In cooperation with Dr. Michie, Dr. Bardeen has investigated the formation of perturbations during the early history of the universe. The growth rates depend on the choice of spacelike hypersurfaces on which the background metric is taken to be independent of position. Since in one coordinate system all density perturbations have zero amplitude at $t=0$, while in another no density perturbations are zero at $t=0$, the conclusion is that it is meaningless to talk about the growth rate or size of density perturbations in a Friedmann universe until a light signal has had time to cross the perturbation.

Yerkes Observatory, University of Chicago, Williams Bay, Wisconsin

Personnel. Members of the faculty during the report period were S. Chandrasekhar, C. R. Cowley, Pierre Demarque, W. A. Hiltner, Lewis M. Hobbs, D. Nelson Limber, R. H. Miller, W. W. Morgan, C. R. O'Dell, Eugene N. Parker, William van Altena and Peter O. Vandervoort. Dr. Hobbs joined the faculty in October 1966, and Dr. Parker in May 1967, the latter simultaneously holding appointments in the Department of Physics and the Enrico Fermi Institute of the University of Chicago. Dr. I. Appenzeller, Dr. A. P. Cowley, Dr. K. S. Krishna Swamy, Dr. Pavel Mayer, and Dr. Brian Warner served as research associates, with Krishna Swamy leaving in September to assume a research position at the Goddard Space Flight Center and Mayer returning to the Charles University, Prague, in December. Dr. Carlos Jaschek was appointed research associate for the period 15 May to 15 June 1967, during which time he and Dr. Mercedes Jaschek conducted several investigations with Morgan. Gerhard Rutkowsky served as resident project engineer for the modernization of the 40-in. refractor and David H. DeVorkin was the 40-in. observer before leaving to resume his graduate studies.

Chairman Morgan and Director Hiltner resigned their administrative positions effective 1 October 1966. D. Nelson Limber then became Chairman of the Department of Astronomy and Astrophysics and C. R. O'Dell became the Director of the Yerkes Observatory.

S. Chandrasekhar was the recipient of a Presidential National Science Medal; Pierre Demarque was named the 1967 recipient of the Helen B. Warner Prize of the American Astronomical Society, and Eugene N. Parker was elected a member of the National Academy of Science. Hiltner served as acting director of the Cerro Tololo Interamerican Observatory from 1 November 1966 to 1 June 1967. Miller was on leave as a senior post-doctoral fellow at the Institute for Space Studies, New York, from 1 February 1967 to 31 May 1967.

The Yerkes Observatory was host to a meeting of the American Astronomical Society from 13 to 15 June 1967. The meeting was the largest held by the society; 207 papers were given and special sessions were held on Diffuse Nebulae, the Origin of the Cosmic Rays, and Stellar Rotation.

National Aeronautics and Space Administration traineeships were held by R. Brucato, Mrs. J. Lesh, D. Mook, L. Rossner, B. Schlesinger, and N. Walborn. National Defense Education Act traineeships were held by T. Grenfell, B. Jones, L. Marschall, and A. Saaf. National Science Foundation traineeships were held by D. York and R. Zappala. Canadian National Research Council Fellowships were held by M. Aizenman and J. Marlborough. Assistantships and University of Chicago Fellowships were held by R. Garrison, P. Jackson, J. Marlborough, R. Schild, E. Noffsinger, Anita Petelinek, and A. Witt. The degree of doctor of philosophy was received by Robert F. Garrison, Rudolph E. Schild, and L. F. Rossner. Robert R. Zappala received the Master of Science degree.

Among colloquium speakers for the year were Dr. N. C. Wickramasinghe, Jesus College, Cambridge, England; Dr. Ilya Prigogine, Enrico Fermi Institute; Dr. J. E. Dyson, University of Wisconsin; Dr. Karl G. Henize, Northwestern University; Dr. R. C. Bless, University of Wisconsin; Dr. E. Anders, Enrico Fermi Institute; Dr. J. Faulkner, California Institute of Technology; Dr. Louise Webster, University of Wisconsin; Dr. R. A. R. Parker, University of Wisconsin; Dr. P. A. Strittmatter, Institute on Theoretical Astrophysics, Cambridge, England; Dr. James Peebles, Princeton University; Dr. Stephen E. Strom, Harvard College Observatory; Dr. L. V. Kuhi, University of California, Berkeley; Dr. M. Harwit, Cornell University; Dr. D. D. Polozhentsev, Pulkovo Observatory, U.S.S.R.; Dr. George W. Preston, Lick Observatory; Dr. J. P. Ostriker, Princeton University; Dr. K. Wurm, Hamburg Observatory; Dr. F. J. Kerr, University of Maryland; Dr. C. O. R. Jaschek, La Plata, Argentina; Dr. C. C. Lin, Massachusetts Institute of Technology; Dr. George W. Collins II, Ohio State University. Dr. Wickramasinghe spent one week at Yerkes during the summer quarter.

A significant revision of the graduate program was formulated and approved by the faculty during the report period and will take effect with the beginning of the academic year 1967–68. Under the new program students will be in residence on the Chicago Campus during the fall, winter, and spring quarters of their first two years. During these quarters they will take courses in astronomy and astrophysics and in physics. Interested students will be encouraged to spend short periods at the Yerkes Observatory during this time to gain famil-

iarity with the observational facilities and to undertake observational research programs. In the summer quarter following their first academic year, all students will be in residence at the Yerkes Observatory. During this quarter they will gain experience with the different kinds of equipment that are important in modern ground-based astronomy through participation in observational research programs and through lectures on radiation measurement. Following the spring quarter of his second academic year, a student will normally begin his thesis research and can choose to be in residence either on the Chicago Campus or at the Yerkes Observatory, the choice depending upon the facilities required by the student and upon his wishes.

Facilities and Equipment. The physical plant of the observatory was changed in several ways during the year. A new IBM 1130 computer with printer replaced the older IBM 1620 machine that had been in use for three years. The ground floor area was reorganized, giving room for an additional research laboratory; the photographic service department was brought into a single work area, and new floors and walls were installed in an undeveloped area that will now be used for housing measuring instruments. The remodeling of the southeast dome in preparation for the new 41-in. telescope was completed. A new floor, wall, pier cap, and rising platform were installed. Delivery of the telescope has been delayed, but is expected in October 1967. The modernization of the 40-in. refractor is described under the section on instrumentation.

Instrumentation. A new polarimeter was designed by Appenzeller and constructed for more efficient polarimetric observations ("A New Polarimeter for Faint Astronomical Sources," *Publ. Astron. Soc. Pacific* **79,** 136, 1967). An achromatic half-wave plate is rotated instead of the analyzer, easily permitting automation.

Optician Richard Monnier has prepared a report on the working properties of the new material being used in the optics of the 41-in. telescope ("The Fabrication of a 104 cm. Mirror from CER-VII^{-R} Low Expansion Material," *Appl. Opt.* **7,** 1437, 1967).

Design work on a standard reflecting telescope, stressing ease of use and rapid changeover of observing programs, was carried out by Miller at the Institute for Space Studies during the winter quarter.

Construction of interferometric spectrometer for use at very high spectral resolving power has been undertaken by Hobbs. This Pepsios-like instrument will employ three Fabry-Perot interferometers for dispersion. It is a photoelectric, pressure-scanned spectrometer intended for use with a band-pass having a full half-intensity width of the order of 10 mÅ. The programs of primary interest will be investigations of various interstellar lines.

Modernization of the 40-in. refractor should be completed in September 1967. To date the telescope has been completely rewired and painted. All of the old manual controls have been removed, which considerably lightens the telescope, and they have been replaced by new electrically operated clamps and setting and guiding motions. Control of the slewing motions has been transferred to the eyepiece end of the telescope. A portable console desk has been built which contains the clocks, drive oscillator, and parallel controls for many of the eyepiece-end controls.

Setup time with the telescope has been greatly decreased with the installation of digital coordinate displays at the eyepiece end of the telescope, which display to $0^m.1$ in right ascension and hour angle and to $1'$ in declination. Two large gears, pitch diameter $=33.75$ in. and 1080 teeth, provide the takeoff point for the hour angle and declination pulse generators. Electronic counters located at the eyepiece end count the pulses and the results are displayed by Nixie tubes. Right ascension is obtained by adding the sidereal time to the hour angle count. A sidereal crystal oscillator, which is an integral part of the right ascension counter, provides a pulse every six sidereal seconds. A button is provided that adds 12 h to the right ascension and changes the sign of the hour angle to facilitate observing on both sides of the pier. The electronics were designed and built to the Yerkes Observatory specifications by the Dynapar Corporation in Gurnee, Illinois. The system has been in operation now for about six months and has proved to be rather trouble free.

A number of other items, which will complete the modernization, are now nearing completion. They include: a rotating equipment mount, a unit at the objective end which will contain the iris diaphragm, wire grating, and objective cover, all electrically operated from the eyepiece end and with remote synchro indicators, and an electric motor for operating the dome shutters.

Most of the mechanical work has been done in the Yerkes Observatory shops by Boro Spotz. The engineering design has been done by Rutkowsky.

An automatic guiding astrometric camera for the 40-in. refractor is nearing completion and should be operating in August 1967. The camera derives its error signal from a knife edge spinning at 1800 rpm and one photomultiplier. The camera was designed by Optics for Industry in Milwaukee in close cooperation with the Yerkes Observatory and is being constructed by the above-mentioned company.

A direct-intensity microphotometer system has been ordered from the Gaertner Scientific Corporation and is scheduled for delivery in October 1967.

Theoretical Astronomy. The following papers were published by Chandrasekhar and his associates:

1. "The Equilibrium and the Stability of the Riemann Ellipsoids. II," *Astrophys. J.* **145,** 842, 1966.
2. "The Post-Newtonian Effects of General Relativity on the Equilibrium of Uniformly Rotating Bodies. II. The Deformed Figures of the Maclaurin Spheroids," *ibid.* **147,** 334, 1967.
3. "Virial Relations for Uniformly Rotating Fluid Masses in General Relativity," *ibid.* **147,** 383, 1967.
4. "On a Post-Galilean Transformation Appropriate to the Post-Newtonian Theory of Einstein, Infeld, and Hoffman" (with G. Contopoulos), *Proc. Roy. Soc.* (*London*) **298,** 123, 1967.
5. "The Post-Newtonian Effects of General Relativity on the Equilibrium of Uniformly Rotating Bodies. III. The Deformed Figures of the Jacobi Ellipsoids," *Astrophys. J.* **148,** 621, 1967.
6. "The Post-Newtonian Effects of General Relativity on the Equilibrium of Uniformly Rotating Bodies. IV. The Roche Model," *ibid.* **148,** 645, 1967.
7. "Suppression of the Jeans Instability in Collisionless Media" (Edward Lee), *ibid.* **148,** 185, 1967.
8. "The Equilibrium of Slowly Rotating Configurations in the Post-Newtonian Approximation: Corrections to Clairaut's Equation" (Elliott Krefetz), *ibid.* **148,** 589, 1967.
9. "The Appearance of a Rotating Configuration as Viewed from Infinity" (Elliott Krefetz), *ibid.* **148,** 613, 1967.

Stars and Stellar Atmospheres. The structure of circumstellar envelopes formed as a result of the continuing rotationally forced ejection of matter by stars has been considered by Limber. The dynamics of such envelopes near their equatorial planes has been treated in a general way for the case of steady-state solutions with arbitrary distributions of temperature and circular component of velocity for the case in which the force field in the radial direction results only from the star's gravitational field, from centrifugal effects, and from pressure gradients. The particular case of steady-state solutions for isothermal envelopes with negligible viscosity has been treated in detail (*Astrophys. J.* **148,** 141, 1967).

In another study by Limber the nature of the support of the circumstellar envelopes of Be stars has been explored. The different forces that appear to deserve consideration have been examined and the observations that provide information concerning the variation of the circular velocity with distance from a particular Be star's rotation axis have been reanalyzed. It has been concluded that the support of these envelopes is for the most part centrifugal, and the viscous agent that is necessary to provide the required transfer of angular momentum from the star to the envelope is one that results either from magnetic fields or from turbulence within the envelope. This latter work has been carried out in collaboration with Marlborough and has been submitted for publication. Work is under way on an attempt to draw information concerning the kinematics of the envelopes of Be stars from their observed time variations.

Marlborough is completing work on the determination of the ionization and excitation state and of the radiation field within a family of model envelopes for Be stars that appear to be kinematically reasonable.

The scope of the second edition of the *Yerkes Atlas of Stellar Spectra* has been increased to illustrate more satisfactory classification criteria for categories such as the peculiar A stars. This has required the reproduction of segments of spectrograms of dispersion considerably higher than that of the first edition. Carlos and Mercedes Jaschek are preparing certain sections of the new text.

Morgan has joined with Dr. A. B. Meinel of the University of Arizona and Dr. Helmut Abt of Kitt Peak National Observatory in preparing a small atlas of standard stellar spectra with grating dispersion. The plates are being taken with the first Kitt Peak 36-in. reflector and a small slit spectrograph; these reproductions will be useful for classifying very low-dispersion slit spectrograms of faint stars obtained with the large reflectors.

Carlos and Mercedes Jaschek collaborated with Morgan in the study of some characteristics of the A stars. An important problem here lies in the progressive change with time of the definition of certain groups, such as the metallic-line stars. The results of this work are being included in the revised edition of the *Yerkes Atlas of Stellar Spectra.* In addition, the Jascheks completed an investigation of the star ζ' Scorpii. They found that lines of certain elements in the spectrum of this super-supergiant vary in a remarkable manner. Of especial interest in this respect are the lines of O II.

The Jascheks and Dr. A. Slettebak of Perkins Observatory carried out an investigation of the helium variable star HD 125823. This star, which had been found by Bidelman to have rapidly varying lines of He I in its spectrum, now appears to be of prime importance in the study of stellar evolu-

tion. In 1948, its spectrum was that of an approximately normal B2V star; in the 15 yr following, the available spectra indicate a progression to a present type (1967) of around B7III, with relatively weak He lines. This appears to be a complicated case of a star whose spectrum may have undergone a progressive change—together with major rapid fluctuations superposed.

The location of AQ Pup has been discussed by Hiltner, J. D. Fernie of David Dunlap Observatory, and R. P. Kraft of Mount Wilson and Palomar Observatories ("The Association II Pup and the Classical Cepheid AQ Pup," *Astron. J.* **71,** 999, 1967).

An unusual stellar emission-line source originally thought to be a very dense planetary nebula is discussed in a paper by O'Dell ("A New Peculiar Emission-Line Object," *Astrophys. J.* **145,** 487, 1966) and has been found to have an underlying G-superluminous spectral-type spectrum.

A. Cowley is studying the triple system B5481. The primary component of the visual pair resembles VV Cephei (M1epIb+B2V). An exceedingly long period of about 75 yr for this spectroscopic binary has been found. The long-term variations in the shell of γ Cas are also being studied. She has published a discussion of the peculiar system 17 Lep ("An Interpretation of the Spectrum of 17 Leporis," *Astrophys. J.* **147,** 609, 1967) The Cowleys and Marlborough have prepared two joint papers ("The Suppression of Hϵ in the Spectrum of AX Monocerotis," *Publ. Astron. Soc. Pacific* **79,** 21, 1967; "On the Classification of Some Newly Identified Metallic-Line A Stars," *Observatory*, to be published).

Zappala has executed an observational program on the variable polarization in late-type stars ("Fluctuating Polarization in Long-Period Variable Stars," *Astrophys. J.* **148,** L81, 1967). Appenzeller and O'Dell have measured the polarization of the intrinsically very cool Taurus infrared source and have found it to be $p = 0.26 \pm 0.08$ mag ("Polarization of the Taurus Infrared Source," *Astrophys. J.* **149,** L5, 1967). The significant intrinsic polarization found in the coolest stars may indicate that appreciable internal reddening and blanketing may be caused by sublimate particles, a matter of considerable importance in determining the atmospheric properties and total luminosities of these stars.

A spectrophotometric investigation of the peculiar object MHα 328–116, which has recently undergone a very large change in luminosity and spectrum, has been completed by O'Dell. The observed flat stellar continuum corresponds to that of a very hot star after correction for the effects of interstellar reddening. This is in contrast to the pre-outburst M spectral type. The relative emission line strengths for [O III] lines were found to vary, as were the lower members of the Balmer series. The Balmer decrement indicates that the nebular envelope is optically thick to this line radiation, a conclusion substantiated by the relative strength of the recombination emission lines and the stellar continuum. ("Photoelectric Spectrophotometry of MHα 328-116," *Astrophys. J.* **149,** 373, 1967.)

The emission-line ratios and continuum flux distribution has been the subject of a continued program of the monitoring of changes in the symbiotic stars by O'Dell. A selected group of the brightest objects are being measured periodically from McDonald Observatory with the spectrum scanner. Large changes in line ratios and continuum colors have been observed in several objects. Various theoretical models are also being calculated on the observatory's computer. The first observations on this program were made in June 1965.

Photometric observations of the I Sco association and classification spectra of all O and early B stars south of $-23°$ in the Bright Star Catalogue have been obtained and are being discussed by Hiltner and Schild. Spectrograms have been obtained of stars brighter than 9.9, north of $-23°$ and having proper motions of at least $0''.5$/yr, half of which were included in Roman's study of high-velocity stars. A catalogue of spectral types and photoelectric photometry is being prepared by Hiltner, A. Cowley, and Witt. Appenzeller has published a list of stellar spectral types ("MK Spectral Types for 185 Bright Stars," *Publ. Astron. Soc. Pacific* **79,** 102, 1967).

The intrinsic polarization of Beta Lyrae has been evaluated by Appenzeller and Hiltner ("True Polarization Curves for Beta Lyrae," *Astrophys. J.* **149,** 353, 1967).

Warner derived equivalent widths and abundances for five hydrogen-deficient carbon stars using coudé plates taken at the Radcliffe Observatory. These stars are found to be similar both in chemical composition and in kinematical properties to the R CrB variables and the helium stars.

A study by Hobbs is under way in collaboration with C. Cowley to determine for the B stars the importance of the quadrupole part of the Stark effect, for line broadening in atoms other than hydrogen. Preliminary application of the general solutions for the one-valence-electron case have been made to the Mg II 4481 line. Although not negligible, the quadrupole contribution is no larger than the ordinary dipole Stark effect, despite the quadratic field dependence of the latter.

Cowley and his course students have extended the work of Cayrel and Jugaku to giants. For the same effective temperature the giants are found

to have lower excitation temperatures than the dwarfs. The atmospheres constructed in this work will be used in abundance analyses of the stars HR 774, π^6 Ori, θ Her, and β Crv.

Appenzeller and E. H. Schröter of University Observatory, Göttingen, have completed two discussions on the solar atmosphere ("Center-to-Limb Variations of the Intensity and the Wavelength of Several Fraunhofer Lines along the Sun's Polar and Equatorial Diameter," *Astrophys. J.* **147,** 1100, 1967; "A Statistical Analysis of the Velocity and Brightness Fluctuations in the Solar Atmosphere," *ibid.*, to be published).

Stellar Interiors. Demarque is currently conducting a study of the evolution of early-type stars with S. C. Morris, and, together with F. D. A. Hartwick and M. Taylor, he is investigating the effects of opacity on Population II stellar models. Comparison of main sequences computer with Keller–Meyerott opacities and Cox opacities show the expected effect that inclusion of bound–bound transitions (in Cox opacities) increased the radius, but does not affect the total luminosity of a stellar model appreciably. The absolute bolometric magnitude of the knee, in the evolution off the main sequence, seems little affected.

Demarque is also collaborating with Schlesinger in a study of the position and implication of a gap just above the main sequence in the color–magnitude diagram of NGC 188. The assumption is made that the observed gap is due to the rapid evolutionary phase corresponding to the hydrogen exhaustion of a formerly convective core. Present models for the main sequence and early evolutionary stages, compared to Sandage's recent photometric data (unpublished) support any of the following possibilities: (1) the currently accepted physics is slightly incorrect; (2) the estimate of the reddening of the cluster members is slightly incorrect; (3) NGC 188 is richer in metals than the sun by approximately a factor 2. If (3) is correct, then the age of NGC 188 may be reduced to about $5\text{–}6\times10^9$ yr.

Demarque and his collaborators have published the following papers during the past year: "The Upper Main-Sequence," *Astrophys.* **64,** 238 (with S. C. Morris); "The Early Evolution of a Star of 1.2 Solar Masses," *Astrophys. J.* **146,** 430 (with E. L. Hallgren); "Hydrogen Convection Zones and Stellar Rotation," *ibid,* **147,** 1188 (with R. C. Roeder); "The Hydrogen and Helium Content of Extreme Population I Objects," *Astrophys. J.* **147,** 1200 (with J. R. Percy); "The Early Evolution of Population II Stars," *ibid.* **149,** 117; "The Hyades Distance Modulus, Distances in the Universe and Stellar Interiors," *ibid.* September 1967; and (with J. N. Bahcall and M. Cooper) "Dependence of the ^{8}B Solar Neutrino Flux on Heavy Element Composition," *ibid.* November, 1967. A book on stellar evolution by Demarque will be ready for publication in the spring of 1968.

Jackson is completing work on the construction of stellar models for synchronously rotating components of close binaries by means of an extension of the Roxborough method. He has completed work on the construction of models for uniformly rotating stars on the basis of an energy principle.

Interstellar Matter. Krishna Swamy and O'Dell have published a discussion of the effects of interstellar grains in H II regions ("Photoelectric Spectrophotometry of Gaseous Nebulae IV. Interaction of Dust, Gas, and Radiation, " *Astrophys. J.* **147,** 529). The same authors have critically evaluated the strengths and weaknesses of the existing tests for model types of the interstellar particles and have developed the use of the optical radar scattering curve that can be derived from the observations of particular reflection nebulae ("Distinction between Models of Interstellar Grains," *Astrophys. J.* **147,** 937, 1967).

Interferometric scans of the interstellar sodium *D* lines in the spectra of 75 stars have been obtained at Lick Observatory by Hobbs and are now being reduced and analyzed.

Krishna Swamy and N. C. Wickramasinghe have discussed the wavelength dependence of the interstellar polarization and other tests of particle models ("Unified Model for Interstellar Extinction and Polarization," *Nature* **213,** 895, 1967).

The nature of the diffuse galactic radiation has been investigated by Witt as part of his doctoral dissertation. New photoelectric measurements in three bandpasses centered at λλ3600, 4350, and 6100 Å were made of the intensity and distribution of the diffuse radiation in the Galaxy in the constellations of Cygnus and Taurus–Auriga with a procedure that minimized the influence of other light sources in the sky. The result of this study is that interstellar particles have an albedo close to unity and isotropic phase function over the observed wavelength range. The observations safely rule out particles consisting of dirty ice or pure graphite, while composite particles of ice-coated graphite are highly unlikely. The observed properties are manifested by the complex molecules proposed by Platt although additional undiscussed models are possible.

An ultraviolet objective-prism spectrogram taken from the Gemini 11 spacecraft has provided the basic material for a re-evaluation of the structure of the large-scale material that constitutes the Barnard Loop Nebula in Orion. Coming from the series taken during three Gemini flights under the supervision of Karl G. Henize of Northwestern

University, this photograph shows an unexpected brightness and structure of this faint nebula. On the assumption of this brightness being primarily due to ultraviolet light from the early-type stars that is scattered by interstellar particles mixed in with the nebular gas, Henize, York, and O'Dell have derived a shell-type model for the distribution of material. This distribution can be explained through the interaction of the radiatively repulsed interstellar particles transferring their momentum to the gas by means of viscous or electrostatic drag forces. ("Structure of the Barnard Loop Nebula as Determined from Gemini 11 Photographs," *Astrophys. J.*, to be published).

The Galaxy and Extragalactic Systems. Mrs. Janet Rountree Lesh has engaged in an investigation of the systemic characteristics of the motions of the nearer B stars, carrying out new MK classifications for 464 stars of HD type B5 and earlier, brighter than magnitude 6.5 and north of declination −20°; these include most of the B-type stars which seem to define the Gould Belt. She also carried out an investigation for the determination of new proper motions for the same stars on the system of the FK4 under the supervision of Dr. Adriaan Blaauw, Director of Kapteyn Astronomical Laboratory at Gröningen. Least-squares solutions for the velocity gradients for the O-B stars within 300 pc of the sun were carried out. From this much-improved observational material she found definite evidence for the presence of an expanding group among the nearby B stars with an expansion age on the order of 70–90 million years. This work put on a more formally precise basis earlier results of Eggen and Bonneau.

Appenzeller has obtained very accurate polarimetric observations for over 300 nearby stars in the direction of the galactic poles. These data will be used to discuss the direction of the nearby interstellar magnetic field.

Morgan and D. E. Osterbrock of the University of Wisconsin completed an investigation of the stellar content of galaxies as determined from integrated spectra. A standard form-sequence of giant galaxies was set up, and the progressive change in the spectra with form type was described. Three principal categories of the population of giant galaxies were outlined; they are: (1) The "Orion" population. (Emission lines superposed on an early-type continuum with B–F type absorption lines.) (2) "Intermediate" population. (Blue-violet spectral type near F8, with high degree of compositeness.) (3) "Amorphous" population. (Spectral type near K0 in blue and violet regions, near K5 in green, and M in red.) For the great majority of giant irregulars, spirals, and ellipticals there is a close relationship between the form types on the Yerkes system and the appearance of the integrated spectrum of the nuclear regions. A comparison was drawn between the spectrum of the nuclear region of M31 and integrated spectra of transparent regions in the Great Star Cloud in Sagittarius obtained by Morgan with the McDonald 82-in. reflector. The spectra of the two galaxies are strikingly similar; and it may be presumed that the stellar populations are also similar. A rich stratum of late M giant stars in the region of the Galactic bulge, discovered by Nassau, was described from an infrared objective prism plate obtained at the Tonantzintla Observatory. A comparison of the frequency of these red giant stars in our galactic nuclear region with the resolved giants near the nucleus of M31 suggests that the two kinds of stars may be similar. A comparison of the spectroscopic characteristics of the nuclear regions of NGC 5194 and its companion NGC 5195 suggests that the population of the latter may resemble that of a globular cluster of intermediate metallic-line intensity. This investigation will be published in Volume IX of the Kupier–Middlehurst Compendium of Astronomy and Astrophysics.

Miller investigated a new method of calculating n-body integrations in stellar dynamics which promises to permit calculations with 10^5–10^6 bodies. Previous calculations have been limited to 100–200. A computer program was developed and run at the Institute for Space Studies in New York which has successfully followed the evolution of systems of 120 000 stars. A report is in preparation, with K. H. Prendergast of the Columbia University Astronomy Department. The method developed earlier to study the reversibility of n-body integrations was developed as a general experimental approach to the study of the numerical stability of approximations to initial value problems (*J. Comput. Phys.* to be published.) Years ago, when the n-body calculations were first undertaken, the object was to seek evidence for the existence (or lack of) higher-order terms (pairs, triples, etc.) in the "BBGKY hierarchy" of distribution functions. Because of the lack of numerical stability in the n-body calculation, machine calculations did not seem to present a reliable approach to this problem. An alternative approach was through a study of the nearby stars. This led to the investigation of the positional correlations from which it appears that the pair term is barely detectable in the solar neighborhood (*Astrophys. J.* **148,** 865).

Vandervoort has continued to work on problems in stellar dynamics. The general solutions obtained previously for the equilibrium configurations of rapidly rotating galaxies (*Astrophys. J.* **147,** 91, 1967) form the basis for the construction of models of the galactic system. Within the framework of

these equilibrium solutions it is possible to discuss a variety of classical problems, including differential rotation, the asymmetry of the peculiar motions of stars in the solar neighborhood, and the gravitational force perpendicular to the galactic plane. In a further investigation of the equilibrium of axisymmetric galaxies, it has been shown that configurations are possible which have time-independent, axisymmetric mass distributions but time-dependent, nonaxisymmetric differential motions. An investigation, related to those above, concerns a third integral of the motion of a star in a highly flattened stellar system. In a low order of approximation, a suitable form of the integral is the action integral (adiabatic invariant) for the oscillation perpendicular to the plane of symmetry of the system. The "third" integral has been constructed through the next higher order of approximation of a star in time-dependent, non-axisymmetric systems.

Saaf is completing the research for his doctoral dissertation on the construction of a formal third integral (in addition to the energy and the conserved component of the angular momentum) of the motion of a star in an axisymmetric gravitational field which departs only slightly from spherical symmetry. This problem bears on the question of whether or not star streaming is possible in slowly rotating stellar systems. The formal integral has been constructed analytically for stars of very low energies, and predictions based on this integral have been confirmed in numerical experiments with the orbits. A general theory of the third integral has been formulated for stars of arbitrary energies. As a by-product of these investigations, the theory of exact integrals that are quartic functions of the peculiar velocities has been developed for motion in a time-dependent, axisymmetric field.

Vandervoort has completed a brief investigation of moving pairs among the A-type stars within a distance of 20 pc from the sun. Among the 20 stars there are three well-defined pairs and a triple. An analysis of the relative motions of the components of these systems yields a lower limit of about 10^{13} yr on the time of relaxation for the motion of a star in the solar neighborhood.

Photometric data on NGC 3115 were prepared for publication by Miller. Data obtained photoelectrically and from isophotal tracings of photographs were combined into a single description with the results quoted as brightnesses along the photographic isophotes. Because of a color change along the minor axis of this system, it did not seem worthwhile to attempt the more complete dynamical study attempted earlier with NGC 3379, although this was the goal at the time the photometry was taken.

Astrometry. The Lick Observatory plate pair which covers the central region of the Hyades and provided the basic data for a recent paper by van Altena ("The Low-Luminosity Members of the Hyades Cluster," *Astron. J.* **71,** 482, 1966) has been accurately measured and a rediscussion of the proper motions is in progress. The more accurate proper motions will provide a better separation of cluster members from the field. Two plate pairs of NGC 2420 and NGC 7062 with average epoch differences of around 50 yr have been measured and reductions are now in progress by van Altena.

The parallax program recently restarted by van Altena consists mainly of large proper motion, low-luminosity stars with particular emphasis on the redder objects. Of the approximately 60 stars on the program only a few have previously published parallaxes. Over 500 exposures have been made in the last report year, most of them 30 min in length. Most of the plates were taken by DeVorkin.

Miscellaneous Research Areas. Spectra of stellar and near-stellar objects taken at McDonald Observatory with the new image-tube spectrograph have been described by Hiltner, A. Cowley, and R. E. Schild ("Observations of Quasi-Stellar and Haro-Luyten Blue Objects," *Publ. Astron. Soc. Pacific* **78,** 464, 1966). An upper limit to the optical polarization of Sco X-1 was established by Hiltner, Mook, D. J. Ludden, and D. Graham ("On the Polarization of Sco X-1," *Astrophys. J.* **148,** L47, 1967). Mook made *UBV* photometric observations of Sco X-1 at Cerro Tololo on 41 consecutive nights. This study of the photometric nature of Sco X-1 is now being evaluated. Hiltner cooperated with Hans Mark of the Lawrence Radiation Laboratory in a joint rocket-ground base program on Sco X-1.

A positive correlation in the positions of Galactic OB Associations and x-ray sources has been published by O'Dell ("Positional Correlations of Galactic Objects and X-Ray Sources," *Astrophys. J.* **147,** 855, 1967).

Appenzeller and Hiltner have measured the polarization of several QSO's ("Polarimetric Observations of 14 Quasi-Stellar Objects," *Astrophys. J.* **149,** L17, 1967).

Comet Rudnicki (1966*e*) was observed by Mayer during early December 1966 with the nebular photoelectric spectrophotometer described in last year's report. Observations on five nights were of sufficient photometric quality to include in a discussion of the relative strengths of the C_2 band sequences 0-0, 1-0, and 2-0; CN band sequences 0-0 and 0-1; and the C_3 features at λ4050. The variation in the intrinsic strength of these features with heliocentric distance is well defined, being very similar for C_2 and CN and significantly less for C_3. Application of Levin's law indicates a parent particle evapora-

tion temperature of 6000°K for C_2 and CN, but only 2000°K for C_3, possibly indicating a different original source coming out of the nucleus. This work is being discussed and interpreted by Mayer and O'Dell.

Warner and Cowley made a study of the line emission of free-burning arcs in LTE. From the observed normalization function for Tu II they were able to construct a model arc similar to the copper arcs used at the National Bureau of Standards. This model showed the normalization function for neutral atoms with ionization potentials less than 8 eV should be very nearly flat. The normalization function for neutral atoms with high ionization potentials and for singly ionized atoms should be essentially the same shape as was assumed by the Bureau of Standards workers. On the basis of the calculated normalization functions, it was possible to explain several puzzling excitation effects in the sun and stars as systematic errors in the oscillator strengths.

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