and nine B.S. degrees were awarded to our graduate or undergraduate students in astronomy. Public Night Lectures were held in each of 5 months of the academic year. The attendance was 1188. As in the past several years, this entire program was administered and executed by the graduate students under the leadership this year of Craig Chester. The Cleveland Astronomical Society met monthly at the Observatory. Many speakers from the astronomical community contributed to its program and incidently to the program of colloquia for staff and students.

IV. PUBLICATIONS

The following papers were published during the period 1 July 1969 to 30 June 1970:


S. W. McCuskey, Director

Washburn Observatory, University of Wisconsin, Madison, Wisconsin

I. PERSONNEL

Dr. A. Gaide from the University of Geneva Observatory spent the year here as a European Space Research Organization Fellow. Code was on leave at the Kitt Peak National Observatory. Parker continued on leave to participate in the NASA Scientist–Astronaut Program at the Manned Spacecraft Center, where he is currently assigned to the Apollo 15 support crew.

Osterbrock served on the Steering Committee of the National Academy of Sciences Astronomy Survey Committee while Code and Bless were members of its Optical Telescope and Space Astronomy Panels, respectively. Code continued to serve on the Astronomy Missions Board of NASA. Osterbrock continued on the Editorial Board of the Astrophysical Journal and the Editorial Committee of the Annual Review of Astronomy and Astrophysics.

J. Boone, H. Ford, D. Jenner, and E. Jones received their Ph.D. degrees.

II. INSTRUMENTATION

Anderson has continued to work on the echelle spectrograph, which has been in operation as a photographic spectrograph since September 1969. The instrument has been described by Schroeder and Anderson (1970, Astron. J., in press). The reduction of photographic spectra will be facilitated by the digitized microphotometer which is now under construction. The reduction, including density-to-intensity conversion, compensation for the echelle blaze characteristic, and correction for image-tube effects, will be carried out by computer.

Presently under development are the attachments required for photoelectric scanning at resolutions of the order of 0.1 A. Two different approaches
are being pursued. First to be implemented will be a simple exit-slot–photomultiplier combination with the scan accomplished by the rotation of the gratings under the control of a PDP-8 computer which will also handle data acquisition and preliminary reduction. Seeing compensation will be provided by a monitor channel photomultiplier which will view about 4% of the object light extracted from the beam by a beam splitter positioned just below the entrance slit. A second, less orthodox technique being developed by McNall will utilize a stack of image intensifiers the phosphors of which will act as storage registers which will be read-out by an image dissector. This latter technique should allow up to 500 picture elements to be covered simultaneously with the precision of pulse-counting photoelectric photometry (McNall, Robinson, and Wampler 1970, Pubi. Astron. Soc. Pacific, in press).

Wu, Anderson, Rosendhal, Marty, and Bucholtz designed and built a spot sensimeter to be used in conjunction with the echelle spectrograph. The device uses an integrating sphere to provide a uniform source of illumination and has been designed so that it can be easily photoelectrically calibrated. A paper describing this sensimeter is being prepared for publication in the AAS Photo-Bulletin.

Code completed a report for Kitt Peak National Observatory on large telescope arrays. The study indicates that multiple apertures are a practical alternative to a very large single aperture. Furthermore, the use of multiple apertures or arrays permits observations not possible with a single collector.

Parker is collaborating with C. R. O’Dell in the development of an echelle spectrograph for observations of interstellar matter from an orbiting vehicle.

III. RESEARCH

A. Stars and Stellar Atmospheres

Anderson has obtained more than 50 photometrically calibrated spectrograms of Arcturus at a resolution of about 25 000 (0.15 Å) well exposed for the Ca II K-line emission feature. Preliminary examination of these shows some evidence for variations of the type reported by Griffin and by Liller, but a full analysis of these data awaits the end of the observing season for this object and the completion of the digitized microphotometer. Anderson has also begun an extensive survey of chromospheric activity and stellar rotation in stars later than F5 at a resolution comparable to that used on Arcturus.

J. Boone completed his photoelectric scanner study of Hα, Hβ, and Balmer-continuum emission in 27 bright Be stars. He finds less variation in the Hα/Hβ ratio from star to star than previous observers. No correlation with effective temperature is apparent. The mean value of this ratio is 2.2. The ratios of line-to-continuum emission suggest similar envelope structures for all of the stars observed, with a slightly greater ratio for shell stars than for pole-on stars. A model envelope for which Marlborough has published both line populations and the Hα profile is in good agreement with the observations.

Rosendhal has continued his investigations of mass motions in the atmospheres of supergiant stars. A study of spectrum variations in the three A supergiants 6 Cas, 9 Per, and ν Cep, undertaken in collaboration with G. Wegner of the University of Washington, was completed and a paper based on this work has been accepted for publication by the Astrophysical Journal. The results of the analysis suggest the existence of a correlation between absolute magnitude, mean value of the microturbulence, and amplitude of variability of both microturbulence and radial velocity. In addition, the presence of a strong correlation between the behavior of the microturbulence and the radial velocity in the case of 6 Cas and 9 Per indicates the existence of a strong coupling between large-scale and small-scale mass motions in the high-luminosity A stars and provides observational evidence for the occurrence of non-linear aerodynamic processes in the atmospheres of these stars. The time resolution of this investigation was, of necessity, rather coarse. Additional studies are now being made using the echelle spectrograph and 36-inch telescope of the Pine Bluff Observatory to look for evidence of spectral variability with time scales of the order of several minutes to several hours in several bright B- and A-type supergiants.

Rosendhal is analyzing photometric data obtained at the Cerro Tololo Inter-American Observatory by M. Snowden of the Mt. John Observatory, New Zealand, for the purpose of looking for possible light variations in the five brightest Large Magellanic Cloud supergiants. Previous observational results on galactic supergiants indicate that these luminous stars (Mv ≈−9 to −10) should be intrinsically variable and, in view of the contradictory results reported in the literature and the theoretical implications of the stability of such massive stars, this problem is being reinvestigated, using a very accurate photometric observing technique.

J. Gallagher and Rosendhal began an abundance analysis of the high-luminosity A stars ν Cep and HD 17378. These stars are respectively members of the I Cep and I Per associations. The objectives of this investigation are (i) to see whether there are any differences between the field A supergiants (as represented by α Cygni) and cluster stars, and (ii) to see whether there are any abundance differences between the two associations. Reduction of the Kitt
Peak and McDonald could spectrograms of these stars is currently in progress.

Hilgart and Rosendhal began a photometric investigation of the group of sharp-line main-sequence A stars denoted by Deutsch as the O Population in order to see whether the photometric behavior of these stars is similar to that of the magnetic stars and to see whether they share any of the other secondary characteristics of the Ap stars.

Code continued to investigate time-dependent radiation transfer problems and published a study of the effects of scattering of pulsar radiation by a scattering envelope about the object. Additional studies were carried out on radiative transfer in a particle-scattering envelope surrounding stars and the radiation transfer in the optically thick hydrogen envelope surrounding a comet.

B. Stellar Structure

Forbes has continued work on post-main-sequence stellar evolution subject to mass loss. Recent observational evidence has suggested that the fractional mass loss may be less severe than the 80% assumed in his previous work, perhaps more like 50%. The intention is to extend these studies to less massive stars in the range 1 to 3 solar masses. Under his direction, E. Jones completed a Ph.D. thesis in which the pulsational characteristics of a mass-loss model calculated by Forbes (1968, Astrophys. J. 153, 495) located in the Cepheid instability strip were studied. A study of a 1.5-solar-mass star subject to mass loss during pre-main-sequence contraction, intended to represent roughly the T Tauri evolutionary phase, was carried out by Forbes in collaboration with L. V. Kuhn of the University of California, Berkeley, and has been published (1970, Astrophys. J. 159, 871).

C. Nebulae and the Interstellar Medium

Osterbrock reviewed the abundances of the elements in gaseous nebulae for the special Symposium in honor of Professor J. S. Greenstein’s sixtieth birthday at Caltech in January 1970. The most accurate helium abundances are quite close to \( N(\text{He})/N(\text{H}) = 0.13 \) in both H II regions and planetary nebulae, and the few H II regions observed in other galaxies also have similar helium abundances, though there may be a variation with position in the galaxy. The Crab Nebula has a considerably higher helium abundance, and the nuclei of Seyfert galaxies seem to exhibit a wide range in helium abundances from \( N(\text{He})/N(\text{H}) = 3 \times 10^{-2} \) to \( 3 \times 10^{-1} \). Abundances of heavier elements are less well determined observationally, but to within a factor of 3 there do not seem to be many large variations. A few peculiar objects are discussed in detail.

Mathis has studied the effects of internal dust on the size of the hydrogen and helium Strömgren spheres, assuming the extinction cross section and albedo of the dust are given as a function of wavelength. The goal is to relate the observed brightness of an H II region in visual scattered light to the error in bolometric magnitude of the star as derived by a Zanstra technique, caused by the scattering dust.

D. Stellar Systems

H. Ford completed his thesis “The Kinematics and Stellar Content of Populous Clusters in the Magellanic Clouds.” He concluded that the blue populous clusters in the LMC can be understood in terms of an initial luminosity function which is the same as that in the Galaxy. Ages and masses of the blue clusters were estimated from galaxian calibrations and published colors and magnitudes, a typical age and mass being \( 3 \times 10^7 \) yr and \( (5 \pm 2) \times 10^4 \) M⊙.

The velocities of the LMC blue clusters were compared to the 27° inclined-plane, radio-center model of the LMC, and after adding a correction term of 36.8 km/sec (because of blending with moonlight) to 15 clusters, were shown to agree with the LMC extreme Population I rotation curve. Because of the moonlight correction, the velocity dispersion could only be bounded, the bounds being 13 or 8 km/sec, depending on the inclusion of NGC 1850 and NGC 1854. It was concluded that kinematically the clusters are Population I systems.

The spectra of the 12 Magellanic Cloud red globular clusters are of type F and it was concluded that there are few or no old clusters in the clouds with nearly normal abundances. The metal lines in NGC 1466 are weak, indicating that clusters of this type are old and metal poor. The metal lines in NGC 1783 and NGC 419 are stronger relative to the \( H \) lines than in the other clusters and it was concluded that the spectra and colors of these clus-
ters (SMC-type) result primarily from F stars near the turn-off of the unseen main sequence. The remaining clusters have weak-line spectra.

The velocities of the ten LMC red clusters have an average residual of 29 km/sec with respect to the velocities predicted by the extreme Population I rotation curve. Though no plausible dynamical explanation can be made for this, it is felt that the 29 km/sec is not a systematic error. The velocity dispersion is bounded by $45 \pm 12$ (s.e.) km/sec and $33 \pm 10$ (s.e.) km/sec by assuming the 29 km/sec is or is not real. It appears that the velocity dispersion ($40 \pm 10$ km/sec) indicates an LMC halo, though it is noted that the clusters probably do not form a dynamically homogeneous system.

The velocities of the three SMC clusters show no departure from the 21-cm peak velocity pattern.

Osterbrock returned in September from a year spent as an NSF Senior Post-Doctoral Fellow at University College London, working on calculations of collision strengths for semiforbidden lines of the $2s^2 1S - 2s2p 3P C III] \lambda 1909$ isoelectronic sequence. After his return, Osterbrock used these calculated cross sections to discuss the excitation of these C III], N IV], and O IV] lines in quasars. The $1S^2 - 2 3P_1$ line occurs as a forbidden electric dipole transition, and $2 3P_{1,2} - 1S_0$ can occur as a permitted magnetic quadrupole transition with considerably smaller probability. The $2 3P_2$ level is collisionally de-excited at high densities, and measurements of the relative strengths of these two lines would give information on the electron density in quasars in the range $10^6 - 10^8$ cm$^{-3}$. The splittings involved are small, from 2 Å in C III] to 4.5 Å in O IV], so the observation would be a difficult one.

Osterbrock and Nussbaumer discussed the excitation of forbidden emission lines of highly ionized stages of Fe in Seyfert galaxies. The excitation of the [Fe VII], [Fe X], and [Fe XIV] emission lines in Seyfert galaxies was considered with special reference to the interpretation of the strengths of these lines in NGC 4151. The [Fe VII] lines probably arise in the same regions as the [Ne V] lines. Collision strengths for [Fe VII] were calculated, and were used to find the relative Fe abundance in NGC 4151, approximately $N(Fe)/N(H) = 1.4 \times 10^{-5}$, with an uncertainty of approximately a factor of 2. The [Fe X] and [Fe XIV] lines may arise in a high-temperature gas, and Sargent first suggested. On this model Osterbrock and Nussbaumer calculated the amount of high-temperature gas by using published collision strengths for [Fe XIV] and published plus estimated collision strengths for [Fe X]. The radiation from this high-temperature gas, if it exists, is energetically sufficient to photoionize much of the "cool" gas in which the other observed emission lines are emitted. Thus the hot gas may be the prime source of photoionization. It may be heated by collisions between clouds moving with velocities corresponding to the observed line widths.

Mathis calculated the profile of emission lines which suffer electron scattering in a spherical atmosphere, and applied the results to the Balmer emission line profiles in the nuclei of Seyfert galaxies using the observations kindly sent by K. Anderson of Lick Observatory. Mathis found that the observations can be interpreted as electron scattering of the lines within small, very dense knots ($N_e \geq 10^{10}$/cc, typically) of probably quite hot ($T_e \approx 2 - 4 \times 10^6$ K) gas.

G. M. MacAlpine has been investigating the ionization and thermal structure of a gas which is excited by a central power-law radiation source. The resulting predicted emission-line strengths for various ions will be compared with their observed values for quasars and Seyfert galaxies in an effort to learn more about the physical properties of those objects. Others have done preliminary work in this area and were able to account reasonably well for the observed features, with a few notable exceptions. MacAlpine is attempting to make his models more physically realistic than previous ones. He considers the ten most abundant elements and takes into account such factors as the variation of electron kinetic temperature in the gas, diffuse radiation in a somewhat simplified spherical geometry, and the contribution of the heavy elements to the electron density and the opacity. In addition, use is made of more accurate atom coefficients such as photoionization cross sections, recombination coefficients, and collision strengths.

Osterbrock reviewed the emission-line spectra of the nuclei of galaxies (including quasars) at the Vatican Semaine d'Etude in April 1970. He emphasized the possibility that many or all of these objects may be cases in which kinetic energy is converted into ultraviolet ionizing radiation. He suggested the possibility that this radiation is then degraded to lower-energy radiation by photoionization. Osterbrock used his calculations of collision strengths for C III] isoelectronic sequence, together with the conservation theorem, scaling procedures, etc. to estimate collision strengths for all semiforbidden lines expected to be important in quasar spectra. These estimates, together with the best available computations of collision strengths for permitted lines, are collected and published in the Proceedings of the Semaine d'Etude.

D. Jenner obtained low-dispersion, image-tube spectra at Kitt Peak of 18 cD galaxies. Only two galaxies showed strong $\lambda 3727$ emission. The redshifts, relative velocities, and angular separations of a set of ten cD and dS galaxies with double nuclei yielded a statistical mean mass of $6(\pm 4) \times 10^9 M_\odot$. 

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E. The Space Astronomy Laboratory

OAO-2, launched 7 December 1968, continued to operate satisfactorily and to return good ultraviolet photometric and spectrophotometric data. The operation of the Wisconsin instrumentation and data analysis have occupied Bress, Code, Doherty, Houck, Lillie, McNall, and Savage.

Doherty analyzed ultraviolet spectrum scans of 27 G-, K-, and M-type stars obtained with the OAO. These scans have a resolution of about 25 Å. Spectral features can be distinguished to about 2000 Å in α Cen and α Aur. The λ2800 doublet of Mg II appears clearly in emission in α Boo, α Tau, β And, α Ori, and α Sco. In G giants, Mg II closely resembles the solar spectrum seen with this resolution. In general, Mg II absorption weakens with later spectral type and the transition to emission occurs at about K2 for both giants and supergiants. For the stars with the strongest Mg II emission, the absolute emission flux appears to be directly proportional to the absolute flux in the emission core of Ca II K. Scans of the remaining stars, for which only upper limits to the Mg II emission can be estimated, are at least consistent with this simple proportionality. No other emission lines have been definitely identified. In the case of α Ori, this means that the Fe II emission lines near 3200 Å, discussed by Weymann, cannot originate in an optically thin envelope. If this were true, the far stronger lines at shorter wavelengths that arise from the same upper levels would be easily observed.

Uncertainties in the scattered light background and effects of the Earth’s radiation belt do not yet permit a determination of accurate energy distributions for these stars. However, scans of α Tau and α Ori suggest a rise in radiation temperature for wavelengths shorter than about 3000 Å.

D. Ward, Code, and Houck have investigated ultraviolet light curves of two eclipsing binary stars—U Ophiuchi and VV Orionis—obtained with the OAO-2. Observations were made in 11 spectral regions between λ4300 and λ6350 Å using the four 8-inch filter photometers. Satisfactory rectification of the U Oph light curve can be effected using only a cos 2θ term coefficient ≈0.10, and the temperature difference of the two components is found to be about 1000°. VV Orionis rectification is much more complicated since Fourier expansion of the light outside eclipse requires significant coefficients for higher-order terms, so that only preliminary reduction has been accomplished.

Bless and Savage have obtained a large number of ultraviolet extinction curves from the OAO scanner data. The extinction curves (which include stars from nearly all parts of the sky) all show a pronounced hump at 1/λ ≈4.6 μ−1 and a broad minimum at 1/λ ≈5.5–6.0. Most of the curves show a rapid rise to the far ultraviolet. Interesting variations in extinction from region to region have also been observed; the character of the hump changes considerably from object to object. Furthermore, marked variations in the far-ultraviolet extinction have been found.

Gilrò has investigated the extinction properties of mixtures of graphite, silicon carbide, and meteoritic silicate particles in an effort to explain the observed optical properties of interstellar grains over all observed wavelength ranges. A good fit to the observations is found with small (0.05-μ) graphite grains providing the observed hump at ν ≈2200 Å, SiC the major contributor in the visual and infrared regions, and silicates providing the very rapid rise in extinction found from OAO observations below 1600 Å. Observations of diffuse galactic light, polarization, and reflection nebulae also seem to be explained by the same mixture.

Savage and Wu, in collaboration with OAO guest investigators from the Princeton University Observatory, are attempting to reduce the OAO data on interstellar Lyman-α absorption. The OAO resolution of 17 Å produces a blend of Ly-α and neighboring stellar lines of Si III and N v. The first problem being undertaken is that of understanding the existing discrepancy between OAO measurements and measurements at higher resolution by sounding rockets. By using the large number of OAO scans in conjunction with high-resolution rocket spectra of a few stars it is hoped that the effects of the stellar line blending can be eliminated.

C. Wu has undertaken a program to study diffuse and semidiffuse interstellar absorption features at λ5780, 5797, 6284 in stars observed by the OAO. Very interesting correlations have already appeared concerning the diffuse feature at λ4430 Å. The central absorption depth of this feature appears to be much more strongly correlated with Ly-α absorption than with color excess. This finding implies that the agent producing the diffuse feature at λ4430 Å is more strongly coupled to the gas than to the dust. Wu is presently making observations of semidiffuse features with the Pine Bluff 36-inch telescope, using the echelle spectrograph with the Carnegie two-stage image intensifier, to see if similar results are obtained for these features.

J. Caldwell, Savage, and Code in collaboration with a large number of OAO guest investigators have undertaken an analysis of the OAO data on the planets Venus, Mars, Jupiter, and Saturn. Preliminary planetary albedo curves have been produced which indicate that there are severe errors in the presently available solar spectrum. A search for narrow absorbers (width ≥40 Å) has revealed that none of the above-mentioned planets has constituents producing absorption whose equivalent width