that the steepness and curvature of the continuum of the BL Lac object AO 0235+164 is due to reddening by dust associated with the atomic hydrogen which produces the 21-cm absorption feature found by M. Roberts et al. at NRAO. It is found that the intrinsic slope must be at least as steep as $\alpha = 2.5$, that the curvature could be due to the 2200-Å feature in the reddening curve, and that a gas-to-dust ratio similar to that in the Galaxy is not ruled out.

G. Burbidge, S. O’Dell, and D. Roberts have considered constraints on models for AO 0235+164 which result from a cosmological interpretation of its redshift and its observed variability at optical, infrared, and radio frequencies. Inherent electron synchrotron models require relativistic motions with $\gamma \geq 30$ and in situ acceleration. This object provides an extreme example of the difficulties associated with compact sources at cosmological distances.

S. O’Dell and D. Roberts have considered the composite Hubble diagram for galaxies, radio galaxies, and QSOs. Contrary to the claims of Lang et al., the data for QSOs do not provide independent evidence for a Friedmann cosmology. The apparent “evolutionary sequence” suggested by Lang et al. is due to selection effects.

S. O’Dell and T. Jones (NRAO) have continued their work on the generation and transfer of polarized radiation in compact radio sources. Special emphasis is being placed on the effects of inhomogeneities and boundary layers. Boundary-layer effects can be significant if self-absorption is important.

G. Burbidge continued work on the effects of radiation pressure and high-energy particles on gas surrounding QSOs. This work is being carried out at UCSD and Max Planck Institut für Astrophysik (Munich), in collaboration with R. Kippenhahn, L. Mestel, D. Perry, and R. Cowisk from Tata Institute, Bombay, India. G. Burbidge has continued work on the physical conditions in sources of nonthermal radiation.

W. A. Stein, S. L. O’Dell, and P. A. Strittmatter (Steward Observatory) have prepared a summary of the BL Lac objects, for the Annual Review of Astronomy and Astrophysics.

E. MARGARET BURBIDGE

IV. LICK OBSERVATORY

A. Personnel

Hamilton M. Jeffers, Astronomer Emeritus, died at his home in Carmel Highlands, 28 May 1976. He was a member of the Lick Observatory staff from 1924 until his retirement in 1961. He was a skillful observer and an authority on the field of positional astronomy, to which he made many contributions.

E. J. Wampler returned to Lick Observatory effective 1 May 1976, after being on leave to serve as first Director of the Anglo-Australian Observatory for over a year and a half. C. Sneden resigned as Assistant Research Astronomer/Lecturer effective 30 September 1975 to accept a faculty position at the University of Wyoming. B. Balick resigned as Postdoctoral Research Astronomer effective 31 December 1975 to accept a faculty position at the University of Washington. D. F. Carbon resigned as Postdoctoral Research Astronomer effective 28 February 1976 to accept a staff appointment at the Kitt Peak National Observatory. S. A. Grandi was appointed Postdoctoral Research Astronomer effective 1 January 1976. V. S. Oskanian of the Byurakan Astrophysical Observatory spent two weeks at Lick in April 1976 as a Visiting Astronomer under the auspices of the National Academy of Sciences-Academy of Sciences of the USSR Exchange Program. O. C. Wilson of the Hale Observatories was at Lick from January through April 1976 as Alexander Morrison Fellow. J. E. Hesser was in residence at Lick for about five weeks in April-May 1976 during his sabbatical leave from the Cerro Tololo Inter-American Observatory. R. Costero returned to the Instituto de Astronomía, UNAM, in December 1975 after working at Lick as a Visiting Research Associate for the better part of a year. R. L. Walker and F. Holden were guest observers at the 36-in. refractor, and B. J. Taylor was a guest observer at the Crossley reflector.


Osterbrock served as chairman of the Lowell Observatory Director Search Committee advisory to M. C. J. Putnam, the Sole Trustee. Rank continued to serve as chairman of the Scientific Advisory Group for NASA’s large cooled infrared telescope SIRTF. Design and feasibility studies have been completed. The project will now go into a new phase of instrument definition and further development which could lead to an operational system in the 1980s. Kraft served during the year on a NASA-sponsored SRT management study committee. Faber continued to serve on the CTIO time assignment committee, while Walker served for a second year on the KPNO Users’ Committee.

Rank took his infrared spectrograph to the Anglo-Australian Observatory in early June 1976. The trip was a collaborative scientific effort with D. K. Aitken of University College London. Primary objectives of the trip were the study of infrared line emission from Sgr A complex of sources, η Car, and galactic H II regions.

During 1975-1976, Walker continued in charge of the Lick Observatory program to establish a new dark-sky observing station on Junipero Serra Peak in Monterey County. In this period, Walker, in collaboration with J. E. Pepper of the Board of Studies in Environmental Studies, UCSC, worked nearly full-time on the preparation of the Environmental Impact Report for this project. This work involved specification of the nature and location of the proposed facilities, collection of field data, and consultations with in-
Interested or affected individuals, groups, and government agencies. By the end of the report period, the first draft of the Environmental Impact Report had been essentially completed.

During 1975–1976, Walker represented the Lick Observatory in discussions with public officials in Santa Clara County on the question of mitigating the effect of city lighting on the observatory facilities on Mount Hamilton. Presentations were made to the Santa Clara Association of Planning Officials, the Public Works Directors of Santa Clara County, and the Inter-City Council. As a result of these meetings, the Inter-City Council requested the Public Works Directors to appoint a committee to study the effects of lighting on Lick Observatory, and to recommend actions to alleviate the problem. The appointed committee consisted of public works directors or city engineers from the cities of Morgan Hill, Palo Alto, San Jose, and Santa Clara, a representative of the Pacific Gas and Electric Company, and Walker representing the Lick Observatory. Meetings of the committee were held during the period from November 1975–May 1976. A report was then prepared by the committee and submitted to the Inter-City Council. The committee found that Lick Observatory is not only one of the leading astronomical research institutions of the world, but also represents one of the major educational and cultural facilities in Santa Clara County, and that its ability to continue to function as a viable scientific facility is continuing to decrease due to the effects of urban lighting. The committee concluded that it is in the interest of the community to preserve the research capability of the Observatory and to that end made the following recommendations:

1. Require the shielding of light fixtures.
2. Require filtering of fixtures which have more than 15% of their emitted flux below 4400 Å.
3. Limit area lighting sources to clear mercury vapor, low-pressure sodium, and incandescent types.
4. Limit outdoor advertising lighting to clear mercury, low-pressure sodium, incandescent, neon-type, fluorescent types with less than 20% of their flux below 4900 Å, and area search lights.
5. Prohibit operation of outdoor advertising and area lighting between midnight and 6:00 AM, except for security purposes, unless the business is in operation during those hours.
6. Prohibit the use of lighting sources not listed above including, but not limited to, high-pressure sodium, metal halide, multivapor, and color-corrected mercury.
7. Exclude the following from these restrictions and requirements:
   a. lights in use prior to adoption of the restrictions,
   b. incandescent residential lighting,
   c. light produced by direct combustion of fuel,
   d. holiday lighting,
   e. operational lighting for facilities such as airports.

The committee drafted a sample outdoor lighting ordinance embodying the above recommendations, as an example of means by which they might be implemented. This report was accepted by the Inter-City Council and has now been referred by that council to the governments of the cities of Santa Clara County for their consideration.

Osterbrock, Walker, and graduate student A. T. Koski obtained spectral scans of the light pollution at Mount Hamilton due to San Jose and other nearby communities. Spectra of several types of street lamps were also obtained, and it is clear from them that the low-pressure sodium lamp would, if adopted, cause the least additional light pollution.

B. Instrumentation

1. 120-in. Telescope

Work has continued to improve the performance of the 120-in. telescope. A time-of-day clock with a noninterruptible power supply, giving accurate standard and sidereal time, has been put into operation. Stepping motors have been installed in both right ascension and declination. Previously, digital position readouts, Rank and Lick engineer Osborne have studied the pointing error of the telescope as a function of position in the sky. They found that relatively simple analytic equations are sufficient to predict the effects of telescope flexure, atmospheric refraction, and aberration as functions of hour angle and declination, so that the telescope can generally be set to within 10" of the desired position. Based on this study, it has also been possible to introduce small drive rates into the declination motors to provide much better tracking of the telescope, and similar rate modifications are to be installed in the right ascension drive. The digital telescope readouts and stepping motor drives can be read and controlled by the PDP-8/I computer in the dome, making it possible to have the computer offset the telescope quickly and precisely by amounts selected by the observer. Those responsible for these improvements include Robinson, Rank, and Baldwin.

At the Cassegrain focus an additional TV camera, with remotely controlled filter slides has been installed. A solid-state memory for the TV guiding system has been installed, replacing the failure-prone circuitry that had previously been used. The PDP-8 computer has been coupled through serial multiplexer units to the telescope stepping motors, to the telescope position readouts, to the time-of-day clocks, and to the remotely controlled spectrograph. This allows automatic changes of spectograph setups, automatic offsetting of the telescope, and automatic recording of spectograph parameters, telescope coordinates, and time of day on the magnetic tapes along with data taken by the image-tube scanner. All of these improvements were made under the supervision of Robinson, Rank, and Miller.

The 120-in. primary mirror was realuminized in December 1975 under the supervision of Miller; H. Cowan, R. Laub, and N. Jern played key roles in this operation.

Herbig, with the assistance of graduate students D. Soderblom and D. Duncan, has designed the optics of a double-pass echelle system having a 4-in. collimated beam for the 120-in. coudé spectograph. It is now under construction, with joint NSF/Lick Observatory support. The detector will be a 3-stage, 40-mm image-intensifier chain plus an image dissector, of the Wampler–Robinson type. Initially, at least, it will be controlled by the same computer system used at the 120-in. Cassegrain. The resolution will be about 0.5 km sec⁻¹. The device is intended for investigations of weak interstellar lines, line structures, and rotational broadening in late-type stars.

Rank has successfully tested a new 0.5-m infrared spectrometer on the 120-in. telescope. The throughput and sensitivity are somewhat better than expected with the 24-
channel detector array which is currently in use. The detector complement will be expanded up to the design maximum of 64 as rapidly as new detectors become available.

2. Crossley Reflector

Herbig has built and tested successfully a 40-mm image intensifier arrangement at the prime focus of the Crossley reflector. The intensifier is cooled by cold nitrogen gas, and is expected to be used for narrow-band direct photography.

Cowan has completed figuring the new 39-in. diameter low-expansion-glass mirror for the Crossley telescope. The cell for mounting it in the telescope is in the design process.

3. 36-in. Refractor

R. R. Shannon of the Optical Sciences Center, University of Arizona, visited Lick as a consultant and made studies of the 36-in. lens. He outlined several tests, which are in progress, to decide whether it is feasible to refit the front surface of the lens and thus remove the microscopic pitting or "crazing" that has gradually appeared over the course of the years.

4. Site Testing

During 1975–1976, 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 on the islands of Hawaii, Madeira, Tenerife, and La Palma, for the purpose of selecting a site for the British Northern Hemisphere Observatory.

C. Scientific Program

1. Astrometric Studies

The general parallax program based on 91-cm refractor plates continues with the measurement of an additional 20 fields. These stars, mainly red and white dwarfs, will form part of the second list of parallaxes.

Work on the proper motion program continues with second-epoch photography at the 51-cm astrograph and the measurement and reductions with the upgraded version of the Gaertner automatic measuring system. About 60% of the second-epoch plates for the full program of 1246 fields at declination –20° and northward have been secured. Most of the photography has been completed for the band from 0° to +65° except for the region of the winter Milky Way. Measurements have been completed for the three zones with centers +25°, +30°, and +35° and lying outside the zone of avoidance. The reductions for proper motions, equatorial coordinates, and photometry are in progress. Results from a series of overlapping fields around the north galactic pole lead to a clearer understanding of the level of accuracy to be expected. A special study of the kinematics of the Sanduleak red stars located around the north galactic pole is in progress. Work has started on the measurement of proper motions of all known flare stars in the region of the Pleiades using finding charts kindly provided by G. Haro. Those active in the astrometric programs include Jones, Klemola, and Wirtanen with the assistance of Harlan at the telescopes. Graduate student R. Gilliland assisted on a part-time basis during the year.

R. L. Walker and F. Holden worked as guest observers with the 91-cm refractor, measuring close double stars with the bifilar micrometer.

2. Stellar Spectroscopy

Kraft, Carbon, and graduate students J. Nocar and E. Kemper continued and essentially concluded their abundance analysis of giant, subgiant, and asymptotic giant-branch stars of the metal-poor globular cluster M92. Realuminization of the 120-in. primary mirror led to a considerable increase in quantum efficiency in the UV and particularly improved observations of the NH bands at $\lambda3360$. About 50 stars in the cluster have been analyzed for Fe, C, and N abundances, using spectral synthesis techniques worked out by Carbon. Contrary to expectation, stars on the subgiant branch show large and, interalia, widely varying N abundances, up to 20 times the expectation, based on the known value of [Fe/H] (≈ ±2.2). Explanations based either on stellar evolution or possibly noneosval star formation are being considered.

Herbig's radial velocity program for T Tauri stars, largely in the Taurus– Auriga dark nebulae, has been completed. For some 26 stars both the absorption-line spectra are measurable and formaldehyde or CO velocities for the coincident molecular clouds are available. To the accuracy of these new velocities ($\sigma = 4$ km sec$^{-1}$), the stars are cloud members. There is no evidence, for example, of systematic outward velocities, as if stars were ejected immediately following formation. A few stars show discrepant velocities. One of these is probably a spectroscopic binary. The statistical properties of the velocities of these 26 stars are close to expectation, if the fraction of binaries among T Tauri stars is the same as among F–G stars of the solar neighborhood. The spectral types of the stars observed range from early G to about M4; unfortunately their distribution does not provide a useful test of evolutionary theories.

Herbig and Duncan searched the 3050–3600 Å region of $\zeta$ Oph for weak interstellar lines, to a limiting equivalent width of about 1 mÅ. This was done by digitizing and combining a series of about 20 3.3 Å mm$^{-1}$ spectrometers obtained by Herbig at the Mauna Kea Observatory, University of Hawaii. Disappointingly, none of the specific features being sought were detected; these included lines of some rare diatomic species, formaldehyde, and Be ii. Likewise, a convincing confirmation was not possible of the detection by Crutcher and Watson of interstellar OH X3078 (at 1.1 ± 0.7 mÅ).

Herbig and graduate student D. Meloy studied some very broad, very shallow depressions found in the 3800–4300 Å region of several reddened B supergiants, in an effort to determine whether they are diffuse interstellar bands lying below the conventional cutoff at 4400 Å. Some or all of these very subtle depressions may instead be of stellar origin, namely H and He i absorptions of very large negative displacement. Further observations will probably be necessary to resolve the question. Herbig is also working on the diffuse interstellar line spectrum between 6800 and 8700 Å in some
of these same stars.

A method for classifying normal A and F stars based on reddening-free Strömgren indices was developed by Faber. The scheme gives approximate MK types with an accuracy of two-tenths of a spectral subclass and one luminosity class.

3. Variable Stars

Taam, Kraft, and graduate student N. Sunztzeff completed a study of the origin and evolution of RR Lyrae stars of high metal abundance. From examination of the space motions and mean metallicity (Fe/H) of the sample, they concluded that metal-rich RR Lyrae stars were found to be only about 1/200 of that of the halo population counterpart. Model zero-age horizontal-branch stars with solar composition ($X = 0.70, Y = 0.28, Z = 0.02$) and helium core mass $M_\odot = 0.45 M_\odot$ were constructed for a mass range $0.49-0.60 M_\odot$, and were evolved through the phase of core helium burning. Evolutionary time scales along the lowest parts of the tracks, within the instability strip, were found to agree with those required by the slow period changes of metal-rich RR Lyrae stars. The models suggest that metal-rich RR Lyrae stars can be mapped from old disk giants only if the latter lost about $0.5 M_\odot$ and lie in a very limited mass range ($\Delta M = 0.02 M_\odot$).

Carbon and Kraft were joined by D. Butler, University of Maryland, in continuation of studies of the metal abundances of RR Lyrae stars in selected galactic star fields. The Preston index $\Delta S$ was measured, in particular, for a small sample of RR Lyrae stars in a region penetrating the galactic nuclear bulge (Baade's window, $l = 1^\circ$, $b = -5^\circ$). They found $\langle \Delta S \rangle = +2.6 \pm 0.9$ (m.e.), corresponding to $[\text{Fe/H}] = -0.65 \pm 0.15$ (m.e.) from Butler's calibration of $\Delta S$. The stars, on the average, are mildly metal poor. Based on the data of Butler et al., the authors concluded that the RR Lyrae stars of the galactic nuclei belong to a stellar population less metal rich than the predominant giant-star population of the region. This result shows that population indicators based on RR Lyrae stars may not safely be used in all cases to infer metal abundances in a stellar system, since the RR Lyrae stars may belong to a minority population.

4. Star Clusters and Associations

Walker has used a direct photograph of the star cluster M7 in the small Magellanic Cloud taken by Blanco with the 4-m Tololo reflector to locate stars too faint to be seen directly on the photographs of this cluster which he obtained with a Spectracon image tube on the Tololo 1.5-m reflector in 1966-1969. The photograph was a 45-min prime-focus exposure on Kodak III-A and through a GG 385 filter. A star close to the detection limit on the photograph was selected which was free from other visible nearby stars and which could be located by projection of a straight line through two brighter stars some distance away. Two 3-h Spectracon exposures in blue light on Ilford L4 nuclear emulsion were then aligned and traced in the Joyce Loebl microdensitometer. The star was detected and found to have a magnitude of $B = 23.8$. The measures on the two exposures differ by 0.2 mag giving a probable error of $\pm 0.1$ mag for a single exposure, compared to $\pm 0.06$ mag predicted from photon statistics. Measurements of this and other electronographically observed stars on the photographic plates taken with the iris diaphragm photometer of the Lick Observatory indicate that while the detection limit of the 4-m prime-focus photograph is about $B = 24$, the practical limit for photometric measurement on this plate is about $B = 22.6$, since fainter than this the calibration curve becomes very steep and non-linear. The seeing was $2^\prime$ for both photograph and electrophorographs.

Klemola is working on the determination of membership of stars in the open clusters NGC 6811, 6830, and 7510, using proper motions measured on plates kindly provided by the Allegheny Observatory.

While in residence at Lick, Hesser wrote up three papers for publication. One dealt with the determination of the interstellar reddening in the directions of four low-latitude globular clusters, and the other two (written in collaboration with W. H. Warren Jr. of NASA-Goddard) dealt with the analysis of $uvby\beta$ photometric data for 525 stars in the Orion OB1 association. He also gave colloquia at Lick and at Berkeley on his current globular cluster research, and spent some time discussing observing opportunities at Cerro Tololo with the Lick staff and students.

5. Gaseous Nebulae

While at the Anglo-Australian Observatory, Wampler used the ITS system attached to the AAT to obtain calibrated spectra of 83 planetary nebula candidates in the Magellanic Clouds. The data reduction and interpretation is still not complete but a number of conclusions are apparent from the data:

(a) As other observers with a smaller sample of data have noticed, the known planetary nebulae in the Large Magellanic Cloud have strikingly higher excitation than those in the Small Magellanic Cloud.

(b) The He/H ratio in the planetary nebulae of the two cloud seems to be the same. Other observers have suggested that the metal abundance in the SMC is lower than that found in LMC nebulae. Although more careful data analysis will be required, the preliminary results indicate that the apparent metal deficiency in the SMC nebulae could result from different excitation conditions.

(c) The survey has increased the number of Magellanic Cloud planetary nebulae with known Wolf-Rayet nuclei from 1 to 3, with three other possible candidates.

Miller and graduate student S. Hawley completed a study of the spectrum of the Ring Nebula using the 120-in. image-tube scanner. They obtained line intensities covering the range 3700-6800 Å at six widely spaced places in the nebula. The data include a wide range of ionization, though they found only a small decrease in the temperature from the center (12,000 K) to the edge (10,000 K). They found that simple correction schemes from ion to total abundances gave consistent results for O, N, and S over a wide range of ionization, but the [Ne III] lines were unexpectedly strong in the low-ionization regions where O is predominantly O\textsuperscript{I}; a
similar behavior was found for Ne in NGC 6853.

Miller and Hawley have completed observations of the nebula around FG Sge. They find that the line spectrum is typical of a low-ionization planetary nebula. The derived abundances of He, N, O, Ne, and S are normal for planetary nebulae. No evidence was found for He II λ4686, implying that the central star was probably never hotter than 50,000 Kelvin.

Miller, in collaboration with W. Krzeminski of Hale Observatories, has studied the central star of the planetary nebula Abell 63. They find it to be an eclipsing binary with period 11.2. The primary eclipse is total with a depth of 4.3. The primary is of late O type, and the amplitude of its radial velocity curve is about 200 km sec^{-1}.

Jesse Bregman finished his thesis on "Infrared Spectra of Compact Nebulæ" and will be leaving in 1976 August to take up an NRC postdoctoral fellowship at the NASA Ames Research Center. His work on the nebulae involved measuring the spatial distribution of line and continuum radiation as well as simple modeling of the observed distributions. As could be expected, some nebulae could be modeled quite accurately while others proved to have more complex structure. The Red Rectangle is a good example of the former class while NGC 7027 typifies the latter class, since significant clumping and density variations are required to explain its infrared spectrum.

Rank has continued to study infrared fine-structure lines in H II regions. Increased sensitivity is revealing widely different stages of ionization with significantly different spatial distributions. The spatial information, in particular, is allowing more accurate determination of some ionic abundances from S, A, Ne, C1, while the permitted lines are being used to provide a measure of extinction which allows direct comparison of the infrared and optical spectra.

Balick used the image-tube scanner to obtain spectra at a regular grid of points in the dusty H II region NGC 2024. The emission lines of H I, [S II], [N II], and [O III] were found at all points, while He I and [O III] lines were very weak or absent at all points. The measured line ratios do not vary across the noticeable dust features in this nebula. The average intensity ratio Hα/Hβ ≈ 10 indicates strong reddening in the nebula. No signs of modification of the ionizing radiation by dust in the nebula could be detected.

6. Normal Galaxies

In collaboration with J. S. Gallagher (Minnesota), G. R. Knapp (Caltech), and B. Balick (Washington), Faber continued to study the H I content of early-type galaxies. The group succeeded in establishing the first certain detection of H I in a normal elliptical galaxy, NGC 4278. Unlike later-type spirals, which have a double-peaked 21-cm profile, the line profile of NGC 4278 is Gaussian, having a FWHM of 440 km sec^{-1}. A survey to a comparable sensitivity limit of many other normal ellipticals by Knapp shows that NGC 4278 has an anomalously large H I content. Study of the gas distribution in NGC 4278 is continuing.

The group also detected H I in the Sombrero galaxy, NGC 4594. The line profile shows two strong peaks, indicating a rotational velocity of the gas at 350 km sec^{-1}. Faber measured the absorption-line stellar rotation curve along the major axis using the image-dissector scanner. Measurements were obtained out to the edge of the dusty disk, or 2.75 in radius. The stellar rotational velocity at 2.75 was consistent with the gas velocity, and the total mass of the galaxy within 3' was found to be $3 \times 10^{11} M_{\odot}$. If all the mass is assigned to the spheroidal component, an upper limit to $M/L_B$ of 3–4 is inferred for the bulge population, a value comparable to recent measurements for $M/L_B$ in the nuclei of elliptical galaxies.

Since the bulge of NGC 4594 resembles an elliptical in several important respects, this upper limit to $M/L_B$ for the halo population may have important implications for the behavior of $M/L$ in normal ellipticals as well. In particular, it suggests that significant increases in $M/L$ in the halos of ellipticals occur, if at all, in the very faint outermost parts, where they will be difficult or impossible to detect directly.

With Gallagher, Knapp, and Balick, Faber continued a general survey of H I in early-type galaxies. Approximately 40 more S0s were observed, with six new detections. This program will be extended into the coming year.

Faber continued to map absorption-line strength in early-type galaxies using the image-dissector scanner. Data along the major and minor axes of ten ellipticals and S0s have been collected and are now being reduced. Nuclear spectra of S0s with and without detectable 21-cm emission are also being assembled for comparison with their neutral hydrogen properties.

Whitford used an evolutionary model to assess the constraints imposed by his finding that the dwarf-sensitive star--Ford band at 9910 Å is below the level of detection in elliptical galaxies and the central bulges of early-type spirals. Power-law mass functions with an exponent $\alpha \approx 2$ were found to be ruled out. Predictions of the observable properties of galaxies from the model were found to be in satisfactory agreement with the strengths of sensitive spectral features, with the observed UVBRJIKL colors, and with recent determinations of the mass--luminosity ratio, if the initial mass function was assumed to be like that near the Sun; substitution of a dwarf-enriched population resulted in disagreement.

Shane with the collaboration of G. E. Kron published the third of a series of papers on the magnitudes of galaxies. In the earlier papers of this series, average aperture corrections for photoelectric measures of galaxies were derived, and the limiting magnitude of the Lick galaxy survey by Shane and Wirtanen was determined. The third paper, published in 1976, gives magnitude corrections to the Zwicky and Shapley--Amer galaxy catalogues.

Faber and graduate student A. Dressler completed the measurement of velocity dispersions in 11 clusters of galaxies, six of them x-ray clusters. Three of the latter, A2256, 2319, and 754 are new measurements. They find that A2319 is probably two separate clusters superposed. Compiling all the available data on x-ray cluster velocity dispersions, they conclude that the existence of a correlation between x-ray luminosity and cluster dispersion is still only a 2.5-$\sigma$ result.

Dressler completed his Ph.D. thesis work on luminosity functions of clusters of galaxies. He compiled data on 12 clusters, with an emphasis on very rich ones. He found statistically significant differences among the luminosity functions in different clusters. These included variations in $L_*$, the magnitude normalization constant, and the steepness of the function at the bright end. The clusters in the sample
containing cD galaxies tended to have steeper slopes at the bright end plus a large gap in magnitude between the first and second brightest cluster members. The most straightforward interpretation of these results is that the bright cD galaxy has been formed through gravitational accretion of the next brightest members, leading to a deficiency in the luminosity function just below the cD. However, other interpretations are possible. Further analysis of the observations is continuing, including a study of the distribution of galaxies as a function of magnitude inside the clusters. Many of the clusters have measured velocity dispersions, and core radii and mass-to-light ratios will be determined.

Graduate student D. Burstein is studying the luminosity distributions and composition gradients inside S0 galaxies. He plans to compare his measured luminosity distributions with computer-generated models in order to derive the bulge-to-disk ratio, the inclination, the length scale of the disk, and, for edge-on cases, the scale height of the disk. Photometric measurements indicate the existence of composition gradients in S0s that are qualitatively similar to those in elliptical galaxies.

7. Radio Galaxies and QSOs

Osterbrock continued spectrophotometric measurements of radio galaxies with the image-tube scanner on the 120-in. telescope. Spectral scans have now been obtained of over 20 radio galaxies and over 60 Seyfert galaxies, as well as about ten other miscellaneous emission-line galaxies. Osterbrock has reduced line intensity and width measurements of 36 Seyfert 1 galaxies, and is preparing this material for publication. Nearly all the Seyfert 1 galaxies observed have broad Fe II emission features in their spectra, while these features are relatively weak or absent in the broad emission-line radio galaxies observed. There is no correlation between Fe II emission-line strength and permitted H I emission-line widths in Seyfert 1 galaxies. The intensity ratio He I λ5876/Hβ has a relatively small range, most Seyfert 1 galaxies having values between 0.10 and 0.30, while the ratio He I λ4686/Hβ covers a much wider range. There is no correlation between Fe II and He I strengths in Seyfert 1 galaxies. The Hα/Hβ/Hγ ratios measured in Seyfert 1 galaxies do not agree with calculated recombination decrements modified by any amounts of normal reddening, and must be affected by self-absorption and/or collisional excitation. Though the emission-line spectra of Seyfert 1 galaxies and broad-line radio galaxies are in most respects similar, it seems to be possible to distinguish between these two classes of objects by the profiles of the H I lines, by the Fe II/Hβ ratio, and by the Hα/Hβ/Hγ ratios in most cases.

Osterbrock and Koski investigated the Seyfert galaxies that are intermediate between the Seyfert 1 and Seyfert 2 types, having Balmer line profiles consisting of sharp components superimposed on broad, weak components. Examples include NGC 4151, NGC 5548, Mk 6, and Mk 372, while Mk 692 is even closer to Seyfert 2 than any of these objects, but still shows weakly the broad H I wings, particularly at Hα, that are characteristic of Seyfert 1 types. A continuous sequence of spectra can be found, which must mean that in nature various relative fractions of the dense (N_e = 10^3 cm^-3) gas that emits the broad components and of the lower-density (N_e = 10^4-10^6 cm^-3) gas that emits the broad components coexist in Seyfert galaxies. The line profiles do not agree well with the charge-exchange models, and it seems more likely that the broad profiles are due to mass motions of some sort.

Osterbrock and graduate student J. Tohline found by comparison of scans of the Seyfert galaxy NGC 7603 taken in November 1974 and November 1975 that its emission-line spectrum had varied significantly in that time. In that time interval the broad H I lines became much weaker, so that it changed from a fairly typical Seyfert 1 to a galaxy much more like a Seyfert 2. Less pronounced but significant changes had earlier been detected in the broad-line radio galaxy 3C 390.3, and spectra of these two objects as well as of the Seyfert 1 galaxy III Zw 2, a known optical and millimeter variable are being obtained on a monthly basis to monitor any further variations that may occur.

Costero and Osterbrock completed their analysis of the optical emission-line spectra of the five narrow-line radio galaxies 3C 98, 3C 178, 3C 192, 3C 327, and PKS 2322-12. All five show relatively strong [O III] and [S II] emission lines, and 3C 98, 3C 192 and 3C 327 also show high-ionization lines such as [Ne v] and [Fe v]. All five galaxies have strong late-type stellar absorption lines in their spectra. Assuming the H I emission lines arise by recombination, the measured line ratios can be approximately corrected for interstellar extinction. The three high-ionization objects have emission-line spectra similar to Cyg A, and can be reasonably well fitted by photoionization models with power-law input spectra. The two lower-ionization objects have emission-line spectra similar to M51 and M81. The continuous integrated-light spectra of the nuclei of these galaxies is not so strongly affected as the gas, which together with the dust is probably confined to relatively small volumes at the centers of the nuclei.

Koski approached completion of his Ph.D. thesis on the spectra of narrow-line radio galaxies and Seyfert 2 galaxies. Spectra were being reduced of five of the former and 23 of the latter objects. In general the spectra of these two classes appear indistinguishable. The Fe II emission features that are strong in most Seyfert 1 galaxies are absent from nearly all the narrow-line radio galaxies and Seyfert 2 galaxies, except one member of each class shows these features rather strongly. The H I relative line strengths approximately fit recombination plus interstellar reddening. It appears that most of these objects have fairly similar emission-line spectra, however with some differences in level of ionization, and that they can be approximately fitted by power-law input photoionization models.

Graduate student M. Phillips analyzed high-dispersion spectrophotometric scans of I Zw 1, the Seyfert 1 galaxy with the strongest Fe II emission features. He confirmed most of Sargent’s original identifications, and found additional weaker Fe II lines in its spectrum. He also found [O III] and [Ne III] emission at a slightly lower redshift than the H I and Fe II redshift. Phillips also identified He I, Ca II, [Ca II], [N II], [S II], and possible Na I and [O I] emission lines, all at the same redshift as the H I and Fe II redshift. Phillips continued his analysis of other Seyfert 1 galaxies with relatively strong Fe II emission, particularly Mk 478, Mk 486, Mk 335, II Zw 136, and Mk 618, and also of a few low-redshift quasars which show Fe II.

Miller has been carrying out a spectroscopic investigation with the 120-in. image-tube scanner of a group of N galaxies and QSOs, the QSOs having been selected for low luminos-
ity on the basis of their redshift and apparent magnitude. The study is concentrating on the similarities and differences between these two groups, as well as an investigation of spectroscopic evidence for associated galaxies. A related study of BL Lac objects is underway in collaboration with Hawley. They have found weak emission lines in the nuclear regions of BL Lac objects to be common and are studying the galaxy components of these systems as well.

Baldwin used the image-tube scanner on the 120-in. telescope to obtain spectra of a sample of 20 QSOs having redshifts $z > 1.2$. He measured absolute continuum fluxes for these objects and looked for correlations between the continuum luminosities and the widths, intensities, or equivalent widths of the emission lines. The equivalent widths of $[O_\text{II}]$, C IV $\lambda 1550$, and $[C \text{III}]$ $\lambda 1909$ are strongly correlated with the continuum luminosity, but it is not clear to what extent this might be a selection effect. These spectra are being studied in more detail to obtain the relative abundances of some of the elements as well as to investigate the ionization and line-broadening mechanisms.

Baldwin and Wampler, in collaboration with Burbridge and Smith (San Diego) used the 220-in. telescope, the Kitt Peak 4-m telescope, and the Anglo-Australian telescope to continue spectrophotometry of the outer parts of the Seyfert galaxy 3C 120. Numerous narrow-lined H II regions were observed. These were superposed on a background emitting a red continuous spectrum which has the general shape of a galaxy continuum about the correct redshift, but in which a preliminary reduction of the data showed no positive evidence of stellar absorption features.

Baldwin, Smith, Burbridge, Hazard, Murdoch, and Jauncey made optical and radio observations of four new high-redshift QSOs. Baldwin, Wampler, Burbridge, Smith, Hazard, and Murdoch continued their optical survey of Molonglo MC2 and MC3 radio sources, and a paper describing these results is in preparation. One of the objects identified in this survey, 1400+162, is a BL Lac object with a weak, narrow $[O \text{II}]$ $\lambda 3727$ emission line and is located in a cluster of galaxies having the same redshift ($z = 0.24$). This is also the only BL Lac object known to have extended double-lobed radio structure.

Grandi worked on several projects in connection with the spectroscopic survey of Seyfert galaxies and emission-line radio galaxies undertaken by Osterbrock. In particular, he investigated PKS 1345+12, a radio galaxy with a rather unusual spectrum, collaborating with Osterbrock and Phillips in the determination of the redshift of Calar Alto 1 (which showed that this proposed nearby galaxy is not a member of the local group), and considered the possible correlations between the radio and optical spectroscopic properties of the observed galaxies.

Grandi also worked on the problem of permitted $O_\text{I}$ emission lines (mainly $O_\text{I} \lambda 8446$) in the spectra of Nova Cygni 1975 and the Seyfert galaxies NGC 1068, 3227, 4151, 7469, and Markarian 231, 486, 506. Observational material for this investigation was obtained both with the ITS system on the Lick 120-in. telescope and with the SIT photon-counting system on the 90-in. telescope of Steward Observatory, University of Arizona. Finally, Grandi has made relatively high-resolution (3–6 Å) observations in the far-red spectral region with the ITS of the absorption line QSOs—PKS 0237–23, Ton 1530, Mk 132, B2 1225+31 and 1331+170—both to check on the reality of previously determined absorption-line redshift systems and to measure and subsequently analyze the equivalent widths of the observed absorption lines.

8. Solar System

Herbig and Harlan obtained a good series of coudé spectrograms of Comet West 1975n. Some of these cover the red and yellow regions at 11 Å mm$^{-1}$, and show a great amount of detail. Although no new molecules were found, cometary H$\alpha$ was definitely present without significant H$_2$O$^+$ contamination, and much new structure was apparent in the H$_2$O$^+$ bands near 6200 Å.

Occasional observations for positions were made for selected comets and minor planets during the course of the year. Harlan discovered a new comet (1976g) on a proper motion program plate.

DONALD E. OSTERBROCK
Director

V. BOARD OF STUDIES IN ASTRONOMY AND ASTROPHYSICS

Preamble

As avid readers will have noticed (although none, curiously, brought the fact to our attention), last year's annual report under this heading was identical with that for the preceding year. To correct the impression that nothing indeed happened in this organization in 1974–1975 we take the opportunity below of occasionally supplementing the record by reporting on the two year period 1974–1976.

A. Personnel and Faculty Activities

Burke, Faulkner, and Taam attended the Seventh Texas Symposium on Relativistic Astrophysics held in Dallas, Texas, in December 1974; Faulkner presented a paper, "Have gravitational radiation predictions been unexpectedly confirmed?" In July 1974 Faulkner attended a meeting in Venice, "The Frontiers of Astronomy in 1975," held in celebration of Sir Fred Hoyle's 60th birthday. He delivered a paper, "From the horizontal branch to the evolution of close binaries" and organized the after-dinner festivities at the associated banquet. Later in July, Faulkner and Taam visited the Institute of Astronomy, Cambridge, to participate in IAU Symposium No. 73, "The Structure and Evolution of Close Binary Systems." Faulkner presented a paper entitled "Gravitational Radiation and the Evolution of Close Binaries," which will ultimately appear in the proceedings of the symposium.

In April 1975 Faulkner spoke in the UCSC Inaugural Lecture Series, asking the question, "Can a beautiful young star find lasting happiness in the arms of a degenerate dwarf?"

Between March and June 1975, Dr. P. P. Eggleton of the Institute of Astronomy, Cambridge, paid an extended visit to work in collaboration with Faulkner and Taam.

Faulkner became Chairman of the UCSC Committee on Budget and Academic Personnel early in 1975, and con-
continued in this capacity through a period of considerable upheaval and turmoil on the Santa Cruz campus.

Brian P. Flannery received the Ph.D. degree, and left in September 1974 to take up a postdoctoral research position at the Institute of Advanced Study, Princeton.

Faulkner and Kraft were local organizers for a small meeting with approximately 40 participants. The “Workshop on FG Sge and related topics” was held at the UCSC campus from 16–19 September 1974.

In 1976 the annual meeting of all University of California research groups took place on the Santa Cruz campus. Well over 100 participants met here for a busy and informative day on 1 May. The meeting was organized by John Faulkner on behalf of both the Lick Observatory and Board of Studies.

Stanford Woosley was appointed Assistant Professor of Astronomy and Astrophysics, joining us from the California Institute of Technology in September 1975. In December Woosley presented an invited paper on “The P-Process in Supernovae” to the West Coast meeting of the American Physical Society. In February Woosley was an invited participant in the Enrico Fermi Institute (Chicago) workshop on “Gravitational Collapse and the Weak Interaction” and in the summer participated in three additional workshops covering the topics “Astrophysical Environments for Element Production” (Aspen, Colorado, 7–27 June 1976), “Isotopic Abundance Anomalies” (Greynog, Wales, 10–13 August 1976), and “Late Stages of Stellar Evolution and Nucleosynthesis” (Darmstadt, Germany, 18–20 August 1976). Woosley also spent two weeks at University College, Cardiff, Wales, working with D. D. Clayton on explanations for isotopic abundance anomalies in meteorites and two weeks at Lawrence Livermore Laboratory, Livermore, California, working with T. A. Weaver on late stages of stellar evolution.


B. Research in Theoretical Astrophysics

1. Stellar Structure

Faulkner and Taam completed their study of the accretion of hydrogen-rich material onto a white dwarf of one solar mass, and a paper was published in the Astrophysical Journal. They also pursued various aspects of their mass-loss studies (with P. P. Eggleton) and the evolution of low-mass semidetached binaries with angular momentum losses due to gravitational radiation and/or mass loss from the system.

Faulkner and former postdoctoral fellow E. L. Robinson (now at Univ. Texas, Austin) completed their study of the peculiar spectrum of AM CVn (HZ 29) and a letter was published in the Astrophysical Journal.

Postgraduate research astronomers Carbon and Taam are investigating the backwarming effects of a circumstellar dust shell upon the structure of a stellar atmosphere. In particular, attempts are made to answer the following questions: (1) does the incident infrared radiation from the dust shell produce a stellar chromosphere, and (2) is the stellar spectrum changed significantly?

Ronald E. Taam collaborated with Robert P. Kraft and Nicholas Suntzeff in a joint study of the paucity of period changes in metal rich RR Lyrae-type stars, as described above.

Bodenheimer and Taam have investigated the penetration of a neutron star into a massive companion star (such as may occur in massive binary x-ray sources). The effects of dynamical friction (i.e., drag on the neutron star), energy release associated with accreted material on the neutron star, and angular momentum transfer from the orbit to the common envelope were included. Preliminary results indicate that the common envelope is not blown off. Work is continuing on the details of the final plunge of the neutron star as it enters the central regions of its supergiant companion.

Woosley and Taam have proposed that x-ray bursts originate from carbon detonations initiated by the accretion of matter onto neutron stars. Rough limits were placed on the accretion rates for which detonations are believed to occur.

Faulkner, Gilliland, and Taam began an investigation of the response of mass-losing stars to bursts of radiation, a situation which may arise when dwarf nova eruptions affect a lobe-filling companion. Their initial studies suggested the need for more extensive investigations of the claimed instabilities of stars filling their Roche lobes.

Peter Bodenheimer made calculations of the effects of angular momentum on the early evolution of the planet Jupiter. The basic assumption is that the planet formed as a subcondensation in the solar nebula. The calculations deal with the initial phase of hydrostatic contraction during which the temperature is low (a few hundred degrees Kelvin) and the energy transport is by radiation. Under the assumptions of constancy of angular momentum of each mass element and a pressure-density relation given by the polytrope of index 3, the detailed calculations are carried to the point where the molecular hydrogen begins to dissociate at the center. If the initial state is a uniformly rotating uniform spheroid with appropriate angular momentum, the calculations reach a point of dynamical instability that probably results in the breakup of the planet by fission. With other physically reasonable distributions of angular momentum the formation of a central planet and a rotating circumplanetary envelope appears to be plausible.

Bodenheimer also continued 2-dimensional hydrodynamic calculations of protostars. The main feature of the results of these calculations is the formation of ring-like structures in the interiors of the collapsing clouds. Three-dimensional hydrodynamic calculations at Livermore, based on such rings as starting points, show instability toward the formation of two or more fragments in orbit. Bodenheimer began an investigation of the consequences of a sequence of such fragmentation stages, with spin angular momentum being transformed primarily into orbital angular momentum at each stage. The purpose of the investigation is to find out under what conditions the formation of main-sequence stars with reasonable angular momentum is possible by such a process.

The calculations of Tschauer and collaborators, based on the same physical assumptions as those of Black and Bodenheimer [Astrophys. J. 206, 138 (1975)] but with a
completely different numerical method, do not show the formation of rings in a collapsing, rotating protostellar cloud. Bodenheimer spent some time at the Max Planck Institute für Physik und Astrophysik in Munich, Germany, in order to make possible a direct and detailed comparison of the results of the two computer programs and to resolve the discrepancies.

Keeley, with P. Goldreich at Caltech, has been studying the linear oscillation modes of the Sun. Work currently in progress concerns the excitation mechanism for the 5-min oscillation. Although there are substantial uncertainties in the theory, it seems possible that the oscillations are driven by noise from the convection zone. Although any one mode near 5 min has very little energy, there are roughly \(10^5\) modes which can contribute to the observed amplitude.

Calculations by several investigators, which neglect turbulent viscosity, find many radial and nonradial modes linearly unstable. This is physically unattractive because no known mechanism seems capable of limiting the amplitude to the observed level; nonlinear interactions do not appear to provide sufficient damping by coupling stable to unstable modes. However, Keeley's calculations including turbulent viscosity show that it may be able to stabilize all the modes; uncertainties in the calculation of the viscous dissipation preclude a definitive statement.

2. Nuclear Astrophysics

Woosley, with W. A. Fowler of Caltech, continued studies of nuclear cross sections of interest to astrophysics. An important modification required for the correct calculation of astrophysical reaction rates is the inclusion of isospin mixing in the Hauser–Feshbach model. Such mixing of analog resonances into ordinary compound nuclear states makes possible nuclear reactions that are ordinarily forbidden by isospin selection rules, e.g., \(^{28}\text{Si}(\alpha,\gamma)^{32}\text{S}\) and can also lead to large enhancements of proton capture cross section in certain cases. This modification and several others of lesser importance are being included in a recalculation of all cross sections of astrophysical interest for target nuclei having masses in the range 20 ≤ \(A\) ≤ 84. Woosley and Fowler also worked on an important nuclear correction factor to the \(^{184}\text{Re}\) cosmochemistry which occurs because the daughter nucleus, \(^{184}\text{Os}\), exists in a distribution of excited states during the \(s\) process. As a result the neutron capture cross section for \(^{187}\text{Os}\) in a star is larger (for current estimates of uncertain nuclear parameters) than what is measured in the laboratory and its resulting \(s\)-process abundance is smaller. This implies more \(^{187}\text{Re}\) must have decayed to produce the current abundance of \(^{187}\text{Os}\) and the \(^{187}\text{Re}\) cosmochemistry is lengthened.

Woosley and W. M. Howard of Lawrence Livermore Laboratory completed a 5-yr investigation into the origin of so-called "\(p\)-process" nuclei. Detailed numerical calculations show that a likely site for the synthesis of these elements exists in those zones of a supernova which, prior to their disruption, have completed hydrostatic carbon burning. During the supernova explosion a variety of photodisintegration reactions transform a preexisting \(s\)-process distribution of seed into the \(p\) nuclei. This scenario differs greatly from previous models in that it does not require proton capture and can therefore be situated in deeper stellar zones (i.e., not hydrogen rich) that more naturally reach the very high temperatures (\(T \approx 2 \times 10^6\) K) known to be required for \(p\) nucleosynthesis. The preexplosive nature of the \(s\)-process seed turns out to be an interesting complication. A great deal more work is required before the origin of the "\(p\)-process" nuclei is fully understood, but a letter on these preliminary results is being prepared.

Woosley and R. Dayras and Z. Switkowski of Kellogg Radiation Lab., Caltech, have completed a study of the neutron branching ratio for carbon burning. The reaction \(^{13}\text{C}(\alpha,\gamma)^{17}\text{O}\) can be an important neutron source during carbon shell burning and the subsequent reaction \(^{22}\text{Mg}(\alpha,\gamma)^{26}\text{Na}\) affects the total neutron-to-proton ratio, an important quantity to the nucleosynthesis that ultimately results in these zones. This combined experimental and theoretical investigation has found that the rate of \(^{13}\text{C}(\alpha,\gamma)^{17}\text{O}\) is about 5 times slower than previously believed at characteristic carbon-shell-burning temperatures.

With D. D. Clayton and E. Dwek of Rice University, Woosley has been studying the nucleosynthesis that might be induced by a hypothetical proton flux in the primitive solar nebula. Such a flux has been suggested as a possible explanation for recently discovered isotopic anomalies in Mg and Ne in meteorites. By examining a variety of possible overproductions Clayton, Dwek, and Woosley have deduced an upper limit on the proton flux that could be experienced by a solid body of roughly solar composition. That limit is roughly \(10^{16}\) protons/cm\(^2\) for protons in the energy range 3 \(< E_p\text{(MeV)} < 5\).

3. Quasistellar Objects and Active Galaxies

Blumenthal and Mathews have worked together on a variety of problems connected with the emission-line region of QSOs and active galactic nuclei. They have described a simple model in which gas clouds (having densities \(n \approx 10^6\) cm\(^{-3}\) and temperatures \(T \approx 10^4\) K) confined by a relativistic plasma are accelerated to 5000–20 000 km/sec by the same ultraviolet radiation responsible for their ionization. The external pressures required are comparable with the pressures inferred from observations of compact radio sources in these same systems and have about the same physical dimensions as that occupied by the system of emission clouds. Under these conditions, Blumenthal and Mathews have shown that logarithmic line profiles will result for the hydrogen lines, in agreement with some of the profiles recently observed by Baldwin.

Mathews has studied the stability of radiation-driven sound waves in QSO clouds. The wave amplitude grows for outward moving waves. However, this instability is relatively unimportant for QSO clouds, which are typically very small in size. In addition, Blumenthal and Mathews have studied the Rayleigh–Taylor-type instabilities expected in QSO clouds which are accelerated by radiation pressure. In the frame of the cloud the acceleration may be regarded as an effective gravitational field. Optically thin clouds are found to be stable on their backside and only slightly unstable on their front (or leading) side. Clouds having layers of neutral gas are violently unstable and will not persist.

As part of this general problem, Blumenthal and Mathews have developed a complete theory for steady-state (general) relativistic winds and accretion flows around a point mass
including relativistic shocks of various strengths. The relativistic winds may be related to the intercloud medium in the emission-like region.

Bregman has developed a hydrodynamic theory for explosions in elliptical galaxies. He has also done some theoretical work on galactic winds in S0 galaxies.

4. General Relativity and Gravitational Radiation

Burke spent the summer at the Institute of Astronomy in Cambridge, England, working mainly on the foundations of general relativity and its relation to the interpretation of experiments. This work is aimed at providing a theory-free language in which to discuss both experiments, such as mass isotropy and preferred-frame experiments, and also theoretical ideas, such as the principle of equivalence. This work is still in process. The spring was spent with the relativity group at Caltech, studying the problem of motion and the radiation damping of binary systems in preparation for review lectures to be given at the Enrico Fermi summer school in Varenna.

5. Theory of Diffuse Galactic Nebulae

Sneden and Balick studied the effects of stellar metal opacities on the predicted ionization structure of H II regions. They found that these effects can be large and must be taken into account in discussions of the effects of dust on the ionizing radiation, as well as in discussions of elemental abundances derived from observations of H II regions.

Peter H. Bodenheimer
Chairman

Center for Astrophysics

Harvard College Observatory and Smithsonian Astrophysical Observatory
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INTRODUCTION

The Center for Astrophysics coordinates the related research activities of the Smithsonian Astrophysical Observatory (SAO) and the Harvard College Observatory (HCO) under a single director. This cooperative venture, combining the facilities of both observatories, draws on the resources of both Harvard University and the Smithsonian Institution. Some 140 scientists on the joint staff are engaged in a broad program of research encompassing most current interests in modern astronomy.

The Center's research activities are organized in eight divisions under the leadership of Associate Directors who are charged with coordinating the investigations and planning the resources required to carry out programs.

Data-gathering facilities include a major observatory in Arizona; an international network of field stations to observe artificial satellites, comets, and flare stars; an optical and radio astronomy facility in Massachusetts; and a radio astronomy and millimeter-wave facility in Texas. Research results are published in the Center Preprint Series, Smithsonian Contributions to Astrophysics, the Special Report series, and other technical and nontechnical bulletins, and distributed to scientific and educational institutions around the world.

The Harvard College Observatory provides major support to Harvard University's Department of Astronomy, with active programs of graduate education in astronomy and astrophysics. Smithsonian scientists are also encouraged to teach in the Department of Astronomy and in other departments. The Center also conducts an extensive public education and information program coordinated by the Smithsonian Public Affairs Office.

The Center sponsors both a Visiting Scientist Program and a Postdoctoral Fellowship Program.

More detailed discussion of the current research objectives of each of the eight divisions follows. Support from various funding agencies is indicated where appropriate.

I. ATOMIC AND MOLECULAR PHYSICS

This division (Associate Director, W. H. Parkinson) includes an experimental spectroscopy laboratory and a theoretical atomic physics group. The experimental work includes the measurement of photoionization cross sections and oscillator strengths for species of astrophysical interest. Theoretical work involves calculations of atomic and molecular structure and of cross sections for the interaction with radiation, using a variety of techniques. A wide range of collision processes is studied. The resulting data provide the basic parameters of atomic and molecular physics required in the interpretation of observational data.

The theoretical studies concentrated on the development of model potential methods for the accurate calculation of properties of complex atoms, and the construction of a relativistic generalization of the random phase approximation for studying the properties of highly stripped atomic species (ERDA, Contract 11-1-2887).

In the field of molecular structure and processes, progress has been made in large-scale ab initio calculations of potential energy curves, methods for including electronic continuum functions in molecular calculations, and the use of model potential and random phase approximation methods in molecular physics.

Theoretical studies of the thermosphere of the Earth have been carried out in which a comparison is made with in situ measurements obtained by the NASA Atmospheric Explorer Satellite Series, in order to obtain a quantitative understanding of the physical and chemical processes. The absorption of solar EUV radiation and photoelectrons in the atmosphere...