installed in October 1966 for operation on 610 MHz. A wide-band ambient temperature parametric amplifier was installed later on 2650 MHz. These new receivers with the liquid-nitrogen-refrigerated parametric amplifier in use for several years on 1415 MHz provide very low noise temperatures at the three frequencies of operation. An IBM 1130 computer is being installed for digitization and preprocessing the data output from all channels of the continuum and hydrogen-line receivers.

Research Programs. The principal observing program with the 260-ft telescope is the source location and sky mapping survey at three frequencies: 610, 1415 and 2650 MHz. About 5000 sq deg of sky have been covered and the survey is continuing at the rate of about 800 sq deg per month. The first results as obtained by Scheer have been published. Dixon, Fitch, and Myers are engaged in the continuing program. Sources are being located at the rate of about one for each 3 sq deg of sky down to a limit of about 0.4 flux units at 1415 MHz. A large number of new sources have been found many of which have unusual spectra. Scheer has observed some of these sources at several frequencies using the Green Bank facilities, while Thompson has worked on their optical identification. A number of the sources have flux density peaks in the centimeter wavelength region.

Data reduction on a full-sky neutral-hydrogen survey is nearing completion. This work is being done by Meng and Brundage and is based on observations with the 260-ft telescope which ended during the latter part of 1966. Carver is completing studies of several types of antennas which are well adapted for radio astronomy observations. Ko is initiating studies of the polarization distribution across extended extragalactic sources. He is also investigating clusters of galaxies and planetary nebulae using the telescopes at Green Bank.

Papers were presented by Mathewson, Meng, Brundage, and Kraus and by Kraus at the Ithaca AAS meeting and by Kraus at the Williams Bay AAS meeting; by Ko at the Munich URSI meetings, and by Taylor and DeJong at the Ottawa URSI meeting.


John D. Kraus, Director

Princeton University Observatory, Princeton, New Jersey

PERSONNEL AND FACILITIES

In October 1966 the offices of the Princeton University Observatory and of the Department of Astrophysical Sciences were moved into Peyton Hall. This building, dedicated on 26 May 1967 to William Charles Peyton, was made possible by a gift from Bernard Peyton and by grants from the National Science Foundation and the Ford Foundation. In addition to some 50 offices and substantial laboratory space the building includes a lecture room seating 130, the Astronomy Library, and two telescopes for instructional purposes.

At the beginning of the academic year E. B. Jenkins joined the sounding rocket program as Research Associate, while P. Bodenheimer accepted a similar position for theoretical research. D. Mihalas resigned as Assistant Professor at the end of the year to accept a position at the Joint Institute for Laboratory Astrophysics, Boulder. Research Associates leaving during the year included G. M. Lawrence, P. M. Solomon, W. K. Rose, and R. Wattson. F. D. A. Hartwick spent the year at the Observatory as Visiting Fellow.

RESEARCH PROGRAM

Stellar Interiors. Auman and Bodenheimer have calculated theoretical lower limits on the effective temperatures of pre-main-sequence and red-giant stars by including the effects of water-vapor opacity and varying the assumptions regarding convection in the surface layers of equilibrium stellar models. They found that the limiting temperature is more sensitive to uncertainties in convection theory than to the effects of water vapor opacity. When the opacity due to water vapor was included and the convective parameters were adjusted within reasonable limits to reduce the convective efficiency, a limiting effective temperature of 2600°K was obtained, which was practically independent of the stellar mass.

Bodenheimer has investigated the collapse phases of early stellar evolution which precede the pre-main-sequence quasi-static contraction. Using Heneyy’s approach to the solution of the equations of stellar structure, modified to include hydrodynamical effects.
namics, he has followed in detail the collapse of configurations of 1 and 12 solar masses from initial mean densities of $10^{-11}$ g/cm³ to final points (corresponding to central densities of about $10^{-3}$ g/cm³ and central temperatures of $3 \times 10^{6}$K) at which strong shock waves have developed near the centers. Bodenheimer and Sweigart have investigated the earlier transparent phases of the evolution of a protostar by calculating the collapse of an isothermal sphere of 10 solar masses through the density range $10^{-18} - 10^{-10}$ g/cm³. They found that the effects of the surface boundary condition and different initial density distributions on the resulting collapse were strongly influenced by the ratio of the freefall time to the time required for sound waves to travel from the surface of the sphere to the center.

### Stellar Interiors—Highly Evolved Stars

Schwarzschild and Härm have continued their investigation of the consequences of a thermal instability occurring in stars with helium-burning shells. They have followed for one specific star the evolution under these unstable conditions for a time interval covering 14 relaxation cycles, a computation requiring nearly 30,000 consecutive models. The results of these computations indicate that this relaxation cycling, though involving variations of the helium-burning rate by $10^5$, appears to have very little consequences for the mean evolution of the star—without one specific exception. The helium shell flash, which initiates each relaxation cycle, causes a steep temperature drop and hence a convective zone to occur just outside the helium-burning shell for a short time once each cycle. From the ninth cycle on the convection zone was found to cut into the hydrogen-rich layers and thus to cause mixing-in of a small amount of hydrogen into the carbon-rich regions of the helium-burning shell. The circumstances here encountered make possible nuclear processes not possible in the preceding evolutionary phases. Sanders has computed in detail the nuclear processes occurring under the precise physical conditions found for the convective mixing phases just mentioned, and has found that the interaction between the mixed-in protons and the available carbon nuclei produce neutrons by the well-known $S$ process in such numbers as to make a substantial contribution of the buildup of heavy $S$-process elements in each relaxation cycle.

In addition, Schwarzschild and Härm have made similar calculations, though of much lesser extent, for two other stars for the purpose of showing that the occurrence of thermal instability caused by a helium-burning shell and the consequent relaxation cycling is not limited to a narrow range in mass or initial helium content. Rose has discovered that a star containing a helium-burning shell in a very late phase of its evolution becomes pulsationally unstable during the peak period of a helium shell flash. He has shown that this superposition of a pulsational instability on a thermal shell instability may plausibly lead to an explanation of the observed phenomenon of planetary nebulae.

Rose has also investigated the phenomena occurring in a star in its pre-white-dwarf state if it is a member of a double star and accretes hydrogen-rich matter from its companion. He found that every time a certain amount of hydrogen-rich matter had been accreted, a hydrogen shell flash occurs and again at the peak of this flash the star becomes pulsationally unstable. In this case the combination of thermal and pulsational instability appears plausibly to lead to an explanation of the observed nova phenomenon.

Hartwick, Härm, and Schwarzschild have investigated the observational consequences of the working hypothesis that the horizontal branch in globular clusters represents the helium core burning phase of stellar evolution. They have found that according to this hypothesis one should find an observable hook at the blue end of the horizontal branch. A comparison with the best available observations is inconclusive but does not exclude the existence of such a hook.

### Stellar Interiors—Rotating Stars

Ostriker and Mark have developed a self-consistent-field (SCF) method for determining the equilibrium structure of rotating stars having a conservative centrifugal potential. The method is applicable for uniform or differential rotation and may be used even when the kinetic energy of rotation is comparable with the gravitational energy.

Ostriker and Bodenheimer, applying the SCF scheme to the construction of white-dwarf stars have found that physically realistic differentially rotating models can be constructed with masses $(1.0 < M/M_\odot < 2.5)$ considerably greater than the Chandrasekhar limit for nonrotating stars and with angular momenta in agreement with those of main-sequence stars having corresponding masses.

Mark has determined the structure of very massive, rapidly rotating, main-sequence stars with the SCF scheme and an approximate stellar interiors program. Differential rotation can cause large changes in the luminosity (e.g., $\Delta M_{\text{bat}} = 2.5$), radius, central temperature, etc. It appears that these changes can leave the rapidly rotating star at a point on the H-R diagram which is approximately on the main sequence for nonrotating stars; that is, the rapidly rotating massive star can have nearly the same luminosity and effective temperature as a nonrotating star of considerably lower mass.

Ostriker and Hartwick have extended the SCF scheme to include (approximately) the effects interior magnetic fields, and applied the method to
construct models of uniformly rotating magnetic white dwarfs. The radius of low-mass (0.5 < M/M⊙ < 1.0) models can be substantially increased by moderate magnetic fields which leave the surface nearly spherical.

Lynden-Bell (Sussex) and Ostriker have completed work on a variational principle for determining the stability of differentially rotating, self-gravitating systems.

Stellar Atmospheres. Model atmospheres for early-type stars have been constructed by Mihalas allowing for departures from LTE in hydrogen, He I, and He II. Hydrogen is approximated with a 15-level atom, of which 10 are not in LTE, while He I is approximated with a 36-level atom of which 31 are not in LTE. Radiative bound–bound transitions are assumed to be in detailed balance, but all other processes are considered in detail. This treatment is valid for discussion of the energy distribution in the continuum. Special techniques are employed to treat the transfer in the Lyman continuum. The effects of the departures on the continuous energy distribution are generally found to be negligibly small, in contrast to earlier results found by other workers using more restrictive atomic models. It is planned to extend this work by including radiative bound–bound transitions.

Morton and Hickok have constructed model atmospheres for O5 and B0 main-sequence stars in radiative equilibrium, taking account of the detailed ultraviolet line blanketing. The effective temperatures are respectively 37 450°K and 28 640°K while the bolometric corrections are −3.7±23 and −2.5±17 for log g = 4.0. Morton and Adams have used these results along with models of cooler stars with line blanketing to obtain new scales of effective temperatures and bolometric corrections for all main-sequence stars hotter than the sun. If these scales are applied to the observed zero-age main sequence, it agrees rather well with that calculated from homogeneous model interiors which include bound–bound opacity. Morton has shown that when the new scale of effective temperatures is applied to the best determined eclipsing binaries, comparison of their mass–luminosity relation with the interior models shows that the helium fraction by mass in A and B stars is Y = 0.24 ± 0.04.

Rogerson and Dressler have made a solar iron abundance determination using observations of a highly excited neutral iron supermultiplet and the Utrecht reference solar atmosphere model. The theoretical curve of growth was computed under the assumption of local thermodynamic equilibrium which may be a reasonable assumption for such highly excited lines. Oscillator strengths for these lines were computed by S. Feldman, using the Bates-Damgaard method. If the logarithm of the hydrogen number density is taken as 12.0, then the logarithm of the iron number density is found to be 7.22 if the solar microturbulent velocity is taken as 1.5 km/sec and 7.10 if the microturbulent velocity is 2.0 km/sec. These values compare with the photospheric determination of 6.70 and a coronal determination of 7.86 (see IAU Symp. No. 26, p. 207).

Cayrel and Rogerson are computing curves of growth for an F8 supergiant model atmosphere in which the turbulent velocity field is specified by its energy spectrum. They are seeking to determine if the curve of growth for ion lines yields a higher microturbulent velocity than that for neutral lines. Since the ion lines are formed over a thicker layer of the atmosphere, longer wavelengths in the energy spectrum will be included as microturbulence for the ion lines and this should show up as a larger microturbulence. This effect is observed.

Auman has calculated model atmospheres with effective temperatures between 2000° and 4000°K. The opacity due to the water vapor lines was included in addition to the continuous opacity. The water vapor opacity is not important for T∗ = 4000°K, but it is important for T∗ ≤ 3500°K. Convection was included using the Bohm-Vitense mixing length theory with the mixing length equal to the local pressure scale height. In the red dwarfs convection begins at r ≤ 0.05 and carries a considerable fraction of the total flux at r ≥ 1.0. In the giants and supergiants convection may begin at small optical depths, but it does not carry a significant part of the total flux until hydrogen begins to be ionized at r ~ 10.0. As the hydrogen begins to be ionized, there exists a transition region where the convective flux increases sharply until almost all the flux is carried by convection. The temperature gradient in this region is very superadiabatic with the result that the temperature fluctuations and the turbulent pressures associated with the convection become sizable.

Solar Physics. Savage has extended calculations on the emission of hydromagnetic waves by an "open" superadiabatic layer to include the effect of surface gravity waves occurring at a density discontinuity separating the layer from an adiabatic region above. The Boussinesq approximation was used, a vertical magnetic field was assumed, and free ("closed") boundary conditions were employed at the bottom of the superadiabatic layer. For parameters characteristic of solar magnetic regions, the presence of gravity waves tends to close the upper boundary of the superadiabatic layer and, as a consequence, reduces the threshold for hydromagnetic wave emission resulting from overstable oscillations in the layer. Applied to sunspot, the stability model predicts hydromagnetic wave emission will occur for sunspot magnetic fields less than approximately 4000 G.
**Planetary Physics.** Moore and Danielson have performed Monte Carlo calculations on the transfer of visible light in clouds. Utilizing Henyey–Greenstein phase functions, the paths of individual photons were followed until they were absorbed or scattered in a cloud layer or until they emerged from the cloud. One important result from the calculations is the large change of transmission of a thin cloud layer (optical scattering thickness of the order of 10) resulting from expected variations in the scattering phase function with wavelength. When applied to terrestrial clouds, the calculations yielded a single scattering albedo which differed from unity by about 0.002.

Savage and Danielson have attempted to interpret the diverse temperature, pressure, and abundance measurements on Jupiter in terms of a two-cloud layer model. One is a thin NH₃ crystal cloud layer having a temperature of about 150°K and the second is a thick H₂O crystal cloud layer having a cloud top temperature of about 200°K. It appears that the observations can be qualitatively understood in terms of a significant fraction of the incident solar radiation penetrating the NH₃ cloud layer at some wavelengths and a negligible fraction at other wavelengths.

Wattson has calculated grey planetary atmospheres in which a power law dependence of the opacity on pressure and temperature is assumed. Applied to Venus, these calculations indicate that possibly as much as an order of magnitude more infrared opacity is required in highly convective models (such as would result from collision-induced opacities) than in purely radiative models. Thus it appears that the total opacity required for greenhouse models of the Venus atmosphere is substantially larger than normally assumed. On the other hand, the highly convective models require a much smaller fraction of the incident solar flux be absorbed at the surface than in the radiative models.

**Stellar Systems.** Ostriker and Lyon have developed a numerical technique for studying the evolution of globular clusters, which is equivalent to the Fokker–Planck equation, but which includes both the classical relaxation processes and the resonance relaxation due to the interactions among stars having similar periods. It appears possible that most of the stars originally within a typical globular cluster have escaped the cluster within 10⁸ yr.

**Short-Period Fluctuations of Stellar Brightness** (Lawrence, Ostriker, and Hesser). A program has been undertaken with the 36-in. telescope to measure the power spectra of the dense stellar objects in the lower left-hand portion of the H-R diagram. A 1P21 UBV photometer, digital recording techniques and modern autocorrelation analysis are used. The period range of interest is between 2 sec and 5 to 15 min. Results obtained to date (Appl. Astrophys. J. 148, L161, 1967) are: (1) confirmation of the 0.03-mag 71-sec period found by Walker in nova DQ Her; (2) discovery that the flickering of nova Cor Bor observed by Walker contains several short-period fluctuations which repeat from night to night; (3) the power spectra of various other stars including white dwarfs and 3C273 appear to be flat in the range 2<P<400 sec; (4) the nuclei of two planetary nebulae appear to flicker over short time intervals; (5) Sco XR-1 does not show periodic fluctuations in the range 2<P<400 sec.

**Spectroscopy Laboratory** (Dressler, Lawrence, and Hesser). The radiative lifetime apparatus, spanning the lifetime range of 3×10⁻⁷ to 3×10⁻¹⁰ sec and the spectral range 500 to 6000 Å, has been used in measurements of intense atomic and molecular emission lines. Lawrence has completed tables of resonance transition probabilities for 238 lines of eleven elements between Z=14 (Si) and Z=82 (Pb). These are based on experimental lifetimes and theoretical branching ratios obtained from intermediate coupling theory. For interpolation of additional strengths, Lawrence has published tables of theoretical radial integrals, extending the tables of Bates and Damgaard for use with resonance transitions of nonmetals. Hesser has prepared tables of band strengths and f values for 17 molecular band systems, based on lifetime measurements, including the strongest ultraviolet transitions of H₂, N₂, NO, CO, CO⁺, CO₂⁺, NO⁺, and NO₂⁺. Dressler and Hesser have investigated the variation of electronic transition moments of valence-shell and Rydberg transitions in isoelectronic sequences and have compared the experimental data with simple theoretical models.

The photoelectric high-resolution spectrometer has been used in measurements of absolute absorption f values in the 900–1100 Å region. The experiment is built around a 3-m Eagle-mount spectrometer with two-stage differential pumping at the entrance slit and with helium or argon continuum light source. The spectrometer serves as absorption cell, with gas pressures in the 10⁻⁶ to 10⁻⁴ mm Hg range, and it contains two windowless photomultipliers for “double-beam” recording of absorption lines with pulse-counting electronics. Lawrence, Mickey, and Dressler have determined the absolute f values of four bands of N₂, b'Πᵤ−X'Σ⁺ₐ (3−0, 4−0), b'Πᵤ−X (0−0), and p'Σ⁺ₐ−X (0−0). The p'−X absorption f value (0.15) is in excellent agreement with Hesser's p'−X lifetime measurement, and the four relative f values agree well with data obtained in other laboratories from electron energy-loss spectra. Lawrence, Hesser, and Brooks have prepared the measurement of line-absorption f values in the strongest bands of H₂, 900–1100 Å.

Dressler has worked out a new analysis and interpretation of the dipole-allowed absorption spectrum.
of N₂. The complexity of the spectrum is found to result from configuration interaction, involving excited valence and Rydberg states of like symmetry species. The new interpretation reduces the number of observed electronic states of valence type to one consistent with theoretical expectations and it identifies a predicted but previously obscured Rydberg state. The new picture is consistent with available spectroscopic data, especially isotope shifts and perturbations in the rotational and vibrational term sequences, and with the absolute and relative f values derived from the measurements in this and other laboratories.

**Stratoscope Program** (Schwarzschild and Danielson). After the three consecutive flight failures encountered in the preceding two years the government sponsors of this project appointed a review committee consisting largely of expert engineers from the Marshall Space Flight Center of NASA. After an extended and very detailed review of all parts of the project the Review Committee recommended to the sponsors the continuation of this project under the condition that prior to the next flight a long and specific list of modifications (including both hardware items as well as management procedures), all aiming at increasing the reliability of the instrument and its flight operation, were executed. The sponsors accepted the recommendation of the Review Committee and in consequence the recommended modifications are presently being executed.

**Sounding Rocket Program** (Jenkins and Morton). During the past year, four Aerobee rockets with Space General attitude-control systems were launched from the White Sands Missile Range to photograph the ultraviolet spectra of stars and planets. In each case when the rocket was pointed at the target a passive gyro rotor was used to steady the objective spectrograph within ±15" in the dispersion direction.

On 20 September 1966 an f/2 all-reflective spectrograph with a 12° diameter field of view obtained spectra of γ, δ, ε, ζ, η, θ, ι, and σ Orionis with 1 Å resolution longward of 1130 Å. Jenkins found the equivalent widths of the interstellar Layman–α line in δ, ε, ζ, and η to be about 9 Å and perhaps a little larger in η and σ. For broadening by radiation damping this width corresponds to H I densities of 1.5×10[^9] cm^{-2} or 0.1 cm^{-3}, which are only one-tenth the values obtained from 21-cm observations in the direction of Orion. As found in a previous flight, the resonance absorption lines of C IV and Si IV were shifted 1000 to 2000 km sec^{-1} to shorter wavelengths in the supergiants ε and ζ and the bright giant δ. In addition, this time the N V and Si III resonance lines were found shifted by about the same amount while an excited C III line at 1175 Å was found shifted by somewhat less. From the equivalent widths of the unsaturated N V and Si IV absorption lines Morton has estimated a rate of mass loss of about 1×10^{-6} M_☉ yr^{-1} from each of the stars.

On two rocket flights, 7 April and 5 May 1967, no spectra were obtained. In the first case there was excessive drift in the attitude control system and a battery failure prevented the camera cassettes from closing. On the second occasion organic compounds from the Tygon tubing used to flush the payload with dry nitrogen were unexpectedly deposited on the optical surfaces just before launch. On 9 June 1967, however, when Venus and Jupiter were only 18° apart excellent spectra were obtained of both planets with 1 Å resolution longward of 2100 for Venus and 2600 Å for Jupiter with an f/2 Schmidt camera using a barium fluoride corrector. These spectra are now being compared with the ultraviolet solar spectrum from differences which may be due to compounds in the planets' atmospheres.

The first three rocket flights were supported by the National Aeronautics and Space Administration while the last one was provided by the Kitt Peak National Observatory while Morton was a visiting astronomer there.

Stone and Morton have analyzed the equivalent widths of the O I, C II, Al II and Si II absorption lines found in the ultraviolet spectra of δ and π Scorpii on a previous flight. On the assumptions that these lines are interstellar and there are no turbulent velocities in excess of 20 km/sec rms, the widths correspond to about 100 times the expected densities of these elements. Alternatively if velocities of 50 km sec^{-1} or higher are present, as might be expected in an intercloud medium, then the densities would be normal or even less than those inferred from the 21-cm data.

**Orbiting Astronomical Observatory Program** (Rogerson, Dressier, Morton, and Spitzer). As a result of the NASA directed rescheduling of Observatory launch dates, much effort has been directed toward improving the performance of the experiment. Improvements that had been planned only for the flight model have now been included in the prototype. The spectrometer has been completely reassembled and realigned to within specifications. An improved guidance error sensor has been designed and is awaiting authorization by NASA. This improvement would eliminate several centimeters of quartz optics (decreasing the light loss) and the electromechanical choppers with their potentially troublesome bearings. The choppers would be replaced by redundant, electronically scanned, quadrant-type photomultiplier tubes.

Thermal plasma tests of the spectrometer, open on one side, confirmed the need for protection of the windowless photomultiplier tubes from this...
type of radiation environment. The shock and vibration qualification of a new 80-cm primary mirror made of fused silica in an egg-crate configuration was successfully completed.

Activity on the flight model has been curtailed by budget restrictions during the last year. **Advanced Princeton Satellite Program** (Danielson, Lowrance, Morton, and Spitzer). Following completion of the preliminary design study of a 40-in. orbital telescope capable of diffraction-limited imagery and high-resolution ultraviolet spectroscopy, a detailed design study was performed on certain aspects of the telescope design. As in the preliminary study, the bulk of the work was performed by the Perkin-Elmer Corporation under close supervision by the Princeton group.

A detailed thermal design of the telescope and instrument package was also developed in the detailed study. Taking advantage of the thermal isolation afforded by magnetically suspending the telescope in the scientific spacecraft, it was found possible to produce a passive thermal design which, in close earth orbit, maintained the temperature gradients in the primary mirror within the close tolerances required for diffraction-limited imagery. The average temperature of the instrument package varied from 240–260°K depending on the orientation of the telescope with respect to the orbit. Such cold temperatures are desirable in order to reduce thermal background noise in integrating television cameras and in guidance sensors.

More detailed design analysis was also performed on the corrector lenses and the imaging microscope. An all-reflecting design for the microscope (which is required to produce the f/200 or larger focal ratios needed for integrating television) was produced which allows high-resolution imagery in the ultraviolet as well as diffraction-limited imagery in the visible. Two designs for corrector lenses (which are required to produce highly corrected guide star images in the visible) were completed. One set of corrector lenses, which would be used in conjunction with an f/2 Ritchey-Chretien primary, produces a diffraction-limited field of view of 30 min of arc; the other set, which would be used in conjunction with an f/3 primary, produces a 40-min of arc diameter guide star field.

A specially designed platform suspended on an air bearing table was constructed in order to experimentally study the “floating telescope” design in which the telescope is pointed to 0.01 arc rms while magnetically suspended in a spacecraft. The test demonstrated the feasibility of critical components such as the chain link transformer (for transmitting power to the telescope), the magnetic pushers (for pointing and centering the telescope), and the capacitive sensors (for sensing the position of the telescope relative to the spacecraft). In the tests, the pointing of the platform was limited to about 0.1 sec of arc by the accuracy of the capacitive sensors, but there is every reason to expect that 0.01 sec of arc guidance will be achieved when an optical sensor is added to the system.*

**Integrating Television** (Lowrance, Danielson, and Spitzer). During the past year, the operational procedures for the Stratoscope II image isicon integrating television camera were developed at RCA Laboratories and on the Princeton 36-in. reflector. For purposes of diffraction-limited imagery, the tests demonstrated that the TV camera (at f/250) can replace the 103a G photographic film (at f/100) as used in Stratoscope II with a probable gain of one or two magnitudes in sensitivity. A Westinghouse SEC vidicon tube and accessory equipment will be delivered shortly and will be tested for use in astronomical research. Detailed comparison will be made between the RCA image isicon and the Westinghouse SEC vidicon.

**Sacramento Peak Observatory**, Air Force Cambridge Research Laboratories, Sunspot, New Mexico

The professional staff of the observatory for the past year was as follows. Astronomers: Jacques M. Beckers, Richard B. Dunn, John W. Evans (Director), Charles L. Hyder, George W. Simon, Paul E. Tallant, and Oran R. White (on leave at University of Hawaii, August 1966 to June 1967). Horst A. Mauter continues responsibility for the operation of large telescopes and their accessories, and Howard DeMastus is in charge of the patrol program.


The emphasis of research has shifted toward various features of solar activity as the sunspot cycle advances toward its expected 1968 maximum.

Beckers and Schröter set out to study the velocity and magnetic fields in a typical sunspot by means of pairs of spectrograms taken simultaneously in right- and left-handed circularly polarized light. They were very fortunate to obtain almost unbroken daily coverage of a simple spot during its passage from limb to limb, with generally excellent
systematic horizontal motions of solar granules
exposures with the spectrograph slit advanced about 2" between exposures to cover the whole sunspot area with a reasonably fine grid. The microdensi-
tometer then traced the profiles of two lines, one with a nul g factor and one with a large g factor, at intervals of 2" along the slit in both modes of polar-
ization. This rather long reduction was accomplished with the aid of a newly installed program-
er, which drives the plate in a predetermined x and y pattern. The IBM 1620 computer converted
the digital output to intensities and punched the profiles on cards for further computation. The
investigators have written and tested a machine program which determines the intensity, sight line
velocity, and the strength and inclination of the magnetic field at each data point in the sunspot.
These calculations are in progress and will lead to charts showing fields of the various parameters
as a function of time and aspect. Their interpretation is a 1968 problem.

In the course of their observation of sunspot spectra, Beckers and Schröter took time lapse pic-
tures of the spot in white light for long intervals during its progress across the solar disk. A number
of these showed the bright umbral grains. They are well separated, occupying a very small fraction
of the umbra area, with diameters usually indistin-
guishable from the resolution limit imposed by seeing (of the order of 700 km). Lifetimes are 20
to 30 min.

Beckers attempted to obtain additional data on velocities in sunspots with a new Zeiss tunable
birefringent filter having a passband of 0.25 Å near Hα. He substituted a Rochon prism for the last
polarizer, obtaining two images simultaneously with their passbands separated by 0.25 Å. When tuned
to a region of smooth continuum, both images showed normal granulation with the rather low
contrast characteristic of the Hα region. However, when the passbands were symmetrically placed
each side of the line Fe 6569, the red image showed granulation in enhanced contrast, while the blue
image showed no perceptible granular structure at all. This effect is due to the systematic tendency for
bright elements to move upward and dark elements downward. Photographs of a sunspot near the limb
with this arrangement showed unequivocally that the horizontal outflow of material (Evershed effect)
is predominantly motion of the dark elements of the radial filamentary structure of the penumbra.
This confirms Beckers' earlier conclusion from a study of spectrograms.

Simon completed a laborious investigation of the systematic horizontal motions of solar granules
within cells of supergranulation. He assumed that the cell boundaries coincided with the coarse net-
work visible on an Hα spectroheliogram and deter-
mined the motions of all granules on 19 successive photographs of an area about 10⁴ km square at the
center of the disk. The problem is difficult because the expected motion is only 0.2 granule diameter
during a granule lifetime. A statistical study of about 44 000 measurements, however, confirms the
expected drift toward supergranule boundaries, at somewhat less than the expected velocity of 0.25
km/sec.

Evans studied four pairs of spectra showing well-
resolved granular structures to determine whether or not they are the same in different colors. An
earlier study by Vassiljeva had indicated that they are not the same, but her result could be due to
effect of atmospheric dispersion. Each of Evans' pairs consisted of two short lengths of spectrum
centered at λ3954 and λ5888, taken simultaneously in the third and second orders of a 1200 groove/mm
grating. The slit was oriented perpendicular to the horizon and parallel to the atmospheric dispersion
(2" in this instance). Microdensitometer tracings across the spectra at continuum wavelengths
showed nearly identical granular structures, with a correlation of 0.85. There were no structural differ-
ences in the two colors that could not be attributed to instrumental effects.

Hyder has obtained observational evidence relevant to his theory of the flarelike brightenings that
often follow the sudden disappearance of a dark Hα filament on the solar disk. A filament (or prominence) which has been lying quietly in a
magnetic trough is suddenly flung upward when some disturbance causes the trough to hump up
into a magnetic mountain. Some of the material flows down the slopes of the mountain. Its impinge-
ment on the chromosphere excites the typical bright ribbons that appear on each side of the origin-
al filament position. The energy calculations are consistent with this picture. Hyder has been
successful in obtaining several spectra during the progress of filament disappearances, and finds the
expected upward and downward velocities with subsequent chromospheric brightenings. The ob-
servational data are still sparse, and Hyder is continuing a systematic program to collect more.

The observatory sent three experiments to the
total eclipse of 12 November 1966 in Peru and Bolivia, all of which were successful.

Dunn again observed the coronal spectrum from
the NASA aircraft in hopes of data on a strong coronal condensation. The spectra were excellent,
but unfortunately no strong condensation appeared at the limb. The eight new coronal lines found in
1965 were confirmed.

Beckers and Noyes successfully observed the
solar limb profile in the infrared at 24 μ with the indispensable help of Frank Low (University of
Arizona), who provided the sensitive element. The