Large off-axis mirrors key to giant astronomical telescope

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Advances in laser metrology and computer-generated holograms allow optical scientists at the University of Arizona to polish the mirrors for the Giant Magellan Telescope.

The Giant Magellan Telescope (GMT), shown in Figure 1, is a next-generation telescope that will have unprecedented sensitivity and angular resolution, enabling studies of distant planets, galaxies, and black holes. The telescope’s primary mirror will consist of seven 8.4m segments, forming a single optical surface with a collecting area equivalent to a 22m telescope and the resolving power of a 24.5m aperture. Each segment is an 8.4m diameter borosilicate honeycomb sandwich mirror similar to the 6.5m and 8.4m mirrors in use at large telescopes in Arizona and Chile. They are the largest segments that can be made, guaranteeing a smooth wavefront over the 8.4m subapertures.

The GMT’s secondary mirror is segmented to match the primary, with seven 1.1m pieces. The small, agile secondary segments will perform the fine alignment for each 8.4m mirror. They will be deformable and enable adaptive optics, phasing, and the coherent combination of the seven subapertures.

GMT’s unique primary mirror segments are manufactured at the University of Arizona’s Mirror Laboratory. The strength of the GMT primary mirrors rests on mature technology for fabrication, support, and thermal control. One aspect of its production that presents a significant challenge is the measurement of the six identical off-axis segments, each of which has 14mm peak-to-valley departure from the best-fit sphere. We have developed a testing regimen that assures excellent performance on the telescope. It includes a full-aperture interferometric test with a unique nonaxisymmetric null corrector and an independent test of low-order aberrations that validates the accuracy of the null corrector.

GMT project staff chose to manufacture the first off-axis segment early to reduce cost and scheduling risks. The Mirror Laboratory cast the 8.4m blank in July 2005 (see Figure 2).1,2 The optical surface has been generated by diamond machining and is currently being lapped with loose abrasives (see Figure 3).

Grinding and polishing are carried out with a system designed for highly aspheric mirrors. A stressed lap bends actively to match the curvature variations across the mirror surface. The figure of the ground surface is measured with a laser-tracker system that determines the position of a retroreflector in three dimensions.3 The accuracy of this system has been improved by adding in situ angular calibration and stability references in the form of distance-measuring interferometers targeting fixed points on the mirror. These reduce the errors in the surface measurement to about 1µm rms, adequate to guide loose-abrasive grinding and provide a useful independent measurement of low-order aberrations.

The Mirror Laboratory installed a 28m optical testing tower to house the measurement systems for the GMT segments. The principal optical test of the off-axis segments uses a null corrector of unprecedented size to convert the beam from a spherical

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wavefront at the interferometer to the off-axis aspheric wavefront at the segment’s surface (see Figure 4). An oblique reflection off a 3.75m spherical mirror provides most of the compensation. Residual compensation comes from reflection off a 0.76m sphere and diffraction by a computer-generated hologram. Tight alignment tolerances are achieved through novel use of such holograms and laser trackers as alignment tools. The large fold sphere was also cast and figured at the Mirror Laboratory.

The corroborating optical test is a scanning-pentaprism system that measures slope errors on the optical surface by scanning it with a narrow collimated beam parallel to the parent optical axis and measuring the position of the focused spot in the parent focal plane. The system will measure the wavefront slope to about 1μrad rms, leading to an accuracy of 200nm rms at the surface in the eight low-order aberrations that are well sampled. This is similar to the low-order accuracy of the principal test and well within the range of correction for the segment’s active support system. Therefore, any figure errors due to the measurements can be corrected after the wavefront is measured with starlight at the telescope. The set of three tests for the GMT segments represents a significant up-front investment for the project. The payoff is a complete production system that will enable rapid manufacturing of all seven mirrors.

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Buddy Martin leads the development of fabrication and testing for large optics. He developed key technology used to make the 8.4m primary mirrors of the Large Binocular Telescope, the 8.4m segments of the GMT, and thin deformable secondary mirrors.

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References


