NO. 172 THE LUNAR AND PLANETARY LABORATORY AND ITS TELESCOPES

by Gerard P. Kuiper

December 31, 1972

1. Introduction

In "Organization and Programs of the Laboratory", *LPL Communication No. 1* (1962), I projected a set of aims and objectives for this Laboratory. This included the telescopes planned for the immediate future and a brief description of the facilities on this Campus. A number of early results were also mentioned: the ORTHOGRAPHIC ATLAS OF THE MOON (1961); the RECTIFIED LUNAR ATLAS, to be issued 1963; and near-infrared spectra of planets and red stars. Late 1963 I summarized elsewhere (*Sky and Telescope*, Jan, Feb, 1964) the activities of this Laboratory for its first three years of operation. I stressed especially the interdisciplinary nature of planetary astronomy with its demands on staff and facilities.

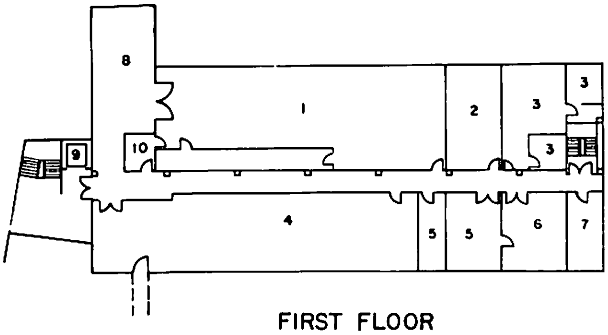
The present *Communication* describes the LPL Campus and Observatory facilities as of 1972. Our several test programs toward the discovery of optimum observatory sites, both in Arizona and elsewhere, are recorded in *LPL Communication No. 199*. That issue also covers the acquisition in 1970 of the 20-acre well-developed Mt. Lemmon summit. Its favorable elevation (9157 ft or 2800 m), latitude (32°N), climate, and accessibility, make it ideally suited for an inter-university Infrared Observatory.

The site-test programs were carried out concurrently with our participation in NASA's Space Missions, especially Ranger and Surveyor (1960-70), and NASA's high-altitude flights (1967-72). The programs helped to define the future roles of research from selected observatory sites compared to feasible observations from aircraft, balloons, and spacecraft. This in turn assisted the design of the ground-based facilities described below. Involved are two prime objectives: high-resolution image recording (e.g. Kuiper 1972) and high-altitude sites selected for their exceptional dryness (*LPL Comm. Nos. 142, 156*). Progress can be recorded in both,but more remains to be done.

2. The Space Sciences Building

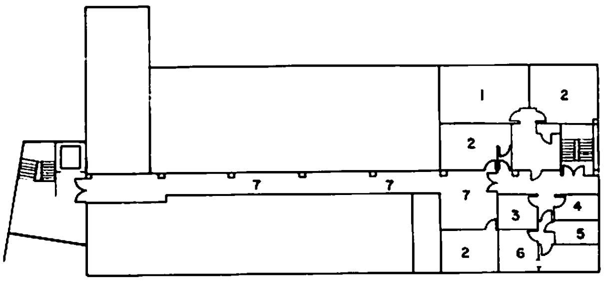
A photograph of the University's Space Sciences Building is shown in Figure 1. It is located on the E. side of the Campus, near the Tucson headquarters of the Kitt Peak National Observatory, the University's Steward Observatory (the Astronomy Department), and the Optical Sciences Center, constructed since. The proximity of these several astronomical centers has facilitated the organization of colloquia and larger scientific meetings.

Fig. 1 Space Sciences Building, University of Arizona



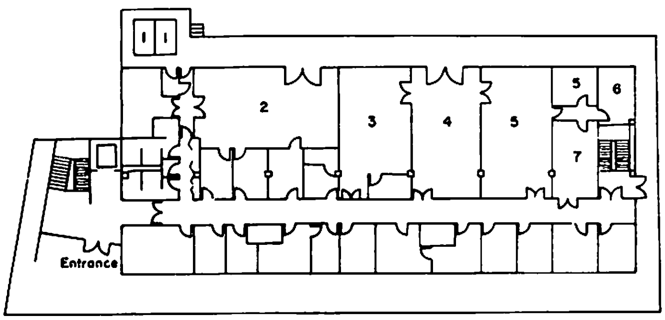
FIRST FLOOR

1. Optical Shop
2. Lunar Model Room
3. IR Labs.
4. Building Heating and Cooling Equipment
5. LPL Publications
6. Instrument Storage
7. Plate Vault
8. Optical Shop Loading and Storage Area
9. Elevator
10. Optician's Office



MEZZANINE

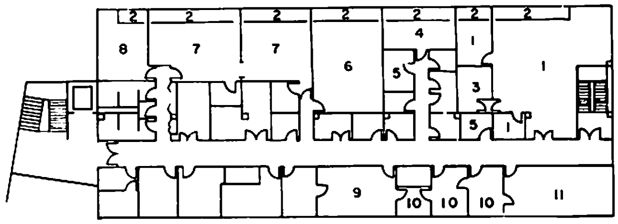
1. Main Office, Photography
2. Darkrooms
3. Office
4. Film Storage
5. Mann Measuring Machine
6. Automatic Processing
7. Globe Projection Tunnel (Moon, Planets)



SECOND FLOOR

1. Loading Dock to Optical Shop
2. Polarimetry Lab.
3. Electronics Lab.
4. Machine Shop
5. IR Lab.
6. IR Detector Production
7. IR Test Lab.

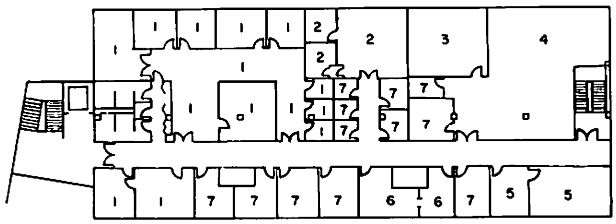
Un-numbered: LPL Offices



THIRD FLOOR

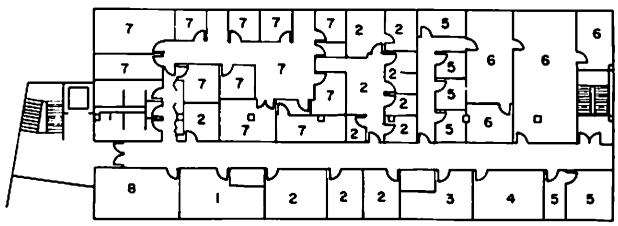
1. Physics Lab.
2. 130-ft. Long Absorption Tube
3. Darkroom
4. Editorial Office
5. Orbiter and Apollo Documents Storage
6. Conference Room
7. Library
8. Drafting Room
9. LPL Main Office
10. LPL Executive Offices
11. Director's Office

Un-numbered: LPL Offices



FOURTH FLOOR

1. Astronomy Lab. and Offices
2. Optical Sciences Lab.
3. Lunar Crater Studies
4. Computer Room
5. Planetary Sciences
6. U. S. Naval Liaison Office
7. LPL Offices



FIFTH FLOOR

1. Smiths. Astr. Obs. Office
2. LPL Lab. and Offices
3. LPL Chemistry Lab.
4. Graduate Students
5. Geochronology Offices
6. Geochronology Labs.
7. Psychology Lab. and Offices
8. Lecture Room

Fig. 2 Floor Plans, Space Sciences Building

The Space Sciences Building was funded by NASA in 1965; LPL has been the principal beneficiary. It thus acquired the necessary office, shop and laboratory facilities. This in turn assisted our participation in NASA missions and in the high-altitude flight program based at NASA-Ames, California; and the LPL observatory programs.

The floor plans of the Space Sciences Building are found in Figure 2. The other University Departments represented participated in the original joint interdisciplinary application to NASA.

Figure 3 shows the Optical Shop. It is entirely below ground level, which ensures the near-constant temperature needed for critical tests. The three LPL opticians, directed by Mr. Robert Waland, have been responsible for the production of nearly all our telescope optics. The primary of the 61-inch was made accurate to 1/40 of a wave, possibly a unique achievement for a mirror of this size. It has no doubt contributed to the quality of our planetary photography. In addition, the Laboratory has its own machine and electronics shops, besides an IR test laboratory and an IR detector production shop. All these are integral parts of the research projects.

Fig. 3 Optical Shop, Lunar and Planetary Laboratory, Mr. R. L. Waland operating main tool; Mr. R. G. Crawford at second large tool. 60" metal mirror in foreground; U. of Minn. 60" blank in box. Forty-inch test flat and smaller grinding tools at left

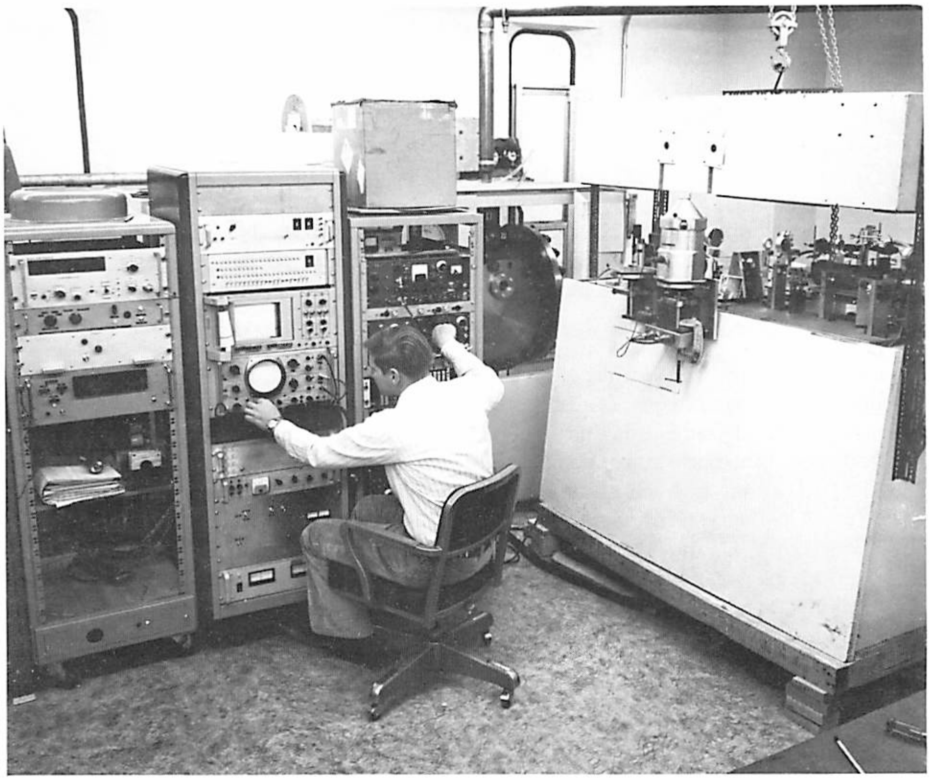


Fig. 4 Dr. H. Larson, operating modified Connes interferometer mounted at 130-ft Absorption Tube. Sunbeam as light source available behind Tube

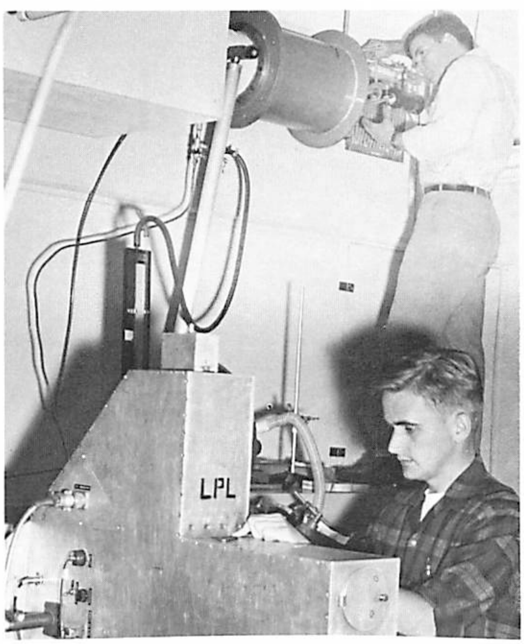


Fig. 5 T. Owen and D. Cruikshank adjusting Absorption Tube to simulate CO_2 in Martian atmosphere using the "A" grating spectrometer (1964)

An important facility is the 130-ft (40-meter) long Absorption Tube on the third floor (Fig. 2), spanning the full length of the Building. It can be used with 2-100 traversals and with pressures 0-10 atm., for calibration and analysis of planetary spectra. Figure 4 shows the original Connes interferometer, on indefinite loan to this Laboratory, mounted in conjunction with this tube. The present large tube is an improved version of an 80-ft tube used in the early 1960's in the LPL wing of the Physics Building (Fig. 5). The spectroscopy done prior to 1967 used two PbS grating spectrometers, A and B, with maximum resolutions 4000 and 8000. The A spectrometer is shown in Fig. 5. It has an F/13.5 collimeter and was used extensively on the McDonald Observatory 82-inch, the KPNO 36-inch and the Catalina 61-inch. The B spectrometer has F/8, designed for and used at the KPNO 84-inch.

Figure 6 shows the Lunar Model Laboratory conducted by Mr. R. Turner, sculptor. The Conference Room (Fig. 7) is used for local and national panel meetings and staff conferences. The Space Sciences Building houses its own small computer, an IBM 1130B, used for photometric data reduction, Fourier spectroscopy computation, and graphical displays. A direct data link with the University's CDC 6400 is being considered. An important asset is the LPL Library which contains numerous special NASA publications among other extensive source material for planetary programs and graduate studies. It was built up through exchanges of publications with other research institutions, gifts, and subscriptions.

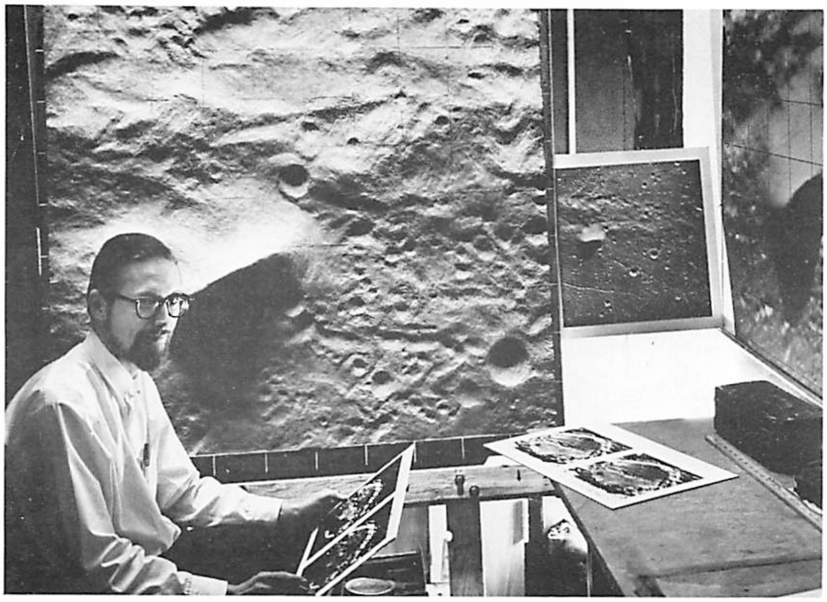


Fig. 6 Mr. R. Turner producing model of central peak of lunar crater Alphonsus for NASA Ranger IX Report

A precisely-made 3-ft aluminum hemisphere coated mat-white is set up at the end of an 80-ft long projection tunnel at the mezzanine level (Fig. 2) and is used for rectified lunar photography (Fig. 8). The RECTIFIED LUNAR ATLAS (1963) was so produced. It has also been used in the rectification of Orbiter photography, in part by the staff of NASA's Langley Spacecraft Center. In addition, Mr. Turner has produced Jupiter and Saturn globes, each of appropriate oblateness, for the

Fig. 7 Conference Room with Dr. Leon Randić measuring IR solar spectral tracings obtained at Mt. Lemmon IR Observatory

rectification and mapping of the cloud patterns on these planets. One of these globes was used in connection with PIONEER 10 preparations; another, in color, was produced for NASA-Ames for the PIONEER mission control.

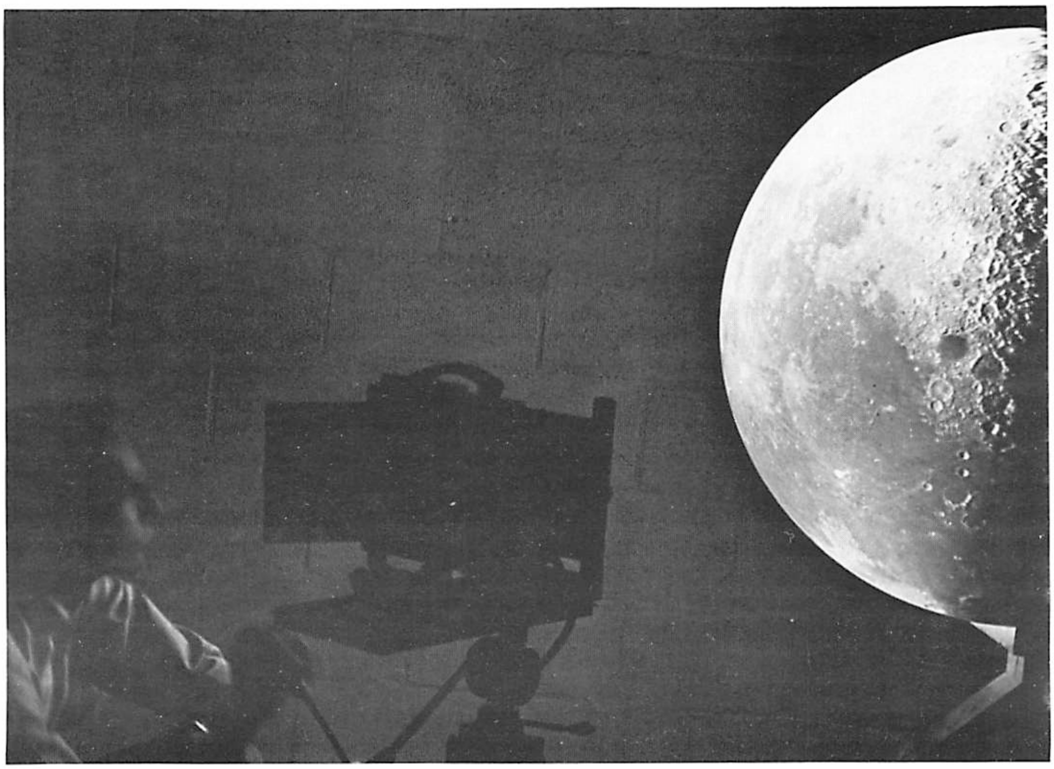


Fig. 8 Dr. W.K. Hartmann rephotographs lunar image projected orthogonally on hemisphere used in production of RECTIFIED LUNAR ATLAS

The Mann measuring machine (Fig. 9) has been widely used for lunar coordinate measurements under the direction of Mr. David Arthur; for motions of planetary cloud masses (Mr. R. B. Minton and others); for comets (Dr. G. Van Biesbroeck); etc. Since 1969,the output of the machine is automatically digitized, directly suitable for machine reduction.

The blink microscope (Fig. 10) has been a key instrument in asteroid studies. It was used for the Palomar-Leiden Survey, initiated by Dr. Kuiper in 1961 as an inter-observatory program between LPL, Palomar (Dr. T. Gehrels, using the 48-inch Schmidt), Leiden and Heidelberg (Dr. and Mrs. C. J. van Houten), and Cincinnati (Dr. P. Herget). The instrument is still used at the Leiden Observatory by the van Houtens, in the continuing joint asteroid programs.

Important instrumentation has been acquired in connection with this Laboratory's lunar and planetary photography programs. Six darkrooms and processing laboratories are available. The large Saltzman enlarger (Fig. 11) was used in the production of the PHOTOGRAPHIC LUNAR ATLAS and the CONSOLIDATED LUNAR ATLAS. An Itek 248 Transflo Processor (24-inch model) has greatly reduced the manual operations and improved uniformity of quality.

The lunar crater counts and diameter-depth measuring program initiated by Mr. Arthur (*LPL Comm. Nos. 11 and 30, 40, 50, and 70*), using earth-based photography, is now conducted by Mr. Charles Wood with two assistants (Fig. 12), in quarters since substantially enlarged. The new program, using Orbiter and Apollo records, extends over the entire moon, for crater diameters in excess of 7 km (for limited regions down to 4 km). It allows greater precision on crater depths, even on the Near Side.

The plate vault (Fig. 2, Room 1-7) is dust proof and well ventilated; it contains the original telescopic LPL lunar and planetary records (8000+ lunar photos, 100,000+ planetary frames, about 20,000 in color); besides positive copies on 70 mm film of the NASA Surveyor missions. Three separate offices (3-347, 339B, 339D) house copies of the NASA Orbiter print series, the Apollo collection, and the Mars Mariner 9 series, all invaluable to the LPL research programs.

The Space Sciences Building has been in full use since late-1966 and was dedicated January 26, 1967. Dr. Homer E. Newell, NASA Associate Administrator for Space Science Applications, and Mr. Oran W. Nicks, Director of Lunar and Planetary Programs, spoke on behalf of NASA. The keynote address was given by Dr. Frederick Seitz, President of the National Academy of Sciences. These addresses, printed in a separate booklet, remain of interest. After Dr. Seitz described the origin of our Western civilization "in the Mediterranean basin under the influence of peoples and cultures associated with that latitude and environment . . .", he noted how "With the decay of Rome a significant portion of the vitality of this tradition jumped north of the Alps. . ." where "modern science, a product of the western Europeans, has been one of the major forces engendering social reform in the world in the past 200 years". . ."To the extent one can understand major trends when one is in the midst of them, it does appear that at the present time our nation is in the process of reconstructing, in its own terms, something in the nature of a Mediterranean culture in the South, Southwest, and Southern California in response to environmental factors quite different from those in the East, Midwest, and perhaps Northwest".

The Lunar and Planetary Laboratory has continued to feel deeply indebted to NASA and to Dr. Seitz for their encouragements and support. The observatory facilities developed by the Laboratory in the favorable climatic and topographic setting of SW United States are described in the following sections.

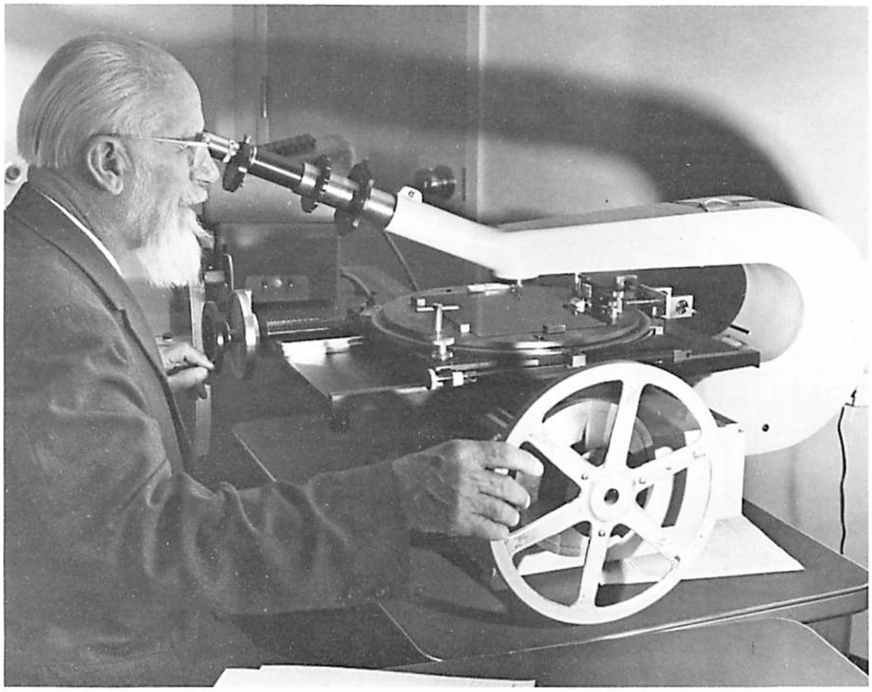


Fig. 9 Dr. G. Van Biesbroeck using Mann measuring machine

Fig. 10 Dr. T. Gehrels at the blink comparator, searching for asteroids

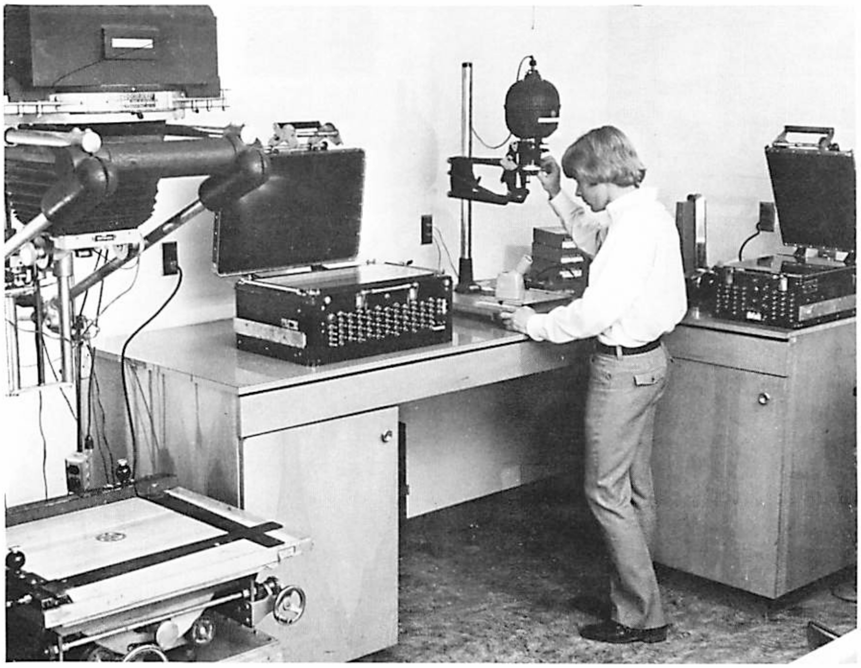


Fig. 11 Saltzman enlarger (at left) and other equipment operated by Mr. J. Fountain

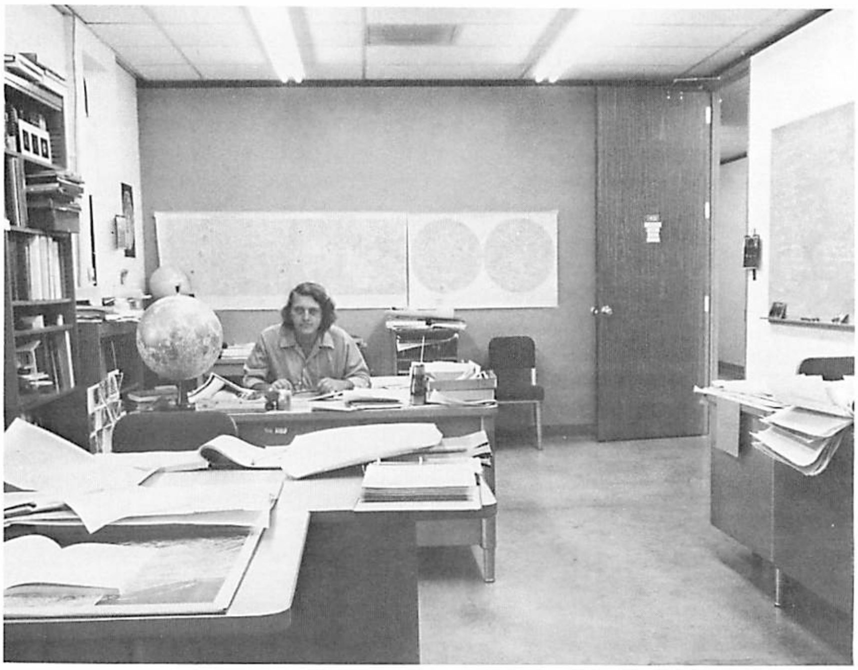


Fig. 12 Crater measuring operation; Mr. C. Wood

3. The Catalina Observatory

When I first considered, late 1960, a suitable location in Arizona for a 60-inch high-resolution telescope for planetary studies, I examined the possibility, in consultation with Dr. E. F. Carpenter, of using a section of the 2-acre area on Kitt Peak that had been assigned to the University in exchange for accommodations to AURA on the University Campus. It became soon apparent, however, that a different and higher site would be preferable for our programs, which at the same time would allow a later expansion for additional telescopes. Exploration from a small airplane, which disclosed the relative seriousness of air turbulence over a large number of peaks in Southern Arizona, led me to choose the nearby Catalina Mts. as the most suitable (near-laminar flow, dark and heavy forest cover, altitudes up to 9160 ft; proximity to Tucson). Two sites were examined in detail, the present Catalina Observatory, a well-developed site (road, electric power, telephone) that was being vacated by the Mountain States Telephone Co., only 36 miles from the Campus; and Mt. Lemmon itself, occupied by a major radar base of the Air Defense Command, but with some adjacent terrain still available. The second site was not developed, not readily accessible, and would have required major expenditures. The first site was selected and ground tests began late 1961. Construction of the 21-inch telescope (*LPL Comm. No. 1*)began December 1962, with observations starting 1 February 1963. Site testing was continued for determining the optimum location and elevation of the 60-inch high-resolution telescope, with the aid of pilot balloons, smoke bombs, and later a test tower. The 61-inch telescope was completed early October 1965 and is described separately (*LPL Comm. No. 200*).

Three additional photometric telescopes were installed later, two of 60-inch and one of 28-inch aperture. One of the 60-inch telescopes is owned by NASA. The three were emplaced on a site about 0.4 miles away, and 200 ft higher, called Site II, Catalina Observatory. When the Mt. Lemmon Radar Base (9157 ft = 2800 m) was being decommissioned, I succeeded in conferences with Air Force and Forest Service representatives to save the developed Mt. Lemmon summit area for infrared astronomical research, either at the national or the university level. Thus the Mt. Lemmon Infrared Observatory was initiated October 1970. During the deliberations, this Laboratory obligated itself to the U.S. Forest Service to vacate Site II, Catalina Observatory,by 1972 and move its telescopes to Mt. Lemmon. This was accomplished on schedule.

At present, the Catalina Observatory has three telescopes, with the 61-inch high-resolution telescope still its main instrument. It was funded by NASA; the building was provided by the University. The telescope has been in continual operation since October 7, 1965. Figure 13 shows the simple camera enlarging attachment for planetary photography. Figure 14*a* shows Dr. Gehrels' photopolarimeter, and Figure 14*b* the Idealab interferometer developed and used by Drs. H. Larson and U. Fink. The Schmidt telescope (Fig. 15) was put into operation in 1972 at the location of the former 21-inch photometric telescope. It has a 7° x 7° field (square), and is used for photography of extended objects and searches for moving objects that can be observed in greater detail with the 61-inch. A 10-room dormitory (six bedrooms), built of California redwood, provides living quarters for the observing staffs (Fig. 16). It was completed January 1966.

The elevation of the Catalina Observatory is 8250 ft (2520 m), one of the highest in full-time use on a year-round basis. Its distance from the Campus of the University is only 36 miles by an excellent road, the Catalina Highway. The Observatory uses commercial power, but has its own standby power plant and its own water supply. The principal observing programs are planetary photography; near-infrared spectroscopy and interferometry; far-infrared broad-band photometry and image scanning; studies of asteroids, both light curves and polarization; comets, both astrometry and photographic studies of structures in coma and tail; positions of asteroids and satellites; and some stellar programs. The telescope has two Cassegrain mirrors, F/13.5, giving 10 arc-sec per mm; and F/45, with 3 arc-sec per mm. The latter has been used primarily for lunar and planetary photography. The photography of the CONSOLIDATED LUNAR ATLAS was obtained with it, with resolutions to 0".15, as is the continued planetary photography (over 100,000 images by 1972). Dr. Frank Low has devised a separate oscillating F/45 mirror, which has enabled him to extend observations beyond 8μ to sources 100x fainter than was previously possible, through a better elimination of background radiation. The positional work and studies of faint objects is done at F/13.5.

The 61-inch telescope was funded by NASA for Dr. Kuiper's NASA-supported research programs; the Schmidt telescope, largely for the programs of Dr. E. Roemer. Very great opportunities remain for both instruments (cf. Figs. 18-27 below).

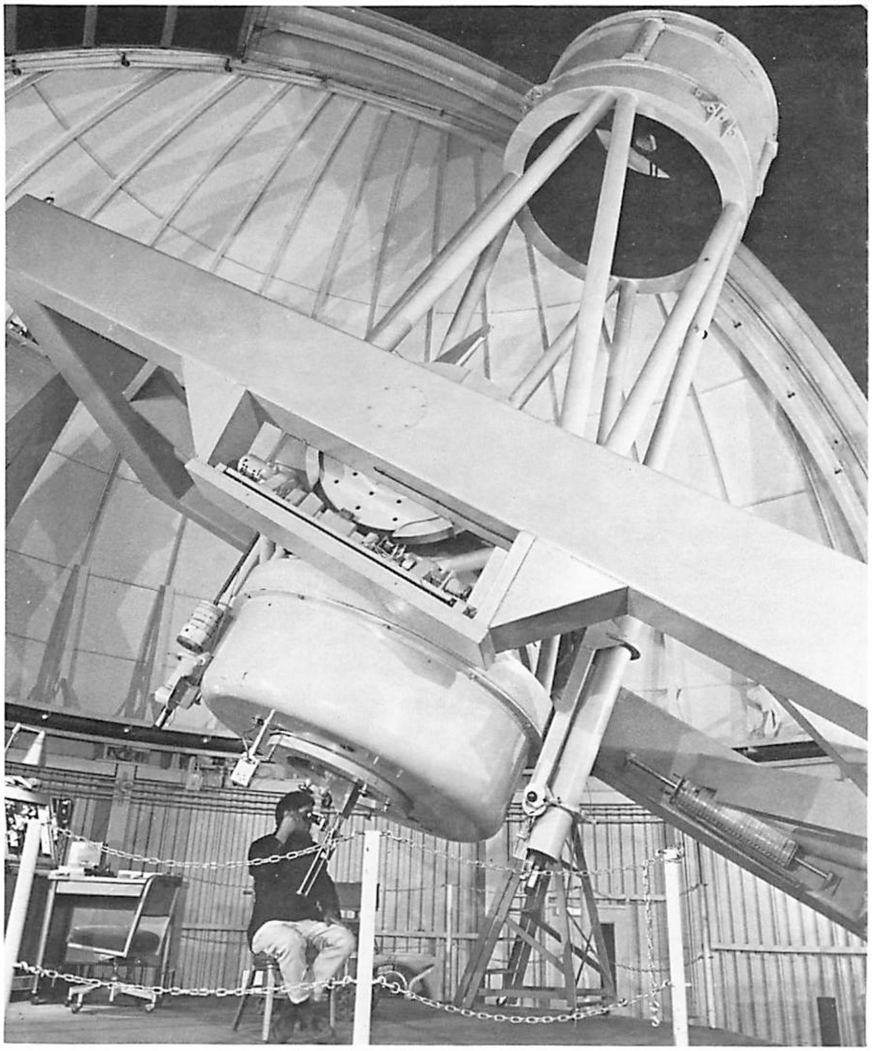


Fig. 13 61-inch Telescope, Catalina Observatory. Mr. C. Titulaer operating the planetary camera

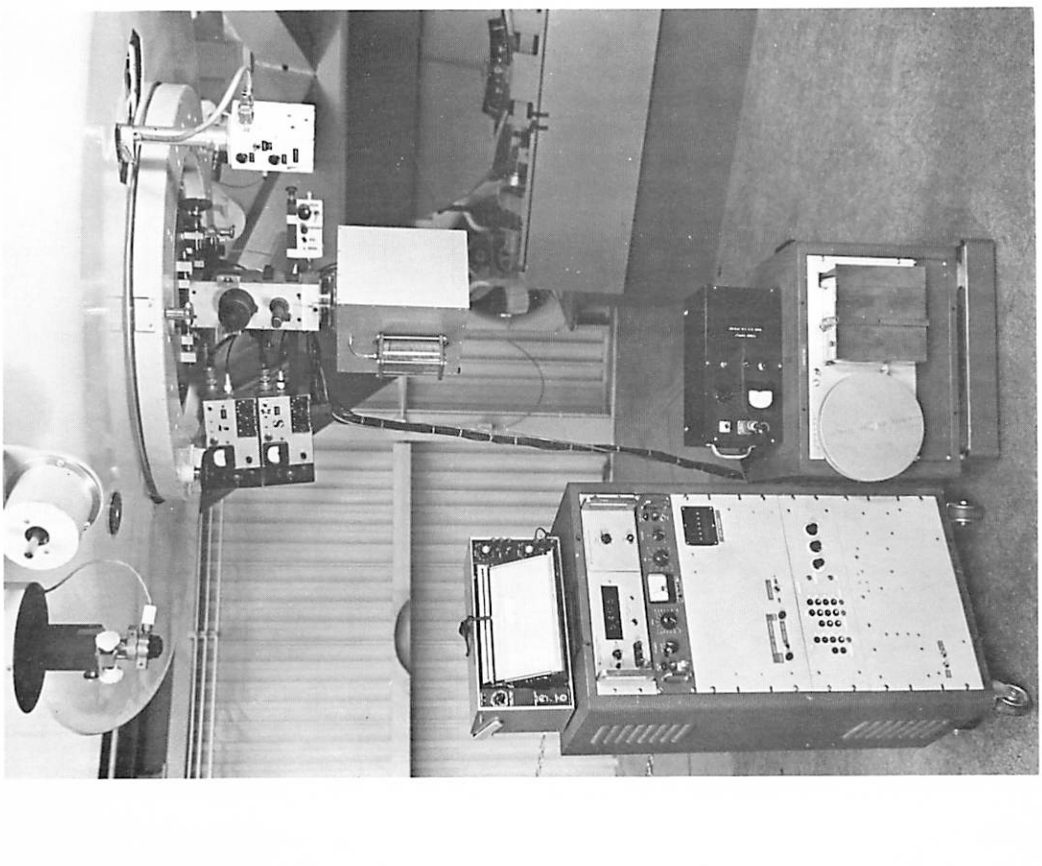


Fig. 14*a* Dr. Gehrels' photopolarimeter

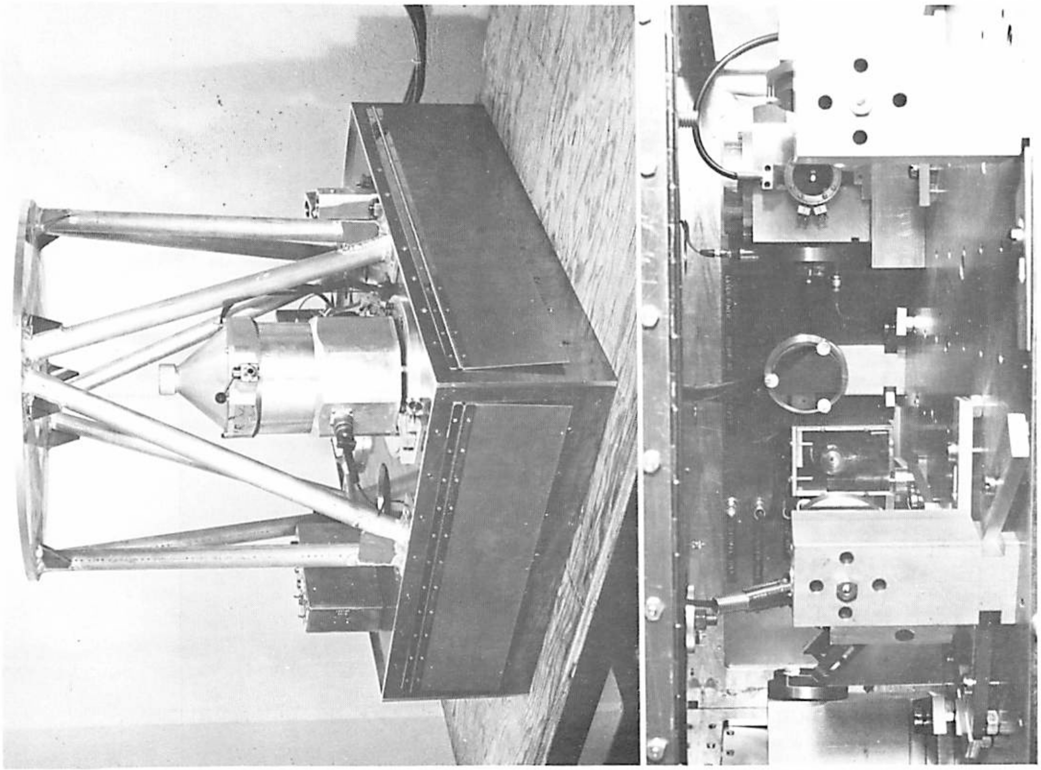


Fig. 14*b* The Idealab interferometer

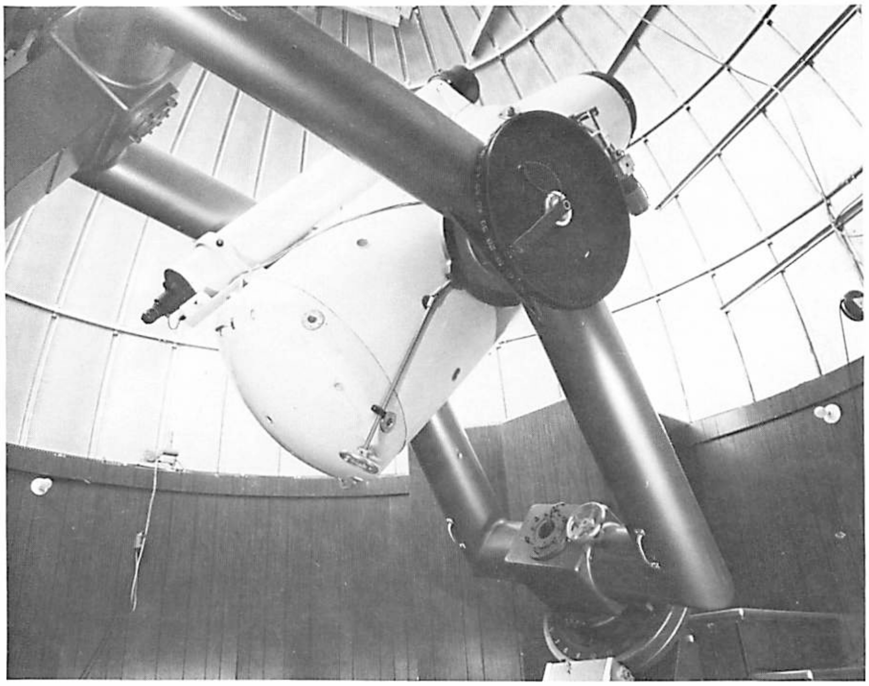


Fig. 15 17-28 inch Schmidt, (42 cm), F/3, Catalina Observatory

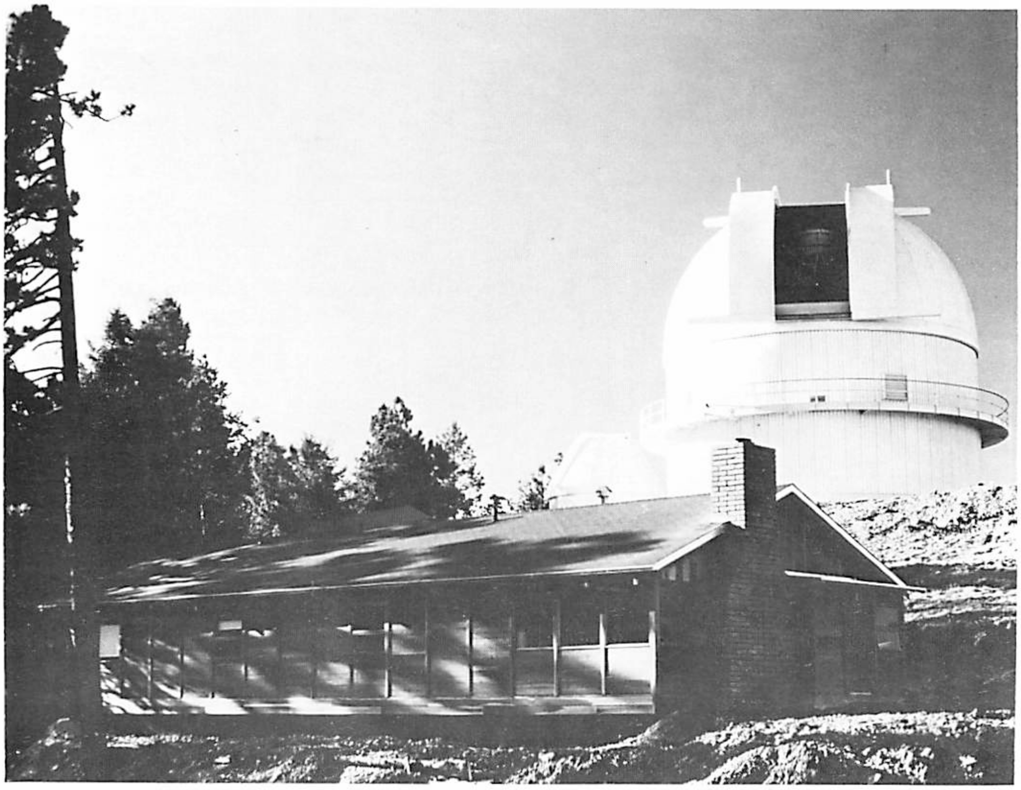
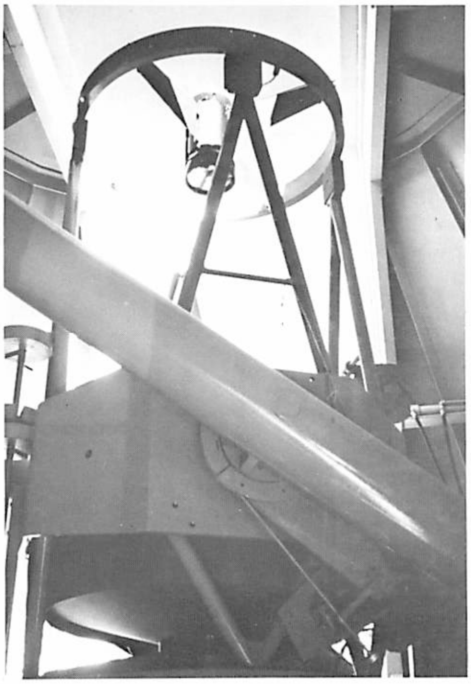


Fig. 16 61-inch Dome and Dormitory, Catalina Observatory



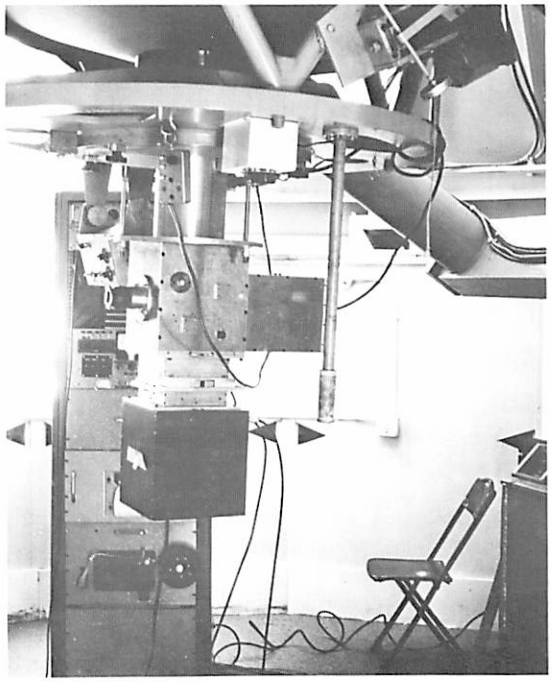


Fig. 17*a&b* 40-inch photometric telescope on Soldier Peak (el. 8570 ft, 2610 m) with photometer attached

On Soldier Peak, 0.3 mile to the SE and 300 ft (90 m) higher, is located a third telescope, 40 inches in diameter (Fig. 17*a&b*), used primarily for planetary and stellar photometric programs. The Peak is symmetrical and heavily-wooded, used by the F.A.A. for aircraft position-finding under remote control from the Tucson International Airport. Agreement was reached with the F.A.A. and the U.S. Forest Service in 1969 for this Laboratory to make astronomical tests and observations there; conceivably it could have superior image quality to the main Catalina telescope. The site has proved satisfactory but would undoubtedly gain further by placing the telescope higher than was allowed by the F.A.A. antenna system (about 28 ft.). This may become possible at some future date.

Sample photographs with the 61-inch telescope are reproduced in Figure 18, as well as in the Frontispiece. With the remarkably successful Mariner 9 coverage of Mars, the remaining telescopic work must be largely concerned with the seasonal and secular albedo changes on that planet, presumably reflecting variable dust deposits on the lava fields, as I postulated in 1957 (*Ap. J.*, *125*, p. 317). Further, the variations of the polar caps and equatorial clouds remain of great interest. For the study of the latter, color photographs are preferred since the clouds are white and the Martian surface ochre. For Jupiter, Saturn, and Venus, the telescopic cloud studies are still our only sources. An example of an interpretative study of the Jupiter Red Spot is shown in Figure 19.

The study of comets, begun at this Laboratory by Prof. G. Van Biesbroeck, has been greatly extended since 1966 when Dr. E. Roemer joined the LPL staff. Photographs of a few objects are reproduced in Figure 20. For a detailed review of this fascinating subject we refer to "Comets, Scientific Data and Missions (Proceedings of the Tucson Comet Conference)" published in 1972.

Fig. 18 Sample photographs of results from 61-inch telescope (next page)

1. Venus, inferior conjunction, in red light, July 19, 1972, 17:20:54 UT
2. Venus at quadrature, in ultraviolet, April 10, 1972, 02:29:37 UT (high level clouds)
3. Mars, in red light, July 18, 1971, 10:42:26 UT (Mare Erythraeum and Solis Lacus)
4. Mars, red, August 27, 1971, 06:23:43 UT (Sinus Sabaeus; South Pole)

5. Jupiter, blue, July 7, 1971, 03:40:28 UT (Red Spot, white oval, SEB disturbance)
6. Jupiter, in 0.89μ CH_4 band, on high speed IR, June 25, 1972, 08:36:05 UT (high level clouds only, Red Spot)
7. Saturn, blue, August 30, 1969, 11:20:26 UT (numerous zones and belts; structure in Ring)
8. Saturn, in CH_4, January 25, 1972, 02:51:44 UT (high level clouds only; crepe Ring)

9. Comet Bennett 1970II, March 28, 1970, 12:36 UT (effects of nuclear rotation on streamers)
10. Orbiter V, near lunar limb (between dots), January 21, 1968, 12:30 UT. Exposure time 10 sec.
11. Apollo 8, near Moon, accompanied by S-IVB, December 23, 1968, 01:30 UT (fluctuations due to tumbling of rocket). Exposure time 2 min.

The crucial importance of choosing optimum resolution in planetary spectroscopy is evident from Figure 21 which shows the computed profiles for one of the most accessible CO_2 bands in the near-infrared. Three resolutions are shown, increasing by steps of only 2. Yet, the detectivity is increased enormously, as is the possibility of deriving rotation temperatures. Our Idealab interferometer resolution is 0.5 cm^{-1}.

In addition to this rather optimum resolution, the Idealab instrument is now provided with a Fourier computer, designed and constructed under the supervision of Dr. Guy Michel during his one-year appointment, 1970-1971. The computer was completed in time for our 1971 Mars flights aboard the NASA CV-990, based on Hickam Field, Hawaii, and worked satisfactorily. The computer co-adds the interferograms as they are received, makes the Fourier transform of the Sun, and displays a small part of the spectrum on an oscilloscope. This display indicates whether the equipment is functioning satisfactorily and, of course, serves as an exposure meter as well. The instrument has been described by Dr. Michel (1972).

Two sets of spectra with our Block interferometer are reproduced here. Figure 22, taken from the Feb. 1970 issue of *Sky and Telescope*, shows the spectrum of the Saturn Rings, obtained on an unusually dry night with the 61-inch telescope; and its interpretation in terms of H_2O ice at about -190°C. Figure 23 shows spectra of the Galilean satellites of Jupiter, compared to the Moon, indicating the presence of H_2O ice on the second and third satellites (Europa and Ganymede), but giving no particular clue to the surface cover of Io and Callisto.

Of the important results obtained with the Connes interferometer on the 90-inch Steward Observatory telescope, we show in Figure 24, ten narrow absorption bands in the Martian polar cap due to solid CO_2.

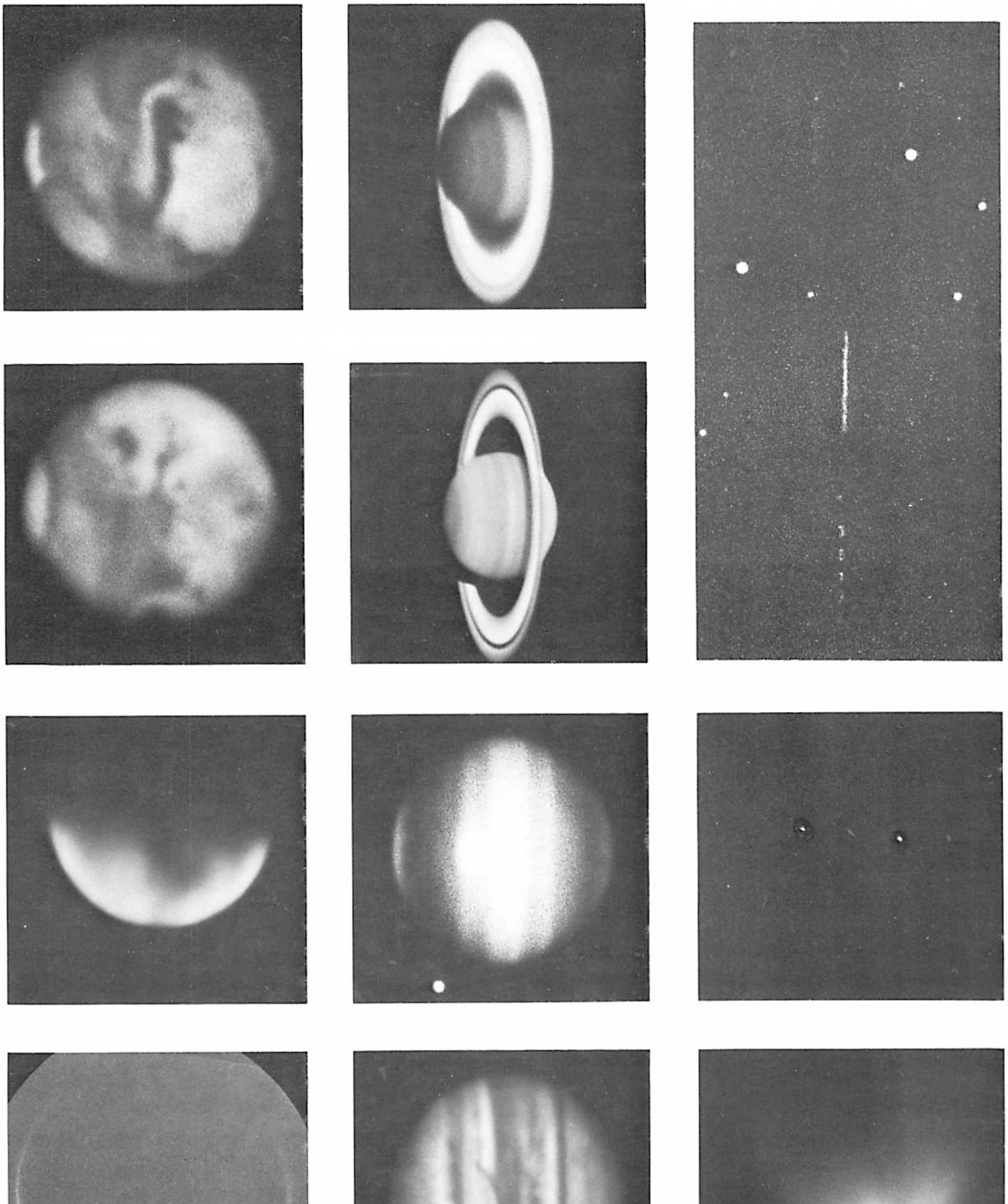


Fig. 18 Sample photographs of planets and distant spacecraft

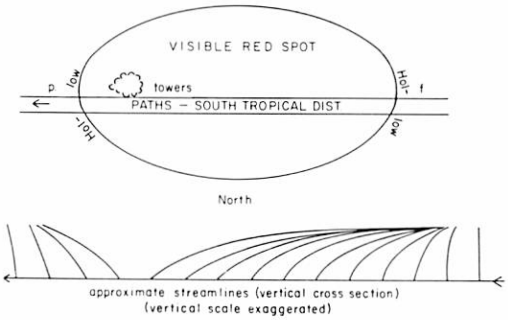


Fig. 19 Horizontal and vertical views of stream lines postulated for the interpretation of Jupiter Red Spot (G. P. Kuiper, *Sky and Telescope*, Feb. 1972, p. 80; and *LPL Comm. No. 173*)

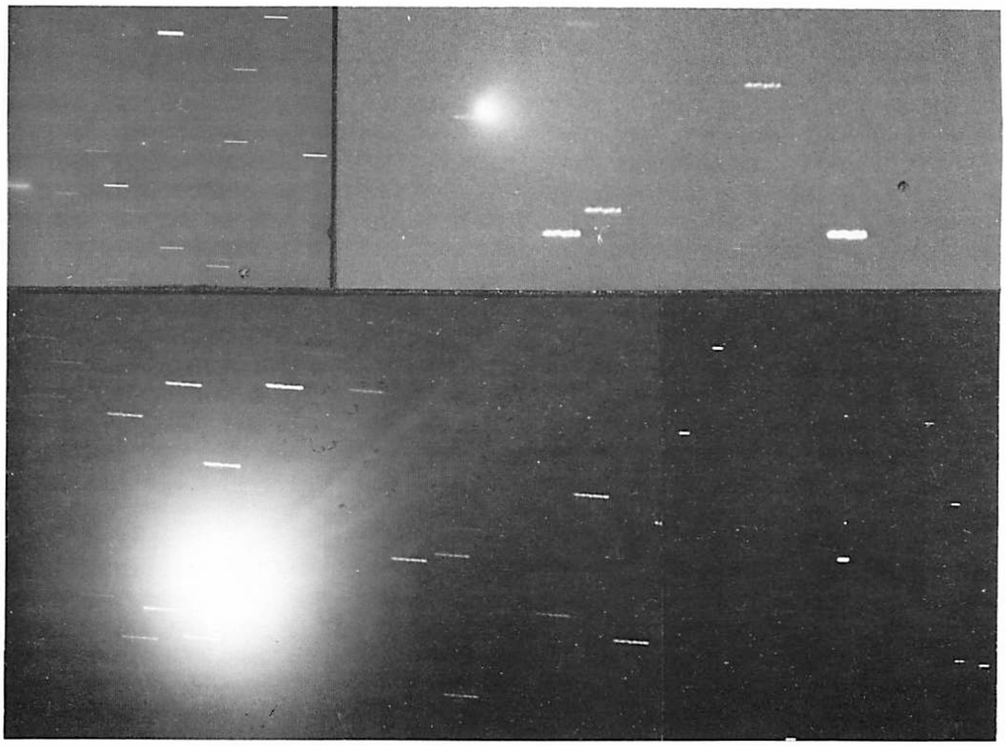


Fig. 20

(a) Recovery observation by Dr. E. Roemer of Periodic Comet Tempel 1, observed previously only in 1867, 1873, and 1879; with the 90" Steward Observatory telescope, Kitt Peak, Jan. 11, 1972; exp. 60 min., on Kodak 103a-O. Comet is small round dot; the stars are trailed because of pre-computed guiding on comet.

(b) Same Comet, May 16, 1972 UT, 90" Steward telescope, exp. 30 min., Kodak 103a-O, showing development of asymmetric coma; computed guiding on comet.

(c) Comet Tago-Sato-Kosaka, observed by Dr. Roemer, Feb. 3, 1970 UT, 90" Steward telescope, exp. 10 min., Kodak 103a-O, showing coma and Type I tails.

(d) Asteroid 1776, recorded by Dr. Roemer with 61" telescope; discovered by Dr. and Mrs. C. V. van Houten and named for this author.

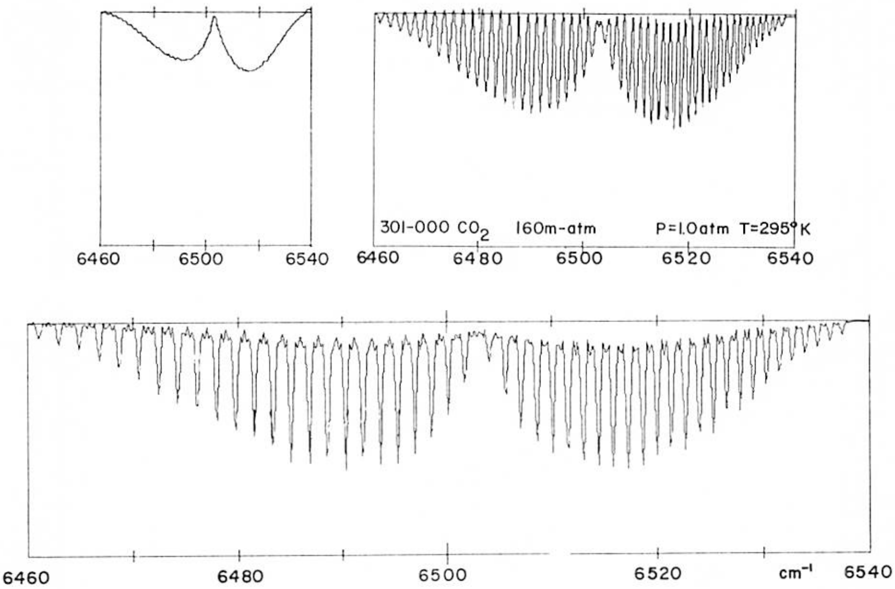
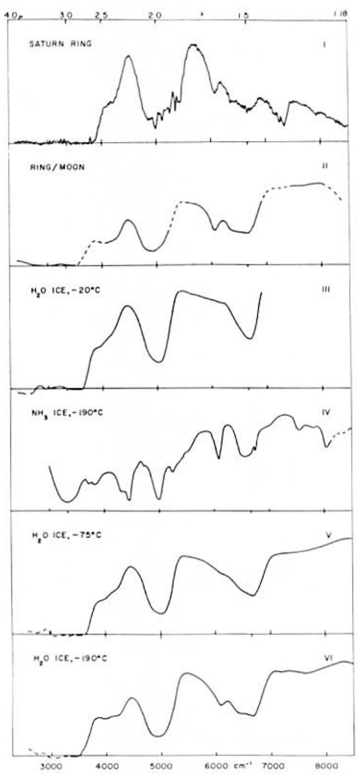
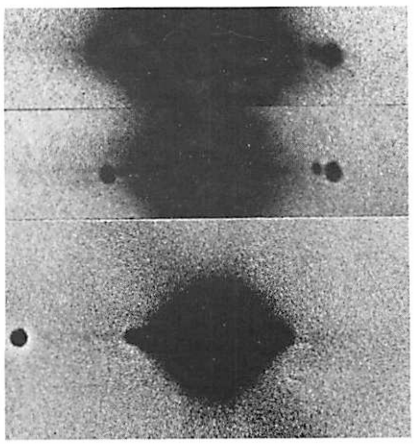


Fig. 21 The 301 band of CO_2 (centered at 1.538μ) shown on 3 resolutions: 1.2, 0.6, and 0.3 cm^{-1}, calculated by Dr. U. Fink, for 160 m-atmospheres of gas at P = 1.0 atm., T = 290°K

Fig. 22 Saturn's Rings - Left: Infrared spectrum and ratio to Moon, on very dry night, 61" telescope; together with laboratory spectra of H_2O and NH_3 ice. H_2O ice at -190°C matches the Rings closely (Kuiper, Cruikshank, and Fink, *Sky and Telescope*, Feb, 1970).



Below: (negative prints) Faint extension of Ring into satellite belt up to near Dione, observed on 61" at nodal passage, 1966-67 (fully discussed in Kuiper 1973): (1) 2 prints of Dec. 12, 1966, $3^h19^m06^s$ UT, exp. 10 sec. at F/13.5, ring tilt 0°.1; (2) Jan. 5, 1967, $1^h34^m53^s$ UT, exp. 40 sec.; extension broadened, ring tilt 0°.5. Two lower prints dodged electronically to show inner parts of image.



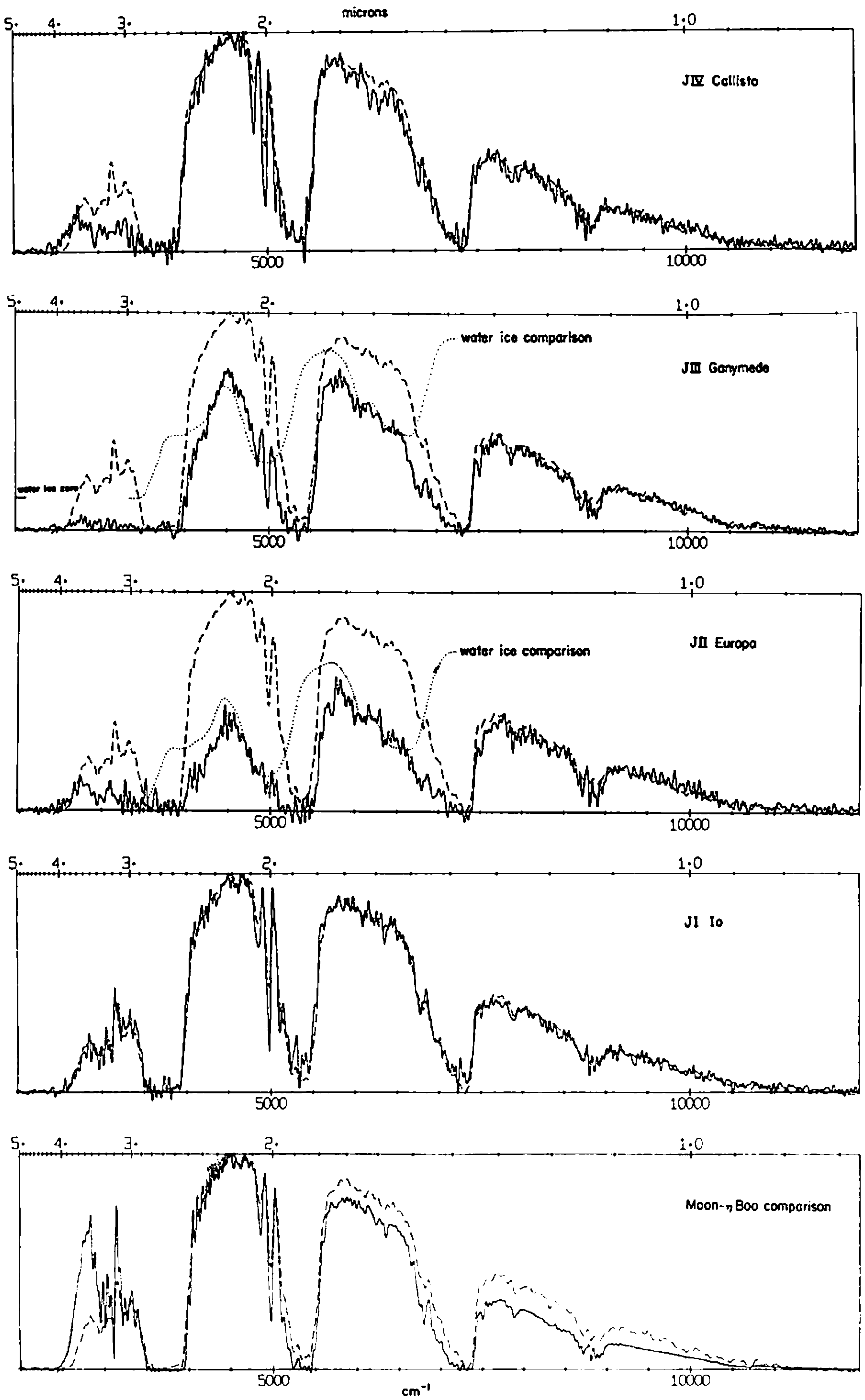


Fig. 23 Infrared spectra of the Galilean satellites of Jupiter, obtained with 61" telescope, by Fink, Dekkers, and Larson (*Ap. J. Letters*, 1 Feb. 1973), using ηBoo for comparison. Note excess Moon emission between 3 and 4μ, due to the Moon's own high temperature. JII and JIII markedly deficient in regions of water-ice absorptions

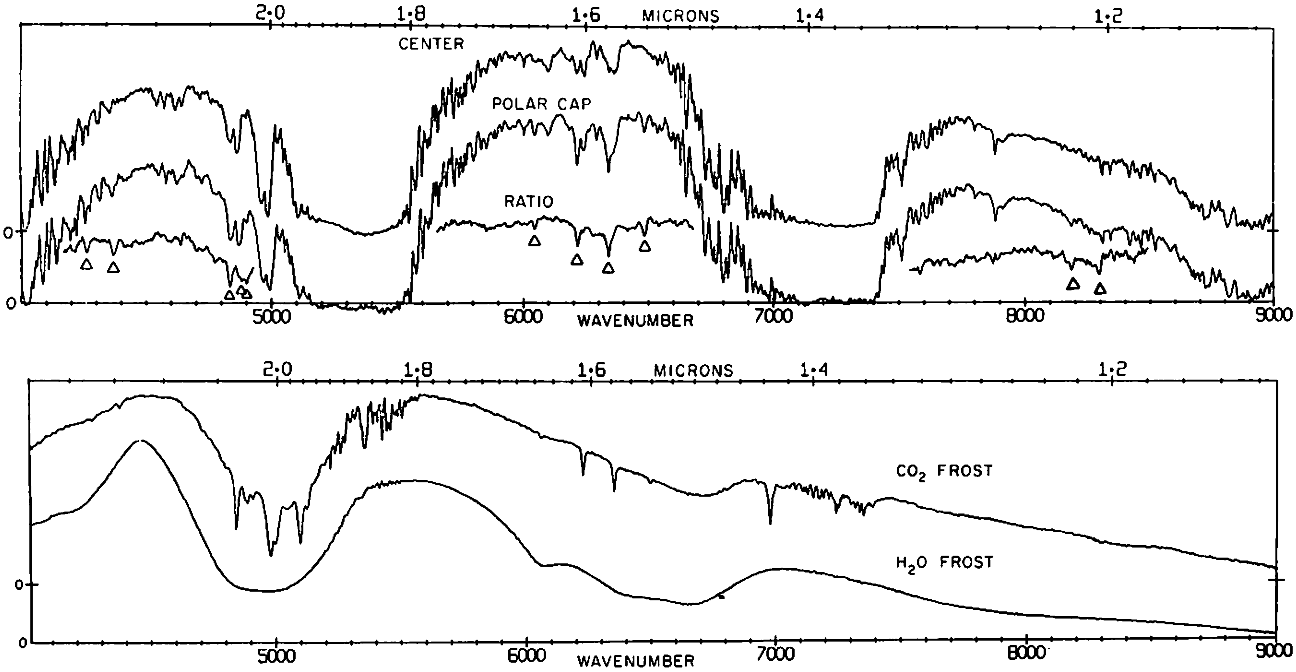


Fig. 24 Spectra of Mars (center of disk), its polar cap, and ratio, with solid CO_2 absorptions marked by triangles. Identifications explained in lower diagram. Connes interferometer at Coudé focus of 90" Steward Observatory telescope (H. P. Larson and U. Fink, *Ap. J. Letters*, 1 Feb, 1972)

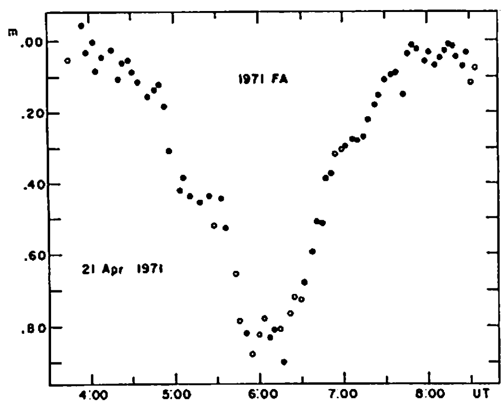


Fig. 25 Light curve of Daedalus, the second asteroid known to come close to the Sun(after Icarus), discovered by Dr. T. Gehrels, and observed at 61" telescope. Phase angle 20°.3;0.00 = 16.22 mag. Note that it dips to below 17.0 mag.at minimum. *(Astron. J., 76*, 607-608, 1971)

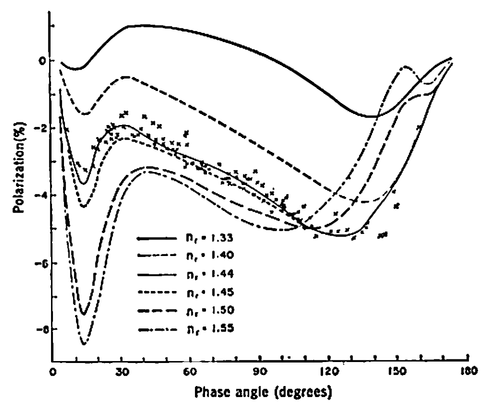


Fig. 26*a* Venus polarization vs phase angle for λ = 0.54μ, 61" Catalina Obs., (crosses); compared to computed curves for spherical particles with different refractive indices. (J.E. Hansen and A. Arking, *Science, 171*, 669-672, 1971)

Figure 25 shows an example of a light curve of a faint nearby asteroid obtained with the 61-inch telescope which, together with similar observations at other epochs, can determine the period of rotation, the approximate shape, and the orientation of the axis of rotation. Figure 26 collects some striking results from polarization measures, for the planet Venus and long-period variable stars with extended envelopes. Finally, Figure 27 shows samples of temperature maps of the planet Jupiter obtained with the 61-inch telescope in the 5-micron region.

While the most sensitive information on planetary gases is contained in the infrared, the solid or liquid condensation products in planetary atmospheres may already appear colored to the eye, as is the case for Jupiter, Saturn, and Venus. Under these conditions broad-band spectral studies in the ordinary photographic range are instructive also, which can be improved upon by the use of a multi-channel spectrometer. A 500-channel spectrometer, using vidicon techniques, is under development, covering the region 0.3-2μ with different vidicons and associated amplifiers.

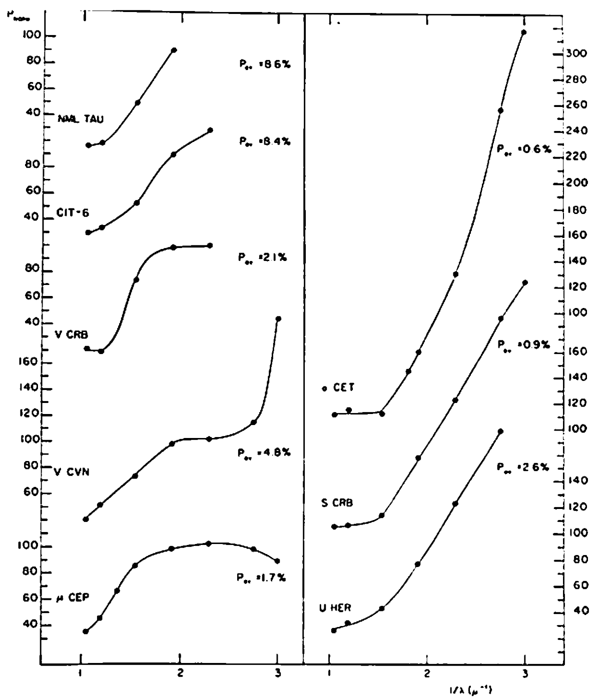
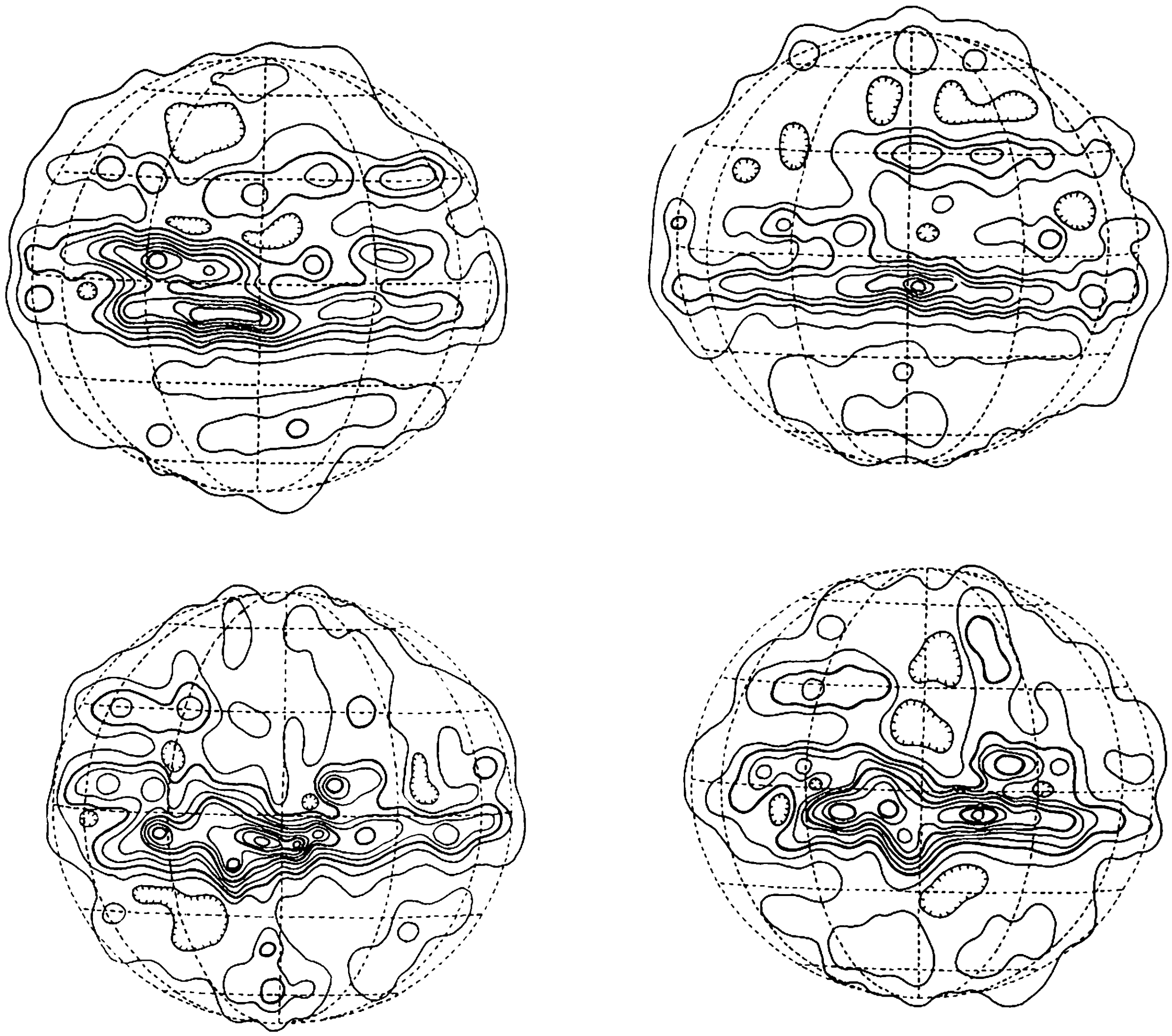


Fig. 26*b* Wavelength dependence of polarizations for several long-period variable stars. The curve for μ Cep is characteristic for interstellar grains; the others are abnormal because of extended envelopes of special interest to solar nebular studies. Observations with 61" telescope, mostly by Dr. A. Kruszewski (Warsaw). (T. Gehrels, VISTAS IN ASTRONOMY, Vol. 15, 1973)



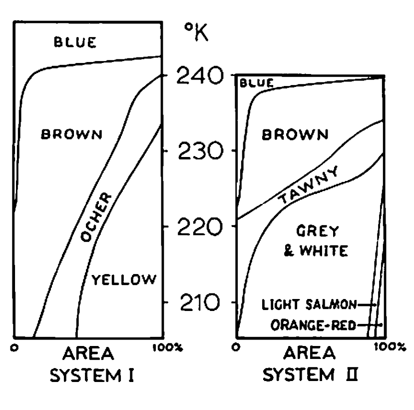


Fig. 27 Four 5μ temperature maps of Jupiter for May 21 and 22, 1972. The coldest regions have internal tick marks, with the contour representing T = 205°K. The other contours indicate, in sequence, T = 215, 222, 227, 231, 234, 237, 240, 242, 245° and 247°K. The temperatures are closely related to visual colors, as indicated in the separate plot. Note that the hottest areas are blue, apparently because of Rayleigh scattering in the absence of a local cloudcover. System I refers to the equatorial zone, from -10° to +10° latitude; P = $9^h50^m30\overset{s}{.}0$; System II refers to the remaining latitudes, P = $9^h55^m40\overset{s}{.}6$. (Keay, Low, Rieke, and Minton, *Ap. J.*, in press, 1973).

4. Mt. Lemmon IR Observatory

This former Radar Base of the Air Defense Command is being developed jointly with other universities interested in infrared astronomical research. The site, at 9157 ft (2800 m), is the highest and driest mountain top on the Continental U.S. that is readily accessible on a year-round basis. It is conveniently located near Tucson with its facilities and the Tucson International Airport, which provides through flights to Los Angeles, San Francisco, Chicago, etc.

In addition to the Lunar and Planetary Laboratory, the following institutions share in the use of the Mt. Lemmon Observatory facilities (which involve buildings, road maintenance, snow plowing for the 4-5 winter months, water obtained from several deep wells and stored in two 500,000-gal. tanks, electric power including standby power, and heating fuel): NASA Goddard and NASA-Marshall; the Universities of Minnesota, California at San Diego, and New York at Stony Brook, L.I.; and Ft. Huachuca, which uses one of the three former radar towers (modified); while the S.A.C. shares in the use of the main road and electric power.

The Laboratory has served as the coordinating organization, under the concept of the Users Group Agreement, implemented through bi-lateral Agreements with the University of Arizona. The 20-acre summit area itself is Federal land, under the jurisdiction of the U.S. Forest Service, and is managed by this Laboratory under the terms of an indefinite Permit with the U.S. Forest Service, signed Oct. 1970. Two buildings on Mt. Lemmon are used by the U.S. Forest Service in summertime, for housing fire-fighting teams serving the Coronado National Forest. Aerial views of the Base were published in *LPL Communication No. 142* (April 1970). The first astronomical plans and some meteorological data were described in *LPL Communication No. 156* (pp. 360-366, Dec. 1970).

A 1972 map of the Mt. Lemmon IR Observatory area is found in Figure 28. The current uses of buildings are identified, with the same numbers used in the aerial photograph (Fig. 29), taken November 1972. Two of the radar domes still shown on the 1970 photographs have now been replaced by astronomical installations. Two additional observatory domes are seen, housing the 60-inch telescope of the Universities of Minnesota and San Diego, California; and the 28-inch LPL telescope (Buildings 20 and 3). The 60-inch C in Building No. 1 is illustrated in Figures 30*a*&*b*. From 1969-72 it was mounted on Site II, Catalina Observatory, and transferred to Mt. Lemmon June 1972. It is the third of a series of three similar metal-mirror telescopes developed by this Laboratory. The prototype was the 60-inch A, currently located at the San Pedro Martir, Baja California, Station, under a joint agreement with the University of Mexico (cf. p. 229). The 60-inch A telescope was constructed on funds provided to Drs. H. L. Johnson and G. P. Kuiper by the National Science Foundation. The Minnesota telescope (Bldg. 20) and the 40-inch on Soldier Peak (Fig. 17) are of the same general design; the 40-inch is a pyrex mirror (1 arc sec resolution). The 60-inch A was described by Dr. Johnson in *LPL Communication No. 111* (1968). The 28-inch telescope, also described there, is shown in its new dome on Mt. Lemmon in Figure 31. It was originally funded by NSF and NOTS, USN, to Drs. Kuiper and Johnson; it is currently operated by Dr. F. Low and his group for IR observation, after extensive modification by Dr. Low, both optically and mechanically. It has the lowest background emission of any large telescope in the infrared and is considered a model for the design of large infrared telescopes in the future. With it, Dr. Low has been able, on Mt. Lemmon, to extend his observations to 40μ.

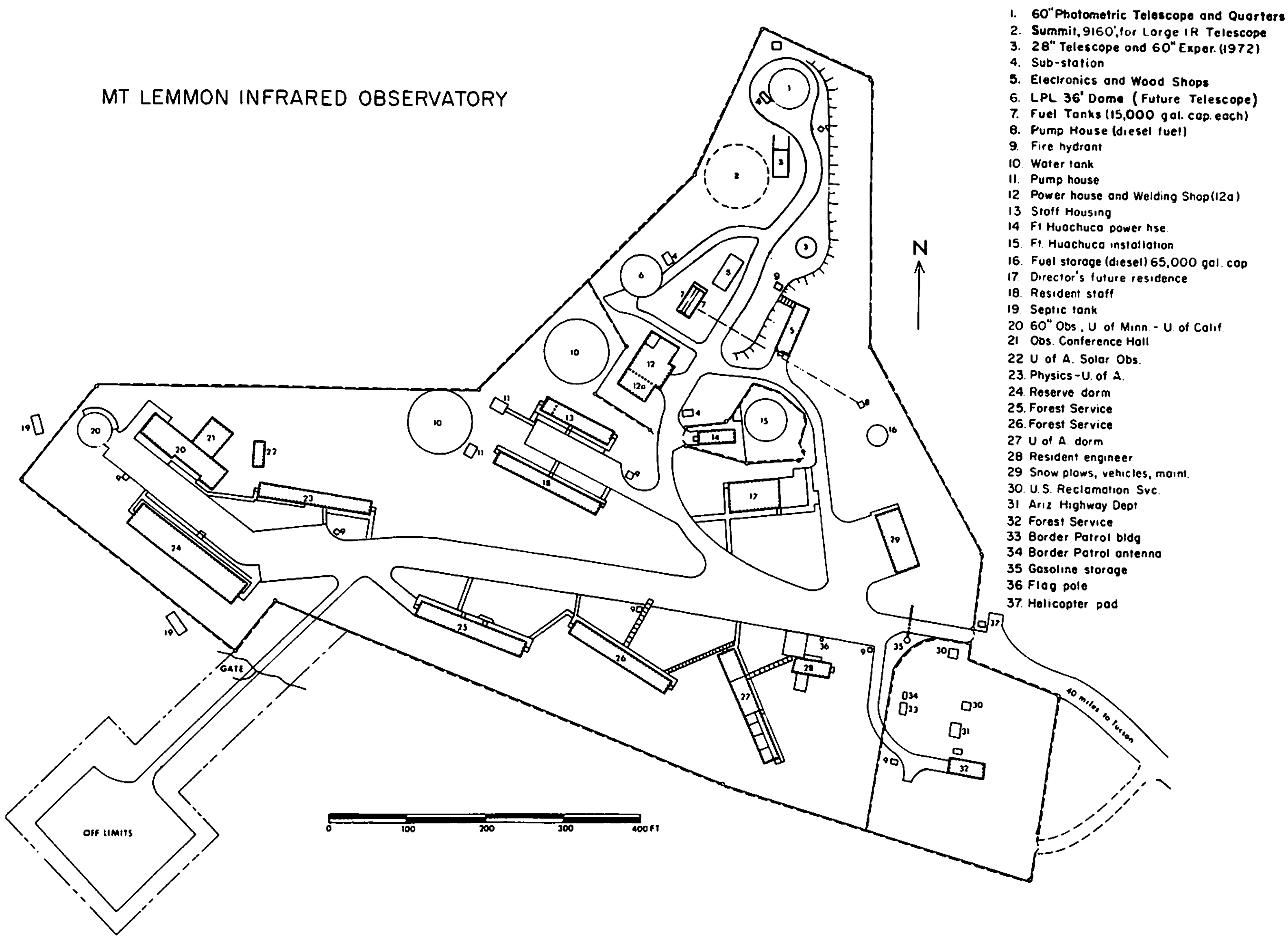


Fig. 28 Map of Mt. Lemmon Infrared Observatory, with building assignments

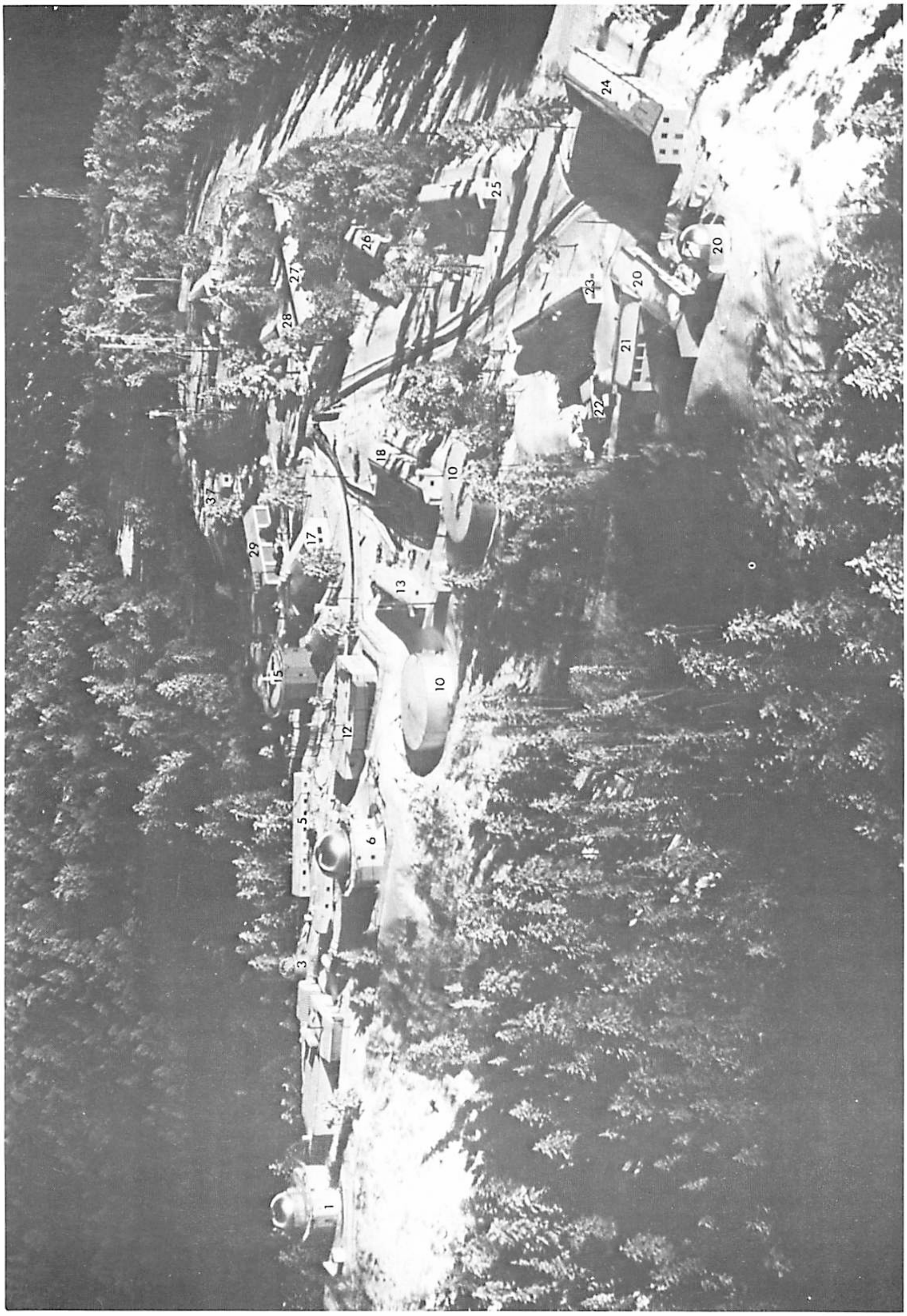


Fig. 29 Aerial view of Mt. Lemmon Infrared Observatory, Nov. '72; cf. map in Fig. 28

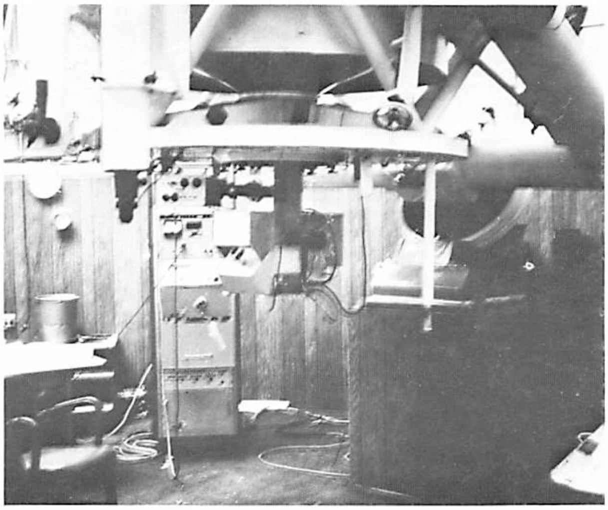
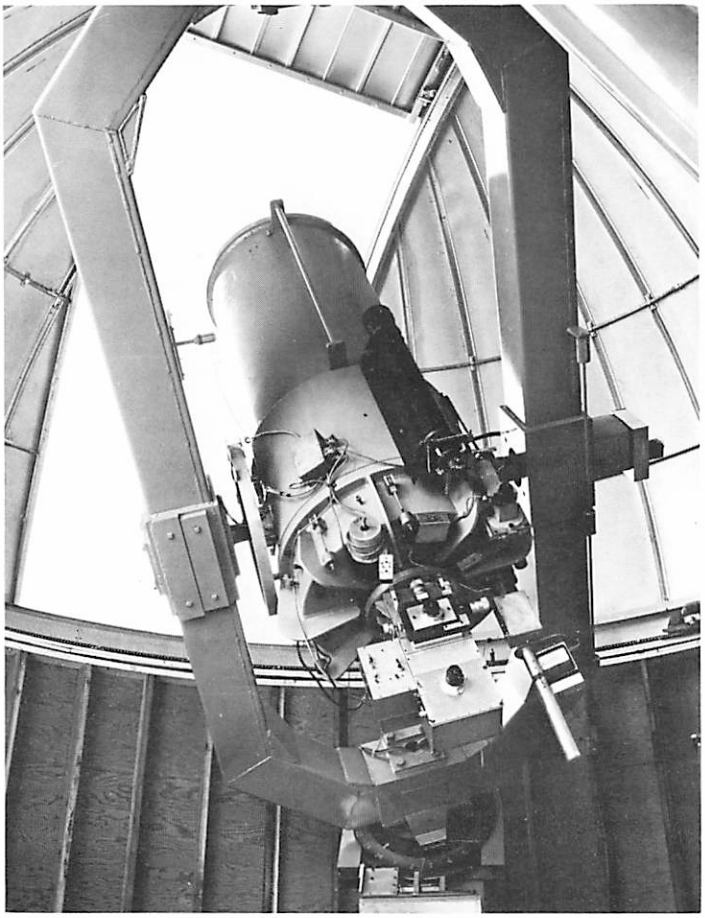


Fig. 30*a*&*b* NASA 60-inch C photometric telescope on Mt. Lemmon with IR photometer attached

Plans for one or two major additional facilities on Mt. Lemmon are currently being developed. One of these involves Building 6 and its new 36-1/2 foot dome recently installed by the University (Fig. 32); another, a test facility at several hundred feet above the summit, to penetrate completely the boundary layer which is the chief cause of reduced image quality.

The spatial relationship of the buildings in Figures 14-17 may be seen from Figure 33. It shows the Catalina Observatory with its two domes, the nearby 40-inch telescope on Soldier Peak, Dr. Hill's 60-ft tall Solar Observatory between the two and beyond; and the University's TV tower on Mt. Bigelow (8550 ft = 2610



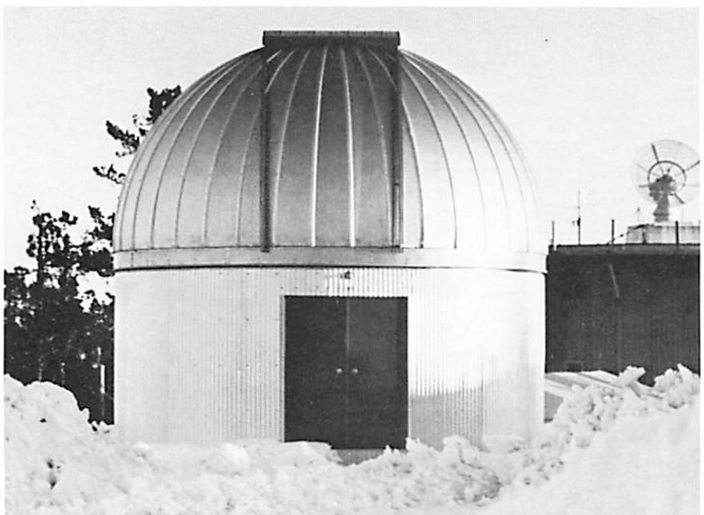


Fig. 31 *a&b* 28-inch telescope and dome on Mt. Lemmon

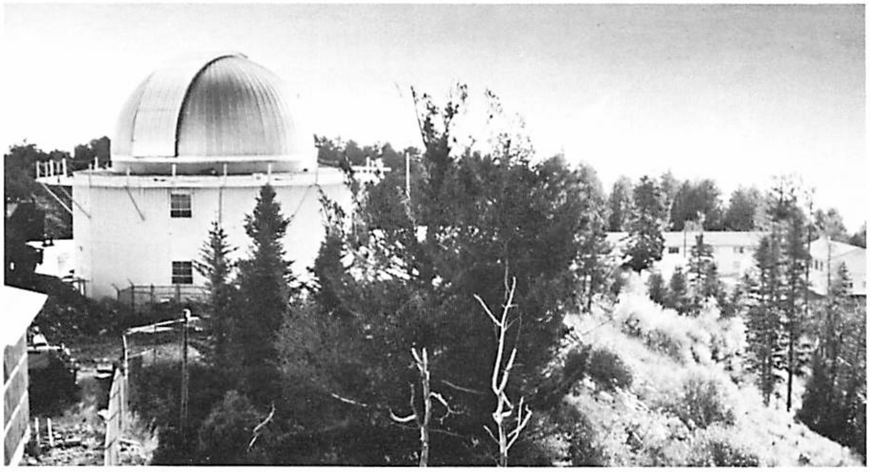


Fig. 32 New University 36-1/2 foot dome (Bldg. No. 6, Mt. Lemmon) for 70-inch telescope. Minnesota dome at extreme right

m). An equally beautiful setting is that of the Mt. Lemmon IR Observatory, seen in Figure 33, which covers the close-up views of Figures 28-32. Figure 34 was taken 7 miles to the left of Figure 33. Mt. Lemmon's shadow in the sky is shown in Figure 35. The full astronomical potential of Mt. Lemmon is still to be developed.

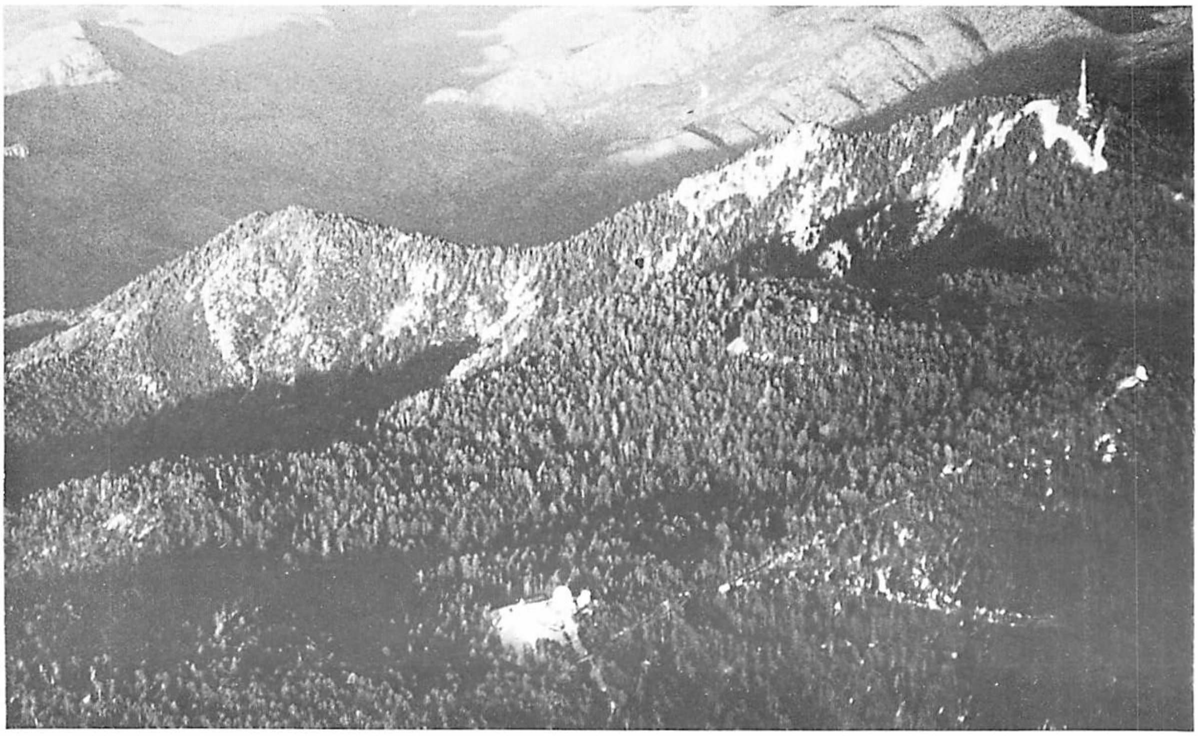


Fig. 33 61-inch and Schmidt domes center, 40-inch dome right, Solar Observatory between and beyond; TV towers upper right

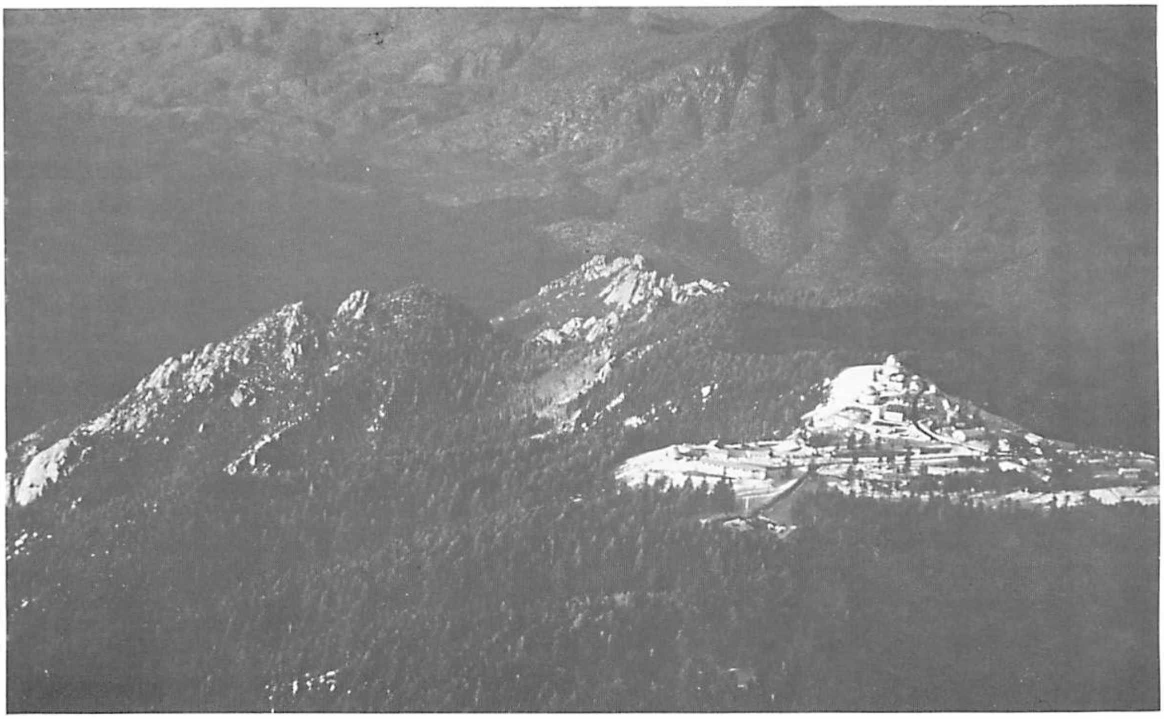


Fig. 34 The Mt. Lemmon IR Observatory seen from 10,500 feet

Fig. 35 Shadow of Mt. Lemmon in sky at sunset

5. Supplementary Observatory Facilities

Tumamoc Hill is an 800-ft basaltic mesa just W. of Tucson, owned by the University (el. 3150 ft = 960 m above sea level). Its location with respect to the Tucson basin and the Catalina Mts. is shown in Figure 36. Tumamoc is an interesting archeological site, occupied by the Hohokam Indians from about 1200-1450 AD as a heavily defended refuge. This was largely discovered and mapped by Mr. and Mrs. S. M. Larson of the LPL staff (Fig. 37). The Hohokam, whose main settlements were in the valley just N. and NE of the mesa, near the Santa Cruz River, apparently kept their families up on Tumamoc, when under attack from the Apaches. One cannot fail to be reminded of the great historic mesa of Israel, abandoned 1900 years ago.

The University's Geochronology Laboratory is located on the N. slope of the Hill, 1/3 of the way up. On the S. rim of the mesa LPL has constructed a dome (Figs. 38, 39) that now houses a 21-inch planetary telescope. The location was selected after comparative tests between the S. and N. rims, extending over nearly a year, using two identical tracking telescopes having 18-inch clear aperture. The air flow over the mesa was observed with pilot balloons and showed the boundary layer to be about 40 ft thick at the center vs. 10-20 ft over the S. rim.

The 21-inch planetary telescope was remodeled from the photometric instrument described in *LPL Communication No. 1.* Two new Cassegrain secondaries are available, F/30 and F/100, with variable enlargements added near the focus. The remodeled telescope in its new dome is shown in Figure 39. A versatile semi-automatic camera has been added. Prior to the 21-inch telescope, the Tumamoc dome was used some 400 ft farther N. for a 16-inch modified Newtonian telescope, especially constructed for Dr. Van Biesbroeck (Fig. 40). Dr. Kuiper's private observatory for visual planetary studies, one mile E. of the Campus, is shown in Figure 41.

LPL Communication No. 199 makes reference to the LPL assistance with cutting the 8-mile road to the summit ridge of San Pedro Martir, Baja California Norte (31°0'N; el. 9300 ft = 2840 m). Figure 42 shows the LPL Observatory Superintendent, Mr. Arnold Evans, who personally cut the 8-mile road during nine very long days without respite. At present, the first 60-inch LPL metal-mirror IR telescope is located at this new observatory, besides a 32-inch telescope owned by the University of Mexico.

In Figure 43, we collect some information on the LPL test observatory on Puu Poliahu, Mauna Kea, Hawaii, lat. 19°49', el. 13,631 ft = 4155 m, erected in May 1964, and used intensively in a 6-month test program with an excellent 12-1/2 inch visual test telescope. The road above 9200 ft was constructed in May 1964 as authorized by Governor Burns personally, and is mostly still in use for the present Mauna Kea Observatory of the University of Hawaii. The test results are compared to other sites in *LPL Communication No. 199.* (Poliahu is the Hawaiian snow goddess).

For programs requiring larger aperture than the 61-inch telescope, the University's Steward Observatory has made available observing time on the 90-inch telescope on Kitt Peak. The programs have especially benefited Dr. E. Roemer's coverage of faint comets, minor planets, and satellites; polarization programs by Drs. Coyne, Gehrels, Serkowski and Zellner; and the infrared spectroscopy with the Connes interferometer by Drs. H. Larson and U. Fink.

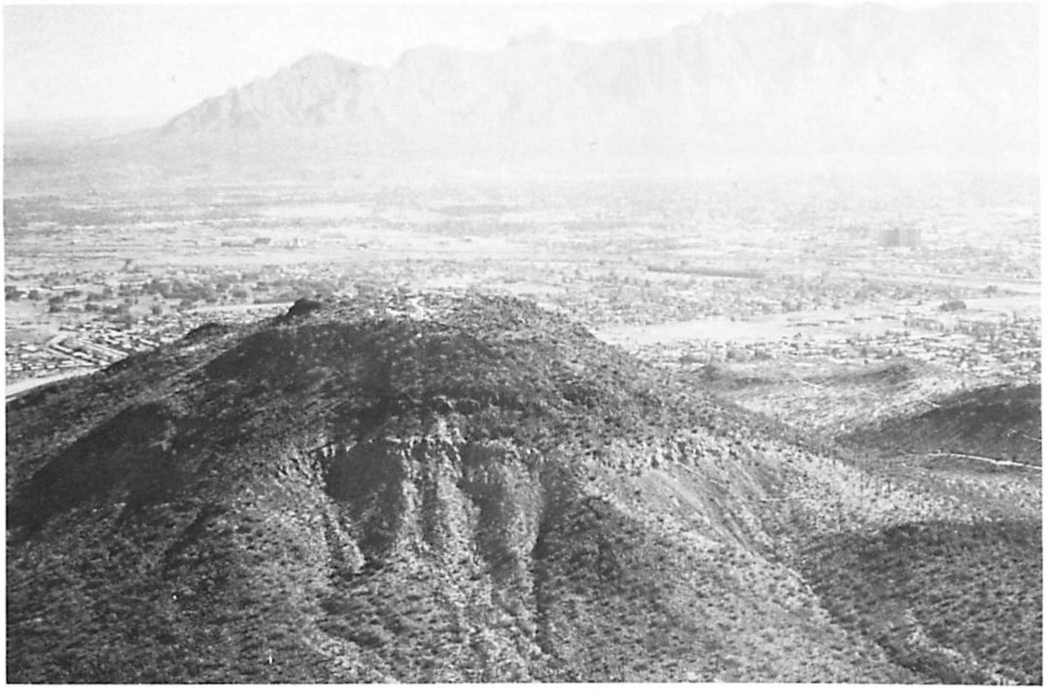


Fig. 36 Structure of Tumamoc (telescope located above dot)

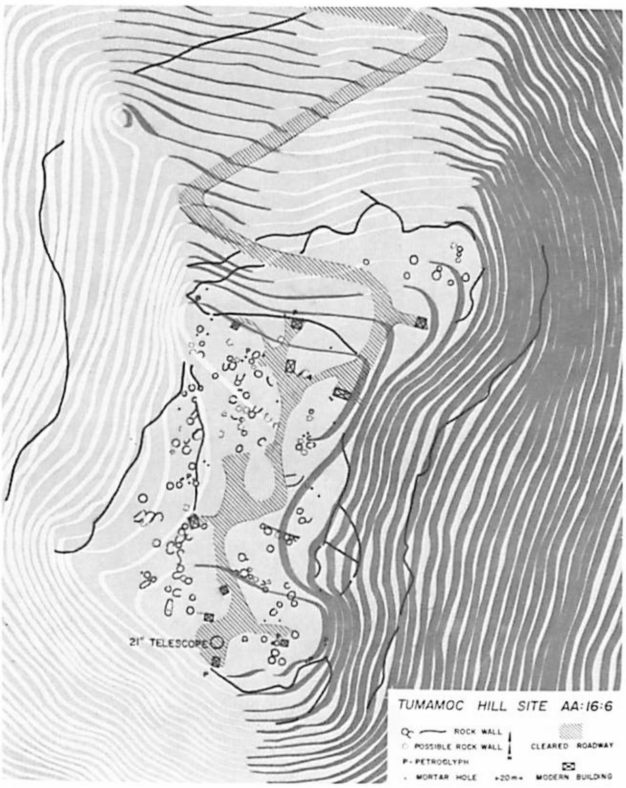


Fig. 37 Hohokam rock structures on Tumamoc (S. Larson). Map shows defense walls and numerous sleeping circles, all built of local basaltic lava blocks

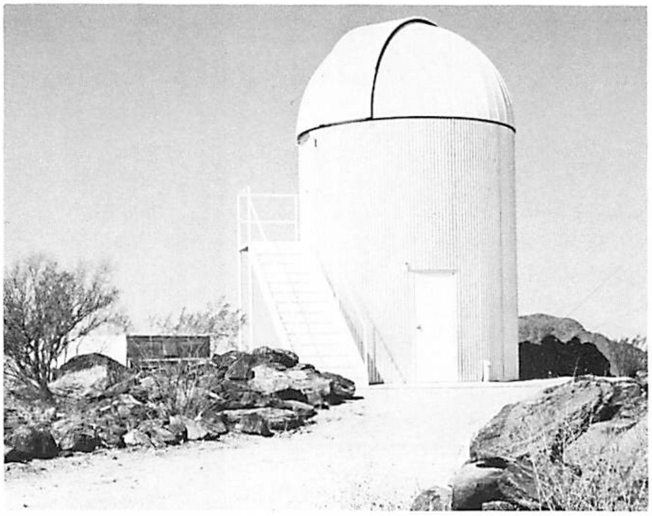


Fig. 38 Observatory on Tumamoc for planetary photography, looking SW

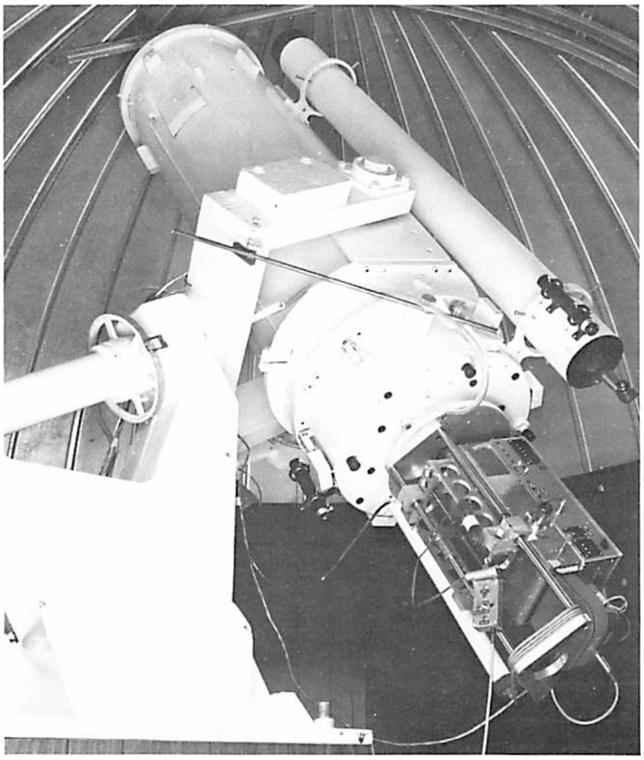


Fig. 39 21-inch planetary telescope on Tumamoc. The rod is clamped after a planetary series starts and has been most effective to quench vibrations in declination (wind, etc.)

Fig. 40 16-inch telescope formerly located on Tumamoc

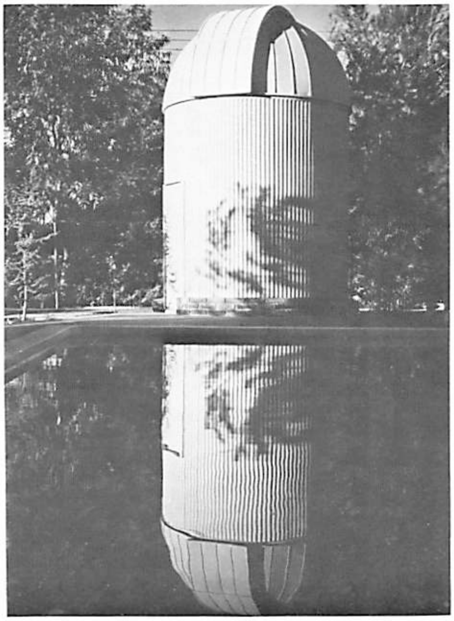


Fig. 41 Private observatory for visual planetary patrol

A major asset to the Laboratory has been the proximity of the Kitt Peak National Observatory, with its Tucson Headquarters immediately adjacent to the Space Sciences Building. A considerable number of the early programs of this Laboratory were carried out with the telescopes on Kitt Peak (55 miles SW of Tucson, el 6800 ft = 2070 m). An aerial photograph of KPNO is shown in Figure 44. The U. of A. 90-inch telescope is at left, in front of the new KPNO 158-inch (4 m) telescope. The first 36-inch and the 84-inch telescopes, used extensively by the LPL staff, are at center, in front of the parking area.

Another important neighboring institution is the Smithsonian Astrophysical Observatory Station. At the suggestion of Dr. Kuiper, it was placed on Mt. Hopkins, 36 miles airline S. of the University. He had noted that the summit area is remarkably free from turbulence when tested with small aircraft. The elevation is 8585 ft = 2620 m. The first developments including a 60-inch telescope were placed at the 7600-ft level (2320 m). The University has provided SAO with some office space in the Space Sciences Building (cf. Fig. 2).

Fig. 42 Mr. A. Evans, cutting observatory road on San Pedro Martir, Baja California

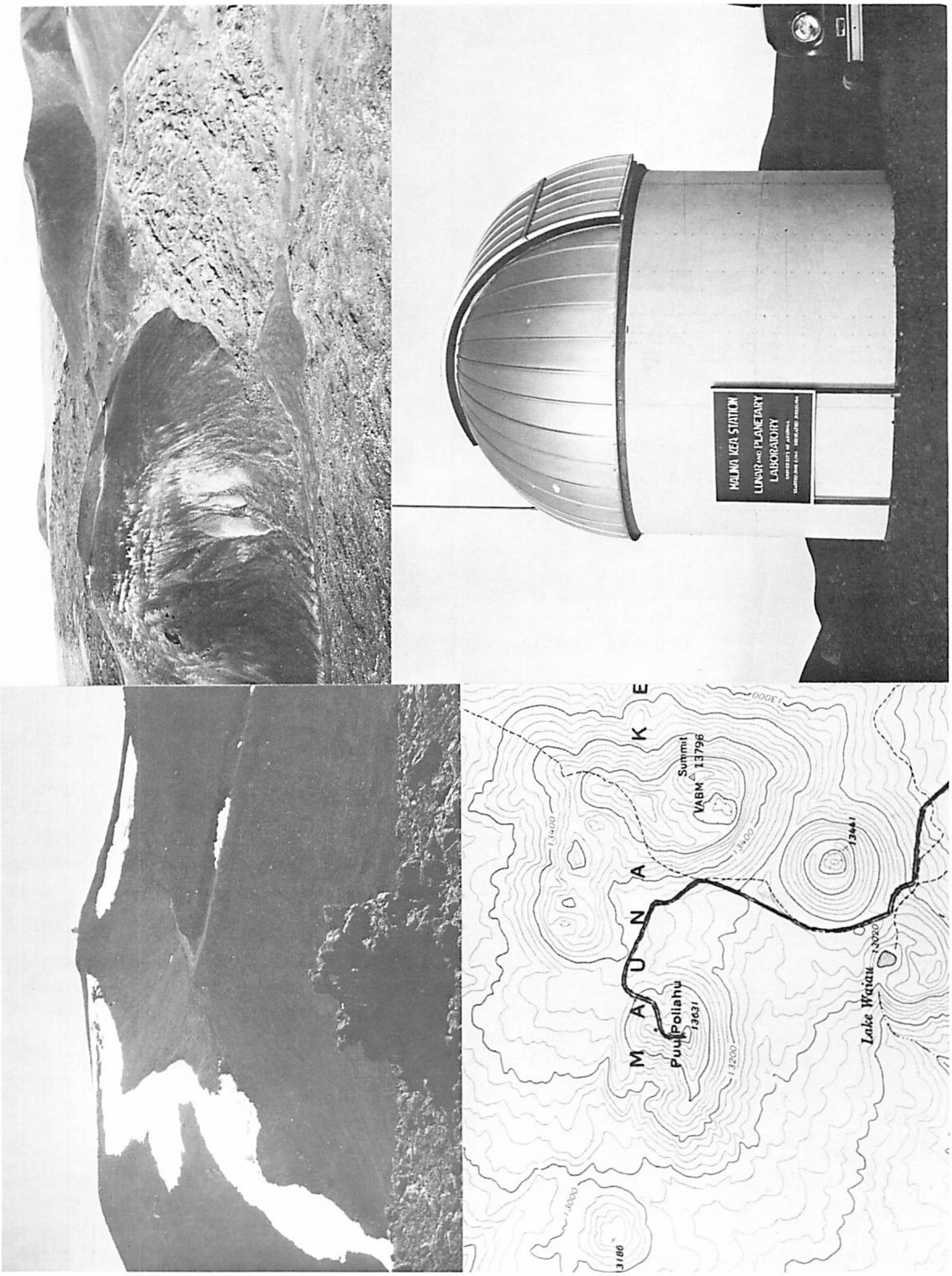


Fig. 43 LPL test observatory on Puu Poliahu, Mauna Kea, Hawaii

Fig. 44 Aerial view of Kitt Peak

6. Airborne Programs

Soon after the establishment of this Laboratory Dr. T. Gehrels initiated the development of the high-altitude balloon program called Project Polariscope. A 28-inch airborne telescope, radio controlled and provided with automatic guiding devices, could be launched to altitudes in excess of 120,000 ft (36 km). The objective was the measurement of polarization in the 2200 Å window above the bulk of the atmospheric ozone. This program was entirely successful and upon its completion the facility was turned over to the NASA-Ames High Altitude Facility near San Francisco where it is currently being operated as a national facility. The balloon program has been described in *LPL Communication No. 108* (1968) and *Space Research* (1970). An extension of this program is concerned with the remote analysis of airborne particles by polarimetry. A paper on this subject was submitted by Dr. D. L. Coffeen at the International Conference on Remote Sensing in Arid Lands, Tucson, 8-10 November 1972, published in the Proceedings of the Eighth International Symposium on Remote Sensing of Environment (1972). More recently, Dr. F. Low has flown a 40-inch IR telescope in a joint balloon program with M.I.T.

The LPL staff has carried out a major program of near-infrared spectrocopy from the NASA CV-990, using two interferometers, with resolutions up to 5 and 0.5 cm^{-1}. It was started in April 1967 and described in some detail in *LPL Communication No. 93*, entitled "A Program of Astronomical Infrared Spectroscopy from Aircraft", and subsequent publications. A 4-meter Czerny-type IR spectrometer was also used extensively on the NASA CV-990 in 1968 with the results published in *LPL Communications Nos. 160-166*, and more definitively in the ARIZONA-NASA ATLAS OF THE IR SOLAR SPECTRUM. Photographs of the large airborne spectrometer are found in *LPL Communication No. 123* (1968). This program has been extended beyond 3 microns aboard the NASA-Ames Lear Jet. The IR spectrometer and telescope mount, attached in the porthole of the Lear Jet, are shown in Figure 45. An earlier version of the spectrometer, hand-guided, flown on three exploratory missions, is seen in Figure 46. The spectrometer is fed by a 3-inch telescope exposed to the slip stream *without cover*; the air seal is inside the instrument allowing a choice of small transparent filters.

The 0.5 cm^{-1} resolution Idealab interferometer, first used in the NASA Mars flights of 1971, is shown in Figure 14*b*. Drs. H. L. Larson and U. Fink are now preparing to use it on the new NASA 36-inch telescope aboard the C141 aircraft based at NASA-Ames, California. We are proud to record that our airborne interferometer program, started early 1967, has consistently produced scientific results on *all* the two dozen NASA operational flights in which LPL has participated.

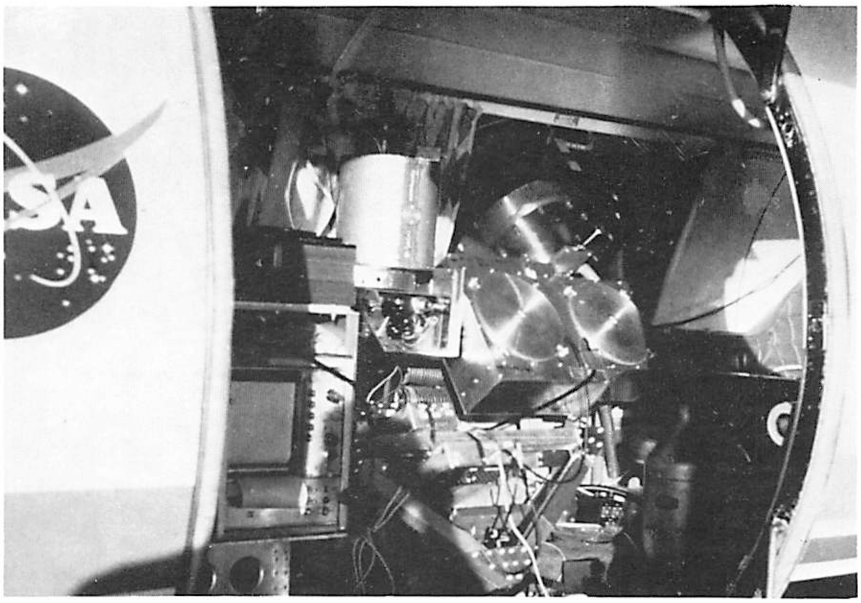


Fig. 45 Lear Jet with IR spectrometer using automatic guiding

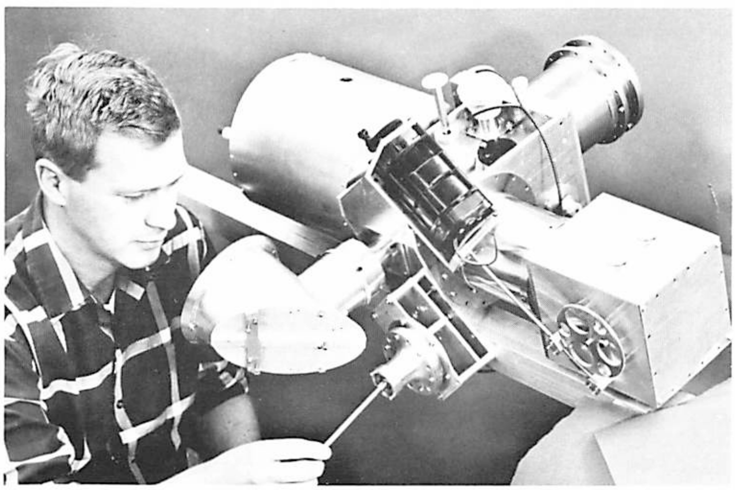


Fig. 46 Earlier model of Lear Jet IR spectrometer, hand-guided on Sun, by Dr. U. Fink

A successful program has been conducted from 5-1000μ by Dr. F. Low and collaborators for several years with the NASA Lear Jet. They succeeded in using a 12-inch telescope with open port, and automatic guiding (Fig. 47). Dr. Low observed the major planets, infrared nebulae, and galaxies; some results are found in Figure 48. The program led, among other things, to the discovery that Jupiter and Saturn radiate more than the amounts of absorbed solar radiation, by factors of about 3. Also, enormously intense radiations were found for the Seyfert galaxies. A description of Dr. Low's Lear Jet program is found in *Astronautics & Aeronautics*, July 1970, and in the more extensive review of "The Instrumentation and Techniques of Infrared Photometry" by Drs. F. J. Low and G. H. Rieke in METHODS OF EXPERIMENTAL PHYSICS, Vol. 12 (Academic Press, New York, 1973).

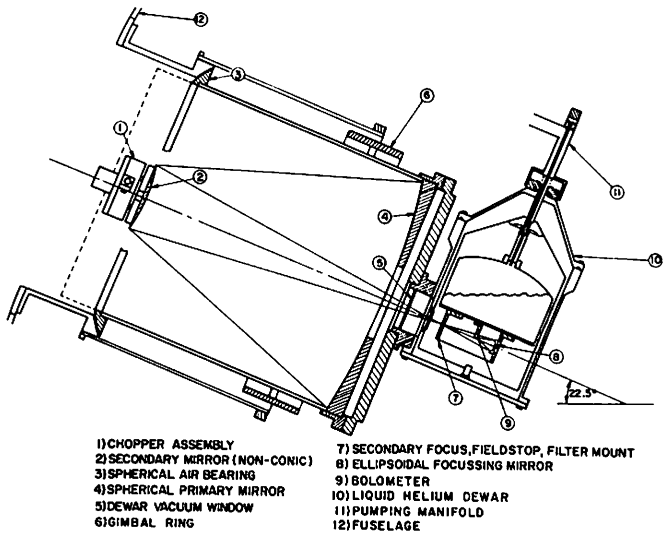


Fig. 47 Dr. Low's 12-inch open-port telescope equipped with liquid-He cooled bolometer, for NASA Lear Jet, automatic guiding, 5 to 1000μ

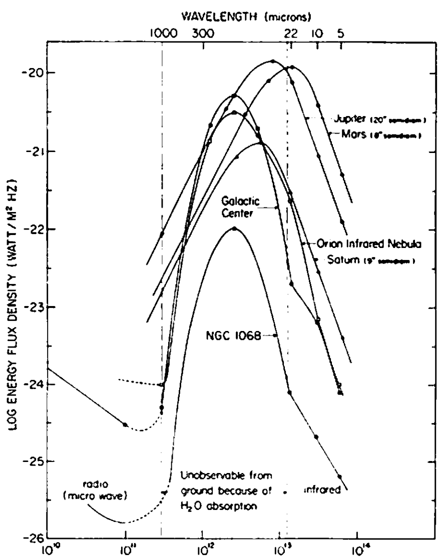


Fig. 48 Measured spectral energy curves of planets, the galactic center, and nebulae, with peaks around 100μ

7. NASA Deep Space Missions

From the outset the academic staff of the Lunar and Planetary Laboratory has participated heavily in the NASA programs, through memberships in NASA Panels and Working Groups, but especially in programs directly associated with deep-space missions. Dr. Kuiper was, in 1960, appointed Principal Investigator in the Ranger program and concentrated his own research and much of the Laboratory activities in direct support. The Lunar Coordinate System, used during the past decade on all NASA-sponsored lunar cartography, is entirely based on the work of Messrs. Arthur and Whitaker, and associates, who first produced a Catalogue of some 4500 base points (mostly pre-existing measures by Saunder and Franz that needed critical integration); and thereupon integrated these data with the charts of the Chicago PHOTOGRAPHIC LUNAR ATLAS published in 1960; which in turn led to the production of the ORTHOGRAPHIC ATLAS OF THE MOON. The NASA-sponsored program of lunar cartography, leading to the well-known LAC series, scale 1:1,000,000, and the more detailed special maps based on the results of the Ranger TV images, were all "proof read" by Mr. Ewen Whitaker and other LPL staff. Throughout this period the NASA-sponsored cartography at the Aeronautical Chart and Information Center (to which Dr. Kuiper provided the initial liaison in 1959-1960 while still at Chicago) has been a source of extreme satisfaction because of the consistently high quality of the maps. Particular thanks are due to Mr. Robert Carder and his staff for a full decade of close cooperation, and to General Thomas for his gracious support.

The scientific evaluation of the Ranger VII, VIII, and IX results began July 1964, immediately after the successful Ranger VII Mission, and extended well into 1966, when the Reports on Rangers VIII and IX were completed. Dr. Kuiper proposed to the International Astronomical Union meetings at Hamburg, Germany, one month after the Ranger VII success, that the small walled mare in which it impacted (the impact point having been chosen by Mr. Whitaker), be named Mare Cognitum, in honor of the first close-up photographic mission to the Moon which had led to this mare "becoming known" with 1000 times the previous resolution. This name was adopted. Early July 1964 Dr. Kuiper was invited to give two extensive briefings on the Ranger results to the Cabinet, the Combined Chiefs of Staff, and the Supreme Court; and two further briefings to the House Astronautics Committee (attended by over 150 Congressmen and staff each). These expressions of interest by the highest levels of the U.S. Government have been a source of continuing inspiration.

Mr. Robert Strom joined the Laboratory staff in 1963 and took a major part in the Ranger evaluation program. He had earlier published a series of papers dealing with lunar topography, the grid system, lunar lava flows, etc. The grid system involved the measurement and location of some 10,000 linear features on the lunar Near Side. The lunar grid clearly reflected much about the dynamical history of the Moon as it became from highly ellipsoidal to more nearly spherical as it receded from the Earth. The geometry of the grid system supported this interpretation.

The mapping of the lava flows in Mare Imbrium, all based on telescopic observation, was an entirely new topic at the time and a vital preliminary to more detailed studies made later by spacecraft. Earth-based photography could be extended to very near the terminator, i.e., with sun angles of only 1 or 2° above the horizon. This made the earth-based discovery of lunar lava flows possible, flows that were often difficult or *impossible* to detect on the lunar Orbiter charts which had been produced with sun angles of about 20° or more. In the introductory text of the CONSOLIDATED LUNAR ATLAS (1967), examples are noted of both lava flows and low domes *invisible on the Orbiter records*. Curiously, the lava flows in the central portions of Mare Imbrium, which this Laboratory recorded and studied, have still not been adequately recorded in any other way.

We note with pride this Laboratory's interpretive studies of the lunar surface, in particular the recognition of very numerous *collapse depressions*, first found in large numbers on the Ranger VII records, and compared to terrestrial collapse depressions in basaltic flows that we studied in considerable detail. It is of historical interest that this interpretation, which we first strongly advanced early in 1965, was not accepted by other students of the Moon for another 4 years. We also point to the first direct determinations of the *bearing strength* of the floor of the lunar crater Alphonsus, based on the observation of rock fragments that could be ascribed to a nearby impact crater, and which were partially buried in the lunar surface materials. This value, some 6 orders of magnitude higher than other estimates then frequently mentioned, was confirmed within a factor of 2 by subsequent measurements from Surveyor 3. Our result was promptly communicated, in 1965, to Dr. Gilruth and staff at the Manned Spacecraft Center.

Another important result was the discovery by Mr. Ewen Whitaker of sharp *color boundaries* on the lunar maria, which in several instances were found to correspond precisely with observable boundaries of lava flows. Later, when direct composition measurements of the lunar basalts were made, it was found that these colors were related to the titanium content of the lunar surface deposits, a high titanium content going with a comparatively bluish tint. This discovery, in turn, now allows us to map the distribution of high- and low-titanium content surface materials for the entire Near Side of the Moon, a program being continued by Mr. Whitaker.

This Laboratory was commissioned by NASA to produce the photographic edition of selected Ranger VII, VIII, and IX records. This was done in 5 volumes, each containing approximately 200,11" x 14", photographic prints, 1000 prints for the entire set. A total edition of 150 sets was produced and all 150,000 photographic prints were inspected and approved by the LPL staff, mostly by Mr. Whitaker personally.

Other NASA missions in which the LPL staff participated extensively are Surveyor (1960-70), especially Dr. Kuiper and Mr. Whitaker, through participation in panels and joint publications. Mr. Whitaker was directly involved in the site selection and other participation of the Orbiter Missions, and this Laboratory assisted the NASA-Langley staff with some rectified photography in our projection tunnel. Mr. Strom participated in the planning of the Orbiter 5 Mission. The appended literature list shows the extent of this participation.

Dr. Kuiper and Mr. Strom were appointed to membership in the TV Science Team of the Mercury-Venus Mission of 1973, which started its work in October 1969. Particularly Mr. Strom contributed, on a nearly full-time basis, in the preparation of the mission sequence for both Mercury and Venus, and he was Deputy Team Leader for a 1-year period. Mr. Strom supervised the issuance of two consecutive IMAGING SEQUENCE DOCUMENTS, JPL internal papers ,of this Mission. An extensive separate investigation was concerned with the image degradation to be expected from different bit error rates, using lunar images as a base. These studies by Mr. Strom contributed very significantly to the final NASA decisions on the communication rates and power specifications for the Venus-Mercury Mission.

Mr. Strom and Mr. Whitaker participated extensively as consultants to the Apollo program and made numerous trips to the Manned Spacecraft Center and Cape Kennedy in this connection. Mr. Whitaker conducted astronaut briefings for Apollo 13, 15, and 16, joined by Mr. Strom on the Apollo 16 mission. Previously, they had been deeply involved in the selection of the scientific targets for photography. Mr. Whitaker, a member of the Photo Team, participated in the conduct of Apollo missions 11 through 17, assisting in making decisions in real time changes in the photo targets and the metric and panoramic camera coverage as changes became necessary.

Dr. Frank Low successfully designed and flew on the Command Module of Apollo 17 an infrared scanner that logged a remarkable total of nearly 100 hours of observation covering nearly 10^8 data points. The average temperature of the dark side of the Moon is around 90°K and numerous interesting deviations, related to the lunar topography, are observed which will be a most productive field of study for some years to come.

Mr. Whitaker, alone, succeeded in identifying the locations on the post-Surveyor Orbiter records of the four Surveyor spacecraft landing sites on the Moon for which adequate data existed. Also, he discovered the impact craters caused by Rangers VII, VIII, and IX, and by the S-IVB's of Apollo 14 and 15. These discoveries are of special interest since the impact energies are known, as well as the seismic responses of the S-IVB impacts; and the special nature of the fresh halos, bright and dark. For these and other contributions, Mr. Whitaker received a personal letter of thanks from the President of the United States.

Dr. Gehrels was appointed Leader for the Photopolarimeter Team on PIONEER 10 and 11 to Jupiter (1970 onward), and has in this capacity participated in numerous panel discussions and consultations with Mission Control at NASA-Ames, near San Francisco.

This Laboratory has been selected by NASA as one of their *depositories of lunar film positives* derived from the Orbiter and Apollo Missions. The document storage facilities and the plate vault of the original LPL planetary and lunar records are mentioned on p. 206.

8. Editorial Projects; Conferences

When I moved from the University of Chicago to the University of Arizona in 1960, I brought with me two large editorial projects, only partly completed: THE SOLAR SYSTEM (4 volumes) and STARS AND STELLAR SYSTEMS (9 volumes). Miss Barbara Middlehurst was Co-editor of both series, and joined me in the transfer. Without her great energies, competence, and perseverance, the completion of these series would not have been possible.

Volume III of the SOLAR SYSTEM BOOKS, *Planets and Satellites*, was published in 1961; Volume IV, *The Moon, Meteorites, and Comets*, in 1963. The possibility of adding an extra volume on *Planets and the Interplanetary Medium* was announced in Volume IV but was dropped in the face of the extreme pressures and advances of the Space Age. I have naturally considered returning to this matter at some future appropriate time.

Our responsibilities with the 9-volume series, STARS AND STELLAR SYSTEMS, were less extensive since each volume had its own Editor(s), and the role of the General Editor and the Associate General Editor was in the nature of extensive consultations and review, including the relations with the publisher, the University of Chicago Press, and the National Science Foundation which assisted with a publication subsidy for each volume, and some incidental office expense. Volumes I and VI, *Telescopes* and *Stellar Atmospheres*, were published in 1960; Volume II, *Astronomical Techniques*, in 1962; Volume III, *Basic Astronomical Data*, in 1963; Volume V,*Galactic Structure*, in 1965; Volume VIII, *Stellar Structure*, in 1965; Volume VII, *Nebulae and Interstellar Matter*, in 1968; and Volume IX, *Galaxies and the Universe*, in 1973. These projects have proved to be a gigantic task on the part of all concerned, made especially difficult in an age where scientific progress was exponential. Yet, we hope that these volumes have assisted in the orderly growth of our Science. It has always been a source of great satisfaction to see how many colleagues have acquired these volumes for their personal libraries. (All scientific writing and all work by the Editors were accomplished without any financial compensation to keep the costs per volume minimal).

In the 1970's this Laboratory has taken the initiative to organize three scientific meetings, all co-sponsored by NASA, each of which has led to a comprehensive publication. Drs. Elizabeth Roemer and Gerard P. Kuiper organized a meeting on comets for April 8-9, 1970, with about 36 participants, the results of which are contained in COMETS, SCIENTIFIC DATA AND MISSIONS, PROCEEDINGS OF THE TUCSON COMET CONFERENCE, published by the Laboratory. This meeting was in part in recognition of the outstanding services to Astronomy by Dr. Roemer who has been responsible for the observation and recovery of the majority of faint comets during the past two decades. In April 1971 she was awarded the Benjamin Apthorp Gould Prize by the National Academy of Science "for distinguished work in astronomical research". "Over the past 18 years she and her associates have been responsible for the first sightings of 51 periodic comets", a number that now stands at 63!

Dr. T. Gehrels organized a meeting, co-sponsored by NASA, on THE PHYSICAL STUDIES OF MINOR PLANETS, which took place March 6-10, 1971. The results have been published in a volume under the same title, NASA SP-267. Later, Dr. Gehrels organized a Conference on Polarimetry which took place November 15-17, 1972, with the chapters of the book well advanced. Plans for additional conferences are under consideration.

The LPL scientists have, of course, participated in numerous other scientific conferences in the U.S. and abroad, and several have received distinctions. Reference is made above to Dr. E. Roemer's National Academy Award. Dr. Frank Low received the Helen Warner Prize of the American Astronomical Society in 1968; Dr. Kuiper, the Dryden Award of the American Institute of Aeronautics and Astronautics, January 20, 1969; and the Kepler Gold Medal of the American Association for the Advancement of Science, on December 28, 1971.

Scientific communication by TV has played a novel role in the Space Program and the LPL staff has shared in the opportunities and excitement. Dr. Kuiper addressed the Soviet TV system in December 1960 from the director's residence of the Pulkovo Observatory (in English). In 1963 he produced one of three full-hour programs for the Erstes Deutches Fernsehen (the first, by a NASA engineer, in English; the second, rather skeptical, by Dr. Warren Weaver; the third, in German, by a University scientist). NASA had recommended me: I insisted that the program be done in Tucson, not Washington. The program director, Mr. J. Schroeder Jahn provided me with historical insights on German rocket development that proved invaluable to me later. I conducted one (German) program in Hamburg in 1964 after Ranger VII. Two full-hour German programs, at LPL and the Observatory, were conducted here by Mr. H. Schiemann and his 6-man staff, Zweites Deutches Fernsehen, in 1966 and 1969. Other programs were carried out for visiting groups in Dutch, Flemish, and Italian. Among the more exciting programs were those conducted by CBS (Mr. Cronkite) as the NASA missions were in progress. Numerous TV programs were presented in Tucson by my colleagues and myself. I believe that NASA has derived great public benefits from these very numerous enthusiastic presentations by active participants in its missions. Besides, our Laboratory has contributed around 80-100 formal lectures *annually* to schools, civic clubs, etc. in Arizona and elsewhere during the past decade. The titles may be obtained from the LPL Annual Reports to the U. of A. Administration.

9. Faculty and Staff

FACULTY:

Gerard P. Kuiper, Ph. D., Director, Lunar & Planetary Laboratory, Research Professor of Astronomy. Solar system studies; NASA high-altitude flight program; Mercury-Venus mission 1973; editorial programs.

A. M. J. (Tom) Gehrels, Ph. D., Professor. Photopolarimetry; asteroid and comet surveys; PIONEER 10 mission; advisory to NASA on future missions.

Frank J. Low, Ph. D., Research Professor of Astronomy. Infrared technology and exploration of planets, nebulae, galaxies; IR mapping of Moon and planets; Apollo 17 IR mapping program.

Elizabeth Roemer, Ph. D., Professor of Astronomy and in the LPL, Chairman, Comm. for the Department of Planetary Sciences. Comets, minor planets, astrometry.

Georges Van Biesbroeck, Ph. D., Consultant, Professor Emeritus of Astronomy, (U. of Chicago). Double stars and comets.

Ferdinand A. de Wiess, Dip. Eng., Associate Professor. Engineering, space technology.

Uwe Fink, Ph. D., Associate Professor. Molecular spectroscopy from aircraft and in laboratory.

William B. Hubbard, Ph. D., Associate Professor. Planetary models, statistical mechanics; physics of very high pressures.

Harold P. Larson, Ph. D., Associate Professor. High resolution interferometry, spectroscopy.

Krzysztof M. Serkowski, Ph. D., D. Sc., Associate Professor. Polarization of starlight, interstellar medium, techniques of astronomical photometry and polarimetry.

Robert G. Strom, M. S., Associate Professor. Geologic processes on Moon and terrestrial planets; Mercury-Venus 1973 mission.

David L. Coffeen, Ph. D., Assistant Professor. Polarization of planets, theory.

George V. Coyne, Ph. D., Assistant Professor (joint appointment with Vatican Observatory). Interstellar and stellar polarimetry.

Thomas A. Lee, Ph. D., Assistant Professor. Photometry, IR astronomy.

Richard Greenberg, Ph. D., Research Associate (Celestial mechanics)
Colin Keay, Ph. D., Research Associate (IR studies). Permanent address: University of Newcastle, New South Wales, Australia.
Robert F. Kurtz, Research Associate (IR studies).
Dietrich Lemke, Ph. D., Research Associate (IR studies). Permanent address: Max Planck Institut für Astronomie, Heidelberg, Germany.
George H. Rieke, Ph. D., Research Associate (IR studies).
Martin G. Tomasko, Ph. D., Research Associate (Radiative Transfer).
Ralph Turner, M. S., Research Associate (Lunar & Planetary Surface Topography).
Robert L. Waland, Research Associate (Chief Optician).
Ewen A. Whitaker, Research Associate (Lunar & Planetary Surfaces; Apollo program).
Wieslaw Z. Wisniewski, Ph. D., Research Associate (Astronomical Photometry).
Benjamin H. Zellner, Ph. D., Research Associate (Photopolarimetry).

Visiting Appointments:

G. de Vaucouleurs, Ph. D., Professor Astronomy, U. of Texas, Austin, Texas.
David Arthur, Research Associate, Center of Astrogeology, U. S. Geological Survey, Flagstaff, Arizona.

ADDITIONAL SCIENTIFIC PERSONNEL: (p = part-time)

Photopolarimetry (Dr. Gehrels)

Marvin E. Arthur
Robert C. Capen, B. S. (p)
J. Laurence Dunlap, M. S. (p)
Jack E. Frecker
John H. Kendall, B. S.
Charles E. KenKnight, M. S.
Shirley J. Marinus, Secretary
Mildred S. Matthews, B.A., Editor
Edward H. Roland
Robert Sather, M. S. (p)
Ronald C. Taylor, M. S. (p)
René H. Toubhans
Carl D. Vesely, M. S. (p)
5 Assistants (p)

IR Microwave, Planetary, Galactic (Dr. Low):

Arnold Davidson, B.S.
Wilbur Griffin
Earl F. Montgomery, M. S.
Linda McDowell, Secretary (p)

Spectroscopy and Chemistry Lab (Drs. Kuiper and H. P. Larson):

D. Chris Benner, B. S.
Thomas N. Gautier, B. S. (p)
Fr. Godfrey Sill, M. S. (p)

Planetary Photography (Dr. Kuiper):

Stephen M. Larson, B. S.
John W. Fountain, B. S.
R. B. Minton
2 Assistants (p)

Lunar and Planetary Surfaces (Dr. Kuiper and Mr. Strom):

Charles A. Wood, M. S.
Ralph Turner, Sculptor (p)
2 Assistants (p)

Library - Sue Morris, B. A. (p)

Editorial Department:

Gerard P. Kuiper, Editor
Elizabeth Roemer, Associate Editor
Micheline Wilson, B. A., Assistant Editor (p)

LPL STAFF:

Administrative:

Melvin J. Simmons, Assistant to the Director and Business Manager
(Mr. Simmons is responsible for managing the contracts and the financial structure of LPL and the Observatories, generally including direction of the LPL Observatory Staff and supervision of much of the Shop work).
Ida A. Edwards, Secretary to the Director
Kathryn Osburn, Secretary, Accountant
Ruth Ash, Secretary

Optical Shop:

Robert L. Waland, Chief Optician
Robert G. Crawford, Optician
Edward J. Plamondon, Optician

Observatories:

Arnold D. Evans, Superintendent
Leland Evans, Resident Engineer
Leonard H. Kelley, Assistant
Jose E. Garcia

Electronics Shop:

James R. Percy
B. L. Belschner
Barry L. McClendon

Machine Shop:

Harold Miller
Ronald J. James

Drafting - Charles L. Edwards (p)

Computer Room:

Allen S. Latham
Richard F. Poppen (p)

Research Assistantships are normally, but not exclusively, assigned to advanced graduate students. Research done as part of the Assistant's duties may, under appropriate conditions, be used for a thesis or as part of a thesis.

10. Department of Planetary Sciences

During the first years of the Laboratory, a number of graduate students did their PhD thesis programs both in the Laboratory and with the KPNO telescopes, under an interdepartmental committee structure. In due time steps were taken toward a formally-organized Department of Planetary Sciences. For the initial year the teaching program was managed by the following interdepartmental Committee:

Advisory Committee:

Chairman, Elizabeth Roemer, Ph. D., Professor of Astronomy and in the Lunar and Planetary Laboratory
(Comets, Minor Planets, Astrometry)
Louis J. Battan, Ph. D., Associate Director, Institution of Atmospheric Physics; Professor of Atmospheric Physics
(Environmental Sciences)
Bart J. Bok, Ph. D., Professor of Astronomy; Astronomer, Steward Observatory
(Galactic Structure)
Leon Blitzer, Ph. D., Professor of Physics
(Dynamics, Resonances)
Gerard P. Kuiper, Ph. D., Research Professor of Astronomy; Director, Lunar and Planetary Laboratory
(Planetary Atmospheres; Origin and Evolution of Solar System)
Frank J. Low, Ph. D., Research Professor, Lunar and Planetary Laboratory; Astronomer, Steward Observatory
(IR Radiometry)

Participating Faculty:

Leon Blitzer, Ph. D., Professor of Physics
(Dynamics, Resonances)
Gerard P. Kuiper, Ph. D., Research Professor of Astronomy; Director, Lunar and Planetary Laboratory
(Planetary Atmospheres; Origin and Evolution of Solar System)
Frank J. Low, Ph. D., Research Professor, Lunar and Planetary Laboratory; Astronomer, Steward Observatory
(IR Radiometry)
Elizabeth Roemer, Ph. D., Professor of Astronomy and in the Lunar and Planetary Laboratory
(Comets, Minor Planets, Astrometry)

William B. Hubbard, Ph. D., Associate Professor, Planetary Sciences
(Physics of Compressed Matter; Jovian Planets)
Harold P. Larson, Associate Professor, Lunar and Planetary Laboratory
(Planetary Atmospheres; IR Fourier Spectroscopy)
Robert G. Strom, Associate Professor, Lunar and Planetary Laboratory
(Lunar and Planetary Surfaces; Spacecraft Imaging of Planetary Surfaces)

Departmental Secretary - Faye L. Larson

It is expected that by mid-1973 the basic organization of the Department will be completed. Faculty members will use the facilities of the Laboratory through joint appointments.

Acknowledgments. I must record my deep indebtedness to President Emeritus Richard Harvill, the late Vice President David Patrick, Provost Bowen Dees, and the present University Administration for their continued interest in and support of this Laboratory and its programs. Our debt to the National Aeronautics and Space Administration is beyond measure. NASA not only assisted the Laboratory with telescopic equipment, the Space Sciences Building, and research support, but through NASA, my associates and I have been privileged to participate in the greatest scientific venture of history.

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3. Institutional publications

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2. ORTHOGRAPHIC ATLAS OF THE MOON, 1961, Arthur, D.W.G. and Whitaker, E. A., ed. Kuiper, G. P., Supplement No. 1 to PHOTOGRAPHIC LUNAR ATLAS.
3. RECTIFIED LUNAR ATLAS, 1963, Whitaker, E.A., Kuiper, G.P., Hartmann, W.K., Spradley, L.H., Supplement No. 2 to PHOTOGRAPHIC LUNAR ATLAS.
4. CONSOLIDATED LUNAR ATLAS, 1967, Kuiper, G.P., Strom, R.G., Whitaker, E.A., Fountain, J.W., Larson, S.M.
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