Joint Institute for Laboratory Astrophysics of the National Bureau of Standards and the University of Colorado
Boulder, Colorado 80302

The Joint Institute for Laboratory Astrophysics functions as a cooperative scientific venture of the National Bureau of Standards and the University of Colorado. Housed on the University of Colorado campus, JILA draws its scientific staff from the two parent organizations. Research is conducted at JILA in a number of areas of atomic physics and astrophysics: stellar atmospheres and radiative transfer; stellar interiors; solar physics; the interstellar medium and galactic astronomy; atomic collisions, both theoretical and experimental; spectroscopy and line broadening; chemical physics; optical resonance phenomena; and precision measurements.

I. PERSONNEL

Dr. Lee Kieffer left JILA on appointment to a position at NBS in Washington. During his 13 years at JILA he had been responsible for the development of the Information Center on Atomic Collisions. In the latter position he has been succeeded by Dr. Earl Beatty.

Dr. J. Levine, Dr. D. W. Norcross, and Dr. W. P. Reinhardt were appointed Fellows of JILA.

In addition to the permanent scientific staff of JILA, ten Visiting Fellows were in residence during 1974–1975. They were Dr. Joseph S. Bakos, Hungarian Academy of Sciences, Budapest; Dr. James N. Bardsley, University of Pittsburgh; Dr. Yu. N. Demkov, Leningrad State University, USSR; Dr. Franz D. Kahn, University of Manchester, Manchester, England; Dr. Joachim Kessler, Westfälische Wilhelms-Universität, Münster, Germany; Dr. James R. Peterson, Stanford Research Institute, Menlo Park, California; Dr. Frank H. Read, University of Manchester, Manchester, England; Dr. Blair D. Savage, University of Wisconsin; Dr. Kiyoji Uehara, University of Tokyo; Dr. Jean-Paul Zahn, Observatoire de Nice, France.

Postdoctoral Research Associates at JILA during the year included: Dr. Morris Aizenman, University of Montreal; Dr. Bruce Bohannan, University of California at Los Angeles; Dr. Marie-Louise Burnichon, Institut d’Astrophysique, Paris; Dr. John Carlsten, Harvard University; Dr. Hsing-Cheng Chen, University of California at San Diego; Dr. Sen-Tsuen Chen, University of Arkansas; Dr. Bernard Cheron, University de Caen, France; Dr. Shih-I Chu, Harvard University; Dr. Takashi Fujimoto, Kyoto University, Japan; Dr. Humberto Gerola, I. A. F. E., Buenos Aires, Argentina; Dr. James Hauser, University of Colorado; Dr. Richard Heppner, University of Michigan; Dr. Karl Heinz Hesselbacher, Kaiserslautern, Germany; Dr. Erwin F. Jaeger, University of California at Berkeley; Dr. George Khayatjah, Yale University; Dr. Richard Klein, Brandeis University; Dr. Paul Kunasz, University of Colorado; Dr. Leo Lam, Columbia University; Dr. Melissa Lambropoulos, Argonne National Laboratory, Illinois; Dr. James Land, Yale University; Dr.
Stan Lawton, University of Massachusetts; Dr. Paul Moskowitz, Johannes Gutenberg-Universitat, West Germany; Dr. Stephen O'Neil, Harvard University; Dr. Ronald Phaneuf, University of Windsor, Canada; Dr. Derek Robb, Queen's University of Belfast; Dr. Richard Scheps, University of Illinois; Dr. Edward Shoub, Stanford University; Dr. Richard Shine, University of Colorado; Dr. James Snyder, State University of New York; Dr. Paul Taylor, University of Colorado; Dr. Randolph Ware, University of Colorado; Dr. John Wheaton, Brown University; Dr. Paul Zittel, University of California at Berkeley.

Others who worked at JILA included: Dr. Dieter Fröhlick, Dr. Catherine Garmany, Dr. Steven Rountree, Dr. George Rybicki, Dr. Artur Stolz, and Dr. Richard Van Brunt.

Twenty-seven graduate students worked toward their Ph.D.s during 1974-1975 and 11 completed their degrees during this period. Of these, five wrote their theses on astrophysical topics. Thomas R. Ayres, who wrote his thesis on "The Lower Chromospheres and Upper Photospheres of Late-Type Stars," has taken a position with the Center for Astrophysics, Harvard University. Douglas Brown did his thesis on "An Empirical Study of Chromospheric Fine Structure Based on Simultaneous Spectrograms in the H, K, 8498 Å and 8542 Å Lines of Ca II." He is now at Sacramento Peak Observatory, Sunspot, New Mexico. John Mahaffy wrote on "Carbon Detonations in Rapidly Rotating Stellar Cores." He is now with the Department of Astronomy, University of Illinois. George Mount, who wrote his thesis on "Models of the Upper Photospheres of the Sun and Arcturus Based on Molecular Spectra," has taken a position with the Department of Physics, The Johns Hopkins University. William Spangenberg's thesis was "A Survey of Pulsation in RR Lyrae Star Models." He presently holds a staff position with the Los Alamos Scientific Laboratories.

II. RESEARCH ACTIVITY

Because the range of interdisciplinary effort in JILA is too broad to describe in full detail here, only work of direct interest to astronomers will be reported. Other activities, primarily in atomic and molecular physics, which strengthen the overall JILA program, are referred to in Sec. III where the year's publications are listed.

A. General Topics

R. H. Garstang presented a survey on high magnetic field spectroscopy to the Liège Astrophysical Symposium which was held in honor of P. Swings.

J. E. Faller continued work on the special-purpose telescope (LURE-Scope) designed for lunar laser ranging, and for other point-source applications. It consists of 80 achromatic lenses, the beams which pass through being brought together by articulated optical links. The telescope will be shipped to the island of Maui in Hawaii.

J. P. Hauser and P. L. Bender have investigated the effects of departures from hydrostatic equilibrium and other atmospheric phenomena on corrections to lunar laser distance measurements. The corrections are expected to be accurate at most times to 0.3 cm for vertical propagation and to 1 cm for a zenith angle of 70°.

B. E. Bohannan has continued his operational responsibilities in connection with the 24-in. telescope of the University Observatory. An exposure meter for the Cassegrain spectograph was installed during the year, greatly facilitating the acquisition of data.

P. S. Conti presented an invited paper on Of and W-R stars at the Liège Astrophysical Symposium. He was awarded a medal by the University of Liège in recognition of his research work on O and Of stars. R. McCoy has received a Guggenheim Fellowship.

B. Stellar Astronomy

P. S. Conti presented an invited paper on O and W-R stars, derived the orbital elements of HD 159176. This consists of two O7 stars, each already evolved from the zero-age main sequence.

B. Bohannan and P. S. Conti have obtained a new orbit for the O-type binary BD +40°4220. This consists of two Of supergiants with equally high luminosity, $M_r \approx -7.1$. The less-massive star is overluminous for its mass, has far the stronger emission lines of the two stars, and has all the properties of a Wolf-Rayet star except for the spectrum. They suggest that BD +40°4220 is on the way to becoming a Wolf-Rayet binary system.

A variety of stellar objects have been identified in recent years as emitters of continuous radio radiation. A detailed discussion shows that their structure, in particular, the strength and extent of surrounding H ii regions on one hand, of dust shells on the other, crosses spectral type and other stellar characteristics. A review of the current status of the problem was prepared by L. Oster. In close collaboration with members of the Max-Planck-Institut für Radiosastronomie in Bonn, Oster explored possibilities to deduce models for the radiation patterns of radio pulsars on the basis of observations and with a minimum of presumptions as to the physical emission mechanism and its geometry. He was able to show that in the simplest geometry, where the emission appears along the circumference of a great circle inclined with respect to the rotational axis of the neutron star, all major types of observations, such as the drifting of subpulses, slow and fast amplitude modulations, interpulses and the like, can be represented by the same general type of model with only small variations of the parameters. In the case of subpulse drifting, quantities such as the angle between magnetic and rotational axis can be obtained directly from observations. Oster and W. Sieber (Max-Planck-Institut, Bonn) are studying specific pulsars and more complex geometries, such as the hollow-cone model suggested by physical models of the neutron star.

B. D. Savage continued his work on ultraviolet photometry from the OAO-2. He completed interstellar extinction curves for 36 stars for the wavelength region 1800-3600 Å. The curves show a bump peaking near 2175 Å. It appears to have an interstellar rather than circumstellar origin. Some data were obtained down to 1100 Å. Savage also obtained high-resolution profiles of the diffuse interstellar features at 5780 Å in 18 heavily reddened stars. The feature is in all cases asymmetrical with its steep side towards the blue. Good fits can be obtained by assuming cold grains containing impurities which produce narrow absorption lines. Savage and Panek (Univ. Wisconsin) measured the Si iv and C iv resonance doublets in 118 O- and B-type stars and studied their behavior as a function of spectral type and luminosity. The observations included some rotating stars, $\beta$ Cephei stars, and stars with peculiar visual spectra.
C. Stellar Atmospheres

R. I. Klein and J. I. Castor have continued their work on the emission-line spectrum formed in the rapidly expanding envelopes of Of stars with an analysis of the He I spectrum. They solve the equilibrium problem for a 31-level helium atom using the dynamical model of an Of star obtained by Castor, Abbott, and Klein. Preliminary results indicate that the calculated He I/He II line-strength ratio is less than is observed, and the fault may lie in the uncertainties inherent in the treatment of the He II λ304 line.

D. C. Abbott has compiled a tabulation of oscillator strengths for all spectral lines expected to be significant in causing mass outflow in early-type stars. These are low-excitation lines of several ions of the elements more abundant than fluorine and lighter than calcium. In addition, new configuration–interaction oscillator strength calculations are underway for the relevant ions of iron and nickel. The total radiation force due to all the lines has been computed taking the fine structure and the effect of line overlap properly into account; a simplified ionization balance was assumed. The total force thus obtained is of the same order as that estimated earlier on the crude assumption that the spectrum of any ion was similar to that of C III.

J. I. Castor has investigated the instabilities that occur in a static stellar atmosphere involving a variable radiation force, following a suggestion of A. G. Hearn. It is found that both vibrational and convective-type instabilities are possible, if the variable component of the radiation force is great enough in relation to the gravity, but such conditions are unlikely to occur. These instabilities are of the type that produces from an arbitrary disturbance a large effect at a fixed point in space, rather than at a point that propagates away at the sound speed.

D. G. Hummer, P. B. Kunasz, and D. Mihalas (HAO) have completed a grid of static spherical non-LTE model atmospheres for O stars and for the nuclei of planetary nebulae. In the case of O-type supergiants, for which observational material is available, the general features of the continuum and the equivalent widths of the hydrogen lines are in reasonable accord with observations. The appearance of He II λ4686 is shown to be an indicator of atmospheric extension. The same authors have developed two methods for solving the spectral line radiative transfer equation written in the comoving frame of the gas in expanding spherical atmospheres. The generalization to multilevel atoms is in hand; when completed it will make possible the accurate calculations of line profiles for models of rapidly expanding atmospheres of O stars and W–R stars.

In collaboration with Kunasz and Mihalas, Hummer has also constructed radiative equilibrium picket-fence models in rapidly expanding spherical atmospheres in order to examine the heating and cooling that occurs because of the velocity-induced shift of line opacity in regions of the continuum. Increases in the surface temperatures of 20% were easily produced; in extreme cases even higher temperatures were found.

D. G. Hummer, P. B. Kunasz, D. Mihalas, and R. Shine (LASP) have solved the line transfer problem using an angle-averaged Doppler redistribution function in the comoving frame of the gas in an expanding planar atmosphere. These results demonstrate that the assumption of complete frequency redistribution in the comoving frame retains its validity even with large velocity gradients.

In collaboration with H. W. Moos, R. C. Henry, and W. Mc Clintock (all of Johns Hopkins U.), J. L. Linsky, R. Shine, and H. Gerola have an ongoing observing program as guest investigators on the Copernicus satellite. They are studying the outer atmospheres of K-type stars, including chromospheres, transition regions, coronae, and stellar winds. Stars presently under study are β Gem, α Boo, α Tau, ε Eri, ε Ind, ε Peg, and λ Vel and the ions under study are Mg II, H I, Si III, O V, O VI, and N V.

One important result of the Copernicus program is the observation of the O V λ1218.4–Å intercombination line in β Gem. This was interpreted as evidence for a corona with a temperature near 260 000°K around the star, and not for a transition region with a much hotter corona. Another important result is that the intensity of the Mg II resonance lines can be used to predict pressures in the stellar transition region and at the base of the corona. These pressures exhibit a trend of decreasing with later spectral type and/or increasing luminosity among the K-type stars.

The Copernicus guest investigators have also found that the Mg II resonance lines in α Boo are asymmetric in the sense that the red emission peaks are far stronger than the blue peaks and the central minima are shifted to the blue. They have interpreted this as indicating large mass loss ~5 × 10⁻⁹ M☉ /yr when the observations were made. They have also found evidence for width–luminosity relationships for the Mg II and Lα lines in K-type stars similar to the classical Wilson–Bappu effect.

T. R. Ayres, J. L. Linsky, and R. A. Shine have shown that an empirical relation between the K₁ and k₁ widths of the Ca II and Mg II lines and stellar absolute visual magnitude can be readily explained by the increase in mass column density above the temperature minimum expected as the stellar gravity is decreased. This width–luminosity relationship is similar to the classical Wilson–Bappu effect and the authors suggest that the latter effect may have the same explanation.

In collaboration with H. Y. Chiu and P. Adams (Goddard Institute for Space Studies) and S. Maran and R. Hobbs (NASA–Goddard), J. L. Linsky and G. Basri are pursuing a ground-based stellar chromospheres observing program using the Kitt Peak Solar Telescope and an SEC vidicon detector system. They have been observing at high-spectral-resolution stars of spectral types A0–V to K5 III primarily in the Ca II H and K lines and CN λ3883–Å bandhead in order to derive models for the chromospheres and upper photospheres of these stars. They have recently studied time variations in the chromosphere of α Boo and find times at which there is little mass loss and other times of very large mass loss.

T. R. Ayres and J. L. Linsky are computing detailed chromospheric models for late-type stars based on spectra of the Ca II and Mg II resonance lines and non-LTE partial redistribution methods. In the study of α Boo they derived a minimum temperature of 3200°K and a temperature–mass column density model up to a temperature of 10 000°K. In collaboration with A. Rodgers (Mt. Stromlo) and R. Kurucz (Center for Astrophysics), they are deriving similar models for α Cen A and α Cen B. They are also studying radiative losses in the photospheres and chromospheres of late-type stars in order to derive the mechanical heating in these atmospheric regions. Ayres has completed an analysis of the Sun and Procyon.

T. R. Ayres and J. L. Linsky have studied the formation of the He line in the wings of the Ca II H line in the Sun and
α Boo. They show that the He source function is photoionization dominated in both stars and that the He line is in emission in α Boo because of significant line optical depth in the chromosphere of this star.

G. H. Mount, T. R. Ayres, and J. L. Linsky have analyzed the CN λ3883 Å bandhead in α Boo. In this non-LTE study they are able to match the observed shape and intensity of the bandhead region for carbon and nitrogen abundances 1/3 of solar and oxygen abundance 60% of the solar value.

B. Haisch has developed a tensor formulation of the equation of transfer for spherically symmetric flows.

J. Toomre and J.-P. Zahn, in collaboration with E. A. Spiegel (Columbia) and J. Latour (Nice), have continued to develop a theory for convection in stars based on anelastic modal equations. This treatment has been applied to the second convection zone in A-type stars, revealing strong overshooting of motions into the adjacent radiative zones. This raises doubts about some interpretations of metallic-line stars which invoke diffusive element separation between the two convection zones. Work is under way to apply the theory to the solar convection zone.

K. B. Gebbie, in collaboration with R. Steinitz (NASA-Goddard), is exploring the effects of ionization and optical depth on the interpretation of the curve of growth in terms of abundance and microturbulence. This work is particularly relevant to the interpretation of spectra in peculiar A-type stars.

P. S. Conti presented an invited review paper on O stars at a "Symposium on HH Regions and Related Topics" held in Mittleberg, Austria. This paper discussed the present status of the data concerning the luminosity, temperature, and masses of O-type stars.

D. Stellar Interiors

The solution of the problem of the pulsational stability of stars in thermal imbalance was essentially completed, both for radial and nonradial oscillations, by M. L. Aizenman, J. P. Cox, and C. J. Hansen, in collaboration with W. R. Davey (Univ. New Mexico). As an outgrowth of this work the formal solution of the problem of the vibrational stability of differentially rotating stars was obtained by Aizenman and Cox. An application to cooling white dwarfs is in progress by Cox and Hansen, with H. M. Van Horn and D. Q. Lamb (Univ. Rochester). An application to massive stars in the immediately post-main-sequence phases during overall contraction following core hydrogen burning showed that these effects would not account for the instability of the β Cephei stars.

A vibrational instability in the lower g+ nonradial modes was found for such models during the hydrogen-shell ignition phases by Aizenman, Cox, and J. R. Lesh (Univ. Denver). This instability, if real, might eventually explain the instability of the β Cephei stars. However, this instability has not been found by at least one other worker, so its reality is presently open to question.

A survey of the nonlinear pulsations of RR Lyrae models was completed by W. R. Spangenberg. The conventional initial-value computational approach was used, but a much improved treatment of the radiation flow in the outer stellar layers was adopted. His computed light curves are perhaps the best available, short of a full-fledged radiation transfer treatment. These calculations did not support in detail Chris-

ty's earlier findings of a well-defined "transition line" between fundamental and first-harmonic modes.

R. A. Siqui completed his discussion of a number of fundamental aspects of the question of the uniqueness of the structure of evolved stellar models and their secular stability. He also discussed the relation between secular stability and the onset of the Schönberg-Chandrasekhar limit.

D. C. Schwank has nearly completed calculations of a set of simple white dwarf models with hydrogen-burning envelopes. The object of his study is possibly to relate the properties of the models (static and pulsational) to those of the dwarf novae and/or ultrashort-period variables. He has found some unstable modes driven by the burning shell but the results are still very preliminary. Schwank also completed his work on weight functions for nonradial oscillations of polytropes.

A new method for obtaining periodic solutions of the nonlinear pulsation equations was developed by R. F. Stellingwerf. This method is very powerful and appears to be most promising for many important problems in stellar pulsation theory. One of these problems concerns the "double-mode cepheids," variable stars whose variations appear to consist of a more-or-less permanent mixture of two radial pulsation modes, usually assumed to be the fundamental (with periods of some 2–4 days) and first harmonic. Another class of such problems concerns pulsating stars with very long e-folding times for pulsation amplitude (such as massive main-sequence stars) or very long switching times among pulsation modes (such as low-mass pulsators of the δ Scuti variety, or perhaps the double-mode cepheids referred to above). However, preliminary initial-value types of calculations by J. P. Cox, A. N. Cox (Los Alamos), and D. S. King (Univ. New Mexico) do not appear, so far, to be in agreement with Stellingwerf's results. Some efforts were made by Cox to apply the Stellingwerf techniques to the Los Alamos hydrodynamical cepheid calculations, and considerable progress was made.

M. L. Aizenman and J. P. Cox are now undertaking a theoretical investigation of mode-coupling phenomena in pulsating stars.

Radial pulsation theory in the linear, nonadiabatic approximation has been applied to determining the masses and radii of the known double-mode cepheids by D. S. King (Univ. New Mexico), C. J. Hansen, R. R. Ross, and J. P. Cox. Since the periods of both modes are known from observations, and since these periods depend almost entirely on mass and radius, then the latter can be computed from the observed periods. These stars are found to be low-mass (1–2 M☉), high-luminosity (several hundred solar luminosities) objects which are not accounted for by current theories of stellar evolution.

The so-called "cepheid mass discrepancy" was also discussed by the above authors. They concluded that most of this discrepancy disappears when the color–effective-temperature relation is modified slightly to yield lower effective temperatures, for given color, by some 300°–400° K than currently fashionable relations give. These authors also cited two actually proposed relations in the literature which meet these conditions.

J. P. Cox continued work on his monograph on the theory of stellar pulsation. He also completed a review article on nonradial stellar oscillations. Cox, with A. N. Cox (Los Alamos), presented an invited review at IAU Colloquium No. 29 at Budapest on Cepheid Pulsation Theory and Mul-
tiperiodic Cepheid Variables. M. L. Aizenman, with J. R. Lesh (Univ. Denver), presented an invited review on Observational Aspects of Multiperiodicity in the $\beta$ Canis Majoris Stars at the same Colloquium.

M. L. Aizenman, C. J. Hansen, and R. R. Ross completed a short study of the stability of upper-main-sequence stars in the mass range $10^{-1} M_\odot \leq M \leq 110$. They found that only the radial fundamental was unstable for $M > 60 M_\odot$ whereas all other modes, radial and nonradial, were stable. Studies involving mode coupling are in progress to explain the apparent lack of unstable upper-main-sequence objects.

The same three investigators have also nearly completed a study of the nonradial modes of oscillation of rotating, isothermal gas cylinders. If such objects are larger than a certain critical size then convection sets in and, in principle, complex $g$-mode structures should appear. These $g$-mode modes do, in fact, exist for some cylinders but if the cylinder size is increased just slightly the complex conjugate $g$-mode splits into two real $g$-mode modes. An application of this study to galactic structure is possible since, for the dynamically unstable $g$-mode, the authors find bar-like density perturbation structure with trailing arms.

H. M. Van Horn (Univ. Rochester) and C. J. Hansen conjectured that the strong magnetic fields observed in some white dwarfs may be the remnant of a field generated by dynamo action during shell flashes in a prior evolutionary state (as an active planetary nebula).

Van Horn and Hansen have considered the possible results of hydrogen-rich mass accretion onto neutron stars. It was suggested that the transient x-ray sources result from the instability which arises when the hydrogen-rich envelope is heated by high-density electron capture to the point where a thermonuclear shell flash can occur. The model places constraints on the before-and-after x-ray luminosities which ought to be observed and on the time interval between outbursts. They also considered the steady-state accretion problem wherein ultrathin hydrogen- and helium-burning shells in the envelope convert accreted material into neutron crustal material at the same rate as matter is accreted. Almost all of these shells are thermally unstable on short time scales (down to milliseconds) which may imply that searches for periodic or quasiperiodic variability in x-ray sources may be worthwhile.

L. Taff (Univ. Pittsburgh), H. M. Van Horn, C. J. Hansen, and R. R. Ross have considered multicomponent isothermal spherical systems in an attempt to elucidate the properties of evolutionary models of globular clusters where more than one species (mass) of stars is present. The inner dynamically relaxed regions of such evolutionary models were successfully reproduced. In addition, some (perhaps) important thermodynamic instabilities inherent in such isothermal systems were pointed out. J. H. Mahaffy and C. J. Hansen made a full hydrodynamic study of a "carbon detonation" supernova in $r$, $z$ geometry where the exploding object is in differential rotation. They found that unless new (and as yet undetermined) physics is introduced into the analysis it seems to be impossible to leave a condensed remnant (e.g., a rotating neutron star) after the supernova explosion of a $3-8 M_\odot$ star. As a byproduct of his work, Mahaffy (with Van Horn and Hansen) has almost completed the computation of a set of differentially rotating, zero-temperature, electron degenerate hydrogen models.

J. Crawford, C. J. Hansen, and K. T. Mahanthappa have completed calculation of the rates of direct deexcitation of iron peak nuclei by neutrino-antineutrino emission using a version of the neutral current theory of weak interactions of Weinberg and Salam. Their results, for about 50 nuclei, are applicable in the temperature range $0.6-6 \times 10^9$ K (the density of the medium does not enter). For a typical high-temperature mixture of nuclear species (based on a model of W. D. Arnett) they find that the neutrino energy loss rate is, at most, about 10% of that from other mechanisms.

C. J. Hansen, with his collaborators from the University of Colorado Nuclear Physics Laboratory, has completed a set of experiments of relevance to nuclear astrophysics. A total of 30 proton-induced reactions have been studied and their reaction rates derived for use in the temperature range of a few times $10^9$ K. The species studied consist of isotopes of the elements C, Si, Ca, Cr, Ti, Fe, Ni, Zn, Ge, and Mo.

J.-P. Zahn studied the nonadiabatic oscillations of a star, driven by an outer rotating gravitational field. This dynamical tide in close binaries applies a torque to a binary component, serving to make it corotate with its companion in a time which can be short compared to the nuclear life. Before that synchronization is achieved, the brightness distribution over the surface of the star is in general phase shifted relative to the external driving potential. Zahn separately examined various physical mechanisms which may produce tidal friction in close binary stars. He found that the two most efficient are turbulent viscosity retarding the equilibrium tide in stars with convective envelopes and radiative damping acting on the dynamical tide in stars with radiative envelopes. Theoretical predictions based on these dissipative processes are in good agreement with observations.

**E. Solar and Chromospheric Physics**

K. B. Gebbie, L. November, and J. Toomre are studying supergranulation velocity fields, using the diode-array instruments at Sacramento Peak and the spectrometers on OSO-8. The work is directed toward determining the variation with height of these convective motions, in order to identify what role they have in the transport of energy through the chromosphere.

K. B. Gebbie, in collaboration with R. Steinitz (NASA–Goddard) and V. Bar (Univ. Tel Aviv), has introduced an embedded feature model for the interpretation of chromospheric contrast profiles. This model has been used to explain Hα contrast profiles in terms of changes in density and turbulence.

K. B. Gebbie, in collaboration with R. Steinitz and G. Epstein (NASA–Goddard) is studying the helium spectrum in order to explain the observed UV line intensities. This relates to the question of energy balance in the chromosphere.

G. Mount and J. L. Linsky have continued their study of solar molecular spectra with non-LTE analyses of the CN λ3883 bandhead region and the CO fourth positive system. They find that for CN the shape and intensity of the λ3883 band are relatively insensitive to the atmospheric model, but are quite sensitive to the carbon abundance. They propose a new carbon abundance of $8.35 \pm 0.15$ on a log scale where carbon is 12. Further analysis of the CO fourth positive system awaits OSO-8 data.

T. Ayres and J. L. Linsky have derived a new model of the average quiet Sun upper photosphere and lower chromosphere by means of a partial redistribution analysis of the Mg II resonance lines from rocket spectra of Kohl and Parkinson.
(Center for Astrophysics) and the Ca II resonance lines. Their model is substantially warmer than many recently proposed models with a temperature minimum of \( \approx 4450 \) K and upper-photosphere temperatures larger than radiative equilibrium models. They find evidence for significant non-radiative heating in these layers. High-spatial-resolution studies of these lines are underway with OSO-8.

R. Shine, T. Ayres, R. Milkey (Kitt Peak National Observatory), and D. Mihalas (High Altitude Observatory) are continuing their study of general line formation with partial frequency redistribution. Recent work has included the study of a five-level Ca II ion in the Sun and the Mg II lines in solar-type stars.

D. L. Glackin and J. L. Linsky, in collaboration with R. D. Chapman, W. M. Neupert, and R. J. Thomas (all of NASA–Goddard), have studied OSO-7 spectra of the first five resonance lines and the continuum of He II. They conclude that the He II-ionization equilibrium is dominated by photoionizations and radiative recombinations, that the higher Lyman lines are formed by recombination processes, and the Lo line is formed more by collisions than recombinations.

R. Shine, H. Gerola, and J. L. Linsky have studied the effects of thermal and concentration diffusion in the solar transition region on the ionization equilibria and spectral line intensities of helium, carbon, and oxygen ions. Their most interesting finding is that the \( \lambda 584 \) and \( \lambda 304 \) resonance lines of He I and He II can be strongly enhanced in quiet and active regions as these species rapidly diffuse to higher-temperature regions where the collisional excitation rates are large. In coronal holes the transition-region temperature gradients are small and diffusion is suppressed. This mechanism may explain why coronal holes appear as dark regions in He I and He II spectroheliograms.

E. H. Avrett and J. E. Vernazza (both of the Center for Astrophysics) and J. L. Linsky are studying the ionization and excitation equilibria of He I and He II in the quiet Sun. Of interest are the roles played by collisional excitation at different layers in the chromosphere and transition region, photoionization, and the diffusion of resonance line photons.

R. A. Shine has considered non-LTE spectral line formation when there are velocity fields with geometrical scales between the microscopic and macroscopic limits. He has studied periodic sinusoidal and shock waves, and finds that the central line intensities for these intermediate-scale velocity fields are often larger than those computed in either the microscopic or macroscopic limits.

E. C. Shoub is studying the non-LTE formation of the hydrogen spectrum with a self-consistent electron energy distribution. In this work departures from a Maxwellian electron energy distribution are computed for different atmospheric parameters and optical depths in the Lo line and continuum. Significant departures occur for Lo optical depths less than \( 10^4 \). This work is being generalized to other atoms and is being applied to realistic solar and stellar model atmospheres.

**F. Interstellar Medium**

W. McClintock, R. C. Henry, and H. W. Moos (all of Johns Hopkins U.) and J. L. Linsky and H. Gerola are studying the properties of the very local interstellar medium by analyzing Copernicus Lo observations of the nearby stars \( \alpha \) Boo, \( \epsilon \) Eri, and \( \epsilon \) Ind. They are finding that for these nearby stars the interstellar Lo absorption feature is not on the damping part of the curve of growth so that local neutral hydrogen densities could be in the range \( 0.01–0.12 \) cm\(^{-3}\) depending on the Doppler broadening parameter. New Copernicus observations just obtained should be able to narrow the range of possible densities and determine the direction and magnitude of the local interstellar medium flow.

J. I. Castor, R. McCray, and R. Weaver have shown that an early-type star with a strong stellar wind will blow a cavity in the ambient interstellar gas with a radius of typically 30 pc. The theory explains the observations of O VI in front of early-type stars and also explains the observations of thin circumstellar shells of cold interstellar gas near these stars. D. Hollenbach, S.-I. Chu, and R. McCray are now developing a theory for formation and rotational excitation of molecular hydrogen in such shells.

F. D. Kahn spent much of his time developing a model for compact H II regions, in particular for W3(A). It seems that the central hole in such regions is maintained by a stellar wind from the exciting star. The shocked wind press the H II region against the ionization front. Finally, the radiation pressure from the stars tends to push the dust grains outwards, so that the interstellar matter which enters the H II region is underabundant in dust. The model seems to fit the observations quite well.

He also wrote and gave an invited lecture on supernova remnants for the XIVth International Cosmic Ray Conference in Munich, August 1975. The lecture reviewed the progress of a supernova from the initial explosion to the final disposal of the remnant a million years later. The importance of instabilities in the evolution was particularly stressed. In the late stages (after about 70,000 yr) they cause the remnant to develop into a rather thick shell, with a very filamentary structure. This lecture will be published in the proceedings of the conference.

**G. High-Energy Astrophysics**

S. Hatchett, J. Buff, and R. McCray have calculated models for non-LTE transfer of x-rays through spherically symmetric gas clouds. The spectrum that emerges from the gas cloud is rich in optical, UV, and x-ray emission lines that may be valuable diagnostics of gas flows in galactic and extragalactic x-ray sources. Hatchett and McCray are now extending these calculations to other geometries such as stellar winds in binary systems.

**H. Atomic and Spectroscopic Data**

J. Cooper (in collaboration with A. J. Barnard, Univ. British Columbia, and E. W. Smith, NBS) has completed calculations of the Stark broadening of the He I 4471- and 4922-Å lines, and tables covering a wide range of densities and temperatures have been published. These results have been successfully used by Cooper and D. Mihalas (HAO) for obtaining He I profiles in B stars which give excellent agreement with observations. Various other aspects of line broadening have been examined, including a formulation, with R. L. Greene, of a unified theory for the Stark broadening of hydrogenic ions and the examination of correlations between Doppler and pressure broadening (with D. N. Stacey, Oxford U.) which fortunately under most conditions of astrophysical interest lead to only minor deviations from a Voigt profile.
Cooper and J. F. Baur made Stark-broadening measurements using a shock tube seeded with cesium powder at a temperature of about 7500 K for the Na I D and Ca II H and K lines. In comparison with predictions of Griem and coworkers, the measured sodium widths were ~16% below the theory and the calcium widths were ~36% below the theory.

A strong resonance has been predicted in the H− spectrum at 1130 Å. It was expected that this resonance should be easily observed in the spectrum of a hydrogen arc, however, Cooper and J. Slater, with W. R. Ott and R. G. Gieres (NBS, Gaithersburg), found no experimental evidence for its existence, possibly due to the resonance being destroyed by the interatomic electric fields in the arc plasma.

W. D. Robb continued his work on the calculation of electron collision cross sections of astrophysical interest. He obtained further results for the excitation of the metastable states of Fe vi. He subsequently devoted much time to similar work for Fe iii, which involved very large calculations.

S. P. Rountree (Texas A and M) participated in some of this work during a visit to JILA.

W. P. Reinhardt and J. Broad have computed the H− total photoabsorption cross section from the detachment threshold up to photon energies of ~100 eV. They are reworking the calculations to obtain the cross sections for the processes

\[ h\nu + H^- \rightarrow H(2s \text{ or } 2p) + e^- \]
\[ h\nu + H^- \rightarrow H^+ + 2e^- \]

Reinhardt and S. V. O’Neil have computed the far-ultraviolet photoabsorption of H2.

D. G. Hummer and D. W. Norcross are calculating oscillator strengths and electron excitation cross sections for all transitions among the n = 1 and 2 levels in He-like ions to very large Z, and for all transitions among the lowest 12 terms in the C, N, O, and Ne ions of the beryllium sequence.

A. H. Mahan, A. C. Gallagher, and S. J. Smith have measured the electron impact excitation cross sections for the 3s, 3p, and 3d states of hydrogen. A. C. Gallagher and D. Leep have measured the electron excitation cross sections of the resonance lines of Mg I and, with S. T. Chen, Sr I.

J. Hall continued his work on the application of precision laser techniques to the remeasurement of the relativistic time-dilation effect. The first results provided a confirmation of the usual Lorentz transformation at an accuracy of 0.5%, so matching in accuracy the best previous result. A further accuracy improvement of about a factor 30 is expected. Hall continued other experiments on lasers, a notable result being his achievement of a spectral resolving power of 4 × 10^11 and his observation of the spectral doublet structure in methane associated with the photon momentum recoil effect.

S. B. Kemic completed his work on the behavior of the Ca II H and K lines in large magnetic fields. R. H. Garstang began the preparation of an extensive review on the spectra of atoms in magnetic fields ranging from 10^4 G upwards, and including both experimental and theoretical aspects of the subject.

H. Hotop and W. C. Lineberger completed a review of binding energies in atomic negative ions.

S.-I. Chu continued work on the rotational excitation of symmetric top molecular ions by electron impact. He also studied collisionally induced hyperfine-structure transitions in OH.

L. J. Kieffer completed a bibliography of low-energy electron and photon cross-section data, covering from 1921 to 1974.

III. PUBLICATIONS

(Coauthors not connected with JILA are shown in parentheses.)


ROY H. GARSTANG