FIRST OF THE TWIN 10-METER KECK TELESCOPES STARTS DOING ASTRONOMY

Near the summit of Mauna Kea, a long-dormant volcano on the island of Hawaii, the first of the two Keck Telescopes has begun doing astronomy, and construction of its identical twin, a stone's throw to the north, is well under way. The individual Keck telescopes, with effective primary-mirror diameters of 10 meters, are by far the largest optical telescopes ever built. And together they will serve as an interferometer with a baseline of 95 meters.

Rising 4200 meters above the Pacific, Mauna Kea is the highest peak anywhere between California and New Guinea. Because its atmospheric conditions are just about the best in the world for optical and infrared astronomy, the mountain is already crowded with telescopes. But an improperly designed facility can degrade even the best "seeing" by allowing the buildup of thermal gradients that propel distorting air currents through the line of sight. Therefore the first pictures from the Near-Infrared Camera, the first of the telescope's scientific instruments to be commissioned, were awaited in March with some anticipation.

"Our biggest surprise was just how good the seeing really is," says Berkeley astronomer Jerry Nelson, principal designer of the telescope. "Astronomy is notorious for poor seeing at good sites. But our seeing turns out to be quite superb. Our median resolution is between 0.5 and 0.6 arcseconds, and on Mauna Kea's best days we sometimes get down to 0.25 arcseconds." Among the exacting precautions taken to get as close as possible to the "free air" seeing limit imposed by outdoor atmospheric conditions is the deployment of huge fans that replace all the air inside the dome every five minutes.

The W. M. Keck Observatory is a joint undertaking of the University of California and Caltech. The site was provided by the University of Hawaii, and the Keck Foundation, a private philanthropy, has given Caltech $145 million toward construction of the twin telescopes. The operation of the observatory is funded by the University of California.

Mosaic

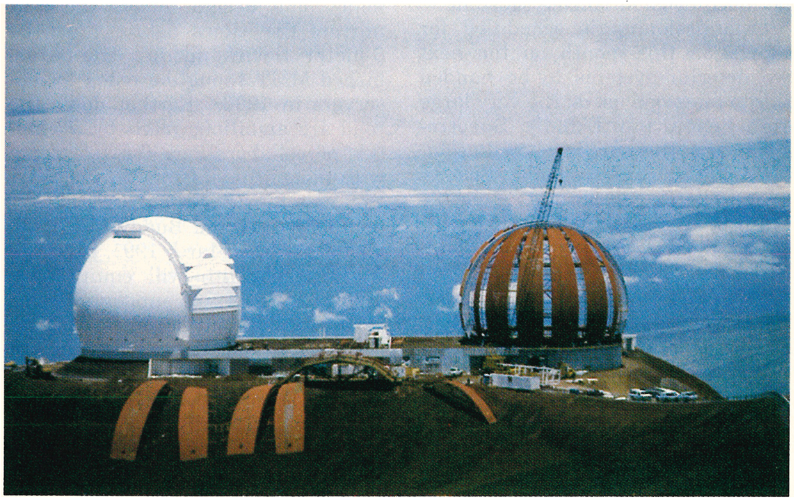
The primary mirror has a light-gathering area equivalent to that of a monolithic mirror 10 meters in diameter. But it is, in fact, a segmented mosaic of 36 hexagonal mirrors, each 1.8 meters across. Nelson and his Berkeley colleagues opted for the segmented design be inordinately thick to maintain its shape against gravitational stresses. That requirement, they concluded, would bring with it prohibitive problems of structural engineering, thermal inertia and cost.

The venerable 5-meter Hale Telescope on Mount Palomar and the 6-meter Soviet telescope in the Russian Caucasus, Keck's largest predecessors, both have monolithic primary mirrors. But the cost of such a conventional design grows as something like the 2.6th power of the mirror diameter. Furthermore, the thermal inertia of the massive 6-meter mirror appears to have contributed to the disappointing performance of the Soviet telescope.

As it tracks an object across the night sky, a large telescope mirror is subjected to constantly shifting gravitational stresses. To preserve the shape of the Keck telescope's primary mirror against such stresses, a complex system of sensors and actuators monitors and adjusts the relative positions and tilts of the 36 hexagonal segments twice every second. Such an active control system is indispensable, because no steel superstructure could, by itself, hold the mirror segments in place with the requisite 50-nanometer tolerances. (That's a tenth of an optical wavelength.)

The individual mirror segments are only 7.5 cm thick. Therefore they are quite light and somewhat flexible. But they are stiff enough to maintain their individual shapes against gravity with only a passive system of multiple supports. Furthermore the mirrors are ground from a special ceramic glass called Zerodur, manufactured by the Schott glassworks in Germany. Because Zerodur is two-thirds crystalline, its thermal expansion is negligible.

Unlike a monolithic mirror, the in-



Atop Hawaii's Mauna Kea, the first Keck Telescope (left) has begun doing astronomy, and its identical twin will be ready in 1995. Together, the two 10-meter telescopes will be an interferometer with a baseline of 95 meters.

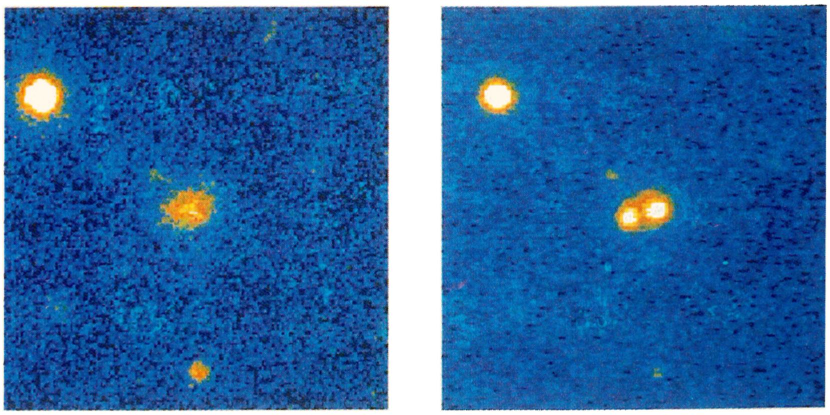
dividual segments of the Keck mosaic are, in general, not axially symmetric. How does one grind such asymmetric shapes? The clever trick devised by Nelson and his colleagues is called stressed-mirror polishing. Forces are applied to the circular perimeter of the mirror blank to temporarily distort it in a calculated way. Thus strained, the mirror segment is polished by conventional means into an axially symmetric shape. Then when the distorting constraint is released after polishing is completed, the mirror segment relaxes elastically into the desired asymmetric shape.

Unfortunately, the subsequent trimming of the polished mirror disk into its hexagonal form introduces small new strains. To remove these distortions the polished and trimmed mirror segments were shipped to Kodak to be finished by means of a sophisticated polishing system that employs a beam of argon ions. When each segment was then mounted into place on the telescope's superstructure, a final fine-tuning of its shape was accomplished with the aid of a "warping harness" that exerts a permanent distorting force on its now hexagonal periphery.

Seeing double

The Keck Telescope will cover more than just the visible spectrum. It will observe all the way from the atmospheric infrared wavelength cutoff at 30 microns to the ultraviolet cutoff at 3000 angstroms. The Near-Infrared Camera was mounted on the telescope in March and it has already begun producing interesting results: The two images on this page show the same patch of sky at two different infrared wavelengths. At 1.3 microns (left panel) the only object visible in the center of the field is the very distant galaxy MG1131+0456, with a redshift of something like 0.8. But at 2.2 microns (right), this "foreground" galaxy becomes largely transparent, revealing the *double* image of a still more distant quasar.

This is a particularly good example of gravitational lensing. The foreground galaxy serves as the lens that creates the double image of the background quasar. That double image had first been observed by radiotelescopes in the 1980s. More recently it was studied at 2 microns by the British 4-meter UKIRT infrared telescope on Mauna Kea. But there was a problem: UKIRT seemed to find a smaller angular separation between the two images than the radiotelescopes had. Such "chromatic aberration" would violate general relativity, which asserts that the bending of light by gravity cannot depend on wavelength.



Gravitational lensing of a background quasar by a foreground galaxy is seen in these exposures of the same patch of sky at two different infrared wavelengths, taken with the Keck Telescope's Near-Infrared Camera.[1] At 1.3 microns (left panel) only the galaxy is visible at the center. At 2.2 microns (right panel) the galaxy is transparent enough to show a double image of the quasar behind it.

The new Keck images at the two infrared wavelengths appear to have resolved the problem. The Near-Infrared Camera group, led by Keith Matthews and Tom Soifer of Caltech, corrected the double image of the quasar for distortions due to the faint remnant of the foreground-galaxy image persisting at 2.2 microns. For this purpose they availed themselves of the exceptionally clear galactic image they had captured at 1.3 microns. When subjected to that correction, the double quasar image gives an angular separation in good agreement with the radiotelescope data, and general relativity is saved.[1]

Quasars are generally variable on a scale of months. By monitoring the two quasar images, Soifer told us, the group hopes to determine the time difference between their optical paths. That would provide a measurement of the much debated Hubble constant.

Commissioning is scheduled for completion this month on the next two detector systems to be handed over to telescope users: the very large High-Resolution Echelle Spectrograph and the smaller Low-Resolution Imaging Spectrograph. Both of these systems will observe at visible and infrared wavelengths shorter than 1 micron. Instruments for infrared imaging and spectroscopy beyond 5 microns are scheduled for commissioning early next year. It is also at these longer wavelengths that the first attempts will be made to correct for atmospheric turbulence by adaptive optics techniques. (See PHYSICS TODAY, February 1992, page 17.)

Because the system of sensors and actuators that preserves the primary mirror's figure is much too slow to keep up with atmospheric distortion, even at long wavelengths where the task is easiest, any adaptive optics would have to be done with much smaller secondary or tertiary mirrors. The relatively simple first step, Nelson told us, will be to move the telescope's small secondary infrared mirror in response to atmosphere-induced image motion. That will be attempted in a year or two. Later, more sophisticated adaptive optics would involve the installation of a small flexible mirror.

Some telescope designers are still opting for large monolithic mirrors, though none as large as 10 meters. Roger Angel (University of Arizona) and collaborators are fabricating 6.5-meter Pyrex-like mirrors for the refurbished Multiple Mirror Telescope in Arizona and the Magellan Telescope in the Chilean Andes. Their honeycomb design makes the new mirrors five times lighter than the 6-meter Soviet mirror. The refurbished MMT should be ready for observers in 1996. Further down the road are ambitious plans by a number of collaborations for telescopes with monolithic mirrors on the order of 8 meters. (See the article by Angel, John Hill and Buddy Martin in PHYSICS TODAY, March 1991, page 22.) All these monoliths will require force-sensitive sensor and support systems to balance gravity. The sensors of the Keck mosaic, by contrast, do not have to monitor forces.

—BERTRAM SCHWARZSCHILD

Reference

1. J. Larkin *et al.*, Astrophys. J. Lett. (1993), in press. ■