# Dawn of a BIG Telescope

## *Astronomers await the debut of Keck's tiled mirror*

By RON COWEN

Fourteen thousand feet above sea level, the summit of Hawaii's Mauna Kea commands a panoramic view of ocean, sky and extinct volcanoes. High above treeline, where the air thins and even simple tasks can require special effort, the summit's barren, windswept landscape of brownish-red volcanic ash presents an otherworldly appearance. Astronomers liken the terrain to that depicted by Voyager images of Mars.

A fitting site, perhaps, for a new optical and infrared telescope — the world's largest — that bucks traditional designs in an attempt to probe distant stars and galaxies inexpensively but accurately, collecting more light than any of its predecessors. Like pieces of a highly polished jigsaw puzzle, 36 hexagonal mirror segments — each measuring 1.8 meters between opposing vertices and fitting into a particular section of a honeycomb-shaped steel frame — will form the 10-meter mirror of the W. M. Keck telescope, now under construction on Mauna Kea and scheduled to begin full operation late next year.

With the first nine of Keck's mirror segments assembled and moving as a single unit thanks to a complex array of computer-controlled pistons, springs and sensors, researchers expect to release next week the telescope's "first light" images — marking a milestone in the sometimes turbulent 13-year development of the instrument. Debate continues over the wisdom of using segmented mirrors as opposed to one of the new, relatively lightweight but still untested single-unit primary mirrors planned for six other large telescopes slated for completion later in the 1990s. Nonetheless, many astronomers agree that Keck will help to usher in a new age of big astronomy.

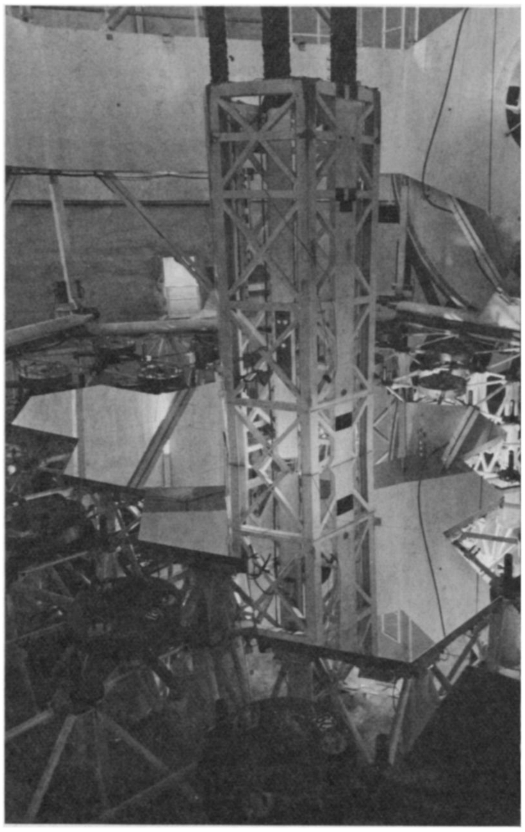
"I think [Keck] is going to drag astronomers kicking and screaming into the modern era of electronically controlled telescopes," says veteran astrophysicist John N. Bahcall of Princeton University. While not affiliated with the Keck project, Bahcall has a poster of the telescope on his office wall. "I'm waiting breathlessly for the first results," he adds.

Bahcall expects the Keck telescope to help solve a number of cosmological mysteries "that we couldn't address before because we didn't have a big enough telescope." He cites as one example Keck's expected ability to detect the absorption spectra of quasars — now too faint to be seen accurately by the limited light-gathering area of existing telescopes. These spectra provide fingerprints of the types of material through which quasar light passes on its way to Earth.

Bahcall says Keck's 10-meter primary mirror will also help to trace the evolution of galaxies over billions of years, from the time they formed after the Big Bang. Using Keck to detect the spectra from faint, ancient galaxies, and comparing these spectra with those of a set of brighter, newer galaxies closer to Earth, may help reveal how closely the chemical composition of older objects resembles more recently evolved galaxies. Analyzing spectra may also provide astronomers with the true "redshift" of a galaxy or quasar, a key tool not only for determining the distance to objects outside the Milky Way, but also for calculating the expansion rate of the universe.

Garth D. Illingworth, an astronomer at the University of California, Berkeley, and cochairman of the Keck Science Steering Committee, notes that the telescope's enhanced infrared resolution should provide new details about star formation, and may also discover planets orbiting

*With the first nine of its 36 hexagonal mirror segments in position, the Keck telescope already has a light-collecting area nearly equal to that of the 200-inch Hale telescope at Mount Palomar.*



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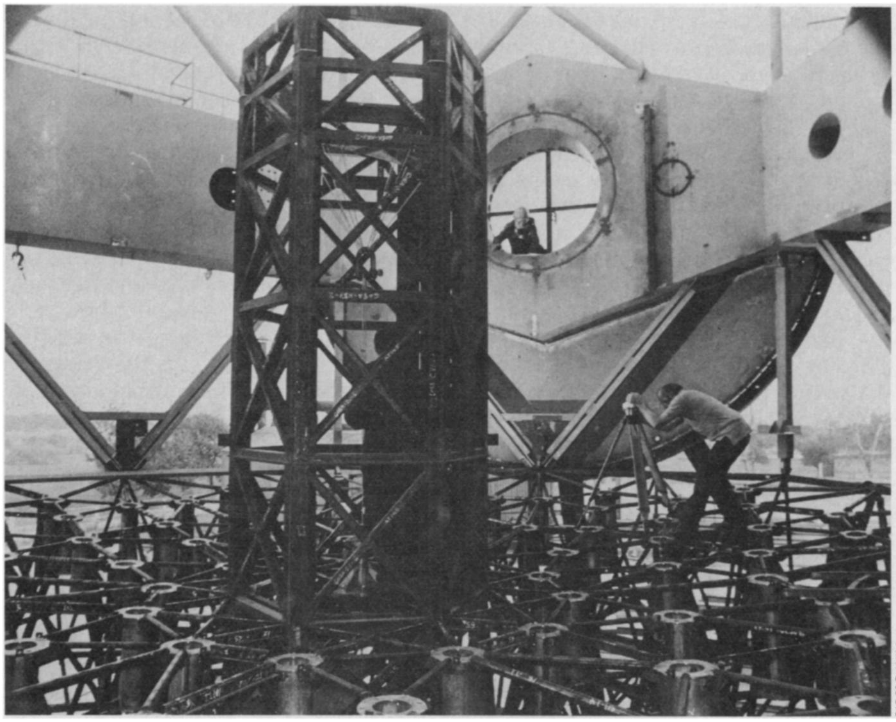
newborn stars — perhaps resembling a more youthful version of our own solar system.

When the Hubble Space Telescope receives its badly needed pair of corrective lenses, he adds, Hubble and Keck may serve as a team. While a corrected Hubble would provide extraordinarily high-resolution images undistorted by the Earth's atmosphere, the instrument's relatively small, 94.5-inch primary mirror has limited light-collecting ability and cannot obtain spectra of extremely faint objects without impractically long exposure times. In contrast, the Keck telescope, with a mirror more than 17 times as large in area, should easily record the spectra of distant objects discovered by Hubble.

Explains astronomer Sandra Faber of the University of California, Santa Cruz: "The space telescope's clear images of distant galaxies would be incomplete without knowledge of how far away — and therefore how old — each object is. The answer will come from the Keck telescope's spectroscopy, which can show us exactly how fast a galaxy is receding and hence its true distance and age." In addition, notes Illingworth, Keck's infrared "eyes" should complement exploration by Hubble, which images objects in visible and ultraviolet light.

Four optical instruments, which technicians should complete next year, promise to enhance Keck's view of the cosmos. They include a near-infrared camera for wavelengths ranging from 1 to 5 microns, a long-wavelength infrared camera sensitive to wavelengths between 8 and 20 microns, and low- and high-resolution spectrographs that use charge-coupled devices, which are highly sensitive to visible light.



Kim Steele

*Workers survey the steel framework of the Keck telescope. The bottom section will hold 36 mirror segments that together will form the 10-meter primary mirror. The telescope tube (center) will support a small mirror that redirects light captured by the primary mirror to the telescope's various detectors.*

While scientists have great expectations for the 10-meter instrument, controversy has dogged this maverick telescope from its inception. As Jerry Nelson, director of the $94 million Keck project, can attest, the journey to the mountaintop has been a rocky one at times.

For Nelson, also at Berkeley, the Keck odyssey began 13 years ago. In 1977, this physicist-turned-astronomer, who developed a bent for mechanical tinkering during years of work on particle accelerators, agreed to serve on a University of California panel considering plans for a new telescope that would exceed the observing capabilities of the university's Lick Observatory.

Almost immediately, Nelson envisioned a far larger telescope than researchers had ever built — one whose primary mirror would span 10 meters in diameter. Nearly twice the diameter of Mount Palomar's famed 200-inch telescope, this mirror would possess four times Palomar's light-gathering ability.

To achieve that goal, three of the five university panelists — Joseph Wampler, Harland W. Epps and David Rank — proposed using a one-piece, "monolithic" mirror — the standard primary mirror in smaller telescopes. But Nelson and panelist Jack Welch rejected that idea.

Aside from the difficulty of producing such single-piece behemoths, Nelson knew that a mirror's gravitational sag grows dramatically as its size increases. In fact, he notes, for every doubling of the mirror's diameter, the gravitational sag increases 16-fold. Mount Palomar's 5-meter-plus telescope "was hard to make," Nelson says. "And it was pushing a lot of technology to the limits to think of doing the 10-meter instrument [in the same way]."

"Why make the problem 16 times harder?" he remembers asking himself. "I thought that was dumb." Nelson instead suggested building the telescope mirror from a mosaic of thin glass tiles.

To resolve the panel's debate over the mirror's design, the university in 1979 put the choice of a monolithic or mosaic mirror to a special committee of older, established astronomers. Informally known as "the graybeards," this committee gave the nod to Nelson and Welch, and the Keck saga began in earnest.

Financing, however, remained uncertain until 1985, when the Keck Foundation donated $70 million to the California Institute of Technology, earmarking the money for building a large telescope. Rather than trying to go solo with its own instrument, Caltech decided to become an equal partner in what had been an exclusively University of California telescope project, and the 10-meter instrument got its name.

The University of California funds development of several of Keck's light-analyzing instruments, and will also assume the telescope's operating costs, estimated at $3.5 million annually. And in exchange for providing the Mauna Kea site, the University of Hawaii will receive some observing time.

The project also faced several hurdles of a more scientific nature. From the start, critics questioned whether optical experts could even produce the key high-resolution mirror segments necessary for Nelson's proposed design. Nelson and his co-workers, including Berkeley physicist Terry Mast, determined that each segment would have to take the shape of a section of a hyperboloid — a geometric figure difficult, if not impossible, to grind accurately. Subsequent analysis indicated that a technique known as stressed mirror polishing would solve the dilemma.

Using weights to carefully bend — or stress — the glass disks for each mirror segment, the manufacturer would polish the disks into perfect spherical mirrors, a far easier feat than constructing hyperboloid sections. When their fabricators later released the weights, the mirrors would presumably "pop" into the desired hyperboloid shape.

The procedure worked well with a small test mirror. However, when Itek

Optical Systems in Lexington, Mass., cut the six-sided mirror segments, another problem arose: warping. Computer-controlled touch-up grinding and polishing failed to fully correct the deformation. So by 1987 Nelson and his colleagues decided they'd correct the warping mechanically. Thirty stiff springs attached to the back of each mirror tile now force each segment into its desired shape.

Well, *almost* to its desired shape.

The spring system, known as a "warping harness," cannot fully correct the warping, Nelson has discovered. He estimates that the 10-meter mirror will ultimately resolve details just 0.25 arc-second across, fractionally better than the 0.3-arc-second resolution attained with the European Southern Observatory's far smaller 3.5-meter telescope in Chile. While Nelson had originally hoped that Keck's intrinsic resolution would reach nearly 0.1 arc-second, he notes that in practice atmospheric turbulence usually prevents any device from achieving such high resolution at optical wavelengths (SN: 11/24/90, p.315).

"On very clear nights, the image quality we will receive is just a little worse [than we would like]," Nelson concedes.

Co-panelist Epps, who has now spent years helping to design and oversee production of Keck's two secondary mirrors and several of its light-detecting instruments, says he believes the telescope won't resolve 0.25-arc-second details until researchers tinker extensively with the instrument's complex array of devices for keeping the mirror segments aligned and free of gravitational stress.

"This is untried technology and it remains to be seen how well it will work," Epps told SCIENCE NEWS. "The Keck telescope has became more and more of an R&D project."

Bahcall and others take another view. "There have been several 'show-stoppers' in this project along the way, but there are none now," says the Princeton astrophysicist. "The problems we've heard about before seem to have been all overcome."

Nelson says he remains confident that the three mirror-control systems he and his colleagues have developed and tested will prove highly accurate. Two "passive" systems minimize deformation within each thin, flexible mirror segment. A third, "active" system maintains the segments' overall alignment to ensure that the 36 tiles act together as one large piece of glass.

"In our case, we are using systems that are quite different from other telescopes," Nelson says. "Because we are unique, we really have to ask: Are we doing the right thing here? Can the mirror make good images? Have the segments been polished correctly? Do the active controls work properly?"

Despite these concerns, Nelson speaks enthusiastically about the telescope's potential to probe more deeply into the distant, early universe. Later, he speculates, Keck may break ground in the pioneering field of optical interferometry, an optical version of the standard radio-wave interference technique in which a computer combines signals detected by separate dish-shaped antennae — sometimes thousands of miles apart — to pinpoint the location of radio sources in the sky.

The current Keck construction site even provides the space for a second, look-alike telescope, complete with a special tunnel so that focused light beams from each twin could merge to produce enhanced images. Another opportunity for interferometry, Nelson notes, may come with construction of the proposed 7.5-meter Japanese National Large Telescope, now slated for a site just 100 yards from Keck.

Workers last summer completed the steel framework holding the Keck mirror segments, housed within a white dome that pokes its head above the volcanic cinders. Today, on a summit nearly half as high as Mount Everest, Nelson doesn't have to look far into the future for the fruits of a dream that has taken more than a decade to realize. □