The New Art of Telescope Making

For nearly 40 years, the Palomar telescope has defined the state of the art in telescope design; but now a wave of fresh technology is taking ground-based astronomy into a new age

WITH the recent announcement of two new telescopes using mirrors 8 meters in diameter, the astronomical community has given its vote of confidence to an innovative new technique for making very large mirrors at a relatively low cost. Not incidentally, the actions confirm that a renaissance in astronomical instrumentation is well under way—the age of the new technology telescopes.

The first announcement came in October of 1986, when the University of Arizona, Ohio State University, and the University of Chicago officially joined in a partnership to build a unique "binocular" telescope atop Arizona's Mount Graham by the early 1990's. The $60-million instrument will actually be two 8-meter telescopes acting in tandem. Individually, each telescope will be 60% larger than the venerable 5-meter instrument atop Palomar Mountain, and will have more than two and a half times the light-gathering power; together, they will have the resolution of a mirror some 20 meters in diameter.

The second announcement came shortly thereafter, when the Carnegie Institution of Washington, the Johns Hopkins University, and the University of Arizona agreed to collaborate on a new 8-meter telescope at Carnegie's Las Campanas observatory in Chile. This instrument will have only one mirror. But when completed in the 1990's it will be by far the largest telescope in the Southern Hemisphere, with a clear view of the Magellanic Clouds and the center of our own galaxy.

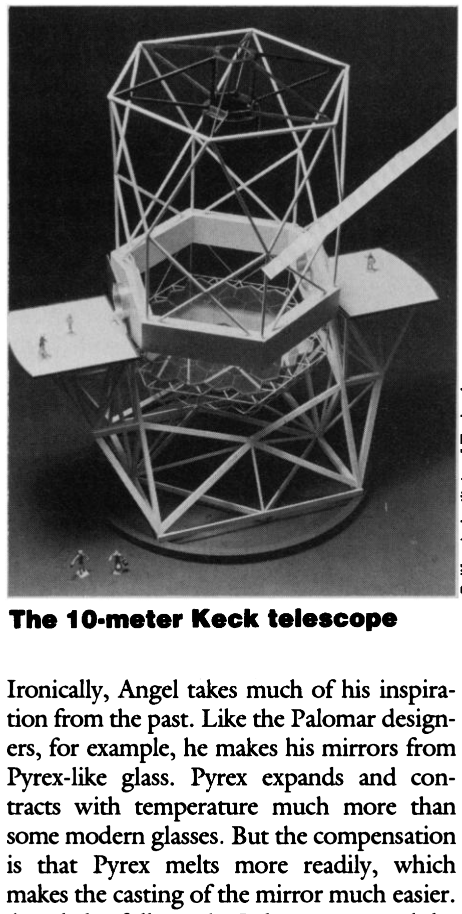
These two announcements are only the latest in what promises to be a long series. The University of California and the California Institute of Technology have already broken ground atop Hawaii's Mauna Kea for their 10-meter Keck telescope. The University of Texas and the Japanese government are both considering 8-meter telescopes. The European Southern Observatory proposes to build a cluster of four 8-meter telescopes at its La Silla site in Chile. And the National Science Foundation is funding development work on a National New Technology Telescope (NNTT), which will be located in this country and which will use four 8-meter mirrors in tandem to form one telescope.

"The time is ripe," says Arthur F. Davidson, head of the Center for Astrophysical Sciences at Johns Hopkins. "Historically, apertures have doubled every 40 or 50 years, which means that we're due for the next phase in the 1990's. And in fact, the technologies are falling into place." Add in the U.S. community's frustration over the slow pace of federal funding, he says—the NNTT is not exactly a top priority in the face of Gramm-Rudman-Hollings—"and people are jumping in to do it themselves."

The enthusiasm for these new behemoths is partly a matter of the astronomers' endless hunger for more photons: the bigger the mirrors, the more photons they can collect, and the easier it is to study faint objects such as distant galaxies. But the enthusiasm is also a testament to the increasing importance of infrared astronomy: 8-meter mirrors will yield high-resolution images at wavelengths of 10 micrometers or more, which are crucial for exploring the dust-shrouded regions of star formation in our own galaxy; in current-generation telescopes the infrared images are degraded by diffraction effects.

The challenge, however, is to devise a multi-ton optical surface that will maintain its precision to sub-micrometer accuracy, even while it tilts and moves to focus on different parts of the sky. In smaller telescopes one can simply depend on the rigidity of the mirror itself, an approach that reached its culmination in 1948 with the 5-meter Pyrex disk of the Palomar telescope. Unfortunately, a Palomar-style mirror scaled up to an 8-meter or 10-meter size would be extremely heavy, if it could be made at all, and would require a prohibitively large and expensive support structure. Worse, such a massive slab of glass would take far too long to come to thermal equilibrium with the cold night air; the heat convecting from its surface would then produce an unacceptable amount of optical distortion. Thus the search for fresh approaches.

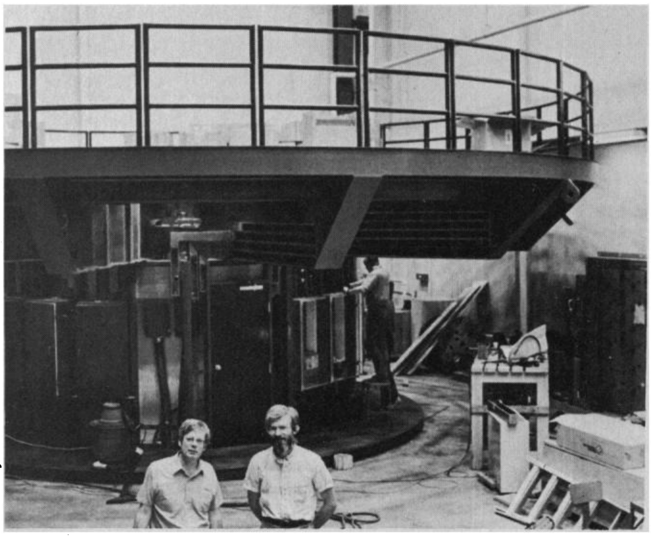
Perhaps the most innovative of the new telescope designers is Arizona's Roger Angel, who will build the 8-meter mirrors for both of the recently announced instruments.


California Institute of Technology

The 10-meter Keck telescope

Ironically, Angel takes much of his inspiration from the past. Like the Palomar designers, for example, he makes his mirrors from Pyrex-like glass. Pyrex expands and contracts with temperature much more than some modern glasses. But the compensation is that Pyrex melts more readily, which makes the casting of the mirror much easier. Angel also follows the Palomar approach by casting his mirrors so that the back is reinforced by a "honeycomb" of ribs, instead of being a solid slab of glass.

However, Angel's design differs in that the ribs are only about a centimeter thick, whereas a Palomar-style mirror scaled up to that size would have ribs about 15 centimeters thick. Thus, the mirror as a whole is proportionately much thinner and lighter. With proper ventilation, it is also much more responsive to changes in air temperature. In another innovation, Angel casts his mirrors in a mold that is rotating instead of stationary. The surface of the molten glass therefore assumes the shape of a paraboloid, which is exactly the curve that's needed for focusing light to a point. Angel does have to keep the mold turning at a precise rate for 24 hours, until the cast honeycomb is cool enough to hold its shape. But the payoff is



University of Arizona

The University of Arizona's 8-meter turntable. *The scale of the spin-casting facility is set by its developer, J. Roger Angel (left), and Larry W. Goble, chief engineer of the university's Steward Observatory.*

that once the mirror comes out of the mold—after additional weeks of very slow cooling to eliminate internal stresses—it is nearly ready for polishing. With a conventional mirror blank, one would first have to rough out the curve by grinding away large masses of glass from a flat surface.

At the polishing stage, however, Angel takes his most ambitious step. One feature shared by all the new technology telescopes, he says, is their trend to shorter and shorter focal lengths. Relative to conventional instruments, this translates into a much shorter telescope length overall, a lighter support structure, better pointing stability, a smaller containment building, a greater ease of handling, and—not least important—a comparatively low cost.

However, a short focal length also translates into a formidable challenge to polishing technology. On the one hand, conventional techniques tend to equalize the curvature from point to point, producing spherical surfaces instead of paraboloids. On the other hand, short-focus mirrors change curvature quite markedly from point to point. Indeed, conventional techniques give out when the focal length is about twice the diameter of the mirror itself—or, in photographer's parlance, when the mirror is *f*/2. Angel's goal is a focal length just equal to the mirror diameter: *f*/1.

"Grinding an *f*/1 paraboloid to within a few microns is relatively easy," he says. "It's getting those last few microns that's the trick." His answer is to develop a new polishing tool that operates under the control of a computer, adapting its own curvature to the required surface as it goes. It appears to work quite well.

In a sense, Angel's spin-casting technique is exactly the inverse of the other major innovation in large mirror construction: the segmented mirror approach being used for the 10-meter Keck telescope. As the name suggests, the main mirror in that instrument will actually be a mosaic of 36 smaller mirrors, with the relative position of each segment carefully controlled by computer to keep the overall surface optically perfect. This does mean that the manufacturing process is tricky, since each segment will lie on a different patch of the overall paraboloid and will thus have a slightly different curvature. In addition, the mirror can only maintain its shape through a complex system of computers, sensors, and mechanical actuators, all of which have to work perfectly if the telescope itself is to work. On the other hand, the individual segments can be relatively thin and light. Looking to the future, moreover, segmented mirrors can in principle be scaled up to much larger sizes than monolithic mirrors.

So in the end the choice comes down to engineering philosophy, says Peter Strittmatter, director of Arizona's Steward Observatory. "Our approach was to emphasize ease of operations and lowness of cost."

Angel's first demonstration of the spin-casting technique was a 1.8-meter *f*/1 mirror blank completed in March 1985. Last summer he and his team moved into the quarters that will house the 8-meter facility. (It is located under the stands of the university's football stadium, Manhattan-Project style.) Now in place is a steel turntable capable of supporting a 100-ton mold, and a 2-megawatt power supply. In January 1987, Angel plans to test-cast a 3.5-meter mirror; if successful, it will be used for the new Apache Point Observatory in New Mexico's Sacramento Mountains. (The observatory will be managed by a five-member consortium consisting of the University of Chicago, the University Washington, New Mexico State University, Princeton University, and Washington State University.) Next will come a 4-meter mirror for the National Optical Astronomy Observatories; a 6.5-meter mirror for the Multiple Mirror Telescope on Arizona's Mount Hopkins; and finally, perhaps in 1988, the first of the 8-meter mirrors. "Once we've convinced ourselves that we know what we're doing with 4 meters," says Angel, "6.5- and 8-meter mirrors are not such a big step."

While all of these new telescopes are obviously at the state of the art technically, they are curiously old-fashioned in another sense: in the tradition of George Ellery Hale and the great telescopes he brought forth in the early decades of this century, most of them will be funded by private donors without recourse to the federal government. (A major exception is the five-university consortium, which is being partially funded by the National Science Foundation.) This is a risky strategy for the universities involved, since not all the money is in hand yet. Nonetheless, the Keck Foundation's $70-million gift to the California project last year suggests that high-prestige science can still attract private money in serious amounts, particularly when scientists are willing to put the donor's name above the door.

Nonfederal sponsorship of an observatory also allows the participating universities to reserve the telescope for their own faculty members, without having to share it with the whole national community. This fits in nicely with certain institutional imperatives—not only for Carnegie, Caltech, and Arizona, which are already powerhouses in astronomy and want to stay that way, but for schools such as Ohio State and Johns Hopkins, which are looking to become powerhouses. Johns Hopkins, for example, is already host to the Space Telescope Science Institute, and hopes to build on that base to enhance its own program.

And finally, of course, a privately funded observatory does not have to risk its continued existence on an increasingly chaotic and uncertain federal budget process. Indeed, given the current budgetary climate, one can legitimately wonder if this flurry of privately funded telescopes might actually turn the tables, preempting the National New Technology Telescope and rendering it unnecessary before the National Science Foundation can find a way to fund it.

The astronomers themselves say they hope not. The planning for the national facility is well along. (It will use four 8-meter mirrors in tandem, much as the binocular telescope will use two; indeed, Angel developed his spin-casting process with financial support from the project.) More important, with a *national* telescope, the new technology would be available to the entire astronomical community, and not just a select few.

For the record, many astronomers are

optimistic. "I see this new wave of telescopes making the NNTT more probable," says Arizona's Strittmatter. "The Palomar 5-meter in 1948 and the Lick 3-meter in the 1950's in fact triggered the development of the National Observatories, and the creation of instruments in places such as Mauna Kea and Chile. So, in the same way, I think these new instruments will make it clear just how exciting the opportunities are. I expect to see a real flowering over the next decade." ■ M. MITCHELL WALDROP

Making Antibodies Work Like Enzymes

The production of antibodies that can catalyze chemical reactions opens the way to making "enzymes" with any desired specificity

ANTIBODY proteins and enzyme proteins share a major point of similarity. They both bind their target molecules with high specificity and affinity. Over the years this resemblance has caused biochemists to wonder whether antibodies might also have the potential to behave like enzymes and catalyze chemical reactions. The answer is now in—and it is yes.

In this issue of *Science*, two independent groups of researchers, one at Scripps Clinic and Research Foundation in La Jolla and the other at the University of California at Berkeley, describe how carefully selected antibodies can catalyze the hydrolysis of certain organic compounds (pages 1566 and 1570). "The work shows for the first time that you can rationally design catalytic antibodies," says Peter Schultz of the Berkeley group. It opens up the possibility that the essentially unlimited diversity of antibody molecules can be tapped to produce enzymes with whatever specificities an investigator wants.

Catalytic antibodies might be designed, for example, that can cut proteins at any desired amino acid sequence. Researchers would like to have a battery of such enzymes that could be used for selectively dissecting proteins, much as restriction enzymes are used for dissecting DNA. The specificities of protein-cleaving enzymes are now largely limited to those provided by nature, however. The equivalent of restriction enzymes for proteins would be valuable for studying the relation between protein structures and function.

Catalytic antibodies also have potential medical applications. Antibodies by themselves do not destroy the target antigens, but essentially serve as signals for triggering the destructive activities of other immune system proteins and cells. Antibodies that can not only bind to proteins, but also cut them, might be useful for such applications as dissolving blood clots or searching out and destroying tumor cells.

The Scripps and the Berkeley groups approached the work with catalytic antibodies from different directions, but both depended on the same operating principle. Enzymes are generally thought to speed up chemical reactions by stabilizing the transition state, the most unstable and therefore the highest energy intermediate formed by the reactants during the conversion to products. Enzymes, by stabilizing the transition state, lower the energy needed for the conversion and consequently increase the rate of the reaction. The trick in producing catalytic antibodies lies in obtaining antibody molecules that will stabilize the transition states of the selected chemical reactions.

"We're excited about the work because this is a way of tapping into the vast repertoire of binding pockets [on antibodies] to do chemical work."

The Scripps workers, Alfonso Tramontano, Kim Janda, and Richard Lerner, began with a compound with a structure resembling the transition state of the reaction that they wanted to catalyze, which is an ester hydrolysis. They then used the compound as an antigen for generating monoclonal antibodies. The idea was that the antigen-binding sites of the antibodies produced would fit the transition state structure of the hydrolysis reaction. When such an antibody bound an appropriate chemical reactant, it would effectively stabilize that chemical in the transition state, thereby catalyzing the hydrolysis.

That is what happened. The Scripps group identified monoclonal antibodies that could speed up ester hydrolysis, although in the early work the catalytic antibodies did not behave exactly like true enzymes. One of the products of the reaction remained attached to the antibody molecule. A true enzyme releases the reaction products so that it can catalyze the reaction over and over again. In their more recent work, the Scripps group used different substrates for the catalytic antibodies, which they call "abzymes," and found that the products were released in the appropriate fashion.

The catalytic antibodies display a number of other characteristic enzyme features, in addition to speeding up the ester hydrolysis. For example, they show substrate specificity, hydrolyzing some esters but not others. The catalytic antibodies can be inhibited, as enzymes are, and the activity of the antibodies has at least a modest dependence on the *p*H of the reaction mixture. "We're excited about the work," Lerner says, "because this is a way of tapping into the vast repertoire of binding pockets [on antibodies] to do chemical work."

Schultz, with his Berkeley colleagues Scott Pollack and Jeffrey Jacobs, started their work with a preexisting antibody that binds the chemical nitrophenyl phosphorylcholine, which they realized is a transition state analog for the hydrolysis of structurally related carbonate compounds. The Berkeley workers found that this antibody catalyzes the hydrolysis of an appropriate carbonate in typical enzymelike fashion. They have since gone on to show that they can generate monoclonal antibodies that can also catalyze carbonate hydrolysis by immunizing with a transition state analog for the reaction.

The original antibody studied by Schultz, Pollack, and Jacobs belongs to a structurally well-characterized class of antibodies. The structural information available suggests, Schultz says, that the transition state in carbonate hydrolysis is stabilized by appropriately situated amino acid residues in the antigen-combining site of the antibody, just as predicted.

The catalytic antibodies identified by the Lerner group speed up the ester hydrolysis by a factor of about 1,000 and those under study at Berkeley accelerate the carbonate hydrolysis by a factor of perhaps 15,000. Nevertheless, as Lerner points out, the accel-