cited state of Ca I including transitions to bound and to autoionizing lines. They have also described the operation of a tunable dye laser in an oscillator-amplifier configuration that achieves a higher brightness than has previously appeared in the literature for tunable sources.

Mitchell used the hook technique to measure for Mg I the relative f-values of the first six lines in the principal series and the intercombination line.

Planetary and Solar System Research

A team of astronomers and data analysts from Harvard College Observatory, the Center for Planetary Sciences (Cornell University), and the Artificial Intelligence Laboratory (Stanford University) received support from the NSF to measure the linear optical polarization of the inner zodiacal light as a function of wavelength at the solar eclipse of 30 June 1973. Four scientists operated 12 photographic cameras at the Loiyengalani site by Lake Rudolf in Kenya, while three others employed a silicon-diode vidicon camera at the site in Chingiquetti, Mauritania. All observations were made through a variety of filter passbands and polaroid orientations. Liller reports that the observations should yield reliable new information on the physics of the inner interplanetary medium.

Opacity distribution functions were calculated by Dalgarno, Fang, and S. W. Wofsy for ultraviolet absorption in the upper atmosphere. The dayglow spectrum of the planet Mercury was calculated by M. Zeilik. A discussion of the red line emission at twilight was presented.

In continuing research on the origin and evolution of the solar system, Whipple studied the effects of the solar nebula on the development of the Moon, with particular attention to the effect of the drag force of the nebula on the orbital motion of the protomoon and the effects of its velocity through the nebula on accretion rate and impact differentiation.

DEPARTMENT OF ASTRONOMY

Enrollment in the Department comprised 22 undergraduate concentrators and 25 graduate students. Eight students received the A.B. degree in June 1973; one received the A.M. degree in March and four in June. The Ph.D. degree was awarded in June to Duane F. Carbon, Frederick R. Chromy, William R. Forman, Robert L. Kurucz, and Robert P. Stefanik.

MISCELLANEOUS

In connection with the 1973 Copernicus quincentennial, Gingerich undertook a series of researches on the dissemination of Copernican astronomy in the 16th century.

Under the continuing chairmanship of Menzel, the Working Group on Lunar Nomenclature of the IAU has carried out a substantial revision of the traditional and outdated system of nomenclature devised some 140 yr ago by Mädler; the revised system is to be presented to the IAU at the General Assembly of 1973 in Sydney, Australia.

The Bart J. Bok Prize was awarded in May to Dr. Andrea K. Dupree in recognition of “her theoretical studies of the interstellar medium and of the Sun.”

A bibliography of Observatory publications for the year 1972-73 is available on request from the Librarian, Harvard College Observatory.

A. Dalgarno
Acting Director

University of Hawaii
Institute for Astronomy, Honolulu, Hawaii 96822

This report covers progress at the Institute for Astronomy over the twelve-month period July 1972 through June 1973.

I. STAFF

The scientific staff during the report period consisted of Lothar W. Bandermann; Ann M. Boesgaard; Walter K. Bonsack (on sabbatical leave for six months); Jean E. Burns; Dale P. Cruikshank; Gerard D. Finn; John T. Jeffries, Director; James C. Kemp; Donald A. Landman; Marie K. McCabe; David Morrison; Donald L. Mickey; Robert E. Murphy; Frank Q. Orrall; Theodore Simon; William M. Sinton (on sabbatical leave); Alan N. Stockton; Richard J. Wolff; Sidney C. Wolff; Ramon D. Wolstencroft, and Jack B. Zirker, who returned from sabbatical leave. Howard C. McAllister of the Department of Physics and Astronomy was affiliated with the Institute in connection with the rocket spectroscopy program. Of these, Burns left to take a position elsewhere. Visiting colleagues in residence were Robert J. Speer of the Department of Physics, Imperial College of Science and Technology, London, England, and Ronald T. Stewart of the Radiophysics Division, CSIRO, Sydney, Australia.

Operations at the Haleakala Observatories were supervised by Mickey the major portion of this period, with Landman assuming the responsibility of Resident Astronomer the balance of the period. At the Mauna Kea Observatory, R. Wolff served as Resident Astronomer until early 1973, when the position of Observatory Superintendent was assumed by William F. McCready. Administrative and engineering services are, respectively, under the direction of Robert J. LoForty, Administrative Officer, and Hans Boesgaard, Chief Engineer.

II. FACILITIES AND INSTRUMENTATION

A. Haleakala Observatory

1. Mees Solar Observatory

The new multichannel coronal spectrophotometer
has been installed on the spar and is operational. The data-acquisition and control system for the instrument is built around a PDP-11/45 computer and all electromechanical instrument functions are affected through CAMAC interfaces. A more sophisticated Si vidicon detector system is nearing completion and will be installed shortly. The system is funded by NASA and is part of the ATM Skylab mission ground-based support.

The Ca K-line filter telescope, which was designed by McCabe and technician J. Born, was completed and mounted on the spar in February. Daily photographs were transmitted via a wire photo system to NASA-MSC in Houston from the commencement of the Skylab program. This project was supported by funds from NOAA.

A high-resolution spectrometer for the existing polarimeter-photometer has been designed under the direction of Mickey and Orrall and is now under construction in the shop. Its purpose is to measure all four Stokes parameters as a function of wavelength within Fraunhofer or emission lines.

Preliminary observations have been made with our Si vidicon SSR Optical Multichannel Analyzer as a detector for the 10-in. coronograph/ouden spectrograph system. The results have been encouraging. This work will be expanded and a variety of new projects using the system are planned for the coming year.

2. Lunar Laser Ranging Observatory

A lunar laser ranging (LURE) observatory is being constructed at the summit of Mt. Haleakala. The project is funded by the National Aeronautics and Space Administration and the design, construction, and operation of the station are being closely coordinated with the LURE team.

Instrumentation has been developed at the University of Maryland, Wesleyan University, JILA University of Colorado, University of Texas, University of Hawaii, and NASA Goddard Space Center.

The laser is frequency doubled Nd YAG operating at three pulses per second; each pulse is 200 picoseconds (FWHM) in duration, and contains 250-350 millijeuxles of energy at 5320 Å.

The laser is coupled into a 40-cm aperture refractor telescope. The telescope expands and collimates the laser pulses, and directs them toward a 68-cm diameter altitude-azimuth mounted flat mirror referred to as a lunastat. The lunastat is positioned so that the reflected beam is pointed at the desired target by fully automatic computer controlled absolute pointing or by offset guiding techniques.

The return signal is received by a multi-lensed telescope referred to as the lenscope. The light collected by eighty 19-cm aperture achromatic lenses is routed to a common focus, spatially and optically filtered, beam-split, and detected by two photomultiplier tubes. The output of each PMT is connected to one channel of a dual channel multi-event timer system.

The event timer determines the epoch (on the station timescale) of events with a resolution of 100 picoseconds. By differencing start and stop event times the travel time of each pulse is determined with a resolution of 200 picoseconds. The station timescale is related to UTC via Loran C.

Two mini-computers are used to generate range predictions, retrieve and store range data, control and telescope drive, read and store meteorological data, and perform numerous other housekeeping duties.

Current planning anticipates ranging to begin during December 1973.

B. Mauna Kea Observatory

An analysis of the quality of the site has been prepared from four years of records of observing conditions. An average of 56% of the nights are photometric for six or more consecutive hours, and an additional 15%-20% are spectroscopic. The median seeing is 1.5 arcsec at the couden focus of the 224-cm telescope and less than 1.0 arcsec at the 61-cm Planetary Patrol telescope. The photometric extinction coefficient in y is 0.09 mag/airmass. In the infrared, the low humidity results in high transparency, as indicated by, for example, the median extinction coefficient of 0.34 mag/airmass in the 16- to 28-μm band. During this year, the station has also been used successfully for observations in the submillimeter (350 μm) and 35 μm. Reports on this site evaluation, which also discuss general weather conditions, climate, and the effects of high altitude, were published.

Construction of a paved road to the midlevel facilities at Hale Pohaku has begun and should be finished by the end of 1973. Preliminary design of a realigned, but unpaved, road from Hale Pohaku to the summit is complete. Design of a permanent midlevel support complex has begun.

During June 1973, all mirrors of the 224-cm telescope were cleaned and the primary was realuminized. At the same time, the first portion of the new control system was installed. This new system replaces electromechanical relays and relay logic and is more reliable, easier to maintain, and simpler to interface to new instrumentation (such as an automatic guider) than the old system.

The IBM 1800 computer has been used extensively. Aside from the slewing mode, all motions of the 224-cm telescope can be placed under computer control. Programs are available to skew automatically the guiding directions for guiding at the couden, to trail a star along any direction (including the couden slit), to move the telescope in a raster pattern, or between two chosen positions, etc. The dome is under computer control. The scanning programs are coupled with data-acquisition programs for use by infrared observers; multichannel analyser programs are available for photometers, and SSR's Optical Multichannel Analyzer has been used at the couden and coupled to the IBM 1800. Implementation of computer controlled slewing is anticipated for the coming year.

Construction of the #4 and #5 cameras is continuing. A couden plate calibrator has been installed in the couden spectrograph. This calibrator exposes on the spectrograms continuous strips of known relative intensity while the stellar spectrum is being taken.

A new image intensifier system, using an RCA C33063 BP-2 tube, was put into operation on the 224-cm telescope in March. The system has been successfully applied by Stockton to observations of quasistellar objects as faint as 19th, and to moderately high-dispersion studies of interacting galaxies.
C. University Campus

Construction began in early 1973 on the Institute's permanent Manoa campus headquarters, which are to be ready for occupancy by mid 1974.

III. RESEARCH

A. Solar Physics

Mickey and Orrall have measured the broadband polarization in sunspots using the Stokes-vector polarimeter at Mt. Haleakala. They found linear polarization confirming the results of Dollfus and Leroy. In addition, they detected circular polarization with $V/f$ between $10^{-5}$ and $10^{-4}$. Circular polarization was unexpected, but has since been confirmed with improved observations, by Mickey, in another spot group. Analysis and interpretation of the data are in progress.

Observations of the center-to-limb variation of the Stokes vector on the disk were completed by Mickey and Orrall. The wavelength band they used (20 Å near 5834 Å) is relatively free of Fraunhofer lines. Within 10 arcsec of the limb, the linear polarization rises steeply to values exceeding $15 \times 10^{-4}$. No circular polarization was detected on the quiet disk. Where their measurements overlap with Leroy's, there is excellent agreement.

Mickey published the first measurements obtained at Haleakala of the linear polarization of the coronal forbidden line Fe XIV 5303 Å. The polarization deviates only slightly from the radial direction and increases from less than 1% near the limb to ~10% at 6 arcmin above the limb.

The complete state of polarization of the Fe XIV corona was measured each day for a month centered on 30 June, 1973 — the date of the total solar eclipse. Mickey, with L. House and C. Querfeld of the High Altitude Observatory, are collaborating in the analysis of these data, with the aim of deriving information on the coronal magnetic field.

Landman made the first preliminary observations of the emission line corona and prominences with the new coronal spectrophotometer in May, Hydrogen, ionized calcium, and helium lines (including 10830 Å) have been measured in prominences. The coronal green line, 5303 Å, has been detected at intensities as low as 35 millionths of the disk brightness. A number of observational programs with this instrument and others are in progress, in collaboration with the ATM experiments aboard Skylab.

An experiment to study the structure of the inner corona and its relation to solar prominences was carried out at the total solar eclipse of 30 June 1973 by Orrall, Zirker, Wolff, and technician G. Miyashiro. Two types of spectrographs were employed: a slit spectrograph covering the range 2950-9000 Å that had performed successfully at three prior eclipses, and a slitless Wadsworth spectrograph, covering the range 2950-9000 Å with three gratings. The concave gratings in this spectrograph were deformed into toroids to reduce the average astigmatism over the spectrum. A dust storm just prior to totality reduced the atmospheric transmission to ~10%. Nevertheless, a number of well-exposed spectra of the corona and prominences were obtained with the slitless spectrograph. Analysis of these results, as well as the excellent slit spectra obtained at the 1970 and 1965 eclipses, is continuing.

Orrall and Speer have detected the inner F and K coronae in the vacuum ultraviolet (850-2150 Å) on slitless spectra obtained by an international group during the eclipse of 7 March 1970. They measured the intensity from 2000 to 2250 Å, and set an upper limit at shorter wavelengths. These measurements set a firm upper limit on the scattering efficiency of the inner interplanetary dust cloud. Their result is interesting in view of the very sharp upturn in the brightness of the zodiacal light below 2500 Å observed by Lillie.

On the same spectra, Orrall and Speer are studying the largely unknown structure that interfaces cool prominence matter ($8 \times 10^{23} \text{ cm}^{-3}$) to the surrounding hot ($2 \times 10^{6} \text{ cm}^{-3}$) corona. The spectra contain monochromatic images of the corona and prominences in spectral lines from numerous ionic species from H I through Ni XV. They find that the prominences are visible through OVI, corresponding to a temperature $\sim 3 \times 10^{5} \text{ K}$. An analysis of the line intensities suggests that the temperature gradient as a function of temperature in the interface is identical to that in the chromosphere-corona transition. This is a surprising result, since the magnetic field (which controls thermal conductivity) is quite differently oriented in prominences and in the transition region.

Landman published two papers on excitation of the Fe XIII ground configuration by proton impact. Using an adaptation of Seaton's semiclassical nuclear Coulomb excitation theory for Fe XIV, Landman treated the entire ground configuration of Fe XIII in intermediate coupling. The resulting proton conclusion cross sections lead to excitation rates that are comparable in all cases to the corresponding electron rates. More exact calculations, involving direct integration of the Schrödinger equation, confirmed these results, except for transition involving the $^1D_0$ state. Using these new cross sections, Finn and Landman estimated the strength of the density-sensitive transitions that arise within the Fe XIII ground configuration (e.g., 3388 Å, 10747 Å, and 10798 Å).

McCabe completed a study of the loop prominence system of 6 March 1970. Her observations, obtained at Mt. Haleakala, included simultaneous filtergrams in Hα and 5505 Å, and spectra at several heights over the range 3850-5950 Å. The results support a model consisting of a system of cool loops within and underlying a corresponding hot-loop system, with individual associated loops not entirely separated from each other.

A developing loop prominence event was observed projected against the solar disk near the west limb, on 29 April 1973. Hα filtergrams, made at nine positions within the line, showed doppler shifted motions in the loops, and the bright emission at the tops of the loops and in the chromosphere at the base. These observations are now being analyzed by McCabe.

Stewart, McCabe, and scientists from other cooperating institutions, are studying a coronal disturbance which occurred on 11 January 1973. For the first time, a moving cloud observed in white light has been associated with a K-corona transient, a moving Type IV burst, and a flare-spray. The radio observations were obtained by the CSIRO Division of Radiophysics, the white-light...
observations by the Naval Research Laboratory experiment on OSO-7, the K-corona observations by the High Altitude Observatory, and the Hα observations by HAO and the Institute for Astronomy. Stewart will present a paper on the subject at the IAU Symposium 57 in Australia in September.

M. Y. Cha and Orrall completed a study (begun while Cha was a graduate student at the University) of the brightness fluctuations in the K-line (Ca II) wings that are associated with photospheric doppler velocity fluctuations, as inferred from a nearby Fraunhofer line. They find that the average power spectra of these two types of fluctuations differ: the velocity spectrum shows primarily the well-known peak at 0.0033 Hz, while the brightness spectrum is broader and shows significant peaks at both ~0.0033 Hz and ~0.001 Hz. That is, the ratio of the brightness spectrum to the velocity spectrum varies with frequency.

A theoretical study of the response of the emergent intensity in a Fraunhofer line to a fluctuation in vertical velocity has been finished by Orrall and Cha. They used the linearized hydrodynamic equations, with radiation damping approximated by Newton’s law of cooling, to calculate the ratio of the intensity and velocity power spectra. The ratio is found to depend on frequency in good agreement with the above observations.

G. W. Simon (Sacramento Peak Observatory) and Zirker completed a study of the fine structure of photospheric magnetic fields. The observations, consisting of spectra of the sensitive Fe I line 6302 Å and Hα filtergrams, were obtained at Sacramento Peak. The intrinsic sizes of field patches appears to exceed one arcsec, although subarcsec photospheric structures have been photographed by R. B. Dunn (Sacramento Peak Observatory).

B. Rocket Spectroscopy

A high-resolution, rocket-borne spectrograph was successfully used to obtain UV solar spectra, in 1969 and 1971, covering the spectral region 1500-1780 Å at a resolution of 0.033 Å and a dispersion of 2.0 mm/Å. McAllister and Jeffers reported an analysis of the emission lines of Si II at 1808.0, 1816.8, and 1817.42 Å. Additional study of these lines is in progress. McAllister has obtained center-to-limb profiles of the A1 autoionization doublet at 1932-1937 Å, Finn and Jeffers have formulated and solved the coupled equations describing the transfer of radiation in these two lines and compared the computed profiles with the experimental results.

McAllister and research associate P. Smith have completed line identifications from the September 1969 rocket flight, and an Atlas covering the region from 1971 to 1987 Å has been prepared. Similar work using the results of the 1971 flight is in progress.

A second spectograph with greatly improved spatial resolution is scheduled to be flown in October 1973. Spectra will be obtained in the 2800 Å and 1700 Å regions.

C. Solar System Studies

1. Planets

Several broadband radiometric studies of the Jovian planets have been carried out, based on data obtained at Mauna Kea. Murphy and graduate student R. A. Fesen measured a 20-μm brightness temperature for the center of Jupiter of 136 ± 4°K, which when interpreted in terms of standard models yields an effective temperature for the planet of 136 ± 5°K. They find excess emission at 20 μm (ΔT ~ 3°K) from the NEB and SEB, and a smaller excess in the STEB, probably related to the hot regions seen at 5 μm. Murphy and Morrison have independently determined the brightness temperature and limb darkening of Saturn at 20 μm.

Murphy, with I. G. Nolt, J. V. Radostitz, D. F. Lester, and R. J. Donnelly of the University of Oregon and H. C. Ford of U.C.L.A. have measured the brightness temperature of Saturn at a mean wavelength of 35 μm using a system developed by the Oregon group. They find that the 28- to 43-μm brightness temperature is ~100°K, corresponding to an effective temperature of ~105°K. These are the first measurements in this wavelength band to be made at Mauna Kea.

An investigation of the atmosphere of Jupiter by its refracted light is being carried out by Murphy, who obtained accurate photometry down to fourteenth magnitude of an eclipse of Callisto in August 1972. A preliminary study of this “refraction tail” suggests that Jupiter’s polar regions contain considerable absorbing material.

Morrison and Cruikshank published brightness temperatures for Uranus and Neptune of 54.7 ± 1.8°K and 57.2 ± 1.6°K, respectively, in the 17- to 28-μm band. Murphy, in collaboration with L. Trafton of The University of Texas, is comparing these observations to model atmospheres. They find that, when revisions in the telluric water vapor abundance are taken into account, the Uranus observations are matched by a model with $T_{\text{e}} = 60°K$ with $He/He = 1$. The Neptune data are inconsistent with any reasonable model cooler than 55°K, suggesting that this planet, like Jupiter and Saturn, possesses an appreciable source of internal energy.

Murphy has measured the temperatures at 20 μm of three components of the rings of Saturn. He finds brightness temperatures of 89 ± 3, 94 ± 2, and 88 ± 4°K for the A, B, and C rings, respectively. The A and B ring masses are readily explained if the ring particles have a geometric albedo of 0.07 and a phase integral of 0.57 and if the A ring has a line-of-sight optical depth of 0.9 and the B ring, 1.4. Additional observations of the B ring by Morrison yield temperatures of 96 ± 3 and 90 ± 3°K at 20 μm and 10 μm, respectively. Morrison also made some measurements of the variation of ring temperature with position, finding that the post-eclipse temperature (at 3 arcmin from the point of emergence from the shadow) is lower by 2°K. When interpreted according to the thermal models of Aumann and Kieffer, this result suggests mean particle sizes in the rings greater than 2 cm.

In a study of the submillimeter transmission of the atmosphere of Earth, T. Martin has compiled the existing high-resolution (0.15 cm⁻¹) solar spectra obtained at Mauna Kea Observatory between 1969 and 1971; the data confirm the appearance of absorptions due to the water vapor dimer (H₂O)₂ between 6 and 10 cm⁻¹. The spectra also serve to demonstrate typical signal levels available from blackbody sources in the several submillimeter windows.
Kemp and Murphy measured the linear polarization of the rings at various wavelengths between 0.37 and 1.7 \( \mu \)m. The polarization showed a minimum of 0.25\% near 0.7 \( \mu \)m and a rise to 0.60\% in the ultraviolet and to over 0.60\% in the infrared. The measured polarization of the portion of the B ring which occults the North Pole was found to be reduced due to the admixture of positively-polarized disk light which has been transmitted through the ring, allowing Kemp and Murphy to make the the first actual measurement of the optical transmittance of the B ring, namely \( (21 \pm 6) \) percent, corresponding to \( \tau = 0.7 \) at normal incidence.

2. Satellites and Asteroids

In continuation of previous work on the Galilean satellites, Morrison and Cruikshank published an analysis of the thermophysical properties of Io, Ganymede, and Callisto derived from an analysis of eclipse cooling and heating curves. New data acquired this year included the first radiometric observations of an eclipse of Callisto. Each of these satellites is characterized by very low thermal conductivity \( [(Kpc)_{1/2} \approx 10^4 \text{ erg cm}^{-2} \text{s}^{1/2} \text{K}^{-1}] \) in the uppermost layer with transition to a material of higher conductivity a few millimeters below the surface. Morrison and Cruikshank interpret these results in terms of a frost-covered surface.

A comprehensive discussion of the anomalous brightening of Io after eclipse appearances has been completed by Cruikshank and Murphy. On two occasions in 1972 they detected the posteclipse brightening, while in 1971 there were several clear negative observations. The time variation of the anomaly seems well established now, and a simple model has been prepared to explain why the effect is not always seen. It is suggested that a gas, such as \( \text{NH}_3 \), can exist over its solid form with a vapor pressure that varies strongly with temperature. Most of the positive observations were made near perihelion, when the satellite temperature should be \( 6^\circ \text{K} \) warmer than at aphelion, when most of the negative observations were made. A \( 6^\circ \text{K} \) temperature variation would cause an order of magnitude variation in the vapor pressure of \( \text{NH}_3 \).

While on sabbatical leave at the Jet Propulsion Laboratory, Sinton developed a model for the atmosphere of Io, suggesting that \( \text{NH}_3 \) was present in significant quantities only near the equinoxes, being largely frozen out at the poles at other times. This model appears to provide a better fit to the posteclipse brightening observations than does that suggested by Cruikshank and Murphy. The atmosphere is predicted to be heated to temperatures above 200 \( ^\circ \text{K} \) as a result of bombardment by protons in the Jovian radiation belts, and Sinton therefore expects observable infrared band emission from Io in the 10-\( \mu \text{m} \) region of the spectrum.

Morrison has continued observations to define the dependence of 20-\( \mu \text{m} \) brightness of the Galilean satellites on orbital phase. Surprisingly large variations, particularly near superior conjunction, have been seen for Io and Europa. This radiometric work is being supplemented by \( \text{W} \text{B} \text{Y} \) photometry of the Galilean satellites by Morrison and graduate students A. Lazarewicz and N. D. Morrison.

Late in the year, Murphy began photometric observations of the mutual occultations and eclipses of the Galilean satellites. Two occultations of Europa by Io in June showed a greater light variation than had been predicted, but closely followed the predicted durations; Murphy and K. Aksnes of Smithsonian Astrophysical Observatory have analyzed these observations in terms of a bright polar cap on Europa. Morrison also obtained 20-\( \mu \text{m} \) radiometry of one of these occultations.

Murphy, with L. W. Logan, J. W. Salisbury, and G. A. Hunt of AFCRL, have made a series of broadband emissivity measurements of a variety of rock powders in simulated space conditions in an effort to match the observations of the Galilean satellites. Preliminary indications are that ultrabasic rock powders are the closest match to the observed emissivities.

A number of radiometric and photometric studies of the satellites of Saturn have been carried out this year. Morrison, Murphy, and Cruikshank obtained extensive observations of the 20-\( \mu \text{m} \) brightness of Iapetus as a function of orbital position in order to define its roughly factor-of-three variations. Morrison has detected thermal radiation from Dione for the first time and has made continued observations of Rhea at 20 \( \mu \text{m} \). He derives radii of \( 600 \pm 100 \) and \( 800 \pm 100 \text{ km} \), respectively, for these two satellites and points out the anomalously low densities indicated for the inner satellites of Saturn, especially Tethys, Enceladus, and Mimas. An extensive photometric study of Iapetus, Titan, Rhea, Dione, and Tethys in six colors was carried out at Mauna Kea from September to January in order to derive the coefficients of orbital and solar phase variation. Participants were Morrison, Cruikshank, and Lazarewicz, together with M. Noland and his collaborators from Cornell University.

Graduate student T. Martin has obtained four photographic spectra of Triton and three of Pluto at a dispersion of 50 \( \text{Å/mm} \) near the methane band at 6190 \( \text{Å} \). No evidence was found for methane absorption on either body, and when finally processed, these data should yield improved upper limits for the abundance of this gas.

Morrison has continued his investigation of the potential of combined infrared radiometry and photometric photometry for the determination of radii and albedos of satellites and asteroids. Comparison of results of this method with polarimetrically determined albedos and with the new occultation radii of Io and Ganymede confirm the accuracy of the technique. Cruikshank and Morrison completed a study of nine asteroids, including Ceres, Pallas, Juno, and Vesta; they find Ceres to be the largest asteroid, with radius of 500 \( \text{km} \); find Vesta to have the highest albedo \( (p_\text{v} \approx 0.22) \), and identify Davida as a very dark object and as the fourth largest asteroid so far measured. Cruikshank also observed the Trojan asteroid Hektor at 20 \( \mu \text{m} \), and finds that it too is a low-albedo object. Between January and June, Morrison observed an additional 20 asteroids at 10 and 20 \( \mu \text{m} \), and he is analyzing the resulting radii and albedos in terms of recent spectrophotometry of the same objects by C. R. Chapman, T. B. McCord, and their collaborators.

Morrison and Cruikshank have begun a comprehensive review paper on the physical properties of the natural satellites, to be published early in 1974.

3. Interplanetary Medium

The reduction and analysis of five color observations
of the polarized component of the night sky brightness are complete. The observations were made by Wolsten
croft on Mt. Chacaltaya in 1964. The results are pre-
seated in a NASA final report, NAS 5-113-3, in the form
of tables and contour maps of the Stokes parameters Q
and U and of the polarized intensity, \( I_P = (Q^2 + U^2)^{1/2} \)
and in the form of maps and histograms of the orienta-
tion angle of the polarization plane, \( \chi = (1/2) \tan^{-1}
[U/Q] \). The maps show significant structure, particularly
in the antisolar hemisphere. The contours defining a
minimum level of the polarized intensity do not gener-
ally center on the antisolar point but are displaced toward
the Milky Way. In the antisolar hemisphere, the polariza-
tion plane deviates most strongly from the theoretical
orientation. These results agree with observations of the
polarized night-sky brightness made with the Institute's
Haleakala polarimeter since 1969. From these observa-
tions, maps of \( I_P \) have been prepared and analyzed for
nine nights between May 1969 and July 1971. They
show structure and day-to-day variations which may be
caued by changes in the orientation of the zodiacal
dust particles. Regions of enhanced polarized brightness
are found near the galactic center, at either end of a
galactic spur. To this date, isophote maps of Q, U, and
I_P, as well as maps of the orientation of the polarization
plane, have been prepared for about 50 nights of observa-
tions of the antisolar hemisphere and are being exami-
ned for day-to-day variations and for deviations of the
polarization plane from the theoretical orientation, for
the influence of the Milky Way and features associated
with the Milky Way, such as regions of enhanced bright-
ness.

More observations of the circularly polarized com-
ponent of the zodiacal light have been made using the
Kemp polarimeter and the 224- and 61-cm facilities at
Mauna Kea. The data are presently being analyzed. Our
search for a physically plausible model of the direction
of alignment of interplanetary dust which explains the
observed dependence of the fractional polarization, q, 
on elongation angle from the Sun, has not been success-
ful and is continuing. A simple theory has been devel-
oped by Bandermann for the circular polarization pro-
duced by single scattering from lossless, nonspherical
particles. The magnitude of q obtained with this mech-
ism is of the order of that observed in the zodiacal
light. The dependence on scattering geometry and par-
cle alignment is similar to that found by Thomas
Schmidt at Heidelberg for absorbing Rayleigh spheroids
(complex index of refraction).

Wolstencroft obtained spectra of the night sky in the
direction of the zodiacal cone and of the north ecliptic
pole, using a Ebert Fastie scanning spectrometer housed
at the Airglow Laboratory of the Kitt Peak National
Observatory. Digital spectra were obtained between
3000 Å and 7454 Å with a projected slit width of 7 Å.
The difference spectra (which are the zodiacal light
spectra) are presently being reduced with the aim of dis-
covering absorption bands associated with iron impuri-
ties or other defects in the grains. Lower resolution spec-
tra obtained in 1970 with the same instrument had
yielded tentative features at 4238 Å and 5187 Å. Be-
cause of problems of blending with foreground airglow
emission bands, and of insufficient averaging of time
variations of the airglow, these features could not defin-
etly be confirmed.

In studies of the dynamics of interplanetary dust, the
nongravitational forces on the grains are usually calcu-
lated for spherical particles, whereas there is now evi-
dence that the particles are nonspherical and preferen-
tially oriented. The effects of nonsphericity on the rela-
tive importance of these forces are therefore being
studied. It is found, for instance, that the solar radiation
force can have important components transverse to
the radial direction. Therefore, the usual radiation
drag can be masked, and there can be a force normal to
the particle orbit which causes the orbital inclination
to change with time.

The conversion of the Haleakala polarimeter data-
acquisition system, from an analog to a digital mode, is
complete. Design and construction of a system that will
allow the on-line computer control of all instrument
functions is well advanced. For the several observa-
tional programs now carried out in the new digital mode,
the data reduction time is a small fraction of that needed
with the analog system.

D. Stellar Astronomy

1. Zeeman Spectroscopy

Bonsack and S. Wolff have continued Zeeman spec-
troscopy of a number of Ap stars, and analyses of
49 Cam and 41 Tau have been completed. In the case of
49 Cam, the magnetic field, the strengths of the spec-
trum lines, and the brightness in each band of the uvby
photometric system vary synchronously with a period
of 428 days. The magnetic field reverses symmetrically with a
range of ± 2000 G. The photometric results show double
minima in the v and b band light curves only; it has been
possible to show that one of the two minima can be ac-
counted for by variations in line blanketing in the filter
bands, and it is proposed that a second minimum may
due to variations in flux redistribution as a result of
strong line blanketing in the ultraviolet. The analysis of
49 Cam was carried out by Bonsack, Wolff, and graduate
student C. Pilachowski.

Photometric observations of 41 Tau by Wolff show
that the period of the light variations is 72172.7. The star
is a also a spectroscopic binary, and since the photometric
period is equal to the orbital period, the rotation and
revolution of 41 Tau are synchronous. The new photo-
metric period is substantially shorter than previously
published periods and is compatible with the period-

Zeeman observations of three additional stars are
presently being analysed by Bonsack and Pilachowski.
They find that the measured magnetic field of 22 Equ
has declined steadily and continuously, through a range of
approximately 1000 Gauss, over the last 25 yr. If the
long-term change is periodic, then the period is at least
50 yr, which is by far the longest period yet proposed
for an Ap star. The star HD 133029 was, like 22 Equ, first
observed by Babcock, and investigators who have re-
discussed his data have suggested periods as short as 130.
Such a period would be the shortest yet determined for
a star with a detectable magnetic field. A new series of
Zeeman spectrograms obtained at Mauna Kea is cur-
rently being analysed in an effort to determine the cor-
rect period of HD 133029. The star HD 49976 is known
to be strongly variable in the strength of the lines of Sr

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II, but there are no published estimates of the period and no reports of observations of magnetic fields. Bonsack and Pilachowski have obtained a series of spectrograms which should permit determination of the details of the spectrum and magnetic field variations. Photoelectric observations of HD 49976 have been made by Wolff.

Wolff and graduate student T. Jones have found that the remarkable star HR 6870 possesses a nonreversing magnetic field that varies from −100 Gauss to −1100 Gauss. The star also appears to be a spectroscopic binary.

Correlations between magnetic field strength and chromospheric activity on the Sun, and between chromospheric activity and age in stars led Boesgaard to look for magnetic fields in young main-sequence stars. Zeeman spectrograms at 3.3 Å/mm were obtained of eight stars FO V-KO V. The three stars which probably have weak magnetic fields all have exceptionally strong Ca II emission, whereas it is weak or absent in the others.

2. Spectroscopy and Photometry of Ap Stars

Various mechanisms have been proposed recently to account for the photometric variability of the Ap stars. These include transfer of flux from the far ultraviolet to the visible, due to either variable line or continuous opacity in the ultraviolet and variable line blocking in the filter bands themselves due to the spectrum variations. The latter effect has been measured directly by Jones and Wolff for the star HD 188041. They find that the deep minimum that occurs in v at the phase of rare earth maximum can be accounted for entirely by line-blocking in the v-filter band. Similar line blocking measurements of HD 125248 and HD 24712 are presently being carried out by Pilachowski and Bonsack.

In an attempt to discover if the phenomenon of spectrum variability in Ap stars is connected statistically with any of the other visible properties of these objects, a survey has been undertaken among the fainter Ap stars which have not previously been studied in this regard. The survey technique consists of obtaining at least three spectrograms at different times at dispersions of 11 or 16 Å/mm of each program star to determine which lines, if any, vary. Approximately 35 stars, which have been classified as Ap on low-dispersion surveys, have been investigated to date; of these, approximately one-fourth do not appear to be different from normal stars in their spectrum at the dispersions used, and of the remainder, approximately one-third have proved to be spectrum variable. No attempt has yet been made to correlate the variability with other properties. This work was begun by Bonsack at the Kitt Peak National Observatory, where he was on sabbatical leave during the first half of 1973.

The first results of a photometric search for Ap stars with very long periods have been reported by Wolff and graduate student N. D. Morrison. They have found that HD 2453 and HD 18078 have periods longer than one yr. They have also determined periods for HD 8441 (P = 69.5 yr), HD 12288 (P = 34.5 yr), and HD 261533 (P = 1720 yr).

A weak line in the spectrum of the beryllium-rich Ap star, K Cnc, has been attributed to B II by Boesgaard and graduate student W. Heacox. Four spectrograms at 6.7 Å/mm dispersion were used to determine the abundance ratios, Be/H ~ 2 × 10⁻⁷. No Li feature was found on a 10Å/m logram yielding an upper limit of Li/H ~ 4.5 × 10⁻⁷. Galactic cosmic ray spallation processes alone are unable to account for the overabundances. It is suggested that either reactions on the stellar surface or a nearby supernova has modified the light element abundances.

3. Spectroscopy of Early-Type Stars

A spectroscopic study of HD 153919, the optical counterpart of the x-ray source 2U 1700-37, has been carried out by S. Wolff and N. D. Morrison. They find that HD 153919 is of spectral type O6.5f. The derived orbital parameters are compatible with a model in which the primary of this system fills its Roche lobe and is losing mass to the secondary. On the assumption that the mass of the primary is normal, the minimum mass of the secondary is 1.4M_☉. Zeeman observations HD 153919 set an upper limit of 3500 G on the net longitudinal field.

As part of her Ph.D. thesis research, N. D. Morrison has obtained coudé (6.7 Å/mm) spectrograms of 20 O-type stars in the blue and ultraviolet, with the intention of studying the behavior of the line of He II at 3020 Å as a function of temperature and luminosity. She has also performed uvby Hg photometry of 102 O-type stars, and expects to establish a photometric temperature scale based on the uvby colors computed by Mihalas [Ap. J. 176, 139, (1972)]. Comparison of this temperature scale with the one based on the spectral lines will be an important consistency check on the non-LTE theory for O-type stars.

Ultraviolet spectrograms of about 40 O and B stars have been searched for interstellar lines of Na I, Be II, Ca II, and Ti II by Boesgaard. A linear relationship has been found between the intensities of interstellar Ca II and interstellar Ti II, whereas the ultraviolet Na I lines show no correlation with other interstellar features.

4. Spectroscopy of F and G Type Stars

Boesgaard and graduate student W. Hagen have determined the age of α Cen (G2 V) to be at least 3 × 10⁶ yr. The high-dispersion (1.7 − 3.4 Å/mm) spectrograms used were obtained at Mauna Kea Observatory. The Li abundance, rotational velocity, and Ca emission intensity all give consistent age estimates. However, the companion, α Cen C, is a flare star which is thought to be younger than 10⁶ yrs.

Boesgaard and graduate student R. Fesen have searched for Ti II in the ultraviolet spectrum of ζ Cap, a G5 barium star. The dispersion used was 3.3 Å/mm and although there is much line blending in the ultraviolet, there is no evidence for Ti II. They conclude that the Ba II stars have evolved from an S star phase and that the transition time is the order of 10⁶ yr or so.

Fesen has obtained photoelectric observations of four suspected δ Scuti stars. The star ε Cep showed marked variations in period and amplitude in the y filter on one night. Observations of τ Peg and 38 Ari agree well with previous observations, while τ Cyg was found to be constant to within 0.005 in all four colors.
5. Circular Polarization

Wolstencroft and Kemp have continued their program of observations of interstellar circular polarization of reddened stars. To the list of six stars already showing this effect, a further 12 stars have been added. These stars all show the previously found change of sign of the circular polarization between the red and blue spectral regions. Four other reddened stars have been found showing the same sign in both red and blue. If this polarization is also of interstellar origin, the theory of circular polarization developed by Martin (presented at the Tucson Colloquium on Polariometry in November 1972) will need revision.

Variable longitudinal magnetic fields have been detected by Kemp and Wolstencroft in three x-ray stars HD 77581, \( \theta^2 \) Orionis, and HD 153919. The fields have been obtained from the circular polarization measured on opposite wings of H\( \beta \) using two narrow interference filters. The maximum fields recorded were \(-2900\) G in HD 77581 and +460 in \( \theta^2 \) Orionis. A study of HD 153919 over four months reveals highly variable circular polarization, whose reality is confirmed by statistical tests. The RMS circular polarization for each night observation is correlated with the x-ray phase. Estimates of the magnetic field strength are complicated by the presence of emission, but the most typical fields averaged over one or two hours are 2000 G, assuming that the emission occurs in regions of negligible field, as indicated from the measurements of Angel et al [Ap. J., 84, 79, (1973)], and that the underlying absorption at H\( \beta \) has an effective width of 1.0 Å.

Variable linear polarization in HD 215441 and 53 Cameloaparalis was detected by Kemp and Wolstencroft using the photodichroic polarimeter and a 15-Å passband centered on H\( \beta \). The polarization is probably caused by the transverse Zeeman effect — at least for 53 Cam. The analysis of eight months of broadband (4700 \( \pm \) 700 Å) and H\( \beta \) observations of polarization in 53 Cam show a clear correlation with the magnetic phase with mean amplitudes of polarization of \( P_{4700} = 4 \times 10^{-4} \) and \( P_{H\beta} = 10 \times 10^{-4} \). The LTE transverse Zeeman effect predicts a polarization too weak by one or two orders of magnitude as Borra has shown. However, a non-LTE process involving resonant scattering in a magnetic field gives the correct magnitude (Finn and Kemp, in preparation). In \( \alpha^2 \) Canum Venaticorum, the broadband polarization is negligible at all phases. There is a variable effect of amplitude \( p = 2 \times 10^{-4} \) in H\( \beta \) with a minimum of \( P_{H\beta} \) at phase 0.5, which occurs at the sharp positive maximum of the longitudinal magnetic field.

6. Stellar Infrared Studies

Morrison and Simon have completed a two-year survey program of broadband stellar photometry at wavelengths of 10 and 20 µm. Of the 76 bright infrared sources observed during this program, approximately 20 have been found suitable as far-infrared photometric standards; 20-µm fluxes for these objects have been determined to within 5%. Observations of Sirius and a number of other stars presumed to have blackbody infrared spectra appear to confirm the 20-µm absolute flux scale previously adopted on the basis of a model atmosphere spectrum of Arcturus. Among the infrared variables, systematic variability has been established with certainty only for Mira-type stars. For most Miras, the 10- and 20-µm brightness changes closely follow the photospheric light curve, but for a small group of Miras, the infrared and visual light variations are distinctly different.

Simon and Morrison have continued their infrared photometry of the premain sequence object, V1057 Cygni. Infrared light curves at 5, 10, and 20 µm, extending from JD 2441142 through JD 2441897, show no decline in the near-infrared flux excess.

E. Extragalactic Studies

Spectrograms obtained by Stockton of the double system NGC 4676 have confirmed the principal predictions of the tidal model put forward by Toomre and Toomre [Astrophys. J. 178, 623 (1972)]. Observations of other interacting systems, including NGC 3561 and IC 1305 are continuing.

Stockton has also begun obtaining spectrograms of faint galaxies in the vicinity of the bright quasistar source 4C31.63 (\( z = 0.297 \)), and has begun spectroscopic observations of the faint nebulousity around the peculiar stellar object BL Lac.

A number of spectrograms of the low-redshift quasistar sources PKS 1217+02 and 3C334 were obtained by Stockton at Kitt Peak in an attempt to clarify the identification of the line often seen near 3200 Å in QSOs. This line is usually identified as H\( \beta \) at 3202 Å (\( n = 5 \) to 3), but the He\( \beta \) at 4686 Å (\( n = 4 \) to 3) line is seldom seen. The identification of this line, in turn, has a bearing on the identification of the line attributed to O\( \beta \) at 3133 Å. This line is the strongest O\( \beta \) line produced in the visible spectrum region by the Bowen Fluorescense mechanism and would normally not appear except in the presence of a strong H\( \beta \) recombination spectrum. The spectrograms will give accurate wavelengths for the features near 3202 and 3133 Å, as well as an upper limit to the ratio I (4686 Å)/I 3202 Å. The material is presently being reduced.

Morrison and Simon continued their broadband photometry at 10 and 20 µm of the Seyfert galaxy NGC 1068. They have found no evidence for variability (such as that reported in the past by other observers) in these two bands since observations were begun in December 1971.

Wolstencroft spent six weeks working with R. Dodd and K. Nandy at the Royal Observatory, Edinburg, Scotland, on the analysis of photometric and polarimetric observations of the Large Magellanic Cloud. The data were obtained from plates taken with the Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory, and automatically measured by "Galaxy," and the first results have been published.

F. Radiative Transfer

Finn considered the transfer of radiation in the autoionizing lines of neutral aluminum at 1932 and 1936 Å. Line profiles were calculated for the BCA and HSR models of the solar atmosphere. Calculated and observed line profiles near the center of the solar disk were found in good agreement. However, towards the limb they did not agree even approximately unless "missing continuous opacity" was supplied in the region of 1930 Å.
Finn formulated expressions for the Stokes parameters of light emitted by a magnetic star. He adopted a dipole model for the stellar magnetic field and assumed that unpolarized light from the interior of the star is scattered once by a layer of oscillating electric dipoles on the surface of the star. Preliminary calculations of the linear polarization have been carried out for the case of a centered dipole magnetic field.

G. Other Activities

The National Research Council of Canada, the Centre National de la Recherche Scientifique of France, and the University of Hawaii have agreed to cooperate in a program to construct a 3.60 m telescope to be located on Mauna Kea.

In June 1973, members of the British Science Research Council visited Mauna Kea in order to initiate site tests there for the UK Northern Hemisphere Observatory.

Orrall acted as Scientific Coordinator at the eclipse site at Chinguittoo, Mauritania, as part of the National Science Foundation expedition to observe the African total solar eclipse of 30 June 1973.

Finn became an associate editor for the Journal of Quantitative Spectroscopy and Radiative Transfer.

Morrison became a member of the Board of Contributors of the journal Comments on Astrophysics and Space Physics.

Boesgaard was awarded a NATO Senior Fellowship in Science to spend three months in Paris working on stellar chromospheres with astronomers at the Observatoire de Meudon and the Institut d'Astrophysique.

Sinton spent twelve months at the Jet Propulsion Laboratory, Pasadena, California on sabbatical leave.

Cruikshank spent five months in the USSR at the Sternberg State Astronomical Institute on the National Academy of Sciences exchange scientist program. He worked with V. I. Moroz on infrared planetary problems.

IV. VISITORS' PROGRAM

The following guest investigators made use of the facilities of the Mauna Kea Observatory during the report period.

J. E. Gaustad, Univ. of California at Berkeley, made spectrometric observations with an interferometer at 10 and 20 µm to determine the composition of dust shells around late-type stars (224-cm telescope).

E. Becklin, G. Neugebauer, and G. Wynn-Williams, Calif. Inst. of Tech., carried out photometry with high-spatial resolution of H II regions in the wavelength range 1.6–20 µm (224-cm telescope).

I. Nolt, H. C. Ford, J. V. Radostitz, and R. J. Donnelly, Univ. of Oregon, observed Orion and Saturn at 350 µm (224-cm telescope), and Saturn at 35 µm (224- and 61-cm telescope).

E. J. Wampler and L. Robinson, University of California at Santa Cruz, carried out direct photography in the red region of areas near the South Galactic Pole to search for distant clusters of galaxies (224-cm telescope).

G. Wallerstein, Univ. of Wash. used the coudé spectrograph to make observations of long-period variable stars, and to measure interstellar line of Ti II, Ca II, and Na I (224-cm telescope).

T. Gehrels, Univ. of Arizona, carried out photometry and polarimetry of the asteroids Toro and Eros (224- and 61-cm telescopes).

F. J. Low and G. H. Rieke, Univ. of Arizona, made observations at 400 µm of the galactic center, H II regions, and extragalactic objects (224-cm telescope).

M. Simon and R. Joyce, SUNY at Stony Brook, made observations at 350 and 450 µm of the galactic center, dust clouds, H II regions, and solar system objects. In addition, they made observations in the 20-µm region, and did exploratory work at 23-33 µm region (61-cm telescope).

K. D. Rakos, Universitäts-Sternwarte Wien, used an area scanner to make UBV photometric measurements of close visual binary systems (61-cm telescope).

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This report covers the period from 1 July 1972 through 30 June 1973.

I. INTRODUCTION

The Haystack Observatory is located at Millstone Hill Field Station about 40 miles northwest of Boston. It is operated by NERC under agreement with Massachusetts Institute of Technology, which owns its facilities. Formerly a field activity of MIT Lincoln Laboratory, Haystack began operations as an Observatory on 1 July 1970, when the U.S. Air Force approved its transfer to university control.

NERC is a nonprofit corporation of educational and research institutions formed in June 1967 to plan for advanced radio/radar research facilities. Its membership includes Boston University, Brandeis University, Brown University, Dartmouth College, Harvard University, Massachusetts Institute of Technology, Polytechnic Institute of Brooklyn, Smithsonian Astrophysical Observatory, State University of New York at Buffalo, State University of New York at Stony Brook, University of Massachusetts, University of New Hampshire, and Yale University.

NERC monitors the Observatory's operation through the Haystack Observatory Office, a representative group comprising an executive and a scientific advisory committee.

In addition to providing observing support, primarily to visiting investigators, for a variety of radio astronomy