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Optical Astronomy's Two New 150-Inch Telescopes

The National Science Foundation and Ford Foundation are funding large telescopes for basic research.

D. L. Crawford

Construction is starting this year on two large telescopes—one in Arizona and one in north-central Chile. When finished, in 5 or 6 years, these telescopes will have doubled the large-telescope observing time available to U.S. astronomers. One of these 150-inch (4.0-meter) telescopes will be located at the Kitt Peak National Observatory, whose headquarters are in Tucson, Arizona, and whose telescopes are on the summit of Kitt Peak, a mountain 2100 meters high, 90 kilometers southwest of Tucson. The second, nearly identical, telescope will be at the Cerro Tololo Inter-American Observatory. Cerro Tololo is a mountain 2200 meters high in north-central Chile, about halfway between the Pacific shore and the crest of the Andes, and about 500 kilometers north of Santiago. Figure 1 shows an overall view of the observatory site. The observatory headquarters are in La Serena, on the coast at Coquimbo Bay.

Construction of the Kitt Peak telescope is being funded entirely by the National Science Foundation, while construction of the telescope at Cerro Tololo was made possible when the Ford Foundation offered $5 million, to be matched by the NSF, so that the two telescopes might be built almost simultaneously.

N. U. Mayall, director of the Kitt Peak National Observatory, is responsible, scientifically and administratively, for the operation of both observatories; V. M. Blanco is the director of the Cerro Tololo Inter-American Observatory.

The Observatories

Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory are two of the four National Research Centers for which the National Science Foundation supplies the funds for capital construction and operating expenses. The other two are the National Radio Astronomy Observatory at Green Bank, West Virginia, and the National Center for Atmospheric Research at Boulder, Colorado. These centers were established by the Foundation in an effort to help the United States gain and maintain leadership in astronomy and atmospheric research and to provide U.S. scientists with facilities in research fields where most individual universities are unable to build and support the large and expensive capital equipment required.

Ground-based optical astronomy is certainly such a field. The 1964 National Academy of Sciences report concerning the needs of ground-based astronomy for the next 10 years (commonly called the Whitford Report) discusses the situation in detail (*1*), but mention of a few of its conclusions here may be helpful. In 1964 there were, in this country, an estimated 620 practicing astronomers with Ph.D.'s. While a few universities are capable, because of the size of the staff and the number of students in their graduate departments of astronomy, of supporting major observing stations in areas where the climate assures good observing conditions, most observational astronomers do not have modern, first-rate telescopes (especially telescopes of large aperture or located in favorable observing sites) available to them for their own research or for that of their students. Naturally, many research problems have been, and many still are, inhibited by lack of adequate facilities. The observatories on Kitt Peak and Cerro Tololo were established in an effort to alleviate this situation.

In 1955 the University of Michigan was given a federal grant to undertake a site survey for a national optical astronomy observatory. Of the many criteria used to evaluate potential sites, three were of major importance: the number of totally clear nighttime hours expected; the quality of "seeing" (basically the smallness of the stellar image as observed in a large telescope; a diameter smaller than 1 second of arc is considered excellent); and the expectation of uncontaminated skies for the lifetime of the observatory (50 years or more). In 1958, Kitt Peak was chosen as the best available site in the United States.

Late in 1957, well before the site was chosen, a nonprofit corporation was formed to operate the observatory—the Association of Universities for Research in Astronomy, Inc. (AURA). The seven charter members were among the universities with well-established gradu-

The author is an astronomer and project manager for telescope projects at Kitt Peak, Arizona, and Cerro Tololo, Chile, with headquarters at the Kitt Peak National Observatory, Tucson, Arizona.

ate departments of astronomy: the University of California, the University of Chicago, Harvard, Indiana University, the University of Michigan, Ohio State University, and the University of Wisconsin. Subsequently, Princeton and Yale joined the group, and the University of Texas became a joint member with Chicago. In addition, to provide representation from smaller organizations, several directors-at-large are appointed, to broaden the scope of the Board. Each of the member universities supplies two Board members, one a scientist (so far, an astronomer in every case) and one an administrator. At present Rupert Wildt of Yale is the Board president. Member universities have no special rights with respect to use of the Kitt Peak or Cerro Tololo facilities. According to current Board policy, 60 percent of the observing time of all the telescopes is allotted to visiting astronomers and graduate students; the remaining 40 percent is used by the resident staff for their research and for development and testing of equipment. The visiting astronomers are allotted time primarily on the basis of the scientific merit of their research programs. In most cases the observatory's scientific staff reviews requests for observing time and makes recommendations to the director regarding assignments; occasionally the advice of outside referees is sought. Visiting astronomers are expected to do their own observing. Graduate students doing research for their theses may apply for observing time as well. When funds are available, Kitt Peak pays the travel and subsistence expenses for these students. It is expected that the observatories will constitute an effective extension of academic research, especially for institutions without adequate facilities of their own.

A 16-inch and a 36-inch telescope (telescopes are "labeled" according to the approximate diameter of the primary mirror) have been in operation on Kitt Peak since 1960; a second 16-inch instrument became operational in November 1963; an 84-inch reflecting telescope went into full-time operation in September 1964; and a second 36-inch telescope began operation early in 1967. The four smaller telescopes are used primarily for photoelectric photometry—for measuring stellar brightness, stellar colors, and spectral features by means of filters and photomultiplier cells. The 84-inch telescope is used for spectrographic work, direct photography, and photoelectric photometry. In addition to these stellar telescopes, the observatory operates the world's largest solar telescope, primarily for solar research but also for observation of the moon, the planets, and some of the brighter stars. The observatory also has a space astronomy program involving Aerobee rocket flights, airglow studies, and theoretical work on planetary atmospheres.

Because of activities in all these fields, the observatory is organized into three research divisions: stellar, solar, and space. There is also an administrative division, which includes accounting, business, operations, engineering, and maintenance shop departments. The observatory has approximately 300 employees, about 35 of whom are based on Kitt Peak.

The Cerro Tololo Inter-American Observatory was founded in November 1962 and is operated by AURA. The goals are the same as those for Kitt Peak National Observatory. Two 16-inch telescopes have been in operation at Tololo for several years, and a 24-inch Schmidt telescope and a 36-inch

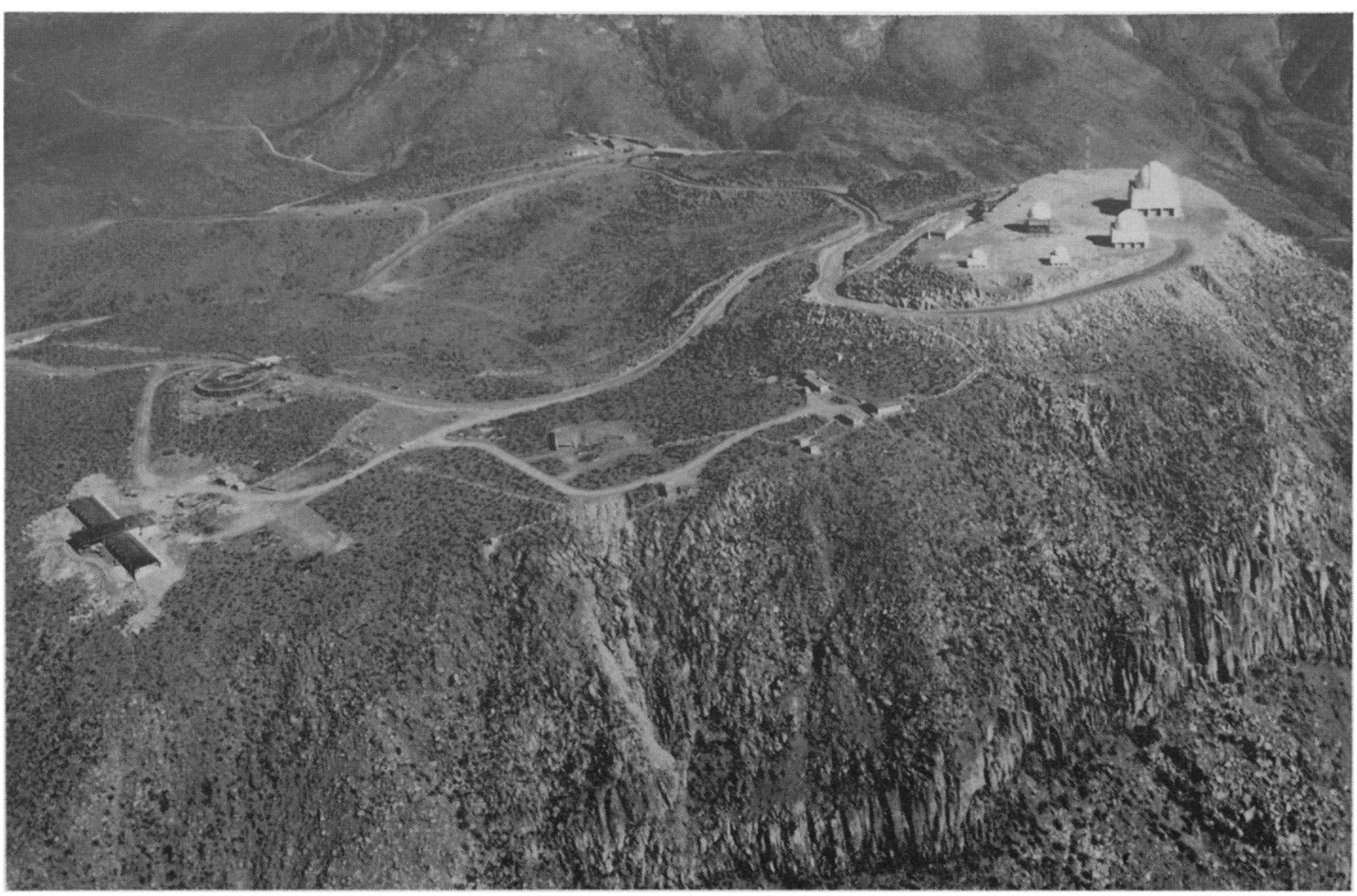

Fig. 1. Overall view of the observing site at Cerro Tololo, Chile. The building and dome for the 150-inch telescope will be erected near the weather mast seen in the background at upper right.

reflecting telescope became operational in April 1967. A 60-inch telescope is scheduled to be in use by the end of this year. With the Tololo telescopes scientists will be able to observe objects in that part of the sky (approximately one-third) that cannot be seen from the Northern Hemisphere.

Currently, Kitt Peak seems to be living up to most of the earlier expectations. Weather conditions, "seeing," and other features are essentially as predicted in the site surveys. For example, the 36-inch telescope was used primarily for photometry (feasible only when the nighttime sky is free of clouds and haze) for 1677, 1775, 1918, 1654, 1707, and 1727 hours, respectively, during the years 1961 to 1966. (At Kitt Peak there are 3465 nighttime hours in a year.) The 84-inch telescope was used for 2208 and 2529 hours, respectively, in 1965 and 1966. Some types of spectroscopic work are possible through light clouds and haze.

The highest temperature recorded so far has been 90°F (as compared to Tucson's 115° during the same period!), and the lowest, 6°F. The wind velocity is below 20 miles (32 kilometers) per hour 82 percent of the time. The "seeing disk" averages less than 2 seconds of arc, and visitors have been able to obtain observations, with the 36-inch telescope, during 61 percent of the hours that had been assigned them. At Kitt Peak the best months for observing are May, June, and October and the worst are July and August, when desert-type thunderstorms are prevalent and the area receives the greater part of its annual rainfall (which averages 30 centimeters). It is during summer months that the West Coast observatories, with their large telescopes, have their best observing weather. Thus Kitt Peak is "out of phase" with them: it has some of its best weather in January and February, when the nights are long and the West Coast has its worst weather.

Visiting astronomers and graduate students are making much use of the facilities, and many proposed programs must be refused. Requests for time on the 84-inch telescope are exceeding the available time by a factor of more than 3, and more requests for time on the smaller telescopes are received than can be accommodated. Since 1960, visitors from 55 different institutions in the United States and from 11 foreign countries have used the Kitt Peak stellar telescopes (*2*). Limited use of the telescopes by observers from outside the United States is permitted in special cases. During 1966, 66 visitors used the telescopes; 18 of these were from "large" institutions or organizations: AURA, the California Institute of Technology, the Smithsonian Astrophysical Observatory, and the Royal Greenwich Observatory. Of the 32 departments of astronomy (those that grant a Ph.D. degree) listed in the Whitford Report, visitors from 28 have observed at Kitt Peak so far; two of the remaining four departments are essentially concerned only with radio astronomy.

With regard to research publications in astronomical journals, by the end of 1966, 220 published papers had been reprinted in the Kitt Peak National Observatory Contributions series.

One additional observatory program deserves mention. Each summer a number of advanced undergraduate and beginning graduate students are employed at Kitt Peak to work with the resident staff in order to gain practical experience at a research center for astronomy. From 1961, when the summer-assistant program was initiated, through 1967, 75 students had been given this opportunity, which, because of limited funds and space, could be offered to fewer than one-fourth of the qualified applicants.

Need for Large Telescopes

In a recent article in *Science* (*3*), H. W. Babcock, director of Mount Wilson and Palomar Observatories, discussed the need for large telescopes for American observational astronomers. During the first half of this century the United States held a dominant position in observational astronomy, because of the large telescopes available in this country. Astronomers were able to collect data on problems at the frontier of astronomical research, and exceptional graduate students were eager to enter these fields of research.

Many of the frontier problems can be tackled only with the largest reflectors, such as the 200-inch Hale telescope at Palomar mountain and the 120-inch telescope at the Lick Observatory near San Jose, California. However, only a very limited number of research problems can be investigated with a single telescope. Astronomical objects that can be observed only with the large reflectors are so faint that the astronomer must continue his observations for many nights in order to collect enough data to attack problems at the frontiers of research. Certainly more large telescopes are urgently needed, to allow current and future observational astronomers to work on problems of this kind. The Whitford Report recommended that three large reflectors in the 120- to 200-inch aperture range be constructed as soon as was financially feasible, and that one of these be the 150-inch telescope already proposed at that time for Kitt Peak. Certainly a National Center, with its fine observing conditions, its battery of smaller telescopes, and its policy of "open competition" for the available time, is an obvious place for such a telescope.

Other large telescope-building projects, in the United States and elsewhere, are under way or are being planned. A number of European countries have joined together to build a major observatory in the Southern Hemisphere. The site will be in Chile, 100 kilometers north of Tololo, and the largest telescope will be a 3.5-meter reflector. A French 5-year national plan includes plans for a 3.5-meter telescope, and the Germans and Italians are actively planning construction of national telescopes of about the same size. The Australians, jointly with the English, are beginning design work on a 150-inch telescope to be erected in Australia. The Russians have recently finished building a 2.5-meter reflector in the Crimea and are reported to be building three more of the same size. They have also begun construction on a 6-meter reflector, which will be the world's largest telescope when finished. The Canadians are planning the Queen Elizabeth II Observatory, which will be located on Mount Kobau in British Columbia. It will have a 150-inch reflector. In the United States there is talk of other large reflectors besides those in the AURA program. The one for which plans are farthest advanced is the 200-inch telescope for the Carnegie Southern Observatory, the proposed "southern branch" of the Mount Wilson and Palomar Observatories, described by Babcock (*3*). It should also be noted that, with varying contributions from NSF and NASA, three new U.S. telescopes in the medium-large (80- to 120-inch) range are approaching completion: a 90-inch instrument (also on Kitt Peak) at the University of Arizona; a 90-inch instrument (on Mauna Kea) at the University of Hawaii; and a 108-inch instrument at the University of Texas (McDonald Observatory).

Certainly there is no lack of exciting research problems for all these proposed telescopes; some were discussed at length by Babcock (3). One example, of current extreme interest in astronomy and physics, is the problem of quasars. These are the faint, stellar-like objects that are interpreted as being extremely distant objects radiating energy at an enormous rate, 10 to 100 times the rate at which energy is radiated from entire normal galaxies. Much theoretical work in physics and astronomy is being done in an effort to explain these objects, but there is no doubt that many more observational data from large optical and radio telescopes are necessary. The time available with present telescopes is just not adequate. Investigators of even the normal and seminormal galaxies, such as those with turbulent or possibly exploding centers, are in urgent need of more data. Quasars and other galaxies at cosmic distances may hold the secrets of the structure and evolution of the universe. With more large telescopes, researchers may find observational clues for unraveling these mysteries. As techniques and facilities for observing improve, imaginative astronomers are better able to study the dynamics and rotations of individual galaxies (to determine their masses); polarization phenomena; and spectral energy distributions, used for identifying the sources of radiation—stars, interstellar gas, energetic particles.

Intensive study of individual faint stars, both in other galaxies and in distant regions of our own galaxy, is seriously needed; insufficient effort is now going into these exciting areas of investigation because the largest telescopes are needed for their effective study. Such research activity is fundamental to an understanding of galactic structure and of such basic questions as the evolution of stars.

Another area of crucial current interest is that of planetary astronomy. Ground-based planetary research is essential as a supplement to in-space techniques, especially for following up findings from space flights. The spectrographs attached to the large reflectors are ideal for attacking problems concerning planetary atmospheres and the interplanetary medium. The equipment used on the telescope can be changed or adapted as experience is gained in working with it; with space techniques, versatility is difficult to obtain. Furthermore, deep space probes are very expensive and provide little observing time. Certainly there is no valid reason for doing any job in space that can be done adequately on the ground.

History of the 150-Inch Telescope Projects

The Kitt Peak large-telescope project had its formal beginning at the March 1961 meeting of the AURA Board, when the decision was made to ask the observatory staff to begin a program of design and location studies for the telescope. The program was to include a study of the physics of "seeing," in an effort to understand quantitatively the physical causes of poor stellar images, which are due both to atmospheric factors and to adverse effects of local conditions on the dome and immediate surroundings of the telescope. The decision to set the size at approximately 150 inches was based on several criteria: the telescope should be large enough for attacking problems at the frontiers of research; it should be large enough for operation of a manned prime focus cage; it should be intermediate in size between the 120- and 200-inch telescopes already in use, so as not to involve a great deal of experimental engineering; and its cost must be consistent with funds likely to be available from the National Science Foundation.

In June 1961, N. U. Mayall, the observatory director, appointed an advisory committee (4) to consult with the staff on large-telescope problems. In September the committee and the staff agreed on general specifications for the telescope.

1) A "large" field of view at the prime focus was deemed essential (Fig. 2 shows schematically the various foci of a large telescope). In large telescopes built in the past, the usable field for direct photography was limited to about 15 minutes of arc; however, present techniques of optical design give a field of about 1 degree. Thus, programs that required many photographic exposures in the past will, with future large telescopes, require only one exposure. The lenses will have to be of glass which transmits ultraviolet radiation (wavelengths down to 3000 angstroms), so that there need be no restriction on the types of problems for which the telescope can be used.

2) The focal ratio at the prime focus should be about $f/2.8$, so that direct photographs of faint objects can be obtained in reasonable exposure times. These large telescopes work like simple cameras a great deal of the time.

3) The Cassegrain focal ratio should be about $f/9$, a ratio which may become optimum for photographic work at the very limit of brightness of faint stellar objects. For slower focal ratios the exposure times are too long, and for faster ratios the sky background comes up too fast relative to the stellar images. This focal ratio also is especially suitable for faint-star spectrographic work and photoelectric photometry.

4) A coudé focus should be included, so that the telescope can be used effectively on bright moonlit nights. It is at the coudé focus that the large, high-dispersion spectrographs can be located.

5) It was decided (at a later meeting) that the primary mirror should be made of fused quartz, so as to minimize any adverse thermal effects on the optics.

6) Last, but by no means least, it was agreed that the telescope should be as versatile as possible without compromising efficiency. Because of the scarcity of large reflectors and the great number of visitors concerned with a wide diversity of problems, it is mandatory to design for the optimum number of hours the telescope can be used on research.

The 150-inch telescope project for Cerro Tololo came into being late in

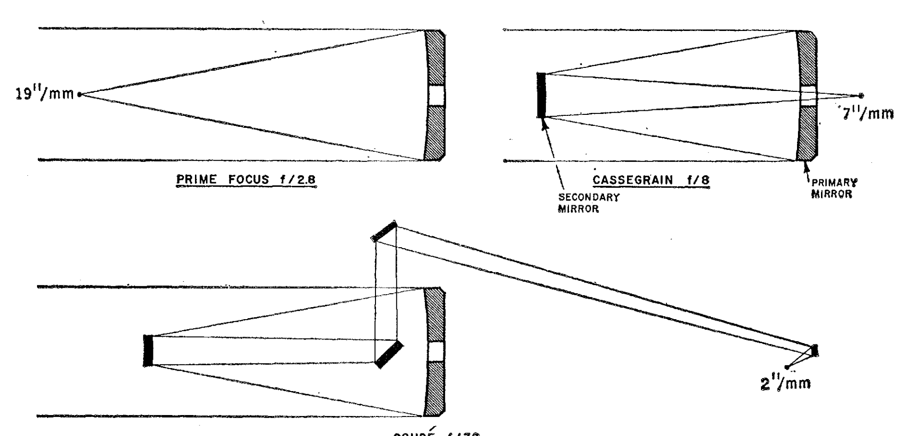

Fig. 2. Schematic diagram of the optical arrangements of the 150-inch telescope. At each focus the plate scale is indicated, in seconds of arc per millimeter; the scales range from 19 seconds at the prime focus to 2 at the coudé focus.

1966, when the Ford Foundation offered to supply $5 million of the approximately $10-million cost of the large telescope; the National Science Foundation was to supply the remainder. The actual grant was made in April 1967, and work on the project began immediately. The formal announcement of the program was made on 13 April at Punta del Este, Uruguay, jointly by President Johnson and President Frei of Chile.

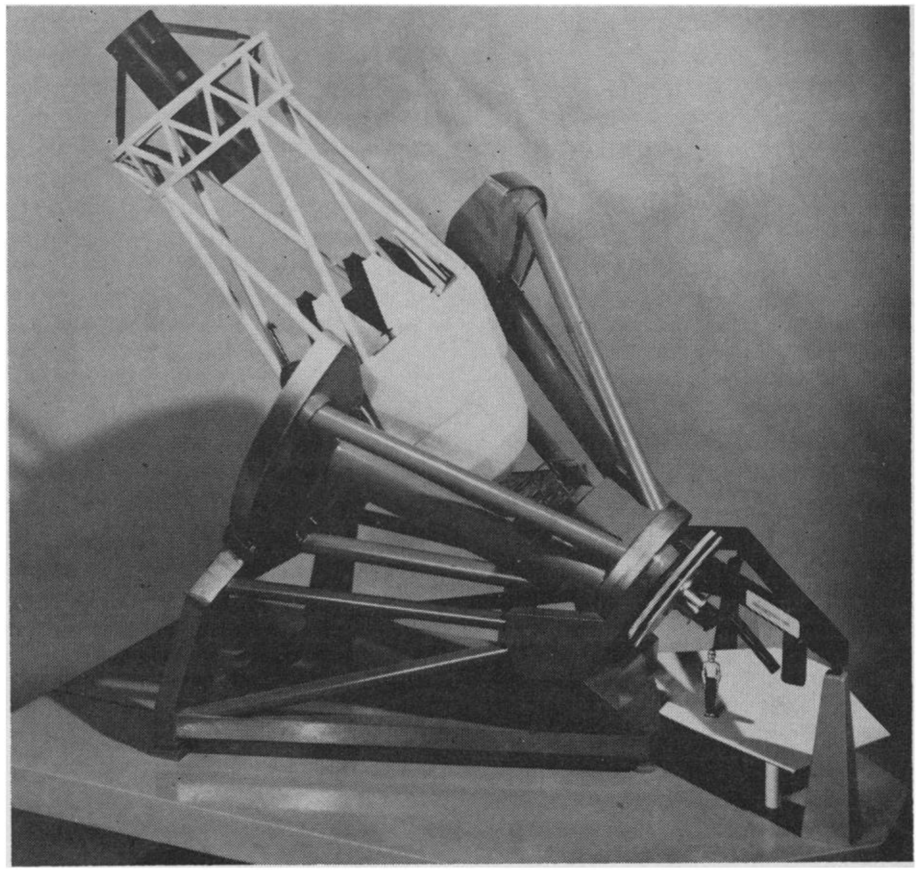

Fig. 3. Model of the 150-inch-telescope mounting, as generally conceived by W. W. Baustian.

The Telescope Design

The general specifications for the two 150-inch telescopes are mentioned above. Certainly no extensive experimental engineering was planned, or has been done. This does not mean that a great deal of engineering work did not have to be done, for a project costing $20 million involves a tremendous number of details, all of which need to be looked into in depth.

The current project has benefited from the experience gained in designing and operating the 200- and 120-inch telescopes, and the smaller telescopes, at Kitt Peak. The Kitt Peak engineering staff includes the two chief engineers who worked on the 120-inch telescope, and many staff members from other observatories have been very generous with their time and knowledge (*5*).

Naturally, in several areas things will be done in new ways, both because of the experience gained with other telescopes and because of advances in the state of the art in areas outside the mainstream of astronomy, such as electronic controls and optical design. Many of these new developments in design were discussed at a formal meeting, held in 1965 in Tucson and Pasadena—the 27th symposium of the International Astronomical Union, on the construction of large telescopes, which was attended by about 80 astronomers and engineers involved in the various large-telescope projects (*6*). Astronomy is fortunate in being a discipline where there is open and frank exchange of information by workers from many countries on problems of common interest. Unfortunately, the Russian astronomers were unable to attend this particular meeting.

The intense interest in large-telescope construction has stimulated many diverse developments in related fields of technology. One such recent advance has been the development of new materials from which large telescope mirror blanks can be made: fused silica (or fused quartz) or Cer-Vit. These materials are much less sensitive to thermal effects than the existing mirrors of pyrex. The physical properties of fused quartz are such that a mirror made from it should be about one-tenth as sensitive to adverse thermal effects as a mirror of pyrex is, and a mirror made of Cer-Vit should be essentially free of such effects. The final optical surface of the glass, which holds the very thin film layer of aluminum that actually reflects the light, must be ground and polished to an accuracy of about a tenth the wavelength of light (that is, an accuracy of 0.05 micron, or about two-millionths of an inch) and then must be supported in the telescope to this accuracy under varying attitudes of the telescope with respect to gravity, as the telescope is pointed to different areas of the sky. Likewise, the surface must not deform more than this amount when subjected to differing temperatures, for the dome and telescope cannot be heated (that is, temperature-controlled). When the temperature of the ambient air changes, an adverse temperature gradient is set up in the mirror and it deforms. The use of quartz or Cer-Vit as a mirror blank will greatly ease this problem.

There are at present two suppliers of large quartz blanks: Corning Glass Works and the General Electric Company. The Canadian and the European large-telescope projects in the Southern Hemisphere are obtaining their mirror blanks from Corning, and Kitt Peak is acquiring its blank from General Electric, whose quartz plant is in Cleveland, Ohio (*7*). Delivery of the mirror blank to Tucson was made in November 1967. The Tololo mirror blank will be supplied by Owens-Illinois, Inc., of Toledo, Ohio, the fabricator of Cer-Vit. The Anglo-Australian and French telescope projects have also ordered their blanks from Owens-Illinois, who were the low bidders on these three blanks.

Optical grinding and polishing of the $1-million General Electric blank, 4 meters in diameter and 60 centimeters thick, will be done in the Kitt Peak optical shop, under the overall direction of A. Keith Pierce of the Kitt Peak staff. An expansion of the shop was necessary for this project, and is now completed. The large grinding machine was installed in August 1967. The first optical-shop work being done on the new machine is work on a 100-inch spherical mirror, made of aluminum, which will be used for testing the convex secondary

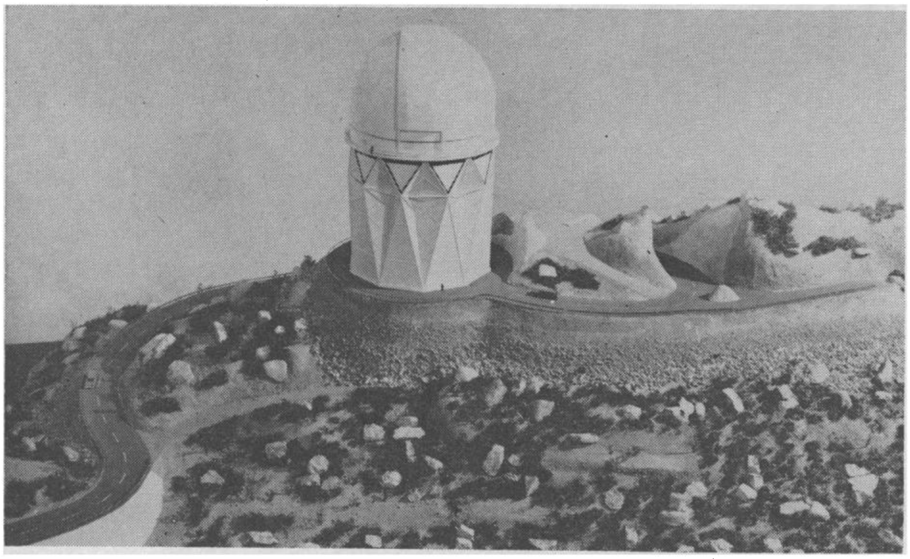

Fig. 4. Model of the Kitt Peak dome and building, as designed by Skidmore, Owings and Merrill of Chicago, architects and engineers.

mirrors of the telescope. After the Kitt Peak mirror is finished, in 2 to 3 years, work on the Cerro Tololo blank will begin.

Design of the support system for the primary mirror is of critical importance, for the final accuracy of the mirror surface will depend vitally on the way in which the mirror is supported in the telescope as it is moved about in pointing to different regions of the sky. Another international meeting of astronomers and engineers was held in Tucson in December 1966 to discuss this limited topic. There were about 80 participants. Design of the support systems is certainly one of the most crucial (but least clear-cut!) of any of the problems of large-telescope design. Types currently in use include lever systems, air bags, and mercury-filled tubes.

The telescope mounting design for the Kitt Peak telescope is shown in Fig. 3. The general concept was developed by W. W. Baustian, chief engineer at Kitt Peak. The design is a modification of a type developed originally for the 200-inch telescope at Palomar Observatory. It is rather like the mounting of that telescope, but in the Kitt Peak design the telescope tube, holding the optical system, swings about an axis (the declination axis) centered within the sides of the large "horseshoe" at the north end of the mounting. This horseshoe is about 12 meters in diameter, and in effect is a precision bearing riding on a thin film of oil. It is large enough in inside diameter to contain the tube and to have sufficient structural stiffness to hold the optical system in alignment, yet small enough to be fabricated on existing vertical milling machines. Oil-pad bearings are also used at the south end of the mounting, and the entire weight of the optical parts, the tube, and the yoke (horseshoe, south bearing, and the struts between them) is carried on the thin film of oil at these bearings. This motion is about the telescope's other axis (the polar axle), which is parallel to the earth's axis. Hence, very smooth and accurate motion of the massive parts is possible. Control and smoothness of the motion to an accuracy of 0.1 second of arc are necessary. The total weight of the moving parts is 270,000 kilograms (300 tons).

Design of the mounting, sufficiently detailed to serve as a basis for requesting bids for the construction, was started late in 1965 by Westinghouse Electric Corporation, Sunnyvale, California, and was finished this year by W. R. Lydster, San Jose, California, a private consulting firm. Both these groups have worked very closely with the Kitt Peak staff. The low bidder on fabrication of the two mountings was Western Gear, Inc., of Lynwood, California.

Flexibility of use is achieved through design features that make it possible to change from operation at any of the foci to another in about 10 minutes. Thus, when cloud conditions or moonlight prevent certain types of observing, the telescope can be shifted to another type of work with a minimum loss of time. In a large telescope, the observer actually rides in an observing cage at the prime focus or Cassegrain observing position. Located in the same assembly as the prime focus station are several secondary mirrors that can be folded into position quickly to activate the Cassegrain or coudé arrangement of the telescope. Since, in the Kitt Peak telescope design, one of the secondaries is too large to fold conveniently, it has been mounted above the prime focus station, and the whole assembly, cage and all, can be flipped upside down to activate this large secondary system. All these motions are electrically powered and are interlocked to prevent trouble (or so we hope!).

Another design departure from earlier large telescopes is in the area of control systems. Solid state, digital circuitry will be extensively used, and a small control computer will be part of the system. The telescope and rotating dome will normally be under computer control, and the system will be used for data handling and for control of electronic instrumentation, as needed. Certainly, taking advantage of new develop-

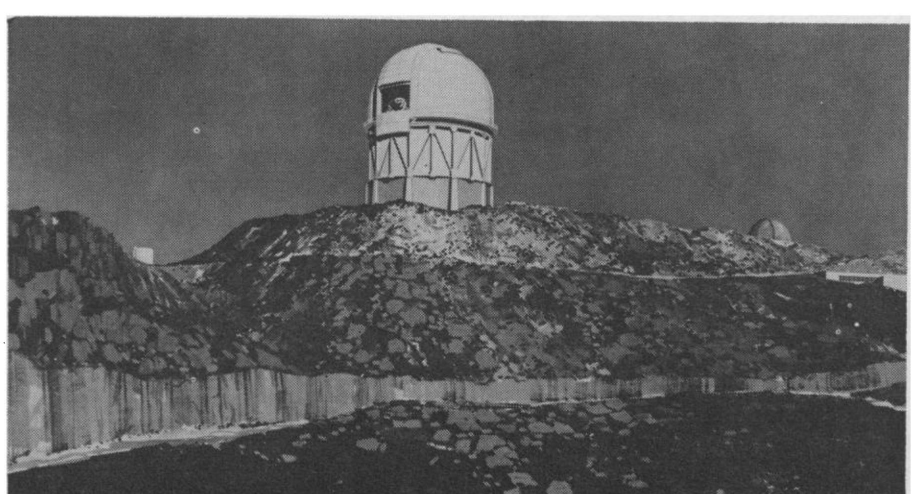

Fig. 5. Model of the Cerro Tololo building, also designed by Skidmore, Owings and Merrill.

ments in electronics should increase the flexibility and efficiency of the telescope. The drives on each axis will have several speeds, for (i) setting the instrument on the object to be observed, (ii) following the object during observation (compensating for the earth's rotation and for atmospheric refraction, for example), and (iii) moving the telescope as needed in using attached instrumentation, such as spectrographs. Readout of the position in the sky to which the telescope is pointed will be accomplished by means of precise digital encoders, and this information will be available at all the observing stations. Great effort is being made to keep the control system versatile and adaptable but still extremely reliable.

There are a number of additional intriguing design problems connected with the mounting, such as those involved in aluminizing the optical surfaces and keeping them dust-free. Of course, allowance must be made for all facets of operation, maintenance, assembly, testing, and so forth, in the design work.

The third major area of design work is design of the rotating dome and the support structure for it and for the mounting. Here the object is to protect the telescope from adverse weather—rain, snow, dust, and wind—and to shield it from the diurnal range of temperature on a mountaintop (a range which averages 8°C at Kitt Peak); to supply the support functions, such as photographic darkrooms and electronic laboratories, necessary for efficient operation; and to do these things without compromising observing work, as by introducing adverse thermal effects or vibration coupling of the building to the telescope. The detailed design work for the dome (35 meters in diameter) and the building was done by Skidmore, Owings and Merrill, of Chicago, the firm that provided the detailed building design for Kitt Peak's large solar telescope. The rotating dome itself will be very similar to the domes of the 200- and 120-inch telescopes. It is to be a double shell, well insulated. The basic requirement is that of keeping the inside temperature during the day as close as possible to the inside nighttime temperature, which is the desired temperature during observing. When the dome shutters are open, minimum temperature gradients should be allowed between the optics, the mounting, the internal air, and the air outside the dome.

The telescope itself rests on a concrete pier, about 30 meters high, isolated entirely from the building and dome that surround it. A model of the Kitt Peak dome and building is shown in Fig. 4. In essence, the rotating dome and all the internal floors and rooms are supported by a "space frame" structure. There are two floors near ground level, for maintenance shops, necessary offices, and other rooms. Near the observing level, about 30 meters above the ground, are several other floors, where operating conveniences such as darkrooms and other laboratories are located. At the top of the dome are several cranes, used for installation of the mounting and, later, for maintenance.

There is a gallery from which the general public can see the telescope, and there are windows near the 30-meter level through which visitors can see the rest of the mountaintop (see Fig. 1) and a good deal of southern Arizona. The total number of such visitors to Kitt Peak has been averaging about 60,000 per year, and completion of the 150-inch telescope will certainly swell this total. There is no question about the average layman's interest in astronomy in general and observatories in particular.

Preparation of the telescope site at the summit of Kitt Peak proper, at the north edge of the mountaintop, is now finished. Rock had to be removed to a depth of about 10 meters in the area where the telescope pier will rise.

The telescope building for Tololo (Fig. 5) has also been designed by Skidmore, Owings and Merrill. In the design, the building is closer to the ground than the building at Kitt Peak, both because of the better thermal conditions near the ground at Tololo and because of the greater earthquake hazard. The rotating domes are identical in the two telescopes, as are the mountings.

Construction work has now begun at both sites, and the buildings and domes should be erected in 2 to 3 years. At that time fabrication of the mountings should be finished, and it will take about 1 year to assemble the mounts at the site and to install the optics. A year of testing and adjusting will follow, before full-scale research can begin.

References and Notes

1. See *Science* **146**, 1641 (1964) for a summary of the report.
2. The 11 foreign countries are as follows: Australia, Canada, Chile, England, Germany, India, Japan, Mexico, the Netherlands, Scotland, and Switzerland. Visitors from the following U.S. institutions have used the Kitt Peak stellar telescopes since 1960: Ames Research Center; Amherst; Brigham Young University; California Institute of Technology; Carnegie Institution of Washington; Case Institute of Technology; Colgate; Columbia; Dudley Observatory; Georgetown College; Harvard College Observatory; Illinois Institute of Technology Research Institute; Indiana University; Institute for Advanced Study, Princeton; Jet Propulsion Laboratory; Lick Observatory; Lockheed Missile and Space Corporation; Louisiana State University; Lowell Observatory; Michigan State University; Mount Holyoke; Mount Wilson and Palomar Observatories; NASA; National Radio Astronomy Observatory; Northwestern; Princeton; Rennselaer Polytechnic Institute; San Diego State College; Smithsonian Astrophysical Observatory; Temple; Tufts; universities of Arizona, California (at Berkeley, Los Angeles, and San Diego), Colorado, Florida, Illinois, Michigan, New Mexico, Oregon, Pittsburgh, Rochester, Southern California, Texas, Virginia, Washington, and Wisconsin; U.S. Geological Survey, Flagstaff; Vanderbilt; Villanova; Warner and Swasey Observatory; Washburn Observatory; Yale; and Yerkes Observatory.
3. H. W. Babcock, *Science* **156**, 1317 (1967).
4. Present members of the Advisory Committee are H. W. Babcock and I. S. Bowen, Mount Wilson and Palomar Observatories; W. A. Hiltner, Yerkes Observatory; A. B. Meinel, University of Arizona; O. Mohler, University of Michigan; A. E. Whitford, Lick Observatory; and Bruce Rule, California Institute of Technology.
5. The debt to some of them, particularly to Dr. I. S. Bowen, cannot be overstated.
6. D. L. Crawford, Ed., *The Construction of Large Telescopes* (Academic Press, New York, 1966).
7. D. L. Crawford, *Sky and Telescope* **29**, 268 (1965).
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