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8442-01, Session 1

Review of small angle coronagraphic techniques in the wake of second-generation adaptive optics systems: choice of coronagraph, optimized wavefront control, observing strategy, and post-processing methods

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High contrast imaging of stellar environments at very small angles is a quadruple challenge, as learned these past 10 years while pushing the limit of existing adaptive optics (AO) systems, building the next-generation extreme AO, proof testing innovative concepts in high-tech labs and on sky. First of all, the coronagraphs chosen must allow accessing this constricted but crucial discovery space. Second, wavefront control over low-order aberrations (tip-tilt, focus, coma, ...) must be exquisite and stable over time. Third, the observing strategies based on spatial modulation (angular, such as in ADI, or spectral such as in spectral deconvolution) which might be valid and/or ideal at larger angles become challenged as room for the modulation shrinks. Finally, post-processing methods must face the fact that information becomes more scarce as fewer pixels are pertinent for systematics estimation and removal.

We will tentatively review these four pillars of high contrast imaging and their intricate interactions at very small angles (between 1 and 5 resolution elements from the star). We will then explore the solutions that were proposed and chosen to tackle each challenge. While emphasizing remaining open questions, we will show with concrete examples (from either simulated, lab or on-sky results) how the trade-off between the four pillars influence instrument design and performance, and how informative the commissioning of nextgen instrument will be in that respect.

Finally, we will show how the lessons of the whole current ground-based experience can be applied to future space-based and giant ground-based facilities.

8442-02, Session 1

Coronagraph focal-plane phase masks based on photonic crystal technology: recent progress and observational strategy

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Photonic crystal, an artificial periodic nanostructure of refractive indices, is one of the attractive technologies for coronagraph focal-plane masks aiming at direct imaging and characterization of terrestrial extrasolar planets. We manufactured the eight-octant phase mask (8OPM) and the vector vortex mask (VVM) very precisely using the photonic crystal technology. Fully achromatic phase-mask coronagraphs can be realized by applying appropriate polarization filters to the masks. We carried out laboratory experiments of the polarization-filtered 8OPM coronagraph using the High-Contrast Imaging Testbed (HCIT), a state-of-the-art coronagraph simulator at the Jet Propulsion Laboratory (JPL). We report the experimental results of 10^8-level contrast across several wavelengths over 10% bandwidth around 800nm. In addition, we present future prospects and observational strategy for the photonic-crystal mask coronagraphs combined with differential imaging techniques to reach higher contrast. We proposed to apply a polarization-differential imaging (PDI) technique to the VVM coronagraph, in which we built a two-channel coronagraph using polarizing beam splitters to avoid a loss of intensity due to the polarization filters. We also proposed to apply an angular-differential imaging (ADI) technique to the 8OPM coronagraph. The 8OPM/ADI mode avoids an intensity loss due to a phase transition of the mask and provides a full field of view around central stars. We present results of preliminary laboratory demonstrations of the PDI and ADI observational modes with the phase-mask coronagraphs.

8442-04, Session 1

A complex apodized Lyot coronagraph for broadband exoplanet imaging and spectroscopy from space

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We review the design, fabrication, performance, and future prospects for a complex apodized Lyot coronagraph for high-contrast exoplanet imaging and spectroscopy. We present a newly designed circular focal plane mask with an inner working angle of 2.5 λ/D. Composed of thickness-profiled metallic and dielectric films superimposed on a glass substrate, the complex apodized Lyot coronagraph provides control over both the real and imaginary parts of the coronagraph wavefront. Together with a deformable mirror for control of wavefront phase, the complex apodized Lyot coronagraph potentially exceeds billion-to-one contrast over dark fields extending to within angular separations of 2.5 λ/D from the central star, over spectral bandwidths of 20% or more, and with throughput efficiencies up to 60%.

The fidelity of our design procedure is validated by laboratory demonstrations with a linear occulting mask, for which we report our best imaging contrast to date. Laboratory contrasts of 3×10-10 over 2% bandwidths, 6×10-10 over 10% bandwidths, and 2×10-9 over 20% bandwidths have been achieved at an inner working angle of 3 λ/D, with the dark field extending to a radius of 15 λ/D. Occulter performance has been analyzed in light of recent experiments and optical models, and prospects for further progress are summarized.

The science capability of the hybrid Lyot coronagraph is compared with requirements for a representative space coronagraph for the direct imaging and spectroscopy of exoplanet systems. This work has been supported by NASA's Technology Demonstration for Exoplanet Missions (TDEM) program.

8442-100, Session 1

Status of the assessment phase of the ESA M3 Mission candidate EChO

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EChO is an M-class mission candidate within the science program Cosmic Vision 2015-2025 of the European Space Agency. It was selected in February 2011 to enter an assessment phase (phase 0/A). Following the internal Concurrent Design Facility study conducted by ESA in June/July 2011, a call for instrument studies was released in September, resulting in two consortia being selected to study the complete science instrument on board EChO throughout 2012. Similarly, two parallel competitive industrial studies of the complete mission will end early 2013.

The instrument study focuses on the design and accommodation in the spacecraft of the scientific instrument, a spectrometer divided into several channels covering the 0.4 to 11 micron (16 micron goal) wave band. It also includes the design of the active cryogenic chain required to operate the instrument focal plane detectors.

The industrial study focuses on the complete system-level design, including the mission analysis and operations, the spacecraft design (both service and payload modules) and also programmatic aspects such as risk mitigation, schedule and cost analyses.

This paper describes the status of the EChO assessment study at the mid term review (June/July 2012). It includes a discussion on the evolution of the science and mission requirements, the description of the telescope trade-off and baseline selection, as well as the status of both instrument consortia and industrial system-level studies.

8442-05, Session 2

High contrast vacuum nuller testbed (VNT) contrast, performance, and null control

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Herein we report on our contrast assessment and the development, sensing and control of the Vacuum Nuller Testbed to realize a Visible Nulling Coronagraphy (VNC) for exoplanet detection and characterization. The VNC is one of the few approaches that works with filled, segmented and sparse or diluted-aperture telescope systems. It thus spans a range of potential future NASA telescopes and could be flown as a separate instrument on such a future mission. NASA/Goddard Space Flight Center has an established effort to develop VNC technologies, and an incremental sequence of testbeds to advance this approach and its critical technologies. We discuss the development of the vacuum Visible Nulling Coronagraph testbed (VNT). The VNT is an ultra-stable vibration isolated testbed that operates under closed-loop control within a vacuum chamber. It will be used to achieve an incremental sequence of three visible-light nulling milestones with sequentially higher contrasts of 108, 109, and ideally 1010 at an inner working angle of 2*λ/D. The VNT is based on a modified Mach-Zehnder nulling interferometer, with a "W" configuration to accommodate a hex-packed MEMS based deformable mirror, a coherent fiber bundle and achromatic phase shifters. We discuss the laboratory results, optical configuration, critical technologies and the null sensing and control approach

8442-06, Session 2

EXCEDE technology development I: first demonstrations of high contrast at 1.2 l/D for an Explorer Space Telescope Mission

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Coronagraph technology is advancing and promises to enable space telescopes capable of seeing debris disks as well as seeing and spectrally characterizing exo-Earths. Recently, NASA's explorer program has selected the EXCEDE (EXoplanetary Circumstellar Environments and Disk Explorer) mission concept for technology development. EXCEDE is a 0.7m space telescope concept designed to achieve raw contrasts of 1e-6 at an inner working angle of 1.2 l/D and 1e-7 at 2 l/D. In addition to doing fundamental science on debris disks, EXCEDE will also serve as a technological and scientific precursor for an exo-Earth imaging mission. EXCEDE uses the Phase Induced Amplitude Apodization (PIAA) coronagraph to provide high throughput and high contrast close to the diffraction limit, enabling aggressive performance on small telescopes. For our wavefront control we are using small Micro-Electro-Mechanical-System deformable mirrors (MEMS DMs), which promises to reduce the size of the beam and overall instrument, a consideration that becomes very important for small telescopes. We report on the latest progress and coronagraphic performance results from our air testbed at NASA Ames. Our results include (at time of this writing): lab demonstration of 1e-6 contrast at 1.4 l/D and 2e-8 at 2 l/D in monochromatic light; a thermal control system with demonstrated sub-mK thermal stability of our lab environment; system and wavefront control models that match real lab behavior; and PIAA optics with quality sufficient (according to models) to reach the required EXCEDE performance in broadband light with wavefront control.

8442-07, Session 2

Technology demonstration of starshade manufacturing for NASA's Exoplanet Mission Program

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It is likely that the coming decade will see the development of a large visible light telescope with enabling technology for imaging exosolar Earthlike planets in the habitable zone of nearby stars. One such technology utilizes an external occulter, a satellite flying far from the telescope and employing a large screen, or starshade, to suppress the incoming starlight sufficiently for detecting and characterizing exoplanets. This trades the added complexity of building the precisely shaped starshade and flying it in formation against simplifications in the telescope since wavefront control is no longer necessary. In this paper we present the results of our project to design, manufacture, and measure a prototype occulter petal as part of NASA's first Technology Development for Exoplanet Missions program. We describe the mechanical design of the star shade and petal, the precision manufacturing tolerances, the metrology approach, and the thermal/mechanical modeling results. We demonstrate that the prototype petal meets the requirements and is consistent with a full-size occulter achieving better than 1e-9 contrast. We also summarize our plans for the second TDEM studying deployment accuracy of a subscale occulter with 3 petals.

8442-08, Session 2

Electric field reconstruction in the image plane of a high-contrast coronagraph using a set of pinholes around the Lyot plane

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In a setup similar to the self coherent camera, we have added a set of pinholes in the diffraction ring of the Lyot plane in a high-contrast stellar Lyot coronagraph. We describe a novel complex electric field reconstruction from image plane intensity measurements consisting of light in the coronagraph's dark hole interfering with light from the pinholes. The image plane field is modified by letting light through one pinhole at a time. In addition to estimation of the field at the science camera, this method allows for self-calibration of the probes by letting light through the pinholes in various permutations while blocking the main Lyot opening. We present results of estimation and calibration from the High Contrast Imaging Testbed along with a comparison to the pair-wise deformable mirror diversity based estimation technique. Tests are carried out in narrow-band light and over a composite10% bandpass.

8442-09, Session 3

Broadband focal plane wavefront control of amplitude and phase aberrations

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The Stroke Minimization algorithm developed at the Princeton High Contrast Imaging Laboratory has proven symmetric dark hole generation using minimal stroke on two deformable mirrors (DM) in series. The windowed approach to Stroke Minimization has proven symmetric dark holes over small bandwidths by using three wavelengths to define the bandwidth of correction in the optimization problem. We address the relationship of amplitude and phase aberrations with wavelength, how this changes with multiple DMs, and the implications for simultaneously correcting both to achieve symmetric dark holes. Operating Stroke Minimization in the windowed configuration requires multiple wavelength estimates. To save on exposures, a single estimate is extrapolated to bounding wavelengths using the established relationship in wavelength to produce multiple estimates of the image plane electric field. Here we demonstrate better performance by improving this extrapolation of the estimate to other wavelengths. The accuracy of the functional relationship will ultimately bound the achievable bandwidth, therefore as a metric these results are also compared to estimating each wavelength separately. In addition to these algorithm improvements, we also discuss a laboratory upgrade and how it can better simulate broadband starlight. We also discuss the possibility of leveraging two DMs in series to directly estimate the electric field over a narrow bandwidth and the challenges associated with it.

8442-10, Session 3

A dark-hole correction test for the step-transmission filter based coronagraph system

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We present the initial test result of the dark-hole correction for the high contrast imaging coronagraph that is based on the step-transmission filter. Such a system will be installed on a future space telescope and used for the direct imaging of an Earth-like exoplant. The dark hole is created by a 12x12 actuator deformable mirror (DM) that will be put on the pupil image plane of the coronagraph. In this test, we use the stochastic parallel gradient descent (SPGD) algorithm to control the phase of the DM to gain an extra contrast in the local dark hole. Finally, it is shown in the test that the dark hole could be created on the coronagraphic image with a ~50 times contrast higher than other regions, which is promising to be used for the direct imaging of an Earth-like exoplanet.

8442-11, Session 3

PICTURE: a sounding rocket experiment for direct imaging of an extrasolar planetary environment

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The Planet Imaging Concept Testbed Using a Rocket Experiment (PICTURE) was designed to image the exozodiacal dust disk of Epsilon Eridani, a Sun-like star. PICTURE carried four key enabling technologies aboard a sounding rocket at 4:25 MDT on October 8, 2011 - 0.5 m dia light weight primary mirror (5.5 kg), a white-light (500-700 nm) nulling interferometer, a 32 x 32 element MEMS deformable mirror and a fine pointing system (<3 mas).

Unfortunately, due to a failure in the science telemetry link, the scientific success of the PICTURE mission could not be attained. Nonetheless, this flight validated the flight worthiness of the lightweight primary and the fine pointing system, a key requirement for future planet-imaging missions.

We outline the challenges we faced in developing such an ambitious system and our approaches. We will also describe the experiment, its subsystems and flight results. This work was funded by NASA grants NNG05WC17G and NNX11AD53G.

8442-12, Session 3

SPICA coronagraph instrument: characterization of atmospheres and physical parameters of giant planets by direct imaging and spectroscopy

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We present the current status of the development of the SPICA Coronagraph Instrument (SCI). SPICA is the JAXA and ESA led, a next-generation 3-meter class infrared telescope, which will be launched around 2020. SCI is the dedicated instrument for direct detection and spectroscopy of extra-solar planets in the near-to-mid infrared

wavelengths to characterize their atmospheres, physical parameters and evolutionary scenarios. SCI is now under the international review process which will be finished in 2012. In this paper, first we present a science case of SCI. The main targets of SCI, not only for direct imaging but also for spectroscopy, are young to matured giant planets. We will also show that we already have ~10 known exoplanets by ground-based direct detection which are good target for SCI, and a number of direct detection planets that are suitable for SCI will be significantly increased in the next decade. Second, a general design of SCI and a key technology including a new high-throughput binary mask coronagraph, will be presented. Furthermore, we will show that SCI is potentially capable of achieving 10^-6 contrast by a PSF subtraction method, even with 0.06 arcsec (0-to-peak) pointing error. This contrast enhancement will be important to characterize low-mass and cool planets.

8442-13, Session 3

Coronagraphic imaging of exoplanets from a high altitude balloon platform

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Direct imaging of exoplanets orbiting nearby stars is a major observational challenge, demanding high angular resolution and extremely high dynamic range close to the parent star. Such a system could image and characterize the atmospheres of exoplanets, and also observe exozodiacal dust within the exoplanetary system. The ultimate experiment requires a space-based platform, but demonstrating much of the needed technology as well as performing valuable measurements of circumstellar debris disks, can be done from a high-altitude balloon platform.

In this paper, we show how progress in key technologies leads to a balloon experiment as a logical future step toward a space mission. The HCIT testbed has shown ultra-high contrast using small optics in a vacuum testbed. A recent ground-based experiment has demonstrated the ability to control three active optics in series - a lightweight controllable primary mirror, and two deformable mirrors - to achieve close to the best wavefront correction possible with large optics in an in-air testbed. We briefly describe the Wallops Arcsecond Pointer (WASP), which as had a very successful first flight, showing the capability of a balloon platform to stably point to the accuracy required for a coronagraph payload experiment. A balloon-borne coronagraph mission would incorporate all of these advances in an instrument that verifies each one in a space-like environment, and enabling forefront science. Such an experiment would be a step toward mitigating the technical risks of a major space-based exoplanet coronagraph.

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8442-14, Session 3

ExoZodi mapper

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Direct detection and imaging of exo-Earths is a prime candidate for the next Astrophysics flagship mission. Many groups are focused on developing various mission concepts and technologies to enable the direct imaging of an exo-Earth. However, several key astronomical unknowns stand in the way of a fully optimized exo-Earth imaging mission; the primary one is the uncertainty in the exozodi brightness. Exozodiacal dust is predicted to exist in the habitable zones of other stars, exactly in the locations where exo-Earths would reside. Reflected light from this dust could be a primary background contribution. We propose a mission concept called the ExoZodi Mapper (EZM) that will obtain definitive measurements of the brightness of the exozodi dust around prime target stars for a future direct detection mission. Our mission concept uses a medium sized starshade that works with a future space telescope to image and characterize the brightness and distribution of exozodiacal dust around ~40 primary target stars. These measurements would provide precise requirements for the eventual exo-Earth flagship mission, which may translate into significant savings. In addition, EZM can provide a host of ancillary science information on these important targets, including detailed maps of their dust distribution, studies of outer, giant planets, and exploration of the overall architecture of these planetary systems. The EZM starshade can also be used to enable high-contrast imaging of other targets of value to the astronomical community such as debris disks around young stars. We present an overview of the science that motivated the mission concept, the driving requirements, and the top level mission architecture.

8442-15, Session 4

SPICES: a 1.5-m space coronagraph for spectro-polarimetric characterization of cold exoplanets

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The study of the physico-chemical properties of wide-separated exoplanets (> 1 AU) is a major goal of high contrast imaging techniques. SPICES (Spectro-Polarimetric Imaging and Characterization of Exoplanetary Systems) is a project of space coronagraph dedicated to the spectro-polarimetric analysis of gas and ice giant planets, super-Earths and circumstellar disks in visible light at a spectral resolution of about 40. After recalling SPICES' science cases, we describe the optical design and the critical subsystems of the instrument. We then discuss the SPICES performance that we derive from numerical simulations.

8442-16, Session 4

NEAT: a space born astrometric mission for the detection and characterization of nearby habitable planetary systems

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The NEAT (Nearby Earth Astrometric Telescope) mission is a proposal submitted to ESA for its 2010 call for M-size mission within the Cosmic Vision 2015-2025 plan. The main scientific goal of the NEAT mission is to detect and characterize planetary systems in an exhaustive way down to 1 Earth mass in the habitable zone and further away, around nearby stars for F, G, and K spectral types. This survey would provide the actual planetary masses, the full characterization of the orbits including their inclination, for all the components of the planetary system down to that mass limit. Only extremely- high-precision astrometry, in space, can detect the dynamical effect due to even low mass orbiting planets on their central star, reaching those scientific goals. NEAT will continue the work performed by Hipparcos (1 milliarcsec precision) and Gaia (7

microarcsec aimed) by reaching a precision that is improved by two orders of magnitude (0.05 microarcsec, 1 sigma accuracy). The NEAT mission profile is driven by the fact that the two main modules of the payload, the telescope and the focal plane, must be placed 40-m away leading to a formation flying option. We propose to present for the first time at SPIE this mission that can be of interest for many scientist in the astrophysical domain.

8442-17, Session 4

Simultaneous coronagraphic imaging and astrometric mass measurement of habitable exoplanets with the diffractive pupil telescope concept

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A concept for high precision astrometry with a conventional wide field telescope is presented, enabling a space telescope to perform simultaneously coronagraphic imaging of exoplanets, astrometric measurement of their orbits and masses, and deep wide field imaging for a wide range of astrophysical investigations.

Our concept uses a diffractive telescope pupil (primary mirror), obtained by placing a regular grid of small dots on the primary mirror. When the telescope is pointed at a bright star, the wide field image contains both a large number of background stars used for astrometric referencing, and faint diffraction spikes created by the grid of dots on the primary mirror. The diffraction spikes encode instrumental astrometric distortions due to optics or the detector, allowing precise measurement of the central star against a large number of faint background stars.

With up to a few percent of the primary mirror area covered by the dots, the fraction of the central starlight located in the diffraction spikes is kept sufficiently small to allow full sensitivity deep imaging over the telescope's field of view. The regularly spaced dots do not diffract light at small angular separations, allowing full coronagraphic imaging capability. We show that combining simultaneous astrometric and coronagraphic measurements allows improved detection and characterization of exoplanets by constraining the planet(s) characteristics with both measurements. Our preliminary astrometric accuracy error budget shows that sub-micro arcsecond astrometry can be achieved with a ~1.5 m diameter telescope, and that astrometric accuracy improves rapidly with telescope diameter.

8442-18, Session 4

High contrast imaging and position sensing at the Princeton occulter testbed

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Direct imaging of Earth-like planets requires starlight suppression of roughly ten orders of magnitude. An external occulter is a promising approach for achieving this level of suppression; it employs a second spacecraft containing a star shade whose shape is designed through optimization methods to produce a deep shadow at the location of the space telescope. At the Princeton Occulter Testbed, we have designed a subscale experiment to test long-distance beam propagation, verifying the numerical diffraction routines used to create optimal occulter shapes. In the past we have presented experimental results that showed that in parts of an annular section of the image plane the required starlight suppression was met. Here we present the design and experimental verification of a new high-contrast mask that achieves the required contrast level throughout the entire annular region. We also present the design and experimental verification of a narrow-band high-contrast mask that demonstrates the feasibility of using out-of-band diffraction leakage for sensing the occulter position in a feedback loop for formation flight alignment of the occulter with the telescope.

8442-19, Session 4

Direct imaging of exoEarths embedded in clumpy debris disks

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The inner solar system, where the terrestrial planets formed and evolve, is populated by small grains of dust produced by collisions of asteroids and outgassing comets. At visible and infrared wavelengths, this dust cloud, also called the zodiacal disk, is in fact the most luminous component in the solar system after the Sun itself, and the Earth appears clearly as an embedded clump in it. Hence, the presence of large amounts of dust in the habitable zone around nearby main-sequence stars is considered as a major hurdle toward the direct imaging of exoEarths with future dedicated space-based telescopes. In that context, we address in this paper the detectability of exoEarths embedded in structured debris disks with future space-based visible coronagraphs and mid-infrared interferometers. Using a collisional grooming algorithm, we produced models of dense dust clouds with resonant structures induced by an Earth-like planet. In a second step, we investigated various viewing geometries and derived limiting dust densities that can be tolerated around nearby main-sequence stars in order to ensure the characterization of exoEarths with future direct imaging missions. These results provide the typical sensitivity that we will need to reach on exozodiacal disks in order to prepare the scientific program of these future exoEarth characterization missions.

8442-20, Session 4

Identification of an exoplanet using multiple speckle-limited images

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Current observations in the context of exoplanet searches with coronagraphic instruments have shown that one of the main limitations to high-contrast imaging is due to residual quasi-static speckles. Speckles look like the image of a planet, but they have a different spectral behavior. All speckles are formed from the same coherent source, the star, and are incoherent with the planet. Moving a deformable mirror (or other changes to the optical layout) changes the speckle pattern as seen on the camera. Since the planet light does not interfere with the speckles, the image of the planet remains untouched (except that speckles may appear on top of the planet). This fundamental coherence property of the speckles (and incoherence with the planet light) guides us to develop methods to take advantage of a changing speckle pattern to distinguish a planet from a speckle. We present a model of estimating the intensity of a planet given a point spread function, and assuming an unknown and locally constant background source as well as speckles and photon noise. We use this model to develop a planet detection algorithm. We perform image analysis of multiple images presuming an independent source of aberrations between images. Work on the development and verification of the algorithm is presented.

8442-99, Poster Session

The Exoplanet Characterisation Observatory (EChO) payload electronics

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The EChO Payload is an integrated spectrometer for covering the 0.4-16 micron wavelength band, subdivided into 6 channel from Visible to thermal IR with a common set of optics spectrally dividing the field of view by means of dichroics and a unique electronics interface to the spacecraft, the Data Control Unit (DCU). DCU is a digital unit whose main tasks are on one side to implement the payload interface to the Satellite, via a dedicated SpaceWire link, and on the other side to interface the front-end electronics (FEEs) for commanding, data and housekeeping (HK) acquisition, conversion and packetisation, and to process the acquired spectra. In addition, DCU is in charge to provide finely regulated voltage levels to FEEs and to implement the FEEs synchronisation.

The analog data sent to DCU by the detector's FEEs are converted inside the unit by a set of ADCs and the internal redundancy scheme is presented as well as the input data multiplexing and conversion schemes.

The EChO proposed digital electronics basically focuses on the data and command flows, the clock/synchronization and power distribution network and on an overall architecture for a trade-off solution removing or reducing any electronics single-point failure.

8442-102, Poster Session

Mechanical and thermal architecture of an integrated payload instrument for the Exoplanet Characterisation Observatory

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The Exoplanet Characterisation Observatory (EChO) is a space mission dedicated to undertaking spectroscopy of transiting exoplanets over the widest wavelength range possible. It is based around a highly stable space platform with a 1.2 m class telescope. The mission is currently being studied by ESA in the context of a medium class mission within the Cosmic Vision programme for launch post 2020. The payload instrument is required to provide simultaneous coverage from the visible to the mid-infrared and must be highly stable and effectively operate as a single instrument.

This paper presents the architectural design for the highly interlinked mechanical and thermal aspects of our instrument design. The instrument will be passively cooled to approximately 40K along with the telescope in order to maintain the necessary sensitivity and photometric stability out to mid-infrared wavelengths. Furthermore other temperature stages will be required within the instrument, some of which will implement active temperature control to achieve the necessary thermal stability. We discuss the major design drivers of this complex system such as the need for multiple detector system temperatures of approximately 160K, 40K and 7K all operating within the same instrument.

The sizing cases for the cryogenic system will be discussed and the options for providing the cooling of detectors to approximately 7K will be examined. We discuss the trade-offs that we are undertaking to produce a technically feasible payload design which will enable EChO's exciting science.

8442-103, Poster Session

EChO SWiR: Exoplanet Atmospheres Characterization Observatory sort-wave infrared channel of the EChO payload

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EChO, a space mission for exoplanets exploration, is considered the next step for planetary atmospheres characterization. It will be a dedicated observatory to uncover a large selected sample of planets spanning a wide range of masses (from gas giants to super-Earths) and orbital temperatures (from hot to habitable). All targets move around stars of spectral types F, G, K, and M. EChO will provide an unprecedented view of the atmospheres of planets in the solar neighbourhood.

The consortium formed by various institutions of European countries is proposing an integrated spectrometer payload for EChO covering the wavelength interval 0.4 to 16 m. This instrument is subdivided into 6 channels: one visible module (0.4-0.9 m), which includes a fine guidance sensor (FGS) and a VIS spectrometer, 2 near infrared channels (SWiR, 0.9-5.2 m), 2 middle infrared channels (MWiR, 5.2-11.5 m), and a long wave infrared module (LWiR, 11.5-16 m). In addition, it contains a common set of optics spectrally dividing the wavelength coverage and injecting the incoming light into the different channels. The proposed payload meets all of the key performance requirements detailed in the ESA call for proposals as well as all scientific goals.

Within the SWiR channel, and due to the wide spectral range to be covered, two spectrometers have been designed: SWiR 1 working from 0.9 to 2.5 m, and SWiR 2, working from 2.5 to 5.2 m. In this paper, the optical and mechanical designs of the SWiR channel, including the identification of critical points and the schedule of the study process to be carried out during 2012 are reported on.

8442-104, Poster Session

The visible and near infrared (VNIR) spectrometer of the EChO Telescope

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In the setting of the EChO instrumentation the Visible and Near Infrared (VNIR) will cover the spectral range from 0.4 to 1 μm. The instrument has to be designed to assure an high efficiency over whole spectral range. It has to be able to observe stars with an apparent magnitude Mv= 9÷12 and able to see contrasts of the order of 10-4÷10-5 in order to measure characteristics of the exoplanets under investigation. The basic idea for VNIR is to have a spectrometer in a cross-dispersed configuration by using a combination of a diffraction grating and a prism to spread the light in different wavelengths and in a useful number of orders of

diffraction. The light separated in wavelengths and orders will be sent on a squared CCD detector of 512 by 512 pixels. At this time, even if a CCD is considered as baseline, other detectors will be taken into consideration to improve the instrument performances. The instrument will be interfaced to the telescope optics by an optical fiber to assure an easier coupling and an easier colocation of the instrument inside the EChO optical bench. The preliminary design of the instrument predicts a resolving power ranging from 400 to 600 depending on the wavelength and a field of view of approximately 2 arcsec.

8442-105, Poster Session

Modelling the science performance of EChO

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EChO - the Exoplanet Characterisation Observatory -, which has been selected for study by the European Space Agency in the frame of its Cosmic Vision program, is a mission dedicated to the investigation of exoplanetary atmospheres. It will provide high resolution, simultaneous multi-wavelength spectroscopic observations on a stable platform that will allow very long exposures. In this paper we describe the principles and the first results of an "end-to-end" modelling facility to study the science performance of EChO. The software toolbox follows a modular architecture with a central engine that runs software modules dealing each with a specific aspect of the model. Relevant parameters can therefore either be computed dynamically within a module, or computed by other means and transferred to the model via a parameter file input. This enables inputs from different disciplines to be combined, and makes it possible to start from a simple representation of the major parameters and to improve its representativeness by an increasing complexity of the description, taking into account second order effects, or new parameters. We highlight the basic parameters that are first implemented in the model and their impact on the overall performance.

8442-106, Poster Session

Characterising the atmospheres of transiting planets with a dedicated space telescope

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With the Exoplanet Characterisation Observatory (EChO) mission under review at ESA, and with the number of known exoplanets surpassing 700, I will present the results of my work on the possibilities of characterising exoplanet atmospheres with a dedicated infrared spectroscopy space telescope such as EChO.

Using the transit technique, in primary transit (where a planet passes its star by our line of sight), and/or secondary eclipse (where a planet transits behind its star, but is fully illuminated before and after), spectroscopy can be used to characterise distant exoplanets. I will present key cases from our study, which assumes a 1.4m space based telescope, showing required integration times (as "number of transits", delimited by the length of the mission divided by the orbital period duration) for a range of planets and stars, with examples in primary transit and secondary eclipse. To compute integration times for each target/star combination using our simulation software, which takes into account parameters such as: stellar properties, observing band, spectral resolution, SNR, instrument and detector performances, I first have to calculate the contrast ratio expected from the star+planet. This is obtained in part by atmospheric modeling and in part by observations. The cases I will be presenting will include a range of target types, from hot gas giants to habitable-zone (HZ) super-Earths (with radii 1.6-1.8 Rearth).

8442-107, Poster Session

A detector technology investigation for the Exoplanet Characterisation Observatory (EChO)

E. Pascale, Cardiff Univ. (United Kingdom)

The Exoplanet Characterisation Observatory (EChO) is currently being studied by ESA as a medium class mission to be launched in the third decade of the new millennium. EChO aims at characterising the atmospheres of transiting exoplanets with an exquisitely stable spectroscopic instrument in L2. The current design implements 6 channels spanning from 0.4 to 16 micron, requiring demanding performances on the focal plane detector systems, both in terms of sensitivity and stability over time-scales comparable to the planet transit times. A programme investigating possible detector solutions for the medium and long wavelength channels, operating from 5 to 10 micron, and from 10 to 16 micron, respectively, is in place at Cardiff, in collaboration with European detector manufacturers. I will report on the progresses of identifying and developing suitable detectors for these channels.

8442-108, Poster Session

The study of magnetic activity and exoplanet magnetospheres using EChO vis-channel spectropolarimetry

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To obtain a comprehensive view of the structure and evolution of exoplanetary atmospheres, it is important to investigate the escape mechanisms of their constituent atomic and molecular species. This necessarily includes the effect of a planetary magnetosphere. Given the distribution of masses and orbital parameters among the currently known gas giant exoplanets, the presence of a significant magnetic field could have some surprising consequences. In analogy with active dynamo-generated fields in close binary star systems, such as the RS CVn stars, such a field could link to that of the parent star, producing a strongly dissipative torque and magnetically and tidally locking the planet to its sun. Investigations of these interactions can shed light on the nature and character of exoplanet magnetospheres.

The EChO satellite presents an opportunity to investigate from space magnetic stellar activity and the nature of magnetic interactions of exoplanets with their host stars using spectropolarimetry. These include auroral phenomena induced by the coupling on the exoplanet, induced flows between the planet and parent star, and a broad range of signatures of enhanced magnetohydrodynamic interactions.

8442-109, Poster Session

An end-to-end approach to the Euclid NISP on-board preprocessing operations: tests and latest results

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In this paper we describe an end-to-end scheme for the on-board pre-processing operations, developed in the framework of the design study for the NISP instrument, part of the Cosmic Vision Euclid Mission. Non-destructive detector readouts are simulated for a number of different readout strategies, taking into account scientific and calibration observations; resulting frames are passed trough a series of steps emulating the on-board pipeline, then compressed to give the final result. To verify performances, computations and memory load we tested this architecture on a number of platforms. Here we give the results of latest tests. This paper mainly reports the technical status at the end of the Definition Phase and it is presented on behalf of the Euclid Consortium.

8442-110, Poster Session

The on-board electronics for the near infrared spectrograph and photometer (NISP) of the EUCLID Mission

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The Near Infrared Spectrograph and Photometer (NISP) is one of the instruments on board the EUCLID mission. The focal plane array (FPA) consists of 16 HAWAII-2RG HgCdTe detectors from Teledyne Imaging Scientific (TIS), for NIR imaging in three bands (Y, J, H) and slitless spectroscopy in the range 0.9-2 micron. Low readout noise (RON) measurements (RON < 8 electrons) are achieved by operating the detectors in multiple non-destructive readout mode for the implementation of both the Fowler and Up-The-Ramp (UTR) sampling, which also enables the detection and removal of cosmic ray events. The large area of the NISP FPA and the limited satellite telemetry available impose to perform the required data processing on board, during the observations.

This requires a well optimized on-board data processing pipeline, and high-performance control electronics, suited to cope with the time constraints of the NISP acquisition sequences. The paper describes the architecture of the NISP on-board electronics, which take charge of several tasks, including the driving of each individual HAWAII-2RG detectors through their SIDECAR ASICs, the data processing, inclusive of compression and storage, and the instrument control tasks.

We describe the implementation of the processing power needed for the demanding on-board data reduction. We also describe the basic operational modes that will be managed by the system during the mission, along with data flow and the Telemetry/Telecommands flow.

This paper reports the NISP on-board electronics architecture status at the end of the Definition Phase, and it is presented on behalf of the Euclid Consortium.

8442-111, Poster Session

The command and data processing unit of the EUCLID visible imager: impact of the data compression needs on the unit design

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The Euclid Visible Imager has been designed to provide high-precision galaxy shape measurements for the evaluation of the weak lensing shear.

The imager focal plane is composed of 4x9 full frame CCDs of 4096x4096 pixels. The instrument is controlled by the Command and Data Processing Unit (VI-CDPU) which is in charge of both collecting and monitoring housekeeping parameters and of executing the instrument measurement and calibration by distributing low level commands. VI-CDPU has the additional task to collect the science data provided by the CCDs and to perform the lossless compression necessary to match instrument data rates and spacecraft telemetry rate. VI-CDPU interfaces the spacecraft Digital Electronics through a MIL-STD-1553B link for telecommands and housekeeping telemetry exchange. Science telemetry is sent directly to the spacecraft mass memory through a dedicated SpaceWire high-speed data link. The VIS internal interfaces, to both the mechanisms control unit and the detectors readout electronics, are implemented through dedicated SpaceWire high-speed data links.

The presented VI-CDPU design implements a fully redundant box including the two separate nominal and redundant units plus a single special I/F section necessary to provide a fault-tolerant interface to the 12 non-redundant SpaceWire links to the focal plane arrays. Data-handling functions are kept separate from the science processing, in order to maximise the reliability of the unit and to minimize the impacts on the instrument operations in case of S/W issues on the scientific data processing side. The results of the trade-off activities carried out to optimize the compressor design are presented as well as the final implementation choices.

8442-112, Poster Session

Euclid NISP thermal control design

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In this paper we describe the thermal architecture of the Near Infrared Spectro-Photometer (NISP) on board the Euclid ESA mission.

The instrument thermal design is based on the combination of two passive radiators coupled to cold space that, exploiting the beneficial conditions of the L2 thermal environment, provide the temperature references for the main sub-systems. One radiator serves as a 135K heat sink for the opto-mechanical structure and for the front-end cold

electronics, while working as an interception stage for the conductive parasitic heat leaks through struts and harness. The second, colder, radiator provides a 95K reference for the instrument detectors.

The thermal configuration has to ensure the units optimal operating temperature needed to maximize instrument performance, adopting solutions consistent with the mechanical specifications. At the same time the design has to be compliant with the stringent requirements on thermal stability of the optical and detector units. The periodical perturbation of filter and grism wheel mechanisms together with orbital variations and active loads instabilities make the temperature control one of the most critical issues of the whole design.

We report here the general thermal architecture at the end of the Definition Phase, together with the first analysis results and preliminary performance predictions in terms of steady state and transient behavior. This paper is presented on behalf of the Euclid

Consortium.

8442-113, Poster Session

Design concept of the electrical ground support equipment for the AIV and calibration of the Euclid NISP instrument

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The Near Infrared Spectro-Photometer (NISP) on board the Euclid ESA mission will be developed and tested at various levels of integration using various test equipment which shall be designed and procured through a collaborative and coordinated effort.

In this paper we describe the Electrical Ground Support Equipment (EGSE) which shall be required to support the assembly, integration, verification and testing (AIV/AIT) and calibration activities at instrument level before delivery to ESA, and at satellite level, when the NISP instrument is mounted on the spacecraft.

We present the EGSE conceptual design as defined in order to be compliant with the AIV/AIT and calibration requirements. The proposed concept is aimed at maximizing the re-use in the EGSE configuration of the Test Equipment developed for subsystem level activities, as well as, at allowing a smooth transition from instrument level to satellite level, and, possibly, at Ground Segment level.

This paper mainly reports the technical status at the end of the Definition phase and it is presented on behalf of the Euclid Consortium.

8442-114, Poster Session

Vega and the absolute calibration of HST

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Vega is the quintessential absolute flux calibrator in Astronomy, and, one of only a few stars calibrated against an SI-traceable blackbody. HST's calibration depends on observation in the Visible of Vega. Its calibration beyond 1 micron is obtained by extrapolating from current visible data via models. To fill in the crucial gap between 0.9 and 1.7 microns, we have acquired grism spectroscpy of Vega in the near infrared with the two WFC3 infrared grisms. Spectra of Vega are obtained using spatial scanning in the -1st and -2nd order. Spectra of two fainter stars are also scheduled to be taken in the +1st and -1st orders of the two IR grisms. The recently enabled gyro scan mode of HST allows scan rates up to ~7 arcsec/sec, providing a fast enough rate to obtain high signal to noise data (SN=3000) of bright stars. We present results obtained from data acquired in Cycle 19.

8442-115, Poster Session

Keeping the Hubble Space Telescope in focus

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The Hubble Space Telescope is a Ritchie-Chrétien optical design with a main primary concave mirror followed by a convex secondary. The focus is determined by the position of each of these two mirrors. The truss containing them is made of graphite epoxy which has very low thermal expansion. Nevertheless, temperature variations do cause the mirror separation to vary by several microns within an orbit. Additionally, outgassing of water vapor causes a long-term shrinkage which soon after launch in 1990 varied by more than 2 microns per month. This necessitated adjusting the position of the secondary mirror every few months. Currently this rate is greatly reduced and adjustments are needed less than once per year.

The focus is monitored monthly to continually assess the need for such adjustments. The measurements have been used to develop models to predict the focus at times between measurements to assist in the analysis of observations. Detailed focus knowledge is of value in photometry, coronography and image deconvolution. The various focus models that have been applied so far are described with a discussion of their performance.

8442-117, Poster Session

Modifications to the Warm Spitzer data reduction pipeline

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The Spitzer InfraRed Array Camera (IRAC) basic calibrated data pipeline is designed to take a single raw frame from a single IRAC detector and produce a flux-calibrated image which has had all well-understood instrumental signatures removed. Here we discuss several modifications to the pipeline developed in the last two years in response to the Warm Spitzer Mission. Due to the different instrument characteristics in the warm mission, we have significantly changed pipeline procedures

for masking residual images and mitigating column pulldown signatures. In addition, the muxbleed correction was turned off as the effect is not present in the warm data. Parameters relevant to linearity correction, bad pixels, and the photometric calibration have been updated and are continually monitored.

8442-118, Poster Session

The IRAC point response function in the Warm Spitzer Mission

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The Infrared Array Camera (IRAC) is now the only science instrument in operation on the Spitzer Space Telescope. The 3.6 and 4.5 micron channels are temperature-stabilized at ~28.7K and the sensitivity of IRAC is nearly identical to what it was in the cryogenic mission. The instrument point response function (PRF) is a set of values from which one can determine the point spread function (PSF) for a source at any position in the field, and is dependent on the optical characteristics of the telescope and instrument as well as the detector sampling and pixel response. These data are necessary when performing PSF-fitting photometry of sources, or for deconvolving an IRAC image, subtracting out a bright source in a field, or for estimating the flux of a source that saturates the detector for the integration time used. Since the telescope and instrument are operating at a higher temperature in the post-cryogenic mission, we re-derive the PRFs for IRAC from measurements obtained after the warm mission temperature set point and detector biases were finalized, and compare them to the 3.6 and 4.5 micron PRFs determined during the cryogenic mission to assess any changes.

8442-119, Poster Session

Optical transmission for the James Webb Space Telescope

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The fabrication and coating of the mirrors for the James Webb Space Telescope has been completed. The spectral reflectivity of the protected gold coated beryllium mirrors has been measured. The predicted end-of-life transmission through the telescope builds from these values. The additional phenomena that have been analyzed are contamination effects and effects of the environment for the JWST operation about the Earth-Sun L2 Lagrange libration point. The L2 environment analysis has been based on radiation testing of mirror samples and hypervelocity testing to assess the micrometeoroid impact effects. The mirror showed no change in reflectance over the VIS-SWIR wavelengths after exposure to 6-9 Grad (Si) that simulated 6 years orbiting the L2 Lagrange point. The effects of hypervelocity particle impacts on the mirrors from test data has been extrapolated to the to the anticipated flux characteristics for micrometeoroids at the L2 environment. The results show that the micrometeoroid effects are orders of magnitude below the particulate contamination effects. The final end-of-life transmission for the mirrors including all of these phenomena will meet the performance requirements for JWST.

8442-120, Poster Session

James Webb Space Telescope stray light performance status update

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The James Webb Space Telescope (JWST) is a large space based astronomical telescope that will operate at cryogenic temperatures. The architecture has the telescope exposed to space, with a large sun shield providing thermal isolation and protection from direct illumination from the sun. The instruments will have the capability to observe over a spectral range from 0.6 um to 28 um wavelengths. The following paper will present updated stray light analysis results characterizing the stray light getting to the instrument focal planes from the full galactic sky, zodiacal background, bright objects near the line of sight, and scattered earth and moon shine. Included is a discussion of internal alignments of pupils at relevant interface planes to stray light. The amount of self-generated infrared background from the Observatory that reaches the instrument focal planes will be presented including the tolerance to the alignment of the edges of the sun shield membranes relative to each other and the telescope.

8442-121, Poster Session

Multi-field alignment of the James Webb Space Telescope

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When the secondary mirror(SM) of a Three-Mirror Anastigmat (TMA) telescope is misaligned with respect to the primary mirror (PM), optical wavefront errors are created. In general, the errors take the form of a dominant coma term, common to all field points, in addition to astigmatism and power terms which vary with field position. The magnitude of the field dependent wavefront is usually only a few percent of that of the common coma term, depending on the size of the field of view being considered. The architecture of the James Webb Space Telescope (JWST), however, presents a unique optical problem in that the common term created by misplacement of the SM is compensated by adjustment of the PM segments. As such, the residual field dependent terms become dominant and can be sensed at multiple field points using phase retrieval techniques. In this paper, we present a linear set of equations that describe the multi-field wavefront errors resulting from a misaligned SM. It is shown that inverting these equations yields corrections for the SM alignment that can independently control the field-dependent astigmatism and the focal-plane tilt. Computer simulations illustrating the correction are presented.

8442-122, Poster Session

Simulating point spread functions for the James Webb Space Telescope

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Experience with the Hubble Space Telescope has shown that accurate models of optical performance are extremely desirable to astronomers, both for assessing feasibility and planning scientific observations, and for data analyses such as point-spread-function (PSF)-fitting photometry and astrometry, deconvolution, and PSF subtraction. Compared to previous space observatories, the temporal variability and active control of the James Webb Space Telescope (JWST) pose a significantly greater challenge for accurate modeling. We describe here some initial steps toward meeting the community's need for such PSF simulations.

The WebbPSF software package currently provides a capability for simulating PSFs for all of JWST's instruments, including direct imaging, coronagraphy, and non-redundant aperture masking observing modes. WebbPSF is intended to provide model PSFs suitable for planning observations and creating mock science data, via a straightforward interface accessible to astronomers; as such it is complementary to more sophisticated but specialized modeling tools used primarily by optical engineers. WebbPSF is implemented using a new flexible and extensible optical propagation library in the Python programming language. While the initial version of WebbPSF used static precomputed wavefront simulations, over time this system is evolving to include both spatial and temporal variation in PSFs, building on existing modeling efforts within the JWST program. Our long-term goal is to provide a general-purpose PSF modeling capability akin to Hubble's Tiny Tim software, and of sufficient accuracy to be useful to the community.

8442-123, Poster Session

The NIRSpec on-ground calibration campaign

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The Near Infrared Spectrograph (NIRSpec) is one of four science instruments aboard the James Webb Space Telescope (JWST). NIRSpec is sensitive in the wavelength range from ~0.6 to 5.0 micron and will be capable of obtaining spectra from more than a 100 objects simultaneously, as well as fixed slit high contrast spectroscopy of individual sources and integral field spectroscopy. We will present results obtained during the first cryogenic instrument testing in early 2011, demonstrating the excellent optical performance of the instrument. We will also describe the planning of NIRSpec's forthcoming second calibration campaign scheduled for mid 2012.

8442-124, Poster Session

The spectro-photometric calibration concept of the JWST NIRSpec instrument

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NIRSpec is the main near-infrared spectrograph on board the James Webb Space Telescope, offering multi-object capabilities as well as an integral field unit and a number of fixed slits for studies of individual objects. In this paper, we describe the unique challenges in calibrating this complex instrument, and the approach taken to deal with them, both in terms of operational procedures and via automated processing of NIRSpec data. We provide a high-level description of the sequence of processing steps required for NIRSpec science data, and the necessary on-ground calibration files. We focus our discussion on the case of a typical multi-object observation with the MSA, in which adjacent micro-shutters are used to sample the science object and the sky background in an alternating way. This dithering strategy is particularly well suited for faint targets, but its guiding principles also apply to other NIRSpec modes.

8442-125, Poster Session

The accuracy of the NIRSpec grating wheel position sensors

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The Near Infrared Spectrograph (NIRSpec) is one of four science instruments on board the James Webb Space Telescope (JWST), offering multi-object, fixed slit, and integral field spectroscopy. In this paper we report on the repeatability and accuracy of the position of NIRSpec's grating wheel assembly (GWA). There are eight optical elements mounted on the GWA (namely six gratings, a double-pass prism, and a mirror) and the precise knowledge of the position and tilt of these elements is critical for target acquisition and for an accurate extraction and calibration of science data.

We present an in depth analysis of the data collected during the first NIRSpec thermal vacuum calibration campaign, showing that the magneto-resistive position sensors installed on the GWA provide accurate information on the actual position of the wheel. The level of accuracy

exceeds the requirements for target acquisition and wavelength calibration. We also discuss how the reliability of the information provided by the GWA position sensors can be further verified and confirmed in orbit, using the internal calibration sources. A proper calibration of

the GWA position sensors will enable more efficient in-flight operations of NIRSpec.

8442-126, Poster Session

James Webb Space Telescope first light boresight to spacecraft alignment determination

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The James Webb Space Telescope is large deployable cryogenic space telescope that is pointed on the sky by control of the attitude of the integrated spacecraft and telescope. The primary mirror has 18 hexagonal Primary Mirror Segment Assemblies (PMSA) that are deployed; 3 each on deployable wings, and 12 from a fixed central section of the Primary Mirror Backplane Support Structure. The Secondary Mirror (SM) is deployed from the Secondary Support Structure that folds out from the backplane, and the complete Telescope and Integrated Science Instrument Module are deployed in extension from the spacecraft. The resulting tolerances will result in a "first light" image that has a spread array of 18 individual images for each point source located within the field of view. The initial attitude of the spacecraft will be adjusted to point the telescope to a desired star field for the initial WFSC commissioning process. The deployment tolerances will result in the telescope field of view being offset from the desired location. By use of a sequence of pointings, a mosaic "first light" image that includes the multiplicity of the 18 misaligned segment images may be created that will allow the calibration of the offset between the telescope boresight and the spacecraft attitude control system to adjust the telescope pointing to the desired commissioning field of view.

8442-127, Poster Session

Global alignment optimization strategies, procedures, and tools for the James Webb Space Telescope (JWST) integrated science instrument module (ISIM)

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During cryogenic vacuum testing of the James Webb Space Telescope (JWST) Integrated Science Instrument Module (ISIM), the global alignment of the ISIM with respect to the designed interface of the JWST optical telescope element (OTE) will be measured through a series of optical characterization tests. These tests will determine the locations and orientations of the JWST science instrument projected focal surfaces and entrance pupils with respect to their corresponding OTE optical interfaces. Thermal, finite element and optical modeling will then be used to predict the on-orbit optical performance of the observatory. If

any optical performance non-compliances are identified, the ISIM will be adjusted to improve its performance. If this becomes necessary, ISIM has a variety of adjustments that can be made. The lengths of the six kinematic mount struts that attach the ISIM to the OTE can be modified and there are five focus adjustment mechanisms and two pupil adjustment mechanisms inside the science instruments that can be adjusted. In order to understand how to manipulate the ISIM's degrees of freedom properly and to prepare for the ISIM flight model testing, we have completed a series of optical-mechanical analyses to develop and identify the best approaches for bringing a non-compliant ISIM Element back into compliance. During this work several unknown misalignment scenarios were produced and the simulated optical performance metrics were input into various mathematical modeling and optimization tools to determine how the ISIM degrees of freedom should be adjusted to provide the best overall optical performance.

8442-128, Poster Session

Measuring segmented primary mirror WFE in the presence of vibration and thermal drift on the light-weighted JWST

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The light-weighted design of the Optical Telescope Element (OTE) of the James Webb Telescope (JWST) leads to additional sensitivity to vibration from the ground - an important consideration to the measurement uncertainty of the wavefront error (WFE) in the primary mirror. Furthermore, segmentation of the primary mirror leads to rigid-body movements of segment areas in the WFE. The ground vibrations are minimized with modifications to the test facility, and by the architecture of the equipment supporting the load. Additional special test equipment (including strategically placed isolators, tunable mass dampers, and cryogenic magnetic dampers) mitigates the vibration and the response sensitivity before reaching the telescope. Moreover, the multi-wavelength interferometer is designed and operated to accommodate the predicted residual vibration. Thermal drift also adds to the measurement variation. Test results of test equipment components, measurement theory, and finite element analysis combine to predict the test uncertainty in the future measurement of the primary mirror. The vibration input to the finite element model comes from accelerometer measurements of the facility with the environmental control pumps operating. One of the isolators have been built and tested to validate the dynamic performance. A preliminary model of the load support equipment and the OTE with the Integrated Science Instrument Module (ISIM) is complete. The performance of the add-on dampers have been established in previous applications. And operation of the multi-wavelength interferometer was demonstrated on a scaled hardware version of the JWST in an environment with vibration and thermal drift.

8442-130, Poster Session

Cryogenic performance test results for the flight model JWST fine guidance sensor

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The flight model Fine Guidance Sensor (FGS) on the James Webb Space Telescope (JWST) has successfully completed its performance verification tests. The overall FGS cryogenic test program is described along with the key guider performance results which have been obtained. In particular we describe the noise equivalent angle (NEA) performance as a function of guide star magnitude, in the acquisition, tracking and fine guiding modes of the two FGS-Guiders. In addition the FGS-Guider function of identifying the field of view using reference (and guide) stars, has been demonstrated. All the testing described has made use of a JWST telescope simulator. We will describe how the test results are interpreted via analysis to estimate the on-orbit expected performance. The NEA of the FGS-Guiders will in part determine the ultimate image quality of the JWST Observatory.

8442-131, Poster Session

Observatory alignment of the James Webb Space Telescope

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The payload portion of James Web Space Telescope (JWST) consists of a deployable, three mirror anistigmat, telescope and an Integrated Science Instrument Model (ISIM) that contains the scientific instruments. This paper describes the overall process and strategy of aligning the Observatory in an efficient manner that reduces risk and strives to be tolerant of faults in the system. A process has been developed consisting of ground calibration of the instruments and alignment testing of the fixed optics to ensure that the telescope is alignable in space. The overall architecture of the alignment process and the processes to safely and efficiently conduct the optical commissioning is described.

8442-132, Poster Session

Space qualification of optics for NIRISS onboard JWST

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The Canadian scientific instrument onboard JWST, the Near-InfraRed Imager and Slitless Spectrometer (NIRISS) is equipped with filters and grisms, some of which are make use of non-standard glasses or have no documented space heritage. NIRISS enables four observing modes, the Single-Object Slitless Spectroscopy (G700XD) producing cross-dispersed spectra between 0.6 and 2.5 microns at a resolving power of R=700, the Wide-Field Slitless Spectroscopy (G150) providing R150-spectra between 1 and 2.5µm, the Sparse Aperture Interferometric Imaging for high contrast imaging at small separations and the Broad-Band Imaging (BBI).

The G700XD grism is composed of KRS-5, an infrared (IR) glass often used for Earth-based instruments, lacking heritage as a space-borne material. The G150 grisms have resin-replicated gratings with undocumented response to proton irradiation and cold exposure. One of the BBI filter is a BK7-PK50-BK7 stack filter with AR layers and its susceptibility to cold delamination was a question. This paper presents space qualification tests of some NIRISS optical components (exposition to protons irradiation, cryogenic cycles and humidity test) as well as characterization of grisms performances (Blaze function and Wavefront Error measurement of the G150 and G700XD grisms).

8442-133, Poster Session

Space environment challenges with the tunable Fabry-Perot etalon for the JWST fine guidance sensor

C. Haley, N. Roy, Z. Osman, N. Rowlands, A. D. Scott, COM DEV Canada (Canada)

The Fine Guidance Sensor (FGS) on the James Webb Space Telescope (JWST) has a science observing capability which was to be provided by a tunable Fabry-Pérot etalon incorporating dielectric coated etalon plates with a small vacuum gap. The JWST flight etalon was more challenging than our existing ground-based operational systems due to the low-order gap, the extremely wide waveband and the environmental specifications. The risks associated with operating the flight model etalon in the space environment, along with changes in scientific priorities, resulted in the

etalon being replaced by a grism-based Near Infrared Imager and Slitless Spectrograph (NIRISS). We describe here the performance of the etalon system and the unresolved risks that contributed to our decision to change the flight instrument.

The etalon for the TFI (tunable filter imager) channel of the FGS instrument measures over the wavelength range of 1.6 to 4.9 microns with a spectral resolution of R~100. We present the key components of the etalon system and results from the extensive testing which was performed on the flight model etalon. The separation of the plates is controlled by the Etalon Control Electronics (ECE) board, using piezoelectric actuators (PZTs) and capacitive displacement sensors (CDS). Closed-loop control of the flight etalon was successfully demonstrated at the cryogenic operating temperatures. Difficulties were encountered in providing the required wavelength range due to variability in the mechanical gap after exposure to the vibration, shock and cryogenic cycling environments required on the JWST mission. We present lessons learned and list potential future applications of the etalons developed for JWST FGS.

8442-134, Poster Session

Design status and performance of the James Webb Space Telescope Observatory

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The James Webb Space Telescope (JWST) is NASA's next Flagship astrophysics mission. At the time of this paper, the mission has passed its mission critical design review, with a number of subsystems and components having completed flight manufacture and test. This paper will visit the main features of the JWST Observatory design; the telescope, sunshield, spacecraft bus and integrated science instrument module. The status of the design and where appropriate, the manufacturing status of the flight hardware will be reviewed. This paper will share the current expectations for JWST's on-orbit performance in critical areas and the challenges that lay ahead on the path to assembly integration and test and finally flight.

8442-135, Poster Session

Optical metrology lessons learned during the cryogenic testing of the JWST primary mirror segments

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The James Webb Space Telescope (JWST) primary mirror is 6.5 m in diameter and consists of 18 hexagonal segments, each 1.5 m point-to-point. Each primary mirror segment assembly (PMSA) is constructed from a beryllium substrate with both a radius-of-curvature actuation system and a six degree-of-freedom hexapod actuation system. With the JWST being an infrared observatory, the nominal operational temperature of a PMSA is 45 K. Each PMSA was optically tested at 45 K twice, first to measure the change in the surface figure & radius-of-curvature between ambient & cryogenic temperatures and then to verify performance at cryo following final polishing. This testing was conducted at Marshall Space Flight Center's (MSFC's) X-Ray & Cryogenic Facility (XRCF), which could accommodate six PMSAs per test. This paper will detail several lessons learned regarding the optical metrology system, which consisted of a high-speed interferometer, a computer-generated holographic null, an absolute distance meter, a tiltable window, and an imaging system for alignment. This system was used to measure surface figure error, radius-of-curvature, conic constant, prescription alignment, clear aperture, and the range & resolution of the PMSA actuation systems. Three of the lessons learned are technical and involve (i) performing a tolerance analysis using modeled wavefront data from a distorted exit pupil, (ii) thermal & mechanical issues with a large vacuum chamber window, and (iii) radius-of-curvature versus power adjustment on an off-axis, aspheric mirror segment. The last lesson is programmatic and involves the flow of an engineering development mirror segment with respect to the flight segments.

8442-138, Poster Session

The focal plane camera for fine guidng and NIR survey on SPICA

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The FPC (Focal Plane Camera) is a fine guiding NIR (Near Infrared) camera of the SPICA (Space Infrared Telescope for Cosmology and Astrophysics). The FPC consists of two cameras: one is an FPC-G (FPC Guidence) for fine guiding less than 0.036" at 0.5 Hz, and the other is an FPC-S (FPC Science) for a back-up of the FPC-G and for science oriented observations in NIR. The FPC-G will use I-band (0.8 μm) with a diffuser for stat identification while the FPC-S has 10 filters including 5 wide band filters (J, H, K, L, M), 3 LVFs (Linear Variable Filter) covering from 0.8 to 5.2 um, and the back-up filter for the FPC-G. The FPC-G/S will have the same optical and detector specs by definition. The field of view of the camera is 5 arcmin for wide area observation. We are going to use InSB 1K x 1K IR array from Raytheon, which can be operated below 30 K. The FPC is being considered as a Korean contribution on the SPICA project so KASI (Korea Astronomy and Space science Institute) is leading the conceptual design and the scientific cases of the FPC with Korea/Japan participants.

8442-139, Poster Session

High-resolution and high-precision color-differential astrometry for direct spectroscopy of extrasolar planets onboard SPICA

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We describe the principles and potential of Color-Differential Astrometry (CDA), a high-resolution technique easily implementable on the Science Coronographic Instrument (SCI) of the SPICA satellite, and aimed here at the direct detection and spectroscopy of giant Extrasolar Planets (ESP). By measuring the photocenter of the source diffraction pattern relatively between dispersed spectral channels, CDA gives access to flux ratio and angular information well beyond the telescope resolution limit. Applied to known ESPs, it can yield the inclination (thus the mass) and spectrum of the planet. More generally, it may also apply to any unresolved source with some wavelength-dependent asymetry. In addition to the ESP cases considered for the scientific signal and to their associated fundamental noises, we also present the instrumental effects (such as

the combined effects of pointing errors, beam tip-tilt optical aberations and variations of the detector gain table) that are taken into account for estimating the potential of this method, and some considerations on the apropriate observational strategy. Our estimates show that low-resolution spectroscopy of Jupiter-radius ESP can be measured within a few hours for planets at orbital distances ranging from 0.05 AU to a few AUs, thus complementing the detection range expected using the coronographic measurements. Our numerical simulations are compared with measurements from a dedicated optical test-bench.

8442-140, Poster Session

SPICA/SAFARI Fourier transform spectrometer mechanism evolutionary design

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TNO, together with its partners, has designed a cryogenic scanning mechanism for use in the SAFARI Fourier Transform Spectrometer (FTS) on board of the SPICA mission. SPICA is one of the missions competing to be launched in ESA's Cosmic Vision Programme in 2018 or 2019. It is developed in collaboration with JAXA.

The FTS mechanism (FTSM) has to meet a 35mm linear stroke requirement with an Optical Path Difference (OPD) resolution of less then 15nm and must fit in a small volume. It consists of two back-to-back roof-top mirrors mounted on a small carriage, which is moved using a magnetic bearing linear guiding system in combination with a magnetic linear motor serving as the OPD actuator. The FTSM will be used at cryogenic temperatures of 4K inducing severe challenges on the technologies to be used especially for the OPD metrology system.

The magnetic bearing enables the optics to move in a free-floating way with no friction, or other non-linearities with sub-nanometer accuracy. This solution is based on the design of the breadboard ODL (Optical Delay Line) developed for the ESA Darwin mission and the MABE mechanism developed by Micromega Dynamics.

During the last couple of years the initial design of the SAFARI instrument was adapted by SRON in an evolutionary way to meet the budget requirements of the SPICA payload module. This presentation will focus on the evolution of the FTSM to meet these changing requirements. This work is supported by the Netherlands Space Office (NSO).

8442-141, Poster Session

Recent progress in the development of mid-infrared medium resolution spectrometer (MRS) installed in SPICA/MCS

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Mid-infrared Medium Resolution Spectrometer (MRS) is one of the four modules of Mid-Infrared Camera and Spectrometers (MCS) that will be onboard SPICA. MRS consists of two channels; the shorter wavelength channel (MRS-S) covers the spectral range from 12.2 to 23.0 micron with a spectral resolution power of R~1900-3000 and the longer wavelength channel (MRS-L) covers from 23.0 to 37.5 micron with R~1100-1500 on the basis of the latest results of the optical design. The distinguish functions of the MRS are (1) the dichroic beam splitter installed in the fore-optics, by which the reflected light in 12-23 micron is lead to MRS-S and the transmitted light in 23-38 micron is lead to MRS-L, and (2) the image slicer as the integral field unit installed in each channel. These functions enable us to obtain the successive 12-38 micron spectra of a point source as well as the extended sources within a common field of view. In this presentation, we plan to summarize the expected performance of the MRS and report the latest progress in the development of the key technological elements such as the dichroic beam splitter, filters and the slice mirrors.

8442-142, Poster Session

Experimental and numerical study of stitching interferometry for the optical testing of the SPICA Telescope

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SPICA is a Japan-led infrared astronomical satellite project with a 3.2-m lightweight cryogenic telescope. The SPICA telescope has stringent requirements such as that for the imaging performance to be diffraction-limited at the shortest core wavelength of 5 microns at the operating temperature of 6 K. The design of the telescope system has been studied by the Europe-Japan telescope working group led by ESA with the European industries, the results of which will be presented in other papers. We here present our recent optical testing activities in Japan for the SPICA telescope, focusing on the numerical and experimental study of stitching interferometry. The full pupil of the telescope is covered by a sub-pupil array consisting of small autocollimating flat mirrors (ACFs), which are rotated with respect to the optical axis of the telescope. The ACFs can suffer significant surface deformation in testing the telescope in a thermal vacuum chamber, which is difficult to be measured directly, especially at cryogenic temperatures. We therefore investigate the effects of the imperfections of the ACFs on stitching results. We discuss how to mitigate the effects by proposing a new method to extract errors of the ACFs independently of the wave-front error of the telescope and subtract them prior to the stitching.

8442-143, Poster Session

Cooled scientific instrument assembly onboard SPICA

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The Space Infrared Telescope for Cosmology and Astrophysics (SPICA) is a large (3.2m physical diameter), cooled (below 6K) telescope mission which covers mid- and far-IR astronomy with unprecedented sensitivity. Here we present an overview of recent design updates of the Scientific Instrument Assembly (SIA), composed of the telescope assembly and the instrument optical bench equipped with Focal Plane Instruments (FPIs). We will outline the FPI international science and engineering review, to determine the FPI suite onboard SPICA. We then highlight key technical issues which impact directly on the science requirements, and also consider the impact of the critical issues on observing efficiency.

The current FPI suite will be consolidated based on the international science and engineering review. The baseline FPIs are: a mid-IR coronagraph (SCI), a mid-IR camera and spectrometer (MCS), an imaging Fourier-transform spectrometer operating in the far-IR (SAFARI), and a focal plane camera (FPC) used for fine guidance. The FPC has two channels for redundancy, one of which is proposed for scientific use at the 0.7-5 micron waveband. The US community is proposing a far-IR/submillimetre spectrometer, which is more sensitive than SAFARI but has no imaging capability, and hence can be complementary with SAFARI.

The design of cryogenic chain is one of the most critical issues. The SIA is cooled below 6K without cryogen, but by two sets of 4K-class Joule-Thomson (JT) cooler. Overview of other critical issues, such as temperature stability of the telescope baffle, electromagnetic interference, and pointing disturbance control will also be provided.

8442-145, Poster Session

Detector systems for the mid-infrared camera and spectrometer on board SPICA

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Mid-infrared Camera and Spectrometer (MCS) is one of focal plane instruments for SPICA (Space Infrared Telescope for Cosmology and Astrophysics), which have 3 m class 6 K cooled telescope.

MCS will provide wide field imaging and low-, medium-, and high-resolution spectroscopic observing capabilities with 4 modules in the wavelength range from 5 to 48 micron.

Large format array detectors are required in order to realize wide field of view in imaging and wide spectral coverage in spectroscopy.

We will use Akari and Spitzer heritage of the detector technology, the silicon impurity band conduction (IBC) or blocked impurity band (BIB) array detectors.

We are planing to cover the wavelength range of 5-26 micron by Si:As IBC 2K x 2K, 20-38 micron by Si:Sb BIB 1K x 1K, and 20-48 micron Si:As extended wavelength BIB 1K x 1K.

The most difficult point in designing the SPICA/MCS detector system is its thermal design.

Each detector must operate with a power consumption of 1 mW or less, and thermal conduction through the wiring is not negligible because the cooling power at the focal plane is limited (less than 15 mW at 4.5 K stage).

These detector needs thermal annealing (20 K) in order to recover from damage of cosmic ray hitting and latent image cause by bright sources while its optimized operating temperature is at 6-3 K.

We will describe the current status of development of the detectors and the detector modules.

8442-146, Poster Session

The instrument control unit of SPICA SAFARI: a macro-unit to host all the digital control functionalities of the spectrometer

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SPICA (Space Infrared Telescope for Cosmology and Astrophysics) is a cooperated mission between JAXA and ESA, optimized for mid- and far-infrared astronomy.

We present here the preliminary design of the Instrument Control Unit (ICU)of the SpicA FAR infrared Instrument (SAFARI), an imaging Fourier Transform Spectrometer (FTS) designed to give continuous wavelength coverage in both photometric and spectroscopic modes from around 34 to 210 μm.

Due to the stringent requirements in terms of mass, volume and power budget, the overall SAFARI warm electronics will be composed by only two main units: Detector Control Unit and ICU.

ICU is therefore a macro-unit incorporating the four digital subunits dedicated to the control of the overall instrument functionalities: the Cooler Control Unit, the Mechanism Control Unit, the Digital Processing Unit and the internal Power Supply Unit. To ease the development and integration activities, the mechanical solution adopted to host the 4 sub-boxes is based on the use of four piled up independent drawers, each one hosting one of the instrument digital sub-units. The adopted ICU electrical architecture is based only on external interfaces, both for the power lines and the high speed digital data links: this sort of "plug and play" solution resulted to be the most effective to solve the problems of integrating units developed by different providers.The resulting mechanical structure design and analysis is presented, as well as the preliminary design of the Power Supply Unit.

8442-147, Poster Session

U.S. instrument options for the SPICA Observatory

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NASA has engaged in studying options for a US contribution to the Japanese-led Space Infra-Red Telescope for Cosmology and Astrophysics (SPICA). This cryogenic 3m-class mid-to-far-infrared telescope provides a natural successor platform to the successful Akari and Herschel missions, building on both a scientific and technological legacy. The primary portion of a US contribution would be a far-infrared high sensitivity spectrometer covering approximately the wavelength range of the Herschel instrument suite. On a cryogenic telescope, the line sensitivity would be several hundred times greater, opening up this wavelength range for study at an unprecedented level and detecting emission lines from galaxies at the highest redshifts. The accommodation available for a US instrument is tightly constrained, putting stringent limits on the design. We describe current efforts to formulate an approach that fits within project and programmatic constraints and fulfills the scientific promise of the SPICA observatory.

8442-148, Poster Session

Wideband infrared spectrometer for characterization of transiting exoplanets with space telescopes

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This paper presents a conceptual design for a spectrometer designed specifically for characterizing transiting exoplanets with space-borne infrared telescopes. The design adopting cross-dispersion is intended to be simple, compact, highly stable, and has capability of simultaneous coverage over a wide wavelength region with high throughput. Typical wavelength coverage and spectral resolving power is 1-13μm with a spectral resolving power of ~ a few hundred, respectively. The baseline design consists of two detectors, two prisms with a dichroic coating and microstructured grating surfaces, and three mirrors. Moving parts are not adopted. The effect of defocusing is evaluated for the case of a simple shift of the detector, and anisotropic defocusing to maintain the spectral resolving power. Variations in the design and its application to planned missions are also discussed.

8442-149, Poster Session

Design, space-heritage, and photometric performance of the fast infrared exoplanet spectroscopy survey explorer (FINESSE) spectrometer subsystem

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The next step beyond identification of exoplanets is measurement and investigation of their composition, processes, and diversity. Molecular spectroscopy in the optical wavelength range provides a straightforward yet challenging approach to achieve these objectives. For these distant objects, spectroscopic measurements with broad wavelength coverage, exceptional stability, and high signal-to-noise ratio are required. The FINESSE mission payload uses a high heritage Offner spectrometer that is enabled by a custom convex grating with multi-facet blaze fabricated by electron beam lithography. This spectrometer and grating have recent heritage on the NASA Moon Mineralogy Mapper Discovery Mission and on three other space missions. The FINESSE spectrometer spans the range from 0.7 to 5 microns with 2.5 nm sampling that includes diagnostic absorption/emission bands of water, methane, carbon monoxide, carbon dioxide, and other molecules. A detailed photometric model of the spectrometer performance has been developed that accounts for the full set of signal and noise sources. A FINESSE spectrometer testbed has been developed as well. The model and testbed have been used to test and validate the expected measurement and retrieval performance of FINESSE. The spectrometer design and results from the photometric model and laboratory testbed are presented.

8442-150, Poster Session

The FINESSE payload: a high-stability spectrophotometer for characterization of exoplanet atmospheres

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The Fast Infrared Exoplanet Spectroscopy Survey Explorer (FINESSE) payload is designed to determine molecular abundances in a large-scale survey of transiting exoplanets. FINESSE' single payload is a spectrophotometer purpose built for high relative photometric precision. Key features of the payload are a 76-cm telescope and an instrument package that includes a spectrometer based on Moon Minerology Mapper (M3) and a fine guidance system (FGS) based on Space Interferometery Mission (SIM). The non-imaging spectrometer captures the full 0.7-5.0 µm spectrum (with R ~1000) in a single shot, without filter wheels or switchable grisms. The FGS observes the target star in the 0.6-1.0 µm band and controls a fine steering mirror (FSM) to stabilize the target on the detector. The payload is passively cooled to 120 K, while the spectrometer and focal plane array are actively cooled to 90 and 70 K respectively. The payload is optimized to reduce systematic errors and improve stability by addressing key design drivers: optomechanical stability over a spacecraft orbital period, inter/intra-orbit pointing stability, and the PSF/pixel relation. Additional periodic monitoring of calibration stars allows us to achieve a spectrophotometric measurement precision of better than 100 parts-per-million (ppm) over 8 hours. The paper will describe payload architecture, configuration, and expected performance.

8442-151, Poster Session

Spectroscopy of exoplanet atmospheres with the FINESSE explorer mission

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FINESSE (Fast INfrared Exoplanet Spectroscopic Survey Explorer) will provide uniquely detailed information on the growing number of newly discovered planets by characterizing their atmospheric composition and temperature structure. This Explorer mission concept is unique in its breath and scope thanks to broad instantaneous spectroscopy from the optical to the mid-IR (0.7 - 5 micron) with unprecedented spectrophotometric precision. With broad instantaneous spectroscopy, FINESSE will measure the chemical composition and temperature structure of the exoplanet atmospheres and trace changes over time and with exoplanet longitude and this for 200 newly discovered planets ranging from Terrestrials to Jovians. It will do so by measuring the spectroscopic time series over a single eclipse, for a primary and secondary eclipse, over the exoplanet orbital phase curve and the former repeatedly over time. We will discuss the flow-down from target-selection over scheduling to the analysis and calibration of the data and how it enables FINESSE to be the mission that will open up the new field of comparative exoplanetology. With spectrophotometric precision being a key enabling aspect for combined light exoplanet characterization, we outline how FINESSE achieves a raw spectrophotometric precision of better than 100 parts-per-million per spectral channel without the need for decorrelation. The exceptional stability of FINESSE will even allow the mission to characterize non-transiting planets.

8442-152, Poster Session

The GAIA photometric data processing

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I will present the processing of the dispersed images for the Blue and Red Photometers in the GAIA Satellite. For every photometer, the data are obtained by the overlapping of the two fields of view. The data are first corrected for CCD related effects in the pre-processing: at this step, the conversion from ADU to electrons, the removal of not uniform bias, of background (consisting of astrophysical background and of charge release trail, caused by the charged injections used to mitigate the radiation damage), of the flux by neighbors are performed. The so obtained “clean spectra” are therefore internally calibrated to the same “mean instrument”, to keep into account that observations of the same object on different CCDs differ because of several effects (for example, varying PSFs, dispersion law depending on the position, flux loss due to the limited window and so on). Also the distortion of the dispersed images due to charge transfer inefficiency caused by radiation damage is taken care of. The mean spectrum will be finally externally calibrated to obtain spectrum and flux in physical units, which will be stored in the final catalogue.

8442-153, Poster Session

High precision astrometry laboratory demonstration for exoplanet detection using a diffractive pupil

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Detection of earth-size exoplanets using the astrometric signal of the host star requires sub microarcsecond measurement precision. One major challenge in achieving this precision using a medium-size (<2-m) space telescope is the calibration of dynamic distortions. We propose a diffractive pupil technique that uses an array of approximately 50µm dots on the primary mirror, generating polychromatic diffraction spikes in the focal plane. The diffraction spikes encode distortions in the optical system and are used to calibrate astrometric measurements. This concept can be used simultaneously with coronagraphy for exhaustive characterization of exoplanets (mass, spectra, orbit). In this paper we present the design and results of the high precision astrometry laboratory developed at the University of Arizona to demonstrate the diffractive pupil concept. We evaluated the technique by introducing distortions in the imaging system and measuring the astrometry of a simulated host start. We also present the results of testing the diffractive pupil with the high contrast PIAA coronograph at NASA Ames. We found that the diffraction spikes did not introduce contamination in the inner working angle of the coronograph within a contrast level of 10-6, and no evidence of contamination at larger contrast levels was found. Moreover, we found the predicted diffraction pattern well outside the coronagraph field of view.

8442-154, Poster Session

Supplementary information on the near infrared spectroscopic data of the infrared camera (IRC) onboard AKARI

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We have investigated the on-orbit properties of the spectroscopic data taken with NIR channel of the Infrared Camera (IRC) onboard AKARI during the phases 1, 2 and 3. We examined the wavelength dependency on the point spread function size and its effect on the spectroscopic data. This information is useful in reducing the spectroscopic data of a point source badly affected by bad pixels and in decomposing the overlapping spectra of sources that are unfortunately aligned in the dispersion direction. We also have determined the boundary shapes of the aperture mask of NIR channel by using the spectroscopic data of uniform zodiacal background emission. Moreover, the relative strengths of the 0th to 1st order light as well as the efficiency profiles of the 2nd order light of the NIR grism data are obtained. These results are useful in modeling and subtracting the spectroscopic background patterns made by the diffuse background emission such as zodiacal emission and the Galactic cirrus emission. In this paper we summarize the supplementary knowledge that will be useful for the advanced data reduction procedures of NIR spectroscopic datasets.

8442-155, Poster Session

Herschel-SPIRE satellite instrument: configurable on-board software for autonomous and real time operation

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The Herschel SPIRE On-Board Software (OBS) is presented. It is a real-time software application that implements the scientific data transmission and the control layer between the SPIRE mission time line commands and the real instruments status. It embeds a multi-threaded engine that interprets Control-Procedures for the detectors and mechanisms subsystems of the SPIRE instrument. A specifically developed low level language is used to codify the Control-Procedures, whose execution timing is driven by a set of software timers. In addition, for more stringent timing needs, a specific interpreter is linked to an HW timer reaching a precision of the order of few microseconds in the execution of each single command. An autonomous monitoring agent keeps control of subsystems status using the corresponding housekeeping information, and takes local decisions based on pre-loaded reaction maps. The behaviour of low level system functions is configurable by additional reaction maps and control procedures. This software is size optimized in a small footprint SW image and is stored in an addressable program area of 128Kw at 48bit. Testing procedures were done on an emulated guest environment and then integrated on the real architecture: Analog Devices ADSP21020 ® / Eonic Virtuoso®, with a communication layer based on MIL-STD-1553B medium. The implemented test environment/simulator is presented as well.

8442-156, Poster Session

ACCESS: design and test performance

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Improvements in the precision of the astrophysical flux scale are needed to answer fundamental scientific questions ranging from cosmology to stellar physics.

ACCESS, Absolute Color Calibration Experiment for Standard Stars, is a series of rocket-borne sub-orbital missions and ground-based experiments that will enable improvements in the precision of the astrophysical flux scale through the transfer of absolute laboratory detector standards from the National Institute of Standards and Technology (NIST) to a network of stellar standards with a calibration accuracy of 1% and a spectral resolving power of 500 across the 0.35 to 1.7 micron bandpass.

The telescope is a Dall-Kirkham Cassegrain with a 15.5-inch primary. The spectrograph is a Rowland circle design, with the grating operating as a low order (m=1-4) echelle. A Fery prism provides cross dispersion, and a HST/WFC3 heritage HAWAII-1R HgCdTe detector is used across the full spectral bandpass.

The telescope mirrors have received their flight coatings. Flight detectors have been selected and initial detector performance is being checked. The detector subsystem is undergoing mechanical tests. Detailed ground based characterization of the detector is expected to begin early spring. Fabrication, integration, and automation of the ground-based calibration subsystem is in progress.

The ACCESS design, calibration strategy, and ground-based integration and test results will be presented. Launch is expected within the year.

NASA sounding rocket grant NNX08AI65G and DOE DE-FG02-07ER41506 support this work.

8442-157, Poster Session

Nano-JASMINE: degradation of charge-coupled device performance and centroid detection

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We have studied the changes in the charge-coupled device (CCD) characteristics employed in Nano-JASMINE, as a result of their performance degradation due to high-energy cosmic radiations encountered in the satellite orbit. It is quite important to achieve high-precision astrometry to establish the technique for correctly measuring stellar image centroids because the performance degradation of a CCD may distort the stellar image profiles.

Nano-JASMINE is a very small astrometry satellite that is ready for launch. It can perform all sky surveys and measure positions of bright stars with an accuracy of 3 mas in an operation period of more than two years in a low earth orbit. The satellite is equipped with a fully depleted 1k x 2k p-channel CCD (Hamamatsu-photonics) operating in the time and delay integration mode. It is anticipated that the cosmic radiation in the orbit will degrade the CCD performance over the observation time. To evaluate the degree of this degradation, we conducted proton and gamma ray irradiation experiments and found an increase in both dark current and charge transfer inefficiency with time. A decrease in the charge transfer efficiency is also observed. The performance degradation on charge transfer action which will distort stellar image profile and cause unwanted errors on centroid detections. In order to avoid these errors, we measured detailed pixel response functions and evaluated the output stellar image profile for both radiation-damaged and undamaged CCDs. We confirmed the validity of this technique by comparing the results of software and hardware stellar image simulation under various signal conditions.

8442-158, Poster Session

SPEX: a remote sensing spectropolarimeter for characterizing planetary aerosols, clouds, and surfaces

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SPEX, the Spectropolarimeter for Planetary EXploration, is a compact, robust and low-mass multi-viewing angle spectropolarimeter designed to operate from an orbiting satellite platform. Its purpose is to simultaneously measure, with high accuracy, the radiance and the state (degree and angle) of linear polarization at optical wavelengths of sunlight scattered in a planetary atmosphere and/or reflected by a planetary surface. In particular the degree of linear polarization is extremely sensitive to the microphysical properties of atmospheric or surface particles. Spectropolarimetric measurements as performed by SPEX are therefore crucial for disentangling the many parameters that describe planetary atmospheres and surfaces.

SPEX uses a novel technique for its radiance and polarization measurements: the instrument transforms the observed spectrum of scattered sunlight into a spectrally modulated spectrum. The amplitude and phase of the modulation are proportional to the degree and angle of linear polarization respectively. The technique is entirely passive, i.e. there are no moving parts or active components employed to establish the polarization modulation.

We will address in detail SPEX' novel spectral modulation technique and discuss its advantages in comparison with more traditional polarimetric techniques. We will present our recently developed prototype instrument, with emphasis on the performance critical elements, and show test results that demonstrate excellent performance and overall behavior. In particular, we find that the prototype instrument has a degree of linear polarization sensitivity of about 0.0002, which is better than the design target. On-ground measurements of the Earth's blue sky indicate that SPEX has the potential to deliver high quality aerosol parameters.

8442-159, Poster Session

To PLAnetary transit or NOT? An extremely large field of view camera with a CaF2 component tested in thermo-vacuum

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Because of its nicely chromatic behavior, Calcium Fluoride (CaF2) is a nice choice for an optical designer as it can easily solve a number of issues, giving the right extra degree of freedom in the optical design tuning. However, switching from tablet screens to real life, the scarcity of information -and sometimes the bad reputation in term of fragility- about this material makes an overall test much more than a "display determination" experiment. We describe the extensive test performed in ambient temperature and in thermo-vacuum of a prototype, consistent with flight CTEs, of a 200mm class camera envisaged for the PLATO mission. We show how the CaF2 lens uneventfully succeeded to all the test and handling procedures, and discuss the main results of the very intensive test campaign of the PLATO Telescope Optical Unit prototype.

8442-160, Poster Session

Habitable planet finder

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A notional space telescope configuration is presented that addresses issues of angular resolution, spectral bandwidth and rejection of host star glare by means of a double dispersion architecture. The telescope resolves angle by wavelength. In an earlier embodiment for surveys, a primary objective grating telescope architecture was shown to acquire millions of objects in one observation cycle, one wave length at a time. The proposed HPF can detect exquisite spectral signatures out of millions of wavelengths in albedos - one exoplanetary system at a time. Like its predecessor, the new HPF telescope has a ribbon-shaped flat gossamer membrane primary objective that lends itself to space deployment, but the preferred embodiment uses a holographic optical element primary objective rather than a plane grating. The HOE provides an improvement in efficiency at select wavelength bands. The considerable length of the membrane can be in the 100 meter class providing angular resolution sufficient to resolve planets in the habitable zone and also spectral resolution sufficient to earmark habitability. A novel interferometric secondary spectrograph rejects host star glare. However, the architecture cannot disambiguate multiple stellar sources and may require unprecedented focal lengths in the primary objective to isolate one system at a time.

8442-161, Poster Session

NanoSpec: a diffraction limited microspectrograph for nano- and pico-satellites

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Here we present a novel photonics-based spectrograph (NanoSpec) designed for integration in the 0.75kg i-INPSIRE satellite at the University of Sydney. NanoSpec is a single mode fibre-fed spectrograph operating very close to the diffraction limit in the visible (450nm to 700nm). By feeding the spectrograph with single mode (and thus diffraction limited) fibres we are able to build an extremely small spectrograph while maintaing a useful spectral resolution. Configured for the i-INSPIRE satellite it achieves a diffraction limited resolving power ($lambda/ Deltalambda$) of 600. The primary goal of NanoSpec is to demonstrate the potential of photonics-driven technology in high altitude and space-based applications. To that end we present the first spectra collected on board the i-INSPIRE satellite and from a short high altitude weather ballon test. These spectra have been used to identify features related to the Earth, Sun and the effects of radiation events on the device. We will also describe the mechanical design of spectrograph and the testing and verification completed in during integration and preparation for launch.

8442-162, Poster Session

Space mission Millimetron for THz astronomy

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We present an overview and current status of the space mission Millimetron. Millimetron - a large 10-m diameter space cooled telescope optimized for operation in the submillimeter and far-infrared ranges. This mission will be able to contribute into solution of several key problems in astrophysics such as study of the formation and evolution of stars and planets, galaxies, quasars and many others. The telescope will have an unprecedented sensitivity in single dish observing mode. It will have an unprecedented high spatial resolution, as an element of a space-earth VLBI system. The mission will have a cryogenic instruments and antenna which will be cooled passively with heat shields and actively with mechanical coolers. With this cooling combination 10-m space telescope may reach the end temperature as low as 4.5K. The planned launch year of the mission is 2017+.

8442-163, Poster Session

An optical design study of future THz heterodyne instrumentation

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A wealth of high spectral resolution astronomical data has and will become available by large ground and space-based astronomical observatories in the far-infrared domain like Herschel-HIFI, SOFIA and ALMA addressing key questions related to the formation of stars, planets and evolution of galaxies. Whereas the science goals of missions like JWST and SPICA can be targeted with ultimate sensitivity and medium spectral resolution, a next generation instrumentation will eventually require high resolution spectroscopy with R ≈ 107 to 108 at far-infrared wavelengths to probe the physical conditions and chemistry involved in for example star formation processes. In addition to improved spatial resolution and frequency extension into the 2-6 THz range a natural extension to state-of-the-art single pixel heterodyne instrumentation will be the application of small imaging arrays improving the overall mapping and observing efficiency.

In this paper we present the results of an optical design study into future heterodyne instrumentation. As a specific case we propose an instrument concept which can for example be applied to the Russian Millimetron mission. Inspired by Herschel-HIFI we describe here a highly flexible and modular optical design. With front optics common to all receiver bands this system enables operation of small and compact THz heterodyne focal plane arrays and provides dual-polarization and/or dual-frequency observing capabilities. As future missions most likely feature a cooled telescope with complementary payload instrumentation requiring low thermal backgrounds special attention has been paid to the thermal architecture in relation to the Local Oscillator injection scheme.

8442-164, Poster Session

Optical telescope BIRT in ORIGIN for high-Z gamma ray burst observing

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The ORIGIN concept is a space mission with a gamma ray, an X-ray and an optical telescope to observe the gamma ray bursts at large Z to determine the composition and density of the intergalactic matter in the line of sight. It was an answer to the ESA M3 call for proposals. The optical telescope is a 0.7-m F/1 with a very small instrument box containing 3 instruments: a slitless spectrograph with a resolution of 20 on a 6' x 6', a multi-imager giving images of a 1' x 1' field in 4 bands simultaneously, and a cross-dispersed Échelle spectrograph giving a resolution of 1000. The wavelength range is 0.5 to 1.7 µm. All instruments fit together in a box of 80 mm x 80 mm x 200 mm. The low resolution spectrograph uses a very compact design of a special triplet that contains spherical surfaces except for one tilted cylindrical surface to disperse the light. To reduce the need for a high precision pointing, an Advanced Image Slicer was added in front of the high resolution spectrograph which uses a simple design with only one mirror as the collimator and camera simultaneously. The Imager contains dichroics to separate the bandwidths and glass thicknesses to compensate the differences in path length. All 3 instruments use the same 2k x 2k detector simultaneously. Telescope pointing and tip-tilt control of a fold mirror permit to place the gamma ray burst on the desired instrument without any other mechanism.

8442-165, Poster Session

CubeSat Deformable Mirror Demonstration Mission

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We present a detailed mission design, called the CubeSat Deformable Mirror Demonstration, whose goal is to characterize the performance of a small deformable mirror over a year in low-Earth orbit. Small form factor deformable mirrors are a key technology needed to correct optical system aberrations in applications such as space-based direct imaging of exoplanets with coronagraphic telescopes. They can also improve distortions and reduce bit error rates for low-power space-based laser communications. While we envision future development of a generic 3U CubeSat platform capable of testing several different mirrors, our first design accommodates a 32-actuator Boston Micromachines MEMs

deformable mirror.

Our approach is simple in order to accommodate all components within the tight mass, volume, and power requirements of a 3U CubeSat (the CubeSat platform allows access to piggyback on a primary payload for launch, and targets university student research). The payload consists of a coherent internal light source directed to the deformable mirror, then split to a Shack-Hartmann wavefront sensor and a detector. The descope option is use a Michelson interferometer approach instead of a wavefront sensor. We will continuously run an optimized set of configurations on the deformable mirror over the mission to characterize on-orbit performance. The MIT Space Systems Lab has expertise in building CubeSat platforms, and we have allocated 1.5U of the 3U CubeSat to the payload. This design has minimal requirements for pointing and attitude control (just for power and communications) but we will develop interfaces with the needs of higher-accuracy future missions in mind.

8442-166, Poster Session

Atmospheric characterization of cold exoplanets with a 1.5-m space coronagraph

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Several small space coronagraphs have been proposed to characterize cold exoplanets in reflected light. Studies have mainly focused on technical feasibility because of the huge star/planet flux ratio to achieve in the close-in stellar environment (10^8 - 10^10 at 0.2”). However, the main interest of such instruments, the analysis of planet properties, has remained highly unexplored so far. We performed numerical simulations to assess the ability of a small space coronagraph to retrieve spectra of mature Jupiters, Neptunes and super-Earths under realistic assumptions. We describe our assumptions: exoplanetary atmosphere models, instrumental numerical simulation and observing conditions. Then, we define a criterion and use it to determine the required exposure times to measure several planet parameters from their spectra (separation, metallicity, cloud and surface coverages) for particular cases. Finally, we attempt to define a parameter space of the potential targets. In the case of solar-type star, we show that a small coronagraph can characterize the metallicity of a Jupiter up to 10 pc and the cloud and surface coverages of a super-Earth up to 4-5 pc.

8442-167, Poster Session

Starshade design driven by stray light from the edges of the occulter

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The use of an external occulter has been proposed as one method for the direct detection and spectral characterization of terrestrial planets around other stars, a key goal identified in ASTRO2010. Because of the observational geometry, one of the concerns is stray light from the edge of the occulter that is scattered into the line of sight of the telescope. We have developed a stray light model using physical properties of a realizable occulter edge geometry and material to calculate the resulting stray light. The background signal due to stray light has been calculated for the two telescope architectures adopted for study by the Exoplanet Exploration Program Analysis Group (ExoPAG), a 4 m monolithic and an 8 m segmented mirror design. Using these results, we have developed a set of design requirements and structure features that will result in a buildable system with stray light levels that meet the overall system sensitivity requirements.

8442-169, Poster Session

The main power and processing unit for the METIS coronagraph aboard the Solar Orbiter Space Mission

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The Multi Element Telescope for Imaging and Spectroscopy (METIS), is the Coronagraph selected for the Solar Orbiter payload, adopted in October 2011 by ESA for the next Implementation Phase. The instrument design has been conceived by a team composed by several research Institutes with the aim to perform both VIS and UV narrow-band imaging and spectroscopy of the solar corona. METIS, owing to its multi-wavelength capability, will address some of the major open issues in understanding the physical processes in the corona and the solar wind origin and properties, exploiting the unique opportunities offered by the SO mission profile.

The Main Power and Processing Unit (MPPU) is the Instrument’s power supply and on-board data handling modular electronics, designed to address all the scientific requirements of the METIS Coronagraph. MPPU manages data and command flows, the timing and power distribution network and its architecture is conceived by several trade-off solutions in order to reduce any possible electronics single-point failure. This paper will present the selected HW architecture and the Application SW database baseline structure adopted after the Preliminary Design Review (PDR), performed by ESA in early 2012.

8442-170, Poster Session

Stray light control for asteroid detection at low solar elongation for the NEOSSat Micro-Satellite Telescope

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The Near Earth Object Surveillance Satellite (NEOSSat) is a small satellite dedicated to finding near Earth asteroids. Its surveying strategy consists of imaging areas of the sky to low solar elongation, while in a sun synchronous polar orbit (dawn-dusk). A high performance baffle will control stray light mainly due to Earth shine. Observation scenarios require solar shielding down to 45 degree solar elongation over a wide range of ecliptic latitudes. In order to detect the faintest objects (approx 20th v mag) given a 15 cm telescope and CCD detection system, background from stray light is a critical operational concern. The required attenuation is in the order of 10e-12. The requirement was verified by analyses; testing was not attempted because the level of attenuation is difficult to measure reliably. We report consistent results of stray light optical modeling from two independent analyses. Launch is expected for April 2012 and commissioning results may be presented.

8442-171, Poster Session

Determination of ghost images for the wide-angle camera of the Rosetta ESA Mission

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Rosetta is a cornerstone mission of the European Space Agency (ESA); it has been launched in March 2004 and it will reach its primary target, the 67P/Churyumov Gerasimenko comet, in 2014.

One of the Rosetta instruments is the OSIRIS camera system, composed of a Wide Angle Camera (WAC) and a Narrow Angle Camera (NAC). The NAC will observe at high resolution regions on the comet surface, while the WAC, 12°x12° FoV, has been mainly designed for observing the weak coma features surrounding the bright comet nucleus. Being the expected contrast between the gas and dust jets radiance and the nucleus one of the order of 1/1000, a high contrast capability is required for the WAC camera. To be able to meet this requirement, its optical design is off-axis and unobstructed; and to deeply study gas and dust emissions, the camera is equipped with 14 filters, each with its proper wavelength selection characteristics, in the range 230-720 nm.

The theoretical achievable contrast capability is limited by multiple ghost images generated by the optical elements in the focal plane assembly, in fact the incoming beam is partially reflected on the surfaces of the filters, on the detector radiation protective glass cover and on the CCD detector itself.

Given that the knowledge of ghost position and intensity is essential for an adequate scientific data reduction, in this paper an analysis of the ghosts, the solutions adopted to limit image degradation and the impact on the WAC imaging performance are presented.

8442-172, Poster Session

SOLAR-T: terahertz photometers to observe solar flare emission on stratospheric balloon flights

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A new solar flare spectral component has been found with intensities increasing for larger sub-THz frequencies, spectrally separated from the well known microwaves component, bringing challenging constraints for interpretation. Higher THz frequencies observations are needed to understand the nature of the mechanisms occurring in flares. A two-frequency THz photometer system was developed to observe outside the terrestrial atmosphere on stratospheric balloons or satellites, or at exceptionally transparent ground stations. Two 76 mm diameter telescopes were designed to observe the whole solar disk detecting small relative temperature changes caused by flares at localized positions at 3 and 7 THz. Golay cell detectors are preceded by low-pass filters to suppress visible and near IR radiation, band-pass filters, and choppers. It can detect temperature variations smaller than 1 K with time resolution of a fraction of a second, corresponding to small burst intensities. The telescopes are being assembled in a thermal controlled box to which a data conditioning and acquisition unit is coupled. While all observations are stored on board, a telemetry system will forward solar activity compact data to the ground station. The experiment is planned to fly on board of long-duration stratospheric balloon flight, coupled to the GRIPS gamma-ray experiment in cooperation with University of California, Berkeley, US. One engineering flight is scheduled for fall 2012 in the USA, and a 2 weeks flight over Antarctica in 2013-2014. Another long duration stratospheric balloon flight over Russia (one week) is planned in cooperation with the Lebedev Physics Institute, Moscow (2015-2016).

8442-173, Poster Session

Echoes: a new concept of spectro-imaging for Jovian seismology

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Echoes is a project of a space-borne instrument which is proposed as part of the JUICE Mission competing in the Cosmic Vision program of the European Space Agency (ESA). It is a Fourier Tachometer dedicated to perform seismic and dynamics studies of Jupiter's interior and atmosphere. Based on a Mach-Zehnder design, the instrumental principle consists in measuring Doppler shift of solar spectral lines, which are reflected by cloud layers of Jupiter's upper troposphere, coupled with imaging capabilities. The scientific specifications require the noise level to be lower than 1 $cm^2s^{-2}\mu Hz$-1 in the frequency range [0.5 -10] mHz and the spatial resolution to be about 200 km. In this paper, we present the prototype which is currently developed at Observatoire de la Côte d'Azur in collaboration with Institut d'Astrophysique Spatiale, to test the real instrumental performance. In particular, we have to demonstrate the operating capabilities in space environment by reaching the requested Technology Readiness Level 5 for the instrument and its components. We present the first results obtained in terms of wavefront quality, transmission, polarisation and control of the thermal stability of the optical path difference.

8442-174, Poster Session

Preliminary internal straylight analysis of the METIS instrument for the Solar Orbiter ESA Mission

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METIS, the Multi Element Telescope for Imaging and Spectroscopy, is the solar coronagraph foreseen for the Solar Orbiter mission. METIS is conceived to observe the solar corona from a near-Sun orbit in three different spectral bands: in the HeII EUV narrow band at 30.4 nm, in the HI UV narrow band at 121.6 nm, and in the visible light band (500 - 650 nm). The visible light from the corona is ten million times fainter than the light emitted by the solar disk, so a very stringent light suppression design is needed for the visible channel.

METIS adopts an "inverted occulted" configuration, where the disk light is shielded by an annular shape occulter, after which an annular

aspherical mirror M1 collects the signal coming from the corona. The disk light heading through the central hole of M1 is back-rejected through the same M1 hole by a suitable spherical mirror.

This paper presents the stray light analysis for this new-concept configuration, performed with the aim of identifying the source of noise in the opto-mechanical structure, and the modifications to be implemented for the suppression of the stray light magnitude below the limit of 10^2 times the coronal signal intensity. A model of the optics and of the mechanical parts of the telescope has been realized with ASAP (Breault Research TM); through an out-of-field ray tracing simulation the critical elements were identified, suggesting enhancements to the original design and the implementation of an effective light trapping structure.

8442-175, Poster Session

THERMAP: a mid-infrared spectro-imager based on an uncooled micro-bolometer for space missions to small bodies of the solar system

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We report on the feasibility study of a mid-infrared (8-18 µm) spectro-imager called THERMAP, based on an uncooled microbolometer detector array. Due to the recent technological developments of these detectors, which have undergone significant improvements in the last decade, we wanted to test their capabilities for the Marco Polo R ESA Cosmic Vision mission. In this study, we demonstrate that the new generation of uncooled microbolometer detectors has all the imaging and spectroscopic capabilities to fulfill the scientific objectives of this mission.

To test the imaging capabilities of the detector, we built an experiment based on a 640x480 ULIS microbolometer array, a germanium lense and a black body. Using this experiment, we show that calibrated radiometric images can be obtained down to at least 258 K (lower limit of our experiment), and that two calibration points are sufficient to determine the absolute scene temperature with an accuracy better than 1 K. Extrapolation to lower temperature should allow to measure the temperature down to 180 K with an accuracy of ~5 K. Adding flux attenuating neutral density mid-infrared filters (transmittance : 50%, 10%, 1%) to our experiment, we were able to evaluate the spectroscopic performances of the detector. Our results show that we can perform spectroscopic measurements with a spectral resolution of R~100 at 350 K, the typical surface temperature of a Near Earth Asteroid at 1 AU from the Sun.

The mid-infrared spectro-imager THERMAP, based on the above detector, is therefore well suited to the Marco Polo R mission.

8442-176, Poster Session

Image stabilisation system of the photospheric and helioseismic imager

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The Photospheric and Helioseismic imager (PHI) on board of the ESA mission Solar Orbiter, to be launched in 2017, will provide measurements with high polarimetric accuracy of the photospheric solar magnetic field at high solar altitudes. The needed accuracy requires an image stabilisation (ISS) to compensate for spacecraft jitter. The image stabilisation system works as a correlation tracker with a high-speed camera and a fast steerable mirror. The opto-mechanical and electronic design of the system will be presented.

8442-177, Poster Session

Studies on the HCIT broadband contrast performance: effects of dust-particles and dependence on the number of actuators used

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The High Contrast Imaging Testbed (HCIT) at the Jet Propulsion Laboratory employs a broadband wavefront correction algorithm called Electric Field Conjugation (EFC) to obtain the required 10-10 contrast. We have investigated the effects of partially-reflecting dust-particles on the surface of an optic on the efficiency of the EFC algorithm in a Lyot coronagraph configuration. We have also studied how much the broadband contrast performance of the HCIT degrades when the number of actuators used are decreased by connecting 1x2, 2x2 and 3x3 actuators togerther. The structural design of the optical system as well as the parameters of various optical elements used in the analysis are drawn from those of the HCIT system that have been implemented with one DM. The simulation takes into account the surface errors of various optics. The optical simulation algorithm uses MACOS (Modeling and Analysis for Controlled Optical Systems) as its analytic tool. Hence it is capable of performing full three-dimensional near-field diffraction analysis on HCIT's optical model. Results of some of these studies will be verified by actual measurements.

8442-178, Poster Session

A wavefront control approach to segment diffraction for high-contrast imaging

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The exquisite angular resolution of segmented extremely large telescopes will provide astronomers with unique science opportunities in exoplanet imaging, from the ability to characterize the birth of exoplanets in star-forming regions to the direct detection of mature exoplanets in reflected light. On-axis segmented telescopes also allow to deploy larger apertures when seeking to image exo-earths from a space based observatory. However such apertures complicate the design of coronagraphic solutions for high-contrast instruments. While fill factor is a crucial figure of merit- e.g. many small segments with small gaps greatly simplify coronagraphic designs compared to a few large segments with large gaps- the static contrast is ultimately limited by optical artifacts due to the image of the segments gaps leaking through the starlight suppression system. Recent developments have shown how to accommodate segmented geometries using tailored coronagraphic designs (such as the generalized APLC and double stage Optical Vector Vortex Coronagraph). The successful implementation of such solutions at the very high contrast level can potentially degrade throughput and render the whole starlight suppression system more sensitive to both manufacturing and segments phasing errors. In this paper we propose an alternative solution that treats secondary support structures and segment gaps as a special case of reflectivity errors, with favorable spatial frequency properties but very high amplitude. Since reflectivity errors will have to be controlled even for a monolithic high-contrast system we argue that one can take advantage for the same starlight suppression system to accommodate for segmented on-axis geometries. We present the results of a numerical study which includes two sequential deformable mirrors as an extra degree of freedom in the design of the coronagraphic solution.

8442-179, Poster Session

The achromatic chessboards: a new concept of phase shifter for nulling interferometry

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Today, the search for Earth-like planets and extraterrestrial life is aimed at by many astronomers. To detect bio-tracers in the planet's atmosphere, one has to measure its spectrum, which require the direct detection of the planet. One possible way is nulling interferometry ability to cancel a large part of the star's light, which implies an achromatic phase shift of π in one arm of a multi-telescopes interferometer. We devised a new phase shifter, which achieves theoretically the proper requirements in terms of contrast and spectral range. It is made of two "chessboard" mirrors (or glass plates), each placed in one arm of the interferometer, composed of several cells with different thicknesses introducing phase shifts that are odd and even multiples of half of a chosen wavelength. This phase shifter is currently used on the bench DAMNED (Dual Achromatic Mask for Nulling Experimental Demonstrator) in order to confront theoretical prediction with experimental results. We present here the results in terms of actual achromatic nulling, for two phase shifters: one made with bulk optics (glass plate) and one using an adjustable segmented mirror.

8442-180, Poster Session

Hybrid coronagraph laboratory testing

N. J. Kasdin, T. D. Groff, A. Carlotti, Princeton Univ. (United States)

Although phase and amplitude aberrations are known to limit the effective contrast of any coronagraph to values as low as 10^6, a contrast of 10^10 will be required to image and characterize Earth-like planets. As a consequence, a wavefront control system capable of phase and amplitude corrections is mandatory. In our high-contrast imaging laboratory, we have been testing a shaped pupil coronagraph together with two deformable mirrors in series to control both types of wavefront aberrations. While the shaped pupils have initially been optimized to provide contrast of 10^10 in an unaberrated system, we recently realized that coronagraphic masks do not need to be designed for contrast higher than the limit set by the optical aberrations. In a similar way to what can be achieved with a pupil mapping system, the deformable mirrors in series can be used not only to correct for aberrations but also to push the contrast beyond that limit. To demonstrate this is possible, we have designed a shaped pupil for a contrast of 10^5 at 2 lambda/D from the star and used it in our high-contrast imaging laboratory in Princeton to increase the contrast up to 10^7. Future work as part of a recently awarded Technology Demonstration for Exoplanet Missions study will move the experiments to the High Contrast Imaging Testbed at the Jet Propulsion Laboratory and push toward a contrast of at least 10^9.

8442-181, Poster Session

Kalman filter estimation for focal plane wavefront correction

T. D. Groff, N. J. Kasdin, Princeton Univ. (United States)

Space-based coronagraphs for future earth-like planet detection will require focal plane wavefront control techniques to achieve the necessary contrast levels. These correction algorithms are iterative and the control methods require an estimate of the electric field at the science camera, which requires nearly all of the images taken for the correction. We demonstrate a Kalman filter estimator that uses prior knowledge to create the estimate of the electric field, dramatically reducing the number of exposures required to estimate the image plane electric field. In addition to a significant reduction in exposures, we discuss the relative merit of this algorithm to other estimation schemes, particularly in regard to estimate error and covariance. As part of the reduction in exposures we also discuss a novel approach to generating the diversity required for estimating the field in the image plane. This uses the stroke minimization control algorithm to choose the probe shapes on the deformable mirrors, adding a degree of optimality to the problem and once again reducing the total number of exposures required for correction. Choosing probe shapes has been largely unexplored up to this point and is critical to producing a well posed set of measurements for the estimate. Ultimately the filter will lead to an adaptive algorithm which can estimate physical parameters in the laboratory and optimize estimation.

8442-182, Poster Session

Phase induced amplitude apodization (PIAA) coronagraphy: recent results and future prospects

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Thanks to the use of aspheric optics for lossless apodization, the Phase Induced Amplitude Apodization (PIAA) coronagraph offers full throughput, high contrast and small inner working angle. It is therefore ideally suited for space-based direct imaging of potentially habitable exoplanets.

The concept has evolved since its original formulation to mitigate manufacturing challenges and improve performance. Our group is currently aiming at demonstrating PIAA corography in the laboratory to 1e-9 raw contrast at 2 lambda/D separation. Recent results from the High Contrast Imaging Testbed (HCIT) at NASA JPL demonstrate contrasts about one order of magnitude from this goal at 2 lambda/D.

In parallel with our high contrast demonstration at 2 lambda/D, we are developing and testing new designs to reduce inner working angle and improve performance in polychromatic light. Some of these new PIAA designs have been tested that can further mitigate PIAA manufacturing challenges while providing theoretically total starlight extinction and offering full throughput with inner working angles less than 1 lambda/D. Recent tests have indeed demonstrated on the order of 1e-6 contrast close to 1 lambda/D, while maintaining better contrast at 2 lambda/D.

8442-183, Poster Session

Count rate non-linearity in near infrared detectors: inverse persistence

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The count rate non-linearity of near-infrared devices was first found in the HST NICMOS. In this report we present a physical model of the cause of this effect in JWST NIR detectors, show how it is related to persistence, and compare the predictions of the model to other observations of anomalous detector behavior. This model is able to not only explain the count rate non-linearity but also several other effects. .

The underlying cause of the count rate non-linearity is the capture of charge by empty traps in the free charge region of the pixels. These traps that capture charge then release the charge in subsequent exposures leading to persistence. These empty traps can also be moved into the free charge region by changing the bias on the detector. In that case we actually observe a negative persistence effect as charge is lost into the traps.

Overall, the excellent agreement between this model and the observations gives us strong confidence that we understand the underlying cause of the count rate non-linearity and should allow us to develop methods to accurately calibrate and remove the effect from JWST observations.

8442-185, Poster Session

Photometry of infrared space telescope images using the grid PRF method Dphot

D. G. Elliott, Jet Propulsion Lab., Retired (United States)

The paper presents results of the Dphot photometry method for multiple, overlapping, crowded-field images from the Infrared Array Camera (IRAC) on the Spitzer Infrared Space Telescope. Dphot fits point response functions (PRFs) at closely-spaced fixed grid points over an area of the observations. There is no PRF position initialization using a coadded mosaic in which the telescope images are shifted and averaged to make images visible above the background noise. Instead, the PRFs in Dphot are close enough together to put one or more PRFs a short distance from any measurable source. The flux densities and positions of detected sources are then found by summing and centroiding adjacent PRF detections. The paper explains the method using simulated data for a pair of closely-spaced sources. Then examples of Dphot photometry are presented for data from IRAC. Details of the photometry steps in crowded fields are presented for star cluster 47 Tuc, where the measured star positions are shown to agree with star postions in a Hubble Telescope mosaic. Dphot results for a crowded star field in the Galactic Center are presented, showing agreement with the sources in a published IRAC source list plus numerous additional detections by Dphot. Detection of lensed images is illustrated for the Einstein Cross. Dphot also measures the size, shape, and flux density of extended objects, as illusrated using data from deep observations of galaxies in GOODS North.

8442-186, Poster Session

Phase retrieval on extended sources in the visible and infrared

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An iterative Fourier-transform algorithm was implemented to reconstruct the phase function of an imaging system using a point source (a single mode fiber) and extended sources (pinholes) as the object. The results indicate that as the object's size is increased the phase retrieval is largely unaffected until it grows to a critical diameter. At this point the phase retrieval results become highly unstable. The critical diameter at which this transition occurs is considerably smaller than predicted by the Rayleigh criterion. In this paper, we will present a detailed description of the imaging system, the source objects and the experimental results.

8442-187, Poster Session

Investigation on the high efficiency volume Bragg gratings performances for spectrometry in space environment: preliminary results

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The special properties of Volume Bragg Gratings (VBGs) make them good candidates for spectrometry applications where high spectral resolution, low level of straylight and low polarisation sensitivity are required. Therefore it is of interest to assess the maturity and suitability of VBGs as enabling technology for future ESA missions with demanding requirements for spectrometry. The VBGs suitability for space application is being investigated in the frame of a contract lead by CSL and funded by the European Space Agency. The goals of this work are divided in two folds: firstly the theoretical advantages and drawbacks of VBGs with respect to other technologies with identical functionalities are assessed, and secondly the performances of VBG samples in a representative space environment are experimentally evaluated.

The performances of samples of two VBGs technologies, the Photo-Thermo-Refractive (PTR) glass and the DiChromated Gelatine (DCG), will be characterized and compared in the H , O2-B and NIR bands.. The tests are performed under vacuum condition combined with temperature cycling in the range of 200 K to 300K. A dedicated test bench experiment is designed to evaluate the impact of temperature on the spectral efficiency and to determine the optical wavefront error of the diffracted beam. Furthermore, the diffraction efficiency degradation under gamma irradiation will be assessed. Finally the straylight, the diffraction efficiency under conical incidence and the polarisation sensitivity will be evaluated.

This paper will present the current status and preliminary results of these investigations.

8442-188, Poster Session

Experimental parametric study of the self-coherent camera

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Direct imaging of exoplanets requires the detection of very faint objects orbiting close to very bright stars. In this context, the SPICES mission was proposed to the Euroapen Space Agency for planet characterization at visible wavelength.

SPICES is using a coronograph to strongly attenuate the central source. However, small optical aberrations, which appear even in space telescopes, dramatically decrease their performance. To reduce these aberrations, we want to estimate, directly on the coronagraphic image, the electromagnetic field, and, with the help of a deformable mirror, correct the wavefront upstream the coronagraph.

We propose an instrument, the Self Coherent Camera (SCC) for this purpose. By adding a small "reference" hole into the focal plane mask, after the coronagraph, we can produce interferences in the focal plane, using the coherence of the stellar light. We developed algorithms to decode the information contained in these Fizeau fringes and retrieve an estimation of the field in the focal plane.

After briefly recalling the SCC principle, we will present the results of a study, based on both experiment and numerical simulation, analyzing the impact of a few key instrumental parameters, like position and size of the reference hole, optical path difference or amplitude of the aberrations.

8442-189, Poster Session

Qualification of a null lens using image-based phase retrieval

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In measuring the figure error of an aspheric optic using a null lens, the wavefront contribution from the null lens must be independently and accurately characterized, in order to isolate the optical performance of the aspheric optic alone. Various techniques can be used to characterize such a null lens, including interferometry, profilometry and image-based methods. Only image-based methods, such as phase retrieval, can measure the null-lens wavefront in situ -- in single-pass, and at the same conjugates & in the same alignment state in which the null lens will ultimately be used -- with no additional optical components.

Due to the intended purpose of a null lens (e.g., to null a large aspheric wavefront with a near-equal-but-opposite spherical wavefront), characterizing a null-lens wavefront presents several challenges to image-based phase retrieval: Large wavefront slopes and high-dynamic-range data decrease the capture range of phase-retrieval algorithms, increase the requirements on the fidelity of the forward model of the optical system, and make it difficult to extract diagnostic information (e.g., the system F/#) from the image data.

In this paper, we present a study of these effects on phase-retrieval algorithms in the context of a null lens used in component development for the Climate Absolute Radiance and Refractivity Observatory (CLARREO) instrument. Approaches for mitigation are also discussed.

8442-190, Poster Session

Space target detection with high-speed polarization spectral imaging telescope

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General, platform of the space target detection task carry multiple loads , such as a spectrometer, a visible and infrared camera.In this paper we designed an optical system based on Cassegrainwhich follow-up optical structure composed of spectrum detection subsystem, polarization detection subsystem and high-speed photography subsystem. It can be used in space-based or ground-based telescope to observe objectives or spacecrafts of near space and low-orbit .There are many different types target in space, including low-and high-speed moving objects with strong background light interference.Multi-target detection, tracking system can judge,according to their spectral and polarization properties , and finally make the information fusion. In order to compact Cassegrain optical follow-up light path in the form of multi-folded situation.

8442-192, Poster Session

End-to-end coronagraphic modeling including a low-order wavefront sensor

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To evaluate space-based coronagraphic techniques and methods for detecting exoplanets in coronagraphic images, end-to-end modeling is necessary to simulate realistic fields containing speckles caused by wavefront errors. The model must include optical aberrations and deformable mirrors. In a dynamically and thermally stable system that can be represented in a model, a static field with reduced speckle intensity around the star can be created using the deformable mirrors to control wavefront errors. Real systems, however, will suffer from pointing errors and thermal and motion-induced mechanical stresses that introduce time-variable wavefront aberrations that can reduce the field contrast. A low-order wavefront sensor (LOWFS) is needed to measure these changes at a sufficiently high rate to maintain the contrast level during observations. We implement here a LOWFS and corresponding low-order wavefront control subsystem (LOWFCS) in end-to-end models of a space-based coronagraph. Our goal is to be able to accurately duplicate the effect of the LOWFS+LOWFCS without explicitly evaluating the end-to-end model at numerous time steps. This is an important step in the development of a speckle field generator for use by the community to study coronagraphic methods.

8442-193, Poster Session

Optimized shaped pupil masks for pupil with obscuration

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The SPICA coronagraphic instrument is currently designed to incorporate shaped pupils for high-contrast. A number of shaped pupils architectures have been studied, all consisting of sets of barcode masks, i.e., apodizers optimized in one dimension. One particular advantage of the barcode mask is that it is freestanding; it can thus be manufactured without a glass substrate, and therefore does not add wavefront aberrations or chromaticity effects. However, we can now optimize masks in two dimensions and therefore take advantage of the geometry of the on-axis telescope to increase the throughput of the masks, often by a factor 2. Unfortunately, most 2D mask designs are not freestanding. We have several proposed solutions to this problem and we present in this paper examples of freestanding 2D masks for various contrast and inner working angles designed for the SPICA telescope. Some of them have been manufactured and tested in the laboratory.

8442-194, Poster Session

Adaptive optics operation with two wavefront sensors in a coronagraph for exoplanet observations

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A stellar coronagraph system for direct observations extra solar planets is under development by combining unbalanced nulling interferometer (UNI), adaptive optics, and a focal plane mask coronagraph. It can reach a high contrast as using lambda/10000 precision optics by lambda/1000 quality ones. However, a sufficient high contrast is not obtained yet in the experiment before. It is thought that the remained speckle noise at the final coronagraph focal plane detector are produced by a “non-common path error” of lambda/100 level, which is a wavefront error of the coronagraph different from that of a wavefront sensor (WFS) of adaptive optics, even when the WFS indicates lambda/1000 conversion. The non-common path error can be removed by the dark zone method that is a way of wavefront correction by wavefront sensing at the final focal plane detector, although it has an issue of operation for very faint targets because of a slow feedback loop. In the present paper, we describe that our coronagraph system becomes practically higher contrast by upgrading the control method of adaptive optics with the WFS assisted by focal plane wavefront sensing method.Then, we control wavefront errors by two feedback loops, first uses a WFS to make fast control for telescope optics deformation and second utilize a focal plane detector to compensate for the non-common path error by slow control. We will also show numerical simulation and experiment results of the coronagraph system performance with both of the two wavefront sensing methods.

8442-196, Poster Session

Analysis of the thermomechanical behavior of lightweight space-based telescope mirrors

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Current design and fabrication techniques allow the realization of very lightweight mirrors for space telescopes, but these mirrors are not quite stiff for space environment and launch conditions. Deformations on the optical figure of a mirror affect the telescope’s most important task which is imaging; these deformations induce some additional aberrations to the images formed by the telescope. In this work, we studied launch survival and optical figure deformation, during operation in orbit, of several lightweight mirrors designed for space telescopes applications with several structures materials and mounts. Then we carried out a comparison of their performances. The analysis was done with finite element method using commercial software ABAQUS.

8442-197, Poster Session

Development of CdZnTe immersion grating for spaceborne application

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We are developing a CdZnTe immersion grating for high-resolution spectroscopy in the mid-infrared wavelength region. A spectrograph using the immersion grating is proposed to be mounted on SPICA, Japanese next-generation space telescope. The goal is to achieve a spectral resolution of 20,000-30,000 in a wavelength range of 12-18 um. The instrument will be the world's first high-resolution spectrograph in space, and it would make great impacts on study of the early evolution of protoplanetary system and the search for bio-markers.

The most challenging issue for the fabrication of immersion grating is to process grooves with nano-level precision on materials that have good transmittance and homogeneity in the required wavelength range. First, we measured the transmittance and the homogeneity for some IR-transparent materials, and selected CdTe, CdZnTe, and KRS5 as suitable materials for our purpose. Next, we carried out test processing to rule grooves on substrates of those materials by diamond cutting (planing). As a result, fine grooves were obtained for all materials (the detail of processing is presented in Sukegawa et al. in this conference). Since only CdZnTe meets requirements of both optical properties and ingot size at this point, CdZnTe is selected as the first candidate. We are now working on fabricating a prism-shaped CdZnTe immersion grating which is one-third the size of that for SPICA. We are also conducting experiments of metal coating on the gratingsurface of the immersion grating.

8442-198, Poster Session

Optimized barcode mask solution for pupil with obscuration

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We present an optimized solution for barcode mask design for telescopes with the pupil obscured by the secondary mirror and its support structure. The single (original) barcode masks make them relatively unattractive because of their relatively low throughput in the case of a circular pupil. These masks are actually an improved and generalized version of the original barcode solution that maximizes the coronagraph throughput(40~50% instead of ~20%). After describing the optimizing method, we point out advantages and specificities of such solution both from a performance and manufacturing point of view. These masks have potential to realize efficient observation for exoplanets with the SPICA coronagraph instrument.

8442-199, Poster Session

Finding clues of life: a numerical simulation analysis of ground versus space opportunities

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Kepler mission confirmed its first planet in habitable zone of Sun-like star. Visible and Near-Infrared spectra of transiting hot Jupiter planets have been observed. The characterization of exoplanet atmospheres and the eventual discoveries of strong bio markers is one of the most exciting research topic of the next decades.

Several bio markers, such as water, carbon monoxide and bondioxide and methane had already been detected from ground based observations during primary and secondary eclipse.

Tuning spectral resolution different kind of observations can be made to optimize the signal coming from different bio-clues.

The scope of this paper is to investigate which of these observations can be performed from the ground or they require (justify) a space mission: we simulate the Star/Planet spectral emissions and compute for different molecules the signal to noise ratio expected in the two case determining at the end observation opportunities for the two different approaches and synergies.

8442-200, Poster Session

How Earth atmospheric radiations may affect astronomical observations from low-orbit satellites

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Telescopes are placed on satellites to avoid the effects of the Earth atmosphere on astronomical observations (turbulence, extinction ...). Atmospheric effects however may subsist when satellites are launched in low orbits, typically mean altitudes of the order of 700 km. We will present first in this paper how we are able to estimate the mean Earth radiation flux when we consider temperature housekeeping data recorded with a specific space solar mission having this orbit property. We will show after how some solar parameters extracted from images recorded with the onboard telescope are correlated with the Earth atmospheric radiation flux.

8442-201, Poster Session

A laboratory experiment for a new free-standing pupil mask coronagraph

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The enormous contrast in flux between the central star and associated planets is the primary difficulty in the direct observation. The typical contrast is 10^{-10} at visible light wavelength and 10^{-6} in the mid-infrared wavelength region. One of the methods the enormous contrast can be improved is a coronagraph. The coronagraph can change the PSF and reduce the gap of luminosity between an exoplanet and its central star. We focused on binary-shaped pupil coronagraph that there is a plan to install in Next-generation infrared space telescope SPICA. A contrast of 1.8x10^{-9} was achieved for PSF subtraction as the results of our laboratory experiments on the coronagraph which was implemented inside a vacuum chamber to achieve higher thermal stability and to avoid air turbulence (Haze et al. 2009). We also carried out multi-color/broadband experiments with center wavelengths of 650nm, 750nm, 800nm and 850nm to demonstrate that the pupil mask coronagraph should work at all wavelengths in principle (Haze et al. 2011). A checker-board mask we previously manufactured with a glass substrate has the problems of light loss by transmission, ghosting from residual reflectance and a slightly different refractive index for each wavelength. Therefore, we developed a new free-standing mask with sheet metal without substrate. As the result of He-Ne laser experiment with the free-standing mask, a contrast of 1.0×10^{-7} was achieved for the raw coronagraphic image. Speckles are the major limiting factor. The free-standing mask demonstrated about

the same ability to improve the contrast significantly as the substrate mask.

8442-203, Poster Session

Mid-infrared low-temperature coronagraph testbed (MILC-T)

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We present Mid-infrared Low-temperature Coronagraph Testbed (MILC-T).

The primary purpose of MILC-T is for the development of the SPICA Coronagraph Instrument, whilst MILC-T can be used for other various use.

The vacuum chamber of MILC-T is ~1.2m x 1.2m x 0.5m size which includes cold work surface and double radiation shields.

Cooling is performed by tow GM-cycle mechanical coolers (i.e, no cryogen is used), and the cold work surface finally reaches to < 5K.

There are six removable large panels, for side panels and two top panels. It is possible to tune the panels flexibly.

At current, optical window, electric connectors, interferometer stage, and its couter weight are equipped.

Results of tests to evaluate the performance of MILC-T are also presented.

8442-205, Poster Session

A coronagraph system with unbalanced nulling interferometer: progress of dynamic range

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We proposed a coronagraph system with an unbalanced nulling interferometer (UNI). The coronagraph system can be composed using the UNI effectively as a following configuration after collimation from a telescope focus. It consists of a first adaptive optics (AO), the UNI, a second AO for phase and amplitude correction (PAC) with two deformable mirrors, and a coronagraph. Here wavefront corrections and star light rejections are made twice in turn in the four-stage optics. One of many kind of coronagraph can be selected as the last stage. The most interesting and important phenomenon is a magnification of the wavefront aberrations in the UNI stage which can be explained by changes of the mean complex amplitude of the electric field, which enable us to compensate for the wavefront aberrations beyond the AO systems capabilities. In our experiments, we observed the aberration magnification of about 6 times and compensated to about lambda/100 rms which means that we reached to lambda/600 level virtually. We put a 3-dimensional Sagnac interferometric coronagraph at the final stage of the system which has an achromatic performance of about 1E-5 nulling at the central part of the image without the AO. At the focal plane of the coronagraph we confirmed the speckle reduction of better than 0.1 with the UNI-PAC coronagraph system, which is almost consistent with theory.

8442-21, Session 5

The next-generation infrared space telescope SPICA

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We present an overview of the SPICA (Space Infrared Telescope for Cosmology and Astrophysics) mission, which is an astronomical mission optimized for mid- and far-infrared astronomy with a cryogenically cooled 3.2 m telescope. Its high spatial resolution and unprecedented sensitivity in the mid- and far-infrared will enable us to address a number of key problems in present-day astronomy, ranging from the star-formation history of the universe to the formation of planets. To reduce the mass of the whole mission, SPICA will be launched at ambient temperature and cooled down on orbit by mechanical coolers on board with an efficient radiative cooling system, a combination of which allows us to have a 3.2 m, cooled (6 K) telescope in space with moderate total weight (3.7t). SPICA is proposed as a Japanese-led mission together with extensive international collaboration. SPICA telescope assembly is to be procured by ESA and one of SPICA's focal plane instruments, SAFARI, is to be developed by the European SAFARI consortium led by SRON, Netherlands. Korea and Taiwan are in charge of part of focal plane instruments. US participation is also being discussed extensively. The target launch year of SPICA is around 2020.

8442-22, Session 5

Far-infrared spectroscopy at the background limit: BLISS for SPICA

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We are developing the Background-Limited Infrared-Submillimeter Spectrograph (BLISS) for SPICA to provide a breakthrough capability for far-IR survey spectroscopy. The actively-cooled (T<6K) SPICA telescope allows mid-IR to submm observations which are limited only by the natural backgrounds, and BLISS is designed to operate near this fundamental limit. BLISS-SPICA provide a line sensitivity of 1e-20 W m^-2, thereby enabling spectroscopy of dust-obscured galaxies at all epochs back to the first billion years after the Big Bang (redshift 6), and study of all stages of planet formation in circumstellar disks.

BLISS covers the 35-430 microns waveband at moderate resolving power (400<R<700) in six grating spectrometer bands, each coupling at least two 2 sky positions simultaneously. The instrument is cooled with an on-board magnetic refrigerator to 50 mK for optimal sensitivity. The detector package is 4200 silicon-nitride micro-mesh leg-isolated bolometers with superconducting transition-edge-sensed (TES) thermistors, read out with a cryogenic time-domain multiplexer. All technical elements of BLISS have heritage in mature scientific instruments, and many have flown. The instrument is carefully designed to fit within the stringent SPICA resource allocations for mass and heat lift, and to mitigate the impact of cosmic rays. We report on this design and our progress in prototyping and validating the BLISS detectors, spectrometers, and prototype cooler.

8442-23, Session 5

Mid-infrared camera and spectrometer on board SPICA

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(Japan)

SPICA (Space Infrared Telescope for Cosmology and Astrophysics) is an astronomical mission optimized for mid- and far-infrared astronomy, envisioned for launch in early 2020s. The core wavelength coverage of this mission is 5 to 200 micron.

Mid-infrared Camera and Spectrometer (MCS) will provide imaging and spectroscopic observing capabilities in the mid-infrared region with 4 modules.

WFC (Wide Field Camera) has two 5 arcminutes square filed of view and covers the wavelength range 5 to 38 micron, HRS (High Resolution Spectrometer) covers the wavelength range 12 to 18 micron with resolving power 20000 to 30000, MRS (Mid Resolution Spectrometer) has integral field units by image slicer and covers the wavelength range 12 to 38 micron simultaneously using dichroic filter and two sets of spectrometers, LRS (Low Resolution Spectrometer) adopts prism disperser and covers the wavelength range 5 to 48 micron with resolving power 50 to 100.

Here, we present detailed specifications of MCS, optical design, pointing stability requirements, and estimated performance on orbit.

8442-24, Session 5

The SAFARI imaging spectrometer for the SPICA Space Observatory

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The Japanese SPace Infrared telescope for Cosmology and Astrophysics, SPICA, will provide astronomers with a long awaited new window on the universe. Having a large cold telescope cooled to only 6K above absolute zero, SPICA will provide a unique environment where instruments are limited only by the cosmic background itself. A consortium of European and Canadian institutes has been established to design and implement the SpicA FAR infrared Instrument SAFARI, an imaging spectrometer designed to fully exploit this extremely low far infrared background environment provided by the SPICA observatory.

SAFARI's large instantaneous field of view combined with the extremely sensitive Transition Edge Sensing detectors will allow astronomers to very efficiently map large areas of the sky in the far infrared - in a square degree survey of a 1000 hours many thousands of faint sources will be detected. A large fraction of these sources will be fully spectroscopically characterised by the instrument. Efficiently obtaining such a large number of complete spectra will be essential to address several fundamental questions in current astrophysics: how do galaxies form and evolve over cosmic time?, what is the true nature of our own Milky Way?, and why and where do planets like those in our own solar system come into being?

8442-25, Session 5

The optical design concept of SPICA-Safari

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The Safari instrument on the Japanese SPICA mission is a zodiacal background limited imaging spectrometer offering a photometric imaging ($R \approx 2$), and a low ($R = 100$) and medium spectral resolution ($R = 2000$ at 100 µm) spectroscopy mode in three photometric bands covering the 34-210 µm wavelength range. The instrument utilizes Nyquist sampled filled arrays of very sensitive TES detectors providing a 2'x2' instantaneous field of view. The all-reflective optical system of Safari is highly modular and consists of an input optics module containing the entrance shutter, a calibration source and a pair of filter wheels, followed by an interferometer and finally the camera bay optics accommodating the focal-plane arrays. The optical design is largely driven and constrained by volume inviting for a compact three-dimensional arrangement of the interferometer and camera bay optics without compromising the optical performance requirements associated with a diffraction- and background-limited spectroscopic imaging instrument. Central to the optics we present a flexible and compact non-polarizing Mach-Zehnder interferometer layout, with dual input and output ports, employing a novel FTS scan mechanism based on magnetic bearings and a linear motor. In this paper we discuss the conceptual design of the focal-plane optics and describe how we implement the optical instrument functions, define the photometric bands, deal with straylight control, diffraction and thermal emission in the long-wavelength limit and interface to the large-format FPA arrays at one end and the SPICA telescope assembly at the other end.

8442-26, Session 6

Euclid: ESAs mission to map the geometry of the dark universe

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Euclid is a space-borne sky survey mission developed and operated by ESA and is designed to understand the origin of the Universe's

accelerating expansion. Euclid will use cosmological probes to investigate the nature of dark energy, dark matter and gravity by tracking their observational signatures on the geomettry of the universe and on the cosmic history of structure formation. The mission is optimised for the measurement of two independent cosmological probes: weak gravitational lensing and galaxy clustering. The payload consists of a 1.2 m Korsch Telescope designed to provide a large field of view. The light is directed to two instruments provided by the Euclid Consortium: a visual imager (VIS) and a near-infrared spectrometer-photometer (NISP). VIS has at least one filterband covering the wavelength range 550-800 nm. The NISP spectrometer operates in the range of 1.1-2.0 micron with a spectral resolution of R~250, the NISP photometric channel consists of three near-infrared imaging bands. Both instruments cover a large common field of view of 0.54 deg2, to be able to survey at least 15,000 deg2 in less than the 6-year nominal mission duration. An overview of the mission will be presented: the scientific objectives, payload, satellite, and science operations. We report on the status of the Euclid project with a foreseen launch in 2019.

8442-27, Session 6

The Wide Field Infrared Survey Telescope: WFIRST

J. C. Green, Univ. of Colorado at Boulder (United States) and The Wide Field Infrared Camera Science Definition Team (United States)

The Wide Field Infrared Survey Telescope (WFIRST) was the top space based recommendation of the 2010 decadal survey in astronomy. WFIRST will complete the statistical census of planetary systems in the Galaxy, from habitable Earth-mass planets to free floating planets, including analogs to all of the planets in our Solar System except Mercury, determine the expansion history of the Universe and its growth of structure in order to test explanations of its apparent accelerating expansion including Dark Energy and possible modifications to Einstein's gravity, and produce a deep map of the sky at NIR wavelengths, enabling new and fundamental discoveries ranging from mapping the Galactic plane to probing the reionization epoch by finding bright quasars at z>10. The WFIRST science definition team completed its interim report in July, 2011, and continues to work towards its final report, due at the end of 2012. I will provide a report on the latest design and capabilities of the WFIRST mission, as well as the predicted science results.

8442-28, Session 6

VIS: the visible imager for Euclid

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Euclid-VIS is a large format visible imager for the ESA Euclid space mission in their Cosmic Vision program, scheduled for launch in 2019. Together with the near infrared imaging within the NISP instrument it forms the basis of the weak lensing measurements of Euclid. VIS will image in a single R+I+Z band from 550-900 nm over a field of view of ~0.5 deg2. Over 4 exposures totalling 2240 sec, VIS will reach to V=24.5 (10sigma) for sources with extent ~0.3 arcsec and smaller. The image sampling is 0.1 arcsec. VIS will provide deep imaging with a tightly controlled and stable PSF over a wide survey area of of 15000 deg2 to measure the cosmic shear from nearly 1.5 billion galaxies to high levels of accuracy, from which the cosmological parameters will be measured. In addition, VIS will also provide a legacy imaging dataset of unprecedented spatial resolution and depth over most of the extra-Galactic sky. Here we will present the results of the study carried out by the Euclid Consortium during the Euclid Definition phase.

8442-29, Session 6

Euclid near-infrared spectrophotometer instrument concept at the end of the phase A study

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The Euclid mission objective is to map the geometry of the dark Universe by investigating the distance-redshift relationship and the evolution of cosmic structures. The Euclid project is part of ESA's program Cosmic Vision with its launch planned for 2019.

The NISP (Near Infrared Spectro-Photometer) is one of the two Euclid instruments operating in the near-IR spectral region (0.9-2µm) as a photometer and spectrometer. The instrument is composed of:

- a cold (140K) optomechanical subsystem constituted by a SiC structure, an optical assembly (corrector and camera lens), a filter wheel mechanism, a grism wheel mechanism, a calibration unit and a thermal control

- a detection subsystem based on a mosaic of 16 Teledyne HAWAII2RG 2.4µm cutoff cooled to100K with their front-end readout electronic integrated on a SiC support structure with the thermal control. The detection subsystem is mounted on the optomechanical subsystem

structure

- a warm electronic subsystem (280K) composed of a data processing / detector control unit and of an instrument control unit that interfaces with the spacecraft via a 1553 bus for command and control and via a Spacewire bus for science data

This presentation will describe the architecture of the instrument, the expected performance and the technological key challenges.

This paper is presented on behalf of the Euclid Consortium

8442-30, Session 6

The optical baseline concept of the NISP near infrared spectrometer and photometer on board of the ESA/EUCLID satellite

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The ESA/EUCLID satellite is equipped with two instruments that are simultaneously observing patches of >0.5sq deg on the sky. The VIS visual light high spacial resolution imager and the NISP near infrared spectrometer and photometer are separated by a di-chroic beam splitter.

This paper shows the baseline concept of the NISP instrument with its two observational modes being low resolution slit-less spectroscopy and three band J, H & K+ photometry.

The drivers for the optical design, the nominal performance as well as the tolerancing approach for NISP are being presented.

The impact of the tolerance approach and the tight tolerances on the opto-mechanical design, assembly, integration and verification is addressed in a special section of this paper.

These results are presented on behalf of the EUCLID consortium.

8442-31, Session 6

First test results of the Euclid grisms made by microlithography

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The ESA mission Euclid is designed to explore the dark side of the Universe and to understand the nature of the dark energy responsible of the accelerating expansion of the Universe. One of the probes is the Baryonic Acoustic Oscillation (BAO) method that requires the redshift measurements of millions of galaxies. In the Euclid design the spectroscopic channel (1-2 micrometers)is based on low resolution grisms used in slitless mode. The classical grism manufacturing method is to replicate a ruled master on the hypotenuse of a prism. In Euclid the combination of low groove density (15 g/mm) and small blaze angle (2 deg) makes the ruling of the grating master extremely difficult. Two years ago we investigated in a R&D program to develop grism by the microlithography process that is well adapted to coarse grating and allows introducing aberration correction by ruling curved and non parallel grooves. During the Euclid Phase A, we developed several prototypes made by microlithography and we present in this paper the test results done in the specific environment of the Euclid mission.

8442-32, Session 6

Euclid Mission: building of a reference survey

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Euclid is an ESA Cosmic-Vision wide-field-space mission which is designed to understand the acceleration of the Universe's expansion. The mission relies on two primary cosmological probes: Weak gravitational Lensing (WL) and Galaxy Clustering (in particular Baryon Acoustic Oscillations, BAO).

The extreme accuracy requested on primary science objectives can only be achieved by observing a large number of galaxies distributed over the whole sky in order to probe the distribution of dark matter and galaxies at all scales. The definition of the Euclid survey, aiming at detecting billions of galaxies over 15 000 square degree of the extra galactic sky, is a key parameter of the mission. It drives its scientific potential, its duration and the mass of the space craft.

The construction of a Reference Survey derived from the high level science requirements, the definition of a main sequence of observation and the associated calibrations was indeed a major achievement of the Definition Phase.

Implementation of this sequence demonstrated the feasibility of covering the requested area in less than 6 years while taking into account the overheads of space segment observing and maneuvering sequence.

This reference mission will be used for sizing the space craft consumable and will be the framework for optimizing the current reference survey toward mission scenario, compliant with space craft capabilities, and optimizing the time on the sky to fulfill the primary science and maximize the Euclid legacy.

8442-33, Session 6

Wavefront sensing for WFIRST with a linear optical model

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In this paper, we develop methods to use a linear optical model to capture field dependence of wavefront aberrations in a nonlinear-optimization-based phase-retrieval algorithm for image-based wavefront sensing. The linear optical model is generated from a ray-trace model of the system and allows the system state to be described in terms of mechanical alignment parameters rather than wavefront coefficients. This approach allows joint optimization over images taken at different field points and does not require separate convergence of individual-field phase-retrieval problems. Because the algorithm exploits field diversity, multiple defocused images per field point are not required for robust convergence. Furthermore, because we can simultaneously fit images of many stars over the field, it is not necessary to use a fixed defocus to achieve adequate signal-to-noise ratio. This allows high-performance wavefront sensing using in-focus science data. We applied this technique

in a simulation model based on the WFIRST IDRM imager, using a linear optical model with 25 field points. We demonstrate thousandth-wave wavefront sensing accuracy in the presence of noise and moderate under-sampling for both monochromatic and polychromatic scenarios using 25 high-SNR target stars. Using these high-quality wavefront-sensing results, we can generate upsampled point-spread functions and use them to determine PSF ellipticity to high accuracy. This reduces the systematic impact of aberrations on the accuracy of galactic ellipticity determination for weak lensing science.

8442-34, Session 6

Euclid NISP GWA and compensating mechanism

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This paper presents the GWA and the Compensating mechanism of the Near Infrared SpectroPhotometer (NISP) instrument of the ESA Euclid mission. The NIS instrument should perform an exposure sequence in the wavelength range [0.9 - 2.0]um with different exposures of the same field of views with different passband grisms with two orthogonal dispersion directions and two wavelength range. These functionalities will be achieved by a mechanism supporting the optical elements: the Grism Wheel Assembly (GWA). The required positioning repeatability is in the order of few arcsec to keep the spectra aligned with the detector pixel columns/rows. The GWA will be assembled to the NISP Optomechanical Assembly (NIOMA) with an operating temperature of 140K. A further mechanism is necessary to compensate the torque perturbances induced by the two large wheels. It is based onto a stepper motor that will drive a flywheel.

8442-35, Session 6

Initial results from a laboratory emulation of weak gravitational lensing measurements

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We will present our progress in emulating weak gravitational lensing measurements in the laboratory in support of cosmology missions such as NASA's Wide Field Infra-Red Survey Telescope (WFIRST) and ESA's Euclid. The required shape measurement accuracy for these measurements, < 1 part in 103, will be very difficult to achieve, even in space. Previous assessments of measurement sensitivities have only been performed under idealized conditions with either simulated images or simplified input signals to real detectors. In contrast, our efforts are directed at providing experimental data to quantify performance of reference designs. The goal is to determine (a) the scale of detector-induced errors under planned observing conditions, (b) whether proposed calibration and analysis methods for shape measurement will deliver the required mission performance when real detectors and optics are in play and (c) identify whether pixel scale will need to be changed to meet accuracy requirements for PSF and galaxy shape measurement.

Our primary tool is a custom 1:1 optical relay which provides exquisite control of PSF quality across over the full field of large format detector arrays, as well as stable illumination and low image motion to support tests of precision photometry and shape measurements on projected images of simulated star fields and extended objects. We will describe initial efforts to measure the PSF and ellipticity of simulated star fields and extended objects and their variation across the field under both well-resolved and undersampled, diffraction-limited conditions using CMOS, CCD and Infrared (IR) arrays.

8442-36, Session 7

Summary of the observations with the infrared camera (IRC) onboard AKARI

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AKARI, the Japanese satellite mission dedicated to infrared astronomy launched in 2006 February, exhausted its liquid helium in 2007 August. During the cold mission phase, the Infrared Camera (IRC) carried out an all-sky survey at 9 and 18 micron with higher spatial resolution and sensitivities than IRAS. Both bands also have slightly shorter wavelength coverage than IRAS 12 and 25 micron bands and thus provide different information on the infrared sky. All-sky diffuse data of the IRC are now in the final processing and will be released to the public at the time of this presentation. After the exhaustion of the cryogen, the telescope and focal plane instruments of AKARI had been kept less than 50K owing to the onboard cryocooler and near-infrared (NIR) imaging and spectroscopic observations with the IRC had continued until 2011 May, when the spacecraft had a serious problem in the power supply system that forced us to terminate the observation. The IRC carried out nearly 20000 pointing observations in total. More than a quarter of them were performed after the exhaustion of the cryogen with the spectroscopic modes, which enabled sensitive NIR spectroscopy from 2 to 5 micron without disturbance of the terrestrial atmosphere. During the warm mission phase, the temperature of the instrument gradually increased and changed the array operation conditions. We present a summary of AKARI/IRC observations, including the all-sky mid-infrared diffuse data as well as the data reduction in the warm mission phase.

8442-37, Session 7

Breakthrough capability for the NASA Astrophysics Explorer Program: reaching the darkest sky

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We describe a mission architecture designed to substantially increase the science capability of the NASA Science Mission Directorate (SMD) Astrophysics Explorer Program for all AO proposers working within the near-UV to far-infrared spectrum. We have demonstrated that augmentation of Falcon 9 Explorer launch services with a 13 kW Solar Electric Propulsion (SEP) stage can deliver a 700 kg science observatory payload to extra-Zodiacal orbit. Over the above wavelength range, observatory performance is limited by zodiacal light. This new capability

enables up to 10X increased photometric sensitivity and 160X increased observing speed relative to a Sun-Earth L2, Earth-trailing, or Earth orbit with no increase in telescope aperture. All enabling SEP stage technologies for this launch service augmentation have reached sufficient readiness (TRL-6) for Explorer Program application in conjunction with the Falcon 9. We demonstrate that enabling Astrophysics Explorers to reach extra-zodiacal orbit will allow this small payload program to rival the science performance of much larger long development time systems; thus, providing a means to realize major science objectives while increasing the SMD Astrophysics portfolio diversity and resiliency to external budget pressure. The SEP technology employed in this study has strong applicability to SMD Planetary Science community-proposed missions and is a stated flight demonstration priority for NASA's Office of the Chief Technologist (OCT). This new mission architecture for astrophysics Explorers enables an attractive realization of joint goals for OCT and SMD with wide applicability across SMD science disciplines.

8442-38, Session 7

The Canadian Space Telescope: a wide-field, high-resolution, imaging telescope

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We describe a proposed Canadian Space Telescope (CST) designed to carry out high-angular resolution, wide-field imaging in the optical-UV spectral regions. With a 1m aperture delivering diffraction-limited (0.1 arcsec) images and slitless spectroscopy over a ~0.5 deg2 field at 354 nm, the CST would have image quality comparable to the Hubble Space Telescope (HST), but with a hundred-fold increase in field of view. We outline the numerous science drivers for the mission, which include cosmology and dark energy, galaxy evolution, nearby galaxies and clusters, Galactic archaeology, stellar evolution, and small bodies in the outer solar system. We also describe the key technical aspects of the design, including the choice of launch vehicle, orbit, optical design, detector system, attitude control, data handling, telemetry, mission operations and science data processing. By filling a key niche in observational astrophysics, the CST would revolutionize space astronomy and provide outstanding synergy with a number of international astronomical facilities, both on the ground and in space, that are expected to be operating at the end of this decade.

8442-39, Session 7

Transiting Exoplanet Survey Satellite (TESS)

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The Transiting Exoplanet Survey Satellite (TESS) will discover thousands of exoplanets in orbit around the brightest stars in the sky. In a two-year survey, TESS will monitor more than 500,000 stars for temporary drops in brightness caused by planetary transits. This first-ever spaceborne all-sky transit survey will identify planets ranging from Earth-sized to gas giants, around a wide range of stellar types and orbital distances. No ground-based survey can achieve this feat. A large fraction of TESS target stars will be 30-100 times brighter than those observed by Kepler satellite, and therefore TESS planets will be far easier to characterize with follow-up observations. TESS will make it possible to study the masses, sizes, densities, orbits, and atmospheres of a large cohort of small planets, including a sample of rocky worlds in the habitable zones of their host stars. TESS will provide prime targets for observation with the James Webb Space Telescope (JWST), as well as other large ground-based and space-based telescopes of the future. TESS data will be released with minimal delay (no proprietary period), inviting immediate community-wide efforts to study the new planets. The TESS legacy will be a catalog of the very nearest and brightest main-sequence stars hosting transiting exoplanets, thus providing future observers with the most favorable targets for detailed investigations.

8442-40, Session 7

The FINESSE mission

M. R. Swain, Jet Propulsion Lab. (United States)

FINESSE, the Fast Infrared Exoplanet Spectroscopy Survey Explorer, is the first mission dedicated to finding out what exoplanet atmospheres are made of, what conditions or processes are responsible for the composition, and how our own solar system fits into the larger family of planets. The last 15 years have witnessed extraordinary success in finding exoplanets; FINESSE is designed to take the next step and enable detailed characterization of a large sample of exoplanet atmospheres. During a two-year mission, FINESSE would survey 200 transiting exoplanets ranging from the most extreme hot-Jovians to cool Neptunes and Super-Earths. FINESSE's science instrument, a spectrograph covering 0.7-5.0 microns, provides excellent sensitivity to important molecular bands of water, methane, carbon monoxide, carbon dioxide, and other molecules. Interpretation of FINESSE measurements will reveal the composition, temperature structure, and chemistry of exoplanet atmospheres and provides a basis for comparing exoplanets in a uniform way. Significantly, all wavelengths in the FINESSE passband are measured simultaneously to remove the confusing effects of any temporal variability in the star/planet system. Engineered for exquisite 100 ppm stability, FINESSE will determine the differences between the dayside and nightside of exoplanet atmospheres by precision measurements of the system phase curve. FINESSE will also make routine observations of calibrator targets allowing spectra taken months apart to be compared, enabling the study of atmospheric dynamics. Implemented as a rapid, low-cost, high-heritage mission, FINESSE is scientifically well matched to the rapidly expanding field of exoplanets.

8442-41, Session 8

The FINESSE instrument: enabling 0.7-5.0 micron spectroscopy of extrasolar planets via precision spectrophotometry

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The Fast Infrared Spectroscopy Survey Explorer (FINESSE), is one of two astrophysics explorer class missions that NASA has recently selected for Phase A. FINESSE is a characterization mission, designed to determine the abundances of key molecular species (H_2O, CO, CO_2, CH_4) and the thermal structures of extrasolar planetary atmospheres in a large scale, two year long survey of transiting exoplanets. FINESSE's spectrophotometer will be built for high precision. We discuss the key features of the instrument and detector systems that enable the raw relative photometric precision requirements FINESSE. In the presentation, we will show how the instrument design and wavelength coverage address the major science requirements, the instrumental photometric error budget, and the capabilities (and limitations) of the infrared detector system baselined for FINESSE.

8442-42, Session 8

LiteBIRD: a small satellite for the studies of B-mode polarization and inflation from cosmic background radiation detection

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LiteBIRD [Lite (Light) satellite for the studies of B-mode polarization and Inflation from cosmic background Radiation Detection] is a small satellite to map the polarization of the cosmic microwave background (CMB) radiation over the full sky at large angular scales with unprecedented precision. Cosmic inflation, which is the leading hypothesis to resolve the problems in the Big Bang theory, predicts that primordial gravitational waves were created during the inflationary era. Measurements of polarization of the CMB radiation are known as the best probe to detect the primordial gravitational waves.

The LiteBIRD working group was authorized by JAXA and has more than 50 members from Japan, USA and Canada. The scientific objective of LiteBIRD is to test all the representative inflation models that satisfy single-field slow-roll conditions and lie in the large-field regime. To this end, the requirement on the precision of the tensor-to-scalar ratio, r, at LiteBIRD is equal to or less than 0.001.

Our baseline design adopts multi-chroic superconducting detector arrays that are read out with high multiplexing factors in the frequency domain for a compact focal plane. The required sensitivity of 2 micro-Kelvin-arcmin is achieved with about 2000 TES bolometers at 100mK. The cryogenic system is based on the JT/Stirling technology developed for SPICA, and the ADR system shares the design with future X-ray satellites. We performed feasibility studies with this baseline design for both L2 and LEO orbits.

8442-43, Session 8

WISH for deep and wide NIR survey of the distant universe

T. Yamada, Tohoku Univ. (Japan)

WISH, Wide-field Imaging Surveyor for High-redshift, is a concept for future Japanese-leading space mission now being developed under JAXA/ISAS Working Group for the mission proposal to launch no earlier than 2018.

WISH has the 1.5m primary mirror and 900-arcmin^2 wide-field imager working at 1-5 micron in NIR wavelength.

The primary science goal of the mission is (i) to observe the formation of first-generation galaxies over the epoch of cosmic reionization at z=8-20, and (ii) search and obtain the light curves of type-Ia SNe in the rest-frame infrared wavelength to obtain the sample of the standard candles with less affected by the systematic error to study the cosmic expansion history.

The main feature is the Ultra Deep Survey observing down to 28AB magnitude in multiple bands in 1-5 micron over 100 deg^2 area. In 5 years, WISH will detect more than 10^4 galaxies at z=8-9, 10^3-10^4 galaxies at z=11^12, and 50-100 galaxies at z=14-17.

In this talk, we report the progress of the research and development of the mission concept including the optical systems, telescope structure, wide-field filter exchanger, and feasible satellite system design.

8442-44, Session 8

The i-INSPIRE Satellite

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i-INSPIRE (initial-INtegrated SPectrograph, Imager and Radiation Explorer) is a small, light-weight, tube-shaped satellite built by a collaboration at the University of Sydney. It is first of its kind to be fully constructed and operated by an Australian university. The unique instrument payload consists of an innovative photonic spectrograph (NanoSpec), a radiation counter and a simple imaging camera.
The satellite has several aims - primarily i-INSPIRE will concretely demonstrate that Australian universities have the potential for leadership in space science and technology. In addition to this the mission has great scientific potential. NanoSpec will measure the first spectra from a space-borne photonic device while the radiation counter will return a radiation map of the Earth which can be compared with the output from NanoSpec to study the effect of radiation on photonic devices. i-INSPIRE will also aim to deliver the first photographs of Australia from an entirely Australian-owned and -operated spacecraft and will pave the way for larger and more complex space-based projects in the near future. I will describe the project and its aims in detail, including analysis and results from ground-based communications and integration tests. I will also describe a short weather balloon flight designed to test the satellite and its systems in a high altitude environment.

8442-45, Session 8

FalconSat-7: a membrane photon sieve CubeSat solar telescope

G. P. Andersen, M. E. Dearborn, G. McHarg, U.S. Air Force Academy (United States)

Diffractive optics are a promising technology for creating ultra-large space telescope primaries deployed from compact packages. Aside from being lightweight and compactable, the use of flat optics greatly reduces engineering constraints over conventional reflective elements. At the US Air Force Academy, cadets and faculty are constructing FalconSat-7: a membrane solar telescope deployed from a 3U CubeSat. In a world's first we plan to demonstrate the deployment of a membrane primary to image the Sun at H-alpha (656nm) wavelengths. The primary in question is a photon sieve - a diffractive optic consisting of billions of tiny pads on a flat transparent polymer sheet.

Our 20cm-diameter, F/2 primary uses a 25 micron thick zero-CTE polyimide having a mass less than 10 grams. The membrane is pulled taut by a triangular pantograph support structure. The membrane, support structure, secondary optics, camera and associated control electronics are all packaged within just half the overall satellite volume. When deployed in a low Earth orbit the deployed telescope will collect images of the Sun for transmission to a ground station at the Academy. Cadets are involved in every aspect of the project from program management to component design and testing. In this talk we will present results of initial experiments and provide details of zero-G testing and 2013 launch.

8442-46, Session 8

A conceptual design of a near infrared satellite for PAH survey

C. Xu, Shanghai Institute of Technical Physics (China); J. Deng, National Astronomial Observatories (China); Y. Zhang, Shanghai Engineering Ctr. for MicroSatellites (China)

We present here a conceptual design of a near infrared survey satellite whose primary goal is to carry out an all sky survey of Polycyclic Aromatic Hydrocarbons (PAH). The searching of PAH is through direct imaging both at and besides its 3.3 um CH stretching vibrations emission bands and make comparison between the “line” and the continuum fluxes. The dawn-dust sun-synchronous orbit is chosen because it is ideal for thermal control and it is suitable for all sky surveys. The “pointing-maneuver-pointing” observing strategy is adopted in order to minimize the effect from the detector read noises. The survey sensitivity is chosen to generally match those of the UKIDSS near IR surveys so their results can be compared more directly. The aperture of the telescope is about 30 cm. The optics is cooled through the combination of passive radiative cooling and active mechanical cooling while the detector is cooled with cryocoolers. The all sky survey is expected to be completed within 3 years.

8442-47, Session 9

The science of EChO: the Exoplanet Characterisation Observatory

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The science of extra-solar planets is one of the most rapidly changing and exciting areas of astrophysics. Since 1995 the number of planets known has increased by almost two orders of magnitude.

The Exoplanet Characterisation Observatory ¬-EChO - will take us to a new phase where we begin to fully understand the physics and chemistry of these objects and, possibly, the detection of the signatures of life on other habitable planets. The ability to repeatedly observe exoplanets over a very extended wavelength range in a single run gives EChO a unique capability unmatched by any current or proposed mission.

EChO is one of the four ESA’s M3 mission candidates. Our EChO consortium is currently composed of scientists from Belgium, Denmark, France, Germany, Italy, Spain, UK and US. Our proposed integrated spectrometer payload for EChO, covering the 0.4 to 16 micron wavelength band, will enable us to maximise the science return of the mission. The instrument will be mounted behind a 1.2 class telescope, placed in a grand halo orbit around L2.

In this paper we will focus on the science of EChO. EChO will provide much needed constraints on atmospheric dynamics and circulation models, photochemical models and planetary formation and evolution processes.

This will be done via careful, repeated, spectroscopic observations of planets around nearby stars. Those planets will span a range of masses (from gas giants to super-Earths), stellar companions (F, G, K, M) and temperatures (from hot to habitable).

8442-48, Session 9

The Exoplanet Characterization Observatory (EChO)

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The direct observational characterization of exoplanet atmospheres is a rapidly developing field. Transiting systems provide a unique opportunity to extract emission or absorption spectra from extra-solar planets on close orbits by light curve analysis, i.e. time-differential measurement, in either broad-band photometry or spectrally resolved. The primary observational challenge in such studies lies in the tiny planet to star contrast: the planetary atmospheric signal in the light curve is only of order 1 mmag in even the most favorable cases, and often much smaller, posing extreme requirements on spectro-photometric stability. The terrestrial atmosphere seriously hampers such work from the ground, and even the performance of multi-purpose space-borne observatories such as the HST is severely limited by instrumental systematic effects because such general observatories have not been optimized for spectro-photometric stability on bright sources.

The Exoplanet Characterization Observatory (EChO) is a candidate mission for the M3 slot in the Cosmic Vision program of the European Space Agency that is currently under study. It is a 1.3m space telescope flying in L2, dedicated to spectroscopy of the atmospheres of transiting exoplanets in the 0.4 to 11 (baseline) - 16 (goal) micrometer spectral region. In this contribution we will present our performance model and apply it to key science cases for EChO, ranging from hot Jupiters to temperate Super-Earths, to illustrate the strengths and limitations of the mission.

8442-49, Session 9

An integrated payload design for the Exoplanet Characterisation Observatory (EChO)

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The Exoplanet Characterisation Observatory (EChO) is a space mission dedicated to undertaking spectroscopy of transiting exoplanets over the widest wavelength range possible. It is based around a highly stable space platform with a 1.2 m class telescope. The mission is currently being studied by ESA in the context of a medium class mission within the Cosmic Vision programme for launch post 2020. The payload suite is required to provide simultaneous coverage from the visible to the mid-infrared and must be highly stable and effectively operate as a single instrument. In this paper we describe the integrated spectrometer payload design for EChO which will cover the 0.4 to 16 micron wavelength band. The instrumentation is subdivided into 6 channels (Visible, 2 x Short Wave InfraRed, 2 x Mid Wave InfraRed; Long Wave InfraRed) with a common set of optics spectrally dividing the field of view via dichroics. We discuss the significant design issues for the payload and the detailed technical trade-offs that we are undertaking to produce a payload for EChO that can be built within the mission and programme constraints and yet which will meet the exacting scientific performance required to undertake transit spectroscopy.

8442-50, Session 9

The visible/infrared spectrometer for EChO

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The Exoplanet Characterisation Observatory (EChO) is a medium class mission candidate within the Cosmic Vision 2015-2025 program of the European Space Agency ESA. EChO is planned to launch as M3 mission between 2022 and 2024 and will be equipped with a ~1.2m class passively cooled telescope and a visible to infrared spectrometer. This instrument covers the wavelength range from ~0.4 - 11 μm (goal: 16 μm) at a spectral resolving power between 30 and 300 in order to characterize the atmospheres of known transiting extrasolar planets ranging from Hot Jupiters to Super-Earths. To achieve the science goals of the mission through differential measurements of the star-planet-systems, the system needs to deliver a high spectro-photometric stability of order 23 ppm (rms) within observing times of 8 hours. This stability is considered among the critical technological drivers for ECHO, in addition to the cryogenic needs for wavelength coverage to preferably 16 μm. In this paper we will present main trade-offs for the spectrograph optical concept, detectors and electronics concept, cooling chain and thermo-mechanical concept established through the dedicated study of the ECHO science payload carried out by our Instrument Consortium during the EChO assessment phase. To safeguard that EChO will deliver photon noise-limited performance we address systematic effects based on physical models of the critical opto-mechanical elements supported through laboratory measurements of potential detectors as performance-critical sub-systems. Results from the definition of the observing and calibration strategy are also reported, which aims on increasing the end-to-end system stability through compensation of system drifts.

8442-51, Session 9

Designing the MWIR channels of EChO

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In this paper, we present our design of the MWIR channels of EChO. The 5-11 micron spectral range is covered by 2 channels. The choice of the boundaries of each channel is a trade-off driven by the science goals (spectral features of key molecules) and several parameters such as the common optics design, the dichroïc plates design, the optical materials characteristics, the detector cut-off wavelength. We also will emphasize the role of the detectors choice that drives the thermal and mechanical designs and the cooling strategy.

8442-52, Session 10

Mirror coatings with atomic layer deposition: initial results

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The new technology of Atomic Layer Deposition (ALD) holds promise to enable a future flagship mission that can address both ultraviolet (UV) astrophysics and optical exoplanet science with a shared telescope. The technology path to a shared telescope requires the development of a mirror coating with high reflectance from 100 nm to 1000 nm, and low polarization effects (i.e., s-p phase shifts vary across a primary mirror) in the optical range. Currently, UV coatings have low reflectance, and optical coatings have poor polarization properties for high-contrast coronagraph applications. We are trying to solve both problems simultaneously by using ALD, taking advantage of the fact that ALD can potentially produce mirror coatings with denser layers than conventional coatings (hence better reflectance and durability), and ALD can potentially produce coatings with new composite materials (hence better control of polarization). We report here the results of our initial experiments with mirror coatings using ALD.

8442-54, Session 10

A laboratory facility for emulating high precision astronomical observations

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As astronomical experiments demand increasing measurement precision, especially in space, it has become essential to validate system performance in the laboratory by emulating the scene to be observed and manner in which the measurements are made, in an end-to-end test of detectors, calibration and analysis methods. Unforeseen issues can be identified, performance and margins can be validated, and cost sensitive mission requirements such as image scale and pointing stability may be relaxed.

We describe the design, performance and application of an achromatic 1:1 optical relay, supporting high precision photometry, shape measurement, and astrometry with diffraction-limited imaging of high resolution target masks over the full area of typical NIR or optical detectors. Two input beams with flat stabilized illumination and optional target masks are combined to allow source/background ratios to be modulated, or flat fields to be interspersed. Typically, many thousands of objects are measured concurrently to probe performance distributions, and test statistical accuracy and analysis methods which use a large ensemble for flux normalization, to sense fine pointing, or calibrate PSF variation or field distortion. The optically induced PSFs have very low ellipticity, while mechanisms are provided to partition residual errors between the input mask, optics and detector. Large interchangeable pupil stops support a range of focal ratios, and elliptical and/or obstructed pupils may be rotated to evaluate the effects of the resulting diffraction. 6-axis positioning of the target mask supports precise focusing and image dithers. Measures to address focus stability, vibration, seeing, scattered light and ghosting are discussed.

8442-55, Session 10

The thermal sieve: a diffractive baffle that provides thermal isolation of a cryogenic optical system from an ambient temperature collimator

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An optical testing configuration utilizing the Thermal Sieve provides thermal decoupling between a cryogenic optical system under test and a collimator operating at ambient temperature, while passing the test wavefront without significant degradation. The thermal sieve placed between the collimator and the unit under test uses a set of thermally controlled baffles with holes that are optimized to use diffraction to pass the collimated light, while attenuating the thermal background by nearly 4 orders of magnitude. Such a system allows accurate and efficient full-aperture testing of large cryogenic telescopes. This paper provides and validates the theory behind the system, evaluates the optimization for performance, and provides the design and analysis for a specific system.

8442-56, Session 10

Innovative optical setup for testing a stereo camera for space applications

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The Stereo Camera (STC) of the Imaging Suite Simbiosys of the BepiColombo ESA mission to Mercury is based on an innovative and compact design in which the light independently collected by the two channels at ±20° separation with respect to nadir falls on a common detector. STC adopts a novel stereo acquisition mode, based on the push-frame concept, never used before on a space mission.

To characterize this camera for obtaining the most accurate data of the Mercury surface, standard calibration measurements have been performed. In addition, we also wanted to demonstrate and characterize the capability of the instrument to reconstruct a 3D surface with the desired accuracy by means of the stereo push-frame concept. To this end, a lab setup has been realized with an evaluation model of STC, in which the problem of working at an essentially infinite object distance over hundred km baselines has been overcome by means of a simple collimator and a couple of precision rotators. The intrinsic and extrinsic parameters of the camera have been obtained with standard stereo procedures, adapted to the specific case. The stereo validation has been performed by comparison of the accurately measured target shape by laser scanning technique, with the shape reconstructed by the adopted stereo algorithm applied to the image pairs under various illumination angles. The obtained results show the goodness of this innovative validation technique, that will be applied also for validating the stereo capabilities of STC flight model.

8442-57, Session 11

Progress towards precision focal-plane astrometry using micropixel centroiding

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In recent years advances in metrology have enabled a significant improvement in the astrometric precision possible with a simple telescope. In this conceptually straightforward approach, the distance between star images in the focal plane is directly proportional to the angular distance between the stars. In the search for earth-like planets in the habitable zones of nearby sun-like stars, the needed astrometric precision is 1 micro-arcsecond, which translates to a few micro-pixels in characterizing each pixel in the focal plane. The Nearby Earth Astrometric Telescope (NEAT) is one example of the use of this approach for creating relatively low-cost near term micro-arcsecond astrometric missions. The elements of this approach are 1) micro-pixel calibration of the pixel response function (includes location and QE profile of each pixel), 2) improved stellar image-position centroiding algorithms, and 3) mitigation of field distortions arising from beam walk on telescope secondary. Our progress so far has been to address the first two elements through experiments and we report our latest results here. Field distortions can either be addressed by using a single-mirror telescope (as done in NEAT) or by calibration of the field distortions. We report our initial investigation of the feasibility of the distortion calibration and whether we will be investigating it next.

8442-58, Session 11

A metrology concept for multiple telescope astrometry

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Medium to large angle observations, e.g. for global astrometry, can be implemented in space by means of either a common telescope, fed by a Beam Combiner (as in Hipparcos), or by individual telescopes set in a rigid geometry (as in Gaia).

We investigate the applicability of auto-collimation and cophasing techniques for implementation of a monitoring system alternative to more conventional point-to-point metrology.

Apart different implementation constraints, the most relevant difference consists in the auto-collimation approach characteristics of monitoring simultaneously comparably large sections of the optical system, thus evaluating collective properties closer to those experienced by the stellar

beams.

The auto-collimation concept is based on a common source, injected by a dedicated device within the telescope, e.g. close to the focal plane; the source is optically matched to the primary mirror and therefore retro-reflected and imaged onto the focal plane, with optical resolution comparable to the stellar images, and high sensitivity to the most critical instrument perturbations.

The basic angle variation is measured by the differential motion of the fringes on the images retro-reflected from different telescopes.

8442-59, Session 11

Gaia´s FPA: sampling the sky in silicon

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ESA´s astrometry satellite Gaia is scheduled for launch in 2013. In a combination of outstanding hardware performance, autonomous object detection and sophisticated data processing, Gaia will chart more than a billion stars of the entire sky to unprecedented accuracy during its 5 years mission. A key element to its mission success is the focal plane assembly (FPA), the largest ever flown to space, comprising a close-butted almost Giga-pixel mosaic of 106 large area CCDs. Manufacturing and extensive testing of the individual devices and detector system units as well as integration on the single-piece, silicon-carbide support structure has been a challenge. The focal plane is now assembled and will undergo its final tests during 2012. The paper summarizes the expected in-flight performances of Gaia´s FPA and the implemented tools and procedures to monitor its operation in space. Accurate knowledge of the impact of FPA performance parameters on individual measurements and its evolution in time is critical to achieve the high accuracy needed in calibrating the science data. An example is the radiation-induced deterioration of the CCD charge transfer efficiency, which acts on distorting the detected object PSFs while observing the sky in continuous scan mode. Through dedicated calibration procedures and directly through the scientific data processing, Gaia will therefore closely track the radiation environment at L2 from the FPA output itself. Detection of transient effects and analysis of persistent damage on the CCDs mainly caused by solar protons converts Gaia's FPA inherently into the largest ever radiation monitor in space.

8442-60, Session 11

Gaia in-orbit realignment: overview and data analysis

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Gaia is an ESA cornerstone mission with a launch scheduled for 2013. It will provide accurate positions, proper motions and parallaxes for a billion stars in the Galaxy. The scientific optical payload consists of two off-axis three-mirror anastigmatic telescopes.

The scientific performance of Gaia critically depends on the telescopes. They must provide near diffraction-limited quality. The launch and subsequent cool-down will introduce large that can be removed if both telescopes are re-aligned in orbit. Therefore, Gaia includes an M2MM (secondary mirror movement mechanism) in each optical path and two fully redundant Shack-Hartmann WaveFront Sensors (WFSs) in the focal plane.

The M2MM can place and rotate the secondary mirror along the three axes using fully redundant actuators. It is characterised by the matrix relating the impact of of each actuation on the wavefront error, which is defined as a sum of bidimensional Legendre Polynomials.

The WFS obtains information on the optical aberrations comparing the spot patterns produced by stars and internal optical sources. Gaia is a revolving scanning satellite operating in time-delay integration. In addition, a slit is placed in front of the WFS to limit aberrations and avoid confusion between microlenses. Therefore, only very bright stars can be used to provide the precision required. The WFS performance depends on the algorithms used for centroiding and wavefront reconstruction.

In this work, an overview of the alignment process and the systems involved is given, with emphasis on the WFS data processing algorithms developed at ESAC.

8442-61, Session 11

Gaia basic angle monitoring system

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The Gaia mission will create an extraordinarily precise three-dimensional map of more than one billion stars in our Galaxy. The GAIA spacecraft, built by EADS Astrium, is part of ESA's Cosmic Vision programme and scheduled for launch in 2013. TNO has developed, built and qualified the all Silicon carbide Basic Angle Monitoring (BAM) system for this mission.

The Gaia satellite measures the position, distance and motion of stars using two telescopes at a fixed mutual angle of 106.5°, named the 'Basic Angle'. The astronomical measurements will be accurate to 24 microarcsec, comparable to measuring the diameter of a human hair at a distance of 1000 kilometres. This requires ultrahigh stability, which can only be achieved by using Silicon carbide for both the optical bench and the telescopes.

In addition the Basic Angle variation between the two telescopes must be measured with a precision of 0.5 microarcsec. Therefore Gaia is equipped with a Basic Angle Monitoring system. This metrology system consists of two laser interferometers and is able to measure an Optical Path Difference (OPD) as small as 1.5 picometers rms.

To fulfil the extremely high stability requirements for such accurate OPD measurements, the entire BAM OMA is constructed of Silicon carbide as well, except for some glass transmission optics. This presentation will give an overview of the integration, alignment and testing (including space-level qualification) of Gaia BAM.

8442-62, Session 12

The exoplanetary circumstellar environments and disk explorer (EXCEDE)

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We present an overview of the EXoplanetary Circumstellar Environments and Disk Explorer (EXCEDE), selected by NASA for technology development and maturation. EXCEDE will study the formation, evolution and architectures of exoplanetary systems, and characterize circumstellar environments into stellar habitable zones. EXCEDE provides contrast-limited scattered-light detection sensitivities ~ 1000x greater than HST or JWST coronagraphs at a much smaller effective inner working angle (IWA), thus enabling the exploration and characterization of exoplanetary CS disks in currently inaccessible domains. EXCEDE will utilize a laboratory demonstrated high-performance Phase Induced Amplitude Apodized Coronagraph (PIAA-C) integrated with a 70 cm diameter unobscured aperture visible light telescope. The EXCEDE PIAA-C will deliver star-to-disk augmented image contrasts of < 10E-8 and a 1.2 lambda/D IWA or 0.14" with a wavefront control system utilizing a 2000-element MEMS DM and fast steering mirror. EXCEDE will provide 144 mas spatial resolution at 0.4 microns with dust detection sensitivity to levels of a few tens of zodis with two-band imaging polarimetry. EXCEDE is a science-driven technology pathfinder that will advance our understanding of the formation and evolution of exoplanetary systems,

placing our solar system in broader astrophysical context, and will demonstrate the high contrast technologies required for larger-scale follow-on and multi-wavelength investigations on the road to finding and characterizing exo-Earths in the years ahead.

8442-63, Session 12

Using the ISS as a testbed to prepare for the next generation of space-based telescopes

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The infrastructure available on the ISS provides a unique opportunity to develop the technologies necessary to assemble large space telescopes. Assembling telescopes in space is a game changing approach to space astronomy. Using the ISS as a testbed enables a concentration of resources on reducing the technical risks associated with integrating the technologies, such as laser metrology and wavefront sensing and control (WFS&C), with the robotic assembly of major components including the primary and secondary mirrors and the alignment of the optical elements to a diffraction limited optical system in space. The capability of assembling the optical system and removing and replacing components via the existing ISS Robotic Systems like the Special Purpose Dexterous Manipulator (SPDM), or by the ISS Flight Crew, allows for future experimentation as well as repair if necessary.

In 2015, first light will be obtained on ISS by the Optical Testbed and Integration on ISS eXperiment (OpTIIX), a small 1.5 meter optical telescope. The primary objectives of OpTIIX include demonstrating telescope assembly technologies and end-to-end optical system technologies that will advance future large optical telescopes.

8442-64, Session 12

Wide field infrared survey telescope [WFIRST]: telescope design and simulated performance

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The Wide Field Infrared Survey Telescope (WFIRST) mission concept was ranked first in new space astrophysics missions by the Astro2010 Decadal Survey, incorporating the Joint Dark Energy Mission (JDEM) payload concept and multiple science white papers. This mission is based on a space telescope at L2 studying exoplanets [via gravitational microlensing], probing dark energy, and surveying the near infrared sky. Since the release of NWNH, the team has been working with the WFIRST science definition team (SDT) to refine mission and payload concepts. We present the current interim reference mission point design of the payload, based on the use of a 1.3m unobscured aperture three mirror anastigmat form, with focal imaging and slitless spectroscopy science channels. We also present the first results of Structural/Thermal/Optical performance modeling of the telescope point design.

8442-65, Session 13

Performance and calibration of the HST wide field camera three

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The Wide Field Camera 3 is the primary science instrument on HST accounts for approximately half of all observations since its installation during Servicing Mission 4 in May 2009. This panchromatic camera provides unsurpassed imaging capabilities from 200nm to 1700nm with a rich set of filters. After more than 2.5 years in orbit, WFC3 has met and generally exceeded our expectations both technically and in its scientific output. This paper discusses the evolution of our understanding of the performance of WFC3 and our development of our annual calibration strategies both to aid future missions and to seek feedback. A key aspect of WFC3 is its high degree of mechanical and photometric stability which has permitted steadily improving calibrations. This paper will present results from detailed photometric and astrometric monitoring programs which demonstrate better than 0.5 percent photometric stability at all wavelengths including the UV and 0.05 pixels astrometric stability since launch, trend histories for the CCD and HgCdTe detectors (the Teledyne HgCdTe detector is proving extremely stable), and quantified measurements of the imaging performance including demonstration of high contrast observations of closely separated sources. Three key topics will also be discussed: (1)The calibration and user support for slit-less spectroscopy with Grisms. This mode has, amongst other accomplishments, enabled the faintest low resolution near infrared spectra every obtained. (2) The techniques used to achieve markedly improved flat field calibrations. These included detailed modeling and compensation for telescope optical variations and internal reflections within the WFC3 detector assembly. (3) The recent implementation of a spatial scanning observing technique which enables very high signal to noise ratio observations of bright sources including exo-planets and also high precision astrometry.

8442-66, Session 13

Characterizing persistence in the IR detector within the wide field camera 3 instrument on Hubble Space Telescope

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Like essentially all IR arrays, the IR detector that is part of the Wide Field Camera 3 (WFC3) instrument on-board Hubble Space Telescope (HST) exhibits after images, known as persistence, following exposures to light that approach or exceed saturation of individual pixels of the detector. The nature of the persistence in the HgCdTe WFC3/IR detector is somewhat unusual in that the amount of persistence is not simply proportional to the exposure level. Instead, the amount of persistence is small until the exposure reaches about half saturation at which point it rises fairly rapidly until the exposure reaches about twice saturation and then it increases gradually with increasing saturation. The persistence does show a typical power law decay with time, at least over the periods of time that are relevant to HST observations. Given the extensive usage of the WFC3/IR detector on HST, it is not possible to completely avoid the effects of persistence in observations obtained with HST by introducing time gaps between IR observations. Therefore, we have developed a parametrized persistence model which we are using to estimate the amount of persistence in all WRC3/IR images. These estimates are available through the Multi-Mission Archive at STScI (MAST) to help HST users remove persistence from their images. Here we discuss the characterization of persistence in the WFC3 detector in orbit, the fraction of observations that are affected by persistence, and the effectiveness of the tools we have developed to reduce the effects of persistence in WFC3 images.

8442-67, Session 13

A Spitzer measure of the zodiacal light

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The dominant non-instrumental background source for space based infrared observatories is the zodiacal light. We present a Spitzer Infrared Array Camera (IRAC) measurement of the zodiacal light at 3.6, 4.5, 5.8, and 8.0 microns. Observations were made of a region near to the north ecliptic pole roughly biweekly over a five year baseline for 5.0 & 8.0 microns and an eight year baseline for 3.6 & 4.5 microns. We compare the IRAC measurements to both data and models of the interplanetary dust from the COBE DIRBE experiment. Our data show a few percent discrepancy from both the amplitude and absolute value of the Kelsall et al. 1998 model. One known reason for this is that Spitzer is moving away from the earth at 0.1 AU per year and therefore sampling a different part of the cloud than DIRBE. Accurate knowledge of the zodiacal light is important for both extragalactic and Galactic astronomy including measurements of the cosmic infrared background, absolute measures of extended sources, and comparison to extrasolar interplanetary dust models.

8442-68, Session 13

Intra-pixel gain variations and high-precision photometry with the infrared array camera (IRAC)

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The Infrared Array Camera (IRAC) on the Spitzer Space Telescope has been used to measure $<10^{-4}$ temporal variations in point sources (such as transiting extrasolar planets) at 3.6 and 4.5 microns. Due to the under-sampled nature of the PSF, the warm IRAC arrays show variations of as much as 8% in sensitivity as the center of the PSF moves across a pixel due to normal spacecraft pointing wobble and drift. These intra-pixel gain variations are the largest source of correlated noise in IRAC photometry. Usually this effect is removed by fitting a model to the science data themselves (self-calibration), which could result in the removal of astrophysically interesting signals. We describe a new technique for significantly reducing the gain variations and improving photometric precision in a given observation, without using the data to be corrected. This comprises: (1) an adaptive centroiding and repositioning method ("peak-up") that uses the Spitzer Pointing Control Reference Sensor (PCRS) to repeatedly position a target to within 0.1 IRAC pixels of an area of minimal gain variation; and (2) the high-precision, high-resolution measurement of the pixel gain structure using non-variable stars. We show that the technique currently allows the reduction of correlated noise by almost an order of magnitude over raw data, which is comparable to the improvement due to self-calibration. We discuss other possible sources of correlated noise, and proposals for reducing their impact on photometric precision.

8442-69, Session 13

Absolute photometric calibration of IRAC: lessons learned using nine years of flight data

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Significant improvements in our understanding of various photometric effects have occurred in the more than nine years of flight operations of the Infrared Array Camera aboard the Spitzer Space Telescope. With the accumulation of calibration data, photometric variations that are intrinsic to the instrument can now be mapped with high fidelity. Using all existing data on calibration stars, the array location-dependent photometric correction (the variation of flux with position on the array) and the correction for intrapixel sensitivity variation (pixel-phase) have been modeled simultaneously. Examination of the warm mission data enabled the characterization of the underlying form of the pixel-phase variation in cryogenic data. In addition to the accumulation of calibration data, significant improvements in the calibration of the truth spectra of the calibrators has taken place. Using the work of Engelke et al. (2006), the KIII calibrators have no offset as compared to the AOV calibrators, providing a second pillar of the calibration scheme. The current cryogenic calibration is better than 3% in an absolute sense, with most of the uncertainty still in the knowledge of the true flux densities of the primary calibrators. We present the final state of the cryogenic IRAC calibration, the current state of the warm IRAC calibration and a comparison of the IRAC calibration to an independent calibration methodology using the HST primary calibrators.

8442-70, Session 14

Space active optics: performance of a deformable mirror for in-situ wave-front correction in space telescopes

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MADRAS (Mirror Active, Deformable and Regulated for Applications in Space) project aims at demonstrating the interest of Active Optics for space applications. It will evaluate performance of a 24 actuators, 100 mm diameter deformable mirror to be included in a space telescope's pupil relay to compensate for large lightweight primary mirror deformation, which is mainly due to thermal dilatation and zero gravity. In this paper we present the mirror design, the system prototyping and its experimental performance. For the active mirror, both precision of correction and mechanical behavior have been optimized with extensive Finite Element Analysis. Considering wave-front errors expected in 3m-class primary mirrors and taking into account space constraints, such as compactness, weight, low power consumption and mechanical strength, the limit of the correction device has been pushed to a mean precision of 8 nm rms. For the system assembly and testing, a dedicated test-bed has been designed to characterize the mirror performance in representative conditions. It consists of two main loops: a telescope simulator feeding the bench with expected large space mirrors wave-front errors and the active correction loop with a wave-front sensor and the MADRAS deformable mirror. Fizeau interferometry, Shack-Hartman wave-front sensing and PSF imaging are used to demonstrate the correction capacity of the system. We developed and characterized a deformable mirror providing an efficient wave-front correction with a limited number of actuators and a design fitting space requirements. Such a system is dedicated and well suited to future space-borne observatories.

8442-71, Session 14

MOIRE: initial demonstration of a transmissive diffractive membrane optic for large lightweight optical telescopes

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The desire to field space-based telescopes with apertures in excess of 10 meter diameter is forcing the development of extreme lightweighted large optics. Sparse apertures, shell optics, and membrane optics are a few of the approaches that have been investigated and demonstrated. Membrane optics in particular have been investigated for many years. The majority of the effort in membrane telescopes has been devoted to using reflective membrane optics with a fair level of success being realized for small laboratory level systems; however, extending this approach to large aperture systems has been problematic. An alternative approach in which the membrane is used as a diffractive transmission element has been previously proposed, offering a significant relaxation in the control requirements on the membrane surface figure. The general imaging principle has been demonstrated in meter-scale laboratory systems using thin glass in place of a membrane. In addition, a 5-meter diameter transmissive diffractive optic has been demonstrated, also using thin glass rather than a membrane. In this paper we discuss MOIRE Phase 1 developments that culminated in the development and demonstration of an 80 cm diameter phase diffractive transmissive membrane optic. This is a precursor for an optic envisioned as one segment of a 10 meter diameter telescope. We present the demonstrated imaging wavefront performance and collection efficiency, discuss the anticipated areal density in relation to existing space telescopes, and identify how such a component would be used in previously described optical system architectures.

8442-72, Session 14

Spherical primary optical telescope (SPOT) segments

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The spherical primary optical telescope (SPOT) project is an internal research and development program at NASA Goddard Space Flight Center. The goals of the program are to develop a robust and cost effective way to manufacture spherical mirror segments and demonstrate a new wavefront sensing approach for continuous phasing across the segmented primary. This paper focuses on the fabrication of the mirror segments. Significant cost savings were achieved through the design, since it allowed the mirror segments to be cast rather than machined from a glass blank. This was followed by conventional figuring at Goddard Space Flight Center. After polishing, the mirror segments were mounted to their composite assemblies. QED Technologies used magnetorheological finishing (MRF®) for the final figuring. The MRF process polished the mirrors while they were mounted to their composite assemblies. Each assembly included several magnetic invar plugs that extended to within an inch of the face of the mirror. Introducing magnetic materials near the polished region can disrupt the MRF tool and affect figuring convergence. By properly selecting the polishing conditions, MRF was able to significantly improve the figure of the mounted segments. The final figuring demonstrates a process that tests and polishes mirrors as an assembly that is very similar to the end-use configuration and minimizes the risk of later performance change due to mounting.

8442-73, Session 14

The path to far-IR interferometry in space: recent developments, plans, and prospects

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The far-IR astrophysics community is eager to follow up Spitzer and Herschel observations with sensitive, high-resolution imaging and spectroscopy, for such measurements are needed to understand merger-driven star formation and chemical enrichment in galaxies, star and planetary system formation, and the development and prevalence of water-bearing planets. The community is united in its support for a space-based interferometry mission. Through concerted efforts worldwide, the key enabling technologies are maturing. Two balloon-borne far-IR interferometers are presently under development. This paper reviews recent technological and programmatic developments, summarizes plans, and offers a vision for space-based far-IR interferometry involving international collaboration.

This paper will refer to US and Japanese balloon-borne far-IR interferometers (BETTII and FITE) and US and European space mission concepts (SPIRIT and FIRI), list the key enabling technologies, and describe current technology maturity levels.

8442-75, Session 14

Multivariable parametric cost model for space telescopes

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Parametric cost models have multiple uses ranging system architecture trades to guiding technology development investments. But these models are only as good as their database. This paper presents a multivariable parametric cost model based on a database which has been revised, expanded and verified over the past two years.

8442-76, Session 15

Design of large aperture solar optical telescope for SOLAR-C Mission

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We present a design of one of major instruments for SOLAR-C mission, which is a 1.5-m-class aperture solar ultra-violet visible and near IR observing Telescope. The SOLAR-C mission aims at fully understanding dynamism and magnetic nature of the solar atmosphere by observing small-scale plasma processes and structures. The optical telescope is designed to provide high-angular-resolution investigation of lower atmosphere from the photosphere to the uppermost chromosphere with enhanced spectroscopic and spectro-polarimetric capability covering a wide wavelength region from 280 nm (Mg II h&k) to 1100 nm (He I 1083 nm).

To attain requirements from science observations, the telescope assembly consisting of all reflective optics is designed to give a diffraction-limited performance in the wavelengths longer than 633 nm in the field of 200 arcsec diameter. We describe optical and structural design of the telescope assembly and optical design of focal plane instruments: wide-band and narrow-band filtergraphs and a spectrograph for high-precision spectro-polarimetry in the solar photospheric and chromospheric lines.

8442-77, Session 15

In-orbit determination of the straylight in the SOHO/LASCO-C2 coronagraph and its temporal evolution

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The LASCO-C2 coronagraph aboard SOHO (the SOlar and Heliospheric Observatory) is continuously observing the solar corona since early 1996. During this long period of time the instrument, as well as the experimental context, underwent many changes and observational constraints. These changes affect its photometric response and consequently the in-orbit calibrations procedures as well as the pipeline process. Monitoring the instrumental evolution is one of the main tasks of the LASCO-C2 team. In this contribution, we will concentrate on the evolution and measure of the coronagraph straylight along the past fifteen years of operations. Its in-orbit determination is complicated by the peculiar conditions of the coronagraph mission and it must be performed for the nominal conditions of observation. Then the crucial point is the correct separation between the useful coronal signal and the straylight. This has been achieved using the daily sets of polarized images and a minimal set of assumptions. These sets allow first to separate the highly polarized K-corona (the plasma component of the solar corona) from the combination of F-corona (the dust component of the solar corona) and straylight, both unpolarized and residuals of the K-corona (resulting from imperfect polarization analysis). We exploit the facts that the F-corona is symmetric and that the straylight pattern remains constant for long periods of time changing abruptly but slightly from time to time. The processing methodology includes the analysis of the quasi periodic photometric changes of the F-corona due to the orbit of SOHO. Four main changes of straylight have been observed since 1996, one of them correlated to the loss of SOHO in 1998. Minor changes are correlative to changes of the SOHO roll angle. The error analysis will be discussed as well as its effects on the final photometric determination of the corona. Specific recommendations for the in-orbit calibration of future space coronagraphs will be presented.

8442-78, Session 15

Optimization of the occulter for the Solar orbiter/METIS coronagraph

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METIS (Multi Element Telescope for Imaging and Spectroscopy investigation), selected to fly aboard the Solar Orbiter ESA/NASA mission, is conceived to perform imaging (in visible, UV and EUV) and spectroscopy (in EUV) of the close solar corona, by means of an integrated instrument suite located on a single optical bench and sharing the same aperture on the satellite heat shield.

As every coronagraph, METIS is highly demanding in terms of stray light suppression. Coronagraphs history teaches that a particular attention must be dedicated to the occulter optimization. The METIS occulting system is of particular interest due to its innovative concept. In order to meet the strict thermal requirements of Solar Orbiter, METIS optical design has been optimized by moving the entrance pupil at the level of the external occulter on the S/C thermal shield, thus reducing the size of the external aperture.

The scheme is based on an inverted external-occulter (IEO). The IEO consists of a circular aperture on the Solar Orbiter thermal shield. A spherical mirror rejects back the disk-light through the IEO.

A breadboard of the occulting assembly (BOA) has been manufactured and used to perform stray light measurements in front of two artificial Sun sources (at Laboratoire d'Astrophysique de Marseille, France, and in Torino, Italy), able to simulate different solar angular dimensions. We describe BOA design and characteristics and we discuss the obtained results.

8442-79, Session 16

Science with the James Webb Space Telescope

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The science objectives of the James Webb Space Telescope fall into four themes. The End of the Dark Ages: First Light and Reionization theme seeks to identify the first luminous sources to form and to determine the ionization history of the universe. The Assembly of Galaxies theme seeks to determine how galaxies and the dark matter, gas, stars, metals, morphological structures, and black holes within them evolved from the epoch of reionization to the present. The Birth of Stars and Protoplanetary Systems theme seeks to unravel the birth and early evolution of stars, from infall onto dust-enshrouded protostars, to the genesis of planetary systems. The Planetary Systems and the Origins of Life theme seeks to determine the physical and chemical properties of planetary systems around nearby stars and of our own, and to investigate the potential for life in those systems. These four science themes were used to establish the design requirements for the observatory and instrumentation. Since Webb's capabilities are unique, those science themes will remain relevant through launch and operations and goals contained within these themes will continue to guide the design and implementation choices for the mission. More recently, it has also become clear that Webb will make major contributions to other areas of research, including dark energy, dark matter, active galactic nuclei, stellar populations, exoplanet characterization and Solar System objects. In this paper, we review the original four science themes and discuss how the scientific output of Webb will extend to these new areas of research.

8442-80, Session 16

Science operations with the James Webb Space Telescope

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The James Webb Space Telescope (JWST) will be a powerful space observatory whose multi-featured instruments will deliver rich imaging and multiplexed spectroscopic datasets to the astronomical and planetary science communities. The ground segment for JWST, now being designed and built, will carry out JWST's science operations. The ground segment includes:

• software that the scientific community will use to propose and specify new observations;

• software that will schedule both science and calibration observations in a way that optimizes observing efficiency while managing the accumulation of momentum;

• the infrastructure to regularly measure and maintain the telescope's wavefront;

• orbit determination, ranging, and tracking;

• communication via the Deep Space Network to command the observatory and retrieve scientific data;

• onboard scripts that execute each observing program in an event-driven fashion, with occasional interruptions for targets of opportunity or time-critical observations;

* and a system that processes and calibrates the data into science-ready products, automatically recalibrates when calibrations improve, and archives the data for initial access by the principal investigator and later worldwide access by the scientific community.

This ground system builds on experience from operating the Hubble Space Telescope, while solving challenges that are unique to the James Webb Space Telescope. In this paper, we describe the design and construction of elements of the JWST ground system, how it will work operationally, and how a typical user will interact with the system to turn his/her idea into scientific discovery.

8442-81, Session 16

Overview and status of the James Webb Space Telescope Observatory

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The James Webb Space Telescope (JWST) is a large aperture (6.5 meter), cryogenic space telescope with a suite of near and mid-infrared instruments spanning the wavelength range of 0.6 µm to 28 µm. JWST's primary science goals are to detect and characterize the first galaxies, study the assembly of galaxies, star formation, and the formation of evolution of planetary systems. JWST has a unique design based on the concept of passive cooling by means of a multi-layer sunshield to achieve the telescope's cryogenic operating temperature. Each of the five layers of the sunshield is approximately the size of a tennis court, and made of aluminized kapton. By maintaining an observatory attitude whereby the sunshield keeps the telescope in the shade from the sun's rays, the telescope and science instruments can operate at cryogenic temperature (~40 K). On the sun facing side of the observatory the spacecraft bus houses most of the electronic sub-systems, and provides a platform for the solar array and communications hardware. JWST is sufficiently large that it cannot fit inside the fairing of its Ariane 5 launcher without being stowed in a more compact configuration, so the ability to deploy its major sub-systems such as the telescope optics and sunshield after launch are another major feature of the observatory. Development of observatory is making rapid progress as major hardware sub-systems near-completion. Polishing of the JWST telescope mirrors is complete with 18 primary mirror segments, the secondary mirror, tertiary and fine steering mirror all gold coated and through acceptance testing. Engineering test articles of each sunshield membrane layer are underway. The first layer 3 membrane is complete and is undergoing testing to evaluate its tensioned shape for compliance with alignment tolerances. As each major sub-system is tested, the expected scientific performance of the observatory can be evaluated using test results and integrated system models of the observatory. We will discuss key performance parameters of the observatory, including thermal performance, image quality, sensitivity, and the ability to achieve background-limited observations. The observatory deployment after launch will also be discussed in the context of recent sub-system testing of deployment mechanisms.

8442-82, Session 16

James Webb Space Telescope optical telescope element mirror development history and results

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In a little under a decade, the James Webb Space Telescope (JWST) program has designed, manufactured, assembled and tested 21 flight beryllium mirrors for the James Webb Space Telescope Optical Telescope Element. This paper will summarize the mirror development history starting with the selection of beryllium as the mirror material and ending with the final test results. It will provide an overview of the technological roadmap and schedules and the key challenges that were overcome. It will also provide a summary of the key tests that were performed and the results of these tests.

8442-83, Session 16

The James Webb Space Telescope sunshield

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The James Webb Space Telescope (JWST) is NASA's next Flagship astrophysics mission. At its heart is a large passively cooled cryogenic telescope, which is enabled by its sunshield. This paper will review the sunshield's requirements, architecture and design. The sunshield is well past its Critical Design Review and in the initial stages of manufacture. This paper will review results from the critical testing to date, status and the path forward and discuss the challenges that lay ahead on the path to assembly integration and test and finally flight.

8442-84, Session 17

Status of the JWST optical telescope element

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Significant progress has been made in the development of the Optical Telescope Element (OTE) for the James Webb Space Telescope (JWST) Observatory. All of the mirror assemblies are complete and through final testing. The composite Pathfinder Primary Mirror Backplane Support Structure (PMBSS) has been completed and the flight structure is making significant progress. This paper will discuss the current status of all the OTE components and the plan forward to completion.

8442-85, Session 17

Statistical analysis of the surface figure of the James Webb Space Telescope mirrors

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The performance of an optical system is best characterized by either the wave front error (WFE) or the optical transfer function (OTF). However, for system budgeting purposes, it is convenient use a single scalar metric, or a combination of a few scalar metrics to track performance. For the James Webb Space Telescope, the Observatory level requirements were expressed in metrics of Strehl Ratio, and Encircled Energy. These in turn were converted to the metrics of total rms WFE and rms WFE within spatial frequency domains. The 18 individual mirror segments for the primary mirror segment assemblies (PMSA), the secondary mirror (SM), tertiary mirror (TM), and Fine Steering Mirror have all been fabricated. They are polished beryllium mirrors with a protected gold reflective coating. The statistical analysis of the resulting Surface Figure Error of these mirrors has been analyzed. The average spatial frequency distribution and the mirror-to-mirror consistency of the spatial frequency distribution are reported. The results provide insight to system budgeting processes for similar optical systems.

8442-86, Session 17

Predicted JWST imaging performance

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The JWST telescope mirror components, 18 individual primary mirror segment assemblies (PMSA), the secondary mirror (SM), tertiary mirror (TM), and Fine Steering Mirror, have all been fabricated. The performance of the telescope based on the as-measured optical components is combined with alignment tolerances and the on-orbit alignment process to predict the imaging performance of JWST. The best estimate of the WFE distribution , Strehl ratio and Encircled Energy is presented.

8442-87, Session 17

Wavefront sensing and controls for the James Webb Space Telescope

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The James Webb Space Telescope (JWST) is a segmented deployable telescope, utilizing 6 degrees of freedom for adjustment of the Secondary Mirror (SM) and 7 degrees of freedom for adjustment of each of its 18 segments in the Primary Mirror (PM). When deployed, the PM segments and the SM will be placed in their correct optical positions to within a few mm, with accordingly large wavefront errors. The challenge, therefore, is to position each of these optical elements in order to correct the deployment errors and produce a diffraction-limited telescope across the entire science field. This paper will describe a suite of processes, algorithms, and software that has been developed to achieve this precise alignment, using images taken from JWST's science instruments during commissioning. The results of flight-like end-to-end simulations showing the commissioning process will also be presented.

8442-88, Session 18

Actuator usage and fault tolerance of the JWST optical telescope element mirror actuators

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The James Webb Space Telescope (JWST) telescope's secondary mirror and eighteen primary mirror segments are actively controlled in rigid body position via six hexapod actuators. The mirrors are stowed to the mirror support structure to survive the launch environment and then must be deployed 12.5 mm to reach the nominally deployed position before the Wavefront Sensing & Control alignment and phasing process begins. The actuation system is electrically, but not mechanically redundant. Therefore, with the large number of hexapod actuators, the fault tolerance of the OTE architecture and WFS&C alignment process has been carefully considered. The details of the fault tolerance will be discussed, including motor life budgeting, failure signatures, and motor life.

8442-89, Session 18

James Webb Space Telescope mirror coatings

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James Webb Space Telescope Optical Telescope Element (OTE) 6.5 m primary mirror consists of 18 primary mirror (PM) segments made out of beryllium. The secondary mirror, the tertiary mirror and the fine steering mirror are also made out of beryllium. To meet the throughput requirements over the JWST spectral region the mirrors require a high reflectance, uniform optical coating on the large 1.5 m point to point PM mirror segments as well as the other mirrors. The coating has to be environmentally stable, radiation resistant and compatible with the cryogenic operating environment. This paper will provide an overview of the JWST OTE coating development program. The paper summarizes key test results including performance of the flight mirrors.

8442-90, Session 18

The integration and test program of the James Webb Space Telescope

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The James Webb Space Telescope (JWST) project has entered into a comprehensive integration and test (I&T) program that over the coming years will assemble the various elements of the observatory (the Optical Telescope Element [OTE], the Integrated Science Instrument Module [ISIM], and the Spacecraft) and verify the readiness of the integrated system for launch. The I&T program as replanned for a 2018 launch readiness date has a number of interesting features. These include a streamlined ISIM cryo-vacuum test program at Goddard Space Flight Center, a streamlined OTIS (OTE + ISIM) test program at Johnson Space Center (JSC), the addition of a second Core cryo-vacuum thermal test, the enhancement of the Pathfinder program at JSC, and enhancement of the subsystem-level testing program for the MIRI cryo-cooler. These latter activities all serve to reduce the risk heading into the end-to-end optical and thermal testing of the telescope at JSC, leading to reduced cost and schedule risk for that critical activity. We report here on the overall I&T program for JWST and on the status of the hardware and plans that support it.

8442-91, Session 18

JWST's cryogenic position metrology system

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The James Webb Space Telescope will undergo a full system test in the cryogenic vacuum chamber A at the Johnson Spaceflight Center in order to verify the overall performance of the combined telescope and instrument suite. This will be the largest and most extensive cryogenic test ever undertaken. Early in the test system development, it was determined that precise position measurements of the overall hardware would enhance the test results. Various concepts were considered before selecting photogrammetry for this metrology. Photogrammetry has been used in space systems for decades, however cryogenic use combined with the size and the optical/thermal sensitivity of JWST creates a unique set of implementation challenges. This paper provides an overview of the JWST photogrammetric system and mitigation strategies for three

key engineering design challenges: 1) the thermal design of the viewing windows to prevent excessive heat leak and stray light to the test article 2) cost effective motors and mechanisms to provide the angle diversity required, and 3) camera-flash life and reliability sufficient for inaccessible use during the number and duration of the cryogenic tests.

8442-92, Session 18

Status of the James Webb Space Telescope integrated science instrument module system

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The Integrated Science Instrument Module (ISIM) of the James Webb Space Telescope (JWST) is discussed from a systems perspective with emphasis on development status and advanced technology aspects. The ISIM is one of three elements that comprise the JWST space vehicle and is the science instrument payload of the JWST. The major subsystems of this flight element and their build status are described.

8442-93, Session 19

The near infrared camera for the James Webb Space Telescope: status and science goals

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JWST's NIRCam instrument is in the final stages of instrument Integration and Test in preparation for delivery to the JWST project. Key milestones include the completion of cryogenic testing of the entire instrument; demonstration of scientific performance requirements; testing of replacement H2RG detectors arrays; and an analysis of coronagraphic performance in light of measured telescope wavefront characteristics. I will summarize the performance of NIRCAM, the science goals of the science team, and results of the testing program.

8442-94, Session 19

The JWST near-infrared spectrograph NIRSpec: status

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The Near-Infrared Spectrograph NIRSpec is one of the four instruments of the James Webb Space Telescope (JWST). NIRSpec will cover the 0.6-5.0 micron range and will be capable of obtaining spectra of more than 100 objects simultaneously in its multi-object spectroscopy (MOS) mode. It also features a set of slits for high contrast spectroscopy of individual sources, as well as an integral-field unit (IFU) for 3D spectroscopy. Manufactured in Europe by EADS Astrium for the European Space Agency (ESA), it is scheduled for delivery to NASA at the end of 2012. We will provide an overview on the current status of the instrument and of its expected performances.

8442-95, Session 19

Overview of MIRI status and first indications of flight performance

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MIRI is one of four instruments to be built for JWST (James Webb Space Telescope). It provides imaging, coronography and integral field spectroscopy over the 5-28.5um wavelength range. MIRI is the only instrument which is cooled to 7K by a dedicated cooler, much lower than the passively cooled 40K of the rest of JWST, and consists of both an Optical System and a Cooler System. The paper will describe the current status of both these parts of MIRI, which follow separate development and delivery paths.

In the past 18 months the flight model of the MIRI Optical System has been through a complete set of environmental testing and a cryogenic performance test designed to demonstrate all the MIRI science functions and capabilities. We will present an overview of the test results with an emphasis on the updated expected scientific performance of MIRI.

8442-96, Session 19

Ambient alignment verification of JWST-MIRI

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We report on the alignment verification activities using optical visible techniques, and performed at ambient temperature before and after environmental and qualification tests, on the Mid InfraRed Instrument (MIRI), one of the scientific instruments on-board the James Webb Space Telescope (JWST). More specifically, the method developed to measure some of the instrument key parameters, such as pupil shear and focus offset, is explained in details. We describe the chosen approach, the associated common hardware, the initial set-up and alignment, then discuss the measurements themselves and finally the data analysis, before concluding on the successful application of such approach to the optical characterization of the MIRI flight model.

8442-97, Session 19

The JWST fine guidance sensor (FGS) and near-infrared imager and slitless spectrograph (NIRISS)

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The Fine Guidance Sensor (FGS) of the James Webb Space Telescope (JWST) features two modules, an infrared camera dedicated for fine guiding and a science camera, the Near-Infrared Imager and Slitless

Spectrograph (NIRRIS) covering the wavelength range from 0.6 to 5.0 µm with a field of view of 2.2'x2.2'. NIRISS has four observing modes: 1) broad-band imaging featuring seven of the eight NIRCam broad-band filters, 2) wide-field slitless spectroscopy at a resolving power of ~150 between 1 and 2.5 µm, 3) single-object cross-dispersed slitless spectroscopy enabling simultaneous wavelength coverage between 0.6 and 2.5 µm at R~700, a mode optimized for transit spectroscopy of relatively bright (J<7) stars and, finally, 4) sparse aperture interferometric imaging between 3.8 and 4.8 µm enabling high-contrast imaging (10-4) at angular separations between 70 and 50 milliarsec. This paper will review the current status of both FGS and NIRISS with an emphasis on the scientific capabilities offered by NIRISS.

8442-98, Session 19

Exoplanet and black hole science with non-redundant interferometric masks on JWST

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Non-redundant masking (NRM) between 3.8-5um is a high resolution technique planned for JWST-NIRISS. It will provide 10 magnitudes contrast as close as 75mas, about 2 magnitudes better than ground-based NRM using F380M, F430M and F480M 3-5% filters. Its search space is complementary to JWST's coronagraphs and future 30-m class ground-based telescopes. The fainter end of Gemini-GPI or ESO-SPHERE targets can also be observed with JWST-NIRISS. We demonstrate how true interferometric imaging and aperture synthesis will also be possible with JWST-NIRISS by applying radio astronomical data reduction methods to simulated noisy images. Modest contrast observations of dusty accretion flows around AGNs is also feasible. Furthermore, NRM substantially reduces mission risk associated with sensing JWST's active primary mirrors. We outline the ways non-redundant ideas can be used to coarse phase JWST's primaries earlier in commissioning than is the baseline plan, and an approach to combining NRM and full aperture PSFs to provide full-aperture fine wavefront sensing.

SPIE Astronomical Instrumentation

8443-01, Session 1

Little mirror, big science

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It will be decades before a flagship class mission in the ultraviolet will be implemented to succeed the Hubble Space Telescope. However, advances in technology can enable smaller aperture systems to achieve and surpass HST sensitivity by reducing attacking the noise portion of the signal/noise calculation. Through the use of ultra-low noise photon counting detectors, low scatter optics, narrow band filters and optical design, instruments in the ultraviolet can be developed that can attack critical science questions that cannot be addressed by current instrumentation, even in a Explorer class mission. I will review the science case for diffuse emission and faint target spectroscopy and the describe the technologies needed to implement low noise detectors. Starw man mission capability caculations for SMEX and EX sized missions will also be presented.

8443-02, Session 1

Observatory-class science with a low-cost EUV astronomy mission

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The various demands on funding agencies make it difficult to sustain the level of expenditure required to provide the broad range of space astronomy missions that the research community would like to have available. Multi-billion pound/dollar observatories such Chandra, XMM-Newton and HST have been enormously successful, but JWST has been delayed and plans for an equivalent large X-ray mission seem to be on-hold. Furthermore, the medium size ESA and NASA missions provide only a small number of opportunities over the next decade. Much exciting and important science, by default, will not be done. If satellite mission costs could be reduced significantly, by a factor of 5-10, we would open up a new parameter space of opportunity that is not currently offered by any agency. Significant improvement in instrument technology coupled with simplification of optical systems and the development of efficient, high performance small satellite platforms and ground systems has led to the prospect of the development of some low-cost opportunities. In this paper, we outline one such possible mission, based on a successful sounding rocket-borne payload. This comprises a high throughput normal incidence extreme ultraviolet spectrometer, with the design adapted for accommodation on the SSTL 300 platform. We make use of a segmented diffraction grating to provide an overall wavelength coverage from ~170-250Å by tuning the multi-layers of the individual elements to different, overlapping ranges. We outline the capability and science goals of the mission, and how they influence the design and operation of the satellite platform.

8443-03, Session 1

An introduction to the World Space Observatory ultraviolet (WSO/UV)

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The World Space Observatory Ultraviolet is a multinational mission under the leadership of Russia with contributions of Germany, Spain and Ukraine. The mission is part of the Spektrum-series and launch is currently scheduled for 2015. It consists of a 1,7m mirror focussing on spectrographs in the range of 102-310nm with a resolution of R>55.000 for high spectral observations, a long-slit-spectrograph for spatial observations and an imager. All spectrographs will use the same detectors build by the IAAT. These spectrographs are designed to observe cosmic plasma with temperatures of several ten thousands Kelvin and atomic transition lines of all important atoms and molecules like H2, CO, OH etc. In the core program the community want to determine the amount of baryonic matter in the universe, extend the knowledge about the formation of galaxies and analyze the atmospheres of extra solar planets and protoplanetar discs. To achieve these goals the IAAT designed in cooperation with ISAS (Leibniz-Institut für Analytische Wissenschaften) the spectrographs. In addition Tuebingen develop and build a new type of micro-channel-plate detector based on gallium nitride cathodes and a cross-strip-anode. We will present the mission itself, the contribution of Tuebingen, the new detectors we design, including the new cathode material and the new electronics and first results of our detector development.

8443-04, Session 1

Development and fabrication of the Colorado high-resolution echelle stellar spectrograph (CHESS)

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A key astrophysical theme that will drive future UV/optical space missions is the life cycle of cosmic matter, from the flow of intergalactic gas into galaxies to the formation and evolution of exoplanetary systems. Spectroscopic systems capable of delivering high resolution with low backgrounds will be essential to addressing all of these topics. Towards this end, we are developing a rocket-borne instrument that will serve as a pathfinder for future high-sensitivity, high-resolution UV spectrographs. The Colorado High-resolution Echelle Stellar Spectrograph (CHESS) will provide 2 km/s velocity resolution (R = 150,000) over the 100 - 160 nm bandpass that includes key atomic and molecular spectral diagnostics for the intergalactic medium (H I Lyman-series, O VI, N V, and C IV), exoplanetary atmospheres (H I Lyman-alpha, O I, and C II), and protoplanetary disks (H2 and CO electronic band systems). CHESS uses a novel mechanical collimator comprised of an array of 10 mm x 10 mm stainless steel tubes to feed a low-scatter, 69 grooves/mm echelle grating. The cross-disperser is a holographically ruled toroid, with 351 grooves/mm. The spectral orders can be recorded with either a 40 mm cross-strip microchannel plate detector or a 3.5k x 3.5k delta-doped CCD. The microchannel plate will deliver 30 micron spatial resolution and employs new 64 amp/axis electronics to accommodate high count rate observations of local OB stars. CHESS is scheduled to be launched aboard a NASA Terrier/Black Brant IX sounding rocket from White Sands Missile Range in the summer of 2013.

8443-05, Session 2

The focusing optics x-ray solar imager: FOXSI

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The Focusing Optics X-ray Solar Imager (FOXSI) is a sounding rocket payload funded under the NASA Low Cost Access to Space program to test hard X-ray (HXR) focusing optics and position-sensitive solid state detectors for solar observations. The FOXSI project is led by the Space Sciences Laboratory at the University of California, Berkeley, currently scheduled to be launch in April 2012. The NASA Marshall Space

Flight Center is responsible for the grazing incidence optics, while the Astro-H team at JAXA/ISAS has provided double-sided silicon strip detectors. FOXSI is a pathfinder for the next generation of solar hard X-ray spectroscopic imagers that will overcome current observational limitations in sensitivity and dynamic range. Such observatories will be able to image the non-thermal electrons within the solar flare acceleration region, trace their paths through the corona, and provide essential quantitative measurements such as energy spectra, density, and energy content in accelerated electrons.

8443-06, Session 2

The EUI instrument on board the Solar Orbiter Mission: from breadboard and prototypes to instrument model validation

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The Solar Orbiter mission will explore the connection between the Sun and its heliosphere, taking advantage of an orbit approaching the Sun at 0.28 AU. As part of this mission, the Extreme Ultraviolet Imager (EUI) will provide full-sun and high-resolution image sequences of the solar atmosphere at selected spectral emission lines in the extreme and vacuum ultraviolet.

To achieve the required scientific performances under the challenging constraints of the Solar Orbiter mission it was required to further develop existing technologies. As part of this development, and of its maturation of technology readiness, a set of breadboard and prototypes of critical subsystems have thus been realized to improve the overall instrument design.

The EUI instrument architecture, its major components and sub-systems are described with their driving constraints and the expected performances based on the breadboard and prototype results. The instrument verification and qualification plan will also be discussed. We present the thermal and mechanical model validation, the instrument test campaign with the structural-thermal model (STM), followed by the other instrument models in advance of the flight instrument manufacturing and AIT campaign.

8443-07, Session 2

The interface region imaging spectrograph for the IRIS Small Explorer Mission

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The Interface Region Imaging Spectrograph (IRIS) is a NASA SMall EXplorer mission scheduled for launch in December 2012.

The primary goal of IRIS is to understand how the solar atmosphere is energized. The IRIS investigation combines advanced numerical modeling with a high resolution UV imaging spectrograph.

IRIS will obtain UV spectra and images with high resolution in space (0.4 arcsec) and time (1s) focused on the chromosphere and transition region of the Sun, a complex interface region between the photosphere and corona.

The IRIS instrument uses a Cassegrain telescope to feed a dual spectrograph and slit-jaw imager that operate in the 133-141 nm and 278-283 nm ranges. This paper describes the instrument with emphasis on the imaging spectrograph, and presents an initial performance assessment from ground test results.

8443-08, Session 2

Multi element telescope for imaging and spectroscopy (METIS) coronagraph for the Solar Orbiter Mission

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METIS, the "Multi Element Telescope for Imaging and Spectroscopy", is a coronagraph selected by the European Space Agency to be part of the payload of the Solar Orbiter mission to be launched in 2017. The unique profile of this mission will allow 1) a close approach to the Sun (up to 0.28 A.U.) thus leading to a significant improvement in spatial resolution; 2) quasi co-rotation with the Sun, resulting in observations that nearly freeze for several days the large-scale outer corona in the plane of the sky and 3) unprecedented out-of-ecliptic view of the solar corona.

This presentation describes the coronagraph concept and the observational tools required to achieve the science drivers of METIS. METIS will be capable of obtaining for the first time: i) simultaneous imaging of the full corona in polarized visible-light (500-600 nm) and narrow-band ultraviolet HI Ly α (121.6 nm); ii) monochromatic imaging of the full corona in the extreme ultraviolet He II Ly α (30.4 nm); iii) spectroscopic observations of the HI and He II Ly α in corona.

These measurements will allow a complete characterization of the three most important plasma components of the corona and the solar wind, that is, electrons, hydrogen, and helium. This presentation gives an overview of the METIS imaging and spectroscopic observational capabilities to carry out such measurements

8443-09, Session 2

The x-ray/EUV telescope for the Solar-C Mission: science and development activities

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We report science and development activities of the X-ray/EUV telescope for the Japanese Solar-C mission whose projected launch around 2019.

The telescope consists of a package of (a) a normal-incidence (NI) EUV telescope and (b) a grazing-incidence (GI) soft X-ray telescope. The NI telescope chiefly provides images of low corona (whose temperature 1 MK or even lower) with ultra-high angular resolution (0.2-0.3"/pixel) in 3 wavelength bands (304, 171, and 94 angstroms). On the other hand, the GI telescope provides images of the corona with a wide temperature coverage (1 MK to beyond 10 MK) with the highest-ever angular resolution (0.5"/pixel) as a soft X-ray coronal imager. The set of NI and GI telescopes should provide crucial information for establishing magnetic and gas-dynamic connection between the corona and the lower atmosphere of the Sun which is essential for understanding heating of, and plasma activities in, the corona.

Moreover, we attempt to implement photon-counting capability for the GI telescope with which imaging-spectroscopy of the X-ray corona will be performed for the first time, in the energy range from ~0.5 keV up to 10 keV. The imaging-spectroscopic observations will provide totally-new information on mechanism(s) for the generation of hot coronal plasmas (heated beyond a few MK), those for magnetic reconnection, and even generation of supra-thermal electrons associated with flares.

An overview of instrument outline and science of the X-ray/EUV telescope will be presented. Also, ongoing development activities in Japan towards soft X-ray photon-counting observations, focusing on high-speed X-ray CMOS detector and sub-arcsecond-resolution GI mirror, will be reported and their perspective discussed.

8443-10, Session 3

Development status of the LAUE project

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The LAUE project is devoted to develop a long focal length petal (20 m) of a Laue lens for soft gamma-ray astronomy (80 - 600keV). The final scientific goal is that of significantly pushing up the sensitivity limits of the current generation of gamma-ray telescopes and, in parallel, improving their imaging capability.

The lens petal will make use of bent crystals that reflect for Bragg diffraction in Laue (transmission) configuration. We will present the development status of LAUE.

The LAUE project is the follow-up of another project (HAXTEL), that has already allowed us to fix the technology for assembling a short focal length lens based on mosaic crystals. The measured performance of the last short focal length prototype were presented at the SPIE conference in San Diego in 2011.

8443-11, Session 3

Critical developments toward building Laue lenses for gamma-ray astronomy

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Laue lenses uniquely enable the concentration of soft gamma rays from a large collecting area onto a focal plane with a reasonably short focal length. In astronomy, they hold the promise of increasing telescope sensitivities by one to two orders of magnitude. The lenses are particularly well suited for observations of faint nuclear gamma ray lines from point sources, but they can also be optimized for continuum sources such as hard X-ray tails from a variety of compact objects. We have been pursuing the technical development of Laue lenses on two fronts critical to the development of a full scale lens. The first is the search for high-reflectivity and reproducible crystals. We have been working to enable high-quality Rh, Ag and Pb crystals in large quantities (in addition to Cu and Ge that are already available). The second is the development of a fast and accurate method to mount the thousands of crystals constituting a lens onto a substrate. We produced a breadboard model of a Laue lens using a novel mounting technique and used this lens to focus an X-ray beam. Here, we report on these two activities, which demonstrate that the two key elements to build a full scale astrophysical lens have been developed.

8443-12, Session 3

Development of electron tracking Compton camera for both balloon and future satellite experiments for MeV gamma-ray astronomy

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To explore MeV gamma-ray astronomy, we have developed Electron Tracking Compton Camera (ETCC) consisting of a Time projection Chamber based on the micro pixel gas counter and pixel array scintillators. By measuring the track of a recoil electron in TPC event by event, ETCC measures the direction of each gamma-ray, and provides both a good background rejection and an angular resolution of ~1degree. A 1m-cubic size ETCC in satellite would be a good candidate for All sky MeV gamma-ray survey of a wide band energy regions on 0.1-100MeV with several ten times better sensitivities of COMPTEL. We carried out the balloon experiment with a small ETCC (Sub-MeV gamma ray Imaging Loaded-on-balloon Experiment: SMILE-I) in 2006, and obtained diffuse cosmic and atmosphere gamma ray. Now we are constructing a 30cm-cube ETCC to catch gamma-rays from the Crab and terrestrial gamma-ray burst in North Pole from 2013. Terrestrial gamma-ray bursts are generated by relativistic electron precipitation in the Pole region. Recently

tracking of the recoil electron tracking has been dramatically improved, which may enable us to come near the ideal efficiency expected in the detector. Also the result of the measurement of the angular resolution for the pair creation in 10-20MeV is presented. In addition, I mention about the unique capability to find a high-z Gamma-Ray Bursts beyond z>10 by ETCC, in particular long duration GRBs over 1000 sec, which are expected due to POP-III stars.

8443-13, Session 3

Concept of a small satellite for sub-MeV all sky survey: the CAST Mission

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Sub-MeV to low MeV energy band from 100 keV to 1-2 MeV contains rich information of high-energy phenomena in the universe. The CAST (Compton Telescope for Astro and Solar Terrestrial) mission is planned to be launched at the end of 2010s, and aims at providing all-sky map in this energy-band for the first time. The main telescope is a semiconductor Compton camera utilizing Si as a scatterer and CdTe as an absorber, and hence provides all-sky sub-MeV polarization map for the first time, as well. The Compton camera technology is based on the design used in the Soft Gamma-ray Detector (SGD) onboard ASTRO-H, characterized by its tightly stacked semiconductor layers to obtain high detection efficiency. The CAST mission is currently planned as a candidate for the small scientific satellite series in ISAS/JAXA, weighting about 500 kg in total. Scalable detector design enables us to consider other options as well. Scientific outcome of CAST is wide. It will provide new information from high-energy sources, such as AGN and/or its jets, supernova remnants, magnetors, black-hole and neutron-star binaries and others. Polarization map will tell us about activities of jets and reflections in these sources, as well. In addition, CAST will simultaneously observe the Sun, and depending on its attitude, the Earth. These data will open up better understanding of particle acceleration with magnetic reconnection and electric field, which are considered to be the major process in these sources.

8443-14, Session 3

Development of a telescope for medium-energy gamma-ray astronomy

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Since the launch of AGILE and FERMI, the scientific progress in high-energy (> ~200 MeV) gamma-ray science has been dramatic. However, neither instrument is optimized for observations below ~200 MeV where many astrophysical objects exhibit unique, transitory behavior, such as spectral breaks, bursts, and flares.

The Advanced Energetic Pair Telescope (AdEPT) is being developed as a future NASA MIDEX mission to exploring the medium-energy (5-200 MeV) energy range. The enabling technology for AdEPT is the GSFC Three-Dimensional Track Imager (3-DTI) gaseous time projection chamber. The high spatial resolution 3-D electron tracking of 3-DTI enables AdEPT to achieve high angular resolution gamma-ray imaging via pair production and triplet production (pair production on electrons) limited by the interaction kinematics rather than Coulomb scattering. Further, the reduction of Coulomb scattering, allows AdEPT to be the first medium-energy gamma-ray telescope to have high gamma-ray polarization sensitivity.

We describe the instrument requirements needed to achieve the science goals of the AdEPT mission, the development of the 3-DTI technology, and the performance of a 30x30x30 cm3 prototype of the AdEPT telescope.

8443-15, Session 3

The space gamma-ray telescope GAMMA-400 for the energy range 100 MeV - 3 TeV

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The preliminary design of the new space gamma-ray telescope GAMMA-400 for the energy range 100 MeV - 3 TeV is presented. The angular resolution of the instrument, 1-2° at E_γ ~100 MeV and ~0.01° at E_γ > 100 GeV, its energy resolution ~1% at E_γ > 100 GeV, and the proton rejection factor ~10E6 are optimized to address a broad range of science topics, such as search for signatures of dark matter, studies of Galactic and extragalactic gamma-ray sources, Galactic and extragalactic diffuse emission, gamma-ray bursts, as well as high-precision measurements of spectra of cosmic-ray electrons, positrons, and nuclei.

8443-16, Session 4

Moscow State University satellite Mikhail Lomonosov: the multipurpose observatory in space

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In honor of the founder of Moscow State University M.V. Lomonosov the scientific and educational satellite “Mikhail Lomonosov” will be launched in 2012. The scientific program is devoted to extreme phenomena in the Universe: ultra- high energy cosmic rays (UHECR) and gamma-ray bursts (GRB). The scientific payload consists of the atmospheric fluorescence detector TUS for study UHECR and detectors measuring GRB in optical, UV, x-rays and gamma- wavelengths. The TUS detector will also provide data on the transient luminous events (TLE) in the upper atmosphere, specifically on study of TLE in their early stage. The satellite will also monitor the magnetosphere particles and radiation.

8443-17, Session 4

Ultra Fast Flash Observatory (UFFO) for observation of early photons from gamma ray bursts

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We describe the space project of Ultra-Fast Flash Observatory (UFFO), which will observe early optical photons from gamma-ray bursts (GRBs) with a sub-second optical response, for the first time. The UFFO will probe the early optical rise of GRBs, opening a completely new frontier in GRB and transient studies, using a fast-response rotatable mirror system which redirects optical path to telescope instead of slewing of telescopes or spacecraft. In our small UFFO-Pathfinder experiment, scheduled to launch aboard the Lomonosov satellite in June 2012, we use a motorized mirror in our Slewing Mirror Telescope instrument to achieve less than one second optical response after X-ray trigger. We describe the science and the mission of the UFFO project which includes a series of GRB space observatories with advanced capabilities, including the UFFO-100 to be launched in 2014. With our program of ultra-fast optical response GRB observatories, we aim to gain a deeper understanding of GRB

mechanisms, and potentially open up the z>10 universe to study via GRB as point source emission probes.

8443-18, Session 4

The Ultra-Fast Flash Observatory (UFFO)-100 for observations of the rise phase of gamma-ray bursts

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At the Research Center for MEMS Space Telescopes (RCMST) of Ewha Womans University, Seoul, we have developed beam-steering systems that can point over >60 degree fields in < 1 sec. Such devices can therefore steer the beam of a conventional optical telescope with much faster response to gamma-ray burst (GRB) triggers than ever before. The Ultra-Fast Flash Observatory (UFFO) concept uses an X-ray coded mask camera to trigger a beam-steering mirror to point an optical-IR telescope to observe GRB and other transients. The UFFO-Pathfinder, a small version of the observatory, with a 10 cm telescope mirror and 191 cm^2 of X-ray detector area, will be launched by June 2012 on the Lomonosov Spacecraft. In late 2014, we plan to launch the UFFO-100 with a 30 cm optical/IR telescope and 1000 cm^2 of CZT collecting area for the X-ray camera. Two cameras will simultaneously measure emission in the optical and IR. In this talk, we give details of the instrument designs, the science plan, and updates on the program, including our designs for an optical polarimeter. The UFFO-100 will detect GRBs nearly as often as Swift in the V band, but it will start observing them much earlier. The near-IR camera will permit detection of most obscured GRB, and the two cameras together will furnish spectral slopes. These advances in response time and instrumentation will enable the UFFO-100 to provide a large sample of optical/IR rise-phase light curves of GRB for the first time.

8443-19, Session 5

Cryogenic micro calorimeters as future imaging detectors for x-ray missions

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The development of cryogenic detectors for high resolution x-ray spectroscopy has made rapid progress in the last decade. Todays, state of the art devices have a spectral resolving power of over 3000 at 6 keV. Among the most promising calorimeter technologies are superconducting transition edge sensors (TES), metallic magnetic calorimeters (MMC) and the recently proposed magnetic penetration depth thermometers (MPT).

Despite the enormous progress, it still remains a major challenge to build large arrays of such detectors with high quality imaging capability. By far the most mature technology in this respect is based on TES detectors, for which arrays with several thousand pixels have already been demonstrated. We will review the current state of the development and discuss prospective for broad-band imaging x-ray spectroscopy using cryogenic micro calorimeters.

8443-20, Session 5

The use of CCDs and EM-CCDs for future soft x-ray spectrometers

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CCDs have been used on several successful X-ray space missions including high resolution soft X-ray spectrometers, such as the RGS on XMM-Newton and the HETG on Chandra. These instruments had a resolving power (E/ΔE) ~300; however, with new technology this can be improved down to the thermal limit. In the soft X-ray band (200 eV to 10 keV) this means a resolution of around 3000 is required resolve all of the possible absorption and emission features. Through the development of instruments for the OP-XGS on IXO and the WHIMEx explorer mission it has been shown that an instrument capable of this resolution on a spacecraft is possible. CCDs are the ideal detector for use in detection of X-rays at this energy as they provide positional information allowing a high level of spatial resolution and their inherent energy resolution allowing diffracted orders to be separated. This paper will also further study the possibility of using EM-CCDs in soft X-ray spectroscopy as the multiplication of the signal in the charge domain can increase the detectability of low energy photons, improving the Signal-to-Noise Ratio. Multiplication gain has been shown to degrade the resolution of a device due to the Modified Fano Factor, so this has to be taken into account in instrument design when overlapping spectral orders are needed to achieved the necessary resolution. The use of optical filters on the CCDs and their effect on quantum efficiency at soft X-ray energies is discussed together with possible improvements to existing technology.

8443-21, Session 5

A new design for the gas pixel detector

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The Gas Pixel Detector, recently developed and continuously improved by Pisa INFN in collaboration with IASF-Roma of INAF, can visualize the tracks produced within a low Z gas by photoelectrons of few keV. By reconstructing the impact point and the original direction of the photoelectrons, the GPD can measure the linear polarization of X-rays, while preserving the information on the absorption point, the energy and the time of arrival of individual photons. Applied to X-ray Astrophysics, in the focus of grazing incidence telescopes, it can perform angular resolved polarimetry with a huge improvement of sensitivity, when compared with the conventional techniques of Bragg diffraction at 45 degrees and Compton scattering around 90 degrees. This configuration has been the basis of POLARIX and HXMT, two pathfinder missions, and was included in the baseline design of IXO, the very large X-ray telescope under study by NASA, ESA and JAXA.We have recently improved the design of this low energy polarimeter (2-10keV) by modifying the geometry of the absorption cell to minimize any systematic effect which could leave a residual polarization signal for non polarized source.We will report on the testing of this new concept.

8443-22, Session 5

Scintillating fibers readout by single photon avalanche diodes (SPAD) for space applications

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We present the design and performances of a radiation detector based on plastic scintillating fibers with double-side readout by means of large-area Single Photon Avalanche Diodes (SPAD). This can be the basic step toward the realization of a large-area, cost-effective position sensitive detector to be employed in future space gamma-ray observatories. SPADs are silicon devices operated above the junction breakdown voltage (with the typical overvoltage of 5V), for which a single photon interacting in the active region is sufficient to trigger a self-sustainable avalanche discharge. SPADs can thus be used for the detection of very low light levels with a fast time response around 50ps FWHM for single photon detection, without spectroscopic capabilities. Large-area SPAD (500 micrometer in diameter) have been designed and fabricated at the CNR-IMM facility, with an intrinsic noise lower than 10kHz at -15°C, and are optically coupled to both ends of 3-meter long BCF-20 scintillating fibers, with the same diameter. Double-side readout is required to operate the devices in coincidence (10ns coincidence window), in order to reduce the rate of false detections to the level of ~1Hz. The detectors have been tested with minimum ionizing particles at CERN PS demonstrating a detection efficiency larger than 90% and a moderate position resolution along the fiber due to the difference in time of arrival between the two photodetectors. Radiation hardness tests on SPADs have also been carried out, showing that large-area SPADs can be safely employed in low-inclination low Earth orbits.

8443-23, Session 5

Progress report on kinetic inductance based x-ray detectors

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Microwave Kinetic Inductance Detectors (MKIDs) are an emerging technology for millimeter to optical astronomy due to their sensitivity and the ease with which they can be multiplexed into large arrays. A MKID is an energy sensor based on a photon-variable superconducting inductance in a lithographed microresonator, and is capable of functioning as a photon detector across the electromagnetic spectrum. With comparatively large energies, X-ray detection with MKIDs is straightforward. However, X-ray MKIDs have yet to demonstrate the energy resolution achievable by Transition Edge Sensors (TESs) of roughly 2 eV at 6 keV. The best energy resolution reported to date for an X-ray MKID was 60 eV at 6 keV (Mazin et al., 2006), limited by the two-level system noise of the substrate. Significantly better results are possible with optimized MKID designs. Here we report our progress toward the construction of X-ray MKIDs with high energy resolution.

8443-24, Session 5

Laboratory tests with soft protons and hyper-velocity dust particles: application to ongoing projects of future x-ray space missions

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We report on our activities, currently in progress, aimed at performing experiments with soft protons and hyper-velocity dust projectiles. They include tests of radiation and debris damage on different type of X-ray detectors and components, and measurements of scattering of soft protons and hyper-velocity particles off X-ray mirror shells. These activities have been identified as a main issue in the context of a number of ongoing space projects. We irradiate SDD detectors for LOFT, similar tests on CCD chips have already been done for eROSITA and may be planned for SVOM. Tests of debris impact on SDD,CCD, micro-calorimeters and possibly filters are important for LOFT,eROSITA,SVOM, ASTRO-H and ATHENA. The investigation of the grazing incidence impact of soft protons and hyper-velocity micrometeroids and debris on X-ray mirror surfaces is crucial to improve the model of the assesment of the risks posed by these particles. We use the Van de Graaf accelerator facility of the University of Tuebingen and the MPIK dust accelerator facility in Heidelberg.In this paper we review the topic of degradation of performances and radiation damage of space-borne X-ray instrumentation, and we present the experimental set-up adopted to perform the tests, the status of the measurements and results achieved at present time.

8443-25, Session 5

Detector and coating technologies that enable the next generation of cosmic baryon mapping missions

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In order to fully trace the baryonic life cycle---the evolution of the IGM, galaxies and stars across cosmic time---the next generation of UV/optical space missions will require significant improvements in throughput and S/N, only recently made possible through advances in technology. Here we describe how UV photon-counting CCD detectors with optimized coatings can be employed in future space missions in order to obtain factors of x10-100 improvement over exisiting capabilities. In addition to a review of the specific technologies and recent progress, we present several case studies that illustrate how these technologies are mission-enabling and enhancing, using HST and other existing mission concepts as a template.

8443-26, Session 6

Optics of the WFXT (Wide Field X-ray Telescope) mission: design and development

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The next generation wide-field X-ray telescope (WFXT), to be implemented beyond eRosita and proposed within the NASA RFI call 2011, requires an angular resolution of 5-10 arcsec constant across a wide field of view (1 deg^2 diameter). To achieve this goal the design of the optical system has to be based on nested modified grazing incidence Wolter-I mirrors, realized with polynomial profiles, focal plane curvature and plate scale corrections. This concept guarantees an improved angular resolution at large off-axis angle with respect to the normally used Wolter I configuration and are optimal for survey purposes. Quartz glass (fused silica), a well-known material with good thermo-mechanical and polishability characteristics, could meet our goal in terms of mass and stiffness. To bring the mirror shells to the needed accuracy, we are developing a deterministic direct polishing method. This method has already been used for past missions (as Einstein, Rosat, Chandra) but the technological challenge now is to apply it for almost ten times thinner shells. Our approach is based on two main steps: i) quartz glass tubes available on the market are grinded to conical profiles, ii) these shells are then polished and shaped to the required polynomial profiles by Computer Numerical Control (CNC) polishing machine. The results of X-ray calibrations performed on WFXT optics prototypes developed ad hoc and tested in full illumination mode at the Panter/MPE facility will be presented.

8443-27, Session 6

Development of high angular resolution x-ray telescopes based on slumped glass foils in Europe

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The mirrors of the International X-ray Observatory (IXO) were based on of a large number of high quality segments, aiming at achieving a global spatial resolution better than 5 arcsec (HEW). A study concerning the hot slumping of thin glass foils is under development in Europe, funded by ESA and led by the Brera Observatory and is continuing even after that the program has been descoped, in the perspective of using the technology under development for other future missions. We have focused our the effort on the "Direct" slumping approach with convex moulds (during the thermal cycle the optical surface of the glass is in direct contact with the mould surface). The thin plates are made of thin glass sheets (0.4 mm thick), with a reflecting area of 200 mm × 200 mm. The adopted integration process foresees the use of reinforcing ribs for bonding together the plates and forming in that way a rigid and stiff stack of segmented mirror shells; the stack is supported by a thick backplane. During the bonding process the plates are constrained to stay in close contact with the surface of a precisely figured master by the application of vacuum pump suction. In this way the spring-back deformations and low frequency errors still present on the foil profile after slumping can be corrected. In this paper we present the status the project and the results of the metrology and X-ray calibration of the x-ray unit prototypes we have developed.

8443-28, Session 6

Next generation x-ray optics: high-resolution, light-weight, and low-cost

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The first approach is precision slumping of borosilicate glass sheets. By design and choice at the outset, this technique makes lightweight and low-cost mirrors. The development program will continue to improve angular resolution, to enable the production of 5-arcsecond x-ray telescopes, to support Explorer-class missions and one or more missions to supersede the original IXO mission.

The second approach is precision polishing and light-weighting of single-crystal silicon mirrors . This approach benefits from two recent commercial developments: (1) the inexpensive and abundant availability of large blocks of monocrystalline silicon, and (2) revolutionary advances in deterministic, precision polishing of mirrors. By design and choice at the outset, this technique is capable of producing lightweight mirrors with sub-arcsecond angular resolution. The development program will increase the efficiency and reduce the cost of the polishing and the lightweighting processes, to enable the production of lightweight sub-arcsecond x-ray telescopes.

Concurrent with the fabrication of lightweight mirror segments is the continued development and perfection of alignment and integration techniques, for incorporating individual mirror segments into a precision mirror assembly. Recently, we have been developing a technique called edge-bonding, which has achieved an accuracy to enable 10-arcsecond x-ray telescopes. Currently, we are investigating and improving the long-term alignment stability of so-bonded mirrors. Next, we shall refine this process to enable 5-arsecond x-ray telescopes. This technology development program includes all elements to demonstrate progress toward TRL-6: metrology; x-ray performance tests; coupled structural, thermal, and optical performance analysis, and environmental testing.

8443-29, Session 7

Technology development of adjustable grazing incidence x-ray optics for sub-arc second imaging

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We report on technical progress made over the past year developing thin film piezoelectric adjustable grazing incidence optics. We believe such mirror technology represents a solution to the problem of developing lightweight, sub-arc second imaging resolution X-ray optics. Such optics will be critical to the development next decade of astronomical X-ray observatories such as SMART-X, the Square Meter Arc Second Resolution X-ray Telescope. SMART-X is the logical heir to Chandra, with 30 times the collecting area and Chandra-like imaging resolution, and will greatly expand the discovery space opened by Chandra's exquisite imaging resolution.

In this paper we discuss deposition of thin film piezoelectric material on flat glass mirrors. For the first time, we measured the local figure change produced by energizing a piezo cell - the influence function, and showed it is in good agreement with finite element modeled predictions. We determined that at least one mirror substrate material is suitably resistant to piezoelectric deposition processing temperatures, meaning the amplitude of the deformations introduced is significantly smaller than the adjuster correction dynamic range. Also, using modeled influence functions and IXO-based mirror figure errors, the residual figure error was predicted post-correction. The impact of the residual figure error on imaging performance, including any mid-frequency ripple introduced by the corrections, was modeled. These, and other, results are discussed, as well as future technology development plans.

8443-30, Session 7

Progress with MEMS x-ray micro pore optics

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We report on our development of ultra light-weight X-ray micro pore optics based on MEMS (Micro Electro Mechanical System) technologies. Using dry etching or X-ray lithography, curvilinear sidewalls are fabricated.

The sidewalls vertical to the wafer surface are smoothed by use of high temperature annealing and/or magnetic field assisted finishing to work as X-ray mirrors. The wafer is deformed to a spherical shape and two spherical wafers with different curvature of radii are stacked to approximate the Wolter type-I optic. A theoretical limit on the angular resolution arises from X-ray diffraction on the order of 10 arcsec.

The MEMS X-ray optics can satisfy requirements of various future astronomy and exploration missions such as DIOS (Diffuse Intergalactic Oxygen Surveyor) and JMO (Jupiter Magnetospheric Orbiter). We started this development since 2007 and are making rapid progress. We have verified the x-ray reflection on the sidewalls (Ezoe et al., 2010 Microsys. Tech.) and the x-ray focusing with a single-stage 4-inch optic (Mitsuishi et al., 2011 Transducers) for the first time in the world with this method. In this paper, we report on the status of the x-ray imaging quality of the single-stage optics, the micro roughness of the sidewalls, the heavy metal coating of the sidewalls with atomic layer deposition, and the assembly of the Wolter type-I optics.

8443-31, Session 7

Novel applications of silicon pore optics technology

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Silicon Pore Optics technology is the baseline technology for large effective area space based X-ray telescopes. It has the advantage of being based on low-cost, widely available superpolished silicon wafers. By shaping (cutting and bending) and direct bonding of these modular silicon mirrors, we can create a variety of structures in a number of well defined shapes. The resulting structure is stiff, lightweight, vacuum compatible and contains only Si, SiO2 and if required a metallic coating to improve the X-ray reflectivity; properties which are optimal for any space based, or even earth based X-ray optics. We will present several applications that are being developed, or that could be realised in the near future, using X-ray mirrors based on bonded and structured superpolished Si wafers, next to the existing Silicon Pore Optics technology.

One novel application is an X-ray half-mirror for X-ray interferometry applications. Flat, structured Si mirrors bonded to a glass support structure with a large open area ratio, let through approximately 50% of one X-ray beam, and reflect 50% of another one, in order to combine two optical paths to form interference fringes. This application is presently being developed in collaboration with the University of Leicester.

A second application is using bent silicon single crystals as a focusing Laue lens for soft gamma rays up to 500 keV. Bent and bonded thin Si mirrors can form optical elements which focus in two dimensions, which is crucial to obtaining a high concentration factor and hence a high telescope sensitivity.

8443-32, Session 7

Progress in the development of critical-angle transmission gratings

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Large area, high resolving power spectroscopy in the soft x-ray band can only be achieved with a state-of-the-art diffraction grating spectrometer. Recently developed critical-angle transmission (CAT) gratings combine the advantages of transmission gratings (low mass, relaxed figure and alignment tolerances) and blazed reflection gratings (high broad band diffraction efficiency, utilization of higher diffraction orders). Since the demise of IXO there are no soft x-ray spectroscopy missions in the pipeline, but several new mission concepts containing CAT grating based spectrometers (AEGIS, AXSIO, SMART-X) promise to deliver unprecedented order-of-magnitude improvements in soft x-ray spectroscopy figures of merit. The CAT grating principle has previously been demonstrated with x rays using small wet-etched samples. We report the latest progress in the fabrication and testing of large (32x32 mm2) CAT grating prototypes with an integrated hierarchy of low-obstruction support structures. The gratings are fabricated from silicon-on-insulator wafers using advanced lithography and highly anisotropic dry and wet etching techniques. We expect to present new experimental results on resolving power and diffraction efficiency with large CAT gratings.

8443-33, Session 7

X-ray interferometer with a x-ray beam splitter

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We report some basic laboratory experiments and computer simulation of a new X-ray interferometer with a X-ray beam splitter. The beam splitter is consisting of a transmission multi-layer. The final objective of this interferometer is a size measurement of some celestial objects. Samples of the X-ray beam splitter and the multi-layer flat mirrors have been fabricated and their flatness was measured. We found that both the X-ray beam splitters and the mirrors can be used for the X-ray interferometer for C-K and/or O-K bands. For laboratory experiments, we have to change the configuration of the X-ray interferometer as a “grazing incident” Mach -Zehnder interferometer instead of the new X-ray interferometer for observation of celestial objects. However, we use the same multi-layer flat mirrors and the beam splitters and they are essentially same. We have started some experiment to get fringe pattern of the X-rays.

Computer simulations of the new X-ray interferometer and the laboratory design, “grazing incident” Mach -Zehnder interferometer, have been performed. For the laboratory design, required tolerances were investigated for the setting angles of the mirrors and for the positions of the mirrors, which will be compared with the experiments. For the new X-ray interferometer, we designed a possible configuration to observe the size of some celestial objects.

8443-90, Poster Session

Progress towards a double flux-locked-loop scheme for SQUID readout of TES detector arrays

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Frequency Division Multiplexing technique for reading TES detectors with SQUID devices, requires high loop-gain up to MHz frequency range in the SQUID feedback loop. Such a requirement is difficult to achieve when the feedback loop has a physical length that makes the propagation times of signals not negligible, as in the case in which the readout electronics is placed at room temperature. A novel SQUID readout scheme, called Double Loop-Flux Locked loop (DL-FLL), has been proposed earlier. According to this scheme it is possible to make use of a simplified cryogenic electronics, featuring low power dissipation, in order to obtain a cryogenic feedback loop that results in reduced propagation times of signals.

Here we present progress toward the final integration of this scheme.

8443-91, Poster Session

Nuclear spallation by cosmic rays in the eROSITA and ATHENA configurations

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Soft protons are recognized as a major possible source of degradation of the performances of Silicon-based detectors in orbit. It was learned from the experience of Chandra and XMM-Newton that they can be funneled through the mirror shells of an X-ray telescope down to the focal plane and hit detectors. This seems the favoured mechanism, since in

general a detector placed at the focal plane is completely shielded from environmental soft protons except that in correspondance of the aperture field of view. However, the bombardment by high-energy cosmic protons can induce spallation reactions in the shield itself and other materials present at the focal plane. These processes generate secondary hadrons at softer energy, which can escape the target and reach the detectors. The products of spallation are soft protons as well as neutrons, which also can have an impact on the performances of a Silicon-based detector. Their number can be relatively large, if the inter-nuclear cascades involve many nuclei.

We study the production of secondary hadrons in the case of the pn-CCDs aboard eROSITA and the DEPFET Wide Field Imager aboard ATHENA, calculate expected doses over the missions duration and discuss possible effects on these detectors.

8443-92, Poster Session

Southwest Research Institute intensified detector development capability

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Imaging detectors for wavelengths between 10 nm and 105 nm generally rely on microchannel plates (MCPs) to provide photon detection (via the photo-electric effect) and charge amplification. This is because silicon-based detectors (CCD or APS) have near zero quantum detection efficiency (QDE) over this wavelength regime. Combining a MCP based intensifier tube with a silicon detector creates a detector system that can be tuned to the wavelength regime of interest for a variety of applications. Intensified detectors are used in a variety of scientific (e.g. Solar Physics) and commercial applications (spectroscopic test instrumentation, night vision goggles, low intensity cameras, etc.). Building an intensified detector requires the mastery of a variety of technologies involved in integrating and testing.

We report on a the internally funded development program within the Southwest Research Institute to architect, design, integrate, and test intensified imaging detectors for space-based applications. Through a rigorous hardware program the effort developed and matured the technologies necessary to build and test a large format (2k X 2k) UV intensified CCD detector. The ICCD is designed around a commercially available CCD that is optically coupled to a UV Intensifier Tube from Sensor Sciences, LLC. The program demonstrates, through hardware validation, the ability to architect and execute the integration steps necessary to produce detector systems suitable for space-based applications.

8443-93, Poster Session

Application of an EMCCD camera for calibration of hard x-ray telescopes

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Recent technological innovations make it feasible to construct efficient hard x-ray telescopes for space-based astronomical missions. Focusing optics are capable of improving the sensitivity in the energy range above 10 keV by orders of magnitude compared to previously used instruments. The last decade has seen focusing optics developed for balloon experiments and they will be used in space missions such as NuSTAR. The full characterization of x-ray optics for astrophysical missions, including measurement of properties like the point spread function (PSF) and scattering distribution as a function of energy requires a very high spatial resolution, high sensitivity, photon counting and energy discriminating, large area detector. Novel back-thinned Electron Multiplying Charge-Coupled Devices (EMCCDs) are highly suitable detectors for ground-based calibrations. Their chip can be optically coupled to a microcolumnar CsI(Tl) scintillator via a fiberoptic taper. Not only does this device exhibit low noise and high spatial resolution inherent to CCDs, but the EMCCD is also able to handle high frame rates. Additionally, thick CsI(Tl) yields high detection efficiency for x-rays.

In this paper, we discuss the advantages of using an EMCCD to calibrate hard x-ray optics. We will illustrate the promising features of this detector solution using examples of data obtained during the ground calibration of the NuSTAR telescopes performed at Columbia University in 2010/2011. Finally, we give an outlook on latest development and optimizations, such as the use of single photon counting mode to enhance spectral resolution.

8443-94, Poster Session

Extending the MPE PANTER x-ray test facility

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In the light of future large X-ray observatories the Panter X-ray test facility is being upgraded to allow in-focus measurements of future large diameter and long focal length (<20m) optics. In particular we will be able to study the imaging performance of individual optical segments as well as mirror sectors with radii up to 2m. Thus units of silicon pore optics for IXO and Athena, respectively, or slumped glass segments can be characterised. A detailed description of functionality of the 13m extension supported by ESA will be given.

The Panter extension should become operative in June 2012.

8443-95, Poster Session

Very fast lossless on-board data compression for future space-based x-ray observatories

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Future space-based X-ray observatories will not only have increased sensitivity and energy resolution but will provide astronomers with high time resolution in the order of microseconds. The detection of millions of single X-rays per second with their precise energy and their time of arrival will produce unprecedented data rates that can not be downlinked to earth in their full extend due to telemetry limitations.

We present the study of a very fast, lossless, on-board data compression implemented in an FPGA-based Leon3 microprocessor.

The Leon3 is the open source modular VHDL-design of a 32bit microprocessor. Since this System-on-Chip (SoC) is build around a standard AMBA AHB/APB bus it can be extended with custom IP cores that allow the Leon3 CPU and memory controller to be directly interfaced with the detector readout electronics. An RTEMS-based and POSIX compliant operating system developed at our institute allows the use of the well known bzip2 compression algorithm to achieve fast and lossless on-board data reduction as well as data handling from the readout electronics to the telemetry. We developed a test setup and implemented a Data Processing Unit (DPU) that was originally designed for the High Time Resolution Spectrometer (HTRS) on the International X-ray Observatory (IXO).

We conclude with performance estimates done with a prototype board based on a Xilinx Spartan XC3S2000 and we give an outlook into further applications of the system that are beeing studied for the IXO successor ATHENA and for the Large Observatory For X-ray Timing (LOFT).

8443-97, Poster Session

Low-power readout electronics for micro channel plate detectors with cross-strip anodes

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Ultraviolet wavelength range between 102 and 310nm during the next decade. It is a multinational project under Russian leadership with contributions from Germany, Ukraine and Spain. Its main instrument, the WSO/UV Spectrographs (WUVS), was designed by our group in collaboration with the Leibniz Institut für Analytische Wissenschaften Berlin. We are developing the corresponding micro channel plate detectors using new combinations of materials for the photo cathode as well as a 64×64 cross-strip anode for event position determination. Charge preamplification is performed by the BEETLE-chip designed at the ASIC laboratory of the MPI für Kernphysik in Heidelberg for LHCb at CERN. It has 128 preamplifiers on one die providing the analog output in a four-fold serial stream. This stream is digitalized by four ADCs and is processed in a Microsemi RTAX-FPGA. Processed data are sent to the instrument control unit via a SpaceWire interface. This concept results in one order of magnitude reduced power consumption in comparison to the use of conventional preamplifiers as well as a reduced volume, weight and complexity of the readout electronics. Our poster presents the architecture of electronics and details of the FPGA-design as well as an estimation of the performance of our setup.

8443-98, Poster Session

A modulated x-ray source for in-flight calibration of high-energy astrophysics instrumentation

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We describe an X-ray source for calibrating high-energy astrophysics instrumentation. Through stimulation of a photocathode using fast UV LEDs, the X-ray source output can be modulated to follow an arbitrary waveform on timescales as short as nanoseconds. Because it can be turned “off” on command, the modulated source is useful for calibrating the timing, gain, and efficiency characteristics of X-ray detectors and optical systems. Radioactive sources produce an “always on” background flux that can reduce the sensitivity of the instrument by exceeding-sometimes by large margins-the ambient particle background rate. Moreover, the highest energy-resolution detectors require precise knowledge of the gain over a broader range of energies than are available from radioactive sources, in order to achieve their design spectroscopy objectives. A modulated electronic X-ray source provides essential calibration information without degradation of the energy resolution or sensitivity. We have made steady progress in reducing the mass, volume, and power consumption of modulated X-ray sources, including the use of UV optical fibers, vacuum getters, and optimization of source geometry. A modulated X-ray source will be flown as part of the X-ray Advanced Concepts Testbed (XACT) sounding rocket payload.

8443-99, Poster Session

Vacuum facility for calibration of space instrumentation in cleanroom

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Calibration of optical systems is a fundamental step in the development of a space instrumentation. We have built a new cleanroom environment, divided in different areas characterized by a different level of contamination control. A vacuum chamber (a tube of 80 cm diameter, and 2 m length), able to accommodate optical components as well as whole instruments, is interfaced with a ISO6 area, allowing the handling of the instrumentation in a clean environment. The vacuum system is dimensioned to reach 10^-7 mbar pressure in the chamber. Inside, a two axis platform allows the rotation of the instrument with respect to the incident collimating beam, in order to test the response of the instrument to light coming from different points of the field of view. A monochromator coupled with different sources provides radiation in the 40-350 nm spectral range, while a parabolic mirror is used as a collimator. As a source, different spectral lamps can be used to generate emission lines, while a Xe lamp can be used to have continuum spectrum. An high brilliant hollow cathode lamp has been fabricated by the group to generate extreme ultraviolet radiation. Different calibrated detectors and other completing optical components are available.

8443-100, Poster Session

The Slewing Mirror Telescope (SMT) of the Ultra Fast Flash Observatory Pathfinder (UFFO-P)

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The Slewing Mirror Telescope (SMT) is one of two instruments of the Ultra Fast Flash Observatory - Pathfinder (UFFO-P) onboard the Lomonosov spacecraft to study the early UV/Optical light curve from gamma ray bursts (GRBs). SMT can point the GRB optical counterparts within 1sec after the GRB trigger by the UFFO Burst Alert Trigger Telescope (UBAT). Motorized beam-steering mirror allows the SMT beam to point over +/-36 degrees in less than one second. It redirects the light at the entrance of SMT to the F/11.4 Ritchey-Chretien Telescope. UFFO-P SMT has a 10cm aperture and a 17 arcmin x 17 arcmin detector FOV. The detector is a 256 x 256 channel ICCD (Intensified Charge-Coupled Device) detector with 3:1 coupling ratio between CCD and MCP and has a 4ms fast readout rate. The SMT is optimized over 200nm - 650 nm wavelength.

We present here the design / fabrication / assembly of SMT, as well as its ground calibration results in preparation for launch in June 2012.

8443-101, Poster Session

The readout system and the trigger algorithm implementation for the UFFO Pathfinder

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The Ultra-Fast Flash Observatory (UFFO) Pathfinder utilizes a coded-mask X-ray camera and a UV/Optical Ritchey-Chretien telescope. The X-ray camera named UFFO Burst Alert & Trigger Telescope (UBAT) should process the fast trigger and location algorithm to determine gamma-ray burst (GRBs) locations with 10 arcminutes accuracy. We have implemented the trigger and location algorithm in a field programmable gates arrays (FPGA), and the implementation of the imaging algorithm is designed to calculate the location within minimum 3ms after trigger. The determined location is transferred to the UV/Optical telescope named Slewing Mirror Telescope (SMT). It starts to observe afterglows using the motorized slewing mirror in a second. These telescopes are connected by the UFFO data acquisition (UDAQ) system. Therefore, the UDAQ manages and controls the operation and communication of each telescope, and is also in charge of the interface with the satellite. We present the architecture, fabrication and integration of the readout system as well as the algorithm implementation for the GRB trigger and imaging.

8443-102, Poster Session

Simulated performance GRB trigger detector of UFFO

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UFFO (Ultra-Fast Flash Observatory) is a GRB detector on board the Lomonosov satellite to be launch in summer 2012. The GRB trigger is provided by a X ray detector, called UBAT (UFFO Burst Alarm Telescope), which consists of coded mask and array of LYSO crystals and multi-anode PMTs. We built a GEANT4 model of UBAT and study the performance by injecting X rays, gamma rays, charged particles (cosmic rays, electron/positron from trapped radiation). We also simulate GRB X ray photons sampled from real GRB events and add noises astronomical background. Final results will be presented at this meeting.

8443-103, Poster Session

Design and implementation of the UFFO burst alert and trigger telescope

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The Ultra Fast Flash Observatory (UFFO) is a telescope system designed for the detection of the prompt optical/UV photons from Gamma-Ray Bursts (GRBs), and it will be launched onboard the Lomonosov spacecraft in June 2012. The UFFO pathfinder consists of two instruments: the UFFO Burst Alert & Trigger telescope (UBAT) for the detection and location of GRBs, and the Slewing Mirror Telescope (SMT) for measurement of the UV/optical afterglow. The UBAT is a coded-mask aperture X-ray camera with a wide field of view (FOV) of 1.8 sr. The detector module consists of the LYSO scintillator crystal array, a grid of 36 multi-anode photomultipliers (MAPMTs), and analog and digital readout electronics. When the γ/X-ray photons hit the LYSO crystal, it produces UV photons by scintillation in proportion to the energy of the incident γ/X-ray photons. The UBAT detects X-ray source of GRB in the 5 ~ 200 keV energy range, localizes the GRB within 10 arcmin, and sends the SMT this information as well as drift correction in real time. All the process is controlled by a field programmable gates arrays (FPGA) to reduce the processing time. We are in the final stages of the development and expect to deliver the instrument for the integration with the spacecraft. In what fallows we present the design, fabrication and calibration of the UBAT.

8443-104, Poster Session

Expected performance of a Laue lens based on bent crystals

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We present the result of simulations of Laue lens based on bent crystals in different assembling configurations (quasi-mosaic and reflection-like geometries) as part of the LAUE project which is devoted to building a long focal length focusing optics for soft gamma-ray astronomy (80 - 600keV). The scientific goal of the project is to significantly overcome the sensitivity limits of the current generation of gamma-ray telescopes simultaneously with improving the imaging capability.

8443-105, Poster Session

Characterization of bent crystals for Laue lenses

E. Virgilli, F. Frontera, V. Liccardo, V. Valsan, V. Guidi, V. Bellucci, R. Camattari, I. Neri, Univ. degli Studi di Ferrara (Italy)

We present results of reflectivity measurements of bent crystals in different assembling configurations (quasi-mosaic and reflection-like geometries). This is being done for the LAUE project devoted to build a long focal length focusing optics for soft gamma-ray astronomy (80 - 600keV).

The measurements are performed at the fixed exit monochromator mounted in the LARIX facility of the University of Ferrara. The final scientific goal of the LAUE project is to significantly overcome the sensitivity limits of the current generation of gamma-ray telescopes and to improve the current gamma-ray imaging capability.

8443-106, Poster Session

Bent crystals as high-reflectivity components for a Laue lens: basic concepts and experimental techniques

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In hard x-ray astronomy many celestial sources emitting high-energy photons are very interesting candidates for investigation. With this aim, bent crystals have been deeply studied as high-efficiency optical components for the realization of a Laue lens for satellite-borne experiments. Unlike for mosaic crystals, which suffer 50%-limit in diffraction efficiency, a curved crystal presents no theoretical limitation of diffraction efficiency and its energy passband is controlled by simply adjusting its curvature. For fabrication of crystals with curved diffracting planes, several techniques have been worked out or are still under consideration. Amongst curved crystals, special interest is given to those that are being bent due to internal forces, i.e., crystals within which the strain is generated with no need for any external devices. Here surface grooving is proposed as an efficient method to reproducibly obtain self-standing bent crystals. In fact, silicon or germanium plates can be plastically deformed by grooving one of their major surfaces. Very good control of the curvature can be afforded by adjusting experimental parameters. Grooved crystals were characterized at European Synchrotron Radiation Facility and efficiently diffracted up to 700 keV, peaking 95% at 150 keV. We present a systematic experimental study and a model based on the theory of anisotropic bent plates to investigate the properties of grooved silicon crystals.

8443-107, Poster Session

Characterization of curved crystals fabricated by surface grooving

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The usage of crystals having curved diffracting planes (CDP) has been proven to be a valuable tool for realization of a highly efficient Laue lens in astrophysics. At Sensors and Semiconductor Laboratory (Ferrara, Italy) we fabricate a series of self-standing crystals with CDP through the method of surface grooving. This technique is easy, cheap, highly reproducible and leads to a permanent curvature within the crystal with no need for external bending devices. The technology of fabrication of individual plate crystal has been established for Silicon and Germanium, highlighting very high diffraction efficiency over a broad range of energies up to 700 keV, peaking 95% at 150 keV for Si. Cylindrically curved crystals by surface grooving can be positioned on the surface of the lens with the diffracting planes parallel to the major surfaces of the crystalline plate. In such a scheme, photons enter the crystals nearly parallel to the diffracting planes and suffer diffraction and undergo focusing onto the detector. We have undertaken a research and development plan to implement Si and Ge grooved crystals onto the lens through several methods. X and gamma-ray characterization of such optical components is our aim to assess the most performing methodology. Important implications in the realization of satellite-borne experiments in astrophysics would be attained if a technology to implement grooved crystals onto a Laue lens is readily available.

8443-108, Poster Session

Quasi-mosaicity as a tool for focusing hard x-rays

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Crystals having curved diffracting planes (CDP) are very promising for broad-band Laue lens, because they allow concentrating x and gamma rays with high reflectivity. However, an intriguing effect of anisotropy in crystal deformation can be exploited to combine the high reflectivity of the CDP with the capability of focusing the radiation onto a very small focal spot. Quasi-mosaicity can be used to fabricate self-standing curved crystals with two curvatures of different crystalline planes. Indeed, a primary curvature imparted to a crystal results in a secondary (quasi-mosaic) curvature of a different plane direction due to quasi-mosaic effect. Here we show that, since the size of the focal spot of the photons diffracted by a crystal can be controlled by the secondary curvature, quasi-mosaic crystals allow focusing with very high resolution. A model, based on the theory of linear elasticity, has been developed to deeply understand the behavior of quasi-mosaicity. The ratio between quasi-mosaic and primary curvature can be calculated as a function of material and crystallographic direction. Self-standing quasi-mosaic crystals can be fabricated through several techniques, such as film deposition or surface grooving method. However, since quasi-mosaicity is a proper effect of anisotropic medium, preservation of the crystalline structure is mandatory.

8443-109, Poster Session

Development and performance of a gamma-ray imaging detector

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In the last few years we have been working on feasibility studies of future instruments in the gamma-ray range, from several keV up to a few MeV,

in collaboration with other institutes. The innovative concept of focusing gamma-ray telescopes in this energy range, should allow reaching unprecedented sensitivities and angular resolution, thanks to the decoupling of collecting area and detector volume. High sensitivities are essential to perform detailed studies of cosmic explosions and cosmic accelerators, e.g., Supernovae, Classical Novae, Supernova Remants (SNRs), Gamma-Ray Bursts (GRBs). In order to achieve the needed performance, a gamma-ray imaging detector with mm spatial resolution and large enough efficiency is required.

In order to fulfil the combined requirement of high detection efficiency with good spatial and energy resolution, an initial prototype of a gamma-ray imaging detector based on CdTe pixel detectors is being developed. It consists of a stack of several layers with increasing thickness of CdTe detectors in order to enhance the gamma-ray absorption in the Compton regime. A CdTe module detector lies in a 11 x 11 pixel detector with a pixel pitch of 1mm attached to the readout chip. Each pixel is bump bonded to a fanout board made of alumina substrate and routed to the corresponding input channel of the readout ASIC to measure pixel position and pulse height for each incident gamma-ray photon.

We will report the main features of the gamma-ray imaging detector performance such as the energy resolution for a set of radiation sources at different operating temperatures.

8443-110, Poster Session

Development of a quasi-monoenergetic 6 MeV Gamma Facility for calibration of the AdEPT Telescope

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The Advanced Energetic Pair Telescope (AdEPT) will explore the universe in the medium-energy range from about 5 MeV to greater than 200 MeV via gamma-ray pair production. AdEPT will provide high angular resolution observations and for the first time high-polarization sensitivity over this essentially unexplored energy range. The 6 MeV Gamma Facility will allow calibration and optimization of the AdEPT telescope at the difficult low end of its energy range to be done in-house.

The 6 MeV Gamma Facility consists of activating oxygen with a 14 MeV pulsed neutron generator in a continuously flowing volume of water around a 2m x 2m x 1m granite monument. The 6 MeV gamma rays are produced via the 16O(n,p)16N reaction. The 16N decays via beta decay to the excited states of 16O with a 7.13 s half-life. Photons of 6.129 MeV are produced from the de-excitation of the second excited state of 16O. The water is continuously circulated around the block of granite to achieve steady-state gamma emission. The granite block acts as shielding for particles emitted by other reactions. By irradiating the water on one side of the granite block and acquiring data on the opposite side, it is possible to obtain a quasi-monoenergetic source of 6 MeV. This paper presents the mechanical design of the facility and the the characterization of the source.

8443-111, Poster Session

VAMOS

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The Volcano Sierra Negra in Puebla, Mexico was selected to host HAWC (High Altitude Water Cherenkov), a unique observatory of wide field of view (2sr) capable of observing the sky continuously at energies up to 100 TeV. HAWC is proposed as an array of 300 Cherenkov detectors consisting of 5m deep and 7.3 m diameter steel container containing 200,000 liters of purified water, each container with 4 Hamamatsu PMTs. The first construction stage of 7 tanks, VAMOS, was finished this year and it is continuously operating. In this work, the Cherenkov detectors and the electronics of VAMOS are described.

8443-112, Poster Session

A water quality monitoring system for HAWC

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HAWC (High Altitude Water Cherenkov), is a gamma ray (γ) large aperture observatory with high sensitivity that will be able to continuously monitor the sky for transient sources of photons with energies between 100 GeV and 100 TeV. HAWC is under construction in Sierra Negra, Puebla, Mexico, which is located at a high altitude of 4100m. HAWC will be an array of 300 Cherenkov detectors with 200,000 liters of highly pure water.

The sensitivity of the instrument depends strongly on the water quality. We present the design and construction of the HAWC water quality monitoring system. We seek monitor the transparency in violet-blue range to achieve and maintain the required water transparency quality in each detector. The system is robust and user friendly. The measurements are reproducible. Also we present some results from the monitoring the water from the VAMOS detector tanks and of the filtering system.

8443-114, Poster Session

Simulations for a proposed gamma-ray space telescope using MEGAlib

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Gamma-ray burst Investigation via Polarimetry and Spectroscopy (GRIPS) is a proposed space gamma-ray mission for gamma-ray astrophysics. It will be capable of imaging gamma-rays via Compton scattering and pair production in the energy range from ~ 200 keV up to ~ 50 MeV. GRIPS will address fundamental astrophysical questions through observations of energetic gamma-ray phenomena such as gamma-ray bursts, blazars and supernovae in this unique energy window.

The Medium-Energy Gamma-ray Astronomy library (MEGAlib) is an open-source object-oriented software library designed to simulate and analyse data from low-to-medium-energy gamma-ray telescopes, especially Compton telescopes such as GRIPS. The library comprises all necessary data analysis steps from initial simulations through to event reconstruction and image reconstruction. Simulations are being carried out to optimize the sensitivity of GRIPS to gamma-ray sources using MEGAlib and the results are presented here. GRIPS will offer an improvement in sensitivity in its operational energy range by a factor of ~ 40 compared with previous missions.

8443-115, Poster Session

Background estimation in a wide-field background-limited instrument such as Fermi GBM

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The supporting instrument on board the Fermi Gamma Ray Space Telescope, the Gamma-ray Burst Monitor (GBM), is an wide-field gamma-ray instrument comprised of 14 individual scintillation detectors, with a field of view which encompasses the entire unocculted sky. The conventional method for background estimation with GBM-like instruments is to either interpolate or fit a function to the background rates. This is generally sufficient for phenomena such as Gamma-Ray Bursts (GRBs) which are characterised by impulsive peaks with sharp rises, often highly structured, and easily distinguishable against

the instrumental background. However, this method is not suited to separating smoother long lived emission from GRBs, or in defining background intervals for solar flares which typically have ill-defined end-points and occur during periods of highly-variable underlying solar activity. We present a description of a background estimation technique which uses the rates from adjacent days when the satellite has approximately the same geographical coordinates, to allow us to determine the background and distinguish low-level emission from the instrumental background. We also present results from the application of this technique to GBM data and discuss the implementation of it in a generalised background-limited detector in a non-equatorial orbit.

8443-117, Poster Session

ISSIS: the imaging and slitless spectroscopy instrument for surveys in the World Space Observatory ultraviolet space telescope

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ISSIS is the Imaging and Slitless Spectroscopy Instrument for the 1.7m primary World Space Observatory- Ultraviolet to be launched in late 2015. ISSIS is a multipurpose instrument designed to carry out high resolution (< 0.1 arcsec) imaging in the far UV with an extension to the optical-infrared. ISSIS has two acquisition channels: the High Sensitivity Channel (HSC) and the Channel for Surveys (CfS). The HSC is equipped with an MCP-type detector to guarantee high sensitivity in the 115-175 nm range and high rejection of lower energy radiation. The CfS is implemented to allow high dynamical range UV observations. Slitless spectroscopy with resolution 300 will be available.

WSO-UV will be at geosynchronous orbit thus lower UV background than the Hubble Space Telescope or GALEX. The high Earth orbit will also allow the efficient monitoring of astronomical sources. Primary scientific objectives of ISSIS are: [1] to track the transit of giant extrasolar planets, [2] to extend the current understanding of magnetic activity (and accretion) to the brown dwarf limit, [3] to study the populations of galactic star forming regions, not covered in the GALEX survey, and of star formation in nearby galaxies, [4] to study the evolution of the Lyman-alpha emitters to redshift z=2, [5] to study gravitational lenses and the diffuse intracluster medium and [6] to analyse the physics of gravitational engines from AGN's power source to protostellar jets.

8443-119, Poster Session

Detector development for the World Space Observatory Ultraviolet (WSO-UV)

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The main instrument of the WSO-UV satellite covers the wavelength range of 102-174nm and 172-310nm with two high resolution spectrographs. The essential requirements for the associated detectors are high quantum efficiency, solar blindness, and single photon detection. To achieve this, we are developing a microchannel plate detector in a sealed tube. We plan to use caesium activated gallium nitride as semitransparent photocathode. The photoelectrons will be multiplied by a stack of two microchannel plates and detected by a cross strip anode. This type of anode in combination with advanced readout electronics will reduce the needed gain and extend the expected lifetime of the detectors to about 10 years.

Challenges in this concept are the fast degradation of the photocathode under atmospheric conditions and the leak tight welding and sealing of the detector body. Therefore we set up two connected UHV chambers with a transfer system and worked out the assembly processes.

We present the detector concept, details of the transfer and sealing processes under UHV, and the current status.

8443-120, Poster Session

EXCEED: an extreme ultraviolet spectrometer onboard SPRINT-A

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The extreme ultraviolet (EUV) telescope EXCEED (Extreme Ultraviolet Spectroscope for Exospheric Dynamics) onboard the Japan's small satellite SPRINT-A will be launched in 2013. The EXCEED instrument will observe tenuous gases and plasmas around the planets in the solar system (e.g., Mercury, Venus, Mars, Jupiter, and Saturn). One of the primary observation targets is Jupiter, whose magnetospheric plasma dynamics is dominated by planetary rotation. In the EUV range, a number of emission lines originate from plasmas distributed in Jupiter's inner magnetosphere. The EXCEED instrument is designed to have a wavelength range of 55-145 nm with a spectral resolution of 0.4-1.0 nm. The spectrograph slits have a field of view of 400 x 140 arc-seconds (maximum), and the attitude fluctuations are stabilized within 5 arc-seconds. The optics of the instrument consists of a primary mirror with a diameter of 20cm, a laminar type grating, and a 5-stage microchannel plate assembly with a resistive anode encoder. The surfaces of the primary mirror and the grating are coated with CVD-SiC. In this paper, we report the general mission overview, the instrumentations, and the results of ground calibrations.

8443-121, Poster Session

Design of UV long-slit spectrometer

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Increasing spectral device's field of view requires long slit. However, receiving acceptable resolution in UV spectral range is complicated task due to impossibility of additional optical elements usage. Mirrors reflection factors are relatively low and there are almost no transmitting materials for that kind of spectral range.

General approaches for solution of this task are shown in this paper on the example of alternative variants of UV long-slit spectrometer.

In this paper it is suggested to use only one optical element as collimating, dispersing and focusing component in FUV spectral range - concave diffraction grating. In NUV spectral range, where mirror coating reflecting factor is higher, it is suggested to use zeroth order of the same grating with subsequent spectral decomposition performed with additional concave diffraction grating. It is known that diffractive grating efficiency depends on form of grooves profile. At the present time there are different methods of acquiring grooves with specified form, however, in the first approximation step profile echelette grating fits quite well for this task.

Usage of concave diffraction grating, placed on Rowland circle, is impossible due to design considerations. In view of this we have used nonsymmetrical layouts, where distance from grating to entrance slit is significantly greater than the one to receiver. In this paper calculations are given for spherical and toroidal grating with aberration correction. Ruled grating with twisted unequally spaced grooves were considered as well

as holographic gratings, recorded with aspherical wavefronts. In last case we have used our previously developed method of concave holographic gratings aberration correction with recording using cylindrical optics.

Resolving spectral power R = $\lambda/\Delta\lambda$ for FUV spectral range is 800 - 2000, if receiver's sensitive surface is plane and it is 1500 - 3200, if receiver's sensitive surface is concave. For NUV spectral range this values are 1100 - 2000 and 1500 - 2500, respectively.

8443-122, Poster Session

Vacuum and environmental testing of an all-reflective spatial heterodyne spectrometer designed for wide input angle measurements of H Ly-alpha at high spectral resolving power

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Scattered solar and collisionally stimulated H Ly-α emission is a proven diagnostic for the study of the Sun, comets, the interplanetary medium, planet atmospheres, aurora, and corona. Basic intensity measurements offer insight into the distribution of H Ly-α emission sources. However, the addition of high resolving power provides access to other important information such as flow velocities and radiative transfer effects along with the ability to separate individual Doppler components in an emission line region such as multimodal populations. High resolving power is infrequently used in the VUV and the instruments that do exist lack the etendue necessary to observe extended targets efficiently. In this paper we discuss the development of a narrow bandpass instrument designed to observe H Ly-α emission at a resolving power of R~100,000 from targets with an angular extent of $\leq$½ degree. The instrument is an all-reflective form of the spatial heterodyne spectrometer (SHS), a self-scanning Fourier Transform Spectrometer (FTS). This SHS design used here utilizes a diffraction grating as a beam splitter to produce two anti-circulating beams that are piloted by mirrors back to the grating where they are recombined. Grating dispersion results in the re-combined wavefronts interfering for all wavelengths except for the one to which the instrument is tuned, with the frequency of interference dependent on the wavelength separation from the tune. We present the initial results from testing of a suborbital flight version of the SHS, including results from visible band calibration, vibration stability tests, and VUV measurements at 121 nm.

8443-118, Poster Session

In-band and out-of-band reflectance calibrations of the EUV telescope mirrors of the atmospheric imaging assembly (AIA) instrument aboard the Solar Dynamics Observatory (SDO)

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Since its launch on February 11, 2010, the Atmospheric Imaging Assembly (AIA) instrument aboard the Solar Dynamics Observatory (SDO) is providing unprecedented views of the solar corona, taking images that span 1.3 solar diameters at 7 EUV wavelength channels (ranging from 9.4 to 33.5 nm) at a resolution of 1 arcsecond, field of view at 41 arcminutes and at a cadence of 10-12 seconds. The AIA is composed of four Ritchey-Chrétien telescopes, each including a primary-secondary pair of mirrors operating at near-normal angles of incidence. Each telescope images at two different wavelengths, accomplished by two different reflective EUV multilayer coatings, with each coating deposited on half the area of each mirror. This talk discusses the reflectance calibrations of the multilayer-coated EUV flight mirrors aboard the AIA instrument. The in-band reflectance (1st order Bragg peak) was mapped across the clear aperture of each EUV multilayer mirror segment and it is shown that the flight multilayer coatings meet all specifications. Measurements of the out-of-band multilayer reflectance in the wavelength range from 4 nm to 90 nm were also recently obtained for each of the 7 EUV AIA channels, using multilayer flight witness samples. The experimental multilayer reflectance data are compared to theoretical models and the relevance of these results to the performance of the AIA/SDO instrument is discussed.

8443-123, Poster Session

Design, performance prediction, and measurements of the Interface Region Imaging Spectrograph (IRIS) Telescope

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Lockheed Martin, along with SAO, Montana State University, and Stanford University are developing the IRIS Small Explorer (SMEX). The mission will examine spectra from the sun in two bands, one centered on 1369 Å, and the other centered on 2810 Å. SAO has built the telescope feed for the spectrometer, which is a joint effort of Lockheed and Montana State University.

This paper discusses the design of the Cassegrain telescope, its intended and measured performance. The telescope posed a number of implementation challenges, which are discussed, including the fact that no effective filters exist to select the science spectra at the exclusion of the rest of the solar flux, making it necessary to allow full sunlight into the telescope.

The IRIS telescope is based on the highly successful AIA telescope design. That design was varied to deal with the change in spectra, mounting method, and desired performance.

Spectra: The UV spectra slated for use in IRIS made it impossible to place filters at the front of the telescope, and thus limit the heat and stray light flux entering the telescope itself. The main wavelength selection is made by the mostly transparent mirror coating placed on both mirrors.

Mounting Method: The AIA telescopes mounted on a main deck, whereas the IRIS telescope is mounted above and inline with the centerline of the spacecraft.

Performance: The IRIS telescope required higher optical resolution than its AIA predecessor. As such a number of design details needed to change, most importantly the mirror mounts.

8443-124, Poster Session

Design of interface region imaging spectrograph (IRIS) primary mirror thermal management system

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The Interface Region Imaging Spectrograph (IRIS) is a complementary follow-on to Solar Dynamics Observatory Atmospheric Imaging Assembly (SDO-AIA) and funded as a member of the NASA SMEX program. This paper presents the overall thermal design of the IRIS telescope with focused descriptions of the IRIS primary mirror thermal design, IRIS telescope active thermal control system, ULE® mirror substrate thermal properties, and the thermal math model supporting the thermal design.

The challenge of the IRIS primary mirror thermal design was to manage the unfiltered solar flux that is directly impinged on the optical substrate while maintaining the mirror within a narrow range of temperatures during the entire mission life of the instrument.

The primary method of managing the solar flux on the IRIS primary mirror is to pass through the visible wavelengths (280-2800um). The thermal energy of the solar flux being passed through the mirror substrate is then managed by a system consisting of an absorber plate located at the trailing end or non-optical surface of the primary mirror and a conductively coupled radiator surface.

The IRIS primary mirror substrate is Corning ULE®, a titania silicate glass. It was chosen for its optical clarity and has extremely low thermal coefficient of expansion over a wide range of temperatures. Testing, however, showed that ULE® exhibits some degradation in its optical clarity when exposed to a broad UV wavelength. The impact this degradation had on the IRIS primary mirror thermal design and mission life is included.

8443-125, Poster Session

Design, analysis, and performance verification of the Interface Region Imaging Spectrograph (IRIS) Telescope primary mirror assembly

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In this paper, the details of the Interface Region Imaging Spectrograph (IRIS) telescope primary mirror assembly design are discussed with direct comparison to its predecessor used in the Solar Dynamics Observatory Atmospheric Imaging Assembly (SDO-AIA) telescopes. Also included are details of the structural modeling and analysis, mirror optical surface modeling, vibration analysis, and a detailed description of the optical performance verification test program and results.

The primary mirror assembly of the IRIS telescope was adapted from an existing design used on the SDO-AIA telescopes. The IRIS telescope is optimized for performance at 1369 Å and 2810 Å with a required 0.4” resolution calling for a significant improvement to the mounted mirror optical surface quality over the existing SDO-AIA design.

To improve the optical performance, the proven bonded flexure heritage design was augmented with a novel “kinematic” mount used to secure the assembly to the telescope tube. The 200 mm diameter concave mirror is fabricated from Corning ULE® Code 7973 EUV Premium Grade, Ultra Low Expansion Glass material and polished to better than 12 Å rms surface roughness. The mirror is supported by three bonded titanium flexures fastened to a rigid titanium cell plate. A 25 Å rms figure error was allocated in the error budget for the mounted, coated primary mirror. The first mode resonance for the mirror was specified to be >100 Hz while surviving an expected launch load of 30G’s. The mirror assembly is designed to operate from +14°C to +26°C with survival limits specified at -20°C to +35°C.

8443-126, Poster Session

Radiometric model of METIS coronagraph telescope on board of the Solar Orbiter Mission

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The Multi Element Telescope for Imaging and Spectroscopy (METIS) coronagraph is an instrument belonging to the SOLar Orbiter(SOLO) mission payload which will perform the imaging of the solar corona in three different spectral ranges: 30.4 nm (He-II Lyman-α line), 121.6 nm (H-I Lyman- α line) and visible spectral range (400-600 nm). Optical coatings with high reflectance performances at the interested wavelengths are required to collect enough photon flux at the detector level. Different multilayer structures based on Si/Mo couples with appropriate capping layers have been already designed and tested to achieve this purpose. A radiometric model has been developed in order to estimate the efficiency’s performances of the instrument on the whole field of view (FoV) by considering the ray paths. The results shown have been obtained taking into account of the experimental results of the multilayers structures and the optical design of the instrument.

8443-127, Poster Session

METIS: a novel coronagraph design for the Solar Orbiter Mission

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METIS, the “Multi Element Telescope for Imaging and Spectroscopy”, is a coronagraph selected by the European Space Agency to be part of the payload of the Solar Orbiter mission to be launched in 2017. The mission profile will bring the Solar Orbiter spacecraft as close to the Sun as 0.28 A.U., and up to 35 deg out-of-ecliptic providing a unique platform for helio-synchronous observations of the Sun and its polar regions. METIS coronagraph is designed for multi-wavelength imaging and spectroscopy of the solar corona. This presentation gives an overview of the innovative design elements of the METIS coronagraph. These elements include: i) multi-wavelength, reflecting Gregorian-telescope; ii) multilayer coating optimized for the extreme UV (30.4 nm, HeII Lyman-alpha) with a

reflecting cap-layer for the UV (121.6 nm, HI Lyman-alpha) and visible-light (500-600); iii) inverse external-occulter scheme for reduced thermal load at spacecraft peri-helion; iv) EUV/UV spectrograph using the telescope primary mirror to feed a 1st and 4th-order spherical varied line-spaced (SVLS) grating placed on a section of the secondary mirror; v) liquid crystals electro-optic polarimeter for observations of the visible-light K-corona. The expected performances are also presented.

8443-128, Poster Session

A prototype of the UV detector for METIS on Solar Orbiter

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METIS (Multi Element Telescope for Imaging and Spectroscopy) is one of the instruments included in the science payload of the ESA mission Solar Orbiter: a coronograph able to perform broadband polarization imaging in the visible, and narrow band imaging in UV (HI Lyman-α) and EUV (HeII Lyman-α). In addition, it acquire spectra of the solar corona simultaneously to UV/EUV imaging. It will be equipped with two detectors: a hybrid APS dedicated to the visible channel and an Intensified APS for the UV/EUV channel. The spectroscopic channel will share the same detector as the UV/EUV corona imaging, with the spectrum imaged on a portion of the detector not used by the corona image.

We present the development of the UV/EUV detector consisting of a CMOS APS imaging device to be coupled with an open-face multichannel plate intensifier. Other than constraints related to the harsh environment (radiation, temperature, visible stray-light), the METIS UV detector has the additional challenge of managing different count rates associated to the three different kind of measurements (UV imaging, EUV imaging and spectroscopy). The required dynamic range is further extended since observations will be planned at different distances from the Sun (varying image scale over a fixed vignetting function). We will present the architecture of this UV detector, describing the prototype developed in order to optimize the performance on the overall dynamic range required by METIS.

8443-129, Poster Session

Imaging polarimetry with the METIS coronagraph of the Solar Orbiter Mission

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METIS, the “Multi Element Telescope for Imaging and Spectroscopy”, is a coronagraph selected by the European Space Agency to be part of the payload of the Solar Orbiter mission to be launched in 2017. The mission profile will bring the Solar Orbiter spacecraft as close to the Sun as 0.28 A.U., and up to 35deg out-of-ecliptic providing a unique platform for helio-synchronous observations of the Sun and its polar regions. The telescope design of the METIS coronagraph includes three optical paths for i) broad-band imaging of the full corona in linearly polarized visible-light (500-600 nm); ii) narrow-band imaging of the full corona in the ultraviolet HI Ly α (121.6 nm) and extreme ultraviolet He II Ly α (30.4 nm), and iii) spectroscopic observations of the HI and He II Ly α in corona.

This presentation describes the optical design of the METIS visible-light path for imaging polarimetry of the K-corona. The linearly polarized brightness (pB) images are used to derive the density distribution of the coronal electrons. The pB measurements are performed with an achromatic electro-optic polarimeter based on liquid crystals. The requirements on polarization sensitivity, achromatic response and instrumental polarization control are described. The expected performances of the visible-light path are also presented.

8443-130, Poster Session

The imaging concept for the spectrometer/telescope for imaging x-rays (STIX) on Solar Orbiter

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Solar Orbiter is an approved ESA mission with NASA participation that will be launched in 2017 into a heliocentric orbit with a 0.28 A.U. perihelion. One of its science goals is to address how solar eruptions produce energetic particles that fill the heliosphere. In order to determine the properties of accelerated electrons at the Sun, STIX, as one of 10 instruments in the payload, measures the timing, intensity, location and spectrum of thermal and non-thermal X-rays. To achieve this, STIX does imaging-spectroscopy from 4 to 150 keV with energy resolution ranging from 1 to 15 keV, an effective area of 6 cm2, a spatial resolution of 7 arcseconds, a 2 degree field of view capable of viewing the full Sun from 0.28 A.U. and statistics-limited time resolution as short as 0.1 seconds.

In order to meet these requirements within mission constraints, (a non-rotating instrument with 4 watt power, 6 kg mass and 700 bps telemetry budgets), STIX imaging uses a bigrid collimator to form a set of X-ray Moire patterns that are viewed by a corresponding set of coarsely pixelated CdTe detectors. The amplitude and phase of each Moire pattern measures a single Fourier component (a visibility) of the source angular distribution. X-ray images are reconstructed on the ground by combining 30 such visibilities measuring different spatial frequencies. This paper describes the Moire imaging technique and its implications for imager design, error budgeting, data handling, self-calibration and optical performance.

8443-131, Poster Session

The spectrometer telescope for imaging x-rays onboard Solar Orbiter Space Mission

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Solar Orbiter is the first M-class mission selected by ESA for the Cosmic Vision program to be flown in 2017 for close-up and high-latitude studies of the Sun [1]. One of the 10 on-board experiments is the Spectrometer Telescope for Imaging X-rays (STIX) that provides information on the timing, location, intensity and spectra of accelerated electrons near the Sun in the 4-150 keV energy range. STIX is based on a Fourier-transform imaging technique similar to that used successfully on board Yohkoh and RHESSI missions [2].

STIX consists of three main parts: an X-ray window, an imager with 32 subcollimators, and a spectrometer with 32 Cadmium Telluride (CdTe) X-ray detectors. The relative count rates of the detectors behind the different sets of grids encode the spatial information that can be subsequently decoded on ground to reconstruct images of the source region at different X-ray energies.

The detection units are hybrid components called Caliste-SO. The design and technology inherit CdTe-based imaging spectrometers developed by CEA, CNES and 3D Plus for high energy astrophysics [3]. Caliste-SO includes a Schottky CdTe pixel sensor, an analog front-end ASIC IDeF-X HD, and circuitry for supply regulation and filtering. Two prototypes have been realized during the Solar Orbiter implementation phase. Before mounting the detector, equivalent noise charge of the electrical body was measured to be 58 electrons rms with a 20 pA leakage current (value expected in the pixels at the operating temperature of 20°C).The full devices will undergo soon spectroscopic characterization.

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8443-132, Poster Session

X-ray reflection gratings and application to future missions

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X-ray reflection gratings have significant flight heritage from suborbital rockets to XMM-Newton. The off-plane mount is a configuration capable of obtaining the high throughput, high spectral resolving power requirements necessary for achieving key science goals.

We detail the current state of off-plane gratings and plans for their technology development. We present a notional spectrometer design and outline the major difficulties involved with grating development, plans on dealing with these issues, and how these factors change as a function of spacecraft design.

8443-34, Session 8

The Chandra X-Ray Observatory: progress report and highlights

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The Chandra X-ray Observatory, the third of NASA’s four Great Observatories and its flagship mission for X-ray astronomy, was launched by NASA’s Space Shuttle Columbia on July 23, 1999. The first X-ray sources were observed on August 12, 1999. The brightest of these sources named Leon X-1 in honor of Chandra’s Telescope Scientist who played the leading role in establishing the key to Chandra’s great advance in angular resolution - sub-arcsecond Full Width at Half Maximum (FWHM). Over the course of a the past years, the Chandra X-ray Observatory’s ability to provide sub-arc second X-ray images and high resolution spectra has established it as one of the most versatile and powerful tools for astrophysical research in the 21st century. Chandra explores the high-energy regions of the universe, observing X-ray sources with fluxes spanning more than 10 orders of magnitude. The longevity of Chandra provides a long observing baseline enabling temporal studies over time-scales of years. We will discuss the current operational status of the Observatory and present recent scientific highlights covering a variety of objects from stars with nearby planets that impact the stellar activity to the deepest Chandra surveys which measured space density of Active Galactic Nuclei (AGN) over a large range of obscuration and redshift.

8443-35, Session 8

XMM-Newton operations beyond the design lifetime

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After more than a decade in orbit, XMM-Newton continues its near faultless operations providing the worldwide astronomical community with an unprecedented combination of imaging and spectroscopic X-ray capabilities together with simultaneous optical and ultra-violet monitoring. The scientific interest in continuing XMM-Newton operations remains extremely high with the last annual Announcement of Opportunity (AO-11) attracting proposals requesting 6.7 times more observing time than is available. All elements of the mission are stable and largely trouble free and the limiting factor is currently fuel usage. XMM-Newton maneuvers using reaction wheels. Fuel is only used to offset changes in reaction wheel speed and for Emergency Sun Acquisitions. Currently, fuel is predicted to last until around 2020. However, ESA is investigating changes in the on-board software that would allow the reaction wheel usage to be optimized which would allow XMM-Newton operations to be extended to 2026.

8443-36, Session 8

MVN: x-ray monitor of the sky on Russian segment of ISS

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MVN (Monitor Vsego Neba) - new small X-ray astronomical experiment, which will be mounted on Russian segment of International Space Station. The main scientific goal for the instrument is the precise measurement of cosmic X-ray background in energy range 6-60 keV, which is important for theories of black hole evolution in the Universe. The ultimate aim of the experiment is to reach the accuracy of the CXB measurements, which will allow us to measure the large scale anisotropy of the Cosmic X-ray Background caused by inhomogeneities of the matter distribution in the local Universe. The MVN instrument is a simple collimated spectrometer, equipped with 4 CdTe pixellated detectors. The field of view of the instrument will be scanning the zenith of the ISS. The accuracy of the instrumental background subtraction, which is the main obstacle for the proposed task, will be provided by a cover, which will periodically block the aperture of detectors. According to our estimates, with not unfavorable radiation environment on orbit of ISS during period of operation of MVN we will be able to measure the CXB surface brightness at different sky directions with accuracy better then 1% after 3 years of experiment.

8443-37, Session 8

Using ACIS on the Chandra X-ray Observatory as a particle radiation monitor II

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The Advanced CCD Imaging Spectrometer (ACIS) is one of two focal-plane instruments on the Chandra X-ray Observatory. The CCDs are vulnerable to radiation damage, particularly by soft protons in the Earth’s radiation belts and from solar storms. The primary effect of this damage is to increase the charge-transfer inefficiency (CTI) of the 8 front-illuminated CCDs and decrease scientific performance. Soon after launch, the Chandra team implemented procedures to protect ACIS and remove the detector from the telescope focus during high-radiation events: planned protection during radiation-belt transits; autonomous protection triggered by an on-board radiation monitor; and manual intervention based upon assessment of space-weather conditions. As Chandra's multilayer insulation ages, elevated temperatures have reduced the effectiveness of the on-board radiation monitor for autonomous protection. The ACIS team has developed an algorithm which uses data from the CCDs themselves to detect periods of high radiation and a flight software patch to apply this algorithm is currently active on-board the instrument. In this paper, we explore the ACIS response to particle radiation through comparisons to a number of external measures of the radiation environment. We hope to better understand the efficiency of the algorithm as a function of the flux and spectrum of the particles and the time-profile of the radiation event.

8443-38, Session 8

Cross-calibration of the instruments onboard the Chandra, Suzaku, Swift, and XMM-Newton observatories using 1E 0102.2-7219: an IACHEC study

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We report on our continuing efforts to compare the time-dependent calibrations of the current generation of CCD instruments onboard the Chandra, Suzaku, Swift, and XMM-Newton observatories using the brightest supernova remnant in the Small Magellanic Cloud, 1E 0102.2-7219 (hereafter E0102). This calibration is a function of time due to the effects of radiation damage on the CCDs and the accumulation of a contamination layer on the filters or CCDs. We desire a simple comparison of the absolute effective areas in the 0.5-1.0 keV bandpass. The spectrum of E0102 has been well-characterized using the RGS grating instrument on XMM-Newton and the HETG grating instrument on Chandra. We have developed an empirical model for E0102 that includes Gaussians for the identified lines, two absorption components, and two continuum components with different temperatures. In our fits, the model is highly constrained in that only the normalizations of the four brightest line complexes (the O VII triplet, the O VIII Ly-alpha line, the Ne IX triplet, and the Ne X Ly-alpha line) and an overall normalization are allowed to vary. In our previous study, we found that based on observations early in the missions, most of the fitted line normalizations agreed to within +/-10%. We have now expanded this study to include more recent data from these missions using the latest calibration updates and we will report on the current level of agreement amongst these instruments.

This work is based on the activities of the International Astronomical Consortium for High Energy Calibration (IACHEC).

8443-39, Session 9

The Neutron star Interior Composition ExploreR (NICER): an explorer mission of opportunity for soft x-ray timing spectroscopy

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The Neutron star Interior Composition ExploreR (NICER) will be a NASA Explorer Mission of Opportunity, currently in a Phase A study, dedicated to the study of neutron stars, the only places in the Universe where all four fundamental forces of Nature are simultaneously important. Answering the long-standing astrophysics question "How big is a neutron star?," NICER will confront nuclear physics theory with unique observational constraints, exploring the exotic states of matter within neutron stars and revealing their interior and surface compositions through rotation-resolved X-ray spectroscopy. Absolute time-referenced data will allow NICER to probe the extreme physical environments of the most powerful cosmic particle accelerators known. Finally, NICER will definitively measure the stabilities of pulsars as clocks, with implications for gravitational-wave detection, a pulsar-based timescale, and autonomous spacecraft navigation. NICER will fly on the International Space Station while Fermi is in orbit and post-RXTE, enabling the discovery of new high-energy pulsars and providing continuity in X-ray timing astrophysics.

8443-40, Session 9

FFAST mission to study the evolution of the universe in hard x-ray

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We are planning to have a "formation flight all sky telescope" (FFAST) that will cover a large fraction of the whole sky area in relatively high energy X-ray. In particular, it will focus on the energy range above 10 keV. It consists of two small satellites that will go in a formation flight. One is the X-ray telescope satellite and the other is the detector satellite. Two satellites will be simultaneously launched by a single rocket vehicle into a low earth orbit. They are in a formation flight with a separation of 20 m+-10 cm. Formation flight technique was studied both in XEUS and in SimbolX that were cancelled. FFAST will employ a different idea from them. The observation direction is determined by the two satellites. Since two satellites are put into the Keplerian orbit, the observation direction is scanning the sky rather than pointing to a fixed direction. One satellite carries an X-ray telescope covering the energy range up to 80 keV. The tele scope is a "super-mirror" that has a multi-layer coating to collect X-rays up to 80 keV. The other is a detector satellite that carries an SDCCD system. The SDCCD consists of a fully depleted CCD and a thin scintillator of CsI so that we can obtain the image up to 80 keV. We are trying to go up to the small scientific satellite project in JAXA

8443-41, Session 9

Concepts for high-performance soft x-ray grating spectroscopy in a moderate-scale mission

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We present concepts for high-throughput (effective area> >500 sq-cm), high-resolution (spectral resolving power R > 3000) soft X-ray grating spectroscopy in a mission of moderate (probe-class) scale. Such a mission can achieve high-priority scientific objectives identified by the Astro2010 Decadal Survey that can be attained in no other way, and

would provide an essential complement to any future large-area X-ray Observatory equipped with non-dispersve spectrometers. We enumerate key science drivers and discuss consequences of various alternative design choices for scientific capability and overall mission cost.

8443-42, Session 9

SMART-X: a large-area high-resolution x-ray observatory for the 2020's

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SMART-X is a concept for a next-generation X-ray observatory with large-area, 0.5" resolution grazing incidence adjustable X-ray mirrors, high-throuput critical transmission gratings, and X-ray microcalorimeter and CMOS-based imager in the focal plane. High angular resolution is enabled by new technology based on controlling the shape of mirror segments using thin film piezo actuators deposited on the back surface. Science application include observations of growth of supermassive black holes sinse redshifts of ~10, ultra-deep surveys overs 10's of square degrees, galaxy assembly at z=2-3, as well as new opportunities in the high-resolution X-ray spectroscopy and time domain.

8443-43, Session 10

The Advanced X-ray Spectroscopic Imaging Observatory (AXSIO)

J. A. Bookbinder, Harvard-Smithsonian Ctr. for Astrophysics (United States)

The 2010 Decadal Survey of Astronomy & Astrophysics, "New Worlds, New Horizons" (NWNH)found the science capabilities of the International X-ray Observatory (IXO) compelling, noting that "Large-aperture, time-resolved, high-resolution X-ray spectroscopy is required for future progress on all of these fronts, and this is what IXO can deliver." Based on NWNH recommendations to reduce cost, the US IXO team has re-evaluated the design to achieve reductions in complexity, mass, and cost while retaining core science capabilities. The result of this study is the Advanced X-ray Spectroscopic Imaging Observatory (AXSIO). In line with the Decadal recommendations, AXSIO has almost 1 m2 of effective area at 1 keV, with 10 arcsec resolution. IXO's movable platform with six instruments was reduced to two fixed detectors - the imaging X-ray Microcalorimeter Spectrometer (XMS) and the X-ray Grating Spectrometer (XGS). The AXSIO XMS is enhanced compared to the original IXO XMS with the addition of a core "Point Source Array", enabling both high count rate observations and energy resolution superior to that on IXO. These two instruments allow AXSIO to accomplish most of the IXO science goals, including what happens close to a black hole, how supermassive black holes grow, how large scale structure forms, and the connections between these processes. The total mission cost has been estimated by the NASA/Goddard Mission Design Lab to be less than $1.9B. We present an overview of the mission's science drivers, its optics and instrumental capabilities, the status of its technology development programs, and the mission implementation approach.

8443-44, Session 10

Mission design and enabling technologies for mapping cosmic baryons in the ultraviolet

D. C. Martin, California Institute of Technology (United States)

A high-priority astrophysics goal is to explain the formation of baryonic structure. Future UV missions will do this by tracing the flow of baryons from the Intergalactic Medium to Galaxies and star-formation regions, and observing how these baryons flow in and out of the circum-galactic media of galaxies. These science goals, endorsed by Astro2010, can be accomplished by UV missions emphasizing wide-field, multi-object, integral-field, and high-spectral resolution spectroscopy. Such a mission can be launched the next 10-20 years only if investments are made this decade in new UV technologies. Most importantly, significant improvements in UV photon-counting detector and coating technologies will make possible scientifically compelling missions that can be afforded in the next 2 decades. In this paper, we describe various mission concepts from probe to flagship, and the technologies that enable them. Most important are UV photon-counting detectors with QE exceeding 50%, with low noise and large, scalable formats, and UV coatings with >90% reflectivity ideally to wavelengths as low as 1000Å. Both of these technological leaps are now achievable with modest funding.

8443-45, Session 10

Status of the diffuse intergalactic oxygen surveyor (DIOS)

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We describe the status and prospects of the small X-ray mission DIOS (Diffuse Intergalactic Oxygen Surveyor), which will be proposed for the 3rd mission in JAXA's small satellite series aiming for launch around 2016. DIOS will perform survey observations of warm-hot intergalactic medium using OVII and OVIII emission lines, with the energy coverage up to 1.5 keV. The instrument will consist of a 4-stage X-ray telescope and an array of TES microcalorimeters, with a total weight of about 400 kg. We will report on the status of the hardware development, including the thermal design of the spacecraft, the wide opening aperture of the instrument system, and the development of the TES array with its readout system in Japan. International collaboration to support the mission is also under discussion.

8443-47, Session 10

Micro-X sounding rocket payload pre-flight performance

E. Figueroa-Feliciano, Massachusetts Institute of Technology (United States)

The Micro-X Sounding Rocket Payload will observe the Puppis A supernova remnant in November 2012. The payload has been in development for six years, and here we present the results of pre-flight testing. An array of 128 TES pixels with resolution between 2-4 eV in the soft X-ray band using a 300 cm^2 2.1 m focal length optic will obtain a 300 second observation in a parabolic flight reaching an altitude of around 300 km. The broadband, high-energy-resolution spectrum will provide an unprecedented measurement of the physics and kinematics of the plasma in this supernova remnant.

8443-178, Session 10

A ray-trace model for AEGIS

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AEGIS, an Astrophysics Experiment for Grating and Imaging Spectroscopy, is a mission concept optimized for the 0.2 to 1 keV soft X-ray band. It consists of six independent Critical Angle Transmission Grating Spectrometers (CATGS) optimally arranged to provide a spectral resolution of 3000 and an effective area exceeding 1000 cm^2 across its passband. Such high spectral resolution and effective area will permit AEGIS to address many astrophysics questions including those that pertain to the evolution of Large Scale Structure of the universe, and the behavior of matter at very high densities.

To realistically assess the spectral performance of the AEGIS design, we are developing an end-to-end Monte-Carlo raytrace program. The ray-trace will provide us with a quantitative understanding of the impact upon the spectrometer's performance from the aberrations caused by misalignments between the various system elements, and the deviation of those elements from their idealized geometry. This information will tell us what the most important distortions are and allow us to make the appropriate design tradeoffs to maximize the performance of the system. We expect this ray-trace to be useful throughout the life of the mission, including its design and calibration, the production of input data products for the development of the various software pipelines, and for observer proposal planning.

8443-48, Session 11

Performance of an Ar-DME imaging photoelectric polarimeter

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Polarimetry in the soft X-ray energy band (2-10 keV) with gas pixel detectors, filled with low Z mixtures, has been widely explored so far. The possibility to extend the technique to higher energies, in combination with multilayer optics, has been also hypothized in the past, on the basis of simulations. Here we present a recent development to perform imaging polarimetry between 6 and 35 keV, employing a new design for the Gas Pixel Detector, filled with a Ar-DME gas mixture at high pressure. In order to improve the efficiency by increasing the absorption gap, while preserving a good parallel electric field, we developed a new configuration characterized by a wider gas cell and a wider GEM. The uniform electric field allows to maintain high polarimetric capabilities without any decrease of spectroscopic and imaging properties. We present the first measurements of this prototype showing that it is now possible to perform imaging and spectro-polarimetry of hard X-ray sources.

8443-49, Session 11

XTP: the X-ray Timing and Polarization Mission

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The X-ray Timing and Polarization (XTP) mission, as the successor of Hard X-ray Modulation Telescope (HXMT), will be the second X-ray astronomy satellite in China. It's dedicated to the study of the physics under extreme conditions and the diffuse X-ray emission. With a detection area of 3~4m2 and an energy range of 1 - 100 keV, XTP will be one of the most competitive missions in the X-ray timing and also polarization research area.

8443-50, Session 11

Soft x-ray polarimetry using multilayer coated mirrors

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We developed an instrument design capable of measuring linear X-ray polarization over a broad-band using conventional spectroscopic optics. A set of multilayer-coated flats reflects the dispersed X-rays to the instrument detectors. The intensity variation with position angle is measured to determine three Stokes parameters: I, Q, and U -- all as a function of energy. By laterally grading the multilayer optics and matching the dispersion of the gratings, one may take advantage of high multilayer reflectivities and achieve modulation factors >50% over the entire 0.2 to 0.8 keV band. This instrument could be used in a small orbiting mission or the approach could be used on a large dispersive spectrometric facility. We present progress on laboratory work to demonstrate the capabilities of key components.

8443-51, Session 11

The background of the gas pixel detectors and its impact on imaging x-ray polarimetry

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The background of the Gas Pixel Detector is expected to be negligible for soft X-ray polarimetry of point sources due to the intrinsic low atomic number and density of the DME-He mixture and to its imaging properties. Also the background for extended sources is expected to be negligible at least down to the smallest flux for sensitive polarimetry in a reasonable observing time. However in the spatial distribution of the background in a laboratory environment we observed an accumulation on the edges of the sensitive plane due to the presence of the nearby cell walls.

Ar based Gas Pixel Detectors to be used for polarimetry at higher energies are also expected to have larger background. We recently developed Gas Pixel Detectors with a new design of the gas cell having a larger distance of the walls from the sensitive plane. In this paper we compare the spatial distribution of the measured background for the two designs and its impact on the possible systematics and on the polarization sensitivity.

8443-52, Session 12

Gamma ray astronomy from space to ground: the harder they come, the deeper they go

G. F. Bignami, Institut de Recherche en Astrophysique et Planétologie (France)

No abstract available

8443-53, Session 12

Small telescopes, big dreams

F. B. S. Paerels, Columbia Univ. (United States)

In another decade, we will have obtained the first high resolution spectroscopy in the Fe K band with microcalorimeter spectrometers (on Astro-H).

We will also have the first real images at energies 10-100 keV (NuSTAR), and the first measurements of X-ray polarization in sources other than the Crab (GEMS). And perhaps we will even be working on the construction of a large throughput general observatory with a true high-resolution imaging spectrometer. Presuming that the latter does indeed come to pass, what are the biggest questions in X-ray astronomy beyond these capabilities' reach? And what would be required to address those questions experimentally?

8443-54, Session 12

The NASA x-ray mission concepts study

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The 2010 Astrophysics Decadal Survey recommended a significant technology development program towards realizing the scientific goals of the International X-ray Observatory (IXO). NASA has undertaken an X-ray mission concepts study to determine alternative approaches to accomplishing IXO's high ranking scientific objectives over the next decade given the budget realities, which make a flagship mission challenging to implement. The goal of the study is to determine the degree to which missions in various cost ranges from $300M to $2B could fulfill these objectives. The study process involved several steps. NASA released a Request for Information in October 2011, seeking mission concepts and enabling technology ideas from the community. The responses included a total of 14 mission concepts and 13 enabling technologies. NASA also solicited membership for and selected a Community Science Team (CST) to guide the process. A workshop was held in December 2011 in which the mission concepts and technology were presented and discussed. Based on the RFI responses and the workshop, the CST then chose a small group of notional mission concepts, representing a range of cost points, for further study. These notional missions concepts were developed through mission design laboratory activities in early 2012. The results of all these activities were captured in the final X-ray mission concepts study report, to be submitted to NASA in June 2012. In this presentation, we summarize the outcome of the study. We will discuss background, methodology, the notional missions, and the conclusions of the study report.

8443-55, Session 12

Science metrics for a NASA large optic x-ray microcalorimeter mission

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In September 2011 NASA released a Request for Information on "Concepts for the Next NASA X-ray Astronomy Mission" and formed a Community Science Team to study the submitted concepts and evaluate their science return relative to the IXO goals identified by the 2010 Astrophysics Decadal Survey "New Worlds, New Horizons" report. A number of the responses described a focal plane with a single calorimeter and optics with various focal lengths and PSF. These missions emphasize different aspects of the IXO and NWNH science programs. After studying the responses and participating in a community workshop, the team identified a number of candidate mission concepts, including one combining large-area optics with new X-ray microcalorimeter technology. However, the exact mission requirements (effective area, focal length, field of view, point spread function, etc.) were not fixed. We will present a range of mission designs, describing the results of the NASA/GSFC Mission Design Lab study of possible missions along with available deltas that would increase capability or decrease cost and/or risk.

8443-56, Session 12

Probing the cosmic history of baryons with x-ray spectroscopy of GRBs and wide field x-ray observations

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Gamma-Ray Bursts provide a unique probe of the cosmic history of baryons and the metal enrichment from the first stars up to the current day Universe. Reconstructing the cosmic history of metals, from the first population of stars to the processes involved in the formation of galaxies and clusters of galaxies, is a key observational challenge. We plan to observe the explosive death of massive stars into a Gamma Ray Burst and to characterize its environment with high resolution X-ray measurements. The same X-ray measurements will also probe and characterize the chemical composition of clusters of galaxies and the cosmic web in the Warm-Hot Intragalactic Medium (WHIM) with an unprecedented accuracy. These latest measurements will take advantage of wide field of view telescopes. We have elaborated these goals into detailed studies of a medium-size mission, proposed to ESA and NASA by an international consortium of institutes. The mission makes use of a fast and autonomous repointing of the satellite following the detection of a Gamma-Ray Burst. This requires a sensitive hard X-ray detector with a large field of view and a wide-field imaging spectrometer in the soft X-ray band which measures the emission and absorption lines in hot and cold gas. This cryogenic instrument provides detailed diagnostics of the temperature, ionisation state, dynamics and abundances in and around the studied sources. The addition of a near infrared telescope for high redshift burst characterizes the ORIGIN mission, while Xenia, recently proposed to NASA RFI, would carry on board a wide field X-ray telescope, tailored to the study of clusters and X-ray surveys.

8443-57, Session 12

Wide Field X-ray Telescope

S. S. Murray, Johns Hopkins Univ. (United States) and and the

WFXT Team (United States)

Sensitive surveys of the X-ray universe have been limited to small areas of the sky due to the intrinsically small field of view of Wolter-I X-ray optics, whose angular resolution degrades with the square of the off axis angle. High angular resolution is needed to achieve a low background per source, minimize source confusion, and distinguish point from extended objects. WFXT consists of three co-aligned wide field X-ray telescopes with a 1 degree field of view and a goal of 5 arcsecond angular resolution (HEW) over the full field. Total effective area at 1 keV will be > 7000 square cm. WFXT will perform two or three surveys that will cover most of the extragalactic sky to 100-1000 times the sensitivity of the ROSAT All Sky Survey, ~3000 square degrees to deep Chandra or XMM-Newton sensitivity, and ~100 square degrees to the deepest Chandra sensitivity. WFXT will generate a legacy X-ray data set of <0x10fc00> 5×10^5 clusters and groups of galaxies to z ~ 2, also characterizing the physics of the intracluster gas for a significant fraction of them, thus providing an unprecedented data set for cosmological applications; it will detect > 10^7 AGN to z > 6, again obtaining spectra for a substantial fraction; it will detect > 10^5 normal/starburst galaxies; and it will detect and characterize star formation regions across the Galaxy. WFXT is the only X-ray survey mission that will match, in area and sensitivity, the next generation of wide-area optical, IR and radio surveys. Seehttp://wfxt.pha.jhu.edu and http://www.wfxt.eu

8443-58, Session 13

ASTROSAT LAXPC energy response simulation

B. Paul, Raman Research Institute (India)

ASTROSAT is an astronomy satellite scheduled to be launched in 2012. It is designed for simultaneous multi-wavelength studies with five payloads in the optical/UV and a broad X-ray energy range. One of the instruments, a set of three Large Area Xenon Proportional Counters (LAXPC) will enable high time resolution X-ray measurements in the 3-80 keV band with moderate energy resolution and large effective area. There are two imaging X-ray spectrometers, one in the soft and one in the hard X-ray band. Two telescopes will provide multi-band imaging in three optical/UV channels. An X-ray sky monitor onboard ASTROSAT, that is similar in concept to the RXTE ASM will be used to study long term intensity variations of bright X-ray sources. This instrument will also facilitate X-ray observations with the LAXPC and other payloads. We will give a brief summary of the design and characteristics of the scientific payloads, their expected sensitivities and present status of ASTROSAT. We will discuss some of the key science topics that can be suitably addressed with ASTORSAT. We will present characteristics of the LAXPC instrument and its data processing scheme. Energy response simulation of the LAXPCs will be presented in detail.

8443-59, Session 13

Ultraviolet imaging telescope on ASTROSAT

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The Ultra Violet Imaging Telescope on ASTROSAT Satellite mission is a suite of Far Ultra Violet (FUV: 130 - 180 nm), Near Ultra Violet (NUV: 200 - 300 nm) and Visible band (VIS: 320-550nm) imagers. ASTROSAT is a multi-wavelength mission of ISRO. UVIT will image the sky simultaneously in three channels with a field of view diameter of ~ 28 arcminutes and an angular resolution < 1.8”. Two identical co-aligned telescopes (T1, T2) of Ritchey-Chretien configuration (Primary mirror of ~375 mm diameter) collect the celestial radiation and feed the detector systems via a selectable filter on a filter wheel mechanism; gratings are available in the filter wheels of FUV and NUV channels for slitless low-resolution spectroscopy. The photon-counting detector system for each of the 3 channels is generically identical. One of the telescopes images in the FUV channel, while the other images in NUV and VIS channels via a beamsplitter. Images from the VIS channel are principally used for measuring drift, used in construction of images on the ground by shift and add, and to reconstruct absolute aspect of the images. Adequate baffling has been provided for reducing the scattered background from the Sun, earth albedo and other bright objects. The one-time opening mechanical cover on each telescope also works as a Sun-shield after deployment.

We will present the overall (mechanical, optical and electrical) design of the payload.

8443-60, Session 13

The Chinese-French SVOM Mission: studying the brightest astronomical explosions

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We present the SVOM (Space-based multi-band astronomical Variable Objects Monitor) mission that the Chinese National Space Agency and the French Space Agency have decided to jointly implement. SVOM has been designed to detect, characterize and quickly localize all known types of gamma-ray bursts (GRBs) and other types of high-energy transients. For this task the spacecraft carries two wide-field high-energy instruments: ECLAIRs, a hard X-ray imager using an array of 6400 CdTe pixels behind a coded mask, and the Gamma-Ray Monitor (GRM), a broadband spectrometer based on a phoswich scintillator. Upon localizing a transient, SVOM will quickly slew to the position of the source and start deep follow-up observations with its two telescopes: the Micro-channel X-ray Telescope (MXT) in the range 0.3-6 keV and the Visible Telescope (VT) in the visible range. The SVOM payload is complemented by ground-based instruments including wide-field cameras to catch the GRB prompt emission in the visible band and two 1-meter robotic telescopes to quickly find the afterglows in the visible and near infrared domains and measure their photometric properties. The nearly anti-solar pointing of SVOM combined with the fast transmission of GRB positions to the ground, with a ground network of VHF antennas, will facilitate the observation of SVOM GRBs by the largest ground based telescopes.

8443-61, Session 13

The current status of the Hard X-ray Modulation Telescope

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HXMT is an X-ray astronomical satellite consisting of three slat-collimated telescopes, the High Energy X-ray Telescope (HE), the Medium Energy X-ray Telescope (ME), and the Low Energy X-ray Telescope (LE). HE is sensitive in 20-250 keV. It contains 18 individual cylindrical NaI(Tl)/CsI(Na) phoswich modules, with a total cdetection area of 5000 cm2. ME contains 3 individual Si-PIN detector arrays sensitive in 5-30 keV. Its total collection area is 952 cm2. LE uses the Swept Charge Device as the detector that is sensitive in 1-15 keV. It also contains 3 individual detector arrays, with a total detection area 384 cm2.

HXMT will perform a sensitive broad band (1-250 keV) X-ray all-sky (or large sky area) scan survey and make pointed observations of X-ray sources to study their spectroscopic and multi-wavelength temporal properties. The typical Field of View (FOV) of HXMT is 6°×1° (FWHM), with other larger FOVs so as to measure the cosmic and particle induced X-ray background components. The 3-σ continuum sensitivity of HXMT is about 0.5 mCrab in most of its energy range.

HXMT entered phase B (the pre-flight mode phase) in the end of 2011, and the scheduled launch date is in late 2014.

8443-62, Session 13

The GEMS photoelectric x-pay polarimeters

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The Gravity and Extreme Magnetism Small Explorer (GEMS) will realize its scientific objectives through high sensitivity X-ray polarization measurements in the 2-10 keV band. The GEMS X-ray polarimeters, based on the photoelectric effect, provide a strong polarization response with high quantum efficiency over a broad bandpass by a novel implementation of the time projection chamber (TPC).

This paper will discuss the basic principles of the TPC polarimeter and describe the details of the mechanical and electrical design of the GEMS polarimeter, including signal processing. We will present performance measurements from a GEMS engineering unit in response to polarized and unpolarized X-rays.

8443-63, Session 14

eROSITA

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eROSITA is the core instrument on the Russian Spektrum-Roentgen-Gamma mission which is scheduled for launch in 2013. eROSITA will perform a deep survey of the entire X-ray sky. The design driving science is the detection of large samples of distant galaxy clusters in order to study the large scale structure in the Universe and test cosmological models including Dark Energy. In addition, eROSITA is expected to yield a sample of around 3 million Active Galaxies, revolutionizing our view of the evolution of supermassive black holes. The survey will also provide new insights into a wide range of other astrophysical phenomena, including X-ray binaries, active stars and diffuse emission within the Galaxy.

8443-64, Session 14

Design, development, and status of the eROSITA x-ray mirrors

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MPE will provide the X-ray Survey Telescope eROSITA for the Russian Spektrum-Roentgen-Gamma Mission. The mirror system consists of a compact bundle of seven co-aligned mirror modules with a focal length of 1600 mm and 54 nested mirror shells each. The 61 arcmin field-of-view will yield a high grasp of about 1000 cm2deg2 around 1 keV. An angular resolution of 15 arcsec HEW on-axis (resulting in an average angular resolution of ~26 arcsec HEW over the field-of-view and ~30 arcsec including all optical and spacecraft error contributions) will help distinguish point sources from extended emission of galaxy clusters which are relevant for cosmological studies. During a four year all-sky survey eROSITA will generate a new rich database of X-ray sources. In a second phase of the mission eROSITA will also perform pointed observations.

After an extended test program with several single mirror shells and test modules the integration of flight mirror modules started in early 2011. Currently, the manufacturing of flight modules is ongoing and some of the partially integrated ones have already been X-ray tested. Calibration of completed mirror modules will start in mid-2012. Parallel to the X-ray mirrors we have developed an X-ray baffle to suppress stray-light from single reflections. It consists of precisely shaped and welded concentric Invar foils which will be mounted on top of each mirror module and aligned by optical means.

We report on the design and the mirror development programme including the X-ray baffle and present the latest results from X-ray measurements.

8443-65, Session 14

SRG/ART-XC

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Spectrum Roentgen Gamma (SRG) is an X-ray astrophysical observatory, developed by Russia in collaboration with Germany. The mission will be launched in the end of 2013 from Baikonur, by a Zenit rocket with a Fregat-SB booster and placed in a 6-month-period halo orbit around L2. SRG will perform an all-sky survey lasting four years and pointed observations in the next three years. The scientific payload consists of two instruments - a soft-x-ray survey telescope built in Germany and a medium-x-ray-energy survey telescope ART-XC, developed by Russian Space research Institute (IKI) and The All-Russian Scientific Research Institute for Experimental Physics (VNIIEF). ART-XC will consist of seven independent, but co-aligned, telescope modules with seven corresponding CdTe focal plane detectors. Each will operate over the approximate energy range of 6-30 keV, with an angular resolution of 1

arcmin, a field of view of ~30 arcmin and an energy resolution about 10% at 14 keV. Four of the mirror modules are being fabricated by NASA's Marshall Space Flight Center (MSFC) while the other three will be fabricated by the VNIIEF. The ART-XC's current development status will be given.

8443-66, Session 14

The Marshall Space Flight Center development of mirror modules for the ART-XC instrument aboard the Spectrum-Roentgen-Gamma Mission

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The Marshall Space Flight Center (MSFC) is developing x-ray mirror modules for the ART-XC instrument on board the Spectrum-Roentgen Gamma Mission under a Reimbursable Agreement between NASA and the Russian Space Research Institute (IKI.) ART-XC will consist of seven co-aligned x-ray mirror modules with seven corresponding CdTe focal plane detectors. Four of the modules are being fabricated by MSFC while the other three will be fabricated by the All-Russian Scientific Research Institute for Experimental Physics (VNIIEF.) Each MSFC module consist of 28 nested Ni/Co thin shells giving an effective area of 65 cm2 at 8 keV, response out to 30 keV, and an angular resolution of 45 arcsec HPD or better. Full details of the mirror modules and their current development status will be given.

8443-67, Session 15

The NuSTAR Observatory on-orbit performance

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The Nuclear Spectroscopic Array, NuSTAR, is an X-ray focusing satellite mission operating in the 5 - 80 keV energy band. This NASA Small Explorer consists of two confocal Wolter-I optics focused on two individual CdZnTe detector modules, separated by a 10 meter extendible mast. One of the great challenges in the data reconstruction of this observatory is correcting for the thermal deformations that will cause the mast to bend slightly and shift the two benches with respect to each other. A laser metrology system is used to keep track of this movement and enables the subsequent source reconstruction. Proper reconstruction relies on a good internal alignment of the instrument, and good mission planning on understanding the mast motions.The NuSTAR simulator, NuSIM, was created specifically to address the concerns of mast motions on event reconstruction, understanding the error terms of misalignments and to help plan science observations.

One of the first on-orbit calibration tasks is the alignment of the observatory and verification of the mast models, since alignment and mast motion have a direct influence on science mission planning. In this paper we will present preliminary analysis of the on-orbit alignment and mast motions and compare them to our pre-launch predictions.

8443-68, Session 15

Analysis of the NuSTAR optics performance by raytracing

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Understanding the telescope performance is crucial for the interpretation of the NuSTAR observational data. The wings of the PSF have influence on the detection sensitivity both with respect to the effective area and to the contamination from stronger sources on weaker ones. During the process of manufacturing the NuSTAR mirrors and the assembly of the optics information on the coating results, the mirror figure, and the scattering properties have been monitored. All this information is used by two independent raytracing codes for the evaluation of the final telescope performance. Detailed measurements of a large number of selected subgroups of layers of the optics have been done in a calibration campaign performed at a long-beam calibration facility. The outcome of this is used as a verification of the raytracing results that eventually will be used for the prediction of the in-orbit behavior. The evaluation of the errors in the effective area and PSF is also done on the basis of the calibration.

8443-69, Session 15

Metrology and x-ray scattering measurements of NuSTAR mirror segments

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The Nuclear Spectroscopic Telescope Array (NuSTAR) will be the first satellite mission to employ focusing optics for observations of the hard x-ray sky. The NuSTAR telescopes rely on a design that approximates a Wolter-I configuration and consist of thousands of thin glass substrates on which multilayer coatings are deposited. The final optics have undergone extensive ground-based calibration prior to launch. Additionally complimentary measurements on individual mirror segments have been used to constrain the power spectral density on all length scales.

This paper describes AFM, Zygo and TEM studies of flight-spare substrates and witness coupons. We also report on measurements performed at the National Synchrotron Light source to understand the scattering properties of the coated mirrors in the hard x-ray regime. We compare the experimental results to those from models computed using the independent metrology data.

8443-70, Session 15

NuSTAR as-coated multilayers

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The Nuclear Spectroscopic Telescope Array (NuSTAR) is slated for a 2012 launch carrying the first focusing hard X-ray (5-80 keV) telescope to orbit. The multilayer coating was carried out at the Technical University of Denmark (DTU Space). Commercially available flat Silicon wafers were included to witness individual flight coating runs. Specular reflectivity response from the witness multilayer was measured up to 100 keV at the Rainwater Memorial Calibration Facility (RaMCaF) for X-ray optics. These measurements are an integral part of the NuSTAR optic response model. In this article we present updated results from the witness campaign,

as well as report on coating uniformity measurements carried out at DTU Space. Implementation of both witness and uniformity results are validated using NuSTAR ground calibration data.

8443-71, Session 16

The ASTRO-H Mission

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ASTRO-H, the new Japanese X-ray Astronomy Satellite following Suzaku, is an international X-ray mission, planed for launch in 2014. ASTRO-H is a combination of wide band X-ray spectroscopy (3 - 80 keV) provided by focusing hard X-ray mirrors and hard X-ray imaging detectors, and high energy-resolution soft X-ray spectroscopy (0.3 - 10 keV) provided by thin-foil X-ray optics and a micro-calorimeter array. The mission will also carry an X-ray CCD camera as a focal plane detector for a soft X-ray telescope and a non-focusing soft gamma-ray detector based on a narrow-FOV semiconductor Compton Camera. With these instruments, ASTRO-H covers very wide energy range from 0.3 keV to 600 keV. The simultaneous broad band pass, coupled with high spectral resolution of <7 eV by the micro-calorimeter will enable a wide variety of important science themes to be pursued. The ASTRO-H mission objectives are to study the evolution of yet-unknown obscured super massive Black Holes in Active Galactic Nuclei; trace the growth history of the largest structures in the Universe; provide insights into the behavior of material in extreme gravitational fields; trace particle acceleration structures in clusters of galaxies and SNRs; and investigate the detailed physics of jets. In this presentation, we will describe the mission, scientific goal and the recent progress of the project.

8443-72, Session 16

The first measurement of the ASTRO-H soft x-ray telescope performance

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ASTRO-H is a Japanese X-ray astronomy satellite under the development led by Japan and US. It will have two Soft X-ray Telescopes (SXTs), among other instruments, that are being developed by NASA's Goddard Space Flight Center. One is for an X-ray micro-calorimeter instrument and the other for an X-ray CCD camera. Their response covers the energy band below ~15 keV.

SXT is a conically approximated, Wolter I grazing incidence optic with 203 nested shells, assembled from quadrant segments. The design is basically the same as that flown on Suzaku, with a longer (5.6 m) focal length and a larger (45 cm) diameter. The gold reflecting surface is replicated from a glass cylindrical mandrel onto a 150-300 micron thick shell substrate with an epoxy buffer layer. The SXT Engineering Model (EM) quadrant was successfully completed and has shown significant performance improvements as compared with the Suzaku mirrors, attributable to a number of changes. The EM was tested at the new Goddard 100-m X-ray beamline (diverging beam) and the ISAS/JAXA beamline (pencil beam scan). The angular resolution was 1.1-1.3 arcmin, and the effective area was 147/116 cm^2 at 1.5/4.5 keV. The first Flight Model (FM) development starts in January, 2012 and will be completed by April, 2012, followed by the second FM. The FM will be tested at both facilities and fully calibrated for the purpose of making response matrices for data analyses as well as understanding its imaging characteristics. In this paper we will report preliminary results of the SXT FM performance, mainly based on testing at the Goddard 100-m beamline.

8443-73, Session 16

The high resolution microcalorimeter soft x-ray spectrometer for the Astro-H Mission

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We are developing the Soft X-Ray Spectrometer (SXS) for the JAXA Astro-H mission, planned for launch in 2014. The instrument is based on a 36-pixel array of semiconductor microcalorimeters that provides high spectral resolution over the 0.3-12 keV energy band at the focus of a high throughput, grazing-incidence x-ray mirror, giving a 3 x 3 arcmin field of view. The instrument is a collaboration between the Institute of Space and Astronautical Science and their partners in Japan, the NASA/Goddard Space Flight Center, University of Wisconsin, the Space Research Organization of the Netherlands, and Geneva University. The principal components of the spectrometer are the microcalorimeter detector system, a low-temperature anticoincidence detector, 3-stage ADR and dewar. The dewar is a long-life, hybrid design with a superfluid helium cryostat, Joule-Thomson cooler, and Stirling coolers. The instrument is capable of achieving 4-5 eV resolution across the array for at least three years in orbit, and can operate without liquid helium or the cooling power of the Joule-Thomson cooler. In this presentation we describe the present design of the SXS and initial test results of a high-fidelity engineering unit that provide an indication if its performance.

8443-74, Session 16

Design and performance demonstration of the cooling system for the Soft X-ray Spectrometer (SXS) onboard Astro-H

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The Soft X-ray Spectrometer (SXS) is a cryogenic high resolution X-ray spectrometer onboard the X-ray astronomy satellite ASTRO-H. The detector array is cooled down to 50 mK using a 3-stage adiabatic demagnetization refrigerator (ADR). The cooling chain from room temperature to the ADR heat-sink is composed of superfluid liquid He, a 4He Joule-Thomson cryocooler, and 2-stage Stirling cryocoolers (Fujimoto et al. 2010, SPIE 7732, 77323H). It is designed to keep 30 L of liquid He for more than 3 years in the nominal case. It is also designed with redundant subsystems throughout from room temperature to the ADR heat-sink, to alleviate failure of a single cryocooler or loss of liquid He.

We have completed the design of the engineering model (EM) of the cooling chain, and have begun fabrication. The EM detector array, ADR, and the aperture assembly developed by NASA will be integrated in early 2012. Starting in May 2012, we will begin a series of function tests and mechanical environment tests of the full EM dewar, to demonstrate the thermal performance of the cooling system, detector performance in the SXS dewar environment with cryocoolers, and to qualify the mechanical design. In this paper, we will present the final design of the cooling system from room temperature to the ADR heat-sink, and initial results of the performance verification tests.

8443-75, Session 16

Soft x-ray imager (SXI) onboard ASTRO-H

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We are developing an X-ray CCD camera (SXI) for ASTRO-H, including many new items. We have employed the CCD, CCD-NeXT4, that is a P-channel type CCD. It has a thick depletion layer of 200um with an imaging area of 30.72mm square. Since it is back-illuminated, it has a good low energy response and is robust against the impact of micro-meteorites. We will employ 4 chips to cover the field of view of 38' square. A mechanical cooler is used so that we can cool the CCD to -120C. We will also introduce an analog ASIC that is placed just below the CCD. We also employ a radio-active source of 55Fe, which is similar to that on the Suzaku XIS. Using the optical blocking filter, the SXI is completely isolated from inside the satellite to avoid the contamination. We are now in the final production phase of the SXI.

8443-76, Session 16

Current status of ASTRO-H hard x-ray telescopes (HXTs)

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ASTRO-H is an international X-ray astronomy satellite of ISAS/JAXA, which will be launched in 2014. One of the main characteristics of ASTRO-H is imaging spectroscopy in the hard X-ray band above 10 keV. ASTRO-H will carry two identical Hard X-ray telescopes (HXTs). Requirements to HXT are an total effective area of > 300 cm2 at 30 keV and an image quality of < 1.7' in half power diameter.

To achieve these requirements, the mirror surfaces are coated with Pt/C depth-graded multilayers to enhance hard X-ray effective area up to 80 keV by means of Bragg reflection, and nested conical reflectors are constructed of thin aluminum substrates with a thickness of 0.2 mm.

We have successfully designed HXTs based on the SUMIT balloon-borne experiment, and the feasibility of the hardware design of HXT (mechanical and thermal) has been confirmed by simulations and test with engineering models.

Mass production of the mirror shells at Nagoya University has been going on since August 2010. Hard X-ray performance of selected mirror shells was measured at a synchrotron radiation facility, SPring-8 beamline BL20B2, and an image quality of 1.65' (HPD) at 30 keV was obtained.

We have finished the critical design review (CDR-1) of HXT, and are moving to fabrication stage.

In this paper, we will present the current status of HXT production and fabrication planning of HXT flight model.

8443-77, Session 16

Hard x-ray imager (HXI) for the ASTRO-H Mission

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The Hard X-ray Imager (HXI) is one of three focal plane detectors on board the ASTRO-H mission (6th Japanese X-ray satellite), which is scheduled to be launched in 2014. By use of the hybrid structure composed of double-sided silicon strip detectors and a cadmium telluride strip detector, it fully covers the energy range of photons collected with the hard X-ray telescope up to 80 keV with a high quantum efficiency. High spatial resolutions of 250 micron pitch and energy resolutions of 1-2 keV (FWMH) are at the same time achieved with low noise front-end ASICs. In addition, thick BGO active shields compactly surrounding the main detection part, as a heritage of the successful performance of the Hard X-ray Detector (HXD) on board Suzaku satellite, enable to achive an extremely high background reduction for the cosmic-ray particle background and in-orbit activation.

We will present the detector concept/design, latest results of the detector development research, and the current status of the hardware.

8443-78, Session 16

Soft gamma-ray detector for the ASTRO-H Mission

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ASTRO-H is the next generation JAXA X-ray satellite, intended to carry instruments with broad energy coverage and exquisite energy resolution. The Soft Gamma-ray Detector (SGD) is one of ASTRO-H instruments and will feature wide energy band (40-600 keV) at a background level 10 times better than the current instruments on orbit. The SGD achieves low background by combining a Compton camera scheme with a narrow field-of-view active shield where Compton kinematics is utilized to reject backgrounds. The Compton camera in the SGD is realized as a hybrid semiconductor detector system which consists of silicon and CdTe (cadmium telluride) sensors. Good energy resolution is afforded by semiconductor sensors, and it results in good background rejection capability due to better constraints on Compton kinematics. Utilization of Compton kinematics also makes the SGD sensitive to the gamma-ray polarization, opening up a new window to study properties of gamma-ray emission processes.

In this paper, we will present the detail design of SGD and the results of the final prototype developments and evaluations. Moreover, we will also present expected performance.

8443-133, Poster Session

Progress report on using magneto-strictive sputtered thin films to modify the shape of a x-ray telescope mirror

M. P. Ulmer, X. Wang, J. Cao, L. Hoffman, M. E. Graham, J. Savoie, S. Vaynman, B. Bellavia, Northwestern Univ. (United States)

We describe a technique of shape modification that can be applied to thin walled (~100-400 micron thickness) electroformed replicated optics or slumped glass optics to improve the near net shape of the mirror as well as the mid-frequency ripple. The process involves sputter deposition of a magnetic smart material (MSM) film onto a permanently magnetic material. The MSM material exhibits strains about 400 times stronger than ordinary ferromagnetic materials. The deformation process involves a magnetic write head which traverses the surface, and under the guidance of active metrology feedback,locally magnetizes the surface to impart strain where needed. Designs and basic concepts as applied to space borne X-ray optics will be described. Then we describe the results of our first tests and plans for the future.

8443-134, Poster Session

Uniform coating of high aspect ratio surfaces through atomic layer deposition

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Innovative x-ray ray imaging optic technologies are often characterised by large length to pore diameter aspect ratios. Such ratios present challenges to the deposition of metallic coatings onto the mirror substrate surfaces, aimed at increasing the surface reflectivity. The technique of Atomic Layer Deposition is perfectly suited to addressing this challenge due to the inherent self limiting nature of the process which yields highly conformal coatings with surface roughness compatible with the requirements of high resolution X-ray imaging. We will present the results of an activity aimed at developing an optimised process to coat samples with a uniform and smooth metallic layer. The design of a custom ALD reactor system and coating results including x-ray reflectivity measurements will be discussed.

8443-135, Poster Session

Coatings with high 102.6-to-121.6 nm reflectance ratio

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Observations in the far ultraviolet (FUV) at wavelengths below ~125 nm, which include the H Lyman series and the spectral lines of many other important species, are expected to unveil fundamental information for solar physics and astrophysics. The available data in this range are still scarce due in part to the low efficiency of optical coatings. Most materials in nature become absorbing when moving from the visible to the FUV, which results in a modest performance of multilayer coatings at these short wavelengths. Coatings for this range have been mostly limited to single layer coatings (sometimes overcoated with a protective overlayer).

Observations of the solar corona at 102.6 nm H Lyman beta are of high interest for solar physics, but they require the rejection of ubiquitous

H Lyman alpha at 121.6 nm. This problem was addressed through the development of novel multilayer coatings with a high reflectance at 102.6 nm and a high rejection at 121.6 nm. An efficient reflection/rejection coating is not straightforward because of the aforementioned lack of high-transmission materials along with a strong influence of contamination in this range. Our group has attempted the development of novel multilayers with various combinations of materials. At the conference we will display the most promising multilayers, which exhibit a high reflection/rejection ratio at the desired wavelengths after storage in a desiccator for a few months.

8443-136, Poster Session

Progress in new ultraviolet reflective coating techniques

M. Beasley, Univ. of Colorado at Boulder (United States); F. Greer, S. Nikzad, Jet Propulsion Lab. (United States)

Current FUV instrumentation is seriously compromised by poor reflectivity. The best existing coatings for the 90 - 115 nm range are SiC (30% reflectivity across the band) and LiF/Aluminum (60% reflectivity from 100 nm to 115 nm). An improved coating therefore would enable the production of vastly more sensitive instruments in the 90 - 200 nm range. An additional goal in the development of an alternate FUV coating is to overcome the well-documented hygroscopic behaviors of LiF coatings, which currently impose handling concerns that in turn drive cost and schedule. The coatings we will develop in this effort must also function well through the conventional silicon-based detector bandpass (200 nm to 1100 nm). By ensuring that these new coatings are usable at many wavelengths, we will make it possible to incorporate ultraviolet instruments into future large missions without compromising the science capability of other instruments or increasing cost and risk due to handling issues. I will discuss the latest results and our upcoming work on the new coatings.

8443-137, Poster Session

Corrosion-resistant high-performance SiC/Mg multilayer coatings for solar physics in the 25-75 nm wavelength region

R. Soufli, M. Fernandez-Perea, J. C. Robinson, S. L. Baker, J. B. Alameda, Lawrence Livermore National Lab. (United States); E. M. Gullikson, Lawrence Berkeley National Lab. (United States)

Silicon carbide/magnesium (SiC/Mg) has the potential to be one of the best-performing reflective multilayer coatings in the 25-75 nm wavelength range with applications as mirror coating in space telescopes for solar and plasma physics. SiC/Mg exhibits superior reflectivity, near-zero stress, and excellent thermal stability and spectral selectivity compared to other candidate multilayer pairs. However, SiC/Mg suffers from corrosion, exhibited as spots which sporadically develop and expand across the coating over time, completely degrading the reflective performance. This insidious problem has prevented SiC/Mg from being implemented in solar missions that require good lifetime stability, such as the Solar Dynamics Observatory (SDO) and the GOES-R missions. Although it is known that Mg is prone to corrosion after exposure to air and humidity, the exact mechanism of corrosion generation and propagation in nanometer-scale SiC/Mg multilayer thin films has not been studied until recently, and there have not been any methods to prevent it. This talk will discuss the origins of corrosion and the mechanisms of its propagation in SiC/Mg multilayers. Novel design concepts and experimental results will also be presented on corrosion-resistant SiC/Mg multilayers, aged for up to 4 years. Transmission and scanning electron microscopy, EUV reflectance and x-ray photoelectron spectroscopy measurements will be shown as part of this work. The results are encouraging towards SiC/Mg fulfilling its promise as a multilayer coating with high performance and long lifetime stability, suitable for solar physics space missions.

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8443-138, Poster Session

Reflective coating for lightweight x-ray optics

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X-ray reflective coating for next generation's lightweight, high resolution, optics for astronomy requires thin-film deposition that is precisely fine-tuned so that it will not distort the thin sub-mm substrates used for such optics with arc-second resolution. This requirement is necessary for single-film deposition of soft x-ray mirrors and is even more stringent for multilayer deposition of hard x-ray mirrors. Deposition of very low stress is required. Alternatively, mirror distortion can be cancelled by precisely balancing the deformation from multiple films. In this paper, we will present results on metallic film deposition, especially of iridium and chromium, for the next generation of lightweight optics under development. These efforts include: low-stress deposition by magnetron sputtering and atomic layer deposition of the metals, balancing of gross deformation with two-layer depositions of opposite stresses and with depositions on both sides of the thin mirrors.

8443-139, Poster Session

Multilayer coating of large telescope mirrors by magnetron sputtering

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The manufacture of telescope mirrors requires a very high precision in order to guarantee the optical performance of the complete telescope system. This paper describes the tool and technology for the coating of large telescope mirrors by magnetron sputtering.

Face-up oriented substrates of 2 m dia., 200 mm height and up to 2000 kg in weight can be coated with multilayer stacks. The magnetron arrangement consists of a revolver drum fitted with 4 independent sputter magnetrons and is placed above the radius of the sample. The magnetron's working distance and its angle can be adjusted in situ. Hence, convex, concave and plane shaped surfaces can be coated. By turning the magnetron drum in-situ, one of four materials can be chosen. Each magnetron can be driven by a maximum 40 kW DC or pulsed DC (up to 350 kHz), depending on the target material. The base pressure of 10-6 mbar can be reached with 2 turbo-molecular plus one cryo-pump. A residual gas analyzer and a quartz balance deposition monitor are integrated for process control.

A typical reflector stack applies three different materials, an adhesion layer, a metallic reflective layer and a protective layer, combining metals and dielectrics. The metals are DC sputtered while the dielectrics are sputtered reactively and in pulsed DC mode. Typical static sputter rates of 500 nm/min up to 2000 nm/min for metals and 90 nm/min for dielectrics are achieved. For homogeneity in the radial direction the magnetron revolver is equipped with a shaper aperture. Homogeneity in the angular direction is achieved by the spin rotation of the substrate. First results of coated substrates will be presented.

8443-140, Poster Session

Ultrathin aluminum/polymer EUV filters with improved infrared blocking and durability

B. M. Lairson, T. Ayers, H. C. Lopez, D. A. Grove, Luxel Corp. (United States)

Ultrathin (20-50nm) aluminum films on free-standing polyimide substrates are used to block infrared light and to reduce thermal loads on microcalorimeters and other cooled detectors. Generally, for these films, far greater aluminum thickness is needed to achieve a desired level of blocking than is predicted from bulk optical constants. We show that the variability in transmission spectra is explained by islanding of the aluminum on the polymer film. Visible and infrared transmission are well described using an effective-index Lorentz oscillator model. We also show how processing variables dramatically affect infrared blocking and resistance to atomic oxygen exposure.

8443-141, Poster Session

Grazing-incidence imaging spectrograph for solar observations in the XUV domain

F. Frassetto, S. Coraggia, P. Miotti, L. Poletto, Univ. degli Studi di Padova (Italy)

We present the design and characterization of an imaging spectrograph that operates at grazing incidence and is stigmatic in a large field-of-view. The instrument may be used for XUV space observations of extended sources, such as the Sun disk.

The design consists of a telescope and a spectrograph giving simultaneously spatial and spectral imaging. The telescope has two sections in the Kirkpatrick-Baez configuration. The telescope 1 consists of a single grazing incidence mirror (cylindrical mirror with parabolic section) that focuses the radiation on the entrance slit of the spectrograph in the spectral dispersion plane. The telescope 2, which is crossed with respect to the telescope 1, consists of two grazing incidence mirrors (cylindrical mirrors with aspherical section in Wolter configuration) focusing the radiation on the focal plane in the direction parallel to the slit. The spectrometer consists of a spherical variable-line-spaced grating with flat-field properties. Finally, the spectrum is acquired by a CCD detector mounted at near normal incidence with respect to the direction of the exit beam. Such unique configuration gives monochromatic images in an extended field-of-view and in an extended spectral range.

A laboratory prototype of such spectrograph has been realized working in the 4-20 nm (310-62 eV) spectral region, with a spectral resolution of 0.1% at 10 nm and a spatial resolution of 3.5 arcsec over a field-of-view of 0.5°, within a total envelope of 1.2 m. The design and the characterization of the instrument in the whole spectral region of operation are presented and discussed.

8443-142, Poster Session

Mirror-concentrator for space telescope with wide field of view and high angular resolution for observation of time-space structure of the atmosphere fluorescence flashes

S. A. Sharakin, B. A. Khrenov, P. B. Klimov, S. A. Potanin, I. V. Yashin, Lomonosov Moscow State Univ. (Russian Federation)

In studies of extreme energy cosmic rays the Earth atmosphere is used as a target where the primary particle interacts and produces cascade of secondary particles. Particles of the cascade generate fluorescent radiation of the atmosphere in near UV (300-400 nm) which can be detected from the satellite orbit if the fluorescent radiation is collected by a large mirror-concentrator (10 m2 or more). Design of such a mirror for space operation meets problems. In this paper design of the space mirror concentrator with area of 10 m2, field of view of about 14° and focal spot angular radius 5 mrad is presented.

8443-143, Poster Session

Development of the super high angular resolution principle for x-ray imaging

C. Zhang, National Astronomical Observatories (China); S. Zhang, Institute of High Energy Physics (China)

Development of the Super High Angular Resolution Principle (SHARP) for coded-mask X-ray imaging is presented. The SHARP is theoretically demonstrated to be equivalent to a coded aperture imaging system with a coding pattern comprised of diffraction-interference fringes of mask pattern. The SHARP is also demonstrated by an optical experiment with a sodium lamp as point light source. The mask used in the experiment has a element size of about 170 micrometer. The baseline is of about 1 m long. The angular resolution achieved in the experiment is of 26 arcsec, beyond the diffraction limited resolution of a single pinhole of 840 arcsec.

The SHARP will be tested on an X-ray beam line facility soon. Potential ways to improve the angular resolution of SHARP and the capability to image distributed source are also shortly discussed.

8443-144, Poster Session

Design and analysis of modules for segmented glass x-ray optics

R. S. McClelland, SGT, Inc. (United States); W. W. Zhang, T. T. Saha, NASA Goddard Space Flight Ctr. (United States)

Advancements in X-ray astronomy demand thin, light, and closely packed optical elements which lend themselves to segmentation of the annular mirrors and, in turn, a modular approach to the mirror design. The emergent issues that develop when hundreds of mirror segments are installed into a structure have been explored through the design and analysis of mirror modules for various space X-ray telescope missions studied. Finite Element Analysis (FEA) was performed of several different module sizes to determine the horizontal and vertical self-weight distortion, launch stress, and on-orbit thermal performance. Studies show that the size of the module structure has a critical impact on the module performance, particularly with respect to self weight deformation and launch stress in the mirror segments. FEA results indicate that horizontal testing of slumped glass mirror modules results in unacceptable distortion for mirror resolutions of 5 arc-seconds and below. A vertical X-ray testing facility is required to test high resolution and light-weight X-ray optics. As module size increases, stress in the mirror segments caused by enforced displacements of the module wall quickly increases. The launch loads, allowable glass strength, and module structure stiffness determine the maximum module size. Design and analysis of various slumped glass mirror modules has resulted in an increased understanding of the emergent issues associated with light-weight segmented X-ray optics.

8443-145, Poster Session

Precise alignment and permanent mounting of thin x-ray segments

M. Biskach, NASA Goddard Space Flight Ctr. (United States)

Next generation X-ray missions must meet precise angular resolution and high collecting area requirements. One approach currently under development by the Next Generation X-ray Optics (NXGO) group at NASA's Goddard Space Flight Center (GSFC) involves aligning and mounting several thousand precisely formed thin glass mirror segments into a flight mirror assembly (FMA). This two step process begins with

mirror segment alignment and mounting into a module that houses hundreds of tightly packed segments each. The FMA is then populated with the completed modules. Currently the segment mounting process under development is focused on populating a single module with segments that meet preliminary FMA resolution requirements of 10 arcseconds. This paper presents recent alignment and segment mounting progress made using a mini-module capable of housing three segment pairs. In addition a broad look at the development track of the FMA up to this point with a description of expected work looking forward will also be presented.

8443-146, Poster Session

Design and tolerance analysis of 1-30 keV nested conical Wolter-I X-ray Telescope

B. Mu, H. Liu, L. Jiang, Z. Wang, Tongji Univ. (China)

Hard X-ray telescope is a key research of next generation satellite programs. We have accomplished the initial design of 1-30 keV X-ray telescope using W/B4C aperiodic multilayer and nested conical structure. The effective area could achieve 71 cm2 and the field of view could achieve 13′ at 30 keV, respectively. The resolution was estimated to be ~10″ in half-power diameter. As a next development effort, we focus on the analysis of tolerance. The main errors lowering image quality are position error, figure error and off-roundness. Position error and figure error are contributing to the shift, the rotation or the surface changing of mirrors, while off-roundness is caused by the shift of support bars. In this paper, the calculation methods of these errors were presented, the changing of spot diagram and resolution were analyzed under different errors. For position error, the shift and the rotation of z direction have no effect on the image quality, but the shift and the rotation of x and y direction influence the distribution of spot diagram and lower the resolution. For figure error, variation of 10 μm in figure error will lower 1 arcmin in HPD. Off-roundness is evaluated by measuring offsets of local area images for all position angles. Each measurement represents image behavior of the corresponding position angle. The reduction of off-roundness is realized by fixing a displacement sensor to the outer end of the support bar. We calculated the opposite program that with certain shift of support bar the resolution reduced clearly. When the off-roundness ranges from -15 ~ 15μm down to -3 ~ 3μm, the distribution of spot diagram from -1.5 ~ 1.5mm reducing to -0.6 ~ 0.6mm and the corresponding resolution from 1′ improving to 13”.

8443-147, Poster Session

Resolution limits of transmission optics for x-ray astronomy

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We report on recent theoretical investigations and first experimental results on diffractive-refractive X-ray lenses as promising candidates for next-generation X-ray telescopes with an ultra-high angular resolution. Relevant imaging properties of purely refractive optical elements made of low-Z materials are analyzed and compared to the focal characteristics of generalized Fresnel lenses, defined by a stepwise arbitrary phase shift per groove. Their potential for wide-field imaging is considered as well as their constraints caused by chromatic aberration. From a technological point of view, the development of large-scale diffractive optics is mainly limited by the wavefront error induced by fabrication tolerances like the “stitching error” in the lithographic process. The sensitivity to astronomical targets is significantly increased if hybrid, i.e. achromatic lens combinations are used. We discuss their capabilities for various design conditions, apodization schemes and different definitions of the achromatic gain and propose an arrangement for enhanced high-throughput imaging around the Fe K-alpha line at 6.4 keV. Using ultra-high purity carbon based materials in particular, efficient components of that type can be realized.

8443-148, Poster Session

Improvements of design scheme and fabrication of the hard x-ray supermirror

Y. Yao, H. Kunieda, H. Matsumoto, Y. Miyata, Nagoya Univ. (Japan)

We present a theoretical study of the hard x-ray supermirror to explain the behavior of the E-M wave propagation in the layered structure designed by the “block method”. The result shows that there is a special condition which may let the spectrum of the layer structure become a box shape, that means the reflectivity curve becomes smooth. In high energy band, because of the low absorption, the reflectivity mainly decided by the contrast of material, so the reverse structure (thin layers at the top and thick ones at the bottom) gives flatter response than usual structure without the lost of the integral reflectivity. We also use the computer algorithm to design a supermirror with flat, smooth and relatively high (30-35% with 100 layer pairs) response which can be used in X-ray telescopes. Our result show the reflectivity has been raise and extremely smoothed by the computer algorithm. In order to enhance the response in high energy band, we introduce a double replica method to overcome the roughness increase as the number of layers exceeds 200 or more.

8443-149, Poster Session

Development of four-reflection x-ray telescope for DIOS Mission

Y. Tawara, S. Sugita, S. Hara, I. Sakurai, K. Tachibana, Nagoya Univ. (Japan)

To search for warm-hot intergalactic medium (WHIM), a small satellite mission DIOS (Diffuse Intergalactic Oxygen Surveyer) is planned and a specially designed four-reflection X-ray telescope (FXT) has been developed as the best fit optics to have a wide field of view and a large effective area. Based on the design of optics and mirror fabrication method developed for FXT, we made the quadrant model with ten nested four-stage mirrors. In the fabrication process, we found that it was difficult to make correct shape of 4th stage mirror with large cone angle due to using cylindrical replica mandrel. To solve this problem, we developed conical replica mandrel using thin glass sheet. In this paper, we describe the expected and the measured performance, such as angular resolution, an effective area and a field of view.

8443-151, Poster Session

The Wolter Telescope Designer (WTD): a user-friendly web facility for the design of x-ray multishell telescopes

V. Cotroneo, Harvard-Smithsonian Ctr. for Astrophysics (United States); D. O. Di Pasquale, CNR Istituto per le Tecnologie della Costruzione (Italy); P. B. Reid, Harvard-Smithsonian Ctr. for Astrophysics (United States)

The design of a Wolter X-ray telescope takes into account the geometrical dimensioning of the shells and the choice of the (monolayer or multilayer) coatings for each of them. In this work we present a user-friendly web interface aimed to the design of multi-shell Wolter telescopes and the calculation of their effective area and mass. Some examples of use cases are presented.

8443-214, Poster Session

Physics of the cosmos technology development program overview

T. Pham, M. C. Clampin, NASA Goddard Space Flight Ctr. (United States)

The Physics of the Cosmos (PCOS) Program Office was established in FY11 and resides at the NASA Goddard Space Flight Center (GSFC). The office serves as the implementation arm for the Astrophysics Division at Headquarters (HQ) for PCOS Program related matters. We present an overview of the Program's technology management activities and the Program's technology development status. We discuss the process for addressing community-provided technology needs and the Technology Management Board (TMB)-vetted prioritization and investment recommendations. This process improves the transparency and relevance of technology investments, provides the community a voice in the process, ensures open competition for funding, and leverages the technology investments of external organizations by defining a need and a customer. Goals for the PCOS Program envisioned by the National Research Council's (NRC) "New Worlds, New Horizons in Astronomy and Astrophysics" (NWNH) Decadal Survey report include science missions and technology development for dark energy, gravitational waves, X-ray astronomy, and inflation. Having lost three missions in formulation in 2011, the PCOS Program shifted its efforts to administering the operational missions and managing mission concept and technology studies. These studies currently include gravitational wave and X-ray astronomy mission concepts. It is the goal of the PCOS Program to shepherd all of these technologies to the point at which they can transition into project technology plans. In so doing, these technologies can serve as the foundation for robust mission concepts for review by the community such that the scientific relevance of proposed missions will be prioritized in subsequent strategic planning.

8443-153, Poster Session

Configuring ACIS as a background particle flux detector

P. G. Ford, C. E. Grant, Massachusetts Institute of Technology (United States)

The ACIS instrument aboard the Chandra Observatory can be easily damaged by low-energy charged particles, principally protons that implant themselves in the X-ray sensitive CCDs, creating charge traps that degrade the energy resolution and detection efficiency. During periods of high background radiation, ACIS must be moved out of the focal plane of the Chandra telescope and, whenever possible, this action should be taken autonomously since the spacecraft only maintains ground contact for limited periods. The EPHIN detector has been monitoring the particle background since Chandra was launched in 1999, but it is no longer sufficiently sensitive to low energy protons, so the question arose whether ACIS could take over this task. Examining the ACIS data archive, a particular measured quantity---the rate of occurrence of CCD pixels found to contain electric charge that exceeded a predetermined threshold---was often correlated with particle background flux. An algorithm was developed to distinguish this behavior from random fluctuations in the above-threshold rate and the algorithm parameters were adjusted to find the maximum number of high radiation flux "triggers" from the data archive with the minimum number of false positives. The algorithm has been encoded as a patch to ACIS flight software and, after extensive ground testing, has been installed within the instrument.

8443-154, Poster Session

Updating the Chandra HETGS efficiencies using in-orbit observations

H. L. Marshall, Massachusetts Institute of Technology (United States)

The efficiencies of the gratings in the High Energy Transmission Grating Spectrometer (HETGS) were updated using in-flight observations of bright continuum sources. The procedure first involved verifying that fluxes obtained from the +1 and -1 orders match, which checks that the contaminant model and the CCD quantum efficiencies agree. Then the fluxes derived using the high energy gratings (HEGs) were compared to those derived from the medium energy gratings (MEGs). The flux ratio was fit to a low order polynomial, which was allocated to the MEGs above 1 keV or the HEGs below 1 keV. The resultant efficiencies were tested by examining fits to blazar spectra.

Support for this work was provided by the National Aeronautics and Space Administration (NASA) through the Smithsonian Astrophysical Observatory (SAO) contract SV3-73016 to MIT for support of the Chandra X-Ray Center (CXC), which is operated by SAO for and on behalf of NASA under contract NAS8-03060.

8443-156, Poster Session

Performance evolution of the x-ray imaging spectrometers aboard the Suzaku X-ray Astronomy Satellite

B. J. LaMarr, M. W. Bautz, S. E. Kissel, E. D. Miller, G. Y. Prigozhin, Massachusetts Institute of Technology (United States)

We summarize the evolution of the performance of the X-ray Imaging Spectrometer (XIS) aboard the Suzaku X-ray Astronomy Satellite. Changes due to the orbital environment and updated operating conditions are discussed.

I'll discuss gain changes due radiation damage and change to charge injection levels.

8443-157, Poster Session

The current status of SSC on-board the MAXI Mission

H. Tomida, Japan Aerospace Exploration Agency (Japan); H. Tsunemi, M. Kimura, H. Kitayama, Osaka Univ. (Japan); M. Sugizaki, RIKEN (Japan); T. Hanayama, Univ. of Miyazaki (Japan)

After the two-year operation in orbit, all of 32 X-ray CCDs in the SSC have been working well, and there is no degradation of cooling ability.

On the other hand, the CCD performances, such as energy resolution, has been degrading due mainly to the increasing CTI (Charge Transfer Inefficiency).

CTI has been increasing by 10^-5/pixel/year for both of the vertical and the horizontal transfer.

The background during night is dominated by charged particles at the high latitude, and the CCD image of the day observation is contaminated with Sun light leak.

After the removal of high background-contaminated data, SSC all-sky image shows many point sources and diffuse structures.

This is the first all-sky X-ray image taken with X-ray CCD.

The lower energy region (<2keV) is not covered with the gas-counter camera of MAXI, and the energy resolution is better than the ROSAT/PSPC.

The spectroscopy of diffuse structure is one of main objectives with SSC.

The Cygnus Super Bubble shows the emission lines in the spectrum, while North Polar Spur doesnot show the line structure.

8443-158, Poster Session

The COS FUV channel: on-orbit performance trends and early characterization of a new detector lifetime position

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The Cosmic Origins Spectrograph (COS) was installed into the Hubble Space Telescope in May 2009, and has been collecting ultraviolet spectra since then. The Far Ultraviolet channel of COS uses an efficient optical design and a two-segment, large-format Cross Delay Line microchannel plate detector to obtain spectra at medium and low resolution in the far ultraviolet. While the overall instrument performance has been excellent, several long-term trends in performance have been noted and are being addressed. These include a slow decrease in overall sensitivity, which is independent of the illumination and may be due to a degradation of the photocathode with time.

In addition, the detector microchannel plates are showing severe gain sag in the regions where the most photons have fallen. As a result, we are in the process of moving the spectra to a new, nearly pristine, location on the detector. This will be the first of several additional lifetime positions which will allow us to collect high-quality spectra for many years to come. We will discuss the factors that led to our decision on where to move next and our progress in moving there, including details of the enabling and calibration activities which are being performed at the new location, and the anticipated performance. We will also address strategies that will be implemented in order to prolong the life at this and subsequent positions.

8443-159, Poster Session

On-ground calibration of AGILE-GRID with a photon beam: results and lessons for the future

P. W. Cattaneo, Istituto Nazionale di Fisica Nucleare (Italy)

AGILE, an Italian Space Agency mission launched in April 2007, is composed of a pair-production Gamma Ray Imager (GRID) sensitive from 30 MeV-50GeV, an X-ray Imager (Super-AGILE) sensitive from 18-60 keV, and a Mini-Calorimeter sensitive to photons and charged particles from 300 keV to 100 MeV. AGILE-GRID has detected both persistent and variable sources, many of which were collected in the first AGILE Catalog.

The instrument was calibrated before launch in the Beam Test Facility at the INFN Laboratori Nazionali di Frascati using a tagged photon beam designed for the purpose.

The data were used to measure the effective area, energy dispersion, and point spread dispersion as a function of pointing direction in instrument coordinates and photon energy under beam test condition and to validate the Monte Carlo simulation to be used for estimating the same quantities in flight condition.

This calibration required first a careful characterization ofthe photon tagging system in terms of efficiency and energy resolution,followed byan analysis of the AGILE data.

During this analysis we identified some problems in thecalibration setup that limited the precision of our calibration.

We discuss these limitations and suggest an improved setup for calibration of future gamma ray telescope on satellite.

8443-160, Poster Session

Calibration of AGILE-GRID with in-flight data and Monte Carlo simulations

A. W. Chen, INAF - IASF Milano (Italy)

AGILE, an Italian Space Agency mission launched in April 2007, is composed of a pair-production Gamma Ray Imager (GRID) sensitive from 30 MeV-50GeV, an X-ray Imager (Super-AGILE) sensitive from 18-60 keV, and a Mini-Calorimeter sensitive to photons and charged particles from 300 keV to 100 MeV. AGILE-GRID has detected both persistent and variable sources, many of which were collected in the first AGILE Catalog. We have used in-flight data and updated Monte Carlo Simulations, to validate the calibration of the AGILE GRID, producing updated response matrices for the e ffective area, energy dispersion, and point spread dispersion as a function of pointing direction in instrument coordinates and photon energy. We present the methods and results of the validation and calibration here.

8443-161, Poster Session

Chromospheric Lyman-alpha spectro-polarimeter (CLASP)

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Observations by the Hinode satellite have revealed that a variety of dynamic events such as jets and waves occur ubiquitously in the solar chromosphere. They must be dominated by magnetic fields in the chromosphere. However, we have poor observational knowledge of chromospheric magnetic fields. Therefore, we have planned a sounding rocket experiment, "Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP)", to explore magnetic fields in the upper solar chromosphere and transition region by measuring the linear polarization in the Lyman-alpha line (121.567 nm). The Lyman-alpha line from a target on the solar disk must be linearly polarized by scattering processes, and the linear polarization at the line center is expected to vary between 0.1-1% by the Hanle effect depending on the strength and orientation of magnetic fields. The CLASP instrument is designed to have a polarimetric sensitivity of 0.1% and a spectral resolution of 0.01 nm, and it consists of a Cassegrain telescope and a spectro-polarimeter. The primary mirror of the telescope is coated with a narrowband multilayer coating that reflects only the Lyman-alpha to minimize heat load and off-band contamination. A constant-line-spacing spherical grating mounted in an inverse Wadsworth geometry disperses the light into two channels: plus and minus 1st-order beams. Both beams pass into a matched pair of imaging systems including polarization analyzers for measuring the orthogonal linear polarizations simultaneously. A rotating half waveplate allows measurement of both Stokes Q and U with these polarization analyzers. We have proposed to launch the CLASP in 2014.

8443-162, Poster Session

X-ray gamma-ray polarimetry small satellite PolariS

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Agency (Japan); H. Kubo, Kyoto Univ. (Japan); N. Anabuki, M. Sadamoto, Osaka Univ. (Japan)

PolariS (Polarimetry Satellite) is a Japanese small satellite mission dedicated for polarimetry of X-ray and gamma-ray sources.

We aim to perform wide band X-ray (2-80 keV) polarimetry of sources brighter than 10 mCrab, employing three hard X-ray mirrors and two types of polarimeters. X-ray and Ggmma-ray polarimetry of transient sources with wide field polarimeters is the second purpose. Most of the components have their prototype used or planned to be used in balloon and other satellite missions. Design is in progress for target launch date in 2010's.

PolariS mirrors are half sized (in focal length and diameters) mirrors those developed for ASTRO-H. Two types of polarimeters are installed on the focal plane. One is scattering imaging polarimeters, of which proto-type was used in PHENEX balloon experiments, cover energy range from 10 to 80 keV. Lower enegy will be covered with a gas imaging polarimeter.

8443-163, Poster Session

The gamma-ray imager/polarimeter for solar flares (GRIPS)

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The balloon-borne Gamma-Ray Imager/Polarimeter for Solar flares (GRIPS) instrument will provide a near-optimal combination of high-resolution imaging, spectroscopy, and polarimetry of solar-flare gamma-ray/hard X-ray emissions from ~20 keV to >~10 MeV. GRIPS will address questions raised by recent solar flare observations regarding particle acceleration and energy release, such as: What causes the spatial separation between energetic electrons producing hard X-rays and energetic ions producing gamma-ray lines? How anisotropic are the relativistic electrons, and why do they dominate in the corona? How do the compositions of accelerated and ambient material vary with space and time, and why? The spectrometer/polarimeter consists of sixteen 3D position-sensitive germanium detectors (3D-GeDs), where each energy deposition is individually recorded with an energy resolution of a few keV FWHM and a spatial resolution of <0.1 mm^3. Imaging is accomplished by a single multi-pitch rotating modulator (MPRM), a 2.5-cm thick tungsten-alloy slit/slat grid with pitches that range quasi-continuously from 1 to 13 mm. The MPRM is situated 8 meters from the spectrometer to provide excellent image quality and unparalleled angular resolution at gamma-ray energies (12.5 arcsec FWHM), sufficient to separate 2.2 MeV footpoint sources for almost all flares. Polarimetry is accomplished by analyzing the anisotropy of reconstructed Compton scattering in the 3D-GeDs (i.e., as an active scatterer), with an estimated minimum detectable polarization of a few percent at 150-650 keV in an X-class flare. GRIPS is scheduled for a continental-US engineering test flight in fall 2012, followed by long or ultra-long duration balloon flights in Antarctica.

8443-164, Poster Session

Design and development of a large area photo-electron x-ray polarimeter

R. Puthiya Veetil, B. Paul, M. R. Gopalakrishna, D. Chelvan R, P. Sandhya, G. Rajagopala, H. N. Nagaraja, Raman Research Institute (India)

The photo-electron X-ray polarimeters which image the tracks of X-ray photo-electrons in a gaseous medium have very high sensitivity for X-ray polarization measurement when used as focal plane detectors with X-ray focusing optics. However, as these detectors use an imaging technique, they are small in dimension. We are developing a large area X-ray photo-electron polarimeter that will enable us to measure X-ray polarisation without using focusing optics. We use a proportional counter with closely spaced wires, interleaved as two sets of anodes . A photo electron emitted along the length of the wire is likely to produce a single pulse, where as an electron emitted perpendicular to the wire direction may produce two simultaneous pulses. For unpolarized X-ray photons, the ratio of the rate of single to double pulses detected from the two sets of anodes should be independent of the instruments orientation with respect to the direction of photon propagation. However, for polarized X-rays, the ratio of the rate of double to single pulses should have an azimuthal dependence that can be used to determine both the degree and direction of polarization of the incident X-rays. This technique will not require an X-ray focusing optics, very high pointing accuracy, or spin of the satellite and is therefore suitable for a small X-ray polarimetry mission. We will present development status and test results with this new design of photo-electron X-ray polarimeter.

8443-165, Poster Session

Thomson x-ray polarimeter for a small satellite mission

M. R. Gopalakrishna, R. Puthiya Veetil, B. Paul, D. Chelvan R, C. M. Ateequlla, C. Maitra, G. Rajagopala, M. S. Ezhilarasi, P. Sandhya, T. S. Mamatha, H. N. Nagaraja, Raman Research Institute (India)

We describe a Thomson X-ray polarimeter under development for a small satellite mission of the Indian Space Research Organisation (ISRO). A laboratory model has been made and tested successfully, an engineering model has been designed and fabrication of the same is in progress. It consists of position sensitive proportional counter detectors and works in the 5-30 keV energy band. This instrument will be suitable for X-ray polarisation measurement in about 50 hard X-ray sources. The accretion powered X-ray pulsars, black hole X-ray binaries, rotation powered pulsars and non-thermal SNR will be the prime targets for this mission. The Thomson polarimeter will be best suited for pulse phase resolved polarisation measurement of accretion powered pulsars which have hard X-ray spectrum. It will also be well suited to determine polarisation characteristics of the reflection component in black hole X-ray binaries in their hard states as the reflection component is largest in the hard X-rays. In spite of its moderate sensitivity, this experiment can give us unique opportunity to expand the field of X-ray astronomy into a hitherto unexplored dimension. This instrument will bridge the low and high X-ray polarisation measurements to be obtained with GEMS and the Compton polarimeters respectively and allow study of polarisation characteristics of X-ray sources over a wide energy band. We will describe the X-ray polarimeter, the event selection logic, and the signal processing pipeline. Different aspects related to mission specifications, instrument design, test results, and sensitivity for polarisation measurement will also be discussed.

8443-166, Poster Session

GEMS x-ray polarimeter performance simulations

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GEMS is an X-ray polarization mission selected as a NASA small explorer and scheduled for launch in 2014. The X-ray Polarimeter on the GEMS mission uses a Time Projection Chamber gas proportional counter to measure the polarization of astrophysical X-rays in the 2-10 keV band by sensing the track of the primary photoelectron excited by the incident

X-ray.

We have simulated the expected sensitivity of the polarimeter to polarized X-rays. We use the simulation package Penelope to model the physics of the interaction of the inital photoelectron with the detector gas and to determine the distribution of charge deposited in the detector volume. We then model the charge diffusion in the detector, amplification in the GEM stage, and take into account the ASIC shaping circuit and noise before producing simulated tracks.

Within the reconstruction algorithm we apply cuts on the track shape and focus on the initial photoelectron direction in order to maximize the overall polarization sensitivity of the instrument. Using this technique we have predicted instrument polarization sensitivities (mu) ranging from 10% to over 60% across the 2-10 keV X-ray band.

8443-167, Poster Session

Development of bent crystal for x-ray imaging polarimetry

K. Okada, Chuo Univ. (Japan)

We are developing a Bragg crystal polarimeter which has high modulation factor. The point we aim is to bend the crystal; by using bent crystal, we can reflect X-ray emission with broadened energy width, focus it on a small detector, which increases S/N ratio, and obtain imaging capability. We bent Si(100) crystal sheets by depositing Diamond-Like Carbon (DLC) on the back side of reflection surface. They are bent by the residual stress between the DLC and crystal. We can control the curvature by changing the DLC thickness. The angular reflectivity was measured with the line emission at 8 keV (Cu-Ka). We confirmed that the angular width is broadened to 2 degree, which is equivalent to the energy width of 0.5 keV. The integrated reflectivity becomes larger, as the curvature radius of crystal becomes small.

The modulation factor of bent Si is 0.8, which is higher than that of the flat Si of 0.5. Having the wide energy band with the high modulation factor, the bent Si crystal can be a new tool for the X-ray polarimeter.

We have also made the bent Ge(111) crystal and measured the same performances.

The modulation factor of both the flat and the bent Ge were about 1, when using the 8 keV (Cu-Ka) beam, as we expected. This means that by choosing crystals, we can make efficient observations with aimed energy band. We report the status of our development.

8443-168, Poster Session

A very thin pyrolytic graphite flexible and commercial sheet to diffract and polarize x-rays

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Pyrolytic Graphite Sheets (PGS) are produced as convenient thermal interfaces because the highly oriented structure allows for an excellent thermal conductivity. Here we report on the fact that this material can also diffract X-rays. We succeeded in diffracting 5.9 keV and continuum photons on a 25 um thick PGS, verifying that the lattice spacing is 3.35 A as expected. The low cost, lightness and the possibility to curve such thin sheets allow to think at new applications in X-ray astronomy. In particular, we will discuss the construction of a very compact polarized source to calibrate photoelectric polarimeters on-orbit.

8443-169, Poster Session

Measuring x-ray polarization in the presence of systematic effects

R. F. Elsner, S. L. O'Dell, M. C. Weisskopf, NASA Marshall Space Flight Ctr. (United States)

We describe a mathematical formalism for determining the 1 and 2 parameter errors in the magnitude and position angle of X-ray polarization. The formalism includes a treatment of systematic effects, such as background and instrumental bias.

8443-170, Poster Session

A 3D CZT hard x-ray polarimeter for a balloon borne payload

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Currently, it is widely recognised that a measurement of the polarization status of cosmic sources high energy emission is a key observational parameter to understand the active production mechanism and its geometry. Therefore new instrumentation operating in this energy range should be optimized also for this type of measurement. In this framework, we present the concept of a small high-performance spectrometer designed for polarimetry between 100 and 500 keV suitable as a stratospheric balloon-borne payload dedicated to perform an accurate and reliable measurement of the polarization status of the Crab pulsar, i.e. the polarization level and direction. The detector with 3D spatial resolution is based on a CZT spectrometer in a highly segmented configuration designed to operate as a high performance scattering polarimeter. We discuss different configuration based on recent development results and possible improvements currently under study. Furthermore we describe a possible baseline design of the payload, which can be also seen as a pathfinder for a high performance focal plane detector in next generation of hard X and soft gamma ray telescopes based on Laue lenses. Finally, we present Monte Carlo evaluations of the achievable sensitivity for polarisation as a function of different detector characteristics.

8443-171, Poster Session

A conceptual design of hard x-ray focal plane detector for simultaneous x-ray polarimetric, spectroscopic, timing and imaging measurements

S. V. Vadawale, T. Chattopadhyay, Physical Research Lab. (India)

Importance of polarization measurement of X-rays from celestial sources has been realized for long time. Such measurements can provide unique opportunity to study the behaviour of matter and radiation under extreme magnetic and gravitational fields. However sensitivity of the X-ray polarimeters has always been an issue and as a result no X-ray polarization measurement has been flown in last three decades. The situation is expected to change in near future with launch of GEMS, but these polarization measurements will be limited to energies below 10 keV. On the other hand most of the X-ray sources are expected to have higher degree of polarization at higher energies. With the advent of high energy focussing telescopes (e.g. NuSTAR, ASTRO-H), it is now possible to design a focal plane Compton polarimeter which can be sensitive upto 80 KeV. However, X-ray polarization measurement is extremely photon hungry. Therefore, a dedicated X-ray polarimeter always has lower sensitivity when compared to any other type of X-ray detector for equal collecting area and time. In this context, we explore a new design of hard X-ray focal plane detector which can provide simultaneous measurements of X-ray polarization measurements along with high resolution X-ray spectroscopy, timing as well as coarse imaging. This design employs a sandwich of a 0.5 mm thick Si detector and 5 mm thick CZT detector which is surrounded by a cylindrical array of scintillator detectors. Here we present results of detailed Geant4 simulations for estimating sensitivity of this configuration and compare them with the semi-analytical calculations.

8443-172, Poster Session

POLAR: the first dedicated gamma-ray burst polarization experiment

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POLAR is the first dedicated Gamma-Ray Burst(GRB) polarization experiment in the energy range 50–500 keV. The detection principle of gamma-ray polarization is the anisotropy of the Compton scattering. POLAR consists of 1600 low-Z plastic scintillator bars, read out by 25 flat-panel multi-anode photomultipliers. Simulations and experiments have shown that the polarization degree and angle can be retrieved from this pattern with the accuracy necessary. POLAR can reach a minimum detectable polarization (3 level) of about 10% for several GRB measurements per year. Construction and assembly of qualification Model(QM) are onging, in view of a flight on the Chinese spacelab TG-2 expected in 2014.

8443-173, Poster Session

Test and calibration on ultraviolet imaging telescope (UVIT)

A. S. Kumar, Indian Institute of Astrophysics (India); S. K. Ghosh, Tata Institute of Fundamental Research (India); P. U. Kamath, S. Kathiravan, P. K. Mahesh, S. Nagbhushan, Indian Institute of Astrophysics (India); K. H. Navalgund, ISRO Satellite Ctr. (India); N. Raj Kumar, M. Nageshwara Rao, Indian Institute of Astrophysics (India); K. S. Sarma, ISRO Satellite Ctr. (India); S. Sriram, C. S. Stalin, S. N. Tandon, Indian Institute of Astrophysics (India); J. Postma, Univ. of Calgary (Canada)

Ultra Violet Imaging Telescope on ASTROSAT Satellite mission is a suite of Far Ultra Violet (FUV; 130 - 180 nm), Near Ultra Violet (NUV; 200 - 300 nm) and Visible band (VIS; 320-550nm) imagers. ASTROSAT is a first multi wavelength mission of INDIA. UVIT will image the selected regions of the sky simultaneously in three channels & observe young stars, galaxies, bright UV Sources. FOV in each of the 3 channels is ~ 28 arc-minute. Targeted angular resolution in the resulting UV images is better than 1.8 arc-second (better than 2.0 arc-second for the visible channel). Two identical co-aligned telescopes (T1, T2) of Ritchey-Chretien configuration (Primary mirror of ~375 mm diameter) collect the celestial radiation and feed to the detector system via a selectable filter on a filter wheel mechanism; gratings are available in the filter wheels of FUV and NUV channels for slit-less low resolution spectroscopy. The detector system for each of the 3 channels is generically identical. One telescope images in the FUV channel, and other images in NUV and VIS channels. One time open-able mechanical cover on each telescope also works as Sun-shield after deployment.

We will present the optical tests and calibrations done on the two telescopes. Results on vibrations test and thermo-vacuum tests on the engineering model will also be presented.

8443-174, Poster Session

Radiometric calibration of PHEBUS: model and results

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A smart model for radiometric calibration has been inspired by the calibration of Probing of Hermean Exosphere By Ultraviolet Spectroscopy (PHEBUS). PHEBUS is a double spectrometer for the Extreme UltraViolet (EUV) and Far UltraViolet (FUV) spectral ranges that will fly on board of the Bepi Colombo mission, whose launch is foreseen on 2014. This instrument will investigate the Mercury's exosphere allowing first observations of additional species like He, Ar, N, etc. The schedule of the calibration testing includes characterizations of optical subsystems, etendue and efficiency measurements at instrument level. From a general point of view the way to approach these activities is based on the Mueller matrix formalism: a complete characterization of optical subsystems together with measurements at the instrument level gives an exhaustive knowledge of the whole instrument. We present the model and the experimental results for the optical components of the qualified and flight model.

8443-175, Poster Session

The LEO radiation environment and the design of the MXT camera on-board the SVOM Mission

E. Perinati, C. Tenzer, A. E. Santangelo, Eberhard Karls Univ. Tübingen (Germany); D. Gotz, B. Cordier, Commissariat à l'Énergie Atomique (France); J. P. Osborne, G. W. Fraser, Univ. of Leicester (United Kingdom)

We present an analysis of the radiation environment in the LEO orbit where the SVOM mission will be flown, overall aimed at supporting the design of the MXT camera. The pn-CCD at the MXT focal plane will be cooled at -60 C, which suggests to carefully explore the potential impact of SAA crossings on the detector performances. We use MonteCarlo simulations to compare different shielding solutions (Aluminum, Copper, Kapton liner) and the related levels of particle-induced background and non-ionizing dose on the pn-CCD.

8443-176, Poster Session

Prospects for the 2013/2014 Nuclear Compton Telescope balloon campaign

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The Nuclear Compton Telescope (NCT) is a balloon-borne soft gamma-ray (0.2-10 MeV) telescope designed to perform wide-field imaging, high-resolution spectroscopy, and novel polarization analysis of astrophysical sources. NCT employs a novel Compton telescope design, utilizing 12 high spectral resolution germanium detectors, with the ability to localize photon interaction in three dimensions. NCT underwent its first science flight from Fort Sumner, NM in Spring 2009, and was partially destroyed during a second launch attempt from Alice Spring, Australia in Spring 2010. We have begun the rebuilding process and use this as an opportunity to update and optimize various aspects of NCT. The cryostat which houses the 12 germanium detectors is being redesigned so as to accommodate the detectors in a new configuration, which will increase the effective area and improve the on-axis performance as well as polarization sensitivity of NCT. We will be replacing the liquid nitrogen detector cooling system with a cryocooler system which will allow for long duration flights. Various structural changes to NCT, such as the use of an all new gondola, will affect the physical layout of the electronics and instrument subsystems. We expect to return to flight readiness by Fall 2013, at which point we will recommence science flights. We will discuss science goals for the rebuilt NCT as well as proposed flight campaigns.

8443-177, Poster Session

The x-ray advanced concepts testbed (XACT) sounding rocket payload

K. C. Gendreau, Z. Arzoumanian, P. V. Deines-Jones, K. M. Jahoda, R. G. Koenecke, J. K. Black, Y. Soong, T. Okajima, L. G. Olsen, P. J. Serlemitsos, D. J. Hahne, S. J. Kenyon, F. G. Huegel, R. G. Baker, K. J. Gregory, K. D. Rush, F. S. Porter, NASA Goddard Space Flight Ctr. (United States); P. E. Kaaret, The Univ. of Iowa (United States)

The scientific objective of the X-ray Advanced Concepts Testbed (XACT) sounding-rocket payload is to measure the X-ray polarization properties of the Crab Nebula, the Crab pulsar, and the accreting binary Her X-1. Polarimetry is a powerful tool for astrophysical investigation that has yet to be exploited in the X-ray band, where it promises unique insights into neutron stars, black holes, and other extreme-physics environments. With powerful new enabling technologies, XACT will demonstrate X-ray polarimetry as a practical and flight-ready astronomical technique. The technologies XACT will bring to flight readiness will also provide important new capabilities for NASA missions in space-based X-ray spectroscopy, timing, and photometry.

8443-180, Poster Session

In-flight calibrations of UVIT on AstroSat

S. K. Ghosh, Tata Institute of Fundamental Research (India); J. B. Hutchings, National Research Council Canada (Canada); V. Girish, ISRO Satellite Ctr. (India); A. S. Kumar, N. S, Indian Institute of Astrophysics (India); J. Postma, Univ. of Calgary (Canada); S. Kasiviswanathan, Indian Space Research Organisation (India); S. S, A. Subramaniam, F. K. Sutaria, C. S. Stalin, S. N. Tandon, Indian Institute of Astrophysics (India)

The Ultra Violet Imaging Telescope (UVIT) on board the multi wave-band Astrosat mission consists of 3 imaging telescopes (on two optical assemblies), designed to be sensitive in the FUV (130-180 nm), NUV (200-300 nm) and Visible (VIS,320-550 nm) bands. With a $28 arcmin $ field of view, in the photon counting mode, the anticipated spatial resolution in the FUV and NUV bands is $sim 1.8 arcsec$, while that in the VIS channel is $sim 2.2 arcsec$. In the small frame ($ 5.5 times 5.5 $ arcmin) read-out mode, a timing resolution of $2 ms$ is expected. We present in this paper, details of the in-flight UVIT calibrations planned for the performance verification stage of Astrosat mission. Briefly, photometric accuracy, spectral calibrations and the PSF variations across the FoV will be done using observations of UV-bright standard stars used by previous missions (notably GALEX), taking into account factors like spacecraft jitter, drift, and the ground based measurements of the PSF distortion induced by the optical assembly. We also map the astrometric accuracy across the FoV, obtained using observations of standard photometric fields (GALEX, HST and ground based optical observations), by incorporating both proper motion of the reference stars, as well as the results from ground-based distortion measurements of the UVIT FoV.

Finally, in order to compare the timing accuracy across instruments on AstroSat, we present simulations of pulsar profile and timing measurements for UVIT, in the case of the UV-bright Crab and Vela pulsars.

8443-181, Poster Session

A study for Compton polarimetry with NuSTAR

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Observations in the hard X-ray band are often essential for characterizing high energy sources, since the radiation originates very close to the object.

Relying only on light curves and spectral information, often implies that several theoretical models can explain the observed data, and therefore it is mandatory to exploit further information to distinguish between possible interpretations. In this picture polarization offers a powerful tool to study those sources that are characterized by the presence of strong magnetic fields.

We estimate through Monte Carlo simulations the capabilities of the Nustar focal plane detector to measure polarization of cosmic sources in the 55-80 keV energy band and the multiple events background expected on the detector in its LEO orbit. The method used is based on the analysis of multiple events in the Nustar CdZnTe detector. Several possible options are explored including the possibility of a dedicated readout mode.

The simulations are obtained by Geant4, reproducing the detector and the satellite structures in high detail and taking into account possibly degrading effects like charge sharing. The aim of the study is to estimate the Minimum Detectable Polarization according to Nustar specifics and to establish a set of sources feasible for polarimetric observations.

8443-183, Poster Session

Ground calibration results for the NuSTAR hard x-ray optics

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NuSTAR is a hard X-ray satellite experiment launched in the Spring of

2012. Two optics, which are extended 10 m from the spacecraft after launch by a deployable mast, focus hard X-rays (5-80 keV) onto CdZnTe detectors. Each conic-approximation, Wolter-I optic is comprised of 133 layers of segmented glass mirrors with depth-graded multilayers coatings to provide broadband reflectivity. The FM1 and FM2 flight optics were built at the same time using similar components, and thus have very similar performance. The ground calibration involves building up an Optics Response Model (ORM) based on a raytrace simulation using measured data from the optics components and witness samples collected throughout the fabrication process. Detailed sets of X-ray measurements for each optic as well as hundreds of multilayer witness samples were acquired at Columbia's Rainwater Memorial Calibration Facility (RaMCaF). We summarize the ground calibration data that was used to build and verify the ORM and present the resulting calibrated model of the PSF and effective area of each optic over the entire detector field of view.

8443-184, Poster Session

The making of the low energy ground calibration of NuSTAR optics

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The Nuclear Spectroscopic Telescope Array (NuSTAR) is a hard X-ray satellite slated to launch in the Spring of 2012. The payload consists of two co-aligned hard X-ray telescopes (5-80 keV), the optics being held 10 m apart from the CdZnTe detectors by a deployable mast. The ground calibration of these optics was done at the Rainwater Memorial Calibration Facility (RaMCaF), where a dedicated 160 m long beamline was constructed. We report here on the steps involved in processing and understanding the calibration data acquired with the two main detectors, a Si drift detector and a Ge detector. Emphasis is on the low energy part of this calibration. We describe how a model of the incident beam was created and how data from the environmental probes and the beam monitor were used to derive a model for the transmission of the beamline. We also describe the development of the detector response matrices for the two main detectors and how they were used.

8443-185, Poster Session

Determination of the eROSITA mirror HEW with subpixel resolution

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The Point Spread Function (PSF) of the eROSITA miror modules is specified to have an on-axis Half Energy Width (HEW) of 15 arcsec. This is only slightly larger than the eROSITA pixel size of 75 microns, which corresponds to 9.6 arcsec at the PANTER test facility, where the PSF is being measured with a prototype of the eROSITA CCD. We have developed a fast algorithm which provides a substantially higher spatial resolution by utilizing the information contained in the charge ratios of split events. By applying this algorithm to measurements where the CCD is systematically shifted in subpixel increments (typically in a 12x12 pattern), we are able to achieve an effective resolution of ~2 arcsec for specific pixel patterns. This algorithm can also be used to compute the two dimensional probability distribution for detecting a photon from an incident point-like beam, for each combination of photon energy, low energy threshold, selected pixel patterns, and subpixel scan properties. These maps allow us to deconvolve the measured PSF and thus to minimize the influence of the spatial detector resolution on the determination of the eROSITA mirror HEW. After launch, the algorithm for improving the spatial resolution by reconstructing the subpixel position will also be applied to the science data.

8443-186, Poster Session

Calibration of the eROSITA calibration source

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Due to the particle background in orbit, CCDs aboard of X-ray astronomical satellites tend to degrade in their performance, especially in the charge transfer efficiency (CTE).

The on-board Fe-55 Calibration Source of eROSITA on Spectrum-Roentgen-Gamma (SRG) will be used to monitor the CTE and the gain. It provides Mn-K_alpha (5.9 keV) and Mn-K_beta (6.4 keV) lines (accompanied by Auger electrons), but also the Al-K (1.5 keV) fluorescence line from an aluminum target.

Measurements with this Calibration Source will be used to compare the CTE with the CTE measured on ground and to modify the CTE correction if needed.

For this the CCDs shall be illuminated by these lines as homogeneous as possible and with a ratio of Al-K to Mn-K intensities close to unity.

This report summarizes campaigns to verify the spatial emission distribution and also the spectral line ratio with the eROSITA Calibration Source and with TRoPIC at PANTER as CCD camera.

The source strength shall take into account the half-life-time of Fe-55 (about 1000 d) such that at the relevant periods at the end of the mission the source is still strong enough to provide enough statistics for proper performance determination.

8443-187, Poster Session

The thermal control system of the x-ray telescope eROSITA on Spektrum-Roentgen-Gamma

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The X-ray telescope eROSITA is the main instrument besides the Russian ART-XC on the Russian Spektrum-Roentgen-Gamma mission. Starting from 2014 an all-sky survey will be performed in the range between 0.1-10 keV, followed by pointed observations. The main objective of this mission is the detection of 100000 galaxy clusters in order to constrain cosmological parameters, amongst others the density and evolution of dark energy.

Due to the minimum lifetime of seven years the thermal control system has to be completely passive without any consumables. With the ideal operational temperature of the CCD cameras being at almost -100°C, this requires a very effective heat rejection system, consisting of a complex heat pipe system, and a good thermal insulation. Simultaneously a very sensitive temperature control via variable conductance heat pipes is implemented. For special outgassing reasons at the beginning of the mission these heat pipes are not working by default but can be switched on any time.

On the other hand the mirror modules have to be tempered at room

temperature and more than 200W of the electronics have to be dissipated without effecting the surrounding components or the satellite structure.

Objectives of this work are the design, manufacturing and verification of a thermal control system that is able to keep up the required temperature range and that guarantees the optimum working conditions for all parts of the instrument. Therefore a lot of calculations and verification tests have to be planned, performed and evaluated.

8443-188, Poster Session

Calibration sources for the soft x-ray spectrometer instrument on ASTRO-H

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The SXS instrument is the Soft X-ray micro-calorimeter Spectrometer planned for the Japanese ASTRO-H satellite, scheduled to be launched in 2014. In this paper we describe the X-ray calibration sources used in this instrument. These sources use light sensitive photo-cathodes to generate electrons, which in turn generate the X-rays. This design has the unique property to allow for fast discrete pulsations of the generated X-rays. This enables the energy scale calibration of the instrument simultaniously with astronomical observations, without adding to the background in the astronomical data.

Flight-model sources have been made, and a number of them have been operating in the past several months to monitor their behaviour. Here we report on the characterisation and performance of these sources.

In addition, we will elaborate on the nature and expected accuracy of the energy calibration, in relation to the expected stability of the instrument, given the calibration source strength and its mode of operation.

8443-189, Poster Session

The Astro-H metrology system

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The Hard X-ray Telescopes on Astro-H have a 12 meter focal length. In order to achieve this long focal length and still launch compactly the hard X-ray detectors are placed at the end of an extendable optical bench that will be deployed in orbit.. Once extended it is important that the detectors and focussing telescopes remain in precise alignment as the spacecraft undergoes distortions primarily due to thermal fluctuations in low-earth orbit. The Astro-H Metrology System (AMS) is a laser alignment system that will measure optical alignment deviations. The AMS is compact, consumes little power, and is stable over a wide temperature range. The system will be used to measure lateral (X/Y) displacement as well as rotational shifts in the optical bench. In addition, the AMS data can be used to enhance image quality from the hard X-ray detectors.

8443-190, Poster Session

Imaging and spectral performance of CdTe double-sided strip detectors for the hard x-ray imager onboard ASTRO-H

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We have developed CdTe double-sided strip detectors (CdTe-DSDs) for the ASTRO-H mission and other future missions. We designed and assembled the CdTe-DSDs for ASTRO-H. These CdTe-DSDs have a strip pitch of 0.25 mm, an imaging area of 3.2cm x 3.2 cm and a thickness of 0.75mm. The double-sided strip electrode configuration enables us to achieve a fine position resolution and a large detection area at the same time with a relatively small number of readout channels. Moreover, the double-sided readout provides high spectral resolution of 1.7--2.0 keV(FWHM) at 60 keV, and additional sensitivity to the interaction depth by comparing the anode signal with the cathode signal.

However, the hard X-ray and gamma-ray response of CdTe-DSD becomes complex because of the small mobility-lifetime product of holes in CdTe semiconductor. Therefore, one of the important issues for the accurate observations is to investigate the response of the CdTe-DSD.

In order to obtain information on the response corresponding to interaction positions and depths, we performed scanning experiments at a synchrotron radiation facility SPring-8. By using a 30 keV monochromic X-ray beam with a size of about 6 um, we scanned both sides of the detector along two axises, and successfully obtained the response dependence on three-dimensional irradiation position.

In this paper, we will present the imaging and spectral performance of the ASTRO-H CdTe-DSDs based on the results of scanning experiment.

8443-191, Poster Session

A Monte Carlo simulation framework to study ASTRO-H in-orbit radiation and detector responses based on Geant4 toolkit

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We are developing a Geant4-based Monte Carlo simulator of ASTRO-H satellite. This carries multiple type X-ray telescopes and detectors, of which developers have their own purpose on the simulator, and each mass model is developed by each group. To eliminate the trouble with parallel geometry development, we designed the framework to place each model in each parallel world supported by Geant4. Typical inputs and outputs of the framework are primary event and output signal lists with FITS format. The I/O designed with commonly-used data format makes the simulation development cycle faster and easier. A brief but entire satellite mass model with almost all components has been implemented, and we succeeded in carrying out end-to-end run. In addition, we implemented them as multi thread software and confirmed that the performance increases almost linearly at least up to 8 CPU cores.

8443-192, Poster Session

A ground calibration of engineering-model of SXT on ASTRO-H using the ISAS 30m pencil beam facility

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The Japanese ASTRO-H mission, planned to be launched in 2014, will carry several instruments for covering a wide energy range from a few

keV to 600 keV. Among them there are four conically approximated Wolter-I X-ray telescopes. Two of them are Soft X-ray Telescopes (SXTs) covering from a few keV to ~12 keV. Each of them focuses an image on the focal plane detectors of the CCD camera (SXI) and on the calorimeter (SXS-XCS), respectively.

In 2011, we performed a ground calibration of a quadrant engineering-model (EM) of SXT that was fabricated at NASA's Goddard Space Flight Center (GSFC). Ground calibration was made with a combination of the measurements at the GSFC and ISAS facilities. In this paper we report the results of the calibration at the ISAS 30 m pencil beam facility. We used a pencil beam at the baseline length of 30 m with a diverging angle of ~20 arcsec at FWZI. By applying a raster scan method, it is preliminary found that an effective area of the quadrant is ~147 cm2 at 1.49 keV, and ~116 cm2 at 4.51 keV, respectively. The effective area is larger than that of the Suzaku soft X-Ray Telescope (XRT) quadrants by 30-40% (~111 cm2 at 1.49 keV, and ~82 cm2 at 4.51 keV). The angular resolution was also significantly improved from that of the Suzaku XRTs.

8443-193, Poster Session

Calibration of x-ray reflectivity around gold M absorption edge of x-ray mirror for soft x-ray telescope onboard the ASTRO-H Satellite

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X-ray reflection mirror of the Soft X-ray Telescope onboard ASTRO-H was coated by gold thin layer.

Gold have M-shell X-ray absorption edge around 2 keV which is included in the energy band covered with the focal plane detector such as Soft X-ray Imager and Soft X-ray Spectrometer.

It is important to make response matrices taken int account the Au M-dege structure especially for the Soft X-ray Spectrometer because It has unprecedented high energy resolution of 5 eV from 0.3 to 12 keV.

We performed the detailed measurements of of reflectivity of the mirror using reflectometer in the synchrotron radiation facility KEK PF BL-11B from Nov. 29, 2011 to Dec. 5.

X-ray beam of BL-11B was monochromatized to E/deltaE of 5000 by Double crystal monochromator using Si(111).

We obtained the reflectivity at the grazing incident angles of 1.0, 1.2, and 1.4 degrees.

While the energy pitch was set to be 2 eV in the 2.1-4.1 keV band, the reflectivity in the 2.2-2.35 keV band was measured in detail with the energy pitch of 0.25 eV.

We report the results and optical parameters of the SXT mirror such as reflectivity, optical constant and roughness calculated from the measurements.

8443-194, Poster Session

A thermal stress test of the depth-graded Pt/C reflectors used in the ASTRO-H Hard X-ray Telescope (HXT)

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The ASTRO-H Hard X-ray Telescope (HXT) to cover hard X-rays up to 80 keV is thin-foil, multi-nested conical optics with depth-graded Pt/C multilayer. The reflectors are made of heat-formed aluminum substrate of the thickness gauged of 200 μm of the alloy 5052, followed by epoxy replication on Pt/C-sputtered smooth Pyrex cylindrical mandrels to acquire the X-ray reflective surface. The epoxy layer is ~20 μm depth. In this paper, we report a thermal stress test of the reflectors of the HXT. The reflectors can experience in various temperature environment either in ground or in space. The temperature range can be as wide as several tens degrees in space dependently on the thermal design of the telescope system.

We kept the reflectors in the three different temperatures at -5, 50 and 60 degrees, respectively, for a week. It is found that the surface of the reflectors at 60 degrees were significantly changed. The change appears as a wrinkle with a typical scale length of a few tens micron meters. It is noticed that the scale length is equivalent to the depth of the epoxy layer, suggesting the existence of the epoxy layer causes the change at the 60 degrees. No changes on the surface were observed from the -5 and 50 degree samples. No change on X-ray reflectivity was also detected from them.

8443-195, Poster Session

Vibration properties of mirror foils for Hard X-ray Telescope on-board satellite

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ASTRO-H is the next version of Japanese X-ray astronomy satellite which is planned for launch by the Japanese rocket H -A in 2014. The aim of this work is to investigate vibration properties of mirror foils of the Hard X-ray telescope (HXT) by conducting vibration test and FEM analyses. The HXT on board the satellite has a cylindrical case which contains mirror foils. Since only several points of the mirror edges are constrained by friction forces between the foil and alignment bars, it is expected that the foil has nonlinear vibration characteristics. From the results of out-of-plane vibration test applying accelerations from 2G to 10G, it appeared that the mirrors had resonant frequencies at 64, 73 and 110Hz. The modal shapes of 64 and 73Hz showed that the maximum amplitude appeared at side edges of the foil. On the other hand, vibration amplitude became maximum at the center in the modal shape of 110Hz. These modal shapes had good agreement with predicted shapes by the FEM analysis. Experimental results of frequency responses of foils agreed well with analytical results except around 64Hz. From the analysis, the 1st mode appeared in the experiment cannot be obtained. It is considered that the resonant mode of 64Hz was strongly affected by circumferential friction forces at the weak constraint points. Improvement of the model is necessary for more precise prediction of vibration characteristics of the foil and the model will be applicable for designing new foils of a HXT in future.

8443-196, Poster Session

The pre-collimator shielding stray lights for the ASTRO-H x-ray telescopes

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We report the recent progress of the pre-collimator (PC) for the stray-light protection of the X-ray telescopes onboard ASTRO-H. The pre-collimator consists of the cylindrical aluminum shells with a radius of 60-225mm, called blades, the alignment frames to support these blades, and the housing. The blades are placed coaxially onto the respective reflector shells to block the off-axis X-rays that create a ghost image within the detector field of view. Since the PC design (the height, thickness, and material of the blades) had been fixed, we started to produce the engineering model (EM) for the Soft X-ray Telescopes (SXTs) in September 2010. The stand-alone vibration test for the EM PC was carried out twice, and then we verified that the PC has sufficient structural strength to withstand the launch environment. The EM PC was then installed onto the mirror housing fabricated at NASA/GSFC to examine the assembly method of the PC without any loss of the effective area. Since August 2011, we have made the blades for the flight model. The heat-forming process is introduced into the blade production to stabilize the blade shape in the orbit. The precise curvature radius (fluctuation within 1mm) and the linearity of the generated line (P.V. < 20um) ensure that the blades do not cover the telescope aperture. We also show the result of the stray-light measurement for the EM SXT at the ISAS 30m beamline facility and discuss the expected PC performance of the stray-light elimination.

8443-197, Poster Session

Recent results of hard x-ray characterization of ASTRO-H HXT at SPring-8

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ASTRO-H is Japan's sixth X-ray satellite mission following to Suzaku satellite. It is planned to be launched in 2014. One of the features of ASTRO-H is a simultaneous observation between 0.3 keV to 600 keV with four sicence instruments.

HXT (Hard X-ray Telescope) which is one of the key instruments in ASTRO-H is thin-foil, multi-nested conical optics as well as Suzaku XRT. Reflector surfaces are coated with depth-graded Platinum and Carbon (Pt/C) multilayer to reflect hard X-rays efficiently.

The mass production of the reflectors for flight model has been going on since August 2010. Currently, we have fabricated 1700 reflectors for HXT-1 FM.

The selected 418 pairs of multilayer mirrors which consist of three segments (167 pairs at Seg. 1, 137 pairs at Seg. 2, and 114 pairs at Seg. 3) have been characterized at a large synchrotron radiation facility, SPring-8 bemline BL20B2. In segment 1, number of total reflector pairs constitutes 80 % of fully packing (213 pairs) in one segment. We have adopted, newly, an active tuning procedure with piezoelectric actuator to improve the off-roundness of focused image. We have measured PSF and effective area at 30, 40, 50, and 60 keV. We have obtained an angular resolution of 1.9 arcmin (HPD) in segment 1 at 30 keV. Also we have measured stray lights from 12 arcmin off-axis angle at 30 and 60 keV.

We present recent results of hard X-ray characterization of HXT at SPring-8.

8443-198, Poster Session

Development of the onboard digital processing system for the soft x-ray spectrometer of ASTRO-H: performace in the engineering model tests

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We present the development status of the Pulse Shape Processor (PSP), which is the on-board digital electronics responsible for the signal processing of the X-ray micro-calorimeter spectrometer instrument (the Soft X-ray Spectrometer; SXS) for the ASTRO-H satellite planned to be launched in 2014. We finished the design and fabrication for the engineering model, and are currently undertaking its performance verification and environmental tests. In this report, we summarize the results obtained in the integration test using the SXS engineering model, which is the first end-to-end test of the instrument with a full signal processing and cooling chain setup.

8443-200, Poster Session

Development and characterization of coatings on silicon pore optics substrates for the ATHENA Mission

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Coatings of Cr/Ir/B4C trilayers and linear graded multilayers from Pt/B4C, W/B4C and W/Si were carried out on silicon pore optic substrates using DC magnetron sputtering. In-depth characterization of the coatings were carried out by measuring using AFM, TEM, stress measurements, X-ray reflectometry and X-ray scattering as well as environmental tests. The tests give a complete picture of reflectivity performance as well as scattering and long-term durability of the coatings.

8443-201, Poster Session

Functional tests of modular elements of segmented optics for x-ray telescopes via an expanded beam facility

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Future large X-ray observatories like ATHENA will be equipped with very large optics obtained by assembling modular optical elements based on the silicon pores or the slumped glass technology. The final quality of the modular optic is determined by the accuracy in the alignment of the

assembly, but also by the compliance of the focusing elements to the nominal shape and the roughness tolerance in order to avoid excessive levels of X-ray scattering. As a very large number of Silicon or glass ribbed stacks have to be manufactured, quality tests need to be routinely performed to assess the technology readiness, and, in a later phase, to select the most performing stacked blocks to be integrated into the final optic. Besides the usual metrology based on profile and roughness measurements, a direct, at-wavelength, focusing measurement in X-rays would be the most reliable test. Synchrotron light beams are in general not sufficiently broad to cover the aperture of a block without scanning it, which requires a focal spot reconstruction. In this paper we describe the project of a small X-ray facility to be realized at INAF/ OAB, devoted to the functional tests of the focusing elements. The facility would produce a wide, parallel and homogeneous beam of X-rays to illuminate the entire aperture of the focusing elements, which would be directly recorded by an X-ray camera at the correct focal distance from the mirrors. The tests are to be performed at 1-2 keV, therefore operating in vacuum is mandatory, and the size of the manipulation chamber to be evacuated has to be as small as possible to characterize a large number of samples in a short time, while the distance to the camera and the beam expander can be permanently kept in vacuum. We show preliminary studies based on grazing incidence parabolic mirror with the source in focus, and a beam expander based on the asymmetric reflection of X-rays onto a crystal as previously done at the Daresbury synchrotron for the SODART calibration.

8443-202, Poster Session

The cryogenic anticoincidence detector for ATHENA-XMS: overview of the baseline detector

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ATHENA is the re-scoped IXO mission, and one of its focal plane instrument is the X-ray Microcalorimeter Spectrometer (XMS) working in the energy range 0.3-10 keV, which is a kilo-pixel array based on TES (Transition Edge Sensor) detectors.

The necessity of a AC detector is legitimated by the results performed with GEANT4 simulations about the impact of the non x-ray background onto XMS. Such results highlight that the residual particle background can be decreased down to the permitted maximum level (0.02 cts/cm^2/s/keV) only if an AC detector is used: the lower the distance to XMS (~ 1 mm), the lower the unrejected background. This is the reason why a cryogenic detector is needed.

This CryoAC it is a TES based detector, as the main array, sharing with it thermal, electrical and mechanical interfaces, so increasing the TRL (Technology Readiness Level) of the main instrument. This choice shows that it is possible to operate such a detector in the so-called athermal regime which gives fast response (~ 1 us), and low energy threshold (above few keV).

Our consortium has both developed and tested several samples, with increasing area, due to the large area of the XMS (64 mm^2).

Here we show the baseline choice, featured by 4 pixel detectors, based on Ir:Au bi-layer TES deposited on Si absorber.

Thermal model of the detector, electrical characterization of the TES and test of the CryoAC single pixel detector will be discussed.

8443-203, Poster Session

Background estimates and reduction for ATHENA-XMS via Monte Carlo simulations

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This paper aims both to estimate the background to be expected on the X-ray Microcalorimeter Spectrometer (XMS) onboard of ATHENA (Advanced Telescope for High ENergy Astrophysics) using Geant4 Montecarlo simulations, and to illustrate several solution to minimize its impacts on the XMS performances.

No X-ray missions were flown to L2 up till now, where ATHENA will be placed, so we use the Geant4 toolkit to simulate the impact of L2 particles with galactic and solar origin on a detailed model of ATHENA, and the background that they induce on the focal plane detector.

We investigate also the rejection efficiency of the anticoincidence system, the ways to improve it, and the impact of residual background on the detector performances. The unrejected background is characterized in terms of energy distribution, composition, and geometrical origin.

8443-204, Poster Session

An x-ray microcalorimeter array design for ATHENA

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We have been developing large-format arrays of microcalorimeters to enable high-resolution X-ray imaging spectrometers for future X-ray observatories. We have adapted our designs to meet the performance requirements of the X-ray Microcalorimeter Spectrometer (XMS) proposed for the ESA mission called Athena. This mission requires a close-packed 32x32-pixel array on a 250-micron pitch with 3.0 eV energy resolution (at 6 keV). Here we present device characterization of our 32x32 arrays which incorporate microstrip wiring, including uniformity of performance, sensitivities to environmental conditions, and thermal management to minimize thermal cross-talk effects. We will describe our latest results in reading out these arrays using both time-domain and code-division multiplexing, and our strategy to use these technologies to design the XMS instrument for Athena with optimal performance and engineering margin.

8443-205, Poster Session

Background simulations for the wide field imager aboard the ATHENA X-ray Observatory

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The Advanced Telescope for High ENergy Astrophysics - ATHENA is a planned multinational X-ray observatory with a focal length of 12 m aiming to perform high sensitivity observations in the energy range from

0.1 - 15 keV. The main detector for high timing and spatial resolution imaging spectroscopy will be the 640x640 pixel² DePFET-based Wide Field Imager which provides a field of view of 24 arcmin. Based upon the WFI's mechanical, thermal and shielding design we present detailed estimates and reduction measures for the detector's cosmic ray induced background obtained from the use of Monte-Carlo simulations.

8443-206, Poster Session

Development of fast data processing electronics for a combined detector system

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ATHENA (Advanced Telescope for High ENergy Astrophysics) is a future X-ray space mission, consisting of two telescopes: one is equipped with a micro calorimeter spectrometer (XMS) and the other with a Wide Field Imager camera (WFI). The WFI is made of a Si-based active pixel matrix that provides high count-rate capabilities with a near Fano-limited energy resolution.

Based on similar projects like SIMBOL-X and IXO, which are using the same type of detector, we have assembled a Science Verification Model (SVM) at the IAAT that can be operated under laboratory conditions that approximate the expected environment in space.

The SVM consists of a 64x64 DePFET-Matrix in front of a CdTe-Caliste module. The detectors were developed at the MPI Semiconductor Laboratory in Neuperlach and the CEA in Saclay, respectively. In this combined structure the DePFET detector works as Low Energy Detector (LED) while the Caliste module (HED) only detects the high energetic photons that have passed the LED.

We use the SVM to test and optimize the performance of the LED operation and data acquisition chain, consisting of an ADC, an event-preprocessor, a sequencer, and an interface controller.

All these components have been developed at our institute with the objective to handle the large amount of data that is created by the high readout rate of approximately 8000 frames per second.

Even though ATHENA is not using a combination of a low and a high energy detector, we are still working on the integration of LED and HED to a combined detector system because a broad sensitivity will be desirable for many future X-ray missions. We report on the development status of the SVM and its associated electronics.

8443-213, Poster Session

ATHENA optimized coating design

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The optimization of the coating design of the ATHENA Mission aims to increase the telescopes on and off-axis effective area in the energy range between 0.1 and 10 keV.

We present the performance of several material combinations, such as W/Si, Ir/B_{4}C, W/B_{4}C, Pt/B_{4}C, Pt/C and Mo/Si, considering simple bi/tri-layers, simple multilayers and linear graded multilayers. To reduce stress in the Ir/B_{4}C coating, we investigated the need of a third stress reducing material as an undercoat to the Ir/B_{4}C bi-layer.

We simulate the mirror performance for the optimized coating design, including on/off-axis effective area curves, and compare those to the mirror performance assuming ATHENA actual coating baseline.

We investigate the effect on the effective area at energies beyond 15 keV by including an additional hard X-ray telescope in the innermost region of ATHENA aperture (0.05 - 0.145 m).

Furthermore, a linear-graded multilayer for the innermost mirror module rows is considered to optimize the throughput for energies between 10 keV and 15 keV.

8443-207, Poster Session

The on-board data handling concept for the LOFT large area detector

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The Large Observatory for X-ray Timing (LOFT) is one of the four candidate ESA M3 missions considered for launch in 2020-2022. It is specifically designed to perform fast X-ray timing and probe the status of the matter near black holes and neutron stars. The LOFT scientific payload is composed of a Large Area Detector and a Wide Field Monitor.

The LAD is a 10m2-class pointed instrument with high spectral (260 eV at 6 keV) and timing (< 10 us) resolution over the 2-50 keV range. It is designed to observe persistent and transient X-ray sources with a very large dynamic range from a few mCrab up to an intensity of 15 Crab.

An unprecedentedly large throughput (~280.000 cts/s from the Crab) is achieved with a segmented detector, making pile-up and dead-time, often worrying or limiting focused experiments (e.g., IXO HTRS), secondary issues.

We present the on-board data handling concept that follows the highly segmented and hierarchical structure of the instrument from the front-end electronics to the on-board software. The system features customizable observation modes ranging from event-by-event data for sources below 0.5 Crab to light curves in several energy bands for the brightest sources. On-board lossless data compression will be applied before transmitting the data to ground.

8443-208, Poster Session

Calibration strategies for the LAD instrument on-board LOFT

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The Scientific objectives of the LOFT mission, e.g., the study of the Neutron Star equation of state and of the Strong Gravity, require accurate energy, time and flux calibration for the 500 thousand channels of the SDD detectors, as well as the knowledge of the detector dead-time and of the detector response with respect to the incident angle of the photons.

We report here the evaluations made to asses the calibration issues for the LAD instrument.

The strategies for both ground and on-board calibrations, including astrophysical observations, show that the goals are achievable within the current technologies.

8443-209, Poster Session

The LOFT (Large Observatory for X-ray Timing) background simulations

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The Large Observatory For X-ray Timing (LOFT) is an innovative medium-class mission selected for an assessment phase in the framework the ESA M3 Cosmic Vision call.

LOFT is intended to answer fundamental questions about the behaviour of matter in the very strong gravitational and magnetic fields around compact objects. With an effective area of 10 square meters, LOFT will be able to measure very fast variability in the X-ray flux and spectra. A good knowledge of the in-orbit background environment is essential to assess the scientific performance of the mission and optimize the instrument design. The two main contributions to the background are cosmic diffuse X-rays and high energy cosmic rays, with a significant contribution also from the Earth albedo.

These contributions to the background for both the Large Area Detector and the Wide Field Monitor will be discussed based on extensive Geant-4 simulations of a simplified LOFT mass model.

8443-210, Poster Session

Simulations of the x-ray imaging capabilities of the silicon drift detectors (SDD) for the LOFT wide-field monitor

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The Large Observatory For X-ray Timing (LOFT), selected by ESA as one of the four Cosmic Vision M3 candidate missions to undergo an assessment phase, will revolutionize the study of compact objects in our galaxy and of the brightest supermassive black holes in active galactic nuclei.

The main instrument on-board LOFT is the Large Area Detector (LAD), devoted to high-time-resolution X-ray observations of collapsed objects with an unprecedented effective area of 10 m2. The scientific payload is completed by a coded-mask Wide Field Monitor, in charge of monitoring a large fraction of the sky potentially accessible to LAD, to provide the history and context for the sources observed by LAD and trigger its observations on their most interesting and extreme states.

In this paper we present detailed simulations of the imaging capabilities of the Silicon Drift Detectors developed for the LOFT Wide Field Monitor detection plane. The simulations explore a large parameter space as regards both the detector design and the environmental conditions, allowing us to choose the optimal detector characteristics and demonstrating that the SDDs can achieve excellent X-ray imaging performance.

8443-211, Poster Session

The LOFT WFM simulator

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The Wide Field Monitor aboard the scientific payload of LOFT is designed to cover a large FoV in the same energy range of the Large Area Detector(almost 50% of the LAD accessible sky in the energy range 2-50 keV), in order to trigger follow-up observations with the LAD for the most interesting sources. Moreover, its design would allow for detection of transient events with flux down to a few mCrab per day, for which good spectral and timing resolution would be also available. In order to investigate alternative WFM configurations able to satisfy these scientific requirements, an end-to-end WFM simulator has been developed.

It is able to perform the following steps a) simulate simultaneously the sources present in the FoV (as expected from an X-ray catalog) for a given pointing b) analyse the photon transmission through the mask (accounting for transparency and vignetting) c) provide the photon position and energy reconstruction on the detector surface (by applying detailed algorithms for the charge cloud reconstruction in Silicon Drift Detector). We will discuss the WFM simulator architecture, the input derived from the simulations to the main parameters of its configuration which affect the sensitivity and the sky coverage, such as the mask open fraction, mask pattern and geometry, etc. and finally the derived WFM response.

8443-212, Poster Session

Pseudo-random coded masks for real-time spaceborne applications

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Coded mask telescopes have been widely used in the past (e.g. Swif/BAT, INTEGRAL/IBIS, SAX/WFCs) for the monitoring of large regions of the sky, providing real-time alerts for astronomical transients, like e.g. Gamma-Ray Bursts. Due to the limited computing power available on board space borne instruments, the detector image deconvolution process - that is required in order to obtain sky images, and hence to localize sources - is limited either to coarsely sampled sky images or to small regions of the sky.

In the framework of the assessment phase study on the Wide Field Monitor on board the ESA Loft mission, we present a study where we investigate different square pixels pseudo-random mask designs. The goal is to design a mask that is mechanically self-sustaining, and that permits a sufficiently rapid on board source localization. At the same time we evaluate the impact of this design on the sensitivity and localization capabilities of the telescope, in real-time on board, as well as with full computing power on the ground.

8443-79, Session 17

Athena: the advanced telescope for high energy astrophysics

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Athena (the advanced telescope for high energy astrophysics) is a next generation X-ray observatory currently under study by ESA for a launch in 2022. The heart of the mission is the X-ray telescope system which uses the innovative Silicon Pore Optics technology to deliver extremely light weight, high throughput optics while retaining excellent angular resolution. Two co-aligned telescopes will feed two focal-plane instruments. The X-ray Microcalorimeter Spectrometer (XMS), provides spatially-resolved, high resolution spectroscopy. The Wide Field Imager provides broad-band imaging and spectra over a large field of view, as well as high time resolution and count rate tolerance. Armed with this array of new capabilities, Athena will be used to map out the innermost flows around black holes, measure the energy flows giving rise to cosmic feedback, trace the growth of black holes over cosmic time, and measure the physical properties and evolution of the hot baryonic component of the Universe.

8443-80, Session 17

Status of the ESA L1 mission candidate ATHENA

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ATHENA (Advanced telescope for High Energy Astrophysics) is the result of the IXO reformulation activities and is one of the three candidates competing for the next large-class mission (L1) in ESA's Cosmic Vision programme, with a launch planned by 2022. ATHENA is an ESA-led project and is conceived as the next generation X-ray observatory. It is meant to address fundamental questions about accretion around black-holes, reveal the physics underpinning cosmic feedback, trace the large scale structure of baryons in galaxy clusters and the cosmic web as well as a large number of astrophysics and fundamental physics phenomena. ATHENA is designed as a facility class mission and would operate for a nominal mission duration of 5 years from a large halo orbit around the second Lagrangian point (L2). The observatory is based on two identical X-ray mirrors, each illuminating a fixed focal plane instrument and with an angular resolution better than 10 arcsec (HEW at 6 keV). The total observatory effective area exceeds 1 m2 at 1 keV and 0.5 m2 at 6 keV. The observatory carries two instruments: a Wide Field Imager, with a semiconductor based detector for high spatial resolution imaging and medium energy resolution spectroscopy, and the X-ray Micro-calorimeter Spectrometer, with a cryogenic detector for imaging and high energy resolution spectroscopy. ATHENA is currently in assessment phase; a decision on the L1 mission moving into definition phase is expected in Q2/2012. This paper summarise the results of the reformulation activities conducted during 2011.

8443-81, Session 17

Silicon pore optics developments and status

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Silicon Pore Optics (SPO) is a lightweight high performance X-ray optics technology being developed in Europe, driven by applications in observatory class high energy astrophysics missions. The ESA science mission candidate ATHENA uses the SPO technology for its two telescopes, in order to provide an effective area exceeding 1 m2 at 1 keV, and 0.5 m2 at 6 keV, featuring an angular resolution of 10” or better.

This paper will report on the developments activities led by ESA, and the status of the SPO technology. The technology development programme and its programmatic context will be addressed, describing the activity streams: environmental compatibility, industrial production and optical performance. In addition, the progress with the X-ray test facilities and associated beamlines will be reported.

8443-82, Session 17

Reference payload of the ESA L1 Mission candidate ATHENA

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The Advanced Telescope for High ENergy Astrophysics (ATHENA) is one of the three candidates competing for the next large-class mission (L1) in ESA's Cosmic Vision programme, with a launch planned by 2022 and is the result of the IXO reformulation activities. ATHENA is an ESA-led project and is conceived as the next generation X-ray observatory. It is meant to address fundamental questions about accretion around black-holes, reveal the physics underpinning cosmic feedback, trace the large scale structure of baryons in galaxy clusters and the cosmic as well as a large number of astrophysics and fundamental physics phenomena. The observatory consists of two identical mirrors each illuminating a fixed focal plane instrument, providing collectively 1 m2 effective area at 1 keV. The reference payload consists of a medium resolution wide field imager (WFI) and a high resolution X-ray micro-calorimeter spectrometer (XMS). The WFI is based on a monolithic Si DepFET array providing imaging over a 24 x 24 arcmin2 field of view and a good PSF oversampling. The sensor will measure X-rays in the range 0.1-15keV and provides near Fano limited energy resolution (150eV at 6keV). The XMS is based on a micro-calorimeter array operating at its transition temperature of ~100mK and provides <3eV resolution. The detector array consists of 32 x 32 pixels covering a 2.3 x 2.3 arcmin2 field of view, co-aligned with the WFI. This paper summarizes the results of the reformulation exercise and provides details on the payload complement and its accommodation on the spacecraft.

8443-83, Session 17

The x-ray microcalorimeter spectrometer onboard of Athena

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The Advanced Telescope for High Energy Astrophysics (ATHENA) is the next major X-ray observatory under study by ESA and includes two instruments: the Wide Field Imager and the X-ray Microcalorimeter Spectrometer (XMS). The XMS is an imaging instrument which with excellent spectral resolution at each point of the image. It is based on X-ray calorimeters with metallic absorbers and uses Transition Edge Sensor thermometers and SQUID readout with time domain multiplexing. With an array of 32 x 32 detector pixels we will be able to combine the good angular resolution of ATHENA (10 arcsec) with an excellent spectral resolution (3 eV) over a 2.3 arcmin x 2.3 arcmin field of view. An anti-coincidence detector is required to suppress the particle-induced background. Due to the large collecting area of the optics, the XMS instrument must be capable of processing high counting rates (10 mCrab) while maintaining the spectral resolution with low deadtime. For the cooling of the instrument down to 50 mK we will employ a combination of Stirling coolers, Joule Thompson coolers and a 3 stage Adiabatic Demagnetization Refrigerator.

In this paper we will summarize the driving scientific requirements and describe how these relate to the instrument design. In addition we will describe the instrument implementation and the status of the technology.

8443-84, Session 17

The wide field imager of the advanced telescope for high energy astrophysics

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ATHENA is an X-ray observatory proposed to ESA as L-class mission in the Cosmic Vision programme. It will use two X-ray telescopes based on silicon pore optics to focus radiation onto its instruments. The instrument suite will comprise a micro-calorimeter and a Silicon-based wide-field imager, each in a fixed position behind one of the telescopes.

The ATHENA Wide Field Imager (WFI) is based on a monolithic wafer-scale pixel matrix and will provide imaging with a 24 arcmin FoV in the 0.1-15 keV range. The DEpleted P-channel Field-Effect Transistors (DEPFET) forming the individual pixels are devices combining the functionalities of both detector and amplifier: Signal electrons are collected in a potential well below the transistor's gate, modulating the transistor current. The signal charge in a DEPFET pixel does not need to be shifted across macroscopic distances in order to be read out, allowing great flexibility in read-out.

In principle, each DEPFET can be read out individually at any time. In WFI, a row-wise read-out scheme is chosen in which one (or several) rows per hemisphere are read out simultaneously, while all other pixels integrate signal. The flexibility of DEPFETs allows read-out of multiple rows in parallel, as well as window modes in which a small window is repeatedly read out while the rest of the full frame is not disturbed during integration. This allows to combine the imaging capabilities of a wide field imager with the fast timing capabilities of a dedicated high-time-resolution instrument.

8443-85, Session 18

LOFT: the Large Observatory For x-ray Timing

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The LOFT mission concept is one of the 4 candidates selected by ESA in 2011 for the third launch opportunity (M3) as Medium Size mission of the Cosmic Vision programme. The launch window is currently planned between 2020 and 2022. LOFT is designed to exploit the diagnostics of very rapid X-ray flux and spectral variability that directly probe the motion of matter down to distances very close to black holes and neutron stars, as well as the physical state of ultradense matter. These prime science goals will be addressed by a payload composed of a Large Area Detector (LAD) and a Wide Field Monitor (WFM). The LAD is a collimated (<1 degree field of view) experiment operating in the energy range 2-50 keV, with a 10 m2 peak effective area and an energy resolution of 260 eV at 6 keV. The WFM will operate in the same energy range as the LAD, enabling a simultaneous monitoring of a few-steradian wide field of view, with an angular resolution of <5 arcmin. The LAD and WFM experiments will allow to investigate variability from submillisecond QPO's to years long transient outbursts. In this paper we will report the current status of the project.

8443-86, Session 18

Status of the assessment phase of the ESA M3 mission candidate LOFT

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LOFT (Large Observatory For X-ray Timing) is one of the four candidate missions selected for the next medium-class mission (M3) in ESA's Cosmic Vision programme, with a launch planned in the period 2020-22. LOFT is intended to answer fundamental questions about the motion of matter orbiting close to the event horizon of a black hole, and the state of matter in neutron stars, by detecting their very rapid X-ray flux and spectral variability. LOFT will operate for a nominal mission duration of 4 years from a low-background equatorial LEO (600 km altitude), and will carry two instruments: a Large Area Detector (LAD) with an effective area (around 10 m2) far larger than current spaceborne X-ray detectors, and a Wide Field Monitor (WFM) that would monitor a large portion of the sky. LOFT is currently in the assessment phase, which was started with an internal study conducted by ESA's Concurrent Design Facility (CDF). Two phase-A, 12-month parallel industrial studies will be kicked-off in February 2012, with the objective of defining a baseline mission that would satisfy all scientific requirements while remaining compatible with the M-class mission programmatic boundary conditions. Some of the main trade-offs at system level that are under assessment include: the selection of the launcher, the configuration of the spacecraft and the LAD, and the power and thermal constraints that limit the pointing of the instruments. This paper will summarise the intermediate results of the assessment studies.

8443-87, Session 18

A large area detector proposed for LOFT: the large observatory for x-ray timing

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LOFT (Large Observatory for X-ray Timing) is one of the four candidate ESA M3 missions considered for launch in 2020-2022. It is specifically designed to perform fast X-ray timing and probe the status of the matter near black holes and neutron stars. The LOFT scientific payload is composed of a Large Area Detector and a Wide Field Monitor. The LAD is a 10m2-class pointed instrument with 20 times the collecting area of the best past timing missions (as RXTE) over the 2-50keV range, which holds the capability to revolutionise studies of X-ray variability down to the millisecond time scales.

Its ground-breaking characteristic is a mass per unit surface in the range of ~10 kg/m2, enabling an effective area of ~10 m2 (@10 keV) at a reasonable weight. The development of such large but light experiment, with low mass and power per unit area, is now made possible by the recent advancements in the field of large-area silicon detectors - able to time tag a X-ray photon with an accuracy <10 micros and an energy resolution of ~260 eV at 6keV - and capillary-plate X-ray collimators. In this respect, the key properties of the Si drift detectors are their capability to read-out a large photon collecting area with a small set of low-capacitance (low-noise) anodes and their very small weight.

In this talk, we will summarize the characteristics of the LAD instrument and give an overview of the expectations for its capabilities.

8443-88, Session 18

The LOFT wide field monitor

S. Brandt, DTU Space (Denmark); M. Hernanz, Consejo Superior de Investigaciones Científicas (Spain)

S. Brandt & M. Hernanz on behalf of the LOFT WFM team:

The Large Observatory For X-ray Timing (LOFT), is under study for the ESA Cosmic Vision M3 mission for a potential launch in 2022. To complement the Large Area Detector instrument (LAD), LOFT will carry a Wide Field X-ray Monitor (WFM). The WFM, based on the coded mask principle, will operate in the 2-50 keV energy range. The field of view will be larger than 3 steradians, and the sensitivity will be better than 5 mCrab for a 50 ks observation.

The instrument will monitor known X-ray sources, and detect and localize with a ~1 arcmin accuracy transients for follow up with LAD.

The baseline design of the WFM instrument uses the same detector type (the Silicon Drift Detector) as the LAD, but an alternative design based on two dimensional Silicon Strip Detectors is under consideration. The latter option would provide full 2-D images, whereas the baseline employs two 1.5-D detectors two establish the 2-D positions for transient detection and monitoring of known sources.

The instrument design status at the time of the workshop and the plans for the on-board data handling will be described.

8443-89, Session 18

The silicon micro-strip detector plane for the LOFT/wide-field monitor

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The main objective of the Wide Field Monitor (WFM) on the LOFT mission is to provide unambiguous detection of the high-energy sources in a large field of view, in order to support science operations of the LOFT primary instrument, the LAD.

The monitor will also provide by itself a large number of results on the timing and spectral behavior of hundreds of galactic compact objects, AGNs and GRBs. The WFM is based on the coded aperture concept where a position sensitive detector records the shadow of a mask projected by the celestial sources. The proposed WFM detector plane, based on Double Sided micro-Strip Silicon Detectors (DSSD), will allow proper 2-dimensional recording of the projected shadows. Indeed the positioning of the photon interaction in the detector with equivalent fine resolution in both directions insures the best imaging capability compatible with the allocated budgets for this telescope on LOFT.

We will describe here the overall configuration of this 2D WFM and the design and characteristics of the DSSD detector plane including its imaging and spectral performances. We will also present a number of simulated results discussing the advantages that this configuration offers to LOFT. A DSSD-based WFM will in particular reduce significantly the source confusion experienced by the WFM in crowded regions of the sky and will in general increase the observatory science capability of the mission.

Conference 8444: Ground-based and Airborne Telescopes IV

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SPIE Astronomical Instrumentation

8444-01, Session 1

The 1.6 m off-axis new solar telescope (NST) in Big Bear

P. R. Goode, W. Cao, Big Bear Solar Observatory (United States)

The NST has been used to observe the Sun for more than three years with ever increasing capabilities. The NST is the first facility-class solar telescope built in the US in a generation, and it has an off-axis design as is planned for the 4 m Advanced Technology Solar Telescope. Lessons learned will be discussed. Current NST post-focus instrumentation includes adaptive optics (AO) feeding photometric and near-IR polarimetric sytems, as well as an imaging spectrograph. On going instrumentation projects will be sketched, including Multi-Conjugate AO, next generation (dual Fabry-Perot) visible light and near-IR polarimeters and a fully cryogenic spectrograph. Finally, images and movies illustrating the high resolution capabilities of the NST will be shown.

8444-03, Session 1

Introduction to the Chinese Giant Solar Telescope

Z. Liu, Yunnan Astronomical Observatory (China); Y. Deng, National Astronomical Observatories (China); H. Ji, Purple Mountain Observatory (China)

In order to detect the fine structures of solar magnetic field and dynamic field, an 8 meter solar telescope has been proposed by Chinese solar community. Due to the advantages of ring structure in polarization detection and thermal control, the current design of CGST (Chinese Giant Solar Telescope) is an 8 meter ring solar telescope. The spatial resolution of CGST is equivalent to an 8 meter diameter telescope, and the light-gathering power equivalent to a 5 meter full aperture telescope. The integrated simulation of optical system and imaging ability such as optical design, MCAO, active maintenance of primary mirror were carried out in this paper. Mechanical system was analyzed by finite element method too. The results of simulation and analysis showed that the current design could meet the demand of most science cases not only in infrared band but also in near infrared band and even in visible band. CGST was proposed by all solar observatories in Chinese Academy of Sciences and several overseas scientists. It is supported by CAS and NSFC (National Natural Science Foundation of China) as a long term astronomical project.

8444-04, Session 1

Large-field high-resolution mosaic movies

R. H. Hammerschlag, Utrecht Univ. (Netherlands); G. Sliepen, Institute for Solar Physics (Sweden); F. C. Bettonvil, Utrecht Univ. (Germany); A. P. Jägers, Utrecht Univ. (Netherlands)

Movies with fields of view larger than normal for high-resolution telescopes will give a better understanding of processes on the Sun, such as filament and active-region developments and their possible interactions. New active regions can influence, by their emergence, their environment to the extent of possibly serving as an igniter of the eruption of a nearby filament. A method to create a large field of view is to join several fields of view into a mosaic. Fields are imaged quickly one after another using fast telescope pointing. Such a pointing cycle was automated at the Dutch Open Telescope (DOT), a high-resolution solar telescope located on the Canary Island La Palma. The observer can draw with the computer mouse the desired total field in the guider-telescope image of the whole Sun. The guider telescope is equipped with an H-alpha filter and electronic enhancement of contrast in the image for good visibility of filaments and prominences. The number and positions of the subfields are calculated automatically and represented by an array of bright points indicating the subfield centres inside the drawn rectangle of the total field on the computer screen with the whole-sun image. When the exposures start the telescope repeats automatically the sequence of the subfields. Automatic production of flats is also programmed including defocusing and fast motion over the solar disk of the image field. It is for the first time that movies were made possible by developed automatic telescope motion from one field to the next. The mosaic movies fill the gap between whole-sun images with limited resolution of synoptic telescopes including space instruments and small-field high-cadence movies of high-resolution solar telescopes.

8444-141, Session 1

Applications of infrared techniques in solar telescopes

Y. Li, Yunnan Astronomical Observatory (China)

This paper presents the applications of infrared techniques in National Vacuum Solar Telescope(NVST) .We give a brief introduction to infrared thermography for nondestructive evaluation, especially for the mesurememt of mirror temperature gradient and the dome tempreture distribution. The results give us more reference for the Mirror Seeing and Dome Seeing improvement.

8444-05, Session 2

The Advanced Technology Solar Telescope: design and early construction

J. P. McMullin, T. R. Rimmele, S. L. Keil, M. Warner, R. P. Hubbard, E. R. Hansen, S. C. Barden, S. L. Hegwer, W. R. McBride, B. Goodrich, S. Bulau, S. Shimko, J. Ditsler, National Solar Observatory (United States)

The Advanced Technology Solar Telescope is the first large U.S. solar telescope accessible to the worldwide solar physics community to be constructed in more than 30 years. The 4-meter diameter facility will operate over a broad wavelength range (0.3 to 28 $micro$m), employing adaptive optics systems to achieve diffraction limited imaging and resolve features approximately 20 km on the Sun; the key observational parameters (collecting area, spatial resolution, spectral coverage, polarization accuracy, low scattered light) enable resolution of the theoretically-predicted, fine-scale magnetic features and their dynamics which modulate the radiative output of the Sun and drive the release of magnetic energy from the Sun's atmosphere in form of flares and coronal mass ejections.

In 2010, the ATST received a significant fraction of its funding for construction. In the subsequent two years, the project has hired staff and opened an office on Maui. A number of large industrial contracts have been placed throughout the world to complete the detailed designs and begin constructing the major telescope subsystems. These contracts have included the mirrors, polishing, optic support assemblies, telescope mount and coude rotator structures, enclosure, thermal and mechanical systems, and high-level software & control systems, as well as preliminary design review for all five facility instruments.

This paper will review the ATST goals and specifications, describe each of the major subsystems under construction, and review the contracts and and lessons learned during the contracting and early construction phases. Schedules for site construction, key factory testing of major subsystems, and integration, test and commissioning activities will also be discussed.

8444-06, Session 2

ATST enclosure final design and construction plans

G. Murga, IDOM (United States); H. K. Marshall, National Solar Observatory (United States); J. Ariño, T. E. Lorentz, IDOM (United States)

The Advanced Technology Solar Telescope (ATST) is a 4-m class solar telescope to be built at the Haleakal High Altitude Observatory Site in Maui, Hawai'i. It will be the largest solar telescope in the world, with unprecedented abilities to view details of the Sun. Using adaptive optics technology, ATST will be able to provide the sharpest views ever taken of the solar surface.

The ATST enclosure is unique in its functionality, as not only it provides protection from adverse weather conditions when not in operation, but it also positions the telescope Aperture Stop which must be accurately aligned so that the primary mirror is fully illuminated, while insolation in other telescope equipment is prevented. The proposed design is based on a multisector shutter system arrangement with an innovative crawler drive system (patent pending) assembled on two steel fabricated arch girders. These arch girders are stiffened by a secondary structure and supported on a steel fabricated base ring. The base ring rests on an azimuth mechanism composed of several driven/idling bogies. The outer shape of the enclosure is configured by the secondary structure which supports the cladding and has been selected so as to minimize the solar irradiated surface and reduce shell seeing in early morning hours when the seeing is the best.

This paper describes the work performed by AEC IDOM and AURA to define both the final design of the Enclosure and the construction plan to erect it at the Observatory Site.

8444-07, Session 2

Progress making the top end optical assembly (TEOA) for the 4-meter Advanced Technology Solar Telescope

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L-3 Integrated Optical Systems (IOS) Division (Brashear lead) has been selected by the National Solar Observatory (NSO) to make the Top End Optical Assembly (TEOA) for the 4-meter Advanced Technology Solar Telescope (ATST) to operate at Haleakala, Maui. ATST will perform to a very high optical performance level in a difficult thermal environment. The TEOA, containing the 0.65-meter silicon carbide secondary mirror and support, mirror thermal management system, mirror positioning and fast tip-tilt system, field stop with thermally managed heat dump, thermally managed Lyot stop, safety interlock and control system, and support frame, operates in the “hot spot” at the prime focus of the ATST and so presents special challenges. In this paper, we describe progress in the L-3 IOS technical approach to meeting these challenges, including silicon carbide off-axis mirror design, fabrication, and high accuracy figuring and polishing all within L-3 IOS; mirror support design; the design for stray light control; subsystems for opto-mechanical positioning and high accuracy absolute mirror orientation sensing; Lyot stop design; and thermal management of all design elements to remain close to ambient temperature despite the imposed solar irradiance load.

8444-08, Session 2

The azimuth axes mechanisms for the ATST telescope mount assembly

H. J. Kärcher, U. Weis, O. Dreyer, MT Mechatronics GmbH (Germany); P. F. Jeffers, National Solar Observatory (United States); G. Bonomi, Ingersoll Machines Tools, Inc. (United States)

The Advanced Technology Solar Telescope (ATST) will be the largest solar telescope in the world - with a 4m aperture primary mirror and a 16m diameter co-rotating laboratory located within the telescope pier.

The ATST Telescope Mount Assembly uses for the Azimuth axes mechanisms bearing and drive technologies as developed for the machine tool industry. An overview on the ATST mount project and design and its verification by analysis, simulation and tests are given in two separate papers of this conference. This paper describes the main design and accuracy features of the bearing and drive subsystems, their adaption to the ATST mount and their influence on the telescope structural design, and gives a hint to the challenges in the upcoming manufactur-ing, installation and commissioning phases.

The azimuth bearing and drive concept is completely new in telescope applications. It is based on existing “linear guide” technology used in great numbers in the machine tool industry. The linear guides are now also available in curved form, so called R-guides. Their great advantage - seen from the systems point of view - is that they are now available in larger diameters than conventional roller bearings. Their layout can be interpreted as “segmented” roller bearings. The larger diameter allows to streamline the load paths in the overall telescope structure and to improve thereby the structural stiffness and related dynamic features. The bearing layout uses a large amount of detailed design features of their application in machine tools as fixation and adjusting devices for the tracks and trucks of the R-guides and for the gear rim and the use of a standard pinion motor. New developed were the fixations and adjusting devices for the scale and the reading heads of the strip encoder.

8444-09, Session 3

The Large Synoptic Survey Telescope final design status

V. L. Krabbendam, National Optical Astronomy Observatory (United States); D. W. Sweeney, LSST Corp. (United States)

The Large Synoptic Survey Telescope (LSST) Project is a public-private partnership that has recently completed its Preliminary Design Review, an important step toward potential construction funding. The science objectives remain consistent with the New Worlds New Horizons decadal survey endorsement of the LSST to conduct a wide fast deep survey and to process and serve the data to the US and Chilean communities without any proprietary period. The engineering requirements and designs remain consistent with a 3-mirror wide field optical system; an 8.4 meter primary, 3.4 meter secondary, and 5 meter tertiary mirror. The reflective optics feed three refractive elements and a 64 cm 3.2 gigapixel focal plane camera. The data management system will reduce, transport, alert, archive the 15 terabytes of data produced nightly, and will serve raw and catalog data accumulating at an average of 7 petabytes per year. LSST has completed risk reduction prototype efforts including data challenges designed to test software and algorithms to significant pre-construction levels. Non-federal funding continues to support the construction of the primary mirror scheduled for a late 2012 completion, funds detector prototype efforts, that have yielded fully functional sensors, and has recently supported the early excavation of the site. Project efforts focus on system engineering, risk reduction through prototyping, interface definition, final designs, and major efforts in end-to-end simulations. The project now has 36 institutional partners and an agreement with AURA to function as an independent center for the construction phase. The Project is preparing for a 2014 construction authorization.

8444-10, Session 3

Manufacturing and testing of the large field corrector lenses for the Dark Energy Survey (DES) Telescope

D. Fappani, Société Européenne de Systèmes Optiques (France);

P. Doel, D. Brooks, Univ. College London (United Kingdom); B. L. Flaugher, Fermi National Accelerator Lab. (United States)

We will explain first what is the Dark Energy Survey (DES) project and which kind of optical telescope/field corrector will be operated. Then, the presentation will review the optical definition and production of the large lenses (1m-class) constituting the field coreector of the telescope, also named the DES Camera (DECAM). Special emphasis will be made onto the optical manufacturing issues and interferometric testing solutions which have been carried out by THALES SESO especially for the biggest entrance lens (very challenging CV/CX meniscus named C1). The presentation will conclude by a brief overview of the corresponding existing "state of the art" at SESO for these technologies

8444-11, Session 3

The Transneptunian Automated Occultation Survey (TAOS II)

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The Transneptunian Automated Occultation Survey (TAOS II) aims to detect occultations of stars by small (~1 km diameter) objects in the Solar System and beyond. Such events are very rare and short in duration (~200 ms), so many stars must be monitored at a high readout cadence. TAOS II will operate three 1.3m telescopes at San Pedro Martir Observatory (SPM) in Baja California, Mexico. The telescopes, currently being fabricated manufactured by DFM Engineering, will be F/4 with a three square degree field of view. The cameras will comprise arrays of custom CMOS imagers which will be back illuminated and thinned. The CMOS imagers will allow high speed sub-aperture readout, enabling the survey to monitor 10,000 stars simultaneously at a readout cadence of 20 Hz. All three telescopes will synchronously monitor the same stars in order to minimize the false positive detection rate. Site development at SPM will commence in the summer of 2012, and all three telescopes will be installed by the end of 2013. The cameras will be built and installed in 2015, and the survey will then begin.

8444-12, Session 3

NGTS: next generation transit survey

B. Chazelas, D. Queloz, Observatory of Geneva (Switzerland); D. Pollacco, Queen's Univ. Belfast (United Kingdom); P. J. Wheatley, The Univ. of Warwick (United Kingdom); R. West, Univ. of Leicester (United Kingdom); H. Rauer, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

NGTS is a new ground-based transit survey aimed at detecting sub-Neptune sized exoplanets around bright stars. The instrument is planned to be built at the ESO Paranal observatory in order to benefit from the excellent observing conditions and follow-up synergy with the VLT and E-ELT. It will be a robotic facility composed of 12, small aperture telescopes equiped with detectors. The primary target for this instrument are the K, G and M stars. The survey will be conducted in the very near infrared (550-900 nm).

8444-13, Session 3

The design of a compact wide field telescope for space situational awareness

D. Lee, A. J. Born, UK Astronomy Technology Ctr. (United Kingdom)

The European Space Agency, in the framework of its Space Situational Awareness (SSA) Preparatory Programme, has commissioned a study for a global network of surveillance telescopes to monitor the ever increasing number of objects in Earth orbit. A possible scenario identified by the study is a network of 20 SSA Telescopes located at various observatory sites. This paper presents the conceptual design of a telescope system optimised for wide field, short exposures and fast tracking - all requirements of SSA.

The requirements of the SSA telescope will be presented followed by a brief review of potential telescope technologies. Following a trade study analysis a 1 m compact Schmidt telescope design was chosen. This design provides a field of view of 3.4 degrees diameter. The design is achromatic and covers the wavelength range 380 - 900 nm. The sensitivity of the telescope is such that it can monitor the orbital parameters of objects as small as 1 cm in low Earth orbit. This is equivalent to 17th magnitude in 0.07 seconds at a signal to noise ratio of 5. The telescope is mounted on an Altitude-Azimuth type mount that enables wide coverage of the sky and fast tracking speeds. The entire telescope is contained within a Calotte type enclosure. The camera, detector control, and telescope control system design will also be presented. Systems engineering aspects will be addressed, with particular attention given to the analysis and flow-down of requirements and a practical and pragmatic process of system-level design trade-offs.

8444-14, Session 4

OAJ: 2.6m Wide Field Survey Telescope

O. Pirnay, G. Lousberg, V. Moreau, AMOS Ltd. (Belgium)

AMOS S.A. is in charge of the development of the telescopes for the "Observatorio Astrofisico de Javalambre" in Spain where a 2.5 m wide field telescope is complemented by an 80 cm telescope. This paper focuses on the 2.5 m telescope: the latter will aim at combining a large collecting surface with a wide field of view for reaching a vast portion of the sky, which is the relevant parameter for surveys, while ensuring an optical imaging quality compatible with the site seeing and a suitable depth in the sky sighting.

The major difficulty consists in maintaining the image quality over a 500 mm focal plane. A good design is the result of a thorough multidisciplinary optimization process where fabrication constraints are a major driving parameter. The complexity of the system led to elaborate innovative solutions for the closed loop control of both image quality and the tracking features.

The design and the methodology of working are presented in detail. The optics fabrication, the integration and acceptance tests are also reviewed.

8444-15, Session 4

Design differences between the Pan-STARRS PS1 and PS2 telescopes

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The PS2 telescope is the second in an array of wide-field telescopes that is being built for the Panoramic-Survey Telescope and Rapid Response System (Pan-STARRS) on Haleakala. The PS2 design has evolved

incrementally based on lessons learned from PS1, but these changes should result in significant improvements in image quality, tracking performance in windy conditions, and reductions in scattered light. The optics for this telescope are finished save for their coatings and the fabrication for the telescope structure itself is well on the way towards completion and installation on-site late this year (2012). The most significant differences between the two telescopes include the following: secondary mirror support changes, improvements in the optical polishing, changes in the optical coatings to improve throughput and decrease ghosting, removal of heat sources inside the mirror cell, expansion of the primary mirror figure control system, changes in the baffle designs, and an improved cable wrap design. This paper gives a description of each of these design changes and discusses the motivations for making them.

8444-16, Session 4

Ground-based search for the brightest transiting planets with the multi-site all-sky camera: MASCARA

I. A. Snellen, Leiden Univ. (Netherlands); R. Stuik, Leiden Univ. (Netherlands) and NOVA (Netherlands); R. Navarro, F. C. Bettonvil, ASTRON (Netherlands); M. A. Kenworthy, Leiden Univ. (Netherlands); E. de Mooij, Univ. of Toronto (Canada); G. Otten, Leiden Observatory (Netherlands)

The Multi-site All-sky CAmeRA MASCARA is an instrument concept consisting of several stations across the globe, with each station containing a battery of low-cost cameras to monitor the near-entire sky at each location.Once all stations have been installed, MASCARA will be able to provide a nearly 24-hr coverage of the complete dark sky, down to magnitude 8, at sub-minute cadence. Its purpose is to find the brightest transiting exoplanets, expected in the V=4-8 magnitude range. While the CoRoT and Kepler space missions are rapidly deciphering the transiting exoplanet population in the Milky Way, they are not capable of find bright/nearby systems, neither do the current ground-based surveys which target stars at V>8. The bright/nearby transiting planets, which MASCARA will discover, will be the key targets for detailed planet atmosphere observations. We will present studies on the detailed design of a MASCARA station, including the camera housing, domes, and computer equipment, and on the photometric stability of low-cost cameras showing that a precision of 0.3-1% per hour can be readily achieved. We plan to roll out the first MASCARA station at the end of 2012. A 5-station MASCARA can within two years discover a dozen of the brightest transiting planets in the sky.

8444-17, Session 4

Design of the LSST secondary mirror system assembly

D. R. Neill, W. J. Gressler, J. Sebag, B. Schoening, J. DeVries, M. Warner, O. Wiecha, National Optical Astronomy Observatory (United States)

The Large Synoptic Survey Telescope (LSST) has a 10 degrees square field of view which is achieved through a 3 mirror optical system. The 3.5 meter secondary (M2) mirror utilizes a 100mm thick meniscus ULE blank completed by Corning Incorporated in 2009. Sub-aperture interferometry will guide the polishing process to meet mirror structure function requirements. The surface of the convex asphere is actively controlled by 72 axial electromechanical actuators (axial actuators). Transverse support is provided by 6 active tangential electromechanical actuators (tangent links). These tangent links utilize an embedded lever system to meet the stiffness and force requirements. The support control system is based on a distributed two-level architecture where a higher level “outer loop controller” is responsible for monitoring and commanding the 6 tangent links and the 72 axial actuators. Several design features are incorporated in response to the precarious downward facing orientation of the M2. The axial actuators have force limiting devices to prevent overloading their mirror mounts which are nominally in tension. The mirror cell incorporates an aperture ring which supports a large baffle. When the aperture ring is installed it captivates the M2 mirror in the event of catastrophic mirror support failure. The M2 mirror cell assembly contains numerous sensors for determining the assembly status including actuator load cells, accelerometers, mirror to mirror cell position sensors, laser retro reflectors, temperature sensors and an inclinometer. The interior of the M2 cell is enclosed and the air conditioned to prevent seeing degradation.

8444-19, Session 5

Current status of the Hobby-Eberly Telescope wide field upgrade

G. J. Hill, J. A. Booth, M. E. Cornell, J. M. Good, K. Gebhardt, H. Lee, P. J. MacQueen, D. M. Perry, M. D. Rafal, T. H. Rafferty, C. Ramiller, R. D. Savage, C. A. Taylor III, B. L. Vattiat, McDonald Observatory (United States); L. W. Ramsey, The Pennsylvania State Univ. (United States); J. H. Beno, T. A. Beets, J. D. Esguerra, R. J. Hayes, J. T. Heisler, I. M. Soukup, J. J. Zierer, Jr., M. S. Worthington, N. T. Mollison, D. R. Wardell, G. A. Wedeking, The Univ. of Texas at Austin (United States); M. P. Smith, Univ. of Wisconsin-Madison (United States)

The Hobby-Eberly Telescope (HET) is an innovative large telescope of 9.2 meter aperture, located in West Texas at the McDonald Observatory. The HET operates with a fixed segmented primary and has a tracker which moves the four-mirror corrector and prime focus instrument package to track the sidereal and non-sidereal motions of objects. A major upgrade of the HET is in progress that will substantially increase the pupil size to 10 meters and the field of view to 22 arcminutes by replacing the corrector, tracker and prime focus instrument package. In addition to supporting the existing suite of instruments, this wide field upgrade will feed a revolutionary new integral field spectrograph called VIRUS, in support of the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX). This paper discusses the current status of this upgrade which will be deployed in 2012.

8444-20, Session 6

ATST telescope pier

P. F. Jeffers, National Solar Observatory (United States); E. Manuel, M3 Engineering & Technology Corp. (United States); O. Dreyer, H. J. Kärcher, MT Mechatronics GmbH (Germany)

The Advanced Technology Solar Telescope (ATST) will be the largest solar telescope in the world with a 4m aperture primary mirror. The telescope, due to the off axis nature of the optical layout, has the proportions of an 8 metre class telescope. Due to the nature of instrumentation for solar observations a 16m diameter co-rotating laboratory (Coudé Rotator) is also located within the telescope pier.

The pier has a lower cylindrical profile with an upper conical section to both support the telescope mount with a 9m bearing diameter and contain the 16m diameter Coudé rotator.

The performance of this pier cannot be considered in isolation but must account for ancillary equipment, access and initial installation. The Coudé rotator structure and bearing system are of similar size to the telescope base structure and therefore this is the proverbial ‘ship in a bottle’ problem.

This paper documents the competing requirements on the pier design and the balancing of these as the design progresses. Also summarized is the evolution of the design from a conceptual traditional reinforced concrete pier to a composite concrete and steel framed design. The stiffness requirements of the steel frame was a unique challenge for both the theoretical performance and overall design strategy considering

constructability. The development of design acceptance criteria for the pier is discussed along with interfacing of the A&E firm responsible for the pier design and the telescope designer responsible for the telescope performance.

8444-21, Session 6

Design concepts for the EST mount

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The European Solar Telescope EST will be, beside the American Advanced Technology Solar Telescope ATST, the largest solar telescope in the world. Both telescopes have a 4m aperture, but are distinguished in their optical layout and their thermal control concept; both projects are described in separate papers of this conference.

The EST has unique optical layout, with an on-axis Gregorian tube system and the altitude axis behind the M1 mirror unit - a great challenge for the mount designer in regard of balancing and related structural dynamics, having in mind particularly the “exposed” operational concept with a fully retractable enclosure. Three different structural design concepts and various alternatives for the bearing and drive systems were investigated. Starting point was a classical altitude over azimuth mount with a yoke type alidade, two altitude and one azimuth bearing. Hydrostatic bearings with direct drives, as used for most of the existing 8m class telescopes, are compared with roller bearings and geared drives, as used e.g. for sub-millimeter radio telescopes. The influence of available bearing and drive technology and related stiffness, diameter and friction features were investigated by FE calculations, dynamic analysis and end-to-end simulations. Outcome is a recommendation for a final design concept based on large-diameter segmented roller bearings and so-called pinion motors in both axes.

The paper explains the structural design concepts, the main features of the alternative axes mechanisms, the related performance verification and the final arguments for the recommended design

8444-22, Session 6

Progress on the preliminary structural and mechanical design of the Giant Magellan Telescope

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The Giant Magellan Telescope (GMT) is a 25 meter altitude-azimuth telescope and one of the first of the next generation of Extremely Large Telescopes (ELTs). In operation it will be used to conduct a broad range of astronomical scientific research at visible and infrared wavelengths at its site in Northern Chile. The telescope optics and instrumentation are mounted in a gimbaled structure, weighing approximately 1130 tonnes and standing approximately 40 meters tall. This paper reports the results of our ongoing preliminary structural analysis and design of the GMT. A major redesign of the Gregorian Instrument Rotator (GIR) resulted in significant changes to the elevation structure. Trade studies of various aspects of subsystems including the main truss, hydrostatic bearing system, main axes drives, M2 Positioner and M3 Subsystem have refined the preliminary design in these areas. Telescope performance related analyses for static flexure, wind shake, mechanical vibration and seismic loading environments are discussed.

8444-23, Session 6

The E-ELT project: the telescope main structure detailed design study

G. Marchiori, A. Busatta, S. De Lorenzi, L. Ghedin, C. Manfrin, C. Battistel, L. Giacomel, F. Formentin, European Industrial Engineering s.r.l. (Italy)

The European Extremely Large Telescope (E-ELT) is the biggest telescope in the world. Within the Detailed Design activities, ESO has awarded EIE Group (European Industrial Engineering) a contract for the Design of the Main Structure to the point where the concept of the telescope has been consolidated, from a construction point of view. All the Design activities have been developed in order to create an integrated system in terms of functionality and performance, while the engineering activities have been performed with the aim of obtaining a telescope that can be built, transported, integrated, with a reduced maintainability.

8444-24, Session 6

E-ELT dome for modified baseline design

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During the last two years a modified baseline design for the E-ELT was developed. The aim of this revision was both to achieve a significant cost saving and to reduce risk on major items. The primary mirror diameter was slightly reduced to 39 m and the total height of the telescope also decreased accordingly. This paper describes the work performed by IDOM under contract with ESO to review the EELT dome and foundations design to match the modified baseline. Detailed design and construction planning, as well as detailed cost estimates were updated for the 39-metre baseline design. In June 2011, ESO Council formally endorsed this modified design as the E-ELT revised baseline.

Key redesign drivers are explained and final redesign details of all major subsystems are outlined. In general, the original compact dome design philosophy is maintained and adapted to the new dimensions. Cost optimisation strategies are applied throughout the detailed design update process. Special attention is also given to some specific new items now included in the modified baseline, such as the special ad-hoc seismic base isolation system for the telescope foundation.

8444-25, Session 6

The E-ELT project: the dome detailed design study

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Further to the re-dimensioning of the E-ELT (European Extremely Large Telescope) telescope to 37 metres, the project of the dome has been completely reviewed, together with the Auxiliary Building and the Foundations. The Dome is now constituted by a structure with a steel hemispherical architecture, 79m.-high, with a 101m.-external diameter and a 42m-wide observing slit. These dimensions require the application of technologies for big structures (like stadiums, hangars, etc.) in order to comply with the manufacturing, transport and assembly constrains.

The dome is characterized by an agglomerate of mechathronic technologies originated by the long experience matured by EIE in the industrial and astronomical fields.

The solutions adopted for VLT, LBT, and VISTA have demonstrated, along the years of service, their functionality, as well as their reliability and maintainability.

Moreover, innovative technologies have been introduced, especially for what concerns the movement systems of the Dome, the louvers, the windscreen, etc. The architecture of the control systems has been

completed re-formulated, and they are now able to manage in real time all the exigencies of the E-ELT Observatory.

All Project phases have been properly analyzed and simulated, guaranteeing the completeness of the constructability and the maintainability.

The entire work has been developed in close cooperation with ESO Project Team, further to a specific contract.

8444-26, Session 7

Seismic structural analysis for the LSST telescope

D. R. Neill, National Optical Astronomy Observatory (United States)

The Large Synoptic Survey Telescope (LSST) will be located on the seismically active Chilean mountain of Cerro Pachón. The accelerations resulting from seismic events produce the most demanding load cases the telescope and its components must be designed to withstand. Seismic accelerations were applied to a comprehensive FEA model which included the telescope, its pier, its foundation and the mountain top. Telescopes are designed for maximum repeatability which minimizes hysteresis producing inherently low natural damping. As a result of this low damping the telescope mount amplifies these accelerations producing significant accelerations on the critical components including the camera assembly and secondary mirror assembly. Accelerations for specific critical components on the telescope were determined by applying spectral and time domain accelerations to the FEA model. Closed form solutions were also utilized to verify the results. The LSST mount incorporates added damping to meets is rapid slew and settle requirements. The effects of this added damping on these component accelerations were investigated. The analysis was repeated for various elevation angles. The accelerations are also affected by the component design life. The fixed infrastructure is expected to survive the entire 30 year design life of the telescope while other components have only a design life of 10 years. The components were therefore analyzed for 300 year (10% chance over 30 years) and 100 year (10% chance over 100 year) earthquake return periods.

8444-27, Session 7

The structural response of the Magellan telescopes to earthquakes

P. Palunas, Carnegie Observatories (United States)

The 2006 earthquake in Hawaii that caused damage to the observatories and the massive mag 8.8 earthquake in Chile prompted a review of earthquake preparedness at Las Campanas Observatory. In addition to basic safety issues we initiated an empirical study of the dynamical response of the Magellan telescopes. The Baade telescope was equipped with a network of 3-axis accelerometers and the response of the telescope to the occasional low-level earthquake has measured. A substantial amplification of the ground accelerations through the structure was found that was not anticipated in the original design. Measures to mitigate this effect are being explored.

8444-28, Session 7

New seismic response models for the telescopes at W.M. Keck Observatory

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On October 15, 2006 a large earthquake damaged both telescopes at Keck observatory resulting in weeks of observing downtime. A significant portion of the downtime was attributed to recovery efforts repairing damage to telescope bearing journals, radial pad support structures and encoder subsystems. In May, 2011 a feasibility study was conducted to review several options to enhance the protection of the telescopes with the goal to minimize the time to bring the telescopes back into operation after a large seismic event. At that time it was determined that new finite element models of the telescope structures were required to understand the response of the telescope to seismic forces. This paper presents the results of two finite element methods, spectrum analysis and time history analysis, used to determine seismic demand forces and seismic response of each telescope. The design earthquakes used were those determined by local governing building codes and USGS seismic data collected on the summit of Mauna Kea. In response spectrum analysis, the seismic restraints were modeled as idealized linear elastic spring supports with the only damping provided by the telescope structure. In the time history analyses, nonlinear material behavior and discrete dampers were modeled. The results of these models will be used in the design of the next generation of seismic restraints for both Keck telescopes.

8444-29, Session 8

GMT Enclosure Wind and Thermal Study

A. Farahani, GMTO Corp. (United States); A. Kolesnikov, L. Cochran, CPP, Inc. (United States); C. L. Hull, M. W. Johns, GMTO Corp. (United States)

The GMT (Giant Magellan Telescope) is a large ground-based telescope for astronomical research at optical and infrared wavelengths. The telescope is enclosed inside an Enclosure that rotates to follow the tracking of the telescope. The Enclosure is equipped with adjustable shutters and vents to provide maximum ventilation for thermal control while protecting the telescope from high wind loads and severe weather conditions. The project will be built at Las Campanas Observatory in Chile on Cerro Las Campanas.

The first part of this paper presents the wind tunnel test data as well as CFD (Computational Fluid Dynamics) study results for the GMT Enclosure. The wind tunnel tests includes simulations for: a) Topography, b) Open Enclosure (all the shutters and vents open), and c) Closed Enclosure (all the vents and shutters closed). The CFD modeling was carried out for a wide range of conditions such as low and high wind speeds at various wind directions, and for the fully open and partially open Enclosure.

The second part of this paper concerns the thermal effects of the Enclosure steel members. The wind speed and member sizes have been studied in relation to the required time to reach a defined temperature inside the Enclosure. This is one of the key performance characteristics of the Enclosure that can affect "Dome Seeing" significantly.

The experimental data and theoretical predications have been used to identify the areas inside the Enclosure that need to be ventilated. The Enclosure thermal control strategy has been determined and an optimized system has been designed based on the final results.

8444-30, Session 8

Vibration mitigation for wind-induced jitter for the Giant Magellan Telescope

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The Giant Magellan Telescope (GMT) is a planned large terrestrial telescope with a segmented primary mirror with a 24.5 meter overall diameter. Like most terrestrial telescopes, the GMT resides within an enclosure designed to protect the telescope from the elements and to reduce the effects of wind on the optical performance of the telescope. Wind impingement on the telescope causes static deformation and vibration in the telescope structure that affects the alignment and image jitter performance of the telescope. Actively controlled primary mirror segments and secondary mirror can correct for the static and low frequency portions of the wind effects, but typically the actuators do not have the bandwidth to address higher frequency components of the wind environment (ref. “GMT Conceptual Design Report”). Preliminary analyses on the GMT indicate that the image jitter associated with wind effects meets budgeted allowances but without much margin. Preliminary models show that the bulk of the residual jitter arises from excitation of a small number of modes in the 9 to 12 Hz range (ref. “Wind Vibration Analyses of Giant Magellan Telescope”, SPIE Conf. 6271). Therefore, as a risk mitigation effort to increase the margin on the wind induced jitter, passive and active vibration mitigation approaches have been examined for the GMT, which will be the focus of this paper.

Using a finite element model of the GMT along with wind loading load cases, several passive and active vibration mitigation approaches were analyzed. These approaches include passive approaches such as tuned mass dampers targeting the worst offending modes, and constrained layer damping targeting all of the modes within the troublesome frequency range. Active approaches evaluated include two active damping approaches, one using several reaction mass actuators and another using active strut type actuators. The results of the study show that although all approaches are successful in reducing the jitter, the active damping approach using reaction mass actuators offers the lightest weight, least implementation impact, and most adaptability of any of the approaches.

8444-31, Session 9

Feasibility studies to upgrade the Canada-France-Hawaii Telescope site for the next generation Canada-France-Hawaii Telescope

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The Next Generation Canada-France-Hawaii Telescope (NGCFHT) is a dedicated, 10m, wide-field, multi-object spectroscopic facility proposed as an upgrade to the existing Canada-France-Hawaii Telescope (CFHT) on the summit of Mauna Kea. The NGCFHT baseline concept assumes the new facility is built on the existing CFHT telescope pier and enclosure pier and occupies the same three dimensional exterior volume. Three technical studies have been planned to examine the validity of these assumptions. The technical studies are executed in series as they represent technical decision points in a logical sequence. The three technical studies in succession are: 1. Telescope Pier Study - Load Capacity and Structural Interface, 2. Enclosure & Fixed Base Study - Telescope and Enclosure Configuration and Load Capacity and 3. Thermal Management Study - Daytime and Nighttime. The paper outlines the status and findings of these studies and discusses the feasible telescope and enclosure configuration in terms of the upgrade assumptions.

8444-32, Session 9

The Astronomical Telescope of New York (ATNY): a new 12-meter astronomical telescope

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The Astronomical Corporation of New York has commissioned a study of a 12-meter class telescope to be developed by a group of NY universities. The telescope concept builds on the basic principles established by the Keck telescopes; segmented primary mirror, Ritchey Chretien Nasmyth instrument layout, and light weight structures. New, lightweight, and low cost approaches are proposed for the primary mirror architecture, dome structure and mechanisms, telescope mount approach, and adaptive optics. Work on the design is supported by several NY based corporations and universities. The design offers a substantially larger aperture than any existing Visible/IR wavelength telescope at historically low cost. The concept employs an adaptive secondary mirror and laser guide star adaptive optics. Two First Light instruments are proposed; A High resolution near infra-red spectrograph and a near infra-red Integral field spectrograph/imager.

8444-33, Session 9

A 3.4 m high-image-quality telescope

A. Ardeberg, B. Afzalifar, Lund Telescope Group (Sweden)

A 3.4 m telescope for visual wavelengths is designed for the Iranian National Observatory (INO). Optical, mechanical and control design is made in collaboration between INO staff and Lund Telescope Group (LTG). The telescope, INO340, is of Cassegrain type. The primary mirror has focal ratio f/1.5 and aspect ratio 18.5. The telescope back-focal distance is 1 750 mm and f ratio F/11.4. There are four focal stations, one on-axis, three perpendicular to the optical axi. With high image quality as first priority, INO340 has an active-optics system with 60 axial and 32 lateral supports and a secondary-mirror 5 degrees-of-freedom mount, all with closed-loop real-time or open-loop control. For first light, a conventional secondary mirror is designed, for second light a light-weight secondary tip-tilt mirror. The instruments include high-resolution imaging, photometry and medium and low resolution spectroscopy. Extensive collaboration with international exploratory programmes is foreseen. A fine site has been found at 3 617 m altitude. The annual number of photometric nights is 150, with 220 useful for spectroscopy. Atmospheric and weather quality was measured over two years, with six masts with micro-thermal sensors, one differential image-motion monitor (DIMM) and a complete weather station. CFD studies were made for the site summit and for the telescope enclosure. Median seeing FWHM is 0.7”, best seeing 0.3”. The wind regime is favourable as are those of temperature variations and local relative humidity. Dust is not a major problem.

8444-34, Session 10

Ground telescopes in the 1m to 4m domain can use existing designs to be affordable

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Synoptic and spaceborne missions will generate new requirements for follow-up studies at a prodigious rate. Significant follow-up can be achieved with stable telescopes in the 1m to 4m regime, especially when dedicated telescopes are available. These telescopes can be optimized over a range of parameters, yet can cost only a fraction of the original if the cost drivers and interfaces are well understood. We will describe a set of ground telescopes, developed for other purposes, but which have many attributes desirable for astronomical survey follow-up. These provide a library of mature features that are applicable to astronomy. We will describe typical attributes, as well as the representative learning curves that can be realized, provided that early interface definition is worked with the astronomical team.

8444-97, Poster Session

Precision attitude control for the BETTII balloon-borne interferometer

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The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII) is an 8-meter baseline far-infrared interferometer to fly on a high altitude balloon. Operating at wavelengths of 30-90 microns, BETTII will obtain spatial and spectral information on science targets at angular resolutions down to less than half an arcsecond, a capability unmatched by other far-infrared facilities. This requires attitude control at a level of less than a tenth of an arcsecond, a great challenge for a lightweight balloon-borne system. We have designed a precision attitude determination system to provide gondola attitude knowledge at a level of 2 milliarcseconds at rates up to 100Hz, with accurate absolute attitude determination at the half arcsecond level at rates of up to 10Hz. A multi-stage control system involving rigid body motion and tip-tilt-piston correction provides precision pointing stability to the level required for the far-infrared instrument to perform its spatial/spectral interferometry in an open-loop control. We present key aspects of the design of the attitude determination and control and its development status.

8444-98, Poster Session

First technological steps toward opening a NEAR-IR window at stratospheric altitudes

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Investigating the possibility to provide the Italian astronomical community with an optical/near-IR balloon borne telescope at a reasonable cost, we have started a series of technological initiatives that concur to eventually test the feasibility of the overall project. Here, in particular, we present the characteristic of two devices we have built: (i) to measure the near-IR sky background emission at stratospheric altitudes during the artic night, when the OH airglow emission should be severely reduced; (ii) to provide the balloon flight with a low cost fine tracking system at a sub-arcsec accuracy. Design, technical solutions and preliminary ground based results are presented for both instruments, along with the current plan for forthcoming in flight applications.

8444-99, Poster Session

SOFIA in operation: telescope performance during the basic science flights

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The Stratospheric Observatory for Infrared Astronomy SOFIA has started in December 2010 with the first series of science flights, and has successfully completed about 30 missions until fall 2011. The science instruments flown included HIPO, FORECAST, GREAT and FLITECAM. Beside their scientific results (see related papers on this conference) the flights delivered an extensive data base which was used for telescope performance characterization operational optimization of the telescope in its unique environment.

The SOFIA telescope is integrated into a Boeing 747SP, and its optics in the open port of the aircraft is exposed to extreme aero-acoustic excitations. The telescope pointing control system is equipped with several subsystems, such as a vibration isolation, a flexible body control and active mass dampers, to handle the excitations in the different frequency ranges.

In this paper we present the status of three different provisions for pointing improvement, particularly: Active mass dampers are used for damping of identified structural resonances like those of the primary mirror in its mirror cell (including internal mirror bending), of the secondary mirror assembly in its exposed position near the cavity shear layer, and of the baffle plate in the rear, which is elastically coupled with the tripod for the secondary mirror. The identified resonances of these subsystems are effectively damped up to more than 300 Hz in frequency. A fast diagnostic camera to be employed for seeing characterization as well as for closed-loop position control with the focal plane imager (FPI). The flexible body control uses the secondary chopper for open loop pointing corrections up to 25 Hz.

A progress report is presented and describes the recent achievements as well as the status of the telescope, gives an update of the SOFIA pointing system, and the further planned pointing optimization activities.

8444-100, Poster Session

A new backup secondary mirror for SOFIA

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The telescope of the Stratospheric Observatory for Infrared Astronomy (SOFIA) is a Cassegrain design with a convex, hyperbolic secondary mirror (M2). It is 352 mm in diameter, was made from silicon carbide and weighs only 1.9 kg. As this material is brittle, and the M2 is indispensable to observations with SOFIA, a backup with the same mass and moments of inertia was made of aluminium in 2004. This mirror, however, allows diffraction-limited observations only above 20 µm and it produces double peaked images. In this paper we discuss the requirements for a new backup M2 that can be employed also at near-infrared and even visible wavelengths and describe the most important aspects of the manufacturing process. The starting point of our analysis was a high-precision measurement of the surface properties of the existing aluminium M2, using the NANOMEFOS technique, which was recently developed by TNO in Delft, the Netherlands. With the exact shape of the mirror as input for a Zemax model we could reproduce the results of actual measurements of its optical performance that had been carried out on SOFIA in 2004. Based on these findings we determined then the specifications to be fulfilled by a new backup M2 in order to meet the requirements on improved optical performance. Finally we discuss some key aspects of manufacturing like selection of the best aluminium alloy, the process of thermal cycling, etc.

8444-101, Poster Session

Upgrade of the SOFIA target acquisition and tracking cameras

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The Stratospheric Observatory for Infrared Astronomy (SOFIA) uses three CCD cameras with different optics for target acquisition and tracking. The Wide Field Imager (WFI with 68mm optics) and the Fine Field Imager (FFI with 254mm optics) are mounted on the telescope front ring and are therefore exposed to stratospheric conditions in flight. The Focal Plane Imager (FPI) receives the visible light from the 2.5 meter telescope and is mounted inside the pressurized aircraft cabin at ~20°C. It is planned to replace all three imagers' CCD sensors with commercial Andor iXon cameras to significantly increase the sensitivity and to allow for tracking on fainter stars. Andor cameras were temporarily mounted on the FPI flange as stand-alone systems to optically measure the telescope's pointing stability and the performance of various telescope sub-systems during engineering flights. Three DU-888 cameras will now be integrated in SOFIA's telescope system, so their image data can be used for target

acquisition and tracking. To replace the WFI and FFI, the cameras will also need to be tested under stratospheric conditions, to ensure that they can be operated safely and without degradation of performance. In this paper we will report about the results of the environmental tests with the cameras, the integration of the camera in the SOFIA tracker and the current status of the upgrade project.

8444-102, Poster Session

The 3.6 m Indo-Belgian Devasthal Optical Telescope: assembly, integration, and tests at AMOS

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AMOS SA has been awarded of the contract for the design, manufacturing, assembly, tests and on site installation (Devasthal, Nainital in central Himalayan region) of the 3.6 m Indo-Belgian Devasthal Optical Telescope (IDOT).

The telescope has a Ritchey-Chrétien optical configuration with a Cassegrain focus equipped with one axial port and two side ports. The meniscus primary mirror is active and is supported by pneumatic actuators. The mount is an Alt-Az type with for the azimuth axis a 5 m diameter hydraulic track.

The telescope was completely assembled and tested in AMOS workshop. This step is completed and successful. The telescope is now ready for shipment to Nainital.

This paper describes the test campaign at sub-system and system level that has taken place to demonstrate that the telescope satisfies the main system requirements. Besides of the functionality of the telescope, the units interacting with the image quality or the tracking performance were plenty tested. Some selected tests directly connected to the performance of the telescope are also looked specifically in this paper.

8444-103, Poster Session

First tests of the compact low scattered-light 2m-Wendelstein Fraunhofer Telescope

U. Hopp, Univ.-Sternwarte München (Germany); R. Bender, Univ.-Sternwarte München (Germany) and MPE Garching (Germany); F. Grupp, Univ.-Sternwarte München (Germany); H. D. Thiele, N. Ageorges, Kayser-Threde GmbH (Germany); P. Aniol, ASTELCO Systems GmbH (Germany); C. A. Gössl, F. Lang-Bardl, W. Mitsch, Univ.-Sternwarte München (Germany); M. Ruder, ASTELCO Systems GmbH (Germany)

The integration of the 2m Fraunhofer telescope started in August 2011 at the Mt. Wendelstein observatory. The logistics of the project are a key problem of the integration as the observatory has no road access. All large or heavy components inlcuding the primary mirror were successfully delivered by helicopter. They are meanwhile integrated in the telescope. The special design features of this alt-az telescope are its compactness and the low-ghost wide field optics (0.7 deg. f.o.v. diameter). We will briefly report on the mountain integration, discuss the first astronomical performances tests of the telescopes, and update on the status of its instruments.

8444-104, Poster Session

SALT's transition to science operations

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The Southern African Large Telescope (SALT) began its re-commissioning phase in April 2011 following the completion of remedial engineering work on the telescope and the major science instrument, the Robert Stobie Spectrograph (RSS). The engineering work required modifications to the spherical aberration corrector, in order to improve the telescope's image quality, and RSS, to improve its throughput. Positive test results included delivery of sub-arcsecond images, essentially meeting the original telescope image quality specifications and exhibiting none of the previous field-dependent aberrations, while the RSS has shown greatly improved efficiency performance. SALT has since transitioned to science operations, as from 1 September 2011, following the first open call for charged science proposals from the SALT partners. This paper discusses the current performance of SALT and it First Generation instruments, initial science results, the proposal process and the operational model for the telescope.

8444-105, Poster Session

LSST: integration and testing of the LSST camera

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The large synoptic survey telescope LSST will employ a 3 giga-pixel camera to study dark energy, galactic structure and transient objects. The modular focal plane is composed of 3x3 sensor arrays called "raft towers". A total of 21 science rafts and 4 corner rafts will be integrated into the cryostat housing over an extended delivery period. Once the focal plane is fully populated the camera optics will be integrated and the complete system tested.

RAFT towers will be tested individually as they arrive. Additionally, at three stages, as the focal plane is populated, integration will pause and several verification tests run. These tests include focal plane metrology testing and associated raft tower height adjustments, iron-55 exposure to test charge transfer efficiency and charge diffusion and a spot projector to test overall system performance and crosstalk. Once the focal plane is fully populated the camera optics will be integrated and optical throughput and image quality verification will be performed.

8444-106, Poster Session

The QUIJOTE-CMB experiment

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The QUIJOTE (Q-U-I JOint Tenerife) CMB Experiment aims to measure the polarization of the CMB and Galactic and extragalactic emission processes in the frequency range 10-90 GHz at large and medium angular scales. The experiment consists of two main telescopes and a set of four instruments plus a dedicated two-antenna interferometer to measure the polarization of extragalactic sources. The main scientific goal is to detect the imprint of B-modes if the tensor to scalar ratio is larger than r=0.05 and measure with high sensitivity the polarization of diffuse foregrounds.

The two telescopes are optimally designed for polarization measurements and each consists of a dual reflector dragonian system (a 3.5m primary and a 1.8m secondary mirror). They will be located at Teide Observatory (2400 m altitude) and supplemented by a two-antenna interferometer that will provide polarization measurements of point radiosources. The first instrument of the series is already built and consists of 5 polarization

channels which operate at 11, 13, 16, 18 and 30 GHz. Each horn feeds a novel cryogenic on-axis rotating polar modulator which can rotate at a speed of up to 1 Hz. The science driver for this first instrument is the characterization of the polarization of the Galactic emission. The second, third a fourth instruments are currently under design and will operate at 30, 40 and 90 GHz, respectively. Each consists of at least 19, 25 and 90 polarimeters, respectively and will survey between 5000 and 10000 sq degrees of sky achieving individually a sensitivity of 1 microK per 1 degree beam.

8444-107, Poster Session

Reviewing off-axis telescope concepts: a quest for higher photometry and dynamic range

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We review the off-axis telescope concepts with their unobstructed pupils. Built and prospective telescopes and their concepts for ground and space astronomy will be presented and discussed. Such concepts offer great advantages in terms of emissivity, throughput, diffraction-limited energy concentration and higher dynamic range. Coronagraphic performance of off-axis telescopes will enable such ground or spaced-based instruments, which are starving for higher dynamic range, for example, faint companion detection and solar studies. Telescope and mirror fabrication technology readiness has allowed the fabrication of SOLAR-C (IfA/Haleakala Observatory), and the New Solar Telescope (NST/NJIT/ Big Bear Observatory). Both are test beds for the Advanced Technology Solar Telescope (ATST Project) for which site construction is beginning on Haleakala.

8444-108, Poster Session

Science requirements and survey strategy for the next generation Canada-France-Hawaii Telescope

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The Next Generation Canada-France-Hawaii Telescope (NGCFHT) is a dedicated, 10m, wide-field, multi-object spectroscopic facility proposed as an upgrade to the existing CFHT on the summit of Mauna Kea. It will be able to obtain simultaneous spectra for up to 3200 targets over a 1.5 square degree field of view, in the wavelength range 0.37 - 1.3 microns, at resolutions of R=2000, 6000 and 20000. It will be the sole facility capable of obtaining the necessary, large, spectroscopic datasets to compliment the many existing and planned imaging and astrometric surveys, such as PanSTARRS, LSST, Euclid and GAIA. Its operational flexibility will enable it to have a transformative effect on science cases as diverse as exoplanetary host characterisation, the interstellar medium, stars and stellar astrophysics, near-field cosmology and the formation of the Milky Way, nearby galaxy structure, AGN, QSOs, galaxy evolution, cosmology and dark energy. Here, I discuss the science drivers for the facility, their impact on the technical and operational requirements, and describe the proposed plans for implementation of large scale surveys while maintaining an essential "Principal Invesitigator" science component.

8444-109, Poster Session

The optics and detector-simulation of the air fluorescence telescope FAMOUS for the detection of cosmic rays

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A sophisticated method for the observation of ultra-high-energy cosmic rays (UHECRs) is the fluorescence detection technique of extensive air showers (EAS).

Originating from outer space, UHECRs constantly hit the atmosphere of the Earth. Here they interact with a nucleus and an EAS evolves in the atmosphere whose particles excite nitrogen molecules. When they de-excite, light in the ultraviolet regime is emitted isotropically. Currently, photomultiplier tubes (PMTs) are employed for the light detection as for instance at the Pierre Auger Observatory - the world's largest cosmic ray detector.

FAMOUS will be a small fluorescence telescope which instead is instrumented with silicon photomultipliers (SiPMs) as highly-sensitive light detectors. In comparison to PMTs, SiPMs promise to have a higher photon-detection-efficiency, do not require a high-voltage and have a compact package of currently up to $36,textmd{mm}^2$. An increase in sensitivity allows to detect more distant and lower energy showers which will contribute to an enrichment of the current understanding of the development of EAS and the mass composition of UHECRs.

The refractive optical design of FAMOUS involves a large Fresnel lens as main component and Winston cones for the concentration of light onto each of the 64 SiPMs of the hexagonal focal plane array. As a result of the wide field of view, the telescope is enabled to overlook an area of several square-kilometers.

An EAS- and a ray-tracing-simulation of FAMOUS permit the compilation of a complete detector response and the evaluation of the performance.

8444-110, Poster Session

Experimental characterization of the turbulence inside the dome and in the surface layer

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We present the concept of a new instrument dedicated to the modeling of the turbulence inside the dome and in the surface layer. It consists of using parallel laser beams separated by non redundant baselines between 0.1 and 2-3m and measuring Angle-of-Arrival (AA) fluctuations from spots displacements on a CCD. We use weighted least-square method to fit the measured AA longitudinal and transverse covariances with theoretical forms deduced from the usual models of turbulence. The surface layer turbulence energy in terms of CN2 constant is provided from the structure function as in the DIMM instrument.

8444-111, Poster Session

Seeing trends from deployable Shack-Hartmann wavefront sensors, MMT Observatory, Arizona, USA

J. D. Gibson, G. G. Williams, T. Trebisky, MMT Observatory (United States)

Deployable Shack-Hartmann wavefront sensors (WFS) for the f/5 and f/9 secondary mirrors at the 6.5-m MMT Observatory (MMTO) have been in routine use since 2003. Probe mirrors for these WFS's are positioned

on axis in the telescope optical path between scientific observations multiple times each night. Results from these wavefront measurements are then used to deform the primary mirror (M1) and to reposition the secondary mirror (M2) to correct for wavefront errors. In addition to measuring the optical wavefront error, the Shack-Hartmann data can be used to determine the delivered seeing using the measured spot sizes. This study attempts to analyze the more than 75,000 WFS aberrations and associated seeing values obtained at the MMTO since 2003. The overall WFS data reduction and analysis procedure is discussed with an emphasis on software changes in the past 3-5 years. This data analysis includes: 1) finding the spots in each image, 2) centroiding the spots, 3) calculating a point-spread function, 4) re-calculating centroids for spots, 5) computing the Zernike coefficients, and 6) determining an average spot width and thus a derived seeing value. Wavefront slopes are calculated from spot displacements and wavefront aberrations are fit with a 19-term Zernike polynomial. As part of this study, WFS results are correlated with other observing parameters, such as secondary mirror, exposure time, and M1 thermal figure, including both spatial and temporal fluctuations. Finally, seasonal climate (e.g., prevailing wind direction) and local weather (e.g., ambient temperature) effects are evaluated.

8444-112, Poster Session

An updated T-series thermocouple measurement system for high-accuracy temperature measurements of the MMT primary mirror

D. L. Clark, J. D. Gibson, MMT Observatory (United States)

The physical installation of a set of radially-distributed type T thermocouples, which are are arranged in both single measurement points and as thermopiles for differential temperature sensing and were installed after the primary mirror polishing was completed is briefly described. We constructed the new electronics with on-board cold-junction compensation, real-time ITS-90 curve fitting, and Ethernet connectivity to output measurements to the MMTO data server. The electronics use a unique pair of boards that can be freely interchanged to measure individual thermocouples (one type of board) and thermopiles (a second type). Both types use a 24-bit ADC and a pair of platinum RTDs for both the thermocouple measurements and the cold-junction measurement. The ADCs are read by a local microprocessor running Jean LaBrosse's uC-OSII, which has tasks spawned to handle reading the data, transforming it to linearized temperatures, and writing it over the network. Each of these major components, thermocouples, measurement boards, microprocessor and software, and network data server are described.

8444-113, Poster Session

Determination of seismic accelerations for the LSST telescope

D. R. Neill, National Optical Astronomy Observatory (United States)

The Large Synoptic Survey Telescope (LSST) will be located on the seismically active Chilean mountain of Cerro Pachón. The accelerations resulting from a seismic event produce the most demanding load cases the telescope and its components must be designed to withstand. Consequently, accurate prediction of these seismic accelerations is required to produce a safe and cost effective telescope. The results of an earlier site specific seismic hazard survey were compared to the Chilean building code and measured seismic accelerations. This determined that a new seismic hazard survey was required and provided appropriate interim baseline peak spectral accelerations (PSA), where the baseline PSA was based on a 500 year return period and 5% damping. As a result of their hysteresis minimizing designs, telescopes have inherently low damping. This baseline PSA was modified to account for this reduction in damping. Utilizing the baseline 500 year return period for the telescope would produce excessively large design accelerations. Consequently, a technique was developed and applied to modify the baseline PSA for variations in return year. Both mathematically exact and simplified methodologies were applied for converting the commonly used PSA into a more useful power spectral density (PSD). These efforts led to an initial design PSD for analysis of the effect of seismic accelerations on the LSST telescope. These input ground accelerations will be applied to the existing comprehensive FEA model of the telescope, pier and mountain top.

8444-114, Poster Session

Modeling seismic behavior of static supports of Giant Magellan Telescope (GMT)

F. W. Kan, A. T. Sarawit, P. G. Cranston, Simpson Gumpertz & Heger Inc. (United States)

The Giant Magellan Telescope (GMT) is a 21.5-meter equivalent aperture optical-infrared ELT to be located at Las Campanas Observatory in Chile. It is being designed and constructed by a group of U.S. and international universities and research institutions. The Project is currently mid-way through its Design Development Phase.

This paper will discuss the modeling of the GMT's static supports (circular arch isolators) during seismic events. Dynamic analyses were performed to determine the response of the telescope structure to earthquake-induced ground motion for operational and survival level earthquake. Ground motion time history data from site specific probabilistic seismic hazard study were used as inputs to non-linear time history analysis. The circular arch type static supports were modeled using connector elements in ABAQUS. The non-linear hysteresis behavior of the connector elements was calibrated from dynamic load-displacement test data collected over a range of displacement and load levels. The results of the analysis in the form of accelerations, displacements, response spectra, and stresses were used in the final design of the telescope structure and its subsystems.

8444-115, Poster Session

Design concept for a spectropolarimetric focal station for the E-ELT

K. G. Strassmeier, I. v. Ilyin, I. DiVarano, M. F. Woche, Leibniz-Institut für Astrophysik Potsdam (Germany); U. Laux, Thüringer Landessternwarte Tautenburg (Germany)

We present and discuss a strawman design for a spectropolarimetric focal station for the European Extremely Large Telescope (E-ELT). Part of the focal station is a dual-beam spectropolarimeter with a Schwarzschild collimator in the symmetric beam of the intermediate f/4.4 telescope focus. The focal station would also be able to provide calibration light for polarimetric instruments in the Nasmyth foci and then shall constitute part of a smart focal plane. The operating wavelength range is 380-1600nm with an ultraviolet option towards the atmospheric cut off. Our concept allows at least two different spectrographs to simultaneously receive light from the spectropolarimeter via two pairs of fibers. Its aim is to detect a differential polarimetric precision of 10-5 in selected spectral lines and minimize the instrumental impact on continuum polarization as much as possible. The entire focal station is retractable to a parking position within the telescope's AO tower.

8444-118, Poster Session

Development status of the prototype of the GMT fast steering mirror

Y. Kim, J. H. Koh, I. Chung, Korea Astronomy and Space Science

Institute (Korea, Republic of); M. K. Cho, National Optical Astronomy Observatory (United States); H. Yang, Korea Research Institute of Standards and Science (Korea, Republic of); H. Kim, Institute for Advanced Engineering (Korea, Republic of); H. Ahn, Gwangju Institute of Science and Technology (Korea, Republic of); B. Park, Korea Astronomy and Space Science Institute (Korea, Republic of)

Fast Steering Mirror (FSM) is a common thick secondary mirror with an added functionality of tip-tilt actuation of the mirror. It is going to be implemented at the Giant Magellan Telescope as one of the secondary mirror systems. FSM is 3.2 m in diameter and has a fast focal ratio of 0.65. FSM consists of seven segments, each of which is 1m in diameter. The surrounding six segments except the center one are off-axis mirrors. FSM compensates image degradations caused by wind disturbances and structure jitter by using a tip-tilt mechanism.

Korea Astronomy and Space Science Institute is developing a prototype of the FSM together with collaborators in Korea and USA. The prototype is a full-size FSM segment, and it is divided into two features functionally; an off-axis mirror and a test-bed for tip-tilt actuation. The off-axis mirror with a diameter of 1.06m is being fabricated. Light-weighting is completed, and polishing, figuring, and testing are prepared to proceed. The tip-tilt test-bed is integrated with a dummy aluminum mirror, three axial supports, a lateral support, and a test-bed frame. The test-bed will verify the tip-tilt parameters. The prototype is expected to be completed by the end of 2012. In this paper, we present progress of the prototype development, and future works.

8444-119, Poster Session

Performance of industrial scale production of ZERODUR mirrors with diameter of 1.5 m proves readiness for the ELT M1 segments

T. Westerhoff, P. Hartmann, R. Jedamzik, A. Werz, SCHOTT AG (Germany)

The two Extremely Large Telescopes under discussion, the Thirty Meter Telescope and the European Extremely Large Telescope, will use a multitude of hexagonal shaped mirror segments to achieve the large aperture of 30 m and 39 m, respectively. The proper functionality of both telescopes will strongly depend upon the variation of material properties between individual segments.

SCHOTT has a well proven experience in production of mirror substrates for segmented telescopes. Today five of the world's six segmented telescopes are using ZERODUR® as mirror substrate material. Since 2003 SCHOTT delivered more than 260 mirrors of 1.5 m in diameter for industrial application not related to astronomy. In this paper the achievements during the serial production of those are presented for specified material properties and dimensional parameters. The presentation includes data on the fulfillment of the CTE specification, the achieved tolerances on surface figure and flatness and other geometrical quality parameters. The data to be presented will demonstrate the excellent reproducibility of ZERODUR®'s material properties and its manufacturing process. The production capabilities at SCHOTT for the successful delivery in time of the multitude of ZERODUR® segments are presented and discussed. They will demonstrate that ZERODUR® is well prepared for the demands of industrial scale production for the two large segmented ELT's in quality, quantity, and in the requested time period.

8444-120, Poster Session

E-ELT project: geotechnical investigation at Cerro Armazones

P. Ghiretti, V. Heinz, European Southern Observatory (Germany); D. Pollak, ARCADIS Chile S.A. (United States); J. Lagos, ARCADIS Chile S.A. (Chile)

The challenges to build the E-ELT do not involve only physical or optical risks but also construction aspects. In order to guarantee reliable and stable performances, a giant telescope like the E-ELT needs a basement at the same level of efficiency as the other telescope's components.

Cerro Armazones seats near one of the most active seismic faults of the world and earthquakes occurred during centuries have influenced the subsoil consistence. ESO has performed, during the year 2011, an in depth geological and geotechnical campaign at Cerro Armazones to define the subsoil characteristics.

This poster describes the main activities made directly on site along with the studies made in specialised laboratories to achieve a meticulous definition of actual ground's characteristics. The outcome from this study is that, even if the subsoil is affected by several cracks due to the high seismicity of the area, soil capacity and stiffness are absolutely aligned with all the challenges the E-ELT will be called to answer during the next decades.

8444-121, Poster Session

Technological developments toward the small size telescopes of the Cherenkov Telescope Array

R. Canestrari, INAF - Osservatorio Astronomico di Brera (Italy) and for the CTA consortium (Italy); T. J. Greenshaw, Univ. of Liverpool (United Kingdom); G. Pareschi, INAF - Osservatorio Astronomico di Brera (Italy); R. White, Univ. of Leicester (United Kingdom)

In the last two decades a new window for ground-based high energy astrophysics has been opened. This explores the energy band from about 100 GeV to 10 TeV by making use of Imaging Atmospheric Cherenkov Telescopes (IACTs). Research in Very High Energy (VHE) gamma-ray astronomy is progressing rapidly and, thanks to the newest facilities such as MAGIC, HESS and VERITAS, astronomers and particle physicists are obtaining surprising implications in the theoretical models.

The Cherenkov Telescope Array (CTA) is the ambitious international next-generation facility for gamma-ray astronomy and astrophysics. CTA is an international project that aims to enhance the sensitivity (by a factor of 10 over current instruments), the energy band coverage (from below 50 GeV to above 100 TeV), the energy and angular resolution to allow precise imaging, photometry and spectroscopy of sources. To achieve this, an extended array composed of nearly 100 telescopes of large, medium and small dimensions is under development. Those telescopes will be optimized to cover the low, intermediate and high energy regimes, respectively.

In this paper, we focus our attention on the Small Size Telescopes (SSTs): these will be installed on the CTA southern hemisphere site and will cover an area up to 10 km2. The energy range over which the SSTs will be sensitive is from around 1 TeV to several hundreds of TeV. The status of the optical and mechanical designs of these telescopes is presented and discussed. Comments are also made on the focal surface instruments under development for the SSTs.

8444-254, Poster Session

SST-GATE: an innovative telescope for the very high energy astronomy

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The Cherenkov Telescope Array (CTA) is an international collaboration that aims to create the world's largest (ever) Very High Energy gamma-ray telescope array, consisting of more than 100 telescopes covering an area of several square kilometers to observe the electromagnetic showers generated by incoming cosmic gamma-rays with very high energies (from a few tens of GeV up to over 100 TeV).

Observing such sources requires - amongst many other things - a large FoV (Field of View). In the framework of CTA, SST-GATE (Small Size Telescope - Gamma-ray Telescope Elements) aims to investigate and to build one of the two first telescopes based on the Schwarzschild-Couder (SC) optical design that delivers a FoV close to 10 degrees in diameter. To achieve the required performance per unit cost, many improvements in mirror manufacturing and in other technologies are required. We present in this paper the current status of our project. After a brief introduction of the very high energy context, we present the opto-mechanical design, discuss the technological trade-offs and explain the electronics philosophy that will ensure the telescopes cost is minimised without limiting its capabilities. We then describe the software necessary to operate the telescope and conclude by presenting the expected telescope performance and some management considerations.

8444-122, Poster Session

A new era for the 2-4 meters class observatories: an innovative integrated system telescope-dome

G. Marchiori, A. Busatta, S. de Lorenzi, F. Rampini, European Industrial Engineering s.r.l. (Italy); C. Perna, G. Vettolani, Istituto Nazionale di Astrofisica (Italy)

The experiences and the lessons learned gained in two decades of activity in Astronomical Industry in Projects like NTT, VLT, LBT, VST, VISTA, ALMA and now E-ELT brought to develop a innovative flexible fully integrated system which could address every astronomic national communities to approach astronomy with a complete self standing facility including Dome, Telescope with 2 to 4 meters class optics and relative instruments with which it is possible to match the desired science cases and objectives.

This work describes the aspects of the flexibility, which is so important to adapt the Design to the Specifications in order to fulfil the various science goals, in the least time possible, through the latest design tools, such as CAD, CAE, FEM, etc. and the best and more cost effective technology experienced with the projects mentioned before.

8444-123, Poster Session

Low-frequency high-sensitivity horizontal monolithic folded-pendulum as sensor in the automatic control of ground-based and space telescopes

F. Acernese, G. Giordano, R. Romano, F. Barone, Univ. degli Studi di Salerno (Italy)

This paper describes a new mechanical implementation of a monolithic folded pendulum based inertial sensor, configurable as seismometer and as accelerometer. The sensor is a compact, light, fully scalable, tunable (1500 in air) instrument, with immunity to environmental noises guaranteed by an integrated laser optical readout. The measured sensitivity curve is in very good agreement with the theoretical one (10^-12 m/sqrt(Hz) in the band (0.1-10 Hz). Although its natural application is in the fields of earthquake engineering and geophysics, its performances and, above all, compactness and full scalability, make it suitable also for applications as sensors in the control of systems requiring large band and low frequency coupled with high sensitivities. This is the case of inertial platforms, that require a careful design not only of the mechanical attenuation stages but also of the control systems, especially if a residual horizontal motion better than 10-15 m/sqrt(Hz) in the band 0.01 - 100 Hz is a requirement. But it is also the case of the mechanical support systems of ground-based or space telescopes that must be carefully controlled in order to maximize their optical performances. In this paper we describe the sensors, their performances, the present applications to the control of mechanical systems, discussing their advantages of their use as sensors in the control system of ground-based and space telescopes.

8444-124, Poster Session

Herzberg Institute of Astrophysics' vibration measurement capabilities with applications to astronomical instrumentation

P. W. G. Byrnes, National Research Council Canada (Canada)

The Herzberg Institute of Astrophysics, Astronomy Technology Research Group's vibration measurement capabilities include modal test via impulse hammer or electro-dynamic exciter, structural response monitoring via piezoelectric accelerometers, and data acquisition via LabVIEW virtual instruments. This poster will review our existing capabilities, and give examples of past and future applications relevant to astronomical instrumentation.

8444-125, Poster Session

ALMA temporal phase stability and the effectiveness of water vapor radiometer

S. Matsushita, Academia Sinica (Taiwan); K. Morita, D. Barkats, R. E. Hills, ALMA (Chile); E. B. Fomalont, National Radio Astronomy Observatory (United States); B. Nikolic, Univ. of Cambridge (United Kingdom)

Atacama Large Millimeter/submillimeter Array (ALMA) will be the world largest mm/submm interferometer, and currently the Early Science is ongoing, together with the commissioning and science verification (CSV). Here we present the temporal phase stability of the entire ALMA system; from telescope to correlator. The data, taken during the last 2 years of CSV activities, consisted of integrations on strong point sources (i.e., bright quasars) at various frequency bands, and at various baseline lengths (up to 600 m). We first verified the temporal phase stability. We observed a strong quasar for a long time (a few tens of minutes), derived the temporal structure function after the atmospheric phase correction using the water vapor radiometers (WVRs), and confirmed that the phase stability of all the baselines reached the ALMA specification. We then verified frequency transfer between bands. We observed a bright quasar and switched between the two frequency bands, and confirmed that the phase returned to the original values within the phase fluctuation.

Since we applied the WVR phase correction to all the data mentioned above, we also studied the effectiveness of the WVR phase correction at various frequencies, baseline lengths, and weather conditions. The phase stability often improve a factor of 2 - 3 after the correction, and sometimes a factor of 7 improvement can be obtained. However, the corrected data still displays an increasing phase fluctuation as a function of baseline length, suggesting either that the phase correction is imperfect or that the dry component of the atmosphere also contributes the phase fluctuation in the data.

8444-126, Poster Session

ALMA array element astronomical verification

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The Atacama Large Millimeter/submillimeter Array (ALMA) is a joint project between astronomical organizations in Europe, North America, and East Asia, in collaboration with the Republic of Chile. ALMA will consist of at least 54 twelve-metre antennas and 12 seven-metre antennas operating as an aperture synthesis array in the (sub)millimetre wavelength range.

The ALMA System Integration Science Team (SIST) is a group of scientists and data analysts whose primary task is to verify and characterize the astronomical performance of array elements (individual, fully equipped antennas) as single dish and interferometric systems. This work is done for antennas being processed for the first time as part of ALMA construction, and for operational array elements which require re-verification following maintenance, repair, or upgrade activities. They also support System Verification, Commissioning and Science Verification, and Array Systems activities as required.

The verification tasks performed varies according to the requirement of the array element in question. The full set of tasks is required for the initial construction phase verification of every array element, and these can be divided roughly into fundamental antenna performance tests (verification of antenna surface accuracy, basic tracking, switching, and on-the-fly rastering) and astronomical radio verification tasks (radio pointing, focus, basic interferometry, and end-to-end spectroscopic verification). These activities occur both at the Operations Support Facility (just below 3000 metres elevation) and at the Array Operations Site at 5000 metres.

8444-127, Poster Session

Trajectory generation for parametric rotating scan patterns at the LMT

D. R. Smith, MERLAB, P.C. (United States); K. Souccar, Univ. of Massachusetts Amherst (United States)

As main axis controllers for large, high precision telescopes have become more sophisticated, astronomers are developing new approaches to observing. Rather than merely pointing at a particular set of coordinates and tracking to account for the rotation of the Earth or for the ephemeris of the source, these new observing techniques often call for a telescope to scan in a pattern around the nominal source coordinates. These motions are conducted at higher rates and accelerations than traditional single point or raster maps, which introduces additional complexity into the control. Additionally, these motions must work in conjunction with an existing trajectory generator.

This paper describes how a general parametric rotating scan pattern has been implemented at the Large Millimeter Telescope (LMT). The desired motion is combined with the existing trajectory generator and allows the addition of an a scan pattern, defined for each axis parametric with time. The pattern can also be continuously rotated at a constant rate as the system tracks the source. The development allows for any parametric scan pattern, but the particular case of a continuously rotating Lissajous pattern is addressed in detail.

8444-128, Poster Session

Atacama compact array antennas

M. Saito, J. Inatani, K. Nakanishi, H. Saito, S. Iguchi, National Astronomical Observatory of Japan (Japan)

ALMA (Atacama Large Millimeter/submillimeter Array) is a radio interferometer array under construction in the Atacama Desert at an altitude of approximately 5000 meters in northern Chile in the frequency range from 31.3 to 950 GHz (10 - 0.35 millimeter in wavelength). ALMA consists of fifty 12-m antennas and “Atacama Compact Array (ACA)”. The ACA system is composed of four 12-m antennas and twelve 7-m antennas both of which are delivered by NAOJ. The ACA system aims to acquire the total-power and short-baseline interferometer data that cannot be taken with the array of only 12-m antennas, which increases reliability of interferometer images of astronomical sources. The requirements of the ACA antennas are very challenging. The four major performances are all-sky pointing (≲ 2.0 arcsec), offset pointing (≲ 0.6 arcsec) surface accuracy (< 25 micrometers), and stability of path-length (15 micrometers over 3 min) under the realistic daytime and nighttime conditions at the site (5000 m). Both 12-m and 7-m antennas are constituted by a symmetrical paraboloidal reflector with a Cassegrain optical layout mounted on an Altitude-Azimuth mount. The primary reflector surface consists of machined aluminum panels with a suitable surface finish to enable direct solar observing. The reflector surface is mounted by means of adjusters onto a reflector backup structure (BUS). The subreflector with its mechanism is supported by feed legs in a quadripod configuration. The position of the subreflector is remotely adjusted with a controlled mechanism for focusing and collimation. The online pointing correction system was introduced to satisfy a stringent requirement of pointing and tracking performances. The ACA antennas have been extensively evaluated at the antenna erection site at an altitude of about 2900 meters. Pointing performance was evaluated with a specially dedicated Optical-Pointing Telescope (OPT) aboard the ACA antenna. Near field holography was used to measure and adjust the reflector surface under various weather conditions. Fast motion capabilities were tested using encoder readings.

8444-129, Poster Session

Very Large Millimeter/Submillimeter Array toward Search for 2nd Earth

S. Iguchi, M. Saito, National Astronomical Observatory of Japan (Japan)

To directly detect 2nd Earth, we have to carefully design the sensitivity and angular resolution of the telescope by conducting trade-off analysis between the confusion limit and the minimum detectable temperature. The result of the sensitivity analysis is derived assuming an array that has sixty-four (64) 50-m antennas with 25- m surface accuracy mainly located within the area of 300 km (up to 3000 km), dual-polarization SSB receivers with the best noise temperature performance achieved by ALMA or better, and IF bandwidth of 128 or 256 GHz.. We temporarily name this telescope “Very Large Millimeter/Submillimeter Array (VLMSA)”. Since this sensitivity is extremely high, we can have a lot of chances to study the galaxy, star formation, cosmology and of course the new scientific frontier.

8444-130, Poster Session

The MWA digital receiver

P. Thiagaraj, K. S. Srivani, P. A. Kamini, M. S. Madhavi, Raman Research Institute (India); A. Roshi, National Radio Astronomy Observatory (United States); F. H. Briggs, Research School of Astronomy & Astrophysics (Australia); M. R. Gopalakrishna, A. A. Deshpande, N. Udayshankar, Raman Research Institute (India)

An FPGA based digital receiver is developed for the Murchison Wide Field Array (MWA), a low-frequency imaging radio interferometer facility being built in the radio-quiet site MRO Western Australia. This digital receiver incorporates many features that aid remote observations with the telescope. During a normal operation the digital receivers can be configured to digitize the 327.68 MHz wide bands from MWA antennas, perform PFB, re-quantization, sub band selection, aggregation, formatting and synchronized transportation of the packaged spectral data through fibers to a centrally located backend facility. During special operations, the receivers can be configured to transmit time slices of the unprocessed digitized outputs from the ADCs or the entire spectra coming out of the PFB in a higher precision format to the backends. During a normal operation, the receiver FPGAs continuously compute signal power, integrated spectra, detect and count number of RFI like features encountered at ADC outputs and in spectral subbands. This metadata depicting data quality can be read out any time or periodically from the receiver as a slower speed stream through an auxiliary interface port provided in the receiver. The receiver design also incorporates few other diagnostics and monitoring tools to help assess normal operation or isolate faults by a remote user. At present, the receiver hardware is also enhanced to incorporate full bandwidth beamforming modes. The talk would outline the implemented architecture of the digital receiver; discuss signal processing involved, operational considerations, merits, enhancements planned, current status; and show results from its operation with the telescope.

8444-253, Poster Session

ACA phase calibration scheme with the ALMA water vapor radiometers

Y. Asaki, Japan Aerospace Exploration Agency (Japan); S. Matsushita, Academia Sinica (Taiwan); K. Morita, National Astronomical Observatory of Japan (Japan)

We propose a phase calibration scheme for the Atacama Compact Array (ACA) using water vapor radiometers (WVRs). In the proposed scheme the WVRs devoted to measurements of tropospheric water vapor content are attached to the four 12-m antennas. The excess path length (EPL) due to the tropospheric water vapor variations aloft is fitted to a simple two-dimensional slope using WVR measurements. Interferometric phase fluctuations for each baseline due to the turbulent water vapor are obtained from differences of inferred line-of-sight EPL and subtracted from the interferometric phases for the correction. We have carried out a series of simulations of the ACA phase calibration and found that the proposed scheme is quite promising. ALMA has started performance verifications in the interferometer mode. In 2010, nine antennas were sighted in a 100-m square region while the other one was located 500-m away from the nine antenna cluster. Four antennas of the cluster were placed on each of the four corners of the square. This array configuration is very suitable to investigate the performance of the ACA phase calibration scheme for the next step. We will report on the feasibility study for the ACA phase calibration by using the ALMA performance verification data.

8444-132, Poster Session

Functional safety for the advanced technology solar telescope

S. Bulau, T. R. Williams, National Solar Observatory (United States)

Since inception, the Advanced Technology Solar Telescope (ATST) has planned to implement a facility-wide functional safety system to protect personnel from harm and prevent damage to the facility or environment. The ATST will deploy an integrated safety instrumented system (SIS) to achieve functional safety throughout the facility rather than relying on individual facility subsystems to provide safety functions on an ad hoc basis.

The Global Interlock System (GIS) is an independent, distributed, facility-wide, safety-related control system (SRCS), comprised of commercial off-the-shelf (COTS) programmable automation controllers (PACs) that monitor, evaluate, and control hazardous energy and conditions throughout the facility that arise during operation and maintenance.

The GIS has been designed to utilize recent advances in technology for functional safety plus revised national and international standards that allow for a distributed architecture using programmable controllers over a local area network (LAN) instead of traditional hard-wired safety functions, while providing an equivalent or even greater level of safety.

Programmable automation controllers provide an ideal platform for controlling the often complex interrelationships between subsystems in a modern astronomical facility, such as the ATST. A large, complex hard-wired relay control system is no longer needed. This type of system also offers greater flexibility during development and integration in addition to providing for expanded capability into the future. The GIS features fault detection, self-diagnostics, and redundant communications that will lead to decreased maintenance time and increased availability of the facility.

8444-133, Poster Session

Facility level thermal systems for the advanced technology solar telescope

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The management and control of the local aero-thermal environment is critical for success of the Advanced Technology Solar Telescope (ATST). In addition to minimizing disturbances to local seeing, the facility thermal systems must meet stringent energy efficiency requirements to minimize impact on the surrounding environment and meet federal requirements along with operational budgetary constraints. This paper describes the major facility thermal equipment and systems to be implemented along with associated energy management features. The systems presented include the central plant, the climate control systems for the computer room and coudé laboratory, the carousel cooling system which actively controls the surface temperature of the rotating telescope enclosure, and the systems used for active and passive ventilation of the telescope chamber.

8444-134, Poster Session

The new K-coronagraph for the Mauna Loa Solar Observatory

A. G. de Wijn, J. T. Burkepile, S. Tomczyk, National Ctr. for Atmospheric Research (United States)

The COronal Solar Magnetism Observatory (COSMO) is a proposed facility dedicated to studying coronal and chromospheric magnetic fields and their role in driving solar activity such as coronal mass ejections (CMEs). COSMO is comprised of 3 instruments: 1) a 1.5 m coronagraph dedicated to the study of coronal magnetic fields; 2) a chromospheric and prominence magnetometer; and 3) a K-coronagraph. The National Center for Atmospheric Research (NCAR) has provided full funding for the COSMO K-coronagraph, which will be deployed to the Mauna Loa Solar Observatory (MLSO) in the summer of 2013. It will measure the polarization brightness (pB) of the K-corona formed by Thomson scattering of photospheric light by coronal free electrons. With a field-of-view of 1.05 to 3.0 solar radii and an image cadence of 15 seconds, it is ideally suited for studying the formation and propagation of CMEs which are the primary driver of space weather at Earth. It will replace the aging MLSO K-coronameter which has been in operation since 1980.

The COSMO K-Coronagraph is currently under construction and will be deployed to the Mesa spar in Boulder, CO, USA in late 2012 for testing. We will present the instrument concept, highlighting technical challenges, and provide an update on the development and construction effort.

8444-135, Poster Session

Quasi-static wavefront control for the ATST

L. C. Johnson, National Solar Observatory (United States); R. S. Upton, Johns Hopkins Univ. Applied Physics Lab. (United States); T. R. Rimmele, S. C. Barden, National Solar Observatory (United States)

The Advanced Technology Solar Telescope (ATST) requires active control of quasi-static wavefront aberrations in order to achieve the image quality set by its science requirements.

Finite element modeling of the telescope mount assembly calculates misalignments of telescope optics caused by changing gravitational forces and thermal gradients.

We interpolate the finite element analysis results to generate expected misalignments over all possible observing angles and thermal profiles.

These misalignments can be input to a ZEMAX model of the telescope to calculate the resulting wavefront errors.

We present results of modeling the quasi-static wavefront errors expected during a typical observing day and demonstrate that our active optics correction algorithm is limited only by wavefront sensor noise.

The active optics reconstructor corrects quasi-static wavefront errors with minimal force applied to the primary mirror while also introducing negligible pointing error due to the active optics correction.

Wavefront sensor noise is determined by the atmospheric averaging time and the target contast.

We present simulations that show an atmospheric averaging time of 60-120 seconds will be sufficient to meet the active optics error budget for typical use cases.

8444-136, Poster Session

The Coronal Solar Magnetism Observatory (COSMO) large aperture coronagraph

D. J. Gallagher, S. Tomczyk, National Ctr. for Atmospheric Research (United States)

The COSMO is a facility dedicated to observing coronal and chromospheric magnetic fields. It will be located on a mountaintop in the Hawaiian Islands and will replace the current Mauna Loa Solar Observatory (MLSO). COSMO will provide unique observations of the global coronal magnetic fields and its environment to enhance the value of data collected by other observatories on the ground (SOLIS, ATST, FASR) and in space (SDO, Hinode, SOHO, GOES, STEREO). COSMO will employ a fleet of instruments to cover many aspects of measuring magnetic fields in the solar atmosphere. The dynamics and energy flow in the corona are dominated by magnetic fields. To understand the formation of CMEs, their relation to other forms of solar activity, and their progression out into the solar wind requires measurements of coronal magnetic fields. The large aperture coronagraph, the Chromospheric and Prominence Magnetometer and the K-Coronagraph form the COSMO instrument suite to measure magnetic fields and the polarization brightness of the low corona used to infer electron density. The large aperture coronagraph will employ a 1.5 meter fuse silica singlet lens, birefringent filters, and a spectropolarimeter to cover fields of view of up to 1 degree. It will observe the corona in faint forbidden emission lines of Fe XIII at 1074.7 nm and 1079.8 nm. These lines are faint and require the very large aperture unlike the typical 20cm aperture coronagraph. NCAR and NSF have provided funding to bring the large aperture coronagraph to a preliminary design review state by the end of 2013. The COSMO K-coronagraph has been fully funded by NCAR. It has already passed a formal design review and will be deployed to Mauna Loa in 2013. This deployment will mark a major advancement in ground based coronal imaging at the MLSO site, replacing the current K-coronameter which has been in operation since 1980. As with all data from Mauna Loa, the data products from COSMO will be available to the community via the Mauna Loa website: http://mlso.hao.ucar.edu

8444-137, Poster Session

Preliminary design and integrated modeling of the Chinese Giant Solar Telescope structure

L. Zago, HEIG-VD (Switzerland); D. Yang, Nanjing Institute of Astronomical Optics & Technology (China); Y. Dai, Yunnan Astronomical Observatory (China)

The Chinese Giant Solar Telescope (CGST) is a next generation ground based large solar telescope with a 8-m segmented ring aperture. The concept takes advantage of the favorable characteristics of a ring aperture in polarization detection and thermal control.

The paper presents the structural and optomechanical design of the telescope as well as an integrated simulation of all structure dynamics effects affecting the ultimate optical performance.

The telescope concept is based on a rather conventional Alt-Az mounted Serrurier struts tube. Taking advantage of the ring aperture, the fork can be reduced in size resulting in a particularly compact base.

Integrated structural modeling is implemented in Matlab/Simulink, including a parametric finite element model, which outputs the various plant models for the various actively controlled systems. Thus the effect of electromechanical design options can be immediately assessed in terms of dynamic performance.

The outcome of the simulation can then directly be input to the global error budget of the optical performance of the telescope.

8444-139, Poster Session

Performance verification of the ATST mount by end-to-end simulations

H. J. Kärcher, A. Ippa, O. Dreyer, MT Mechatronics GmbH (Germany); P. F. Jeffers, National Solar Observatory (United States); G. Bonomi, Ingersoll Machines Tools, Inc. (United States)

The Advanced Technology Solar Telescope (ATST) will be the largest solar telescope in the world - with a 4m aperture primary mirror and a 16m diameter co-rotating laboratory located within the telescope pier.

The ATST Telescope Mount Assembly uses for the main axes mechanisms bearing and drive technologies as developed for the machine tool industry. The approach was initiated by the encounter of telescope mount designers (MT Mechatronics MTM) with machine tool manu-facturers (Ingersoll Machine Tools IMT) and acknowledged by the AURA project team. The final decision for the proposal of the machine tool bearing and drive concept was based on a performance test on an existing IMT machine tool under telescope like operational scenarios, with a very promising outcome. During the preliminary design phase of the mount, which was finished in December 2011, all details of the mount structure and the axes mechanisms were elaborated by 3D CAD models, Finite Element calculations and end-to-end simulations. The performance verification covered pointing, jitter and drift under all relevant environmental scenarios inside the ATST enclosure.

An overview on the ATST mount project and design is given in a separate paper of this confe-rence. This paper describes the integrated modeling approach combining multiple techniques, like top-down system engineering guidelines, error budgets, finite element analysis, tests and end-to-end simulations, to verify this challenging decision for a new technology in a normally conservative telescope engineering environment. Special attention is given to structural opti-mizations including structural flexure and dynamics, and the end-to-end simulation of wind buffeting and bearing friction, including a comparison with executed tests at IMT.

8444-140, Poster Session

Behavior of a horizontal air curtain subjected to a vertical pressure gradient

J. S. Linden, L. Phelps, National Solar Observatory (United States)

We present the details on an experiment to investigate the behavior of an air curtain that is subjected to a transverse pressure gradient. The setup simulates the conditions that will be present in the Advanced Technology Solar Telescope (ATST), a 4-meter solar observatory that will be built on Haleakala, Hawaii. A test rig was built to replicate the region at which the optical path crosses a temperature and pressure boundary between the Telescope Mount region, which is at the ambient temperature and pressure, and a warmer, pressurized lab space directly below. Use of an air curtain in place of an optically-transmitting window at the interface would allow science observations at a wider range of scientific wavelengths. With the air curtain exhibiting transitional flow behavior across the boundary, and applied pressure gradients of up to 6.5 Pa, we found that the air curtain was able to hold a pressure gradient of 0.25 Pa. As the applied pressure was increased, transient turbulent regions formed at the interface, and predictable flow behavior only occurred in the region closest to the air curtain blower. Computer modeling is used to validate the test data, identify laminar regions of the air curtain where minimal image distortion would occur, and explore the relationship between the applied pressure, effective pressure difference, and air curtain profile.

8444-143, Poster Session

ATST telescope mount: machine tool or telescope

P. F. Jeffers, National Solar Observatory (United States); G. Stoltz, G. Bonomi, Ingersoll Machines Tools, Inc. (United States); O. Dreyer, H. J. Kärcher, MT Mechatronics GmbH (Germany)

The Advanced Technology Solar Telescope (ATST) will be the largest solar telescope in the world, and will be able to provide the sharpest views ever taken of the solar surface. The telescope has a 4m aperture primary mirror, however due to the off axis nature of the optical layout, the telescope mount has proportions similar to an 8 metre class telescope.

The technology normally used in this class of telescope is well understood in the telescope community and has been successfully implemented in numerous projects.

The world of large machine tools has developed in a separate realm with similar levels of performance requirement but different boundary conditions. In addition the competitive nature of private industry has encouraged development and usage of more cost effective solutions both in initial capital cost and thru-life operating cost.

Telescope mounts move relatively slowly with requirements for high stability under external environmental influences such as wind buffeting. Large machine tools operate under high speed requirements coupled with high application of force through the machine but with little or no external environmental influences.

The benefits of these parallel development paths and the ATST system requirements are being combined in the ATST Telescope Mount Assembly (TMA). The process of balancing the system requirements with new technologies is based on the experience of the ATST project team, Ingersoll Machine Tools who are the main contractor for the TMA and MT Mechatronics who are their design subcontractors.

This paper highlights a number of these proven technologies from the commercially driven machine tool world that are being introduced to the TMA design. Also the challenges of integrating and ensuring that the differences in application requirements are accounted for in the design are discussed.

8444-144, Poster Session

Introduction of a 2.5m telescope mount

G. Wang, B. Gu, X. Jiang, Z. Zhang, S. Yang, Y. Ye, Nanjing Institute of Astronomical Optics & Technology (China)

The 2.5m optical/infrared telescope introduced in this paper is a cooperation project between Nanjing Institute of Astronomical Optics and Technology (NIAOT) and Sagem Défense Sécurité for Moscow university. Sagem is in charge of optics while NIAOT is in charge of mount structure and control system. On September of 2011, the mount has finished its Factory Acceptance Test (FAT). The mount structure and its control system will be introduced in this paper. Meanwhile, the performance tested during the FAT of each sub-system will also be given in the corresponding sections. In the last part of the paper, some lessons learned from mount-making and project management will be shared by authors.

8444-145, Poster Session

Installation and verification of high precision mechanics in concrete structures at the example of ALMA antenna interfaces

V. Heinz, M. Kraus, European Southern Observatory (Germany); E. Orellana, Bautek S.A. (Chile)

For the ALMA interferometer at the array operation facility near San Pedro de Atacama at 5.000 meters asl 192 concrete antenna foundations had to be equipped with coupling points for 66 antennas. These antennas will be frequently moved between the foundations and placed on these interfaces without further adjustment.

To position the ALMA antennas with the required accuracy, high precision inserts need to be installed in previously casted concrete foundations. Very tight mechanical tolerances have to be applied to civil structures, with standard tolerances of not less than millimeters. This is extremely difficult considering the material (mortar and steel in a concrete slab) to be used and the environmental conditions on site. Special tools had to be designed and an installation and alignment procedure developed, tested and improved. Important was to have a robust process, which allows highest precision installation without major re-machining for approx 600 interface blocks. Installation material, which could cope with the conditions, was specially tested for these requirements.

The geometry of the interface and other parameters such as horizontal and vertical stiffness must be verified after the installation. Special metrology tools to measure reliable at micron level at high altitude had been selected.

The experience and knowledge acquired will be beneficial for the installation of any opto-mechanical device in civil engineering structures, such as telescope and dome track rails, but also in optical interfe-rometer installations. Metrology requirements and environmental conditions in most of these cases are equally challenging.

8444-146, Poster Session

E-ELT telescope main structure

A. Orden, A. Dilla, M. Alcantud, N. Ballesteros, Empresarios Agrupados (Spain)

The European Extra Large Telescope is ESO's biggest astronomical telescope project. It will be installed in Cerro Armazones, Antofagasta Region, Chile, at an altitude of 3046 metres above sea level.

This paper will describe the Telescope Main Structure (MS) developed by Empresarios Agrupados (Spain) during the FEED Studies performed from June 2009 to July 2011 in the frame of ESO Contracts.

The E-ELT is an active and adaptive telescope. It has an astigmatic optical solution (5 mirrors, including two flats). The telescope structure is

an alt-azimuth type able to support a primary mirror of 39 m equivalent diameter.

The scope of the paper will describe and justify the configuration chosen for the telescope structure (azimuth rings, azimuth and altitude structures), interfaces with bearings and drives and report on how the telescope will behave statically and dynamically. The optimization of the MS mass, inertia and overall stiffness were key issues addressed during the design phase. Aspects related to transport and final erection at site also had to be taken into account in the final configuration adopted, due to the need to elaborate a design with an optimized cost and that could be ready to operate on a tight schedule.

The telescope will be installed in a high seismicity zone. This significantly affected the boundary conditions and safety aspects considered during the project.

Most of the solutions implemented were extrapolated from existing installations in which Empresarios Agrupados has participated, adjusting for the extra large size of this new telescope.

8444-147, Poster Session

Testing, characterization, and control of a multi-axis high-precision drive system

I. M. Soukup, J. H. Beno, C. E. Penney, T. A. Beets, J. D. Esguerra, R. J. Hayes, J. T. Heisler, J. J. Zierer, G. A. Wedeking, M. S. Worthington, D. R. Wardell, The Univ. of Texas at Austin (United States); J. M. Good, J. A. Booth, G. J. Hill, M. E. Cornell, M. D. Rafal, McDonald Observatory (United States)

A multi-axis, high precision drive system has been designed and developed for the Dark Energy Experiment upgrade to the Hobby-Eberly Telescope at McDonald Observatory. Design, performance and controls details will be of interest to designers of large scale, high precision robotic motion devices. The drive system positions the 21-ton star tracker to a precision of less than 5 microns along each axis and is capable of 4 meters of X/Y travel, 0.3 meters of hexapod actuator travel, and 46 degrees of rho rotation. The positioning accuracy of the new drive system is achieved through the use of high-precision drive hardware in addition to a meticulously tuned high-precision controller. A comprehensive understanding of the drive structure, disturbances, and drive behavior was necessary to develop the high-precision controller. Thorough testing has characterized manufacture defects, structural deflections, sensor error, and other parametric uncertainty. Positioning control through predictive algorithms that analytically compensate for measured disturbances has been developed as a result of drive testing and characterization. The drive structure and drive dynamics are described as well as key results discovered from testing and modeling. Controller techniques and development of the predictive algorithms are discussed. The latest results are included, illustrating the current performance of several axes of the drive system, and future work that could further improve performance is discussed.

8444-148, Poster Session

Enclosure rotation on the Large Binocular Telescope

J. Howard, R. L. Meeks, D. S. Ashby, Large Binocular Telescope Observatory (United States); W. B. Davison, Steward Observatory (United States); J. Wiese, J. Urban, R. Hansen, J. Schuh, Large Binocular Telescope Observatory (United States)

After several years of operation the enclosure rotation system of the LBT is exhibiting wear and other performance issues that may impact operations. This paper reviews the system design and assumptions used, describes the current performance and observed symptoms, and discusses recent improvements made to improve performance and reliability.

The rotating enclosure of the LBT is a 2200 ton structure riding on four bogies with a total of 20 wheels. Identified deficiencies include wheel bearing capacities, bogie misalignment, and rail loading. These are partially due to excess enclosure weight, which was supposed to be 1600 tons, but also due to design errors.

The most serious problem was the failure of several wheel bearings. The bearings were not designed for field serviceability, so a crash program began to determine how to replace them. This got us back on sky quickly, but a review of the engineering calculations identified an error which led to the use of undersized bearings. A method of installing a larger bearing was found, and these are currently being installed.

One set of bogie wheels are misaligned so severely the structure makes loud popping and banging noises when the direction of building rotation changes. The bogie needs to be rotated about its vertical axis, but there was no provision in the design for this.

The circular rail the bogies roll on is wearing faster than expected. The rails are extremely difficult to replace, so the short term plan is to study the problem.

8444-150, Poster Session

The 3.6 m Indo-Belgian Devasthal Optical Telescope: the hydrostatic azimuth bearing

J. Deville, C. Bastin, M. Pierard, AMOS Ltd. (Belgium)

AMOS SA has been awarded of the contract for the design, manufacturing, assembly, tests and on site installation (Devasthal, Nainital in central Himalayan region) of the 3.6 m Indo-Belgian Devasthal Optical Telescope (IDOT).

The telescope has a Ritchey-Chrétien optical configuration with a Cassegrain focus equipped with one axial port and two side ports. The primary mirror is a meniscus active mirror. The mount is an Alt-Az type with for the azimuth axis a 5 m diameter hydraulic track. This paper presents the solution adopted by AMOS to meet the specific requirements for the azimuth axis. The track is designed to be able to control the positioning of the telescope around the azimuth axis with an accuracy of 0.05 arc second for all tracking configurations. The challenge came from this tight accuracy with a mass in rotation weighting 125 tons. The azimuth track was mounted and tested in AMOS workshop; the tests and performances are also discussed.

8444-151, Poster Session

Telescope positioning and drive system based on magnetic bearings, technical challenges and possible applications in optical stellar interferometry

R. Lemke, Ruhr-Univ. Bochum (Germany); L. Noethe, European Southern Observatory (Germany); H. J. Kärcher, MT Mechatronics GmbH (Germany)

The paper describes the envisaged positioning and drive system for telescopes of the 2m class, gives some basic analysis for power consumption and positioning performance and proposes next steps for verification of the concept. A possible application could be in optical stellar interferometry where an additional delay could be spared if the positioning performance is better than 10nm. Fast re-positioning of the telescopes should allow for multiple baselines during one observing night giving the opportunity to obtain high spatial stellar images with high time resolution.

8444-152, Poster Session

Enclosure design for the ARIES 3.6m optical telescope

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A 3.6-m, f/9 optical telescope is planned at Devasthal, India (Long : 79 d 41m 04s E, Lat: 29 d 21 m, 40s N, Alt: 2450 m) . The telescope has Cassegrain focus and alt-azimuth mount. The planned back-up instruments will provide high resolution spectral and seeing-limited imaging capabilities at visible and near-infrared wavelengths. The design of the telescope enclosure and the auxiliary building includes a fixed base enclosure, a telescope pier, a rotating dome structure, an auxiliary building, ventilation and component handling systems. The design is optimized for thermal, mechanical, structural, as well as for telescope installation and maintenance requirements. The design aims to provide seeing limited images within the telescope enclosure.

8444-153, Poster Session

An innovative alt-alt telescope for small observatories and amateur astronomers

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This paper want to show an innovative amateur oriented telescope with an unconventional alt-alt configuration. The goal is to make a telescope with good optical quality reducing production costs by adopting a gimbal based mounting to develop an alt-alt configuration suitable for a telescope. Reduce costs while preserving the optical quality is a necessary condition to allow small groups of amateur astronomers, schools and cultural clubs, with reduced economic resources, to acquire an astronomical instrument that encourages learning and advancing astrophysical knowledge. This unconventional mechanism for the realization of a telescope alt-alt provides significant advantages. The traditional rotary motors coupled with expensive precision bearings are replaced with two simple linear actuators coupled to a properly preloaded gimbal joint and the cell becomes the primary structure of the telescope. A second advantage would be secured by mechanical simplicity evident in the easy portability of the instrument. The alt-alt configuration has some limitations on the horizon pointing but does not show the zenith blind spot of the alt-az mount. A dedicated alt-alt pointing and tracking model is under development to be compatible with commercial telescope softwares and with the proposed new mounting.

8444-154, Poster Session

Prototype enclosure design for KMTNet project

N. Kappler, L. G. Kappler, TBR Construction & Engineering (United States); B. Park, C. Lee, S. Kim, S. Cha, Korea Astronomy and Space Science Institute (Korea, Republic of); W. M. Poteet, H. Cauthen, CP Systems, Inc. (United States)

TBR Construction and Engineering (TBR) has under development for the Korea Astronomy and Space Science Institute (KASI), a project to provide three 1.6 meter optical telescopes observatories in three southern countries: Chile, South Africa, and Australia. The contracting team has chosen to develop a full scale prototype of the observatory. This will become a functional assembly and testing facility for all three project telescopes in Tucson, Arizona. This prototyping concept is meant to allow the optics team to make changes to the observatory as needed for the scientific mission while minimizing the expense of making changes in remote countries.

It will also allow the perfecting of the construction methods and processes to proceed in optimal conditions close to the designers and builders location of Tucson. Little or no additional travel or mobilization expenses are expected to be incurred as the prototype is refined. Once the prototype is tested and approved, remote field modifications to meet contract requirements should be minimal. Once the prototype is accepted by the customer and the design architect, two full material sets along with templates and special tools will be shipped; one to Chile and one to South Africa. The prototype will remain intact as a learning laboratory and model in Tucson during the installation of the next two observatories for the benefit of the installation contractors in the various countries. Once the prototype has served its purpose, the entire enclosure is meant to be dismantled (less the foundation), shipped, and reassembled in its Australian home.

8444-18, Poster Session

Initial alignment and commissioning plan for the LSST

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The planned construction and completion of the Large Synoptic Survey Telescope (LSST) Project consists of phased activities. The initial telescope construction period will transition to a multi-year commission phase, which will conclude with final hand off to science operations. The telescope integration plan includes optical tests of the primary/tertiary (M1M3) mirror assembly to verify the M1M3 pre-shipping support matrices. This test configuration will also be used to build the initial look-up tables for the M1M3 support. Integration of the secondary (M2) mirror system assembly and an independent commissioning camera installed on the science camera rotator/hexapod assembly will enable three-mirror testing. The initial telescope alignment will utilize laser tracker fiducials and nodal aberration theory to exploit the diffraction limited on-axis imaging performance of the three-mirror optical system. Engineering First Light will demonstrate on-axis image quality with a test camera and support the transition to the commissioning phase. Commissioning is defined roughly by two phases: a technical period of systems integration and test, followed by a period focused on science verification. Systems integration and test activities are designed to complete the technical integration of the three LSST subsystems (Telescope, Camera, and Data Management). Final science verification tasks will be based solely on the measured on-sky performance of the LSST system and are designed to show compliance with the survey performance specifications.

8444-155, Poster Session

Dark energy camera installation at CTIO: overview

T. M. Abbott, F. Muñoz, A. R. Walker, Cerro Tololo Inter-American Observatory (Chile); C. Smith, National Optical Astronomy Observatory (Chile); A. Montane, B. Gregory, Cerro Tololo Inter-American Observatory (Chile); R. Tighe, P. Schurter, N. S. van der Bliek, National Optical Astronomy Observatory (Chile); G. Schumacher, E. Mondaca, M. Warner, D. Hernandez, R. Schmidt, Cerro Tololo Inter-American Observatory (Chile)

The Dark Energy Camera (DECam) has been installed on the V. M. Blanco telescope at Cerro Tololo Inter-American Observatory in Chile. This major upgrade to the facility has required numerous modifications to the telescope and improvements in observatory infrastructure. The telescope prime focus assembly has been entirely replaced, and the f/8 secondary change procedure radically changed. The heavier instrument means that telescope balance has been significantly modified. The telescope control system has been upgraded. NOAO has established a data transport

system to efficiently move DECam's output to the NCSA for processing. The observatory has integrated the DECam high-pressure, two-phase cryogenic cooling system into its operations and converted the Coudé room into an environmentally-controlled instrument handling facility incorporating a high quality cleanroom. New procedures to ensure the safety of personnel have been introduced.

8444-156, Poster Session

Dark Energy Camera installation at CTIO: technical challenges

F. Muñoz, A. Montane, R. Tighe, M. Warner, T. M. Abbott, Cerro Tololo Inter-American Observatory (Chile)

The Dark Energy Camera (DECam) is a new prime focus, wide-field imager for the V. M. Blanco 4-m telescope at CTIO. Instrumentation includes large, five-lens optical corrector mounted on hexapod mechanism for fine adjustment, filters, and a 519 Megapixel camera vessel; all integrated in a cage similar to the existing telescope prime focus structure. Currently Blanco allows a flip of this structure such that the f/8 secondary mirror, mounted on the back of the cage, points towards the primary mirror for Ritchey-Chretien observations. DECam will maintain this capability by attaching the existing F/8 mirror cell to the front of the new cage. Installation of this 8,600 kg instrument required the removal from the telescope of the primary mirror, the removal of the old prime focus assembly, and fine adjustment of large, over-constrained mechanisms followed by reassembly. A large facility shutdown was scheduled for this upgrade and several tools, fixtures, monitoring systems and procedures were developed in order to identify and then recover the optical alignment of the system, to control the distribution of stresses during tuning of the installation and to maintain the balance of the telescope with significant added mass. The final goal has been to maintain high performance of the telescope for both the existing f/8 Ritchey-Chretien focus mounted instruments and the new DECam instrument now in commissioning. The challenges presented in handling large elements, real-time monitoring, alignment, verification and feedback are described.

8444-157, Poster Session

KMTNet: science cases

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In this contribution, we present the science cases with the Korean Microlensing Telescope Network (KMTNet) system. The main aim of the KMTNet project is to explore the structure and diversity of planetary systems and variable objects.

Since the system is mainly optimised to conduct gravitational microlensing survey, it will enable us to detect very low-mass exoplanets potentially down to the mass of Mars that are inaccessible by other techniques.

The primary scientific goal of the project is to discover a large number of exoplanets with statiatically unbiased range of masses, down to terrestrial planets in the habitable zone. To ahieve this goal, the three wide field telescopes installed in three southern continents with a diameter of 1.6m and an FOV of 2 degree by 2 degree will monitor 4 degree by 4 degree field toward Galactic bulge at an interval of 10 minutes uninterruptedly 24 hours a day.

In addition to the primary scienctific goal, we plan to conduct photometric monitoring in major parts of the southern sky, from which discoveries of extragalactic planets in the Magellanic Coulds, surveys of type I supernovae, and ultra faint dwarf galaxies can be possible.

We anticipate that KMTNet system will discover lots of new exoplanets and variable objects, which will contribute to most modern issues related to the variability search.

8444-158, Poster Session

Design and development of a wide field telescope

I. Moon, S. Lee, Korea Research Institute of Standards and Science (Korea, Republic of); J. Lim, Kyung Hee Univ. (Korea, Republic of); H. Yang, H. Rhee, J. B. Song, Y. W. Lee, Korea Research Institute of Standards and Science (Korea, Republic of); J. U. Lee, Cheongju Univ. (Korea, Republic of); H. Jin, Kyung Hee Univ. (Korea, Republic of)

A prototype of large wide field telescope is a Cassegrain telescope which covers 2° field of view with two hyperbolic mirrors, a 0.5 m primary mirror and a 0.2 m secondary mirror with multiple correction lenses. To fulfil the optical and mechanical performance requirements in design and development phase extensive finite element analyses using NX NASTRAN and optical analyses with CODE V and PCFRINGE have been conducted for the structure of optical system. Analyses include static deformation (gravity and thermal), frequency, dynamic response analysis, and optical performance evaluations for minimum optical deformation. Image motion is also calculated based on line of sight sensitivity equations integrated in finite element models. A parametric process was performed for the design optimization to produce highest fundamental frequency for a given weight, as well as to deal with the normal concerns about global performance. Alignment and test results for an optical system will be discussed as well.

8444-159, Poster Session

A concept for a powerful flexible Southern Spectroscopic Survey Telescope

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We describe a concept for a facility designed to carry out multi-object, wide-field, large-scale spectroscopic surveys to support upcoming photometric surveys of the Southern Sky and to complement future large-aperture facilities such as GMT and E-ELT. The concept for this new facility--the Southern Spectroscopic Southern Telescope, SSST--is comprised of four parts, (a) a near-clone of a 6.5m Magellan telescope to be built at Las Campanas Observatory to take advantage of that local support infrastructure, (b) an f/4.8 secondary and wide field corrector designed to deliver a fiber-friendly two-degree diameter field of view, (c) a system of 3500-4000 optical fibers that can be used while a comparable number is deployed for subsequent observations, and (d) a set of multi-mode optical spectrographs, each fed by 180-200 fibers. The key feature of the SSST is the ability to deploy any fiber to any location in the field which, when combined by the multiple modes supported by the spectrographs, allows the SSST to support numerous specialized surveys simultaneously. We describe the detailed capabilities of the SSST and compare these to other planned spectroscopic surveys, and we outline a range of science cases the SSST can support. We also describe a number of upgrade paths for future SSST campaigns, including fiber IFUs, ultra-high precision radial velocity spectrographs and infrared channels.

8444-160, Poster Session

Achieving high precision photometry for transiting exoplanets with a low cost robotic DSLR-based imaging system

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We describe a low cost high precision photometric imaging system, which has been in robotic operation for one year on the Mauna Loa

observatory (Hawaii). The system, which can be easily duplicated, is composed of commercially available components, offers a 150 sq deg field with two 70mm entrance apertures, and 6-band simultaneous photometry at a 0.01 Hz sampling. The detectors are low-cost commercial 3-color CMOS array, which we show is an attractive cost-effective choice for high precision transit photometry. We describe the design of the system and show early results.

A new data processing technique was developed to overcome pixelization and color errors. We show that this technique, which can also be applied on non-color imaging systems, essentially removes pixelization errors in the photometric signal, and we demonstrate on-sky photometric precision approaching fundamental error sources (photon noise and atmospheric scintillation). We conclude that our approach is ideally suited for exoplanet transit survey with multiple units. We show that in this scenario, the success metric is purely cost per etendue, which is at less than $10000s per square meter square degree for our system.

8444-163, Poster Session

An active surface upgrade for the Delingha 13.7-m Radio Telescope

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An upgrade program is proposed for the Delingha 13.7-m radio telescope to implement active surface for multi-beam observation at 3 mm wavelength. The upgrade involves three critical development aspects. One is the displacement actuator, which must fit the existing position, space and connections of the panels and backup structure, meanwhile, must be as compact and lightweighted as possible. The second is that a new sub-reflector is necessitated by the multi-beam observation, where a new hyperbolic surface figure is optimized. The third, more crucial and difficult, is to realize active control of the actuators and real-time closed-loop of the full active surface. This paper is to present the progress of the development work, test and experiments associated with the three areas. With one of the spare panels of the telescope, an experiment system is carried out with six sets of actuator and control electronics. Another experiment system of a novel laser-based closed-loop measurement concept is also conducted with four smaller dummy panels. Both experiment setups have output expected results and further experiments are going on with them. In this paper, based on the two experiments, we will describe the special design and test of the actuator, including the design of its special mounting and connecting mechanisms. The design and manufacture and measurement of the new hyperbolic sub-reflector will be detailed as well as the principle, simulation and realization of the laser-based measurement system. Besides, the control strategy of the large scale use of the hundreds of actuators is also covered.

8444-164, Poster Session

Development of a new CRFP sub-reflector of the Delingha 13.7-m radio telescope

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A new sub-reflector was developed for the Delingha 13.7-m radio telescope to implement for multi-beam observation at 3 mm wavelength. The multi-beam observation requires the new sub-reflector to be shaped in convex hyperboloid instead of the original paraboloidal figure. This paper reports the development and measurement of the new sub-reflector with an aperture of 1.08 m in diameter. As a substitution of an existing sub-reflector on a telescope in operation, constraints such as specific dimensions, interfaces and weight are posted onto the design and fabrication of the new sub-reflector. Carbon Fiber Reinforced Plastic (CFRP) has been used to fabricate the reflecting panel of the new sub-reflector, while lightweighted aluminum alloy used to manufacture the inner support structure and interfaces to the back adjusting system. The final product of the new sub-reflector meets the required specifications very well. The working surface of the sub-reflector was measured by a 3D Coordinate Measuring Machine and cross-checked by a 3D Laser tracker. The measurement results show that the fitted surface is better than 40 um RMS. And a weight of ~34 kg also agrees very well with the original.

8444-165, Poster Session

Development of a compact precision linear actuator for the active surface upgrade of the Delingha 13.7-m radio telescope

G. Zhou, A. Li, D. Yang, Z. Zhang, G. Li, National Astronomical Observatories (China)

The Delingha 13.7-m radio telescope is to be upgraded with an active surface for multi-beam observation at 3 mm wavelength. Its primary reflector is paved with 72 aluminum panels which are originally supported by 480 fixtures. One of the critical tasks associated with the upgrade program is development of precision linear displacement actuators to replace the panel fixtures hence to Listed first in the upgrade program is actively drive and position the panels. The linear actuator is required to fit the existing positions, dimensions and connections of the panels and the backup structure, also implicitly required to be as compact and lightweighted as possible. This paper is to report in detail the development and experiment of the compact, folded, precision linear actuator according to given technique requirements and constraints, including the description of the flexible adaption of the fixture of the actuators and the special design of the connecting mechanism with the panels. The experiment system is established with one of the spare panels of the telescope, and six sets of actuator and control electronics are included for driving the panel. This paper will present the test results measured on a single actuator prototype as well as the actuators working together in the spare panel experiment. The test results prove that the actuator manifests positioning accuracy of microns and load capacity of 10 kg. The related connection and electronics design of the actuator also meets the requirements of the update program of the telescope.

8444-166, Poster Session

Upgrading the TNT Telescope: remote observing and future perspectives

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The Teramo Normale Telescope (TNT) is a 0.72 m Cassegrain telescope operating at the INAF-Teramo since the 1994. At the end of the 2011, the whole system has been completely upgraded in order to improve the overall performance of the instrument and to allow safe and fully remote observations, without the need of local operators. Most of the hardware components have been replaced and a new software package has been developed. This has led to the set up a suitable and more reliable facility that allows remote observers to control all critical subsystems and to monitor their status in real-time. Moreover, the increased automation of several main tasks (pointing, guiding, focusing, schedule execution) has considerably reduced the dead times during the night. Great attention has been also paid to the instrumentation safety, introducing different and redundant hardware and software solutions against any possible risks (i.e. watchdogging, video surveillance, weather monitoring, etc.) and safety-related policies. The main result of this work is to have paved the way to further steps towards the development of a fully robotic

observatory. Described herein is a general description of the new system and the next goals we foresee to achieve.

8444-167, Poster Session

ESPRESSO: design and analysis of a Coudé-train for a stable and efficient simultaneous optical feeding from the four VLT unit telescopes

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ESPRESSO is a fibre-fed, cross-dispersed, high-resolution, echelle spectrograph. Being the first purpose of ESPRESSO to develop a competitive and innovative high-resolution spectrograph to fully exploit the VLT (Very Large Telescope), and allow new science, it is important to develop the VLT array concept bearing in mind the need to obtain the highest stability, while preserving its best efficiency. This high-resolution ultra-stable spectrograph will be installed in the VLT at the Combined Coudé Laboratory (CCL), fed by four Coudé Trains, which brings the light from the Nasmyth platforms of the four VLT Unit Telescopes to the CCL. A previous trade-off analysis, considering the use of mirrors, prisms, lenses or fibres and several possible combinations of them, pointed towards a Full Optics solution, using only conventional optics to launch the light from the telescope into the front-end unit. In this case, the system is composed of a set of prisms and lenses to deliver a pupil and an image in the CCL, including an Atmospheric Dispersion Compensator. In this paper, we present the optical design of the Coudé Trains, the opto-mechanical concept, the main characteristics and expected performances.

8444-169, Poster Session

Recent performance improvements for the LBT primary mirror system

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Over the last several years the primary mirror support systems for the Large Binocular Telescope have been upgraded to improve on-sky performance. We describe improvements made to the support actuators, hardpoints, and control algorithms to improve stability and motion control over the full range of telescope operating conditions (temperature, wind, and so forth). Previous papers have discussed the performance of individual subsystems. This paper describes the overall system and presents some recent system performance measurements.

8444-170, Poster Session

Modernization of the 1 meter Swope and 2.5 meter Du Pont telescopes at Las Campanas Observatory

F. S. Perez, Carnegie Observatories (United States)

The Observatories of the Carnegie Institution for Science have operated the 1 and 2.5-meter telescopes since the early 1970's with only minor changes to the original control systems. We discuss the replacement of the original 4004 micro-processor based telescope control system with modern high-speed servo controllers and motors, absolute main axis encoders, modern closed-loop controls and PC-based main operating software. We also discuss the original relay-based interlock systems that have been replaced with PLC systems and have been interfaced into the new telescope control system. The modernization of both telescopes also includes many hardware upgrades to allow for remote observing and scripted automatic observations. These upgrades also include the modernization of shutter drives, wind-screens and dome controls to improve the reliability and safety required for remote observing from an existing facility.

8444-171, Poster Session

A happy conclusion to the SALT image quality saga

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We are pleased to report on the successful completion of the Southern African Large Telescope (SALT) Image Quality (IQ) project. A lengthy diagnostic process pointed to a problematic interface between the telescope and the Spherical Aberration Corrector (SAC). This transmitted mechanical and thermal stresses to the secondary optics and thus disrupted the alignment of the four corrector mirrors. Images suffered a severe focus gradient and various other aberrations. The SAC was removed from the telescope in 2009 April in order to replace the interface and then the four mirrors were re-aligned and tested. Testing was conducted over a range of temperatures and with the SAC both vertical and at the extremes of its operational envelope of 37±6 degrees in Y and 0±6 degrees in X. The surface figure of each mirror was also verified during the repair campaign, in a vain attempt to trace the source of inexplicable doubled/mutilated on-sky images that had occasionally been seen. The final system test yielded a RMS wavefront error of 0.17 waves and the SAC was re-installed on the telescope in 2010 August. Subsequent on-sky testing confirmed that the focus gradient had been eliminated, but the dreaded doubled images soon appeared and were found to vary on timescales of a second or two. The problem was promptly traced to instability of the mount for the auto-collimator (the system that maintains the SAC's attitude with respect to the primary mirror). Resolving this delivered uniform sub-arcsecond images over the telescope's full 9 arcminute field.

8444-172, Poster Session

Facility calibration unit of Hobby Eberly Telescope wide field upgrade

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The Hobby-Eberly Telescope (HET) Wide-Field Upgrade (WFU) will be equipped with new Facility Calibration Unit (FCU). The FCU is in support of VIRUS and the facility instruments and consists of the head and source box. The FCU head, connected to the source box through two liquid light guides, is attached to the bottom of the WFU Wide-Field Corrector (WFC) and can be deployed into the beam to inject calibration light through the WFC whenever calibration is needed. A set of Fresnel lenses is used in the FCU head to mimic the caustics of M1 as much as possible to re-produce the telescope's focal plane illumination pattern. Specially designed/arranged non-imaging optical components (e.g. Compound Parabolic Concentrators and Cone reflectors) are used for efficient coupling between different types of calibration lamps and light guides, covering wavelengths from 350nm to 1800nm. In addition, we developed an efficient and tunable Light-Emitting Diode (LED) based

source and coupler for UV and Visible spectral flat field calibration. This paper presents the designs, prototypes, and as-built components / subsystems of the FCU.

8444-173, Poster Session

Solid telescopes for interferometric enhancement of existing telescopes

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This paper describes a concept study for a simple and cost effective approach to upgrade of existing infrastructures.

A conventional monolithic telescope can be endowed with a set of identical small telescopes combined coherently to enhance the resolution, as already proposed e.g. for the 25m PETAL (Photon Energy Transformation & Astrophysics Laboratory) solar collector.

The solid telescope represent a convenient solution for a simple and replicated small telescope.

The solid telescope is intrinsically suited to be used in diffraction limited mode down to visible wavelengths.

This may allow a viable dual feed mode for both guiding and phase referenced imaging.

In this paper we analyze some of the critical engineering aspects and outline a possible implementation approach.

8444-35, Session 11

Early science results from SOFIA

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SOFIA, the Stratospheric Observatory for Infrared Astronomy, is a joint project between NASA and DLR to provide a 2.5-m telescope that flies at stratospheric altitudes. Designed to observe wavelengths between 0.3 microns to 1.6 mm, SOFIA provides access to large parts of the otherwise obscured infrared spectrum. SOFIA successfully conducted its first year of science observations in 2011, performing 30 science flights. Named “Early Science”, this period of time was intended to demonstrate the observing potential of SOFIA while still undergoing development as a facility. Observations were primarily conducted with the FORCAST mid-infrared camera and the GREAT heterodyne spectrometer, and were drawn from the science programs of the instrument teams as well as from an open proposal solicitation for the world-wide astronomical community. Additionally, a very successful occultation by Pluto was conducted using the HIPO photometer. The occultation observations required precise location of SOFIA in time and geographical coordinates. In this paper we present some of the science highlights from the early science period.

8444-36, Session 11

Active Damping of the SOFIA Telescope Assembly

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The NASA/DLR Stratospheric Observatory for Infrared Astronomy (SOFIA) employs a 2.5-meter reflector telescope in a Boeing 747SP. The telescope is housed in an open cavity and is subjected to aeroacoustic and inertial disturbances in flight. To meet pointing requirements, SOFIA must achieve a pointing stability of approximately 0.5 arcseconds RMS. An active damping control system is being developed for SOFIA to reduce image jitter and image quality degradation due to resonance of the telescope assembly. A need for this system was anticipated early in the development of SOFIA, however particular modes targeted for active damping have changed to some degree now that the telescope dynamics and open-cavity flight environment have been characterized in actual flight tests. Our paper will summarize the history of the active damping design for SOFIA. We begin with a brief overview on the analysis and testing leading to the current design. Next we will provide a summary of the current implementation, its performance in ground and flight tests. We conclude with a brief outline of the currently foreseen steps to completion.

8444-37, Session 11

Evaluation of the aero-optical properties of the SOFIA cavity by means of computional fluid dynamics and a super fast diagnostic camera

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The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a 2.5m reflecting telescope housed in an open cavity on board of a Boeing 747SP. During observations, the cavity is exposed to transsonic flow conditions. The oncoming boundary layer evolves in a free shear layer being responsible for aberrations and for aerodynamic and aeroacoustic disturbances within the cavity.

While the aero-acoustical excitation of an airborne telescope can be minimized by using passive flow control devices, the aero-optical properties of the flow are free of any improving manipulation. Hence it is important to know how much the image seen through the SOFIA telescope is perturbed by so called Seeing effects.

Prior to the SOFIA science flights Computional Fluid Dynamics (CFD) simulations using URANS and DES methods have been carried out to determine the flow field within the cavity and hence in the optical path in order to provide an assessment of the aero-optical properties under baseline conditions.

In addition and for validation purposes, out of focus images have been taken during flight with a Super Fast Diagnostic Camera (SFDC). Depending on the binning and the subarray size, the SFDC is able to take and to read out images at very high frame rates.

The paper explains the numerical approach based on CFD to evaluate the aero-optical properties of SOFIA. The CFD data is then compared to the high speed images taken by the SFDC during flight

8444-38, Session 11

Optical characterization of the SOFIA Telescope using fast EM-CCD cameras

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The Stratospheric Observatory for Infrared Astronomy (SOFIA) has recently demonstrated its scientific capabilities in a first series of

astronomical observing flights. In parallel, special measurements and engineering flights were conducted aiming at the characterization and the commissioning of the telescope and the complete airborne observatory. To support the characterization measurements, two commercial Andor iXon EM-CCD cameras have been used, a DU-888 dubbed Fast Diagnostic Camera (FDC) running at frame rates up to about 400 fps, and a DU-860 as a Super Fast Diagnostic Camera (SFDC) providing up to about 2000 fps. Both cameras have been mounted to the telescopes Focal Plane Imager flange in lieu of the standard tracking camera. Their fast image sequences have been used to analyze and to improve on the telescope's pointing stability, especially to tune active mass dampers that suppress eigenfrequencies in the system, to characterize and to optimize the chopping secondary mirror and to investigate the structure and behavior of the shear layer that forms over the open telescope compartment in flight. In June 2011, a collaboration of the FDC and the science instrument HIPO led to the first SOFIA observation of a stellar occultation by the dwarf planet Pluto in the South Pacific.

This paper will describe the FDC/SFDC system, summarize measurements done with it on SOFIA and give an outlook on the future use.

8444-39, Session 12

SOFIA observatory performance and characterization

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The Stratospheric Observatory for Infrared Astronomy (SOFIA) has recently concluded a set of engineering flights for Observatory performance evaluation. These in-flight opportunities have been viewed as a first comprehensive assessment of the Observatory's performance and will be used to address the development activity that is planned for 2012, as well as to identify additional Observatory upgrades. A series of 8 SOFIA Characterization And Integration (SCAI) flights have been conducted from June to December 2011. The HIPO science instrument in conjunction with the DSI Super Fast Diagnostic Camera (SFDC) have been used to evaluate pointing stability, including the image motion due to rigid-body and flexible-body telescope modes as well as possible aero-optical image motion. We report on recent improvements in pointing stability by using an Active Mass Damper system installed on the Telescope Assembly. Measurements and characterization of the shear layer and cavity seeing, as well as image quality evaluation as a function of wavelength have been performed using the HIPO+FLITECAM Science Instrument configuration (FLIPO). A number of additional tests and measurements have targeted basic Observatory capabilities and requirements including, but not limited to, pointing accuracy, chopper evaluation and imager sensitivity. SCAI activities included in-flight partial Science Instrument commissioning prior to the use of the instruments as measuring engines. This paper reports on the data collected during the SCAI flights and presents current SOFIA Observatory performance and characterization.

8444-40, Session 12

The balloon-borne large-aperture submillimeter telescope for polarimetry--BLAST-Pol: performance and results from the 2010 Antarctic flight

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The Balloon-borne Large Aperture Submillimeter Telescope for Polarimetry (BLAST-Pol) is a suborbital mapping experiment designed to study the role played by magnetic fields in the star formation process. Using a 1.8m Cassegrain telescope, BLAST-Pol images the sky onto a focal plane of 280 bolometric detectors in three arrays, observing simultaneously at 250, 350, and 500µm, with sub-arcminute angular resolutions. The polarimeter consists of photolithographic polarizing grids mounted in front of each bolometer and a rotating 4K achromatic half-wave plate. In its first flight from McMurdo, Antarctica in December 2010, BLAST-pol made polarization maps of molecular clouds, providing a much needed bridge in spatial coverage between larger-scale, coarse resolution surveys and narrow field of view, high resolution observations of molecular cloud cores. I will report on the status of the experiment in preparation for the second flight in 2012, and on the performance obtained in 2010.

8444-41, Session 13

The Cherenkov Telescope Array (CTA): status of the project and development of the telescopes

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The Very High Energy band (above a few tens of GeV up to 100 TeV) is the natural domain where the study of the astrophysical sources is tangled with the realm of the particle physics. Several outstanding results were obtained so far by the HESS, MAGIC, and VERITAS Cherenkov arrays, both on Galactic and extra-Galactic sources. The forthcoming Cherenkov Telescope Array (CTA), with its innovative approach based on the use of three different sizes of telescopes (with dishes of 24, 12 and 7 m respectively), will obtain a sensitivity of 1 mCrab, i.e. one-order-of-magnitude improvement with respect to the current Cherenkov telescope performance. CTA will consist of two arrays (one in the north, one in the south) for full sky coverage and will be operated as open observatory. In this talk I will review the technological aspects being developed for the CTA telescopes, in particular on structures and mirrors. We will also report on the status of the project.

8444-42, Session 13

Optical design and calibration of a MST (medium size telescope) prototype for the CTA (Cherenkov Telescope Array)

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The Cherenkov Telescope Array (CTA) is designed to make a major improvement in the sensitivity of ground based VHE (Very High Energy,

defined as > 50 GeV to 100s of TeV) gamma-ray telescopes. Not only will the differential-flux sensitivity be an order of magnitude better than the currently operating Cherenkov telescopes, but there will also be significant improvements in the energy, spectral and angular resolution. Delivering these features cost-effectively requires several telescope sizes and designs - a few large size telescopes (25 m diameter) are targeted for the lowest energies, a large number of small size telescopes (~6 m diameter) to increase the overall collection area which helps at the highest energies and some Medium Size Telescopes (MST, ~12-10 m diameter, depending on the dish design) to provide the greatest sensitivity at ~1 TeV. To provide complete sky coverage, CTA will have both a Northern Hemisphere and a Southern Hemisphere site.

A prototype for a MST design (currently under development) will be set up in Berlin by mid 2012. This MST prototype has a modified Davies-Cotton tessellated dish, with individual facets ~1.2 m diameter. The mirrors are three-point mounted on the dish structure, having two powered actuators for alignment adjustments. In addition a number of CCD cameras that are mounted at various positions in the dish are also used for calibration. Here we present the various optical calibration tasks - optimizations of the optical PSF and the pointing of this MST prototype, along with initial results.

8444-43, Session 13

Development of a mid-sized Schwarzschild-Couder Telescope for the Cherenkov Telescope Array

R. A. Cameron, SLAC National Accelerator Lab. (United States)

The Cherenkov Telescope Array (CTA) is a ground-based observatory for very high-energy (10 GeV to 100 TeV) gamma rays planned for operation starting in 2018. It will be an array of dozens of optical telescopes, known as Atmospheric Cherenkov Telescopes (ACTs), of 8 m to 24 m diameter, deployed over an area of more than 1 square km, to detect flashes of Cherenkov light from showers initiated in the Earth's atmosphere by gamma-rays. CTA will have improved angular resolution, a wider energy range, larger fields of view and an order of magnitude improvement in sensitivity over current ACT arrays such as H.E.S.S., MAGIC and VERITAS.

Several institutions have proposed a research and development program to eventually contribute 36 medium-sized telescopes (9 m to 12 m in diameter) to CTA to enhance and optimize its science performance. The program aims to construct a prototype of an innovative, Schwarzschild-Couder telescope (SCT) design that will allow much smaller and less expensive cameras and much larger fields of view than conventional Davies-Cotton designs, and will also include design and testing of camera electronics for the necessary advances in performance, reliability and cost. We report on the progress of the mid-sized SCT development program.

8444-44, Session 14

Status and performance of the Discovery Channel Telescope during commissioning

S. E. Levine, T. A. Bida, T. Chylek, P. L. Collins, W. T. DeGroff, E. W. Dunham, P. J. Lotz, A. J. Venetiou, S. Zoonematkermani, Lowell Observatory (United States)

Lowell Observatory's Discovery Channel Telescope is a 4.3-meter telescope designed for optical and near infrared astronomical observation. At first light, the telescope will have a cube capable of carrying five instruments and the wavefront sensing and guider system at the f/6.1 Ritchey-Chrétien (RC) focus. The corrected RC focus field of view is 30 arc-minutes in diameter. Nasmyth and prime focus can be instrumented subsequently. Early commissioning work with the installed primary mirror and its support system started out using one of the wave front sensing probes mounted at prime focus, and has continued at RC with the recent installation of the secondary mirror. We will report on the on-sky pointing and tracking performance of the telescope, initial assessment of the functionality of the active optics system, and tests of the early image quality of the telescope and optics. We will also describe the suite of first light instruments, and early science operations.

8444-45, Session 14

The Large Binocular Telescope

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The Large Binocular Telescope (LBT) Observatory is a collaboration between institutions in Arizona, Germany, Italy, Indiana, Minnesota, Ohio and Virginia. The telescope on Mt. Graham in southeastern Arizona uses two 8.4-meter diameter borosilicate honeycomb primary mirrors mounted side-by-side to produce a collecting area equivalent to an 11.8-meter circular aperture. A unique feature of LBT is that the light from the two primary mirrors can be combined to produce phased-array imaging of an extended field. This coherent imaging along with adaptive optics gives the telescope the diffraction-limited resolution of a 22.65-meter telescope. The first on-sky phasing of the two telescopes in the mid-infrared occurred in October 2010 with the LBTI instrument in Fizeau mode. The Telescope Control system has been upgraded to allow binocular (2-sided) observations with pairs of instruments. The prime focus cameras (LBC) routinely operate in this mode, although mixed instrument binocular observations are yet to be tested. Improved collimation and pointing models have been deployed to keep both sides collimated and pointed at the same target. The control system has also been upgraded to allow observations of solar system objects at non-sidereal tracking rates. Science observations are scheduled for 60% of the nights including a significant fraction of adaptive optics imaging with the first adaptive secondary mirror and the FLAO system with natural guide stars. MODS1, a nearUV-optical spectrometer, has been added to the suite of science instruments along with LBC (visible imagers) and LUCI1 (near infrared spectrometer).

LMIRCam (3-5 microns) and PISCES (1-2.4 microns) have been used for adaptive optics imaging. The remaining nights are scheduled for telescope and instrument commissioning activities as new instruments arrive. The second of the two F/15 adaptive secondary mirrors has been installed on the telescope in Fall 2011 and will be commissioned on-sky in Spring 2012.

8444-46, Session 14

New Fraunhofer Telescope Wendelstein: assembly, installation, and current status

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Due to the exposed location of the Wendelstein Observatory on the steep summit of mount Wendelstein in the Bavarian Alps, no road exists to transport telescope components and heavy equipment to the observatory site for installation. A two step installation concept was therefore followed to mitigate any risks and the complete telescope was assembled and tested at the factory site prior to diassembly and lifting all components on the mountain with a heavy lift helicopter.

This paper reports on the telescope factory assembly and tests, including on-sky tests, which were performed in early summer 2011 at the factory site to make sure, that the telescope and all essential subsystems are working properly before the telescope would be installed on the mountain. After disassembly and transport, lifting of all structural subsystems and the optics up to the mountain Observatory with the help of a heavy lift helicopter and installation will be presented in detail, looking at specific design drivers, logistic aspects and special tools for installation of the telescope and its mirrors. The Handling and transport concept for the M1 mirror installation, which also will have

to be followed when the mirror needs to be recoated, is presented. Up to end of 2011 the telescope installation and pre-alignment could be completed including first on-sky tests. The system will undergo a detailed performance test campaign in the first half of 2012. Current performance results of these commissioning activities will be reported

8444-47, Session 14

VST: from commissioning to science

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The VLT Survey Telescope has started the scientific operations in the Paranal Observatory of European Southern Observatory, after a successful commissioning period. It is the largest telescope in the world designed for surveying the sky in visible light. The VST is dedicated to survey programmes, supporting the VLT with wide-angle imaging by detecting and pre-characterising sources, which the VLT Unit Telescopes can then observe further.

8444-48, Session 14

Commissioning results from the Large Binocular Telescope

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Commissioning of a telescope facility such as the Large Binocular Telescope presents us with unprecedented challenges. The logistical and managerial balance act of scheduling commissioning of telescope, adaptive optics and twelve focal stations with subsequent commissioning of the instruments that populate the focal stations, while still providing for adequate science opportunity with already operational instruments is an equation that is problematic to solve in a way that meets the interests of all stakeholders. This paper presents strategies and priorities used at the LBTO, and status of telescope commissioning programs. We provide a summary of telescope commissioning results, including a discussion about specific efforts to improve performance of the LBT.

8444-49, Session 14

Discovery Channel Telescope active optics system early integration and test

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The Discovery Channel Telescope (DCT) is a 4.3-meter telescope with a thin meniscus primary (M1) and a honeycomb secondary (M2). The optical design is an f/6.1 Ritchey-Chrétien (RC) with an unvignetted 0.5° field-of-view at Cassegrain focus. We describe the design, implementation and performance of the DCT active optics system (AOS). The DCT AOS maintains collimation and controls the figure of the mirror so as to provide seeing limited images across the focal plane. To minimize observing overhead, rapid settling times are achieved using a combination of feed-forward and low-bandwidth feedback control using a wavefront sensing system.

In 2011, a custom wavefront sensor was mounted at the prime focus of M1, Prime Focus Test Assembly (PFTA), to test the AOS with the wavefront sensor, and the feedback loop. The incoming wavefront is decomposed using Zernike polynomials, and the mirror figure is corrected with a set of bending modes. Components of the system that we tested and tuned included the Zernike to Bending Mode transformations, and the open-loop feed-forward coefficients. Results are presented here.

In early 2012, the PFTA was replaced by M2, and the wavefront sensor moved to its normal location on the Cassegrain instrument assembly behind a RC field corrector. Early open loop wavefront test results with the full optical system and instrument cube are presented, along with refinements to the overall control loop operating at RC Cassegrain focus.

8444-168, Poster Session

Optics and the mechanical system of the 62-cm telescope at the Severo Diaz Galindo Observatory in Guadalajara, Jalisco, Mexico

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We present the results of a modification performed to the optical system of the telescope of 62 cm at observatory “SEVERO DIAZ GALINDO” property of the University of Guadalajara, Mexico. This modification consist in change the distance between the primary and secondary mirror from 1027 to 1135 mm in order to get astronomical images and data. The latter was necessary because errors in the original system were presented. Beside, the telescope has new accurate and adequate mechanics installed on November 2011. Here we present details of this mechanical system and design.

8444-174, Poster Session

Orthogonal vector bending modes for the Magellan primary mirrors

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We develop an orthogonal set of vector elastic bending modes for control of the Magellan 6.5m primary mirrors. These modes have the advantage that they can be directly fitted to data from slope based wavefront sensors such as the Shack-Hartmann sensor. Using displacement based bending modes (or Zernike modes) has the disadvantage that the derivative of these modes are not an orthogonal set of functions. The modes are derived by taking the gradient of the bending influence functions and performing a singular value decomposition on the resulting vector functions.

8444-175, Poster Session

Folded Cassegrain sets of the Gran Telescopio Canarias (Grantecan)

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The Gran Telescopio Canarias (GRANTECAN) will widen its observation capabilities by enabling operations in the Folded Cassegrain foci, where instruments such as CanaryCam, MEGARA and MIRADAS will be installed. IDOM has been responsible for the design and procurement of the Folded Cassegrain Sets, which include the Instrument Rotator, and the Acquisition and Guiding (AG) Mechanics.

The instrument rotator, guided by a precision crossed roller bearing and driven by a direct drive brushless motor, supports and rotates instruments of up to 1000 kg with an accuracy better than 10 arcsec. It also drives the movement of the cable chain with supplies for the science instrument and the AG-system. The cable rotator is an evolution of the rolling loop design featuring a guiding lightweight intermediate structure, which eliminates the need for a static housing, minimizing weight and impact on the telescope tube.

The AG-System pointing capabilities are provided by a rotation table with a geared precision bearing and two spur gears in antibacklash configuration, combined with a commercial rotation stage which carries the pick-off arm. The focusing system is performed by a commercial linear stage mounted in a detachable optics box. This pointing mechanism provides positioning repeatability of 20 milliarcseconds with a stability better than 75 milliarcseconds.

The design proposed by IDOM combines a compact layout of the mechanical system, enhanced by the innovative cable wrap design, resulting in a smooth and precise movement, whilst guaranteeing good access to important components even if the science instrument is mounted, maximizing the maintainability.

8444-176, Poster Session

Design, testing, and installation of a high-precision hexapod for the Hobby-Eberly Telescope dark energy experiment (HETDEX)

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Engineers from The University of Texas at Austin (Center for Electromechanics and McDonald Observatory) have designed, built, and laboratory tested a high payload capacity, precision hexapod for use on the Hobby-Eberly telescope as part of the HETDEX Wide Field Upgrade (WFU). The hexapod supports the 3150 kg payload which includes the wide field corrector, support structure, and other optical/electronic components.

This paper provides a recap of the hexapod actuator mechanical and electrical design (2010 SPIE paper 7733-49) including a discussion on the methods used to help determine the actuator travel to prevent the hexapod payload from hitting any adjacent, stationary hardware. The paper describes in detail the tooling and methods used to assemble the full hexapod, including many of the structures and components which are supported on the upper hexapod frame. Additionally, details are provided on the installation of the hexapod onto the new tracker bridge, including design decisions that were made to accommodate the lift capacity of the Hobby-Eberly Telescope dome crane. Laboratory testing results will be presented verifying that the performance goals for the hexapod, including positioning, actuator travel, and speeds have all been achieved.

This paper may be of interest to mechanical and electrical engineers responsible for the design and operations of precision hardware on large, ground based telescopes. In summary, the hexapod development cycle from the initial hexapod actuator performance requirements and design, to the deployment and testing on the newly designed HET tracker system is all discussed, including lessons learned through the process.

8444-177, Poster Session

Prototype pipeline for LSST wavefront sensing and reconstruction

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The Large Synoptic Survey Telescope (LSST) uses an active optics system (AOS) to maintain system alignment and surface figure on its three large mirrors. Corrective actions fed to the LSST AOS are determined from 4 curvature based wavefront sensors located on the corners of the inscribed square within the 3.5 degree field of view. Each wavefront sensor is a split detector such that the halves are 1mm on either side of focus. In this paper we describe the development of the Active Optics Pipeline prototype that simulates processing the raw image data from the wavefront sensors through to wavefront estimation on to the active optics corrective actions. We also describe various wavefront estimation algorithms under development for the LSST active optics system. The algorithms proposed comprise of the Zernike compensation routine which improve the accuracy of the wavefront estimate. Algorithm development has been aided by a bench top optical simulator which we also describe. The current software prototype combines MATLAB modules for image processing, tomographic reconstruction, atmospheric turbulence, and Zemax, for optical ray-tracing to simulate the closed loop behavior of the LSST AOS. We describe the overall simulation model and results for image processing using simulated images and initial results of the wavefront estimation algorithms.

8444-178, Poster Session

Active optics in Large Synoptic Survey Telescope

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The Large Synoptic Survey Telescope (LSST) has 3.5° field of view and F/1.2 focus that makes the performance quite sensitive to misalignments and mirror surface deformations . In order to maintain the images quality, LSST has an active optics system to measure and correct the telescope misalignments and mirror deformations. The principle method for determining the corrections is based on the least square minimization algorithm, in which the target merit function is constructed from the rms variation of the wavefront measured from the sensors distributed on the 4 corners of the focal plane array. In this paper, we also discussed the singularity and stability of the solution, which determine the minimum number of sensors required and the measurement tolerances. A simulation model, which combines Zemax as a ray tracing engine and Matlab as an analysis platform, is setup to simulate the pipe line of the active correction. Several simulation results are presented.

8444-179, Poster Session

Keck 1 deployable tertiary mirror (K1DM3)

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The Keck I Deployable Tertiary Mirror is a deployable tertiary mirror for the Keck I (K1) telescope. It will provide a 5' field-of-view (FOV) to any Nasmyth port, satisfying the observational needs of all current and planned instrumentation on K1 at this focus. Ideally, this mirror will shift between states (stowed, deployed) in less than 15 minutes and provide observations with any K1 instrument on any given night. K1DM3 will be a major enhancement of flexible observing at Keck, enabling rapid targets of opportunity observations, cadence programs, and 'bad weather scheduling' using the suite of K1 instrumentation. The K1DM3 will have the ability to switch between Nasmyth platforms and lock to any desired instrument on either platform. When stowed, it will track with the Cassegrain instrument below (LRIS or MOSFIRE) in order to remain out of the instrument's FOV. In all other respects the design will be entirely interchangeable and identical in form, fit, and function to the existing M3 equipment module.

8444-181, Poster Session

Metrology systems of Hobby-Eberly Telescope wide field upgrade

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The Hobby-Eberly Telescope (HET) Wide-Field Upgrade (WFU) will be equipped with new metrology systems to actively control the optical alignment of the new four-mirror Wide-Field Corrector (WFC) as it tracks sidereal motion with respect to the fixed primary mirror. These systems include a tip/tilt sensor (TTS), distance measuring interferometers (DMI), guide probes (GP), and wavefront sensors (WFS).

While the TTS and DMIs are to monitor the mechanical alignment of the WFC, the WFSs and GPs will produce direct measurement of the optical alignment of the WFC with respect to the HET primary mirror. Together, these systems provide fully redundant alignment and pointing information for the telescope, thereby keeping the WFC in focus and suppressing alignment-driven field aberrations. We describe the current snapshot of these systems and discuss lab/on-sky performance test results of the systems.

8444-183, Poster Session

Optics derotator servo control system for SONG Telescope

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SONG is an initiative to construct a global network of 1-m class robotic telescopes. Chinese standard node of SONG is an Alt-Az Telescope of F/37 with 1m diameter. Optics derotator control system of SONG telescope adopts the development model of “Industrial computer + UMAC motion controller + servo motor”. Industrial computer is the core processing part of the motion control, motion control card(UMAC) is in charge of the details on the motion control, Servo amplier accepts the control commands from UMAC, and drives the servo motor. The position feedback information comes from the encoder, to form a closed loop control system. This paper describes in detail hardware design and software design for the optics derotator servo control system. In terms of hardware design, the principle, structure, and control algorithm of servo system based on optics derotator are analyzed and explored. In terms of software design, the paper proposes the architecture of the system software based on Object-Oriented Programming.

8444-185, Poster Session

Active optical control system design of the SONG-China Telescope

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The standard SONG node is an altazimuth telescope with an aperture of 1m and the focal length of 36.7m. There are 3 fixed supports and 33 adjustable force actuators on the back of the primary mirror. Every force actuator can be adjusted to change the surface shape of the mirror using for correction of curvature radius and low frequency form error. In operation there is a wave front sensor (Shack-Hartmann), which collects the information to computer to generate corrections to the forces. The pneumatic actuator is used in the active system for its simpleness, economy and fast response.

The active optical control system is a distributed system including a host control computer and a slave intelligent controller. A PLC based system is used for intelligent controller, considering the advantage of off-the-shelf hardware and HMI/SCADA software. The responsibility of the host control computer is collecting the information from wave front sensor and sending the commands to the slave computer to realize a closed loop model. This system combines with the characteristics of IPC and PLC to make up a control system with powerful and reliable.

8444-186, Poster Session

The 3.6 m Indo-Belgian Devasthal Optical Telescope: the active M1 mirror support

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AMOS SA has been awarded of the contract for the design, manufacturing, assembly, tests and on site installation (Devasthal, Nainital in central Himalayan region) of the 3.6 m Indo-Belgian Devasthal Optical Telescope (IDOT).

The telescope has a Ritchey-Chrétien optical configuration with a Cassegrain focus equipped with one axial port and two side ports. The primary mirror is a meniscus active mirror (3.7 m diameter, 165 mm thick). It is supported by 69 axial actuators and 24 lateral astatic levers. The axial actuators are active pneumatic systems that deliver the forces needed to keep the right mirror figure. While tracking, the forces have to vary continuously to compensate for the effects of gravity whose orientation changes, as well as thermal and cell effects. The system operates in open or close loop with a wavefront sensor. This paper describes the opto-mechanical design of the mirror support and presents the solution adopted by AMOS to meet the specific requirements. Moreover, the support was mounted and tested in AMOS workshop with dummy and actual mirror; the tests and performances are also presented in this paper.

8444-187, Poster Session

Synchronous Redundant Control Algorithm in The Telescope Drive System

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The modern large telescope is endowed with advanced imaging systems and active optics, resulting in high peak angular resolution. The drive systems for the telescope must consequently be able to guarantee a tracking accuracy better than the telescope angular resolution, in spite of unbalanced and sudden loads such as wind gusts and in spite of a structure that, because of its size, can’t be infinitely stiff, which puts forward a great challenge to the telescope’ drive system. Modern telescope’s drive system is complicated, which performance and reliability directly affect the telescope tracking performance and reliability. Redundant technology is one of the effective ways to improve the security of the system. This paper will introduce one redundant synchronous control method for direct drive torque motor of large diameter telescope drive system, which can effectively improve the telescope drive system tracking precision and improve the reliability, stability and anti-jamming ability.

8444-188, Poster Session

The M2&M3 positioning control systems of a 2.5m telescope

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The 2.5m optical/infrared telescope is a F/8 telescope comprising one Cassegrain focus (C1), two Nasmyth foci (N1 and N2) and two student Nasmyth foci (N3 and N4). It has three mirrors, M1 which is the primary mirror, M2 which is the mirror at the top of the structure and M3 which transfers light to the Nasmyth foci. The positioning control systems of M2 and M3 are the systems that enable respectively alignment and focus adjustment of the telescope and the light transmission to the Nasmyth foci. The M2 mirror is capable of 5 axis movements (focus, 2 decenters and 2 tilts). A rotating and escapable M3 mirror unit distributes the light towards the four Nasmyth foci through the elevation axles.

This paper presents a brief description of the instrumentation, conceptual design and implementing measure in the positioning control system of M2&M3. The graphical user interface application (QT) is adopted to design the software. During the full working range the M2 focus and decenter achieve the positioning accuracy ±4μm and the M2 tilt 10 μrad. The M3 angular positioning and locking accuracy is better than 10 arcsec and repeatability is better than 2 arcsec RMS.

8444-189, Poster Session

Progress of the active reflector antenna using laser angle metrology system

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Active reflector is one of the key technologies for constructing large telescopes, especially for the millimeter/sub-millimeter radio telescopes. This report presents a new and substantial progress on the efficient laser angle metrology system for the active reflector antenna of the large radio telescopes, with a plenty of active reflector experiments based on the 65-meter radio telescope prototype constructed by Nanjing Institute of Astronomical Optics and Technology (NIAOT). The test results shows that the precision of the laser spot detection is 0.02 pixel, the precision of the surface shape segmenting is up to 2μm, the precision of range measuring is up to 5μm, and the accuracy of the surface shape maintaining achieves 5μm (RMS) with a time-response less than a quarter. Therefore, the laser angle metrology system is proved to be workable for the sub-millimeter radio telescopes, both in accuracy and time-response.

8444-190, Poster Session

The active optics system of the VST: concepts and results

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The active optics system of the VST adopts a positioning system for the secondary mirror, a system to support and modify the shape of the 2.6m primary mirror, and a Shack-Hartmann wavefront sensor. This paper describes the theory of the VST active optics and the commissioning of the whole system on the ESO's Paranal Observatory.

8444-191, Poster Session

Performance comparison between two active support schemes for 1-m primary mirror

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Active support scheme may decide the deformation of the optical surface figure of the primary mirror. Two active support schemes have been designed for 1-m primary mirror, and the performance of each support scheme is conducted. Finite element analysis (FEA) is employed to analyze the optical surface figures of the primary mirror, and optimizations are carried out by using ANSYS for each support scheme to obtain the locations and forces of the axial support. When the locations are determined, axial support force sensitivities are calculated for the two support schemes in a case that a single axial support has a force error of 1N. The correction ability of the both active support systems are analyzed when an arbitrary axial support is failure. Several low order Zernike modes are modeled with MATLAB procedure, and active optics corrections are applied to these modes for the both active supports. Thermal deformation of the mirror is also corrected for the two schemes. Through the performance comparison of the two support active schemes, we can search out which support system may more suitable for the 1-m primary mirror.

8444-192, Poster Session

Design, development, and testing of the DCT Cassegrain instrument support assembly

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The 4.3m Discovery Channel Telescope delivers an f/6.1 unvignetted 0.5° field to its RC focal plane. In order to support guiding, wavefront sensing, and instrument installations, a Cassegrain instrument support assembly has been developed which includes a facility guider and wavefront sensor package (GWAVES) and multiple interfaces for instrumentation. A 2-element, all-spherical, fused-silica corrector compensates for field curvature and astigmatism over the 0.5° FOV, while reducing ghost pupil reflections to minimal levels. Dual roving GWAVES camera probes pick off stars in the outer annulus of the corrected field, providing simultaneous guiding and wavefront sensing for telescope operations. The instrument cube supports 5 co-mounted instruments with rapid feed selection via deployable fold mirrors. The corrected beam passes through a dual filter wheel before imaging with the 6K x 6K single CCD of the Large Monolithic Imager (LMI). We describe key development strategies for the DCT Cassegrain instrument assembly and GWAVES, including construction of a prime focus test assembly with wavefront sensor utilized in fall 2011 to begin characterization of the DCT primary mirror support. We also report on 2012 on-sky test results of wavefront sensing, guiding, and imaging with the integrated Cassegrain cube.

8444-193, Poster Session

A laser guide star system for LAMOST

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The closed-loop correction must be carry out before observation of Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) to eliminate the low-frequency errors. A natural guide star S-H sensor in the focal plane of LAMOST is used to conduct wavefront sensing. The designed limiting magnitude of the S-H sensor is 10th magnitude, and the beacon must be located in the center of field of view, or slightly deviated from the center. The survey time of LAMOST is 2 hours before and after transit, wherefore the active optical correction should be completed within half of an hour, so it is necessary to make the wavefront sensing time as short as possible. Since the magnitude of guide star and

atmospheric seeing have important effect on the efficiency of wavefront sensing, 9th magnitude or brighter stars are adopted in operation. For 9th magnitude stars, sky coverage will be about 100%, but at most of time, the beacons are not located in the center of field of view, so we propose to design a laser guide system based on Rayleigh scattering to provide a beacon whose brightness is equivalent to a 7th or 8th magnitude star and to launch the beacon in the center of field of view at any observational sky. In this paper, we describe the optical design of the implementation involved a laser system with 532nm in wavelength, beam diagnostics, a launch telescope with 350mm in diameter, and receiving wavefront sensor.

8444-195, Poster Session

Experience of primary surface alignment for the LMT using a laser tracker in a non-metrology environment

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The 50-metre Large Millimeter Telescope (LMT) successfully completed first light observations in June 2011, operating with an initial 32-metre diameter collecting area. This consists of 84 surface segments measuring approximately 3x5m, each attached to the backstructure at four points, which can be adjusted remotely using actuators. A segment is composed of eight precision subpanels fixed to a support frame using threaded adjusters. Initial surface alignment of segments is achieved through manually setting the adjusters. For first light observations the segments were aligned offsite using a gantry CMM and subsequently fitted to the design parabola on the antenna backstructure using first a total station, then fine tuning the segment position using holography.

In preparation for the next observing season the 32m primary is being re-aligned at site, using a commercial laser tracker for surface alignment of each segment. Two approaches are being pursued: transfer of segments to the telescope basement for individual alignment, which offers an enclosed environment with stable temperature, or in-situ alignment of individual segments carried out on the antenna surface at night. There are advantages and disadvantages to both methods.

In this paper we present our experiences on the use of a laser tracker to conduct surface alignment on-site, at an isolated location 5,700m (18,700ft) above sea level and in the absence of dedicated metrology facilities. Emphasis will be placed on the practical limits to surface mapping and adjustment, paying close attention to achievable work schedules and the optimization of the adjustment process on the LMT primary surface.

8444-196, Poster Session

Using a laser tracker for active alignment on the Large Binocular Telescope

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The Large Binocular Telescope currently achieves collimation using a combination of collimation models and closed-loop active correction schemes. Shack Hartman wavefront sensors with off-axis guide stars are used for Gregorian modes, and a geometrical closed-loop correction scheme is used for the prime focus cameras. While in general this combination serves to produce alignment residuals well below a good seeing limit within a few minutes on-field, the uniquely asymmetrical structure of the LBT is prone to producing large deflections of the telescope optics when the ambient temperature is changing unusually rapidly. These deflections are difficult to model satisfactorily, and are an ongoing source of inefficiency in telescope operations. Furthermore, none of the current approaches to telescope collimation are particularly “OPD aware”; a situation that needs to be improved on now that the LBT is commencing operations with the first of its beam combining instruments, LBTI.

The laser tracker is a metrology instrument capable of automatically measuring optical element positions with better than 100 micron precision within a 20 m spherical volume centered on the tracker head. With the ability to directly measure optics into position to this accuracy built into the Telescope Control System (TCS), the LBT would always be starting observations from a point of near-collimation, the component telescopes would be co-pointed, and the OPD would be well within the capture range of the beam combining instrument’s internal phasing systems.

This paper describes first results from engineering investigations into using the laser tracker to automatically align the optics on the LBT.

8444-197, Poster Session

Generic misalignment aberration patterns and the subspace of benign misalignment

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How many wavefront sensors does a telescope need? To what order must the wavefront be measured? How often? The answers to these questions implicit in the design of the LSST -- four wavefront sensors measuring 36 Zernike terms once every 15 seconds -- may seem extreme.

But something close to this may be needed to meet the stringent requirements for cosmological weak gravitational lensing measurements.

We consider idealized telescopes with infinitely stiff mirrors and report on the generic misalignment aberration patterns that such telescopes produce. By way of example we consider the case of a three mirror anastigmat. We introduce the “subspace of benign misalignment” in which the generic misalignment aberration patterns associated with defocus, coma and astigmatism are controlled and zeroed. A minimum of 3 wavefront sensors and control of at least 2 rigid surfaces is needed to stay within the subspace of benign misalignment. One or more additional higher order wavefront sensors may be needed to measure wavefront errors due to non-rigid mirrors.

8444-198, Poster Session

The VST alignment: strategy and results

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In a wide-field telescope like the VST, the requirements for alignment are tighter than for traditional instruments. The same amount of misalignment can be negligible in traditional telescopes with fields of some arcminutes, but unacceptable when the field is one order of magnitude larger. We describe the alignment procedure implemented during the telescope commissioning on the Paranal ESO observatory, as well as the final results.

8444-199, Poster Session

Alignment strategies for high-resolution space camera

X. Meng, Y. Zhou, Beijing Institute of Space Mechanics and Electricity (China)

The high-resolution camera is a three mirror on-axis system with limited field 0.77×0.77 degree. In this paper, we describe the opto-mechanical alignment procedure of primary mirror, the secondary and the tertiary onto the mechanical structure of the space camera. The alignment procedure does not rely on the mechanical precision of the mirrors. it will be achieved using the gradual aberration optimization, discussed in the paper, which define the relationship between system wavefront aberration and Zernike coefficient based on vector aberration theory, and then construct a sensitive matrix about the misalignment optical system. Finally, the methods used to achieve the absolute positioning accuracy and the test results obtained in the ambient temperature meet the initial requirements of optical system design.

8444-200, Poster Session

Test system for a Shack-Hartmann sensor based telescope alignment demonstrated at the 40cm Wendelstein Telescope

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A commercial Shack-Hartman wavefront sensor is being used in a test setup installed at the Wendelstein 40cm telescope to test methods for telescope alignment based on reverse optimization. Measured low Zernike order wave-fronts are being used to determine the misalignment of the telescopes optical elements. Then a procedure to optimize performance by aligning the telescope secondary mirror is applied.

The setup contains a collimating optical system, the Shack-Hartman sensor and a guiding and acquisition camera.

8444-201, Poster Session

An improved collimation algorithm for the Large Binocular Telescope using source extractor and an on-the-fly reconstructor

D. L. Miller, A. Rakich, T. Leibold, Large Binocular Telescope Observatory (United States)

A recent upgrade of the LBTO's Wavefront Reconstruction algorithm in the Active Optics system has proven to reduce the collimation time by a substantial amount and to provide a much more stable telescope collimation as observing conditions change.

The new reconstruction algorithm uses Source Extractor to detect the spots in a Shack-Hartmann wavefront sensor camera image. With information about which Shack spots are detected, a reconstructor matrix is calculated on-the-fly that only includes the illuminated sub-apertures. This drastically improves the wavefront reconstruction for a highly aberrated wavefront when many sub-apertures contain no information. This is generally the situation at the beginning of the night when the collimation of the telescope is set only from models rather than on-sky information and occasionally when a new observational target is acquired. Similarly, the undersized tertiary mirror can cause vignetting of the pupil seen by the Shack-Hartmann wavefront sensor for far off-axis guide stars and again some sub-apertures have no wavefront information.

We will present a brief description of the Active Optics system used at the Gregorian focal stations at the LBTO, discuss the original wavefront reconstruction algorithm, describe the new Source Extractor algorithm and compare the performance of these two approaches in several conditions (low signal to noise, highly aberrated wavefront, vignetted pupil, poor seeing).

8444-202, Poster Session

Features of a laser metrology subsystem for astrometric telescopes

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In astrometric instrumentation a laser subsystem may be used for precise metrology of instrumental response.

Such subsystems do not require diffraction limited imaging, but can be tailored to specific application needs.

We describe an interferometric arrangement for high precision monitoring of telescope line of sight and evaluate its performance as function of some design parameters.

We deduce that a good sensitivity can be achieved over a significant range of e.g. focusing conditions, provided proper cautions are adopted for detection and data processing.

8444-203, Poster Session

Conceptual design of a 5-m terahertz telescope at Dome A

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A 5-meter terahertz telescope is proposed by the Chinese Center for Antarctic Astronomy (CCAA) for the East Antarctica site of the Dome A plateau. The Dome A 5-m terahertz telescope (DATE 5) will be operated at sub-millimeter waveband taking the unique advantage of the transparent atmospheric windows between 200 and 350 μm wavelengths at Dome A. A preliminary design has been conducted according to the given technical requirements and the special environmental conditions at Dome A. A symmetric R-C Cassegrain optical system is designed for the telescope, with a primary f-ratio of 0.4 and a wide field of view of 10 arcmin. The magnification of the sub-reflector is 9.4, leading to the final focal ratio of 3.76 and the focus 0.2 m below the vertex of the primary reflector. To ensure surface accuracy of the reflectors precise as small as 10 um RMS, we consider using Carbon Fiber Reinforced Plastics (CFRP) to build the backup structure (BUS) of the primary reflector and the sub-reflector itself. An alt-azimuthal mounting is adopted and a tall base structure beneath the telescope is set up to lift the telescope above the low atmosphere turbulent layer. All the mechanics, as well as control electronics, are strictly designed to fit the lower temperature operation in the Dome A environment. This paper is to generally present the mentioned systematic optical, structural and electronic design of the DATE 5 telescope.

8444-204, Poster Session

Astronomy in the Canadian high arctic: two new exoplanet survey instruments at a new observatory

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We describe a new observatory located in the Canadian High Arctic. The facility, under construction near the PEARL station on Ellesmere Island, at 80 degrees latitude, offers 24-hour darkness combined with dark skies and long cloud-free periods during the winter. Our first astronomical surveys conducted at this site are aimed at transiting exoplanets; compared to mid-latitude sites, the Arctic has greatly improved detection efficiency for longer-period transiting planets. We describe the design, construction, and testing of the first two components of the survey: a robotic telescope and a very wide-field imaging camera. The 20-inch robotic telescope has a 0.8-square-degree field of view and is designed to search for potentially habitable exoplanets around low-mass stars. The very wide field camera system is a 200-square-degree imager pointed at Polaris, designed to serve as a pathfinder for an instrument containing many cameras which will search for transiting planets around bright stars. The telescopes and observatory infrastructure are currently under construction and testing, as a collaboration between the Dunlap Institute and HIA. The wide-field imaging survey started in winter 2011/2012; the robotic telescope is currently undergoing testing in New Mexico and will be installed in the Arctic in summer 2012.

8444-205, Poster Session

A simple wide-field telescope design for Antarctica

W. Saunders, Australian Astronomical Observatory (Australia)

The Antarctic plateau offers unparalleled site quality for optical and near-infrared astronomy. Hewever, because of perceived technical difficulties, no O/IR telescope even as large as 1m diameter has yet been deployed there. We here offer a design of great simplicity and robustness, to alleviate these perceived difficulties. The design is a modified f/8 Hobby-Eberly telescope, with a flat sidereostat steering mirror, a fixed spherical primary mirror, and pairs of small aspheric mirrors for spherical aberration correction. There are just 4 required mechanisms for normal use (steering mirror azimuth and elevation, image rotation, focus), reducible to 2 for an equatorial mounting. The design has diffraction-limited optics for multiple Individual fields of up to 10'x10' (a single HAWAII 4RG detector). There are only 2 warm mirrors, and cold-stopping comes for free with the spherical aberration correctors. It is easy to incorporate fast guiding into the system, with the tip-tilt mirror conjugate to a useful height. Overall, diffraction-limited imaging should be obtainable in median conditions at 2.4 microns with a 2.5 to 4m-class telescope. Because the telescope has no prefered axis, the overall field of view is arbitrarily large, limited only by detector cost, and by the inevitable obscuration caused by the focal plane being within the beam.

8444-206, Poster Session

Cases for infrared astronomy and astrophysics for Antarctica

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We propose to investigate the most suitable science cases and telescope, adaptive optics system and focal instrument(s) for an optical and infrared facility in the Antarctica (DomeC) environment. Three astrophysical key domains will be studied: the chase and characterization of Type Ia supernovae and the investigation of the distant Universe, the stellar populations and evolution in the local group of galaxies, the identification and characterization of extra-solar planets. Compliant with sciences cases telescope, adaptive optics and focal instrument suitable for winterization at DomeC will be studied and at the end proposed.

8444-207, Poster Session

The package cushioning design of the first AST3 and its dynamics analysis

H. Wen, Nanjing Institute of Astronomical Optics & Technology (China)

Dome A has been considered as one of the best observation sites on the earth. The First AST3(three Antarctic Survey Telescopes) is on its way to Dome A by the 28th Chinese National Antarctic research expedition. It will be the largest Optic telescope in Dome A after assembling and testing in this austral summer. Firstly, this paper reports the way of collecting the vibration and shock data from ShangHai to Dome A and analyses the data. Secondly, the package cushioning design of the first AST3 is introduced in this paper according to the vibration and shock data. Finally, the paper introduces the result of the dynamics analysis of the design and a test was done to verify the performance of the package cushioning design. The dynamics analysis and the test indicate that the package cushioning design can meet the demand of the Antarctic inland transportation.

8444-208, Poster Session

Nonlinear disturbance of Large Optical Antarctic Telescope

S. Yang, Nanjing Institute of Astronomical Optics & Technology (China)

Large Optical Antarctic Telescope, LOAT hereafter ,is a new research hotspot nowadays. For example,a 2.5m KDUST, eg Kunlun Dark UniverSe Telescope is on anvil. It's difficult for main axis of large telescope tracking system to track the target precisely with ultra-low speed because of nonlinear disturbances due to unique ultra-low temperature. This paper presents these nonlinear disturbances.

8444-209, Poster Session

Where is Ridge A?

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First identified in 2009 as the site with the lowest precipitable water and best terahertz transmission on earth, Ridge A is located approximately 150 km south of Dome A, Antarctica. To further refine this optimum location prior to deployment in 2012 of a robotic THz observatory, we have modelled the atmospheric transmission as a function of location

over a 1000 km square grid using three years of data from the Microwave Humidity Sounder on the NOAA satellite. The modelling identifies a broad area of exceptionally low water vapour close to the 4,000 metre elevation contour, reaching below 25 microns for extended periods of time.

8444-210, Poster Session

Two years of polar winter observations with the ASTEP400 telescope

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The ASTEP program is dedicated to exo-planet transit search from the Concordia Station located at Dome C, Antarctica. It comprises two instruments: a fixed 10cm refractor pointed toward the celestial South Pole, and a 400mm Newton telescope with a 1x1 degrees field of view. This work focuses on the latter instrument. It has been installed in November 2009, and has been observing since then during the two polar winters 2010 and 2011. After presenting the main science observing programs, we review the telescope installation, performance, and describe its operating conditions as well as the data reduction and handling strategy. The resulting lightcurves are of unprecedented quality for a telescope of that size, comparable with a 1-m class telescope located at a tempered site.

8444-211, Poster Session

HETDEX tracker control system design and implementation

J. H. Beno, C. E. Penney, R. J. Hayes, I. M. Soukup, The Univ. of Texas at Austin (United States)

To enable the Hobby-Eberly Telescope Dark Energy Experiment, the University of Texas Center for Electromechanics and McDonald Observatorydeveloped a precision tracker and control system - a 15,000 kg robot to position a 3,100 kg payload within 10 microns of a desired dynamic track. Performance requirements to meet science needs and safety requirements that emerged from detailed Failure Modes and Effects Analysis resulted in a system of 13 precision controlled actuators and 100 additional analog and digital devices (mostly sensors and safety limit switches). This level of system complexity and emphasis on fail-safe operation is typical of large modern telescopes and numerous industrial applications. Due to this complexity, demanding accuracy requirements, and stringent safety requirements, a highly versatile and easily configurable centralized control system that easily links with modeling and simulation tools during the hardware and software design process was deemed essential. The Matlab-Simulink simulation environment, coupled with dSPACE controller hardware, was selected for controls development and realization. The dSPACE real-time operating system collects sensor information; motor commands are transmitted over a PROFIBUS network to servo amplifiers and drive motor status is received over the same network. Custom designed position feedback loops, supplemented by feed forward force commands for enhanced performance, and algorithms to accommodate self-locking gearboxes (for safety), reside in dSpace. To interface the dSPACE controller directly to absolute Heidenhain sensors with EnDat 2.2 protocol, a custom communication board was developed. This paper covers details of control software, algorithms, tuning, debugging, testing, and lessons learned.

8444-212, Poster Session

An upgrade to the telescope control system (TCS) for the Canada-France-Hawaii Telescope

K. K. Ho, W. L. Cruise, J. N. Thomas, Canada-France-Hawaii Telescope (United States)

CFHT has been in operation and serving the astronomical community since 1978. Some of the original systems are still is use and in need of an overhaul, in the particular the telescope control system (TCS). The computing hardware and software have been upgraded over the past decades but the servo hardware has largely remained untouched. As an ongoing program to maximize telescope efficiency and to improve performance and reliability, the TCS servo hardware is being redesigned. The plan is to replace obsolete and obsolescent components and to leverage on the modern state-of-the-art controllers such as the Delta Tau PMAC controllers. The high level software will remain intact but the underlying software will be modified to support the new hardware. The upgrade should take the telescope to end of its life, sometime in late 2020.

8444-214, Poster Session

Automation of the OAN/SPM 1.5-meter Johnson Telescope for operations with RATIR

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The Reionization And Transients Infra-Red (RATIR) camera is intended for robotic operation on the 1.5-meter Johnson telescope of the Mexican Observatorio Astronómico Nacional on Sierra San Pedro Mártir in Baja California. This paper describes the work we have carried out to successfully automate the telescope. One of the novel aspects of this is the use of finder telescopes with moderate-format CCDs to provide wide-field images that can be calibrated astrometrically by the astrometry. net software. Thus, we can precisely determine the pointing of the finder telescopes every 1.5 seconds and thereby perform closed-loop control of the pointing and guiding of the main telescope. The pointing accuracy has improved from several arcmin RMS to about 15 arcsec RMS, with the remaining error dominated by non-repeatibilities in the flexure between the main telescope and the finders.

8444-216, Poster Session

The first Antarctic Survey Telescope control system

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The first Antarctic Survey Telescope (AST) is a 50/68cm Equatorial telescope, the first Chinese automated telescope operating on the Antarctic plateau, planned to be in operations at Dome A the highest peak on the Antarctic plateau in January 2012. The telescope is unmanned during night-time operations in the Austral winter. The telescope optics and mechanics, as well as the motors and position sensors, are exposed to a very harsh environment. The mechanics is enclosed with a foldable tent-like dome to prevent snow, diamond dust and ice. While the telescope main control system (TCS), is located inside the warm instrumental cabin. This article describes the challenges and issues the telescope control system faced for night-time operations, such as the power supply limit, the harsh meteorological condition, unattended operation, automatic operation and protection, remote control and telemetry, etc. Some possible solutions are also discussed in this paper, which are applied on the AST and waiting for validation. AST is also an exploration of a larger telescope on the Antarctic.

8444-217, Poster Session

Development of an EtherCAT enabled digital servo controller for the GBT

P. G. Whiteis, National Radio Astronomy Observatory (United States)

EtherCAT (Ethernet for Control Automation Technology) is gaining wide spread popularity in the automation industry as a real time field bus based on low cost, Ethernet hardware. EtherCAT maximizes use of 100Mbps Ethernet hardware by using a collision free ring topology, efficient Ethernet frame utilization (> 95%), and data exchange “on the fly”. These characteristics enable EtherCAT to achieve Master to Slave node data exchange rates of > 1000 Hz.

The Green Bank Telescope, commissioned in 2000, utilizes an analog control system for motion control of 8 elevation and 16 azimuth motors. This architecture, while sufficient for observations at frequencies up to 50GHz, has significant limitations for the current scientific goals of observing at 115GHz. Accordingly, the Green Bank staff has embarked on a servo upgrade project to develop a digital servo system which accommodates development and implementation of advanced control algorithms.

This poster describes how the new control system requirements, use of existing infrastructure and budget constraints led us to define a distributed motion control architecture where EtherCAT real-time Ethernet was selected as the communication bus.

Finally, design details are provided that describe how NRAO developed a custom EtherCAT-enabled motor controller interface for the GBT’s legacy motor drives in order to provide technical benefits and flexibility not available in commercial products.

8444-218, Poster Session

Design and development of telescope control system and software for the 50/80 cm Schmidt telescope

K. S. Tripurari, R. Banavar, Indian Institute of Technology Bombay (India)

In this paper, we describe the details of telescope controller design for the 50/80 cm Schmidt telescope at the Aryabhatta Research Institute of observational sciencES (ARIES). We present the in-house design aspects of hardware including the PWM based PI controller for twin-motor drive, interfacing electronics for sensors, power amplifiers and filters. A telescope control software is developed in Visual C++ which runs multiple process threads for communication, data logging and provides a GUI for commanding the telescope. The telescope control architecture features a distributed network of simple low cost PIC microcontrollers over CAN thus providing redundancy, modularity, design simplification, seamless upgradation and ease of trouble shooting. Testing and basic functionality can also be implemented using the dedicated RS232 port per board. The RA and Dec axis are driven by twin motors for backlash-free motion and coupled to on-shaft encoders for absolute position measurements. The focus mechanism is driven by a bipolar stepper motor and an on-shaft encoder along with a LVDT are used for determining the absolute position. It has been observed that the rms velocity errors at slew, set, guide, fine and tracking speeds are negligible. At fine speeds the telescope exhibits limit cycles due to nonlinear friction which can be removed with an additional nonlinear compensator. At speeds over 3.90 × 10^−02 radians/sec, the friction becomes a linear function of velocity and the PI controller is able to track the reference with peak errors less than 1%.

8444-219, Poster Session

Upgrading the MMT primary mirror actuator test stand: a unique vehicle for evaluating EtherCAT as a future I/O standard for systems

D. L. Clark, S. Schaller, MMT Observatory (United States)

In 2010, MMTO began the process of replacing old electronics and software used on a test stand built by the Steward Observatory Mirror Lab in the early 2000s with a more modern solution. The approach taken was to select new hardware that was inexpensive, portable, and had new features, such as auto-calibration of the data acquisition system. This was also a chance to evaluate fairly new Ethernet-based bus standard, called EtherCAT, that was well-constrained in scope. Additionally, we were able to move the test stand software to a general-purpose Linux PC running a standard Fedora distribution, and avoid large costs in proprietary hardware and operating systems. We describe the new test stand hardware, data acquisition software, and the results of this evaluation of EtherCAT as a candidate for future i/o systems.

The presentation will cover the basics of EtherCAT communication with hardware, the auto-calibration circuit design that provides for measurement of the i/o offsets and gains, the software design that abstracts the low-level EtherCAT communication up to the user GUI, and the operation of the system in comparison with the old software and hardware.

8444-220, Poster Session

MMT nightly tracking logs: a web-enabled database for continuous evaluation of tracking performance

D. L. Clark, J. D. Gibson, D. Porter, T. Trebisky, MMT Observatory (United States)

The MMT mount control system automatically logs slew and tracking information to a logging data server. The logging can also be manually triggered by a telescope operator when a problem is noticed. These logs are collected daily and processed to produce time-series and FFT data, along with relevant statistics about the tracking performance (e.g. RMS tracking error). The output plots are available via a web page, which displays not only printable versions of the tracking data plots, but the statistics and weather conditions at the time of the tracking data file are available “at a glance”. The reduced log files are saved to a MySQL database and makes possible to collect long-term tracking performance information and correlate it to wind buffeting and other conditions. The raw data files are likewise saved and are always available for later, more detailed inspection. The poster will show the logging software, data

server connections, web interface, and relationship of the data collection and analysis to internally-published tracking reports.

8444-221, Poster Session

Pointing and tracking results of VST telescope

P. Schipani, C. Arcidiacono, INAF - Osservatorio Astronomico di Capodimonte (Italy); J. Argomedo, European Southern Observatory (Germany); M. Dall'Ora, S. D'Orsi, INAF - Osservatorio Astronomico di Capodimonte (Italy); J. Farinato, D. Magrin, INAF - Osservatorio Astronomico di Padova (Italy); L. Marty, INAF - Osservatorio Astronomico di Capodimonte (Italy); R. Ragazzoni, INAF - Osservatorio Astronomico di Padova (Italy); G. Umbriaco, Univ. degli Studi di Padova (Italy)

The VLT Survey Telescope (VST) is the latest telescope installed at ESO's Paranal Observatory. The exceptional quality of this top site imposes tight requirements on the telescope performance in terms of pointing modeling and tracking. This paper describes the control strategy and the results obtained during the commissioning of the telescope.

8444-223, Poster Session

Design and fabrication of three 1.6-meter telescopes for the KMTNet Project

W. M. Poteet, H. Cauthen, CP Systems, Inc. (United States)

The KMTNet telescope Project, sponsored by The Korea Astronomy and Space Science Institute (KASI), is fabricating three wide-field equatorial mount telescopes of 1.6 meter aperture to conduct continuous observations of the Galactic bulge region to search for extra-solar planets. Southern latitude sites secured for these telescopes are SAAO (South Africa), CTIO (Chile), and SSO (Australia). A prime-focus configuration, along with a four-lens corrector achieves the 2.8 degree diagonal FOV. The basic mechanical design utilizes a scaled-up version of the successful 2MASS Telescopes built by the authors in the late 1990's. Scaling up of components has presented challenges requiring several iterations of the detailed mechanical analysis as well as the optical analysis due to interaction with mounting assemblies for the optical components. A flexure-style focus mechanism, driven by three precision actuators, moves the entire headring assembly and provides real-time focus capability, and active primary mirror cooling is implemented for the Zerodur primary. KMTNet engineering specifications are met with the current design, which uses Comsoft's Legacy PCTCS for control. A complete operational telescope and enclosure are scheduled for installation in Tucson, AZ prior to shipping the first hardware to CTIO in order to verify tracking, optical characteristics at various attitudes, and overall observatory functionality. The cameras, being fabricated by The Ohio State University Department of Astronomy, Imaging Sciences Laboratory (ISL), are proceeding in parallel with the telescope fabrication, and that interface is now fixed. Specifics of the mechanical and optical design are presented, along with the current fabrication progress and testing protocols.

8444-224, Poster Session

Introduction of Chinese SONG Telescope

G. Wang, B. Gu, S. Kou, C. Ren, L. Xu, X. Jiang, Z. Zhang, D. Niu, Y. Ye, Nanjing Institute of Astronomical Optics & Technology (China)

SONG (Stellar Oscillation Network Group) is an international initiative to design, build, and utilize a global network of eight 1-meter class telescopes to be operated as a whole-Earth telescope initiated by Danish. SONG's primary goals are to study the internal structure and evolution of stars using an advanced technique called asteroseismology, and to search for and characterize extroplanets. China has joined the international SONG project in 2009 and will build one 1-meter telescope as the node of SONG global network in China. Now the telescope is during the period of building. The telescope structure, instruments and installation site will be introduced in this paper.

8444-225, Poster Session

Perspectives of astronomy in Kazakhstan: from new ground-based telescopes to space ones

C. T. Omarov, Z. S. Zhantayev, Fessenkov Astrophysical Institute (Kazakhstan)

Astronomical observations in Kazakhstan are carried out for over 60 years. The advantage of the geographical location makes it possible to set and conduct programs of stationary ground-based observations, that from the most observatories of other countries are difficult or impossible. Three 1-m and smaller telescopes are actively used for last 20-30 years, located at 2700m altitude. However outdated technical condition of scientific equipment, which include ground-based optical telescopes, poses a direct problem to the development of astronomy in Kazakhstan. In addition, observational data in the other spectral bands from space telescopes are needed.

Therefore, in order to create a modern experimental astrophysical base today in Kazakhstan two projects are being put forward in the frame of national space program: 1) a new optical telescope with a primary mirror 3.6 meters (completed in 2016) which supposed to be the biggest telescopes in central Asian region, and 2) participation in the international space project "World Space Observatory -Ultraviolet" that to be launched in 2014. Currently the feasibility study is done and negotiations with potential manufacturers of 3.6-m telescope are under way.

8444-226, Poster Session

Development and deployment status of the Las Cumbres Observatory Global Telescope Network

A. J. Pickles, W. E. Rosing, Las Cumbres Observatory Global Telescope Network (United States); L. d. net,

LCOGT is currently testing complete 1-m and 40-cm telescope prototypes, instruments, enclosures, weather system and operating software at its base facility in Goleta (near Santa Barbara) in California. Both classes of telescope are working well under robotic control. The java based Telescope Control System (jTCS) includes software agents to handle all astrometry, telescope, enclosure, weather, thermal and instrument services and to monitor and log all systems. An engineering interface to this layer is implemented as a GUI accessible via standard web browsers, including a web-based FITSviewer. The flash reduction carried out on local clusters at each site includes use of Astrometry.net to quickly provide on-sky coordinate reference to the TPK astrometric kernel. This enables automatic Tpoint modeling and easy polar alignment. Full removal of instrument signature, astrometric fit and source extraction are done after data transfer to our base facility, in a pipeline running under ORAC. Source information from this pipeline will be stored in a database maintained for us by IPAC.

We have developed and are successfully testing our Proposal Observation Network Database (POND) which monitors observations from request to completion. We are also developing a comprehensive network scheduler which takes observing requests from all scientific participants, schedules them across the network into each site POND, and re-schedules them as necessary to cope with changing circumstances, time-critical observations and targets of opportunity.

Science partners, including institutions hosting LCOGT sites, access

network time rather than time on specific telescopes or at specific sites. The Scottish University Physics Alliance (SUPA) has increased its share of network time by helping to fund the deployment and operation of additional 1-m telescopes.

We will describe progress towards our initial deployment goal of providing eight fully networked 1-m telescopes to our Southern sites by end-2013, to enable coverage of southern targets including micro-lensing targets in the Galactic Bulge. Additional 40-cm telescopes housed in clamshell enclosures at each site provide scientific and educational support via the network.

8444-227, Poster Session

The microwave holography system for the Sardinia Radio Telescope

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Microwave holography is a well-established technique for mapping surface errors of large reflector antennas, especially ones designed to operate at high frequencies.

We present here a holography system based on the interferometric method for mapping the primary reflector surface of the Sardinia Radio Telescope (SRT). SRT is a new 64-m-diameter antenna located in Sardinia, Italy, equipped with an active surface and designed to operate up to 115 GHz.

The system consists mainly of a two radio frequency low-noise coherent channels designed to receive a Ku-band digital TV signal incoming from a geostationary satellite. Two commercial primary focus low-noise block converters are respectively installed on the radio telescope under test and on a small reference antenna. Then the signals are amplified, filtered and down-converted into baseband. An innovative digital back-end based on FPGA technology has been implemented to digitize two 5MHz-band signals and calculate their cross-correlation in real-time. This is carried out by using a 16-bit resolution ADCs and a FPGA reaching a very large amplitude dynamic and reducing post-processing time. The final digital data post-processing are performed by using the CLIC reduction software developed by IRAM.

The system was successfully tested during several holography measurement campaigns recently performed at the Medicina 32-m radio telescope. Two 65-by-65 maps using an on-the-fly raster scan with on-source phase calibration were performed pointing the radio telescope at 38 degrees elevation. The high SNR (greater than 60 dB) and the good phase stability led to get an accuracy on the surface errors map better than 200 µm.

8444-228, Poster Session

Structural optimization of the outer ring of FAST Telescope

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The two-axis steering mechanism installed in the FAST focus cabin can be seen as a universal joint consisting of two ring beams and makes role in the process of real-time adjustment of the receiver orientation. The outer ring of the mechanism is a large-span curve beam with strict mass and rigidity requirements. The aim of this paper is to develop a simple and effective method for constructing a truss-shape structure for the outer ring under the upper-limit constraints of certain structural weight and mid-span deflection. Two truss configurations for weight minimization problems are presented. One assumes consistent beam height. The second design proposes varying heights along the ring. Deflections of the structure are calculated based on the finite element method. In numerical optimization of the structure, some key geometrical parameters are selected to be optimized. The optimization is subsequently achieved by the steepest descent method, which is based on the sensitivity analysis of the variables (reduced to be dimensionless) in each iteration. Several sets of initial conditions for optimization have been generated randomly. Corresponding optimum results have small mutual deviations. Finally a comparison of the two designs considering stiffness-to-mass ratios is given in the numerical examples.

8444-229, Poster Session

Experimental study on the damping of FAST cabin suspension system

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The focus cabin suspension of the FAST telescope has structurally weak-stiffness dynamics with low damping performance, which makes it quite sensitive to wind-induced vibrations. A reasonable estimation about the damping is very important for the control performance evaluation of the prototype. It is a quite difficult task as the telescope is no at available yet. In the paper, a preliminary analysis is first made on the aerodynamic damping.

Then a series of experimental models are tested for measuring the total damping. The scales of these models range from 10m to 50m in diameter while 6 test parameters are specially designed to check the damping sensitivity. The Ibrahim time domain (ITD) method is employed to identify the damping from the measured cabin response. The identification results indicate that the lowest damping ratio of the models is about 0.2%~0.4%. Friction-type cabin-cable joint seems to have main influence on the system damping.

8444-230, Poster Session

Control algorithm for the petal-shape segmented-mirror telescope with 18 mirrors

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A 3.8 m segmented telescope is planned to be build at the Okayama Astrophysical Observatory by the joint program among Kyoto university, Nagoya university, NAOJ, and Nano-Optonics Energy Co.

This is the world's first optical-infrared segmented-mirror telescope with 18 petal-shape segments.

To investigate the best layout of the displacement sensors as well as to study the control algorithm, we have developed a simulation software for the segmented petaloid mirrors. This simulator calculates the vertical position differences between the segments at the 60 displacement sensors based on the three-dimensional movements of the 54 actuators, and enables us to test the control algorithms under various conditions including random noise on the displacement sensors, random movement errors of the actuators, and unexpected lateral shifts of the segments. The outputs of the simulator are not only the phase error of the primary mirror, but also the PSF image with its statistical parameters taking the structure function of the optical surfaces into account.

We found that the 18 petal-shape segments are controllable based on the singular value decomposition method within the required errors of 15nm under the following three conditions:

1) staggered layout of the displacement measurement sensors between segments,

2) axisymmetric layout of the displacement measurement sensors with respect to the optical axis, and

3) the relative lateral shifts and rotations of each segment up to 500 um and 0.05 degree, respectively.

In this report, the control algorithm, requirements for the layout of the displacement measurement sensors, and the simulated performance will be presented.

8444-231, Poster Session

How to calibrate edge sensors on segmented mirror telescopes

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The next generation of large ground based telescopes use segmented mirrors. Sensors mounted on the edge of the segments measure the relative heights of the segments. The segments are actively controlled in height by three actuators per segment, but lateral motion is only passively constrained. Thus there will be some small change in the gap and shear between segments as changing telescope orientation and temperature make small distortions in the telescope structure. These “in-plane” motions place an additional performance burden on the edge sensors, and on the precision with which they must be mounted relative to the optical surface. In addition, sensor edge height readings also vary with changes in gap and with sensor tilts and rotations.

Our method for correcting the inplane motion induced errors in the primary mirror has three parts.

First, the edge sensors are modified to report segment-to-segment gap, as well as the height difference, to give observability to the in-plane segment positions. Second, the mirror segments are phased optically, at a set of zenith angles and temperatures, to give a set of “measured sensor readings”. Finally, during observing, a calibration procedure combines these data into “desired sensor readings” which are optimal for the current telescope state. We have included this calibration process in a control loop model of the Thirty Meter Telescope primary mirror control system. We present our calibration method and the model.

8444-232, Poster Session

Outdoors phasing progress of dispersed fringe sensing technology in NIAOT, China

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A telescope with a larger primary mirror can collect much more light and resolve objects much better than one with a smaller mirror, and so the larger version is always pursued by astronomers and astronomical technicians. Instead of using a monolithic primary mirror, more and more large telescopes, which are currently being planned or in construction, have adopted a segmented primary mirror design. Therefore, how to sense and phase such a primary mirror is a key issue for the future of extremely large optical/infrared telescopes. The Dispersed Fringe Sensor is a non-contact method using broadband point light sources and it can estimate the piston by the two-directional spectrum formed by the transmissive grating’s dispersion and lenslet array. In this paper we introduce you the current research progress of the successful design, construction and alignment of our dispersed Hartmann sensors together with its design principles and simulations for indoor segmented mirror experiment system and outdoor segmented mirror experiment system. We also conduct many successful real phasing tests and phasing corrections in the visible waveband using our existing indoor and outdoor segmented mirror optics platform. Finally, some conclusions are reached based on the test and correction of experimental results

8444-233, Poster Session

The new TNG-DIMM: calibrations and first data analysis

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During the last two years the Italian TNG at the Observatorio del Roque de los Muchachos (ORM, Canary Islands, Spain) had been equipped with a new DIMM, completing the sometimes incomplete data set which presently characterize the environment of the island Observatory.

A classical design was adopted and built in house, including control and analysis software. Comparison with other analog system in la Palma or Teide conformed the validity of the instrument.

Complementing the seeing data with the information from our meteo station we are able to collect a data set to investigate for observed behaviors in order to develop a model for seeing forecast. This will help in the development of the ORM future instrumentation, both day and night time.

We notice, with our 6 month data, the clear presence of a bi-seasonal meteorological condition, which also show different pattern in the seeing distribution at TNG.

8444-234, Poster Session

E-ELT site testing: first statistics of atmospheric seeing and isoplanatic angle at Jbel Aklim site in Moroccan Anti-Atlas

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In this paper we present an analysis of the statistical and temporal properties of seeing and isoplanatic angle measurements obtained with combined Differential Image Motion Monitor (DIMM) and Multi-Aperture Scintillation Sensor (MASS) at Jbel Aklim candidate site for the Eauropean Extremely Large Telescope (E-ELT).

These data have been collected from February 2008 to Jun 2010. The overall seeing statistics for Jbel Aklim site are presented, broken into total seeing, free atmosphere seeing and isoplanatic angle, and ground-layer seeing (difference between the total and free-atmosphere seeing). We examine the statistical distributions of seeing measurements and investigate annual and nightly behavior.

The properties of the seeing measurements are discussed in terms of the geography and meteorological conditions at Jbel Aklim site.

8444-235, Poster Session

Atmospheric turbulence measurements at Ali Observatory, Tibet

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The atmospheric turbulence characteristics are important to evaluate the quality of ground-based astronomical observatory. In order to assess Ali observatory, Tibet, continuously the vertical profiles of both optical turbulence and wind speed, we have developed a single star Scidar (SSS) system. The main SSS configuration includes a 40cm telescope and a CCD camera for fast sampling the star scintillation pattern. The SSS technique analyzes the scintillation patterns in real time, by computing the spatial auto-correlation and at least two cross-correlation images, and retrieves both Cn2(h) and V(h) vertical profiles from the ground to 30km above. This paper presents the turbulence measurements with SSS at Ali observatory in October to November,

2011. We have successfully obtained the profiles of optical turbulence and wind speed, as well as the key parameters for adaptive optics, such as seeing, coherence length, coherence time, and isoplanatic angle. The favourable results indicate that Ali observatory can be an excellent astronomical observatory.

8444-236, Poster Session

New Moroccan site testing study

E. A. Siher, Univ. Sultan Moulay Slimane (Morocco)

After the two first sites survey: Oukaimeden (31°12' North; 7°52' West, 2700 m a.s.l) and Jbel Aklim (30°8' North, 8°19' West, alt=2393 m a.s.l) for the ELT site prospection, we will use satellite data to present one preliminary study of another site in the Atlas mountain. This site called Tamjerjt (32°17' North; 6°17' West, 1267 m a.s.l) is located at 14 Km from Beni Mellal by a good road where one potential University exists. The Beni Mellal town is at 200Km from Marrakesh.

8444-237, Poster Session

E-ELT seeing and isoplanatic angle: comparison of Aklim site and El Roque de Los Muchachos Observatory

M. Sabil, Z. Z. Benkhaldoun, M. Lazrek, A. Habib, A. M. Benhida, Y. Hach, Y. El Azhari, T. El Halkouj, Univ. Cadi Ayyad (Morocco)

The new Extremely Large Telescope projects need accurate evaluation of the candidate sites, Aklim site located in Moroccan Anti-Atlas at the geographic coordinates 30°7'39" N, 08°18'39" W, and Observatorio del Roque de Los Muchachos (ORM), located in La Palma, Canary Islands, at 28°45'00 N, 17°53"10 W are tow pre-selected sites to house the E-ELT in the Northern hemisphere.

In this work we present the seeing, free seeing and isoplanatic angle comparison between these tow sites, statistics of the mentioned parameters are obtained from the whole data recorded from May, 09th 2008 to November, 09th 2009 using the Multi Aperture Scintillation Sensor - Differential Image Motion Monitor (MASS-DIMM) system, more representative results and statistics are shown hereafter.

8444-238, Poster Session

Comparison between astroclimatic parameters and 200 mbar wind at ELT and TMT candidate sites

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In a previous paper published in the Monthly Notices of the Royal Astronomical Society we made a comparison between astroclimatic parameters provided by the MASS and the 200 mbar wind at Paranal observatory. In this paper we follow the same procedure concerning the data of all candidate sites for the ELT (Extremely Large Telescope) and the TMT (Thirty Meter Telescope) projects and other sites with publically availible data.

Ground level winds and high atmopheric level winds are compared to the seeing of six atmospheric levels, the free atmosphere seeing, the wavefront coherence time and the isoplanatic angle.

The idea is to draw some correlations according to the geographical location of the site

8444-239, Poster Session

Dust concentration and soil properties at the TMT candidate sites

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We describe the experimental setup of the experiments addressing the soil and dust properties as measured during the TMT site testing campaign. At a Chilean site we also installed two sets of ground heat flux plates and soil temperature sensors at different depths, allowing to measure the energetic properties of the summit soil at Cerro Armazones directly. We also will discuss the potential use of such measurements on improving the local seeing.

8444-240, Poster Session

Surface layer turbulence measurements on the LSST site El Peñon using microthermal sensors and the lunar scintillometer LuSci

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Results from determining the surface layer turbulence profile on the LSST site, El Peñon, located on Cerro Pachón (Chile) are presented. As part of the LSST site characterization campaign, microthermal measurements were taken on the LSST site in order to determine the contribution of the surface layer turbulence. Such measurements are commonly used for this purpose where pairs of microthermal sensors mounted on a 30m tower measure atmospheric temperature differences as their fast thermal response allows monitoring of small and rapid air temperature variations.

In addition, the lunar scintillometer LuSci was also installed on El Peñon for short campaigns near full moon to determine the surface layer turbulence. LuSci is a turbulence profiler based on measuring spatial correlation of moonlight scintillations. It uses the moon light to measure the night-time surface layer turbulence by recording its temporal fluctuations over a linear array of photodetectors. During the site characterization campaigns, simultaneous measurements were taken using both LuSci and the microthermal sensors. The comparison of the measurements of the index of refraction structure constant Cn2 by both instruments is also provided in this paper.

8444-241, Poster Session

Overview of site monitoring at the SAAO

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We present a comprehensive review of the first two years of a site monitoring campaign at the South African Astronomical Observatory (SAAO) located outside Sutherland, South Africa. This campaign is in support of the Southern African Large Telescope (SALT), a 11-metre fixed-elevation optical telescope located at SAAO. The heart of this observing campaign involves continuous monitoring of the site by a MASS-DIMM instrument. The MASS-DIMM has been in routine use since March 2010 and its operation is now fully automated. At the beginning of this campaign, simultaneous observations were also made

by a SLODAR instrument, which allows high resolution observations of the lower atmosphere. In August 2011, a two week campaign was carried out with a two-channel Generalized Seeing Monitor (GSM) telescope along with a lunar limb profiler (Profileur Bord Lunaire; PBL). Combined with the MASS-DIMM data these observations provide multiple independent measurements of atmospheric turbulence as a function of height. They also help improve the calibration of our site for more direct comparison to other major astronomical observatories. Our results so far indicate that the atmospheric conditions at the SAAO Sutherland site have deteriorated compared to past measurements. The ground layer accounts for the majority of the integrated seeing, while the free atmosphere seeing is comparable with other major sites. Finally, we highlight how these measurements will be used in future instrument planning for SALT.

8444-242, Poster Session

Evaluations of new atmospheric windows at thirty micron wavelengths for astronomy

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Thirty micron is one of the most important wavelengths for studying dusty universe. Unfortunately atmosphere around thirty micron is so opaque that we cannot make astronomical observations normally from the ground. But it is accessible from extremely high sites including the summit of Co. Chajnantor (altitude ~ 5,640m) in the Atacama desert, Chile.

We have made site developments of Co. Chajnantor for a 6.5-meter TAO telescope for over ten years (Yoshii et al. 2010). The pilot 1.0-meter mini-TAO telescope was installed in 2009. We have also developed a mid-infrared camera MAX38 (Asano et al. in this conference), and have carried out five observing runs (total 29 nights) at thirty micron since November 2009.

In order to assess the atmospheric conditions at thirty micron wavelengths for astronomy, data taken by the mini-TAO/MAX38 were statistically analyzed. This is the first quantitative evaluations of the atmospheric windows at thirty micron. It is revealed that the atmospheric transmittance drastically changes within a short time scale and the change is well correlated with values of precipitable water vapor (PWV). The transmittance over 20% is achieved when the PWV below 0.6 mm, giving a good agreement with the ATRAN atmospheric model. We have also found that the transmittance decreases up to 10% in some cases. It may be caused by patchy distribution of the water vapor. Liquid water or ice in the atmosphere might also affect it.

We will report the results of the evaluations of the atmospheric windows at thirty micron in detail.

8444-243, Poster Session

Atmospheric seeing measurements obtained with MISOLFA in the framework of the PICARD Mission

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PICARD is a space mission launched in June 2010 to study mainly the geometry of the Sun. The PICARD mission has a ground program consisting in some instruments based at the Calern Observatory (Observatoire de la Côte d'Azur). They allow recording simultaneous solar images and data from ground. The ground instruments consist in SODISM II, the qualification model of the PICARD space instrument, standard sun-photometers and a pyranometer for estimating a global sky quality index, and MISOLFA a generalized daytime seeing monitor. Indeed, astrometric observations of the Sun using ground-based telescopes need an accurate modeling of optical effects induced by atmospheric turbulence. MISOLFA is founded on the observation of Angle-of-Arrival (AA) fluctuations and allows us to analyze atmospheric turbulence optical effects on measurements performed by SODISM II. It gives estimations of the coherence parameters characterizing wave-fronts degraded by the atmospheric turbulence (Fried's parameter, size of the isoplanatic patch, the spatial coherence outer scale and atmospheric correlation times). We present in this paper the seeing measurements obtained at Calern observatory with MISOLFA and their statistical analysis.

8444-244, Poster Session

Optical system of Chinese SONG telescope

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The telescope will be delivered by the end of 2012. Network observation of SONG can do microlensing 200 times efficient than traditional telescopes, may solve the question: "How common are plants like the earth".

8444-245, Poster Session

Design of an off-axis optical reflective telescope systems

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At the present time the majority of reflective optical systems of telescopes, which are being developed are axial and, therefore, suffer from central obscuration, which results in effective aperture ratio reduction and high order diffraction intensity growth comparing to intensity of first order of diffraction. That in turn leads to reduction of resolution ratio and contrast. Therefore, one of the most promising area in design of optical systems described above is off-axial optical reflective systems development. It becomes especially important for systems working in IR spectral range because of the mirror heat radiation ratio being significantly lower than lens one.

Existing off-axial optical systems aberration theories are based on series expansion of optical path function (eikonal function). However, it was noticed, if off-axial optical system suffers from significant first-order aberrations, in general aberration values obtained with series expansion of optical path function differ from ones obtained with exact ray-tracing. For such cases we have used an aberration theory, developed by the Japanese authors T. Namioka and M.Koike for aberration analysis of optical systems with concave reflective diffraction gratings. In this theory, based on series expansion of exact ray-tracing equations, it is shown, that expressions for high-order aberration coefficients include expressions for low-order ones.

Numeric evaluations, conducted in this paper, have shown, that the most accurate results are obtained with this theory, based on series expansion of exact ray-tracing equations. We have used just that very method in our search of optimal decision for off-axis optical reflective telescope systems, consisting of axisymmetrical mirrors as well as mirrors having

one or two symmetry planes. It is shown, that usage of mirrors with one symmetry plane allows to increase telescope's field of view and aperture compared with axial analogues, consisting of off-axial optical elements, for instance off-axial analogues of Cassegrain or Ritchie-Cretien optical systems. Examples are shown illustrating these findings.

8444-246, Poster Session

Interferometric apodization of circular aperture using homothety, part II: application to stellar coronagraphy

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We present in this work the application of the interferometric apodization using homothety of circular aperture to stellar coronagraphy. We present the first results of similations. We consider that the optical system is perfect and there are no effects of optical aberrations. We also shows that theinterferometric apodization using the homothety is equivalent toapodization that would give a circular aperture of transmittancestaircase. We also discuss the influence of various parameters on the rejection of the Lyot and Roddier 's coronagraph.

8444-248, Poster Session

The dome flat-fielding system for the 1.3m Araki Telescope

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We report the system/optics design and performance of the dome flat-fielding system for the Araki Telescope, which is the 1.3m optical/near-infrared telescope at Koyama Astronomical Observatory in Japan. The flat-fielding system should be available for the varieties of instruments. The optical imager, which is intended to search for exoplanets requires the illumination flatness within 1% and 10% on the focal plane over the 20 arcmin FOV and on the pupil plane, respectively. The illumination flatness at the pupil plane as well as the focal plane of the telescope is essential to calibrate the transmittance of the optical element (e.g., lenses, filters, and so on). The high resolution optical and near-infrared spectrographs, on the other hand, require the illuminance greater than 0.8mW/m^2 on the slit. We make an optical design of the flat-fielding system to satisfy the illumination flatness, using a non-sequential ray tracing software, LightTools. We consider the far-field illumination pattern of the light sources, the scattering surface reflectance distribution of the screen, the telescope structure like the spiders, primary/secondary mirrors, and primary/secondary mirror baffles. As the result of the simulation, we achieved the ~1.1% and ~4% flat illumination distribution at the focal plane and at pupil plane, respectively. To achieve both the high and low illumination on the focal plane, we used six high power (100W) halogen lamps and the by-pass circuit to an autotransformer. The voltages of lamps are controlled by a consumer-use thyristor-driven dimmer and are remotely operated from the observation control room via Ethernet connection.

8444-249, Poster Session

Fast and compact wide-field Gregorian telescope

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A traditional Gregorian telescope features an intermediate focus which makes the system longer than an equivalent Cassegrain design. One could shorten the Gregorian system by inserting a flat mirror before the secondary. We explore the potential of this compact configuration for sky survey imaging with relaxed requirements for angular resolution. A 0.5m f/1.4 telescope with 4 deg. full field is presented. The design consists of two elliptical mirrors and a folding flat in between. A plano-convex field flattener is used near the focal plane. The telescope optical performance is analysed and possible improvements are discussed.

8444-250, Poster Session

Optical design for amateur reflecting telescopes based on tilted axial-symmetrical planoidal mirror

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Optical system with tilted planoidal mirror in the entrance pupil commonly discussed for space and large ground telescopes cause cost of produce of its surface. Nevertheless, for low angle of tilt in small sized amateur telescopes these surface can be manufacture as very cheap central-symmetrical. Both the reflecting Wright also as Schmidt are possible. The maximum relative aperture of the these systems depends on the diameter of the entrance pupil. Calculations showed that the relative aperture is interesting for the practice of visual and astrophotography up to 0.5 m diameter in the visible range.

Wide spectral range, resistance to misalignment, there is no spurious reflections, the possibility of expanding the FOV by the small rotations planoidal mirror, ease of fabrication and low cost are advantages of such systems.

Extremely small tilt angle of the planoidal mirror in the "mirror-Wright" system is the cause of serious problems to defend the focal plane from straight light. There are three baffles in the optical system "mirror Wright" are necessary to protect the focal plane - the "tube with entrance door", the "cone of the central hole" and the "front screen". The forms and sizes these baffles can be calulated from focal ratio, airspace, position and diameter of the focal plane.

A sample of the "mirror Wright" in diameter and 155 mm focal length 720 mm was manufactured and tested his resolution by the author. Field of view of the sample, protected from straight light, is 1.7 degrees.

8444-251, Poster Session

Preliminary optical design for the WHT two-degree prime focus corrector

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We present the preliminary optical design for the two-degree refractive prime focus corrector for the 4.2m William Herschel Telescope optimised for the wide-field multi-object spectroscope, WEAVE (WHT Enhanced Area Velocity Explorer). From the two conceptual designs described previously, the counter-rotating atmospheric dispersion corrector design was selected and further optimized to meet the flat image surface requirement. The preliminary design provides good polychromatic image quality. The PSF is no larger than 0.6 arcsec (80% encircled energy) over a wavelength range from 370 to 1000 nm, over a two degree FOV for zenith angles up to 65 degrees. We describe the corrector's performance and the trade-off between telecentricity and flat image surface. We present the results of the tolerance and thermal analyses, ghost and scattered light calculations and the finite element analysis that are necessary to establish the PSF error budget for the corrector.

8444-252, Poster Session

Optical system and design of the quasi-Richy-Cretien 1.6 meter wide-field telescope for Sayan Observatory

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In this report we present and discuss the design, construction and capabilities of the two meters class wide field survey telescope. The designs based on modified R-C system with two or three lens correctors in visible and near infrared (2,2 mkm) spectral range. The optical systems of the 1.6 meters telescope with up to 3 degrees field of view and less than 15% obscuration area are considered in detail. Optical performance of system, its mount and separate element of the active optics system are examined.

8444-50, Session 15

E-ELT update of project and effect of change to 39m design

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During the last year a modified baseline design for the E-ELT has been developed. The aim of this revision was both to achieve a significant cost saving and to reduce risk on major items. The primary mirror diameter was slightly reduced to 39 m and the total height of the telescope also decreased accordingly. This paper describes the work performed by ESO and a variety of contractors to review the EELT design to match the modified baseline. Detailed design and construction planning, as well as detailed cost estimates were updated for the 39-metre baseline design. In June 2011, ESO Council formally endorsed this modified design as the E-ELT revised baseline.

8444-51, Session 15

Thirty Meter Telescope project update

L. M. Stepp, G. H. Sanders, Thirty Meter Telescope Observatory Corp. (United States)

The Thirty Meter Telescope is an optical/infrared telescope that will be located near the summit of Mauna Kea on the big island of Hawai'i. This paper will provide an overview of progress in formation of the international partnership, approval of the Environmental Impact Statement for construction on Mauna Kea, design of the facility, telescope, adaptive optics systems and instruments, and fabrication and testing of prototype subsystems, including full-scale full-asphericity primary mirror segments.

8444-52, Session 15

Giant Magellan Telescope: overview

M. Johns, P. J. McCarthy, K. Raybould, A. Bouchez, A. Farahani, J. M. Filgueira, G. H. Jacoby, S. A. Shectman, M. Sheehan, Giant Magellan Telescope Project (United States)

The Giant Magellan Telescope (GMT) is a 25-meter optical/infrared extremely large telescope that is being built by an international consortium of universities and research institutions. It will be located at the Las Campanas Observatory in Chile. The GMT primary mirror consists of seven 8.4-m borosilicate honeycomb mirror segments made at the Steward Observatory Mirror Lab (SOML). Six identical off-axis segments and one on-axis segment are arranged on a single nearly-paraboloidal parent surface having an overall focal ratio of f/0.7. All of the fabrication, testing and verification procedures required to produce the closely-matched off-axis mirror segments were developed during the production of the first mirror. Production of the second off-axis segment is underway.

GMT incorporates a seven-segment Gregorian adaptive secondary to implement three modes of adaptive-optics operation: natural-guide star AO, laser-tomography AO, and ground-layer AO. A wide-field corrector and ADC are available for use in seeing-limited mode over a 20-arcmin diameter field of view. Up to seven instruments can be mounted simultaneously on the telescope in a large Gregorian Instrument Rotator. Conceptual design studies were completed for six AO and seeing-limited instruments, plus a multi-object fiber feed, and a roadmap for phased deployment of the GMT instrument suite is being developed.

The partner institutions have made firm commitments for ~40% of the funds required to build the telescope. Project Office efforts are currently focused on advancing the telescope and enclosure design in preparation for subsystem- and system-level preliminary design reviews which are scheduled to occur in the second half of 2012.

8444-54, Session 15

Science with the re-baselined European Extremely Large Telescope

M. Kissler-Patig, J. Liske, European Southern Observatory (Germany)

The modifications to the European Extremely Large Telescope (E-ELT) baseline design were accompanied by an evaluation of their impact on science. We will present the conclusions of this evaluation.

The Design Reference Mission served as benchmark for the evaluation. None of the modifications critically affect the Science Case. In particular, the full instrumentation suite can still be implemented allowing for the full foreseen suite of science cases. The largest impact is induced by the reduced diameter. For a large fraction of the science cases this can be offset by increasing the exposure times by ~20-34%. Where spatial resolution is the limiting factor, the limits have to be reduced by 9%.

The exoplanet case deserves a special mention: two of the three components of this case (detection of Earth twins by the radial velocity method, and characterisation of the atmospheres of transiting planets) are unaffected; for the third component (direct imaging of Earth-like planets) the same results as for the original baseline can be achieved, but only at 20% smaller distances.

Overall, all of the major science cases of the E-ELT can essentially be maintained.

8444-55, Session 17

Opacity measurements at Summit Camp in Greenland and PEARL in northern Canada with 225 GHz tipping radiometer

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We report the first measurements of atmospheric opacity at 225 GHz at Summit Camp (Latitude 72.57 N; Longitude 38.46 W; Altitude 3250 m) in Greenland and the Polar Environment Atmospheric Research Laboratory (PEARL: Latitude 80.05 N; Longitude 86.42 W; Altitude 600 m) in Northern Canada with a tipping radiometer. Summit Camp and PEARL are research stations mainly for meteorology and geophysics, and they are potentially excellent sites for astronomical observations at sub-millimeter wavelength. We purchased the tipping radiometer from the Radiometer Physics GmbH. After a test run at the summit of Mauna Kea, Hawaii, the radiometer was deployed to PEARL in February 2011, and then relocated to Summit Camp in August 2011. The atmospheric

opacity has been monitored during February 14, to May 10, 2011 at PEARL and since August 17, 2011 at Summit Camp. The median values of the measured opacities varied from 0.15 on Feb. to 0.19 on May at PEARL. And those at Summit Camp varied from 0.19 on Aug. to 0.06 on Nov. Together with the existing radiosonde data and a meteorological model, Summit Camp in Greenland is expected to be an excellent site for sub-millimeter and Tera-hertz astronomy, and we plan to set up a 12-m telescope for VLBI and single-dish observation. In this paper, we report latest status of opacity monitoring at Summit Camp.

8444-56, Session 17

Site characterization studies in high plateau of Tibet

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The site survey in western China has been carried out since 2003, in order to identify appropriate sites for constructing large telescopes for East-Asian communities. Remote studies and local surveys are performed over the vast land of plateau, and Oma site, on the Ali plateau in southwest Tibet, has been selected in 2005 to make site testing measurements. Following the site selection process of ELT projects , we could identify Ali area as the best choice for astronomical observations over the East Asian regions. A new site, near the central town of the Ali area, has been further identified in 2009 for small telescope projects, and simultaneously for detailed characterization of the site, and has begun the construction in 2010. This paper briefly reviews our long term site testing works, presents site characteristics of Tibetan sites, and introduces current status of the new Ali observatory.

8444-57, Session 17

New instruments to calibrate atmospheric transmission

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Changing atmospheric transmission accounts for the largest systematic errors limiting photometric measurement precision and accuracy for ground-based telescopes. While considerable resources have been devoted to correcting the effects of the atmosphere on image resolution, the effects on precision photometry have largely been ignored. To correct for the transmission of the atmosphere requires direct measurements of the wavelength-dependent transmission in the same direction and time that the supported photometric telescope is acquiring its data.

We describe the multi-wavelength lidar, the Facility Lidar for Astronomical Measurement of Extinction (FLAME) that observes the stable upper stratosphere, and a spectrophotometer (the Astronomical Extinction Spectrophotometer - AESoP) that creates and maintains NIST absolute standard stars, the combination of which enables high photometric precision of both the stellar spectra and atmospheric transmission. The throughput of both FLAME and AESoP are calibrated to NIST radiometric standards.

This inexpensive and replicable instrument suite provides the lidar-determined monochromatic transmission of Earth's atmosphere at visible and near-infrared wavelengths to better than 0.25% per airmass and the wavelength-dependent transparency to better than 1% uncertainty per minute. These atmospheric data are merged to create a metadata stream that allows throughput corrections from data acquired at the time of the scientific observations to be applied to broadband and spectrophotometric scientific data. This new technique replaces the classical use of nightly mean atmospheric extinction coefficients, which invoke a stationary and plane-parallel atmosphere and ultimately limit ground-based all-sky photometry to 1% - 2% precision.

This work supported by NIST Award 60NANB9D9121 and NSF Grant AST-1009878.

8444-58, Session 18

The Kunlun Dark Universe Survey Telescope

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The Kunlun Dark Universe Telescope (KDUST) is a wide field survey telescope with the goal of mapping part of the southern sky at an unprecedented spatial resolution and depth. The primary mirror is 2.5 meter in diameter, and will be installed at the Chinese Kunlun Station at Dome A, Antarctica. The major scientific goals are the dark matter and dark energy of the universe and the search for exoplanets. The data products include (1) a deep high quality imaging survey of more than 5000 sq degree for the purpose of weak lensing maps of dark matter and dark energy; (2) a deep near infrared survey at the wavelength around 2.4 micron down to KAB about 27 mag to search for the first stars and galaxies in the Universe; (3) a Type Ia supernova program that aims to discover supernovae up to redshift of 2; (4) search and follow up of exoplanets.

8444-59, Session 18

A new telescope for ground-based THz astronomy

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In the spring of 2010, the Academia Sinica Institute of Astronomy and Astrophysics, and the Smithsonian Astrophysical Observatory, acquired the ALMA North America prototype antenna - a state-of-the-art 12-m diameter dish designed for submillimeter astronomy. Together with the National Radio Astronomy Observatory and the MIT-Haystack Observatory, the plan is to retrofit this antenna for cold-weather operation and equip it with a suite of instruments designed for a variety of scientific experiments and observations.

The primary scientific goal is to image the shadow of a Super-Massive Black Hole in M87 in order to test Einstein's theory of relativity under extreme gravity. This requires the highest angular resolution, which can only be achieved by linking this antenna with others already in place to form a telescope almost the size of the Earth. We are therefore developing plans to install this antenna at the peak of the Greenland ice-sheet. This location will produce an equivalent North-South separation of almost 9,000 km when linked to the ALMA telescope in Northern Chile, and an East-West separation of about 6,000 km when linked to SAO and ASIAA's Submillimeter Array on Mauna Kea, Hawaii, and will provide an angular resolution almost 1000 times better than that of the most powerful optical telescopes.

Given the quality of the atmosphere at the proposed telescope location, we also plan to make observations in the atmospheric windows at 1.3 and 1.5 THz. We will present plans to retrofit the telescope for cold-weather operation, and discuss potential instrumentation and projected time-line.

Paper 8444-60, Session 18

Status of the first Antarctic Survey Telescopes for Dome A

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The preliminary site testing carried out since the beginning of 2008 shows the Antarctic Dome A is very likely to be the best astronomical site on earth,There Antarctic Survey Telescopes (AST3) were proposed for observations of supernovas and extrasolar planets searching there.The first telescope was successfully mounted on Dome A in Jan. 2012 and the automatic observations were started from Mar. 2012.

8444-61, Session 18

Ukpik: testbed for a miniaturized robotic astronomical observatory on a high Arctic mountain

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Mountains along the northwestern coast of Ellesmere Island, Canada, possess the highest peaks nearest the Pole. This geography, combined with an atmospheric thermal inversion restricted to below ~1000 m during much of the long arctic night, provides excellent opportunities for uninterrupted cloud-free astronomy - provided the challenges of these incredibly remote locations can be overcome. We present a miniaturized robotic observatory for deployment on a High Arctic mountaintop. This system tested the operability of precise optical instruments during winter, and the logistics of installation and maintenance during summer. It is called Ukpik after the Inuktitut name for the snowy owl, and was deployed at two sites accessible only by helicopter, each north of 82 degrees latitude; one on rock at 1100 m elevation and another on a glacier at 1600 m. The instrument suite included at first an all-sky-viewing camera, with the later addition of a small telescope to monitor Polaris, both protected by a retractable weather-proof enclosure. Expanding this to include a narrow-field drift-scanning camera for studying extra-solar planet transits was also investigated, but not implemented. An unique restriction was that all had to be run on batteries recharged primarily by a wind turbine. Supplementary power came from a methanol fuel-cell electrical generator. Communications were via the Iridium satellite network. The system design, and lessons learned from three years of operation are discussed, along with prospects for time-domain astronomy from isolated, high-elevation polar mountaintops.

8444-62, Session 18

The Gattini South Pole UV experiment

A. M. Moore, California Institute of Technology (United States)

The Gattini South Pole UV experiment was deployed to the South Pole dark sector in February 2010 and has recently completed a highly successful first season of winter time observations. The experiment has, for the first time ever, measured and categorized the optical night sky brightness at the very blue wavelengths. The experiment consists of a remotely operated 6” aperture custom designed telescope. The telescope feeds a blue sensitive imager with 4 degree field of view that contains a bank of 3 filters: sloan g’, Bessel U and a custom “super U” filter specifically designed to probe the sky emission at wavelengths approaching the atmospheric cut-off. The filters are continually cycled with exposure times ranging from 30 to 300 seconds throughout the winter period. The telescope, in addition, feeds a 2 degree long slit VPH grating spectrograph with R~1000. The bandwidth is 350-450nm. The spectra are recorded simultaneously with the imager exposures. The experiment is designed for low temperature Antarctic operation and resides on the roof of the MAPO building in the South Pole Antarctic sector. The primary science goals are to categorize the Antarctic winter time sky background at the very bluest of wavelengths as a pathfinder for the Antarctic Cosmic Web Imager. We present a technical overview of the experiment and results from the first winter season.

8444-63, Session 18

PLATO-R: a new concept for Antarctic science

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PLATO-R is an autonomous, robotic observatory that can be deployed anywhere on the Antarctic Plateau by Twin Otter aircraft. It provides heat, data acquisition, communications and up to 1kW of electric power to support astronomical and other experiments throughout the year. PLATO-R will be deployed in January 2012 to Ridge A, believed to be the site with the lowest precipitable water vapour (and hence best THz transmission) on earth. PLATO-R improves upon previous PLATO designs that were built into ten-foot shipping containers by being much smaller and lighter, allowing it to be field deployable within 48 hours by a crew of four.

8444-64, Session 19

Canada-France-Hawaii Telescope image quality improvement initiative: thermal assay of the observing environment

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As part of the image quality (IQ) assessment and improvement initiative being carried out at 3.6m Canada France Hawaii Telescope (CFHT) on Mauna Kea, Hawaii, our objective in the work reported here is to obtain a systematic assay of thermal sources within the dome and in the summit environment around the observatory, and therefore mitigate their contributions to dome seeing and ground layer turbulence. Toward this, we undertook a nighttime overflight to capture thermal images with a calibrated infrared camera of the outer structures of CFHT and the neighboring observatories on the summit ridge, and of a significant area of the surrounding terrain. The same thermal camera was then used to capture heat sources within the dome. Using a convective heat transfer model, all these measured surface temperatures were converted to heat

fluxes to the ambient. In addition, using button type temperature loggers, we directly measured the nighttime dome skin temperatures of CFHT and two other observatories to evaluate the efficacy of different paints and coatings used to minimize supercooling of the dome skin. Though similar studies have been carried out at other observatories, the results are rarely available in published literature. Therefore, here we explain our methodologies, and a detailed discussion of our results and inferences as a resource for the larger observing community.

8444-65, Session 20

New optical telescope projects at Devasthal Observatory

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Devasthal (79E,29N,2.5km), in western Himalayan region of India is emerging as among the best optical astronomy sites in the continent. The minimum recorded atmospheric seeing at the site is 0.6 arcsec with median value at 1.1. Currently, a 130-cm F/4 wide field (66' FoV) optical telescope is operating at the site. In near future, a 400-cm Liquid mirror telescope in collaboration with Belgium and Canada, and a 360-cm optical telescope in collaboration with Belgium is expected to be installed in 2012-13. The telescopes will be operated by Aryabhatta Research Institute of Observational Sciences. The first instruments on the 3.6 meter telescope will be in-house designed and assembled Faint Object Spectrograph and Camera. The second generation instruments will be including a large FoV imager, High resolution spectrograph, Integral field unit, and a near-IR imager. The 130-cm telescope is primarily used for wide field photometry imaging while the liquid mirror telescope will see a time bound operation to image half a degree wide strip in the galactic plane. There will be an aluminizing plant at the site to coat mirrors of sizes up to 4 meter. The Devasthal observatory and its geographical importance in between major astronomical observatories makes it important for time critical observations requiring continuous monitoring of variable and transient objects from ground based observatories. The site characteristics, its expansions plans and first results from the existing telescope will be presented.

8444-66, Session 20

Towards a National Astronomy Observatory for the United Arab Emirates

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This is the first presentation of the projected UAE national astronomy facility. Our presentation is a status report and will focus on the overall concept and goals of such a UAE astronomy facility, and on the initial geographical site survey, in which we was conducted in order to identify an initial list of potential candidate sites to host the telescope(s) on UAE territory. Sites were investigated in view of overall geographical suitability, light pollution, access, etc. This study will form the basis for a proper future site testing campaign within UAE.

8444-67, Session 20

The 3.6 m Indo-Belgian Devasthal Optical Telescope: general description

N. Ninane, C. Flebus, AMOS Ltd. (Belgium); B. Kumar, Aryabhatta Research Institute of Observational Sciences (India)

AMOS SA has been awarded of the contract for the design, manufacturing, assembly, tests and on site installation (Devasthal, Nainital in central Himalayan region) of the 3.6 m Indo-Belgian Devasthal Optical Telescope (IDOT).

The telescope has Ritchey-Chrétien optical configuration with one axial and two side Cassegrain ports. The meniscus primary mirror is active and it is supported by pneumatic actuators. The azimuth axis system is equipped with hydrostatic bearing.

The telescope was completely assembled and tested in AMOS workshop. This step is completed and successful. The telescope is now ready for shipment to Nainital.

This paper describes the telescope and summarizes the test results performed at AMOS to demonstrate that the telescope satisfies the main system requirements.

8444-68, Session 20

Designing, manufacturing, testing, and integrating a 2.5m telescope

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Over the past few years, Sagem REOSC has designed, manufactured and tested a 2.5m ALT/AZ telescope and its complete observatory. The next stage - integration - should occur in 2012. The aim of this paper is to develop the different stages of the project from technical and management's point of view.

The telescope is a 2.5m-class telescope with an aperture of F/8. It is composed of a 2.5m primary mirror made of Zerodur©, a silica secondary mirror and a rotating tertiary mirror that allows pointing at Nasmyth foci. In addition, a wide field corrector can be adapted either at Cassegrain focus or at Nasmyth focus. Results achieved on the realization of such optics will be presented.

An emphasis on the concurrent engineering and the problem solving approach will also be presented.

8444-69, Session 21

E-ELT optomechanics: overview

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The E-ELT is a project led by the European Southern Observatory (ESO) for a 40-m class optical, near- and mid-infrared, ground-based telescope.

When it will enter into operation, the E-ELT will be the largest and most powerful optical telescope ever built. It will not only offer unrivalled light collecting power, but also exceedingly sharp images, thanks to its ability to (at least partially) compensate for the adverse effect of atmospheric turbulence on image sharpness.

The basic optical solution for the EELT is a folded three-mirror anastigmat, using a 39-m segmented primary mirror (M1), a 4-m convex secondary mirror (M2), and a 4-m concave tertiary mirror (M3), all active.

Folding is provided by two additional flat mirrors sending the beams to either Nasmyth foci along the elevation axis of the telescope. The folding arrangement (flat M4 and M5 mirrors) is conceived to provide conveniently located flat surfaces for an adaptive shell (M4) and field stabilisation (M5).

That paper provides an overview of the specifications, design, and expected performance of the E-ELT optical systems.

8444-70, Session 21

E-ELT M1 test facility

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During advanced design phase of the EELT project prototypes of several critical components have been developed based on subsystem specifications. During the last year some of them have been tested and some have been integrated into dedicated test stands. Especially, for the EELT M1 unit a reduced implementation with 2 active and 2 passive segments on a representative piece of support structure has been setup.

The test stand is equipped with complete prototype segment subunits, support mechanisms and class segments, carrying edge sensor prototypes and position actuators for control and additional metrology for monitoring. The purpose is to test calibration, alignment and handling procedures, study control strategies and achievable component and subsystem performances, and identify interface issues in view of the telescope design.

In this paper an overview of the E-ELT M1 prototyping activities will be presented with a particular focus on the M1 unit test facility and experiences and results obtained up to now.

8444-71, Session 21

Active damping strategies for control of the E-ELT field stabilization mirror

B. Sedghi, M. Dimmler, M. Mueller, European Southern Observatory (Germany)

The fifth mirror unit (M5) of E-ELT is a field stabilization unit responsible to correct for the dynamical tip and tilt caused mainly due to the wind load on the telescope.

The unit is composed of: i) an electromechanical subunit, ii) an elliptical mirror with a size of approximately 2.4 by 2.7-m. The M5 unit has been designed and prototyped using a three point support of the mirror actuated by piezo actuators without the need of a counter weight system. To be able to meet the requirements of the telescope, i.e. sufficient wavefront rejection capability, the unit shall exhibit a sufficient bandwidth for tip/tilt reference commands. In the presence of the low damped mechanical resonant modes, such a bandwidth can only be guaranteed thanks to an active damping loop. In this paper, different active damping strategies for M5 unit are presented. The efficiency of the approaches are analyzed using a detailed model of the unit. On a scale one prototype active damping is implemented and the efficiency was demonstrated.

8444-73, Session 21

Repairing stress induced cracks in the Keck primary mirror segments

D. McBride, J. S. Hudek, W. M. Keck Observatory (United States)

The revolutionary segmented mirror design of the Keck Observatory telescopes pioneered the way for the creation of a new generation of large telescopes. Supporting segmented mirrors presents unique challenges. The Keck primary mirror segments are supported by two types of bonded Invar attachments. Radial in-plane loads of each mirror are supported by six pads bonded around the circumference of a 254mm diameter blind hole in center of the mirror segment. Axial loads are supported by thirty-six inserts bonded at the bottom of 18mm diameter holes in the segment. There are twelve additional axial insert attachments which support sensors to align the mirror segment to its neighbors. Stress induced cracks in the Zerodur glass have developed at adhesive bonds for both the radial and axial supports. This has been a slow process that has advanced over the 20 year life of the telescopes. All eighty four mirror segments (including twelve spares) exhibit cracks to varying degrees. The number and severity of cracks has now reached a stage at which repairs are mandatory. A project is under way to determine the root causes of the cracks, and to develop a repair strategy. New supports and bonding methods are being designed and tested that will replace all of the original supports.

8444-117, Session 21

Development of a fast steering secondary mirror prototype for the Giant Magellan Telescope

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The Giant Magellan Telescope (GMT) will be a 25m class telescope currently in the design and development phase. The GMT will be a Gregorian telescope and equipped with a fast-steering secondary mirror (FSM). This secondary mirror is 3.2 m in diameter and built as seven 1.1 m diameter circular segments conjugated 1:1 to the seven 8.4m segments of the primary. The prototype of FSM (FSMP) development effort is led by the Korea Astronomy & Space Science Institute (KASI) with several collaborators in Korea, and the National Optical Astronomy Observatory (NOAO) in USA. The FSM has a tip-tilt feature to compensate image motions from the telescope structure jitters and the wind buffeting. For its dynamic performance, each of the FSM segments is designed in a lightweight mirror. Support system of the lightweight mirror consists of three axial actuators, one lateral support at the center, and a vacuum system. A parametric design study to optimize the FSM mirror configuration was performed. In this trade study, the optical image qualities and structure functions for the axial and lateral gravity print-through cases, thermal gradient effects, and dynamic performances will be discussed.

8444-74, Session 22

Alignment algorithms for the Thirty Meter Telescope

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A variety of computer algorithms utilized in the alignment of segmented telescopes were developed for and implemented on the 36-segment Keck telescopes in the 1990s. The algorithms associated with the Keck segmented primary mirrors are very similar to those that will be used for the Thirty Meter Telescope (TMT). However, there are alignment or related wavefront measurement tasks associated with the TMT secondary and tertiary mirrors for which the corresponding Keck algorithms either did not exist or are not adequate for TMT. We discuss two particular algorithms associated with the TMT secondary and tertiary mirrors.

8444-75, Session 22

Phasing metrology system for the GMT

D. S. Acton, Ball Aerospace & Technologies Corp. (United States); A. H. Bouchez, Giant Magellan Telescope Project (United States)

The Giant Magellan Telescope is a 25.4 m diameter ground-based segmented Gregorian telescope, composed of a 7 x 8.4 m primary mirror segments, and 7 x 1.0 m adaptive secondary mirror segments. Co-phasing of the integrated optical system will be partially achieved by making real-time measurements of the wavefront from an off-axis guide star. However, slowly varying aberrations due to thermal and gravitational effects, as well as wind buffeting, will make it difficult to maintain alignment based on real-time optical measurements alone. Consequently, we are proposing internal metrology systems to maintain the relative alignment of the optical elements. In this paper we describe a differential capacitive edge sensing system to maintain the relative alignment of the adaptive secondary mirror reference bodies. We also propose an

interferometric system for sensing of the relative displacements of primary mirror segments.

8444-76, Session 22

Performance prediction of the fast steering secondary mirror for the Giant Magellan Telescope

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The Giant Magellan Telescope (GMT) is a 25m telescope which is one of the extremely large telescope projects in the design and development phase. Fast-steering secondary mirror (FSM) is one of the GMT two Gregorian secondary mirrors. The FSM is 3.2 m in diameter and built as seven 1.1 m diameter circular segments conjugated 1:1 to the seven 8.4m segments of the primary. The FSM has a tip-tilt feature to compensate image motions from the telescope structure jitters and the wind buffeting. The support system of the lightweight mirror consists of three axial actuators, one lateral support at the center, and a vacuum system. A parametric study and optimization of the FSM mirror blank and central lateral flexure design were performed. This paper reports the results of the trade study. For the optimized FSM configuration, the optical image qualities and structure functions for the axial and lateral gravity print-through cases, thermal gradient effects, and dynamic performances will be discussed.

8444-77, Session 22

Dynamics, active optics, and scale effects in future extremely large telescopes

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The next generations of earth-based telescopes, with primary mirrors in the range of 30m-diameter and beyond, will give access to unprecedented optical performances with respect to the current generation of 10-meter class telescopes. Building on the success of the technologies developed for the Keck Telescopes, telescope designers will resort to dense segmentation to build those large primary mirrors.

However, the general change in scale of the whole optomechanical system composing the telescope will pose new challenges. Amongst them, maintaining the overall shape of the primary mirror and the relative position of its segments within optical tolerances (from a few hundreds to a few tens of nanometers) in face of external disturbances is becoming critical.

The first part of the paper examines the modelling and the control strategy for active optics. The model has a moderate size due to the separation of the quasi-static (primary) behaviour of the mirror from the dynamic response. The control strategy considers explicitly the primary response of the telescope through a singular value controller. The control-structure interaction is addressed with the general robustness theory of multivariable feedback systems, where the dynamic response is considered as uncertainty.

The second part addresses the scaling laws that allow extrapolating the results obtained with existing telescopes to future ones, and the most relevant parameters are highlighted. The study is illustrated with a set of examples of increasing sizes. This numerical study confirms that scaling laws can be used in confidence in the preliminary design of large segmented telescopes.

8444-78, Session 23

The development of the actuator prototypes for the active reflector of FAST

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Upon its completion, the Five-hundred-meter Aperture Spherical radio Telescope (FAST) will be the largest single dish radio telescope ever in the world. The construction has been initiated in March 2011 in the Guizhou province of China. The whole construction process is expected to be completed in September 2016, with duration of 5.5 years.

With an aperture of 500 meters and an illumination aperture of 300 meters, the active reflector is one of the most important parts of FAST. The reflector is composed of a ring beam, a cable net and thousands of panels, tie-down cables, actuators and anchors. For the observation process of source switching and source tracking, the parabola shape of the reflector is achieved by the drawing of the tie-down cables by the actuators. The motion performance and the reliability of the actuators are of great importance to the telescope.

In this paper, the motion models of the actuators are analyzed for the observation process of source switching and source tracking. Several design schemes are proposed, including mechanical and hydraulic design. The electric, mechanical and hydraulic characteristics of these designs are discussed. Related experimental studies are performed to investigate the electric and mechanical performances of these actuator prototypes. Based on the analysis and test results, a final type of actuator will be optimally concluded to meet the requirements of the reflector of FAST.

8444-79, Session 23

Modeling a large submillimeter-wave observatory with recent results

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The 25 meter aperture segmented Cornell Caltech Atacama Telescope (CCAT) will provide enormous increase in sensitivity and mapping speed in the submillimeter bands compared to existing observatories, provided it can establish and maintain excellent image quality. To accomplish this at a low cost, it is necessary to conduct accurate engineering trades, including the most effective segment and wavefront sensing and control approach, to determine the best method for continuously maintaining wavefront quality in the operational environment. We describe an integrated structural/optical/controls model that provides accurate performance prediction. The model uses segment edge sensors to measure six degree-of-freedom (6DOF) segment motions followed by a 6DOF segment state estimate and 3DOF per segment wavefront control to align the segmented primary mirror. A simple model is also developed to study system performance with segment cupping due to thermal gradient through the segment and its compensation under various segment cupping distributions. We detail the analysis methods used to quantify critical design trades and discuss wavefront performance predictions after compensating for segment gravity displacements from our recent simulation studies.

8444-80, Session 24

Design, development, and manufacturing of highly advanced and cost effective aluminium sputtering plant for large area telescopic mirrors

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The design, development and manufacturing of a fully automated and cost effective aluminium sputtering unit for the deposition of aluminium on large area telescopic mirrors (maximum diameter of 3600mm) is presented here. The unit employs DC planar magnetron sputtering for the deposition process. A large area glow discharge unit is also designed for the pre-cleaning of the mirrors prior to aluminium coating. A special kinematic support structure with rotation is designed to support heavy mirrors of large area to minimise the deflection of the mirrors during deposition process. A custom designed ‘mask’ is employed in the magnetron system to improve the thickness uniformity within <±3%. The adhesion, thickness uniformity and reflectivity properties are studied in detail to validate the sputtering plant. Special jigs have been designed for the system to accommodate smaller mirrors and studies have been conducted for the coatings and reported in the paper. The unit was successfully tested at HHV facility in Bangalore and will be installed at the ARIES Facility, Nainital.

8444-81, Session 25

The Square Kilometre Array

M. P. van Haarlem, SKA Organisation (United Kingdom)

The Square Kilometre Array (SKA) will be a revolutionary radio telescope with ultimately about one square kilometre of collecting area, giving 50 times the sensitivity and 10,000 times the survey speed of the best current day radio telescopes. It will give astronomers insight into the formation of the first stars and galaxies after the Big Bang, how galaxies have evolved since then, the role of magnetism in the cosmos, the nature of gravity, and studies in astro-biology. The SKA is a global project in which astronomers and engineers from more than 70 institutes in 20 countries, together with industry partners, are participating in the scientific and technical design. The SKA will employ antenna systems to cover, initially, the frequency range from 70 MHz to 10 GHz (4 m to 3 cm wavelength). Fifty percent of the total antenna collecting area will be concentrated in the core region, 15-20 km across, with the remainder in outlier stations at distances of up to at least 3000 km to provide very detailed images of the cosmos. Signals received by the antennas will be transferred to a central signal processing system and high performance computer by optical fibre links carrying up to 420 Gbits/sec per dish and 16 Tbits/sec per aperture array. The special purpose central processing system will process as much as 1 petabyte of astronomical data every 20 seconds, so that exascale computing and exabyte data storage will be required. A sophisticated data archive and distribution system will provide access to the data by astronomers and physicists anywhere in the world. Two candidate locations are under consideration: Australia - New Zealand and Southern Africa. A decision on where the telescope will be sited is expected in 2012.

8444-82, Session 25

ASKAP: the Australian SKA Pathfinder

A. E. Schinckel, Commonwealth Scientific and Industrial Research Organisation (Australia)

The Australian Square Kilometre Array Pathfinder (ASKAP) will be the fastest cm-wave survey radio-telescope and is under construction on the new Murchison Radio-astronomy Observatory (MRO) in Western Australia. ASKAP consists of 36 12-meter 3-axis antennas, each with a large checkerboard phased array feed (PAF) operating from 0.7 to 1.8 GHz, and digital beamformer preceding the correlator. The PAF has 96 dual-polarization elements (192 receivers) and the beamformer will provide about 30 beams (at 1.4 GHz) to produce a 30 square degree field of view, allowing rapid, deep surveys of the entire visible sky. The large data-rates involved (~ 2 Tb/sec per antenna) and the need to do pipeline processing has led to the antenna incorporating a third axis to fix the parallactic angle with respect to the entire optical system (blockage and phased array feed).

The first antenna was deployed at the MRO in late 2009, and has been used for VLBI observations. Thirteen more antennas were deployed during 2010 and 2011 and all 36 will be completed by mid-2012.

The MRO, 315 kilometres north-east of Geraldton, Western Australia, is being developed as an SKA-ready site. The world’s most robust Radio Quiet Zone has been implemented for the site by the Australian Communications and Media Authority (ACMA), with extremely tight controls on licensed transmitters in the region. The primary infrastructure construction is now complete, including installation of the fiber connection from the MRO site to Perth via Geraldton (with the full cable appropriate for the SKA).

8444-83, Session 25

LOFAR, the low frequency array

R. Vermeulen, ASTRON (Netherlands)

LOFAR, the Low Frequency Array, is a next-generation radio telescope designed by ASTRON, with antenna stations concentrated in the north of the Netherlands and currently spread into Germany, France, Sweden and the United Kingdom; plans for more LOFAR stations exist in several other countries. Utilizing a novel, phased-array design, LOFAR is optimized for the largely unexplored low frequency range between 30 and 240 MHz. Digital beam-forming techniques make the LOFAR system agile and allow for rapid re-pointing of the telescopes as well as the potential for multiple simultaneous observations. Processing (e.g. cross-correlation) takes place in the LOFAR BlueGene/P supercomputer, and associated post-processing facilities. With its dense core (inner few km) array and long (more than 1000 km) interferometric baselines, LOFAR reaches unparalleled sensitivity and resolution in the low frequency radio regime.

The International LOFAR Telescope (ILT) is now issuing its first call for observing projects that will be peer reviewed and selected for observing starting later this year. Allocations will be based in part on reserved fractions assigned by national consortia in return for contributions from their country to the ILT, and in part will be on the basis of Open Skies. In this invited talk, the gradually expanding complement of operationally verified observing modes and capabilities will be reviewed, and some of the exciting first astronomical results will be presented.

8444-84, Session 25

The MeerKAT Radio Telescope

J. Jonas, Rhodes Univ. (South Africa)

The MeerKAT radio telescope is a precursor for the mid-frequency SKA dish array: it will be located on one of the two SKA candidate sites, it is a pathfinder for SKA engineering development, and its science drivers are closely allied to the SKA key science programme. It will be the most sensitive centimetre-wavelength radio telescope in the southern hemisphere and equal the sensitivity of the EVLA. It is primarily being designed for executing deep imaging and sensitive time-domain surveys, but will also allow general facility observations.

The MeerKAT array will comprise of 64 gregorian offset antennas, each with a projected diameter of 13.5 m and fitted with a suite of up to four single-pixel, cryogenically cooled receivers covering the operating frequency range (580 MHz - 14.5 GHz). Initially the array will extend to 10 km baselines. The choice of optical configuration and receiver strategy resulted from an extensive programme of electromagnetic simulation, mechanical finite-element analysis and system-wide performance optimization. Key metrics in this optimization were sensitivity (Ae/Tsys), imaging and spectral dynamic range, cost (both capital and operating) and operational issues (including maintenance). The methodology and results of this analysis will be presented.

The capital and operating costs of the antennas are a dominant component of the MeerKAT (and SKA) budget. The robust system engineering and value engineering processes that have been employed to control costs while achieving the required specifications will be described, as will the novel technologies used for implementation and construction.

Novel techniques and devices are being developed for the receiver packages, including the feed horns, ortho-mode transducers (OMTs), cryogenic systems, direct digitization processors and digital signal transmission systems. The technical details and implementation of these components will be discussed.

The MeerKAT array processor will provide a correlator for continuum and spectral line imaging, and a coherent tied-array beamformer for time-domain observations and baseband recording (e.g. VLBI). Full bandwidth digital voltage data “spigots” will be implemented for user-provided processing systems, in particular for wide-field fast transient surveys. Although the front-end of the digital processor will use FPGA technology based on the CASPER hardware and firmware products, the switch-based signal transport architecture seamlessly allows for heterogeneous processing elements in the downstream signal path. The back-end processing (e.g. calibration and imaging) will also be implemented on heterogeneous fabric of processing platforms. The architecture and implementation of these digital and computing systems will be presented.

The MeerKAT is to be located within the Karoo Radio Astronomy Reserve, an extensive and inherently radio-quiet radio facility that has been established for radio astronomy facilities and experiments. This arid, remote location provides operational challenges for the MeerKAT, and in this regard it is also an operations pathfinder for the SKA. The establishment of the infrastructure for the Reserve and the operations model for the facility will be described.

8444-85, Session 26

The RAEGE VLBI 2010 radiotelescope design

E. Sust, MT Mechatronics GmbH (Germany); J. A. López Fernández, Instituto Geográfico Nacional (Spain)

The RAEGE (Red Atlantica Estaciones Geodinamicas Espaciales) VLBI 2010 radiotelescopes are belonging to a new generation of radiotelescopes suitable for high precision geodetical earth observation and measurements, that shall allow to built up a high precision global reference system.

The design of the radiotelescopes has been finished by MT Mechatronics in summer 2011 and currently three radiotelescopes are being manufactured. The first one is scheduled for installation in summer 2012 at Yebes Observatory close to Madrid. The two others will be installed at the Azores, Santa Maria Island as well as at Tenerife.

The radiotelescope is designed as elevation/azimuth turning head telescope. The optical design is based on a 13,2m ring focus reflector. In the basic configuration, the observation frequency is in the range from 2 - 40 GHz. It can be enhanced up to 100 GHZ by using additional options.

Essential for geodetical telescopes is the possibility of measuring the position of the intersection between azimuth and elevation axis. Therefore a concrete pillar is installed at the center of the telescope tower, allowing the installation of a measurement system, located at the axis intersection, being visible from the outside through openings.

For multiple dish VLBI arrays one important requirement is the path length stability. Active measurement of deformation and “flexible body compensation” (FBC) is foreseen to handle the path length errors analogue to the established methods used for surface and focus/pointing error corrections.

The telescope design as well as the provisions for achieving the challenging requirements are discussed here.

8444-86, Session 26

Architecture of the metrology for the SRT

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The Sardinia Radio Telescope (SRT) Metrology team, is planning to install an initial group of devices on the new 64 meters radio-telescope. These devices will be devoted for the realization of the antenna deformation control system: an electronic inclinometer able to monitor the alidade deformations and a Position Sensing Device (PSD) able to map the antenna secondary mirror (M2) displacements and tilts. The inclinometer will be used to map the rail conditions, the azimuthal axis inclination and the thermal effects on the alidade structure. The PSD will be used to measure the secondary mirror displacements induced by the gravity and by the thermal deformations that produce shifts and tilts with respect to its ideal optical alignment. The PSD will be traced by diode laser installed on a mechanically stable position inside the elevation equipment room. The inclinometer has been tested in laboratory with the aim to compare its performances with a reference measurement system. The PSD and the laser have been characterized by a long-term tests to assess their stability and accuracy, thus simulating the open air conditions that will be experienced by the device during its operative life. M2 may move freely in space thanks to a six axis actuator system (hexapod). The PSD measurements are processed by a hexapod kinematic model (HKM) to evaluate the correct actuator elongations, thus closing the control loop. The sensors will be acquired and recorded by a dedicated PC installed in the Alidade equipment room and connected to the sensors via the Ethernet network.

8444-87, Session 26

Requirements and considerations of the surface error control for the active reflector of FAST

M. WU, Q. WANG, X. GU, B. ZHAO, National Astronomical Observatories,CAS (China)

The Five-hundred-meter Aperture Spherical radio Telescope (FAST) is currently under construction at a Karst depression in the Guizhou province of China. The active reflector of the telescope is composed of 4395 triangular panels laid on a cable-net structure. The aperture of the spherical surface is 500 meters, with open angle of about 110~120 degrees. Acting as the nodes of the reflector, the joint of these panels are adjusted by 2235 down-tie cables drawn by actuators. The RMS error of the parabola reflector is expected to be 5mm.

To form the parabola shape of the reflector, for each of the actuators, a minimal working stroke of 950mm is required, with maximal speed of 1.6mm/s at the load of 50kN. Considering the elastic deformation of the down-tie cable and other factors, a positioning error within 0.25mm is required for the actuators.

In this paper, the base formula for the motion of a general actuator at a typical observation time is studied analytically. The results are used to estimate the control error of the actuators and the pointing error of the whole reflector. Based on the designed error budgets, a statistical method is employed to estimate the overall surface error of the parabola reflector. The overall surface error is a comprehensive result of the panel design error, panel fabrication error, thermal deformation error, panel wind load induced error, cable-net error, installation error, measurement and control error etc. The results may be used as a reference in the measurement and control of the active reflector when in operation.

8444-88, Session 26

Adjustment and alignment of the Sardinia Radio Telescope mirrors

M. Süss, D. Koch, MT Mechatronics GmbH (Germany); H. Paluszek, sigma3D (Germany)

The Sardinia Radio Telescope (SRT) is the largest radio telescopes recently built in Europe - a 64m Radio Telescope designed to operate in a wavelength regime down to 1mm.

The SRT is designed in a classical Gregorian configuration, allowing access to the Primary mirror focus (F1), the Gregorian Focus (F2) as well a further translation to different F3 using a beam waveguide system and an automated change between different F3 receiver positions.

The primary mirror M1, 64m in diameter, is composed by 1008 individual panels. Its surface, as well as the one of the 8.5m Gregorian subreflector, needed to be adjusted after panel mounting at the Sardinia site. The measurement technique used for this effort is photogram-metry, in case of the large scale M1 a dedicated combination of a large scale and a small scale approach developed to achieve extremely high accuracy on the large scale dimension. The measurement/alignment efforts have been carried out in 2010 and 2011, with a final comple-tion in spring 2012. The results obtained so far are presented and discussed in combination with an outlook towards future tasks.

The overall alignment approach also included the absolute adjustments of M2 to M1 and the alignments of M3, M4 and M5. M3 is a rotating mirror guiding the RF beam to a M4 or M5, depending on the operational scenario. These adjustements were based on Lasertracker mea-surements and have been carried out in an integrated approach.

8444-89, Session 27

Atacama large millimeter/submillimeter array (ALMA): construction and start of early science

M. W. M. de Graauw, ALMA (Chile); S. Iguchi, National Astronomical Observatory of Japan (Japan); M. M. McKinnon, National Radio Astronomy Observatory (United States); W. Wild, European Southern Observatory (Germany); R. J. Kurz, R. E. Hills, ALMA (Chile)

The Atacama Large Millimeter/submillimeter Array (ALMA) is an international observatory under construction in the Atacama region of northern Chile. ALMA is an radio interferometer made of 54 12-meter and 12 7-meter antennas providing a collecting area of 6600 m2 with baselines from 18 meters to 16 km. All antennas will be equipped with identical (sub)millimeter-wave receivers covering 84 to 950 GHz. State-of-the-art superconductor, microwave, digital and photonic techniques will be used to capture the signals, transfer them to a correlator while maintaining accurate synchronization between all array elements. ALMA will provide the astronomical community with a (sub)mm facility to address key questions in all areas of astronomy, with Hubble Space telescope type detail, a velocity resolution of ~100m/s and with great sensitivity and fidelity.

This presentation provides an update on the status of construction, commissioning and science verification with first results from the Early Science observations, that started in September last year.

8444-90, Session 27

ALMA commissioning and science verification

R. E. Hills, A. B. Peck, Joint ALMA Observatory (Chile)

ALMA is a large and complicated telescope and the process of bringing it into operation is a substantial task. This paper will describe the steps required to get from the stage where the sub-systems - antennas, receivers, correlators, etc. - have been assembled and tested, to the point where the complete system is functioning as a telescope and the astronomical data it produces have been shown to be valid. These have included building up an appropriate team, developing the test procedures and methods for tracking issues, and then carrying out a great deal of detailed work to solve the problems that were identified. Illustrative examples of these will be described to give some idea of their nature and range, along with what had to be done to resolve them. Naturally difficulties have arisen in both hardware and software components, and often, not surprisingly, involve a combination of both of these. Once basic operation had been established, a start was made on science verification observations, which in this context mainly involves taking data on objects that have already been observed with existing millimetre-wave arrays and checked whether or not our results are consistent with theirs. Some of these results, together with other commissioning data, will be shown and commented on. The paper will conclude with a summary of the progress to date and an outline of what further work remains to be done to complete the commissioning and science verification program.

8444-91, Session 27

Final tests and performances verification of the European ALMA antennas

G. Marchiori, F. Rampini, European Industrial Engineering s.r.l. (Italy)

The Atacama Large Millimeter Array (ALMA) is under erection in Northern Chile. The array consists of a large number (up to 64) of 12 m diameter antennas and a number of smaller antennas, to be operated on the Chajnantor plateau at 5000 m altitude. The antennas will operate up to 950 GHz so that their mechanical performances, in terms of surface accuracy, pointing precision and dimensional stability, are very tight.

The AEM consortium constituted by Thales Alenia Space France, Thales Alenia Space Italy , European Industrial Engineering (EIE GROUP), and MT Mechatronics is being assembling and test of 25 antennas. Today the first set of antennas have been delivered to ALMA for science.

During the test phase with ESO and ALMA the European antennas shown excellent performances ensuring the specification requirements widely.

The purpose of this paper is to present the different results obtained during the test campaign: surface accuracy, pointing error, fast motion capability and residual delay. Very important was also the test phases that led to the validation of the FE model showing that the antenna is working with a good margin than predicted at design level thanks also to the assembly and integration techniques.

8444-92, Session 27

ALMA system verification

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ALMA, the Atacama Large Millimeter/submillimeter Array, is an international astronomy facility and synthesis radio telescope currently under construction in the Atacama desert of northern Chile at an altitude of 5,000 meters above sea level. In this paper we present the organization and process of ALMA System Verification (SV); also several verification results will be discussed.

The purpose of SV is to measure the performance of the integrated instrument being delivered with respect to the System Technical Requirements. These tests are being carried out as a multidisciplinary effort by scientists, engineers and control software developers.

Examples of the principal System Requirements include:

- antenna surface and pointing accuracy,
- primary beam characteristics and stability,
- receiver temperatures,
- cross-polarization levels,
- cross-polarization stability with time, angle and frequency,
- total radiometric power stability with time,
- array phase and amplitude stability with time and angle,

- spectral bandpass stability,
- spurious signal levels, and the suppression of spurs using LO off-setting and 180d Walsh switching,
- return to phase after frequency change and/or bandpass change
- array switching time between target sources, observing frequencies, and correlator configurations,
- plus many more.

Some of these verification will be discussed here and others will be discussed in additional papers given in this conference.

As SV tests are being performed, unexpected problems and instabilities are sometimes discovered; System Verification then becomes System Diagnostics as the testing is redirected to characterize and understand the origin of performance defects, and to develop mitigation plans.

8444-93, Session 28

The Large Millimeter Telescope (LMT): current status and preparations for early science observations

D. H. Hughes, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico)

The Large Millimeter Telescope recently conducted successful first-light observations using the first generation of instruments that include an ultra wide-band spectrometer (35 GHz bandwidth) operating in the 3mm wavelength atmospheric window and a 1.1mm wavelength continuum camera. These first-light observations, using only the interior 32-m diameter of the full 50-m diameter primary surface, demonstrate that the LMT is capable of detecting starformation in the nearby and distant universe. Furthermore, at 3mm in particular, the combination of the available telescope diameter, the quality of the site and the intrinsic sensitivity of the instrumentation already makes the LMT a competitive facility for the detection of molecular gas in the high-redshift universe. The project is now concentrating on addressing the engineering work required to increase the efficiency of the telescope following the experiences and information obtained during the early commissioning tests and first-light observations. The improvement in the current surface accuracy of the antenna is the highest priority, with a final goal of reaching the design specification of 75 microns r.m.s. In this summary of the LMT project I will review the successful first-light observations, the current status of the telescope including the plans for an early-science programme, and the transition of the project towards an operational observatory ready to support the scientific community.

8444-94, Session 28

The CCAT 25 m diameter submillimeter-wave telescope

D. P. Woody, Owens Valley Radio Observatory (United States); S. Padin, P. Rasmussen, California Institute of Technology (United States); D. C. Redding, A. Kissil, J. Z. Lou, Jet Propulsion Lab. (United States); E. Chauvin, Consultant (United States)

CCAT is a 25 m diameter Ritchey Chretien telescope operating in the 2 to 0.2 mm wavelength range. It will be located at an altitude of 5600 m on Cerro Chajnantor in Northern Chile. The telescope will be equipped with wide-field, multi-color cameras for surveys and multi-object spectrometers for spectroscopic follow up. Several innovations have been developed to meet the 10 Hz. The mount utilizes hydrostatic azimuth and elevation bearings and direct drive motors.

The primary will have excellent performance with a simple elevation dependent look up table for the segment actuators. If needed, the surface will be controlled based on measurements with a new type of segment edge sensor consisting of an LED collimator and CCD camera.

8444-95, Session 28

High performance holography mapping with the LMT

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When making holography measurements on a large telescope, there are many factors that make it difficult to obtain a consistent map. Two of these factors are variations of the satellite and temperature-induced deformations of the reflecting surface. The former requires frequent returns to the center of the map to check the satellite and the latter requires that the map be completed rapidly. While holography mapping has traditionally been performed using point-by-point or raster scanning, these methods involve substantial overhead in the frequent movements back to the center of the map.

In performing holography maps of the Large Millimeter Telescope (LMT) for the first light campaign, the observing team proposed a radial scanning approach. This strategy has the advantage that every scan passes through the center of the map. However, such a scan results in a disproportionate amount of telescope time near the center region. To achieve more uniform coverage, the team proposed a velocity profile that is inversely proportional to the distance from the center of the map. Because the velocity profile is defined with respect to position rather than time, this new approach required an extension of the existing parametric scanning capabilities at the LMT. The high axis rates resulting from this velocity profile presented additional challenges.

This paper describes the implementation and performance results for holography maps that use a radial scan pattern with a position dependent velocity profile at the LMT. Both theoretical and experimental results are presented.

8444-96, Session 28

Photonic local oscillator technics for large-scale interferometers

H. Kiuchi, M. Saito, S. Iguchi, National Astronomical Observatory of Japan (Japan)

Photonic generation of microwave and millimeter-wave signals is promising for various applications. Especially important is that this technique can provide very stable phase noise and low-loss transmission of very-high-frequency signals. We have developed a Photonic microwave signal generator using the optical modulator, and a real-time/ post-processing transmission phase stabilizer as an alternative ALMA photonic LO system. We have also developed the holography receiver with the direct photonic technique for the ALMA antenna surface measurement, which provide evidence of the Photonic LO effectiveness. The measured RMS surface error is better than 4.4 um, the repeatability is better than 2 um.

It is known that the transmission signal phase staggers when the fiber is waving. This is not the effect of fiber length change but that of refractive index change, which is easily generated by the temperature gradient and antenna motion. Chromatic dispersion is caused by the fact that single mode fibers transmit light of different wavelengths. For optical fiber, the index of refraction is a function of the wavelength of light, the principle we all know from seeing a prism break light into a spectrum. When we are dealing with very high frequency signal over very long distances it can add up. Optical signal stabilizers can be classified into two categories. One is single optical-signal stabilizer, and the other is a microwave-signal stabilizer in the form of frequency difference between two coherent light-waves. The transmission phase stabilizer of the Radio on fiber for interferometry should be belonging to the later category.

8445-01, Session 1

Cophasing segmented pupils with sparse-aperture interferometry

P. G. Tuthill, A. K. Cheetham, The Univ. of Sydney (Australia); A. Sivaramakrishnan, Space Telescope Science Institute (United States); J. P. Lloyd, Cornell Univ. (United States)

Aperture masking has proven a reliable technique for the recovery of complex structures, and more recently high contrast companions, at diffraction limited scales. The largest current and planned next generation telescopes employ segmented primary mirrors which must be precisely co-aligned to form a continuous surface. Existing methods rely on separate dedicated hardware which can introduce a non-common optical path. In this paper we show that mirror segments can be measured to interferometric precision using common-path science hardware with as few as two trial exposures using sparse-aperture methods.

8445-02, Session 1

Probing dusty circumstellar environments with polarimetric aperture-masking interferometry (THESIS)

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Aperture-masking interferometry allows diffraction-limited images to be recovered despite the turbulent atmosphere. Here, this approach has been combined with polarimetry to form a novel technique allowing the dusty environments of mass-losing stars (so-called AGB stars) and proto-planetary and debris disks to be imaged, the characterisation of which is key to understanding the recycling of matter and the formation of new planetary systems. Polarimetric aperture-masking interferometry produces images by exploiting the fact that starlight scattered by circumstellar dust becomes strongly polarised. Essentially, aperture-masking allows access to the small spatial scales (~10mas) necessary while polarimetry allows light from the dust and star to be differentiated. Furthermore, measurements at multiple wavelengths allow dust grain sizes to be calculated using Mie scattering theory. Excellent results have already been obtained at near-IR wavelengths using the NACO instrument at the VLT. The next step is to leverage the higher spatial resolution and polarisation signal found in the visible, rather than near-IR. To this end, a new instrument allowing precision polarimetric aperture masking interferometry at 600-800nm is being developed for an 8m class telescope, details of which will also be presented.

8445-03, Session 1

Super resolution from diffraction limited images with kernel-phases

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Usually scaring potential users away because of its apparent complexity, interferometry is yet a powerful tool producing high-quality observable quantities that can be calibrated with exquisite accuracy. Invented for radio interferometry, and later transposed to optical wavelengths, closure-phase is the best known example of a self-calibrating observable. Closure-phase acquired with non-redundant masking interferometry for example recently led to the detection of a planetary candidate clearing the gap in the known transition disk host LkCa 15 system.

Closure-phase was demonstrated to be a special case of a wider family of observable quantities called kernel-phases, that can be extracted from any type of diffraction limited image, and are not restricted to a non-redundant pupil. On well corrected full-aperture AO images and images acquired from space telescopes, kernel-phases analysis leads to new discoveries and/or to improved relative astrometric and photometric measurements.

The paper presents the latest developments and applications of the technique to a series of archive HST/NICMOS observations, and discusses its potential impact on future observations with existing and planned high angular resolution instrumentation.

8445-04, Session 1

Progress and challenges with the Dragonfly instrument: an integrated-photonic pupil-remapping interferometer

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High contrast imaging techniques such as aperture masking interferometry allow for the detection of faint companions such as exoplanets by utilising light from the planet itself. This allows access to study a larger population of planetary companions as compared to the transit technique where only systems viewed edge-on can be studied, for example. However, aperture masking has several shortcomings including, low throughputs, limited Fourier coverage, and leakage of residual atmospheric noise due to phase corrugations across each sub-apertures. These limitations can be overcome by remapping the pupil with single-mode waveguides instead. We present an integrated pupil remapping interferometer which aims to do just that, known as Dragonfly. We will discuss the progress we have made over the past year in developing a stable and robust instrument and elucidate challenges and the innovative solutions that were applied. Finally we will discuss the direction for the instrument to make it useful for future scientific endeavours and outline the expected performance limitations.

8445-05, Session 1

Detecting extrasolar planets with sparse aperture masking

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Extrasolar planets are directly detected most easily when they are young and can have contrasts only a few hundred times fainter than their host stars at near- and mid- infrared wavelengths. However, planets and other solar-system scale structures around solar-type stars in the nearest star forming regions require the full diffraction limit of the world's largest telescopes, and have not been able to be detected with conventional AO imaging techniques. I will describe the recent successes of long-baseline interferometry in detecting planetary-mass companions, focussing on the transitional disk system LkCa 15. I will outline why aperture-masking has been so successful in its resolution and sensitivity niche, and will outline the algorithms needed to calibrate the primary observable of closure/kernel phase to the level needed for extrasolar planet detection.

8445-06, Session 2

Exo-zodiacal light around nearby main sequence stars: What did we learn with the Keck interferometer nuller?

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The determination of nearby main sequence stars zodiacal emission level has long been identified as crucial information for planetary dynamical formation, planet-disk interaction models, and for the proper design of direct exoplanet imaging space missions. We summarize here the results gathered by all 4 exo-zodi observing campaigns conducted with the Keck Interferometer Nuller between 2008 and 2011. A total of 49 stars were observed -mostly A to K dwarfs-, with a typical sensitivity (1-sigma) of 150 solar zodis at 8.5 microns. Based on these measurements, we look for statistically significant trends and possible correlations between the observed mid-infrared excess levels and basic stellar properties.

8445-07, Session 3

Design and status of the Balloon Experimental Twin Telescope for infrared interferometry (BETTII): an interferometer at the edge of space

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The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII) is an 8-meter baseline far-infrared interferometer to fly on a high altitude balloon. BETTII uses a double-Fourier Michelson interferometer to simultaneously obtain spatial and spectral information on science targets; the long baseline provides subarcsecond angular resolution, a capability unmatched by other far-infrared facilities. This makes it ideally suited for a wide range of scientific studies, including studies of clustered star formation and nearby active galactic nuclei. The BETTII project began in January 2011, and a preliminary design of all systems has been completed. Here, we present key aspects of the overall design of the mission and provide an overview of the current status of the project. We also discuss briefly the implications of this experiment for future space-based far-infrared interferometers.

8445-08, Session 3

Spaceborne intensity interferometry via spacecraft formation flight

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Interferometry in space has marked advantages: long integration times and observation in spectral bands where the atmosphere is otherwise opaque. When installed on separate spacecraft, it also offers extendable and versatile geometries for better filling of the uv plane. Intensity interferometry has an additional advantage, being insensitive to telescope and path errors; but, unfortunately, it is much less sensitive than amplitude interferometry. In planning towards a space-borne intensity interferometry mission, we are experimenting with some issues which can potentially limit observationally. To this end, we have constructed a system of three miniature satellite models floating on an air table in formation, with an autonomous orbit control. Each such device holds its own light collector, detector, and transmitter, to broadcast its intensity signal to a central receiving ground station. At this station, we implement parallel radio receivers, analogue to digital converters, and a digital three-way correlator, aimed at recovering the intensity of a given light source.

Current technology limits us to ~1GHz transmission frequency, which corresponds to a comfortable 0.3m accuracy in light-bucket shape and in its relative position. Naïve calculations place our limiting magnitude at ~7 in the blue and ultraviolet, where amplitude interferometers are limited. The correlation signal rides on top of this huge signal with its own Poisson noise, requiring a very large dynamic range, which needs to be transmitted in full. We are looking at open questions such as deployable optical collectors and radio antennae of similar size of a few meters, and how they might influence our data transmission and thus set our flux limit.

8445-09, Session 3

Developing wide-field double-Fourier interferometry for far-IR applications

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We summarize an ongoing effort to develop and learn the practical limitations of an interferometric technique that will enable the acquisition of high-resolution far-IR integral field spectroscopic data with a single instrument in a future space-based interferometer. This technique was central to the SPIRIT and SPECS space mission design concepts, and it will first be used on the Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII). Our experimental approach combines data from a laboratory optical interferometer (the Wide-field Imaging Interferometry Testbed, WIIT), computational optical system modeling, and spatio-spectral synthesis algorithm development. We summarize recent experimental results and future plans.

We describe the overall experimental approach, the testbed, and the optical system model; we show representative testbed data, summarize error and visibility loss terms; we compare testbed data with model predictions; and we compare synthesized spatial-spectral data cubes with "truth" input to the testbed and model. Two companion papers will describe hyperspectral scene generation for WIIT (Bolcar et al.) and provide more detailed information about the spatial-spectral data cube synthesis algorithm (Lyon et al.).

8445-10, Session 3

Wide-field imaging interferometry spatial-spectral image synthesis algorithms

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Developed is an algorithmic approach for wide field of view interferometric spatial-spectral image synthesis. The data collected from the interferometer consists of a set of double-Fourier image data cubes, one cube per baseline. These cubes are each three-dimensional consisting of arrays of two-dimensional detector counts versus delay line position. For each baseline a moving delay line allows collection of a large set of interferograms over the 2D wide field detector grid; one sampled interferogram per detector pixel per baseline. This aggregate set of interferograms, is algorithmically processed to construct a single

spatial-spectral cube with angular resolution approaching the ratio of the wavelength to longest baseline. The wide field imaging is accomplished by insuring that the range of motion of the delay line encompasses the zero optical path difference fringe for each detector pixel in the desired field-of-view. Each baseline cube is incoherent relative to all other baseline cubes and thus has only phase information relative to itself. This lost phase information is recovered by having point, or otherwise known, sources within the field-of-view. The reference source phase is known and utilized as a constraint to recover the coherent phase relation between the baseline cubes and is key to the image synthesis. Described will be the mathematical formalism, with phase referencing and results will be shown using data collected from NASA/GSFC Wide-Field Imaging Interferometry Testbed (WIIT).

8445-11, Session 4

Recent progress at the Keck interferometer

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The Keck Interferometer (KI) combines the two 10 m diameter Keck telescopes providing milliarcsecond angular resolution. KI has unique observing capabilities such as sensitive K-band V2, L-band V2, and N-band nulling operations. The instrument status of the Keck Interferometer since the 2010 SPIE meeting is summarized along with examples of the science enabled by KI's capabilities. We discuss performance of more recently implemented visibility observing modes. Operational improvements including simplified reliable operations are highlighted. Statistics on lost sky time due to weather, and telescope, adaptive optics and interferometer problems are presented. We will conclude with a brief review of the achievements of KI during the past decade. The dual field phase referencing and astrometry developments are presented elsewhere at this conference.

8445-12, Session 4

The Very Large Telescope interferometer v2012+

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The ESO Very Large Telescope Interferometer (VLTI) offers access to the four 8-m Unit Telescopes (UT) and the four 1.8-m Auxiliary Telescopes (AT) of the Paranal Observatory located in the Atacama Desert in northern Chile. The two VLTI instruments, MIDI and AMBER deliver regular scientific results. In parallel to the operation, the instruments developments are pursued, and new modes are studied and commissioned to offer a wider range of scientific possibilities to the community and increase sensitivity. New configurations of the ATs have been offered and are frequently discussed with the science users of the VLTI and implemented to optimize the scientific return. The PRIMA instrument, bringing astrometry capability to the VLTI and phase referencing to the instruments is being commissioned. The visitor instrument PIONIER is now fully operational and bringing imaging capability to the VLTI.

The current status of the VLTI is described with successes and scientific results, and prospects on future evolution are presented.

8445-13, Session 4

First faint dual field phase referenced observations on the Keck interferometer

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Ground-based long baseline interferometers have long been limited in sensitivity by the short integration periods imposed by atmospheric turbulence. The first observation fainter than this limit was performed on January 22, 2011 when the Keck Interferometer observed a K=11.5 target. This observation was made possible by simultaneously measuring the real-time effects of the atmosphere on a nearby bright guide star, and correcting for it on the faint target. This dual-field phase-referencing (DFPR) instrument was developed under the NSF-funded ASTrometry and phase-Referencing Astronomy (ASTRA) project.

As a prelude to this demonstration, we first present the implementation of dual field phase referencing on the interferometer. We then detail its on-sky performance focusing on the accuracy of the turbulence correction, on the resulting fringe contrast stability, and on the limiting magnitude. We conclude the DFPR chapter with an overview of the faint science made possible by the DFPR instrument: faint Active Galactic Nuclei, and the Galactic Center.

Following the demonstration of DFPR, we also report on the ASTRA project getting ready to perform its first narrow-angle astrometry measurements.

8445-14, Session 4

Status of PRIMA for the VLTI: heading to astrometry

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The PRIMA facility for the VLTI, is being installed and tested in the observatory of Paranal.

Since January 2011 the integration and individual testing of the different subsystem has come to a necessary minimum. At the same time the astrometric commissioning phase has begun.

In this contribution we give an update on the status of the facility and present some highlights and difficulties on our way from first dual-feed fringe detection to first astrometric measurements. We focus on technical and operational aspects. In particular, within the context of the latter we are going to present a modified mode of operation that scans across the fringes. We will show that this mode, originally only intended for calibration purposes, does not only facilitate the detection of dual-fringes but can furthermore provide valuable data for astrometry.

8445-15, Session 5

Imaging rapid rotators with the PAVO beam combiner at CHARA

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With a 0.3 micron simultaneous bandwidth and almost all of the light from the 1m CHARA apertures being used in 1.5" or better seeing, PAVO@CHARA is the world's most sensitive visible beam combiner capable of closure-phase measurements. As a result, PAVO@CHARA achieves the highest angular resolution yet achieved (~0.3 mas) for stars V=8 magnitude and brighter. Reconstructed images of the surface of fast rotating stars at such high angular resolution could supply valueable observational evidence to understand why fitting based on the simplest von Zeippel models (assuming a point mass and solid rotation) yields a poor fit to the observed gravity darkening data, driving theory to consider the more complex physics of differential rotation or convection in equatorial regions. Although the PAVO beam combiner at CHARA can now routinely produce well calibrated visibility

data, the same cannot yet be said of the closure phase signals. In order to fully explore the systematics of closure phase recovery with PAVO, we use data on the simplest non-point symmetric targets - binary stars. We describe the calibration of closure-phases for binary stars of visual magnitude between 3.6 and 6.3, and describe the difficulties in correctly accounting for bias in closure-phases down to the correlated magnitude limit for PAVO of 8.5.

8445-16, Session 6

Recent technical and scientific highlights from the CHARA array

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Georgia State University's Center for High Angular Resolution Astronomy operates a six-telescope, optical/near IR interferometric array on Mount Wilson, California. The CHARA Array currently possesses the world's longest operational OIR baselines and is scheduled on a competitive basis from April through Christmas. With 65 refereed scientific publications in print at the time of submission of this abstract, the scientific output from the Array represents a diversity of applications of interferometry and interferometric imaging. This paper will present examples of recent scientific results, provide an overview of upgrades to our beam combination capability, and summarize near-term developments at CHARA.

8445-17, Session 6

PIONIER: a status report

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PIONIER is fast-track visitor instrument designed to provide VLTI with improved imaging capabilities and sensitivity. It combines four 1.8 m Auxilliary Telescopes or four 8 m Unit Telescopes. The instrument is dedicated for aperture synthesis imaging and allows robust and precise closure phases and visibilities to be measured. At the heart of the instrument an integrated optics chip recombines the four incoming signals, providing excellent compactness and stability. PIONIER was approved by the ESO Science and Technical Committee in November 2009. The instrument was integrated at IPAG in December 2009 and shipped to VLTI in October 2010. After a few nights of commissioning the instrument started routinely delivering scientific data in November 2010. The initial goals of PIONIER were to provide spatially resolved diagnostics for the close environments of planet-forming stars of various masses (T-Tauri, AeBe stars) and various evolutionary status (young stellar objects, transition disks, debris disks). In addition, several other topics have emerged during these two years such as the study of the mass transfer processes in interacting binaries, the search for stellar and sub-stellar companions, and the study of multiplicity in various type of stars. In this paper we recall the challenges that had to be tackled to design, built and commission an instrument in less than 12 months. We summarize the typical performances achieved with PIONIER at VLTI. We finally present the astrophysical results obtained so far.

8445-18, Session 7

Study of exoplanets host stars with VEGA/CHARA

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In the framework of the understanding of extrasolar systems, the study of host stars is a fundamental point. We need to understand the link between them and the presence of companions, i.e. what makes a star becoming a host star.

In this perspective, we performed interferometric measurements of host stars in the visible wavelengths, providing a good spatial resolution. Also, we reach low visibilities allowing to make measurements in the second and third lobe of visibility, and giving access to limb darkening measurements, one of the very few directly measurable constraints on a stellar atmosphere structure. From this we can derive stars fundamental parameters. A precise measurement within spectral lines is also a very powerful tool to study the temperature and density structure of the atmosphere of distant stars.

Besides, the detection of exoplanets is also related to this method. Combined with the radial velocity method and the transit method, one can study the atmosphere of exoplanets and learn more about their internal structure.

We will present here the results of two year of host stars observations with VEGA/CHARA, an optical interferometer located at Mount Wilson (California). Our first target is a F4V star, θ Cyg, that shows quasi-periodic radial velocities, and which diameter evolves in a non regular way. Other host stars have been observed and a very good constraint on their radius have been performed, leading to a better accuracy on the planets parameters.

8445-19, Session 8

Performance, results, and prospects of the visible spectrograph VEGA on CHARA

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I will review the current performance of the VEGA/CHARA visible spectrograph and make a review of the most recent astrophysical results. I will describe the original way we are combining high spectral resolution and multi-beam combination. The science programs take benefit of the exceptional angular resolution, the unique spectral resolution and one of the main features of CHARA: Infrared and Visible parallel operation. A discussion of the future developments will complete the presentation, directed towards new detectors and possible new beam combination scheme for improved sensitivity and imaging capabilities.

8445-20, Session 8

Building the next generation science camera for the Navy optical interferometer

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The Visible Imaging System for Interferometric Observations at NOI (VISION) is the next generation science camera for Navy Optical Interferometer (NOI). In comparison to current beam combiner of NOI, VISION will deliver a higher precision data products and a better flexibility by incorporating single mode fibers for spatial filtering that removes the effect of atmospheric turbulence and also by using low-noise detectors. VISION can coherently combine up to six telescope beams using a spatially-modulated image-plane combination scheme, resulting in visibility amplitudes and closure phases that can be used for image reconstruction. Having a spatial resolution 200 times sharper than what is possible with the Hubble Space Telescope, VISION allows one to reconstruct multipixel images of stars. The full system of VISION will be deployed in early 2012.

8445-21, Session 8

Science and technology progress at the Sydney University stellar interferometer

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This paper presents an overview of recent progress in both science and technology at the Sydney University Stellar Interferometer (SUSI). The actual on-sky performance metrics for our PAVO beam combiner are detailed here for the first time, with discussion of the ongoing science programs enabled by this third-generation instrument. Development of PAVO has continued, including an investigation into its use at high spectral resolution. The MUSCA beam combiner for high-precision differential astrometry using visible light phase referencing will be the subject of a separate paper. Because SUSI was one of the pioneering interferometric instruments, some of its original systems are old and have become difficult to maintain. We are undertaking a campaign of modernization of systems: (1) the replacement of the aged single-board computer local controllers for the siderostats and the longitudinal dispersion compensator is nearing completion; (2) an upgrade of the Optical Path Length Compensator IR laser metrology counter electronics from a custom system which also uses an obsolete single-board computer to a modern one based on an FPGA interfaced to a Linux computer is underway - in addition to improving maintainability, this upgrade should allow smoother motion and higher carriage speeds; (3) the large beam reducing telescope has been replaced with a pair of smaller units with separate accessible foci.

8445-138, Session 8

Recent developments at the Navy Optical Interferometer (NOI)

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Instrumentation developments at the Navy Optical Interferometer (NOI, formerly NPOI) since the last SPIE meeting in 2010 are summarized. The commissioning of new siderostat stations, progress towards the installation of four 1.8m telescopes, and other instrumentation and control system upgrades, are reviewed.

8445-22, Session 9

Intrincate visibility effects from resolved emission of young stellar objects: the case of MWC158 observed with the VLTI

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In the course of our VLTI young stellar object PIONIER imaging program we have identified a strong visibility chromatic dependency that appeared in certain sources. This effect, decreasing values of visibilities with increasing wavelengths over one baseline, is also present in previous published and archival AMBER data. Intriguingly it has been overlooked and sometimes wrongly attributed to a bias effect. In this paper we show that it has instead an astrophysical origin. The H bans is generally located at the transition between the star and the disk predominance in flux for Herbig AeBe stars. We believe that this phenomenon is responsible for the strong chromatic effect. We present a method to correct the visibilities from this effect in order to allow "gray" image reconstruction software, like MIRA, to be used. In parallel we probe the interest of carrying an image reconstruction in each spectral channel and then combine them to obtain the final broadband one. As an illustration we apply these imaging methods to MWC158, a (possibly Herbig) B[e] star intensively observed with PIONIER. Finally, we compare our result with a parametric model fitted onto the data.

8445-23, Session 10

The Magdalena Ridge Observatory interferometer: a status update

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The Magdalena Ridge Observatory Interferometer has been designed to be a 10 X 1.4m aperture long-baseline optical/near-infrared interferometer in an equilateral "Y" configuration being deployed west of Socorro, NM on the Magdalena Ridge. The design of all subsystems is basically complete, with laboratory assembly and testing, and installation of many components at the facilities on the Ridge underway as well. First light for the facility has been unfortunately delayed due to a slow in funding. This paper serves as an overview and update on the facility's present status, and the plans for future funding and eventual operations of the facilities.

8445-24, Session 10

New horizons for VLTI 10 micron interferometry: first scientific measurements with external PRIMA fringe tracking

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We report recent success to stabilize the VLTI/MIDI-10um beam-combiner with K-band fringe tracking, provided by PRIMA (FSU). After encouraging commissioning results, presented during the last SPIE, we accomplished in November 2011 a successful run of science demonstration. A broad range of targets were observed, from planet-hosting stars over YSO disks to AGN. We will present first results, focussing on the improvements on sensitivity and precision with respect to classical MIDI stand-alone observations. MIDI broad-band dispersion and group-delay can be reliably predicted by the fringe tracker to enable coherent integration beyond coherence time.

8445-25, Session 10

MATISSE: perspective of imaging in the mid-infrared at the VLTI

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MATISSE is a mid-infrared spectro-interferometer combining the beams of up to four UTs/ATs of the Very Large Telescope Interferometer (VLTI) of the European Southern Observatory.

MATISSE will constitute an evolution of the two-beam interferometric instrument MIDI. New characteristics present in MATISSE will give access to the mapping and the distribution of the material (typically dust) in the circumstellar environments by using a wide mid-infrared band coverage extended to L, M and N spectral bands. The four beam combination of MATISSE provides an efficient uv-coverage : 6 visibility points are measured in one set and 4 closure phase relations which can provide aperture synthesis images in the mid-infrared spectral regime.

We will present the expected performances of the instrument and the Science Cases. We will show on a few examples how the instrument would be operated : functionalities and VLTI fringe tracker. The project involves the collaborations of several agencies and institutes : the Observatoire de la Côte d'Azur of Nice and the INSU-CNRS in Paris, the Max Planck Institut für Astronomie of Heidelberg; the University of Leiden and the NOVA-ASTRON Institute of Dwingeloo, the Max Planck Institut für Radioastronomie of Bonn, the Institut für Theoretische Physik und Astrophysik of Kiel, the Vienna University, and the Konkoly Observatory.

8445-26, Session 11

Narrow-angle astrometry with PRIMA (THESIS)

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The Extrasolar Planet Search with PRIMA project (ESPRI) aims at characterising and detecting extrasolar planets by measuring the host star's reflex motion using the narrow-angle astrometry capability of the PRIMA facility at the Very Large Telescope Interferometer. A first functional demonstration of the astrometric mode was achieved in early 2011. This marked the start of the astrometric commissioning phase with the purpose of characterising the instrument's performance, which ultimately has to be sufficient for exoplanet detection. We show results obtained from the observation of bright visual binary stars, which serve as test objects to determine the instrument's astrometric precision, its accuracy, and the plate scale. Finally, we report on the current status of the ESPRI project, in view of starting its scientific programme.

8445-27, Session 12

GRAVITY: observing the universe in motion

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GRAVITY is the second generation Very Large Telescope Interferometer instrument for precision narrow-angle astrometry and interferometric imaging. With its fiber-fed integrated optics, wavefront sensors, fringe tracker, beam stabilization and a novel metrology concept, GRAVITY will push the sensitivity and accuracy of astrometry and interferometric imaging far beyond what is offered today. Providing precision astrometry of order 10 microarcseconds, and imaging with 4-milliarcsecond resolution, GRAVITY will revolutionize high angular resolution imaging and dynamical measurements of celestial objects: it will probe physics close to the event horizon of the Galactic Center black hole; unambiguously detect and measure the masses of black holes in massive star clusters throughout the Milky Way; uncover the details of mass accretion and jets in young stellar objects and active galactic nuclei; and probe the motion of binary stars, exoplanets and young stellar discs. This presentation summarizes the science opportunities and the technical concept of GRAVITY and gives an update on the current state of the instrument development.

8445-28, Session 12

On-sky testing of the LBT interferometer: steps toward routine AO-stabilized interferometric observations

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We report results from on-sky testing of the Large Binocular Telescope Interferometer. LBTI achieved first fringes in late 2010, with seeing-limited operation. Initial tests verified the feasibility of the setup and allowed us to characterize the phase variations from both the atmosphere and mechanical vibrations. Integration of the secondary-base AO systems is currently underway to allow phase-stabilized operation. Single aperture,

diffraction-limited, operation has been commissioned and is used as a productive mode of the LBTI with the LMIRCam subsystem. We describe initial science results with the LBTI in single aperture mode, and describe progress in commissioning the system for dual aperture observations.

8445-29, Session 12

LINC-NIRVANA: assembly, integration, and verification update

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We present an update on the LINC-NIRVANA (LN) instrument, an innovative Fizeau-mode beam combiner for the Large Binocular Telescope (LBT). LN will deliver 10 mas spatial resolution in the near infrared over a 10 arcsec field of view. In addition to optical-path-difference control, the instrument must correct a wide field of view on the sky using multi-conjugated adaptive optics. This substantially increases sky coverage for fringe tracking reference stars.

Subsystem delivery and testing is almost complete, and final Assembly, Integration, and Verification are well advanced. We report on closed-loop control of a number of subsystems, including fine-tuning and optimization of the delay line. Measurement and remediation of instrument flexure are a key to its success. Several laboratory performance experiments demonstrate that components are within specification. As with any interferometer, vibrations are a major concern. LINC-NIRVANA will eventually integrate with the OPD and Vibration Monitoring System at LBT, allowing feed-forward correction of piston.

With several interacting subsystems, LN faces a complexity challenge. A pathfinder experiment at LBT will verify multiple aspects of LINC-NIRVANA and the telescope starting in winter 2011-2012.

8445-30, Session 13

VLTI/AMBER differential interferometry of the broad line region of the QSO 3C273

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In AGNs, the region located inside the dust sublimation radius, which should include the BLR, has a quite unknown spatial and kinematic structure. Spectro photometry, spectroscopy, polarimetry and time resolved spectro interferometry (reverberation mapping) give ambiguous constraints. The innermost part of the dust torus is very barely resolved and the BLR is completely unresolved for VLTI and KI optical interferometric visibility and closure phase. However the differential phase, which yields the displacement of the source photocentre with wavelength, provides decisive degeneracy solutions. Although it is still impossible to fringe track on any AGN, we have been able to successfully observe the QSO 3C273 with the VLTI/AMBER instrument used in medium resolution (R=1500) in the red shifted Paschen alpha line. This has been achieved by implementing a “blind” observation mode in which individual frames with a SNR much lower than one are combined to provide accurate cross spectrum and hence differential phase measurements. We report the first observations and the constraints they set on the structure of the innermost dust ring as well as on the gas producing the BLR. This results represent a double breakthrough, because they open the AGN science topic to spectro-interferometry in emission lines and also because the “blind mode” changes the limiting magnitudes for interferometry, up to the way they are defined.

8445-31, Session 13

Studying hot exozodiacal dust with near-infrared interferometry

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Since our first detection of a resolved near-infrared emission around the main sequence star Vega, which we identified as the signature of hot dust grains close to the sublimation limit, we have been systematically searching for similar signatures around a magnitude-limited sample of nearby main sequence stars with the FLUOR instrument at the CHARA array. About 50 targets with spectral types ranging from A to K have been observed within the last 5 years, leading to first statistical trends on the occurence of the bright exozodi phenomenon as a function of spectral type. Our target sample is balanced between stars known to harbour cold dust populations from space-based missions (e.g., Spitzer, Herschel) and stars without cold dust, so that the occurence of abundant hot dust can also be correlated with the presence of large reservoirs of cold planetesimals. In this talk, I will present the main conclusions and lessons learned from the CHARA/FLUOR survey. I will also present the first results obtained in 2011 with the new PIONIER visiting instrument at the VLTI, which is now used to extend our survey sample to the Southern hemisphere and to fainter targets. The first measurements of the dust/star flux ratio as a function of wavelength within the H band will be presented, thanks to the low spectral resolution capability of PIONIER. Finally, I will discuss our plans for extending the survey to fainter targets in the Northern hemisphere with an upgraded version of the FLUOR beam combiner.

8445-32, Session 14

Five years of infrared imaging at CHARA with MIRC

J. D. Monnier, Univ. of Michigan (United States)

The CHARA Array possesses the longest baselines in the world for infrared and visible interferometry, while the Michigan Infrared Combiner (MIRC) is the most advanced beam combiner for imaging. CHARA+MIRC has allowed imaging the surfaces of rapid rotators, interacting binary stars, and magnetically-active stars all for the first time. In this presentation, I will give an overview of the discoveries made by MIRC over the past five years and discuss technical and scientific lessons learned. This crucial practical experience with imaging has led to a number of unanticipated conclusions that run counter to conventional wisdom.

8445-33, Session 14

Imaging from the first 6-beam infrared combiner

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Michigan InfraRed Combiner (MIRC) is a near-infrared image-plane combiner at the CHARA array which consists of six 1-m diameter

telescopes with the longest baseline of 330m. MIRC was upgraded to a full 6-beam combiner in July 2011, which now records interferometry data of 15 baselines and 20 triangles simultaneously. The improved snapshot UV coverage has greatly boosted the ability for imaging complicated targets such as the asymmetry of circumstellar disks, interacting binaries and the surfaces of spotted stars. In addition, the Photometric Channels subsystem, which directly measures the real time flux of individual beams, has been upgraded to increase the light throughput to improve the visibility and closure phase calibration. The system sensitivity has been improved as well to allow fainter objects such as Young Stellar Objects (YSOs) to be observable with MIRC for the first time. Two on-going projects CHARA-Michigan Phasetracker (CHAMP) and CHARA Adaptive Optics system will furthermore extend the sensitivity limit of MIRC by several magnitudes, promising more types of imaging targets for MIRC in the near future. Our presentation will conclude with first preliminary results from 6-beam MIRC observations for YSOs, and for the binary Be system Delta Sco during its periastron in 2011.

8445-71, Poster Session

Revealing habitable exoplanets through their spectral features

E. Schwartz, S. G. Lipson, E. N. Ribak, Technion-Israel Institute of Technology (Israel)

The extremely low signal contrast between an Earth-like extra-solar planet (exoplanet) and a parent star is a difficult obstacle in their detection, imaging and spectroscopic analysis. We suggest a method of using selected parts of the Fourier interferogram of the combined light sources (both planet and sun) in order to increase the signal to noise ratio and identify the specific spectral features from the planet in the background of the parent star.

A habitable exoplanet is expected to reflect and emit a luminosity which is many orders of magnitude less than that of the parent star. However, its spectral features are much different, being much narrower than its sun. Narrower lines are more coherent, so their Fourier spectrum extends to much larger delays. Thus they can be discriminated for by looking at an off-center part of a Fourier spectrogram. As the center (with the shorter delay) has all the power from the star's wider features, these will not affect the result. Now all the power will be distributed at the longer delays (where the exoplanets lines appear), improving the signal to noise ratio. We support this idea by realistic simulations which include photon and thermal noise, and show it to be feasible at a luminosity ratio of 10^-6 in the infra-red for a Sun-like star and an Earth-like planet. We also carried out a laboratory experiment to illustrate the method. The results suggest that this method should be applicable to a very large number of candidate stars.

8445-72, Poster Session

Self-phase-referencing interferometry with SUSI

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The Sydney University Stellar interferometer (SUSI) is being fitted with a new beam combiner, called the Micro-arcseconds University of Sydney Companion Astrometry (MUSCA), for the purpose of high precision astrometry of bright binary stars. Operating in the visible wavelength regime where photon-counting and post-processing fringe tracking is possible, MUSCA will be used in tandem with SUSI's primary beam combiner, PAVO, to record high spatial resolution fringes and thereby measure the separation of fringe packets of binary stars. With continued monitoring of stellar separation vectors at precisions in the tens of micro-arcseconds over timescales of years, it will be possible to search for the presence of gravitational perturbations in the orbital motion such as those expected from planetary mass objects in the system. This paper describes the first phase of the development, which includes the setup of the dual beam combiner system and the methodology applied to stabilize fringes of a star by means of self-phase-referencing.

8445-73, Poster Session

Effects of anisoplanatism on the visibility amplitudes and phase variances measured by the PRIMA fringe trackers

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During dual-field observations with the VLTI PRIMA facility, the fringe tracking quality of the fringe sensor unit (FSU) observing the secondary object depends on the angular separation between the two objects being simultaneously observed, the detector integration time (DIT) and the weather conditions. We describe the algorithm we developed to compute visibilities from the FSU data and discuss the results of our study on the angular anisoplanatism measured through the dependence of the visibility amplitudes and phase variances on the angular separation and DIT.

We extrapolate our results to the PRIMA+AMBER case and conclude on the advantages of combining both interferometers using the FSU as an off-axis fringe tracker.

8445-74, Poster Session

Study on the possibility of using PRIMA in the faint object science mode

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The IRIS infra-red detector of PRIMA (the dual feed interferometer of ESO) has four quadrants, paired in a way such that the beam coming from the bright reference star is going to one quadrant and the beam coming from the science object is going to the other quadrant, each pair being addressed to a telescope. As the light ducts of the VLTI are not evacuated, the seeing inside them might affect the path of the light beams, having an impact on the positions of the beams in each quadrant of IRIS. If the motion of both beams is correlated, we can use PRIMA with AMBER for faint object science, without tracking on the beam from the scientific (faint) source. We discuss the impact of the low variation turbulence in the light ducts and defocus effects in the telescopes in the correlation between the beam positions on the quadrants of IRIS, and conclude on the feasibility of the faint object science mode of PRIMA.

8445-75, Poster Session

Long-term trends in the VLTI auxiliary telescopes pointing models

S. Stefl, A. Lundgren, European Southern Observatory (Chile)

The VLTI baseline configuration is changed in average after every 3-4 weeks. 6 parameter pointing models of the four 1.8m telescopes are re-determined after every telescope relocation. The database of the pointing

models offers a rare opportunity -- for the first time for moving telescopes -- to study long-term trends in the model parameters, which are related to the aging or mechanical changes not only of the telescopes but also of the stations. Monitoring of four identical telescopes permits to generalize conclusions.

The index error in elevation, tube flexure and non-perpendicularity in elevation show little dependence on the station and large trends on a time-scale of years. The other parameters, north-south misalignment, index error in azimuth and the east-west misalignment of the azimuth axes are almost constant on the same time-scale, but exhibit large systematic differences from station to station. The analysis of the variations is done with the aim to investigate the stability of the models and to link the parameter trends with mechanical changes in the telescopes. A comparison will be made to ALMA, whose telescopes also are moved around, resulting in changes for some pointing parameters, particularly the index error in azimuth.

8445-76, Poster Session

Final results of the PERSEE experiment

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The PERSEE breadboard, developed by a consortium including CNES, IAS, LESIA, OCA, ONERA and TAS since 2005, is a nulling demonstrator that couples an infrared nulling interferometer with a formation flying simulator able to introduce realistic disturbances in the set-up. The general idea is to prove that an adequate optical design can considerably relax the constraints applying at the spacecrafts level of a future interferometric space mission like Darwin/TPF or one of its precursors. The breadboard is now fully operational and the measurements sequences are managed from a remote control room using automatic procedures. A set of excellent results were obtained in 2011. The measured polychromatic unpolarized null depth is 8.8 10-6 stabilized at 9 10-8 in the 1.65-2.45 µm spectral band (37 % bandwidth) during 100 s. This result was extended to a 7h duration thanks to an automatic calibration process. The various contributors are identified and the nulling budget is now well mastered. We also proved that harmonic disturbances in the 1-100 Hz up to several ten's of nm rms can be very efficiently corrected by a Linear Quadratic Control (LQG) if a sufficient flux is available. These results are important contributions to the feasibility of a future space based nulling interferometer.

8445-77, Poster Session

Discrete optical multi-aperture combiner: instrumental concept

S. Minardi, Friedrich-Schiller-Univ. Jena (Germany); L. Labadie, Univ. zu Köln (Germany); S. Lacour, LESIA - Observatoire de Paris (France)

Simultaneous combination of multiple apertures is a goal of contemporary optical interferometry which would lead to higher accuracy and dynamics of imaging. Recently, the use of two-diemensional arrays of coupled waveguides was proposed as a way to combine an arbitrary large number of telescopes on a three-dimensional (3D) photonic chip (the discrete beam combiner, DBC). Here we propose the concept of DOMAC (Discrete Optical Multi-Aperture Combiner), an optical interferometric instrument designed to combine many sub-apertures within the pupil of a telescope by means of a 3D photonic chip based on DBC. We analyze the technical constraints in the design of the instrument and present simulations of expected performance of the instrument based on real coupling data from a fiber-fed instrument. Several configurations combining quadruplets or sextuplets of apertures will be discussed.

8445-78, Poster Session

Glass fiber reinforced plastics within the fringe and flexure tracker of LINC-NIRVANA

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The Fringe and Flexure Tracking System (FFTS) is meant to monitor and correct atmospheric piston variation and instrumental vibrations and flexure during near-infrared interferometric image acquisition of LINC-NIRVANA. In close work with the adaptive optics system the FFTS enables homothetic imaging for the Large Binocular Telescope.

One of the main problems we had to face is the connection between the cryogenic upper part of the instrument, e.g. detector head, and the lower ambient temperature part where the moving stages are situated which move the detector head in the given Field of View. We show in what way we solved this problem using the versatile material glass fiber reinforced plastics (GFRP's) and report in what way this material can be worked. We discuss in detail the exquisite characteristics of this material which we use to combine the cryogenic and ambient environments to a fully working system. The main characteristics that we focus on are the low temperature conduction and the tensile strength of the GFRP's. The low temperature conduction is needed to allow no heat-exchange between the cryogenic and ambient part whereas the tensile strength is needed to support heavy structures like the baffle motor and to allow for a minimum of flexure for the detector head. Additionally, we discuss on the way we attached the GFRP to the remaining parts of the FFTS using a two component encapsulant.

8445-79, Poster Session

Observing the sun with micro-interferometric devices: a didactic experiment

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Measuring the angular diameter of celestial bodies has long been the main purpose of stellar interferometry and was its historical motivation. Nowadays, stellar interferometry is widely used for various other scientific purposes that require very high angular resolution measurements. In terms of spatial scales probed, observing distant stars located at 10 to 100 pc away with a large hectometric interferometer is equivalent to observing our Sun with a micrometric baseline. Based on this idea, we have manufactured a set of micro-interferometric devices and tested them on the sky. The micro-interferometers consist in a chrome layer deposited on a glass plate that has been drilled by laser lithography to produce micron-sized holes with configurations corresponding to proposed interferometer projects such as CARLINA, ELSA, KEOPS,

and OVLA. In this paper, we describe the interferometric devices and present interferometric observations of the Sun made in the framework of Astrophysics lectures being taught at the Liege University. By means of a simple photographic camera placed behind a micro-interferometric device, we observed the Sun and derived its angular size. This experiment provides a very didactic way to easily obtain fringe patterns similar to those that will be obtained with future large imaging arrays. A program written in c++ also allows to reproduce the various point spread functions and fringe patterns observed with the micro-interferometric devices for different types of sources, including the Sun.

8445-80, Poster Session

Self-nulling spectrograph for star glare rejection

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We introduce a notional nulling interferometer for extinction of glare from single star exoplanetary systems. The principle of double dispersion telescopy correlates an incident angular position with a unique wavelength. In such telescopes, a secondary spectrograph is used to disambiguate overlapping wavelengths from the primary disperser. A single rejection band can be created in the secondary spectrograph based on the resulting wavelength modulation. Two optical paths are directed from the slit situated between the primary and secondary dispersers. Angles of incidence and path lengths are slightly offset between the pair of post-slit wave trains. By this configuration, a half wave path difference is established at the position and diameter of the host star, causing phase cancellation at a unique spectral band. Having a single rejection band avoids repetitive banding endemic to conventional interferometric telescopy. There is a trade-off with chromatic aberration in the images of the exoplanets.

8445-81, Poster Session

Design of a beam combiner for polarization measurements

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Present optical interferometry measurements ignore the effects of polarization. In the future, these instruments will be observing faint and intrinsically polarized sources. Faint sources are normally further away, which means significant interstellar polarization that could affect the calibration of both polarization dependent and independent observations. Intrinsic polarization mechanisms include electron scattering, dust scattering, Zeeman splitting, and cyclotron emission. All of these mechanisms provide insights into the physical structures of sources. For example, an early star appears unpolarized when observed with a single telescope because of azimuthal symmetry. This symmetry is broken when such objects are observed by an interferometer equipped with a polarimeter. Polarization is also important when observing artificial targets -- the polarization of geosynchronous satellites can vary by a factor of four (10% to 40%) during a night.

8445-82, Poster Session

Accuracy of the ReRRCA algorithm using the Ronchi test and interferometry analysis

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In this paper, we calculate the accuracy of the ReRRCA algorithm (Recuperation of the Ronchigram using Random Coefficients of Aberration), developed by Aguirre et al. (2011). For this, we perform a comparison between the aberration coefficients recovered with this algorithm vs the aberration coefficients obtained from the interferograms analysis using a Fizeau interferometer of Zygo brand. In other words, these coefficients are used as reference to calculate the accuracy of our algorithm. For some experimental ronchigrams which were obtained for different surfaces (spherical and aspherical), some results are shown.

8445-83, Poster Session

Approaches for achieving broadband achromatic phase shifts for visible nulling coronagraphy

M. R. Bolcar, R. G. Lyon, NASA Goddard Space Flight Ctr. (United States)

Visible nulling coronagraphy is one of the few approaches to the direct detection and characterization of Jovian and Terrestrial exoplanets that works with segmented aperture telescopes. Jovian and Terrestrial planets require at least 10^9 and 10^10 image plane contrasts, respectively, within the spectral bandpass and thus require a nearly achromatic π-phase difference between the arms of the interferometer. Herein we describe several techniques, including sequential thick glass plates, distributed thin-film coatings, and total-internal reflection methods.

An achromatic π-phase shift can be achieved by several techniques, including sequential angled thick glass plates of varying dispersive materials, distributed thin-film multilayer coatings, and techniques that leverage the polarization-dependent phase shift of total-internal reflections. A viable technique must achieve the achromatic phase shift while simultaneously minimizing the intensity difference, chromatic beam spread and polarization variation between each arm.

In this paper we describe the above techniques and report on efforts to design, model, fabricate, align the trades associated with each technique that will lead to an implementations of the most promising one in Goddard's Visible Nulling Coronagraph (VNC).

8445-84, Poster Session

Demonstration of the wide-field imaging interferometer testbed using a calibrated hyperspectral image projector

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The Wide-field Imaging Interferometer testbed (WIIT) at NASA's Goddard Space Flight Center uses a dual-Michelson interferometric technique. The WIIT combines stellar interferometry with Fourier-transform interferometry to produce high-resolution spatial-spectral data over a large field-of-view. This combined technique could be employed on future NASA missions such as the Space Infrared Interferometric Telescope (SPIRIT) and the Sub-millimeter Probe of the Evolution of Cosmic Structure (SPECS). While both SPIRIT and SPECS would operate at far-infrared wavelengths, the WIIT demonstrates the dual-interferometry technique at visible wavelengths.

The WIIT will produce hyperspectral image data, so a true hyperspectral object is necessary. A calibrated hyperspectral image projector (CHIP) has been constructed to provide such an object. The CHIP uses Digital Light Processing (DLP®) technology to produce customized, spectrally-diverse scenes. CHIP scenes will have approximately 1.4-micron spatial resolution and the capability of producing arbitrary spectra in the band between 380 nm and 1.6 microns, with approximately 5-nm spectral resolution. Each pixel in the scene can take on a unique

spectrum. Spectral calibration is achieved with an onboard fiber-coupled spectrometer.

In this paper we describe the operation of the CHIP. Results from the WIIT observations of CHIP scenes will also be presented.

8445-85, Poster Session

Wavefront correction inside unbalanced nulling interferometer

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The purpose of our research is direct detection of exo-planets. Since a planet like the solar system is darker than a central star about 10 orders of magnitude, the planet is hidden under the diffraction light of the star and the scattered light by wavefront errors, and they make direct detection of the planet difficult. We suggested and developed a high contrast four-stage coronagraph system for direct detection of exo-planets. It corrects wavefront errors with high precision using an unbalanced nulling interferometer (UNI) and phase and amplitude correction adaptive optics system (PAC), and will make the scattered light lower than the planet level. In UNI, the incidence light from a telescope is divided, and they interfere by a reverse phase with different amplitude. Thereby, phase errors are magnified and we can correct a wavefront with higher precision by subsequent PAC. But, as two light beams overlap again after including different wavefront errors by different mirrors in UNI, phase errors of the incident wave will be magnified together with the wavefront errors inside UNI. Now, I develop the adaptive optics which removes the wavefront errors inside the interferometer by operating the phase of the light to a suitable value before dividing, and interfering with the same wavefront form. In a simulation, the result was that wavefront accuracy improved by about 3 times with this technique, and also the comparable effect was acquired experimentally.

8445-86, Poster Session

Sub-nanometer scale measurement of thermal deformation for telescope components by a heterodyne laser interferometer

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A heterodyne metrology interferometer was stabilized down to a noise level of sub-nanometer as a root-mean-square (RMS) value integrated between 0.3mHz and 1Hz.This interferometer can be used in precise characterization of deformation for satellite components against thermal exposure. JASMINE is an abbreviation of Japan Astrometry Satellite Mission for INfrared Exploration. The JASMINE mission will measure annual parallaxes, positions on the celestial sphere in an infrared band, and proper motions of many stars in the bulge of the Milky Way (the Galaxy) with high accuracies of about 10 micro-arcsec. In order to achieve such high accuracy observation, thermal stability will be needed for satellite components. Then, the amount of thermal deformation of the satellite components was obtained using the heterodyne metrology interferometer, and the thermal stability was evaluated from the results.

8445-87, Poster Session

Non-redundant aperture masking with diffraction-limited integral field unit spectrographs

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Broad bandpass imaging using non-redundant aperture masks (NRM) behind adaptive optics systems on 5-10m class telescopes is now widespread. We report on the first NRM data ever taken with an IFU, and present the design of the sparse aperture mask in Gemini Planet Finder (GPI). Our design trades Fourier coverage, bad actuator location, hole size and expected residual wavefront error. GPI's NRM complements its coronagraph design by targeting moderate contrast companions that lie behind its coronagraphic occulter. GPI's NRM can also be used without dispersion in a dual-polarization mode.

8445-88, Poster Session

Aperture masking at the Large Binocular Telescope

J. Stürmer, A. Quirrenbach, Landessternwarte Heidelberg (Germany)

Preliminary investigations for an Aperture Masking Experiment at the Large Binocular Telescope (LBT) and its application to stellar surface imaging are presented. An algorithm is implemented which generates non-redundant aperture masks for the LBT. These masks are adapted to the special geometry of the aperture of the LBT, which consists of two separate mirrors. At the same time, the masks are optimized to provide a uniform UV-coverage. It is also possible to favor certain baselines to adapt the UV-coverage to observational requirements. The optimization is done by selecting appropriate masks among a large number (order 10^8) of randomized realizations of non-redundant masks. Using results of numerical simulations of the surface of red supergiants, synthetic interferometric data are generated as would be available with these masks at the LBT while observing Betelgeuse. An image reconstruction algorithm is used to reconstruct images from Squared Visibility and Closure Phase data. It is shown that a number of about 15 holes per mask is sufficient to retrieve detailed images.

In addition, noise is added to the data in order to simulate the influence of measurement errors such as photon noise. Both the position and the shape of surface structures are hardly influenced by this noise. However, the flux of these details changes significantly.

8445-90, Poster Session

JouFLU: an upgraded FLUOR beam combiner at the CHARA array

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FLUOR, which has been operational on CHARA since 2003, is an infrared fiber beam combiner. The telescope array will be soon fitted with an adaptive optics system, which will enhance interferometer performance. In this framework, FLUOR has been entirely redeveloped and will be able to measure visibilities with higher accuracy. The technical upgrades consist of improving some existing systems, and developing new features. The bench, which is now remotely operable, primarily offers spectral dispersion (long fringes scanning), a more sensitive camera and a Fourier Transform Spectrometer. After presenting the main JouFLU operating modes, we give technical details about each upgraded sub-system, and the first results obtained during the commissioning.

8445-91, Poster Session

MATISSE: concept, specifications, design, and performances

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MATISSE (Multi AperTure mid-Infrared SpectroScopic Experiment) is the future spectro-interferometer of the European Southern Observatory VLT operating in the spectral bands L, M and N, and combining the beams of up to four telescopes UTs/ATs.

This paper describes the concept, the specifications and the expected performances of the MATISSE instrument.

On the basis of the general instrumental concept, MATISSE was decomposed into modules whose functions and detailed characteristics are given. The specifications have been established including transmission and contrast degradation budgets. An assessment of performances will be given taking into account the instrument and VLTI characteristics.

8445-92, Poster Session

Final mechanical and opto-mechanical design of the Magdalena Ridge Observatory interferometer

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Most sub-systems of the Magdalena Ridge Observatory Interferometer (MROI) have progressed towards final design, construction and testing since the last SPIE meeting in San Diego - CA. The first 1.4-meter telescope has successfully passed factory acceptance test, and construction of telescopes #2 and #3 has started. The beam relay system has been prototyped and is under test on site, and full construction is awaiting funding. A complete 100-meter length delay line system, which includes its laser metrology unit, has been installed and tested on site, and the first delay line trolley has successfully passed factory acceptance testing. A fully operational fringe tracker is integrated with a prototyped version of the automated alignment system for a closed looping fringe tracking experiment. In this paper, we present details of the final mechanical and opto-mechanical design for these MROI sub-systems and report their status on fabrication, assembly, integration and testing.

8445-34, Session 15

Dependence of the quality of an image with the number of telescopes of an array

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We present simulations of interferometric observations with the VLTI in two different cases: AMBER/PIONIER like, with power-spectra and closure phases, and GRAVITY/PRIMA+AMBER like, with power-spectra and (referenced) visibility phases. A key aspect of this work is the inclusion of realistic noise models for visibility phase and closure phase, following the work of Tatulli & Chelli, including cross-correlation between the observables. This noisy data is then used to reconstruct images using the Multi-aperture image Reconstruction Algorithm (MiRA).

Further to the classical imaging beauty contest fidelity analysis, we address essential issues such as the optimal number of telescopes for image reconstruction. Indeed, although the (u, v) coverage is increased with the number of telescopes being simultaneously combined, the Signal-to-Noise ratio (SNR) decreases due to the combination process. We analyse the variation of the SNR in the amplitudes and phases and discuss the quality of the images for different configurations of the array and sets of data by means of an accuracy function.

We conclude by presenting the optimal number of telescopes for referenced phase and closure phase image reconstructions.

8445-35, Session 15

Construction of a 57m hypertelescope in the southern Alps, France

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For information-rich direct images at high resolution, hypertelescopes combine light from a sparse array of many sub-apertures, using pupil densification. Among the possible architectures, the Arecibo-like spherical class has fixed mirrors arrayed as elements of a common spherical locus, matching approximately the natural curvature of a crater or valley. A focal gondola, suspended on the focal sphere, is tracking the primary star image. Since no delay lines are needed, hundreds of mirrors can be used for reaching the theoretical information gain with respect to fewer apertures. The aperture size of such instruments may range from 50 to perhaps 1200m at available terrestrial sites.

As an example of their broad science capabilities, we have simulated the resolved imaging (and spectro-imaging) of an exoplanet transiting across the disk of its parent star, achievable with adaptive optics. Faint cosmological sources may also become observable if a Laser Guide Star can be fitted.

We describe the current construction and in situ opto-mechanical testing of a 57m hypertelescope, later expandable to 200m with 100 or more sub-apertures. The preliminary operating experience gained in a year (stability of the gondola, control of attitudes in 3 directions, feasibility of optical alignment), without stellar fringes yet, indicates the likely feasibility of larger versions at suitable sites. It is worthwhile to note that our prototype construction is environment friendly and its impact on the natural surroundings is minimal. Labeyrie et al., (this conference) discuss an "Extremely Large Hypertelescope " (ELHyT) having a 1200m sparse aperture and, at similar cost, a larger collecting area and higher limiting magnitude than a 40m ELT.

8445-36, Session 15

Concept of an extremely large hypertelescope (ELHyT) with 1200m sparse aperture for direct imaging at 100 micro-arcsecond resolution

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The hypertelescope construction initiated in the southern Alps (Allouche et al., this conference) has provided some preliminary operating experience indicating that larger versions, up to perhaps 1200m, are probably feasible at suitable sites. The Arecibo-like architecture of such instruments does not require the large mount and dome which dominate the cost of a 40m ELT . For the same cost, an "Extremely Large Hypertelescope " (ELHyT) may therefore have a larger collecting area. It may thus in principle reach higher limiting magnitudes, both for seeing-limited and, if equipped with a Laser Guide Star and adaptive phasing, for high-resolution imaging with gain as the size ratio, i.e. about 30 with respect to a 40m ELT.

Like the radio arrays of antennas, such instruments can be grown progressively. Also, they can be up-graded with several focal gondolas, independantly tracking different sources.

Candidate sites have been identified in the Himalaya and the Andes . We describe several design options and compare the science achievable for both instruments, ELTs and ELHyTs. The broad science addressed by an ELHyT covers stellar chromospheres, transiting exo-planets and those requiring a high dynamic range , achieved by array apodization or coronagraphy . With a Laser Guide Star, it extends to faint compact sources beyond the limits of telescopes having a smaller collecting area, supernovae, active galactic nuclei, gamma ray bursts . The sparse content of remote galaxies seen in the Hubble Deep Field appears compatible with the crowding limitations of an ELHyT having 1000 apertures.

8445-37, Session 15

Gravitation astrometric measurement experiment (GAME)

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GAME is a novel concept for a medium class mission aimed at Fundamental Physics tests in the Solar system, by means of an optimised instrument in the visible, based on smart combination of coronagraphy and Fizeau interferometry.

The targeted precision on the "γ" and "β" parameters of the Parametrised Post-Newtonian formulation of General Relativity are respectively in the 10^{-8} and 10^{-6} range, improving by one or two orders of magnitude with respect to the expectations on current or near future experiments.

Such precision is suitable to detect possible deviations from the unity value, associated to generalised Einstein models for gravitation, with potentially huge impacts on the cosmological distribution of dark matter and dark energy from a Solar system scale experiment.

The measurement principle is based on the differential astrometric signature on the stellar positions, i.e. based on the spatial component of the effect rather than the temporal component as in the most recent experiments using radio link delay timing variation (Cassini).

The instrument concept is based on multiple field, multiple aperture Fizeau interferometry, observing simultaneously regions close to the Solar limb (requiring the adoption of coronagraphic techniques), and others in opposition to the Sun. The diluted optics approach is selected for achieving an efficient rejection of the scattered solar radiation, while retaining an acceptable angular resolution on the science targets. The multiple field observation is aimed at cost-effective control of systematic effects through simultaneous calibration.

We describe the science motivation, the proposed mission profile, the instrument concept and the expected performance.

8445-38, Session 15

A fibered optical long baseline interferometer on the International Space Station

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After 13 years in construction, the International Space Station is becoming a research laboratory in near-earth orbit. It has been designed to give an easier access to space to a wide range of research experiments. Astronomy is one of the fields that could benefit from this platform.

This contribution investigates the concept of an optical long-baseline interferometer installed on the ISS. The concept would use small telescopes attached to the outside of the station, with single mode fibers transporting the light to delay lines and beam combiners located in one of the experiment racks inside the station. Taking into account available external attach points, the interferometer could have up to ~5 telescopes, with baselines covering up to 45m x 45m, corresponding to an angular resolution of 2.3 to 11.5 mas at wavelengths of 0.5 to 2.5 microns respectively.

This contribution first describes the concept, showing that single mode fibers are the only reasonable way of implementing an interferometer on the ISS. Then the adequacy of the station as an interferometric platform is looked into, considering vibrations, attitude stability, pointing capabilities and accuracy.

8445-39, Session 16

Recent advances in the development of mid-IR integrated devices for interferometric arrays

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Small-scale integration and miniaturization of key subsystems on optical stellar interferometers are fundamental aspects to achieve high-precision interferometry. This is obtained with single-mode photonics devices such as fibers or integrated-optics, which offer high instrumental stability, stiff integration of the beam-combination and photometric functions, and excellent wavefront filtering. Despite the numerous advantages, it is well known that the current astronomical exploitation of this approach is spectrally limited due to a maturity gap between the near and mid-IR photonics beyond 3µm.

However, this spectral range (L, M, N bands) is of major interest for the direct characterization of young exoplanets and disks using closure-phase, synthesis imaging or nulling techniques that rely on single-mode multi-beam combination.

In this paper, we report recent and major advances we have obtained on the fabrication of two and three-telescope mid-IR integrated beam combiners, with significant improvement over the simplest channel waveguide as the long-lived only available structure. We have used device-writing techniques based on CW lasers and femtosecond lasers to obtain, respectively, planar and 3D arrangement of devices in chalcogenide glasses, where cross-talk between channels is avoided.

Single-mode and multi-mode devices have been produced and

characterized in narrow and broadband light, in the L and N bands. We have measured instrumental contrasts up to 0.99 at 10µm with 0.1% accuracy. We have derived a first estimation of the propagation losses to be in the range [0.7-3]dB/cm at 10µm, and investigated possible polarization effects. We conclude proposing a preliminary study of possible on-sky demonstration setups.

8445-40, Session 16

Discrete beam combiners: exploring the potential of 3D photonics for interferometry

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The possibility to manufacture miniaturized astronomical instruments by use of photonic circuits is an appealing perspective in every field of astronomy. Development in recent years has shown inequivocally the advantages in terms of stability and accuracy of photonic beam combiners for optical interferometry. Yet scaling to the combination of many telescopes is still limited to a few units due to the fabrication constraints of planar photonics.

Here we present the results of first laboratory tests of a prototype of photonic beam combiner based on the evanescent coupling in a two dimensional array of waveguides. These components (named discrete beam combiners) offer the potential of simple manufacturing through direct laser writing in a variety of materials, and scaling for the combination of many telescopes thanks to an inherent three-dimensional construction. The results of the tests show that the beam combiner can be used to retrieve simultaneously phase and visibilities with an accuracy of a few percent in a three-beam combination scheme. The impact of our results on multibeam metrology and imaging with astronomical interferometers will be discussed.

8445-41, Session 17

Least-squares deconvolution of AMBER dispersed visibilities

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We acquired AMBER low, medium and high spectral resolution dispersed visibilities of an active pre-main-sequence spectroscopic binary surrounded by a circum-binary disk. The FINITO fringe tracker was used in conjunction with AMBER in the medium and high spectral resolution acquisition. The object (HD10237) was at the limiting magnitude of the system in these modes. The data was calibrated using standard techniques. The dispersed visibilities present signals coincident with the Br gamma emission line. By using the high spectral resolution data we confirmed that the Br gamma signals are spectrally unresolved.

By comparing the low spectral resolution data with the intermediate and high spectral resolution data we found gray visibility drops indicative of calibration problems. In this communication we present an original extraction procedure that takes into account the spectral dispersion function (the spectral analog of the PSF) that we call least-squares deconvolution. It allows the recovery of the relative line to continuum visibility amplitude ratio and the relative line to continuum visibility phase signals. The method only uses as input the AMBER data making the sole hypotheses that the signal is spectrally unresolved. It is extremely robust being able to recover line to continuum visibility and phase at very low (<1) signal-to-noise conditions. The method can be trivially generalized to similar instruments as those available at CHARA and Keck-I.

Least squares deconvolution opens the possibility of delivering legacy quality measurements from the AMBER archive without relying on visibility calibration or environmental effects such as vibrations. It is therefore a key tool for the astrophysical exploitation of this instrument.

8445-42, Session 17

Using statistical distributions to accurately measure visibility measurements: application to FLUOR/CHARA data

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Long baseline interferometry is a unique technique that allows observations to be taken at extremely high angular resolutions as it is not limited by the size of the apertures but instead by the distance separating them. However, from the ground, interferometric measurements are largely corrupted by atmospheric turbulences which introduce fast random fluctuations both in the differential phases and intensities of the different baselines. Recently, Hanot et al. (2011) have demonstrated that by using the statistical distributions of phase and intensity errors, it was possible to retrieve interferometric quantities with an unprecedented precision. They applied this technique to data obtained with a nulling interferometer using a fringe tracking device. In this paper, we extend this technique to long baseline interferometers using fringe scanning such as FLUOR at CHARA and PIONIER at VLTI and demonstrate its performance on data obtained with the FLUOR instrument.

8445-43, Session 17

Coherent integration in optical interferometry

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Optical Interferometry has long been limited by low SNR making it nearly impossible to measure the small visibilities required to make resolved images. Although the SNR exists in the raw data, much SNR is lost in the conventional squared-visibility processing. In modern interferometers fringes are recorded simultaneously at many wavelengths and baselines. This makes phase-referencing possible, which is the key to coherent integration, which in turns can greatly improve the SNR of interferometric measurements, making small-amplitude resolving measurements possible. In this paper we will detail the theory of coherent integration. We will also explain why coherent integration should, in most cases, be carried out during post-processing in software rather than in real-time in hardware. We will then compare it to conventional processing approaches for some data from the Navy Optical Interferometer. We will demonstrate how coherent integration can improve the accuracy of observations.

8445-44, Session 17

Geometrical model fitting for interferometric data: GEM-FIND

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The spatial information given by current optical interferometers is still limited and therefore models are needed for the data interpretation. We developed the tool GEM-FIND that allows to constrain the morphology and brightness distribution of an object. The software is fitting chromatic geometrical models to spectrally dispersed interferometric measurements of visibility and differential phase in the N-band. GEM-FIND is written in the IDL language and is based on a 2-dimensional Levenberg-Marquardt method. Each model includes a set of wavelength-independent and/

or wavelength-dependent parameters. An appropriate handling of the errors is guaranteed by the determination of confidence regions on each parameter.

GEM-FIND has been successfully tested on the MIDI observations of the AGB star SV Psc. The results are in good agreement with hydrodynamic simulations showing that a close companion could be responsible for the entrainment of gas and dust into a circumbinary structure.

As GEM-FIND allows a fast (few minutes) determination of the most suitable morphology using the spatio-chromatic dependence of interferometric measurements, this tool could also be used to constrain the inital image for Image Reconstruction Algorithms.

8445-45, Session 17

Chromatic imaging with self-calibration in optical interferometry

F. A. Millour, M. Vannier, Observatoire de la Côte d'Azur (France)

We present here a new recipe for imaging in optical interferometry. It is similar in its principle as the self-calibration technique, nowadays commonly used in radio-interferometry, but for the first time applied to optical interferometry data. Therefore we call it also « self-calibration ». It uses the wavelength-differential phase as a proxy of the object phase to build-up a full-featured complex visibility set of the observed object. This technique needs a first image-reconstruction run with an available software, using closure-phases and squared visibilities only. We used it for two scientific papers with great success. We will discuss here the pros and cons of such imaging technique.

8445-46, Session 18

Multi-wavelength imaging algorithm for optical interferometry

E. M. Thiébaut, F. Soulez, Observatoire de Lyon (France)

Optical interferometers provide multiple wavelength measurements. In order to fully exploit the spectral and spatial resolution of these instruments, new algorithms for image reconstruction have to be developed. Early attempts to deal with multi-chromatic interferometric data have consisted in recovering a gray image of the object or independent monochromatic images in some spectral bandwidths. The main challenge is now to recover the full 3-D (spatio-spectral) brightness distribution of the astronomical target given all the available data. We describe how we have modified the MiRA algorithm to implement multi-wavelength image reconstruction. In particular, following our work on hyper-spectral imaging from integral field spectroscopy data, we have designed an original spatio-spectral regularization which is able to cope with the voids in the data sampling (notably the u-v coverage) while preserving sharp features such as spectral lines, point-like sources or raw edges. We show the gain in image quality achieved by globally taking into account all the data instead of dealing with independent spectral slices. Another advantage of our approach is that it reduces the number of degeneracies of the image restoration problem from optical interferometry observables such as phase closures and differential phase data. Like its ancestor, the new version of the algorithm, dubbed MiRA-3D, will be soon freely available.

8445-47, Session 18

5D image reconstruction for optical interferometry

F. Baron, J. D. Monnier, Univ. of Michigan (United States)

We demonstrate the use of SQUEEZE 2, an image reconstruction software for optical interferometry capable of 5D imaging of multiple systems. One or several stars can be modelled in three dimensions, with both the time and wavelength dependencies of this model taken into account during the image reconstruction process. Our algorithm relies on the Compressed Sensing and Bayesian Evidence paradigms, and its implementation leverages the computing power of GPUs through the use of the OpenGL and OpenCL libraries.

8445-48, Session 19

The 2012 interferometric imaging beauty contest

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We present the results of the fifth Optical/IR Interferometry Imaging Beauty Contest. The contest consists in blind imaging of test data sets derived from model sources and distributed in the OI-FITS format. Two imaging scenarios were be offered for reconstruction: imaging a Young Stellar Object (YSO) with VLTI, and imaging a spotted star with CHARA. There were 9 different algorithms competing this time: the Building Block Method by Kraus; BSMEM the Bispectrum Maximum Entropy Method by Young; CASA by Elias; GPAIR2 by Kloppenborg; IRS by Hofmann, Schertl and Weigelt; MACIM by Che and Monnier; RPR by Rengaswamy; MIRA by Thiebaut; an unnamed algorithm by Vannier and Mary; and OYSTER by Hummel. The contest model images, the data delivered to the contestants and the rules are described as well as the results of the image reconstruction obtained by each method. These results are discussed as well as the strengths and limitations of each algorithm.

8445-49, Session 20

Beating the confusion limit: the necessity of high angular resolution for probing the physics of Sagittarius A*, GRAVITY (VLTI) and LINC-NIRVANA (LBT)

A. Eckart, G. Witzel, N. Sabha, C. Straubmeier, Univ. zu Köln (Germany)

The super-massive 4 million solar mass black hole (SMBH) SgrA* shows flare emission from the millimeter to the X-ray domain.

A detailed analysis of the infrared light curves allows us to address the accretion phenomenon in a statistical way.

The analysis shows that the near-infrared flare amplitudes are dominated by a single state power law, with the low states in SgrA* are limited by confusion though the unresolved stellar background.

We show that for 8-10m class telescopes blending effects along the line of sight will result in artificial compact starlike objects of 0.5-1 mJy that last for about 3-4 years.

The SgrA* also allows us to study the interaction of the SMBH with the immediate interstellar and gaseous environment of the central stellar cluster (bow-shock sources and dusty filaments).

We discuss how the imaging capabilities of GRAVITY at the VLTI and LINC-NIRVANA at the LBT contribute to the investigation of the low variability states of SgrA*.

8445-50, Session 20

The MIDI AGN Large Programme: a statistical sample of resolved AGN tori (THESIS)

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Interferometric observations with MIDI/VLTI in the mid-infrared made studies of the central dusty tori of Active Galactic Nuclei (AGNs) possible and proved their existence in a number of nearby galaxies. Both type 2 and type 1 galaxies showed dust on the parsec-scale whose general properties were comparable -- consistent with (but not proving) the “unifying model” for radio-quiet galaxies. Existing studies were, however, mostly based on single or very few sources and therefore dominated by the characteristics of individual galaxies. For a more comprehensive approach, a larger sample is needed. This statistical basis is set up as a VLTI/MIDI Large Programme that comprises 14 AGNs for which torus properties are being determined. Observations and data reduction are finished and show resolved dust emission in almost all of the sources. They represent the largest sample of resolved AGN tori so far, allowing to ask a number of questions, ranging from unification to the physics of accreting galactic nuclei. In particular, the observations allow us to dissect the parsec-scale infrared emission and to determine the sizes and fluxes of the various components. These AGNs are among the faintest objects ever studied with MIDI and require the data reduction software to be adjusted. In the talk, both our data reduction technique for these weak sources and the scientific highlights from the Large Programme will be presented.

8445-51, Session 20

New opportunities with spectro-interferometry and spectro-astrometry

S. Kraus, Univ. of Michigan (United States)

Latest-generation spectro-interferometric instruments combine a milliarcsecond angular resolution with spectral capabilities, resulting in an immensely increased information content. Here, I present new methodological work and results obtained with VLTI/AMBER, which illustrate the fundamentally new scientific insights provided by spectro-interferometry with very high spectral dispersion (R=12,000) or in multiple line transitions (Brackett and Pfund lines). In addition, I will discuss some pitfalls in the interpretation of spectro-interferometric data. In the context of our recent studies on Beta CMi and Zeta Tauri, I will present the first position-velocity diagram obtained with optical interferometry and provide a physical interpretation for a phase inversion, which has in the meantime been observed for several classical Be-stars. In the course of our study on the Herbig B[e] star V921 Scorpii, we combined, for the first time, spectro-interferometry and spectro-astrometry, providing a powerful and resource-efficient way to constrain the spatial distribution as well as the kinematics of the circumstellar gas with an velocity resolution up to R=100,000. Finally, I will discuss our phase sign calibration procedure, which has allowed us to calibrate AMBER differential phases and closure phases for all spectral modes.

8445-93, Poster Session

Portable intensity interferometry

E. P. Horch, M. A. Camarata, Southern Connecticut State Univ. (United States)

A limitation of the current generation of long baseline optical interferometers is the need to make the light interfere prior to detection. This is unlike the radio regime where signals can be recorded fast enough to use electronics to accomplish the same result. This paper describes a modern intensity interferometer based on electronics with picosecond timing resolution. The instrument will allow for portable optical interferometry with much larger baselines than currently possible by using existing large telescopes. With modern electronics, the limiting magnitude of the technique at a 4-m aperture size is not far from amplitude-based interferometers currently working in the visible. The instrumentation will permit a wireless mode of operation with GPS clocking technology, extending the work to extremely large baselines. We discuss the basic observing strategy, a planned observational program at the Lowell Observatory 1.8-m and 1.0-m telescopes, and the science that can realistically be done with this system.

8445-95, Poster Session

Interferometric imaging of geostationary satellites: signal-to-noise considerations

A. M. Jorgensen, New Mexico Institute of Mining and Technology (United States); H. R. Schmitt, U.S. Naval Research Lab. (United States); D. Mozurkewich, Seabrook Engineering (United States); J. T. Armstrong, S. R. Restaino, R. B. Hindsley, U.S. Naval Research Lab. (United States)

Geostationary satellites are generally too small to image at high resolution with conventional single-dish telescopes. An alternative to a 100+ m diameter telescope is to use an optical/infrared interferometer consisting of multiple smaller telescopes in an array configuration. In this paper we focus on what is required to achieve the required signal-to-noise ratio to image. We will look at the signal-to-noise ratio required to track fringes on satellites on multiple baselines, a pre-requisite to imaging. We will also look at how to achieve the required signal-to-noise required for image reconstruction. We compare these performance specifications to the performance of existing interferometers as well as that of a new interferometer concept optimized for satellite imaging.

8445-96, Poster Session

The MROI’s capabilities for imaging geosynchronous satellites

J. S. Young, C. A. Haniff, D. F. Buscher, Univ. of Cambridge (United Kingdom); M. J. Creech-Eakman, I. Payne, C. Jurgenson, V. D. Romero, New Mexico Institute of Mining and Technology (United States)

Interferometry provides the only practicable way to image meter-scale structure in geosynchronous satellites. This capability represents a unique commercial opportunity for astronomical interferometry, but to date no interferometer has been able to make an image of such a satellite. We discuss the challenges of imaging these objects and present results of sensitivity calculations and imaging simulations which show that the Magdalena Ridge Observatory Interferometer is likely to be well-suited to this application.

8445-97, Poster Session

Systems design and engineering for the Laser Interferometer Gravitational-wave Observatory (LIGO) project

D. Coyne, California Institute of Technology (United States)

The LIGO project is in the process of installing its second generation interferometers at both of its observatories, with design capability to detect a strain of one part in 10^22. (An overview of the LIGO project and the astrophysical motivations are described in another paper in these proceedings.)

The interferometer's requirements, principles of operation, system design and architecture is described, including the principal design trades, selected key parameters and enabling technologies. The basic optical design is a power and signal recycled Michelson interferometer with Fabry-Perot resonant arm cavities, each 4 km long. The Fabry-Perot cavity mirrors are large, exceptionally low loss optics which are isolated from disturbances by placing them in a high vacuum system and by supporting them with multiple stages of active and passive vibration isolators. The length and angular alignment degrees of freedom of the coupled optical cavities are sensed by RF techniques and controlled by low noise electro-magnetic and electro-static actuators. The material choices and designs of the suspension/pendulum systems are based on thermal noise considerations. Thermal management and active compensation of thermal lensing is required for the 800 kW of power (1064 nm wavelength) circulating in the arm cavities. The servo-control systems for the interferometer length and alignment, as well as the vibration isolation system, are all digital.

The systems engineering approach/practices, modeling and simulation tools and methods, prototyping approaches and methods, integrated system-level test approach and some lessons learned will be discussed.

8445-98, Poster Session

Simulated imaging with an interferometer on a boom

H. R. Schmitt, U.S. Naval Research Lab. (United States); D. Mozurkewich, Seabrook Engineering (United States); J. T. Armstrong, U.S. Naval Research Lab. (United States); A. M. Jorgensen, New Mexico Institute of Mining and Technology (United States); E. K. Baines, S. R. Restaino, R. B. Hindsley, U.S. Naval Research Lab. (United States)

We simulate the observations of stars, asteroids and active galaxies with an optical interferometer mounted on a boom. This instrument has an advantage over more traditional interferometers because it significantly reduces the number of reflections and surfaces, thus allowing one to combine a larger number of telescopes without a significant loss of sensitivity. We investigate two telescope arrays distributed on a hexagonal pattern, one which produces a non redundant coverage of the uv-plane and one which produces a redundant coverage of the uv-plane. These simulated observations are combined with traditional aperture synthesis techniques to reconstruct images and determine the accuracy of these images relative to the original ones.

8445-99, Poster Session

A low-cost fiber-based near-infrared heterodyne interferometer

E. A. Michael, L. Pallanca, Univ. de Chile (Chile)

We are presenting a low-cost near-infrared heterodyne interferometer based on 1.55μm fiber-components, amateur telescopes and a 3-GSPS-ROACH-based correlator. First performance is sufficient for the brightest stars, enabling application in site-testing, e.g. to characterize the yet unknown outer scale of atmospheric turbulence, but we expect science-relevant astronomical performance, given the following improvements. To stabilize coupling to the fibers, the control of commercial tip-tilt adaptive optics transmissive elements is being developed. For now we use 2GHz-InGaAs-photodiodes (NEP ≈ 10-15WHz-0.5), but will test them cryogenically and intend also to investigate the application of single-photon-detectors. An ALMA prototype line-length corrector is being implemented to stabilize the path length difference of the two interferometer fiber arms. This way, extremely long baselines will be feasible, and the fiber approach gives flexibility with them. Larger telescopes, e.g. at Cerro Tololo or La Silla, could then be considered, or testing at the pointing-telescope slots of ALMA. An extension to three or even more (with amateur telescopes) baselines would be facilitated by the low-cost-approach.

8445-101, Poster Session

Coherencing of a large diluted telescope mirror using a supercontinuum laser source and first observations with a focal gondola

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Studies are currently underway to propose a generation of interferometers post-VLTI (VLDT ,OHANA, Keops, etc.). Such interferometers will open new fields of research in astrophysics by imaging the surfaces of supergiant stars, gravitational microlensing, AGN, etc. To achieve these goals, they will have to meet several criteria: high angular resolution (Baseline > 100 m), a good coverage of uv spatial frequencies and a better sensitivity than regular interferometers (VLTI, Keck, Chara, etc.). A Very Large Diluted Telescope (VLDT) could meet all these criteria.

VLDT is an optical interferometer configured like a diluted version of the Arecibo radio-telescope. Above the diluted primary mirror, made of fixed co-spherical segments, a helium balloon, or cables suspended between two mountains, carry a gondola containing the focal optics, and detector. At this moment, we are testing the entire optical train of the diluted telescope on a 10m baseline prototype at Haute-Provence observatory. We describe the stabilization system and the metrology device. We obtained in 2010-2011 white metrology fringes. The position of the primary mirrors has been adjusted on the sphere within a few micron accuracy. We will also present the focal gondola.

It should be possible to build within the next 10 years a scientific demonstrator with baselines in the 100-200 meter range. Considering its expected specifications, VLDT will operate in complementarily with ELTs and very long baseline interferometers.

8445-102, Poster Session

The GRAVITY spectrometers: optical design

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Operating on 6 interferometric baselines, i.e. using all 4 UTs, the 2nd generation VLTI instrument GRAVITY will deliver narrow angle astrometry with 10μas accuracy at the infrared K-band and will be able to detect the positional shift of the photocenter of a flare at the Galactic Center within its orbital timescale of ~20min, using the flares as dynamical probes of the gravitational field around SgrA*.

Within the international GRAVITY consortium, the Cologne institute is responsible for the development and construction of the two spectrometers: one for the science object and one for the fringe tracking object, both being operated at cryo-vacuum.

In this contribution we present the final optical design of the two spectrometers as it passed the Final Design Review in October 2011. Optimised for highest optical throughput and sensitivity, the fringe tracking spectrometer uses a double prism and provides a single low spectral resolution of R=22. The science spectrometer is serving a wider range of scientific requirements with three user selectable spectral resolutions (R=22, R=500, R=4500), realised by a single prism and two grisms. Both spectrometers feature a user selectable Wollaston prism for polarimetric studies.

The optical input of each spectrometer are the 24 output channels of its integrated optic beam-combiner device, located in the object plane. The science spectrometer uses a HAWAII2RG and the fringe tracker a SELEX eAPD detector.

In addition, the spectrometers feed the four beams of the powerful laser metrology of GRAVITY backwards into the beam-combiner, propagating to the M2 mirrors of the telescopes.

8445-103, Poster Session

The GRAVITY spectrometers: metrology laser blocking system

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A three stage blocking system is implemented in the GRAVITY science and the fringe tracking spectrometer optical design. The blocking system consists of a dichroic beam splitter and two long wave band-pass filters with the top level requirements of high transmission of the science light in the K-Band (1.95 - 2.45 µm) region and high blocking power optical density (OD) $\geq$ 8 for each filter at the metrology laser wavelength of 1.908 µm. The laser metrology blocking filters were identified as one critical optical component in the GRAVITY science and fringe tracker spectrometer design.

During the Phase-C study of GRAVITY all the filters were procured and individually tested in terms of spectral response at K-band, transmission, blocking (OD) and reflection at the metrology laser wavelength. We present the measurements results of the full metrology blocking system in its final configuration as to be built in the GRAVITY spectrometers, with and optical density of OD > 16 for the metrology laser wavelength.

8445-104, Poster Session

A linear displacement mechanism for the GRAVITY spectrometers

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GRAVITY belongs to the 2nd Instrument generation of the Very Large Telescope Interferometer (VLTI) and will operate in K-band on 6 baselines using all 4 Unit Telescopes of the VLT. With an unprecedented astrometrical accuracy of 10µas it will be, amongst others, capable of detecting the highly relativistic motion of the photocenter of a flare surrounding the supermassive black hole at the Galactic Centre, and thus probe General Relativity.

The contribution of the University of Cologne within the international GRAVITY-Consortium is the design, manufacturing, qualification and assembly of the Fringe Tracking Spectrometer and the Science Spectrometer in the Beam Combiner Instrument (BCI). The Spectrometers will be operated at 80K in a 200K environment in the BCI.

We present the design and qualification of a linear displacement mechanism, which will be used at the focus stages of the detectors in both spectrometers and at the zoom stage in the Fringe Tracking Spectrometer . The mechanism consists of 4 double-hinged compliant joints which support the stage and provide a linear motion along the optical axis. The stage characterization at room and cryogenic conditions are presented.

8445-105, Poster Session

Phase-shifting fringe tracking method for sparse aperture interferometer arrays

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Because they will comprise more and more collecting telescopes, modern interferometric facilities such as the Very Large Telescope Interferometer (VLTI), Center for High Angular Resolution Astronomy (CHARA) or the future Magdalena Ridge Observatory (MRO) interferometer should provide new and astounding visible and near-IR high angular resolution images in the near future. In this perspective, such interferometer arrays should be equipped with new generation fringe trackers, being able to combine all the beams originating from an increasing number of telescopes and to sense differential piston errors varying between them in real time. Here is described a new method suitable for co-phasing many interferometer sub-apertures at the same time, by means of a multi-axial integrated optics beam combiner associated with a phase-shifting technique originally intended for image plane wavefront sensing. We present the principle of the method and its achievable performance in the cases of four, six and eight telescope arrays as function of the magnitude of the guide star in presence of various noise sources. Numerical simulations are carried out assuming typical VLTI parameters for what concerns geometry and radiometry. The main results are discussed in the concluding section, showing an increasing advantage in favour of the phase-shifting technique when more and more collecting telescopes are operating together.

8445-106, Poster Session

The cryostat for the GRAVITY beam combiner instrument at the VLTI

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GRAVITY is a second generation VLTI instrument for high-precision narrow-angle astrometry and phase-referenced interferometric imaging in the astronomical K-band. The cryostat of the beam combiner instrument provides the required temperatures for the various subunits ranging from 40K to 290K with a milli-Kelvin temperature stability for some selected units. The bath cryostat is cooled with liquid nitrogen and makes use of the exhaust gas to cool the main optical bench to an intermediate temperature of 240K. The fringe tracking detector will be cooled

separately by a single-stage pulse tube cooler to a temperature of 40K. The pulse tube cooler is optimized for minimum vibrations. In particular its warm side is connected to the 80K reservoir of the LN2 cryostat to minimize the required input power. All temperature levels are actively stabilized by electric heaters. The cold bench is supported separately from the vacuum vessel and the liquid nitrogen reservoir to minimize the transfer of acoustic noise onto the instrument.

8445-107, Poster Session

Birefringence compensation in PIONIER

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In the PIONIER instrument (an H-band four-telescope instrument for the VLTI, this conference), polarization-maintaining optical fibers are used to carry the light from the (free-space propagation) optical delay units to the integrated optics beam combiner (IOBC). While the four fibers are carefully equalized for group delay, the large birefringence intrinsic to such fibers introduces phase and group delay residuals between the two orthogonal linear polarizations (parallel and perpendicular to the substrate of the IOBC). One solution is to separate the two polarizations at the output of the IOBC, and to detect and process them independently; this is detrimental to signal-to-noise.

We decided instead to compensate the birefringence before the fiber injection. This is realized by inserting in each optical arm of the interferometer a birefringent plate with adjustable tilt angle. The design equations and the merits of various materials are briefly discussed. The adopted design features Lithium Niobate, X-cut with a thickness of 2mm, and a typical inclination of 20°. The two polarizations are detected without separation, with full fringe contrast.

This simple solution has been part of the PIONIER instrument for one year of regular science operation. The compensation is stable on timescales of at least one observing run, i.e. several days.

8445-108, Poster Session

The integrated optics beam combiner assembly of the GRAVITY/VLTI instrument

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Gravity aims at enhancing infrared imaging at VLTI to significantly improve our understanding of the physical processes related to gravitation and accretion within compact objects (young objects for planet and star formation, active galactic nuclei for galaxy formation and evolution, the Galactic Center black hole and gravitation effects in the strong field regime). With its fibre-fed integrated optics, infrared wavefront sensors, fringe tracker, beam stabilisation and a novel metrology concept, GRAVITY will push the sensitivity, accuracy of astrometry and interferometric imaging far beyond what is offered today. Four telescopes will be combined in dual feed in the K band providing precision astrometry of order 10 microarcseconds, and imaging with 4-milliarcsecond resolution.

The Fringe tracker and the scientific instrument host an identical integrated optics beam combiner made by silica-on-silicon etching technology that are put inside a cryogenic vessel cooled at -70°C to reduce thermal background and increase sensitivity.

This paper gives the design of the integrated beam combiner and of its fibred array that allows to fed the combiner with stellar light. Lab measurement of spectral throughput and interferometric performance for beam combiners made by Flame Hydrolysis Deposition and by Plasma-Enhanced Chemical Vapor Deposition (PECVD) are given. The procedure to glue together the beam combiner and its fibred array is described as well as the tests to validate the performance and the ageing effects at low temperature. Finally the thermal analysis and the eigen-frequency study of the whole device are presented.

8445-109, Poster Session

Simulation of Kalman-filter fringe tracking with PRIMA and FINITO OPD measurements

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To improve fringe stability at VLTI, two fringe trackers are presently available: FINITO, an H band three telescope fringe tracker, and the PRIMA Fringe Sensor Unit (FSU), a K-band two telescope fringe tracker. They were respectively installed at VLTI in 2007 and 2008. Since then, both instruments have been used to track fringes during observations and commissioning. The OPD measurements archived in the VLTI database are thus representative of most observing conditions at VLTI.

GRAVITY is a second generation instrument for the VLTI that will combine four telescopes in the K band. To achieve astrometric precision of 10µas and angular resolution of 4mas for object with magnitude down to K=16 in the science beam, it will stabilize fringes to 350nm rms on a reference star as faint as magnitude 10. To efficiently correct for both atmospheric piston and VLTI longitudinal vibrations, the fringe tracker controller is a predictive algorithm based on Kalman filtering. We present here the results of fringe tracking simulations on FINITO and PRIMA OPD measurements to validate the concept of Kalman-filter fringe tracking at VLTI.

8445-110, Poster Session

Development of new optical adjustment system for FITE (far-infrared interferometric experiment)

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We have developed a balloon-borne, astronomical far-infrared interferometer, FITE. Since this is a Fizeau-type 2-beam interferometer consisting two off-axis parabolic mirrors, it is important to establish a method by which the two beams can be adjusted simultaneously. A conventional Hartmann test was originally employed, which has two disadvantages: we cannot measure two beams simultaneously, and it takes long time. We have developed a new optical adjustment system that can measure and evaluate two beams simultaneously with a Shack-Hartmann wave-front sensor. At the first stage, the FOV of a wave-front sensor is adapted to the full beam size of 40 cm (the beam diameter), and the mirror surface accuracy, as well as the mirror alignment, is measured and adjusted for one beam. After adjustment of both beams, the both focuses are coincided at the input aperture hole of the far-infrared sensor system by expanding the FOV of the wave-front sensor so as to include both beams. With this new method, we can make real-time measurement and analysis of converging beams, and also can make fast switching between the single beam mode and the double beam mode. We have demonstrated this new adjustment method by laboratory measurement,

and made design and manufacturing of the new optical adjustment system for FITE.

8445-111, Poster Session

A new fast data acquisition system for the NOI

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The Navy Optical Interferometer (NOI) has three spectrographs each with 32 spectral channels based on Avalanche Photodiodes with the fringe scanned at 500 Hz. Potons are binned synchronized to the stroke, currently in 64 bins. However the existing data acquisition system was designed for 8 bins and is not able to handle the 3 MB/s throughput that would result. For that reason only 32 channels (16channels on each of two spectrographs) are currently recorded, and the duty cycle of the instrument is reduced to allow buffers to flush. To increase the usefulness of the NOI we have undertaken to design a new system, which is easily able to sample all channels at 128 bins per 2 ms, resulting in a 6 MB/s continuous throughput. This is expected to increase the amount of scientific data from the NOI by an order of magnitude over the current system. In this paper we discuss the hardware and software components of this system.

8445-112, Poster Session

Optimizing the transmission of the GRAVITY/VLTI near-infrared wavefront sensor

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The GRAVITY instrument's adaptive optics system consists of a novel cryogenic near-infrared wavefront sensor to be installed at each of the four unit telescopes of the VLT. In combination with the already available deformable mirror (M8) close to the Coudé focal plane of each telescope, the VLT interferometer will be equipped with an adaptive optics system that is sensitive in the near-infrared spectral band. In order to feed the GRAVITY wavefront sensor with light in the 1.4 - 2.2 micrometer band, while suppressing laser light originating from the GRAVITY metrology system, custom-built optical components are required. Here we report on optical and near-infrared testing of the silicon entrance windows of the wavefront sensor cryostat and other reflective optics used in the warm feeding optics.

8445-113, Poster Session

Coherent integration of optical interferometric data on a graphics processor

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Coherent integration is central to extracting maximum signal-to-noise ratio (SNR) from optical interferometric data, with post-processing being the most effective. More sophisticated algorithms produce better results, but also use more computing time produce, sometimes as much as several minutes of computing time per second of observation. As data volumes continue to increase, it is becoming impractical to transfer the data to a super computer. To address this problem, we have explored using a General Purpose Graphics Processor (GPGPU) to perform these computations on a local machine, exploiting the fact that the problem is, in principle, massively parallel. In this paper, we discuss methods to optimize the fringe-tracking algorithm. In particular, we emphasize the parameter extraction process, and describe implementations utilizing both genetic algorithms and powell's method. Using these methods, we were able to improve performance by a factor of 100.

8445-114, Poster Session

Beam control for LINC-NIRVANA: from the binocular entrance pupil to the combined focal plane

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LINC-NIRVANA is the near-infrared interferometric imaging camera for the Large Binocular Telescope. Once operational, it will provide an unprecedented combination of angular resolution, sensitivity and field of view.

To meet the tight requirements that result from long exposure interferometric imaging over a large field of view, active control beyond fringe tracking and adaptive optics has to be in place in the telescope and in the instrument domain. The incoming beams of the binocular telescope have to be controlled along the entire optical path, from the entrance pupil to the combined focal plane. The beams have to coincide in the focal plane of the science detector, their pointing origins, offsets, orientations and plate scales have to match each other and must not change during the observation. Non-common path effects between AO and science channel, flexure and thermal effects have to be compensated and offloading requests from the adaptive optics and fringe tracking systems have to be arbitrated without introducing unwanted optical path length differences or changes in the geometry of the binocular entrance pupil.

Beam Control aspects include pointing, co-pointing and field derotation, active optics and collimation control. In this presentation, the constraints for coherent imaging over a 1.5 arcminute field of view are discussed together with a concept for a distributed control scheme.

8445-115, Poster Session

The final design of the GRAVITY acquisition camera and associated VLTI beam monitoring strategy

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The GRAVITY acquisition camera measurements are part of the overall beam stabilization by measuring each second the tip-tilt and the telescope pupil lateral shits, while monitoring at longer intervals the full telescope pupil, the longitudinal pupil position and the VLTI beam higher order aberrations.

The infrared acquisition camera implements a mosaic of field, pupil, and Shack Hartman type images for each telescope. Star light is used to correct the tip-tilt while laser beacons placed at the telescope spiders are used to measure the pupil lateral positions. Dedicated optimized algorithms are applied to each image extracting the beam parameters

and storing them on the instrument database.

The final design is built into the gravity beam combiner, around a structural plane where the 4 telescope folding optics and field imaging lenses is attached and a fused silica prism assembly, kept around detector temperature, is placed near to the detector implementing the different image modes.

8445-116, Poster Session

Second generation fringe tracker real time architecture

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Fringe tracking is a CPU intensive real time application. Rates of up to 1 KHz are needed to be able to freeze the atmosphere; in addition, each available baseline must be tracked independently. To be able to overcome the CPU performance limits, VLTI 1st generation trackers, PRIMA FSU and FINITO, were implemented in a distributed architecture separating the sensor from the controller. A side effect of this was that the control loop delay increases as the system runs asynchronously causing an increase of the phase RMS value. This is in conflict with the objective of stabilizing the fringes with the smallest possible phase RMS.

VLTI 2nd generation trackers (GRAVITY and ESO 2GFT) currently being designed, will operate with up to 6 baselines and need to achieve phase RMS values smaller than 200 [nm]. These demands make the current architecture poorly suited for the purpose. This paper will describe a new real time architecture for fringe tracking in which both the sensor and the controller plus its state machine operate from a single multi-core CPU with the tasks performed synchronously. It will be shown how the intrinsic parallelism can be exploited to simplify the software development and how one identical task, instantiated for each baseline, will be targeted into each separate core. Finally, the effect of this new architecture in terms of phase RMS will be quantified using a simulation with real OPD data obtained with the 1st generation trackers.

8445-117, Poster Session

LINC-NIRVANA: optical components of the fringe and flexure tracker

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LINC-NIRVANA (LN) is a German/Italian interferometric beam combiner camera for the Large Binocular Telescope. Homothetic imaging will allow LN to make use of an exceptionally large field-of-view. As part of LN, the Fringe-and-Flexure-Tracker system (FFTS) will provide real-time, closed-loop measurement and correction of pistonic and flexure signals induced by the atmosphere and inside the telescope-instrument system. Such compensation is essential for achieving coherent light combination over substantial time intervals (about 10 min.). The FFTS is composed of a dedicated near-infrared detector, which can be positioned within the curved focal plane of LN. The system is divided into a cryogenic (detector head) and ambient (detector positioning unit) temperature environment, which are isolated from each other by a moving baffle. We present an overview of the final opto-mechanical design, the implementation, and characterization of the periscope and dispersive elements of the detector head. The periscope, located between filter wheel and detector, is used to accomodate part of the incoming light on a dedicated part of the detector for flexure (slow image motion) tracking. The dispersive elements, attached to the filter wheel will be used to correct for atmospheric differential refraction or to artificially introduce dispersion in order to better exploit the observational-conditions parameter space.

8445-118, Poster Session

Fringe and flexure tracking system laboratory tests

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LINC-NIRVANA is the German/Italian beam combiner camera for the Large Binocular Telescope (LBT). In close cooperation with the Adaptive Optics systems of LINC-NIRVANA the Fringe and Flexure Tracking System is a fundamental component to ensure a complete and time-stable wave front correction at the position of the science detector. This allows for long integration times at interferometric angular resolutions.

We present our latest lab tests and results from our qualifying test campaign.

The mechanical assembly contains a cryogenic (detector) and an ambient (linear stages) temperature environment, the interface is a moving baffle. We use components made of glass- fiber reinforced plastic for isolation. In particular we will show the warm and cryogenic tests of the mechanical components. This includes the cooling concept, the spring suspension of the baffle and as well the coordinated motion of the baffle and linear stages. The test results and system parameters, as precision, flexure, and stability are discussed too.

8445-119, Poster Session

Functional and performance tests of the fringe and flexure tracking system for LINC-NIRVANA

C. Rauch, A. Eckart, M. Horrobin, B. Lindhorst, S. Rost, S. Smajic, C. Straubmeier, E. Tremou, J. Zuther, I. Wank, Univ. zu Köln (Germany)

LINC-NIRVANA is the NIR homothetic imaging camera for the Large Binocular Telescope (LBT) located at Mount Graham in Arizona (USA). LINC-NIRVANA is composed of a LBT interferometric camera (LINC) and a Near-IR/Visible Adaptive interferometer for Astronomy (NIRVANA). An incident wavefront follows a turbulent path traveling through different atmospheric layers. In order to be able to observe interferometric data at high angular resolution for long integration times it is mandatory to ensure a complete time-stable wavefront at the position of the science detector. This is achieved by a combination of the Adaptive Optics system of LINC-NIRVANA and the Fringe and Flexure Tracking System (FFTS). The FFTS has to sample a large Field of View and to follow the reference source to an positioning accuracy of less than 2 micrometers. This precision as well as repeatability has to be assured for different inclinations. Therefore a complete knowledge of the flexure for different tip-tilt angles inside the instrument is important. We present the test setup and campaign to measure the accuracy of the detector positioning stages at different inclination angles.

8445-121, Poster Session

The LINC-NIRVANA fringe and flexure tracker control system

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We present the latest status of the control system of the LN (LINC-NIRVANA) FFTS (Fringe and Flexure Tracker System) for the LBT. The software concept integrates the sensor data and control of the various subsystems and provides the interaction with the whole LN instrument. Varying conditions and multiple configurations for observations imply a flexible interconnection of the control loops for the hardware manipulators with respect to the time-critical data analysis of the fringe detection. In this contribution details of the implementation of the algorithms on a real-time Linux PC are given. By considering the results from simulations of the system dynamics, lab experiments, atmospheric simulations, and telescope characterization the optimal parameter setup for an observation can be chosen and basic techniques for adaption to changing conditions can be derived.

8445-122, Poster Session

Control interface concepts for CHARA 6-Telescope fringe tracking with CHAMP+MIRC

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Cophasing six telescopes from the CHARA array, the CHARA-Michigan Phasetracker (CHAMP) and Michigan Infrared Combiner (MIRC) are pushing the frontiers of infrared long-baseline interferometric imaging in key scientific areas such as star- and planet-formation. Here we review our concepts and recent improvements on the CHAMP and MIRC control interfaces, which establish the communication to the real-time data recording & fringe tracking code, provide essential performance diagnostics, and assist the observer in the alignment and flux optimization procedure. For fringe detection & tracking with MIRC, we have developed a novel matrix approach, which displays the fringe information for our 15 baselines in an intuitive way and provides the user with predictions of the fringe positions based on cross-fringe information.

8445-137, Poster Session

Double polarization active Y-junctions in the mid-IR, based on Ti:diffused lithium niobate waveguides

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Double polarization active beam combiners have been developed for mid-infrared applications, in particular, in the field of high contrast interferometry in astronomy. As the objective of these beam combiners is to achieve high rejection ratios based on proper recombination of the fundamental modes guided by each arm (better than 40dB at the desired wavelength), we will focus our discussion on the fringe contrast obtained, using a monochromatic source and scanning the dark fringe, by internal modulation. In a second time, white light interferograms will be presented, in order to address the spectral dispersion (chromaticity of the combiners), and the efficiency of the modulator in the wideband regime. We will also show our prototypes for improving the effective electro-optic coefficient, based on the fabrication of photonic crystals inside the waveguides.

8445-123, Poster Session

Data analysis pipeline and data quality of the CHARA array CLIMB beam combiner

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The CHARA Array is a six telescope optical/IR interferometer run by the Center for High Angular Resolution Astronomy of Georgia State University and is located at Mount Wilson Observatory just to the north of Los Angeles California. The CHARA Array has the largest operational baselines in the world and has been in regular use for scientific observations since 2004. Our most sensitive beam combiner capable of measuring closure phases is the CLassic Interferometry with Multiple Baselines beam combiner know as CLIMB. In this paper we discuss the design and layout of CLIMB with a particular focus on the data analysis methodology. This analysis is presented in a very general form and will have applications in many other beam combiners. We also present examples of on sky data showing the precision and stability of both amplitude and closure phase measurements.

8445-125, Poster Session

Image reconstruction for observations at high dynamical range: the case of LINC-NIRVANA simulation of a stellar jet (THESIS)

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We report the results of a simulation and reconstruction of an observation of a young stellar object (YSO) jet with the LINC-NIRVANA (LN) interferometer to be mounted on the Large Binocular Telescope (LBT). This simulation has been performed in order to investigate the ability of observing the weak diffuse jet line emission against the strong IR stellar continuum through narrow band images in the H and K windows.

In general, this simulation provides clues on the image quality that could be achieved in observations with a high dynamical range. In these cases, standard deconvolution methods, such as Richardson-Lucy, do not provide satisfactory results: we therefore propose here a new method of image reconstruction. It consists in considering the image to be reconstructed as the sum of two terms: one corresponding to the star (whose position is assumed to be known) and the other to the jet. A regularization term is introduced for this second component and the reconstruction is obtained with an iterative method alternating between the two components.

An analysis of the results shows that the image quality obtainable with this method is significantly improved with respect to standard deconvolution methods, reducing the number of artifacts and allowing us to reconstruct the original jet intensity distribution with an error smaller than 10%.

8445-126, Poster Session

AIRY: a complete tool for the simulation and the reconstruction of Fizeau interferometric images (THESIS)

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AIRY (acronym for Astronomical Image Restoration in interferometrY) is a software tool designed to perform the image simulation and/

or deconvolution of Fizeau interferometers and of all kind of optical telescopes. AIRY is written in IDL and is a Software Package of the CAOS Problem Solving Environment (PSE): it is made of a set of modules, each one representing a specific task.

We present here the last version of the software, arrived at its sixth release after 10 years of development. This version of AIRY summarizes the work done in recent years by our group, both on AIRY and on AIRY-LN, the version of the software dedicated to the image restoration of LINC-NIRVANA (LN), the Fizeau interferometer of the Large Binocular Telescope (LBT). AIRY v.6.0 includes a renewed deconvolution module implementing regularizations, accelerations, and stopping criteria of standard algorithms, such as OSEM and Richardson-Lucy. A new denoising module, based on steerable pyramid techniques, is also present. Several modules of AIRY have been improved and, in particular, the one used for the extraction and extrapolation of the PSF. In addition, AIRY has modules dedicated to the simulations of interferometric images and utility modules for data reading, writing, and visualization.

After a brief description of the whole set of the modules, we provide examples and how-to's in order to give to the astronomical community a powerful tool for preparation of the observations and for real data deconvolution.

8445-128, Poster Session

Accompanying the optical interferometry: the JMMC tools and services

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This poster summarizes the main points about the Jean-Marie Mariotti Center which provides software and services for optical interferometry. Its mission and organisation are presented before listing the current software suite. Finally some facts and perspectives are mentioned.

8445-129, Poster Session

Calibration of coherently integrated visibilities

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Coherent integration is a analysis approach which can greatly increase the SNR of optical interferometric visibilities compared to those computed by the traditional squared visibility power spectrum technique. Coherent integration relies on phase-referencing, optimally through post-processing fringe-tracking, to effectively create long coherent integrations of the fringe. At the Navy Optical Interferometer (NOI) this phase-referencing is achieved by a combination of wavelength bootstrapping and baseline bootstrapping. The result is that the complex visibility with full phase information is retrieved, and that the poor noise associated with the power spectrum approach is greatly reduced. For small visibilities, which are most important in resolving objects, the SNR can be improved sometimes by orders of magnitudes, sometimes making the difference between easy and practically impossible observations. The fringe-tracking portion of coherent integration is limited by the SNR of the tracking signal, and the noise of that causes some fringe smearing which must be calibrated. In this paper we develop a theoretical model of the resulting fringe smearing and its correction. We then demonstrated its validity through simulation and on observations from the NOI.

8445-130, Poster Session

Description of the Navy optical interferometer data base

A. M. Jorgensen, T. R. Hall, New Mexico Institute of Mining and Technology (United States); J. T. Armstrong, U.S. Naval Research Lab. (United States); D. Hutter, Naval Observatory Flagstaff Station (United States); D. Mozurkewich, Seabrook Engineering (United States)

The Navy Optical Interferometer (NOI) has now been recording astronomical observations for the better part of two decades. During that time period hundreds of thousands of observations have been obtained, with a total data volume of multiple terabytes. Additionally, in the next few years the data rate from the NOI is expected to increase significantly. To make it easier for NOI users to search the NOI observations and to make it easier for them to obtain data, we have constructed a easily accessible and searchable database of observations. The database is based on a MySQL server and uses the standard SQL query language. We will describe the data base table layout and show examples of how to use the database.

8445-131, Poster Session

High-precision correction of low-resolution interferometric differential phase

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We propose here a description of the observation strategy and post-processes applied to the low-spectral Differential Phase (DP) in order to improve its accuracy, and to cope in particular with the chromatic Optical Path Delay (OPD) effects. This demonstration is based on observational data obtained with AMBER/VLTI instrument between 2009 and 2011.

Removing the detection artifacts (mainly drifts in the detector and optics) using, in our case, the AMBER Beam Commutation Device, is an important preliminary step. We then briefly present and discuss three possible approaches to get rid of the chromatic OPD: 1) A fit of

DP by standard chromatic dispersions laws parametrized by some global coefficient (representing the path lengths and the dry and wet air amplitudes), 2) a fit of the science DP by the calibrator DP, assuming that only the path lengths and pistons have changed, 3) a subtraction of the chromatic OPD using an estimate from measured path lengths and known ambient conditions parameters. We explain that the best strategy would be to combine 2) and 3). Our analysis shows that calibrated low-resolution differential phase can then reach an accuracy of a few milliradians (RMS) along the K band.

8445-132, Poster Session

Parasitic interference in classical and nulling stellar interferometry

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A variety of instrumental effects can corrupt the observable quantities in optical or nulling stellar interferometry. One such effect is parasitic interference, which can occur inside an interferometric instrument. Because of diffraction effects related to beam propagation along finite size optics, or parasitic reflections inside transmitting optics, a coherent crosstalk may occur between the beams and create a parasitic interference pattern superimposed on the genuine one. We developed an analytical approach to describe the impact of this effect on the observables of classical and nulling stellar interferometers. Considering classical interferometry, we show that differential phase and closure phase are both corrupted, depending on the crosstalk level and the residual piston between the beams. Considering typical specifications of piston correction of ground-based interferometers (~ 100 nm), the detection of hot Jupiter-like planets by differential phase implies a tolerance on the parasitic flux to about 5% of the incident intensity. Also, we show that the closure phase relation does not remove this parasitic contribution. The corresponding corrupted closure phase is not zero for an unresolved source and it depends on the residual piston. Considering nulling interferometry, we show that parasitic effects modify the transmission map level, depending on the crosstalk level and the phase shift between primary and secondary beams. In the extreme case of a pi-phase shift, the crosstalk effect implies a decrease of the final output signal-to-noise ratio. Numerical simulations, adapted to handle consistently crosstalk, are then performed to estimate this degradation on a concrete example, the FKSI mission concept.

8445-133, Poster Session

Precise stellar diameters from coherently averaged visibilities

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Optical interferometry is the only means of directly measuring the sizes of stars. The most precise angular diameter measurements, however, depend on measuring complex fringe visibilities V at spatial frequencies where Re(V) crosses zero. We can then use the spatial frequency B/lambda of the zero crossing as a measure of the stellar diameter via theta(UD) = 1.22 lambda/B, where lambda and B are the wavelength and baseline length at which Re(V) = 0 and theta(UD) is the equivalent uniform disk diameter. The variation in limb darkening with wavelength leads to a corresponding variation in theta(UD) with lambda, even at fixed B, which allows us to measure the limb darkening in detail and probe the structure of the atmosphere. However, in order to take data at those spatial frequencies, we need some form of bootstrapping, in wavelength, baseline length, or both. Reduction of these bootstrapped data benefits greatly from the increase in SNR offered by coherent averaging. We demonstrate the effect of limb darkening on theta(UD)(lambda) with simulated observations based on model atmospheres, and compare them to coherently averaged NOI data.

8445-134, Poster Session

Bandwidth smearing in optical interferometry: analytical modeling of the transition to the double fringe packet.

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A common assumption in optical interferometry is the exact overlapping of the fringe packet envelopes produced by the different parts of a source. The finite bandwidth ensures that it is not exactly the case, and the fringe contrast and position are impacted. This bandwidth smearing has been largely tackled in image space by radioastronomers and is nowadays mostly overcome with software recombination.

Relatively little has been done in optical interferometry, where imaging is not ripe enough for routine imaging, and soft recombination is technically impossible. So far, only the clearly separated double-packet case has been given attention.

In this paper, we show how the analytical modelling of the fringe packets quantifies the smearing of interferometric observables, visibility and phase, provided that the full interferogramme is obtained. As an example of smeared observations, we model data obtained on lambda Sco, a well separated binary, with the Precision Integrated-Optics Near-infrared Imaging ExpeRiment (PIONIER) at the Very Large Telescope Interferometer.

8445-135, Poster Session

Speckle imaging observations of 2005 YU55 with the NACO-VLT no-AO mode

S. Rengaswamy, C. Dumas, J. H. V. Girard, V. Ivanov, European Southern Observatory (Chile)

We present the K-band images of the asteroid 2005 YU55,reconstructed from the no-AO mode data of the NACO-VLT, recorded on November 8, 2011 during its closest approach to the Earth. We estimate the size of the asteroid and compare our reconstructed images with those of adaptive optics observations at Keck (albeit with a few hours difference) and those obtained from the shift and add method. We demonstrate the potential of no-AO mode (speckle imaging mode) of NACO-VLT in imaging faint near-Earth objects.

8445-136, Poster Session

A fiber fed interferometer for the optical and infrared

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We propose to construct a labtop demonstrator of a fiber fed interferometric system initially operating in the optical (568nm). The interferometer will consist of a two aperture Fizeau type architecture but with the lights paths brought together via optical fiber connections.

Phase corrections will be via physical manipulation of the fibers and via the analysis of lithium niobate crystals. This will be to show a robust method of phase re-alignment in the face of harsh, optically inhospitable space environments, even via a challenging physical path. Further investigations are to be made into pupil modification via manipulated fibers with the aim of high angular resolution imaging (sub lambda/d) with non-homothetic pupil alignment.

8445-52, Session 21

Tracking faint fringes with the CHARA-Michigan phasetracker (CHAMP)

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The CHARA-Michigan Phasetracker (CHAMP) has successfully tracked fringes in 4-telescope and 6-telescope modes when observing high-visibility targets. We have found that our primary targets (Young Stellar Objects) have unexpectedly low visibility fringes (<20%) for most baselines at CHARA, below our tracking thresholds. We have undertaken an upgrade cycle in 2011-2012 to re-optimize CHAMP to allow group-delay tracking the faintest fringes possible. We describe our multi-pronged strategy using special dicroics, new piezo scanners, and our first attempts to explore CHARA J-band made possible by using special metrology-blocking laser filters.

8445-53, Session 21

GRAVITY: report on the fringe tracker algorithms with a laboratory prototype

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GRAVITY is a second generation instrument for the VLTI and whose first light is scheduled for 2014. Its main and most demanding science case is the Galactic Center and the super-massive black hole Sgr A*, with high precision astrometry to detect flares motion and study gravity in strong field in the closest vicinity of the black hole, and high resolution imaging to study the environment of the Galactic Center at a larger scale. GRAVITY will combine four telescopes of the VLTI in the K band. It will achieve astrometric precision of 10µas and angular resolution of 4mas for object with magnitude down to K=16 in the science beam whose fringes are stabilized by tracking on a reference source. The fringe tracker is one of the key subsystems. It will stabilize fringes to 350nm rms on a reference star as faint as magnitude 10 despite atmospheric turbulence, longitudinal vibrations, and flux dropouts due to tip-tilt jitter.

A prototype of the fringe tracker has been developed to test the performance and robustness of the algorithms. Realistic disturbances have been added to test the state machine of the system. We present here the results of this prototype and the current status of the fringe tracker of GRAVITY.

8445-54, Session 21

Fringe tracking performance monitoring and prediction: FINITO at VLTI

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Since April 2011, realtime fringe tracking data are recorded simultaneously with data from the VLTI/AMBER interferometric beam combiner. Not only this offers possibilities to post-process AMBER reduced data to obtain more accurate interferometric quantities, it also allows to estimate the performance of the fringe tracking.

First we propose to define fringe tracking performance metrics in the AMBER context, in particular as a function of AMBER's integration time. The main idea is to determine the optimal exposure time for AMBER: short exposures are dominated by readout noise and fringes in long exposures are completely smeared out.

Then we present this performance metrics correlated with Paranal local ASM (Ambient Site Monitor) measurements, such as seeing, coherence time or wind speed for example. Finally, we also present some preliminary results of attempts to model and predict fringe tracking performances, using Artificial Neural Networks.

8445-55, Session 21

The Nova Fringe Tracker: a second-generation cophasing facility for up to six telescopes at the VLTI

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The Nova Fringe Tracker (NFT) is a proposed solution to the call by ESO for a second-generation fringe tracking facility. This instrument at the VLTI will enable the cophasing of up to 6 telescopes simultaneously. Using broad band optics with detection from 1.2 to 2.4 microns, a unique configuration is employed that eliminates so-called "photometric crosstalk." This refers to imbalance in the beam combiner which results in fluctuations of the incoming wavefronts and the proportion of power accepted by a spatial filter masquerading as a visibility, a common problem afflicting previous interferometric instruments and fringe trackers. Also proposed for use in "science instruments" (for the measurement of visibility), the "Polarization-Based Collimated Beam Combiner," with its achievement of photometric symmetry in hardware, is particularly suited for combined use of the smaller AT (1.8 meter) telescopes with the UT (8 meter) telescopes involving a 20:1 intensity ratio of the interfering beams, and also for fringe tracking using highly resolved sources having a very small visibility. Recent enhancements to the proposed fringe tracker include selectable modes which detect only a single quadrature phase, both quadrature phases, or an uneven combination of the two. Optimization of partial spatial filtering using pinholes has been performed using a wavefront simulator and simulated tracking loop. Aiming for an instrument achieving the best limiting sensitivity, analysis and simulations predict that reliable cophasing will be obtained using the 1.8 meter AT telescopes tracking on an unresolved reference star with a K magnitude of 10.

8445-56, Session 21

Chromatic phase diversity for cophasing future large array of telescopes

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This presentation will review the laboratory results we have obtained on the demontration of a cophasing algorithm based on the chromatic phase diversity method. This testbed is dedicated to the demonstration of the direct imaging capabilities of future arrays of telescope. We have developed and modelized a piston sensor based on the chromatic dependance of the spectral density phase. This method allows a global cophasing of the array over a capture range of many wavelengths aiming at improving the robustness of the method.

8445-57, Session 21

The MROI fringe tracker: closing the loop on ICoNN

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Characterization of ICoNN, the Magdalena Ridge Observatory Interferometer's fringe tracker, through the closed-loop fringe experiment is presented detailing its design, layout, controls and software. The performance limits of an interferometer are set by its ability to keep the optical path difference between combination partners minimized. This is the job of the fringe tracker. Understanding the behavior and limits of the fringe tracker in a controlled environment is key to maximize the science output. Laboratory simulations of on-sky fringe tracking are under way. This includes synthesising a white light source and atmospheric piston with estimation of the tracking error being fed back to mock delay lines in real time. In conjunction with this, numerical simulations of an interferometric beam train are being performed to aide in algorithm development and testing. We report here on the progress of the closed-loop fringe tracking experiments and algorithm developments.

8445-58, Session 22

GRAVITY: metrology

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GRAVITY is a 2nd generation VLTI instrument, combining the light of four telescopes and two objects simultaneously. The main goal is to obtain astrometrically accurate information. Besides correctly measured stellar phases this requires the knowledge of the instrumental differential phase, which has to be measured optically during the astronomical observations. This is the purpose of a dedicated metrology system. The GRAVITY metrology covers the full optical path, from the beam combiners up to the reference points in the beam of the primary telescope mirror, minimizing the systematic uncertainties and providing a proper baseline in astrometric terms. Two laser beams with a fixed phase relation travel backward the whole optical chain, creating a fringe pattern in any plane close to a pupil. By temporal encoding the phase information can be extracted at any point by means of flux measurements with photo diodes. The reference points chosen sample the pupil at typical radii, eliminating potential systematics due to aberrations in the optics. We present the final design and the performance estimate, which is in accordance with the overall requirements for GRAVITY.

8445-59, Session 22

An experimental testbed for NEAT to demonstrate micro-pixel accuracy

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NEAT is an astrometric mission proposed to ESA with the objectives of detecting Earth-like exoplanets in the Habitable zone of nearby solar-type stars. In NEAT, one fundamental aspect is the capability to measure stellar centroids at the precision of 1e-6 micro-pixel.

Current state of the art methods for centroid estimation have reached a precision of about 4e-5 pixel at Nyquist sampling, this was demonstrated at the JPL. Yet simulations showed that a precision of 2 micro pixels can be reached, if intra and inter pixel quantum efficiency variations are calibrated and corrected for and if the following conditions are respected: a single optic is used (to avoid beam walk errors), the peak to valley variation of pixel individual quantum efficiencies is less then 10% and the quantum efficiency map of every pixel is modeled by a 2D Fourier transform with coefficients up to the 3rd order.

The European part of the NEAT consortium is designing and building a testbed in vacuum in order to reach 5e-6 pixel precision for the centroid estimation. The goal is to provide a proof of concept for the precision requirement of the NEAT spacecraft. We give the basic relations and tradeoffs that come into play for the design of a centroid testbed, using the Fourier method mentioned above. We detail the different conditions necessary to reach the targeted precision, present the characteristics of our current design and describe the present status of the demonstration.

8445-60, Session 22

The role of adaptive optics correction for optical/infrared interferometer arrays with moderate sized (D<3m) unit telescopes

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Enhancing the faint-source sensitivity of optical/infrared interferometry is one of the "holy grails" of research at existing ground based facility arrays. While the use of adaptive optics is in principle attractive, a number of pragmatic issues suggest that its true benefits may be less clear. In particular, for natural guide star-based systems, the question as to how to best balance the competing needs of a photon-hungry wavefront sensor, tip-tilt sensor, fringe tracker and science instrument means that the effectiveness of any particular implementation requires a system-wide analysis.

In this paper we explore these trades for interferometer arrays using unit telescopes of moderate size (i.e. with D<3m) for a variety of different astronomical targets whose colors can strongly moderate the flux available in different bandpasses. Our study focuses on how to realise the best sensitivity for faint targets for observations in the visible and near-infrared wavelength regions, and exploits the performance statistics of the large number of mature AO systems at existing 4-8m class telescopes so as to best capture the pragmatic limitations that have been experienced over the past 5 years.

8445-61, Session 23

To be or not to be asymmetric? VLTI and the mass loss geometry of red giants (THESIS)

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The mass-loss process of red giants and in particular its geometry is a major but still unsolved question.

Seeing that a large portion of planetary nebulae are asymmetric, it is crucial to understand how the morphology changes during the evolution from Asymptotic Giant Branch (AGB) to the post-AGB phase.

Thanks to the high angular resolution, interferometry is the only tool able to observe deep inside the atmosphere of AGB stars, where the onset of dust formation and mass-loss are located.

In this contribution I will give an overview on the status of our ongoing ESO

Large Program which aims to study asymmetries in the mass-loss process of AGB stars by combining Herschel/PACS, MIDI, and VISIR observations.

I will present the first detection of an asymmetry in the envelope of a Carbon-rich Mira star through the MIDI differential phase.

Chromatic geometrical models of the visibility and the differential phase suggest the presence of a companion. We find this secondary object to be located in the C2H2-HCN layer of the AGB star. These molecules are the building blocks of dust and therefore we cannot exclude that the companion is enshrouded by a dusty disk. Also, the nature of the companion is still unclear.

Imaging with the second generation VLTI instrument MATISSE will give an even better insight into this mystery.

8445-62, Session 24

The LINC NIRVANA fringe and flexure tracking system: final assembly and predicted on sky performance

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The LINC NIRVANA Fringe and Flexure Tracking System (FFTS) has completed assembly in the lab in Cologne, and will soon be ready for shipment and integration into the full LINC NIRVANA system at MPIA Heidelberg.

The first part of this paper provides an overview of the final assembly and testing phase in Cologne, concentrating on those aspects which directly affect instrument performance, including the detector performance and stability of the detector positioning system.

The second part discusses the predicted on sky performance of the FFTS system, the expected limiting magnitudes and accuracy of fringe tracking achieved in simulated observations.

8445-63, Session 24

Tracking near-infrared fringes on BETTII: a balloon-borne 8m-baseline interferometer

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We present the design of a fringe-tracking system for the Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII). BETTII is a balloon-borne, far-infrared, 8m-baseline interferometer with two 50cm siderostats. Beams from the two arms are combined in the pupil plane (Michelson) to enable double-Fourier, spatio-spectral interferometry. To provide quality data, we need an active control of the optical path difference (OPD) between the two arms. The fringe-tracking system will work in the near-infrared and will use a reference star within the field of view to achieve two goals: overlap the beams coming from the two siderostats, and track the location of the central fringe packet, which is a measure of the OPD. The fringe-tracker will share most of the optical train with the science instrument. This system is part of the overall control architecture that feeds fast steering tip/tilt mirrors and a warm delay line to ensure proper beam combination and OPD control for the science instrument. We investigate the different sources of perturbations that are expected at float altitude, and derive the sensitivity of the fringe-tracking system. We show progress on validating our design using a visible light, broadband Mach-Zehnder interferometer that was developed at NASA/GSFC. This system demonstrates the viability of our OPD determination approach and provides a means of testing and characterizing several OPD determination and control algorithms.

8445-64, Session 24

GRAVITY: beam stabilization and light injection subsystems (THESIS)

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We present design results of the 2nd generation VLTI instrument GRAVITY beam stabilization and light injection subsystems. Designed to deliver micro-arcsecond astrometry, GRAVITY requires a unprecedented stability of the VLTI optical train. To meet the astrometric requirements, we have developed a dedicated 'laser guiding system', correcting the longitudinal and lateral pupil position as well as the image jitter. The actuators for the correction are provided by four 'fiber coupler' units located in the GRAVITY cryostat. Each fiber coupler picks the light of one telescope and stabilizes the beam. Furthermore each unit provides field de-rotation, polarization analysis as well as atmospheric piston correction. Using a novel roof prism design offers the possibility of on-axis as well as off-axis fringe tracking without changing the optical path. Finally the stabilized beam is injected with minimized losses into single-mode fibers via parabolic mirrors.

We present lab results of the first guiding- as well as the first fiber coupler prototype regarding the closed loop performance and the optical quality. Based on the lab results we discuss the on-sky performance of the system and the implications concerning the sensitivity of GRAVITY.

8445-120, Session 24

The MROI fast tip-tilt correction and target acquisition system

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The fast tip-tilt correction system for the Magdalena Ridge Observatory Interferometer (MROI) is being designed and fabricated by the University of Cambridge. The design of the system is currently at an advanced stage and the performance of its critical subsystems has been verified in the laboratory.

The system has been designed to meet a demanding set of requirements including: operation in ambient temperatures down to -5 degrees Celsius while maintaining the stability of the tip-tilt reference direction over a 5 degree temperature change; a limiting visual magnitude of 16; a target acquisition mode with a 60 arcsecond field-of-view; and application of time-variable offsets to the reference direction to accommodate angular dispersion and the possible use of an off-axis guide star.

We describe the important technical features of the system, which uses an Andor electron-multiplying CCD camera protected by a thermal enclosure, a transmissive optical system with mounts incorporating passive thermal compensation, and custom control software running

under Xenomai real-time Linux. We also report results from laboratory tests that demonstrate (a) the high stability of the custom optic mounts and (b) the low readout and compute latencies that will allow us to achieve a 50 Hz closed-loop bandwidth on bright targets.

8445-66, Session 25

Calibration and imaging algorithms for full-Stokes optical interferometry

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Optical interferometers will eventually possess full-Stokes polarization measuring capabilities. When new instruments observe exotic or more distant objects, polarization effects will even affect measurements of scalar (~ Stokes-I) visibilities. Calibration and imaging algorithms, as well as simulations, are critical for the success of optical interferometric polarimetry (OIP). We discuss end-to-end instrument requirements, e.g., fringe tracking, photometry, and instrumental polarization repeatability versus pointing. We present two possible calibration algorithms, namely an instrumental polarization model maintained by regular observations of standards, and nearly concurrent observations of science targets and standards. We describe possible imaging and modeling algorithms. CASA, the official data-reduction package for the EVLA and ALMA, already has wideband calibration and imaging capabilities that can be adapted to optical interferometry. We demonstrate some of these capabilities on simulated Be star data using CASA multi-frequency synthesis imaging.

8445-67, Session 25

A degeneracy in interferometric astrometry

D. F. Buscher, Univ. of Cambridge (United Kingdom)

Interferometric astrometry serves as a high-precision tool for measuring the positions of stars, and also for determining the baselines of the interferometer. In most ground-based experiments the interferometric baselines and the celestial target positions are estimated simultaneously from the same data. This can lead to degeneracies where errors in the star coordinates are masked by corresponding errors in the baselines. A familiar degeneracy is where an offset in right ascension of all the stars is indistinguishable from a rotation of all the baselines. A much less well-known degeneracy exists in the star declinations and is present in any observation where the declination range of the stars used does not span the entire range from pole to pole. I discuss this degeneracy and its effects on a range of interferometric experiments.

8445-68, Session 25

High-precision closure phase for optical interferometry

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Interferometric Closure Phase (CP) yields information on the asymmetries of the source brightness distribution. While accurate closure phases are the key for detecting, modelling and imaging low contrast features, their experimental accuracy is usually far from what it could be: in the case of the AMBER/VLTI instrument, the guaranteed accuracy calibration is between 3 and 5 degrees, while the theoretical limit is better than 0.01 deg for bright sources.

Closure phase should first be corrected for detection artifacts (mainly drifts in the detector and optics), using in our case the AMBER Beam Commutation Device. We show that closure phase is nevertheless contaminated by the pistons drifts of each baseline. This effect is attributed to a cross-talk between the fringes peaks, which cannot be completely avoided in a multi-axial beam combiner with a limited readout window.

We show that the variable bias on CP is a linear function of the external pistons. This relationship can be determined from the calibration source data and applied for correcting the science data. The global process both un-biases and stabilizes the average CP, yielding, with our measurements, an accuracy of 0.3 deg for 1 minute exposures with ATs, which is close to the fundamental limit for our K=4 source. It also allows to correct the chromatic OPD effect by comparison with a well chosen calibrator, displaying a CP vs. wavelength curve with a RMS error of 0.1 deg per spectral channel, about a factor 4 better than with a straight calibration.

8445-70, Session 26

The GRAVITY spectrometers: system design

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Operating on 6 interferometric baselines, i.e. using all 4 UTs, the 2nd generation VLTI instrument GRAVITY will deliver narrow angle astrometry with 10µas accuracy at the infrared K-band, and will be able to detect the positional shift of the photocenter of a flare at the Galactic Center within its orbital timescale of ~20min, using the flares as dynamical probes of the gravitational field around SgrA*.

Within the international GRAVITY consortium, the Cologne institute is responsible for the development and construction of the two spectrometers: one for the science object, and one for the fringe tracking object. Both spectrometers are operated at 80K within a 200K surrounding in the GRAVITY cryostat. In this contribution we present the current spectrometer system design:

The two GRAVITY integrated-optics beam combiners feed each spectrometer with 24 input channels. The science spectrometer fulfills a wide range of scientific requirements with three user selectable spectral resolutions (R=22, R=500, R=4500), while the fringe tracking spectrometer is optimized for high optical throughput and provides a single low spectral resolution of R=22. Both spectrometers feature an optional Wollaston prism for polarimetric studies. In addition to the grism wheel and a mechanism providing the Wollaston deployment, the electro-mechanical design includes focus stages for the science (HAWAII2RG) and fringe tracking (SELEX eAPD) detectors. The two spectrometers also feed the beams of the metrology laser system of GRAVITY backwards into the integrated optics beam-combiner, and special high-OD blocking filters shield the detectors from the metrology light.

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8446-01, Session 1

Advances in instrumentation at the W. M. Keck Observatory

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In this paper we describe both recently completed instrumentation projects and our current development efforts in terms of their role in the strategic plan, the key science areas they address, and their performance as measured or predicted. Projects reaching completion in 2012 include MOSFIRE, a near IR multi-object spectrograph and the Observatory's second laser guide star adaptive optics facility on the Keck I telescope. Projects in development include a new seeing limited integral field spectrograph for the visible wavelength range called the Keck Cosmic Web Imager (KCWI), an upgrade to the telescope control systems on both Keck telescopes, an upgrade to the guide camera for the HIRES instrument on Keck I, and a near-IR tip/tilt sensor for the Keck I adaptive optics system.

8446-02, Session 1

Overview of the ESO instrumentation programme

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The ESO instrumentation programme now encompasses both an on-going programme for La-Silla Paranal observatory and a new programme for construction of the instruments for the E-ELT. The scale and ambition of the combined programme will present a future challenge for the European instrument-building community and for ESO as managing organisation. The current status and plans will be summarised.

8446-03, Session 1

Instrumentation at Subaru Telescope

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Subaru telescope has eight facility instruments including laser guide star adaptive optics and three visiting instruments currently operating. One such instrument, HiCIAO, a coronagraphic imager combined with adaptive optics (AO188), is being used for exoplanet search and planetary disk studies which is a Subaru strategic program. The laser guide star mode of AO188 has been available for open-use observation since 2011. FMOS, which is a near-IR multi-object spectrograph with configurable 400 fibers, was commissioned and will be used for a Subaru strategic program for cosmological survey. Suprime-Cam and FOCAS were damaged by an accident of a coolant leak at the prime focus which occurred in July 2011, but the repair work is ongoing and they will be operational in the summer of 2012. Commissioning work for Hyper Suprime-Cam (HSC), the successor of Suprime-Cam with a 1.5 deg FoV, is scheduled for 2012. As a future facility instrument, Prime-Focus Spectrograph (PFS) was approved by Japanese community. The PFS is a fiber multi-object spectrograph with 2400 fibers covering a 1.3 deg FoV and wavelengths ranging from 0.38 - 1.3 um. The first light of PFS will be around 2017-18. These two instruments will strengthen Subaru's wide field capability. Subaru will also provide opportunities for small-scale instruments designed for specific scientific purposes or act as a test-bed for future instruments. Six new such carry-in instruments are planned to be installed in 2013-15. Upgrade of MOIRCS (detector and MOS unit upgrade), IRCS (higher spectral resolution using immersion grating) and HDS (add fiber-fed multi-object capability) are also ongoing.

8446-04, Session 1

Gemini's instrumentation program: latest results and long-range plan

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Gemini Observatory is going through an extraordinary time with astronomical instrumentation. New powerful capabilities have been delivered and are entering scientific operations. In parallel, new instruments are being planned and designed to align the Observatory's strategy with the community needs and enhance the competitiveness of the Observatory for the next decade. We will give a broad overview of the instrumentation program, focusing on achievements, challenges and strategies with a scientific, technical and management perspective. In particular we will discuss the following instruments and projects: GMOS-CCD refurbishment, Flamingos-2, GeMS (MCAO system and imager GSAOI), GPI, new generation of A&G, GRACES (fiber feed to CFHT ESPaDOnS) and GHOS (Gemini High-resolution Optical Spectrograph), and provide some updates about detector controllers, mid-IR instruments, Altair, GNIRS, GLAO and future work-horse instruments.

8446-05, Session 1

An overview of instrumentation for the Large Binocular Telescope

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An overview of instrumentation for the Large Binocular Telescope (LBT) is presented. The LBT incorporates two 8.4 m primary mirrors with fully adaptive secondary mirrors on a common mount to achieve the effective collecting area of an 11.8 m telescope and the angular resolution of a 23 m telescope. Five fixed and two auxiliary focal station pairs are available for instruments. Optical instrumentation includes the Large Binocular Camera (LBC), a pair blue-red optimized wide-field (27' x 27') mosaic CCD imagers at the prime foci, and the Multi-Object Double Spectrograph (MODS), a pair of double-beam, blue-red optimized, long-slit spectrographs mounted at the straight-through F/15 Gregorian foci incorporating multiple slit masks for multi-object spectroscopy over a 6' field and spectral resolutions of 300-2000. Infrared instrumentation includes a modular near-infrared (0.85-2.5 microns) imager and spectrograph pair (LUCI) mounted at the bent-front Gregorian F/15 foci and designed for seeing-limited imaging, long-slit spectroscopy, and multi-slit spectroscopy utilizing cooled masks over a 4' field and diffraction-limited imaging and long-slit spectroscopy over a 0.5' field. Strategic instruments under development for the remaining two combined bent focal stations and which can utilize the full 23 m baseline of the LBT include a cryogenic beam combiner with mid- and thermal-infrared cameras for Fizeau imaging and nulling interferometry (LBTI) and an optical bench near-infrared beam combiner utilizing multi-conjugate adaptive optics for super high-angular resolution imaging (LINC-NIRVANA). In addition, a fiber-fed bench spectrograph (PEPSI) capable of ultra high resolution optical spectroscopy and spectropolarimetry (R = 40,000-300,000) will be available as a principal investigator instrument. The LBC has been in regular use since 2008 and was recently accepted

as a facility instrument. The seeing-limited modes of LUCI1 have been available for routine use since 2010. Delivery of LUCI2 is expected in mid-2012. Recently, MODS1 was commissioned and is now available for routine use by LBT partners. Commissioning of LBTI with a 3-5 micron camera (LMIRcam) and the facility adaptive optics system is currently underway.

8446-06, Session 1

Instrumentation at the Magellan Telescopes 2012

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Upgrades to existing instruments as well as the commissioning of several new instruments over the last couple of years have provided the Magellan Telescopes with a superb instrumentation suite at the start of our second decade of scientific operations at the Carnegie Institution's Las Campanas Observatory. The Baade Telescope operates with an f/11 Gregorian secondary feeding any one of three active instruments: IMACS - upgraded with a new CCD Mosaic for the f/4 camera; FIRE, a new near-infrared echellette spectrograph (PI. Rob Simcoe); and FourStar, a new wide field near-infrared imager (PI. Eric Persson). The Clay Telescope also operates normally with an f/11 Gregorian secondary feeding any one of three active instruments: MIKE; MagE; and LDSS3. In addition, the Clay Telescope now operates alternatively with a Cassegrain secondary feeding either of two new f/5 instruments: MegaCam, a wide field optical imager (PI. Brian McLeod) and MMIRS, a near-infrared multi-object spectrograph (PI. Brian McLeod). Here we briefly describe the operations and performance of the full suite of facility instruments available at Magellan with a particular emphasis on enhanced wide field imaging and a renaissance in near-infrared observational capabilities.

8446-07, Session 1

The La Silla - Paranal instrumentation program

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Beyond 2020 La Silla - Paranal Observatory (LPO) will still play, together with ALMA and the E-ELT, a crucial role in European ground based astronomy. ESO is preparing the strategy for a competitive LPO Instrumentation program, with the aim of keeping its instrumentation at the forefront beyond year 2020, in the ELT era.

The LPO instrumentation program is fully dedicated to this task, and foresees,in addition to the completion of running projects (IInd generation VLT/I instruments, Adaptive Secondary for UT4) to start one new project every year in the 2013 - 2020 period.

A roadmap for the instrument selection strategy is also proposed.

8446-08, Session 2

The SALT HRS spectrograph: instrument integration and laboratory test results

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SALT HRS is a fibre-fed, high dispersion échelle spectrograph being constructed for the Southern African Large Telescope. It has four pairs of object and sky fibres, giving a choice of spectral resolutions from R≈16,000 to R≈67,000; the higher resolutions being attained through the use of image slicers. Wavelength coverage is from 370-890 nm, split across red and blue dedicated channels. The instrument includes two specialist modes: a high resolution, high stability mode (with the ability to superimpose iodine reference spectra for improving long-term spectral stability) and a low resolution mode (capable of nod and shuffle operation for superior sky subtraction). In this paper we highlight notable component tests, describe the integration sequence and present some first light results in the laboratory. The instrument construction is well advanced and we report on the attainment of the required mechanical and thermal stability and provide a measurement of the focal ratio degradation of the fibre feed when laid out as if on the telescope. The initial optical alignment of both the fibre input optics including image slicers and the spectrograph optics has taken place and is described. The imaging sub-systems have been fully characterised and we report on their performance, particularly the red detector's susceptibility to cosmic rays and performance of the on-chip anti-fringing reduction. The first light observations of the imaging sub-system include a measurement of the image quality obtained by placing a continuum light source at the intermediate focus and capturing images via a LabView-based instrument control system.

8446-09, Session 2

Performance of the CHIRON high-resolution echelle spectrograph

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CHIRON is a high-resolution (R=80000) fiber-fed echelle spectrograph built primarily for measuring precise radial velocities (RV). We present the instrument performance as determined during integration and commissioning. We discuss the PSF, the effect of glass inhomogeneity on the cross-dispersion prism, temperature stabilization, stability of the spectrum on the CCD, and detector characteristics. The RV precision with an iodine cell or a ThAr lamp as wavelength reference is characterized. The overall efficiency (about 5%) suffered from guiding errors, but was improved during an instrument upgrade.

8446-10, Session 2

New fully-depleted, high resistivity CCDs for the low resolution imaging spectrograph at W. M. Keck Observatory: commissioning and science operations.

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We report on the successful replacement and subsequent science operation of the fully depleted, high resistivity CCD detectors in the red channel of the Low Resolution Imaging Spectrograph for the W. M. Keck Observatory. The two replacement 2k x 4k CCDs are 300 microns thick, and were developed by Lawrence Berkeley National Laboratories. The new CCDs were commissioned in December, 2010. We describe the laboratory and on-sky testing of the recommissioned instrument, performance monitoring, and highlight the science performance.

8446-11, Session 2

SITELLE--an imaging Fourier transform spectrometer for the Canada-France-Hawaii Telescope: expected science and data simulations

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SITELLE, an imaging Fourier transform spectrometer (FTS) to be installed at Canada-France-Hawaii telescope in April 2013, will be capable of obtaining the visible (350 nm - 950 nm) spectrum of every source of light in a field of view of 12 arcminutes, with 100% spatial coverage and a spectral resolution ranging from R = 1 (deep panchromatic image) to R = 10 000 (for gas dynamics). Equipped with two 2k x 2k e2v CCDs, it will be used to study the structure and kinematics of HII regions and ejecta around evolved stars in the Milky Way, emission-line stars in clusters, chemical abundances in the gas and stellar populations of nearby gas-rich galaxies as well as the star formation rate through the ages in the Universe. We present here an updated science case for this instrument and its expected characteristics and performances based on the current design. The concept, data acquisition and data reduction of an imaging FTS being so different from that of traditional, dispersive integral field spectrographs, will also introduce a data simulator designed to help future users to plan their observations.

8446-12, Session 2

VISIR upgrade: overview and status

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In this contribution we present an overview of the VISIR upgrade project. The plan is to have the upgraded instrument available for general use in Sep 2012. VISIR is the mid-infrared imager and spectrograph at ESO's VLT. The project team is comprised of ESO staff and members of the original VISIR consortium: CEA Saclay and ASTRON. The project plan is based on input from the ESO user community with the goal of enhancing the scientific performance and efficiency of VISIR by a combination of measures: installation of improved hardware, optimization of instrument operations and software support. The cornerstone of the upgrade is the 1k by 1k Si:As Aquarius detector array (Raytheon) (4x) which has demonstrated very good performance (sensitivity, stability) in the TIMMI2 IR test facility. A prism spectroscopic mode will cover the N-band in a single observation. New scientific capabilities for high resolution and high-contrast imaging will be offered by sub-aperture mask (SAM) and phase-mask coronagraphic (4QPM/AGPM) modes. In order to make optimal use of favourable atmospheric conditions a water vapour monitor has been deployed on Paranal. Improved pipelines will provide better support to astronomers. VISIR will be a powerful instrument providing background limited performance for diffraction-limited observations at an 8-m telescope. It will offer synergy with facilities such as ALMA, JWST, VLTI and SOFIA, while a wealth of targets is available from survey work (e.g. VISTA, WISE). The upgraded VISIR will bring confirmation of the technical readiness and scientific value of potential mid-IR instrumentation at Extremely Large Telescopes.

8446-13, Session 2

ARCONS: a 1024 pixel superconducting integral field spectrograph

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We present a superconductor-based Integral Field Spectrograph called ARCONS, the Array Camera for Optical to Near-infrared Spectrophotometry. ARCONS was recently commissioned at the Coudè focus of the 200-inch Hale Telescope at the Palomar Observatory. At the heart of this unique instrument is a 1024-pixel Microwave Kinetic Inductance Detector (MKID). MKIDs count individual photons with microsecond timing accuracy, and like X-ray calorimeters, can determine the energy of each photon to several percent without read noise, dark current, and with nearly perfect immunity to cosmic rays. They are sensitive over a wide wavelength range, with good quantum efficiency from the UV through near-IR. This ground-breaking instrument represents the first optical/NIR MKID camera and the largest optical/NIR superconducting focal plane of any type by almost an order of magnitude.

The instrument is lens-coupled with a pixel scale of 0.23"/pixel, with each pixel recording the arrival time (<1 μsec) and energy of a photon (~10%) in the optical to near-IR (0.4-1.1 microns) range. The frequency domain multiplexed readout scheme is well suited to eventually producing the large megapixel arrays required by modern astronomy.

While almost all astronomical applications will benefit from the read-noise free, low resolution spectroscopy offered by each pixel, we will highlight the specific science goals of ARCONS. These include redshift determination, the rapid classification of transient phenomena, and the study of compact objects. We will present a summary of the capabilities of ARCONS, recent results from the commissioning observations, and a look towards the future prospects for cameras utilizing MKID technology.

8446-14, Session 2

On-sky performance of the multi-object double spectrograph for the Large Binocular Telescope

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The Multi-Object Double Spectrographs (MODS) are two identical high-throughput optical low- to medium-resolution CCD spectrometers being deployed at the Large Binocular Telescope (LBT). Operating in the 340-1000nm range, they use a large dichroic to split light into separately-optimized red and blue channels that feature reflective collimators and decentered Maksutov-Schmidt cameras with monolithic 8×3K CCD detectors. A parallel infrared laser closed-loop image motion compensation system nulls spectrograph flexure giving it high calibration stability. The two MODS instruments may be operated together with digital data combination as a single instrument giving the LBT an effective aperture of 11.8-meter, or separately configured to flexibly use the twin 8.4-meter apertures. MODS1 saw first-light on the LBT in September 2010, finished commissioning in May 2011, and began regular night-time science operations in September 2011. MODS2 is the final stages of assembly and lab testing, and will be delivered to LBT and installed on the telescope in late 2012. This paper describes the on-sky performance of the MODS1 spectrograph and presents highlights of the first science results obtained by LBT partner astronomers.

8446-15, Session 2

Performance of the Apache Point Observatory Galactic Evolution Experiment (APOGEE) high-resolution near-infrared multi-object fiber spectrograph

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The Apache Point Observatory Galactic Evolution Experiment (APOGEE) uses a dedicated 300-fiber, narrow-band near-infrared (1.5-1.7 micron), high resolution (R~22,500) spectrograph to survey approximately 100,000 giant stars across the Milky Way.

This survey, in operation since late-summer 2011 as part of the Sloan Digital Sky Survey III (SDSS III), will revolutionize our understanding of kinematical and chemical enrichment histories of all Galactic stellar populations. We present the performance of the instrument from its first year in operation. The instrument is housed in a separate building adjacent to the 2.5 m SDSS telescope and fed light via approximately 45-meter fiber runs from the telescope. The instrument design includes numerous innovations including a gang connector that allows simultaneous connection of all fibers with a single plug to a telescope cartridge that positions the fibers on the sky, numerous places in the fiber train in which focal ratio degradation had to be minimized, a large mosaic-VPH (290 mm x 475 mm elliptically-shaped recorded area), an f/1.4 six-element refractive camera featuring silicon and fused silica elements with diameters as large as 393 mm, three near-infrared detectors mounted in a 1 x 3 mosaic with sub-pixel translation capability, and all of these components housed within a custom, LN2-cooled, stainless steel vacuum cryostat with dimensions 1.4 m x 2.3 m x 1.3 m.

8446-16, Session 2

FLAMINGOS-2: on-sky acceptance and commissioning results

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We report on the performance results of the FLAMINGOS-2 near-infrared camera and multi-object spectrograph on the Gemini South 8-meter telescope during its acceptance tests and commissioning observations. FLAMINGOS-2 was delivered to Gemini Observatory and underwent acceptance testing in late 2009. The instrument was accepted in early 2010 and began commissioning observations, which were completed in late 2011 and early 2012 after the replacement of the science detector array. We review the image quality, throughput, and noise performance of the instrument as well as its achieved on-sky signal-to-noise.

8446-17, Session 2

MOSFIRE: the multi-object spectrometer for infrared exploration at the Keck Observatory

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This paper describes MOSFIRE, a new multi-object spectrometer and imager for the Cassegrain focus of the 10-m Keck 1 telescope. MOSFIRE provides near infrared (0.97 to 2.45 microns) multi-object spectroscopy over a 6.14' x 6.14' field of view with a resolving power of R~3,500 for a 0.7" (0.508 mm) slit width (2.9 pixels in the dispersion direction), or imaging over a field of view of 6.9' diameter with 0.18" per pixel sampling. A single diffraction grating can be set at two fixed angles, and order-sorting filters provide spectra that cover the K, H, J or Y bands by selecting 3rd, 4th, 5th or 6th order respectively. A folding flat following the field lens is equipped with piezo transducers to provide tip/tilt control for flexure compensation at the <0.1 pixel level. Instead of fabricated focal plane masks requiring frequent cryo-cycling of the instrument, MOSFIRE is equipped with a cryogenic Configurable Slit Unit (CSU) developed in collaboration with the Swiss Center for Electronics and Microtechnology (CSEM). Under remote control the CSU can form masks containing up to 46 slits with ~0.007-0.014" precision. Reconfiguration time is <6 minutes without thermal cycling the instrument. Slits are formed by moving opposable bars from both sides of the focal plane. An individual slit has a length of 7.0" but bar positions can be aligned to make longer slits in increments of 7.5". When masking bars are retracted from the field of view and the grating is changed to a mirror, MOSFIRE becomes a wide-field imager. The detector is a 2K x 2K H2-RG HgCdTe array from Teledyne Imaging Sensors with low dark current and low noise. Results from integration and commissioning are presented together with an overview of the as-built design.

8446-76, Poster Session

Design of a full-Stokes polarimeter for VLT/X-Shooter

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X-shooter is one of the most popular instruments at the VLT, offering instantaneous spectroscopy from 300 to 2500 nm. We present the design of a single polarimetric unit at the polarization-free Cassegrain focus that serves all three spectrographs of X-shooter. It consists of a calcite Savart plate as a polarizing beam-splitter and a rotatable crystal retarder stack as a ``polychromatic modulator". Since common ``superachromatic" wave plates have a wavelength range that is too limited for X-shooter, this novel modulator is designed to offer close-to-optimal polarimetric efficiencies for all Stokes parameters at all wavelengths. We analyze the modulator design in terms of its polarimetric performance, its manufacturing tolerances, its temperature sensitivity, and its polarized fringes. Furthermore, we present the optical and mechanical design of the polarimetric unit. We conclude that the X-shooter polarimeter furnishes a myriad of science cases: from measuring stellar magnetic fields (e.g., Ap stars, white dwarfs, massive stars) to determining asymmetric structures around young stars and in supernova explosions.

8446-77, Poster Session

Concept of a simultaneous polarimeter and rapid camera in 4 bands: SPARC4

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We present the concept of a new astronomical instrument for the Brazilian community: SPARC4 - the Simultaneous Polarimeter and Rapid Camera in 4 bands. SPARC4 will provide photometry and polarimetry in four optical broad bands simultaneously. This is achieved by the use of dichroics beam splitters. The square field of view is ~6 arcminutes on a side. The instrument will use EMCCDs with a sub-second time resolution for photometry and somewhat longer for polarimetry. The main motivation for building SPARC4 is to explore astrophysical objects which exhibit fast temporal variability in flux and polarization. The instrument will be installed in the 1.6-m telescope of the Observatório do Pico dos Dias (Brazil). Here we present a summary of the conceptual design report.

8446-78, Poster Session

Acousto-optical imaging spectrometer for 2.5 m telescope at Caucasian Mountain Observatory

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We report design and prototype performance of an acousto-optical imaging spectrometer for the 2.5 m Cassegrain telescope being constructed at Caucasian Mountain Observatory of Lomonosov Moscow State University. The spectrometer has an angular acceptance that corresponds to 1:10 focal ratio and has 20 mm clear aperture in focal plane. The instrument construction is independent on the telescope diameter. Two mechanically interchanged monochromators cover the range from 380 to 600 µm and from 600 to 1100 µm with spectral resolution of 4 1/cm. Development of our instrument will make a breakthrough in study of planetary nebulae providing data for distribution of elements across the object.

An operational prototype of the instrument was commissioned at 0.6 m telescope (focal ratio 1:12.5) at Crimean Station of Lomonosov Moscow State University. The spectral transmission has a FWHM of 12 Å at Hα emission line. Apodization of acoustic field has allowed to decrease the level of spurious side maxima to -17 dB. Spatial resolution was about 1". Maximum transmission of the monochromator can reach 90 % in working light polarization.

The instrument made possible to detect rapid spectral variability of Hα emission line in Seyfert galaxy NGC 4151 nucleus with a small telescope. Spatial distribution of H, N, S, Ar, and O emission was studied for NGC 7027 and NGC 7009 planetary nebulae.

8446-79, Poster Session

The F/5 instrumentation suite for the Clay Telescope

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The F/5 instrumentation suite for the Clay telescope was developed to provide Magellan Consortium members with wide field optical imaging and multiobject NIR spectroscopy capability. The suite consists of several major subsystems including two focal plane instruments. Megacam is a panoramic, square format CCD mosaic imager, 0.4° on a side. It is instrumented with a full set of Sloan filters. MMIRS is a multislit NIR spectrograph that operates in Y through K band and has long slit and imaging capability as well. These two instruments operate both at Magellan and the MMT. Megacam requires a wide field refractive corrector and a Topbox to support shutter and filter selection functions, as well as wave front sensing. Both the corrector and Topbox designs were modeled on previous designs for MMT, however features of the Magellan telescope required considerable revision of these designs. In this paper we discuss the optomechanical, electrical, software and structural design of these subsystems, as well as operational considerations that attended delivery of the instrument suite to first light.

8446-80, Poster Session

The AAO's gemini high-resolution optical spectrogrph (GHOS) concept

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The proposed Gemini High-Resolution Optical SpecTrograph (GHOST) will fill an important hole in the current suite of Gemini instruments. We describe the Australian Astronomical Observatory (AAO)-led concept for GHOST, which consists of a multi-object, compact, high-efficiency, fixed-format, fiber-fed design.

The spectrograph itself is a multi-channel variant of the asymmetric white-pupil Echelle Kiwispec spectrograph produced by Industrial Research Ltd. This spectrograph has an R4 grating and a 100mm pupil, and separate cross-dispersers and camera optics for each arm, optimized for their respective wavelength ranges. We feed this spectrograph with a miniature lenslet-based IFU that sub-samples the seeing disk of a single object into 7 hexagonal sub-images, reformatting this into a slit with a second set of double-microlenses at the spectrograph entrance with relatively little loss due to focal-ratio degradation.

This reformatting enables high spectral resolution from a compact design that fits well within the relatively tight GHOST budget. We will describe both our baseline 2-object R~45,000 design with full wavelength coverage from the ultraviolet to the silicon cutoff, as well as expansion options to 4 objects and higher spectral resolution with finer sampling of the seeing disk.

8446-81, Poster Session

GRACES--the Gemini remote access CFHT ESPaDOnS spectrograph: initial design and testing

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The Gemini Remote Access CFHT ESPaDOnS Spectrograph, GRACES, is an innovative, collaborative instrument experiment between Gemini Observatory, CFHT, and HIA. The goal is to bringing high-resolution optical spectroscopy to Gemini-North in ~1 year at a small fraction of the cost of a new spectrograph. An unfortunate reality in astronomy is that many instruments spend a low percentage of time conducting observations; therefore, viewed in its entirety, the astronomical community uses its resources very inefficiently because of so many duplicative instruments. With typical instrument costs of millions of dollars for large telescopes, finding alternatives is desirable. One alternative, well suited for Mauna Kea, is to share instruments. ESPaDOnS is an existing high-resolution optical spectrograph on the CFHT, while the Gemini-North telescope, located next door, is in need of this capability. By feeding ESPaDOnS with an optical fiber from Gemini-North, both communities can achieve higher resource efficiencies. To convert the 8-m F/16 Gemini beam to the beam expected by ESPaDOnS, a 170-µm fiber and a new image slicer has been designed by HIA. At Gemini, two fibers (sky/star) will be inserted into GMOS-N using a special filter cassette; a 270-m multi-pair armored fiber cable will connect ESPaDOnS. The new image slicer will reside on a new mechanism in front of ESPaDOnS, which allows either the CFHT or Gemini fiber to be used without any impact on the CFHT configuration. Simulations show excellent sensitivity >600 nm (HR 5501, S/N>500, 500-900 µm, R~47,000, seeing=0.72", t=30 sec, V=5.67, AM=1.29).

8446-82, Poster Session

BASIS: Bayfordbury single-object integral field spectrograph

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As the role of integral field spectrographs grows year by year it is necessary to teach the fundamentals to the next generation of astronomers. Here we present an inexpensive (<$500) and easily replicable integral field unit for use on small aperture telescopes. Based on a commercial small spectrograph (SBIG Self-Guiding Spectrograph) and an integral field unit of 19 hexagonally packed optical fibres each with 50µm cores and a pitch of 125µm; it has an overall field-of-view of 30 arc seconds (2.5arcsec/core). With a resolution of 7Å from 4710-6830Å and a signal-to-noise ratio of 10 for a 20min exposure of a 13mag/arcsec^2 source, the performance allows for teaching the principles of experimental and observational integral field spectroscopy. For example, even with a modest continuum signal-to-noise ratio, the H-alpha emission line position can readily be used as a powerful tracer of a galaxy's velocity field. Beyond teaching, it can provide a first-pass survey of 10^2 - 10^3 nearby galaxies in 100 nights. Initial observations and analysis of 50 galaxies will act as a proof of concept for the survey mode.

8446-83, Poster Session

iSHELL: a 1-5 micron cross-dispersed R=70,000 immersion grating spectrograph for IRTF

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iSHELL is 1-5 micron high spectral resolution spectrograph being built for the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii. Dispersion is accomplished with silicon immersion gratings in order to keep the instrument small enough to be mounted at the Cassegrain focus of the telescope. The white pupil spectrograph is designed to produce resolving powers of up to R=70,000. Cross-dispersing gratings

mounted in a tilt-able mechanism at the second pupil allow observers to select different wavelength ranges and slit lengths ranging from 5 to 25 arcseconds, as is required by the wide-ranging science case. One Teledyne 2048x2048 H2RG array is used in the spectrograph, and one Raytheon 512x512 Aladdin 2 array is used in the slit viewer for object acquisition, guiding, and imaging. About $4 million in funding has been provided by NSF and NASA. First light is expected in about 2015. In this paper we discuss the science drivers, instrument modeling, the optical design, and present an overview of the overall instrument design.

8446-84, Poster Session

The AAO fiber instrument data simulator

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The fiber instrument data simulator is an in-house software tool that simulates detector images of fiber-fed spectrographs developed by the Australian Astronomical Observatory (AAO). In addition to helping validate the instrument designs, the resulting simulated images are used to develop the required data reduction software. Example applications that have benefited from the tool usage are the HERMES and SAMI instrumental projects for the Anglo-Australian Telescope (AAT). Given the sophistication of these projects an end-to-end data simulator that accurately models the predicted detector images is required. The data simulator encompasses all aspects of the transmission and optical aberrations of the light path: from the science object, through the atmosphere, telescope, fibres, spectrograph and finally the camera detectors. The simulator runs under a Linux environment that uses pre-calculated information derived from ZEMAX models and processed data from MATLAB. In this paper, we discuss the aspects of the model, software, example simulations and verification.

8446-85, Poster Session

Front end of the SPIRou spectropolarimeter for Canada-France Hawaii Telescope

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SPIRou is a near-IR (0.98-2.35µm), echelle spectropolarimeter / high precision velocimeter being designed as a next-generation instrument for the 3.6m Canada-France-Hawaii Telescope on Mauna Kea, Hawaii, with the main goal of detecting Earth-like planets around low-mass stars and magnetic fields of forming stars. The unique scientific and technical capabilities of SPIRou are described in a series of eight companion papers.

In this paper, the Front End of the instrument is presented. Positioned at the Cassegrain Focal plane of the telescope, the front end is constituted of an atmospheric dispersion corrector, a field viewer with an image stabilization unit (0.03 arc seconds RMS stabilization goal), a calibration wheel and an achromatic polarimeter unit based on Fresnel Rhombs. The polarimeter permits the circular and linear polarization analysis. The retardance of the Fresnel rhombs is nominal to better than 0.5% in the whole spectral domain. The evaluation and the reduction of the thermal background of the Front end is a challenging part of the instrument.

8446-87, Poster Session

Stability achieved for the environmentally stabilized FOCES echelle spectrograph (FOCES stability IV)

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The FOCES Echelle spectrograph is currently under use for laboratory studies under pressure and temperature stabilized conditions. We present first optical measurement results and compare them to simulations previously published in this series of papers.

We show the movement of the image on the CCD with changes of pressure and temperature, as well as with changes of the camera (CCD) temperature. In addition we show stability of the spot positions in the stabilized system. Measurements are done using a ThAr gas discharge source and alternatively a broad band optical frequency comb.

8446-88, Poster Session

Gemini high-resolution optical spectrograph conceptual optical design

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The instrument group of the Herzberg Institute of Astrophysics has been commissioned by the Gemini Observatory as one of the three competing organizations to conduct a conceptual design study for a new Gemini High-Resolution Optical Spectrograph (GHOS). This paper outlines the main features of the optical design, including the Cassegrain-mounted science input unit, the bench-mounted spectrograph and the fiber relay system. The predicted imaging performance and efficiency are presented with the design trade offs explored in the study.

8446-89, Poster Session

A single-shot optical linear polarimeter for asteroids studies

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Polarimetric studies of minor Solar System bodies are extremely useful to obtain information on some physical parameters, including geometric albedo, which are both important and difficult to derive by means of other remote sensing techniques. Current activities in the field of asteroid polarimetry are limited by the fact that most instruments adopted in recent observing campaigns use photomultipliers as detectors. These devices are intrinsically very suitable for observations of objects exhibiting fast variations of the degree of polarization, but they have the problem of generally low quantum efficiency. As a consequence,

there are severe limitations on the number of objects which can be observed, since many interesting targets are simply too faint, using small or medium-size telescopes. In the case of asteroid polarization measurements, the time variation of the polarization state is not sufficiently fast to prevent the use of detectors which can be intrinsically slower, but more sensitive, like in the case of CCD-based polarimeters.

We have designed and are currently developing a new CCD-based polarimeter based on a “double-Wollaston” configuration. The adopted optical configuration allows for simultaneous acquisition of the three Stokes parameters I, Q, U without use of any moving parts. In this way, the linear polarization degree may be measured accurately, ideally even for targets with fast polarization variations.

The polarization analyzer is actually in calibration phase at the F/12.5 Cassegrain focus of one of 1 meter telescope of the C2PU facility (Observatoire de la Côte d’Azur, Plateau de Calern, France).

8446-90, Poster Session

Gemini high-resolution optical spectrograph conceptual mechanical design

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The instrument group of the Herzberg Institute of Astrophysics has been commissioned by the Gemini Observatory as one of the three competing organizations to conduct a conceptual design study for a new Gemini High-Resolution Optical Spectrograph (GHOS). This paper outlines the main features of the mechanical design, including the Cassegrain-mounted science input unit, the bench-mounted spectrograph and the fiber relay system. Topics include the design challenges associated with multi-object fiber relays in the science unit, environmental stability of the spectrograph bench and routing and handling of fibers in the Gemini dome environment.

8446-91, Poster Session

RINGO3: a multi-colour fast response polarimeter

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GRB jets contain rapidly moving electrons which will spiral around magnetic field lines. This causes them to emit polarized synchrotron emission.

We have built a series of polarimeters (RINGO and RINGO2) to investigate this by measuring the polarization of optical light from GRBs at a certain single wavelength. The instruments are mounted on the Liverpool Telescope, which is a fully robotic (i.e. unmanned) telescope on La Palma which reacts to triggers from satellites such as the NASA SWIFT mission. This has had great success, with the first ever detections of early time optical polarization being made. In addition the first measurements of the change in optical polarization from a GRB as the jet expands have recently been obtained.

In this paper we describe the design and construction of RINGO3. This will be a multi-colour instrument that can observe simultaneously at three wavelengths. By doing so we will be able to unambiguously identify where in the burst the polarized emission is coming from. This will allow us to distinguish between three possibilities: (1) Magnetic instabilities generated in the shock front, (2) Line of site effects and (3) Large-scale magnetic fields present throughout the relativistic outflow. The instrument design combines a rapidly rotating polaroid, specially designed polarization insensitive dichroic mirrors and three electron multiplying

CCD cameras to provide simultaneous wavelength coverage with a time resolution of 1 second.

8446-93, Poster Session

ECHARPE mechanical design

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ECHARPE spectrograph - Espectrógrafo ECHelle de Alta Resolução para o telescópio Perkin&Elmer - is being designed at LNA - Laboratório Nacional de Astrofísica, Brazil - to be mounted on 1.60 meter telescope at Pico dos Dias Observatory, Brazil. It will offer a spectral resolution of R ~ 50000, in the interval 390-900 nm and in a single exposition. It will be a fiber fed, bench spectrograph with two channels: blue and red, fed by two optical fibers (object, sky or calibration) with aperture of 1.5 or 2.0 arcseconds. This paper reports on technical characteristics of the spectrograph mechanical design and presents a new developed mounting system for echelle grating and collimator and relay mirrors, which allows linear and rotational adjustments in all degrees of freedom without using springs.

8446-94, Poster Session

aTmcam: a simple atmosphere transmission monitoring camera for sub 1% photometric precision

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Traditional color and airmass corrections can achieve ~1% precision in photometric observing conditions. A major limiting factor is the variability in atmospheric throughput, which changes on timescales of less than a night. We present preliminary results for a system to monitor the throughput of the atmosphere, which should enable photometric precision when coupled to more traditional techniques of less than 1% in photometric conditions. The system, aTmCam, consists of a set of imagers each with a narrow-band filter that monitors the brightness of suitable standard stars. Each narrowband filter is selected to monitor a different aspect of the atmospheric transmission, including the amount of precipitable water, aerosol optical depth, etc. We present performance modeling results and comparison of narrowband photometric measurements with spectroscopic measurements of the atmosphere; we show that the narrowband imaging approach can predict the throughput of the atmosphere to better than ~10% across a broad wavelength range.

8446-95, Poster Session

Image quality tests on the Canarias InfraRed Camera Experiment (CIRCE)

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In this paper we present the results of image quality tests performed on the optical system of the Canarias InfraRed Camera Experiment (CIRCE), a visitor-class near-IR imager, spectrograph, and polarimeter for the 10.4 meter Gran Telescopio Canarias (GTC). The CIRCE optical system is comprised of eight gold-coated aluminum alloy 6061 mirrors. We present surface roughness analysis of each individual component as well as optical quality of the whole system. We found all individual mirror surface roughness are within specifications except Fold mirror 2. We plan to have this component re-cut and re-coated. We used a flat 0.2-arcseconds pinhole mask placed in the focal plane of the telescope to perform the

optical quality tests of the system. The pinhole mask covers the entire field of view of the instrument. The resulting image quality allows seeing-limited performance down to seeing of <0.3 arcseconds FWHM. We also observed that our optical system produces a negative field curvature, which compensates the field curvature of the Ritchey-Chretien GTC design once the instrument is on the telescope.

8446-96, Poster Session

Upgrading CRIRES-VLT to cross-dispersed mode

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The cryogenic high-resolution IR echelle spectrograph - CRIRES - is the ESO infrared (0.95-5.4 microns) high-resolution spectrograph operating at the Nasmyth A focus of VLT-UT1. The instrument provides long-slit (31”) spectroscopy with resolving power up to R=100,000 over a quite narrow wavelengths range (about 1/70 of the central wavelength).

Observations of compact objects (e.g. stellar photospheres) could be made much more efficient by implementing a cross-dispersed mode, which increases the simultaneous spectral coverage by an order of magnitude or more. Moreover, in the range 0.95 to 2 microns CRIRES suffers from order contamination and flat-fielding problems which cross-dispersion will solve in passing.

This paper presents the design of a relatively simple system to add cross-dispersed modes to CRIRES with a minimum impact on the instrument optics and mechanics.

8446-97, Poster Session

MSI: a visible multispectral imager for 1.6-m telescope of Hokkaido University

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We have built a visible multi-spectral imager (MSI) for the 1.6-m Pirka telescope of the Hokkaido University in Hokkaido, Japan. The instrument is equipped with two liquid crystal tunable filters and a 512 x 512 pixel EMCCD camera. One of the major purposes of this instrument is to obtain multi-spectral images (series ofnarrow-band images at many different wavelengths) of the solar planets rapidly. These tunable filters are a Lyot filter with liquid crystal variable retarders and thus can tune the transmitting wavelength rapidly without moving parts. Their spectral ranges are 400-720 nm and 650-1100 nm and the bandwidth is typically 10 nm on both filters. The EMCCD camera can obtain images at a frame rate of about 32 Hz, which also enables us to improve the spatial resolution with the shift-and-add or the Lucky imaging techniques. The field of view is 3.3 x 3.3 arcmin with a pixel scale of 0.39 arcsec/pixel. The instrument also has UBVRI-band broad-band filters and several narrow-band filters. MSI is mounted at the f/12 Cassegrain focus of the telescope. It had the first light on February 2011, and then have been used for several astronomical and planetary science programs as a major facility instrument at this telescope. We describe the design, construction, integration, and performance of this multi-spectral imager.

8446-98, Poster Session

The MUSE instrument detector system

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The MUSE (Multi Unit Spectroscopic Explorer) instrument (see Bacon et al., this conference) for ESO’s Very Large Telescope VLT employs 24 integral field units (spectrographs). Each of these is equipped with its own cryogenically cooled CCD head. The heads are individually cooled by continuous flow cryostats. The detectors used are deep depletion e2v CCD231 84 with 4096x4112 active 15 µm pixels. The MUSE Instrument Detector System is now in the final integration and test phase on the instrument.

The paper gives an overview of the architecture and performance of the complex detector system including ESO’s New General detector Controllers (NGC) for the 24 science detectors, the detector head electronics and the data acquisition with Linux Local Control Units. NGC is sub-divided into 4 Detector Front End (DFE) units each operating 6 CCDs. All CCDs are read out through 4 ports simultaneously to achieve short readout times at low noise levels.

All science grade CCDs were thoroughly characterized on ESO’s optical detectors testbench facility and the test results processed and documented in a semi-automated, reproducible way. We present the test methodology and the results that fully confirm the feasibility of these detectors for their use in this challenging instrument.

8446-99, Poster Session

Laboratory performance tests of PANIC, the panoramic NIR imager for Calar Alto

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PANIC, the Panoramic Near Infrared Camera, is an instrument for the Calar Alto Observatory which is currently integrated in the laboratory. Four Hawaii-2RG detectors yield a nearly contiguous field of view of 0.5x0.5 degrees at a pixel scale of 0.45arcsec/pixel at the 2.2m telescope and twice the pixel scale over a still large field of view of 0.25x0.25 degrees at the 3.5m telescope.

The spectral range extends from 0.8 to 2.5 micron, corresponding to the astronomical Z to K-bands. The optical design allows the use of narrow band (bandwidth 1% of central wavelength) filters.

PANIC will have a low thermal background due to cold stops.

Weight and size limits have lead to interesting mechanical design features which have been presented in some detail in a previous SPIE contribution (SPIE 2010, 7735-138).

In this contribution we present results of the laboratory tests, which include detailed studies of the four detectors, alignment of the optics and optical imaging quality assessment.

8446-101, Poster Session

Low-loss fiber link for the SPIRou near-infrared spectropolarimeter at CFHT

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SPIRou is a near-infrared (0.98-2.35µm), echelle spectropolarimeter / high precision velocimeter being designed as a next-generation instrument for the 3.6m Canada-France-Hawaii Telescope on Mauna Kea, Hawaii, with the main goal of detecting Earth-like planets around low-mass stars

and magnetic fields of forming stars. The unique scientific and technical capabilities of SPIRou are described in a series of eight companion papers.

SPIRou fiber link connects the polarimeter unit to the cryogenic spectrograph unit (40 meter apart). Some challenging aspects will be discussed on this paper. In particular, the fiber link should ensure a very-low attenuation of the star signal (< 11 dB/Km) in the non-usual fiber spectral domain from 0.98 µm to 2.35 µm. Manufacturing process of this near infrared fiber will be presented.

This paper will also focus on the scrambling performance of the fiber link to reach high accuracy radial velocity measurements (1 m/s). This part of the paper will benefit of the large experience of the Geneva observatory in radial velocity measurements (ESPRESSO, HARPS).

Finally, some aspects as the fiber link feedthrough into the cryogenic chamber and the rearrangement of the fiber link to form a slit compatible with the entrance specifications of the spectrograph will also be explored.

8446-102, Poster Session

Control and protection of outdoor embedded camera for astronomy

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The purpose of CABERNET- Podet-Met (Camera Better Resolution Network, Pole sur la Dynamique de l'Environnement Terrestre - Meteor) project is the automated observation, by triangulation with three cameras, of meteor showers to perform a calculation of meteoroids trajectory and velocity. The scientific goal is to search the parent body, comet or asteroid, for each observed meteor.

To install outdoors cameras in order to perform astronomy measurements for several years with high reliability requires a very specific design for the box. For these cameras, this contribution shows how we fulfilled the various functions of their boxes, such as cooling of the CCD, heating to melt the snow and the ice, the protecting against moisture, lightning and Solar light. We present the principal and secondary functions, the product breakdown structure, the technical solutions evaluation grid of criteria, the adopted technology products and their implementation in multifunction subsets for miniaturization purpose. To manage this project, we aim to get the lowest manpower and development time for every part. In appendix, we present the measurements of the evolution of the image quality when cooling the CCD, and some pictures of the prototype.

8446-103, Poster Session

Design and construction progress of LRS2-B: a new low resolution integral-field spectrograph for the Hobby-Eberly Telescope

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The upcoming Wide-Field Upgrade (WFU) has ushered in a new era of instrumentation for the Hobby-Eberly Telescope (HET). Here, we present the design, construction progress, and lab tests completed to date of the blue optimized, second generation Low Resolution Spectrograph (LRS2-B). LRS2-B is a dual channel, fiber fed instrument that is based on the design of the Visible Integral-field Replicable Unit Spectrograph (VIRUS), which is the new flagship instrument for carrying out the HET Dark Energy Experiment (HETDEX). LRS2-B utilizes a microlens coupled integral field unit (IFU) that covers a 7"x12" area on the sky having unity fill-factor with ~300 spatial elements that subsample the median HET image quality. The fiber feed assembly includes an optimized dichroic beam splitter that allows LRS2-B to simultaneously observe 372 nm to 470 nm and 460 nm to 700 nm at fixed resolving powers of R~1900 and 1200, respectively. We discuss the departures from the nominal VIRUS design, which includes the IFU, fiber feed, camera correcting optics, and volume phase holographic grisms. Additionally, the motivation for the selection of the wavelength coverage and spectral resolution of the two channels is briefly discussed. One such motivation is the follow-up study of spectrally and (or) spatially resolved Lyman-alpha emission from z~2.5 star-forming galaxies in the HETDEX survey. LRS2-B is planned to be a commissioning instrument for the HET WFU and should be on sky by January 2013. Finally, we mention the current state of LRS2-R, the red optimized sister instrument of LRS2-B.

8446-104, Poster Session

Optical design of a red sensitive spectrograph

E. C. Martin, D. L. DePoy, J. L. Marshall, Texas A&M Univ. (United States)

We present a preliminary design for a red-sensitive spectrograph. The spectrograph is optimized to operate over the 600-1000nm spectral range at a resolution of ~2000 and specifically for the 2.7-m Harlan J. Smith Telescope at McDonald Observatory. The design is compact and cost-effective and should have very high throughput. The principles of the design can be extended to other purposes, such as a unit spectrograph for the DESpec project or other projects that require good performance in the red.

8446-105, Poster Session

Optimal resolutions for optical and NIR spectroscopy through atmospheric emission lines

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We study the effects of atmospheric emission lines in the background sky on spectroscopic measurements in the 0.4-2.4 micron range at resolutions ranging from 10-50,000 to determine an optimal observing resolution. We build a model of the background sky spectrum consisting of emission lines, thermal emission, and sky continuum. We define and calculate the fraction of pixels free of emission lines in 7 different band passes while varying the resolution and moon phase. We then discuss the effect of the background emission on the SNR of targets of various magnitudes to determine an optimal resolution at which to observe. Preliminary results show that emission lines have little to no effect in the selection of resolution in the optical, but that in the wavelengths greater than 1.5 microns the effects of atmospheric emission lines suggest a resolution of at least 2000 is optimal.

8446-106, Poster Session

HexPak and GradPak: variable-pitch dual-head IFUs for the WIYN 3.5m telescope bench spectrograph

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We present two new fiber integral field units (IFUs) -- HexPak and GradPak -- for the WIYN 3.5m Telescope Nasmyth focus and Bench Spectrograph. We describe their design, construction, and performance. These are the first IFUs to provide formatted fiber integral field spectroscopy with simultaneous sampling of varying angular scales. HexPak and GradPak are in a single cable with a dual-head design, permitting easy switching between the two different IFU heads on the telescope without changing the spectrograph feed: The two heads feed a variable-width double-slit. Each IFU head is comprised of a fixed arrangement of fibers with a range of fiber diameters. The layout and diameters of the fibers within each array are scientifically-driven for

observations of galaxies: HexPak is designed to observe face-on spiral or spheroidal galaxies while GradPak is optimized for edge-on studies of galaxy disks. HexPak is a hexagonal array of 2.8 arcsec fibers subtending a 40.9 arcsec diameter, with a high-resolution circular core of 0.94 arcsec fibers subtending 6 arcsec diameter. GradPak is a 39 by 55 arcsec rectangular array with rows of fibers of increasing diameter from angular scales from 1.9 arcsec to 5.6 arcsec across the array. The variable pitch of these IFU heads allows for adequate sampling of light profile gradients while maintaining the photon limit at different scales. We report laboratory tests of the throughput and focal ratio degradation properties of each IFU based on results from Eigenbrot et al. (these proceedings). This research was supported by NSF/AST-0804576 and 1152009.

8446-107, Poster Session

OCTOCAM as a visitor instrument at the 10.4m GTC

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OCTOCAM is a multi-channel imager and spectrograph with high-time resolution capabilities that has been designed to be used at the 10.4m Gran Telescopio Canarias. Dividing the light into 8 different channels it provides high-efficiency simultaneous imaging of a 2'x2' field of view in u, g, r, i, z, J, H, K. Long slit spectroscopy allows to cover the complete range from 4,000 to 23,000 A with a resolution of ~1,000 or ~3,000, depending on the selected slit mode. Using fast frame transfer detectors this can be done with basically no dead time between exposures and with time resolutions of up to tens of ms.

This paper gives an update on the instrument design to be used in one of the folded Cassegrain foci of the GTC, aimed at optimising the instrument to be used as a visitor instrument. The design includes a new implementation of the acquisition and guiding system with a redesigned derotator unit.

8446-108, Poster Session

Science with OCTOCAM at the 10.4m GTC

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OCTOCAM is a multi-channel imager and spectrograph with high-time resolution capabilities that has been designed to be used at the 10.4m Gran Telescopio Canarias. Dividing the light into 8 different channels it provides high-efficiency simultaneous imaging of a 2'x2' field of view in u, g, r, i, z, J, H, K. Long slit spectroscopy allows to cover the complete range from 4,000 to 23,000 A with a resolution of ~1,000 or ~3,000, depending on the selected slit mode. Using fast frame transfer detectors this can be done with basically no dead time between exposures and with time resolutions of up to tens of ms.

In this paper we review the different scientific possibilities that such an instrument opens in many different fields: Solar system sources, extrasolar planets, compact binary systems, gamma-ray bursts, active galactic nuclei, etc.

8446-109, Poster Session

A new deep-depletion CCD for the red channel of the Palomar double spectrograph

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The red channel of the Palomar Double Spectrograph (DBSP) on the 200-inch Hale Telescope has been upgraded with a new deep-depletion CCD from LBNL. Its redder response produced a significant increase of the throughput above 550 nm, and its longer dimension more than doubled the spectral coverage. A special dewar was designed to accommodate a detector mount which includes features to minimize CCD motion due to thermal cycling, in spite of the very simple "picture frame" packaging of the CCD. The new dewar also includes some novel features to improve the liquid nitrogen hold time while staying within the size envelope allowed in the Cassegrain cage. We describe these changes along with the detector characterization.

8446-110, Poster Session

SPIRou @ CFHT: spectrograph optical design

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SPIRou is a near-infrared, echelle spectropolarimeter/velocimeter under design for the 3.6m Canada-France-Hawaii Telescope (CFHT) on Mauna Kea, Hawaii. The unique scientific capabilities and technical design features are described in the accompanying (eight) papers at this conference. In this paper we focus on the lens design of the optical spectrograph. The SPIROU spectrograph is a near infrared fiber fed double pass cross dispersed spectrograph. The cryogenic spectrograph is connected with the Cassegrain unit by the two science fibers. It is also fed by the fiber coming from the calibration box and RV reference module of the instrument. It includes 2 off-axis parabolas (1 in double pass), an echelle grating, a train of cross disperser prisms (in double pass), a flat folding mirror, a refractive camera and a detector. This paper describes the optical design of the spectrograph unit and estimates the performances of such a system according to the system specifications. In particular, an optimisation model of the spectrograph is presented in accordance with the science goal of the instruments. This analysis is followed by the development of a cryogenic optical design. The paper also includes the opto-mechanical sensitivity, thermal sensitivity, slit non-uniformity and profile and transmission.

8446-112, Poster Session

Optical design of the multichannel (Vis-NIR) reionization and transient infrared (RATIR) camera

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The RATIR optical design represents an optimization compromise for simultaneous visible and near-infrared multi-band imaging for the recently robotized Mexican 1.5m Johnson telescope. Two dichroics in the visible arm feed a pair of commercial CCD cameras, covering each the same 5.3x5.3 arcmin field (0.16"/pixel), without magnification of the F/13 telescope beam. The first dichroic reflects $\lambda \leq 0.7\mu m$ light towards a 10-slot filter wheel for u to r observations. The second dichroic feeds in reflection the i-band CCD, while longer wavelengths pass through to a NIR reimaging system. A pair of triplets (field-lens and camera groups) combine to form a cold-pupil and to yield a wider field (9.8x9.8 arcmin) and a more convenient plate scale that boost the NIR performance. These warm optics come before a cryogenic dewar, within which a third dichroic (behind the cold-pupil) reflects the Z-Y bands to a H2RG, while

transmitting longer λs to a second H2RG. A Z-Y split-filter covers the eastern-half of the field (5x10 arcmin) with the Z-band and the other half with the Y-band. Similarly, a J-H split-filter is placed before the second NIR detector. Since all three dichroics are tilted slabs in converging beams, their induced field-aberrations where effectively controlled by wedging their exit surface. To control the pupil location and aberrations, one surface of the 6-lens re-imager required aspheric terms. The system then provides high-quality quasi-simultaneous observations in six bands (r, i, Z, Y, J & H) for a quick identification of high-redshift gamma-ray bursts and for general astronomical programs.

8446-113, Poster Session

STELES mechanical design

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The SOAR Telescope Echelle Spectrograph - STELES - is part of the Brazilian participation on the 4.1m SOAR telescope second-generation instrumentation. In view of SOAR´s high image quality and moderately large collecting area and the near UV capability, it will be able to yield high quality spectroscopic data for a large variety of objects of astrophysical interests. The spectrograph is a R4 cross-dispersed echelle fed by the SOAR Nasmith focus, operating in a quasi-Littrow white pupil configuration, and a resolving power of R ≈ 50,000, covering the 300-900nm spectral range in one shot.

STELES is a bench spectrograph which will be mounted vertically on the SOAR Telescope yoke. The ninety-degree inversion of the componentes, due to the vertical position of the bench, plus the proximity of most components, due to the spectrograph compactness, were requirements carefully observed during the design process. This paper describes technical characteristics of the spectrograph mechanical design. It is described how the bench's vertical fixation and its adjustments was solved and special features about its components supports.

8446-114, Poster Session

CARMENES: optical and opto-mechanical design

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CARMENES is a fiber-fed high-resolution echelle spectrograph for the Calar Alto 3.5m telescope. The instrument is build by a German-Spanish consortium under the lead of the Landessternwarte Heidelberg.

The search for planets around M stars with a RV accuracy of 1m/s is the main focus of the science planned.

Two channels, one for the visible, one for the NIR range, will allow for observations in the complete wavelength range from 0.55 to 1.7µm.

To ensure the stability, the instrument is working in vacuum in a thermally controlled environment.

The optical design as well as the opto-mechanical design of both channels of the instrument and the front-end are described.

8446-115, Poster Session

Perfomance verifications of the ground-based mid-infrared camera MAX38 on the MiniTAO Telescope

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Mid-infrared wavelengths of 25-40 micron are one of the most important wavelengths to observe dusty astronomical objects such as star forming regions, mass losing stars, and planetary/debris disks.

However there are few mid-infrared instruments in the world.

In particular, instruments on the ground which covers the wavelength range of 25-40 micron has not existed so far, because these wavelengths are heavily absorbed by the atmosphere.

We have developed a mid-infrared camera MAX38 (Mid-infrared Astronomical eXplorer) for observations at 8-38 micron.

It is mounted on the University of Tokyo Atacama 1.0-m(miniTAO) telescope which is the world's highest ground-based telescope at the summit of Co. Chajnantor in Northern Chile.

Thanks to the high altitude(5,640m) and dry weather condition of the Atacama site, we can access the 30-micron wavelength region from the ground.

Five observing runs have been conducted since November 2009. The observations were carried out in daytime in addition to nighttime.

Sky conditions in the mid-infrared range in daytime were found to be almost comparably good in nighttime.

Performance verifications of the MAX38 have been completed.

We confirmed that the MAX38 achieves a diffraction-limited spatial resolution at 8-38 micron.

System efficiencies of MAX38 around 10-micron are measured as approximately 3%.

In addition to the imaging mode, a capability of low-resolution spectroscopy in the N-band will be added in the spring 2011.

In this paper, we will describe the performances of the MAX38. Preliminary scientific results will be also reported.

8446-116, Poster Session

Gemini high-resolution optical spectrograph conceptual design

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The instrument group of the Herzberg Institute of Astrophysics has been commissioned by the Gemini Observatory as one of the three competing organizations to conduct a conceptual design study for a new Gemini High-Resolution Optical Spectrograph (GHOS). This paper outlines the science case development and requirements flow-down process that leads to the configuration of the HIA instrument and describes the overall GHOS conceptual design. In addition, this paper discusses design trades examined during the conceptual design study.

8446-117, Poster Session

ECHARPE: a fiber-fed echelle spectrograph for the Pico dos Dias Observatory

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At least during the last ten years, the Brazilian astronomical community has been asking for an echelle spectrograph for the 1.6 m telescope installed at Pico dos Dias Observatory (Brazópolis, MG, Brazil, OPD/MCTI/LNA). Among the scientific cases are topics related to the chemical evolution of the Galaxy, asteroseismology, chemical composition and chromospheric activities of solar type stars and the relations between solar analogues and terrestrial planets. During 2009 the project finally got started. The called ECHARPE spectrograph (Espectrógrafo ECHelle de Alta Resolução para o telescópio Perkin-Elmer) is being projected to offer a spectral resolution of R ~ 50000, in the interval 390-900 nm and in a single exposition. It will be a bench spectrograph with two channels: blue and red, fed by two optical fibers (object, sky or calibration) with aperture of 1.5 or 2.0 arcseconds. The instrument will be placed in one of the telescope pillar ramification, in the originals installations of a Coudé spectrograph and in a specially created environment controlled room. In this work we will present the scientific motivations, the conceptual optical design, the expected performance of the spectrograph, and the status of its development. ECHARPE will be delivered to the astronomical community in 2014, fully prepared and optimized for remote operations.

8446-118, Poster Session

MOSFIRE lens bonding, assembly, and alignment

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We present the assembly and optical alignment process used for the optics and the focal plane of MOSFIRE, the Multi-Object Spectrometer for Infra-Red Exploration at the W. M. Keck Observatory. The optical design accommodates the Y, J, H, and K passbands at a resolving power of R~3,500 with a 0.7” slit width. Up to 46 slits can be located anywhere in the 6’ by 3’ spectroscopic field of view. In imaging mode, MOSFIRE addresses a roughly 6’ by 6’ (262 by 262 mm) field. Both the collimator and camera are fully dioptric (lenses) designed by H. Epps (UCSC) and fabricated by Jenoptik (Florida, USA) with coatings by Evaporated Coatings, Inc., (Pennsylvania, USA). The six-element collimator produces a 125-mm beam. The seven-element 250-mm focal length camera operates at ~f/0.9 underfilled. The optics use fragile materials such as CaF2, BaF2, ZnSe, and Ohara S-FPL51, which must function in the 120 K vacuum cryogenic environment. All thirteen lenses are mounted with multiple thermally-matched metal pads epoxied to the lens girdles. The pads are connected via flexures to aluminum lens cells, which are stacked and bolted together to form into the collimator and the camera barrels, respectively. The flexure mount system allows our fragile lenses to be held rigidly to the lens cells without accumulating thermal stresses as the instrument cools from laboratory temperature to 120 K. All told, the lens assembly process took roughly one year. The optics were installed in June 2010, prior to MOSFIRE’s fifth cooldown. Within minutes of cold operations we achieved sharp focus. Since then, the optics have survived five thermal cycles and they continue to produce pixel-limited performance in all passbands without refocus.

8446-119, Poster Session

An experimental VLT cryo-cooler instrumentation vibration analysis

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Cryo-coolers were introduced at ESO about 20 years ago. Nowadays they are widely used to provide the required temperature levels of ESO’s VLT instrumentation suite, mainly for infrared instruments and their detectors. Nevertheless, mechanical vibrations induced by these refrigerator systems have become a serious issue during the last years. Especially for the extremely sensitive VLT-Interferometer (VLT-I) even micro vibration levels can be critical or unacceptable. As a consequence ESO started some time ago a comprehensive vibration reduction program. Major tasks involved are the quantification of typical cryo-cooler instrument vibration levels and their impact on the VLT / VLT-I optical stability, the definition of perturbation minimizing design recommendations and admissible vibration specifications for future instruments. This paper describes the design, construction and calibration of a dedicated VLT dummy instrument comprising six powerful state-of-the-art 2-stage cold heads arranged in different spatial orientations and the subsequent comprehensive vibration measurement test campaign. Therefore the instrument had to be installed and operated in all three VLT foci, similar to actual Cassegrain-focus, Nasmyth-focus or Nasmyth-platform instruments, while simultaneously recording vibrations of the instrument structure and the generated total optical path length difference of the 8-m telescope main mirror system. A wide matrix of variegated configurations could be covered. All measurements were carefully analyzed. As a result trendsetting cryo-cooler instrument design, operations and vibration specifications are presented.

8446-120, Poster Session

A simple high efficiency high resolution spectropolarimeter

S. C. Barden, National Solar Observatory (United States)

A simple concept is described that uses volume phase holographic gratings as polarizing dispersers for a high efficiency, high resolution spectropolarimeter. Although the idea has previously been mentioned in the literature as possible, such a concept has not been explored in detail. Performance analysis is presented for a concept that could be utilized for both solar and night-time astronomy. Instrumental peak efficiency can approach 100% with spectral dispersions permitting R~200,000 spectral resolution with diffraction limited telescopes. The instrument has 3-channels: two dispersed image planes with orthogonal polarization and an undispersed image plane. The concept has a range of versatility where it could be configured (with appropriate waveplates) for slit-fed spectroscopy or without slits for snapshot/hyperspectral spectroscopic imaging. Multiplex gratings could also be used for the simultaneous recording of two separate spectral bands or multiple instruments could be daisy chained with beam splitters for further spectral coverage.

8446-121, Poster Session

CYCLOPS2: the fibre image slicer upgrade for the UCLES high resolution spectrograph

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Lawrence, D. R. Orr, S. Miziarski, S. Case, L. Gers, Australian Astronomical Observatory (Australia); D. J. Jones, Prime Optics (Australia)

CYCLOPS2 is an upgrade for the UCLES high resolution spectrograph on the Anglo-Australian Telescope, scheduled for commissioning in semester 2012A. By replacing the 5 mirror Coudé train with a Cassegrain mounted fibre based image slicer CYCLOPS2 simultaneously provides improved throughput, reduced aperture losses and increased spectral resolution. Sixteen optical fibres collect light from a 5.0 arcsecond^2 area of sky and reformat it into the equivalent of a 0.6 arcsecond wide slit, delivering a spectral resolution of R=70000 and up to twice as much flux as the standard 1 arcsecond slit of the Coudé train. CYCLOPS2 also adds support for simultaneous ThAr wavelength calibration via a dedicated fibre.

CYCLOPS2 consists of three main components, the fore-optics unit, fibre bundle and slit unit. The fore optics unit incorporates magnification optics and a lenslet array and is designed to mount to the CURE Cassegrain instrument interface, which provides acquisition, guiding and calibration facilities. The fibre bundle transports the light from the Cassegrain focus to the UCLES spectrograph at Coudé and also includes a fibre mode scrambler. The slit unit consists of the fibre slit and relay optics to project an image of the slit onto the entrance aperture of the UCLES spectrograph. CYCLOPS2 builds on experience with the first generation CYCLOPS fibre system, which we also describe in this paper.

We will present the science case for an image slicing fibre feed for echelle spectroscopy, describe the design of CYCLOPS and CYCLOPS2 and present results from testing and commissioning.

8446-122, Poster Session

Echelle gratings for the near-infrared

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We report on echelle gratings with groove spacings coarser than 20 lines per mm. Increasing the groove spacing of an echelle reduces the free spectral range. A smaller free spectral range allows near-infrared orders matched to the detector size. Using a sample diamond turned grating we investigate the suitability of a 15 line/mm R3 echelle for use in the 1 - 5 micron infrared. Coarse echelle gratings have wide application in both ambient temperature as well as cryogenic astronomical echelle spectrographs. Diamond turned reflection echelles are currently in use in space-based high-resolution spectrographs for 2 - 4 micron planetary spectroscopy.

8446-123, Poster Session

Fully optimized shaped pupils: preparation for a test at the Subaru Telescope

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New shaped pupils, fully optimized in 2 dimensions, make it possible to design optimal apodizers for arbitrarily complex apertures, for instance on-axis telescopes. We have designed masks with inner working angles of 2 and 3 lambda/D, and for contrast ranging from 10^5 to 10^7. The masks are inherently free-standing as long as the outer working angle exceeds a maximum value, typically 10 lambda/D. Beyond that limit, new constraints can be added to obtain free-standing masks. We have manufactured some of these masks using Princeton University nanofabrication facilities. Our main objective is to test the effective performance of these masks in the laboratory, both in Princeton and in Hawaii, in preparation for potential tests on the sky that may occur in summer 2012.

8446-124, Poster Session

From the most plain coronograph to the most populated spectrograph: a suite of some new instruments for LBT

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The Large Binocular Telescope (LBT) is one of the most unusual 8m class telescope and surely it has been inspirational to a number of novel concepts and innovations.

We present here a small collection of recently traced opto-mechanical designs to fit some niches in the parameters space of astrophysical usage.

A coronograph, as simple as possible, to take advantage of the LBT XAO ability dedicated to the ExoPlanet detection, an MCAO camera with entrance at the level of the pupil (and related baffling problems), and two versions of a multiple very wide field spectrographs, one in which a relatively small number of complex cameras are envisaged and one in which a large number of tiny ones is foreseen, all with equal optical elements but for the pupil aberration corrector, the difference between the last two consisting in different compromises between the Field of View spatial sampling and the achieved optical quality.

8446-125, Poster Session

Optical bi-stable shutter development/ improvement

J. Lizon, European Southern Observatory (Germany); N. Haddad, R. Castillo, European Southern Observatory (Chile)

Two of the VLT instruments (Giraffe and VIMOS) are using the large magnetic E/150 from Prontor (with a aperture diameter of 150 mm. As we were facing an unacceptable number of failures with this component some improvement plan was discussed already in 2004. The final decision for starting this program was conditioned by the decision from the constructor to stop the production.

The opportunity then was taken to improve the design in order to reduce the thermal dissipation building a fully bi-stable mechanism.

The project was developed in collaboration between the two main ESO sites doing the best use of the manpower and of the technical capability available at the two centers. In this frame the iris blades have been cut in VIMOS mask plates using the laser Mask Manufacturing Unit.

Our paper describes the development including the intensive and long optimization period. To conclude this optimization we proceed with a long life test on two units. These units have demonstrate a very high level of reliability (up to 10 000 cycles without failure which can be estimated to an equivalent 6 years of operation of the instrument)

A new controller has also been developed. Some of the highlights of this unit are the fully configurable coil driving parameters, usage of breaking strategy to dump mechanical vibration and reduce mechanical wearing, configurable usage of OPEN and CLOSE sensors, non volatile storage of parameters, user friendly front panel interface.

8446-127, Poster Session

A new more efficient grating for the Keck integral field spectrograph OSIRIS

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OSIRIS is a near-infrared integral field spectrograph operating behind the Keck II adaptive optics system at W.M. Keck Observatory. OSIRIS was designed with a single fixed diffraction grating to ensure spectral stability with minimal deviations in spectral point spread functions and location. This grating is used in multiple orders to cover traditional near-infrared wavebands: K (2.2 microns) is sampled in 3rd order, H (1.6 microns) in 4th, J (1.3 microns) in 5th, and Z (1.1 microns) in 6th. The grating is challenging to manufacture with a coarse ruling of 27.9 grooves per mm at a shallow blaze angle of 5.76 degrees, and there are only a few vendors worldwide that have the capability of ruling such a grating. Unfortunately, the sensitivity of OSIRIS has been limited by the grating efficiency that is less than one-half of what was expected due to poorly ruled grooves. We present our recent efforts to provide an improved grating with at least 2 times more efficiency than the original. The result would be a factor of 2 improvement in signal-to-noise ratio (SNR) for detector limited observations (2.0 microns). Our team has measured the direct efficiency of the original grating in the laboratory and we plan to measure the efficiency of the new grating before installation. Higher sensitivities afforded by a more efficient grating will have a large impact on integral field spectrograph scientific studies.

8446-128, Poster Session

An integrated 1-5 micron test bench for the characterization of cryogenic optical elements

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We report on the final design and current status of a 1-5 micron infrared test bench at the ETH Zurich Institute for Astronomy. This facility will enable us to characterize infrared optics, both reflective and transmissive, at cryogenic operating temperatures for both ground- and space-based applications. A focus of our lab is to develop instrumentation for the detection and characterization of extra-solar planets. The test bench is designed to characterize a range of spectrally dispersive and diffraction suppression optics such as filters, grisms, and gratings, as well as focal and pupil plane components for coronagraphy. The test bench is built around a 2048x2048 Hawaii 2-RG detector from Teledyne Imaging Systems. The optical bench is envisioned to operate down to 30 K. We will outline the status of the project, and describe the capabilities of the test bench in detail in order to alert potential collaborators to this new capability.

8446-129, Poster Session

An on-sky demonstration of a single mode fibre fed spectrograph (NanoSpec)

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NanoSpec is a single mode fibre-fed spectrograph design operating very close to the diffraction limit in the visible (400nm to 715nm). It is the first on-sky implementation of PIMMS#0 (photonic integrated multimode micro-spectrograph), that harness's the multimode to single mode conversion of the photonic lantern and a bulk optics spectrograph. Here it is configured with a resolving power ($lambda/Deltalambda$) of 1000 and coupled to the prime focus of a 305cm (12”) Schmidt-Cassegrain telescope (Meade LX200GPS), via a photonic lantern. The photonic lantern efficiently converts multimode light from the telescope focus to many single mode fibres that form a pseudo-slit in the spectrograph. By feeding the spectrograph with the single mode fibres from the photonic lantern we are able to build a spectrograph whose performance is essentially diffraction limited and independent of the telescope it is attached to. Here we first present the design and performance characteristics of the NanoSpec, followed by sample spectra of the Moon and local planets.

8446-130, Poster Session

Redesign of the integrated photonic spectrograph for improved astronomical performance and frontiers in the mid-IR

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The Integrated Photonic Spectrograph (IPS) has seen considerable development in the last few years, culminating in the first successful on-telescope test of a prototype device, with spectra taken from stellar sources using a photonic spectrograph. Modified arrayed waveguide grating chips, which are commercially mass-fabricated, were used in the prototype device as the primary disperser with integrated optics. However the device’s performance (in terms of resolving power and wavelength coverage) was limited by the predominantly telecommunications-grade design parameters used in chip manufacturing. As a fully-photonic spectrograph platform provides benefits such as having no moving parts, high stress and temperature resistance and is far smaller than existing spectrographs, its development is of extreme importance, and at this stage required a substantial redesign of underlying features to optimise it for astronomy.

In this body of work we present a comprehensive redesign of arrayed waveguide grating chips (currently used as the backbone of the IPS) to improve specific performance parameters of interest to astronomy. These include the free-spectral range, resolving power and the operational wavelength for the devices, with an analysis of the limitations and benefits of the redesigns for specific science goals. We propose how the redesigns, along with other advancements in astrophotonics, can be used in conjunction with adaptive-optics systems to make a prototype instrument with competitive throughput and resolving power. Moreover, we discuss the technologies required for MIR operation of the IPS, and the exciting science possibilities that a completely-photonic spectrograph operating in this wavelength domain can offer for ELTs.

8446-131, Poster Session

GNOSIS: a new near-infrared OH suppression unit at the AAT

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The near-infrared (NIR) is an important part of the spectrum for cosmology because light from objects in the early Universe is redshifted to these wavelengths. However, deep NIR observations are extremely difficult to make from ground-based telescopes due to the bright background emission from the atmosphere. 98% of the background comes from the bright, narrow emission lines of atmospheric hydroxyl (OH) molecules. The atmospheric background cannot be easily removed from the data because the brightness fluctuates unpredictably on short time-scales. The progress of ground-based optical astronomy far exceeds that of NIR astronomy because of this long-standing problem.

GNOSIS is a new prototype astrophotonic instrument at the 4-meter Anglo-Australian Telescope that utilizes complex fiber Bragg gratings to suppress the 103 brightest atmospheric emission lines between 1.47 and 1.7 microns before feeding the signal to the IRIS2 spectrograph. Unlike previous atmospheric suppression techniques the gratings in GNOSIS suppress the lines before dispersion resulting in darker inter-line regions uncontaminated by scattered light from the bright atmospheric lines. Thus, long integrations are possible and more of the inter-line region may be used for science. We present the results of laboratory and the on-sky tests from instrument commissioning. These tests reveal excellent suppression performance by the gratings and high inter-notch throughput, which combine to produce high fidelity OH-free spectra. These exciting results show promise for the future of FBG OH suppression, which on a 10- or 30-meter class telescope would be a simple and cost-effective alternative to spaced-based observations for NIR astronomers.

8446-132, Poster Session

MAIA--the mercator advanced imager for asteroseismology: performance verification and first test results

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The Mercator Advanced Imager for Asteroseismology - MAIA - has been designed to perform photometry observations on rapidly pulsating stars with pulsation periods in the sub-minute domain. In order to precisely resolve different pulsation modes, the amplitude ratios of two separate color bands with respect to the SDSS u color band need to be measured simultaneously. Dichroic beamsplitters are used to separate a collimated light beam in three color bands corresponding approximately to an SDSS u, g, r+i photometric system. The color bands are measured simultaneously with three frame-transfer CCDs that allow full-frame sample rates down to 20s. The controller is designed to simultaneously use up to 10 windows on the detectors and as such reduce the sampling time even more. Each CCD covers a large field of view of 9.4' x 14.1'. They are cooled to 160K with a compact Stirling-type cryocooler. Image degradation due to radial thermal expansion of the optical elements with respect to the instrument structure, is compensated by the opto-mechanical mounting design. Furthermore, the opto-mechanical mountings allow small adjustments for aligning the instrument prior to installation. This alleviates the manufacturing tolerances on the mechanical parts. A software tool has been developed in-house to estimate the performance of the total instrument. The post-alignment performance of the integrated instrument is characterized and compared with the predicted performance. Finite element models of the instrument have been used throughout the design to verify compliance with the requirements in structural flexure and structural dynamics. The structural and thermal performance of the instrument are tested, and the image quality is verified. This paper presents the results of the laboratory performance and of the first on-sky observations of MAIA.

8446-133, Poster Session

OSIRIS commissioning and lessons learned

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OSIRIS is the optical camera-spectrograph of the 10.4m Spanish telescope GTC. This instrument, whose operation started in March 2009, covers from 365 up to 1000 nm with a resolution 2500. OSIRIS observing modes include direct imaging, narrow band imaging with tunable filters, long slit and multiple object spectroscopy, and fast spectrophotometry. The contribution presented here provides the measured overall instrument performance, the calibration results of the different observing modes, the problems encountered during commissioning and operation, and the lessons learned.

8446-134, Poster Session

Improving absolute spectroradiometry of standard stars

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Many astronomical measurements depend on accurate knowledge of the luminosity of calibrated "standard" stars. The now-extensive catalogs of photometric and spectrophotometric standards are all at some level tied to calibrations of Vega and a small set of comparably bright stars made in the 1970s. While these calibrations were state-of-the-art at the time, they are no longer sufficient for certain science programs or next-generation surveys such as the LSST. Notably, calibrations of standard stars are now a limiting factor in supernova cosmology. Advances in radiometry, laboratory instrument characterization and atmospheric monitoring over the past few decades inspired the National Institute of Standards and Technology (NIST) to establish an observatory on Mt. Hopkins, AZ dedicated to re-calibrating Vega and other standards. Mt. Hopkins' unique topography allows us to observe a calibration light source alternately with target stars, maintaining the calibration of the telescope and spectrograph throughout each night of observing. We have also developed facility tools for atmospheric monitoring that allow us to make a direct measurement of atmospheric extinction along the line of sight to either the calibration source or target star during each observation. Here, we present progress toward our goal of sub-1% calibrations of stellar spectra, focusing on spectrograph characterization and atmospheric monitoring along the line of sight to our calibration source. We summarize our program for monitoring extinction along the line of sight to target stars, with a more detailed account to appear elsewhere in these proceedings.

8446-135, Poster Session

A water vapour monitor at Paranal Observatory

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We present the performance characteristics of a water vapour monitor that has been permanently deployed at ESO's Paranal observatory as a part of the VISIR upgrade project. After a careful analysis of the requirements and an open call for tender, the Low Humidity and Temperature Profiling microwave radiometer (LHATPRO), manufactured by Radiometer Physics GmbH (RPG), has been selected. The unit measures several channels across the strong water vapour emission line at 183 GHz, necessary for resolving the low levels of precipitable water vapour (PWV) that are prevalent on Paranal (median ~2.5 mm). The unit comprises the above humidity profiler (183-191 GHz), a temperature profiler (51-58 GHz), and an infrared radiometer (~10 µm) for cloud detection. The instrument has been commissioned during a 2.5 week period in Oct/Nov 2011, by comparing its measurements of PWV and atmospheric profiles with the ones obtained by 22 radiosonde balloons. In parallel an IR radiometer (Univ. Lethbridge on loan from Giant Magellan Telescope) has been operated, and various observations with ESO facility spectrographs have been taken. The RPG radiometer has been validated across the range 0.5 - 9 mm demonstrating an accuracy of better than 0.1 mm. Currently, the radiometer is being integrated into the Paranal infrastructure to serve as a high time-resolution monitor in support of VLT science operations. The water vapour radiometer's ability to provide high precision, high time resolution information on this important aspect of the atmosphere will be most useful for conducting IR observations with the VLT under optimal conditions.

8446-136, Poster Session

Design and lab performance of high resolution Florida IR silicon immersion grating spectrometer

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We report design, lab integration and performance study of Florida IR Silicon immersion grating spectromeTer (FIRST). This new generation cryogenic IR spectrograph offers broad-band high resolution IR spectroscopy with R=72,000 at 1.4-1.8 um in a single exposure with a 2kx2k H2RG IR array. It is enabled by a compact design using an extremely high dispersion silicon immersion grating (SIG) with a 50 mm diameter pupil (an immersion echelle grating with 16.1 l/mm and 54.74 degree blaze angle) in combination with an Image Slicer. FIRST also offers R=60,000 and nearly complete coverage at 0.8-1.35 µm in a single exposure using a commercially available echelle grating. FIRST is designed to couple with the robotically controlled Tennessee State University (TSU) 2-meter telescope through a 1.9 arcsec fiber (a 75 um diameter fiber) at Fairborn Observatory in Arizona for IR high resolution spectroscopy observations starting in fall 2012. While FIRST is a general purpose instrument, our primary science applications are the identification and characterization of extrasolar planets, especially rocky planets in habitable zones, orbiting low mass M dwarf stars through high precision Doppler measurements. It will also be used for the detection and characterization of giant planets around active and young stars, follow-up of transiting planets around M dwarfs identified by the Kepler mission and the MEarth survey, investigations of young stellar objects (YSOs), magnetic fields, binaries, brown dwarfs (BDs), ISM and stars. FIRST can reach S/N ~150 per pixel in a 15 min exposure for a J=8.9 or H=8.2 mag M6 dwarf. The corresponding photon noise limited Doppler precision is approximately 2 m/s, and the projected measurement limit is <3.7 m/s after including uncertainties from calibration and telluric line contamination removal. Results from FIRST design, integration and lab characterization will be presented.

8446-137, Poster Session

Commissioning of the WWFI for the Wendelstein Fraunhofer Telescope

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LMU Muenchen operates an astrophysical observatory on Mt. Wendelstein which has been equipped with a modern 2m-class telescope recently. The new Fraunhofer telescope is designed to deliver the excellent (< 0.7" median) seeing of the site over a 0.2 deg^2 FoV for optical wavebands utilizing a camera built around a customized 64 MPixel Mosaic. The Wendelstein Wide Field Imager (WWFI, 2010SPIE.7735E.106G) had its commissioning in the course of the last few months. Here we report on lab tests and first test observations with the telescope.

8446-138, Poster Session

Testing of the Tor Vergata Fabry-Pérot interferometer prototype

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Fabry-Pérot tunable filters are of great interest in high spectral resolution imaging for both ground-based and space applications.

The prototype here presented has been developed as part of the study for the narrow band channel of the ADAHELI mission.

The ADvanced Astronomy for HELIophysics (ADAHELI) is a solar satellite designed to investigate the dynamics of solar atmosphere as part of the Italian Space Agency (ASI) program.

Although our main goal was to realize an instrument for space use, other ground-based applications have been considered, expecially in the frame of the new 4-meter class of solar telescopes (e.g. ATST, EST). In order to understand the feasibility of a space Fabry-Pérot interferometer, a laboratory prototype has been tested for general mechanical behavior. Spectral profile of the instrument is presented. Spectral and temperature stability and tuning repeatibility are planned to be measured via laboratory tests.

8446-144, Poster Session

Commissioning results of MMT-POL: the 1-5um imaging polarimeter leveraged from the AO secondary of the 6.5m MMT

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MMT-POL is an adaptive optics optimized imaging polarimeter for use at the 6.5m MMT. By taking full advantage of the adaptive optics secondary mirror of the MMT, this polarimeter offers diffraction-limited polarimetry with very low instrumental polarization. MMT-POL permits observations as diverse as protoplanetary discs, comets, red giant winds, (super)novae and ejecta, galaxies, and AGN. We report on the on-sky commissioning results of the instrument including a brief description of the instrument.

8446-145, Poster Session

New scientific results with SpIOMM: a testbed for CFHT's imaging Fourier transform spectrometer SITELLE

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SpIOMM is an imaging Fourier transform spectrometer (FTS) attached to the 1.6-m telescope of the Observatoire du mont Mégantic. It is an integral field spectrometer capable of obtaining spectra of every source of light in a 12 arcminute field of view in selected bandpasses of the visible (350 - 850 nm). Recently upgraded with a new 2k x 2k CCD camera on its second output port, it is now fully functional and as such is an excellent testbed for SITELLE, an imaging FTS being designed and built for the Canada-France-Hawaii telescope. We will present new scientific data obtained with SpIOMM on Galactic clusters and nebulae, as well as nearby galaxies to illustrate its spatial and spectral capabilities. In particular, we will show spatially resolved spectra of supernova remnants Cas A and the Cygnus Loop, the star-forming regions W4 and M42, the planetary nebula M27 and the nearby galaxies M31 and M63. Monochromatic maps and spatially resolved kinematics in a series of emission lines are produced for all objects, as well as diagnostic diagrams allowing us to determine the ionisation mechanisms and chemical enrichment. We will also show stellar spectra to illustrate the absorption-line capabilities of SpIOMM.

8446-146, Poster Session

First results from the GIANO spectrometer

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GIANO is a high resolution (R=50,000) IR spectrograph which provides a quasi-complete coverage of the 0.95-2.5 microns wavelengths range in a single shot. The instrument is being integrated and tested in Arcetri-INAF (Florence) and will be used at the 3.58m TNG Italian telescope in La Palma. The major scientific goals include the search for rocky planets with habitable conditions around low-mass stars, quantitative spectroscopy of brown dwarfs, accurate chemical abundances of high metallicity stars and stellar clusters. This presentation describes the status of the instrument and presents the first results.

8446-147, Poster Session

Testing GIANO spectral stability

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GIANO is a high resolution (R=50,000) IR spectrograph with a quasi-complete coverage of the 0.95-2.5 microns wavelengths range. It was assembled in Arcetri-INAF (Florence) and at present it is under final test.

We present our measurements of internal wavelength stability of Giano spectra. We are using a new approach which gives both the wavelength and field tilts. We also show the comparison with the usual mono-dimensional approach.

8446-148, Poster Session

Improved red sensitivity deep depletion e2v devices for the Gemini North GMOS instrument

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The GMOS-N instrument was upgraded with new detectors in October 2011. The deep depletion devices are manufactured by e2v (42-90 with multi-layer 3 coating) and extend the useful wavelength range of GMOS-N to 0.98 microns (compared to 0.94 microns previously). These detectors also exhibit much lower fringing than the original EEV detectors which have been in use since GMOS-N was commissioned in 2002. All other characteristics of the new detectors (readout speed, pixel size and format, detector controller, noise, gain) are similar to the original CCDs. However, we have been operating the new detectors in all amps mode (as opposed to best amps only) which effectively decreased the readout speed by a factor of 2. The new devices were selected to provide a quick and relatively simply upgrade route while technical issues with the Hamamatsu devices, originally planned for the upgrade, were investigated and resolved. We discuss the rationale for this interim upgrade, the upgrade process and attending issues. The new detectors have been used for science since November 2011, and we also present commissioning results illustrating the resulting gain in sensitivity over the original detector package. Gemini is still committed to installing Hamamatsu devices, which will further extend the useful wavelength range of GMOS to 1.03 microns, in both North and South GMOS instruments. We discuss the current plans for these future upgrades.

8446-149, Poster Session

DeSSpOt: a prototype for the determination of stellar spin orientation

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We have developed an alternative method for the determination of the position angle of stellar rotation axes. Based on spectro-astrometric analysis of high resolution spectra we present here the related concept and the first test results of the prototypes: Differential imagE rotator for Stellar Spin Orientation (DeSSpOt) and its respective echelle spectrograph (DeSSpOtS).

Stellar rotation causes a slight line tilt on the spectrum whose inclination and amplitude are dependent on its position angle and rotational velocity. However, the line tilt is sensible to seeing perturbations. Hence the signature changes between two consecutive exposures.

Consequently DeSSpOt is composed of two optical paths imaging anti-parallel orientations of the star on the slit and producing two almost

identical spectra simultaneously. Thus the recorded spectra are affected by the same perturbations.

DeSSpOt saw first light at the 2m Alfred Jensch Telescope in Tautenburg with the Coude echelle spectrograph. To operate DeSSpOt at the Oskar-Lühning Telescope (OLT) at Hamburg Observatory we constructed the DeSSpOt Spectrograph. DeSSpOtS is based on a white pupil design and combines both high resolution and compactness for being mounted to the Cassegrain focus of the OLT. Moreover, we equipped the system with a tip-tilt adaptive optic (AO) unit in order to reduce the first order optical abberations and to concentrate the light on the slit of the spectrograph.

8446-150, Poster Session

The alignment strategy for LINC-NIRVANA

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LINC-NIRVANA is the near-infrared interferometric imaging camera for the Large Binocular Telescope. Once operational, it will provide an unprecedented combination of angular resolution, sensitivity and field of view.

These ambitious goals go along with a high level of complexity of the instrument, which has to be masted in all phases of the development. LINC-NIRVANA cosists of variety of systems and subsystems. Their internal alignment, the instrument wide alignment and the alignment to the binocular telescope require careful planning.

An alignment strategy for LINC-NIRVANA has to consider the tight requirements that result from wide field interferometric imaging. Two focal planes with identical parameters (orientation, plate scale) have to coincide on the science camera. Instrumental optical pathlength differences have to be minimized. The geometry of the exit pupil within the instrument has to match the geometry that is defined by the telescope. The Adaptive Optics systems share parts of the optical paths of the science channel. These and other aspects impose restrictions on the sequence and methods of the alignment.

In this presentation, a brief overview on the various optical subsystems within the instrument is given, the major constraints for the alignment are described and our strategy for the instrument alignment is outlined.

8446-152, Poster Session

First light observation of GIGMICS (germanium immersion grating mid-infrared cryogenic spectrograph) by Kanata 1.5-m Telescope at Higashi-Hiroshima Observatory

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We have developed a germanium immersion grating mid-infrared cryogenic spectrograph (GIGMICS) designed for the Nasmyth focus stage of NAOJ Subaru 8.2-m telescope, which operates at N-band (8-13 μm) in wavelength (λ) with maximum resolving power R ($\equiv\lambda/\Delta\lambda$) ~ 50,000. A single crystal germanium echelle immersion grating (30 × 30 × 72 mm) for collimated beam size of 28 mmϕ was fabricated by utilizing ultra precision micro-grinding method coupled with the ELID (ELectrolytic In-process Dressing) technique (Ohmori, H. 1992, Ebizuka et al. 2003, Tokoro et al. 2003). After the critical test for the application to the laboratory gas-phase IR high-resolution spectroscopy(Hirahara et al. 2011), we have conducted the “first light” astronomical observation of GIGMICS by the Kanata 1.5-m telescope at Higashi-Hiroshima Observatory from January to April, 2011. Toward many astronomical objects such as the Moon, Venus, Jupiter, circumstellar envelopes of late-type stars, proto-planetary nebulae, and interstellar molecular clouds in the vicinity of star-forming regions, we conducted spectroscopic observations in the N-band region.

8446-153, Poster Session

An unobscured four spherical mirrors based collimator as a trade-off solution for the optical ground support equipment (OGSE) of the high resolution camera (HRIC) of Simbio-sys

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The authors present the trade-off and the merit criteria that lead to the selection of the Michael Brunn “un obscured four mirrors based telescope” as the heart part of the collimator of the Optical Ground Support Equipment In the frame of the Assembly Integration and Verification (AIV) activities forecast for the optical characterization of the High Resolution Camera (HRIC) on board of the Simbio-sys mission to Mercury, instrument currently under development and manufacturing at Selex Galileo facilities in its Florence site. Several optical configurations have been accounted for the design and manufacturing of the three meters focal length, diffraction limited and wide field of view (0.4X0.6 degs) toolkit. From the classical un obscured systems such as the Three Mirror Anastigmat (TMA) to the off axis Schmitt’s, working under an f -number of twelve, the Brunn’s solution revealed excellent optical quality free from coma, astigmatism and spherical aberration accomplished by an ultra compact design in within a volume of 1.2x1.0 x0.5 cubic meters and other basic advantages such as the relative easy way in aligning and manufacturing the mirrors.

8446-154, Poster Session

Commissioning of a new multi-band camera for REM

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Results of the commissioning of a new multi-band visible camera for the robotic REM telescope in La Silla (Chile) are provided, with details of the final design choices of this compact system. The optical design is based onto dichroic beamsplitters to separate light into four different Sloan g’, r’, i’, z’ bands, that are directed onto four different quadrants of a 2kx2k CCD detector, that allow fast and fully simultaneous multi-band acquisitions. Many efforts have been spent to optimize performances within the available tight budgets, both in term of image quality, throughput, distortion, manpower and cost.

8446-155, Poster Session

Simulations and performances of AMICA at Dome C

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We present the results coming from the computation of expected performances of AMICA (Antarctic Multiband Infrared Camera) the near (2-5 micron) and mid-infrared (5-28 micron) instrument that will be mounted on ITM (Infrared Telescope Maffei, formerly IRAIT) at Dome C,

in Antarctica. They have been calculated through the images obtained by a focal plane simulator that allows a closest and more accurate representation of real data. The input parameters, the numerical methods and the simulation pipeline we used are also discussed in this work. Numerical simulations, exploit the bi-dimensional distribution of sources signal and noise contributions, taking into account all the telescope and camera characteristics (optics, read-out electronics and detectors) and the Antarctic site properties (although partially known). Available data about Dome C sky (transmission and emission curves) have been used to reproduce the photon flux from different source types, combined with background flux contributions. Moreover, the measurement of the S/N ratio on the obtained images is used to evaluate the best observing procedures, according to the selected filters and the sources properties. The simulation algorithm and all collected information will be also useful to define the schedule of the robotic observatory.

8446-156, Poster Session

WINERED: performances of a warm infrared echelle spectrograph

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WINERED is a newly built high-efficiency (throughput > 25-30%) and high-resolution (R_max = 100,000) spectrograph customized for short NIR bands at 0.9-1.35 um. WINERED will be equipped with portable design with a ZnSe and ZnS immersion grating, ambient temperature optics, and a cryogenic camera using a 1.7 um cutoff HgCdTe HAWAII-2RG detector array. WINERED have been located at the Nasmyth platform of 1.3 meter Araki Telescope at Koyama Astronomical Observatory of Kyoto Sangyo University. We have just completed the engineering test with the conventional echelle grating, which can cover the entire wavelength range simultaneously with R_max = 30,000. In this poster paper, we will present the results of optical testing for checking spectral resolution and throughput. We will also report the performance of the detector at 80 K as well as the low-background performance of WINERED with the warm optics. We plan to complete the immersion grating mode, which provides R_max = 100,000 in 2012.

8446-157, Poster Session

Characterizing the near-infrared sky brightness in the Canadian high Arctic

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We present the first monitoring of sky background longward of 1 micron North of 80 degrees latitude, in the Canadian High Arctic. There has been considerable recent interest to set up an astronomical observatory on Ellesmere Island, which is in the Canadian High Arctic. Initial site testing has shown promise for a site suitable for astronomical observations near Eureka, Nunavut. Sky background measurements in the Antarctic during the winter night revealed markedly lower near-IR emission when compared to a good mid-latitude astronomical site due to reduced emission from hydroxyl airglow lines. This is possibly a polar effect, and may also be present in the High Arctic. To test this hypothesis, we constructed a J-band photometer capable of enduring the harsh arctic conditions, and carried out observations of near-infrared sky brightness from the Polar Environment Research Laboratory near Eureka, Nunavut (latitude: 80 degrees N). The initial measurements suggest a lower J-band background than a good mid-latitude site. We present the design of our ruggedized photometer and our results from our Arctic observing campaigns.

8446-158, Poster Session

APOGEE cryostat performance

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The Apache Point Observatory Galactic Evolution Experiment (APOGEE) is a newly initiated survey of all Galactic stellar populations employing an R~22,500 spectrograph operating in the near-infrared (1.5-1.7μm) wavelength range. The 300 fiber-fed spectrograph is housed in a large (1.4m x 2.3m x 1.3m) stainless steel cryostat and is located in a building near the 2.5m Sloan Digital Sky Survey (SDSS) telescope to which it is coupled. The fully-integrated spectrograph was delivered to APO in late-April 2011, has been commissioned, and is in the first months of collecting science-quality data on a three year survey. Over 40,000 stellar spectra have been taken in 2011. APOGEE is one of four experiments that are part of Sloan Digital Sky Survey III (SDSS-III).

Performance of the cryostat, the subject of this report, has exceeded design specifications for heat load, thermal stability, and vacuum quality. The cryostat is providing the stable, maintenance-free service needed for a long-term survey operations. This report summarizes the final configuration of the cryostat relative to thermal and vacuum performance, details performance parameters, and discusses useful strategies for improving thermal and vacuum performance of LN2 cooled large spectrographs.

8446-159, Poster Session

AMICA at Dome C: results from the first year of automatic operation tests in Antarctica

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The results from the first year of AMICA operations at Dome C are presented. AMICA (Antarctic Multiband Infrared CAmera) is a NIR-MIR (2 - 24 micron) astronomical camera to be mounted at the focal plane of the 80-cm telescope ITM (Infrared Telescope Maffei, formerly IRAIT). It is designed to work at the extreme environmental conditions of the Antarctic Plateau and to be operated without human intervention.

With the exception of the cryostat, AMICA control and readout devices are hosted inside a thermally insulated rack, provided with an extensive set of temperature sensors, heaters and coolers. These devices are controlled by a PLC which also records the electrical parameters. As a result, a robotic system (Environmental Control System) is set up in order to continuously keep the operating conditions of each device around their optimal values.

AMICA has been shipped to Antarctica in November 2010. During 2011, the rack automatic control has been tested under the severe environmental conditions of the Antarctic winter (temperatures down to below -80 C, pressure around 630 mbar, extremely dry air).

More than 100 days, 24-hour each, have been obtained. About 250 telemetries have been continuously recorded, at time intervals not exceeding 1 minute, reporting all the operating parameters.

The results show an excellent performance of the system, with a very poor statistical sample of problems or critical conditions. A quality factor indicating the robotic performance is computed as a function of the external conditions. A few critical points to be corrected are finally described.

8446-161, Poster Session

A new nasmyth mirror mechanism increases the number of focal stations of the Mercator Telescope

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Originally, the Mercator telescope (Roque de Los Muchachos Observatory, La Palma) only had one cassegrain and one nasmyth focal station available. Both foci are currently occupied and the exploitation scheme of the Mercator telescope does not allow regular instrument changes. To accommodate our new instrument MAIA and to allow flexible scheduling with rapid follow-up of transient phenomena, we have designed and built a new mechanism for the nasmyth mirror that enables the use of the second nasmyth focal station and of two compact intermediate foci at the front and the rear side of the telescope tube. This mechanism uses high-precision gears, bearings and optical encoders to allow for flexible and very accurate positioning of the nasmyth mirror along the rotation and seesaw axes. It is controlled by a programmable logic controller (PLC) that is the precursor of a completely new PLC and OPC-UA based telescope control system. We present the design, the construction and the performance of this tertiary mirror mechanism. We also give an overview of the instrumentation suite installed at the cassegrain and nasmyth foci of the Mercator telescope. It consists of three optical instruments that are permanently available: a direct imager with a 16-positions filter wheel, a fiber-fed high-resolution echelle spectrograph and a three-channel imager that offers simultaneous observations in three color bands over a wide field of view.

8446-162, Poster Session

LINC-NIRVANA--integration of an interferometric camera: First verification results

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LINC-NIRVANA is an interferometric imaging camera, which combines the two 8.4 m telescopes of the Large Binocular Telescope (LBT). The instrument operates in the wavelength range from 1.1 µm to 2.4 µm, covering the J, H and K-band, respectively. The camera, which combines the AO corrected beams of both telescopes, is designed to deliver a 10 arcsec x 10 arcsec diffraction limited field of view. The optics and cryo-mechanics are designed for operation at 60 Kelvin. Equipped with a HAWAII-2 detector mounted on a rotation stage in order to compensate for the sky rotation, a 22 position filter wheel and a dichroic wheel to split the light into the science channel and the fringe tracking channel, the camera is fairly large and complex and requires certain features to be considered and tested.

The verification of all these components follows a challenging AIV plan. We describe this AIV phase from initial integration of individual units to the final verification tests of the complete system, including the strategy on how to manage the complex interactions with other instrument parts. We report the performance of the cryogenic optics and of the science detector, and we demonstrate the functionality of the cryo-mechanics and the cryo-cooling, as well as for the complete system.

8446-164, Poster Session

KiwiSpec: design and prototype performance of a new high resolution astronomical spectrograph

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A new advanced high resolution spectrograph has been developed by Kiwistar Optics of Industrial Research Ltd., New Zealand. The instrument, KiwiSpec R4-100, is bench-mounted, fibre-fed, compact (0.75m by 1.5m footprint), and is well-suited for small to medium-sized telescopes. The instrument makes use of several advanced concepts in high resolution spectrograph design. The basic design follows the classical white pupil concept in an asymmetric implementation and employs an R4 echelle grating illuminated by a 100 mm diameter collimated beam for primary dispersion. A volume phase holographic grating-based grism (VPHG) is used for cross-dispersion. The design also allows the addition of two or more camera and detector channels to allow for extended wavelength coverage at high efficiency. A single channel prototype of the instrument has been built and successfully tested with a 1-m telescope. Targets included various spectrophotometric standard stars and several radial velocity standard stars to measure the instrument's light throughput and radial velocity capabilities. The prototype uses a 725 lines/mm VPHG, an off-the-shelf camera objective, and a 2k x 2k CCD. As such, it covers the wavelength range from 420nm to 660nm and has a resolving power of R=40,000. Precision radial velocity and spectrophotometric results from the on-sky testing period will be reported, as well as results of laboratory-based measurements.

8446-165, Poster Session

Catadioptric focal reducers for classic reflectors

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Several optical designs of catadioptric focal reducers for upgrading existing medium- and large-aperture telescopes are presented. Primary design goals were increase of photographic speed and achievement of good seeing sampling with high-resolution large-format CCD photodetectors, improving system's throughput in survey work when compared with available traditional solutions and simultaneously keeping low cost of upgrade using small-pixel CCD array. Developed units are lowering focal ratio from f/4 to f/1.8-f/2 for prime-focus configuration with parabolic mirror and from f/13-f/15 to f/1 for Cassegrain configuration. Focal reducer for Armenian ZTA 2.6 m reflector currently in production will allow use of STA-1600A CCD detector of 95x95 mm sensitive area and 9 um pixels (111 megapixels total). This will allow upgraded system to compete with dedicated survey telescopes with Wynne family prime-focus correctors and large-format CCD mosaics, while single-chip CCD camera costs a fraction of mosaic with comparable pixels count. Use of catadioptric optical design allows focal reduction without expensive special glasses, large optical components of reducer are made of same and arbitrary optical glass, like BK7 in presented designs, or, for example, fused silica if UV transmission is desired. Glass selection is performed only for field corrector of small size. Designs based on Mangin mirror are explored, including Hamiltonian and Zonnefeld designs for prime-focus reducers without intermediate parallel beam and Hamilton-Cassegrain collimator + folded Hamilton camera design for Cassegrainian focus unit. Prime-focus unit is developed to be easily interchangeable with Cassegrain secondary mirror and easily integrating with existing telescope.

8446-167, Poster Session

A comparison of the mechanical design of fiber feeds for GRACES and GHOS

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The instrument group of the Herzberg Institute of Astrophysics has been commissioned by the Gemini Observatory to participate in a competing conceptual design study for a new Gemini High-Resolution Optical Spectrograph (GHOS). Concurrently this same group is working in partnership with both the Gemini and CFH Telescopes to design the Gemini Remote Access to CFHT ESPaDOnS Spectrograph, (GRACES). Both these instruments will use a fiber feed allowing light received at the telescope to be processed via remotely positioned instruments. This paper will explore the similarities and differences in requirements, inherent challenges, concepts, design solutions and areas of concept sharing.

8446-168, Poster Session

Tools for DIY site-testing

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Our group has designed, sourced and constructed a radiosonde/ground-station pair using inexpensive open-source hardware. Based on the Arduino platform, the easy to build system allows the atmospheric science community to test and deploy instrumentation packages that can be fully customized to their individual sensing requirements. This sensing/transmitter package has been successfully deployed on a tethered-balloon, weather balloons, a UAV airplane, and most recently within a student-built rocket. The relatively low system cost also opens up the possibility of having wide-spread sensor networks able to provide higher spatial resolution. The system and potential applications will be described along with the science drivers of having full control and open access to a measurement system in an age when commercial solutions have become popular but are restrictive in terms of proprietary sensor specifications, “black-box” calibration operations and data handling routines, etc. The ability to modify and experiment with both the hardware and software tools is an essential part of the scientific process. Without an understanding of the intrinsic biases or limitations in your instruments and system, it becomes difficult to improve them in order to advance the knowledge in any given field.

8446-169, Poster Session

First light with the high resolution near infrared spectrometer for zodiacal light studies

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We have completed the instrument tests and had the first light with the high throughput cryogenic Fabry-Perot spectrometer for measuring near infrared absorption lines in the zodiacal light spectrum. Based on large diameter temperature tuned silicon etalons the instrument delivers high resolution (R=20,000). This allows to reliably measure Fraunhofer lines equivalent width in the zodiacal light spectrum. A numbe rof lines in J band around 1.2 um was selected. The results of these measurements will be very important not only for the zodiacal light studies itself, but for accurate subtraction of zodiacal light foreground and thus accurate measure of the remainder, the extragalactic background light. We present the instrument development results and the first light data.

8446-170, Poster Session

Rapid infrared imager-spectrometer (RIMAS) for the Discovery Channel Telescope

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As a collaborative effort between GSFC, UMd and Lowell observatory we are developing a Rapid near infrared IMAger-Spectrometer - RIMAS. The primary goal of this instrument is to rapidly conduct follow up observations on GRB afterglow detections to determine the redshift and potentially IGM properties via high resolution spectroscopy. The instrument is being designed for the newly built 4.3m Discovery Channel Telescope. RIMAS has three operation modes: imaging, low spectral resolution of R~20 and high resolution mode of R~5000. The spectral coverage spans from 0.9um to 2.4um (Y,J, H and K bands). The optical layout has two arms with two detectors allowing for simultaneous imaging in two bands. Besides YJHK filters we plan to have a number of specialty filters provided by the individual programs of interest. RIMAS is a fully cryogenic instrument with optical elements placed inside of a cryostat. The imaging modes are designed to be diffraction limited, with one pixel corresponding to 0.35 arcseconds. With broad spectral coverage and both imaging and spectral modes available, RIMAS will be a flexible tool for a variety of imaging and spectroscopic studies.

8446-171, Poster Session

Cryogenic mechanical design: SPIROU spectrograph

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This paper presents an overview of the PDR level mechanical and opto-mechanical design of the cryogenic sprectrograph unit of the nIR spectropolarimeter (SPIROU) proposed as a new generation instrument for CFHT. The design is driven by the need of high thermo mechanical stability in therms of RV of 0.5m/s during 1 night, with the requirement for thermal stability set at 1 mK/24 hours. This paper describes stress-free design of the cryogenic optical mounts, mechanical design of the custom-build cryostat, mechanical design of the optical bench, and thermal design for 1 mK thermal stability. Thermal budget was calculated using lumped mass model thermal analysis, implemented in Modelica multi-domain modeling language. Discussion of thermal control options to achieve 1 mK thermal stability is included.

8446-172, Poster Session

On-sky operations and performance of LMIRcam at the Large Binocular Telescope

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The L/M-band (3-5 microns) InfraRed Camera (LMIRcam) sits at the combined focal plane of the Large Binocular Telescope Interferometer (LBTI), ultimately imaging the coherently combined focus of the LBT's two 8.4-meter mirrors. LMIRcam achieved first light at the LBT in May 2011 using a single AO-enabled 8.4-meter aperture. Taking advantage of the recently installed adaptive secondary mirror, LBTI delivered near diffraction-limited images to LMIRcam with measured Strehl ratios upwards of 0.95 at M-band. We report on the performance of this single-eye configuration and characterize the noise performance of LMIRcam's HAWAII-2RG 5.3-micron cutoff array paired with the Cornell FORCAST readout electronics. In addition, we describe early results from upcoming operational modes such as dual-aperture interferometry, grism spectroscopy, and coronagraphic phase plates. Finally, given LMIRcam's on-sky performance, we discuss a sample of potential contributions to the scientific community.

8446-173, Poster Session

ISAS: interferometric stratospheric astrometry for solar system

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The Interferometric Stratospheric Astrometry for Solar system (ISAS) project is designed for high precision astrometry on the brightest planets of the Solar System, with reference to many field stars, at the milli-arcsec (mas) level or better.

The science goal is the improvement on our knowledge of the dynamics of the Solar System, complementing the Gaia observations of fainter objects.

The technical goal is the validation of basic concepts for the proposed Gamma Astrometric Measurement Experiment (GAME) space mission, in particular, combination of Fizeau interferometry and coronagraphic techniques by means of pierced mirrors, intermediate angle dual field astrometry, smart focal plane management for increased dynamic range and pointing correction.

We discuss the suitability of the stratospheric environment, above 99% of the atmosphere, i.e. close to space conditions, to the astrometric requirements.

The instrument concept is a dual field, multiple aperture Fizeau interferometer, observing simultaneously two fields, in order to improve on the available number of reference stars.

Coronagraphic solutions are introduced to allow observation of internal planets (Mercury and Venus), as well as of external planets over a large fraction of their orbit, i.e. also close to conjunction with the Sun.

We describe the science motivation, the proposed experiment profile and the expected performance.

8446-174, Poster Session

Analysis of stellar radiance contamination in observed satellite spectra

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Reflectance spectra of Earth orbiting satellites can be readily observed with small diameter telescopes (D < 1m) by utilizing a method known as slitless spectroscopy. This method treats satellites as point sources for unresolved small diameter telescopes. Satellite spectra can then be observed by simply placing a transmission grating within the collimated optical path of the telescope without the need to image through a slit. The simplicity of the slitless spectroscopy design makes it a promising alternative to spatially resolving satellites with larger and more expensive diameter telescopes for applications of space situational awareness. However, accurately observing satellite reflectance spectra without imaging through a slit requires a dark and homogeneous background. This requirement is frequently violated as background stars streak across the image due to the slewing motion of the telescope during satellite tracking. Rather than throwing out all images with noticeable stellar contamination, a principle component analysis of contaminated images showed that it may still be possible to assess and identify satellite characteristics depending upon the amount of stellar contamination in the spectral region of interest.

8446-176, Poster Session

The GRAVITY spectrometers: final mechanical design

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GRAVITY is a 2nd generation VLTI Instrument which operates on 6 interferometric baselines by using all 4 UTs. Assisted by an adaptive optics it will offer narrow angle astrometry in the infrared K-band with an accuracy of 10µas. The main unit is the beam combiner instrument inside a large cryostat. In front of the two spectrometers the 4 beams from each UT are combined by integrated optics to 24 channels.

The University of Cologne is part of the international GRAVITY consortium and responsible for the design and manufacturing of the two spectrometers. One is optimized for observing the science object, providing three different spectral resolutions and optional polarimetry, the other is optimized for a fast fringe tracking at a spectral resolution of R=22 with optional polarimetry. In order to achieve the necessary image quality, the final mechanical design includes altogether 5 mechanisms operated under cryogenic conditions.

This contribution presents the final mechanical design of both spectrometers and will give a detailed description of the cryogenic mechanisms: two linear stages based on compliant joints and extender drives, a filter wheel with a ratchet device and two in/out mechanisms also driven by extender wheels. Further aspects of the final design covered by this paper are the manual adjustments, the optical mounts for the cryogenic environment and the stray light suppression.

Moreover this presentation will include an overview of the subassemblies or prototypes which have already been built.

8446-177, Poster Session

Optical interferometric spectral construction

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Interferometric spectral construction multiplies a spectrograph's resolution by large factors across its full and simultaneous bandpass.

The method combines a cavity-delay series of externally-dispersed interferometer recordings in a manner analogous to radio astronomy spectral reconstruction techniques. We report our progress in refining spectral reconstruction analyses methods and applying them to achieve order of magnitude improvements in effective spectral resolution across large swaths of the near-infrared pass band, where we compare our spectral constructions to telluric features.

We investigate the application of spectral constructions to high-resolution template spectra used for radial velocimetry(RV) planet searches. The template spectral-noise sensitivity of RV measurements, challenged by present point-spread function deconvolution techniques, may prove amenable to spectral reconstruction's frequency sampling.

8446-178, Poster Session

Khayyam: a tunable spatial heterodyne spectrometer for observing diffuse emission line targets

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We describe first-light results from a new instrument-telescope configuration that combines all of the capabilities necessary to obtain high resolving power visible band spectra of diffuse targets from small aperture telescopes where significant observing time can be obtained. This instrument -Khayyam- is a tunable all-reflective spatial heterodyne spectrometer (SHS) that is mounted to a fixed focal plane shared by the 0.6m Coude auxiliary telescope and the 3m Shane telescope on Mt. Hamilton. Khayyam has an up to 78 arcmin input field of view, resolving power up to 176000, and a tunable bandpass from 350-700 nm. It is being field tested for initial use to study spatially extended solar system targets where high resolving power is necessary to separate multimodal signals, crowded molecular bands, and to sample low (<10 km/s) velocities and rapid temporal cadence is necessary to track physical evolution. The initial target is comet C/2009 P1 (Garradd), a dynamically new comet that will be observable during the first 6 months of 2012 as it recedes from the Sun and decreases in activity.

8446-179, Poster Session

Tips and tricks for aligning an image derotator

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One of the possible key reference element in optical alignment is represented by a rotational stage, a mechanical bearing, with enough accuracy and precision in the rotation such that the optical tolerances are reasonably larger than the imperfections in the rotational movement. This allows for a safe, reliable, determination of both rays parallel to the axis or to their centering within almost any plane. An image derotator, made up by three flat mirror arranged in a so called K-mirror layout, moving together on a precision rotating stage, seems to be the most safe, solid, and self built-in alignment tool. However, just because the nature of the two effects is very similar, care has to be given when internally aligning and aligning externally with respect to an existing opto-mechanical system, are to be accomplished within a certain degree of precision.The specific case study of the two K-mirrors on board LINC-NIRVANA is here depicted along with a few lessons learned.

8446-374, Poster Session

A powerful ethernet interface module for digital camera control

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We have found a commercially-available ethernet interface module with sufficient on-board resources to largely handle all timing generation tasks required by digital imaging systems found in astronomy. Two separate implementations of this hardware concept have been successfully accomplished for both science and guide camera CCD systems.

8446-18, Session 3

Status of the KMOS multi-object near-infrared integral field spectrograph

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KMOS is a unique multi-object near-infrared integral field spectrograph being built by a consortium of UK and German institutes for the ESO VLT. During the past two years the various subsystems of KMOS have been completed by the consortium partners, and the final integration and test phase has begun at the UK ATC. We report on the activities undertaken during the integration phase, and the results of the final system verification and performance tests, prior to the instrument being shipped to Paranal to begin commissioning in summer 2012.

8446-19, Session 3

The second generation VLT instrument MUSE: final assembly in Europe and performance assessment

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The Multi Unit Spectroscopic Explorer MUSE is a second generation VLT instrument. MUSE is an innovative wide field integral field spectrograph operating in the visible.

It is designed to achieve high throughput, high spatial resolution, wide

field of view and large simultaneous spectral range.

MUSE will be assisted by the VLT ground layer adaptive optics ESO facility using four laser guide stars. The instrument is a large assembly of 24 identical high performance integral field units, each one composed of an advanced image slicer, a spectrograph and a 4kx4k detector. The instrument has recently been fully assembled and tested. In this paper we review the measured global performance of the instrument before it is sent to Paranal for commissioning.

8446-20, Session 3

Subaru FMOS now and future

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Fiber Multi Object Spectrograph “FMOS” on Subaru Telescope has been in operation and available for general users since May 2010. While it was operated initially with 200 fibers (out of 400 in total) fed to one of the two spectrographs operating in the Low Resolution (LR) mode (0.9--1.8 microns is covered simultaneously with R=600) only, commissioning works have been done in parallel and from the year of 2011, 400 fibers have become available for configuration and spectroscopy. From 2012, the High Resolution (HR) mode (a section of 0.2 microns between 0.9 and 1.8 microns is covered with R=2200) as well as LR mode will be available on the two spectrographs and observers can choose either of them. In this article, first we will give an overview of the instrument and its current status with highlighting some details of the subsystems and showing example data.

Recently we have started an upgrade project of fiber configuration to use a “metrology camera”, through a collaboration with the “PFS” (Prime Focus Spectrograph) project, a next generation wide-field fiber multi object spectrograph on Subaru. After this upgrade, the positions of the 400 fibers on the focal plane will be measured quickly and the fiber configuration time, which is currently 13 minutes, will be shortened significantly (the overhead in the total observing time is expected to be reduced from 30 percent to less than 10 percent). In this article, we will also report the status of this upgrade project and upcoming schedule of commissioning.

8446-21, Session 3

VIRUS: production of a massively replicated fiber integral field spectrograph for the upgraded Hobby-Eberly Telescope

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The Visible Integral-field Replicable Unit Spectrograph (VIRUS) consists of a baseline build of 150 identical spectrographs (arrayed as 75 pairs) fed by 33,600 fibers, each 1.5 arcsec diameter, at the focus of the upgraded 10 m Hobby-Eberly Telescope (HET). VIRUS has a fixed bandpass of 350-550 nm and resolving power R~700. VIRUS is the first example of industrial-scale replication applied to optical astronomy and is capable of surveying large areas of sky, spectrally. The VIRUS concept offers significant savings of engineering effort, cost, and schedule when compared to traditional instruments.

The main motivator for VIRUS is to map the evolution of dark energy for the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX), using 0.8M Lyman-alpha emitting galaxies as tracers. The full VIRUS array is due to be deployed in late 2012 and will provide a powerful new facility instrument for the HET, well suited to the survey niche of the telescope, and will open up large surveys of the emission line universe for the first time. VIRUS is now in production. We will review the production design and lessons learned in reaching volume production.

8446-22, Session 3

SuperMOS: a new class of low resolution multiobject spectrographs

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Microwave Kinetic Inductance Detector (MKID) arrays, recently demonstrated at the Palomar 200” telescope, are a new superconducting detector technology that has great potential for astrophysics. MKIDs count individual photons with microsecond timing accuracy, and like X-ray calorimeters, can determine the energy of each photon to several percent without read noise, dark current, and with nearly perfect rejection of cosmic rays. They are sensitive over a wide wavelength range, with good quantum efficiency from the UV through near-IR.

We propose a new type of Superconducting Multi-Object Spectrograph (SuperMOS) that uses MKIDs in conjunction with a focal plane mask. Using pre-existing imaging, a mask is drilled with holes corresponding to known locations of galaxies, one hole placed within each square grid location. The mask is placed in the focal plane, enabling the light from the galaxies to be mapped, one source per pixel, onto a MKID array. Pixels without sources will be used to generate a spatial/spectral/temporal model of the sky for sky subtraction.

Here we explore the design and science goals of a SuperMOS designed for LSST follow-up. Housing a 100,000 pixel MKID array with energy resolution R=50-100 and a 0.35-1.35 μm bandwidth, Giga-z will be capable of measuring 2 billion spectra over 20,000 square degrees in 3 years down to mi=24 on a dedicated 4-meter telescope, 1000 times the number of galaxies that could be measured with any other proposed LSST spectroscopic follow-up. Giga-z will significantly improve upon the Dark Energy and galaxy evolution science returned by LSST alone.

8446-23, Session 4

WEAVE: the next generation wide-field spectroscopy facility for the William Herschel Telescope

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WEAVE is new project to develop a wide field high-multiplex spectroscopy facility for the William Herschel Telescope to complement ground and space-based all-sky survey programmes such as GAIA and LOFAR. The main capabilities of WEAVE are 1000 MOS fibres accessing a 2 degree field of view at prime focus, and feeding a single dual-beam spectrograph which provides full coverage from 370-1000nm at R=5000 in a single exposure. The VPH gratings can be exchanged to give R=20000 over a limited wavelength range in each arm. The spectrograph can also receive input from single and multiple integral field units which can be deployed within the WEAVE positioner. WEAVE is now in its PDR phase, with first science light expected at the WHT in early 2017.

8446-24, Session 4

Mapping the universe with BigBOSS

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The BigBOSS experiment is a redshift survey designed to map the large scale structure of the universe and probe the nature of dark energy. Using massively-multiplexed fiber spectroscopy over 14,000 deg ^{2} of sky, the survey will deliver more than 20 million galaxy and quasar redshifts. The resulting three dimensional sky map will contain signatures from primordial baryon acoustic oscillations (BAO) that set a 'standard ruler' distance scale. BigBOSS will measure the BAO distance scale to sub-percent accuracy from 0.5

8447-01, Session 1

Status of the ARGOS ground layer adaptive optics system

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ARGOS, the Advanced Rayleigh guided Ground layer adaptive Optics System for the LBT (Large Binocular Telescope), is built by a German-Italian-American consortium. It will be a seeing reducer correcting the turbulence in the lower atmosphere over a field of 2' radius. In this way we expect to improve the spatial resolution over the seeing by a factor of between two and four and to increase the throughput for spectroscopy accordingly. In its initial implementation, ARGOS will feed the two near-infrared imaging spectrographs LUCI I and LUCI II.

The system comprises six Rayleigh lasers - three per eye of the LBT. The lasers are launched from behind the two adaptive secondary mirrors of the LBT. ARGOS has one wavefront sensor unit per primary mirror, each with three Shack-Harmann sensors imaged on one detector.

In 2010 and 2011, we have already mounted parts of the instrument at the telescope to provide an environment for the main sub-systems. The commissioning of the instrument will start in 2012 in a staged approach.

We will give an overview of ARGOS and its goals and report the status and new challenges we have encountered during the building phase. Finally we will give an outlook of the upcoming work, how we will operate the system, and the further possibilities enabled by its design.

8447-02, Session 1

'Imaka: working towards very wide-field of view AO

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Ground-layer adaptive optics (GLAO) has the potential to dramatically increase the efficiency and capabilities of existing ground-based telescopes over a broad range of science observations. Recent studies of the optical turbulence above several astronomical sites (e.g. Mauna Kea, Paranal, and Antarctica) show that GLAO can be extended to much larger fields than previously thought (tens of arcminutes) with angular resolutions close to the free-atmosphere seeing. This is a pivotal result since GLAO science cases benefit from the largest possible corrected fields of view. The corrected areal field of a GLAO system is potentially 2-3 orders of magnitude larger than has been demonstrated to date. The `Imaka team is working toward an instrument that takes full advantage of the one-degree field afforded by Mauna Kea. In this paper we summarize the design/simulation work to date

8447-03, Session 1

Wide-field adaptive optics for Subaru Telescope

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We started a feasibility study of next generation adaptive optics (AO) system for Subaru Telescope. The current AO system at Subaru Telescope is a single conjugate 188-element AO (AO188) with single laser guide star or single natural guide star.

AO188 is installed at Nasmyth platform and operates together with IRCS (InfaRed Camera and Spectrograph), HiCIAO (High Contrast Imager with AO), SCExAO (Subaru Coronagraphic Extreme AO), Kyoto 3D-II (Visible IFU spectrograph and Fabry-Perot imaging interferometer).

While various instruments at the Nasmyth IR with single conjugate AO are used or planned, the wide field near-infrared instrument with advanced AO system at Cassegrain focus is one of anticipated directions to the future. Simulation of wide field AO showed us that GLAO is preferable for the near-infrared instrument at Cassegrain focus up to 20 arcmin field of view (FOV). This result is support the previous study of GLAO at Mauna Kea, where the best site for GLAO. In parallel, the key components for GLAO, such as a deformable secondary mirror, control algorithm of GLAO, multiple laser system, wavefront sensor for multiple LGS and NGS, are under consideration.

Additionally, preliminary study of wide field instrument is undergoing. We start investigating how to realize the maximum size of FOV in imaging

and spectroscopy through the preliminary optical design.

In this presentation, we introduce the status of feasibility study on wide field AO as well as wide field near infrared instrument at Cassegrain focus of Subaru Telescope.

8447-04, Session 1

Robo-AO: autonomous and replicable laser-adaptive-optics and science system

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Robo-AO is an autonomous laser guide star adaptive optics (AO) system specifically engineered for few-meter class telescopes. The system takes advantage of cost-effective advances in deformable mirror and laser technology and integrates visible and near-infrared instrumentation. Robo-AO has demonstrated wavefront correction sufficient for diffraction-limited resolution imaging at visible and near-infrared wavelengths at the Palomar Observatory 60-inch telescope, 0.1”-0.25”, with early results being included in several science publications. Software automations will keep target-to-target observing overheads at less than 1 minute and allow Robo-AO to observe hundreds of targets per night. This will enable the exploration of science parameter spaces such as extremely large (10K+) targeted AO surveys, rapid AO imaging and characterization of transient events and long-term AO monitoring not feasible on large diameter telescopes. The first Robo-AO system is mid-way through its on-sky commissioning period which precedes a month long science demonstration at the 60-inch telescope, expected in the fall of 2012. Three other implementations of Robo-AO are in various stages of development: work on a clone of Robo-AO for the 2-m IUCAA Girawali Observatory near Pune, India is starting in early 2012; a natural guide star only system for the 1-m Table Mountain telescope is being led by Pomona College; and a system dedicated to precision near-infrared astrometry is being studied for deployment at the South Pole.

8447-05, Session 2

Overview of deformable mirror technologies for adaptive optics and astronomy

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From the ardent bucklers used during the Syracuse battle to set fire to Romans’ ships to more contemporary piezoelectric deformable mirrors widely used in astronomy, from very large voice coil deformable mirrors considered in future Extremely Large Telescopes to very small and compact ones embedded in Multi Object Adaptive Optics systems, this presentation aims at giving an overview of Deformable Mirror technology for Adaptive Optics and Astronomy.

It will start with a recall of the main drivers for the design of Deformable Mirrors, not only related to atmospheric aberration compensation but also to environmental conditions or mechanical constraints. Then the different technologies available today for the manufacturing of Deformable Mirrors will be described, pros and cons analyzed. A review of the Companies and Institutes with capabilities in delivering Deformable Mirrors to astronomers will be presented, as well as lessons learned from the past 25 years of technological development and operation on sky. In conclusion, perspective will be tentatively drawn for what regards the future of Deformable Mirror technology for Astronomy.

8447-06, Session 2

TMT DMs final design and advanced prototyping results at Cilas

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In order to prepare for the construction phase of the two deformable mirrors (DMs), which will be used in the Thirty Meter Telescope (TMT) first light Adaptive Optics (AO) system, Cilas has advanced the design of these two large size piezo DMs and has manufactured and tested a scaled demonstration prototype.

The work done allowed significant reduction of the risks related to the demanding specifications of the TMT DMs; the main issues were:

(i) Large pupil (up to 370 mm) and high order (up to 74x74);

(ii) Relatively low operational temperature (DMs working at -30C);

(iii) New piezo material.

It is important to develop such a prototype to take into account these three specifications all together (dimension, low temperature and new piezo material). The new prototype is a 6x60 actuators and has the same characteristics as the future TMT DMs.

In this paper, we will give the conclusions of the work through the presentation of the following items:

(i) Design and finite element analysis of the two DMs and prototype;

(ii) Test results obtained with the prototype with validation of the finite element analysis and compliance with the TMT AO specifications;

(iii) Special focus on thermal behavior, actuator reliability and shape at rest stability.

8447-07, Session 2

Low-cost unimorph deformable mirror with high actuator count for astronomical adaptive optics

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Bimorph/unimorph deformable mirrors (DM) are attractive and widely applied in the field of astronomical imaging, laser beam shaping, vision science etc., due to their simple structure, light-weight and excellent correction capability. During past two decades, many kinds of bimorph/unimorph DMs have been designed and fabricated by both industries and research institutes. However, most of these DMs have no more than 200 actuators and are usually used for the low-order aberrations correction.

Here, we report the development of a low-cost unimorph DM with high actuator count for astronomical adaptive optics. The DM consists of a 400 μm thick silicon layer and 200 μm thick PZT layer, which is much thinner than many commercial unimorph DMs. The thin structure means that large stroke can be obtained by a low drive voltage (less than 200 V). Aiding with the MEMS technology, the fabricated DM has 214 actuators with annular arrangement in its 50 mm effective aperture. And the DM has a potential to be fabricated with more than 1000 actuators. This paper presents the performances of the fabricated unimorph DM, such as actuator influence, stroke, dynamical response and mirror quality. Furthermore, the correction capability for astronomical applications will be demonstrated by generation of both low-order and high-order Zernike polynomial shapes.

8447-08, Session 2

The actuator design and the experimental tests of a new technology large deformable mirror for visible wavelengths adaptive optics

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Recently, Adaptive Secondary Mirrors showed excellent on-sky results in the Near Infrared wavelengths. They currently provide 30mm inter-actuator spacing and about 1 kHz bandwidth. Pushing these devices to be operated at visible wavelengths is a challenging task. Compared to the current systems, working in the infrared, the more demanding requirements are the higher spatial resolution and the greater correction bandwidth. In fact, the turbulence scale is shorter and the parameter variation is faster. Typically, the former is no larger than 25 mm (projected on the secondary mirror) and the latter is 2 kHz, therefore the actuator has to be more slender and faster than the current ones. With a soft magnetic composite core - a dual-stator and a single-mover -, VRALA, the actuator discussed in this paper, attains unprecedented performances with a negligible thermal impact. Pre-shaping the current required to deliver a given stroke greatly simplifies the control system, whose output supplies the current generator. As the inductance depends on the mover position, the electronics of this generator, provided with an inductance measure circuit, works also as a displacement sensor, providing the control system with an accurate feed-back signal.

A preliminary prototype, built according to this simple, effective and low power consumption electronic design, as well as to several FEA thermo-magnetic analyses, has undergone some laboratory tests. The results of these checks, matching the design results in terms of motion and power, show that the control system approach, the magnetic design and the electronic hardware architecture address the severe specifications.

8447-09, Session 3

Extragalactic science with adaptive optics

R. I. Davies, Max-Planck-Institut für extraterrestrische Physik (Germany)

I will present some recent adaptive optics results about black hole mass measurements, gas inflow and outflow in nearby active galaxies, and the structure of star forming galaxies in the early universe. I will describe the trade-offs one needs to consider when observing extragalactic targets at high spatial resolution, and the current successes and limitations of using AO. I will discuss which AO developments might be beneficial to this work, and finish by outlining some requirements imposed by extragalactic science on current and future adaptive optics systems.

8447-10, Session 3

Adaptive optics observations of the galactic center

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Adaptive Optics observations have dramatically improved the quality and versatility of high angular resolution measurements of the center of our Galaxy. In this paper, we quantify the quality of our Adaptive Optics observations and present results that have provided precision measurements of the central potential of the Galaxy and revealed several unexpected properties of the stars in the central nuclear star cluster. These results provide the best evidence to date that supermassive black holes exist at the center of normal galaxies, that star formation does proceed in the vicinity of central black holes despite the strong tidal fields, and that the giant star population does not have the predicted cusp distribution. Future observations of stellar orbits have the potential for detecting post-Newtonian effects in the short-period stars and should probe the distribution of orbital parameters at larger radii, which is key to testing Einstein's theory of General Relativity in an unexplored regime and understanding star and cusp formation around a central supermassive black hole.

8447-11, Session 3

Adaptive optics for high contrast imaging

M. Kasper, European Southern Observatory (Germany)

The talk will motivate the science requirements for high-contrast imaging illustrated by actual observation results. After an introduction to the high-contrast-imaging problem, the state-of-the-art will be reviewed putting emphasis on the exciting lab and on-sky data obtained on the various high-contrast imaging instruments already existing or close to commissioning. Finally, the challenges and required R&D in view of future XAO for ELTs will be described.

8447-12, Session 3

Quantitative solar system science with AO systems

F. Marchis, SETI Institute (United States)

We will present the latest results in the field of AO. We will collect and analyze the parameters needed to provide good science in the field of ground-based AO for solar system study.

Various techniques of observations, such as direct imaging, slit spectroscopy, IFU data, and LGS and the associated data-processing algorithms will be discussed.

To show the potential of next generation AO systems on 8-10m class telescopes and future ELTs, we will run simulations of observations (including ephemeris calculation) which will help identify the needed accurately of factors (SR, FWHM, photometry, astrometry,...) to perform good science, the limited effect of these factors, and the requirements for future AO systems.

8447-13, Session 4

Progress in laser guide star adaptive optics and lessons learned

P. L. Wizinowich, W. M. Keck Observatory (United States)

LGS AO on large telescopes has become a very productive science tool for the astronomical community. Astronomical objects can now be observed at an unprecedented resolution over much of the sky. The science enabled by LGS AO and the capabilities and limitations of these systems will be discussed, along with the lessons learned that can be applied to LGS AO systems on existing and planned telescopes.

8447-14, Session 4

An overview of guidestar laser technologies

D. T. Gavel, Univ. of California, Santa Cruz (United States)

We present a summary update of sodium laser guidestar technology, including an overview of the results from a series of Laser Guidestar Workshops hosted by the Center for Adaptive Optics over the past few years. There has been considerable advancement in the understanding of laser light interaction with mesospheric sodium which has an impact on the choice of laser systems where the objective is to produce the best

wavefront measurement with a minimum of laser power and expense. We will also summarize our efforts on an NSF funded MRI program to build a high-Strehl AO system for imaging and spectroscopy covering the near IR science bands from 0.9 to 2.2 micron wavelength. The system includes a new 10 watt pulsed fiber laser developed by Lawrence Livermore National Laboratory tuned in spectral and pulse format for optimum sodium return.

8447-15, Session 4

RFA-based 589-nm guide star lasers for ESO VLT: a paradigm shift in performance, operational simplicity, reliability, and maintenance

A. Friedenauer, B. Ernstberger, W. G. Kaenders, TOPTICA Photonics AG (Germany); V. I. Karpov, D. Wei, W. R. L. Clements, MPB Communications Inc. (Canada)

Large telescopes equipped with adaptive optics require 20-25W CW 589-nm sources with emission linewidths of ~5MHz. These Guide Star (GS) lasers should also be highly reliable and simple to operate and maintain. Under contract from ESO, industrial partners Toptica and MPBC are nearing completion of the development of GS lasers for the ESO VLT, with delivery of the first of four units scheduled for December 2012. We report on the design and performance of the fully-engineered Pre-Production Unit, including system reliability/availability analyses, the successfully-concluded qualification testing, long-term component and system level tests and long-term maintenance and support planning.

The laser design is based on ESO's patented narrow-band Raman Fiber Amplifier (RFA) technology. A master oscillator signal from a linearly-polarized Toptica 20-mW, 1178-nm CW diode laser, with stabilized emission frequency and controllable linewidth up to a few MHz, is amplified in an MPBC polarization-maintaining (PM) RFA pumped by a high-power 1120-nm PM fiber laser. With efficient stimulated Brillouin scattering suppression, an unprecedented 40W of narrow-band RFA output has been obtained. This is then mode-matched into a resonant-cavity doubler with a free-spectral-range matching the sodium D2a to D2b separation, allowing simultaneous generation of an additional frequency component (D2b line) to re-pump the sodium atom electronic population, thereby increasing the return flux. With demonstrated doubling efficiencies >80%, output powers at 589nm easily exceed the 20W design goal.

The fiber-based lasers provide excellent beam quality and are modular, turn-key, maintenance-free, reliable, ruggedized devices whose compactness allows installation directly on the launch telescope structure.

8447-16, Session 4

Towards a practical sodium guide star laser source: design for >50 watt LGS based on OPSL

J. L. A. Chilla, J. D. Berger, S. Govorkov, J. F. P. van Nunen, A. Y. Lepert, Coherent, Inc. (United States)

To produce sufficiently bright laser guide stars (LGS), lasers at 589 nm with powers of around 20 W Continuous Wave (CW) and extremely good beam quality are needed. A number of laser technologies have been developed for LGS. The current state-of-the art in LGS systems are narrowband, CW high-power Raman fiber amplifiers (RFAs) feeding compact 589-nm laser heads.

Our group has pioneered the commercial application of Optically Pumped Semiconductor (OPS) Lasers. OPS lasers have several advantages, relevant for guide star applications are their power scalability and wavelength flexibility. While these lasers are now commercially available with narrow line width operation and diffraction-limited beam quality at 20 Watts of power at 532 nm, 3-chip cavities with >50 Watt of TEM00 power have been demonstrated in the laboratory. Products emitting in a variety of wavelengths in the visible range are available, emission wavelength is not limited to a few atomic transitions, but can be dialed in with the design of the semiconductor structure. Lasers emitting at different colors can be built with the same cavity design and similar components, simply tuned for different wavelength.

We present laser results of OPS structures based on highly strained InGaAs quantum wells emitting at 1178nm and frequency doubled to produce high power, high beam quality laser radiation at 589nm. The laser architecture is the same as in our commercial offerings, allowing us to achieve the desired results with a system significantly simpler than alternative approaches.

8447-17, Session 4

Simulations of pulsed sodium laser guide stars: an overview

R. Holzlöhner, European Southern Observatory (Germany); S. M. Rochester, Rochester Scientific, LLC (United States); D. Bonaccini Calia, European Southern Observatory (Germany); D. Budker, Univ. of California, Berkeley (United States) and Rochester Scientific, LLC (United States); T. Pfrommer, European Southern Observatory (Germany); J. M. Higbie, Bucknell Univ. (United States)

Sodium laser guide stars (LGS) are used as artificial beacons for Adaptive Optics in many large telescopes. An LGS is a luminous column of 10-20 km height in the mesosphere, centered at about 93 km altitude, where naturally occurring sodium is excited with resonant light at 589 nm (orange), which is followed by fluorescence. The LGS facilities require lasers with excellent beam quality and a power of 5-25 watt per star. In order to optimize the brightness of the guide stars, detailed understanding of light-atom interaction physics is required. We find that the excitation efficiency depends nontrivially on the laser spectrum, polarization, the geomagnetic field, and other parameters. While a format optimization is already a challenging task for continuous-wave lasers, temporal modulation of the laser power introduces an additional level of complexity.

Almost all sodium LGS systems in the world are actually based on pulsed lasers. We review the relevant sodium physics and compare different laser-pulse formats. Selected formats are discussed on the basis of numerical simulation results. One of the key findings is that the brightness of most existing LGS facilities could be boosted at, as we argue, reasonable expense. Recommendations are presented to enhance the LGS return flux and to design future LGS lasers, including those suitable for spot tracking in the mesosphere to mitigate the spot elongation problem.

8447-94, Poster Session

The wavefront correction control system for the Advanced Technology Solar Telescope (ATST)

E. K. Kinney, K. Richards, L. C. Johnson, T. R. Rimmele, S. C. Barden, National Solar Observatory (United States)

The ATST Wavefront Correction Control System (WCCS) is the high-level control software for the Wavefront Correction (WFC) system. The WFC is comprised of a set of subsystems: the high-order adaptive optics system for correction of wavefront aberrations, an active optics system that calculates corrections for low-order distortions caused by optical misalignments, a context viewing camera to provide quick look quality analysis data, and a limb guider for positioning an occulting mask on the solar disk. The operation and configuration of the WFC is determined by the operational modes set by the operator. The Telescope Control System

(TCS) sends these operational modes to the WCCS, which provides the interface between the telescope and the WFC.

The WCCS adopts a modular approach to the organization of the software. At the top-level there is a high-level management controller which is the interface to the TCS. This management controller is responsible for the validation of commands received from the TCS and for the coordination and synchronization of the operation of the WFC subsystems. Separate subsystem controllers manage the functional behavior of each WFC subsystem. In this way the WCCS provides a consistent interface to the TCS for each subsystem while synchronizing and coordinating the components of the Wavefront Correction system.

8447-95, Poster Session

Adaptive optics real time processing design for the advanced technology solar telescope

K. Richards, L. C. Johnson, E. K. Kinney, S. C. Barden, T. R. Rimmele, National Solar Observatory (United States)

The four meter Advanced Technology Solar Telescope (ATST) adaptive optics (AO) system will require at least fifteen times the real time processing power as the Dunn Solar Telescope AO system. An FPGA solution for ATST AO real time processing is being pursued instead of the parallel DSP approach used for the Dunn AO76 system. An analysis shows FPGAs will have lower latency and lower hardware cost than an equivalent DSP solution. Interfacing to the proposed high speed camera and the deformable mirror will be simpler and have lower latency than with DSPs. This paper will discuss the current design and progress toward implementing the FPGA solution.

8447-96, Poster Session

The Robo-AO software: autonomous operation of a laser guide star adaptive optics system

R. L. Riddle, California Institute of Technology (United States); M. P. Burse, Inter-Univ. Ctr. for Astronomy (India); S. Tendulkar, C. Baranec, California Institute of Technology (United States); A. N. Ramaprakash, Inter-Univ. Ctr. for Astronomy (India); N. M. Law, Univ. of Toronto (Canada); R. G. Dekany, California Institute of Technology (United States); A. R. Rudy, National Central Univ. (Taiwan); M. Sitt, Stanford Univ. (United States); A. Arya, Mississippi State Univ. (United States); A. Papadopoulos, Aristotle Univ. of Thessaloniki (Greece)

Robo-AO is the first astronomical laser guide star adaptive optics (AO) system designed to operate completely independent of human supervision. A single computer commands the AO system, the laser guide star, visible and near-infrared science cameras (which double as tip-tilt sensors), the telescope, and other instrument functions. Control is achieved through a custom C++ software suite that is composed of several system daemons that communicate over TCP/IP, and includes a utility layer for basic functions, a hardware interface layer, and a control layer to manage each hardware subsystem. A sequencing and management system orchestrates the operation of the entire Robo-AO system, with extensive error control and watchdog processes in case of problems. The Robo-AO software has been developed with modularity in mind to allow for both the adaptation of future hardware resources and so subsystems can be used independently (for example, the core AO subsystem is being used separately in the Pomona College AO system). The software includes an intelligent queue system to coordinate multiple contemporaneous science programs: extremely large scale targeted surveys, rapid observations of transient events, and long term monitoring of objects, to name a few. Autonomous startup and shutdown sequences as well as concatenated visible observations were demonstrated in late 2011. The fully robotic software will be showcased during a month long demonstration of Robo-AO in the fall of 2012 at the Palomar Observatory 60-inch telescope.

8447-97, Poster Session

Recent development in real time control system of Subaru LGSAO-188

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In this paper, we report recent development in real-time control system of 188-element Laser Guide Star Adaptive Optics for Subaru Telescope (Subaru LGSAO-188). After the success of the commissioning for open use last year, as the total system including LGS mode, we are planning some enhancements in control system to archive further performance. The major item is to invoke the optimum gain control, which is being implemented on the data handling system and attached to the real time control system. The function of the automatic gain control is as already mentioned in author's previous SPIE paper, by calculating temporal spectrum of the deformable mirror and the curvature sensing, optimum feed back gain is calculate and adjusted continuously. This is expected to enhance the performance during the long time exposure where the condition of turbulence is changing. The status of the work is reported. We also explain about other new features on the control system including general response acquisition system as an expanded replacement for the response matrix acquisition routine. This enables acquisition of the response of the system to the impulse on any part of the system including DM or TT when the loop is closed or not. It will help to set up more precise control matrix for laser guide star mode.

8447-98, Poster Session

SPARTA for the VLT: status and plans

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SPARTA, the ESO Standard Platform for Adaptive optics Real Time Applications, is the high-performance, real-time computing platform serving 3 major 2nd generation instruments at the VLT (SPHERE, GALACSI and GRAAL) and possibly a fourth one (ERIS).

SPARTA offers a very modular and fine-grained architecture which is generic enough to serve a variety of AO systems. It includes the definitions of all the interfaces between those modules and provides libraries and tools for their implementation and testing, as well as a mapping to technologies capable of delivering the required performance. These comprise, amongst others, VXS communication, FPGA-aided wavefront processing, command time filtering and I/O, DSP-based wavefront reconstruction, DDS data distribution and multi-CPU number crunching, most of them innovative with respect to ESO standards in use.

An scaled-down version of the platform, namely SPARTA-Light, will employ a subset of the SPARTA technologies to implement the AO modules for the VLT auxiliary telescopes (NAOMI) and is the baseline for a new VLTI instrument (GRAVITY).

For the above instrument portfolio, SPARTA provides also a complete implementation of the AO application, with features customised to each instrument's needs and specific algorithms.

In this paper we describe the architecture of SPARTA, its technology choices, functional units and test tools. End-to-end as well as individual module performance data is provided for the XAO system delivered to SPHERE. Initial performance results are presented for the GALACSI and GRAAL systems under development.

8447-99, Poster Session

FPGA-based real time controller for high order correction in EDIFISE

L. F. Rodríguez-Ramos, H. M. Chulani, Y. Martín-Hernando, T. Dorta, A. Alonso-Sánchez, J. Jimenez Fuensalida, Instituto de Astrofísica de Canarias (Spain)

EDIFISE is a technology demonstrator instrument developed at IAC, intended to explore the feasibility of combining Adaptive Optics with attenuated optical fibers in order to obtain high spatial resolution spectra at the surroundings of a star, as an alternative to coronography. It has been tested at the OGS telescope an is intended to be installed at the WHT telescope.

This paper describes the FPGA-based real time control of the High Order unit, responsibly of the computation of the strokes of a 97-actuactor deformable mirror (11x11) with the information provided by a configurable wavefront sensor of up to 16x16 subpupils at 500 Hz (128x128 pixels). The reconfigurable logic hardware will allow both zonal and modal control approaches, will full access to select which mode loops should be closed and with a number of utilities for influence matrix and open loop response measurements. The system has been designed in a modular way to allow for easy upgrade to faster frame rates (1500 Hz) and bigger wavefront sensors (240x240), accepting also several interfaces from the WS and towards the mirror driver.

The FPGA-based real time controller provides bias and flat-fielding corrections, pupil displacement to modal matrix computation for up to 97 modes, independent servo loop controllers for each mode with user control for independent opening or closing, mode to actuator matrix computation and non common path aberration correction capability. It also provides full housekeeping control via UPD/IP for matrix reloading and full system data logging. The design of the system is depicted plus the development status and the available results.

8447-100, Poster Session

An AO real-time control solution for ELT scale instrumentation and application to EAGLE

A. G. Basden, N. A. Dipper, R. M. Myers, E. J. Younger, Durham Univ. (United Kingdom)

EAGLE is a proposed multi-IFU instrument for the E-ELT, with a full multi-object AO system. Current baseline designs for this MOAO system include up to six laser guide stars and five natural guide stars.

Twenty science channels will be corrected using a corresponding number of independent 84x84 actuator deformable mirrors, though the applied corrections will not be observed by the wavefront sensors. In addition to this, the E-ELT M4 mirror is also part of the AO system, and will operate in closed loop.

One possible design for a real-time control system for EAGLE is presented here, based on the Durham AO Real-time Control platform (DARC). Using hardware that we have available, we will present performance results based on the implementation of a sub-set of EAGLE, a single IFU channel. This can then be replicated twenty times to obtain a full EAGLE real-time control system, since each channel is independent.

We also consider the implementation of real-time control systems for other ELT instruments, and how far our approach can take us.

8447-101, Poster Session

Operation of the adaptive optics system at the Large Binocular Telescope

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The Adaptive Optics System at the Large Binocular Telescope Observatory consists of two Adaptive Secondary (ASM) mirrors and two Pyramid Wavefront sensors. The first ASM/Pyramid pair has been commissioned and is being used for science operation using the NIR camera PISCES on the right side of the binocular telescope. The left side ASM/Pyramid system is currently being commissioned, with completion scheduled for the Fall of 2012.

We will discuss the operation of the first Adaptive Optics System at the LBT Observatory including interactions of the AO system with the telescope and its TCS, observational modes, user interfaces, observational scripting language, time requirement for closed loop and offsets and observing efficiency.

8447-102, Poster Session

Pupil rotation compensation for LINC-NIRVANA

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The interferometric imager LINC-NIRVANA will use four pyramid wavefront sensors for layer oriented multi field of view multi conjugated AO. For all of them, a derotator will produce a static field on the pyramids, but a rotating pupil image on the CCD. On the adaptive secondary mirror, the pupil image will rotate as well because of the Alt/Az mount. For long exposure times, we have to take into account this effect to command the deformable mirror properly by changing the command matrix on the fly. We reproduce on bench this configuration, including a telescope simulator, to test different ways for the compensation of this effect, and to characterize side effects induced, like small pupil translations. In this paper, we present the results obtained and the optimal solution we have selected for use on sky and which will be tested with the pathfinder (GLAO part of LINC-NIRVANA) in the next months.

8447-103, Poster Session

FOAM: modular adaptive optics framework

T. van Werkhoven, Leiden Observatory (Netherlands); L. Homs, Utrecht Univ. (Netherlands); M. Rodenhuis, C. U. Keller, Leiden Observatory (Netherlands)

Adaptive optics is widely used to obtain diffraction-limited images through the turbulent atmosphere of the Earth. Software controlling these systems has in general been custom built and is usually very specific in nature. We present FOAM, a portable, modular adaptive optics framework for controlling andsimulating adaptive optics systems.

FOAM provides portability both for different control computers and adaptive optics setups. We use standard Unix libraries and compilation procedures. We implemented a hardware abstraction layer in FOAM such that various hardware can easily be controlled.

FOAM includes a versatile simulation mode for testing purposes. The simulation starts with a turbulence screen, which is corrected by a deformable mirror and then propagated through a lenslet array and imaged onto a camera. Because of the hardware abstraction, new AO algorithms can be implemented in the simulation mode first before being used in production systems.

We have successfully tested FOAM on an experimental AO system developed for the Extreme Polarimeter (ExPo), a high-contrast imaging polarimeter working in broadband visible light. Results of these tests, performed in a laboratory environment, are presented here. Science observations with this system, targeting protoplanetary disks around nearby stars, are scheduled at theWilliam Herschel Telescope on La Palma this summer. In the future, FOAM will also be used for microscopy and solar adaptive optics.

FOAM is freely available under the GPL license and can be used by anyone.

8447-104, Poster Session

General purpose computer cluster for real-time adaptive optics

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Computers for real time adaptive optics systems must have low input-to-output latency and jitter. This requirement is unusual in the community of high performance computing, and often led us to develop specific tools and architectures for AO. But the strong timing specifications put on AO computers are mainly driven by the coherence time of the turbulence faced by telescopes. This physical value did not change since the beginning of AO, while computer technology progressed following the More's law. There is a time when the performance of general purpose computing tools will meet all AO requirements. To give and overview of the current situation, this paper describes how a general purpose computer was used to implement an end-to-end model of a VLT-class extreme AO system. The test cluster is made of 12 nodes connected together using Infiniband, each node having 2 GPU units and 4 CPU cores. One node is emulating the wavefront sensor camera, and another receives the output vectors like a true deformable mirror. All software tools were chosen among the most widespread standards: MPI, CUDA and openMP. The benchmark results show that general purpose tools can definitely be used for real adaptive optic systems, and are scalable to large problem size.

8447-105, Poster Session

Multivariate simplex B-splines for large scale wavefront reconstruction

C. C. de Visser, R. Fraanje, M. Verhaegen, Technische Univ. Delft (Netherlands)

A new method for wavefront reconstruction (WFR) is proposed with application to the extreme adaptive optics (XAO) systems for the next generation of ground based optical telescopes. The new method is based on bivariate simplex B-splines which are a special class of multivariate polynomial splines that are defined on triangular partitions. The new method has a number of advantages over existing methods for wavefront reconstruction. Firstly, the new method is independent of sensor and actuator geometry, with the result that it can be used on imperfectly aligned sensor arrays, and on apertures with multiple holes and obstructions. Secondly, the new method is highly resilient to noise because the Simplex B-splines act as a local filter. Finally, the method can be parallelized for application in large scale adaptive optics systems like the XAO on the E-ELT. The new method was validated using large scale closed loop simulations, as well with experiments performed on an optics bench. In the simulations it was shown that the spline based WFR method achieves Strehl ratios higher than 0.90 when correcting simulated E-ELT turbulence phase screens using a 100x100 sensor grid. Experiments were also conducted on an optics bench equipped with a Shack-Hartmann sensor consisting of 127 lenslets, and a deformable mirror with 37 piezoelectric actuators. The performance of the spline based WFR method was validated using known phase screens and compared with results obtained with existing WFR methods.

8447-106, Poster Session

LQG control performance with the CANARY MOAO pathfinder

G. Sivo, Univ. Paris 13 (France) and ONERA (France); C. Kulcsar, Univ. Paris 13 (France); J. Conan, ONERA (France); H. G. Raynaud, Univ. Paris 13 (France); E. Gendron, F. Vidal, LESIA - Observatoire de Paris (France); A. G. Basden, Durham Univ. (United Kingdom)

Many concepts of Wide Field AO (WFAO) systems are under development, especially for Extremely Large Telescope (ELT) instruments.

Multi-Object Adaptive Optics (MOAO) is one of these WFAO concepts, well suited to high redshifts galaxy observations with a very wide FoV. The E-ELT instrument EAGLE will use this approach. CANARY, the on-sky pathfinder for MOAO, has obtained the first compensated images on Natural Guide Stars (NGSs) at the William Herschel Telescope in September 2010.

We present in this paper numerical and experimental validations of an optimal control law. Linear Quadratic Gaussian (LQG) control is an appealing strategy that provides optimal control for an explicit minimum variance performance criterion. It also provides a unified formalism that allows accounting for multi WaveFront Sensors (WFSs) channels, both on Laser Guide Stars (LGSs) and NGSs, and for various disturbance sources (turbulence, vibrations). Our objective is to obtain a first on-sky demonstration of tomographic LQG control during phase B observing runs, featuring LGS and NGS WFSs.

We show how the specific MOAO CANARY configuration can be embedded in a state-space framework. We present simulations that demonstrate the gain brought by tomographic LQG control, both in CANARY and ELT context. We present also the first experimental laboratory validation on the CANARY testbed. Model identification and off-line calculations necessary for a robust on-sky operation are discussed. Finally the on-sky test plan for the coming observing runs (Summer 2012) is presented.

8447-107, Poster Session

Fixed and scheduled LQG control of an adaptive optics system

J. Folcher, M. Carbillet, Univ. de Nice Sophia Antipolis (France)

Over the last decades many research works have studied the best achievable performance of adaptive optics (AO) systems aiming at compensating the turbulent wavefront disturbance. In many cases the linear quadratic Gaussian (LQG) control is used to minimize the residual wavefront variance and is optimal for a given turbulent wavefront model. Unfortunately, the physical parameters characterizing the turbulence (and in the very first place the wind velocities and the strength of the turbulence) can change rapidly and the resulting performance can be far from optimal. In this paper we first propose an LQG-based control which ensures satisfactory mean square performance despite variations of the atmospheric turbulence ; the second approach is then rather different and involves gain scheduling techniques by simply switching between fixed LQG controllers. The performance of the controllers is compared numerically by means of detailed simulations making use of the Software Package CAOS.

8447-108, Poster Session

High performance AO control for time-variant wavefront distortions

N. Doelman, TNO (Netherlands)

Optimality based control methods for Adaptive Optics aim at a performance improvement over the classic integrator-based AO control. These high performance control methods - as described by terms such as Predictive control, LQG control, H2-optimal control or Kalman filter-based control - all require an accurate dynamic model of the wavefront distortions.

The dynamics of turbulence-induced wavefront distortions however, are time-variant on a time-scale ranging from seconds up to minutes. To track the turbulence temporal fluctuations and to maintain the high performance, the optimal AO controller should become adaptive. In an adaptive setting the controller coefficients are updated in real-time in order to track their time-varying optimal values.

An adaptive implementation of AO control induces a high computational demand on the real-time controller platform. An alternative approach to dealing with time-variant wavefront distortions is the use of a robust AO controller. Here, a robust controller is designed such that its performance has a reduced sensitivity towards variations in the wavefront distortion.

The paper proposes and describes both an adaptive control algorithm and a robust control method for AO. A performance comparison is made between the two control methods for typical temporal fluctuations in turbulence characteristics, in particular the Fried parameter and the wind velocity of a single turbulence layer. Furthermore, the results are supported by control experiments with on-sky telescope wavefront sensor data.

8447-109, Poster Session

Infinite impulse response modal filtering in visible adaptive optics

G. Agapito, C. Arcidiacono, F. Quiros-Pacheco, A. T. Puglisi, S. Esposito, INAF - Osservatorio Astrofisico di Arcetri (Italy)

High performance wavefront corrections in Near Infrared opened the possibilities to have diffraction limited resolution adaptive correction also in visible wavelengths. But higher level corrections require tougher specifications. All the different components of the adaptive optics (AO) system may be sources of wavefront errors that could compromise such as goal. We point our attention to control strategies: using modal control we found infinite impulse response filters that optimize the wavefront correction. As starting point we used the actual First Light AO (FLAO) for LBT experience and the numerical simulation tool we wrote in its design and commissioning phases. We considered a generic single reference AO system for an 8 meter class telescope. The spatial and temporal characteristics of the AO are optimizing the correction for visible wavelengths according to previous studies. On this system we computed the infinite impulse response filter coefficients that afterwards we tested through full end to end numerical simulations. The actual practicability of the algorithms depends on both robustness and knowledge of the real system: errors in the starting conditions may even worsen the performance.

In particular we checked the robustness of the algorithms in different noise and mis-alignment conditions. The errors estimation is based on the FLAO experience and on the vibrations and seeing parameters actually measured at the LBT telescope.

8447-110, Poster Session

On application of constrained receding horizon control in astronomical adaptive optics

M. V. Konnik, J. Welsh, The Univ. of Newcastle (Australia)

Control system design for adaptive optics is becoming more complex and sophisticated with increasing demands for the compensation of the atmospheric turbulence. Contemporary controllers used in the adaptive optics systems are optimised in the sense of cost function (linear quadratic regulators) or to a worst case scenario (robust H_infty controllers). Prediction, to some extent, can be incorporated into the controllers thanks to the Kalman filter and a model of the atmospheric turbulence.

Despite the growing number of publications on adaptive optics control systems, only the unconstrained case is usually considered. Accounting the physical constraints of the adaptive optics system components, such as limited actuators stroke and dynamics, still presents a problem. As a possible solution, one can consider constrained receding horizon control (RHC), also called as Model Predictive Control (MPC). The ability of RHC to handle constraints and make predictions of the future control signals makes it attractive for the application in astronomical adaptive optics. The main difficulty with the application of RHC is its heavy computational load.

The paper presents preliminary results on numerical simulations of the adaptive optics system controlled by a constrained RHC controller. The case of output disturbance rejection is considered. The results of the numerical simulations are provided. Methods for improving the computational performance of constrained receding horizon controllers in adaptive optics are discussed.

8447-111, Poster Session

Analysis and experimental demonstration of adaptive optics based on the modal control optimization

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A modal control optimization method for adaptive optics on the tempo-spatial domain is presented. The spatial modes of the adaptive optics system can be obtained by the singular value decomposition of the response function matrix for the adaptive optics system. The number of correction modes is determined dynamically by the root mean square estimation of the residual aberration obtained with the different number of correction modes. A Smith predictor is designed to reduce the time delay effect on the closed-loop system. The modal optimization method is verified by compensating the atmosphere-like optical turbulence generated by the rotating glass phase-screen. Experimental results show that wavefront correction accuracy for the adaptive optical system can be significantly improved in comparison to the generic modal gain integrator approach with the fixed number of correction modes. The modal control optimization method is an attractive and practical alternative to adaptive optics control.

8447-112, Poster Session

Mitigation of transient meteor events in sodium layer by TMT NFIRAOS

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Small meteors usually burn up near the bottom of the sodium layer. Meteor trails can lead to temporary dramatic changes in the altitude of

the sodium layer

This altitude change is very rapid, typically over 1 second, and after some unpredictable period of 10-20 seconds, can transition back to the nominal mean altitude also in about 1 second. The altitude change is very drastic and can jump by up to 1 km which, on the face of it, would cause 4 micrometres defocus errors on LGS WFS measurements for a 30-m telescope, unless properly tracked. Measurements by the UBC Lidar detected ~20 meteor trails / hour, and of these, 1-2 are significant events.

We report on a full end-to-end Simulink simulation for TMT NFIRAOS including: meteor events measured by the UBC Lidar; on-instrument NGS focus sensor running at 90Hz (median sky coverage frame rate); optimal temporal blending with LGS WFS focus measurements; LGS WFS centroiding matched filter update and Truth WFS update very 3s; full trombone servo model including non-linear focus range vs stage position. We optimized our control architecture and traded off motor power dissipation versus residual wavefront error and Shack-Hartmann spot displacement and found range tracking errors induce 11 nm WFE in normal conditions and brief (1s) jumps of 30-80 nm WFE at the beginning and ending of meteor transients.

8447-113, Poster Session

Experimental test of wavefront forecasting for adaptive optics

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Short time-scale prediction of the evolution of turbulent processes is of interest in many applications, among these Adaptive Optics (AO).

Several approaches to this problem attempt to predict its evolution either through Auto Regressive Moving Average modelling or Neural Networks and even simple linear extrapolation. Each of these approaches involves an algorithm to forecast a future turbulence state using as input the knowledge of N past measured states.

An experimental test to compare different approaches has been set up at the Tor Vergata University Solar Physics Laboratory: a known spectrum aberration is introduced in the optical path of an AO system and the data acquired by a Shack-Hartmann sensor is used to predict the successive state of the wavefront error.

We feeded the system with real seeing data to simulate actual observation conditions and forecast the future turbulence states using as inputs the N past Shack-Hartmann measures.

The results, advantages and drawbacks of the forecasting approach are presented and discussed.

8447-18, Session 5

GeMS: first on-sky results

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GeMS is the Gemini MCAO system. It uses 5 laser guide stars (LGS), 3 natural guide stars (NGS) and 2 deformable mirrors to compensate the turbulence in a large FoV of 2 arcmin diameter. Since January 2011, GeMS is in commissioning and first results were obtained as soon as April 2011. From May to November, we took advantage of the Chilean winter time to perform a five months suthdown, and fix, upgrade and repair all the subsytems based on the experiences learned on-sky. Since November 2011, the GeMS team resumed the work on-sky,

focusing on performance optimization and science commissioning. At the time of writting this abstract, first images with a full MCAO compensation over the whole field were obtained, demonstrating the unique system capabilities.

In this paper, we present an overall view of GeMS performance and the first images obtained on-sky. The MCAO correction provides a uniform compensation level over the whole field, producing impressive images. To illustrate the gain brought by MCAO, we compared on-sky the performance obtained in different mode (Open Loop vs. SCAO vs. GLAO vs. MCAO). So far, we have found that the performance was very stable and reproducible against different conditions. A particular effort to optimize the performance was the compensation of the Non Common Path Aberrations (NCPA) and the calibation of their drift with the LGS WFS centroid gains.

8447-19, Session 5

The ESO adaptive optics facility: integration completed and readiness for system tests

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The ESO Adaptive Optics Facility (AOF) consists in an evolution of one of the ESO VLT unit telescopes to a laser driven adaptive telescope with a deformable mirror in its optical train. The project has completed the procurement phase and several large structures have been delivered to Garching (Germany) and are being integrated (the AO modules GRAAL and GALACSI and the ASSIST test bench). The 4LGSF Laser (TOPTICA) has undergone final design review and a pre-production unit has been built and successfully tested. The Deformable Secondary Mirror is fully integrated and system tests have started with an engineering thin shell mirror; in the meantime a first science grade shell has been delivered by SAGEM. The integrated modules will be tested in stand-alone mode in 2012 and upon delivery of the DSM in late 2012, the system test phase will start. A commissioning strategy has been developed and will be updated before delivery to Paranal. A substantial effort has been spent in 2011-2012 to prepare the unit telescope to receive the AOF by preparing the mechanical interfaces and upgrading the cooling and electrical network. This preparation will also simplify the final installation of the facility on the telescope. A lot of attention is given to the system calibration, how to record and correct the misalignment and control the whole facility. A plan is being developed to efficiently operate the AOF after commissioning. This includes monitoring a relevant set of atmospheric parameters for scheduling and a Laser Traffic control system to assist the operator during the night and help/support the observing block preparation.

8447-20, Session 5

Tests of open-loop LGS tomography with CANARY

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CANARY is an on-sky demonstrator AO system that in 2010 provided the first on-sky demonstration of open-loop tomographic adaptive optics correction using natural guide stars. Phase B of the CANARY experiment aims to extend the instrument from its original configuration by also measuring wavefronts from four off-axis Rayleigh laser guide stars. This upgrade allows CANARY to perform tomographic wavefront sensing over a 2.5' FOV using any mix of up to seven off-axis WFSs (four LGS and three NGS) simultaneously. AO correction within CANARY is performed on-axis along a single line of sight using a 52-actuator deformable mirror being controlled in open-loop. Here we give an overview of the Phase B LGS MOAO system, discuss the calibration of such a mixed NGS/LGS tomographic system and present the recent laboratory and on-sky results from the Phase B commissioning.

8447-21, Session 5

Image quality and high contrast capability improvements on VLT/NACO

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NACO is the famous and versatile diffraction limited NIR imager and spectrograph at the Very Large Telescope (VLT). With NACO, ESO just celebrated 10 years of Adaptive Optics at the VLT. Since two years a substantial effort has been put in understanding and fixing issues that directly affect the image quality and the high contrast performances of the instrument. Experiments to compensate the non-common-path aberrations(NCPA) and recover the highest possible strehl ratios have been carried successfully and a plan is hereafter describe to perform such measurements regularly. The drift associated to pupil tracking since 2007 was fixed in october 2011. NACO is therefore even more suited for high contrast imaging and can be used with coronagraphic masks in the image plane (i.e Lyot, 4QPM). Some contrast measurements are shown and discussed. The work accomplished on NACO will serve as reference for the next generation instruments on the VLT, especially the ones working at the diffraction limit and making use of angular differential imaging.

8447-22, Session 6

Scientific results from ESO's MCAO demonstrator MAD

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Wide-field adaptive optics instruments were an indispensible component of ESO's original concept for an extremely large telescope. Thus, demonstrating that MCAO works in the lab and on sky was a high priority activity within the OWL project. ESO thus decided to build an instrument that would allow to test the hardware and the algorithms for atmospheric tomography on the VLT. This led to a project to build an MCAO demonstrator, which could be done at a relatively low cost using components already available from other AO projects. This was the genesis of MAD, ESO's Multi-conjugate Adaptive optics Demonstrator. MAD used three (natural) guide stars brighter than V~12 within it's 2' diameter field of view (the Shack-Hartmann wavefront sensors worked in the visible). An ideal asterism therefore was an equilateral triangle centered on, and encompassing, the targets.

The MAD project started in January 2002 and closed the loop in the laboratory in October 2005 and on-sky in March 2007. Both in the lab and on-sky MAD worked remarkably well and produced data of scientific value soon after seeing first light. This remarkable achievement prompted ESO's Scientific and Technical Committee (STC) to urge ESO to offer MAD to the community for shared-risk projects. MAD was thus offered in science demonstration mode for 19 nights distributed in 3 runs in Nov 2007, Jan 2008, and Aug 2008. The observations were done by the MAD team in close coordination with the PI's. A total of 24 proposals were received, but a few had to be rejected because their asterisms were unsuitable.

The science efficiency of MAD during the 3 runs was close to 76% (mostly due to weather losses: clouds or poor seeing). About 66% of the programs were completed, and about 10% were executed only partially. One of these was the MAD Deep Field that required long exposures and which therefore did not produced published results. Until December 2011 MAD has produced 19 papers published in refereed journals, most of which deal with stars in crowded fields: star forming regions, globular clusters, and field stars in extragalactic systems. In this contribution I will review the scientific results produced by MAD. I will also review results from other MCAO systems on 8m class that are currently in the final construction or commissioning phases and that should produce scientific results in the course of 2012.

8447-23, Session 6

Results from the commissioning of the Gemini South adaptive optics imager (GSAOI) at Gemini South Observatory

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We present the results from the commissioning of the Gemini South Adaptive Optics Imager (GSAOI). Capable of delivering diffraction limited images in the near-infrared, over an 85" X 85" square field-of-view, GSAOI was designed for use with the Gemini Multi-Conjugate Adaptive Optics (GeMS) system in operation at Gemini South Observatory. The instrument focal plane, covered by an array of four HAWAII 2RG detectors, contains 4080 X 4080 pixels and has a plate scale of 0.02" -- thus capitalizing on the superb image quality delivered by both the

all-refractive optical design of GSAOI and the Gemini South MCAO system. Here, we discuss our preliminary findings from the GSAOI commissioning, concentrating on on-sky performance, delivered image quality, detector characterization, and throughput. Further specifics about the Gemini MCAO system can be found in other presentations during this conference (i.e. Rigaut et al; Neichel et al.)

8447-25, Session 6

Microarcsecond relative astrometry with MCAO using a diffractive mask

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We present a new ground-based technique to detect or follow-up long-period exoplanets via precise relative astrometry of host stars using Multi-Conjugate Adaptive Optics (MCAO) on 3-5 meter telescopes equipped with diffractive masks.

MCAO improves relative astrometry both by cancellation of high-altitude atmospheric layers, which induce dynamic focal-plane distortions, and the improvement of centroiding precision with sharper PSFs. However, exoplanet mass determination requires multi-year reference grid stability of ~10-100 µas or ~nanometer-level stability on the long-term average of out-of-pupil phase errors, which is challenging with MCAO (e.g., Meyer et al. 2011). The diffractive pupil technique calibrates dynamic distortion via extended diffraction spikes generated by a dotted primary mirror, which are referenced against a grid of background stars (Guyon et al. 2011). We show that the diffractive pupil improves MCAO's long-term astrometric stability to the microarcsecond level.

A diffractive 3-5-meter telescope with diffraction-limited MCAO in K reaches < 10-20 µas relative astrometric error per coordinate perpendicular to the zenith vector in one hour on a bright target star in fields of moderate stellar density (~10-40 stars per sq. arcm). Final relative astrometric precision is limited by differential tip/tilt jitter. We discuss alternatives to the dotted pupil concept, including diffractive masks mounted to the secondary mirror and the use of diffraction spikes created by hexagonal primary mirror segments, showing that these stabilize MCAO's astrometric reference grid to < 50 µas. We present a design for a diffractive mask on a 1-m telescope to test this concept in 2012.

8447-160, Session 6

High-contrast imaging in the Hyades with snapshot LOCI

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To image faint substellar companions obscured by the stellar halo and speckles, scattered light from the bright primary star must be removed in hardware or software. We apply the "locally-optimized combination of images" (LOCI) algorithm to 1-minute Keck Observatory snapshots of GKM dwarfs in the Hyades using source diversity to determine the most likely PSF. We find a high degree of correlation in the Keck AO PSF with time as well as optical axis. New brown dwarf and low-mass stellar companions to Hyades primaries are found in a third of the 84 targeted systems. This campaign shows the efficacy of LOCI on snapshot imaging without the need for time-consuming ADI observations, reaching contrasts sufficient for imaging 625-Myr late-L/early-T dwarfs purely in post-processing.

8447-26, Session 7

Advances in detector technologies for visible and infrared wavefront sensing

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The success of the next generation of instruments for 8 to 40-m class telescopes will depend on the ability of Adaptive Optics (AO) systems to provide excellent image quality and stability. This will be achieved by increasing the sampling, wavelength range and correction quality of the wave front error in both spatial and time domains.

The modern generation of AO wavefront sensor detectors started in the late nineties with the development of the CCD50 detector by e2v technologies under ESO contract for the ESO NAOS AO system. With a 128x128 pixels format, this 8 outputs CCD offers a 500 Hz frame rate with a readout noise of 7e-.

A major breakthrough has been achieved with the recent development by e2v technologies of the CCD220. This 240x240 pixels 8 outputs EMCCD (CCD with internal multiplication) has been jointly funded by ESO and Europe under the FP6 programme. The CCD220 detector and the OCAM2 camera are now the most sensitive system in the world for advanced adaptive optics systems, offering less than 0.2 e readout noise at a frame rate of 1500 Hz with negligible dark current. Extremely easy to operate, OCAM2 only needs a 24 V power supply and a modest water cooling circuit. This system, commercialized by the First Light Imaging spinoff, is extensively described in this paper. An upgrade of OCAM2 is foreseen to boost its frame rate to 2500 Hz, opening the window of XAO wavefront sensing for the ELT using 4 synchronized cameras and pyramid wavefront sensing.

Since this major success, new developments started in Europe. One is fully dedicated to Laser Guide Star AO for the ELT with ESO involvement. The spot elongation from a LGS Shack Hartman wavefront sensor necessitates an increase of the pixel format. Two detectors are currently developed by e2v. The NGSD will be a 880x840 pixels CMOS detector with a readout noise of 3 e (goal 1e) at 700 Hz frame rate. The LGSD is a scaling of the NGSD with 1680x1680 pixels and 3 e readout noise (goal 1e) at 700 Hz frame rate. New technologies will be developed for that purpose: advanced CMOS pixel architecture, CMOS back thinned and back illuminated device for very high QE, full digital outputs with signal digital conversion on chip. In addition, the CMOS technology is extremely robust in a telescope environment. Both detectors will be used on the European ELT but also interest potentially all giant telescopes under development.

Additional developments also started for wavefront sensing in the infrared based on a new technological breakthrough using ultra low noise Avalanche Photodiode (APD) arrays within the RAPID project. Developed by the Sofradir and CEA/LETI manufacturers, the latter will offer a 320x240 8 outputs 30 microns IR array, sensitive from 0.4 to 3.2 microns, with 2 e readout noise at 1500 Hz frame rate. The high QE response is almost flat over this wavelength range. Advanced packaging

with miniature cryostat using liquid nitrogen free pulse tube cryocoolers is currently developed for this programme in order to allow use on this detector in any type of environment. First results of this project are detailed here.

These programs are held with several partners, among them are the French astronomical laboratories (LAM, OHP, IPAG), the detector manufacturers (e2v technologies, Sofradir, CEA/LETI) and other partners (ESO, ONERA, IAC, GTC). Funding is: Opticon FP6 and FP7 from European Commission, ESO, CNRS and Université de Provence, Sofradir, ONERA, CEA/LETI and the French FUI (DGCIS).

8447-27, Session 7

Measured performance of the prototype polar coordinate CCD array

S. M. Adkins, W. M. Keck Observatory (United States)

This paper describes the testing of a prototype of a high frame rate CCD imager called the polar coordinate detector developed as part of a project led by the W. M. Keck Observatory and funded by the Adaptive Optics Development Program and the Thirty Meter Telescope Project. The polar coordinate detector is designed to address the problem of adaptive optics (AO) laser guide star (LGS) spot image elongation in Shack Hartmann wavefront sensors (WFS) for extremely large telescopes. The prototype detector, designated the CCID-61, was developed in collaboration with the MIT Lincoln Laboratory. The CCID-61 implements a 30 x 30 subaperture WFS for one quadrant of the planned 60 x 60 subaperture LGS WFS of the TMT early light AO system NFIRAOS. Testing of backside thinned, packaged detectors has been completed and performance results including read noise, readout speed, charge diffusion, dark current, and quantum efficiency will be reported.

8447-28, Session 7

The Subaru coronagraphic extreme AO (SCExAO) high sensitivity wavefront sensor: performance comparison between a non modulated pyramid and a non linear curvature wavefront sensor

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The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system uses advanced coronagraphic technique for high contrast imaging of exoplanets and disks as close as 1 lambda/D from the host star.

In addition to coronagraph optics, achieving high contrast at this small angular separation requires a wavefront sensing and control architecture which is optimized for exquisite control and calibration of low order aberrations.

SCExAO receives a partially corrected beam from the Subaru facility AO system, and the wavefront is further corrected by SCExAO's tip-tilt mounted MEMS-type deformable mirror.

SCExAO relies on two high accuracy low-speed (<100 Hz) infrared wavefront sensors for accurate wavefront calibration and control free on non-common path errors.

The system also includes a high speed, high sensitivity WFS operating in visible light, specially designed for Extreme-AO, which is the focus of this paper.

Two options are currently being evaluated: a non-modulated Pyramid WFS, and a non-linear Curvature WFS. Both choices offer uniquely high sensitivity to low order aberrations.

Last on-sky results acquired downstream Subaru AO188 AO system, and first comparisons of performances between the two visible wavefront sensors used on SCEXAO will be presented.

8447-29, Session 7

The AOLI low-order non-linear curvature wavefront sensor: a method for high sensitivity wavefront reconstruction

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Current adaptive optics system typically rely on Shack Hartmann sensors to determine the effects of atmospheric distortions on incoming wavefronts. These sensors distribute the light of a reference star amongst a large number of sub-apertures, requiring the use of bright reference objects which occur infrequently across the sky. A low-order non-linear curvature wavefront sensor based on methods developed by Guyon et al. offers a dramatic increase in sensitivity allowing nearly 100% sky coverage using natural guide stars.

This paper describes the adaptive optics system being developed for the Adaptive Optics Lucky Imager (AOLI) project comprising a fixed component non-linear curvature wavefront sensor and photon-counting EMCCD detectors. We describe the optical design of the wavefront sensor where two photon counting CCDs provide a total of four reference images. Simulations and laboratory experiments of the optical characteristics of the system are discussed, including chromaticity, with their relevance to low and high order AO system designs. The development and optimisation of high speed wavefront reconstruction algorithms are also presented. Finally we discuss the results of simulations and lab tests to demonstrate the sensitivity of the system.

8447-31, Poster Session

Stability and robustness of LBT FLAO system performances during the science demonstration time observations

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The First Light Adaptive Optics (FLAO) systems for LBT are two

adaptive optics systems designed to operate on the two sides of the binocular telescope. Each system comprises one adaptive secondary and one pyramid wave-front sensing unit. The potential of the design has been shown during commissioning of the first unit on the right side of the telescope, while the second system is currently under commissioning. In this paper we discuss the results obtained during the Science Demonstration Time (SDT) observations that followed the commissioning of the first unit. In particular we focus on performance stability and robustness of the FLAO system in different closed loop scenarios dictated by the specific science targets observed.

8447-115, Poster Session

GALACSI system design

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GALACSI is one of the Adaptive Optics (AO) systems part of the ESO Adaptive Optics Facility (AOF). It will use the VLT 4-Laser Guide Stars system, high speed and low noise WaveFront Sensor cameras (<1e-, 1000Hz) the Deformable Secondary Mirror (DSM) and the SPARTA Real Time Computer to sharpen images and enhance faint object detectability of MUSE Instrument. MUSE is an Integral Field Spectrograph working at wavelengths from 465nm to 930nm. GALACSI implements 2 different AO modes; in Wide Field Mode (WFM) it will perform Ground Layer AO correction and enhance the collected energy in a 0.2” by 0.2” pixel by a factor 2 at 750nm over a Field of View (FoV) of 1’ by 1’. The 4 LGSs and one tip tilt reference star (R-mag <17.5) are located outside the MUSE FoV. Key requirements are to provide this performance and a very good image stability for 1hour long integration time. In Narrow Field Mode (NFM) Laser Tomography AO will be used to reconstruct and correct the turbulence for the center field using the 4 LGSs at 15” off axis and the Near Infra Red (NIR) light one reference star on axis for tip tilt and focus sensing. In NFM GALACSI will provide a moderate Strehl Ratio of 5% (goal 10%) at 650nm. The NFM hosts several challenges and many subsystems will be pushed to their limits.

8447-116, Poster Session

Status of the GRAAL system development: very wide-field correction with 4 laser guide-stars

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GRAAL manufacturing started in 2010, and is now complete, excepted the WFS cameras and the other AOF components (DSM and Laser).

The system will be tested in Germany in the coming months, to be shipped to Chile in 2013.

In Garching, the alignment of the system is in progress at the time of writing.

The first wave-front sensor camera will be integrated in May 2011.

The DSM being available later, full-system tests will be performed for a large part without it.

The testing of GLAO systems has been thought through: practical calibration of pseudo-synthetic interaction matrices, alignment verification without deformable mirror for instance.

Some operational aspects of the acquisition are described: selection of guide-star, automation of some phases of the acquisition, mosaics of corrected images with different position angles among others.

8447-117, Poster Session

VLT GRAAL main assembly instrument design, manufacturing, integration, and test

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The GRound Adaptive optics system Assisted with Lasers (GRAAL) is one of the two Adaptive Optics Facility (AOF) AO modules for the VLT #4 telescope in ESO facilities in Chile. It will provide ground layer adaptive optics correction for HAWK-I a wide field infrared camera.

The paper summarizes the main aspects of the Manufacturing, Integration and Test to validate the mechanical, electrical and optical performances. We then presents in detail the main qualification test results, which illustrate the outstanding quality and accuracy of the system.

8447-118, Poster Session

Deploying the testbed for the VLT adaptive optics facility: ASSIST

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The ESO Very Large Telescope Adaptive Optics Facility (VLT-AOF) will transform the VLT Unit Telescope 4 to an Adaptive Telescope. In absence of an intermediate focus before the Adaptive Secondary in this Ritchey-Chrétien type telescope and in order to reduce the testing and calibration of the system on-sky, ASSIST, The Adaptive Secondary Setup and Instrument STimulator, was developed. It provides an off-sky testing facility for the ESO AOF and will provide a full testing environment for three elements of the VLT Adaptive Optics Facility: the Deformable Secondary Mirror (DSM) and the AO modules for MUSE and HAWK-I (GALACSI and GRAAL). ASSIST was delivered to ESO Garching, where it was assembled and tested. Currently ASSIST is being integrated with the Deformable Secondary Mirror, the first step in the full system testing of the two AO systems for the VLT AOF on ASSIST. This paper briefly reviews the design and properties of ASSIST and reports on the first results of ASSIST in stand-alone mode.

8447-119, Poster Session

Infrared differential imager and spectrograph for SPHERE: performance status with extreme adaptive optics before shipment to ESO/VLT

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(France); F. Wildi, Observatory of Geneva (Switzerland); C. Petit, T. Fusco, ONERA (France)

SPHERE is a second generation instrument for the VLT optimized for very high-contrast imaging around bright stars. Its primary science goal is the detection and characterization of giant planets, together with observation of circumstellar environment. The infrared differential imager and spectrograph (IRDIS), one of the three science instruments for SPHERE, will provide simultaneous differential imaging in the near infrared, among with long slit spectroscopy, classical imaging and infrared polarimetry. IRDIS achieves very high contrast with the help of extreme-AO (Strehl > 90%), coronography, exceptional image quality (including non-common-path aberrations compensation), very accurate calibration (including star centering) and very advanced data processing for speckle suppression. In this context, we report on the latest experimental characterizations of IRDIS performed with SPHERE/SAXO before the preliminary acceptance in Europe. We describe the performances, the calibrations, the observing efficiency, and the operation strategy of such complex instrument. In particular we present the achievable level of contrast for all observing modes under various external conditions (seeing, star magnitude, pupil or field stabilization) in preparation for scientific exploitation.

8447-120, Poster Session

GLAO performance characterization

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Ground Layer Adaptive Optics is considered one of the future workhorses AO techniques needed no only to take full advantage of the aperture and light gathering capabilities of the future ELTs, but also to expand the capabilities of current 10m-class telescopes in operation. In this work we present a performance characterization analysis of the GLAO as a function of the ground layer strength. The analysis compares simulated performance of the GLAO system for different atmospheres with the real results obtained with Multi-Laser system at the MMT telescope. This system uses five range gated and dynamically refocused rayleigh beacons and active secondary dformable mirror with 336 actuators. The intensity of the turbulence distribution at diffrent heights has been measured using a multi-laser SLODAR approach customized to the hexapolar arrangement of the Shack-hartmann sensor of the laser camera and also adapted to the geometry of the beacon constellation. The turbulence measurements are validated twofold: Using a wind profiler implemented using temporal covariance of the measured laser slopes and using a lunar scintillometer. Finally, the performance of the system versus other variables such as, tip-tilt guide star brightness are also sampled and charaterized.

8447-122, Poster Session

Laboratory performance of the Magellan adaptive optics VisAO camera

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We present laboratory results of the closed-loop performance of the Magellan Adaptive Optics (AO) Adaptive Secondary Mirror (ASM), pyramid wavefront sensor (PWS), and VisAO visible adaptive optics camera. The Magellan AO system is a 585-actuator low-emissivity high-throughput system scheduled for first light on the 6.5 meter Magellan Clay telescope in October 2012. Using a dichroic beamsplitter near the telescope focal plane, the AO system will be able to simultaneously perform visible (500-1000 nm) AO science with our VisAO camera and either 10 μm or 3-5 μm science using either the BLINC/MIRAC4 or CLIO cameras, respectively. For the last 6 months, the ASM, PWS, and VisAO camera have been undergoing final system tests in the solar test tower at the Arcetri Institute in Florence, Italy, reaching Strehls of 73% in i'-band with 500 modes and simulated turbulence of 13 cm ro at v-band. We present images and test results of the assembled VisAO system, which includes our prototype advanced Atmospheric Dispersion Corrector (ADC), prototype calcite Wollaston prisms for SDI imaging, and a suite of beamsplitters, filters, and other optics. Our advanced ADC performs in the lab as designed and is a 58% improvement over conventional ADC designs. We also present images and results of our unique Calibration Return Optic (CRO) test system and the ASM, which has successfully run in closed-loop at 1kHz. The CRO test is a retro reflecting optical test that allows us to test the ASM close-loop off-sky using an artificial star formed by a fiber source.

8447-123, Poster Session

Increasing sky coverage with the Gemini North ALTAIR/LGS AO system

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The Gemini North (GN) AO system, Altair, has been routinely operating in LGS mode since 2007. Due to the initial optical design, the NGS field-of-view (FoV) is limited to a radius ~ 25 arcseconds which limits the potential science. To improve this, we have tested the the AO/LGS operation using a peripheral wavefront sensor (PWFS) which patrols a field ~ 4-7 arcminutes from the target. This expanded NGS FoV permits greater sky coverage but with decreased resolution, FWHM ~ 0.1 -- 0.2 arcseconds making this mode very suitable for non-imaging, e.g. NIR (NIFS & GNIRS) and optical (GMOS with red-sensitive CCDs). We present the hardware and software upgrades to PWFS and Altair as well as the software necessary for making this observing mode a routine and integral part of GN operations. Characterization and performance of this new operation mode are presented.

8447-124, Poster Session

Status of the Raven MOAO science demonstrator

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Raven is a Multi-Object Adaptive Optics (MOAO) scientific demonstrator which will be used on-sky at the Subaru observatory. Raven is currently being built at the University of Victoria AO Lab. In this paper, we present an overview of the final Raven design and then describe lab tests involving prototypes of Raven subsystems. The final design includes three open loop wavefront sensors (WFSs), a laser guide star WFS and two figure/truth WFSs. Two science channels containing deformable mirrors (DMs) feed light to the Subaru IRCS spectrograph. Central to the Raven MOAO system is a Calibration Unit which contains multiple sources, a telescope simulator including two phase screens and a ground layer DM that can be used to calibrate and test Raven. We are working with the final Raven Calibration Unit and prototypes of open loop WFSs and science pickoffs to test and validate our open loop calibration and alignment techniques.

8447-125, Poster Session

ShaneAO: an enhanced adaptive optics and infrared imaging system for the Lick Observatory 3-meter Telescope

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The Lick Observatory 3-meter telescope has a history of serving as a testbed for innovative adaptive optics techniques. In 1996, it became the first astronomical observatory to employ laser guide star (LGS) adaptive optics as a facility instrument available to the astronomy community. Work on a second-generation LGS adaptive optics system, ShaneAO, is well underway, with plans to deploy on telescope in late 2012. In this paper we discuss key design features, performance predictions and implementation plans for the ShaneAO adaptive optics system. Once again, the Shane 3-m will host a number of new techniques and technologies vital to the development of future adaptive optics systems on larger telescopes. Included is a woofer-tweeter based wavefront correction system incorporating a voice-coil actuated, low spatial and temporal bandwidth, high stroke deformable mirror in conjunction with a high order, high bandwidth MEMs deformable mirror. The existing dye laser, in operation since 1996, will be replaced with a fiber laser recently developed at Lawrence Livermore National Laboratories. The system will also incorporate a high-sensitivity, high bandwidth wavefront sensor camera. Enhanced IR performance will be achieved by replacing the existing PICNIC infrared array with an Hawaii 2RG. The updated ShaneAO system will provide opportunities to test predictive control algorithms for adaptive optics. Capabilities for astronomical spectroscopy, polarimetry, and visible-light adaptive optical astronomy will be supported.

8447-126, Poster Session

An adaptive optical system based on 61-element deformable secondary mirror on 1.8-meter telescope

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In 2009, A 127-element adaptive optical system had been manufactured and installed at the Coude room of the 1.8m telescope at the Gaomeigu Site of Yunnan Astronomical Observatory, Chinese Academy of Sciences. A set of new adaptive optical system based on a 61-element deformable secondary mirror is being developed and will be integrated into the 1.8-meter telescope. The 61-element deformable secondary mirror with convex reflecting surface is designed to compatible with the Cassegrain focus of the 1.8-meter telescope. Comparing with the AO system of Coude focus, the AO system based on the deformable secondary mirror adopts much less reflections and consequently restrains the thermal noise and increases the energy transmitting to the system. The details of this system, the simulation result will be described in this paper. Furthermore, the test result of the deformable secondary mirror in the lab is also presented.

8447-127, Poster Session

Adaptive optics for the CHARA array

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The CHARA Array is a six telescope optical/IR interferometer run by the Center for High Angular Resolution Astronomy of Georgia State University and is located at Mount Wilson Observatory just to the north of Los Angeles California. The CHARA Array has the largest operational baselines in the world and has been in regular use for scientific observations since 2004. In 2011 we received funding from the NSF to begin work on Adaptive Optics for our six telescopes. Phase I of this project, fully funded by the NSF grant, consists of designing and building wavefront sensors for each telescope that will also serve as tiptilt detectors. Having tiptilt at the telescopes, instead of in the laboratory, will add several magnitudes of sensitivity to this system. Phase I also includes a slow wavefront sensor in the laboratory to measure non-common path errors and small deformable mirrors in the laboratory to remove static aberrations. Phase II of the project will allow us to place high speed deformable mirrors at the telescopes thereby enabling full closed loop operation. The system will be quite simple, have reletively few actualtors, a very small field of view and will use star light for wavefront sensing. We are currently seeking funding for Phase II. This paper will describe the design of the system and give the current status of the project.

8447-128, Poster Session

The 2012 status of MCAO at the GREGOR Solar Telescope

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The MCAO system of the GREGOR solar telescope incorporates 3 deformable mirrors to compensate for turbulence in 0, 5, and 15 km height. We present the results of the laboratory testbed after 2 years in operation. It is planned to move the MCAO system to the telescope in Spring 2012, and to run the three-DM-MCAO system on the Sun. We will report on this campaign.

We will also comment on dynamic misregistration occuring in a MCAO system.

8447-130, Poster Session

Recent progresses on the portable solar adaptive optics

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The portable solar adaptive optics is a compact system that will the first visitor solar adaptive optics in the world. As so, it will be able to work with any solar telescope in the size range of 1.0~2.0 meters, which will cover the largest solar telescope currently operational. The portable AO also features high-performance, and is a duplicable and affordable system. It will provide efficient wave-front correction down to the 0.5-μm

wavelength, and will be used for solar high-resolution imaging in the near infrared as well as the visible. It will also be the first AO system that is using the LabVIEW's high quality parallel and block-diagram based programming, which fully takes advantage of today's multi-core CPUs, and makes a rapid development of an AO system possible. In this publication, we report our recent progresses on the portable adaptive optics, which includes the laboratory test for performance characterization, and initial on-site observations.

8447-131, Poster Session

Designing the METIS adaptive optics system

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METIS, the Mid-infrared E-ELT Imager and Spectrometer is foreseen to be the third instrument on the European Extremely Large Telescope (E-ELT) and the only instrument to provide high sensitivity imaging and spectroscopy to the E-ELT. In order to reach the maximum resolution and sensitivity, an adaptive optics system is required. Since the operational wavelength of METIS is the longest of all E-ELT instruments and the field is relatively small, the complexity of the AO system is significantly reduced, both in required speed as well as order of the AO system. Adaptive Optics has been demonstrated to deliver consistently high performance for the current generation of 6-10 meter class telescopes at mid-infrared wavelengths, and similar performance is expected for METIS on the E-ELT. But in order to provide a reliable system on the E-ELT, several effects which have a minor impact on 6-8 meter class telescopes will need to be investigated for their impact on METIS AO. These effects include refractivity, atmospheric composition variations, but also the operation in a complex operational environment given by both METIS as well as the E-ELT. In this paper we describe the scientific requirements on the METIS AO system, the specific issues related to Adaptive Optics in the mid-IR and expected performance of the METIS AO system on the E-ELT.

8447-132, Poster Session

ERIS adaptive optics system design

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The Enhanced Resolution Imager and Spectrograph (ERIS) is the next-generation instrument planned for the Very Large Telescope (VLT) and the Adaptive Optics facility (AOF). It is an AO assisted instrument that will make use of the Deformable Secondary Mirror and the new Laser Guide Star Facility (4LGSF), and it is planned for the Cassegrain focus of the telescope UT4. The project is currently in its Phase A awaiting for approval to continue to the next phases.

The Adaptive Optics system of ERIS will include two wavefront sensors (WFS) to maximize the coverage of the proposed science cases. The first is a high order 40x40 Pyramid WFS (PWFS) for on axis Natural Guide Star (NGS) observations. The second is a high order 40x40 Shack-Hartmann WFS for single Laser Guide Stars (LGS) observations. The PWFS, with appropriate sub-aperture binning, will serve also as low order NGS WFS in support to the LGS mode with a field of view patrolling capability of 2 arcmin diameter. Both WFSs will be equipped with the very low read-out noise CCD220 based camera developed for the AOF. The real-time reconstruction and control is provided by a SPARTA real-time platform adapted to support both WFS modes.

In this paper we will present the ERIS AO system in all its main aspects: opto-mechanical design, real-time computer design, control, calibrations and operational strategy. Particular emphasis will be given to the system performance obtained via dedicated numerical simulations.

8447-133, Poster Session

Toward an ELT-scale sodium LGS wavefront sensing on-sky experiment

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The two first light adaptive optics (AO) instruments for the European Extremely Large Telescope (E-ELT) will both rely on several Sodium Laser Guide Stars (LGS). In using this technology, the E-ELT diameter comes with new challenges mainly raised by spot elongation. Before the final design studies of the E-ELT instruments, a Sodium LGS wavefront sensing (WFS) on-sky experiment at this scale is mandatory to provide meaningful spatial and temporal measurement error and performance evaluation. For this purpose, we propose to use Canary, the Multi-Object AO demonstrator installed at the WHT (4.2m). Canary is now undergoing a Rayleigh LGS upgrade and also provides natural guide star WFS. It could easily be adapted to the Sodium LGS case. Additionally, a transportable laser system, such as the one developed at ESO, positioned at a varying distance from the WHT could be used to provide off-axis launching (up to 40m), simulating the whole range of spot elongations. Full scale simulations of a Sodium LGS WFS on the E-ELT have guided us in the definition of the experiment we are proposing. Previous simulation results in the literature have stressed that an estimate of the Sodium profile is necessary to reduce measurement error to an affordable level. Hence simultaneous high resolution Sodium profiling is mandatory in the proposed experiment. In this paper, we present the simulation results as well as the specifications for both the Sodium LGS WFS and profiler to be used on Canary.

8447-134, Poster Session

Optical calibration and testing of the E-ELT M4 adaptive mirror

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Innovative optical interferometry test setups, together with improved control SW techniques, have been proposed and studied to be coupled with the M4 adaptive optics mirror of the E-ELT. The system is composed of three main sub-systems, each one optimized to fulfil some of the calibration requirements. The first sub-system is based onto computer generated holograms, to take fast simultaneous phase acquisitions of the full area of one segmented shell of the M4 mirror. An optical test tower, delivering a collimated beam up to 1.5-m diameter, has been designed for such purpose. A second sub-system is based onto a relatively large stitching interferometer, to calibrate the mirror at much higher spatial resolution, and to cope with the initial stages of the calibration. A third sub-system has been developed to perform differential piston and differential tilt removal, by an array of optical piston sensors. Two of

these sub-systems have been built and tested onto the demonstration prototype of E-ELT M4, and one is currently under development and optimization in the lab. Here we report on the full scheme that will be implemented in the final system.

8447-135, Poster Session

The Giant Magellan Telescope laser tomography adaptive optics system

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The Giant Magellan Telescope presents a unique optical design with seven 8.4m diameter primary mirrors matched by seven adaptive secondary mirrors (ASM).

The ASMs can be controlled in several different Adaptive optics (AO) observing modes coupled to the telescope.

One of these AO systems, the Laser Tomography Adaptive Optics (LTAO) system is currently in its preliminary design phase.

The LTAO observing mode will provide a Strehl ratio in H band of at least 30% over more than 20% of the sky and an ensquared energy in K band of at least 40% in a 50 milli--arcsec spaxel over more than 50% of the sky.

To achieve its performance requirements, the LTAO observing mode uses six 20W Laser Guide Stars (LGS) with six order--50x50 Shack--Hartmann wavefront sensors.

The LGSs are launched from three locations at the periphery of the telescope primaries.

A natural guide star (NGS) is used separately to measure tip--tilt, focus and low--bandwidth--low--order aberrations.

A open--loop controlled deformable mirror corrects the off-axis NGS infrared wavefront.

We give an update on the design of the LTAO WFSs, the LGS facility, the on--instrument wavefront sensors and the tomography and control algorithms.

8447-136, Poster Session

Optical designs with LGS WFS system for GMT-LTAO

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The Laser Tomographic Adaptive Optics (LTAO) system for Giant Magellan Telescope (GMT) uses a single conjugated deformable mirror, the segmented Adaptive Secondary Mirror (ASM), to correct atmospheric wavefront aberrations with the help of a constellation of six laser beacons equally spaced on the sky. We will present different approaches for the design of the Laser Guide Star (LGS) Wave Front Sensor (WFS) system for GMT to cover all sodium altidudes and telescope elevations, from 80 km to 200 km range and how the preliminary design was derived from these approaches. The designed LGS WFS system includes a defocus-compensation mechanism working with a simple zooming optics to achieve the pupil image with constant pupil size, nearly constant wavefront correction, as well as pupil distortion correction.

Either a trombone-mirror structure or a direct LGS-WFS translation is used for the defocus compensation, when conjugating the LGS altitudes in the sky. In the designs, a zooming collimator images the ASM in the GMT at the exit pupil of the LGS WFS system, where the designed lenslet-array is tailored for the selected CCD format for the required plate scale on the sky. Additionally, we have proposed a novel and simple solution for pupil-image segmentation when working with smaller CCD arrays. This novel solution consists of a single multi-aperture blaze grating (MABG) for pupil segmentation in the system.

8447-137, Poster Session

Design and predicted performance of the GMT ground-layer adaptive optics mode

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The Giant Magellan Telescope is planning to provide correction of the low layers (<1 km) of atmopsheric turbulence in support of wide-field instrumentation. This ground-layer adaptive optics (GLAO) mode will use the adaptive secondary mirrors to provide improved image quality over approximately 7 arcminutes FOV. We present a comparison between the use of a laser guide star constellation plus natural guide stars versus natural guide stars only on the average seeing width improvement. The study includes the possibility of varying the projected angular radius of the laser guide stars constellation to optimize the system performance. The performance predictions are based on atmospheric measurements carried out at Las Campanas over the last several years. The layout and components of both (laser beacon based and natural star only based) GLAO concepts are described and the impact and interaction with other GMT sub-systems is analyzed.

8447-138, Poster Session

The Giant Magellan Telescope phasing system

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The 25 m Giant Magellan Telescope consists of seven circular 8.4 m primary mirror segments with matching segmentation of the Gregorian secondary mirror. Achieving the diffraction limit in the adaptive optics observing modes will require equalizing the optical path between pairs of segments to a small fraction of the observing wavelength. This is complicated by the fact that primary mirror segments are separated by up to 40 cm, and composed of borosilicate glass. The phasing system therefore includes both edge sensors to sense high-frequency disturbances, and wavefront sensors to measure their long-term drift and sense atmosphere-induced segment piston errors.

The major subsystems include a laser metrology system monitoring the primary mirror segments, capacitive edge sensors between secondary mirror segments, a phasing camera with a wide capture range, and an additional sensitive optical piston sensor incorporated into each AO instrument. We describe in this paper the overall phasing strategy, controls scheme, and the expected performance of the system with respect to the overall adaptive optics error budget. Further details may be found in specific papers on several of the subsystems.

8447-142, Poster Session

Optical design of a Cassegrain mounted AO relay for 'Imaka

J. S. Pazder, National Research Council Canada (Canada)

The IMAKA is a ground layer adaptive optics system proposed for the Canada-France-Hawaii Telescope. This paper presents the optical design of a Cassegrain mounted IMAKA for a 0.8 degree field of view. The design incorporates Takeshi concentric ADC and an f/8 to f/5.7 reducer. This is followed with a novel double pass system to image thepupil on a 300mm mildly concave DM and re-image the system on the detector. The design meet the required 0.15" 80% encircled energy image performance including correction for atmospheric dispersion. The optical design is presented with the predicted imaging performance.

8447-143, Poster Session

A preliminary simulation result of the next-generation wide-field AO at Subaru Telescope

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A wide-field adaptive optics system based on an adaptive secondary mirror (ASM) is one of a future plan for the next-generation Subaru adaptive optics system.

The main application of ASM based AO will be a ground-layer adaptive optics (GLAO) in combination with a new wide-field multi-object infrared camera and spectrograph. GLAO is designed to correct the ground-layer of atmospheric turbulence, which is dominant component of accumulated turbulence strength and commonly affects the objects scattered on wide field-of-view.

Mauna Kea is known as one of the best suited place for GLAO in all over the world because the atmospheric turbulence is concentrated in low-altitude.

The performance of GLAO correction is expected to be better than 0.2 arcseconds FWHM in the K-band over FOV of about 10 arcminutes or more.

The high Strehl ratio of on-source correction expected by high-order ASM (order of 1000) and possibly considering tomography, is another important application.

The reduction of emissivity is also expected by replacing room-temperature mirrors of existing AO system with only one ASM will be also advantageous for infrared-wavelength range where thermal emissivity is dominant-noise source.

Simulations have been performed for the above-mentioned modes, to study the conceptual system design. In this paper, we report and discuss on a preliminary result of simulations for the next-generation wide-field Subaru adaptive optics.

8447-144, Poster Session

Dimensioning and performances of an AO system for the SALT

L. Catala, Univ. of Cape Town (South Africa) and South African Astronomical Observatory (South Africa); M. Carbillet, Univ. de Nice Sophia Antipolis (France); L. Jolissaint, aquilAOptics (Switzerland)

The Southern African Large Telescope (SALT), located at the South African Astronomical Observatory (SAAO) site near Sutherland, South Africa, is a 11-metre fixed-elevation telescope operating at UV-visible wavelengths (320-950 nm). To help take full advantage of SALT's available aperture, a feasibility study for an Adaptive Optics (AO) system is under way. Using the results from the site monitoring campaign that has been ongoing at SAAO since early 2010 we have begun carrying out AO simulations to investigate the dimensioning of different AO systems and how they might perform.

We will present the parameters of an optimization study and performance results for a single on-axis NGS AO system on SALT. These results have been obtained using both the analytic simulation tool PAOLA and the end-to-end Software Package CAOS. We will also present some preliminary work on the performance of a lucky imaging AO-aided mode in the visible and blue bands.

8447-145, Poster Session

System analysis and characterization of the FFREE bench

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Detection of exoplanets implies the measure of extremely weak signals, usually below intensity perturbations in the PSF caused by static aberrations. In particular, it will be essential to understand how to correct the residual static aberrations due to non common path between the detector and the instrument (i.e. residual optical aberrations, optics alignments, optics polishing, etc.) before the beam reaches the scientific focal planes.

We made optic simulations which included the impact of the physical propagation of the electric field (i.e. Fresnel propagation). To validate these simulations, we need a laboratory experiment.

So, we have finished the construction of a new test bench called FFREE (Fresnel Free Experiment for EPICS). The scope of the FFREE experiment is the active speckles correction using off-line cancellation techniques (Phase Diversity, Curvature Sensing).

This bench contains a tunable laser, a deformable mirror (32 by 32 actuators) and an infrared camera. In addition, we can place on it two types of pupil apodizer (PAP and APLC), a focal mask and two phase masks. In this paper, we will describe the system analysis and the impact of using optics on the shelf. We will discuss some characteristics like the chromatism and the environmental stability of the bench.

Many experiments are in progress. The first main results will be the active correction of the speckles by adapting the Electric Field Conjugation method and to quantify the chromatic effects on the speckles by using spectral deconvolution in the objective of a future instrument EPICS for the telescope E-ELT.

8447-146, Poster Session

Holographic combination of low-resolution Shack-Hartmann sensor and holography-based modal Zernike wavefront sensor

S. Dong, T. Haist, W. Osten, T. Ruppel, O. Sawodny, Univ. Stuttgart (Germany)

Holography based modal wavefront sensing (HMWS) detects directly the amplitude of Zernike components of an aberrated wavefront employing diffractive optical elements. The sensor is linear for the detection of single modes or multiple modes with small amplitudes. However, due to crosstalk effects, the linearity and the accuracy of the sensor are reduced when large aberrations are present in the beam. In this paper, a low resolution Shack-Hartmann sensor (LRSHS) is introduced to extend the dynamic range of HMWS. The holograms for LRSHS and HMWS

are superposed and further binarized to obtain one static binary phase hologram, allowing us to combine two sensor principles in one compact scheme. When the aberrated beam illuminates the hologram, the diffraction image on the detector shows both the shifted spots array for measuring local tilts of the wavefront using Shack-Hartmann sensing and the diffraction pattern for the HMWS. If the aberrations are large, low-order terms, which dominate the wavefront error, can be first corrected using the LRSHS. The system then switches to HMWS after one or two corrections to obtain better sensor sensitivity and accuracy under small aberration conditions.

In this contribution we explain in detail the working principle of this new sensor combination and the performance of the sensor is examined statistically with random aberrations created in accordance to the atmospheric turbulence model. The simulation results show that the sensor performance is improved using the proposed strategy. First experimental results are shown for validating the method.

8447-147, Poster Session

Woofer-tweeter adaptive optics in very strong turbulence using a magnetic liquid deformable mirror

D. Brousseau, Univ. Laval (Canada); J. Véran, National Research Council Canada (Canada); S. Thibault, E. F. Borra, Univ. Laval (Canada)

A woofer-tweeter AO system is an AO system where the wave-front correction is spatially and temporally distributed between two deformable mirrors. We have built such a woofer-tweeter system using a 37-actuator magnetic liquid DM (MLDM), a magnetic 97-actuator ALPAO DM and a Shack-Hartmann WFS. The MLDM, which has a very large single actuator and inter-actuator stroke (> 30 um), but a low bandwidth (< 10 Hz), is used has woofer, whereas the high bandwidth (~500Hz) lower stroke ALPAO DM is used as tweeter. With proper split of the correction, this combination can provide the woofer stroke at almost the tweeter speed, and therefore deliver significant AO correction in strong and fast turbulences that have been so far out of the working range of classical AO systems. Each deformable mirror was first experimentally characterized individually by i) measuring the step response of the actuators using stroboscopic wave-front measurements; and ii) measuring the rejection transfer function of the AO system when only one of the DMs is active using the AO telemetry data. These measurements were used to model the end-to-end performance of the woofer-tweeter bench and to optimize the spatial and temporal controller that optimally distributes the correction between the woofer and the tweeter. The setup was then experimentally used to correct a strong turbulence created by a rotating phase mask and the performance compared to what is obtained by each individually operated DM.

8447-148, Poster Session

Tomographic reconstructor for multi-object adaptive optics using artificial neural networks

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Multi-object adaptive optics (MOAO) requires a tomographic reconstructor to compute the AO correction for scientific targets within the field, using measurements of incoming turbulence from guide stars angularly separated with respect to the science targets. The tomographic reconstructor error is one of the main sources of error in MOAO, in particular when the turbulence varies in strength and/or position when observing. Besides the standard least-squares reconstructor, which places 'virtual' DMs at fixed altitudes, recent research presented the 'Learn and Apply' reconstructor, which is computed with the current atmospheric conditions. We have developed a reconstructor using an artificial neural network, which is trained in simulation only, with a realistic configuration of guide stars. Then the reconstructor is tested with real atmospheric profiles in simulation as well as in the laboratory, obtaining similar or better results than current reconstructors. The method is robust under typical noise conditions and unlike other reconstructors, can cope very well with variations in the atmospheric conditions without having to re-calculate its parameters. We present the technique, our latest results in simulation and laboratory and future plans for tests in CANARY, the on-sky MOAO demonstrator for the William Hershel Telescope.

8447-149, Poster Session

Image based deformable mirror control for adaptive optics in satellite telescope

N. Miyamura, The Univ. of Tokyo (Japan)

We are developing an adaptive optics system for earth observing remote sensing sensor. In this system, high spatial resolution has to be achieved by a lightweight sensor system due to the launcher's requirements. Moreover, simple hardware architecture have to be selected to achieve high reliability. Image based AOS realize these requirements without wavefront sensor. In remote sensing, it is difficult to use a reference point source unless the satellite controls its attitude toward a star or it has a reference point source in itself. We propose the control algorithm of the deformable mirror on the basis of the extended scene instead of the point source. In our AOS, a cost function is defined using acquired images on the basis of the contrast in spatial or Fourier domain. The cost function is optimized varying the input signal of each actuator of the deformable mirror. In our system, the deformable mirror has 140 actuators. We use basis functions to reduce the number of the input parameters to realize real-time control. We constructed the AOS for laboratory test, and proved that the modulated wavefront by DM almost consists with the ideal one by directly measured using a Shack-Hartmann wavefront sensor as a reference.

8447-150, Poster Session

Laboratory demonstration of real time frame selection with Magellan AO

J. R. Males, L. M. Close, D. A. Kopon, V. Gasho, The Univ. of Arizona (United States)

The Magellan AO system combines a pyramid wavefront sensor (WFS) and high-order adaptive secondary mirror, and will see first light on the Magellan Clay telescope in October 2012. With a 23 cm projected actuator pitch, this powerful system will enable good correction in the optical (0.5 to 1 microns). Realistic laboratory testing has yielded Strehl ratios greater than 40% in i' (0.765 microns) on bright simulated stars. On fainter stars our visible AO camera, VisAO, will work in the partially corrected regime with only short moments of good correction. We have developed a form of lucky imaging, called real time frame selection, which uses a fast shutter to block moments of bad correction, and quickly opens the shutter when the correction is good, enabling long integrations on a conventional CCD while maximizing Strehl ratio and resolution. The decision to open or shut is currently based on reconstructed WFS telemetry. Here we report on our implementation and testing of this technique in the Arcetri test tower in Florence, Italy.

8447-151, Poster Session

Residual tip-tilt motion of LGS in monostatic scheme

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Atmospheric Optics (Russian Federation)

Atmospheric turbulence is a serious limitation for astronomical observations. The application of adaptive optical systems can significantly improve the quality of images observed through the turbulent atmosphere. The current distributions of turbulent inhomogeneities of the medium are obtained in AO systems from measurements with the use of guide sources.

There is analyzed the possibility the general tilt correction of the wave front on base of the laser guide star (LGS) signal. The calculation of the image motion of the spherical wave (that position the source of radiation also fluctuated) with random center is conducted. The exact formula for random vector defining the position of the image of the spherical wave in focal plane of the telescope is offered.

The variance of residual fluctuations has been calculated. The variance behavior of this residual motion from optical experiment parameters are analyses. The similar problem for decision of the some practical tasks, including the possibility of the wave front “global” tilt correction with using single and multi-elements LGS, was appeared. We have considered the outer scale and features of coherent turbulence effects for image jitter in ground-based telescopes.

8447-152, Poster Session

Adaptive optics for laser space debris removal

R. Conan, N. Paulin, The Australian National Univ. (Australia); I. T. Ritchie, C. H. Smith, EOS Space Systems Pty. Ltd. (Australia); F. H. Bennet, K. Uhlendorf, The Australian National Univ. (Australia)

Space debris in low Earth Orbit below 1500km and ranging in size from 1 to 10cm is becoming an increasing threat to satellites and spacecrafts.

Radar and Laser tracking are currently used to monitor the orbits of thousands of space debris.

The removal of the space debris is a preferred more definitive solution.

Space debris removal could be achieved through laser ablation.

A Laser beam corrected with an adaptive optics system could in theory allows laser ablation.

We are developing an experiment to demonstrate the feasibility of laser ablation.

This laser ablation demonstrator is using a pulsed sodium laser to probe the atmosphere ahead of the space debris and the sun reflection of the space debris to get the atmospheric tip--tilt information.

Then a deformable mirror is shaped to correct an infrared laser beam on the uplink path to the debris.

We present here the design and the expected performance of the system.

8447-153, Poster Session

Concepts, laboratory, and telescope tests results of the plenoptic camera as a wavefront sensor

L. F. Rodríguez-Ramos, Instituto de Astrofísica de Canarias (Spain); J. M. Rodríguez-Ramos, M. López-Marrero, J. J. Fernández-Valdivia, Univ. de La Laguna (Spain)

The plenoptic camera has been proposed as an alternative wavefront sensor adequate for extended objects within the context of the design of the European Solar Telescope (EST), but it can also be used with point sources. Originated in the field of the Electronic Photography, the plenoptic camera directly samples the Light Field function, which is the four-dimensional representation of all the light entering a camera. Image formation can then be seen as the result of the photography operator applied to this function, and many other features of the light field can be exploited to extract information of the scene, like depths computation to extract 3D imaging or, as it will be specifically addressed in this paper, wavefront sensing.

The underlying concept of the plenoptic camera can be adapted to the case of a telescope by using a lenslet array of the same f-number placed at the focal plane, thus obtaining at the detector a set of pupil images corresponding to every sampled point of view. This approach will generate a generalization of Shack-Hartmann, Curvature and Pyramid wavefront sensors in the sense that all those could be considered particular cases of the plenoptic wavefront sensor.

Theoretical derivations and comparison with other wavefront sensors are included in the paper, but also laboratory results obtained with extended objects, phase plates and commercial interferometers, and even telescope observations using the Moon as an extended object are presented in the paper, clearly showing the capability of the plenoptic camera to behave as a wavefront sensor.

8447-154, Poster Session

An updated 37-element low-order solar adaptive optics system for 1-m new vacuum solar telescope at Full-shine Lake Solar Observatory

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A low-order solar adaptive optics (AO) system, which consists of a fine tracking loop with a tip/tilt mirror and a correlation tracker, and a high-order correction loop with a 37-element deformable mirror, a correlating Shack-Hartmann wavefront sensor and a real-time controller, had been successfully developed and installed at 1-m New Vacuum Solar Telescope (NVST) of Full-shine Lake Solar Observatory. This system is an update of the 37-element solar adaptive optics system designed for the 26-cm Solar Fine Structure Telescope at Yunnan Astronomical Observatory in 2009. The arrangement of subapertures of the Shack-Hartmann wavefront sensor was changed from square to hexagon in the updated system to achieve better compensation performance. Moreover, the imaging wavelengths of the system are both 1555nm and 710nm.

The low-order adaptive optics system was integrated into the solar telescope and saw the first light on February 24th, 2011, using solar granulation as the beacon. Later, the AO-corrected high resolution sunspots images were obtained using sunspots as the beacon. The observational results show that the contrast and resolution of the solar images are improved evidently after the correction by the AO system. The design of the system and the observational results will be presented, and the performance will be analyzed in this paper

8447-155, Poster Session

Performances analysis of SINFONI with the laser guide star facility

J. O’Neal, F. Y. J. Gonte, European Southern Observatory (Chile)

SINFONI is an near infrared integral Field spectrograph isntalled on the cassegrain focus of UT4 of the Paranal Observatory and fed by an adaptive optics system based on a curvature wavefront sensor and a bimorph deformable mirror. This instrument can work with a natural guide star or a laser guide star and a tip-tilt NGS for the adaptive optics.

Since a year the performance of the system is measured systematically to better understand its behaviour and define a new calibration and optimization strategy. This proceeding will present the results of the analysis and propose an optimization of the instrument.

8447-156, Poster Session

High contrast enhancement to long slit spectroscopy

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One of the major challenges of the coming decade is the direct imaging and the direct spectroscopic followups of giant exoplanets from the ground. Experiments to combine a pupil plane coronagraph with long slit spectroscopy have been carried out using VLT/NACO. The main idea is to enhance the contrast for spectroscopy the way it can be done for imaging and to be able to perform deep follow-up spectroscopy of faint sub-stellar companions at small inner working angles. We used NACO's Apodizing Phase Plate (APP) optimized around 4µm to conduct this study and present high contrast spectroscopic data acquired on-sky using very bright stars. We compare our results with simulated data and discuss the results and issues encountered. Finally, we present alternative and efficient ways to combine such a coronagraph with a long slit spectrograph and place our findings in perspective with other apodizing and spectroscopic techniques.

8447-157, Poster Session

Temporal evolution of quasi-static speckle in high-contrast imaging

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The major noise source limiting high-contrast imaging is due to the presence of quasi-static speckles. An understanding of quasi-static speckles originating from instrumental errors is paramount for the search of faint stellar companions, as they do not average over time and are difficult to calibrate.

Their temporal evolution knowledge is needed for the quantification of the gain expected with angular differential imaging, as well as to determine the timescale on which speckle nulling techniques should be carried out.

From the analysis of a time series of adaptively corrected, coronagraphic images recorded in the laboratory with the High-Order Testbench (extreme adaptive optics test bench at the European Southern Observatory), we evidence that fast-evolving quasi-static speckles at the angstrom/nanometer level are affecting the stability of the static speckle noise in the final image after the coronagraph. The temporal evolution of the quasi-static wavefront error exhibits linear power law, which is used to model quasi-static speckle evolution in high-contrast imaging instruments. Such a model is compared to data obtained with the SPHERE instrument, currently in its integration and test phase.

8447-158, Poster Session

Image quality analyzer

V. P. Lukin, N. N. Botugina, P. A. Konyaev, O. N. Emaleev, L. V. Antoshkin, V.E. Zuev Institute of Atmospheric Optics (Russian Federation)

Image quality analyzer (IQA) which used as device for efficiency analysis of adaptive optics application is described. In analyzer marketed possibility estimations quality of images on three different criterions of quality images: contrast, sharpnesses and the spectral criterion. At present given analyzer is introduced on Big Solar Vacuum Telescope in stale work that allows at observations to conduct the choice of the most contrasting images of Sun. Is it hereinafter planned use the analyzer in composition of the ANGARA adaptive correction system.

8447-159, Poster Session

Science with Magellan AO: simulated performance and new frontiers in high spatial resolution AO science

K. B. Follette, The Univ. of Arizona (United States)

We present updated science cases and simulated images convolved with real point spread functions for the soon-to-be integrated Magellan adaptive secondary AO system. This revolutionary system, with its combination of high actuator count (585 actuators with 23cm pitch), fast and precise wavefront sensing (1kHz, 500 modes) and exceptionally high Strehl ratios (>70% at H, 98% in MIR, and 73% at V band with simulated 13cm r0 turbulence) has exceeded expectations in test tower performance. The success of the Large Binocular Telescope system, of which the Magellan system is a clone, leads us to expect that the Magellan ASM will be capable of matching or even exceeding (owing to its slightly higher actuator pitch, and better seeing on site) the remarkable on-sky performance of the LBT system. In preparation for Fall, 2012 commissioning, we have simulated the performance of all three cameras: VisAO at 0.63-1.05µm, Clio2 at 1-5µm and BLINC/MIRAC4 at 8-26µm for a number of Natural Guide Star science targets using a combination of real data and Monte Carlo radiative transfer modeling. We anticipate that Magellan will provide the community with a uniquely powerful suite of instruments capable of unprecedentedly high spatial resolution study of circumstellar disks, tight binaries, and geologically active objects in our own solar system, including Titan and Io.

8447-161, Poster Session

Early science results from the first light AO (FLAO) system for LBT

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The First Light Adaptive Optics (FLAO) system for LBT has been commissioned in October 2011. In Science Verification and Science Demonstration time the capabilities of the AO to provide optimal Science-grade imaging using the PISCES Near Infrared Camera have been proven. In this paper we collect sample results of the observations made, in order to exemplify the different abilities: astrometry and photometry made on very different targets such as Solar System objects, Planetary Nebulae, Star Formation regions, Exoplanets and retrieving high spatial resolution images of typical high galactic latitudes (External Galaxies and QSO). We will discuss the observation strategies and procedures extrapolating typical performance numbers for photometric and astrometric precisions.

8447-162, Poster Session

Solar adaptive optics at the Hida Observatory: latest achievements of current system and design of new system

N. Miura, J. Miyazaki, S. Kuwamura, Kitami Institute of Technology (Japan); N. Baba, Hokkaido Univ. (Japan); Y. Hanaoka, National Astronomical Observatory of Japan (Japan); M. Yamaguchi, S. Ueno, Y. Nakatani, S. Nagata, R. Kitai, K. Ichimoto, Kyoto Univ. (Japan); H. Takami, National Astronomical Observatory of Japan (Japan)

We develop a solar adaptive optics (AO) system at the 60cm domeless solar telescope in the Hida Observatory, Japan. Our current AO system has a deformable mirror with 97 electromagnetic actuators, a Shack-Hartmann wavefront sensor with a 10x10-microlens array and standard personal computers. It usually operates with about 900 Hz, and hence the -3dB cutoff frequency of the system is theoretically about 100 Hz. Although it is not high enough to realize full correction under Hida's typical seeing conditions, we have frequently observed the suppression of image variation in a variety of observational situations. We think that the current AO system is useful for correcting low-order wavefront errors. We will present the details of our current system and results of solar observations using it.

In parallel to developing the current system, we are designing a new full-scaled AO system applicable to various observations, such as high-dispersion spectroscopy, simultaneous wide-range spectroscopy, narrow-passband imaging and high-precision polarimetry. The new system using another deformable mirror with 97 piezo-actuators will work as a classical AO system at first. We plan to upgrade it to a multi-conjugate AO system in future. We will also report the design of the new AO system.

8447-163, Poster Session

Optical absolute calibration of capacitive sensors for AO deformable mirrors: strategy and preliminary results

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The LBT contactless, voice-coil actuators feature a working point that ranges from 10 to 100um, with a typical position noise of a few nm.

Such operating gap allows a large stroke for AO, field stabilization and chopping.

To fully take advantage of it, an absolute calibration of their internal metrology system, based on capacitive sensors, is requested.

We implemented and tested an optical calibration technique, that is based on the fast interferometer detection of a low order mode with non-zero piston. A dynamic Twyman-Green interferometer was used for the differential sampling of the commanded steps, at a frequency of 25 Hz; a set of actuators is kept in a steady state to allow the step-by-step optical reconstruction of the superimposed piston.

This procedure has been tested in dome environment at the Large Binocular Telescope.

8447-164, Poster Session

Keck I laser guide star AO system and performance

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The Keck I Laser Guide Star (LGS) Adaptive Optics (AO) system is scheduled to begin shared-risk science observations at the end of May, 2012. The OSIRIS near-IR integral field spectrograph, currently used with the Keck II LGS AO system, will be integrated with the Keck I LGS AO system. The higher power and sodium coupling efficiency of the Keck I laser and the implementation of a center launched laser versus the side launch on Keck II should result in a higher performance system. We will discuss the major components of the Keck I LGS AO system including the laser, free space transport system and AO system, and present the initial performance results for the components and overall system.

8447-165, Poster Session

La Silla Paranal Observatory laser guide star facility operation: latest performance and future upgrades

J. L. Alvarez, J. Beltran, M. Riquelme, European Southern Observatory (Chile)

The Laser Guide Star Facility (LGSF) has been in operation for more than five years now. Mayor improvements has been done in the system since its installation and commissioning. This facility is installed on the UT4 (Yepun) telescope at the La Silla Paranal Observatory on Paranal in Chile.

In this contribution, we report on the latest technical performance achieved by the LGSF in operational conditions. We also present a breakdown of the technical problems faced so far by using the information available on the Paranal Problem Report System [PPRS]. A subsystem analysis is performed providing information about the fraction of the problems caused by each subsystem. We also present the latest evolution of the human resources needed to operate and maintain the LGSF system. Finally, we present and discuss the possible replacement of the PARSEC laser source of the LGSF for a new light source based on a "State of the Art" fiber laser.

8447-166, Poster Session

Performance of the SOAR adaptive module with UV Rayleigh guide star

A. A. Tokovinin, R. Tighe, P. Schurter, R. Cantarutti, N. S. van der Bliek, M. Martinez, E. Mondaca, S. R. Heathcote, Cerro Tololo Inter-American Observatory (Chile)

The adaptive module of the 4-m SOAR telescope (SAM) has been tested on the sky by closing the loop on natural stars. Then it was re-configured for operation with low-altitude Rayleigh laser guide star in early 2011. The LGS loop was first closed in April 2011. We report on the performance of this system designed to compensate ground-layer turbulence and improve the delivered image quality at visible wavelengths. Parameters of the LGS sub-system (return flux, spot size, polarization, laser operation) have been determined. The gain in imaging resolution and energy concentration over field will be quantified, depending on turbulence profile and other factors.

8447-167, Poster Session

Testing and integrating the laser system of ARGOS: the ground layer adaptive optics for LBT

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The Laser Guide Star facility ARGOS will provide Ground Layer Adaptive Optics to the Large Binocular Telescope (LBT). The system operates three pulsed laser beacons above each of the two primary mirrors, which are Rayleigh scattered in 12 km height. This enables correction over a wide field of view, using the adaptive secondary mirror of the LBT. The ARGOS laser system is designed around commercially available, pulsed Nd:YAG lasers working at 532 nm. In preparation for a successful commissioning, it is important to ascertain that the specifications are met for every component of the laser system. The testing of assembled, optical subsystems is likewise necessary. In particular it is required to confirm a high output power, beam quality and pulse stability of the beacons. In a second step, the integrated laser system along with its electronic cabinets are installed on a telescope simulator. This unit is capable of carrying the whole assembly and can be tilted to imitate working conditions at the LBT. It allows alignment and functionality testing of the entire system, ensuring that flexure compensation and system diagnosis work properly in different orientations.

8447-168, Poster Session

Vibration compensation for the ARGOS laser launch path

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Present and future adaptive optics systems aim for the correction of the atmospheric turbulence over a large field of view combined with large sky coverage. To achieve this goal the telescope must be equipped with multiple laser beacons. Still usually a guide star for correction of the tilt-aberrations is needed. For some fields even such a tilt-star is not available and a correction on the laser beacons alone is applied.

For this method to work well the laser beacons must not be affected by telescope vibrations on their up-link path.

For the ARGOS system this jitter of the beacons is specified to be below 0."05. To achieve this goal a vibration compensation system is necessary to mitigate the mechanical disturbances.

The ARGOS vibration compensation system is an accelerometer based open loop system. The accelerometer measurements are fed into a real time controller. To achieve high performance the controller of the system is model based. The output is then applied to a fast steering mirror.

In the following the concept of the ARGOS vibration compensation, tests of the hardware, and laboratory results will be presented.

8447-169, Poster Session

A sodium guide star adaptive optics system for the 1.8 meter telescope

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We are developing a sodium guide star adaptive optics system for the 1.8 meter telescope, which consists of three main parts: (i) 20W microsecond pulsed laser system, (ii) Φ200mm laser launch telescope and (iii) 37-elements adaptive optics system. All of these three parts are mounted on the 1.8 meter telescope which is located in Gaomeigu site of Yunnan Astronomical Observatory, Chinese Academy of Sciences. The pulsed laser system and the launch telescope are rotated with the azimuthal base of the telescope. A miniaturized 37-elements low-order adaptive optics system including a 37-elelment deformable mirror and a 6×6 array Hartmann-Shack wavefront sensor is mounted at the Cassegrain focus taking account of the pulsed laser mode. A separate tip-tilt correction loop is also integrated into the system. This paper describes the details of this system, the simulation result and the test result in the lab. After the indoor test, the whole system will be shipped to 1.8 meter telescope. The latest commissioning status and results is presented also in this paper.

8447-170, Poster Session

Investigations of long pulse sodium laser guide stars

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Long pulse length sodium laser guide stars (LGS) are useful because they allow for Rayleigh blanking and fratricide avoidance in multiple LGS systems. Bloch equation simulations of sodium-light interactions in Mathematica show that certain spectral formats and pulse lengths, on the order of 30 microseconds, with high duty cycles (20-50%) should be able achieve photon returns within 10% of what is seen from continuous wave (CW) excitation. In this work, we investigate the time dependent characteristics of sodium florescence, and find the optimal format for the new LGS that will be part of the upgraded AO system on the Shane 3 meter telescope at Mt. Hamilton. Results of this analysis are discussed along with their general applicability to other LGS systems. The potential benefits of uplink correction are also considered.

8447-171, Poster Session

Improving stability, robustness, and performance of laser systems

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The vast majority of large telescopes are now equipped with Adaptive Optics (AO) systems, and many use lasers to create artificial stars (laser guide stars, LGS). Despite the significant advances in the use of LGS for AO, some problems persist during the operations. In particular, achieving a satisfactory performance in terms of delivered power and beacon spot quality usually requires a constant and complex alignment of the laser and beam transfer optics. To provide easier calibrations of beam transfer optics and faster pre-setting of the system during routine operations, we propose to introduce active elements (deformable mirrors) in the laser beam before it is propagated to the sky. A first design for the Gemini MCAO system (GeMS) is proposed based on its current configuration and by simulating the main sources of wavefront aberrations occurring on the laser beam and possible ways to compensate them.

8447-172, Poster Session

Design, analysis, and testing of the optical tube assemblies for the ESO VLT four laser guide star facility

R. Henselmans, D. Nijkerk, M. Lemmen, N. Rijnveld, F. Kamphues, TNO (Netherlands)

TNO has developed the Optical Tube Assemblies (OTAs) for the ESO VLT Four Laser Guide Star Facility. The OTAs are Galilean 20x beam expanders, expanding a 15 mm diameter input beam (25W, 589 nm CW) to a steerable 300 mm diameter output beam. TNO has recently successfully completed acceptance testing of the four units, showing compliance to the challenging requirements on output wavefront quality, thermally induced defocus under operational conditions, absolute pointing accuracy and polarization extinction ratio (PER).

TNO applied its corrective polishing in combination with the NANOMEFOS measurement machine to produce the 380 mm diameter aspherical output lens, resulting in 20 nm rms output wavefront quality.

The thermal behaviour of the system has been analyzed by combining optical, lumped mass and FE analyses. A design that is passively athermalized over a large temperature range as well as under the influence of thermal gradients has been developed. Extensive thermal testing has shown a thermally induced defocus of less than 0.15 waves under the operational conditions of 0-15°C and upto -0.7°C/hr gradient. A custom tip-tilt mechanism was designed to steer the output beam over a 4.8 arcmin radius, with less than 0.1" (3sigma) accuracy at 1 Hz update rate. The PER was also measured under operational (thermal and tilt) conditions and demonstrated to be well above 99%. This paper describes the design, modelling and analysis, and the test results of these instruments.

8447-173, Poster Session

Multiple laser guide stars wavefront sensor prototype for the EELT: design and alignment

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Almost all the scientific instruments foreseen to be installed on the European Extremely Large Telescope claim for the Sodium Laser Guide Stars for an effective adaptive optics correction of the aberrated wavefront over a large fraction of the sky. These artificial sources are elongated, irregular and variable with time. Thus the local wavefront measurement inside the sub-apertures, by means of a Shack-Hartmann wavefront sensor, requires investigations on advanced centroiding algorithms for the extended spots position measurement to reduce the residual wavefront error. The laboratory prototype presented in this paper reproduces the expected conditions, for an Extremely Large Telescope case, when measuring the wavefront of a Laser Guide Star by means of a Shack-Hartmann wavefront sensor. A simplified version of the prototype has been successfully integrated and tested in 2010. We describe the design and the alignment phases of new components that achieve the following features: a programmable setting of the elongated source intensity profile to be able to reproduce realistically the time variable Sodium layer density vertical profile; the simulation, one at a time, of a multiple laser guide stars launching system by means of an optical derotator that rotates the elongated spot pattern on the detector plane; the implementation of a two layers turbulence model that introduces a differential wavefront aberration according to the azimuth angle of the laser guide stars and simulates the time evolution of the turbulence. The alignment results and the scheduled test program are finally presented.

8447-175, Poster Session

Dynamical refocussing laser guide stars with membrane mirrors

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Laser guide stars created in the earth's sodium layer are the choice for all ELTs as adaptive optics reference. With the thickness of the sodium layer spanning up to 10km, the apparent image of the guide stars on the adaptive optics wavefront sensors is elongated. The further away sub-apertures of the WFS are from the guide star launch location, the more elongated the guide star appears on the sensor. To counteract the decreased signal from the elongation, usually an increased laser power is demanded or special format radial CCDs are proposed. Another known possibility is to utilize pulsed lasers and follow dynamically the propagating pulse on its way through the sodium layer, creating a sharp spot at the wavefront sensor location. Similar processes have been used for laser guide stars created with Rayleigh scattering in the lower atmosphere, increasing greatly the number of photons that can be received from the guide star.

We present here the design and first laboratory tests of such a dynamically refocus device, based on membrane mirrors. Driven acoustically at high frequencies the stroke and phase of the mirror can be controlled. With a compact appearance the system seems to be easy to use and could enable precise wavefront control with lower power pulsed lasers at ELTs and other telescopes.

8447-176, Poster Session

Characterization of the sodium layer at Cerro Pachon and impact for GeMS performance

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The Gemini MCAO System (GeMS) uses 5 LGS to measure and compensate for atmospheric distortions. A good knowledge of the sodium abundance is therefore crucial to understand the fluctuations of the brightness of the LGS during the year, and the effect and limitations on GeMS performance. In this paper, we present data from a laser experiment that was carried out at Cerro Tololo to monitor the abundance and altitude of the mesospheric sodium in 2001, during a 5 runs covering a period of 1 year. This data is used to derive the following parameters: (i) mesospheric sodium column density, (ii) temporal behavior of the sodium layer mean altitude, (iii) sodium layer thickness and appearance of sporadic behavior. We compare these results with the data gathered during the first year of GeMS commissioning / operations.

8447-177, Poster Session

Recent developments in aircraft protection systems for laser guide star operations

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The astronomy community's use of high power laser guide star adaptive optics systems presents a potential hazard to aviation. Historically, the most common and trusted means of protecting aircraft and their occupants has been the use of safety observers (aka spotters) armed with shut-off switches. These safety observers watch for aircraft at risk and terminate laser propagation before the aircraft can be adversely affected by the laser. Efforts to develop safer and more cost effective automated aircraft protection systems for use by the astronomy community have been inhibited by both technological and regulatory challenges. This paper discusses recent developments in these two areas. Specifically, with regard to regulation and guidance we discuss the 2011 release of AS-6029 by the SAE as well as the potential impact of DO-278. With regard to the recent developments in the technology used to protect aircraft from laser illumination, we discuss a novel Transponder Based Aircraft Detection (TBAD) system being installed at Keck Observatory. Finally, we discuss our strategy for evaluating TBAD compliance with the regulations and for seeking appropriate approvals for LGS operations at Keck using a fully automated, flexibly configured, multi-tier aircraft protection system incorporating this new technology.

8447-261, Poster Session

A decade of operations with the Laser Traffic Control System: paradigm shift and implied development directions

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Skvarc, Isaac Newton Group of Telescopes (Spain)

The Laser Traffic Control System (LTCS) is a software solution to the problem of laser beam avoidance, using priority based collision resolution and an optional built-in laser shutter command interface. LTCS uses static site survey information, dynamic telescope pointing and control data, and a configurable “rules” scheme, to monitor laser beam geometry (Rayleigh and LGS) and warn or prevent undesired emission at participating institutions. LTCS was developed for use on Mauna Kea in 2001, but through collaborative efforts with multiple institutions, has since been enhanced and installed at several sites around the world. Functional implementations, either operational or in prototype form, exist for Mauna Kea, LaPalma, Cerro Pachon, Cerro Paranal, and Haleakala. Since the last LTCS SPIE update in 2006, many important features have been added. There has also been some new site testing activity that has resulted in lessons learned and the development of new analysis/test tools. Finally, an important lasing operations paradigm shift has emerged on Mauna Kea and is anticipated for Paranal. The trend is clearly away from static collision priority rule determination, toward dynamic “negotiated” priority determination. The implications of this paradigm shift, discussion of forced collision test results and lessons learned, and a status update on development activities since the last update will be presented in the paper.

8447-178, Poster Session

Speckle nulling experiments with the FFREE bench

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The Fresnel-Free Experiment for EPICS (FFREE) is a test bench developed in the frame of high contrast imaging for ELTs. Its purpose is to support the EPICS project (Exo-planets Imaging Camera and Spectrograph) for the European Extremely Large Telescope. FFREE is dedicated to the investigation of chromatic effects in the cancellation of static speckles either actively with a deformable mirror or by post-processing of scientific images. Emphasis is put on Fresnel diffraction chromatic effects that are known to be a strong limitation in broadband high contrast imaging, especially on an ELT. We show how FFREE has been designed to permit the introduction of known Fresnel effects with phase screens that can be conjugated to different distances to the pupil. In this paper, we will present experimental results about active speckle nulling using two different methods, the Electric Field Conjugation method and a method based on a classical phase diversity approach. The impact of Fresnel effects on the performance will be tackled.

8447-179, Poster Session

Dense aperture mapping for high contrast imaging: first laboratory results

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Dense Aperture Mapping (DAM) is a new pupil remapping technique, which enhances the high angular resolution and the high contrast imaging capabilities of a large telescope equipped with an Adaptive Optic (AO).

DAM provides a high-Strehl image thanks to a simple and passive optical component, composed of a double lenslet array, which sub-divides the entrance pupil in many spatially filtered sub-pupils. This paper deals with the first laboratory results on a testbed named VISIDAM. We focus our attention on the point spread function (PSF) properties of DAM, on the chromatic effects as a function of the spectral bandwitch in the visible wavelength, and on the aliasing effects as a function of the off-axis position of the object. The results show an excellent comparison between experience and simulation. They validate the quality of the optical component to use it on sky. They show the simplicity and the great potential of DAM for high contrast imaging application, even without an AO. The next objectif will be to test a DAM with an AO, first in laboratory and then on sky, so as to demonstrate the interest of DAM coupled with high-contrast imagers such as NACO and SPHERE at the VLT or within EPICS on EELT, to detect and characterize exoplanets.

8447-180, Poster Session

Intelligent vibration control of ELTs and large AO hardware

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LINC-NIRVANA, the MCAO-supported Fizeau imager for the LBT, serves as pathfinder for future ELT-AO imagers in terms of size and technology. MPIA is also partner of the E-ELT first-light NIR imager MICADO (both SCAO and MCAO assisted).

We present an overview of our vibration control strategies for optical path and tip-tilt stabilization, involving accelerometer based real-time vibration measurements, vibration sensitive active control of actuators, and the development of a dynamical model of the LBT. Our experiences, made with LINC-NIRVANA, are fed into MICADO structural AO design to reach highest on-sky sensitivity.

8447-181, Poster Session

Development of new concepts to minimize the impact of fast telescope vibrations seen by the E-ELT/MICADO wavefront sensors

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We present our recently started effort to realize feedforward vibration control loops with a full AO-testbed in the laboratory. A piezo-driven tip-tilt mirror unit introduces an arbitrary, but controllable, vibration power-spectrum to simulate telescope mirror vibrations of any kind on the wavefrontsensor. Our ultimate goal is to demonstrate in realistic laboratory tests, how telescope vibrations faster than atmospheric tip-tilt can be measured by accelerometers, and controlled in real-time feedforward to allow for longer and more sensitive WFS integrations.

8447-182, Poster Session

Extremely linear WFS probes to aid LGSs in the ELT design

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Open loop (like in MOAO) or partially open loop (like in virtual DMs) AO techniques demands for very linear Wavefront Sensors. If these approaches are used to the aim of gaining significant sky coverages with solely NGS or to significantly reduce the requirements in terms of power and reliability of LGSs, also high sensitivity is to be achieved. These kind of extremely efficient and highly linear Wavefront Sensors can be achieved through locally closed loop in which on one side the actual wavefront sensor can perform around its best conditions and on the other the full dynamic range offered by the corrective DM employed is at hands. Although position driven DM s could ameliorate such requirement Internal metrology can be achieved optically in a number of ways in order to minimize non common path aberrations and constraints on the path leading to some loss of sensitivity. We investigate here the realm of possible opto-mechanical realization of a probe, capable to co-exist with the currently foreseen E-ELT LGS probes and giving the possibility to exploit the open loop wavefront sensing operation with the aim of reaching a preliminary design of such a system.

8447-183, Poster Session

DRAGON: a wide-field multipurpose real time adaptive optics test bench

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DRAGON will be a new and in some ways unique adaptive optics test bench. Initially, it will test new and existing concepts for CANARY, the laser guide star tomographic adaptive optics demonstrator on the WHT, then later it will be used to explore concepts for other existing and future telescopes.

The modular design is such that it is well suited to prototyping novel AO technologies. Woofer/Tweeter control, multi-LGS MOAO and MCAO are all operating modes that can be studied with the system design. In addition to natural guide stars, both Rayleigh and Sodium laser guide stars can be simulated. In particular, a novel method for simulating elongated sodium LGSs launched through turbulence, using an excited fluorescent dye to emulate the atmospheric sodium layer, will be implemented.

Unique features of DRAGON include realistic modeling of the atmosphere using custom manufactured phase screens, a wide field of view and scintillation effects. The Durham Adaptive Optics Real-time Controller (DARC) is used to provide real-time control over capable DRAGON configurations, with the system running at realistic, on-sky frame rates in excess of 500Hz.

Currently, DRAGON is in its design stage. Construction and alignment of the system began in early 2012. First results, from using the test-bench in its MOAO configuration are expected soon.

8447-184, Poster Session

Toward an experimental validation of new AO concepts for future E-ELT instrumentation

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The developement of new instrumentations for the future E-ELT will require new developments in adaptive optics in terms of simulation (end-to-end simulator for an ELT), optimisation of command laws (traditional Kalman filter methods will show limitations because of the power of necessary calculation, multi-stages correction) and experimental validation of new Wavefront concepts.

In order to address these key aspects, a new multi-purpose experimental AO bench is developed at LAM. It is based on the use of a Shack-Hartmann WFS in front of a 140 actuators micro-deformable mirror (Boston), dedicated to "low orders" modes, while a Pyramid wavefront sensor (PWFS) will be combined to a Liquid Crystal Spatial Light Modulator for "high orders" correction. Both systems could be merged in a two stages AO concept allowing us to study the coupling of a telescope pre-correction with a dedicated large M4 deformable mirror and a post focal high order AO system. Analysis and optimisation of the spatial and temporal split of the AO correction between the two systems is therefore essential.

Finally, we will use the world's fastest and most sensitive camera system OCAM2 (developed at LAM) with the pyramid concept (proposed by R. Ragazzoni), to demonstrate a homemade fast and hyper-sensitive PWFS (up to 100x100 sub-apertures) dedicated to the first generation instruments for ELTs.

All these studies are led in collaboration with ONERA and L2TI.

8447-185, Poster Session

The HIA MCAO laboratory bench

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This paper presents an update on the design and deployment of the HIA MCAO laboratory bench. This bench directly supports the development of NFIRAOS, the first light MCAO facility for the Thirty Meter Telescope. The bench implements a closed-loop MCAO system, with two magnetic DMs, four LGS Shack-Hartmann WFSs, two NGS T/T WFS, one NGS T/T/F WFS and one higher order Truth WFS, making up a scaled down version of NFIRAOS. The bench includes several artificial turbulence screens and reproduces realistic LGS spot elongations. It is driven by software in Matlab, frame-rates ranging from 1Hz to 15Hz.

The goals of this bench are to anchor the NFIRAOS end-to-end simulation tools; to exercise real-time LGS tomographic AO in a variety of well controlled conditions, such as faint and poorly corrected NGSs, non-uniformities in the sodium layer and field dependant Non-Common-Path Aberrations (NCPAs); develop and demonstrate calibration procedures, such PSF reconstruction and tomographic reconstruction and correction of field dependant NCPAs; and to validate optimization methods that operates at 10+ second time scales, which is not tractable in a numerical simulation, such as matched filter update and Cn2 estimation using a SLODAR method.

8447-186, Poster Session

A test bench for ARGOS: integration of sub-systems and validation of the ground layer reconstruction

G. O. de Xivry, S. Rabien, Max-Planck-Institut für extraterrestrische Physik (Germany)

Argos, the wide field Laser Guide Stars adaptive optics system for the Large Binocular Telescope, is now entering its installation phase. In the meanwhile, we have started a test bench in order to integrate various Argos sub-systems and validate its ground layer correction scheme. Indeed, the test bench aims to include realistically the Argos wavefront camera system including a large fast frame, high quantum efficiency and low readout noise pnCCD, the slope - DSP based - computer, the optical gating units, and part of the Argos software. Additionally, we have started a first turbulence module, to simulate a ground layer and a higher layer turbulence, and a first source module that allows us to place guide stars at different location in the field. This first test bench attempts to integrate up to a system level different Argos components and to confront our ground layer reconstruction with simulation.

8447-187, Poster Session

A prototype phasing camera for the Giant Magellan Telescope

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Achieving the diffraction limit with the adaptive optics system of the 25m Giant Magellan Telescope will require that the 7 pairs of mirror segments be phased. Phasing the GMT is made difficult because of the 30-40cm gaps between the primary mirror segments. These large gaps result in atmospheric induced phase errors making optical phasing difficult at visible wavelengths. The large gaps between the borosilicate mirror segments also make an edge sensing system prone to thermally induced instability. We describe an optical method that uses twelve 1-m square subapertures that span the segment boundaries. The light from each subaperture is mapped onto a MEMS mirror segment and then a lenslet array which are used to stabilize the atmospherically induced image motion. Centroids for stabilization are measured at 700nm. The piston error is measured from the fringes visible in each of the 12 stabilized images at 2.2 microns. We are constructing a prototype camera to be deployed at the 6.5m Magellan Clay telescope.

8447-188, Poster Session

Final optical design of Raven: a MOAO science demonstrator for Subaru

O. Lardière, R. Nash, Univ. of Victoria (Canada); D. R. Andersen, National Research Council Canada (Canada); C. H. Bradley, Univ. of Victoria (Canada)

Raven is a Multi-Object Adaptive Optics (MOAO) technical and scientific demonstrator which will be used on Subaru telescope with IRCS spectrograph. The optical and opto-mechanical designs are finalized and the system is now being integrated in the lab at UVic. Raven features three open-loop wavefront sensors (WFS) patrolling a 3.5' field of regard (FoR), one on-axis LGS WFS, two science channels each equipped with a pick-off arm, a 11x11 actuator DM, a closed-loop WFS for calibration and performance comparison and an image rotator. The main requirements of Raven which drove the opto-mechanical design are the optical interface with Subaru and IRCS, a throughput greater than 80% of AO188 throughput in order to keep the multiplex advantage of Raven, and a registration error between WFSs and DMs less than 6% of a subaperture for any pick-off location in the whole FoR and for any wavelength from 0.5 to 2.5microns. These challenging requirements led to a quite unique optical design based on a telecentric system involving mainly powered mirrors. This paper presents in detail the optical design and its performance, as well as the opto-mechanical design.

8447-189, Poster Session

Design and test results of the calibration unit for the MOAO demonstrator RAVEN

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The UVic AO Lab in collaboration with HIA and the Subaru telescope is designing Raven, a multi-object adaptive optics (MOAO) demonstrator that will be coupled to the Subaru Infrared Camera and Spectrograph. Its main goal will be to demonstrate MOAO feasibility on the sky while allowing astronomers to beneficiate from the increased observing efficiency associated with such systems.

INO has designed, assembled and tested the Raven calibration unit. This sub-system consists in a telescope simulator that will allow aligning Raven's components during its integration, testing its AO performances in the laboratory and at the telescope, and calibrating the AO system by building the interaction matrix and measuring the non-common path aberrations (NCPA).

The calibration unit will provide a 9x9 grid of broadband (0.6 to 2.5 µm) natural guide stars diffraction limited above 1.0 µm and located in a 2.7' circular FoV. This grid ca rotate to simulate sky rotation during observations. The NGS sources intensity can be adjusted to emulate star magnitudes ranging from R=8 to R=16. An on-axis laser guide star conjugated to altitudes varying from 85 km to 180 km and intensity ranging from mag 5 to mag 11 is also available in combination with a bright alignment source conjugated to infinity.

This paper presents the analysis strategy and the tools developed during the design phase to meet the focal plan and exit pupil plane tight optical requirements when considering manufacturing and positioning tolerances. The system test results are presented and compared to the model predictions.

8447-190, Poster Session

MOAO test bench in Tohoku University

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We are assembling a test optical bench to simulate an Multi-Object Adaptive Optics system in the optical lab, targeting MOAO system on the next generation ground-based large telescopes. In an MOAO system, 3D structure of the atmospheric turbulence will be evaluated with wavefront measurements in multiple directions and tomographic reconstruction. Applying the wavefront correction independently to each direction based on the 3D estimation, each object is expected to be observed in a condition close to the diffraction limit. In order to evaluate the tomographic estimation method, we prepared a test optical bench to simulate an MOAO system in our optical lab. The system consists with 1) four light sources with single-mode fibers simulating three guide stars and one target objects, 2) multiple phase plates simulating atmospheric turbulence structure, and 3) 4 Shack-Hartmann wavefront sensors. Imaging data from the sensors will be reduced with tomographic algorithm. The accuracy of the tomographic wavefront estimation and the usage of GPU-based PCs will be examined. Additionally, open-loop control of an AO system is under testing with an independent optical system. Once the method of open-loop control is established, the module will be installed in the tomography test bench and entire system will be evaluated as an MOAO system. In parallel, we are conducting a development of a large stroke MEMS deformable mirror which is a key component of an MOAO system for the large telescopes. Latest status of the development will be reported.

8447-191, Poster Session

Atmospheric coherent turbulence

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This paper summarizes results received by authors for last decade on the problem of the atmospheric coherence turbulence. According to our data the coherent turbulence is the result of the self-organizing non-linear processes in continuous media, including in the atmospheric air. New theoretical and experimental data are considered, it confirm the effect

of the decreasing of the opitcal waves fluctuations in the coherence turbulence.

Experimental data of the surface measurements of the key turbulence characteristics in various geographical areas and meteosituations published earlier in articles of authors is shown, that in the open atmosphere the extensive areas are often observed in which one coherent structure has the defining influence. Turbulence in such areas usually is called as coherent. In present article the short review of properties of the coherent turbulence is given. New data of the experimental observations of the coherent structures arising in the presence of obstacles for air streams and roughnesses of the underlying surface are adduced.

8447-192, Poster Session

Impact of Cn2 profile on tomographic reconstruction performance: application to E-ELT wide field AO systems

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New techniques of Adaptive Optics (AO), generically called Wide Field AO, have been developed in the frame of the design study for new instruments for Extremely Large Telescopes (ELT). Concepts such as Multi-Conjugate AO are based on a tomographic reconstruction of the turbulent volume followed by a projection onto DM(s) in order to ensure a good correction in a large Field of View. These systems require a 3D phase reconstruction and a statistical representation of the turbulent volume through the knowledge of the Cn^2 profile, which has a strong impact on performance.

In the framework of wide field AO systems developed for the future E-ELT, we focus our study on the structure and the parameters which define the Cn^2 profile. We analyze their impact on the performance on MCAO system for an ELT. By establishing a comprehensive error budget of this system, we emphasize the terms which are directly linked to the knowledge of the real Cn^2 profile and to the estimated Cn^2 profile which is used as a model in the reconstruction process. We determine and discuss the level of the accuracy needed on the Cn^2 profile to limit the tomographic error term and to ensure a good performance. We emphasize the needed trades-off to have a good performance and a reasonable size of the system.

8447-193, Poster Session

Distributed model identification for efficient prediction of turbulent wavefronts

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Model-based wavefront reconstruction and prediction has the potential to further improve the imaging resolution and contrast of adaptive optics (AO) systems. However, with the increasing apertures of ground based telescopes, such as in Extremely Large Telescopes, the number of sensors, actuators and the sampling frequency of AO systems are considerably increasing, resulting in complex models describing wavefront dynamics. The computational complexity of identifying such models from measured data, as well as the wavefront reconstruction and prediction may become very large.

In this paper we propose a spatially distributed model structure for describing the dynamics of the turbulent phase. We start with the identification of local auto-regressive models which only depend on current and past measurements from a small neighborhood. The complexity of the local AR model is only determined by the number of neighboring sensors, and thus it is independent of the total amount of sensors. Therefore, the identification of such models can be done much more efficiently.

We will show that the complexity of the local model can be further reduced by performing model order reduction. To this end, the local auto-regressive model can be transformed into a multidimensional state-space model, which describes the propagation of the wavefront in time and space.

The wavefront predictor is derived from the low order multidimensional state-space model, which is compared to the optimal wavefront predictor in terms of accuracy and computational complexity for a simulated von Karman type of turbulence.

8447-194, Poster Session

Accurate measurement of Cn2 profile with Shack-Hartmann data

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All Wide Field Adaptive Optics systems for the ELTs need a precise tomographic reconstruction of the turbulent volume. The Cn2 profile, representing the turbulence strength, becomes a critical parameter for the tomographic reconstruction performance. We propose a new Cn2 profilometry method named COSLIDAR (COupled Slope and scIntillation Detection And Ranging), that uses correlations of slopes and of scintillation indexes recorded on a Shack-Hartmann (SH) from two separated stars. COSLIDAR leads to a precise Cn2 retrieval for both low and high altitude layers. Here, we present an end-to-end simulation of the Cn2 profile measurement, and it will be compared to Cn2 profiles obtained from correlations of slopes only (SLODAR-like) or correlations of scintillation indexes only (SCIDAR-like). The detection noises are taken into account using binary stars of magnitudes 3 to 6, which are observed on a 1.5 meter telescope with a realistic optical transmission. Different SH geometries and Cn2 profiles are considered. We evaluate the accuracy of the Cn2 reconstructions and their altitude resolution by defining a dedicated metric. The impact of the Cn2 profile quality on the tomographic reconstruction is evaluated.

8447-195, Poster Session

MOSE: a feasibility study for optical turbulence forecast with the Meso-Nh mesoscale model to support AO facilities at ESO sites (Paranal, Armazones)

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We present very encouraging preliminary results obtained in the context of the MOSE project, a study aiming to quantify the feasibility of the forecast of the optical turbulence and meteorological parameters (in the free atmosphere as well as at the surface) at Cerro Paranal and Cerro Armazones. The study employs the Meso-Nh atmospheric mesoscale model and aims to supply a tool to support the scheduling of the scientific programs and the use of AO facilities at the VLT and the E-ELT. In this study we take advantage of the huge amount of measurements performed so far at Paranal and Armazones by ESO and the TMT consortium in the context of the site selection for the respective ELTs to constraint/validate the model. Being that the optical turbulence depends on most of the main atmospheric parameters (wind speed and direction, temperature and relative humidity) a detailed analysis of the model performances in reproducing these parameters is carried out. Preliminary results indicate a great accuracy of the model in reproducing all the main atmospherical parameters in statistical terms as well as in each individual night. The study is co-funded by ESO and INAF.

8447-196, Poster Session

MOSE: zooming on the Meso-NH mesoscale model performances at the surface layer at ESO sites (Paranal, Armazones)

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In the context of the MOSE project, in this contribution we present a more detailed analysis of the model performances and their dependency on the model and orography horizontal resolutions in proximity of the ground. We demonstrate that, to well reconstruct the observed state of the atmosphere (wind, temperature) in the surface layer (up to a few tens of meters), a horizontal resolution higher than what is required for the free atmosphere is needed. In both sites results are very promising. The study is co-funded by ESO and INAF.

8447-197, Poster Session

First light AO (FLAO) as test bench for the LINC-NIRVANA adaptive optics system

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The commissioning of the First Light Adaptive Optics #2 for the Large Binocular Telescope offered the opportunity to check some of the operation modes of the LINC-NIRVANA multi-conjugate adaptive optics system. In daytime using a retro-reflector optics in front of the adaptive secondary mirror (ASM) and during night on sky time we measured performance of the adaptive optics loop in particular conditions similar to the one that the LINC-NIRVANA ground and mid-high wavefront sensors (WFS) will experience. In LINC-NIRVANA pupil re-rotator optics and pyramid modulation are not implemented, just the opposite with respect to the FLAO system solution. In LINC-NIRVANA the pupil rotation is taken into account by computing the Reconstruction Matrix (RM) through linear interpolation starting of a set of measured Interaction Matrix taken at different pupil clocking. The RM is loaded in real time on the Digital Signal Processor (DSP) control board of the ASM. Frame rate and linear interpolation limits are addressed. Theory and measurements made on the ESO multi-conjugate adaptive optics demonstrator (MAD) suggest that the lower the correction performance the larger should be the modulation to be applied to focal plane image of the guide star around the pyramid pin.

These two issues have been investigated in order to verify the solution implemented in LINC-NIRVANA to overcome or to minimize the drawbacks. A quantitative analysis of these and other possible error source components is finally given.

8447-30, Session 8

Natural guide stars adaptive optics system at LBT: FLAO commissioning and science operations status

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Large Binocular Telescope is disclosing its nature of adaptive binocular telescope. On both channels a First Light Adaptive Optics (FLAO) system is installed. The system key elements are an high order single pyramid wavefront sensor and a 672 actuators Adaptive Secondary Mirror (ASM). On the so called right side of the telescope the FLAO#1 system has been fully commissioned in October 2011 and started astronomical imaging operations using the PISCES camera.

This system already shown the capability to perform extreme adaptive optics correction in the infrared light.

PISCES is a 1Kx1K NIR Hawaii-I camera with a platescale of 19mas: it allowed the Science Verification of the imaging capabilities.

On the left side the commissioning of the FLAO#2 started in December 2011 and is in progress. In this paper we present the status of the two systems and a preview of the scientific results achieved by the FLAO#1 system such as Solar System objects imaging, stellar population studies of globular cluster and exoplanets color characterization.

8447-32, Session 8

Status and performance characterization of the Gemini MCAO systems

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GeMS is the Gemini MCAO system. It uses 5 laser guide stars (LGS), 3 natural guide stars (NGS) and 2 deformable mirrors to compensate the turbulence in a large FoV of 2 arcmin diameter. Since January 2011, GeMS is in commissioning and first results were obtained as soon as April 2011. From May to November, we took advantage of the Chilean winter time to perform a five months shutdown, and fix, upgrade and repair all the subsystems based on the experiences learned on-sky. Since November 2011, the GeMS team resumed the work on-sky,

focusing on performance optimization and science commissioning. At the time of writing this abstract, first images with a full MCAO compensation over the whole field were obtained, demonstrating the unique system capabilities. This paper presents a general status of the GeMS project, and a detailed analysis of its performance. Particular emphasis will be given to the high-order, Tip-Tilt and plate scale loop characterization. We compare the performance obtained with different reconstructors (e.g. MMSE vs. LSE), different LGS or NGS magnitude, different conditions of Seeing and Cn2 profile. Performance is measured as (i) average Strehl Ratio (SR), (ii) its variation over the field, and (iii) the astrometric precision obtained on-sky over an 85x85arcsec2 FoV. GeMS is currently integrated with the remainder of the observatory and should be available for science in the second half of 2012.

8447-33, Session 8

First closed-loop visible AO test results for the advanced adaptive secondary AO system for the Magellan Telescope: MagAO's performance and status

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The Magellan Clay telescope is a 6.5m Gregorian telescope located in Chile at Las Campanas Observatory. The Gregorian design allows for an adaptive secondary mirror that can be tested off-sky in a straight-forward manner. We have fabricated an 85 cm diameter aspheric adaptive secondary with our subcontractors and partners, the ASM passed

acceptance tests in July 2010, and the entire System was “end-to-end” closed-loop system level tested from June 2011-December 2011 at the ASM test tower at Arcetri Observatory, Florence Italy. This secondary has 585 actuators with <1 msec response times (0.7 ms typically). This adaptive secondary will allow low emissivity AO science. We fabricated a high order (585 mode) pyramid wavefront sensor similar to that now successfully used at the Large Binocular Telescope. The relatively high actuator count allow moderate Strehls to be obtained in the visible (0.63-1.05 µm). We have built a prototype AO CCD science camera called “VisAO”. Complete “end-to-end” lab tests of MagAO achieve a solid 49% Strehl at 0.76 um with the VisAO camera in 0.8” simulated seeing (13 cm ro at V) with fast 33 mph winds and a 40 m Lo locked on R=8 mag artificial star. These high optical wavelength Strehls are made possible by our powerful combination of a next generation ASM and a Pyramid WFS with 400 controlled modes and 1000 Hz sample speeds (similar to that used successfully on-sky at the LBT). Currently only the VisAO science camera is used for lab testing of MagAO, but this high level of measured performance in the optical promises even higher Strehls with our IR science cameras. On bright (R=8 mag) stars we should achieve very high Strehls (>70% at H) in the NIR (1-5 microns) with the existing MagAO Clio2 science camera/coronagraph or even higher (~98% Strehl) the Mid-IR (8-26 microns) with the existing BLINC/MIRAC4 science camera. The VisAO science camera is fed by an advanced triplet ADC and is piggy-backed on the WFS optical board. We have designed an additional (as yet unfunded) “clean-up” very fast (2 kHz) tilt stabilization system for attenuation of any additional vibrations that may occur at the telescope. Also a high-speed shutter will be used to block periods of poor correction. The entire system passed CDR in June 2009, and we finished the closed-loop system level testing phase in December 2011. Final system acceptance “pre-ship” tests are scheduled for February 2012 with first light in October 2012. The system performance requirements, and an overview the design, interface, acceptance test results, and schedule for the Magellan AO system are presented here.

8447-34, Session 8

Results from the PALM-3000 high-order adaptive optics system

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The first of a new generation of high actuator density AO systems developed for large telescopes, PALM-3000 is optimized for high-contrast exoplanet science but supports operation with natural guide stars as faint as V ~ 18. PALM-3000 began commissioning in June 2011 on the Palomar 200” telescope and has to date nearly 60 nights of observing. The AO system consists of two Xinetics deformable mirrors, one with 66 by 66 actuators and another with 21 by 21 actuators, a Shack-Hartman WFS with four pupil sampling modes (ranging from 64 to 8 samples across the pupil), and a full vector matrix multiply real-time system capable of running at 2KHz frame rates. We present the details of the completed system, and initial results. Operating at 2 kHz with 8.3cm pupil sampling on-sky, we have achieved a K-band Strehl ratio as high as 82% in ~1.0 arcsecond visible seeing.

8447-121, Session 8

LINC-NIRVANA pathfinder: testing the next generation of wave front sensors at LBT

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LINC-NIRVANA (Herbst et al., SPIE, 2010) will employ four wave front sensors to realize multi-conjugate correction on both arms of a Fizeau interferometer for LBT. Of these, one of the two ground-layer wave front sensors, together with its infrared test camera, comprise a stand-alone test platform that follows in the footsteps of the multi-conjugate adaptive optics demonstrator (MAD) (Marchetti, et al., 2003). Unlike MAD, however, this system, called the LINC-NIRVANA Pathfinder, will achieve ground-layer AO correction via an adaptive secondary; the 672-actuator thin shell at the LBT. Since reporting our progress at AO4ELT2 (Conrad, et al., AO4ELT2, 2011), we have initiated design and development in three key areas: a software interface for external control of the adaptive secondary, a software extension to the instrument interface to the telescope control system, and calibration. We will report on our progress and future plans in these three areas, and on the project overall.

8447-35, Session 9

Vibration mitigation in adaptive optics control

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Perturbations affecting image formation on ground-based telescopes are composed of signals that are not only induced purely by the atmosphere.

They often include vibrations induced by wind or other sources of excitation (cooler, shutter, etc).

Using state-space control design techniques (e.g.; LQG/Kalman filtering, H-infinity), efficient perturbation compensation can be incorporated into AO control. However, this requires an accurate dynamical perturbation model with manageable complexity. The purpose of this paper is to investigate how such models can be constructed and identified from wavefront sensor (WFS) measurements.

Several identification approaches will be compared, ranging from off-the-shelf techniques such as subspace identification, recursive least-squares or extended Kalman filter, to application-specific methods. Their distinctive features (e.g., time or frequency domain-based, recursive or batch data processing...) and inherent performance-trade-offs (model and algorithm complexity, reliance on data vs. prior information, ability to handle model variation...) will be discussed in relation with the specific

constraints and requirements of the AO vibration mitigation problem. Results will be also compared with controllers that do not account for vibrations, like integrator or MMSE reconstructor. Performance improvement will be illustrated in numerical simulations and by applications to on-sky data sets.

8447-36, Session 9

Distributed control of large deformable mirrors

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While it is attractive to integrate a deformable mirror (DM) for adaptive optics (AO) into the telescope itself rather than using relay optics within an instrument, the resulting large DM can be expensive, particularly for extremely large telescopes. A low-cost approach for building a large DM is to use voice-coil actuators, and rely on feedback from mechanical sensors to improve the dynamic response of the mirror sufficiently that it can be used in a standard AO control system. The use of inexpensive voice-coil actuators results in many lightly-damped structural resonances within the desired control bandwidth. We present a robust control approach for this problem, and demonstrate performance in a closed-loop AO simulation, incorporating realistic models of low-cost actuators and sensors. The first contribution is to demonstrate that high-bandwidth active damping can be robustly implemented even with non-collocated sensors, by relying on the "acoustic limit" of the structure where the modal bandwidth exceeds the modal spacing. Next we introduce a novel local control approach, which significantly improves the high spatial frequency performance relative to collocated position control, but without the robustness challenges associated with a global control approach. The combination of these "inner" control loops results in DM command response that is demonstrated to be sufficient for integration within an AO system.

8447-37, Session 9

Design of frequency-based controllers for vibration mitigation at the Gemini-South telescope

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Reduction of tip and tilt vibrations at the Gemini South MCAO System (GeMS) is addressed in this paper. A frequency framework for the synthesis of controllers is described, with particular emphasis on the minimization of H2 and H-infinity norms. Previous results have shown that modeling the turbulence via identification tools can lead to non optimal solutions, resulting in excessive rejection of certain frequencies or unbalanced residual spectrum due to poor modeling of vibrations using standard AR or Laplace representations. A new approach reconstructs the open loop slopes (pseudo-open-loop) and then performs a fine tuning of the controller by finding the parameters that yield to the least possible value of the residual's standard deviation. The results are evaluated using the same residual data from NGS and LGS wave-front sensors and also from the Strehl ratio achieved at the scientific imager (GSAOI).

8447-38, Session 9

On the rejection of vibrations in adaptive optics systems

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In modern adaptive optics systems, lightly damped sinusoidal oscillations resulting from telescope structural vibrations have a significant deleterious impact on the quality of the image collected at the detector plane. Such oscillations are often at frequencies beyond the bandwidth of the wave-front controller that therefore is either incapable of rejecting them or might even amplify their detrimental impact on the overall AO performance.

A technique for the rejection of periodic disturbances acting at the output of unknown plants, which has been recently presented in literature, has been adapted to the problem of rejecting vibrations in AO loops. The proposed methodology aims at estimating phase and amplitude of the harmonic disturbance together with the response of the unknown plant at the frequency of vibration. On the basis of such estimates, a control signal is generated to cancel out the periodic perturbation. Additionally, the algorithm can be easily extended to cope with unexpected time variations of the vibration's frequency by adding a frequency tracking module based either on a simple PLL architecture or on a classical extended Kalman filter. Oversampling can be also easily introduced to efficiently correct for vibrations approaching the sampling frequency.

The approach presented in this contribution is compared against different algorithms for vibration rejection available in literature, in order to identify drawbacks and advantages.

Finally, the performance of the proposed vibration cancellation technique has been tested in a realistic scenario exploiting pseudo-open-loop tip/tilt time series reconstructed from MACAO measurements.

8447-39, Session 10

Comparison of LGS wavefront-sensing with pyramid, yaw, and quad-cell types wavefront sensors

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LGS wavefront sensing is a topic of importance for future ELTs. However, the elongation effect of the sodium beacon makes this task particularly difficult on a large aperture, where large format detectors are required. An alternative solution is to use quad-cell types wavefront sensors : either quad-cell shack-hartmann, or pyramid (that use only 4 pixels per phase measurement, either modulated of fixed), or yaw (an optical differentiation wavefront sensor proposed recently, that also uses 4 pixels, like the pyramid).

We propose in this paper a comparison of the functionning of these devices. We show that it is possible to develop a common model for all of them, so that their behavior can be directly compared and their differences enlighted more easily. We derive performance of these sensors and compare with classical shack-hartmann.

8447-40, Session 10

Wavefront sensing and correction with the Gemini Planet Imager

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High-contrast imaging is a growing observational technique aimed at discovering and characterizing extrasolar planets. The Gemini Planet Imager (GPI) is designed to achieve contrast ratios of 10^6-10^7 and

requires unprecedented wavefront correction and coronagraphic control of diffraction. GPI is a facility instrument now undergoing integration and test, and scheduled for first light on the 8-m Gemini South telescope towards the end of 2012. In this paper, we focus on the wavefront sensing and correction aspects of the instrument. To measure the wavefront, GPI combines a Shack-Hartmann wavefront sensor and a high-accuracy infrared interferometric wavefront calibration system. The Shack-Hartmann wavefront sensor uses 1700 subapertures to precisely sample the wavefront at 1.5 kHz and features a spatial filter to prevent aliasing. The wavefront calibration system measures the slower temporal frequency errors as well as non-common path aberrations. The wavefront correction is performed using a two-stage adaptive optics system employing a 9x9 piezoelectric deformable mirror and a 43x43 actuator MEMS deformable mirror operating in a woofer-tweeter configuration. Finally, an image sharpening technique is used to further increase the contrast of the final image. In this paper, we describe the three wavefront sensing methods and how we combine their respective information to achieve the best possible contrast.

8447-41, Session 10

Wave front sensing strategies for SPHERE: concepts, performance, and experimental results

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Direct exoplanet detection implies nanometric precision control of wave-front during the whole acquisition. Such a precision implies a fast, accurate and high order measurement of the turbulence combined with nanometric calibration of quasi-static internal aberrations. We present in this paper the complete wavefront sensing scheme (based on multiple wavefront sensors [WFS]) developed for the SPHERE instrument allowing to reach such challenging goals. The main WFS is dedicated to turbulence correction and based on a filtered Shack-Hartamn WFS concept combined with a extremely sensitive CCD. The quasi-static internal aberrations are measured with an optimised phase diversity concept allowing to insure a flat (smaller than a few nanometer rms) wavefront at the level of the coronagarphic focal plane. Finally a differential Tip-Tilt sensor ensures a ultra-precise positionning (better than 0.5 mas) on the coronagraphic mask.

The three wfs tightly interact and requires very precise cross-calibrations. We present here that pulling out the highest accuracy from these different WFS implies the development of particular procedures. We also present experimental validation of these procedure obtained in the Framework of the SPHERE XAO system SAXO integration and test. The WFS performance will allow the full coronagraphic performance of SPHERE instrument. Endly, we present an extension of these WFS procedure and strategy to the frame of EPICS, the future ELT instrument dedicated to exoplanet direct detection, particularly with the direct utilisation of a coronagraphic phase diversity.

8447-42, Session 10

Instrumental aberrations retrieval from AO corrected sky PSF using phase diversity

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Non-common path errors, high order telescope errors, and post-AO aberrations in the instrument arm generate static aberrations which can sometime significantly affect the overall performance of AO correction. Focal plane phase diversity is a demonstrated efficient way to retrieve these aberrations from defocused calibration lamp based PSF, which are then feed back as an offset to the deformable mirror for pre-compensation. In order to capture the whole static aberration of the optical system telescope+AO+instrument, though, natural guide stars based PSF are required, with AO correction, in order to limit the image spread and maximize the PSF signal/noise ratio. In this paper, we present the results of a sky, long exposure, AO-PSF based phase diversity campaign, with the Keck-II AO system, and discuss the sensitivity of the method with respect to the guide star noise, the seeing variation between the different defocused PSF acquisition, and most importantly, the sensitivity to the definition of the pupil transmission. We show that our results are consistent and demonstrate that NGS sky PSF based phase diversity can be used as a reliable tool in particular for the more general process of AO systems PSF reconstruction.

8447-43, Session 10

Design of a truth sensor for the GMT laser tomography adaptive optics system

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The GMT laser tomography adaptive optics system will have a truth sensor guiding on a natural guide star. The function of truth sensors on existing LGS AO systems is to correct for effects of the laser guide star elongation. However, we show that the effect of LGS elongation effects are minor for a WFS detector with adequate sampling of the spot. Instead, the truth sensor will be used to calibrate non-common path aberrations, measure telescope segment piston errors and correct low-order aberrations caused by differences in altitude between the LGS and the science object. We demonstrate that an infrared AO-corrected static pyramid wavefront sensor meets all the requirements and can operate with any star bright enough to be used as a tip-tilt sensing star.

8447-199, Poster Session

Simulations for the AO systems of the E-ELT

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In this paper, we present simulation work done on the AO systems for the E-ELT. First, we adress the effect of various external (to the AO) perturbations (like scalloping, M4 recentering) on the AO system. Secondly, we investigate the parametric dependance of the performance of instrumental (MC/LT/AO) systems, as a function of the number of LGSs, DMs, etc. Finally a brief status on the work of comparing various fast reconstructors (including Cure and Frim) for MCAO will be presented. In particular, sensitivity to spot elongation will be investigated.

8447-200, Poster Session

A study of MOAO behind GLAO for EAGLE

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An MOAO corrected multi-IFU instrument, such as the EAGLE instrument proposed for the E-ELT has a deformable mirror correcting each IFU sub-field. Additionally, EAGLE will also use the E-ELT deformable M4 mirror to apply a global (closed-loop) MOAO correction. Here, we investigate the impact on MOAO performance if a global GLAO correction is applied across the whole field, rather than the optimised global MOAO correction (which may or may not be identical). The differences in M4 correction (between GLAO and optimal MOAO) will depend on the position of IFU pick-offs in the science field, and also on the turbulence, for example, MOAO DM stroke may be minimised if more than the ground layer is corrected by the M4 DM, depending on how fast turbulence decorrelates across the field of view. We consider the impact on MOAO DM stroke, the effect on performance, and study both tomographic and non-tomographic GLAO corrections. Such a situation may arise if for

example a combined multi-object spectrograph and multi-IFU instrument is designed, such as would result from the integration of EAGLE with another proposed E-ELT instrument. We demonstrate here that performance of EAGLE will not be significantly affected by being placed behind another such instrument. The results presented will be obtained using full end-to-end Monte-Carlo simulations using the Durham AO Simulation Platform. We also present a number of algorithms which can be used to improve AO performance, both in pixel processing and multi-mirror control.

8447-201, Poster Session

Control system modeling and development for the Raven multi-object adaptive optics demonstrator

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Raven will be a Multi-Object Adaptive Optics (MOAO) technology and science demonstrator on the Subaru telescope. It will be capable of deploying up to 3 natural guide star (NGS) wavefront sensors (WFS) as well as an on-axis laser guide star (LGS) WFS. Open loop correction will be performed on two independent science fields. In order to meet the key science requirement, 30% of the energy of an unresolved point spread function (PSF) must be ensquared within a 140 mas slit using existing WFS camera and deformable mirror (DM) technology. Results from the most recent performance modeling of Raven have helped to establish the system parameters and characteristics which will lead Raven to meet or exceed the baseline performance requirements. Moving from theory to a real system introduces specific control and computation requirements. In order to gain a more realistic expectation of performance and to facilitate the development of aspects of the control system, modifications to the Raven model include the introduction of a modal approach to extracting and controlling the low order LGS drift modes, the temporal splitting of tip/tilt correction in the science paths between the DMs and their tip/tilt stages, and a preliminary examination of the wavefront reconstruction approach with a focus on the benefits of modal versus zonal tomography. As a further step in moving from model to reality, simulated turbulated input wavefronts are replaced by real data generated by Raven's calibration unit, which has been designed as a telescope simulator and a three layer turbulence generator.

8447-202, Poster Session

GMT AO system requirements and error budgets in the preliminary design phase

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Error budgets are an indispensable tool for assuring that project requirements can be and are being met. An error budget will typically include terms associated with different subsystems which are being designed by different teams of engineers, and fabricated by different vendors.

It is a useful tool at all levels of design since it provides a means to negotiate design trades in the broadest possible context. Error budgeting is in many ways fundamental to the mission of systems engineering and of course to the overall project success.

In this paper we will describe the GMT Adaptive Optics flow down requirements and their integration with their wavefront error budgets. We will focus on The GMT Adaptive Optics wavefront error budgets for the following observing modes:

- Laser Tomography Adaptive Optics
- Natural Guide Start Adaptive Optics
- Ground Layer Adaptive Optics

Finally, a description of each error budget and the close link between the error budget and other parameter such as sky coverage, zenith angle, etc will be discussed in this paper.

8447-203, Poster Session

Multi-conjugate AO for the European Solar Telescope

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The European Solar Telescope will be a 4-meter diameter world-class facility, optimized for studies of the magnetic coupling between the deep photosphere and upper chromosphere. It will specialize in high spatial resolution observations and therefore it has been designed to incorporate an innovative built-in Multi-Conjugate Adaptive Optics system (MCAO). It combines a narrow field high order sensor, with 50x50 subapertures, that will provide the information to correct the ground layer and a wide field low order sensor, with 19 subfields with 13x13 subapertures each, for the high altitude mirrors used in the MCAO mode. One of the challenging particularities of solar AO is that it has to be able to correct the turbulence for a wide range of observing elevations, from zenith to almost horizon. Also, seeing is usually worse at day-time, and most science is done at visible wavelengths. Therefore, the system has to include a large number of high altitude DMs. In the case of the EST an arrangement of 4 high altitude DMs is used, forming a system with approximately 4000 actuators. Fast reconstruction algorithms are necessary to deal with such large amount of degrees of freedom. For this reason, we have studied the implementation of the Fractal Iterative Method (FrIM) and the Fourier Transform Reconstructor (FTR), to the EST MCAO case. Using OCTOPUS, the end-to-end simulator at ESO, we have performed several simulations with both algorithms, being able to reach the science requirement of a homogeneous Strehl higher than 50% all over the 1 arcmin fov.

8447-204, Poster Session

Benefits of optimal projection on deformable mirrors with the fractal iterative method for different tomographic AO objectives

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FrIM-3D is a novel fast algorithm currently developed to reach high performance in Adaptive Optics (AO) on the European Extremely Large Telescope (E-ELT). It particularly solves the problem of the tomographic reconstruction involved in AO. Until recently however, it was missing an optimal projection of the reconstructed atmosphere on the deformable mirrors space, which would guarantee the best performance to every tomographic AO system. The reconstruction of the turbulent layers was restricted to identical altitudes and samplings as the ones of the deformable mirrors. Although FrIM-3D produced already good performance compared to the classical method implemented in ESO simulator, such limitation leads to pessimistic results.

We have searched for a formal solution to the projection problem, and developed a fast algorithm to be included in FRiM-3D. A continuous setting is chosen to clearly analyze the modeling approximations. Mathematical assumptions are clarified and made consistent with the

general approach of FrIM-3D. The projector is defined with respect to AO objectives, which are different for every wide-field AO. The focus here is clearly set on the case of multi-conjugate AO.

First, we present a general formalism and a derivation of the solution to the optimal projection problem. In a second step, we focus on a particular algorithm developed following the constraints of low computational complexity, in order to implement the projection in the context of FrIM-3D. Finally, we discuss the evaluation of the performance and benefit of the optimal projection for AO. Such benefit is assessed depending on the atmospheric conditions.

8447-205, Poster Session

Ground layer adaptive optics system simulation for the 2.5m telescope in Dome A

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The Antarctic is an ideal place for the optical and infrared astronomy observations. There are many plans for installing telescopes for several countries in the Antarctic. Chinese scientists are planning to set up a 2.5m telescope in Dome A. The atmospheric turbulence in Dome A is mainly distributed below 15m and at this height the seeing is about 0.3 to 0.4 arc sec. The telescope in Dome A will be mounted in a tower to avoid the atmospheric turbulence below the height 15m. The Ground Layer Adaptive Optics (GLAO) will also be installed to further improve seeing. A GLAO system has been designed and simulated in an end-to-end Monte Carlo simulation for the 2.5m telescope. The system will use one laser guide star and a rotating mirror to sample the ground layer turbulence. The wavefronts from the different positions of the laser guide star will be, in sequence, detected by a wide-field Shack-Hartmann wavefront sensor. The deformable mirror will correct the wavefront calculated by averaging the wavefornts from the different positions of the laser guide star. The simulation results demonstrate that the Strehl ratio has increased 4 to 5 times and the Strehl ratio difference in the field of view of 20 arc min is less than 0.1 in the infrared and optical bands (from 430nm to 2200nm).

8447-206, Poster Session

Adaptive optics performance simulation on the basis of MASS/DIMM data obtained on Mt. Shatdjatmaz in 2009-2011

B. S. Safonov, Sternberg Astronomical Institute (Russian Federation)

On the basis of 95500 MASS/DIMM measurements of optical turbulence profile obtained on Mt. Shatdjatmaz in 2009-2011 we have constructed 2 atmosphere models for this summit: one consisting of 9 typical turbulence profiles, and other of 1000 randomly selected profiles. Profiles represent Cn2 and wind speed values estimated at 13 standard MASS altitudes. We discuss advantages and disadvantages of these models from the point of view of AO simulation. We used these models as input parameters in analytical simulation (using modified PAOLA tool) of AO system of future 2.5-m telescope of SAI. This simulation was used to estimate optimal parameters of this system and performance characteristics corresponding to these parameters. Second 1000-profiles atmosphere model allowed to evaluate the performance in terms of statistical distributions of metrics. E.g. for subaperture size 0.35m and exposure 12ms, the NGS AO system will deliver Strehl number more than 0.1 in V-band using V=13 guide star for 31% of time.

8447-207, Poster Session

Performance simulation of the ERIS pyramid wavefront sensor module in the VLT adaptive optics facility

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This paper describes the simulations performed to estimate the performance of the Pyramid Wavefront sensor Module (PWM) to be included in ERIS, the new Adaptive Optics (AO) instrument for the Adaptive Optics Facility (AOF).

There are two different PWM modes of operation:

Low-order wavefront sensing mode. The PWM is used as a Natural Guide Star (NGS) low-order wavefront sensor (WFS) for assisting the Laser Guide Star (LGS) observations. We will present in this section the performance characterization of the PWM used as NGS low-order WFS for assisting the LGS observations. In this mode of operation, the PWM measures and drives the correction of the Tip-Tilt (TT) and possibly also the Focus mode.

High-order wavefront sensing mode. The PWM measures and drives the correction of all controlled modes in Single-conjugate AO (SCAO) configuration using a NGS as a reference source. We will present in this section the performance characterization of the PWM working as a high-order NGS-AO system controlling all degrees of freedom of the VLT Deformable Secondary Mirror.

8447-208, Poster Session

Calibration strategy of the pyramid wavefront sensor module of ERIS with the VLT deformable secondary mirror

A. Riccardi, R. Briguglio, E. Pinna, G. Agapito, F. Quiros-Pacheco, S. Esposito, INAF - Osservatorio Astrofisico di Arcetri (Italy)

ERIS is a new Adaptive Optics Instrument for the Adaptive Optics Facility of the VLT. Attracted by the recent Adaptive Optics results of the FLAO system of the Large Binocular Telescope (LBT) based on a pyramid sensor and a concave adaptive secondary mirror, the ERIS instrument foresees in its design phase a Pyramid Wavefront Sensor Module (PWM) to be used with the VLT Deformable Secondary Mirror (VLT-DSM) as corrector. Because VLT-DSM is convex, as opposite to the concave secondary mirror of LBT, on-telescope calibration of the interaction matrix (IM) between the PWM and the DSM is not foreseen on-telescope during day-time. In this paper different options of calibration are evaluated and compared with particular attention on the synthetic evaluation and on-sky calibration of the IM. A trade-off of the calibration options, the optimization techniques and the related validation with numerical simulations are also provided.

8447-209, Poster Session

Identification and calibration of the interaction matrix parameters for AO and MCAO systems

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New tomographic AO concepts require a good knowledge of the system geometry and characteristics. These parameters are used to feed the tomographic reconstructors. In this paper we present a method to precisely identify the parameters required to construct an accurate synthetic set of models such as influence functions, mis-registrations, directions of analysis or altitude of the DMs. The method is based on a

multi-parameter fit of the interaction matrix.

This identification method finds also its application in high contract AO systems, such as SPHERE : in that case it is used as a diagnostic tool in order to precisely realign the system. The method has been tested and successfully implemented on HOMER, SPHERE and GeMS.

Experimental results for these three systems are presented.

8447-212, Poster Session

Analysis techniques for adaptively controlled segmented mirror arrays

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The employment of adaptively controlled segmented mirror architectures has become increasingly common in the development of current astronomical telescopes. Optomechanical analysis of such hardware presents unique issues as compared to that of monolithic mirror designs. Performance analysis issues include simulation of adaptive control, execution of polynomial fitting, calculation of best fit rigid body motions, and prediction of line-of-sight error. The generation of finite element models of individual segments involves challenges associated with correctly representing the geometry of the optical surface. Design issues include segment structural design optimization and optimum placement of actuators. Manufacturing issues include development of actuation inputs during stressed optic polishing. Approaches to all of the above issues are presented and demonstrated by example with SigFit, a commercially available tool integrating mechanical analysis with optical analysis.

8447-213, Poster Session

Refined E2E simulator for the high degrees of freedom

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In this paper we present a refined E2E simulator developed to deal with all the complexity coming with the new generation of the AO systems for E-ELT such as (MOAO, MCAO or LTAO). This code is based on an iterative resolution of the linear model with high number of degrees of freedom, taking advantages of sparse routine dedicated to will manage with the rectangular sparse matrices, and including new concepts of filtering and coupling between LGS and NGS to effectively manage modes such as tip / tilt and defocus in the entire process of tomographic reconstruction.

The direct application of this new simulation tools is the study of performance and calibration process of EAGLE, a flagship instrument for the future E-ELT and based on a MOAO scheme. EAGLE combines high order LGS (6) and NGS (up to 5) wavefront sensors in order to acquire enough data for a full tomographic reconstruction in extremely large FoV (> 25 arcmin^2). A complete end to end simulation of this system, accounting for all the MOAO aspects and specificities, is proposed to assess a preliminary error budget derived in a previous phase A study using simpler and less accurate simulation tools.

8447-214, Poster Session

Comparison between end-to-end and analytical numerical modeling of astronomical adaptive optics systems: CAOS versus PAOLA

M. Carbillet, Univ. de Nice Sophia Antipolis (France); L. Jolissaint, aquilAOptics (Switzerland)

We compare the analytic approach together with the so-called end-to-end approach in the framework of astronomical adaptive optics (AO) modeling, in particular in natural guide star mode. The two tools used for this purpose are the analytic code PAOLA (Jolissaint, 2010) and the end-to-end Software Package CAOS (Carbillet et al., 2005), well known within the astronomical AO community. This is indeed done in order to inter-validate the two codes, but also in order to search for trade-offs permitting then to face either exploratory researches or large instrumental project performance evaluations, while combining robustness and speed. As preliminaries, we have first tested the fundamental AO errors (fitting, aliasing, anisoplamatism and servo-lag) and find a very satisfactory agreement. We then perform a full comparison study by simulating a complete 8m-class telescope AO system, and put the emphasize on the comparison of noise propagation modeling, optimal loop gain determination, and equivalence between Fourier modes (PAOLA) and system modes (CAOS).

8447-215, Poster Session

GPUs for adaptive optics: simulations and real-time control

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With the emergence of General Purpose computations on Graphic Processing Units (GP-GPUs) this architecture has become amazingly attractive for large scale applications such as numerical simulations of complex systems. While the number of degrees of freedom of an adaptive optics (AO) system scales with the square of the telescope diameter, the system model exhibits a rather high level of parallelism especially when using Shack-Hartmann (SH) wavefront sensors (WFS). The use of massively parallel devices such as GPUs to simulate next generation AO systems for the European Extremely Large Telescope (E-ELT) thus makes a lot of sense. Our team has developed such simulation tools and first results show that speeds of thousands of iterations per second were achievable on a single high-end GPU for an eXtreme (X)AO system such as SPHERE including a single layer turbulence model generated on-the-fly. These numerical models include all the operations executed by the real-time controller (RTC) of a real system. The achieved simulation speeds show that a single high-end GPU could drive a XAO system on the VLT and, depending on the centroiding algorithm and the control scheme chosen, could even drive a classical AO system on the E-ELT. While the main challenge resides in the data transfer speed to and from the GPU, developing and testing AO control algorithms for the simulation code on the same hardware as the system RTC would bring a lot of benefits. In this paper we present the simulation results as well as strategies to build GPU-powered AO systems.

8447-216, Poster Session

Efficient iterative atmospheric tomography reconstruction from LGS and additional tip/tilt measurements

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Adaptive Optics systems for the new generation of extremely large telescopes require fast mathematical methods for the computation of the shape of the deformable mirrors. MCAO or MOAO systems use laser guide stars for the reconstruction of the turbulent atmosphere. However, measurements from laser guide stars contain no information on the tip/tilt of the incoming wavefronts. Assuming that additional tip/tilt

measurements of wavefronts from natural guide stars are available, we present an iterative Kaczmarz reconstructor that computes the turbulent atmospheric layers from the wavefronts of both the laser and natural guide stars. We show in particular that the resulting algorithm meets the quality and speed requirements for ELTs.

8447-44, Session 11

Turbulence modeling and estimation for AO systems

A. Beghi, A. Cenedese, A. Masiero, Univ. degli Studi di Padova (Italy)

Nowadays, deformable mirrors (DMs) and adaptive optics (AO) technologies are of fundamental importance to reduce the effect of atmospheric turbulence in the astronomical images obtained from current and next generations of large ground telescopes. To this aim, it is beneficial for the AO system to know as much as possible the turbulence characteristics, in order to tune the control action on the DM and optimize the performance.

In this paper, we present algorithms for the AO system that estimate the turbulence properties from sample data, being the turbulence model based on two reasonable assumptions:

1 - the turbulence is formed by a discrete set of layers moving over the telescope lens,

2 - each layer is modeled as a Markov-Random-Field (MRF).

While the first assumption is commonly agreed to account for the continuous variability of the whole atmospheric layer, the proposed MRF approach is exploited for estimating the layers' characteristics.

Then, a linear predictor of the turbulent phase, based on the computed information on the turbulence layers, is constructed. Since scalability and low computational complexity of the control algorithms are important requirements for real AO systems, the computational complexity properties of the proposed model are investigated. Interestingly, the proposed model shows a good scalability and an almost linear computational complexity thanks to its block diagonal structure.

The performance of the procedure are investigated by means of some simulations.

8447-45, Session 11

Mesospheric sodium structure variability and its impact on adaptive optics

T. Pfrommer, European Southern Observatory (Germany); P. Hickson, The Univ. of British Columbia (Canada)

Adaptive optics (AO) systems of modern telescopes use laser guide stars, produced by resonant excitation of sodium atoms in the mesosphere at around 92 km. Wavefront sensor subapertures, if sufficiently far away from the axis, resolve the internal structure of the sodium layer. The variability of this structure is caused by the influence of gravity waves and wind shear turbulence. The relevance of such dynamics to AO has been investigated over the past four years. A high-resolution lidar system, employed at the 6-m liquid mirror telescope, which is located near Vancouver, Canada, has been used to study mesospheric dynamics, such as the temporal behavior of the mean altitude. I will review the main results from this study.

The mean altitude structure on horizontal scales of order 10s of meters has been studied by introducing a tip/tilt stage that enables the laser pulse to be swapped within 1 arcmin. The horizontal mean altitude structure function has been measured on 21 observing nights between February and August 2011. Results reveal severe structural differences and a strong horizontal anisotropy, even within 1 arcmin. Individual laser beacons in a laser guide star asterism will therefore have at the same time significantly different focus heights. By propagating this 2d structure function to the entrance pupil of a 39 m telescope, we derive a differential focus wavefront error map. Values of order 0.5 microns in mean wind direction and an order of magnitude larger in meridional directions have been found.

8447-46, Session 11

Lunar scintillometer to validate GLAO turbulence distribution measurements

K. Newman, M. Hart, The Univ. of Arizona (United States); E. A. Bendek, College of Optical Sciences, The Univ. of Arizona (United States); E. Bustos, Cerro Tololo Inter-American Observatory (Chile)

A lunar scintillometer, LuSci, is an inexpensive and robust instrument which deploys a linear array of photodiodes pointed toward the moon to measure scintillation produced by atmospheric turbulence. Covariances between the signals from the photodiodes are analyzed to derive estimates of the turbulence profile within a few hundred meters above the ground. Instrument parameters and phase of the moon are taken into account. This method has been used for site testing and monitoring. We present the development of a new LuSci instrument used to validate the ground-layer turbulence distribution measured from the laser wavefront sensor signals of the Ground Layer Adaptive Optics system at the MMT. The near-simultaneous measurements are used to characterize the performance of the GLAO system. We describe the instrument, its operation, approaches to data reduction, comparison with other methods of measuring ground-layer turbulence, and use in performance characterization of a GLAO system.

8447-47, Session 11

Estimation of vertical profiles of wind from MASS measurements

M. V. Kornilov, Lomonosov Moscow State Univ. (Russian Federation)

The problem of wind profile restoration from MASS (Multi-Aperture Scintillation Sensor) scintillation indices was studied on the base of long-term experiment with the set of different exposure times on Mt.Shatdjatmaz in 2009--2011. Three different methods for the problem (general nonlinear case and two limiting cases) were stated and then implemented in experimental branch of 'atmos' software.

We show that we are able to obtain wind profiles on standard MASS altitude grid with reasonable accuracy and altitudinal resolution.

Free atmospheric coherence time is also calculated. We found that the results are in moderate agreement with NCEP/NCAR re-analysis model.

The software performance also allows us to restore the profiles online to use them for supporting and scheduling of astronomical observations. The data obtained with MASS over the world may be reprocessed using one of presented methods. Further calibrations on independent measurements would be useful for the method verification.

8447-48, Session 12

Vibrations in AO control: a short analysis of on-sky data around the world

C. Kulcsar, G. Sivo, H. G. Raynaud, Univ. Paris 13 (France); B. Neichel, F. Rigaut, Gemini Observatory (Chile); J. C. Christou, Gemini Observatory (United States); A. R. Guesalaga, Pontificia Univ. Católica de Chile (Chile); C. Correia, J. Véran, National Research Council Canada (Canada); E. Gendron, F. Vidal, G. C. Rousset, LESIA - Observatoire de Paris (France); T. J. Morris, Durham Univ. (United Kingdom); S. Esposito, F. Quiros-Pacheco,

G. Agapito, INAF - Osservatorio Astrofisico di Arcetri (Italy); E. Fedrigo, L. Pettazzi, R. M. Clare, European Southern Observatory (Germany); R. Muradore, Univ. degli Studi di Verona (Italy); S. C. Meimon, J. Conan, ONERA (France); O. Guyon, F. Martinache, Subaru Telescope, National Astronomical Observatory of Japan (United States)

“- This is unacceptable: these images are of poor quality!

- Yes Captain, they come from Earth. There is evidence of vibrations’ attacks over there.

- I see, an investigation is necessary Mr Spock: where do they come from, what are the signs of their existence? They have to be disintegrated! Do we have enough power Scotty?”

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Several tip-tilt on-sky data registered on adaptive optics systems are analysed: vibration peaks can be detected, and it is shown that their presence and location depend on several parameters, in particular the type and number of science instruments and devices attached to the telescope. Each team gives its conclusions on the behavior and on the effects on astronomical images for different telescopes around the world. What kind of solutions could be envisioned to mitigate vibrations? Is robustness an issue? What is to be expected in terms of computational load? Examples of open-loop AO control performed thanks to on-sky data replay illustrate this problem and give an idea of the gain in performance that could be achieved with off-the-shelf identification and control techniques.

8447-49, Session 12

Tolerancing the fabrication errors of static optical elements for ELT-size wide-field AO systems

J. Véran, J. S. Pazder, National Research Council Canada (Canada)

Advanced wide-field AO systems, such as Multi-Conjugate AO (MCAO) systems often require many static optical elements (mirror and lenses) in addition to the active ones (deformable mirrors). These static elements induce additional wave-front errors due to random fabrication errors such as polishing errors. For ELT-size AO systems, these optical elements can be very large, and thus their cost and availability critically depends on how of much fabrication error can be tolerated. Therefore, a rigorous tolerance analysis is absolutely critical. Requirements can, in principle be relaxed, on account that fabrication errors with spatial scales larger than the inter-actuator spacing of the deformable mirrors (DMs) can be corrected. However, this process is significantly complicated by the fact that these optical elements are often conjugated far away from the DMs, and therefore DM correction cannot be achieved over a wide field of view (FOV).

In this paper, we present our tolerance analysis in the context of NFIRAOS, the first-light MCAO system for the Thirty Meter Telescope. We start from two top-level error budgets: the “on-axis” error budget, which specifies the acceptable residual wave-front error in the narrow 17”x17” science FOV; and the “off-axis” error budget, which specifies the acceptable residual wave-front error at the edge of the 2’ diameter technical FOV. The former directly relates to science image quality, whereas the latter directly relates to sky coverage. For different assumptions on the spatial power spectrum of the polishing errors, we derive the requirements on each optical element in NFIRAOS using a Monte-Carlo analysis of the predicted off-axis performance of the system with on axis AO correction.

8447-50, Session 13

Wavefront correction on the Advanced Technology Solar Telescope

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The Advanced Technology Solar Telescope (ATST) is an off-axis 4-meter class telescope currently under construction on Haleakala for the detailed studies of the Sun over the next 50 years. State of the art adaptive optics is a critical technology required to allow solar observations with fine spatial resolution at the diffraction limit of the telescope at optical wavelengths. Wavefront correction on ATST includes the high order adaptive optics for correction of atmospheric turbulence with both a fast tip tilt mirror and a deformable mirror with 1300 to 1900 actuators working at 2 kHz. Low order active optics is also part of the system for the correction of telescope related aberrations and tracking misalignment errors. ATST is expected to be commissioned in 2018. The current status of the ATST wavefront correction design and development will be presented. State of the art advances in adaptive optics within the overall solar community will also be summarized.

8447-52, Session 13

Subaru laser guide adaptive optics system: performance and science operation

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The Subaru adaptive optics system (AO188) is a 188-element curvature sensor adaptive optics system that is operated in both natural and laser guide star modes. AO188 is installed at Nasmyth platform of the 8m Subaru telescope as a facility AO system. The laser guide star mode for AO188 has been commissioned and offered for use in science operation since 2011. The performance of AO188 in the laser guide star mode has been well verified from on-sky data obtained with the infrared camera and spectrograph (IRCS). In this presentation, we show the result of the on-sky performance evaluation of AO188 in the laser guide star mode and the characterization of the laser guide star, together with the obtained science results. We also describe the operation procedure and observing efficiency for the laser guide star mode.

8447-53, Session 14

Toward the adaptive optics for the 40 m class European ELT

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This paper will provide an overview of the activities being carried out by ESO for the development of new Adaptive Optics capabilities for the Very Large Telescope and for the European Extremely Large Telescope. This paper will also focus on the progresses, challenges and remaining risks of the AO key technologies and concepts and will present an enabling technology roadmap to mitigate these risks in close cooperation with the ESO community and industry.

8447-54, Session 14

The Giant Magellan Telescope adaptive optics program

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The Giant Magellan Telescope adaptive optics system will be an integral part of the telescope, providing laser guide star generation, wavefront sensing, and wavefront correction to most of the currently envisioned instruments. The system will provide three observing modes: Natural Guidestar AO (NGSAO), Laser Tomographic AO (LTAO), and Ground Layer AO (GLAO).

All observing modes will use the telescope's segmented adaptive secondary mirror to deliver a corrected beam directly to the instruments. High-order wavefront sensing for the NGSAO and LTAO modes is provided by a set of wavefront sensors replicated for each instrument and fed by visible light reflected off the cryostat window. An infrared natural guidestar wavefront sensor with open-loop AO correction is also required to sense tip-tilt, focus, segment piston, and slowly-varying calibration errors in the LTAO mode. GLAO mode wavefront sensing is provided by a facility GLAO wavefront sensing assembly, fed by a dichroic ahead of the Gregorian focus. A laser guidestar facility will project 120 W of 589 nm laser light in 6 beacons from the periphery of the primary mirror. An off-axis phasing camera and primary and secondary mirror edge sensor systems will ensure that the telescope optics remain phased.

We will describe the system requirements, overall architecture, results of performance simulations, and innovative solutions found to the challenges presented by high-order AO on a segmented extremely large telescope. Further details may be found in specific papers on each of the observing modes and major subsystems.

8447-55, Session 14

TMT adaptive optics program status report

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We provide an overview of the Thirty Meter Telescope (TMT) first light AO architecture, emphasizing the progress made since 2010.

The first light facility AO system for TMT is the Narrow Field Infra-Red AO System (NFIRAOS). NFIRAOS is an order 60x60 laser guide star (LGS) multi-conjugate AO (MCAO) system. It will provide uniform, diffraction-limited performance in the J, H, and K bands over 18-30 arc sec diameter fields with 50% sky coverage at the galactic pole, as is required to support a wide range of TMT science cases. The LGS Facility (LGSF) for NFIRAOS incorporates 6 20-25W lasers mounted to the telescope elevation journal, mirror-based beam transfer optics, and a 0.4m laser launch telescope behind the TMT secondary mirror. The NFIRAOS and LGSF systems have now successfully completed their Preliminary- and Conceptual Design Reviews, respectively, during the second half of 2011.

Protoyping activities continue for lasers, wavefront sensing detectors, and deformable mirrors. Work on the associated detector readout and actuator drive electronics systems has also been initiated. AO modeling topics which have received particular attention include sky coverage analysis; algorithm refinements for tomographic wavefront reconstruction, deformable mirror control, and PSF reconstruction; component modeling of deformable mirrors, wavefront sensors, laser guidestars, and opto-mechanical implementation errors; and potential future AO system upgrades for TMT. Finally, experiments and field tests continue at the University of British Columbia LIDAR facility to measure the spatial and temporal variability of the sodium layer, and to characterize the sodium coupling efficiency of candidate laser for TMT.

8447-56, Session 14

Dual-channel multiple natural guide star wavefront sensor for the E-ELT multiconjugate adaptive optics module

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Adaptive optics systems based on sodium Laser Guide Stars (LGS)

may exploit Natural Guide Stars (NGS) to solve intrinsic limitations of artificial beacons, such as tip-tilt indetermination and, in the case of Multi-Conjugate Adaptive Optics (MCAO), tip-tilt anisoplanatism. NGSs are also required to mitigate the impact of sodium layer structure and variability: on 8-meter telescopes the main effect is focus instability; on a 40-meter class telescope, as a consequence of the sodium layer perspective elongation and of the finite field of view of the LGS WaveFront Sensor (WFS), additional spurious aberrations are generated. The sodium layer may also have transverse structures leading to significant differential effects among LGSs. All these aspects show up in MAORY, a concept for a MCAO module for the European Extremely Large Telescope designed to provide uniform correction over an extended field of view. Starting from the analysis and modeling of the input perturbations to be measured by the NGS WFS, we describe the design of this crucial sub-system and show its impact on global performance. The NGS WFS of MAORY is based on three probes, each one consisting of a fast tip-tilt/focus channel and of a channel for monitoring the aberrations induced by the sodium layer. The dual-channel design and the adopted wavefront sensing schemes allow the efficient exploitation of the few NGSs typically available in the field of view, while providing a way to monitor the potential anisoplanatism due to the differential sodium effects among the LGSs.

8447-57, Session 14

Wavefront sensor design for the GMT natural guide star AO system

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The Giant Magellan Telescope (GMT) will be an adaptive telescope mounting in its optical train an adaptive secondary mirror composed by seven deformable shells. The adaptive optics system will include a Natural Guide Star (NGS) single conjugated mode. The NGS system will deliver high-performance wavefront correction for narrow-field instruments. The NGS Wave-Front Sensor Subsystem (NGWFSS) will be in charge of the entire wavefront error measurement: atmospheric turbulence and telescope aberrations, including the segment differential piston error. The phase A study identified the NGWFSS as a pyramid wavefront sensor to be replicated at all the GMT focal stations that will require the NGS AO correction. Here we present the NGSWFSS preliminary design that includes the opto-mechanical layout, electronic design and control SW architecture. After this the paper presents numerical simulations that quantifies the performance of the entire NGS AO system taking into account the AO correction and real time differential piston control of the full telescope.

8447-58, Session 14

TMT NFIRAOS: adaptive optics system for the Thirty Metre Telescope

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NFIRAOS is the first-light adaptive optics system planned for the Thirty Meter Telescope, and is being designed at the National Research Council of Canada's Herzberg Institute of Astrophysics. NFIRAOS is a laser guide star multi-conjugate adaptive optics system. NFIRAOS' design is a practical approach to providing diffraction limited image quality in the NIR over a 30" field of view, with high sky coverage. This will enable a wide range of TMT science that depends upon the large corrected field of view and high precision astrometry and photometry. We review recent progress developing the design and performance estimates for NFIRAOS.

8447-59, Session 15

Wave-front sensing and adaptive optics using curvilinear component analysis

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Curvilinear component analysis (CCA) is a recent mathematical tool for reducing high-dimensional and non-linearly related data sets. The method consists on the projection of the input data onto a subspace where the topology of the final points matches the original one in the best possible way through a set of neurons, each having two weight vectors: one for the input and another one for the output. We modified and improved this method for use in an adaptive optical context. The spot images from a Shack-Hartman wave-front sensor can be analyzed using CCA and one can directly obtain the coefficients of each Zernike polynomials that were chosen to make up the reference basis for describing the wave-fronts. The regular influence matrix that relates the wave-front parameters to the actuator currents is not required in CCA. We show that the main advantages of CCA are less sensitivity to noise and a better accuracy due to the information redundancy that is part of each pixel of the

CCD frame. In adaptive optics, this method can improve the control of deformable mirrors because it gives a description of the wave-front in terms of actuator currents even in non-linear regimes. At the computing level, after an initial calibration is done, the whole procedure only needs two classical interpolation steps, followed by a simple mathematical subtraction to derive the correction values. The final result is a faster and more robust control system.

8447-60, Session 15

LIFT--a noise-effective low order focal-plane sensor: from theory to full experimental validation

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Laser Tomographic systems, such as ATLAS, will rely on natural guide stars to sense low order aberrations. LIFT is a novel focal plane wavefront sensor (WFS), performing a maximum likelihood phase retrieval on a single image, with better sensitivity than a 2x2 Hartmann-Shack WFS.

We first present a characterization of LIFT's noise propagation performance and working domain by means of simulations. We then show the results of experiments on ONERA's adaptive optics bench "BOA". These experiments validate the estimation of tip/tilt and focus, in monochromatic light and in large bandwidth (for a spectral resolution of 2), as well as the expected noise propagation. They also confirm the validity of the imaging models used for simulations. Additionally, we discuss the lessons learned from the practical issues encountered during this experiment as to how LIFT must be calibrated, which parameters need to be carefully taken into account to avoid estimation errors, etc. Finally, we focus on an on-sky validation.

8447-61, Session 16

The ESO transportable laser guide star unit for on sky measurements of LGS photon return and other experiments

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Sodium laser guide stars (LGS) are used and planned to be used as artificial beacons for Adaptive Optics in many present and future large and extremely large telescopes.

We believe several aspects of the LGS have not yet been studied systematically and thoroughly enough. For this ESO has designed and built with support from industry an experimental, transportable laser guide star unit (WLGSU), composed of a compact laser based on the ESO Raman Fiber Amplifier (ERFA) patented technology attached to a 30cm launch telescope.

Besides field tests of the new ERFA laser technology, the purpose of the WLGSU is to conduct joint field experiments related to LGS and LGS-AO, useful for the optimization of future LGS-AO systems. Among the proposed ones are the validation of LGS return flux simulations as a function of laser format, the feasibility of line-of-sight Lidar operation, LGS spot tracking, and tests of AO operation with elongated LGS.

After a description of the WLGSU and its main capabilities, results on the WLGSU commissioning and LGS return flux measurements will be presented.

8447-62, Session 16

Gemini South multi-conjugate adaptive optics (GeMS) laser guide star facility on-sky performance results

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With two to three deformable mirrors, three Natural Guide Stars (NGS) and five sodium Laser Guide Stars (LGS), the Gemini Multi-Conjugate Adaptive Optics System (Gemini MCAO a.k.a. GeMS) is the first facility-class MCAO capability to be offered for normal science observations world-wide starting in 2012.

The engineering and science commissioning phase of the project was kicked off in January 2011 when the Gemini South Laser Guide Star Facility (GS LGSF) propagated its 50W laser above the summit of Cerro Pachón, Chile. GeMS commissioning then proceeded throughout 2011 and the beginning of 2012 at a pace of one 6- to 8-night run per month with a 5-month pause during the 2011 Chilean winter.

This paper will focus on the LGSF-side of the system and provide an overview of the LGSF subsystems, their top-level specifications, design, integration with the telescope, and on-sky performance throughout commissioning and beyond. Subsystems of the GS LGSF include a diode-pumped solid-state 1.06+1.32 micron sum-frequency laser producing over 50W of output power at the sodium wavelength (589nm), Beam Transfer Optics (BTO) that transport the 50W beam up the telescope, split the beam five-ways and configure the five 10W beams for projection by the Laser Launch Telescope (LLT) located behind the Gemini South 8m telescope secondary mirror, and a variety of safety systems to ensure safe laser operations for observatory personnel and equipment, neighbor observatories, as well as passing aircrafts and satellites.

8447-63, Session 16

Photon returns test of the pulsed sodium guide star laser on the 1.8 meter telescope

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A microsecond pulsed sodium has been developed in TIPC laser physics research center, the power of this laser is around 20W and the length of the pulse is about 100 microseconds. The prediction of the return flux across the mesosphere has been simulated based on the laser parameter and the geographic location. In 2011, an experiment to project the TIPC prototype laser to the sky and measure the photon returns of the laser has been held on the 1.8 meter telescope in Yunnan observation site. During the sky test, an artificial sodium beacon has been successfully generated, and the brightness of the sodium beacon is around 8.7M in V Band. More test of this laser has been scheduled at beginning of 2012, and in the coming test campaign, the sodium density facility will be mounted on the telescope to test the local sodium density and structure in order to have the accurate coupling efficiency value of this kind pulsed laser, and the latest result will be presented in this paper.

8447-64, Session 17

Optimal control of plate-scale modes in laser-guide-star-based multi-conjugate adaptive optics

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In laser-tomography multi-conjugate adaptive optics (MCAO) systems, the tilt indeterminacy problem implies that both tip/tilt and certain modes of tilt anisoplanatism (plate-scale) are unobservable to the laser guide star (LGS) wave-front sensor (WFS).

Tilt anisoplanatism arises from a combination of few modal components of the atmospheric profile. These components are a combination of quadratic wave-front aberrations that produce field-dependent tip/tilt, which cannot be measured by the LGS WFS. They are therefore called plate-scale modes, in analogy to deformations given by the solutions to classical plate equations. A better correction of the plate-scale modes leads to a better sky-coverage since fainter stars can potentially be used for guiding. Therefore, since fainter stars require lower temporal sampling rates, using a minimum-variance controller (that achieves the maximum Strehl-ratio altogether) based on the Linear-Quadratic-Gaussian techniques can better compensate for the temporal delay introduced, limit noise propagation and be generalised to account for vibrations and other common and non-common path disturbances.

In this paper we show how to model the plate-scale modes and how a minimum-variance controller can be built. We use end-to-end Monte Carlo simulations that show the a considerable improvement with respect to classical integrator-based controllers, specially for fainter stars.

8447-65, Session 17

Ensemble transform Kalman filter, a dynamic control law for AO on ELTs: theoretical aspects and first simulations results

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Optimal control laws for new AO concepts (wide field tomographic AO) require the implementation of techniques intended for real time identification of the atmospheric turbulence. The Kalman Filter (KF) based control law enables estimation and prediction of the turbulent phase from the measurements and corrects efficiently the different modes of this phase on the basis used for the factorization. But using such kind of processes within the frame of an AO system for any ELT class telescope will be extremely difficult because of the numerical complexity of the computations involved in the matrices calculations (especially the Kalman gain which is computed off-line by solving the Riccati algebraic matrix equation) as well as the recording of large covariance matrices. We propose a new method developed for Geophysics and Meteorology applications which allows to dramatically reduce the computation burden while allowing to deal with dynamic (non stationary) behaviors of turbulence parameters. We briefly present a first approach: the Ensemble Kalman Filter (EnKF) and some drawbacks of this statistical method. Then an extension of this approach, the Ensemble Transform Kalman Filter (ETKF) is deeply analyzed. In particular, the reduced computational complexity and the possibility of using a non stationary model combined with distributed parallel environment implementations are highlighted and studied in the context of an ELT application. First simulation results are proposed to assess our theoretical analysis and to demonstrate the potentiality of this new approach. Finally, the path toward an experimental validation of this approach is described.

8447-66, Session 17

Wind prediction with multiple guide stars reduces tomographic errors and expands MOAO field of regard

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We present a Kalman filter for predictive control in multi-guide star (GS) tomography that identifies and tracks wind in layers separated by height. We demonstrate the technique in simulation and present preliminary experiments on a multi-GS LTAO/MOAO testbed. The filter is an extension of published methodology (Poyneer+07) for predictive control in single-GS systems. In addition to reducing temporal error budget terms, we show that multi-GS predictive control additionally can reduce the tomographic error, a fundamental error in wide-field AO systems defined by GS constellation geometry. The combination of height information from multiple guide stars and wind velocity estimates breaks degeneracies in volumetric phase reconstruction, particularly in volumetric elements sampled by only one GS, allowing for an expansion of the diffraction-limited field of regard. The mid-to-high spatial frequency component of tomographic phase error in a given layer is uncorrelated in velocity with the frozen flow motion of that layer.

In simulation, assuming a realistic breakdown of pure Taylor frozen flow motion and slowly-evolving wavefront error as measured on-sky (20-40% of controllable phase power in frozen flow; Poyneer+09) on an 8-m telescope, we demonstrate a reduction in the spatially averaged tomographic error of 5-10%, depending on LGS geometry and subaperture size, translating into potential gains in the areal field of regard of 10-20%. Testbed experiments of MOAO with an 8-m telescope, 5 LGS's, 100% Taylor frozen flow in three layers, and realistic wind speeds (10-20 m/s) show reductions of the spatially averaged tomographic error of 15%.

8447-67, Session 17

Experimental comparison of tomographic control schemes using the Onera WFAO facility

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Wide Field Adaptive Optics (WFAO) concepts, such as Ground Layer AO (GLAO), Laser Tomography AO (LTAO) or Multi-Conjugate AO (MCAO) are currently being studied in the perspective of future ELT instrumention. In that context, the experimental validation of the various smart control solutions proposed by several teams in the past years is now essential.

In this paper we present experimental validation and comparison of different control schemes for GLAO, LTAO and MCAO concepts using the Onera WFAO facility (HOMER bench). Gathering a 3D turbulence generator, laser and natural guide stars, two deformable mirrors with variable altitude positions and a PC-based flexible and user-friendly RTC, HOMER allows the implementation of control schemes from the simplest least-square to the optimal Linear Quadratic Gaussian solutions including Virtual DM and Pseudo-Open Loop Control (POLC) approaches. These four control laws are tested and compared in term of performance and robustness. In particular, low and high noise conditions are explored, for several fields of views. We also discuss the implementation, calibrations and tuning issues related to each control solution.

8447-68, Session 17

Control and calibration strategies for SPHERE eXtreme AO system: concepts, implementation, and experimental validations

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The SPHERE (Spectro-Polarimetry High-contrast Exoplanet Research) instrument is an ESO project aiming at the direct detection of extrasolar planets. It should equip one of the four VLT 8-m telescopes in 2010. The heart of the SPHERE instrument is its eXtrem Adaptive Optics (XAO) subsystem, SAXO that should deal with a tight error budget. To fulfill SAXO challenging requirements a mixed control law has been designed. It includes both an optimized modal gain integrator to control the Deformable Mirror (DM) and a LQG control law to manage the tip-tilt mirror and filter possible vibrations.

A specific control scheme has been developed and presented in the past to avoid cross-talk between the control laws and provide the best correction. Actuator saturation and wind-up effects management are crucial for an operational system. However the usual procedures must be adapted to our specific control scheme and to the high system complexity. Finally, optimization of the performance requires regular updates of the control laws parameters that rely on specific identification procedures. We describe the overall control architecture and focus on these main issues. We present in lab performance obtained with the full SAXO bench and compare these performance with numerical and also consider the interactions of the main control loop with other subsystems.

8447-69, Session 18

How ELTs will acquire the first spectra of rocky habitable planets

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ELTs will offer angular resolution around 10mas in the near-IR and unprecedented sensitivity. While direct imaging of Earth-like exoplanets around Sun-like stars will stay out of reach of ELTs, we show that habitable planets around nearby M-type main sequence stars can be directly imaged. For about 300 nearby M dwarfs, the angular separation at maximum elongation is at or beyond 1 lambda/D in the near-IR for an ELT. The planet to star contrast is 1e-7 to 1e-8, similar to what the upcoming generation of Extreme-AO systems will achieve on 8-m telescopes, and the potential planets are sufficiently bright for near-IR spectroscopy. We show that technologies required to achieve this goal already exist :

(1) The PIAACMC coronagraph can deliver full starlight rejection, 100% throughput and sub-lambda/D IWA for the E-ELT, GMT and TMT pupils. A closely related coronagraph is part of SCExAO on Subaru.

(2) Diffractive focal plane masks enable broadband coronagraphy at the required IWA and contrast level

(3) Wavefront sensing techniques making full use of spatial coherence across the pupil offers several order of magnitudes gain over conventional SH-based WFS. Among them, the non-linear Curvature WFS is being deployed on two separate ground based telescopes.

We conclude that large ground-based telescopes will acquire the first high quality spectra of habitable planets orbiting M-type stars, while future space mission(s) will later target F-G-K type stars.

8447-70, Session 18

The Subaru coronagraphic extreme AO project: first observations

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In 2009 our group started the integration of the SCExAO project, a highly flexible, open platform for high contrast imaging, inserted between the coronagraphic imaging camera HiCIAO and the 188-actuator AO system of the Subaru Telescope.

The current version of SCExAO combines a MEMS-based wavefront control system, driven by a pyramid-type wavefront sensor, feeding a high performance PIAA-based IR coronagraph as well as a visible non-redundant masking interferometry imager.

At the time of this conference, SCExAO will have gone through most of its engineering observations. This paper presents the status of the experiment as well as recent on-sky results.

8447-71, Session 18

The SPHERE XAO system SAXO: integration, test, and laboratory final performance

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Direct detection and spectral characterization of extra-solar planets is one of the most exciting and challenging areas in modern astronomy due to the very large contrast between the host star and the planet at very small angular separations. SPHERE (Spectro-Polarimetric High-contrast Exoplanet Research in Europe) is a second-generation instrument for the ESO VLT dedicated to this scientific objective. It combines an extreme adaptive optics system, various coronagraphic devices and a suite of focal instruments providing imaging, integral field spectroscopy and polarimetry capabilities in the visible and near-infrared spectral ranges.

The extreme AO system, SAXO, is the heart of the SPHERE system, providing to the scientific instruments a flat wavefront corrected from all the atmospheric turbulence and internal defects. We will present a final analysis of SAXO assembly integration and performance. Main requirements and system characteristics will be briefly recalled, then each sub system will be individually presented and fully characterized. Finally the full AO loop performance will be quantified. It will be demonstrated that SAXO meets its challenging requirements. Performance of the AO within the full SPHERE system is proposed. Thanks to a coronagraphic analysis of the AO residuals, a detailed comparison between actual and simulated residual intensity profiles will be provided and will help to adjust the expected performance of the SPHERE system on sky, knowing that its first light is foreseen for end 2012.

8447-72, Session 18

Project 1640: the world's first ExAO coronagraphic hyperspectral imager for comparative planetary science

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Project 1640, a high-contrast spectral-imaging effort involving a coordinated set of instrumentation and software, built at AMNH, JPL, Cambridge and Caltech, has been commissioned and is fully operational.

This novel suite of instrumentation includes a 3388+249-actuator adaptive optics system, an optimized apodized pupil Lyot coronagraph, an integral field spectrograph, and an interferometric calibration wave front sensor.

Project 1640 is the first of its kind of instrumentation, designed to image and characterize planetary systems around nearby stars, employing a variety of techniques to break the speckle-noise barrier. It is operational roughly one year before any similar project, with the goal of reaching a contrast of 10^-7 at 1 arcsecond separation. We describe the instrument, highlight recent results, and document on-sky performance during the start of a 3-year, 99-night survey at the Palomar 5-m Hale telescope.

8447-73, Session 18

Extremely fast focal-plane wavefront sensing for extreme adaptive optics

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We present a promising approach for the extremely fast sensing of small wavefront errors in extreme adaptive optics systems with 10,000 to 100,000 actuators that correct the image of a point source. The approach is based on a sequential phase diversity technique where the phase diversity, induced by the extreme deformable mirror itself, minimizes the computational complexity. This method is well suited for high-contrast astronomical imaging such as the direct detection and characterization of exoplanets, and it works even in the presence of a coronagraph that suppresses the central point source. We will demonstrate the performance advantages with simulations, including simulations of EPICS, the exoplanet imager for the E-ELT, and compare our method with conventional approaches.

8447-74, Session 18

On advanced estimation techniques for exoplanet detection and characterization using ground-based coronagraphs

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The direct imaging of planets around nearby stars is exceedingly difficult. Only about 14 exoplanets have been imaged to date that have masses less than 13 times that of Jupiter. The next generation of planet-finding coronagraphs, including VLT-SPHERE, the Gemini Planet Imager, Palomar P1640, and Subaru SCExAO have predicted contrast performance of roughly a thousand times less than would be needed to detect Earth-like planets. In this paper we review the state of the art in exoplanet imaging, most notably the method of Locally Optimized Combination of Images (LOCI), and we investigate the potential of improving the detectability of faint exoplanets through the use of advanced statistical methods based on the concepts of the ideal observer and the Hotelling observer. We provide a formal comparison of tehniques through a blind data challenge and evaluate performance using the Receiver Operating Characteristic (ROC) and Localization ROC (LROC) curves. In this paper we place particular emphasis on the understanding and modeling of realistic sources of measurement noise in ground-based AO-corrected coronagraphs. The work reported in this paper is the result of interactions between the co-authors during a week-long workshop on exoplanet imaging that was held in Squaw Valley, California, in March of 2012.

8447-217, Poster Session

New results on a Cn2 profiler for GeMS

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GeMS (the Gemini MCAO System) is a facility instrument for the Gemini-South telescope that among its features, includes a Cn2 profiler. The method integrates a SLODAR type of technique with a wind profiler (time correlation approach) that uses pseudo-open-loop slopes from 5 laser guide stars wave-front sensors and actuator values from 3 deformable mirrors optically conjugated at 0, 4.5 and 9km.

The first part of this paper presents the results obtained from this unified approach for different observation nights showing the performance and limitations of the technique for different turbulence profiles. Special consideration is given to dome-seeing turbulence and ways to estimate their relative strength. The problem of estimating absolute values for the turbulence is also addressed.

Finally, we present a new technique to estimate the profile by inverting an explicitly stated non-linear matrix model of the turbulence using the frozen flow hypothesis. The solution is found by iteratively finding local minima with a fast conjugate-gradient algorithm.

8447-219, Poster Session

What can be retrieved from adaptive optics real-time data?

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In an AO system the correction to be applied to the Deformable Mirror (DM) is computed at each loop cycle from the residual slopes on the Wavefront Sensor (WFS) and the Interaction Matrix (IM) of the system DM/WFS. All these data carry a lot of very precious information about not only the status of atmospheric turbulence during the scientific exposure, but also the AO and more generally telescope behavior while the loop was closed.

In this paper we will present a non-exhaustive list of what can be learned from such data, applied to the example of the NACO instrument at the VLT that provided the appropriate data during technical nights in 2010 and 2011, in the framework of the preparation of the algorithms for the AO Facility.

The topics presented include the reconstruction of the input turbulence in the WFS domain (pseudo open-loop slopes), the estimation of the seeing, turbulence profile, coherence time, wind speed and direction, the measurement of LGS spot size, the detection of vibrations via modal transfer functions, the identification of DM/WFS mis-registration and the optimal loop gain computation. The seeing estimated by the AO instrument will also be compared with other seeing estimations at Paranal.

8447-220, Poster Session

Developing a new software package for PSF estimation and fitting of adaptive optics images

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Adaptive Optics (AO) images are characterized by structured Point Spread Function (PSF), with sharp core and extended halo, and by significant variations across the field of view. In order to enable the extraction of high-precision quantitative information and improve the scientific exploitation of AO data, efforts in the PSF modeling and in the integration of suitable models in a code for image analysis are needed. We present the current status of a study on the modeling of AO PSFs based on observational data taken with present telescopes (VLT and LBT) and on simulated images generated with synthetic PSFs available from the Phase-A study of the E-ELT MCAO system (MAORY). The methods under development include parametric models and hybrid (i.e. analytical / numerical) models adapted to various types of PSFs that can show up in AO images. The specific features of AO data, such as the mainly radial variation of the PSF with respect to the guide star position in single-reference AO, are taken into account as much as possible. The final objective of this project is the development of a flexible software package, based on the Starfinder code (Diolaiati et Al 2000), specifically dedicated to the PSF estimation and to the astrometric and photometric analysis of AO images with complex and spatially variable PSF.

8447-221, Poster Session

PSF reconstruction for wide field AO systems: application to the GALACSI-MUSE instrument on the VLT

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The second generation instrument MUSE for the VLT has been designed to profit of the ESO Adaptive Optics Facility (AOF). The two Adaptive Optics (AO) modes (GLAO in Wide Field Mode [WFM] and LTAO in Narrow Field Mode [NFM]) will be used. To achieve its key science goals, MUSE will require information on the full system (Atmosphere, AO, telescope and instrument) image quality and its variation with Field position and wavelength. For example, optimal summation of a large number of deep field exposures in WFM will require a good knowledge of the PSF.

In this paper, we will present an exhaustive analysis of the MUSE Wide Field Mode PSF evolution both spatially and spectrally. For that purpose we have coupled a complete AO simulation tool developed at ONERA with the MUSE instrumental PSF simulation. Relative impact of atmospheric and system parameters (seeing, Cn^2, LGS and NGS positions etc ...) with respect to differential MUSE aberrations per channel (i.e. slicer and IFU) is analysed. The results allow us to define pertinent parameters (fit parameters using a Moffat function) for a PSF reconstruction process (estimation of this parameters using GLAO telemetry) and to propose an efficient and robust algorithm of PSF reconstruction to be implemented in the MUSE pipeline. In particular we focus on the PSF evolution in the FoV by computing residual anisoplanatism effects accounting for the 4 LGS and the NGS positions.

First experimental validation of the PSF reconstruction algorithm is proposed using the ONERA wide field bench HOMER.

8447-222, Poster Session

Estimation of errors on the PSF reconstruction process for myopic deconvolution

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Images obtained with adaptive optics (AO) systems can be improved by using restoration techniques such as deconvolution, the AO correction being only partial. To get the best performance, these methods usually require an accurate knowledge of the system point spread function (PSF). Using data from the wavefront sensor (WFS), as well as statistical information about the turbulence, it is possible to estimate the system response during a given science observation. Of course, such reconstruction is not perfect, the accuracy being limited by several approximations (the residual phase is assumed to be stationary Gaussian) as well as the estimation of the noise. This effects can significantly impact the consistency of the optical transfer function (OTF) reconstruction especially in the case of moderate to poor correction levels. Techniques such as myopic deconvolution can be used to mitigate restoration errors due to the imperfect knowledge of the PSF by restoring jointly and under constraints the object and the PSF. In this paper, we explore the possibility of retrieving such constraints on the PSF from the PSF reconstruction process. Using simulated data, we derive an accurate error budget for the whole reconstruction process for various observing conditions. This error budget is then used, under the form of a power spectral density of the PSF variations, to feed a myopic deconvolution algorithm. An estimate of the error on the reconstructed object is given as well as the potential accuracy on astrometry and photometry that could be reached using such a restoration pipeline.

8447-223, Poster Session

Statistical moments of the Strehl ratio

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The knowledge of the statistical characteristics of the Strehl ratio is essential for the performance assessment of the existing and future adaptive optics systems. For this assessment not only the mean value of the Strehl ratio is important, but also higher statistical moments. The variance is related to the stability of an image and the skewness reflects the chance to have in a set of short exposure images more or less images with the quality exceeding the mean. Skewness is a central parameter for the lucky imaging application.

We present a rigorous theory for the mean, variance and skewness of the Strehl ratio. In our approach we represent the residual wavefront as being formed by independent cells. The level of the adaptive optics correction defines the number of cells and the variance of the cells which are the two main parameters of our theory. So our theory covers all types of adaptive optics: from the low order to the extreme adaptive optics. The deliverables are the values of the three moments as the functions of the correction level. We make no further assumptions accept for the statistical independence of the cells.

The PEACE breadboard (Phasing sEnsor with Adaptive Optics Control Experiment) installed at ESO premises has all necessary components to measure the statistical behavior of the Strehl ratio: turbulence generator, controllable segmented mirror and adaptive optics. It is also equipped with a high-resolution infrared imaging camera.

We cross-check the results of the theory with the simulation and with the experimental results obtained with the PEACE breadboard.

8447-224, Poster Session

Experimental validation of optimization concepts for focal-plane image processing with adaptive optics

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We show our most recent simulations and experimental results to validate promising joint-optimization concepts for adaptive optics (AO) and post-processing focal-plane images. The simulations indicate that the computational requirements of traditional phase-diversity (PD) algorithms can be reduced, by using wavefront-sensor information, by a factor of 20 without significant loss in performance. We will also investigate algorithms using small-phase approximations permitting a linear, extremely fast, phase-reconstruction directly from focal-plane images, given that a deformable mirror can be applied to iteratively correct the wavefront. The techniques are evaluated through simulations and on a small AO-setup with an 37-actuator membrane mirror.

8447-225, Poster Session

Preserving the photometric integrity of companions in high-contrast imaging observations using locally optimized combination of images

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Direct imaging and spectroscopy can advance our understanding of planet formation and migration through the detection and characterization of extrasolar planets on wide orbits. Accurate photometry and astrometry of detected companions are of crucial importance to derive the planet physical properties. Differential imaging techniques are now commonly used to reduce the limitation due to bright speckles in the point spread function (PSF) of the parent star, improving planet detection capabilities and reachable contrast between the star and its planet. Focusing on speckle suppression and the detection problem, these techniques can suffer from photometric biases in the planet signal measurement. We present an extension of the Locally optimized combination of images (LOCI) method to measure the highest-fidelity photometry as well as accurate astrometry of detected companions. Exploiting the knowledge that a companion is indeed present in the data, this new method optimizes the PSF subtraction while simultaneously solving for the companion flux. We present results obtained with simulated high-contrast images. This algorithm is also generalized to Integral-Field Spectrograph (IFS) data processing, giving advantages of a simultaneous angular and spectral differential imaging reduction, retrieving high-fidelity spectra from PSF-subtracted cubes.

8447-226, Poster Session

Specifications and design of the E-ELT M4 adaptive unit

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A 39 meters telescope does require adaptive optics to provide few milli arcseconds resolution images. In the current design of the E-ELT, M4 provides adaptive correction and has also to cancel part of telescope wind shaking and static aberrations. The 2.4 meters adaptive mirror will provide as well Nasmyth focus selection.

We will present the main design drivers and the main specifications quaternary mirror will have to meet. We will discuss what the challenges are in term of stability and performance of the associated key technologies. We will finally describe the current baseline design and the required schedule and work plan to adequately manufacture the E-ELT quartenary mirror.

8447-227, Poster Session

Numerical modeling and simulation studies for the M4 adaptive mirror of the E-ELT

M. Carbillet, Univ. de Nice Sophia Antipolis (France); A. Riccardi, INAF - Osservatorio Astrofisico di Arcetri (Italy)

We report in this poster on the progress of numerical modeling and simulation study of the M4 adaptive mirror for the European Extremely Large Telescope (E-ELT). This is based on both dedicated routines and the existing code of the Software Package CAOS, and the points approached are basically the specific problems encountered with this particular type of mirror on the E-ELT, namely and mainly:

- the segmentation of the adaptive mirror, implying a fitting error due also to the edges of the segments (six petals in the present case), as well as possible co-phasing problems to be evaluated in terms of interaction with the wavefront sensor (a pyramid here),

- the necessary presence of “master” and “slave” actuators which management, in terms of wavefront reconstruction, is studied by comparing different strategies.

The first results obtained for the two above points will be described in details.

8447-228, Poster Session

LBT adaptive secondary mirrors: procedures and optical calibration for chopping on the test bench

R. Briguglio, M. Xompero, A. Riccardi, INAF - Osservatorio Astrofisico di Arcetri (Italy)

In this paper we will describe the chopping capabilities of the LBT adaptive secondary mirrors. The chopping procedure has been implemented at the Arcetri Test Tower in Florence, Italy, together with the optical testing set-up.

We calibrated a flat mirror shape at both chopping positions (+- 25um tilt with respect to the nominal position,corresponding to +-2.5 arcsec on sky), running a flattening procedure that converged to a figuring error compatible to that at zero tilt, i.e. 30 nm RMS WFE.

The dynamical optical analysis was performed using a fast, dynamic Twyman-Green interferometer and a running trigger sampling, that allowed us to measure the optical figuring throughout the chopping movement; a final 4 ms time resolution was therefore achieved.

The figuring error measured at a +25um tilted position while the mirror was chopping at 10Hz is within requirements for seeing limited mode observations.

These laboratory results indicate the possibility offered by deformable secondary mirrors for chopping, seeing limited operations. The AO closed loop at a chopped position will be also addressed, reviewing issues and performances.

8447-229, Poster Session

Novel unimorph adaptive mirrors for astronomy applications

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Over the past 6 years we have developed a novel type of unimorph deformable mirror. Our newly developed fabrication process allows the use of prefabricated, super-polished glass substrates furnished with a highly reflective coating. Reflectivities higher than 99.998% paired with a surface roughness <1.5 Å rms are achieved by a state-of-the-art sputtering process. Originally intended to be used for high power laser

applications, the mirror's unique features suggest the use in a variety of astronomical applications. As the wave-front measurement error of a laser guide star system (LGS) is linearly proportional to the LGS spot size, the mirror can be used to compensate for the atmospheric aberrations seen by the laser beam during propagation. The mirror would allow simultaneous pre-compensation and alignment of the LGS-system. The high quantum efficiency imposed by the extremely low-scattering surface (total integrated scattering <0.01%) also permits operation in low light conditions. We have scaled our initially small laser mirror towards a clear aperture of 50 mm diameter to take into account the Lagrange invariant of large aperture telescopes. In conjunction with the very thin overall thickness, the mirror allows a stroke of several tens of microns, which gives raise to possible use in woofer-tweeter systems. Future concepts of large space telescopes are based on primary mirrors which cannot meet the required optical surface figure and are likely to generate several microns of wave-front errors. In order to correct for these errors, deformable mirrors with sufficient stroke and high optical quality are required. Our mirror concept meets these requirements.

8447-230, Poster Session

Deformable mirrors for open-loop adaptive optics

A. Kellerer, F. Vidal, E. Gendron, Z. Hubert, D. Perret, G. C. Rousset, Observatoire de Paris à Meudon (France)

We present the results of characterizing the performance of deformable mirrors that may have to work in an open-loop regime. This technique is to be applied in Multi Object Adaptive Optics (MOAO), or in closed-loop shemes where an improved accuracy is required. Deformable mirrors are usually characterized by standard parameters, such as influence functions, linearity, hysteresis, etc. We will show that these parameters are not sufficient to derive the open-loop error and that a deeper analysis of the mirror behaviour can be achieved. As an example we show measurements made on the mirrors we have tested in our SESAME Facility.

8447-232, Poster Session

Conceptual design for a deformable mirror for use with x-ray sources

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High-energy beams of X-rays such as those generated by free electron lasers or synchrotron sources find very frequent use in studies of organic and inorganic molecular structure. Typically, however, the beams from these sources suffer degradation of wavefront quality as they propagate through the beamline elements which leads to poorly characterized point-spread functions and diffraction patterns generated on interaction with the study samples. Some form of adaptive optics can in principle improve the wavefront quality by appropriate adjustment of a deformable mirror in the beam train. Conventional deformable mirrors are unsuitable because they are not intended for use at the grazing incidence angles necessary for reflection of such short wavelengths, and do not maintain the required long-term stability of the optical surface. In this paper we report the results of a conceptual design study for a new deformable mirror that addresses the requirements of this unusual application of adaptive optics technology. Our design draws on the successful strategies employed in the adaptive secondary mirrors operating at the MMT and LBT telescopes, including the use of voice-coil actuators with collocated position sensors of high accuracy and stability.

8447-233, Poster Session

Reference design of deformable mirror electronics for ELT AO systems

K. Caputa, G. Herriot, National Research Council Canada (Canada); J. Niebergal, A. Zielinski, Univ. of Victoria (Canada)

Adaptive Optics (AO) systems for the Extremely Large Telescopes (ELT) will be based on Deformable Mirrors (DM) with an order of magnitude larger number of actuators than in the AO systems presently operational. One of the first ELT AO systems to be deployed will be NFIRAOS of the Thirty Meter Telescope (TMT). NFIRAOS is currently being designed at the National Research Council of Canada's Herzberg Institute of Astrophysics (HIA) and incorporates two DMs with 3125 and 4548 piezoelectric actuators respectively. The DM electronics to drive these two large DMs must be appropriately scaled for the number of output channels and command communication bandwidth, while avoiding the corresponding linear scaling of the cost, dissipated power, physical volume and mass, of the DM electronics currently offered commercially.

To aid the procurement of the DME for NFIRAOS, a DME reference design is under way at the HIA. We have designed the overall architecture, defined a command communication interface and developed a compact and cost-efficient high voltage amplifier suitable for duplicating in 7673 copies for driving the two NFIRAOS DMs. We have successfully prototyped a 32-channel DM drive circuit board and are progressing on a prototype 96-channel DM drive module designed as a building block for high order DM electronics. In this paper we report the DME architectural choices, experimental results with the prototype DM drive module as well as progress in the design of the command communication interface.

8447-234, Poster Session

Testing the fast iterative algorithm (FIA) for the real-time control of SCExAO MEMS deformable mirror

C. Blain, Univ. of Victoria (Canada); O. Guyon, Subaru Telescope, National Astronomical Observatory of Japan (United States); C. H. Bradley, Univ. of Victoria (Canada); C. S. Clergeon, F. Martinache, Subaru Telescope, National Astronomical Observatory of Japan (United States)

A turbulence generator, equipped with a rotating turbulence phase plate, was recently added to the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system. The MEMS DM in SCExAO is used both for sensing (open loop control) and correction (closed loop control). The Fast Iterative Algorithm (FIA) is dedicated to control SCExAO's 1024-actuator MEMS deformable mirror. This paper presents the performance of the FIA with this new setup and in real-time.

8447-235, Poster Session

Ziegler-Nichols frequency response method for high-order adaptive optics system of the Advanced Technology Solar Telescope

J. Curamen, National Solar Observatory (United States)

We present the study and results on automatic tuning and optimizing the closed-loop control gains of the Proportional Integral (PI) controller for the high-order adaptive optics (HOAO) system. The Ziegler-Nichols frequency response (ZNfr) method is examined using the Nyquist stability criterion to implement the automatic tuning of PI controller by determining the critical gain, Ku, and critical period, Tu, of a process model, which consists of components from adaptive optics (AO) system. The dB gain criterion, $0.5 \leq \text{dB} \leq 2.3$, is identified and considered as the optimization method, which established the stability of the PI controller. Matlab scripts

are developed to execute iterative calculation of control algorithm, which automates real-time simulation of the Simulink high-order adaptive optics (Sim-HOAO) models. Simulink block diagrams are used to represent transfer functions, which described the temporal behavior of the AO system. Sampled data sets, which are used as data input of the Sim-HOAO models, are collected from scientific observations at the Dunn Solar Telescope's HOAO (DST-HOAO) system and compared with simulation results from Sim-HOAO models. In one of the sampled data sets, we achieved from 2.3 dB maximum gain a mean rms value of 44.89 nm and 75.86 nm of residual wavefront error for Sim-HOAO models and DST-HOAO system, respectively, and the Fried's parameter from sampled data is r0(500 nm) = 20 cm . The values of Strehl ratio are S = 0.77 and S = 0.41 for Sim-HOAO models and DST-HOAO system, respectively.

8447-237, Poster Session

An overview of the ESO adaptive optics wavefront sensing camera

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The detector controller requirements for Adaptive Optics (AO) cameras present numerous challenges in the design of the electronics, all of which have led to highly customized developments in order to meet the requirements of high frame rate, low-noise and low image latency in a compact size camera.

This paper presents an overview of AONGC, the ESO's detector controller for AO; the challenges and excellent progress in achieving detector limited performance from the e2v EMCCD CCD220 along with test results demonstrating sub-electron read noise at frame rates in excess of 1500 Hz. Pre-series cameras have been delivered for use in 2nd Generation VLT instruments (AOF and SPHERE).

8447-238, Poster Session

Laboratory characterization of the ARGOS laser wavefront sensor

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We present the results of the optical alignment of the ARGOS wavefront sensor (WFS) and the preliminary laboratory tests performed during the integration of the WFS. ARGOS is the laser guide star adaptive optics system of the Large Binocular Telescope (LBT). It is designed to implement a Ground Layer Adaptive Optics (GLAO) correction for LUCIFER, an infrared imager and multi-object spectrograph (MOS), using 3 pulsed Rayleigh beacons focused at 12km altitude. The WFS unit contains 3 independent Shack-Hartman sensors sampling the pupil with 15x15subapertures. In the WFS each LGS is independently stabilized for on-sky jitter and gated to reduce spot elongation. The 3 LGS are arranged on a single lenslet array and on a single detector.

The WFS was assembled at Arcetri Observatory premises during 2011. We discuss here the results of the WFS optical alignment with respect to the tolerances evaluated by the optical project. We describe also the tests performed for the acceptance of the WFS. These tests were aimed at demonstrating the functionality of the internal control loops of the WFS and at measuring its performance simulating an adaptive closed-loop correction using a MEMS deformable mirror.

8447-239, Poster Session

Integration and testing of the GPI calibration unit

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The Gemini Planet Finder (GPI) will be the first extreme AO system to be installed at the Gemini Observatory in Chile. It is currently being integrated and assembled at University California Santa Cruz and shall be delivered during 2012. The Gemini pupil spans over 43 MEMS/tweeter actuators for high order correction over the pupil diameter, whereby low spatial orders are handled by a conventional stacked array DM (woofer) with 7 actuators across the pupil. A calibration unit built by JPL is dedicated to control the fine centring on the coronagraphic mask and non-common path aberrations. A sophisticated design combining a low order Shack-Hartman WFS with a Mach-Zehnder type interferometer senses low temporal frequency distortions to a few nm and offloads them to the fast running AO loop to potentially achieve contrasts as high as 10-8 a few airy rings apart. In this paper we give insights to the challenges encountered during the integration of the calibration unit into GPI.

8447-240, Poster Session

Characterization of an off-the-shelf detector for high-order wavefront sensing in solar adaptive optics

L. C. Johnson, K. Richards, T. R. Rimmele, S. C. Barden, National Solar Observatory (United States)

When completed, the Advanced Technology Solar Telescope (ATST) will be the largest and most technologically advanced solar telescope in the world. As such, it faces many challenges that have not previously been solved.

One of these challenges is the high-order wavefront sensor (HOWFS) for the ATST adaptive optics. The HOWFS requires a 960 x 960 pixel detector array running at a 2 kHz frame rate for the adaptive optics to achieve its required bandwidth. This detector must also be able to accurately image low-contrast solar granulation to identify subaperture shifts using correlation.

Previous proposals for solar high-order wavefront sensing have assumed a costly custom camera architecture would need to be developed for this application. However, we have identified the Vision Research DS-440 as a possible off-the-shelf solution and report results showing that the camera will be able to lock the adaptive optics loop on solar granulation in good seeing conditions (r0 > 10 cm).

Tests presented quantify the noise, linearity, gain, stability, and well depth of the camera. Laboratory tests with artificial targets demonstrate its ability to accurately track low-contrast objects and on-sky demonstrations showcase the camera's performance in realistic observing conditions.

8447-241, Poster Session

Development of adaptive optics elements for solar telescope

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Zuev Institute of Atmospheric Optics (Russian Federation); P. G. Kovadlo, Institute of Solar-Terrestrial Physics (Russian Federation); P. A. Konyaev, E. A. Kopulov, V.E. Zuev Institute of Atmospheric Optics (Russian Federation); V. I. Skomorovsky, V. D. Trifonov, S. A. Chuprakov, Institute of Solar-Terrestrial Physics (Russian Federation)

The devices and components of adaptive optical system “ANGARA”, which is developed for image correction in the Big solar vacuum telescope (BSVT) at Baykal astrophysical observatory are described. It is shown that the use of modernized adaptive system on BSVT not only reduces the turbulent atmospheric distortions of image, but also gives a possibility to improve the telescope developing new methods of solar observations. A high precision Shack-Hartmann wavefront (WF) sensor has been developed on the basis of a low-aperture off-axis diffraction lens array. The device is capable of measuring WF slopes at array sub-apertures of size 640X640 m with an error not exceeding 4.80 arc. sec. Also the modification of this sensor for adaptive system of solar telescope using extended scenes as tracking objects, such as sunspot, pores, solar granulation and limb, is presented. The software package developed for the proposed WF sensors includes three algorithms of local WF slopes estimation (modified centroids, normalized cross-correlation and fast Fourier-demodulation), as well as three methods of WF reconstruction (modal Zernike polynomials expansion, deformable mirror response functions expansion and phase unwrapping), that can be selected during operation with accordance to the application.

8447-242, Poster Session

Aligning a more than 100 degrees of freedom wavefront sensor

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LINC-NIRVANA is the Fizeau beam combiner for the LBT, with the aim to retrieve the sensitivity of a 12m telescope and the spatial resolution of a 22.8m one.

Despite being only one of the four wavefront sensors of a layer-oriented MCAO system, the GWS, which is retrieving the deformation introduced by the lower atmosphere, known to be the main aberration source, reveals a noticeable internal opto-mechanical complexity.

The presence of 12 small devices used to select up to the same number of NGSs, with 3 optical components each, moving in a wide annular 2’-6’ arcmin Field of View and sending the light to a common pupil re-imager, and the need to obtain and keep a very good super-imposition of the pupil images on the CCD camera, led to an overall alignment procedure in which more than a hundred of degrees of freedom have to be contemporary adjusted.

The rotation of the entire WFS to compensate for the sky movement, moreover, introduces a further difficulty both in the alignment and in ensuring the required pupil superimposition stability.

A detailed description of the alignment procedure is presented here, together with the lessons learned managing the complexity of such a WFS, which led to considerations regarding future instruments, like a possible review of numerical versus optical co-add approach, above all if close to zero read-out noise detectors will be soon available.

Nevertheless, the GWS AIV has been carried out and the system will be soon mounted at LBT to perform what is called the Pathfinder experiment, which consists in ground-layer correction, taking advantage of the Adaptive Secondary deformable Mirror.

8447-243, Poster Session

A novel high sensitivity wavefront sensor design for the MMT

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We are in the process of building a novel, highly sensitive wavefront sensor called the non-linear Curvature Wavefront Sensor (nlCWFS) for the MMT. The nlCWFS is based on the principal of curvature wavefront sensing. With illumination from a natural star, intensity measurements are recorded in four planes displaced by precise distances from an image of the telescope pupil. The complex field in the pupil is estimated from these data by an iterative algorithm which models the Fresnel propagation between the pupil and the measurement planes. Since the nlCWFS relies on images from a diffraction-limited source recorded with the full aperture, it offers an enormous improvement in sensitivity compared to conventional wavefront sensors which operate in the seeing limit. In the lab we have conducted an experiment to compare the sensitivity of the nlCWFS with the Shack Hartmann (SH) WFS and the Modulated Pyramid (MPY) WFS. We find the nlCWFS to be more sensitive than the SHWFS and the MPYWFS by orders of magnitude for low and mid order spatial frequencies.

The nlCWFS we describe will become part of the existing MMT Natural Guide Star (NGS) adaptive optics (AO) system to supplement the present SHWFS. Currently we are pursuing two designs. The first uses dichroic beam splitters to create four channels each at a unique propagation distance from the pupil. The second uses chromatic re-imaging optics which corrects chromatic aberration and introduces a prescribed amount of pupil propagation. Both designs are being tested in the lab and one will be implemented on the MMT. Initially we will compare the performance of the nlCWFS and the SHWFS with open loop on-sky data. Eventually we will close the loop with the nlCWFS.

8447-244, Poster Session

The LINC-NIRVANA high layer wavefront sensor laboratory experiment: progress report

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LINC-NIRVANA is a near infrared interferometric imager with a pair of layer-oriented multi conjugate adaptive optics systems (ground layer and high layer) on the Large Binocular Telescope. To prepare for the commissioning of LINC-NIRVANA, we have integrated the high layer wavefront sensor and its associated deformable mirror (a Xinetics-349) in a laboratory, located at Max Planck Institute for Astronomy, in Heidelberg, Germany. Together with a telescope simulator, which includes a rotating field and phase screens that introduce the effects of the atmosphere, we tested the acquisition of multiple guide stars, calibrating the system with the push-pull method, and characterizing the wavefront sensor together with the deformable mirror. We have closed the AO loop with up to 200 Zernike modes and with multiple guide stars. The AO correction

demonstrated that uniform correction can be achieved in a large field of view. We report the current status and results of the experiment.

8447-245, Poster Session

Piramidal wavefront sensor using diffractive lenses

P. J. Valle, M. A. Cagigas, M. P. Cagigal, Univ. de Cantabria (Spain)

Wavefront sensing devices are commonly used in different fields like optical testing, LASIK surgery, confocal microscopy, adaptive optics, etc. Several techniques have been proposed for obtaining an accurate wavefront description. The standard Shack-Hartmann and curvature sensors have now to compete with more sophisticated sensors to provide not only accuracy but also high resolution and a large dynamic range. In this context we propose an optical device composed by a couple of lenses and a diffractive filter between them. It is based on the optical differentiation wavefront sensor. However, in the current improved version the sensor is able to offer the same information as a Pyramidal one. Our sensor produces four pupil replicas so that the x wavefront derivative can be deduced from a couple of them and the y derivative from the other two. The four copies are detected simultaneously using a CCD camera so that the post processing can be performed straight away. In the first stages the results seem to be very promising.

8447-246, Poster Session

Development of a pyramidal wavefront sensor testbench at INO

J. Gauvin, S. Turbide, J. Lavigne, M. Wang, M. Savard, F. Châteauneuf, INO (Canada)

The pyramidal wavefront sensor has considerably gained in popularity over the last past few years due to its demonstrated increased sensitivity compared to the Shack-Hartmann wavefront sensor. The major challenge in the design of such a WFS is the pyramid manufacturing that requires tight tolerances on the facet angles, and to minimize the edge and tip width to maximize the throughput. INO is currently developing a P-WFS testbench to qualify multiple manufacturers for the pyramid fabrication and to test alternative approaches to the beam separation in the focal plane.

It is also a goal to compare the results obtained on the testbench to the predictions from the diffraction theory. To do so, phase screens are generated using a spatial-light-modulator and the reconstruction error is computed for different input wavefront RMS error and for different pyramid modulation angles. Results are compared to the predictions of the P-WFS simulation code developed at INO.

8447-247, Poster Session

Testing the pyramid wavefront sensor without modulation used in the closed-loop adaptive optics system

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The pyramid wavefront sensor (PWFS) is an innovative device with the special characteristics of variable gain and adjustable sampling in real time to enable an optimum match of the system performance, which make it an attractive option for next generation adaptive optics system compared with the Shack-Hartmann. At present most of the PWFS are used with modulation based on oscillating optical component in order to give a linear measurement of the local tilt, but the PWFS without modulation would greatly simplify the optical and mechanical design of the adaptive optics system and also give highest sensitivity as expected to be achieved. The aim of this paper is to clearly present the choices that can be made to design the PWFS without modulation used in the closed-loop adaptive optics system.

Firstly, the feasibility and performance of the PWFS without modulation used in closed-loop adaptive optics system is briefly analyzed and the numerical simulation results based on a nonmodulated PWFS will be shown to explain the special behavior of this sensor. Secondly, we describe the optical setup of our adaptive optics system with nonmudulated PWFS. In this system, the pyramid wavefront sensor with 8*8 sub-subapertures in the pupil diameter has been designed, and the deformable mirror with 61 actuators is used to introduce aberrations into the system, as well as to correct them afterwards. Finally, closd-loop correction results of single order Zernike aberrations and the Kolmogorov turbulence phase screen show that the PWFS without modulation can work as expected for closed-loop adaptive optics system.

8447-248, Poster Session

Phasing segmented deformable mirrors with the Zernike phase contrast method

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A new technology of segmented deformable mirrors for adaptive optics made from silicon wafers with bimorph piezoelectric actuation has been sizes of silicon wafers mass produced for the microelectronic industry. A demonstrator with three hexagonal segments of 90 mm corner to corner has been built at our premise. The morphing capability of the segmented mirror has been studied and validated by simulations and on a test bench. In this paper, we demonstrate with simulations and on a test bench the phasing of the segmented bimorph mirror with the Zernike phase contrast method. A description of the test bench is outlined in these proceedings and the preliminary results obtained on the bench are presented. Aspects such as phasing in the presence of segment aberrations, measureable capture range, and influence of edge effects and gaps on the phasing accuracy will be investigated.

8447-249, Poster Session

Applications of absolute optical surface metrology

E. E. Bloemhof, National Science Foundation (United States)

A simple but potentially powerful technique was devised recently for measuring absolute surface figures of optical flats with a commercial Fizeau interferometer (E. E. Bloemhof, Opt.Lett. 35, 2346, 2010). The optic under test is shifted laterally in X- and Y- directions, and the resulting maps are differenced with that from the starting position. These maps are phase/height differences (~slopes) between neighboring positions on a grid on the surface of the test optic, and they are absolute (they are no longer contaminated by the unknown additive phase error map introduced by the interferometer's reference surface). These absolute difference maps may be converted to absolute phases/heights on the test optic by standard techniques of wavefront reconstruction. The new technique is simpler and more accurate than other solutions to this classical problem, such as the "three-flat test", and may be viewed more generally in many situations as a phase calibration for the effects of any intervening additive phase screen. Here some extensions and applications in interferometry and adaptive optics are discussed.

8447-250, Poster Session

Temporal analysis of aliasing in Shack-Hartmann wave-front sensing

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A Shack-Hartmann wavefront sensor samples the wavefront in the pupil. The wavefront shape will be undersampled, since despite the wavefront average spatial spectrum is a rapidly decreasing function of spatial frequency, it contains frequencies higher than the Nyquist limit : this well-known phenomenon is known as aliasing. The impact of aliasing in adaptive optics is difficult to estimate. Some methods have been proposed, that aim at optically filter out high wavefront frequencies ; some authors gave an estimate of this error, but most of the time these estimations are based on Monte-Carlo simulations of wavefront sensor.

We propose in this paper an analytical study of the aliasing effect, and study how the aliasing error distributes over temporal frequencies.

An analytical expression of the temporal spectrum of the aliasing error maybe of importance for system modelling or performance prediction in adaptive optics.

8447-251, Poster Session

Comparison between Shack-Hartmann and pyramid wavefront sensors from simulations for an E-ELT-like telescope

A. Garcia-Rissmann, Lab. Nacional de Astrofísica (Brazil); M. Le Louarn, European Southern Observatory (Germany)

The design of the next generation of extremely large telescopes poses several challenges in scaling up current AO systems. Since the number of the system parameters increases significantly, it is worth investigating how the performance is impacted by e.g. non-linear effects in the correction. The pyramid wavefront sensor has been tested in recent years giving satisfactory results, and proved to be more sensitive than the Shack-Hartmann wavefront sensor at least in low modulation regimes (Vérinaud 2004, Opt Commun, 233, 27). The pyramid modulation, a property which allows the sensitivity even to be tuned up in real time, gives good advantages in ExAO applications. But it seems to fail in giving better results for the case of extended sources as LG stars, as shown by a previous study of Le Roux (2010, SPIE Proceedings, 7736, 773657). Using system parameters similar to those of the E-ELT we show the preliminary performance results for a SCAO system with both types of wavefront sensors. This performance assessment is obtained through simulations carried out with the parallelized ESO OCTOPUS code (e.g. Le Louarn 2010, SPIE Proceedings, 7736, 773618), as a first step to address the suitability of use of such sensors in large AO systems.

8447-252, Poster Session

Theory and application of differential OTF (dOTF) wavefront sensing

J. L. Codona, The Univ. of Arizona (United States)

A new image-based technique for measuring the complex field in the pupil of a telescope is presented. The simplest form of the method uses two point source images, one with a small modification introduced in the pupil. The processing of the images is very simple and non-iterative. The method is based on a specially-defined complex functional derivative of the OTF: the dOTF. The dOTF is approximated empirically by the difference between the Fourier transforms of the two PSFs. Due to the complex conjugate in the OTF, the dOTF has two complex images overlapping at the point of pupil modification. By placing the modification near the edge of the pupil, the overlap region can be minimized. This happens for every point in the modification, so the images are the pupil field convolved with the change. The overlap region is typically small, but can be eliminated altogether by using a second modification and a third image. The technique can use broadband light, but the result incurs a radial blurring proportional to the fractional bandwidth. This is also easily dealt with using another modification and image. Systems with non-shift-invariant PSFs allow straightforward tomographic reconstruction of 3-D aberrations and vignetting away from the pupil plane. Since this is a differential method, many photons are required to make a measurement making dOTF a poor match for high frame rate astronomical AO. However, for segment phasing, imaging system diagnostics and testing, and unconventional wavefront estimation problems, dOTF has many potential uses. Theory, experiments, and potential applications will be shown.

8447-253, Poster Session

Application of differential OTF wavefront sensing to tomography

M. Hart, J. L. Codona, The Univ. of Arizona (United States)

A new method to estimate the complex pupil-plane field from a functional derivative of the optical transfer function (OTF) is described elsewhere in these proceedings by Codona. It is in principle a diversity technique that uses two simultaneous focal-plane images with a known difference in the pupils of the two optical trains. Unlike other diversity methods, however, the dOTF wavefront estimation algorithm is non-iterative and very fast. Furthermore, to within limits imposed by considerations of signal-to-noise ratio and isoplanatism, the field can be estimated from extended sources by taking advantage of temporal correlations between successive images in cases where the aberration changes with time but the observed object does not, as with an astronomical adaptive optics system. The technique may be further extended in a straightforward way to tomographic wavefront sensing from scenes whose angular extent exceeds the isoplanatic limit by insertion of a mask in a focal plane of the optical system. Holes in the mask are sized to transmit light from regions of the scene smaller than the isoplanatic angle. Two cameras, one in each of the two optical trains, and each of which captures all the regions at once, are then sufficient to derive the tomographic information to characterize the non-shift-invariant point-spread function over the full field. In this paper we show the results of a study to demonstrate the tomographic application of differential OTF wavefront sensing from an extended scene.

8447-254, Poster Session

Experimental evaluation of differential OTF (dOTF) wavefront sensing

J. L. Codona, The Univ. of Arizona (United States); N. Doble, New England College of Optometry (United States); M. Hart, The Univ. of Arizona (United States); F. Vera Diaz, New England College of Optometry (United States)

dOTF is an image-based non-iterative technique for measuring the complex pupil field. The technique relies on the difference between two PSF images when a small modification is introduced near the pupil's edge. The nature of the modification is of minor importance and can consist of a transmission blockage or a phase shift introduced by poking a single DM actuator. Even without calibration, dOTF yields an accurate estimate of the complex amplitude over the pupil plane. We experimentally evaluate the technique in several different optical systems, using both transmission and phase modifications to the pupil, monochromatic and broadband light sources, and different modification areas and poke depths.

The experiments will include a continuous Boston Micromachines DM and a segmented IrisAO DM and a simple dark object inserted into the light near the pupil's edge. The test scenarios are designed to measure wavefront sensitivity and accuracy, the effect of poke depth and modification convolution. The tests will also include cases that

are designed to be difficult for iterative techniques, such as unknown or misaligned pupils. Since the technique is simple and fast, we will show results from a prototype real-time complex field camera being used while the optical system is being adjusted. This presentation is the experimental supplement to Codona's dOTF theory talk [AS12-AS106-208].

8447-255, Poster Session

Focal plane wavefront sensing and control for ground-based imaging

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We evaluate the performance of existing wavefront sensing and control techniques, including speckle nulling and electric field conjugation, and discuss their applicability to high-contrast imaging spectrographs such as the Gemini Planet Imager (GPI). These techniques can be highly useful in correcting system phase errors, and can potentially improve instrument operating efficiency by working in conjunction with the dedicated adaptive optics (AO) wavefront sensor. We discuss the particular challenges of wavefront sensing with a spectrograph and present results from a combination of lab tests and simulations employing detailed models of both the science instrument and the GPI AO system.

8447-256, Poster Session

Bilinear solution to the phase diversity problem for extended objects based on the Born approximation

R. M. Andrei, R. Fraanje, M. Verhaegen, Technische Univ. Delft (Netherlands); C. U. Keller, V. A. Korkiakoski, Utrecht Univ. (Netherlands); N. Doelman, TNO (Netherlands)

We propose a new approach for the joint estimation of aberration parameters and unknown object from diversity images with applications in astronomical ground-based observations, solar telescopes or general extended sources. The motivation behind our idea is to decrease the computational complexity of the phase diversity algorithm and avoid the convergence to local minima due to the use of nonlinear estimation algorithms. The method is based on the Nijboer-Zernike theory of diffraction integrals containing small wavefront phase aberrations or in other terms the Born approximation. When the wavefront phase aberrations are small, the wavefront can be approximated with a linear phase term which leads to a quadratic point-spread function. For the representation of the wavefront we use Zernike basis functions. The given approach involves recording two or more diversity images and solving a system of bilinear equations, in the aberration parameters and the object, which is obtained by subtracting from each diversity image the focal plane image. Increasing the number of diversity images increases the accuracy of the proposed algorithm. Simulation experiments, done both in the noise free case and with white Gaussian noisy measurements, show that the computation time for 1 iteration of the phase diversity algorithms can be reduced with a factor of 2 up to 3. Being an object dependent method, it works best for small sources. Moreover, this approach proves to give improved performance when applied to the conventional phase diversity algorithm through the fact that the gradients of the point-spread functions can be analytically computed.

8447-257, Poster Session

Linear analytical solution to the phase diversity problem for extended objects based on the Born approximation

R. M. Andrei, R. Fraanje, M. Verhaegen, Technische Univ. Delft (Netherlands); C. U. Keller, V. A. Korkiakoski, Utrecht Univ. (Netherlands); N. Doelman, TNO (Netherlands); C. S. Smith, Technische Univ. Delft (Netherlands)

The problem of wavefront estimation using phase diversity (PD) is considered. Our goal is to overcome the main disadvantages of the PD algorithms, namely the large computational complexity and the convergence to local minima. Our approach is able to give a good starting point for an iterative algorithm based on solving a linear system of equations. The proposed algorithm can also be used as a new wavefront estimation method. The method is based on the Born approximation of the wavefront for small phase aberrations which leads to a quadratic point-spread function. We take the differences between the focal plane image and two diversity images and we eliminate the object, considered constant, from the two equations. The result is an overdetermined set of linear equations which in the noise free case is solved by the linear least squares algorithm. In the noise case we give three solutions - least squares, total least squares and bounded data uncertainty. We give an analysis of how the two diversities can be chosen as a function of the null space of the underlying linear system's matrix. We are also working on a method to optimally determine the best diversities. Simulation results show that the algorithm is faster with a factor of 20 with respect to 1 iteration of the conventional PD algorithms in the noise free case and with a factor of 10, 2, 1.5, respectively, for the three methods mentioned above, in the presence of white Gaussian noise with a signal-to-noise ratio of 25dB.

8447-258, Poster Session

Fast phase diversity wavefront sensing using object independent metrics

C. S. Smith, A. J. den Dekker, R. Andrei, R. Fraanje, M. Verhaegen, Technische Univ. Delft (Netherlands)

Phase-diversity methods allow to estimate both the wavefront disturbance as well as the object that is being imaged and that is extended in space. Hence, in principle, phase-diversity methods can be used for wavefront sensing as well, without the need to spill part of the observed light to wavefront sensing with a dedicated wavefront sensor.

However, the use of phase-diversity in real-time applications is prevented by its high computational complexity, determined by the number of parameters quantifying the wavefront and the object.

To reduce the computational complexity, metrics have been proposed that are independent of the object, that allow to only estimate the wavefront, but still yield a nonlinear inverse problem.

To further reduce the computational complexity of the wavefront estimation methods we consider linear approximations of these metrics, that allow to update the estimate of the wavefront by solving a linear least squares problem.

We study the estimation error w.r.t. the presence of noise and the spectral content of the extended object, and compare metrics presented in literature.

8447-259, Poster Session

A first order wavefront estimation algorithm for P1640 calibrator

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States); R. G. Dekany, California Institute of Technology (United States); B. R. Oppenheimer, American Museum of Natural History (United States); S. Hinkley, California Institute of Technology (United States); D. S. Brenner, American Museum of Natural History (United States); F. E. Vescelus, Jet Propulsion Lab. (United States)

P1640 calibrator is a wavefront sensor working with the P1640 coronagraph and the Palomar 3000 actuactor adaptive optics system (P3K) at the Palomar 200 inch telescope. It measures the wavefront by interfering post-coronagraph light with a reference beam formed by low-pass filtering the blocked light from the coronagraph mask. The system has a similar architecture to the Gemini Planet Imager (GPI), in which, a major performance limitation is quasi-static speckles generated by wavefront errors due to non-common optical path for the light to arrive at the AO wavefront sensor and the coronagraph mask.

By measuring the post-corongraph wavefront, this error can be estimated and corrected by feeding back the error signal to the deformable mirror (DM) of the P3K AO system. Here, we present our first order wavefront estimation algorithm and an instrument calibration scheme used in experiments done in November and December, 2011. P1640 calibrator measures the wavefront at the pupil after the coronagraph, whose relation to the wavefront at the DM pupil is modeled as a low spatial frequency phase factor with proper normalization, which is calibrated by separately measuring single arm intensities. The P1640 calibrator responses to a regular sparse DM poking pattern at different amplitudes are used to calibrate the low spatial frequency phase actor and establish the registration of the DM actuators at the pupil camera of the P1640 calibrator, necessary for wavefront correction. Improvment of imaging qaulity after feeding back the wavefront correction to the AO system demonstrated the efficacy of the algorithm.

8447-260, Poster Session

MCAO: wavefront sensing only as a tool for high precision photometry?

V. Viotto, R. Ragazzoni, INAF - Osservatorio Astronomico di Padova (Italy); M. Bergomi, Univ. degli Studi di Padova (Italy) and INAF - Osservatorio Astronomico di Padova (Italy); A. Brunelli, M. Dima, J. Farinato, D. Magrin, INAF - Osservatorio Astronomico di Padova (Italy); L. Marafatto, G. Piotto, Univ. degli Studi di Padova (Italy)

In MCAO the correction of the wavefront for an extended Field of View is obtained at the expense of a stretching of the actual instantaneous metapupils over the high altitude layers, just to compensate their average curvature. While this effect does average out in long term exposures and is of secondary interest in compensated imaging, it gives the input for the idea of using MCAO-like information, collectable over a certain Field of View, to assess in a time resolved mode (not necessarily in real time) the actual geometrical light throughput in a given direction. In principle this would allow, with proper time tagging, to achieve high precision photometry, as part of the scintillation could be measured on line during the observation. Simple averaging of neighbor stars to flat field starlight, for example, represents the equivalent of this concept for the ground-layer correction only.

It can be seen that, once a direction is defined, it is relevant only the derivative of the wavefront around or in the proximity of that edges, but the range at which this happen is a crucial parameter. However, the strong interest in high precision measurements of planetary passages for exploring Time Transit Variation and their possible causes (like other planets or moons) could make this approach not as lunatic as it could sound.

8447-75, Session 19

Computer simulations and real-time control of ELT AO systems using graphical processing units

L. Wang, B. L. Ellerbroek, Thirty Meter Telescope Project (United States)

The AO systems for future ground based ELTs are so complex that end-to-end numerical simulations in the time domain are an essential part of detailed performance analysis. The AO simulations at TMT for the first light AO system NFIRAOS have been carried out using the C based simulator called MAOS (freely available at http://github.com/lianqiw/maos). Mission-critical parts of MAOS, such as wavefront sensing, wavefront reconstruction, performance evaluation etc, have recently been ported to GPU using NVIDIA CUDA technology. We achieved a 10 fold speed up for each GTX 580 used. Each time step of full scale NFIRAOS simulation takes 0.1 second in a desktop with two GTX 580s, which means a minute of real time can be simulated in slightly more than an hour. We also exercised the actual MCAO RTC algorithm in GPU and found that this processor option may meet the required latency in a few years with rapid advancement of the technology. More specifically, 30 iterations of the conjugate gradient (CG) tomography algorithm, from 6 order 60x60 LGS WFS to 6 turbulence layers can be accomplished in 25 milliseconds in a single GTX 580. The Fourier domain preconditioned CG algorithm with 3 iterations can be accomplished in 5 milliseconds, which is only 5 times away from the requirement. However, iterative algorithms are hard to parallelize through multiple GPUs due to bandwidth and latency limitation of the PCI-E interface.

8447-76, Session 19

Modeling anisoplanatism in the Keck II laser guide star AO system

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A primary source of photometric and astrometric error in single-conjugate adaptive optics is anisoplanatism. For example, anisoplanatism limits the accuracy of stellar orbital measurements in the Galactic Center. We describe our project to model the off-axis optical transfer function in the Laser Guide Star Adaptive Optics system at the Keck II telescope. Our model accounts for both the effects of atmospheric anisoplanatism and field-dependent instrumental aberrations. Our model of the instrumental field-dependent aberrations rests on measurement of these errors with the NIRC2 camera using an artificial source in the Nasmyth focal plane. We model the atmospheric portion of the anisoplanatic transfer function using DIMM/MASS measurements. Here we present the results of a validation campaign using observations of naturally guided visual binary stars under varying conditions of the r_0 and theta_0 parameters of the C_n^2 atmospheric turbulence profile. We also discuss our plans to extend the work to laser guide star operation.

8447-77, Session 19

Size of the halo of the adaptive optics PSF

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It is a widely accepted conjecture that the width of the incoherent halo in an adaptive optics PSF should decrease with the level of correction. Using end-to-end simulations we prove that this is not the case and the halo is actually increasing in width, albeit at a decreasing overall brightness level as must be the case with increasing correction. We ran seeing-limited to XAO-type cases for a 3.5m telescope.

Since size of the halo is inversely proportional to the size of the "cell" in the wavefront ensemble, we also investigate this latter quantity. This wavefront cell has various disparate definitions in the literature. We propose the definition which is consistent with that of Goodman's (in the field of statistical optics) and Fried's (in non-compensated imaging). The size of the cell is important in itself as it defines the statistics of the speckles and the Strehl ratio. Therefore we compare the theory of speckle statistics with the results of the simulations.

Finally we check the predictions of the simulations and the associated theory on the short-exposure images obtained with the "extreme-adaptive-optics" system at the 3.5m Starfire Optical Range telescope located in New Mexico, US.

8447-78, Session 19

A Fresnel propagation modeling of NFIRAOS/IRIS high-contrast exoplanet imaging capabilities

C. Marois, J. Véran, C. Correia, National Research Council Canada (Canada)

The thirty-meter telescope (TMT) offers great potential to find and study nearby planetary systems, possibly imaging down to super-Earth size planets or still accreting distant planets in very young star forming regions. Since no first generation dedicated exoplanet finding instruments have been selected for TMT, initial direct exoplanet imaging will have to rely on the NFIRAOS/IRIS facility AO/imaging systems. I will present end-to-end Fresnel NFIRAOS/IRIS simulations using their current optical designs (as well as possible upgrades) and expected aberrations to evaluate the system multi-wavelength high-contrast imaging capabilities. Long exposures have been simulated using the expected AO-delivered phase screens and by including the various optical rotation planes. It is shown that NFIRAOS/IRIS could offer contrasts comparable to GPI (an optimized NIR planet-finding instrument that will soon be installed on the Gemini South 8-m telescope), but would have to rely strongly on multi-wavelength processing to achieve this level of performance. Without a coronograph and higher order AO corrections, NFIRAOS/IRIS are not expected to achieve higher contrast at very small IWA, which are potentially accessible with a 30-meter telescope. However, TMT, with its larger aperture and better angular resolution, will acquire higher SNR planet spectra and will achieve an astrometric accuracy three times smaller than GPI, resulting in better atmospheric characterization and faster orbital parameters determination.

8447-79, Session 20

Aperture masking behind AO systems

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Sparse Aperture-Masking Interferometry (SAM or NRM) behind Adaptive Optics (AO) has now come of age, with more than a dozen astronomy papers published from several 5-10m class telescopes around the world. I will describe the reasons behind its success in achieving relatively high contrasts (~1000:1 at lambda/D) and repeatable binary astronomy at the diffraction limit, even when used behind laser-guide star adaptive optics. Placed within the context of AO calibration, the information in an image can be split into pupil-plane phase, Fourier amplitude and closure-phase. It is the closure-phase observable, or its generalisation to Kernel phase, that is immune to pupil-plane phase errors at first and second-order and has been the reason for the technique's success. I will outline the limitations of the technique and the prospects for aperture-masking and related techniques in the future.

8447-80, Session 20

Recent advances in adaptive optics PSF reconstruction for Gemini-North and W.M. Keck systems

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We present here the last results of our adaptive optics PSF reconstruction (PSF-R) project for Altair/Gemini, a modal control based system, and the W.M. Keck telescopes AO system, which is zonal control based. The main challenges are with the determination of the system's post-AO static aberrations and the determination of the true seeing seen at the telescope. For the Keck system, the static aberrations are retrieved from a phase diversity procedure applied on the long exposure, AO corrected sky PSF (a premiere), and we discuss here the limits and sensitivity of the method, in particular with respect to the seeing variation. For ALTAIR/GEMINI, the static aberration is retrieved from both a calibrated model of the telescope optics aberrations (essentially M2-based) and phase diversity applied on defocused calibration lamp images. Seeing and outer scale of turbulence are determined from the DM commands, and we show here that our DM-based seeing is very well correlated with the seeing extracted from focal plane seeing limited (AO-off) PSF. With the conclusion that PSF-R now works well for the bright NGS case, we have started to explore PSF-R on moderately bright to dimmer NGS, and we show here our preliminary results for both systems.

8447-81, Session 20

Long exposure point spread function estimation for laser guide star multi-conjugate adaptive optics

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This paper discusses a simulation-based approach for long exposure point spread function reconstruction (PSFR) for laser guide star (LGS) multi conjugate adaptive optics (MCAO). The approach is based on (i) processing the on-axis high-order LGS wavefront sensor (WFS) second-order tip/tilt removed (TTR) statistics to compute via simulation a TTR structure function (SF) for the science target at infinite range, and (ii) processing similarly the low-order NGS WFSs controlling tilt anisoplanatism (TA) over an extended field of view (FoV) to compute via simulation a tip/tilt (TT) SF for the science target, and (iii) finally summing both SFs. Such an approach is also applicable to classical single conjugate adaptive optics (SCAO).

8447-218, Session 20

Temporal convergence of phase spatial covariance matrix measurements in tomographic adaptive optics

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The Multi Object Adaptive Optics (MOAO) is a new adaptive optics (AO) technique developed during the last ten years in order to compensate for sparsely distributed objects in wide (5-10 arcmin) fields of view (FoV). It works in open-loop and requires a tomographic wavefront reconstruction.

In order to prove the viability of the MOAO and confirm its predicted performance, an on-sky demonstrator called CANARY has succesfully been deployed at the 4.2 m William Herschel Telescope on the island of La Palma (Spain) in 2010. The tomographic wavefront reconstructor of CANARY was computed using the Learn & Apply (L&A) method, which is based on the on-sky estimation of the spatial covariance matrices of the phase gradient measured by the off-axis WFS.

The level of accuracy of these covariance coefficients depends on the acquisition time they've been averaged over: it requires enough time to get a good matrix estimation, otherwise the covariance matrix is mis-estimated mainly because of a convergence problem linked to the turbulence statistics.

In this paper, we focus on the study of this convergence problem related to the Kolmogorov spectrum, and we measure the convergence speed on some experimental data taken with CANARY. We also describe some improvements of the L&A method in order to speed up the convergence process, keeping the same accuracy but using a shorter acquisition time.

8447-83, Session 21

First on-sky calibration of an high order adaptive optics system

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The calibration of any adaptive optics system is a crucial step for the delivery of the expected correction. This applies especially to high order AO systems and when the wavefront sensor presents a non-linear response. The calibration is usually done with a dedicated setup during daytime. Here we present the results of the first on-sky calibration of an high order AO system. We measured a modal interaction matrix for the LBT FLAO system using a lock-in technique. We will describe the calibration procedure that starts generating a low-medium order synthetic interaction matrix and ends with a full system calibration in closed loop on a bright reference star. We will present the performances reached with the on-sky calibration compared with those obtained with the standard daytime one. The described technique allows calibrating the AO system without any dedicated hardware. This is particularly attractive for systems that requires complex calibration systems such as those with a convex adaptive secondary like the MMT and the planned VLT AOF. Finally, the on-sky closed loop technique presented calibrates the system in the real operational condition, taking in to account the effects of the telescope optical train and the actual wavefront sensor working regime.

8447-84, Session 21

Optimization of adaptive optics correction during observations: fast algorithms and system parameters identification in closed-loop

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Although current adaptive optics (AO) systems usually work fine after a calibration, the new generation of AO will require an online optimization of the system parameters in order to guarantee their specified performance. As a matter of fact, the AO on the E-ELT, as well as earlier pathfinders like the Adaptive Optics Facility (AOF), at the VLT in 2014, will no longer be stationary AO systems. AO is no longer isolated on a bench, but some elements are directly in the optical train of the telescope, suffering environment and constrains changes during the observations. The systems complexity will also go on increasing. In order to guarantee good performance at any observing time, an automatic optimization strategy must be developed.

Our approach for such automatic optimization is based on an identification method. We focused at the moment on one of the most challenging aspects, which is the identification of system parameters during closed-loop observations without introducing any additional disturbance. Such problem is known in the identification theory to be difficult to solve.

We present the advances we have recently obtained in our study. We discuss the accuracy of the estimation and the possibility to automatically update some control parameters (like the integrator gain for instance). We also discuss, from simulations results, the benefit of considering such algorithms from the beginning of the AO real-time computer conception and design. This appears to be a key point to reach the expected performance of the system or even to improve it.

8447-85, Session 21

Calibration strategy of the AOF

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The AOF project will transform one of the VLT UT into an adaptive telescope by replacing the secondary mirror by a deformable mirror. This configuration presents new challenges but also provides new opportunities for integration of the Adaptive Optics in the global telescope control scheme and performance improvement.

In particular the Interaction Matrix (IM) between the Deformable (DM) and Wavefront Sensor (WFS) of the system cannot be measured on an artificial source as there is no intermediate focal plane ahead of the deformable mirror. The baseline for the AOF is to use a pseudo-synthetic IM (PSIM), i.e. computer-generated but fine-tuned thanks to measured parameters of the system: Influence functions, WFS characteristics, mis-alignments.

This paper presents the simulation code that will be used to generate the PSIM for the AOF, the reconstruction strategy to get the Control Matrix (CM) in the GLAO and LTAO cases, and the ideas for updating this CM depending on the estimation of varying parameters such as DM/WFS mis-registration, LGS spot size and turbulence properties.

8447-86, Session 21

A high-performance FPGA platform for adaptive optics real-time control

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Adaptive Optics Real-Time Control Systems for next generation ground-based telescopes demand significantly higher processing power, memory bandwidth and I/O capacity on the hardware platform than those for existing control systems. We present a FPGA based high-performance computing platform that is developed at Dominion Radio Astrophysical Observatory and is very suitable for the applications of Adaptive Optics Real-Time Control Systems. With maximum of 16 computing blades, 110 TeraMAC/s processing power, 1.8 Terabyte/s memory bandwidth and 19.5 Terabit/s I/O capacity, this ATCA architecture platform has enough capacity to perform pixel processing, tomographic wave-front reconstruction and deformable mirror fitting for first and second generation AO systems on 30+-meter class telescopes. As an example, we demonstrate that with only one computing blade, the platform can handle the real time tomography needs of NFIRAOS, the Thirty Meter Telescope first light facility Multi-Conjugate Adaptive Optics system. The High-Performance FPGA platform is integrated with Board Software Development Kit to provide a complete and fully tested set of interfaces to access the hardware resources. Therefore the firmware development can be focused on unique, user-specific applications.

8447-87, Session 21

Design and implementation of the PALM-3000 real-time control system

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This paper reflects, from a software engineering perspective, on the experience gathered in designing and implementing real-time control for the PALM-3000 adaptive optics system currently in use at the Palomar Observatory. We report on our experience of developing a component-based architecture that not only enables distributed communication and control across multi-GPU machines at frame rates exceeding 2 KHz using full vector-matrix multiplication of 8192 slope measurements, but also supports recording of telemetry data at full processing rate for live viewing and offline playback. Furthermore, we describe a framework that provides flexibility and extensibility associated with plug-and-play software.

8447-88, Session 22

VLT deformable secondary mirror: integration and electromechanical tests results

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The VLT Deformable secondary is planned to be installed on the VLT UT#4 as part of the telescope conversion into the Adaptive Optics test Facility (AOF). The adaptive unit is based on the well proven contactless, voice coil motor technology that has been already successfully implemented in the MMT, LBT and Magellan adaptive secondaries, and is considered a promising technical choice for the forthcoming ELT-generation adaptive correctors, like the E-ELT M4 and the GMT ASM. The VLT adaptive unit has been recently assembled after the completion of the manufacturing and modular test phases. In this paper, we present the most relevant aspects of the system integration and report the results of the electromechanical tests performed on the unit. This test campaign is a typical major step foreseen in all similar systems built so far: thanks to the metrology embedded in the system, that allows generating time-dependent stimuli and recording in real time the position of the massively controlled mirror on all actuators, typical dynamic response quality parameters like zonal or modal rise and settling time and modal transfer functions can be acquired without employing optical measurements. In this way the system dynamic and some aspect of its thermal and long term stability are fully characterized before starting the optical tests and calibrations.

8447-89, Session 22

Manufacturing of glassy thin shell for adaptive optics: results achieved

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Glassy thin shells are key components for the development of adaptive optics and are part of future & innovative projects such as ELT. However, manufacturing thin shells is a real challenge. Even though optical requirements for the front face - or optical face - are relaxed compared to conventional passive mirrors, requirements concerning thickness uniformity are difficult to achieve. In addition, process has to be completely re-defined as thin mirror generates new manufacturing issues. In particular, scratches and digs requirement is more difficult as this could weaken the shell, handling is also an important issue due to the fragility of the mirror.

Sagem, through REOSC program, has recently manufactured different types of thin shells in the frame of European projects: E-ELT M4 prototypes and VLT Deformable Secondary Mirror (VLT DSM).

E-ELT M4 prototypes were developed and manufactured to compare the feasibility of a 2.7m-diameter monolithic mirror - the largest thin shell manufactured up to present day - and of a segmented mirror. Both solutions were delivered and promising results were obtained in terms of thickness uniformity as well as process validation as it demonstrated that it was possible to polish and handle such kind of mirror. Results obtained and further considerations on future E-ELT M4 will be presented.

VLT DSM was manufactured in Sagem REOSC facility during the past year. This convex shell presented significant challenges during its development and manufacturing. Its achievement will be a good start to develop information on the results obtained on both faces.

8447-90, Session 23

Global wavefront sensing for extremely large telescopes

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The (distorted) cylinder of turbulent atmospheric column on top of the entrance pupil of an ELT is not a dark region. A significant photon density can be estimated there by starlight coming from directions in ranges up to half a degree and that can easily lead to estimable knowledge on the actual wavefront deformation of any starlight passing in that volume. Developments in very low noise detectors coupled with efficient wavefront sensing can give basic information that can be re-arranged in order to globally reconstruct the wavefront deformation for almost any given direction with a certain degree of accuracy. Limits supposedly imposed by fundamental rules in terms of spatial sampling of the turbulence can be easily overcome at most in a number of ways. This can be done with adoption of Extremely Linear Wavefront Sensors that are doable today. The quest for a very large searchable Field of View together with the state of the art in RON noise allows to perform numerically a

number of the techniques that were envisaged for MCAO on 8m class telescopes but that then lacked the necessary degree of investment for being properly tested, remaining raw (and much larger) territory for current 40m class apertures. Tuning of spatial and temporal properties to a specific layer and exploiting the Taylor hypothesis are just some. We devise a simplified but convincing model of the noise propagation of this kind of approach and, together with a small number of assumptions, we can trace out some estimates of potential sky coverages at a given degree of wavefront compensation.

8447-91, Session 23

An interferometric wavefront sensor for high-sensitivity low-amplitude measurements

N. A. Bharmal, R. M. Myers, A. G. Basden, Durham Univ. (United Kingdom)

As adaptive optics becomes increasingly specialised, we present here a wavefront sensor design for the purpose of high-Strehl AO. The scientific cases, principally faint companion detection and characterisation, demands high-fidelity wavefront sensing and a design solution is to employ hierarchial wavefront sensing for optimal SNR when guiding with faint stars. The design of an interferometric wavefront sensor with no moving parts is presented here, inspired by holographic design principles. It offers approximately two orders of magnitude increase in sensitivity over a conventional Shack-Hartmann design for the same spatial resolution and has attractive design features such as the ability to directly reconstruct the wavefront using a Fourier algorithm and the use of wide-bandwidth light for creating the fringe pattern. Its limitations are principally in the range of wavefront aberrations that can be detected (+/-1 micron OPD) before fringe visibility declines to zero. The conceptual design of our sensor is presented, together with simulation results for a 4.2m telescope case-study, comparing the use of a conventional 32x32 SH wavefront sensor with the use of a combination of a (low-order) 8x8 SH sensor and our new WFS design. A prototype design has been fabricated, using only transmissive optics and the corresponding results from laboratory experiments are also presented.

8447-92, Session 23

A phase-shifting Zernike wavefront sensor for the Palomar P3K adaptive optics system

J. K. Wallace, F. Loya, Jet Propulsion Lab. (United States)

A phase-shifting Zernike wavefront sensor has distinct advantages over other types of wavefront sensors. Chief among them are: 1) improved sensitivity to low-order aberrations and 2) efficient use of photons for sensing (hence reduced sensitivity to photon noise). This makes the sensor well-suited to adaptive optics where photons are precious, and equally important to high-contrast, narrow-angle science where improved sensing of aberrations at small inner working angles is critical to detecting faint companions.

This talk will first briefly review the principles of a phase-shifting Zernike wavefront sensor. Next, we will discuss the engineering required to integrate this sensor with the current P3K AO system. It will cover the opto/mechanical engineering as well as the control hardware and real-time software integration. We will highlight current status of the hardware to be integrated into the P3K system in the near future.

8447-93, Session 23

Fast computer-free holographic adaptive optics

G. P. Andersen, F. Ghebremichael, U.S. Air Force Academy (United States)

We have constructed an adaptive optics system incorporating a holographic modal wavefront sensor with the autonomous closed-loop control of a MEMS deformable mirror (DM). HALOS incorporates a multiplexed holographic recording of the response functions of each actuator in a deformable mirror. On reconstruction with an arbitrary input beam, pairs of focal spots are produced. By measuring the relative intensities of these spots a full measurement of the absolute phase can be constructed. Using fast photodiodes, direct feedback correction can be applied to the actuators.

In this talk we will present the results from an all-optical, ultra-compact system that runs in closed-loop without the need for a computer. It incorporates a MEMS-based deformable mirror with 32 actuators but the 100 kHz speed is limited only by a single actuator response time and not the number of actuators. Furthermore, the system is largely insensitive to obscuration. We will present information on how HALOS can be used for image correction and beam propagation as well as several other novel applications.

Conference 8448: Observatory Operations: Strategies, Processes, and Systems IV

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8448-01, Session 1

ALMA: the first year of science operations

A. Lundgren, L. Nyman, European Southern Observatory (Chile)

The Atacama Large Millimeter/Submillimeter Array (ALMA) is a major new interferometer in the northern Atacama desert. When completed in 2013, ALMA will consist of an array of fifty 12 m antennas, with baselines up to 16 km, and the Atacama Compact Array (ACA) - an additional compact array of twelve 7 m, plus 4 independent 12 m antennas that greatly enhance ALMA's ability to image extended targets. It is designed to work at millimeter and sub-millimeter wavelengths, and will cover atmospheric windows from 20-870 GHz (15 mm - 350 micron).

ALMA is a partnership between North America, Europe, and East Asia in cooperation with the Republic of Chile. ALMA construction and operations are led on behalf of Europe by the European Organization for Astronomical Research in the Southern Hemisphere (ESO), on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI), and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO), located in Santiago, Chile, provides the unified leadership and management of the construction, commissioning and operation of ALMA.

We are currently in the first year of science observations using a partial array. This phase is called ALMA Early Science Cycle 0, and the capabilities are defined to be: an array of at least sixteen 12 m antennas, receiver bands 3, 6, 7 & 9 (wavelengths of about 3, 1.3, 0.8 and 0.45 mm), baselines from 18 m to 125 m (compact configuration) and from 36 m to 400 m (extended configuration), single field imaging and mosaics of up to 50 pointings, and a set of correlator modes that will allow both continuum and spectral line observations.

I will present the telescope and its instrumentation and I will talk about the challenges we face operating telescope of this scale at Chajnantor, a plateau 5000 meter above sea level in one of the driest places of earth. I will also present statistics from the proposals and the observations and finally I will show some science highlights from the first year of ALMA science operations observations.

8448-02, Session 1

The building blocks for JWST I&T to operations: from simulator to flight units

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The James Webb Space Telescope (JWST) has a long Integration and Test (I&T) phase due to long procurement times of various components and recent launch delays. The JWST Ground Segment and Operations group has developed a roadmap of the various ground and flight elements and their use in the various JWST I&T test programs. The JWST building block approach to the eventual operational systems, while not new, is complex and challenging. The complexity is that a large-scale mission like JWST involves international partners (CSA/ESA), many vendors across the United States, and competing needs for the same systems. One of the challenges is resource balancing so simulators and flight products for various elements congeal into integrated systems used for I&T and flight operations activities. Another challenge is maintenance of older simulators to stay current with the delivered flight systems so certification of products and training provides the most value possible.

This building block approach of the incremental buildup provides a means for identifying problems early with simulators as well as exercises the flight operations systems, products, and interfaces during the JWST I&T test programs. Currently, JWST has completed some of the early I&T with the simulators, engineering models, and some of the operational ground system. JWST has now started testing with the various flight units as they are delivered and will continue the building blocks for the entire flight and operational system. JWST has already and will continue reaping the value of the building block approach on the road to launch and flight operations.

8448-03, Session 1

Spaceborne survey instrument operations from Planck/LFI to Euclid NISP: lessons learned and new concepts

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Planck and Euclid are two ESA space missions, mainly devoted to Cosmology. Both are survey missions and require a careful control of instrumental systematic effects.

The Low Frequency Instrument (LFI), on-board the ESA Planck mission, has already been successfully operated for more than two years. A complex radiometric array and a sophisticated active cryo chain have required the development of a fully integrated approach to operations between the ground and space segments, which started and evolved during the on-ground test activity and has been verified during the on-going flight operations. The Near-Infrared Spectro-Photometer is one of the two instruments on-board the ESA-selected M-class Euclid mission, to be launched in 2019. The instrument includes cryo mechanisms, active thermal control, high-performance Data Processing Unit and requires periodic in-flight calibrations and instrument parameters monitoring.

We present the lessons learned by authors from the Planck/LFI operations and their evolution to the Euclid NISP operation concept, which they are developing. In particular, we discuss the strong integration of test and calibration activities with the Ground Segment, starting from early pre-launch verification activities. This paper mainly reports the technical status at the end of the Definition phase and it is presented on behalf of the Euclid Consortium.

8448-04, Session 1

Updating Chandra high-radiation safing in response to changing observatory conditions

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The science instruments on-board the Chandra X-ray Observatory may be damaged by high fluxes of energetic particles produced in Solar storms. For twelve years the on-board commanding used to safe the science instruments when a high-radiation environment was identified included stopping all on-board scheduled activity. Over this time the conditions of the observatory have changed: the orbit has evolved to lower perigee and the thermal protective surfaces have degraded. The likelihood of an unplanned unload of spacecraft angular momentum, a spacecraft component exceeding thermal limits, or an eclipse passage without planned commanding occurring following a Solar storm during the upcoming Solar-maximum due to the lack of scheduled commanding led us to update the Chandra response to a high-radiation environment; commands are sent to safe the science instruments but vehicle related commanding (maneuvers, angular-momentum unloads, eclipse commands) are allowed to continue. While this was a conceptually simple change, it touched all elements of the program, including flight software, the planning and commanding systems, flight-load verification tools, and ground-based data processing. A key to successful and timely implementation was the establishment of a working group with representation from all elements of the program.

8448-05, Session 1

Improving operations prioritization by detecting emerging patterns in trouble tickets

N. M. Radziwill, James Madison Univ. (United States)

Most observatories maintain one or more databases of problem reports from users, such as JIRA and Bugzilla, and work through the issues captured by those databases to continuously improve observing systems and data analysis software. Although commercial bug tracking systems sometimes include analytics capabilities to mine the problem reports to identify patterns, these functions are rarely available in free or open-source bug tracking systems. The free statistical software R provides many functions that handle text mining and classification, including sublanguage analysis. This study examines observatory trouble ticket databases to illustrate how open source natural language processing algorithms can be used to detect patterns and emerging trends, strengthening the ability to set operational priorities for maintenance and repair.

8448-06, Session 1

The slitmask alignment tool: robust, efficient, and astronomer-friendly software for aligning multi-object slitmasks

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Multi-object spectroscopy is a key capability at Keck, but the on-sky slitmask alignment process can be complex, inefficient, and prone to error, often costing observers significant on-sky time. Inexperienced observing teams may not come prepared with adequate finder charts and often struggle to master the procedure. Even experienced observers are susceptible to catastrophic errors in field identification that can waste precious sky time.

In this contribution we describe the design and operation of the WMKO Slitmask Alignment Tool (SAT), a new IDL-based GUI which simplifies and unifies the slitmask alignment process across all three Keck instruments supporting multi-slit spectroscopy. The SAT uses Digital Sky Survey images to achieve rapid initial mask alignment without requiring detailed finder charts, prevents field misidentification by verifying that the telescope pointing and instrument position angle match the designed values, employs detector binning and windowing to save readout time, applies an optical model to predict the image coordinates of alignment boxes, automates alignment box identification via an algorithm that accounts for flexure-induced image displacement, and accommodates both rectangular and trapezoidal alignment box shapes. The SAT allows even novice observers to achieve robust, efficient, and accurate alignment of slitmasks, thereby saving substantial observing time.

8448-07, Session 2

Operational concept of the VLT's adaptive optics facility and its instruments

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The Adaptive Optics Facility (AOF) will transform UT4 of the VLT into a laser driven adaptive telescope in which the corrective optics, specifically the deformable secondary mirror, and the four Laser Guide Star units are integrated. Three instruments, with their own AO modules to provide field selection capabilities and wavefront sensing, will make use of this novel system to provide a variety of observing modes that span from large field IR imaging with GLAO, to integral field spectroscopy with both GLAO and LTAO, to SCAO high Strehl imaging and spectroscopy. Each of these observing modes carries its specific demands on observing conditions. Optimal use of telescope night-time, with such a high in demand and versatile instruments suite, is mandatory to maintain and even improve upon the scientific output of the facility. This implies that the standard VLT model for operations must be updated to cover these partly new demands. In particular, we will discuss three key aspects: (1) the need for an upgrade of the site monitoring facilities to provide the operators with real-time information on the environmental conditions, including the ground layer strength, and their evolution throughout the night; (2) a set of tools and procedures to effectively use these data to optimize the short-term scheduling (i.e. with granularity of one night) of the telescope and (3) the upgrade of the current laser beam avoidance software to better cope with the AOF operational scheme, where the four laser units are continuously operated as long as the atmospheric conditions allow.

8448-08, Session 2

Improving the observing efficiency of SINFONI and KMOS at the VLT by factors of 2-4: sophisticated sky subtraction algorithms

N. A. Thatte, Univ. of Oxford (United Kingdom); N. Scott, Swinburne Univ. of Technology (Australia); R. Houghton, Univ. of Oxford (United Kingdom); D. Nuernberger, European Southern Observatory (Chile); R. N. Abuter, European Southern Observatory (Germany); M. Tecza, Univ. of Oxford (United Kingdom)

We describe a technique to improve the observing efficiency of SINFONI, KMOS and other near-infrared integral field spectrographs by almost eliminating the need for blank sky exposures. We achieve this improvement by employing a sophisticated sky subtraction algorithm that correctly subtracts the flux in the night sky emission lines for all elements of the data cube.

Sky subtraction in near infrared Integral field spectrographs is limited by the fact that measurement of the night sky emission from one part of the field cannot be used to correctly subtract it from other parts of the field. We have determined that this stems from variations in the spectrograph

line spread function. Using data that allows us to hypersample the line spread function for all spaxels at the wavelengths of all sky emission lines, we create a database that allows for extremely accurate sky background subtraction.

We present the algorithm, and its implementation for SINFONI H band science data from the VLT archive. Further improvement (beyond eliminating the need for sky exposures) comes from using multiple measurements to form a very low noise estimate of the sky background flux (spectrally resolved), thus almost removing the excess noise associated with subtracting the night sky background. Possible implementation for the VLT KMOS spectrograph will also be discussed.

8448-09, Session 2

Optimisation of solar synoptic observations

M. Klvana, M. Sobotka, M. Svanda, Astronomical Institute of the ASCR, v.v.i. (Czech Republic)

The development of instrumental and computer technologies is connected with steadily increasing needs for archiving of large data volumes. The current trend to meet this requirement includes the data compression and growth of storage capacities. This approach, however, has technical and practical limits. A further reduction of the archived data volume can be achieved by means of an optimisation of the archiving that consists in data selection without losing the useful information. We describe a method of optimised archiving of solar images, based on the selection of images that contain a new information. The new information content is evaluated by means of the analysis of changes detected in the images. We present characteristics of different kinds of image changes and divide them into false changes with a disturbing effect and real changes that provide a new information. In block diagrams describing the selection and archiving, we demonstrate the influence of clouds, the recording of images during an active event on the Sun, including the period before the event onset, and the archiving of long-term history of solar activity. The described optimisation technique is not suitable for helioseismology, because it does not conserve the uniform time step in the archived sequence, and removes the information about solar oscillations. In case of long-term synoptic observations, the optimised archiving can save a large amount of storage capacities. The actual capacity saving will depend on the setting of the change-detection sensitivity and on the capability to exclude the false changes.

8448-10, Session 3

User-support models at the Isaac Newton group of telescopes

C. R. Benn, Isaac Newton Group of Telescopes (Spain)

The Isaac Newton Group of Telescopes (ING) runs the 4.2-m William Herschel Telescope (WHT) and the 2.5-m Isaac Newton Telescope (INT) on La Palma. The user-support model varies with instrument and with telescope, and has evolved dramatically over the last few years in response to financial constraints, while continuing to provide a high level of support for visiting observers at both telescopes.

We summarise our experience with different models for night-time support (e.g. by staff astronomers vs students) for different types of observing (e.g. adaptive optics vs other instruments) and for different kinds of user, and discuss the metrics used to monitor how well a given model is working (e.g. observer feedback, downtime statistics).

8448-11, Session 3

User support to Guoshoujing Telescope (LAMOST)

X. Chen, A. Luo, Y. Zhao, National Astronomical Observatories (China)

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST, i. e. Guoshoujing Telescope) has started its pilot survey since October 2011. To support user activities and promote effective use of LAMOST data (network services), 'User Supporting' enables users to easily obtain current information, which will be integrated with as many information resources and communication media as possible. In detail we take care of the solution of users' problems related to LAMOST data, the consulting and administration of users in all questions related to LAMOST data, and users' immediate response. According to users' feedback, new requirement for LAMOST data reduction pipeline will be suggested, and a series of examples are given in this presentation.

8448-12, Session 4

The role in the virtual astronomical observatory in the era of massive data sets

G. B. Berriman, California Institute of Technology (United States)

The Virtual Observatory (VO) is realizing global electronic integration of astronomy data, tools, and services for use by individuals around the world. One of the long-term goals of the U.S. VO project, the Virtual Astronomical Observatory (VAO), is development of services and protocols that respond to the growing size and complexity of astronomy data sets. VAO staff are active in such development efforts, especially in innovative strategies and techniques that recognize the limited operating budgets likely available to astronomers even as demand increases. The project has a program of professional outreach whereby new services and protocols are evaluated.

The approaches under study by the VAO include:

- Innovations in data discovery. The VAO is exploring an innovative indexing scheme for data stored in databases (source catalogs, metadata catalogs), in which the indices are stored in memory. The technique offers speed-ups in data discovery times of up to x1000 over current schemes.

- Innovations in scalable data analysis. The VAO is developing methods for cross matching multi-billion record source catalogs.

- Emerging technologies. VAO staff are engaged understanding how astronomy can apply powerful new technologies, such as investigations into the cost and performance of cloud computing techniques.

- Compute infrastructure: Exploiting developments cyber-infrastructure to support new projects; e.g dissemination of transient events by the LSST.

- Advising new projects on data management and data curation practices, and on developing high-performance, portable applications.

Presented on behalf of the VAO team.

8448-13, Session 4

Running a distributed virtual observatory: U.S. Virtual Astronomical Observatory operations

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Operation of the US Virtual Astronomical Observatory shares some issues with modern physical observatories, e.g., intimidating data volumes and rapid technological change, and must also address unique concerns like the lack of direct control of the underlying and scattered data resources, and the distributed nature of the observatory itself. In this paper we discuss how the VAO has addressed these needs to provide the astronomical community with a coherent set of science-enabling tools and services.

The distributed nature of the virtual observatory - with data and personnel spanning geographic, institutional and regime boundaries - is simultaneously a major operational headache and the science motivation for the VAO. Most astronomy today uses data from many resources. Facilitating the cross-comparison of heterogeneous datasets is the raison

d'etre of the virtual observatory.

Key aspects of our approach include continuous monitoring and validation of VAO and VO services and the datasets provided by the community, monitoring of user requests to optimize access, caches for large datasets, and distributed storage services that allow the user to collect results near large data repositories.

The distributed nature of the VAO requires careful attention to what can be straightforward operations at a conventional observatory, e.g., collection and combined analysis of usage logs. All of our strategies use and extend protocols developed by the international virtual observatory community. Our long-term challenge is working with the underlying data providers to ensure high quality implementation of data access protocols - virtual 'telescopes', assisting astronomical developers to build robust integrating tools - virtual 'instruments', and coordinating with the research community to maximize the science enabled.

8448-14, Session 4

The TAOS II Observatory operations and data management system: another multi-petabyte project

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The Transneptunian Automated Occultation Survey (TAOS II) aims to detect occultations of stars by small objects (~1 km diameter) in the outer Solar System (Lehner et al, this conference). These occultations are short (~200 ms) and extremely rare, requiring a high readout rate and a wide field of view to include enough bright stars. TAOS II will use 3, 1.3-m telescopes with ~90 million pixel CMOS cameras read at 20 HZ (Geary et al, this conference). ~10,000 stars will be monitored in each field via sub-aperture readout. Each telescope will monitor the same field to minimize false positive detections. The observatory operations system will determine the appropriate field, direct the telescopes to that field, acquire a pointing image (~ 1 s), optimize the pointing, determine the necessary sub-apertures and start a multi-hour series of 20 Hz exposures. Real-time analysis of a few sub-apertures per camera will provide guiding information. A key feature of the system will be synchronizing the data streams from the three cameras. The data management system will coordinate photometry of the bright stars in the sub-apertures, and manage writing the images, photometry and house keeping information to a database. TAOS II will generate ~13x10^9 photometric measurements per night and ~500x10^9 pixels of sub-aperture images. The photometry database produced will be comparable in size to that produced by the Large Synoptic Survey Telescope.

8448-15, Session 4

The GTC and Calar Alto Virtual Observatory archives

E. Solano, Ctr. de Astrobiología (Spain) and Spanish Virtual Observatory (Spain); R. Gutierrez, J. M. Alacid, F. Jimenez, Ctr. de Astrobiología (Spain)

In the last years, there is an increasing awareness by scientists and funding agencies of the need to maximize scientific return on the costly investments required by astronomical projects. In this context, archives play a fundamental role ensuring this return: The long-standing IUE (with every single spectrum retrieved more than five times from the archive), and HST (with more papers published with archived data than with newly acquired data) projects are paradigmatic examples of efficiency in scientific data exploitation. This, together with the fact that archival information is dramatically growing in size, has made of archives a fundamental research infrastructure for modern astrophysics.

The Virtual Observatory (VO) is the international initiative that guarantees an ease and efficient access and analysis of the information hosted in astronomical archives and services. VO is opening new lines in the astronomical research as demonstrated by the growing number of VO-refereed papers. Spain takes part in this endeavor since 2004 through the Spanish Virtual Observatory (SVO) whose core team is located at the Centro de Astrobiologia (Madrid).

The Gran Telescopio Canarias (GTC) and the Calar Alto Observatory are two top-level astronomical infrastructures. GTC is the largest optical-infrared telescope in the world whereas Calar Alto is the most important observatory in continental Europe. Having an archive perfectly integrated in the VO framework constitutes an added value of enormous importance for these projects.

The SVO group at CAB is the responsible for the development and maintenance of the GTC and Calar Alto VO archives. In this presentation we describe their main characteristics and functionalities.

8448-16, Session 4

Current status and future directions of the ESO science archive facility: content and services

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ESO's Science Archive Facility serves the double purpose of long-term preservation of the data from ESO's telescopes and its distribution to the user's community, PIs and archive researchers alike.

In terms of content, the ESO Science Archive Facility hosts all raw observations performed at the La Silla Paranal Observatory, including the NTT, MPG-ESO 2.2m, ESO 3.6m, VLT/VLTI and APEX telescopes, together with selected data products, which are both generated in house and contributed by the community. In particular, contributions from the community have recently gained more prominence with the implementation and consolidation of ESO's policy on Public Surveys and Large Programmes, whereby PIs and their teams return a variety of high-level data products to the archive for the community at large to access and exploit. This is the so-called "Phase 3", which closes the loop of end-to-end data flow system after the submission of observing proposals (Phase 1) and of the detailed observation strategy (Phase 2).

In this talk, we present the current status and future directions of the ESO Science Archive Facility in terms of content and services built upon it.

8448-17, Session 4

The JWST data management system engineering database

M. A. Nieto-Santisteban, Space Telescope Science Institute (United States)

The James Webb Space Telescope Data Management System will be collecting calibrated engineering values for about 15,000 parameters, 300 million samples per day, with a potential daily database growth of 14 GB, 5 TB per year, 50 TB for a 10-year mission.

While data is mostly received in time and parameter order, fast access requires translation into parameter and time organization. How we organize and index the data will affect the final space requirements as well as ingest and access efficiency. Fast access is critical to pipelines processing and calibrating science data.

This paper describes the design under consideration and presents preliminary performance results from an early prototype.

8448-18, Session 5

Meaningful metrics for observatory publication statistics

A. H. Rots, S. L. Winkelman, G. E. Becker, Smithsonian Astrophysical Observatory (United States)

Observatories have wrestled for decades with the questions how to measure their importance to the astronomical community, what their scientific impact is, and how their performance in that respect compares to that of other observatories. There is a general sense that the answer is to be found in the publication record - specifically, in the refereed journal articles. However, simple parameters (such as the number of papers) are not helpful, because in isolation (applied to a single observatory) they are meaningless, while in comparison between observatories they are subject to external influences that all but invalidate the comparisons.

We were fortunate in having the Chandra X-ray Observatory's bibliographic database with its rich variety of metadata available as a resource for experimenting with more sophisticated metrics. Out of this project we propose a modest set that contains meaningful information when viewed in the isolation of a single observatory as well as in comparison with other observatories. Even so, we urge users not to draw conclusions on the basis of the face value of the comparisons, but only after a serious analysis of potential causes for any differences or similarities.

We have designed our metrics to provide useful information in three main areas of interest: speed of publication; fraction of observing time published; and archival usage. The basic measured parameters are the percentage of available observing time published as a function of the data's age, at a few specific age values; the median time it takes to publish observations; and similar parameters for multiple publications of the same observations.

Citation of results is a fourth category, but it does not lend itself well to comparisons and defies the search for definite statements.

8448-19, Session 5

Telescope bibliographies: an essential component of archival data management and operations

A. Accomazzi, Harvard-Smithsonian Ctr. for Astrophysics (United States); E. Henneken, Smithsonian Astrophysical Observatory (United States); C. Erdmann, Harvard-Smithsonian Ctr. for Astrophysics (United States); A. Rots, Smithsonian Astrophysical Observatory (United States)

Assessing the impact of astronomical facilities rests upon an evaluation of the scientific discoveries which their data have enabled. A well-established, objective method to assess this impact is the quantitative analysis of the scientific output published in the literature based on the use of such data. A requirement of such analysis is the creation of telescope bibliographies which annotate and link data products with the literature, thus providing a way to use bibliometrics as an impact measure for the underlying data.

The creation of such links represents more than just a useful way to generate metrics. From the prospective of a research scientist, the data-literature connections provide a critical path to data discovery and access. Thus, by leveraging the efforts of librarians and archivists, one can make use of telescope bibliographies to support the scientific research process.

The NASA Astrophysics Data System (ADS) provides services which support both activities described above: librarians use ADS's search capabilities to discover and tag data products appearing in the literature, and ADS harvests the data-paper links that have been generated by librarians to provide discovery of data products via literature searches. In this paper we argue that the creation and maintenance of telescope bibliographies should be considered an integral part of an observatory's operations. We review the existing tools, services, and workflows which support these curation activities, giving an estimate of the effort and expertise required to create and maintain an archive-based telescope bibliography.

8448-20, Session 5

DOME: operational metrics under one roof

F. Primas, S. Marteau, L. Tacconi-Garman, V. Mainieri, M. Rejkuba, European Southern Observatory (Germany)

Thirteen VLT/I instruments plus some extra critical components like the block-scheduling of Laser Guide Star Facility and VLTI baselines make for a rather complex machine that constantly challenges our operational efficiencies.

DOME (Dashboard for Operational Metrics at Eso) is an ongoing project developed, implemented and maintained by the ESO User Support Department that aims at providing an ESO-internal dashboard where key operational metrics are published and updated at regular intervals.

The rationale behind this effort is at least twofold: i) to improve our understanding of operational efficiencies with a regular monitoring effort; ii) to respond in a professional and reliable way to the increasing demand of providing a variety of operational statistics.

The first release of DOME has taken place in December 2011. It is about the first phase of an observing cycle (Phase 1) and has thus focused on "Proposals and Scheduling." At the meeting, we will report on Phase 2 and post-Phase 2 operational efficiencies that will be tackled during 2012.

8448-21, Session 5

CFHT Legacy Survey: calibration and curation of the final official release T0007

J. J. Cuillandre, Canada-France-Hawaii Telescope (United States)

The 2,200 hour multi-band (u,g,r,i,z) CFHTLS observing program using the MegaCam 1 square degree optical imager started in 2003 and was completed six years later. It took three more years to thoroughly analyze the entire survey and added ancillary calibration data to reach a collection photometrically flat within 1% in all bands across the entire survey area (~160 sq.deg.). Adding to this an internal astrometric accuracy of 0.02 arcsec. (0.2 arcsec. external), the CFHTLS can now be considered a reference in deep photometry (stars & field galaxies) for future works. The Supernovae Legacy Survey (SNLS) imaging program within the CFHTLS set the tightest constraints on the photometric calibration of the MegaCam imager: after the SNLS 3 year analysis demonstrated that uncertainties affecting the photometric calibration of the survey still dominated the error budget in the measurement of the dark energy equation of state, a special calibration program was developed, eventually leading to a 5 milli-magnitude level external inter-calibration with the SDSS surveys. The calibration was bootstrapped to the Wide component of the CFHTLS to achieve the final result. These steps forward on the photometry led to the final official release of the CFHTLS "T0007" (spring 2012) produced by the Terapix data center in France and archived at the CADC in Canada. The CDS ingested in its extensive VO interfaces the catalogs and images, offering the world community access to the extensively curated data set in a familiar environment.

8448-22, Session 5

Applying decades of HST experience to JWST data processing

F. Pierfederici, M. Swam, G. Greene, Space Telescope Science Institute (United States)

The Space Telescope Science Institute (STScI) has been operating the Hubble Space Telescope (HST) for the last twenty years. The valuable experience gained by running the HST data management system as well as providing data and science software to the community proved extremely valuable in designing the James Webb Space Telescope science data processing (SDP) architecture.

The HST experience has been distilled in two main "products": on one hand a rich set of requirements for the full JWST SDP system, on the other a large dataset (using both current and historical instruments) that will be of vital importance in exercising and validating the architecture for the new mission.

During the past year the JWST project has made significant progress in areas of architecture design, selection of relevant technologies and development of a functional prototype pipeline orchestration and workflow management system (the Condor-based OWL).

Recently, the HST mission office has started a three year project to replace the aging HST SDP system with the one being developed for JWST. This is proving to be a tremendous opportunity to not only give HST operations a technology refresh; but also validate the architecture being developed for JWST.

The present paper describes the lessons learned from HST operations, how we are applying them to JWST design and development as well as our ongoing progress on the joint HST-JWST development and operations.

8448-23, Session 6

Timekeeping for observatory operations

R. L. Seaman, National Optical Astronomy Observatory (United States); A. H. Rots, Smithsonian Astrophysical Observatory (United States)

A proposal remains in front of the International Telecommunication Union (ITU) whether to redefine Coordinated Universal Time (UTC). If this happens many space and ground-based observatory systems, familiar observing practices, and much astronomical software will require mitigation, almost certainly dwarfing the impact and expense of remediation of the millennium bug (Y2K) for astronomy. Whatever the outcome the infrastructure of astronomical timekeeping is evolving just as the time domain is growing in importance to address the science priorities of the astronomical community. We will discuss the current status of UTC and possible future directions for observatory and community timekeeping.

8448-24, Session 6

Connecting the time domain community with the virtual astronomical observatory

M. J. Graham, A. A. Mahabal, A. J. Drake, S. G. Djorgovski, California Institute of Technology (United States) and VAO (United States); R. L. Plante, Univ. of Illinois at Urbana-Champaign (United States) and VAO (United States); J. Kantor, LSST Corp. (United States)

The time domain has been identified as one of the most important areas of astronomical research for the next decade. The Virtual Observatory is in the vanguard with dedicated tools and services that enable and facilitate the discovery, dissemination and analysis of time domain data. These range in scope from rapid notifications of time-critical astronomical transients to annotating long-term variables with the latest modeling results. In this talk, we will review the prior art in these areas and focus on the capabilities that the Virtual Astronomical Observatory (VAO) is bringing to bear in support of time domain science.

We are developing standards and services that will enable access to time domain data in distributed archives, and will allow scientists to feed into available tools, including provision for bulk activities. Potential science applications of these include discovery of gamma-ray bursts, discoveries of extrasolar planets, and astroseismology. In particular, we will focus on scalability and quality-of-service issues required by the next generation of sky surveys, such as LSST and SKA, and the issues involved in managing the heterogeneous collections of ancillary data associated with astronomical transients.

8448-25, Session 6

Rapid alerts for following up gravitational wave event candidates

P. S. Shawhan, Univ. of Maryland, College Park (United States)

Gravitational waves carry unique information about high-energy astrophysical events such as mergers of neutron stars and black holes, core collapse in massive stars, and other sources. Large gravitational wave (GW) detectors utilizing exquisitely sensitive laser interferometry--namely, LIGO in the United States and GEO and Virgo in Europe--have been successfully operated in recent years and are currently being upgraded to greatly improve their sensitivities. Many signals are expected to be detected in the coming decade. Simultaneous observing with the network of GW detectors enables us to identify and localize event candidates on the sky with modest precision, opening up the possibility of capturing optical transients or other electromagnetic counterparts to confirm an event and obtain complementary information about it. We developed and implemented the first complete low-latency GW data analysis and alert system in 2009-10 and used it to send alerts to several EM observing partners; the system design and lessons learned will be described. We will then discuss prospects for improving this capability for future observations. (Presented on behalf of the LIGO Scientific Collaboration and the Virgo Collaboration.)

8448-26, Session 6

Responding to the event deluge

R. D. Williams, California Institute of Technology (United States); S. Barthelmy, NASA Goddard Space Flight Ctr. (United States); R. B. Denny, DC-3 Dreams, SP (United States); M. J. Graham, California Institute of Technology (United States); J. Swinbank, Univ. van Amsterdam (Netherlands)

We present existing and planned infrastructure for large-scale rapid follow-up of astronomical events, including selection, annotation, machine intelligence, and coordination of observations. The VOEvent standard is central to this vision, as well as the GCN and Skyalert software, but these will be distributed and replicated rather than centralized facilities. Event authors and follow-up observers can already send and receive event notices via multiple protocols: the original GCN socket, VO-GCN broker, Dakota broker, Jabber/XMPP, email, RSS/Atom feed, etc. This technology will become more important in the coming years, with new event streams from Gaia, LOFAR, LIGO, LSST, and many others.

8448-27, Session 6

High-level simulation of JWST event-driven operations

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(United States)

The James Webb Space Telescope (JWST) has an event-driven architecture: an onboard Observation Plan Executive (OPE) executes an Observation Plan (OP) consisting of a sequence of observing units (visits). During normal operations, ground intervention to update the OP is expected to be necessary about once a week. This architecture is designed to tolerate uncertainty in visit duration, and occasional visit failures due to inability to acquire guide stars, without creating gaps in the observing timeline. The operations concept is complicated by the need for occasional scheduling of time-critical science and engineering visits that cannot tolerate much schedule slippage without inducing gaps, and also by onboard momentum management. A prototype Python tool called the JWST Observation Plan Execution Simulator (JOPES) has recently been developed to simulate high-level OP execution and to analyze OP execution results for both nominal and contingency scenarios. Incorporating both deterministic and stochastic behavior, JOPES has potential to be a powerful tool for several purposes: requirements analysis, system verification, systems engineering studies, and operations training. It has already been successfully applied to a scheduling study of overhead estimation bias: whether to use conservative or average-case estimates for timing components that are inherently uncertain, such as those involving guide-star acquisitions. In the next year we plan to enhance JOPES to support interfaces to the operational Proposal Planning Subsystem (PPS) now being developed, with the objective of “closing the loop” between testing and simulation by feeding simulated event logs back into the PPS.

8448-28, Session 7

Remote observing with NASA’s Deep Space Network

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The Deep Space Network (DSN) communicates with spacecraft as far away as the edge of the Solar System boundary with the interstellar medium. To make this possible, large sensitive antennas at Canberra, Australia, Goldstone, California, and Madrid, Spain, allow for constant communication with interplanetary missions. We describe the procedures used for radioastronomical observations using this network. Remote access to science monitor and control computers by authorized observers is provided by two-factor authentication through a gateway at the Jet Propulsion Laboratory (JPL) in Pasadena. To make such observations practical, we have devised schemes based on SSH tunnels and distributed computing. At the very minimum, one can use SSH tunnels and VNC (Virtual Network Computing, a remote desktop software suite) to control the science hosts within the DSN Flight Operations network. In this way we have controlled up to three telescopes simultaneously. However, X-window updates can be slow and there are issues involving incompatible screen sizes and multi-screen displays. Consequently, we are now developing SSH tunnel-based schemes in which instrument control and monitoring, and intense data processing, are done on-site by the remote DSN hosts while data manipulation and graphical display are done at the observer’s host. We describe our approaches to various challenges, our experience with what worked well and lessons learned, and directions for future development. JPL is operated by the California Institute of Technology for the National Aeronautics and Space Administration.

8448-29, Session 7

Pi of the Sky: system of autonomous robotic telescopes for monitoring the sky

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``Pi of the Sky” is a system of robotic telescopes designed for observations of astrophysical phenomena varying on scales from seconds to months, especially for prompt optical GRB emission. The full system will consist of 2 sites separated by a distance of the order 250 km, each site consisting of 12 survey CCD cameras. Pairs of cameras from two sites will work in coincidence and observe the same field of view to allow rejection of false signals coming from near-earth objects. The whole system will be capable of continuous observation of about 1.5 steradian of the sky, which roughly corresponds to the field monitored by the Swift satellite,

As since March 2011 we have operated from 2 locations, in San Pedro de Atacama in Chile and in the INTA El Arenosillo Test Centre in Spain, two separate sites have allowed to develop and test new algorithms and strategies of observations. First, algorithms for analysis of parallax for determination of a distance of observed transient have been successfully tested in real time. Second, simultaneous observations of geostationary satellites have been used to test algorithms for orbit determination. Synchronization of observations between two sites requires a flexible control system which allows for dynamical modification target list. For example, if the bad weather forces the dome to be closed in one site, so that synchronous observations of the same FOV is not longer possible, the second site is notified and its control software chooses another target.

8448-30, Session 8

Review of data processing operations for LAMOST pilot survey

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LAMOST Pilot survey started Oct 21, 2011. A data processing system, or called pipeline, had been developed to due with the multi-fiber spectra. In this presentation, we first give a brief introduction to the history and requirements of the pipeline, and show current performance of the system. During the pilot survey, all instruments of LAMOST are fixed, and the pilot dataset is used to debug and update the pipeline. With the survey goes, more and more operation experience has been accumulated. To prepare a more effective data processing system for the formal survey of LAMOST, a lot of new requirements should be satisfied. From the experience of data processing operation, time of achieving the goals and plans of remain software tasks is estimated, and the staffing needed for long-term code maintenance and operations is also discussed.

8448-31, Session 8

The use of a genetic algorithm for ground-based telescope observation scheduling

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A prototype genetic algorithm (GA) is being developed to provide assisted and ultimately automated telescope observation scheduling functionality. Harnessing the logic developed for manual queue preparation, the GA can build suitable sets of queues for the potential combinations of environmental and atmospheric conditions. Evolving one step further, the GA can select the most suitable observation for any moment in time, based on allocated priorities, agency balances, and real-time availability of the sky conditions.

8448-32, Session 8

The 4MOST facility simulator--new fiber-to-target assignments, VISTA/NTT, and positioner trade-offs: results from 5 years observation of scheduling simulation for Gaia and eROSITA sources

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We describe the functionality of the 4MOST Facility Simulator, the details and goals/milestones towards completion as obtained in March 2012. A new dynamic fiber re-allocation module has been developed by MPE to obtain the highest efficiency to assign objects from Gaia, eROSITA and other mock catalogues. We summarize the 4MOST Facility Simulator subsystems and the lessons learnt from the interface between other 4MOST subsystems. The Facility Simulator will be used as a basis for trade-off decisions between telescopes and positioner concepts based on a five year fully realistic simulations of operations, observing conditions, sky access etc. at both La Silla and Paranal sites.

8448-33, Session 8

eROSITA in-orbit calibration strategy and plan

M. J. Freyberg, K. Dennerl, Max-Planck-Institut für extraterrestrische Physik (Germany)

eROSITA is an X-ray astronomical observatory on-board Spectrum-Roentgen-Gamma (SRG) with an expected launch in late 2013.

It consists of 7 identical mirror modules with 7 identical CCD cameras as focal plane instrumentation. It will observe the X-ray sky in the 0.3-10 keV range.

Another instrument aboard SRG, ART-XC, will extend the spectral range to higher energies.

In this paper we describe how the on-ground calibration is planned, with respect to maximum scientific exploitation, in combination with an in-orbit calibration.

This will be performed within one module and between the 7 eROSITA modules, and also cross-calibration with ART-XC will take place.

If XMM-Newton will still be operational, a dedicated cross-calibration campaign is envisaged.

Emphasis will be on the selection of the celestial targets and on the procedure of the measurements with the internal Fe-55 calibration source.

8448-47, Poster Session

Pointing effects and their consequences for Spitzer IRAC exoplanet observations

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The Spitzer Space Telescope has made many spectacular contributions to the characterization of exoplanets, and exoplanet science has become an ever increasing component of its overall science program. Spaceborne and stable, the Infrared Array Camera is both a unique resource and a workhorse for characterizing the ever-increasing number of known exoplanets. While the Spitzer's pointing system was not designed to support milli-magnitude precision photometry, its performance has consistently exceeded its design requirements. Combined with flight software enhancements and optimal observing practices, observations of exoplanets now routinely yield accuracies of better than one part in 10,000. However, there remain a number of issues that limit the attainable precision, particularly for long duration observations. These include pointing jitter, periodic and non-periodic thermal effects due to solar insolation and onboard systems, and long term pointing drifts which when coupled with small scale, intrapixel sensitivity variations produce correlated photometric noise. We examine each of these issues in turn, discussing their causes and their respective contributions to the error budget. We describe possible and planned mitigation techniques and their consequences for the ultimate noise floor for these types of observations.

8448-57, Poster Session

Fermi Large Area Telescope operations: progress over 4 years

R. A. Cameron, SLAC National Accelerator Lab. (United States)

The Fermi Gamma-ray Space Telescope was launched into orbit in June 2008, and is conducting a multi-year gamma-ray all-sky survey, using the main instrument on Fermi, the Large Area Telescope (LAT). Fermi began its science mission in August 2008, and has now been operating for almost 4 years. The SLAC National Accelerator Laboratory hosts the LAT Instrument Science Operations Center (ISOC), which supports the operation of the LAT in conjunction with the Mission Operations Center (MOC) and the Fermi Science Support Center (FSSC), both at NASA's Goddard Space Flight Center. The LAT has a continuous output data rate of about 1.5 Mbits per second, and data from the LAT are stored on Fermi and transmitted to the ground through TDRS and the MOC to the ISOC about 10 times per day. Several hundred computers at SLAC are used to process LAT data to perform event reconstruction, using over 1 PB of disk capacity to hold the processed data so far. The gamma-ray photon data are subsequently delivered to the FSSC for public release within a few hours of being detected by the LAT. We summarize the current status of the LAT, and the evolution of the data processing and monitoring performed by the ISOC during the first 4 years of the mission. We also summarize plans for future changes to detected event data processing and instrument operations and monitoring.

8448-58, Poster Session

Telescope infrastructure maintenance at high altitude: lessons learned from Atacama Pathfinder Experiment operations

M. Cantzler, European Southern Observatory (Germany)

Telescopes located at high altitude are becoming increasingly popular as a consequence of the various advantages that high altitude conditions have, especially for IR observations.

However, building, operating and maintaining telescopes and their associated infrastructure under these conditions has several difficulties that tend to increase costs, reduce equipment availability, pose safety hazards and in general make life hard for those involved in this "line of business".

Based on the author's experience as responsible for the maintenance of APEX observatory's infrastructure located at the Chajnantor plateau at 5.100 m on the Atacama desert, this presentation gives an overview of the above mentioned difficulties, their effect on its operation and maintenance, and recommends concrete actions and strategies to be followed in order to deal with the adverse factors, minimizing their negative impact on the observatory.

8448-59, Poster Session

Research on schedulers for astronomical observatories

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The main task of a scheduler applied to astronomical observatories is the facility time optimization and the maximization of the scientific return. Scheduling of astronomical observations is an example of the classical task allocation problem known as the job-shop problem (JSP), where N ideal tasks are assigned to M identical resources, while minimizing the total execution time. A problem of higher complexity, called the flexible-JSP (fJSP), arises when the tasks can be executed by different resources, i.e. by different telescopes, and it focuses on determining a routing policy (i.e., which machine to assign for each operation) other than the traditional scheduling decisions (i.e., to determine the starting time of each operation). In most cases there is no single best approach to solve the planning system and, therefore, various mathematical algorithms (Genetic Algorithms, Ant Colony Optimization algorithms, Multi-Objective Evolutionary algorithms, etc.) are usually considered to adapt the application to the system configuration and task execution constraints. The scheduling time-cycle is also an important ingredient to determine the best approach. A short-term scheduler, for instance, has to find a good solution with the minimum computation time, providing the system with the capability to adapt the selected task to varying execution constraints (i.e., environment conditions).

We present in this contribution an analysis of the task allocation problem and the solutions currently in use at different astronomical facilities. We also describe the schedulers for three different projects (TJO, CARMENES and CTA) where the conclusions of this analysis are applied to develop a suitable routine.

8448-60, Poster Session

MABEL at IPAC: managing address books and email lists at the Infrared Processing and Analysis Center

M. Crane, C. Brinkworth, D. Gelino, E. O'Leary, California Institute of Technology (United States)

The Infrared Processing and Analysis Center (IPAC), located on the campus of the California Institute of Technology, is NASA's multi-mission data center for infrared astrophysics. Some of IPAC's services include administering data analysis funding awards to the astronomical community, organizing conferences and workshops, and soliciting and selecting fellowship and observing proposals. As most of these services are repeated annually or biannually, it becomes necessary to maintain multiple lists of email contacts associated with each service. MABEL is a PHP/MySQL web database application designed to facilitate this process. It serves as an address book containing up-to-date contact information for thousands of recipients. Recipients may be assigned to any number of email lists categorized by IPAC project and team. Lists may be public (viewable by all project members) or private (viewable only by team members). MABEL can also be used to send HTML or plain-text emails to multiple lists at once and prevents duplicate emails to a single recipient. This work was performed at the California Institute of Technology under contract to the National Aeronautics and Space Administration

8448-61, Poster Session

Cryogenics maintenance strategy at the ALMA Observatory

F. Cruzat, ALMA (Chile)

ALMA is an interferometer composed of 66 independent systems, with specific maintenance requirements for each subsystem. To optimize the observation time and reduce downtime maintenance requirements are very demanding. One subsystem with high maintenance efforts is cryogenics and vacuum.

To organize the maintenance the cryo and vacuum department is using and implementing different tools. These are monitoring and problem reporting systems and CMMS. This leads to different maintenance approaches: Preventive Maintenance, Corrective Maintenance and Condition Based Maintenance.

In order to coordinate activities with other departments the preventive maintenance schedule is kept as flexible as systems allow.

To cope with unavoidable failures, the team has to be prepared to work under any condition with the spares on time. CMMS will help to manage inventory control for reliable spare part handling, the correct record of work orders and traceability of maintenance activities.

For an optimized approach the department is currently evaluating where preventive or condition based maintenance applies to comply with the individual system demand.

Considering the change from maintenance contracts to in-house maintenance will help to minimize costs and increase availability of parts.

Due to increased number of system and tasks the cryo team needs to grow. Training of all staff members is mandatory, in depth knowledge must be built up by doing complex maintenance activities in the Cryo group, use of advanced computerized metrology systems.

8448-62, Poster Session

Challenges and peculiarities of ESPRESSO data flow cycle: from target choice to scientific results

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Since the beginning of the ESPRESSO (Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations) project it has been recognized that the expected challenging scientific results can be achieved only if an integrated view of the end-to-end operations is properly tackled. Hunting for rocky exoplanets and/or studying the possible variations of physical constants requires not only a dedicated, state-of-the-art spectrograph in terms of hardware and optics, but also a tailored observation strategy, data reduction pipeline and data analysis tools (ESPRESSO will be the first ESO instrument for which a customized Data Analysis Software will be provided to the community by the Consortium). In this paper we present the planned data flow system (DFS) for ESPRESSO as emerged after the Preliminary Design Review held in November 2011. Main requirements in terms of observation strategy/preparation and data reduction/analysis are analyzed and the corresponding foreseen (conceptual) design, able to fulfill them, discussed. Eventually, peculiarities and challenges needed to adapt ESPRESSO DFS in the pre-existing ESO/VLT DFS framework are outlined.

8448-63, Poster Session

Long term performance of the VISIR/VLT instrument before the upgrade

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The ESO's VLT Spectrometer and Imager for the Mid--Infrared (VISIR) has been in operation in the Paranal Observatory since 2005. It is equipped with two DRS (formerly Boeing) 256 x 256 BIB arrays. The project to upgrade detectors into new Raytheon, 1k x 1k AQUARIUS devices, is under way. Detector replacement will create a well defined break point in VISIR's characteristics.

For nearly 7 years of the instrument operations we have been collecting and processing calibration observations. They include data taken with the purpose of monitoring health of the detectors, as well as observations of both imaging and spectroscopic standard stars. The derived quality control parameters have been systematically written into a database. This allows the analysis of the temporal behaviour of the parameters.

We will present an overview of the long term variations of the VISIR quality control parameters, like sensitivities, conversion factors, background level estimations, etc. We will discuss the results with connection to the instrument performance and assessment of stability of the mid-infrared calibrators.

8448-64, Poster Session

Preparing the Pico dos Dias Observatory for fully remote operations

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In this work we will describe the adaptation process of the Pico dos Dias Observatory, in order to offer fully remote operation for its users. OPD is a 32 years old observatory installed at Brazópolis, MG, Brazil, and operated by the Laboratório Nacional de Astrofísica (MCTI/LNA). In particular, we intend to give the option in two of its telescopes: Perkin-Elmer 1.6 m and Boller & Chivens 0.6 m. The automation process requires a severe update in most of the equipments, which also will extend the lifetime of the observatory as a scientific laboratory. In the last few years, a number of equipments have been installed to provide, to local and future remote users, on-line data about the night conditions onsite, which are necessary to optimize the observations and for the safety of the telescopes. A new control system, named TCSPD, has been developed and allows the full control of the telescopes by any internet browser. The instruments (spectrographs, polarimeter, optical/IV cameras and CCDs) are also being adapted or have planned modifications, including the development of new software of control and/or hardware implementation. The possibility of operate the telescopes of the OPD from anywhere in the world will maximize the science results based on its facilities and will assure the optimal use of the site.

8448-65, Poster Session

Scheduler for the JPAS survey

A. Ederoclite, D. Cristobal-Hornillos, M. Moles, A. J. Cenarro, A. Marin-Franch, A. Yanes Díaz, N. Gruel, J. Varela López, S. Chueca, F. Rueda, S. Rueda, Ctr. de Estudios de Física del Cosmos de Aragón (Spain)

Observational strategy is a critical path in any large survey. The planning of a night requires the knowledge of the fields observed, the quality of the data already secured, and the ones still to be observed to optimize scientific returns. Finally, field maximum altitude, sky distance/brightness during the night and meteorological data (cloud coverage and seeing) have to be taken into account in order to increase the chance to have a successful observation.

To support the execution of the J-PAS project at the Javalambre Astrophysical Observatory, we have prepared a scheduler and a sequencer (SCH/SQ) which takes into account all the relevant mentioned parameters. The scheduler first selects the fields which can be observed during the night and orders them on the basis of their "figure of merit". It takes into account the quality and spectral coverage of the existing observations as well as the possibility to get a good observation during the night. The sequencer takes into account the metereological variables in order to modify the schedule for the night. During the commissioning of the telescopes at OAJ, we expect to improve our figures of merit and eventually get to a system which can function semi-automatically.

This paper describes the design of this software.

8448-66, Poster Session

Conceptual design of the data handling for the European Solar Telescope

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We present an overview of the conceptual design of the data handling unit of the ECS, the Control System for the European Solar Telescope (EST). We will focus on describing the critical requirements for this unit resulting from the overall design of the telescope, together with its architecture and the results of the feasibility analysis carried out to date.

8448-67, Poster Session

All sky monitoring network with amateur telescopes

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We describe here a multiband all sky monitoring system under construction using amateur resources. The system consists of a data management center and a network of telescopes. The total number of telescopes in this network can be huge and all the telescopes are not affected by their local weather or their operability so this network is capable of monitoring the whole night sky simultaneously in many different bands. The telescopes in the network can be operated on individual basis or on coordinated mode. The data taken by the telescopes in the network are sent to the data management center via internet where calibration, data fusion, data analysis are performed. The routine operations of the system and data analysis include searching of transient events, multi-wavelength campaign, general and specific surveys, coordinated observations. We analyze in detail the statistical

coverage of sky and wavelength by the telescope network, analyze the sensitivity of the coordinated observations, and discuss the calibration strategy for the network of telescopes with their heterogeneous nature.

8448-69, Poster Session

The next GALEX chapter: transition of a space astrophysics observatory from NASA to private operation

K. Forster, D. C. Martin, California Institute of Technology (United States); K. Erickson, Jet Propulsion Lab. (United States)

The Galaxy Evolution Explorer is one of the longest operating NASA astrophysics missions. Launched in April 2003, GALEX has surveyed the sky in the space ultraviolet, completing its primary mission objective of studying star formation in galaxies and its evolution with time, and also providing the astrophysics community with a space observatory run on the NASA model of publicly funded operations. GALEX was transferred to the California Institute of Technology early in 2012 and is now the worlds first privately funded space astrophysics observatory. We will present the challenges involved in this transition and the operations concept that will accomplish the goals of the GALEX sky completion project in 2012.

8448-70, Poster Session

Optimizing the observing efficiency of the James Webb Space Telescope

K. D. Gordon, V. Balzano, W. Blair, H. Ferguson, W. M. Kinzel, J. Lotz, Space Telescope Science Institute (United States); G. Sonneborn, NASA Goddard Space Flight Ctr. (United States); J. Tumlinson, Space Telescope Science Institute (United States)

One of the goals of the operations system being developed at the Space Telescope Science Institute for the James Webb Space Telescope is to produce the most efficienct use of the observatory that is scientifically justified. To first order, this means maximizing the amount of time spent collecting photons on science targets while ensuring the health and safety of the observatory and obtaining the necessary calibration data. Recent efforts by our group at STScI toquantify the expected observing efficiency based on current plans for the operations system will be presented. These include collecting the expected observatory and instrument overheads and updating a set of prototypical observing programs that will approximate over one full year of JWST observations. The combination of these two efforts will be used to investigate the expected observing efficiency and determine revised strategies to minimize overheads and maximize this efficiency.

8448-71, Poster Session

Calibration plan for J-PAS and J-PLUS surveys

N. Gruel, J. Varela López, M. Moles, D. Cristobal-Hornillos, A. J. Cenarro, A. Marin-Franch, S. Chueca, A. Yanes Díaz, S. Rueda, F. Rueda, A. Ederoclite, Ctr. de Estudios de Física del Cosmos de Aragón (Spain)

J-PAS survey consists of an 8000 square degree photometric sky survey with a set of 52 narrow-band and 2 broad-band filters. The main goal is to produce a photo-redshift catalog of ~15 millions red, early-type galaxies with a precision $\sigma(z)\sim0.003(1+z)$ to measure the Baryonic Acoustic Oscillation (BAO).Such precision requires specific care in the photometric calibration survey. This contribution presents the calibration protocol developed at CEFCA for the J-PAS data and to be applied from its first day. An auxiliary telescope T80 will perform an initial survey, J-PLUS, available one year before J-PAS, to create a set of flux calibrated stars in all J-PAS fields. Seven reference stars were already chosen to calibrate in flux the J-PLUS survey. J-PLUS 12-filter system was also specifically optimized to retrieve stellar parameters, T, log(g), [Fe/H], through the fitting of flux calibrated models. J-PLUS will be used as the standard network of flux calibrated stars to create synthetic spectro-photometry for J-PAS 56-filter system and to achieve the 2% photometric precision required for BAO measurements.

8448-72, Poster Session

An observation planning algorithm applied to multi-objective astronomical observations and its simulation in COSMOS field

Y. Jin, Y. Gu, Z. Chao, Univ. of Science and Technology of China (China)

Multi-Object Fiber Spectroscopic sky surveys are now booming, such as LAMOST already built by China, BIGBOSS project put forward by the U.S. Lawrence Berkeley National Lab and GTC (Gran Telescopio Canarias) telescope developed by the United States, Mexico and Spain. They all use or will use this approach and each fiber can be moved within a certain area for one astrology target, so observation planning is particularly important for this Sky Surveys. One observation planning algorithm used in multi-objective astronomical observations is developed. It can avoid the collision and interference between the fiber positioning units in the focal plane during the observation in one field of view, and the interested objects can be ovserved in a limited round with the maximize efficiency. Also, the observation simulation can be made for wide field of view through multi-FOV observation. After the observation planning is built ,the simulation is made in COSMOS field using GTC telescope. Interested galaxies, stars and high-redshift LBG galaxies are selected after the removal of the mask area, which may be bright stars. Then 9 FOV simulation is completed and observation efficiency and fiber utilization ratio for every round are given. Otherwise,allocating a certain number of fibers for background sky, giving different weights for different objects and how to move the FOV to improve the overall observation efficiency are discussed.

8448-73, Poster Session

Testing JWST's proposal planning system: early progress

I. J. E. Jordan, A. P. Patterson, D. C. Taylor, W. M. Kinzel, R. A. Downes, Space Telescope Science Institute (United States)

The observer program implementation, planning, and scheduling subsystems are undergoing software development for the James Webb Space Telescope front-end ground segment and are being tested in tandem. This part of the ground system leverages what was developed and fine-tuned for the Hubble Space Telescope over previous decades. This paper will describe the testing design, methods, results, plus the current capabilities and elements still to be developed for this subsystem through the time of publication. From an operations perspective we will point out elements from Hubble's system which have been preserved for the new telescope and those which are requiring redevelopment.

8448-74, Poster Session

Observatory bibliographies: current practices

J. P. Lagerstrom, Space Telescope Science Institute (United States); S. L. Winkelman, Smithsonian Astrophysical Observatory (United States); U. Grothkopf, European Southern Observatory (Germany); M. J. Bishop, National Radio Astronomy Observatory (United States)

Astronomical facilities, both large and small, space-and ground-based, independently create and maintain publication databases that can be used to characterize the scientific productivity and impact of these facilities. This paper will present the results of a new survey that will reveal how these individual observatories manage bibliographies as well as their motivations behind them. We will examine such factors as: criteria for paper inclusion, metadata collected, FTE employed, interoperability, etc. In addition, we will learn how these data are analyzed by each facility. In sum, the survey results will characterize methods and motivations currently at work in astronomical facilities.

8448-75, Poster Session

Autonomous real-time all-sky cloud detection over Mauna Kea

W. Mahoney, G. Morrison, G. Matsushige, Canada-France-Hawaii Telescope (United States)

Canada France Hawaii Telescope (CFHT) maintains and operates under automation an all-sky mid-IR camera providing the Mauna Kea community with real-time cloud detection and monitoring solutions. From the cloud's mid-IR black body emission, time-based differentials are obtained between 10µm and 12µm permitting clouds to be detected for global and specific sky regions above Mauna Kea. The instrument interfaces with CFHT environmental monitors for autonomous operations and weather-induced shutdowns. Development efforts are continuing to eventually provide the following additional data products: cloud cover determination, photometric quality assessment, sky and cloud brightness and color temperatures. The initial dataset provided by the instrument has shown to be invaluable to all modes of ground-based astronomical observing.

8448-76, Poster Session

Spitzer operations: scheduling the out years

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The Spitzer Warm Mission has continued to exhibit a robust Mission Operation System while meeting or exceeding the planned science objectives with exceptionally high efficiency since the cryogenic mission ended in mid-2009. Spitzer is in an Earth-trailing orbit at a distance that now exceeds 1 AU making telecommunications increasingly difficult. However, analysis has shown that the link margin is sufficient to both maintain normal communications through at least 2017 with minimal loss in observing efficiency and to allow recovery from a potential anomaly. To date a downlink rate of at least 1.1 Mbps has been possible, however, by the fall of 2012 the rate will need to be dropped to 550 kbps for any reasonable configuration of the Deep Space Network (DSN). The science program continues to emphasize the characterization of exoplanets, time domain studies, and deep surveys, all of which can be routinely supported even though they can impose tight scheduling challenges. Recent upgrades have significantly improved on-board data compression, which both enables certain high volume observations that were previously impractical and reduces Spitzer's demand for competitive DSN resources.

8448-77, Poster Session

PROP: ESO's portal for reporting of operational problematics

S. Marteau, S. Rahimpour, J. Lockhart, European Southern Observatory (Germany)

Modern observatory operations can involve many groups each supporting a part of the overall data flow. To ensure smooth operations and an efficient resolution of problems it is critical that all parties be able to communicate through common information channels. On the other hand, members of the astronomical community must be able to submit questions related to their observing programmes without having to know about the organization of the Observatory "behind the scenes."

The ESO Portal for Reporting of Operational Problematics, aka PROP, caters to all these needs via a single web application. By channeling their questions through a single support centre, users are automatically certain that they will get in touch with the operational group most suited to answer their request. From the inside, ESO operations staff can freely ask for the input of their colleagues or even external experts while keeping all the information in one place, thus allowing for complete traceability. As a corollary this also opens the possibility to compile a knowledge base and to easily derive statistics on problem resolution, e.g. to monitor better the quality of service.

8448-78, Poster Session

The ESO telescope bibliography at your fingertips

U. Grothkopf, S. Meakins, European Southern Observatory (Germany)

Bibliometric studies have become increasingly important in evaluating individual scientists, specific facilities, and entire observatories. The ESO Library has developed and maintains the Telescope Bibliography (telbib), a database of refereed papers that use observational data generated by ESO's facilities.

Recently, a new public telbib interface has been released. In addition to classical queries for bibliographic and/or facilities-related information, it provides advanced features like faceted searches and filtering, autosuggest support for author, bibcode and programID searches, hit highlighting as well as recommendations for other papers of possible interest.

An additional tool offers the possibility to create graphical statistics on the fly based on user-defined criteria.

The ESO Telescope Bibliography is available at http://telbib.eso.org

8448-79, Poster Session

A software complex for TNG Observatory efficiency measurements

E. Molinari, N. Hernandez, Telescopio Nazionale Galileo (Italy)

In recent years the necessity to exploit at maximum the efficiency of observing time led to the ascertainment that we are often missing the proper way to measure the status of astronomical use of an observatory.

At TNG we are developing a series of software tools that allows both the continuos monitoring of actual work during the night and regular reports about the completeness of observing programs during each semester.

The active input from human astronomers and operators still remains crucial for an honest evaluation of the effectiveness of an observatory.

8448-80, Poster Session

The on-board software of the HERSCHEL/PACS instrument: three successful years of in-flight operations

S. Pezzuto, Istituto di Fisica dello Spazio Interplanetario (Italy); A. Mazy, Univ. de Liège (Belgium); R. Ottensamer, Univ. Wien (Austria); H. Feuchtgruber, Max-Planck-Institut für extraterrestrische Physik (Germany); A. M. Di Giorgio, Istituto di Fisica dello Spazio Interplanetario (Italy); B. Vandenbussche, Katholieke Univ. Leuven (Belgium); M. Benedettini, S. J. Liu, S. Molinari, D. Schito, Istituto di Fisica dello Spazio Interplanetario (Italy)

PACS is one of the three instruments of the ESA space mission Herschel. Its warm electronics consists of 4 computers connected through 1355 links. Each computer is equipped with a DSP-21020 microprocessor, each running its own software. In this poster we describe the main features of the different software with some emphasis on the FDIR (Failure Detection Isolation and Recovery) procedures implemented on-board: we describe the FDIR design and we show how the few anomalies that occurred since the Herschel launch three years ago, have been successfully handled autonomously by the instrument.

8448-81, Poster Session

An integrated scheduling and program management system, MMT Observatory, Arizona, U.S.

D. Porter, J. D. Gibson, G. G. Williams, MMT Observatory (United States)

An integrated scheduling and program management system is being developed for the MMT Observatory (MMTO), Arizona, USA. A systems engineering approach is used to combine existing and new relational databases, spreadsheets, file storage systems, and web-based user interfaces into a single unified system. An overview of software design, data management, user interfaces, and techniques for performance assessment is presented. Goals of this system include streamlined data management and an optimized user experience. The MMTO has over a dozen different telescope configurations, including three secondary mirrors and a wide range of observing instruments. Scheduling is complex for the varying telescope configurations, limited available observing time, and appropriate astronomic conditions (e.g., lunar phase) for each science project. Scheduled telescope configurations can be used to perform safety checks of actual configuration during telescope operations. Programmatic information is automatically input into nightly telescope operator (TO) logs by the system. The TO's provide additional information into the system on telescope usage, observing conditions (e.g., weather conditions), and observatory closure (e.g., from instrument malfunction or inclement weather). All of this information is synthesized to assess telescope and observatory performance. Web interfaces to the system can be used by observers to submit information, such as travel plans, instrumentation requirements, and observing catalogs. A service request (SR) (i.e., trouble report) system has also been developed for tracking operational issues. The specific needs of the MMTO have been met through in-house software development of this integrated scheduling and program management system.

8448-82, Poster Session

Success of long term preventive maintenance on telescope subsystems using the example of the VLT adapter-rotators at the ESO Paranal Observatory

F. Salgado, G. Hudepohl, J. P. Haddad, R. Medina, European Southern Observatory (Chile)

More than 11 years have passed, since the first of the four Unit Telescopes of the VLT on Cerro Paranal has entered into operations.

To keep four such complex telecopes at a high level of availability with only around 3 percent of technical down time does not only depend on a good and robust design and manufacturing process, but long term also on a sound preventive maintenance plan and program.

In this paper the Instrument Adapter-Rotators, twelve of which are installed at the observatory, have been chosen to show how a preventive maintenance plan has been developed, implemented and executed and what the results are.

In the first part the most common problems are shown and some larger interventions are described and listed. It explains the tests that have been developed to follow the status of the systems by measuring key parameters such as position error, motor current, torque and encoders status in order to detect at an early stage any degradation in performance parameters.

Depending on the test results preventive actions can be planned well ahead of serious failures, making optimum use of scheduled technical time periods and consequently reducing loss of observing time.

Finally some statistic charts show how problems have been reduced as a result of the preventive maintenance plan.

8448-83, Poster Session

Operation, control, and data system for Antarctic Survey Telescope

Z. Shang, Tianjin Normal Univ. (China) and National Astronomical Observatories (China); K. Hu, Y. Hu, National Astronomical Observatories (China); J. Li, Tianjin Univ. (China); J. Li, Q. Liu, B. Ma, National Astronomical Observatories (China); J. Sun, Tianjin Univ. (China); L. Wang, Purple Mountain Observatory (China) and Texas A&M Univ. (United States); J. Xiao, Tianjin Univ. (China); J. Yu, National Astronomical Observatories (China); C. Yu, M. Yang, Tianjin Univ. (China); Z. Zeng, National Astronomical Observatories (China)

The first of the three Antarctic Survey Telescopes (AST3) will be deployed to Dome A, Antarctica in early 2012. This first optical survey telescope in Antarctica is equipped with a 10Kx10K CCD. The huge amount of data, limited satellite communication band, low temperature, low pressure and limited energy supply all place challenges to the control and operation of the telescope. We have developed both the hardware and software systems to operate the unattended telescope and carry out the survey automatically. We are also able to control the telescope remotely. Our systems include the main survey control, data storage, and real-time pipeline and database, for all of which we have dealt with various technical difficulties. These include developing customized computer systems and data storage arrays working at the harsh environment, temperature control for the disk arrays, automatic and fast data reduction in real-time, and building robust database system.

8448-84, Poster Session

Remote observing at the Isaac Newton group of telescopes

I. Skillen, R. Karjalainen, Isaac Newton Group of Telescopes (Spain)

The widespread availability of high-bandwidth, low-latency computer networks allows the possibility of observing remotely from the telescope, either at an observatory's local base, or indeed, from sites located in the community it serves. This can generate significant savings in both travel and operating costs, and can promote greater opportunity for training and participation of student groups in observing campaigns. In the era of queue-scheduled observing, the importance of active student participation in observation planning and execution cannot be overstated.

The Isaac Newton Group of Telescopes (ING) serves the astronomical communities of the Netherlands, Spain and the United Kingdom. It comprises the 4.2m William Herschel Telescope (WHT) and the 2.5m Isaac Newton Telescope (INT), which are situated on the rim of the

Caldera de Taburiente National Park, La Palma at an altitude of 2.4km, and about 50km by road from Santa Cruz de La Palma, where its headquarters are located.

The ING hosts a remote-observing office at its sea-level base from which network connectivity to the WHT has a full-duplex bandwidth of 100Mbs, with latency consistently less than 2msec. Virtual Network Computing (RealVNC) allows all observing and instrument-control desktops to be displayed and operated efficiently from the remote observing office. An H.323-protocol video-conferencing system hosts two-way audio and video communications between the remote observing office and the WHT control room.

This facility is used mainly by ING's astronomy and technical staff, and we describe our experiences using it for instrument configuration and trouble-shooting, training of staff and students, and general service observing, and also our plans for its future development.

8448-85, Poster Session

HTTP-based remote operational options for the Vacuum Tower Telescope, Tenerife

J. Staiger, Albert-Ludwigs-Univ. Freiburg (Germany)

The Vacuum Tower Telescope (VTT) is currently in a transition phase from handling standard solar observations towards being used as a facility dedicated to long-term solar investigations nowhere else possible. One of the first scientific programs to be carried out under these new rules will be the helioseimic analysis of the solar atmosphere at unprecedented height resolution. The extended recording runs required for these type of observations may be automated to a significant degree and do not require permanent presence of operational staff. We are currently developing a new telescope operating system allowing to handle telescope pointing and data recording under remote access conditions. For the first time a targeting tool will be implemented making use of the near-realtime, web-based imaging products of the new SDO/HMI satellite. We have developed a new Fabry-Perot based spectrometer optimized for remote control handling and adjustment. We have developed and tested an integrated communications and storage protocol specifically designed for these tasks and being basically an extension of the HTTP standard.

8448-86, Poster Session

Observatory bibliographies: not just for statistics anymore

S. L. Winkelman, A. Rots, Smithsonian Astrophysical Observatory (United States)

Creating and maintaining an observatory bibliography is labor intensive, so why not use it to its maximum potential? The information gathered during the curating process can be used by data discovery and research tools as well; the key is to collect sufficient metadata during the classification phase. The Chandra X-ray Center has taken this approach from the inception of its bibliography and we believe it has paid off.

As an example we provide links between datasets and astronomical publications to the Astrophysics Data System (ADS) so users of the ADS can directly access Chandra data associated with a publication. Those same links are used by WebChaser, the Chandra data access tool, so users can directly access articles associated with the data they are reviewing. We are expanding our exchange with the ADS to include details about the observations, proposals and bibliographic classifications related to the data in publications. This information will be used by the ADS to provide new semantic literature search capabilities. These interactions with the ADS and WebChaser have improved scientists' ability to discover Chandra data in meaningful ways.

In this paper we will cover how the Chandra bibliography has grown over the years and the many ways we have used our bibliography metadata for statistics, user services, and data discovery aids.

8448-88, Poster Session

The plate candidates and tiling method for LAMOST pilot survey

H. Yuan, National Astronomical Observatories (China)

A LAMOST survey observation plate should have a bright star in the center for Shack-Hartmann wave front estimation. Given the plate position, there should be at least one proper guide star on each guide CCD after a small angle focal plate rotation. The detailed requirements vary according to different observation condition. As a consequence, the plate center cannot be placed arbitrarily. Using the HIPMAIN star catalog as the initial candidates and the USNO-B1.0 catalog for neighbor star reference, several lists of acceptable survey plate centers are generated for different observation conditions. The sky area coverage is tested with each plate list. Tiling algorithms using these finite plate centers are optimized for the purpose of evenly sampling and catalog completeness. The tiling is much easier for dark nights than bright nights as there are more optional plate centers. The result is applied in the LAMOST pilot survey for verification and feedback is used to update the lists retentively.

8448-89, Poster Session

Estimation of system efficiency of fiber spectroscopic telescope

H. Zhang, Z. Bai, W. Zhang, National Astronomical Observatories (China)

For a fiber spectroscopic telescope, it is not easy to measure the whole system efficieny,it is not a simple multiply of the measured efficiency of each single elements. System efficiency estimated with stellar objects are often under-estimated by different fiber positioning error, seeing and weather conditions. To beter determin the system throughput excluding the uncertainty, a simultaneous observation of the same sky area using both LAMOST and 2-meter telescope at Xinglong station was carried out by December 2010, the absolute flux was determined for sky emission lines, then we use calibrated sky emission line to estimate the system throughput of LAMOST telescope. The peak of the system efficiency is 13% in blue and 25 % in red.

8448-34, Session 9

JWST observation specification and expansion to support planning and scheduling

W. M. Kinzel, R. E. Douglas, Jr., Space Telescope Science Institute (United States)

The James Webb Space Telescope (JWST) will be a large infrared space observatory orbiting the Sun-Earth second Lagrange Point. The Astronomer's Proposal Tool (APT), originally developed for the Hubble Space Telescope, has been extended to support JWST proposal development, using an Observation Template concept to provide Observers with a simple, focused interface to the primary observing capabilities of JWST, such as imaging, spectroscopy, or coronagraphy. APT will provide the Observer with the ability to specify more complex Observations by adding layers such as mosaics using a minimal set of inputs. APT will then expand each Observation to create one or more Visits where each Visit contains a set of exposures that can be performed using a single Guide Star. This paper will describe the capabilities required and the process used by APT to convert the high level Observation specification into lower level Visit structures, including the additional capabilities needed to support Muti-Object Spectroscopic Observations. We will also include a summary of the current state of APT implementation and remaining work.

8448-35, Session 9

Measuring the effectiveness of simulated LSST observing programs

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The Large Synoptic Survey Telescope will record approximately 2.5x10^6 images over a 10-year interval, using 6 optical filters, and exploring a wide range of temporal scales from seconds to years. The observing program will so large and rapid (a new field of view each ~15 seconds) and dependent on changing conditions, that it can only be realized with heavily automated scheduling. Furthermore, the extremely complex requirements for sequences and cadences ensure that simple scheduling rules will not suffice. The LSST Opsim group has devised a schedule Simulator to support development of the required scheduling capability. This paper addresses the complex problem of how to measure the success of a schedule simulation for realization of science objectives. Tools called Merit Functions evaluate the patterns and other properties of scheduled image acquisitions. In some cases Merit Functions are closely tied to science requirements, such as in timing of image sequences for supernova search and characterization. Other Merit Functions measure characteristics of the simulation that can offer intuitive understanding of the science capability. The currently available sets of Merit Functions are: Airmass, Astrometry, Early Good Images, Randomization, Solar System, Variables & Transients, and Uniformity. Merit functions are presented graphically for insight into the schedule and the coverage of observing parameters. Metric Values are single numbers characterizing Merit Functions, as e.g. mean values, scatter, min-max, number of fields achieving a minimum requirement, etc. These numerical values provide a description of a simulation performance in a list of discrete values, which are suitable for head-to-head comparison of simulations.

8448-36, Session 9

Evolution of RTS2: meta-queues scheduling for FLWO 1.2m Telescope

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RTS2, or Remote Telescope System 2nd Version, is an open-source, distributed and modular observatory control system. It has been under development for over a decade. From an original goal of a TOO capable system to observe possible optical transients of GRBs, it has evolved into a system capable to control observatories under complex observing scenarios.

It this presentation, we will share our experiences with meta-queue scheduling, developed primarily for the F. L. Whipple Observatory (FLWO) 1.2m telescope robot upgrade. Meta-queues scheduling allows observers to quickly build and combine different observation scenarios, while still retaining TOO and weather interuption capabilities. Thanks to GUI for queue control, observers can use the system without the need to understand complex functions used in the traditional merit function scheduling. By combining meta-queues and merit function scheduling observatories can offer their users different options for how to schedule their observations, so the acquired data will match observers' scientific expectations.

8448-37, Session 9

Introducing precipitable water vapour as an observing constraint for infrared observations on Paranal

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Precipitable Water Vapour (PWV) is one of the main, and variable, sources of opacity in the earth's atmosphere at infrared wavelengths. The PWV contents of the atmosphere may thus be expected to be a limiting factor for the sensitivities that can be reached using infrared instruments at ground-based telescopes. As part of the upgrade project of VISIR, the mid-infrared imager and spectrograph at the VLT, ESO has recently deployed a 183 GHz radiometer (an L-HATPRO unit manufactured by Radiometer Physics Gmbh) which is capable of providing accurate measurements of the column of PWV above Paranal in real-time. In this contribution we will present an overview of the first eight months of measurements produced by the new PWV monitor, its integration into the existing Paranal meteorological conditions database, and an overview of recent efforts to optimize observations at infrared wavelengths by matching the actual PWV conditions to the scientific needs of each programme carried out in service-mode.

8448-39, Session 10

Keeping the Hubble Space Telescope operating efficiently in its third decade

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Summer 2009 saw the final shuttle visit to the Hubble Space Telescope (HST). In addition to new science instruments, gyroscopes and batteries were replaced, allowing HST to remain productive through the end of the decade. Recent improvements to the planning and scheduling process will maximize scientific return over HST's remaining years.

The return to 3-gyro operations increased the scheduling opportunities for science on HST. In addition, the scheduling of programs through the South Atlantic Anomaly (SAA) was addressed to optimize efficiency. The process was improved to take advantage of programs that could completely "hide" the SAA, as well as those that could schedule in partially impacted orbits. Attention was also paid to minimizing the gaps between observations. The improvements allowed the scheduling of 1-2 more orbits (1-3 hours) of science per week.

The inclusion of three Multi-Cycle Treasury (MCT) programs - several hundred orbits each - has increased the need for efficient scheduling. An RA-asymmetry in the HST target distribution caused periods of heavy and low subscription. To rectify the problem going forward, "exclusion zones" have been defined in the Cycle 21 (10/2012 - 10/2013) Call for Proposals where no large (> 30 orbits) programs will be accepted. Small programs in those exclusion zones will have restrictions allowing maximal flexibility.

Process improvements to HST scheduling in its twilight years not only allow the continuation of groundbreaking science, but also serve as a bridge to the planning and scheduling systems of the James Webb Space Telescope.

8448-40, Session 10

Science commissioning of JWST: applying Hubble's lessons to the Webb

C. P. Biagetti, Space Telescope Science Institute (United States)

The Space Telescope Science Institute (STScI) has the primary role for planning and carrying out the science program for the James Webb Space Telescope (JWST). It also has a lead role, in support of the Prime Contractor, in planning and carrying out the science instrument commissioning program designed to enable, post-launch, the start of Observatory science. The STScI has, for the entire lifetime of the Hubble Space Telescope (HST), designed and carried out similar programs for commissioning that observatory for science; programs that were implemented not only in the aftermath of its 1990 deployment, but also following each of the five STS (space shuttle) servicing missions, which spanned the years 1993 to 2009. In this paper, we address planning principles and operational lessons stemming from our Hubble experience and show how those principles and lessons are being applied to the science commissioning plans for the JWST Observatory. In doing so, we contrast JWST's expected early-life operations with Hubble's post-servicing performance, and address any adjustments needed in our HST principles and lessons in order to effectively apply them to the specific challenges of JWST science commissioning.

8448-41, Session 10

Mixing completion, commissioning, and operations at the LBT

R. F. Green, J. M. Hill, J. G. Brynnel, J. H. Slagle, D. S. Ashby, N. J. Cushing, J. K. Little, Large Binocular Telescope Observatory (United States); R. M. Wagner, Ohio State Univ. (United States)

By July 2012, the Large Binocular Telescope Observatory will be supporting scientific observing 60% of the time with binocular prime focus imaging, single-sided optical and near-IR imaging and spectroscopy, and adaptive optics imaging. Interspersed in the last year were installation and commissioning of the second adaptive optics system and re-commissioning of the LUCI near-IR instrument with a replacement detector. Initial commissioning of mid-IR interferometry is underway as well. We examine the lost time statistics and distribution of issues that reduced on-sky access in the context of the limited technical support provided for observing. We discuss some of the root causes of and responses to a critical operational readiness review. The manner in which programs are selected and scheduled for the different partners is reviewed. The goal is to apply the lessons learned to the continuing period of observation plus commissioning anticipated as new spectroscopic, adaptive optics, and interferometric capabilities are added through 2014.

8448-42, Session 10

Organizational transformation into the operational phase of the GTC

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In this paper we will review the various issues encountered when the GRANTECAN project evolved from the construction phase of a large facility into the phase of operation. GRANTECAN now operates the 10.4m segmented telescope, GTC. The advent of operational pressures to scientifically exploit the telescope enforced a number of organizational changes as priorities shifted towards achieving a reasonable level of operational effectiveness. In this paper we will treat the GRANTECAN experience as a case study of the limitations and problems that were encountered throughout this change. We will focus on the processes and strategies applied in order to achieve the necessary changes. We will place our experience in the framework of the McKinsey 7S model, highlight a number of key performance indicators, and will reflect on how cultural aspects can influence the way objectives are achieved. We will present a recommendation based our experience.

8448-43, Session 11

66 antennas, up to 15 km baselines, 5000 m elevation, 28 km from support; the coming challenge of ALMA Observatory antenna group operations and maintenance

D. Chalmers, F. Daruich, B. Hoff, C. Jara, A. Ginsberg, ALMA (Chile)

The ALMA Observatory is under construction at 5000 m above the sea level on the Chajnantor plateau located in the Atacama Desert, Chile. When complete it will be comprised of 66 parabolic reflector antennas that can be configured in various arrays using a subset of 192 different stations with baselines from 150 to 16000 m. The Antenna Group in the ALMA Department of Engineering is responsible for maintenance of the antenna mechanical, control and structural systems, antenna relocations and mechanical aspects of astronomical instrumentation exchanges. The large number of antennas, expanse, elevation, weather conditions of the Array Operation Site (AOS) and its distance from the Operations Support Facilities (OSF) will make operations and maintenance for the Antenna Group a challenge.

Currently approximately one third of the antennas are in place at the AOS and the first period of Early Science is underway. Operational strategies and specialized equipment developed for preventive and corrective maintenance, array reconfiguration and weather event response are being put to the test and revised based on real experience.

This paper will explain the operational environment, the constraints it imposes and some of the strategies and specialized equipment being developed to reduce reaction time and resources needed to maintain the array and maximize availability for science operations.

8448-44, Session 11

New challenges for the maintenance strategies on large astronomical facilities at remote observing sites

A. Silber, European Southern Observatory (Chile) and ALMA-JAO (Chile)

The Change from a reacting to a proactive maintenance concept represents for large Observatories at remote operational sites a new challenge, considering the increasing numbers of complex subsystems. Conventional operational maintenance models will not cover all the requirements, will lead to more down time and the operational cost cannot be reduced. For the successful astronomical observation with large telescope facilities new strategies have to be applied.

In this contribution we will demonstrate on the example of the 80 Cryogenic Sub-systems of ALMA how a proactive maintenance strategy help to increase the efficiency, to reduce the operational cost and the required staff resources.

With respect to the growing number of complex subsystems on future telescope facilities the operational staff needs proper diagnostic and monitoring tools to allow a precise prediction respectively synchronization of the service activities. This leads away from a pure scheduling of preventive maintenance and enables a longer availability of the subsystems as tendencies and performance are monitored and controlled. Having this strategy considered during the developing phase of future large astronomical facilities allows the optimization of the required Infrastructure, a proper definition of the LRU strategy and to which level maintenance can be cost efficient on site.

8448-45, Session 11

Taming the beast: operating the world largest low-frequency radio observatory LOFAR

A. Schoenmakers, H. Munk, ASTRON (Netherlands)

The LOFAR radio telescope finished construction recently, and is now preparing itself to run a large variety of science projects for the years to come. LOFAR is a unique and widely distributed radio telescope consisting of 41 stations,using a novel design with phased array technology. It operates between 10 and 250 MHz using two different kinds of antennas. Geographically, it is situated largely in the Northern part of the Netherlands, complemented by 8 stations in Germany, France, UK and Sweden. It is operated and maintained by ASTRON, the Netherlands Institute of Radio Astronomy in Dwingeloo, The Netherlands.

LOFAR stations produce about 4 Gb/s of data each, which is sent to a central processing facility hosted by the University of Groningen's HPC center. There, the signals are combined and processed to produce astronomically meaningful data. The processed data is archived in several large datacenters and made available to end-users. LOFAR produces science for radio pulsar studies, cosmic ray studies, sensitive wide-field imaging and many other applications. Much of the flexibility of LOFAR has been made possible by the large use of software and general purpose based hardware in its design.

The versatility and geographical spread of the telescope stations and its resources leads to fascinating challenges in operations and maintenance. In this presentation we will introduce the operational concepts and challenges of the LOFAR telescope, and the solutions we have found for these.

8448-52, Session 11

The Observatorio Astrofisico de Javalambre: goals and current status

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The Observatorio Astrofísico de Javalambre (OAJ) is a new astronomical facility under development at the Sierra de Javalambre in Teruel (Spain), specifically conceived for carrying out large-sky astronomical surveys in robotic mode. With this aim the observatory will consist of two telescopes of large fields of view (FoV): T250, a 2.55m R-C altazimuthal with a 3deg diameter FoV, and T80, an 82cm R-C german-equatorial with a 2deg diameter FoV. The two telescopes have lens field correctors at the Cassegrain optical path to ensure the image quality inside the nominal FoV. The observatory, responsability of the Centro de Estudios de Física del Cosmos de Aragón (CEFCA; http://www.cefca.es), is expected to be fully operative by the end of 2013. Both telescopes are scheduled to be on site throughout 2012.

The OAJ key project is the Javalambre-PAU Astrophysical Survey (J-PAS; http://j-pas.org), which during 4-5 years will observe 8000deg2 in 54 optical, narrow-band, contiguous filters (plus 2 broad filters at the blue and red edges), allowing to face key questions in Cosmology and Astrophysics. The implementation and scientific exploitation of J-PAS is being carried out through an international consortium of several astronomical institutes in Spain and Brasil.

This talk aims to present a general overview of the whole project: the OAJ scientific goals, the telescope observing techniques, the definition, design process, and technical performances of the telescopes and their respective panoramic cameras, as well as the status of the OAJ civil work, buildings and domes.

8448-87, Session 11

Goals and strategies in global control design of the OAJ Robotic Observatory

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There are many ways to solve the challenging problem of making a high performance robotic observatory from scratch.

The Observatorio Astrofísico de Javalambre (OAJ) is a new astronomical facility located at the Sierra de Javalambre (Teruel, Spain) whose primary role will be to conduct all-sky astronomical surveys. The OAJ control system has been designed under a global point of view including not only astronomical subsystems but also infrastructure and other facilities.

Three main factors have been considered in the design of a global control system for the robotic OAJ: quality, reliability and efficiency. We propose CIA (Control Integrated Architecture) design and OEE (Overall Equipment Effectiveness) as a key performance indicator in order to improve operation processes, minimizing resources and obtain high cost reduction maintaining quality requirements.

The OAJ subsystems considered for the control integrated architecture are the following: two wide-field telescopes and their instrumentation, active optics subsystems, facilities for sky quality monitoring (seeing, extinction, sky background, sky brightness, clouds distribution, meteorological station), domes and several infrastructure facilities such as water supply, glycol water, water treatment plant, air conditioning, compressed air, LN2 plant, illumination, surveillance, access control, fire suppression, electrical generators, electrical distribution, electrical consumption, communication network, Uninterruptible Power Supply and two main control rooms, one at the OAJ and other remotely located in Teruel at 40km from the observatory, connected through a microwave radio-link.

Here we present the OAJ strategy in control design to achieve maximum quality efficiency for the observatory processes and operations, giving practical examples of our approach.

8448-46, Session 12

Spitzer Space Telescope: maximizing the science return in the extended mission phase

L. J. Storrie-Lombardi, California Institute of Technology (United States); S. R. Dodd, Jet Propulsion Lab. (United States)

The Spitzer Space Telescope is executing the third observing cycle in the `warm' extended phase of the mission. For the warm mission, the observatory was effectively reinvented as a new, scientifically productive mission operating at a substantially lower cost. In this paper we describe the ongoing implementation of improvements in science capabilities during the extended mission phase even as the project budget continues to shrink. Improvements in pointing stability, data compression and data analysis techniques allow for new science opportunities more than 8 years after launch. Engineering analyses have shown that the mission can operate with high reliability and minimal technical risk through at least January 2017.

8448-48, Session 12

Paranal instruments: installation, maintenance, optimization, and operation

F. Y. J. Gonte, A. Smette, European Southern Observatory (Chile)

A second generation of scientific instruments has started to be installed on the Paranal Observatory. The numbers and complexities of these instruments to be installed in the next years has imposed a

change in the management of their integration, commissioning but also operation. In parallel, the first generation of instrument is being upgraded to obtain better performances and/or against obsolescence. On Paranal observatory to asses the load of these tasks the instrument responsibilities in operation is shared between an engineer and a scientist while the instrument integration and commissioning is shared between a system engineer, an instrument scientist and the project manager in Garching.

This management approach is detailed and the improvement obtained is described.

8448-49, Session 12

The Keck way: vision and reality of technical operations at Keck

H. A. Lewis, R. Matsuda, W. M. Keck Observatory (United States)

We describe the goals, guiding principles, and implementation of the Keck technical operations model and how scientific success is critically dependent on the symbiotic connection with the overall scientific strategy of the observatory. We examine management approaches, organization and staffing that result from this approach. We discuss the choices made at the observatory in balancing regular operations and new scientific and technical capabilities, and the tradeoffs and consequences of these choices. We then elaborate on our plans to evolve operations in the areas of people and processes over the next few years. Finally, we conclude with how the model could be improved, and its applicability to the next generation of extremely large telescopes.

8448-50, Session 12

NuSTAR Observatory operations

K. Forster, F. A. Harrison, California Institute of Technology (United States); M. Bester, Univ. of California, Berkeley (United States)

The Nuclear spectroscopic telescope array, a NASA small explorer mission scheduled for launch in March 2012, will be the first focusing high energy X-ray mission, opening the hard X-ray sky for sensitive study for the first time. NuSTAR will search for black holes, map supernova explosions, and study the most extreme active galaxies.

NuSTAR mission operations is a collaboration between the Science Operations Center in the Space Radiation Laboratory at Caltech and the Mission Operations Center based at the Space Sciences Laboratory on the UC Berkeley campus.

We will present NuSTAR mission operations, from science target planning and observatory operations, to the automated data processing pipeline and public archive. We will address the challenges of achieving the goals of the mission within the two year primary mission timeline which includes many coordinated observations with other observatories.

8448-51, Session 12

A minimalist operating mode for UKIRT

T. Kerr, G. R. Davis, S. C. Craig, C. Walther, T. Chuter, Joint Astronomy Ctr. (United States)

In late 2010, driven by funding pressure from its governing body, the United Kingdom Infrared Telescope (UKIRT) underwent the most significant operational change in its history culminating in a new “minimalist mode” operation. Since 13th December 2010 this telescope, situated at the summit of Mauna Kea, Hawaii, has been operated remotely from the Joint Astronomy Centre in Hilo, with a priority on completing the UKIRT Infrared Deep Sky Survey (UKIDSS) but also continued support of other international programmes. In mid-2012, while remaining in minimalist mode, the observatory plans to start a new and ambitious near-infrared survey of the northern sky called the UKIRT Hemisphere Survey.

The change to minimalist mode has resulted in the following: the cost of running the observatory has been reduced from $4.5M to $2.2M yet despite the changes, which included a reduction in staff and support, the UKIRT continues to operate at 90% efficiency, a level it has operated at for the last several years. The fault rate remains extremely low (approximately 3%) and has not been affected by remote operations and no time-losing faults have yet to be attributed to operating remotely.

This paper discusses the motivations behind the change to minimalist mode, the new mode of operation itself, the effect, if any, of the change on operational efficiency and the challenges facing a remotely operated telescope at a remote mountain site.

8448-53, Session 12

All-sky mid-infrared imagery to characterize sky conditions and improve STELLA’s observational performance

M. Weber, Leibniz-Institut für Astrophysik Potsdam (Germany); D. Klebe, Denver Museum of Nature and Science (United States); K. G. Strassmeier, T. Granzer, Leibniz-Institut für Astrophysik Potsdam (Germany); R. D. Blatherwick, Univ. of Denver (United States)

The All Sky Infrared Visible Analyzer (ASIVA) is an instrument principally designed to characterize sky conditions for purposes of improving ground-based astronomical observational performance. The ASIVA’s primary functionality is to providee radiometrically calibrated imagery across the entire sky over the mid-infrared (IR) spectrum (8-13 µm). Calibration procedures have been developed for purposes of quantifying the photometric quality of the sky. These data products are used to provide the STELLA scheduler with real-time measured conditions of the sky/clouds, including thin cirrus to better optimize observing strategy. This information is available as a map of the visible sky, taken every 5 minutes. This information is used by the observatory control system to determine if the conditions are good enough for observing. Furthermore the spacial and average sky quality values can be used by an observing program to optimize the quality of the data. We describe how this is implemented in our scheduling system.

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8449-01, Session 1

Thermal seeing modeling validation through observatory measurements

K. Vogiatzis, A. C. Otarola, W. A. Skidmore, T. Travouillon, G. Z. Angeli, Thirty Meter Telescope Observatory Corp. (United States)

Thermal seeing is a critical effect influencing the optical performance of ground-based telescopes. Computational Fluid Dynamics (CFD) can be used to obtain the refractive index field along a given optical path and calculate the corresponding image quality utilizing optical modeling tools. This procedure is validated using measurements from the Keck II and CFHT telescopes.

CFD models of Keck II and CFHT observatories on the Mauna Kea summit have been developed. The detailed models resolve all components that can influence the flow pattern through turbulence generation or heat release. Unsteady simulations generate time records of velocity and temperature fields from which the refractive index field at a given wavelength and turbulence parameters are obtained.

At Keck II the Cn2 and lo (inner scale of turbulence) were monitored along a 63m path sensitive primarily to turbulence around the top ring of the telescope tube. For validation, these parameters were derived from temperature and velocity fluctuations obtained from CFD simulations.

At CFHT dome seeing has been inferred from their database that includes telescope delivered image quality. For this case CFD simulations were run for specific orientations of the telescope respect to incoming wind, wind speeds and outside air temperature. For validation, temperature fluctuations along the optical beam from the CFD are turned to refractive index optical path differences (OPD) then to point spread functions (PSF) that are ultimately compared to the record of image quality.

8449-02, Session 1

A fluid dynamic study of the CFHT dome using CFD and water tunnel tests

M. R. Baril, T. Benedict, K. G. Thanjavur, Canada-France-Hawaii Telescope (United States); K. Vogiatzis, Thirty Meter Telescope (United States); R. Racine, Univ. de Montréal (Canada); D. Salmon, Canada-France-Hawaii Telescope (United States); S. Wang, Y. Chang, Academia Sinica (Taiwan)

Studies of astronomical seeing at the Canada France Hawaii Telescope (CFHT) site, from both inside and outside the dome, show that the full potential of the excellent seeing conditions at the CFHT site has never been fully exploited. Tests have been performed to identify the causes of the “pathologies” of the unvented hemispherical CFHT dome revealed by the seeing studies and to find ways of mitigating them. In particular, we have investigated installing vents in the dome skin to improve air exchange between outside and inside the enclosure. A number of vent geometries were tested using water tunnel models at the University of Washington Aerodynamics Laboratory (UWAL). We derive from these tests relative flushing times for various dome slit to prevailing wind directions for different vent geometries compared to an unvented dome. The general flow characteristics observed with these low Reynolds number tests were validated by comparison with computational fluid dynamics (CFD) simulations of the CFHT dome performed in collaboration with the Thirty Meter Telescope (TMT) project. The water-tunnel and CFD studies are consistent with the results of wind-tunnel observations performed by the Academica Sinica Institute of Astronomy and Astrophysics (ASIAA) and night-time thermal infrared imagery of the CFHT site.

8449-03, Session 1

LSST summit enclosure: facility design optimization using aero-thermal modeling

J. Sebag, National Optical Astronomy Observatory (United States); K. Vogiatzis, Thirty Meter Telescope (United States); J. D. Barr, D. R. Neill, National Optical Astronomy Observatory (United States)

This paper describes Computational Fluid Dynamic (CFD) analyses combined with thermal analyses for modeling the effects of passive ventilation, enclosure-building configuration and topography on the optical performance of the Large Synoptic Survey Telescope (LSST). The primary purpose of the analyses is to evaluate the seeing contribution of the major enclosure-facility elements and to select the features to be adopted in the baseline design from among different configurations being explored by the LSST project and their contracted AE design team.

Several simulations for different telescope orientations are performed including different zenith angles and wind-telescope relative azimuth angles. Using a previously presented post-processing analysis, the effects of turbulence and thermal variations within the airflow around the buildings and inside the telescope-enclosure configuration are determined, and the optical performance due to the thermal seeing along the optical path is calculated. Finally, the LSST telescope pointing histogram distribution is used to compare the mean seeing contribution with the allocation in the image quality error budget.

8449-04, Session 1

Wind responses of the LSST secondary mirror

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The Large Synoptic Survey Telescope (LSST) optical design calls for a large annular 3.4 m diameter meniscus convex aspheric Secondary Mirror (M2). The M2 has a mass of approximately 1.5 metric tons and the optimized mirror support system consists of 72 axial actuators, mounted at the mirror back surface, and 6 tangent link lateral supports mounted around the outer edge. A fully integrated M2 Finite Element Model (FEM) including the mirror and the support systems has been developed to investigate the performance of the M2 assembly and to determine the image degradation due to dynamic wind loading. Detailed wind response analysis was performed based on the input from Computational Fluid Dynamics (CFD) simulations. Image quality calculations of the time history responses and Power Spectrum Density (PSD) are addressed.

8449-05, Session 2

Systems engineering implementation in the preliminary design phase of the Giant Magellan Telescope

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The 24.5-meter Giant Magellan Telescope (GMT) is truly a complex system. The primary and secondary mirrors of the GMT are segmented and actuated with two operating modes: natural seeing and adaptive optics. Multiple science instruments will be operated in those modes. Development will take place over a geographically distributed set of collaborators.

The need to implement good systems engineering processes for managing the development of this system becomes imperative. The management of the requirements flow-down from the science (i.e., top level) requirements down to the component level requirements is inherently a difficult task in itself. The interfaces must also be negotiated so that the interactions between subsystems and assemblies are well defined and controlled.

This paper will provide an overview of the systems engineering processes and tools implemented for the GMT project during the preliminary design phase. This will include requirements management, documentation and configuration control, interface development and technical risk management. Because of the complexity of the GMT system and the distributed team, using web-based tools for collaboration is vital. Key to this is the use of Cognition Cockpit for managing and documenting the product tree, architecture, error budget, requirements, interfaces, and risks. Additionally, drawing management is accomplished using Solidworks PDM Enterprise vault. Docushare, a documentation and configuration management tool is used to manage workflow of all documents and drawings for the GMT project. These tools electronically facilitate collaboration in real time, enabling the GMT team to track, trace and report on key project metrics and design parameters.

8449-06, Session 2

System engineering of the Atacama Large Millimeter/submillimeter Array

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The Atacama Large Millimeter/submillimeter Array (ALMA will be composed of 66 high precision antennae located at 5000 meters altitude in northern Chile. This paper will present the methodology, tools and processes adopted to system engineer a project of high technical complexity, by system engineering teams that are remotely located and from different cultures, and in accordance with a demanding schedule and within tight financial constraints. The technical and organisational complexity of ALMA requires a disciplined approach to the definition, implementation and verification of the ALMA requirements. During the development phase, System Engineering chairs all technical reviews and facilitates the resolution of technical conflicts. We have developed tools to analyse the system performance, incorporating key parameters that contribute to the ultimate performance, and are modelled using best estimates and/or measured values obtained during test campaigns. Strict tracking and control of the technical budgets ensures that the different parts of the system can operate together as a whole within ALMA boundary conditions. System Engineering is responsible for acceptances of the thousands of hardware items delivered to Chile, and also supports the software acceptance process. In addition, System Engineering leads the troubleshooting efforts during testing phases of the construction project. Finally, the team is conducting System level verification and diagnostics activities to assess the overall performance of the observatory.

8449-07, Session 2

Modeling and simulations in systems engineering of the Large Synoptic Survey Telescope

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The LSST is a proposed facility to produce, over a 10-year period, a multi-color, multi-epoch survey of more than 18000 square degrees of the southern sky. The end product of the LSST will be an archive of images and data products from which a wide variety of precision statistical studies can be carried out. To accomplish this, the LSST project has developed a multi-facetted suite of modeling and simulation tools to develop the system requirements and architecture, and to validate that the system design will yield data products with the desired statistical properties. In this paper we describe the development and validation of the LSST system design through multiple simulation efforts, including end-to-end image simulations, operational kinematic simulations, and catalog based simulations of the procedures for data calibration. We also describe the models used in these simulations including catalogs representing the observable universe, detailed photon propagation through the atmosphere, telescope, and instrument, and the conversion of these photons to simulated digital images.

8449-08, Session 2

Management of the JWST MIRI pFM environmental and performance verification test campaign

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The Mid-Infrared Instrument (MIRI) is one of four scientific instruments on the James Webb Space Telescope (JWST) observatory, scheduled for launch in 2018. It will provide unique capabilities to probe the distant or deeply dust-enshrouded regions of the Universe, investigating the history of star and planet formation from the earliest universe to the present day. To enable this the instrument optical module must be cooled below 7K, presenting specific challenges for the environmental testing and calibration activities.

The assembly, integration and verification (AIV) activities for the proto-flight model (pFM) instrument ran from March 2010 to September 2011 at RAL where the instrument has been put through a full suite of environmental and performance tests with a non-conventional single

cryotest approach.

In this paper we present an overview of the testing conducted on the MIRI pFM including: ambient alignment testing; vibration testing; gravity release testing; cryogenic performance and calibration testing; functional testing at ambient and operational temperatures; thermal balance tests; and Electro-Magnetic Compatibility (EMC) testing. We discuss how tests were planned and managed to ensure that the whole AIV process remained on schedule and give an insight into the lessons learned from this process. We also present how the process of requirement verification for this complex system was managed and documented. We describe how the risks associated with a single long duration test at operating temperature were controlled so that the complete suite of environmental tests could be used to build up a full picture of instrument compliance.

8449-09, Session 3

Developing an instrument simulator: experience feedback from the JWST/NIRSpec and VLT/MUSE simulators

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The Centre de Recherche Astrophysique de Lyon (CRAL) has recently developed two instrument simulators for spectrographic instruments. These numerical models are based on Fourier optics, and model the whole chain of acquisition, taking into account both optical aberrations and diffraction effects, by propagating a wavefront through the instrument, according to the Fourier optics concept. One simulates the NIRSpec instrument, a near-infrared multi-object spectrograph for the future James Webb Space Telescope (JWST). The other one models the Multi Unit Spectroscopic Explorer (MUSE) instrument, a second-generation integral-field spectrograph for the Very Large Telescope (VLT). The two simulators have been developed in different contexts (subcontracted versus developed internally), and for very different instruments (space based versus ground based), which strengthen the CRAL experience. This paper describes the lesson learned while developing these simulators: development methods, phasing with the project, points to focus on, getting data, interacting with scientists and users, etc.

8449-10, Session 3

Transitioning from conceptual design to construction performance specification

P. F. Jeffers, M. Warner, R. P. Hubbard, National Solar Observatory (United States); S. C. Craig, Joint Astronomy Ctr. (United States); H. K. Marshall, National Solar Observatory (United States)

On successful completion of a conceptual design review by a funding agency or customer there is a transition phase before construction contracts can be placed. The nature of this transition phase depends on the Project's approach to construction and the particular subsystem being considered.

There are generically two approaches; project retention of design authority and issuance of build to print contracts, or issuance of subsystem performance specifications with controlled interfaces.

This paper relates to the latter where a proof of concept (conceptual or reference design) is translated into performance based sub-system specifications for competitive tender. This translation is not a straightforward process and there are a number of different issues to consider in the process. This paper deals mainly with the Telescope mount and Enclosure subsystems.

The main subjects considered in this paper are:

- Typical status of design at Conceptual Design Review compared with the desired status of Specifications at Request for Quotation.
- Methods for effective use of conceptual engineering design work without compromising a performance based specification.
- Options for capture and tracking of system requirements flow down from science / operating requirements and sub-system requirements derived from reference design.
- Requirements that may come specifically from the contracting approach.
- ICD's for systems and contract management.
- Capture of functional requirements inherent in reference design.
- Management of project team's expectation relating to design.
- Effects on cost estimates from reference design to actual.

This paper is based on experience and lessons learned through this process on both the VISTA and the ATST projects.

8449-11, Session 3

Usability-driven evolution of a space instrument

A. J. McCalden, SRON Netherlands Institute for Space Research (Netherlands)

The concept of usability is something many people are becoming more familiar with, as manufacturers of consumer electronics strive ever harder to persuade us that their gadget is the easiest to use. This paper looks in detail at how the cradle to grave timeline of a space instrument might be radically changed by similarly considering usability from the start. The methodology includes giving early priority in a programme to the iterative development of a simulator that models instrument operation, and allowing this to evolve ahead of the actual instrument specification and fabrication. The advantages include reduction of risk in software development by shifting it to much earlier in a programme than is typical, plus a test programme that uses and thereby proves the same support systems that may be used for flight. In addition, the methods may help to create an improved understanding between the various diverse disciplines involved in the design, test and operation of a space instrument, leading to a better overall system.

A suggested detailed developmental flow is derived from this concept, showing how the system engineering phases typically used by NASA could be reworked in line with this proposal. The result should be an instrument that better captures the science needs, implements them more accurately with less wasted effort, and allows the best ideas from all team members to be considered. The work is underpinned by PhD research into many usability ideas in the space science context.

Some prior publication of this work has taken place:

1.The paper reports on and brings up to date work carried out for a PhD at UCL, London. http://discovery.ucl.ac.uk/14194/

2.A brief outline of the work was described in Astronomy & Geophysics, December 2009, pp 6.1 - 6.3.

http://onlinelibrary.wiley.com/doi/10.1111/j.1468-4004.2009.50627.x/abstract

8449-12, Session 3

Building information models (BIM) for astronomy projects

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A Building Information Model is a digital representation of physical and functional characteristics of a building. BIMs represent the geometrical characteristics of the Building, but also other properties like detail

definition of systems/components (technical specifications, operation/maintenance manuals, bills of quantities, etc), status of material in the different stages of the project, project economic data, system interfaces, etc.

The BIM methodology, which is well established for conventional buildings, has been brought one step forward in its application for scientific installations which have specific needs caused by the added complexity, the concurrence or a larger number of design teams and the need to achieve a higher integration throughout the design and construction phases. In the case of Telescope Enclosures, apart from steel/concrete structures and M&E equipment, there is a large amount of mechanisms involved as a fundamental part of the facility. In order to allow the coordinated work of different engineering teams, the detail design definition is typically implemented specific software packages for steel and concrete structures, mechanisms and mechanical and electrical equipment. The overall model is progressively integrated in a roaming software which is used for checking interferences, planning the construction sequence (4D simulation), studying maintenance operations, reporting to the project office, etc. The cost control can also be easily integrated in the BIM providing the model with an additional dimension (5D).

This paper presents the BIM methodology as implemented by IDOM with the E-ELT and ATST Enclosures as application examples.

8449-14, Session 3

Astrometric instrument modeling in the Gaia astrometric verification context: tasks and activities

D. Busonero, INAF - Osservatorio Astronomico di Torino (Italy)

Micro-arcsecond precision must rely on the detailed knowledge of instrument parameters and observing conditions for optimal definition of data reduction and calibration procedures. The variation of instrumental response over the field of view with wavelength and in time is potentially critical and often unavoidable.

With this work we give an overview of Astrometric Instrument Model (AIM) system within the Astrometric Verification Unit (AVU), recalling on the original motivations for its realization, the changes occurred during the last two years and the actual AIM structure and goals, pointing out the most critical parts from the point of view of the modeling of the astrometric instrument and of the scientific treatment of the Gaia data.

Waiting the Gaia operations starting date, we present first results of AIM system performance from the on-progress testing campain of the Gaia data reduction software systems.

8449-64, Session 3

Managing successful industry engagement: the ASKAP experience

C. A. Jackson, Commonwealth Scientific and Industrial Research Organisation (Australia)

The management of industry engagement has been one of the significant challenges in realising the $154M Australian SKA Pathfinder (ASKAP). Not only did ASKAP evolve in scope and scale during its aggressive delivery timeline (2008 - 2013), but its relationship to the proposed international Square Kilometre Array (SKA) radio telescope had to be recognised. In this paper I describe how we have successfully navigated this challenge, forging excellent working relationships with a range of national and international companies, complimented by the establishment of a supportive national industry cluster (ASKAIC).

8449-15, Session 4

The information management tool (IMT) of Gaia DPAC and its potential as tool for large scale software development projects

G. Comoretto, J. Gallegos, S. G. Els, G. Gonzalo, T. Lock, E. Mercier, W. O'Mullane, European Space Astronomy Ctr. (Spain)

We will describe the software tool which was developed in the Gaia-DPAC framework and is now used to track requirements, testing activity and thus allows a quantitative software progress monitoring. It is currently ingesting the latex based DPAC documentation, but could easily be extended for other types of documentation and quality metrics.

8449-16, Session 4

The organization and management of the Virtual Astronomical Observatory

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The U. S. Virtual Astronomical Observatory (VAO; us-vao.org) has been in operation since May 2010. Its goal is to enable new science through efficient integration of seamless integration of distributed multiwavelength data. The VAO project comprises eleven member institutions that use their collective expertise to operate the VAO and provide user services, the equivalent of instruments in a physical observatory. The distributed nature of the project, and its tight budget, places strong demands on its management. This paper will describe the management practices of the VAO, informed by an NSF workshop on "Building Effective Virtual Organizations."

A Limited Liability Corporation oversees the VAO, appoints a Director and establishes contracts with the institutions to execute an annual Project Execution Plan, based on needs and past performance. The Plan is derived in close consultation with an external Science Council, and is informed by an aggressive program of community outreach, led by the Project Scientist. The technical work is negotiated by a Program Council representing the member organizations, and then divided into work areas, each with a designated lead reporting to the Program Manager and the Director.

The project places strong emphasis on regular electronic and face-to-face communications to assess progress and respond to new problems. Communications include formal reporting, regular video and telephone meetings, and informal one-on-on communication. Development is based on industry-standard life cycle models, but the project performs regular assessments of their effectiveness and invites the feedback of the team in tailoring them to the project.

8449-17, Session 4

Managing distributed software development in the Virtual Astronomical Observatory

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B. Refsdal, Smithsonian Astrophysical Observatory (United States) and SAY Media, Inc. (United States); B. Thomas, National Optical Astronomy Observatory (United States); R. Thompson, Space Telescope Science Institute (United States)

The U.S. Virtual Astronomical Observatory (VAO) is a product-driven organization that provides new scientific research capabilities to the astronomical community. Software development for the VAO follows a light-weight framework that guides development of science applications and infrastructure. Challenges to be overcome include distributed development teams, part-time efforts, and highly constrained schedules. We describe the process we followed to conquer these challenges while developing Iris, the VAO application for analysis of 1-D astronomical spectral energy distributions (SEDs). Iris was successfully built and released in less than a year with a team distributed across four institutions. The project followed existing International Virtual Observatory Alliance (IVOA) interoperability standards for spectral data and contributed a SED library as a by-product of the project. We emphasize lessons learned that will be folded into future development efforts. A well-defined process that provides guidelines to ensure the project is cohesive and stays on track is key to success. Internal product deliveries (or "drops") with a planned test and feedback loop are critical. Drops are measured against use cases established early in the process, and provide the opportunity to assess priorities and make course corrections during development. Also key is the participation of a stakeholder such as a lead scientist who manages the technical questions, advises on priorities, and is actively involved as a lead tester. Finally, frequent scheduled communications (for example a bi-weekly teleconference) assure issues are resolved quickly and the team is working toward a common vision.

8449-18, Session 4

Observatory facility staff requirements and local labor markets

D. Rabanus, European Southern Observatory (Chile); M. Keating, ALMA (Chile)

Current large observatories, both in operation and projects in development and construction, face the challenge that skilled personnel needs to be found for integration and operation. Typical locations of these observatories are found to be remote, mainly due to electromagnetic pollution prevention, which in many if not all cases reduces the attractiveness of the work posts. Additionally, budget limitations restrict the recruitment radius to the local labor market in order to save on expatriation spending. This paper outlines these constraints in more detail and depicts the requirement for elaborate training programs on various levels, which as such may also be costly. This, in turn, requires policy making of the organizations for staff retention and career path developments. Therefore, financial modeling, contingency, risk and quality management, and the reliability, availability, and maintainability of an observatory are directly coupled to the local embedding in the labor market of the host country.

8449-19, Session 4

Astronomical large projects managed with MANATEE: management tool for effective engineering

M. L. García-Vargas, FRACTAL S.L.N.E (Spain); E. Mujica-Alvarez, A. Pérez Calpena, FRACTAL S.L.N.E. (Spain)

This paper describes MANATEE, which is the Management project web tool developed by FRACTAL, especifically designed for managing large astronomical projects. MANATEE facilitates the management (not only the planning) by providing an overall view of the project and the capabilities to control the three projects parameters: scope, schedule and budget. MANATEE is an application of the FRACTAL System & Project Suite, which is composed by other two tools: GECO (System Engineering Tool) and DOCMA (Documentation Management Tool). These tools are especially suited for those Consortia that collaborate in a multi-discipline, complex project in a geographically distributed environment. Our Management view has been applied successfully in several projects and currently is being used for Managing MEGARA, the next instrument for the GTC 10m telescope.

8449-20, Session 4

The important role of maintenance in the functionality and life of the observatories: the international standard S1000D for ALMA antennas

G. Marchiori, F. Formentin, A. Busatta, L. Fardella, L. Giacomel, S. Grotto, European Industrial Engineering s.r.l. (Italy)

Prepare user and maintenance manuals for all the instruments and equipment of Large Observatories working in harsh environment, requires great efforts to be complete as well as user friendly. For this purpose, a standardized system such as S1000D, widely used in aerospace industry, was firstly investigated and than adopted representing undoubtedly one leap forward. Specifically in the ALMA project, this standardized system was applied for the maintenance manual of the European antennas. This choice led to a series of benefits which will be outlined in this paper through a brief explanation of the S1000D standard and some excerpts of the manual. The benefits mainly consist in the time saved during the writing and editing of the maintenance manual, its completeness due to the module based workflow and its readiness of use for the end user.

8449-21, Session 5

Management of large astronomical contracts: the E-ELT case

A. M. McPherson, D. Tait, J. Spyromilio, European Southern Observatory (Germany)

E-ELT is a very large astronomical project with the aim of constructing a 40m class optical telescope on Cerro Armazones in Chile. Such programmes are very demanding for astronomical organisations to plan and manage. The methodology to manage control

Key redesign drivers are explained and final redesign details of all major subsystems are outlined. In general, the original compact dome design philosophy is maintained and adapted to the new dimensions. Cost optimisation strategies are applied throughout the detailed design update process. Special attention is also given to some specific new items now included in the modified baseline, such as the special ad-hoc seismic base isolation system for the telescope foundation.

8449-22, Session 5

The Large Synoptic Survey Telescope project management control system

J. Kantor, LSST Corp. (United States)

The Large Synoptic Survey Telescope (LSST) program is jointly funded by the NSF, the DOE, and private institutions and donors. The LSST Data Management System (DMS) is one of three main subsystems of the LSST, and is a large data management project by astronomy standards, processing and archiving over 70 petabyes of image data and producing over 20 petabytes of catalogs, and generating 2 million transient alerts per night. Over the 6-year construction and commissioning phase, the DM project is estimated to require 600,000 hours of engineering effort. In total, the DMS cost is approximately 60% hardware/system software and 40% labor.

From an NSF funding standpoint, the LSST is a Major Research Equipment and Facilities (MREFC) project and the funding process requires proposals and R&D reviews to include: activity-based budgets and schedules; documented basis of estimates; risk-based contingency analysis; cost escalation and categorization.

The commercial tool Primavera P6 contains approximately 90% of the planning and estimating capability needed to satisfy R&D phase requirements "out of the box", and is customizable/configurable for remainder with relatively little effort. We describe the customization/configuration and use of Primavera for the LSST Project Management Control System (PMCS), assess our experience to date, and describe future directions.

8449-23, Session 5

But I'm an engineer--not a contracts lawyer!

M. Warner, H. S. Bass, National Optical Astronomy Observatory (United States)

Industrial partners, commercial vendors, and subsystem contractors play a large role in the design and construction of modern telescopes. Because many telescope projects carry relatively small staffs, engineers are often required to perform the additional functions of technical writing, cost estimating, and contract bidding and negotiating. The skills required to carry out these tasks are not normally taught in traditional engineering programs. As a result, engineers often learn to write Request for Proposals (RFPs), select vendors, and negotiate contracts by trial-and-error and/or by adapting previous project documents to match their own requirements. Typically, this means that at the end of a contract the engineer has a large list of do's, don'ts, and lessons learned for the next RFP he or she must generate. This paper will present one such engineer's experience writing and bidding proposal packages for large telescope components and subsystems. Included are: thoughts on structuring SOWs, Specs, ICDs, and other RFP documents; modern methods for bidding the work; and systematic means for selecting and negotiating with a contractor to arrive at the best value for the project.

8449-24, Session 5

Assembly, integration, and verification (AIV) in ALMA: series processing of array elements

B. Lopez, R. Jager, N. D. Whyborn, L. B. G. Knee, Atacama Large Millimeter Array (Chile); J. P. McMullin, National Solar Observatory (United States)

The Atacama Large Millimeter/submillimeter Array (ALMA) is a joint project between astronomical organizations in Europe, North America, and East Asia, in collaboration with the Republic of Chile. ALMA will consist of at least 54 twelve-meter antennas and 12 seven-meter antennas operating as an aperture synthesis array in the (sub)millimeter wavelength range. It is the responsibility of ALMA AIV to deliver the fully assembled, integrated, and verified antennas (array elements) to the telescope array.

After an initial phase of infrastructure setup AIV activities began when the first ALMA antenna and subsystems became available in mid 2008. During the second semester of 2009 a project-wide effort was made to put in operation a first 3-antenna interferometer at the array operations site. In 2010 the AIV focus was the transition from event-driven activities towards routine series production. Also, due to the ramp-up of operations activities, AIV underwent an organizational change from an autonomous department into a project within a strong matrix management structure. When the subsystem deliveries stabilized in early 2011, steady-state series processing could be achieved in an efficient and reliable manner. The challenge today is to maintain this production pace until completion towards the end of 2013.

This paper describes the way ALMA AIV evolved successfully from the initial phase to the present steady state of array element series processing. It elaborates on the different project phases and their relationships, presents processing statistics, illustrates the lessons learned and relevant best practices, and concludes with an outlook of the path towards completion.

8449-25, Session 6

Managing complex space missions: the James Webb Space Telescope

W. R. Ochs, NASA Goddard Space Flight Ctr. (United States)

Mr. Ochs has been a project manager for several NASA space projects since the late 1990's. He is currently the JWST project manager. Based on his Project Management experience, he will discuss what he believes is working well for managing space projects and what can or should be improved. He will also provide a JWST project overview and discuss the specific management structure and some of the challenges on the JWST project.

8449-26, Session 6

Successfully project managing a large European consortium in a trans-Atlantic relationship

J. Thatcher, EADS Astrium Ltd. (United Kingdom)

Mr Thatcher is the Project Manager for the ten-nation European Consortium providing the European share of the Mid-Infrared Instrument (MIRI) for JWST. He has worked in the space industry for 30 years and been in his present role since 2004. He will outline the approach taken to achieve the successful development and delivery of this instrument in a complex, multi-national environment. This will include his personal opinions on the critical success factors along with lessons to be drawn for future projects.

8449-28, Session 6

PS2: managing the next step in the Pan-STARRS wide field survey system

W. S. Burgett, Univ. of Hawai'i (United States)

The Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) is unique among the existing or currently planned major ground-based optical survey systems as the only "distributed aperture" system. The concept of increasing system etendue by replicating small telescopes and digital cameras presents both management and systems engineering opportunities and challenges compared to survey systems whose etendue is based on a single optical train. In this paper, those opportunities and challenges are described based on the experiences from building the Pan-STARRS PS1 system (fully operational since early 2010) and the soon-to-be completed PS2 system. After a brief overview of the Pan-STARRS hardware, software, and data management design and performance, the focus is on management lessons learned from PS1, and how those have been used to update and shape the management plan for PS2. The management plan components emphasized here include technical development management, financial and schedule planning, and critical path and risk management. Finally, the status and schedule for PS2 are presented, including PS2 integration with PS1 to form the "PS1+2" system scheduled to begin full science operations in early 2014.

8449-37, Session 6

Incentive contracts for development projects

D. T. Finley, General Dynamics SATCOM Technologies (United

States); W. T. DeGroff, Lowell Observatory (United States); B. W. Smith, X Double Dot, LLC (United States)

Finding a contract vehicle that balances the concerns of the customer and the contractor in a development project can be difficult. The owner wants a low price and an early delivery, with as few surprises as possible as the project progresses. The contractor wants sufficient cost and schedule to cover risk. Both want to clearly define what each party will provide. Many program offices do not want to award cost plus contracts because their funding sources will not allow it, their boards do not want an open ended commitment, and they feel like they lose financial control of the project. A fixed price incentive contract, with a mutually agreed upon target cost, provides the owner with visibility into the project and input into the execution of the project, encourages both parties to save costs, and stimulates a collaborative atmosphere by aligning the respective interests.

8449-29, Session 7

Systems modeling of the James Webb Space Telescope

D. M. Muheim, M. T. Menzel, NASA Goddard Space Flight Ctr. (United States)

The James Web Space Telescope (JWST) is a large, infrared-optimized space telescope scheduled for launch in 2018. JWST is an international collaboration between NASA, the European Space Agency (ESA), and the Canadian Space Agency (CSA). The NASA Goddard Space Flight Center is managing the development effort. The prime contractor is Northrop Grumman; the Space Telescope Science Institute is responsible for JWST science operations after launch. The imaging performance of the telescope will be diffraction limited at 2μm, defined as having a Strehl ratio >0.8. System-level verification of critical performance requirements will rely on integrated observatory models that predict the wavefront error accurately enough to verify that allocated top-level wavefront error of 150 nm root-mean-squared (rms) through to the wave-front sensor focal plane is met. Furthermore, responses in several key disciplines are strongly cross-coupled. The size of the lightweight observatory structure, coupled with the need to test at cryogenic temperatures, effectively precludes validation of the models and verification of optical performance with a single test in 1-g. Rather, a complex series of incremental tests and measurements are used to anchor components of the end-to-end models at various levels of subassembly, with the ultimate verification of optical performance is by analysis using the assembled models. The assembled models themselves are complex and require the insight of technical experts to assess their ability to meet their objectives. This paper describes the breadth of the systems engineering and modeling approach used on the JWST including technical performance metrics management. The scope of the systems-level modeling includes stowed dynamics, deployed dynamics, thermal, thermal distortion, straylight, optics and attitude control systems.

8449-30, Session 7

Integrated telescope model for James Webb Space Telescope

J. S. Knight, A. A. Barto, P. A. Lightsey, Ball Aerospace & Technologies Corp. (United States)

Integrated modeling is a valuable tool for analyzing complex optical-mechanical systems such as the James Webb Space Telescope. An implementation, the Integrated Telescope Model (ITM), has been developed for JWST to analyze the performance of the Observatory. ITM is an end-to-end physical math model starting from stellar photons through the image produced by the science data pipeline. The model also includes all effects that contribute to the formation of the image including pointing errors, vibration and thermal distortions of the optical system, and the mechanical response of the mirrors and actuation devices. A time domain interface to the attitude control system rounds out the capabilities. The model is used over the life-cycle of the JWST program including: development, verification and on-orbit operation. ITM is used to perform verification analysis on the set of test data resulting in a statistical assessment of the expected observatory performance. This capability offers numerous advantages to the verification of the system, validation of the wavefront sensing and control (WFS&C) system along with system level studies for design assessments. ITM has been developed to interface to the ground control system in the same way as the actual observatory. This allows it to be used as substitute for the actual observatory for training, mission planning and operational trades.

8449-31, Session 7

The Large Synoptic Survey Telescope (LSST) instrument model development

D. K. Gilmore, S. M. Kahn, P. Hascall, M. Nordby, A. J. Roodman, SLAC National Accelerator Lab. (United States); V. J. Riot, Lawrence Livermore National Lab. (United States)

The purpose of an astronomical camera instrument model is to:

1. Accurately predict the camera scientific performance based on the camera physical effects through analysis, simulations, and measurements of camera components.
2. Present a complete performance model based on these effects that will then help assess systematics with the as-built system for use in science analysis.
3. Continually update the model during the course of R&D and construction as data are accumulated.

The development of an instrument model is standard practice in particle physics, but is currently much less common in astronomy. With the evolution of astronomical instruments and systems now requiring more detailed knowledge of the exact performance of the individual components, modeling is necessary to factor in and calibrate out systematic errors and variations in performance of each component. Therefore, for instrument design attempting high precision observations today, an instrument model is a necessary part of the design and implementation process.

The LSST instrument model is designed to identify and quantify the potential degradation of all components, i.e., electrical, optical, mechanical or sensor, of image quality and throughput. The LSST instrument model process, status and contributions to understanding the performance of the LSST camera, the largest and most demanding astronomical camera today, that will make precision observations to help understand the nature of dark energy and dark matter using lensing techniques and photometric redshifts, will be presented.

8449-33, Session 7

Simulation of Chinese SONG telescope

L. Gao, Nanjing Institute of Astronomical Optics & Technology (China) and Graduate Univ. of Chinese Academy of Sciences (China); G. Wang, Nanjing Institute of Astronomical Optics & Technology (China); C. Li, Nanjing Institute of Astronomical Optics & Technology (China) and Graduate Univ. of Chinese Academy of Sciences (China)

SONG (Stellar Oscillation Network Group) is an international initiative to design, build, and utilize a global network of eight 1-meter class telescopes to be operated as a whole-Earth telescope initiated by Danish. China has joined the international SONG project in 2009 and will build one 1-meter telescope as the node of SONG global network in China. This paper shows the electromechanical integrated modeling and simulation of Chinese SONG telescope. Firstly the mechanical model is made using finite element analysis software ANSYS. With the help of this model and ANSYS software, some structural characteristics can be calculated, such as stiffness, eigenfrequency. Secondly, the control system model is made using Matlab/simulink. The two models are combined with the interface and communication protocol between the two softwares to make the simulation of electromechanical system. In the second part we will give the simulation results and performance of the whole system based on the design parameters and give some correction suggestions.

8449-27, Session 8

Managing large astronomy projects: Herschel-HIFI and ALMA

M. W. M. de Graauw, R. J. Kurz, ALMA (Chile); K. Wafelbakker, SRON Nationaal Instituut voor Ruimteonderzoek (Netherlands)

As astronomical projects are aiming for higher angular and spectral resolution and larger collecting area, the project teams have become more complex to deal with the wider variety of technologies, and are geographically more distributed to meet the larger budgetary requirements.

Two recent examples are the Heterodyne Instrument for the Far-Infrared (HIFI) on-board ESA's Herschel Space Observatory and the Atacama Large Millimeter/submillimeter Array (ALMA) a ground based observatory under construction in the Andes in the North of Chile.

Both projects are indeed large international projects in terms of scope, carried out by large consortia of institutes with a wide geographic distribution. We will describe and analyse the governance and management approaches for these two projects, the similarities and differences in their programmatic and technical management and the tools used during the various phases of the program.

8449-34, Session 8

The black hole of U.S. export controls: effective techniques for navigating away from the gravitation pull

K. Scarlott, Goulston & Storrs (United States)

No abstract available

8449-35, Session 8

Managing SPHERE, a multinational instrument project for VLT

P. Puget, Lab. d'Astrophysique de l'Observatoire de Grenoble (France)

SPHERE (Spectro-Polarimetric High-contrast Exoplanet Research) is a second generation instrument for the ESO Very Large Telescope (VLT), optimized for very high-contrast imaging around bright stars. We intend to present how the management of the development of such a very challenging instrument, both in terms of performances (many components are very close to the technological limits) and of the needed operational reliability (foreseen use at high rates for over 10 years), requires a specific approach during all phases of the project. In particular, high level R&T programs should be initiated early in the project, in order to demonstrate the availability of several critical components, in parallel with conceptual studies and end-to-end simulations. These early steps are required to secure the project selection. Also the level of the required budget leads to the organization of a quite large consortium of institutes (12 in the case of SPHERE), and involves additional negotiations with several funding agencies. Later in the project life, critical issues include the follow-up of the development taking place at several locations, the monitoring of the numerous interfaces at the levels of components and sub-systems, as well as the integration and tests of all sub-systems allowing to start the global integration and characterization. During this last phase, the project management will obviously be faced with critical choices between loss of performances, schedule delays and budgetary issues, in order to allow for early science observations in the context of a very strong international competition. Finally, the diversity of background and cultural approach of the numerous teams involved in the project can prove to be critical.

8449-36, Session 8

The MUSE project face to face with reality

P. Caillier, Observatoire de Lyon (France)

MUSE (Multi Unit Spectroscopic Explorer) is a second generation instrument built for ESO (European Southern Observatory) to be installed in Chile on the VLT (Very Large Telescope) at the end of year 2012. The MUSE project is supported by a European consortium of 7 institutes.

After the critical turning point of shifting from the design to the manufacturing phase, the MUSE project has now completed the realization of its different sub-systems and should finalize its global integration and test in Europe by July 2012.

To arrive to this point many challenges had to be overcome, many technical difficulties, non compliances or procurements delays which seemed at the time overwhelming. Now is the time to face the results of our organization, of our strategy, of our choices. Now is the time to face the reality of the MUSE instrument.

During the design phase a plan was provided by the project management in order to achieve the realization of the MUSE instrument in specification, time and cost. This critical moment in the project life when the instrument takes shape and reality cannot be avoided is the opportunity to look not only at the outcome but also to see how well we followed the original plan, what had to be changed or adapted and what should have been.

Finally, we will have a glimpse on the remaining challenges to reach the final step of our journey on MUSE project with the installation and acceptance on the telescope.

8449-38, Session 9

Modeling the polarimetric behavior of optical systems with the M&m's code

M. de Juan Ovelar, F. Snik, Leiden Observatory (Netherlands); R. Roelfsema, ASTRON (Netherlands); C. U. Keller, Leiden Observatory (Netherlands)

Polarimetry is a very powerful technique that has gained presence in night astronomy due to the valuable information that it provides and that can't easily be retrieved by other means. Currently most telescopes include more or less advanced polarimetric facilities and large telescopes count on it for their planet-finder instruments like SPHERE-ZIMPOL on the VLT or EPICS on the future E-ELT. One of the main limitations of this technique is the polarization created by the telescope and the optical system up to and including the polarimeter, which can often be larger than the signal to be measured, and which is therefore crucial to characterize such that quantitative and accurate polarimetry can be performed. This instrumental polarization can be calibrated to a certain degree for a particular system but in most cases it changes over time and is dependent on the errors affecting the optical elements of the system. We have modeled different telescope layouts to characterize the instrumental polarization generated on their optical paths and analyze its dependency on physical parameters using the M&m's code, an error budget and performance simulator for polarimetric systems currently being applied to characterize the VLT and E-ELT telescopes for their respective polarimeters. The M&m's code is able to analyze separately the effect of errors in the system predicting beforehand the polarimetric performance of an instrument as a function of e.g. telescope pointing and wavelength, and how the instrumental polarization is dependent on the characteristics of the system.

8449-39, Session 9

CODEX optical stability under microvibration environment: Is the Nasmith focal station suitable or not?

M. Riva, F. M. Zerbi, INAF - Osservatorio Astronomico di Brera (Italy); L. Pasquini, European Southern Observatory (Germany)

This paper wants to address the optomechanical stability of the Codex instrument pending onto vibration environment. CODEX is a study for an high resolution spectrograph for the European ELT. CODEX is conceived to reach the highest precision and stability, allowing the execution of programs spanning many years. The CODEX design is based on its precursor at VLT named ESPRESSO, which is an extension of the positive HARPS experience. In particular the aim of the work is a preliminary verification of the instrument performances if mounted at the E-ELT Folded Nasmith location. The target of the activity was to address the relationship between ground vibration noise and the image stability of CODEX. For this reason the Dynamic environment of the Coudè and the folded Nasmith locations were alternatively applied to the optical layout to verify the image performances in terms of image displacements and FWHM deformations. In particular a random vibration analysis has been conducted considering 5ug/Hz^(1/2) of PSD onto a representative Finite Element Model dummy of the main fork of the E-ELT. A possible PSD of the Nasmith location has been obtained and applied to the CODEX Finite Element Model connection points. The displacements RMS (6 DoF) of the optical elements have been applied to the BLUE arm of the optical layout obtaining optical perturbations. In addition damping strategies has been verified for the improvement of the performances.

8449-40, Session 9

Using local entropy as a merit function in a sensorless AO arrangement

V. Suc, Univ. Politècnica de Catalunya (Spain) and Pontificia Univ. Católica de Chile (Chile); S. Royo, Univ. Politècnica de Catalunya (Spain); A. Jordan, Pontificia Univ. Católica de Chile (Chile)

We present a method for measuring focus, field curvature and collimation aberrations on wide field telescopes based on an entropy analysis of a series of images at different positions of the focuser.

The system is calibrated using the evolution of the entropy as a function of both the position in the field and the focuser position.

This gives us a model defining the tilt of the detector, the position of the optical axis in the frame and the field curvature. We compare the stability of this method with a similar algorithm using the fwhm of the stars and show that the shape-independent property of the entropy makes the system more robust in the case of highly defocused images.In a next step, local entropy measurements over the image can be used in order to get an estimation of collimation and focusing from a single image.

8449-41, Session 9

Modelling the optical pathway of the Large Binocular Telescope

M. Böhm, Univ. Stuttgart (Germany) and Max-Planck-Institut für Astronomie (Germany); J. Pott, Max-Planck-Institut für Astronomie (Germany); O. Sawodny, Univ. Stuttgart (Germany); T. M. Herbst, M. Kürster, Max-Planck-Institut für Astronomie (Germany)

In this paper, a linear model describing the Large Binocular Telescope's optical pathway is derived in modal coordinates. For modal basis functions, physically motivated sin() and cos() functions are used. At first, an approximation of the modal shapes and eigenfrequencies is given using a finite element method. Afterwards, the modal parameters, including modal damping, are identified using experimental modal analysis. The experiment is described and the results are compared with the FEM analysis. In the second half of the paper, we will incorporate disturbances, such as wind forces and single excitations induced by vibrating machinery, into the model. In the end, simulation results for the model derived from experiments will be presented and compared to measured time series.

8449-42, Session 9

Dynamical attitude model for Gaia and attitude reconstruction

D. Risquez, Leiden Observatory (Netherlands); F. van Leeuwen, Univ. of Cambridge (United Kingdom); A. G. A. Brown, Leiden Observatory (Netherlands)

The Dynamical Attitude Model (DAM) is a simulation developed to achieve a detailed understanding of the Gaia spacecraft attitude.

The main goal of the Gaia mission (due to be launched in 2013) is to obtain extremely accurate astrometry, and this astrometry is measured with respect to the attitude of the spacecraft. Therefore a detailed knowledge of the spacecraft attitude is required.

This simulation is implemented in Java and takes into account disturbances such as solar radiation pressure, thermal infra-red emission from spacecraft surface, impact of micro-meteoroids and clanks (discontinuities in the attitude while the angular rate is constant). It considers as well internal hardware components controlling the satellite like the AOCS (Attitude and Orbit Control System), sensors (a star tracker and an angular rate sensor attached to the main instrument) and micro-Newton thrusters.

The spacecraft attitude is measured using CCDs working in TDI (Time Delay Integration) mode. Hence the measured attitude is not the true (instantaneous) one, but the averaged attitude during integration times. Additionally, due to the configuration of the Gaia focal plane, there is not a single integration time but a set of possible integration times. And finally the measured attitude is fitted using polynomials. All these steps introduce noise which has to be characterised.

This contribution provides a brief description of DAM and an analysis of the noise introduced in Gaia's scientific output due to the attitude reconstruction. This work will allow to test the Gaia software prior to launch with very realistic data as part of the pipeline validation.

8449-44, Session 10

E-ELT seismic devices analysis and prototype testing

C. Gomez, A. Aviles, A. Bilbao, IDOM (Spain); F. Koch, P. Ghiretti, European Southern Observatory (Germany); D. Siepe, P. Nawrotzki, GERB Schwingungsisolierungen GmbH & Co. KG (Germany)

During the E-ELT Dome and Foundations FEED Study, IDOM developed a Base Control System for protection of the E-ELT Main Structure against the effect of high level earthquakes. The proposed design was aimed to provide an effective isolation during heavy seismic events, whereas in normal observation conditions it presented a high stiffness to avoid interferences with the pointing accuracy of the telescope.

In a subsequent phase, a representative prototype was envisaged by IDOM, in close collaboration with GERB, to evaluate the performance of this system, correlate the results from prototype testing with the behaviour predicted by a calculation model and finally validate the design conceived during the FEED Study.

The assessment of the results from the prototype tests has been focused on checking the level of compliance with the demanded requirements:1) the Base Control System isolates the upper structure from ground in

case of high magnitude seismic events; 2) in operational conditions, the system -by means of Preloaded Devices (PLDs)- provides a stiff interface with the ground; 3) regarding the performance of the PLDs,the finite element model simulates accurately the non-linear behaviour, particularly the zero crossing when the direction of the excitation changes; 4) there is no degradation of the stiffness properties of the seismic devices, after being submitted to a heavy seismic event.

The prototype was manufactured by GERB and pseudo-integrated tests were performed on a shaking table at the premises of the Institute of Earthquake Engineering (IZIIS) in Skopje, Macedonia.

8449-45, Session 10

A new optomechanical structural optimization approach: coupling FEA and Raytracing sensitivity matrices

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The design of astronomical instrument is growing in dimension and complexity, following the new requirements imposed by ELT class telescopes. The availability of new structural material like composite ones is asking for more robust and reliable designing numerical tools. This paper wants to show a new opto-mechanical optimization approach developed starting from a previously developed integrated design framework. The basic Idea is to reduce number of iteration in a multivariable structural optimization taking advantage of the embedded sensitivity routines that are available both in FEA software and in raytracing ones. The approach obtain sensitivity matrixes that directly connect the structural parameters (plate thickness, beam radius, ...) to optical performances. FEA software usually have routines that provide sensitivity matrixes of selected structural values respect to target parameter, for example the diameter of a rod respect to its tip displacement. On the other hand the raytracing software can provide optical sensitivity matrixes of optical quality (displacement or aberrations) respect to optical element displacement. By simply multiplying this matrixes one directly obtain sensitivity of optical quality respect to structural parameters. The technique developed is based onto Matlab commands and run in parallel the FEA and Raytracing sensitivity extrapolation, evaluate then the new parameters for the following optimization step and run the new analysis. This approach provide reduced iteration number mainly in case of high number of structural variable parameters.

8449-46, Session 10

Dynamic analysis of active control system for CGST

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The Chinese Giant Solar Telescope (CGST) is the next generation solar telescope of China with diameter of 8 meter. The unique feature of CGST is that its primary is a ring, which facilitates the polarization detection and thermal control. CGST is now in its design and development phase. Mosaic mirror with 24 trapezoid segments is a candidate scheme for its primary mirror, which depends on a segment active control system to achieve the optical quality of a monolithic mirror. The most significant difference of the segment control system of a ring telescope from other full-aperture telescopes is that in addition to edge measurements, tip measurements of each segment are required to complete the feedback information of control system. High precision real-time tip sensing is crucial for such control system. Its precision depends on integration time (or work bandwidth) when the optical metrology is used, which should match the bandwidth of segment control system. In this paper, a dynamic analysis of segment control system of CGST is presented, which demonstrates how the dynamic interaction between the segment control system and the telescope structure impacts the telescope's optical performance in the wind disturbances. The dynamic analysis helps to understand the bandwidth limit for segment control system, and thus give the demand for tip sensing implementation.

8449-47, Session 10

Integrated modeling support of the FINESSE mission: achieving a very stable LOS in low-earth orbit

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The demand for increasingly stable platforms for space-based observations has meant launching into a Lagrange point orbit (L2) or an earth trailing orbit. This results in a higher mission cost due to the larger launch vehicles and more sophisticated telecommunication hardware. FINESSE (Fast Infrared Exoplanet Spectroscopy Survey Explorer) is an Explorer class mission dedicated to characterizing transiting exoplanet atmospheres. The spectrograph operates in the 0.7-5.0 microns wavelength range and measures the exoplanet system light curve with a precision of 100 ppm. To achieve this line-of-sight (LOS) stability, the FINESSE observatory has been carefully engineered with knowledge gained from previous missions such as Kepler and well validated modeling tools. Several papers are presented at this conference on FINESSE and the approach to engineering a stable platform1,2,3. In this paper we address use of EOSyM (End-to-end Optical System Model), an integrated modeling environment, to support the JPL error budget process and in particular minimizing high frequency vibrations due to cryocoolers and reaction wheels, and the effects of a time-varying temperature field and attitude control system drift components. We also discuss validation of the integrated model from use on other programs.

8449-57, Session 10

Modeling for instrument diagnostics: study and analysis of Gaia non-nominal configurations impact on astrometric performance

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The Gaia mission will perform global astrometric measurements with micro-arcsecond level accuracy on positions, parallax and proper montions of one bilion stars ever produced.

Knowledge of the instrumental outputs as well as possible is one of the crucial aspects of maintenance such a goal.

The Gaia payload is a highly sophisticated system and many of its instrumental behaviors will be tested at proper accuracy only during the operational phase.

However simulation results are critical parts of developing system integration and test plans, as well as in understanding unexpected behavior during implementation and commissioning.

The data analysis procedures are sensitive to several instrument parameters, which can be either disentangled from each other or estimated as collective contributions when degenerate, and to their variation over the field and with time.

In case of parameter degeneration, specific parametrization algorithms can support a set of suitable acceptable solutions.

We focused our dissertation on the study and analysis of non-nominal configurations effects on astrometric accuracy.

We identify and quantify the effects and obtain parametric relations between possible instrument configuration parameters and the degradation of the Gaia image profile.

We move from this forward analysis to look at the data and will realize, from the models, the monitoring and diagnostic procedures with the intent of recovering as much as possible of the astrometric damage caused by the instrumental deviations and therefore mitigate possible degradation in the mission accuracy.

We conducted the study in the context of the Astrometric verification unit as one of the essential activity for the verification of GAIA measurements.

8449-48, Poster Session

ALMA band 3 receiver maintenance plan

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Under the "Memorandum of Understanding between the National Radio Astronomy Observatory/Associated Universities Incorporated, Herzberg Institute of Astrophysics (HIA) and the University of Calgary related to Canadian ALMA Construction Phase Work Packages", HIA is committed to deliver a suite of seventy-three Band 3 100 GHz receiver cartridges to the ALMA Project. After the acceptance of each cartridge at the Front End Integration Centers, HIA is responsible to perform any post-delivery maintenance, repair and rework of the cartridges for a warranty period of up to one year. This paper defines a framework for the maintenance and repair services for the Band 3 cartridges after the post-delivery warranty period has expired. This framework consists of a detailed work breakdown structure, timelines and labour effort estimates of the major tasks related maintenance and repair services of ALMA Band 3 cartridges. The Band 3 cartridge maintenance program to be conducted at HIA between 2012 and 2014 will be subdivided into the following work breakdown structures:

1) Transfer of a cartridge test system to the ALMA Observatory support Facility (OSF);

2) Perform cartridge diagnostics and repair services at HIA until the cartridge test facility at the OSF is established in January 2015;

3) Perform diagnose and repair services for any faulty 2SB mixers and cryogenic LNA sub-system assemblies; and

4) Provide a set of spare subsystem compoments as line replaceable units (LRU) in support of the telescope operations for two years.

8449-49, Poster Session

Product and quality assurance processes and ECSS compliance within a science ground segment using Gaia as an example

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The ESA satellite Gaia aims to measure the main astrometric parameters and generate an astrometric catalogue of 109 objects with an accuracy on the micro-arcsec level. To reach this goal the European scientific community has formed the Gaia Data Processing and Analysis Consortium (DPAC). DPAC includes also the Science Operation Centre (SOC) at ESAC and together they constitute the Gaia science ground segment, including a total of more than 400 scientists and engineers. Such a large group of developers represent a massive development effort which requires effective quality monitoring and assurance mechanisms and reporting structures to be in place. In this paper we will outline the procedures and mechanisms setup within the consortium to assure that DPAC software products and the necessary hardware will be ready when they are needed and fulfil their expectations. The experiences gathered in the employed PA/QA process, which is based on the relevant ECSS standards, will be described and will prove useful for other projects of similarly large scale.

8449-50, Poster Session

Gemini planet imager (GPI): project managment and oversight

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In 2004 Gemini commissioned a project to create an extreme adaptive optics coronagraph capability for the Gemini South telescope. A competitive conceptual design study resulted with the Gemini Planet Imager (GPI), a next-generation, fully optimized, exoplanet-finding instrument designed to detect and fully characterize Jovian-sized planets at both near-infrared wavelengths and high contrast ratios (planet/star ratios of 10-7). In 2006 Gemini Observatory signed contracts with Lawrence Livermore National Laboratory (LLNL), Herzberg Institute of Astrophysics (HIA), Jet Propulsion Laboratory (JPL), University California: Los Angeles (UCLA), University California: Santa Cruz (UCSC) and American Museum of Natural History (AMNH) to design, manufacture, test and deliver GPI to Gemini South. With a total project budget of ~$25m LLNL were contracted to lead and manage the other institutes work on behalf of Gemini. With this challenging project nearing completion this paper examines the project management from both the customer's (Gemini Observatory) and contractor's (Lawrence Livermore National Labs) perspective, describing how the project was structured, managed and overseen.

8449-51, Poster Session

The preresearch of the deploy technology for the large aperture space astronomical telescope

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The spherical primary mirror (Mb) of the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is segmented and composed of 37 hexagonal sub-mirrors, and segmented active optics method is successfully developed in it. LAMOST project has passed through the project acceptance in 2009, and the success of LAMOST makes deployable primary mirror possible. In the future the deployable large aperture space astronomical telescope is one of the most development potential space observation spacecrafts. Taking LAMOST which has a 6.67X6.05m primary mirror as the goal, this paper presents the feasibility of the deployable structure of the large reflecting space telescope's primary mirror. According to the analysis of the design scheme for the deployable primary mirror and basing on the feature and the design of LAMOST, a subdivision type deployment scheme has been given. The locating principle of the both side wings and the locking device after deployment has been analyzed in this paper, and in addition the problems in the process of deployment is preliminary discussed.

8449-52, Poster Session

Gaia mock-up: an educational demonstrative Gaia model

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Gaia is ESA's next-generation space mission aimed at global astrometry at the microarcsecond level. Its science case is devoted to the understanding of our Galaxy's structure, evolution and composition.

The GAIA payload includes two identical telescopes separated by a Basic Angle that, to fulfill the astrometry goal, must be measured with

high accuracy. To this purpose, an interferometric sub-system, the Basic Angle Monitoring (BAM) assembly, has been introduced. The BAM optical concept is based on a pair of laser beams per telescope, producing fringes on a dedicated CCD. The basic measurement principle of BAM consists in monitoring the stability of the fringe pattern phase.

We are developing a mock-up of the Gaia payload (telescopes and BAM) for educational purposes, considered representative of the main concepts embedded in Gaia.

In this paper we describe the design guidelines and analyze some of the key elements related to demonstration of the basic angle monitoring concept.

8449-53, Poster Session

VST system engineering and management of commissioning

P. Schipani, INAF - Osservatorio Astronomico di Capodimonte (Italy)

This paper describes the system engineering work at the VLT Survey Telescope on the ESO's Paranal observatory. The error budget, as well as many subsystems and their integration in the overall telescope system, have been deeply reviewed in the last years of construction and commissioning. The lessons learned in the management of the commissioning of a complex system in a remote site are also analyzed.

8449-54, Poster Session

Analysis and optimization of the SONG Telescope

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SONG is an international initiative to design, build, and utilize a global network of eight 1-meter class telescopes to be operated as a whole-Earth telescope. The telescope is composed of system of azimuth axis, rotating table , fork , system of elevation axis, top-ring, up and down truss, system of primary mirror and so on. For an astronomical telescope mount, having a high stiffness to support the mirror cell and instruments is its basic function. Finite element method (FEM) is a powerful tool to help structure design engineer to achieve this goal. In this paper, with the help of ANSYS, the static and modal analysis, calculation and optimization of the SONG telescope mount will be given. The modal result which is used for avoiding resonance and fatigue failure of the telescope acquire natural frequency of telescope. The FEM results show that the structure, designed for SONG telescope, is feasible and reliable and have a high stiffness-to-weight ratio to meet the optical demands.

8449-55, Poster Session

ALMA system performance analysis tool

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We are developing ALMA system performance analysis tool, which is a package of softwares to predict system performance of ALMA by combinations of models and of measured performance of subsystems. The analysis tool consists of calculation programs compiled by Matlab and database. We adopt graphical user interface and allow users to perform calculations for various conditions easily. Database can be updated via web browsers, thus authorized persons can contribute to maintain the database from anywhere. Eleven calculators, which correspond to each system performance such as system noise temperature, beam pattern, aperture efficiency, and amplitude stability, are available to date.

We are planing to use the analysis tool for verification activities of system performance. Database will be also useful to trend analysis of various performance in future operation.

8449-56, Poster Session

Use of failure modes and effects analysis in design of the tracker system for the HET wide-field upgrade

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In support of the Hobby-Eberly Dark Energy Experiment (HETDEX), the Center for Electromechanics at the University of Texas at Austin was tasked with developing the new Tracker and control system to support the HETDEX Wide-Field Upgrade. The tracker carries the 3,100 kg Prime Focus Instrument Package and Wide Field Corrector approximately 13 meters above the 10m primary mirror. Its safe and reliable operation by a sophisticated control system, over a 20 year life time is a paramount requirement for the project. To account for all potential failures and potential hazards, to both the equipment and personnel involved, an extensive Failure Modes and Effects Analysis (FMEA) was completed early in the project. This task required participation of all the stakeholders over a multi-day meeting with numerous follow up exchanges. The event drove a number of significant design decisions and requirements that might not have been identified this early in the project without this process. The result is a system that has multiple layers of active and passive safety systems to protect the tens of millions of dollars of hardware involved and the people who operate it. This paper will describe the background of the FMEA process, how it was utilized on HETDEX, the critical outcomes, how the required safety systems were implemented, and how they have worked in operation. It should be of interest to engineers, designers, and managers engaging in complex multi-disciplinary and parallel engineering projects that involve automated hardware and control systems with potentially hazardous operating scenarios.

8449-32, Poster Session

MESS: the METIS instrument software simulator

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Instrument software simulators are becoming essential for both supporting the instrument design and planning the future operations. In this paper we present MeSS, the Software Simulator developed for the METIS coronagraph, an instrument of the Solar Orbiter ESA mission. We describe its architecture and the modules it is composed of, and how they interchange data to simulate the whole acquisition chain from the photons entering the front window until the stream of data received and analysed on ground.

Each software module simulates an instrument subsystem by using a mix of theoretical models and measured subsystem properties. A web-based application handles remote user interface from the various Institutions constituting the METIS Consortium, allowing users from various sites to overview and interact with the data flow, making possible for instance input and output at intermediate nodes.

Description of the mode of uses of the simulator, both present and future, are given with some results. These includes not only design-aid tasks, as the evaluation and the tuning of the image compression algorithms, but also those tasks to plan the in-flight observing sequences , based on the possibility provided by the simulator to perform end to end simulation of science cases.

8449-58, Poster Session

Thermo-structural analysis of stresses during fabrication of an optical element for the APF camera

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During the development of the APF (Automated Planet Finder, new telescope/instrument facility at UCO/Lick) camera lens assembly the largest optical element fractured during the fabrication processing. The glass grade is a relatively robust material and not known for any special sensitivity. Transient thermal and structural FEA modeling was performed on the element geometry for several glass materials to better understand the mechanics involved and the relative nature of the properties and response of the glass that failed. Results show that the glass in question yielded the highest stresses of all considered. The analysis technique described here is a simple tool that can be used to evaluate a material and make valid comparisons with others.

8449-59, Poster Session

Design and analysis of China SONG Telescope control system

C. Ren, Nanjing Institute of Astronomical Optics & Technology (China)

SONG (Stellar Oscillations Network Group) is a Danish initiative to design and build a global network of 1-m class telescopes. The plan is to design and build a global network of small telescopes located at 8 existing observatories around the world. The scientific goals of SONG need to obtain long-term and continuous observations (weeks to months). The group behind the SONG proposal has devised a new and innovative concept to overcome these problems in a cost-effective way. China, as one of the eight sites, its 1-m class telescope can achieve the goal for long time continuous, uninterrupted, full automatic observation and works in the diffraction limit condition. At the same time the telescope must realize 0.3 arc second tracking precision without guide star, which is a very challenge and difficult task for 1 meter telescope tracking system .This paper discusses the design and control of the tracking system of Chinese song telescope in detail.

8449-60, Poster Session

The design and simulation of a six-axis vibration isolator for space applications

Y. Zhang, Beijing Institute of Technology (China)

This paper reports on a six-axis vibration isolator for space applications. It is divided into three parts. The first part represents the design of two-stage isolation system for single-axis vibration isolator based on the velocity and acceleration feedback. The second part discusses the optimization for the parameters of the two-stage isolation system. The third part is devoted to the simulation for the six-axis vibration isolator based on the Centralized control.

8449-61, Poster Session

An end-to-end instrument model for the proposed E-ELT instrument METIS

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Today, instruments rely critically on detailed performance requirements. They need to be modelled to give the science and engineering teams a preview of the performance of the instrument, to guide the design process, to prove the capabilities of the instrument and to prepare science ready software tools before the instrument is operational. METIS, the Mid-infrared E-ELT Imager, is an instrument concept for the E-ELT that covers the thermal infrared wavelengths from 2.9-14um (L, M and N band). It contains a diffraction limited imager and an integral field high resolution spectrograph. The instrument consists of two independent units, the imager and the spectrograph, and is entirely encased in a cryostat to maintain the stable low temperatures required for good performance at mid-infrared wavelengths. METIS was selected in November 2011 as the third instrument to be built for the E-ELT, after two first light instruments. Because in the mid-infrared the Earth's atmosphere and the telescope mirrors radiate and produce a very high thermal background, it is crucial to develop techniques and mechanisms to measure and reduce this background, to achieve the desired performance of an E-ELT. To demonstrate the capabilities of METIS, years before the actual instrument is built and can be tested, we are developing an end-to-end instrument model, which will simulate the full capacity of METIS. The structure of the model and first results of the performance evaluation will be shown.

8449-62, Poster Session

A new calculation of LAMOST optical vignetting

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A new method to calculate the optical vignetting of LAMOST (Large Sky Area Muti-Object Fiber Spectroscopic Telescope) is presented. With the pilot survey of LAMOST, it is necessary to have thorough and quantitative estimation and analysis on the observing efficiency which is affected by various factors: the optical system of the telescope and the spectrograph that is vignetting, the focal instrument, and the site condition. The wide field and large pupil of LAMOST fed by a Schmidt reflecting mirror, with a fixed optical axis coinciding with the local polar axis, lead to significant telescope vignetting, caused by the effective light-collecting area of the corrector, the light obstruction of the focal-plate, and the size of the primary mirror. A calculation of the vignetting has been presented by Xue et al. (2007), which considered 4 meter circle limitation and based on ray-tracking. In fact, there is no effect of the 4 meter circle limitation, so that we compute the vignetting again by means of obtaining the ratio of effective projected area of the corrector. All the results are derived by AUTOCAD. Moreover, the vignetting functions and vignetting variations with declination at which the telescope is pointed and the position considered in the focal surface are presented and analysed. Finally, compared with the ray-tracing method to obtain the vignetting before, the validity and availability of the proposed method are illustrated.

SPIE Astronomical Instrumentation

8449-63, Poster Session

WaFER: a tool to derive the focal surface of optical configurations and characterise their optical response

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In the framework of the Italian Space Agency (ASI) Technological Developments aimed at the measurement of the Cosmic Microwave Background (CMB) polarisation, a new method to define and characterize focal surfaces of millimeter wave telescopes has been implemented in a software package named WaFER (Wave Front Error evaluatoR). The purpose of this tool is to rapidly optimize and characterize wide focal planes and to provide the information to select the best optical configuration among those analyzed. This method is based on the GRASP9 Multi-Reflector GTD for the computation of the weighted wave front error and the software output is the 3D focal surface minimizing this figure of merit, in terms of feed horn locations and orientations for polarization measurements. The GRASP9 Physical Optics is iteratively used for the main beam simulations and spillover evaluation. WaFER provides the main descriptive parameters of the main beams computed coupling feed horns located on the evaluated focal surface and the optics. The method has been applied at several telescope configurations and WaFER could be used to define the focal surface of any reflector antenna system that can be studied with GRASP9. It can be used to characterized the main beam descriptive parameters also in terms of polarization properties and straylight. Finally, an estimate of the computational time is reported for each computational step (focal surface evaluation, main beam simulations, polarization alignment).

8450-02, Session 1

Silicon carbide optics for space and ground-based astronomical telescopes

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Silicon Carbide (SiC) optical materials are being applied widely for both space based and ground based optical telescopes. The material provides a superior weight to stiffness ratio, which is an important metric for the design and fabrication of lightweight space telescopes. The material also has superior thermal properties with a low coefficient of thermal expansion, and a high thermal conductivity. The thermal properties advantages are important for both space based and ground based systems, which typically need to operate under stressing thermal conditions. The paper will review L-3 Integrated Optical Systems - SSG's (L-3 SSG) work in developing SiC optics and SiC optical systems for astronomical observing systems. L-3 SSG has been fielding SiC optical components and systems for over 25 years. Space systems described will include early work, including the Miniature Infrared Camera and Spectrometer (MICAS) developed for NASA JPL, and more recently launched systems such as the Long Range Reconnaissance Imager (LORRI) developed for NASA-GSFC. Review of ground based applications of SiC will include supporting L-3 IOS- Brashear's current contract to provide the 0.65 meter diameter, aspheric SiC secondary mirror for the Advanced Technology Solar Telescope (ATST).

8450-03, Session 1

LISA telescope assembly optical stability characterization

A. L. Verlaan, TNO (Netherlands)

The LISA Optical Stability Characterization project is part of the LISA CTP activities to achieve the required TRL level for all of the LISA technologies used. This activity aims demonstration of the Telescope Assembly (TA), with a structure based on CFRP technology, that a CTE of 10-7/K can be achieved with measures to tune the CTE to this level. In addition the demonstration is required to prove that the structure exhibits highly predictable mechanical distortion characteristics when cooling down to -90°C, during outgassing in space and when going from 1g environment to 0g.

This paper describes the test facilities as well as the first test results. A dedicated test setup is designed and realized to allow monitoring dimensional variations of the TA using three interferometers, while varying the temperature in a thermal vacuum chamber. Critical parameters of the verification setup are the length metrology accuracy in thermal vacuum and the thermal vacuum flexibility and stability. The test programme includes Telescope Assembly CTE measurements and thermal gradient characterization.

8450-04, Session 1

Vibration damping for the Segmented Mirror Telescope

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The Segmented Mirror Telescope (SMT) is an experimental testbed for new and emerging lightweight imaging technologies at the Naval Postgraduate School (NPS) in Monterey. With its 3-meter 6-segment primary mirror and advanced wavefront sensing and correction capabilities, the SMT is a prime example of a next-generation deployable telescope with advanced imaging capabilities. This telescope provides research and educational opportunities for the NPS Spacecraft Research and Design Center (SRDC) in high resolution adaptive optics, active vibration and jitter control, integrated system design, and distributed imaging systems. The SMT primary mirror segments collapse into a small volume; once on location, these segments open to the full 3-meter diameter. The segments must be very accurately aligned after deployment and the segment surfaces are actively controlled using numerous small, embedded actuators.

The testbed includes a passive damping system to complement the actuators and mitigate the effects of low-frequency (<40 Hz) vibration modes of the primary mirror segments. Each of the six segments has three or more modes in this bandwidth, and resonant vibration excited by acoustics or small disturbances on the structure can result in phase mismatches between adjacent segments thereby degrading image quality. The damping system consists of two tuned mass dampers (TMDs) for each of the mirror segments. An adjustable TMD design with passive magnetic damping was selected to minimize sensitivity to changes in temperature. The TMDs have been tuned to adjust both frequency and damping characteristics for optimal vibration mitigation. Another feature of the magnetic TMD design is that it can be converted to an active damper if increased performance is required.

Modal testing has been performed to characterize the SMT segments with and without TMDs. Objectives of this test were to determine operating deflection shapes of the mirror and to quantify segment edge displacements; alignment of /4 or better is desired. The testing was performed and vibration mitigation performance was demonstrated with laser vibrometer measurements. The TMDs attenuated the vibration amplitudes better than the goal of 30% and reduced adjacent segment phase mismatches to acceptable levels.

8450-05, Session 1

Mechanical design of First Antarctic Survey Telescope

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According to site testing efforts of recent years, Dome A of the Antarctic plateau is regarded as an extremely good astronomical site on the earth. CSTAR (Chinese Small Telescope ARray), which is composed of four small telescopes with 145mm aperture, has been installed at 2008. First AST3 (Three Antarctic Survey Telescope) has been on its way to Dome A this year by the 28th Chinese National Antarctic expedition team. First Antarctic Survey Telescope is a 500/680mm modified Schmidt telescope with auto-focusing, pointing and tracking function, mainly aimed for observation of supernovae and searching of extra solar planets. This paper presents main mechanical design and special consideration of first AST3, including optical tube, mount, foldable dome and support tower. From domestic testing and observation, it has been proved that this telescope could meet the requirements of harsh environment of Antarctic inland.

8450-06, Session 1

Overall performance of the ALMA antenna during solar observation

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The Atacama Large Millimeter Array (ALMA) consists of a large number of 12 m diameter antennas that will operate up to 950GHz. The antenna must meet all primary operational performances also during solar observation. When the antenna is pointing directly the sun or when the sun is close to the boresight axis, the solar power concentrated by the mirrors cannot damage any part of the antenna. When the antenna is pointing toward the sun, the power absorbed by a black body positioned in the secondary focal area shall not exceed 0.3 W/cm2.

To achieve these requirements, the primary surface of the antenna has a suitable surface scattering treatment. The same thing was done for the surface of the subreflector. Specific tests were performed on the panels surface and secondary mirror during the prototype and production phase in order to optimize the best behaviour. A particular care must be applied in the control of the secondary area, where the entire solar power spectrum, from the UV to the infrared, reflected by the primary mirror, can contribute to overheat reflecting areas support structures.

In this report we provide a series of analysis and results obtained during the solar observation.

8450-07, Session 1

The GREGOR dome, pathfinder for the EST dome

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The completely open-foldable dome of the GREGOR telescope is a further development of the DOT dome, respectively 9 and 7 meter in diameter. New technical developments are implemented and tested at the GREGOR dome, which are important for the design of the much larger dome for the EST, 28 meter in diameter. The GREGOR dome is the first with more than one clamp working simultaneously for closing the dome and bringing the membranes on the required high tension for storm resistance. The storm Delta with 245km/h 1-minute mean maximum at the location of the GREGOR gave no problems nor did the storms afterwards. Opening and closing experiences are up to 90 km/h without problems. Good observing circumstances never occur with higher wind speeds.

A double layer of membranes is applied in the GREGOR construction whereas the DOT dome is equipped with a single layer. Simultaneous climate measurements inside and outside the dome have proven the thermal-insulation capability of this double-layer construction.

The experiences with the GREGOR showed that the elongation by tensioning of the pre-strained membrane material is much lower than originally expected. In the meantime, more strong and stiff membrane material is available and is applied in the EST design. As a consequence, the clamps of the EST can have a relatively much shorter length and there is no need anymore for simultaneous operation of the clamps and the main actuators in low speed with help of a frequency inverter. The clamps can close after finishing of the main bow operation. This simplifies the electrical control.

8450-08, Session 1

The solid telescope as answer to specific application requirements

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Modern astronomical instrumentation is often developed through non traditional configurations and free form optics. Recent technological development allows the manufacturing of exotic surfaces, sometimes very far away from rotationally symmetric geometries.

We propose new developments of the solid telescope concept using multiple reflections between the faces of a single lens.

Taking advantage of modern materials and manufacturing solutions, a compact, robust, and easily replicable optical subsystem could represent an optimal solution for small telescopes tailored to specific applications.

8450-09, Session 2

The opto-mechanical performance prediction of thin mirror segments for E-ELT

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The mirror segments for the E-ELT and TLT are nearly equal in size and shape (hexagonal, 1.2 m over flat sides) and very thin compared to their size (about 50 mm). Supporting these mirrors and obtaining high optical performance is a true challenge from design and manufacturing point of view. TNO has designed and build three identical prototypes for supporting the mirror segments of the E-ELT. These mirror segments vary in size. Hence the gravity deformation of the mirror segments will vary also when no measures are taken to compensate this effect. The paper will concentrate on the design and analysis of the specific design features within the support structure to minimize the mirror deformation due to gravity. These features concern passive and active means to influence the mirror segment shape and to compensate for deformation differences.

8450-10, Session 2

Co-phasing of the segmented mirror based on the generalized phase diversity wavefront sensor

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The stochastic parallel gradient descent algorithm based on the generalized phase diversity wave-front sensor is presented for the co-phasing of the segmented mirror. In order to achieve high accuracy for co-phasing, three phase diversity functions with increasing amplitudes are applied to the sensor for improving the strength of output signal from the wave-front sensor during the aberrations of the segmented mirror decreasing with the co-phasing process. A simulated segmented mirror is used to test the feasibility of this method. The numerical experiments show that the co-phasing accuracy is very high for the aberrations of the segmented mirrors less than 1.5 wavelengths. And the algorithm is very robust and noise tolerant.

8450-11, Session 2

Extremely stable piezo mechanisms for the new Gravitational Wave Observatory

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Detection and observation of gravitational waves requires extreme stability in the frequency range 1e-4 Hz to 1 Hz. NGO will attain this by creating a giant interferometer in space, based on free floating proof masses in three spacecrafts.

To operate NGO, the following piezo mechanisms are needed:

1. A piezo stack mechanism

Due to time delay in the interferometer arms, the beam angle needs to be corrected. A mechanism rotating a mirror with a piezo stack performs this task. The critical requirements are the contribution to the optical path difference (less than 1.4 pm/√Hz) and the angular jitter (less than 8 nrad/√Hz).

2. A piezo sliding mechanism

To switch from primary to the redundant laser source, a Fibre Switching Unit Actuator (FSUA) is developed. The critical requirements are the coalignment of outgoing beams of <+/-1 micro radian and <+/-1 micro meter. A redundant piezo sliding mechanism rotates a wave plate over 45 degrees.

3. A piezo stepping mechanism

Due to seasonal orbit evolution effects, beams have to be corrected over a stroke of +/-2.5 degrees. The critical requirements are the contribution to the optical path difference (less than 3.0 pm/√Hz) and the angular jitter (less than 1 nrad/√Hz). Due to the large stroke, a piezo stepping concept was selected. Dedicated control algorithms have been implemented to achieve these challenging requirements.

This paper gives description of the designs and the ongoing process of qualifying the mechanisms for space applications.

8450-12, Session 2

Metrology for a Solar imaging Fourier transform spectrometer working in the far UV: from the instrumental concept to the first experimental results

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The spectroscopy of the far UV emission lines of the solar emission spectrum combined with an imaging capability is essential to understand the physics of the solar outer atmosphere. An imaging Fourier transform spectrometer is an attractive solution to perform such far-UV solar observations. Working in the far UV involves high precision metrology to mantain the optical path difference(OPD) during the entire interferogram scanning process. It also involves a compact all-reflection optical design for a space-based application.

We present the specifications of a servo-system that enables dynamic tip/tilt alignment compensation and optical path difference sampling measurement of the IFTSUV scanning mirror. We also discuss the first mock-up experimental results, as well as a preliminary design of a device in view of a space-based application.

8450-13, Session 2

Shape memory alloys for astronomical instrumentation: space and ground-based applications

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This paper wants to show possible applications of Shape Memory Alloy (SMA) as functional devices for space and ground based application in Instrumentations for Astronomy. Thermal activated Shape Memory Alloys are materials able to recover their original shape, after an external deformation, if heated above a characteristic temperature. If the recovery of the shape is completely or partially prevented by the presence of constraints, the material can generate recovery stress. Thanks to this feature, these materials can be positively exploited in Smart Structures if properly embedded into host materials. Will be presented here some technological processes developed for an efficient use of SMA-based actuators embedded in smart structures tailored to astronomical instrumentation. Some possible modeling approaches of the actuators behavior will be addressed taking into account trade-offs between detailed analysis and overall performance prediction as a function of the computational time. The Material characterization procedure adopted for the constitutive laws implementation will be described as well. Deformable composite mirrors, opto-mechanical mounting with superelastic kinematic behavior, damping of launch loads onto optical element or differential preloading systems are feasible applications that will be deeply investigated into this paper with the aim of Finite Element Models properly developed. In addition a possible approach with some preliminary results for an efficient control system for the strongly non-linear SMA actuators will be presented.

8450-14, Session 2

Liquid atmospheric dispersion corrector

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A liquid atmospheric dispersion corrector (LADC) is investigated to compensate atmospheric dispersion for modern extremely large telescopes (ELTs). Unlike a traditional atmospheric dispersion corrector using two or more thin glass prisms, the LADC uses a pair of immiscible liquids in a small glass container which can be placed very close to the telescope focal plane. A pair of liquid prisms is formed and the apex of the two prisms varies with telescope zenith because of gravity. Therefore, the LADC is an adaptive device and can correct atmospheric dispersion automatically. The idea is that a large number of independent deployable units (e.g., AAO's 'Starbugs') would each carry its own LADC, of a few mm in diameter. It is attractive for ELTs, for which traditional glass ADC's are so large as to be a major cost and risk. However, suitable liquids have to meet specific requirements, making them difficult to find. The LADC must contain two liquids of closely matching refractive index, but widely differing dispersions. After the investigation of thousands of chemicals, three pairs of liquids were identified and their optical and physical properties were verified. We experimentally verified the dispersion properties of LADCs at different apexes and its dispersion varies with the tangent of Zenith distance. It is demonstrated that an LADC can correct atmospheric dispersion of 0.34° at a Zenith Distance of 48°, over a wavelength range of 370nm to 655nm. The experimental results show very good agreement with the Zemax model.

8450-15, Session 2

Analysis of gravitational effects on liquid lenses (ANGEL)

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Liquid lenses have been developed as a means for fast and reliable variable-focus optics by using an adjustable curvature in a liquid-liquid interface. The use of liquid lenses also provides the benefit of reducing the number of elements in a system, and providing a degree of freedom without any moving parts. Different methods for surface curvature actuation have been developed, including aperture adjustment, mechanical actuators, stimuli-responsive hydrogels, and mechanical-wetting. Current liquid lens designs are limited to small apertures (less than 4mm) and density-matching fluids to lessen the negative effects of gravity. By creating a lens intended for use in a microgravity environment, the aperture size can be increased by orders of magnitude, and optimal fluids can be used regardless of their density. Using a large-aperture (12.5mm) liquid lens, imaging and surface metrology was conducted using a fixed-focus configuration. The Software Configurable Optical Test System (SCOTS) method was utilized to test the effect of microgravity, standard gravity, and hypergravity on the liquid lens during parabolic flights. Under standard gravity, the RMS wavefront error (WFE) was 22.5 waves, while microgravity conditions allowed an improvement to 17 waves RMS WFE. Test performance can be improved by using lower viscosity fluids or longer duration microgravity flights. The experiment also served as an engineering demonstration for the SCOTS method in an environment where other methods of optical metrology would be impossible.

8450-16, Session 2

Flexure mount for a MEMS deformable mirror for the Gemini Planet Imager

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Small deformable mirrors (DMs) produced using microelectromechanical systems (MEMS) techniques have been used in thermally stable, bench-top laboratory environments. With advances in MEMS DM technology, a variety of field applications are becoming more common, such as the Gemini Planet Imager's (GPI) adaptive optics system. Instruments at the Gemini Observatory operate in conditions where fluctuating ambient temperature, varying gravity orientations and humidity and dust can have a significant affect on DM performance. As such, it is crucial that the mechanical design of the MEMS DM mount be tailored to the environment. GPI's approach has been to mount a 4096 actuator MEMS DM, developed by Boston Micromachines Corporation, using high performance optical mounting techniques rather than a typical laboratory set-up. Flexures are incorporated into the DM mount to reduce deformations on the optical surface due to thermal fluctuations. These flexures have also been sized to maintain alignment under varying gravity vector orientations. This paper is a follow-up to a previous paper which presented the preliminary design. The completed design of the opto-mechanical mounting scheme is discussed and results from finite element analysis are presented, including predicting the stability of the mirror surface in varying gravity vectors and thermal conditions.

8450-17, Session 2

Curvature wavefront sensing performance simulations and tests for active correction of wide field telescopes

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Active Optics (AO) is a common method to keep a telescope aligned. In particular, for the large field of view of the Observatorio Astrofísico de Javalambre (OAJ) telescopes (T250 and T80), several AO procedures are foreseen. In order to maintain image quality during operation, the T250 deformations and rigid body motions of this wide field telescope must be actively controlled to minimize optical aberrations, which arise primarily from forces due to gravity and thermal expansion. The aberrations of the telescope will be measured with four curvature sensors at the T250 focal plane. To correct the measured distortions, the secondary mirror (hexapod) and the camera position can be modified in a close loop. Currently, multiple software tools have been developed to accomplish this goal, constituting the OAJ Active Optics Pipeline. We present a comprehensive analysis of the wavefront sensing system, including the availability of reference stars, automatic identification of stars and pupil registration, Gureyev-Nugent and Ribak wavefront estimators and a novel iteration matrix evaluation technique. Simulations have been made using a telescope model to evaluate the effects produced by the modification of the seven freedom degrees of the system to recover optical quality. Additionally, several algorithms implemented have been tested with images obtained with T80, to evaluate the performances using on-sky images under different atmospheric turbulence conditions. In this way, we are demonstrating that this system will perform to the specifications required to meet the scientific performance goals.

8450-18, Session 2

Active optics: deformation systems compensating for optical aberrations with a limited number of actuators

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Active optics consists in controlling optical surfaces' shapes. Its main applications are the manufacturing of high quality aspherical mirrors with stress polishing, the maintaining of large thin mirrors' optimal shape and the use of dynamic optical components in instruments' design. This technique is based on deformable mirrors, which are designed to fulfill a specific need with both simplicity and efficiency. In this paper, we present two original concepts of deformable mirrors to compensate for first orders optical aberrations with a minimum number of actuators: one optical mode is generated with one actuator. Deformation systems are designed regarding elasticity theory and optimized with Finite Element Analysis. Starting from instrument specifications, we explain the methodology to design a correcting device dedicated to a specific function. The Variable Off-Axis parabola (VOALA) concept is a 3-actuators, 3-modes system able to generate independently Focus, Astigmatism3 and Coma3. The Correcting Optimized Mirror with a Single Actuator (COMSA) is a 1-actuator system able to generate a given combination of optical aberrations. In both cases, the optical surface is deformed through the transfer of bending moments at the edges of thin mirrors. The systems are designed, optimized and characterized with Finite Element Analysis. We will highlight their interest by presenting their expected performances on some study cases. The limited number of degrees of freedom of such systems makes them easy to set up and monitor, which is a significant advantage, notably for a space use.

8450-19, Session 2

Stabilized dispersive focal plane systems for space

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As the costs of space missions continue to rise, the demand for compact, low mass, low-cost technologies that maintain high reliability and facilitate high performance science is increasing. One such technology is the Stabilized Dispersive Focal Plane System (SDFPS). This technology provides image stabilization while simultaneously delivering spectroscopic or direct imaging functionality using only a single optical path and detector. Typical systems require multiple expensive optical trains and/or detectors, sometimes at the expense of photon throughput. The SDFPS is ideal for performing wide-field low-resolution space-based spectroscopic and direct-imaging science surveys. In preparation for a balloon flight, we have built and ground tested a prototype SDFPS that will concurrently eliminate unwanted image blurring due to the lack of adequate platform stability, while producing science images in both spectroscopic and direct-imaging modes. We present the overall design, testing results, and potential scientific applications.

8450-21, Session 3

The vector-APP: a broadband apodizing phase plate that yields complementary PSFs

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The apodizing phase plate (APP) is a solid-state pupil optic that clears out a D-shaped area next to the core of the ensuing PSF. To make the

APP more efficient for high-contrast imaging, its bandwidth should be as large as possible, and the location of the D-shaped area should be easily swapped to the other side of the PSF. We present the design of a broadband APP that yields two PSFs that have the opposite sides cleared out. Both properties are enabled by a half-wave liquid crystal layer, for which the local fast axis orientation over the pupil is forced to follow the required phase structure. For each of the two circular polarization states, the required phase apodization is thus obtained, and, moreover, the PSFs after a quarter-wave plate and a polarizing beam-splitter are complementary due to the antisymmetric nature of the phase apodization. The device can be achromatized in the same way as half-wave plates of the Pancharatnam type. By applying an additional quarter-wave plate in front, the device also acts as a regular polarizing beam-splitter, which therefore furnishes high-contrast polarimetric imaging. If the PSF core is not saturated, the polarimetric dual-beam correction can also be applied to polarized circumstellar structure.

8450-22, Session 3

Lab results of the circular phase mask concepts for high-contrast imaging

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Circular phase mask concepts represent promising options for high contrast imaging and spectroscopy of exoplanets. Depending on their design, they can either work as a diffraction suppression system or as a focal plane wavefront sensor. While the apodized Roddier coronagraph uses a pi-phase mask to obtain complete suppression of the star image in monochromatic light, the Zernike sensor uses a pi/2-phase shift mask centered on the star image to measure the residual aberrations in the focal plane by encoding them into intensity variations in the relayed pupil. Possible implementations of the Zernike sensor can be considered in exoplanet imagers such as VLT-SPHERE, Gemini planet imager, Palomar-P1640 or Subaru-SCExAO to enlarge their capabilities. However, such concepts have not been validated experimentally up to now. Our goal is to perform lab demonstration of this concept on our visible coronagraph testbed at LAM and to propose an upgrade design for SPHERE. In this communication, we report on results of lab measurements of different circular coronagraph design, in particular the apodized Roddier coronagraph and its achromatized version, the dual zone phase mask coronagraph. In addition, we present measurements of the Zernike sensor and determine its accuracy to small wavefront errors.

8450-215, Session 3

Architecture impacts on planning and activity scheduling in external occulter missions

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Architecture choices impact planning and scheduling of activities for two widely separated spacecraft envisioned to be part of an astrophysics mission to observe extrasolar-planets. The two spacecraft consist of a large space telescope and an external occulter, separated by tens of thousands of kilometres. The science need is to maintain alignment at the tens of milliarcseconds level (~ metres) or less on given target stars after moving one of the spacecraft tens of thousands of kilometres. Doing this efficiently presents operational and architectural design tradeoffs that rely on appropriate navigation, propulsion, and alignment technologies, vehicle configuration, and activity scheduling strategies. Challenges inherent in the general system architecture are described with emphasis on potential problems and the need for sound and appropriate integration of architecture planning, subsystem choice, and activity scheduling.

8450-23, Session 4

A review of the KMOS IFU component metrology programme

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The K-Band Multi-Object Spectrometer Integral Field Unit (KMOS IFU) is a complex optical instrument with over 1000 diamond machined optical surfaces. Many of these surfaces are highly unorthodox and pose a significant challenge with regard to their accurate characterisation. We summarise here the form metrology of these complex surfaces. Specific interferometric test procedures used in this work have been outlined previously. Here we focus on a general analysis of all the form measurement results. The measurement of such a large number of surfaces offers an unprecedented opportunity for the general analysis of the diamond machining of complex optical surfaces. The wealth of statistical information is of exceptional value in refinement of the manufacturing process. In particular, we analyse in some detail the variation of form error contributions with spatial frequency. In general, there is a substantial reduction in form error contribution with spatial frequency. This form error variation with spatial frequency may also be modelled using Zernike polynomials. This approach is particularly suited to optical modelling of systems incorporating such perturbed components. As such, this knowledge can be applied directly to the modelling of form errors in new optical designs. Application to tolerance modelling of future instrument designs is discussed at length.

8450-24, Session 4

Test results of high-precision large cryogenic lens holders

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The Near Infrared Spectrometer and Photometer (NISP) of EUCLID requires high precision large lens holders (170 mm) at cryogenic temperatures (150K). The four lenses of the optical system are made of different materials: fused silica, CaF2, and LF5G15 that are mounted in a separate lens barrel design. Each lens has its separate mechanical interface to the lens barrel, the so called adaption ring.

The performance of the lens holder design is verified by an adapted test facility including an optical metrology system. The characterization of the lens deformation and displacement (decenter, tilt) due to mechanical loads of the holder itself as well as thermally induced loads are driven by the required submicron precision range and at the operational thermal condition.

The surface deformation of the lens and its holder is verified by interferometric measurements, while tilt and position accuracy are measured by fibre based distance sensors. The selected distance measurement sensors have the capability to measure in a few mm range with submicron resolution at ultra high vacuum, in vibration environments and at liquid nitrogen temperatures and below.

The calibration of the measurement system is of crucial importance: impacts of temperature fluctuation, surface roughness, surface reflectivity, straylight effects, etc. on the measured distance are carefully calibrated. Inbuilt thermal expansion effects of the fibre sensors are characterized and proven by applying a lens dummy, which has practically zero CTE.

The paper presents the test results and measured performance of the high precision large cryogenic lens holders attained by the metrology system. These results are presented on behalf of the EUCLID consortium.

8450-25, Session 4

CTE measurement setup with 10 ppb/K sensitivity for characterizing lightweight and highly stable materials for space applications

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To characterize materials with ultra-low coefficient of thermal expansion (CTE) near room temperature, we developed a measurement setup based on a specifically designed heterodyne interferometer with demonstrated pm sensitivity in translation measurement. Materials under investigation are thermally and mechanically highly stable glass ceramics such as Zerodur and Clearceram as well as ULE (ultra-low expansion) glass and CFRP (carbon-fiber reinforced plastics). These materials are the basis for highly stable instruments in terrestrial and space applications, e.g. telescopes or interferometers. In our setup we characterize sample tubes, which are mounted on a support made of Zerodur in order to minimize a tilt of the tube. Reference and measurement mirrors of the interferometer are mounted inside the tube, using specific mirror clamps, which, in principle do not affect the CTE measurement. To determine the CTE of a sample, a sinusoidal temperature variation is provided by a radiative heating system surrounding the tube. A tilt of the two mirrors is measured using differential wavefront sensing. The tilt information is used for correction of the translation measurement and to analyze systematic errors. With our setup, we characterized ultra-stable materials, e.g. Zerodur, Clearceram and ULE, and compared our measurement data to the values given by the manufacturers. For a tube made of Zerodur, we obtain a CTE value of 0±3*x10^-8 1/K at room temperature, demonstrating a sensitivity in the 10 ppb/K range. We assume, that our measurement sensitivity is still limited by systematic errors due to a tilt of the whole sample tube.

8450-26, Session 5

Wavefront calibration testing of the James Webb Space Telescope primary mirror center of curvature optical assembly

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The James Webb Space Telescope (JWST) Optical Telescope Element (OTE) consists of a 6.6 m clear aperture, all-reflective, three-mirror anastigmat. The 18-segment primary mirror (PM) presents unique and challenging assembly, integration, alignment and testing requirements. A full aperture center of curvature optical test is performed in cryogenic vacuum conditions at the integrated observatory level to verify PM performance requirements. The Center of Curvature Optical Assembly (CoCOA), designed and being built by ITT Exelis satisfies the requirements for this test. The CoCOA contains a multi wave interferometer, patented reflective null lens, actuation for alignment, full in situ calibration capability, coarse and fine alignment sensing systems, as well as a system for monitoring changes in the PM to CoCOA distance. Two wavefront calibration tests are utilized to verify the low and Mid/High spatial frequencies, overcoming the limitations of the standard null/hologram configuration in its ability to resolve mid and high spatial frequencies. In this paper the methods and results of the wavefront calibration tests are presented.

8450-27, Session 5

Tunable laser techniques for improving the precision of optical astronomy

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Improving the precision of optical astronomy requires not only new telescopes and instrumentation, but also advances in observing protocols, calibrations and data analysis. The Laser Applications Group at the National Institute of Standards and Technology in Gaithersburg, Maryland has been applying advances in detector metrology and tunable laser calibrations to problems in astronomy since 2007. Using similar measurement techniques, we have addressed a number of seemingly disparate issues. We have made: in-situ measurements of the wavelength-dependent response of cameras and telescope optics to reduce systematic uncertainties in supernova photometry and its subsequent analysis; accurate maps of the instrumental PSF of a fiber-fed spectrograph to improve sky subtraction in baryon acoustic oscillation measurements; stray light corrections in optical spectrographs; and near-ideal wavelength calibrations of a fiber-fed, multi-object echelle spectrograph to aid the search for extrasolar planets. In each case, we rely on robust, commercially-available laboratory technology that is readily adapted to use at an observatory. In this paper, we give an overview of these techniques and present selected results.

8450-28, Session 5

Results of the new metrology system of the European ALMA antenna

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The Atacama Large Millimeter Array (ALMA) consists of a large number of 12 m diameter antennas that will operate up to 950GHz. To guarantee the scientific requirement in term of pointing stability and residual delay a dynamic an thermal metrology system must be integrate in the antenna. As a matter of fact the antennas must work at full performances in free air during night and day. Consequently performances are affected by all the not repeatable error sources such as the temperature variations and wind blowing from different directions. The antenna is very light and stiff structure, the elevation structure is in carbon fibre with also a very low thermal expansion coefficient, but to achieve the ALMA specification thermal and dynamic correction must be applied.

The thermal metrology is composed by a number of thermal sensors distributed in the antenna that compensate the elevation axis deformation due to the temperature variation.

The dynamic metrology is based on two high accuracy inclinometers with a very short recovery time opportunely placed on the main structure.

This report show the excellent results of the tests performed in the AEM antenna with both system. It is evident the good performance of the systems allowing the antenna to meet the specification during all observation conditions and modes.

8450-29, Session 5

An imaging displacement sensor with nanometer accuracy

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A new imaging displacement sensor (IDS) has been developed for closed loop surface control of CCAT, a 25 m diameter telescope operating in the 2 to 0.2 mm wavelength range. The required measurement accuracy for the relative position of two neighboring segments is <100 nm for translation over a +- 1 mm range and <1 microradians over +-1 deg with good stability on a timescale of several month and over a temperature range from -20 to +15 C.

The IDS developed for CCAT uses a simple LED pinhole collimator on one segment with a CCD chip camera ~100 mm away on the neighboring segment. A robust centroiding algorithm has been developed that is not sensitive to collimator brightness or CCD imaging artifacts. An aluminum prototype IDS achieved an Allan deviation of 30 nm for a single 0.03 s frame and <1 nm for averaging times of 100 s and <100 nm for the four month duration of the test. The temperature dependence was ~10 nm/C and should be significantly better for an IDS fabricated from Invar. The accuracy and linearity evaluation was limited by the measurement setup but still yielded <0.05% of full scale accuracy with <140 nm rms deviation from linearity.

The IDS is very versatile with each sensor producing X and Y positions transverse to the collimator beam. A pair of sensors packaged together with the collimators and CCDs interchanged measures two translation and two angular motions. Combining two pairs of sensors with their beams directions rotated at an angle relative to each other yields four more measurements determining all 6DOF with some redundancy.

8450-192, Session 5

Fine optical alignment correction of astronomical spectrographs via in-situ full-field moment-based wavefront sensing

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Image moment-based wavefront sensing (IWFS) utilizes moments of focus-modulated focal plane images to determine modal wavefront aberrations. This permits fast, easy, and accurate measurement of wavefront error (WFE) on available finite-sized targets across the entire focal plane (FP), thereby providing not only in-situ fullfield image quality assessment, but also deterministic alignment correction of imaging systems under test. We present an experimental demonstration where fine alignment correction of a fast camera system in a fiber-fed astronomical spectrograph, called VIRUS, is accomplished using IWFS.

8450-31, Session 6

SCOTS: a large dynamic range reverse Hartmann test for Giant Magellan Telescope primary mirrors

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A software configurable optical test system (SCOTS) based on the geometry of fringe reflection or phase-measuring deflectometry was developed as a verification test for the GMT primary mirror segments. SCOTS is fast, accurate, and independent of the main interferometric test.

SCOTS acts as a Hartmann test in reverse. The traditional Hartmann test sends light from a point source, through a mask with holes near the mirror under test, to a 2-D detector. SCOTS reverses the roles of source and detector, sending light from a computer screen, through the mirror, to a pinhole camera. The image on the camera serves the role of the Hartmann mask by identifying each point on the mirror with a point on the screen. Comparing the camera's image with the pattern on the screen effectively traces each ray back from the pinhole through the mirror to the screen, giving the same information as the Hartmann test. The huge advantages of SCOTS include: the size and resolution of the screen give it a high dynamic range for slope errors in the mirror; the resolution of the pinhole camera gives it high spatial resolution on the mirror; the blur spot due to the test setup and the mirror's figure error can be as large as the screen; no physical Hartmann mask is needed.

Slope measurement precision of 0.1 μrad has been achieved for the GMT segments. SCOTS has been an excellent complement to the interferometric test, especially where slope errors are beyond the capture range of the interferometric test.

8450-32, Session 6

Applications of subaperture stitching interferometry for very large mirrors

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Full aperture interferometric metrology has enabled fabrication and verification of large primary mirrors with nm precision. The measurement of mirrors that are several meters in diameter with flat or convex aspheric surfaces can be performed using interferometric measurements of overlapping subaperture regions, then stitching these measurements together to provide a full map. This paper explores the application of this measurement technique for very large mirrors, including the following:

- Using data redundancy to provide self-calibration of the test
- Estimate of measurement accuracy as function of subaperture size and overlap
- Issues for calibration of flats
- Coupling of alignment and calibration for aspheric mirrors
- Issues relating to mirrors with active supports.

Specific examples for testing large astronomical mirrors are provided.

8450-33, Session 6

Photochromic point diffraction interferometer for optical testing

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The point diffraction interferometer (PDI) is a common path interferometer which provides a self referencing system inherently stable and relatively insensitive to vibrations, to be applied for the optical testing when no reference beam is available, such as in many adaptive optics systems. We propose a new point diffraction interferometer, which exploits the tunable transmittance of photochromic materials in the visible range. These new materials easily allow to customize the devices in terms of pin-hole sizes and absorbance requests of the semitransparent zone. Pin-holes suitable for a wide range of optical apertures can be obtained by laser writing. The main advantage of this new method is that the fringe visibility can be optimized in real time by progressive bleaching of the semitransparent zone of the photochromic layer, thus providing unexpected image quality, well comparable with classical interferometers. Moreover, a theoretical model to predict fringe visibility as a function of photochromic film parameters and pinhole sizes has been developed. The system has been calibrated with a reference sphere and different mirrors ranging from f/16 to f/4 have been successfully tested, in perfect agreement with classical Fizeau interferometer analysis. With photochromic materials, phase shifting between reference and test beam, which is necessary to improve interferogram resolution, can be accomplished in an easy way. As a matter of fact, the object beam is phase shifted during the bleaching of the photochromic layer, altering the refractive index of the medium.

8450-34, Session 6

Testing large flats with computer generated holograms

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The test and calibration of meter-class flat mirrors with high-accuracy is a complex task, since they are intrinsically difficult to measure unless the collimated beam from the interferometer and the reference optic are as large as the test flat. Techniques with null lenses can be developed, but their cost is prohibitive for flats larger than one meter in diameter, even requiring the stitching approach to cover larger areas. As an alternative, the Ritchey-Common test and the scanning pentaprism system have been used in the past. A different test approach, based on a computer-generated hologram (CGH), is able to combine both accurate reference surface and self-alignment tools, overcoming the size problem of the null optic.

We describe the optical design of a large flat based onto a spherical mirror and a dedicated CGH. The spherical mirror, which can be accurately manufactured and tested in absolute way, allows to obtain a quasi collimated light beam, and the hologram performs the residual wavefront correction. Alignment tools for the spherical mirror and the hologram itself are encoded in the CGH. Sensitivity to fabrication errors and alignment have been evaluated. Test to verify the effectiveness of our approach are now under execution.

8450-35, Session 6

Full characterization of photochromic computer generated holograms for optical testing

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In recent years, the design of optical telescopes and instrumentation has more and more recourse to aspherical optics, which enable aberrations reduction with simplified optical systems. Computer-Generated Holograms (CGHs) have been demonstrated to be effective in the optical testing of complex surfaces through null interferometry when reference optics are not available. In this background, we recently developed rewritable CGHs for the interferometric test of aspheres based on photochromic layers. Photochromic CGHs are rewritable and their production is straightforward, any process after the writing step being not required. CGHs have been produced by means of a maskless lithographic tool and the writing process has been optimized, as regards writing speed and light power, as function of film thickness and optical absorbance. The obtained holograms have been fully characterized using specific interferometric techniques, in order to determine their accuracy and to find the sources of errors. A comparison with standard CGHs is also featured for giving an indication of the reliability of this photochromic technology.

8450-36, Session 7

Second generation OH suppression filters using multicore fibers

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Ground based near-infrared observations have long been plagued by poor sensitivity when compared visible observation counterparts as a result of the bright narrow line emission from atmospheric OH molecules. The new prototype GNOSIS instrument recently commissioned at the Australian Astronomical Observatory uses Photonic Lanterns in combination individually printed single mode fiber Bragg gratings to filter out the brightest OH-emission lines between 1.47 and 1.7 microns. GNOSIS, reported in a separate paper in this conference, demonstrates excellent OH-suppression, providing very “clean” filtering of the lines. It represents a major step forward in the goal to improve the sensitivity of ground based near-infrared observation to that possible at visible wavelengths, however, the filter units are relatively bulky and costly to produce.

The 2nd generation fiber OH-Suppression filters based on multicore fibers are now under development. The development aims to produce high quality, cost effect, compact and robust OH-Suppression units in a single optical fiber with numerous isolated single mode cores that replicate the function and performance of the current generation photonic lantern based device. In this paper we present the early results from the multicore fiber development and multicore fiber Bragg grating imprinting process.

8450-37, Session 7

On-telescope performance simulations of a fibre Bragg grating-based instrument for high spectral and temporal resolution astronomical observations

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The detection and analysis of spectral line-shifts and variability is commonplace in astronomy. Indeed our current insights into the expanding nature of the universe are underpinned by this relatively simple methodology. However, the detection of spectral line-shifts is limited to detection times on the scale of minutes in the optical and infrared due to the limitations of current astronomical instrumentation. New detection techniques combining both high spectral and fast (sub-second) temporal resolution are needed to expand our knowledge of dynamic astronomical phenomena such as stellar flares, close binary systems or stellar oscillations, which are all well known, but not well understood. Here, we present an investigation into the feasibility of using Fibre Bragg gratings (FBGs) as single line spectral filters specifically for high spectral and temporal resolution astronomy. We present the device concept and discuss it in the context of two readily available FBG profiles. We demonstrate the performance of the instrument for a range of telescope sizes and object magnitudes. We show that this instrument concept could resolve spectral shifts down to 0.02 nm (3.9 km s-1) with sub-second temporal resolution for an object of magnitude 8 on a 4-m class telescope, which is far superior to existing techniques that attain resolutions of 0.05 nm over several minutes.

8450-39, Session 7

Light propagation in a fiber-brush-shape converter

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More and more fibers were introduced to telescopes to transfer light from the focus point to spectrometers. The diameter of these fibers depend on the seeing of the location of the telescope. However, narrow slits are set in front of spectrometers. There are many kinds of the image slicers applied to get the high resolution spectrograph, such as Bowen, Bowen-Wairaven, Richardson image slicers.

In this paper, a novel designed, all-fiber slicer was designed to transfer circle spot to a line-shape output. The shape of the mode converter is like a brush. So we call this all-fiber slicer as fiber-brush converter. The fiber-brush-shape converter consists of several bare fibers at one end, one fiber at the other end and a taper between them. The light propagation could be calculated with the beam propagation method. According to the theoretical and calculated results, the power of the light could be confined in the core of the fiber if the parameters of the taper are appropriate. The loss of the converter is about 0.2dB within the working wavelength.

The light propagating from the bare fibers of the converter to the single fiber will be coupled. The taper shape has a direct effect on the coupling efficiency among local modes inside the taper. Some mathematical models were used to represent the actual taper shape, such as linear shape, raised cosine shape and modified exponential shape. By optimizing the taper shape, the loss of the light propagated can be very low even can be ignored.

8450-40, Session 7

Enabling photonic technologies on seeing limited telescopes: fabrication of integrated photonic lanterns on a chip

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Multimode fibres have been used by astronomers for many years to transport or to reformat light from the telescope focus to instruments placed off telescope. All fibre fed spectrographs used in astronomy today use multimode (MM) fibre inputs. There are definite advantages for single-mode (SM) fibres, as for example, many photonic devices only function with SM inputs. Furthermore, current astronomical spectrographs employ macroscopic optics - they are thus bulky, expensive, and not readily scalable. Technologies for miniaturisation using integrated photonics show great promise. The integrated photonic spectrograph requires light input from a single-mode optical fibre. The small core diameters and large mode mismatch of SM fibres with the seeing limited point-spread function of stellar targets makes it difficult to feed these fibres and hence use them to transport the light directly. A solution to this problem is to use a photonic lantern, which converts a MM fibre core into a series of SM fibre cores. The original fabrication method is based on fibres. Here we use the direct laser writing technique to inscribe the photonic lantern waveguides within a glass sample with ultrafast laser pulses. Its main advantage is the miniaturisation of the device leading to a feasible approach to realising devices operation in the visible. We are exploring a range of refractive index contrasts and transition parameters in order to obtain the highest throughput at both visible and infrared wavelengths. We have fabricated and characterised several devices for which results will be presented here.

8450-124, Session 7

Optical fibers for precise radial velocities: an update

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Optical fibers are an essential component for some of the most precise radial velocity instruments. They provide image and pupil scrambling that allow to illuminate the instrument is a constant way. Square and octoganal fibers have been investigated as a potential improvement for the precise radial velocity instruments and have already shown a great potential. Here we present an updated caracterization of these fibers and present the first results they have on the HARPS North instrument.

Advances have been made in the understanding of the far field patterns and measurement have been performed on naked fibers. Some exploration of the modal noise aspects will be shown.

8450-128, Session 7

Nano-optical fiber evanescent field sensors

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The nano fiber - optic evanescent field sensor based on a changed cladding part as a sensor presented numerically. The influences of numerical opening, core radius of the fiber, the wavelength is effected on the light source and the submicron fiber on the sensors are promise to studied in this work. The results pointed out the sensitivity of the sensor increases when the numerical opening of the fiber is increases and the core radius is decreases. The NA of the fiber affects the sensitivity of the sensor. In the uniform core fiber, the increase in the NA increases the sensitivity of the sensor. Therefore, one should choose a fiber with high NA for the design of an evanescent-wave-absorption sensor if the core of the sensing segment uniform in diameter, so that the increase in the penetration depth or number of ray reflections or both, increases the evanescent absorption field and hence the sensitivity of the sensors.

8450-41, Session 8

Developments in high-density Cobra fiber positioners for the Subaru Telescope's prime focus spectrometer

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The Prime Focus Spectrograph (PFS) is a fiber fed multi-object spectrometer for the Subaru Telescope that will conduct a variety of targeted surveys for studies of dark energy, galaxy evolution, and galactic archaeology. The key to the instrument is a high density array of fiber positioners placed at the prime focus of the Subaru Telescope. The requirements, design, and prototyping efforts for the fiber positioner system for the PFS are described here as are the plans for modular construction, assembly, integration, functional testing, and performance validation.

8450-42, Session 8

Concepts for multi-IFU robotic positioning systems

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Following successful commissioning of SAMI (Sydney-AAO Multi-object IFU) the AAO has undertaken concept studies leading to design of a new instrument for the AAT (HECTOR). It will use an automated robotic system for the deployment of hexabundles to the focal plane. We have analysed several concepts, which could be applied in a design of new instruments as well as a retrofit to existing positioning systems. We look at Starbugs as well as new breed of manipulators for magnetic buttons.

8450-43, Session 8

Recent testing of a micro autonomous positioning system for multiobject instrumentation

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A multiple pick off mirror positioning system has been developed for the deployment of mirrors within multi-object instrumentation. The positioning system is a two wheeled differential drive robot, approximately 20 x 20 mm. This report details open looped linear testing that has been conducted on the coarse positioning system. These results will show that the robot is capable of positioning within $\leq$ 30 µm. Reasons for using a power floor over a battery powered system will also be explained. Finally, testing of the power floor is described showing important variables that need to be tightly controlled.

8450-44, Session 8

Starbugs: all-singing, all-dancing fibre positioning robots

J. Gilbert, J. Heijmans, M. Goodwin, R. Muller, S. Miziarski, J. K. Brzeski, L. G. Waller, W. Saunders, A. Bennet, J. Tims, Australian Astronomical Observatory (Australia)

Starbugs are miniature piezoelectric robots with the ability to simultaneously position many optical payloads across a telescope's focal plane. This technology has been developed to enable fast and accurate field reconfigurations without the inherent limitations of traditional positioning techniques. We report on our successes in demonstrating Starbug technology and the recent improvements made to the system, including i) using a vacuum to attach Starbugs to a field plate, ii) optimised electronics, and iii) simplified mechanical design. A method of rotating Starbugs has also been devised. We present measured performance data from a prototype system comprising multiple Starbugs under computer control.

8450-45, Session 8

Analysis of heat transfer on the fiber positioning unit and the focal plane of LAMOST

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Many heating units exist on the fiber positioning units of LAMOST,and the heat has some certain effect on the observation of telescope. Experimental and theoretical analysis methods are used in this paper to study the heat effect on the focal plane caused by heating units. A temperature acquisition system is established on a simplified focal plane. The thermal analysis software I-DEAS is used to analyse the temperature field of that device. The models of 4000 fiber positioning units are established in I-DEAS to analyse the temperature field distribution in heat conduction and natural air convection situations.

8450-46, Session 9

Wide field tracking of moving objects with a compact multi-object dispersed fixed-delay interferometer

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We report early results from lab demonstration of wide field tracking of moving objects with a multi-object dispersed fixed-delay interferometer (DFDI) to expand the DFDI applications to non-astronomy fields. The DFDI instrument is a combination of a Michelson type interferometer with a fixed optical delay and a medium resolution spectrograph. This takes advantage of the strength of the DFDI approach for high radial velocity (RV) precision measurements over the traditional cross-dispersed echelle spectrograph approach: multi-object, high throughput and compact design. The combination of a fiber integral field unit (IFU) with a DFDI instrument allows simultaneous sampling of all of the objects within the observing field of view (FOV) to provide differential RV measurements of moving objects over background objects. Due to the three-D nature of the IFU spectroscopy, the object location and spectral features can be simultaneously acquired. Adding RV signals to the measurements, this approach allows precise extraction of trajectories and spectral properties of moving objects (such as space debris and near Earth Objects (NEOs)) through sequential monitoring of moving objects. Measurement results from moving objects in a lab and moving cars in a field using this innovative approach are reported.

8450-47, Session 9

Optical MEMS for space spectro-imagers

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Optical MEMS could be major candidates for designing future generation of space instruments. In addition to their compactness, scalability, and specific task customization, they could generate new functions not available with current technologies. After a wide comparison of the currently available components, it can be concluded that the most mature components for space applications are the TI's DMD, the micro-deformable mirrors, the PMDG and the pointing micro-mirrors. Among a few tens of MEMS-based or MEMS-enhanced payloads concepts, we perform a first trade-off to select the 6 most promising instruments. After the 6 preliminary instrument studies, 2 concepts are finally retained for preliminary design. First concept is a programmable slit for

straylight control. According to the proximity of bright sources close to the scientific targets, and to the straylight level in spectro-imagers; the system proposed consists in replacing the current slit by an active row of MEMS. This concept is justified by the fact that the scattering within the spectrometer, i.e. after the slit, clearly and largely dominates the overall straylight. The second concept is a push-broom imager for which the acquired spectrum can be tuned by optical MEMS. This system is composed of two diffractive elements and a DMD component. The possibility to play with spectral selection for an instrument having a wide field-of-view is something very new and the potential seems to be very high. Dichroics filters, strip filter, band-pass filter could be replaced by a sub-level instrument. It offers the possibility to perform multi-applications missions.

8450-48, Session 9

Large micromirror array for generating programmable slit masks for multi-object spectroscopy

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Multi-object spectroscopy (MOS) is a powerful tool for space and ground-based telescopes for the study of the formation and evolution of galaxies. This technique requires a programmable slit mask for astronomical object selection.

We are engaged in a European development of micromirror arrays (MMA) for generating reflective slit masks in future MOS, called MIRA. The 100 x 200 µm2 micromirrors are electrostatically tilted providing a precise angle. The main requirements are cryogenic environment capabilities, precise and uniform tilt angle over the whole device, uniformity of the mirror voltage-tilt hysteresis and a low mirror deformation.

A first MMA with single-crystal silicon micromirrors was successfully designed, fabricated and tested. A new generation of micromirror arrays composed of 2048 micromirrors (32 x 64) and modelled for individual addressing were fabricated using fusion and eutectic wafer-level bonding. These micromirrors without coating show a peak-to-valley deformation less than 5 nm, a tilt angle of 20° for an actuation voltage of 120 V. Individual addressing capability of each mirror has been demonstrated using a line-column algorithm based on an optimized voltage-tilt hysteresis. Devices are currently packaged, wire-bonded and integrated to a dedicated electronics to demonstrate the individual actuation of all micromirrors on an array. An operational test of this large array with gold coated mirrors has been done at cryogenic temperature (162 K): the micromirrors were actuated successfully before, during and after the cryogenic experiment. The micromirror surface deformation was measured at cryo and is below 20 nm peak-to-valley.

8450-49, Session 9

Optical metrology for the James Webb Space Telescope microshutters

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The James Webb Space Telescope (JWST) relies on several innovations to complete its five year mission. One vital technology is microshutters, the programmable field selectors that enable the Near Infrared Spectrometer (NIRSpec) to perform multi-object spectroscopy. Mission success depends on acquiring spectra from large numbers of galaxies by positioning shutter slits over faint targets. Precise selection of faint targets requires field selectors that are both high in contrast and stable in position. We have developed test facilities to evaluate microshutter contrast and alignment stability at their 35K operating temperature. These facilities used a novel application of image registration algorithms to obtain non-contact, sub-micron measurements in cryogenic conditions. The cryogenic motion of the shutters was successfully characterized. Optical results also demonstrated that shutter contrast far exceeds the NIRSpec requirements. Our test program has concluded with the delivery of a flight-qualified field selection subsystem to the NIRSpec bench.

8450-38, Poster Session

Understanding incomplete scrambling in fibres: experimental investigations

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Recent advances in detection and characterization of exo-planets have led to increasing standards for barycentre repeatability of future high-resolution spectrographs. This requires the use of optical fibres due to their scrambling ability - but this is subject to fundamental limits.

This experimental investigation assesses the theoretical proposals made in a companion paper (Allington-Smith et al.), thus allowing inside in the true nature of scrambling, unlike previous mainly phenomenological studies.

The paper starts out with a discussion of the application to precision spectroscopy, including the fundamental role of barycentre stability for exo-planet research, but also considering its impact on applications like astroseismology and the study of variable stars.

The experimental setup is described. The fibre response for input parameters like focal ratio, tilt and offset is investigated. The following data analysis derives the classical scrambling gain factor (Avila et al.), but also scrutinizes features of the characteristic intensity pattern which exhibits similarities with the theoretical predictions. The results are presented to then critically assess the validity of the proposed model.

8450-114, Poster Session

Optical fiber systems for the BigBOSS instrument

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We describe the design, requirements, and performance of fiber optics systems and elements for use in BigBOSS, a proposed massively multi-object spectrograph for the Kitt Peak Mayall 4-meter telescope that will measure baryon acoustic oscillations to explore dark energy. Each of the 5000 BigBOSS fibers is to be precisely aligned to and positioned by an actuator at the telescope prime-focus, routed 40m through the telescope facility, and then terminated in a 500-fiber convex spectrograph slit.

We report on our fiber component modeling, development, and performance measurement program. Results include the comparison of numerical and analytical models of focal ratio degradation (FRD) with measurements of actual fiber components' FRD; and observations of FRD in both collimated and converging beams, using different types of fiber terminations, mechanical connectors, and fusion-splice connections.

8450-115, Poster Session

BigBOSS: guiding, focus and alignment system

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BigBOSS is a proposed Stage IV dark energy experiment using the baryon acoustic oscillation (BAO) technique. The redshifts of 20 million galaxies will be determined using a multi-object spectrometer fed by 5000 remotely actuated optical fibers. BigBOSS has been designed for installation at the Mayall 4 meter telescope at Kitt Peak, Arizona.

Survey success is directly related to the total optical throughput. The guiding, focus and alignment system is designed to maximize optical throughput. The guiding portion of the system both centers and maintains galaxy image location on the fibers tips. The focus and alignment portion of the system reduces blurring of the galaxy images.

The system is designed to operate without cooling in order to minimize both prime focus complexity and heat load inside the optical path. Even at ambient temperature, the system will provide 1 Hz guide signals with <0.005 arcsec accuracy and micron level focus and alignment corrections.

8450-116, Poster Session

Design and performance of an R-θ fiber positioner for the BigBOSS instrument

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The BigBOSS instrument is a proposed multi-object spectrograph for the Mayall 4m telescope at Kitt Peak, which will measure the redshift of 20 million galaxies and map the expansion history of the universe over the past 8 billion years, surveying 10-20 times the volume of existing studies. For each 20 minute observation, 5000 optical fibers are uniquely positioned by a close-packed array of 5000 robotic positioner mechanisms. Key mechanical constraints on the positioners are: ϕ12mm hardware envelope, ϕ14mm overlapping patrol zones, open-loop targeting accuracy $\leq$ 40µm, and step precision $\leq$ 5µm, among other requirements on envelope, power, stability, and speed. This paper describes the design and performance of a newly-developed fiber positioner with R-θ polar kinematics, in which a flexure-based linear R-axis is stacked on a rotational θ-axis. Benefits over the usual SCARA-type parallel axis θ-θ kinematic approach include faster repositioning, simplified anti-collision schemes, and inherent anti-backlash preload. Performance results are given for complete positioner assemblies as well as sub-component hardware characterization.

8450-117, Poster Session

Metrology system for the calibration of multi-dof precision mechanisms

L. Zago, HEIG-VD (Switzerland)

We have developed a novel metrology system for precision XY measurements based on a concept developed originally in an industrial vision context by which USB cameras observe a target with a special dots pattern. The system has then been extended to Rx-Ry (tip-tilt), Z and Rz measurements by adding more cameras within a suitable configuration. The basic principle is described, first validated on a preliminary experimental implementation used for testing a new type of hexapod. We then illustrate the setup designed as calibration bench for hexapods used as positioning devices of the secondary mirrors of astronomical telescopes. The stability/resolution of this metrology system is $\leq$1 µm along linear degrees of freedom, respectively 0.5 arcsec for tip-tilt; repeatability is respectively 3 µm, 0.75 arcsec.

8450-118, Poster Session

A predesign setup for fiber end position measurement of fiber positioner

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We are trying to pre-design a mechanical instrument for BigBOSS which could precisely acquire the geometric center of the fiber end and locate the whole measuring system on the edge of focal plane to measure some reference fiber which provide the high precise result could revise the error measured from the fiber view camera.

8450-119, Poster Session

A high-resolution measurement device for detecting the positioning accuracy of the optical fiber positioner

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The optical fiber positioner with double revolving mechanism is driven by two stepping motors. One stepping motor drives center revolving mechanism and the other drives decentered slewing mechanism. Photogrammetry is currently used to detect the positioning accuracy of the optical fiber positioner, but it cannot achieve high precision because of the small size of the fiber's diameter.

So, a new measurement device, which mainly contained optical microscope, CCD camera and two-dimensional precision mobile platform, was established in this paper. One tip of the optical fiber (the other tip was lighted by filament lamphouse) was imaged on the CCD sensor in a magnified way through the optical microscope, and the image was processed to build the position feedback mechanism in real time. Then the two-dimensional mobile platform was controlled by PID control method to track the optical fiber, and the fiber was always kept to locate in center of the CCD image in order to eliminate the aberrations of the optical microscope lens. Finally, the position changes of the moving fiber could be obtained by the coordinates of the two-dimensional precision mobile platform. The experimental results demonstrate that the resolution of this measurement device is 0.1µm and the accuracy of repeat positioning is 1µm. The measurement device could satisfy the testing requirement.

8450-120, Poster Session

A high-density integrated optical focal plane positioning system

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Modern multi-spectral sky survey requires the use of greater quantity and smaller size of the fiber positioner. This paper presents a high-density integrated optical focal plane positioning system, which includes 150 groups fiber positioning module and a 1 meter diameter honeycomb-shaped focal plane framework in that have about 150 hexagonal hole. Each module has a pedestal includes 37 holes and 37 fiber positioner of 12 mm diameter. 37 fiber positioner integrated can greatly reduce the difficulty of the design and installation. The modular

structure also facilitates maintenance and replacement in the field of telescope, and greatly reduce the difficulty of the drive system design. Numerical simulation results show that: the honeycomb-shaped focal plane framework whose thickness is 100mm and who is in a variety of working positions and load conditions, its maximum deformation is about 0.02mm. This meet the needs of the general astronomical telescopes. The positioning accuracy of test 12mm diameter fiber positioner is about 0.04 mm, and it is expected to reach 0.01mm if have the closed-loop control.

8450-121, Poster Session

LAMOST fiber unit positional precision detection exploiting the technique of template matching

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The large sky area Multi-object Fiber Spectroscopic Telescope (LAMOST) is an innovative reflecting schmidt telescope, promising a high spectrum acquiring rate of several ten-thousands of spectra per night, it makes reconfiguration of fibers accurately according to the positions of objects and fine adjusting the fibers. As a key problem, high precision positioning detection of LAMOST fiber positioning unit has always been highly regarded and active detection method, which determines the final accurate position of optical fiber end with the help of lighting the fiber, has been most widely researched, but it couldn't be applied in real-time observation for it needs projecting light. A novel idea exploiting the technique of template matching is presented in this paper. Regarding LAMOST site conditions, contactless vision detection is used here. As we know, final position of a specific fiber end can be easily inferred by its corresponding revolving angles of the central axle and bias axle in double revolving style, and the edge and shape of the specific revolving axle in fiber unit can offer useful information about its relevant revolving angles, so once the template aiming at these characteristics for one specific fiber unit is set up, template matching technique can be explored to acquire the matching parameters from its real-time collected imagery in one observation, and thus determine the corresponding revolving angle of the central axle and bias respectively. Experiments results obtained with data acquired from LAMOST site are used to illustrate verify the feasibility and effectiveness of this novel method.

8450-122, Poster Session

A novel calibration method of CCD camera for LAMOST

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Large Sky Area Mulit-object Fiber Spectroscopic Telescope - LAMOST, with a 1.75m-diameter focal plane on which 4000 optical fibers are arranged, is one of major scientific projects in China. During the surveying process of LAMOST, the optical imaging system makes the astrometric objects be imaged in the focal plane, and the optical fiber positioning system controls the 4000 fibers to be aligned with these objects and obtain their spectrum. In order to correct the positioning error of these optical fibers, the CCD camera is used to detect these fibers' position in the way of close-range photogrammetry.

As we all know, the calibration quality of the CCD camera is one of the most important factors for detection precision. However, the camera calibration has two following problems in the field work of LAMOST. First, the camera parameters are not stable due to the changes of on-site work environment and the vibration during movement. So, the CCD camera must be on-line calibrated. Second, a large-size high-precision calibration target is needed to calibrate the camera, for the focal plane is very big. Making such a calibration target, it is very difficult and costly. Meanwhile, the large calibration target is hard to be fixed on LAMOST because of the space constraint.

In this paper, an improved bundle adjustment self-calibration method is proposed to solve the two problems above. The results of experiment indicate that this novel calibration method needs only a few control points while the traditional calibration methods need much more control points to get the same precision. So the method could realize the on-line high-precision calibration of CCD camera for LAMOST.

8450-123, Poster Session

Applied stress on coated multimode optical fibres: a different point of view on bending losses

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The power losses introduced by bending multimode optical fibres have been studied since the last forty years, when the efficient transmission of those fibres was regarded as very useful for devices that require the transmission of spatially incoherent light, e.g. Integral Field Units (IFU) for Astrophysics. In the literature, the influence of the fibre coating on transmission properties is rarely taken in account, i.e. the fibres under test are frequently stripped, however, in practical applications the fibres are used with their coating. We present the results of an experimental study of attenuation due to bending stress on several large-core multimode non-stripped optical fibres. In this experiment the attenuation is studied as a function of applied stress in kilo pounds squared inches [kpsi]. The fibres under test are those typically used in IFUs, or used as probes for chemical sensing, amongst other applications. We cover a range of different core diameters for both all-silica and hard cladding step-index fibres. As optical-fibres manufacturers are offering a variety of coating materials, the tested fibres are coated with the following: silicone, polyimide, two types of fluorine doped acrylate, and acrylate.

We show that for a given coating material, regardless of bending radius, applying the same bending stress on fibres of different core diameters, these introduce the same amount of attenuation. We also show differences in attenuation due to the use of different coating material. We present results of RSoft simulations describing a modal behaviour in agreement with the experimental results.

8450-125, Poster Session

Development of different kind of IFU prototypes for the OPTIMOS-EVE study for the E-ELT

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The OPTIMOS-EVE concept provides optical to near-infrared (370-1700 nm) spectroscopy, with three spectral resolution (5000, 15000 and 30000), with high simultaneous multiplex (at least 200). The optical fibre links are distributed in four kinds of bundles: several hundreds of mono-object systems with three types of bundles, fibre size being used to adapt spectral resolution and 30 deployable medium IFUs (about 2"x3"). We are optimising the design of deployable IFUs to warrant sky subtraction for the faintest extragalactic sources.

This paper gives the design and results of the prototype for the high resolution mode and the preliminary design of a medium IFU developed in collaboration between the GEPI and the LNA.

8450-126, Poster Session

Development of the fibres of MOONS

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MOONS will exploit the full 500 square arcmin field of view offered by the Nasmyth focus of the Very Large Telescope and will be equipped with one or two dual-arm spectrographs covering the wavelength range 0.8µm-1.8µm, with a possible extension down to 0.5µm. Each double-arm spectrograph will produce spectra for 250 targets simultaneously, each with its own dedicated sky fibre for optimal sky subtraction. The system will have both a medium resolution (R~3000-5000) mode and a high resolution (R~20000) mode.

This paper presents the design of the fibre management module and describes the specific developments required to optimise its performances.

8450-127, Poster Session

Development of the single fibres and IFUs of WEAVE

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WEAVE is a new wide-field spectroscopy facility proposed for the prime focus of the 4.2m William Herschel telescope. The facility comprises a new 2 degree field of view prime focus corrector with a 1000-multiplex fibre positioner, a small number of individually deployable IFUs, and a large single IFU. The IFUs and the MOS fibres can be used to feed a dual-beam spectrograph that will provide full coverage of the majority of the visible spectrum in a single exposure at a resolution ~20000.

This paper sums up the design of these 2 modes and describes the specific developments required to optimise the performances of the fibre system.

8450-129, Poster Session

Optical fiber tapers: focal reduction and magnification

D. M. Haynes, J. Olaya, Leibniz-Institut für Astrophysik Potsdam (Germany); S. G. Leon-Saval, The Univ. of Sydney (Australia); R. Haynes, Leibniz-Institut für Astrophysik Potsdam (Germany)

Optical fiber tapers show great promise as a simple and highly effective means of efficiently coupling broadband light into astronomical instruments. Fiber tapers can replace bulk optics systems such as focal plane reduction and magnification optics by controlling and manipulating image scale and beam angle in a small, robust and cost effective device.

Like any new photonic device fiber tapers must be thoroughly characterised before they can be applied to astronomy. The specific characteristics of importance are the device's ability to maintain the etendue of the system and to transmit light over a broad wavelength range with minimal loss. In this paper we present results of beam conversion and throughput for fiber tapers with ratios greater than 4 and various taper transition lengths. We also present a method of design and manufacture that produces fiber taper devices that can improve telescope focal plane to spectrograph coupling.

8450-130, Poster Session

Multimode to single-mode converters: new results on 1-to-61 photonic lanterns

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Photonic Lanterns are a new fibre-based component performing the adiabatic conversion from a multimode fibre to a series of singlemode fibres. This conversion is required for combining fibre-based instruments used in astronomy with complex photonic functions. As any fibre-based system, the optical properties of the Photonic Lanterns need to be fully evaluated. In this paper, we present new results on the performance of a 1-to-61 Photonic Lantern in terms of spectral transmission and modal noise characteristics.

8450-131, Poster Session

Multicore fibre Bragg grating developments for OH suppression

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Here we present the development of multi-core fibre Bragg gratings (FBGs) to be applied to astrophotonics, more specifically to near-infrared J- and H-band spectroscopy for ground-based instruments, and discuss its feasibility. For this purpose the multi-core FBGs should have many notches (more than 100), which reject all the unwanted OH lines in a broad wavelength range; at least 160 nm. The number of cores of the fibre should correspond to the number of modes in multi-mode fibers and should be large enough to be able to capture a sufficient amount of light from the focus of the telescope.

A phase-mask based FBG writing technique is utilized to develop the multi-core FBGs. In order to determine the ideal parameters for fabricating efficient multi-core FBGs we have considered the degree to with which the fibre is hydrogenated and hence its photosensitivity, the size of laser beam to support the larger diameter of the multi-core fiber (230 - 250 micrometer) and the intensity of the laser light or exposure time. However, the main problem is the non-uniformity in grating properties across the cores of the fiber. To achieve consistent performance across all the FBGs inscribed in each of the cores, the cores should be exposed to the same intensity of laser light. However, the air-cladding interface of the multi-core fiber acts as a cylindrical lens such that some cores do not receive enough UV light to achieve the desired refractive index variations. We discuss techniques used to overcome this issue.

8450-132, Poster Session

Tests of VPHGs in the NIR at cryogenic temperatures

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We report on the performances measured at room temperature and in cryogenic conditions of a set of NIR Volume Phase Holographic Gratings (VPHGs) manufactured at the Miguel Hernández University (Elche, Spain) aimed at their use in astronomical instrumentations. VPHGs are novel optical components which can replace standard ruled transmission

gratings, offering some advantages. Instead of a surface modulation, a diffraction index modulation printed in a volume of material generates the diffraction according to the required specifications. While VPHGs are becoming an option for instruments working in the optical regime at room temperature, their use is still minimal in the NIR wavebands due to the stringent requirements impose by the cryogenic environment. But their good properties in terms of high transmission and compact mechanical design are kept even in cryogenic, so efforts to develop such devices functional at cryogenic temperatures are underway in several institutions. We report results on transmission and wavefront deformation of newly manufactured VPHGs and these are compared in the two temperature regimes, namely room and cryogenic temperatures. These results were achieved through a collaborative effort within the European network OPTICON, WP6 New Materials and Processes in Astronomical Instrumentation, and whose participating institutions are Instituto de Astrofísica de Canarias (IAC), Universidad Miguel Hernández, Osservatorio Astronomico di Brera (INAF) and Politecnico di Milano. The measurements were done at the Optical Lab of the IAC using dedicated equipment, which include the ability to perform transmission and image quality tests with the grating being maintained at cryogenic temperatures.

8450-133, Poster Session

Slanted VPHGs in astronomical instrumentation: tests and perspectives

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Volume Phase Holographic Gratings are becoming the dispersing element of choice in many astronomical instrumentations of the next generation, thanks to their peculiar properties in terms of efficiency, robustness, dispersion. In this framework, an increasing interest is devoted to the slanted VPHGs, where the grating pattern shows a certain angle in respect to the grating normal. In such gratings, it is possible to shift the conditions of large efficiency (usually the Bragg condition) independently from the dispersion conditions (grating equation) acting on the slanting angle. This flexibility allows to design VPHGs for some new applications, for example as cross-disperser in echelle instrumentation or as dispersing element with controlled anamorphism and simpler structure. In respect to classic VPHGs, slanted gratings require a larger effort both for the design phase and for the realization phase. Here a full characterization of some samples produced by Kaiser Optical Systems is reported focusing mainly on the diffraction efficiency (blaze and superblaze curves) as function of the grating features. The discussion is then carried out considering the reliability of these dispersing elements and focusing on some application cases.

8450-134, Poster Session

Reflective coating for near infrared immersion gratings

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Achieving high reflectivity from an immersed grating facet can be challenging in the near infrared. The reflectivities of metallic coatings in common use such as Al or Cr/Au decrease at shorter wavelengths in the near IR. A layer of copper on ZnSe or ZnS should have high immersed reflectivity based on tabulated values of refractive index, but in fact performs poorly. We attribute this to a chemical reaction between the copper and the selenium or sulfur. Similar issues are anticipated if silver is used as a reflective material.

A non-reactive intermediate layer can avoid this problem. Since Fresnel reflectivity increases with increasing difference in refractive index, it is beneficial to choose an intermediate layer of low index. A further improvement is gained by adjusting the layer thickness so that reflections from the two interfaces of the intermediate layer add constructively.

We sputtered 130 nm of SiO2 onto ZnSe and ZnS substrates, followed by 200 nm of Cu and 5 nm of SiC as a protective capping layer. Measured immersed reflectivity exceeded 95% between 1500 and 1100 nm and exceeded 90% down to 850 nm. Results of reflectivity measurements after long term exposure to high humidity conditions (RH > 80%) will be reported.

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8450-135, Poster Session

Fabrication and testing of germanium grisms for LMIRcam

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We are diamond flycutting 2 sets of germanium grisms for the LMIRcam 3-5 micron Fizeau imager for the combined focus of the Large Binocular Telescope (LBT). The grisms mount in a filter wheel near a pupil to enable moderate resolution (R~300) spectroscopy. Both sets have a blaze angle of 2.8°. The first set has a groove period of 40 lines/mm and will be used in first order with peak efficiency at 3.6 µm. The second set has 32 lines/mm. It can operate in first order with an efficiency peak near 4.4 µm and in second order with a peak near 2.3 µm. First results from testing the grisms in the instrument on the sky with the LBT are presented.

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8450-136, Poster Session

Large filters for wide field survey telescope LSST

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The LSST design foresees the use of six wide-band large optical filters that can alternatively be moved in front of the CCD camera. Each of the six filters has a different band-pass covering all the wavelengths from 300 nm to 1200 nm. The way to achieve this is to coat an optimized optical thin film on a filter substrate. Each filter requires a specific design using specific appropriate materials. The main characteristics of these filters, that constitute a real technological challenge, are: their relatively large size - Their radius of curvature (about 5.6 m) that represents a sagitta of 12,5 mm that increases the uniformity complexity, the large rejection band requirements that must be lower than 0.01 % out of the band and o transmission of 95 % aver the band-pass. I propose to show the problematic and the results obtained at LMA (Laboratoire des Matériaux Avancés-FRANCE) in the purpose to realize the filters. In a first step, I will expose the results obtained coating HighPass/LowPass and Fabry-Perot structure, the advantages and drawbacks of each approach concerning the control of the positions of the front, the transmittance in the bandpass and the rejection band. Experimental results will be exposed concerning the U-band (321-391 nm) and the R-band (552-691 nm). I will also expose the work done to make cartography of transmittance of large filters integrating fiber optic transfer holder and a 60mm Integrating Sphere for LAMBDA 1050 spectrophotometers.

8450-137, Poster Session

MUSE optical coatings

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Optical coatings are one of the key elements of the second generation instrument MUSE (Multi Unit Spectroscopic Explorer), developed for ESO (European Southern Observatory). MUSE will be assembled to the VLT (Very Large Telescope) in 2013. It is a panoramic integral field spectrograph (1x1arcmin^2 Field of View) operating in the visible wavelength range (465 nm - 930 nm).

This article first focuses on the throughput, one of the most important parameters of MUSE instrument, which aims at observing very faint objects.

Then, the different reflections and refractions required by the optical design of MUSE are presented: between the output of the VLT and the final detectors of MUSE, photons are typically reflected 7 times by mirrors and transmitted 24 times by antireflective coatings.

A comparison between different metallic and multi-dielectric coatings are then exposed in order to explain the best compromise that has been chosen for MUSE purpose.

Systematic optical coating tests have been conducted, so as to check the durability under severe constraints: humidity, temperature change, scratch...

Finally, the stress induced by the optical coatings on the substrates is presented: the stress of large band, high reflectivity (>99%) multi-dielectric coating, is simulated. This leads to simulations and measurements of the deformation of the MUSE optics due to multi-dielectric coating.

In the end, the choice of high quality optical coatings should allow MUSE to reach a global throughput of about 40%.

8450-138, Poster Session

Design of the J-PAS 56 filter system

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J-PAS (Javalambre-PAU Astrophysical Survey) is a Spanish-Brazilian collaboration to conduct an innovative photometric survey of the northern sky using an unprecedented system of 56 filters, 54 narrow-band (FWHM ~12.5nm), covering the 330-1000nm wavelength range, plus 2 broad-band filters over more than 8000 square degrees. The survey will be carried out using JPCam, a 14-CCD mosaic camera using the new e2v 9k-by-9k 10μm pixel detectors, mounted on a dedicated 2.55-m wide-field telescope at the OAJ (Observatorio Astrofísico de Javalambre) in Teruel, Spain. The camera's filter unit will be designed to admit 4 filter trays, each one will mount 14 square filters corresponding to the 14 CCDs of the mosaic. Each CCD will view only its corresponding filter avoiding optical cross-talk from their neighbors. The filters will operate close to, but outside, the dewar window in a fast (f/3.64) converging beam. This optical configuration imposes challenging requirements for the J-PAS filters, some of them requiring the development of new filter design solutions. Our talk will describe the design of the J-PAS filters and how the most strict requirements have been fulfilled. In particular, emphasis will be made on the most demanding and unusual ones, such as the continuous coverage of the optical spectrum, central wavelength uniformity across the filters' 104x104mm clear aperture, the tight filter thickness control and the strategy for minimizing of the filters' out-of-band reflectivity to avoid ghosts in the final images.

8450-139, Poster Session

Research on a project of the new computational hyperspectral imager

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Hyperspectral imagers combine spectral technology and imaging technology, get both the image of the target and the spectrum of the pixel to recognize the materials on the objects, have broad applied foreground on astronomical domain. That arrests extensive attention abroad.

There are two difficult problems for conventional spectral image mode at present.

One is barging up against to improve both spatial resolution and spectral resolution. Because the spectrum is divided into a lot of parts, several nanometer as usual, that results the energy collected by each pixel reduced. Retricted by signal-to-noise ratios (SNR), the spatial resolution and spectral resolution can't improve at the same time.

The other is the numerous data processing. Because spectral imagers divide the spectrum subtly, producing a large number of data, that bring a big difficulty to transfers and storage later.

This paper brings hyperspectral technology and compute image together. On the basis of geometrical optics theory and compressed sensing theory, puts forward a new computational spectral Imaging technology. That raises two to four times on spatial resolution and double on spectral resolution compared conventional hyperspectral imagers. Owing to have finished compressing when getting the imaging signal, that could resolve the conflict between the mass of data bringing with high resolution and transfers and storage. The paper carries out a project to the new hyperspectral imager.

8450-140, Poster Session

Reflectivity, polarization properties and durability of metallic mirror coatings for the European Solar Telescope

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In the context of the conceptual design study for the European Solar Telescope (EST) we have investigated different metallic mirror coatings in terms of reflectivity, polarization properties and durability. Samples of the following coating types have been studied: bare aluminum, silver with different dielectric layers for protection and UV enhancement, and an aluminum-silver combination. From 2009 to 2011 we have carried out a long-term durability test under realistic observing conditions, with 3 repeated exposure periods of about half a year, at the VTT solar telescope of the Observatorio del Teide (Tenerife/Spain). After each VTT exposure period, the reflectivity of the mirror samples has been measured over the full EST spectral working range between 300 nm and 20 μm. In addition we have measured the polarization properties (Mueller matrix) of the coating samples as a function of incidence angle. The reflectivity data allow us to assess ageing effects and to predict the frequency of re-coating cycles. The results of the polarization measurements are

a valuable input for the EST telescope polarization model, helping to meet the stringent requirements on polarimetric accuracy. Based on our test results we suggest a bare Al coating for the EST main mirror and enhanced silver coatings for the other mirrors. For incidence angles larger than about 30°, the polarization properties of enhanced silver coatings show significant deviations from a pure silver coating. In addition the crosstalk between linear and circular polarization exhibits strong angular gradients which can result in a significant field-dependent polarization behavior.

8450-141, Poster Session

Developing metal coated mesh filters for mid-infrared astronomy

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A metal mesh filter is appropriate to a band-pass filter for astronomy in the mid-infrared between 25 and 40 micron, where most of optical materials are opaque. This filter does not require dielectric materials unlike interference filters. The transmission characteristics are determined by surface plasmon-polariton (SPP) resonances, which are excited on a metal surface of periodic structure. We have been developing the metal mesh filters for mid-infrared astronomy from ground and space.

The mesh filters have been fabricated with gold films of two-micron thickness. To suppress leakages at stop-bands, four identical filters have been stacked incoherently. By laboratory evaluations, it has been confirmed that the transmittance of the stacked filter is less than 0.2 % at the stop-bands, and is 80 % at the peak wavelength of 37.5 micron. A ground-based mid-infrared camera MAX38 has equipped the stacked filter and successfully obtained diffraction-limited stellar images at 37.5 micron.

The classical-type mesh filter does not have adequate mechanical strength for larger aperture and for use in space. We have developed mesh filters with higher strength by applying membrane technology for X-ray optics. The newly developed filter is made of SiC, which is a semiconductor with high mechanical strength, and is coated by a thin gold layer. The optical performances of the mesh filter are independent of internal materials in principle since the SPP resonances are excited only on the metal surface. By measurements of the fabricated filters, it has been confirmed that the metal-coated mesh filter has higher mechanical strength and comparable optical performances to the classical-type mesh filter.

8450-142, Poster Session

Octadecanthiol for tarnish-resistant silver coatings

A. C. Phillips, A. Cowley, Lick Observatory (United States)

Octadecanethiol self-assembling monolayers have been reported to protect silver against tarnish in typical environments. We have undertaken a study to investigate whether such coatings have potential use for silver-based mirror coatings for astronomy, particularly in instruments where mirror coatings would be protected from dirt and potential mechanical damage. We find that simple treatment of bare silver with octadecanethiol does significantly reduce the rate of tarnish while preserving silver's excellent reflectivity. We describe the simple process of application, how the coatings are evaluated, and directions for further investigations.

8450-143, Poster Session

Design and preparation of antifrost coating for the Antarctic Telescope

J. Wang, Nanjing Institute of Astronomical Optics & Technology (China)

As current ever-growing research hotspots, the Antarctic Telescope has many problems to be solved. The telescope's mirror freezing in the extremely low temperature environment in Antarctic Pole region is one of problems. Anti-frost film of ITO (Indium Tin Oxide) has been used in multiple telescopes in the Antarctic. Usually, ITO transparent conductive thin film is made up of only one layer of ITO material. If the thin film of ITO can be taken as one layer of antireflection coating, it will largely increase transmittance in the visible light region. If the transparent conductive film (TCO) can be applied to the mirror of reflecting telescope, the observation with large reflecting telescope will become possible in Antarctica. In this paper, we discuss the technology of TCO film-forming in low temperature, the design and preparation of anti-frost antireflection and high reflection coating.

8450-144, Poster Session

Development of an integral field unit for a near-infrared multi-object imaging spectrograph SWIMS

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We are developing an integral field unit (IFU) for a near-infrared multi-object imaging spectrograph SWIMS (Simultaneous-band Wide-field Multi-object Spectrograph). SWIMS is an instrument for the University of Tokyo Atacama Observatory (TAO) project on the summit of Co. Chajnantor (altitude of 5,460m) in northern Chile. All near infrared integral field spectrographs (IFSs) on 8-10m class telescopes are used with adaptive optics and have fine spatial sampling. Comparing with them, SWIMS has higher sensitivity for extended objects because it has coarser spatial sampling optimized for seeing-limit observations. We have investigated the feasible optical design, and reached two possible solutions; field of view is about 10 x 7 arcsec^2 with 0.2 arcsec slice width and 14 x 10 arcsec^2 with 0.4 arcsec slice width. All IFU mirror arrays will be made from aluminum alloy to match the thermal expansion with support structures, as they are placed in a cryogenic environment. And they will be fabricated monolithically with high precision machining to reduce alignment process. We have carried out a fabrication test of one spherical surface and confirmed that surface roughness and surface figure error were enough low for near-infrared light. As a next step, fabrication of a prototype mirror array with 3 reflective surfaces is planned. In this presentation, we will show our project outline, the IFU optical design and the results of prototyping works.

8450-145, Poster Session

An Offner-spectrograph for tilted focal planes: the BATMAN case for TNG

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Multi-Object Spectrographs can be designed around MOEMS devices such as digital micromirror devices (DMD) which allow the remote control of the multi-slit configuration in real time. An all-reflective Offner relay system has been designed to match the tilted focal plane represented by the DMD surface, delivering high quality images and spectra. A refractive relay optics convert the F/11 Galileo telescope beam onto a

faster F/4, thus covering a field of view of 7x4 arcmin2, and producing up to simultaneous 200 spectra over the detector area. The selected wavelength range, from 420 to 850 nm, has been selected to maximize the scientific return of the demonstrator.

This demonstrator will be used to check on sky performances as throughput, contrast, stray light control, PSF, spectrum distortion, and calibration issues.

8450-146, Poster Session

Electro-optical polarimeters for ground-based and space-based observations of the solar K-corona

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Polarimeters based on electro-optically tunable liquid crystals (LC) represent a new technology in the field of observational astrophysics. LC-based polarimeters are good candidates for replacing mechanically rotating polarimeters in most ground-based and space-based applications. During the 2006 total solar eclipse, we measured the visible-light polarized brightness (pB) of the solar K-corona with a LC-based polarimeter and imager (EKPol). In this presentation, we describe the results obtained with the EKPol, and we evaluate its performances in view of using a similar device for the pB imaging of the K-corona from space-based coronagraphs. Specifically, a broad-band LC polarimeter is planned for the METIS (Multi Element Telescope for Imaging and Spectroscopy) coronagraph for the Solar Orbiter mission to be launched in 2017. The METIS science driver of deriving the coronal electron density from pB images requires an accuracy of better than 1% in the measurement of linear polarization. We present the implications of this requirement on the METIS design to minimize the instrumental polarization of the broad-band visible-light (500-600 nm) polarimeter and of the other optics in the METIS visible-light path. Finally, we report preliminary ellipsometric measurements of the optical components of the METIS visible-light path.

8450-148, Poster Session

Photopolymer-based volume phase holographic grating for astronomical instrumentations

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Liquid green sensitive photopolymers have been studied to produce volume phase gratings (VPHGs) to be used as dispersing elements in astronomical instrumentations. These gratings have been obtained using a Lloyd mirror holographic set-up equipped with a 532 nm laser. Then, they have been characterized determining the parameters that play a crucial role in determining the diffraction efficiency; those parameters include thickness, refractive index modulation, light exposure, grating's line density, etc. Different prototypes have been produced varying all the selected parameters in order to reach the best performances achievable, especially in term of diffraction efficiency, which was measured at different wavelengths (in the 400 - 1000 nm spectral region). Moreover, the optical proprieties of the devices were investigated to understand the quality of the gratings; in particular measurements of transparency and interferometric analysis of the wavefront were performed. The results were encouraging: a peak efficiency of 90% were obtained in several produced gratings, therefore, to experience the real possibility to produce a VPHG for astronomical applications, low dispersion prototype (300 lines/mm) has been produced, and it will be mounted (using a GRISM configuration) in the AFOSC camera (182 cm Telescope, Asiago, Italy).

8450-149, Poster Session

Spectrally-quantified chemical reactivity optical fluids and materials in the GMACS spectrograph for GMT

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We present a compatibility review of index-matching fluids with commonly used optical assembly materials. The optical coupling fluids used in the Giant Magellan Areal Camera and Spectrograph (GMACS) for the Giant Magellan Telescope (GMT) will be selected based on these empirical results. Although we focus on fluid candidates for GMACS, the results of the conducted experiments are applicable to all instruments that use optical index-matching fluids. The experiment presented here identifies potentially corrosive matchings of fluids and materials. In the experiment, a material (RTV, polyethylene, delrin, etc.) is submerged in a quartz cuvette of fluid (Cargille liquids, glycerin, etc.). Contamination is observed by using a spectrometer to measure the absorption spectrum at various post-submersion times. The final results will track the percent degradation in the UV transmission as a function of post-submersion time.

8450-150, Poster Session

Echelle VPHG: a step forward

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The technology of Volume Phase Holographic Gratings strongly affected, in the last decade, the design and performances of low dispersion astronomical spectrographs. The large efficiency, the tunability and the robustness make such dispersing elements the choice for the next generation instrumentation. Unfortunately classical VPHGs are not suitable for applications in high dispersion spectrographs where an echelle grating is required, because of the low efficiency in high diffraction orders. A solution for increasing the diffraction efficiency in higher orders is to change the shape of the refractive index profile. In particular, binary gratings are interesting in this sense. Here a full optimization of binary volume gratings is reported as function of the grating parameters in the visible spectral range. The height of the binary element, the duty cycle and the modulation of the refractive index have been optimized in order to obtain large peak efficiency, but also a good overlap between the different orders efficiency. The results show that it is possible to reach efficiencies of 90% and 40% at peaks and orders boundaries, respectively, for different orders (9 - 15, grating with 200 l/mm) when the duty cycle is really large (0.95) also for moderate refractive index modulations. Moreover by slightly changing the incident angle, the visible spectral range can be covered with efficiencies larger than 60% for unpolarized light. The optimization has been also carried out considering the real possibility of making such devices. First results on a low order grating are reported to support the theoretical analysis.

8450-151, Poster Session

Comparing modelling techniques when designing VPH gratings for BigBOSS

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BigBOSS is a Stage IV Dark Energy based on the Baryon Acoustic Oscillations (BAO) and Red Shift Distortions (RSD) techniques using spectroscopic data of 20 million ELG and LRG galaxies at redshifts between 0.5 and 1.6 in addition to several hundred thousand QSOs at redshifts between 0.5 and 3.5. When designing BigBOSS instrumentation, it is imperative to maximize throughput whilst maintaining a resolving power of between R=1500 and 4000 over a wavelength range of 360-980 nm. Volume phase Holographic (VPH) gratings have been identified as a key technology which will enable the efficiency requirement to be met, however it is important to be able to accurately predict their performance. In this paper we quantitatively compare different modeling techniques in order to assess the parameter space over which they are more capable of accurately predicting measured performance. Finally we present baseline parameters for grating designs that are most suitable for the BigBOSS instrument.

8450-152, Poster Session

A single-mode Echelle spectrograph: eliminating modal variation, enabling higher precision Doppler study

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An innovative compact---yet high resolution---cross-dispersed echelle spectrograph has been designed, built, and deployed at TSU's 2-meter robotic telescopes for initial tests and commissioning. This design eliminates one of the primary systematic noise sources in spectrographs being used for precision Doppler studies in exoplanet searches-mode noise in fiber-fed spectrographs. The modal variation presents a variable input image to the spectrograph, reducing measurement repeatability, which is especially important for m/s precision exoplanet Doppler searches. In order to overcome this limitation a spectrograph with a new design, based on single mode fiber (SMF) was developed.

The use of SMFs brings several advantages. First, SMF allows only one mode to pass and this automatically removes modal variation. Second, the spectrograph's input image is small so all optics in the spectrograph are similarly small (and inexpensive), and compact (thus stable). Third, to match the small input image (3 microns) to common CCD pixels (10-25 microns), the spectrograph must magnify the image, consequently the beam for the camera is slow, making the camera focus very stable and allowing simple lenses to be used. As compared to de-magnifying standard echelles with 6-7 element custom cameras, a simple off the shelf doublet is sufficient. SMFs have one significant disadvantage of having low throughput as compared to multi-mode fibers. This limitation can be reduced by using adaptive optics or to put it in space where the wavefront is not corrupted; the compact design is well suited for such deployment.

8450-153, Poster Session

Planar integrated photonics spectrograph on silicon-nitride-on-insulator: densely integrated systems for astrophotonics and spectroscopy

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Conventional Arrayed Waveguide Grating (AWG) has been modified, without receiver waveguides, for non-conventional applications such as Astro-Photonics and spectroscopy where the input signal could be a continuum of light/spectrum. The proposed AWG can focus light, in the output star-coupler, on a flat image-plane compared to curved image-plane of a conventional AWG. This scheme, in essence, allows resolving of any two-wavelengths (launch to the AWG) with given resolution and access the entire image-plane to receive the spectrally resolved data. Further, with proper optics the entire flat-image-plane could be projected on to a CCD array as used in Astronomical spectrographs, making it suitable for spectroscopy (an Integrated Photonic Spectrograph - IPS).

However when the entire focal plane is imaged using a CCD array, it needs to be calibrated accurately. Integration of high Q-factor ring-resonators on the same platform permits realisation of Frequency-COMB based calibration source and IPS on a single chip with dense-integration. Material system chosen for the IPS design is silicon-nitride/SiO2/Si (Si3N4-SiO2-Si) due to its (Si3N4) high non-linear coefficient with the absence of two-photon absorption. This choice of material system would allow monolithically integration of high-Q ring-resonator based calibration source and IPS on the same platform. The first proposed IPS, with flat image-plane, designed to resolve 48 spectral channels with 0.4nm (50GHz) resolution and adjacent channel/ITU-grid cross-talk level ~ -26dB/-35dB. Calculated insertion loss non-uniformity is about 2.5dB. The foot-print of high index contrast (delta=23%) IPS is ~ 12.8x8.5 mm2. The method could be utilised in other material systems with given resolution.

8450-217, Poster Session

A high-resolution Fourier transform spectrometer for astronomical: observations and development of wavelength standards

U. Lemke, A. Reiners, S. Schäfer, G. Anglada, Univ. Göttingen (Germany)

At the Institute for Astrophysics Goettingen (IAG), we are installing a high resolution Fourier Transform Spectrograph (FTS) for astronomical observations and development of calibration standards aiming at high wavelength precision.

Astronomical spectrographs working in the regime of very high resolution (resolving powers lambda/delta lambda = 10^5 and higher) now achieve unprecedented precision and stability. As a long-term scientific goal, the evolution of galaxy redshift due to dark energy can be monitored. Also, the detection of relatively low-mass, down to Earth-mass planets via the radial velocity method will become feasible. Hereby, M-dwarfs are promising objects where an orbiting exo-Earth can cause a wavelength shift large enough to be detected. Emitting mainly in the near infrared, these objects require novel wavelength calibration standards. Current methods under consideration are gas cathode lamps (e.g. CN, UNe) and a highly stable Fabry-Pérot Interferometer (FPI) to act as a cost-effective alternative to the laser-frequency comb. In addition to lab experiments, light will be fed from our telescopes at IAG.

Our Vacuum Tower Telescope (VTT) and the 50 cm cassegrain telescope allow to investigate stellar and spatially resolved light at our facilities.

8450-154, Poster Session

Immersion grating mount design for IGRINS and GMTNIRS

B. Moon, Korea Astronomy and Space Science Institute (Korea, Republic of); W. Wang, The Univ. of Texas at Austin (United States); I. Yuk, C. Park, M. Chun, Korea Astronomy and Space Science Institute (Korea, Republic of)

The IGRINS (Immersion GRating INfrared Spectrometer) is a high resolution wide-band infrared spectrograph developed by Korea Astronomy and Space Science Institute (KASI) and the University of Texas at Austin (UT). Immersion grating is a key component of IGRINS, which disperses the input ray by using a Silicon material with a lithography technology. Opto-mechanical mount for the immersion grating is important to keep the high spectral resolution and the optical alignment in a cold temperature of 130±0.06K. The optical performance of immersion grating can maintain within the de-center tolerance of ±0.05mm and the tip-tilt tolerance of ±1.5arcmin.

The mount mechanism utilizes the flexure and the kinematic support design to satisfy the requirement and the operation condition. When the IGRINS system is cooled down to a cold temperature, three flexures compensate the thermal contraction stress due to the different material between the immersion grating and the mounting part(Aluminum 6061). They also support the immersion grating by an appropriate preload. Thermal stability is controlled by a copper strap with proper dimensions and a heater. Generally structural and thermal analysis was performed to confirm the mount mechanism. This mechanism will also be applied to the GMTNIRS(Giant Magellan Telescope Near InfraRed Spectrograph) instrument, which is a first generation candidate of the GMT telescope.

8450-155, Poster Session

A common tool-less cryogenic mounting solution for flat optics

N. Tromp, J. W. Kragt, M. P. Zijlstra, E. J. Elswijk, ASTRON (Netherlands)

The MATISSE Cold Optics instrument combines all four ESO-VLT into one interferometric fringe pattern. For this purpose dozens of Fused Silica fold mirrors must be positioned accurately in a cryogenic aluminum instrument. Research was started to develop a common tool-less mounting solution that meets the following requirements: accurately position these mirrors with minimum deformation, be simple in use and small in design, be applicable in a cryogenic environment and lower the risks and cost of MAIT. The result is a compact sheet metal assembly of only three different parts that snaps the mirror in its final position. This poster presents the development of this mounting solution, the hardware and test results.

8450-156, Poster Session

Improved stress prediction in adhesive bonded optical components

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Adhesives are widely used in opto-mechanical structures for bonding optical components to their mounts. The main advantage of using adhesives is the excellent strength to weight ratio.

In space applications, adhesive bonded joints are exposed to severe inertial and thermal loads. Therefore, accurate prediction of stress and deformations is required. It is a well known fact that mechanical properties of the adhesive are of major importance in stress predictions in bonded joints. However, representative mechanical data for structural adhesives is very difficult to find.

Adhesives show strong temperature and loading history behavior. Therefore, a viscoelastic material model is needed for accurate prediction of stresses and strains in bonded joints.

In this research the relevant mechanical properties of commercially available adhesives are measured. The measured data are modeled with a viscoelastic material model, and implemented in ANSYS finite element modeling software. The use of this software model allows for more reliable and accurate stress prediction in opto-mechanical structures.

This paper shows the results of the characterization experiments, modeling techniques, stress predictions and the impact on optical mount design in the EUCLID and TROPOMI programs as described in “Ultra stable iso-static bonded optical mount designs for harsh environments, J.A.C.M. Pijnenburg et al”.

8450-157, Poster Session

Passive vibration isolation in the closed cycle cooler refrigerated cryostats for SITELLE

M. R. Baril, T. Benedict, G. A. Barrick, K. K. Ho, Canada-France-Hawaii Telescope (United States)

The SITELLE Imaging Fourier Transform Spectrometer system being developed by l’Université Laval at ABB-Bomem for the Canada France Hawaii Telescope (CFHT) will require two identical CCD detector systems. Our requirements for the cryogenic system in these cameras are: cooling to below 173 K, extremely low vibrational input from the cryogenic system (<1 mg RMS from 0-2 kHz), hands-off operation over long periods of time and low original capital outlay and continued operation cost. These constraints drove towards the selection of a PolyCold PCC cooled system that exhibits relatively low vibrational noise and can efficiently achieve the required cooling power in our target temperature range. This paper will present work performed to passively mitigate high frequency vibrations imparted by the PolyCold PCC cryo-head on the detector cryostat. Considerations made in the dewar design to improve vacuum holding time in this relatively warm cryostat will also be detailed.

8450-158, Poster Session

Cryogenic actuator for subnanometer positioning

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This paper discusses the development, realization, and qualification of a positioning actuator concept specifically for cryogenic environments. Originally developed for quantum physics research, the actuator also has many applications in astronomic cryogenic instruments to position optical elements with nanometer level accuracy and stability. It is not only suited to manipulate lenses or mirror, but an enlarged actuator optimized for a non-magnetic, cryogenic filter wheel is also being researched.

The actuator is nicknamed the ‘PiezoKnob’ because it is piezo based and it is compatible with the manipulator knob often found in standard system for optical benches, such as linear stages or tip/tilt lens holders. Actuation with high stiffness piezo elements enables us to deliver forces of up to 50 Newton to deal with relatively stiff guiding mechanism or large pre-loads. A 5 millimeter linear displacement range is achieved using an inertia based stepping mechanism. The PiezoKnob has been qualified at 77 Kelvin and was shown to work down to 2 Kelvin. As part of the qualification program, the custom developed driving electronics and set point profile have been fine-tuned, by combing measurements with the predictions from a dynamic model, to maximize efficiency and thus minimize power dissipation. Furthermore, the actuator holds its position without power and thanks to its mechanical design it is insensitive to drift of the piezo elements or the driving electronics.

8450-159, Poster Session

Cryogenic actuator testing for the SAFARI ground calibration setup

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For the on-ground calibration setup of the SAFARI instrument cryogenic mechanisms are being developed at SRON Netherlands Institute for Space Research, including a filter wheel, XYZ-scanner and a flipmirror mechanism. Due to the extremely low background radiation requirement of the SAFARI instrument, all of these mechanisms will have to perform their work at 4.5 Kelvin and low-dissipative cryogenic actuators are required to drive these mechanisms.

In this paper, the performance of stepper motors, piezo actuators and cryo-torquers as cryogenic actuators are compared. We tested stepper motor mechanical performance and electrical dissipation at 4K. The actuator requirements, test setup and test results are presented. Furthermore, design considerations and early performance tests of the flipmirror mechanism are discussed. This flipmirror features a 102 x 72 mm aluminum mirror that can be rotated 50°. A Phytron stepper motor with reduction gearbox has been chosen to drive the flipmirror. Testing showed that this motor has a dissipation of 25mW at 4K with a torque of 60mNm.

Thermal modeling of the flipmirror mechanism predicts that with proper thermal strapping the peak temperature of the flipmirror after a single action will be within the background level requirements of the SAFARI instrument. Early tests confirm this result. For low-duty cycle operations commercial stepper motors appear suitable as actuators for test equipment in the SAFARI on ground calibration setup.

8450-160, Poster Session

MATISSE selection mechanism development

J. W. Kragt, N. Tromp, G. Kroes, A. Jaskó, ASTRON (Netherlands)

MATISSE (Multi AperTure mid-Infrared SpectroScopic Experiment) will be a mid-infrared spectro-interferometer combining the beams of up to four telescopes of the European Southern Observatory Very Large Telescope Interferometer (ESO VLTI), providing phase closure and image reconstruction. MATISSE will produce interferometric spectra in the LM and in the N band (2.3 to 13.5 micron) and is as such a successor of MIDI. All beams pass through the warm pre-optics, entering the cold optics where they are combined on the detector creating one spectral interference pattern per band.

Instruments with a large wavelength bandwidth like MATISSE usually comprise mechanisms for selection of various observation modes by switching filters, dispersive elements, pinholes and slits. The cryogenic operating environment poses several challenges to these mechanisms like differential thermal shrinkage, physical property change of materials, accurate drive and (re)positioning and lack of lubrication.

For the MATISSE instrument two concepts of selection mechanisms can be distinguished: linear selection mechanisms (sliders) and rotating selection mechanisms (wheels). Both mechanisms provide high accuracy and repeatability. The feature density is high in a limited space envelope. Cryogenic motors are used as an actuator for all these mechanisms. This paper describes the design and realization of these linear and rotating selection mechanisms.

8450-161, Poster Session

Cryogenic fast shutter design and test results for the MATISSE instrument

J. W. Kragt, E. J. Elswijk, A. P. van Duin, ASTRON (Netherlands)

MATISSE is the mid-infrared spectro-interferometric instrument for ESO's Very Large Telescope Interferometer (VLTI). It combines the light of up to four Unit Telescopes and operates in both L- and M-band and in N-band. A battery of 8 cryogenic shutters select the active telescopes at the entrance of the cold optics subsystem. In order not to destabilize the temperature of the system, the shutter uses a minimum amount of power for switching and can maintain its state completely passive. On top of that the shutter must block incoming beams within 30 milliseconds for detector remanence calibration. A fast shutter was designed, meeting these requirements at both ambient temperature and in a 38 K vacuum cryogenic environment. This paper describes the design of the shutter and discusses the performance test results, including life time tests, speed tests and electromagnetic interference tests.

8450-162, Poster Session

Conceptual phase; a design of a cryogenic shutter mechanism for the SAFARI flight instrument

U. J. Wehmeier, ETH Zurich (Switzerland); G. Messina, A. Vuilleumier, RUAG Space AG (Switzerland); M. R. Meyer, ETH Zurich (Switzerland)

We present a conceptual design for a cryogenic mechanism planned as part of the SAFARI instrument. SAFARI is a long wavelength (35-210 micron) imaging Fourier Transform Spectrometer (FTS) proposed as a contribution by the European Space Agency to the JAXA SPICA mission projected to launch in 2019. SPICA is a large 3 meter class space telescope which itself will operate cold (less than 6K). The SAFARI shutter is a single point of failure flight mechanism designed to operate in space at a temperature of 4K. As such, it should meet redundancy and reliability requirements for this challenging mission. The conceptual design is part of a phase A study led by ETH Institute for Astronomy and conducted by RUAG Space AG.

8450-163, Poster Session

Engineering technology development in the UK for HARMONI: an E-ELT first light instrument

D. M. Montgomery, A. M. Gallie, UK Astronomy Technology Ctr. (United Kingdom)

HARMONI is an integral field spectrograph working at visible and near-infrared wavelengths, over a range of spatial scales from ground layer corrected to fully diffraction-limited. The instrument has been chosen to be part of the first-light complement at the European Extremely Large Telescope (E-ELT).

This paper describes the engineering technology development being undertaken at the UKATC and Oxford University Department of Astrophysics to support E-ELT HARMONI instrument in its pre-phase-B stage. This includes the description of technology demonstrators for a tracking optical de-rotator to be located within the instrument vacuum vessel, a cryogenic shutter and a compact thermally compensating lens mount system. In addition the material testing facilities available at the UKATC are described which will enable the measurement of material and bolted joint thermal conductivities to 4K and friction/wear properties of material combinations to 20K. This work is undertaken to improve the instrument performance and reduce technical, cost and schedule risk.

8450-164, Poster Session

Frida integral field unit optomechanical design

S. Cuevas, Univ. Nacional Autónoma de México (Mexico); S. S. Eikenberry, Univ. of Florida (United States)

FRIDA (inFRared Imager and Dissector for the Adaptive optics system of the Gran Telescopio Canarias) has been designed as a cryogenic and diffraction limited instrument that will offer broad and narrow band imaging and integral field spectroscopy (IFS). Both, the imaging mode and IFS observing modes will use the same Teledyne 2Kx2K detector. This instrument will be installed at Nasmyth B station, behind the GTC Adaptive Optics system. FRIDA will provide the IFS mode using a 30 slices image Integral Field Unit (IFU). This IFU design is based on University of Florida FISICA where the mirror arrays are diamond turned on monolithic metal blocks.

FRIDA IFU performs mainly 3 mirrors blocks with 30 spherical mirrors each. It also performs a Schwarzschild relay based on two off axis

spherical mirrors and a two parabolic off axis afocal system. Including the two insertion mirrors the IFU holds 96 metal mirrors.

Each block or individual mirror is attached on its own mechanical mounting. In order to study beam interferences with mechanical parts, ghosts and scattered light, an iterative optical-mechanical modeling was developed. In this work this iterative modeling is described including pictures showing actual ray-tracing on the mechanical components. Furthermore it is exposed the slices cross talk analysis.

8450-166, Poster Session

An alternative design for a metal image slicing IFU for EAGLE

C. M. Dubbeldam, D. J. Robertson, S. Rolt, G. Talbot, Durham Univ. (United Kingdom)

The Centre for Advanced Instrumentation (CfAI) of Durham University (UK) has developed a conceptual design for the Integral Field Unit (IFU) for EAGLE based on diamond machined monolithic multi-faceted metal mirror arrays as an alternative to the glass IFU which is currently baselined. The CfAI has built up substantial expertise with the design, manufacture, integration, alignment and acceptance testing of such systems through the successful development of an IFU for the Gemini Near-InfraRed Spectrograph (GNIRS) and 24 IFUs for ESO's K-band Multi-Object Spectrometer (KMOS). The unprecedented performance of the KMOS IFUs (Strehl > 0.8 across the field, throughput rising from 86% at a wavelength of 1 micron to 93% at 2.5 micron) demonstrates that the current state-of-the-art technology is sufficiently mature to meet the demanding requirements for EAGLE. In addition, the use of monolithic multi-faceted metal mirror arrays will greatly simplify the manufacture, integration and alignment of such systems thus potentially reducing technical and programmatic risks and cost. Through the timely completion of the KMOS IFUs, which required the fabrication of an unprecedented 1124(!) optical surfaces, the CfAI have demonstrated that they have the capacity to produce the required volume within reasonable schedule constraints. All the facilities (design, fabrication e.g. diamond machining, metrology, integration and test) required for the successful realisation of such systems are available in-house, thus minimising programmatic risks. This paper presents the opto-mechanical design and predicted performance (based on the actual measured performance of the KMOS IFUs) of the proposed metal IFU.

8450-167, Poster Session

Modeling and structural analysis of honeycomb structure mirror

Y. Li, Nanjing Institute of Astronomical Optics & Technology (China)

In development of large-scale astronomical telescopes, some promising new technology and method such as honeycomb structure mirrors and silicon carbide mirrors are applied for primary mirrors. Especially in space telescopes, honeycomb structure mirrors are normally required to reduce the cost and increase the feasibility of the telescopes system. In this paper, a parameter FEA model of a two meters honeycomb structure mirror has been built, by using the engineering analysis software ANSYS. Through this model, the structural analysis, thermal analysis and the simulation active correction of low-order frequency aberration by the finite element method have been presented.

8450-168, Poster Session

CARMENES (III): an innovative and challenging cooling system for an ultra-stable NIR spectrograph

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The CARMENES project, which is currently at FDR stage, is a last-generation exoplanet hunter instrument to be installed in the Calar Alto Observatory by 2014. It is split into two different spectrographs: one works within the visual range while the other does it in the NIR range. Both channels need to be extremely stable in terms of mechanical and thermal behavior. Nevertheless, due to the operation temperature of the NIR spectrograph, the thermal stability requirement (±0.07K in 24 hours; ±0.01K (goal)) becomes actually a major challenge. The solution here proposed consists of a system that actively cools a shield enveloping the optical bench. Thus, the unstability produced on the shield temperature is further damped on the Optical Bench due to the high mass of the latter, as well as the high thermal decoupling between both components, the main heat exchange being produced by radiation.

This system -which is being developed with the active collaboration and advice of ESO (Jean-Louis Lizon)- is composed by a previous unit which produces a stable flow of nitrogen gas. The flow so produced goes into the vacuum tank of the NIR spectrograph and removes the radiative heat load incoming to the radiation shield by means of a group of properly dimensioned heat exchangers.

The present paper describes and summarizes the cooling system designed for CARMENES NIR as well as the analyses implemented.

8450-170, Poster Session

Unintended consequences on vacuum hold time with conversion to PolyCold closed-cycle coolers

T. Benedict, G. A. Barrick, Canada-France-Hawaii Telescope (United States)

Over a year ago, the Canada-France-Hawaii Telescope converted the dewar for the ESPaDOnS spectrograph from using liquid nitrogen cooling to using a PolyCold closed-cycle cooler. The cooling worked well and the vacuum in the dewar held for almost a full year. The recent failure of the cold-cathode vacuum gauge and the decision to replace it with a Pirani-type gauge pointed out an unintended and unfortunate consequence to the conversion. It was found that the new, higher temperature of the closed-cycle cooler degraded the efficiency of the carbon getter for maintaining the vacuum in the presence of o-ring diffusion to the point that the vacuum could not be maintained for longer than about two weeks without the additional pumping effect of a cold-cathode gauge. This paper will detail this vacuum issue along with some experiments done to show the pumping rates of the carbon getter and cold-cathode vacuum gauges. A light-baffle design to suppress the light produced by the cold-cathode gauge will also be described.

8450-50, Session 10

Performance of a laser frequency comb calibration system with a high-resolution solar echelle spectrograph

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Laser frequency combs (LFC) provide a direct link between the radio

frequency (RF) and the optical frequency regime. The comb-like spectrum of a LFC is formed by exactly equidistant laser modes, whose absolute optical frequencies are controlled by RF-references such as atomic clocks or GPS receivers. While nowdays LFC are routinely used in metrological and spectroscopic fields, their application in astronomy was delayed until recently when systems became available with a mode spacing and wavelength coverage suitable for calibration of astronomical spectrographs.

In a cooperation between the Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany and the Max-Planck-Institute for Quantenoptik, Garching, Germany, a frequency comb based calibration system for the existing echelle spectrograph at the German Vacuum Tower Telescope (VTT) on Tenerife, Canary Islands, was developed and successfully installed in late 2011. The system covers a wavelength range of 480 - 640 nm with a mode spacing of 5.5 GHz (~50 Milliangstroem @ 500 nm) while the spectral resoluton of the spectrograph is about 1000 000.

To characterize the calibration performance of the instrument, we use an all-fiber setup where sunlight and calibration light is fed to the spectrograph in the same single-mode fiber which minimizes any effects due to variable illuminaton of the spectrograph optics and the grating. The spectrograph was not designed for stability and shows a drift of several m/s per hour, which can however accurately be tracked with the frequency comb and first data indicates that an absolute calibration at 1 m/s is feasible.

8450-51, Session 10

Generation of an optical frequency comb for wavelength calibration of an astronomical spectrograph

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Micro-resonator based optical frequency comb generation for wavelength calibration of astronomical spectrographs is numerically and experimentally investigated. The temporal and spectral nonlinear dynamics are analyzed by solving the Nonlinear Schrodinger Equation (NLSE) incorporating a periodic condition that emulates the wave propagation in those resonators. We compare the NLSE approach with previous investigations that solve the coupled propagation equations in the presence of four wave mixing (FWM). The frequency comb noise characteristics are described in cavities having high (larger than 10^6) and moderate (smaller than 10^6) quality factors (Q) for the cases of critically coupled as well as the under- and over-coupled regimes.

The noise characteristics of micro-resonator based combs are compared with noise in fiber based combs. It is shown that noise in combs generated by self phase modulation spectral broadening in nonlinear fibers are closely linked to soliton fission dynamics; while noise in micro-resonators follows a more complex dynamics: the free-spectral range being strongly power dependent give rise to a complex dynamics due to pump power variation as the light is coupled into the resonator.

Finally, our simulations are compared with first experimental results of comb generation in micro-resonators. Our findings are a step further to determine the conditions for low noise generation of combs with linewidths and stability compatible with the calibration of spectrographs having medium and high resolution. We discuss stability issues of this kind of optical frequency comb for wavelength calibration of the Potsdam Multi-Aperture Spectrophotometer at the Calar Alto Observatory.

8450-52, Session 10

A near infrared frequency comb for Y-band astronomical spectroscopy

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Radial velocity surveys supported by high precision wavelength references (notably ThAr lamps and I2 cells) have successfully identified hundreds of exoplanets; however, as the search for exoplanets moves to cooler, lower mass stars, the optimum wave band for observation moves into the NIR and new wavelength standards are required. To address this need we are following up our successful deployment of an H band(1.45-1.7µm) laser frequency comb based wavelength reference with a comb working in the Y and potentially J bands (0.98-1.3µm). This comb is optimized for use with a 50,000 resolution NIR spectrograph such as the Penn State Habitable Zone Planet Finder. We present design and performance details of the current Y band comb.

8450-53, Session 10

Potential applications of ring resonators for astronomical instrumentation

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Ring resonators consist of a looped waveguide coupled to one or more input/output bus waveguides. Light from the input waveguide couples into the ring, whereupon it constructively and destructively interferes with itself until only light at the resonant wavelength of the cavity remains. Ring resonators can be used to efficiently filter, and drop, a series of wavelengths at the resonant frequencies of the ring. Both these properties are of use for astronomical applications. The dropped signal provides a frequency comb that can be used to provide a very accurate wavelength calibration for precision radial velocity measurements. The free spectral range of such a device can be made much larger than that from a laser frequency comb, removing the requirement to perform subsequent filtering. The filtered signal could be used to efficiently suppress specific wavelengths, e.g. those corresponding to atmospheric emission lines. These devices could be fully integrated into a photonic chip containing all the components of an astronomical instrument. We have modelled these devices using weak-coupled mode theory and finite difference time domain analysis. We will present the expected performance of devices designed for both applications and discuss their advantages and limitations.

8450-54, Session 10

TIGER: the photonic integral field microspectrograph

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The photonic TIGER instrument is a hand-held compact, lightweight fibre fed medium to high resolution diffraction-limited integral field spectrograph. This instrument can be used in two different configurations: the single-mode fibre and the multimode fibre integral field units (IFUs). The single-mode fibre IFU configuration uses a sole multicore fibre with several ten's of single-mode cores coupled into by a lenslet array, instead of independent multiple fibres, as the IFU. The multimode fibre IFU configuration uses a multimode fibre hexabundle formed of multicore photonic lanterns. The microspectrograph comprises of really simple off-the-shelf optics and detector. The multiple spectra coming out of the single-mode cores of the multicore fibre are all projected onto the same detector by adjusting the fibre rotation angle of the output multicore array with respect to the wavelength dispersion plane of the spectrograph. We demonstrate a proof of concept photonic TIGER design with R~1000 in the visible, with a wavelength range of 400-715 nm. The designed integral-field spectrograph fits onto the palm of a hand and weights less than 200 grams. This low cost and lightweight

design could be deployed in small spacecrafts for earth and astronomy observations.

8450-55, Session 11

Development of a slicer integral field unit for the existing optical spectrograph FOCAS

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We are developing an integral field unit (IFU) with an image slicer for the existing optical spectrograph FOCAS (Faint Object Camera And Spectrograph) on Subaru telescope. Basic optical design has already finished. The slice width is 0.4 arcsec, the slice number is 24, and the field of view is 13.5 x 9.6 arcsec^2. Sky spectra separated by about 3 arcmin from an object field can be simultaneously obtained, which allows us precise background subtraction. The IFU will be installed as a mask plate and set by the mask exchanger mechanism of FOCAS. Slice mirrors, pupil mirrors and slit mirrors are all glass, and their mirror surfaces are fabricated by polishing. Multilayer dielectric reflective coating with high reflectivity (> 98%) is made on each mirror surface. Slicer consists of 24 glass plates which need to be arraigned with high angular accuracy. For such alignment, we will use an alignment jig made with high precision machining. Some pupil mirrors need off-axis ellipsoidal surfaces to reduce aberration. We are conducting fabrication tests of the slicer and the off-axis ellipsoidal surface. And we are planning to make a prototype IFU with only 5 channels in order to verify an assembly method. Prototyping works will be finished in first quarter of 2012. Fabrications, assembly and performance verifications will be done in 2012. First light will come in 2013.

8450-56, Session 11

The KMOS Integral Field System: fabrication, alignment and test of 1000+ optical surfaces

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The Centre for Advanced Instrumentation (CfAI) of Durham University (UK) has recently successfully completed the development of 24 Integral Field Units (IFUs) for the K-band Multi-Object Spectrometer (KMOS). KMOS is a second generation instrument for ESO's Very Large Telescope (VLT) which is due for delivery during the summer of 2012. The KMOS IFU is based on the Advanced Image Slicer Concept developed by the CfAI and previously successfully implemented on the Gemini Near-InfraRed Spectrograph and JWST NIRSpec. Each IFU contains 14 channels which have to be accurately aligned. In addition, all 24 IFUs have to be co-aligned requiring the accurate alignment of an unprecedented grand total of 1124 optical surfaces. In this paper we describe how this has been achieved through the use of complex monolithic multi-faceted metal mirror arrays, which were fabricated in-house by means of freeform diamond machining. We will summarise the results from the metrology performed on each of the optical components and describe how these were integrated and aligned into the system. We will also summarise the results from the system level acceptance tests, which demonstrate the excellent performance of the IFUs. Each of the 24 IFUs is essentially diffraction limited across the entire field (Strehl ratios ~ 0.8) with throughput predictions (based on measurements of the surface roughness) rising from 86% at a wavelength of 1 micron to 93% at 2.5 micron. We believe that this level of performance has not previously been achieved in any image slicing IFU and showcases the potential of the current state-of-the-art technology.

8450-57, Session 11

Multiplexing 32,000 spectra onto 8 detectors: the HARMONI field splitting, image slicing and wavelength selecting optics

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HARMONI, the High Angular Resolution Monolithic Optical & Near-infrared Integral field spectrograph is one of two first-light instruments for the European Extremely Large Telescope. Over a 256 x 128 pixel field-of-view HARMONI will simultaneously measure approximately 32,000 spectra. Each spectrum is about 4000 spectral pixels long, and covers a selectable part of the 0.47-2.45 micron wavelength range at resolving powers of either R~4000, 10000, or 20000.

All 32,000 spectra are imaged onto eight HAWAII4RG detectors using a multiplexing scheme that divides the input field into four sub-fields, each imaged onto one image slicer that in turn re-arranges a single sub-field into two long exit slits feeding one spectrograph each. In total we require eight spectrographs, each with one HAWAII4RG detector. A system of articulated and exchangeable fold mirrors and VPH gratings allows one to select different spectral resolving powers and wavelength ranges of interest while keeping a fixed geometry between the spectrograph collimator and camera avoiding the need for an articulated grating and camera.

In this paper we describe both the field splitting and image slicing optics as well as the optics that will be used to select both spectral resolving power and wavelength range.

8450-58, Session 11

A new numerical tool for Zemax® to build an image slicer

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In this paper, we present a new software package associated with Zemax® optical design software for building an image slicer. An image slicer system is usually composed of a slicer mirror array associated with rows of pupil mirrors and slit mirrors. These components are formed by a segmented assembly of several tilted, and spherical or flat mirrors. Making use of ZEMAX, the classical modeling method consists in using the multi-configuration mode. This modeling is time-consuming because of the large number of parameters (i.e. curvatures, tilts, decenters for each sub-mirror) and configurations (one by sub-mirror) that the optical designer has to handle.

We propose an alternative method making straightforward the simulation of segmented surfaces (i.e. slicer mirror array and rows of mirrors). In this paper, we will present an integrated numerical tool specifically developed to simplify the design of image slicers. In particular, we will illustrate the gains in term of manufacturing and costs saving offered by the use of this tool.

8450-59, Session 11

CEOI microslice spectrograph

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We developed the technology of microslice integral field units some years ago as the next step in SAURON type microlens IFU design with typically 5 times more spatial elements (spaxels) for the same spectrograph and spectral length aiming at 1,000,000 spaxels IFUs. A full instrument for

laboratory demonstration composed of the fore-optics, the IFU, the spectrograph and the detector has now been built and tested. It has about 10,000 spatial elements and spectra 150 pixel long. Our IFU has 5 cylindrical microlens arrays along the optical axis as opposed to one hexagonal array in the previous design. Instead of imaging pupils on the spectrograph input focal plane, our IFU images short slitlets 17 pixel long that keep the spatial information along the spatial direction then giving 17 spaxels per slitlet instead of one in pupil imaging. This removes most of the lost space between spectra leaving place for more and keep the spatial information over the element size while pupil images lose it. The fore-optics re-images the field on the input of the IFU. They are made of cylindrical optics to get the desired different magnifications in both directions. All the optics and detector fit in a cylinder 35 mm in diameter and 280 mm long. With a different set of fore-optics on a 4-m telescope, a field of 43” x 6.7” with spatial elements of 0.14” x 0.22” could be observed so 12 of these mini-spectrographs would cover a field surface area of about 1 arcmin2 and 120,000 spaxels.

8450-60, Session 12

Fast solar polarimeter: a new instrument for polarimetric observations on the Sun

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A new imaging polarimeter is under development at the Max Planck Institute for Solar System Research, with the aim of carrying out high-precision polarimetric observations on the Sun, combined with increased spatial resolution. This polarimeter is based on pnCCD detector technology from PNSensor. The CCD detector has a very low readout noise and can be operated at frame rates of up to 1000 frames/s to suppress spurious polarization signals induced by atmospheric turbulence or instrument jitter. We plan to use a polarization modulator based on two ferro-electric liquid crystals (FLCs), which allow to measure the complete polarization state quasi-simultaneously. In this paper we present the conceptual design of the polarimeter and the laboratory test setup to evaluate the polarimetric performance of the overall system. As part of the laboratory tests, the properties of the individual FLCs will be characterized. By measurements and theoretical modeling we will assess in particular the effect of the finite FLC switching time on polarimetric accuracy, and the FLC performance limitations in the blue part of the visible spectrum, due to internal reflections between the FLC material and the enclosing glass plates.

8450-61, Session 12

Electro-optical spectro-polarimeter for ground- and space-based observations of coronal line-emission

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The Lyot filter is one the most used instruments for the spectroscopy of line-emission from the solar corona. In this presentation, we describe the “Coronal Magnetograph” (CorMag) telescope that uses the Liquid Crystals Tunable Lyot-Filter and Polarimeter (LCTP) for spectro-polarimetric imaging of the FeXIV line-emission (5303 Å) from the inner corona. The LCTP is a four stage Lyot filter with a full width at half maximum of 0.15 nm at a wavelength of 530.3 nm. The center wavelength of the bandpass is tunable in 0.01 nm steps from 528.64 nm to 533.38 nm, with a free spectral range of 2.7 nm. The wavelength tuning is non-mechanical using nematic liquid crystal variable retarders (LCVR’s). A separate LCVR of the Senarmont design, in tandem with the filter, is used for the polarimetric measurements. Here, we report the CorMag results from the observations of the 2010 total solar eclipse.

The high resolution bandpass together with the polarimetric and imaging capabilities with no moving parts makes this LC Lyot-filter a good candidate not only for ground-based coronagraphs, but also for space-based coronal observatories. Here, we present the results of the study, carried out during the ESA “Startiger” project, for using this LC Lyot-filter on the ASPIICS coronagraph (Association de Satellites Pour l’Imagerie et l’Interférométriede la Couronne Solaire) on-board the ESA PROBA-3 formation flying satellites.

8450-62, Session 12

Near field calibration of an objective spectrophotometer to NIST radiometric standards for the creation and maintenance of standard stars for ground- and space-based applications

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NIST-calibrated detectors will be used by the ground-based 100mm diameter Astronomical Extinction Spectrophotometer (AESoP) to calibrate the spectral energy distributions of bright stars to sub-1% per spectral resolution element accuracy. AESoP will produce hundreds of spectroradiometrically calibrated stars for use by ground- and space-based sensors. This will require accurate and near-continuous NIST calibration of AESoP, an equatorially mounted objective spectrophotometer operating over the wavelength range 350nm - 1050nm using a CCD detector. A near-identical, removable 100mm transfer standard telescope (CAL) is mounted physically parallel to AESoP.

The CAL transfer standard is calibrated end-to-end by NIST, wavelength-by-wavelength at ~ 1nm spectral resolution. In the field, CAL is used in a near-field configuration to calibrate AESoP. Between AESoP science observations, AESoP and CAL simultaneously observe clear sub-apertures of a 400mm diameter collimator. Monochromatic light measured by AESoP and CAL is dispersed by the objective grating onto the AESoP pixels measuring the same wavelength of starlight, thus calibrating both wavelength and instrumental throughput, and onto a unique low-noise CAL detector providing the required throughput measurement. System sensitivity variations are measured by linearly translating the AESoP/CAL pair so that CAL can observe the AESoP sub-aperture.

Details of this system fundamental to the calibration of the spectral energy distributions of stars will be discussed and its operation will be described. Demonstrations of system performance will be provided, and a plan of action to extend these techniques firstly into the near infrared, then to fainter stars will be described.

8450-63, Session 12

The ERA2 facility: towards application of a fibre-based astronomical spectrograph for hyperspectral imaging in life science

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High-performance broadband optical spectrographs combined with deployable fiber bundles are increasingly used for integral-field spectroscopy in astronomy, among others, for 3rd generation VLT instrumentation, and the E-ELT. Such instruments typically exhibit a large field of view and high spectral resolution and throughput, making them promising tools for multi-object astronomical surveys, but also for low-light applications outside astronomy, e.g. hyperspectral imaging and high-throughput applications in life science, pharmacy, and others. By exploring their multiplexing capabilities an enormous gain of knowledge is expected. This approach holds great promise for non-invasive, spatially and time resolved spectral investigations of morphological and biochemical processes in organic samples. It might lead to the development of improved endoscopic systems for cancer screening or novel applications in material inspection, environmental monitoring, forensics, and microscopy. We present progress towards development of a lab demonstrator consisting of an optical spectrograph with fiber-fed input operating in the visible and near IR wavelength range coupled to a science grade 4K by 4K CCD chip. The system is based on the modular concept developed by the MUSE Consortium for the 2nd generation ESO-VLT instrument MUSE. The fibre bundles used contain 400 optical fibres arranged in a two-dimensional square array at input while a one dimensional slit feeds the spectrograph. The system can be applied to various applications by using different spectroscopic techniques, such as fluorescence and Raman-spectroscopy, broadband laser illumination and time resolved methods. We will report on the implementation of the lab demonstrator and on the projected next steps towards first prototypes.

8450-64, Session 12

CARMENES (V): non-cryogenic solutions for YJH-band NIR instruments

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Currently, every single instrument using NIR detectors is cool down to cryogenic temperatures to minimize the thermal flux emitted by a warm instrument. Cryogenization, meaning the use of liquid nitrogen to reach the working temperature, is a must when the K band is needed for the science case. This results in more complex and more expensive instruments. However, science cases that do not benefit from observing in the K band, like the detection of exoplanets around M dwarfs through the RV technique, can make use of non-cryogenic instruments. CARMENES is currently the only instrument implementing such a solution. It is being built by a consortium of eleven Spanish and German institutions and will conduct an exoplanet survey around M dwarfs . Its concept includes two spectrographs, one equipped with a CCD for the range 550-1050 nm, and one with HgCdTe detectors for the range from 0.9-1.7 ¦Ìm, covering therefore the YJH bands. In this contribution, different possibilities are studied for the non-cryogenic solution to be used in CARMENES, all of them demonstrated to be feasible, within the requirements of the SNR requested by the science case.

8450-65, Session 12

PRAXIS: a low background NIR spectrograph for fibre Bragg grating OH suppression

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Fibre Bragg grating (FBG) OH suppression is capable of greatly reducing the bright sky background seen by near infrared spectrographs. By filtering out the airglow emission lines at high resolution before the light enters the spectrograph this technique prevents scattering from the emission lines into interline regions, thereby reducing the background at all wavelengths. In order to take full advantage of this sky background reduction the spectrograph must have very low instrumental backgrounds so that it remains sky noise limited. Both simulations and real world experience with the prototype GNOSIS system show that existing spectrographs, designed for higher sky background levels, will be unable to fully exploit the sky background reduction. We therefore propose PRAXIS, a spectrograph optimised specifically for this purpose.

The PRAXIS concept is a fibre fed, fully cryogenic, fixed format spectrograph for the J and H-bands. Dark current will be minimised by using the best of the latest generation of NIR detectors while thermal backgrounds will be reduced by the use of a cryogenic fibre slit. Optimised spectral formats and the use of high throughput volume phase holographic gratings will further enhance sensitivity. Our proposal is for a modular system, incorporating exchangeable fore-optics units, integral field units and OH suppression units, to allow PRAXIS to operate as a visitor instrument on any large telescope and enable new developments in FBG OH suppression to be incorporated as they become available. As a high performance fibre fed spectrograph PRAXIS could also serve as a testbed for other astrophotonic technologies.

8450-66, Session 13a

MATISSE cold optics: optomechanical design strategy, an iterative approach

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MATISSE (Multi AperTure mid-Infrared SpectroScopic Experiment) will be a mid-infrared spectro-interferometer combining the beams of up to four telescopes of the European Southern Observatory Very Large Telescope Interferometer (ESO VLTI), providing phase closure and image reconstruction. Due to the requirements of the concept and the limited space available in the VLTI lab, about 24 meters of light of the Cold Optics section and about 100 optical components had to be folded in a box no bigger than 0.2m3. The challenging demands and limitations for the development of such a small and complex opto-mechanical instrument demanded the use of a short-looped iterative strategy of cooperation between the various disciplines. As the amount of people involved in the core concept development was limited - in the order of ten - one iterative cycle could be kept short allowing for fast iterative cycles allowing a rapid development and a relatively fluent adjustment to the inevitable changes in requirements along the way. Key engineering disciplines that extensively had to work together were, amongst others, optical and mechanical designers with a constant check on manufacturability (tolerances, accessibility & size), general accessibility (AIT, servicing, electrical harness) and risk (planning, budget). In addition, counter intuitively, a higher degree of single part complexity was allowed if this would keep the instrument small and the overall tolerance chains short (no adjustment philosophy). This paper presents the final design of the MATISSE COB with a primary focus on the link between this short-loop iterative strategy and the final result.

8450-67, Session 13a

Cryogenic tests on FRIDA optomechanical building blocks

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FRIDA (inFRared Imager and Dissector for the Adaptive optics system of the Gran Telescopio Canarias) has been designed as a cryogenic and diffraction limited instrument that will offer broad and narrow band imaging and integral field spectroscopy (IFS) capabilities.

The FRIDA optical design is based on CaF2/S-FTM16 infrared cryogenic achromatic doublets. These doublets together with their cryogenic mounts perform the FRIDA optics building blocks. In order to allow alignment at room temperature and to perform diffraction limited imaging those doublets must remain aligned to <+/-30 micrometers from room temperature to 77 K. Furthermore the integrity of lenses must be preserved allowing reduced temperature gradients.

A prototype of FRIDA building block was built and tested from room to cryogenic temperatures. Furthermore a method for measure the lens displacements inside a cryostat was developed. It is possible to measure lens displacements to ±2 micrometers. In this work the FRIDA building block is described along with the performed cryogenic tests and their results.

8450-68, Session 13a

Experience on a cryogenic linear mechanism based on superconducting levitation

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The instrumentation of many space missions requires operation in cryogenic temperatures. In all the cases, the use of mechanisms in this environment is a matter of concern, especially when long lifetime is required.

With the aim of removing lifetime concerns and to benefit from the cryogenic environment, a cryogenic contactless linear mechanism has been developed. It is based on the levitation of a permanent magnet over superconductor disks. The mechanism has been designed, built, and tested to assess the performances of such technology.

The levitation system solves the mechanical contact problems due to cold-welding effects, material degradation by fatigue, wearing, backlash, lubrication,...etc, at cryogenic temperatures. In fact, the lower is the temperature the better the superconductor levitation systems work.

The mechanism provides a wide stroke (18mm) and high resolution motion (1μm), where position is controlled by changing the magnetic field of its environment using electric-magnets.

During the motion, the moving part of the mechanism levitates supported by the magnetic interaction with the high temperature type II superconductors after reaching the superconductor state down to 90K.

This paper describes the results of the complete levitation system development, including extensive cryogenic testing to measure optically the motion range, resolution, run-outs and rotations in order to characterize the levitation mechanism and to verify its performance under cryogenic environment.

8450-69, Session 13a

The JWST MIRI flight model wheel mechanisms characterisation for open loop drive

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The Mid-Infrared Instrument (MIRI) is one of four scientific instruments on board the James Webb Space Telescope (JWST), scheduled for launch in 2018. JWST will provide unique capabilities to probe the distant or deeply dust-enshrouded regions of the universe, investigating the history of galaxies as well as star and planet formation from the earliest universe to the present day.

The high reliability of the mechanisms of any space instrument is one of the most critical and challenging requirements. This is even more advanced in the case of cryogenic instruments like MIRI - which will be cooled down to below 7K. MIRI hosts three wheel mechanisms for filter, grating and dichroic selection. All of them have an open loop torque drive and thus the precise characterisation of the mechanisms and their motors is fundamental to achieve minimum heat load and maximum reliability of the mechanism movements over the lifetime.

In this paper we present an overview of the characterisation and verification of the MIRI wheel mechanisms. Our method is based on measuring back EMF voltages generated by the two phase cold redundant motors of the wheel mechanisms after they had been fully integrated into the MIRI optical module. We also present the analysis of the data and some results. We discuss the optimisation of the open loop drive, as well as the verification of the measurement results and the physical model of the motors and mechanisms.

8450-70, Session 13a

Development of the METIS cold chopper demonstrator

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The Mid-infrared E-ELT Imager and Spectrograph, or METIS, is foreseen as the third instrument for the European Extremely Large Telescope (E-ELT). A key part of METIS is the Cold Chopper (MCC) which switches the optical beam between the target and a nearby reference sky during observation for elimination of the fluctuating IR background signal in post-processing. This paper discusses the development of the MCC demonstrator.

The chopper mirror (Ø64mm) has to tip/tilt in 2D with a combined angle of up to 13.6mrad with 1.7μrad stability and repeatability within 5ms (95% duty cycle at 5Hz) at 80K. As these requirements cannot be met in the presence of friction or backlash, the mirror is guided by a monolithically integrated flexure mechanism. The angular position is actuated by three linear actuators and measured by three linear position sensors, resulting in a fast tip, tilt, and focus mirror. Using the third actuator to introduce symmetry, homogeneity in forces and heat flux is obtained.

Both the actuators and the sensors are key components. A voice coil actuator had to be custom designed, to achieve the required acceleration force within the specified 1W heat load. The requirements for the displacement measurement can be met with a commercially available, fibre interferometry system. For integration of this system, stray light elimination is a critical design aspect and retro-reflectors have been used to reflect sufficient power into the fibre at large tip/tilt angles.

8450-71, Session 14a

Development of a cryogenic all-silicon imaging telescope (CAIT)

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Single crystal silicon (SCSi) is one of the most stable materials for cryogenic applications due to its superior properties. Its low coefficient of expansion and low total contraction to cryo temperatures, combined with its isotropic behavior and homogeneous crystal structure provide for components with near zero residual stress and therefore no undesirable distortions. Also, SCSi's high thermal conductivity and thermal transport (thermal diffusivity) mean rapid cooling with virtually no gradients or distortions. Incorporating McCarter's patented and proprietary fabrication methods for SCSi provide components free of sub-surface damage and

related residual stress.

The Author continues to fabricate SCSi mirrors in a range of sizes, shapes and areal densities, but has only recently embarked on a program to fabricate two, three and/or four-mirror, all-SCSi imaging telescopes suitable for cryogenic space applications. The telescopes are robust instruments based on prior designs, but adapted for the cryogenic space environment. They employ low stress frit- bonding technology for both expansion matching threaded metal inserts and fabrication of complex structures.

As designed, the CAIT reduces floor-to-floor cost and schedule over competing materials such as beryllium and silicon carbide. This paper demonstrates that such an instrument can and is being produced and is suitable for production.

8450-72, Session 14a

Ultra stable isostatic bonded optical mount designs for high-performance space telescopes

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Through the years many stable optical mounts have been designed, analyzed and tested at TNO. This paper gives an overview of the design principles used and the achievable performance with an isostatic bonded mount concept.

The use of adhesives in combination with an isostatic design allows the mounting of optical components in a small volume with limited deformation of the optical surfaces due to thermal and mechanical loads. Large differences in thermal expansion over significant temperature ranges can be overcome using a simple and predictable design at reasonable costs. Although adhesives have limited dimensional stability and loadability it is demonstrated that stable optical mounts can be realized when proper design principles are used. This paper interconnects with the work described in: “Improved stress prediction in adhesive bonded optical components”, J. de Vreugd e.a.

The following isostatic bonded optical mount designs will be described:

1. LISA/NGO mirror mounts with 30 g RMS launch loads. WFE 33 g RMS launch loads. WFE 13 g RMS random vibrations loads. WFE < 25 nm PV.

Stability verification test results of the abovementioned designs will be presented in this paper.

8450-74, Session 14a

Glue test results for high-precision large cryogenic lens holder

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The Near Infrared Spectrometer and Photometer (NISP) of EUCLID requires high precision large lens holders (170 mm) at cryogenic temperatures (150K). The lenses of the optical system are glued into separate lens holders, the so called adaption rings. For the selection and verification of a suitable adhesive extensive glue selection tests are performed and results presented in this paper. With potential glue candidates handling, single lap shear and connection tension, shear tests are carried out at RT and 150K. For the NISP optical system DP490 is selected as most suitable adhesive.

The test results have shown that an evenly distribution of the glue in glue gap is of crucial importance for the functioning and performance of the bonded lens system. The different CTE between lens and lens holder produces large local mechanical stress and might cause lens breakage or failure of bonding. The design of the injection channel and the gluing procedure are developed to meet the lens performance requirements. An example is shown that after thermal cycling the remaining 0.5 mm - 1 mm thick adhesive in the injection channel results in large local mechanical stresses, and hence, damage of the lens. For a successful performance of the glue interface not only an optimum glue gap of 80 - 150 µm is important, yet micro cracks of the glass at the gluing area have to be avoided.

The performed glue tests with DP490 for 3 different lens/ring material combinations show sufficient mechanical tension and shear strength for bonding of the lens system. Titanium/LF5G15 and Invar/Fused Silica combinations have reached the strength of 30MPa at RT and 50GPa at 150K. These results are presented on behalf of the EUCLID consortium.

8450-75, Session 14a

A new generation active arrays for optical flexibility in astronomical instrumentation

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Throughout the history of telescopes and astronomical instrumentation, new ways were found to open up unexplored possibilities in fundamental astronomical research by increasing the telescope size and instrumentation complexity. The ever demanding requirements on instrument performance pushes instrument complexity to the edge. In order to take the next leap forward in instrument development the optical design freedom needs to be increased drastically. The use of more complex and more accurate optics allows for shorter optical trains with smaller sizes, smaller number of components and reduced fabrication and alignment verification time and costs.

Current optics fabrication is limited in surface form complexity and/or accuracy. Traditional active and adaptive optics lack the needed intrinsic long term stability and simplicity in design, manufacturing, verification and control. This paper explains how and why active arrays literally provide a flexible but stable basis for the next generation optical instruments. Combing active arrays with optically high quality face sheets more complex and accurate optical surface forms can be provided including extreme a-spherical (freeform) surfaces and thus allow for optical train optimization and even instrument reconfiguration.

A zero based design strategy is adopted for the development of the active arrays addressing fundamental issues in opto-mechanical engineering. The various choices are investigated by prototypes and Finite Element Analysis. Finally an engineering concept will be presented following a high stable adjustment strategy allowing simple verification and control. The Optimization metrology is described in an additional paper for this conference by T. Agócs et al.

8450-76, Session 15a

Fabrication and tolerances of moth-eye structures for perfect antireflection in the mid-infrared wavelength region

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Mid-infrared, 25-45 microns, is very important wavelength region to investigate the physics of lower temperature environments in the universe. Unfortunately, transparent materials in this wavelengths are very limited. Silicon is transparent, but the reflection on a silicon surface reaches as high as 30% because of its high refractive index (~3.4). To apply silicon to mid-infrared astronomical instruments, antireflection is needed. One of the best ways is to form moth-eye structures. Since the moth-eye structure consists of a monolithic structure, it keeps durable under cryogenic environments, which is advantageous to mid- infrared

instruments.

We have developed the moth-eye structures on plane silicon surfaces. The structures consist of cones of 16 microns height with intervals of 5 microns. Three samples were fabricated by electron-beam photo-lithograph and reactive ion etching. The processed areas of two samples have a diameter of 25mm and the other has a diameter of 40mm. Remarkable performance of transmittance of 96% or higher was achieved in the wide range of 20-50 microns. The best transmittance was higher than 98%. On the contrary, the transmittance of moth-eye surfaces is theoretically expected as 100%. We have examined the discrepancy between the theory and the fabrications with electromagnetic simulations, rigorous coupled-wave analysis. It has been revealed that gaps at the base of the moth-eye cones seriously affect the transmittance and that shape of the cones determines profiles of spectra. We have estimated tolerances for manufacturing the moth-eye structures to achieve sufficient transmittance of nearly 100%.

8450-77, Session 15a

Progress in UCO's search for silver-based telescope mirror coatings

A. C. Phillips, J. S. Miller, M. Bolte, B. DuPraw, M. V. Radovan, D. Cowley, Lick Observatory (United States)

We report on the on-going effort at University of California Observatories Astronomical Coatings Lab to develop robust protected-silver coatings suitable for telescope mirrors. We have identified a very promising recipe based on YF_3 that produces excellent reflectivities at wavelengths of 340 nm and greater, has ~1.5% emissivity in the thermal IR, and does not contain problematic materials for the Mid-IR, such as SiO_2 and Al_2O_3. The recipe holds up extremely well to aggressive environmental testing (80C and 80% RH; high-H_2S atmosphere), and currently is being evaluated under real observatory conditions. This coating may satisfy the need for telescope mirror coatings that are long-lasting (~5 years or more) and have good reflectivity into the UV.

In addition, we describe recent upgrades to our coating facilities allowing us to deposit ion-assisted e-beam coatings on optics up to ~1m. This novel arrangement places the e-gun and ion source on a pivoting "swing-arm", allowing the position to move radially without changing the e-gun/ ion source/ substrate geometry. Large substrates can be coated with good uniformity using single-axis rotation only. This technique is scalable to arbitrarily large substrate sizes.

8450-78, Session 15a

Enhanced MgF2 and LiF over-coated Al mirrors for FUV space astronomy

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Astronomical observations in the Far Ultraviolet (FUV) spectral region are some of the more challenging due to the very distant and faint objects that are typically searched for in cosmic origin studies such as origin of large scale structure, the formation, evolution, and age of galaxies and the origin of stellar and planetary systems. The problem is compounded by the very limited option of reflecting coatings to use at FUV wavelengths and the modest reflectivity offered by those coatings such as Al+MgF_2 [typically 82% at Lyman-alpha, 1216 Å) that are used on reflecting surfaces of FUV instrumentation. Improved reflective coatings for optics, particularly in the ultraviolet part of the spectrum, could yield dramatically more sensitive instruments and permit more instrument design freedom.

This paper will present recent advances in reflectance performance for Al+MgF_2 mirrors optimized for Lyman-alpha wavelength by comparing an ambient or "cold" deposition with another where the deposition temperature for the MgF_2 layer is done at elevated temperatures. We will also consider this improved procedure for the deposition of LiF overcoated Al mirrors in order to realize similar reflectivity gains at even shorter wavelengths.

8450-79, Session 15a

Further advances in the use of SOL-GEL for high-performance optical and IR antireflection coatings

J. S. Miller, A. C. Phillips, D. Hilyard, B. Dupraw, Lick Observatory (United States)

We have continued our development of anti-reflection coatings based on SOL-GEL applied on spinning substrates. Single layer SOL-GEL and multilayer SOL-GEL plus vacuum-deposited sublayers have resulted in extremely effective coatings for both optical and near infrared uses. Substrates 25 mm to 1000 mm in diameter have been coated by these techniques. Extensive experiments have shown that the optical thickness of a SOL-GEL coating is very accurately directly proportional to the amount of dilution of the original SOL-GEL liquid with ethanol and inversely proportional to the square root of the spin angular velocity. Highly effective broadband coatings have been developed for the entire region from 340-1100 nm, and for the near infrared over 900-2500 nm. Exposure to a highly concentrated ammonia atmosphere for 40 hours hardens the coatings so that they can be easily cleaned with standard techniques with no damage to the coatings. After hardening, because of shrinkage the optical thickness of the SOL-GEL coatings are 0.86 0f the pre-hardened amount. Long-term aging tests of SOL-GEL coatings in real observatory environments are underway, and results of the latest status will be presented.

8450-80, Session 15a

Towards ultra-precise optical interference filters on large area: computational and experimental optimization of the homogeneity of magnetron-sputtered precision optical filters

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Ultra narrow band pass optical filters are important for numerous astronomical imaging projects. Large area filters are important e.g. for the solar orbiter mission where a band pass filter has to be realized on 6 cm diameter. The center wavelength and FWHM pass band width is 617.4 nm and 0.28 nm, respectively. The combination of large area and ultra-precision is a very tough requirement for the deposition technology. Particle-in-cell plasma Monte-Carlo simulations where performed to optimize the magnetron sputter process on a new high-precision production tool "EOSS", developed at Fraunhofer IST. Critical factors influencing the thickness distribution will be evaluated.

8450-81, Session 15a

Optical coatings from VUV to IR

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Optical coatings are an integral part of superior optical components. Space applications place especially high demands on these coatings, not only with regard to their optical performance but also to their mechanical and environmental stability, their thermal properties, and their radiation resistance. This contribution presents a short overview of several coating solutions developed in recent years in order to meet the challenging demands of astronomical applications.

Applications related to solar observation require coatings for the EUV/VUV spectral region. It will be shown that multilayer periodic coatings (Mo/Si, Sc/Si...) and single thin silicon carbide and boron carbide based coatings can be successfully applied in the wavelength region between 30 and 100 nm for narrowband and broadband reflective profiles, respectively. For VUV applications in the wavelength region above 100 nm a promising coating solution based on aluminum films was developed. A reflectivity above 73% for near normal incidence can be achieved by applying a capping layer based on LiF, MgF2, and AlF3 to prevent oxidation. Silver based coatings are applied to achieve high reflectivity in a wide spectral region from the VIS to the IR range. An optimized silver-based coating has been developed in order to coat the mirrors of the RapidEye imager. A very different technology is the application of thick amorphous silicon layers on top of ultra-precision machined Al or AlSi mirror-substrates. These silicon films are advantageous for the subsequent polishing process. Very low roughness values below 1 nm rms have been achieved due to their application.

8450-82, Session 13b

JWST: Tinsley achievements on the largest beryllium polishing project

J. Kincade, J. Daniel, L-3 Communications Tinsley Labs. Inc. (United States); T. Hull, L-3 Communications Tinsley Labs. Inc. (United States) and Univ. of New Mexico (United States)

Polished 1.5m bare beryllium, off-axis aspheric mirror segments, constituting the cryogenic primary mirror of NASA's ambitious Flagship Mission, the James Webb Space Telescope, have been successfully completed at Tinsley. Tinsley has finished the secondary, tertiary, fine steering and spare mirrors as well. We will describe both the end results, where it was demonstrated that visible quality mirror results can be achieved on large extremely lightweighted compliant off-axis mirrors, and the steps taken at Tinsley to achieve these results. Over 26 meters2 of bare beryllium were optically processed twice, first for room temperature figure, then for the cryo-null figure for the cryogenic differences measured at XRCF. The efforts made by the Tinsley team, the lessons learned, and the JWST legacy of technology and project knowledge will be summarized.

8450-83, Session 13b

Zero-expansion glass ceramic ZERODUR®: recent developments reveal high potential

P. Hartmann, R. Jedamzik, T. Westerhoff, SCHOTT AG (Germany)

ZERODUR® is a well-established material in astronomy and all fields of applications where temperature gradients might limit extreme precision and stability. Together with its rich heritage come a series of recent developments, which reveal the potential of the material for broader and more demanding applications. The outstanding degree of light-weighting achieved with progress in CNC grinding in the last two years shows its high suitability for space telescope mirrors. This is supported by new data on strength enabling higher mechanical loads.

Also ground based telescopes benefit from the improved light-weight processing such as solar telescopes and downstream mirrors of extremely large telescopes. More and better data have been collected demonstrating the unique CTE homogeneity of ZERODUR and its very high reproducibility a necessary precondition for large series mirror production. The minute delayed reaction effects of glass ceramics delayed elasticity and CTE hysteresis are now much better understood and mastered to even benefit demanding applications.

8450-84, Session 13b

Prototypes segment polishing and testing for ELT M1

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Sagem - Reosc has been awarded by ESO a contract for the manufacturing and testing of seven prototype segments of the E-ELT primary mirror in 2008. The purpose of this contract was to demonstrate the ability to produce aspherical off-axis hexagonal segments with very little edge effect and very high quality wavefront error and plan the production of the 931 segments needed for the primary mirror and spares.

The manufacturing of the prototype segments is now completed. They have been delivered. Sagem has achieved for the best segment integrated on its support an overall surface error of 23 nm RMS and 6 nm RMS after removal of the allowed amount of Focus, Astigmatism and Trefoil. This article will present the process developped by Sagem and its performance.

Sagem has also assessed the performances of an alternate manufacturing process based on the polishing of the segments under stress conditions (Stress Mirror Polishing). The results obtained by this process will also be presented

8450-86, Session 13b

Tinsley proves stress mirror polishing for giant segmented telescopes

J. Daniel, U. Muller, J. B. Barentine, L-3 Communications Tinsley Labs. Inc. (United States)

Giant astronomical telescopes, with primary mirrors consisting of many hundreds of off-axis aspheric mirror segments, are viable only if very rapid optical finishing is available. No method is more rapid or efficient or repeatable that the combined use of stress mirror polishing (SMP) for the majority of the optical material removal, followed by minimal small tool optical work for final cleanup. Twenty years ago, Tinsley used SMP in the fabrication of all the mirror segments for the two Keck Telescopes. We will describe updated methods recently matured by Tinsley to address and enable the largest of these telescopes, the European Extremely Large Telescope (E-ELT) for the European Southern Observatory. This extends similar methods that have been demonstrated by Tinsley and previously discussed for Thirty Meter Telescope (TMT). The current state of effectiveness at rapidly addressing low, mid and high spatial frequency errors will be illustrated.

8450-87, Session 13b

Stress polishing of segments for future extremely large telescopes: results obtained on a full scale demonstrator

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We present the results obtained at Laboratoire d'Astrophysique de Marseille (LAM) on the 1.5m stress polished segment demonstrator for the European Extremely Large Telescope (E-ELT). The stress polishing method is developed at LAM since more than 40 years, and this mature technology has recently been used with success to provide super-smooth aspherical mirrors for VLT instruments. Several advantages of this manufacturing method will be highlighted. By spherically polishing a warped blank with a full-sized tool, high quality off axis parabolas can be rapidly obtained with less than 1µm RMS of form errors and with a minimal amount of high spatial frequency ripples. Thanks to this

quality, this method is competitive compared to the time consuming sub-aperture tool method. We will detail the versatile warping harness designed and optimized with FEA, and its integration on the POLARIS 2.5m polishing facility. We will also detail the coupled mechanical and optical metrology developed for a full monitoring of the experiment that will allow identifying the most relevant mechanical measurement to avoid optical tests during mass production.

8450-85, Session 14b

Edge-control and surface-smoothness in sub-aperture polishing of mirror segments

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This paper focuses on substantial progress recently made, addressing the two most challenging requirements for polishing hexagonal segments for extremely large telescope. These are:- i) control of edge and corner profiles in small-tool polishing of hexagons, and ii) achieving the required smoothness of the bulk aspheric form.

We briefly describe the output of the CNC-grinding process used to create the off-axis asphere, and then summarize the Zeeko CNC machines, and the specialized tooling for smoothing ground mid-spatials, pre- and corrective polishing and final smoothing.

Two cases highly relevant to telescope projects are then considered in more detail, and quantitative results on sample parts presented. Case 1 assumes that all processing stages are performed after the segment is cut hexagonal, requiring some 15-20 microns of DC-removal in polishing the ground asphere. Case 2 considers a segment roundel, CNC pre-ground to the asphere. We review the merits of small-tool technology as a candidate for polishing the roundel before cutting hexagonal. Lastly, we consider the final form-correction required for the cut hexagon, which demands only 2-3 microns of DC-removal, and we present CNC polishing as an attractive alternative to ion-figuring in vacuum.

The general strategy we describe for handling edges deploys tooling delivering large Gaussian polishing spots to give fast removal, proceeding through tools with progressively smaller footprints. Each process-step leaves turned-up edge and corner zones, which are reduced in size and width by each successor, avoiding turning-down the extreme edge at any stage. The final narrow up-stand is removed by a separate rectification process combined with fine surface-smoothing.

The paper concludes with an assessment of the relative merits of the two process chains presented.

8450-88, Session 14b

Status of test production of the segmented mirror for the Thirty Meter Telescope

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As the next generation ground-based telescope, the Thirty Meter Telescope(TMT) is developing. The TMT primary mirror consists of 492 off-axis aspheric mirrors, 6 sets of 82 patterned segmented mirrors.

In this paper, status of test production of a segmented mirror for the TMT is described. Segmented mirror of the most aspheric in the TMT (departed almost 200 microns from sphere) is chosen for the producibility testing and produced from the Clearceram blank.

Coarse mirror figuring is done with bending harness polishing and the mirror figure reaches 5% accuracy from designed form. Then, mirror surface figure is precisely measured by Canon-made high-precision free-form measurement machine, and the mirror finely polished by polishing machine comes up to the specification of the TMT.

Finally, the plan for the future work would be described.

8450-89, Session 14b

Support design for the polishing experiment of the primary mirror segments of the TMT

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In 2009 China declared the participation in the Thirty Meter Telescope Project (TMT) as an observer to jointly develop the one of the world's biggest optical telescopes. According to the protocol between National Astronomical Observatories/Nanjing Institute of Astronomical Optics and Technology (NAOC-NIAOT) and TMT, NAOC-NIAOT is developing the processes and technologies for polishing and fabricating TMT primary mirror segments, by using mainly the existing facilities in NIAOT. Three glass-ceramic mirror blanks including one 1.52 m diameter and two 1.1 m diameter has been transported to NIAOT. Three types sub-mirror with different off-axis distance respectively will be polished. This paper is to report the mirror support design during the testing for the mirrors. Besides, we will also include the support design and optimization for the auxiliary testing mirrors.

8450-90, Session 14b

Production of 8.4 m segments for the Giant Magellan Telescope

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Production of segments for the Giant Magellan Telescope is well underway at the Steward Observatory Mirror Lab. We report on the completion of the first 8.4 m off-axis segment, the casting of the second segment, and preparations for manufacture of the remaining segments. The complete set of infrastructure for serial production is in place, including the casting furnace, two 8.4 m capacity grinding and polishing machines, and a 28 m test tower that incorporates four independent measurement systems. The first segment, with 14 mm p-v aspheric departure, is by some measures the most challenging astronomical mirror ever made. Its manufacture took longer than expected, but the result is an excellent figure and demonstration of valuable new systems that will support both fabrication and measurement of the remaining segments. Polishing was done with a 1.2 m stressed lap for smoothing and large-scale figuring, and a series of smaller passive rigid-conformal laps for deterministic figuring on smaller scales. The interferometric measurement produces a null wavefront with a 3-element asymmetric null corrector including a 3.8 m spherical mirror and a computer-generated hologram. In addition to this test, we relied heavily on the new SCOTS slope test with its high accuracy and dynamic range. Evaluation of the measured figure includes simulated active correction using both the 160-actuator mirror support and the alignment degrees of freedom for the off-axis segment.

8450-91, Session 14b

Light-weight glass optics for segmented x-ray mirrors

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One of the most challenging tasks for future X-ray observatories is the enhancement of collecting area combined with very good angular resolution. We are developing a technology based on thermally slumped thin glass segments as a possible alternative to silicon pore optics. In particular, we follow the approach of indirect slumping and aim to produce parabola and hyperbola in one piece. Currently we focus on a combination of a ceramic mould with glass type D263. X-ray tests of previously slumped glasses have shown that the quality of existing moulds as well as the thickness variations in the glass add substantially to the HEW values of the glass segments. This led us to the production of a new mould with significantly improved surface quality and the development of possible ways to reduce the thickness variations in the glass prior to the slumping process. The experimental set-up and the slumping process are described in detail; furthermore we report on the metrology methods used for measuring figure and thickness of the glass. Results of the X-ray test of several integrated glass sheets are described. Finally we present a first concept for integration of the slumped glass sheets into a segmented mirror module.

8450-92, Session 15b

Astrositall application in astronomical and space optics production

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There is a description of Astrositall properties including CTE distribution and CTE homogeneity distribution, examples of this material usage in production of astronomical and space optics. There are also results of long term testing of Astrositall material.

8450-93, Session 15b

Diamond turning and polishing tests on new RSP aluminum alloys

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For years now conventional Aluminum 6061 T6 has widely been used for mirrors in astronomical instruments, being diamond turned or since a few years also being optically polished. This allows the development of optical systems that can be tested and operated at any temperature, without being affected by CTE effects. Using traditional Aluminium the manufacturing methods could in some cases not deliver the required surface shape, accuracy and roughness due to the increasing demands from optical systems. Over the last few years RSP Technology developed a new series of Aluminum alloys for several applications, produced with a Rapid Solidification Process. Both on a macroscopic and microscopic level these new aluminum alloys have different material characteristics compared to the traditional Aluminum alloys. TNO and NOVA-ASTRON have performed diamond turning and polishing tests on these new aluminum alloys. This paper presents results of several diamond turning and polishing tests obtained over the last year and show the potential of these new alloys with surface roughness values of 1 nm on RSA 6061 and RSA 708 acquired with both polishing and diamond turning.

8450-94, Session 15b

New era of metal optics for visible applications: bare Be, bare Al and EN cladding

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While the advantages of metal optics have been long-recognized for space, surveillance and astronomy, recent advances at Tinsley bring bare aluminum and beryllium optics into the realm of visible performance previously available only by using glass or ceramic mirrors. Newly established processes for bare aluminum mirrors allow advanced aspheric optical forms to be produced at a fraction of the cost of equivalent glass optics. Furthermore, since the same material is used for the mirrors and metering structure, athermal and even snap-together strategies are available to the system architect. Bare Al has been successfully used down to liquid helium (LHe) temperatures. With electroless nickel (EN) cladding, microfinishes can be extended to “lithographic grade”, routinely in the 0.5 nm rms to 0.1nm rms realm. Having just completed the James Webb Space Telescope mirror suite, Tinsley has polished significantly more area of bare beryllium than that polished by all other optical companies combined. Each JWST mirror segment is an off-axis asphere, and was polished to better than 20nm rms (/32). We will describe the current state of the art of bare beryllium optical polishing at Tinsley, including cyro-null figuring. Parameters will be given for effectively designing with bare aluminum, bare beryllium and EN clad mirrors for future astronomical systems.

8450-95, Session 15b

Design, fabrication, and testing of an aluminum scene mirror for the thermal infrared sensor instrument

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The Thermal Infrared Sensor (TIRS) is a 140mm aperture mid-wave IR sensor for the Landsat Data Continuity Mission (LDCM) which will launch in late 2012. An elliptical scene mirror is used to turn the incoming beam 90 degrees, allowing multiple calibration sources to be viewed by the instrument.

The aluminum scene mirror is an open-back, light-weighted design with a single-point diamond turned flat (250 nm RMS) surface, with a thin gold coating. The mirror met all design requirements at its operating temperature of 2 degrees C.

To ensure that the mirror would meet requirements, a large number of 76mm test mirrors were used to evaluate the polishability and figure stability over temperature of various types of aluminum and heat treatment processes. RSA6061 (rapid solidification), 6061-T651, and 6061-T6511 were evaluated. Several flexure mounting schemes were also evaluated. A single-crystal silicon test mirror was also mounted and tested as a potential replacement for the aluminum mirror, which significantly exceeded the design requirements.

In this paper, we summarize results of the design development, thermal and opto-mechanical analysis, material testing, and environmental testing (mounted and unmounted) that was accomplished to successfully produce the flight scene mirror. Lessons learned shall also be presented.

8450-96, Session 15b

The 3,2m sintered sic telescope for Spica

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Placed on the L2 Lagrangian point, SPICA will operate in the 5 to 210 µm wavelength range. Astrium has been awarded by ESA/ JAXA to study the faisability of the 3,2m sintered SiC telescope.

The Telescope driving requirements are the large diameter (3,2m) especially critical for the manufacturing aspects, the WFE which has to be kept below 350 nm rms, and the operational temperature below 5K which requires to master the distortions wrt ambient environment.

The main features developed in the presentation are:

- the 15th years Astrium background in the Silicon Carbide proven in flight technology for mirror and structural parts based on the large experience of HERSCHEL/Gaia project (brazing, polishing, assembling, iso-static mountings) which are applied and improved to the SPICA telescope development.

- the predicted performances which are taking advantage from the Silicon Carbide properties, especially considering the homogeneity of the single-phase material inside the structure its stability from ambient to the operational temperature range. The study shows that the Silicon Carbide Telescope design can fulfil the mechanical and optical requirements.

- the verification policy and the optical tests definition which is a key-factor in the qualification of the Telescope. Due to the gravity effects on the wave front error, specific devices and configurations have to be realized, from the first polishing step to the final tests under vacuum at Helium temperature.

8450-97, Session 15b

Manufacturing of high-precision aspherical and freeform optics

A. Hoogstrate, R. Henselmans, B. van Venrooy, C. van Drunen, TNO (Netherlands)

Aspherical and freeform optical elements have a large potential in reducing optical aberrations and to reduce the number of elements in complex high performance optical systems. However, manufacturing a single piece or a small series of aspherical and freeform optics has for long been limited by the lack of flexible metrology tools.

With the cooperative development of the NANOMEFOS metrology tool by TNO, TU/e and VSL, we are able to measure the form of aspheres and freeforms up to 500 mm in diameter with an accuracy better than 10 nm rms.

This development opened the possibility to exploit a number of iterative, corrective manufacturing chains in which manufacturing technologies such as Single Point Diamond Turning, freeform grinding, deterministic polishing and classical polishing are combined in an iterative loop with metrology tools to measure form deviation (like CMM, LVDT contact measurement, interferometry and NANOMEFOS) and surface roughness (like whitelight interferometry).

This paper will discuss the results of the various iterative manufacturing chains, we explored in the manufacturing of high performance optics for astronomical purposes such as:

- Manufacturing of Aluminium freeforms for the SCUBA-2 instrument.

- Manufacturing of the L2 of the Optical Tube Assembly of the four laser guide star facility of the ESO VLT, a Ø380 mm NBK7 concave + convex aspherical lens.

Based on these results we will give an outlook into the new challenges and solutions in manufacturing high-precision optics.

8450-98, Session 15b

Development of CFRP mirrors in low-temperature application for satellite telescopes

S. Utsunomiya, Japan Aerospace Exploration Agency (Japan)

CFRP is widely applied to satellite structures and mission sensor structures. Its dimensional stability suits to components which require high accuracy such as radio reflectors and telescope structures. However, telescope mirrors, which request the highest dimensional accuracy, are still commonly made of low expansion glasses or ceramics such as SiC. One of the reasons is micro asperity of CFRP surface called fiber print-through. We have reported on improvement of surface roughness of CFRP mirrors by using a replica technique. Surface accuracy of our all-CFRP sandwich mirrors was achieved to 1 µm RMS and roughness less than 5 nm RMS, which is sufficiently demonstrated useful for ultra-stable mirrors for space telescopes. In this paper, our recent progress and low temperature behavior on CFRP mirrors will be reported. The surface accuracy was measured using a Zygo laser interferometer from room temperature to liquid nitrogen temperature. Surface accuracy was evaluated against best-fit spherical figure, and PV (peak to valley) and RMS were measured by removing effects of rougher kinds of the asperities. There observed at least four patterns of deformation of the mirrors, overall warping or twisting, line patterns with several hundred micron meters pitch, core shape patterns with ten millimeters pitch and so-called fiber print through of several micron meters pitch and nm height. All kinds of the asperities were affected by magnitude of temperature change. Improvement of surface roughness of all-CFRP mirrors will be discussed with respect to the kinds of asperities.

8450-171, Poster Session

Optimization of the process chain for mirrors made of silicon carbide

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Different grades of silicon carbide (SiC) became an established material for structural components as well as optical mirrors in space-borne applications. But the manufacturing still causes high efforts and restraints an extension of application. Therefore, the research project MirrorFab aims for a qualification of an optimized process chain for manufacturing mirrors made of Cesic®. Cesic® consists of a matrix of SiC reinforced with microscopic carbon fibers. There is a space qualified Cesic® manufacturing process and an established network for the supply chain. The project addresses the required gain in efficiency and flexibility and an enhancement of manufacturing capabilities. The consortium covers the major parts of the process chain, namely manufacturing of the ceramic body, grinding, pre-polishing, coating and final figuring. On the one hand, the performance of each manufacturing technology is increased. On the other hand, the consideration of the complete process chain enables a holistic optimization approach. For example, the points of hand-overs between manufacturing technologies are determined in regard to the overall effort and not according to the capabilities of individual technologies. This paper deals particularly with the process optimization in grinding and pre-polishing. The influence of different grinding kinematics, tools and process parameters on the wear and the grinding forces are discussed. In polishing, the focus is set to the investigation of the influences of various polishing pads and slurries on the material removal rate, surface figure and roughness. Finally, different combinations of grinding and pre-polishing processes are evaluated in regard to the overall efficiency.

8450-172, Poster Session

Deformation dynamic response test of the active stressed lap based on PXI platform

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We have designed an active stressed lap whose control mode is that a computer sends control orders to the control system of the active stress lap, under windows operating system. The control mode has a shortage, which is a limit exists when we ues the lap to complete an aspheric surface deformation task with a fast focal ratio, because windows system is not real-time. Therefore, we have designed a real-time deformation control system for the active stressed lap based on PXI bus.

This paper firstly makes an introduction to the deformation calculation of conicoid active stressed lap. For any processing mirror, to obtain corresponding deforming force, we should first calculate the position of different beams and the aimed deforming range of the active stresses lap under different rotation angles according to the given parameters. Secondly, the paper makes an introduction to the structure of the deformation control system of the active stressed lap based on PXI platform. The overall structure of this system is an open PXI-1082 platform based on PXI bus, taking an embedded PXI-8133 as its controller. Finally, the paper makes a deforming test on the platform and provides its result.This project is subsidized by Chinese National Natural Science Funds (11003033).

8450-173, Poster Session

ZERODUR® for stress mirror polishing II: improved modeling of the material behavior

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In the preceding part I of this paper stress mirror polishing was stated as one of the processes assumed for the polishing of non-axisymmetric mirror blanks like the mirror blanks for the two ELT projects (the ESO E-ELT and the TMT). For this process it is important to have a precise knowledge of the elastic behavior of the glass ceramic mirror substrate materials. In reality glasses and glass ceramics do not react perfectly instantaneous to stresses at room temperature. This effect is called “delayed elasticity”

It was shown that the delayed elasticity effect of ZERODUR® is small in size (less than approximately 1% of the applied deformation) and fully reversible in time. A mathematical model on the relaxation of shear modulus and bulk modulus of ZERODUR® has been introduced to predict the delayed elasticity at room temperature and different load cases. This second paper is focusing on an updated model approach with the target to improve the model prediction accuracy. The model results will be compared to new high accuracy measurements of the effect.

8450-174, Poster Session

Fabrication of the LSST monolithic primary-tertiary mirror

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As previously reported (at the SPIE Astronomical Instrumentation conference of 2010 in San Diego), the Large Synoptic Survey Telescope (LSST) utilizes a three-mirror design in which the primary (M1) and tertiary (M3) mirrors are two concentric aspheric surfaces on one monolithic substrate. The substrate material is Ohara E6 borosilicate glass, in a honeycomb sandwich configuration, currently in production at The University of Arizona’s Steward Observatory Mirror Lab. We will provide an update to the status of the mirrors and metrology systems, which have advanced from concepts to hardware in the past two years. In addition to the normal requirements for smooth surfaces of the appropriate prescriptions, the alignment of the two surfaces must be accurately measured and controlled in the production lab, reducing the degrees of freedom needed to be controlled in the telescope. The surface specification is described as a structure function, relating to the expected atmospheric turbulence. Both the pointing and centration of the two optical axes are important parameters, in addition to the axial spacing of the two vertices. This paper details the manufacturing process and metrology systems for each surface, including the alignment of the two surfaces. M1 is hyperboloidal and can utilize a standard Offner null corrector, whereas M3 is an oblate ellipsoid, so has positive spherical aberration. We have placed a phase-etched computer-generated hologram (CGH) between the mirror surface and the center-of-curvature. Laser trackers are relied upon to measure the alignment and spacing as well as rough-surface metrology during loose-abrasive grinding.

8450-176, Poster Session

Accomplished the task of production of primary and secondary mirrors of DOT telescope under the project ARIES (India, Belgium, Russia): fabrication features

A. P. Semenov, Lytkarino Optical Glass Factory JSC (Russian Federation)

Under the contract with firm AMOS LZOS, JSC has accomplished the manufacturing works of Primary and Secondary Mirrors of Devasthal Optical Telescope (DOT) for Aryabhatta Research Institute of Observational Sciences (ARIES). Primary mirror specifications: diameter 3700 mm, vertex radius 14639 mm (F/1.96), conical constant -1.03296, asphericity 111 microns. Secondary mirror specifications: diameter 980 mm, vertex radius 4675 mm (F/1.78), conical constant -2.79561, asphericity 47 microns. The results of works under this project is presented in this paper.

8450-178, Poster Session

Methods of testing of large size convex secondary mirrors with diameter up to 4m

M. A. Abdulkadyrov, Lytkarino Optical Glass Factory JSC (Russian Federation)

There are presented different testing methods of convex secondary mirrors including stages of grinding and polishing of optical parts. There are described the testing method by spherometer in longitudinal and linear directions, testing methods by overlapping of wavefronts in horizontal and vertical layouts. A possible testing layout of a convex hyperboloid with diameter up to 4m is presented also in this paper.

8450-179, Poster Session

Methods of fabrication and testing of unique large size optics in LZOS, JSC (VST, VISTA and other projects)

A. P. Semenov, M. A. Abdulkadyrov, S. P. Belousov, V. E. Patrikeev, V. V. Pridnya, Lytkarino Optical Glass Factory JSC (Russian Federation)

There is described computer - controlled methods of treatment of large optics with testing of ground surfaces by a set of spherometers

and IR-interferometers, testing of lens correctors and CGH correctors, measuring of Radius by a laser tracker on examples of astronomical mirrors production under projects VST, TNT, VISTA, etc. There is a graph describing a degree of complexity of fabricated optics for various telescopes all over the world and there is data about the astronomical mirrors produced in LZOS for different projects.

8450-180, Poster Session

Mirror fabrication of the prototype of fast steering secondary mirror for GMT

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In this paper, we report the progress in the development of prototype of GMT (Giant Magellan Telescope) fast-steering secondary mirror, which we call FSMP in this paper. In this development, KRISS (Korea Research Institute of Standards and Science) takes part in the manufacturing of secondary mirror. Its diameter is 1.062 m and the weight is about 97 kg. The whole shape is a meniscus type so we started machining by curve generation of the back surface. Then, the lightweighting of the mirror was carried out. After that, the mirror surface was fabricated. During the grinding and early stage of polishing, the profilometry was used to measure the surface form error. The interferometry with CGH (Computer Generated Hologram) installed on the testing tower was used during the rest of the fabrication process.

8450-181, Poster Session

Diamond milling of metal mirros with optical surface quality

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The 1. Physics institute of the University of Cologne is establishing a production line to manufacture directly diamond milled, optical metal mirrors with low form errors and surface roughnesses (<= 50nm, rms). It will be possible to manufacture plane, spherical and aspherical metal mirrors with dimensions up to 40cm.

Optical components made from metal (mirrors, image slicers, gratings, ...) are commonly used in astronomical instruments. Our goal is to produce cost-effective, optical metal components (e.g. aluminium with a nickel-phosphorous layer) that can be delivered on short timescales. These mirrors are manufactured using a Kern Evo milling machine by direct diamond milling in three or more axes. The milling machine is temperature stabilized and vibration isolated. The already high-standard precision of this machine is improved by e.g. using diamond cutters with radii similar to the lowest occuring radius of curvature of the surface to be milled. Quality control is provided by our optics laboratory using various interferometric setups (monochromatic and white-light).

Here, we present some optical metal mirrors that have been manufactured. Currently, potential post-processing steps, like polishing, are under investigation to improve surface roughness beyond 50nm (rms).

8450-182, Poster Session

Fabrication of Φ550mm aspheric surface by ion beam figuring

Y. Wang, J. Zhang, L. Xu, R. Fu, Beijing Institute of Space Mechanics and Electricity (China)

Aspheric reflective optics are becoming more and more important for space optical system. Ion figuring is an optical fabrication method that satisfies the requirement of the manufacture of such highly precise optical surfaces, which provides highly deterministic error correction of previously polished optical surfaces using a directed, inert and neutralized Argon ion beam to physically sputter material from the optical surface. Figure error correction is accomplished by varying the velocity of the constant-output ion source as it scans across the optic surface. Given the sample of Φ550mm K4 aspheric mirror, Offner compensator was designed and fabricated for measuring aspheric surfaces to which 0.0015 micro-meter rms wavefront error was reached. Then, the surface figure error was corrected by ion figuring, which makes surface error reduced from 0.052 micro-meter rms to 0.015 micro-meter rms in two test-figure iterations. The demonstration provided information and repuirements for future processing of Zerodur and other glass-silicon carbon materials, and clearly showed the applicability of ion beam figuring to the final correction of large, complex optics.

8450-183, Poster Session

Manufacturing and testing of a convex aspherical mirror for assist

R. ter Horst, ASTRON (Netherlands); R. Stuik, Leiden Univ. (Netherlands)

ASSIST is the testbed for the ESO Adaptive Optics Facility. The main objective of this project is the characterization of the 1.2 meter deformable mirror which will replace the existing secondary on one of the VLT telescopes. A large concave 1.7 meter aspherical primary mirror combined with a 150 mm convex aspherical secondary forms the main optical system of ASSIST. Two additional optical units provide the light sources and the wave front analyzing optics. Without having the possibility for checking the entire optical system as a whole, each individual mirror had to be manufactured and tested using reliable techniques. The secondary mirror for Assist (AM2) is made of an optically transparent material (BK7) with a specific and accurate backside radius in order to achieve a null test in transmission. The aspherical surface is tested in double pass using an optical flat and an interferometer with a transmission sphere. Manufacturing of this asphere is mainly done by hand at the optical lab of NOVA-ASTRON. The final surface accuracy of the a-spherical surface is within the required 25 nm RMS with a surface roughness of less than 2 nm RMS. This paper reports in more detail on manufacturing and testing of the a-spherical convex mirror.

8450-184, Poster Session

Design of a null compensator for testing convex secondary mirror of extremely large aperture optical telescope

X. Li, C. Xu, J. Pan, Nanjing Institute of Astronomical Optics & Technology (China)

Convex hyperboloid is wildly applied for secondary mirror of astronomical telescope. The most common test for theses surfaces has been implemented by using a Hindle sphere. The problem with this method is that a very large concave spherical surface, much larger than the surface under test, is required. For example, when TMT (Thirty Meter Telescope) secondary mirror with 3.1 meters in diameter is tested with Hindle method, the diameter of the Hindle sphere will not be less than 20 meters, which seems inoperable.

In this paper, A method of combining a concave reference mirror and a class of small lenses is proposed to test convex hyperboloidal secondary mirrors with large aperture and fast focus ratio. The aperture of the reference mirror is about 1.8 times as large as that of the concave mirror under test. Two null compensation systems are discussed. The first consists of a concave ellipsoidal mirror and two small lenses. The second consists of a concave spherical mirror and four pieces of small lens. The design results indicate that the aberration of every testing system is well

corrected and the spot diagram is smaller than diffraction limit.

The advantage of the proposed method is that the reference concave mirror is much smaller then that of the Hindle method, more over, the quality of the small lenses is easy to control. So, it looks very suitable for testing convex secondary hyperboloidal mirror of extremely large aperture optical telescope.

8450-185, Poster Session

The development of testing convex hyperbolic mirror using Hindle method based on stitching technology

Z. Jiang, Nanjing Institute of Astronomical Optics & Technology (China)

The test method of Large-diameter convex secondary mirror in development process is the key to making large telescope technology. Classical means HINDLE to test using of non - aberration points needs a spherical reflect mirror which larger than the secondary mirror several times. This new hindle test method based on stitching technology can significantly reduce their standard mirror's size, drop the difficulty of processing and cut down the costs.

In This paper, the hindle testing basic principles which base on stitching technology is introduced firstly, then principle of stitching and least square method. Following the parameters of inside and outside standard mirrors are derived. Then translation and rotation transformation algorithm of different sub-aperture interferometer array data is given. Finally the preliminary results of the radial stitching experiments are given. The results showed that the relative error is RMS = 6.1%, PV = 5.11%. With improving and perfection, this method can be used in the E-ELT, CFGT convex secondary mirror telescope test.

8450-186, Poster Session

Game-changing approaches to affordable advanced lightweight mirrors II: new cases analyzed for extreme ZERODUR® lightweighting and relief from the classical polishing parameter constraint

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In an earlier paper, we established that the combination of new fabrication parameters for open-backed monolithic lightweighted ZERODUR® mirror substrates, coupled with new methods for optical finishing of aggressively lightweighted these mirrors, together have relieved classical mirror design constraints imposed upon 1.2m diameter lightweight mirrors. In the past when the highest degree of lightweighting and highest stiffness was required, designers have gone to sandwich mirror designs. We demonstrated that openback mirror substrates now offer comparable mass, Eigenfrequency and substructure print-through performance to the sandwich-mirror architecture, but with considerably less manufacturing effort than for sandwich mirrors.

This paper extends the analyses of the first paper from 1.2m diameter down to 0.6m in diameter (potentially accessible to NASA/ESA/JAXA Explorer Class and Balloon Missions), and up to 2.4m diameter and 4m diameter mirrors (addressing what may be considered for future NASA/ESA/JAXA Flagship Missions). We will explore how performance figures-of-merit for these mirror sizes compare to those figures-of-merit of the classical sandwich approach, and for each size, suggest openback design parameters that are appropriate for state-of-the-art manufacturing.

We will also discuss the latest experimental results on quilting removal from the ideally suited Brashear large MRF machine and consider how the requirement of unobscured systems will affect both mirror design, and available methods for blank production and for optical finishing. We will also consider practical mirror mounts, load paths, 1g to 0g predictions, and typical launch vibration and acoustic loads, as they constrain these mirrors.

8450-187, Poster Session

Development of high-throughput silicon lens and grism with moth-eye antireflection structure for mid infrared astronomy

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In the mid-infrared region, transparent optical materials are limited. Although silicon is often used owing to its high transparency and workability, its high refractive index produces reflection loss of ~30% on its surface. The moth-eye antireflection structure can dramatically reduce the reflection loss. In addition, it is desirable for mid-infrared optics. The moth-eye structure consists of a single material. It is indestructible under cryogenic environment needed for mid-infrared instruments. We have been developing high-throughput optical elements for mid-infrared optics with the moth-eye structures. The moth-eye structures are optimized for the wavelength of 25-45microns. Aligned cones with a height of ~18microns are arranged at 5microns interval. They are formed on silicon substrate by the electron-beam photo-lithography and reactive ion etching method. As the first application of the moth-eye, a plane-convex silicon moth-eye lens (Size: 30mm square, f=185mm) has been fabricated. The moth-eye structures were formed on the curved surface. It has been confirmed by an electronic microscope image that the moth-eye structures have been formed almost successfully even on the curved surface, and no significant image-degradations have been seen in mid-infrared images focused by this lens. As the next step, developments of a biconvex double-sided moth-eye lens (D=33mm, f=94mm) and a double-sided moth-eye grism (Size: 24mm square, Blaze angle: 2.41deg, Grating constant: 314.8microns) have been in progress. Although it is more difficult to form the moth-eye structure on both surfaces and nonplanar surfaces, their completion will open up the new way for mid-infrared instruments. We present these developments and evaluations.

8450-189, Poster Session

Development of full shell foil x-ray mirrors for NICER

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NICER will be using full shell aluminum foil X-ray mirrors, similar to those that are currently being developed for the optics to be used for the XACT sounding rocket mission. Similar X-ray optics have been being produced at Goddard Space Flight Center since the late 1970's. The mirror geometry used in the past and on some present missions consists of concentric quadrant shell mirrors with a conical approximation to the Wolter 1 geometry. For the XACT sounding rocket, we are developing the next generation of these optics. Two innovations introduced for XACT are that the mirrors are complete shells and a curve is introduced into the mirror profile so that the focus is more concentrated than with a conical approximation. Since XACT and NICER are using the optics as X-ray concentrators, rather than full imaging optics, only one set of reflections is necessary. For NICER, the largest shell is only 10 cm across allowing the full shell development to be utilized, benefiting the telescope by providing a stiffer design and less support structure, thus increasing effective area per unit mass. This has also led to an innovative design of the mirror mounting structure. With 56 optics on NICER, each consisting of 24 full shell mirrors, an effiective production process is needed for effecient manufacture of these mirrors. This production process has been based off that used for previous generations of foil mirrors, but has been refined for the new type of mirrors. This paper presents this production process of the innovative full shelled optics and present results of optical and X-ray tests of integrated optics.

8450-30, Poster Session

New modelling of freeform surfaces for optical design of astronomical instruments

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Freeform optics offer additional degrees of freedom that can lead to a simplification of instrument optical designs with compact solutions. In this context, we propose innovative desisgns with a new mathematical description of freeform surfaces. This new mathematical formalism, based on the "eigen-modes" of Bernstein polynomials was developed for off-axis highly aspherical surfaces modelling. It allows to take into account different kind of deformations: from low to high order deformations of the optical surface with local influence capabilities. It has been implemented into Zemax making use of the User-Defined Surface (UDS-DLL) to be used for optical design of astronomical instruments. We present the mathematical formalism developed and then we focus on the optical analysis of an innovative design. The advantages provided by this new modeling are examined and we discuss the possibility of improving performances of complex instruments by use of these freeform optics.

8450-190, Poster Session

Experimental validation of advanced dispersed fringe sensing (ADFS) algorithm using advanced wavefront sensing and correction testbed (AWCT)

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Large aperture telescope commonly features segment mirrors and a coarse phasing step is typically needed to bring these individual segments into the fine phasing capture range. Dispersed Fringe Sensing (DFS) is a powerful coarse phasing technique and its alteration is currently being used in JWST. An Advanced Dispersed Fringe Sensing (ADFS) algorithm is recently developed to greatly improve the performance and robustness of previous DFS algorithms with better accuracy and unique solution. The first part of the paper introduces the basic ideas and the essential features of the ADFS algorithm and presents the result of the algorithm sensitivity study with various noises and perturbations. The second part of the paper describes the full details of algorithm validation process through the advanced wavefront sensing and correction testbed (AWCT): first, the optimization of the DFS hardware of AWCT to ensure the data accuracy and reliability is illustrated. Then, a few carefully designed algorithm validation experiments are implemented, and the corresponding data analysis results are shown. Finally the fiducial calibration using Range-Gate-Metrology is carried out and a <10nm or <1% algorithm accuracy is successfully demonstrated.

8450-191, Poster Session

Image moment-based wavefront sensing for in-situ full-field image quality assessment

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A new concept of using focus-diverse point spread functions (PSF) for modal wavefront sensing (WFS) is explored. This concept is based on relatively straightforward image moment analysis of measured PSFs, which differentiates it from other focal-plane WFS techniques. The presented geometric analysis shows that the image moments are nonlinear functions of wave aberration coefficients but notes that focus diversity essentially decouples the coefficients of interest from others, resulting in a set of linear equations whose solution corresponds to modal coefficient estimates. The presented simulations suggest the potential of this method in in-situ full field image quality assessment and deterministic alignment control of wide field imaging systems.

8450-193, Poster Session

Opto-mechanical design, manufacturing and metrology of MUSE image slicer

E. Renault, D. Boudon, J. Kosmalski, Observatoire de Lyon (France); Y. Salaun, Winlight System S.A. (France); F. Laurent, L. Adjali, E. Daguisé, Observatoire de Lyon (France)

The Multi Unit Spectrograph Explorer (MUSE) is a 2nd generation instrument for the Very Large Telescope of the European Southern Observatory. Today this 24 channel integral field spectrograph is almost finished and it will be installed onto the VLT about the beginning of 2013. This article describes the design, the manufacturing and the metrology of the 24 Image Slicer of MUSE. The opto mechanical design , including the choice of materials, the glass/metal and metal/metal interfaces, finite elements calculations, ghosts and diffuse light baffling solutions, will be discussed. Then, the manufacturing of the mechanical support and the optical parts, the assembling solutions (clamping or gluing) will be presented. And also, all the metrology, applied onto the single components and the wide system, will be described with the results of the whole series.

8450-194, Poster Session

MAPS: where have the robots got to?

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Most of the sky is black: picking off the interesting bits is the challenge. By placing pick-off mirrors in the focal plane of an instrument, it is

possible to select light from only the desired sub-fields. The Micro Autonomous Positioning System (MAPS) is a method to manoeuvre pick-off mirrors into position by giving each mirror its own set of wheels. This poster details the metrology algorithms that have been developed to provide real-time feedback of the robots' positions. This is achieved through imaging of high-resolution targets on the robots and analysis of the power floor on which they move.

8450-195, Poster Session

The optical alignment of the Gemini Planet Imager adaptive optics bench

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The Gemini Planet Imager (GPI) is a facility instrument under construction for the 8-m Gemini south telescope. This paper describes the methods used for optical alignment of the adaptive optics (AO) bench. The optical alignment of the off-axis paraboloid mirrors was done using a pre-alignment method utilizing a HeNe laser and alignment telescopes followed by a fine-tuning using a Shack Hartmann wavefront sensor and a shear plate. A FARO arm measuring system was used to place the fiducials for the alignment. Using these methods the AO bench was aligned to 13nm RMS WFE.

8450-196, Poster Session

4DAD, a device to align angularly and laterally a high-power laser using a conventional sighting telescope as metrology

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The 4DAD, Four Dimensions Alignment Device was developed in the frame of the project 4LGSF (4 Laser Guide Star Facility) for the AOF (Adaptive Optics Facility) on the ESO VLT (Very Large Telescope). It is used to accurately align with respect to kinematic interfaces and mirror alignment targets, a 20 W-class laser source in lateral and angular directions. 4DAD is of size 25x25x15cm and is based on a commercial CCD beam profiler.

The incoming beam is highly attenuated at 589 nm and split in two parts through a set of beam conditioning optics. One beam is directed onto the detector revealing lateral movements whereas the other part is refocused to reflect angular changes in the incoming beam. Both lateral and angular beam positions are simultaneously recorded as pixel coordinates on the single CCD.

The distinctive feature of 4DAD is its metrology, i.e. the pixel reference coordinates are recorded through the cross projection from a conventional sighting telescope. The device is capable of being used with a low-power white light sighting telescope (alignment reference) as well as with a high power laser beam (to be aligned) without any optical configuration change.

Mounted on a reference frame, it can align all 4LGSF laser units beams, giving them equal optical interface and interchangeability.

The sighting telescope is the main alignment equipment for the 4LGSF, thus all sub-systems, including 4DAD are aligned, merged, using a simple, single, practical and well-known alignment instrument.

The alignment strategy, the design, and results of 4DAD are presented.

8450-197, Poster Session

Finite element simulation in fabrication of high-precision reflector panels

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Millimeter and sub-millimeter wave observations, however, which largely depend on the instrumentation techniques, provide vital experimental verifications for the theoretical studies of stars formation. To obtain the stronger and more precise radio spectrum signals, high precision reflector panels that are demanded in great amount especially for the large-aperture antenna and antenna-array. Many years, experts have put emphasis on the precise forming of reflector panels. This paper presents the high-precision panels with a sandwich-type construction of one skin-plate and one aluminum backup structural combined with structural adhesive, with high precision modules as the fundamental condition. The skin-plate fit the module well due to its flexible. The structural adhesive, with good flow-ability, automatically compensate the deviations between the skin-plate and the backup structural. In the end, individually shaped sandwich-like panels assemble up the high surface-accuracy reflectors. The internal stress analysis of skin-plate and structural adhesive are of utmost importance. Therefore, several kinds of skin-plate and structural adhesive in different material properties are listed and simulated with finite element method (ANSYS). Based on the simulation results, processing parameters of the panels fabrication are determined more efficient and accurate.

8450-198, Poster Session

The research on large aperture telescope drive control technology

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The direct drive motor of large aperture telescope, integrated with the telescope mechanic structure, should against high load torque and moment of inertia. The control method of driving should be specially designed for the heavy load. This article aims to list the key issues of engineering technology applied to large aperture telescope. A drive control method and control architecture is discussed including multi-way power driver control and communication, electronic circuit design and debug, DSP programming , system simulation and analysis, software, etc. Finally, we discuss the design requirements of segmented direct drive motor of large astronomic telescope and give some experimental data.

8450-199, Poster Session

Design and control of one precise tracking simulation bed for Chinese 30 meter optic infrared telescope

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The modern large telescope will be endowed with advanced imaging systems and active optics, resulting in very high peak angular resolution. The drive systems for the telescope must consequently be able to guarantee a tracking accuracy better than the telescope angular resolution, in spite of unbalanced and sudden loads such as wind gusts and in spite of a structure that, because of its size, can not be infinitely stiff. Direct drive system has many advantages over more traditionally used friction and rack/pinion drive. The advantages include high stiffness, no friction, easy alignment and low maintenance. As direct drive technology develop, it might push to more reliable and cheaper solutions for 30-m telescope complex motion system.

However, this requires the design and realization of unusually large torque motors, which must be manufactured piecewise and assembled on-site. On the other side, in spite of their very large size, the torque motors must be controlled with a very high control bandwidth; the torque slew rate must be extremely steep too. For all these reasons, a conventional torque motor design appears inadequate. This paper explores One Direct Drive Torque Motor for large Telescope, By which we can very easily manufacture a telescope direct drive motion system.

However, the precise ultra low speed tracking drive system is one

high integrated electromechanical system, which one complexly electromechanical design method is adopted to improve the efficiency, reliability and quality of the system during the design and manufacture circle. The precise Tracking Bed is one ultra-exact, ultra-low speed, high precision and huge inertial instrument, which some kind of mechanism and environment of the ultra low speed is different from general technology. This paper explores the design process based on complex electromechanical optimizing design theory.

8450-200, Poster Session

Potential of phase-diversity for metrology of active instruments

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We investigate the potential of phase-diversity (PD) algorithms in the calibration of active instruments. A set of images is recorded with the focal-plane scientific camera, each image having a known and unique defocus. The PD algorithms with the recorded images are used to estimate the non-common path aberration that needs to be compensated by correct alignment of the instrument. We demonstrate by extensive simulation results that conventional PD is a sufficient detection method to fully correct wavefronts with an rms error up to at least 4 rad --- but this requires several, 5--10, iterative wavefront corrections.

8450-201, Poster Session

Control system for a novel active 6-DOF mechanism for sub-mirrors in giant telescopes

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Giant telescopes with extremely large aperture widely adopt segmented mirror active optics technology, so active adjustment mechanism of displacement is one of the critical techniques. A novel 6-DOF mechanism featuring structural compactness in size and partial decoupling in DOFs has been proposed as a potential supporting mechanism for sub-mirrors. It is of important significance to carry out profound study on the control strategy for large scale use of the 6-DOF adjustment mechanism in a highly segmented giant telescope. This paper presents first the control system design for a prototype of the 6-DOF mechanism and further the control strategy modeling for the future large-scale application of the mechanism in giant telescopes. The control system implemented for the prototype mechanism has been successfully tested by photogrammetry at lab. It provides closed-loop control and real-time measurement of all motors of one 6-DOF mechanism and is proved to be a system of high precision and efficiency. Afterwards, we explore and extend the control design of the novel 6-DOF mechanism to large-scale use in all sub-mirrors in a giant telescope. The principle, constitution, control algorithm and realization are covered and commented. The study and experiment carried out in this paper are also informative for the control of parallel manipulators in other industries.

8450-202, Poster Session

Optimizing optical systems with active components

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The increasing requirement on the performance of optical instruments lead to complex optical paths including active optical components. The role of these components is to remove environmental influences on the instrument and reduce manufacturing and alignment residuals. We describe a method that can be used to design and operate instruments with active components that are not necessarily located in the pupil. After the optical system is designed, the next step is to analyze the degrees of freedom (DOF) necessary and include those in the active component. For an actively controlled mirror it leads to the definition of the number and location of the actuators along the clear aperture. Based on the sensitivity matrix and using eigenvalue analysis like singular value decomposition (SVD), the smallest number of independent DOF for the active component can be calculated. In operation of the instrument, the wavefront in the pupil is reconstructed from phase diversity; a metrology having minimal impact on instrument design. Using this method, the convergence efficiency of the optimization is a critical parameter. Information from the SVD and reverse optimization are used to model the process, explore the parameter space of the methods and acquire knowledge on convergence. The results are presented for some generic problems.

8450-203, Poster Session

Design and test of a novel cost-effective piezo driven actuator with a two-stage flexure amplifier for chopping mirrors

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A fast chopping secondary mirror is the critical functioning assembly in an astronomical telescope for infrared observation. Normally, a chopping mirror is driven by precision high-load and high-stiffness linear actuators which are expected to be lightweight, compact and further cost-effective. The stroke of the actuator is typically required to up to several hundred microns with typical load capacity up to several hundred Newtons. We developed a novel piezo-based prototype linear actuator with a two-stage rhombic flexure amplifier. In this paper, first we present the detail design scheme of the actuator by analytical calculations with comprehensive Finite Element Analysis (FEA) verification. Afterwards, we also present the procedures and results of tests of linearity, load capacity, eigenfrequency and stiffness. The selected piezoelectric drive unit is a block of 35x10x10 mm3 with output force up to 4000 N. The two-stage displacement amplifier is simply integrated by two identical singular rhombic flexures orthogonally mounted together. Each stage, one rhombic flexure with a longer axis of 76 mm long, is designed with an ideal amplification ratio of 3, which leads to a final theoretical compound amplification ration of 9. In order to realize the basic triangular-amplification principle in a rhombic flexure, we introduced flexure joints at all the eight ends of its four edge bars. The singular rhombic flexures can be efficiently manufactured by electrical discharge wire-cutting process at a time in batch by being overlapped in layers. Afterwards we carried out related measurements to test its performance.

8450-204, Poster Session

Research of active optics force actuator based on voice coil motor

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Active optics is the key technology in the researching of large-scale

telescope, and the active optics system, consisted of wavefront sensor, computer control system, calibration element and force actuator, is a closed-loop control system for correcting the wavefront error. Because the main error resources are system errors that caused by optics processing, machining, assembly, calibration, and telescope deformation resulting from the change of gravity and temperature gradient, the calibration frequency is about 10-2 Hz. However, the calibration frequency must reach 10 Hz if it is needed to correct the atmospheric disturbance around the main mirror and the error caused by wind. Therefore, the force actuator must have good dynamic response and high-precision positioning. At the same time, the cost of the force actuator must be low because of the large number of them.

So, a new scheme of force actuator, in which linear voice coil motor is used as the driver and linear grating is used as the displacement sensor, is proposed in this paper. With using the deadbeat control theory, the force actuator could achieve fast response, no steady-state error, small overshoot, rapid recovery, and high-resolution which cannot be deeply improved by the traditional PID control method. Finally, the calibration frequency can reach 20 Hz which has met the system design requirement. Computer simulation and actual experiment demonstrates that this kind of control method can effectively improve the performance of the force actuator, and the conclusion provides a valuable reference to the research and design of the force actuator.

8450-205, Poster Session

Extinction controlled adaptive mask coronagraph Lyot and phase mask dual concept for wide extinction area

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The Adaptive Mask Coronagraph using “non-solid” masks features was developed to improve coronagraphs observational efficiency (Bourget et al. 2004). The first issue of this concept was the Hg-mask Lyot coronagraph.To reach the high contrast imaging in a small angular separation not allowed by the Lyot coronagraph an adaptive phase mask was also developed following the Roddier & Roddier coronagraph concept (1997). Here we propose an active nulling control by modulation of the transmission through the focal plane outside of the phase mask. The control loop is done by a direct measurement of the nulling efficiency with an avalanche photodiode at the coronagraph output. The optical modulation is done by the means of liquid-crystal polarization properties also used to produce the π phase shift. An Hg-Mask Lyot coronagraph and an Adaptive Phase Mask Roddier & Roddier coronagraph working simultaneously in two different polarizations compose the instrument concept.

8450-206, Poster Session

A VUV half-wave polarimeter optimized for observations of resonance scattering polarization from diffuse H Ly-α sources in the solar system

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Low to moderate velocity neutral hydrogen is present throughout the solar system, including components from planetary coronae, comets, the penetrating neutral interstellar medium, and the atmospheres of the giant planets. Single scattering of solar H Ly-α emission induces a linear polarization state directly related to the angles between the Sun, target, and observer. This process allows us to use polarization measurements to study opacity effects, turbulence, aurora, and geometric distribution for a variety of targets. We report on a new instrument designed to measure Ly-α polarization that will be incorporated into a sub-orbital wide-field observatory. The polarimeter consists of a rotating half-wave plate that is paired with a Brewster angle reflector to obtain the Stokes parameters of an incoming source. The waveplate is a 2 mm thick LiF crystal with a magnitude of retardation that can be tailored to a wavelength being studied through the application of stress perpendicular to the incoming beam direction. The Brewster mirror is composed of diamond. This presentation includes a discussion of the characteristics of the polarimeter, the results of testing at near UV wavelengths and then at H Ly-α. In particular we will provide results on the polarimetric efficiency of the instrument as a function of wavelength and stress, along with discussions of net instrumental throughput and the uniformity of retardation across the face of the LIF crystal.

8450-207, Poster Session

Analog front end board electronics proposal for the HAWC observatory

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HAWC (High Altitude Water Cherenkov) is a high energy, second generation, Gamma ray detector-telescope (energy between 100GeV to 100TeV) under construction at an altitude of 4100 m in the Sierra Negra volcano, Mexico. HAWC is a international Mexico/USA collaboration and when completed it will consist of a array of 300 tanks filled with high transparency water and three or four photomultipliers tubes near the bottom of each tank. Charged particles traveling through the water of the tanks produce Cherenkov effect blue light that will be captured by the photomultiplier tubes. This work discuss some analog electronics solutions and the use of high speed differential amplifiers for tracking the high frequency pulses from the photomultiplier tubes. It also looks towards the update of the present analog front end board electronics of the water detector tanks.

8450-208, Poster Session

ELENA MCP detector: absolute efficiency measurement for low-energy neutral atoms

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Microchannel plates (MCP) detectors are frequently used in space instrumentation for detecting a wide range of radiation and particles. In particular, the capability to detect non-thermal low energy neutral species is crucial for the sensor ELENA (Emitted Low-Energy Neutral Atoms), part of the package SERENA (Search for Exospheric Refilling and Emitted Natural Abundances) on board the BepiColombo mission to Mercury to be launched in 2014.

ELENA is a TOF sensor, based on a novel concept ultra-sonic oscillating shutter (Start section)which is operated at frequencies up to 50 kHz; a MCP detector is used as a Stop section. It is aimed

to detect neutral atoms in the range 10 eV - 5 keV, within 70° FOV, perpendicular to the S/C orbital plane. ELENA will monitor the emission of neutral atoms from the whole surface of Mercury thanks to the spacecraft motion. The major scientific objectives are the interaction between the environment and the planet, the global particle loss-rate and the remote sensing of the surface properties. In particular, surface release processes are investigated by identifying particles release from the surface, via solar wind-induced ion sputtering (100 eV) as well as Hydrogen back-scattered at hundreds eV.

MCP absolute detection efficiency for very low energy neutral atoms (E< 30eV) is a crucial point not yet investigated. At the MEFISTO facility of the Physical Institute of University of Bern (CH), measurements on three different MCPs (with and without coating) have been performed providing the behaviors of MCP detection efficiency in the range 10eV-1keV. Outcomes from such measurements are here discussed.

8450-209, Poster Session

Coarse-fine actuator for positioning of large telescope mirror segments

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The extremely large telescopes of the near future (e.g. E-ELT and TMT) will be composed of many mirror segments that need to be positioned with accuracies of a few nanometers. For these actuators a low cost solution is desired due to the high number of subsystems. For E-ELT a stability of 1.7 nm RMS for a stroke of 15 mm is required, while supporting between 0 and 900 N. The present paper concentrates on the testing of a prototype of such an actuator to measure the performance under different loads and orientations with respect to gravity.

The actuation is done by use of a stepper motor (coarse stroke) and a voice coil (fine stroke) while the mass off-loading is done by use of a spring. This so-called “soft” actuator makes good use of passive isolation properties for ground vibrations, while requiring a high performance control system to withstand wind excitations. A linear encoder is added to the actuator to provide positioning feedback for control. As the coarse actuator introduces disturbances of a transient nature, advanced control algorithms are tested to achieve the positioning stability with the fine stroke, during slow motion of the coarse stroke.

8450-210, Poster Session

Synchronous control design for active surface of radio telescope

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This paper outlines the method of synchronize in controller network of active surface of radio telescope. Controller regulates clock and frequency using IEEE1588 Precision Time Protocol to get coordinate with the master clock. This paper elaborates the design and realization of IEEE1588 protocol in embedded Ethernet protocol stack without operating system. Synchronous packet is packaged in UDP message over IPv4. The slave clock reads Pulse-Per-Second released by the master clock and coordinates with the PPS signal. All Controllers response the motion instruction congruously, and the shape of active surface is adjusted in real-time.

8450-211, Poster Session

New technologies and new performances of the JCMT radio-telescope: a preliminary design study

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With a diameter of 15m the James Clerk Maxwell Telescope (JCMT) is the largest astronomical telescope in the world designed specifically to operate in the submillimeter wavelength region of the spectrum. It is situated close to the summit of Mauna Kea, Hawaii, at an altitude of 4092m. Its primary reflector currently consists of a steel geodesic supporting structure and pressed aluminium panels on a passive mount. The major issues of the present reflector are its thermal stability and its panels deterioration.

A preliminary design study for the replacement of the JCMT antenna dish is here presented. The requested shape error for the new reflector is <20µm RMS.

The proposed solution is based on a semi-monocoque backing structure made of CFRP and on high precision electroformed panels. The choice of CFRP for the backing structure allows indeed to improve the antenna performance in terms of both stiffness and thermal stability, so that the required surface accuracy of the primary can be achieved even by adopting a passive panels system. Moreover thanks to CFRP, a considerable weight reduction of the elevation structure can be attained.

The performance of the proposed solution for the JCMT antenna has been investigated through FE analyses and the assessed deformation of the structure under different loading cases has been taken into account for subsequent error budgeting.

Results show that the proposed solution is in line with the requested performance.

With this new backing structure, the JCMT would have the largest CFRP reflector ever built.

8450-212, Poster Session

A smart car for the surface shape measurement of large antenna based on laser tracker

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The geometric accuracy of the surface shape of large antenna is an important indicator of antenna’s quality. Currently, high-precision measurement of large antenna surface shape can be performed in two ways: photogrammetry and laser tracker. Photogrammetry is a rapid method, but its accuracy is not enough good. Laser tracker can achieve high precision, but it is very inconvenient to move the reflector (target mirror) on the surface of the antenna by hand during the measurement. So, a smart car is designed to carry the reflector in this paper.

The car, controlled by wireless, has a small weight and a strong ability for climbing, and there is a holding bracket gripping the reflector and controlling reflector rise up and drop down on the car. During the measurement of laser tracker, the laser beam between laser tracker and the reflector must not be interrupted, so two high-precision three-dimensional miniature electronic compasses, which can real-time monitor the relative angle between the holding bracket and the laser tracker’s head, are both equipped on the car and the head of laser tracker to achieve automatic alignment between reflector and laser beam. With the aid of the smart car, the measurement of laser tracker has the advantages of high precision and rapidity.

8450-213, Poster Session

Study on functional integration of the SKA and the solar thermal power system

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Construction of the Square Kilometre Array (SKA) can be costly. Yet based on the current technology, it is not likely to significantly reduce the cost aiming to achieve the desired scientific objectives. After the completion of SKA, the power load will reach 50 ~ 100MW and a separate building of solar power plants may take hundreds of millions of euros. The dish-Stirling system is one of the concentrating solar thermal power(CSP) technologies. Considering the dish-Stirling system is structurally similar to a radio telescope, with its diameter similar to the antenna that is used in the SKA, It is assumed that a radio telescope and the dish-Stirling system could be functionally integrated in the design for time-based sharing, thus to reduce the SKA and the dish-Stirling system in the repeated construction costs on the reflecting

surface, the two-axis tracking mechanism, the civil engineering, and the roads, etc. At the same time, this may be favorable to attract industry investment, where the grid could generate economic benefits to solve the operating costs after the SKA is built. Based on the above idea on the functional integration of devices, whilst taking account on the functional requirements of the SKA and the dish-Stirling system, the structural design of functional integration is conducted, including optical systems, panel and support structure, two-axis tracking & pointing mechanism, and the switching device of the feed and the stirling engine. In addition, the multi-functional reflector regarding its processing and coating technology is covered.

8450-216, Poster Session

High stability piezomotor driven mirror mounts for LINC-NIRVANA

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We present a design of a twin pair of gimbal mirror mounts with large aperture for holding the warm dichroic mirrors of the LINC-NIRVANA (LN) project. Because of the very limited space and very high mechanical stability requirements a classical design based on DC- / Stepper actuators could not be used. A solution based on a very compact piezoelectric walk drive was found. This drive unit is integrated inside the frame structure and placed on maximum radial position to optimize system stiffness. Together with a LVDT type of sensor an absolute position is achieved within an angular range of +/-2 degree and a closed loop resolution of 0.3arcsec. This drive concept allows an extremely low thermal signature to keep a position constant and is self-locking at power shut down. The minimum natural frequency is 125 Hz with a moved mass of about 2,3kg. The static position stability within an elevation 0° up to 90° is below 15 arc seconds.

8450-99, Session 16

Near infrared metrology of high-performance silicon immersion gratings

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Compact silicon immersion gratings offer size and cost savings for high-resolution near-infrared spectrographs. The IGRINS instrument at McDonald Observatory and iSHELL at the NASA IRTF will employ high-performance silicon immersion gratings to achieve resolutions ranging from R=40,000 to 80,000 instantaneously over the long wavelength end of J- and all of the H-, K-, L-, and M- near-infrared band atmospheric windows, a massive bandwidth increase over existing instruments. We chronicle the metrology of an R3 silicon immersion grating for IGRINS. The grating is 30 x 80 mm, etched into a monolithic silicon prism. Optical interferometry of the grating surface in reflection indicates high phase coherence (< λ/6 peak to valley OPD over a 25 mm beam at λ=632 nm). Optical interferometry shows periodic position errors of the grating grooves. These periodic errors manifest as spectroscopic sidelobe ghosts. High dynamic range monochromatic spectral purity measurements reveal ghost levels relative to the main diffraction peak at 3 x 10-3 at λ=632 nm in reflection and 10-2 at λ=1523 nm in immersion. Improved grating surfaces demonstrate reflection-measured ghosts at negligible levels of 10-4 of the main diffraction peak. On-blaze efficiency exceeds 60%. We investigate the immersion grating blaze efficiency performance over the entire operational bandwidth 1500 < λ/nm < 2500 at room temperature. The projected performance at operational cryogenic temperatures meets the design specifications. In addition to the gratings we have patterned with UV photolithographic masks, we present the performance of gratings patterned with electron-beam lithography.

8450-100, Session 16

Development of silicon immersed grating for METIS on E-ELT

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We are developing the technology to manufacture an immersed grating in silicon for the Mid-infrared E-ELT Imager and Spectrograph, METIS. We show that we can meet the required diffraction-limited performance at a resolution of 100000 for the L and M spectral bands. Compared to a conventional grating, the immersed grating drastically reduces the beam diameter and thereby the size of the spectrometer optics. As diffraction takes place inside the high-index medium, the optical path difference and angular dispersion are boosted proportionally, thereby allowing a smaller grating area and a smaller spectrometer size. The METIS immersed grating is produced on a 150 mm industry standard for wafers and replaces a classical 400 mm echelon. Our approach provides both a feasible path for the production of a grating with high efficiency and low stray light and improves the feasibility of the surrounding spectrometer optics.

In this contribution we compare the classical-grating solution for the spectrometer with our novel immersed-grating-based design. We describe in detail the immersed-grating based optical design. Furthermore, we discuss the production route that is based on our long-standing experience for space-based immersed gratings. We use standard techniques from the semiconductor industry to define grating grooves with nanometer accuracy and sub-nanometer roughness. We then use optical manufacturing techniques to combine the wafer and a prism into the final immersed grating. Results of development of the critical technology steps will be discussed.

8450-101, Session 16

Optical performance of silicon immersion gratings

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We report results from lab characterization of large format silicon immersion gratings (SIGs) and grisms of astronomical observation quality. The SIGS are developed for high resolution infrared spectroscopy (R~70,000) in the near infrared (IR) (1.1-2.5 um) while the grisms are developed for R~4000 IR spectroscopy with existing near IR cameras. The SIGs include one with a 54.74 degree blaze angle (R1.4), 16.1 l/mm groove density, and 50x86 mm2 grating area, and another one with a 63.5 degree blaze angle (R2), 5.4 l/mm, and the surface area is 80mm x 50mm. The grisms have a 22 blaze angle, 137 l/mm groove density and 30x30 mm etched area. The R1.4 silicon immersion grating has an antireflection (AR) coating at the grating entrance and a gold coating on the grating surface to increase its throughput at 1.1-2.5 um while the silicon grisms have AR coatings on both entrance and grating surface to increase their transmission at 1.1-2.5 um. The lab measurements show that the SIG has delivered a spectral resolution of R=114,000 at 1.55 um with a lab testing spectrograph with a 20 mm diameter pupil. The measured peak grating efficiency is 72% at 1.55 um, which is consistent with the results from the grating modeling. This SIG will be installed in a new generation cryogenic IR spectrograph, called Florida IR Silicon immersion grating spectromeTer (FIRST), to offer broad-band high resolution IR spectroscopy with R=72,000 at 1.4-1.8 um in a single exposure with a 2kx2k H2RG IR array at the robotically controlled Tennessee State University (TSU) 2-meter telescope at Fairborn Observatory in Arizona. FIRST is designed to provide high precision Doppler measurements (~2 m/s) for the identification and characterization of extrasolar planets, especially rocky planets in habitable zones, orbiting low mass M dwarf stars. It will also be used for other high resolution IR

spectroscopy observations such as young stars, brown dwarfs, magnetic fields, star formation and interstellar mediums. The silicon grisms will be used for scientific observations with the ARIES IR spectrograph at the MMT.

8450-102, Session 16

Optical performance of the ZnSe immersion grating for the short NIR infrared application

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ZnSe has a high refractive index (n~ 2.45) and a low optical loss (< 0.1/cm) from 0.7 to 14 um. Therefore ZnSe immersion gratings can enable high-resolution spectroscopy over a wide wavelength range.

We are developing ZnSe immersion gratings for a ground-based NIR high-resolution spectrograph WINERED (Kondo et al. 2012), and a space MIR high-resolution spectrograph HRS mounted on the infrared space telescope (SPICA) (Sarugaku et al. 2012).

LLNL previously machined a 30 um pitch grating on a 25 mm ZnSe substrate (Kuzmenko et al. 2008) with good surface irregularity (< lambda/8), low surface roughness (< 5 nm rms), and small random pitch error (< 3 nm). This satisfied our requirements for short NIR applications (Ikeda et al. 2008).

Extending this technology, we produced a large prism-shaped ZnSe immersion grating with a grooved area 50mm x 58mm (Ikeda et al. 2010).

However, optical testing showed inter-order ghosts in the diffraction pattern. We believe they originate in differences between odd and even grooves due to the back-and-forth motion of the tool in the cutting process. This effect may be enhanced by subsurface damage in the substrate.

Recently, we re-machined the grating using unidirectional cutting. The grooved surface and subsurface damage had been removed by chemical etching. In this paper, we will report the results of optical testing and discuss its feasibility as an optical element for astronomical spectrometers.

8450-103, Session 16

High-performance astronomical gratings by Canon

T. Sukegawa, S. Sugiyama, T. Kitamura, Y. Okura, M. Koyama, Canon Inc. (Japan)

Canon is manufacturing a variety of gratings, such as DOE for high-class camera lens, reflective echelle grating for DUV spectroscopy, and transmission gratings for pulse compression. Our original free-forming machine has accuracy of a few nano-meter in positioning and stability. It works one of a kind ruling engines. Our standard reflective echelle gratings for deep-ultraviolet is 360 mm in length, and 60 mm in width. Typical diffraction wavefront accuracy is less than 60nm(PV) and spacing error is less than 2nm(rms) within grooved area in 350mmx55mm.

By making use of our technologies and experiences, Canon is now developing a large immersion grating that can be a good solution for high-resolution infrared spectroscopy with the next-generation large ground-based and space telescopes. A type of immersion grating which covers from near- to mid-infrared wavelength region is made from KRS5, and another type of immersion grating optimized for mid-infrared wavelength region is made of CdZnTe. Especially CdZnTe immersion grating is the key-device to realize the high-resolution spectrograph for “SPICA”, Japanese next-generation infrared space telescope.

The grooves are shaped by diamond cutting (planing) on the hypotenuse area(30mmx10mm) of a CdZnTe prism with the spacing accuracy of <5nmRMS and the surface roughness of <10nmRMS.

In addition to the result of the trial immersion grating, we introduce a variety of grating manufacturing capabilities of Canon.

8450-104, Session 16

Materials for VPHGs: practical considerations in the case of astronomical instrumentation

A. Bianco, G. Pariani, A. Zanutta, INAF - Osservatorio Astronomico di Brera (Italy); C. Bertarelli, Politecnico di Milano (Italy)

The role of Volume Phase Holographic gratings in the modern astronomical instrumentation is undoubtedly relevant. Indeed all the largest facilities bear VPHGs and the next generation instrumentations are being designed based on such dispersing elements. The production of a VPHG is in principle simple, since the classical two beam holography is used. However, main issues regard the sensitive material employed as holographic substrate, which has to show some properties, namely: large modulation of the refractive index, ability to form films with a well-controlled thickness e good optical properties, high sensitivity to the laser writing light of the holographic set-up, large spatial resolution. Dichromated Gelatine (DCG) is the most used material, showing the best performances especially in terms of refractive index modulation and optical quality; unfortunately, it is difficult to handle and to develop, thus limiting the VPHG opportunities. It follows that new materials have been recently considered for making holographic diffractive elements, such as silver halides, photochromic materials, photopolymers. Some of them, in particular the photopolymers, allow to make VPHGs easily, but the performances are usually lower, whereas the large nonlinearity strongly affects the grating performances in the case of photochromic materials. In this contribution, an overview of the opportunities, the performances and the prospects will be highlighted focusing mainly on the astronomical field.

8450-105, Session 16

Performance of volume phase gratings manufactured using ultrafast laser inscription

D. Lee, UK Astronomy Technology Ctr. (United Kingdom); R. R. Thomson, Heriot-Watt Univ. (United Kingdom); C. R. Cunningham, UK Astronomy Technology Ctr. (United Kingdom)

The Ultrafast Laser Inscription (ULI) of glass is a process where a high peak power laser is used to modify the refractive index of glass allowing complex three-dimensional waveguide structures to be made. Recently ULI is being developed to manufacture Astrophotonics devices such as fibre gratings and multi-mode to single mode couplers. This paper describes the initial results of a project to investigate the use of ULI to generate volume phase grating structures. A volume phase grating generated using ULI has the potential to be manufactured in a variety of substrate materials. The ULI process also provides freedom to produce complex diffractive patterns or blazed gratings.

A number of prototype gratings with 333 lines per mm were manufactured in Fused Silica and Gallium Lanthanum Sulphide substrates. The gratings were tested to measure their diffraction efficiency and scattered light performance. The best Fused Silica grating had first diffraction order peak efficiency of 37 % at 633 nm but produced approximately 40 % integrated scattered light. The Gallium Lanthanum Sulphide gratings exhibited considerable better performance with first diffraction order peak efficiency of 75 % at 633 nm and less than 5 % scattered light. The gratings produced are extremely robust and survive cooling to 20 K.

The paper will summarise the grating design and ULI manufacturing process and provide details of the diffraction efficiency performance and blaze curves for the prototype ULI gratings.

8450-106, Session 16

Novel diffraction gratings fabricated by means of plasma nanotechnologies

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A VPH (Volume Phase Holographic) grating achieves very high diffraction efficiency up to 100% for S or P polarized light at the first diffraction order. However diffraction efficiency of the VPH grating for non-polarized light becomes low according as Bragg angle becomes large, and bandwidth of diffraction efficiency becomes narrow according as refractive index modulation of grating lattice becomes small. A volume phase binary grating with rectangular lattice, consists of high and low refractive index media with a large or small duty ratio, is able to achieve very high efficiency nearly 100% and a wide band width for both S and P polarization light.

We have successfully fabricated germanium immersion gratings of step groove shape with resolving power of 45,000 at 10 micron by using a nano-precision 3D grinding machine and ELID (ELectrolytic In-process Dressing) method. However the method requires a large amount of machine times and efforts. We had proposed a novel immersion grating with slot shape lattice of total reflection mirrors, which achieves high performance and lower fabrication cost.

We would introduce photolithography and the latest plasma nano-technologies for fabrications of the novel diffraction gratings in our presentation.

8450-107, Session 16

High-performance dielectric diffraction gratings for space applications

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Gratings are essential components in spectroscopic instruments of different earth-observation and scientific space missions. As space missions typically operate close to the technologically accessible limits also the realization of the respective gratings is extremely demanding. Among others the most critical parameters are typically the diffraction efficiency and its polarization dependency, the wave-front error introduced by the grating, stray-light performance, and usability in a space environment. All these properties need to be controlled precisely on sometimes rather large grating areas of several hundred square-centimeters.

Compared to classical grating fabrication techniques like ruling or interference lithography, the method of electron beam lithography is relatively new in the field. In the past e-beam written gratings often suffered from grating ghosts and very inefficient fabrication. As we will show in the current contribution, these drawbacks have been overcome by modern lithography tools and special writing regimes. Thus, the very high resolution and positioning accuracy of e-beam lithography can now be exploited for such high performance applications and offers extensive options for their optimization. In particular the transfer of modern concepts of highly efficient dielectric reflection gratings, initially developed for special laser applications, to spectroscopic applications becomes possible. Their special configuration composed of a dedicated dielectric layer stack and a well-controlled grating structure etched into its top-layer gives a huge design freedom to tailor the optical performance with respect to the above mentioned parameters.

Another example to be presented is the design and fabrication of the grating for the Radial-Velocity-Spectrometer of the GAIA-mission of the ESA which is based on an effective refractive index sub-wavelength structure.

8450-108, Session 17

Innovative technology for optical and infrared astronomy: an updated roadmap

C. R. Cunningham, C. J. Evans, UK Astronomy Technology Ctr. (United Kingdom); F. Molster, Leiden Univ. (Netherlands)

Advances in astronomy are often enabled by adoption of new technology. This can come through several routes. It can be invented specifically for astronomy, although that is actually quite rare. Often, it is adopted from another application area, either scientific or industrial. There are two processes for introduction and adoption of new technology: incremental by a series of small improvements; and disruptive, where a new technology completely replaces an older one. The OPTICON Key Technology Network has been carrying out a technology forecasting exercise for some years, as reported to previous SPIE Astronomy meetings. We report on the outcomes of a series of workshops, with particular emphasis on a recent event focussing on radical, potentially disruptive technologies.

8450-109, Session 17

Recent advances in diffractive optics

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Diffraction is the change of direction of the propagation of light energy, due to spatial variations of the refractive index. Diffraction can be a nuisance such as in imaging and scanning where it detemines the ulitmate limit of resolution. It can however also be exploited such as in spectroscopy or realize optical elements that redirect light in such a way that a desired intensity distribution is obtained. Recently, diffractive nanostructures with feature sizes of the order of the wavelngths have been applied in several applications. Diffraction grating structures and photonic crystals are used to the increase the absorption in solar cells and to enhance and redirect the emission from (O)LEDs. Diffractive structures in metals can be used to excite plasmon surface waves for highly sensitive sensing and extraordinary transmission. Furthermore, diffractive structures are applied to obtain subwavelength spots and hence to realize super-resolution in imaging. We shall discuss several examples of these modern applications of diffraction optics.

8450-110, Session 17

Extremely aspheric mirrors: prototype development of an innovative manufacturing process based on active optics

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The next generation of focal-plane astronomical instruments requires technological breakthroughs to reduce their system complexity while increasing their scientific performance. Applied to the optical systems, recent studies show that the use of freeform reflective optics, in the design phases, allows competitive compact systems, with less optical components. In this context, our challenge is to supply an active freeform mirror system, using a combination of different active optics techniques. The optical shape will be provided during the fabrication using the mechanical property of metals to plasticize and will be coupled with a specific actuator system to compensate for the residual form errors, during the instrument operation phase. We present the development of an innovative manufacturing process based on cold hydro-forming method, with the aim to adapt it for visible and infra-red requirements, in terms of optical surface quality. It can operate on thin and flat polished initial substrates. A first prototype, for a 100 mm diameter mirror, is realized to compare the mechanical behaviors obtained by tests and by Finite Element Analysis, for different materials. Then, the formed samples will be characterized optically. The opto-mechanical results will allow a fine tuning of FEA parameters to optimize the residual form errors obtained through this process. It concerns the microstructure considerations, the springback effects and the work hardening evolutions of the samples, depending on the initial substrate properties and the boundary conditions applied. Modeling and tests have started with axi-symmetric highly aspherical shapes and will continue with freeforms.

8450-111, Session 17

Fast figuring of large optics by reactive atom plasma

M. Castelli, R. Jourdain, P. Morantz, P. Shore, Cranfield Univ. (United Kingdom)

The next generation of ground-based astronomical observatories will require fabrication and maintenance of extremely large segmented mirrors tens of metres in diameter. At the present time, the production of thousands of segments required by projects like E-ELT and TMT poses time frames and costs feasibility questions. This is principally due to a bottleneck stage in the optical fabrication chain: the final figuring step. State-of-the-art figure correction techniques, so far, have failed to meet the needs of the astronomical community for mass production of large, ultra-precise optical surfaces. In this context, Reactive Atom Plasma (RAP) is proposed as a candidate figuring process that combines nanometre level surface figure correction accuracy with high material removal rates. RAP is a form of plasma enhanced chemical etching at atmospheric pressure based on Inductively Coupled Plasma technology. The rapid figuring capability of the RAP process has already been proven on medium sized optical surfaces made of silicon based materials. In this paper, the figure correction of a 3 metres radius of curvature 400mm diameter spherical surface of a mirror made of Corning ULE® material is presented. This result demonstrates the processing capability of the Reactive Atom Plasma process onto large scale optical surfaces. The figuring is carried out by applying an in-house developed procedure that promotes rapid convergence. A 2.5 µm p-v initial figure error is removed within three iterations, and for a total processing time of less than two hours. The residual error is reported as ~λ/20 rms. This result highlights the possibility of processing a metre-class mirror segment using the RAP process within ten hours.

Conference 8451: Software and Cyberinfrastructure for Astronomy II

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8451-01, Session 1

A next-generation open-source toolkit for FITS file image viewing

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The astronomical community has a long tradition of sharing and collaborating on FITS file tools, including viewers. Several excellent viewers such as DS9 and Skycat have been successfully reused again and again. Yet this “first generation” of viewers predate the emergence of a new class of powerful object-oriented scripting languages such as Python, which has quickly become a very popular language for astronomical (and general scientific) use. Integration and extention of these viewers by Python is cumbersome. Furthermore, these viewers are also built on older widget toolkits such as Tcl/Tk, which are becoming increasingly difficult to support and extend as time passes.

Subaru Telescope’s second-generation observation control system (Gen2) is built on a foundation of Python-based technologies and leverages several important astronomically useful packages such as numpy and pyfits. We have written a new flexible core widget for viewing FITS files which is available in versions for both the modern Gtk and Qt-based desktops. The widget offers seamless integration with pyfits and numpy arrays of FITS data. A full-featured viewer based on the Gtk version has been developed, and supports a plug-in architecture in which new features can be added by scripting simple Python modules. In this talk we will describe and demonstrate the capabilities of the new widgets and viewer and discuss the architecture of the software which allows new features and widgets to easily developed by subclassing a powerful abstract base class. The software will be released as open-source.

8451-03, Session 1

The science ground segment for the ESA Euclid Mission

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Euclid is the recently-approved M2 mission of the ESA Cosmic Vision 2015-2025 Plan, aimed at understanding the nature of dark energy and dark matter by accurately measuring the accelerated expansion of the Universe, using simultaneously two probes (weak lensing and baryon acoustic oscillations). The launch is planned in Q4 of 2019.

The success of the mission heavily relies on careful design and implementation of its ground segment facilities. The Science Operations Centre (SOC) operated by ESA and a number of Science Data Centres (SDCs) in charge of data processing, provided by a Consortium of 12 European countries, are the elements of the Euclid Scientific Ground Segment (SGS). ESA/SOC and the Euclid Consortium have developed, and are committed to maintain, a tight collaboration in order to design and develop a single, cost-efficient and truly integrated SGS.

The distributed nature of the data processing and of the collaborative software development, the data volume of the overall data set, and the needed accuracy of the results are the main challenges expected in the design and implementation of the Euclid SGS. In particular, the huge volume of data (not only Euclid data but also ground based data) to be processed in the SDCs will require a distributed storage to avoid data migration across SDCs. The leading principles driving the development of the SGS are expected to be the simplicity of system design, a component-based software engineering, virtualization, and a data-centric approach to the system architecture where quality control, a common data model and the persistence of the data model objects play a crucial role.

8451-04, Session 1

The VO-Dance web application at the IA2 Data Center

M. Molinaro, C. Knapic, R. Smareglia, INAF - Osservatorio Astronomico di Trieste (Italy)

IA2 (Italian Astronomical Archives, http://ia2.oats.inaf.it) data center is an INAF national infrastructure project that provides services for the astronomical community. It hosts instruments’ archives, LBT and TNG the main telescopes involved, providing user portals with proprietary and public data access, maintains portal mirrors from other projects (REM, BaSTI, ITVO), both from observational data and from theoretical simulations, and hosts data for resource’s publishing, from user portal development to VO (Virtual Observatory) services deployment. Archiving systems and web interfaces are developed to be extremely flexible about adding new instruments from other telescopes. Data publishing through the self standing portals is joined to VO resource publishing, i.e. astronomical resources deployed through VO compliant services (at present SIAP, Cone Searches, SSAP, TAP). Since the IVOA (International Virtual Observatory Alliance) provides many protocols and standards for the various data flavors (images, spectra, catalogues ...), and since the data center has as a goal to grow up in number of hosted archives and services providing, the idea arose to find a way to easily deploy and maintain VO resources. VO-Dance is a java web application developed at IA2 that addresses this idea creating, in a dynamical way, VO resources out of database tables or views. It is structured to be potentially DBMS and platform independent and consists of 3 main tokens: an internal DB to store resources description and model metadata information, a restful web application to deploy the resources to the VO community and an administrative interface to fill in the DB records.

8451-56, Session 1

Data mining and exploration resources for astronomy in the web 2.0 age

S. Cavuoti, Univ. degli Studi di Napoli Federico II (Italy); M. Brescia, INAF - Osservatorio Astronomico di Capodimonte (Italy); M. Annunziatella, M. Garofalo, M. Guglielmo, Univ. degli Studi di Napoli Federico II (Italy); A. Mercurio, INAF - Astronomical Observatory of Capodimonte (Italy); A. Nocella, M. Paolillo, G. Longo, Univ. degli Studi di Napoli Federico II (Italy)

The DaME (DAta Mining & Exploration) Program exposes a series of web-based services to perform scientific investigation on astronomical massive data sets. The infrastructure vision is based on an easier and efficient Knowledge Discovery in Databases (KDD) process, by making available, in a transparent way to the user, machine learning algorithms and data manipulation tools on top of an hybrid distributed computing platform, mixing CLOUD, GRID and GPU paradigms and by taking full advantage of the possibilities offered by Web 2.0 technology. Both technical description of the infrastructure and main scientific use case results are reported.

8451-05, Session 2

Distributed agile software development for the SKA

A. J. Wicenec, The Univ. of Western Australia (Australia); R. J. Parsons, ThoughtWorks, Inc. (United States); S. Kitaeff, The Univ. of Western Australia (Australia); P. Nelson, D. Reed, ThoughtWorks, Inc. (United States); K. Vinsen, C. Wu, The Univ. of Western Australia (Australia)

The SKA software will most probably be developed by many groups distributed across the globe and coming from different backgrounds, like industries and research institutions. The SKA software subsystems will have to cover a very wide range of different areas, but still they have to react and work together like a single system in order to be able to achieve the scientific goals and satisfy the challenging data flow requirements. Designing and developing such a system in a distributed fashion requires proper tools and the setup of an environment to allow for efficient detection and tracking of interface and integration issues in particular in a timely way. Agile development can provide much faster feedback mechanisms and also much tighter collaboration between the 'customer' (scientist) and the developer. Continuous integration and continuous deployment on the other hand can provide much faster feedback of integration issues from the system level to the subsystem developers. This paper describes a study for a potential SKA development environment based on existing science software development processes like ALMA, the expected distribution of the groups potentially involved in the SKA development and experience gained in the development of large scale commercial software projects.

8451-06, Session 2

Applying the agile organizing framework to astronomical software development

N. M. Radziwill, M. C. Benton, James Madison Univ. (United States)

Using a structured case study, the Agile Organizing Framework (AOF) was developed to provide an understanding of how and why agile methods work in practice. The AOF exposes agile enablers and agile inhibitors to illuminate the values and behaviors that can contribute to the success of an agile team. Because astronomical software development typically involves developing and integrating components and systems that are unique to an instrument, this presentation applies the AOF to this environment in two ways: for building software, and for teaching teams how to develop software in an agile way. Accomplishing these goals simultaneously requires 1) helping the team and the stakeholders find a way to change, adapt and learn at the same rate, 2) encouraging self-organization, and 3) stimulating continuous improvement while preserving the innovative environment. Practical examples from the AOF case studies will be provided to illustrate how the principles can be applied in the astronomical instrumentation environment, whether or not a software development manager is actively applying agile methods.

8451-07, Session 2

Discovery Channel Telescope software component template and state design: principles and implementation

P. J. Lotz, M. J. Lacasse, R. C. Godwin, Lowell Observatory (United States)

The Discovery Channel Telescope is a 4.3m astronomical research telescope in northern Arizona constructed through a partnership between Discovery Communications and Lowell Observatory. The control software for the telescope and observatory systems consists of stand-alone, state-based components that respond to triggers (external signals or internal data changes). Component applications execute on Windows, real-time, and FPGA targets. The team has developed a template for a system component, the implementation of which has yielded large gains in productivity, robustness, and maintainability. These benefits follow from the dependence of the template on common, well-tested code, allowing a developer to focus on application-specific particulars unencumbered by details of infrastructure elements such as communication, and from the separation of concerns the architecture provides, ensuring that modifications are straightforward, separable, and consequently relatively safe. We describe a repeatable design process for developing a state machine design, and show how this translates directly into a concrete implementation utilizing several design patterns, illustrating this with examples from components of the functioning active optics system. We also present a refined top-level state machine design and rules for highly independent component interactions within and between hierarchies that we propose offer a general solution for large component-based control systems.

8451-08, Session 2

Instrument control software development process for the multi-star AO system ARGOS

M. Kulas, J. L. Borelli, W. Gässler, Max-Planck-Institut für Astronomie (Germany); L. Barl, S. Rabien, Max-Planck-Institut für extraterrestrische Physik (Germany)

The ARGOS project (Advanced Rayleigh guided Ground layer adaptive Optics System) will upgrade the Large Binocular Telescope (LBT) with an AO System consisting of six Rayleigh laser guide stars.

This adaptive optics system integrates several control loops and many different instruments like lasers, calibration swing arms and slope computers that are spread all over the telescope.

The purpose of the instrument control software (ICS) is running this AO system and providing convenient user interfaces to the instruments and the control loops.

The challenges about the ARGOS ICS are the development of a distributed and safety-critical software system with no defects in a short time, the creation of huge and complex software programs with a maintainable code base, the delivery of software components with the desired functionality and the support of geographically distributed project partners.

To tackle these difficult tasks, the ARGOS software engineers reuse existing software like the novel middleware from LINC-NIRVANA, an instrument for the LBT, provide many tests at different functional levels like unit tests and regression tests, agreed about code and architecture style and deliver software incrementally while closely collaborating with the project partners.

Many ARGOS ICS components are already successfully in use in the laboratories for testing ARGOS control loops.

8451-09, Session 3

Data management for the EVLA

B. J. Butler, C. J. Chandler, National Radio Astronomy Observatory (United States)

The Expanded Very Large Array (EVLA) project is the next generation instrument for high resolution long-millimeter to short-meter wavelength radio astronomy. It is currently in early science operations, with full science operations to commence in January 2013. The EVLA construction project provided new software for all aspects of operation of the telescope, including both that required for controlling and monitoring the instrument and that involved with the scientific workflow. As the telescope transitions into full operations we are also developing the software and operations policies that allow us to manage the large amounts of data collected by the instrument (up to terabytes for a single observation; petabytes per year for all observations). We will present an overview of our data management software and policies for the EVLA, as well as some early experience we have gained with the storage and distribution of data, post-processing, automatic processing, and centralized reprocessing of data, and storage of derived products back into our science archive.

8451-10, Session 3

Design and capabilities of the MUSE data reduction software and pipeline

P. Weilbacher, O. Streicher, T. Urrutia, Leibniz-Institut für Astrophysik Potsdam (Germany); A. Jarno, A. Pécontal-Rousset, R. M. Bacon, Observatoire de Lyon (France)

MUSE, the Multi Unit Spectroscopic Explorer, is an integral-field spectrograph being constructed for the ESO VLT to see first light end of 2012. It can record spectra of a 1'x1' field on the sky at a sampling of 0.2"x0.2", over a wavelength range from 4650 to 9300 Angstrom. Data reduction for this instrument, presented in this paper, is the process which converts raw data from the 24 CCDs into a combined datacube (with two spatial and one wavelength axis), that is corrected for instrumental and atmospheric effects. Since the instrument is subdivided into many subunits (24 integral-field units, each slicing the light into 48 parts, i.e. 1152 regions with a total of almost 90000 spectra per exposure), this task consists of many steps and is computationally expensive, in terms of processing speed, memory usage, and disk input/output.

The data reduction software is designed to be mostly run as an automated pipeline and to fit into the open source environment of the ESO data flow as well as a database system based on AstroWISE. We describe the functionality of the pipeline, highlight details of new and unorthodox processing steps, discuss which algorithms and code could be used from other projects. Finally, we show the performance on both laboratory data as well as simulated scientific data.

8451-11, Session 3

Significantly reducing the processing times of high-speed photometry data sets using a distributed computing model

P. F. Doyle, F. Mtenzi, Dublin Institute of Technology (Ireland); N. Smith, Cork Institute of Technology (Ireland)

The scientific community is in the midst of a data analysis crisis. The increasing capacity of scientific CCD instrumentation and their falling costs is contributing to an explosive generation of raw photometric data. This data must go through a process of cleaning and reduction before it can be used for high precision photometric analysis. Many existing data processing pipelines either assume a relatively small dataset or are batch processed by a High Performance Computing centre. A radical overhaul of these processing pipelines is required to allow reduction and cleaning rates to process terra-byte sized datasets at near capture rates using an elastic processing architecture. The ability to access computing resources and to allow them to grow and shrink as demand fluctuates is essential, as is exploiting the parallel nature of the datasets. A distributed data processing pipeline is required. It must incorporate data compression, allow for data segmentation and support processing of data segments in parallel. Academic institutes can collaborate and provide an elastic computing model without the requirement for large centralised high performance computing data centres. Using these concepts this paper demonstrates how an order of magnitude increase in processing time has been achieved using a distributed computing architecture spanning multiple academic institutes. We propose that future photometry cleaning and reduction pipelines must embrace a distributed architecture and utilise an elastic resourcing model. This architecture will enable us to meet the challenge of processing terra-byte sized photometry datasets while being portable to other data reduction pipelines.

8451-12, Session 3

The Dark Energy Survey data processing and calibration system

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The Dark Energy Survey (DES) is a 5000 deg^2 grizY survey reaching characteristic photometric depths of 24th magnitude (10 sigma) and enabling accurate photometry and morphology of objects ten times fainter than in SDSS. Preparations for DES have included building a dedicated 3 deg^2 CCD camera (DECam), upgrading the existing CTIO Blanco 4m telescope and developing a new high performance computing (HPC) enabled data management system (DESDM).

The DESDM system will be used for processing, calibrating and serving the DES data. The data volumes are high (~4PB), and so considerable effort has gone into designing an automated processing and quality control system. Special purpose image detrending and photometric calibration codes have been developed to meet the data quality requirements, while survey astrometric calibration, coaddition and cataloging rely on new extensions of the AstrOmatic codes which now include tools for PSF modeling, PSF homogenization, PSF corrected model fitting cataloging and joint model fitting across multiple input images.

The DESDM system has been deployed on dedicated development clusters and HPC systems in the US and Germany. An extensive program of testing with small rapid turn-around and larger campaign datasets has been carried out, and acceptance testing is scheduled for Spring 2012. The system has also been tested on large real datasets, including the Mosaic2, CFHT Megacam and Pan-STARRS . In late Spring 2012 the DESDM system will be used for DECam commissioning, and in Fall 2012 the system will go into full science operations.

8451-13, Session 3

ALTEC DPC infrastructure and operations in support of the Italian participation to the Gaia data processing

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This paper will describe the design and the implementation of the Italian Data Processing Centre multi-tier software and hardware infrastructure built by ALTEC to support the Italian participation to the Gaia data processing tasks. In particular paper will focus on the software and hardware architectural choices done to manage both big data volume and complex operations scenarios. The DPCT system has been designed as an integrated system which will manage all data processing pipeline phases: data receiving, data processing, data extraction, data archiving

and data sending. In addition, the DPCT system includes also data access and analysis tools allowing Italian scientists to be active system users during operations.

8451-14, Session 3

Automated and generalized integral-field spectroscopy data reduction using p3d

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Integral-field spectrographs (IFS) are well suited instruments to observe extended and faint objects, such as planetary nebulæ and galaxies. A result of such observations are large quantities of raw data, which mostly require an expert to derive accurate scientific spectra. Most instruments handle up to several thousand spectra simultaneously, using a unique file format, together with numerous instrument-specific issues, which only an experienced expert can resolve. p3d is an open source processing tool that is designed to handle raw data of any fiber-fed IFS, reducing IFS data quickly, easily, and accurately. Separate tools are available that handle everything from cosmic-ray hit rejection in single spectrum images, the combination of images, tracing of spectra on the detector, determination of spatial profiles of any shape, handling of images for flat fielding, different versions of spectrum extraction, combination of multi-detector data, and correction for atmospheric differential refraction. The same approach and code is used with all instruments. No license is required when using p3d, even though it is based on the proprietary software IDL; this is made possible through pre-compiled binary files that are always distributed together with the source code. I will here present some of the latest capabilities of the nearly complete program.

8451-15, Session 4

INO340 Telescope control system architecture and development

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The Iranian National Observatory telescope (INO340) is a 3.4m Alt-Az reflecting optical telescope under design and development. It is f/11 Ritchey-Chretien with a 0.5° field-of-view. INO340 will be installed at Gargash summit (3617m) near Kashan, Iran and the first light is planned for 2016.

The INO340 control system utilizes a uniform and well-defined architecture that achieves to better system robustness, efficiency/performance, reliability and security. Besides improving system parameters, this architecture focuses on some important features for observation activities such as usability, remote observation, short service time, upgradability and extensibility. For this purpose distributed control through 4 different systems has been designed:

Telescope Control System (TCS) is responsible for the control of the telescope structure with its mirrors and dome.

Observation System provides user interfaces for loading observing configurations, observation scheduling, resource allocation and etc. It also includes Instrument Control System (ICS) which is responsible for control of instruments and science data management.

Interlock/Safety System (ILS) comprises all interlocks/safety related components required to guarantee person and equipment safety at the observatory.

Another system plays the monitoring role for the whole observatory: Observatory Monitoring System (OMS). In brief, the OMS includes logging and archiving system for all engineering, operation and performance data.

In this paper, we present the fundamental of the INO340 control system including high level architecture, operational modes, main sub-system design and interfaces, communication technologies, middle ware and front-end. It also includes the development plan of control system which addresses development process for different sub-systems, tasks, deliveries, schedule, and resource allocation.

8451-16, Session 4

Development of the ACS+OPCUA-based control system for a CTA medium size telescope prototype

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The Cherenkov Telescope Array (CTA) is the next generation Very High Energy (VHE, defined as > 50 GeV to 100s of TeV) telescope facility, currently in the design and prototyping phase, and expected to come on-line around 2016. The array would have both a Southern and Northern Hemisphere sites, together delivering nearly complete sky coverage. The CTA array is planned to have ~100 telescopes of several different sizes to fulfill the sensitivity and energy coverage needs.

Each telescope has a number of subsystems with varied hardware and control mechanisms; a drive system that could be controlled with PLC via OPCUA, mirror alignment systems based on XBee/ZigBee protocol and/or CAN bus, weather monitor accessed via serial/Ethernet ports, CCD cameras for calibration, Cherenkov camera, and the data read out electronics, etc. Integrating the control and data-acquisitions of such a distributed heterogeneous system calls for a framework that can handle such a multi-platform, multi-protocol scenario. The CORBA based ALMA Common software (ACS) satisfies these needs very well and is currently being evaluated as the base software for developing the control system for CTA.

A prototype for a Medium Size Telescope (MST, ~12 m) is being developed and will be deployed in Berlin, by mid 2012. We present the development being carried out to integrate and control the various hardware subsystems of this MST prototype using ACS.

8451-17, Session 4

Software control of the Advanced Technology Solar Telescope enclosure PLC hardware using COTS software

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As PLCs evolve from simple logic controllers into more capable automation controllers (PACs), observatories are increasingly using such devices to control complex mechanisms. This paper describes use of COTS software to control such hardware using the Advanced Technology Solar Telescope (ATST) Common Services Framework (CSF). We present the Enclosure Control System (ECS) currently under development in Spain and the UK.

The paper details selection of the commercial PLC communication library PLCIO. Implemented in C and delivered with source code, the library separates the programmer from PLC communication details through a simple API. Capable of communicating with many types of PLCs (including Allen-Bradley and Siemens) the API remains the same irrespective of the PLC in use.

The ECS is implemented in Java using the observatory's framework that provides common services for software components. We present a design following a connection-based approach where all components access the PLC through a single connection class. The link between Java and PLCIO C library is provided by a thin Java Native Interface (JNI) layer. Also presented is a hardware simulator based upon the PLCIO Virtual PLC. This creates a simulator operating below the library's API and thus requires no change to ECS software. It also provides enhanced software testing capabilities prior to hardware becoming available.

Results are presented in the form of communication timing test data, showing that the use of CSF, JNI and PLCIO provide a control system capable of controlling enclosure tracking mechanisms, that would be equally valid for telescope mount control.

8451-18, Session 4

Simultaneous control of multiple instruments at the ATST

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The Advanced Technology Solar Telescope (ATST) is a 4-meter solar observatory under construction at Haleakala, Hawaii. The simultaneous use of multiple instruments is one of the unique capabilities that makes the ATST the premier ground based solar observatory. Control of the instrument suite is accomplished by the Instrument Control System (ICS), a layer of software between the Observatory Control System (OCS) and the instruments. The ICS presents a single narrow interface to the OCS and provides a standard interface for the instruments to be controlled. It is built upon the ATST Common Services Framework (CSF), a set of software components and tools for the implementation of a distributed control system.

The ICS responds to OCS commands and events, coordinating and distributing them to the various instruments while monitoring their progress and reporting the status back to the OCS. The ICS requires no specific knowledge about the instruments. All information about the instruments used in an experiment is passed by the OCS to the ICS, which extracts and forwards the parameters to the appropriate instrument controllers. The instruments participating in an experiment are managed in two groups: those instruments whose participation is critical to the experiment and those instruments whose participation is not critical to the experiment. In addition, instruments may participate in eavesdrop mode, outside of the control of the ICS.

All instrument controllers use the same standard narrow interface, which allows new instruments to be added without having to modify the interface or any existing instrument controllers. A simple proxy controller is provided for support of visitor instruments. The degree to which the visitor instrument implements the abstract methods provided in the proxy determines the level of facility-like control they receive.

8451-19, Session 4

The STELLA robotic observatory on Tenerife

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The STELLA project is made up of two 1.2m robotic telescopes to simultaneously monitor stellar activity using a fiber-fed high-resolution echelle spectrograph on one telescope, and an wide-field imaging instrument on the other telescope. The STELLA Echelle spectrograph (SES) along with the building has been in operation successfully since 2006, and is producing spectra covering the visual wavelength range between 390 and 900 nm at a resolution of 55 000. The stability of the spectrograph over the entire two year span, measured by monitoring 15 radial velocity standard stars, is 30 to 150 m/s rms. The wide-field stellar imager and photometer (WIFSIP) was put into operation in 2010, when the SES-lightfeed was physically moved to the second telescope. We report on the efficiency of the use of our STELLA control system software. Both the observatory control system and the individual instrument and telescope control systems are run in unattended mode. The internet link its used for monitoring the health status of the observatory, upload new observing programs, and to download the data on a daily basis.

8451-02, Poster Session

The EMIR experience in the use of software control simulators to speed up the time to telescope

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One of the main problems facing development teams working on instrument control systems consists on the need to access mechanisms which are not available until well into the integration phase. The need to work with real hardware creates additional problems like, among others: certain faults can not be tested due to the possibility of hardware damage, taking the system to the limit may shorten its operational lifespan and the full system may not be available during some periods due to maintenance and/or testing of individual components.

These problems can be treated with the use of simulators and by applying software-hardware standards. Since information on the construction and performance of electro-mechanical systems is available at relatively early stages of the project, simulators are developed in advance (before the existence of the mechanism) or, if conventions and standards have been correctly followed, a previously developed simulator might be used.

This article describes our experience in building software simulators and the main advantages we have identified, which are: the control software can be developed even in the absence of real hardware, critical tests can be prepared using the simulated systems , test system behavior for hardware failure situations that represent a risk of the real system, and the speed up of in house integration of the entire instrument. The use of simulators allows us to reduce development , testing and integration time.

8451-57, Poster Session

More flexibility in representing geometric distortion in astronomical images

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There are a number of popular software tools in the public domain that are used by astronomers, professional and amateur alike, but some of the tools which have similar purposes cannot be easily interchanged. For example, SCAMP and SExtractor, available from www.astromatic.net, perform astrometric calibration and source-object extraction on image data, and image-data geometric distortion is computed in celestial coordinates with polynomial coefficients stored in the FITS header with the PV keywords. Another successful astrometric-calibration package, Astrometry.net, solves for distortion in pixel coordinates using the SIP convention that was introduced by the Spitzer Science Center. Up until now, due to the complexity of these distortion representations, it was very difficult to interchange these packages. New Python software, along with faster-computing C-language translations, have been developed at the Infrared Processing and Analysis Center (IPAC) to convert FITS-image headers from PV to SIP and vice versa. It is now possible to straightforwardly use Astrometry.net for astrometric calibration and then SExtractor for source-object extraction. The new software also enables astrometric calibration by SCAMP followed by image visualization with tools that support SIP distortion, but not PV. The software has been incorporated into the image-processing pipelines of the Palomar Transient Factory, which generate FITS images with headers containing both distortion representations. The software will also handle the

proposed TPV distortion polynomials, thus permitting conversion of archived images, such as from the Spitzer Heritage Archive and NASA/IPAC Infrared Science Archive, from SIP to PV or TPV.

8451-58, Poster Session

Network infrastructure to support dynamic system reconfiguration in ALMA

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ALMA is the first astronomical project being constructed and operated under industrial approach due to the huge amount of elements involved. In order to achieve the maximum through put during the engineering and scientific commissioning phase, several production lines have been established to work in parallel. This decision required modification in the original system architecture in which all the elements are controlled and operated within a unique Standard Test Environment (STE). The advance in the network industry and together with the quick maturing of virtualization paradigm allowed us to provide a solution, which can replicate the STE infrastructure without changing their network address definition. This is possible with Virtual Routing and Forwarding (VRF) and Virtual Lan (VLAN) concepts. The solution allows dynamic reconfiguration of antennas and other hardware across the production lines with minimum time and zero human intervention in the cabling. We also push virtualization concept even further, classical rackable servers are being replaced and consolidated in blade system. Virtualized servers are administrated with VMWare ESXi. With this approach hardware costs and system administration effort has been reduced considerably. This mechanism has been established and operated successfully during the last two years. This experience gave us confidence to propose a solution to divide the main array into sub-arrays using the same concept which will introduce huge flexibility and efficiency in ALMA daily operations and eventually will simplify the complexity of ALMA core observing software.

8451-59, Poster Session

Software latency test of the LINC-NIRVANA wavefront-sensor system

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LINC-NIRVANA is an imaging Fizeau interferometer, for use in near infrared wavelengths, being built for the Large Binocular Telescope. Multi-conjugate adaptive optics (MCAO) increases the sky coverage and the field of view over which diffraction limited images can be obtained. For its MCAO implementation, Linc-Nirvana utilizes four total wavefront sensors; each of the two beams is corrected by both a ground-layer wavefront sensor (GWS) and a high-layer wavefront sensor (HWS). The GWS controls the adaptive secondary deformable mirror (DM), which is based on an DSP slope computing unit. Whereas the HWS controls an internal DM via computations provided by an off-the-shelf multi-core Linux system. Using wavefront sensor data collected from a prior lab experiment, we have shown via simulation that the Linux based system is sufficient to operate at 1kHz, with jitter well below the needs of the final system. Based on that setup we tested the data throughput and latency introduced by the current software implementation of the AO loop. We will present our loop control structure and the results of those performance tests

8451-60, Poster Session

Reflector adjustment for large radio telescope based on active optics

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The reflector deformation caused by gravity, temperature, humidity, wind loading and so on can reduce the global performance of the large radio telescope. In this paper, considering the characteristics of active reflector of a 13.7 m millimeter-wave telescope a novel reflector adjustment method based on active optics has therefore been proposed to realize on-line collecting of a huge amount of actuators' status and the control of the active surface through the communication between active surface computer and intelligent controller based on Controller Area Network, which estimate and control the real time active surface figure at any elevation angle, reduces or eliminates the adverse effects of the reflector deformation to increase the resolution and sensitivity of the telescope due to the more radio signal collected. The actuator is driven by a stepper motor and controlled by an embedded intelligent controller.

8451-61, Poster Session

A mask quality tool for the OSIRIS multi-object spectrograph

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OSIRIS multi object spectrograph uses a set of user-customised-masks, which are manufactured on-demand. The manufacturing process consist of drilling the specified slits on the mask with the required accuracy. Ensuring that slits are on the right place when observing is of vital importance.

We propose a tool for checking the quality of the process of manufacturing the masks which is based on testing the instrument images obtained with the manufactured masks on place . The tool extracts the slit information from these images, performs a matching operation to relate specifications with the extracted slit information ,and finally it evaluates a comparation operation which tells the operator if the manufactured mask fullfills the mask designer expectations. The proposed tool has been quickly built using scripting languages and reusing standard libraries such as opencv, pyraf and numpy. The software architecture, advantages and limits of this tool in the lifecycle of a multiobject acquisition are presented.

8451-62, Poster Session

ALMA software regression tests: the evolution under an operational environment

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The ALMA software is a large collection of software modules, which implements the functionality needed for the observatory day-to-day operations, including among others Array/Antenna Control, Correlator, Telescope Calibration and Data Archiving. Many software patches must periodically be applied to fix problems detected during operations or to introduce enhancements into the system identified after a release has been deployed and used under regular operational conditions. Under this scenery, it has been imperative to establish, besides a strict configuration control system, a weekly regression test to ensure that modifications applied do not impact system stability. A test suite has been developed for this purpose, which reflects the operations performed by the commissioning and operations groups, and that aims to detect problems associated to the changes introduced at different versions of ALMA software releases. This paper presents the evolution of the regression test suite, which started at the ALMA Test Facility, and that has been adapted to execute it under the current operational conditions. Topics about the selection of the tests to be executed, the validation of the data obtained and the automation of the test suite will also be presented.

8451-63, Poster Session

ALMA operation support software and infrastructure

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The Atacama Large Millimeter /sub-millimeter Array (ALMA) will be a unique research instrument composed of at least 66 reconfigurable high-precision antennas, located at the Chajnantor plain in the Chilean Andes at an elevation of 5000 m. Each antenna contains instruments capable of receiving radio signals from 31.3 GHz up to 950 GHz. These signals are correlated inside a Correlator and the spectral data are finally saved into the Archive system together with the observation metadata. This paper describes the progress in the development of the ALMA operation support software infrastructure. The operation support software infrastructure aims to increase the efficiency of the testing, distribution, deployment and operation of the core observing software. It becomes critical as the core observing software is being used for Early Science operation while the construction has not finished yet.

In order to support and maintain the core observing software, it is essential to have a mechanism to align and distribute the same version of software packages across all systems. This is achieved rigorously with weekly-based regression tests and strict configuration control. A build farm to provide continuous integration and testing in simulation has been established as well. Given the large amount of antennas, it is imperative to have also a monitoring system to allow trend analysis of each component in order to trigger preventive maintenance activities. A challenge for which we are preparing this year consists in testing the whole ALMA software performing complete end-to-end operation, from proposal submission to data distribution to the ALMA Regional Centers. The experience gained during deployment, testing and operation support will be presented.

8451-64, Poster Session

Development of telescope control system for the 50cm telescope of the UC Santa Martina Observatory

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The main telescope of the UC Santa Martina Observatory is a 50cm optical telescope donated by ESO to Pontificia Univesidad Catolica de Chile. During the past years the telescope has been refurbished and used as the main facility for testing and validating new instruments under construction by the center of Astro-Engineering UC. As part of this work the need to develop a more efficient and flexible control system arises. The new distributed control system has been developed on top of Internet Communication Engine (ICE), a framework developed by Zeroc. This framework features a lightweight but powerful and flexible inter-process communication infrastructure and provides binding to classic and modern programming languages, such as, c/c++, java, c#, ruby-rail, objective c, etc. A classical control software architecture has been chosen which comprise an observation control system (OCS), the orchestrator of the observation, which controls the telescope control system (TCS), and detector control system (DCS). The real time control and monitoring system is deployed and running over ARM based single board computers. Other features such as logging and configuration services have been developed as well. Inter-operation with other main astronomical control frameworks are foreseen in order achieve a smooth integration of instruments when they will be integrated in the main observatories in the north of Chile. The result of this work will be presented in this paper which shows ICE as a real alternative for CORBA and other de facto distribute programming framework.

8451-65, Poster Session

The MUSE observation preparation tool

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MUSE (Multi Unit Spectroscopic Explorer) is an integral-field spectrograph which will be mounted on the Very Large Telescope (VLT). MUSE is being built for ESO by a European consortium under the supervision of the Centre de Recherche Astrophysique de Lyon (CRAL).

In this context, CRAL is responsible for the development of a dedicated software to help MUSE users prepare their observations. This software, called MUSE-PS, is based on the ESO SkyCat tool that combines visualization of images and access to catalogs and archive astronomical data. MUSE-PS has been developed as a plugin to SkyCat to add new features specific to MUSE observations.

In this paper, we present the MUSE observation preparation tool itself and especially its specific MUSE functionalities: definition of the the center and orientation of the MUSE field of view, selection of the VLT guide star for guiding the telescope, selection of Adaptative Optics (AO) reference star for the different MUSE modes of operations (Narrow Field Mode or Wide Field Mode, with or without AO).

We will also show customized displays for MUSE (zoom on specific area, help with MUSE mosaicing and generic offsets, finding charts, ...).

8451-66, Poster Session

Data management plan for the KMTNet project

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The Korea Astronomy and Space Science Institute (KASI) is developing three 1.6m optical telescopes with 18k x 18k mosaic CCD cameras. These telescopes will be installed and operated at Chile, South Africa, and Australia for Korea Micro-lensing Telescope Network (KMTNet) project. The main scientific goal of the project is to discover earth-like extra-solar planets using the gravitational micro-lensing technique. To achieve the goal, each telescope at three sites will continuously monitor the specific region of Galactic bulge with 2.5 minute cadence for five years. Assuming 12 hour observation in maximum for a night, the amount of 200 GB file storage is required for one night observation at one observatory. If we consider the whole project period and the data processing procedure, a few PB class data storage, high-speed network, and high performance computers are essential. In this paper, we introduce the KMTNet data management plan that handles gigantic data; raw image collecting, image processing, photometry pipeline, database archiving, and backup.

8451-67, Poster Session

On-board data handling of current and future IR space observatories

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The Herschel Space Observatory is in operation at L2 since three years with great success. One of its peculiar systems is the on-board compression and reduction software of the PACS instrument, which carries out various lossy and lossless reduction steps to ensure that the data fit into the downlink budget.

We take a look at the in-flight performance of the Herschel/PACS on-board data processing software, analyze the feasibility of an alternative compression scheme based on Compressed Sensing and its impact on

the map-making process on ground.

With an on-board software platform for upcoming missions in mind we show which software modules can be carried over from PACS to new projects such as EChO and SPICA/SAFARI. We outline additional functionalities that are being developed for the new missions and point out problem areas for on-board data handling at present.

8451-68, Poster Session

HARPS-N: software path from the observing block to the image

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HARPS North is the twin of the HARPS (High Accuracy Radial velocity for Planetary Search) instrument (located on the 3.6m ESO telescope at the La Silla observatory in Chile) built for being installed in 2012 on the TNG in La Palma observatory and used to follow-up, by radial velocity, the “hot” candidates delivered by the Kepler satellite.

HARPS-N is delivered with its own software that completely integrates with the TNG control system. A special care has been dedicated to develop tools that will assist the astronomers during the whole process of taking images: from the observation schedule to the real image acquisition.

Following the workflow of the observation operations, we present: Short Time Scheduler, which is the observation preparation tool, Sequencer - the core of the instrument control SW, TCS - the fully automated telescope operating system and UCAM - the detector operating system.

The software main goal is to provide a stable and reliable system. For this reason it has been developed keeping in mind concepts like failover and high-availability. HARPS-N is made of heterogeneous systems, from normal computer to real-time systems, that’s why the standard message queue middleware (ActiveMQ) was chosen to provide the communications between different processes.

The path of operations starting with the Observing Blocks and ending with the FITS frames is fully automated and could allow, in the future, the completely remote observing runs optimized for the time and quality constraints.

8451-71, Poster Session

Research of simulation framework for telescope wireless networks control system

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With increasing aperture of telescope, telescope control system (TCS) becomes more and more complicated. It is challenge for very large or large telescope control system because TCS contains thousands of controlled objects. TCS using Wireless Networks Control System (WNCS) is a trend. The main attraction of WNCS include: cost effectiveness, convenience, flexibility, tetherless access to the information infrastructure. While wireless networks is always subject to physical and environmental conditions like interference which can lead to latency and packet loss. In the telescope WNCS, there is still a gap between the modeled and real-life designs. Building a distributed control system supported by wireless networks is a challenging task that requires a new design and simulation approach.

Simulation is a powerful technique that can be used at several stages of WNCS development. To capture both the system dynamics and wireless network communication events, to depict the real WNCS accurately, co-simulation platform must be developed. The simulation platform consists of wireless networks simulation sub-system, actuator simulation sub-system, control simulation sub-system and interface sub-system. The wireless networks connect the controllers and the plant. The co-simulation framework can help TCS designer understand and improve the performance of the control system.

This paper has described a co-simulation framework for telescope wireless networks control system. Co-simulation platform captures both the system dynamics and communication events, can help telescope WNCS designer optimize the design of telescope control system and improve the performance of the TCS.

8451-72, Poster Session

Toolkit of automated database creation and cross-match

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Astronomy steps into a fullwave and data-avalanche era. Astronomical data is measured by Terabyte, even Petabyte. How to save, manage, analyze so massive data is an important issue in astronomy. In order to let astronomers free of the data processing burden and expert in science, various valuable and convenient tools (e.g. Aladin, VOSpec, VOPlot) are developed by VO projects. To suit this requirement, we develop a toolkit to realize automated database creation, automated database index creation and cross-match. The toolkit provides a good interface for users to apply. The cross-match task may be implemented between local databases, remote databases or local database and remote database. The large-scale cross-match is also easily achieved. Moreover, the speed for large-scale cross-match is rather satisfactory.

8451-73, Poster Session

MUSE instrumentation software

G. Zins, Lab. d’Astrophysique de l’Observatoire de Grenoble (France)

Multi Unit Spectroscopic Explorer (MUSE) is a second-generation VLT panoramic integral-field spectrograph whose prime objective is the understanding of the young galaxy formation and their evolution processes. The instrument is a large assembly of 24 identical high performance integral field units, each one composed of an image slicer, a spectrograph and a 4kx4k detector. It is assisted by the VLT ground layer adaptive optics ESO facility, named GALACSI, using four artificial laser guide stars (LGS) feeding the instrument with diffraction limited images at visible wavelengths.

MUSE Instrumentation Software (MUSE INS) is the software devoted to the control of all devices belonging to instrument; Atmospheric Dispersion Corrector (ADC), derotator, calibration lamps, shutters, etc. Moreover, it implements the slow guiding system, used to remove effects of differential drifts between telescope guide probe and instrument, which consists in tracking a set of auto-selected guide stars, to reach high image stability (<0.03 arcsec RMS stability). It also includes an advanced and user-friendly GUI to display all detector raw data as well as the on-line reconstructed images allowing users to assess the quality of the data in real time. It also implements all the observing, calibration and maintenance procedures, the interactive GUIs, and manages the software interfaces with the VLT facilities and the data flow management system.

In this paper we report the software design and describe the developed tools which provide the astronomer with an efficient support for operating this complex instrument at the telescope.

8451-74, Poster Session

SPHERE instrumentation software: a progress report

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SPHERE INS is the software devoted to the control of the SPHERE "Planet Finder Instrument". SPHERE is a second generation instrument for the VLT whose prime objective is the discovery and study of new extrasolar giant planets orbiting nearby stars. The instrument is currently being assembled and is expected to undergo Preliminary Acceptance in Europe in mid-2012.

SPHERE INS, besides controlling the instrument functions, implements all observation, calibration and maintenance procedures. It includes on-line data reduction procedures, necessary during observations and calibrations, as well as quick-look procedures that allow monitoring the status of ongoing observations. SPHERE INS also manages the external interfaces with the VLT Telescope Control Software, the High-level Observing Software and the Data Handling System. It provides both observing and engineering graphical user interfaces.

In this paper we give a brief review of the SPHERE INS design.

We then report about the current status of the software, the activities concerning its integration with the Instrument and the testing and validation procedures.

8451-75, Poster Session

Remote monitoring and fault recovery for FPGA-based field controllers of telescope and instruments

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As the increasing scale and more and more functions , modern telescopes have widely used the control architecture, i.e. central control unit plus field controller. FPGA-based field controller has the advantages of field programmable, which provide a great convenience for modifying software and hardware of control system. It also gives a good platform for implementation of the new control scheme. Because of multi-controlled nodes and poor working environment in scattered locations, reliability and stability of the field controller should be fully concerned.

This paper mainly describes how we use the FPGA-based field controller and Ethernet remote to construct monitoring system with multi-nodes. When failure appearing, the new FPGA chip does self-recovery first in accordance with pre-recovery strategies. In case of accident, remote reconstruction for the field controller can be down through network intervention if the chip is not be restored. This paper also introduces the network remote reconstruction solutions of controller, the system structure and transport protocol as well as the implementation methods. The idea of hardware and software design is given based on the FPGA. After actual operation on the large telescopes, desired results have been achieved. The improvement increases system reliability and reduces workload of maintenance, showing good application and popularization.

8451-76, Poster Session

Commissioning the VST telescope control software

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Although the VST telescope control software is based on the heritages of the other ESO Paranal telescopes, there is almost no module which has not been at least customized for the specific system. This paper reviews the lessons learned during commissioning in terms of advantages and disadvantages coming from the reuse of the VLT and ATs software.

8451-77, Poster Session

Using ODGWs with GSAOI: software and firmware implementation challenges

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The Gemini South Adaptive Optics Imager (GSAOI) has recently been commissioned on the Gemini South telescope. Designed for use with the Gemini GeMS multi-conjugate adaptive optics system, GSAOI makes use of the HAWAII-2RG On-Detector Guide Window (ODGW) feature where guide windows positioned in each of the four H2RG detectors provide GeMS with tip-tilt and flexure corrections. This paper concentrates on the complex software and firmware required for operating the ODGWs and for delivering the performance required by GeMS. Procedures for handling the interleaving of ODGW data with science data readouts are described. Data quality issues arise from the detector reset phase. We discuss how these impose a particular readout scheme that avoids science exposure artefacts. Detector defects, such as hot-pixels, complicate guide-star centroiding. We describe the centroiding algorithms that have been adopted. Software architecture, algorithms, performance and the implementation platform for the current on-telescope solution are detailed.

8451-78, Poster Session

Cure-WISE: HETDEX data reduction with Astro-WISE

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The Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) is a blind spectroscopic survey to map the evolution of dark energy using Lyman-alpha emitting galaxies as tracers. The survey instrument, VIRUS, consists of 75 IFUs distributed across the 22-arcmin field of the upgraded 9.2-m HET. Each exposure gathers 33,600 spectra. Over the projected five year run of the survey we expect about 150 GB of data per night. For the data reduction we developed the cure pipeline. Cure is designed to automatically find and calibrate the observed spectra, subtract the sky background, and detect and classify different types of sources. Cure employs rigorous statistical methods and complete pixel-level error propagation throughout the reduction process to ensure poisson-limited performance and meaningful significance values.To automate the reduction of the whole dataset we implemented the cure pipeline in the Astro-WISE framework. This integration provides for HETDEX a database backend with complete dependency tracking of the

various reduction steps, automated checks, and a searchable interface to the detected sources. It can be used to create various web interfaces for data access and quality control. Astro-WISE allows us to reduce the data from all the IFUs in parallel on a compute cluster. This cluster allows us to reduce the observed data in quasi real time and still have excess capacity for rerunning parts of the reduction. Finally, the Astro-WISE interface will be used to provide access to reduced data products to the general community.

8451-79, Poster Session

Multiple guide star acquisition software for LINC-NIRVANA

T. Bertram, Max-Planck-Institut für Astronomie (Germany)

LINC-NIRVANA is the near-infrared interferometric imaging camera for the Large Binocular Telescope. Once operational, it will provide an unprecedented combination of angular resolution, sensitivity and field of view. Its layer-oriented MCAO systems (one for each arm of the interferometer) are conjugated to the ground layer and an additional layer in the upper atmosphere.

The wavefront sensors can use up to 12 natural guide stars for wavefront sensing. Up to 12 opto-mechanical units have to be accurately positioned to coincide with the positions of the natural guide stars in the focal plane. A positioning software will coordinate the motion of these units. It has to fulfill a number of requirements: Collisions between the opto-mechanical units have to be prevented at any time. The units shall be positionable as close as possible to each other without touching their neighbors. To reduce the acquisition overhead, the units shall move in parallel. Different positioning modes have to be supported: Guide star acquisition, but also positioning model corrections and common offsets will be commanded.

In this presentation we will outline the requirements and use cases of the positioning software. The logic that will be used to prevent collisions will be discussed as well as the algorithm that can be used to assign the opto-mechanical units to the guide stars.

8451-80, Poster Session

OpenROCS: a software tool to control robotic observatories

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We present the Open Robotic Observatory Control System (OpenROCS), an open source software platform developed for the robotic control of telescopes. It acts as a software infrastructure that executes all the necessary processes to implement responses to the system events and alarms that appear in the routine and non-routine operations associated to data-flow and housekeeping control. The OpenROCS software design and implementation provides a high flexibility to be adapted to different observatory configurations and event-action specifications. It is based on an abstract model that is independent of the specific hardware or software and is highly configurable. Interfaces to the system components are defined in a simple manner to achieve this goal. It has a modular architecture developed in PHP and XML configuration files, and uses standard communication protocols to interface with applications for hardware monitoring and control, environment monitoring, scheduling of tasks, image processing and data quality control.

We give a detailed description of the software and we provide two examples of how it is used as the core element of the control system in two robotic observatories: the Joan Oró Telescope at the Montsec Astronomical Observatory (Catalonia, Spain) and the SuperWASP Qatar Telescope at the Roque de los Muchachos Observatory (Canary Islands, Spain).

8451-82, Poster Session

The 3.6 m Indo-Belgian Devasthal Optical Telescope: the control system

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AMOS SA has been awarded of the contract for the design, manufacturing, assembly, tests and on site installation (Devasthal, Nainital in central Himalayan region) of the 3.6 m Indo-Belgian Devasthal Optical Telescope (IDOT).

This paper describes the architecture deployed for the whole telescope control. It contains, in others, the Telescope Control System (TCS), the Active Optic System (AOS) and the Auto Guiding Unit (AGU). The TCS generates the telescope axes trajectory from the celestial coordinates selected by the operator and drives the main axes. The AOS generates the force set points for each M1 actuator and the position set point of the M2 hexapod from the data given by a wave front sensor. The AGU sends the main axes corrections from the movement of the guide star on the guiding CCD. The modules shall communicate between them to optimize the telescope behavior and with the Observatory Control System (OCS) for data reporting and synchronization with the instrument.

8451-83, Poster Session

Technical solutions in preparing data for the Keck Obervatory archive

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The Keck Observatory Archive (KOA), which began curating and serving data in 2004, was developed many years after the W. M. Keck Observatory (WMKO) came into operations. Since much of the data produced from instruments on the twin Keck telescopes were never designed with the archive in mind, the metadata contained in the original FITS headers were not adequate for proper archiving. Some examples of the challenges facing the process of making the data suitable for archiving include: assigning data to the correct owner and program, especially on split nights, distinguishing science files from calibration files, and identifying the type of calibration. We present some software techniques that prepare and evaluate the data, adding content to the FITS headers and "retrofitting" the metadata in order to support archiving Keck legacy data. We also describe tools developed to ensure a smoother ingestion of data for current and future instruments. We present briefly our method for controlling and monitoring the data transfer between WMKO in Hawaii and the NASA Exoplanet Science Institute (NExScI) in California, where the data are physically hosted.

8451-84, Poster Session

Verification of the LINC-NIRVANA derotation control software

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LINC-NIRVANA is the near-infrared interferometric imaging camera for the Large Binocular Telescope. Once operational, it will provide an unprecedented combination of angular resolution, sensitivity and field of view.

Its layer-oriented multi-conjugate adaptive optics systems (MCAO) consist of two ground layer wavefront sensors and two high layer wavefront sensors. Due to geometrical constraints, field rotation has to be compensated for each of the four wavefront sensors and for the science detector individually. The fields of the high layer wavefront sensors are derotated by the use of K-Mirrors, whereas the ground layer wavefront sensors and the science detector can be rotated themselves. All these derotator subsystems use the same software base for their motion control, with different requirements on timing and positioning

accuracy.

One K-Mirror is integrated into a laboratory setup at MPIA, which comprises the full optical path of the high-layer adaptive optics system. One ground layer wavefront sensor will be tested on the LINC-NIRVANA optical bench. The science detector hardware is available for cryogenic tests of the detector derotation mechanism. On all of these test platforms the derotator control software is tested and verified. In this paper we will present the whole derotator package with its requirements, the corresponding hardware, the derotator service, and the results of the verification tests.

8451-86, Poster Session

OPERA: open source pipeline for ESPaDOnS reduction and analysis

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OPERA is a Canada France Hawaii Telescope open source collaborative software development project for an ESPaDOnS echelle spectro-polarimetric image reduction pipeline. OPERA is designed to be fully automated performing calibrations and reduction producing one-dimensional intensity and polarimetric spectra. While primarily designed around CFHT data, the pipeline is being written to be extensible to other echelle spectrographs. A primary design goal is to make use of fast, modern object-oriented technologies. Processing is controlled by a harness, which manages a set of processing step modules, that make use of a collection of native OPERA libraries and standard external libraries. The harness and modules are completely parametrized by site configuration and instrument parameters. The software is open-ended, permitting users of OPERA to extend its capabilities. All these features have been designed to provide a portable infra structure that facilitates collaborative development, code re-usability and extensibility. OPERA is free software and is designed to be easily ported to Linux or OSX platforms. The pipeline is hosted on SourceForge under the name opera-pipeline. The OPERA team is keen to discuss the possibility of involvement and collaboration with other instruments/observatories.

8451-87, Poster Session

MESA: Mercator scheduler and archive system

F. Merges, S. Prins, Mercator Telescope (Spain) and Katholieke Univ. Leuven (Belgium); W. Pessemier, G. Raskin, Katholieke Univ. Leuven (Belgium); J. Perez Padilla, Mercator Telescope (Spain); H. Van Winckel, Katholieke Univ. Leuven (Belgium)

We have developed an observing scheduling and archive system for the 1.2 meter Mercator Telescope. The goal was to optimise the specific niche of this modern small telescope in observational astrophysics: the building-up of long-term timeseries of photometric or high-resolution spectroscopic data with appropriate sampling for any given scientific program.

This system allows PIs to easily submit their technical requirements and keep track of the progress of the observing programmes. The scheduling system provides the observer a near-optimal real-time schedule taking into account the current observing conditions, and the priorities and requirements of the programmes in the queue, thus making it very convenient to plan an observing night and to quickly adapt to changing conditions. The archiving system automatically processes new files as they are created, including reduced data, extracting metadata and normalizing it. A user can query, inspect and retrieve observing data at any time and see the progress of individual programmes, including timeline and reduced data plots. MESA is based on free and open source software (FOSS) using Python programming language. The system is fully integrated with the MOCS observing control system.

8451-88, Poster Session

Service-oriented architecture for the ARGOS instrument control software

J. L. Borelli, Max-Planck-Institut für Astronomie (Germany); L. Barl, Max-Planck-Institut für extraterrestrische Physik (Germany); W. Gässler, M. Kulas, Max-Planck-Institut für Astronomie (Germany); S. Rabien, Max-Planck-Institut für extraterrestrische Physik (Germany)

The Advanced Rayleigh guided Ground layer adaptive Optics System, ARGOS, equips the LBT with a six rayleigh laser guide star system and a wavefront sensing facility.

The instrument control software has the complex task to orchestrate several devices, control loops, including vibration and flexure compensation, and high-level services, such as the already existing adaptive optics system and telescope control software.

The approach used by the ARGOS software engineers is to develop a distributed control system based on loosely-coupled services which are under the responsibility of different ownership systems.

This service-oriented architecture provides an uniform mechanism to start, offer, discover, and reuse these distributed services.

The design, implementation, and functionality of the main ARGOS control software are presented in this paper.

8451-89, Poster Session

SDAI: a key piece of software to manage the new wide band backend at Robledo

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Recently, a new wide band backend for Radio Astronomy at the NASA's Robledo tracking station was installed. From the hardware viewpoint, this backend consists on an IF processor and a set of FFT spectrometers, which manage thousands of spectroscopic channels in real time.

All these equipments need to be controlled and operated by a common software, which has to syncronize activities among affected devices, and also with the observing program. The final output should be a calibrated spectrum, readable by standard radio astronomical tools for further processsing.

The developed software at this end is named "Spectroscopic Data Acquisition Interface" (SDAI). SDAI is written in python 2.5, using PyQt4 for the User Interface. By an ethernet socket connection, SDAI receives astronomical information (source, frequencies, Doppler correction, etc.) and the antenna status from the observing program. Then it syncronizes the observations at the required frequency by tuning the synthesizers through their USB ports; finally SDAI controls the FFT spectrometers through UDP commands sent by sockets. Data are transmitted from the FFT spectrometers by TCP sockets, and written as standard FITS files.

8451-91, Poster Session

Confronting the numerical simulations of the VLT/MUSE instrument with the first real data

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The Multi Unit Spectroscopic Explorer (MUSE) instrument is a second-generation integral-field spectrograph in development for the Very Large Telescope (VLT), operating in the visible and near IR wavelength range

(465-930 nm). Given the complexity of MUSE we have developed a numerical model of the instrument, which includes the whole chain of acquisition from the atmosphere down to the telescope and including the detectors, and taking into account both optical aberrations and diffraction effects, by propagating a wavefront through the instrument, according to the Fourier optics concept. This simulator has been used to produce simulated exposures, in order to develop the data reduction software and to develop and validate the test procedures of the assembly, integration and tests phase. The MUSE instrument is currently being integrated in CRAL, and first real exposures have been taken. This paper compares and analyzes the differences between the real data and the numerical simulations, and describes the techniques used to improve the numerical model in order to match the real instrument.

8451-92, Poster Session

The future of TNG telescope control system

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TNG is going to present a new Telescope Control System following the new paths targeted for this medium size, ground based telescope.

The core of this new TCS is based on a new system and software architecture which allows the telescope to reach the new goals with a higher grade of efficiency, automation and flexibility.

In a nutshell, we present:

* New Core Architecture and Software Structures. They hold the new TCS based on messages queues and Java EE application Servers. Also, we present new telescope data structures wrapped on XML and HTTP.

* Telemetry Cache. It is a new telemetry subsystem to support the telemetry requests based on an in-memory cache.

* Observing Control Software (OCS). New telescope commander which sequences customized commands to the telescope.

* Observing Manager (OM). GUI Interface to monitor the status of the OCS.

These four points set the foundations for holding HARPS-N and forthcoming generation instruments to hook into the telescope.

8451-93, Poster Session

A simulation and testing framework for the Magdalena Ridge Observatory interferometer control system

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The Magdalena Ridge Observatory Interferometer (MROI) software system is a collection of hierarchically structured distributed systems, corresponding to the major functional divisions of the interferometer (Unit Telescope, Delay Line System, Automated Alignment System, etc.) managed by a centralized Supervisory System. Generic interface software, in Java or C, is automatically generated from spreadsheets that describe system-specific commands for each subsystem. This software communicates over gigabit Ethernet using a TCP/IP protocol that is independent of the subsystem implementation language. This code generation framework also generates a standalone test environment for each subsystem, including a GUI that can be used to enter the control commands. The spreadsheet can be used to specify configuration parameters and describe data to be monitored, collected, or logged. The subsystem is executable as a completely operational, standalone system. This framework can also be used to construct a comprehensive simulation environment that can be used to test new versions of the Supervisory System. The high-level interface software is described as well as the standalone test and simulation environment. This software will be used extensively in the construction phase of the interferometer, but we also expect it to be a permanent part of the MROI operations as future enhancements are developed.

8451-95, Poster Session

A standard framework for developing instrument controllers for the ATST

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The Advanced Technology Solar Telescope (ATST) is a 4-meter solar observatory under construction at Haleakala, Hawaii. The simultaneous usage of multiple instruments is one of the unique capabilities that makes the ATST the premier ground based solar observatory. Although the operation of the instruments and the data collected varies widely across the ATST instrument suite, the basic control functions and data recording capabilities are similar. Each instrument must be capable of controlling its devices, mechanisms, and hardware, interacting with the Instrument Control System (ICS), and saving science data. Because of these similarities, the ATST Software Group has developed the Standard Instrument Framework (SIF); a set of controllers that can be used to implement similar instrument controllers for all ATST instrumentation.

The SIF is built upon the ATST Common Services Framework (CSF) and includes controllers capable of interfacing with the ICS and managing other sub-controllers, managing multiple camera systems, coordinating the instrument mechanical mechanisms and hardware.. The key to this framework is the principle that each controller has a small well defined task and when the individual pieces are combined a complete and powerful control system may easily be implemented. Moreover, because most of the instruments for the ATST are being developed by partner institutions, the SIF allows for standardization of the instrument control systems throughout the instrument suite and reduced software development time for the partners. This will lead to significant code reuse and a smaller code base that will be easier to maintain.

8451-96, Poster Session

Software-centric view on the LINC-NIRVANA beam control concept

J. Trowitzsch, T. Bertram, Max-Planck-Institut für Astronomie (Germany)

The near-infrared interferometric imaging camera for the Large Binocular Telescope, LINC-NIRVANA, is fed by dedicated multi-conjugated adaptive optics systems and will provide an unprecedented combination of angular resolution, sensitivity, and field of view.

Tight requirements resulting from long exposure interferometric imaging over a large field of view need to be fulfilled. Both incoming beams have to coincide in the focal plane of the science detector. Their pointing origins, offsets, orientations, and plate scales have to match each other and must not change during observations. Therefore, an active beam control beyond fringe tracking and adaptive optics is essential. The beams need to be controlled along the complete optical path down to the combined focal plane.

This paper describes the beam control aspects from a software-centric point of view. We give an outline on the overall distributed control software architecture of LINC-NIRVANA. Furthermore, we center on the beam control specific features and related functionality as foreseen and implemented in the LINC-NIRVANA software packages.

8451-97, Poster Session

Database design of LAMOST data processing and production

Y. Guo, A. Luo, F. Wang, Z. Bai, J. Li, National Astronomical Observatories (China)

Before LAMOST spectra release, raw data need to go through a series of processes after being observed, including 2D reduction, spectral analysis, eyeball identification. It is a proper strategy that utilizing a database to integrate them. By reducing the coupling between relative modules, add/remove of them becomes more convenient, and the input/output will no longer purely depend on the file system. With the dataflow being more clear, information of a specific object, from target selection to intermediate results and spectrum production, can be efficiently accessed and traced back through the database search, rather than via fits reading. Furthermore, since the pipeline has not been perfected yet, it is inevitable to join the eyeball identification before the spectra are released, an appropriate database can make the feedback period of eyeball check result more conveniently, so that the improvement of pipeline will be more purposely. Finally, database can be a capable assistant for the statistics and analysis of massive astronomical data. This article focuses on the database design and the data processing flow built on this database for LAMOST. It will introduce the database design requirement of existing pipelines, such as input/output, the relationship/dependence between them. Accordingly, the database structure suited for multiple version data process and eyeball verification is presented. The dataflow, how the pipelines are integrated relied on such a dedicated database system and how they worked are also explained, as well as some user interfaces, statistical tools.

8451-98, Poster Session

OSIRIS software tools for multi-object spectroscopy

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This article presents an overview of the software applications developed to support the Multi Object Slit mode of the OSIRIS instrument. OSIRIS is an imager and spectrograph for the optical wavelength range, located in the Nasmyth-B focus of GTC. OSIRIS covers the wavelength range from 0.365 to 1.05 μm with a field of view of 7.8 x 8.5 arcmin (7.8 x 7.8 arcmin unvignetted), and 8 x 5.2 arcmin, for direct imaging and low resolution spectroscopy respectively.

OSIRIS multi object spectrograph uses a set of user-customised-masks, which are manufactured on-demand. We have been developing a software workbench that deals with the needs related to: observation preparation, mask design, mask manufacturing, mask quality , target acquisition and maintenance of multi-object tools. A brief description of how these applications work together is given.

8451-99, Poster Session

The improvement of CCD auto-guiding system for 2.5m telescope

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The CCD Auto-Guiding Star System is a significant part in the telescope control system for minimizing the tracking errors, and acquiring high-resolution data. In this paper, the improved algorithms of the off-axis CCD Auto-Guiding Star System is proposed and applied. Especially the de-rotator algorithm is added for the large-field Alt-Az Telescope to keep stars at original positions. The software that can communicate with the CCD camera is designed to rapidly, accurately and efficiently collect, analyze and process data, and then sent data to Alt-Az control system in real time less than 160ms. The algorithms are proved to be high-resolution and reliable for system, because the precision of star centroid is about 0.02 pixel. In addition, experiments showed that the software could work steadily in long time. Now the CCD Auto-guiding Star System has been successfully applied on the f/8 reflecting Alt-Az telescope with 2.5m aperture, 1-degree field of view, in Russia.

8451-100, Poster Session

Diving into the Sardinia Radio Telescope minor servo system

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The Sardinia Radio telescope (SRT) is a new 64 metres, gregorian-shaped antenna built in Sardinia (Italy). It is designed to carry out observations up to 100 GHz.

The telescope is provided with three focus positions: primary, gregorian and Beam Wave Guide.

This paper describes the project of the servo system which allows the focus and receiver selection during the instrument setup. This system also operates, at the observation stage, the compensation of some of the stucture deformations due to gravity, temperature variations and other environmental effects.

We illustrate the system features following a bottom-up approach, analysing all the project layers from low-level systems as the hardware controls to the design and implementation of high-level software, which is based on the distributed objects ACS (ALMA Common Software) framework.

Particular focus will be put on the links among the hierarchical levels of the system, and on the solutions adopted in order to guarantee that the control of the servo system is abstracted from the underlying hardware.

8451-101, Poster Session

The control software for the Sardinia Radio Telescope

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The Sardinia Radio Telescope (SRT) is a new 64-meter shaped antenna designed to carry out observations up to 100 GHz.

This large instrument has been built in Sardinia, 35 km north of Cagliari, and is now facing the technical commissioning phase.

This paper describes the architecture, the implementation solutions and the development status of NURAGHE, the SRT control software.

Aim of the project was to produce a software which is reliable, easy to keep up to date and flexible against other telescopes. The most ambitious goal will be to install NURAGHE at all the three italian radiotelescopes, allowing the astronomers to access these facilities through a common interface with very limited extra effort. We give a description of all the control software subsystems (servo systems, backends, receivers, etc.) focusing on the resulting design, which is based on the ACS (Alma Common Software) patterns and comes from linux-based, LGPL, Object-Ordiented development technologies.

We also illustrate how NURAGHE deals with higher level requirements, coming from the telescope management or from the system users.

8451-102, Poster Session

Open-source framework for documentation of scientific software written on MATLAB-compatible programming languages

M. V. Konnik, J. Welsh, The Univ. of Newcastle (Australia)

Numerical simulators for adaptive optics systems have became an essential tool for the research and development of the future advanced astronomical instruments. However, as the code of a simulator becomes more sophisticated, the maintenance and further development is becoming more complex. The problem of adequate documentation of the astronomical software for adaptive optics simulators may complicate the development, since the documentation must contain up-to-date schemes and mathematical descriptions implemented in the code. Although most modern programming environments like MATLAB or Octave have in-built documentation abilities, they are often insufficient for the description of such sophisticated code as a typical adaptive optics simulator.

This paper describes a general cross-platform framework for the documentation of scientific software using open-source tools such as LaTeX, mercurial, Doxygen, and Perl. Using the Perl script that translates M-files MATLAB comments into C-like, one can use Doxygen to generate and update the documentation for the scientific source code. The documentation generated by this framework contains the current code description with mathematical formulas, images, and bibliographical references.

A detailed description of the framework components is presented as well as the guidelines for the framework deployment. Examples of the code documentation for the scripts and functions of a MATLAB-based adaptive optics simulator are provided.

8451-103, Poster Session

A motion control networked solution for the PAUCam slow control

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PAUCam consists of an array of 18 red-sensitive CCDs of 4kx2k pixels with a system of 36 narrow-band (10 nm) filters and 6 wide-band filters which will be installed at the William Herschel Telescope(WHT).

The PAUCam Slow Control is in charge of some key aspects of the camera like internal moving parts, vacuum and temperature sensors, temperature actuators and alarm generation.

Its implementation is based on a Siemens Motion Controller D435, which allows us to control the six servomotors of the camera (2 for each filter tray jukebox and 2 for the shutter).

Using industrial standard profibus periphery any kind of analog or digital input/output can be interfaced, allowing to connect standard sensors, TTL signals (shutter trigger),etc.

The Slow Control is the first mechanism to react if a risk or hazardous situation is detected in the camera. When a risk is detected the Slow Control can start security routines to protect the CCDs. Alarms are sent to the operator GUI and are also broadcast to the WHT alarms system.

To enable communication between the Slow Control and the PAUCam Camera Control system a new communication protocol library based on the TCP communication has been developed. This library allows us to interface the Siemens part from any socket capable operative system. Main features are: multi-client system, read/write registers, Test points (any register can be sent cyclically)...

The modular approach used on the software allowed us to reuse the system for other systems like an XY metrology table.

8451-104, Poster Session

Design and implementation of a distributed system for the PAUCam camera control system

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PAUCam consists of an array of 18 red-sensitive CCDs of 4kx2k pixels with a system of 36 narrow-band (10 nm) filters and 6 wide-band filters which will be installed at the William Herschel Telescope(WHT).

The PAUCam Camera Control System (CCS) is the software system in charge of the coordination of the several subsystems to acquire exposures with PAUCam.

The PAUCam CCS is based on a central node (Observation Control System, OCS) and several satellites. The satellites implement interfaces to subsystems of PAUCam or the telescope, while the OCS is in charge of their coordination to acquire an exposure. The list of satellites includes: Slow Control interface, Data Acquisition interface, On line Quality analysis, Guider, Telescope Control system interface, Storage and Alarms.

The PAUCam CCS is a distributed software system which uses "Advanced Messaging Queue Protocol"(AMQP) to implement the communication system. A Shared Variable Engine has been developed on top of AMQP, allowing satellites to share variables in real time. The OCS, by means of Remote Procedure Calls (RPC), sends requests to satellites which are executed on a sandbox environment. With this procedure we ensure that satellites are not compromised if an error occurs and the communication with the satellite is not lost.

The OCS will be operated either in manual or in supervised mode. On supervised mode a list of targets will be processed sequentially, while in manual mode, the operator has to set the targets.

8451-105, Poster Session

Progress on the development of an electronic inverter of the radiative transfer equation

J. C. del Toro Iniesta, Instituto de Astrofísica de Andalucía (Spain)

The needs for high-speed processing of data in the era of distant (limited telemetry capabilities) space missions and state-of-the-art telescopes producing huge amounts of spectropolarimetric information is increasing exponentially. Primarily conceived for the SO/PHI instrument aboard the ESA's Solar Orbiter mission, but readily adaptable to other applications for either the space or the ground, our group is designing an electronic inverter of the radiative transfer equation for polarized light. A report on the development status and a summary of the aimed capabilities will be given.

A specifically conceived and designed electronic device, a field programmable gate array (FPGA), is being developed for carrying out the inversion of the radiative transfer equation for polarized light. Such an inversion being a non-linear, iterative, least-square fit between synthetic and observed Stokes spectra, and hence highly computationally demanding, can only be currently carried out off line with the help of powerful computer clusters. It translates polarization information into the vector magnetic field and the line-of-sight velocity of the solar plasma. This novel use of an FPGA reduces by orders of magnitude the time needed for the computation, thus enabling (almost) on-line applications that need magnetic and dynamic information of the solar atmosphere. Here we report on the current status and achievements of the development.

8451-106, Poster Session

GCS component development cycle

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In order to increase the productivity, the aims of the GCS component architecture model are: 1)The simplification of the component development cycle inside a project scope, using the component as the base piece of building and 2)The reusability of common services and the generic library of components in different projects, using it as a common framework.

A component development cycle aimed at their conceptual specification and a Distribute Application Framework (DAF) that hides the CORBA issues allows the GTC project to decrease the knowledge curve, restricting the component development to the problem domain.

The conceptual specification of a component consists in the following information: name, methods, monitors, properties, alarms and deployment. From that specification our development environment generates automatically the component code, compile it and execute it in only one step and thanks to our inspector application the component interface can be manage without any additional effort.

The common services (logging, monitoring, alarm and configuration) plus a generic library of components that support a wide range of hardware allows the GTC project to reuse this infrastructure in future projects.

The poster will include a practical demo of a component creation.

8451-107, Poster Session

Automated site monitoring at the SAAO

T. E. Pickering, S. M. Crawford, L. Catala, South African Astronomical Observatory (South Africa)

We provide an overview of the hardware and software used for automated site monitoring at the South African Astronomical Observatory (SAAO). The systems discussed include a MASS turbulence profiler, a DIMM seeing monitor with a fast IEEE1394 camera, an off-the-shelf SBIG all-sky camera, and PLC control retro-fitted onto an existing roll-off enclosure. While the systems involved are not unique, many challenges were faced in making such a heterogeneous mixture of hardware and software components robust, reliable, and completely automated. It was also a challenge to find a readily-available, open-source software package for acquiring and analyzing DIMM data. We present our 'timDIMM' software that supports any IIDC-compliant IEEE1394 camera, runs on any platform supported by the open-source libdc1394 libraries (tested and run under linux and OS X), and supports Meade, Astro-physics, and Celestron mount protocols. It is also capable of controlling our MASS instrument and roll-off enclosure as well as monitoring several SAAO weather stations. Its simple, modular design makes it easy to customize as needed.

8451-108, Poster Session

Control software for the CARMENES instrument

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The overall purpose of the CARMENES instrument is to perform high-accuracy measurements of stellar radial velocities (1 m/s) with long-term stability. CARMENES will be installed in 2014 at the 3.5 m telescope in the Calar Alto Observatory and it will be equipped with two channels for spectroscopic data collection at near-IR and visible windows. It will make use of its near-IR capabilities by observing late-type stars, whose peak of the spectral energy distribution falls in the relevant wavelength interval. The technology beyond such an instrument represents a challenge at all levels.

The instrument coordination and management is handled by the Instrument Control System (ICS), which is responsible to carry out the operations of the different subsystems providing a tool to operate the instrument from low to high user interaction level. The main goal of the ICS and the CARMENES control layer architecture is maximizing the instrument efficiency by reducing time overheads and operating it in an integrated manner. ICS interacts with the following subsystems: the near-IR and visible channels, composed by the detectors, exposure meters, calibration units and environment sensors; the front-end electronics; the acquisition and guiding module; the interfaces with telescope and dome; and, finally, the software subsystems for task scheduling, data processing, and data archiving.

We present the ICS design, which implements the CARMENES operational design. A description of the ICS architecture and the APIs for low- and high-level communication is given. The Internet Communications Engine (ICE) is the technology selected to implement most of the interface protocols.

8451-109, Poster Session

RTS2: multichannel experience

P. Kubanek, M. Prouza, Institute of Physics of the ASCR, v.v.i. (Czech Republic); I. V. Kotov, P. O'Connor, Brookhaven National Lab. (United States); P. E. Doherty, Harvard Univ. (United States); J. S. Frank, Brookhaven National Lab. (United States)

RTS2, or Remote Telescope System 2nd Version, is not used only for observatory control. Thanks to system modularity, it is also used as master controller to run CCD tests for the LSST.

We would like to focus this presentation on an upgrade of the system functionalities, which allows system to integrate multi-channel devices. We will show how this was done, which parts of the system were affected, and how this affect overall system design. Also we will share how easy and fast it was to run the multi-channel instrument on sky during prototype CCD testing. And demonstrate how the complex routines, such as twilight skyflats acquistions, worked out of the box.

8451-110, Poster Session

A complete solar eruption activities processing system with robotization and real time

G. Lin, National Astronomical Observatories (China)

Solar activities forecast, geo-effective events and space weather are getting more and more attention, and the data volume of solar observation is becoming larger and larger. As solar data producer, these more reasons make us must to adopt new techniques and means to provide value information to solar activities forecast users and to provide convenient and fast processed products to the other users in time.
In order to achieve this goal, author presents a whole automatic and real time detecting architecture for the different solar erupt activities, a software development process, software modules, methods(image noise process, image standardizing, adaptive threshold, morphological operations, statistics, etc) and final possible service products (solar eruption event notice, the eruption event parameters, the event tables, the eruption event evolutionary movies, the events query tool, etc) as a development result of these designs and methods.

8451-111, Poster Session

Evolution of the top level control software of astronomical instruments at ESO

E. Pozna, European Southern Observatory (Germany)

The Observation Software (OS) is the top level control software of astronomical instruments which is managing the actions during exposures and calibrations carried out at ESO (at various sites VLT, VLTI, La Silla, VISTA). The software framework Base Observation Software Stub (BOSS) provides the foundation of the OS, in use for a decade. BOSS contains 26000 lines of C++ code and covers the functionalities of a simple OS (configuration, synchronization of the subsystems, state alignment, exposure and image file handling). The need for ever increasing precision and speed imposes a consequent increase in complexity on the astronomical instrument control software. Thus makes the OS a critical component in the instrument design. This is reflected by the size of the BOSS applications varying between 0-12000 lines including additional scheduler mechanism, calculation of optical phenomena, online calibrations etc. This article focuses on the progress of OS and BOSS, and their functionality over time.

8451-112, Poster Session

Design and first commissioning results of PLC-based control systems for the Mercator Telescope

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The 1.2m optical Mercator Telescope (based at the Roque de Los Muchachos Observatory at La Palma) is currently in the commissioning phase of a third permanently installed instrument called MAIA (Mercator Advanced Imager for Asteroseismology), a three-channel frame-transfer imager optimized for rapid photometry. Despite having three cryostats, MAIA is designed as a highly compact and portable instrument by using small Stirling-type cryocoolers, and a single PLC in charge of all temperature control loops, cryocooler interaction, telemetry acquisition and other instrument control related tasks. To accommodate MAIA at the Nasmyth B focal station of the telescope, a new mechanism for the tertiary mirror had to be built since the former mechanism only allowed motor controlled access to the Cassegrain and Nasmyth A focal stations. A second PLC has been installed in order to control the two degrees of freedom of this mirror mechanism by interfacing with its motor controllers, high-precision optical encoders, and limit switches. This PLC is not dedicated to the tertiary mirror control but will serve as a general purpose controller for various tasks related to the telescope and the observatory, as part of a new Telescope Control System primarily based on PLCs and OPC UA communication technology. Due to the central location of the PLC inside the observatory, the position control loops of the mirror mechanism are distributed using EtherCAT as the communication fieldbus. In this paper we present the design and the first commissioning results of both the MAIA instrument control and the tertiary mirror control.

8451-113, Poster Session

A mask designer tool for the OSIRIS multi-object spectrograph

J. J. Vaz-Cedillo, A. Ederoclite, J. C. López-Ruiz, A. M. Bongiovanni, Instituto de Astrofísica de Canarias (Spain)

This article describes the characteristics of the OSIRIS Mask Designer tool, a graphical and interactive utility to define the exact positions and shapes of slits in a focal plane mask in order to perform multi-object spectroscopy (MOS) with the instrument OSIRIS on the GRANTECAN telescope.

OSIRIS is an imager and spectrograph for the optical wavelength range, located in the Nasmyth-B focus of GTC. OSIRIS multi object spectrograph uses a set of user-customised-masks, which are manufactured on-demand.

Mask Designer generates automatically the files needed by the manufacturing process to build the needed masks. The main design concepts, the functionality and particular features of the software are discussed.

8451-115, Poster Session

ESPRESSO front-end guiding algorithm

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This paper present Espresso Front End guiding algorithm. ESPRESSO, the Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations, that will be installed on ESO's VL. The Front End is the subsystem that collect the light coming from the Coudè Trains of all the Four Telescope Units (UT), provides Field and Pupil stabilization via piezoelectric tip tilt devices and inject the beam into the Spectrograph fiber. The field and pupil guiding is obtained through a reimaging system that elaborates the halo of the light out of the Injection Fiber and a telescope pupil beacon. The guiding algorithm split the FP in four areas and compute the sum of the photon counting of each pixel in that area. The unbalancing of the photon sums will give the centroid misalignment information that will handled by the controller. Different controllers architectures have been evaluated and implemented in order to select a strategy that enables the FE to guide up to 20 relative magnitude. The guiding algorithm is under test validation with a bread boarding activity of one Front End Module.

8451-116, Poster Session

Image acquisition system with three CCD cameras

B. Li, Y. Zhang, Kunming Univ. of Science and Technology (China); L. Yang, W. Mao, Yunnan Astronomical Observatory (China)

A new astrometric telescope is building in the Yunnan Astronomical Observatory. Its main imaging device is a digital CCD camera without refrigeration because the telescope is not used to observe very faint stars. As an astrometric telescope, some special errors from the horizon and the altitude axis of the telescope must be measured. Thus 2 analog video CCD cameras are used. The digital camera is connected to a digital frame grabber via a Camera Link cable, while the 2 video cameras are connected to an analog frame grabber by 2 custom-made cables. The 2 frame grabbers are mounted in a workstation and operated in trigger mode. 2 trigger signals are generated by the telescope control system, one for the digital camera, another for the 2 analog cameras. The software of image acquisition is build using Sapera ++ LT. This paper presents an imaging system solution for the telescope, programming skills of image acquisition and the test observation results.

8451-117, Poster Session

Final redshift determination of LAMOST pilot survey, including star, galaxy, and QSO spectra

F. Wang, A. Luo, H. Zhang, National Astronomical Observatories

(China)

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) pilot survey have obtained amount of spectra since Oct., 2011. The available large focal plane accommodates up to 4000 fibers to collect light of distant and faint celestial objects. Spectroscopic reduction software is employed to classify obtained-spectra to star, galaxy, and QSO in a form of pipeline. For each type of above objects, we derived the redshift or radial velocity by a Chi-square cross-correlation with templates and another two method to valid our final redshift. We calibrate the redshift measurement by compare with SDSS release results and other high-resolution spectra for zero-point and validation of our methods for final redshift determination.

8451-118, Poster Session

Design and realization of the backup field controllers for LAMOST spectroscopes

J. Wang, Z. Han, Y. Zeng, Z. Hu, Y. Zhu, L. Wang, Y. Hou, Nanjing Institute of Astronomical Optics & Technology (China)

The China-made telescope, LAMOST, consists of 16 spectroscopes to detect stellar spectra via 4000 optical fibers. In each spectroscope, many movable parts work in phase. Those parts are real-time controlled and managed by field controllers based on FPGA. The master control board of controllers currently being used are constructed by Altera's Cyclone II Development Kit. However, now Altera no longer produce such Kits. As the needs for maintenance and improvement, a backup control board is developed, so that once any field controller is broken, another can changed in time to ensure the control system not being interrupted. Using the newer Altera FPGA chip 3C40 as master control chip can minimize the change in the original design frame of the control structure so as to reduce the workload of software and hardware migration.

This paper describes the design process of the spectroscopes backup field controller based on Cyclone 3C40 and gives the problems and solutions encountered during migration for controller hardware and software. The improved field controller not only retains the original controller functions, but also can serve for more motors and sensors due to the increase of input and output pins . Besides, no commodity supply limits, which saves expenses. The FPGA- field controller can also be used in other telescopes, astronomical instruments and industrial control systems as well.

8451-119, Poster Session

LAMOST 2D pipeline

Z. Bai, National Astronomical Observatories (China)

The data 2-dimensional reduction pipeline of LAMOST(Large Sky Area Multi-Object Fibre Spectroscopy Telescope) is described, including fiber tracing, flux extraction, wavelength calibration, flat field dividing, sky subtraction and flux calibration. The fibers are traced using the flat field exposure by centroid method. The fiber is described by a profile similiar to Gauss function and the coefficients are calculated. The fluxes are extracted using profile fitting method. Wavelength calibration is done using arc lamp exposure. We use both lamp and twilight exposures as flat field to wipe the difference among the fibers out. The night sky is fitted by several sky fibers by B-spline and subtracted. We use F8 stars as flux standard stars to get the total response curve of the spectrogragh. All spectrum are corrected by this curve.

8451-120, Poster Session

Design and practice multichannel real time system on deformation control of optical plate

Y. Zheng, Y. Wang, Nanjing Institute of Astronomical Optics & Technology (China)

Optical plates (OP) play more and more important role in modern ground-based telescopes. They can be as segments composing primary mirror, deformable mirror for correcting air turbulence or active stressed lap used in polishing large aspherical optics. When control the deformation of these plates, we always confronts with common situations: high shape precision requirement, high deformation frequency with real time demand, intrinsic multi-channel coupling characteristic. So how to improve OP deformation performance becomes a critical task in practical design. In this paper, three-layer control architecture is first introduced. They are application layer, control layer and execute layer. Then we designed a prototype system following this framework, targeting active stressed lap which has twelve motion channels. Both the hardware and software development are discussed thereafter. OP surface deformation experiments are carried out and surface shape obtained using LVDT array. Results verify the effectiveness of the design. And the last chapter is focused on extend this method to more channel and time demanding applications.

8451-121, Poster Session

Support vector machines for photometric redshift measurement of quasars

H. Zheng, North China Electric Power Univ. (China); Y. Zhang, National Astronomical Observatories (China)

Based on photometric and spectroscopic data of quasars from SDSS DR7 and UKDISS DR5, support vector machines (SVM) is applied to predicting photometric redshifts of quasars. Different input patterns are tried and the best pattern is presented. Comparing the result using optical data with that using optical and infrared data, the experimental results show that the accuracy improves with data from more bands. In addition, the quasar sample is firstly clustered into two groups by SVM, then the photometric redshifts of the two groups are separately estimated by means of SVM. The results based on the whole sample and the two groups are comparable.

8451-122, Poster Session

Review of techniques for photometric redshift estimation

H. Zheng, North China Electric Power Univ. (China); Y. Zhang, National Astronomical Observatories (China)

A photometric redshift provides an estimate for the distance of an astronomical object, such as a galaxy or quasar, which is a powerful statistical tool for studies of evolutionary properties of galaxies, in particular of faint galaxies, since their spectroscopic data are hard or impossible to obtain. At present, there are amounts of methods to estimate photometric redshifts of galaxies and quasars. These methods are grouped into three kinds: empirical methods, template fitting methods and machine learning methods. Each kind of approaches has its pros and cons.

8451-123, Poster Session

Survey of approaches for targeting quasars

Y. Zhang, A. Luo, Y. Zhao, National Astronomical Observatories

(China)

The study of quasars is of great importance to the formation and evolution of galaxies and the early history of the universe. With the development and employment of large sky spectroscopic survey projects (e.g. 2dF, SDSS), the number of quasars increases to more than 200,000. For improving the efficiency of high-cost telescopes, careful selecting observational targets is necessary. Therefore various selecting algorithms are used and developed. We summarize them in detail.

8451-124, Poster Session

Upper computer software design for active optics

C. Li, G. Wang, L. Gao, Nanjing Institute of Astronomical Optics & Technology (China)

China has joined the international global network SONG project and will build one 1-meter telescope as one node of SONG network. This paper shows the upper computer software system design under Debian Linux 5.0 operating system for active optics control system of Chinese SONG telescope. The upper computer software developed in this paper under Linux OS has three functions: detection of S-H wavefront, calculation of mirror correction force and communication with the controller of hardwares. We will introduce the three modules developed under Debian Linux 5.0: wavefront image processing module, communication module and GUI module. In the second part, we will give the performance of the upper computer software used in our project.

8451-125, Poster Session

A spectral featured-based stellar parameter pipeline: comparison version for estimation of LAMOST stellar parameter

B. Du, A. Luo, J. Zhang, Y. Wu, Y. Guo, National Astronomical Observatories (China)

Refereing to SDSS/SEGUE pipeline for stellar parameters SSPP, we developed a dedicated pipeline for LAMOST. This paper give a detailed introduction to the requirement and structure design of a similar pipeline, and the integration of different methods which used in the pipeline. The pipeline is based only on spectral feature without considering color information. We compared LASP with SSPP by using both LAMOST observed spectra and SEGUE spectra. This pipeline is as a comparable version for LAMOST stellar parameter

8451-126, Poster Session

An automatic program to identify morphological characteristics of sunspot groups from white light images

J. Park, Y. Moon, Kyung Hee Univ. (Korea, Republic of); S. Choi, Korea Astronomy and Space Science Institute (Korea, Republic of) and Kyung Hee Univ. (Korea, Republic of)

Sunspots usually appear in a group which can be classified by certain morphological criteria. We are developing an automatic program to compute morphological characteristics from sunspot groups. The program is made of image processing techniques for detection and clustering of sunspots. In this study, we examine the morphological characteristics of sunspot groups using every six hours continuum images from SOHO/MDI in 2003. Sunspot group area and the number of sunspots in a group calculated by the program are compared with those by NOAA. The comparisons show very good correlations (r=99%, r=90%). The morphological characteristics are analyzed with McIntosh classifications by NOAA. We are extending this program to automatic sunspot classification (e.g., McIntosh classification) and flare forecasting.

8451-127, Poster Session

The optical synthetic aperture image restoration based on the improved maximum-likelihood algorithm

Z. Geng, Q. Xu, B. Zhang, Z. Gong, Zhengzhou Institute of Surveying and Mapping (China)

In order to acquire the high-resolution astronomic and remote sensing images, it has to enlarge the aperture size and focus length of optical system. However, subject to the constraints such as satellite payload, manufacturing techniques, cost and so on, a 4.5m space-based system and 10m ground-based system have reached the limit of current system design and affordability. To overcome above difficulties and further enhance the telescope's observing capabilities, the optical synthetic aperture imaging (OSAI) technology came into being.

But, the light collection area of OSAI system is smaller than a fully-filled's, and the response to mid-band spectrum is evidently attenuated in its modulation transfer function, which induces the image degradation and blur. Consequently, images obtained by OSAI have to be post-processed to de-blur images, approaching true ones as best as possible.

A maximum likelihood(ML) reconstruction algorithm was proposed by F. Benvenuto in 2008, which takes Gaussian and Poisson mixed noise into account. The point spread function (PSF), however, is assumed to be known and unchangeable in reconstruction. Actually, the PSF is unknown in most cases. To overcome these limitations, an improved maximum likelihood reconstruction algorithm of blurred images observed by OSAI was presented in this paper, which cooperated PSF estimation with ML, and estimation of PSF was updated during iteration. To reflect objectively the effects of given algorithm, peak signal to noise ratio, mean square error and the average contrast are opted as evaluation indexes. Experiment results show that the proposed algorithm performs much better than current one.

8451-129, Poster Session

Estimate stellar parameters of O type stars for LAMOST commissioning spectra by POLLUX

F. Zuo, A. Luo, J. Zhang, National Astronomical Observatories (China)

With the highest efficiency of gathering spectra by LAMOST telescope, a large number of spectra have been obtained during commissioning observation, which included a lot of spectra of O type star. It's a difficult task to obtain accurate parameters for hot star, lacking of a good model. Several stellar models, such as MAFAGS, ATLAS, Marcs etc, do not cover the parameter range which temperature exceeds 25000K. POLLUX is a database of synthetic stellar spectra, in which CMFGEN provides atmosphere models for the O type stars (Teff >25000K). A method of estimating stellar parameters for hot stars is presented in this paper, based on matching LAMOST observed spectra with the theoretical spectra library. We convert the resolution of CMFGEN spectra, which is about 150000 to LAMOST resolution of 2000. By comparing with the CMFGEN template spectra, we can obtain the parameters of observed hot stars. Estimation for the errors of the final parameters shows that low efficiency of LAMOST blue arms of the spectrographs does not affect O type star observations.

8451-130, Poster Session

Data access and analysis system for Gaia data handling during operations: scientific validation and results monitoring approach in support of the AVU operations

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This document is the first, systematic description of the approach adopted to support the operations of the Gaia Astrometric Verification Unit (AVU) subsystems.

A further subsystem that collects and provides useful tools for a scientific oriented approach to Data Analysis and Access (DAAS) is designed and integrated in the DPCT (Data Processing Center of Turin). Specifically, its aim is to provide to the AVU system an operative and versatile set of diagnostic elements useful for the analysis and the manipulation of the stored data.

Examples of the different scenarios targeted by the operation efforts are:

- Visualization of the “Run time” mission status;

- Archive and recovery data, using graphs and log files contained in the Data Base;

- get “On demand” informations for ad hoc analyses and data mining;

- Production of tables and reports retrieving custom data in the database.

The different cases are described in terms of the methods and the environments in which these take place.

8451-132, Poster Session

The global sphere reconstruction for the Gaia mission in the Astrometric Verification Unit

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The Gaia mission will provide, in about 10 years from now, an all-sky catalog of sim10^9 objects with 5D astrometric data, multi-band photometry, and spectroscopic information. The absolute character of the results, as in the case of Hipparcos, would suggest the set up of two independent consortia for the data reduction. The dimensions of the problem, however, prevented the adoption of this solution, and therefore the Gaia Data Processing and Analysis Consortium (DPAC), decided to replicate some of the most delicate tasks in the so-called Astrometric Verification Unit (AVU).

One of these concerns the core task of the Gaia mission, i.e. the solution of the Global Astrometric Sphere, which is to provide the astrometric reference frame for the Gaia catalog that will constitute the main outcome of the mission. This task, named Global Sphere Reconstruction (GSR), is the counterpart of the Astrometric Global Iterative Solution (AGIS) that will run in parallel on the Gaia data reduction pipeline. While AGIS puts its efforts in maximizing the number of objects of the reduced sphere, GSR focusses on an implementation of the astrometric sphere solution for a well-defined subset of the AGIS solution, which is based on an independent astrometric model and on a different solution algorithm. This contribution will analyze the implementation of GSR and its implications as a High Performance Computing application.

8451-133, Poster Session

Qsys NOC-based MPSOC design for LAMOST spectrometer

Z. Han, J. Wang, Y. Zeng, J. Shao, Nanjing Institute of Astronomical Optics & Technology (China)

At present, FPGA-based SOPC was used to design the China’s LAMOST telescope spectrometer control system. But with the increase of the controlled objects and requirement of telescope’s accuracy, the problems like system performance, I/O source shortage, real-time multi-task processing, Fmax, Logic Element (LE) Usage have to be solved immediately. The combination of multi-processor (NIOS II) method and NOC technology can meet this requirement effectively. This article mainly introduced how to realize the NOC-based MPSOC in the Altera’s Cyclone III FPGA experimental board by Qsys tool. According to the function of task, the system was divided into several subsystems which also include two NIOS II CPU subsystems (implement the control strategies & remote update tasks separately). These different subsystems are interconnected by NOC hierarchical interconnection idea. The results illustrate that this solution can improve system performance, double the Fmax, decrease LE usage, and save the maintenance cost compared with the previous SOPC-based approach. The motor control system designed by this approach also can be applied to other astronomy equipments and industrial control fields.

Supported by LAMOST project, NSFC project Distributed astronomical instrument control technology based on system on chip (NO. 10778722) and NSFC project New Technology Research of Space Solar-Filter Control System (NO. 11178022).

8451-135, Poster Session

The current status of OCS

S. Sun, A. Luo, National Astronomical Observatories (China)

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) had been built. Observatory Control System (OCS) is the “nerve center” of the LAMOST, which is gigantic, complex and a highly automate astronomic telescope. It’s main mission includes: managing, coordinating and controlling the operations of all subsystems. The beta of OCS has been used.Now, in this paper, I will introduce its modules, includes: the software frame of LAMOST and OCS, the runned status of commands, OCS’s main interface, the exposure module, the FTIS collector, the Log module and the PipeLine of OCS.

8451-136, Poster Session

The system software development for prime focus spectrograph on Subaru Telescope

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The Prime Focus Spectrograph (PFS) is a wide field multi-fiber spectrograph using the prime focus of the Subaru telescope, which is capable of observing up to 2400 astronomical objects simultaneously.

The instrument control software will manage the observation procedure communicateing with subsystems such as the fiber positioner “COBRA”, the metrology camera system, and the spectrograph and camera systems.

Before an exposure starts, the instrument control system needs to access to a database where target lists provided by observers are stored in advance, and accurately position fibers onto astronomical targets as requested therein. This fiber positioning will be carried out interacting with the metrology system which measures the fiber positions. In parallel, the control system can issue a command to point the telescope to the target position and to rotate the instrument rotator. Finally the telescope

pointing and the rotator angle will be checked by imaging bright stars and checking their positions on the auto-guide and acquisition cameras.

After the exposure finishes, the data are collected from the detector systems and are finalized as FITS files to archive with necessary information.

The observation preparation software is required, given target lists and a sequence of observation, to find optimal fiber allocations with maximizing the number of guide stars.

To carry out these operations efficiently, the control system will be integrated seamlessly with a database system which will store information necessary for observation execution such as fiber configurations.

In this article, the conceptual system design of the observation preparation software and the instrument control software will be presented.

8451-137, Poster Session

Test results for the Gemini Planet Imager data reduction pipeline

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The Gemini Planet Imager (GPI) is a new facility instrument for the Gemini Observatory designed to detect and characterize planets and debris disks orbiting nearby stars. Realizing this goal requires automated processing of the observations delivered by GPI's integral-field spectrograph and imaging polarimeter instrument, including the conversion of raw data into datacubes, the calibration of those data, and the subtraction of point spread functions (PSFs) using a variety of algorithms. Because GPI will be a facility instrument available to the community, its data pipeline must be both robust and straightforward to use, yet also flexible enough to accommodate a variety of observing strategies. To meet these requirements, we have developed a modular data reduction system including a back-end pipeline, graphical user interface, and simple calibration database. It incorporates the entire image reduction and calibration process, including wavelength solution, astrometric and photometric calibrations and speckle suppression. This pipeline is now functional as an automated processing chain, and has recently passed its acceptance testing review by Gemini. Here we summarize the results from this recent pipeline testing, present recent developments of additional processing routines, and demonstrate reductions of lab test data from the actual IFS hardware. This open-source IDL software will be made available to the community after GPI commissioning, with first light currently planned for late 2012.

8451-138, Poster Session

Electronics and mechanism control system for FRIDA: infrared imager and dissector for adaptive optics

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FRIDA will be a common-user near infrared imager and integral field spectrograph covering the wavelength range from 0.9 to 2.5 microns. Primary observing modes driven the instrument design are two: direct imaging and integral field spectroscopy. FRIDA will be installed at the Nasmyth B platform of the Gran Telescopio Canarias (GTC) behind the GTC Adaptive Optics (GTCAO) system. Instrument will use diffraction-limited optics to avoid degrading the high Strehl ratios derived by the GTCAO system in the near infrared.

High-performance astronomical instruments with a high reconfiguration degree as FRIDA, not only depends on optical and mechanical efficient designs but also on the good quality of its electronics and control systems designs. In fact, astronomical instruments operating performance on telescope greatly relies on electronics and control system.

This paper describes the main features of both the electronics and the control software design for the FRIDA mechanism embedded control system. FRIDA will be a reconfigurable infrared instrument that mainly comprises eight cryogenic mechanisms and one room temperature mechanism, accurately positioned by control algorithms which in turn are programmed according to the FRIDA operating modes. Embedded control software for some prototypes of these mechanisms has been programmed. A characterization of FRIDA house-keeping system is also presented.

8451-141, Poster Session

SPIRou @ CFHT: data reduction software and simulation tools

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SPIRou is a near-IR (0.98-2.35µm), echelle spectropolarimeter / high precision velocimeter being designed as a next-generation instrument for the 3.6m Canada-France-Hawaii Telescope on Mauna Kea, Hawaii, with the main goal of detecting Earth-like planets around low-mass stars and magnetic fields of forming stars. The unique scientific and technical capabilities of SPIRou are described in a series of eight companion papers. Here we focus on the SPIRou data reduction software (DRS) and data simulation tool. SPIRou's stringent science requirements of RV precision <1m/s, and polarization accuracy of 1% in the nIR poses specific data-processing challenges, principally:(i) optimal spectral extraction in the presence of significant telluric absorption, numerous telluric emission sky lines, and high thermal background, (ii) precise, stable wavelength calibration, and (iii) detectors with significant persistence and poorer cosmetics than CCDs. Building upon the extensive experience of our team members on three existing optical spectrographs, SOPHIE, HARPS, and ESPADONS, class leaders in high precision RV and spectropolarimetric measurements, we have developed unique methods of meeting these design requirements. In order for the DRS to be fully functional for SPIRou's first lights in 2015, we have also developed a data simulation tool that incorporates all foreseen instrumental and observational effects. We present an overview of the DRS and the simulation tool architectures, as well as ongoing work to minimize the impact of telluric absorption features on RV measurements of cool stars.

8451-142, Poster Session

SPIRou @ CFHT: design of the instrument control system

G. A. Barrick, T. Vermeulen, Canada-France-Hawaii Telescope (United States); S. Baratchart, Institut de Recherche en Astrophysique et Planétologie (France); S. Wang, Academia Sinica (Taiwan); J. Dunn, National Research Council Canada (Canada); F. Dolon, Observatoire Astronomique de Marseille-Provence (France); O. Hernandez, Univ. de Montréal (Canada); F. Pepe, Observatoire de Genève (Switzerland); F. Bouchy, Lab. d'Astrophysique de Marseille (France); M. Dupieux, G. Gallou, T. Gharsa, M. Le Floch, Institut de Recherche en Astrophysique et Planétologie (France); F. Moreau, Observatoire Astronomique de Marseille-Provence (France); L. P. Parès, Institut de Recherche en Astrophysique et Planétologie (France); V. A. Reshetov, National Research Council Canada (Canada); J. N. Thomas, Canada-France-Hawaii Telescope (United States); C. Yan, Institute of Astronomy and Astrophysics (Taiwan)

SPIRou is a near-IR (0.98-2.35µm), echelle spectropolarimeter / high precision velocimeter being designed as a next-generation instrument for the 3.6m Canada-France-Hawaii Telescope on Mauna Kea, Hawaii, with the main goal of detecting Earth-like planets around low-mass stars and magnetic fields of forming stars. The unique scientific and technical capabilities of SPIRou are described in a series of eight companion papers. In this paper, the means of controlling the instrument are discussed. For most of the instrument control is fairly normal, using off-the-shelf components where possible and reusing already available code for these components. Some aspects, however, are more challenging. In particular, the paper will focus on the challenges of doing fast (50 Hz) guiding with 30 mas repeatability using the object being observed as a reference and on thermally stabilizing a large optical bench to a very high precision (~1 mK).

8451-143, Poster Session

Data reduction for the imaging Fourier transform spectrometers SpIOMM and SITELLE

T. Martin, L. Drissen, G. Joncas, Univ. Laval (Canada)

SpIOMM is an imaging Fourier transform spectrometer capable of obtaining the visible spectrum of every source of light in a field of view of 12 arcminutes. Even if it has been designed to capture both outputs of the Michelson interferometer, up to now only one output was used. Here we present the main aspects of the installation of a camera with new characteristics on the second output port and the reduction process we had to design in order to take advantage of the new two-output data and take into account the different characteristics (pixel size, sensitivity) of the two cameras. We found that merging interferograms using the standard procedures does not preserve the relative energy of the spectrum from one point of the image to another and as a result does not provide correct spectral images. We thus propose an enhanced way to merge the interferograms. Then, since this whole reduction pipeline will be used for SITELLE, the direct successor of SpIOMM, which will be installed at the Canada-France-Hawaii Telescope in 2013, we also describe the software design choices we made to ensure a total compliance with those main quality characteristics: accuracy, usability, time and resource efficiency, maintainability and portability (as described by the standard ISO/IEC 9126).

8451-20, Session 5

Virtual clouds on an astronomical observatory: virtualization at ESO, its status and its future

A. Balestra, European Southern Observatory (Germany)

Virtualization and Cloud Computing are hyped buzzwords in today's computing world, but, regardless of this, they are also consolidated technologies that offer many opportunities to improve the efficiency of a cyberinfrastructure. At ESO they are used from several years in various domains, from IT infrastructure to development and simulation as well as in data handling. Different models, tools and vendors have been extensively investigated. In this contribution we describe virtualization and cloud computing usage at ESO as well as what are the plans for the future. Moreover, based on our experience, we envisage what a "cloudy" astronomical observatory may look like.

8451-21, Session 5

Towards dynamic light-curve catalogues

B. Scheers, Ctr. voor Wiskunde en Informatica (Netherlands) and Astronomical Institute Anton Pannekoek, Univ. of Amsterdam (Netherlands)

Next generation astronomical observatories are designed for high-speed all-sky surveys, searching for rapid transient and variable sources, cataloguing all measurements of millions of sources. Consequential, these facilities will produce high cadence rates and tens of terabytes per day.

The International LOFAR Telescope paves the way for the new-generation instruments. One of its products is an up-to-date catalogue of all sources detected by LOFAR, a spectral lightcurve database, with real-time capabilities to cope with the gradual growth of 50-100 TB/yr. It makes it the largest dynamic astronomical catalogue to date, although still an order of magnitude smaller than the upcoming facilities of LSST and SKA.

The open source column-store database MonetDB is in active use in the automated LOFAR imaging and transients software pipelines. We exploit the SciLens infrastructure, a 300+ node, 4-tier locally distributed cluster focussed on massive I/O, to enter areas of exploration of scientific databases hitherto shielded from use.

On the software front, we use a new array-based query language, called SciQL, (an extension of SQL:2003). It provides a seemless integration between the relational paradigm and array-based computations and simplifies data exploration and data mining.

In this talk (and paper), I will give an overview how MonetDB/SciQL on its SciLens platform manages the millions of sources and their lightcurves for LOFAR. Initial benchmark results confirm the linear scale-up performance over several tens of TBs of extracted data using tens of nodes. It is complemented with lessons learned and best practices in using modern database technology for astronomy.

8451-23, Session 5

Mirror support system controller design for INO340 Telescope

A. Jafarzadeh, R. Ravani, Institute for Studies in Theoretical Physics and Mathematics (Iran, Islamic Republic of)

The Iranian National Observatory telescope (INO340) is a 3.4m Alt-Az reflecting optical telescope under design and development. It is f/11 Ritchey-Chretien with a 0.5° field-of-view. INO340 will be installed at Gargash summit (3617m) near Kashan, Iran and the first light is planned for 2016.

The major part of INo340 control system is the active support system. This technology maintains the shape of large flexible primary mirror under varying environments to achieve the optimum optical quality and performance.

The INO340 primary mirror figure which is more than 4 tons is controlled by a set of active supports based on pneumatic bellows. They are driven in order to elastically compensate wave-front deformations measured by a wave-front sensor in a feedback loop. The mirror is supported by means of axial and lateral pads. INO340 has 60 axial actuators distributed on four concentric rings, which include from the center out, 6, 12, 18 and 24 pads, respectively. The axial pad distribution was analyzed by means of Finite Elements Analysis (FEA). Also INO340 has 24 lateral actuators. Hardpoints were designed to include loadcells and were accommodated within the constrains posed by the existing design of the mirror cell.

In this paper, we present an innovative active support system, discuss the different aspects of our system based on related simulation and show the results of our analytical models. In our design process, we briefly compare the performance, response time, stiffness and other factors between pneumatic and electro-mechanical actuators.

8451-36, Session 5

UAF: a generic OPC unified architecture framework

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As an emerging Service Oriented Architecture (SOA) specifically designed for industrial automation and process control, the OPC Unified Architecture specification should be regarded as an attractive candidate for controlling scientific instrumentation. Even though an industry-backed standard such as OPC UA can offer substantial added value to these projects, its inherent complexity poses an important obstacle for adopting the technology. Building OPC UA applications requires considerable effort, even when taking advantage of a COTS Software Development Kit (SDK). The OPC Unified Architecture Framework (UAF) attempts to reduce this burden by introducing an abstraction layer between the SDK and the application code in order to achieve a better separation of the technical and the functional concerns. True to its industrial origin, the primary requirement of the framework is to maintain interoperability by staying close to the standard specifications, and by expecting the minimum compliance from other OPC UA servers and clients. UAF can therefore be regarded as "a" software framework to quickly and comfortably develop and deploy OPC UA-based applications, while remaining compatible to third party OPC UA-compliant toolkits, servers (such as PLCs) and clients (such as SCADA software). In the first phase, as covered by this paper, only the client-side of UAF has been tackled in order to transparently handle discovery, session management, subscriptions, monitored items etc. We describe the design principles and internal architecture of our open-source software project, the first results of the framework running at the Mercator Telescope, and we give a preview of the planned server-side implementation.

8451-134, Session 5

Design and implementation of a general main axis controller for the ESO telescopes

S. Sandrock, N. Di Lieto, L. Pettazzi, T. M. Erm, European Southern Observatory (Germany)

Most of the real-time control systems at the existing ESO telescopes were developed with "traditional" methods, using general purpose VMEbus electronics, and running applications that were coded by hand, mostly using the C programming language under VxWorks.

As we are moving towards more modern design methods, we have explored a model-based design approach for real-time applications in the telescope area, and used the control algorithm of a standard telescope main axis as a first example.

We wanted to have a clear work-flow that follows the "correct-by-construction" paradigm, where the implementation is testable in simulation on the development host, and where the testing time spent by debugging on target is minimized. It should respect the domains of control, electronics, and software engineers in the choice of tools.

It should be a target-independent approach so that the result could be deployed on various platforms.

We have selected the Mathworks tools Simulink, Stateflow, and Embedded Coder for design and implementation, and LabVIEW with NI hardware for hardware-in-the-loop testing, all of which are widely used in industry.

We describe how these tools have been used in order to model, simulate, and test the application.

We also evaluate the benefits of this approach compared to the traditional method with respect to testing effort and maintainability.

For a specific axis controller application we have successfully integrated the result into the legacy platform of the existing VLT software, as well as demonstrated how to use the same design for a new development with a completely different environment.

8451-25, Session 6

The last mile of the ALMA software development: lessons learned

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At the end of 2012, ALMA software development will be completed. While new releases are still being prepared following an incremental development process, the ALMA software has been in daily use since 2008. Last year it was successfully used for the first science observations proposed by the ALMA scientific community. This included the whole project life cycle from proposal preparation to data delivery, taking advantage of the software being designed as an end-to-end system. This presentation will report on software management aspects that became relevant in the last couple of years. These include a new feature driven development cycle, an improved software verification process, and a more realistic test environment at the observatory. It will also present a forward look at the planned transition to full operations, given that upgrades, optimizations and maintenance will continue for a long time.

8451-26, Session 6

Adoption of new software and hardware solutions at the VLT: the ESPRESSO control architecture case

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ESPRESSO is a fiber-fed cross-dispersed echelle spectrograph which can be operated with one or up to 4 UT (Unit Telescope) of ESO's

Very Large Telescope (VLT). It will be located in the Combined-Coudé Laboratory of the VLT and it will be the first permanent instrument using a 16-m equivalent telescope. The ESPRESSO control software and electronics are in charge of the control of all instrument subsystems: the four Coudé Trains (one for each UT), the front-end and the fiber-fed spectrograph itself contained within a vacuum vessel. The spectrograph is installed inside a series of thermal enclosures following an onion-shell principle with increasing temperature stability from outside to inside. The proposed electronics architecture will use the OPC Unified Architecture (OPC UA) as a standard layer to communicate with PLCs (Programmable Logical Controller), replacing the old Instrument Control LCUs for ESO instruments based on VME technology. The instrument control software will be based on the VLT Control Software package and will use the IC0 Field Bus extension for the control of the instrument hardware. In this paper we present the ESPRESSO software architectural design proposed at the Preliminary Design Review as well as the hardware architecture.

8451-27, Session 6

Conceptual design of the control software for the European Solar Telescope

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Aim of this paper is to present an overview of the conceptual design of the Control Software for the European Solar Telescope (EST), as emerged after the successful Conceptual Design Review held in June 2011 which formally concluded the EST Preliminary Design Study. After a general description of ECS (EST Control Software) architecture end-to end, from operation concepts and observation preparations to the control of the planned focal plane instruments, the paper focuses on the arrangement devised to date of ECS to cope with the foreseen scientific requirements. EST major subsystems together with the functions to be controlled are eventually detailed and discussed.

8451-28, Session 6

Software systems for control, monitoring, and data acquisition of the South Pole Telescope

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We present the software and hardware system used to control and operate the South Pole Telescope. The South Pole Telescope is a 10-meter microwave telescope designed to map CMB polarization anisotropy at fine angular resolution. In the austral summer of 2011/12 we installed a new polarization-sensitive camera of 1536 transition-edge-sensitive bolometers that are read out using 36 independent digital frequency multiplexed (dfmux) readout boards controlled by embedded processors. These autonomous boards control and read out data from the focal plane with on-board software and firmware, which is controlled by a suite of software running on a separate control computer. An overall control software system sends commands to the dfmux boards as well as controlling all other aspects of the cryostat and telescope operation. This control software collects and real-time monitors data, stores it to disk and sends a subsample to the United States for analysis.

8451-29, Session 6

A modern approach to upgrading the telescope control system of the CTIO Blanco 4-m Telescope

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In preparation for the arrival of the Dark Energy Camera (DECam) at the CTIO Blanco 4-m telescope both the hardware and the software of the Telescope Control System (TCS) have been upgraded, in order to meet

the more stringent requirements on cadence and tracking required for efficient execution of the Dark Energy Survey. This upgrade was also driven by the need to replace obsolete hardware, some of it now over half a century old.

In this paper we describe the architecture of the new control system, and in particular the method used to develop and implement the servo-driver portion of the new TCS. This portion of the system had to be completely rethought, when an initial approach, based on commercial off the shelf components, lacked the flexibility needed to cope with the complex behavior of the plant. Central to our design approach was the early implementation of extensive telemetry, which allowed us to fully characterize the real dynamics of the telescope. These results then served as input to extensive simulations of the proposed new servo system allowing us to iteratively refine the control model. This flexibility will be important later when DECam is installed, since this will significantly increase the moving mass and inertia of the telescope.

Based on these results, a fully digital solution was chosen and implemented. The core of this new servo hardware is modern cRIO hardware, which combines an embedded processor with a high-performance FPGA, allowing the execution of LabVIEW applications in real time.

8451-30, Session 8

Data management cyberinfrastructure for the Large Synoptic Survey Telescope

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The Large Synoptic Survey Telescope (LSST) project is a proposed large-aperture, wide-field, ground-based telescope that will survey half the sky every few nights in six optical bands. LSST will produce a data set suitable for answering a wide range of pressing questions in astrophysics, cosmology, and fundamental physics.

The 8.4-meter telescope will be located in the Andes mountains near La Serena, Chile. The 3.2 Gpixel camera will take 6.4 GB images every 15 seconds, resulting in 15 TB of new raw image data per night. An estimated 2 million transient alerts per night will be generated within 60 seconds of when the camera's shutter closes.

Processing such a large volume of data, converting the raw images into a faithful representation of the universe, automated data quality assessment, automated discovery of moving or transient sources, and archiving the results in useful form for a broad community of users is a major challenge.

We present an overview of the planned computing infrastructure for LSST. The cyberinfrastructure required to support the movement, storing, processing, and serving of hundreds of petabytes of image and database data is described. We also review the sizing model that was developed to estimate the hardware requirements to support this environment beginning during project construction and continuing throughout the 10 years of operations.

8451-31, Session 8

ALMA software scalability experience with growing number of antennas

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The ALMA Observatory is a challenging project in many ways. The hardware and software pieces are frequently designed specifically for ALMA, based on overall scientific requirements. The observatory is still in its construction phase, but already started Early Science observations with 16 antennas in September 2011, and has currently (December 2011) 26 antennas available on the high site, with around 2 new antennas delivered every month. The finished array will integrate up to 66 antennas in 2013.

The on-line software is a critical part of the operations: it controls from the low level real-time hardware up to the observations scheduler and data storage. Many pieces of the software design are eventually affected by a growing number of antennas, as more processes are integrated into the distributed system, and more data flows to the Correlator and Database. Although some scalability tests were performed in a simulated environment, the system proved to be very dependent on some real deployment conditions and several unforeseen scalability issues have been found in the last months, starting with a critical number of about 15 antennas. Processes that grow proportional to the number of antennas tend to quickly demand more powerful machines, unless alternatives are implemented.

This paper describes the practical experience of dealing with (and hopefully preventing) blocking scalability issues during the construction phase, while the expecting users push the system to its limits. This may also be a very useful example for other upcoming radio-telescopes with a large number of receivers.

8451-32, Session 8

The DIRP framework: flexible HPC-based scientific processing of petabyte scale surveys

C. J. Harris, A. J. Wicenec, A. Checcucci, S. Kitaeff, D. Pallot, K. Vinsen, C. Wu, P. J. Quinn, The Univ. of Western Australia (Australia)

The immense scale of data production from modern radio interferometer arrays results in processing demands that require HPC facilities to produce scientific results. However, in the modern era such facilities are more complex than a single monolithic HPC system. The transfer and processing of scientific data must be managed across hierarchies of storage and a range of processing architectures; including traditional HPC, heterogeneous HPC, database and visualisation systems. The ICRAR Data Intensive Research Pathfinder (DIRP) will consist of an integrated system of the hardware, middleware, tools and interfaces to support ICRAR data intensive research primarily focused on data flowing from the ASKAP and MWA telescopes.

8451-33, Session 8

A complete history of everything

K. Lanclos, W. T. S. Deich, Lick Observatory (United States)

This paper discusses Lick Observatory's local solution for retaining a complete history of everything. Leveraging our existing deployment of a publish/subscribe communications model that is used to broadcast the state of all systems at Lick Observatory, a monitoring daemon runs on a dedicated server that subscribes to and records all published messages. Our success with this system is a testament to the power of simple, straightforward approaches to complex problems. The solution itself is written in Python, and the initial version required about a week of development time; the data are stored in PostgreSQL database tables using a distinctly simple schema.

Over time, we addressed scaling issues as the data set grew, which involved reworking the PostgreSQL database schema on the back-end.

We also duplicate the data in flat files to enable recovery or migration of the data from one server to another. This paper will cover both the initial design as well as the solutions to the subsequent deployment issues, the trade-offs that motivated those choices, and the integration of this history database with existing client applications.

8451-34, Session 8

UKIRT remote operations fail-safe system

B. H. Gorges, C. Walther, T. Chuter, Joint Astronomy Ctr. (United States)

Remote operation of a four meter class telescope on the summit of Mauna Kea from 40 kilometers away presents unique challenges. Concerns include: communication links being severed, the computer controlling the enclosure becoming inoperable, non-responsive software, inclement weather, or the operator forgetting or unable to close the dome during a personal emergency. These issues are addressed at UKIRT by a series of deadman handshakes starting on the operator's end with a graphical user interface that requires periodic attention and culminates with hardware in the telescope that will initiate a closing sequence when regular handshake signals do not continue. Software packages including Experimental Physics and Industrial Control Systems (EPICS) and Drama were used in this project to communicate with hardware control systems and to coordinate systems. After testing, this system has been used in operation since January 2011.

8451-35, Session 9

Interaction design challenges and solutions for ALMA operations monitoring and control

E. Pietriga, INRIA (France) and CIRIC (Chile); P. Cubaud, Conservatoire National des Arts Métiers (France); J. Schwarz, M. Schilling, European Southern Observatory (Germany); R. Primet, INRIA (France); D. Barkats, E. Barrios, B. Vila-Vilaro, Joint ALMA Office (Chile)

The ALMA radio-telescope, currently under construction in northern Chile, is a very advanced instrument that presents numerous challenges. From a software perspective, one critical issue is the design of graphical user interfaces for operations monitoring and control that scale to the complexity of the system and to the massive amounts of data users are faced with. Early experience operating the telescope with only a few antennas has shown that conventional user interface technologies are not adequate. They consume too much screen real-estate, require many unnecessary interactions to access relevant information, and fail to provide operators and astronomers with a clear mental map of the instrument. They increase extraneous cognitive load, impeding tasks that call for quick diagnostic and action.

To address this challenge, the ALMA software division adopted a user-centered design approach. For the last two years, astronomers, operators, software engineers and human-computer interaction researchers have been involved in participatory design workshops, with the aim of designing better user interfaces through an iterative process, based on state-of-the-art visualization techniques such as: multi-scale interfaces, highly-coordinated views, adjacency matrices for the representation of dense baseline networks, treemaps for the representation of hierarchical hardware structures, and advanced time-series visualizations of monitoring points. This paper describes the process that led to the development of those interface components and to a proposal for the science and operations console setup: brainstorming sessions, rapid prototyping, joint implementation work involving software engineers and human-computer interaction researchers, feedback collection from a broader range of users, further iterations and testing.

8451-37, Session 9

The readout and control system of the Dark Energy Camera

K. Honscheid, The Ohio State Univ. (United States)

We present the data acquisition and control system of the Dark Energy Camera (DECam), which will be the primary instrument used of the Dark Energy Survey (DES). DES is a high precision multibandpath wide area survey of 5000 square degrees of the southern sky. DECam is a 3 square degree mosaic camera mounted at the prime focus of the Blanco 4m telescope at the Cerro-Tololo International Observatory (CTIO). The imager and the optical corrector arrived at CTIO in December 2011 and an extensive commissioning program has begun with first light scheduled for early summer 2012. The success of this program depends critically on the availability and performance of the DECam data acquisition system (SISPI). SISPI has been installed at CTIO in 2011. It is implemented as a distributed multi-processor system with a software architecture built on the Client-Server and Publish-Subscribe design patterns. We will briefly review the system architecture, the image pipeline, and the instrument control system but the main focus of our presentation will be on the observer interface, quality assurance, image displays etc - the tools we have developed to support commissioning of the instrument and later operations. This includes our experience with HTML5 and the web sockets protocol, electronic logbooks as well as the interfaces to the telescope control system and data management.

8451-38, Session 9

Instrument control software for the visible broadband imager using ATST common services framework and base

A. Ferayorni, National Solar Observatory (United States)

The Advanced Technology Solar Telescope (ATST) Common Services Framework (CSF) and Base provide the technical framework and building blocks for developing telescope and instrument control systems. The ATST Visible Broadband Imager (VBI) is a high priority instrument with science use cases requiring an Instrument Controller (IC) capable of executing deterministic motion control tasks and synchronizing those tasks with other systems in the observatory. The VBI IC is the first ATST instrument controller designed and developed using the ATST CSF and Base components, and therefore provides insight into the strengths and weaknesses of using distributed control software in the instrument domain. In this paper we lay out the design of the VBI IC, examine how the underlying ATST CSF and Base components are utilized, and discuss where custom software is incorporated to meet real-time performance and synchronization requirements. We present our preliminary results of the system performance against three of the VBI use cases.

8451-39, Session 9

Intercontinental network control platform and robotic observation for Chinese Antarctic telescopes

L. Xu, Nanjing Institute of Astronomical Optics & Technology (China)

The Chinese astronomical exploration in Antarctic region has been initialized and stepped forward. The R&D roadmap in this regard identifies each progressive step. For the past several years China has set up Kunlun station at Antarctic Dome-A, and Chinese Small Telescope ARray (CSTAR) has already been up and running regularly. In addition, Antarctic Schmidt Telescopes 3 (AST3) has been transported to the area and ready for installation there, followed with telescopes in larger size predictably more to come. Antarctic region is one of a few best sites left on the Earth for astronomical telescope observation, yet with worst fundamental living conditions for human survival and activities. To meet such a tough challenge it is essential to establish an efficient and reliable means of remote access for telescope routine observation. This paper outlines the remote communication for CSTAR and AST3, and further proposes an intercontinental network control platform for Chinese Antarctic telescope array with remote full-automatic control and robotic observation and management. A number of technical issues for telescope access such as the unattended operation, bandwidth based on iridium satellite transmission as well as the means of reliable and secure communication among other things are all reviewed and further analyzed.

8451-131, Session 9

GMT software and controls overview

J. M. Filgueira, M. Bec, J. Soto, N. Liu, Giant Magellan Telescope Project (United States)

The Giant Magellan Telescope Organization (GMTO) is designing and building a ground-based 25-meter extremely large telescope (ELT). The GMT project represents a significant increase in complexity and performance requirements over 8-10 meter class telescope control systems. The GMT will require a larger number of subsystems with demanding patterns of interaction between them. Many of these subsystems will be developed by different organizations. At the same time the operation of the system must be reliable, robust, efficient and cost-effective. These requirements present new challenges that the design of the software and hardware architecture has to address, while ensuring the maintainability of the system. This paper presents how recent software and hardware technologies and the lessons learned from the previous generation of large telescopes can help to address some of these challenges.

8451-40, Session 10

A distributed data management system for data-intensive radio astronomy

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Many observatories are able to use a single data centre to store their data products. These data centres take full advantage of current networking and storage technologies to provide convenient, efficient, and fault-tolerant access to the archives.

The next generation of telescopes, such as the Square Kilometre Array (SKA), will generate orders of magnitude more data than previous instruments. At the current Internet2 land speed record rate of 9 gigabits per second, moving a 20 terabyte file will take 5 hours. For a sample SKA data set of 10 square degrees, moving that 500 terabyte data cube would take over a week at this rate. It is similarly unfeasible to hold a copy of that data at every storage facility as it would take over 100 of the highest capacity disk drives available each. The current replicated data store model that served us well in the past cannot support such large volumes.

To address this problem, we propose an architecture where data is distributed over several archive sites, each holding only a portion of the overall data, that provides efficient and transparent access to the archive as a whole. This paper describes that architecture in detail and the design and implementation of a prototype system, based on the Integrated Rule-Oriented Data System (iRODS) software. The prototype is currently used to support CyberSKA, a distributed cyberinfrastructure platform aimed at addressing the needs of data-intensive astronomy. The impact of our architecture on data query, visualization, and processing will also be explored.

8451-41, Session 10

J-PAS data management pipeline and archiving

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J-PAS survey is going to observe 8000 deg^2 in 56 optical filters. The survey will produce 1.2PB of data at a rate of 340TB/year. The treatment of about 1.5TB per night, coming by the 14+1 detectors of the two cameras in the T250 and T80 telescopes, shall be performed during the day after the operations. This contribution presents the software and hardware architecture designed to archive, process and validate the data. The software will run automatically in parallel in 300 processing cores. The cosmetic part of the pipeline, which deals with instrument imprint corrections is implemented in Python. The astrometric and photometric calibration, image co-adding and source extraction use software from the community which are integrated through Python wrappers. The software uses a database to control the process by storing the operations performed, parameters used and quality checks. This permit fast reprocessing to retrieve intermediate stages of the treatment from the raw data for any data release. This approach saves disk space by avoiding the storage of the processed individual frames. We present the architecture of the final catalog database which will be 20 TB at the end of the survey. The data archiving and processing will be done in a datacenter 30km away from the observatory. It will be equipped with 2PB of storage capability to store the raw data and final mosaics of the 56 filters, and processing power to deal with the incoming data.

8451-42, Session 10

The LOFAR long term archive: e-infrastructure on petabyte scale

H. Holties, ASTRON (Netherlands)

The LOFAR Long Term Archive (LTA) is the distributed data information system responsible for the long-term storage, distribution, and analysis of LOFAR data products. For astronomers, the LOFAR LTA is the principal interface not only to LOFAR data retrieval and data mining but also to processing facilities for this data. Each site involved in the LTA provides storage capacity and optionally processing capabilities. To allow collaboration with a variety of institutes and projects, the LOFAR LTA merges different technologies (EGI, global file systems, AstroWISE dataservers).

The LTA builds on international e-Infrastructure provided by EGI related facilities such as the Dutch Big Grid project and facilities provided by the German Forschungs Zentrum Juelich as well as nationally funded projects such as Target. For its connectivity it utilizes the national research networks and explores new technologies for high bandwidth on demand and long distance data streaming through the EU FP7 funded NEXPReS project. A centrally operated catalogue provides a searchable database for scientific products stored in the LTA from raw visibilities to calibrated images and derived source lists. The user administration synchronises accounts across the LTA and is designed to connect to federated infrastructures. For its data analysis capabilities it builds on the data processing frameworks provided by EGI and AstroWISE.

In this paper we will present the architecture, the challenges and the first experience with operating the peta-scale LOFAR LTA.

8451-43, Session 10

The MWA archive infrastructure: archiving terabytes of data over dedicated WAN connections

A. J. Wicenec, D. Pallot, A. Checcucci, C. J. Harris, S. Kitaeff, K. Vinsen, C. Wu, The Univ. of Western Australia (Australia)

The Murchison Wide Field Array (MWA) is being upgraded from 32 tiles to 128 tiles of dipole antennas. In the course of this project also the software and the data infrastructure is undergoing a major overhaul

in order to be able to cope with a more continuous and remote operational model and the substantial increase in data rate (100 MB/s from the correlator plus 160 MB/s from the real time imaging pipeline). During the course of 2012/13 all the data collected by the MWA will be transported via a dedicated 40 Gbit WAN network link between the Murchison Radio Observatory (MRO) and Perth (760 km). However, this network will not be available for some time and until then data will be transported on disk arrays instead. Once in Perth, data will be ingested into a tape library. The archiving process itself consists of various steps executed either at the MRO site or in Perth and makes use of a modified version of the archiving system from ALMA. This includes the extraction of meta-data from the original raw data and the ingestion and generation of the appropriate data links for the MWA archive. The MWA correlator generates a collection of small files all belonging to the same observation. In order to optimise the network transfer and the storage of those files they are transparently packed into larger containers at the MRO site and subsequently handled as one big file. This paper describes the setup of the MWA archiving infrastructure.

8451-44, Session 10

ESO archive data and metadata model

A. Dobrzycki, C. da Rocha, I. Vera Sequeiros, M. Vuong, T. Bierwirth, V. Forchí, N. Fourniol, C. Moins, S. Zampieri, European Southern Observatory (Germany)

We present the data and metadata handling model utilised in the ESO Archive activities.

The ESO Archive is one of the biggest astronomical archives in the world, combining two roles: science and operational. Both roles recently underwent significant upgrades. In addition to storage and bookkeeping of data obtained at the ESO telescopes and internally generated products, the archive now employs a new infrastructure for handling inflow of processed data generated by PIs (the "Phase 3" data). On the data delivery end of the activities, the archive now uses the new request-handling tool, allowing for delivery of data via download manager. The request handler now allows to utilise a new tool for associating raw frames from the Paranal Observatory instruments with calibration frames.

Those rather diverse activities utilise a model in which frame metadata are separated from the data upon ingest to the archive and stored in a metadata warehouse. Both data and metadata are considered archive assets. A separate infrastructure is employed for controlling access to the assets and for publishing them. While data themselves are never modified, the model allows to update/augment the metadata. Updates may sometimes be necessary because of evolving ESO interface specifications, and sometimes because of the fact that this is an operational archive for a living observatory, which on occasions must abandon scheduled observations to accommodate ad-hoc observations of unanticipated transient phenomena.

Data and metadata are merged again when the relevant frames are requested. The delivered frames reflect the most up to date content.

8451-45, Session 11

The ALMA OT in early science: supporting multiple customers

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The ALMA Observatory is currently operating "Early Science" observing whereby a subset of antennas, receivers and commissioned observing modes are made available to the community while the observatory is still being constructed and commissioned. The Cycle0 and Cycle1 Calls for Proposals are part of this Early Science, and in both the ALMA Observing Tool plays a crucial role. Firstly as the primary ALMA tool to be used by prospective ALMA users from the community in preparing "Phase I" proposals, and secondly as the tool used by ALMA staff to prepare "Phase II" detailed observing programmes. Furthermore the ALMA OT is also used by the commissioning team to develop and verify new observing modes and capabilities for future cycles. Lastly the tool is also used for antenna verification procedures.

This paper describes briefly how the ALMA OT tackles the problem of making millimeter/submillimeter interferometry accessible to the wider community, while allowing commissioning users and "experts" the power and flexibility they need. The intelligence behind the comparatively simple user interface and how it aids the users is outlined.

We will also describe our approach to the challenges of supporting the multiple customers, and explore the lessons learnt from the Early Science experiences. Finally we will look ahead to the challenges presented by future observing cycles, the additional capabilities they will introduce, and the continuing need to keep ALMA easy to use.

8451-46, Session 11

Evolution of the phase 2 preparation and observation tools at the VLT

D. Dorigo, T. Bierwirth, Y. Jung, F. Sogni, European Southern Observatory (Germany)

Throughout the course of many years of observations at the VLT, the phase 2 software applications supporting the specification, execution and reporting of observations have been continuously improved and refined. Specifically the introduction of astronomical surveys propelled the creation of new tools to express more sophisticated, longer-term observing strategies often consisting of several hundreds of observations. During the execution phase, such survey programs compete with other service and visitor mode observations and a number of constraints have to be considered. In order to maximize telescope utilization and execute all programs in a fair way, new algorithms have been developed to prioritize observable OBs taking into account both current and future constraints (e.g. OB time constraints, technical telescope time) and suggest the next OB to be executed. As a side effect, a higher degree of observation automation enables operators to run telescopes mostly autonomously with little supervision by a support astronomer.

We describe the new tools that have been deployed and the iterative and incremental software development process applied to develop them. We present our key software technologies used so far and discuss potential future evolution both in terms of features as well as software technologies.

8451-47, Session 11

Accelerated speckle imaging with the ATST visible broadband imager

F. Wöger, A. Ferayorni, National Solar Observatory (United States)

The Advanced Technology Solar Telescope (ATST), a 4 meter class telescope for observations of the solar atmosphere currently in construction phase, will generate data at rates of the order of 10 TB/day with its state of the art instrumentation.

The high-priority ATST Visible Broadband Imager (VBI) instrument alone will create two data streams with a bandwidth of 960 MB/s each.

Because of the related data handling issues, these data will be post-processed with speckle interferometry algorithms in near-real time at the telescope using the cost-effective Graphics Processing Unit (GPU) technology that is supported by the ATST Data Handling System.

In this contribution, we lay out the VBI-specific approach to its image processing pipeline, put this into the context of the underlying ATST Data Handling System infrastructure, and finally describe the details of how the algorithms were redesigned to exploit data parallelism in the speckle image reconstruction algorithms.

An algorithm redesign is often required to efficiently speed up an application using GPU technology; we have chosen NVIDIA's CUDA language as basis for our implementation.

We present our preliminary results of the algorithm performance using our test facilities, and base a conservative estimate on the requirements of a full system that could achieve near real-time performance at ATST on these results.

8451-48, Session 11

The MOSFIRE desktop: a highly customizable, GUI-building user interface for the MOSFIRE instrument

J. L. Weiss, Univ. of California, Los Angeles (United States)

At an observatory like the W. M. Keck Observatory, there are many users of an instrument, including the astronomers, the support astronomers, and the engineers, each with their own idea of how the user interface should look. With the MOSFIRE Desktop, the instrument interface can be easily tailored to the needs of the specific user, and GUIs specific to that user can be rapidly created simply by editing XML GUI specification files without any coding or rebuilding necessary. Built around the flexibility of MVC and the extensibility of Java, the MOSFIRE Desktop links the standard Keck KTL keyword layer to customizable widgets that can display and modify keyword values in a number of ways. Widgets can be arranged in custom dialogs, and dialogs can be arranged in custom desktops, all encapsulated in XML definition files for preservation. Due to abstraction, the Desktop system could be modified to work with any number of data models or instrument and observatory architectures. This paper describes the system, and explores how the Desktop could be extended for use beyond the Keck paradigm.

8451-49, Session 11

Advanced PANIC quick-look tool using Python

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PANIC, the Panoramic Near Infrared Camera, is an instrument for the Calar Alto Observatory which is currently being integrated in laboratory and whose first light is foreseen for this year. PANIC will provide a copious stream of new, high-quality astronomical data. Nowadays, modern IR instruments must be equipped with software well suited to a wide range of purposes starting from the low level controls and going through acquisition, handling, fast quick-look of data and full science data reduction. We present here how the PANIC Quick-Look tool (PQL) and pipeline (PAPI) are being implemented, leveraging existing rapid programming Python technologies and packages, together with well-known astronomical software suites (Astromatic, IRAF) and parallel processing techniques. The goal is to provide scientists with a friendly quick inspection tool for PANIC datasets, which will allow a first order background subtraction, flatfielding and astrometric and flux calibration. The PQL is integrated with the Observation Tool (OT), in order to get the metadata (data about data contents) for data grouping. We will briefly describe the structure of the PQL tool, whose original characteristics are in the use of the SQLite database and PyQt, a Python binding of the GUI toolkit Qt.

8451-50, Session 12

Astro-WISE information system

E. A. Valentijn, A. Belikov, G. Verdoes Kleijn, SRON Nationaal Instituut voor Ruimteonderzoek (Netherlands)

Astro-WISE (http://www.astro-wise.org) is an astronomical information system in which geographically distributed research communities collaboratively perform processing and scientific analysis of wide-field imaging surveys.

The system includes a grid of data storage and data processing facilities and is integrated with the BiGGrid (Dutch National Grid Initiative) processing facilities.

Astro-WISE supports survey operations: calibration, quality assessment control, archiving and publishing (also to Virtual Observatory), scientific analysis (for example variability studies, morphometry and photometric redshift determination), i.e. the processing from raw to final products and scientific results.

All data products are stored in the system with full data lineage.

The user can trace back the data processing chain and processing parameters used up to raw data.

Astro-WISE implements a sophsticated access right system including private and public environments (from 'myDB' to public Virtual Observatory) .

Users can be grouped in projects to share data and and its processing for particular instrument or survey.

The Kilo Degree Survey consortium uses Astro-WISE to deliver its 440 night survey.

In addition, Astro-WISE supports data processing for other surveys (e.g., VIKING, Coma Legacy Survey, WFI at MPG/ESO 2.2m surveys) and about a dozen instruments, (OmegaCAM at VST, VIRCAM at VISTA, WFC at INT, MegaCAM at CFHT, SuprimeCAM at Subaru).

The public-private Target project (http://www.rug.nl/target) develops information systems based on the Astro-WISE concept, including LOFAR Long-Term Archive and Multi Unit Spectroscopic Explorer (MUSE) data processing. Presently the Target infrastructure hosts 10 Petabytes of data storage.

The talk will explain the concept behind Astro-WISE system and will demonstrate integrated quality control system of Astro-WISE, web services for data browsing and processing, adaptability to changes in the data model and pipelines, forward and backward chaining in the dependencies of the data items in the system and distributed data storage and processing.

8451-51, Session 12

EVALSO, a high-bandwidth communication infrastructure to efficiently connect the ESO Paranal and the Cerro Armazones observatories to Europe: demonstration activities and start of operations

R. Lemke, R. Chini, Ruhr-Univ. Bochum (Germany); F. Comeron, G. Filippi, European Southern Observatory (Germany); J. Emerson, Queen Mary, Univ. of London (United Kingdom); K. Kuijken, Leiden Univ. (Netherlands); D. Dobrzycka, European Southern Observatory (Germany); A. Wright, European Southern Observatory (Chile); S. Zampieri, European Southern Observatory (Germany); F. Liello, Univ. degli Studi di Trieste (Italy)

EVALSO (Enabling Virtual Access to Latin-American Southern Observatories) is an international consortium of nine astronomical organisations, and research network operators, part-funded under the European Commission FP7, to create and exploit high-speed bandwidth connections to the observatories of Cerro Paranal and Cerro Armazones

in Chile. The communication infrastructure was delivered in November 2010 and this paper reports on the initial results of the project and the demonstrations of its capabilities, including the possibilities that the new infrastructure opens up in the geographically distributed operation of the observatories.

8451-52, Session 12

Enabling efficient electronic collaboration between LIGO and other astronomy communities using federated identity and COmanage

S. Koranda, Univ. of Wisconsin-Milwaukee (United States); H. Flanagan, Internet2 (United States); M. Huynh, Univ. of Wisconsin-Milwaukee (United States); K. Klingenstein, B. Oshrin, Internet2 (United States)

Identity federations throughout the world including InCommon in the United States, SURFnet in the Netherlands, DFN-AAI in Germany, GakuNin in Japan, and the UK Access Management Federation for Education and Research have made federated identities available for a large number of astronomers, astrophysicists, and other researchers. The LIGO project has recently joined the InCommon federation and is beginning the process to both consume federated identities from outside of LIGO and to make the LIGO identities issued to collaboration members available for consumption by other research communities.

Leveraging federated identity, however, is only the beginning. Realizing the promise of multi-messenger astronomy requires efficient collaboration among individuals from multiple communities. Efficient collaboration begins with federated identity but also requires robust collaboration management platforms providing consistent, scalable identity and access control information to collaboration applications including wikis, calendars, mailing lists and science portals. LIGO, together with collaborators from Internet2, is building the COmanage suite of tools for Collaborative Organization Management. Using COmanage and leveraging federated identities we plan to streamline electronic collaboration between LIGO and other astronomy projects so that scientists spend less time managing accounts and access control and more time doing science.

8451-53, Session 12

REMOTES: a reliable and modular telescope solution for seamless operation and monitoring of various observation facilities

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Astronomers often need to put several pieces of equipment together and have to deploy them at a particular location. This task could prove to be a really tough challenge, especially for distant observing facilities with intricate operating conditions, poor communication infrastructure and unreliable power source. To have this task even more complicated, they also expect secure and reliable operation in both attended and unattended mode, comfortable software with user-friendly interface and full supervision over the observation site at all times.

During reconstruction of the D50 robotic telescope facility, we faced many of the issues mentioned above. To get rid of them, we based our solution on a flexible group of hardware modules controlling the equipment of the observation site, connected together by the Ethernet network and orchestrated by our management software. This approach is both affordable and powerful enough to fulfill all of the observation requirements at the same time. We quickly figured out that the outcome of this project could also be useful for other observation facilities, because they are probably facing the same issues we have solved during our project.

In this contribution, we will point out the key features and benefits of the solution for observers. We will demonstrate how the solution works at our observing location. We will also discuss typical management and maintenance scenarios and how we have supported them in our solution. Finally, the overall architecture and technical aspects of the solution will be presented and particular design and technology decisions will be clarified.

8451-54, Session 12

A symbiotic relationship between HST and JWST operations software systems development

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The Space Telescope Science Institute was awarded the contract for the James Webb Space Telescope Science Operations, to use their Hubble Space Telescope Science Operations expertise in developing this new mission. Not only has JWST development benefitted from this arrangement, but so has HST development and operations. Systems that are common to both missions have been undergoing changes and improvements needed for JWST. HST systems have been able to take advantage of those improvements, which might not have been possible with HST resources alone, while providing a free, live testbed for further JWST development. This paper will describe some of the improvements HST systems have undergone and how they have helped an aging mission keep up with newer technologies. Some of these improvements include a visual tool for defining mosaic observing, a new scheduling engine and resource model for more efficient planning of observations, a secure web interface for maintaining personal information on investigators, better database maintenance and documentation, and a different desktop computing environment for HST Operations.

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8452-01, Session 1

A new era of wide-field submillimetre imaging: on-sky performance of SCUBA-2

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SCUBA-2 is the largest submillimetre wide-field bolometric camera ever built. This 43 square arc-minute field-of-view instrument operates at two wavelengths (850 and 450 microns) and has been installed on the James Clerk Maxwell Telescope on Mauna Kea, Hawaii. SCUBA-2 has been successfully commissioned and operational for general science since October 2011. This paper presents an overview of the on-sky performance of the instrument during and since commissioning in mid-2011. The on-sky noise characteristics and NEPs of the 450um and 850um arrays, with average yields of approximately 3600 bolometers at each wavelength, will be shown. The observing modes of the instrument and the on-sky calibration techniques are described. The culmination of these efforts has resulted in a scientifically powerful mapping camera with sensitivities that allow a full degree of sky to be mapped to 10 mJy/beam (850um) and 60 mJy/beam (450um) rms in good weather in under an hour and a half.

8452-02, Session 1

The NIKA 2011 run: results and perspectives towards a resident camera for the Pico Veleta Observatory

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The Néel Iram Kids Array (NIKA) is a prototype instrument devoted to millimetric astronomy that has been designed to be mounted at the focal plane of the IRAM 30-meter telescope at Pico Veleta (Spain). After the runs of 2009 and 2010, we carried a third technical run in October 2011. In its latest configuration, the instrument consists of a dual-band camera, with bands centered at 150GHZ and 220GHz, each of them equipped with 116 pixels based on Lumped Element Kinetic Inductance Detectors.

During the third run we tested many improvements that will play a crucial role in the development of the final, kilopixel sized camera. In particular, a new geometry based on a Hilbert curve has been adopted for the absorbing area of the LEKIDs, that makes the detectors dual-polarization sensitive. Furthermore, a different acquisition strategy has been adopted, which has allowed us to increase the photometric accuracy of the measurements, a fundamental step in order to get scientifically significant data.

In this paper we describe the main characteristics of the 2011 NIKA instrument and outline some of its key features, discussing the results we obtained and giving a brief outlook on the future NIKA camera which will be installed permanently on site.

8452-03, Session 1

First observations with SuperCam and future plans

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SuperCam is a 345 GHz, 64-pixel heterodyne imaging spectrometer for the Heinrich Hertz Submillimeter Telescope (HHSMT). By integrating SIS mixer devices with Low Noise Amplifiers (LNAs) in 8 - 1x8 modules, the size needed for the cryostat and the complexity of internal wiring is significantly reduced. All subsystems including the optics, cryostat, bias system, IF boxes, and spectrometer have been integrated for all 64 pixels. In the fall of 2011, the optics were installed in the apex room of the HHSMT. In the spring of 2012, SuperCam will be installed and the receiver will begin its survey of 500 square degrees of the Galactic plane in 12CO J=3-2. This large-scale survey will help answer fundamental questions about the formation, physical conditions, and energetics of molecular clouds within the Milky Way. The data set will be available via the web to all interested researchers. In this paper we will present the results of the first SuperCam engineering run on the HHSMT and discuss future plans for the instrument.

8452-04, Session 1

Status of MUSIC, the multicolor submillimeter inductance camera

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We present the status of MUSIC, the Multicolor Submillimeter Inductance Camera, a new instrument for the Caltech Submillimeter Observatory. MUSIC has a 14' field of view consisting of 2304 detectors in 576 spatial pixels and four spectral bands at 0.86, 1.0, 1.3, and 2.0 mm. MUSIC will be used to study dusty star-forming galaxies, galaxy clusters using the Sunyaev-Zeldovich effect, and star formation in our own and nearby galaxies. It uses broadband superconducting phased-array slot dipole antennas to form beams, lumped element on-chip bandpass filters to define spectral bandpasses, and microwave kinetic inductance detectors to sense incoming light. The instrument uses a pulse tube cooler and 3He/3He/4He closed-cycle cooler to provide a sub-250 mK base temperature. Dielectric and metal-mesh filters are used to block thermal infrared radiation. The focal plane is fabricated in 8 tiles consisting of 72 spatial pixels each. The focal plane resides in a multi-layer magnetic shield and is coupled to the telescope via a warm ellipsoidal mirror and a cold reimaging lens. A cold stop sits at the image of the primary formed by the ellipsoid. Each focal plane tile is read out by a single pair of coaxes and a HEMT amplifier. The readout system consists of 16 copies of custom-designed ADC/DAC and IF boards coupled to the ROACH platform. We focus on recent updates on the instrument design and results from the commissioning run of the full camera in early 2012.

8452-05, Session 1

First results of the polarimeter for the Large APEX Bolometer Camera (LABOCA)

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The Polarimeter fuer Bolometer-Kameras (PolKa) has been recently commissioned for operation in combination with the Large APEX Bolometer Camera (LABOCA) on the Atacama Pathfinder Experiment (APEX), a 12-m submillimeter telescope located at 5100 m.a.s.l. on Llano de Chajnantor in northern Chile.

This instrument, based on uncommon design solutions, working in combination with LABOCA has shown unprecedented capabilities at mapping linear polarization on relatively large scales with the resolution of 19 arcsec at 345 GHz in a relatively short time. We give an overview of the instrument, a description of the observing modes and an evaluation of the on-sky performance.

We also present some scientific results from observations done during the science verification that followed the commissioning. The polarimeter, developed and built by the Max-Planck-Institut fuer Radioastronomie (Bonn, Germany) has the status of a PI instrument, but is offered to the community through the APEX calls for proposals.

8452-06, Session 1

Design and first-light performance of TES bolometer arrays for submillimeter spectroscopy with ZEUS-2

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We have recently commissioned the 2nd generation redshift(z) and Early Universe Spectrometer (ZEUS-2) at the Caltech Submillimeter Observatory. ZEUS-2 is a long-slit grating spectrometer (R~1000) for observations in the submillimeter wavelength regime that is optimized for observations of redshifted far-infrared spectral lines from galaxies in the early universe. Here we report on the design and first light performance of the first TES bolometer array installed in ZEUS-2. This array features 280 pixels each 1.26 mm square and arranged to provide ~35 pixel spectra at ~8 spatial positions on the sky. A 1/4-wavelength back short of 100 micron and gold mesh absorber matching the impedance of free space provides near 90% quantum efficiency for the 350 and 450 micron telluric windows. Array readout is done using SQUID multiplexers and the Multichannel Electronics. We will also report on the progress to install two additional arrays tuned to provide similar performance across the remaining telluric windows between 200-850 microns.

8452-07, Session 2

Scaling the summit of the submillimetre: instrument performance of SCUBA-2

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SCUBA-2 is a revolutionary 10,000 pixel wide-field submillimetre camera, recently commissioned and now operational at the James Clerk Maxwell Telescope (JCMT). Twin focal planes, operating at wavelengths of 450 and 850 microns, each consist of four 32 by 40 sub-arrays of superconducting Transition Edge Sensor (TES) bolometers, forming the largest low temperature bolometer arrays in operation. SCUBA-2 was designed to map large areas of sky more than 100 times faster than the original ground breaking SCUBA instrument and has achieved this goal. In this paper we describe the performance of the instrument and present results of characterising the eight science grade TES bolometer arrays. We discuss the steps taken to optimise the setup of the TES arrays to maximize the mapping speed and show how critical changes to the sub-array module thermal design, the introduction of independent focal plane and 1K temperature control and enhancements to the cryogenics have combined to significantly improve the overall performance of the instrument.

8452-08, Session 2

TES arrays for the short wavelength band of the SAFARI instrument on SPICA

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SPICA is a Japanese-led mission to fly a 3.25 m diameter IR telescope with a cryogenically cooled mirror (~ 5 K). SAFARI is an imaging Fourier transform spectrometer instrument on SPICA that covers the wavelength range of 34-210 μm. It requires sensitive detector arrays with high optical coupling efficiency over extremely wide bandwidths ($\Delta\lambda/\lambda$ ~ 1).

In collaboration with a number of European institutes we are developing detectors for SAFARI's short wavelength band (34-60 μm).

These are based on TiAu TES bolometers with thin Ta film absorbers on silicon nitride (SiN) membranes, in which long and narrow SiN legs act as thermal links between the TES and the bath. We describe the design and the dark test results of our latest detectors that include measured dark NEPs of 4.2×10^-19 W/√Hz for a single pixel and 5-6×10^-19 W/√Hz for an array of 8×9. A high coupling efficiency can be achieved by using multi-mode coupling optics and detectors with thin Ta film absorbers.

It depends on the horn and cavity geometries, the effective impedance and area of the absorbing Ta films. We measure a coupling efficiency of 70% for a detector in a 500 μm diameter hemispherical cavity with an absorber area of 200×200 μm^2, a square resistance of 400 Ohms coupled to a conical horn with an exit aperture of 46 μm. Furthermore, we describe the design and measurements of optimized TES detector arrays coupled to square horn arrays in the wavelength range of 34-60 μm.

8452-09, Session 2

Ultra low-noise transition edge sensors for the SAFARI L-band on SPICA

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The Far-Infrared Fourier transform spectrometer instrument SAFARI-SPICA which will operate with cooled optics in a low-background space environment requires ultra-sensitive detector arrays with high optical coupling efficiencies over extremely wide bandwidths. We describe the design, fabrication and testing of 388-element arrays of MoAu Transition Edge Sensors (TESs) designed for the SAFARI L-band (110–210 μm) having measured noise equivalent powers in the low 10–19W/pHz, an improvement of two orders of magnitude over TESs for groundbased applications, and saturation powers of order 10 fW. The 100 × 100μm2 MoAu TESs have transition temperatures of order 100mK and are coupled to 320 × 320μm2 thin-film -phase Ta absorbers to provide impedance matching to the incoming fields. We describe optical measurements of representative pixels operated in a 500μm hemispherical cavity coupled to a conical horn and with flat back-shorts coupled to pyramidal horn arrays. The measured and modeled optical efficiency is dominated by the 90 sheet resistance of the Ta absorbers.

8452-10, Session 2

Measurements of the optical performance of the SPICA/SAFARI bolometer arrays

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We have measured the optical response of detectors for SAFARI, the far-infrared imaging spectrometer for the SPICA satellite. To take advantage of SPICA's cooled optics, SAFARI's three bolometer arrays are populated with extremely sensitive (NEP~2×10^-19 W/rtHz) transition edge sensors with a transition temperature close to 100 mK. The extreme sensitivity and low saturation power (~4 fW) of SAFARI's detectors present challenges to characterizing them. We have therefore built up an ultra-low background test facility with a cryogen-free high-capacity dilution refrigerator, paying careful attention to stray-light exclusion. Our use of a pulse-tube cooler to pre-cool the dilution refrigerator required that the SAFARI Detector System Test Facility provide a high degree electrical, magnetic, and mechanical isolation for the detectors. We have carefully characterized the performance of the test facility in terms of background power loading. The test facility has been designed to be flexible and easily reconfigurable with internal illuminators that allow us to characterize the broad-band and spectral response of the detectors. We describe the test facility and the steps we took to create an ultra-low background test environment. We present the results of our optical measurements and discuss them in terms of the SAFARI detector performance.

8452-11, Session 2

Hybridized, kilopixel, backshort-under-grid bolometer arrays with superconducting through wafer vias for far infrared imaging, spectroscopy, and polarimetry

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We have demonstrated a technology for the production of 1,280 pixel, high-filling-fraction long wave infrared through millimeter bolometer arrays. The Backshort-Under-Grid (BUG) array architecture is composed of three individual components merged into a single operating unit through the use of superconducting Through Wafer Vias (TWV) and indium bump bonding. The superconducting transition edge sensor (TES) bolometer array has a quarter-wavelength resonance backshort integrated, mechanically, into the suspension grid structure for high efficiency optical coupling. The bolometer-backshort assembly is hybridized, through the use of indium bump bonds, to superconducting quantum interference device (SQUID) multiplexer readouts. We have optimized our Through Wafer Via process using Atomic Layer Deposited (ALD) superconducting TiN to coat the inner walls of the microvias, providing electrical connection from the TES bolometer to the SQUID readout. We report on the design, fabrication, and first electrical tests of kilopixel BUG arrays.

8452-64, Poster Session

POLOCAM: a millimeter wavelength cryogenic polarimeter prototype for MUSIC-POL

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MUSIC (Multiwavelength Sub/millimeter kinetic Inductance Camera) is a facility class instrument currently being built for ground-based astronomical observations at the Caltech Submillimeter Observatory (CSO) and utilizes a new type of superconducting detector that allows simultaneous four-color, multi-wavelength observations. Future plans for MUSIC include the development of a cryogenically cooled polarimeter (MUSIC-POL) that will be used in conjunction with MUSIC to map the polarized emission from Galactic molecular clouds at wavelengths of 0.85 - 2 mm. As a proof-of-concept, we have constructed and tested a working cryogenic polarimeter in the laboratory as a prototype for MUSIC-POL. The POLOCAM instrument consists of a rotating cryogenic polarization modulator (sapphire half-waveplate) and polarization analyzer (lithographic copper polarizers deposited on a thin film) placed into the optical path at the Lyot stop (4K cold pupil stop) in a cryogenic Dewar. We present an overview of the project, design and performance results of the POLOCAM instrument (including polarization efficiencies and instrumental polarization), as well as future application to the MUSIC-POL instrument.

8452-65, Poster Session

BoA: a versatile software for bolometer data reduction

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The Bolometer Array data analysis software (BoA) is a data reduction package that has been developed in the last few years to process data acquired with large bolometer arrays. It was initially designed to reduce the data acquired with the Large APEX Bolometer Camera (LABOCA). It is used every day to process data acquired with all bolometer array instruments at APEX, and it could also be used to analyse data coming from other present and future telescopes.

From the beginning, the main driver for the development of a new software has been modularity. As such, it has been easy to add functionalities for processing data obtained with the polarimater newly installed at APEX. In addition, the philosophy of BoA is to provide a user-friendly, easy to understand language for performing the reduction tasks. I will present the main features of this software and illustrate its use with various examples.

8452-66, Poster Session

Development of an extremely low background test facility for the SPICA-SAFARI on-ground calibration

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SAFARI is a far-infrared camera that is being developed by a European consortium led by SRON. It will be launched in 2020 onboard the SPace Infrared telescope for Cosmology and Astrophysics (SPICA) satellite, developed jointly by JAXA and ESA. SAFARI offers imaging spectroscopy and imaging photometry in the wavelength range of 35-210 μm with detector NEP of 2 10-19 W/√Hz. To reach this sensitivity TES (Transition Edge Sensor) detectors, operated at 50 mK, are used.

A cryogenic test facility for SAFARI on-ground calibration and characterization is being developed. The main design driver is the required low background of a few attoWatts per pixel. This prohibits optical access to room temperature and hence all test equipment needs to be inside the cryostat at 4.5K. The instrument parameters to be verified are interfaces with the SPICA satellite, sensitivity, alignment, image quality, spectral response, frequency calibration, and point spread function. The instrument sensitivity is calibrated by a calibration source providing a spatially homogeneous signal at the attoWatt level. This low light intensity is achieved by geometrical dilution of a 150K source to an integrating sphere. The beam quality and point spread function is measured by a pinhole/mask plate wheel, back-illuminated by a second integrating sphere. This sphere is be fed by a stable wide-band source, attenuated by ND filters and providing spectral lines via a cryogenic etalon.

8452-67, Poster Session

The DCU: the detector control unit of the SAFARI instrument onboard SPICA

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The SpicA FAR infrared Instrument (SAFARI) is a European instrument for the infrared domain telescope SPICA, a JAXA space mission. The SAFARI detectors are Transistor Edge Sensors (TES) arranged in 3 matrixes. The Detector Control Unit manages the readout of the TES by computing and providing the AC-bias signals (1 - 3 MHz) to the TES and by computing the demodulation of the returning signals. The DCU uses a specific technique to compensate for different system's delays: the BaseBand FeedBack (BBFB). This digital data processing is done for the 3500 pixels in parallel. Thus, to keep the DCU power budget within its allocation one have to specifically optimize the architecture of the digital circuit with respect to the power consumption.

We will present the DCU architecture. We will particularly focus on the BBFB technique and on the optimization done to reduce the power consumption of the digital processing circuit.

8452-68, Poster Session

A generic readout system for astrophysical detectors

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We have developed a generic digital architecture to fulfill the needs for the development of new detectors in astrophysics, which is used in lab, for ground-based telescopes instruments and also in prototype versions for space instruments development.

This system is based on hardware FPGA electronic board (called MISE) together with software on a PC computer (called BEAR). The MISE board generates the fast clocking which reads the detectors thanks to a programmable digital sequencer and performs data acquisition, buffering of digitalized pixels outputs and interfaces with others boards. The data are then sent to the PC via a SpaceWire or Usb link. The BEAR software sets the MISE board up, makes data acquisition and enables the visualization, processing and the storage of data in line. These software tools are made of C++ and Labview (NI) on a Linux OS.

MISE and BEAR make a generic acquisition architecture, on which dedicated analog boards are plugged, so that to accommodate with detectors specificity: number of pixels, the readout channels and frequency, analog bias and clock interfaces.

We have used this concept to build a camera for the P-ARTEMIS project including a 256 pixels sub-millimeter bolometer detector at 10Kpixel/s (SPIE 7741-12 (2010)). For the EUCLID project, a lab camera is now working for the test of CCDs 4Mpixels at 4*200Kpixel/s. Another is working for the testing of new near infrared detectors (NIR LFSA for the ESA TRP program) 110Kpixels at 2*100Kpixels/s. Other projects are in progress for the space missions PLATO and SPICA.

8452-69, Poster Session

RF characterization of a cold-electron bolometer integrated with a unilateral finline

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The Cold-Electron Bolometer (CEB) is a very sensitive millimetre-wave detector with high saturation power, fast response and is easy to integrate with planar circuits. We have designed, fabricated and tested CEB detectors integrated across the slot of a unilateral finline on silicon substrate. Bolometers were fabricated using e-beam direct-write trilayer technology. The CEB performance was tested in a He3 sorption cryostat HELIOX-AC-V at a bath temperature of 310 mK. DC IV curves were measured in a current bias mode and optical response was measured by irradiating samples with signals from a black body source mounted inside the cryostat. The finline chip with CEB device was mounted in a waveguide block and connected to the readout system by bond-wires. The RF signal was focused onto the waveguide input using a horn. The signal response was measured by comparing different IV curves in current-biased mode at different RF source temperatures. The voltage response obtained from the IV curves was about 155 uV for 15 K RF source temperature difference, which corresponds to the voltage to power response of dV/dP = 1.52x10^7 V/W. The measured total votage noise is Vn = 15 V/Hz^1/2. In this paper we shall report details of the experimental measurements and through analysis of the experimental results.

8452-70, Poster Session

Phase-controlled polarization modulators

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We report technology development of millimeter/submillimeter polarization modulators that operate by introducing a a variable, controlled phase delay between two orthogonal polarization states. The variable-delay polarization modulator (VPM) operates via the introduction of a variable phase delay between two linear orthogonal polarization states, resulting in a variable mapping of a single linear polarization into a combination of that Stokes parameter and circular (Stokes V) polarization. Characterization of a prototype VPM is presented at 350 and 3000 microns. We also describe a modulator in which a variable phase delay is introduced between right- and left- circular polarization states. In this architecture, linear polarization is fully modulated. Each of these devices consists of a polarization diplexer parallel to and in front of a movable mirror. Modulation involves sub-wavelength translations of the mirror that change the magnitude of the phase delay.

8452-71, Poster Session

Water vapour radiometers for the Australia Telescope compact array

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We have developed Water Vapour Radiometers (WVRs) for the Australia Telescope Compact Array that are capable of determining excess path fluctuations by virtue of measuring small temperature fluctuations in the atmosphere using the 22.2 GHz water vapour line for each of the six antennae. By measuring the line of sight variations of the water vapour, the induced path excess and thus the phase delay can be estimated and corrections can then be applied during data reduction. This reduces decorrelation of the source signal. In this presentation, we discuss the design of the WVRs, an uncooled quadruple filter radiometer capable of detecting water line temperature fluctuations to a sensitivity of 12 mK. The design process of the WVRs is discussed with an emphasis on the modelled sensitivity requirements, filter placement, radio frequency interference mitigation and we conclude by demonstrating how this water vapour radiometry system recovers the telescope's efficiency and image quality as well as how this improves the telescope's ability to use longer baselines at higher frequencies, thereby resulting in higher spatial resolution.

8452-72, Poster Session

The cosmology large angular scale surveyor (CLASS): 40 GHz optical design

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The Cosmology Large Angular Scale Surveyor (CLASS) instrument will measure the polarization of the Cosmic Microwave Background at 40, 90, and 150 GHz from Cerro Toco in the Atacama Desert of northern Chile. In this paper, we describe the optical design of the 40 GHz telescope. The telescope is a diffraction limited catadioptric design consisting of a front-end Variable-delay Polarization Modulator (VPM), two ambient temperature mirrors, two cryogenic dielectric lenses, thermal blocking filters, and an array of 36 smooth wall scalar feed horn antennas. The feed horns guide the signal to antenna-coupled transition-edge sensor(TES) bolometers. Polarization diplexing and bandpass definition are handled on the same microchip as the TES. The feed horn beams are truncated at 10 dB edge taper by a 4 K Lyot-stop to limit detector loading from stray light and control the edge illumination of the front-end VPM. The field-of-view is 18 deg in diameter with a resolution for each beam on the sky of 1.5 deg FWHM.

8452-73, Poster Session

ALMA nutator design and preliminary performances

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We report the past two years of collaboration between the different actors on the ALMA nutator. Building on previous developments, the nutator had seen changes in most of the design. A high modulus carbon fiber structure had been added on the back of the mirror in order to transfer the voice coils efforts without deformations, thus eliminating delay problems. The controller is now an off the shelf NI-cRIO, and the amplifier a class D drive from Advanced motion controls, with high peak power able to drive the coils at 300VDC. The stow mechanism had been totally redesign to improve on the repeatability and precision of the stow position, which is also the reference for the 26 bits Heidenhain encoders. This also improve on wind load capability. Finally, the software, written largely with NI LabView's, had been extensively developed. We will discuss these changes and the preliminary performances achieved.

8452-74, Poster Session

Large-aperture, wide-bandwidth, antireflection-coated silicon lenses for ACTPol

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The increasing scale of cryogenic detector arrays for millimeter-wavelength astrophysics has led to the need for large, high-efficiency, cryogenic optics with excellent polarization properties. High purity Silicon has a high thermal conductivity, high refractive index and low loss within the millimeter wave bands. With a suitable anti-reflection coating Silicon serves as a nearly optimal material for refractive optics. Single crystal silicon ingots have been grown as large as 450 mm in diameter. We describe the pros and cons of a range of anti-reflection coating techniques, primarily focusing on simulated-dielectric coatings created by removing material from the surface. We present the details of design (including tolerances), fabrication, and measurement of the lenses fabricated for ACTPol; a cosmic microwave background polarization experiment. These lenses are up to 33.4 cm in diameter and incorporate a two-layer polarization-symmetric simulated-dielectric anti-reflection coating micro-machined using a silicon dicing saw. This coating is optimized to operate in a 50 GHz wide band centered at 145 GHz at angles of incidence up to 30 degrees. The band average reflectance is ~<0.1% at normal incidence and ~<0.5% at an oblique incidence of 30 degrees which is a significant improvement over a simple quarter-wave anti-reflection layer.

8452-75, Poster Session

Stereolithographed W-band waveguide components for large-format array instruments

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Radio to millimeter wave instruments to be used use in future astronomical projects need large format arrays of hundreds if not thousands of pixels in order to reach the highest sensitivity. Projects dedicated to the detection of B-modes of the Cosmic Microwave Background will also require exquisite RF performance that only waveguide components can deliver. These focal plane arrays will then require light and easily mass-produced waveguide components.

We are reporting on the development and characterization of W-band (75 - 110 GHz) waveguide components (waveguides, corrugated horns and OMTs) made of metal coated plastic. While these components are light and easy to manufacture they retain the high RF performance associated with similar metallic devices.

8452-76, Poster Session

Aperture and spill-over measurements in the Atacama Cosmology Telescope

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The Atacama Cosmology Telescope (ACT) is a 6 m telescope designed to map the Cosmic Microwave Background (CMB) simultaneously at 145 GHz, 220 GHz and 280 GHz.

The receiver in ACT, the Millimeter Bolometer Array Camera, features 1000 TES bolometers in each band. The detector performance depends critically on the total optical loading, requiring the spill-over contributions from the optics to be minimal. This inspired the use of a Lyot Stop to limit the illumination of the primary and the use of guard rings surrounding the primary and secondary reflectors. Here we present a direct measurement of the illumination aperture for both reflectors and of the attenuation level outside the main optical path. We used a 145 GHz, 1 mW source and a chopper wheel to produce a time-varying signal with a broad beam profile. We sampled the response of the camera for different locations of the source, placed in front and beside the primary or secondary mirrors. The aperture of the primary was measured to be 5.72 (+-0.17) m in diameter (95(+-3)% of its geometrical size), while the aperture of the secondary yielded 2 (+-0.12) m in diameter. Both apertures are consistent with the optical design. We found that the attenuation outside the primary aperture was -16 (+-2) dB, which is above the theoretical expectations, and -22 (+-1) dB outside the secondary aperture, which is consistent with simulations. These results motivated the extension of the baffles surrounding the secondary mirror, with the following reduction in detector optical loading from 2.24 pW to 1.88 pW.

8452-77, Poster Session

Far-sidelobe measurements in the Atacama Cosmology Telescope

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The Atacama Cosmology Telescope (ACT) is a 6 m telescope designed to map the Cosmic Microwave Background (CMB) simultaneously at 145 GHz, 220 GHz and 280 GHz. It's off-axis Gregorian design is intended to minimize far sidelobes, which is critical for science purposes. The expected sidelobe level for this kind of design is less than -50 dB and are difficult to measure. Here we present a measurement of the 145 GHz far sidelobes of ACT done on the near-field. We used a 1 mW microwave source placed 13 meters away from the telescope and a chopper wheel to produce a varying signal that could be detected by the camera for different orientations of the telescope. The source feed was designed to produce a wide beam profile. Given that the coupling is expected to be dominated by diffraction over the telescope shielding structure, we propose that this setup behaves in a similar way to a source placed in the far-field. Our results show that the far sidelobe level is consistently below -75 dB, satisfying the design expectations.

8452-78, Poster Session

Optical performance of the Keck array polarimeter at the South Pole

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The Keck Array is a suite of degree-scale microwave polarimeters that observe from the South Pole in search of a signature of Inflation imprinted as B-mode polarization in the Cosmic Microwave Background (CMB). After a successful first season of observation with the initial three receivers, the Keck Array is currently in its second season of observing, now with five receivers for increased sensitivity. The Keck Array follows the field-proven BICEP/BICEP2 strategy of using small, cold, on-axis refractive optics, allowing for excellent control of systematics while maintaining a large field of view. We characterize the far-field performance of each receiver in situ using microwave sources. I will discuss the performance of the Keck Array optical system, including beam shape, polarization efficiency and polarization angle, ghost images, sidelobe response, and directional mismatch of orthogonal polarization detector pairs.

8452-80, Poster Session

Experimental performance comparison of two polarimeter techniques for CMB applications

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Polarisation modulators are necessary for present and next generations of CMB polarisation experiments. Because of the very faint B-mode signal expected, these instruments have not only to be extremely sensitive but also to have low and well-characterised systematic effects.

The beam RF characterisation of two polarimeter pixels using the same corrugated horn and waveguide Ortho-Mode Transducer (OMT) has been performed. They have been assembled and tested with two different modulators: a waveguide rotator modulator and a quasi-optical half-wave plate.

We present for each modulator technology the co- and cross-polarisation beam measurements that have been characterised using a W-band (75-110GHz) Vector Network Analyser. The comparison of their beams with the one produced by their common system composed of the corrugated horn and the OMT is showing the systematic effects introduced by each modulator. The beams have been integrated across the bandwidth in order to deduce the overall cross-polarisation of each pixel while complementary measurements are giving the return and insertion losses.

8452-81, Poster Session

A negative refractive index metamaterial wave plate for millimetre-wave applications

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Wave plates are used to modulate the polarisation of radiation passing through them. By using birefringent materials of a specific thickness it is possible to induce a phase shift between the two orthogonal linear polarisation components. This phase shift is proportional to the birefringence of the material which in many materials is of the order of a few tenths.

Here we use metamaterials, artificially made sub-wavelength structures that are arranged periodically, to create wave plates that have very large birefringence by virtue of having refractive indices of different signs in each axis. With large birefringence comes the ability to create plates that can have sub-wavelength thicknesses. However such wave plates are narrow band in nature due to the requirement of producing a resonance to create a negative refractive index band. We overcome this by applying Pancharatnam's theory to cascade these wave plates with their axes rotated with respect to each other to increase the usable bandwidth.

We design the metamaterial cell structures with finite element analysis software (Ansoft HFSS) and optimise the wave plate design using transmission line theory. The wave plate's construction is based on the photolithographic techniques used to build metal mesh filters. The experimental results from prototypes are compared to the expected modelled predictions.

8452-83, Poster Session

The optical design of the QUBIC beam combiner

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The Q and U Bolometric Interferometer for Cosmology (QUBIC) is a ground-based interferometer that aims to meet one of the major challenges of modern cosmology in the detection of B-mode polarization anisotropies in the Cosmic Microwave Background. B-mode anisotropies originate from tensor fluctuations of the metric produced during the inflationary phase of the early Universe. Their detection would therefore constitute a major step towards understanding the primordial Universe. The expected level of these anisotropies is however so small that detection requires instruments with high sensitivity and extremely good control of systematic effects.

The QUBIC instrument is based on the novel concept of bolometric interferometry, and exploits the sensitivity advantages of bolometric detectors along with the greater control of systematics offered by interferometry.The instrument will directly observe the sky through an array of entry horns whose signals will be combined optically onto an array of bolometers cooled to around 300mK. The whole set-up is located inside a cryostat. The sensitivity of the instrument is maximised if equivalent baselines produce identical fringe patterns on the focal plane. This requires the minimization of wavefront aberrations for a wide field-of-view and a fast system. We present here the quasi-optical design and analysis of the dual reflector designed to do this. We report on the loss of sensitivity for different levels of optical aberration in the combiner.

The sensitivity of the QUBIC instrument is comparable with that of an imager with the same number of horns but with much greater control over systematics.

8452-84, Poster Session

Development of the experimental interferometer for ALMA

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The ALMA Experimental Interferometer (AEI) appeared as an infrastructure solution to increase both ALMA time availability for science activities and time availability for Software testing and Engineering activities at a reduced cost (<30000K USD). A joined effort between ADC and ADE-IG took the challenge of generate the Experimental Interferometer from an already defined design for operations which imposed a lot of complex restrictions on how to implement it. Through and intensive design and evaluation work it was determined that is possible to make an initial implementation using the ACA Correlator and now it is also being tested the feasibility to implement the Experimental Interferometer connecting antennas at AOS with Correlator equipment installed at the OSF, separated by 30 Km. app. Lastly, efforts will be done to make work interferometry between AOS and OSF Antennas adding a new baseline of 30Km. approximately.

8452-85, Poster Session

Nonequilibrium superconductivity in kinetic inductance detectors due to readout power dissipation

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Superconducting Kinetic Inductance Detectors (KIDs) are attractive candidates for realising large arrays of very high sensitivity detectors for astronomical observations. The KID consists of a thin superconducting film patterned to form a high-Q resonator, which is operated at a temperature well-below the transition temperature of the superconductor Tc. An important consideration is that the microwave probe signal that is used to readout the resonator as, for example, incident optical power or photon fluxes are changed is itself dissipative and modifies the quasiparticle distribution. The interaction of the microwave probe signal with the superconducting resonator has been modeled using the approach described by Chang and Scalapino1 for the case where the photons of the probe have energies well-below the threshold for breaking Cooper pairs and at equilibrium temperatures well-below Tc. Quasiparticle and phonon distributions for the driven KID have been calculated as a function of probe-power levels and are found to be modified significantly from thermal distributions for typical experimental probe-powers. The driven transfer function S12 also deviates from that of the closest thermal distribution measured in the limit of zero probe-power. Ultimately dissipation by the probe limits the achievable sensitivity of the KID.

[1] J. J. Chang and D. J. Scalapino, J. Low Temp. Phys. 31, 1, (1978).

8452-86, Poster Session

MKID readout for 100-kilopixel arrays

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Microwave Kinetic Inductance Detector (MKID) arrays, with up to a 100 thousand detectors will likely power the next-generation of game-changing far-infrared (FIR) and mm-wave instruments, both for ground-based astronomical and space-based research applications. While the technology to build these arrays already exists, the digital processing of their signals remains a major challenge. We present an affordable, flexible and scalable readout solution supporting several thousands of pixels on a single multiplexed readout line. In order to process up to a billion data points per second in frequency domain, we rely on the fast-growing computing power of graphical processors (GPUs) in combination with commercially available digital sampling (ADC/DAC) electronics, and PCs. The approach aims to provide a solution that is both cheap (less than $10 per channel today, and becoming cheaper), scalable, and easily upgraded with the latest commercial technologies.

8452-87, Poster Session

Recent advances in the development of SWIFTS for broadband millimeter spectroscopy

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We present latest developments of the millimetric Stationary Waves Integrated Fourier Transform Spectrometer (SWIFTS) that uses the Kinetic Inductance Detectors (KID) technology. SWIFTS is an on-chip autocorrelator spectrometer where the incoming signal forms an interferogram by reflection in a short-circuited coplanar wave-guide. By collecting electromagnetic (EM) energy along the guide, one can retrieve this interference pattern. A subsequent off-line Fourier transform gives spectral information with a moderate resolution (~500-1000). The SWIFTS concept has already been proven to work in the optical and microwave (<20 GHz) bands. It will be useful in any application where integrated and broadband spectral analysis is needed, as an example it will be a practical alternative to Martin-Pupplet interferometer. In practice, fabrication of such a device is very challenging mostly because the set of detectors has to collect energy without destroying the interference pattern. As a consequence, design of the coupling parts is a crucial problem that has to be tackled with the help of EM simulation tools. We present here the SWIFTS principle of operation, details of fabrication, and the latest simulations and testing results.

8452-88, Poster Session

A 3mm multipixel SIS receiver for Pico Veleta Telescope

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A 3mm band focal plane array heterodyne receiver is being developed for the IRAM 30-m telescope at Pico Veleta in the Sierra Nevada, Spain. This receiver will comprise 25 dual linear polarization pixels operating across the 80-116GHz nominal band. Design efforts are being made to enlarge the band to cover the full 3mm atmospheric transmission window available at Pico Veleta, i.e. 70-116GHz. The instrument will be coupled to the Pico Veleta Telescope via a purely reflective low-loss optical system that includes a de-rotator. The receiver will be based on 5 x 5 cryogenically cooled dual-linear polarized feedhorns cascaded with orthomode transducers (OMT) and side band separating (2SB) SIS mixers, a technology which offers state-of-the-art performances already used in other IRAM receivers.

8452-89, Poster Session

Electromagnetic design for SuperSpec, a lithographically-patterned millimeter-wave spectrograph

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SuperSpec is an innovative, fully planar, compact spectrograph for mm/sub-mm astronomy. SuperSpec is based on a superconducting filter-bank consisting of a series of planar half-wavelength filters to divide up the incoming, broadband radiation. The power in each filter is then coupled into titanium nitride (TiN) Lumped Element Kinetic Inductance Detectors (LEKIDs), facilitating the read out of a large number of filter elements. We will present electromagnetic simulations of the different components that will make up an R=700 prototype instrument. Antenna coupling, filter bank design and LEKID coupling optimisation will all be discussed.

8452-90, Poster Session

SuperSpec: circuit design

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SuperSpec is a pathfinder for future lithographic spectrometer cameras, which promise to energize extragalactic astrophysics at (sub)millimeter wavelengths: delivering 200--500 km/s spectral resolution over and octave bandwidth for every pixel in a telescope's field-of-view. We present circuit simulations that prove the concept, which enables complete millimeter-band spectrometer devices in just a few square-millimeters footprint. We evaluate both single-pole and two-pole channelizing filter designs, which separate channels into an array of broad-band detectors, such as bolometers or MKID devices. We discuss to what degree losses (by radiation or by absorption in the dielectric) and fabrication tolerances affect the resolution or performance of such devices, and what steps we can take to mitigate these effects. Such design studies help us formulate critical requirements on the materials and fabrication process, and help understand what practical limits currently exist to the capabilities these devices can deliver today or over the next few years.

8452-91, Poster Session

1.6 THz twin-slot antenna coupled NbN HEB mixers

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Here we report on a superconducting NbN twin-slot antenna coupled hot electron bolometer (HEB) mixer designed for 1.6 THz. Terahertz (THz) radiation is quasi-optically coupled to the HEB with an uncoated elliptical Si lens. Measured DSB receiver noise temperatures are 1500 K at 0.85 THz, 1200 K at 1.27 THz, 1100 K at 1.31 THz, 1100 K at 1.4 THz, and 1000 K at 1.63 THz,. The frequency dependence of the noise temperature is consistent with the FTS spectral response. The measured far-field beam patterns of the lens/antenna combination show nearly collimated beams with the side lobes below -15dB by adding a 40 micron extension to a standard Si elliptical lens, which is understood by a slightly lower dielectric constant of Si (Si) of 11.4 instead of 11.7 at lower temperatures. Such good performance makes it suitable for future high-resolution spectroscopic astronomical applications.

8452-92, Poster Session

Vertically illuminated TW-UTC photodiodes for terahertz generation

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More efficient continuous-wave photonic near-infrared mixers as terahertz sources are motivated by the need of more versatile local oscillators for submillimeter/terahertz receiver systems. So-called Uni-Travelling Carrier (UTC) photodiode are very prospective candidates for this in the submm-range, but have been reported so far as lumped-elements or as edge-illuminated optical waveguide integrated TW-devices. To overcome the associated power limitations, we are developing a novel concept for a traveling-wave (TW) photomixer by combining vertical velocity-matched illumination with a distributed UTC, a so-called velocity-matched TW-UTC PD. In-situ velocity matching of the beat-fringes of the line-foci of the two angled laser beams with the submm/THz-wave on the stripline, and therefore minimum frequency roll-off, is achieved by tuning the angle between the two laser beams. A first design of these TW-UTC PDs from our Terahertz Photonics Laboratory at University of Chile has been micro-fabricated at the MC2 cleanroom facility at Chalmers Technical University. Now we report and discuss results from first optical/terahertz testing of these novel devices.

8452-93, Poster Session

A 4mm spectroscopic dual-beam receiver for the Robert C. Byrd Green Bank Radio Telescope

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The Robert C. Byrd Green Bank Telescope, with a 100m aperture and recent improvements to its surface accuracy and servo system upgrades, is the most sensitive telescope operating at 90 GHz. A dual-feed heterodyne receiver has been developed for observations at the lower frequency end of the 3-4mm atmospheric window (67-93 GHz). The science goals are primarily molecular spectroscopic studies of star formation and astrochemistry, both internal and external to the Milky Way galaxy. Studies of the structure and physical properties of star-forming, cold-cloud cores will be revolutionized with molecular spectroscopy of the deuterium and other important species within the band. Essential for spectroscopy is the ability to remove slow gain and atmospheric variations. An optical table external to the cooled components rotates into the path of either beam: an ambient temperature load, an offset mirror for viewing an internal cold load, or a quarter wave plate that produces circular polarization for VLB observations. A composite waveguide window comprised of HDPE, Zitex, and z-cut quartz provides a high strength, low loss medium for transmission of the signal to the cooled corrugated feed horn. An orthomode transducer separates the polarization components which are amplified by low noise HEMT amplifiers. Warm W-band MMIC amplifiers are required to compensate a negative gain slope and to reduce noise contributions from the down conversion to the GBT IF frequencies. Initial science results and receiver performance during commissioning observations will be presented, along with details of the component design.

8452-94, Poster Session

Cryogenic analog-to-digital converters using spread spectrum technology for coherent receivers

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Device Labs. (Taiwan); T. Chiueh, National Taiwan Univ. (Taiwan); R. Hu, National Chiao Tung Univ. (Taiwan)

We propose a backend system with analog-to-digital converters (ADCs) with spread spectrum technology in cryogenic receivers or at warm room temperature. As receiver signals are processed and stored digitally, ADCs play a critical role in backend read-out systems. To minimize distortion, the down-converted signals should be digitized without further transportation. However, digitizing the signals in or near receivers may cause signal interference. We suggest that using spread spectrum technology can reduce the interference significantly.

Moreover, cryogenic ADCs at regulated temperature in mm/sub-mm receivers may also increase the bandwidth usage and simplify the backend digital signal process with fewer temperature-varied components before digitization. While semiconductor technology continuously alleviates ADC power consumption, low power high speed cryogenic ADCs may become a better solution for coherent receivers. To examine the impact of cooled ADCs on receivers, first, we design 4-bit 65nm CMOS ADC specifically in 10 K temperature condition, which commonly is the second stage temperature of dewars. The development of 65nm and 40 nm CMOS ADCs are still on-going. The estimated ENOB is 2.4 at 10 GSPS, corresponding to the correlation efficiency, 0.87. The power consumption is less than 20 mW, a small amount of thermal budget from modern coolers.

8452-95, Poster Session

A 4 GHz digital receiver using the UniBoard platform

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The Uniboard is a general purpose board, developed as a part of the Radionet FP7 program, that hosts 8 Altera Stratix5 FPGAs interconnected by high speed links. It can be used standalone or as a part of a more complex system.

The Digital receiver application uses a single Uniboard to implement a flexible packetization of a wideband signal in the frequency domain. It accepts a 4 GHz (8 GS/s) input bandwidth and provides up to 64 output bands. The bandwidth and position of each output band can be independently adjusted.

The input signal is first analyzed by a polyphase filterbank, that splits the input band into 32 sub-bands with a bandwidth of 190 MHz and a spacing of 128 MHz. The overlap among adjacent bands allows the positioning of the output bands without dead regions. This filterbank is followed by an array of digitally defined downconverters, each one composed of a mixer/LO and a variable decimation filter. The filter band can be adjusted in binary steps from 1 to 128 MHz. Using tap recirculation, the filter shape remains constant over this whole range, with about 80 dB of stopband rejection and 90% usable passband.

The output bands are packetized according to the VDIF VLBI standard, over eight 10G Ethernet links. Further processing can be done either on board, or in a cluster of conventional PCs.

In addition, high speed ADC are in-house developed (ASIC 65nm CMOS STmicroelectronics) to feed the Uniboard card with 8GS/s, 4GHz BW, 3bits samples.

8452-96, Poster Session

The UniBoard: generic hardware for radio astronomy signal processing

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The UniBoard is a generic high-performance computing platform for radio astronomy, developed as a Joint Research Activity in the RadioNet FP7 Programme. The hardware comprises eight Altera Stratix IV Field Programmable Gate Arrays (FPGAs) interconnected by a high speed transceiver mesh. Each FPGA is connected to two DDR3 memory modules and three external 10Gbps ports. In addition, a total of 128 low voltage differential input lines permit connection to external ADC cards. The DSP capability of the board exceeds 644E9 complex multiply-accumulate operations per second.

The first production run of eight boards was distributed to partners in The Netherlands, France, Italy, UK, China and Korea in May 2011, with a further production run underway in December 2011.

The function of the board is determined by the firmware loaded into its FPGAs. Current applications include beamformer and correlator for Apertif, digital receivers, RFI Mitigation for Pulsar Astronomy, and pulsar gating and a new correlator for the European VLBI network (EVN).

The latter uses an FX architecture with half the resources of the board devoted to station based processing: delay and phase correction and channelization, and half to the correlation function. A single UniBoard can process a 64MHz band from 32 stations, 2 polarizations, sampled at 8 bit. The total bandwidth of the correlator can be expanded by adding more UniBoards. The design is able to process both pre-recorded and real time (eVLBI) data.

8452-97, Poster Session

Practical implementation and on the field test results of an enhanced algorithm for polarization optimization of the line length corrector of ALMA central local oscillator

J. A. Castillo, ALMA (Chile) and Univ. de Chile (Chile); E. A. Michael, Univ. de Chile (Chile)

This paper describes the practical implementation and on the field test results of an Enhanced algorithm, based on Jones matrix Eigen analysis, to find the minimal polarization change points for the ALMA's line length corrector fiber stretcher. These points are complicated to find because they can be located at any point of the Poincare sphere and they also change after manipulation of fibers and with time, so the optimization of the fibers stretcher needs to be systematically checked and redone. The execution time of the previous algorithm takes up to 20 minutes depending on the starting polarization state. This enhanced algorithm reduces this time to less than a minute, with no dependency on the starting point.

8452-98, Poster Session

ALMA band 1 development at Universidad de Chile

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The lowest spectroscopic band devised for the Atacama Large Millimeter Array (ALMA), the so-called Band 1, covers the frequency range from 31 to 45 GHz. This band was not implemented during the first construction phase of the telescope, but will be most probably included during a second ALMA development phase. It will allow the study of several important phenomena, like molecular gas in high red-shift galaxies, high resolution CMB, and conventional observations of southern hemisphere targets. During the past 4 years our group has been working on the development of technology to cover this band, complying with the demanding ALMA specifications. Among the most burdensome challenges are the stringent specifications on noise temperature, the large required bandwidth, and the limited space available for this receiver within the ALMA cryostat. In this paper we present some of the technologies we have developed, including the design of key components, like the horn, lens, ortho-mode transducer, and low noise amplifiers. We also present an evaluation of third third-party components which can be used in the receiver. The work is used to present a preliminary layout of the Band 1 receiver.

8452-99, Poster Session

European low-noise MMIC technologies for cryogenic millimetre wave radio astronomical applications

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Low Noise technology has a paramount relevance on radiotelescopes and radiometers performances. Its influence on sensitivity and temporal stability has a deep impact on obtainable scientific results. As well known, front end active part of scientific instruments are cryocooled in order to drastically reduce the intrinsic noise of its electronic parts and consequently increase the sensitivity. In this paper we will describe the results obtained by an activity funded by the Italian Space Agency. The aim is to validate MMIC Low Noise Technologies and designs for cryogenic environments. As active device, HEMT (High Electron Mobility Transistor) are considered the best device for high frequency and low noise cryo applications. But not all the semiconductor foundry process are suitable for cryogenic applications. Two European Foundries has been selected and two different HEMT based Low Noise Amplifiers design had been produced. The main goal of this activity is identify an European technology substrate for space and ground based low noise cryogenic applications. Design, Layout, architecture, foundry process and results will be compared.

8452-100, Poster Session

Development of receiver and local oscillator components for Atacama large-millimeter/submillimeter array (ALMA) band-1 in Taiwan

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An international collaboration between Taiwan, Canada and Chile are formed to develop the components and cold cartridge assembly of the ALMA Band-1 receivers. In Taiwan, a series of 31.3-45.0GHz millimeter-wave components are developed for the ALMA band-1 receivers. The components are mainly based on 0.15-um GaAs MHEMT MMICs. The key components include two three-stage 31.3-45GHz low-noise amplifiers (LNA), bandpass or high-pass filters, a cascode PHEMT mixer and a 4-12GHz IF amplifier. The MMIC designs are iterated several times, the latest results measured by probe and then tested in packaged modules.

The 30-50GHz MMIC LNA exhibits 20-28 dB gain and 20-30K noise temperature under 16 K cryogenic temperature environments. The cascode PHEMT mixer uses a common-source transistor as gain stage and the following cascode transistor as mixing device. The measured results in the packaged module shows -5 to +2dB conversion gain under 2-dBm LO power over 4-14GHz IF frequency range. The filters designed and fabricated by GaAs foundry service shows in-band insertion loss less than 3 dB and the out-band rejection as high as 30-40dB.

The local oscillator aiming for 27.3-33GHz frequency tuning range is composed by a phase-locked GaAs HBT MMIC voltage-controlled oscillator cascaded by a buffer amplifier. For comparison on the phase noise performance, an ALMA baseline design based on the commercially available 13-17GHz YIG-tunes oscillator with active frequency doubler is also developed. The measured RMS jitter of the HBT VCO LO is around 51 fs and the version of YIG is less than 30fs over 1K to 1MHz frequency offset.

8452-101, Poster Session

A cryogenic set-up for accurate measurements of S-parameters

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State of the art receivers in the millimeter and sub-millimeter domain devoted to astrophysical measurements are using cryogenic front-ends which needs to be carefully characterized.

For this purpose we have developed a set-up to perform measurements of S-parameters on devices operated at low temperature, using a Vector Network Analyzer in combination with a cryogenic chamber. High accuracy in the characterization of the devices is obtained using a set of TRL calibration standards operated at the same cryogenic temperature of the DUT. Measurements have been performed on Front-End-Modules of mm-wave receivers including cryogenic LNA developed within our collaboration.

8452-102, Poster Session

The broadband backend for host country radio astronomy in the Spanish DSN Robledo complex

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The NASA Deep Space Network hosts three complexes worldwide for spacecrafts tracking. The Spanish complex, the Madrid Deep Space Communications Complex (MDSCC), operates a set of highly sensitive antennas, which are used for Host Country Radio Astronomy (HCRA) during a percentage of their operational time.

We have designed, developed and built a broad band backend for HCRA in MDSCC, which greatly improves its available facilities, and opens new scientific cases to be tackled. It is able to sample up to 6 GHz of instantaneous bandwidth, in the frequency range from 18 to 50 GHz, in two different antennas. An intermediate-frequency (IF) processor downconverts the two-polarization signals to four base-band channels of 1.5 GHz width. Digitalisation is done through a set of FPGA-based FFT spectrometers, which can provide spectral resolutions from 7 to 200 kHz, and spectral coverages from 100 MHz to 1.5 GHz each.

This new facility enables HCRA to afford new scientific projects, such as extragalactic radio astronomy and spectral surveys; at the same time, the available time for HC is greatly optimized. It was necessary the development of dedicated software for spectra acquisition and control of the equipment, and also the upgrading of the existing observing programs. Once end-to-end assembled, the whole backend was tested through a set of commissioning observations.

In this contribution the main features of the new backend are described, including the IF processor, the FFT spectrometer and the developed software. The commissioning results are also included.

8452-103, Poster Session

An 8 GHz digital spectrometer for millimeter-wave astronomy

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We have designed and tested a digital spectrometer suitable for analyzing 8 GHz baseband signals. It is based on a 16-Gsps, 5-bit ADC from e2v and a Stratix-IV FPGA employed for later filtering and signal processing. Digitized data is received and synchronized via twenty high-speed 4-Gbps transceivers integrated in the FPGA. A 64-channel polyphase filter bank separates the input signal into 250-MHz sub-bands, allowing subsequent high-resolution analysis. To obtain continuous spectral information over the input bandwidth, we have implemented a 50% overlapping architecture solution. Subsequently these sub-bands are processed using Fast Fourier Transform modules.

This system meets present-day demands on high-resolution wideband digital back-ends for millimeter-wave telescopes. This technology will be part of the next generation wideband correlator for the future upgrade of the IRAM Plateau de Bure interferometer (NOEMA project).

8452-104, Poster Session

The L-band 180° hybrid for the L-P dual-band coaxial receiver

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In this paper we will present two different configurations of 180° hybrids power combiners, to be used in the L-Band channel of the dual-band L-P (305-425 MHz - 1.3-1.8 GHz) coaxial receiver for the primary focus of the Sardinia Radio Telescopes (SRT). The devices will be different for both the architecture and the technology used. The first hybrid is based on a double ridge waveguide cavity that integrates also a band pass filter. This configuration has three ports consisting of N-type coaxial connectors whose central pins are connected to the launching probes located inside the double ridge waveguide structure. At cryogenic temperature the measured output reflection coefficient was less than -17 dB, the coupling and the phase difference between inputs and output was respectively, 3.0±0.25dB and 180°±0.90 over the full band. The second hybrid is based on the planar technology (in this case we adopted a microstrip). This configuration has four ports connected with SMA-type coaxial connectors, but with only three ports used to the shell, and the last one closed on a 50Ω load. At cryogenic temperature the measured output reflection coefficient was less than -24 dB, the coupling and the phase difference between the inputs and outputs were respectively, 3.0 ±0.45dB and 180°±5° over the full band. In the final section we will compare the two 180° hybrids to choose the one of them that gives the best performances for the dual-band coaxial receiver.

8452-105, Poster Session

From a MMIC chip to a working cryogenic low-noise amplifier: a detailed study on packaging

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Cryogenic Low Noise Amplifiers, based on MMIC HEMT technology, require a careful packaging to reach optimal performance. Differences between modeled and measured performance can often be related to chip mounting details. In the framework of the development of new cryogenic LNAs, described in a companion paper (see Cremonini et al.), we have developed a specific packaging to host W-band cryogenic MMIC LNAs. We present here some of the main factors analyzed in the package design and activities of the die chips integration inside LNA and the LNA integration along the radiometric chain. activities. In particular, mechanical and thermal modeling, LNA die chip gluing and adhesive properties, sensitivity to the die components assembling accuracy (i.e. deviation from the ideal orientation) , as well as the morphology of LNA body. Preliminary test measurements results are also reported.

8452-106, Poster Session

The DBBC environment for millimeter radioastronomy

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The Digital Base Band Converter project developed in the last decade produced a general architecture and a class of boards, firmware and software, giving the possibility to build a general purpose back-end system for VLBI or single-dish observational activities. Such approach suggests the realization of a “digital radio system”, i.e. a receiver with conversion not realized with analogue techniques, maintaining only amplification stages in the analogue domain. This solution can be applied until a maximum around 16 GHz, the present limit for the instantaneous input band in the latest version of the DBBC project, while in the millimeter frequency range this maximum limit of 0.5-2 GHz of the previous versions allows the intermediate frequency to be processed in the digital domain.

A description of the elements developed in the DBBC project is presented, with their use in different environments. The architecture is composed of a PC controlled mainframe, and of different modules that can be combined in a very flexible way in order to realize different instruments. The instrument can be expanded or retrofitted to meet increasing observational demands. Available modules include ADC converters, processing boards, physical interfaces (VSI and 10G Ethernet).

Several applications have already been implemented and used in radioastronomic observations: a DDC (Direct Digital Conversion) for VLBI observations, a Polyphase Digital Filter Bank, and a Multiband Scansion Spectrometer. Other applications are currently studied for additional functionalities like a spectropolarimeter, a linear-to-circular polarization converter, a RFI-mitigation tool, a phase-reference holographic toolkit.

8452-107, Poster Session

A 3mm dual polarization heterodyne HEMT receiver for Pico Veleta Telescope

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At ambient temperature, the signal provided by a 67-91GHz Gunn oscillator is coupled into the RF signal path through a -6 dB waveguide coupler (IRAM). The local oscillator (LO) and RF signals are mixed by a 3 mm Schottky mixer (IRAM) to provide a first 17-25 GHz Intermediate Frequency (IF) band. A second mixer pumped by a fixed 29 GHz DRO local oscillator performs a second downconversion to a 4-12GHz IF band (new IRAM standard).

The 15K receiver part is composed of:

- One HDPE lens with antireflection coating rectangular grooves (IRAM);
- One corrugated feed-horn (IRAM);

- One Orthogonal Mode Transducer (NRAO);
- 2 pairs of cryogenic MMIC HEMT LNAs (UMASS) connected through a cryogenic isolator (Millitech).

8452-108, Poster Session

Spurious signal suppression for ALMA

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The Atacama Large Millimeter/submillimeter Array (ALMA) is an international radio telescope under construction in northern Chile. Currently the early science operation is ongoing, together with the commissioning and the system verification activities. In this report, we present results of investigation of spurious signal for ALMA. We have conducted intensive surveys of spurious signal in several receiver bands and have detected several strong unwanted signals. Several experiments in which we changed instrument parameters have been done to understand the origin and coupling mechanism of spurious signals. We also used the technique of 180 deg phase switching and local oscillator offsetting to suppress these spurious signals.

Through above efforts, we succeeded in suppressing the spurious signal level to that specified in the system requirements.

8452-109, Poster Session

ALMA SIS mixer optimization for stable operation

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The Atacama Large Millimeter/Submillimeter Array (ALMA), an interferometric radio telescope under construction in the Atacama Desert in northern Chile, will have 66 array elements when complete. The Front End (FE) system is the first element in a complex chain of signal receiving, conversion, processing and recording. The ALMA FE is designed to accommodate up to 10 receiver bands covering most of the wavelength range from 10 to 0.3 mm (30-950 GHz). Superconductor-insulator-superconductor (SIS) mixers are employed for Band 3 (~3 mm) through 10 (~0.3 mm) to down-convert the received signal to a common IF prior to subsequent processing.

Ordinarily the SIS junction bias is selected to achieve the lowest receiver noise temperatures. However, in order to obtain the lowest detection threshold, the junction bias also needs to be optimized with respect to receiver stability. There are also other parameters like the magnetic field strength used to suppress the Josephson currents and avoidance of Shapiro steps that have a bearing on the overall receiver performance.

This paper will summarize the results of work carried out to derive the optimal operating parameters for the large number of mixers in use on the telescope so as to keep the telescope operating reliably and repeatably. We will present the results obtained from recent tests with new SIS mixer optimization for ALMA operation.

8452-110, Poster Session

Photonic phased array technology for radio telescope systems

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The application of novel photonic technologies in radio telescope systems is increasingly attractive thanks to their excellent (broadband) performance and recent advances on the terrain of fabrication technologies that enable better performance and lower costs. In addition to analog and digital photonic technologies for signal transport throughout the telescope system, also analog photonic signal processing technologies are available for application in the receiver section of a radio telescope. Whereas photonic signal transport technologies are already being used in operational systems, photonic signal processing technologies need further cost level reduction before they can be applied.

This cost level reduction can be obtained by applying photonic integrated circuit (PIC) technology. Currently this technology is being developed around the globe. To investigate the possibilities of the latest PIC technology for radio telescope systems like the SKA, a photonic phased array system development track is being performed at ASTRON, in which a number of photonic phased array demonstrators are built and experimentally investigated.

In the past years a discrete component based photonic phased array tile with optical analog links and a photonic TTD beamformer was developed. Currently a photonic phased array tile is being built with hybrid integrated optical transmitter and beamformer technology.

In the paper the status of PIC signal processing technology and the way it can be applied in radio telescopes is treated. In addition, the design and construction of both photonic phased array demonstrators will be described and measurement result will be given.

8452-111, Poster Session

New capabilities for the Southern 1.2-m mm-Wave Telescope

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During the 1980's the Northern and Southern 1.2-m mm-Wave Telescopes produced the first CO map of the Galactic plane at 115 GHz. While the Northern Telescope, now at CFA, has been modernized and is still operational, its twin telescope operated only until 1998. In 2010 the Southern Telescope completed its move from the original site at the Cerro Tololo Inter-American Observatory to Cerro Calán, at the Universidad de Chile in Santiago, close to the laboratory and accessible to students.

To make the telescope more efficient for astronomical observations in its new and lower site (850 m), modernization of both the front and back ends is taking place. A Gunn oscillator and a HEMT amplifier were incorporated to the original configuration, a Klystron oscillator and Schottky mixer without RF amplification, increasing the band from 110-115 GHz to 86-115 GHz. Now we aim for a sideband separating receiver to suppress the image sideband noise. Most front-end components (RF hybrid and E-plane bifurcation) have been designed and are being constructed in our facilities.

The back end consists of two 256 channel filter banks, with 0.1 and 1.0 MHz channel-widths. We are developing a modern digital spectrometer, based on the Reconfigurable Open Architecture Computing Hardware (ROACH), to ease the operation and improve the spectral resolution up to a factor of 4.

8452-112, Poster Session

A new phase-lock algorithm for the ALMA receivers

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In this work, a new phase-lock algorithm for the Local Oscillator system of the ALMA receivers is presented.

The old algorithm was based on the use of look-up tables (LUT) that specified the photomixer current require to achieve lock at a given frequency. In this scheme, every receiver should have its own LUT, composed by up to 300 frequencies, making it hard to implement and maintain. The photomixer current is a direct measure of the reference level provided to the PLL therefore, a failure in the adjustment of this quantity will cause the PLL not to lock. The overall lock-failure rate was ~3%. The new algorithm replaced the look-up table based scheme by adjusting dynamically not the photomixer current but a another quantity related to the RF power level reaching the phase detector. The new development is able to correct aging and non-linearities of the YIG oscillators used in the LO system. The solution provided reduces the locking time in up to a factor of ten, improving lock success rate up to 99.2%

8452-113, Poster Session

The status of the QUIJOTE multifrequency instrument

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The QUIJOTE-CMB project has been described in previous publications. Here we present the current status of the QUIJOTE I instrument which is a multi-channel instrument with five separate polarimeters (providing 5 independent sky pixels): two which operate at 10-14 GHz, two which operate at 16-20 GHz, and a central polarimeter at 30 GHz. The optical arrangement includes 5 conical corrugated feedhorns staring into a dual reflector crossed-draconian system, which provides optimal cross-polarization properties (designed to be < –35 dB) and symmetric beams. Each horn feeds a novel cryogenic on-axis rotating polar modulator which can rotate at a speed of up to 1 Hz. The science driver for this first instrument is the characterization of the galactic emission. The polarimeters use the polar modulator to derive linear polar parameters Q, U and I and switch out various systematics. The detection system provides optimum sensitivity through 2 correlated and 2 total power channels. The system is calibrated using bright polarized celestial sources and through a secondary calibration source and antenna. The acquisition system, telescope control and housekeeping are all linked through a real-time gigabit Ethernet network. All communication, power and helium gas are passed through a central rotary joint. The time stamp is synchronized to a GPS time signal. The acquisition software is based on PLCs written in Beckhoffs TwinCat and ethercat. The user interface is written in LABVIEW. The status of the QUIJOTE I instrument will be presented including early results of commissioning and laboratory testing.

8452-114, Poster Session

The control system architecture of QUIJOTE multifrequency instrument I

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The QUIJOTE-CMB experiment has been described in previous publications. Here we describe the architecture of the control system, hardware and software, of the QUIJOTE I instrument. It is a multi-channel instrument with five separate polarimeters: two which operate at 10-14 GHz, two which operate at 16-20 GHz, and a central polarimeter at 26-36 GHz. Each polarimeter can rotate at a speed of up to 1 Hz and also can move following discrete angular positions which allow the linear polar parameters Q, U and I to be derived. The instrument is installed in an alt-azimuth telescope which implements several operational modes: movement around the azimuth axis at a constant velocity while the elevation axis is held at fixed elevation; tracking of a sky object; raster of a rectangular area in telescope coordinates and raster of a sky rectangular area, both about 10 degrees. The control system of both, telescope and instrument, is based on the following technologies: an LXI-VXI bus is used for the signal acquisition system; an EtherCAT bus implements software PLCs developed in TwinCAT to perform the movement of the 5 polarimeters and the 2 axes of the telescope. Science signal, angular positions of the 5 polarimeters and telescope coordinates are sampled at up to 4000 Hz. All these data are correlated by a time stamp obtained from an external GPS clock implementing the Precise Time Protocol-1588 which provides synchronization to less than 1 microsecond. The control software also acquires HK from the different subsystems: cryostat and ambient temperatures, vacuum level, etc. LabVIEW implements the instrument user interface.

8452-115, Poster Session

Instrument status and performance of the ACTPol receiver

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The initial performance and characterization of ACTPol, a polarized receiver for the Atacama Cosmology Telescope (ACT), designed to make sensitive maps of the Cosmic Microwave Background (CMB) at arcminute scales and millimeter wavelengths will be described. Observations of the CMB temperature and polarization with high angular resolution will enable us to explore structure formation, constrain the sum of the neutrino masses, probe early dark energy, and perform other cosmological tests. ACT is a six-meter telescope located in Chile at an elevation of 5200 m. The new ACTPol receiver will contain three arrays comprised of a total of ~1500 feedhorns each coupled to two polarization-sensitive transition edge sensor (TES) bolometers. The full receiver is projected to achieve approximately a factor of 4 improvement in 150 GHz sensitivity over the current ACT receiver. The ACTPol TES bolometers have a target superconducting transition temperature of 150 mK and will be cooled to a bath temperature of ~100 mK with a dilution refrigerator. Detector multiplexing and amplification are achieved with three stages of superconducting quantum interference devices and read out with a time-division multiplexing scheme. We will field one 150 GHz array in 2012, followed shortly by a second, along with a multichroic array with simultaneous 150 GHz and 90 GHz sensitivity. I will present an overview of the status and performance of the ACTPol instrument with a focus on the integration and array level characterization of the first 150 GHz detector array and preliminary data from the development of the multichroic array.

8452-116, Poster Session

Characterization system with cryogenically cooled loads for next-generation CMB polarimeters

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Polarimeters used in the cosmic microwave background (CMB) experiments are required to be well characterized and well calibrated to measure faint CMB polarization patterns with low systematic errors.

Reproduction of the observing condition is important for characterization of the polarimeter.

Characteristics of polarimeters can be different with different load temperatures.

We developed a characterization system for the polarimeters with cryogenically-cooled loads.

The loads generate unpolarized radiation (~10 K and ~30 K), comparable to the sky temperature of typical sites on the ground, e.g., the Atacama desert in Chile.

The radiation from the loads reflects on a metal mirror in the cryostat, yielding a partially polarized radiation (~100 mK), going into a feed horn of a polarimeter.

Rotation of the mirror varies the incident angle of polarization and causes a periodical variation of the load temperature for Y-factor measurements.

Using the characterization system, we characterized polarimeters developed for an upgrade of QUIET (QUIET-II), which is able to obtain Stokes parameters I, Q, and U, simultaneously. A wide range of polarimeter bias condition was surveyed.

For an integrated polarimeter, we confirmed a similar level of noise temperature to that of the low noise amplifier itself.

The measurements also demonstrate validity of the characterization system.

Since the principle of the characterization system is not limited by the frequency or the detection scheme, this technique is very promising to various types of state-of-the-art polarimeters.

8452-117, Poster Session

New demodulation scheme for coherent polarimeters in CMB experiments

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B-modes are special patterns in cosmic microwave background (CMB) polarization. They are smoking-gun signatures of primordial gravitational waves. In general, the CMB polarization signal is a few orders of magnitude lower than polarimeter noise level.

Therefore, low polarimeter noise is one of the most important requirements for the experiments. In addition to that, whiteness of the noise is also important.

The experimental sensitivity could be degraded if the whiteness of the noise is not guaranteed.

We propose a new idea for the demodulation scheme; the demodulation with three-point differentiation significantly improves the feature of the noise.

Unwilling frequency structures of the polarimeter noise, which remain in the original demodulation scheme, are suppressed in the frequency domain.

The noise floor could be improved about 5% in the case of coherent polarimeter which uses low noise amps with a knee frequency of 1 kHz.

We confirmed these impacts by using the prototype polarimeter for the future experiment QUIET-II; disappearance of the many spikes in the frequency domain, and about 5% improvement of the noise floor.

We will present details of the scheme and understanding of it.

8452-118, Poster Session

Multichroic CMB polarimeter arrays

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Multi-chroic polarimeters allow the simultaneous measurement of the temperature and polarization of cosmic microwave background (CMB) radiation at multiple frequency bands. Multi-chroic detection not only increases the spectral coverage and sensitivity of instruments, but also aids in the control of systematic errors. Our approach is to develop multi-chroic feed-horn coupled transition-edge-sensor (TES) polarimeters for operation over an octave of bandwidth.

The polarimeter incorporates a wide band planar ortho-mode transducer connecting to resonant- stub diplexing filters, a hybrid tee and a TES. The initial focus is to develop detectors operating at 90/150 GHz, which offer the highest CMB polarization to foreground ratio, and 220/270GHz, which provides a monitor for infrared point sources. We plan to deploy an array of 256 multi-chroic 90/150 GHz polarimeters with 1024 TES detectors on ACTPol in 2013. The combination of excellent control of beam systematics and sensitivity make this technology ideal for future ground, balloon, and space missions. In this presentation we will show design and results from detectors, and report the status of this work.

8452-119, Poster Session

Design and characterization of 90 GHz feedhorn-coupled TES polarimeter pixels in the SPTPol camera

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The SPTpol camera is a dichroic, polarization-sensitive bolometer receiver deployed on the 10 meter South Pole Telescope in January 2012. SPTpol is designed to study the faint polarization signal in the Cosmic Microwave Backround, with two primary scientific goals. The first is to constrain the tensor-to-scalar ratio of primordial plasma density fluctuations, and thus to constrain the space of possible inflationary models. The second is to measure the weak lensing effect of large-scale structure on CMB polarization, which can be used to constrain the sum of neutrino masses. The SPTpol focal plane consists of 588 150 GHz pixels in 7 84-element monolithic arrays and 180 90 GHz pixels in individual feedhorn modules. We present the design and lab characterization of the 90 GHz detectors. Each 90 GHz polarimeter module houses two stacked, crossed, single-polarization molybdenum-gold bilayer Transition-Edge Sensor (TES) bolometers, each with a lossy gold half-wave resonator in a waveguide, and coupled to the sky through a contoured feedhorn. These detector modules were developed at Argonne National Lab and the Kavli Institute for Cosmological Physics. Topics to be discussed include polarization efficiency, optical band pass, optical efficiency, electrothermal feedback and stability, noise, thermal properties, optical beams, and mechanical assembly.

8452-120, Poster Session

Feedhorn-coupled TES polarimeter camera modules at 150 GHz for CMB polarization measurements with SPTpol

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The SPTpol camera is a multichroic polarimetric receiver at 90 and 150 GHz. The focal plane consists of 180 dual Transition Edge Sensor (TES) polarimeters at 90 GHz and seven 84-polarimeter modules (a total of 1176 detectors) at 150 GHz. We present the design, dark characterization, and in-lab optical properties of the seven 150 GHz modules in the focal plane. Each module consists of a photo-lithographed array of dual TES polarimeters coupled to a silicon platelet array of corrugated feedhorns, both fabricated at NIST-Boulder, and also contains a set of passive readout electronics for digital frequency-domain multiplexing. At the heart of the modules are flexible invar tabs that mechanically couple the silicon feedhorns/detectors with copper/aluminum parts that interface with the millikelvin focal plane plate. Across the modules, the detectors average a critical temperature of 483 mK, saturation power of 23 pW, time constant of ~0.6 ms in transition, and (detector-only) optical efficiency of ~90%.

8452-121, Poster Session

The polarization calibration of the new South Pole Telescope polarimeter (SPTpol)

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SPTpol is a multiple year program for measuring the Cosmic Microwave Background (CMB) polarization with the South Pole Telescope (SPT). One of the SPTpol objectives is probing inflationary physics by measuring the scalar-to-tensor ratio, r, to better than ~0.01. Achieving this level of precision requires knowing the individual polarization angle of all ~1500 detectors to better than 0.2 degrees. To perform this calibration, we built a custom polarized source located 3 km from the SPT in the far-field of the telescope. The source is a chopped thermal black body polarized by wire grids located in the center of a large reflector to reduce the atmospheric loading on the detectors from the horizon. We present a description of this polarized source, the calibration process, as well as results of the calibration.

8452-122, Poster Session

Performance of the SCUBA-2 dry dilution refrigerator: 4 years of operation at the JCMT

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Cryogen free or ‘dry’ dilution refrigerators that integrate a cryocooler such as a two stage pulse tube to replace the conventional liquid helium bath and 1K pot, have become a practical alternative for cooling astronomical detectors to mK temperatures and offer many advantages. SCUBA-2, the new submillimetre camera in operation at the JCMT, on the summit of Mauna Kea, Hawaii, was one of the first instruments to use such a fridge design. The dry dilution fridge for SCUBA-2 has now been in service for 4 years during commissioning at JCMT. In the most recent astronomical commissioning phase, the dilution fridge was in continuous operation for 10 months with no loss of base temperature or cooling power, cooling the SCUBA-2 detector arrays to below 100mK while maintaining a further 100Kg of enclosure, shields and SQUID amplifiers at 1K. In this paper we review the lessons that we have leant in operating a dry dilution fridge at the JCMT and the necessary changes that have been incorporated. We present the performance of the fridge and discus its role in ensuring the success of SCUBA-2.

8452-123, Poster Session

The high altitude qualification tests of the cryogenic and vacuum system for ALMA

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The Cryogenic System of ALMA is one of the core sub systems of the Front End low noise receiver and its failsafe operation is mandatory to ensure successful astronomical observations. ESO has done a comprehensive test campaign on the ALMA operational site Chajnantor at an altitude of 5000m, to qualify this system for the harsh operational conditions.

In this contribution we will present an overview of those Qualification tests which have been carried out on ALMA`s 4K Cryogenic and Vacuum System components and the additional required measures to operate

the system under the special environmental conditions, respectively the operational constraints. That will include the findings concerning the optimization of remote diagnostic and the definition of additional monitor and control parameters. The resulting solutions have considerable influence on the maintenance processes, the operational staff requirements and the reduction of the operational costs in particularly with regards to the large system number of 66 antennas.

8452-124, Poster Session

POLARBEAR-2 optical and polarimeter designs

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POLARBEAR-2 (PB-2) is a ground based Cosmic Microwave Background (CMB) radiation experiment observing from Atacama, Chile. The science goals of PB-2 are to measure the CMB polarization signals originating from the inflationary gravity-wave background and weak gravitational lensing. In order to achieve these science goals, PB-2 employs 7588 polarization sensitive Transition Edge Sensor bolometers at observing frequencies of 95 and 150 GHz with 6 and 4 arcmin beam width respectively. The telescope is the off-axis Gregorian, Huan Tran Telescope, on which the POLARBEAR-1 receiver is currently mounted. The PB-2 polarimetry is based on modulation of the polarized signal using a rotating half-wave plate and the rotation of the sky. We present the developments of the optical and polarimeter designs including the cryogenically cooled refractive optics that achieve the overall 4.8 degrees field of view, the optical system thermal filter design, the broadband anti-reflection coating, and the rotating half-wave plate.

8452-125, Poster Session

A bolometric polarimeter for the Large-scale Polarization Explorer

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The balloon-borne LSPE mission is optimized to measure the linear polarization of the CMB at large angular scales. The bolometric polatimeter on LSPE is composed of 3 arrays of multimode bolometers cooled at 0.3K , with optical components and filters cryogenically cooled below 4K to reduce the background on the detectors. Polarimetry is achieved by means of large rotating half wave plates and wire grid polarizers in front of the arrays. The polarization modulator is the first component of the optical chain, reducing significantly the effect of instrumental polarization. In the bolometric polarimeter angular resolution is traded for sensitivity: the diameter of the entrance pupil of the refraction telescope is 40 cm, while the field optics is optimized to collect tens of modes, thus boosting the absorbed power. This results in a FWHM resolution of 2.4, 1.9, 1.6 degrees at 90, 140, 220 GHz respectively. The expected performance of the three channels is limited by photon noise, resulting in a final sensitivity around 0.1-0.2 microK per beam, for a 15 days survey covering 25% of the sky.

8452-126, Poster Session

Thermal stability of the BICEP 2 Telescope

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The BICEP2 Telescope, currently in its third season of observations at the South Pole, is an on-axis, refractive microwave telescope studying the polarization of the Cosmic Microwave Background (CMB). To observe the faint B-mode signal in the CMB's large angular scale polarization -- a unique prediction of cosmological inflation -- we require high sensitivity with stringent control over experimental systematic effects. One of the foremost engineering challenges is to precisely control the thermal stability of the Transition Edge Superconducting (TES) bolometers. This is accomplished by isolation of the thermal stages as well as by active and passive thermal control of the detector focal plane. This paper discusses the motivation for, design, and implementation of, the BICEP2 thermal control system.

8452-127, Poster Session

Multichroic dual-polarization bolometric focal plane for studies of the cosmic microwave background

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We are developing multi-chroic antenna-coupled TES focal planes for CMB polarimetry. In each pixel, a dual polarized sinuous antenna collects light over a two-octave frequency band. Each antenna couples to the telescope with a contacting silicon lens. The antenna couples the broadband RF signal to microstrip transmission lines, and then filter banks split the broadband signal into several frequency bands. A TES bolometer detects the power in each frequency band and linear polarization. We will describe the design of this device and demonstrate its performance with optical data taken from prototype pixels. Our measurements show beams with few percent ellipticity, percent level cross-polarization leakage, and properly partitioned bands in banks of 2,3, and 7 filters. We will also describe developments on broadband anti-reflection coatings for the high dielectric constant lens. The broadband anti-reflection coating has over 100% bandwidth and negligible loss at cryogenic temperature. Finally, we will describe upgrade for the POLARBEAR CMB experiment and installation for the LiteBird CMB satellite experiment with focal planes of these detectors to increase mapping speed and provide greater discrimination of polarized galactic foregrounds.

8452-128, Poster Session

Stray light suppression in the Goddard IRAM 2-millimeter observer

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The Goddard IRAM Superconducting 2-Millimeter Observer(GISMO) has operated under technical operation/observation time for the past few years at the IRAM 30 Meter Telescope. Beginning in April of 2012, GISMO will be offered to the community for observations at the IRAM 30 Meter Telescope. In March of 2012, we plan to install a cryogenic extension to the entrance window of the current GISMO cryostat to reduce stray light entering the window and increase its performing capability. We will describe the design, fabrication and installation of the extension as well as present data to demonstrate the system performance both before and after the installation.

8452-12, Session 3

Low-dimensional phononic structures for ultra-low-noise transition edge sensors

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Major advances have been made in the development of ultra-low-noise Transition Edge Sensors (TESs) for far-infrared astronomy. Arrays having 400 pixels and NEPs as low as 4x10-19 WHz-1/2 can now be manufactured routinely. Understanding the thermal behaviour of low-dimensional dielectric support structures, patterned in <500 nm amorphous dielectric membranes, has been an essential part of this work. To advance the technology further, we wish to produce low-dimensional phononic components that minimise low-temperature (<500 mK) thermal conductance, heat capacity, and suppress and thermal fluctuation noise. Such components would also increase optical packing. Although attempts have been made in the past to control thermal characteristics by patterning features into membranes, progress has been slow because there have been no physical models for designing structures and interpreting experimental results. In this paper, we describe a technique for modelling the low-temperature thermal behaviour of phononic components. Ballistic, elastic diffusive, localized and inelastic diffusive transport are included. Crucially, the respective scattering lengths can be comparable with the scale sizes of the patterned features. The model gives important insights into the physical processes that determine behaviour. Not only does the scheme give the average thermal fluxes of components having statistically characterized microstructure, it also gives the spread in behaviour of notionally identical devices. We present a number of illustrative simulations, including a Fabry-Perot filter.

8452-13, Session 3

Improved performance of TES bolometers using digital feedback

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Voltage biased, frequency multiplexed TES bolometers have become a widespread tool in mm- and sub-mm wave science. However, stability, performance, and multiplexing factors are limited by parasitic impedance and dynamic range issues. Here, we present novel methods of overcoming these limitations, achieved through digital feedback, implemented on an FPGA. In the first method, known as Digital Active Nulling (DAN), the current sensor (e.g. SQUID) is nulled in a separate digital feedback loop for each bolometer frequency, a control system similar to baseband feedback. This removes both the dynamic range limitation on the current sensor, as well as hugely increasing its linearity and reducing its effective input impedance. Additionally, DAN removes constraints on wiring lengths and maximum multiplexing frequency, enabling satellite applications through a much higher multiplexing factor and longer wiring. DAN has been fully implemented and tested. Integration for current experiments, including the South Pole Telescope, will be discussed. We also present a digital mechanism for strongly increasing stability in the presence of large series impedances, known as Digitally Enhanced Voltage Bias (DEVB).

8452-14, Session 3

Frequency division multiplexed readout of TES detectors with baseband feedback

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SRON is developing an electronic system for the multiplexed read-out of an array of transistion edge sensors (TES) by combining the techniques of frequency domain multiplexing (FDM) with base-band feedback (BBFB). FDM is based on a set of sinusoidal AC carriers which bias the TES detectors in their set points and are amplitude modulated when the TES detectors sense a signal. It allows the read-out of multiple TES pixels in one amplifier channel which uses only one SQUID-based current sensor. This significantly reduces the wire count to the cold stage and hence the wiring complexity and heat-load. BBFB cancels the error signal in the SQUID sumpoint and further improves the bandwidth and the loop gain.

The astronomical applications are the read-out of soft X-ray microcalorimeters in an instrument on the European X-ray mission-under-study ATHENA and far-infrared bolometers for the SAFARI instrument on the Japanese mission SPICA. In recent work we showed that the basic requirements on the electronic read-out noise were met, and demonstrated multiplexed closed-loop low-noise read-out of 51 pixels.

In this paper we present the baselined system design of the FDM read-out for the SAFARI instrument, and demonstrate multiplexed low-NEP operation of TES bolometers, as a step towards the SAFARI Demonstration Model. The cross-talk between pixels is measured and the relative contribution of various mechanisms is discussed.

8452-15, Session 3

Development of fast, background-limited transition-edge sensors for the background-limited infrared/sub-mm spectrograph (BLISS) for SPICA

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We report experimental progress toward demonstrating background-limited arrays of membrane-isolated transition-edge sensors (TESs) for the Background Limited Infrared/Sub-mm Spectrograph (BLISS). BLISS is a space-borne instrument with grating spectrometers for wavelengths λ= 35-435µm and with R=$\lambda/\Delta\lambda$=400-700. The goals for BLISS TESs are: noise equivalent power (NEP)= 5×10-20 W/Hz^{1/2} and response time τ<30ms. We fabricated superconducting thermistors from Ti (T_C=565mK), Ir (T_C=130mK), and Mo/Cu proximitized bilayers (T_C=65mK), where T_C is the thermistor transition temperature. We measured the TES arrays in our 50mK adiabatic demagnetization refrigerator testbed, which can measure up to eight 1x32 arrays simultaneously using a time-division multiplexer. In our initial experiments, the Ir TES arrays exhibited the best performance with NEP=2×10-19 W/Hz^{1/2} and τ~5ms at T_C=130mK. Given these results, we expect background-limited performance from bilayer TESs with T_C=65mK and G=15fW/K. However, such TESs cannot be operated at 50mK unless stray power on the devices, or dark power P_D, is less than 200aW. Our initial experimental setup had P_D=1fW, and we have subsequently upgraded our optical light rejection and electrical filtering techniques to further mitigate P_D. We describe the effectiveness of the newly implemented P_D mitigation techniques to meet the P_D=200aW requirement and present updated results from our array measurements. We also compare low frequency noise observed in different multiplexer readout chips from NIST with our TESs. Finally, we detail our efforts to increase α in our thermistors, which exhibit the lateral proximity effect, in order to lower τ to meet the BLISS goal for speed.

8452-16, Session 3

Low-temperature readout system for the POLARBEAR-2 experiment

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We describe the design fo the low temperature readout system for the POLARBEAR-2 (PB-2) experiment. PB-2, an upgrade to the POLARBEAR experiment, is a ground-based Cosmic Microwave Background (CMB) polarimeter.

PB-2 has 7,588 Transition Edge Sensor (TES) bolometers in a 365mm focal plane. 1897 pixels fill the focal plane, each with dual band (150 GHz and 90 GHz) and dual polarization detectors. The TES bolometers are cooled to 250 milli-Kelvin to reduce thermal noise. These TES bolometers are read out by a frequency multiplexing technique.

The high channel density and limited area require well-designed readout hardware. Our design efficiently utilizes focal plane area by placing readout components behind the detectors. In addition, electronic components for the frequency modulation are modularized for easier maintenance.

8452-17, Session 4

Systematic effects introduced by lenses at mm-wavelengths in CMB applications

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The optics for the next generation of CMB (Cosmic Microwave Background) experiments could be based on either reflective (such as Planck, Clover) or refractive (BICEP, COrE, SPIDER). Both techniques have advantages and disadvantages. Lens based telescopes can be compact and have an on-axis design while off-axis reflective configurations can be large. However, while RF performances of mirror based telescopes are very well understood, lens based systems have a lower technology readiness level. Specifically, the systematic effect (aberrations, beam ellipticity and cross-polarisation) that they can introduce need to be accurately quantified at millimetre range. This paper reports on both RF modelling and experimental studies of a representative lens configurationcoupled with feed-horn antennas for which the co- and cross-polarisation beam patterns are characterised. The refractive components are made of anti-reflection coated high-density polyethylene representing the best option for low-systematics and large lens systems.

8452-18, Session 4

Review and comparison of recent and future CMB telescope optics designs

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In the last two decades, the enormous scientific reward from cosmic microwave background (CMB) temperature and polarization anisotropy measurements has motivated the development of a large variety of instruments. As CMB measurement precision and resolution have improved, the instrument optics designs have evolved from simple systems using only feedhorns to complex systems that include reflectors, refractive optics, and large arrays of detectors with a range of different optical coupling approaches. A primary motivation for the optical complexity is the need for greater diffraction-limited throughput to maximize sensitivity with larger detector arrays. We review the recent evolution of CMB optics, highlighting the optics designs of the CMB satellites and other select instruments, and comparing the off-axis Gregorian South Pole Telescope and Atacama Cosmology Telescope designs. We conclude with a discussion of high-throughput crossed-Dragone optics designs and describe a next generation instrument design that mitigates some of the difficulties associated with crossed-Dragones by use of reimaging optics.

8452-19, Session 4

Dielectrically embedded mesh half wave plate beam impact studies

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Quasi-optical Half Wave Plates are commonly used in mm-wave polarimeters to modulate the incoming linearly polarised radiation. These devices used to be manufactured using expensive birefringent crystals. However, future CMB experiments will require large focal plane

arrays and therefore large diameter HWPs that cannot be built using this classic technology. A recently developed alternative solution is based on the same photolithographic techniques used to manufacture mesh filters: planar metallic grids with sub-wavelength structures that behave differently along two orthogonal axes emulating the behaviour of birefringent materials.

The design of these new HWPs is normally based on transmission-line codes that implicitly assume plane waves and normal incidence conditions. In real instruments these devices will modulate the polarisation of converging Gaussian beams. Taking into account the effects of such convergent beams is a computationally heavy task that anyway would not include the real horn antenna beam characteristics.

We present an experimental study of the impact of a dielectrically embedded photolithographic HWP on the beam shape of a corrugated horn. The measurements, carried out using a W-band Vector Network Analyser, consist of co- and cross-polarisation beams of the HWP-horn system. In addition, we have also measured the differential phase-shift introduced by the mesh-HWP across the beam.

8452-20, Session 4

Optical modeling of horn antenna coupled TES detectors towards the SAFARI instrument for SPICA

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The next generation of space missions targeting far-infrared wavelengths will require large-format arrays of extremely sensitive detectors. Transition Edge Sensor (TES) array technology is being developed for future Far-Infrared (FIR) space applications such as the SAFARI instrument for SPICA where low-noise and high optical efficiency is required to achieve ambitious science goals. Being able to accurately model the optical behavior of such systems would mark a significant advance in optimization of any design configurations.

In high sensitivity TES detector technology the ability to control the electromagnetic and thermo-mechanical environment of the detector is critical. For this reason multi-mode horn antennas are being proposed which feed integrating cavities in which the TES detectors with superconducting film absorbers are mounted. In this paper we describe the electromagnetic modeling based on modal analysis of such waveguide structures. Simulating and understanding the optical behaviour of such detectors at far IR wavelengths requires the novel development of existing analysis tools.

The proposed approach based on waveguide mode matching offers a computationally efficient technique to describe the partial coherent response of the full pixel in terms of beam properties, optical efficiency and any mutual coupling between pixels. The work carried out as part of an ESA Technical Research Programme project on optical modeling is described including the analysis of a full prototype SAFARI pixel consisting of a multi-mode horn feeding an integrating cavity containing the detector absorber and also allowing for power leakage out of the detector cavity through a free-space gap to neighboring pixel.

8452-21, Session 4

Silicon platelet feedhorn arrays for astrophysics

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Corrugated feedhorns have excellent performance in millimeter-wave through far infrared detection for astrophysics. However, they have historically been difficult to fabricate in large arrays, with low weight and low thermal mass. We have developed large arrays of corrugated feedhorns based on gold-plated silicon platelets with lithographically etched features. This all-silicon feedhorn technology has great promise.

The current generation of arrays for millimeter-wave polarimetry have single-moded operation with a band center near 150 GHz and >30% fractional bandwidth, optimized for cosmic microwave background polarization observations. We find that high-resolution photolithography and wafer-scale etch tools yield feedhorns with symmetric beam patterns and low cross-polar response, with excellent uniformity across the array, low loss, and excellent reproducibility. Furthermore, the resulting arrays are thermal contraction matched to silicon-based detector arrays down to cryogenic temperatures. We have fabricated seven 84-pixel feedhorn arrays from 150 mm diameter silicon wafers that have been deployed on the South Pole Telescope Polarimeter (SPTpol). We have also fabricated the first of two 522-pixel feedhorn arrays (1044 polarizations channels) on 150 mm diameter silicon wafers for the Atacama Cosmology Telescope Polarimeter (ACTPol).

Extending this fabrication technique for multichroic detectors, we have defined ring-loaded structures in the feedhorn throat to achieve octave (66% fractional) bandwidth. These feedhorns enable the use of multi-chroic detectors, which maximizes focal-plane usage. We will present the polarized angular response of a 90/150 GHz dual band silicon feedhorn. This multi-chroic feedhorn is a prototype for the third ACTPol array scheduled for observation in 2013.

8452-22, Session 5

Dynamical behaviour of kinetic inductance detectors under readout-frequency, readout-power, and signal-power switching

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Kinetic Inductance Detectors (KIDs), based on superconducting resonators, are being developed for submillimetre-wave, optical, and x-ray astronomical imaging. The sensitivity, saturation power, and response time all depend on the degree to which the effective quasiparticle temperature is driven above that of the phonons when readout and signal power are applied. Experimentally, it is well known that as the readout power is increased, the frequency response curve first distorts, and then switches hysteretically between two stable states. Recently, we proposed a model for saturation in KIDs, and found that hysteretic switching appears in a natural way. The model equates the power dissipated in the resonator to the power lost through quasiparticle-phonon cooling. In this paper we extend the work significantly. A diagrammatic representation of the parameter space, together with an operating point trajectory, allows pulse shapes and transition times to be calculated for changes of state driven by readout-frequency, readout-power, and signal-power switching. We present illustrative simulations of KIDs relaxing back to equilibrium and switching between hysteretic states. We discuss physical and dynamical aspects of the model.
The work has four applications: (i) Understanding the quasiparticle cooling mechanism, and its functional dependence on film and substrate thickness. (ii) Recovering quasiparticle cooling functions from

experimental measurements. (iii) Understanding the relationship between the optimum readout power and device and material parameters. (iv) Characterising the time-dependent behaviour of photon-counting KIDs, including nonlinearity and pile up.

8452-23, Session 5

Electronics and data acquisition for kilopixels kinetic inductance camera

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A prototype of digital frequency multiplexing electronics allowing the real time monitoring of microwave kinetic inductance detector (MKIDs) arrays for mm-wave astronomy has been developed. It requires only two coaxial cables for instrumenting a large array.

The prototype can instrument simultaneously 400 pixels over a 500MHz bandwidth. The design relies on the use of 6 latest generation FPGAs, one 1GSPS 12 bit ADC and five 16 bit dual 1GSPS DAC. The latter is able to take digital information at 250MHz and to provide analog samples at 1GHz, thanks to the programmable digital upmixers, interpolators and very steep filters it features.

The central FPGA, which is connected to the ADC, uses a very steep polyphase filter coupled to digital downmixers to split the 12 bit 1GHz data flow in five 250MHz data flows representing the frequency content of five 100Mhz adjacent bands shifted to baseband.

Each of the 5 remaining FPGA, associated to one of the aforementioned DAC, is generating 80 excitation frequencies in its 100MHz bandwidth and perform Digital Down Conversion on each individual frequency. The tones are generated by 10 bit CORDIC and summed to form the frequency comb. The DDC are using the data flow provided by the central FPGA and the sine and cosine of each generated tones. The DAC outputs feed a passive combiner which then provides the full frequency comb.

The chosen solution and the performance achieved on a 224 pixels MKID array, designed for the NIKA (New IRAM KID Arrays) experience, are presented.

8452-24, Session 5

A pathfinder instrument for on-sky demonstration of low-cost 350 micron imaging arrays

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Although submillimeter cameras now have up to 10^4 pixels (SCUBA 2), there is a strong need for even larger instruments. For example, the proposed CCAT 25-meter submillimeter telescope recently recommended in the Astro2010 decadal survey will feature a 1 degree field-of-view. In order to fully populate the focal plane at 350 microns, more than 10^6 photon-noise limited pixels would be needed. However, such an instrument is not affordable unless a dramatic reduction in the per-pixel cost can be achieved. In turn, this implies that very simple detectors and high-density multiplexing are essential. We are addressing this challenge through the development of frequency-multiplexed superconducting microresonator detector arrays. These arrays feature lumped-element, direct-absorption resonators made by patterning titanium nitride films deposited on silicon substrates. We will discuss our current progress toward constructing a 350 micron pathfinder instrument for on-sky demonstration of a 32x32-pixel subarray that is read out with a single line. A project overview will be presented including a description of the cryogenics, electronic readout, array development, preliminary results, and a timeline for reaching first-light measurements.

8452-25, Session 5

Development of 1000 arrays MKID camera for the CMB observation

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We have been developing antenna-coupled Microwave Kinetic Inductance Detector (MKID) at NAOJ in cooperation with KEK and RIKEN, aiming for a precise measurement of the Cosmic Microwave Background (CMB). In particular, the B-mode polarization of the CMB is one of a few probes for inflation era, but it hasn't successfully measured yet. We need a millimeter camera with high sensitivity and large number of arrays to find it. MKID camera, which consists of array of superconducting resonators, is one of the possibilities to accomplish such requirements. The advantages of MKID camera are: hundreds of pixels can be read out with only single line by frequency dominant multiplexing; the fabrication process is simple and that leads to high yield rate; high sensitivity with NEP (Noise Equivalent Power) of about 10-19 can be ideally achieved.

We have successfully developed 102-pixel MKID camera for the frequency of 440GHz with epitaxially-formed Al on Si wafer, and beam measurement with Si lens array is underway. In parallel, we are developing 1000 pixels camera with mosaic design. Each module consists of 256 MKIDs, and we are also constructing a new test-bench with optimizing the system. The optimization includes antenna design, Si lens size for each pixel and optics system inside the cryostat.

We would like to present the status of the development of the 1000 pixels camera with its performance assessments such as yield rate, comparison of the measured parameters (resonant frequency, Q value etc.) to the design values and optical characteristics.

8452-26, Session 5

MKID development for SuperSpec: an on-chip, mm-wave, filter-bank spectrometer

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SuperSpec is a novel, ultra-compact spectrograph-on-a-chip for millimeter and submillimeter wavelength astronomy. Its very small size, wide spectral bandwidth, and highly multiplexed detector readout will enable construction of powerful multibeam spectrometers for high-redshift observations. SuperSpec employs a filter bank consisting of planar, lithographed superconducting transmission line resonators. Each mm-wave resonator is weakly coupled to both the feedline and to the inductive portion of a lumped element Microwave Kinetic Inductance Detector (MKID). Incoming mm-wave radiation breaks Cooper pairs in the MKID, modifying its kinetic inductance and resonant frequency, allowing for frequency-multiplexed readout. The design is realized using thin film lithographic structures on a Si wafer, with titanium nitride MKID resonators. We will discuss the design and optimization of the MKID detectors for SuperSpec and the measured performance of a laboratory test device. We will also describe the ongoing development of a demonstration instrument which will consist of two 500-channel, R=700 spectrometers, one operating in the 1-mm atmospheric window and the other covering the 650 and 850 micron bands.

8452-27, Session 5

Design of a far-infrared kilo-pixel array using radio-frequency kinetic inductance detectors

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We are developing superconducting Kinetic Inductance Detectors (KIDS) for measurements at 350 microns with the goal of producing a kilo-pixel array with a photon limited noise equivalent power (NEP).

Traditional KIDs are fabricated using quarter-wave transmission lines or lumped element LC resonators and read out at microwave frequencies. Designing LC resonators which operate at radio-frequency (RF; < 100 MHz) simplifies the readout electronics, reducing cost and allowing larger scale arrays.

Our RF resonators are fabricated using a series meander inductor and interdigitated capacitor (IDC). The IDC provides a high material quality factor and minimizes two level system (TLS) noise relative to a parallel plate design. Preliminary measurements indicate that TLS noise should be suppressed below the photon noise when operating at 300 mK. TiN is a high normal resistivity metal used for our superconductor. The high resistivity allows impedance matching to the incident radiation, and its high inductance is used to reduce the readout frequency. Reaching these low frequencies requires long meanders which have higher order resonances; these ultimately limit the available measurement bandwidth.

We are designing devices that should operate with sufficiently high resonator quality factors (Qs) to fit the array within the available measurement bandwidth. Operation under heavy loading (~50 pW) increases the quasi-particle density significantly, the geometry and readout conditions necessary in this regime become constrained to achieve the desired NEP. The physics and response of the resonator response under heavy load, device design and geometry, and preliminary resonator response measurements are discussed.

8452-28, Session 6

The GISMO-2 bolometer camera

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We present the concept and expected performance of the GISMO-2 bolometer camera, which will be used at the IRAM 30m telescope at Pico Veleta, Spain. GISMO-2 will operate simultaneously in the 1mm and 2mm atmospherical windows. The 1 mm channel uses a 32 x 40 TES-based Backshort Under Grid (BUG) bolometer array, the 2 mm channel operates with a 16 x 16 BUG array. The camera utilizes almost the entire full field of view provided by the telescope.

The optical design of GISMO-2 was strongly influenced by our experience with the GISMO 2mm bolometer camera that is successfully operating at the 30m telescope. GISMO is accessible to the astronomical community through the regular IRAM call for proposals. We describe GISMO's performance, the improvements we made during its commissioning phase, and show how these fed into the design of GISMO-2.

8452-29, Session 6

The PILOT experiment for the measurement of interstellar dust polarization: the camera ground calibration

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PILOT is a balloon borne experiment designed to measure the polarized emission from dust grains in the galaxy in the submillimeter range. The payload is composed of a telescope at the optical focus of which is placed a camera using 2048 bolometers cooled to 300 mK. The camera performs measurements in two spectral bands (240 μm and 550 μm) and two polarizations. The polarization measurement is based on a cryogenic rotating half-wave plate and a fixed mesh grid polarizer placed at 45° separating the beam into two orthogonal polarized components each detected by a detector array.

The Institut d'Astrophysique Spatiale is responsible for the design, integration, tests and spectral calibration of the camera. Two optical benches, one including a Fourier Transform Interferometer, have been designed for its characterization and spectral calibration. Theses benches allow to validate the alignment of the camera cryogenic optics, to check the optical quality of the images, to determine time and intensity detector response, and to characterize the overall spectral response. A numerical photometric model of the instrument was developed simulating the optical configuration during calibration tests (spectral), functional tests (imager) on the ground, and flight configuration at the telescope focus, giving an estimate of the optical power received by the detectors for each configuration. The first flight is planned for early 2013.

8452-30, Session 6

Development of a 4.7-THz frontend for the GREAT heterodyne spectrometer on SOFIA

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Heterodyne spectroscopy of molecular rotational lines and atomic fine-structure lines is a powerful tool in astronomy and planetary research. It allows for the investigation of the chemical composition, the evolution,

and the dynamical behaviour of astronomical objects such as molecular clouds and star-forming regions. For frequencies beyond 2 THz, SOFIA, the Stratospheric Observatory for Infrared Astronomy, is currently the only platform which allows for heterodyne spectroscopy at these frequencies. One example is the OI fine structure line at 4.7 THz, which is a main target to be observed with GREAT, the German Receiver for Astronomy at Terahertz Frequencies, on board of SOFIA.

We report on the progress toward a 4.7-THz frontend for the GREAT heterodyne spectrometer on SOFIA. The local oscillator (LO) combines a quantum-cascade laser (QCL) with a compact, low-input-power Stirling cooler. The 4.7-THz QCL is based on a two-miniband design and has been developed for continuous-wave operation, high output powers, and low electrical pump powers. The mixer is a phonon-cooled NbN hot electron bolometer (HEB). It consists of a 2-μm-wide, 0.2-μm-long, and 5.5-nm-thin NbN stripe on a high-resistivity (> 5 kΩ) silicon substrate located in the center of a planar logarithmic spiral antenna and glued onto the flat side of an extended hemispherical 12-mm-diameter silicon lens. In addition, we will present results obtained with a liquid-cryogen-free front end, which is integrated in a pulse-tube cooler (PTC). It is based on a QCL-LO, which is mounted on the first cold stage of the PTC, and a HEB mixer mounted on the second cold stage.

8452-31, Session 6

Sensitive semiconductor detectors of terahertz radiation for spaceborne applications based on Pb1-xSnxTe(In)

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We propose to use narrow-gap lead telluride - based alloys heavily doped with indium for construction of sensitive photodetecting systems in the terahertz spectral region. Pb1-xSnxTe(In) photodetectors have a number of advantageous features that allow them to compete successfully with the existing analogs:

Internal accumulation of the incident radiation flux;

Possibility of effective fast quenching of an accumulated signal;

Microwave stimulation of the quantum efficiency up to 10^2;

Possibility of realization of a “continuous” focal-plane array;

Possibility of application of a new readout technique;

High radiation hardness.

We report on the physical principles of operation of sensitive terahertz photodetectors based on Pb1-xSnxTe(In). The optical NEP value down to 6*10^(-20) W/Hz^(1/2) at T=1.57 K has been demonstrated at the wavelength of 350 mcm. It is shown that the spectral response of a Pb1-xSnxTe(In) photodetector spreads out at least up to 500 mcm.

8452-32, Session 6

DESHIMA: redshift machine based on an on-chip filterbank

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DESHIMA (Delft SRON High-z Mapper) is a project to build an imaging spectrograph to instantaneously cover the entire bands of multiple submillimeter telluric windows in the range of 320-950 GHz, with a resolving power sufficient for resolving redshifted atomic and molecular lines from submillimeter galaxies (f/df ~ 1000). We are currently following a design which utilizes the rapidly advancing technology of superconducting microresonators twofold. The signal received by the antenna is separated into different frequency channels by using submillimeter wave resonators, made of superconducting NbTiN, as band pass filters. At the exit of each channel is a microwave resonator with a strip of Al, making the resonator act as a Microwave Kinetic Inductance Detector (MKID). The first prototype of such an integrated filterbank (IFB) device, which uses a circuit consisting of coplanar waveguides on a Si substrate, showed strong coupling to stray light radiation. In the conference we will report the current status of the development of DESHIMA, with special focus on the first optical experiment of an IFB, as well as possible solutions for reducing stray light coupling.

8452-33, Session 6

The Kilopixel Array Pathfinder Project (KAPPa), a 16 pixel integrated heterodyne focal plane array

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KAPPa (the Kilopixel Array Pathfinder Project) is developing key technologies to enable the construction of heterodyne focal plane arrays in the terahertz frequency regime with ~1000 pixels. The leap to ~1000 pixels requires solutions to several key technological problems before the construction of such a focal plane is possible. The KAPPa project will develop a small (16-pixel) 2D integrated heterodyne focal plane array for the 660 GHz atmospheric window as a technological pathfinder towards future kilopixel heterodyne focal plane arrays. KAPPa will use SIS devices fabricated on SOI membranes with beam lead alignment and connection features, designed for high yield and fast installation. A SiGe low noise amplifier with on-chip bias tee will be integrated directly into the mixer block immediately adjacent to each mixer. This amplifier has been designed to yield adequate gain and low noise temperature, while dissipating less than 2mW of power. The SIS and LNA devices will be mounted in a 2D integrated metal micromachined mixer array consisting of a backshort block containing the SIS device and LNA, and a horn block using drilled smooth-wall feedhorns. Magnetic field will be delivered to the devices via compact, permanent magnets embedded in the horn block. We will also develop cryogenically compatible IF flex circuits to replace individual semi-rigid coaxial lines for IF signal transmission. Once completed, this instrument will demonstrate the critical technologies necessary to construct coherent arrays approaching 1000 pixels for large single-dish THz telescopes like CCAT and SPT.

8452-34, Session 7

Stabilized HEB-QCL heterodyne spectrometer at super-terahertz

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In the terahertz (THz) frequency range a high resolution heterodyne spectrometer is of crucial importance for astronomical observations and atmospheric remote sensing applications, based on its combination of high spectral resolution and sensitivity. As the mixer, a superconducting NbN hot-electron bolometer (HEB) mixer has demonstrated excellent sensitivities up to 5.3 THz. As the local oscillator (LO), terahertz quantum cascade lasers (QCLs) have shown advantages at frequencies above

2 THz, based on their single mode emission, wide frequency operating range, high output power and long term stability. Several progresses have been made for a THz QCL to be used as the local oscillator (LO) in a heterodyne receiver, such as a heterodyne spectroscopy measurement in the lab.[see Y. Ren et al, Appl. Phys. Lett., 98, 231109(2011).]. Here we report a new experiment on high-resolution heterodyne spectrometer using a 3.5 THz QCL as LO and a HEB as mixer by stabilizing both frequency and amplitude of the QCL. We have already achieved the following results. The frequency locking of the QCL was demonstrated by using a molecular absorption line, a proportional-integral-derivative (PID) controller, and a direct power detector [Y. Ren et al, submitted to Appl. Phys. Lett.]. The intensity of the QCL emission is also stabilized by means of swing-arm actuator placed in the beam path using a second PID controller [D.J. Hayton et al, submitted to Appl. Phys. Lett.].

8452-35, Session 7

Stabilized HEB heterodyne receiver at 2.5 THz

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We report on a method to stabilize a hot electron bolometer (HEB) mixer. HEB mixers are currently the most sensitive heterodyne receivers above 1.5 THz, with applications that include astronomical observations, atmospheric remote sensing and imaging. Astronomical sources, in particular, are often weak with the signal deeply embedded in the noise, requiring long integration periods.

In this paper we report a new stabilization technique that utilizes the sensitive direct detection properties of an HEB to implement feedback control of the local oscillator (LO) laser power by means of novel swing-arm actuator placed in the optical beam path. Rapid control of the LO power is used to maintain a constant operating bias point of the HEB and thus stabilize the mixer conversion gain and output noise, leading to longer Allan times. We demonstrate that this technique yields a factor of 50 improvement in the spectroscopic Allan variance time which is shown to be over 30 sec in a 12 MHz noise fluctuation bandwidth. Furthermore, this method can in principle compensate for the signal direct detection effect often observed in small area HEB's.

This method can easily be applied to practically any LO source and at any frequency. LO stabilization is demonstrated here for a CO2 pumped gas laser at 2.5 THz. The enhanced stability afforded by the proposed technique will make astronomical observing routines such as 'on the fly mapping (OTF)' significantly more efficient as fewer off source reference scans will be needed.

8452-36, Session 7

Terahertz-frequency waveguide HEB receivers

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We develop waveguide-based receivers operating at atomic and molecular transition frequencies of [C II], [O I], OH and HD lines expected respectively at 1.9, 2.06 and 2.5 and 2.7 THz. Future instruments for missions like SOFIA will require an order of magnitude more pixel elements to produce the required science data. Looking ahead to the future, we thus require scalability in terms of both pixel count and frequency. In increasing pixel count, an approach is to produce a filled focal plane array, for example, like a high-frequency version of Supercam, a 64-pixel 0.35 THz camera being built by the University of Arizona. Waveguide mixers offer a compact arrangement as well as the possibilities to implement more sophisticated mixer topology and integration with a local-oscillator source. However, simultaneously increasing the design frequency and pixel count we push conventional machining techniques beyond their practical limits. Recognizing this, we are investigating a lithographic microplating technique, pioneered for this application, for example, by Chalmers. By utilizing microplating approach, we can mass-produce waveguide circuits with micron-level precision and nanometer wall smoothness. Thus, using the lithographic microplating technique, we obtained very sensitive single waveguide-based HEB mixers with DSB receiver noise temperatures of 850 and 965 k at 1.45 and 2.7 THz, respectively. Furthermore, these concepts would facilitate the downscaling for operation at higher frequencies, particularly around 5 THz for the detection of atomic oxygen OI line. We present in detail the main steps of development and experimental results.

8452-37, Session 7

Local oscillator sub-systems for array receivers in the 1-3 THz range

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Successful implementation of single-pixel tunable frequency-multiplied sources for the 1 2 THz regime was an enabling feature of the HIFI instrument onboard the Herschel Space Observatory. The next generation of heterodyne instruments that have been proposed or are under consideration will relay on array receivers to increase science return but will still require broadband performance. This places a considerable challenge on developing efficient LO architectures that can enable array receivers with 100's of pixels in the far-Infrared regime. This talk will discuss the various LO sub-system options that have been investigated for a 32-pixel array receiver at 1.9 THz. Combination of advanced amplifiers around 100 GHz and in-phase power combining schemes have resulted in a modular LO sub-system that can provide pump power for this array with at least 0.002mW of power per pixel. The LO scheme utilized is based on a x2x3x3 chain with GaN amplifiers providing >500 mW of input power around 100 GHz. Further improvement can be achieved by utilizing 'on-chip' power combining and more efficient LO coupling schemes. The trade-offs between different LO architectures will be discussed and latest results that demonstrate more than 0.05 mW of power at 1.9 THz will be presented.

8452-38, Session 7

Membrane-based quasi-optical superconducting HEB mixers at terahertz frequencies

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Superconducting Hot Electron Bolometer mixers offer the highest sensitivity for heterodyne detections at frequencies above 1 THz. Important efforts have been made these recent years to further increase the HEB mixers' sensitivity and working frequency and also to design multi-pixel configuration.

We present in this paper the developments of a non-standard quasi-optical membrane based HEB mixer where the commonly used focusing element, the silicon lens, is replaced by a micro-mirror and a membrane based back-short. This configuration offers many advantages: easier processing for circuits at very high frequencies, better noise temperature brought by lower RF coupling loss and higher gain of the antenna. This design is also considered very attractive for multi-pixel receivers. The devices are made of phonon-cooled NbN HEB mixers processed on 1.4 µm thick stress-less Si3N4/SiO2 membrane. Both spiral and double slot antennas have been studied in the frequency range from 0.6 to 2.5 THz. The design and the device fabrication process will be discussed and the measurement results will be analyzed and compared with simulations.

8452-40, Session 8

Sideband separating SIS mixer for 600-720 GHz for ALMA band 9 upgrade

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For high-frequency observational bands like ALMA Band 9 (600-720 GHz), which tend to be dominated by atmospheric noise, implementation of sideband-separating mixers can reduce, up to a factor of two, the integration time needed to reach a certain signal-to-noise ratio for spectral line observations. Because of very high oversubscription factor for observation in ALMA Band 9, an upgrade of the current Double Sideband (DSB) mixer to a Single Sideband (SSB) or Two Sideband (2SB) configuration is a promising option for future ALMA development.

The developed 2SB mixer includes a waveguide RF hybrid block, which have been produced on a micro-milling machine and equipped with standard Band 9 SIS mixer devices. These two SIS mixers have been separately tested in DSB mode.

The 2SB mixer has the sideband rejection ratio as high as 15 dB over the full RF band, well within the ALMA specifications of 10 dB. The SSB noise temperature is, also within the ALMA requirements of 336 K over 80% of the band, and 500 K over the entire band. We will present the 2SB mixer in details and will discuss the possible schemes of the ALMA Band 9 upgrade.

8452-41, Session 8

A wideband superconducting parametric amplifier for the microwave and millimeter-wave bands

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We have observed wideband gain in a traveling-wave implementation of a microwave frequency superconducting parametric amplifier. The device is based on the nonlinearity of the kinetic inductance of a coplanar waveguide transmission line made of NbTiN. Periodic loading of the transmission line is used to engineer its dispersion relation. The nonlinearity is analogous to the Kerr effect in optical fibers and supports parametric gain through four-wave mixing. As the device is nearly free of dissipation, it need not add noise beyond what is required by quantum mechanics, and noise measurements place an upper limit on the sensitivity of a prototype device of 3 quanta at 10 GHz. The large dynamic range of this amplifier makes it suitable for many applications for which cryogenic transistor amplifiers are used including the microwave domain readout of superconducting detector arrays. Potentially, this type of device may operate up to nearly the (>1 THz) gap frequency of NbTiN, providing a quantum limited gain element well into the millimeter and submillimeter wave bands.

8452-42, Session 8

The ALMA photonic local oscillator system

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The ALMA Photonic Local Oscillator (PLO) is an advanced photonics system that generates and distributes all of the LO and timing references for ALMA. These are used by the receivers and electronics at the antennas, and by the Correlator in the central building. Due to the unprecedented combination of high sky frequencies (up to 950 GHz) and long baseline lengths of up to 15 kilometers, the ALMA 1st LO requirement is particularly stringent, with extremely precise timing and synchronization needed down to ~10 femtosecond level.

The unique requirements, design, and implementation of the ALMA PLO will be reviewed and presented. The challenging synchronization requirements affected the design of all of the modules and subassemblies. The final system thus includes many novel and state-of-the-art optoelectronics and photonics modules. This includes four Laser Synthesizers which generates the 1st LO reference spanning 27-122 GHz, with low phase noise and fast switching capability. Additionally, there is a Line Length Corrector (LLC) module which implements a round trip phase correction to stabilize the LO phase for good astronomical visibility. This LLC uses a piezo-activated fiber stretcher that stabilizes the central building to antenna path by creation of a fiber optic interferometer on each fiber link. This interferometer uses an ultra stable and coherent master laser as the phase reference. This system has been installed in the Array Operations Building which is centrally located to the array, and it is now in routine use supporting the ALMA Early Science Phase.

8452-43, Session 8

Performance highlights of the ALMA correlators

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Two large correlators have been constructed to combine the signals captured by the ALMA antennas deployed on the Atacama Desert in Chile at an elevation of 5000 meters. The Baseline correlator, was fabricated by a NRAO/European team to process up to 64 antennas for 16 GHz bandwidth in two polarizations and another correlator, the Atacama Compact Array (ACA) correlator, was fabricated by a Japanese team to process up to 16 antennas. Both correlators meet the same specifications except for the number of processed antennas. The main architectural differences between these two large machines will be underlined. Selected features of the Baseline and ACA correlators as well as the main technical challenges met by the designers will be briefly discussed. The Baseline correlator is the largest correlator ever built for radio astronomy. Its digital hybrid architecture provides a wide variety of observing modes including the ability to divide each input baseband into 32 sub-bands for high spectral resolution and to be operated as a conventional 'lag' correlator for high time resolution. The various observing modes offered by the ALMA correlators to the science community for 'Early Science' are presented as well as future observing modes. Coherently phasing the array to provide VLBI maps of extremely compact sources is another feature of the ALMA correlators. Finally, the status and availability of these large machines will be presented.

8452-44, Session 8

Interferometry using dual photon response of submm direct detectors

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When two or more photons arrive to a detector at the same time they produce an interference signal with frequency which is the difference of photons individual frequencies. If the detector's internal integration time is small enough this differential photon signal is present at the detector's output. This signal preserves photon's differential phase and thus can be used for non beam combining interferometry. In this contribution we demonstrate experimentally the single detector differential photon operation mode as well as differential dual photon non beam combining interferometer using two of such detectors. We use superconductor-insulator-superconductor (SIS) junction as detector. Applications of this dual photo interferometry for current and future instruments will be discussed.

8452-45, Session 9

QUIET science results and instrument performance: towards a measurement of inflation using the polarized cosmic microwave background

L. Newburgh, Princeton Univ. (United States) and for the QUIET Collaboration (United States)

I will present science results and an instrument performance summary for the Q/U Imaging Experiment (QUIET). QUIET is a ground-based Cosmic Microwave Background (CMB) polarization experiment based on correlation polarimetry using high electron mobility transistor (HEMT) amplifiers. QUIET is designed to measure CMB polarization on angular scales where the spectrum from inflationary gravity waves during the recombination epoch is predicted to peak. QUIET operates at two frequency bands centered at 43 GHz and 95 GHz, which allows us to discriminate between synchrotron emission and the cosmological signal. The two receiver arrays were deployed sequentially during the QUIET observing seasons: the 43 GHz receiver observed from October 2008 - June 2009, and the 95 GHz receiver observed between July 2009 - December 2010. Analysis of the 43 GHz data (ApJ 741:2 2011) showed that we achieved the lowest levels of systematic errors of any CMB experiment yet. We also confirmed polarization power spectra from previous experiments, and that we measured an excess of polarized emission in one scanning region which we attribute to a synchrotron foreground. Analysis of the 95 GHz data set is underway; we expect similar or lower levels of instrument systematic errors than with the 43 GHz array. I will discuss the performance and calibration of both instruments, the science results from the 43 GHz analysis, and the status and science prospects of the 95 GHz data.

8452-46, Session 9

BICEP2 and Keck array operational overview and status of observations

R. W. Ogburn IV, Stanford Univ. (United States); T. B. Collaboration, T. K. Collaboration,

The BICEP2 and Keck Array experiments are designed to search for primordial gravitational waves by measuring their imprint on the polarization of the cosmic microwave background (CMB). They build on the success of the original BICEP experiment by adopting a new detector technology, with TES detectors coupled to beam-defining slot antennas fabricated in the same silicon wafer. This monolithic design and the multiplexed SQUID readout have allowed BICEP2 and the Keck Array to field larger numbers of detectors for improved mapping speed. BICEP2 was deployed in 2009 with 512 detectors at 150 GHz, and has observed at the South Pole through 2010 and 2011. The Keck Array was deployed in late 2010, with three BICEP2-style telescopes, and has observed through 2011. A Keck Array upgrade, now in progress, will add two additional receivers for the 2012 observing year. We report on the operations and observing history of the two experiments.

8452-47, Session 9

Optimization and sensitivity of the Keck array

S. A. Kernasovskiy, Stanford Univ. (United States)

The Keck Array (SPUD) began observing the cosmic microwave background's polarization in the winter of 2011. Keck Array follows the success of the pathfinder experiment BICEP-2, using five on-axis refracting telescopes. They have a combined imaging array of 2500 antenna-coupled TES bolometers read with a SQUID-based time domain multiplexing system. We will discuss the optimization of the readout and the achieved sensitivity.

8452-48, Session 9

The POLARBEAR experiment

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We present the design and characterization of the POLARBEAR experiment. POLARBEAR will measure the B- mode polarization of the cosmic microwave background (CMB) on angular scales ranging from the experiment's 4' beam size to several degrees. The experiment utilizes a unique focal plane of 1,274 antenna-coupled, polarization sensitive transition-edge sensor (TES) bolometers cooled to 250 milli-Kelvin. Employing this focal plane along with stringent control over systematic errors, POLARBEAR is designed to detect the expected small scale signal due to gravitational lensing and search for the large scale signal from inflationary gravitational waves.

POLARBEAR was assembled for an engineering run in the Inyo Mountains of California in 2010 and was deployed in late 2011 to the Atacama Desert in Chile. An overview of the instrument is presented along with characterization results from both the California engineering run and observations in Chile.

8452-49, Session 9

The bolometric focal plane array of the POLARBEAR CMB experiment

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The POLARBEAR Cosmic Microwave Background (CMB) polarization experiment is currently observing from the Atacama Desert in northern Chile. It will characterize the expected B-mode polarization due to gravitational lensing of the CMB, and search for the possible B-mode signature of inflationary gravitational waves. Its 250 mK focal plane detector array consists of 1,274 polarization-sensitive antenna-coupled bolometers, each with an associated lithographed band-defining filter. Each detector's planar antenna structure is coupled to the telescope's optical system through a contacting dielectric lenslet, an architecture unique in current CMB experiments. We present the initial characterization of this focal plane.

8452-50, Session 10

SPTpol: an instrument for CMB polarization measurements with the South Pole Telescope

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SPTpol is a multichroic polarimetric camera designed and optimized for measurement of the polarized component of the Cosmic Microwave Background (CMB) at arcminute scales and was deployed to the South Pole Telescope in January 2012. The current cosmological model predicts the existence of small amplitude anisotropies in the polarized CMB that can be used to constrain some aspects of fundamental physics, including the total mass of the neutrino species and the amplitude of gravitational waves during inflation. Measurement of these signals requires significantly improved instrument sensitivities and finer control of systematics compared to the previous generation of CMB experiments. SPTpol system-level sensitivities are maximized by fully and efficiently populating the focal plane with 768 pixels (180 operating at 90 GHz and 588 at 150 GHz), each consisting of two Transition Edge Sensors (TES) coupled to orthogonal polarizations for simultaneous measurement at two polarization angles. Systematics are controlled in a variety of ways, including the use of single-moded feedhorns to produce well defined beams, multichroic observation for the spectral identification and removal of foreground sources, and the use of TES pairs that have well matched electrothermal properties in each pixel. In this work we provide an overview of the scientific rationale and instrumental design of SPTpol and review the detector and readout technologies used. We also provide the project status and projections.

8452-51, Session 10

Performance and on-sky optical characterization of the SPTpol instrument

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In January 2012 the SPTpol camera was deployed on the 10m South Pole Telescope to observe the polarization of the the Cosmic Microwave Background (CMB). Measurements of CMB polarization at small angular scales yields fine scale maps of weak lensing, which can constrain the sum of the neutrino masses, and at large angular scales can inform the energy scale of inflation. SPTpol is a dichroic mm-wave camera that consists of 180 dual-Transition Edge Sensor (TES) polarimeters at 90 GHz and 588 dual-TES polarimeters at 150 GHz. The full complement of 150 GHz detectors consists of 7 arrays of 84 Ortho-Mode Transducers (OMTs) stripline coupled to two TES detectors each, developed with the TRUCE collaboration at NIST. Each 90 GHz pixel consists of two antenna-coupled absorbers coupled to two TES detectors, developed with Argonne National Labs. The 1536 total detectors are read out with Digital Frequency domain Multiplexing (DfMUX). The SPTpol deployment represents the first on-sky tests of both of these detector implementations, and some of the first science observations with DfMUX readout technology. We present the details of the design, commissioning, deployment, on-sky optical characterization and detector performance of the complete SPTpol focal plane.

8452-52, Session 10

Fully monolithic focal planes of antenna-coupled TES bolometers for a diverse assortment of CMB polarimetry experiments

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Caltech and NASA JPL have developed monolithic focal planes of phased-array antenna coupled TES bolometers for CMB polarimetry B-mode searches and we will summarize our efforts in this talk. Our detectors have already found widespread use in the community, specifically in the ground based BICEP-2, Keck Array, and POLAR-1 telescopes as well as the balloon bourn SPIDER. Our team has advanced beyond the stage of initial field deployments in BICEP-2 and Keck and we are fine-tuning the detector's properties, which includes controlling unwanted beam steering off boresight and optimizing the detector noise for the low-background environments that experiments like SPIDER or EPIC will experience.

While we have thus far deployed exclusively 150GHz cameras, we have built 90GHz ones for Keck and SPIDER to control for galactic foregrounds and are designing additional cameras for 220GHz and 280GHz. We are currently exploring a variety of materials to use as microstrip dielectrics with the goal of moving all detectors to the focal plane edge. This will facilitate dual-color focal planes with pixel sizes optimally matched to the telescope optics at both channels' band centers. We have adapted a modular design for POLAR and other future experiments that will let us easily swap individual tiles, allowing for higher detector yield. Finally, we have taylored our antenna's feed network with a gaussian illumination pattern to minimize spillover loss onto specific optics deigns. This is particularly important for experiments like Polar and EPIC that will use Crossed Dragone optics.

8452-53, Session 10

The POLARBEAR-2 experiment

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POLARBEAR-2 (PB-2) is an upgraded experiment based on the POLARBEAR experiment (PB-1), which aims to observe B-mode polarization of Cosmic Microwave Background (CMB) and is now observing from the Atacama Desert in Chile. The goal of PB-2 is to further improve precision of CMB B-mode search. For PB-2, we will build a new receiver that has three key features; dichroic antenna-coupled Transition Edge Sensor (TES) bolometer, a 4.3 degree diameter field-of-view and 0.1K cooling system. Each pixel can observe in two bands at 95GHz and 150GHz simultaneously. A total of 7,588 bolometers are employed on the focal plane and the bolometers will be read out via a 32 channel frequency domain multiplexing scheme. A large focal plane (365mm in diameter) and three cold lenses will provide a large 4.3 degree field-of-view. The experiment will be deployed in two phases. In phase 1, Al-Ti bilayer TES operated at 0.25 Kelvin will be used, but they will be replaced with Al-Mn operated at 0.1K by an adiabatic demagnetization refrigerator (ADR) in phase 2. The final PB-2 array will have a 5.7 uK s^0.5 NET, a factor of 2.5 better than PB-1. We expect the PB-2 survey to set 95% C.L. upper limit on the tensor to scalar ratio r of 0.01 with two years of observation and 10% sky coverage. It will also measure the sum of neutrino masses with an uncertainty of 0.09 eV. PB2 is planning to start observation in 2014. We will present the PB-2 project overview and progress.

8452-54, Session 10

Design and integration of ACTPol, a polarization sensitive receiver for the Atacama Cosmology Telescope

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In this proceeding, we highlight considerations for the design and integration of ACTPol, a new receiver for the Atacama Cosmology Telescope (ACT), capable of making polarization-sensitive observations of the Cosmic Microwave Background (CMB) at arcminute angular scales. ACT is a six-meter telescope located in northern Chile, dedicated to enhancing our understanding of the structure and evolution of the early universe by direct measurement of the CMB. We describe the design of the first ACTPol 150 GHz detector array package, which, along with a second 150 GHz array package and a multichroic array package with simultaneous 90 GHz and 150 GHz sensitivity, comprises the ACTPol focal plane. Each of these detector array packages reside behind a set of normal-incidence, high-purity silicon reimaging optics with a novel anti-reflective coating geometry. The 150 GHz array package consists of 1044 transition-edge sensor (TES) bolometers used to measure the response of 522 feedhorn-coupled polarimeters, which enable characterization of the linear orthogonal polarization of incident CMB radiation. The polarimeters are arranged in three hexagonal and three semi-hexagonal silicon wafer stacks, mechanically coupled to an octakaidecagonal, monolithic corrugated silicon feedhorn array (~140 mm diameter). Readout of the TES polarimeters is achieved using time-division SQUID multiplexing. Each array package is cooled using a custom dilution refrigerator providing a 100 mK bath temperature to the detectors, which have a target Tc of 150 mK. Given the unique cryomechanical constraints associated with this large-scale monolithic superconducting focal plane, we address design considerations necessary for integration with elements of the ACTPol receiver.

8452-55, Session 11

The primordial inflation polarization explorer (PIPER)

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The Primordial Inflation Polarization Explorer (PIPER) is a balloon-borne instrument to measure the gravity-wave signature of primordial inflation through its distinctive imprint on the polarization of the cosmic microwave background. PIPER combines cold (1.5 K) optics, 5120 bolometric detectors, and rapid polarization modulation using VPM grids to achieve both high sensitivity and excellent control of systematic errors. A series of flights alternating between northern and southern hemisphere launch sites will produce maps in Stokes I, Q, U, and V parameters at frequencies 200, 270, 350, and 600 GHz (wavelengths 1500, 1100, 850, and 500 μm) covering 85% of the sky. We describe the PIPER instrument and discuss the current status and expected science returns from the mission.

8452-56, Session 11

Silicon feedhorn-coupled TES polarimeter arrays for SPTpol, ACTPol and next-generation CMB experiments

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To meet the demands of increased focal plane sensitivity and low systematic errors for cosmic microwave background (CMB) experiments, we are developing feedhorn-coupled TES polarimeter arrays. Silicon corrugated feedhorns together with planar orthomode transducers couple light from the CMB to an array of multiplexed transition-edge sensors (TES). Three experiments use this technology at 150 GHz. Single pixel polarimeters are currently being deployed with metal feedhorns in the Atacama B-mode Search (ABS). Silicon feedhorn arrays coupled to 150 GHz polarimeter arrays with over 500 polarimeters are being deployed on the South Pole Telescope Polarimeter (SPTPol) and the Atacama Cosmology Telescope Polarimeter (ACTPol) in 2012, followed by an ACTPol upgrade to over 1000 polarimeters in 2013. We discuss how this technology is adapted and optimized for each experiment. We demonstrate this technology by characterizing the optical properties of a laboratory array similar in design to an SPTpol subarray. To maximize usage of limited focal plane area, we are also developing dual-band (multichroic) polarimeters coupled to octave-bandwidth silicon feedhorns. We discuss the status of 90/150 GHz and 220/270 GHz multi-chroic polarimeters that are based on the 150 GHz design. We currently plan to deploy a 90/150 GHz multi-chroic array as the third ACTPol array in 2013. The multi-chroic detectors have also been proposed for use in next generation balloon and ground-based experiments.

8452-57, Session 11

A novel experiment for CMB polarization measurement using highly multimoded bolometers

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We propose a new ground-based experiment to measure the polarization of the cosmic microwave background (CMB). One of the most exciting targets for the CMB polarization measurements is the faint signal from the primordial gravity waves predicted by inflationary models. Currently existing experiments and those under construction would constrain or detect such signal at around r=0.01, where r is the tensor to scalar ratio. In order to further improve the measurement, experiments for the next generation have to combine the following three: 1) excellent sensitivity, 2) multi-frequency measurement for the removal of galactic foregrounds, and 3) well-controlled systematics. We propose an experiment using highly multi-moded polarization-sensitive bolometers developed at NASA Goddard Space Flight Center. The instrument, consisting of fewer than 100 pixels, will achieve a sensitivity equivalent to several thousand pixels of single-moded bolometers. Each pixel can be configured to be sensitive to a different frequency band, allowing very wide frequency coverage by a single focal plane. This enables us to clean galactic synchrotron and dust components with our data alone, and achieves an effective array sensitivity to the CMB of 8 uK sqrt(s) even after accounting for the sensitivity degradation from foreground removal. We discuss the design and the development status of the instrument.

8452-58, Session 11

GroundBIRD: an experiment for CMB polarization measurements at a large angular scale from the ground

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The B-mode polarization of the cosmic microwave background (CMB) at large angular scales is a smoking-gun signature of the inflationary universe. Especially, detecting an ionization bump at l<=10, where l is the multipole of the B-mode power spectrum, should be a clear evidence for the primordial gravitational wave induced by inflation. GroundBIRD is designed to detect such a large angular-scale B-mode power from the ground. We are going to use a superconducting detector array with a small telescope which is also in the cryogenic system. The basic design can be applied to a future satellite experiment.

GroundBIRD employs a special turn table for continuously rotating the telescope instead of the system for the ordinary azimuth scan. This allows us to perform high-speed scans (20 rpm) without any deceleration. As a result, the sky coverage is extended without suffering from the detector 1/f noise. Our target l range is 6 <= l <= 300.

We plan to start commissioning the system in Japan in early 2014. The instruments will then by moved to the Atacama desert in Chile for science observations. We will present the status of the system development.

8452-59, Session 11

Detector architecture of the cosmology large angular scale surveyor status and preliminary results

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The cosmic microwave background (CMB) provides a powerful tool for testing modern cosmology. In particular, if inflation has occurred, the associated gravitational waves would have imprinted a specific polarized pattern on the CMB. Measurement of this faint polarized signature requires large arrays of polarization-sensitive, background-limited detectors, and an unprecedented control over systematic effects associated with instrument design. To this end, the ground-based Cosmology Large Angular Scale Surveyor (CLASS) employs large-format,

feedhorn-coupled, background-limited Transition-Edge Sensor (TES) bolometer arrays operating at 40, 90, and 150 GHz bands. The detector architecture has several enabling technologies. An on-chip symmetric planar orthomode transducer (OMT) is employed that allows for highly symmetric beams and low cross-polarization over a wide bandwidth. Furthermore, the quarter-wave backshort of the OMT is integrated using an innovative indium bump bonding process at the chip level that ensures minimum loss, maximum repeatability and performance uniformity across an array. Care has been taken to reduce stray light and on-chip leakage. In this paper, we report on the architecture and performance of the first prototype detectors for the 40 GHz channel, including detailed dark and optical characterization measurements of the TES bolometers operating at 150mK.

8452-60, Session 12

Millikelvin cryocooler for space and ground-based detector systems

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A 4 Kelvin to sub 0.1 Kelvin cryocooler module has been developed which can be coupled to a mechanical 4 K cryocooler to provide a complete 300 K to millikelvin cryocooler cooling solution. This development has come about through the MSSL space and ground based cryocooler development programme funded by the STFC and the EPSRC. The millikelvin cryocooler module is currently in the final phase of manufacture (December 2011) and will undergo testing in February 2012. The cooler module weighs 7.5 kg with dimensions 355 mm length, 56mm depth and 120 mm width. The module uses two magnetically screened double adiabatic demagnetisation refrigerators (ADRs) operated in tandem to provide continuous cooling at any temperature from the module interface temperature of 4 K to the base temperature, predicted to be 80 mK, making this an extremely versatile cooler. The module under construction is predicted to provide 1 μW of cooling power at the base temperature of 80 mK and 5 μW of cooling power at 100 mK. The system is however scalable, so larger cooling powers can be provided at these temperatures with an increase in module size.

ADRs are an extremely reliable method of millikelvin refrigeration when coupled to a 4 K cryocooler. For example a cryocooler (pulse tube) cooled single shot double ADR developed by us for the European Space Agency (ESA), with a base temperature of 25 mK, ran continuously for 13 months, only then being warmed due to the end of the experiment. This system was also fully automated and could be operated remotely via the internet. We would thus expect the millikelvin cooler module coupled to a 4 K cryocooler to be able to provide, if required, years of millikelvin continuous cooling, making it ideal for extremely low/zero maintenance detector systems for ground based instruments. While this system is primarily for ground operation adaptation for space use will only require modest changes due utilisation of similar components to the ESA system. In this paper we present details of the cooler design, construction, operation and performance.

8452-61, Session 12

Thermal architecture of the SPICA/SAFARI instrument

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The SAFARI instrument is a far infrared imaging spectrometer that is a core instrument of the SPICA mission. Thanks to the large (3 meters) SPICA cold telescope, to the ultra sensitive detectors (NEP~10-19 W/root(Hz)) and to a powerful Fourier Transform Spectrometer, this instrument will give access to the faintest light never observed in the 34 μm - 210 μm bandwidth with a high spectral resolution. To achieve this goal, TES detectors, that need to be cooled at a temperature as low as 50 mK, have been chosen. The thermal architecture of the SAFARI focal plane unit (FPU) that fulfils the TES detector thermal requirements is presented. In particular, an original 50 mK cooler concept based on a sorption cooler in series with an adiabatic demagnetization refrigerator will be used. The thermal design of the detector focal plane array (FPA) that uses three temperature stages to limit the loads on the lowest temperature stage, will be also described. The current SAFARI thermal budget estimations are presented and discussed regarding the limited SPICA allocations. Finally, preliminary thermal sensitivity analysis dealing with thermal stability requirements is presented.

8452-62, Session 12

Performance and impact of the cryogenic cooling system on Planck

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The unprecedented performance of the Planck instruments in measuring the anisotropies of the cosmic microwave background is enabled by the Planck cryogenic cooling system. A combination of radiative cooling to space, an 18-K JT hydrogen sorption cooler, a 4-K 4He mechanical JT cooler, and a 0.1-K 3He-4He dilution cooler, provides optimal conditions for the amplifiers (~20 K) and bolometers (0.1 K) of the Low Frequency Instrument and the High Frequency Instrument, respectively. We discuss the design and performance of the cooling system, its advantages, and its applicability to future missions.

8452-63, Session 12

The optical, mechanical, and thermal design and performance of ZEUS-2

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We have built a new long-slit grating spectrometer (ZEUS-2) for observations in the submillimeter wavelength regime (200-850 micron). ZEUS-2 is optimized for observations of redshifted far-infrared spectral lines from galaxies in the early Universe. The spectrometer employs three transition-edge sensed bolometer arrays, allowing for simultaneous observations of multiple lines in several telluric windows. Here we will discuss optical, mechanical, and thermal requirements of ZEUS-2 and their subsequent design and performance. The entire instrument is cooled by using a pulse tube closed-cycle cooler and an Adiabatic Demagnetization Refrigerator (ADR). A sophisticated two-stage frame fixated by Kevlar strings holds the detector package and makes the thermal load through the mount-structure negligible compared to the detector wires. The cryogen-free approach enables remote control of the cooling system and allows for deployment of ZEUS-2 to telescope sites where access is limited. The compact and light-weight design of ZEUS-2 is also within the size and weight constraints of several submillimeter telescopes, making ZEUS-2 deployable at a variety of sites.

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SPIE Astronomical Instrumentation

8453-01, Session 1

Photon counting EMCCDs: new opportunities for high time resolution astrophysics

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Electron Multiplying CCDs (EMCCDs) are used much less often than they might be because of the challenges they offer camera designers more comfortable with slow-scan detector systems. However they offer an entirely new range of opportunities in astrophysical instrumentation. This paper will show some of the most exciting new results obtained with these remarkable devices and talk about their potential in other areas of astrophysical application. We will then describe how they may be operated to give the very best performance at the lowest possible light levels. We will show that clock induced charge may be reduced to negligible levels and that, with care, devices may be clocked at significantly higher speeds than usually achieved. As an example of the advantages offered by these detectors we will show how a multi-detector EMCCD curvature wavefront sensor will revolutionise the sensitivity of adaptive optics instruments.

8453-02, Session 1

Characterization results of EMCCDs for extreme low-light imaging

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Until now, only the CCD97 has been characterized with the CCD Controller for Counting Photons. The results showed that it was possible to greatly lower the level of the Clock Induced Charges (CIC) generated during the read-out of the EMCCD by using this controller. This low noise level allows the EMCCDs to be operated in photon counting, which gets rid of the Excess Noise Factor (ENF) induced by the stochastic multiplication process. This yields a photon counting detector in the visible with > 80% QE and less than 0.001 electron/pixel/frame of noise. The characterization of other EMCCDs (such as the CCD60 and CCD201-20) is of interest as the CCD97 is limited in speed (~33 fps full frame) and FPA size (8.2 mm ^2), two aspects that can be covered by the smaller CCD60 (up to ~1k frames/s) and larger CCD201-20 (13mm ^2). These results will give an insight of the performances that will be attainable with the newer 4k x 4k split-FT EMCCD now being developed by e2v, which is greatly awaited by the astronomical community for high resolution spectroscopy, fast photometry, and scanning applications.

8453-03, Session 1

Charge-coupled devices for the ESA Euclid M-class Mission

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The European Space Agency has funded e2v's development of an image sensor for the visible instrument in the Euclid space telescope. Euclid has been selected for one of two medium class mission launch opportunities in 2017 and 2019. The project aims to map the dark universe with two complementary methods; a galaxy red-shift survey and weak gravitational lensing using near infrared and visible instruments.

The baseline for the visible instrument was the CCD203-82 which has been successfully flown on NASA's Solar Dynamics Observatory. To optimise the device for Euclid, e2v have designed and manufactured the CCD273-84. This device has a higher responsivity lower noise amplifier, enhanced red response, parallel charge injection structures and narrower registers for improved low signal charge transfer efficiency.

Development models for Euclid have been manufactured with a low voltage process that reduces the clock voltage swing and therefore the power dissipation. In addition, the devices are more tolerance of ionising radiation damage.

This paper describes the imager sensor in detail and focuses on the novel aspects of the device, package and interface.

8453-04, Session 1

CCD research and development at Lawrence Berkeley National Laboratory

S. E. Holland, P. Denes, D. E. Groom, S. Haque, A. Karcher, W. F. Kolbe, J. S. Lee, N. P. Palaio, G. Wang, Lawrence Berkeley National Lab. (United States)

We describe work at Lawrence Berkeley National Laboratory to develop enhanced performance, fully depleted, back-illuminated CCDs for astronomy and astrophysics. The CCDs are fabricated on high-resistivity substrates and are typically 200 - 300 µm thick for improved near-infrared response. The primary research and development areas include methods to reduce read noise, increase quantum efficiency and readout speed, and the development of fabrication methods for the efficient production of CCDs for large focal planes. In terms of noise reduction, we will describe technology developments with our industrial partner Teledyne DALSA to develop a buried-contact technology for reduced floating-diffusion capacitance, as well as efforts to develop "skipper" CCDs with sub-electron noise utilizing non-destructive readout amplifiers allowing for multiple sampling of the charge packets. Improvements in quantum efficiency in the near-infrared utilizing ultra-high resistivity substrates that allow full depletion of 500 µm and thicker substrates will be described, as well as studies to improve the blue and UV sensitivity by investigating the limits on the thickness of the backside ohmic contact layer used in the LBNL technology. Improvements in readout speed by increasing the number of readout ports will be described, including work on high frame-rate CCDs for x-ray synchrotrons with as many as 192 amplifiers per CCD. Finally, we will describe improvements in fabrication methods, developed in the course of producing over 100 science-grade 2k x 4k CCDs for the Dark Energy Survey Camera.

8453-05, Session 2

UV photon-counting CCD detectors that enable the next generation of UV spectroscopy missions: low-noise and high-dynamic range

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We are developing photon counting UV sensitive detectors with breakthrough performance capabilities resulting from the combination of e2v Low Light Level CCDs and the JPL delta doping process. These detectors have demonstrated UV sensitivity (detected photons per incident photon) of over 50% across the FUV and NUV bands and are poised to enable new NASA missions with greatly enhanced capabilities at reasonable cost. In this paper, we provide an overview of the characteristics of these devices, including a discussion of their noise characteristics. We present our measurements and discuss their implications for a range of astronomical application scenarios.

8453-06, Session 2

UV photon-counting CCD detectors that enable the next generation of UV spectroscopy missions: why the red-leak is a non-problem

D. Schiminovich, Columbia Univ. (United States)

A proper assessment of a detector's utility for astronomy requires characterization of its performance in realistic applications and observing conditions. While detector technologies may provide demonstrated efficiency, noise, background rate, dynamic range, pixel size and array size, additional sources of noise may include astrophysical foregrounds/backgrounds including signal from out-of-band light. A commonly-stated requirement for UV detectors is that they should be "solar-blind" in order to mitigate the impact of enhanced background due to the detection of red photons. Here we critically assess this requirement, considering a wide range of potential applications for UV detectors, realistic considerations of foregrounds and backgrounds and target spectral energy distributions, and laboratory simulations. We show that there is a large parameter space of observations for which a UV-photon counting CCD detector, coupled with a spectrograph, is not sensitivity-limited by the red-leak. We also show how the application of conventional UV reflective filters, such as those used on GALEX and other space missions, can further increase the parameter space of astrophysical applications for which the red leak is a non-problem.

8453-07, Session 2

Far ultraviolet sensitivity of silicon CMOS sensors

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We describe vacuum ultraviolet sensitivity measurements of a new high performance silicon-based CMOS sensor from Teledyne Imaging Sensors. These sensors do not require the high voltages of MCP detectors, making them a lower mass power alternative to the more mature MCP technology. These devices demonstrate up to 40 percent quantum efficiency at vacuum ultraviolet wavelengths, either meeting or greatly exceeding 10 percent quantum efficiency across the entire 100-200 nm wavelength region. As with similar visible sensitive devices, backside illumination results in a higher quantum efficiency than frontside illumination. Measurements of the vacuum ultraviolet sensitivity of the Teledyne silicon PIN detectors were made by directing a known intensity of ultraviolet light at discrete wavelengths onto the test detectors and reading out the resulting photocurrent. The sensitivity of the detector at a given wavelength was then calculated from the intensity and wavelength of the incoming light and the relative photodiode to NIST-traceable calibration diode active areas. A custom electromechanical interface was developed to make these measurements within the SwRI Vacuum Radiometric Calibration Chamber. While still in the single pixel stage, full 1K x 1K focal plane arrays are possible using existing readout electronics and hold great promise for inclusion in future spaceflight instrument concepts.

8453-08, Session 2

UV photon-counting CCD detectors that enable the next generation of UV spectroscopy missions: AR coatings that can achieve 80-90% QE

E. T. Hamden, D. Schiminovich, Columbia Univ. (United States); S. Nikzad, Jet Propulsion Lab. (United States); D. C. Martin, California Institute of Technology (United States)

We describe recent progress in the development of anti-reflection coatings for use at UV wavelengths on CCDs and other Si-based detectors. In previously published work, we have demonstrated a set of coatings which are able to achieve greater than 50% QE in 4 bands from 130nm to >300nm (Nikzad, 2011). All but one of these coatings was made with a simple, single-layer film using fairly standard UV transparent materials. We now present new refinements of these AR-coatings which will greatly improve performance (theoretical QE's well above 80%) in a narrower bandpass. We will also demonstrate robustness, repeatability, and long-term stability and the testing of coated devices both in the lab and in flight-like environments. Finally, we will mention a number of applications for high QE UV devices.

8453-09, Session 3

Temperature dependence of the dark current and activation energy at avalanche onset of a GaN avalanche photodiodes

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We report a study of the performance of an avalanche photodiode (APD) as a function of temperature from 564 K to 74 K.

The dark current at avalanche onset decreases from 564 K to 74 K by approximately a factor of 125 and from 300 K to 74K the dark current at avalanche offset is reduced by a factor of about 10. The drop would have been considerably larger if the activation energy at avalanche onset (Ea) did not also decrease with decreasing temperature. These data give us insights into how to improve the single-photon counting performance of a GaN based ADP.

8453-10, Session 3

UV photon counting detectors enabling the next generation of UV spectroscopy missions

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Future UV/optical missions under planning and review will search for Earth-like exoplanets, search for life in planets far from our own, perform spectroscopic studies of intergalactic medium, and perform planetary atmospheric studies. These new instruments place exacting requirements on detectors. One such requirement is the ability to detect single photons with high efficiency. We report on our latest results on photon counting detectors with >50% QE response in the far UV and near UV. To achieve these results, we engineer the detector surface and interfaces with atomic scale precision control using Molecular Beam Epitaxy (MBE) and Atomic Layer Deposition (ALD). We discuss these results and processes, status of development and readiness, as well the JPL's high throughput end-to-end back illumination processes and report on its applications to other CCD and CMOS detectors.

8453-11, Session 4

Optical lumped element microwave kinetic inductance detectors

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Microwave Kinetic Inductance Detectors (MKIDs) are energy sensors based on a photon-variable superconducting inductance in a lithographed microresonator. They are capable of functioning as photon detectors across the electromagnetic spectrum as well as particle detectors. Due to their sensitivity and the ease with which they can be multiplexed into large arrays, MKIDs have already been proven as a powerful cryogenic detector technology. We describe the first successful campaign to create and test a photon-counting, energy-resolving ultraviolet, optical, and near infrared MKID focal plane array, as well as further developments to optimize their performance in future campaigns.

Optical Lumped Element (OLE) MKID arrays have significant advantages over semiconductor detectors such as charge coupled devices (CCDs). They can count individual photons with essentially no false counts and determine the energy and arrival time of every photon with good quantum efficiency. Their physical pixel size and maximum count rate are well matched with large telescopes. These capabilities enable powerful new astrophysical instruments usable from the ground and space. MKIDs have the potential to eventually supplant semiconductor detectors for most astronomical instrumentation, and may prove to be useful for other disciplines, such as quantum optics and biological imaging.

8453-12, Session 5

Backside-illuminated, high-QE, 3e- RoN, fast 700fps, 1760x1760 pixels CMOS imager for AO with highly parallel readout

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The success of the next generation of instruments for 8 to 40-m class telescopes will depend upon improving the image quality (correcting the distortion caused by atmospheric turbulence) by exploiting sophisticated Adaptive Optics (AO) systems. One of the critical components of the AO systems for the E-ELT has been identified as the Laser/Natural Guide Star (LGS/NGS) WaveFront Sensing (WFS) detector. The combination of large format, 1760x1760 pixels to finely sample (84x84 sub-apertures) the wavefront and the spot elongation of laser guide stars, fast frame rate of 700 (up to 1000) frames per second, low read noise (90%) makes the development of such a device extremely challenging. Design studies by industry concluded that a thinned and backside-illuminated CMOS Imager as the most promising technology. This paper describes the multi-phased development plan that will ensure devices are available on-time for E-ELT first-light AO systems; the different CMOS pixel architectures studied; measured results of technology demonstrators that have validated the CMOS Imager approach; the design explaining the approach of massive parallelism (70,000 ADCs) needed to achieve low noise at high pixel rates of ~3 Gpixel/s ; the 88 channel LVDS data interface; the restriction that stitching (required due to the 5x6cm size) posed on the design and the solutions found to overcome these limitations. Two generations of the CMOS Imager will be built: a pioneering quarter sized device of 880x840 pixels capable of meeting first light needs of the E-ELT called NGSD (Natural Guide Star Detector); followed by the full size device, the LGSD (Laser Guide Star Detector).
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8453-13, Session 5

High-performance CMOS image sensors at BAE Systems Imaging Solutions

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In this paper, we present an overview of high-performance CMOS image sensor products developed at BAE SYSTEMS Imaging Solutions designed to satisfy the increasingly challenging technical requirements for image sensors used in advanced scientific, industrial, and low light imaging applications. We discuss the design and present the test results of a family of image sensors tailored for high imaging performance and capable of delivering sub-electron readout noise, high dynamic range, low power, high frame rates, and high sensitivity. We briefly review the performance of the CIS2051, a 5.5-Mpixel image sensor, which represents our first commercial CMOS image sensor product that demonstrates the potential of our technology, then we present the performance characteristics of the CIS1021, a full HD format CMOS image sensor capable of delivering sub-electron read noise performance at 50 fps frame rate at full HD resolution. We also review the performance of the CIS1042, a 4-Mpixel image sensor which offers better than 70% QE @ 600nm combined with better than 91dB intra scene dynamic range and about 1 e- read noise at 100 fps frame rate at full resolution.

8453-15, Session 6

Recent progress on developments and characterization of hybrid CMOS x-ray detectors

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Future space-based X-ray telescope missions are likely to have significantly increased demands on detector read out rates and radiation hardness due to increased collection area, and there will be a desire to minimize radiation damage in the interests of maintaining spectral resolution. While CCDs have met the requirements of past missions, active pixel sensors are likely to be a standard choice for some future missions due to their inherent radiation hardness and fast, flexible read-out architecture. One form of active pixel sensor is the hybrid CMOS sensor. In a joint program of Penn State University and Teledyne Imaging Sensors, hybrid CMOS sensors have been developed for use as X-ray detectors. Results of this development effort and tests of fabricated detectors will be presented, along with potential applications for future missions.

8453-16, Session 6

Characterization of an x-ray hybrid CMOS detector with low interpixel capacitive crosstalk

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New X-ray space missions are on the horizon and these missions require high performance x-ray detectors. We present the results of measurements on an X-ray hybrid CMOS detector that uses a Teledyne H2RG ROIC and a unique bonding structure. The Si absorber array has a 36 micron pixel size, and the readout array has a pitch of 18 microns; but only one readout circuit line is bonded to each 36x36 micron absorber pixel, giving the readout an effective pitch of 36 microns. We find the increased pitch between readout bonds significantly reduces the interpixel capacitance of the CMOS detector. We also present other characteristics of this detector.

8453-17, Session 6

Development of monolithic CMOS detectors as x-ray imaging spectrometers

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We present preliminary results from our ongoing program to develop CMOS imaging detectors as single photon counting, soft X-ray imaging spectrometers. SAO in collaboration with the Sarnoff Corporation has been developing monolithic CMOS detectors optimized for x-ray astronomy.

The largest detector consists of an array of 1k x 1k 16micron pixels manufactured on 15micron epitaxial Si. These detectors will be packaged and back-thinned for back illumination.

Expected gain for these detectors will be ~40uV/electron. Noise is expected to be < 4e rms. The devices have on-chip CDS and are optimized to have very high read-out rates. Such devices would be ideal candidate detectors for focal planes in solar and other space-borne x-ray astronomy missions. The high through-put, low noise and excellent low energy response, provide high dynamic range and good time resolution; solar flares and other time varying x-ray features could be temporally and spectrally resolved without saturation.

We present details of our camera design and device performance with particular emphasis on those aspects of interest to single photon counting x-ray astronomy. These features include noise, x-ray spectral response and quantum efficiency.

8453-18, Session 6

Development and performance of Kyoto's x-ray astronomical SOI pixel sensor

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We have been developing a novel X-ray sensor, X-ray SOIPIX (Silicon-On-Insulator pixel sensor) for the next generation astronomical X-ray satellites. It has a very low non-X-ray background rate and offers wide-band and high-resolution imaging spectroscopic observation. We present the outline of the project and current status of the development in this talk. We successfully developed a prototype sensor, 'XRPIX1' and its modified version of 'XRPIX1b', with the pixel size of 30.6 micron and the format of 32 x 32. Each pixel has its own trigger circuit, thus the sensor is capable to output the hit timing and pixel position. The energy resolution of 278 eV (FWHM) at 8.0 keV, readout noise of 14.6 e (rms) and the thickness of the depletion layer of 250 micron have been achieved so far. The full-depleted back illumination type of XRPIX1 successfully detects Al-K line at 1.5 keV. We also report results from the operation in the trigger-driven mode and the development of Delta-Sigma ADC to be implemented into the sensor.

8453-19, Session 7

Scientific focal plane array advancements at MIT Lincoln Laboratory

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MIT Lincoln Laboratory develops scientific CCD and CMOS-based image sensors for space and ground-based astronomy. Specialized design and fabrication techniques on high resistivity substrates are applied to produce low read noise, low dark current, good quantum efficiency, and fast frame rate for large-format arrays. In this paper we present an overview of our technology development, which includes the recent transition from 150-mm to 200-mm wafers for front and back-illuminated imagers. In addition, we show examples of unique and three-dimensionally integrated sensors developed for adaptive optics, Pan-STARRS, and the next-generation of high-resolution, large-format arrays.

8453-20, Session 7

A gigapixel commercially manufactured cryogenic camera for the J-PAS 2.5m Survey Telescope

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The J-PAS (Javalambre Physics-of-the-Accelerating-Universe Astrophysical Survey) project will perform a five-year survey of the northern sky from a new 2.5m telescope in Teruel, Spain. We describe the design concept of a complete cryogenic camera with a mosaic focal plane and 1.2 gigapixel science array which is to be commercially supplied. The focal plane is contained within a novel liquid-nitrogen-cooled vacuum cryostat, with proximity drive electronics designed to achieve a 4 e- readout noise from the 224-channel CCD system.

The camera incorporates a precision cryogenic focal plane with science, guide, and wavefront sensor detectors. The focal plane is approximately 500 mm diameter with fourteen 85 megapixel science sensors, each with sixteen outputs to allow a 10 second readout time. Guide and wavefront sensor CCDs have independent readout modules and all sensors are controlled by a custom electronics module with high bandwidth host-PC control interface. The camera incorporates thermal control and local vacuum pumping together with cryogen management. The electronics uses differential and digital correlated double sampling (DCDS) to ensure lowest read-noise and maximum external noise rejection.

8453-21, Session 7

GPC1 and GPC2, the Pan-STARRS 1.4 gigapixel mosaic focal plane CCD cameras with an on-sky, on-CCD, tip-tilt image compensation

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We will report on the on-sky, on-CCD, tip-tilt (orthogonal transfer) image compensation performance of GPC1, the 1.4 gigapixel mosaic focal plane CCD camera for wide field surveys with a 3 degree diameter field of

view. The camera uses 60 Orthogonal Transfer Arrays (OTAs) with a novel 4 phase pixel architecture and the STARGRASP controller for closed loop multi-guide star centroiding and image correction. The Pan-STARRS project is also constructing GPC2, the second 1.4 gigapixel camera using 64 OTAs. GPC2 will include enhancements (based on lessons learned from GPC1) including a new generation of OTAs, titanium mosaic focal plane with adjustable three point kinematic mounts for the OTAs, cyro flex wiring and the recently developed software distributed on 32 controllers. We will discuss the design, cost, schedule, tools developed, shortcomings and future plans for the two largest digital cameras in the world.

8453-22, Session 7

Development of the LSST raft tower modules

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The science focal plane of the Large Synoptic Survey Telescope is made up of 21 modules designated "raft towers". Each raft tower module (RTM) is an autonomous, fully-testable and serviceable 144 Mpix imager consisting of nine highly-segmented CCDs with complete readout electronics chain. To minimize noise and obscuration the RTM is housed in a compact enclosure fully contained within the camera cryostat. The RTM is required to meet strict performance goals for image plane flatness, readout speed, noise, and power dissipation. Key components include the 4K x 4K fully-depleted CCDs with 16 outputs each; ceramic CCD support structure; and ASIC electronics for video processing and clock/bias generation. In addition to CCD signal handling, the RTM electronics also includes monitoring for temperature, voltage, and current; makeup heater control; ASIC configuration and readback; powerdown modes; and specialized diagnostic outputs. Digitized data is transmitted out of the camera cryostat over a single 3Gb/s serial link.

We will describe the conceptual design of the CCD array, front and back end electronics, and mechanics, then discuss test system integration and present initial measurements of flatness metrology, optical, electronic, and thermal performance.

8453-23, Session 7

4K×4K format, 10 micron pixel pitch H4RG-10 hybrid CMOS visible focal plane array for space astronomy

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Teledyne's silicon hybrid CMOS focal plane array technology has matured into a viable high performance and high TRL alternative to scientific CCD sensors for space-based applications for UV-visible-NIR wavelengths. This paper presents the latest results from Teledyne's low noise silicon hybrid CMOS visible focal place array produced in 4K×4K format with 10 micron pixel pitch. The H4RG-10 readout circuit retains all of the CMOS functionality (windowing, guide mode, reference pixels) and heritage of its highly successful predecessor (H2RG) developed for JWST, with additional features for improved performance. Combined with a silicon PIN detector layer, this technology is termed HyViSI (Hybrid Visible Silicon Imager). H4RG-10 HyViSI arrays achieve high pixel interconnectivity (>99.99%), low readout noise (90% broadband), and large dynamic range (>13 bits). Pixel crosstalk and interpixel capacitance (IPC) have been predicted using detailed models of the hybrid structure and these predictions have been confirmed by measurements with Fe-55 X-ray events and the single pixel reset technique. For a 100 micron thick detector, IPC of less than 3% and total pixel crosstalk of less than 5% have been achieved for the H4RG-10 HyViSI. The H4RG-10 array is mounted on a lightweight silicon carbide (SiC) package that has been qualified to Technology Readiness Level 6 (TRL-6). As part of space qualification, the H4RG-10 HyViSI array passed radiation testing for low Earth orbit environment.

8453-24, Session 8

New simulation and measurement results on gateable DEPFET devices

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Adaptive optics is often used to improve the performance of earth bound optical telescopes. For this a deformable mirror a wave front sensor and a reference guide star are necessary. Guide stars can be generated in the atmosphere by using pulsed lasers. An optimized peak to background value is achieved if the exposure time of the wave front detector is synchronized with the resulting pulsed guide star. So a shutter with a well-defined timing is needed.

One detector concept, developed at the MPI HLL, well suited to these requirements is the so called Gateable DEPFET. The DEPFET itself is an active pixel sensor based on a fully depleted bulk. It combines internal amplification, readout on demand, analog storage of the signal charge and a low readout noise with full sensitivity over the whole bulk thickness. A Gateable DEPFET has all these benefits and provides a built-in electronic shutter.

First measurements on single pixel level were done for two Gateable DEPFET concepts. For both a proof of principle measurement was done. Several important values have been evaluated for part of the parameter space. The best measured suppression ratio was 1e-4. This value was verified by simulations, which also predict a reachable suppression ratio of 1e-5 or better after optimizing the operational parameter.

Based on these results a new DEPFET concept was created. This new device not only provides an electronic shutter but also stores the rejected signal. Two layouts have been submitted and are currently in production.

8453-25, Session 8

A new four side buttable camera for x-ray imaging and spectroscopy with large dynamic range for future x-ray missions

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For future applications in high energy astrophysics a new type of pnCCD camera is being developed. The instrument presented here is the next generation X-ray imager, designed for applications on ground and in space. The devices are 4-side buttable with an insensitive gap of approximately 1.5 mm in between. The new pnCCD module consists of 1024 x 1024 pixel arrays having a total, monolithic sensitive area per module of about 60 cm2, infinitely large focal planes could be realized that way. For an e.g. 240 cm2 large detector with 4 megapixel (75×75 µm2) the dead area in the focal plane is less than 4%. The device is back illuminated with a thin radiation entrance window for photon energies with high QE from 100 eV up to 20 keV. Each megapixel unit in an independent detector system with frame rate capabilities up to 200 frames per second. It has a noise floor below 3 electrons. In the spectroscopic mode every pixel can cope with approx. 1 × 104 electrons, in a low gain mode this goes up to 106 electrons per pixel. The focus of the talk will be on the improvement of the performance of the pnCCDs in terms of charge handling capacity, readout speed and the realization of very different focal plane configurations due to the new modular 4-side buttable concept. Thermal, mechanical and electrical designs will be presented as well as measurements from prototype devices. Various planned applications and their experimental boundary conditions will be highlighted.

8453-26, Session 8

Design and performance of the eROSITA focal plane instrumentation

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The approved German X-ray telescope eROSITA will be launched in near future to Lagrange point L2 on the Russian satellite SRG. The general scientific goal is the exploration of the X-ray Universe in the energy band from 0.3 keV up to 10 keV with excellent energy, time and spatial resolutions and large effective telescope areas. The observational program divides into an all-sky survey and pointed observations. The mission duration is scheduled for 7.5 years.

The detection of single X-ray photons with precise information about their energy, arrival angle and time is accomplished for eROSITA by an array of seven identical and independent PNCCD cameras. Each camera is assigned to a dedicated mirror system of Wolter-I type.

The key component of the camera is a 5 cm   3 cm large, back-illuminated, 450 µm thick and fully depleted frame store PNCCD chip. It is a further development of the sensor type, which is in operation as focal plane detector aboard the XMM-Newton satellite since 1999. Development and production of the CCDs for the eROSITA project were performed in the MPI Halbleiterlabor.

We present the design of the seven flight cameras including the camera electronics and the filter wheel. The results of the various functional and performance tests which have been accomplished for a detailed characterization of the eROSITA camera system are reported and discussed.

8453-27, Session 8

DEPFET macropixel detectors for MIXS: integration and calibration of the flight hardware

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The Mercury Imaging X-ray Spectrometer (MIXS) is an instrument on board of the 5th ESA cornerstone mission BepiColombo. This Spectrometer comprises of two instruments for imaging x-ray spectroscopy of the Mercury surface. The detector plane arrays (DPA) for the energy and spatial resolved detection of x-rays for both instruments are based on DEPFET (Depleted P-channel FET) macropixel detectors with each 64x64 pixel and 300x300µm² pixel size. The MIXS target energy band is from 0.5 to 7keV with an energy resolution better than 200eV at 1keV at mission end. This allows to access the Fe-L line at about 0.7keV, which was not accessible to previous instruments, and to separate the x-ray lines of the elements of interest.

Before a detector chip is integrated into a detector module, it is electrically pre-characterized in order to select only the best chips for the complex and time-consuming integration. The high degree of complexity of the integration process comes from the need to thermally decouple the detector chip from its readout and steering ASICs by a sophisticated mechanical structure, due to the limited amount of cooling power available for the instrument. After the spectroscopic characterization of the detector modules, the flight and flight spare detectors were calibrated at the PTB beamlines at BESSY.

We report on the pre-characterization, integration and calibration of MIXS flight and flight spare DPAs, which is now successfully completed.

8453-28, Session 8

Performance of new generation swept charge devices for lunar x-ray spectroscopy on Chandrayaan-2

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The Chandrayaan-2 Large Area Soft-X-ray spectrometer (CLASS) is due to be launched by the Indian Space Research Organisation (ISRO) in

2014. It will map the elemental composition of the lunar surface, building on the Chandrayaan-1 X-ray spectrometer (C1XS) heritage. CLASS will use an array of e2v technologies CCD236 swept charge devices (SCD) providing an active detector area of 70 cm2, almost three times the active area of C1XS which used the first generation of SCD the CCD54. The CCD236 is designed as a soft X-ray detector, operating from 0.8 keV to 10 keV, and benefits from improvements in design over the CCD54 flow on C-1 to allow for increased detector area, improved detection of X-ray events and improvements to radiation hardness. This paper describes the investigation into the performance of the CCD236, focussing on an optimisation of the energy resolution of a device irradiated to the estimated worse case end of life proton fluence.

8453-29, Session 8

Development status of a CZT spectrometer prototype with 3D spatial resolution for hard x-ray astronomy

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The development of new focusing optics based on wide band Laue lenses operating from ~60 keV up to several hundred keV is particularly challenging. This type of hard X-ray or gamma ray optics require a high performance focal plane detector in order to exploit to the best their intrinsic capabilities. We describe a three dimensional (3D) position sensitive detector prototype suitable as the basic module for a high efficiency Laue lens focal plane detector. This detector configuration is currently under study for use in a balloon payload dedicated to performing a high significance measurement of the polarization status of the Crab between 100 and 500 keV. The prototype is made by packing 8 linear modules, each composed of one basic sensitive unit bonded onto a supporting thin ceramic layer. Each unit is a drift strip detector based on a CZT crystal, irradiated transversally to the electric field direction. The anode is segmented into 8 detection cells, each comprising one collecting strip and 8 surrounding drift strips. The drift strips are biased by a voltage divider. The cathode is divided into 4 horizontal strips for the reconstruction of the Z interaction position. The detector readout electronics is based on RENA-3 Asics's and the data handling system uses a custom designed FPGA based electronics to provide the ASIC setting, the event handling logic, and the data acquisition. We show the results of the electronics test and characterization and some preliminary spectroscopic measurements. obtained using this prototype.

8453-30, Session 9

Evaluation and optimization of NIR HgCdTe avalanche photodiode arrays for adaptive optics and interferometry

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The performance of present generation high speed near infrared HgCdTe sensors operating in fringe trackers and wavefront sensors is severely limited by the noise of the silicon interface circuit (ROIC), even if state-of-the- art CMOS designs are used. To overcome this limitation, amplification of the photoelectron directly at the point of absorption inside the pixel by means of avalanche gain is used. Unlike silicon, HgCdTe offers noiseless avalanche gain. This has been verified with the LPE grown, HgCdTe prototype eAPD sensor (320x256 pixels, lambda cutoff=2.5 micron) from SELEX which was originally developed for laser gated imaging. Performance results such as readout noise, quantum efficiency, nonlinearity, point spread function and cosmetic quality versus temperature will be presented. The readout noise of the non optimized prototype for a single CDS at a pixel rate of 5MHz/channel is 3 electrons rms and can be reduced to 1electron rms with Fowler sampling.

A further contract has been placed with SELEX to develop a custom specific ROIC called SAPHIRA. This device has been optimized for lower noise and has 32 parallel video channels and novel windowing options using the full multiplexing advantage for reading dispersed fringes. This allows increased frame rates and the further reduction of the readout noise with multiple sampling techniques. Special reset options have been implemented to avoid edge effects for the windowed readout. In a second step the LPE grown HgCdTe loophole arrays will be replaced by MOVPE arrays in an attempt to further improve the quantum efficiency and the cosmetic quality.

8453-31, Session 9

Operation and performance of new NIR detectors from SELEX

D. C. Atkinson, N. Bezawada, UK Astronomy Technology Ctr. (United Kingdom); N. Shorrocks, L. G. Hipwood, H. Milne, SELEX Galileo Infrared Ltd. (United Kingdom)

The European Space Agency (ESA) has funded SELEX Galileo, Southampton, UK to develop large format near infrared (NIR) detectors for its future space and ground based programs. The UKATC has worked in collaboration with SELEX to test and characterise these new detectors produced during phase-1 of this development program. As part of this program, several detectors were tested and evaluated for their performance in a detector test facility at the UKATC. In order to demonstrate the detector material performance, the HgCdTe detector diodes (grown on GaAs substrate through MOVPE process in small 320x256, 24 m pixel format) are hybridised to the existing SELEX SWALLOW CMOS readout chip. The substrate removed and HgCdTe thinned detector arrays were then tested and evaluated at the UKATC following screening tests at SELEX. This paper briefly describes the test setup, the operational aspects of the readout multiplexer and presents the performance parameters of the detector arrays including: conversion gain, detector dark current, read noise, linearity, quantum efficiency and persistence for various detector temperatures between 80K and 140K.

8453-32, Session 9

Development of the H4RG-15 focal plane array

R. Blank, J. W. Beletic, D. E. Cooper, M. C. Farris, Teledyne Imaging Sensors (United States); D. N. B. Hall, K. W. Hodapp, Univ. of Hawai'i (United States); G. A. Luppino, GL Scientific (United States); E. C. Piquette, M. Xu, Teledyne Imaging Sensors (United States)

In preparation for the large number of pixels required in the era of Extremely Large Telescopes, Teledyne has been funded to develop the next generation of large-format infrared array for ground-based astronomy; the 4096×4096 pixel (15 micron pitch) H4RG-15. Teledyne has successfully designed and produced the first generation of the H4RG-15 detector arrays. This paper reports on the functionality and performance test results of the first generation H4RG-15 detector arrays. Status of the H4RG-15 2012 pilot production is also presented.

8453-33, Session 9

Performance of the first HAWAII 4RG-15 arrays in the laboratory and at the telescope

D. N. B. Hall, Univ. of Hawai'i (United States); R. Blank, M. C. Farris, Teledyne Imaging Sensors (United States); S. M. Jacobson, Univ. of Hawai'i (United States); M. Loose, Markury Scientific, Inc. (United States); K. W. Hodapp, Univ. of Hawai'i (United States)

The HAWAII 4RG-15 (H4RG-15) aims to provide a 16 MPxl 4096x4096 format at significantly reduced price per pixel while maintaining the superb low background performance of the H2RG. However the design also incorporates new features, notably clocked reference output and interleaved reference pixel readout, that promise to significantly improve noise performance while the reduction in pixel pitch from 18 to 15 microns should improve transimpedance gain although degrading full well and crosstalk.

In preparation for Phase-2, the six hybrid arrays produced during the Phase-1 H4RG-15 development have been screen tested. The most promising of these are being extensively characterized in University of Hawaii's KSPEC and ULBCam test facilities developed for the JWST H2RG program. The best will then be used for astronomical observations at the UH 88-inch telescope on Mauna Kea to confirm performance.

We report the performance of these Phase-1 H4RG-15s within the context of established H2RG performance for key parameters (read noise, dark current, transimpedance gain, and cross-talk), highlighting the improvements from the new readout modes.

8453-66, Poster Session

EMCCD camera noise performance for the Brazilian tunable filter imager

D. F. Andrade, Univ. de São Paulo (Brazil); O. Daigle, Nüvü Caméras Inc. (Canada); D. Guzman, Pontificia Univ. Católica de Chile (Chile); K. Taylor, C. Mendes de Oliveira, J. Ramirez-Fernandez, Univ. de São Paulo (Brazil)

We present in this paper a performance characterization of an Electron Multiplication CCD (EMCCD) camera which has been deployed on the Brazilian Tunable Filter Imager (BTFI) instrument for the SOAR telescope in Chile. The BTFI instrument has two e2v CCD207 EMCCDs with a format of 1600-by-1600 pixels. The CCD207s are full-frame devices and are read out at a pixel rate of 10MHz with very low noise using an EMCCD controller (the CCD Controller for Counting Photons or CCCP for short) which was custom-built by a group based in the University of Montreal" to "which was custom-built by a group based in the University of Montreal and is now commercialized by Nüvü Cam ras. The first laboratory characterizations were done in Montreal in October, 2011 and the "first-light" results with the camera operating at the telescope are presented.

8453-67, Poster Session

Readout of LSST CCDs with the ASPIC2 chip

C. Juramy, P. E. Antilogus, P. Bailly, Univ. Pierre et Marie Curie (France); J. Jeglot, Univ. Paris-Sud 11 (France); H. Lebbolo, D. Martin, Univ. Pierre et Marie Curie (France); V. Tocut, Univ. Paris-Sud 11 (France)

The ASPIC2 (Analog Signal Processing Integrated Circuit) is an ASIC chip designed for the readout of CCDs in the Large Synoptic Survey Telescope (LSST) in AMS 0.35μ technology. Its role is to amplify the CCD output and subtract the CCD reset noise through the technique of DSI (Dual Slope Integrator). LSST CCDs will be large and highly segmented, each 4k*4k pixels divided into 16 channels, with the goal to perform the readout of the whole focal plane in 2s. To achieve this speed, each ASPIC2 reads 8 channels and can function at readout frequencies of up to 1MHz, with a nominal working frequency of 550kHz. To minimize readout noise, the ASPIC2 chips are integrated to cold front-end boards directly connected to the CCDs, with a working temperature of -100°C.

Characterization of ASPIC2 show that it meets the LSST specifications on linearity (non-linearity inferior to 0.5% of full scale), noise (5 μV), dynamic range (300 mV maximum input), crosstalk (inferior to 0.025%), and power consumption (25 mW per channel). As expected, noise decreases with decreased temperature and increased power consumption in the input amplifiers. We also quantified the wake-up time from energy saving mode, the memory effect from saturated pixels to the following low light pixels, and the asymmetry issue in our implementation of the DSI. We will show the results of the readout of a LSST pre-prototype CCD with an ASPIC2 in cryostat, and of the long-term tests to evaluate the longevity of this technology at -100°C.

8453-68, Poster Session

First results from a novel curving process for large area scientific imagers

O. Iwert, European Southern Observatory (Germany); D. Ouellette, M. P. Lesser, The Univ. of Arizona (United States); B. Delabre, European Southern Observatory (Germany)

Observations in seeing limited imaging conditions with an extremely large telescope - such as the European Extremely Large Telescope (E-ELT) - will require large detectors and very fast cameras (around F/1.0). The correction of field curvature is a complex task, requiring numerous optical elements operating with high incidence angles. Large format (60 to 90 mm square) concave detectors with a curvature radius between 500 and 250 mm would considerably simplify the optical design, while improving image quality and cutting cost of optical components. Potential applications are not limited to astronomy exclusively. The associated advantages of curved image sensors inside (mosaicked) focal planes have been described in our paper "The challenge of highly curved monolithic imaging detectors", presented at SPIE 2010.

This paper compares in a first step important developments in the area of curving CCD and CMOS detectors using different technical approaches linked to specific thinning processes with a novel approach followed after ESO's initial feasibility study: First results of the latter are described with a report on the chosen curving technology aimed at producing 500 to 250 mm radius of curvature silicon detectors of approximately 60 mm square format (typical astronomical 4k x 4k CCDs). The curvature technique developed has been for front-illuminated devices with the goal of extending the process to back-illuminated sensors in the near future. We will discuss the fabrication process of curving the devices as well as the difficulties encountered during development. Characterization results from a curved detector, including metrology, and electrical performance before and after curvature are presented.

8453-69, Poster Session

Hyper Suprime-Cam: characteristics of 116 fully depleted back-illuminated CCDs

Y. Kamata, S. Miyazaki, H. Nakaya, National Astronomical Observatory of Japan (Japan); H. Suzuki, Y. Miyazaki, M. Muramatsu, Hamamatsu Photonics K.K. (Japan)

Hyper Suprime-Cam (HSC) is a wide field (1.5 degree diameter) imaging camera, which is to be installed at the prime focus of the Subaru Telescope. The large field of view is realized by the 116 2K x 4K fully depleted back-illuminated CCDs with 15 um pixels. The CCD had been developed specifically for this application by the HAMAMATSU Photonics K. K. and the National Astronomical Observatory of Japan (NAOJ). The visible-enhanced type with high quantum efficiency (QE) from blue to red is used for HSC. We started the acceptance inspection of all CCDs

at the end of 2009 and finished it at the end of June 2011 in the detector laboratory of the NAOJ Advanced Technology Center. The measurement items include charge transfer efficiency, noise, dark current, linearity and full-well for all CCDs and QE for 21 CCDs. The measured performance is excellent. The QE was 37.8 +/- 0.7 % at 1000 nm and 51.7 +/- 1.9 % at 400 nm. Approximately half of CCDs were good quality free of column defect. After the acceptance, the 116 CCDs were installed on the cold plate inside the HSC dewar on November 2011. We will present statistical properties of the key measuring parameters for the 116 CCDs. The detail of the installation procedures is also given.

8453-70, Poster Session

High quantum efficiency performance and specifications for a back side illuminated (BSI) CCD based spectral image sensor

S. Kullar, D. R. Cochrane, N. O, G. R. Allan, T. Pian, F. Dion, Teledyne DALSA (Canada)

In this paper we present performance measurements and specifications for a Teledyne DALSA fabricated CCD spectral image sensor with emphasis on enhanced quantum efficiency (QE) through back illumination techniques and use of anti reflection (AR) coatings. In an astronomical image sensor or in a spectral device low light signal levels require that an imager sensor have high QE. For example in remote sensing the use of a diffraction grating combined with high speeds reduce the available light signal. In astronomy light signals often come from very distant faint objects. The high QE is achieved through thinning of and back illumination of the CCD sensor along with an antireflection coating directly applied to the back thinned surface. High 90% peak QE is achieved in the 600nm to 700 nm range and QE is greater than 60% from 450nm to 850nm. In addition to the high QE achieved we also present results for a spectral image sensor operating at 300 frames per second in split frame transfer mode with resolution of 2048 x 280 and 30um square pixels. This imager is designed to achieve line (vertical) transfer times as small as 250ns which provides a very low smear performance. Also considered are multiple layer AR coatings to further improve QE.

8453-71, Poster Session

Deep-depletion Hamamatsu CCDs for the Gemini multi-object spectrograph

T. Hardy, National Research Council Canada (Canada); K. Hanna, Gemini Observatory (United States); K. Szeto, G. Burley, National Research Council Canada (Canada)

The Herzberg Institute of Astrophysics was commissioned by the Gemini Observatory to develop a new focal plane assembly for the Gemini Multi-Object Spectrograph with an array of three deep-depletion Hamamatsu CCDs. The main objective of the upgrade is to improve the sensitivity of the instrument in the red and near-infrared wavelengths, with the additional benefits of reduced fringing, faster readout, and better performance in the “nod and shuffle” mode. We describe what we learned about these relatively new CCDs, and report on the performance of the system.

8453-72, Poster Session

Detailed PSF measurement and modelling for wide-field of view telescope, and its applications in analysis and simulation of the ‘Pi of the Sky’ detector data

L. W. Piotrowski, Univ. of Warsaw (Poland)

The ultimate goal of the ``Pi of the Sky” apparatus is observation of optical flashes of astronomical origin. We search mainly for optical emission of Gamma Ray Bursts, but also for variable stars, novae, blazars, etc. This task requires an accurate measurement of the source’s brightness, which is difficult as “Pi of the Sky” single camera has a large field of view of about 20x20 degrees. This causes a significant deformation of PSF, reducing quality of brightness and position measurement with standard algorithms. Improvement requires careful study and modelling of PSF, which will be the main topic of the presented talk. A dedicated laboratory setup has been created for obtaining isolated, high quality profiles, which in turn were used as the input for mathematical models. Two different models are shown: diffractive, simulating light propagation through lenses and effective, modelling the PSF shape in the image plane.

The effective model, based on PSF parametrization with selected Zernike polynomials was used in photometry and astrometry analysis of the data coming from “Pi of the Sky” prototype in Chile, including new determination of limits on the optical precursor to GRB080319B. The model was also used to develop a dedicated tool to generate Monte Carlo samples of images corresponding to the “Pi of the Sky” observations. The simulator allows for a detailed reproduction of the frame as seen by our cameras, taking into account PSF, electronics and mechanical fluctuations, and is an invaluable tool for future “Pi of the Sky” hardware and software development.

8453-73, Poster Session

UV calibration of CCD

Q. Song, National Astronomical Observatories (China); P. Li, National Institute of Metrology (China); Z. Feng, Y. Liu, National Astronomical Observatories (China)

In order to calibrate the response of a CCD system on the UV band from 200nm to 350nm wavelength, the method of monochromator plus integrate sphere is reformed to deal with the problem of too low light intensity for photodiode sensitivity. A calibration system is setup and the test result is discussed.

8453-74, Poster Session

ESA’s CCD test bench for the Euclid visible channel

P. Verhoeve, N. Boudin, U. Telljohann, H. Smit, T. Beaufort, B. Butler, I. Escudero-Sanz, D. Martin, European Space Research and Technology Ctr. (Netherlands)

Euclid is the ESA mission to map the geometry of the dark Universe using two cosmological probes, namely Weak Lensing and Baryonic Acoustic oscillations. The mission will observe galaxies and clusters of galaxies out to a red-shift of z~2, in an all-sky survey covering 15 000 deg^2. It consists of a 1.2m diameter telescope with three focal plane instruments. One of the instruments, a CCD based optical imaging channel will be used to measure the shapes of galaxies in one single wide visual band spanning the wavelength range of 550-900 nm. With the weak lensing technique, the mass distribution of the lensing structures can be traced back. This technique requires an unprecedented accuracy to which the shapes of the galaxies have to be measured. In particular, radiation damage effects in the CCDs will challenge this accuracy during the mission.

While the baselined CCDs for Euclid are e2v 4kx4k devices with four readout nodes, the Euclid Imaging Consortium (EIC) has performed extensive test campaigns on both irradiated and unirradiated devices of the 1kx4k Euclid precursor variant CCD204. In support of the CCD development and characterisation, and to enable an independent assessment of CCDs, ESA/ESTEC has built a test bench. This test bench allows for a flexible operation and readout of the CCDs and provides the basic tools for noise and gain calibration, and CTI, QE, MTF and PRNU measurement. In addition, the bench provides spot illumination with a spot size well below the pixel size, for measurement of the intra-pixel response of the CCDs. This set-up will also allow for simulation of typical Euclid sky images in the lab.

The capabilities and validation of this bench at ESA will be described in this paper.

8453-75, Poster Session

Preliminary results of CCD characterisation at ESA in support of the Euclid visible channel

N. Boudin, European Space Research and Technology Ctr. (Netherlands) and Cosine Research BV (Netherlands); P. Verhoeve, T. Oosterbroek, U. Telljohann, D. D. Martin, European Space Research and Technology Ctr. (Netherlands)

Euclid is the ESA mission to map the geometry of the dark Universe using two cosmological probes, namely Weak Lensing and Baryonic Acoustic oscillations. The mission will observe galaxies and clusters of galaxies out to a red-shift of z~2, in an all-sky survey covering 15 000 deg². It consists of a 1.2m diameter telescope with three focal plane instruments. One of the instruments, a CCD based optical imaging channel will be used to measure the shapes of galaxies in one single wide visual band spanning the wavelength range of 550-900 nm. With the weak lensing technique, the mass distribution of the lensing structures can be traced back.

The baselined CCDs are e2v CCD203-82, or their variant CCD204. For Euclid, the accuracy with which the shape of the galaxies has to be measured is considerable: 1% and has never been demonstrated. The radiation damage effects will play a big role in lowering it and thus need to be characterized.

Therefore, several test campaigns on the characterisation of the CCD radiation damages for Euclid are carried out by ESA and by the Euclid Imaging Consortium.

For this purpose, a test bench has been implemented at ESTEC to characterise CCD devices, with radiometric measurements, point source illumination and lab simulation of typical Euclid sky images. The preliminary results obtained at ESA will be shown in this presentation, including noise and gain calibration, CTI, QE, MTF and PRNU measurements as well as sub-pixels scanning of the device and its response to a field illumination.

8453-76, Poster Session

An advanced CCD emulator with 32MB image memory

J. Fried, P. O'Connor, I. V. Kotov, Brookhaven National Lab. (United States)

As part of the LSST sensor development program we have developed an advanced CCD emulator for testing new multichannel readout electronics. The emulator, based on an Altera Stratix II FPGA for timing and control, produces 4 channels of simulated video waveforms in response to an appropriate sequence of horizontal and vertical clocks. It features 40MHz, 16-bit DACs for reset and video generation, 32MB of image memory for storage of arbitrary greyscale bitmaps, and provision to simulate reset and clock feedthrough ("glitches") on the video channels. Clock inputs are qualified for proper sequences and levels before video output is generated. Binning, region of interest, and reverse clock sequences are correctly recognized and appropriate video output will be produced. Clock transitions are timestamped and can be played back to a control PC.

A simplified user interface is provided via a daughter card having an ARM M3 Cortex microprocessor and miniature color LCD display and joystick. The user can select video modes from stored bitmap images, or gradient, bar, chirp, or checkerboard test patterns; set clock thresholds and video output levels; and set row/column formats for image outputs. Multiple emulators can be operated in parallel to simulate complex CCDs or CCD arrays.

8453-77, Poster Session

Development of an optical test bench for analysis of charge transfer in radiation damaged CCDs for Euclid

E. A. H. Allanwood, N. J. Murray, D. J. Hall, T. A. Greig, J. P. D. Gow, A. D. Holland, The Open Univ. (United Kingdom)

The ESA Euclid mission is set to map an area of the dark universe using Weak Gravitational Lensing (WGL). WGL is measured through the analysis of the distortions in the apparent shapes of galaxies, however, the quality of such measurements is partially dependent on the imaging system used. Radiation-induced charge transfer inefficiency (CTI) in the Euclid visual instrument (VIS) will 'smear' images in the direction of charge transfer, interfering with the measurement of the changes in shape due to WGL. Therefore, there is a requirement for temporal modelling in order to understand, and hence be able to correct for, these changes throughout the mission duration. To measure changes in the PSF, a sub-5μm spot must be cast on the CCD to measure the spread and trail in the cast of CTI. This paper follows the development of an optical test arrangement designed to measure the PSF in CCDs following various levels of irradiation in which the light and optics are externally translated outside the vacuum chamber housing the CCD and the spot projected via a window. We will present data from an e2v CCD204 for both irradiated and un-irradiated control regions of the CCD and demonstrate the distortions to be encountered. We will discuss the impact of these measurements, and steps which will be undertaken to fully calibrate the effects in-orbit.

8453-78, Poster Session

PAU camera: detectors characterization

R. Casas, Consejo Superior de Investigaciones Científicas (Spain); L. Cardiel-Sas, Institut de Física d'Altes Energies (Spain); J. Castilla, Ctr. de Investigaciones Energéticas, Medioambientales y Tecnológicas (Spain); J. Jiménez Rojas, Consejo Superior de Investigaciones Científicas (Spain); M. Maiorino, Institut de Física d'Altes Energies (Spain); I. Sevilla, J. de Vicente, Ctr. de Investigaciones Energéticas, Medioambientales y Tecnológicas (Spain)

PAUCam is a wide field camera that will be mounted at the Prime Focus of the William Herschel Telescope (Observatorio del Roque de los Muchachos, Canary Islands, Spain) in next months.

The focal plane of PAU Camera is composed by 18 CCD detectors of 2048 x 4096 pixels with a pixel size of 15 microns, manufactured by Hamamatsu Photonics. This mosaic covers a field of view of 60 arcmin, 40 of them unvignetted.

The behavior of these 18 devices, plus four spares, was characterized and their electronic response was optimized for the use in the PAUCam. This characterizations were carried out in the laboratories of the ICE/IFAE and the CIEMAT.

The electronic optimization was carried out by means of an OG (Output Gate) scan and maximizing the detectors CTE (Charge Transfer Efficiency) while minimizing the read-out noise.

The device response was obtained with different tests: the Photon Transfer Curve to evaluate electronic gain, linearity vs. light stimulus and full well capacity, the read-out noise, the dark current, the cosmetic defects, the stability vs. temperature and in time and the charge trapping.

The results are summarized in the poster.

8453-79, Poster Session

Performance characterization of the near infrared detector system for RSS-NIR on SALT

M. J. Wolf, D. J. Thielman, M. P. Smith, K. P. Jaehnig, A. I. Sheinis, G. Mosby, Univ. of Wisconsin-Madison (United States)

We present results on the performance characterization of the detector system for the Robert Stobie Spectrograph Near Infrared Arm (RSS-NIR) for the Southern African Large Telescope (SALT). The detector is a HAWAII-2RG array with a 1.7 micron cutoff wavelength. The system utilizes a Teledyne cryogenic SIDECAR ASIC board inside the dewar and a FPGA interface board, developed by the Inter-University Centre for Astronomy and Astrophysics (IUCAA), outside the dewar. System characterization is performed at the University of Wisconsin in a laboratory test dewar containing a thermal control system to maintain a stable operating temperature of 120 K. Light is provided to the detector either by near infrared LEDs and a diffusing screen inside the dewar, or externally through a window from an integrating sphere and relay system. We present measured data on system noise, gain, dark current, linearity, and persistence characteristics. Because SALT is a queue-scheduled telescope that observes many different science programs in a night, detector persistence effects could substantially impact the science data from RSS-NIR. The development of persistence mitigation techniques and strategies are a high priority in the RSS-NIR instrument design.

8453-80, Poster Session

Scientific CCD characterisation at Universidad Complutense LICA Laboratory

S. M. Tulloch, Isaac Newton Group of Telescopes (Spain); J. Gallego Maestro, A. Gil de Paz, J. Zamorano Calvo, Univ. Complutense de Madrid (Spain)

A CCD test-bench has been built at the Universidad Complutense´s LICA laboratory. It is initially intended for commissioning of the MEGARA (Multi Espectrógrafo en GTC de Alta Resolución para Astronomía) instrument but can be considered as a general purpose scientific CCD test-bench. The test-bench uses an incandescent broad-band light source in combination with a monochromator and two filter wheels to provide programmable narrow-band illumination across the visible band. Light from the monochromator can be directed to an integrating sphere for flat-field measurements or sent via a small aperture directly onto the CCD under test for high accuracy diode-mode quantum efficiency measurements. Point spread function measurements can also be performed by interposing additional optics between sphere and the CCD under test. The whole system is under LabView control via a clickable GUI. Automated measurement scans of quantum efficiency can be performed requiring only that the user replace the CCD under test with a calibrated photodiode after each measurement run. A 20cm diameter cryostat with a 10cm window and Brooks Polycold PCC closed-cycle cooler also form part of the test-bench. This cryostat is large enough to accommodate almost all scientific CCD formats but will initially be used to house an E2V CCD230 in order to fully prove the test-bench functionality. This device will be read-out using an Astronomical Research Camera controller connected to the UKATC´s UCAM data acquisition system.

8453-81, Poster Session

Test set up description and performances for HAWAII-2RG detector characterization at ESTEC

P. Crouzet, F. De Wit, J. Ter Haar, T. Beaufort, B. Butler, H. Smit, C. van der Luijt, European Space Research and Technology Ctr. (Netherlands)

In the frame work of the Cosmic Vision program, the Euclid mission has the objective to map the geometry of the Dark Universe. Galaxies and clusters of galaxies out to z~2, in a wide extragalactic survey covering 20 000 deg², plus a deep survey covering an area of 40 deg² will be targeted on the visible and infrared by an imaging and spectroscopic channel.

For the infrared channel, stat-of-the-art detectors, HAWAII-2RG detectors associated with the SIDECAR ASIC readout electronic, will achieve the frames acquisition.

To characterize and validate performances of these detectors, a test bench has been designed, tested and validated.

A description of performances of the actual test set up for dark current, readout noise, linearity and persistence effect measurements will be presented.The future test bench design for illuminated tests will be also shown.

To evaluate the impact and performances of the SIDECAR ASIC, a dedicated test bench has also been designed.

A description of capabilities of this test bench will be presented.

8453-82, Poster Session

NIRSpec detectors: how bad pixels impact operation and sensitivity

M. Sirianni, P. Ferruit, P. Jakobsen, S. M. Birkmann, G. Giardino, T. Böker, G. De Marchi, European Space Research and Technology Ctr. (Netherlands); M. Stuhlinger, European Space Astronomy Ctr. (Spain); P. L. Jensen, P. Strada, European Space Research and Technology Ctr. (Netherlands); B. J. Rauscher, D. J. Lindler, NASA Goddard Space Flight Ctr. (United States)

The Near Infrared Spectrograph (NIRSpec) of the James Webb Spece Telescope (JWST) is a near-infrared multi-object spectrograph capable of simultaneously obtaining more than 100 spectra. Four Micro Shutter Arrays (MSA) will give NIRSpec its multiobject capability. Dithering capabilities will be limited within a dedicated “slitlet” consisting of three adjacent microshutters limiting the possibility to mitigate the presence of bad pixels in the detectors. NIRSpec employs two λ 5 µm cutoff HgCdTe HAWAII-2RG (H2RG) detector arrays in the focal plane. We will present the characterization of the different types of bad pixels seen in the NIRSpec detectors and their overall impact in the sensitivity figure of merit.

8453-83, Poster Session

The ESO 4-Kelvin mid-IR detector test facility

G. H. Jakob, D. J. Ives, H. Käufl, F. Kerber, European Southern Observatory (Germany)

One major goal of the upgrade of ESO’s VLT mid-infrared imager and spectrograph VISIR is the replacement of the current detector with a larger and more sensitive device, the 1k x 1k AQUARIUS detector array. In this context the laboratory characterization of the performance and properties of the AQUARIUS array is key. For this purpose the Thermal Infrared Multi-Mode Instrument TIMMI-2, which was formerly installed at ESO’s La Silla 3.6-m telescope, was re-commissioned at ESO headquarters in Germany. This instrument provides a 150-liter volume vacuum vessel with an integrated cryogenic optics system optimized for the wavelength range of interest, five cryo-mechanisms for apertures, filters, and objectives, a polarimetric mode selection, a 4-Kelvin cryo-cooler and an IR-window with external calibration source feed-in option. After successful reproducibility measurements with the original optical and detector set-up, it was successively upgraded to a multi-purpose (mid-) infrared detector test facility. Emphasis was placed on complying with the special electrical, optical, mechanical, thermal and low background requirements of the new detector. A new detector mount was developed which allows detector operational temperatures down

to 4 K, whilst at the same time ensuring good shielding characteristics, electrical isolation of the detector system and operation of the cryogenic pre-amplifier at 120 K. Extremely high mechanical stability and very accurate reproducibility of the detector mount has been demonstrated. We present an overview of the IR test facility capabilities. This will include the challenging developments and technical highlights such as the highly-conductive, electrical isolated thermal straps in combination with high-thermal inertia materials below 10 K, the implementation of a newly developed cryogenic Manganin/Copper-based harness and results from recent VISIR AQUARIUS detector mount qualification tests.

8453-84, Poster Session

Assessment of MCT detectors for the EChO Mission

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The Exoplanet Characterisation Observatory (EChO) is one of four missions currently being studied in an assessment phase for the M3 launch slot of the ESA Cosmic Vision 2015-2025 program. For the near- to mid-infrared wavelength range of EChO, Mercury Cadmium Tellurite (MCT) detectors are the baseline. These detectors are already widely used for wavelengths below 5 microns but their applicability specifically for EChO for wavelengths up to 11 micron is investigated. In this paper, we report results from the cryogenic characterization of European MCT detectors in order to assess their suitability for future astronomical space missions such as ECHO.

8453-85, Poster Session

Development and characterization of very low dark current p/n MCT detector arrays at CEA: a candidate for ECHO LWIR detectors

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ESA is currently funding R&D programs to push European research toward the development of very low background HgCdTe infrared arrays for demanding space missions. In this context, we have recently designed and characterized a SWIR detector. Dark current as low as 0.06el/sec/pixels has been demonstrated.

In addition to this development, we are also preparing a dedicated LWIR demonstrator for the 5 - 11um spectroscopic channels of the M-Class ESA Exoplanet Characterization Observatory (EChO).

Using the liquid phase epitaxy HgCdTe p/n planar technology of CEA LETI, the challenge is to reach a dark current in the range of 500el-/sec/pix at 40K for a cutoff wavelength of 12um, this working point being located on the widely used heuristic RULE07.

However, the difficulty for this very low bandgap detector is to keep the MCT junctions in the diffusion regime instead of being limited by generation-recombination, tunneling or surface leakage currents. At these wavelengths, the advantage of our LPE technology over molecular beam epitaxy is important, as it allows a better control of the very sensitive cadmium stoechiometretry and a very high crystalline quality with a very low background doping. This MCT layer is doped n type by introducing indium during growth, then implanted with arsenic to form photodiodes. The final layer is hybridized on a specific CEA designed Si CTIA ROIC to produce a 320 x 240 pixels array.

Characterization of such a low dark current LWIR detector is made in a light tight cryostat, providing a 5K radiative environment; dedicated custom low noise readout electronics and test station will also be presented.

8453-86, Poster Session

Standard modes of MPIA's current H2/H2RG-readout systems

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During the last 15 years MPIA has built 8 sets of read-out electronics (ROE) for 8 different kinds of astronomical infrared instruments. The generic infrared camera software GEIRS (spoken like 'cheers') is used in these instruments either as a pure read-out software layer or as an overall control software for IR-instruments, the last one in particular with instruments for the Calar-Alto observatory in Spain.

Even though the last instruments built with the current generation of MPIA-ROE are offering in the meantime most of the standard read-out modes, the next generation ROE is based on the experience of the last years, and besides other properties like small volume, more channels, less power consumption, etc., it will also allow extended read-out modes in the near future by using the detector engineering and data interfaces of GEIRS.

The Hawaii-2-RG detector has a large amount of operational flexibilities to support extended read-out modes. With special properties in the pattern generator of the ROE and in GEIRS, new extended read-out modes can be implemented identically for the Hawaii-2 and the Hawaii-2RG in multichannel mode.

This paper presents an overview of the standard read-out schemes and describes additional selectable options, offered idle-modes, and some new extended modes available with this generation of MPIA-ROE for the next instruments and instrument updates using HgCdTe-detectors.

8453-87, Poster Session

Investigation of linear-mode, photon-counting HgCdTe APDs for astronomical observations

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The unique linear avalanche properties of HgCdTe preserve the Poisson statistics of the incoming photons, opening up new opportunities for GHz bandwidth LADAR and space communications applications. Raytheon has developed and previously reported on unique linear mode photon counting arrays based on combining advanced HgCdTe linear mode APDs with their advanced high gain SB415B readout. By using HgCdTe APDs, these enable Poisson statistics preserving (noiseless) photon counting. This technology is of great potential interest to infrared astronomy but requires extension of noiseless linear HgCdTe avalanching to much lower bandwidths (100 to 0.001 Hz) with corresponding reduction in dark count rate.

We have hybridized the SB415B readout to SWIR HgCdTe APDs optimized for low dark count rate and have characterized their photon counting properties at bandwidths down to 1 KHz. As bandwidth is reduced, the performance becomes limited by the intrinsic properties of the SB415B readout. We report the results of these measurements and the status of hybrid arrays utilizing a newly developed readout which draws on Raytheon's astronomical readout heritage to achieve much lower dark count rate operation.

8453-88, Poster Session

Ultra-low noise, large-area InGaAs quad photoreceiver with low crosstalk for space-based gravitational wave detection

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Quad photoreceivers, namely a 2 x 2 array of p-i-n photodiodes followed by a transimpedance amplifier (TIA) per diode, are required as the front-end photonic sensors in several applications relying on free-space propagation with position and direction sensing capability, such as long baseline interferometry, free-space optical communication, and biomedical imaging. It is desirable to increase the active area of quad photoreceivers (and photodiodes) to enhance the link gain, and therefore sensitivity, of the system. However, the resulting increase in the photodiode capacitance reduces the photoreceiver's bandwidth and adds to the excess system noise. As a result, the noise performance of the front-end quad photoreceiver has a direct impact on the sensitivity of the overall system. One such particularly challenging application is the space-based detection of gravitational waves by measuring distance at 1064nm wavelength with ~10pm/√Hz accuracy over a baseline of 5,000,000 kilometers.

We present a 1 mm diameter quad photoreceiver having an equivalent input current noise density of <1.7pA/√Hz per quadrant in 2MHz to 20MHz frequency range. This performance is primarily enabled by a rad-hard-by-design dual-depletion region InGaAs quad photodiode having 2.5pF capacitance per quadrant. Moreover, the quad photoreceiver demonstrates a crosstalk of <-45dB between the neighboring quadrants, which ensures an uncorrected direction sensing resolution of <50nrad. The sources of this primarily capacitive crosstalk are presented. Finally, a linear photoreceiver operation is demonstrated up to a DC photocurrent of 0.13mA per quadrant, providing a 2x margin over existing designs.

8453-89, Poster Session

Enabling large focal plane arrays through mosaic hybridization

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We have demonstrated the hybridization of large mosaics of far-infrared detectors, joining separately fabricated sub-units into a single unit on a single, large substrate. We produced a single detector mockup on a 100mm diameter wafer and four mockup readout quadrant chips from a separate 100mm wafer. The individually fabricated parts were hybridized using a Suss FC150 flip chip bonder to assemble the detector-readout stack. Once all of the hybridized readouts were in place, a single, large and thick silicon substrate was placed on the stack and attached with permanent epoxy to provide strength and a Coefficient of Thermal Expansion (CTE) match to the silicon components underneath. Wirebond pads on the readout chips connect circuits to warm readout electronics; and were used to validate the successful superconducting electrical interconnection of the mockup mosaic-hybridized detector. This demonstration is directly scalable to 150 mm diameter wafers, enabling pixel areas over ten times the area currently demonstrated.

8453-90, Poster Session

EMIR high-dynamic range readout modes and performances

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EMIR is the NIR imager and multiobject spectrograph being built as a common user instrument for the GTC. EMIR is currently entering in the verification phase at system level after having completed its integration. EMIR is being built by a Consortium of Spanish and French institutes led by the IAC. EMIR is designed to realize one of the central goals of 10m class telescopes, allowing observers to obtain spectra for large numbers of faint sources in a time-efficient manner.

In this contribution we describe the read-out modes and associated performances in laboratory of the EMIR detector, a 2048x2048 Rockwell Hawaii2 FPA, after two full calibrations campaigns. Besides the standard set of modes (read-reset, CDS, Fowler, Follow-up the ramp), the modified SDSU-II hardware and home made detector controller software will also offer not so common high dynamic range read-out modes, which will improve the ability of the instrument to sound densely populated areas which often are made of objects with large differences in brightness. This high dynamic range read-out modes are based on line by line detector reading: Correlated double sampling with very short integration time (CDSST), Fowler readout with very short integration time and high-dynamic range Fowler readout.

8453-91, Poster Session

Improvements in performance of the H2RG infrared sensor

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The 2K×2K, 18 micron pixel pitch, H2RG array is the highest performance imaging sensor for low flux astronomy, and is the most widely used infrared array for ground-based and space observatories. The performance of the H2RG infrared array continues to be improved and the arrays being produced now are better than the performance discussed at the 2010 SPIE astronomical instrumentation symposium. This paper presents the most recent performance data for 1.75, 2.5 and 5.0 micron cutoff arrays, including the higher temperature operation that is planned for dark energy missions.

8453-92, Poster Session

X-ray performance of 0.18 µm CMOS APS test arrays for solar observation

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Solar-C is the third generation solar observatory led by JAXA. The accepted 'Plan-B' payload calls for a radiation-hard solar-staring photon-counting x-ray spectrometer. CMOS APS technology offers advantages over CCDs for such an application such as increased radiation hardness and high frame rate (instrument target of 1000 fps). Looking towards the solution of a bespoke CMOS APS, this paper reports the x-ray spectroscopy performance, concentrating on charge collection efficiency and split event analysis, of two baseline e2v CMOS APSs not designed for x-ray performance, the EV76C454 and the Ocean Colour Imager (OCI) test array, and compares them to a high performance EMCCD, e2v technologies' CCD97. The EV76C454 is an industrial 5T APS designed for machine vision, available back and front illuminated. The OCI test arrays have varying pixel design across the chips, but are 4T, back illuminated and have thin low-resistivity and thick high-resistivity variants. The OCI test arrays' pixel variants allow understanding of how pixel design can affect x-ray performance.

8453-93, Poster Session

Experimental measurements of charge carrier mobility: lifetime products for a large sample of pixilated CZT detectors

S. V. Vadawale, Physical Research Lab. (India)

A conceptual design of hard X-ray focal plane detector for simultaneous X-ray polarimetric, spectroscopic, timing and imaging measurements: sensitivity estimation with Geant4 simulation and comparison with semi-analytical calculations

8453-94, Poster Session

Modelling charge transport in swept charge devices for Chandrayaan-2 large area soft x-ray spectrometer (CLASS)

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Chandrayaan-2 Large Area Soft X-ray Spectrometer(CLASS) is being developed for ISRO's upcoming mission Chandrayaan-2 to complete the major objective of mapping lunar surface chemistry. To achieve improved sensitivity in detection of X-ray Fluorescence(XRF) emission lines from the Moon even during weak and quiescent solar conditions, CLASS is designed to have a total area of 64cm2 using Swept Charge Devices(SCD's - X-ray CCD 236) developed by e2V Technologies Ltd., UK. It uses an array of 16 SCD's, each with an area of 4cm2.

To optimise event selection, maximise event recovery, and improve spectral modelling, a clear understanding of charge generation, collection and loss mechanism is essential. Charge clouds are generated at different interaction depths(z(E)) which are subjected to drift and diffusion enroute to the collecting zone. Loss mechanisms like recombination, partial charge collection and split events distort the true spectrum of the source under study, as they exhibit energy(E) dependency. Thus, characterizing the energy-dependent Spectral Redistribution Function(SRF) of detector is a pre-requisite to model the incoming X-ray spectrum. In this paper we model the charge transport in CCD 236 to estimate the fraction of split events as a function of energy. We also attempt to compute the energy-dependent SRF to account for charge loss mechanisms in CCD 236 to model the incident X-ray spectrum in the detector.

8453-95, Poster Session

Development of a BI CCD for low-energy x rays

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We are developing back-illuminated(BI) CCDs for achieving high quantum efficiency in the lowest X-ray energies, 0.1-2.0 keV.

These devices will enable us to apply to the focal plane detector of the high resolution X-ray grating spectrometors for use on the upcoming missions e.g. WHIMex. We have developed a new BI CCD device fabricated in Hamamatsu Photonics. K.K. It has a thin dead layer of SiO2 on its acceptance surface and moderate thickness of depletion layer. It shows a moderate spectral performance of 164 eV at 5.9keV with FWHM. We have measured averaged quantum detection efficiency (QE) at the PTB beamline at the Bessy synchrotron facility.

Monochromatic X-rays in the enegy range of 0.15-2 keV were employed.

The absolute quantum efficiency was measured with respect to a well calibrated photo-diode. As a results, we obtained about 40% of QE at 0.3keV and found that there is several nm of SiO2 layer on the surface.

Addition to SiO2 layer, we found that there is about 100nm of Si layer insensitive to X-rays probably due to a weak electric field near the chip surface.

8453-96, Poster Session

High-resolution gamma-ray detection using phonon-mediated detection

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The recent breakthroughs in hard X-ray/soft gamma-ray optics, as characterized by the NuSTAR and NEXT missions, have finally opened up the 10–100 keV band to detailed astronomical observation. The current state-of-the art in focal plane detectors, such as the CdZnTe detectors on NuSTAR, have a FWHM resolution of around 1 keV at 70 keV. If a resolution of 0.1 % could be achieved, the velocity of the ejecta at the mass cut could be measured using lines associated with the decay of Ti44, whose yield is affected by supernova dynamics. We are presenting the results of our ongoing efforts to develop a new type of focal plane detector to obtain this order of magnitude in sensitivity. The device will measure energy and position by using microwave kinetic inductance detectors (MKIDs) to sense athermal phonons created by photon absorption in a dielectric substrate. It will use a 1 cm Ge substrate to stop the gammas, and convert their energy to athermal phonons. These phonons propagate quasiballistically, providing event position information as well as energy. The MKID phonon sensors are highly multiplexable, requiring a single pair of readout lines to instrument an entire substrate with area at least 2 cm x 2 cm. We have fabricated a proof-of-concept detector of size 2 cm x 2 cm x 1 mm on silicon, which has demonstrated a baseline energy resolution of σ = 0.449 keV and σ = 0.869 keV at 30 keV.

8453-98, Poster Session

Circuit design of an EMCCD camera

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EMCCDs have been used in the astronomical observations in many ways. We have recently developed a camera using EMCCD TC285. The CCD chip is cooled to -100°C in an LN2 dewar. The power supplies and driving clocks of the CCD are provided by a driving board, the timing generator is located in a control board. The timing generator and an embedded Nios II CPU are implemented in an FPGA. Moreover the ADC and the data transfer circuit are also in the control board, and controlled by the FPGA. The data transfer between the workstation and the camera is done through a Camera Link frame grabber. The software of image acquisition is build using Sapera ++ LT. We describe the camera structure, schematics of some circuit design, the timing generator and the custom-made Nios CPU. Some simulation and testing results are presented and analyzed in the paper.

8453-99, Poster Session

Architecture of PAU survey camera readout electronics

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PAUcam is a new camera for the study of the physics of the accelerating universe (PAU survey project). The camera is a mosaic of 18 Hamamatsu CCDs 2Kx4K (sixteen for science and two for guiding) with up to 42 narrow and wide band filters for high precision photo-z measurements. The camera will be installed in proximate future in the prime focus of the WHT (William Herschel Telescope) at La Palma.

In this contribution, the architecture of the readout electronics system designed for low noise measurements is presented. The system is divided in back-end and front-end electronics. Back-end consists of clock, bias and video processing boards mounted on Monsoon crates. The front-end is based on two kind of boards: patchpanel (Mix) and preamplifiers (Preamp) boards. The Mix boards plugged outside the camera feedthrough panel are in charge of signal distribution. Inside the camera, individual preamplifier boards plus kapton cable completes the path to connect to CCDs. The overall signal distribution and grounding scheme is shown in this paper.

8453-100, Poster Session

The Dark Energy Camera readout system

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The Dark Energy Camera (DECam) was developed for use by the Dark Energy Survey (DES). The camera will be installed in the Blanco 4M telescope at the Cerro Tololo Inter-American Observatory (CTIO) and be ready for observations in the second half of 2012. The focal plane consists of 62 2x4K and 12 2x2K fully depleted CCDs. The camera provides a 3 sq. degree view and the survey will cover a 5000 sq. degree area.

The development of the electronics to readout the focal plane was a collaborative effort by multiple institutions in the United States and in Spain. The goal of the electronics is to provide readout at 250 kpixels/second with less than 15e- rms noise. Integration of these efforts and initial testing took place at Fermi National Accelerator Laboratory. DECam currently resides at CTIO and further testing has occurred in the Coudé room of the Blanco. In this paper, we describe the development of the readout system, test results and the lessons learned.

8453-101, Poster Session

Hyper Suprime-Cam: performance of the CCD readout electronics

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Hyper Suprime-Cam (HSC) employs 116 pieces of 2kx4k fully-depleted CCD (FDCCD) with a total of 464 signal outputs to cover the 1.5 degrees diameter field of view with the 0.17 arcseconds pixel scale. The readout electronics was designed to achieve 5 e of the readout noise and 150,000 e of the fullwell capacity with 20 seconds readout time. Although the image size exceeds 2 GBytes, the readout electronics supports the 10 seconds readout time for the entire CCDs. Because the frontend electronics (FEE) is placed in the vacuumed dewar, the heat generated from the FEE circuit taken away through the aluminum-core printed circuit board (PCB) and the dewar structure to the outside of the dewar. The board temperature can be lower than 50 degrees Celsius even during the 10 seconds continuous reading, and the outgass generated from the FEE boards does not degrade the vacuum of the dewar. All of the FEE boards and the CCDs are now in the dewar. Those test results of the CCD readout electronics will be presented.

8453-102, Poster Session

Software solution for autonomous observations with H2RG detectors and SIDECAR ASICs for the RATIR camera

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The Reionization And Transients InfraRed (RATIR) camera has been built for rapid Gamma-Ray Burst (GRB) followup and will provide quasi-simultaneous imaging in ugriZYJH. The optical component uses two 2048x2048 pixel Finger Lakes Imaging ProLine detectors, one optimized for the SDSS u, g, and r bands and one optimized for the SDSS i band. The infrared portion incorporates two 2048x2048 pixel Teledyne HgCdTe HAWAII-2RG detectors, one with a 1.7-micron cutoff and one with a 2.5-micron cutoff. The infrared detectors are controlled by Teledyne's SIDECAR (System for Image Digitization Enhancement Control And Retrieval) ASICs (Application Specific Integrated Circuits). While other ground-based systems have used the SIDECAR before, this system also utilizes Teledyne's JADE2 (JWST ASIC Drive Electronics) interface card and IDE (Integrated Development Environment). Here we present a summary of the software developed to interface the RATIR detectors with Remote Telescope System, 2nd Version (RTS2) software. RTS2 is an integrated open source package for remote observatory control under the Linux operating system and will autonomously coordinate observatory dome, telescope pointing, detector, filter wheel, focus stage, and dewar vacuum compressor operations. Where necessary we have developed custom interfaces between RTS2 and RATIR hardware, most notably for cryogenic focus stage motor drivers and temperature controllers. All detector and hardware interface software developed for RATIR is freely available and open source as part of the RTS2 distribution.

8453-103, Poster Session

Performances and results of the detector acquisition system of the GIANO spectrometer

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GIANO is a high resolution (R=50,000) IR spectrograph covering the 0.95-2.5 microns wavelengths range. It is equipped with a Hawaii-II PACE array. We describe the main features of the detector acquisition system which has been designed and built at INAF-Arcetri. The paper also describes a few special features which have been developed to optimize the noise performances and minimize spurious effects intrinsic to the detector, such as reset anomaly and persistency.

8453-104, Poster Session

The detector control system for the ISAS balloon-borne experiment

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In this paper we present the concept for the detector control system on board of the Interferometric Stratospheric Astrometry for Solar system (ISAS) mission. This project is designed for high precision astrometry on the brightest planets of the Solar System, with reference to many field stars, at the milli-arcsec (mas) level or better.

The ISAS mission is proposed as a balloon-borne experiment. This involves a pointing stability problem, which has to be mitigated in order to achieve the planned accuracy in the measurement.

The ISAS detector system will be based on visible band CCDs; we propose to use Orthogonal-transfer CCDs (OTCCDs) in order to implement tip-tilt correction that otherwise would require additional moving parts.

In the paper we discuss the architecture of a detector control electronics suitable to drive OTCCDs, and we compare its performance with the requirements derived from the expected condition on a stratospheric balloon location and from the main scientific objectives.

8453-105, Poster Session

A simple controller for bidimensional detectors

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In this work, a simple, small and reliable controller for bidimensional CCD detectors where reading speed is not a critical parameter is proposed. The system is based on the Texas Instrument's MSP430 Launchpad equiped with a MSP430G2231 microcontroller and a 256 Kbit serial RAM. The clock frequency of the microcontroller is 16 MHz, so a 2MHz@8bits reading cycle per pixel is easily obtained. Depending on the size of the detector, a single frame can be stored in the serial memory an later transferred to a computer via USB. The cost of this system is very low and can be used as a functional controller or in a test bench. It can even be scaled to acquire multiple quadrants of a CCD.

8453-107, Poster Session

Interfacing the new Small-Cam Leach controller with a suborbital flight control system

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As part of the CHESS suborbital rocket flight project (French et al., this meeting), we have built the focal plane array for the instrument using a prototype modular construction (Veach et al., this meeting) and used the new Small-Cam Leach controller from Astronomical Research Cameras, Inc. (ARC) as the interface between the detector and the flight control system. This paper outlines the lessons learned in using the new controller and compares the performance and differences in its use when compared with the industry-familiar ARC products such as the San Diego State controllers in use at observatories such as PanSTARRS and Gemini.

8453-108, Poster Session

Torrent: meeting observatory budget constraints with a generic image acquisition system

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Most observatories that are operating multiple telescopes have developed standards for such engineering functions as mechanism-control, temperature-control, etc. These systems use common architectures, common hardware, and common software which allows savings in operational costs and usually reduces downtime because of the technical familiarity of the support staff.

However, for a variety of often compelling reasons, detector controllers are usually not required to be 'standard issue' and this places a burden on the operational support staff to become familiar with each different controller type or variant while at the same time complicating the issues of spares inventories and maintenance records.

As a natural follow on to the scalable MONSOON image acquisition system development program, we at NOAO have developed the Torrent detector controller which is a 'standard' image acquisition system for instrumentation employing visible and NIR detector technologies. In this poster we present the key features that allow this open source controller technology to replace existing (and possibly obsolete) controller technologies while optimally supporting today's and future detector technology using one standard design.

8453-109, Poster Session

A readout for large arrays of microwave kinetic inductance detectors

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Microwave Kinetic Inductance Detectors (MKIDs) are superconducting detectors capable of counting single photons and measuring their energy in the UV, optical, and near-IR. MKIDs feature intrinsic frequency domain multiplexing (FDM) at microwave frequencies, allowing the construction

and readout of large arrays. MKIDs do not require the complex cryogenic multiplexing electronics used for similar low temperature detectors, such as Transition Edge Sensors (TESs), but instead transfer this complexity to room temperature signal processing electronics. Here, we describe the first successful effort to build a readout for a photon counting optical/near-IR astronomical instrument, the ARray Camera for Optical to Near-infrared Spectrophotometry (ARCONS). This readout is based on open source signal processing hardware developed by the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER). Designed principally for radio telescope backends, it is flexible enough to be used for a variety of signal processing applications.

8453-110, Poster Session

SIDECAR ASIC implementation and performance

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The SIDECAR is a unique custom-designed application specific integrated circuit (ASIC) that provides all of the functionality of focal plane control electronics on a single CMOS chip. The SIDECAR ASIC has been operating flawlessly in space for nearly three years, and has been implemented successfully in several space missions and at a number of ground-based astronomical observatories. The SIDECAR ASIC is very versatile, and is presently being used to operate both CMOS and CCD arrays, with the ASIC at room temperature down to the very cold (37K) operating regimes required for some space astronomy missions. This paper provides a summary of the SIDECAR ASIC architecture, and the packaging options that have been developed for ground and space. The SIDECAR ASIC performance, with emphasis on noise and power, is presented for a wide variety of operating conditions and temperatures. This paper provides guidelines for operation that can be used for estimating performance in a proposed instrument.

8453-111, Poster Session

Frequency analysis of the noise in the Fowler(n) with the SIDECAR ASIC

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The readout noise of a H2RG HgCdTe NIR detector from Teledyne is measured at a temperature T=100K. In a previous work, we have analysed the evolution of the readout noise as a function of the number of reads in terms of the frequency power spectrum of the noise with our in-house hybrid readout electronics. The new measurements with the SIDECAR ASIC provided by TIS are compared to the previous ones.

8453-112, Poster Session

The low earth orbit radiation environment and its impact on the prompt background of hard x-ray focusing telescopes

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The background minimization is a science-driven necessity in order to reach deep sensitivity levels in the hard X-ray band, one of the key scientific requirements of the future hard X-ray focusing telescopes (e.g. Nustar, ASTRO-H). It requires a careful modeling of the radiation environment and new concepts of shielding systems. We exploit the Bologna Geant4 Multi-Mission Simulator (BoGEMMS) features to evaluate the impact of the Low Earth Orbit (LEO) radiation environment on the prompt background level for a hybrid Si/CdTe soft and hard X-ray detection system and a combined active and passive shielding system.

For each class of particles, the spectral distribution of both the background counts and the particles interacting with the detection devices is simulated, exploring the effect of different materials (plastic vs inorganic active scintillator) and configurations (passive shielding enclosing/surrounded by the active device) on the background count rate.

While protons are efficiently removed by the active shielding, an external passive shielding causes the albedo electrons and positrons to be the primary source of background. Albedo neutrons are instead weakly interactive with the active shielding, depositing background counts below 100 keV via elastic scattering. The best shielding configuration in terms of background and active shielding count rate is given by an inorganic scintillator placed inside the passive layers, with the addition of passive material to absorb the intense fluorescence lines of the active shielding and avoid escape peaks on the CdTe detector.

8453-113, Poster Session

The effects of radiation damage on the spectral resolution of the Chandrayaan-1 x-ray spectrometer over the full mission duration

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The Chandrayaan-1 X-ray Spectrometer (C1XS) was launched onboard the Indian Space Research Organisation (ISRO) Chandrayaan-1 lunar mission in October 2008. The instrument consisted of 24 swept-charge device silicon X-ray detectors providing a total collecting area of ~24 cm2, corresponding to a 14 degree field of view (FWHM), with the ability to measure X-rays from 0.8 - 10 keV. After a two week journey to the Moon the spacecraft was located in a 100 km polar orbit around the Moon for a period of 10 months, observing a number of solar flare X-ray events, along with calibration data from X-ray sources housed inside the movable door of the instrument. This paper presents an analysis of flight calibration data collected in '3-pixel mode' towards the end of the mission, adding an additional data point to previously published work, such that the degradation of the C1XS spectral resolution for the full 10 month mission duration can now be presented. The observed spectral degradation is compared to the simulated resolution change modelled prior to launch to validate the proton radiation environment model used.

8453-114, Poster Session

A multiplexer for the AC/DC characterization of TES-based bolometers and microcalorimeters

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SRON is developing the Frequency Domain Multiplexing (FDM) for the read-out of the TES-based detector array of the infra-red spectrometer SAFARI on board of the space mission SPICA and of the X-ray Microcalorimeter Spectrometer (XMS) on the Advance Telescope for High ENergy Astrophysics (ATHENA). In the FDM configuration the TES is AC voltage biased at well defined frequencies (between 2 to 5MHz) and acts as an AM modulating element. To achieve the excellent performance of the TES sensors observed under DC bias, further optimizations of the FDM read-out scheme and of the magnetic field environment are needed.

We describe the performances of a multiplexer set-up designed to increase the experimental throughput in the characterization of ultra-low noise equivalent power (NEP) TES bolometers and high energy resolving power x-ray microcalorimeters arrays under AC and DC bias. Special care has been taken to design the magnetic shielding and to improve the uniformity of the applied magnetic field across the array. The AC read-out is based on a two-stage SQUID current sensor with on chip linearization and high Q lithographic LC resonators, while in the DC case a MUX dc-SQUID developed for Time Domain Multiplexing (TDM) is employed. We discuss the results obtained both using SRON TiAu TES bolometer arrays with measured dark NEP of 4.2×10^(-19) W/sqrt(Hz) and saturation power of 12 fW and GSFC MoAu xray TES microcalorimeters with demonstrated energy resolution of about 2eV for x-ray photons at 6keV.

8453-115, Poster Session

A system for the characterization of the HAWC PMTs sensitivity

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The HAWC Project is a very high-energy gamma-ray observatory under construction at Sierra Negra volcano (4100 meters above sea level) in Pico de Orizaba National Park located in central Mexico. HAWC will reuse the 900 Hamamatsu R5912 photomultipliers (PMTs) from Milagro. In order to characterize their present performance it is necessary to scan the active area of the photocathode by measuring its quantum efficiency (QE) and gain. A mechanical device was designed and manufactured to achieve an automated measurement over 100 points distributed on the PMT active spherical surface. Preliminary results show the variation of QE of PMTs with respect to the angle of incoming photons, as well as the changes in the PMTs response due to the Earth's magnetic field and gain vs. high voltage. The mechanical device allows automated PMT calibration improving its performance, reliability, precision and repeatability. In this work we present the mechanical device and preliminary results on the PMT efficiency.

8453-116, Poster Session

BoGEMMS: the Bologna Geant4 multi-mission simulator

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The BoGEMMS (Bologna Geant4 Multi-Mission Simulator) is a software project based on the Geant4 set of libraries (for prompt background evaluation) has been developed at the INAF/IASF Bologna which allows to interactively set the geometrical and physical parameters (e.g. physics list, materials and thicknesses), recording the interactions (e.g. energy deposit, position, interacting particle) in FITS or ROOT/CERN format output files and filtering the output as a real observation in space, to finally produce the background detected count rate and spectra. This approach allows us to rapidly develop and test geometries of detector or spacecraft configurations without the complexity of the Geant4 event structures.

The BoGEMMS is a multi-mission tool, generally designed to be applied to any high energy mission for which the shielding and instruments performances analysis is required. This tools has been used for simulations of the detection efficiency and background evaluation of the Simbol-X and NHXM missions, as well as for the XMM-Newton soft protons funnelling and the general analysis of the shielding efficiency in LEO.

8453-119, Poster Session

HST/WFC3 UVIS detectors: radiation damage effects and mitigation

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Detectors in low-earth orbit are susceptible to the cumulative effects of radiation damage and the Hubble Space Telescope Wide Field Camera 3 (HST/WFC3) UVIS devices are no exception. Such damage not only generates new hot pixels but also degrades the charge transfer efficiency (CTE), causing a loss in source flux due to charge traps as well as a systematic shift in the object centroid as the trapped charge is slowly released during readout. Based on results from both internal and external monitoring data, we provide an overview of the consequences of the nearly 3 years of radiation damage to the WFC3 CCD cameras. The use and efficacy of the available mitigation options are discussed, including formulaic corrections to aperture photometry, WFC3 charge injection, a mode now available to observers, and pixel-based image reconstruction similar to the method adopted for the HST Advanced Camera for Surveys (ACS).

8453-34, Session 10

An overview of astronomy detector development at Raytheon Vision Systems

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For decade ground-base and spaceborne astronomy have been a strong catalyst and driving force for the development of advanced large format detectors ranging from visible to the far infrared. Through close collaboration with principal investigators scientists in the astronomy community, many high performance detectors have been developed at Raytheon Vision Systems (RVS). They include VISTA, a mosaic of sixteen 2048x2048 HgCdTe arrays, VIRGO, our standard very low noise and high quantum efficiency HgCdTe arrays in 1024x1024 and 2048x2048 format, AQUARIUS, Si:As IBC detectors with response to 30 microns in 1024x1-24 and 2048x2048 format. Recent advancement in large format HgCd on silicon detectors at RVS has the potential to significantly reduce the cost of large format detectors for future astronomy programs such as SASIR, GMT, TMT, ELT, and WFIRST.

In this paper, we will present an overview of recent advancement in detector development at RVS, ranging from photon-counting HgCdTe avalanche photodiode (APD) detectors, to visible and shortwave infrared and far infrared detectors. We will also discuss how these advancements can benefit future astronomy programs by offering high performance at affordable cost, made possible by improved manufacturing processes and HgCd on silicon technology development.

8453-35, Session 10

Read noise for a 2.5µm cutoff Teledyne H2RG at 1-1000Hz frame rates

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A camera operating a Teledyne H2RG in H and Ks bands is under construction to serve as a near-infrared tip-tilt sensor for the Keck-1 Laser Guide Star Adaptive Optics system. After imaging the full field for acquisition, small readout windows are placed around one or more natural guide stars anywhere in the AO corrected field of view. Windowed data may be streamed to RAM in the host for a limited time then written to disk as a single file, analogous to a "film strip", or be transmitted continuously via a second fiber optic output to a dedicated computer providing real time control of the AO system. The various windows are visited at differing cadences, depending on signal levels. We describe a readout algorithm, which maximizes exposure duty cycle, minimizes latency, and achieves very low noise by resetting infrequently then synthesizing exposures from Sample up the Ramp data. To illustrate which noise sources dominate under various conditions, noise measurements are presented as a function of synthesized frame rate and window sizes for a range of detector temperatures. The consequences of spatial variation in noise properties, and dependence on frame rate and temperature are discussed, together with probable causes of statistical outliers.

8453-36, Session 10

The EUCLID NISP detectors system

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The Euclid mission objective is to map the geometry of the dark Universe. The mission will investigate the distance-redshift relationship and the evolution of cosmic structures. The EUCLID project is part of ESA's program Cosmic Vision which is the current cycle of ESA's long-term planning for space science missions. Euclid has been selected by ESA's Science Program Committee for implementation, with launches planned for 2019, on a Soyuz vehicle, from Europe's Spaceport at Kourou, French Guiana.

The NISP (Near Infrared Spectro Photometer) is an instrument that will operate in the near-IR spectral region (0.9-2 µm). It will be equipped with a focal-plane based on a mosaic of 16 Teledyne HAWAII2RG 2.4 µm cutoff with their front end readout electronic. A description of this focal plane focusing on the detectors specifications and requirements, their implementation and the expected performances at the end of the Phase A study will be given in this paper.

8453-37, Session 10

Improved infrared sensor reliability

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Teledyne has developed a pixel architecture that improves the reliability of near-IR detectors arrays, including the H1RG, H2RG and H4RG arrays used for astronomy. The improved process has been demonstrated to achieve high performance on near-infrared arrays, and its long term reliability is being qualified for flight by the James Webb Space Telescope (JWST) Project. Teledyne's improved process enables high resiliency to long-term ambient storage that is required by the JWST. This paper describes the old hybrid detector architecture, and presents the improved architecture that mitigates the barrier issue that affected JWST. Data from arrays operated in the low flux environment of space astronomy will be presented, showing that the improved process retains the high quantum efficiency, low dark current and low readout noise expected from H1RG and H2RG infrared arrays. The improved process is now baseline for all infrared arrays made at Teledyne, providing increased reliability for future astronomy, Earth science and planetary science space missions.

8453-38, Session 10

AQUARIUS, the next generation mid-IR detector for ground-based astronomy

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ESO has recently funded the development of the AQUARIUS detector at Raytheon Vision Systems, a new mega-pixel Si:As Impurity Band Conduction array for use in ground based astronomical applications at wavelengths between 3 - 28 um. The array has been designed to have low noise, low dark current, switchable gain and be read out at very high frame rates. It has 64 individual outputs capable of pixel read rates of 3MHz, implying continuous data-rates in excess of 300 Mbytes/second. It is scheduled for deployment into the VISIR instrument at the VLT in 2012, for next generation VLTI instruments and baselined for METIS, the mid-IR candidate instrument for the E-ELT. A new mid-IR test facility has been developed for AQUARIUS detector development which includes a low thermal background cryostat, high speed cryogenic pre-amplification and high speed data acquisition and detector operation at 5K. We report on all the major performance aspects of this new detector including conversion gain, read noise, dark generation rate, linearity, well capacity, pixel operability, low frequency noise, persistence and electrical cross-talk. We describe the many possible readout modes of this detector and their application. We also report on issues with the operation of these detectors at such low temperatures. Finally we report on the electronic developments required to operate such a detector at the required high data rates and in a typical mid-IR instrument.

8453-39, Session 11

Pixel classification for the JWST fine guidance sensor

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The James Webb Space Telescope Fine Guidance Sensor makes use of three 2048x2048 five micron cutoff HAWAII-2RG HgCdTe detectors from

Teledyne Imaging Systems. The FGS consists of two Guider channels and a Near-InfraRed Imager and Slitless Spectrograph (NIRISS) channel. We report here on the characterization of the flight detectors at the sub-system level and after integration to the flight instrument. The FGS-Guider has a number of unique readout modes which are required to support observatory operations. Of critical importance is the identification and classification of pixels which, if left unmasked or unprocessed, would compromise the guider performance. We report on these classification methods and on the evolution of these classifications over the elapsed detector lifetime to date.

8453-40, Session 12

CMOS sensor and camera for the PHI instrument onboard the Solar Orbiter Mission: evaluation of the radiation tolerance

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The ESA/NASA Solar Orbiter mission, to be launched in 2017, will explore the Sun at a much closer distance than any previous solar observatory. On board the spacecraft, a high-resolution magnetograph (PHI) will provide two-dimensional measurements of the photospheric vector magnetic field and the line-of-sight velocity.

The environmental conditions encountered during the mission, together with the stringent performance requirements of the instrument, define the set of specifications for the camera system.

A custom designed CMOS sensor (with 2048x2048 pixels) has been developed to fulfill the aimed radiation hardness and performance. This sensor must demonstrate a cadence above 10 fps with a full well capacity higher than 10^5 electrons in a 10-µm pixel pitch. We report the characterization and qualification tests. The radiation test campaign has been completed up to a TID of 150 krad (Si), a proton fluence up to 4x10^11 at 10 MeV and 2x10^11 at 20 MeV, and heavy ions to check for latch-up and SEFI failures. In parallel, a radiation tolerant camera electronic readout system has been built to control the camera and readout images, digitize the data, and communicate with the data handling system of the PHI instrument.

In addition, we present the main issues related to the camera design and future perspectives.

8453-41, Session 12

Modelling charge transfer in a radiation damaged charge coupled device for Euclid

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As electrons are transferred through a radiation damaged Charge Coupled Device (CCD), they may encounter traps in the silicon in which they will be captured and subsequently released. This capture and release of electrons can lead to a 'smearing' of the image. The dynamics of the trapping process can be described through the use of Shockley-Read-Hall theory, in which exponential time constants are used to determine the probability of capture and release. If subjected to a hostile radiation environment, such as in space where the dominant charged particle is the proton, these incident protons can cause displacement damage within the CCD and lead to the formation of stable trap sites. As the trap density increases, the trapping and release of signal electrons can have a major impact on the Charge Transfer Efficiency (CTE) to the detriment of device performance. As the science goals for missions become ever more demanding, such as those for the ESA Euclid and Gaia missions, the problem of radiation damage must be overcome. In order to gain a deeper understanding of the trapping process and the impact on device performance, a Monte Carlo simulation has been developed to model the transfer of charge in a radiation damaged CCD. This study investigates the various difficulties encountered when developing such a model: the incorporation of appropriate clocking mechanisms, the use of suitable trap parameters and their degeneracy, and the development of methods to model the charge storage geometry within a pixel through the use of three-dimensional Silvaco simulations.

8453-42, Session 12

Assessment of proton radiation-induced charge transfer inefficiency in the CCD273 detector for the Euclid Dark Energy Mission

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Euclid is a medium class mission selected for launch in 2019, with a primary goal to study the dark universe using the weak lensing and baryonic acoustic oscillations techniques. Weak lensing depends on accurate shape measurements. Preliminary work has demonstrated that the instrument's ability to accurately measure elipticity is affected by radiation-induced CTI, and therefore it is beneficial that the effects of radiation-induced charge transfer inefficiency (CTI) in the Euclid CCD over the six year mission are both minimised, and understood to enable correction of CTI effects in the image. A new custom CCD has been designed by e2v for the Euclid VIS instrument, termed the CCD273. This paper describes the initial study performed on the CCD273, where comparisons were made on device operation, specifically to the radiation induced CTI, to the Euclid radiation test structure CCD204. The CCD273 is a custom CCD produced based on a radiation damage assessment performed on the CCD204 and discussions between e2v technologies plc. and the Euclid consortium. This paper describes the results of the initial experimental test campaign conducted on the prototype CCDs, and discusses their impact on the VIS instrument's measurement of weak lensing.

8453-43, Session 12

Mitigating radiation-induced charge transfer inefficiency in full-frame CCD applications by 'pumping' traps

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The charge transfer efficiency of a CCD is based on the average level of signal lost per pixel over a number of transfers. This value can be used to directly compare the relative performances of different structures, increases in radiation damage or to quantify improvements in operating parameters. This number does not however give sufficient detail to mitigate for the actual signal loss/deference in either of the transfer directions that may be critical to measuring shapes to high accuracy, such as those required in astronomy applications (e.g. for Gaia's astrometry or the galaxy distortion measurements for Euclid) based in the radiation environment of space.

Pocket-pumping is an established technique for finding the location and activation levels of traps; however, a number of parameters in the process can also be explored to identify the trap species and to sub-pixel accuracy.

This information can be used in two ways to increase the sensitivity of a camera. Firstly, the clocking process can be optimised for the time constant of the majority of traps in each of the transfer directions, reducing deferred charge during read out. Secondly, a correction algorithm can be developed and employed during the post-processing

of individual frames to move most of any deferred signal back into the charge packet it originated from.

Here we present the trap-pumping techniques used to optimise the charge transfer efficiency of p- and n-channel e2v CCD204s and demonstrate the use of a correction algorithm on an optical projection on a proton irradiated n-channel CCD204.

8453-44, Session 13

Characterization of the silicon drift detector for NICER instrument

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We have studied timing properties of the Amptek Silicon Drift Detectors (SDD) using pulsed X-ray source designed at Goddard Space Flight Center. The proposed Neutron Star Interior Composition Explorer (NICER) mission will use 56 of these detectors as X-ray sensors in an attached payload to the International Space Station to study the time variability of millisecond X-ray pulsars.

Using a rastered pinhole, we have measured the delay times for single X-ray photon detection as a function of the impact position on the detector, as well as signal rise time as a function of impact position.

We find that interdependence of these parameters allows us to determine photon position on the detector by measuring the signal rise time.
In addition, we can improve the accuracy of the photon arrival time measurement.

Other factors contributing to the overall arrival time measurement error budget were also evaluated.

8453-45, Session 13

Development of a laboratory-based XRF facility for measuring elemental abundance ratios in planetary analogue powder samples

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This paper describes the use of a swept-charge device (SCD) silicon X-ray detector in a laboratory based X-ray fluorescence (XRF) facility for calculating elemental abundance ratios from planetary analogue powder samples. The facility was developed to support the Chandrayaan-1 X-ray Spectrometer (C1XS) detector development and calibration activities prior to the flight of the instrument onboard the Indian Space Research Organisation (ISRO) Chandrayaan-1 mission to the Moon in 2008. The test facility has subsequently been used to carry out XRF analysis of homogenous samples made from mixtures of MgO, Al2O3 and SiO2 powders, all of grain size <44 um, across a range of mixture ratios and at a high level of X-ray flux data in order to develop an algorithm which will allow the calculation of elemental abundance ratios. This paper also presents an analysis of XRF data collected from terrestrial anorthosite and basaltic rock samples, corresponding to the different regions of the Moon from which the collected C1XS lunar dataset derives. The operation of the SCD, the XRF test facility, the sample preparation methodology and the process of obtaining elemental abundance ratios from planetary analogue samples using the test facility are discussed in this paper.

8453-46, Session 13

A compact, high-speed pnCCD camera for optical and x-ray applications

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The pnCCD is a fully depleted silicon detector, which is already widely used in X-ray telescopes (e.g. XMM-Newton, eRosita). In the optical as well as the X-ray wavelength range, it has a quantum efficiency, which is only limited by reflection at the entrance window (100 % fill factor) and by transmission through the 450 um thick silicon.

We developed a compact camera which houses a thermo-electric cooled pnCCD with 264 x 264 pixels of 48 um square size. It can be read out with up to 400 Hz with a readout noise of about 2.5 electrons rms and with up to 1000 Hz with a readout noise of about 4 electrons rms. The camera can be operated as table-top instrument with a glass or a thin beryllium window for optical and X-rays respectively and it can be connected to a vacuum system by omitting the window.

The camera can easily be attached to optical telescopes. High-speed astronomical observations can be performed with moderate and low light levels. The results of test measurements will be presented.

As the camera system is highly adaptive, it is well suitable for any ground based preparation measurements for future X-ray missions. For X-ray single photon exposure, the spatial position of each photon can be determined with significant sub-pixel resolution. New results on the accuracy for low energy X-rays (< 1 keV) will be presented.

8453-47, Session 14

Charge diffusion measurement using 55Fe x rays

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Tight requirements on the Large Synoptic Survey Telescope point spread function (PSF) demand sensor contribution to PSF be both small and well characterized. The sensor PSF is determined by the lateral charge diffusion on the drift path from the CCD window to the gates.Different techniques for charge diffusion characterization have been developed, each with its own systematics and measurement difficulties.

A new way to measure charge diffusion using a 55Fe X-ray source is presented. We demonstrate the effectiveness and limitations of our technique.

8453-48, Session 14

A test-based comparison between commercial cameras for solar simulators characterization

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A solar simulator is an optical system that reproduces the angular

dimension of the solar disk superimposed on an ideally totally dark background. Actually every solar simulator facility presents some residual level of stray-light. In the context of the development of an optical tool to validate solar simulators, Laboratoire d'Astrophysique de Marseille (LAM) is developing a dedicated tool to identify the upper limit of this background light noise. One of the most critical component is the detector which has to be properly selected to satisfy the requirement of the experiment. The measurements have to be normalized to the intensity level of the source used as Sun. For this reason the ideal camera should be able to detect very bright sources and very low light signals and, possibly, perform imaging in order to easily locate eventual bright areas. Moreover, due to the required accuracy, the camera has to prove reliable, provide reproducible performances and introduce as low noise as possible. In order to identify the best suited camera for this characterization, we carried out a test campaign at LAM evaluating several commercial cameras implementing different detector technologies. For each investigated cameras we estimated the dynamic range, the dark noise, the linearity response and the readout noise introduced by the electronics, using the Photon Transfer Curve method. This paper presents the results of the test campaign providing a quantitative comparison between the investigated cameras and a qualitative judgment based on our interaction with the provided user interfaces.

8453-49, Session 15

Development of a test system for the characterisation of DCDS CCD readout techniques

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A system has been designed and built for developing and evaluating the technique of Digital Correlated Double Sampling (DCDS) to cancel reset noise in CCD camera systems. A wide range of DCDS processing algorithms have been investigated using a CCD203 from e2v technologies. The test system is described and sub-system noise characterisation test results are presented and compared with the theoretically expected performance. It has previously been reported that significant noise improvements can be achieved through the use of weighted averaging of samples. This has been tested using a range of coefficient distributions and the results are presented along with a comparison of the test results against DCDS theory. The CCD203 has the capability to provide a pseudo differential output. This facility has been used to provide a brief comparison of single ended and differential measurements. Finally, test results using a Fast Fourier Transform (FFT) method to analyse pixel sample data and minimise system noise are presented.

8453-50, Session 15

Subelectron readout noise in CCDs

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The 1/f noise limit on CCDs is overcome by replacing the traditional correlated double sampling by a custom digital filter. Using this method a readout noise of 0.5 e- RMS is achieved. The implementation of this new noise reduction technique will be discussed in this presentation. The 1/f noise limit is also defeated using a recently developed skipper CCD, fabricated in a high resistivity silicon substrate, for which noise of 0.2 e- is achieved. The performance of this detector will also be discussed in the presentation.

For more details of the work see:

http://arxiv.org/abs/1107.0925

http://arxiv.org/abs/1106.1839

8453-51, Session 15

Reducing the read noise of near-infrared detector systems by improved reference sampling and subtraction

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We described a method for significantly reducing the read noise of HAWAII-2RG (H2RG) and SIDECAR application specific integrated circuit (ASIC) based detector systems by making better use of reference signals. "Improved Reference Sampling & Subtraction" (IRS2 ; pronounced "IRS-square") is based on: (1) sampling reference pixels more frequently in the time domain and (2) Wiener-optimal subtraction of the reference output, the reference pixels, and possibly other references in the noise's eigenspace. Using engineering grade detectors and SIDECARs, IRS-square readout has achieved read noise suppression factors of 2x or more. We are experimentally validating IRS-square now using near flight-grade James Webb Space Telescope (JWST) components and flight-representative science exposures.

We developed IRS-square readout to mitigate correlated noise that was observed in the flight JWST Near Infrared Spectrograph (NIRSpec) detector subsystem. Principal component analysis (PCA) revealed that about half of NIRSpec's ~6.5 e- rms total noise is correlated, and therefore amenable to subtraction when the correct references are used. The same PCA revealed that the reference pixels need to be sampled more frequently than is possible in traditional H2RG readout. In IRS-square readout, the H2RG's guide window is used to interleave reference pixel samples and normal pixel samples throughout readout. These additional reference pixels, the reference output, and potentially other references are subtracted simultaneously using a Wiener optimal approach.

8453-52, Session 15

SIDECAR ASIC, its operation and performance with VIRGO2K near-infrared detectors

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Large format near infrared detectors from Teledyne Imaging Systems (TIS) and Raytheon Vision Systems (RVS) are widely used in both ground and spaced based astronomical instruments. TIS have designed and developed an ASIC controller (SIDECAR) specifically for the Hawaii-RG family of NIR and visible hybrid detectors. The ASIC replaces conventional controller electronics which are often bulky and power consuming and reduces power dissipation, cryogenic cable harness and hence the thermal burden on the cooling systems all of which simplify the detector sub-system design and reduces the overall cost of the instrument. The ASIC, although its programming is non-trivial, can be adapted to operate other detectors such as VIRGO from RVS with a suitable cryogenic interface board which opens up the choice of detectors for applications using ASIC as controller. This paper presents the design and development of a cryogenic level shifter circuit board to translate the clocks, biases and signal outputs between the ASIC and the VIRGO detector and describes the implementation of the ASIC micro-code for VIRGO detector operation. The cryogenic operation and performance of the ASIC with an engineering VIRGO detector will be presented.

8453-53, Session 16

Modeling and model verification for the Euclid CCD273 detector

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Euclid is one of the M-class missions selected for the next phase of ESA's long-term Cosmic Vision programme. The primary goal of this mission is to observe the distribution and shapes of distant galaxies, with the aim of mapping and characterising the dark energy which makes up about 70% of the universe. This will be achieved by measuring the effects of weak lensing on the captured images, in terms of the distortion caused to the PSF and shape of galaxies.

The e2v CCD273 was designed for the Euclid mission and is adapted from an older design (the CCD204) with changes made to improve CTE under irradiation by solar protons. Reducing the effects of radiation damage in the image sensor will result in images which have minimal distortion due to radiation damage.

This paper is focused on the on-going development and verification of 3D device models and their integration with Monte Carlo radiation damage models. Parameters such as charge interaction volume versus signal size, pixel full well capacity, and charge transfer behaviour for both the parallel and serial registers will be discussed.

The main mission goals are aimed at measuring distortion due to weak lensing, so it is important to differentiate this from distortion due to radiation damage. This work will eventually lead to a method of post processing images to remove the effects of radiation damage.

8453-54, Session 17

Charge-coupled devices for the ESA PLATO M-class Mission

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PLATO is a candidate mission for an ESA M-class launch opportunity. The project aims to detect planets from their transits across their host star and to characterize those stars by studying their oscillations, hence the name PLATO for, PLAnetary transits and Oscillations of stars. In order to achieve this aim the mission proposes to fly a satellite with a focal plane of up to 34 mini-telescopes, each containing 4 large area back illuminated CCDs to provide ultra high precision photometry. If successful, the satellite will have nearly 0.9 m^2 of image sensors and will be by far the largest composite detector focal plane ever flown.

To meet the mission requirements e2v have developed the CCD270 which has 4510 by 4510 pixels, each pixel is 18 um by 18 um. The development has been funded by the European Space Agency. This large area (81 mm x 81 mm) full frame image sensor is intended for precision photometry with a dynamic range of at least 30,000.

The CCD270 has been manufactured with a thin gate dielectric and a higher buried channel dose to increase the full well capacity in the image area. The additional advantages of the thin gate are lower power dissipation, smaller clock voltage swing for standard channel doses and higher tolerance to ionising radiation.

These devices have been manufactured and back thinned, proving that a viable yield can be obtained from one device per wafer.

This paper describes the imager sensor in detail and focuses on the novel aspects of the device, package and interface.

8453-55, Session 17

Persistence and charge diffusion in an E2V CCD42-90 deep-depletion CCD

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The ESPaDOnS spectrograph at the Canada-France-Hawaii Telescope was recently upgraded to use an E2V CCD42-90 deep-depletion CCD. While changing to this device from a standard silicon CCD42-90 had many benefits such as much higher red QE and much lower fringing, it was also found that the new device exhibited persistence. After talking with E2V, a solution to the persistence was found, but this resulted in reduced resolution on the spectrograph from charge diffusion. This paper will describe the solution found to allow the detector to run with no persistence and with limited charge diffusion.

8453-56, Session 17

Recent astronomical detector development at the University of Arizona

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The University of Arizona Imaging Technology Laboratory (ITL) has been developing detectors and detector technologies for several astronomical projects in recent years. These projects include the WIYN telescope One Degree Imager (ODI) mosaic of Orthogonal Transfer Array CCDs, the VIRUS detectors for the University of Texas' Hobby-Eberly Telescope Dark Energy Experiment (HETDEX), detector and packaging development for the Large Synoptic Survey Telescope (LSST), and 10kx10k pixel CCDs for several instruments. In this paper we discuss these projects with an emphasis on backside processing issues and detector characterization results which may be relevant to other groups. We will also focus packaging techniques and metrology for achieving very flat and stable focal planes. Results will include device flatness at cryogenic temperatures, process yield, photo-response non-uniformity and cosmetic issues at various wavelengths, quantum efficiency, read noise, linearity, charge transfer efficiency, and photon transfer data. We will also report on the uniformity of device performance for samples of devices spanning multiple lot runs.

8453-57, Session 17

STA1600LN: low-noise 10560 x 10560 pixel high-resolution CCD for astronomy

R. A. Bredthauer, G. R. Bredthauer, K. L. Boggs, Semiconductor Technology Associates Inc. (United States); M. P. Lesser, The Univ. of Arizona (United States)

The demand from the astronomical community for high resolution low noise CCDs has led to the development of the STA1600LN, a 10560 x 10560 pixel, 95mm x 95mm, full-frame CCD imager with 9x9 μ2 pixels. The device improvements include noise reduction to below 3e- at 100kHz, improved quantum efficiency, as well as packaging developments for improved fill factor in mosaic systems. We provide test results from production devices, along with updates on scientific systems utilizing the STA1600LN for astronomy.

8453-58, Session 17

A novel CCD for application in high-frame rate geostationary space-based imaging

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The Geostationary Lightning Mapper (GLM) instrument selected to fly on the National Oceanic and Atmospheric Administration (NOAA) GOES-R Series environmental satellites has very unique requirements for an imaging array. GLM's requirements to monitor lightning on a global scale will provide new insight into the formation, distribution, morphology and evolution of storms.

A 500 frame per second backside illuminated frame transfer CCD imager (STA3900A) with variable pixel size has been developed to meet these requirements. A variable pixel architecture provides a near uniform mapping of the curved surface of the earth, while 56 outputs running at 20 Mhz yield greater than a 1.1 Ghz data rate with low RMS noise and high MTF. This paper will provide detailed information on design trades required. We will report read noise, dark current, full well capacity, quantum efficiency of the CCD

8453-59, Session 18

Performance and calibration of H2RG detectors and SIDECAR ASICs for the RATIR camera

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The Reionization And Transient Infra-Red (RATIR) camera has been built for rapid Gamma-Ray Burst (GRB) followup and will provide simultaneous optical and infrared photometric capabilities. The infrared portion of this camera incorporates two 2048x2048 pixel Teledyne HgCdTe HAWAII-2RG detectors, one with a 1.7-micron cutoff and one with a 2.5-micron cutoff. Run simultaneously at ~80 K in 32 channel readout mode, these detectors are controlled by Teledyne's SIDECAR (System for Image Digitization Enhancement Control And Retrieval) ASICs (Application Specific Integrated Circuits). While other ground-based systems have used the SIDECAR before, this system also utilizes Teledyne's JADE2 (JWST ASIC Drive Electronics) interface card and IDE (Integrated Development Environment). Together, this setup comprises Teledyne's Development Kit, which is a bundled solution that can be efficiently integrated into future ground-based systems. In this presentation, we characterize the system's read noise, dark current, conversion gain, and sensitivity. We also provide a summary of the detector subsystem's test setup and grounding scheme used to minimize noise.

8453-60, Session 18

Hemispherical infrared focal plane arrays: a new design parameter for the instruments

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In ground based astronomy, all designs of space survey telescopes are limited by the requirement that the focal surface is curved and the optical detecting surface is flat. Two kinds of solution have been investigated up to now. The first one consists in adding optical correction systems; however this solution complicates the design and increases the system size. Somehow, this solution increases the weight and price of the system. The second solution is based on a mosaic of several detectors, which are positioned in a spherical shape. However, this attempt is dedicated to small radius of curvature and is limited by the technical difficulty to control the detectors alignment and tilt between each others.

Today we would like to propose an ideal solution which is to curve the detector in a spherical shape, with a 100% optical fill factor thanks to a monolithic process based on silicon thinned substrates. Two infrared uncooled cameras have been performed, using 320 x 256 pixels and 25 µm pitch micro-bolometer arrays presenting an 80 mm bending radius. These two bio-inspired micro-cameras illustrate the optical system simplification and miniaturization involved by curved focal plane arrays. Moreover, a simulation of the opto-mechanical architecture of the spectrometer Optimos-Eve for the European Extremely Large Telescope (E-ELT) shows also the interest of curved detectors on the optical performances (Point Spreading Function), as well as for volume and cost savings.

8453-61, Session 18

Control electronics for large mosaics of SIDECAR ASIC driven detectors

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Several of the next generation instruments require high resolution visible or infrared focal plane arrays that can only be achieved by building large mosaics of individual detector arrays. This raises the question of how to effectively control and operate such a large number of detectors in parallel. A significant step towards enabling these mosaics has been the introduction of the SIDECAR ASIC by Teledyne Imaging Sensors, a single chip for generating biases and clocks to the image sensor, and for digitizing up to 36 sensor outputs. The next step now requires to provide a solution for operating many SIDECAR ASICs in parallel.

We have developed a new control electronics approach that operates up to 32 SIDECAR ASIC / HxRG detectors in parallel. Important properties of the electronics include separately programmable voltage supplies for each ASIC (each supply has programmable over-current and over-voltage protection), synchronized operation of all ASICs, and support for post-processing of science data (i.e. co-adding of frames, centroiding, etc.). All ASIC and detector modes are supported, including window/guide mode operation. The electronics uses a full mode CameraLink interface to provide 544 MBytes/s of sustained bandwidth.

We will present an overview of the electronics architecture, including the general computer infrastructure for data acquisition, storage and sharing. We will discuss benefits and features of the chosen approach, and present performance data captured using SIDECAR ASICs and H2RG detectors. The effort has been funded by NASA's WFIRST project as part of an initial technology demonstration for large space-based detector mosaics.

8453-62, Session 18

Characterization of HAWAII-2RG detector and SIDECAR ASIC for Euclid Mission at ESA

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In the frame work of the Cosmic Vision program, the Euclid mission has the objective to map the geometry of the Dark Universe. Galaxies and clusters of galaxies out to z~2, in a wide extragalactic survey covering 20 000 deg^2, plus a deep survey covering an area of 40 deg^2 will be targeted on the visible and infrared by an imaging and spectroscopic channel.

For the infrared channel, stat-of-the-art detectors, HAWAII-2RG detectors associated with the SIDECAR ASIC readout electronic, will achieve the frames acquisition.

To characterize and validate performances of these detectors, a test bench has been designed, tested and validated.

The test set up and first performances about dark current, readout noise, linearity and persistence effect will be presented.

To evaluate the impact and performances of the SIDECAR ASIC, a dedicated test bench has also been designed.

SIDECAR ASIC characterization results regarding power consumption, the external reference/bias generator and the SAR ADC will be also shown.

8453-63, Session 18

Performance of the HgCdTe detector for MOSFIRE, an imager and multi-object spectrometer for Keck Observatory

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MOSFIRE is a new multi-object near-infrared spectrometer for the Keck 1 telescope with a spectral resolving power R~3500 for a 0.7″ slit (2.9 pixels). The detector is a substrate-removed 2K x 2K HAWAII 2-RG HgCdTe array from Teledyne Imaging Sensors with a cut-off wavelength of 2.5 µm and an operational temperature of 77K. Spectroscopy of faint objects sets the requirement for low dark current and low noise. MOSFIRE is also an infrared camera with a 6.9′ field of view projected onto the detector with 0.18″ pixel sampling. Broad-band imaging drives the requirement for 32-channel readout and MOSFIRE's fast camera optics implies the need for a very flat detector. In this paper we report the final performance of the detector selected for MOSFIRE. The array is operated using the SIDECAR ASIC chip inside the dewar and v2.3 of the HxRG software. Dark current plus instrument background is measured at <0.008 electrons/s/pixel on average. Fowler sampling and Up-The-Ramp (UTR) sampling are both available. A read noise of <5e- rms is achieved with 16 Fowler samples and the lowest noise of 3e- rms occurs for 64 samples. Charge persistence depends on exposure level and shows a large gradient across this detector. However, the decay time constant is always ~600s. Linearity and stability are also discussed.

8453-64, Session 18

NIRSpec detectors: noise properties and the effect of signal dependent inter-pixel crosstalk

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NIRSpec (Near Infrared Spectrograph) is one of the four science instruments of the James Webb Space Telescope (JWST) and its focal plane consists of two HAWAII-2RG sensors operating in the wavelength range 0.7 - 5.0 micron. For most science operations, NIRSpec's detectors will acquire up-the-ramp sampled data at a constant cadence (MULTIACCUM pattern). We have measured the noise properties of these detectors in terms of MULTIACCUM derived count-rates for different levels of illumination and compared the observed values with theoretical expected levels on the basis of the measured flux and read-noise. In dark exposures, the observed total noise is higher than expected because of the 1/f-noise component introduced by the detector electronics and not accounted for in the theoretical modeling. At high flux, we observe significantly lower total noise levels than expected. We interpret this effect as due pixel-to-pixel correlations introduced by a signal dependent inter-pixel crosstalk term, on top of the known Inter-Pixel Capacitance (IPC) coupling. We find correlation levels of approximately 10% for a signal of ~ 40,000 counts, which is well below the pixel saturation point.