No. 1 ORGANIZATION AND PROGRAMS OF THE LABORATORY

by GERARD P. KUIPER

February 12, 1962

1. Aims and Objectives of the Laboratory

THE purpose of organizing the Lunar and Planetary Laboratory at the University of Arizona in the fall of 1960 was to create, in a favorable academic setting, a research and teaching unit concerned with the study of the moon and the planets. Favorable has reference to (a) the presence of research scientists in supporting fields, such as meteorology, geology, geochemistry, physics, and electrical engineering; (b) clear skies, low humidity, accessibility to modern telescopes and electronic computers; (c) proximity to national laboratories and industrial facilities; (d) a well-developed or developing graduate school; (e) proximity to interesting geological terrain features for comparative studies of moon and earth.

The group was to be concerned with (1) research; (2) publication of major collections of scientific records; (3) graduate instruction and Ph.D. programs.

The need for such a university group had become increasingly apparent for some years. The recently accelerated national space programs with their scientific and personnel requirements made the execution of these plans timely.

We are greatly indebted to Dr. A. R. Kassander, Director of the Institute of Atmospheric Physics, and his staff for their interest in the welfare of the Laboratory and for the administrative and scientific assistance they have given us in the initial stages of organization. The programs of IAP are of great interest to the planetary program, and the Laboratory staff is looking forward to a continued valuable association. This mutual interest is recognized through continued joint staff appointments. Dr. E. F. Carpenter, Director of the Steward Observatory, has assisted the Laboratory in many ways, and has made available office space for the editorial project.

The instrumentation and the programs of the Laboratory are applicable to related stellar investigations. For instance, the infrared spectrometers developed for planetary work are equally useful in stellar investigations. The same applies to programs in photometry and polarimetry. For these and related reasons a number of stellar programs were undertaken as well.

With the appointment of Drs. Meinel and Johnson the interest in stellar investigations has broadened. This is reflected in the additional research programs planned for the second year of the Laboratory.

2. Research Programs and Staff

The Laboratory's active research programs fall into the following categories:

(a) Lunar Studies. Cartography and the production of atlases and position catalogues; selenodesy (the equivalent on the moon of geodesy); theory of the moon's rotation and librations; systematic lunar photography; tectonic surface studies — visual and photographic; polarization studies with broad wavelength coverage; associated laboratory and geomorphological studies; and nomenclature.

(b) Planetary Atmospheres. Planetary spectroscopy; IR spectrophotometry in the PbS region (1-3μ), and beyond; associated laboratory studies of atmospheric gases; polarization studies, cloud phenomena; composition and photochemical studies. A number

of recently discovered but as yet unidentified band systems are under study (Jupiter, Uranus, Neptune). Special emphasis will be placed upon laboratory studies of the greenhouse effect in the Venus atmosphere.

(c) Satellite Systems. Photography of the satellites of Mars, Jupiter, Saturn, Uranus, and Neptune; orbit determinations. Planetary dynamical oblateness; satellite masses for Saturn and Uranus. Satellite diameters, densities, compositions. Surface properties (color, polarization variability with rotation, ice deposits on the outer satellites).

(d) Asteroids. Continued studies of asteroid light curves for determination of shapes, orientation of axes of rotation, and deviations from simple periodicity. Variability of polarization with rotation. Asteroid survey to 20th magnitude, for determination of numbers and space distribution of fainter asteroids. Collisional production of smaller asteroids and meteorites.

(e) Zodiacal Light. Polarization — wavelength dependence.

(f) Stellar Spectra, especially in the IR.

(g) Stellar Photometry and Polarization.

(h) Development of IR Instruments, in particular photometers and spectrophotometers, using commercially available photo-electric and photoconductive cells and, later, a germanium balometer now under development at Texas Instruments Company, which is a detector of greatly increased sensitivity in the region of 1–1000 microns (but requiring a complex cooling technique at about 1°K).

(i) Development of Powerful IR Telescopes, with reduced tolerances appropriate for the IR.

(j) Development of a Spectroscopic Laboratory, for associated stellar studies: IR spectra of metallic oxides and hydrides (in an effort to identify a number of newly-discovered band systems in the cooler stars).

(k) The development of equipment for detection and analysis of extremely *tenuous planetary atmospheres* (moon, Mercury).

(l) Development jointly with the Institute of Atmospheric Physics of *balloon-borne* planetary observations, for UV polarization studies and IR spectroscopy.

(m) The development of equipment to detect *very faint emissions* from planetary atmospheres (Venus, Mars).

(n) Mr. Kuiper and Mr. Gehrels have been appointed Experimenter by NASA on lunar and planetary projects, respectively.

After January 1, 1962, the scientific staff of the Lunar and Planetary Laboratory will be as follows. The letters following each name indicate broadly the research interest in the programs listed above.

- Dr. Gerard P. Kuiper, Director and Research Professor *(a,b,c,d,f,h)*
- Dr. Aden B. Meinel, Research Professor† *(b,f,i,j,m)*
- Dr. Harold L. Johnson, Research Professor *(g,h,i)*
- Dr. Tom Gehrels, Associate Professor‡ *(a,b,c,d,e,g,l)*
- Dr. Stuart Hoenig, Associate Professor, part time *(b,k)*
- Miss Barbara Middlehurst, Research Associate *(f,j)*
- Mr. David Arthur, Research Associate *(a)*
- Mr. Ewen Whitaker, Research Associate *(a,c)*
- Mr. Alika Herring, Research Associate *(a)*
- Mr. Richard Mitchell, Research Associate *(g,h)*
- Mr. Richard Goranson, Research Assistant *(b,h)*
- Mr. Thomas Teska, Research Assistant‡ *(e,g,l)*
- Mr. Tobias Owen, Research Assistant *(b,j,m)*
- Mr. Harold Spradley, Research Assistant *(a)*
- Mr. William Hartmann, Research Assistant *(a)*
- Mr. Elliott Moore, Research Assistant *(a)*
- Miss Ann Geoffrion, Research Assistant *(a)*
- Mr. Carl Huzzen, Research Assistant *(a)*
- Mr. Alan Binder, Research Assistant *(b)*
- Mr. Donald Collins, Research Assistant *(b,k)*
- Mr. Dale Cruikshank, Research Assistant *(b)*
- Mr. Dwight Hoxie, Research Assistant *(b,f,j,m)*

Most of the research assistants are on half time, pursuing also a graduate program; Mr. Goranson and Mr. Spradley are full-time assistants. Secretaries are Mrs. D. Heisler, Miss C. Morris and Mrs. S. Marinus (office); and Mrs. C. Norman (editorial); while Mrs. Alice Fabe, Miss Patricia Mitchell and Mr. Charles Wood assist in the lunar reduction program; Mr. Pellicori in the balloon project; and Mrs. Fabe in drafting.

Close liaison is maintained with the staff of the Applied Research Laboratory of the University (Professor Ernest L. Morrison, Director), who are collaborating on the design and construction of electronic equipment.

The balloon program is being supported by NSF through a grant to the Institute of Atmospheric Physics of the University of Arizona. Dr. Gehrels is the principal investigator, while the program is executed in close liaison with Dr. A. R. Kassander,

† Joint appointment with Steward Observatory.
‡ Joint appointment with Institute of Atmospheric Physics.

Director of the Institute of Atmospheric Physics; and Professor E. L. Morrison, Director of the Applied Research Laboratory. The actual flight operations will be conducted by the National Center of Atmospheric Research. The Kitt Peak National Observatory is providing the telescope optics for the balloon.

Several staff members presented papers at scientific conferences. Messrs. Kuiper and Arthur attended the IAU Symposium on the Moon in Leningrad, December, 1960; Messrs. Kuiper and Whitaker the IAU General Assembly at Berkeley, August, 1961; Mr. Whitaker the Denver meetings of the American Astronomical Society, December, 1961; Messrs. Kuiper and Gehrels, in different meetings, presented papers at the Lunar and Planetary Exploration Colloquium of North American Aviation Company, California; and Mr. Kuiper gave an invited paper at Space Technology Laboratory May, 1961 and a series of lectures at the University of California Extension Division during the week of January 15 to January 18, 1962. Several meetings were held with representatives of ACIC, both in St. Louis and Tucson, on problems of lunar cartography and the production of lunar atlases.

3. *The Development of Telescopic Facilities*

(a) Existing Data and Facilities.—The text of the Photographic Lunar Atlas (University of Chicago Press, 1960) describes the several plate series on which this Atlas was based. It includes the selenodetic series started with the 40-inch telescope of the Yerkes Observatory in the fall of 1958 and also a series taken at the Cassegrain focus of the 82-inch telescope of the McDonald Observatory started in 1956. We are fortunate that it has been possible to arrange for a continuation of both these programs after the transfer of the staff of the lunar project from the University of Chicago to the University of Arizona about October 1, 1960. The Yerkes selenodetic series is unique in that it is the only photographic series in existence with adequate calibrations of scale and orientation made on every night that plates were secured. This series is the first to supersede the basic work on lunar coordinates founded on the heliometer measures of the 19th century. Since the physical librations include terms in excess of one year and since the observations at southern declination have a lower quality, the continuation of the selenodetic series over several years is most desirable. In addition, a fair number of plates of excellent quality, usable for topographic studies, was obtained in the Yerkes series, as may be seen from Figure 1. The graph shown gives the number of nights on which

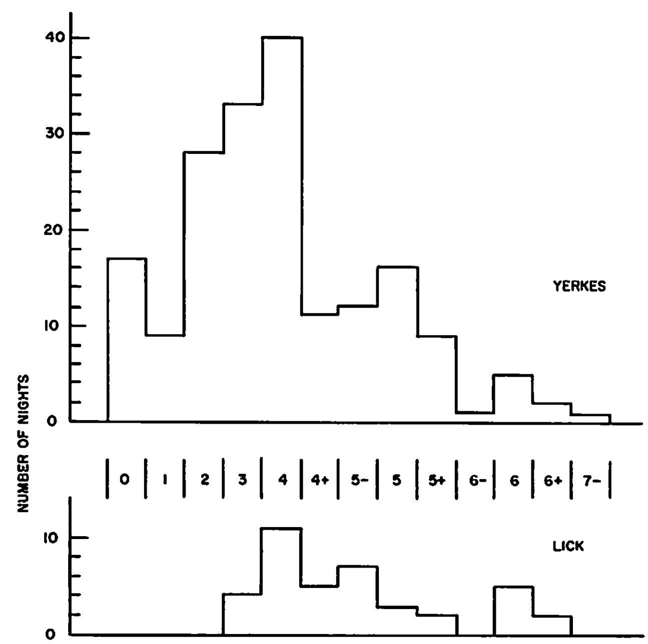


Fig. 1. Frequency curve of number of nights on which plates of a given quality were obtained at Yerkes Observatory, interval early 1959 to September 1960. The plate quality is defined as follows: qualities 1, 2, 3, 4, 5, 6 and 7 (see numbers across figure at center) correspond to crater diameters in the intervals between ∞, 5.0, 3.8, 2.8, 2.1, 1.6, 1.2, 0.9, and 0.7 miles. For comparison, Ritchey's plates used by Saunder had quality 4+ (1.6 miles). The "resolution" as normally defined is about *half* this crater diameter. The plot of Lick refers to the selected material used in the Photographic Lunar Atlas.

lunar plates of a specified quality were obtained from early 1959 through September 1960. The plates were taken by Mr. Moore, graded by Mr. Whitaker and the plot compiled by Mr. Moore. Mr. Moore used every opportunity to observe the moon during the assigned nights, which led to the accumulation of many indifferent plates as well as the maximum number of good plates attainable. With the program continuing, an ever-improving selection can be made for the selenodetic series to be measured. The distribution of the Lick Observatory plates used in connection with the Photographic Lunar Atlas is also shown, with the key to the quality designations used in the legend.

Through a cooperative arrangement with the Air Force Aeronautical Chart and Information Center of St. Louis, the Lunar and Planetary Laboratory has access to the lunar photography currently performed at the Pic-du-Midi Observatory in France under an Air Force contract with the University of Manchester, England. As a result a number of good to excellent photographs were recently added to the LPL working collection.

(b) New Telescopes.—Plans for new telescopic

facilities for the Laboratory have developed in two directions: (1) a high-quality optical telescope of about 60 inches aperture with focal lengths appropriate for high resolution photography as well as for the observation of faint satellites; and also equipped for visual, polarimetric, and spectroscopic investigations; (2) a powerful "infrared" telescope, with relaxed image tolerances, intended to provide a comparatively inexpensive instrument of great light-gathering power for the study of infrared and millimeter wave radiations of the moon, the planets, and the cooler stars.

Clearly, the first instrument will need to be placed on a site with superior optical seeing, the second instrument on a site with a minimum amount of precipitable water in the overlying atmosphere. The criteria for sites 1 and 2 are not necessarily incompatible and it would, of course, for practical reasons be advantageous to use a single site for both operations. A preliminary survey of available sites in Arizona has been made, mostly from meteorological data and studies with light aircraft (turbulence); comparative optical studies on two favorable sites selected are scheduled for 1962.

Preliminary design studies for the 60-inch telescope have been made and a more detailed report will be published in one of the forthcoming Communications of the Laboratory.

Studies for an infrared telescope of large aperture have been made for two dimensions, 28-foot and 10-foot aperture. Mosaic mirrors have been considered in each case, 54 mirrors placed in three rings for the larger aperture and 24 placed in two rings for the smaller. The general design of the 10-foot instrument is shown in Figure 2. The design resulted from a joint study by Drs. Meinel and Johnson, who had the benefit of several discussions with other telescope designers and industrial firms.

In addition to the need for larger facilities of the type just mentioned it has been felt that a smaller telescope was needed, preferably located on a site near the University, which would serve as a test telescope for the development of auxiliary equipment, for pilot program, and for the training of graduate students. The Laboratory was fortunate in receiving a grant from the Naval Ordnance Test Station at China Lake, California (NONR N123-(60530)27887A), which made possible the construction of a 21-inch Cassegrain telescope. This telescope was designed by Mr. Johnson, based on the specifications of the 20-inch Lowell Observatory reflector also designed by him, with certain modifications introduced to adapt the instrument to our needs. The broad design features of the telescope may be seen from Figure 3. The instrument is under construction by the W. L. Richards Company of Austin, Texas, and is expected to be ready for installation in March, 1962. The mirrors are being manufactured by Perkin-Elmer Corporation. A site on Tumamoc Hill, approximately 350 feet above the city of Tucson and 4 miles west of the University, has been selected, on the grounds of the Geochronology Laboratory, where road, electric power, water, and office facilities are already available. The coordinates are 111°0′ W, 32°13′ N, elevation 2700 feet or 820 meters. The telescope is a very rugged instrument, suitable for attachments up to 400 lbs. We are greatly indebted to the scientific staff of the Naval Ordnance Station for their interest in and support of our research programs.

The Laboratory is further indebted to Mr. Alika Herring, who joined the staff about October 1, 1961, for making available his excellent 12½-inch reflector for visual studies of the moon and the planets. The instrument is being mounted on the Tumamoc Hill site.

4. Editorial Program

Miss Barbara Middlehurst and Mr. Kuiper are editing a 5-volume series, "The Solar System," of which the third volume, "Planets and Satellites," appeared in August, 1961. Volume IV, dealing with the moon, meteorites, and comets, has mostly gone to press.

Mr. Kuiper is also serving as General Editor and Miss Barbara Middlehurst as Associate General Editor for the 9-volume series, "Stars and Stellar Systems," of which two volumes appeared in 1961: "Telescopes" and "Stellar Atmospheres." A third volume, on "Astronomical Techniques," is in page proof and the remaining six volumes are in various stages of preparation. The editorial work has been supported in part by grants of the National Science Foundation, grants G2704, G3446, G7173 and grant G17454.

Other publications by the Laboratory staff are referred to below, in section 6.

5. Facilities

At present the facilities consist of 2500 square feet of office and laboratory space on the fifth floor of the new Physics-Mathematics-Meteorology Building, plus 2000 square feet in a separate one-story building (T6). By the summer of 1962 a new 8000 square-foot laboratory will have been completed, in a new wing of the Physics Building. Approximate

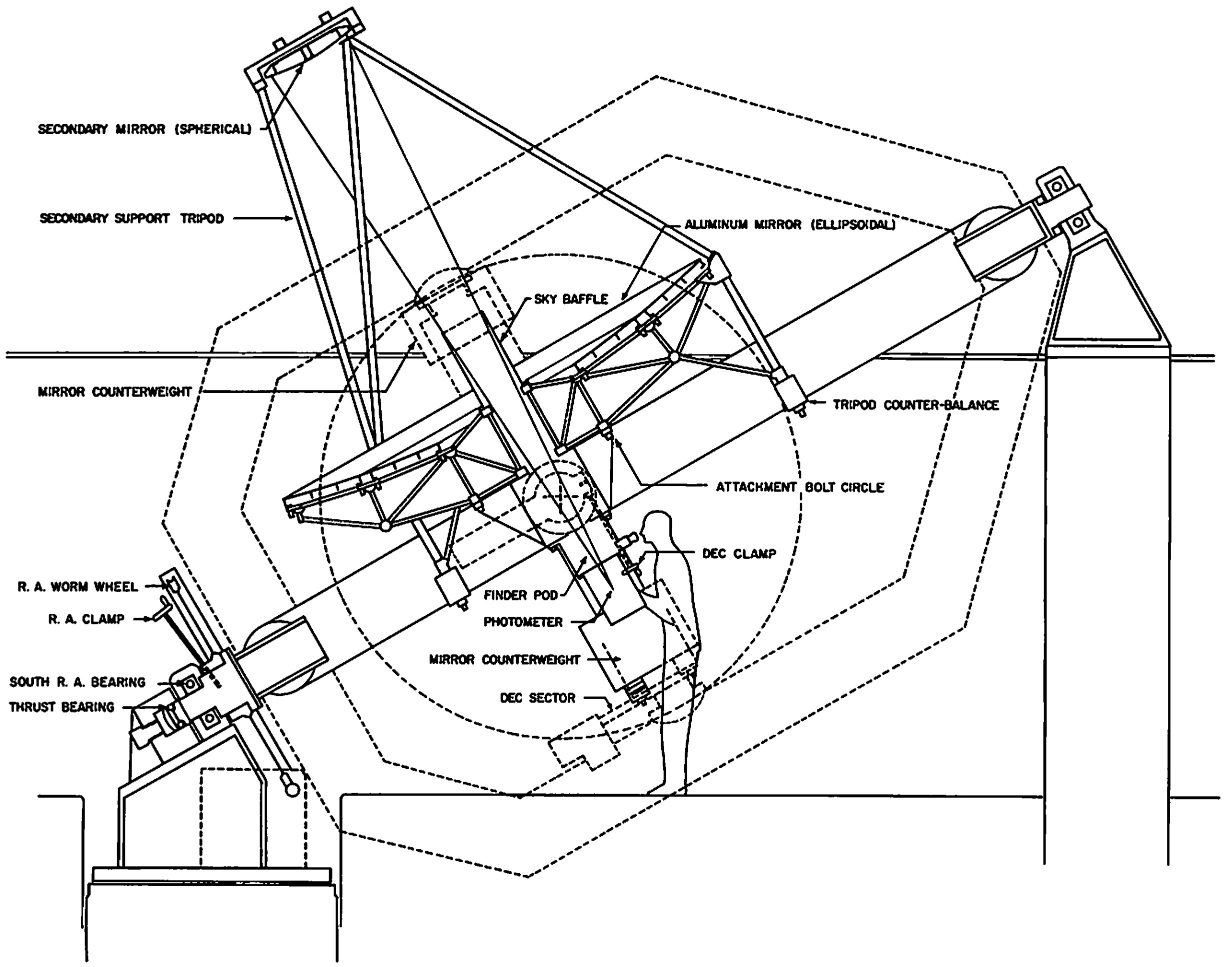


Fig. 2*a*. Preliminary design for a 10 ft. IR telescope, used at Cassegrain focus. *Dotted line* shows fork in 6-hour East position.

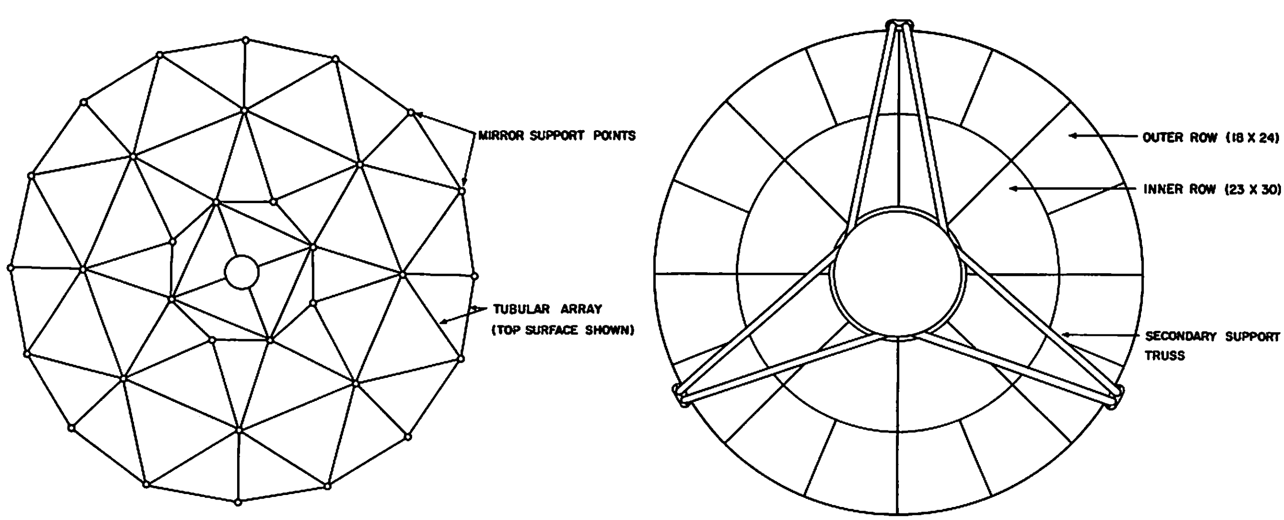


Fig. 2*b*. *Left:* Plan view of mirror support truss; each intersection provides collimation for one or more mirrors. *Right:* Plan view of mosaic mirror and secondary support system.

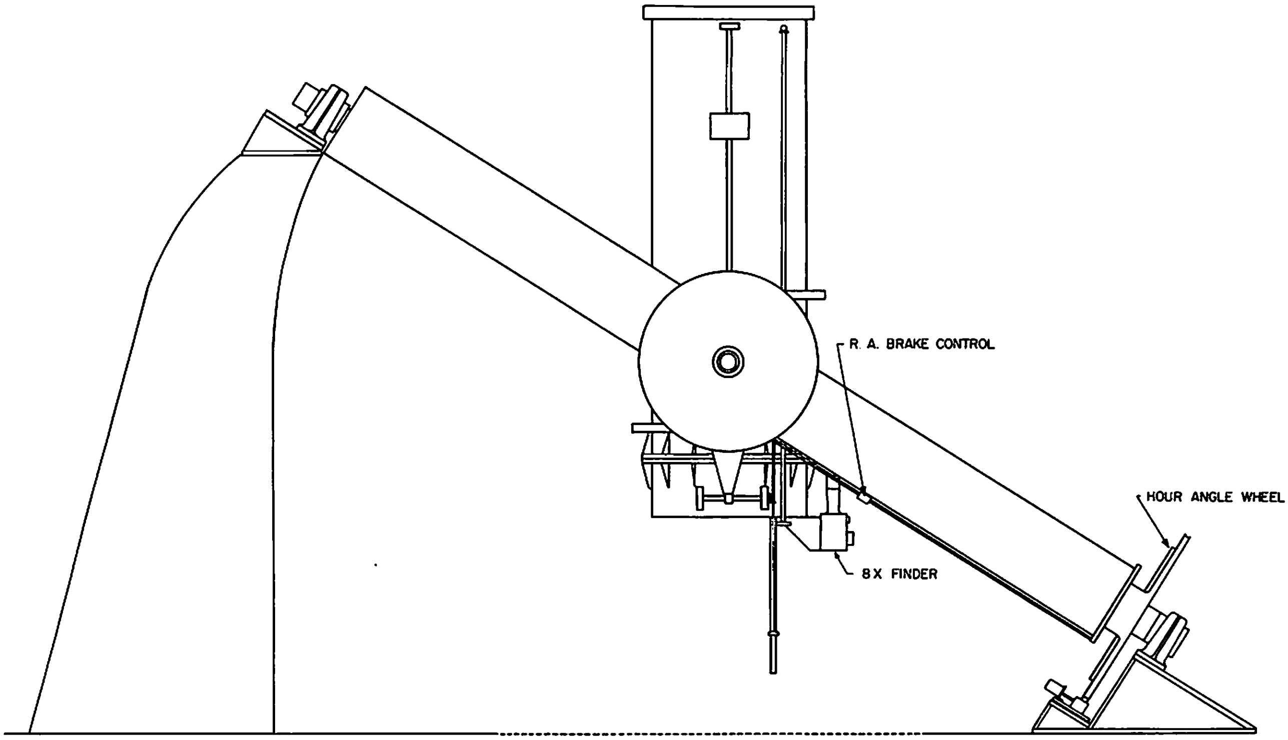


Fig. 3*a*. Design drawing of 21-inch telescope by W. L. Richards Co. of Austin, Texas, manufacturers of this instrument.

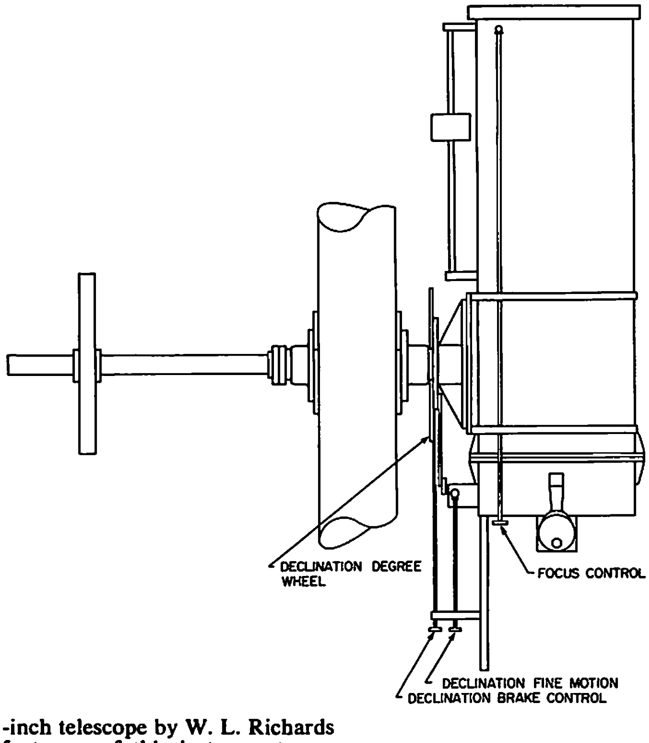


Fig. 3*b*. Design drawing of 21-inch telescope by W. L. Richards Co. of Austin, Texas, manufacturers of this instrument.

floor plans of the present facilities are shown in Figure 4; the floor plan of the new laboratory is shown in Figure 5.

6. Report on Scientific Programs

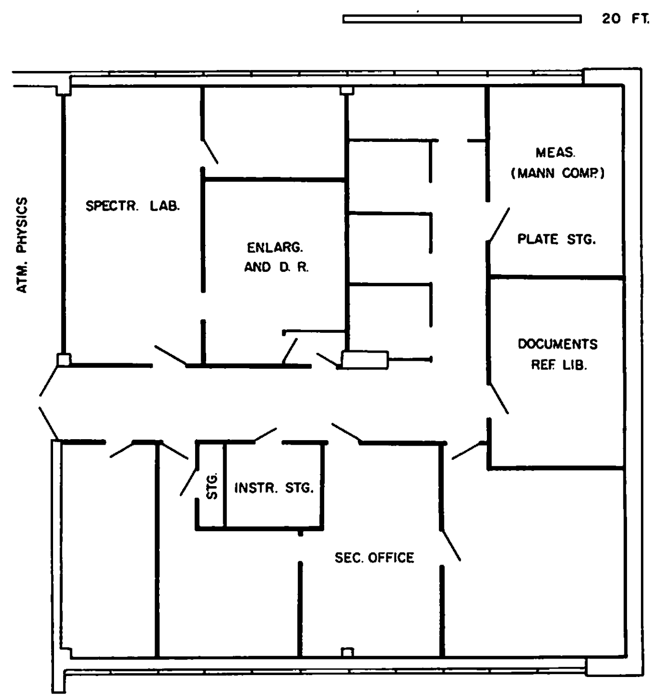
The divisions of this section follow the order used in Section 2.

(a) Lunar Studies

During the first year of operation the lunar group of the Laboratory has been chiefly concerned with four publications:

(1) *The Orthographic Atlas of the Moon.* This atlas has been prepared largely by Messrs. Whitaker and Arthur and was published in two parts, Part I dealing with the central areas of the lunar disk and Part II with the limb areas. Part I appeared about January 1, 1961, and Part II one year later. The Orthographic Atlas was published in two editions, A and B, Edition A showing the orthographic grid only and B the orthographic grid and the latitude-longitude grid, the latter overprinted in color. Edition B is identical to an Air Force edition issued by the Aeronautical Chart and Information Center at St. Louis. The Orthographic Atlas was produced in close cooperation with ACIC. For the central areas the orthographic grid was derived at the Lunar and Planetary Laboratory by interpolation between the coordinates taken from a consolidated catalogue of base points, containing approximately 5,000 entries. For the limb areas, however, the base points were insufficient in number; and ACIC agreed to compute the grid intersections for every 0.01 of the lunar radius in both coordinates, on the basis of the topocentric librations of the individual plates used. With the theoretical system of grid lines known, apart from a scale factor which could be readily determined, the measured base points near the limb (mostly due to Franz) sufficed for the determination of the lunar coordinate system. During this fitting process well over 100 errors were found in the published coordinates of the limb points.—ACIC also computed the latitude-longitude grid from the orthographic grid, with the standard trigonometric formulae, and superposed the latitude-longitude system onto the orthographic grid system constructed at the Lunar and Planetary Laboratory. We are greatly indebted to ACIC for this very effective collaboration. Further information may be found in the introductory text of the Orthographic Atlas. A sample field is shown in Plate 1.1 on a reduced scale; it carries the orthographic grid only (Edition A).

(2) Associated with the production of the Orthographic Atlas was the composition of a *catalogue of*



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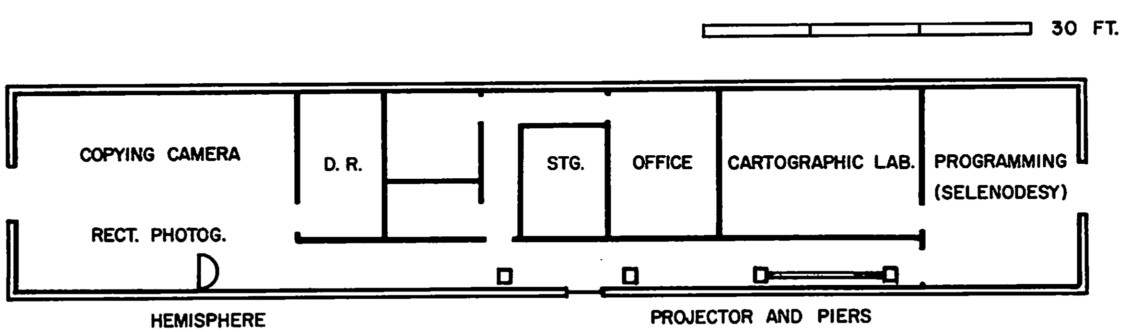

4*b*

Figs. 4*a* and *b*. Floor plans of Laboratory used from 1 October 1960 to about 1 July 1962. Rooms not otherwise designated are staff offices.

coordinated points, based on the measures published by Saunder and by Franz, and some 2,000 unpublished measures by Mr. Arthur. Thus, about 5,000 coordinated points were available and the data from the three series were reduced to a single system by Mr. Arthur. As mentioned above, the compilation of the Orthographic Atlas uncovered many errors in the limb data. Even for the central areas many errors were found in that some dust specks as well as lunar craters had been included. As a result the number of valid entries in the position catalogue was reduced well below the original 5,000. The final catalogue is nearly ready for publication; each entry has been rechecked against the Orthographic Atlas for reality and the values of the coordinates themselves.

(3) The sheets of the Photographic Lunar Atlas have been used for the measurement of crater *diameters* in excess of approximately 2 miles for the limb regions and 1.5 miles for the central areas of the lunar disk. Each crater was measured on at least five sheets independently and the average values are accurate to approximately 2 per cent (errors up to 30 per cent are not uncommon in some of the published series). The catalogue of crater diameters has about 8,000 entries and is expected to go to press in March, 1962. Projects (2) and (3) have both been under the direction of Mr. Arthur.

(4) One of the most useful tools in the lunar studies has proved to be a three-foot precision hemisphere, coated white, set up in Building T6 which provides a projection path in excess of 70 feet or 20 meters (See Fig. 4). This globe has been used for the removal of the foreshortening toward the limb, by optical projection. The different plate series (Mt. Wilson, Lick, Yerkes, McDonald, Pic-du-Midi) required different projection distances; this was done through the use of several piers on which the optical bench carrying the projector could be placed and adjusted. The globe was first designed and installed in the lunar laboratory at the Yerkes Observatory in the fall of 1958, by Messrs. Arthur and Whitaker. Improvements were introduced after the new installation in Tucson was completed, mostly by Mr. Spradley, resulting in a greater depth of focus and better definition. In the final adaptation, little resolution was lost from the original negatives, in spite of the several copying stages required. The geometry was such that the distortions in the new photography were unimportant except for the foreshortening stemming from the curvature of the globe itself.

The globe photography was directed toward several programs, the largest of which was the production of the "Rectified Lunar Atlas." In addition, separate series were taken for the study of the lunar maria, the principal ray systems (such as shown in Plate 1.2), and various tectomic features. The globe photography was carried out largely by Mr. Spradley and Mr. Hartmann. A description of the installation by Mr. Spradley is found in Communications No. 7.

The production of the *Rectified Lunar Atlas* at scale approximately 1:4,000,000, is well advanced. The visible hemisphere has been divided into segments of 30° x 30° selenocentric, except for the polar caps, with the result that 30 fields suffice to cover it. Each field is normally shown in three illuminations, sunrise, noon, and sunset. A fourth sheet is provided for each field, containing interpretative data, nomenclature, and an approximate latitude-longitude grid. A typical set of four sheets is shown on a reduced scale in Communications No. 7. The photography is essentially complete, with over 200 selected 14- by 17-inch photographs on hand (not counting another 200-300 duplicates or seconds). The final selection of the approximately 100 atlas photographs from the 200 available prints will be completed February, 1962. The coordinate and interpretative sheets have still to be prepared. The publication of the Rectified Lunar Atlas will follow the system used with the Orthographic Atlas; that is, there will be an Air Force and a University edition.

The preparation of all four publications referred to was supported by the National Aeronautics and Space Administration, through Grants NsG-37-60 and 161-61.

Work has progressed on two other major and several minor lunar research projects. The two larger projects are the LPL *selenodetic program* and the development of the *theory of the rotation of the moon*. Both are under the direction of Mr. Arthur. The plates for the selenodetic program are being taken with the 40-inch refractor of the Yerkes Observatory by Mr. E. Moore. So far well over 1600 plates have been secured of which the upper one-third in quality is being kept as the basic plate collection at Tucson. A two-screw Mann Company measuring machine Model No. 422C56 has been acquired, under Air Force Contract 19(604)8064. This machine is being adapted, through the introduction of several minor improvements, to the measuring program. Various preparations for the reductions have been made, in that several experimental reduction procedures have been tested with the University of Arizona IBM 650 by Mr. Moore under Mr. Arthur's direction. The selenodetic program was supported by AF Contract 19(604)8064.

The theory of the rotation of the moon is being critically reviewed by Mr. Arthur, who has completed the first two papers on the subject (Communications Nos. 9 and 10. Such a review was called for for two reasons: (1) The theory has been developed in various stages of approximation, in different notations, by several authors, in several languages. (2) The numerical accuracy of the tables constructed on the basis of the existing theories is inadequate for modern selenodetic work, while the likelihood exists that even the theory itself has not as yet been carried far enough to meet modern requirements. The latter criticism has also been made by Sir Harold Jeffreys. The numerical developments by Koziel have now been verified without substantial alterations, although some misprints in the formulae were found. Koziel's developments are concerned with the solution of the third of 3 differential equations. The solutions of the first and second equations are being made currently. The original developments by Hayn were based on an inadequate orbital theory and his calculations are of limited accuracy.

The projection of the moon on the globe has brought to light several structures that had escaped detection before. Among these are a number of heavily eroded craters, whose fragmented walls stood out as connected circular patterns, once the foreshortening was removed. Also, several systems of concentric mountain walls, surrounding lava-field basins, were noticed, particularly by Mr. Hartmann. The clearest of these are described in Communications No. 12. Another globe application is Mr. Whitaker's study of the Russian photography of the far side of the moon and its comparison with reprojected earth-based photographs, described in Communications No. 13.

The preparation of *Rectified Lunar Atlas* showed the difficulty of obtaining satisfactory representations of the extreme limb areas of the moon from single photographs. The global projection becomes increasingly unsatisfactory toward the limb owing to obscuration of lower terrain by higher elevations in the foreground. The best representation one can derive for the extreme limb areas is from a combination of all available photography, with various librations including the maximum, and different illuminations. Mr. A. Herring has begun a program of the mapping of the extreme limb regions, in 12 fields of 30° each encompassing the entire lunar limb. The first two fields are described in Communications No. 4. Mr. Herring will verify and improve his drawings as additional observations, visual and photographic become available.

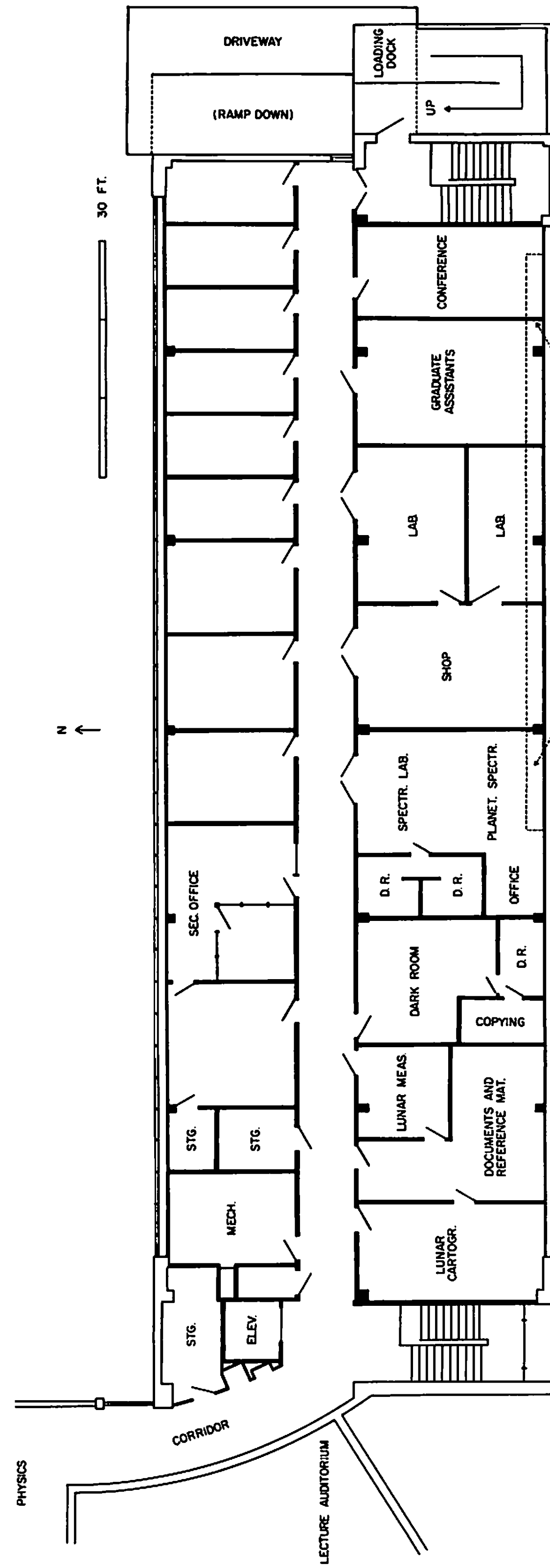

Fig. 5. New Laboratory expected to be occupied by midsummer 1962. Rooms not otherwise designated are staff offices.

Additional descriptive studies of the lunar surface, by Mr. Kuiper and Mr. Whitaker, are in preparation.

Dr. Gehrels has made a study of the polarization of 7 selected lunar areas in different wavelengths in the interval 0.3 to 1 micron. A striking increase in the polarization is found with decreasing wavelength, amounting to nearly a factor of 3 for the interval stated. This is illustrated in Figure 6. These results are being published in a forthcoming Communication.

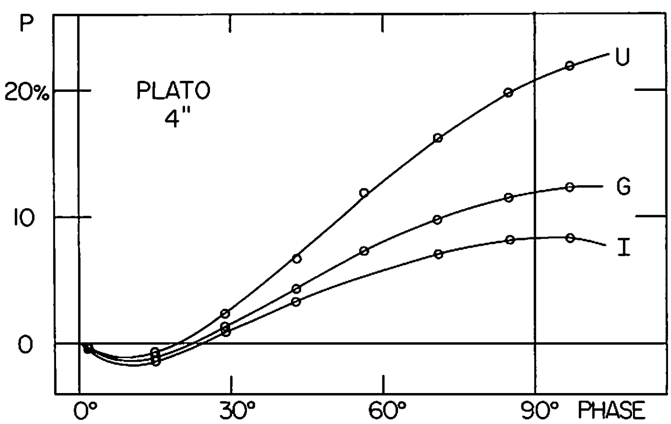

Fig. 6. Increase of polarization of moon light with decreasing wavelength discovered by Dr. Gehrels, illustrated by one of seven regions investigated (a 4-second-of-arc area on the floor of Plato). Observations of April 23-30, 1959, 82-inch telescope; wavelengths: ultraviolet, green, infrared.

Dr. Kuiper had meetings with astronomers and representatives of ACIC and the U. S. Geological Survey in an effort to affect coordination in the conventions used in lunar cartography. They concerned the unit used in expressing altitudes on lunar contour maps, the use of the terms east and west on lunar maps, and the conventions of placing either north up or south up. Agreement was obtained that elevations would be expressed in metric units, that astronomical maps of the moon would continue to use south up, that astronautical maps would have north up; that the terms east and west be dropped from astronomical maps and be used on astronautical maps in accordance with the terrestrial convention, in the sense that east is leading in rotation. These conventions were discussed at the Berkeley meetings of the International Astronomical Union, August 1961, and were adopted by Commission 16 (Planets and Satellites).

(b) Planetary Atmospheres

The new IR Spectrometer, described under *e* below, has been used to obtain a number of spectra of Jupiter and Venus between 1μ and 2.5μ which show more resolution and detail than those previously obtained. A band at 1.5μ in Jupiter, previously suspected, was definitely confirmed. The results will be published in a forthcoming Communication.

Through the kind cooperation of Professor Gerhard Herzberg, Director of Division of Physics, Canadian Research Council, a two-meter multiple absorption tube, able to withstand pressures up to 100 atmospheres, and temperatures from at least —200 to +200°C, was acquired on an indefinite loan. Mr. T. Owen has installed this instrument in the Laboratory, after a visit to Ottawa to receive the necessary instructions. His initial program is a study of the greenhouse effect of CO_2 at different temperatures and pressures, with application to the Venus atmosphere.

A 72-ft. (22-meter) long absorption tube of 8 inches diameter, thermally insulated, is being installed in the new floor of the Lunar and Planetary Laboratory, to replace a similar tube in the present wing, which had not yet been entirely completed. It is expected to provide for path lengths up to about 4 km.

Mr. Owen examined the night sky spectrum of Venus with the 36-inch telescope of the Kitt Peak National Observatory. He used special precautions not used in the earlier work by Kozyrev but was unable to find the emissions reported by him. It is possible that the earlier suspected emissions refer to the strongest parts of the instrumentally-scattered planetary spectrum. The results are being published in Communication No. 5.

(c) Satellite Systems

A number of additional plates of the Uranus system of satellites was taken by Dr. Kuiper with the 82-inch telescope. Preparations for the measurements of the mass satellites positions from the plates obtained during the oppositions of 1954, 1956 and 1958 are underway.

Dr. Kuiper published an account of his previous satellite surveys with the 82-inch telescopes in Chapter 18 of *Planets and Satellites* (1961).

(d) Asteroids

An asteroid survey down to the 20th magnitude, in collaboration with three other observatories, was begun September 1960. The problem is to determine the numbers and approximate orbits of the fainter asteroids from an adequate sample down to the limit obtainable with the 48-inch Schmidt telescope of the Palomar Observatory. Dr. Gehrels took the plates in September and October, 1960, covering the same selected area in the ecliptic, near the opposition

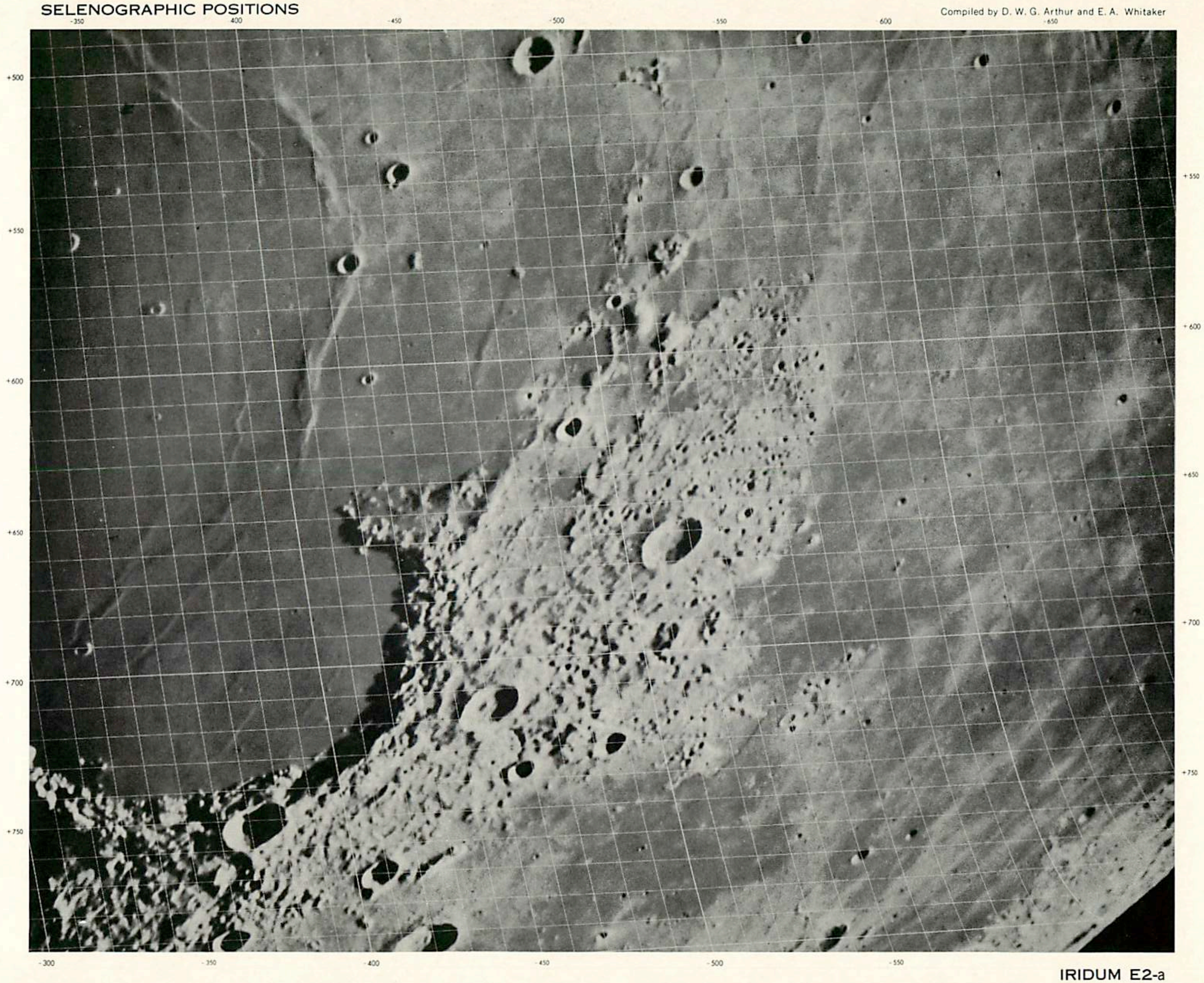

Plate 1.1. Sample sheet of Orthographic Atlas of the Moon, showing Sinus Iridum and Jura Mountains, on a reduced scale (0.45 times). The Orthographic grid shown is that of Edition A of the Atlas (Edition B carries, in color overprint, the latitude-longitude grid as well). The finite libration causes the grid lines to be ellipses. Grid spacings 0.010 lunar radii or 10.8 miles or 17.4 km near the center of the disk.

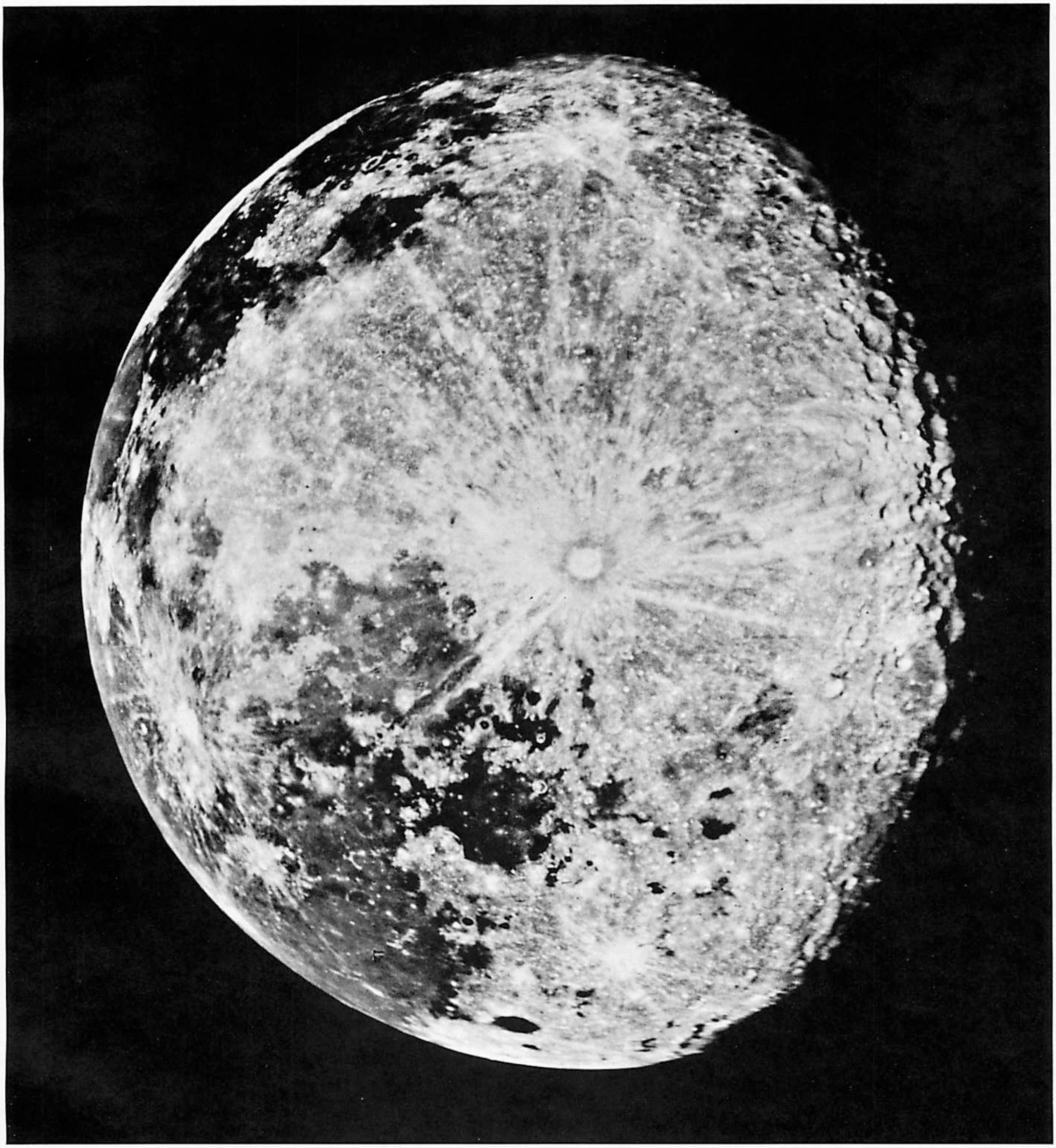

Plate 1.2. Globe photograph of the ray system of Tycho based on a full-moon photograph that showed the south pole region in favorable illumination. Used also on the cover to the series.

point, during at least four epochs spread over two consecutive lunations. The plates were sent to the Leiden Observatory where Dr. and Mrs. C. J. Van Houten have begun making a systematic search of the faint asteroids by blinking and subsequent measurement. To date approximately half the material has been evaluated. The National Science Foundation, through Grant No. NSF G-17910 is supporting the construction of a suitable blink miscroscope for this program; pending the completion of the instrument the blink survey has been started at the Heidelberg Observatory, Germany, through the kind cooperation of its Director and the cooperation of Dr. and Mrs. Van Houten. Our thanks are due to Dr. I. S. Bowen for the use of the Palomar telescope and to Dr. J. H. Oort for agreeing to consider the asteroid survey a joint project. Dr. P. Herget kindly agreed to have all orbit computations of the newly discovered asteroids carried out at the Cincinnati Observatory.

Work on lightcurves of individual asteroids has proceeded with the reduction of the 82-inch observations of Pallas made by Dr. Kuiper and the 36-inch McDonald observations of Asteroids 61 and 11 by Mr. H. J. Wood of Indiana University. The results are to be published by Messrs. Wood and Kuiper as Paper X of "Photometric Studies of Asteroids," in the Astrophysical Journal and these Communications.

An earlier paper on "Photometric Studies of Asteroids. IX. Additional Light-Curves," by T. Gehrels and D. Owings is scheduled to appear in the May 1962 issue of the Astrophysical Journal. Lightcurves were obtained for 15 asteroids, of which 6 for the first time, with the 36-inch and 82-inch telescopes of the McDonald Observatory. Iris was observed nearly pole-on. Large obliquities often occur, and there apparently is some alignment of the poles. The ecliptic longitudes of 8 asteroid poles were determined to be between 104° (284°) and 194° (14°), with none occurring between 14° and 104°, or between 194° and 284°. This apparent partial alignment of the asteroid poles is very curious, and demands an intensified effort in the study of these interesting bodies. The study of asteroid light curves and the survey to the 20th magnitude are supported by NSF grant G19184.

Mr. Kuiper presented a paper on the "Collisional Production of Asteroids and Meteorites" at a symposium at Arizona State University, March 10, 1961. The results are being published in Volume V of *The Solar System.*

(f) Infrared Stellar Spectra

With a lead-sulfide stellar spectrometer built in 1946 Mr. Kuiper had obtained spectra in the region 1.0-2.5μ for the brighter stars, with types ranging from A0 (Sirius) to late M (R Leonis and *o* Ceti at minimum) and N. The resolution $\lambda/\Delta\lambda$ used was about 80. With this low resolution only the Paschen and Brackett series of hydrogen were seen in Sirius, and the 1.1μ band of TiO in the M stars (Astrophys. J. *106*, pp. 248-249, 1947).

A few years later Mr. Kuiper obtained resolution 250 by using an analyzing slit over the PbS cell; but the instrument was not very efficient and only α Orionis and the planets Mars and Venus were so observed.

An Ebert-type grating spectrometer constructed by Mr. L. Salanave for a geophysical program and kindly made available by Dr. A. R. Kassander, was adapted by Mr. Kuiper to the 82-inch telescope and, with successive improvements, used by him for three short sessions at the McDonald Observatory (around February 1, April 1 and June 1, 1961). The weather was unfavorable during these runs but some results of interest were obtained on Venus, α Orionis and other stars. He made also two short runs with the Kitt Peak Observatory 36-inch telescope, which gave good data on the planet Jupiter. During the second half of 1961 the spectrometer was completely rebuilt and Mr. Kuiper had an excellent run with the 82-inch (December 14-28, 1961) which yielded a large quantity of new data. Messrs. Salanave, Goranson, Binder, and Cruikshank assisted during these successive observing periods, each making their contribution to improved equipment design.

Two groups of new absorption bands were discovered in α Orionis in the April run, one between 1.5-1.75μ and one from 2.3-2.4μ. A reproduction of a sample spectrum is given in Figure 7 for the 1.6μ bands, in Figure 8 for the solar and telluric comparison spectrum, and in Figure 9 for the 2.3μ bands. The resolutions $\lambda/\Delta\lambda$ are about 500. In the June run resolution 1000 was attained and it was found that near 1.6μ the spectrum of Antares matches the spectrum of Betelgeuse closely; also that these bands in Arcturus and α Herculis are appreciably different.

Records with much better resolving power were obtained in December 1961 for five stars: Arcturus (K2), Aldebaran (K5), Betelgeuse (M1), R Leonis (maximum, M6), Mira Ceti (minimum, M8). Resolutions up to 2000 were used at 1.6μ and up to 3000 at 2.4μ. The new records showed dozens of new stellar absorptions; the rotational structure of the 2.3μ

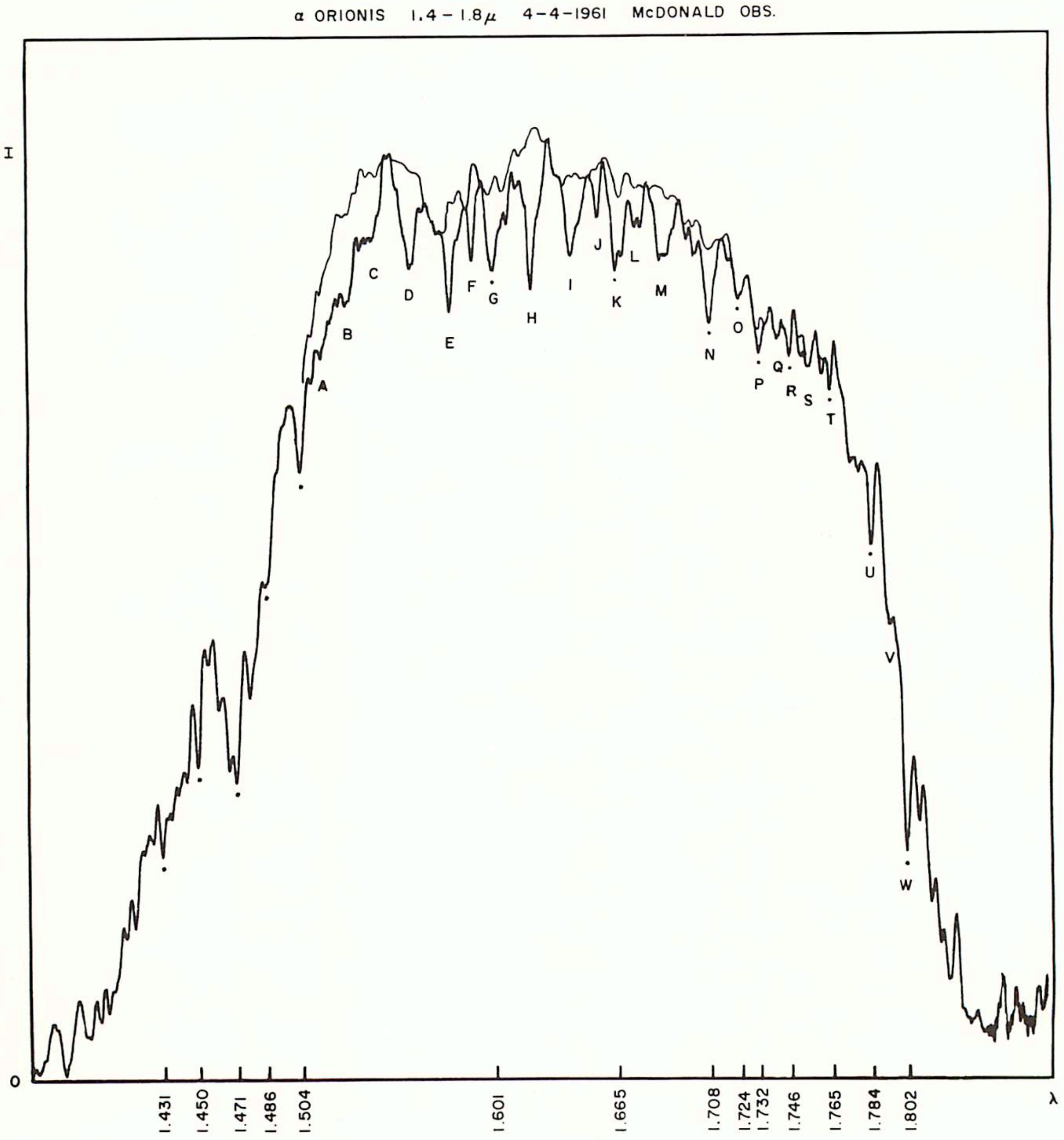

Fig. 7. Photographic reproduction of one of four almost identical spectra of α Orionis, region 1.4-1.8μ, obtained April 4, 1961. with 82-inch telescope. The wavelengths marked are those of telluric features, marked by dots, also shown in Figure 8. Upper fine curve corresponds to telluric spectrum recorded in Figure 8; difference between curves due to stellar absorptions, which appear prominent from A to S. Compare Figure 10.

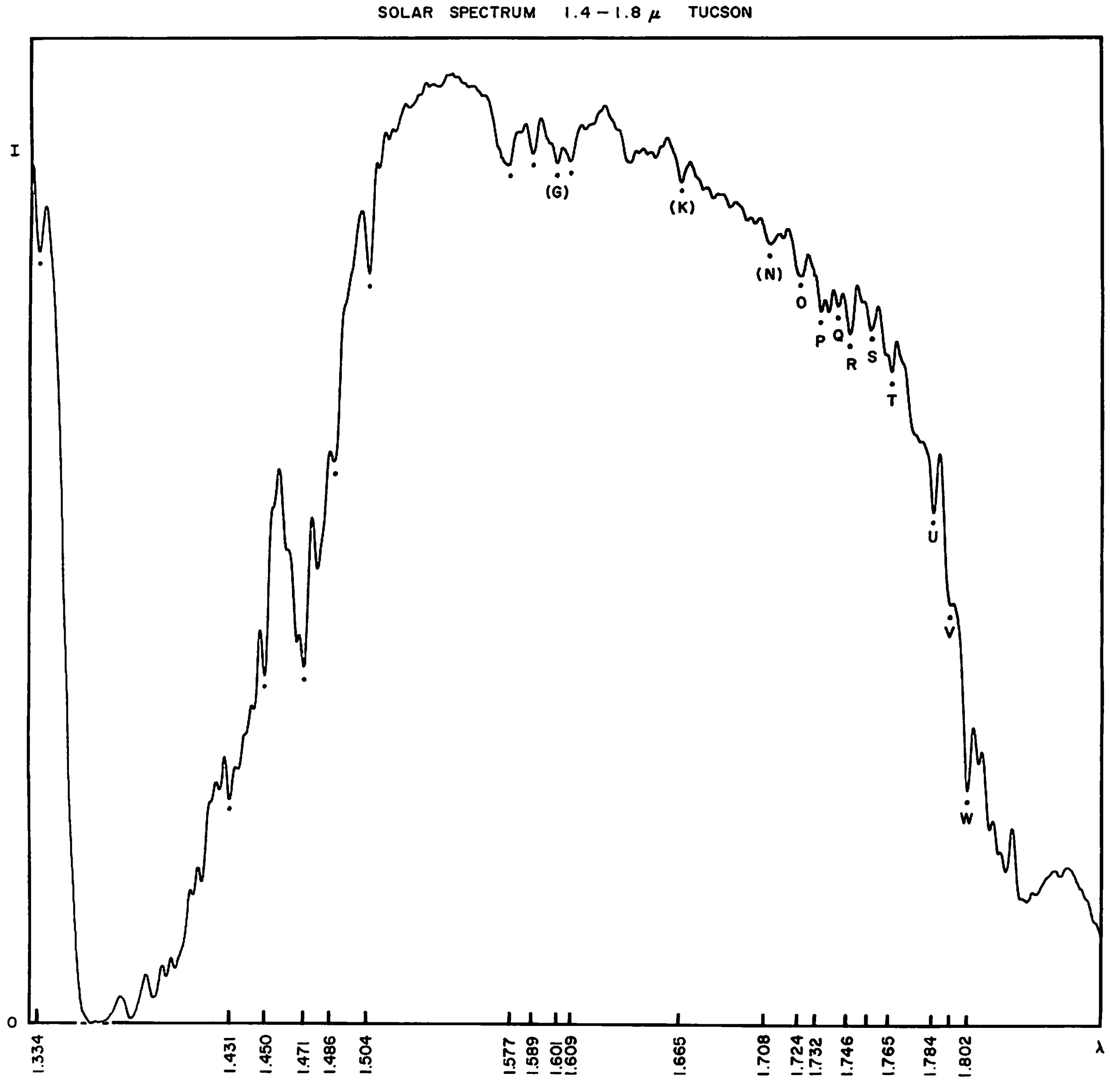

Fig. 8. Photographic reproduction of solar spectrum serving as comparison spectrum for α Orionis, shown in Figure 7. Nearly all features shown are due to H_2O; four dips near G are due to atmospheric CO_2.

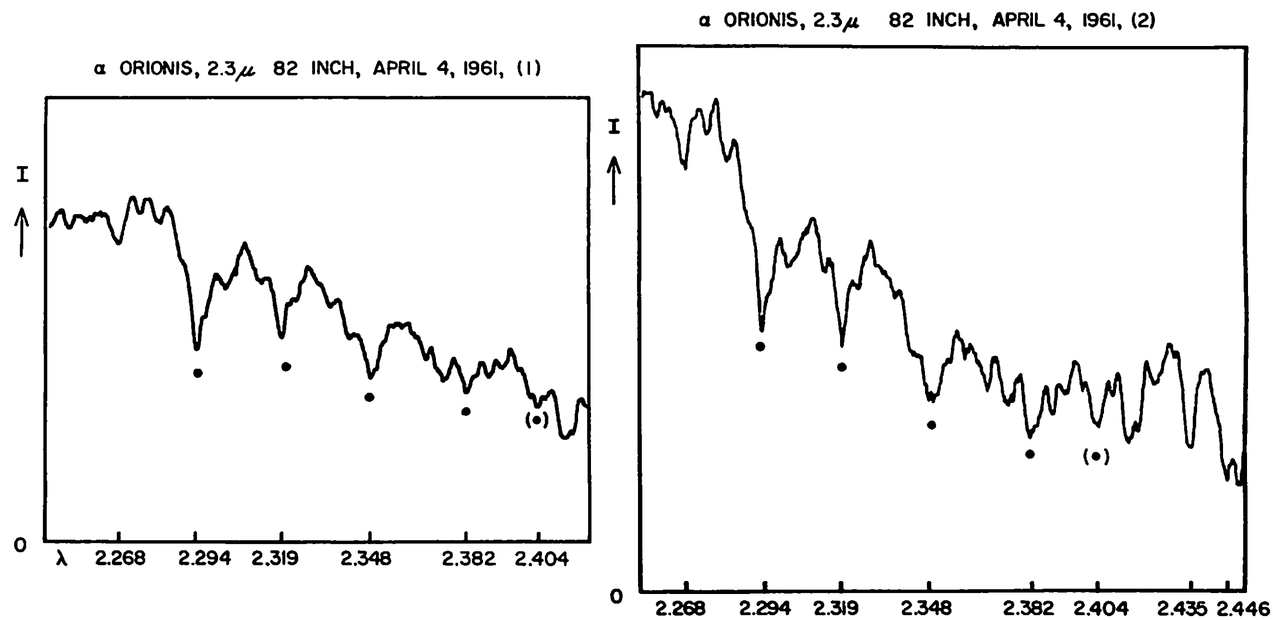

Fig. 9. Photographic reproductions (slightly reinforced) of two spectra of α Orionis, region 2.25-2.45μ, obtained with 82-inch telescope. Weak second-order spectrum present. Dots indicate new stellar absorptions. Compare Figure 11.

bands was resolved and possible identifications were derived by Dr. Meinel (see below). Mr. Kuiper will describe this work more fully in Communication No. 13. Meanwhile, one sample record of part of the 1.6μ system and two records of the first of the 2.3μ bands are reproduced here, in Figures 10 and 11. The assigned letters and numbers are for reference purposes only, pending full identification of the bands. The intensity variations of the 1.6μ bands with spectral type (K2-M8) are complex, showing that more than one system is involved; but the 2.3-2.4μ group appears to belong together, with Arcturus (K2) having nearly equal intensities of all four or five bands of the group; R Leonis and Mira Ceti showing the first of the 2.3μ bands very strong and the other members much reduced; while in Betelgeuse the decrease with increasing wavelength is intermediate.

Wavelength determinations in IR stellar spectra pose problems in spite of the scattered telluric features present. For this reason some of the scans were made with overlapping orders. Figure 11 shows one scan with the first order present only, and one with the second order included as well.

The bands were described by Dr. Meinel at the Denver meetings of The American Astronomical Society, December 1961, in his paper "Infrared Astronomy".

(g) Stellar Photometry and Polarization

Dr. Johnson developed a completely digitized photometer which measures the brightness of stars and planets at nine different wavelength bands, designated by U, B, V, R, I, J, K, L and M. The approximate effective wavelengths of these are 0.35, 0.44, 0.55, 0.68, 0.87, 1.3, 2.2, 3.6, and 5.0μ respectively. This device produces a punched paper tape upon which are recorded automatically all of the data that are needed for the reductions and analysis. Messrs. Johnson and Mitchell have written the computer program and tested it on more than 3000 observations of stars and other objects. Both the photometer and the program were developed at the University of Texas, but were transferred to the Lunar and Planetary Laboratory through the generous cooperation of the University of Texas.

In addition to the stellar observations, Dr. Johnson made a number of observations of Mercury, Venus, and Mars, out to magnitude L (3.6μ). He made such observations also on a number of areas of the moon.

Dr. Johnson hopes to begin in the near future an extensive program of the observation of the brightest stars in magnitudes U, B, V, R, I, J and K. Many of the brightest stars have no modern photometry at all and observation of these stars over the wide range of wavelengths, from 0.35 to 2.2 microns, will provide a wealth of new information.

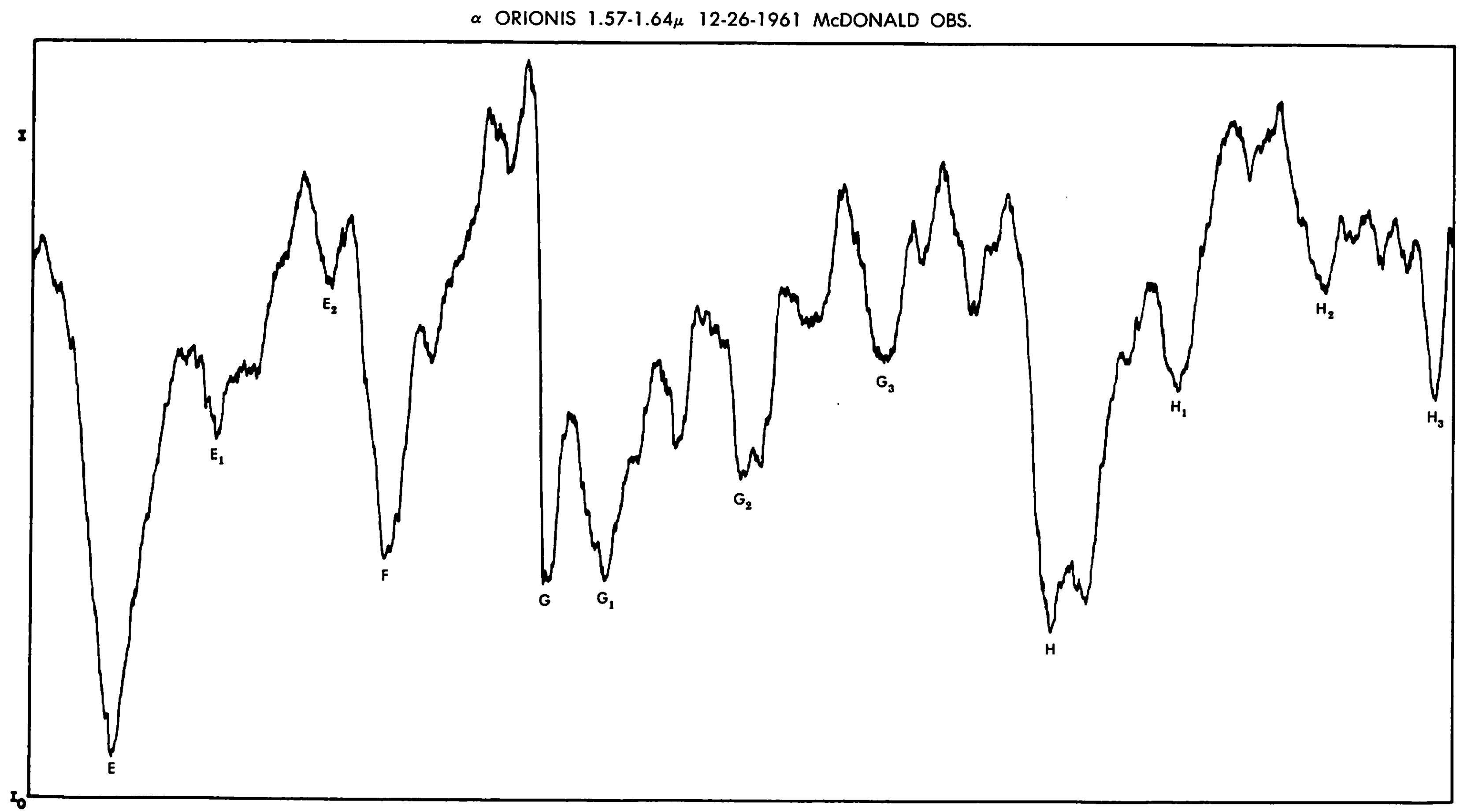

Fig. 10. Photographic reproduction of part of spectral trace of α Orionis, from 1.57-1.64μ, taken with 0.25 mm cell, 1.6μ grating (resolution 2000). Precise wavelengths not yet determined. Zero off scale to bring out absorptions. Note improvement over Figure 7.

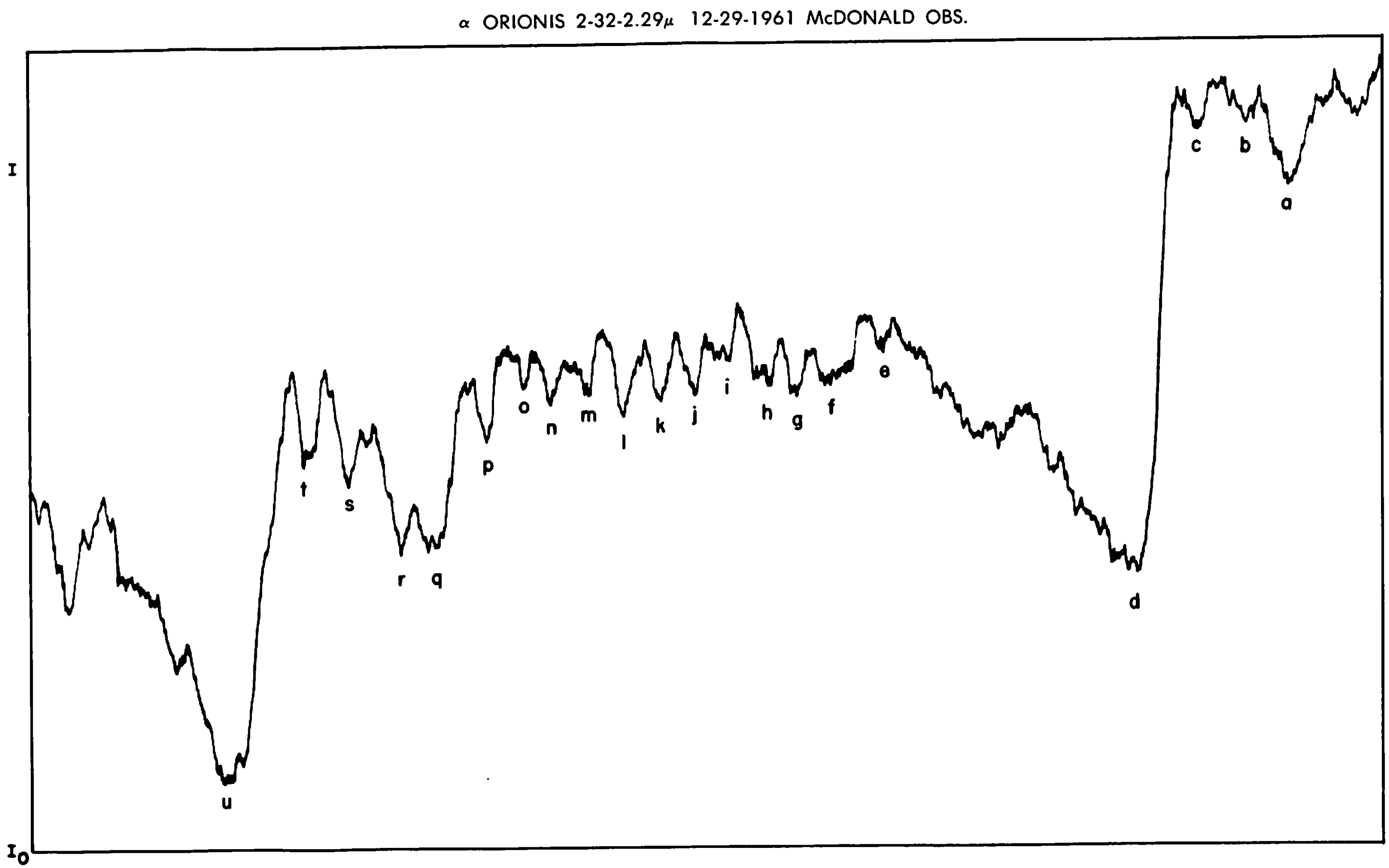

Fig. 11*a*. Photographic reproduction of part of spectral trace of α Orionis, from 2.32-2.29μ (wavelengths decreasing), 0.25 mm cell, 1.6μ grating, 2μ interference filter cut-off, resolution about 3000. Two of the five dotted bands of Figure 9 (2.319 and 2.294μ) are shown here. Letters are added for ease of comparison with Figure 11*b*. Zero off scale.

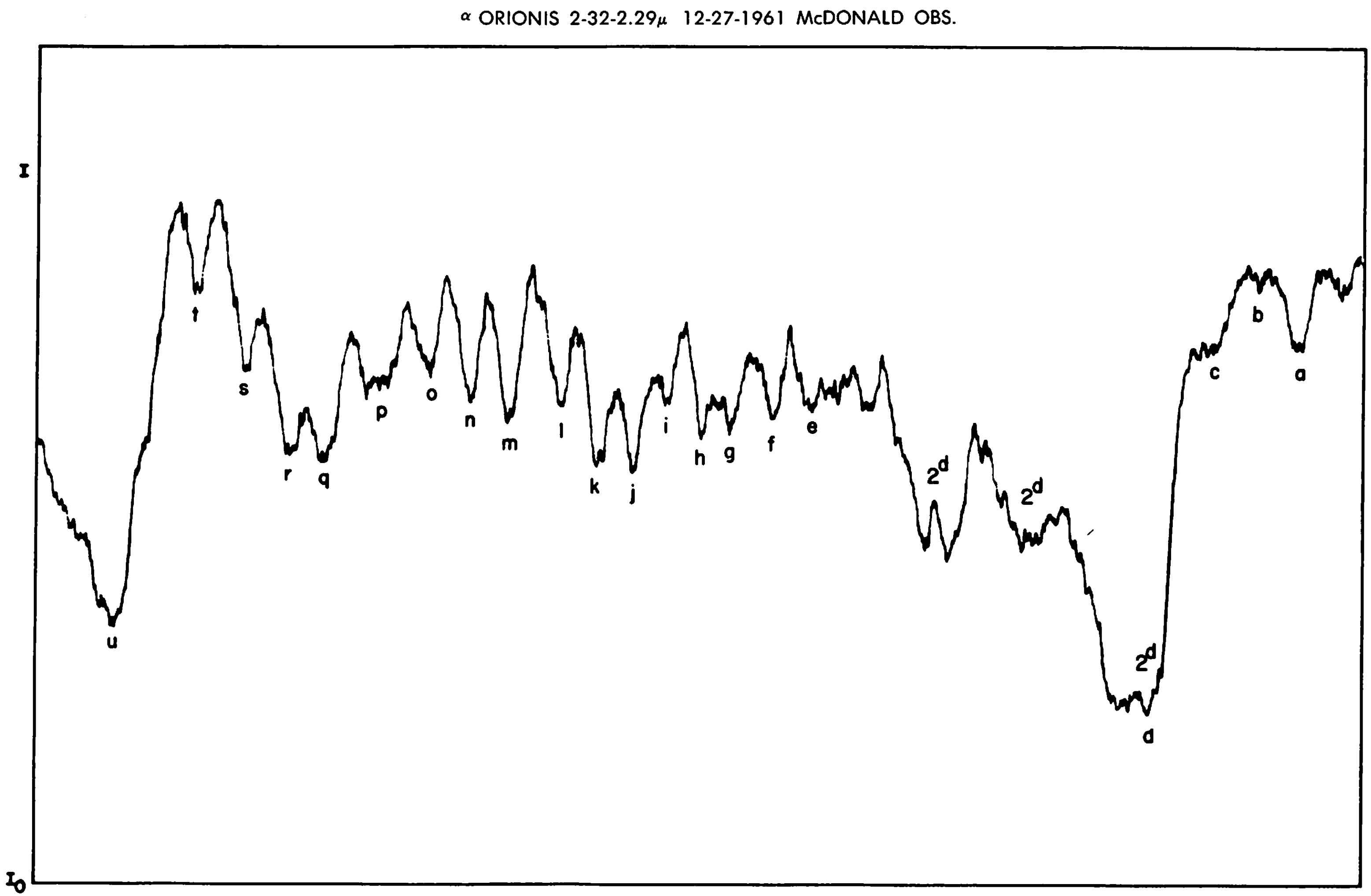

Fig. 11*b*. Same as 11*a*, but with 1μ filter cut-off, allowing second-order spectrum to be superposed. Strongest features so caused are marked "2[d]," including the blunting of absorption *d* (2.294μ). Rotational structure confirmed, though precise analysis still to be made. Zero off scale.

Dr. Johnson also obtained observations on a large number of unreddened and reddened O-type stars in magnitudes U, B, V, R, I, J, K and L (J, K, and L only for the brightest ones). He is now analyzing these data and preparing them for publication.

The Office of Naval Research has supported Dr. Gehrels' polarization program with grants to Indiana University and presently to the University of Arizona. He and associates have studied the wavelength dependence of instrumental polarization, the interstellar polarization, and of the polarization of the sunlit blue sky. Papers on these subjects will be reprinted in these LPL Contributions. Further papers are in preparation on the polarization of the Jupiter poles, of Venus, and of small selected regions on the lunar surface. The study of the interstellar polarization is being continued jointly with Dr. A. S. Meltzer of the Rensselaer Polytechnic Institute. The present balloon program is undertaken jointly with Dr. Z. Sekera, of the University of California at Los Angeles, for a detailed study of scattering within planetary atmospheres.

(h) IR Instruments

Reference is made under (f), above, to a new IR stellar spectrometer using PbS cells as detectors. The design is of the Ebert type, with three interchangeable gratings blazed for 1.0, 1.6 and 2.0μ, respectively. Overlapping orders are cut out by filters mounted in front of the cell having short-wave cutoffs at 0.7, 1.0 and 2.0μ, respectively. The 1.0 and 1.6μ gratings have 600 lines per mm, the 2.0μ grating 300 lines per mm. The focal lengths of collimeter and camera are 60 cm. Lead-sulfide cells were obtained from Eastman Kodak (Ektron) and IR Industries, Inc., of width 2.0, 1.0, 0.5, 0.25 and 0.1 mm, respectively, and lengths 2.0 or 2.5 mm. The resulting resolutions are about 250, 500, 1000, 2000 and 5000 at 1.6μ, and 1½ times this at 2.4μ if the 1.6μ grating is used, otherwise ⅔ times. Since 0.1 mm corresponds to 0.74 seconds of arc at the Cassegrain focus of the 82-inch telescope, resolution 5000 can be obtained on bright stars if the seeing is excellent; 2000 is feasible on average good nights. Stellar spectra are taken with a spectrograph slit wide open (slitless); planetary spectra with the slit width matching the cell. About 5 cells of each width were purchased and intercompared in the laboratory and the best in terms of signal/noise retained in each case for actual operations. Variations in S/N by a factor of 10 among cells of a given size were not uncommon so that the examination of many cells for each desired width was vital. The cells are used at dry ice temperature. They are all mounted in identical, easily interchangeable nylon rods, designed by Mr. Goranson. Each cell has its own load resistor, connected through a switch.

The preamplifier and amplifier used were designed by Dr. Johnson and built by Mr. Gardiner in 1956 for Mr. Kuiper's earlier IR program. The time constants provided are 1.2, 6 and 12 seconds; the chart speed on the Brown recorder normally used is 1 inch in 2 minutes. Three scanning rates are provided, covering 2000A in 4, 40, and 120 minutes, respectively.

As the resolution of the spectrometer was increased during successive runs at the telescope, the irregularities in the drive of the grating table became increasingly noticeable. Close comparison of the abscissae in Figures 10 and 11 will illustrate this problem. For this reason a new precision drive is being installed which at the same time provides greater versatility in scanning rates. The latter are being matched to the steps in gain used in the Johnson amplifier, which are 0.5 mag. intervals over a total range of 15 magnitudes or 10^6 times in intensity. The time constants of the amplifier and the scanning rates are matched to the same 0.5 mag. steps. Thus, for a star 0.5 mag. fainter, one step increase in gain will restore the amplitude of the signal; a step of 2.5 times increase in the time constant will restore the noise; and steps of 2.5 times (decrease) in the scan rate and in the chart speed will restore the abscissae (wavelength) scale. Essentially identical spectra will thus be obtained over a dynamic range given by the practical upper and lower limits of the time constant, 40 seconds and 1 second, or a range of $(2.5)^4$; i.e. over 4 x 0.5 magn. or 2.0 magnitudes. One merely trades time for brightness; and it requires, of course, that the amplifier is linear through zero, which is the case.

The increase of resolution for stars (if observed with good seeing) is obtained at little expense, but this is not true for planets with large disks. The cell noise is proportional to the square root of the cell width, so that doubling the spectral resolution on stars (as long as the stellar image is smaller than the cell width) decreases the signal to noise ratio by only $\sqrt{2}$. For large planets the slit width must be reduced as well so that the loss in that case is by the factor $2\sqrt{2}$. The predicted one-half power law for stars was found to be approximately realized among the best cells of various widths used in the spectrometer.

The spectrometer, amplifier, and accessories will be described in these Communications by Mr. Goranson.

The maximum resolution attained in the present spectrometer is 5000 at 1.6μ, or about 3A. In wave numbers this corresponds to a 0.3A resolution at 5000A. At 2.4μ the resolution is twice this. A further increase in resolution could be obtained by the development of cells narrower than 0.1 mm (used with extremely good seeing) or by the use of larger optics, thereby scaling up the dispersion proportionally. It is noted that temporary lapses in the seeing (i.e. increases in image size) will, with the spectrometer used in slitless form, not lead to spurious absorption features in the spectrum but only to a local loss of resolution.

For *fainter sources,* lower resolutions or longer integration times, or both, must be used. Also, it follows from what has been said that the lower resolution should not be sought with the same spectrometer using a wider cell, but instead with a separate instrument having a much-reduced angular dispersion and a narrow cell. Still further gains result from the use of a multichannel spectrometer, having an array of many cells each with its own amplifying system. The gain in S/N is proportional to the square root of the number of cells working. Maximum power is therefore obtained by use of a very low dispersion spectrometer (say, resolution 0.2μ or $\lambda/\Delta\lambda = 8$ at 1.6μ), having an unlimited integration time and using as many channels as are needed to cover the spectrum (10 in the case suggested). To attain maximum efficiency for objects with finite disks (such as planets) as well, the camera should be as fast as is compatible with effective cooling. This puts the limit at about F/5.

A ten-channel spectrometer of the type just described has been designed and constructed, and is at present undergoing tests. It uses the optics of the IR stellar spectrometer built in 1946, which had an F/5 camera and two sets of prism optics, a 20° quartz prism giving $\lambda/\Delta\lambda = 8$ and two heavy flint glass prisms with 63° apex angle giving $\lambda/\Delta\lambda = 80$, both for 0.25 mm cell width. A 10-element Ektron mosaic cell is used, with overall width of 2.5 mm. The electronic system has been designed by Professor E. Morrison, director of Applied Research Laboratory of the University, and has been built under his direction. He will describe it in a forthcoming issue of these Communications. The integration time is 3 minutes, the output digital, printed on tape. The same observation may be repeated as many times over as is desired, so that one could observe an object for most of a night or longer. The reductions are made automatically by machine. The limiting magnitude is thus indefinite, depending on the observing time spent; but 10th magnitude objects of solar type should be well within reach. For the higher resolution, 80, the practical limit will be around 7 mag. The 10-channel instrument is regarded preliminary to more powerful and versatile equipment.

The construction of the 10-channel spectrometer and associated equipment was made possible by the grant NONR N123 (60530) 27887A.

Reference is made to Section *(g)* for Dr. Johnson's infrared photometer program; and to Section *(h)* for its potential extensions.

(j) Spectroscopic Laboratory

Dr. Meinel set up a spectroscopic laboratory (Fig. 4a) which was wired for 230V, 60 amp. AC service for use with arc sources. A 1.5 meter Bausch and Lomb grating spectrograph, equipped with an extra concave grating for the photographic infrared, covers the region of 0.2-1.2μ. The IR spectrometer mentioned in Section *(h)* covers the region 1μ-3μ, while a Perkin-Elmer Spectrometer is on order to extend the observations to 8μ. The latter instrument will be modified to allow the recording of spectra of fluctuating light sources.

Dr. Meinel, assisted by Mr. Hoxie, has begun investigating the spectrum of lightning-type discharges in a CO_2 atmosphere. He has proposed that lightning may occur in a highly convective Venus atmosphere and, with Mr. Hoxie, has prepared a paper "On the Spectrum of Lightning in the Venus Atmosphere," which will appear in these Communications. The paper discusses quantitative aspects of the problem and proposes new instrumentation allowing a search to be made for the presence of the λ4267 CII emission observed in the laboratory spectrum. Dr. Meinel has designed a new AC photometer that should be 10^2-10^3 times more sensitive for atomic emissions from planetary atmospheres than was the photographic method used by Kozyrev, Newkirk, and Owen in their separate investigations. When this equipment is completed a search will be made of both Venus and Mars for the presence of characteristic emissions from airglow, auroral, and lightning activity.

Dr. Meinel has also examined the unidentified bands in α Orionis found by Dr. Kuiper. He studied the rotational structure of the 2.3μ group (Figures 11a and 11b) and, while the identification is not yet certain, the bands appear to be the ground state, $X^1\Sigma^+$, rotation-vibration bands of CO. A theoretical analysis of the temperature profiles to be expected for these bands is in progress and should resolve the remaining uncertainty. A laboratory investigation of the CO absorption spectrum in the far infrared will be carried out by means of the Herzberg multiple path absorption tube as a final check on the identification.

Dr. Meinel's study of the 1.6μ bands has indicated that these are apparently due to more than a single molecular species. One band system is probably another member of the CO rotation-vibration system mentioned above, the other bands may be due to a polyatomic molecule, but identification is made difficult by the lack of laboratory data at stellar temperatures for polyatomic molecules. While H_2O was considered as a possible identification (visible in the high J-numbers), it is now discounted as the correct one. The possibility of identification with CH_3 is still under study, but little can be accomplished from general consideration until laboratory work is initiated in this spectral region.

Mr. Owen's laboratory work on the absorption spectra of planetary atmospheres is referred to in Section *b*.

(k) Tests for Tenuous Planetary Atmospheres

Dr. Hoenig and Mr. Collins are attempting to develop a new type of gas detector, for testing the presence and composition of highly-rarified planetary atmospheres. The system is to be based on the change in the work function of a tungsten filament when oxygen chemisorption occurs. The device is to consist of a tungsten filament and a cylindrical collector. For a measurement, the filament is to be flashed to 2000°C; this removes all adsorbed gases and will establish a reference current that is controlled by the Richardson equation. Thereupon the filament is allowed to cool to a predetermined temperature, around 1500°C, and the time interval is measured for the emission current to fall to a preset value, e.g. 10^{-10} amperes. This time interval is a function of the cooling of the filament and the ambient pressure of oxygen. The dependence on the oxygen pressure exists because of the strong chemisorption reaction between oxygen and tungsten, resulting in an increased work function.

Computations by Mr. Collins, based on a modification of the Richardson equation that allows for the chemisorption of O_2, indicate that pressures down to 10^{-14} mm Hg of O_2 can be detected. At present Mr. Collins is assembling laboratory apparatus for testing the theory experimentally. The present gauge is specific for O_2; other filaments will be investigated for the presence of traces of N_2 and H_2.

(m) Faint Planetary Emissions

A brief report on this subject has been combined with that on Laboratory Spectroscopy (Section *j*, above).

Acknowledgements. — A large fraction of the work reported in these Communications is supported by grants from the National Aeronautics and Space Administration (NsG 37-60 and NsG 161-61). Specific projects by individual staff members are supported by grants of the National Science Foundation, and Office of Naval Research, as indicated in Section 6 above. The production of the lunar atlases was a cooperative program with the Air Force Aeronautical Chart and Information Center at St. Louis, and various phases of the preparation were supported by Air Force Contract No. 19(604)8064. Mr. Kuiper's program in planetary atmospheric studies is supported by Air Force Contract No. AF 19(604)7260.

Our warm appreciation is due to the Universities of Chicago and Texas for the manner in which they facilitated the transfer of the Lunar Project and its contracts to the University of Arizona, and for continued use they allowed the project staff to make, without charge, of the Yerkes and McDonald telescopes.