Planning instrumentation for the Thirty Meter Telescope

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A next-generation astronomical facility will incorporate a segmented mirror and cameras designed to study dark energy, search for extrasolar planets, and examine the origin and evolution of the universe.

What is dark energy? And dark matter? How did galaxies and supermassive black holes form and evolve in the early universe? What is the origin of stars, planets, and life itself? Answers to these and related questions require new developments in space- and groundbased astronomy coupled with advances in experimental and theoretical physics. It is becoming increasingly clear that we must push to much fainter sources with much better data than currently possible to make significant progress on solving many of the key problems. We are designing the Thirty Meter Telescope (TMT) to rise to that challenge. It will work synergistically with other major observatories, including the James Webb Space Telescope (JWST) and the Atacama Large Millimeter Array. We are also mindful that, as history demonstrates, many discoveries cannot be foreseen. We must therefore design the most powerful and versatile facility that we can afford.

The TMT project is rapidly moving toward construction of a telescope with a primary mirror diameter of 30m, offering 10 times more light-gathering power than the current largest telescopes. In addition, from the outset we are designing TMT to deliver perfect (diffraction-limited) images over much of its operating wavelength range. As a result, many science programs will realize a 100-fold gain in the detection and study of faint sources. Some key capabilities, like the detection of faint planets orbiting nearby stars, will increase by factors of up to 1000. A 30m mirror currently offers the optimum balance between science benefit, cost, technological readiness, and development schedule.

The telescope will have an f/1 primary mirror composed of 492 1.4m hexagonal segments, building upon the experience gained with the 10m Keck telescopes. Perhaps the biggest engineering challenge is to ensure that all of the individual mirror segments operate as one mirror. In addition, the entire system must be capable of being pointed quickly anywhere in the sky and then precisely tracking celestial objects without disturbances from wind buffeting or mechanical vibrations. TMT will not only be much larger than current telescopes, the angular scale of the diffraction-limited images becomes proportionally smaller, compounding the challenge. The telescope’s design is illustrated in Figure 1 and that of the enclosure in Figure 2.

Raw images produced by the telescope will be corrected for atmospheric and mechanical perturbations by rapid sensing and compensation using a technique known as adaptive optics (AO). This system uses a bright natural guide star or laser light source to provide the information needed for image correction. This laser-guide-star AO facility will provide diffraction-limited resolution (8 and 15 milliarcseconds at 1.2 and 2.2 μm, respectively) over a 30 arcsecond field of view. Six of the eight instruments planned will use this system or built-in AO systems to exploit the diffraction-limited capability. Figure 3 shows the layout
Figure 2. The TMT enclosure will be a structurally very efficient spherical ‘calotte’ design with an array of almost 100 vents that permit excellent ventilation of the enclosure to minimize temperature variations and turbulence that would distort the images.

Figure 3. Diagram showing the AO systems and instruments, located on the two large flanking Nasmyth structures, and how they will be addressed by the articulated tertiary mirror. The IR Multislit Spectrograph (IRMS) will be located on the side port of the Facility Adaptive Optics System (NFIRAOS) during the first years of operation. The Alignment and Phasing System (APS) will coordinate the 492 segments of the primary mirror and the optical system as a whole. HROS: High-Resolution Optical Spectrograph. WFOS: Wide-Field Multi-object Optical Spectrograph. IRMOS: NIR Multi-Object Spectrograph. IRIS: IR Imaging Spectrometer. NIRES: NIR Echelle Spectrograph. WIRC: Wide-field Infrared Imager. PFI: Planet Formation Imager. MIRES: Mid-IR Echelle Spectrograph. MIRAO: Mid-IR Adaptive Optics system.

of the AO system and instruments.

The instruments also exploit the entire operational wavelength range from 0.31 to 28 µm. They include a high-contrast imager optimized for detecting planets orbiting bright stars and instruments with a wide variety of field sizes, up to 20 arcminutes in diameter for studying large-scale structure in the universe. One of the first to return data will be the IR Imaging Spectrometer (IRIS), a near-IR (NIR) instrument consisting of a high-resolution imager and an integral-field spectrometer, which produces spectra for each spatial pixel of a 2D array. One way of illustrating the power of IRIS is to recall that the diffraction-limited spatial resolution of TMT will enable us to investigate structures with dimensions of only a few tens of kilometers at the distance of Jupiter. More details on all instruments are given by Crampton, Simard, and Silva.2

Various probes of dark energy will be employed, including precise measurements of the expansion history and baryonic power spectrum of the universe at low and high redshifts using supernovae, gamma-ray bursters (GRBs), and the intergalactic medium with the Wide-Field Multi-object Optical Spectrograph (WFOS), the High-Resolution Optical Spectrograph (HROS), and the NIR Echelle Spectrograph (NIRES). These instruments will also be used to investigate physics in the most extreme laboratories in the universe: GRBs, SNIIn-type supernovae, and flares from black holes in galactic nuclei. Problems such as determining whether there are variations in the fundamental physical constants require high spectral-resolution observations with signal-to-noise ratios that only an extremely large telescope can provide.

For studies of the sources of first light in the universe and cosmic reionization, TMT will offer strong synergy with JWST and future 21cm surveys using radio telescopes. Although it is anticipated that JWST will detect the brightest of such sources, TMT should go at least one magnitude fainter and perhaps much more, depending on their size. Some research projects will benefit not only from the huge sensitivity gain, but also because the overlap (chance superpositions) of stars will be reduced by the larger scale and smaller images of TMT. This will help alleviate the confusion that places a fundamental limit on the study of crowded fields, such as those in the center of the Milky Way and in nearby galaxies. Other projects will gain from the increased astrometric precision that will enable us to measure accurate positions of relatively nearby targets and track them over many years. Many more examples and details of programs enabled by TMT and its instruments are discussed in the detailed science case.3 A full description of the TMT observatory is given in a series of foundation documents.4

The project is currently in a very active preliminary design

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phase that will be complete in June 2009. We are also developing very detailed, reliable estimates for costs and schedules. Partial funding for the construction phase has already been announced and we look forward to achieving first light toward the end of the next decade.

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References