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REPORTS OF OBSERVATORIES, 1965–1966

Allegheny Observatory, University of Pittsburgh, Pittsburgh, Pennsylvania

Personnel. Kiewiet de Jonge has received the title of Associate Professor and Beardsley, Assistant Professor. C. W. Kamper served as graduate assistant. H. A. Hegerle and J. G. Rachuba were full time assistants. Part time observers were W. A. Feibleman, D. J. Peart, R. L. Scherer, and G. A. Winterhalter. Public evening lecturers were W. McCall, J. J. Mullaney, R. C. Patterson, J. G. Rachuba, and E. R. Stehle. Summer assistants were S. G. Levy, E. R. Stehle, W. A. Snyder, and J. H. Snyder. Mrs. J. T. Martin continued as secretary, A. Graziani, machinist, and J. Micklos, custodian.

Observations. There were 1154 plates obtained with the Thaw refractor for the astrometric programs. Observations were made on 122 nights—96 evenings and 70 mornings with both evening and morning plates on 44 nights. The telescope was in use 293 h. The Keeler reflector and Mellon spectrograph were used to obtain 153 plates on 39 nights—the total observing time being 87 h.

This telescope was out of service until mid-September due to refiguring of the secondary mirror following installation of a new primary-mirror support system in July. Wave front errors due to the secondary mirror were successfully reduced to the point where, for a typical night, the resulting wave front at focus exhibited a progressive shift from under- to overcorrection due to the thermal response of the primary mirror. This thermal response was dampened by application of a thermal jacket around the edge face of the mirror. A crossover time some 3 h into the night was achieved, at which time the optics are approximately diffraction limited. A slight thermal drift remains. The refiguring work was undertaken by V. Nacin, optician with American Optical Company, and performed in the Observatory's optical shop. Current plates show significantly improved line definition while the instrument is approximately twice as fast as before the optical rehabilitation of the telescope.

R. C. Patterson considerably improved the stability and sensitivity of the spectrograph integrating exposure meter by modification of the circuitry which is based on that developed at Dominion Astrophysical Observatory.

Research. Stellar parallax plates measured numbered 827. Of these 630 were measured under a National Science Foundation grant. Sixteen parallaxes were completed. Two of these stars were listed by Strand in 1956 as subdwarfs of considerable astrophysical interest. One, Yale catalogue 1890, gave a relative parallax of $+''.007 \pm ''.008$ compared with the catalogue absolute parallax of $+''.041 \pm ''.011$. The other, Y5098, yielded a relative parallax of $+''.026 \pm ''.006$. The catalogue absolute value is $+''.041 \pm ''.006$ from three determinations. A combined right ascension and declination solution by Kamper for the bright companion, BD+4°4048, of van Biesbroeck's intrinsically very faint star gave a parallax of $+''.156 \pm ''.006$ from 99 plates, only 17 of which were morning plates. Other significant results included a parallax of $+''.268 \pm ''.006$ for τ Ceti, $+''.062 \pm ''.009$ for GC 25394, and $+''.029 \pm ''.004$ for Y5292 for which the catalogue value is $+''.084 \pm ''.013$. A few more preliminary parallaxes for faint white dwarfs were derived. Kamper presented a paper on the Σ2398 system at the March meeting of the American Astronomical Society. A letter on the parallax of 2 And by Kamper appeared in *The Observatory* **85**, 265.

Kiewiet de Jonge undertook a study of the longitudinal mobility of the focal plane in Cassegrain reflectors as induced by a translation of the secondary mirror. In error theory, he derived a quadrature formula to establish the systematic

effect of accidental errors in proper motion on the mean of the logarithms in total proper motion. Both studies are being prepared for publication.

From old Allegheny radial velocities Beardsley has found a period of 880 days for 6 Lac, and variations of 0.52 day for HD 124224, and 0.19 day for α Lyr. He also found astrometric evidence for a possible 7-yr period for the short-period spectroscopic binary 95 Leo. At the IAU Symposium No. 30 in Toronto, Beardsley reported preliminary results on the astrometric–spectroscopic investigation of γ Gem. The star has a period of about 12.7 yr in a highly eccentric orbit. A rapid change from negative to positive radial velocity is expected late in 1966. Efforts to prepare 2952 radial velocities, obtained at Allegheny from 1906 to 1917, for publication are continuing. The project will be completed in the coming year.

Miscellaneous. "The Gamma Cygni Nebulosity" by Feibleman appeared in *Astrophys. J.* **144**, 1222. "The Finest Deep-Sky Objects," by Mullaney and McCall was published in three numbers of *Sky and Telescope* and will be available in reprint form. Mullaney also reviewed "Starlight Nights" by Leslie C. Peltier, for *Sky and Telescope.*

A total of 206 students were in the four trimesters of undergraduate courses. Thirty-five of these did laboratory work. Beardsley had five students in a graduate course and Kiewiet de Jonge, one. In the two semester laboratory course at Chatham College, Kiewiet de Jonge had 26 students. An enlarged graduate program is planned for the coming year.

Visitors totaled 5882—3910 on 157 nights in the Frick Public Evening Service and 1972 in 148 daytime groups. Staff members gave 25 lectures to about 1500 people outside the Observatory. Beardsley's 65-part "Astronomy in the Space Age" continues to be shown by Westinghouse Broadcasting Company television stations around the country. Jean Texereau inspected the telescopes of the Observatory and Philip Ianna obtained some Hartmann test and cluster plates with the Thaw telescope.

A gift from Stephen H. Forbes will provide for the purchase of many books and for general updating of the library. Malcolm Priest has turned over his extensive library on celestial mechanics to the Observatory. A new finder telescope for the 13-in. refractor was donated by R. L. Scherer. Other donations of books and equipment from R. Clutter, F. M. Garland, K. Kobus, J. J. Mullaney, A. L. Ott, Buhl Planetarium, and North American Aviation, Inc., are gratefully acknowledged.

N. E. WAGMAN, *Director*

Dyer Observatory, Vanderbilt University, Nashville, Tennessee

Personnel. During the year ending 30 June 1966, staff changes were as follows: A. M. Heiser was promoted to Associate Professor of Physics and Astronomy; M. E. Krebs joined the staff on 1 January as Superintendent; R. L. Sears left on 1 September to join the Astronomy Department at the University of Michigan; student-assistants included L. Cathey, J. Hayes, L. Lieberman.

Research. Heiser and Hardie determined magnitudes and colors photoelectrically of the two components of the close binary, Giclas 175–34, and confirmed Giclas' suggestion that one component is a white dwarf. A short account of this work appeared in the *Publications of the Astronomical Society of the Pacific.*

Heiser together with Cathey and Hayes investigated comprehensively two galactic clusters, NGC 7380 and NGC 7063. Some 268 stars down to about $15^m.3$ (visual) in the first, and 200 down to $15^m.5$ in the second were examined by U, B, V photographic photometry. Further work is in progress, particularly to establish more reliable photoelectric sequences than are on hand.

Heiser has observed HR 4715 photoelectrically to determine whether the star is variable. The results of five nights of monitoring indicate that the star is probably a δ Scuti variable, with varying amplitude and complex beat periods.

Heiser and J. Smyre investigated the photographic color equations governing plates secured at the reflector–corrector focus. While small terms were discernible, the effects appear to be obscured by large residual inaccuracies and the study will be resumed with better quality plate material.

While securing colors and magnitudes of the components of ADS 9537 in a collaborative investigation with A. H. Batten of the Dominion Astrophysical Observatory, Hardie established that they were both variables of the W Ursa Majoris type, with periods of 0.35 and 0.29 days, probably the first known instance of this type. A brief account, in abstract form, may be found in *Astron. J.* **70,** 666, 1965.

Hardie secured four plates of regions near Pluto in order to continue the search for stars near its path over the next year. The plates have been measured by I. Halliday at the Dominion Observatory and no new candidates of suitable brightness for likely occultation by Pluto were found. Good positions of Pluto were secured from the plates in order to keep a continuing check on the increasing positional errors in the Nautical Almanac.

Hardie and R. Zawislak reduced a large body of

U, *B*, *V* photometric data on the eclipsing binary MR Cygni. The data are now in suitable form for rectification of the 3 light curves and for a final analysis.

Hardie and Lieberman observed the magnetic variable HD 124224 on a few nights in order to secure an improved period and to provide concurrent phase information requested by J. Hardorp, who is carrying out spectroscopic studies of the star. A brief note is in preparation.

Three-color photometry of HD 10783, a magnetic variable, has been commenced by Hardie and will be continued.

Critical studies of the techniques used in photographic photometry have been under way for some time and are continuing, with the aim of improving the reliability and accuracy of the techniques. The influences of exposure time, slightly out-of-focus images and other effects are being evaluated for both low and high *f* ratios. A grating is now under design for immediate construction in order to permit extrapolation of the photoelectric sequences to about 17 mag and thus reduce our reliance on larger telescopes elsewhere for such tasks.

The objective prism has been fitted with an adapter which permits it to be used on the telescope in the Cassegrain mode. A dispersion of about 75 Å/mm at Hγ is secured and the system is relatively efficient, 8th mag being reached in 15 min with generous widening (0.5 mm or 10 sec of arc). Initial tests of the quality of the spectra are under way. Evaluation is also being made of the use of the objective prism together with the photoelectric photometer as a spectral-scanning system, in a manner similar to that initiated some years ago by D. A. MacRae and J. Stock at the Warner and Swasey Observatory. It is already apparent that the long-focus Cassegrain arrangement diminishes the difficulties experienced with a Schmidt telescope–photometer system by these observers, and a scanning program is now being prepared.

A technical study is in progress concerning the differences in flexure between the 6-in. guider and the 24-in. telescopes which effectively limit the exposure time of direct photographs taken at the corrector–reflector focus.

W. W. Deane has re-examined some objective-prism plates taken in Hα some years ago by C. K. Seyfert and has discovered five new emission objects previously unrecognized in other emission star surveys. A note is in preparation.

Plans and drawings are now on hand for additional office and work space in anticipation of construction in the near future.

Visiting Investigators. The past year saw the growth of a cooperative program with colleagues of other institutions and their graduate students. Observing time was offered to a limited extent, commensurate with our own activities, to help alleviate the general shortage of telescope facilities now being widely felt.

R. C. Barnes, a graduate student in astronomy at Indiana University, spent considerable time working with Hardie on the analysis of three-color photometry of the eclipsing binary CM Lacertae. The work is now complete and is being prepared for publication.

D. Weedman, a graduate student in astronomy at the University of Wisconsin, observed during two sessions using a narrow-band interference filter to photograph certain globular clusters in a search for planetary nebulae. While the search was successful, the results were negative; these will be published elsewhere.

E. Milone, a graduate student in astronomy at Yale University, during an observing session attempted photoelectric photometry of certain eclipsing binaries but had almost consistently poor sky conditions.

S. Demers, a graduate student in astronomy at the University of Toronto, carried out a photoelectric study of W Virginis stars, and secured a large body of useful data. The results are to be published elsewhere.

C. Dahn, a graduate student in astronomy at the Case Institute of Technology, spent a brief observing period evaluating techniques for a nebula-scanning study prior to observing sessions at Kitt Peak Observatory.

A. U. Landolt of Louisiana State University observed during several sessions securing Cassegrain and corrector–reflector plates of several regions in connection with studies of T Tauri variable stars.

Miscellaneous. The public and school children's visiting programs were continued with a total attendance of about 1500 visitors. Visiting astronomers were J. C. Brandt of the Institute for Space Studies in New York, O. Franz of the Lowell Observatory, A. Landolt of Louisiana State University, J. L. Locke formerly of the Dominion Observatory, G. W. Preston of Lick Observatory, V. C. Reddish of the Royal Edinburgh Observatory, L. W. Schroeder and R. Jenks of Oklahoma State University, and C. R. Tolbert of the Kapteyn Astronomical Laboratory.

Heiser continued in the Visiting Scientist Program of the Tennessee Academy of Sciences and participated in the NSF Visiting Professor Program. He attended a meeting of the Southeast Section of the APS held in Charlottesville, where he contributed a paper. He gave a colloquium and conferred with colleagues at King College.

Hardie served on the ONR Astronomy Advisory Committee, and as a Director-at-Large of AURA Inc. He contributed papers to and attended the AAS meeting in Ann Arbor, the Symposium on Ap and Am stars held at the Goddard Space Flight Center, and the first ESO Colloquium on Photometry held near Groningen, the Netherlands.

Acknowledgments. The Dyer Observatory gratefully acknowledges a gift from the estate of the late Wesley Halliburton, who had been the last surviving member of the Vanderbilt Engineering Class of 1892, and a lifelong friend of his classmate, the late Arthur J. Dyer.

The continuing support of the Vanderbilt Natural Science Research Committee and the National Science Foundation is gratefully recognized.

Publications.

A. J. Dyer Reprint No. 34. "An Upper Limit for the Diameter of Pluto," by I. Halliday, R. H. Hardie, O. G. Franz, and J. B. Priser, *Publ. Astron. Soc. Pacific* **78**, 113, 1966.

A. J. Dyer Reprint No. 35. "*U, B, V* Photometry of the Lowell Proper Motion Object G175–34," by R. H. Hardie and A. M. Heiser, *Publ. Astron. Soc. Pacific* **78**, 171, 1966.

Unnumbered abstracts.

"*U, B, V* Photographic Photometry of Five Galactic Clusters," by A. Heiser and R. Hardie, *Bull. Am. Phys. Soc.* **11**, 520, 1966.

In press.

A. J. Dyer Reprint No. 36. "Three-Color Photometry of DQ Cephei," by L. Schroeder, R. Jenks, and A. Heiser, *Astrophys. J.* **146**, Dec. 1966.

R. H. HARDIE, *Director*

University of Florida Observatory, University of Florida, Gainesville, Florida

Personnel. The Observatory staff consisted of Dr. Alex G. Smith, professor of physics and astronomy, Dr. T. D. Carr, associate professor of physics and astronomy, C. N. Olsson, assistant professor of physical sciences and astronomy, Dr. G. R. Lebo and Dr. K–Y. Chen, assistant professors of astronomy, W. W. Richardson, technical aide, R. J. Leacock, administrative assistant, W. B. Greenman, V. M. Robinson and R. S. Flagg, electronics engineers, and Betty Keyser, secretary. G. W. Brown, R. B. Carr, F. F. Donivan, F. A. Herrero, D. J. Kennedy, J. May, W. A. Morton, M. P. Paul, D. A. Rekenthaler, I. Shever, J. G. Simmons, D. L. Smoleny and C. F. Tiberi were employed as graduate research assistants. A. R. Dakan, P. S. Marks, D. K. McDuffie, D. R. McGinnes, J. E. Moeller, R. W. Palmer, G. R. Shipman, R. K. Sisler, J. D. Teller, D. E. Warrensford and J. M. Winder served as undergraduate assistants. C. Thomas, M. Hubbard and J. Stepp took part in the work of the Observatory under the National Science Foundation Summer Research Participation Program for Secondary School Students.

Southern hemisphere radio observations at Maipu, Chile, were conducted by Heins Bollhagen, Jorge May, and Jorge Levy, while the Huanta, Chile, radio station was run by Vladimir Papic, both with the administrative assistance of Sr. Claudio Anguita, Director of the National Observatory of Chile. These stations are operated in cooperation with the University of Chile, under grants from the National Science Foundation and the National Aeronautics and Space Administration. During part of the year Dr. Smith served as Acting Director of the Cerro Tololo Interamerican Observatory in Chile.

Instrumentation. Site testing for a new location for the Florida radio installations was conducted throughout most of the year, and negotiations are now under way for a 60-acre tract in Dixie County, some 50 miles west of Gainesville. This area is remote and unlikely to be encroached upon within the next 10 yr. A 30-in. Cassegrainian–Newtonian optical telescope is under construction at Tinsley Laboratories, with delivery expected in early 1967. Site testing for this instrument is currently under way in the vicinity of Gainesville. Both of these new facilities were made possible through a $4.2 million NSF Science Development Grant.

Scientific Program. The radio staff has continued its program of monitoring the long-wavelength emission of the planets, with primary emphasis on Jupiter. Observations of the 1965 apparition began on 1 July and were continued until 8 June 1966. The Observatory's Jupiter records now span a decade, with all of the data, together with pertinent solar, geophysical and satellite parameters, being available in punch-card form for machine analysis.

As a result of combining the decametric data with 430 Mc/sec data obtained with the 1000-ft radio telescope at Arecibo, Carr and Gulkis have concluded that all of the observations can be approximated by a uniform rotational period for Jupiter's magnetic field, together with a 12-yr modulation of the decametric period caused by the varying zenocentric latitude of the earth. Using a much larger body of data, Olsson and Smith have confirmed the original conclusion that the apparent change in the decametric period decreases as the

observing frequency is increased in the range 15–28 Mc/sec. They have also shown that the occasional millisecond or "spitting" pulses found in the Jovian signals show a significant correlation with System III longitude, tending to concentrate in the vicinity of the B source. This result suggests that the pulses are formed in the neighborhood of the planet, or that the source characteristics are such as to produce a sharply different type of interplanetary scintillation. Analysis of the data obtained from the Huanta station in the Andes shows that near the middle of the apparition 18 Mc/sec radiation was received 80% of the time when the primary source A was near Jupiter's central meridian, suggesting that the emission may have been quasi-continuous. The probability of detection at Huanta was double that at Maipu and Gainesville, emphasizing the caution that must be exercised in interpreting statistics from less ideal sites.

During the year the eclipsing binaries VV Orionis, 44i Bootis, Beta Persei, and SX Cassiopeiae were observed by Chen, R. Carr, and Rekenthaler with the $12\frac{1}{2}$ in. optical telescope at the Gainesville Observatory. In April and May of 1966, Chen spent 20 nights at the Cerro Tololo Interamerican Observatory in Chile, obtaining complete light curves for the binaries BV 513, BV 419, and variable HD 116994. Reduction of these data is currently under way.

It is a pleasure to acknowledge the assistance of the Office of Naval Research, the National Science Foundation, the Army Research Office (Durham), and the National Aeronautics and Space Administration in supporting the work of the Observatory.

Publications of the Observatory staff during the year included:

"Results of Recent Investigations of Jupiter's Decametric Radiation," T. D. Carr, S. Gulkis, A. G. Smith, J. May, G. R. Lebo, D. J. Kennedy, and H. Bollhagen, *Radio Sci.* **69D**, 1530–1536, 1965.

Radioastronomi, A. G. Smith and T. D. Carr (Bokförlaget Aldus/Bonniers, Stockholm, 1965) [Swedish translation of *Radio Exploration of the Planetary System* (D. Van Nostrand Company, Princeton, New Jersey, 1964)].

"Asymmetrical Stop Zones in Jupiter's Exosphere," S. Gulkis and T. D. Carr, *Nature* **210**, 1104–1105, 1966.

"Decametric Radio Pulses from Jupiter: Characteristics," C. N. Olsson and A. G. Smith, *Science* **153**, 289–290, 1966.

"Jovian Rotation Periods and the Origin of the Decametric Burst Structure," A. G. Smith, G. R. Lebo, C. N. Olsson, W. F. Block, N. F. Six, and T. D. Carr, *Proceedings of Caltech-JPL Lunar and Planetary Conference*, California Institute of Technology, 1966, pp. 128–133.

"Photoelectric Observation of HD 116994," K-Y. Chen, Commission 27 of the IAU *Information Bulletin on Variable Stars*, No. 142, 27 June 1966.

"Photoelectric Photometry of 44i Bootis," K-Y. Chen and D. A. Rekenthaler, *Quart. J. Fla. Acad. Sci.* **29**, 1–12, 1966.

"Infrared Photometry of Beta Persei," K-Y. Chen and E. G. Reuning, *Astron. J.* **71**, 283–296, 1966.

"Influence of the Terrestrial Environment on the Temporal and Statistical Characteristics of Jovian Decametric Radiations," A. G. Smith, W. F. Block, W. A. Morton, G. R. Lebo, T. D. Carr, and C. N. Olsson, *Radio Sci.* (to be published October 1966).

Radio Exploration of the Sun, A. G. Smith, a text written for the Commission on College Physics (D. Van Nostrand Company, Princeton, New Jersey, to be published 1966).

"Morphology of Jupiter's Decametric Radio Sources," A. G. Smith, G. R. Lebo, and T. D. Carr, *Magnetism and the Cosmos*, S. K. Runcorn, Ed. (Oliver and Boyd, Edinburgh, to be published 1966).

"Jupiter," A. G. Smith, *McGraw-Hill Yearbook of Science and Technology for 1967* (McGraw-Hill Book Company, Inc., New York, to be published).

ALEX G. SMITH, *Director*

Four College Observatory: Amherst College, Amherst, Massachusetts; Mount Holyoke College, South Hadley, Massachusetts; Smith College, Northampton, Massachusetts; University of Massachusetts, Amherst, Massachusetts.

Personnel. During the year 1965–66, the professional staff of the Four College Astronomy Department consisted of Professor Albert P. Linnell, Associate Professor Robert H. Koch, Assistant Professors Stanley Sobieski and Frank Stienon, Instructor Stephen Adler, and Research Associate Thomas Arny. Dr. Robert L. Gluckstern (Chairman of the Physics Department at the University of Massachusetts) served as Acting Chairman of the Department.

At the close of the academic year Dr. Linnell resigned to accept a position as Chairman of the Astronomy Department at Michigan State University. Dr. Koch resigned to accept a position at the University of New Mexico, and Dr. Sobieski

resigned to accept a position at the NASA–Goddard Space Flight Center.

Effective 1 September 1966, Dr. William M. Irvine (formerly of the Harvard–Smithsonian Observatories) has accepted a position as Associate Professor at the University of Massachusetts and Chairman of the Four College Astronomy Department. E. R. Harrison (formerly of the Rutherford High Energy Laboratory) has accepted a position as Professor of Astronomy at the University of Massachusetts. Dr. Arny has been promoted to Assistant Professor and his appointment has been transferred to the University of Massachusetts.

Research. Linnell completed a series of papers on computer calculation of eclipse functions. A computer program using these routines was written which permits a point by point comparison of observed light curves and calculated light values for spherical stars moving in circular orbits, without reflection effects. An analysis of the metallic-line binary RR Lyncis was completed. Observations were made at the Kitt Peak National Observatory of the eclipsing binary VV Ori.

Koch pursued the analyses of observations of BH Vir and U Oph and continues as coordinator of the SX Cas campaign for Commission 42 of the IAU.

Sobieski worked on the Rossiter effect on eclipsing binaries.

Stienon is continuing his analysis of absorbtion line profiles in early-type stars. These spectra are compared with line strengths predicted by model stellar atmospheres using the hydrogen lines as indicators of surface gravity.

Adler has been studying the structure of sunspots and changes in their structure at the time of solar flares, using both visual and photographic observations.

Arny is continuing his study of the growth of density perturbations in rotating, collapsing gas clouds with density gradients. Thermal instabilities in such clouds are also being studied. This research is designed to elucidate the process of star formation.

The following papers have been published or are in press:

Koch, R. H. 1965, "On the Rotation of Spectroscopically–Invisible Binary Components, *Astron. J.* **70,** 681 (Abstract).

Linnell, A. P. 1965, "The Calculation of Direct Eclipse Functions, II," *Astrophys. J. Suppl.* **12,** 288.

——. "The Calculation of Direct Eclipse Functions, III, IV, and V," *ibid.* (to be published).

——. "*UBV* Photometry of RR Lyncis." *Astron. J.* **71** (to be published).

Sobieski, S. 1965, "The Monochromatic Reflection Effect. Part I: Phase Laws for Algol-Type Binaries; Part II: The Monochromatic Reflection Coefficient," *Astron. J. Suppl.* **12,** 263.

—— (with S. Cristaldi, M. G. Fracastoro, and T. Saitta). "Photoelectric Observations and Elements of Algol at λ6560," *Mem. Soc. Astron. Ital.* (to be published).

Arny presented a paper at the 14th International Astrophysical Symposium at Liege in June of 1966.

Instruction. There were 22 astronomy majors in the Four College Department.

There were 13 Four College Astronomy Department Colloquia and 9 Joint Physics–Astronomy Colloquia. Speakers included: Dr. Helen S. Hogg, Dr. John D. Landstreet, Dr. E. M. Burbidge, Dr. Thornton Page, Dr. Thomas Arny, Dr. Stephen E. Strom, Dr. A. G. W. Cameron, Dr. Jack Goldstein, Dr. E. R. Harrison, Dr. William Irvine, Dr. A. Ollongren, Dr. Peter Roll, and Dr. Malvin Ruderman.

The Department held seven Open Houses during the academic year, as well as several private tours for special groups.

WILLIAM M. IRVINE, *Chairman*

Goethe Link Observatory, Indiana University, Bloomington, Indiana

Personnel. Dr. Goethe Link (Honorary Director), Professors Robert d'E. Atkinson, Frank K. Edmondson (Director and Chairman), and Marshal H. Wrubel; Associate Professors James Cuffey (Assistant Director) and Hollis R. Johnson (Acting Chairman, 2 Feb.–16 March); and Assistant Professors Martin S. Burkhead and Benjamin F. Peery, Jr., comprised the resident academic staff. Dr. Samuel C. Vila continued as Research Associate.

Cuffey submitted his resignation in order to accept an appointment as Professor of Astronomy at the New Mexico State University at Las Cruces effective 1 September 1966.

Wrubel was awarded a senior professorial title, University Professor of Astronomy, effective 1 July 1966.

Mrs. Beryl H. Potter and Mrs. Delores J. Owings continued as full-time Research Assistants. Mrs. Potter retired on 30 June 1966. She had done all of the blinking and most of the measuring of asteroid positions ever since the program was started in 1949.

Mrs. Sandra S. Butler and Mrs. Sherry Sterrett

served as secretaries. Mrs. Sterrett was succeeded by Mrs. Barbara J. Randall 1 January–30 April 1966. Mrs. Lorraine Dolynchuk has served since 1 May 1966. Additional secretarial services were performed by Mrs. Kathleen Kennerson.

The following students were part-time Teaching and Research Assistants: Galen Ross Barnes, Stephen H. Butler, Edward Churchwell, Howard Cohen, H. Melvin Dyck, Theodore Faÿ, John D. Fix, Allen S. Grossman, Paul J. Guyer, Bernard V. Jackson, Charles Keller, Daniel Klinglesmith, Irene R. Marenin, George Marshall, Terry J. Mears, Joseph E. Michlovic, Arthur Poland, Donald V. Pytko, Michael Seeds, Heywood Sobel, Gerry R. Thrasher, John T. Vollertsen, Arthur Young (Indianapolis), and Hong Sik Yun.

Warren Sparks held a Link Fellowship for the first semester and a Zaccheus Daniel Fellowship for the second semester. Douglas S. Hall, and James G. Peters continued to hold NSF Cooperative Fellowships, and Carolyn J. Murphy held a Graduate School Fellowship. Ronnie C. Barnes, Herbert A. Beebe, Reta F. Beebe, James B. DeVeny, Sue Ann Hagerman, John W. Hutson, William J. Kaufmann, and Robert W. Milkey held NASA Traineeships. Thomas E. Morgan held an NSF Traineeship.

Equipment. The 36-in. reflector of the Goethe Link Observatory was dismantled in March and taken to Austin, Texas, for refurbishment and modernization by Astro-Mechanics, Inc. A new tube and mirror supports will be provided, and the optical system will be changed from $f/5$ Newtonian to $f/10$ Cassegrain. The telescope should be back in operation by the end of October.

A new site has been developed in the Morgan–Monroe State Forest north of Bloomington. This was necessary to get a darker sky for photometry, because the sky brightness at the Goethe Link Observatory has been increasing due to the growth of Indianapolis and installation of mercury-vapor lamps at many farms and country homes near the Observatory. A Boller and Chivens 16-in. reflector was installed at this site and put into scheduled operation on 15 April 1966. The planning and installation was supervised by Burkhead.

The Board of Trustees of Indiana University has named the new site *The Morgan-Monroe Station of the Goethe Link Observatory.*

Research. Atkinson's two papers on relativity, mentioned in last year's report, were published in the *Astronomical Journal*, October 1965. Another paper, "Pivot Errors and Axis Flexure in the Seven-inch Cooke Transit Circle" appeared as *Royal Observatory Bulletin* No. 109, 1966. A paper on "A New Method for Obtaining the True Orbit of a Visual Binary" has been accepted for publication by the *Publications of the Astronomical Society of the Pacific.* Investigations on several problems in fundamental astronomy are in progress.

Burkhead has started to collect photographic and photoelectric data for the following clusters: NGC 2506, NGC 6939, and NGC 2141. He had observing periods at the McDonald Observatory in January and June, both with unfavorable weather conditions.

Cuffey published two articles: "A Photometric Atlas of Messier 53," *Astronomical Journal*, November 1965, and "Colors of Stars in the Nucleus of Messier 53", *Astronomical Journal*, April 1966. A third article, "Light Curves of Three New Variables in Messier 53" is scheduled to appear in the *Astronomical Journal*, August 1966. He has continued work on light curves of variable stars in M53 and M38.

Johnson was co-author with L. W. Fredrick and T. D. Faÿ of a paper entitled "Infrared Stellar Spectroscopy with a Mica–Window Tube" in *Advances in Electronics and Electron Physics* **22,** 1966 (Academic Press Inc., New York, 1966). He and his students are continuing their work on several projects related to stellar atmospheres, line formation, and stellar spectroscopy.

Peery's paper "Spectroscopic Observations of VV Cephei" appeared in the *Astrophysical Journal*, May 1966. Further observations are needed before the work on ZrO bands can be completed. He has also been reducing spectrograms of the peculiar Be star π Aquarii taken with the Link spectrograph, in order to follow up a suggestion made by Sahade.

Wrubel published two papers: "Studies of Stellar Rotation. II. The Effect of Rotation on Colors and Magnitudes of A- and F-Type Stars in the Hyades" (with R. P. Kraft), *Astrophysical Journal*, August 1965. "Transport of *s*-Process Elements to the Surfaces of Stars" (with Vern Peterson) in *Stellar Evolution*, Stein and Cameron, Eds. (Plenum Press, New York). His students worked on such problems as: the *s* process as it might take place in a star of nine solar masses during its evolution, the effect of rotation on the colors of stars in clusters, the evolution of stars of low mass, sunspot models, the evolution of close binaries, and Cepheid pulsations.

Vila extended his studies of pre-white dwarf evolution, taking into account the effects of neutrino energy loss. Papers on these results were read at the Ann Arbor, Michigan, and Hampton, Virginia, AAS meetings, and the first paper on this work has been accepted for publication in the *Astrophysical Journal.*

Positions and magnitudes of 450 asteroids were published in nine issues of the *Minor Planet Circulars.* Four hundred sixty-nine additional posi-

tions were completed by Mrs. Potter, but have not yet appeared in the *Minor Planet Circulars*. Absolute magnitudes of 1243 asteroids, measured by Mrs. Owings were published in 18 issues in the *Minor Planet Circulars*.

Teaching. Enrollment in the elementary course was 351 during the first semester and 271 during the second, an increase of 93 and 52 over the previous year. Summer Session enrollment was 77 in A100 (Solar System) and 18 in A105 (Stellar Astronomy). Closed-circuit TV was used to transmit the class to Purdue for the third year and to the Indianapolis Regional Campus for the second year. Edmondson made nine video-tapes in January to take care of the lectures he missed while in Chile during February and March.

Advanced courses given during the regular academic year include: General Astronomy (for majors), Astronomical Photography, Modern Observational Techniques, Spherical Astronomy, Astrometry and Least Squares, Introductory Astrophysics, Astronomical Spectroscopy, Binary Stars, Planetary Physics, Stellar Interiors, Interstellar Matter, Advanced Astronomical Spectroscopy, Stellar Atmospheres, and Galactic Structure.

Catherine Doremus received the first B.S. in Astrophysics, William J. Delaney and Joseph E. Michlovic received the A.B. degree in Astronomy. Katherine Bracher and Willet Beavers received the Ph.D. degree in Astronomy and Astrophysics, respectively.

Miscellaneous. The Planetarium continued to be used primarily as a teaching aid. However, Dyck gave special lectures to outside groups by appointment with a total attendance of approximately 1200 persons.

Three Public Nights were held at the Goethe Link Observatory with lectures by James G. Peters, Theodore Fay, and Douglas S. Hall. The Kirkwood Observatory was open to the public on clear Wednesday evenings.

Cuffey gave lectures to five different school groups, ranging from 5th grade through high school. Johnson gave talks to two different grade school classes, and served as Merit Badge Counsellor for Astronomy in the local Boy Scouts of America Organization. He also served as a Science Fair Judge. Edmondson and Peery gave lectures to the Astro-Sciences Workshop at the Adler Planetarium. Perry and Wrubel continued their participation in the AAS–NSF Visiting Professors Program. Several faculty members gave Colloquia at neighboring universities.

Edmondson served as Chairman of the Chile Committee of the AURA Board of Directors. Following the resignation of Dr. Jurgen Stock, he served as Acting Director of the Cerro Tololo Inter-American Observatory during the period 2 February–16 March. He is a member of the Visiting Committee for the Astronomy Department of the Case Institute of Technology, and was an invited participant at the IAU Symposium "Determination of Radial Velocities and their Applications," University of Toronto, 20–24 June. He was re-elected Treasurer of the American Astronomical Society for the 5th three-year term.

Johnson served as a member and secretary of the Working Group on Solar Astronomy of the Space Science Summer Study directed by the National Academy of Sciences at Woods Hole, Massachusetts, June–July, 1965. He has been appointed a member of the Astronomy Advisory Sub-Committee of the Space Science Steering Committee of the National Aeronautics and Space Administration for the year beginning 1 July 1966.

Peery and Edmondson attended the Otto Struve Memorial Symposium and dedication, May 1966.

Wrubel was elected Chairman of the Advisory Panel for Astronomy, National Science Foundation. He is a member of the AAS Council, Chairman of the Publications Committee of the AAS, a member of the Astrophysical Journal Editorial Board, a member of the Journal of Computational Physics Editorial Board, and a Consultant to the Los Alamos Scientific Laboratory.

Visiting Colloquium speakers included: Sterling A. Colgate, Fred T. Haddock, Robert Hardie, Paul Herget, Robert Leighton, Sir Bernard Lovell, Gordon J. F. MacDonald, G. C. McVittie, Thomas Mullikan, Nancy Roman, and Richard Tousey.

Other visitors included: Donald D. Clayton, Arnie Heister, Arlo Landolt, Edward C. Olson, and Tadao Takenouchi.

FRANK K. EDMONDSON, *Director*

Harvard College Observatory, Cambridge, Massachusetts

PERSONNEL

Professors L. Goldberg, M. Krook, D. Layzer, W. Liller, A. E. Lilley, D. H. Menzel, C. Payne-Gaposchkin, F. L. Whipple, and C. A. Whitney served as the Harvard College Observatory Council.

A change of administration occurred on 1 April 1966, with the resignation of Donald H. Menzel as Director of the Observatory and the appointment of Leo Goldberg as his successor. Menzel had served as Acting Director in 1952–54, following the retirement of Professor Harlow Shapley, and had been

Director since 1954. He continues his research and teaching programs.

Dr. C. C. Lin was at the Observatory as Honorary Research Associate from October 1965 to the close of the academic year. Dr. W. W. Salisbury became a Research Fellow in January 1966. Appointments as Research Fellow went to Dr. M. H. Liller in October 1965, and to Dr. P. D. Usher in March 1966. Dr. S. Gaposchkin retired as Astronomer at the start of the academic year, but continued working as a Special Scientist. Dr. E. Constantinides resigned as Research Fellow in September 1965.

EQUIPMENT

W. Liller completed the construction of a two-channel photoelectric spectrophotometer which is now in operation at the Cassegrain focus of the 61-in. telescope at Agassiz Station. While one photomultiplier monitors the sky transparency and seeing by measuring the intensity of the zero-order image from a concave diffraction grating, a second photomultiplier scans the spectrum with a pass-band usually several tenths of an angstrom wide. With this instrument, Dr. S. Strom, D. Peterson, and T. Simon are obtaining absorption line profiles to test various model atmospheres. Liller is continuing his work on the K-line emission component.

Because of the increasing interest in the determination of precise line profiles, Liller, with engineering assistance from N. L. Hazen, has started a preliminary design for a coudé spectrograph and spectrophotometer for the 61-in. reflector. Tests are in progress to evaluate the suitability of modern echelle gratings for stellar spectroscopy.

Under the Damon patrol program a system has been set up for quality control of the size of the stellar images, which are measured with a Mann precision measuring engine. The three cameras—blue, yellow, and red—at Agassiz Station are operational; the yellow camera has started taking plates for the NSF-sponsored sky patrol and atlas. Emulsion-filter combinations are: blue, IIa-O and GG-13; yellow, 103a-G and GG-11; red, 103a-E and RG-2. The exposure time is 3 h for the yellow plates; it has not yet been set for the blue and red.

A 16-in. Cassegrain telescope, $f/18$, with quartz mirrors, is on order for Agassiz Station, to be used mainly for instruction.

Tests were conducted on the use of an ITT FW-109A (one-stage) image converter (S_1 response) in the laboratory and at the 12-in. refractor at Agassiz Station. In the laboratory the resolution was measured as 20 line pairs/mm for paraxial rays. The tube has been tested at dry ice temperatures for thermal emission. A cryostat for liquid nitrogen for image converters is being designed. A commercial cryostat and an RCA 7102 photomultiplier (S_1 response) were used to reduce the dark current by a factor of 5×10^6. A similar reduction in the background of the image converter is expected. The cooled image converter will be mounted at the Newtonian focus of the 61-in. for stellar and planetary photography with shortened exposure times.

Several new facilities were added to the laboratories of the solar satellite project this year, most notably a "laminar-flow" clean room and "laminar-flow" assembly benches.

In mid-June the shock-tube spectroscopy laboratory received a new microdensitometer, built by the David W. Mann Company, to be used in conjunction with the present microdensitometer and digitized data-handling system.

A copper-doped germanium detector operating at the temperature of liquid helium was purchased and tested in the infrared project laboratory. The measured NEI was 4.5×10^{-2} W/cps bandpass, and the peak sensitivity is at 23 μ.

At Sacramento Peak, New Mexico, two instruments were added to the 12-ft equatorial spar for use by Harvard patrol personnel. The first, a completely new telescope, employs four separately guided 8-in. mirrors with an 0.5-Å birefringent filter to provide large-scale simultaneous viewing of four chromospheric regions. It gives a 1-in. image on 16-mm film. The telescope was designed primarily for use with a closed-circuit television unit, but a beam-splitting device will allow it to be used photographically also with a 16-mm Acme camera. The second instrument is an improved version of the system used to project a 20-cm white-light image of the sun, from which sunspots are daily drawn and counted to supplement the 6-in. white-light photographic patrol.

At the Radio Astronomy Station in Fort Davis, Texas, a new receiver covering the band 10–25 Mc/sec is being put into operation with the existing equipment. It is planned to increase the radio coverage of the sun to higher frequencies within the next year, if possible up to 2 Gc/sec. A temperature-controlled electronics room, $6\times6\times7$ ft, capable of holding six full racks of equipment, has been installed at the focus of the 85-ft antenna.

RESEARCH

Variable Stars. An investigation of the variable stars in the Large Magellanic Cloud, under the direction of Payne-Gaposchkin and the sponsorship of the NSF, will lead to photographic and visual magnitudes for some 2000 variables on 550 plates

by methods developed in the previously completed study of the variable stars in the Small Cloud.

Stellar Spectra. While at The Observatories, Cambridge University, England, during the 14 months ending in August 1965, W. Liller used the three-channel photoelectric spectrophotometer mounted at the coudé focus of the Cambridge 36-in. reflector to monitor the size and shape of the emission component of the *K* line in 10 stars for a period of 12 months. With the same apparatus, M. and W. Liller measured the central intensity of the λ6362 auto-ionization feature of Ca I in 50 stars, and compared the measurements with theoretical predictions.

The Lillers completed the reduction and interpretation of spectral scans of the spectral energy distribution of Zeta Aurigae made with the Agassiz 61-in. reflector in January 1964. In October 1965, W. Liller secured 173 direct photographs of selected planetary nebulae with the 60- and 100-in. reflectors of Mount Wilson Observatory. Both Lillers are now measuring the positions of the edges, filaments, and other features on these plates and on plates taken with the same telescopes early in the century, to determine what angular expansions have occurred in the intervening years. This work, supported by the NSF since June 1966, will extend their earlier studies based on lower scale Crossley plates.

Planetary, Galactic, and Extragalactic Radio Astronomy. The research programs in planetary, galactic, and extragalactic radio astronomy at the Harvard Radio Astronomy Station, Fort Davis, Texas, continued under the supervision of Dr. A. Maxwell, with support from the NSF. A parametric receiver, operating at 5.00 Gc/sec, has been used with the 85-ft paraboloid antenna to measure flux densities from 31 discrete radio sources of angular dimensions less than 5 arc min. Maxwell and R. Rinehart compared these data with other observations in the microwave band and reviewed the spectral indices of the sources. M. P. Hughes obtained radiometric measurements of the planets with the same equipment during the period November 1965–March 1966, and determined disk temperatures for Venus, Mars, Jupiter, and Saturn. D. Downes and Rinehart completed a survey of Cygnus X, a conglomeration of H II regions near the galactic plane.

J. H. Taylor used the 85-ft antenna with a receiver at 0.95 Gc/sec to observe the occultations of radio sources CTA 21, 3C17, 3C132, 3C444, and the Crab Nebula. He determined the position of the source CTA 21 to 1 arc sec, derived positions to within 8 arc sec and some limited structural information for 3C17 and 3C132, and constructed two-dimensional contour maps for 3C444 and the Crab Nebula.

The restoration methods, used by radio astronomers to handle data on radio sources obtained by the method of lunar occultation, have been applied to analyze occultation observations of the optical star Antares. Taylor's analysis of observations made in South Africa in the early 1950's indicates that the star consists of a bright central component about 0.019 arc sec in radius, surrounded by an outer shell extending to about 0.028 arc sec in radius.

Downes, Maxwell, and Dr. M. L. Meeks made a series of observations of the galactic center region at 8 and 15.5 Gc/sec, with the 120-ft antenna at MIT Lincoln Laboratory, during the summer of 1965. Downes and Maxwell have reviewed the over-all problem of radio emission from the region of the galactic center, dealing in particular with the complicated spectrum of the radio source Sagittarius A, which is at present identified with the galactic nucleus.

The radio astronomy group at the Agassiz Station, under the direction of Lilley, continued research on interstellar spectral lines. OH emission at 1665 and 1667 Mc/sec from the source W-49 (3C398) was observed with the 60-ft telescope at 3 kc (0.54 km/sec) resolution; a number of narrow features were obtained over the range of 0 km/sec to +21 km/sec. Using the 140-ft radio telescope at the National Radio Astronomy Observatory, P. Palmer, a graduate student working jointly with the departments of Physics and Astronomy at Harvard, and B. Zuckerman, a graduate student in the Department of Astronomy, observed the sources W-49, Orion, W-75, and the galactic center at each of the four OH transitions. Their observations, made with both linearly and circularly polarized feeds, clearly show the predominantly circular polarization character of the OH emission at 1612, 1665, 1667, and 1720 Mc/sec.

The initial detection of recombination lines of interstellar hydrogen at 18 and 21 cm was achieved by the Agassiz Station group, and the galactic H II regions W-51 and M17 (W-38) were studied in detail at the transitions $n_{160}-n_{159}$ (1620.672 Mc/sec), $n_{159}-n_{158}$ (1651.541 Mc/sec) and $n_{157}-n_{156}$ (1715.673 Mc/sec). In each instance that OH emission and recombination hydrogen lines have been observed in the same source, the velocities have coincided, indicating a close association between the OH emission region and the galactic H II region. The Agassiz Station 60-ft radio telescope with its 10-channel maser radiometer was also used to measure three of the recombination lines of interstellar helium. Antenna temperatures

of 0.02°K±0.01°K were obtained for the helium lines corresponding to $n_{160}-n_{159}$ (1621.332 Mc/sec), $n_{159}-n_{158}$ (1652.214 Mc/sec) and $n_{157}-n_{156}$ (1716.372 Mc/sec). Integration of the radiometer output data over periods of 10 to 20 h was necessary to obtain the required sensitivity of these measurements.

Menzel has been working to obtain an improved theory of hydrogen emission and radio wavelengths. In particular, new and simple expressions were developed for the intensities of the hydrogen lines of high series members. Further analysis will apply to the continuous background produced by bound–free and free–free emissions.

Scientists and engineers of the space radio project, which is sponsored by NASA and directed by Dr. G. R. Huguenin, prepared the instrumentation for an Astrobee 1500 rocket probe to make spectral observations of the cosmic noise background between 0.25 and 4 MHz. Launching of the rocket is scheduled for November 1966.

Preliminary feasibility tests of a high-directivity data-processing antenna system were undertaken at the project's Lancaster (Massachusetts) field site, and NASA is now sponsoring a more thorough ground feasibility test of the novel antenna system. If feasibility is demonstrated, this system could provide a steerable 10 arc deg pencil beam at 1–5 MHz on an Explorer-class satellite.

D. Wunsch, under the guidance of Dr. R. W. P. King, Dr. S. R. Seshadri, and Dr. Huguenin, has studied the behavior of linear electric antennas in a magneto-ionic medium. He has been able to derive the radiation resistance of an antenna of finite length and finite thickness at an arbitrary angle to the magnetic field over all important regions of plasma behavior. He also derived the radiation resistance of such an antenna in a warm plasma.

Huguenin initiated studies of models of the low-frequency spectra of discrete radio sources. C. J. Hughes, working with Huguenin, continued the evaluation of models of nonthermal radio emissions from the terrestrial exosphere.

Planets. Under the program of multicolor photometry of the brighter planets, sponsored by NASA and directed by Menzel and Dr. W. Irvine, observations were completed in December 1965. The results should extend present knowledge of phase curves, spectral reflectivities, and monochromatic albedos of the planets in the wavelength region 0.32–1.05 μ. Irvine continued his theoretical studies of light scattering and radiative transfer in planetary atmospheres, needed for interpretation of the observations. A study was made of the correction to the usual radiative transfer theory, required when the scattering centers are very large and densely packed.

Dr. C. Sagan and Dr. J. B. Pollack have investigated several aspects of the surface environment of Mars. With Dr. R. M. Goldstein they have analyzed the radar Doppler spectra of Mars, obtained at the Goldstone tracking facility of JPL, as a function of Martian longitude. The results bear on elevation differences on Mars, the surface pressures, and the planetary oblateness. They have devised a model of wind-blown dust, transported between the Martian bright and dark areas, which accounts quantitatively for the photometric and polarimetric properties of the Martian blue haze, and the seasonal and secular changes. The possibility that Martian seasonal changes have inorganic origins is not an argument against life on Mars. In a study of several thousand photographs of the earth by Tiros and Nimbus meteorological satellites, Sagan and colleagues have found that seasonal variations in terrestrial vegetation, and other signs of life on earth, are extremely difficult to detect.

Sagan has discussed solar proton irradiation of the surface of Mercury and, with Pollack, has analyzed Martian cratering statistics from Mariner IV and problems of radiative transfer in the atmosphere and clouds of Venus. Sagan and colleagues investigated, with an IBM 7094, the question of the chemical composition at thermodynamic equilibrium of the atmospheres of the earth, Mars, Venus, and Jupiter. The results bear on questions of the evolution of the Venus atmosphere, the source of the coloration of the Jovian clouds, and the origin of trace constituents of the earth's atmosphere.

Moon. Under the direction of H. C. Ingrao and Menzel, and the sponsorship of NASA, infrared observations of the moon continued, though on a reduced scale because of poor weather. The project therefore concentrated on the data processing aspects of the work. In association with the Harvard Computing Center, all the programs developed to reduce infrared measurements to brightness temperatures were integrated into one data-reduction package, LUNAR. From the raw data input card, the program will now produce: date, universal time, orthographic coordinates of the lunar area under measurement, air mass through which it was observed, hour angle and declination, elevation of the earth and sun for the given orthographic coordinates, earth azimuth from the sun, phase angle, scan number to identify the original record, amplitude of the infrared signal, and the lunar brightness temperature.

J. T. Holland and Ingrao studied the thermal response of the lunar surface at the landing site

during the descent of the Lunar Excursion Module (LEM) for eight assumed models of the surface. J. L. Linsky analyzed different models of the lunar surface including temperature-dependent thermal properties.

From a study of lunar photographs Menzel has suggested that, as the moon cooled, layers of foamy rock formed on its surface. Later the floating mass cracked, allowing hot lava to flow from the interior over the surface. He suggests this process may account for such formations as "ghost craters" and the general eroded nature of the lunar surface.

Whipple analyzed estimates of meteoritic impact rates and crater formation on the moon and showed that the larger craters fit expectations for large-body impact, whereas the small impact craters are less numerous than expected.

Salisbury has proposed a method of translunar communication by means of subsurface radio waves in the moon.

Comets and Meteors. D. Douglas-Hamilton and Whipple continued their investigation on the slow decay of brightness in periodic comets, particularly Comet Encke over the last 180 yr. Whipple has postulated that chondrules may have been produced by lightning in the primitive solar nebula before or during the formation of the asteroidal bodies producing meteorites. Under the direction of Salisbury, preparations are now being made to test this hypothesis in the laboratory.

Responsibility for operating the high-power radar system for meteor research at Havana, Illinois, was transferred to the Smithsonian Astrophysical Observatory as of January 1966.

Solar Studies. Menzel directed various aspects of solar research with continuing support from the Air Force Cambridge Research Laboratories. His investigation into the nature of sunspots and solar activity, begun previously in collaboration with Dr. B. Shore, continued to develop new information about complex sunspots. The ideas developed in these studies seem to have important applications to such other questions as the origin of spicules and the form of the solar corona, as well as to the atmospheric structure of magnetic stars.

Dr. B. Bell and R. J. Defouw furthered their investigation into the possible lunar modulation of geomagnetic activity, with analysis of the magnetic character figure C_i over the years 1884–1959.

The observers at Sacramento Peak, New Mexico, continued their intensive patrol of solar phenomena. Solar activity associated with the new cycle 20 increased during the year. From July 1964 through June 1965, some 400 flares were observed compared to 190 for the preceding year. The yellow coronal line at λ5694 was observed on 28 February and 1 March in association with the strongest green-line emission found to date in the new cycle.

Patrol personnel obtained observations of Comet Ikeya-Seki (1965*f*) in the light of the green coronal line λ5303 both before and after perihelion on 20 October 1965. Numerous coronal spectrograms were also taken.

At Fort Davis, Texas, observations of the sun with sweep-frequency equipment covering the band 25–320 Mc/sec continued under the supervision of Maxwell, with support from the Air Force. A marked upswing occurred in the number of radio bursts recorded during the first quarter of 1966, heralding the approach of the new sunspot maximum.

P. Cummings assembled a catalogue of high-energy solar particle events that occurred during 1957–61, for use in conjunction with existing Station catalogues of solar radio bursts of spectral types II and IV. The Station will take part in an international proton flare project, which will examine the characteristics of high-energy flares that may occur during the rise of the present cycle.

Solar Satellite Project. Scientists and engineers of the solar satellite project, which is sponsored by NASA and directed by Goldberg and Dr. E. M. Reeves and Dr. W. H. Parkinson, continued work on a number of rocket and satellite experiments to observe features of the far-ultraviolet solar spectrum. They carried out a design study for a photoelectric scanning Fastie–Ebert spectrometer that will register the solar spectrum in the region 1450–1950 Å with high photometric accuracy and with a resolution of approximately 0.05 Å, a considerable improvement over the 0.2 Å presently available from rocket spectrographs. The experiment will stress the determination of absolute energy fluxes for investigation of the temperature variation in the region of the solar temperature minimum. This first instrument is now being built; launching is expected early next year. A second instrument of similar type is under consideration, in which wavelength resolution will be modified to obtain center-to-limb scans in approximately 1 Å bands between 1450 and 1950 Å with high spatial resolution.

The Orbiting Solar Observatory (OSO) series of satellites provides the main facilities for observing the solar spectrum in the region 300–1300 Å, with a spatial resolution of 1.0 arc min for constructing spectroheliograms over a wide range of excitation energies. The OSO–D prototype, flight No. 1 and No. 2 spectrometers, were completed and integrated into the spacecraft in preparation for total observa-

tory tests. Design parameters for the next OSO experiment (OSO–G) have been established.

In March the Advanced Orbiting Solar Observatory (AOSO) was canceled for budgetary reasons, but some developmental studies in optics and engineering are continuing.

An optical ray-tracing study was completed for the Johnson–Onaka spectrometer employed in both the OSO and AOSO instruments. The mounting was studied for the case of a single entrance and exit slit, and the results compare favorably with those measured from the OSO–D instrument.

The Manned Apollo Spacecraft has provided an opportunity for experiments utilizing the ability of the astronauts to point and control the instrument in flight. Harvard instruments, including the modified AOSO and rocket spectrometers, are scheduled for inclusion on several of the manned missions.

The project began a study of the reflectivity of mirrors and gratings in the vacuum ultraviolet, 300–1600 Å. Goals include the qualification of replica mirrors and gratings for satellite use under thermal cycling conditions at ultra-high vacuum ($<10^{-9}$ Torr).

The project initiated a study with the North American Aviation Company in Downey, California, under contract with NASA, of the parameters required to establish the largest possible solar telescope in earth or stationary orbits for the period ca. 1980. This telescope will provide resolution of 0.1 arc sec from the far ultraviolet to infrared. A variety of instrumentation will be studied to achieve, as nearly as practicable, the versatility of a ground-based observatory.

Spectroscopy and Atomic Physics. Work in the shock-tube spectroscopy laboratory, directed by Parkinson and Reeves, is now being carried on with four fully instrumented and operating shock-tube light sources. Research continues to emphasize quantitative measurements of oscillator strengths and absorption coefficients, performed on normal atomic and molecular lines, auto-ionizing transitions, and ionization continua. The absorption spectra of indium and thallium vapor have been studied both in a shock tube and in a furnace by Parkinson and Reeves, in collaboration with Professor W. R. S. Garton, Imperial College, London.

G. Newsom examined calcium in a furnace, an arc, and a hollow cathode. He discovered seven new energy levels and measured the oscillator strengths and half-widths of seven auto-ionizing lines.

In addition to his work on CO, J. C. Rich measured the bound–free absorption coefficient of Si I in the laboratory. The identification and analysis of CO and the silicon continuum have increased our understanding of the solar spectrum, particularly around 1500 Å.

Dr. D. W. Weeks continued her work on the measurement of wavelengths and analysis of the iron spectrum. The observations revealed 21 new energy levels that classify some 209 lines.

Interferometric techniques were successfully applied to the shock-tube light sources. Dr. R. Day combined a Fabry–Perot interferometer and spectrometer to begin a detailed study of Stark and van der Waals broadening in silicon lines. Dr. M. Huber used the hook method, which combines a Mach–Zehnder interferometer and Littrow spectrograph, to measure f values of lines of neutral and ionized iron.

Theoretical Astrophysics. Whitney's work on the theory of radiative transfer and hydrodynamic motions in stellar atmospheres continued under Air Force sponsorship. Whitney developed a theory of the continuous optical spectrum emitted by pulsating variable stars. During the summer of 1965, Dr. R. Street and Dr. Y. Uchida visited the project and investigated the response of the solar atmosphere to forces impressed on it by the underlying convection zone. Dr. W. Kalkofen completed a study on radiative transfer in lines for media in statistical equilibrium, and extended his work on the calculation of line spectra without the restrictive assumption of local thermodynamic equilibrium. R. Stefanik investigated analytical and numerical approaches to the problem of the formation and propagation of shock waves in the atmospheres of pulsating stars. He developed a computer program employing the method of characteristics to investigate supersonic flow in a gravitational field. R. Kopp made a study of shock in the outer layers of stellar atmospheres, directed toward a description of the propagation and decay of a train of shocks traveling outward through the corona. He has obtained numerical solutions for a rather general total differential equation for the shock strength as a function of distance, which should allow quantitative comparison of the importance of several physical phenomena. Usher completed a study on the development of mathematical methods for the construction of stellar models.

Layzer directed the research of groups working on problems of atomic energy levels and transition probabilities, and on cosmogony and cosmology, both sponsored by the NSF. Dr. E. Godfredsen and Layzer collaborated on a detailed numerical study of the application of the variational screening theory, previously developed by Layzer, to the structure of complex atoms.

Dr. M. N. Lewis, in collaboration with Layzer,

continued her calculations of atomic properties for single states and of transition probabilities between states. Lewis and Dr. Z. Horak obtained the energy of the $2s2p^1\ P$ auto-ionizing state of helium by the Z-expansion method through the major contribution of the second-order terms.

Shore developed an approach to the theory of resonance attenuation from scattering theory, which he has applied to photon attenuation, with particular attention to auto-ionizing lines.

Goldberg carried out a number of theoretical investigations concerned with the astrophysical implications of auto-ionization, with the intensities of hydrogen recombination lines at radio frequencies, and with the interpretation of the solar spectrum.

J. Allen studied the effects of microturbulence upon Fraunhofer line profiles, by calculating profiles with an assumed turbulent velocity dependent on depth. The results support a model in which the microturbulence increases with depth in the atmosphere. He also calculated the coronal ionization equilibrium, including dielectronic recombination, for silicon and oxygen.

Mrs. A. Dupree is determining coronal abundances from the far-ultraviolet spectrum. She is also investigating the distribution of selected elements in the corona and in coronal condensations by considering the effects of the solar wind and diffusion processes.

Allen and Dupree used a Hartree–Fock approximation with configuration interaction to obtain oscillator strengths of transitions observed in the ultraviolet and others required for ionization equilibrium calculations.

Dr. G. Withbroe investigated the theoretical behavior of the solar auto-ionization doublet of Al I. His calculations, made with models containing a temperature minimum, indicate that the Al I auto-ionization lines may develop strong emission cores at the solar limb. He has interpreted with photospheric models the center-to-limb variation observed in solar C_2, CO, CN, and CH lines.

DEPARTMENT OF ASTRONOMY

On 30 June 1966, Liller completed his term as Chairman of the Department of Astronomy; Goldberg succeeds him. Enrollment comprised 28 undergraduate concentrators in astronomy, and 43 graduate students. Seven students received the A.B. degree in June 1966; six received M.A. degrees. The Ph.D. was awarded to three students: J. Dolan, W. Sacks, and P. Usher.

MISCELLANEOUS

For administrative reasons, Harvard College Observatory withdraws on 1 July 1966 as a participating member of the Boyden Observatory, with the Smithsonian Astrophysical Observatory replacing it as a member. Most of the Harvard equipment now at Boyden will be transferred to other members for continued use there.

A bibliography of Observatory reports and publications for the year July 1965 to June 1966 is available on request from the Librarian, Harvard College Observatory.

DONALD H. MENZEL, *Director*
(July 1965–March 1966)
LEO GOLDBERG, *Director*
(from 1 April 1966)

University of Illinois Observatory, Urbana, Illinois

Personnel. The permanent senior staff consisted of Drs. G. C. McVittie, S. P. Wyatt, K. M. Yoss, J. R. Dickel, E. C. Olson, J. B. Kaler, Mr. K. S. Yang, and of Dr. G. W. Swenson, Jr., who held quarter-time appointments in Astronomy and in Electrical Engineering. Dr. Swenson also held a half-time appointment at the National Radio Astronomy Observatory where he was engaged on the development of the very-large-array radio telescope. There were 15 graduate students registered for higher degrees in astronomy during the year.

New Facilities. Eighty-two acres of land were purchased near Oakland, Illinois, approximately 30 miles south of campus, for the new 40-in. reflector. The original request to the National Science Foundation for a 48-in. reflector and coudé spectrograph was changed to 40-in. and Cassegrain spectrograph. The spectrograph is to be a duplicate of the new instrument for the 84-in. reflector at Kitt Peak. The National Science Foundation awarded a grant in April 1966 for the full amount requested ($285 200). The Board of Trustees of the University of Illinois accepted the grant and authorized an equal sum for the project on 18 May 1966. Plans are also being developed for re-erecting the 4-in. Ross camera at the Oakland site by the fall of 1966 or early in 1967. The timetable for construction envisages the completion of the 40-in. telescope by the middle of April 1968.

Work on an eastward extension of the Observatory building in Urbana began on 13 January 1966 and the extension should be completed by December 1966. The office and laboratory space available to

the Astronomy Department will be doubled in size when the building is completed.

Long-range plans at the Vermilion River Observatory include the provision of up to three 120-ft parabolic dishes to be used with the parabolic cylinder radio telescope as a variable base-line interferometer. The Stanford Research Institute is studying for this project, the feasibility and the design of a 120-ft dish of limited declination and hour-angle coverage.

Research Activities. G. C. McVittie discovered a class of solutions of Einstein's equations of general relativity which had not been noticed before. They refer to spherical masses of gas that are either collapsing under their own gravitational attraction or, alternatively, are exploding after the manner of the spherical blasts of classical gas dynamics. The work was presented at the 14th International Symposium on Astrophysics, Liege, Belgium, in June 1966, and also in a lecture to the Institut Henri Poincare, Paris, France. McVittie also developed a theory of the meaning that can be attached to the terms "distance" and "velocity of recession" of a galaxy whose redshift is known. This was presented at a lecture to the Institut Henri Poincare in June 1966.

G. W. Swenson continued to supervise the compilation of the Vermilion River Observatory catalogue of radio sources. He also supervised the program of ionospheric research by means of radio signals from earth satellites. Swenson also carried out an observing program with the National Radio Astronomy Observatory's 140-ft and 300-ft radio telescopes. The first instrument was used to observe the Andromeda Galaxy at 6-cm wavelength; the second, to study the same object in the continuum at 21-cm wavelength. The data are in process of being reduced.

S. P. Wyatt continued his investigations on the production of gas and dust by comets, the dynamics of interplanetary particles, and the production and maintenance of the zodiacal cloud. In December 1965 he began the supervision of a Ph.D. thesis by Leo Standeford that is to be devoted to charging mechanisms of interplanetary grains, and to perturbative forces acting on these grains, with special reference to the effect of interplanetary magnetic fields. OGO–B, the second Orbiting Geophysical Observatory, was launched from Cape Kennedy in June 1966 and aboard was a gegenschein experiment designed to establish the nature of the feeble glow opposite the sun. Co-investigators on this project with Wyatt are Charles Wolff and Kenneth Hallam of Goddard Space Flight Center.

In summer 1965 Wyatt continued as Co-Director of the Elementary School Science Project of the University of Illinois, supported by the National Science Foundation. The summer of 1965 was the penultimate writing conference of the project. Four books were produced: *Gravitation* (4th ed.), *The Message of Starlight* (2nd ed.), *The Life Story of a Star* (1st ed.), and *Galaxies and the Universe* (1st ed.).

K. M. Yoss has used his digitized microphotometer to develop a procedure for automatic measurement of stellar radial velocities. A paper tape unit was attached to the digitizer, permitting continuous digitization of spectrographic data. This new equipment essentially replaced the "direct-intensity" unit previously in use, in the sense that conversion from transmission to direct intensity will be done with the electronic computer. The method was described in a paper read at the 119th meeting of the American Astronomical Society.

Most of the programs are now written and working for the reduction of the digitized data from the David Dunlap spectrographic plates (2000 spectrograms of 800 stars). From the digitized data, spectral types, luminosities, and CN strength will be obtained. Microphotometry of spectra of several hundred stars obtained with the 36-in. reflector at the Kitt Peak National Observatory and the 60-in. reflector at Mount Wilson Observatory is in progress. Most of these stars have accurate absolute magnitudes, and the results will be used to strengthen the calibration of the data used for determining absolute magnitudes of the Dunlap program stars.

Yoss obtained five nights at Mount Wilson Observatory on the 60-in. reflector for additional spectrographic observing in June 1965; two nights were made available on the 84-in. at Kitt Peak. The 36-in. spectrograph was used with the 84-in. for obtaining two spectrograms of two stars in the galactic cluster M92 (6-h exposures). These two Population II giants will also be used in the calibration of luminosity data; however, they are so underabundant in metals that they may not fit into the ordinary classification procedure.

A program for determination of abundances in late-type giants and subgiants has been started using moderate dispersion spectra obtained with the 100-in. reflector at Mount Wilson. The spectra are being processed with the digitized microphotometer, using the new paper tape unit. E. C. Olson also has used the paper tape unit in his binary star program.

This work is supported by National Science Foundation grant GP-4292; Thomas Lutz and Paul Lee (graduate students) and Charles Bolton (undergraduate) also worked on the project.

J. R. Dickel reports that the 610.5 MHz survey

of the sky with the Vermilion River Observatory radio telescope has been progressing well during the past year. The results of the 40–44° region of the sky have now been published and observations have been completed between the declinations of 15° and 22°. The reductions of the data for this section of the sky are nearing completion under the direction of J. R. Dickel and K. S. Yang. The program for digital recording and reduction of the data is being completed by H. R. Dickel, J. R. Dickel, and K. S. Yang. Three graduate students are also working on this project.

In addition, several interesting extended sources have been found within the area covered by the survey including M31, W51, the supernova remnants HB21, VRO42.05.01 and OA184. Contour maps have been made of some of these regions. Studies are in progress on the spectral index and emission distributions across these sources by J. R. Dickel and K. S. Yang. The program of regular monitoring of various quasars and standard sources for possible secular variation is continuing with negative results to date.

H. R. Dickel, assisted by J. R. Dickel, had 10 nights in July 1965 as a guest investigator using the photoelectric spectrophotometer on the 24-in. telescope at the University of Michigan. She obtained Balmer line and forbidden oxygen line intensities for M8, M16, M17, and M20.

J. R. Dickel spent three weeks at the National Radio Astronomy Observatory in February 1966, observing Venus and Jupiter at 6 cm with the 140-ft telescope and also M31 at 40 cm with the 300-ft.

J. B. Kaler received a grant from the National Science Foundation, awarded as of 1 September 1965 for the study of hydrogen and helium spectra in gaseous nebulae. Work has continued in the spectrophotometry of gaseous nebulae, much of it in collaboration with L. H. Aller, and others. Studies of the planetary nebulae NGC 3242 and NGC 7662 have been completed and published. A study of NGC 2440 has been finished and is awaiting publication. Spectra of IC 2165 are presently in the reduction stage. Spectrograms of NGC 6543 and IC 2149 have been obtained in two trips to Kitt Peak National Observatory comprising eight nights of observation. In addition, spectrograms of the visual regions of a large number of planetary nebulae are in the process of reduction.

A study of the wavelength dependence of the characteristic curves of IIa–O plates has been completed, and is awaiting publication.

Work has continued on the measurement of central star temperatures of planetary nebulae using the spectrophotometric data mentioned above and an adaptation of Stoy's method to include the effects of helium absorption.

Progress has been made in the building of an ionization and expansion model of the Orion Nebula to explain the observed radial velocities. A confirmation of the differential expansion of the Nebula was reported at the 119th meeting of the American Astronomical Society.

The problem of the hydrogen and helium spectra of gaseous nebulae has received further attention. A paper demonstrating the deviations from theory of the line intensities for several nebulae was published. A graduate student, Paul Lee, has begun working on the confluence of the Balmer lines in gaseous nebulae to determine departures from thermal equilibrium in the high quantum levels, to test various collisional processes and to solve some of the problems of the deviations from theory of the hydrogen and helium line intensities. Some tentative correlations have been established between deviation from theory and nebular parameters related to optical depth in nebulae.

A graduate student (Wm. Greig) has begun to work on a method of measuring optical depths of planetary nebulae using the central star work measured above.

Kaler has also begun to compile a catalogue of the spectrum lines observed in gaseous nebulae in an attempt to improve the identifications of ions by cross-correlating different nebulae.

Since he joined the University of Illinois faculty on 1 February 1966, Edward C. Olson has continued working on a spectrographic investigation of eclipsing binary systems to determine spectral classes and absolute magnitudes corrected for spectral contamination and equatorial rotational velocities of the components. The latter will be used to extend an earlier study of axial-orbital synchronism. This work is supported by a National Science Foundation grant. Funds from this grant are also being used to construct a narrow-band photoelectric photometer. The instrument is being built from modified plans of the Kitt Peak National Observatory photometer. It will be usable with the 12-in. refractor and the 40-in. reflector.

Instruction. The total enrollment in undergraduate and graduate courses in Astronomy was 522, which represents an increase of 8% over the previous year. Graduate enrollment represented 15% of the total.

Colloquia were given during the year by the following visiting scientists: Dr. Leo Goldberg (Harvard College Observatory); Dr. M. H. Rogers (University of Bristol, England); Dr. K. Aa. Strand (U. S. Naval Observatory).

The program of Visitors' Nights at the Observa-

tory in Urbana drew an attendance of 971 members of the general public and of local school groups.

G. C. McVittie, *Director*

Joint Institute for Laboratory Astrophysics of the National Bureau of Standards and the University of Colorado, Boulder, Colorado

INTRODUCTION

The Joint Institute for Laboratory Astrophysics (JILA) functions on the campus of the University of Colorado at Boulder. The work of the National Bureau of Standards staff members in JILA is described in this report along with that of their colleagues appointed by the University.

The construction of a new permanent building neared completion, and preparations to assume occupancy were under way. The building should be completely occupied by October 1966.

JILA sponsored, or joined in sponsoring, four conferences. Three were held in Boulder. They were: the workshop on Lowering of the Ionization Potential and Related Problems of the Equilibrium Plasma (held 12 and 13 November 1965); the Bell Sphere Reentry Meeting (held at the National Bureau of Standards Boulder Laboratories, 17 and 18 March 1966); the Advanced Research Projects Agency Institutes Meeting (held 6 and 7 May 1966). The fourth conference, the Interdisciplinary Symposium on Radiative Transfer sponsored jointly by the Office of Naval Research, General Electric, and JILA was held at Philadelphia, 24–26 February 1966. JILA acted as host to the IAU Colloquium on Atomic Collision Processes (held 11 through 15 July 1966).

Dr. Roy H. Garstang was appointed chairman of JILA effective 1 January 1966. During the year, appointments to the permanent staff were accepted by David G. Hummer, John C. Stewart, and Richard N. Zare. These appointments went into effect during the summer of 1966. Dr. James Faller left to join the faculty of Wesleyan University, Middletown, Connecticut.

Eleven Visiting Fellows have been in residence at JILA during the year. They are: Milan Blaha, Astronomical Institute, Czechoslovak Academy of Sciences; Joseph C. Y. Chen, Brookhaven National Laboratory; Alan H. Cook, National Physical Laboratory, England; Erling Holøien, Institute for Theoretical Physics, University of Oslo; Kurt Hunger, Institute for Theoretical Physics, Hanover, Germany; Gabor Kalman, University of Paris (Orsay); K. Karamcheti, Stanford University; Neal F. Lane, The Queen's University of Belfast; Kenneth B. McAfee, Bell Telephone Laboratories; J. William McGowan, General Atomic, San Diego; John C. Stewart, General Atomic, San Diego.

Postdoctoral appointments include Oleg Bely, Paris Observatory (Meudon); Burkhard Brehm, Physics Institute, Freiberg; Alan Corney, Oxford; T. Neil Divine, California Institute of Technology; Alan Gallagher, Columbia University; Carole Jordan, University of London Observatory, England; Donald Kouri, University of Wisconsin; Robert C. Long, Yale University; Noboru Ohyama, Hiroshima University; Bert Van Zyl, University of Washington; Shien-Biau Woo, Washington University, St. Louis.

Other scientists who have visited include Benjamin Bederson, New York University; Beno L. Moiseiwitsch, The Queen's University of Belfast; George W. Series, Oxford University; Andrew Weiss, National Bureau of Standards; Philip L. Altick, University of Nevada; Edward M. Purcell, Harvard University.

During the year, 33 graduate students worked at JILA. Two, Paul L. Patterson and Gary C. Tisone, received their Ph.D's.

Lists of JILA publications and reports may be obtained by writing to Mrs. Gwen Eurich, Scientific Reports Editor, JILA, Boulder, Colorado. The report series comprises unpublished manuscripts, usually preprints of forthcoming publications.

WORK CARRIED OUT DURING THE PAST YEAR

A. Physics of Atomic Collisions: Experimental. S. B. Woo continued the experimental program in ion mobilities. Mobilities and reactions of negative ions in oxygen (O^-,O_2^-,O_3^-) have recently been studied.

P. L. Patterson completed his study of the temperature dependence of helium ion mobilities in helium.[1]

Work on the structure and photodetachment spectrum of the OH^- ion was completed by L. M. Branscomb.[2] Work was also in progress on the photodetachment of O_2^- at room temperature. G. C. Tisone completed his work on the detachment of electrons from H^- by electron impact.[3,4]

Under the direction of S. J. Smith, measurements were made of the angular distribution of Lyman-α photons excited by electron impact.

L. J. Kieffer's program on the energy distributions of H^+ and D^+ from dissociative ionization of H_2 and D_2 was continued.

G. H. Dunn continued measuring and calculating cross sections for dissociative collisions of molecular ions as a function of impacting particle energy, with emphasis on dissociation of H_2^+ by photons and electrons.[5,6]

J. L. Hall calculated the two-quantum photoionization rate for cesium as a function of wavelength from the two-photon to the single-photon threshold.[7]

K. B. McAfee (Visiting Fellow) continued his studies of the interaction of solids and gases at hypersonic velocity in the upper reaches of the earth's atmosphere.

B. Brehm completed a paper on mass spectrometric investigations of the photoionization of molecules, based on experiments performed in Freiburg.[8] The design and construction of a new negative-ion beam apparatus was begun in collaboration with J. L. Hall and L. M. Branscomb.

Other work published during the year included efficiency curves for the excitation of 2^3S and 2^1S states of helium by electron impact[9] and kinetic energy measurements of electrons released in Penning ionization.[10]

B. Physics of Atomic Collisions: Theory. O. Bely developed an improved exchange approximation for treating electron–ion inelastic collisions.[11–13] He performed detailed calculations on a number of astrophysically important ions.[14,15]

J. C. Y. Chen worked on formal theories[16] for rearrangement collisions and applied these theories to atomic and molecular processes such as associative detachment, dissociative attachment,[17] and electron-transfer processes. He also worked on resonance phenomena in electron scattering by atoms and molecules.[18,19]

S. Geltman and E. Holøien calculated the energy level structure of some quartet states in three-electron atomic systems. The electron affinities in He^- have been found, and a number of previously unidentified spectral lines in Li have been identified.[20]

D. Kouri continued an extensive theoretical study of proton hydrogen atom collisions taking account of nonadiabatic coupling terms. A study was begun of the possibility of resonances in H^+-H collisions.

J. W. McGowan worked on a monograph on the role of excited particles in collisions processes. He also studied the ionization threshold laws and the characteristic parameters of the scattering resonances for elastic scattering of H and the ionization of H and H_2.

R. H. Garstang made an analysis of electron impact data for He and N_2 in terms of generalized oscillator strengths and obtained a new value for the transition probability of the electric quadrupole part of the Lyman–Birge–Hopfield bands of N_2.

Papers were also prepared during the year on the excitation of molecular rotation by slow electrons,[21] on single- and double-quantum photodetachment of negative ions,[22] on the $^1S^e$ auto-ionizing states[23,24] of He and H^-, and on the convergence of the superposition of configurations.[25] The theory of the rotational excitation of a diatomic molecule in a collision with an atom was studied,[26] and work was published on the high-energy cross sections for electron excitation of excited hydrogen atoms.[27] A paper on electron scattering by He^+ was scheduled for publication.[28]

C. Astrophysics and Radiative Transfer Theory. J. P. Cox has continued his work on nonlinear stellar pulsations in collaboration with a group at Los Alamos.[29,30] A new set of calculations has been started for Cepheid models with deep envelopes. Work on the monograph on stellar structure neared completion.

T. N. Divine continued his work on the structure and evolution of model helium stars, including relativistic Thomas–Fermi equation-of-state calculations.

Studies of the collapse phase of pre-main sequence stellar evolution, using machine calculations, were started by N. Ohyama.

M. Blaha (Visiting Fellow) studied the excitation of ionized atoms in the solar corona and chromosphere. In collaboration with O. Bely, he studied the relative line intensities of Fe XV in coronal conditions.

K. Hunger (Visiting Fellow) and D. Van Blerkom constructed model atmospheres for pure helium stars and began the analysis of the spectrum of the hydrogen-deficient star BD +10° 2179.

G. McHugh continued with calculations pertaining to convective motions in the solar atmosphere.

S. Jordan continued his work on the problem of heating of the solar chromosphere and related problems.

J. C. Stewart has worked on various problems of radiative transfer.[31–33]

A. H. Cook (Visiting Fellow) made a study of radio frequency emission from OH in galactic sources and suggested an optical pumping mechanism for creating an inversion of the level populations of the doublet.[34,35]

C. Jordan has calculated the ionization equilibria of many atoms under solar coronal and chromospheric conditions. She extended her analysis of the solar extreme-ultraviolet spectrum and improved the determination of solar abundances.

Other work published during the year was concerned with abundances and negative ions in late-type stars,[36–40] with relativistic instability of large massive systems with magnetic field,[41] and with Dernizir's theory of sunspots.[42]

D. Spectroscopy and Optical Resonance Phenomena. P. L. Bender made theoretical and experi-

mental studies of collisional relaxation and line broadening for alkali atoms.

E. U. Condon continued work on the revision of his book *The Theory of Atomic Spectra*. In collaboration with R. N. Zare he began a project for the systematic graphic portrayal of the wave functions of all electrons in atoms and ions throughout the periodic table. With H. Odabasi he performed calculations of spin-orbit interaction parameters from the Hartree–Fock–Slater self-consistent wave functions obtained by the method of Herman and Skillman.[43]

R. H. Garstang continued writing his book on spectrum line intensities. He made an investigation of transition probabilities in the Fe XVII spectrum.[44] With S. J. Hill he calculated[45] oscillator strengths for astrophysically important lines of Ba II. They also made calculations of oscillator strengths using a self-consistent field wave function for an atomic ground state and a Coulomb approximation excited state. With L. J. Shamey he completed calculations[46] on Si II and continued work on Fe III. With Mrs. J. Van Blerkom he investigated the effect of Pauli-excluded transitions in the f-sum rule. J. C. Stewart (Visiting Fellow) used his program, devised earlier,[47] to calculate a number of important transition probabilities.

A. Gallagher continued his work on the measurement of the lifetimes of ^2P states in ionized atoms. Results were obtained for Mg II, Ca II, Sr II, and Ba II. He also measured the branching ratios for the lines emitted by the ^2P states in the latter three ions. A. Corney made attempts to use the Hanle effect to measure the lifetimes of some excited states in helium. Experimental difficulties prevented the success of these experiments.

Other work prepared for publication during the year included a study of the magnesium isoelectronic sequence[48] and a set of programs for configuration interaction calculations.[49]

E. Aerodynamics, Plasma Physics, and Statistical Mechanics. T. G. Jones continued work on the measurement and theoretical calculation of the pressures produced by detonation waves on reflection at a rigid surface. Work was begun on microwave conductivity measurements in reacting gases. C. F. Dewey continued work with cesium plasma. J. Sanmartin analyzed the stability of a one-component plasma. G. C. Vlases made improvements to his inverse pinch machine.

W. E. Brittin and D. Choi continued work on the functional formulation of statistical magnetohydrodynamics. Conservation laws have been derived which include the electromagnetic field.

G. Kalman (Visiting Fellow) worked on a relativistic Green's function formalism for plasmas in a magnetic field, the properties of a neutron gas in the Hartree approximation, and the cyclotron and Čerenkov radiation of an ion in a plasma.

K. Karamcheti studied the use of laser lines for determining absorption profiles and velocity distribution functions in a gas. He also studied interaction of gas molecules with those of a solid bounding the gas. He studied the development of shock-tube flow from the point of view of the mechanics of the gas molecules.

J. Cooper commenced preparations for experimental work on the shift-to-width ratios of Stark broadened spectral lines and on forced autoionization in barium with a view to studying the lowering of the ionization potential. He also extended the theory of Stark broadening of spectral lines to take into account quadrupole transitions.

Work published during the year included a paper by J. C. Stewart and K. D. Pyatt on the lowering of the ionization potentials in plasma,[50] lectures on nonequilibrium statistical mechanics,[51,52] a study of fluctuations in an arc plasmajet,[53] and a paper on the decay theory of closely coupled unstable states.[54]

F. Miscellaneous. A. H. Cook (Visiting Fellow) studied the potentials which are solutions of the Hamilton–Jacobi, Schrödinger, and Laplace equations in the coordinate systems in which all three equations are separable. He showed that no solution exists in ellipsoidal coordinates.[55]

R. N. Thomas prepared for publication the Proceedings of the Fifth Symposium on Cosmical Gas Dynamics. He also edited much of the proceedings of the Symposium on Interdisciplinary Aspects of Radiative Transfer. The proceedings of an earlier workshop on radiative transfer were published.[56]

P. L. Bender, J. L. Hall, and J. E. Faller began work on the determination of the speed of light using lasers and long path interferometry. Bender and Faller continued their investigation of the feasibility of using optical radar and a corner reflector on the moon to obtain very accurate range measurements. They examined the potential accuracy of geophysical and lunar information obtainable from an extended series of range measurements.

J. Cooper edited the proceedings of the conference on the lowering of the ionization potential.[57]

J. Faller continued his work on the measurement of the absolute value of the local acceleration of gravity. He started to prepare for observing the eclipse of November 1966.

The data center on collision cross sections, under the direction of L. J. Kieffer, issued a new bibliography of electron collision cross section data[58] and a critical review of electron impact ionization cross

section data.[59] Work was under way on a review of electron inelastic scattering cross section data for atoms (by S. J. Smith and B. L. Moiseiwitsch) and of total scattering cross section data (by B. Bederson).

R. H. GARSTANG, *Chairman*

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Staff. Dr. George Field joined the department as Professor in July 1965 and Dr. L. V. Kuhi accepted the position of Acting Assistant Professor on the same date. Professors George Wallerstein and Paul Hodge left to accept positions at the University of Washington. Dr. Valerie Meyerscough is visiting the department for two years on a Miller Institute Fellowship. Drs. Erika and K. H. Böhm arrived in March for a six-month visit.

Instrumentation. The relocation of the Leuschner Observatory is nearing completion. The buildings and domes are occupied, and the 20-in. telescope has been moved to the new site. Delivery of the 30-in. telescope has been promised for late August.

Theoretical Astrophysics. Sidney Parsons has calculated a model stellar atmosphere relating to F5 giant stars, for the purpose of calculating line strengths that can be used to derive abundances. He has allowed for the flux carried convection through a nonlocal treatment of the vertical currents. Detailed absorption coefficients are computed and used. Line properties are currently being computed using the program developed by Dr. S. E. Strom.

Roger Ulrich has been investigating the problem of convection in stellar and solar atmospheres. Due to the extremely sharp peak in the superadiabatic gradient it has been necessary to take into account the full variation of the physical parameters over

the path of the moving material. This peak in the solar case has a width of about one-quarter of a pressure scale height. A series of flight path integrals leads to a convective flux which can be used to calculate the next model in an iterative sequence.

Henyey has examined the technique of computing non-gray model atmospheres. As a tool to be used for the purpose of iterating the temperature he has analytically solved the integral equation relating the flux and source function to obtain a rigorous expression giving the Planck function at each depth and frequency in terms of the run of the flux throughout the atmosphere. After introducing an approximation relating monochromatic flux changes to integrated ones, a scheme for iterating the problem is proposed which should converge rapidly at all depths.

K. H. Böhm is computing stationary convective modes for the solar hydrogen convection zone. He is trying to take into account turbulent viscosity and conductivity, assuming that a crude approximation for these functions can be derived from the mixing length theory. He also continues to calculate non-gray model atmospheres for central stars of planetary nebulae ($4\times10^4°\text{K}\leq T_{\text{eff}}\leq 2\times10^5°\text{K}$). A modified version of this program, using L. G. Henyey's new temperature correction procedure is being prepared.

E. Böhm-Vitense is investigating the structure of atmospheres with effective temperatures around 10^4°K and with reduced hydrogen abundances. Especially the behavior of Hγ was studied. For hydrogen abundance reductions up to a factor 10, the electron pressures at a given optical depth E and therefore also the hydrogen-line intensities increase. Such stars should have abnormally strong hydrogen lines. For much lower hydrogen abundances the hydrogen-line intensity decreases because the continuous absorptions of He^-, O, N, and C become more important than the one of H. The stars then also appear redder.

For periodically variable magnetic stars theoretical line profiles, including the Zeeman splitting, have been studied as a function of phase, assuming the oblique rotator hypothesis to be correct.

William Hubbard has used quantum-mechanical Kubo expressions to evaluate the electrical and thermal conductivities and the shear viscosity of a degenerate gas in the Lorentz gas approximation. He showed that the mean free path of the electrons depends on the pair distribution function of the ions. Agreement with previous theories of thermal conduction in degenerate matter is found within an order of magnitude. The values of the viscosity coefficient are being used in a consideration of the possible existence of convective degenerate cores.

An extension of the Berkeley stellar evolution program has been worked out by J. E. Forbes to permit the study of models losing mass. He has used this to study the effects of mass loss on the post-main-sequence evolution of a $5M_\odot$ star of approximately solar composition. A comparison of the resulting tracks in the ($\log T_e$, M_{bol}) diagram with that for a model of $5M_\odot$ constant mass shows that even a loss of over 50% of the original mass has very little effect on the track as long as the star is near the low-temperature extremity of the giant branch, and furthermore that, even at the higher T_e values occurring during the subsequent helium-burning phase (by which time the model has been reduced in mass to some still lower value M_{final}), the luminosity remains far higher than for a star of constant mass M_{final}.

The theoretical evolution of stellar configurations of mass 1.35 and 1.55 is under study by Forbes, Henyey, Over, Simpson, and Ulrich. The calculations started with a pre-main-sequence state, and reproduced the main sequence conversion of hydrogen which left a complex distribution of hydrogen, helium, and CNO isotopes through the mass. After leaving the main-sequence with a hydrogen shell source convective envelopes developed which brought up material that had previously been processed by the nuclear reactions in the interior. The depleted case turned out to be far from isothermal. The reactions $^{14}\text{N}(\alpha,\gamma)\,^{18}\text{F}(e^+\nu)\,^{18}\text{O}$ caused the onset of the helium flash, before the 3α burning started. At this point the calculations ran into technical difficulties arising from an unforseen physical phenomenon. Each star developed a convective core whose size, mass, and temperature increased on a time scale such that the boundary overtook the radiative signal coming from the core and produced what is almost a discontinuity in the radiative flux outside the core.

An evolutionary sequence of models for $5M_\odot$ and a roughly solar composition has been carried out from the pre-main-sequence stage through hydrogen and helium burning. A stage is reached where the hydrogen-burning shell has become at least temporarily inactive and has been replaced by a helium-burning shell as the principal source of luminosity. The central temperature at this point is rising toward values for which carbon and oxygen burning, as well as energy losses via neutrinos, will become important, but the calculation has been stopped at this point because of the extreme depth of that part of the convective envelope in which the gradient $d\ln T/d\ln P$ is strongly superadiabatic.

J. L'Ecuyer has continued a study of helium stars of small mass. Particular attention was given to the abundance of carbon and oxygen at the end of

the helium-burning phase: it was found that the ratio of X_c to X_0 reaches a maximum for a helium star of around $1M_\odot$ and that to obtain the cosmically observed value of this ratio (1:2 or 1:3) one would have to use a very low $^{12}C(\alpha,\gamma)^{16}O$ rate, as given, for instance, by Reeves.

Silvia Peimbert has started a study of the stability of high-mass stars. The actual instant at which instability may set in during their evolutionary development is the prime concern in the investigation. The existence of very deep superadiabatic layers, during the early pre-main-sequence phases, presents difficulties in the calculation of the models.

Field has continued work on various problems in interstellar gas dynamics. With B. Basu, he has reviewed the problem of acceleration of interstellar clouds by expanding H II regions. Several lines of evidence indicate the mechanism may be too weak if there is not a strong magnetic field present to inhibit dissipation. With J. Rather, B. Basu, and S. Orszag, Field has carried out computations of infrared emission by interstellar shock waves. Cooling times were very short, largely because of the inclusion of new cooling rates due to collisions of ions with H atoms. He has reported on work carried out previously on the ultraviolet extinction (1000–3000 Å) by ice grains. Absorption edges appear which would permit identification of H_2O, CH_4, and NH_3. This work was done with H. Sobel and B. Partridge. Work has continued with J. Scargle on the circular polarization of synchrotron radiation, while, in collaboration with G. Herbig and J. Hitchcock, Field has reported new data on the excitation of the $J=1$ rotational level of interstellar CN in ζ Oph and ζ Per. It has been shown that this excitation could be explained if the blackbody radiation detected at other wavelengths were present at $\lambda 2.6$ mm as well, with an intensity corresponding to about 3°K. Calculations of collision cross sections for a charged particle passing and exciting a molecule were undertaken with W. Goss. M. Peimbert has analyzed the electron temperature in the Orion Nebula, finding that corrections for light scattered by interstellar grains are important if the Balmer continuum is to be used in the analysis.

Star Clusters. King has modified his theoretical models of star clusters to include a mixture of nine stellar types. This improvement makes possible a finer fitting of the luminosity function, as well as the inclusion of white dwarfs. S. Prata has made an additional modification to allow for the possible addition of nonstellar mass, and he is now introducing anisotropic velocity distributions.

King's star-counting program is essentially complete, and the results are being prepared for publication. About 50 counts were added this year and the program now includes all clusters north of $\delta=-40°$ for which counting seems at all worth while, plus a few good southern clusters for which material was available. For a few clusters with very small central cores, new large-scale photographs have been taken for study of the distribution of integrated light.

J. L. Hitchcock measured photoelectric brightness of concentric annuli of the globular clusters M2, M13, and M15 and the elliptical galaxy M32, using annular apertures constructed photographically for the purpose. This technique permits the determination of radial photometric profiles without the problems of either measuring with a small spot or else using small differences between measures made through circular apertures.

Spinrad and B. J. Taylor began an extensive program of photoelectric scanning of standard stars, globular clusters and galaxies with Wampler's scanner at the Crossley and the 120-in. To date, good 33-color photometric observations have been secured for the galaxies M31, M32, M81, NGC 4472, and NGC 3379. The object of the work is to synthesize the stellar content of galaxies by suitable stellar mixtures. Towards the achievement of a unique solution, the scanner data measures both spectral lines and continuum regions.

Galactic Structure. King obtained plates for a study of colors and magnitudes of stars in S.A. 51, 57, and 68, using Baum's faint photoelectric magnitude sequences. Since most of the faint stars in these high-latitude regions can be expected to be main-sequence halo stars, the program should give information about star densities many kiloparsecs out into the halo.

Galaxies. Reduction of King's surface photometry of elliptical galaxies continued. In the three galaxies completed so far, results of long- and short-exposure plates from two different telescopes agree well. Radial profiles in all three can be fitted by the simple theoretical models recently published by King. New plates were secured for additional ellipticals: the available material will lead to M/L values for the centers of about 20 galaxies whose internal velocity dispersions have been determined by Minkowski.

King took guided spectra on the major axes of several elliptical galaxies; these will be measured for rotation.

Solar System. B. O'Leary observed Venus photometrically at phase angles between 153° and 165° before and after inferior conjunction, in order to search for a brightening that would correspond to the 22° halo phenomenon in the earth's atmosphere.

Hexagonal ice crystals of more than micron size in the Venus clouds should produce such an effect, whose phase angle depends on the index of refraction of the material. Although the difficulties of observing an extremely bright object in a daytime sky make the results uncertain, the observations indicate a halo effect of amplitude $0^m.05$. Existing polarization observations tend to confirm this conclusion. An unexpected by-product was that Venus was a tenth of a magnitude redder in $B-R$ color after inferior conjunction than before inferior conjunction. This would indicate a difference in cloud properties on the morning and afternoon sides of the planet.

Giver and Spinrad found the H_2 rotational temperatures of both Saturn and Uranus to be near 130°K.

Spinrad, Schorn, Moore, Giver, and Smith have completed detailed observations of Mars CO_2 and H_2O lines: The CO_2 lines at λ8700 give a CO_2 content $w=90\pm27$ m atm and yield a surface pressure $P_s=10_{-5}^{+10}$ mbar for Mars. The Martian water line variation has been studied, and a manuscript recently submitted to the *Astrophysical Journal.*

Stellar Spectroscopy. Spinrad, in collaboration with M. S. Vardya (Utrecht) has computed approximate abundances of the light elements H:C:N:O in the atmospheres of several M stars. Molecular equilibria calculations were used to transform the observed molecular concentrations to atomic abundance ratios. The most interesting results are that many normal M giants have $O/C\simeq1.05$, only slightly above unity, and R Leo (M8e) and α Ori (M2Ib) have $N/C\simeq2$, a large N excess.

Spinrad's work with Greenstein, Conti, Wallerstein and Vardya on [O I] λ6300 in K giants has continued. It is hoped that the history of oxygen production in the galaxy may be traced out by examining the neutral oxygen lines in many old stars, but the problem requires very high dispersion spectrograms of faint stars. Evidence so far accumulated indicates that the oxygen to "metals" ratio has probably changed substantially since the early days of the galaxy.

Wing, Kuhi, and Spinrad have observed the infrared spectra of four "infrared stars." They are the Cygnus object, the Taurus object, the Leo Minor object, and TX Cam. Scanner data, *UBV* photometry, and infrared coudé spectrograms indicate the following features of these *very red* stars: The Cygnus object is extremely red, and probably nonvariable. It could be reddened by interstellar or circumstellar material. The Tarus object is a *very cool* Mira variable with $P\sim600$ days. It probably has a low O/C ratio like S stars. TX Cam seems to be a normal abundance, but exceptionally cool Mira, and the LMi source, observed only twice, is undoubtedly the coolest carbon star yet discovered!

Spinrad and Wing have accumulated data on Pγ hydrogen emission in Mira variables from coudé spectrograms and photoelectric scans. Stars showing strong Pγ near or past maximum light are: R And, *o* Cet, R Gem, R Cnc, R Cyg, R Leo, R Aql, X Cyg, and the Taurus infrared star. Pγ emission is usually broad in these stars; although the phenomenon resembles the usual Mira Balmer emission (like Hδ) at maximum light, the line profile for the infrared H line suggests a considerable opacity difference over λλ10940–4102.

The infrared spectra of several bright WR stars (HD 192163, WN6; HD190918, WN5+09.5 III; HD193077, WN5+B0; HD192641, WC6 and HD192103 WC7) and the O9V star 10 Lac were obtained by Kuhi with the photoelectric spectrum scanner at Mount Wilson Observatory. The WC stars show an extremely well-developed spectrum of C III and C IV; in particular most hitherto unobserved and unidentified emission lines can be ascribed to transitions between fixed principal quantum numbers in C IV. The WN stars, on the other hand, show very few lines in the infrared, the strongest lines being He II λ10124 and He I λ10830. The observed widths agree with a Doppler explanation, i.e., lines that are 30–40 Å wide around λ5000 are 60–80 Å wide around λ10000. The profiles are symmetrical with only He I λ10830 showing a violet-displaced absorption feature. In general neither the radially expanding model nor the equatorial ejection one can satisfactorily account for the line profiles. Some kind of large-scale prominence-type activity seems more attractive. The variations in emission line intensities as a function of phase for the eclipsing system V444 Cygni have also been measured with the spectrum scanner. The results strongly suggest that the lines of highest excitation and ionization come from a hot region between the two stars or at least on the regions of the stars facing each other. Analyses of two other eclipsing systems CQ Cep and CV Ser are also being completed. The irregular variation of emission lines seems to be a common feature of all WR stars, the usual variation being $\lesssim10\%$. However HD50896 exhibits variations as large as 30% and also changes in continuum intensity (λ5556) by ~0.3 mag. The variation appears irregular but a periodicity of ~90 days may also be present.

Photoelectric spectrum scans have been obtained by Kuhi for the brighter T Tauri stars to investi-

gate their continuous energy distribution and other peculiarities. The ultraviolet continuous emission which appears in several T Tauri stars is found to be strongly correlated with the strength of Hα in emission, suggesting that the uv emission is Balmer in origin. Furthermore a separate source of non-thermal radiation as suggested by Gordon seems to be ruled out by the lack of correlation of the redness of the star with its uv excess. Stars showing the uv emission have the same range in redness as those that do not. The detailed wavelength distribution of the uv emission is being determined to allow theoretical estimates of the temperature and the nature of the emission to be made. Observations are also being extended to the infrared ($\sim 1\ \mu$) to investigate the extremely red nature of T Tauri stars as recently discovered by Mendoza and their possible connection with some of the infrared stars discovered by Neugebauer, Martz, and Leighton. Preliminary indications are that much of the red color is due to reddening (perhaps circumstellar in origin) for such stars as AS205, AS209, and T Tauri. The circumstellar nature is suggested by the large values of total absorption obtained from the ratios of Paschen to Balmer emission lines. The possible presence of a very late-type companion was ruled out for T Tauri and FU Ori by the lack of expected molecular features in the infrared.

Theoretical calculations of evolutionary models for a $1.5M_{\odot}$ star with mass loss (as suggested by the line profiles of T Tauri stars) have been started by Kuhi and Forbes to determine the effect of mass loss on the time scale and the contractive track. Preliminary results indicate that mass loss shortens the time scale to reach the same point on the H-R diagram.

Simultaneous spectral and photoelectric (scanner) observations of δ Scuti stars have been obtained by Kuhi and Danziger at Mount Wilson Observatory. The analysis of ρ Puppis results in amplitudes of 11 km/sec, 0.15 mag and 280°K for the radial velocity, light, and temperature variations, respectively. Estimates of the absolute luminosity and mass from the observed surface gravity and the $Q=P(\rho/\rho_0)^{\frac{1}{2}}$ relationship suggest that ρ Puppis must be pulsating in a higher harmonic mode than the first or that the mechanism of pulsation is not properly understood. Analysis of δ Del, δ Scuti and other such stars are in progress.

Laboratory Spectroscopy. The analysis of the Swan system of the C_2 molecule by Phillips and S. P. Davis of the Department of Physics has been completed, and tabulations are being prepared for publication. The listings include data on 37 bands. High-intensity arc spectrograms of TiO are being made using a new plane grating spectrograph operated in the tenth order. The dispersion of 0.4 Å/mm makes possible a much more complete resolution of the complex head regions of these bands than was possible with the concave grating.

Radio Astronomy. The principal efforts of the laboratory during the past year have been directed toward studies of the emission from the interstellar OH radical at 18-cm wavelength. Weaver, Williams, and Dieter have found OH emission in the direction of six diffuse galactic nebulae. Each of these sources shows highly anomalous line ratios among the members of the multiplet formed in the ground state of the molecule—quite unexplainable on the basis of equilibrium conditions. In addition, the components of the profiles within a single line of the multiplet are extremely narrow in frequency and appear (in several of the sources) to come from small, separated regions near the edge of the nebulae. We have observed some of these components to be highly linearly polarized and, in two sources, to be variable in intensity with time.

Goss has begun extensive measurements of OH absorption, with the addition of many new sources of absorption and two new sources in which emission also appears. He is plotting maps of the areas around these sources to investigate the sizes and densities of OH clouds.

In cooperation with astronomers at the California Institute of Technology (in particular, Dr. G. W. Rougoor), Cudaback has used the interferometer at Owens Valley to determine the positions and sizes of the OH components with much greater accuracy than is possible at Hat Creek. Two sources have been studied in enough detail to show their very small-scale structure and others will be observed soon.

A theoretical investigation of the excitation mechanism for the OH emission is under way by Turner. The proposed excitation is of the maser type, involving overpopulation of some molecular energy levels with respect to others and stimulated emission from these levels. Various methods for achieving this overpopulation have been studied in detail using the 7094 computer.

A brief survey of the nebulae in which OH emission has been observed was made in the excited hydrogen line at 1683 Mc/sec by Williams and Dieter. In every case a positive result was obtained which yielded more accurate radial velocities for these objects than has been previously obtained.

High-resolution observations of the optical spectrum of CH in the laboratory by Goss yielded a prediction of the frequencies of the three ground-state microwave lines of the CH molecule. The difference in frequency from earlier work and the

precision of these measurements made a new search for interstellar CH seem advisable. A preliminary search was unsuccessful, possibly due to our lack of a low-noise amplifier at the appropriate frequency.

Williams has made (with Dr. T. K. Menon) a survey of the H I absorption in 58 radio sources using the new 140-ft facility at Green Bank. The results have yielded a significant fraction of new absorption and, in particular, the distance to Tycho's supernova has been determined from these measurements. Extremely high angular and frequency resolution in these observations are providing interesting studies of the deep absorption line in the bright sources.

During March the spectrum of Venus was studied by Welch and Thornton with an eight-channel receiver of over-all width 300 Mc/sec centered at the 22.2 Gc absorption frequency of water vapor. The initial reduction shows no spectral feature; final reductions should lead to an upper limit on the water content of the planet's atmosphere. A series of observations of the source 3C273 made during the same period showed an increase of 5–10 times in the source flux over what had been observed at 1.5 cm during September 1964.

JOHN G. PHILLIPS, *Chairman*

Lick Observatory, University of California, Mount Hamilton, California

Santa Cruz Headquarters. The staff of Lick Observatory will take up residence on the Santa Cruz campus in November 1966, when the offices, laboratories, and shops move to quarters on the campus. The program of graduate instruction will be in operation by the fall quarter of 1967–68. The observing station on Mount Hamilton will be administered from Santa Cruz and will continue to be a Universitywide facility, open to astronomers and graduate students from any campus.

Telescope Users. The service role of the Observatory is reflected in the distribution of telescope assignments for 1965–66: (1) Forty-seven percent of the nights on the 120-in. reflector went to astronomers not on the Lick staff, nearly all of them members of the University faculty. (2) In all, 63 persons participated in observations with the Mount Hamilton telescopes; of these 27 (including Lick Fellows) were associated with Lick Observatory, 30 were from campus departments, and six were not connected with the University of California. (3) Twenty-seven observers, or 42% of the total were students.

PERSONNEL

Staff Changes. Lewis M. Hobbs came from the University of Wisconsin on 6 November 1965 to begin an appointment as Junior Astronomer. E. J. Wampler was promoted from Acting Assistant Astronomer to Assistant Astronomer effective 1 July 1966. Peter S. Conti has accepted a position as Assistant Astronomer effective 15 August 1966.

Dr. Guido Chincarini returned to Asiago from September 1964 to March 1965, when he resumed his appointment as Project Associate. Dr. John Beckman of the University of London served as Project Associate during Chincarini's absence. Goro Ishida of the Okayama Observatory, University of Tokyo, was an Astronomical Assistant from December to March.

David H. DeVorkin and Conrad Sturch, Project Assistants, left at the end of the summer of 1965, the former to return to his studies on the Los Angeles campus, the latter to accept an appointment on the staff of the Mees Observatory at the University of Rochester. Irakly Papiashvili resigned as Project Associate in September to go to the Flagstaff Station of the U. S. Naval Observatory.

Kazimierz Stepień of Warsaw, Dr. Tadeusz Ciurla of Wroclaw, and John Vollertsen have accepted appointments as Astronomical Assistants beginning 1 September 1966.

Roderick L. Jones accepted an appointment as Electronic Engineer on 1 October 1965. Hans Boesgaard, who had designed most of the auxiliary instruments for the 120-in. telescope since he came to the Observatory in 1958, left for an engineering position at the University of Hawaii on 17 June 1966.

Staff Activities. Preston was awarded the Warner Prize of the American Astronomical Society for 1965. Kinman, Preston, and Vasilevskis lectured in the Natural Science survey course on the Santa Cruz campus during the winter term. Herbig was on sabbatical leave from July to December 1965 and visited several institutes and observatories in Europe with an extended stay at the Institut d'Astrophysique in Paris. In the spring quarter he again taught a course in Astronomy for Physical Scientists at Stanford University. Walker attended the Symposium on Image Devices in London in September and the IAU Symposium on Instabilities in Galaxies at Burakan in May. Vasilevskis visited the Yale–Columbia Southern Observatory at El Leoncito, Argentina, in April in order to assist the Yale Observatory in coordinating the Southern Astrograph Program with the Lick Proper Motion Survey.

Students. The Lick Fellows for 1965–66 were

Robert F. Wing, Sidney C. Wolff, and William F. van Altena; van Altena resigned on 1 April to accept an appointment at Yerkes Observatory, University of Chicago. Ann Merchant and Diane Pyper held appointments as Research Assistants at the Observatory throughout the report year. Other University of California graduate students in residence during the summer of 1965 included Baidyanath Basu, John Hitchcock, Frans Over, Manuel Peimbert, Stephen Prata, and Donald Goldsmith of Berkeley, and Donald Hayes, James Moorhead, and Richard Freedman of Los Angeles. Other graduate students who came to Mount Hamilton during the year to observe with the telescopes included Michael Breger, Dorothy Hannibal, Brian O'Leary, Sidney Parsons, Silvia Peimbert, John Rather, Ben Taylor, David Wilson, and Richard Wolff from Berkeley, and Steven Kilston and Roslyn Reeve from Los Angeles.

Visitors. In addition to colloquium speakers from within the University of California, 10 scientific visitors gave colloquia: Drs. J. M. Burch, Peter S. Conti, Kenneth Freeman, Theodor Schmidt-Kaler, C. R. O'Dell, Andrzej Pacholczyk, C. W. Rougoor, Edward A. Spiegel, P. A. Sturrock. Other scientific visitors included: L. Biermann, E. G. Bowen, O. J. Eggen, J. Hardorp, R. O. B. Hinsch, W. Krzeminski, A. G. Millikan and W. F. Swann, Paris Pişmiş, Aert Schadee, John Shimmins, Uli Steinlin and Rolf Fenkart, Peter Strittmatter, E. W. Titterton, and Susan Wyckoff.

INSTRUMENTS

Spectrographs and Cameras. The 80-in. Schmidt camera for the coudé spectrograph of the 120-in. telescope went into service during the year. Under Walker's guidance an $f/1$ all-mirror camera with a self-contained grating has been installed as a part of the coudé spectrograph. The design, due to Dr. I. S. Bowen of the Mount Wilson and Palomar Observatories, uses two concentric spherical mirrors in an inverse Cassegrain configuration, and has ample space around and beyond the focal plane for mounting large image tubes. The resolution is quite satisfactory over a 20-mm field. Construction was aided by a grant from the National Science Foundation.

Mounts for both the Lallemand image tube and the Carnegie image tube have been installed at the focus of the 160-in. camera of the coudé spectrograph. The former was made in collaboration with Dr. Hyron Spinrad of the Berkeley Department, with financial aid from the Jet Propulsion Laboratory.

A prime focus spectrograph designed by Kinman for use with the Carnegie image tube was completed and went into service in the spring. The straight-through optics use Zeiss lenses and a transmission grating on a prism, and give a useful range of 4000 to 7500 Å. At 600 Å/mm, the exposure is limited to 30 min by sky background.

Kron's campaign to reduce the background in two-chamber electronographic image tube was well advanced when he left for Flagstaff on 1 September 1965; Papiashvili collaborated. Subsequent tests have shown that the increased clearances and larger electrode radii were effective in eliminating field emission. The office of Naval Research supported the work.

Wampler and Jones, with the aid of a NASA grant, are building a two-channel fast pulse counting system for simultaneous star–sky photoelectric measurements with punched-card recording. The first use will be in connection with the scanning spectrometer.

The automatic measuring engine for the Proper Motion Survey was put through its acceptance tests by Vasilevskis at the Gaertner Corporation plant in Chicago. The machine met the specifications satisfactorily; repetition of the same plate gave a probable error of 0.36 μ. Installation at Santa Cruz is to be completed in September 1966.

SCIENTIFIC PROGRAM

Solar System. On high-dispersion coudé spectrograms of Comet 1965*f* (Ikeya–Seki), observed about 36 h after perihelion passage, Preston found emission lines of [O I], Na I, K I, Ca II, Cr I, Mn I, Fe I, Ni I, Cu I, and CN. A formal temperature of 4500°K was derived from a curve-of-growth analysis of Fe I. Both Fe I and Ni I lines are affected by fluorescence. From Na I and K I lines an upper limit of 2600°K for the excitation temperature was derived. The abundance ratio K I/Na I was found to be low, and the ratio Cu I/Fe I high. The absolute intensities of the emission lines gave 8000 Na I atoms cm^{-3} and 180 Fe I atoms cm^{-3} near the nucleus.

Walker has collaborated with Spinrad of the Berkeley Department in obtaining infrared coudé spectrograms of Venus and Jupiter, using the Lallemand electronic camera. With the improved technique for preserving S-1 cathodes, worked out with Chincarini's aid, successful all-night operation is possible, and a gain of about 70 is realized over most of the wavelength range covered by the Z plate; beyond 11 000 Å the gain is higher. The rotational fine structure of the methane band at 10 900 Å was well resolved in the Jupiter spectrum. The Venus plates show the isotopic $^{13}C^{16}O_2$ band

near 12 000 Å; the resolution is probably adequate for measurement.

Spinrad and L. P. Giver, a Berkeley student, have analyzed the rotational inclination of ammonia lines on high-dispersion spectrograms of Jupiter obtained in November 1965. The tilt was uniformly 50% that of the solar lines, and no anomalies were found.

Visual observers from the Astrogeology Branch of the U. S. Geological Survey in Menlo Park used the 36- and 12-in. refractors for a continuation of the program for geologic mapping of the lunar surface. Thirteen quadrangles have been completed. Certain geologic units are identified as debris ejected from mare basins at the time of impact, while other overlaying material has been shown to be of volcanic origin. Several volcanic deposits at the edges of the maria are found to be younger than the mare material. The program is in charge of Harold Masursky and other observers include M. H. Carr, O. J. Milton, H. J. Moore, N. J. Trask, and D. E. Wilhelms.

Additional photographs used in geologic mapping of the moon were obtained at the 36-in. refractor and the coudé focus of the 120-in. reflector, using special cameras furnished by the Geological Survey; Preston made the 120-in. exposures.

Parallaxes, Proper Motions. For almost all of the 100 faint red and white dwarf stars on the initial parallax program undertaken by Vasilevskis with the 36-in. refractor, the minimum of 20 plates spread over 3 yr has accumulated. Evaluation can begin as soon as the automatic measuring engine is available. For the 16 U Geminorum variables on the program additional plates over a longer period are being taken. Sanders has collaborated in the series of observations.

A proper motion study of the open cluster IC 4665, based on Allegheny plates, is in progress. In preparation for a pilot program to test procedures for measuring stellar proper motions relative to the background galaxies, prior to the second eopch exposures of the Lick Proper Motion Survey, Sanders has established photoelectric standards in 100 selected fields. The measurements were made with the 24-in. reflector.

Kinman has photographed Field 1196 of the Palomar Sky Survey with the Carnegie astrograph in order to derive proper motions of blue stars identified in this field by G. Haro of Tonanzintla Observatory. The first-epoch plate is from the Lick Proper Motion Survey collection. Vasilevskis is collaborating.

Double Stars. D. M. Popper of the Los Angeles Department found that the eclipsing binary PW Her shows double lines, and is one of a very few such binaries having a spectral type in the range G5 to K0. The luminosity class appears to be either IV or V. The cooler component shows *H* and *K* emission.

Preston has obtained spectrograms of the 16-day Cepheid RW Cam for the purpose of estimating the luminosity ratio of the Cepheid to its companion. The analysis, which depends on the depth of the *K* line at maximum, at minimum, and at mean light, is being carried out in collaboration with Joseph Miller, a graduate student at the University of Wisconsin.

Variable Stars. Preston has discovered that the δ Scuti star δ Del is a double-lined spectroscopic binary with a provisional period of 40 days. Because of the high eccentricity double lines are visible for only about three days of the orbital cycle. More observations are required. Spectrograms on 4 June 1966 showed intrinsic velocity variations for both components.

Single-trail spectrograms of the 1.3 day Cepheid-like variable BL Her, obtained by Preston, showed well-marked emission lines of H and Ca II for about 2 h during rising light. Simultaneous *UBV* photometry by Steven Kilston, a Los Angeles graduate student, showed that the emission and the atmospheric velocity reversal occur during a still-stand on the light curve. Single trail spectrograms of the strong-lined RR Lyrae stars DX Del and AN Ser also show H and Ca II emission during rising light, with the Ca II/H emission intensity ratio greater than in weak-lined RR Lyrae variables, as would be expected from the previously established metal-to-hydrogen ratio.

David Taylor has been observing the light curve of RR Lyrae on the *UBV* system in order to follow long-period changes in the nature of the 41-day cycle.

Photoelectric observations by Sturch have shown that V439 Oph is a Cepheid with a period of 1.893 days, rather than an RR Lyrae variable of period 0.395 day, as listed in the *General Catalogue of Variable Stars.*

Herbig has summarized his search for physical companions of long-period variables based on examination of spectra obtained with the Crossley nebular spectrograph near minimum light. Out of 53 newly observed M stars, one possible composite (RV Her) was found. From the 22 newly observed S stars, three (W Aql, T Sgr, WY Cas) were composite. Since nebular lines were not seen, the new companions are probably ordinary F or G stars, rather than hot, peculiar objects like o Cet B or R Aqr B.

Observations of Nova Her 1963 by Chincarini at

the 24-in. reflector showed irregular variations, with a possible period of $6^h39^m.5$.

Stellar Spectra, Abundance Studies. Herbig and Richard Wolff (of the Berkeley campus) have determined the Li abundance in 12 subgiants of types F6 to K1 from coudé spectrograms at a dispersion of 8 Å/mm. For subgiants with $B-V<+0.75$ the observed Li abundances can be understood in terms of the original main-sequence values: Iben's evolutionary tracks locate the region on the main sequence from whence these stars came, and his calculations demonstrate that there is negligible convective dilution. For stars with $B-V>+0.75$, the low abundances in subgiant stars can be explained to be a result of modification of the main-sequence Li content by convective dilution.

Herbig is deriving accurate equivalent widths of the *H*, *K* emission components in a number of F4–K2 main-sequence stars from heavily exposed spectrograms at 8 Å/mm. The objective is a more quantitative comparison with Li abundances.

Ann Merchant has determined the Li abundance in 58 M-type giants and supergiants on coudé spectrograms of dispersion 4, 8, and 16 Å/mm. The values range from 2 to 10^{-2} times the solar value. This spread can be explained as a consequence of the varying amount of main-sequence depletion, depending on the mass of the star, and of the post-main-sequence convective dilution of Li. There is no need to postulate that Li is formed on the surface of evolved stars. In general later spectral types show less Li.

Dr. Wallace Sargent of the University of California, San Diego, has been investigating He abundance in hot blue stars of the galactic halo, in collaboration with Dr. Leonard Searle of the Mt. Stromlo Observatory. Coudé spectrograms of substantially all of the Feige stars down to the 12th magnitude have been obtained at a dispersion of 48 Å/mm. The stars hot enough to show helium lines fall into three classes: (1) The very blue stars classified as sd0 show strong He I and He II lines. (2) Five out of 18 have weak He I, Si, Mg, and C lines, and a small Balmer discontinuity; these are Population II stars like those in the blue horizontal branch of globular clusters. The He/H ratio is estimated to be as much as 100 times less than normal. (3) Stars with normal He and metallic lines are interpreted as members of the horizontal branch in an old Population I, or possibly as "runaway" B stars projected into the galactic halo.

Sargent also observed six horizontal branch stars in the globular clusters M13 and M92 with the prime focus spectrograph; the dispersion was 200 Å/mm. The Balmer series, visible to $n=14$ or $n=15$ in these stars, does not show the abnormally sharp lines described as a characteristic of field horizontal branch stars by other observers. The strength of the *K* line indicates a greater metal deficiency in M92 than M13. Stars in both clusters show a low helium abundance.

Dr. John Phillips of the Berkeley Department has obtained coudé spectrograms of three carbon stars for determination of the $^{12}C/^{13}C$ isotope ratio in both the C_2 and CN bands, and of the C/N abundance ratio. He also has high-dispersion spectrograms of β Aqr and α Per; Sidney Parsons is analyzing them in a study of the atmospheres and chemical composition of F stars.

Dr. Edward K. L. Upton of the Los Angeles Department is observing the spectra of evolved stars of Population II, particularly those stars that are beyond the helium flash. Four CH stars are being studied on spectrograms at 16 and 32 Å/mm; the coolest, TT CVn Cp5 and V Ari C5p5, are probably similar to Harding's star in ω Cen, which lies at the red end of the giant branch. A horizontal branch blue star, BD +39°4926, appears to be an A2 II–III metal deficient star with C and O overabundant by factors of 3 and 20 times the respective solar abundances. The narrow linewidths for higher members of the Balmer series and the large Balmer discontinuity are anomalous, however. A third phase of the program involves RV Tauri stars and other semiregular variables; a spectrogram of AC Her has been obtained and is the first candidate for analysis. Roslyn Reeve has been collaborating in the observations and analysis.

Dr. George Wallerstein of the University of Washington, Seattle, obtained spectrograms of A and F supergiants for comparison with the hydrogen-poor star HD 30353. Preliminary analysis indicates the He/H ratio of the latter is about 10^4 and the effective temperature 10 000° to 12 000°K. Profiles of strong absorption lines on spectrograms of two main-sequence members of the Hyades obtained by Wallerstein were fitted to model atmospheres calculated by K. S. Krishna Swamy, formerly of the Berkeley Department. The best fit indicates a metal abundance for the Hyades stars 25%±25% (limit of error) greater than the metal content of the sun.

Preston has observed the spectra of 40 F stars of luminosity classes II–III to Ib at a dispersion of 5.4 and 8 Å/mm. The distribution of rotational velocities in the sample will be compared with that expected for evolved main-sequence stars and with the distribution for Cepheids and other F-type variables in the Hertzsprung gap.

David Taylor has classified 240 F and G stars

on the MK system on spectrograms which he obtained at the 36-in. refractor.

Sargent has observed the spectra of 89 Her (F2 Ia) and ρ Cas (F8 Ia) in order to follow changes in the features indicating mass loss. The double absorption lines of ρ Cas have not changed appreciably since 1958. Changes in the circumstellar lines in 89 Her were observed in 1965–66; the Hα profile fluctuated with a time scale of a few months, while the blue displaced components of the Na I D lines show no change since 1966.

Stellar Magnetic Fields. Preston has compared the profile of the null line λ4065 of Fe I in β CrB on two spectrograms taken at dispersion of 1.3 Å/mm with profiles calculated for rotating, limb-darkened stars. The upper limit $v_{\rm rot}\sin i \leqslant 3$ km/sec thus derived is larger than the value quoted in the 1964–65 Annual Report and leads to an upper limit for the inclination $i \leqslant 30°$, assuming the star is an oblique rotator. The revised value does not alter the conclusion of Preston and Sturch that the magnetic axis must lie close to the rotational equatorial plane. In the magnetic star HD 188041 Preston has found that the equivalent width of Fe I lines increases with increasing z value; David Taylor collaborated in the analysis. This intensification effect would be expected if the splitting of the σ and π groups of Zeeman components exceeds the thermal or microturbulent Doppler parameter.

Preston is accumulating spectrograms of magnetic stars in Babcock's catalogue in order to increase the number known to show either periodic or irregular magnetic variations.

Diane Pyper is making a detailed study of the A-peculiar star α^2 CVn. Variations of brightness (on the *UBV* system), line strengths, radial velocities, and magnetic field are being examined for evidence to support either the oblique rotator or the oscillator model of a magnetic star.

Sargent has obtained Zeeman spectrograms of three peculiar B stars: (1) 41 Eri, both components of which are "manganese" stars; (2) BD −4°1164 and BD −4°1187, two stars in the Orion I association with abnormally weak He I lines. Preliminary measurements show no magnetic field as large as 1000 G.

Cool Stars. Dr. Hyron Spinrad, Robert F. Wing, and Dr. L. V. Kuhi of the Berkeley Department have observed four "infrared" stars with the photoelectric scanning spectrometer. The Taurus object and TX Cam are very cool Mira variables. In the former the oxide bands H_2O, VO, and TiO are weak for the very red color, but strengthen as the star becomes fainter; the star may be related to S stars with a low O/C ratio. The Cygnus object is nonvariable at 1.0 μ, and has weak TiO and VO bands; the extremely red color is probably partly due to interstellar or circumstellar absorption. The Leo Minor object is a very cool carbon star, resembling V Cygni in the infrared. In mid-June 1966 the visual magnitude was $V=14.0$.

Dr. Ivan King of the Berkeley Department photographed the Taurus and Cygnus infrared stars in good seeing at the prime focus of the 120-in. telescope. Microphotometer tracings by Michael Breger, a Berkeley student, showed the image size to be indistinguishable from that of normal stars.

Spinrad and Walker have obtained infrared spectrograms of R Leo and χ Cyg with the Lallemand image tube. Out to 12 000 Å only a few rather diffuse stellar features were found.

Young Stars. The spectrum of FU Ori as analyzed by Herbig resembles that of an F supergiant; he classifies it as F2:p I–II. There are also resemblances to the spectrum of T Tauri stars: broad absorption lines, an expanding shell, Ca II emission originating below the shell, incipient fluorescence in Fe I lines, and high lithium abundance. Photometric evidence suggests $M_v=-1$ to -2, $R/R_\odot=20$ to 25 and $T_e=6800$°K. Herbig concludes that the 120-day rise from $m_{pg}=16$ to $m_{pg}=10$ in 1936 could have been a collapse from a cooler body of $R/R_\odot=325$ and $T_e\approx 2100$°K, and that the phenomenon can be identified as the final part of the unstable contraction to the top of the vertical, purely convective track in the H-R diagram predicted in the theories of Cameron and Hayashi. The association of FU Ori with the dark cloud B35 and the λ Ori complex, a region which contains both young high-luminosity stars and T Tauri stars, makes such an interpretation plausible.

Kuhi has observed the brighter T Tauri stars with the photoelectric scanning spectrometer. The continuous ultraviolet emission shortward of 3700 Å is strongly correlated with the strength of Hα emission, and the two vary together in the same star; this suggests a Balmer emission continuum. A nonthermal origin can be ruled out by the lack of correlation with other parts of the energy curve. The strong infrared radiation in T Tauri stars found by Mendoza has also been analyzed with the scanning spectrometer, and the possible connection with the very cool infrared stars was not confirmed. The explanation appears to be reddening by interstellar or circumstellar material. The ratio of Paschen to Balmer emission lines in AS 205, AS 209, and T Tau gives such large values for total absorption as to suggest a circumstellar origin.

Walker has obtained additional spectra of YY Orionis stars in young clusters. Sethanne Howard is studying the line profiles and measuring velocity

shifts in order to analyze the apparent infall of material.

Spectrophotometry. Wing has been engaged in a spectrophotometric study of late-type stars with the photoelectric scanning spectrometer on the Crossley reflector. Both the continuum and molecular bands are measured over the range 7800 to 11 000 Å. These observations are supplemented by *UBV* photometry, particularly for variable stars.

Donald Hayes of the Los Angeles Department is using the photoelectric scanning spectrometer on the Crossley reflector to compare Oke's standard stars with a carefully calibrated ribbon filament lamp. Special attention is being given to Vega, for which the energy distribution falls between that given by Oke and by Code; the Balmer discontinuity is 0.07 mag greater than given by Oke. When fitted to a model atmosphere these data give $\log g \approx 3.9$ and $T_e \approx 9200°$K. Final results depend on calibration of the lamps in the Happel Laboratorium in Heidelberg, which originally made the lamps available through an arrangement between Kron and Dr. Hans Kienle.

Planetary Nebula. Dr. Lawrence Aller of the Los Angeles Department has obtained the major share of the spectrographic observations required for determination of the intensities of emission lines in planetary nebulae. During the report year 33 planetaries were observed over the range 3100 to 5700 Å with the prime focus spectrograph of the 120-in. reflector. Spectra of the central stars were also obtained, the brighter ones at the coudé dispersion.

Walker has collaborated with Aller in observations of planetary nebulae with the coudé spectrograph and the Lallemand camera. The speed gain is especially useful in the green–yellow region where the "green dip" of photographic emulsions makes exposures adequate to bring out faint lines prohibitive. In general low excitation nebulae show only λ5876 of He I and λ5198 of [N I]. In NGC 6741, a high excitation nebula, 17 new lines were identified in addition to the seven previously known from Wyse's work; these include lines of [Fe VI] and [Fe VII]. Twelve nebulae were observed over the range 5100 to 5900 Å. A single exposure on NGC 6543 with the S-1 cathode showed no emission in the range 9100–9700 Å, though the exposure reached the continuum of the central star.

Analysis of these data depends in part on target area calculations for collisional excitation of certain ions. There is preliminary evidence for a large spread in the Ne/H and O/H abundance ratios between various planetaries.

Interstellar Medium. Hobbs is making a high-resolution study of interstellar Na I *D* lines with a three-etalon pressure-scanning interference spectrometer made available by the Physics Department of the University of Wisconsin. The instrument is set up at the coudé focus of the 120-in. reflector. A scan of 0.6 Å with a passband of 0.01 Å (resolving power = 600 000) is covered in 20 min and stars as faint as $V = 5.0$ give an acceptable signal-to-noise ratio. A comparison channel permits compensation for variations in atmospheric transmission.

Of the 75 stars thus far observed, 40 showed interstellar lines. The others were mostly bright nearby stars, where the high resolution has not yet led to the certain detection of previously unknown interstellar lines. A strong line appears in scans of 2 And at 19 pc, not new; for α Oph, at 18 pc, the results are uncertain. In a few more distant stars not previously reported as having interstellar lines, an interstellar *D* line was found. Stars listed by Adams as showing interstellar Ca II lines have shown a larger number of interstellar Na I components in 90% of the cases thus far observed. These results, when complete, will give data on individual clouds and cloud velocities. The profile of an absorption line arising in a single cloud indicates the internal velocity distribution of the gas in the cloud.

Herbig has completed his survey of diffuse interstellar absorption lines over the spectral range 4300 to 6700 Å. Accurate wavelengths and intensities have been derived for 26 interstellar features in the spectra of reddened early-type stars. A study of the λ4430 feature in HD 188143 (B7Ia) shows the line is symmetrical, without wide shallow wings. There is no observable fine structure as large as 0.15 Å. The line center is at 4428.0 Å.

Spectra of hot stars located in the direction of high-velocity clouds of H I, taken by Wallerstein with the coudé spectrograph, failed to show any Ca II lines with the same velocity as the hydrogen. Stephen Prata of Berkeley is using the material to set limits on the distances and densities of the hydrogen clouds.

Star Clusters. Sargent has obtained coudé spectrograms of 10 horizontal branch stars in M67 at a dispersion of 48 Å/mm. From the Hγ profile and the Balmer discontinuity values the effective temperature and surface gravity are derived, and used in connection with the known distance modulus to obtain masses. The preliminary results for eight stars give a mass of $0.7\mathfrak{M}_\odot$, indicating mass loss if stars at the main-sequence turnoff point have a mass of $1.1\mathfrak{M}_\odot$, as previously estimated. Two stars had masses of 2.7 and $1.9\mathfrak{M}_\odot$, normal for their position on the extrapolated mean sequence. There

is thus evidence for two stages of star formation in M67.

From a study of the proper motions, magnitudes and colors of 778 stars in the vicinity of the Hyades cluster van Altena concluded that the cluster has 500 members. The total mass is estimated to be $250\mathfrak{M}_\odot$ and the fainter members are concentrated to the center. The main sequence extends to $M_v \approx +14$, with no evidence for members in the contracting phase. Some subdwarfs are probably members. The luminosity function reaches a maximum near $M_v = +13$ and then appears to decrease rapidly.

Chincarini obtained preliminary photoelectric observations of 20 stars in NGC 7039, reported by Schoeneich to have an anomalous giant sequence. The observations indicate a gap on the main sequence.

John Hitchcock of the Berkeley Department is determining the radial brightness profiles of globular clusters, and of the elliptical galaxy M32, by means of photoelectric measurements through concentric annular diaphragms.

Galactic Structure. King has taken a set of photographs of Selected Areas Nos. 51, 57, and 68 at the prime focus of the 120-in. telescope and is using them to determine the colors and magnitudes of faint stars in these high-latitude regions. The objective is to investigate the space density of main-sequence halo stars out to several thousand parsecs from the galactic plane.

In Kinman's RR Lyrae survey the reductions are well advanced in the three anticenter fields; the magnitude calibration is complete and periods of the newly found variables have been determined in two of these fields. In the two remaining fields of the 10 originally selected, those at intermediate galactic latitudes, blinking is about half completed. Wirtanen and Lamla have contributed extensively to the work on this program.

Galaxies. Twelve blue galaxies identified by G. Haro in Field 1196 of the Palomar Sky Survey have been studied by Kinman. From spectrograms obtained at the prime focus of the 120-in. telescope (400 Å/mm) redshifts in the range $0.010 < z < 0.167$ were derived. Photoelectric measurements on the B,V system gave apparent magnitudes $14.4 < V < 17.2$ and colors $+0.34 < (B-V) < +0.69$. Assuming $H = 100$ km sec^{-1} Mpc^{-1} the absolute magnitudes are $-17.0 < m_{pg} < -21.7$. The colors appear to be bluer as the luminosity increases, after an allowance for the K correction is made. The maximum linear dimensions range from 3 to 16 kpc and are correlated with absolute magnitude. The data confirm the results of previous studies: the Haro galaxies are a heterogeneous group. The space densities derived from the present small sample show a smooth variation from 10^{-3} Mpc^{-3} for $M_{pg} = -17$ to 10^{-6} Mpc^{-3} for $M_{pg} = -22$. These densities are comparable with those estimated by van den Bergh for irregular galaxies, but show a smaller spread over the same range of luminosities.

Walker has combined blue and infrared photographs of the Sc galaxy NGC 2903 to make a composite print in which blue areas appear black and red areas white. A white area along the major axis is interpreted as reflecting an underlying population difference, rather than as a reddening effect.

Walker, with the collaboration of Chincarini and Miss Howard, has continued his study of velocity fields in galaxies. An analysis of the velocity curves of NGC 1068 along various position angles has led to the conclusion that the observed maxima and minima are consistent with an arm system that is expanding as well as rotating. An inner arm system tilted with respect to the rest of the galaxy would furnish an alternate explanation. An expansion could be the result of an earlier generation of violent events like that now observed to be occurring in the nucleus of the galaxy.

Whitford has observed the central portions of several galaxies in the local group and the Virgo cluster with the photoelectric scanning spectrometer, using both the Crossley reflector and the 120-in. telescope. The objective is the determination of improved energy curves, particularly for elliptical galaxies, in order to derive K corrections. The wavelength range covered is from 3200 to 11 000 Å.

Spinrad and Ben Taylor, a Berkeley student, have begun a scanner program on galaxies, globular clusters, and standard stars. Both lines and continuum are measured over the range 3880 to 10 700 Å. The purpose is to synthesize the stellar content of the nuclei of galaxies.

King is using photographs of the central regions of several elliptical galaxies made with the 120-in. telescope at times of good seeing to derive photometric profiles. The central brightness peak is always broader than star images on the same plate used to evaluate the instrumental profile. Spectra of the nuclear regions of E and S0 galaxies have been observed in an attempt to measure rotation.

Shane has completed the discussion of the galaxy counts made over the whole sky north of $\delta = -23°$ by Shane and Wirtanen. The counting limit was approximately $m_{pg} = 18.8$. Although the absorbing material in our galaxy is not uniform, a smoothed fit to the cosecant law gives an optical half thickness of 0.50 mag. Several aggregations or superclusters of linear dimensions 6 to 30 Mpc are found.

The mean density of matter concentrated in galaxies is calculated to be 4.3×10^{-31} g cm^{-3}.

Dr. Margaret Burbidge of the University of California, San Diego, has used the prime focus spectrograph at the 120-in. telescope to obtain radial velocities of additional newly identified radio galaxies. Spectra of nearby nonradio galaxies were also observed as a part of a continuing study of internal motions and emission line intensities.

Quasi-Stellar Radio Sources. A program for identification and further study of quasi-stellar radio objects has been undertaken by Kinman in collaboration with Dr. J. G. Bolton of the CSIRO Radiophysics Laboratory, Sydney. The radio data are from the Parkes radio telescope. Preliminary optical identifications suggested by Dr. Bolton have been tested by Lamla and Kinman, using the Ryle–Sandage two-exposure method of finding objects with an ultraviolet excess. Further confirmation has come from comparison of high-precision radio positions with optical positions measured by Wirtanen and Kinman. During the year 27 sources were identified, a significant increase in the number of identified quasi-stellar radio objects at southern declinations. *UBV* photometry was completed for a number of these sources.

Kinman and Margaret Burbidge have obtained redshifts for 14 quasi-stellar sources, seven of them discovered in the above-mentioned program. The Carnegie image tube spectrograph accelerated this work and was particularly useful in the visual and red regions of the spectrum. The redshifts are in the range $0.361<z<1.982$. The spectrum of one of several radio sources identified with very red compact optical objects (1107+10) suggests a low absolute magnitude; possibly the object is associated with NGC 3547, and Sc galaxy about 2′ away.

In addition to the above-mentioned redshifts Margaret Burbidge established redshifts for 3C208 ($z=1.109$) and 0106+01 ($z=2.107$). The object 3C191 had a redshift $z=1.952$ from emission lines, but all of a considerable number of narrow absorption lines were consistent in showing $z=1.9460$. The narrow absorption lines gave reason to question whether a large velocity spread in the emitting gas is a satisfactory explanation for the broad emission lines in quasi-stellar objects. An examination of the spectra of 48 objects by Geoffrey and Margaret Burbidge, Fred Hoyle, and C. R. Lynds showed the permitted lines Ly-α, C IV λ1549, and Mg II λ2728 are generally wider than forbidden lines. A difference in line width in this sense would be expected in an electron-scattering medium. An empirical model based on this finding is able to account for the observed spectroscopic features in these objects.

Wampler has made scanner measurements of four quasi-stellar objects ($0.595<z<2.012$) over the spectral range 3100 to 7000 Å. In general the continuum can be represented by a straight line on a ν, $\log f_\nu$ plot. The three objects observed across the redshifted wavelength of the Balmer limit show no detectable discontinuity, contrary to expectation if the continuum is ascribed to radiation from an optically thin hydrogen gas. The red wing of the Mg II line in 3C345 appears to be variable and a slight change of color with brightness was observed. Variations of the Mg II line were also noted by Margaret Burbidge on her spectrograms.

Dr. George Field of the Berkeley Department, Dr. Philip Solomon of Princeton and Wampler used the latter's scanner observations of 3C9 down to 3050 Å (source wavelength = 1012 Å) to evaluate the intergalactic density of H_2 molecules. The upper limit to the possibly observed absorption by the Lyman bands shortward of 1108 Å leads to a maximum molecular density of 4×10^{-9} cm^{-3}, a completely negligible fraction of the cosmological density. If the intergalactic gas is principally in the form of H II, hydrogen molecules would not survive the radiation field, and their absence is consistent with the absence of H I found by Gunn and Peterson.

Kinman, Lamla, and Wirtanen are carrying on a program for photographic monitoring of the brightness of quasi-stellar radio sources, using the Crossley reflector and the Carnegie astrograph. In 3C345 variations of several tenths of a magnitude with a time scale of the order of 20 days were found by Donald Goldsmith (a Berkeley student) and Kinman in mid-1965. Larger and more rapid variations were observed in October and December 1965. In 1966 the object has remained quiescent. The object 3C279 has brightened significantly in the past year.

Blue Stellar Objects. All but one of the blue stars identified by G. Haro on Field 1196 of the Palomar Sky Survey proved to have a stellar spectrum when surveyed by Kinman with the prime focus spectrograph of the 120-in. telescope. The exception, PHL 938, shows the broad emission lines and blue continuum characteristic of radio sources. A redshift $z=1.93$ was derived from three emission lines. Absorption features were detected in the shortward wings of Ly-α and C IV λ1549. The magnitude and color are typical of a quasi-stellar radio source ($V=17.16$, $B-V=+0.32$, $U-B=-0.88$). The luminosity computed from a cosmological interpretation of the redshift places PHL 938 among the brightest of the radio sources. J. G. Bolton was

unable to detect any radio emission with the Parkes radio telescope; the limits of detection were 0.1 flux unit at 11 cm and 0.15 flux unit at 50 cm.

X-Ray Source. A faint nebula on a direct photograph made by Margaret Burbidge with the 120-in. telescope was considered as a possible identification of the radio source Sco X–R 1. A spectrum obtained by Mrs. Burbidge showed the object to be a normal external galaxy without strong emission lines. Another possible candidate proved to be a galactic star. Dr. Ricardo Giacconi of American Science and Engineering furnished information on positions.

A. E. WHITFORD, *Director*

Lockheed Observatory, Astronomical Sciences Laboratory, Lockheed-California Company, Burbank, California

Personnel, From 1 July 1965 to 26 July 1965 the Lockheed Observatory was under direction of D. S. Webber. After this period it was under the supervision of L. G. Stoddard. The solar observing staff consisted of H. E. Ramsey as Chief Observer with Sara F. Smith, George A. Carroll, Samuel Miller, and Neil W. Christie (until May 1966) as full-time staff members. Donald G. Carson was Chief Observer of the Lunar and Planetary Program on the 30-in. Stony Ridge reflector with Marshall Ogne as a part-time staff member.

Visiting astronomers during the past year included Dr. D. H. Menzel, Director of Harvard Observatory, Dr. Peter Sturrock of Stanford University, Dr. R. A. Howard of Mt. Wilson and Palomar Observatories, Dr. H. Zirin of California Institute of Technology, Mr. Victor Gaizauskas of the Dominion Observatory, Ottawa, Canada, Dr. Richard White of Sacramento Peak Observatory, and Richard Hansen and Jack Harvey of High Altitude Observatory.

Equipment. In October solar observations with the spar at Briar Summit were discontinued and the spar returned to High Altitude Observatory. Prior to this, however, the observational program had been transferred to the new spar at Lockheed's Rye Canyon Research Center. This new location is at an elevation of 1260 ft at longitude 118° 34′.7 *W* and latitude 34° 27′.3 *N*. Experience to date indicates that the site is excellent for cinematographic observations of the sun. Image quality appears to be somewhat superior to Briar Summit, and the percentage of clear sky greater.

The new spar structurally is quite unusual and is designed to reduce weight while maintaining sufficient stiffness. The 12-ft spar member is of truss construction with an x-shaped cross section and is equatorially mounted in a short fork. A photoelectric guider is mounted in a tube which forms the hub of the spar. The entire spar with optical systems is enclosed in a cylindrical cowling with various access doors to the interior instruments. The improved aerodynamic shape and higher frequencies on the mount have considerably reduced wind buffeting.

Nested within the four internal quadrants of the spar are the various optical systems attached to the truss member that serves essentially as an optical bench.

In one quadrant is the Hα combined disk and limb patrol system (Carroll, G., *Publ. Astron. Soc. Pacific* **77**, 431, 1965).

The second quadrant contains a large-scale Hα system employing a 7-in. objective that will give a more detailed view of active regions. An identical system employing a calcium II K_3 line birefringent filter will occupy the third quadrant of the spar. Both of these systems will give a solar image 50 to 150 mm in diameter.

The fourth quadrant will be filled with an all reflecting system employing a 6-in. off-axis quartz paraboloid. With this achromatic system observations can be extended into the near ultraviolet as well as into the infrared.

Observing Program. The Hα combined solar disk and limb patrol is operated during all possible observing times. During the period of this report, 2430 h of photographic observations were obtained. Exposures are programmed to give frames in which the 0.5 Å bandpass of the birefringent filter is centered sequentially on Hα and about 0.5 Å from Hα on each side. The rate is two to six frames a minute, depending on the level of solar activity. Under a contract with the Environmental Science Services Administration, the results of the patrol are reported daily to the Radio Warning Service as well as being sent to World Data Center A.

A program of time-lapse photography on large scale utilizing a 3 Å interference filter centered on Hα was initiated in 1965 as a means of correlating photospheric and chromospheric phenomena. The 3 Å filter used in conjunction with higher contrast type 5E film is capable of recording all changes in photospheric features as well as the flash phase of chromospheric flares. Features exhibiting strong Doppler shifts (high-speed ejecta) normally not visible in narrow band are clearly visible with the new broad-band system. Ellerman bombs, low chromospheric in origin, and also not detectable with a narrow-band filter, are also easily seen.

The narrow band (0.5 Å) high-resolution time-lapse studies of the sun in Hα are continuing with

a threefold purpose. First in connection with large-scale broad-band studies to further correlate photospheric and chromospheric activity. Second, to obtain high-resolution observations of the development of major solar flares. These objectives are being attained with observational material of extremely high quality.

The third objective is to extend an idea started by Jack Harvey while at Lockheed in order to obtain information on strong chromospheric magnetic fields. This is a technique for exploiting the Zeeman effect in narrow-band Hα photography, and thus vastly improving time and spatial resolution for detection of changes in strong magnetic fields associated with flares. The system was modified by adding a rotatable quarter-wave plate. Minor changes in the camera and intervalometer permitted acquisition of photographic pairs of pictures with different polarization and less than one second apart in time. Photographic subtraction between the pairs reveals the general appearance of the longitudinal magnetic fields. Since the two frames are taken less than a second apart, atmospheric seeing differences are minimized. Results to date have been very promising and the development of this technique will continue.

Lunar observations with the 30-in. Stony Ridge reflector were confined to bandpass photography of selected areas taken at the Cassegrainian focus with the specially built Lockheed 70-mm lunar camera. A large portion of this effort was contract work for JPL. In addition, the Ranger IX impact was photographed in 35-mm time lapse with color film. However, results were negative.

Attempts were made by Carson to detect lunar luminescence in the bottom of the Hα line using a 0.5 Å birefringent filter with the 4-in. portable solar telescope. Luminescence was detected but improved filters with better thermal control are required before meaningful quantitative results can be obtained. Narrower bandpasses and more accurate thermal control is required in order to stay in the bottom of the line. Intensity in the bottom of the line is compared photoelectrically with the nearby continuum. This effort is being undertaken to investigate possible correlation between solar flares and lunar luminescence.

Research. The program of solar research is based on the concepts of regular patrol-type observations of the sun over periods as long as are practicable, and the analysis of these observations by cinematographic projection. In this way percursor phenomena have been recorded for many interesting chromospheric events as well as the events themselves, and the analysis has tended to emphasize and provide the means of studying these events in terms of their developments in time.

A study was made of abruptly disturbed filaments photographed in Hα at 10-sec intervals by the Lockheed flare patrol. This study has been supported to considerable extent by ARPA through ONR Contract Nonr-4537 (00). The abrupt disturbance of each filament was initiated during the occurrence of a major flare at a separate location on the solar disk. The results of this study by Ramsey and Smith have been presented in the *Astronomical Journal*, April 1966.

Eclipse Expeditions. With Air Force support, Lockheed sent two expeditions to Africa, and obtained large-scale high-quality photographs of the annular eclipses of 31 July 1962 and 25 January 1963. The major system employed a horizontal telescope consisting of a 17-in. coelostat (using a Mt. Wilson flat), a 12-in. *f*/57 mirror and a K-22 aerial camera body as the film transport system. Eastman S0-105, a slow, high-resolution blue-sensitive emulsion was used. These films, obtained for selenodetic purposes were reduced under Air Force Contract AF 19 (628)-4162 and the results published in July 1966 issue of *Icarus*.

Lockheed sent an expedition to Hogan Hill, Alaska, to observe the total eclispe of 20 July 1963. The system used in Africa plus a smaller system were used for coronal and limb-darkening studies. Thin cirrus rendered any photometric work questionable. Consequently only a geometrical study of the polar rays as photographed with the large system was deemed the only valuable result of the expedition. The results were presented in the September 1966 issue of the *Astrophysical Journal.*

A fourth expedition funded by the Air Force under Contract AF 19 (628)-5714 observed the annular eclipse of 23 November 1965 from Chiengmai, Thailand, again with selenodetic objectives in mind. The photographs from this expedition are presently being reduced under Air Force Contract AF 19 (628)-5997.

LAURENCE G. STODDARD, *Manager*

Louisiana State University Observatory, Baton Rouge, Louisiana

Personnel. Raymond T. Grenchik and Arlo U. Landolt make up the astronomy group of the Department of Physics and Astronomy. Drs. Charles L. Perry and David Sher will join the staff in September 1966 as Assistant Professors, and Dr. Graham Hill as a postdoctoral fellow. Assistantships for the academic year were held by John Hubbell, William J. Reynolds, and Randall L.

Stephens. Planetarium and open house lectures at the 11½-in. refractor telescope were given by Gary Fortmayer and Marion Soileau. Lewis M. Cook served as an undergraduate research assistant. Misses Melissa Hood and Michelle Menton were Data Reduction Technicians.

Research. The photographic investigation by Landolt of variable stars in Taurus and Scorpio–Ophiuchus has been continued with support from the National Science Foundation. A new blink microscope, duplicate of the Kitt Peak model, has been acquired from the Humboldt Instrument Company, and is presently being used in the variable star program. It can accommodate plates up to the size of the National Geographic–Mount Palomar Sky Survey (14 in. square).

A study of O–Of stars was initiated by Landolt with support from the National Aeronautics and Space Administration. The program has two immediate objectives: (1) to check the spectroscopic evidence which indicates the possible variability of the N III emission lines at λλ 4634, 4640, and λ 4641, and (2) to investigate the suitability of these nitrogen emission lines as luminosity criteria. The behavior of the λ 4686 (He II) line is also being monitored. The observational index to be defined at each effective wavelength results from a comparison of the intensity observed through a 40 Å half-width filter to that measured through a filter of 180 Å half-width. Observations have been made with the 16- and 36-in. telescopes of Kitt Peak National Observatory; data reduction is in progress. Additional photoelectric observations, also acquired at Kitt Peak, were made in three colors of the eclipsing binary V382 Cygni in a continuing effort to detect any possible variations in this massive system. A grant to Landolt from the Louisiana State University Graduate Research Council allowed a trip to Cerro Tololo in Chile, and the subsequent acquisition of additional *U*, *B*, *V* photoelectric data on the eclipsing binaries GV Car and BF Cen, apparently members of the galactic clusters NGC 3532 and NGC 3766, respectively. The light curves for both systems are now well covered observationally: data reduction is in progress. Observations in *U*, *B*, *V* were made of long-period variables near maximum brightness by Landolt at the Kitt Peak 16-in. telescope. He also made *U*, *B*, *V* photoelectric observations of the recently announced very short period ($P < 0^d.1707$), variable radial velocity star HD 107904, and found a maximum light variation of 0.10 mag in *V*. Insufficient data were available to unravel the observed variable light curve which indicated the presence of multiple periods. This latter material is in press.

Equipment. The National Science Foundation has awarded a grant of $227 900 to Louisiana State University for construction of a 36-in. Cassegrain reflector and supporting facilities. The telescope will be located on LSU's Idlewild Plantation some 37 miles from the Baton Rouge Campus, and four miles southeast of Clinton, Louisiana. The university will supply a minimum of matching funds. A short screw (100 mm) Gaertner measuring engine is on order; it will also possess motion in the *Y* coordinate.

Instruction. In the two semesters and the past summer the enrollment in the elementary classes and laboratories has climbed to over 1800. Advanced classes were given in Introduction to Stellar Astrophysics, Astronomical Spectroscopy, Galactic Structure, and a Special Topics Seminar course on binaries and photometric problems. Grenchik taught the Astronomy–Physics section of the SSTP program for high school students this summer. Degrees awarded in the Departments' Physics and Astronomy Program included: Gary Fortmayer, Bachelor Degree; David H. Potter, Master's degree; and Fred Ellis, a Ph.D. degree.

Miscellaneous. Grenchik continued as a participant in the Visiting Scientist program to high schools in Louisiana. Grenchik and Landolt took part in the NSF Visiting Professors Program to colleges in the southern states. Grenchik has been appointed to the Committee on Education in Astronomy.

Visitors and lecturers to the Department during the 1965–66 academic year were Drs. John Bahcall, Richard Sears, Arthur Vaughan, Jr., Robert H. Koch, Graham Hill, William Irvine, and A. J. Harris.

ARLO U. LANDOLT, *in charge*

Lowell Observatory, Flagstaff, Arizona

Personnel. O. G. Franz and Wm. A. Baum were appointed to the staff; Baum as Director of the Planetary Research Center. G. E. Fischbacher and S. D. Pratt joined the Center. K. Rost was hired as an electronics specialist. Other appointments were as follows: As illustrators in the Air Force (ACIC) Group, G. L. Gibbons, J. L. Inge, T. F. Mitchell, C. E. Snyder, Jr; and as an observer, L. A. Riley, and B. J. Wong as photographic technician. E. A. Roe was appointed as instrument maker and B. Hargraves as secretary. Placed on temporary appointment were R. Millis, T. A. Abdoo, J. B. DeVeny, H. L. Cohen, D. B. Hoyt, M. R. Myers and C. McIntyre. Resignations were B. G. Bush, D. R. Gathright, E. J. Lawson. Guest in-

vestigators included: J. Adler, W. K. Ford, Jr., R. C. Hall, G. Hunt, K. Johansen, M. Jerzykiewicz, E. H. Olsen, T. Roark, V. C. Rubin, J. W. Salisbury and K. Serkowski.

Physical Plant. The 69-in. Cassegrain mirrors in the Perkins reflector of the Ohio Wesleyan and Ohio State Universities at the Lowell Observatory were replaced in September by a 72-in. Cassegrain primary, made of low-expansion Duran-50 glass, and a quartz secondary. As a result, the amount of scattered light has been reduced by factors of 10 to 30 (depending on wavelength) and the exposure times for spectroscopic work in the blue region have been cut in half. This important change, together with a revised declination slewing and setting system, was made possible by an NSF grant.

A 30-in. spherical primary mirror, which is a part of a Schmidt system delivered to the Lowell Observatory by Perkin-Elmer during World War II, was installed in place of the damaged 42-in. primary mirror in the mounting made by Alvan Clark in 1909. A secondary mirror designed by D. Schulte to match the primary was figured at Tinsley Laboratories. The combination gives very satisfactory axial images.

The mechanical parts for a completely new tracking drive for the 24-in. Lowell refractor were designed and completed. This new system will incorporate new fine motions in right ascension.

Planetary Research Center. Considerable progress has been made in the organization and distribution of photographic material. This work has been continued by Stuart Jones and Kent De Groff, assisted by C. McIntyre, S. Pratt, and T. Abdoo.

The most important addition resulted from the copying of the entire Lick collection of planetary photographs dating back to 1890. Two of the four sets of photographic copies made of the Lick collection have been sent to Meudon in connection with the international exchange program. Each set included 485 copies of Mars, 1153 of Jupiter, 174 of Saturn, and 90 of Venus. Four copies were also made of 139 plates obtained at Mount Wilson Observatory by Wilson and Richardson during the 1958 opposition of Mars. Three copies, one for Meudon, were prepared of a continuous time-laspe sequence of Jupiter obtained by Jones and Horstman in 1964.

Two years ago, the preparation of data cards and two complete sets of punched cards of the Lowell plate collection was begun. This task was carried through to completion by Helen Horstman early this year. Since then, similar cards have also been prepared for the collections copied from Lick Observatory, Mount Wilson Observatory (1958), Yerkes Observatory, and McDonald Observatory. The preparation of cards will now be kept current with new observations as they are obtained. A computer program was completed by De Groff for calculating various geometric parameters associated with photographs in the combined Planetary Research Center collection.

Other material received and catalogued included films and prints from the Data Center at Meudon, New Mexico State University Observatory, and JPL's Table Mountain Observatory.

Using copies of Mars plates from the Lowell collection, J. Pollack of the Harvard College Observatory and Smithsonian Astrophysical Observatory has undertaken a study of yellow clouds to compare with theoretical ideas as to their origin. As a collaborator in this program, Stuart Jones has supervised the preparation of photometrically controlled duplicates of original plates with sensitometric calibration on them.

A program for the systematic study of all Mars plates was initiated for the purpose of collecting data on the distribution of clouds and haze. This program, aided by supplementary support from JPL, is being carried forward under Baum's direction. A special instrument for projecting Mars images at an adjustable scale and orientation is being built by the Richardson Camera Company from a design developed by Baum. A preliminary survey of the Mars plates and of cloudiness criteria is being made by Fischbacher and De Groff.

Five sector-wheel sensitometers of a new design by Baum and Millis are nearing completion in the Observatory shop. Four of these will be used elsewhere so that plates taken at five different locations may be calibrated in the same way.

Jupiter was observed photographically by De Groff in January and Febraury in cooperation with New Mexico State University Observatory for the purpose of determining cloud motions in the vicinity of the great red spot. He also made tests at the 24-in. refractor on several different types of 35-mm films to determine which type provided the most image information per unit exposure time. The best results were obtained with Eastman Type III and Type IV spectroscopic emulsions for exposure times in the range of 1 to 10 sec. De Groff also obtained photographs of Comet Ikeya-Seki 1965*f* in October and November.

Experiments were made by Baum with a prechargeable thermoluminescent phosphor, together with a special photographic device, to determine whether planetary photographs could be made in the infrared by such a technique. Present materials were found to be too grainy and nonuniform, but subsequent developments may open up new possibilities.

Proper Motion. The proper motion survey of the northern hemisphere with the 13-in. photographic telescope for stars with motions $>0''.27$/yr has been continued by R. Burnham, Jr., and N. G. Thomas under the direction of H. L. Giclas.

Two Lowell Observatory Bulletins containing further results have been published, and material for an additional 10-plate series containing 659 stars is being prepared for publication. *Lowell Bulletin* No. 129 lists 612 proper motion stars, 277 of which are newly discovered. Three have motions $>1''.0$/yr and 48 have motions $>0''.5$/yr. *Lowell Bulletin* No. 132 lists 462 stars, 138 of which are newly discovered. One has a motion $>1''.0$/yr, 34 have motions $>0''.5$/yr. Eighteen white dwarf suspects with motions $>0''.27$/yr are included in these publications.

During the year, the white dwarf character of over 100 suspects listed in these publications has been verified chiefly by Greenstein spectroscopically and Eggen photoelectrically. The star with the largest proper motion ($2''.27$/yr) discovered thus far in this program, G175-34, turned out to be an interesting close double star of an approximately constant separation of about 6 sec of arc, but changing in position angle by about one degree per year. One component is red, the other very probably a white dwarf as indicated by the value of $U-B = -0^{m}.53$ determined by Hardie.

M. Jerzykiewicz has observed a number of the catalogue stars photoelectrically.

Interferometric Spectroscopy. Boyce and Sinton observed with L. Mertz, using the latter's interferometer on the 61-in. reflector of the Harvard College Observatory in April 1966, and obtained numerous infrared spectra of late-type stars.

Sinton and Boyce concluded their interferometric spectral survey of stars in the 2.0 and 2.6 μ region. Sinton completed a computer program which computes the equivalent width of the stellar CO bands at 2.93 μ and also determines the depression of the continuum from 2.0 to 2.27 μ caused by stellar water vapor, thus providing a measure of the strength of the stellar water vapor band at 1.9 μ. The equivalent widths of the CO bands at 2.93 have been determined as a function of spectral type and luminosity. CO first appears at spectral type K and is much stronger in supergiants. In addition, the variation of the CO and H_2O bands has been studied as a function of phase in the long-period variables χ Cygni and R Leonis. The CO equivalent width remains essentially constant in R Leonis but the H_2O strength varies in phase with the light variations as might be expected. In χ Cygni, both CO and H_2O vary, but not in phase with the light variations.

Spectrophotometric Observations. Boyce, using the Lowell Observatory spectrophotometer, continued his photoelectric investigation of the emission line intensities as a function of position in the Orion Nebula and initiated a program of planetary nebula observations. Boyce and Jerzykiewicz determined the energy distribution for five β Canis Majoris stars using the standard stars calibrated by Oke.

Miss Myers, working in collaboration with Boyce, has developed a versatile computer reduction program for spectrophotometric observations of stars and nebulae.

Ikeya-Seki 1965*f*. Boyce and Sinton observed the sun-grazing comet during daylight hours from 19 October to 22 October with the spectrophotometer attached to the 24-in. reflector. They found strong emission in the sodium *D* lines and ionized calcium *H* and *K* lines. They were unable to detect any of the usual cometary bands.

Area Scanning. An area scanning attachment for the Lowell Observatory spectrophotometer was designed and constructed under the supervision of Boyce. He demonstrated the usefulness of such equipment by obtaining photoelectric intensity profiles of several planetary nebulae in the light of various atoms. The stratification was immediately apparent despite the poor analogue output from the multichannel analyzer. This program is being continued with improved digital readout.

Franz and Boyce, using the Rakos area scanner, carried out observations of several eclipses of the Galilean satellites of Juptier. The results, although scanty and only preliminary in nature, are substantially in agreement with those previously reported by Cruikshank and Binder.

Lunar Mapping. The air Force (ACIC) Group has completed mapping 30 out of 77 lunar regions at a scale of 1:1 000 000. Eighteen of 20 equatorial regions have been mapped at twice the scale or 1:500 000. Visual and photographic observations obtained with the Lowell 20- and 24-in. refractors and the Perkins 72-in. reflector played a prominent role in the acquisition of the basic data required.

Seven maps were completed from data obtained from Ranger VIII and six maps from Ranger IX photographs.

At the request of the ACIC Group, the Naval Observatory has kindly obtained a number of photographs of the full moon with its 61-in. astrometric reflector. These long-exposure photographs (up to 90 sec in duration) taken chiefly by J. B. Priser of the U. S. Naval Observatory are of remarkably high quality; they have provided accurate selenodetic data and have been used as a basis for preparation of a photomosaic of the equatorial zone of the moon.

Photoelectric Scans of Close Double Stars. Using

the photoelectric area scanner developed by Rakos (1965), Franz (1966) carried out exploratory photometric and astrometric observations of visual double stars with separations as small as 2 sec of arc. The results of these experiments led to the following conclusions:

A photoelectric area scanner specifically designed for double star work and used in conjunction with a suitable system of signal integration and data recording can be expected to yield accurate photometric data for the components of double stars heretofore inaccessible to photoelectric methods.

This scanning technique also yields relative positions of double star components with an accuracy at least equal to that attainable by the much more laborious technique of multiple-exposure photography.

Solar Variations. K. Serkowski has continued the observations for the Solar Variations program through the 1965–66 observing period. This program, begun in 1950, is now being concluded and the final report is being prepared by M. Jerzykiewicz and K. Serkowski.

The photometric observations of Neptune, corrected for the effects of changing distance, indicate a decrease in the blue magnitude from 8.25 to 8.23 during the years 1953 to 1962; in the 1963 to 1966 interval this magnitude is constant and equal to 8.24. The intrinsic brightness of Uranus does not indicate changes during the years 1950 to 1966 if the observations are reduced on the assumption that the surface brightness of the planet at its pole is 20% less than at the equator.

The 16 stars of spectral types F and G, with which the brightness of planets was compared, indicate remarkable constancy of brightness during the interval 1955 to 1966.

Colorimetry and Polarimetry. The photoelectric observations of the color and polarization of NGC 2068, 7023, and IC 349, mentioned in the previous report, were published (*Lowell Obs. Bull.* **VI**, No. 135, 257–269, 1966). Most of this joint program was carried on at the 69-in. Perkins telescope by A. Elvius and J. S. Hall. Color observations of the nebulosity south of Merope were later made on four nights in the fall of 1965 with the new 72-in. optics.

Photoelectric narrow-band photometry with interference filters has been used by Karen Johansen for spectral classification of A0, G, and K stars. A0 stars brighter than the 6th mag, A0 stars in clusters and the variables AR Aurigae and β Aurigae have been observed through Hβ filters and in four spectral regions corresponding to the Stromgren *uvby* system. In collaboration with K. Gyldenkerne at the Copenhagen University Observatory nearly all stars (470) of spectral types G5 to K5 and luminosity classes mainly from II to IV, brighter than the 5.5th mag and north of $-30°$ declination, have been observed through seven filters. Their half widths are from 30 to 95 Å, and their centers between 3900 and 4970 Å. This system is an improvement of Gyldenkerne's three-dimensional classification system (*Publ. Medd. Kobenhavns Obs.* No 178 and 180). In addition, some high-velocity stars brighter than the 8th mag and two RV Tauri variables, R Scuti and U Monocerotis, have been observed on this system by Erik Heyn Olsen.

UBV observations of 172 stars in the region of the open cluster Stock 2 in Perseus, made by W. Krzeminski and K. Serkowski at the 60-in. Mount Wilson reflector and the Lowell 42-in. reflector respectively, indicate that the distance of this cluster is 316 pc, its mean reddening $E_{B-V}=0.37$ mag, and the ratio of total-to-selective interstellar extinction for this nearby region is $R=3.4$. Polarimetric observations support the conclusions drawn from photometric and astrometric evidence that four red giants are members of the cluster (to be published).

Polarimetric observations of red long-period variables by K. Serkowski revealed that most of these stars have variable intrinsic polarization which is larger in the ultraviolet than in the yellow and blue spectral regions. The position angle of the plane of vibration is usually different in each spectral region, changing gradually from yellow to ultraviolet. (*Astrophys. J.* **144**, 857, 1966, and *IAU Inform. Bull. Variable Stars* No. 141.)

The wavelength dependence of interstellar polarization for about 30 stars in the *UBV* spectral regions was measured by K. Serkowski with the Perkins telescope and the 24-in. Morgan telescope during the autumn of 1965 with a polarimeter constructed by J. S. Hall. He found a very anomalous wavelength dependence of interstellar polarization for the star HD 148889. Its polarization in the ultraviolet is half that in the yellow. This result was confirmed by observations made by Serkowski with the 61-in. telescope of the Lunar and Planetary Laboratory of the University of Arizona in Tucson with a polarimeter constructed by T. Gehrels.

The polarimetric observations of β Lyrae companions B and F indicate that their polarization is similar to that of β Lyrae at secondary minimum. This suggests that the intrinsic component of polarization vanishes for β Lyrae at secondary minimum.

M. Jerzykiewicz made a long series of photoelectric *UBV* observations of several variable stars of the β Canis Majoris type. His paper "Possibility of a Beat Phenomenon in the Light Variation of

Delphini" was published in *Lowell Observatory Bulletin* No. 133.

Image Tubes. RCA cascaded converters were used in combination with a DTM grating spectrograph attached to the Cassegrain focus of the Perkins 72-in. telescope for observations of several types of objects by W. K. Ford, Jr., V. Rubin, W. A. Baum, O. G. Franz, and P. B. Boyce. These included spectra of quasi-stellar sources, exploratory classification spectra of galactic nuclei, classification spectra of visual double-star components, and spectra of gaseous nebulae. Boyce and Ford used the infrared converter to obtain spectra of the Leighton infrared object in Taurus, which clearly shows the presence of stellar water vapor, and of the central star in the Orion Nebula, O′ (C) Orionis, which shows a sharp absorption line at λ10830 due to interstellar helium (*Publ. Astron. Soc. Pacific* **78**, 163, 1966).

A new Cassegrain Schmidt optical system designed by I. S. Bowen was completed by Davidson Optronics and was fitted into a special mounting and focus-control system designed by Baum. The Cassegrain Schmidt will provide improved input imaging to the photocathode. Tests of performance are in progress. A study of parallel-field electron focusing with permanent magnets was completed by Baum and reported on at the Third Symposium on Photoelectronic Image Devices in London.

Historic Landmark. The Lowell Observatory was designated by the U. S. Department of the Interior as a Registered National Historic Landmark on 14 June 1966. The bronze plaque reads, in part, "This Site Possesses Exceptional Value in Commemorating or Illustrating the History of the United States of America."

JOHN S. HALL, *Director*

The Observatories of The University of Michigan

THE OBSERVATORY OF THE UNIVERSITY OF MICHIGAN

The 12-in. Refractor and the Walker Meridian Circle, and The Students' Observatory. The four telescopes in these units of the Observatory were used almost exclusively for undergraduate instruction at an introductory level. The number of students enrolled in courses that use these instruments has for several years been limited by the allotted classroom space and the observing time available. Dr. Hazel Losh and Dr. John Williams have been responsible for the efficient use of these facilities under almost impossibly crowded conditions.

The 37-in. Reflector. Dr. McLaughlin supervised the continuing program until the beginning of his sabbatical leave at the end of August 1965. After that date, Dr. Bidelman assumed the responsibility for the research programs. During the year 1 July 1965 to 1 July 1966, 400 spectrograms, mostly of Be stars, were obtained.

The detailed Michigan records for the B-type emission-line stars 105 Tauri and 8^N Lacertae have been prepared for publication by McLaughlin.

High-dispersion studies of the brighter Be stars were continued with the 37-in. reflector, and the program also included considerable activity in spectral classification and determination of radial velocities for stars that have been classified as weak-metal objects by Bidelman on objective-prism plates. Other programs in spectral classification are in progress.

Miss J. Robinson obtained spectra in the visual region of more than 100 of the brighter early-type stars in a 60° by 60° region centered at $l=180°$, $b=0°$. Several new Hα-emission stars were found, the most notable is HR 1906. Miss Robinson's program will be extended to include all of the earlier-type members of the Orion association.

THE LAMONT–HUSSEY OBSERVATORY

A second list of measurements of the stars discovered at this observatory to be double has been prepared for publication by Mr. Frank Holden, Astronomer-in-Charge. Holden has continued his close cooperation with the astronomers of the Republic Observatory, and other active measurers of double stars.

THE MCMATH–HULBERT OBSERVATORY

Maintenance and Construction. The dome and the coelostat of the McGregor tower telescope were completely renovated and repainted. The library was repainted and refurbished. The observing room for the vacuum spectrograph and the storage building for tools were repainted. The solar telescopes, spectrographs, ionospheric and geomagnetic recorders have been maintained in efficient and effective running condition. The shop has constructed new components for driving the grating in the vacuum spectrograph, the third version of the double-pass system, oscillating slits for the spectrohelioscope, and an infrared spectrometer.

Observational Programs. Daily observations of calcium plages were contined in the 50-ft tower. These observations are the fundamental bases for the McMath–Hulbert programs but they are also distributed to other users. The developing activity that forms the ascending branch of solar cycle 20 has directed special interest to the daily records.

In the calendar year 1965, calcium spectroheliograms were secured on 291 days. This number of days is about 5% below the average.

During the 12 months covered by this report, the McGregor solar telescope and vacuum spectrograph were used on 155 days. Observations were obtained on the fine structure of Fraunhofer lines, profiles of the *H* and *K* lines in integrated sunlight, and from selected areas of the sun's disk, and the magnetic polarities of all sunspots. The McGregor telescope was out of use from 5 June 1965 to 25 July 1965, while the dome and coelostat were being painted.

The patrol program for the Lyot photoheliograph has continued. Approximately 182 000 Hα photographs of the solar disk were secured during 1565 observing hours. Measurements of the photographs made with this instrument have been contributed to the centers designated as repositories for solar flare data. These same measurements are fundamental for the observatory's research studies.

Research Studies Based on Observations at the McMath-Hulbert Observatory. Dr. Teske has compared the scale of magnetic field measurements made at the McMath–Hulbert Observatory with the scales of the measurements made at other solar observatories. His study suggests that there is no unique relationship between sunspot area and magnetic field strength. The relationships that have been derived and published seem to be heavily biased by systematic observational errors.

Teske also secured detailed measurements of the magnetic fields in a large spot group during a fairly large solar flare that occurred on 31 March 1966. Concomitant observations were made with the 50-ft tower spectroheliograph and the Lyot photoheliograph.

Dr. Elste continued his study in detail of the center-to-limb variations in faint lines of the solar spectrum. He has also attempted a differentiation between the profiles of lines formed in the umbrae and those formed in the penumbrae of sunspots.

In cooperation with the working group of the International Astronomical Union Commission 12 on central line intensities, a large number of photoelectric recordings of the solar spectrum lines Fe 5295.3 Å and Ti 5145.5 Å were made using the fifth order of the vacuum spectrograph in the McGregor solar tower under carefully specified conditions.

Teske continues to collect and to measure profiles of the central regions of the Ca II *H* and *K* lines. The profiles have been obtained for lines formed at many different positions of the solar disk. The amount of parasitic light in the centers of the lines has been re-evaluated. Turbulent velocities, derived from the profiles of lines formed within and near plage areas, and formed in regions far from plages are being compared.

Miss Hedeman has completed her extensive survey of the solar activity during solar cycle 19. The principal solar and geophysical events of this 10-yr interval have been published jointly with Drs. Jonah and Prince in a five-volume catalogue (*Solar Activity Catalog*, Volumes 1, 2, 3, 4, 5: NASA Manned Spacecraft Center, Houston, 1965).

The entire staff of the McMath–Hulbert Observatory continued to direct special attention to the level of solar activity and the development of solar cycle 20 through the closing months of the International Years of the Quiet Sun (1964–65). Dr. Prince and Miss Hedeman studied particularly patterns connected with the occurrence of flares. They have concluded that the forecasting of solar flares is closely related to the forecasting of general solar activity. Initial studies of the ascending branches of solar cycles 17 through 20 indicate, however, that certain patterns in the occurrence of regions containing many flares merit further study in efforts to anticipate the course of solar activity.

Drs. Mohler and Prince have continued a long-standing effort to bring into closer accord the features observed on hydrogen and calcium spectroheliograms and the detailed structures photographed in the centers of the Hα and *K* lines in high-resolution and high-dispersion spectra. The comparisons have progressed from large features such as flares, plages, and filaments to selected very small-scale and background features. The comparisons are difficult, but one-to-one correspondences can be established with some certainty.

As permitted by observing conditions, Dr. Teske and Bennett measured the polarities and magnetic fields for all sunspots. These measurements have been of exceptional value in studies dependent upon the increase of solar activity in cycle 20.

John Kirk studied, as part of the observational program undertaken in connection with his doctoral dissertation, a series of solar spectra secured at the McMath solar telescope of the Kitt Peak National Observatory. Similar spectra obtained with the McGregor tower and the vacuum spectrograph were also used in an attempt to derive the sizes of velocity structures in the upper atmosphere of the sun.

THE OBSERVATORIES IN THE STINCHFIELD WOODS

The Radio Astronomy Observatory. Observational Program. The observational program has included the detection of large variations in the radio emis-

sion of quasi-stellar sources, absolute flux measurements of radio sources (including planets and planetary nebulae), polarization measurements, and lunar occultations.

Variations in the radio emission of the quasi-stellar sources, 3C273, 3C279, and 3C345 were discovered, and the observational evidence was published for the first time. The reported variations were based on repeated measurements of the flux densities in some 35 nonthermal radio sources that have been monitored since July 1962 at 3.8-cm wavelength. These significant results pose fundamental questions for any cosmological interpretation of the observed large redshifts from the quasi-stellar sources.

Observations have been made to detect quasi-stellar sources not yet observed at 3.8 cm. Periodic measurements of the known variable sources are also being made at 1.8 cm. Variations at this wavelength are typically greater than those observed at 3.8 cm.

Measurements of the temperature of Mars at 3.8-cm wavelength were made throughout a five-month interval near the time of the 1965 opposition of the planet. The measurements yielded the most accurate value for the temperature, $182°\pm11°$K that has as yet been published. No variation of temperature greater than 5°K with change in phase angle was observed.

Measurements of the temperature of Mercury have been made throughout the year in an attempt to find a phase variation for this planet. The measurements have been made very difficult by the close angular separation of Mercury and the sun, and by interference from radar signals.

Additional observations of Saturn have continued throughout the year. The average measured blackbody temperature of the planetary disk is $164°\pm9°$K.

Polarization measurements of various sources have been made at 3.8-cm wavelength. Techniques have been investigated for improving the polarization measurements at this wavelength.

Observations of planetary nebulae have continued during the year at 3.8 cm. Starting in the first half of 1965, some of the planetary nebulae previously observed at 3.8 cm, were re-observed at 1.8 cm. Observations of the planetary nebula NGC 7027 were completed and reported. The absolute flux density was found to be 6.07×10^{-26} W m^{-2} cps^{-1} with an estimated accuracy of 7%.

Lunar occultations of 3C17 were observed at 38 cm. The position of the center of the source and the dimension for one position angle were deduced from the measurements.

The radiometers and other equipment associated with the radio telescope have been improved. Construction of a new radiometer has begun. A number of computer programs have been written to aid in processing the observational data more efficiently.

The Curtis Telescope. Observational Program. The Curtis telescope has operated as demanded for the report period. Mrs. Susan Simkin has completed her use of the telescope in the program of the Committee for Institutional Cooperation. The mirrors have been re-coated with aluminum and other adjustments in the operating conditions have been made as required.

Bidelman and MacConnell continued taking 10° spectrum plates at Hα in a search for new emission-line stars along the galactic plane and in an area centered at 60° latitude. Three stars, not previously known to have emission lines, were found in the open cluster, NGC 2421, as well as many other new objects. MacConnell continued a search for flare stars in the Cepheus IV association.

Considerable exploratory work directed toward the best utilization of the 10° plates in the visual and infrared regions was done. In preparation for the transfer of the Schmidt to Cerro Tololo, a program of testing of emulsions, filters and developers was carried out.

The Francis C. McMath Memorial Telescope. Observational Program. The observational program, under the direction of Dr. John A. Williams, consists in the observation of main-sequence stars of spectral types F and G. The stars are observed in five wavelength bands of intermediate width in the blue and red spectral regions in an attempt to find the distribution of, and evaluation for the relative importance of small differences in metal-to-hydrogen ratios and microturbulent velocities.

The Francis C. McMath Memorial Telescope has been used by Dr. Hélène R. Dickel, of the University of Illinois, and by David Gray, graduate student at The University of Michigan, in addition to Williams. Dr. Dickel used the telescope for two weeks in July 1965 for observation of emission lines in several diffuse nebulae. Gray observed the distribution of energy in the spectra of the brighter components of three visual binary stars. He was able to compute the radii of these stars by a comparison of his observational results with theoretical predictions.

ROCKET AND SATELLITE INSTRUMENTATION

Space Radio Astronomy. The principal space radio astronomy activities are: a radio astronomy rocket experiment; Eccentric Orbit Geophysical Observatory (OGO–B) experiment; Polar Orbit

Geophysical Observatory (POGO) experiment; preliminary design studies of a kilometer wave orbiting telescope; theoretical studies; and data processing. This program continues under the direction of Dr. F. T. Haddock and the engineering management of W. J. Lindsay. It is sponsored by the National Aeronautics and Space Administration.

An advanced payload for verification and extension of the results of cosmic noise spectrum measurements from the 1962 rocket experiment was launched in June 1965. The payload reached a height of 1700 km. Preliminary results indicate a successful flight. Data reduction is in process. More than 50 computer programs for data reduction had been generated by the time of this report.

The 2 to 4 Mc sweep receiver for the observation of solar and Jovian burst activity underwent acceptance tests and integration on board the third OGO satellite during 1965–1966. Considerable effort has been expended in attempts to increase the reliability of the antenna and to reduce spacecraft interference. This satellite was launched on 6 June 1966.

The flight experiment for the POGO satellite was launched in October 1965. This instrument is designed to survey the cosmic noise at 2.5 Mc/sec using the theoretically predicted ionospheric focusing to obtain angular directivity.

A versatile, narrow-band, multiple frequency, step-tuned radiometer is presently being constructed for the OGO–E satellite. This satellite will have an eccentric orbit similar to that of the OGO–A and –B satellites. The experiment employs eight frequencies ranging from 50 kc/sec to 2 Mc/sec. A 60-ft antenna is used. This experiment should permit a great extension of observations of the cosmic noise spectrum and of burst from the sun and Jupiter to lower frequencies. The prototype unit has been built and accepted by the spacecraft contractor. Flight units are under construction. Launch is scheduled for mid-1967.

Preliminary studies are continuing on the feasibility of a kilometer-wave orbiting telescope. The design objective is the attainment of a significant angular resolution at frequencies around 1 Mc/sec.

An applied analysis group supports the radio astronomy staff in mathematical analyses and in applications of digital computers. Digital computer programs have been written for the processing of lunar occultation data; to reduce and graphically display the EGO satellite data, to trace electromagnetic waves through the ionosphere, including the effects of the earth's magnetic field; and to display textual, numerical, or graphical results generated by the digital computer.

A digital equipment group provides technical support to other activities of the radio astronom program in the specification, design, and operatio of special data-handling equipment, as required In the past year this group has completed an operated the tape-to-film converter, a data con version facility that accepts data from digita magnetic tape and generates intensity-modulate images on photographic film. Data now bein received from the radio astronomy experimen aboard the OGO–A spacecraft are reduced with th aid of this device. More than 1000 tapes have bee received and processed.

The rocket program requires conversion of dat from analogue magnetic tape to digital magneti tape. Equipment for this task is now complete an functioning. The experiment aboard the OGO–((POGO) spacecraft will require a special cathode-ra display connected to a digital computer. A facilit for this task is in the design stage.

Space Solar Astronomy. Under the supervisio of Dr. Teske, an instrument designed to detect th soft x-ray component of solar radiation was pre pared for flight in OSO–C. The satellite carryin the instrument was launched 24 August 1965. I failed to reach a satisfactory orbit and fell into th Atlantic. Another effort to attain a successful orb will be made with spare equipment in a satellit during the summer of 1966. All of the instrumen for this project have been made by the Consolidate Systems Corporation under the supervision of Th University of Michigan's Space Physics Researc Laboratory.

Dr. Teske and Dr. Mohler have completed feasibility study investigating an orbiting corona graph to be operated as part of a manned orbitin laboratory. The study shows that a great extensio in ability to study the corona would result fro the operation of the proposed instrument.

RESEARCHES ASSOCIATED WITH THE OBSERVATORIE

Studies in the Theory of the Solar Atmospher George Withbroe, working with Dr. Elste, finishe an investigation of the center-to-limb variation the spectrum of the CH molecule in the sol atmosphere. No departures from local therm dynamic equilibrium could be established, b macroturbulent motions must be postulated for satisfactory explanation of the line shapes. Th best representation of Withbroe's observations w obtained from a nonhomogeneous model atmo phere with constant temperature differences f equal differences in geometrical depths.

Elste suggested a method for the computation mean intensities and fluxes for the radiation fro a model solar atmosphere in a recent publicatio

This method has now been fully developed and programmed for automatic computation.

Elste has also investigated a method for the correction of measured intensities within sunspots for the influence of image distortion by atmospheric seeing. He has used a method of successive approximations that involves two-dimensional convolution integrals. In applying this technique to measurements in line spectra an upper limit for the seeing function is obtained from the condition that the minimum intensity in centers of strong lines should never become negative. This procedure shows that for spectra of the small spot of 5 December 1963 (area only 17 millionths of the visible hemisphere) the width of the seeing function must have been less than 1.5 sec of arc.

A critical discussion of the published intensity ratios of umbra to photosphere, listed in Bray and Loughhead's book on sunspots, has been carried out because of the problems introduced in the measurement of such ratios by instrumentally scattered light and atmospheric seeing. From the use of data recently published by Stankiewicz (1962), Makita (1963), and data derived from spectra taken at the McMath–Hulbert Observatory it can be shown that the temperature in sunspot umbrae does depend on the umbral area. The dependence is less pronounced than that found by Michard (1953), but its existence contradicts the conclusions of Zwaan (1965).

The investigation of photospheric velocity fields by studies of line profiles is being continued by a number of students working with Dr. Elste.

The Atmospheres of B-Type Stars. In preparing the summary work by L. H. Aller and J. Jugaku on the spectra of B-type stars for publication, Elste found from recomputation of the curves-of-growth for Mg II, C II, and C III that the carbon lines show very wide wings that cannot be detected by photographic photometry, but which may influence the derived spectral energy distribution. Corrections for this possibility have been considered.

Spectra of Peculiar A- and B-Type Stars. Bidelman extended his studies of the spectra of the peculiar A stars, and with J. Baumert, investigated the southern star HR 4487 as recorded on a Mount Stromlo spectrogram. The most striking peculiarity of this object is its very high abundance of yttrium and zirconium; it is, at present, unique in this regard. Bidelman spent the month of May 1966 at the Dominion Astrophysical Observatory inspecting spectrograms of B- and A-type stars. A significant number of new peculiar and metallic-line stars were found during this work; also several B-type stars were noted as showing variable helium lines.

Stellar Evolution. Dr. Sears continued his work on the evolutionary sequences of stellar models around one solar mass in the main-sequence and post-main-sequence stages. Early computations made at California Institute of Technology produced an excellent fit of the color–magnitude diagram of the old galactic cluster, M67, and the computer locus of constant time at 5×10^9 yr, except for a discrepancy between the Eggen–Sandage gap in the observed stellar distribution and the computed gap. In an investigation with R. Berger it was shown that no reasonable adjustment of the luminosity function of M67, even after allowance for long-term escape of low mass stars, could remove the discrepancy. Evidently the models need revision, probably a very minor one, such as in the assumed distribution of heavy elements that contribute to the opacity. This particular possibility is being explored, with first attention being given to implications for the revision (probably very minor) of the solar model.

The earlier computations have also been applied to O. C. Wilson's diagram that gives the distribution of rotational velocities near the main sequence. Wilson's empirically suggested evolutionary track is very well fitted by the computations, and the dividing line of the main sequence between large and small rotational velocities is close to 1.3 times the mass of the sun.

A comparison of observed color–magnitude diagrams of globular clusters with computed diagrams of loci of constant time has shown a very poor match. This suggests a possible necessary revision of the models. Another possibility, however, was suggested by rotating the observed diagrams, which gave a considerably improved match with the theoretical diagrams. This procedure may be interpreted as suggesting a revision in the blanketing corrections for *UBV* photometry. This possibility is under investigation with the aid of the six-color photometry of subdwarfs carried out earlier at Lick Observatory.

Photoelectric Photometry. Dr. Williams' doctoral dissertation, "Metal-to-Hydrogen Ratios in the Galaxy as Indicated by Narrow-Band Photometry of Cepheids," will shortly appear in the *Astronomical Journal.*

The results of Williams' photometry of Cepheids, presented in the 1965–66 report, are in preparation for publication.

Plasma Physics. Dr. Wentzel's work on the dissipation of interstellar magnetic fields is continuing, with emphasis on the plasma physics relevant to shock waves and magnetic neutral points when their scale lengths are less than the mean free path between hydrogen atoms.

Wentzel and A. Solinger, graduate student in physics, have noted that shocks traveling through the inhomogeneous solar chromosphere are best described as isothermal shocks guided by magnetic fields and satisfying Witham's approximate theory. Results have been applied to effects of solar flares and to the formation of solar spicules.

Dr. Hardev Gurm, research associate, has studied magnetic fields in stellar radiative zones, especially for times in the star's life near the end of the pre-main-sequence contraction. Solinger has investigated the thermal instability of blast waves, and a possible application to the filaments of M82, in the hope of providing parameters for the expected flux of x rays.

OTHER OBSERVATORY ACTIVITIES

The open houses for the several observatories continue to be well attended. There are now a total of 25 days per year when some one of the telescopes is assigned to public use. Many special visiting hours are arranged by appointment.

From 3 August through 6 August 1965, the Observatories and the Department of Astronomy were hosts to the 119th meeting of the American Astronomical Society. More than 300 members attended the meetings. Dr. W. P. Bidelman was in general charge of local arrangements.

Most of the staff members serve on one or more important national and international committees. These assignments are only indirectly related to the work of the Observatories, and such service represents a sizable contribution from the University to astronomical science.

The Horace H. Rackham School of Graduate Studies conferred doctoral degrees on George L. Withbroe, William A. Dent, and John G. Kirk during the period covered by this report.

It is fitting to end this report with a special reference to the untimely death of Professor Dean B. McLaughlin on 8 December 1965 at the age of 64. Professor McLaughlin had been associated with The University of Michigan Observatories for more than forty years. His detailed knowledge of the operation of all the instruments and of the best observational procedures in the Michigan Observatories is irreplaceable.

ORREN C. MOHLER, *Director*

National Bureau of Standards, Washington, D. C.

Atomic Spectra. Effort has continued on the observation, description, and analysis of spectra in the lanthanon group of rare-earth elements. These data form an essential part of Vol. IV of "Atomic Energy Levels."

Encouraging progress has been made with the very complex spectrum Ce I. W. C. Martin reports that there are 64 low levels known from the configurations $4f\ 5d\ 6s^2$ and $4f\ 5d^2\ 6s$. Combinations of these levels with some 600 high even levels account for more than half of the observed lines in the range 3000 to 9000 Å. The present excellent homogeneous line list and Zeeman observations will provide a splendid analysis as the work goes forward.

J. Reader and S. P. Davis at Berkeley are collaborating on the investigation of Pm spectra. Further observations are needed and will be made. In Pm I most of the reversed lines have been classified. About 375 lines have been classified as combinations from the two low terms, $^6H°$ and $^6F°$, of the configuration $4f^5\ 6s^2$ with 127 high levels.

In Pm II 8 low levels of the terms $4f^5\ 6s\ ^{7,5}H°$, and 29 high levels are known. The classified lines total 120. This work is still in its initial stage.

Reader has also made a more detailed study of the nuclear magnetic dipole and electric quadrupole moments of ^{147}Pm from the optical hfs observations of Pm II.[1]

W. F. Meggers is completing the analyses of Yb I and Yb II. This work has been delayed by the untimely death of G. Racah, a collaborator whose brilliant interpretation of rare-earth spectra is an inspiration to all who knew him.

W. F. Meggers and C. H. Corliss have published a paper on *Wavelengths, Intensities, and Zeeman Patterns in Ytterbium Spectra* (Yb I, II, III, IV),[2] that is of special astrophysical interest. The data on these spectra, now recorded for 7300 spectral lines, increase by fourfold the earlier results. Similar observations of thulium spectra have been completed by W. F. Meggers and J. Sugar for more than 20 000 lines.

Thorium spectra have been reobserved and measured by R. Zalubas, in the interval 5000 to 9750 Å. Zeeman observations to 9060 Å have, similarly, been measured and interpreted.

J. Reader and J. Sugar have derived interpolated ionization potentials for the first spectra of the lanthanon group of elements.[3]

New observations of Ni II have been made by V. Kaufman with the 35-ft vacuum spectrograph. Measurements of these spectrograms (735 to 2400 A) have been provided by C. H. Corliss for A. G. Shenstone to extend his analysis of this spectrum, which has turned out to be a surprisingly complex spectrum.

V. Kaufman and J. F. Ward have combined newly measured wavelengths of N I with known data to derive calculated wavelengths of 78 lines

in the vacuum ultraviolet region.[4] Their uncertainty is estimated as 0.001 Å or less.

Atomic spectra are also being observed in the Far Ultraviolet Physics Section of the Bureau, by means of synchrotron light as a background source. R. P. Madden and K. Codling have obtained improved spectra of Kr and Xe in the regions 300 to 600 Å, and are attempting to interpret and analyze them. They have analyzed the absorption spectrum Ne I,[5] observed from 150 to 275 Å, in terms of two basic types of transition: (1) the excitation of a subshell $2s$ electron to outer p orbits and (2) the simultaneous excitation of two outer $2p$ electrons. Many cases of configuration interaction are apparent. Good theoretical calculations are needed to explain the observations.

A 3-m grazing incidence monochromator has been constructed for use with the synchroton in the region 50 to 800 Å.[6] It has been used to determine the absolute absorption cross section in the region of selected broader resonance profiles in the photoionization continua of He, Ne,[5] and Ar.[7]

Transition Probabilities. W. L. Wiese and his staff in the Plasma Spectroscopy Section have continued experimental and theoretical work on the determination of atomic transition probabilities. With a wall-stabilized arc source several S I and S II multiplets have been studied. The Coulomb approximation by Bates and Damgaard is shown to give fairly reliable results. Observed and calculated Stark broadening parameters also agree well for S I, but for S II the measured widths are much larger than the theoretical ones.

Transition probabilities of several prominent lines of C II have been observed with a magnetically driven shock tube as source. These are important for the study of configuration interaction.

By a delayed coincidence method, lifetime's of some $4p$ and $5p$ levels of Ar I have been determined. These measurements provide the first accurate scale of transition probabilities for Ar I lines in the visible region.

In the Data Center on Atomic Transition Probabilities a new bibliography covering material through 1965 has been published.[8] Numerical values have also been critically evaluated and tabulated for the 10 lightest elements, H through Ne. These results are now in print.[9]

C. H. Corliss in the Spectroscopy Section has prepared a Supplement to the Bureau Monograph 32 on Spectral-Line Intensities, which contains a calibration of some 1400 lines short of 2450 Å.[10]

He and B. Warner have extended the study of oscillator strengths of Fe I to include 2000 lines between 2080 and 4150 Å.[11] In collaboration with J. Z. Klose, a paper on transition probabilities and lifetimes in Ne I is in course of preparation.

H. Mendlowitz has calculated the relative strengths in Ni II of transitions in intermediate coupling, in the configurations $3d^8\,4s - 3d^8\,4p$.[12]

A. Weiss is carrying out extensive calculations on the transition probabilities of lines from low-lying levels in the spectra C I, C II, Mg I, and Si II. His results take into account configuration interaction and thus provide better agreement with experimental values than those determined by other methods.

Molecular Spectra. A Monograph on "The Band Spectrum of Carbon Monoxide" has been completed by P. H. Krupenie.[13] It contains a literature review and critical compilation of the observed and predicted spectroscopic data of CO, CO^+, and CO^{2+}.

In the Section on Infrared and Microwave Spectroscopy, D. R. Lide and his group have worked on selected molecules of astrophysical interest. T. Kasuya and D. R. Lide have measured about 100 emission lines in the first and second positive systems of the nitrogen molecule, observed with a pulsed laser as the source.

By means of Stark effect measurements, D. Lide and W. Kirchhoff have derived an improved value of the dipole moment of H_2O, namely 1.84 D.

W. Bruce Olsen has analyzed the spectrum CH_3D in the region 2400 to 3400 cm^{-1} and derived a set of molecular constants. He has recorded the spectrum from 1800 to 4700 cm^{-1}.

Astrophysics. The large mongraph entitled *The Solar Spectrum 2935 Å to 8770 Å*,[14] by C. E. Moore, M. G. J. Minnaert, J. Houtgast, is now finished and in press. It is a compendium of solar wavelengths and intensities that is essentially a second revision of Rowland's Preliminary Table of Solar Spectrum Wavelengths, corrected and supplemented by material from the Utrecht Photometric Atlas. Revised identifications together with laboratory data on the classifications of atomic and molecular lines are included.

Work is continuing on the preparation of subsequent Sections of "Selected Tables of Atomic Spectra."[15] Section 2 will contain revised Atomic Energy Levels and a revised Multiplet Table of Si I.

CHARLOTTE E. MOORE,
Atomic Physics Division

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National Radio Astronomy Observatory, Charlottesville, Virginia

This report covers the period July 1965 through June 1966. During this period the NRAO Visiting Committee was composed of E. F. McClain (U. S. Naval Research Laboratory, Chairman), G. R. Burbidge (University of California, San Diego), J. F. Denisse (Observatoire de Paris, France), W. C. Erickson (University of Maryland), A. E. Lilley (Harvard College Observatory) and A. R. Thompson (Stanford University).

VISITORS

The facilities of the Observatory are available to scientists and graduate students from any institution. The NRAO Green Bank facilities include a 300-ft meridian telescope, a 140-ft fully steerable telescope capable of operating down to a wavelength of about 2 cm, two 85-ft telescopes operating as a variable baseline interferometer, a number of smaller telescopes, and a number of radiometers that operate at frequencies from about 200 MHz to 100 GHz. A 36-ft millimeter-wave telescope is under construction at a site on Kitt Peak in Arizona and is expected to be available for visitor use in late 1966 or early 1967. Visitors may also use their own radiometers on the telescopes. The NRAO Charlottesville laboratory, occupied in December 1965, now contains most of the scientific staff, the computer division, the main library, and a few administrative and electronics personnel. The facilities of the shop, libraries, laboratories and the computer, as well as technical assistance, are available to visitors. Technical Data Sheets describing the telescopes and receiver systems are available and will be sent to potential observers on request. Inquiries concerning the use of NRAO facilities are invited from interested persons.

Visitors were scheduled on the 300- and 140-ft telescopes for more than 60% of the time, in accord with Observatory policy. Approximately 32 visiting scientists and students from 14 different institutions made observations with telescopes during the course of the year. Visiting colloquia were delivered by R. J. Allen, H. C. Arp, G. L. Berge, H. Y. Chiu, M. H. Cohen, C. R. Cowley, R. J. Davis, A. J. Deutsch, E. Epstein, C. Heiles, G. R. Huguenin, H. C. Ko, D. S. Mathewson, L. Oster, D. E. Osterbrock, H. P. Palmer, F. Perkins, C. Sagan, E. L. Schücking, E. A. Spiegel, A. R. Thompson, A. Toomre, C. Varsavsky, G. Verschuur, and L. Woltjer.

About 10 graduate students obtained data from NRAO telescopes for their dissertations during the year. During the summer of 1965, approximately 27 other undergraduate and graduate students attended 25 lectures on radio astronomy and assisted the resident staff in their research.

The Observatory established a Users' Committee during this report period, consisting of 13 users and potential users of NRAO facilities from nine different institutions. The purpose of this committee is to advise the Director with regard to the construction of telescopes and radiometers that will be made available by the Observatory for future observations by the nation's radio astronomers.

PERSONNEL

J. W. Findlay left the Observatory on a one-year leave of absence to assume the directorship of the Arecibo Ionospheric Observatory in Puerto Rico. G. W. Swenson, Jr., worked half-time on the Very Large Array project, was appointed chairman of the VLA design group, and will return to the NRAO full time in August 1966. S. Weinreb joined the staff as head of the electronics division in October 1965. P. Stumpff returned to the staff as associate scientist in June 1966. R. Conway began a one-year appointment as visiting scientist in May 1966. W. Altenhoff, C. V. Sastry, J. Schraml, and Z. Turlo joined the NRAO as research associates. M. M. Small, project manager for the 140-ft telescope, left the Observatory to assume new duties at the Brookhaven National Laboratory. B. Höglund returned to the Chalmers Institute, Sweden, after a two-year stay. J. Marymor joined the administrative staff as contracts officer and business manager. H. Wendker (Münster), C. Heiles (Princeton), and K. Riegel (Maryland) obtained Ph. D. degrees from their home institutions based on observations taken at the NRAO.

STAFF RESEARCH PROGRAMS

The following section gives a brief resume of major resident staff and student scientific activity. Visitor activities at the NRAO will usually be found in the Reports of their own institutions.

I. Solar System. Turlo has observed the solar occultation of 3C446 and 3C2 at 11 cm using the NRAO interferometer. Scattering of the order of 5 sec of arc was positively detected at distances of about 3 solar radii. No measurable effects due to the solar corona were observed at distances larger than 5 solar radii. Kassim, Kellermann, and Pauliny-Toth have investigated the radio emission from a number of planets at 1.9 cm. Mercury was found to have a mean temperature of about 300°K with no more than 100°K difference between the day and nighttime sides. The measured temperature for the other planets were about 500°K for Venus, 175°K for Jupiter (thermal component only), 200°K for Saturn, 220°K for Uranus, and 180°K for Neptune. No radiation was found from Pluto greater than 0.05 flux unit. Clark and Kellermann used the interferometer to observe Saturn at 11 cm and found that most, if not all, of the emission originated from the planetary disk and not from an extended radiation belt.

II. Galactic Studies.

A. H I Studies. The observations by Menon and Williams (Berkeley) of the galactic 21-cm absorption in the spectra of a number of sources taken with the 300-ft telescope in 1964 were supplemented by further data obtained with the 140-ft telescope in order to derive more accurate optical depth values for the absorption lines. On the basis of the new absorption measurements, the distance of the remnant of Tycho's supernova has been found to be about 3.5 kpc. Hence the minimum initial expansion velocity is about 9000 km/sec. New distances have also been determined for a number of distant galactic H II regions in the plane of the galaxy. Howard and Westerhout (University of Maryland) continued their study of the neutral hydrogen distribution in the vicinity of more than 30 galactic clusters.

B. OH Studies. Menon carried out observations of absorption lines due to the OH molecule in the spectra of a number of bright sources. A number of sources for which absorption lines had not been reported previously, such as Cyg A and 3C147.1, were found to have significant absorption.

C. Hydrogen Recombination Lines. Höglund and Mezger finished a survey of the 109α recombination line at 5009 MHz in 20 galactic sources. Line emission was found in 16 of these sources. Using kinematic distances, the distribution of these H II regions in the galactic plane was determined. The average electron temperature of the H II regions was found to be about 6000°K, and the rms velocity of internal turbulence was found in most cases to be higher than the velocity of sound.

D. Planetary Nebulae. Kassin continued her survey of planetary nebulae at 1400 and 750 MHz. Fifty-one planetary nebulae were detected out of a total of 70 observed. Some planetary nebulae which apparently had nonthermal emission were mapped, and it was found that the excess of radiation at the lower frequency could be attributed to the contribution of nearby sources in the beam. Another survey at 5000 MHz was made of 85 planetary nebulae, of which 60 had detectable signals.

E. Extended Galactic Sources. Henderson (University of Maryland) and Mezger investigated the continuum radiation of galactic sources at 5000 MHz. Most of the investigated sources were resolved into two or more components. In the case of H II-regions, their emission measures, electron densities, and total masses of ionized hydrogen were determined. Mezger and Schraml observed about 30 weaker galactic sources at the same frequency prior to a more extended recombination line survey of galactic H II regions. Mezger and Schraml, in a joint program with Terzian (Arecibo Ionospheric Observatory), investigated the brightness temperature distribution of selected galactic regions at 1415 and 750 MHz.

III. Discrete Sources.

A. Lunar Occultations. Three new radiometers, having transistorized rf amplifier front ends (T_s ~250°K), operating at 234, 256, and 405 MHz, have been assembled and permanently mounted on the 140-ft telescope. Occultations of 3C76.1, 3C192, 3C154, and 3C444 were observed by J. Taylor (Harvard) and DeJong with the new equipment. Seven observations of 3C273 have been made by Von Hoerner at 234, 256, 205, 734, and 2695 MHz, with up to four frequencies being observed simultaneously. Both components of 3C273 are elongated along the line connecting them. The shapes of the components depend strongly on frequency. The center of component B appears as a peak at high frequencies but as a dip at the lowest frequencies. Component A shows a flat extension about 23 sec of arc at low frequencies. The spectrum of component B has a low-frequency cutoff between 200 and 400 MHz.

B. Polarization. Sastry measured the linear polarization characteristics of 55 sources at 6-cm

wavelength in collaboration with Kellermann and Pauliny–Toth. Mezger and Schraml determined the polarization, brightness temperature distribution and integrated relative flux densities of Cas A, Tau A, Vir A, Cyg A, 3C84, and 3C273 at 15 GHz using the 140-ft telescope with an angular resolution of 2 min of arc. For Cyg A they determined the individual polarization parameters of the two components.

C. Spectral Studies and Time Variations. Kellermann and Pauliny–Toth made flux density measurements at 2, 6, and 11 cm with the 140-ft telescope and at 20 and 40 cm with the 300-ft telescope. At centimeter wavelengths many sources were found to have spectral indices about 0.5 steeper than at longer wavelengths. A few sources, including Parkes 2145+06, NRAO 140, NRAO 150, 3C120, 3C216, and 3C446 were found to have anomalously high flux densities at short wavelengths. Several other sources, such as NRAO 190, CTD 93, and Parkes 2127+04 have maximum radio intensity in the range 500 to 1500 MHz. A comparison of observations made at different times has been made, and significant variations were found in the intensity of 3C84, 120, 273, 279, 345, 418, 454.3, NRAO 140, 190, and 530. Of particular interest is the QSS 3C273 which had been increasing at a rate of 10%/yr near 2 cm, but near the end of 1965 the rate of increase became about 50%/yr.

D. Sources. By observing interplanetary scintillation of 3C279 at 1400 MHz, Hogg and Menon have established the existence of a small angular diameter component of this source, confirming a suggestion made earlier on theoretical grounds. Through observations made at 2695 MHz with the NRAO interferometer, which affords an effective angular resolution of 8 sec of arc, Wade has found that each of the two major components of Cyg A consists of several intense "hot spots" superimposed on a much fainter background which is either filamentary or made up of numerous faint spots of small angular size.

E. Theory. Kellermann has investigated the evolution of radio source spectra and has concluded that the observed variety of source spectra can be understood if the relativistic electrons are injected in a series of recurring bursts. Heeschen has found an empirical relation between absolute radio luminosity and surface brightness of extragalactic sources that is well defined over a range of at least nine orders of magnitude in each parameter. Spiral and irregular galaxies appear to form a separate sequence distinct from that of the more intense radio galaxies. Quasi-stellar sources form a continuation of the radio galaxy sequence, if they are at cosmological distances.

F. Interferometer Studies at 2695 MHz. Clark and Hogg have completed a survey of 146 sources made at a spacing of 21 500 wavelengths. There appears to be no frequency dependence of source structure for radio galaxies, but quasi-stellar sources have generally higher visibilities at 2695 Mc/sec than at 158 Mc/sec. Accurate positions for 39 objects have been obtained. Hogg has completed observations that will yield the positions and source structure of about 30 quasars. Clark has continued a study of the brightness distributions and positions of moderately small sources on baselines of 1200, 1800, 2100, and 2700 m. Bash has completed the observations of about 225 extragalactic radio sources, including 50 quasars, at antenna spacings of 1200, 1500, 1800, 2100, and 2700 m. The distribution function of visibilities for the group, excluding the quasars, appears to be almost flat from $\gamma=0.2$ to $\gamma=1.0$ at spacings of 2100 and 2700 m. The quasi-stellar group shows a flat distribution function from $\gamma=0.2$ and 0.8 with a pronounced peak at $\gamma=0.9$, at these same two spacings. Tyler has undertaken programs designed to measure instrumental characteristics of the interferometer.

IV. Galaxies. Sastry and Roberts collaborated on the reduction of 21-cm data on NGC 6503. Roberts observed M31, M33, and M81, as well as a large number of other systems. He has obtained new data on the hydrogen "companions" of galaxies and has conducted a search for isolated hydrogen clouds to test the hypothesis that they exist only as companions. Using the 140-ft telescope, he made measurements for the 1665 OH line in several galaxies over a search range of 360 km/sec in 100-kc filters centered on the systematic velocity. An upper limit of $T_a<0.1$°K can be placed on OH absorption or emission features for M51, M31 (N. f. region and center), M81 and NGC 6822. This value is approximately twice the rms over the entire 2-MHz bandwidth. DeJong continued his analysis of the spectral indices of normal galaxies by observing 20 galaxies at 5000 MHz. Comparing these observations with existing data at 750 and 1400 MHz, he finds no evidence at 5000 MHz of a thermal contribution to the radio emission.

V. Miscellaneous. Kellermann and Pauliny–Toth attempted to detect 2- and 6-cm radio emission from a number of blue stellar objects, Seyfert galaxies, and the star α Ori. No emission was found from any of these objects greater than 0.1 flux unit. Hogg placed an upper limit of 0.03 flux unit for the flux at 15 GHz from the bright infrared source R Mon. Further studies by Hogg of the x-ray source x-1 Sco, using the 300-ft telescope at 1400 and 750 Mc/sec, show that there are two

faint sources, each of approximately 0.4 flux unit at 1400 MHz, in the region of the x-ray source.

140–FOOT TELESCOPE

The 140-ft telescope was completed in mid-1965. Between July and October the antenna underwent a series of tests by the NRAO staff, and in October 1965 the telescope was formally dedicated. The electrical and mechanical characteristics meet design specifications, and these parameters continue to be under active investigation by the staff. Table I summarizes the main electrical characteristics:

TABLE I. Summary of characteristics of the 140-ft telescope.

Parameter				
Wavelength (cm)	11.1	5.99	1.95	0.95
Half-power beam-width (min of arc)	11.8	6.4	1.9	~1.2
Aperture efficiency (%)	59	53	40[a]	15[b]
Beam efficiency (%)	78	81	54	23
First sidelobe intensity (dB below main beam)	<-28	<-24	<-17	...

[a] Value becomes 20% at 80° zenith distance.
[b] Value decreases markedly with zenith distance.

The instrumental pointing error is less than 2^s in right ascension within six hours of the meridian at Dec. +40° and less than 2.5 min of arc in declination on the meridian for most of the declination range of the telescope. The short-term pointing repeatability (< one hour) is of the order of 5 sec of arc, while the long-term repeatability (~ days) is of the order of 30 sec of arc.

The first experiment on the 140-ft resulted in the confirmation of the existence of hydrogen recombination lines. Other programs by visitors and staff included H and OH line investigations and continuum studies of source spectra and polarization. The telescope is now in full, routine use. It is scheduled for observing over 85% of the time, with more than 60% of this time devoted to visitors.

CONTINUING PROJECTS

I. Very Large Array Project (VLA). Development of an engineering plan for the Very Large Array (VLA) is being carried on at the National Radio Astronomy Observatory. This radio telescope is being designed to produce an angular resolution of 3 sec of arc in its initial phase, with expansion to 1 sec in a later phase. Intensive studies are in progress concerning the meteorological problem, site selection, array configuration, electronic systems, data processing, and the theory of aperture synthesis. This work is being performed by a group of Observatory scientific personnel, assisted by several members from universities and by industrial contracts. G. W. Swenson, Jr., has been appointed chairman of this group.

II. Largest Feasible Steerable Telescope Project (LFST). The NRAO is also undertaking design studies for a large, steerable, filled-aperture telescope. A small engineering study group has been formed to investigate various design concepts, some of which have been undertaken by subcontracts. A number of these designs are presently available including: (1) a feasibility study of an air-supported floating sphere inside of which the structure of the reflector could be built; (2) a concrete shell floatable on water with a similar reflector built inside; (3) a large, fixed focal point telescope; (4) a telescope that might be built utilizing a "homology" principle such that the surface would deform under gravitational forces from one paraboloid of revolution into another when the structure is tilted in elevation angle. The "homology" telescope is now under study by Von Hoerner, who is investigating the feasibility of the concept through a computer analysis.

III. 36-ft Millimeter-Wave Telescope. This instrument, located on Kitt Peak, is nearing completion and should be operational by late 1966. The telescope is on an altazimuth mount, located in a 90-ft dome and will be controlled by a DDP-116 computer that will perform such functions as pointing, tracking, and monitoring. A limited amount of data processing will be possible after the control system has been checked out. The antenna should be useful for observations at wavelengths of 3 mm and longer and will be available for visitor use on the same basis as other NRAO telescopes.

NEW PROJECTS

I. Three-Element Interferometer. Erection of a third 85-ft antenna at Green Bank was begun in the late summer of 1966. Located on the baseline of the present two-element system, it will provide data at close antenna spacings. Simultaneous three-element operation will be possible by a DDP-116 computer for data acquisition and antenna control located in a new interferometer building near the two movable antennas. This system should be in operation early in 1967.

II. Very Long Baseline Interferometer. In conjunction with the Arecibo Ionospheric Observatory,

the NRAO plans to construct a very long baseline interferometer with independent atomic standard local oscillators and tape-recorded intermediate frequency signals of 200 kc/sec bandwidth. Correlation of the intermediate frequencies will be done by one-bit multiplication in a digital computer. The receivers are planned to be self-contained and, once constructed, should be operable between any two radio telescopes capable of mounting feeds of the appropriate frequency. Initial operation is planned to be between the 1000-ft telescope at AIO and the 140-ft telescope at the NRAO, at a frequency of 610Mc/sec, giving a baseline of 5.2 million wavelengths. The receivers are expected to be in operation in the winter of 1966.

ELECTRONICS INSTRUMENTATION AND DEVELOPMENT

New radiometers at wavelengths of 2, 6, 11, 18, and 21 cm were constructed and used on the 140-ft telescope. The 2- and 6-cm receivers utilize tunnel-diode amplifiers; parametric amplifiers are used at the other wavelengths. Coherent radiometers (and calibration loads) operating at wavelengths of 3.5 and 9.5 mm have been completed for use on the 36-ft telescope. The front- and back-end electronics in the 11.1-cm interferometer system have been improved. The total system noise temperature is 120–130°K with a bandwidth of 10 MHz. Detailed design of a 416-channel digital autocorrelation receiver has been completed. The receiver should be completed by spring 1967 and will be used for observations of spectral lines. This equipment will utilize integrated circuits and will operate at a clock rate of 20 MHz. A new solid-state standard continuum receiver has been designed and a prototype has been completed. This receiver is highly flexible, allowing intermediate frequency frequencies between 1 and 300 MHz and radiometer switch rates between 1 and 400 MHz.

The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

D. S. HEESCHEN, *Director*

U. S. Naval Observatory, Washington, D. C.

Commander L. W. Woolley, USNR, served as Acting Superintendent until his retirement on 31 August 1965. Captain J. M. McDowell, USN, reported for duty as Superintendent on 10 September 1965. Commander J. F. Stanfill, USN, continued as Deputy Superintendent.

Dr. V. M. Blanco was appointed Director of the Astrometry and Astrophysics Division on 1 September 1965. Dr. G. E. Kron was appointed Director of the Flagstaff Station on 1 September 1965. Other appointments to the Scientific Staff were: R. J. Andrukitis, H. E. Durgin, Elizabeth G. Giovane, R. E. Keating, J. D. Lavanceau, J. O. Martin, R. F. Olfenbuttel, I. I. Papiashvili, P. K. Seidelmann, and J. G. Tellier. G. K. Larson was reappointed after having resigned in the fall of 1965 to return to Ohio State Graduate School.

Temporary appointees for the summer of 1966 were: G. S. Brown, L. G. Buc, C. A. Dean, A. D. Fiala, L. W. Fullerton, H. M. Heckathorn, P. D. Hemenway, E. R. Holdenried, R. E. Laubscher, H. S. Liszt, R. C. Price, P. H. Schultz, M. A. Seeds, M. Solarz, J. R. Thompson, and J. W. Zielenbach.

Resignations from the Scientific Staff were: H. F. Fliegel, O. G. Franz, Mrs. J. Potts, R. Rawlings, Elizabeth Roemer, Mrs. D. B. Stanley, Mrs. Elaine B. Thorp, K. D. Thorp, and F. B. Winn.

Public tours during the year in Washington were attended by approximately 9300 persons.

Seven tours for a total of 262 persons were arranged for visiting groups at NOFS.

The American Ephemeris and Nautical Almanac for 1967 was issued 20 October 1965. *The Nautical Almanac* for 1967 was issued 3 May 1966. The three parts of *The Air Almanac* for 1966 were issued 18 August 1965 and 8 February and 9 June 1966. *Astronomical Papers* XVIII, "Expansions in Elliptic Motion," by Milton P. Jarnagin, Jr., was issued 18 February 1966.

The 1967 edition of *The Ephemeris* was prepared for the Bureau of Land Management, Department of the Interior.

Phases of the Moon, 1800 to 1959 were published in *U. S. Naval Observatory Circular* No. 112.

Tables of sunrise and sunset for 42 additional locations were published 28 February 1966.

Local circumstances for points along the path of the annular eclipse of 20 May 1966 and large-scale maps were printed in *U. S. Naval Observatory Circular* No. 109. Similar data on the total solar eclipse of 12 November 1966 were published in *U. S. Naval Observatory Circular* No. 110. Specialized data in connection with the circumstances of these eclipses were computed for numerous expeditions by Mrs. J. S. Duncombe.

Development of methods has been carried forward by T. C. Van Flandern for observing and analyzing "grazing occultation" to more precisely determine the figure, motion, and profile of the moon.

Successful observations of two grazing occultations were carried out by volunteer observers under the direction of P. Espenschied and F. Gauss.

D. Pascu and Miss L. B. Weston have carried

out electronic computer programs to compute astronomical data for checking out celestial navigation equipment in response to official requests from the Department of the Navy.

There has been an increase in the number of specialized tables of the sun and moon produced in response to requests from the U. S. Weather Bureau, the U. S. Air Force, and the Federal Aviation Agency. Mrs. B. L. Morrison, Mrs. V. L. Meiller, Mrs. G. W. Council, and A. Thomas have shared in this project.

Considerable progress has been made in the project of producing extensive navigation tables for the U. S. Naval Oceanographic Office.

Direct control of a photocomposing machine by the output of a high-speed electronic computer has been used to produce magnetic tapes for the composing of "Sight Reduction Tables for Marine Navigation," *H. O. Publication* No. 229, Vols. 4, 5, and 6. Considerable progress was made in developing the same process for the production of "Sight Reduction Tables for Air Navigation," *H. O. Publication* No. 249, Vol. 1 (Epoch 1970.0).

The photocomposing process was used in producing sample pages for "Sight Reduction Tables for Orbital Plane Determination" for the U. S. Air Force. Experimental work has been carried forward to photocompose daily pages for the Air Almanac. Thomas wrote the electronic computer programs for the sight reduction tables. D. K. Scott has been extremely successful in developing programs to edit and translate the computed data for automatic photocomposition.

Fiala and Seidelmann have written programs to generate Topocentric Lunar Ephemerides with tabulations at short intervals for use in the transmission of signals between two stations. The transmission system uses the moon as a passive reflector. R. F. Haupt and Fiala have developed a simple graphical method for predicting times of possible transmission for this system by using the Lunar Ephemeris in the Nautical Almanac.

The program has been carried forward comparing Clemence's new theory of the motion of Mars with observations extending from 1750–1960 to determine the definitive values of the constants.

W. J. Klepczynski, Fiala, and D. A. O'Handley have made progress in the program for the determination of a correction to the mass of Jupiter. Preliminary orbits have been computed for six of the minor planets whose motions are being analyzed, and they are being compared with observations.

The completed catalogues plus other astronomical data in machine-readable form are listed by S. Elvove in *U. S. Naval Observatory Circular* No. 111.

The program of keypunching and verifying star catalogues in cooperation with Yale University has been continued by Mrs. Duncombe and Mrs. J. B. Hampton. The Cape Photographic Catalogues for 1950 (−76° to −80°), (−72° to −76°), (−68° to −72°), (−64° to −68°) are being verified. The *Albany Catalogue for 1910, Preliminary General Catalogue of 6,188 Stars for 1900, San Luis Catalogue for 1910*, and Vol. 37 of *Cordoba General Fundamental Catalogue for 1950* are being punched.

The new astronomical constants which were adopted by the IAU in 1964 are being introduced in the *American Ephemeris* beginning with the volume for 1968. In cooperation with the H. M. Nautical Almanac Office, Royal Greenwich Observatory, there have been prepared (a) an *Appendix* to explain how the new constants can be used to correct parts of the *American Ephemeris* where the old constants are still used and (b) a *Supplement to the A. E. 1968*, containing an exposition of the new system, an analysis of its introduction into the ephemerides, and a detailed derivation of the corrections required to the existing ephemerides. Reprints of this Supplement are available, free on request, to serve with subsequent editions and as a supplement to the *Explanatory Supplement.*

In preparation for the new IBM 360/40, programming classes were conducted for the entire scientific staff. Systems programming for the new computer has been carried out by Klepczynski, Seidelmann, Elvove, O'Handley, and L. E. Doggett.

The following observations were made by the Time Service Division using the photographic zenith tubes (PZT's): 3339 stars on 217 nights at Washington; 3982 stars on 240 nights at Richmond, Florida. Results were published in "Time Signals Bulletin" 208.

Observations were made on 52 nights using the moon camera at Washington; 68 sets of 4 plates each were obtained.

Observations with a Danjon astrolabe were obtained on 147 nights at Richmond, Florida.

Two photographic zenith tubes, designated Nos. 4 and 5, designed by W. Markowitz, are under construction in the Instrument Shop. PZT No. 4 will be operated in Argentina and No. 5 in Canada, by these countries.

Atomic oscillators of the hydrogen maser and cesium-beam types are used for deriving atomic time, A.1. The hydrogen masers are at the Naval Research Laboratory. The Naval Observatory controls the precise time and frequency transmissions of the Naval Radio stations, the navigational systems Loran-C and Omega, and the Navy navigational satellites.

The Precise Time Synchronization Service was formed as an operational branch of the Technical

Division in November 1965 with C. A. Lidback as the Supervisor. The Service was established as a phase of implementation of the responsibilities assigned to the Observatory by the Department of Defense.

Portable cesium beam clocks are presently in use to transfer the epoch of time, as maintained by the Department of Defense Master Clock at the Naval Observatory, to remote user locations anywhere in the world with microsecond accuracy. Since January 1966, the clocks have serviced 18 Department of Defense users in continental United States, and at various foreign locations traveling a combined distance of 51 000 miles.

No observations were made with the 7-in. transit circle during the year. During this time, however, the modification of the instrument for use in the southern hemisphere mentioned in the last report was completed by J. A. Hughes. In addition, a clock system consisting of two quartz crystal sidereal clocks, one mean time oscillator and devices for intercomparing the clocks among themselves as well as with VLF transmissions, was obtained. Trial observations are now in progress prior to shipment of the instrument and its auxiliary equipment to El Leoncito, Argentina.

Observations of 939 stars selected from 10 photographic zenith tube star lists were rigorously reduced to the FK4 and compiled into a catalogue of positions by Hughes. This material was presented to the Columbia University in partial fulfillment of the requirements for a Ph.D degree which was awarded to Hughes in June 1966.

E. S. Jackson and C. A. Smith, respectively, continued their discussions of the close double stars and Parenago stars observed earlier with the 7-in. transit circle.

The compilation of a catalogue of final positions of 21 505 reference stars for the AGK3 was continued by F. P. Scott and J. L. Schombert. All results have been reduced to the system of the FK4 and, when necessary, corrected for clamp differences. An intercomparison of the results from the participating observatories is in progress. T. E. Corbin assisted by E. J. Coyne continued a collection of all worthwhile, earlier observations of these stars, as time permitted.

Observations of the southern reference stars, SRS, continued to progress at Abbadia, Bordeaux, Bucharest, Cape, Nicolaiev, San Fernando, Santiago, and Tokyo. Apparent place and refraction computations for this program are being made under the supervision of J. W. Kitchens. As of this date, over 122 000 apparent places and 57 000 refractions have been computed.

A list of double stars that might be troublesome to measure on the Bergedorf, Cape, and Yale photographic plates was completed, largely by Corbin, and sent to interested persons including Dr. R. H. Stoy, President of Commission 8, IAU. This star list was compiled in accordance with criteria established by a working group of that Commission.

Fundamental observations of the sun, moon, planets, minor planets, and the "Bright Star List" were continued by the Six-Inch Transit Circle Division. R. W. Rhynsburger is supervising the observations and preliminary reductions of this program. A total of 8341 observations was made during the year. The first one-third of the current program was completed in April 1966. Total observations for this period amounted to 34 044.

Discussions and final reductions of the 1956–1962 program were continued by A. N. Adams and D. K. Scott. *Publications of the U. S. Naval Observatory* **XIX**, Pt. 1, containing, "Results of Observations made with the Six-inch Transit Circle, 1949–1956" was printed and circulated in February 1966.

Farrand Optical Company, Inc., of New York, was awarded a contract in November 1965 for the construction of an electronic circle with digital readout of the angular pointing of the telescope and in February 1966 for an automatic photoelectric star and planet tracking micrometer and the interface to connect the above systems to an electronic data acquisition and storage system. The specifications for these systems were worked out by Adams, B. L. Klock, and F. S. Gauss of the Naval Observatory and Farrand engineers in many conferences extending over the past two years. When delivered in about one year, the new equipment will be adapted to the 6-in. transit circle and will be tested and compared with the known performance of that instrument. It is hoped that a mean error of 0.05 arc sec may be reached in these phases of the measurement of absolute star positions.

Proposals for the design and construction of an automatic transit circle incorporating the above items have been received. Special considerations are being given to the thermal properties and rigidity of the telescope and mounting in order to reduce the systematic errors of the present transit circle which was designed more than 70 yr ago. This instrumental development program is being supported by the Office of Naval Research.

A new observing facility to accommodate the automatic transit circle at the Naval Observatory Flagstaff Station is in the planning stage. The larger number of clear days and higher transparency will permit more effective use of the instrument for day and night observations.

Periodic Comet Giacobini–Zinner was recovered by Miss Roemer on 17 September. Miss Roemer, aided by Mrs. Slusser, Lloyd, and Dean, analyzed

a total of 179 astrometric plates of comets, minor planets, satellites, and Pluto taken with the 40-in. reflector. Miss Roemer concluded her observational program at NOFS on 3 November but continued reduction of her observational material until her departure in May.

A total of 151 astrometric plates of selected minor planets was taken by Mrs. B. F. Mintz with the 15-in. astrograph and the 40-in. reflector on 38 nights. She also measured and reduced 85 plates taken for accurate positions of asteroids. The derived positions are to be used in a more precise determination of the mass of Jupiter. A reduction program for the IBM 1410 computer to derive minor planet positions from measurements on the 15-in. astrographic plates was also prepared by her.

For the program of parallaxes and proper motions, 3412 plates were taken with the 61-in. astrometric reflector. A total of 862 plates was measured with the new automatic measuring machine (described below) all in the last three months of the report year. This total included 48 first epoch plates of 19 open clusters and one globular cluster taken for the program of astrometric investigations of clusters.

Worley and Walker continued their programs of visual micrometric measures of double stars with the 12 and 26-in. refractors in Washington, and the 40 and 61-in. reflectors at Flagstaff. They made 2922 observations during the report year. Papers describing micrometric measures of 1164 and 256 double stars were prepared for publication by Worley and Walker, respectively.

A total of 348 plates of double stars was taken with the 26-in. refractor on 68 nights and 345 plates with the Lowell 24-in. refractor on 19 nights during the report year. Measurements of 684 plates were completed and the results for 444 plates reduced. These measures represent nearly 300 000 settings made with the Mann comparator. Mean errors in x and y of 3.6 and 3.7 μ were obtained. Further investigations of the scale of the 26-in. refractor were carried out by A. H. Mikesell and F. J. Josties.

A copy of a catalogue of U, B, V photometry initiated at the Warner and Swasey Observatory by Blanco and developed further by P. M. FitzGerald was transferred to the U. S. Naval Observatory for further work. At present the catalogue contains photometric information on 16 965 stars.

A photovisual determination of the magnitude difference between the components of Sirius has been initiated by I. W. Lindenblad. A thin-wire objective grating mounted on a hexagonal diaphragm is used at the 26-in. refractor for this purpose.

A study of variability among carbon stars selected spectroscopically has been initiated by V. V. Kallarakal.

Photometric observations of the Hγ line in 80 early-type stars in the region of the II Scorpii association were completed by H. H. Guetter. G. E. Kron, in collaboration with C. D. Shane, has initiated an observational program of surface photometry of galaxies using different diaphragm apertures.

A program for securing isophotes in several galaxies with the aid of plates taken with the 40-in. reflector was started by H. D. Ables.

J. B. Priser completed a U, B, V photometric study of 111 8th and 9th mag stars in the even-numbered northern Selected Areas.

R. K. Riddle completed a photometric study of the galactic cluster NGC 2437 (M46). He also outlined electronic computer programs for the reduction of photographic and photoelectric photometry data.

A total of 24 early-type stars in the galactic anticenter direction was observed by J. W. Christy for spectral types and radial velocities. Christy also made a study of the precision with which radial velocities can be obtained with the Carnegie image tube spectrograph developed by Dr. W. K. Ford at the Carnegie Institution of Washington. Mean errors of the order of ± 6 km/sec can be obtained in a spectrogram of an early-type star with 10 measurable lines. This equipment was also used by Blanco for the spectral classification of three proper motion stars with a Giclas color class of 4. Spectral types M5 to M6 were assigned to these stars.

A. R. Upgren continued his work on spectral classification of stars at intermediate galactic latitudes with the aid of objective-prism plates obtained at the Dyer Observatory, Vanderbilt University. The aim of this program, which is carried out in collaboration with the Rev. M. F. McCarthy, S. J., of the Vatican Observatory, is to determine stellar densities at intermediate galactic latitudes.

Guetter obtained spectra of several stars in the I Lacertae association for classification purposes.

The solar program devoted to positions, areas, and counts of sunspots was continued. The sun was observed on 222 days. The mean sunspot area for the report year was 315.3 millionths of the solar disk. The 40-ft photoheliograph used in this program, formerly located at ground level, was relocated on top of the Simon Newcomb Laboratory and solar observations were initiated there on 13 November.

Under the supervision of Mikesell, a portable hand-held photometer was developed for observing scintillation due to clear air turbulence or jet streams. This equipment was used by P. W. Kadlec of Eastern Air Lines, under a Federal Aviation

Agency contract, to observe scintillation from an aircraft at an altitude of 31 000 ft.

A new measuring machine was delivered by Nuclear Research Instruments, Inc., of Berkeley, California, in February. The machine, based on specifications prepared by Strand, incorporates the following novel features: granite structural members, air bearings on movable parts, automatic centering, automatic acquisition, and moiré-fringe position recorders. Output data are obtained on punched cards, and the repeatability of independent settings is within 1 μ. So far, this machine has been used principally in the parallax and double star programs, where it reduces measuring time to one-third that required with the Mann manually controlled measuring engine.

A 23-in. refractor formerly located at Princeton University Observatory was acquired in August and transferred for storage to the Flagstaff Station in November. Plans are being made for erecting this telescope at NOFS for use in the double star programs.

The Department of Terrestrial Magnetism of the Carnegie Institution of Washington presented one of their image tubes to NOFS.

A spectrograph for the 61-in. telescope was received in March from Boller and Chivens Company. The spectrograph will be adapted for use with the Carnegie image tube, in addition to regular photographic work. The spectrograph is similar to the Mt. Wilson Observatory 60-in. Cassegrain instrument and provides for a variety of dispersions ranging between 50 and 300 Å/mm.

The electronic cameras and related facilities developed with ONR support by Kron at the Lick and Mt. Stromlo Observatories were transferred from the Lick Observatory to the Flagstaff Station in September. Further refinements of the electronic camera were carried out by Kron in collaboration with Papiashvili. Plates taken in April with a prototype of the Lick–Stromlo–Naval Observatory electronic camera attached to the 61-in. reflector indicate an information gain of 6 over regular photography. A new camera used experimentally in May shows an information gain of 11. For some applications the information gain is numerically equivalent to a corresponding increase in telescope light-gathering power.

Publications of the staff in addition to those mentioned above were:

Adams, A. N., Bestul, S. M., and Scott, D. K. 1964, "Results of Observations made with the Six-inch Transit Circle 1949–1956." *Publs. U. S. Naval Observatory* XIX, Pt. 1.

Adams, A. N., and Scott, D. K. 1965, "Observations of the Sun, Moon, and Planets—Six-Inch Transit Circle Results," *U.S. Naval Obs. Circ.* 108.

Duncombe, J. S. 1965, "Annular Solar Eclipse of 20 May 1966," *U. S. Naval Obs. Circ.* 109; "Total Solar Eclipse of 12 November 1966," *U. S. Naval Obs. Circ.* 110.

Duncombe, R. L., and Haupt, R. F. 1965, "Printing of Astronomical and Sight Reduction Tables," *Navigation* **12,** No. 2.

Elvove, S. 1966, "Astronomical Data in Machine Readable Form," *U. S. Naval Obs. Circ.* 111.

Franz, O. G., and Priser, J. B. (with I. Halliday and R. Hardie) 1966, "An Upper Limit for the Diameter of Pluto," *Publ. Astron. Soc. Pacific* **78,** 113.

Hemenway, P. D. 1966, "The Washington 6-inch Transit Circle," *Sky and Tel.* **31,** 72.

Hoag, A. A. 1966, "Open Cluster Distance Moduli," in *Vistas in Astronomy*, A. Beer and K. Aa. Strand, Eds. (Pergamon Press, London), Vol. 8.

Klock, B. L. 1965, "HD 21803, a Beta Cephei Variable," *Astron. J.* **70,** 476.

Kron, G. E. 1966, "A Photometric Study of the Globular Cluster 47 Tucanae," *Publ. Astron. Soc. Pacific* **78,** 143.

Morrison, B. L. 1966, "Phases of the Moon 1800–1959," *U. S. Naval Obs. Circ.* 112.

Roemer, E. 1965, "Comet Notes," *Publ. Astron. Soc. Pacific* **77,** 223, 300, 396, and 475; also: 1966, **78,** 83, 178. 1965, "Orbital Motion of Alpha Ursa Minoris from Radial Velocities," *Astrophys. J.* **141,** 1415 (*Contrib. Lick Obs.* 180). 1965, "Observations of Comets and Minor Planets," *Astron. J.* **70,** 397. 1966, "Introductory Report Section I—Cometary Nuclei" and "The Dimensions of Cometary Nuclei," 13th International Astrophysical Colloquium, Liége.

Sharpless, S. 1965, "Distribution of Associations, Emission Regions, Galactic Clusters, and Supergiants: Chap. 7, Galactic Structure," A. Blaauw and M. Schmidt, Eds. (University of Chicago Press, Chicago); 1966, "Stellar Systems of the Trapezium Type," in *Vistas in Astronomy*, A. Beer and K. Aa. Strand, Eds. (Pergamon Press, London), Vol. 8.

Sharpless, S., Riegel, K., and Williams, J. 1966, "An Analysis of the Light Curve of μ Cephei," *J. Roy. Astron. Soc. Canada* **60,** 15.

Strand, K. Aa. 1966, "Astrometry," in *The Encyclopedia of Physics*, R. M. Besancon, Ed. (Reinhold Publishing Corporation, New York); "The 61-inch Astrometric Reflector, Basic Design and Accuracy," in *Vistas in Astronomy*, A. Beer and K. Aa. Strand, Eds. (Pergamon Press, London), Vol. 8.

Upgren, A. (with V. C. Rubin) 1965, "An Old Open Cluster near the North Galactic Pole," *Publ. Astron. Soc. Pacific* **77,** 355.

Worley, C. E. 1966, "The Parallax and Proper

Motion Program of the 61-inch Astrometric Reflector," in *Vistas in Astronomy*, A. Beer and K. Aa. Strand, Eds. (Pergamon Press, London), Vol. 8.

In addition, Roemer contributed astrometric data published in *IAU Circ.* 1923, 1925, 1928, 1929, 1931, and 1951; and in *Minor Planets Circ.* 2529, 2530, 2531, and 2536 during the report year.

K. Aa. STRAND, *Scientific Director*

The Observatories of the Ohio State and Ohio Wesleyan Universities, Columbus and Delaware, Ohio

PERSONNEL

The academic staff, remaining unchanged since last year, consisted of Drs. N. T. Bobrovnikoff, W. K. Bonsack, E. R. Capriotti, G. W. Collins, II, P. C. Keenan, W. E. Mitchell, Jr., and Slettebak at the Ohio State University, and P. Stanger at Ohio Wesleyan University. Dr. Bobrovnikoff retired at the end of the academic year after many years of service at the two universities, and Dr. Bonsack left to take a position at the University of Hawaii.

The research staff at the Perkins and McMillin Observatories included research associates P. Barnhart, P. Byard, and P. Myers, and research assistants J. Avellone, R. Culver, R. Hodge, J. Muster, and D. Price. The Perkins Observatory staff also included secretary Mrs. Delores Chambers, instrument makers W. B. Decker and L. Decker, draftsman P. Stoycheff, electronics technician J. Hynek, observing assistant P. Buerger, librarian Mrs. Doris Mauck, and caretaker C. Smale. On the Ohio State University campus R. Culver, A. Markowitz, J. Muster, S. Price, and N. White served as graduate teaching assistants, and Mrs. Katherine Goldthwait as secretary of the Department of Astronomy.

Keenan was elected Chairman of Section D (Astronomy) and Vice-President of the American Association for the Advancement of Science for the year 1966. Mitchell participated in the Visiting Professor Program of the American Astronomical Society. Slettebak served on the Council of the American Astronomical Society, National Academy of Sciences Committee on Astronomy Advisory to the ONR, Board of Directors of AURA, Inc., and Steering Committee of the Earth Science Curriculum Project.

FACILITIES AND INSTRUMENTATION

The Perkins 69-in. telescope, operated near Flagstaff, Arizona, in collaboration with the Lowell Observatory, became a 72-in. telescope during the year. This was made possible with the help of a National Science Foundation grant to the Lowell Observatory for a new mirror of Duran-50 glass and a quartz secondary mirror. The new optics, in addition to their greater temperature stability, represent a considerable gain in speed over the old mirrors. Major mechanical improvements, carried out under the supervision of Dr. John S. Hall, Director of the Lowell Observatory, include a new support system for the 72-in. mirror and a new declination motion system. Bonsack received a grant from the National Science Foundation for the construction of a new spectrograph, with scanning and image-tube capabilities, for the Perkins 72-in. telescope. Spectroscopic observations during the year were made by Bonsack, Capriotti, Ianna, Keenan, Meisel, Mitchell, and Slettebak.

The drive errors in the Schottland 32-in. reflector and 16–24-in. Schmidt telescope at the Perkins Observatory were traced to deficiencies in the worm and miter gears by Mitchell, in consultation with Warner and Swasey Company engineers. Replacement of these gears have essentially eliminated these errors. Bonsack designed and had built in the Observatory shops a new variable speed, right ascension, slow motion system for the 32-in. telescope. The Meinel $f/2$ spectrograph for this telescope, with a scale of 80 Å/mm, produces excellent spectrograms. The conversion of the Schmidt telescope from film to glass plates was carried out under the direction of S. C. Simonson. Fine spectra of dispersion 1000 Å/mm at Hγ can now be obtained with the two-degree objective prism.

RESEARCH

Spectra of Late-Type Stars. Bonsack and Culver made a study of the widths of weak absorption lines in the spectra of K-type stars, based on published data and measurements from coudé spectrograms. The principal result was the demonstration of a statistically significant linear correlation between the mean widths of the weak spectral lines and the widths of both the Ca II $K2$ emission line and the Hα absorption line. The $K2$ and Hα lines, which are correlated with luminosity, are formed in the "chromospheres" of the stars, while the weak lines are formed in the "photospheric" layers. The result demonstrates that the phenomenon which causes the chromospheric lines to have widths related to the star's luminosity also influences deeper layers, although with reduced amplitude. Microturbulence velocities determined for the 58 stars studied are not well correlated with the widths of the chromospheric lines. Thus the motions which determine the widths of the weak lines, and which are strongly

correlated with luminosity, are motion of elements of gas large compared to a photon free path. This work is described in a paper which is in press in the *Astrophysical Journal.*

Bonsack and Culver continued their program, supported by the Air Force Office of Scientific Research, to determine wavelengths, equivalent widths, and identification of the lines recognizable in the spectrum of the normal late G-type giant ϵ Virginis on high-dispersion Mount Wilson spectrograms. Measurements and reductions are complete for 6500 lines in the wavelength range 0.40 to 0.90 μ, and identifications have been begun.

Keenan completed a catalogue of spectra of Mira variables of types Me and Se, in which spectral types and intensities of lines and bands for 253 stars are tabulated. From these data, an improved table of mean spectral type at maximum light as a function of period was derived. This work was supported by a National Science Foundation grant.

At the invitation of the Universidad Nacional de La Plata, Keenan spent the months of January and February 1966 at the Observatories of La Plata and Cordoba in Argentina. At Cordoba the spectrograms of late-type southern stars taken by Dr. J. Landi Dessy were classified and the results submitted to the *Astrophysical Journal* as two Notes written jointly with Dr. Landi Dessy.

Culver investigated the Ca I lines of multiplet 53 in auto-ionization in 25 K-type stars on coudé spectrograms. Observed equivalent widths were compared with equivalent widths computed assuming a linear curve of growth, solar abundance of calcium, and parameters of the stellar atmospheres from published analyses. Within the rather substantial errors of both the predictions and the observations, agreement was obtained. Severe blending problems probably make these lines nearly useless for stellar atmosphere analyses. This work has been submitted for publication to the *Publications of the Astronomical Society of the Pacific.*

Solar Spectrum. Mitchell used the McMath–Hulbert spectrometer attached to the Snow telescope of the Mount Wilson Observatory during September 1965 to obtain high-resolution photoelectric records at visual wavelengths and of the H and K lines on the solar disk and integrated over the entire disk. The shapes of the H and K cores have been measured free of scattered light for the case of light integrated over the entire disk. At the center of the disk, the intensity at the line centers appears to vary by a factor of 2 or more in neighboring small regions. This work is being supported by a National Science Foundation grant.

Planetary Nebulae. The effects on the Balmer line and Paschen line spectra made by various degrees of escaping of Lyman line radiation were determined by Capriotti. Comparisons with observed Balmer line and Paschen line spectra give best results when the Lyman line radiation is partially destroyed; that is, when conditions are between the extremes of infinite optical depth and zero optical depth. However, the optical depths in planetary nebulae for which there is best agreement between the predicted and observed spectra correspond to optical depths in the continuum at the Lyman limit between 0.1 and 0.05. The accepted values for this optical depth are closer to unity.

Capriotti is also studying the de-excitation of the 2^3S state of helium in planetary nebulae, with the aim of determining whether λ10 830 photons suffer a sufficiently large number of scatterings to account for the observationally determined de-excitation rate of the 2^3S state.

The statistical equilibrium of the helium triplet states in gaseous nebulae is being solved by R. R. Robbins, using recently determined values for collision cross sections and transition probabilities. The transfer theory used includes simultaneously the effects of curvature, incomplete redistribution in frequency, and a velocity gradient in the medium. The predicted spectra will be compared with observed spectra in order to determine the models which best describe the nebulae.

J. P. Harrington is investigating the ionization structure of planetary nebulae, including the dynamics of the nebula. The hope is that the evolution of a planetary nebula can be simulated by a series of quasi-static models. An attempt will be made to include the changing conditions of the central star as the nebula evolves.

Numerical Methods for Solving the Transfer Equation. Collins collaborated with Dr. A. D. Code of the University of Wisconsin in a paper dealing with some numerical methods used in solving the transfer equation. Collins and Capriotti plan to use some of these techniques to investigate the transfer of resonance line radiation in planetary nebulae.

Stellar Axial Rotation. Collins extended his work on the continuum emission of an early-type, rapidly rotating star to include the nongray case. The resultant theory, modified to include some recent results on rotating stellar interiors by I. Roxburgh, J. Griffith, and P. Sweet, was used to compute spectral energy distributions for 46 models having various masses, rotational velocities, and angles of inclination. The possible application of this work to rotational studies of stars in OB associations was considered. It was found that disentanglement of V_e from $V_e \sin i$ is not possible on the basis of continuum studies alone.

Collins and Harrington completed a study of Hβ line profiles for early-type, rapidly rotating stars, including the effects of gravity darkening, limb darkening, and shape distortion. Calculations of Hγ line profiles for rotating stars are near completion.

Slettebak completed a study of axial rotation in 56 emission-line stars of later B type. The frequency distribution of rotational velocities is consistent with the assumption that all the stars are rotating with an equatorial velocity near 350 km/sec but have their rotation axes randomly distributed in space. A comparison of the largest observed rotational velocities for O9.5–F0 stars with computed equatorial breakup velocities for stars of corresponding spectral types shows that the region of minimum difference between the observed and computed velocities is approximately that occupied by the Be stars.

Rotational velocities and spectral types of 77 A-type stars near the north galactic pole have been estimated by Slettebak and R. Wright, in a study of axial rotation at high galactic latitudes. Studies of axial rotation in the Scorpio–Centaurus and h and χ Persei clusters are also under way.

Infrared Stellar Photometry. Mitchell and Barnhart completed their work on infrared stellar photometry, supported by the Advanced Research Projects Agency. Their published report contains (1) a description of the operation of the Ohio State–Eastman Kodak infrared photometer, (2) infrared measurements of 84 late-type stars in the 2.2 and 3.7 μ atmospheric windows, (3) a discussion of the available photometry in the 10 μ window, (4) black- and gray-body approximations in predicting infrared brightnesses of late-type stars, (5) efficiencies of photoconductive detectors for the detection of cool stars, (6) lists of 530 stars predicted to be the strongest 10 μ emitters in the sky and data for similar predictions in the 2.2, 3.7, and 10 μ bands from *V* magnitudes and spectra.

The A-type Spectrum Variable 73 Draconis. A. Markowitz measured equivalent widths of a large number of lines in the spectrum of 73 Draconis from spectrograms obtained with the Perkins 72-in. reflector. He found rapid fluctuations in the hydrogen lines, thereby confirming earlier work, and established that these are due to the hydrogen-line wings themselves and not to blending metallic lines. The line variations indicate a possible difference in the spectroscopic and photometric periods of the star.

Laboratory Astrophysics. The study of spectra of astrophysical interest in the McMillin Observatory shock-tube laboratory continues under the direction of P. L. Byard, who received his Ph.D. degree from the University of London during the year. Absolute *f* values for 43 lines of neutral iron have been measured by photographic photometry of reflected shock spectra, and the results are being prepared for publication. Known quantities of iron carbonyl were introduced into the argon carrier gas of a conventional helium-driven shock tube. Reversal temperatures for the gas behind the reflected shock were measured by a photoelectric adaptation of the method described by Byard and Roll. A spectrograph has been built to enable photoelectric measurements of selected spectral lines to be made. Observations of the iron spectrum will be extended to include ionized lines, for which very few *f* values are available. A program in progress by J. Avellone is the comparison of molecular spectra produced in the shock tube with observed spectra of late-type stars.

History of Astronomy. Bobrovnikoff essentially completed his history of astronomy in first-draft form. He plans to condense the manuscript and offer it for publication within a year or two.

PUBLICATIONS (1 July 1965–30 June 1966)

Barnhart, P. E., and Mitchell, W. E., Jr. 1966, "Infrared Astronomical Photometry," *Contrib. Perkins Obs.* Ser. II, No. 16, 157 pp.

Bonsack, W. K., and Culver, R. B. 1965, "Doppler Line-Broadening in the Atmospheres of K-Type Stars," *Astron. J.* **70,** 668 (Abstract).

Byard, P. L., and Roll, R. E. 1965, "Temperature Measurement in Shock-Heated Gases," *J. Quant. Spectry. Radiative Transfer* **5,** 715–722.

Capriotti, E. R. 1965, "Mean Escape Probabilities of Line Photons," *Astrophys. J.* **142,** 1101–1119.

Capriotti, E. R. 1965, "Lyman Continuum Optical Depths of Planetary Nebulae," *Astron. J.* **70,** 669 (Abstract).

Collins, G. W., II. 1965, "Continuum Emission from a Rotating Non-Gray Stellar Atmosphere," *Astrophys. J.* **142,** 265–277.

Collins, G. W., II, and Code, A. D. 1965, "Some Numerical Methods for the Solution of the Equation of Transfer," *Astrophys. J.* **142,** 1576–1587.

Collins, G. W., II, and Harrington, J. P. 1965, "Hβ Line Profiles for Rapidly Rotating Early-Type Stars," *Astron. J.* **70,** 320 (Abstract).

Keenan, P. C. 1966, "A Catalogue of Spectra of Mira Variables of Types Me and Se," *Astrophys. J. Suppl.* No. 118.

INSTRUCTION AND PUBLIC EDUCATION

The total number of registrations in astronomy courses taught on the Ohio State University campus was 647. The number of graduate students seeking advanced degrees in astronomy increased

to 21 full-time and 3 part-time students. Of these, 8 held teaching or research assistantships and 6 held NDEA or NASA fellowships. Four students received the M.S. degree in astronomy during the year.

Stanger taught the astronomy courses at Ohio Wesleyan University during the year with a total enrollment of 162.

About 1800 persons attended the Public Night sessions or visited the Perkins Observatory during the year.

ARNE SLETTEBAK, *Director*

Ohio State University Radio Observatory, Columbus, Ohio

This report covers the period 1 July 1965 to 30 June 1966.

Personnel. The senior staff consists of H. C. Ko, J. D. Kraus, D. S. Mathewson, and R. T. Nash. L. T. Fitch is Electronics Engineer and P. N. Myers is Computer Programmer. D. S. Mathewson who was a Visiting Professor during the year has returned to Australia to work at the Mt. Stromlo Observatory. M. L. DeJong accepted a staff position and will come later in 1966. The technical staff members are: J. G. Cox, R. H. Gast, R. S. Mardis, G. C. Mikesell, M. A. Shaner, F. L. Spanbauer, D. E. Smith, E. J. Teiga, W. Truss and R. Vertrees. Graduate students are: W. D. Brundage, K. R. Carver, J. H. Cook, F. D. Dietrich, R. S. Dixon, L. T. Fitch, D. A. Guidice, P. F. Honsberger, H. S. King, S. Y. Meng, N. C. Nykopp, D. J. Scheer, W. Stutzman, and J. R. Thompson. Meng and Scheer are completing their Ph.D. dissertations and Carver and Dixon are in early dissertation phases. Visiting colloquia were delivered by: M. L. DeJong, J. R. Dickel, M. Kamesaroff, P. G. Mezger, and J. Witting.

Facilities. During the period July to October 1965 the reflecting surfaces of the 260-ft telescope were replaced with new screen having smaller wire spacing. The ground plane was also resurfaced. As a result of these improvements the telescope efficiency was increased by 40% at 1400 Mc and the usable high-frequency limit raised to 3000 Mc.

Research Programs. The sky mapping and source survey at 610 and 1415 Mc was resumed in November 1965. About 3500 sq deg of the northern sky have been covered and it is estimated that a list of about 1200 radio sources with flux densities above 0.3 flux unit at 1415 Mc will be obtained. All data reduction is being done by computer programs. Scheer, Dixon, and Myers are engaged in this work. Owing to the improved reflector surfaces radiometers are to be added at 2700 Mc to supplement the 610 and 1415 Mc data.

The continuum sky survey was supplemented starting in April 1966 by a neutral hydrogen survey of the entire sky accessible to the telescope at galactic latitudes above 10° in the velocity range +60 to −250 km/sec. The survey greatly extends the work initiated by the Dutch and has resulted in the discovery of many neutral hydrogen clouds and cloud complexes at high galactic latitudes which have a large range of negative velocities with respect to the local standard of rest. Mathewson, Meng, and Brundage have been conducting this study.

Observations of clusters of galaxies and of planetary nebulae were initiated by Ko using facilities at Green Bank, West Virginia. He has examined about 100 clusters of galaxies and found radio emission from over 70% of them. The emission appears to be largely from individual galaxies rather than from the cluster as a whole. In his studies of planetary nebulae he has determined the electron temperature by using the Hβ intensity and the radio flux density.

A 481-page textbook on radio astronomy by Kraus was issued by McGraw-Hill late in June 1966.

Publications (1 July 1965–30 June 1966)

Kraus, J. D., and Dixon, R. S. 1965, "A High Sensitivity Survey of M31 and Surroundings at 1415 Mc/s," *Nature* **207**, 587–589.

Brundage, W. D., and Kraus, J. D. 1965, "Preliminary Results of a Hydrogen-Line Survey of M31 with the O.S.U. Radio Telescope," *Astron. J.* **70**, 669.

Ko, H. C. 1965, "A Radio Survey of Clusters of Galaxies," *Asrton. J.* **70**, 681.

Tiuri, M. E., and Kraus, J. D. 1965, "Is the Satellite Ionization Phenomenon Responsible for the Decametric Radiation from Jupiter?," *Astron. J.* **70**, 695.

Nash, R. T. 1965, "Some High Galactic Latitude Observations at 600 and 1415 Mc," *Astron. J.* **70**, 846.

Kraus, J. D. 1965, "The Satellite Ionization Phenomenon as Studied by CW-Reflection and Pulse Radar Techniques," in *Interactions of Space Vehicles with an Ionized Atmosphere*, F. Singer, Ed. (Pergamon Press, Oxford), pp. 325–372.

Meng, S. Y., and Kraus, J. D. 1966, "Preliminary Results of 21-cm Line Observations of M33," *Astron. J.* **71**, 170.

Scheer, D. J., and Kraus, J. D. 1966, "A High Sensitivity Study of the North Galactic Polar Region at 1415 Mc/sec," *Astron. J.* **71**, 179.

Kraus, J. D., Dixon, R. S., and Fisher, R. O. 1966, "A High-Sensitivity Study of the M31 Region at 1415 Mc/sec," *Astron. J.* **144**, 559.

JOHN D. KRAUS, *Director*

Princeton University Observatory, Princeton, New Jersey

PERSONNEL AND FACILITIES

During the year R. Kulsrud was appointed Lecturer with Rank of Professor; K. Dressler and D. Morton were appointed Lecturers with Rank of Associate Professor. J. Ostriker joined the staff as Research Associate and Lecturer, transferring at the end of the year to Assistant Professor. J. T. Jefferies spent two months in Princeton as Visiting Professor during the fall term, while P. G. Burke was Visiting Lecturer for two months during the second term, each giving a series of graduate lectures. P. Bodenheimer and M. Clement spent the year at the Observatory as Postdoctoral Fellows, the former with a National Science Foundation Fellowship. At the end of the year Professor Kulsrud resigned to accept a position at Yale University, while W. Stein left the Stratoscope group to accept a position at the University of California at La Jolla.

A 36-in. Boller and Chivens reflecting telescope was installed during the year, replacing the Fecker 23-in. refractor, with objective by Alvan Clark (1876), which was sold to the U. S. Naval Observatory. The primary mirror is a compound fused silica blank by Heraeus, made originally as a backup for Stratoscope II; the optics were figured by the J. W. Fecker Division of the American Optical Company. The new telescope, which was financed in part by a grant from the National Science Foundation, will be used for a variety of programs. Among these will be tests of instrumental techniques of particular interest for space astronomy, such as the use of television cameras for direct imaging and for spectrophotometry.

RESEARCH PROGRAM

Stellar Interiors. Schwarzschild and Härm have investigated in detail the character of the thermal instability they had found in a star of one solar mass at the evolution phase when the nuclear energy sources are concentrated in two narrow shells, one with helium burning and one with hydrogen burning. By applying the brute-force method of constructing an evolutionary model sequence consisting of over 10 000 models but covering only two million years they have found that, at least in their case, the thermal instability leads to a relatively harmless relaxation phenomenon; in their model sequence 12 flashes occur in which the helium burning reaches peaks of 10 to 1000 times its normal value. These flashes occur in groups of two or three with relatively quiescent periods lasting about 200 000 years in between.

Rose has continued his investigation of stellar models aimed at an eventual understanding of very late stellar evolution phases. Specifically, he has included in his numerical technique for the construction of these models the terms representing the gravitational energy release. He has found that for the evolution phases he is considering, the same thermal instability is of importance as that found previously by Schwarzschild and Härm for earlier evolution phases. Rose's latest results suggest that the occurrence of this instability may, at least for certain stars, lead to a substantially earlier transition from the shell-burning phase to the white dwarf phase than would be the case without the instability.

Bodenheimer has started to investigate in detail the nonhydrostatic contraction phase that should occur in the evolution of a star just preceding the semistatic Hayashi phase. For this purpose he has introduced into the Henyey method for the construction of stellar models the hydrodynamic acceleration term in the simplest form appropriate for the application of the implicit method. This procedure has given satisfactory stability in the numerical results. The first and still very tentative results of this investigation suggest that the transition from the hydrodynamic to the semihydrostatic contraction phase may be less violent than might have been suspected.

Ostriker and Bodenheimer have utilized an energy principle to derive models of rapidly rotating polytropes and white dwarfs, allowing for the differential rotation that would occur in a frictionless fluid. The preliminary models of white dwarfs indicate that the classical mass–radius relation and mass limit can be substantially modified by differential rotation.

Stellar Atmospheres. Morton and Adams have constructed a model atmosphere for a B4V star in radiative equilibrium, taking account of the detailed ultraviolet line blanketing expected from hydrogen and heavier elements. The flux in this model is constant with optical depth to 1% or better. The effective temperature is 16 800°K and the bolometric correction is −1.40, in contrast with 17 684°K and −1.64 for an unblanketed model with the same visual spectrum.

Mihalas is attempting to calculate models for early-type stars, allowing for deviations from LTE in hydrogen and helium. This calculation takes into account radiative and collisional processes in the continuum and collisional processes between bound states; radiative processes between bound states are assumed to be in detailed balance. Such a calculation should yield correct results for the continuum energy distribution, but with no information concerning the lines.

Auman has calculated the opacity due to water in the spectral region between 0.8 and 12.5 μ for the temperatures of 1680°, 2016°, 2520°, and 3360°K. The positions and the strengths of the individual spectral lines were calculated, and the spectrum was reconstructed assuming that the lines were broadened only by Doppler motions. The harmonic mean opacity was calculated in intervals of 100 cm^{-1} for the assumed rms turbulent velocities of 2, 4, and 8 km/sec. It was found that for solar abundances, water is an important source of opacity in the infrared for $T=3360$°K and is the dominant source of opacity for $T\leq 2520$°K. In order to determine the effect of the opacity due to water on the atmospheres of late-type stars, the model atmosphere of a star with $T_e=2520$°K and log $g=3.0$ has been calculated both including the opacity due to water and neglecting it. Convection has been included using the mixing-length theory. At the bottom of the atmosphere 98% of the flux was transported by convection. In the region where convection was carrying most of the flux, the inclusion of the opacity due to water resulted in a decrease of the density of the stellar material at a given temperature by a factor of approximately 7. In addition, the boundary temperature was lowered by 9% when the opacity due to water was included.

Solomon and Stein have identified two very strong infrared features observed in the photometry of late-type stars, at $\lambda=1.2$ μ and $\lambda\approx 5$ μ as due to thousands of lines of the CO and CN molecules. In addition to H_2O these molecules are the dominant source of opacity in late-type stars. The absorption coefficient of CO is presently being calculated in the region of the fundamental band at 4.7 μ and the overtone band at 2.35 μ.

Planetary Physics. Solomon and Danielson have investigated collision-induced transitions as a source of opacity for the Venus greenhouse effect. Optical depths in excess of 500 are produced in the strongest collision-induced bands if one assumes a CO_2, N_2 atmosphere on Venus with a surface pressure of the order of 100 atm and a surface temperature of about 600°K. The harmonic mean opacity of such an atmosphere depends sensitively on the shape of the wings of the collision-induced bands as well as the shape of the wings of the allowed bands. Conservative estimates of the bandwidths yield a harmonic mean optical depth (based on the Planck distribution at 600°K) of at least 50. Thus it appears that collision-induced opacities are an important source of opacity in the Venus atmosphere, particularly near the hot surface where H_2O clouds cannot play a role.

Savage and Danielson have computed models of Jupiter's atmosphere for several different abundances and effective temperatures. Collision-induced rotational and translational transitions in H_2 are the dominant source of opacity in these models. The observed abundances, temperatures, and pressures appear to be consistent with H/C ratios which are somewhat lower than in the sun and with effective temperatures which are larger than expected from insolation. Some preliminary attempts to take scattering by clouds into account were included in this study.

Stellar Systems. Ostriker and Davidsen have investigated the time of relaxation in an infinite, homogeneous, stellar system and have found that the momentum exchange due to distant encounters converges without a cutoff in impact parameter if the time dependence of these interactions is taken into account.

The evolution of galactic nuclei, and the radiation emitted by the interstellar matter liberated in stellar collisions, has been considered by Spitzer and Stone, following earlier work by Spitzer and Saslaw. The evolution of a contracting nucleus has been followed to a later stage, in which the stellar system evolves into a flattened, rapidly rotating disk. To take into account the exchange of energy between newly formed stars and older stars two idealized models are analyzed. The peak rate of energy liberation depends both on the model and on the angular momentum; if ϵ, the ratio of the rotational velocity to the random stellar velocity, measured at the time when collisions first begin to dominate over evaporation, is as low as 0.01, the peak luminosity is in the general neighborhood of 10^{45} ergs/sec.

Interstellar Matter. The theory of magnetic alignment of interstellar grains has been reconsidered by R. V. Jones (at Harvard) and Spitzer. An alternative analysis has been given of the Davis–Greenstein method for orientation by magnetic dissipation; this analysis, which is exact only for certain limiting cases, emphasizes equilibrium states and takes properly into account the inverse processes ignored by Davis and Greenstein. The predicted orientation vanishes if the internal grain temperature T_i equals the gas kinetic temperature T_g, but is about equal to the Davis–Greenstein result if T_i is much less than T_g. The magnitude of the magnetic dissipation to be expected in interstellar grains has been discussed, using recent theories for the complex physical processes. If iron atoms are present either in magnetic domains or in "superparamagnetic" clumps, orientation of the grains in magnetic fields as low as 10^{-6} G seems plausible.

The density of intergalactic hydrogen molecules has been investigated by Solomon in collaboration with G. Field of the University of California and J. Wampler of Lick Observatory. Spectra of 3C9

($z=2.01$) in the region 3050–3300 Å show a lack of any observable features ($\tau<1$) due to the ultraviolet lines of H_2. This indicates an upper limit of 4.2×10^{-9} cm^{-3} for the intergalactic density of H_2 in the region $z=2$. Since an upper limit has also been set on intergalactic atomic hydrogen the only possible form for intergalactic matter of appreciable density is apparently H II.

Spectroscopy Laboratory (Dressler, Lawrence, Hesser, Mickey and Savage). Lawrence and Savage have measured radiative lifetimes for some 50 ultraviolet multiplets by the phase-shift method. The measurements include the strongest transitions of the neutral and singly ionized elements B, C, N, O, Ne, Si, P, S, Cl, Ar, Ge, Se, Br, Sn, Pb, and I. For the elements heavier than Ne Lawrence has calculated relative transition probabilities on the basis of intermediate coupling theory. With these calculations the radiative lifetime data were converted into absolute multiplet transition probabilities. For the same elements, Lawrence has evaluated numerical solutions of the radial Schrödinger equation for the p^n and $p^{n-1}s$ configurations, enabling extrapolation of the Bates–Damgaard tables for use with resonance transitions of the nonmetals.

Hesser has measured radiative lifetimes of strong ultraviolet transitions in H_2, N_2, N_2^+, Co, CO^+, CO_2^+, NO, NO^+, BF, CF, and in polyatomic species excited by electrons passing through BF_2, CF_2, and SiF_2. Preliminary measurements of relative emission intensities have been made to enable conversion of the lifetime data into absolute oscillator strengths.

The strongest absorption bands of N_2 in the 960 to 980 Å region have been recorded by Lawrence, Mickey, and Dressler to evaluate absolute absorption f values. A 3-m spectrograph served as absorption cell, with accurately monitored N_2 gas pressures in the 10^{-4} to 10^{-6} mm Hg range, using the helium continuum with differential pumping, and double-beam, windowless photoelectric recording with pulse-counting electronics. More than 10 times higher spectral resolution (0.04 Å) than previously reported in photoelectric absorption work in this spectral region was achieved, thus enabling work at substantially reduced pressure×pathlength products. The consequent substantial reduction of the effects of line saturation made possible the resolution of an apparent discrepancy between earlier low-resolution optical data from other laboratories and inelastic electron scattering cross sections in N_2.

Stratoscope Program (Schwarzschild, Danielson, Rose, Stein and Wattson). The fourth and fifth flights of Stratoscope II (aimed at high-definition direct photographs) were carried out in July 1965 and May 1966, respectively. Both resulted in complete failures. The balloon launching and flight operations were carried through successfully and the telescope was in practically flawless radio command, telemetry, and television contact with the ground control station throughout the night of each of the two flights. However, in each case a mechanical failure (different for the two flights) prevented the unlatching of the telescope and thus made any astronomical observations impossible. Between the two flights, as well as after the last one, continuous efforts have been made to increase the mechanical reliability of the instrument.

Sounding Rocket Program (Morton). During the past year four Aerobee rockets were launched from the White Sands Missile Range to study ultraviolet stellar spectra. In each case a Space General attitude control system (ACS) was used to orient the whole rocket towards the desired target. Three of the payloads contained objective spectrographs mounted on a platform free to pivot in the dispersion direction. Fine stabilization about this axis was provided by the passive action of a large gyro rotor also attached to the platform, but free to precess about a perpendicular axis (see Morton and Spitzer, *Astrophys. J.* **144**, 1). A fourth payload consisted of a scanning spectrometer with a star-tracker for fine guidance. Three of the flights were supported by NASA contracts and a fourth was carried out while Morton was a Visiting Astronomer at the Kitt National Observatory.

On 13, October 1965 a Schmidt camera with a lithium fluoride corrector obtained spectra of δ, ϵ, ζ, η, ι, and κ Orionis with about 3 Å resolution longward of 1200 Å. Emission lines of Si IV at 1402.7 and C IV at 1549.5 were identified in ϵ and ζ. Strong absorption lines of both components of the Si IV doublet and the unresolved C IV doublet also were found in ϵ and ζ, but shifted to shorter wavelengths by velocities of 1900 km/sec. The Si IV doublet was present also in δ shifted by 1400 km/sec in the same direction. The displaced absoprtion features have been interpreted as formed in gas escaping from these hot supergiants at these remarkably high velocities. Preliminary estimates suggest that the rate of mass loss from ζ could be as high at 10^{-5} $M_\odot$yr^{-1}. Absorption lines at 1216 Å in the spectra of δ and ζ have been attributed to Lyman-α absorption by interstellar hydrogen atoms.

On 2 February, 1966 the spectrometer was directed at α Virginis within 1°, but the fine startracker apparently failed to acquire the target. Sporadic arcs in the high-voltage circuits of the fine-guidance system disabled this system during the critical acquisition time, and prevented the recording of any useful data about the star. Excess noise in the data signals from the windowless photomultiplier tube provided for the far ultraviolet may have been caused by arcs induced by ionospheric plasma. On

9 March another pair of gryostabilized Schmidt cameras was flown, this time supported by Kitt Peak. Unfortunately a yaw valve failed in the ACS and it did not stabilize on a target.

The most recent flight on 24 May also used a gyro for fine stabilization but this time a single, all-reflective camera with a 12° diameter field was mounted on the platform. The ACS did stabilize, but 17° off the target of the 09.5V star ζ Ophiuchi. A faint spectrum was obtained with 1 Å resolution from 2550 to 3670 Å instead of the desired region at shorter wavelengths. No outstanding spectral features were observed, consistent with both theoretical and ground-based observational results for stars of this type.

Orbiting Astronomical Observatory Program (Rogerson, Dressler, Morton and Spitzer). Detailed testing of the prototype continues and construction of the flight model hardware has begun. As a result of information gained from the tests and from other space astronomy flights a number of changes have been made in the Princeton telescope-spectrometer. The fine-error sensor has been simplified, with the linear range restricted to less than 1 arc sec; during acquisition a velocity signal from the spacecraft gyro is used to facilitate rapid acquistion. Shielding against relativistic electrons, trapped in the Van Allen belts, has been provided for all photomultiplier tubes, and the techniques for excluding ionospheric plasma from the spectrometer (and thus from the windowless photomultiplier tubes) have been improved. The high-voltage power supply has been modified to place greater reliance on venting in the elimination of arcs, and also to ensure that arcs, if they do occur, do not damage the electronics. Verification that arcs will not impair the performance of the system in space is still a problem (see sounding rocket program).

The noise level in photomultiplier tubes resulting from energetic particles was investigated by Dressler and Spitzer. Laboratory studies were carried out with a dozen different types of photomultipliers, all manufactured by Electro-Mechanical Research Inc., irradiating them with γ rays from a ^{60}Co source. Results verified the suggestion by Jerde, Petersen, and Stein that a single relativistic particle produces one large pulse followed by a train of small pulses, which for sapphire windows can include as many as 70 separate pulses. For other types of windows the number of pulses per event does not exceed 10, and for some tube types is less than 3.

Advanced Princeton Satellite Program (Danielson, Morton, Rogerson and Spitzer). A preliminary study has been carried out on the technical problems of a high-resolution satellite in orbit around the earth. The bulk of this study has been performed at the Perkin-Elmer Corporation, under close supervision by the Princeton group, and has led to a preliminary design for a 40-in. diffraction limited telescope. This instrument would make use of the OAO spacecraft for power, coarse guidance, telemetry, etc. However, it would float inside the OAO experimental cylinder, positioned by electromagnets, and would have its own self-contained fine guidance system, with a pointing stability of better than 0.03 arc sec. The optical design includes an $f/2$ parabolic primary, of egg-crate fused silica construction, and a Cassegrain secondary yielding an $f/10$ beam. To achieve the 30-min field required for offset guidance with stars of the eleventh magnitude, a three-lens corrector is provided for the off-axis rays. The instrumentation compartment behind the primary includes two redundant television cameras, which may be used either for direct imagery of a small field at a re-imaged $f/200$ focus, or for spectrophotometry between 900 and 3000 Å, using an $f/10$ echelle spectrograph to spread several strips of spectrum across the photocathode of the camera. Detailed studies of the guidance optics and electronics indicate that the proposed system should have the necessary pointing stability, and thermal studies indicate that thermal perturbations will not degrade the over-all resolution, provided the sunshade is closed whenever light from the sunlit earth would strike the primary mirror.

While the initial plan called for an unmanned instrument, the study was extended to consider the possibility of using man for the initial adjustment, operation, maintenance and repair of the instrument. The Grumman Aircraft Engineering Corporation analyzed some of the problems involved in the use of the Apollo spacecraft with this advanced satellite. The astronauts would return to earth after a period of 2 to 4 weeks, leaving the OAO to operate unmanned for a year. It appears that a 300-mile orbit provides a reasonable compromise between orbital life of at least one year and a tolerable radiation level for man. A soft gimbal mounting of the OAO to the Apollo appears technically feasible, and offers certain advantages of accessibility. During the period of initial manned operation, a photographic film cassette would replace one of the television cameras, though shielding of the film against penetrating radiation presents problems, especially when the Apollo is passing through the South Atlantic anomaly. Analysis of astronaut schedules and of the necessary weight and power requirements indicate that the proposed system is practical. If two astronauts are launched for a 15-day mission, and pressurized space is available only in the Apollo Command Module, with the Lunar Excursion Module not included, a Saturn Ib rocket can apparently launch the Apollo and

OAO spacecrafts into orbit, together with spare parts and other equipment. A return flight of the astronauts six months later would be desirable to repair, maintain and possibly modify the astronomical instrumentation. This program would be an important preliminary step toward a larger, permanently manned telescope.

LYMAN SPITZER, JR., *Director*

Ricard Observatory, Santa Clara University, Santa Clara, California

Personnel. Dr. John Drahmann, Chairman of the Physics Department, Santa Clara University, has acquired jurisdiction over the telescopes of Ricard Observatory. Under his direction, Dr. Frederick R. West, Astronomer, and a group headed by David Goodreau, a 1965 physics graduate of SCU, are working to renovate the observatory for student research. Other members of this group are Thomas McCall, Anthony Marshall, Brian McGuire, William Eisele, and Robert Bettencourt. Don Cordero, S. J., a student at Alma College, began a two-month period as a summer observer on 27 June. Under the direction of Dr. William Barker, Professor of Physics at SCU, a group of undergraduate physics majors are carrying out calculations on hydrogenlike atoms that may be formed in ambiplasmas at the center of our galaxy or in quasars. The principal members of his undergraduate group are F. A. Costanzi, Wayne Angel, W. Honzik, D. Monohan, Tom Simko, and M. Williams

Equipment. The main instrument is a 16-in. refractor of 257-in. focal length, manufactured by Alvan Clark, Cambridgeport, Massachusetts, in 1882. The observatory also has two smaller refractors of 8- and 3-in. aperture, and a horizontal solar telescope. There are two seismographs and a meterorological station in Ricard Observatory.

Astronomical Projects. The year 1965–6 saw considerably increased activity at Ricard Observatory, especially in the use of the 16-in. Alvan Clark refractor. Goodreau, McCall, and Marshall have been working on the renovation of the observatory since 1960. Prior to then, the observatory had been idle for many years.

A series of Hartmann test plates in blue, visual, red, and near-infrared wavelengths were obtained in September 1965 and May 1966. Measurement of the Hartmann plates has shown that the objective lens of the 16-in. telescope has Hartmann criteria $<0''.2$ in visual (5500 Å), red (6500 Å), and near-infrared (8200 Å) wavelength. These Hartmann criteria are considerably less than the diffraction limit of the objective aperture at these wavelengths. The 16-in. objective lens is optically excellent.

The polar axis of the 16-in. refractor mounting has been aligned within a few minutes of the north celestial pole. The alignment improvement has resulted in allowing untrailed images to be made on photographic exposures of 2–3 min.

West and Goodreau were the principal observers on these two projects; they were assisted by McCall, McGuire, Marshall, Eisele, and Cordero.

A $4000.00 grant has been obtained from the Research Corporation for renovation of the Observatory for routine student research. Priority has been given the 16-in. telescope which will be used for photographic work in research projects by several undergraduates in the Physics Department who are especially interested in problems of astrophysical interest. A group of undergraduate physics students under the direction of Professor William Barker and led by students Costanzi, Angel, Honzik Monohan, Simko, and Williams are making calculations of the wavelengths of quanta emitted and absorbed in quantum transitions in hydrogenlike atoms that may be formed in an ambiplamsa (mixture of matter and antimatter). The atoms being studied are protonium, positronium, and muonium. The question of whether these atoms can exist long enough to emit quanta before annihilation occurs is being examined along with the problem of detection of such emission. The last two problems require considerable additional work. These hydrogenlike atoms in ambiplasmas may be present to a significant degree in quasars. In this connection by next year, the renovation of the 16-in. refractor should make possible photographing the brightest quasars such as 3C273. We may also be able to record quasar intensity variations.

A course in Elementary Astronomy will be offered by the Physics Department starting next September. The 8-in. refractor will be used to provide the students with practice in observing.

Wire crosshairs have been installed in the filar micrometer and it can now be used for some double star and planetary satellite positional measurements

Current plans call for extensive work on the 16-in. refractor drive and slow-motion mechanisms and for the installation of an optical system for precise guiding of photographic exposures. By July 1967, the 16-in. should be able to take photographic exposures of 1 h or longer with no image trailing.

Open Houses. Four open houses were held at Ricard Observatory in the past year. These were arranged under the Open House Committee, headed by McGuire and Eisele. At three of these, popular lectures were given, two by West on the moon and Jupiter, and one on the sun by a guest lecturer, Sheldon Smith, a solar astronomer. In addition to the lectures, the 8- and 16-in. telescopes were focused on celestial objects of interest for public

viewing. Also, a film of some of the expeditions to study glaciers made by Rev. Hubbard, the "glacier priest," was shown at each open house. A collection of Father Hubbard's films and mementos is also housed in the Observatory. Plans have been made to resume Open Houses at the Observatory on a regular basis starting September 1966.

JOHN DRAHMANN, *Chairman, Physics Department*

Rutherfurd Observatory, Columbia University, New York

This report covers the period July 1963–June 1966. During the past three years the Astronomy Department at Columbia University has undergone a major expansion. In January 1964 the undersigned was appointed Chairman of the Department to succeed Dr. Jan Schilt, who in 1962 had retired as Rutherfurd Professor of Astronomy after 31 yr at Columbia. At the close of the period covered by this report, the academic staff consisted of the following: Professors W. J. Eckert, L. Motz, K. H. Prendergast, and L. Woltjer; Associate Professor I. Epstein; Assistant Professor N. Baker; Adjunct Associate Professors J. C. Brandt and N. Woolf; Research Associates B. Barbanis, Mrs. Emilia P. Belserene, M. Fujimoto, and L. Lucy; and Research Scientist E. R. Tomer. Also during the period covered, G. Setti was Research Associate for more than a year; visitors for a few weeks to a few months included S. Chandrasekhar, F. D. Kahn, and R. P. Kraft, At the Yale–Columbia Southern Observatory, which was officially opened on 30 March 1965, C. Jackson was Resident Director and A. Klemola, Research Associate. The number of graduate students in the Department rose from four during the first year to nine during the last. During the period, three M. S. degrees were awarded and J. Hughes received a Ph. D. degree. Two physics students, M. Tiger and J. Landstreet, received Ph. D. degrees in physics for research done with members of the Department.

Research in the Department was concentrated in areas of theoretical astrophysics, but a vigorous effort was started to develop a strong program in observational astrophysics. Research included the following:

Structure, Evolution, and Variability of Stars. Detailed calculations on models of main-sequence stars with masses near 1.5 $\odot$ and with both an inner and outer correction zone have been made by Motz in collaboration with Dr. A. Bennick. Baker, in collaboration with Dr. S. Temesváry, has revised and extended the "Tables of Convective Stellar Envelope Models." These tables are particularly useful for fitting convective envelopes to interior models in evolutionary calculations for the lower main sequence. Results for a wide range of chemical compositions are given. The tables will be published by the Goddard Institute for Space Studies in New York.

In collaboration with Dr. R. Kippenhahn, Baker studied the pulsational instability for a star of 7 $\odot$. Qualitatively, the results fit well with the observed Cepheid strip, although some differences in detail were noted. Preliminary calculations indicate that the location of the instability strip is sensitive to chemical composition. To better understand the physical nature of pulsating stars, a simplified "one-zone" model of a Cepheid was developed by Baker. The nonlinear behavior of this model is presently being studied. Baker investigated new numerical techniques for the study of periodic solutions of nonlinear equations and the mathematical nature of these solutions in collaboration with D. Moore and E. Spiegel.

A very complete study of the stability of a Cepheid model of 7 $\odot$ is being made by Epstein. No *a priori* assumptions are made about the magnitude of the nonadiabatic terms, and special attention is given to the outer boundary conditions.

Lucy has been investigating mass loss from early-type supergiants. It is suggested that the small-amplitude variability of these stars, which have helium-burning cores, is due to the high temperature dependence of the helium-burning reaction. The star avoids the very large amplitudes to be expected from this instability by setting up an expanding envelope through which progressive waves can leave the star. Another investigation concerns the β Cephei stars. It has been shown that the small light amplitudes of these stars are consistent with the ratio of luminosity to radius amplitudes given by linear pulsation theory when the bolometric correction is allowed for. This disposes of one of the arguments favoring nonradial oscillation for these stars.

With regard to matters of a more observational character in this area, Dr. Belserene continued her studies of the period changes of the RR Lyrae stars in ω Centauri. It appears that if extreme periods and *c*-type variables are excluded, a systematic effect can be found in the sense that the periods show a rather strong tendency to increase, the median change being 0.11 days per million years, a result of importance in evolutionary considerations. In the spring of 1966, Epstein obtained photoelectric observations of RR Lyrae stars in the Strömgren *ubvy* system both at McDonald and at Kitt Peak. The results are being evaluated.

Two physics students did thesis research under Woltjer's direction on late stages of stellar evolution. J. Landstreet studied the effects of strong

magnetic fields in white dwarfs. The thermal conductivity of the stellar material was investigated with both lattice effects and magnetic fields taken into account. A strong large-scale magnetic field was found to lead to a detectable nonuniform brightness of the stellar surface. Neutrino processes associated with the motion of the degenerate electrons in the magnetic field were studied and shown to be rather negligible in the cooling of white dwarfs. W. Y. Chau studied the energy loss by gravitational radiation from various oscillating and rotating neutron stars. The Kelvin modes appear to be damped quite rapidly, while a detailed discussion of the quasi-radial puslations of a rotating mass of gas showed that the pulsation energy is radiated rapidly unless the rotational velocity is much less than the maximum for a neutron star.

Dynamics of Galaxies. The structure of a stellar system is determined by the Boltzmann and Poisson equations. If stationary axisymmetric systems are considered (elliptical galaxies), distribution functions that are arbitrary nonnegative functions of the energy E and the angular momentum J satisfy the Boltzmann equation.

Prendergast, working with Tomer, has developed techniques for the numerical solution of Poisson's equation, which, after elimination of the density in terms of the distribution function, is a nonlinear equation for the potential. The density and the potential are represented by sums of products of functions of the radial coordinate and Legendre polynomials involving the angular variable. As a first case, a distribution function, $f(E,J)=A\exp(-\alpha E-\beta J)$, was chosen with a cutoff at a finite negative energy. Solutions of different central concentrations were obtained for $\beta=0$ and subsequently for values of β up to a value for which the model has so much angular momentum as to become a ringlike structure. These models are being projected on various planes for convenient comparison with observation. E. W. Ng is completing a thesis on similar fully self-consistent models for disks of vanishing thickness. An extensive study of the dynamics of barred spirals was completed earlier by Prendergast. Many stellar orbits were calculated and an interpretation of the theta spirals given. The motion of gas in a barred spiral was studied, and a circulation in the direction of rotation was found. A stationary shock wave is formed in this circulation, and this explains the existence of certain dark absorption lanes observed in the bars. The "third integral" was studied by Barbanis who studied the transition from an isolating to a nonisolating integral in a resonance case.

The spiral structure of galaxies was further considered. Barbanis and Prendergast showed that the potential of disklike distribution of matter can be best discussed in a system of spheroidal coordinates (ξ, η, φ). The density distribution can then be represented by a sum of products of Legendre polynomials in η and sines and cosines of φ. Poisson's equation can then be integrated easily, and thus the potential corresponding to an arbitrary disklike distribution of matter can be found. A program was written for the IBM 7094 in which all the required expansions and reductions have been incorporated. It is planned to use this program in investigations of the motion of gas in the disk of the galaxy. Barbanis continued the calculation of orbits of stars in a gravitational field which is a superposition of a Schmidt model and a spirallike gravitational perturbation. One of the aims of this investigation is to study the random motions generated in the stars of the galactic disk by the effects of spiral structure. Fujimoto studied the motion of gas through the gravitational perturbation associated with spiral structure. In a case of a tightly wound spiral, some essential simplifications can be made. In the models the gas crosses a large number of identical arms in succession, and periodic solutions for the flow are obtained. In many cases a shock wave forms not far from the arm axis. For an isothermal equation of state for the gas and with realistic parameters, ratios of about 4 between maximum and minimum density can be obtained, but the maxima are rather narrow.

Radio Sources. A first investigation of the propagation of relativistic particles in radio sources under conditions when the energy density of the particles is large compared to that in the magnetic field was made by Setti and Woltjer. Preliminary results indicate that the electromagnetic fields generated by the particles themselves may dominate the further motion in certain cases. The early evolution of supernova remnants was studied by Woltjer. It appears difficult to avoid the conclusion that—at least in the Crab Nebula— the shell must have been formed before the supernova outburst, and a connection with planetary nebulae was suggested. The x-ray emission of the Crab Nebula was interpreted as synchrotron radiation. If this interpretation is correct, relativistic electrons responsible for the radiation must be effectively accelerated since the time in which they would radiate half their energy is of the order of a year. A stringent test of the nature of the x rays could be provided by polarization measurements. Apparatus for the detection of x-ray polarization is being constructed by Dr. Novick and his associates in the Columbia Radiation Laboratory in the Physics Department.

Setti and Woltjer discussed the minimum values for the masses of quasi-stellar objects in a local theory and concluded that the total mass and energy involved in such a theory are prohibitive.

Woltjer also considered the inverse Compton radiation in these objects and concluded that the excessive rate found by other authors can be avoided when the lack of isotropy of the relativistic electrons and of the radiation field in these objects is taken into account. In collaboration with P. D. Noerdlinger and J. R. Jokipii of the University of Chicago, Woltjer considered the ratios of blueshifts and redshifts to be expected on a local theory of the quasi-stellar objects in which the spectral shifts are of kinematical origin and in which these objects originate from many galaxies. It appears that a notable preponderance of blueshifts would be expected, contrary to observations.

The research activities in the Department received generous support from the National Science Foundation, the Air Force Office of Scientific Research, the National Aeronautics and Space Administration, and the Research Corporation.

Facilities and Instrumentation. The east wing of the 14th floor of Pupin, where the Department is housed, was completely renovated in 1964 with a gain of six offices and a seminar room. At El Leoncito near San Juan, Argentina, the buildings for the Yale-Columbia Southern Observatory were completed and the twin 20-in. astrograph was installed. The instrument has been functioning satisfactorily and the plates obtained appear to be of excellent quality. Plans for a small observing facility about 50 miles from Columbia have been finalized. A photoelectric photometer and associated electronics was constructed by Epstein. A two-dimensional Mann measuring engine was purchased.

L. WOLTJER, *Director*

Sacramento Peak Observatory, Air Force Cambridge Research Laboratories, Sunspot, New Mexico

The professional staff of the observatory during the past year was as follows. Astronomers: Jacques M. Beckers, George Wm. Curtis (resigned in June 1966 to go to the High Altitude Observatory), Richard B. Dunn, John W. Evans (Director), Charles L. Hyder, George W. Simon (working throughout the year at the Max-Planck-Institut für Astrophysik in Munich), and Oran R. White. Horst A. Mauter continues his work in charge of the operation of the large telescopes and their accessories. Howard DeMastus is Chief Observer in charge of the expanding solar patrol program. Robert B. Hunter, Jr., is the Administrative Assistant to the Director.

Visiting Astronomers: John H. Reid, Dunsink Observatory, August 1965 to August 1966; Egon H. Schröter, Göttingen Observatory, May 1966 to May 1967; L. D. de Feiter, Utrecht Observatory, June 1966 to June 1967; C. Zwaan, Utrecht Observatory, August 1966 to August 1967. Robert W. Noyes, Smithsonian Astrophysical Observatory, summers of 1965 and 1966.

The principal research programs which have reached a reportable stage are the following.

Beckers looked for a systematic variation of photospheric temperature between the centers and boundaries of supergranulation cells. He assumed that the coarse network appearing on a K spectroheliogram outlined the supergranulation. Using a raster microphotometer scan over five white light photographs of the sun, he determined the average brightness in concentric rings between the centers of 1652 coarse network cells and their boundaries. His result is that there is an $0.1 \pm 0.02\%$ increase in brightness toward the boundaries, corresponding to a temperature increase of 1.5°K. This finding conflicts with the usual assumption that the supergranules are due to convective flow of hot material upward at the centers and cooled material downward at the boundaries. It suggests either that the supergranulation is not a convective phenomenon, or that the K coarse network is only loosely correlated with supergranulation.

Simon used the analogue "correlating machine" at the California Institute of Technology to detect a small but highly significant negative correlation between small-scale mottlings on Hα spectroheliograms and brightness in the white light photosphere. Apparently the photospheric granules do have some slight effect on the immediately overlying chromosphere at heights comparable to the granule diameters.

White and Curtis are continuing a study of the height variation of source functions up through the temperature minimum. They spent the winter months observing center to limb variations of the profiles of the *D* lines of Na and the *b* lines of Mg with the 13-m double-pass spectrograph. White has developed some refinements of the standard methods for recovering the true profile from the observations, and will apply them here. The observations confirm Waddell's conclusion that the lines of the same multiplet have the same source function, but show appreciably lower central intensities for the *D* lines than he found in 1960.

Evans has continued work on the bright "threads" in the solar spectrum produced by bright granules. Through the wings of strong lines and in the cores of lines of moderate strength, most threads are displaced perpendicular to dispersion from their positions in the continuum. Since light in the lines originates at a higher level in the solar atmosphere than does the continuum, Evans interprets this shift as evidence that the bright granules are highly in-

clined columns seen at different heights in continuum and lines. The rms horizontal displacements in the *b* lines of Mg and Fe 4348 are about 500 km, and in the *H* and *K* lines, about 1000 km. The spectra show only the component of displacement along the slit of the spectrograph. In order to obtain a more complete picutre of the phenomenon, Evans is trying to obtain simultaneous spectroheliograms in a line and the continuum for stereoscopic comparison.

White has continued his study of center to limb variations of the Hα, Hβ, and Hγ line profiles to determine opacity and excitation temperatures as a function of distance from the line centers. He confirms his earlier findings that the excitation temperatures for the three lines are significantly different, and that the opacities at line centers, particularly in Hα, are high. This conflicted sharply with Zirin's observation of a sharply defined "inner limb" on Mt. Wilson spectroheliograms and Lockheed filtergrams, which he estimated to be about 2000 km above the white light limb. White (along with others) suspected that the inner limb was in fact the white light limb imaged on the photographs in parasitic continuum light from outside the nominal passbands of the observing instruments. To settle the question, White and Simon, with the cooperation of Zirin and Howard at Mt. Wilson, and Ramsey at the Lockheed Observatory, compared measurements of parastic light in the instruments that showed an inner limb with those at Sac Peak which did not. The measured parasitic light fully accounted for the difference. As a further test, White and Ramsey found that the inner limb completely disappeared in Lockheed filtergrams when they inserted an interference filter of 1.8 Å bandwidth in the optical path. White concluded that the inner limb is instrumental rather than solar, and there is no observational reason to doubt the high opacity he found at the center of Hα in the chromosphere.

Beckers and Noyes are studying the spicular structure of the chromosphere at the limb in the lines Hα, Hβ, Hϵ, D_3, *H* and *K*, and a few rare earth lines near these. They assembled a prism system in front of the slit of the 13-m spectrograph which permits them to obtain simultaneous spectrograms from two chromospheric levels separated by 2000 km. They find that the chromospheric structure shown in Hϵ and D_3 are well correlated, while their correlation with *H* and *K* is notably lower, though still significant. The rare earth lines, seen only at low levels, show no spicular structure. The marked self-reversed absorption cores seen in Hα, *H* and *K* at low levels do not share the Doppler shifts of the spicules, and must originate in an interspicular medium. Many spicules at high levels, where line of sight superpositions are statistically ruled out, show lines with marked inclinations. They appear to be in rotation with characteristic velocities of 15 km/sec. This may partially account for the broadened *H* and *K* profiles so often observed in most, but not all, spicules. The gross Doppler shifts in a few of the individual spicules reverse during the spicule lieftime, suggesting a reversal of vertical velocity.

Beckers and Noyes with Frank Low of the University of Arizona made observations of the solar infrared limb profile at $\lambda = 24\mu$ with Low's germanium bolometer. On the basis of models of the solar atmosphere similar to the Utrecht model, the radiation at this wavelength should originate above the temperature minimum at the limb, and produce limb brightening. With the 60-in. telescope of the University of Arizona, the resolution of the system was about 20″, and the profile at $<20''$ from the limb is not easily recovered in the face of the observed noise. The observations do not show the expected brightening, but the limited resolution and observational noise could conceivably have hidden it. Beckers and Noyes have prepared equipment and will attempt to determine the limb profile at the November eclipse in South America, where the resolution should be a fraction of an arc second.

At the eclipse of 30 May 1965, Dunn observed the coronal spectrum from the NASA aircraft with a telescope–spectrograph of his own design (see below). Curtis, with Jefferies and Orrall of the University of Hawaii, used an identical instrument on the ground at Bellingshausen Island. Both expeditions were successful in obtaining spectra which showed the coronal continuum at most wavelengths, as well as the emission lines. Eight new lines appear in both sets of spectra. The reductions necessary to determine the behavior of all observed lines in a coronal condensation are under way.

At the same eclipse, Hyder photographed the corona from an aircraft in the Fe XIV 5303 line through a Savart plate to determine the polarization of this emission line. He found it strongly polarized, and is analyzing the photographs to determine the directions of the magnetic fields from their effects on resonance polarization.

DeMastus, with four assistants, has expanded the solar patrol program in response to Air Force requirements and the anticipated needs of the observatory for continuous data during the coming sunspot maximum. The group makes continuous photographic observations of the sun in Hα, on and off band, and watches for large events (particularly flares) on a TV screen. They make intermittent observations of the intensities of the strong coronal emission lines, and when the sky is favorable

take time-lapse motion pictures of coronal and prominence activity. A teletype circuit to all users permits quick notification of major events and the transmission of routine data two or three times daily The principal users are the Solar Forecasting Center of the Air Weather Service, U. S. Air Force, and the Environmental Science Services Adminstration of the Department of Commerce.

Three instrumental developments at the observatory should be mentioned.

Work has commenced on the construction of a 30-in. aperture evacuated solar tower telescope designed by Dunn (*Appl. Opt.* **3**, 1353, 1964). The contract date for completion is September 1968.

Dunn designed a fast telescope and grating spectrograph unit for eclipse observations of the corona. The spectrum is formed by an $f/5$ optical system with an average dispersion of about 30 Å/mm. Two samples were made, one for the University of Hawaii for observation from the ground, and one for the Sacramento Peak Observatory for observation from an aircraft. Dunn built a gyrostabilized servo system to guide the aircraft unit, and succeeded in achieving a guiding accuracy of about 10″ during the eclipse of May 1965.

For the patrol program, Dunn has construcetd and is in the last stages of adjusting an instant playback time lapse motion picture system. The Hα image of a solar active center falls on a Vidicon camera tube and is recorded on a standard TV magnetic tape unit at intervals of 7 to 60 sec. Between successive exposures the tape plays back the last 200 or more frames at the standard rate of 30 per second. At the cost of a short interruption of the observing sequence, the whole day's history can be played back. Thus the observers can see in rapid motion the activity leading up to the current state of the active center. The hope is that this will be a step toward the short interval prediction of flares.

JOHN W. EVANS, *Director*

Sagamore Hill Radio Observatory, Air Force Cambridge Research Laboratories, Bedford, Massachusetts

The effort of the Sagamore Hill Radio Observatory is concentrated on solar radio astronomy, atmospheric studies by means of radio astronomical and satellite techniques, and to a lesser extent spectral index of sources and H and OH studies. The group uses a 150 ft and an 84-ft antenna in both single antenna and interferometer modes for studies of lunar radio reflections, the occultation of Taurus and radio star scintillations. A 28-ft and an 8-ft paraboloid are used for solar studies. Other small antennas are scattered through the main site at Hamilton, Massachusetts, and a second site at North Ipswich, Massachusetts. In addition, the 1000-ft spherical reflector at Arecibo, Puerto Rico, has been used for studies in the range of 22–38 MHz. The program is operated by the Radio Astronomy Branch of the Space Physics Laboratory.

Solar Studies. In 1965 and 1966, a centimeter–decimeter wavelength solar patrol was put into daily operation making systematic observations similar to those which had been conducted sporadically since 1956. The primary mission is to provide high absolute accuracy ($\pm 3\%$) flux measurements of the undisturbed sun at 606 and 1415 MHz. A 28-ft polar mounted paraboloid is used for this operation. Routine observations are made also at 2695, 4995, and 8800 MHz. with an 8-ft paraboloid. High relative accuracy but lower absolute accuracy ($\pm 10\%$) is the objective. In recording burst activity where an absolute accuracy of 10% is sought, high- and low-gain channels are used with each receiver at all frequencies. Typical Dicke radiometer configuration with analogue and digital recording is employed for each receiver. All data are stored on punched cards for computer processing. A 20–40 MHz swept frequency interferometer is being routinely operated at Sagamore Hill by Lowell Technological Institute Research Foundation. The Solar Observatory, under the direction of J. Castelli, is staffed by Air Weather Service personnel under Capt. G. Michael. The solar patrol serves as one of the principal stations of the Air Weather Service Solar Activity Forecast Network. Teletype facilities provide for routine and priority reporting and reception of solar information. Data are reported in the *E.S.S.A. Monthly Bulletin on Solar Activity* and in the *AFCRL Quarterly Bulletin of Solar Geophysical Data.*

Observations of the 20 May, 1966 annular eclipse were made in Olymbus, Greece, by J. Castelli and R. Straka. An 8-ft diameter radio telescope was used to make simultaneous observations of the radio sun at 1415, 2695, 4995, and 8800 MHz. The prime objective was to obtain spectral information on the localized enhanced radio regions on the sun. Fortunately, three relatively new, isolated, and prominent regions were present on the sun during the eclipse; a preliminary examination of the data reveals spectral information on these regions. The preliminary values of residual flux at times of totality are: 18.9% at 1415 MHz, 16.5% at 2695 MHz, 12% at 4995 MHz, and 7.3% at 8800 MHz; these percentages have been corrected for lunar temperature contribution. Similar spectral observations of the 12 November, 1966 total eclipse will be conducted at the same four frequencies. Observations will be made at Ancon, Peru, in association with the Instituto Geofisico del Peru.

The occultation of the Crab Nebula by the solar corona was observed during June at three frequencies, 63, 113, and 228 MHz, using an interferometer consisting of the 150-ft and the 84-ft paraboloids, spaced about 200 m apart. Analysis of the data is in progress by T. Elkins of Boston University and Wentworth Institute.

Atmospheric Studies. The second Symposium on Radio Astronomical and Satellite Studies of the Atmosphere was held in October 1965 in Boston, Massachusetts, under the joint sponsorship of AFCRL and NATO. Papers from this symposium will be printed in the October 1966 issue of *Radio Science.*

Observations of scintillations of Cassiopeia and Cygnus at frequencies from 30 to 3000 MHz made from 1961–1964 have been analyzed with results obtained on frequency dependence, latitude variations, and magnetic effects. The data have been compared to satellite scintillations from beacons ranging from 20–136 MHz; the principal governing factor in scintillation occurrence is the magnetic latitude with angle of elevation and sunspot number playing subordinate roles. R. Allen and J. Aarons have performed several studies on the multifrequency data.

Measurements of the axial ratio and orientation of the polarization ellipse and scintillation index of radio telemetry signals from the synchronous satellite, Early Bird, have been taken. Total ionospheric electron content changes were determined by continuous monitoring of the signal; these are being compared to observations of the high-inclination satellite S-66.

Celestial Radio Astronomy. To determine the spectra of certain discrete radio sources at frequencies between 22 and 39 MHz, observations were made in October and November 1964 and April 1965 with the 1000-ft Arecibo radio telescope. In order to avoid radio interference and to minimize the effects of ionospheric absorption, records were taken during the 2200 to 0500 local time period. The flux densities of nine radio sources were measured. Anticipated errors were roughly 10% for the stronger sources, 15% for the weaker sources. The spectra of the core and halo sources 3C47 and 3C274 show no appreciable curvature while the spectra of the five elliptical or double galactic sources (3C33, 3C98, 3C123, 3C348, and 3C353) show evidence of downward curvature at lower frequencies. The spectra of the supernova remnants 3C157 (IC443) reaches a turnaround point at about 30 MHz. D. Guidice performed the measurements and analysis under the direction of H. C. Ko of Ohio State University.

In March 1966, observations were attempted by Guidice at four frequencies within the 22 to 39 MHz range with the objective of mapping the galactic spur region. Unfortunately, massive broad-band power-line interference severely limited our data. Using the one night's data perfectly free from interference, we have made contour maps of the galactic spur region for the four frequencies. The maps show consistent results on all four frequencies. Some analysis of the brightness temperature spectra and the contour structure is now in process.

Based on the data taken at the Arecibo Ionospheric Observatory in 1964 and 1965, J. Aarons and D. Guidice determined the size of nighttime low-latitude ionospheric irregularities by noting the occurrence or absence of scintillation for sources of different angular diameter. Various discrete sources with angular diameters ranging from 5′ to less than 1′ always scintillated to some degree while the sources 3C392 and 3C157 with angular diameters of 16′ and 29′, respectively, showed no scintillation. Utilizing diffraction and scattering concepts an autocorrelation distance or "irregularity size" of 1.1 km was found. This is the shorter dimension (*EW*).

An unsuccessful search has been made in the W3 region for the Ω doublet transition in the $^2\pi_{\frac{1}{2}}$, $J=\frac{1}{2}$ state of the CH free radical. With a resolution of 200 kc/sec and using the 84-ft antenna, an upper limit of approximately 1°K was determined for emission in the frequency range from 2800 MHz to 3500 MHz. High-resolution studies (850 Hz bandwidth) are being made of the 1665 MHz line of the OH free radical in various regions around the galactic plane. T. Elkins is carrying out this program.

JULES AARONS, *Chief Radio Astronomy Branch*

Sproul Observatory, Swarthmore College, Swarthmore, Pennsylvania

The year course in descriptive astronomy was given by Peter van de Kamp and James F. Wanner. Dr. Wanner gave a seminar in astrophysics during the second semester. Peter van de Kamp and Sarah Lee Lippincott continued to participate in the NSF-AAS Visiting Professors Program. Visiting lecturers included W. Butler Burton, Dimitri Mihalas, Stephen E. Strom, and Martin Pomerantz.

Mrs. Mary Jackson and Mrs. Elizabeth Kuhlman continued with the measuring and reduction of photographic plates; Michael D. Worth continued as assistant with the observing, measuring and miscellaneous activities. Graduate students Chao-Yuan Yang, and Nahide G. Gökkaya from the University of Ankara, were research assistants. Undergraduate students Sandra Moore, Jean Warren, Timothy Barker, and Susan Andersen assisted with the night work. Sandra Moore was summer assist-

ant in 1965; she made an astrometric study of the visual binary Hu 1176.

Photographic observations with the 24-in. refractor were made on 153 nights, a total of 3553 plates were taken. Evening observations were made on 136 nights, morning observations on 101 nights; 84 nights included both evening and morning observations. For the fourth year in succession a high accumulation of photographic plates was maintained, new monthly records were made in March (470 plates) and April (373 plates). The plate total for the year would have been higher, except for the dismantling of the refractor on May 9 for the first time since its installation in 1911. The telescope is expected to be out of commission for several months during which a mechanical overhaul and various improvements will be made.

Remeasurements of plates on Barnard's star, involving two measurers, throw some light on the temporal constancy of the 50-yr-old Gaertner long-screw measuring machine and on the personal equation of the measurers. The comparisons refer to the position of Barnard's star referred to three reference stars (*Astron. J.* **68**, 515, 1963); the measurements cover the interval 1943.4–1966.0.

Second *minus* first measurements.

Measurers	Coordinates x	Coordinates y	p.e. measurement one plate	No. of plates
	mm	mm	mm	
Lippincott minus Lippincott	+.0004	.0000	±.0008	183
Jackson minus Jackson	−.0001	.0000	±.0011	308
Jackson minus Lippincott	−.0015	−.0010	±.0020	363

We conclude that with one and the same measuring machine, the same measurer systematically repeats herself most satisfactorily. For different measurers, however, appreciable personal equation exists. A series of plates, limited in number, can easily be measured in a short time by one measurer. For extended series continuing over several decades, where thousands of plates are involved, a study of personal equation is desirable. A more impersonal setting than is provided by bisection is very much desired.

The Observatory held open nights the second Tuesday of each month during the academic year; some 250 people visited the Observatory, exclusive of out-of-town groups.

The continued support of the National Science Foundation for our research, as well as the NSF grant toward the renovation of the telescope, are gratefully acknowledged.

PETER VAN DE KAMP, *Director*

Van Vleck Observatory, Wesleyan University, Middletown, Connecticut

Personnel. During the year ending 30 June 1966 the Director, Thornton Page, was on leave of absence as National Academy of Sciences Research Associate at Smithsonian Astrophysical Observatory. The staff consisted of Emery S. Fletcher Acting Director; Herbert J. Rood and F. R. Zabriskie, Assistant Professors; and James Gibson, Research Associate. Peter van de Kamp of Swarthmore and Samuel J. Goldstein of University of Virginia were Visiting Professor and Visiting Associate Professor, respectively, during the summer of 1966. At the end of the academic year, Zabriski resigned to accept a position at Pennsylvania State University.

Graduate Student Assistants were: David L. DuPuy, Wayne H. Osborn, Gummuluru N. Sastry, Fred L. Wefer and Ching-Yew Yang. Mrs. Helen Dondero resigned as Administrative Assistant after eight years' service; Mrs. Elizabeth Tucker was appointed Administrative Assistant for the coming year, and Mrs. Evelyn Randall served as Secretary.

During the summer 1965, three NSF summer Undergraduate Research Participants, Richard T. Doherty, David M. Friedman and Leo D. Geoffrion, were in residence at VVO, supervised by Fletcher and Osborn.

Research. Professor (Emeritus) Carl L. Stearns continued his investigation of periodicity in the motion of astrometric binaries.

The Van Vleck Observatory program of parallax and proper motion continued with NSF support under the supervision of Fletcher until 31 December, 1965, at which time Wesleyan University assumed support until the end of the fiscal year. Gibson took 886 plates in the 15 months ending 30 June. This small number reflects unusually poor observing conditions in the first half of 1966. Plate measurements were carried out by graduate student assistants. Parallaxes of three late-type dwarf stars were measured and reduced from older plate series and prepared for publication by Osborn and Yang.

Page, at Smithsonian Astrophysical Observatory, published reports on radiation spikes in H II regions and masses of galaxies. He concluded arrangements to modernize the 61-in. Cordoba telescope and to put an image tube on the fast spectrograph that had been built at Wesleyan for use on this telescope. During summer 1965 he worked on the Earth Sciences Curriculum Project in Boulder

Colorado, and later reviewed the Army School system.

Fletcher studied evidence for and against the cosmological nature of quasi-stellar radio sources, concluding that current observational data are entirely consistent with the hypothesis that these radio sources are small objects near our own Galaxy ejected by an explosion at the center of the galaxy about 4×10^6 yr ago. He also made several trips to the 61-in. telescope at Agassiz Station of Harvard College Observatory to obtain spectra of galaxies.

Rood, assisted by Sastry and DuPuy, continued to derive optical brightness distributions along the major and minor axes of Coma Cluster galaxies using 200-in. plate material. The study is being made in collaboration with Dr. William W. Baum of Lowell Observatory. Rood determined the morphological types and micrometric dimensions of a large sample of Coma Cluster galaxies. Initial results indicate that the percentage of very flat S0 galaxies is larger than expected if these galaxies are approximated by an oblate spheroidal model.

Zabriskie continued observations of Jupiter at long wavelengths with the long baseline interferometer until solar activity terminated observations. Reductions of observations made during the 1964 apparition were completed and work started on the output of the 1965 observations. Although the sensitivity was low, it was possible to conclude that the most active regions at low frequencies (to 3.5 Mc) are not those favored at higher frequencies (15 Mc), and that the satellite Io has a strong effect on low-frequency radiation which differs from its effect at high frequency.

Gibson had several nights on the Harvard 61-in. telescope for observations of faint comets, but there were scattered clouds through the best of those nights.

Graduate student research included the following: Mrs. Elizabeth P. Bozyan, with Fletcher, surveyed evidence for nonthermal radio radiation in the Cygnus X region and later performed radio scans of the Coma Cluster of galaxies with the 1000-ft radio telescope in Arecibo, Puerto Rico, to construct a higher-resolution higher-sensitivity radio mapping of the region. Osborn, with Fletcher, surveyed the Van Vleck plate files of parallax series for a count of binary stars of 2″–30″ separation and a determination of their separation and position angles. Wefer, with Rood and Fletcher, constructed a two-component model of the galaxy in which the center of rotation and/or center of density of the stellar component did not coincide with that of the gaseous (H I) component. Yang, with Rood, worked out procedures for calculating orbits of stars in clusters with polytropic mass distributions; procedures for obtaining relaxation times of stars with radial and with circular orbits were also developed.

Equipment and Facilities. The 20-in. telescope was used on 201 nights out of 15 months. The use of the 4-in. photoelectric Polaris-tracking telescope, constructed by Henry A. Hill of the Physics Department, was terminated and the telescope is now being replaced by the 6-in. student refractor which originally occupied the dome.

EMERY S. FLETCHER, *Acting Director*

Warner and Swasey Observatory, Case Institute of Technology, Cleveland, Ohio

RESEARCH

The research programs under way at the Warner and Swasey Observatory fall in the broad category of low-dispersion astronomical spectroscopy and applications to galactic structure together with theoretical studies of the interstellar medium. The principal instruments employed in the observational studies are the 24–36 in. Burrell Schmidt-type telescope at the Nassau Astonomical Station and the 36-in. Cassegrain reflector at the Warner and Swasey Observatory. With the former are associated four objective prisms of various dispersions and with the latter, an ultraviolet-transmitting grating spectrograph. Basic photoelectric photometry required for some of the studies has been done with the telescopic equipment of the Kitt Peak National Observatory. The research recently completed or currently under way is summarized in the following paragraphs.

Search for Remote Wolf-Rayet Stars. The objective-prism survey for WR stars brighter than $m_{pg}=15$ to 15.5, mentioned in last year's report (*Astron. J.* **70**, 652, 1965), has been completed. Seven new objects were found. None of these are in the quadrant of galactic longitude, approximately $l^{II}=135°$ to 225°, in which no WR stars were previously known. It appears that this quadrant of avoidance is by no means a result of systematic neglect of the winter sky by northern observers, but is a real gap in the distribution of these objects. A paper describing this research has been submitted for publication (Stephenson).

Two-Dimensional Spectral Classification of Visual Binaries. The spectra of 270 visual binaries with separation of components for the most part less than 2 sec of arc have been observed with the Cassegrain uv spectrograph on the 36-in. reflector at a dispersion of 130 Å/mm. The binaries under observation were those expected to have one component above the main sequence. A comparison between the real composite spectrum for a close pair and a synthetic composite spectrum made by super-

posing two exposures of stars of differing but known MK spectral type does not seem to yield spectral classifications which are as reliable as comparisons made with individual examples of MK standards. This conclusion is based upon spectra in the blue and ultraviolet.

Masses of 109 visual binaries with known orbits and 215 physical pairs have been derived from data on trigonometric or spectroscopic parallaxes. For only 19 of these systems can masses of the individual components be derived. Mean masses for stars in blocks of the H-R diagram have been determined. And by using the data for 29 above-main-sequence components of spectrophotometric binary systems, mean masses of early-type above-main-sequence stars and supergiants were obtained. In general the mean masses derived for those components of binary systems lying above the main sequence at classes A0–A5 are higher by a factor of 2 than the corresponding masses for stars on the main sequence. For the F stars the factor is about 1.5; for the G stars, the factor is 2 to 3, increasing as the luminosity of the group increases (Sanwal, Stephenson).

Observations of Carbon Stars. All of the spectra of carbon stars noted in the course of the Luminous Star Surveys IV and VI (see last year's report) have been systematically re-examined in conjunction with a program for establishing carbon star standards. Observations both with the objective prisms and with the Cassegrain uv spectrograph have been made. Approximately 100 of these *Luminous Star Survey* IV and VI stars had not been previously identified as carbon stars. Several new instances of stars showing the C_2 bands, discussed long ago by Sanford (*Publ. Astron. Soc. Pacific* **38**, 177, 1926) and others and identified by Kleman (*Astrophys. J.* **123**, 162, 1956) as SiC_2, were found. Half a dozen new cases of stars that may resemble GP Ori in combining carbon and S-type characteristics were identified. The objective-prism evidence for the latter is rather subtle and confirmation at higher spectroscopic resolution will be necessary. A previously known coarse clustering of N-type stars in Monoceros extends to fainter magnitude limits than those previously reached. The results of this study have been published (*Astrophys. J.* **142**, 712, 1965) (Stephenson).

Observations of "Infrared Stars." Spectra in the near infrared for some of the stars observed photometrically by Johnson, Mendoza, and Wisniewski (*Astrophys. J.* **142**, 1249, 1965) are being accumulated. Studies of those spectra available in our plate collection tend to confirm the conclusion reached by the above authors that the Haro–Chavira objects belong to the class of M-type stars rather than to the class of carbon stars. Indeed, Haro–Chavira No. 2 appears to be star RM-WS 70 (spectral type M1) listed in the paper "Reddened Early M- and S-Type Stars near the Galactic Equator" by Nassau, Blanco, and Morgan (*Astrophys. J.* **120**, 478, 1954). Spectra were available for only two of the Hetzler objects. On the basis of a single 1N plate for each object, Hetzler I-1 appears to be a late M-type star and Hetzler IV-1 appears to be an S-type star (Pesch).

Galactic Structure in the Direction of the Galactic Center. This study was reported in some detail in last year's Observatory Report. Accurate photoelectric magnitudes and colors in four fields near Sgr A ($\alpha = 17^h43^m$; $\delta = -29°.0$) were determined with the instrumental equipment of the Kitt Peak National Observatory. V magnitudes, $B-V$ colors and $V-I$ colors for 75 sequence stars were obtained as basic standards to be used for photographic photometry. By means of this photometric data and spectral-type data taken from a previous study by Purbosiswojo (unpublished), for 340 stars of OB and early main-sequence types, color excesses, interstellar reddening and absorption were derived for three regions ($b^{II} = +1°.5$, $-0°.3$ and $-1°.8$) at $l^{II} = 0°$. The results for the interstellar absorption A_v, in magnitudes, as a function of distance are:

	Distance (kpc)					
b^{II}	0.5	1.0	2.0	3.0	5.0	7.0
$+1°.5$	2.6	2.6	2.6	2.6	2.6	2.6
$-0°.3$	1.5	1.6	2.4	2.9	3.2	3.2
$-1°.8$	0.9	1.9	1.9	1.9	2.0	2.2

Thus it appears that the bulk of the absorbing material is relatively near the sun.

Late M-type stars were classified on spectrum plates sensitive in the near infrared. Additional classification based upon the correlation between $V-I$ color indices and spectral types for M stars (Blanco, V. M., *Astron. J.* **69**, 730, 1964) was used where necessary. Altogether a catalogue of 162 M-type stars in 9 areas along the galactic equator totalling 2.25 sq deg was constructed. The V magnitudes range as faint as 16.0; B–V and V–I color indices were determined for all of these stars. A preliminary study of the spatial distribution of these M2 to M10 stars indicates the following:

Distance (kpc)	0.6	1.0	2.0	3.0	4.0
Space density (No. per 10^6 pc^3)	35	8.7	8.4	8.2	4.7

These space densities are greater by a factor of 2 than the space densities for a similar grouping of M-type stars at comparable distances in Groningen-

Palomar Field 2, at $l^{II}=4°$, $b^{II}=+11°$ (Wehinger, Blanco).

The Stellar Space Distribution Near the Galactic Anticenter. A catalogue containing spectral classifications, V magnitudes and, for some stars, $B-V$ colors has been completed for this area of about 20 sq deg. In the general catalogue 3620 stars to $V\cong 12.2$ are included. A study of the distribution in space of these stars is under way. A detailed study of the spatial distribution of the 134 OB stars is also being made. Infrared spectra of M-type and carbon stars are now being classified. A comparison of these detailed spatial stellar distributions with similar studies for the region of the galactic center should strengthen our current knowledge of the sun's position relative to the local spiral structure of the galaxy (McCuskey).

The Galactic Structure in Five Southern Fields. This project was initiated last year in collaboration with the staff of the Bosscha Observatory, Lembang, Indonesia. Centers for the areas being studied are listed in last year's annual report. Spectrum plates for all areas and all plates necessary for the photometry for 4 or the 5 areas have been obtained. Photometric plates for one area remain to be taken. Each area covers about 25 sq deg. A study of the A and the gK stars and of the luminous stars in these areas is now under way (McCuskey, The, Drilling).

Studies of the Cepheus IV Association.

(a) A detailed study of the surface and space distributions of emission objects, flare stars, variables and obscuration in 24 sq deg of the sky centered approximately at $\alpha=23^h59^m$; $\delta=+66°36'$ (1900) has been completed. Basic photoelectric photometry in the area was established on the standard UBV system by use of the 36-in. reflector of the Kitt Peak National Observatory. The photoelectric standards were distributed in five areas of the survey field so as to minimize systematic plate errors in the subsequent photographic photometry. Use of a neutral half-filter permitted the photographic photometry, which was done with the Burrell Schmidt-type telescope, to be extended to $B\sim 18$; $V\sim 18$; $U\sim 17$ with, of course, some reduction in accuracy. The results of the study may be summarized as follows:

(1) Stars *practically certain* to be members of the association include those reported by Blanco and Williams (*Astrophys. J.* **130**, 482, 1959) together with three known Be stars, an eclipsing binary, and 25 intermediate and late B-type stars outside the obscuring cloud. Stars *probably* members of the association include the central stars of several reflection nebulae, two possible giant stars, a new flare star, and many probable T Tauri-type stars.

(2) The obscuring dust cloud is found to have a well-defined border. All of the reflection nebulae are distributed along the boundary of the cloud. From the spectral types and photometry of the illuminating stars it appears that the reflection nebulae are within the cloud but near the boundary toward the sun. A normal ratio $R=A_v/E_{B-V}$ is found for the cloud; its distance is 825 pc. The average A_v is 4.7 mag.

(3) The correlation between spectral–luminosity type and reddening found by Blanco and Williams probably can be explained by the fact that the heavy absorption in the cloud permits the detection of only the absolutely brightest members of the associated stars (MacConnell, Blanco).

(b) A second study just initiated concerns the wavelength dependence of the interstellar reddening in the area of Cepheus IV. An objective grating of 24-in. aperture for use with the 24–36 in. Burrell Schmidt-type telescope is being constructed. This will be used for photographic spectrophotometry of selected stars in Cepheus IV (Honeycutt, Reddish).

M-Type Stars near the North Galactic Pole. A summary of this research was presented in the 1964 Observatory Report (*Astron. J.* **69**, 720, 1964). The large number (1260) of M stars in 120 sq deg of the polar cap to $V=17$ may be interpreted in two ways:

(1) It may be argued on fairly good grounds that those M stars with $V\gtrsim 13$ are most probably M dwarfs. If so, analysis indicates that the general luminosity function in the solar neighborhood is deficient by a factor of 3 to 4 at $M_v=13$. Proper motion studies now extant do not confirm this large excess of dM stars.

(2) On the other hand, if the majority of these stars are gM stars the space density at large distances from the galactic plane is much higher than formerly supposed. A preliminary analysis indicates a rapid decrease in the number of gM stars from 1.8 per 10^6 pc^3 at $z=400$ pc to 0.07 at $z=2500$ pc. Following this rapid decrease the number falls slowly to 0.004 per 10^6 pc^3 at $z=20\,000$ pc.

Further investigation of these alternatives is under way and details will soon be published (Sanduleak).

Galactic Survey of A and K stars. A beginning has been made on a comprehensive survey of main sequence A and giant K stars in the galactic belt 12° wide centered at $b^{II}=0°$ observable from this Observatory. The new 1°.8 uv transmitting prism (dispersion 1100 Å/mm at Hγ) attached to the 24–36 in. Schmidt-type telescope is being used. Preliminary tests with Kodak IIa-O plates and exposure times of 20 min indicate a reasonable magnitude limit $V=13.5$ for the detection of main sequence A stars and giant K stars. The detailed

spatial arrangement of these stars around the sun, their relationship in current ideas concerning the transition from main sequence to the giant branch of the H-R diagram are to be studied (McCuskey).

Spectroscopic Observations of Interesting Objects Noted in the Luminous Stars Survey .

(a) Stars reported in the *Luminous Stars* catalogues as being strongly space reddened are being observed with the Cassegrain uv spectrograph attached to the 36-in. reflector in order to search for possible new absorption features associated with interstellar dust.

(b) The brighter supergiants having Hα reported in emission have been observed in the Hα spectral region at dispersions of 65 and 130 Å/mm in a search for shell-star characteristics. Here the curious fact has emerged that most objects listed in the *Luminous Stars* III and V catalogues as having Hα in emission do not, at least at the time of observation with the Cassegrain spectrograph, show any Hα emission.

(c) Most of the stars listed in these catalogues brighter than $m_{pg}=9.0$ and having the Balmer continuum in emission (ce stars) have been observed with the Cassegrain spectrograph in the blue spectral region. Such stars are included in the catalogues generally on the basis of extremely weak ce characteristics. Nevertheless about 60% of the 22 stars so far observed at higher dispersion do have the Balmer continuum in emission. Of these not all show line emission in the blue spectral region at a resolution of 2 Å, but all show decisive evidence of rapid rotation. This study has been published (*Astrophys. J.* **142**, 309, 1965) (Stephenson).

Observational Studies with the Cassegrain uv Spectrograph. This instrument, which yields 65, 130, or 390 Å/mm depending upon the grating used, has been in continual use on various problems. These may be summarized as follows:

(a) A peculiar emission star discovered in July 1965 in Cygnus was observed at a dispersion of 130 Å/mm. The star, MHα 328–116 in the Mt. Wilson catalogue compiled by Merrill and Burwell, increased in light from $m_{pg}\sim 15$ to $m_{pg}\sim 11.8$ between 1963 and 1964. The spectrum was found to be similar to a symbiotic variable. Emission-line identifications and a light curve have been published (*Astrophys. J.* **144**, 1135, 1966) (FitzGerald, Houk, McCuskey, Hoffleit).

(b) All OB stars brighter than $m_{pg}=11.5$ in the region LF5 ($\alpha=1^h41^m$; $\delta=+60°18'$; $l^{II}=129°$; $b^{II}=-2°$) in Cassiopeia are being observed at a dispersion of 130 Å/mm. There are 115 objects of this type for which accurate spectral classifications are being sought. The observational program is about one-half completed (McCuskey, Houk).

(c) A representative sample of 28 Ap and Am stars has been observed at 130 Å/mm for a study of the reliability of detection of these objects from objective-prism spectra (280 Å/mm). It was found that only 2 of the 15 slit spectra of Am stars, so identified on objective-prism plates, and none of the spectra of Ap stars so identified showed metallic or peculiar characteristics. Variations of seeing, length of exposure time, quality of plates (guiding, focus, etc.) give rise to the presence, at times, of additional features in objective-prism spectra not normally observed at this low dispersion in A-type stars. A brief summary of this work is in press (Honeycutt, McCuskey).

(d) Rapid irregular variations in the spectrum of the Ap star 73 Draconis have been observed. Variations in the relative strengths of the narrow core and the broad, shallow component of the Ca *K* line have been found to occur in intervals of less than an hour. A dispersion of 130 Å/mm was used for this work. Continuing observations at 65 Å/mm are under way. An initial paper concerning this star has appeared in *Publ. Astron. Soc. Pacific* **78**, 153 1966 (Honeycutt).

(e) Interesting late-type variable stars, approximately 80 in number, are being observed in the near-infrared part of the spectrum at a dispersion of 390 Å/mm (resolution 5 Å). The grating used for this work is blazed for the infrared. Well-exposed spectra for variables near minimum light as faint as $m_v=14.2$ have been obtained with this spectrograph-36-in. reflector combination (Wyckoff, Stephenson).

(f) An emission-like feature at λ6400 Å, noted in low-dispersion objective-prism spectra of M stars is being investigated with the slit spectrograph at a dispersion of 390 Å/mm. This feature seems to be real and not an emission line but rather is associated with the incipient appearance of the ZrO band at λ6474 Å (Honeycutt).

(g) Very late M-type dwarf stars are being observed in the infrared (λλ6800–8800 Å) to furnish comparison material for eventual observation of some of the infrared proper motion stars found in the survey mentioned in the last Observatory Report. Preliminary data indicate that these objects can be photographed with the 36-in. reflector and the infrared-efficient grating at a spectroscopic resolution of 5 Å as faint as $m_v=12$ (Stephenson).

(h) A program of observation of visual binaries containing a B-type star has been initiated. The dispersion used is 130 Å/mm. A considerable number of known B-star common proper-motion systems lack accurate spectral classifications. Our program should provide these. It is hoped that a larger sample of common proper motion pairs will be available through the continuing record of astrometric observations of double stars being main

tained at the U.S. Naval Observatory. Additional binary stars of this type will be placed upon the spectrographic program as they are discovered. This program should furnish a check on the extent to which the B-star luminosity calibration derived from galactic clusters is representative of stars in the general field (Stephenson).

Spectral and Magnitude Variability of Giant M Stars.

(a) *Magnitude variability of giant M stars* in Groningen–Palomar Field 2 ($\alpha = 17^h06^m$; $\delta = -19°24'$: $l^{II} = 4°$; $b^{II} = +11°$) is being studied on plates taken with the Palomar and the Case Schmidt telescopes. With a blink comparator 750 M stars have been examined individually for variability on each of 7 pairs of plates well spaced in time. Approximately 140 suspected new variables, mostly of low amplitude, were found. These are in addition to those detected in an earlier blink survey of the region by Plaut (unpublished). Information concerning the magnitude ranges is being obtained by photographic photometry of all 750 stars, plus 150 control stars, on 20 plates covering 12 epochs. Additional information on the ranges is being derived from Palomar Schmidt telescope plates by de Kort and co-workers at Nijmegen (Houk, Plaut).

(b) *Spectral variations of long-period variables* in Groningen–Palomar Field 2 are being studied. Approximately 120 stars having appreciable amplitudes of light variation have been classified spectroscopically on a large number of infrared- and red-sensitive plates taken with the 24–36 in. Burrell Schmidt-type telescope and 4° objective prism. The range of spectral type variation with phase has been determined from observations at 5 to 15 epochs. For variables having amplitudes greater than 2 mag the range in spectral type is considerable. Nearly all such variables reach spectral type M7 or later during some portion of their light cycle, even though at times they may be very early M types. Magnitude measures in the blue, the visual and the infrared spectral regions are planned in order to study the $V-I$ color index variation with phase. In many cases the photometric data cover the same epochs as the spectral classification data (Houk).

(c) *Magnitude and spectral variability of giant M stars* in VSF 193 ($\alpha = 18^h27^m.5$; $\delta = -23°.5$; $l^{II} = 9.7°$; $b^{II} = -6.3°$) in Sagittarius are being studied in an area of 20 sq deg. All M stars brighter than m_{pg} 14.5 and all long-period variables with maximum $m_{pg} \leq 14.5$ are included in the study—a total of 400 stars. Published and unpublished information on the positions and magnitudes of the variable stars was provided by Dr. Dorrit Hoffleit of the Maria Mitchell Observatory. About two-thirds of the M stars not known to be variable were examined for variability on 35 well-spaced plates from the Harvard and the Maria Mitchell collections to provide a check on the completeness of discovery of the variables.

Spectral types and magnitudes of the M stars have been derived from Burrell Schmidt-type telescope material in the Warner and Swasey Observatory collection. About 150 of the 400 M stars appear to be variable to some degree. The frequency of occurrence of variability as a function of spectral subtype will be studied in comparison with the similar, but more extensive, study for Groningen–Palomar Field 2 mentioned above (Houk).

Spectrum Changes in Red Variables. The study of 50 selected late-type variable stars, initiated some years ago by the late J. J. Nassau, is being continued and will soon be concluded. Spectra in the near infrared taken with the 4° objective prism (resolution about 70 Å) attached to the Burrell Schmidt-type telescope and covering nearly all phases of the light variation have been obtained. There are 20 S-type and 30 M-type stars included in the study (Terrill, Stephenson).

Photometric Study of Selected Reflection Nebulae. Photoelectric U, B, V measurements of color variation as a function of distance from the illuminating star have been obtained for the reflection nebulae IC 1435, IC 4592, and IC 4604 with the Kitt Peak 36-in. and the U.S. Naval Observatory 40-in. reflectors. The $B-V$ color difference (star minus nebula) for IC 1435 was found to decrease from +0.50 at 1'.0 south of Merope to 0.00 to 11'.0 south. The corresponding $U-B$ variation was reliably obtained only to a distance of 4'.0 south due to poor weather conditions. At this point the color difference had decreased to +0.04 from +0.25 at 1'.0 south.

The intrinsic faintness of both IC 4592 and IC 4604 in the visual region prevented the determination of a reliable $B-V$ color index variation for these two objects. Their variations in the $U-B$ color index were similar to those quoted for IC 1435 with the former decreasing from +0.60 at 1'.0 north to +0.18 at 11'.0 north and the latter decreasing from +0.65 at 1'.0 east to + 0.25 at 9'.0 east.

A preliminary comparison of the results for IC 1435 with plane parallel model nebulae employing a first-order scattering solution to the radiative transfer problem indicates some preference for graphite over ices as the scattering agents (Dahn, Pesch).

Catalogue of Photoelectric Data. A catalogue containing data on photoelectric magnitudes and colors for 17 000 stars has been compiled from a search of the literature. All stars for which there are published data on the Johnson–Morgan UBV system and the Cape U_cBV system are included. The catalogue includes for each star the following: HD or other number; 1900 position; 100-yr precession;

unweighted average V, $B-V$, $U-B$ or U_c-B; spectral class; references to the individual observations. Data for clusters and for established magnitude sequences are listed separately. The publication of the catalogue will be undertaken in the near future then it is hoped that tape or card versions will also be available.

The data from the catalogue are being used for a study of the galactic distribution of interstellar absorbing material in the solar vicinity. As a preliminary step, the intrinsic colors of stars of all MK spectral types and of some peculiar classes have been redetermined. The intrinsic colors thus obtained differ little from those found in the literature. The intrinsic index $(U_c-B)_0$, derived for stars measured at the Cape, seems to be sufficiently different from $(U-B)_0$ to warrant treating it as an independent index. The slope of the two-color reddening lines as a function of spectral class, galactic position, and reddening is being studied. Preliminary results indicate a dependence of the ratio E_{B-V}/E_{U-B} upon all three of these (FitzGerald, Blanco).

Bright Blue Stars in M67. Observations of eight "blue stragglers" in this old cluster were reported in last year's summary (*Astron. J.* **70**, 652 1965). Radial velocities for these stars do not indicate that they are large-amplitude spectroscopic binaries as would be required by the theory of mass transfer proposed by McCrea (*Monthly Notices Roy. Astron. Soc.* **128**, 147, 1964). Spectral classifications for these blue stars are now being made. The plates for the radial velocity work and for the spectral classification were taken with the 84-in. reflector of the Kitt Peak National Observatory (Pesch).

Mean Absolute Magnitude and Dispersion for F Stars. An analysis of proper motion and radial velocity data for the 6th mag F0, F2, F5 stars listed in the *Yale Catalogue of Bright Stars* (3rd ed.) has yielded a mean absolute visual magnitude $M_s=+2.6$ and a dispersion $\sigma_s=0.9$ mag for this group as a whole per unit volume of space. Application of these parameters to the evaluation of space densities in 22 galactic regions reduces but does not remove the rapid decreases in density with distance from the sun previously found for this stellar group (McCuskey, S. W., "The Distribution of A and F Stars near the Galactic Plane," *IAU* Paper 13, Joint Discussion A, *Trans. IAU* **XIIB**, 425, 1966). This study has been completed and the results are in press (McCuskey, Rubin).

Theoretical Studies of the Interstellar Medium.

(a) Investigations of the dynamical events and the physical processes involved in the evolution of H II regions are under way. In particular the study embraces a combination of the dynamical evolution of the region with the details concerning radiative transfer of the Lyman continuum, the photo-ionization and recombination properties of hydrogen and helium, and the cooling due to forbidden-line emission in both visual and infrared spectral regions by ions of oxygen, neon, and nitrogen. The most important dynamical events concern the transition from supersonic expansion of the ionized region into the undisturbed material to expansion where the shock proceeds into the undisturbed gas and the ionized gas drives the dense neutral shell following the shock outward at supersonic velocities. The coupling between the shock and the ionization is usually not isothermal. Hence the expansion of an H II region during most of its lifetime can be treated dynamically only when the detailed structure of both the relaxation region of the shock and the ionization front are considered at each point in time (Hjellming).

(b) The properties of dense H I shells are being investigated from the point of view of the scattering, the formation and the destruction properties of the dust present. In particular the possibility of accelerated molecule formation due to the high density in these shells is being studied (Hjellming).

(c) The problem of a comparison of the observable properties of certain H II regions with predictions made by detailed physical models is being studied. Theoretical models are being computed for a density distribution obtained from radio and optical observations on the assumption that thermal and ionization equilibrium exist in the majority of the H II regions. Six regions for which comparisons are being made are: the Orion nebula, the Rosette nebula, IC 410, M16, NGC 2175, and NGC 6820 (Rubin, Hjellming).

(d) The transfer of radiation through H II regions and the associated dense H I shells is under study. In particular an examination is being made of the transfer of both continuum radiation and radiation in lines for which the medium has a finite optical depth (Roberts, Hjellming).

(e) A large atlas to be used in comparing large amounts of data about the interstellar medium is under construction. This is planned to cover the entire Milky Way belt to $\pm 30°$ in b^{II}. Transparent overlays will present data on obscuring clouds; reflection and emission nebulae; O and T Associations; selected 21-cm data; selected data concerning thermal radio emission in selected wavelengths; and other objects such as WR stars, dark globules, OH emission, and absorption sources. The data will be restricted to that which is likely to be fundamental. A reference background grid of coordinates will be provided (Grossenbacher, Hjellming).

PERSONNEL

The faculty of the Department of Astronomy during the year under review consisted of Professors Blanco, Hjellming, McCuskey, Pesch, and Stephenson. Professor V. M. Blanco, a long-time and valuable member of the staff, resigned on 1 September, 1965 to accept a responsible position at the U.S. Naval Observatory. His presence will be sorely missed. During the period 1 February 1966 to 1 June 1966, Dr. V. C. Reddish, Royal Observatory, Edinburgh, Scotland, served as Visiting Professor under the auspices of the Foreign Visiting Professorship Program of the American Astronomical Society Dr. Reddish contributed invaluably to the graduate instructional program and to the research program of the Observatory.

Dr. Pik-Sin The, the Director of the Bosscha Observatory, Lembang, Indonesia, continues to serve as a scientific collaborator on problems connected with the southern Milky Way.

Other members of the staff of the Observatory are Associate Astronomer John Finnerty, Librarian Mrs. Betty Stephenson, and Instrument-Maker John Svenstrom. All of these contribute importantly to the smooth daily running of the Observatory.

Sixteen graduate students were in residence during the year. Two others were finishing their Ph.D. theses in absentia. Two Ph.D. degrees were conferred by Case on candidates from the Department of Astronomy at the June 1966 Commencement.

Colloquia were held on the average of once every three weeks. Both foreign visiting astronomers and those from the U. S. contributed to this series. Staff and students alike were stimulated by these discussions.

Public Nights were held at the Observatory during each of five months of the academic year. The total attendance for the 10 nights was about 1500. Groups of high school and junior high school students, science clubs, and interested adults made up the audiences. This program, begun in the 1920's by the late Professor J. J. Nassau, continues to attract an enthusiastic response from the public. At present the lectures and associated programs are carried out entirely by the graduate students. The public response to their efforts has been very gratifying.

PHYSICAL FACILITIES

Financial assistance from the National Science Foundation enabled us to purchase a National Spectrographic Laboratories microphotometer. This will allow the staff and students to embark upon many astrophysical studies hitherto precluded by our lack of such an instrument. The microphotometer will accommodate the 8-in. sq plates taken with the Schmidt-type telescope as well as the smaller plates taken with the Cassegrain uv spectrograph. An interesting feature of the instrument is the large display screen on which the spectrum, magnified 20 times, may be viewed during the scanning.

With the collaboration of the personnel of the Engineering Design Center at Case the Eichner astrophotometer has been provided with automatic setting of the iris diaphragm and digital readout on typewriter paper and on punched tape. Further development of this instrumentation is under way.

The design has been completed for an optical system at the Newtonian focus to convert the $f/3.5$ beam of the Schmidt-type telescope to $f/14$. This will permit our photoelectric equipment to be used interchangeably on the 9.5-in. refractor, the 36-in. Cassegrain reflector and the Schmidt. Mechanical work on the unit is under way.

PUBLICATIONS

The following papers were published during the period 1 July 1965 to 30 June 1966:

McCuskey, S. W. 1965, "Distribution of Common Stars in the Galactic Plane." in *Galactic Structure* A. Blaauw and M. Schmidt, Eds., Vol. V of *Stars and Stellar Systems*, G. P. Kuiper, General Ed. (University of Chicago Press, Chicago), Chap. 1.

Blanco, V. M. 1965, "Distribution and Motions of Late-Type Giants," in *Galactic Structure*, A. Blaauw and M. Schmidt, Eds., Vol. V of *Stars and Stellar Systems*, G. P. Kuiper, General Ed. (University of Chicago Press, Chicago), Chap. 12.

Nassau, J. J., Stephenson, C. B., and MacConnell, D. J. 1965, *Luminous Stars in the Northern Milky Way VI* (Hamburger Sternwarte and Warner and Swasey Observatory, Hamburg-Bergedorf).

Stephenson, C. B., Nassau, J. J., and MacConnell, D. J. 1965, *Luminous Stars in the Northern Milky Way VIa: Identification Charts* (Hamburger Sternwarte and Warner and Swasey observatory, Cleveland).

Stephenson, C. B. 1965, "Spectroscopic Observations of ce Stars in the *Luminous Stars in the Northern Milky Way* Catalogues," *Astrophys. J.* **142**, 309.

Stephenson, C. B. 1965, "Spectral Classifications for New or Previously Unclassified Carbon Stars," *Astrophys. J.* **142**, 712.

Philip, A. G. D. 1966, "The Stellar Space Distribution in Pegasus at $b^{II} = -29°$," *Astrophys. J. Suppl.* **XII**, No. **112**, 391.

Blanco, V. M., and Plaut, L. 1965, "Variability among M Giants," *Publ. Astron. Soc. Pacific* **77**, 466.

Stephenson, C. B. 1965, "Astrophysical Investigations Utilizing Objective Prisms," *Vistas in Astronomy*, A. Beer, Ed. (Pergamon Press, Oxford), Vol. VII, p. 59.

McCuskey, S. W. 1965, "The Stellar Luminosity Function," *Vistas in Astronomy*, A. Beer, Ed. (Pergamon Press, Oxford), Vol. VII, p. 141.

Philip, A. G. D., and Sanduleak, N. 1966, "Low-Dispersion Spectra of Stars and Galaxies," *Publ. Astron. Soc. Pacific* **78**, 30.

FitzGerald, M. P., Houk, N., McCuskey, S. W., and Hoffleit, D. 1966, "A Peculiar Emission Star in Cygnus, MHα 238-116," *Astrophys. J.* **144**, 1135.

Honeycutt, R. K. 1966, "Apparent Rapid Spectral Changes in 73 Draconis," *Publ. Astron. Soc. Pacific* **78**, 153.

McCuskey, S. W. 1966, "The Distribution of A and F Stars near the Galactic Plane," IAU Paper 13, Joint Discussion A, *Transactions of the International Astronomical Union*, J.-C. Pecker, Ed. (Academic Press Inc., New York), Vol. XIIB, p. 425.

The research programs of the Observatory have been given generous financial support during the year under review by the National Science Foundation and the Office of Naval Research. This continued support is gratefully acknowledged.

S. W. McCuskey, *Director*

Washburn Observatory, University of Wisconsin

Personnel. Osterbrock served as a member of the NSF Advisory Panel in Astronomy. Bless, Mathis, and Parker served on the NSF Visiting Astronomer Program. Osterbrock was elected to the National Academy of Sciences. Mathis returned from a year's leave of absence spent at Los Alamos Scientific Laboratory. Jos van Boeckel and Wolfgang Haupt joined the Observatory's Space Astronomy Laboratory as NASA postdoctoral fellows.

M. A'Hearn and R. Williams received the Ph.D. degree.

An Advanced Summer Seminar on Interstellar Gas Dynamics was held 20 June–15 July, 1966 under the sponsorship of the National Science Foundation. Lectures and discussions were given by 10 visiting lecturers and by 5 members of the Washburn Observatory staff, and were attended by about 40 post-Ph.D.'s and graduate students from all over the country, as well as by University of Wisconsin graduate students.

Instrumentation. Under Parker's supervision an efficient photoelectric stellar scanner has been completed in the Observatory shop. The optical design is that described by Schroeder (*Appl. Opt.* **5**, 545, 1966). This instrument, along with a new offset guider, has just been put into operation and results indicate that at 80 Å resolution stars as faint as $14^{m}.5$ can be observed with the Pine Bluff 36-in. reflector. The scanner can be used at resolutions from 20 Å to greater than 800 Å. A new system of data handling at the telescope has also been installed for use with the scanner. The primary purpose of the system is to provide rapid scanning at rates as high as 2000 Å/sec. It is expected that in this way the effects of variations in atmospheric transparency can be eliminated in the determination of relative energy distributions. Preliminary results confirm this expectation. Because very little information is obtained in one such rapid scan, the grating is repeatedly stepped across the spectrum and the photomultiplier output fed to the appropriate channels of a digital memory oscilloscope until a sufficient number of counts has accumulated. The data are then printed out in digital form.

Schroeder has considered various designs in search of the best type of instrument for a high-resolution (about 1–2 Å/mm at the exit slit) scanning spectrometer-spectrograph for use on the 36-in. Pine Bluff telescope. It appears that a compact instrument with the necessary resolution can be made by using a ruled echelle crossed with a diffraction grating to separate the different echelle orders. Such an instrument can be used for studies of both emission and absorption line objects. A preliminary design has been made and laboratory studies of the instrument are under way.

The Sun and Planets. Ellis Monash, at the Smithsonian Astrophysical Observatory, has been working on a thesis concerning the heat balance of the chromosphere. He has evaluated the radiative losses for existing chromospheric models and compared these results with the observed chromospheric spectrum. The agreement is reasonable. He then evaluates the energy input from conduction and mechanical heating for these same models and finds that these models cannot be in equilibrium. It is possible, however, to construct a chromospheric model in which heat balance is maintained.

Michael A'Hearn completed his study of polarization measurements of Venus. He obtained data on the net polarization of Venus for phase angles less than 25° at eight wavelengths between 3225 and 10 960 Å. These measurements had not previously been made. The percentage polarizations found were generally larger than those found by other observers at other phases. He also found a continuous rotation of the position angle with phase. In order to compare these data with theoretical predictions, A'Hearn calculated sets of model planetary atmospheres for different optical depths and scattering matrices. The observational data are completely inconsistent with a Rayleigh scattering

model. Even with the very highly forwardscattering matrix of ice crystals the agreement between theory and observation is not substantially improved. It is likely that no form of molecular scattering can account for the observed polarization. The rotation of position angle cannot occur for any homogeneous atmosphere with randomly oriented particles.

Stellar Interiors. Mathis continued investigations started while at Los Alamos of the hydrodynamics of direct stellar collisions and has treated the problem of an on-axis collision of two solar-type models. He found that nuclear reactions cannot affect the chemical composition of the stellar material, although the temperature in most of the material of the composite configuration reaches 10^8°K for about 200 sec.

Mathis and Terry Edwards worked on a perturbation theory of stellar interiors, in which small changes from a previously determined model can be found by simple quadratures. Edwards, now at the University of Missouri, is applying the results to helium-flash models, seeing if an improved equation of state will change the mixing of the core and envelope material. He has completed tables of physical properties of partially degenerate electron gases.

Miss Laura P. Bautz, now at Northwestern University, has continued her investigation of contracting, partially degenerate models with carbon cores and helium envelopes.

Mathis and Joseph Boone have begun an investigation of the causes of differences in the apsidal motion of eclipsing binaries as observed and as predicted from theoretical models.

Stars. Further observations of Balmer lines of A-type peculiar stars were undertaken by William Gebel. No variations in the equivalent width of Balmer lines of ϵ UMa were found greater than 5% in Hδ and 8% in Hγ over periods of an hour. These variations coincided with the range of error determined by scanning the normal star α Peg. Changes in the Hδ line of α And were slightly greater than the expected errors. Scans of the Hβ lines in these stars are being reduced.

Joseph Miller is carrying out an investigation of light variations of the central stars of planetary nebulae using the 36-in. Pine Bluff reflector. He is employing filter–photomultiplier combinations which avoid most of the nebular emission lines, producing intensity measurements having less than a 15% nebular contribution. Approximately 25 stars are involved in the program, which is aimed at detecting short time-scale (hours to days) as well as long time-scale (months to a year or more) light variation.

As part of his Ph.D. thesis research, Robert Millis has undertaken a search for δ Scuti variables in order to better derive the properties of the group and its relation to other stars. Photoelectric spectrum scans of a few variables will be made to determine the physical characteristics of these stars. Millis is carrying out most of the observational work at Lowell Observatory.

Miss Flather continued making multicolor observations of high-velocity red giants.

Miss Mengeot and Doherty reduced the photoelectric spectrum scans of the July 1965 eclipse of 32 Cyg.

Radiative Transfer. The numerical solutions of the equation of radiative transfer treated by Collins (now at Ohio State University) and Code (*Astrophys. J.* **142**, 1576, 1965) while extremely flexible are nevertheless restricted to those problems that may be treated as axially symmetric point by point. In problems such as the illumination of a reflection nebula this is not the case. In order to solve the three-dimensional transfer problem Code and Collins adopted the method of random walk. Large high-speed digital computers make this a satisfactory approach. A computer program was written to follow individual photons through a medium. This program has been tested on simple cases that could be compared to the exact one-dimensional transfer equation solutions and with the single scattering approximations, with good results. This comparison indicates that in general it will be necessary to follow about 10^5 photons in order to obtain satisfactory representation of the radiation field. Since the intensity is a function of two coordinates and two angles, further programming is desirable to provide readily interpretable output of the data. Such a program will also be suitable for dealing with time-dependent transfer problems.

Nebulae. Osterbrock and Parker studied the excitation of the optical emission lines in quasi-stellar radio sources. A model with $T=15\,000$°K and $N_e=3\times10^6$ cm^{-3} gives the best over-all agreement with the average observed line spectrum of the quasi-stellar sources. At this density the [Ne IV] λ2424 line is strongly de-excited collisionally, and its weakness in comparison with [Ne III] λλ3869, 3967 and [Ne V] λλ3425, 3345 can be understood on this basis. Several semiforbidden intercombination lines such as $2s^2\,2p^2P^0-2s2p^2\,^2P$ C II] λ2326 and O IV] λ1406 are predicted to be reasonably strong according to this quasi-stellar source model.

Osterbrock, Joseph Miller, and Daniel Weedman completed the reduction of the profiles of H I, He II, [O III] and [N II] emission lines in planetary nebulae from coudé spectrograms taken by Osterbrock as a guest observer at Mount Wilson Observatory in 1964. The individual spectrograms were traced on the microphotometer at Yerkes Observatory, and the tracings were then read into

punched cards using a two-dimensional curve reader and punch recently set up at Washburn. Further processing to reduce the profiles was carried out in the IBM 1620 computer of the Space Astronomy Laboratory. The tracings show that the lines are wider than the expected thermal Doppler widths, which indicates that there are significant mass motions within planetary nebulae. These observationally determined profiles may be used to test the predictions of physical models of expanding planetary nebulae. Only a few such models exist at present, all extremely simplified, but comparison with assumed sample models shows that the distribution of emission with radial velocity must have a fairly well-defined peak.

Parker is continuing the reduction of his spectrophotometric observations of filaments in the Cygnus Loop.

William Gebel began work on a thesis whose object is the measurement of Hα and Hβ fluxes from diffuse nebulae. The Hα and Hβ bands will be isolated by interference filters of 10 Å half-width which will be mounted in front of the objective of a small telescope to avoid the problem of a convergent beam. The object of the thesis is to evaluate the interstellar reddening by comparing measured Balmer fluxes with those predicted from radio fluxes. While the new photometer for this thesis is under construction, observations have been carried out by Gebel with the spectrum scanner of the 36-in. telescope at Hα, Hβ, Hγ, [O III] 5007, and [O II] 3727. Line ratios for a region near the Trapezium agree well with those published by Aller *et al.* (1965) The ratios of [O III] and [O II] relative to Hβ appear to be similar for Orion and NGC 2175 while the same ratios for IC 405 are quite different, [O III] being particularly weak. The Hβ flux computed for NGC 2175 assuming uniform surface brightness agrees with the value measured by Osterbrock and Stockhausen (covering the entire nebula) indicating considerably greater uniformity than occurs in Orion. The surface brightness at the center of Orion is found to be 100 times that of IC 405 and about 50 times that of NGC 2175.

Daniel Weedman calculated the expected profile of a hydrogen radio-frequency recombination line in the Orion nebula on the basis of the published optical spectroscopic measurements of Wilson, Münch, Flather, and Coffeen. His calculated profile, which takes into account the observed variation of velocity along the line of sight (due mostly to thermal and turbulent motions) and the observed variation over the face of the nebula (due mostly to turbulent motions) matches very well the observed profile of the 109α line ($\lambda = 6$ cm) in the Orion Nebula, as observed by Höglund and Mezger. This result strengthens the conclusion that Doppler broadening is the only significant widening mechanism in the observed hydrogen radio-frequency recombination lines.

Weedman is also searching for planetary nebulae in nearby globular clusters. He uses an interference filter to isolate the N_1 line and effectively screen the background stars in direct photographs of the clusters. These observations are made with the 24-in. reflector at Dyer Observatory.

Joseph Miller has begun a thesis research program on radial velocity studies of H II regions. All observations are being made with the 36-in. Cassegrain spectrograph of the Kitt Peak National Observatory. The instrument produces a dispersion of 126 Å/mm at Hα in the first order, and typical exposures range from 1 to 3 h. Using neon as a comparison Hα and the [N II] lines at λ6548 and λ6583 are being measured for radial velocities on the Grant machine in Tucson. To date 27 H II regions, of which 23 have published distances, have been observed. A preliminary study indicates that, for the majority of the H II regions studied so far, photometric distances are in good agreement with kinematic distances obtained from the radial velocities and M. Schmidt's model of the Galaxy. Also, there does not appear to be any systematic difference between the velocities of the nebulae and their associated stars. Several nebulae, e.g., NGC 2244 and IC 405, show velocity differences from place to place within the nebula amounting to 20 km/sec or more. Observations of an additional 12 to 15 H II regions are planned for the fall.

Eduardo Schmitter and Robert Millis have been working on a program of planetary nebulae photometry. The object of this project is to obtain the ratio of intensities of the [O III] lines λ5007 and λ4363, and from it the excitation temperature of the nebulae. The reduction of the data is being done with the IBM 1620 at the Space Astronomy Laboratory.

Robert Davies has begun a thesis on the distribution of neutral hydrogen in the vicinity of galactic clusters. He is using data obtained with the 140-ft and 300-ft radio telescopes at NRAO and will spend the year 1966–67 at Charlottesville.

Galactic Structure and Cosomology. Charles Lillie is studying the interstellar radiation field. He is utilizing the photometric data on the radiation background between 4000 and 2000 Å obtained from an Aerobee rocket flight instrumented by the Department's Space Astronomy Laboratory. In order to supplement the data he is constructing a multichannel photometer to obtain similar data on the radiation field from 4000 Å to 1 μ. It is hoped that comparable data will soon be available down to 1000 Å; however, the data on hand should provide a basis for extrapolation into the ultraviolet.

Mrs. Susan Simkin has continued her Ph.D. thesis program on multicolor isophotometry of Sb galaxies. The data consist of five-color photographic photometry utilizing the University of Michigan Curtis Schmidt (by arrangement through the CIC), supplemented with photoelectric scans of selected parts of each galaxy in these same colors. The photoelectric measurements provide calibration data for the photographic isophotometry. Mrs. Simkin is currently attempting to interpret the data in terms of the distribution of stellar populations and interstellar dust, and correlating these results with the structural features of these galaxies.

Kristian has looked for evidence of the cosmological distortion effect (*Astrophys. J.* **143**, 379, 1966) in nearby regions of space on Sky Survey plates of the Cetus region, and in more distant regions on 200-in. direct plates of clusters of galaxies. The effect was not observed in either case, and the cluster data have been used to set an upper limit on the corresponding components of the local Riemann–Christoffel tensor.

Space Astronomy Laboratory. Bless, Code, Doherty, Houck, McNall, and West continued their activities in the Department's Space Astronomy Laboratory.

Orbiting Astronomical Obersvatory. A considerable portion of the Laboratory's activities during the year concerned the final preparations for launch and operation of the Wisconsin Experiment Package on the Orbiting Astronomical Observatory (OAO $-A_1$). The satellite was launched on 8 April 1966 and placed in a near-perfect 500-mile circular orbit. A failure in the spacecraft's power supply system, however, resulted in excessively high-battery operating temperature and the remaining lifetime of OAO-A_1 (about two days) was spent in unsuccessful "rescue" operations. None of the experiments aboard OAO-A_1 were turned on. The limited status data collected from the Wisconsin Experiment Package in its power-off launch configuration was as predicted before launch, but no scientific data could be collected before communication with the satellite ceased. Construction and calibration of a similar set of telescopes for OAO-A_2 entered their final phases with delivery to NASA for acceptance testing scheduled for the fall of 1966.

Sounding Rockets. New computer programs verified the identifications of stars observed by Aerobee 4:55 launched in 1964 and the results of the observations at λ2800, λ2500, and λ2100 are being readied for publication. In May 1966 a similar set of telescopes sensitive to bands about 400 Å wide at λ2800, λ2500, λ2100, and λ1850 were flown on Aerobee 4:171. Because of the λ1850 photometer, the experiment package for 4:171, unlike 4:55, was unpressurized, and corona discharge form the photomultiplier high-voltage supplies caused by insufficient venting of the experiment before power turn-on resulted in the loss of the λ2800, λ2500, and λ1850 photometers. The attitude problem for Aerobee 4:171 has been solved by Van Boeckel and Haupt using data from magnetometers flown in the rocket, and identification of about 50 stars observed by the λ2100 photometer is nearly complete. Design and development was begun on an Aerobee payload scheduled for the spring of 1967. The photometers will be similar to those already flown except for the inclusion of a shorter wavelength uv photometer and an x-ray telescope to be provided by W. Kraushaar of the U. W. Physics Department.

X-15 Program. Daylight photography of stars in the ultraviolet from the X-15 experimental rocket plane continues to be hampered by poor weather, by the relatively low altitudes achieved by the modified X-15, by the limited roll angle available during the reaction controlled portion of the flight, and by the scattering of sunlight on the vehicle into the camera optics—a problem similar to that encountered in the Mercury and Gemini attempts at visual observation of stars in a sunlit vehicle. Modifications to the current X-15 instrumentation include the installation of light baffles on the uv cameras and a photoelectric uv scanner for spectrophotometry of the uv dayglow.

Instrumentation and Laboratory Work. The 8-in. portable monochromator–collimator system for calibrating ultraviolet photometers was successfully used for prelaunch calibration of the OAO-A_1 Wisconsin Experiment Package at the Goddard Space Flight Center and at the Grumman Aircraft Engineering Corporation. It has been used extensively at the Laboratory for most calibrations above λ2000. Under the supervision of Fairchild, the 16-in. laboratory vacuum monochromator–collimator system was installed and used in calibrating the OAO-A_2 Wisconsin Experiment Package, for wavelengths below 2000 Å. Ultraviolet interference filters and high-reflectivity mirror coatings were made for the A_2 experiment and for the Aerobee instrumentation. Work continued on the problem of absolute energy calibration in the vacuum ultraviolet.

Under the supervision of McNall, a program investigating the use of field-effect transistors and insulated gate field-effect transistors (MOSFETS) in direct current photomultiplier amplifiers resulted in the development of compact low-power amplifiers with negligible drift over 100° F temperature range. Unfortunately, currently available MOSFETS are extremely sensitive to induced electrostatic charges which may destroy the input MOSFET and hence presently limit the applications of this type of amplifier to use under laboratory conditions by

experienced personnel. Undergraduate students employed by the Laboratory on a part-time basis and supervised by McNall are converting the 8-in. automatic telescope at Pine Bluff from an analogue feedback servosystem to a digital system. The conversion will enable the telescope to operate directly under control of a PDP-8 computer which can simultaneously reduce the observations.

ARTHUR D. CODE, *Director*

University of Washington, Seattle, Washington

I. FACULTY, GRADUATE PROGRAMS, AND EQUIPMENT

The faculty now consists of Professors Jacobsen, Wallerstein, and Hodge, the last two of whom joined the department in August of 1965. A graduate program has been initiated and three students were accepted to commence graduate work in September of 1965. In addition four graduate students are following a joint program with the physics department.

A 16-in. Boller and Chivens reflector has been installed at a site in central Washington 20 miles northeast of Richland. The telescope is located on a ridge at an altitude of 3700 ft. It will be equipped with a photoelectric photometer and S-20 cell for photometry on a *UBVR* system. An auroral spectrograph operated by Dr. K. Clark of the physics department is also located at the observatory.

Two portable 6-in. refractors are being used to evaluate the seeing at a number of potential observatory sites in the dry regions of central Washington. Observations by automatic cameras of sky cover during the winter of 1965-6 indicated little difference from one place to another but several sites higher than 5000 ft have rather severe winds and rime ice accumulation during midwinter, although total snowfall was only about 4 ft. It appears that the most favorable sites are at an elevation of about 4000 ft in an area bounded by Grand Coulee Dam, Lake Chelan, Ellensburg, and Hanford.

II. RESEARCH

Solar System—Meteoritic Dust Research. In cooperation with Dr. F. W. Wright of the Smithsonian Institution, Dr. P. W. Hodge continued study of microscopic meteoritic particles in space, in the atmosphere, in glacial sediments, and in the soil surrounding meteorite craters. They have investigated particles from 11 volcanoes and find no particles like the majority of those recovered from 750-yr-old ice in Greenland by C. L. Langway of CRREL. Instead, the latter are probably meteoric in origin. Hodge completed analysis of particles from the Henbury meteorite craters, and with Wright began study of meteoritic fallout around the Boxhole and Odessa craters. Brownlee designed and built two meteoritic dust-collecting devices for use in balloon flights to 110 000 feet. In cooperation with Hodge and Wright, he prepared samples as guest investigators on the Duldey Observatory's meteoritic dust experiment (lost by the astronaut) on Gemini 10, and they also have prepared samples to be flown on the AFCRC's Venus Fly Trap rockets late in 1966. Wright and Hodge discussed results of their experiments with making artificial microscopic meteoritic spherules.

Stellar Astronomy. Dr. G. Wallerstein and two students, Greene and Tomley, have been analyzing high-dispersion spectrograms of the hydrogen-poor star HD 30353. The analysis is complicated by the fact that not only are the temperature and surface gravity not known *a priori* but the source of opacity depends upon the chemical composition. With the help of spectral scans by Dr. Danziger at Mt. Wilson and model atmospheres by Dr. E. Böhm-Vitense an effective temperature between 10 000° and 12 000°K has been derived and a surface gravity between $\log g = 2$ and 3 has been deduced, leading to an electron pressure of about 10 dyn/cm^2 at the optical depth of line formation. These parameters are being improved using the line spectrum which shows at least two stages of ionization of N, Si, S, and Fe. Severe stratification is in evidence and it appears that the Fe I lines are formed in a cool outer layer. In addition circumstellar features of Hα, [N II], and possibly λ5876 of He I are present in emission and Hα, Na I, and probably Ca II in absorption.

In cooperation with Dr. H. L. Helfer of the University of Rochester Wallerstein has completed the analysis of the ratios of iron to hydrogen in 29 K giants. Correlations between spectroscopically determined abundances and various photometric parameters were discussed (*Astron. J.* **71**, 350, 1966).

From the work of several investigators it appears that the classical Cepheid variable U Sgr is very likely a member of the galactic cluster M25. Yet the systemic velocity obtained from the most detailed radial velocity curve (Stibbs 1955) differs by 5 km/sec from the average of the velocities of the B-type cluster members. Since the evidence for the membership depends in parts on the agreement of the systemic velocity of an earlier velocity curve (Joy 1937) with the average velocity of the cluster stars, a further test is desirable.

Two of the four spectra taken by Kraft of U Sgr (Palomar, 9 Å/mm) in 1963 show sharp, intense, well-separated absorption components of H, K, D_1, D_2 at and around minimum light. The spectra of several of the B-type cluster members (Palomar,

13 Å/mm) also show sharp i.s. Ca II and Na I lines. A test for the intersteller nature of the sharp U Sgr absorptions is being carried out by Dr. T. S. Jacobsen on the following principle: If the sharp absorptions in both B-type stars and Cepheid are identical in core strength and radial velocity, and show no variation with phase, the lines are interstellar, and both U Sgr and the cluster B stars are beyond the same absorption region in space. This is a partial check on membership in the cluster.

A few preliminary results for the Na I velocities are now available.

M25 No. 91, No. 97. Av. vel.	−9.8 km/sec
U Sgr (4 plates)	−11.2 km/sec

A beginning has also been made to solve the question of the variation with phase of the U Sgr Na I velocities. Besides the original material, three more plates taken during the last 3 yr by Kraft and Wallerstein have been measured. Photospheric velocities were derived from lines of Ba, Fe, and Ca in a limited spectral region near the *D* lines. The plot of seven good points show a photospheric curve of much the same shape and position as the one by Stibbs.

Work has started on the second part of the test dealing with core intensities. Microphotometer traces of all relevant spectra and comparison spectra were personally produced with the instrument of the California Institute of Technology Department of Astronomy. These traces will be of great help not only in the photometry of the cores, but also in interpreting measurements of blended features. Such measurements properly interpreted may help disentangle any possible circumstellar component.

X-Ray Astronomy. J. Cassinelli has started calculations of possible optical line emission from high-temperature gases. Applications to x-ray sources are being considered. T. Greene is working with Dr. L. Wilets of the physics department on the internal structure of neutron stars.

Galactic Research. Using limits that can be set on the orbit of the Fornax dwarf galaxy by its tidal radius and its radial velocity. Hodge derived a value for the mass of our Galaxy that is independent of more local methods. The derived mass is $2.5\pm1.0 \times 10^{11}\ M_\odot$, but the observations must be refined before the method can have a high degree of reliability.

Extragalactic Research. A study of the spatial distributions of H II regions and young stars in various types of galaxies was begun by Dr. P. Hodge using data from the *Atlas of H II Regions in Galaxies*, to be published by the Astronomy Department in August 1966. He also completed surface photometry of the Sculptor dwarf galaxy, finding that its integrated magnitude is 8.8 and its color is $B-V=+0.7$. The Sculptor galaxy and the other five dwarf elliptical galaxies of the local group were discussed in terms of their tidally limiting radii, their orbital properties, and their very small central densities and long relaxation times. Continuing his study of S0 galaxies, Dr. Hodge and Miss A. E. Merchant of the University of California at Berkeley published results of their photoelectric and photographic photometry of NGC 128. Welch began a dynamical study of NGC 128 to see if its anomalous structure could be understood in terms of tidal effects caused by its satellites, NGC 127 and 130. Dr. Hodge completed surface photometry of all of the bright members of the Fornax Cluster of galaxies and readied these for publication. He and Hitchcock of Berkeley published results of a survey of apparent axial ratios of irregular galaxies concluding that irregular galaxies are almost as flat as spirals, in general. He and Brownlee described an efficient method of photographically producing isophotes for galaxies, based on experiments by Richter and Högner. He and Lucke investigated methods of photometrically determining the stellar makeup of a galaxy when the brighter part of its color–magnitude diagram and luminosity function is exactly known. Lucke developed a computer program for this project, which will be applied to observations of local group galaxies.

The *Large Magellanic Cloud*, including 167 photographic identification charts plus extensive tabular and textual material, was published by Hodge and F. W. Wright of the Smithsonian Observatory. They continued their study of Cepheid variables in the Cloud, and published a description of 51 newly discovered variables. Hodge and John Sexton of Berkeley published their catalogue of 457 new star clusters in the LMC.

GEORGE WALLERSTEIN, *Chairman*

Yale University Observatory, New Haven, Connecticut

Personnel. The death of Dirk Brouwer on 31 January 1966 left the Observatory without a director, a post which Dr. Brouwer had held continuously since 1941 concurrently with his position as chairman of the department of astronomy. The Yale Corporation appointed Rupert Wildt chairman of the department. G. M. Clemence, senior research associate, has been appointed to a full professorship and A. Wesselink was promoted to senior research associate and lecturer. Dr. Andre Deprit of the Boeing Scientific Research Laboratory held an appointment as visiting professor for the fall term. Alexander Ollongren of the Computer Institute of Leiden University held a research staff position

for the academic year, and Joachim Schubert of the Astronomisches Rechen-Institut (Heidelberg) was a research staff member for six months. Also appointed to the research staff in January was Edwin Bishop.

CURRENT RESEARCH

Celestial Mechanics. Clemence continued his research on the second-order theory of the orbital motion of the earth. He also commenced an investigation of second-order and third-order relativistic effects on the motion of planets. J. Danby carried out further developments in the formulation and interpretation of planetary theory, with special attention to asymptotic orbits in the restricted problem. Moreover, he investigated the dynamical properties of interstellar matter near a star.

Ollongren worked on two research problems: in the first, "Dynamical Systems with Two Degrees of Freedom," attention was given to the mathematical question of constructing the most general Lagrangian function which admits orbits of a given topology in its configuration space. This problem was solved for the case of the topology of a harmonic oscillator. Applications to the problem of stellar orbits have been worked out in some detail; in the second, "Restricted Problem of Three Bodies," by means of numerical interpretation of the equation of motion, an invariant section was studied for motions in the vicinity of the triangular equilibrium point at the critical mass ratio. For values of the Jacobi constant equal to 3 and slightly larger than 3 all possible recurrent motions were classified.

Deprit's principal area of research was concerned with the problem of three bodies and periodic orbits.

Schubart worked principally in the area of Hilda commensurability in the restricted problem of three bodies.

Astrometry. Miss Hoffleit continued to direct the measurements and reductions for the zone-catalogue program, which is supported by a contract with the Army Map Service.

The zones from declination 30 south to 70 south are all measured and the reductions are in progress. In the zones south of 70 south the measurements are one-third completed.

Theoretical Astrophysics. Numerical work on the temperature distribution in a modified gray atmospheric model, making rigorous allowance for induced emission at local thermodynamic equilibrium is being continued by Wildt and Mrs. Schwartz. Wildt has carried his thermodynamic theory of the classical gray atmosphere one step farther by constructing from a novel variational principle a non-equilibrium source functoin that approaches the Planck function asymptotically at great depth. The research of L. Oster and his student was centered on the physics of the outer atmosphere of the sun and stars and investigations of thermal instability. In particular, a consistent theory of shock dissipation, taking into account radiative losses, flow generation and thermal conduction, allowed to predict the structure of the outer atmospheres of stars with hydrogen convection zones (Ulmschneider). The conditions under which solar prominences could originate from thermal instability were investigated (Raju), but an explanation by the same mechanism of the density inhomogeneities observed in planetary nebulae proved impossible (Sofia).

J. Hunter developed a numerical code for integrating the nonlinear equations of hydrodynamics including self-gravitation and thermal effects, in order to study the initial phases of star formation in the interstellar gas The accuracy of the numerical code is probably very great, since it can reproduce known analytical solutions with an accuracy of at least 12 significant figures. This work is continuing at present.

Observational Astrophysics. Wesselink devoted a good deal of his energy to matters relating to the new 40-in. reflecting telescope which was installed in January at the Bethany Observing Station. Several months of adjustment to the electronic and mechanical components have been necessary to make the telescope completely operational. Only a few minor adjustments remained to be completed at the end of June.

Two graduate students, Miss C. Williams and E. Milone, are working toward their thesis under the supervision of Wesselink. Milone has used the 20-in. reflector at the Bethany Observing Station to acquire observational data on eclipsing variables for his thesis on multicolor photometry of some selected variable stars. Miss Williams has undertaken the measurement and reduction of photographic plates taken with the Loomis telescope to derive the position of the north celestial pole with respect to the positions of three reference stars.

A successful rocket experiment (Sloan) measured the intensity of the Lyman-α radiation from the sun with an angular resolution of close to 2″, thus, by a factor of 50 better than previous attempts. It could be shown that the intensity differences in the unperturbed background amount to not more than a factor of 2.

Radio Astronomy. The resignation in June 1965 of J. N. Douglas, who accepted a position at the University of Texas, lead to the decision to discontinue research in operational radio astronomy. Ownership of the instrumentation on hand was transferred from Yale to Texas, where the research could be continued under Douglas' supervision, and

the moving of all items of equipment has been completed.

Yale–Columbia Southern Observatory. Consequent upon the death of D. Brouwer, Clemence was elected president of the corporation and Wesselink was appointed to the newly created position of executive director; he is in immediate charge of programs at the Southern Observatory.

The main program of the Yale–Columbia Southern Observatory has been in essentially full-scale operation during the year, with Klemola as principal observer. This program consists of an astrometric survey of the southern sky, south of declination 20° south, complementing the survey of the northern sky by the Lick Observatory, with the object of referring stellar motions directly to the frame of reference given by the extragalactic nebulae. In addition, a number of observations of selected minor planets have been obtained.

Cyril Jackson continued as resident director, although his resignation became effective at the end of June.

The construction of the building for the U.S. Naval Observatory's meridian circle is nearly complete.

Miscellaneous. The Directors of the Astronomical Society of the Pacific voted to honor Dirk Brouwer by the award of the Bruce Gold Medal and notified him of this action of the Board. Unfortunately, a public announcement could not be made before Dr. Brouwer's death, so that this award became the only posthumous one in the history of the Society. Wildt was named recipient of the Eddington Medal of the Royal Astronomical Society. In March he was re-elected President of the Association of Universities for Research In Astronomy (AURA, Inc.) for a one-year term.

Clemence continued as Chairman, Division of Physical Sciences, National Research Council, and as Chairman of the Section of Astronomy of the National Academy of Sciences. He served as member of the Visiting Committee of the Department of Astronomy, Case Institute of Technology, and accepted an invitation to become a member of the Visiting Committee of the Lick Observatory. In April he gave the Townsend Memorial Lecture to the Royal Astronomical Society of Canada.

Danby delivered lectures at the Massachusetts Institute of Technology, North Carolina State University, and at a meeting of the Association of Computing Machinery held in Washington in March.

V. Szebehely completed the manuscript of his book *Theory of Orbits in the Restricted Problem of Three Bodies*, to be published by the Academic Press. He also edited (jointly with R. L. Duncombe) Vol. 17 in the *Progress Series of Astronomical Sciences of the American Institute of Aeronautics and Astronautics*, published by the Academic Press.

At the 14th Annual Astrophysical Symposium held in Liège, Belgium, in June, Hunter presented two papers on "Galaxy Formation in a Steady State Universe" and "Star Formation," respectively.

During the year Ollongren delivered lectures at the University of Rochester, Boeing Scientific Research Laboratory, the Jet Propulsion Laboratory of the University of California, Douglas Aircraft Corporation, Amherst, and Harvard College.

Oster accepted an invitation to spend the summer semester 1966 at Bonn University as Visiting Professor and has been granted a leave of absence for the 1966/67 academic year to accept a Visiting Fellowship he has been awarded by the Joint Institute of Laboratory Astrophysics, University of Colorado.

Szebehely gave invited lectures on various subjects in celestial mechanics at Harvard, Massachusetts Institute of Technology, University of Washington, North Carolina State University, NASA–Boston, and West Point.

A total of 520 visitors attended the "Open Nights" program at the Bethany Observing Station with demonstrations at the Butler telescope. W. G. Cleaver conducted the program which occupied 28 nights, the majority of them in the fall and spring.

R. WILDT, *Chairman, Department of Astronomy*

Yerkes Observatory, University of Chicago, Williams Bay, Wisconsin

Personnel. Dr. William F. van Altena was appointed to the faculty on 1 April 1966. Dr. K. S. Krishna Swamy was appointed research associate on 1 October 1965, Dr. Pavel Mayer on 1 January 1966, and Dr. Immo Appenzeller on 1 May 1966. Professor Adriaan Blaauw was appointed research associate for the period 6 June to 19 June, 1966 during which time he gave a series of lectures on galactic structure.

National Aeronautics and Space Administration traineeships were held by Mrs. J. Lesh, M. McKee, D. E. Mook, L. Rossner and B. Schlesinger. A National Science Foundation traineeship was held by R. Zappala. National Defense Education Act traineeships were held by T. Grenfell, B. Jones, and A. Saaf. A Canadian National Research Council fellowship was held by M. Aizenman. Assistantships and University of Chicago scholarships were held by R. Garrison, P. S. Jackson, E. I. Krefetz, J. L'Ecuyer, J. M. Marlborough, R. W. Mackoney, C. E. Rosenkilde, R. E. Schild, and A. Witt. Yoram Gelman and J. Mosley were technical assist-

ants. The Ph.D. degree was awarded to J. L'Ecuyer and R. Hjellming.

Among colloquium speakers for the year were: Drs. H. F. Weaver, University of California; Nancy G. Roman, NASA; William L. Kraushaar, University of Wisconsin, Su-Shu Huang, Northwestern University, Peter Bodenheimer, Princeton University, George W. Preston, Lick Observatory; Kevin Prendergast, Columbia University; Neville J. Woolf, University of Texas; John S. Mathis, University of Wisconsin; Stanislaus Vasilevskis, Lick Observatory; Icko Iben, Massachusetts Institute of Technology; Donald E. Osterbrock, University of Wisconsin; A. Blaauw, Kapteyn Astronomical Laboratory; Robert E. Danielson, Princeton University; Donald C. Morton, Princeton University; Pierre Demarque, University of Toronto; Theo. Schmidt-Kaler, Universitäts-Sternwarte, Bonn; George Wallerstein, University of Washington.

Facilities and Equipment. A new laboratory–observatory building was constructed close to the site of the former Bruce telescope building and was completed in March 1966. This facility satisfies the pressing need for a well-equipped laboratory servicing two adjacent domes designed for experimentation with original projects not demanding large apertures. Financed by the University, the building provides two 16-ft domes separated by a 30×15 ft electronics and optics laboratory. The building is aligned north–south with the north dome higher, providing clear access to the southern horizon. Each dome contains a permanent, sturdy equatorial mounting with a universal mounting plate for taking various equipment packages. The building is proving to be very functional in its use, for it was planned according to the needs of experimentation with new methods of observation. The initial experiment in the south dome is the newly rebuilt 7-in. $f/4$ Schmidt telescope now being used for searches along the Milky Way for very distant associations as described below. The north dome now contains the nebular spectrophotometer also described below.

A photoelectric nebular spectrophotometer, designed by O'Dell and constructed in the Yerkes shops for efficient studies of comet tails and diffuse nebulae was completed in April 1966. A highly specialized instrument system, it was designed to be very fast for that class of problems where the celestial source subtends a much larger size than the spectrophotometer entrance aperture, in which case the speed is determined by the optical beam size. Working with a beam off the grating of 6-in. and a focal ratio of f4 throughout, it is uniquely suited for studies of diffuse sources. All mechanical and optical components were manufactured in the Yerkes shops while the corresponding electronic apparatus was assembled from a number of commercial firms. Although it can be used as a wavelength scanner, the normal mode of operation employs the instrument as a programmed monochromator with a stepping motor driving the grating to preselected positions sequentially according to a determined program of observations. The signal from the photomultiplier is fed to a discriminator-scaler pulse counting system that operates at up to 100 Mc/sec and is recorded automatically on an IBM typewriter.

The 40-in. refractor is now undergoing extensive modernization. The main features of this modernization are the installation of an accurate syncro-system for the display of right ascension, declination and hour angle at the eyepiece end of the telescope; redesign of the electric clamps for the two axes; transfer of slewing controls to the eyepiece end of the telescope; and installation of a desk console at the telescope pier where the clocks auxiliary light controls and drive oscillator will be located.

The final step in the 40-in. modernization program is the installation of an automatic guiding astrometric camera. Preliminary designs have been drawn for this camera which will derive its error signal from a spinning knife edge and one photomultiplier instead of the more often used pyramid and four photomultipliers.

The southeast dome at Yerkes Observatory is now partially remodeled for the new 40-in. reflector. The telescope is under construction at the Warner and Swasey Company. Floor assembly at the plant should start in September and erection at Yerkes during the winter. The telescope follows the general design of the McDonald 82-in. reflector. The optics for the telescope are being made in the Yerkes Optical shop by Richard Monnier. The new Cer-Vit glass from Owens-Illinois, Inc., will be used throughout.

An image tube spectrograph was constructed in the mechanical shop by Boro Spotz. The spectrograph employs a folded $f/2$ Schmidt camera so that the focus is accessible with image tubes.

The 7-in. $f/4$ Schmidt discussed in an earlier report has been placed in operation. The limiting magnitude for direct photography is approximately 18 and approximately 15 with the objective prism.

Miller prepared a paper (*Science* **153**, 581, 1966) on the feasibility of a 1-km Michelson stellar interferometer.

Theoretical Astronomy. The following papers were published by S. Chandrasekhar:

1. Chandrasekhar, S. 1965, "The Equilibrium and the Stability of the Riemann Ellipsoids. I," *Astrophys. J.* **142**, 890.

2. Chandrasekhar, S. 1965, "The Post-Newtonian Equations of Hydrodynamics in General Relativity," *Astrophys. J.* **142**, 1488.
3. Chandrasekhar, S. 1965, "The Post-Newtonian Effects of General Relativity on the Equilibrium of Uniformly Rotating Bodies. I. The Maclaurin Spheriods and the Viral Theorem," *Astrophys. J.* **142**, 1513.
4. Chandrasekhar, S. 1965. "The Stability of Gaseous Masses for Radial and Non-Radial Oscillations in the Post-Newtonian Approximation of General Relativity," *Astrophys. J.* **142**, 1519.

Limber carried through a study of the structure and dynamics of circumstellar envelopes formed as a result of the continuing rotationally forced ejection of matter by stars. A paper based upon this study and entitled "Circumstellar Envelopes Formed through Rotationally Forced Ejection. II" has very recently been completed and submitted to the *Astrophysical Journal* for publication. In this paper, the dynamics of such envelopes near their equatorial planes is treated in a general way for the case of steady-state solutions with arbitrary distributions of temperature and circular component of velocity, and the particular case of steady-state solutions for isothermal envelopes with negligible viscosity is treated in detail. The over-all problem of continuing rotationally forced ejection in stellar evolution is treated in a general way. Included are brief discussions of the energy and viscosity problems, the relation of the problem of continuing rotationally forced ejection to that of the solar wind, the nature of possible applications and tests of the hypothesis of continuing rotationally forced ejection, and the possibility of non-steady-state solutions and their implications for stellar evolution. Further work dealing with the role of rotationally forced ejection in stellar evolution is in progress.

Vandervoort is investigating problems in stellar dynamics. The principal effort during the last year concerns the dynamics of rapidly rotating galaxies. For an axisymmetric galaxy in a steady state a simultaneous solution of the Liouville equation ("collisionless Boltzmann equation") and the Poisson equation has been constructed as a formal series in powers of small parameters characterizing the departures of stellar orbits from circular orbits and the small thickness of the system as a whole. Since this solution involves several arbitrary functions, it provides a basis for the construction of a variety of models of galaxies. It is planned to construct a number of such models. This method of solution involving small parameters can be extended to the study of small, nonaxisymmetric perturbations of rapidly rotating galaxies. A preliminary analysis of such perturbations indicates that it will be possible to construct solutions for spiral density waves.

Cowley has calculated complete curves of growth for a number of lines based on solar models with high and low boundary temperatures. He finds that the basic effect on a lowered boundary temperature in the outer layers of a solar-type model is to enhance the weak and medium-strong lines arising from low excitation potentials relative to similar lines arising from high excitation potentials. Strong lines on the damping portion of the curve of growth show a very slight model dependence.

Miller has studied the polarization of stellar dynamical medium. Forces in a stellar dynamical system are balanced so that moving one star causes the surrounding stars to move collectively (polarize the medium) in such a way that their reaction on the original star enhances the initial displacement. Orbits are affected in the sense that for any orbit there exists another orbit, initially arbitrarily close, which departs from it with a separation increasing exponentially with the time. Epicyclic motions and random velocities tend to reduce the growth rate. The implications of this defect for the dynamics of stellar systems are being studied.

Krishna Swamy has studied the strong line profiles in two F stars of the Hyades cluster (*Astrophys. J.*, December 1966). It was found that the observed and the computed profiles could be fitted only by increasing the metallic abundances in the Hyades stars by a factor of about 1.5 as compared to that of solar value. This is in conformity with the curve of growth study.

Krishna Swamy and O'Dell have made a study of the various tests that can be applied to the interstellar particles. The importance of applying various tests simultaneously before a particle may be considered as a possible model has been emphasized. It has been pointed out that the backscattering curves can be used effectively as an additional test for discriminating between various types of particles Based on the existing observations and the various tests (reddening curve, albedo, backscattering curve and polarization) that are available at the present time, one can rule out definitely pure iron and an Oort–van de Hulst sized distribution of dirty ice. Ice-coated graphite spheres is found to generally satisfy all the tests reasonably well. Results of this investigation have been submitted for publication in the *Astrophysical Journal.*

Krishna Swamy and O'Dell also have continued their theoretical investigation of the results of the presence of interstellar grains in H II regions. Detailed calculations of the motion of particles under the influence of stellar radiation pressure in the Orion Nebula were made in order to predict the influence on the reddening curve for this region.

Although the calculations indicate that the observed deficiency of dust in the inner region can be explained in this manner, the mechanism has to be rejected as the resultant reddening curve suffers little change since the effective size distribution of particles changes very little. This mechanism also has the fundamental uncertainty caused by the possible effects of a strong electrostatic drag force caused by the electrical charge on the grains. Evaporation of particles caused by absorption of continuum radiation followed by infrared emission maintaining an excessive temperature has to be rejected as a fundamental mechanism for grain destruction operating in the Orion Nebula since the energy density of stellar continuum radiation is actually lower there than in several other H II regions in which large amounts of grains are known to exist. Since it is a resonance line, the Lyman-α energy density in these nebulae can be quite high and related quantitatively to the surface brightness of the nebula in Hβ. This indicates that the Lyman-α density in the Orion Nebula is much higher than in other H II regions and that the energy input is sufficient to evaporate grains as stable as H_2O ice, probably accounting for both the dust deficiency and the deviant reddening curve. For dense nebulae, destruction of Lyman-α photons by absorption on grains can be nearly complete and the optical depth in the Lyman continuum can alter the ionization structure.

As grains are radiatively repulsed from the hot exciting stars in H II regions, they quickly approach a condition of being linked to the gas, because of viscous and electrostatic drag. This means that the radiation pressure force acting on the grains will eventually be given to the gas, causing an inverse square force term. Calculations of the equilibrium configurations resultant from such a force can easily explain the inner holes known to exist in several nebulae of the Rosette Nebula class. Detailed models considering both this pressure term and the natural hydrostatic terms have not been constructed, but it has been shown that this radiation pressure term through dust can be dominant in the inner regions of many nebulae. Results of this investigation have been submitted for publication in the *Astrophysical Journal.*

L'Ecuyer completed and submitted for publication work dealing with the evolution of helium stars of small mass. In this paper an evolutionary sequence of models is constructed for each of two stars of mass 0.5 $M_\odot$ and 0.7 $M_\odot$ initially made of pure helium. The whole life span from the helium-burning main sequence to the white-dwarf stage is covered. The Henyey method is used throughout with a special surface approximation; neutrino energy losses are excluded. The resulting paths in the H-R diagram are compared with that of the nuclei of planetary nebulae. There is some evidence that the carbon and oxygen flashes do not occur, at least not unless neutrino energy losses drastically modify the situation.

Jackson is now completing a study of the construction of stellar models for uniformly rotating stars on the basis of an energy principle. He has developed a general method for this purpose and is applying it to the construction of models for rapidly rotating stars.

Marlborough is engaged in a study of the radiative properties of model envelopes that appear to be reasonable and self-consistent for Be and shell stars.

Saaf is investigating the integrals of the motion of a star in an axisymmetric gravitational potential which departs only slightly from spherical symmetry. The aim is to construct a third integral (in addition to the energy and the conserved component of the angular momentum) as a formal series in powers of the departure of the potential from spherical symmetry.

Astrometry. With the appointment of van Altena to the faculty, astrometric programs with the 40-in. refractor have been started. The initial astrometric programs will include the determination of trigonometric parallaxes of intrinsically faint stars with particular emphasis on the yellow white dwarfs and the extremely red stars at the lower end of the main sequence. A second part of the program will be the determination of accurate proper motions for a large number of the Ross proper motion stars which had first epoch plates taken in the 1940's. The determination of cluster membership based on proper motions will also be an integral part of the program and will utilize the unique collection of early photographs taken with the 40-in. refractor beginning in 1900.

Stellar and Nebular Astronomy. Morgan and his associates have continued work on the new edition of the *Yerkes Atlas of Stellar Spectra.* In connection with this project, the concept of "coeval sequences" has been developed to permit a satisactory classification of members of both younger and older galactic clusters. Such a distinction appears to be necessary for main-sequence stars as late as G in certain clusters. Morgan and his assoicates also continued their study of early-type associations (see *Astrophys. J.* **142**, 974, 1965, and *Vistas in Astronomy*, A. Beer, Ed., Vol. 8, p. 83, 1966).

An observational program of the symbiotic stars begun in June 1965 by O'Dell has been continued through the report period. The purpose of this program is to provide accurate fundamental data that will enable one to determine the true physical nature of these stars. The approach adopted is one

of the determination of the relative line intensities of the first four members of the Balmer series and the $N1$ and $\lambda 4363$ lines of [O III] and the relative strength and flux distribution of the stellar continuum radiation. The observations are being made with the Cassegrain spectrophotometer on the 36-in. and the 82-in. telescopes at the McDonald observatory with observations being made at time intervals of several months in order to follow the time-dependent fluctuations. The spectra of these same objects are also being studied with plates obtained with the classification spectrograph on the 40-in. telescope. Not only are the measured emission lines the brightest in the objects, but these lines are also indicators of the conditions of electron density, temperature and optical depth. It is expected that observations over several years will be necessary before definitive trends can be established.

The peculiar emission line object M1-2 (VV8) originally discovered by Minkowski has been the subject of a continued investigation by O'Dell. Although the emission spectrum is that of a very dense planetary nebula, the underlying continuum is that of a G2 supergiant. No obvious velocity variations were detected on a series of spectrograms obtained with the 120-in. telescope at Lick Observatory. Photoelectric spectrophotometry with the Otto Struve telescope confirms the earlier results of the relative line intensities and defines well the energy distribution in the contiuum radiation. The continuum distribution cannot be fitted by a G2 star with a hot companion, a fact which in combination with the lack of radial velocity variations makes the binary nature of the system appear doubtful. The low radial velocity with respect to the local standard of rest (-21 km/sec) allows one to set an upper limit of $+1.8$ to the visual luminosity of the system (using the apparent magnitude of 14.0) which is certainly not that of a supergiant! Likewise, the $H\beta$ luminosity of the object is less than that of the usual young planetary nebula although not greatly dissimilar from a few of the very youngest objects. Since this system is similar in many ways to both the planetary neublae and the symbiotic stars, it is tempting to consider this object as intermediate between the two classes of objects that is, a transition phase in the development of the ejected mass shell. The recent discovery of two similar objects in the southern sky by Miss Webster at Mt. Stromlo Observatory strengthens the argument that such objects are not highly rare and may be important in the study of the late stages of stellar evolution.

Electron temperatures have been determined from the relative strengths of the $N1$ and $\lambda 4363$ lines of [O III] in two low-density planetary nebulae and two galactic diffuse nebulae. It was shown that the electron temperatures for the dense planetary nebulae with relatively cool central stars were about the same as for the low-density nebulae that have very hot central stars. This obviously more efficient cooling in the low-density nebulae is attributed to the operation of the interlevel cooling mechanism arising from transitions between hyperfine levels. These levels are largely collisionally de-excited at higher densities, which allows the same temperature to be maintained as in the low-density nebulae with much hotter exciting stars. The average temperature for low-density H II regions of 7800°K remains above the values predicted by the best current models for ionization regions although within the uncertainties of the theoretical calculations.

In the absence of bright comets, the new spectrometer described above is used for the determination of the Balmer decrement of low surface brightness planetary nebulae that could not be measured in earlier programs. The purpose of this study is to investigate whether or not the Balmer decrements in these nebulae are different from those in the higher optical depth, bright planetaries where deviations from the predictions of recombination theory have been reported.

Cowley has begun a long-term program to investigate the effect of the temperature structure of late-type stellar atmospheres on the observable Fraunhofer spectra. We have found that the low turbulent velocities and excitation temperatures in the extreme metal-poor subdwarfs HD 140283 and HD 19445 may be explained from an atmospheric model with a different temperature and turbulent structure from that of the sun. It appears that these differences arise because of a magnetic suppression of turbulence and nonradiative heating of the outer atmospheres of these subdwarfs. A similar situation also applies to the metal-poor giant HD 122563.

A program of high-dispersion spectrographic studies of peculiar binaries and stars with extended envelopes was continued by A. Cowley. In the course of this investigation a newly formed metallic shell was found in the ultraviolet spectrum of Boss 5481 (*Astrophys. J.* **144**, 824, 1966). It may possibly represent a grazing atmospheric eclispe of the B star by the M supergiant. Plates taken in June of 1966 show a slight weakening of this shell spectrum since October 1965.

A paper on 17 Leporis by A. Cowley is in press (*Astrophys. J.*). From coudé observations of the faint M component, orbital elements and probable masses have been determined. The red star appears to fill its inner Lagrangian lobe and the star may have shed considerable mass onto what is now the primary of the system. The novalike character of the blue star is discussed.

Moderate dispersion spectra of the three components of β Mon have been obtained by A. Cowley on nights of good seeing at McDonald. It is found that the intermediate component is also a Be star although its emission lines are very weak. This star appears to have a lower rotational velocity than the other two (*Publ. Astron. Soc. Pacific* **78**, 165, 1966).

A. and C. Cowley and Marlborough have initiated a study on the anomalous suppression of Hϵ which has occasionally been observed in the spectrum of AX Mon.

Schild has continued his study of the Be stars in the h and χ Persei Association with new classification dispersion spectrograms and some new *UBV* photometry. A type of Be star with very strong hydrogen emission and veiling of the helium lines has been recognized on these spectrograms, and on the basis of spectroscopic appearance and location in the H-R diagram these have been interpreted as stars undergoing rapid core contraction subsequent to exhaustion of central core hydrogen (*Astrophys. J.*, October 1966). In a comparison of the H-R diagram for stars in the well-known extensive association of supergiants with recent evolutionary models, several age groups have been recognized. Nine young O stars are found in the association but not in the clusters. A group of somewhat older stars probably related in age to the h Persei upper main sequence is also recognized in the greater association. A still older group of stars, rich in Be stars and red supergiants, is found in the nucleus of χ Persei and in a cloud 65 pc in diameter surrounding χ Persei. χ Persei is found to be 350 pc more distant than h. A report of these results has been submitted for publication in the *Astrophysical Journal.*

Garrison completed an investigation on some characteristics of the B and A stars in the upper Scorpius complex. He found a main sequence extending to spectral type F0 for the inner region of the Upper Scorpius group. He also found several peculiar Sr II stars in this region, and a group of B7–B9 stars which exhibit a large discrepancy between the two-dimensional spectral types and the results from narrow-band photometry.

Mrs. Lesh began a program of spectral reclassification of all northern B0–B5 stars brighter than magnitude 6.5. This work is being carried out by use of the MK classification system as revised recently by Morgan, and has as its purpose a rediscussion of the kinematic characteristics of the nearer groups of B stars.

Witt began an observational program on the diffuse radiation in the Galaxy. The intensity of the diffuse galactic light is measured as a function of wavelength and as a function of position in the Cygnus and Taurus–Auriga regions. Preliminary results for the Taurus–Auriga region do not favor dirty ice as a material for interstellar grains but require a more strongly absorbing substance. Theoretical calculations on graphite particles with ice shells are in satisfactory agreement with the observations.

Mook, Zappala, and Hiltner have observed periodic magnetic variables and a few eclipsing stars for variable polarization. Thus far no evidence has been found for variable polarization in the magnetic stars (*Publ. Astron. Soc. Pacific*, August 1966). However, variable polarization was found in the eclipsing Wolf-Rayet system V444 Cyg (*Astrophys. J.* **143**, 1008, 1966).

Hiltner and Schild published (*Astrophys. J.* **143**, 770, 1966) an atlas of Wolf-Rayet spectra.

Galaxies. The study of the morphology of clusters of galaxies has been continued with Janet R. Lesh and Robert F. Garrison, with special emphasis on further investigation of the supergiant D galaxies. See W. W. Morgan and Janet Rountree Lesh, "The Supergiant Galaxies," *Astrophys. J.* **142**, 1364, 1965.

Hiltner, A. Cowley, and Schild observed quasi-stellar and Haro-Luyten blue objects with the image tube spectrograph mentioned above. Of 19 Haro-Luyten objects observed only two showed emission lines and were redshifted. (*Publ. Astron. Soc. Pacific*, October, 1966.)

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