radio, infrared, and optical observations in order to determine the nature of the infrared emission. They concluded that the infrared emission can be attributed to thermal reradiation by dust grains, rather than nonthermal synchrotron emission.

G. Burbidge has continued his work on various problems concerning the nature of extragalactic objects (such as QSOs and the BL Lac-type sources), the extended double radio sources, and cosmic rays. He and S. O’Dell are conducting further statistical studies into the properties of QSOs.

2. Solar System Astrophysics

Dr. H. Alfvén continued his work on the origin and evolution of the solar system. Lately he has been concentrating on clarifying certain basic plasma and hydromagnetic processes in the early circumsolar nebula, including the ionization, stopping, and differentiation of various chemical species from an infalling nebula and their subsequent acceleration. The research during the last five years has resulted in a comprehensive monograph (jointly with Dr. G. Arrhenius), “The Structure and Evolution of the Solar System,” which will shortly be published by NASA.

Dr. D. A. Mendis continues his investigations into the nature and origin of comets. Both the normal and abnormal behavior of certain comets have been explained in detail in terms of a loosely consolidated grainy model of the nucleus. He has also studied (together with H. Alfvén) the generation of the observed magnetic fields in the tails of comets, and the properties of the magnetospheres of outer planets (together with W. I. Axford).

Dr. W.-H. Ip’s research has been concerned mainly with the orbital evolution of small bodies in the solar system under the influence of planetary perturbations, resonances, and mutual collisions. A new type of resonance of small bodies due to planetary perturbations in close approaches has been established for a number of asteroids. Dr. Ip has also studied the primeval heat structure of large bodies (planets and satellites) accreting from grains. Dr. B. R. De has been studying the condensation of grains in the primeval solar nebula.

F. Radio Astronomy

1. Solar Wind Project

Daily measurements of the solar wind velocity and turbulence spectrum using the technique of interplanetary scintillation (IPS) have continued throughout the year. The structure of high-speed streams (their recurrence period, their lifetime, and their extent in solar longitude and latitude) has been investigated. Good agreement has been found between near-Earth spacecraft measurements and the IPS solar wind velocities. In an attempt to locate the solar origin of the streams, the IPS data have been compared with solar active regions and also with coronal holes.

The form of the plasma turbulence spectrum has been studied from the IPS spectra measured at 74 MHz. While a power law of exponent near –3 describes much of the data, there is often a change of exponent such as one might expect from a microscale turbulence.

The IPS technique has been applied to the solar wind near the Sun (4–60 solar radii). Preliminary recordings at 3.8-cm wavelength from the 130-ft dish at Owens Valley indicate the possible presence of large random velocities near the Sun. More extensive multiple-site observations are now in progress both at Owens Valley and at Goldstone.

The theory of scintillation is also under study. In particular, results have been obtained for the scintillation index and intensity spectrum for a simple power law turbulence spectrum (with exponents between –2 and –6), including the difficult case of strong scintillations.

People on the solar wind experiment are J. W. Armstrong, W. A. Coles, J. K. Harmon, J. J. Kaufman, S. Maagoe, B. J. Rickett, S. Scott, and D. G. Sine; on the theoretical side are M. Marians and V. H. Rumsey.

2. Pulsars

Work continues on the fine structure in the radio signals from pulsars. In the last year more data have been recorded at the Arecibo Observatory at frequencies of 111, 196, 318, and 430 MHz. These have involved single frequency and full polarization or two frequencies simultaneously in single polarization. The data are being computer processed at University of California at San Diego to remove the smearing of interstellar dispersion. Reduction of the polarization data is still in progress. The two-frequency data show that for some pulsars the microstructure is correlated over the range 111–318 MHz. This puts important constraints on the emission mechanism and will also allow the measurement of dispersion accurate to a few parts in 10⁸. The statistics of the microstructure versus time and frequency are being compared with quantitative predictions from a model of the radiation characterized by amplitude-modulated Gaussian noise.

Extensive studies of the pulsar PSR 1919 + 21 have revealed relationships between the radio-frequency dependence of the matching subpulses, the fluctuation spectra, and the notch in the average profile. People on the pulsar project are J. M. Cordes, T. H. Hankins, and B. J. Rickett.

IV. LICK OBSERVATORY

A. Personnel

A. E. Whitford retired from the active faculty and
became Astronomer/Professor Emeritus effective 1 July
1973. E. L. Robinson was appointed Postdoctoral Re-
search Associate effective 1 September 1973. R. D.
Schwartz was appointed Postdoctoral Research As-
socite effective 1 October 1973. J. S. Miller was
promoted to Associate Astronomer/Associate Professor
effective 1 July 1974. C. Hazard, G. W. Preston, and
P. Strittmatter held temporary appointments as Re-
search Astronomers and were in residence at Lick for
various periods during the year. J. Lutz held a temporary
position as Postdoctoral Research Associate begin-
ing 9 June 1974. S. Wolff and R. Wolff spent six
months at Lick on sabbatical leave from the University
of Hawaii. L. P. Bautz, M. Kaftan-Kassim, H. Mur-
dock, L. Hultquist, L. A. Willson, and S. Wyckoff
spent various periods of time at Lick as research vis-
itors. R. L. Walker and F. Holden used the 36-in. re-
fractor as guest observers for double-star measures-
ments. R. P. Kraft was on sabbatical leave at Kitt
Peak and Princeton during much of the year, and also
lectured at Yale and Columbia during this period.

Staff Activities

Walker, Vasilevskis, Whitford, Klemola, and L.
Robinson attended the 15th General Assembly of the
IAU in Sydney, Australia in August 1974. Walker was
elected Chairman of the Working Group on Image
Tube Devices of Commission 9, and President of Com-
mision 50, created at this Assembly to deal with the
problems of Identification and Preservation of Astra-
omical Observing Sites. In March 1974, Walker at-
tended the Conference on Electronography organized
by the Astronomy Department of the University of
Texas at Austin. In May 1974, Walker attended the
ESO/SRC/CERN Conference on Research Programmes
for the New Large Telescopes, held in Geneva. During
1973–1974, Walker continued to serve as Consultant
to the Royal Observatory, Edinburgh, on their program
to site testing for the British Northern Hemisphere Ob-
servatory. In October 1973, he made a visit to the site
being investigated by the Edinburgh group on the is-
land of Madeira, and in February 1974, he visited their
site on Mauna Kea, on the island of Hawaii.

Miller presented an invited review paper on "Chem-
ical Abundances in the Ionized Gases of Nebulae and
Extragalactic Systems" at the December 1973, Ameri-
can Astronomical Society meeting in Tucson, Arizona.

Miller completed a review paper on planetary
nebulae for Vol. 12 of Annual Review of Astronomy
and Astrophysics, scheduled to appear in October
1974.

D. Pike completed his second year at Lick on a
SRC/NATO studentship. During this time, he collabo-
rated with Walker on programs involving the Spectra-
con, and collected material for a thesis on the metal
content of globular clusters by means of narrow-band
photometry on the DDO system, using both photo-
graphic and electronographic observations of the clus-
ters.

Kaftan-Kassim discussed technical questions con-
ected with the projected Iraqi Optical Observatory
with various faculty and staff members during her visit
to Lick.

B. Instrumentation

Astrometric Instrumentation

Klemola, Robinson, and Vasilevskis have completed
the modification to the Lick Gaertner Automatic Measur-
ing Engine. It now operates completely under the
control of a PDP 8/I computer with a great im-
provement in reliability and ease of operation. The
necessary computer programs in the FOCAL language
for the simultaneous operation of the surveying and
measuring machine on a time-sharing basis have been
prepared by Robinson and Klemola. Various checking
and data transfer programs have been prepared for
routine use.

120-in. Telescope

The improved (third) version of the Varo image-
tensifier installation for medium-dispersion spectro-
scopy is now in operation as an option at the 120-in.
Coudé. It features cooling by cold nitrogen gas boiled
off a liquid N₂ tank, which in convenience and tem-
perature constancy is a large improvement over former
methods of intensifier refrigeration. The same
technique will be used in the arrangement for direct
photography with intensifiers now under construction
for the Crossley prime focus.

The new spectrograph for use at the Cassegrain
focus of the 120-in. went into regularly scheduled op-
eration in January 1974. Constructed under the super-
vision of Miller, it is designed principally to be used
with the image-tube scanner. It features complete re-
 mote operation and position readout of movable parts
and can operate at dispersions from 50 to 400 Å/mm.
To date operation has been very satisfactory, and a 3
to 5 times gain in sensitivity has been found with this
instrument compared to the previously used spectro-
graph.

Robinson and Wampler have continued development
of the Lick Image Dissector Scanner. Work continued
on improving the performance and stability of the Lick
ITS system. Additional stability was provided in the
sweep circuits, the high-voltage distribution was rede-
signed, and additional electrical shielding was provided
around the output end of the dissector. These im-
provements have increased the capabilities and reliabil-
ity of the instrument. Significant improvements in
wavelength stability have been achieved, with variation
of less than 0.2 Å for a full-scale dispersion of 2500 Å
being observed over intervals of several hours. A new
UV-sensitive image tube obtained from ITT has proven to be very effective. Speed gains by a factor of 3–4 over the old blue-sensitive tube have been measured at λ3500.

Robinson and Ricketts have developed and installed a parallel serial data interface to the PDP 8 computer at the 120-in. telescope. This allows digital data to be sent and received from the computer at high speed over a pair of coaxial cables, reducing the weight of cables on the telescope and allowing easy communication between the computer and equipment located anywhere in the telescope building. The same system is used to control the new automated spectrograph.

As a first step toward computer-aided control of the 120-in. telescope Melshheimer, Robinson, and Ricketts have installed a digital readout of declination, hour angle, and right ascension. These data are accessible to the computer via the serial data interface. Precision of readout is about 1 arcsec.

Robinson, Ricketts, and Klemola have prepared a number of technical reports, chiefly for internal use, describing the Lick PDP 8/I computer systems and the software used with them.

Rank has completed development of the medium-resolution Cassegrain infrared spectrometer, and it is now in regular use on the 120-in. telescope. The resolving power of this spectrometer is approximately 500.

Rank has started construction of a new high-resolution Cassegrain infrared spectrometer for use on the 120-in. telescope. The resolution of this instrument will be approximately 5000. Rank has also continued development of infrared photoconducting detector arrays and data processing systems.

Site Testing

During 1973–1974, Walker continued to collaborate with the site testing group of the Royal Observatory, Edinburgh, processing and evaluating films taken with the Lick and Edinburgh Polaris Trail telescopes located on the islands of Fogo in the Cape Verde Islands, Madeira, and Hawaii. In collaboration with B. McInnes of the Royal Observatory, Edinburgh, a study of the seeing at Izaña, Tenerife, and Fuente Nueva, La Palma, in the Canary Islands was completed and prepared for publication. This investigation demonstrates the importance of local topography on the quality of the seeing at sites in otherwise good locations. The fact that the seeing at Izaña is not as good as one might expect at such an island site appears to result from the concave shape of the island toward the direction of the incoming airflow and to the presence of the higher Pico de Teide. This study suggests that the very best seeing may be found on islands, in cold oceans or regions with maritime tropical stable air masses, having the shape of a conical peak rising out of the sea, where the peak is of sufficient height that its top rises above the top of the inversion layer into the region where the air flow is laminar as a result of its passage over the ocean.

C. Scientific Program

Astrometric Studies

Klemola continued work on the proper motion program with the taking of second-epoch photographs and the selection of special stars for inclusion in the program. Wirtanen continued the survey for reference galaxies on the plates. Klemola reported the discovery of the relatively high-inclination and high-eccentricity asteroid 1973 JA. The determination of trigonometric parallaxes for stars in 16 fields of the Hyades has been nearly completed by Klemola. Preliminary results from these van Altena stars indicate a distance modulus near 3.30. Klemola and Harlan obtained a series of direct photographs of Comet Kohoutek (1973F) with the astrograph which were measured for positions.

The parallax program at the 36-in. refractor continued under Vasilevskis’ supervision. Almost all of the observation was done by Harlan, with occasional participation of graduate student K. Cudworth. A total of 236 stars have been put on the program. Of these, 18 fields have been discontinued, mostly due to faintness of the stars. Observing of most of the selected stars has been completed. Nearly 100 fields have been measured, mostly by Wirtanen, and occasionally by Klemola, particularly at the initial period of operating the upgraded automatic measuring system. McNamara has assisted in recent measurements. Most of the measurements have been reduced. By the process of analyzing the results, it was found that systematic errors can be caused by coma and plate tilt due to flexure of the telescope depending on hour angle. Plate constants for removal of these errors have been introduced into the computer program, and all the fields were recomputed with these terms added. This latest modification has brought the Lick parallax program up to the routine stage.

Cudworth has completed his study on new proper motions, statistical parallaxes, and kinematics of planetary nebulae. New proper motions have been measured for 51 planetary nebulae. The study has confirmed the existence of two kinematically distinct classes of these objects, but has removed some of the earlier advocated differences between them in regard to their space distribution. The kinematics of both classes are consistent with their being the offspring of Mira variables. The new distance scale does not call for a drastic revision of the scale of the galaxy.

Proper motions for most of the 63 faint blue stars found in the region of the galactic anticenter by Rubin and Losee were measured by Cudworth. A few of these stars have detectable proper motions and are probably nearby white dwarfs, but most must be
distant high-luminosity objects.

Graduate student R. Hanson has completed his study of the motion, membership, and distance of the Hyades cluster. New absolute proper motions referred directly to external galaxies, photographic photometry, and cluster membership probabilities have been determined for over 600 faint stars in the Hyades region. These have been used to investigate the Hyades convergent point and distance. The convergent point analysis of the new absolute Hyades proper motions represents the first Hyades distance determination independent of all meridian circle proper motion systems. The resulting Hyades distance modulus is $m - M = 3.42 \pm 0.20$, significantly greater than all previous values from proper motions, in agreement with predictions of the Hyades distance from stellar structure theory, and with the results of "secondary" distance indicators. Incorporating this value, the most likely value of the mean Hyades distance modulus from all sources is $m - M = 3.29 \pm 0.08$. The quote error represents a larger and more realistic estimate of the true errors than has been generally stated.

R. L. Walker (U.S. Naval Observatory, Flagstaff) and F. Holden worked as guest observers with the 36-in. refractor, measuring close double stars with the bifilar micrometer.

Stellar Spectroscopy

The spectrum of the hot, H-deficient, carbon star MV Sgr has been observed by Herbig in the red and infrared, at maximum light of this R CrB-like variable. In this region it shows a rich emission-line spectrum, mainly of Fe II but with Si II, N I, O I, and Hα as well. No such spectrum has been found in any other R CrB star, but there is some resemblance to the H-deficient object ν Sgr. The emission lines in MV Sgr probably originate in an extended cloud at low temperature, possibly the same region responsible for the infrared excess found by Feast and Glass.

Kraft and graduate student D. Scullian scanned approximately 50 giant, subgiant, and asymptotic giant branch stars in the metal-poor globular cluster M92 with the new Cassegrain ITS and Miller spectrograph. Extending the preliminary results of Zinn, they found that all stars on the subgiant branch had strong g bands (CH), but the stars of the AGB and giant branches had weak g bands, for the most part. Observations are being extended, using the new blue tube, to the NH bands at $\lambda 3360$.

As part of an ongoing study of rotational velocities in evolved A and F stars, Faber has investigated the use of Strömgren and Hα photometry in classifying A and F giants and supergiants. A list of all such stars having accurate photometry and spectral types was compiled. Reddening-free parameters $c_1$ and $m_1$ were determined for these stars after the manner of Strömgren. For these stars, the coefficients in the definitions of $c_1$ and $m_1$ differ significantly from those previously published for hotter stars by Strömgren. Using two-color plots of $c_1$, $m_1$, and $β$, it is possible to classify A and F stars quite accurately on the MK system. Convenient diagrams for rapid classification have been constructed.

Graduate student W. R. Alscluhler completed his thesis study of Li depletion and surface rotational velocity decay in F and G giants, based on his Li abundances and $v \sin i$'s determined from intensifier spectrograms of 64 stars between F4 III and G5 III. His results conflict with existing theoretical predictions of lithium dilution and rotational braking in these stars (assumed to have masses between 2.4 and 3.0 $M_\odot$) as they cross the Hertzsprung gap for the first time, although agreement could be achieved by some adjustments to the models. Another possible explanation of the observations is via a systematic variation in mean mass across this range is spectral type.

Rank (with Townes, Berkeley) has continued a spectroscopic program for cool stars and circumstellar shells in the 4–5-μ region. The observations are made with a resolution of approximately 20 000 with the Coudé IR Fabry–Perot. Rank has also been studying spectral features in the infrared due to dust surrounding cool stars.

During the six months they spent at Lick Observatory, S. Wolff and R. Wolff completed work on a study of the Hg–Mn stars. In order to determine the rate of incidence of these stars, the Wolffs had obtained at Mauna Kea Observatory low-dispersion (50 Å mm$^{-1}$) spectrograms, in the region $λ 3450–3500$ where the strongest lines of Mn occur. A total of 194 stars of types B4–B9 were examined, and 24 were found to be Mn stars. The Hg line is definitely present in 20 of these stars. The Mn stars occupy the limited temperature range $0.33 < θ_e < 0.48$, and in the range $0.36 < θ_e < 0.42$, approximately 30% of the stars examined were found to be Mn stars. All the Mn stars have $v \sin i < 75$ km sec$^{-1}$. The high rate of incidence and the rotational velocity distribution indicate that the Mn stars constitute at least half—and probably substantially more—of the slowly rotating stars in the temperature range in which they occur. Two Mn stars are members of the Scorpio–Centaurus association, so the time scale for the formation of Mn stars is less than 10$^7$ yr. The most satisfactory model proposed so far to account for the observed properties of the Mn stars is that, because of the slow rotation, the atmospheres of these stars are sufficiently stable for diffusion processes to be effective.

Variable Stars

Herbig has published (for limited circulation as Lick Bulletin No. 658) a catalog of Herbig–Haro objects known to him up to 1972, much of it based on unpublished Lick data collected in 1946–1965. The catalog
contains accurate coordinates, brightness estimates, identification charts, and spectroscopic information for about 80 nuclei in some 43 distinct objects.

E. L. Robinson joined Kraft at the KPNO 50-in. telescope in a photometric $B_V$ program on dMe stars in the Pleiades and Hyades. Small variations in brightness with time scales of the order of days were found in several Pleiades dwarfs in the spectral type range K3 V to M0 V; Hyades stars of similar types are constant. The brightness variations are accompanied by small or nonexistent color variations and thus are probably similar to those found by Krzeminski, Chugainov, and others in field dMe stars. Flares are not directly responsible for the variation, even though the variations are usually found in flare stars. The material suggests that brightness variations are fairly common in late-K- and early-M-type dwarfs of age $3 \times 10^7$ yr, but essentially disappear at an age near $5 \times 10^8$ yr.

Robinson also continued his investigations of cataclysmic and related variable stars. His analysis of spectra of the dwarf nova EM Cyg showed it to be a binary system with masses of 0.90 $M_\odot$ for the late-type star, and 0.70 $M_\odot$ for the white dwarf. Robinson is in the process of analyzing photometry of eruptions of AH Her and V426 OPH taken with the high-speed photometer he built for the Crossley telescope. Robinson and Faulkner obtained high-time-resolution spectroscopy of the peculiar variable white dwarf AM CVn.

As a postgraduate research astronomer, Schwartz has pursued theoretical models of radiative transfer in circumstellar dust shells. A radiative transfer model for grey shells due to Huang has been generalized and applied to VY Canis Majoris. The infrared spectrum emitted by nongrey, optically thick dust shells composed of iron and silicate grains is under investigation.

In addition, Schwartz continued observational studies of T Tauri nebulae and Herbig–Haro nebulae. Kitt Peak 2.1-m image-tube spectra of the emission and reflection nebulae associated with T Tauri reveal large radial velocity differences between the star and the nebulae. Since the emission-line spectrum has many similarities to that expected from the shock-wave models of Cox, it is suggested that the T Tauri nebulae and Herbig–Haro nebulae may be produced by a strong stellar wind interacting with the ambient intracloud medium.

Graduate student N. Kameswara Rao finished his thesis investigation of the spectrum and colors of R CrB during minimum light, using Lick material collected since 1962. Among the numerous hypotheses that have been advanced to account for the minima, Rao found that the observations were best explained by a veiling of the photosphere by a dust layer which forms at a low level in the atmosphere and hence leaves the chromosphere exposed, so that the bright lines dominate the spectrum when the star is faint.

Scanner spectrophotometry indicates that graphite particles of radii 400–600 Å can account for the wavelength-dependent extinction. There is good evidence for subsequent expansion of the dust layer, which presumably accounts for the recovery in light. Curve-of-growth analysis of both the absorption and emission spectrum, and a study of the C I line profiles, lead to estimates of particle densities, temperatures, and turbulent velocities in those regions of R CrB. Unlike the well-studied case of RY Sgr, no evidence has been found for periodic light variability in R CrB.

Butler, under Kraft’s general direction, completed his Ph.D. thesis study of the Preston $\Delta S$ index for RR Lyrae stars in 12 globular clusters. A correlation $[\text{Fe/H}] = -0.16 \Delta S - 0.23$ was set up, based on coarse analysis of 35 Coudé spectrograms of 13 field RR Lyrae stars; from a single $\Delta S$ measurement of an RR Lyrae star in a globular cluster, Butler estimates that $[\text{Fe/H}]$ can be found with a precision of $\pm 0.3$. Application to globular cluster RR Lyrae stars yields metal abundances $[\text{Fe/H}]$ ranging from $-2.2$ to $-0.4$ for NGC 6712. Butler and Kraft plan to use the correlation to study metal abundances of RR Lyrae stars in the galactic halo and galactic nucleus.

Graduate student L. McDonald, under Kraft’s general direction, has begun a systematic study of the absolute magnitudes of RR Lyrae stars of different metal abundances, based essentially on Wesselink’s method.

**Star Clusters**

Walker continued the study of star clusters in the Magellanic Clouds on electrographs taken with the Spectracon and the 60-in. Tololo reflector in 1968–1969. In December 1973 and January 1974, Walker observed with the 60-in. reflector at Tololo to set up photoelectric standards in a number of the clusters for which electrographs were obtained with the Spectracon in 1968–1969. In particular, observations were obtained of stars in the “blue globular” cluster NGC 1866 in the LMC. As discussed in the last report, these observations were needed to provide both a very accurate photometric zero point and an accurate determination of the reddening in order that the electronographic photometry could be used to determine the distance of the cluster by main-sequence fitting. From these observations, the reddening of the cluster was found to be $E_{B-V} = (m - M)_0 = 18.05 \pm 0.10$. This value is considerably smaller than that generally accepted for the LMC, but agrees with the distance determined by Divan using the Barbier, Chalonge, Divan method for the determination of the absolute magnitudes of the supergiants in the LMC.

In collaboration with Pike and J. D. McGee (Imperial College), observations were obtained with the Spectracon attached both to the prime focus of the 120-in. reflector and the Cassegrain focus of the 24-in.
photometric reflector of a number of star clusters in our galaxy, including NGC 5053, NGC 6356, and NGC 6366. In addition, experiments were made in the use of the Spectracon for the transfer of photometric scales and zero points from standard regions to unknown fields by procedures similar to those in photographic transfers; owing to the linear response of the electronographic process, photometric transfers using electronographic cameras should avoid the problems encountered in photographic transfers and yield an accuracy comparable with the establishment of photometric standards using a photoelectric photometer. Reduction of these observations is in progress.

Interstellar Matter; Gaseous Nebulae

Herbig's large program on the diffuse interstellar lines between 4400 and 6850 Å has been completed, and a full account is in press. Thirty-nine features certainly or very probably interstellar are now known, plus a number of additional possible interstellar absorptions. The evidence is now very good that this spectrum either is produced by a single carrier, or by a very homogeneous mixture of absorbers, because the internal correlation in line strengths from star to star is excellent. The average correlation with color excess is poorer, but improves markedly when certain regions having anomalously weak lines (per unit reddening) are excluded. Empirical wavelengths established for a number of the narrower features in the yellow-red make it possible to determine radial velocities to about \(\pm 2\) km sec\(^{-1}\), for comparison with the multiple structure of the atomic interstellar lines. No support is found for the notion that the same material is responsible for the minima observed in type I supernova spectra, or that the type of background stellar spectrum somehow affects the diffuse spectrum. No identification of the carrier has been achieved, despite the large amount of data now on hand. The most plausible hypothesis, which accounts for some of the observational systematics, is that the diffuse line spectrum is produced by some material in the very small (\(\sim 300\) Å) interstellar grains, which are believed to be responsible for the far-ultraviolet extinction.

Herbig has written a descriptive account of the fine structure of the globules and elephant trunks in the Rosette nebula, as observed at 120-in. scale. Emphasizing the tear-drop shapes of the small globules, and their preferential orientation toward the central star cluster, he believes that these small dark spots are not protostars but merely a late stage in the dissolution of dust concentrations in a hot radiation field. It is estimated that the lifetime remaining to a very small (\(\sim 3\) arcsec) globule is about 1000 yr.

Rank has been studying fine-structure lines and spectral features due to dust in planetary nebula with the infrared spectrometer on the 120-in. telescope.

Osterbrock obtained Coudé spectrograms of the planetary nebula NGC 7027 with sufficiently high dispersion to resolve the H\(\alpha\), H\(\beta\), and H\(\gamma\) line profiles. Comparison of the blue and red sides of these profiles showed no differences that can be attributed to internal extinction by dust within this object. The bulk of the observed optical extinction must therefore occur outside the nebula, although the measured infrared excess shows definitively that there is some heated dust within the nebula also.

Under Miller's supervision graduate student Barker completed his Ph.D. thesis on abundances in planetary nebulae. His study included scanner measurements of line intensities for about 30 nebulae selected for their kinematical properties and position in the galaxy. With the exception of the previously studied planetary in the globular cluster M15 and in the direction of the north galactic pole, there was little difference in the abundances of O, Ne, S, N, and He relative to H for the objects studied, even though the sample includes objects several thousand parsecs from the plane of the galaxy and objects with high radial velocities.

Osterbrock and Phillips obtained spectrophotometric measurements of the bright knots, the "Hourglass," in M8. A large number of emission lines were measured.

M. Kaftan-Kassim, SUNY at Albany, spent ten days in November 1973 at Lick discussing the interpretation of high-resolution radio observations of planetary nebulae, and the possible correlation with available optical data, as well as the prospects of obtaining further optical contours.

Galaxies: Stellar Populations

Using plates taken with the Lallemand electronic camera at the focus of the Coudé spectrograph of the 120-in. reflector and photographic spectra taken with the 120-in. prime-focus spectrograph, Walker derived an improved rotation curve for the nuclear region of M31. The observations cover the range \(0 \leq r \leq 24\) arcsec and show that the rotation curve, which has its maxima in PA = 52° (the major axis of the bright, elliptical nuclear region of M31) increases linearly from zero at \(r = 0\) to \(V_c = 104\) km/sec at \(r = 19\), beyond which it drops approximately as \(V_c = r^{-1/2}\). Making an approximate correction for the effect of seeing and instrumental resolution, the radius of the nucleus is \(r = 55\) or 5.2 pc, the rotational period \(3.1 \times 10^5\) yr, and the mass \(1.6 \times 10^8\) M\(_\odot\).

In collaboration with Pike and McGee, observations were obtained with the Spectracon mounted at the prime focus of the 120-in. reflector of three systems of galaxies in which one member has a redshift very different from that of the other(s). These were the systems NGC 4319 plus Markarian 205, Seyfert’s Sextet, and NGC 7603 plus companion. In NGC 4319, observations were made in the near-infrared using a Spectracon with an S-20 photocathode and through a Schott RG-8 filter in order to investigate the existence of an
infrared bridge between NGC 4319 and Markarian 205 as reported by Arp. No evidence of such a connection was found, down to an intensity level of about 2% or 3% of the brightness of the night sky. Likewise, no connection between the galaxy with the discordant redshift in Seyfert's Sextet and the other members could be detected—in integrated light—down to a brightness level of 1.5% of the night sky. In NGC 7603, a luminous connection to the companion galaxy does exist, with a minimum brightness of about 2.6% of the night sky in integrated light. However, the spectrographs do not confirm the existence of a bright rim in the halo of the companion where it overlaps the connecting filament. Thus, there is no direct evidence for physical interaction between the filament and the companion, and the system could therefore be the result of the chance superposition of objects at very different distances.

Using the above equipment and collaborators, observations were also obtained of the nebulosity around 3C 120. Several 90-min spectrographs in yellow, blue, and integrated light confirm an earlier observation obtained by Walker in collaboration with Cromwell and Weymann using the Spectroan on the 90-in. Steward reflector, in showing that the bright semistellar source is situated at the center of a smooth, elliptical nebulosity whose outer dimensions, at the level of 1.0% of sky, are 44 × 63 arcsec, and whose mean color is B − V = + 0.85 ± 0.15. These observations are consistent with the interpretation of N-type systems as quasistellar objects located at the centers of elliptical galaxies.

Electrograph observations of the systems Leo I, Leo II, and of certain associations in M33 were also obtained by Walker, Pike, and McGee using the Spectroan on the 120-in. reflector, for the purpose of deriving C–M diagrams. Reduction of these observations is in progress.

Faber has continued to use the image-dissector scanner to study the properties of normal early-type galaxies. Together with graduate student Robert Jackson, she has explored the possibility of measuring velocity dispersions from scans of E galaxy nuclei using the Fourier transform technique. This approach appears promising although final results are not yet available. These nuclear scans are part of a broader study of composition and composition gradients in early-type galaxies. Jointly with Whitford, this work has been enlarged to include SO galaxies in order to compare composition parameters in disk and spheroidal star systems.

The image-dissector scanner has also proven an effective instrument for studying the strength of the absorption feature due to Na I at 8190 in galaxy spectra. This line is useful for discriminating between dwarf and giant M stars in galaxies but is badly confused by atmospheric water vapor. The IDS scans, however, provide sufficient resolution to disentangle the two features, which is not possible with traditional scanner photometry. Measurements of the strength of this line in the nucleus of M31 do not confirm a dwarf-enriched model of the stellar population like that suggested by Spinrad and Taylor.

As part of the general attack on the characteristics of early-type galaxies, Faber has collaborated with J. S. Gallagher (University of Minnesota) and B. Balick in setting new limits to the neutral hydrogen content of these systems. Limits for elliptical galaxies and for many SOs are embarrassingly small. In fact, as a result of the ejection of gas into the interstellar medium from planetary nebulae alone, detectable amounts of neutral hydrogen should collect in only 10^6 yr. No successful method for storing sufficiently large amounts of gas in indetectable form was devised. Thus the evidence favors the existence of some active removal mechanism, possibly galactic winds.

Several SO galaxies have detectable 21-cm emission. Faber has obtained nuclear spectra of some of these and has found a wide variety of spectral characteristics. Almost none, however, show either strong hydrogen lines in absorption or any trace of emission. Thus the distinctive object NGC 5102, with its early-type spectrum concentrated to the nucleus, appears to be unusual.

Together with graduate student A. Dressler, Faber is measuring velocity dispersions in clusters of galaxies with the image-dissector scanner. A number of x-ray clusters have been observed for the purpose of comparing x-ray intensities with cluster velocity dispersions. Data have been obtained on a total of five clusters, four of them x-ray sources, but no results are yet available.

Graduate student R. Jackson has begun a thesis to study the local anisotropy in the Hubble flow. The possibility of such an anisotropy has been raised by Rubin, Ford, and Rubin using Sc I galaxies as standard candles. Jackson plans to check their results for the velocity range 5000–10 000 km sec⁻¹ using first-brightest ellipticals in clusters of galaxies.

Bautz and Blumenthal investigated characteristics of de Vaucouleurs' groups to check the contention of Gott et al. that the elliptical groups are physical associations but the spiral groups are not. They found no correlation of crossing time with galaxy type or with mass discrepancy. The number distribution of crossing times is only weakly bimodal and is consistent with a small number of the groups being real and all the rest being statistical fluctuations.

Galaxies: QSOs; Radio Galaxies

Survey work on quasistellar sources was continued by Wampler, L. Robinson, and graduate student J. Baldwin in collaboration with M. Burbidge (UCSD). Much of the effort was directed toward completing the optical investigation of radio identifications supplied.
by Hazard, Murdoch, and Jauncey. Surprisingly, no new large-redshift QSOs were discovered. The neutral color candidates identified by accurate radio positions were found to have steep-power-law spectra, often highly polarized. In this respect they resemble BL Lacertae.

In the course of the survey it was found that 4C 11.50 = 1548 + 115 is a double QSO with the two components separated by 5 arcsec. The redshifts of the two components were very discordant; for the brighter component \( z = 0.436 \) and for the faint component \( z = 1.901 \). Although one cannot eliminate the possibility that this pair is a chance optical superposition of a nearby and a distant QSO the probability for this is low. This discovery adds support to noncosmological theories of redshifts.

Wampler, L. Robinson, Baldwin, and M. Burbidge started to obtain spectrophotometry of the nebular wisps seen near some QSO images. In agreement with Arp they found sharp emission lines in the nebula surrounding 3C 120. These lines give essentially the same redshift as the emission lines from the nucleus. All lines, even the permitted Balmer lines, are sharp. In the nebula the \([\text{O III}]\) lines are much stronger relative to \(H\beta\) than in the nucleus, resembling the spectrum of a high-excitation planetary nebula. 3C 48 was also found to have a similar nebular spectrum with the redshift of the nebula agreeing with that of the nucleus. These observations present serious difficulties for any theory that suggests gravitational redshift to be a substantial component of the redshift of QSOs.

Wampler, L. Robinson, Baldwin, and M. Burbidge also scanned the nebula surrounding BL Lac and did not verify the redshift found by Oke and Gunn (1974). The nebular spectrum appears continuous. Unlike the spectra of 3C 48 and 3C 120, no emission lines are seen and the Lick data do not show the galaxy absorption spectrum seen by Oke and Gunn. The nature of BL Lac remains an enigma.

Osterbrock and Miller obtained spectrophotometric measurements of the radio galaxy Cyg A with the image-tube image-dissector scanner. The interstellar extinction was determined from measured Balmer-line ratios, and all the measured line and continuum strengths were corrected for this extinction. The physical conditions in the ionized gas, and the input mechanism to it were discussed on the basis of these observed line ratios. The abundances of the observed elements are approximately normal. Photoionization input by stars is ruled out by the great strength of \([\text{O I}]\), \([\text{N I}]\), and \([\text{S II}]\). Shock-wave heating is ruled out by the \([\text{O III}]\) temperature, unless a large amount of ultraviolet ionizing radiation is emitted in the shock. Published calculations of photoionization by a synchrotron spectrum approximately match the observed Cyg A emission-line spectrum, as does the observed Crab nebula emission-line spectrum, except for abundance differences.

Osterbrock obtained spectrophotometric measurements of varying degrees of completeness of approximately 15 radio galaxies, to discuss the physical conditions in these objects. Further observational work is being continued on this program. Three of the galaxies observed to date, 3C 382, 3C 390.3, and 3C 445, have broad Balmer-line wings extending over a greater range in wavelength than reported to date in any Seyfert galaxy. Analysis of these profiles is being actively pursued.

Solar System

In collaboration with Harlan and Kemper, Herbig obtained a number of 16 and 32 Å mm\(^{-1}\) Coudé spectrograms of Comets Kohoutek (1973f) and Bradfield (1974b) when they were bright in early 1974. Over 800 emission lines are measurable between 4700 and 8600 Å on these plates. Most are conventionally identifiable with rotational structure of \(C_2\), \(CN\), \(NH_2\), etc. Among the most interesting results was the identification of \(H_2O^+\) in the coma and tails of both comets, thanks to a very recent laboratory study of that molecular ion by G. Herzberg and H. Lew (Ottawa). Taking advantage of the new analysis, Herbig examined the interstellar absorption spectrum of ξ Oph for interstellar lines from the lowest rotational levels of \(H_2O^+\). None were found.

Rank has been studying the middle-infrared spectrum of Jupiter.

Donald E. Osterbrock
Director

V. BOARD OF STUDIES IN ASTRONOMY AND ASTROPHYSICS

A. Personnel and Faculty Activities

John Faulkner completed a period of sabbatical leave at the Institute of Astronomy, Cambridge, England. He and graduate student Brian Flannery were invited to attend the 1973 NATO Advanced Study Institute, "Physics and Astrophysics of Compact Objects," held at Cambridge in July 1973. Talks were given both at Cambridge and at other United Kingdom universities. In September Faulkner (with Kraft) visited Warsaw, Poland, attending two "Copernican" symposia of the IAU No. 64, "Gravitational Radiation and Gravitational Collapse" and No. 66, "Late Stages of Stellar Evolution." Faulkner's invited review paper "The theory of novae and nova-like systems" will appear in the proceedings of the latter meeting.

Two students, William Alschuler and Kyle Cudworth, received their Ph.D. degree during the academic year.

Richard Durisen departed from his postdoctoral position in August 1973, taking up a National Research
Council Associateship at NASA Ames Research Center, Moffett Field, California. Ronald E. Taam was appointed to a postdoctoral position, joining us from Columbia University in October 1973. Bruce Balick, formerly at NRAO, arrived in September 1973 to accept a postdoctoral appointment.


B. Research in Theoretical Astrophysics

1. Stellar Structure and Gravitational Radiation

Faulkner, with Dr. Peter P. Eggleton and graduate student Ronald F. Webbink of the Institute of Astronomy, Cambridge, began a study of the transient structural responses of main-sequence-like stars to arbitrarily assumed rates of mass loss. Such stars can persistently exhibit properties (radii, luminosities, etc.) differing substantially from their constant-mass counterparts. Faulkner and Taam later completed these studies, which shed light on the eigenvalue situation which arises when similar stars are members of close binary systems.

It has been suggested that gravitational radiation may play an important role in the evolution of short-period binaries such as dwarf novae. In that case, a canonical rate of mass transfer ($\sim 10^{-16} \, M_\odot$ per annum) is to be expected. Although the site of outbursts is still controversial, an obviously important question related to the nuclear burning mechanism arises, viz., "Can accretion at $10^{-16} \, M_\odot$ induce nuclear runaways on white dwarfs of $\sim 1 \, M_\odot$?" Taam and Faulkner have shown this can happen, with details depending upon the white dwarf's thermal history and stage of development. Their results represent a necessary, but by no means sufficient condition for gravitational radiation losses to be important.

Faulkner, Flannery, and Taam also computed detailed evolutionary sequences of close binaries containing low-mass pairs with and without mass loss from the system. The parameters were chosen to model dwarf novae where an apparently young star is transferring material to a white dwarf. A wide variety of self-consistent mass transfer rates can occur, depending upon initial parameters.

Durisen completed a study, begun at Lick, of the upper mass limits for secularly and dynamically stable differentially rotating nonmagnetic white dwarfs under nonaxisymmetric perturbations. These limits are $\sim 2.5 \, M_\odot$ and $\sim 4.6 \, M_\odot$, respectively, for the explicit case where the prescribed angular momentum distribution corresponds to that of a uniformly rotating homogeneous sphere. The results are probably not particularly sensitive to the assumed distribution, however; a check calculation of the dynamical stability limit for a distribution given by the polytrope of index 1.5 yielded a closely similar value.

Flannery completed a thesis entitled "Gas Flows in Cataclysmic Variable Stars." He devised and used a hydrodynamic scheme for numerically simulating the early stages of mass transfer into Roche lobes occupied by compact stellar masses. The dissipative effect of radiative cooling in shocks results in the rapid formation of a ring of orbiting material and an optically thick, relatively confined shock front where the incoming stream intersects the disk. The temperature and location confirm the major elements of the "hot spot" model proposed on observational grounds for cataclysmic variables stars. Flannery also corrected results in the literature on particle orbits which were widely used and erroneous.

Peter Bodenheimer carried out a study of the hydrodynamical evolution of Jupiter during the earliest phases of its history. He used a standard code for solving the equations of hydrodynamics and radiative transfer including an equation of state appropriate for low-mass stars. The basic assumption made was that the planet formed as a subcondensation in the primitive solar nebula (before the Sun itself had become a central, condensed object). Rotation was not included. The calculation was started at the Jeans limit for one Jovian mass (density of $1.5 \times 10^{-11} \, g \, cm^{-3}$ and temperature of 400°K) and was carried to a point where an equilibrium configuration had been established at a central density of 0.5 g cm$^{-3}$ and a temperature of $2.5 \times 10^4 \, K$. During the early part of the evolution the object was found to contract in quasihydrostatic equilibrium for a time of about $7 \times 10^4$ yr. Then hydrodynamic collapse occurred, induced by the dissociation of hydrogen molecules. After completion of dissociation the planet regained hydrostatic equilibrium with a radius of only 4–5 times its present value. The subsequent slow contraction to the present radius has been treated by Graboske, Pollack, Grossman, and Olin. The end point of the hydrodynamical calculation is consistent with their results. These results were first reported at the meeting of the Division of Planetary Sciences in Palo Alto, April 1974.

Bodenheimer, in collaboration with J. Ostriker of Princeton, completed work on a paper describing calculations of light curves for type II supernova events, based on the Ostriker–Gunn pulsar acceleration mechanism. The calculations start with a red-giant en-
velope model and a central rotating neutron star. The magnetic dipole radiation produced by the pulsar fills the central cavity and drives the expansion of the envelope. The development of the supernova shock wave has been calculated and its progress through the envelope followed by use of a shock-fitting technique. When the shock reaches the surface the material of the original envelope is confined to a relatively thin spherical shell. The evolution of this shell has been followed with the inclusion of radiative energy transport until it became optically thin. The resulting light curves are in good agreement with observations as far as the time scale for decay in light is concerned, photospheric expansion velocities are in good agreement with observed values, and the behavior of the effective temperature with time is consistent with the observations of Kirchner, Oke, Penston, and Searle. However, the calculated time for rise to maximum light is somewhat too long, the decrease in photospheric velocity with time suggested by observation is not represented, and the total stellar mass for which best agreement with observation is obtained is 2.4 $M_\odot$, somewhat too low for the expected mass range for type II events. Further work to consider these problems is being pursued.

Keely has been working on a linear nonadiabatic stability analysis of long-period variables. Preliminary results suggest that secular instabilities with time scales on the order of a few thousand days may be important in these stars, and perhaps may be the cause of relaxation oscillations found in nonlinear calculations.

Faulkner and Lick postdoctoral researcher Edward L. Robinson made a study of the short-period system HZ 29, using the Wampler, L. Robinson, and Miller Cassegrain scanner/spectrograph system of the 120-in. Lick antenna to perform synchronous spectrophotometry. The results support a previously published model of the system, including a rate of mass transfer deduced from spectroscopic considerations which is consistent with that predicted on the basis of gravitational radiation losses of angular momentum.

Burke's studies on gravitational radiation and its detection have moved into the study of random wave fields. The strong collective signal from all of the binary systems in the galaxy is a known source of such a signal whose detection would be an important one for gravitation theory. A careful study of very-large-scale random waves has just been finished. The scintillation problem for such fields is being looked into.

2. Theory and Observations of Diffuse Galactic Nebulae

B. Balick, in conjunction with R. H. Gammon and R. M. Hjellming (NRAO), completed a model for the structure of the Orion nebula and the extensive neutral complex behind it. The H II region is thought to be a partial cavity on the near side of the neutral complex which is formed by the central exciting star $\theta$ C. Relatively undiluted ionizing radiation from the star falls predominantly on the neutral region behind the nebula and creates a sonic flow of ionized gas of relatively high density ($n_e = 10^{5.5}$ cm$^{-3}$ or higher in smaller regions). The gas then freely expands away from the central cavity into the more vacuous surroundings. The neutral region appears to be collapsing isothermally in its outer parts, and the trapezium stars partake in the motions of the collapse. Such a model successfully serves as a framework for the interpretation of the large amount of optical and radio data available.

B. Balick completed analysis of radio synthesis maps of the galactic center and the nearby giant H II region Sgr B2 in collaboration with R. Sanders (NRAO). They detected what appears to be a compact H II region associated with the bright infrared complex in the galactic nucleus. The density of the H II region is consistent with the general concentration of neutral gas towards the galactic center seen at distances greater than 100 pc and the concentration of older population stars seen within 100 pc (mass loss from these stars can account for the material in the H II region). Sgr B2 was found to be an extreme example of a compact H II region in the sense of its large density ($n_{HII} = 10^{5.5}$ cm$^{-3}$) and large excitation.

B. Balick, observing with R. L. Brown (NRAO), discovered an intense source of radio emission situated in the center of the bright infrared complex and compact H II region in the galactic nucleus. Using the new 35-km baseline interferometer of the NRAO, they found the source to be smaller than 0.1" and brighter than 10$^7$ K. The object is apparently not positionally coincident with any of the bright infrared objects or compact components of the H II region. An understanding of the nature of the object must await further observations. In addition, Balick and Brown surveyed galactic H II regions for the presence of similar objects, but the data are not yet reduced.

B. Balick, R. H. Gammon (NRAO), R. L. Brown (NRAO), and J. Knapp (Caltech) reported the detection of strong carbon recombination lines at 5 GHz in a dark cloud (Rho Oph) and a reflection nebula (NGC 2023). The carbon emission regions in both sources are found to be dense ($n_{HII} = 100-1000$ cm$^{-3}$) and cold ($T = 10-30$ K), and are probably excited by mid- to late-B-type stars.

Development of a computer model to predict the effects of dust on the ionization and thermal structure of an ionized nebula was begun by B. Balick. It is hoped that the results of the model will be compared to optical observations of forbidden lines in dusty nebulae in the forthcoming year.

3. Galaxies, Quasistellar Objects, and X-Ray Astronomy

During the year George Blumenthal and Wallace
Tucker wrote a review article on compact x-ray sources for the *Annual Reviews of Astronomy and Astrophysics*. Blumenthal wrote a paper on the Eddington limit and Poynting-Robertson effect in sources of hard photons (x-ray and γ-rays) where the classical formulae are no longer valid. Blumenthal also studied the conditions leading to the formation of x-ray binaries. In particular, he studied the effects of the pulsar-forming supernova explosion on the parameters of the binary.

Blumenthal and Mathews have collaborated on studies of emission lines from QSOs and Seyfert nuclei. They showed that the line profiles can be understood in terms of radiation pressure acting upon gas clouds. They also considered the Balmer decrement for nearby QSOs and Lyman decrement for more distant objects. These line ratios might be understood if collisional excitation and radiative transfer effects are considered. Finally, Blumenthal and Mathews investigated the equations for a general relativistic stellar wind. They are presently investigating the radiation from such winds as it may apply to extragalactic radio sources.

Mathews in collaboration with graduate student Joel Bregman began a study of the equilibrium configurations, gravitational collapse, and ultimate fate of ionized gas clouds located at the center of giant elliptical galaxies. This study, still in progress, indicates that an extremely dense cluster of low-mass stars will develop, perhaps leading to the onset of stellar collisions.

Students Steven Hawley and Douglas Duncan determined the ratio of total to selective absorption in the galactic plane by combining published and unpublished data on optical and radio observations of planetary nebulae.


4. Astronomical Data Analysis Techniques

J. Scargle has developed a new method for the analysis of data from a physical process which is inherently random. It involves a generalized shot-noise representation of the process, and the computer algorithm gives an estimate of the shape of the pulses as well as the times at which they occurred. The method has been applied to data on QSO variability, flickering of optical and x-ray sources, and the distribution of galaxies in space.

William G. Mathews

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This report describes the astronomical activities of the Department of Physics and Astronomy for the period 1 October 1973 through 30 September 1974. Since previous reports (Neff 1971, 1972, 1973, and 1974) contained extensive descriptions of facilities and instrumentation, only substantial changes will be noted in this report.

1. PERSONNEL

The faculty engaged wholly or to a significant extent in astronomical work is the following:

Dr. James A. Van Allen, Carver Professor of Physics and Head of Department;
Dr. John S. Neff, Associate Professor of Astronomy;
Dr. John D. Fix, Associate Professor of Astronomy;
Dr. Donald A. Gurnett, Professor of Physics;
Dr. Stanley D. Shawhan, Associate Professor of Physics;
Dr. Christoph K. Goertz, Assistant Professor of Physics;
Dr. Bruce A. Randall, Assistant Research Scientist;
Dr. John M. Rankin, Assistant Research Scientist;
Dr. Emmanuel T. Sarris, Assistant Research Scientist.

Dr. T. G. Northrop of Goddard Space Flight Center was a Visiting Professor of Physics the second semester 1973–1974.
Dr. John M. Rankin resigned September 1974 to become Assistant Professor of Astronomy at Cornell University.