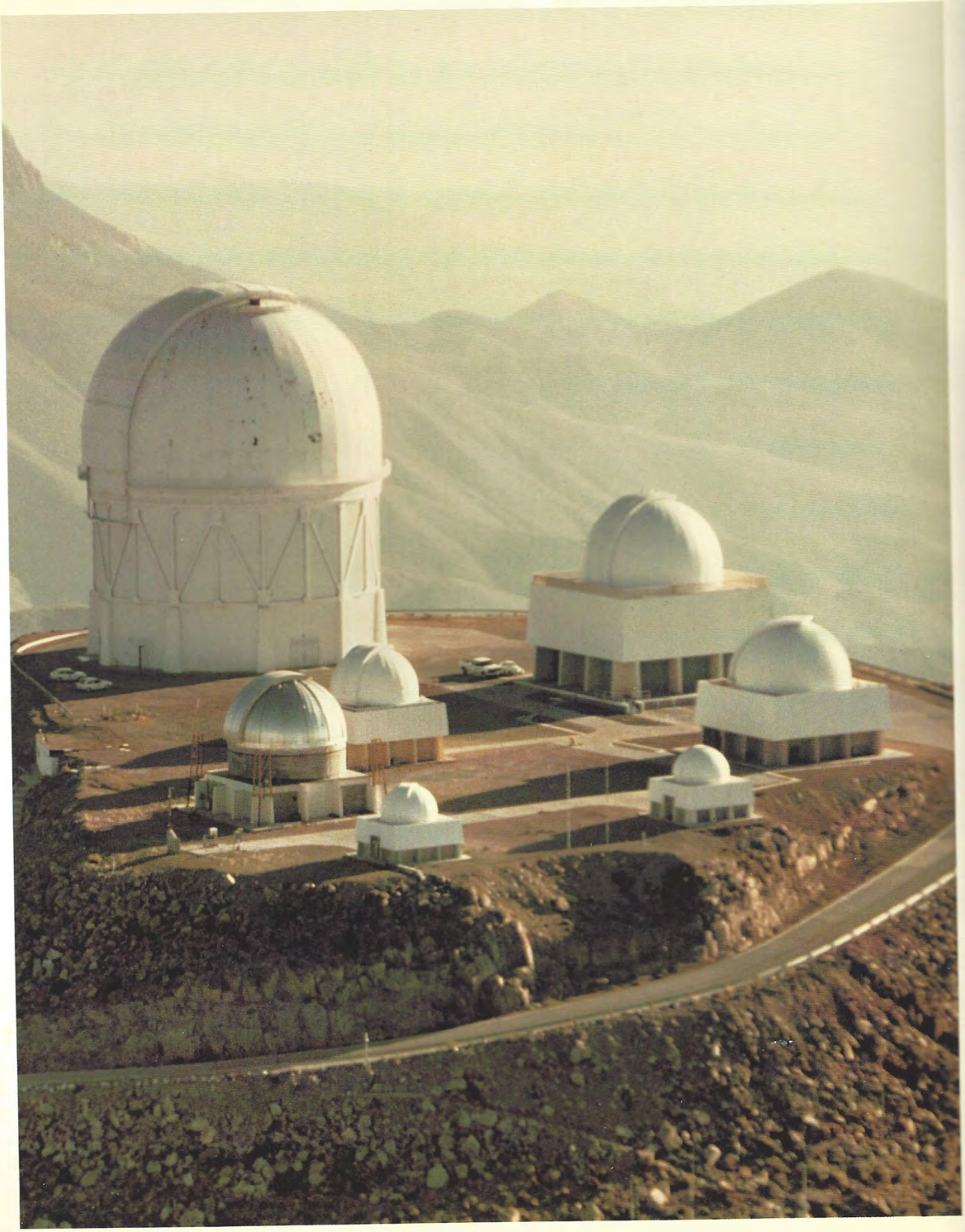
AURA

THE FIRST TWENTY-FIVE YEARS 1957-1982

AURA
ASSOCIATION OF UNIVERSITIES FOR RESEARCH IN ASTRONOMY
ARIZONA 1957

The Association of Universities
for Research in Astronomy, Inc.



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February, 1983

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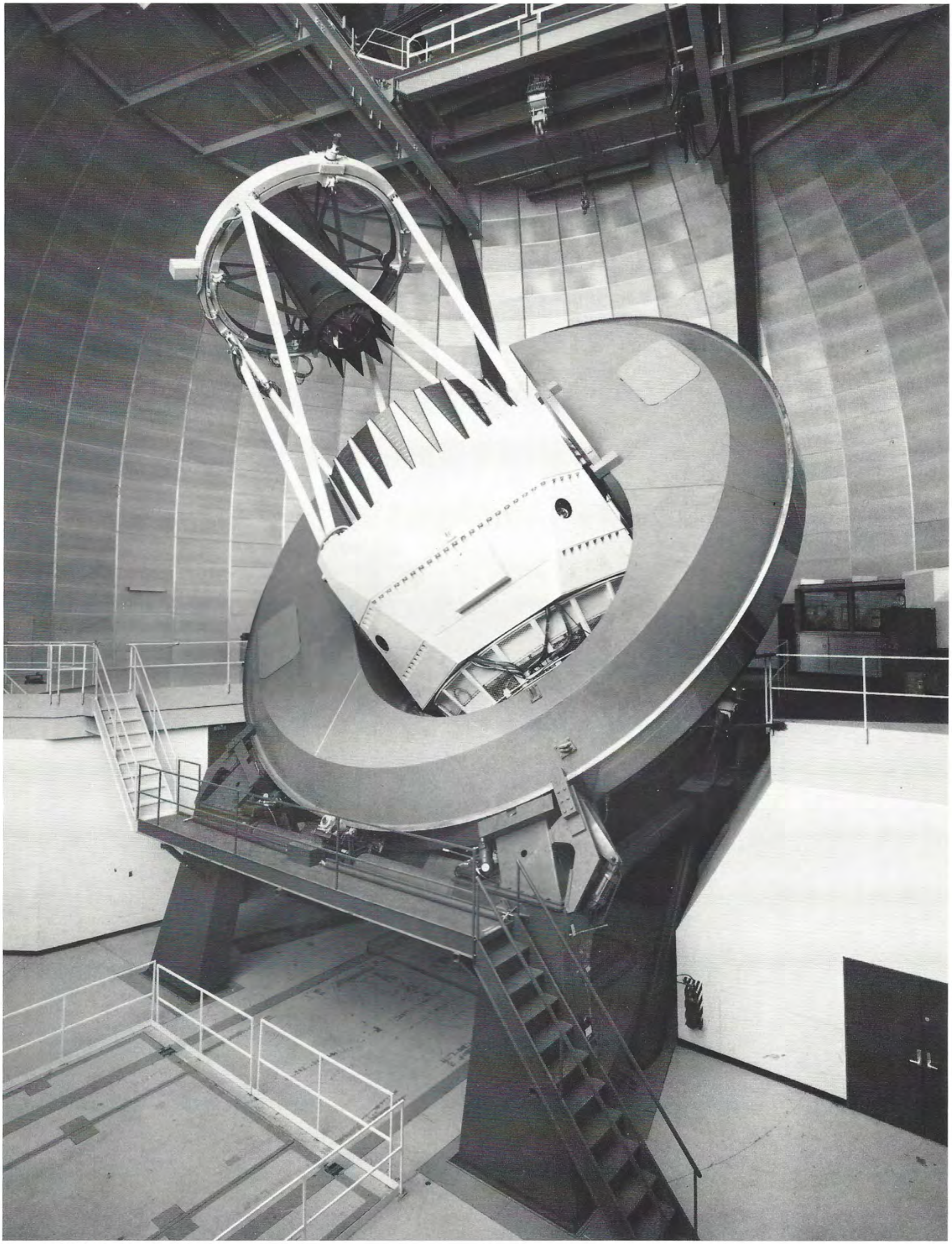
Kitt Peak from the air



One of AURA's two 4-m telescopes

INTRODUCTION

During the past quarter of a century, AURA's contributions to astronomy have been fruitful ones. Although AURA's purpose has remained unchanged, the scope of its mission and its organization have evolved considerably during this time.

AURA's mission initially focused on establishing in Arizona the first national optical observatory, KPNO, accessible to all US astronomers and equipped with facilities for both solar and nighttime observations of stars and nebulae. AURA's mission expanded during the early 1960's to include establishing a similar observatory, CTIO, in the southern hemisphere, with an international constituency for nighttime observations of the southern skies. The later 1960's and 1970's were focused on constructing and equipping world class telescopes at both sites and, more generally, to providing state-of-the-art capabilities to serve rapidly increasing numbers of visiting astronomers. During the mid-1970's AURA's mission with respect to solar astronomy broadened through acquisition of the responsibility for management of SPO. At the beginning of the 1980's, AURA's mission evolved further to encompass the responsibility given it by NASA for establishing and operating the Space Telescope Science Institute, which will have a broad international community of users. Thus, the complexity of AURA's contractual obligations for management of astronomical facilities has increased significantly during the past 25 years.

AURA's corporate organization has evolved accordingly. During this period, the number of AURA member universities has more than doubled, with most of the additions made during the past decade. Until 1972, a member of the Board of Directors served as AURA President. By that year, however, the demands upon the then President, Rupert Wildt, had increased to exceed what could reasonably be expected from anyone carrying other academic responsibilities. Hence, the Board amended its By-Laws to permit employment of a full-time President. Gilbert L. Lee, Jr., a founding member of the AURA Board and who was then serving as the administrative director from the University of Chicago, was selected as the initial incumbent of this position. A Board Chairman and Vice-Chairman have since been elected annually from among the institutional Directors on the Board. These officers and the President are assisted by a small Corporate Office staff. Former and current Corporate officers and staff are listed in Appendix I.

Initially, CTIO was organized as a southern extension of KPNO with its Director reporting to the KPNO Director, who reported directly to the Board. When AURA was given interim responsibility for SPO in 1976, the AURA/NSF contract for management of KPNO was amended to include SPO. During 1977-78 AURA's organization evolved further. At the Corporate level, a search was made for a new President with a scientific as well as an administrative background and who would serve as AURA's principal representative to Federal sponsors. The Directors of each of the three ground-based observatories thereafter reported to the Board through the President, in recognition of their status as major facilities in their own right, operated under separate contracts with the NSF. With the establishment of the ST ScI, its Director also reports to the Board through the President.

During the past 25 years AURA has clearly shown its willingness to change and grow in response to the changing needs of the astronomical community. Among university consortia with similar purposes, AURA has been one of the more dynamic organizations, i.e. characterized by change, both in the number of facilities under its management and in its organizational development.

The 25th Anniversaries of AURA (28 October 1982) and KPNO (1 March 1983) and the 20th Anniversary of CTIO (23 November 1982) provide an opportunity both to review the past and to look at the future. We have attempted to describe the events leading to AURA's founding, and to set the place of AURA and each of the four AURA-managed Centers in the astronomical community. We have set forth some of the highlights of their formulation and the players who made it possible, as well as the scientific thrust of the Centers. We have made some attempt to look to the future of this organizational entity and potential future astronomical missions and tasks in which AURA might play a significant role.

Eagle Nebula in Serpens—M16, NGC 6611, KPNO 4-m photograph.

A HISTORY OF AURA, INC.

From the very beginning the primary purpose of AURA was to be of service to the entire astronomical community by providing modern, major facilities available to qualified scientists from all universities. The Act of Congress that created the National Science Foundation in 1950 made provision for NSF to fund research through grants. NSF could also fund research facilities but could not operate them. However, the law did not permit NSF to contract for the construction and operation of research facilities. AURA was formed for the express purpose of contracting with NSF for the construction and operation of a "National Optical Observatory."

The Beginning

The NSF budget provided little more than housekeeping money during its first two years, but beginning in 1952, research proposals were solicited and the first grants were made. Among the proposals declined by Astronomy was the first facilities proposal, submitted by the University of Arizona, Indiana University and The Ohio State University. The NSF Astronomy Panel voted on August 1, 1952 to decline this proposal, but also recommended that NSF look into requirements for modern astronomical facilities. This was implemented when NSF appointed an *Ad Hoc* Panel on Astronomical Instrumentation consisting of Robert R. McMath (chairman), I. S. Bowen, Otto Struve, and A. E. Whitford. Roger L. Putnam, sole trustee of the Lowell Observatory, also participated as a guest. This panel proposed that NSF sponsor a conference on the need for facilities for photoelectric photometry. The conference was organized by a Committee, A. E. Whitford (chairman) and J. B. Irwin (secretary), and was held at the Lowell Observatory on August 31–September 1, 1953.

Site Survey

The Flagstaff Photoelectric Conference recommended that NSF appoint a Panel to study the need for a National Optical Astronomy Observatory not limited to photoelectric photometry. If the need for such an observatory was demonstrated, it was recommended that the Panel should conduct a site survey to find a suitable location. NSF appointed the "Advisory Panel for National Astronomical Observatory" in early 1954, adding Bengt Stromgren to the earlier *Ad Hoc* Panel. The Advisory Panel had six consultants, including Leo Goldberg, who later became a member of the Panel. The work of the Panel was funded through grants to the University of Michigan, the home base of the Panel Chairman, Dr. Robert R. McMath. Its first meeting was held on November 4-5, 1954. There was immediate agreement on the need for the Observatory, and a decision was made to appoint Dr. Aden B. Meinel, then at the Yerkes Observatory, to serve as Executive Secretary of the Panel and to direct the day-to-day operations of the site survey.

Arizona was chosen by the Panel to get outside the California weather cycle, and Dr. Meinel set up a field office in Phoenix and selected a number of sites in Arizona to be tested. Meinel designed new equipment to test astronomical "seeing" conditions and placed this equipment in towers at several locations, including Kitt Peak on the Papago Indian Reservations. Dr. Edward H. Spicer, Professor of Anthropology at the University of Arizona, was very helpful in the process of securing permission from the Papago Tribal Council for Meinel and his associates to investigate Kitt Peak.

A small group of astronomers and anthropologists met and decided that the Tribal Council and Schuk Toak District Council should be invited by Dr. Edwin F. Carpenter to come to the Steward Observatory on the

Above: Robert R. McMath, Chairman, Advisory Panel for NSO. Later to be AURA President, 1957–59, and Board Chairman, 1959–62.
Left: Seeing towers on Kitt Peak, 1956

University of Arizona campus to view the Moon through the 36-inch reflector. Following this, permission was granted for the "men with long eyes" to climb Kitt Peak and set up test equipment. The Papago Tribal Council also said they would be willing to negotiate a long-term lease for the use of Kitt Peak if it proved suitable for an astronomical observatory. The seeing towers on Kitt Peak were in operation by early 1956.

AURA's Founding

A meeting organized by Leo Goldberg, acting for the McMath Panel, was held in Ann Arbor on March 29, 1957, to discuss forming a corporation that could build and operate the optical observatory under contract with NSF. Seven universities (California, Chicago, Harvard, Indiana, Michigan, Ohio State, and Wisconsin) were represented at this meeting, and the agreement to incorporate was formally signed by representatives of the seven universities a short time later. This consortium was designated the Association of Universities for Research in Astronomy, Inc. (AURA).

The Organizing Committee for AURA met in Ann Arbor on July 1, 1957. Leo Goldberg was elected Permanent Chairman, and he handled all the details leading to the incorporation of AURA. The first meeting of the AURA Board of Directors took place in Ann Arbor on October 28, 1957, immediately following the signing of the Articles of Incorporation. Each university was represented on the Board by both a scientist and an administrator, and provision was made for several director-at-large appointments to the Board to broaden the base of representation in the astronomical community. Yale University became a member in 1958, and Princeton University joined in 1959.

AURA was incorporated shortly before the site survey was completed. The Michigan operation was phased out, and AURA's contract with NSF was signed by AURA on December 13, 1957, and shortly thereafter by NSF. William B. Harrell, University of Chicago Administrative Representative, signed as AURA Contracting Officer after NSF Counsel advised that President McMath and Vice President Edmondson should not sign because of possible conflict of interest perception due to previous service in NSF.

The Site and Lease

Dr. Meinel was named Observatory Director by the AURA Board in Phoenix on December 12, 1957. His Final Report of the Site Survey was evaluated by the Scientific Committee of the AURA Board, and on March 1, 1958, Kitt Peak was formally chosen as the site for the observatory. NSF approval was announced on the following March 14.

The next step was to negotiate a lease with the Papago Tribal Council for use of Kitt Peak. This required a special Act of Congress. Legislation providing that "the term of the lease shall be for as long as the property is used for scientific purposes" was approved by Roger Ernst, Assistant Secretary of the Interior on July 24, 1958, and submitted to the 85th Congress by Senator Barry Goldwater on July 29, 1958. It was passed by the Senate on July 31 and by the House of Representatives on August 28 and signed into law by President Dwight D. Eisenhower shortly thereafter. The Schuk Toak District Council met on March 5, 1958, and passed a resolution authorizing negotiation of a lease with the NSF. Following this necessary first step, the Tribal Council passed a resolution on March 7, 1958, approving the proposed lease in principle. The lease was negotiated after the authorizing legislation was passed, and it was signed on October 3, 1958, by Mark Manuel, Chairman of the Papago Tribal Council, and by Dr.A.T.Waterman, Director of the National Science Foundation, on October 24, 1958.

KPNO

The Dedication of the Kitt Peak National Observatory took place on March 15, 1960. Dr. W. W. Morgan, Director of the Yerkes Observatory, gave the Dedicatory Address. Other speakers were Dr. Paul Gross,

Above left: Aden Meinel, KPNO Director, 1957–60.
Above: C. D. Shane, AURA Board President, 1959–62.
Left: Nicholas U. Mayall, KPNO Director, 1960–71.

Vice Chairman of the NSB; Dr. Alan Waterman, NSF Director; Dr. Robert McMath and Dr. Aden Meinel. Dr. C. D. Shane was Master of Ceremonies.

Dr. Meinel had developed an interest in planning a 50-inch aperture space telescope, and the AURA Board established a Space Division at KPNO in March 1959, with Meinel serving as Associate Director in addition to his duties as Director. NSF made a $160,000 grant to AURA to support the feasibility study for an orbiting telescope. Dr. Meinel resigned as Director of KPNO at the time of the 1960 Dedication but continued to serve as Associate Director of the Space Division until March 1961. He resigned as Associate Director effective September 1, 1961, to accept a position at the University of Arizona. Dr. Nicholas U. Mayall of the Lick Observatory became Director of KPNO on October 1, 1960, and served until August 31, 1971. His experience with the construction of the 120-inch reflector at the Lick Observatory was valuable background for his direction of the planning and construction of the 150-inch (4-meter) telescopes for KPNO and CTIO.

Dr. Joseph W. Chamberlain was appointed Associate Director of the Space Division by the AURA Board at its March 12, 1962, meeting. He came aboard on October 1, 1962, and served until June 30, 1970, when he was succeeded by Dr. Lloyd Wallace. He left the Observatory on May 31, 1971. The name of the Division was changed to Planetary Science Division in 1969. During Chamberlain's term a research program using sounding rockets launched from White Sands was developed. Budgetary priorities caused the AURA Board to terminate the rocket program in 1973.

The "Chile Project"

Professor Federico Rutllant, Director of the Observatorio Nacional of the University of Chile, visited the United States in July 1958 for the purpose of encouraging the interest of U.S. astronomers in locating telescopes in Chile. His visit to the Yerkes Observatory bore fruit, when Dr. Gerard P. Kuiper and Dr. W. A. Hiltner became interested. The U.S. Air Force was already supporting Hiltner's galactic structure research, and the Chile Telescope was added as a contract amendment. Kuiper and two Air Force officials visited Chile in March 1959 to initiate the project. A cooperative agreement for construction of the Observatory was signed by the University of Chicago, the University of Texas and the University of Chile. Dr. Jurgen Stock, who had been appointed Resident Astronomer at the McDonald Observatory of the University of Texas, was transferred to the Chile Project and began the site survey in 1959.

Complications developed when Kuiper left the University of Chicago in mid-1960 to accept a position at the University of Arizona. The University did not want to continue the project without Kuiper and desired to have AURA take over. The University of Chile agreed to this change, and a joint Chicago/Texas

The meeting of the Schuk Toak District Council with AURA representatives on March 5, 1958 at which the District Council approved a resolution authorizing the Kitt Peak Lease to the NSF. Mark Manuel, Chairman of the Papago Tribal Council, and Chester Higman, Administrative Assistant to the Chairman, are seated at the table. At extreme left is Harold Thompson, engineer on the site survey, and standing at extreme right is Aden B. Meinel, first director of KPNO.

membership in AURA took care of the interests of the University of Texas, which did not qualify for separate membership in AURA at that time. The AURA Board agreed in principle to take over the "Chile Project" on June 6, 1960, and the Executive Committee voted on June 30 to take the necessary actions to transfer responsibility to AURA. Dr. Stock continued the site survey under AURA auspices, and NSF replaced the Air Force as the funding agency.

CTIO

Dr. Shane and Dr. Mayall visited Chile in December 1960 and again in 1961. Dr. Edmondson made a visit in April 1962. Finally, AURA and NSF representatives met in Chile in November 1962 to evaluate the results of the site survey. Cerro La Peineta near Copiapo and Cerro Tololo near La Serena were visited, and meetings were held with local government officials. Finally, at a meeting held in the Hotel Carrera in Santiago on November 23, 1962, the decision was made to build the observatory on Cerro Tololo. The name of the Cerro Tololo Inter-American Observatory was approved by the Executive Committee on December 1, 1962. Dr. Jurgen Stock was appointed Director of CTIO and served until December 31, 1965. Following a series of short-term Acting Directors (Edmondson, Mohler, Hiltner, Alex Smith, Hoag and Hiltner a second time), Dr. Victor Blanco was appointed Director by the AURA Board on July 15, 1967, and served until January 1, 1981, when Dr. Patrick Osmer became Director.

The Dedication of CTIO took place on November 6-7, 1967. AURA was honored by the personal participation of President Eduardo Frei, who spent the night on Tololo. Speakers at the November 6 ceremony at the La Serena Headquarters were: Sergio Ossa, Minister of Public Works; Eduardo Sepulveda, Intendente of the Coquimbo Province; Edward Korry, U.S. Ambassador; Philip Handler, Chairman of the National Science Board; Rupert Wildt, President of AURA; Enrique d'Etigny, Dean of Physical Sciences and Mathematics of the University of Chile; Dr. Otto Heckmann, Director of the European Southern Observatory (ESO) and President of the International Astronomical Union.

Capability Expansion

Dr. Leo Goldberg became Director of KPNO on September 1, 1971, and served until September 30, 1977. The organization of the scientific staff was changed by amalgamating the separate stellar, solar and planetary

Chilean officials at Dedication of CTIO, November 6–7, 1967. At center is Chilean President Eduardo Frei, and facing Frei with back to camera is Victor M. Blanco, CTIO Director at the time. At upper left is Patricio Zamorano, CTIO employee.

Top: Dr. Jurgen Stock, CTIO Director until December 31, 1965. Above: Gilbert L. Lee, Charter Board member and first full-time AURA President, 1972–77.

science divisions. The 4-meter telescopes for KPNO and CTIO were put into operation during this period, and the solar vacuum telescope was added to the McMath facility. Planning was begun for a very large aperture telescope. Unfortunately, a reduced rate of increase of NSF funding coupled with accelerating inflation had a strong negative impact on both planning for the future and the current operations of KPNO. Staff levels were cut severely and services to visitors reduced in order to operate within the available budget.

The Gratings Laboratory

Beginning about 1950 Dr. George Harrison of M.I.T. produced the best available diffraction gratings for scientific use. Starting with one of A. A. Michelson's ruling engines, Harrison developed and improved the techniques. In 1966 he started construction of his "C" engine, which was capable of ruling gratings as large as 16 x 24 inches (400 x 610 millimeters). In the two years prior to January 1974, this engine was the only source available for large gratings. AURA and KPNO were asked to consider taking over and refurbishing the Harrison "C" engine and to set up a Gratings Laboratory to produce the large gratings needed by many astronomers as a research tool. After lengthy negotiations, the laboratory was set up in Tucson in 1974, and the first grating for KPNO was produced in late 1975.

Dr. Victor Blanco and Dr. Fred Gillet served as Acting Director of KPNO from October 1977 through February 1978, and from April 1978 through October 1978, respectively. Dr. Geoffrey Burbidge's term as KPNO Director began on November 1, 1978. Visitor support and technical services were reorganized to increase efficiency, but the continuing reduction of NSF support has lowered staff levels and services to visitors.

Sacramento Peak Observatory

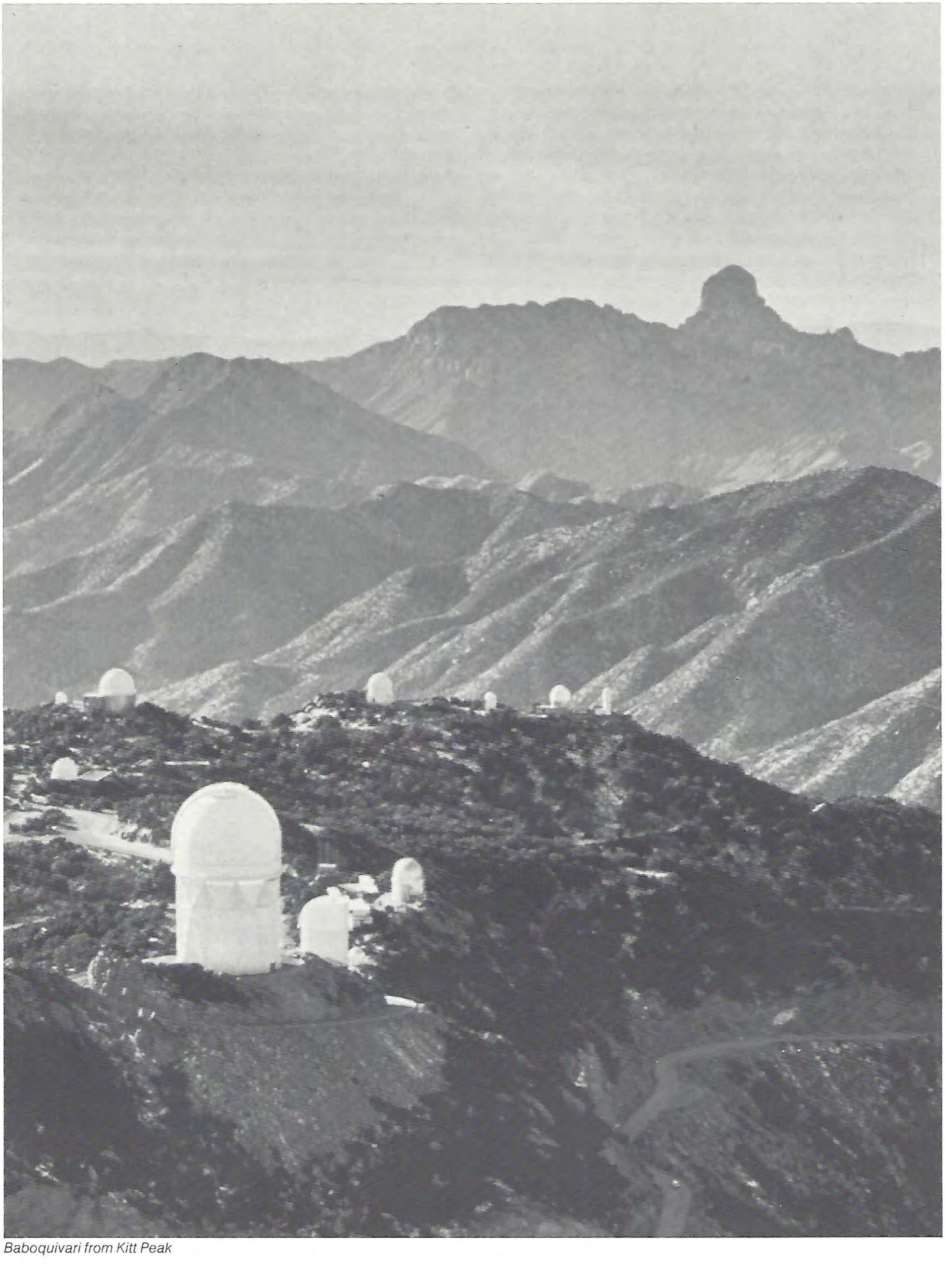
When the U.S. Air Force announced its intention to phase out support of SPO, NSF convened a panel of eminent astronomers to make a recommendation regarding disposition of the observatory. This panel strongly endorsed SPO as the world's outstanding solar observatory, and recommended that the NSF assume responsibility for its support. A major expansion of AURA's responsibilities came when NSF asked AURA in 1976 to assume temporary management of the Sacramento Peak Observatory. As a result of AURA's proposal in response to the NSF Request for Proposals, AURA was selected as permanent manager in October 1978. Thus, since 1976, SPO has been under AURA management, with a small group of Air Force Geophysical Laboratory (AFGL) astronomers and support staff remaining in residence at SPO, and who are thoroughly integrated into the operations of SPO. Dr. Jack Zirker served as Acting Director from 1976 through October 1978, and has served as Director since that time.

Corporation Development and Ancillary Activities

The President of AURA was elected from the Board and served on a part-time basis until 1972 at which time, Gilbert L. Lee, Jr. was selected as the first full-time, salaried President and established the AURA Corporate Office. Mr. Lee managed the procurement of funds for and the erection of a new Corporate headquarters building in Tucson. He was succeeded by Dr. John M. Teem in 1977. The most important new programmatic activity since 1972 was the preparation of the proposal to NASA for the contract to establish and operate the Space Telescope Science Institute (ST ScI). The award of the contract to AURA in early 1981 has provided new and challenging responsibilities and an increased workload for the Corporate Office.

AURA's university members have been increased over the years since 1972 to the present membership of seventeen. In addition to the original seven plus Yale and Princeton, AURA membership now includes the following universities: the University of Arizona, California Institute of Technology, University of Colorado, University of Hawaii, University of Illinois, The Johns Hopkins University, Massachusetts Institute of Technology and the University of Texas at Austin.

AURA and KPNO have hosted visits and meetings of many professional and other groups over the years. The American Astronomical Society has met in Tucson three times (December 1949, April 1963, and December 1973). The Council of the European Southern Observatory visited KPNO on March 17, 1969, enroute to Chile for the Dedication of ESO. The first meeting west of the Mississippi of the National Conference of Editorial Writers was held in Tucson on October 3-6, 1962. A visit to Kitt Peak was a major event for this meeting. The most recent of many scientific conferences was the Kitt Peak National Observatory Conference on Optical and Infrared Telescopes for the 1990s, on January 7-12, 1980.



Baboquivari from Kitt Peak

KITT PEAK NATIONAL OBSERVATORY

As a national center for optical astronomy, Kitt Peak National Observatory fulfills a three-fold role in American astronomy. Its objectives include the following:

1) the provision of first-rate research facilities to the nation's astronomers. In this respect, Kitt Peak provides direct services to scientists.
2) the continuance of excellent research programs by its resident scientific staff. In this respect, Kitt Peak functions as a research center.
3) the continued development of new and innovative astronomical facilities and instruments.

During 1981, 334 individual astronomers, plus 100 graduate students, came to Kitt Peak to utilize the observational facilities. The data reduction and analysis (data and image processing) facilities were used by 223 scientists. Thus, a large fraction of the nation's astronomers continue to rely on Kitt Peak entirely, or in some part, for scientific research facilities. (See Appendix IV for more details).

In addition to its role in providing or overseeing the effectiveness of research support provided to users of the facilities, the KPNO scientific staff carries out astronomical research programs. Many of these programs utilize KPNO facilities while others, mostly of a collaborative nature, involve space programs, such as the Space Telescope, the Infrared Astronomy Satellite (IRAS) and the Solar Orbiting Telescope (SOT).

In order that the Kitt Peak research facilities remain among the best available, the KPNO scientific and technical staff are continuing the development of telescopes, instrumentation and data reduction facilities. The observatory's highest priority in this respect is the construction of a National New Technology Telescope of 15 meters aperture. Such a telescope would exceed the light-gathering power of all existing U.S. telescopes.

The Kitt Peak Site

The selection of a site for the national observatory involved balancing a number of factors. Not only should the observatory site be in a clear (dry) climate, but the site should be selected with use by visiting astronomers as a major consideration. For instance, travel outside the continental U.S. would have been more expensive for the astronomer and for the initial installation, so such sites were excluded from consideration. It was thought that astronomers living at low elevations would find it difficult to adapt quickly to efficient work at elevations above 8,000 feet, so this conservative upper limit was adopted. In addition, winter conditions at higher elevations would sometimes cause problems of access and observing. On the other hand, it was known that seeing (the sharpness of astronomical images) would be better on a mountain peak above 6,000 feet in elevation.

Finally, there were sometimes-conflicting requirements, such as a long distance from populated areas so that the scattered city lights would not fog astronomical photographs, but still close enough to allow staff use of urban housing, schools, shopping, airports, etc. There was concern not only with current populations, but also with likely future growth. It was preferable that the observatory be located near a major university for the advantages of scientific, technical, and cultural exchanges.

It soon became obvious that the best conditions were in the arid southwest—in New Mexico, Arizona, or California. A total of 150 mountain sites in those states were explored by Aden Meinel and Helmut Abt between early 1955 and late 1956 by means of maps, small planes, jeeps, by foot, and by horseback—sometimes camping overnight on mountaintops to assess city lights. The possibilities were soon reduced to six sites: Chevalon Butte, south of Winslow; Kitt Peak, on the Papago Reservation; Mormon Mountain, southeast of Flagstaff; Summit Mountain, south of Williams; the Hualapai Mountains, south of Kingman; (all in Arizona) and Junipero Serra Peak, near King City in coastal central California. The California site was soon

Above: Geoffery R. Burbidge, KPNO Director

eliminated from serious consideration. Chevalon Butte and Summit Mountain were shown to have inferior seeing conditions, and they, too, were eliminated. The remaining sites were tested with telescopes in tall towers to monitor the apparent size of Polaris and with portable 16-inch telescopes for sky transparency.

The choice between the two final competing sites—Kitt Peak and the Hualapai Mountains—was based on 20 criteria, including clear weather, seeing, low winds, steady temperatures, low air and light pollution, developable area, water and power access, road construction, nearby university, etc. Kitt Peak excelled in eleven criteria, tied with the other site on five others, and it was chosen as the site for the observatory.

Kitt Peak and the Papago Indians

Dr. Edward H. Spicer

The place chosen by AURA for the national observatory, Kitt Peak, is unique not only in climatic and topographic features, but also for its role in human history. The Quinlan Mountains, the range in which Kitt Peak is located, has been important in the lives of the Papago Indian natives of the region for centuries. The highest mountain in the range is known to the Papagos as *Baboquivari* (13 miles south of Kitt Peak) and is the most sacred place in the Papago country. It is, in their mythology, the "Navel of the World," that is, the center of the universe where men found themselves after the Great Flood and in relation to which they have oriented themselves ever since. Baboquivari Peak is the home of I'Itoy, the Papago culture hero. There are other sacred places in the Quinlan Mountains, one of which is Kitt Peak, where offerings were made to the supernaturals in gratitude for the gifts of food and materials for baskets. Kitt Peak is thus part of an area which has had special meaning for a native American people over the centuries. It played a significant role in Papago understanding of the universe long before it was chosen by AURA to figure in the modern unraveling of the nature of the universe.

Elizabeth Estrada, AURA's buyer of Papago crafts.

Superficially, Kitt Peak appeared on maps as just another piece of Federal wasteland, but a closer inspection revealed another dimension: Kitt Peak is located on the Papago Indian Reservation, which meant that it was the property of the Papago Tribe, for whom the Federal government held the land in trust. Obtaining it for AURA's use was not simply a matter of asking the Federal government. The Papago Indians had to consent to any lease. Since it was part of their Holy Land, they would have to know what use was to be made of the land. Therefore, AURA's concept of use in the interests of furthering the knowledge of mankind would have to be brought into a working relationship with the Papagos' concept of the peak's place in the universe. In short, some human beings would have to sit down together and find points of common interest in two different world views and cultural traditions. When they began, as events demonstrated, neither understood very well the other's standpoint.

After preliminary talks between Dr. Aden Meinel and tribal officials, the full process was initiated by Dr. Edwin Carpenter, astronomer at the Steward Observatory on the University of Arizona campus. In consultation with Dr. Carpenter and anthropologists of the University of Arizona, it was decided by Dr. Meinel that it would be desirable to give the Papago leadership a clear demonstration of just what would be built on the sacred peak. It was hoped this would set to rest fears that it would be a foot in the door for more extensive uses that would override Papago interests.

Dr. Carpenter invited a group of Papago representatives to the Steward Observatory. There under his guidance, they viewed the moon and the stars through the 36-inch telescope, asked questions, and discussed what was planned for Kitt Peak. It was a concrete demonstration, rather than just words, and had an immediate favorable effect. Mark Manuel, chairman of the Papago Tribal Council, and some of his associates became firm supporters of the Kitt Peak dream from that point on. At the same time that the Indian leaders gained a new understanding, the representatives of AURA also acquired respect and understanding for the Papagos with whom they were dealing.

The new basis of understanding, however, was just the beginning. Negotiations had to be carried out through the proper channels of the tribal organization. The Bureau of Indian Affairs had encouraged the Papagos in 1936 to establish a constitutional, representative form of tribal and local government, and the Papagos had been managing their affairs by this means since that date. Kitt Peak lies in a political subdivision of the reservation—the Schuk Toak District—which has its own governing council under the overall authority of the Papago Tribal Council. The District Council actually had the ultimate decision, for the Tribal Council could not make an agreement to lease without the District Council's approval. The Papago way of doing business through its elected representatives often seems long and drawn out to white men, but it is no more than a relaxed way of using the democratic process. Full explanation of the business at hand and much discussion are its keynotes.

The understanding of the AURA objectives which Mark Manuel, the Tribal Chairman, and some of the Tribal Council had gained as a result of their visit to the Steward Observatory had to filter downward through other members of the Tribal Council and thence outward to the residents of the Schuk Toak District and their District Council. Over a period of three years, while AURA was engaged in other planning and exploratory activities, the discussions proceeded. A resolution approving a preliminary agreement for astronomical testing on Kitt Peak was passed by the Tribal Council in 1955. An important meeting explaining what was planned took place with the District Council in 1956. During 1958 an agreement on the terms of the lease was worked out, and finally the lease was signed by the Tribal Council and NSF in October, 1958.

AURA had made unusually effective efforts to bring about full understanding and had taken careful steps to go through the proper channels of the tribal government. That AURA's procedure was sound was indicated in a sequel to the signing of the lease. In 1959, the following year, a new Tribal Chairman was elected who had not been present at the Steward Observatory, and serious doubts were expressed by him and his associates about whether the signing of the lease had been proper. It was apparent that new explanations and discussions were required. A meeting was called of the Schuk Toak District Council which AURA representatives attended. Long discussion in the Papago language was carried out, and eventually the District and Tribal Council members were satisfied and approval was reaffirmed. From that time on, cooperation was assured, and the relations between AURA and the Papago Tribe have been amicable ever since.

Early in the negotiations, AURA had plans for a Visitor Center on Kitt Peak. This Center was to present not only the scientific aspects of the observatories and

The KPNO Astronomical Museum and Visitor's Center, with the McMath Solar Telescope in the background.

their work, but also some of the history and cultural background of the Papago people on whose land the facilities were erected. These objectives were realized, and today's visitors become acquainted with the nature of Papago life and culture at the same time that they stand on Kitt Peak and survey the 2,500,000 acres of the Reservation with the sacred Baboquivari Peak in the distance. In addition, the Visitor Center has provided during the past 25 years a sales outlet for Papago crafts, especially their beautiful and well-known basketry made from materials, such as bear grass, which grow on the peak. Papagos have been employed on Kitt Peak through the years, and efforts have been made to interest Papago youths and provide training in astronomy.

Thus the Kitt Peak National Observatory has provided direct benefits to Papagos as proprietors of the land, as well as contributing broadly to the knowledge of mankind. The ancient tradition of the mountain range as the center of the universe has in some degree been augmented, rather than erased, by the placement of new technology in the heart of the Papago country. *—E. H. S.*

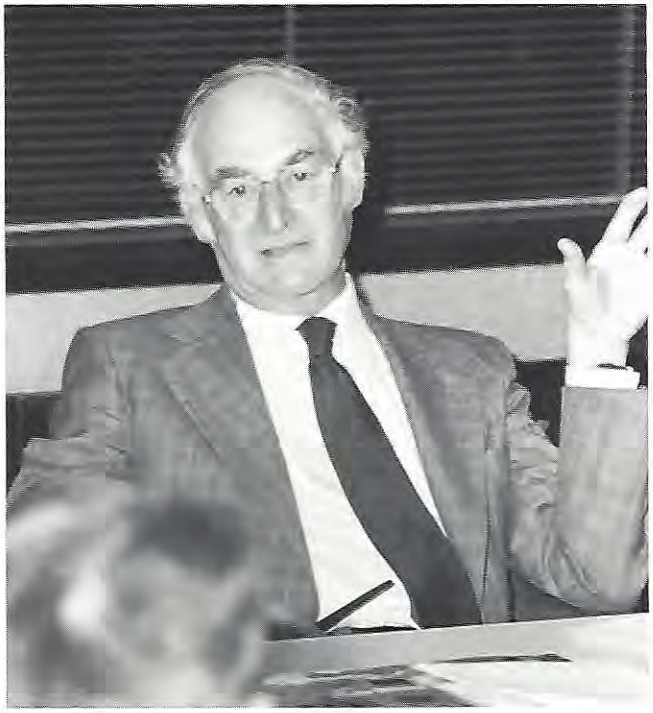
Construction of the Observatory

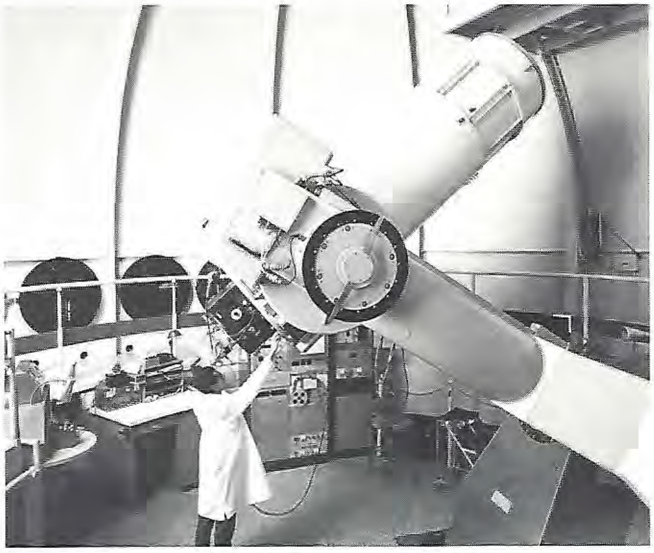
Even before the selection of Kitt Peak as the national observatory site, roads and facilities were constructed for site testing. The triple-power Polaris-monitoring telescope required building a bulldozer trail to the mountaintop; it had grade up to 70 percent, going straight up the east side of the mountain. Traces of that trail remain today. Then a five-mile dirt construction road with grades up to 28 percent was built along the northeast ridge. Travelers phoned the mountain secretary before starting up or down the road because parts were one lane. The final road, costing $2.5 million, was started in early 1960 and completed in January 1963; it is twelve miles long, has a steady 5 percent grade, and was built for 35 mph driving. The final surface was added later.

Even though Kitt Peak averages 18 inches of rain a year, most of it drains into the valleys; springs are rare on the mountain. The problem of providing water for the observatory was solved by coating a two-acre basin with concrete and collecting and purifying the 50,000 gallons of water that fall on it in each one-inch rainfall. As a reserve water supply, a lake was created by building a dam in Horseshoe Valley.

The first research telescope on Kitt peak was one of the 16-inch site-survey telescopes, remounted in a concrete building and small dome. The first visiting astronomer, a graduate student at Indiana University, Arlo U. Landolt, came in mid-1959. The first permanent major telescope, the No. 1 36-inch, was completed in the spring of 1960 at a construction cost of $113,000 for the building (by Murray J. Shiff Co.) and $69,000 for the mounting. That mounting soon became a model for the many other telescopes built by Boller & Chivens.

The most innovative stellar telescope was the 2.1-meter designed by Aden Meinel, William Baustian, and others. The pyrex primary mirror was the first



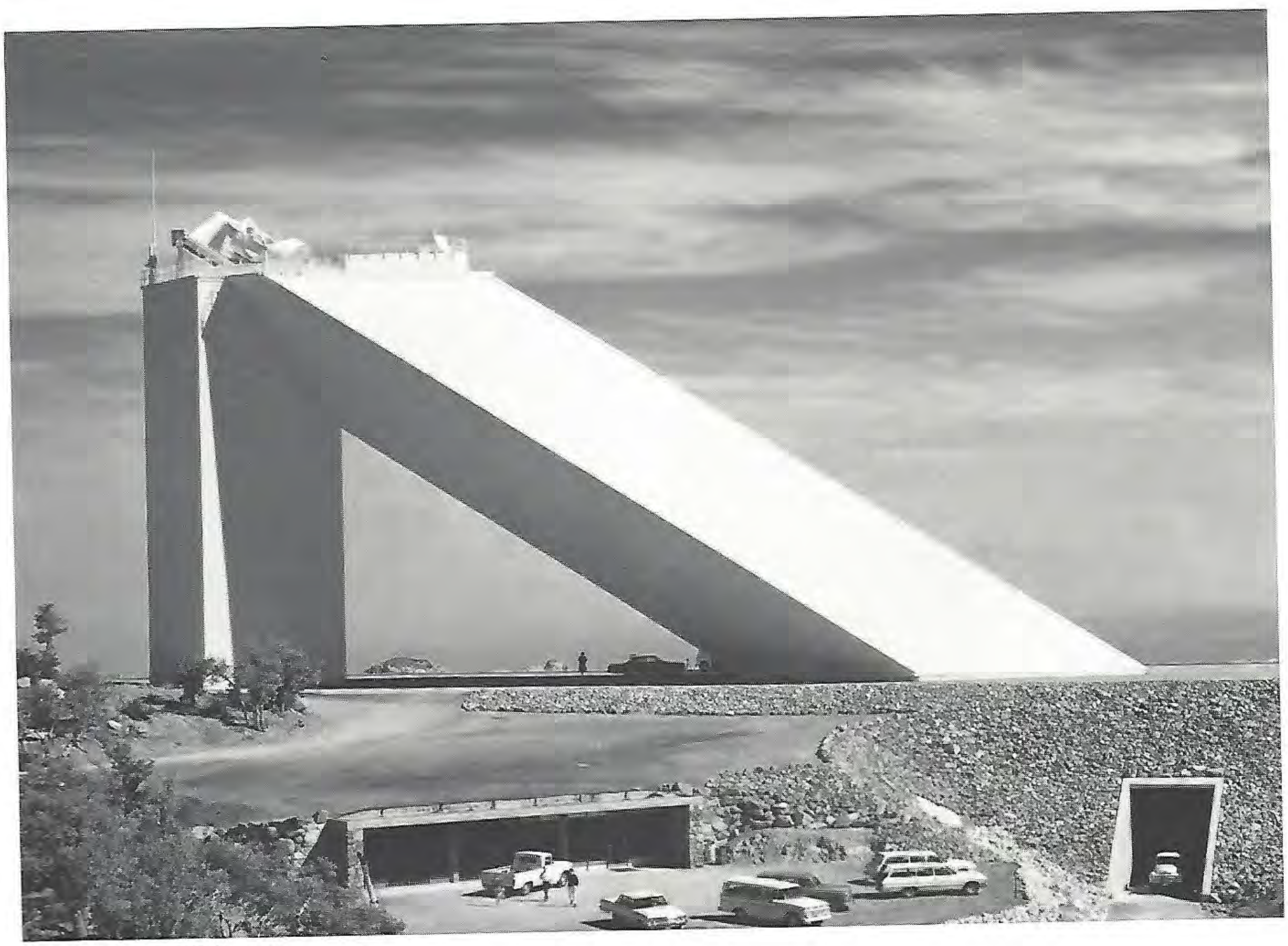


The #1 36-inch, Kitt Peak's first permanent telescope. Shown is Earl Koch, Assistant Engineer, in the early 1960s.
Left: Leo Goldberg, KPNO Director, 1971–77

made with the "slumping" process, producing a blank of sufficiently uniform hardness that grinding, polishing, and figuring took only 15 months. The fast f/2.6 primary was a major advance in astronomical optics and allowed a relatively fast f/7.6 Cassegrain. The resulting short telescope tube allowed a smaller, and therefore less expensive, dome. A secondary flip-top allows changes between the Cassegrain and Coudé in less than five minutes. Work on the dome and mounting started in 1959, and the telescope was opened to visiting astronomers in 1964, with Dr. G. Van Biesbroeck as the first visitor, when he used the telescope on January 21, his 84th birthday.

The unique McMath Solar Telescope had extreme requirements: mirrors that should not distort when exposed to warm sunlight; a need to keep a 500-foot path, partly above and partly below ground, constant in temperature; a mounting rigid enough, even in a strong wind, so that the solar image 780 feet away will not vibrate by more than a small fraction of an inch, etc. The structure, designed by Skidmore, Owings, and Merrill in 1959, involved a concrete tower, shielded by a steel structure, supporting an 82-inch mirror and two smaller ones; a diagonal structure having a copper skin (6,000 lbs. of copper), painted with TiO paint, with tubes inserted to accept 19,000 gallons of antifreeze as a refrigerant; various additional mirrors below ground reflecting solar images to underground spectrographs and a spectroheliograph. The telescope, the world's largest, was dedicated on November 2, 1962.

The largest stellar telescope on Kitt Peak is the Mayall 4-meter telescope, started in 1967 from building designs by Skidmore, Owings, and Merrill and constructed by M. M. Sundt Co. The Kitt Peak engineers and the Westinghouse Electric Corp. designed the mounting. Dr. David Crawford served as Project Manager. The 158-inch quartz primary mirror and the many smaller ones were ground, polished, and figured on a special new grinding machine and test tower at the Tucson headquarters. Most of the instruments attached to the telescope were designed and/or built at the Tucson headquarters. Dedicated on June 20, 1973, the telescope is the largest one available to most of the astronomers and graduate students in this country.



The McMath Solar Telescope

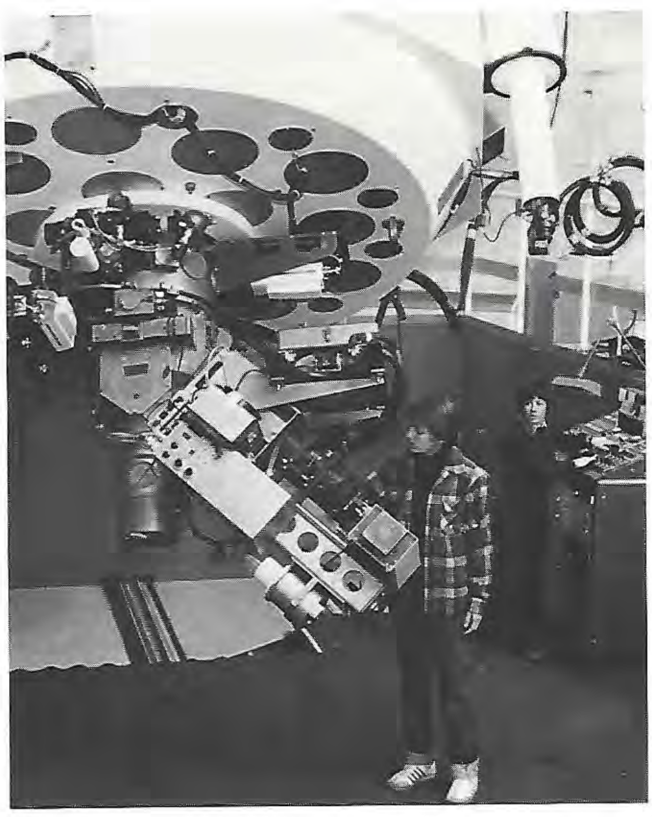
At last count, the mountaintop has 58 buildings for telescopes, offices, laboratories, living quarters, construction and mechanical repairs, visitors use, etc. Space has been made available to other organizations for telescope installations such as the University of Arizona with three; the National Radio Astronomy Observatory, one 36-foot radio telescope; the University of Michigan/Dartmouth/M.I.T. group with one and a second in the planning stages; and Case-Western Reserve with one. There are now a total of 16 telescopes on Kitt Peak, 15 optical and one radio, and one additional optical in the advanced planning stages as this is written. As long as astronomy in this country grows and new techniques are developed, KPNO will grow and strive to fill the needs of the ever-increasing numbers of both American and foreign astronomers.

Operation of Kitt Peak National Observatory—Facilities & Services Available

Kitt Peak National Observatory is one of four national centers managed by AURA. The observatory staff consists of a total of 250 scientific, administrative, operations, and engineering personnel.

The observatory is organized into four major divisions. The scientific staff, comprised of 32 members, includes solar astronomers, non-solar astronomers, theoreticians, and four research associates. The Administrative Division, which is responsible for all personnel and accounting procedures, also takes responsibility for the operation of the Kitt Peak headquarters. The Personnel Office, a part of the Administrative Division, takes responsibility for all of the AURA centers except the Space Telescope Science Institute. The majority of the accounting associated with the centers is carried out at the Tucson headquarters. The Engineering and Technical Services Division is responsible for the building and development of all new instrumentation and telescopes and for a considerable amount of the maintenance of all of this equipment. Finally, the Operations Support Division takes full responsibility for the operation of mountain facilities. It provides all the technical support for the operation of the telescopes and operates what is essentially a small hotel on the mountain with a total of 52 rooms used by visiting astronomers and a number of KPNO employees. Further, the Operations Support Division is responsible for the Visitor Center on Kitt Peak, which each year has more than 100,000 public visitors. Finally, the Operations Support Division takes responsibility for the KPNO computers.

Currently, there are 250 people engaged in these activities, a significant reduction from the numbers even a few years ago—in 1978 there were 333 individuals employed at Kitt Peak. The reduction in



Above: John Kirk, resident (left), and Ed Frazier, visiting solar astronomer.
Right: Kitt Peak astronomers Carol Christian (left) and Caty Pilachowski at the 2.1-m.

number has been due in part to the fact that for a good many years the funds available to support the Observatory have not kept up with the inflation. Decreased purchasing power has forced us to continuously try to do more with less. In spite of this, we are accomplishing the mission that AURA has set for us—namely to provide major optical facilities for all qualified U.S. astronomers and in addition to maintain a leadership role both in science and technology.

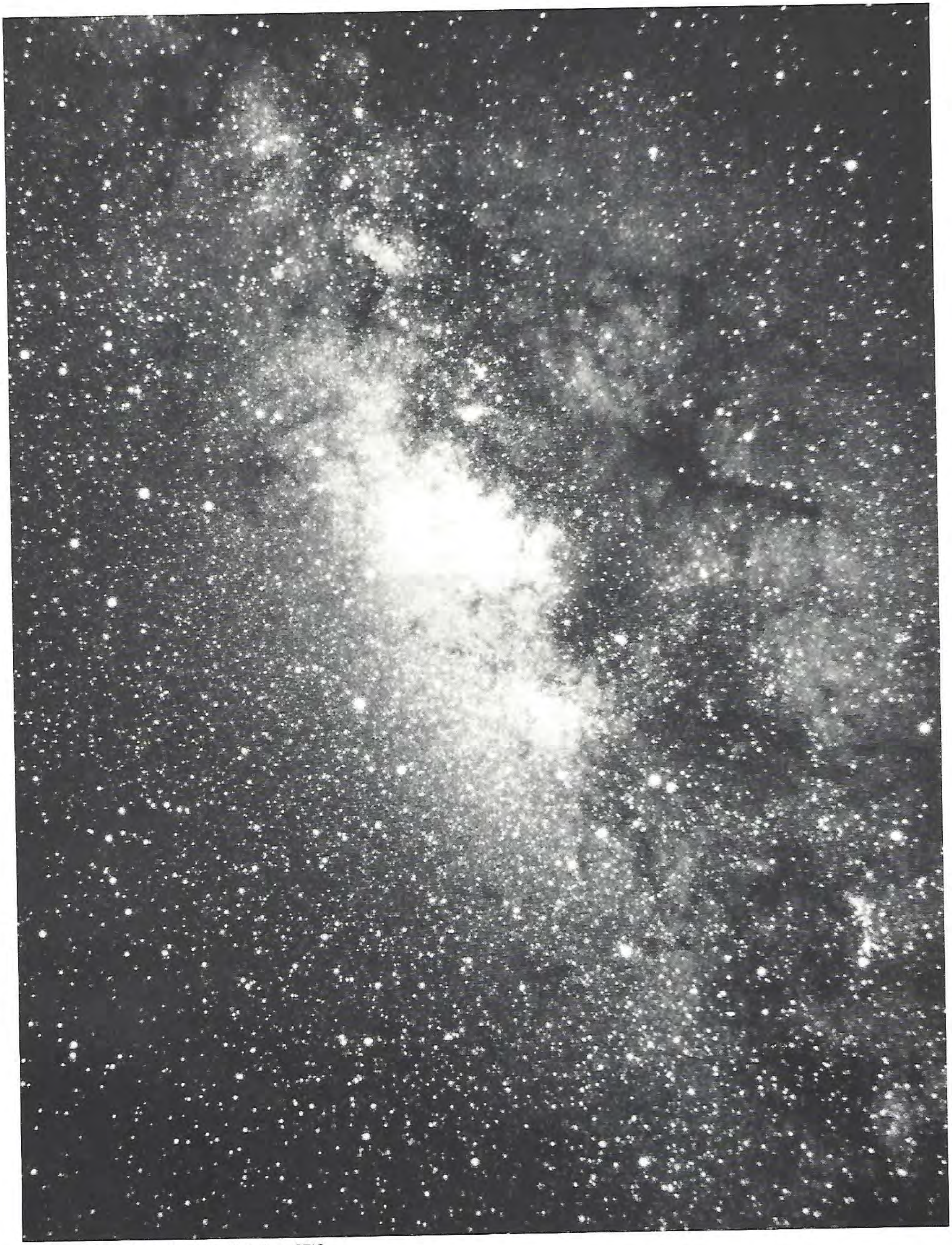
Currently there are 19 telescopes located on Kitt Peak, of which 16 are in routine use. In addition to the Mayall 4-meter, 2.1-meter, auxiliary coude' feed, 1.3-meter, #1 0.9-meter, #2 0.9-meter, McMath East auxiliary, McMath West auxiliary, Vacuum and RAZDOW patrol telescopes, KPNO also acts as host for the Steward Observatory 90-inch, 36-inch and now inactive 20-inch telescopes; the McGraw-Hill 50-inch telescope, whose sponsors (the University of Michigan, Dartmouth and the Massachusetts Institute of Technology) have received funding for the 1983 construction and installation on Kitt Peak of a 100-inch telescope; the National Radio Astronomy observatory 36-foot millimeter wave telescope; and the Burrell-Schmidt telescope operated jointly with Case Western Reserve University. There is also a RAZDOW solar patrol telescope, plus two inactive 0.4-meter telescopes (closed in 1981 because of budget reductions). A very broad assortment of instruments is available for use with these telescopes, including photographic plates, image tube cameras, video TV cameras, digital TV cameras, polarimeters, and high, medium and low dispersion spectrometers. Some of the equipment has been optimized for use in the visible spectrum while other instruments are available for observations in the infrared spectrum.

Although Kitt Peak has eleven major observational facilities available, the requests by the nation's astronomers for the use of the facilities far exceeds the available time on the telescopes. For this reason, use of the facilities is adjudicated by a Telescope Allocation Committee whose members include scientists from KPNO and other institutions. The services provided to users of the facilities include, in addition to meals, lodging and transportation, scientific and technical assistance in the use of the telescopes and instrumentation, as well as professional assistance in the reduction of observational data.

Research at Kitt Peak

It is impossible in a few sentences to give any real idea of the scope of the research being carried out at Kitt Peak. Since we have the world's largest solar telescope—the McMath telescope—Kitt Peak has been a center for studies of the Sun for many years. Investigations involving study of the solar surface, its composition, and its variability are all carried out using highly sophisticated, modern techniques.

The largest telescope used for nighttime work is the 4-meter Mayall telescope, and with it astronomers are able to study some of the faintest objects in the Universe—galaxies of stars as they were billions of years ago. Between these two extremes, the Sun and the most distant galaxies, studies of almost every kind of star in our own galaxy, and of gas and dust between the galaxies, are carried out with a wide variety of highly sensitive detectors. One of the major tools of the astronomer is a spectrograph which enables the study of the chemical composition of stars and galaxies and, through the Doppler shift, the measurement of motions of these objects through space and their internal motions. What astronomers are interested in is the life history of the stars from birth to death, what they are made of, their chemical composition, and how the whole Universe of galaxies of stars evolves. The scope of the research can best be seen in some direct pictures and spectra taken with the major instruments on Kitt Peak.



Star clouds and dust in the Milky Way, from CTIO

CERRO TOLOLO INTER-AMERICAN OBSERVATORY

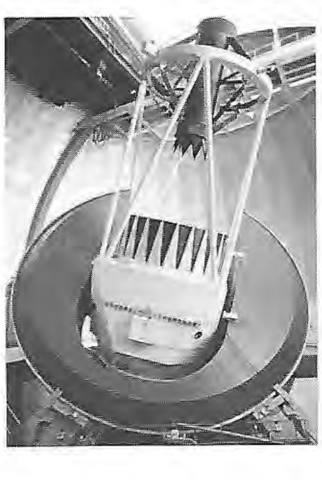
The role of the Cerro Tololo Inter-American Observatory is to provide excellent research facilities in the Southern Hemisphere to all astronomers, especially those from all the Americas, on an open and competitive basis. To accomplish this end, the Observatory operates seven telescopes, ranging in size from 0.6 to 4-meters, the latter being the largest telescope in the Southern Hemisphere. The power of these telescopes has been increased many fold in recent years by the installation of modern detectors and computer systems, with the result that visiting and staff astronomers may carry out a wide variety of research programs at the frontiers of optical and infrared astronomy. More than 200 visiting astronomers a year from the United States, Latin America, Canada, and Europe use CTIO's facilities. Among the visitors are qualified graduate students making observations for their doctoral theses; CTIO therefore contributes to the training of new astronomers by giving them access to its facilities at the earliest stages of their careers. CTIO also has an outstanding staff of resident astronomers who carry out their own research programs in addition to assisting with the operation and development of the Observatory. The technical and administrative staff are renowned for their ability to operate a high technology facility on a remote peak in the foothills of the Andes and for their contributions in instrumentation and computer programming.

Toward the end of the last century, some of the leading American observatories started operating southern observing stations. Outstanding examples that made lasting contributions to the advancement of astronomy were the Harvard College Observatory facilities in Arequipa, Peru, and Bloemfontein, South Africa, and the Lick Observatory Mills Expedition Station in Santiago, Chile. By 1960, unfortunately, these facilities either had been shut-down or were being closed mostly because they were antiquated and costly to operate. New modern facilities were urgently needed, not only as a replacement but also to provide larger telescopes and modern technology.

The importance of the Southern Hemisphere to astronomy has been apparent for many years. Indeed the Harvard expeditions to Peru led to Henrietta Leavitt's discovery in 1912 of the period-luminosity relation in cepheid variables in the Small Magellanic Cloud, a relation that has become fundamental to the distance scale of the Universe. It is often said that if astronomers had been more familiar with the southern skies, they would not have held to the notion that the solar system was near the center of the Milky Way galaxy. A mere glance at how the Milky Way brightens in the direction of Sagittarius would have indicated that the Earth must be located at considerable distance from the center of the galactic system. Subsequently, the need to study the southern Milky Way has often been cited as one of the reasons to build a major southern hemisphere observatory. The Magellanic Clouds are equally cited as a major justification for CTIO. Being the nearest external galaxies and yet observable only from the southern hemisphere, the Clouds hold the key to many problems in stellar and galactic evolution.

There is a multitude of other reasons for going south, where some of the best examples of many classes of astronomical objects are most favorably observed. The globular star clusters, which contain some of the oldest known stars in the galaxy, and which have turned out to be invaluable laboratories for testing theories of stellar evolution, are concentrated in their distribution in the southern skies. At distances beyond our own Local Group of Galaxies, two of the three nearest groups of galaxies pass overhead at CTIO. One, the Sculptor Group, is already being used to refine the distance scale for the Universe. The other, the Centaurus group, contains the nearest known active galaxy, NGC 5128, a powerful source of radio and X-ray radiation.

Developments in space astronomy have made it even more important to have first-rank ground-based observatories in both hemispheres. Many objects discovered by rockets and satellites cannot be identified



Above: Patrick S. Osmer, CTIO Director without further observations through telescopes on the ground. To exploit the all-sky coverage of satellites requires northern and southern observatories such as Kitt Peak and Cerro Tololo. Not surprisingly, the great majority of galactic X-ray sources discovered from space are located in the southern Milky Way. The Einstein satellite alone produced enough X-ray data to have kept a major telescope at CTIO busy for years.

Finally, southern hemisphere observations are making increasingly important contributions to the study of the large scale structure of the universe. With the local Supercluster of galaxies being located in the North, the South provides regions of lower galactic density to help establish the overall properties of space. By now some of the best available quasar samples are those in the southern hemisphere as a result of techniques pioneered at Cerro Tololo; their development was due in part to the excellence of the observing conditions in Chile.

Two other major international observatories have built in Chile: the European Southern Observatory (ESO), headquartered in West Germany, and the Las Campanas Observatory, with headquarters in La Serena, Chile. Six European nations (France, West Germany, Holland, Belgium, Denmark, and Sweden) joined together to form ESO and selected a site on Cerro La Silla, 60 miles north of Cerro Tololo. ESO, now expanded to include Italy and Switzerland, has developed a major facility with 12 telescopes, the largest having a 3.6-meter diameter mirror. A 2.2-meter telescope is soon to be added, and a new 3.5-meter telescope is being planned. ESO maintains support operations in Santiago and La Serena.

The Las Campanas Observatory is operated by the Carnegie Institution of Washington and is located north of La Silla. Its principal instruments are a 2.5-meter telescope and a 1-meter telescope. In addition, the Soviet Union Academy of Sciences, with the cooperation of the University of Chile, started operating a large Maksutov telescope on Cerro El Roble, north of Santiago in 1970. The discovery and survey of the excellent observing sites in Chile was therefore a significant scientific contribution by AURA to worldwide astronomy.

The importance of these developments to astronomy cannot be overestimated. It should be noted that the total telescopic light-gathering power at the Cerro Tololo Inter-American Observatory alone surpasses that which existed in the entire southern hemisphere in 1960.

ESO and Las Campanas have much in common with CTIO, and there is frequent contact among the staff members. This can take the form of scientific interchanges relating to research programs or technical discussions about observatory operations and plans for new equipment. There is reciprocal use of library facilities, guest accommodations in La Serena and Santiago, housing (if available), and some administrative services. For example, CTIO provided cryogenic supplies to ESO until it obtained its own equipment, and CTIO still assists Las Campanas in this area. Naturally most of the operations are independent because of the distance separating the observatories, but the contacts that do occur are mutually beneficial.

Taken together, the four observatories constitute the largest collection of telescopes in one region located anywhere in the southern hemisphere, and are one of the largest in the world. Because of the excellent observing conditions in Chile, this potential is unsurpassed.

Construction of CTIO

Since construction companies were not interested in bidding seriously for the job of building the La Serena CTIO facilities, it was necessary to do the construction with AURA-employed workers and AURA-owned machinery. The successful completion of the early building program in La Serena led to the eventual construction by AURA of all of its buildings, including the

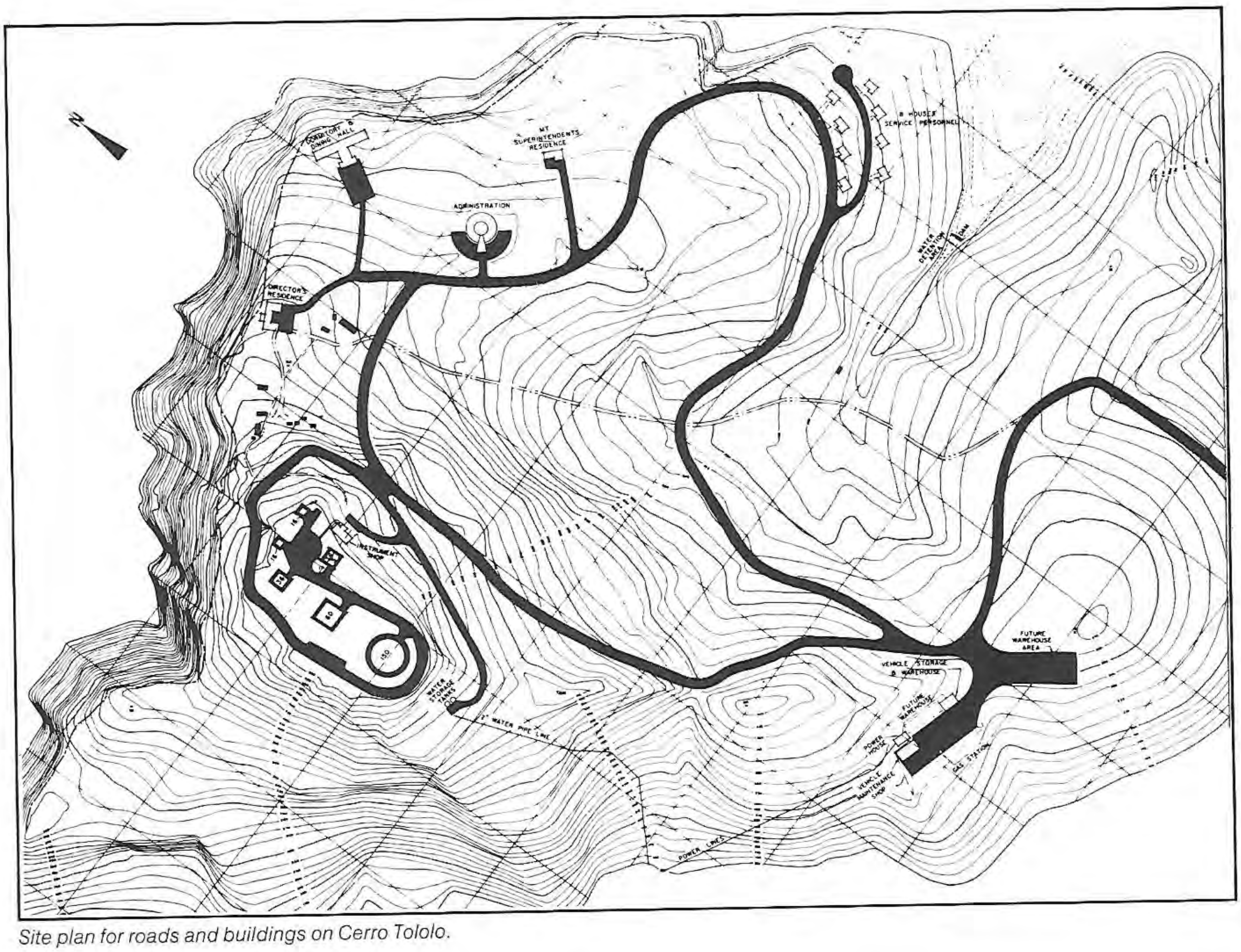
Victor M. Blanco, CTIO Director, 1967–81. During Dr. Blanco's tenure, major telescopes were constructed and CTIO gained international recognition.

monumental building that would eventually house the 4-meter telescope. AURA also constructed a 38 kilometer road from the La Serena-Vicuna highway to the top of Tololo.

In March 1964 the AURA Board approved a five-year master plan for the development of CTIO. That plan, included building a road, leveling a mountaintop, and developing reliable sources for water and electricity. The establishment of direct radio communication between KPNO and CTIO in 1964 was an important factor in implementing the master plan.

The development of a reliable water source had high priority. At about one kilometer below the Tololo summit, two natural springs in Los Placeres provided a convenient source. By June 1964 water was being pumped from Los Placeres to Cerro Tololo. The water delivery system was later improved, and by December 1965, a 50,000 gallon storage tank had been built near the mountain summit, and the pumping station had automatic filtering and chlorinating facilities. Unfortunately, the springs at Los Placeres dried up, and CTIO had to develop another water source in 1975. At that time, two more 50,000 gallon tanks were added for storage at the summit.

AURA's importation into Chile of the instruments and building materials required in developing CTIO were initially handled by the University of Chile, which generously made it possible for AURA to use its duty-free franchises. In January 1963, with University of Chile sponsorship, the Chilean Congress passed and President Alessandri signed into law a decree that permitted direct duty-free importations by AURA. Furthermore, in 1968 the Chilean Government, then headed by President Frei, extended to AURA the rights and privileges enjoyed by foreign employees of the United Nations branch office in Santiago. These included freedom from Chilean income taxes. During the trucking strikes in 1972 and 1973, President Allende took



Site plan for roads and buildings on Cerro Tololo.

steps to see that deliveries of food to the observatory were not impeded. In 1977 President Pinochet signed a decree declaring that CTIO holdings were a "privileged scientific sanctuary" where mining is prohibited. This removed a potential danger of the well-being of CTIO.

In 1963, the National Science Foundation approved funding for a 0.92-meter telescope for CTIO. Excavations for the buildings to house the 0.92- and the 1.5-meter telescopes, which had been funded by the U.S. Air Force, were started within weeks of the leveling of the Tololo summit in 1964. Also started then was the permanent housing for the 0.41-meter telescope that had been temporarily mounted during the site survey of Tololo in 1961 and for a second site-survey telescope of similar size and design that was received from KPNO. Due to excessive wear and maintenance costs, the old site-survey instruments were replaced in a few years by new ones of the same size.

The need for a Schmidt-type telescope at CTIO was satisfied by an agreement concluded in 1966 between AURA and the University of Michigan to transfer the Curtis telescope to CTIO on a 10-year loan basis, extended by 25 years in 1975. A building for this telescope was completed early in 1967, and the telescope was installed and first used in April of that year. Meanwhile, permanent buildings for the two previously mentioned 0.41-meter telescopes were completed in 1965 and soon thereafter, these telescopes began regular operations. The buildings for the 0.92- and 1.5-meter telescopes were completed early in 1967. The 0.92-meter telescope acquired from the Boller and Chivens Co. was installed outdoors in March 1967 and used by Dr. W. A. Hiltner, then the Acting CTIO Director; it was moved to its permanent building in May of that year. The 1.5-meter telescope, whose mounting was built by the Westinghouse Company, was installed in October 1967, and first light was seen through it on the night of November 6, 1967.

The 1.5-meter telescope had to be ready on that date since the official inauguration of CTIO was scheduled for the next day. The inauguration ceremony was attended by NSF and AURA officials, a delegation of U.S. Congressmen, the President of Chile, Sr. Eduardo Frei, and some 100 guests. Though the timely completion of the 1.5-meter telescope proved to be a very difficult task, the inauguration took place on schedule. One may add here that late in 1966, the Ford Foundation decided to donate up to $5 million on a matching-fund basis for the fabrication of a southern hemisphere 4-meter telescope similar in design to

Construction of 4-m on Cerro Tololo

the one then being planned for KPNO. The National Science Foundation was successful in persuading Congress to appropriate an equal amount of money, and also agreed to provide funds for long-range operations. On April 14, 1967, U.S. President Lyndon B. Johnson and Chilean President Eduardo Frei jointly announced at the Punte del Este Conference that the telescope would be installed at Tololo. Thus the future of CTIO as a truly major observatory was assured. This gave much importance to the November 7, 1967, inauguration as the guests could be shown the site of the future big telescope and be told about what could be expected from it.

Soon after the inauguration the decision was made to locate in the La Serena holdings all of the CTIO facilities that were not needed on the mountain top. Therefore, plans were initiated to relocate the observatory's instrument shop, the electronic and mechanical engineering facilities, the library, the receiving warehouse, the vehicle maintenance shop, and a computing center. At this planning stage, adequate offices were at last envisioned for the engineering and scientific staff. On Tololo were to be kept the relatively small electronic, instrument, and machine shop facilities required for quick maintenance of telescopes and vehicles, and also a storage warehouse.

The need to expand the La Serena facilities led to the acquisition of additional grounds contiguous to the eight hectares acquired in 1963. In 1965 a one-hectare lot with a residence was leased with option to purchase. It was occupied by several Acting Directors of CTIO during 1966 and 1967 before being refurbished. Eventually, this house was to be used as a school to serve the growing number of children of the U.S. engineers and scientists. Another land purchase in La Serena was made in 1968 when eight additional hectares were added. Eventually, nineteen prefabricated houses and apartments and a 9-bedroom motel-type building with lounge were erected on the newly acquired acreage. For recreational purposes, a tennis court and an indoor swimming pool were built with AURA corporate funds.

The main construction effort at CTIO in the year following the November 1967 inauguration was related to the 4-meter telescope. In the early long-range planning, space on the southern part of the Tololo summit was reserved for such a telescope. The excavation for the building started in December 1967. The "AURA Construction Company" tackled this job and successfully completed it in late 1972. The "topping" of the arch-girders that would support the rotating 475-ton dome took place on September 4, 1969. According to Chilean tradition, the last section of the arch-girders, located 43 meters above ground level, had national flags attached. The occasion was followed by a memorable barbecue for the 175 workers then employed in the construction.

Meanwhile, a 4-meter CerVit mirror blank was cast in June 1969 by the Owens-Illinois Company of Toledo, Ohio, and was being figured in the KPNO Optical Shop. Although a 150-inch blank had been ordered, expansion of the CerVit-casting moulds resulted in the delivery of a 158-inch blank i.e., exactly 4.013-meters. In order to take advantage of the additional inches, the telescope tube was enlarged during its design stage. The CTIO 4-meter telescope mounting and a similar one for KPNO were constructed by the Western Gear Corporation near Seattle, Washington. Dr. David Crawford and Engineer Lawrence Randall, both from KPNO, served as the in-house coordinators of the development work for the CTIO and KPNO 4-meter telescopes. Most of the telescope components arrived in the port of Coquimbo on June 1, 1973, in 86 boxes weighing a total of about 500 tons. Their transport to the Tololo summit was a memorable undertaking since parts of the shipment were very large. In the photo can be seen how a road-bed had to be dug up. An underpass had to be by-passed by an AURA-built road for the largest boxes in the shipment. Erection of the telescope mounting was started on June 24, 1973. This was accomplished by a team of fewer than ten

Low bridge!

individuals headed by a mechanic who had observed the erection of the KPNO 4-meter telescope. The mirror arrived on Tololo in September 1974, and on November of that year, an informal prime focus "first-light" ceremony was held. Fine tuning of the telescope and the addition of the Cassegrain secondary were completed by November 1975 and the first visiting astronomers started observing with this telescope in January 1976.

Meanwhile, in 1969, AURA built the housing for a 0.6-meter telescope that the Lowell Observatory acquired for planetary observations from Tololo. This telescope became AURA property five years later. In 1974, Yale University agreed to lend CTIO its 1-meter telescope, and it was put into operation in an AURA-built dome within a year.

In the 13 years that passed since the decision to develop CTIO, AURA has thus put into operation eight telescopes including the one that still is the southern hemisphere's largest. Only seven years transpired from the time its funding became available until it first saw light, an extraordinary achievement when one considers the complex support that telescopes require to operate effectively at their remote locations.

Facilities and Services at CTIO

CTIO offers one of the best observing sites on earth and some of the most sophisticated instrumentation available today to about 200 visiting astronomers annually.

The Four-Meter Telescope. In operation since January 1, 1976, the Cerro Tololo 4-meter aperture (158 inch) telescope ranks as the largest telescope in the southern hemisphere. Now equipped with both CCD (charge coupled device) and vidicon cameras and spectrographs, this telescope can measure faint objects at the limit of current technology. The observatory offers the following advanced instrumentation to visitors: a prime focus camera for photography or with

Rosette Nebula in Monoceros–NGC 2237, CTIO 61-cm Schmidt photograph a "grism" (grating/prism) for low-dispersion spectra; an advanced CCD camera which can reach 25th magnitude in one hour exposures; a spectrograph at the Cassegrain focus equipped with vidicon and CCD detectors; an echelle spectrograph for high-dispersion spectrometry equipped with a SIT (intensified) vidicon camera; and an IR photometer for mapping and star magnitude measurements in the infrared region of the spectrum. The telescope and its auxiliary instrumentation are operated by an extensive system of computers called "TOLNET." Finally, the observer need not wait to become dark-adapted to find the faint objects to be observed. The 4-meter telescope has several integrating acquisition television systems which enable the observer to find and guide on very faint objects.

Announced jointly by Chilean officials and the U.S. President at the Punta del Este Conference in April, 1967, the 4-meter telescope project began in the same month. Funding for the telescope was provided by the Ford Foundation and the U.S. National Science Foundation, each organization contributing approximately half of the cost.

The heart of the telescope is a 4-meter (158-inch) CerVit mirror fabricated by the Owens-Illinois Company. Opticians at Kitt Peak National Observatory, in Arizona, worked some 30 months to bring the mirror to perfection, and many scientists regard it as the finest large telescope mirror in the world.

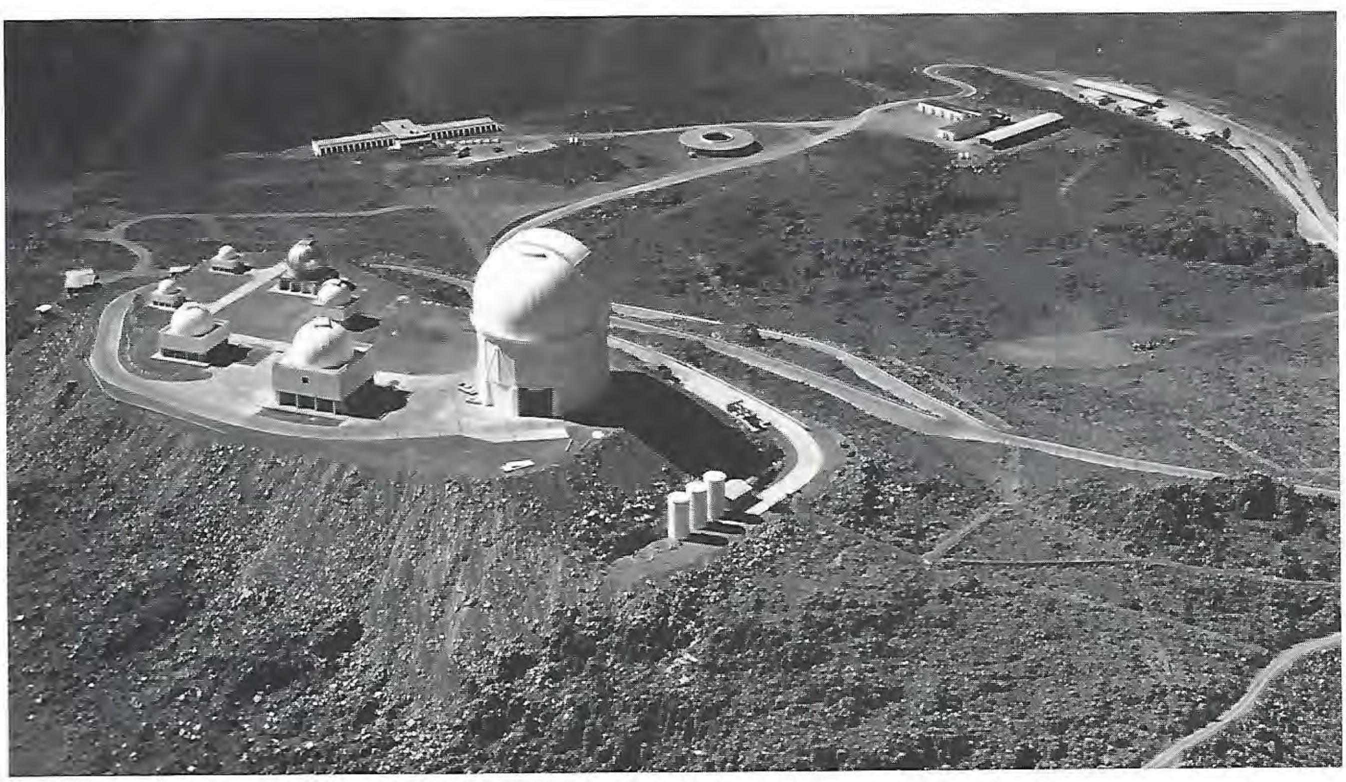
Housed inside a 38-meter (135-foot) high building and dome, the finished telescope has a length of 14 meters (45-feet). Its movable portion weighs some 300 tons, yet is so delicately balanced that one person can move it by hand. Also inside the 33-meter (108 foot) diameter circular building are shops, storage areas, offices, laboratories, and a modern library.

With its fast prime focus (f/2.8) and a unique "flip secondary" allowing fast instrumentation changes, the Cerro Tololo 4-meter telescope is among the world's most efficient and versatile instruments.

Other Telescopes at Cerro Tololo. Six other telescopes share Cerro Tololo: a 1.5-meter, a 92-centimeter, a 41-centimeter reflector, a 61-centimeter Schmidt telescope on loan from the University of Michigan, a 1-meter telescope on loan from Yale University, and a 61-centimeter telescope originally installed by the Lowell Observatory, Flagstaff, Arizona, for planetary observations.

All telescopes are equipped with cameras, spectrographs, or photometers, and all are used for visitor and staff research programs.

As an example of CTIO's site support for long-term research projects, it should be mentioned that beginning in 1982, CTIO will host a research program of the Columbia University. Columbia astronomers will complete an all-sky survey begun in the northern hemisphere at the millimeter wavelengths of carbon monoxide nebular emission.



Finally, CTIO offers computers for data-reduction support for visiting astronomers at the La Serena headquarters. The CTIO staff astronomers are always available to visitors for help both on the mountain and in La Serena. The CTIO libraries provide visitor and staff with research-level reference material so that their scientific productivity is in no way compromised while on a mission in Chile.

CTIO Visitors and Staff Research and its Scientific Impact

Undoubtedly, the major scientific impact of the establishment of CTIO was the opening of a major, modern southern outlet to American and indeed to world-wide astronomy. CTIO's greatest contribution has been its capability to offer astronomers a combination of excellent observational equipment, including the southern hemisphere's largest reflector, the 4-meter, as well as reliable observing conditions at an advantageous southern latitude. The observing opportunities that AURA created at CTIO led to important advancements in the understanding of the Galaxy and of the Universe at large.

CTIO's establishment was unusually timely since with the decade of the 1960s, astronomy entered a veritable golden age which has so far included the discovery of quasars in 1963, cosmic background radiation in 1965, pulsars in 1967, and Uhuru x-ray sources in 1970, neutron-star binaries in 1974, gamma-ray bursts in 1979, and most recently, gravitational lenses. One should also mention the findings of the International Ultraviolet Explorer and the Einstein x-ray satellites, and such spectacular advances in solar system astronomy as the discovery of solar coronal holes in 1973, the abnormal solar neutrino flux found in 1976, and all the remarkable results obtained by the planetary explorers. All this has led to drastic revisions in concepts of the large scale structure of the Universe and of the evolution of planets, stars, and galaxies. Astronomers are also now aware that extremely violent and energetic processes can occur in galactic nuclei. In short, astronomy had not advanced in such an accelerated way since the invention of the telescope. CTIO has made important contributions to these outstanding new developments.

Astronomy's new golden age resulted from an explosion in the application of high technology to astronomical observation. CTIO also contributed significantly to these technological breakthroughs. For example, the CTIO 1.5-meter telescope, inaugurated in 1967, marked a major improvement in anastigmatic large telescope optics. CTIO has been a pioneer in the development of computer-controlled telescopic data acquisition.

Garo Timmerman, CTIO scientist at work.

CERRO TOLOLO

Numerous scientific papers based on CTIO observations have been published in widely read journals. These papers represent the collective output of many hundreds of CTIO visitors and staff members. A measure of the way that CTIO has met the needs of American astronomers is the fact that 80 percent of the observers come from the U.S. Nevertheless, in keeping with the Inter-American nature of the observatory, practically all currently active Latin-American astronomers have observed at CTIO. Part of CTIO's role has been in helping in the further education and training of young astronomers. Some 75 graduate students have obtained doctoral-thesis data at the observatory.

The scientific impact of the work done at CTIO can only be summarized here in broad outline by mentioning some highlights. As one would expect, the most often quoted papers based on CTIO work have to do with the unique astronomical objects observable only at a southern hemisphere observatory. Foremost among these are the studies of our nearest external galaxies, the Magellanic Clouds. The first reliable determinations of their chemical compositions and of the evolution of their compositions with time were carried out at CTIO. Our knowledge of the structure of the Clouds as shown by their luminous young stars, by the medium-old asymptotic giant branch stars, and by the very old RR Lyrae stars, was considerably advanced at CTIO. Striking differences were found at CTIO when the ratio of the number of red giants of Carbon and M-types in the Clouds was compared to that in the Galaxy. This finding has given much impetus to the theory of stellar evolution beyond the main sequence. At CTIO color-magnitude diagrams of Magellanic Cloud clusters were determined as early as 1974 to magnitude 23. This pioneering work yielded the first reliable photometry ever made of extremely faint stars. At present this photometry is proving of great value in the calibration of the new charge-coupled-device two-dimensional detectors. Eight of the thirteen novae found in the Large Magellanic Clouds were discovered at CTIO, and the CTIO studies of the nature of the brightest stars in the clouds firmed up the determination of distances to remote galaxies.

The elucidation of the nature of galactic x-ray sources including the so-called x-ray bursters is largely based on CTIO studies. These x-ray sources are found most frequently in the central bulge of the Milky Way, a region that transits near CTIO's zenith and that can therefore be observed most conveniently. From this work which called at times for simultaneous optical and satellite x-ray observations, it was possible to conclude that the majority of galactic x-ray sources are binary systems with a neutron-star component.

Globular clusters may be regarded as fossil remains from the earliest stages in the evolution of our galaxy. These clusters are predominantly southern hemisphere objects, and the two brightest ones, ω Centauri and 47 Tucanae, are at high southern declinations. Globular clusters have in the past been regarded as formed by coeval stars of similar chemical composition, but new CTIO observations show that these assumptions may have to be re-examined. The appreciable width found by CTIO observers for the giant branch of ω Centauri may not be explained without assuming non-uniform chemical composition and/or a lack of coevality. The spectra of individual stars in, say, 47 Tucanae also suggest appreciable composition differences.

Cosmological advances based on CTIO observations have also been significant. The all-sky coverage provided by combining CTIO and northern hemisphere observations has resulted in new insights into the properties of the expansion of the universe. The most distant known components of the universe, the quasars, have received much special attention at CTIO. Most of the known high redshift quasars, whose study now suggests strongly that few quasars with redshifts higher than 3.5 exist, were discovered at CTIO. Interpretation of the quasar redshift as caused by the expansion of the universe suggests that the visible edge of the universe may have been detected. Can anything be found that is still farther out? Symbolic of CTIO's role in frontier astronomical research has been the recent search by means of infrared scans of objects that may be older and farther away than the quasars with the highest redshifts.

Vacuum Tower Telescope at Sacramento Peak Observatory

SACRAMENTO PEAK OBSERVATORY

Located at Sunspot in southern New Mexico at an altitude of 9,200 feet, the Sacramento Peak Observatory was founded and operated by the United States Air Force from 1952 until 1 July 1976, when AURA assumed management responsibility under contract with the National Science Foundation.

Role of SPO in American Astronomy

SPO is a national solar observatory with two major tasks: to provide research facilities and services for visiting observers (primarily from U.S. universities and observatories, but with a few every year from abroad) and to carry out in-house research programs on several of the frontiers of solar physics. The scientific staff is comprised of 15 astronomers, including six funded by the Air Force and NASA.

In the belief that parochialism in solar astronomy should be actively resisted, SPO invites visiting astronomers, usually from abroad, to spend one or two years at Sacramento Peak. They are encouraged to be active in giving colloquia at other institutions and in attending the solar symposia that occur during their stays. One or two such visitors are usually in residence at any one time, and their contributions enrich both the observatory program and solar physics on the national scene.

Recruiting experience over the years has emphasized the shortage of bright young people particularly interested in solar physics. As a partial remedy, SPO has supported a group of eight or ten graduate students of physics or astronomy for twelve weeks each summer. These students serve as assistants to staff scientists and learn some of the "nuts and bolts" of observational research. Typically, one or two of them each year have gone on to write dissertations based on their observations at SPO.

Another SPO activity for the solar physics community is a symposium held each fall at the observatory. It is always devoted to some limited topic, such as sunspot physics or solar research instruments, and is planned with the expectation that attendance will be limited to a small group of specialists. The symposia have always had more than ample attendance, with a good fraction of the participants coming from other countries.

AURA Assumes Manager Role

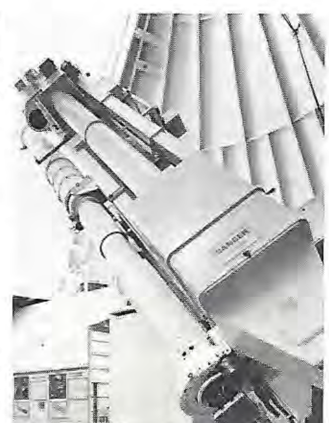
After building SPO and operating it for 22 years, the U.S. Air Force reluctantly decided to end its support of this basic research activity and to transfer the observatory to some other supporting agency. The field of potential supporters quickly narrowed to the National Science Foundation which accepted the responsibility for SPO after a favorable report in early 1976 on the observatory's scientific credentials by the ad hoc Committee on the Sacramento Peak Observatory, headed by Dr. Martin Schwarzschild. On 1 July 1976 NSF designated AURA as the temporary manager for SPO while a permanent manager was being selected.

The Foundation then assembled a Special Advisory Committee, chaired by Dr. Arthur B. C. Walker, to consider the proper role for the observatory and an appropriate level of support. On receiving the committee's report in the spring of 1977, NSF adopted its recommendations. The Foundation then issued a formal Request for Proposals for SPO management and after considering several proposals, selected AURA as the permanent manager in October 1978. SPO became a user-oriented, national observatory with the remainder of its mission essentially identical to that originally established by the Air Force.

Air Force Activities at SPO

Even though the Air Force (AF) no longer felt it could justify continued total support for a basic science institute of SPO's magnitude, there were, however, some portions of SPO research that the AF regarded as highly relevant to the AF mission. Accordingly, an agreement was negotiated between NSF and the AF to retain at SPO the Solar Physics Branch (SPB) of the Air Force Geophysics Laboratory (AFGL). This is a group

Above: Jack B. Zirker, SPO Director



varying from four to seven astronomers supported by a research assistant, a programmer, an electronics engineer and a secretary. Normally there is also one Senior Research Associate appointed for one year by the National Research Council and funded by the AF. Five of the SPB staff had been SPO employees long before the transition to AURA, a fact which eased the melding of SPB into the SPO program. The members of SPB are regarded as members of the observatory family, with the same access to instruments, shops, services, and supplies as the AURA employees. The SPB astronomers share in the assistance from and training of the summer graduate students. They join with their AURA colleagues in the containment of the summer students' extracurricular exuberance, including the annual end-of-season volley ball challenge to the observatory staff.

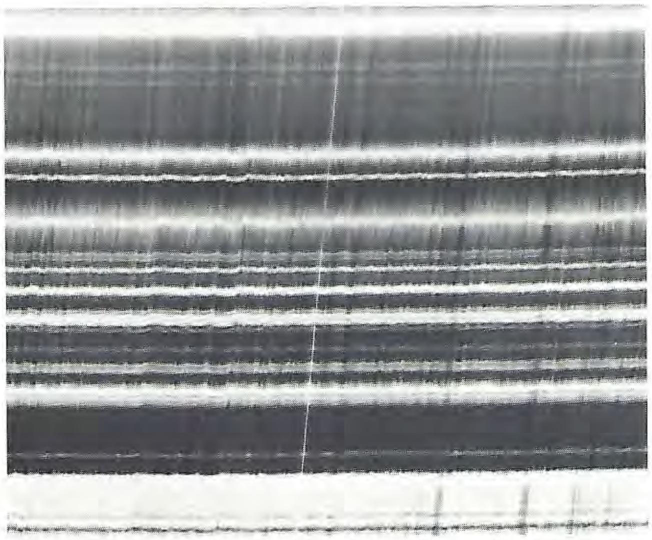
The SPB mission is the study of those solar phenomena that excite geophysical responses, and the physical links between the solar and terrestrial activities. In particular, their work includes the high energy and magnetic phenomena of the flares and their whole solar environment, from below the photosphere into the corona. One of the astronomers works mainly on the detectable forms of activity of the solar-type stars, using the 48-inch Cloudcroft telescope.

In addition to funding its employees at SPO, the AF also contributes its fair share toward the operation of the observatory. It has also contributed quite substantially to the instrumentation of the observatory, often in outright grants, and occasionally by the purchase of some needed item, such as a charge coupled device (CCD) array.

SPO Service to Visiting Observers

SPO's responsibility as a national observatory is to develop the most advanced solar observational tools and to make them easily available to visiting observers. The excellence and effectiveness of the visitor program takes first priority for the SPO astronomers and the observers who operate the instruments. The friendly relations between the staff and their guests, and the lively scientific interaction, are incidental benefits of considerable value to both SPO and the visitors.

Any researcher with a worthy solar project appropriate to the SPO facilities is encouraged to consult an SPO User's Manual at his library or department and to submit a proposal. One or more external referees evaluate all proposals for scientific merit and feasibility. The observatory Telescope Allocation Committee then assigns the proposals to available time on the observing schedule. Each visiting observer has an assigned host and advisor from the staff, one who has some experience related to the visitor's proposed research. The host shows the visitor the ropes of the slightly spartan life at Sacramento Peak and assists when needed with the scientific project. The extent of the advisor's involvement varies from merely smoothing the way for an experienced observer to helping an inexperienced observer with the design of an achievable observing campaign from start to finish. Often,



Above: A small length of the Solar Spectrum (7.7Å) centered near λ = 3886 Å–Tower Telescope with echelle spectrograph.
Right: The sun in Hα light, about 150,000 by 170,000 km.

the advisor's participation grows into a genuine collaboration lasting far beyond the observing sessions and resulting in one or more joint papers.

The principal observing equipment consists of the Tower Telescope, which has excellent resolution, and the 40-centimeter Coronagraph, each with its accessories. The Tower Telescope was designed to provide the sharpest possible image of small solar details. It has a 76-centimeter aperture and 55-meter focal length. Its optical path is enclosed in an evacuated tube to avoid internal convection, which would otherwise blur the image. The telescope projects the solar image onto the slit of an unique Echelle Spectrograph, which can be set up to record simultaneously half a dozen short segments of the spectrum at chosen wavelengths. The spectrum is recorded photographically, or by a divisible linear diode array that can be shifted to any desired position in the focal plane. Two CCDs are also heavily used by visiting observers.

Another popular arrangement consists of a sturdy bench that can hold an experimental instrument in the focal plane of the telescope. Visitors use it to try devices such as a high speed guider to eliminate atmospheric image jitter, testing of a very narrow band filter built for a Spacelab experiment, and tests of various active "rubber mirror" devices to compensate for wave front distortions produced by poor seeing.

The 40-centimeter Coronagraph at the "Big Dome" feeds light through a hollow polar axis to a fixed solar image, which may be projected onto a 13-meter high dispersion spectrograph or a 1.5-meter universal spectrograph. The 13-meter spectrograph records photographically, or it may be used as a photoelectric double pass scanning spectrometer, recording line profiles either digitally on magnetic tape, or on a chart recorder. A CCD array detector is also available. Some of the other observing instruments are the 20-centimeter full limb filter coronagraph, white light flare polarimeter, a photoelectric coronal photometer, and others which make up a list of some 30 items.

For the photographic data analysis the principal instrument is the Fast Microphotometer, which digitally records the film density at a rate of up to 7500 data points per second, in a highly flexible raster pattern.

Computer facilities are available for digital recording of observational data, data processing, and scientific calculations. The equipment includes a Perkin Elmer 3242 with three 300 megabyte disk drives and four tape drives, multiple terminals and a number of other peripherals. There is also a Perkin Elmer 3220 computer at the Tower Telescope and one at the coronagraph, each with quick-look facilities and a number of peripherals for managing the flood of data that pours in from the various diode arrays.

For more general computations not involving observational data, a few users have acquired terminals at their home institutions and consequently have used the 3242 background capacity. The rather scant experience with this kind of operation indicates that it is reasonably satisfactory.

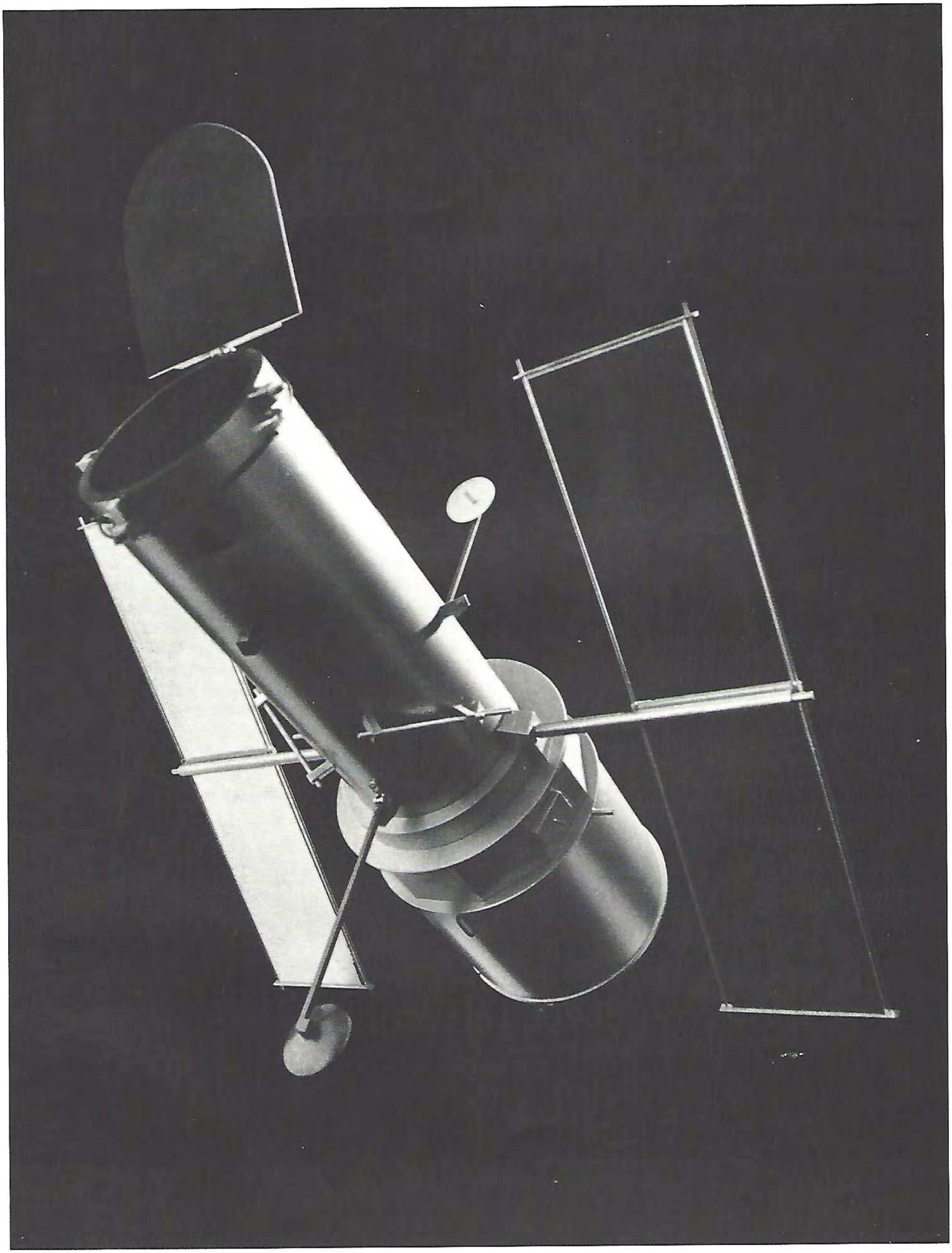
Research

The majority of staff and visitor research projects deals with the intimately related problems of the internal structure of the Sun as revealed by the large- and small-scale modes of surface oscillations (solar seismology), cyclonic flows, boiling on the Sun's surface, the non-uniform rotation of the Sun, and the resulting magneto-dynamic phenomena responsible for the 22-year solar activity cycle. Other solar problems currently being investigated are: the physical nature of flares and other forms of solar activity, the structure of the corona and its merging with the solar wind, and the probing of sunspot structure below the visible surface by observable umbral and penumbral oscillations.

The Sacramento Peak Observatory has also undertaken a long-term commitment to the study of the Sun as a star, hoping to stimulate activity in this potentially very rewarding field among solar and stellar astronomers elsewhere. The SPO observers are finding luminosity variations in Sun-like stars of the Pleides and Hyades clusters. They tentatively attribute these variations to gigantic dark "starspots" on the rotating stars.

Since the beginning of solar research from space, SPO has participated as a ground-based partner. A sizable class of experiments require simultaneous observations in the visible spectrum from Sac Peak and in the x-ray or ultraviolet spectrum from a spacecraft. In a number of instances, SPO astronomers have participated as co-investigators in the initiation and design of space experiments, and in the direction of the experiments during flight.

SPO looks forward to joining forces with the Solar group at Kitt Peak National Observatory. One important effort will be upgrading the McMath telescope for use in long-term monitoring of rotation, chromospheric activity, magnetic field, and especially for surface oscillations in solar-type stars.



Model of the Space Telescope

SPACE TELESCOPE SCIENCE INSTITUTE

C. Robert O'Dell

The Space Telescope will be the greatest single advance in optical astronomy since Galileo's first astronomical telescope. This statement is well founded because optical astronomy has progressed only in small increments in the last three and one-half centuries. The cumulative progress has been enormous, but the Space Telescope will stretch the frontiers more than any other step. Our ability to image faint objects is limited by the random aberrations of the atmosphere (seeing) to a figure of about one arcsecond with enormous efforts made to locate observing sites less than a factor of two better. The Space Telescope will certainly provide images a factor of ten better in the visual window and perhaps an additional factor of four in the ultraviolet. The wonders revealed by unambiguous direct imaging at 0.1 to 0.025 arcseconds resolution are difficult to predict, but they should be many. Astronomers will be able to look into the nuclei of galaxies, at regions of star formation, at the weather patterns of the outer planets, and detect Jupiter type planets if they exist around nearby stars.

Not only will the Space Telescope form clearer images, it will also detect fainter objects. The sharp contrast of the small Space Telescope images against the dark sky found in earth orbit will give limiting brightnesses of detection about 50 times fainter than large ground-based instruments.

There is a wealth of observational programs to be carried out using the wide wavelength range, high optical resolution, and faint object detection capabilities of the Space Telescope. There have already been several conferences to identify the most important areas to be exploited, but even these projections are based on questions that astronomers know how to formulate. Many of the most significant contributions of the Space Telescope will probably be to areas of investigation about which nothing is known at this time.

The Origins of the Space Telescope

The concept of a space observatory goes back to the writings of Herman Oberth in 1923 and a more realistic, yet still visionary, appraisal by Lyman Spitzer, Jr., in 1946, the latter writing more than a decade before the first artificial earth satellite and the formation of a United States space agency. The construction of a space observatory soon became a national long-range goal of the National Aeronautics and Space Administration (NASA) science program, but other projects had to be done first to establish the technology base for the Space Telescope. In the late 1960s the National Academy of Sciences strongly endorsed what was then called the Large Space Telescope, and in 1971 NASA began direct activity to carry out this program. After many delays, the Space Telescope program began hardware development in 1977.

The Space Telescope is not just another space science project. It is the first quasi-permanent space observatory, being designed to be serviced and modified for decades from orbit and by means of brief returns to earth. Moreover, it is an observatory in the same mold as existing ground-based giant telescopes. Its roots are in the pioneering spirit of space astronomy as well as in traditional optical astronomy. Many of the planners have come from both backgrounds. Space Telescope will not make large ground-based telescopes obsolete, it will make them even more valuable.

The Design

The observatory design is very naturally divided into specific elements: the optical telescope which forms the images; the scientific instruments, which utilize the images; the spacecrafts, which provides the services of pointing, control, power, data storage, and communications.

The optical telescope is a 2.4-meter, F/24 Ritchey-Chretien design. The optical surface of the mirror has been measured to have a system wave front

Right: Riccardo Giacconi STScI Director error of less than 1/60° of a wavelength rms at 633 nanometer. This quality reflects the precision of the primary and secondary mirrors and also the alignment stability of the graphite-epoxy supporting truss structure. Many innovations in design have been made to allow construction of such a lightweight but precise optical system.

The five scientific instruments which share the Space Telescope's focal plane are independent of one another. There are two cameras of various field sizes and resolutions, and two spectrographs which provide spectral resolutions little better than simple colors to very high purity as needed for studying the interstellar medium. The final instrument is a photometer, capable of very high (microsecond) time resolution. A critical part of the guidance system are the three Fine Guidance Sensors. These can function as an astrometric instrument since only two are needed for guiding. This complement constitutes a versatile observing capability, similar to that on large ground telescopes. Like ground telescopes, this complement is expected to change with time as new, even more powerful instruments are developed.

The spacecraft portion of the observatory provides the support systems necessary for operating the telescope/scientific instrument combination. In the toroidal ring surrounding the primary mirror are the electronics necessary for communicating with the ground, storing data, distributing electrical power, and monitoring the status of the observatory. The solar arrays are attached to this portion. These arrays, like one of the cameras, are being provided by the European Space Agency. Commands and data will flow through the Tracking and Data Relay Satellite, which will provide real time control of the observatory about 20 percent of the time. The remainder of the time the observatory will be controlled by commands stored on-board and will store the scientific data on tape recorders.

The operations system is an integrated net of facilities that starts with the spacecraft, progresses through the Tracking and Data Relay Satellite System, includes the Payload Operation Control Center at the Goddard Space Flight Center, then starts and stops at the Space Telescope Science Institute. The complex division of responsibilities reflects the need for NASA's retention of operations authority and the need for the Space Telescope Science Institute to determine the science that is done.

State of Development

Eleven years have been spent in developing the Space Telescope program. The remaining period will be very busy, although major elements have already been completed. The primary and secondary mirrors have been completed and are being mounted. The structural components are complete and the whole telescope assembly is being brought together. The scientific instruments are in final fabrication and will be delivered by the summer of 1983. The myriad other elements are all well under way, leading to integration into a total observatory in 1984. The schedule calls for launch of the Space Telescope aboard the Space Shuttle in March 1985. There is nothing to indicate that the date cannot be met, or at least one in the first half of 1985. Space Telescope is a large and ambitious undertaking, and the launch of the Space Telescope will be only the beginning of the program for many scientists, including those involved in the decade of development. It will be well worth the effort.

—C. R. O'D.

ST ScI Site Selection and Proposal to NASA

AURA chose The Johns Hopkins University (JHU) Homewood Campus in Baltimore as the site for the Space Telescope Science Institute through a selection process started with consideration of the report of the Hornig Committee (established by the National

The Space Telescope's primary mirror after coating

Academy of Sciences), entitled "Institutional Arrangements for the Space Telescope." This report set forth a number of criteria which the Hornig Committee deemed applicable to possible geographic settings for the ST ScI. As a consortium of universities spanning the nation from Massachusetts to Hawaii and from Wisconsin to Texas, AURA had no *a priori* preference for a particular location for the Institute. Thus AURA's *ad hoc* Committee for the Space Telescope Science Institute identified ten potential locations that satisfied the siting criteria recommended by the Hornig Committee. Starting in December 1978, AURA began informal inquiries to determine if there was interest at several potential host institutions in cooperating with AURA to develop cases for locating the ST ScI at those sites. As a result, six informal cooperative agreements were made which led to the joint preparation of preproposals by AURA and the potential host institutions. These preproposals proved to be good tests of how well AURA might work with each of the host institutions and provided a means for developing the best joint ideas on what would be important in managing the ST ScI.

Since AURA did not have the financial resources either to acquire needed land or to construct the building required for ST ScI, a significant aspect of the preproposals was the host institution's commitment to supply land and housing for the Institute. Other intangible factors considered included an assessment of the synergistic relationships that could exist between AURA ST ScI, the astronomical community and the host institution. Each host institution was asked to prepare those portions of a preproposal which dealt with the particular location and site characteristics and financial factors involved. AURA provided those portions of the six preproposals which dealt with:

- background, roles and organizational interfaces;
- why AURA for ST ScI management;
- the ST user community and its needs;
- functions required of ST ScI;
- ST ScI startup requirement and management approach;
- plan for ST ScI startup/criteria phase operation; and
- transition to fullup institute operations.

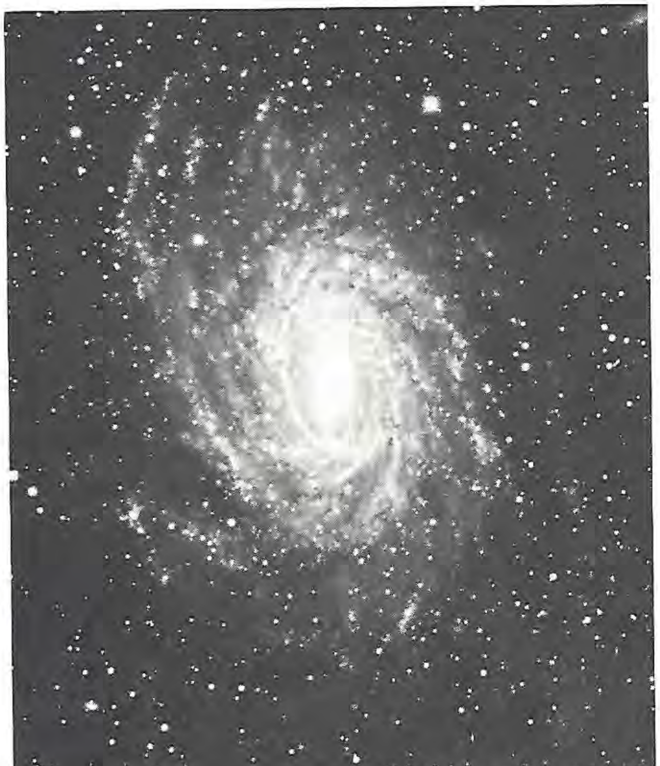
The six preproposals were reviewed by a panel of eight reviewers selected for their collective knowledge or background in the fields of space astronomy, management, and operation of national centers similar to the ST ScI, as well as by AURA's *ad hoc* Committee for the ST ScI. In addition, the preproposals were evaluated by two European astronomers chosen because of their perspectives on the needs of astrono-

A model of the ST launch from the Space Shuttle.

mers associated with the ESA community. AURA also enlisted the services of the Chief Executive Officer of Blanton and Company, Tucson-based architectural and engineering firm. His task was to review the preproposals and evaluate the realism, completeness, rigor, and advantage to AURA and to NASA of the physical site, proposed financial arrangements, proposed buildings, and the implications of geographic location with regard to communications quality and expense. Based on the information in the preproposals, each reviewer prepared a "bottom line" recommendation as to the best combination of site and AURA-management approach.

The results of the evaluation of the preproposals judged the AURA/JHU preproposal as the strongest, the AURA/JHU team as the best combination, and the JHU site as the best location for the ST ScI. The *ad hoc* committee recommended and the AURA Board of Directors confirmed JHU as AURA's choice for host institution and site for the ST ScI.

In anticipation of the detailed and complex proposal to be submitted to NASA for establishment and management of the ST ScI, AURA entered into a Teaming Agreement with the Computer Sciences Corporation (CSC) of Silver Spring, Maryland, for assistance in the preparation and production of the proposal. CSC would also serve as a major sub-contractor if AURA were to be chosen to establish and manage the ST ScI. Dr. Barry Lasker headed the team which developed the technical/scientific portions of the proposal; Dr. David F. Welch was responsible for the business portions; Dr. John Teem had overall responsibility for the proposal; and Dr. Arthur D. Code, as Chairman of the AURA Board of Directors, provided guidance and oversight.



Galaxy in Pavo—NGC 6744. The ST will enable more detailed study of galaxies like this.

The proposal was developed over a six month period and involved other AURA employees, consultants, CSC scientists and management personnel, AURA Board members and JHU faculty and staff. The initial seven-volume submission to NASA was on March 3, 1980. During the following several months, a NASA Source Evaluation Board (SEB) studied the proposals submitted by AURA and other bidders. This process resulted in a series of questions to bidders on their submissions designed to clarify for the SEB certain aspects of the proposals. AURA's final proposal clarification was submitted on October 31, 1980.

The ten weeks which followed seemed interminable; however, on January 16, 1981, NASA Headquarters announced that AURA had been selected to manage the ST ScI. The contract was negotiated and signed on April 10, 1981, to be effective as of February 17, 1981.

The Role of the ST ScI in Astronomy

The Space Telescope Science Institute (ST ScI) is an independent research institute operated by AURA under contract with NASA. The primary function of the ST ScI is to conduct the science program of the ST so as to maximize scientific return. This is of singular importance because of the magnitude of the ST project and the enormous leap ST will provide in man's capability to probe and understand many aspects of the universe. Constituted largely in accordance with the recommendations of a 1976 National Academy of Sciences Working Group, the ST ScI represents an entirely new approach to NASA's operation of facility class scientific missions. It is an experiment whose outcome may profoundly influence the manner in which the next generation of facility missions are operated.

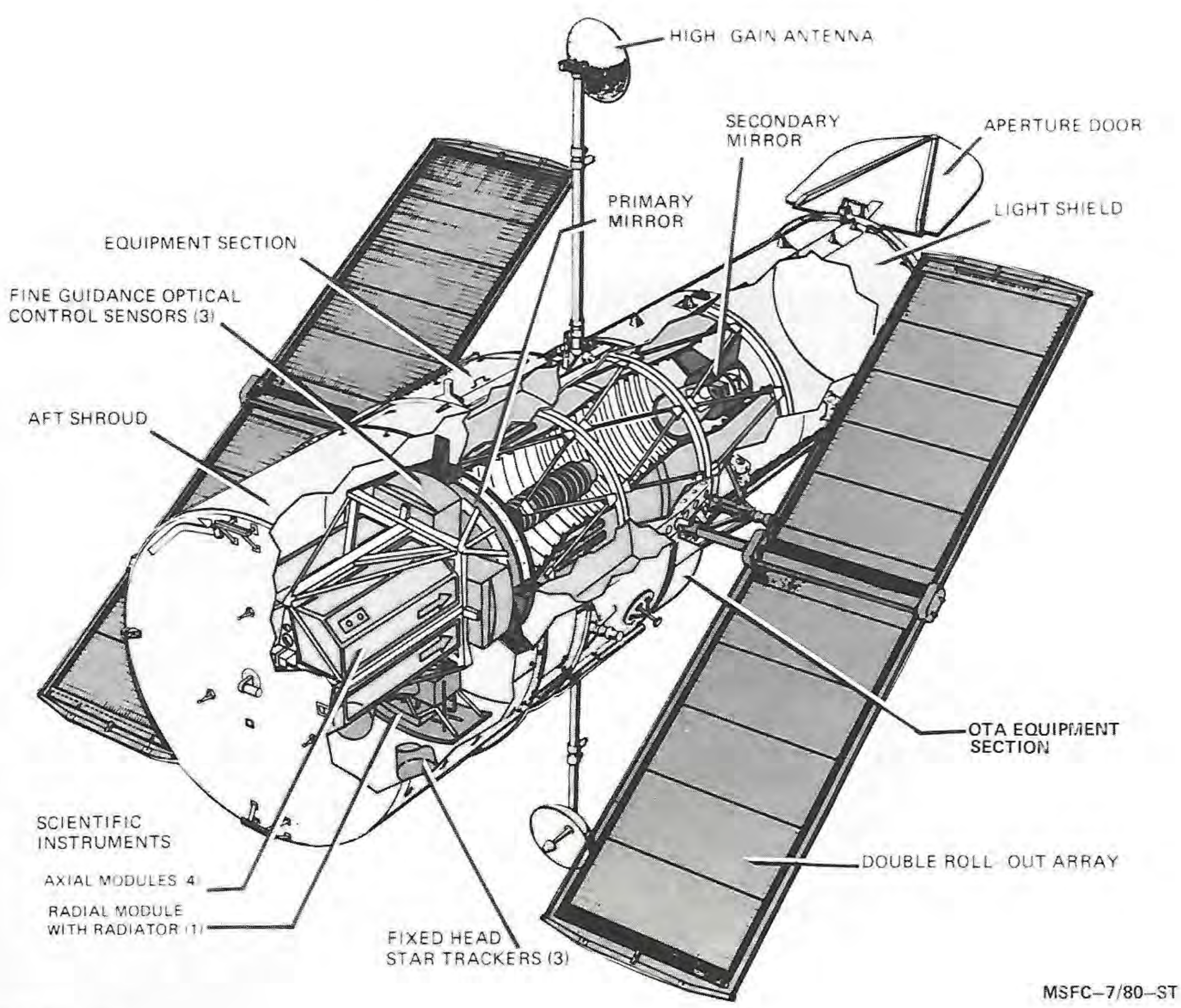
The ST ScI is still in its infancy and many of its eventual roles in astronomy are not apparent today. However, several major areas are readily foreseeable.

Members of the astronomical community will interact with the ST ScI as proposers, observers, archival researchers, instrument definition team members and visiting scientists and by attending meetings, seminars and workshops. They influence the ST ScI through their representation on the AURA Board of

Directors, the Space Telescope Institute Council (STIC) and the members of the Visiting Committee, Users Committee, Time Allocation Committee and Search Committee. Through a formal NASA/ESA memorandum of understanding, ESA is appointing 15 ST ScI staff from member countries. Proposals to observe with ST are expected to come from throughout the international astronomical community. In addition to the community interactions, the ST ScI has responsibility to

- develop science observations capability procedures;
- develop an integrated observing schedule to control the scientific use of the ST and its instruments;
- process, archive, and publicize the scientific data derived with the ST, making this information accessible; and
- evaluate the scientific performance of the ST observatory and its individual scientific instruments and advise NASA on observatory status, and the necessity for instrument repair, refurbishment, or replacement.

Pivotal to the concept of the ST ScI is the need to establish a scientific staff whose members, individually and jointly, are of the first rank to perform the functions outlined above and to conduct their own research related to the ST. It is ST ScI policy that scientific staff appointments be based principally on research ability and a staff of the highest research caliber is currently being recruited. The assembling of a staff of more than 40 research scientists with diverse interests, backgrounds, nationalities, and previous organizational affiliations is a situation unique in current astronomy. It is apparent that staff research at ST ScI has the potential to play a major role in the Astronomy of the 1980's and beyond.



ST configuration

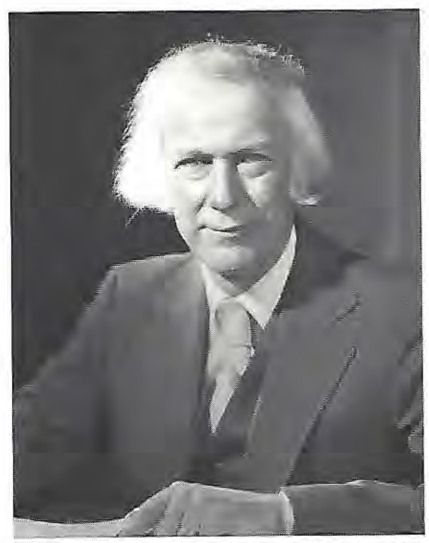
Present Status of ST ScI

The ST ScI began its existence in mid-March 1981 when the AURA interim staff began assembling at The Johns Hopkins University (JHU) in Baltimore, Maryland, under the leadership of the Acting Director, Dr. Arthur D. Code. The initial permanent Director, Dr. Riccardo Giacconi, was appointed early in the fall, and by the end of 1981 the ST ScI was staffed almost entirely by permanent appointees.

As of September 1, 1982, the ST ScI staff consists of 51 AURA personnel and 16 Computer Science Corporation (CSC) personnel provided under an AURA/CSC subcontract arrangement. The current scientific staff of 18 (including the first of ten ESA-appointed scientists and two postdoctoral fellows) is drawn from 15 disparate organizations and now clearly constitutes a 'critical mass.' It is ST ScI policy to support the scientific staff in active research programs and most of the scientific staff are continuing the previous research and/or moving into new areas.

The ST ScI staff are presently housed in temporary office space rented from JHU on the JHU Homewood Campus. Construction by JHU of a new facility to permanently house the ST ScI staff is proceeding on schedule near the western perimeter of the campus. The building is expected to be occupied in the spring of 1983. It will provide a congenial research atmosphere with offices looking out onto wooded parkland, a library, an auditorium and a cafeteria. Computer operations and laboratory facilities are also included.

Long-lead and time-critical activities are already well underway at ST ScI. Definition of technical management and operations concepts has been crystallized and preliminary documents have been submitted. The Guide Star Selection System (GS^3) which will select reference stars used to point ST is proceeding on schedule. Schmidt survey plates and supporting photometry are being obtained. Two VAX 11/750 computers are operational, and the first of two Perkin Elmer 2020-G PDS measuring engines was delivered in August 1982. The development of a Science Data Analysis System is proceeding and a VAX 11/780 is being procured. Instruments Scientists are participating in the integration and calibration of scientific instruments. ST ScI staff are interacting



Left: The Science Institute Facility under construction.
Above: Arthur D. Code, Acting Director STScI, January 15–September 1, 1981, and AURA Board Chairman, 1977–80.

with TRW in development of the Science Operations Ground Support System (SOGS) which will support operation of ST and acquisition of data.

The Function of the ST ScI After Launch

After launch the primary function of the ST ScI will be to conduct the science program of the ST. After an initial system checkout and science verification activity lasting three months, observing time has been assigned to the scientists associated with the development of ST and the Science Instruments, for a steadily decreasing fraction of available time: 100% for two months, 50% for an additional six months, 25% for the next year and 10% for the next ten months. This amounts to an average use of 30% time during the first two and one-half years of the mission; correspondingly an increasingly large fraction of the time, amounting to 70% in the first two and one-half years, will be devoted to openly solicited, peer-reviewed, and competitively selected proposals. Scientific staff members of the ST ScI will also obtain observing time through this competitive procedure. It is expected that on the average scientists from ESA member states will capture at least 15% of available time for Guest Observers (GOs).

The observing process will begin with a solicitation for proposals (planned to be issued every six months). A user's guide containing detailed descriptions of the ST, the science instruments (SI) and ground system will be provided by the ST ScI. This guide will contain instrument parameters, filter/grating selection, exposure/integration times and data format, instrument sensitivity, background, wavelength range, resolution, and other relevant parameters. (These parameters will be updated as orbital data are accumulated.) The user' guide will also contain target acquisition modes, calibration requirements and lists of standard calibration targets—in short, the necessary information to design a scientific observation.

Proposals will be analyzed by ST ScI staff for technical feasibility and scheduling constraints. They will be submitted to expert outside reviewers for comments on scientific merit. Results of the evaluation will be made available to the Time Allocation Committee (TAC) which will advise the Director on priorities. The TAC will be composed of eight to twelve scientists broadly representative of astronomical disciplines, chaired by a senior ST ScI scientist, and will include a NASA and an ESA observer.

Priority allocation is the responsibility of the Director. A Director's discretionary time, consisting of a fraction between 0% and 15% of available time, is reserved for non-peer-reviewed observations that may become necessary for scientific support activities, for acquisition of targets of opportunity, and for high-risk or long-term programs not amenable to peer review. Actual utilization of this time will be reported periodically by the Director to the STIC.

Upon scientific proposal selection, the mission operation and scheduling group will begin to prepare an integrated observing plan six months prior to execution. This is required to prepare for Guide Star selection, for full identification of instrument modes and calibration requirements and for detailed sequencing of observations. In general, individual targets from several GO programs will be intermixed in the sequencing process. Some planning constraints are related to each fixed phenomenon, such as the location of the South Atlantic Anomaly, Tracking & Data Relay Satellite System (TDRSS) visibility and location of ground-based observatories. The ephemeris of ST will be known some 60 to 30 days in advance of observation with sufficient accuracy to set absolute times for events. At this point, monthly operating plans can be forwarded for comments and successive interactions to the Science Support Center (SSC) which will generate Science Missions Specifications, and transmit them to the Payload Operations Control Center (POCC), some 24 days prior to observations. The program will be finally fixed in detail some 24 hours prior to observations.

The Host Scientist is a key concept in the ST ScI support of Guest Observers. Most scientists on the ST ScI staff will serve as Host Scientists. The specific assignments will attempt to match the nature of the GO program with the expertise of the staff scientist. Hosts will be named in the Director's letter awarding ST time. The Host will remain in contact with the GO as the program develops. As needed, the Host will refer the GO to the guide star selection, the scheduling, and the observing groups, who will be responsible for the detailed support. After the GO arrives at the ST ScI, the Host will discuss with the GO the operation of the ST ScI, the observing procedures, and the data reduction and analysis facilities.

The routine day-to-day operations of the Observations Support System (OSS) will be carried out by members of the ScI staff—the Operations Astronomers (OAs), and Console Operators (COs). There will be many routine observations that require no real-time interaction and, hence, the GO need not be present. In these cases the OAs will monitor the execution of these observations, noting any problems in areas such as target acquisitions, SI performance, and data quality. Logs of any comments will be available to the GO when he accesses the data. There may be some cases when the GO cannot be present during a real-time observation, in which case the Host Scientist or OA will fill in. Experienced GOs will usually carry out their observations with the OAs and COs, with no need for the Host Scientist to be available in the OSS. In all real-time interactions, the COs or OAs will be responsible for initiating command procedures. GOs and OAs will be responsible for evaluating the data quality and deciding which command procedure to initiate. GOs will be responsible for making scientific decisions.

Archival Research

Archival Research will be another major area of the ST science program. ST data will be maintained in an archive at the Science Institute. As this data base builds up, there will be increasing interest within the scientific community to use it for purposes other than those for which it was originally collected. Astronomers will be able to propose archival research (AR) programs that make use of this data base.

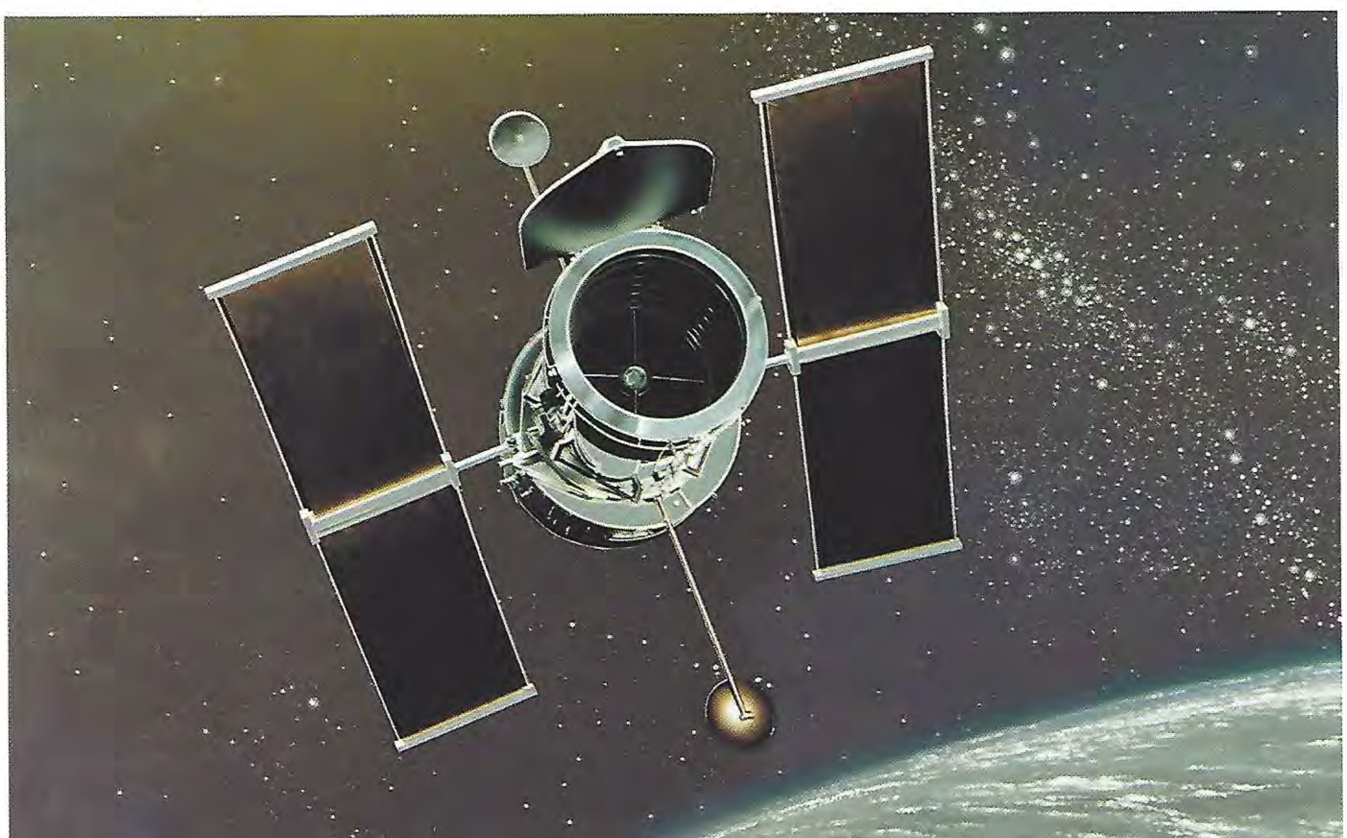
The observation catalog will index all the science data taken with the ST. There also will be information as to where the archived data are stored (e.g. tape labels). There will be a software mechanism available that will allow a user to query the archive catalog to determine what data are available. The mechanism for providing this information to users outside the ST ScI is not yet defined, although a remote link is a possibility.

An AR proposer will use the catalog search to determine whether the archives contain data relevant to a specific research interest. Based on the conviction that the archives are likely, or guaranteed, to contain relevant data, and AR will submit a proposal to the ScI. The information required for an AR proposal will be substantially less than for a GO proposal. The Science Planning and Scheduling System (SPSS) will be used to enter proposal information, search for duplicate proposals, verify that the requested data are in the archives, and prepare summary and statistical breakdowns of the AR proposal pool to the Director. Ideally, all scientifically valid AR programs would be approved.

The Impact of ST ScI on Astronomy

It is clear that use of the ST promises significant advances in the pursuit and extension of many of the outstanding astrophysical problems of current interest.

ST will make a fundamental contribution to the determination of the distance scale and age of the Universe by providing an extension of a factor of ten in



Artist's rendering of the Space Telescope.

the distance over which the properties of the standard candles used in the logical ladder leading to the determination of the Hubble constant can be measured.

Studies of clusters of galaxies and individual galaxies at larger redshifts than are currently possible from the ground will provide significant tests of world models and cosmic evolution.

The extension of morphological classification of galaxies to redshifts of order of one and the extension of stellar population studies at very faint levels will provide important clues on the formation, dynamics, and evolution of galaxies.

Studies of the central regions of active galactic nuclei and quasars (QSOs) may provide the basic data necessary to understand the physics of the nuclear regions of galaxies and the source of the tremendous energies released there, possibly giant collapsed objects.

ST promises the extension of stellar studies in our own galaxy to the faint stars which populate the corona. Studies of physical conditions and chemical composition of the interstellar medium and of the injection of material through stellar winds, evolution of outer atmospheres of stars, coronal winds, circumstellar shells, planetary nebulae and supernova remnants can be extended with ST to the ultraviolet (UV) range of wavelengths.

An area of great potential for ST observations related to the study of the birth and evolution of single and binary stars and of globular star clusters. Future extensions of ST capabilities to longer wavelength in the infrared will further improve the capabilities for this type of research.

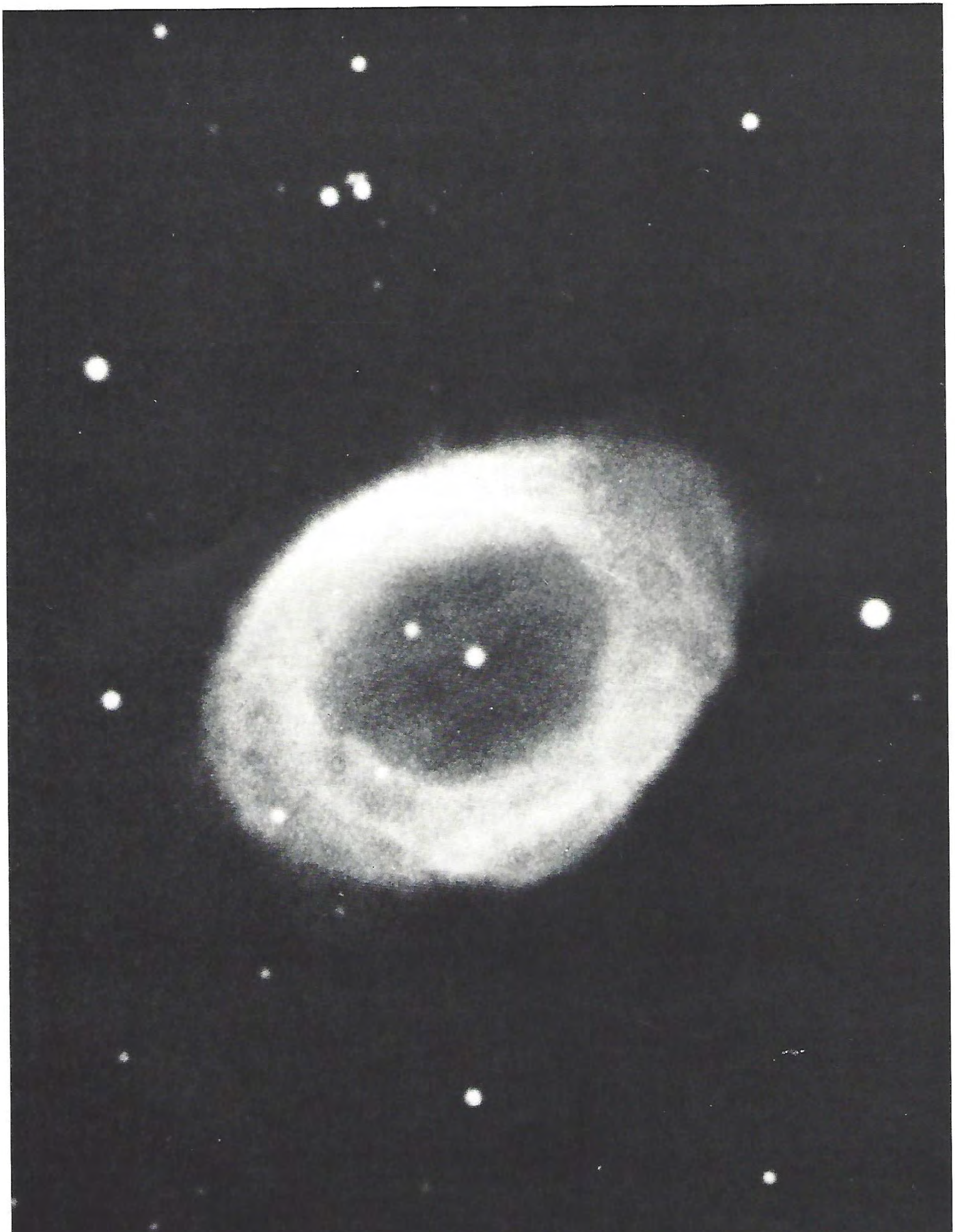
Astrometric measurements with ST promise an improvement in precision of a factor of ten. This will have a dramatic effect on many fundamental problems of astronomy. Parallaxes can be obtained with the same precision for objects ten times more distant than is possible from the ground. Visual orbits of some spectroscopic binaries can be obtained with a substantial improvement in knowledge of stellar masses. A search can be carried out for planetary systems of other stars. Finally, a link can be forged between optical, radio, and dynamical reference frames, and the inertial reference frame can be tied down by measurement of star motions relative to QSOs.

In planetary astronomy ST will play a major role in the coming decade in part because of the decreased commitment of NASA to major planetary flyby missions, but also because of the possibility of performing synoptic studies of planetary atmospheres, high resolution and UV studies of comets, and astrometric studies of the motions of the moons of the outer planets.

One of the benefits which will result from the improvement in sensitivity provided by ST is that it will permit observations of faint optical counterparts of objects of primary interest to radio and high energy astronomy.

ST is not only desirable but essential to continue carrying out the study of cosmic objects over the entire range of wavelengths available, from radio waves to X-rays, an approach which has proven so powerful in the recent past. It may well be that this approach will be the one which will provide the most unexpected and startling returns from ST: the discovery of new classes of astrophysical objects with unsuspected physical properties.

The impact of ST on astronomy will manifest itself in many aspects of the research enterprise besides the intrinsic value of the scientific data. It will be the first time that a national or international optical observatory will have capabilities clearly superior to privately developed telescopes, a fact which may influence the career development of many young astronomers. It is hoped that the data handling and archival capabilities which will have to be provided will be used as a tool in many other astronomical applications. The substantial development effort which will culminate in ST will provide the astronomical community with not only newly developed technology which already has found application in ground-based observatories, but even more significantly, with a new generation of astronomers who have developed the skills and self-confidence to undertake the construction of substantial new observational facilities. After a period of hiatus in which astronomers seemed to be most involved in the digestion of the results flowing from the capital investment of the previous generation, it may well be that the next two decades will be remembered as the heroic construction phase for observational astronomy.



Ring Nebula in Lyra–KPNO 4-m photograph.

A LOOK TO THE FUTURE

Through its quarter-century of existence, AURA has clearly shown its willingness to change and grow in response to the changing needs of the astronomical community. Among university consortia with similar purposes, AURA has been one of the more dynamic organizations, i.e. characterized by change, both in the number of facilities under its management and in its organizational development. In attempting to look into the future, we can anticipate this characteristic to continue. Forecasting how AURA's organization and missions may further evolve during the next twenty-five years is a speculative venture; nevertheless, some possibilities can be identified.

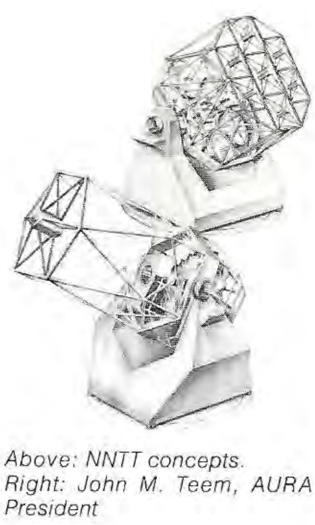
Looking forward into the next twenty-five years, AURA's most immediate challenges will be in effectively fulfilling its current mission assignments. The problems of continuing effective operation for the NSF of AURA's national ground-based observatories—all of which have existed for 20–30 years—are qualitatively different from those of establishing and operating for NASA an effective Space Telescope Science Institute—which is not expected to be fully operational for almost two years. In each case, however, the challenges to be faced are primarily ones of management rather than of a scientific or technical nature.

AURA's primary concerns regarding the future of KPNO, CTIO and SPO arise from the trend of progressively declining resources available due to the combination of NSF funding constraints and the exceptionally high rates of inflation experienced during recent years. As a result, purchasing power of the combined budgets for these three observatories declined during the period 1977–1982 at an average exponential rate of 4.5 percent per year, and the observatories' staffs have decreased by 25 percent over all. Some observing facilities have been closed and others threatened. Support for those remaining has been qualitatively reduced and the rates of improvement of auxiliary instrumentation cut back. While inflation rates seem to have abated (with Chile being an unknown at this writing) there appears to be little hope that net funding trends will reverse significantly—at least during the next few years. At best, perhaps, one can forecast constant purchasing power budgets at currently restricted levels. This difficult situation will call for wisdom in establishing project priorities and in partitioning resources among the observatories so that astronomy as a whole can best be served within the limited funds available.

This situation is characteristic of much of science in 1983; a consensus is growing that the scientific community must take a new look at its institutions and ways of operating. Looking to the future, one can anticipate that AURA's organization may indeed evolve further to improve the effectiveness of its management, the scientific and technological exchange among observatories, and to facilitate the best scientific output possible during this time of fiscal constraint. If recent funding trends continue, however, such approaches cannot prevent significant reduction of the roles these national observatories play in the advancement of astronomy nor, indeed, assure their survival.

Organizational Changes

As previously noted, AURA's organization has evolved during the past 25 years to meet changing needs, and further organizational changes, if necessary, may be expected. One organization change that is certain is in the structure and make-up of AURA's Board of Directors. As the number of AURA member universities has increased, the size of its Board has grown to the current 40 members. Interest of additional universities, which could probably meet AURA's membership criteria, has been growing with the assignment of the ST ScI mission to AURA. Although much of the Board's work is currently being done by smaller committees, the Board perceives that its size has become, or soon could be, unnecessarily large.



Above: NNTT concepts.
Right: John M. Teem, AURA President

Accordingly, at its Annual Meeting in 1982, AURA adopted changes in its By-Laws that will become effective in 1985. These will:

a) reduce the number of directors designated by each of the presidents of its member universities from two to one, who would be either a scientist or an administrator;
b) expand the maximum number of directors-at-large, elected by the Board, from seven to twelve with a minimum of five (three from non-AURA-member U.S. institutions and two from foreign institutions) and,
c) provide that at all times the Board shall be composed of at least one-half scientists and at least one third administrators; this balance will be considered in the election of directors-at-large and in advice provided by AURA's President to member university presidents regarding AURA's needs.

It was perceived that these changes will provide:

i) a smaller Board which will be less expensive to support and its meetings less unwieldy;
ii) a more appropriate balance of scientists to administrators;
iii) increased flexibility in selecting and re-electing directors-at-large;
iv) a modest growth in the number of member institutions.

Interacting galaxies, KPNO.

In an accompanying action, the Board also established a moratorium on considering further membership applications until 1985.

Stellar

A Dark Sky Survey project, managed by KPNO but involving technical contributions of a broader group of scientists, is well under way. This survey will provide one set of inputs to the question of where a large ground-based telescope should best be located. Criteria for siting such a facility are not yet definitive, but as S. M. Faber has emphasized, ["Optical and IR Telescopes of the 1990's," p. 306]—"...seeing [quality] is the most important single driver in the choice of site and in the technical trade-offs in construction costs." In addition, siting should permit reasonable visibility of the galactic center, all other things being equal. If more than one very large telescope were constructed (e.g., one by Europeans and one by the U.S.), it would seem desirable for one telescope to be located in the northern hemisphere and one in the southern. It is also important that the site have currently developed access and that further site development should not require a large fraction of the telescope's cost. It is not likely that AURA's current National Observatory sites in the northern hemisphere would adequately meet these criteria, although clearly a careful trade-off among the different criteria would be necessary in site selection. Depending upon the results of such trade-offs, if it proves possible to meet the goal of establishing and operating such a very large ground-based telescope for general use, AURA's operations could well be expanded to an additional location within its second quarter century.

Solar

After a thorough study, AURA has concluded that a merger of its solar programs at SPO and KPNO will improve both staff and visitor research and will lead to more efficient use of both facilities. Under a single administration, the AURA solar staff at both sites will be encouraged to interact more productively in generating new instruments and in forming collaborations. Visiting scientists can be assigned telescope time at the sites that best meet their observational requirements. Instrumentation and observing modes that meet the needs of the growing field of solar/stellar physics can be developed more flexibly. A better balance of staff among observers, theorists and instrumentalists can be attained. In short, AURA believes that the establishment of an integrated program will have great internal benefits and will stimulate progress in the fields of solar and solar/stellar astronomy.

Space Programs

The immediate management challenges AURA faces at the ST ScI relate in part to the necessity of establishing an environment conducive to research excellence at the Institute. These challenges also include meeting critical mileposts for delivery of the major subsystems for which it is responsible and for assembling an excellent scientific and technical staff who will be fully integrated and trained as a team before the Space Telescope is launched to provide the operational functions of the Institute 24 hours a day. Even greater, probably, is the challenge presented by the complex interfaces with other developers and operators of the ST system. AURA is fully committed to making the ST ScI a success, including the effective integration of European staff members from ESA-member nations and those from the Computer Sciences Corporation, AURA's major subcontractor. Assuring the success of the ST and the quality of the science produced with it over the next quarter of a century is a prime AURA objective, and AURA is dedicated to that goal. AURA believes that the ST will provide many of the most exciting astronomical research opportunities of the next 20 years.

Expanded Missions

During the next 25 years, might AURA expand its missions relating to space astronomy beyond the Space Telescope? Assuming that current responsibilites for ST ScI have been successfully carried out and such potential new efforts would not interfere with continued success of the ST ScI, AURA might indeed aspire to further missions compatible with its purpose. Such potential missions could well include ground operations analogous to those performed at the Institute for the ST, but for other astronomical space craft intended for broad use by the astronomical community. Such space facilities could include those designed to operate at wavelengths outside the infrared/visible/ultraviolet ranges within which AURA has traditionally worked. The most likely such candidate within NASA's

Eta Carinae Nebula, CTIO 4-m photograph.

current planning horizon is the Advanced X-Ray Astronomical Facility (AXAF), but analogous support of space facilities for IR observations such as the proposed Space Infrared Telescope Facility, (SIRTF) or one for solar research would also be appropriate candidates. It is also anticipated that the astronomical community will desire a larger version of the Space Telescope. Hopefully, it will be given serious consideration during the coming quarter century. While AURA's potential role in such an endeavor is not yet well defined, AURA would try to support such a venture within its capabilities at the time.

NNTT

During the next decade, AURA's highest priority goal related to potential augmentation of its mission lies in the construction and operation of a very large, ground-based telescope for broad astronomical use. A consensus is developing among the community ["Astronomy in the 1980's," a 1982 report of a National Academy of Sciences committee chaired by George Field] that such a telescope of 15-meters diameter or equivalent, often referred to as a National New Technology Telescope (NNTT), is needed to complement the other existing astronomical facilities such as the ST, the VLA (the large radio telescope array of NRAO) and potentially the SIRTF, AXAF and VLBA (very long baseline radio array). Many advancements in the astronomical sciences over the past quarter century have come about through complementary studies of objects at different wave lengths. Indeed, nearly half of the current requests for time on the KPNO and CTIO 4-meter telescopes are concerned with follow-up observations to earlier discoveries made with radio, UV or X-ray instruments. Available telescopes—even when equipped with the efficient detector arrays now becoming available—are limited

Caty Pilachowski, Sondra Yorka Roger Lynds, Ruth Peterson.

in their photon collecting ability. Thus, measurements of important classes of objects either take unrealistic observing times, or are not possible for very faint objects.

Spectrophotometric measurements at visual and infrared wavelengths of faint and/or extended objects are essential for understanding evolution of galaxies and their clusters and for fundamental cosmology. Similar needs exist for high resolution spectrophotometry of faint objects in studying quasars and other object classes with energetic nuclei, the structure of our Milky Way galaxy, chemical evolution in various galaxies and for studying stars in formation and during late stages of their evolution, among other fields. Although many such areas of research will clearly be significantly advanced if an order of magnitude increase in light collecting power for spectrophotometry and higher IR spatial resolution becomes available. Indeed we may expect the "unexpected" to be the most significant science that will result.

Clearly, any large telescope should have potentially greater performance if placed into operation in space. For the next 10 years, however, the cost of deploying a telescope with spectrophotometric capabilities comparable to those anticipated for the NNTT probably will be considerably in excess of that required for construction and operation on the ground. Thus, AURA's rationale for establishing its highest priority on efforts relative to a large ground-based telescope is based on the reasonable assumption that the expected benefits for astronomy can be achieved more cost effectively in this way. In fact, it seems likely to AURA planners that a 15-meter telescope could be built—after on-going research and development are completed—for $120—150M in FY 1982 dollars. It is noteworthy that the current value of the approximately $6M raised in 1928 for construction of the 5-meter Hale telescope for Caltech's Palomar Observatory would be, if this were inflated by the ratio of cost-price indices for 1982 and 1928, over $140M—approximately the estimated cost of a 15-meter New Technology Telescope!

AURA's interest in a large ground-based telescope began about 1976 when Leo Goldberg, then Director of KPNO, initiated a series of conceptual design studies for a New Generation Telescope (NGT) of 25-meter equivalent diameter. Approximately six design concepts were considered in sufficient detail to establish confidence that such a large facility could be built and that the indicated major cost reductions were potentially achievable. To address the technological questions, in 1980 KPNO joined forces (with AURA's and the NSF's encouragement) with three member universities—Arizona, California and Texas—who were also actively interested in designing large telescopes based upon new technologies. The Smithsonian Astrophysical Observatory, which operates the 4.6-meter Multiple Mirror Telescope in partnership with the University of Arizona, also participates on the Technical Development Program (TDP) Committee through representation in the NNTT-TDP. A coordinated TDP, carried out under the direction of four co-principal investigators, one from each university plus the KPNO Director, has been established to solve the remaining problems of constructing large optical collecting areas and incorporating them in an optimum way in a National New Technology Telescope (NNTT) of 15-meter equivalent diameter.

AURA Board, April 1982

Frank K. Edmondson, President 1962–65, Chairman, Anniversary Planning Committee

W. A. Hiltner, President, 1968–71

Rupert Wildt, President 1965–68 & 1971–72, Chairman 1972–74

Jesse L. Greenstein, Chairman, 1974–77

Harlan J. Smith, Chairman, 1980–83

APPENDIX I
Facts About AURA

AURA Board—1957

University of California
- C. D. Shane
- James M. Miller

University of Chicago
- Gerard P. Kuiper*
- William B. Harrell

Harvard University
- Donald H. Menzel*
- Edward Reynolds

Indiana University
- Frank K. Edmondson
- J. A. Franklin*

University of Michigan
- Robert R. McMath*
- Gilbert L. Lee Jr.

The Ohio State University
- P.C. Keenan
- C. F. Miller

University of Wisconsin
- A. E. Whitford
- A. W. Peterson*

*Deceased.

AURA Board—1982

Directors	*Year Appointed*
University of Arizona	
Peter A. Strittmatter	1975
Albert B. Weaver	1972
California Institute of Technology	
Harold Zirin	1977
David W. Morrisroe	1979
University of California	
Robert P. Kraft	1979
Leonard V. Kuhi	1978
University of Chicago	
Lewis M. Hobbs	1974
Cynthia Greenleaf	1982
University of Colorado	
Peter S. Conti	1977
Theo Volsky, Jr.	1980
Harvard University	
Robert W. Noyes	1978
Paul C. Martin	1979
University of Hawaii	
John T. Jefferies	1978
Howard P. McKaughan	1978–80, 1982
Johns Hopkins University	
Arthur F. Davidson	1982
Richard A. Zdanis	1982
University of Illinois	
David Pines	1980
Theodore L. Brown	1982
Indiana University	
Frank K. Edmondson	1957
Lynne L. Merritt, Jr.	1975
Massachusetts Institute of Technology	
George Clark	1981
John Deutch	1982
University of Michigan	
W. A. Hiltner	1974
James F. Brinkerhoff	1977
Ohio State University	
Robert F. Wing	1982
Colin B. B. Bull	1979
Princeton University	
Edwin L. Turner	1980
Richard A. Rossi	1972
University of Texas	
Harlan J. Smith	1972
G. J. Fonken	1979
University of Wisconsin	
John S. Mathis	1982
Reuben H. Lorenz	1962
Yale University	
Pierre Demarque	1974
Charles K. Bockelman	1978

Directors-at-Large	
University of Chile	
Claudio Anguita	1967–70, 73–76, 77–80, 81
Lowell Observatory	
Arthur A. Hoag	1982
University of Minnesota	
Roberta Humphreys	1981
University of Washington	
Bruce Margon	1982
Instituto di Astronomia, Firenze, Italy	
Franco Pacini	1981

Councilors-at-Large *Space Telescope Institute Council*	
Instituto di Astronomia, Firenze, Italy	
Franco Pacini	1979
University of Arizona	
Bradford A. Smith	1979
Princeton University	
Lyman Spitzer, Jr.	1981
Sterrewacht Leiden—Huygen Laboratorium	
H. C. van de Hulst	1981

Corporate Officers and Staff–1982

Chairman	Harlan J. Smith
Vice Chairman	Reuben H. Lorenz
President	John M. Teem
Secretary	Albert B. Weaver
Treasurer	John Marian
Assistant Secretary/Treasurer & Administrative Executive	David F. Welch
Corporate Staff Scientist	Robert W. Milkey
Administrative Aide to the President	Phyllis McDowell
Assistant to President for Board Support	Muriel Fults
Administrative Assistant	Judith West

Former Directors

Robert Alberty	MIT	1981
David G. Barlow	Harvard University	1975–79
Harold E. Bell	University of Chicago	1973–80
Earl C. Bolton	University of California	1966–70
Ronald W. Brady	University of Illinois	1981
Geoffrey R. Burbidge	University of California	1972–74
E. Margaret Burbidge	University of California	1974–79
Orvin W. Campbell	University of California	1964–65
Eugene R. Capriotti	Ohio State University	1979–81
Gordon B. Carson	Ohio State University	1960–71
Arthur D. Code	University of Wisconsin	1958–69 1971–82
James H. Corley	University of California	1960–64
Alexander Dalgarno	Harvard University	1971–78
Robert E. Danielson	Princeton University	1969–73
John E. Ecklund	Yale University	1967–78
Joseph A. Franklin	Indiana University	1957–75
Roy C. Fredrickson	University of California	1970–74
Charles S. Gage	Yale University	1958–67
Leo Goldberg	Harvard University	1966–71
Jesse L. Greenstein	California Institute of Technology	1972–77
W. B. Harrell	University of Chicago	1957–67
G. H. Herbig	University of California	1971–72
W. A. Hiltner*	University of Chicago	1959–71
Carl W. Janke	Harvard University	1971–75
Philip C. Keenan	Ohio State University	1957–61
Gerard P. Kuiper	University of Chicago	1957–59
Bernard J. Lachner	Ohio State University	1971–72
Gilbert L. Lee Jr.	University of Michigan University of Chicago President Treasurer Consultant	1957–67 1967–72 1972–77 1977–78 1978–79
Gardner Lindzey	University of Texas	1973–75
Milton E. Lipetz	University of Colorado	1977–80
Robert R. McMath	University of Michigan	1957–62
Donald H. Menzel	Harvard University	1957–66
C. F. Miller	Ohio State University	1957–60
James M. Miller	University of California KPNO-Assoc. Director, Admin.	1957–60 1960–72
Orren C. Mohler	University of Michigan	1962–74
Edward Q. Moulton	Ohio State University	1972–79
Lewis Nosanow	University of Chicago	1981–82
C. Robert O'Dell	University of Chicago	1971–72
Donald E. Osterbrock	University of Wisconsin	1969–71
Mark Owens, Jr.	University of California	1974–77
A. W. Peterson	University of Wisconsin	1957–62
Wilbur K. Pierpont	University of Michigan	1967–77
Cornelius J. Pings	California Institute of Technology	1972–79
Edward Reynolds	Harvard University	1957–61
C. D. Shane	University of California	1957–62
Barbara Z. Siegel	University of Hawaii	1980–82
Arne E. Slettebak	Ohio State University	1961–79
Lyman Spitzer, Jr.	Princeton University	1959–69
Archie W. Straiton	University of Texas	1973
Eldon Sutton	University of Texas	1976–79
William F. van Altena	University of Chicago	1973–74
Ray J. Weymann	University of Arizona	1972–75
Albert E. Whitford	University of Wisconsin University of California	1957–58 1962–71
L. Gard Wiggins	Harvard University	1961–71
Rupert Wildt	Yale University	1958–76
David T. Wilkinson	Princeton University	1973–80
Raymond J. Woodrow	Princeton University	1959–72

*Currently represents the University of Michigan on AURA Board.

Former Directors-at-Large

Claudio Anguita	University of Chile	1967–70, 73–76, 77–80
Willaim A. Baum	Lowell Observatory	1976–79
Edwin F. Carpenter	University of Arizona	1958–61
George W. Clark	Massachusetts Institute of Technology	1978–81
Stirling A. Colgate	New Mexico Tech. Institute	1973–77
Arthur F. Davidsen	Johns Hopkins University	1979–82
Enrique d'Etigny	University of Chile	1964–67
Robert D. Gehrz	University of Wyoming	1976–79
John S. Hall	Lowell Observatory	1967–70
Robert H. Hardie	Vanderbilt University	1965–68
Martin O. Harwit	Cornell University	1978–81
Albert P. Linnell	Amherst College	1962–65
S. W. McCuskey	Warner & Swasey Observatory	1963–66
Hugo Moreno	University of Chile	1970–73
Gerry Neugebauer	California Institute of Technology	1970–72
Edward P. Ney	University of Minnesota	1972–75
Tobias Owen	State University of New York at Stony Brook	1973–76
David Pines	University of Illinois	1975–76 1979–80
Judith L. Pipher	University of Rochester	1979–82
Vera C. Rubin	Carnegie Institution of Washington	1973–76
F. Rutllant	University of Chile	1961–63
E. E. Salpeter	Cornell University	1970–73
Carl K. Seyfert	Vanderbilt University	1957–60
Stewart L. Sharpless	University of Rochester	1966–69
Alex G. Smith	University of Florida	1960–63
Stephen E. Strom	State University of New York at Stony Brook	1971–72
James A. Van Allen	University of Iowa	1968–71
Peter van de Kamp	Swarthmore College	1957–60
George Wallerstein	University of Washington	1969–70
Daniel W. Weedman	Vanderbilt University University of Pennsylvania	1978–80 1980–81

Former Consultants

Claudio Anguita	University of Chile	1970, 1976, 1980
H. W. Babcock	Mt. Wilson/Palomar	1964–65
Ira S. Bowen	Mt. Wilson Observatory	1958–62
Edwin F. Carpenter	University of Arizona	1962–63
Gerald Clemence	U.S. Naval Observatory	1963
John W. Evans	Sacramento Peak Observatory	1959–60
Herbert F. Friedman	U.S. Naval Research Lab.	1963
Leo Goldberg	University of Michigan	1957
Norman Hackerman	University of Texas Rice University	1964–70 1970–74
Donald Hendryx	Mt. Wilson Observatory	1957–58
Robert F. Howard	Hale Observatories	1978–79
Ivan R. King	University of California—Berkeley	1976–80
Gerald E. Kron	Lick Observatory	1959–60
Nicholas U. Mayall	Lick Observatory KPNO Director	1958–60 1960–71
Orren C. Mohler	McMath-Hulbert Observatory	1959–60
David Pines	University of Illinois	1978–79
H. D. Rhodes	University of Arizona	1963–69
Bruno Rossi	Massachusetts Institute of Technology	1969–70
Bruce H. Rule	California Institute of Technology	1957–58
Alex G. Smith	University of Florida	1964–68
Otto Struve	University of California	1957–58
Merle A. Tuve	Carnegie Institution	1963–64
Albert B. Weaver	University of Arizona	1970–72
W. Gordon Whaley	University of Texas	1960–64

Former Presidents & Board Chairmen

Robert R. McMath	President Chairman	1957–59 1959–62
C. D. Shane	President	1959–62
Frank K. Edmondson	President	1962–65
Rupert Wildt	President	1965–68
W. A. Hiltner	President	1968–71
Rupert Wildt	President Chairman	1971–72 1972–74
Jesse L. Greenstein	Chairman	1974–77
Arthur D. Code	Chairman	1977–80
Harlan J. Smith	Chairman	1980–83
Gilbert L. Lee, Jr.	President	1972–77
John M. Teem	President	1977–

APPENDIX II
Facts About NSF

National Science Board—1957

Detlev W. Bronk, Chairman	Rockefeller Institute of Medical Research
Sophie D. Aberle	University of New Mexico
Roger Adams	University of Illinois
Robert P. Barnes	Howard University
Gerty T. Cori	Washington University
Charles Dollard	Carnegie Corporation of New York
T. Keith Glennan	Case Institute of Technology
Laurence M. Gould	Carleton College
Paul M. Gross	Duke University
Theodore M. Hesburgh, C.S.C.	University of Notre Dame
William V. Houston	Rice University
George D. Humphrey	University of Wyoming
Robert F. Loeb	Columbia University
Donald H. McLaughlin	Homestake Mining Company
Edward J. McShane	University of Virginia
George H. Merck	Merck & Co. Inc.
Frederick A. Middlebush	University of Missouri
Joseph C. Morris	Tulane University
Samuel M. Nabrit	Texas Southern University
Andrey A. Potter	Purdue University
Julius A. Stratton	Massachusetts Institute of Technology
Edward L. Tatum	Rockefeller Institute for Medical Research
Warren Weaver	The Rockefeller Foundation
Douglas M. Whitaker	Rockefeller Institute for Medical Research
Alan T. Waterman (ex officio)	Director National Science Foundation

National Science Foundation—1957

Director	Alan T. Waterman
Associate Directors	Paul E. Klopsteg James M. Mitchell
General Counsel	William J. Hoff
Special Assistants to the Director	William G. Colman Neil Carothers III
Secretary, National Science Board	Vernice Anderson
Assistant Director of Mathematical, Physical, and Engineering Sciences	E. A. Eckhardt
Deputy Assistant Director	Raymond J. Seeger
Program Director for Astronomy	Geoffrey Keller

National Science Board—1982

Lewis M. Branscomb, Chairman	International Business Machines, Inc.
Mary L. Good, Vice Chairman	UOP, Inc.
Jay Vern Beck	Brigham Young University
Eugene H. Cota-Robles	University of California at Santa Cruz
Peter T. Flawn	University of Texas at Austin
Ernestine Friedl	Duke University
Robert S. Gilkeson*	Philadelphia Electric Co.
Charles E. Hess*	University of California—Davis
Michael Kasha	Florida State University
Peter D. Lax	Courant Institute of Mathematical Sciences
Walter E. Massey	Argonne National Laboratory
William F. Miller*	SRI International
John H. Moore*	Stanford University
Homer A. Neal	State University of New York at Stony Brook
William A. Nierenberg*	Scripps Institute of Oceanography
Mary Jane Osborn	University of Connecticut School of Medicine
David V. Ragone	Case Western Reserve University
Norman C. Rasmussen*	Mass. Institute of Technology
Donald B. Rice, Jr.	The Rand Corporation
Stuart A. Rice	University of Chicago
Edwin E. Salpeter	Cornell University
Roland W. Schmitt*	General Electric Company
Charles P. Slichter	University of Illinois
Edward A. Knapp (ex officio)	Director National Science Foundation
Margaret L. Windus	Executive Officer

National Science Foundation—1982

Director	Edward A. Knapp
Deputy Director	Donald N. Langenberg
Senior Science Associate	Peter Wilkniss
General Counsel	Charles H. Herz
Assistant Director, Directorate for Astronomical, Atmospheric, Earth, and Ocean Sciences (AAEO)	Francis S. Johnson
Deputy Assistant Director, AAEO	Albert L. Bridgewater
Senior Staff Associate	William E. Howard III
Director, Division of Astronomical Sciences	Laura P. Bautz
Project Officer, KPNO & CTIO	Claud M. Kellett
Project Officer, SPO	Seth L. Tuttle

Former Directors—National Science Foundation

Alan T. Waterman	1950–63
Leland J. Haworth	1963–69
William D. McElroy	1969–72
H. Guyford Stever	1972–76
Richard C. Atkinson	1977–80
John B. Slaughter	1981–82

*Appointment subject to Senate confirmation.

Former Members—National Science Board

Sophie D. Aberle	1950–58
Roger Adams	1954–60
W. O. Baker	1960–66
Chester I. Barnard	1950–56
Robert P. Barnes	1950–58
R. H. Bing	1968–74
Raymond L. Bisplinghoff	1976–82
Detlev W. Bronk	1950–64
Harvey Brooks	1962–74
Mary I. Bunting	1965–70
W. Glenn Campbell	1972–78
H. E. Carter	1964–76
Robert A. Charpie	1970–76
Rufus E. Clement	1960–67
Jewel Plummer Cobb	1974–80
James B. Conant	1950–53
Lloyd M. Cook	1970–82
Gerty T. Cori	1950–57
John W. Davis	1950–56
Robert H. Dicke	1970–76
Herbert D. Doan	1976–82
Charles Dollard	1950–58
Lee A. DuBridge	1950–54, 1958–64
Conrad A. Elvehjem	1960–62
Henry Eyring	1962–68
William A. Fowler	1968–74
Edwin B. Fred	1950–56
David M. Gates	1970–76
T. Keith Glennan	1956–58
Julian R. Goldsmith	1964–70
Laurence M. Gould	1953–62
Paul M. Gross	1950–62
Norman Hackerman	1968–80
William W. Hagerty	1964–70
T. Marshall Hahn Jr.	1972–78
Philip Handler	1962–74
Clifford M. Hardin	1966–70
Anna J. Harrison	1972–78
Hubert Heffner	1972–75
Theodore M. Hesburgh, C.S.C.	1954–66
Roger W. Heyns	1967–76
John R. Hogness	1976–82
William W. Houston	1954–66
W. N. Hubbard Jr.	1974–80
William F. Hueg, Jr.	1976–82
George D. Humphrey	1950–62
O. W. Hyman	1950–56
Charles F. Jones	1966–72
Thomas F. Jones, Jr.	1966–72
Marian E. Koshland	1976–82
Saunders Mac Lane	1974–80
James B. Macelwane, S.J.	1954–56
James G. March	1968–74
Katharine E. McBride	1962–68
Kevin McCann	1958–64
Donald H. McLaughlin	1950–60
Edward J. McShane	1956–68
William H. Meckling	1972–78
George W. Merck	1951–57
Frederick A. Middlebush	1950–62
Edward L. Moreland	1950–51
Robert S. Morison	1963–72
Joseph C. Morris	1950–66
Marston Morse	1950–54
Grover E. Murray	1968–80
Samuel M. Nabrit	1956–59
William A. Nierenberg	1972–78
Morrough P. O'Brien	1958–60
Russell D. O'Neal	1972–78
Joseph M. Petit	1976–82
Harvey Picker	1965–70
E. R. Piore	1961–72
A. A. Potter	1950–58
Frank Press	1970–76
Mina S. Rees	1964–70
James A. Reyniers	1950–54
Joseph M. Reynolds	1966–78
Alexander Rich	1976–82
William W. Rubey	1960–66
Jane A. Russell	1958–64
Glenn T. Seaborg	1960–61
Paul B. Sears	1958–64
L. Donald Shields	1974–80
Frederick E. Smith	1968–74
John I. Snyder, Jr.	1964–65
Athelstan F. Spilhaus	1966–72
E. C. Stakman	1950–54
Earl P. Stevenson	1951–56
H. Guyford Stever	1970–72
Julius A. Stratton	1956–62, 1964–67
Richard H. Sullivan	1966–72
Edward L. Tatum	1956–68
F. P. Thieme	1964–76
Ralph W. Tyler	1962–68
Ernest H. Volwiler	1958–64
Eric A. Walker	1960–66
Warren Weaver	1956–60
Douglas M. Whitaker	1954–60
Malcolm M. Willey	1960–64
Charles E. Wilson	1950–51
Patrick H. Yancey, S.J.	1950–54
James H. Zumberge	1974–80

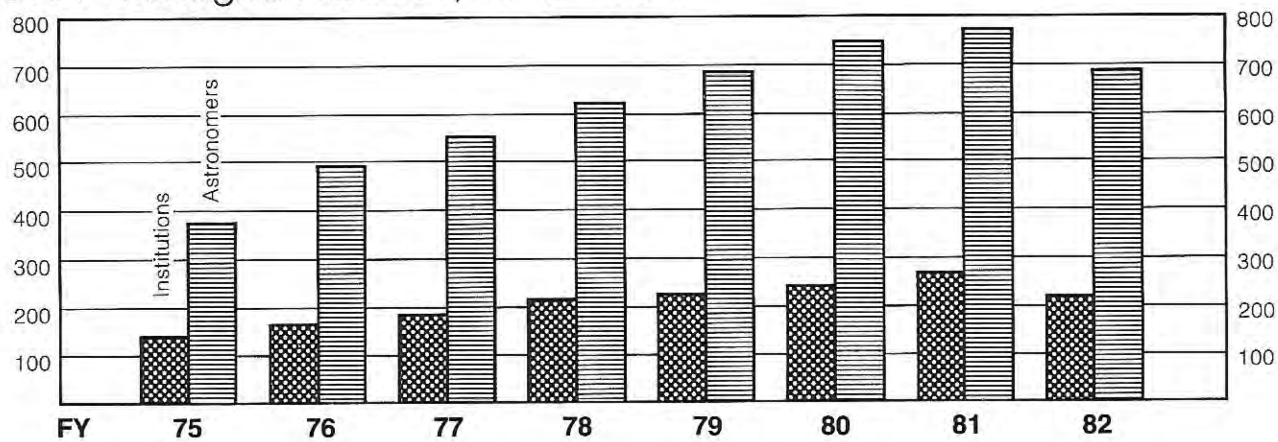
APPENDIX III

NASA Officials

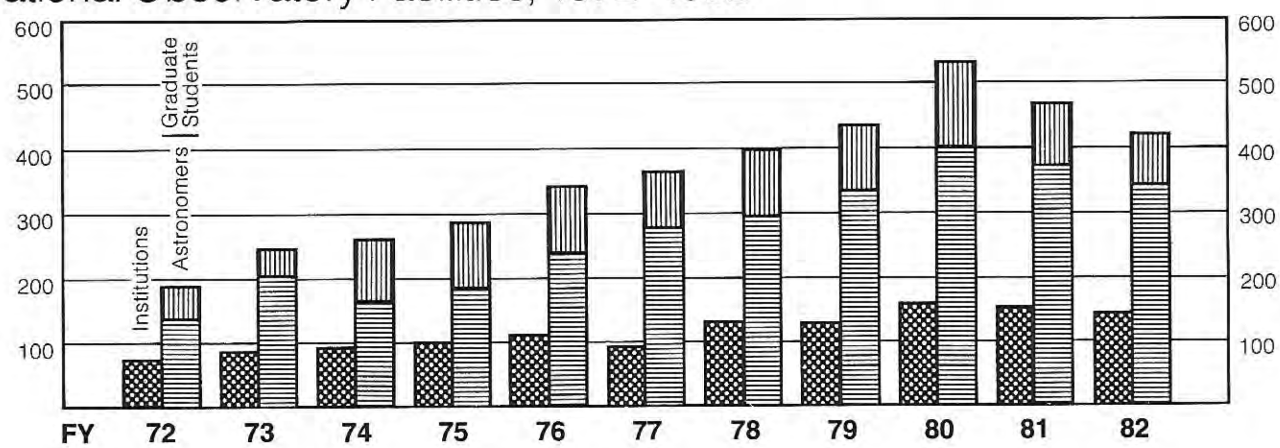
Administrator	James M. Beggs
Deputy Administrator	Hans Mark
Chief Scientist, NASA	Frank McDonald
Associate Administrator	Burton I. Edelson
Deputy Associate Administrator	Samuel W. Keller
Director, Astrophysics Division	Frank D. Martin
Acting Chief, Observatory Development Branch & Acting Manager, Space Telescope	Marc Bensimon
Program Engineer, Space Telescope	Arthur Reetz
Chief, Astronomy/Relativity Branch	Edward Weiler
Director, Goddard Space Flight Center	Noel Hinners
ST Project Manager, GSFC	Gerald L. Burdette
Deputy ST Project Manager, GSFC	Arun Guha
Manager, ST Science Operations, GSFC	Mona Tycz
Contracting Officer, GSFC	Mary Stotler
Manager, ST Project Office Marshall Space Flight Center	Fridtjof A. Speer
Assistant Project Scientist for ST, MSFC	Charles Meegan

APPENDIX IV

Number of Visiting Astronomers and Institutions Using AURA-Managed Facilities, 1975–1982



Number of Visiting Astronomers and Institutions Using Kitt Peak National Observatory Facilities, 1972–1982



Public Visitors to AURA Managed National Observatories, 1975–1982