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This annual report covers the period September 1996 through August 1997.

1. PERSONNEL

During the period covered by this report the regular academic staff of the Department of Astronomy included Richard N. Boyd, Darren L. DePoy, Jay A. Frogel, Andrew P. Gould, Eric Herbst, Gerald H. Newsom, Patrick S. Osmer (chairman), Bradley M. Peterson, Marc Pinsonneault, Richard W. Pogge, Anil K. Pradhan, Barbara S. Ryden, Robert J. Scherrer, Kristen Sellgren, Gary Steigman, Donald M. Terndrup, Terrence P. Walker, David H. Weinberg, and Robert F. Wing. Michelle Kaufman held an appiontment as Research Scientist. Emeritus members of the Astronomy Department are Eugene R. Capriotti, George W. Collins II, Stanley J. Czyzak, Phillip C. Keenan, Geoffrey Keller, William M. Protheroe, and Arne Slettebak.

The staff of the Imaging Sciences Laboratory (ISL) included Bruce Atwood (director), S. Ralph Belville, David F. Brewer, Paul L. Byard, Kevin R. Duemmel, Jerry A. Mason, Thomas P. O'Brien, Daniel P. Pappalardo, David Steinbrecher, and Robert Stonebreaker.

Michael R. Savage was manager of the Astronomy Department computer resources. Thomas Burns was Director of the Perkins Observatory.

In Flagstaff, R. Mark Wagner held the position of Research Scientist, while Ray C. Bertram was Research Associate.

Postdoctoral researchers is Astronomy during this period included Rupert A.C. Croft, Julia Kennefick, Sultana N. Nahar, João F.C. Santos, Keven I. Uchida, Ignaz Wanders, and Honglin Zhang. Santos returned to Brazil in January 1997, and Wanders left in May 1997 for a position at the University of St. Andrews, Scotland.

Graduate students in the Astronomy Department during the academic year included Manuel A. Bautista, Andreas Berlind, Dixie Burns, Alberto Conti, Mark E. Everett, Scott B. Gaudi, Cheongho Han, Anita Krishnamurthi, Leslie E. Kuchinski, Paul Martini, Vijay Krishna Narayanan, J. Michael Owen, Piotr Popowski, Solange V. Ramírez, Patrizia Romano, Andrew W. Stephens, Aniruddha R. Thakar, and Glenn P. Tiede. In addition, Emanuela Pompei was a visiting graduate student, and Yongquan Yuan arrived for the Summer quarter, 1997. The M.S. degree was awarded to Burns and Ramírez, and the Ph.D. degree to Bautista, Han, Kuchinski, Owen, Thakar, and Tiede.

Peterson was appointed Chair of the NASA Astrophysics Working Group. Wing was re-elected Chair of the IAU Working Group on Peculiar Red Giant Stars.

2. FACILITIES AND INSTRUMENTATION

In 1997 Ohio State formally joined the Large Binocular Telescope project. OSU has a one-eighth share of the LBT, which is under construction at the Mount Graham International Observatory in Arizona. Ohio State also received a grant of observing time from the Research Corporation, which increases its share of observing time on the telescope to one-sixth of the total. Other partners in the project are the University of Arizona, astronomical consortia in Italy and Germany, and the Research Corporation. The LBT, with twin 8.4-m mirrors, will be the world's largest telescope on a single mount when it is completed in 2003 and will have a 23-m baseline for interferometric observations. OSU is also joining the MDM Observatory on Kitt Peak, Arizona, and will have a one-quarter share of the observing time on its 2.4-m and 1.3-m telescopes effective July 1, 1998. This year OSU has a one-eighth share of the MDM observing time.

OSU also informed Lowell Observatory and Ohio Wesleyan University that it will be withdrawing from its 37-year partnership with them for the operation of the 1.8-m Perkins Telescope at Lowell because of its entry into the LBT project and MDM. The Department will continue its outreach programs with the Perkins Observatory in Delaware, Ohio, although it will no longer be able to provide financial support.

These events are a major milestone in OSU's efforts that began in the mid-1980s to gain access to major telescope facilities. Participation in the LBT and MDM observatories will be the cornerstone of OSU's observational program well into the next century.

In the past year, our instrumentation program completed the upgrade of the MDM/Ohio State Active Infrared Camera (MOSAIC) to a 512×1024 InSb array. The array was provided by the National Optical Astronomy Observatories (NOAO) and the U.S. Naval Observatory and was part of the ALADDIN array development program. MOSAIC was used by observers from several institutions on the Kitt Peak National Observatory 4-m and 2.1-m telescopes and at the MDM 2.4-m and 1.3-m telescopes. Further, the ISL continued working on CCD controller systems for Wise Observatory and Michigan State University. There was substantial progress on a project to build cameras for multi-color microlensing event follow-up. These cameras will be capable of simultaneous optical and infrared imaging; they will be used for microlensing monitoring on the CTIO/Yale 1-m telescope and a South African Astronomical Observatory 1-m telescope starting in 1998.

The ISL also continued to support the use of the Ohio State InfraRed Imager/Spectrometer (OSIRIS), the Imaging Fabry-Perot Spectrometer (IFPS), and the Boller and Chivens Spectrograph at the 1.8-m Perkins Telescope. These instruments were used extensively by Ohio State and Lowell Observatory personnel.

Frogel measured extinction coefficients and sensitivity values in the *JHKL* bandpasses on nearly 200 nights of observing between 1978 and 1992 on the 1.5-m and Blanco 4-m telescopes at Cerro Tololo Inter-American Observatory. Analysis of these data showed the following: There are seasonal variations in both the extinction coefficients and sensitivity values that are qualitatively consistent with expected variations in the amount of H_2O in the atmosphere — relatively high in the summer months, lower in the winter months. The linear correlation coefficients between most of these quantities are statistically significant. The yearly mean values of these quantities also show significant variability of a few hundredths of a magnitude. The correlations between these yearly means are again consistent with variations in the H_2O content of the atmosphere. At least some of these longer-term variations are closely correlated with quantitative measures of the strength of the atmospheric and oceanic El Niño Southern Oscillation phenomenon. Since, at the time of writing this annual report, the strongest ENSO ever recorded is in progress, this work has proven to be particularly timely.

3. STARS AND STELLAR EVOLUTION

Pinsonneault and J. Bahcall (IAS) have studied constraints on solar neutrino fluxes from helioseismology as well as changes in calculated solar neutrino fluxes resulting from recent improvements in nuclear reaction cross-sections. The sound speed as a function of depth calculated from solar models which include gravitational settling of helium and heavy elements is in very close agreement (0.2%) with the values inferred from helioseismology. Models with deep mixing were found to disagree with helioseismology on the sound speed in the solar interior at the 8% level. Recent revisions in nuclear reaction cross-sections and the treatment of screening have been found to cause modest decreases in the predicted solar neutrino fluxes (at the 20% level for the Homestake experiment); this still leaves a large discrepancy between experiment and theory. The close agreement between the thermal structure of the Sun inferred from seismology and that predicted by the models makes a solar model solution of the solar neutrino problem unlikely.

Pinsonneault, in collaboration with D. Duncan, F. Primas, J. Thorburn (all U. of Chicago), R. Peterson (Lick), and C. Deliyannis (Yale), has measured the beryllium abundance in the α Centauri system and the boron abundance of the Hyades giants. In related work, Pinsonneault, Thorburn and Deliyannis measured beryllium and lithium abundances in 110 Her, an F star in the ''Li dip'' region. Since beryllium and boron burn at higher temperatures than the fragile light element lithium, the simultaneous study of these three elements provides a strong test of mixing in the envelopes of main-sequence stars and dilution in giants.

Pinsonneault completed a review article on mixing in stars for the Annual Review of Astronomy and Astrophysics. The thesis work of Krishnamurthi resulted in new theoretical models for the angular momentum evolution of low-mass stars; the range of initial rotation rates was found to require star-disk locking in the T Tauri stage for a range of time scales from 0 to 10 Myr, a mass-dependent saturation threshold for angular momentum loss, and a time scale for core-envelope angular momentum transport between 100 Myr and the age of the Sun. These models were then applied to the problem of mixing in low-mass main sequence stars.

In related work, Pinsonneault and Narayanan studied lithium depletion in moderate-aged to old open clusters; Krishnamurthi studied the connection between lithium abundances, rotation, and activity in young clusters; and Pinsonneault, Walker, Steigman, and Narayanan examined ^{6}Li and ^{7}Li depletion in halo stars and the implications for cosmology. The observed distribution of initial conditions needed to explain rotation in young open clusters produces a strongly peaked distribution of lithium depletion factors (for the slowly-rotating majority of stars) and a smaller population of over-depleted stars. This pattern is consistent with the distribution of lithium abundances seen in open clusters and halo stars. The absolute depletion in halo stars was found to be constrained by both the observed dispersion in abundance and the survival of ^{6}Li in one halo star. The cosmological implications are discussed in section 10. Krishnamurthi found that there are slowly rotating stars with high lithium abundance, contradicting claims that there is a strong relationship between rapid rotation and high lithium abundance in young cool stars.

Krishnamurthi completed her Ph.D. dissertation on the rotational properties of stars in the Pleiades open cluster. In a recent preprint, she reports the results of an extensive photometric survey to detect rotational periods through modulation by sunspots and explores the connections between rotation and chromospheric/coronal activity. Her work is part of an extensive collaboration with Pinsonneault, Terndrup, J. Stauffer (CfA) and many others. Recently, this collaboration published the results of a spectroscopic survey of faint main-sequence stars in the Hyades (Stauffer *et al.* 1997), which showed that M dwarfs in this cluster are rotating fairly rapidly. Combined with similar data in the Pleiades (Stauffer *et al.*, in preparation), this indicates that the time scale for significant angular momentum loss for stars with $M > 0.5 M_\odot$ is several hundred Myr and that the rotational distribution is thus indicative of the initial distribution of rotation rates.

Gould is currently focusing his work on applications of microlensing and the local distance scale. Microlensing studies include detection of planets, resolution of stellar atmospheres, resolution of accretion disks around quasars, development of a new type of pixel lensing camera, and investigation of the relation between star counts and microlensing. Local distance-scale work includes measurement of the extinction toward Baade's Window, measuring R_0 from RR Lyrae stars, constraining R_0 from the proper motion of Sgr A*, calibrating RR Lyraes using statistical parallax, and constraining the distance to the LMC using supernova light echos.

DePoy and Gould initiated a program of microlensing follow-up observations designed to detect planets outside the solar system. The project will first design and build special cameras for the observations that will be capable of simultaneous imaging at an optical and an infrared wavelength (probably V and H). The multi-color microlensing observations will be used to remove degeneracies in the interpretation of the light curves.

DePoy and Stephens completed an infrared imaging survey of the LMC around 30 Dor. A large number of potential protostars, late-type supergiants, and carbon stars were identified. Follow-up infrared spectroscopy of many of these objects was obtained as well. The observations suggest that there are no embedded, high-mass stars forming in the molecular complex stretching south from 30 Dor to N159.

Tiede, Martini, and Frogel completed an initial study of the giant branches of open clusters as indicators of metallicity and as a test for stellar evolution theory. They applied the giant branch slope – [Fe/H] relation derived by Kuchinski, Frogel, *et al.* for globular clusters to a sample of open cluster giant branches. They found that the slope of the giant branch in K vs. $J-K$ color-magnitude diagrams correlates with [Fe/H] for open clusters as it does for metal-rich globular clusters, but that the open cluster data are systematically shifted to less negative values of giant branch slope at constant [Fe/H]. A comparison with isochrone models revealed, in part, the reason behind this finding. Tiede *et al.* found that the theoretical expectation is that *the slope of the relationship* will remain constant with decreasing population age but that the *relation itself* shifts to less negative values of giant branch slope as age is decreased. Both of these theoretical predictions agree with the trends they found in the data. They also derived new coefficients for the giant branch slope – [Fe/H] relations for 3 different populations: metal-rich globulars, bulge stars, and open clusters.

Frogel and P. Whitelock (South African Astronomical Observatory) completed a study comparing long period variables (LPVs) in globular clusters and the galactic bulge. These types of stars are important because they mark the end point of the nuclear burning lives of many low and intermediate mass stars; they can be the most luminous stars in old stellar populations, hence the possibility that they are good distance indicators; and they are responsible for ejecting significant amounts of grains in the interstellar medium. They derive the frequency of occurrence of LPVs in globular clusters and in the Baade's Window field of the Galactic bulge. LPVs occur only in clusters with $[Fe/H] \geqslant -1.0$. In these clusters their frequency of occurrence relative to the number of giant stars appears to be independent of metallicity. Integrated over all metallicities, Baade's Window appears to be deficient in LPVs. Frogel and Whitelock estimated [Fe/H] values for Baade's Window LPVs from their period and a log P vs. [Fe/H] relation derived from cluster variables and found that LPVs with $[Fe/H] \geqslant 0.0$ are absent from Baade's Window. They proposed that this is because of enhanced mass loss rates in these LPVs with a consequently abbreviated lifetime compared to lower metallicity LPVs. A typical lifetime for cluster LPVs is about 3×10^5 yrs. Finally, they call attention to the need for a much more complete survey for LPVs in globular clusters.

Keenan, in collaboration with C. Barnbaum (STScI), has studied the unusual carbon star DY Per by means of spectra of high resolution in the yellow and red regions, and low resolution in the blue. The suggestion of Alksnis and others that DY Per is an R CrB variable is supported by its light curve and interval between minima (averaging 792 days), and by the multiple components of the D-lines of sodium in its spectrum. The highest velocity among these was –174 km s^{-1} observed just after the star reached maximum light. Such fast-moving puffs or jets are characteristic of R CrB variables. Since there is evidence of a slight hydrogen deficiency, the spectral type is revised to C–Hα 4+, which implies a temperature of $T_{\rm eff}\approx3200°$K. This temperature is intermediate between those of R stars and N stars and is several thousand degrees cooler than is normal for R CrB variables. Perhaps DY Per is near the beginning of its variable phase and has not yet blown off much of its atmospheric hydrogen.

Wing, in collaboration with U.G. Jørgensen and A. Borysow (Niels Bohr Institute) and S. Höfner (Vienna U. Observatory) used the MARCS code, augmented to include the opacity of polyatomic molecules including HCN, C_2H_2, and C_3, to investigate the atmospheric structure of dwarf carbon stars. The dC stars, about 12 of which are currently known, are thought to be the result of mass transfer in binary systems and were represented in the calculations by main-sequence models enriched in carbon. Collision-induced absorption by $H_2 - H_2$ pairs was found to be a significant opacity source in metal-deficient stars whenever the temperature is low enough for H_2 to be abundant; in solar-metallicity stars, however, opacity by H^- is more important. Grain formation can be substantial in the cooler solar-metallicity stars, especially when nano-diamonds are allowed for, and its effect is to heat the surface layers, resulting in a reduction in the opacity from polyatomic molecules. Synthetic spectra and *JHK* colors calculated from these models show that dC stars have significantly different colors from giant C stars of the same effective temperature, but that the displacement in the $J-H$, $H-K$ diagram is along the temperature sequence, making difficult the recognition of dC stars from their near-infrared colors alone.

Encouraged by the recent availability of dynamical models capable of producing realistic synthetic spectra for Mira variables, Wing has restored to machine readability his 27-color scanner photometry obtained at Lick Observatory during the years 1965-67. With these data and new plotting routines, Wing and Yuan have documented the loops often executed by Miras in diagrams of bandstrength vs. color. They have also studied the dependence of amplitude on wavelength for a number of well-observed Miras.

Wing received an early distribution of Hipparcos astrometric data for a number of red giants and supergiants thought likely to be close enough for parallax measurement. Several giant carbon stars were successfully measured, although only one (U Hya) was found to lie within 200 pc of the Sun, and none as close as the dC star G77-61. The absolute visual magnitudes of M-type semi-regular variables show a strong dependence on spectral type, the cooler stars being fainter; this dependence can be attributed to the effect of TiO absorption, which reaches 2 mag or more in M8 stars. The trend is reversed for absolute magnitudes at infrared continuum points. The nearest Miras variables were found to be R Leo, χ Cyg, and R Cas; the greater distance measured for o Cet is surprising and may be spurious, since the presence of its companion causes an 11-month wobble in its photocenter.

Wing and E. Guinan (Villanova U.) have explored the consequences of the Hipparcos measurement of the parallax of α Ori, the nearest M-type supergiant. The measured parallax, 7.63 ± 1.64 mas, implies a distance of 131 ± 30 pc and a distance modulus $(m-M)_{\rm o} = 5.59\pm0.48$ mag. For $\langle V\rangle$

$= 0.50$ and $E(B-V)=0.05$, the mean M_V is -5.24, consistent with a Iab luminosity classification. The corresponding near-infrared absolute magnitude, $\langle M(104)\rangle = -8.34$, is also consistent with the value found for M2 Iab supergiants in h & χ Per for an adopted distance modulus of 12.0.

With collaborators from the Center for EUV Astrophysics in Berkeley, Pradhan has been studying white dwarfs observed with the *Extreme Ultraviolet Explorer* satellite. Main areas of investigation are the atmospheres and abundances in hot, young white dwarfs as they form and evolve along the stellar sequence. Analysis of observations by the EUVE showed that 'radiative levitation' of heavy elements such as iron strongly influences the spectra and abundances in hot DA white dwarfs. A close binary system consisting of a white dwarf accreting material from a red dwarf companion was shown to have a slow accretion rate, possibly due to magnetospheric interaction (Vennes *et al.* 1997).

4. INTERSTELLAR MEDIUM

Everett continued his dissertation research, supervised by Pogge, on the excitation of H_2 spectra excited by the shocks in young stellar outflows. Most recently they have analyzed $1-2.5\ \mu$m cross-dispersed long-slit OSIRIS spectra to determine the H_2 emission-line ratios at multiple positions in the OMC–1 outflow H_2 emission-line ''fingers.'' Certain line ratios are sensitive to the temperatures, densities, and UV radiation fields in the H_2-emitting gas. Because of this, the near-infrared H_2 line ratios are important diagnostics for studying the shock physics and excitation processes occurring in molecular clouds. They found that in the OMC–1 outflow fingers there are significant changes in the H_2 line ratios with position and that these changes could be understood in the context of the large-scale outflow morphology. The complexity of the H_2 excitation conditions observed in this region indicates a need for more detailed theoretical shock models. Nonetheless, it appears likely that a combination of different pre-shock environments, shock velocities, and excitation mechanisms affect the H_2 emission.

Bautista received his Ph.D. in August 1997; his thesis was on *Emission Spectra and Ionization Structure of Iron in Gaseous Nebulae and Partially Ionized Zones*. He is currently at NASA/GSFC working on high-energy photoionization models of AGN. Bautista and Pradhan studied the ionization structure and emission spectra of iron in low-excitation nebulae. This work includes: (i) the use of the new atomic data: photoionization cross sections, total electron-ion recombination rates, collision strengths, and transition probabilities for Fe I–Fe VI; (ii) a detailed study of the excitation mechanisms of Fe ions; and (iii) a study of the physical structure of nebulae including density and temperature variations and kinematic effects. They have reported (Bautista and Pradhan 1997, in press) a comprehensive theoretical analysis of Fe II, III, and IV spectra of the benchmark test case, the Orion nebula. Some of the findings relevant to H II regions in general are: (i) high electron densities ($N_e \approx 10^5 - 10^6$ cm^{-1}) in the H II/H I partially ionized zones (PIZ) embedded in the ionization fronts, (ii) a stringent Fe II/O I correlation in the PIZ, and (iii) large variations in gas-phase Fe abundance as deduced from Fe II, III, and IV spectra.

In the last year, R. Bettens (OSU Physics, currently Australian National University) and Herbst have reported results of their extended gas-phase chemical models of interstellar clouds, which include molecules with up to 64 carbon atoms. The new and larger molecules are linear and cyclic bare carbon clusters and hydrocarbons. The cyclic species are composed of singly and triply ringed molecules as well as soccer-ball-like structures known as fullerenes. The reactions leading to the syntheses of the complex species are based on laboratory results. Polycyclic aromatic hydrocarbons have not yet been included in their networks because it is unclear how they can be synthesized via low temperature gas-phase processes. The extended model networks have been used to study the formation of large molecules in both diffuse and dense interstellar clouds. To produce significant abundances of large molecules in diffuse clouds, Bettens and Herbst found that it is first necessary to make smaller ''seed'' molecules under conditions in which the molecules are not exposed to the harsh interstellar radiation field. One possibility is that these seeds can be formed in a dense cloud, which then begins to dissipate. Once a significant concentration of seed molecules is produced, larger molecules, which are stable in the presence of UV radiation, can be synthesized even under diffuse conditions. The results indicate that the suggestion that large molecules are the carriers of the diffuse interstellar bands is reasonable, and that the most recent suggestion that some of the lines are due to the ion C_{60}^{+} is plausible. Bettens and Herbst have also studied the formation of large molecules in dense interstellar clouds.

Gas-phase models of interstellar clouds are still afflicted by uncertainties in the rates of assorted chemical processes which have not been sufficiently studied in the laboratory. Two classes of poorly understood low-temperature processes are reactions involving neutral species (so-called ''neutral-neutral'' reactions) and reactions between molecular ions and electrons. In a continuing program to understand neutral-neutral reaction rates at low temperature, Herbst, in collaboration with the quantum chemist D. Woon (Molecular Research Institute, Palo Alto), has theoretically investigated the rate of the reaction

$$CN + C_2H_2 \rightarrow HC_3N + H$$

which is thought to be the dominant formation reaction for the well-known interstellar molecule HC_3N. The reaction was found to be rapid at all temperatures below 300 K, in agreement with recent experimental studies, suggesting that this reaction does indeed synthesize most of the observed interstellar HC_3N.

Despite their limited success in understanding whether certain neutral-neutral reactions are rapid or slow at low temperatures, Herbst and co-workers have not been able to generalize their results to the many possible neutral-neutral reactions which might be important in interstellar clouds. They have therefore constructed three major model networks — labelled the new standard model, the new neutral-neutral model, and Model 4 — in which neutral-neutral reactions are assumed to be, respectively, of little importance, of great importance, and of moderate importance. Results from these model networks have been published by H.-H. Lee (OSU

Physics), Bettens and Herbst and stored in the CDS data archive in Strasbourg, France. In general, the best agreement with observed molecular abundances is achieved with the new standard model, suggesting that although certain neutral-neutral reactions are rapid at low temperature, most are not.

All gas-phase models of interstellar clouds are still dominated by ion-molecule reactions, which are well-studied in the laboratory even at very low temperatures, and which synthesize molecular ions. These ions recombine with electrons in dissociative processes known as dissociative recombination reactions. Although the rates of such processes have been measured in the laboratory, until recently very little was known about the reaction products. Two groups, one Swedish and one Danish-Israeli, have begun to measure reaction products of dissociative recombination reactions using storage rings. Their results have differed from previous theoretical estimates of the reaction products, mainly in the large extent of dissociation found. To determine the effect of these new results on gas-phase chemical models of interstellar clouds, Herbst and Lee generalized the experimental results to the many reactions assumed to occur in clouds. Their new model calculations, using the new standard model, show that the generalized experimental results do not in the main have a significant effect on previously calculated abundances.

A theoretical program in understanding non-thermal desorption of interstellar molecules from dust particles is continuing. A recent school of thought holds that shock waves can desorb molecules intact from dust grain mantles. F. Dzegilenko (OSU Physics, currently NASA-Ames), T. Uzer (Georgia Tech), and E. Herbst recently used the classical trajectory technique to determine the branching fraction among intact desorption, fragmentation, and desorption with fragmentation for molecules on grain mantles under shocked conditions. Their results are very dependent on the bond strengths of the desorbing molecules and suggest that molecules with weak bonds will fragment as they desorb from interstellar grains.

J. Pearson (OSU Physics, currently JPL), K. Sastry (New Brunswick), E. Herbst, and F. De Lucia (OSU Physics) have recently utilized their newly measured millimeter-wave and submillimeter-wave spectrum of the known interstellar molecule ethyl alcohol (a.k.a. ethanol, booze) to identify transitions of the first excited torsional state of this molecule in interstellar clouds. This state, known as the ''gauche'' state, lies only 60 K above the ground trans state and is an indicator of warm portions of interstellar clouds near regions of high-mass star formation.

Using the IRAM Plateau de Bure Interferometer, Kaufman, N. Brouillet (Bordeaux), F. Combes (Paris), A. Baudry (Bordeaux), and F. Bash (U. Texas) have measured ^{12}CO line emission from six molecular complexes in M81. It has long been a puzzle as to how M81 is forming massive OB associations in the presence of so little molecular gas. These high resolution (5″ FWHM) data include the first identification of ^{12}CO emission associated with a giant H II region in M81. The complexes have radii ~100 pc but very narrow linewidths as compared to Galactic clouds of the same radius.

Using the OVRO Interferometer, Kaufman, W. Wall (INAOE), R. Rand (U. New Mexico), and Bash have mapped the ^{13}CO/^{12}CO intensity ratio in a spiral arm of M51 to look for a systematic variation in the temperature of the molecular gas across the spiral arm.

Sellgren and her collaborators at the Institut d'Astrophysique Spatiale have used the *Infrared Space Observatory* (ISO) to obtain high-resolution spectra from 2.4 to 45 μm of two reflection nebulae, NGC 7023 and NGC 2023. The ISO spectra show the well-known interstellar emission features at 3.3, 6.2, 7.7, 8.6, and 11.3 μm, as well as other, weaker features at 11.0 and 12.7 μm. The ''7.7'' μm feature is resolved into three distinct features centered at 7.46, 7.60 and 7.81 μm; the one at 7.46 μm is a newly discovered feature. They detect continuum emission, distinct from the interstellar emission features, throughout their entire 2.4 – 45 μm spectrum of NGC 7023. This continuum emission appears to be very smooth at their spectral resolution. They also detect both pure rotational lines and vibrational-rotational lines of H_2. Their spectrum is the highest resolution mid-infrared spectrum to date of interstellar gas and dust in a photodissociation region surrounding a B star without ionizing radiation.

Uchida, Sellgren, and M. Werner (JPL) have submitted a paper on the results of imaging spectroscopy of the reflection nebula vdB 133, obtained with the infrared camera and circular variable filter wheel on ISO. Their observations reveal the infrared emission features (IEFs) at 6.2, 7.7, 8.6, 11.3, and 12.7 μm, and an associated 5 – 15 μm continuum emission. The stellar system illuminating vdB 133 has the lowest ratio of ultraviolet (shortward of 0.4 μm) to total flux of any stars discovered to date to excite the IEFs and associated continuum emission from adjacent interstellar dust, as opposed to circumstellar dust. The low fraction of UV flux from this system poses a problem for existing models for the emission mechanism and emitting material, which all require substantial UV radiation for the excitation of the IEFs and associated continuum. They are continuing this project by obtaining ISO imaging spectroscopy of other reflection nebulae of different effective temperature to test specific identifications for the IEFs, such as polycyclic aromatic hydrocarbon molecules and hydrogenated amorphous carbon grains. Martini, Sellgren, and DePoy are obtaining long-slit 1–2.5 μm spectra of the same reflection nebulae in order to determine the excitation mechanism for H_2 emission at different positions within the nebulae. Sellgren, Uchida, Martini, and Gaudi are also obtaining supporting ground-based observations of CO emission, H_2 emission, near-infrared continuum emission, and extended red emission in reflection nebulae imaged by ISO to study the spatial distributions between different emitting components of the ISM.

5. OUR GALAXY

Sellgren, J. Carr (NRL), and S. Balachandran (U. Maryland) have made the first measurements of iron abundances in stars within the central few parsecs of the Galactic Center. They use near-infrared spectra obtained at high spectral resolution ($\lambda/\Delta\lambda = 40{,}000$) with CSHELL on the NASA Infrared Telescope Facility. A detailed spectral analysis of the Galactic Center M supergiant star IRS 7 yields a solar iron abundance, [Fe/H] $= -0.01 \pm 0.14$. This result is quite surprising, in view of the high metallicity assumed to hold for the centers of galaxies, and demands follow-up work on more stars and more elements.

Ramírez has recently received a Gemini Fellowship to pursue her Ph.D. thesis research on chemical abundances of stars in the central few hundred parsecs of the Galaxy. She is collaborating with her advisor, Sellgren, and with Carr, Balachandran, R. Blum (CTIO), and Terndrup, to perform a detailed abundance analysis of high-resolution ($\lambda/\Delta\lambda = 40{,}000$) $K-$band spectra, obtained with CSHELL at the IRTF. Serabyn & Morris (1996) have recently proposed that inflow of gas from the disk, perhaps driven by a bar, results in continuing star formation in a ''central molecular zone'' (CMZ) within a radius from the Galactic Center (GC) of $R \leqslant 200$ pc. Ramírez plans to compare abundance patterns in two groups of GC stars, one inside the CMZ ($R \leqslant 30$ pc) and one outside ($R = 300$–400 pc), which may have had different star formation histories. She will also explore whether the GC environment favors formation of massive stars by measuring both iron and $\alpha-$element abundances. The abundance analysis uses model atmospheres for late-type giants and supergiants from Brown *et al.* (1989) and Plez (1992) and the spectral synthesis program MOOG (Sneden 1973).

Uchida is continuing his studies of the Galactic Center non-thermal ''filaments,'' seven linear radio continuum features believed to be the manifestations of a strong (~mG), perhaps pervasive, vertical magnetic field in the Galactic Center region. The filaments are thought to be illuminated by the interaction with molecular clouds, which causes magnetic reconnection and the subsequent acceleration of electrons to relativistic velocities along the field lines. Also apparently requisite are nearby ionizing sources (e.g. an early-type star) to provide an ample supply of free electrons. M. Morris (UCLA), G. Serabyn (Caltech) and Uchida are exploring and refining this hypothesis, using the Very Large Array (VLA) to detail the northern tip of the non-thermal filament G359.1–0.2 where a cloud/filament/H II region coincidence is found. R. Güsten (MPIfR) and Uchida are using ISO to observe the portion of the Galactic Center radio arch that is interacting with a massive molecular cloud and an H II region. Uchida is part of a collaboration, led by Staguhn (U. Maryland), that has just completed a multi-wavelength study of G359.5+0.18, the non-thermal filament north of the Sgr C complex.

There is mounting evidence of past energetic activity in the Galactic Center region, perhaps in the form of episodic bursts of star formation. Morris and Uchida are using the VLA to image the continuum emission of one such potential by-product of this activity, the western edge of the Galactic Center lobe/AFGL 5376 region, a large-scale (~100 pc) candidate shock feature arising from the Galactic Center.

Uchida is developing a 3-D kinematic code to investigate the effects of shear motions on large-scale expanding bubbles in the GC region and, specifically, the possibility that shear is responsible for the longitudinal elongation of the Sgr A East non-thermal bubble toward the Galactic Center. Shear is inherently strong in the central region and may have significant influence on the evolution of large-scale features, in terms of both their morphology and their expansion timescales.

Güsten and Uchida are measuring the line-of-sight magnetic field component in the dense gas (10^{5-6} cm^{-3}) in 11 star-forming regions and H II regions by observing Zeeman splitting in the 13 GHz transition of SO with the 100-m antenna at Effelsberg. The sensitivities achieved should give clues into the nature of ambipolar diffusion in clouds and its role in the collapse process leading to star formation.

Tiede and Terndrup have completed their study of the kinematics of stars in the bulge and inner disk of the Galaxy. Part of this work, which constitutes the bulk of Tiede's Ph.D. dissertation, has been published (Tiede & Terndrup 1997); the remainder will be submitted in early 1998. They find significant asymmetries about the minor axis of the bulge in the kinematics of both the bulge and inner disk. These are qualitatively consistent with the expectations from models of the Galaxy which contain an inner bar, but it appears that the length of the bar may have been underestimated in photometric deprojections of the light from the bulge.

In collaboration with R.C. Peterson (Astrophysical Advances), E. Sadler (U. of Sydney), and A. Walker (CTIO), Terndrup received a small allocation of time on the new Two-Degree Field multifiber instrument at the Anglo-Australian Telescope. In a paper now in preparation, they report the discovery of hot ($T_{\rm eff} > 15{,}000$ K) horizontal-branch stars in the bulge. Such stars are believed responsible for the copious ultraviolet flux from ellipticals and the bulges of other spirals, and they can be used as probes of helium enrichment and mass loss in the bulge.

R.M. Rich (Columbia) and Terndrup have published a review article on the bulge of the Galaxy, which summarizes the talks and discussion at a celebratory conference at Lick Observatory on the occasion of Albert Whitford's 90th birthday (Rich & Terndrup 1997).

6. EXTRAGALACTIC ASTRONOMY

Kuchinski and Terndrup, in collaboration with A. Witt and K. Gordon (U. of Toledo), have submitted a study of the effects of dust on optical/infrared colors of the bulges of highly inclined galaxies. This work, which makes up much of Kuchinski's Ph.D. dissertation, combines Kuchinski's *BVRIJHK* surface photometry and the Witt/Gordon models of radiative transfer in galaxies for a first-ever test of models with plausible dust geometry and scattering properties.

Pogge and P. Eskridge (U. of Alabama) completed an H II region abundance study of the polar ring galaxy NGC 2685. They have found solar abundances in the ring H II regions, much higher than expected if the ring material is a tidally accreted gas-rich dwarf galaxy, which in the field have abundances of 0.1–0.3 solar. Suggestions of similar abundance patterns have also been found in MMT spectra of two other polar ring galaxies: A0136−0801 and NGC 660. These data throw open the question of the origin and evolution of these systems; in particular, their enrichment history might suggest that they are strongly self-gravitating (to retain their metals) and long-lived so as to self-enrich substantially.

Pogge has continued a study of the interacting starburst galaxy NGC 7714/15 with B. Smith (IPAC) and C. Struck (Iowa State U.). They found that the bridge connecting NGC 7714 and 7715 is rich in star formation, but that the H I in the bridge is spatially offset from the bright H II regions and the underlying stellar continuum, suggesting sequential star formation induced by the interaction. A brief follow-up search for CO J=1-0 emission with the NRAO 12-m failed to detect any warm molecular gas associated with the bridge. An Hα velocity field map has been acquired with the OSU IFPS and is being reduced and compared with the H I data from the VLA. In parallel, Struck is leading an effort to develop a numerical simulation of the encounter using gas+stars models that combine a stellar N-body calculation with an SPH code to model the gas.

Thakar (now Johns Hopkins U.), with Ryden, completed his dissertation on the formation of massive counterrotating disks in spiral galaxies using numerical simulation. His models can select between two types of gas dynamics: ''sticky'' particles, and Smoothed Particle Hydrodynamics (SPH). Results with sticky particles have established the viability of secular, adiabatic gas infall (for early and late-type spirals) and gas-rich dwarf mergers (early-type spirals only) as producers of counterrotating disks when the infall or merger occurs on a retrograde orbit with respect to the rotation of the spiral's (primary's) disk. A case study of the S0/Sa(r) galaxy NGC 4138, in which there is evidence of recent formation of a counterrotating disk, has yielded new hope for the gas-rich dwarf merger theory of counterrotating disk production in early-type primaries with hot, compact disks. Both of the models tested, gas infall and a gas-rich dwarf merger, yield counterrotating gas disks that match the observed disks in NGC 4138 in terms of mass and size. Gas infall is by definition a slower process and is more gentle on the primary disk than a merger, but the heating of the primary disk in both cases is of the order of the numerical heating due to two-body effects. SPH simulations have shed new light on the structure and dynamics of the counterrotating disks formed. Models for both types of primaries have been revisited with SPH. The counterrotating disks produced with SPH are comparable in size but are considerably thinner and kinematically colder than the corresponding sticky particle disks and the primary stellar disks. Exponential radial profiles (similar to the primary disk profiles) are not a natural by-product of the formation processes investigated and require the initial conditions to be just right. This is consistent with the sticky-particle results. In contrast to the sticky-particle results, however, SPH simulations show that the presence of primordial prograde gas in the primary disk has a dramatic effect on the dynamics of the counterrotating gas, indicating that the primary disk needs to have little or no prograde gas for a counterrotating disk to form successfully.

Terndrup, Ryden, and Pogge continue their investigation of the surface photometry of dwarf galaxies in the Virgo cluster. With T. Statler (Ohio U.), they are starting a program of *BVRI* photometry of dwarf ellipticals. The multicolor photometry will constrain stellar populations and permit an exploration of surface brightness fluctuations in early-type dwarfs. Accurate determination of surface brightness fluctuations will permit a calculation of the upper end of the stellar luminosity function and may help to determine the three-dimensional distribution of dwarf ellipticals within the Virgo cluster.

E.-C. Sung (Korea Astron. Obs.), C. Han (Chungbuk National U.), M.-S. Chun (Yonsei U.), H.-I. Kim (Korea Astron. Obs.), and Ryden have measured the apparent shapes of blue compact dwarfs (BCDs) and used the information to place constraints on their intrinsic shapes. The apparent shapes are inconsistent with the BCDs being randomly-oriented oblate spheroids; however, the hypothesis that they are all prolate cannot be ruled out. If the BCDs are triaxial spheroids, their intrinsic shapes are consistent with a distribution of apparent shapes that peaks at the axis ratios 0.55:0.66:1. The apparent shapes of the BCDs are flatter than those of a sample of dwarf elliptical galaxies; the difference between the two samples is significant at the 90% confidence level.

6.1 The OSU Galaxy Survey

Frogel has initiated a collaboration with Windhorst's galaxy group at Arizona State University. They are obtaining deep $U-$band images for many of the galaxies in the OSU survey. Such data will reveal much about star formation and help in predicting the appearances of these galaxies at large redshift. In addition, the OSU survey group can now use the automatic classification and analysis scheme developed by S. Odewahn (ASU). All galaxies on the survey master list in the summer/fall sky have been observed both optically and in the near-IR. Kuchinski advanced the data reduction for survey galaxies. She and R. de Jong (Univ. of Durham) have developed a suite of programs that greatly speeds up the reduction and image-combining process. A new grant to the OSU galaxy survey team from the NSF is allowing completion of the data taking, acquisition of the hardware necessary for cd-rom data storage, and, most importantly, the hiring of a postdoctoral fellow for 3 years to work on analysis with Frogel, Sellgren, and DePoy.

7. ACTIVE GALACTIC NUCLEI AND QUASARS

Kennefick, Osmer, P. Hall (Arizona), and R. Green (NOAO) completed their work on additional spectroscopy of quasar candidates in the Deep Multicolor Survey. They identified 9 new quasars with $0.3 < z < 2.8$ and $16.8 < B < 21.6$, all of which were selected for their ultraviolet excess. No additional quasars with $z > 3$ have been found in the survey. Consequently the DMS results now show improved agreement with the predictions of other surveys for the numbers of faint quasars. They also showed there is good agreement between their modeling of quasar colors and the observations, which is important for establishing the selection efficiencies of the survey. They are preparing for publication the complete catalog of the 21,375 'stellar' objects in the survey together with the results of the spectroscopic observations of all the candidates observed. Martini is carrying out a study with Osmer of M stars in the survey. The purpose is to make a new determination of their luminosity function. First results show good agreement with a Salpeter function for $M>0.6M_{\odot}$ but a decrease for $M<0.6M_{\odot}$, in agreement with other recent results.

Kennefick, Osmer, M. Smith (CTIO), and R.R. de Carvalho (Observatório Nacional, Brasil) are adding z-band CCD data to existing JFN DPOSS plate data to search for quasars at 4.8 $<z<$ 6.5 to a limit of $i=18.5$. So far they have imaged 700 deg^2 in z using the KPNO and CTIO Schmidt telescopes and have been allocated time at CTIO for more. The data in hand will allow limits to be placed on space densities of bright quasars at $z>5$ and should help distinguish between different characterizations of the evolution of the quasar luminosity function with redshift as determined by different groups who conducted surveys for quasars at $z<5$. The group began follow-up spectroscopy in 1997 where candidates from $\sim$300 deg^2 were examined. All of the candidates were identified as late-type M dwarfs. This survey should be complete to stars as late as M9 in the solar neighborhood and to correspondingly larger distances for earlier M dwarfs. With Martini's collaboration, these stars will be classified and published as a catalog. The large area coverage and rigorous selection methods of the survey will enable a statistical investigation of the turnover in the mass function reported by Gould, Bahcall, and Flynn (1996) near the hydrogen-burning limit.

Kennefick and Osmer are involved in two collaborations with P. Hall, R. Green, and M.G. Smith to search for faint quasars at high redshift using the BTC at the CTIO 4-m. The first is a survey for quasars at $z>5$ down to $I=22$ using I, V, and B band imaging with a target area of 50 deg^2. Extrapolating from current QLFs, the survey should contain between 10 and 25 quasars at $z>5$. Twenty deg^2 were imaged in March 1997. The data have been reduced and catalog construction, using the SKICAT catalog management system (Weir *et al.* 1995), is proceeding in order to prepare for follow-up spectroscopy in spring 1998. The group also has 4 nights for imaging in November 1997 at the CTIO 4-m where an additional $\sim$20 deg^2 will be imaged in BVI. The detection or non-detection of the most distant objects in the universe and the characterization of their QLF with this survey will yield important constraints on models of massive galaxy formation and on the ionizing UV background at high z. Such quasars will also probe the intervening high-z gas and act as markers around which to search for normal galaxies forming at high redshift. The second survey is an 8 deg^2 BRI survey to $R=23.5$ to search for quasars at $3.3<z<5.0$. This survey should contain $\sim$200 $z=$ 3.3 – 4 and $\sim$30 z $=$ 4 – 5 quasars, enough to investigate the shape and evolution of the QLF at $z>3.3$ and $-26.5<M_B<-23.5$. Quantifying the QLF faint-end slope and its evolution from $z=3.3-5$ will put strong constraints on galaxy formation models and on the quasar contribution to the UV and x-ray backgrounds. Also, this faint quasar survey will complement the brighter surveys for high redshift quasars to enable separation of redshift and luminosity dependences in quasar spectral properties. In collaboration with Conti, U and V band imaging data will be added over 3 deg^2 in order to build a statistical sample of galaxies for which photometric redshifts will be computed. This galaxy sample will be used to examine the time evolution of the relation between the observable properties of galaxies (luminosities, scale lengths, colors, morphologies, velocity widths, etc.) and the physical parameters that characterize them in the theoretical framework (halo masses, halo density profiles, baryon fractions, initial angular momenta, collapse redshifts, star formation histories, and merger histories). This will also allow quasar selection to $M_B=-23$ at $z<3$.

Conti, Kennefick, Martini and Osmer conducted a search for faint quasars and AGN in the Hubble Deep Field crude combined images using *U, B, V, I* to limiting magnitudes of 26.2, 28.0, 27.8 and 26.8, respectively. FOCAS was used to produce a catalog of objects in each band. Matched catalogs were produced with SKICAT and for each detected source aperture magnitudes where computed using the IRAF PHOT routine. For object classification, a set of routines were developed to distinguish resolved from unresolved objects by means of their radial profiles. Synthetic quasar spectra in the range $2.0<z<5.5$ were generated. These include the effects of intrinsic emission lines and absorption by Lyα forest and Lyman-limit systems. Expected quasar colors were then used to identify areas of multicolor space where quasars might be expected. Two possible low redshift candidates were identified by combining their UV-excess with their radial profile information. No clear high redshift candidates were found.

Peterson, Wanders, Pogge, Wagner, and Bertram concluded their program of weekly spectroscopic monitoring of bright Seyfert galaxies. Since late 1988, they have used the CCD spectrograph on the 1.8-m Perkins Telescope at Lowell Observatory to obtain weekly high signal-to-noise ratio spectra of the Hβ spectral region of more than a dozen low-redshift Seyfert galaxies. The primary goal of this program was to determine the time delay between continuum and emission-line flux variations, which are ascribed to light travel-time delays within the broad-line region. The time delays for the galaxies studied range from about a week (for the lowest luminosity Seyfert studied, NGC 4051) to a little more than two months (for the highest luminosity galaxy in the sample, Mrk 509). The data are currently being analyzed and prepared for publication. In addition to the broad-line region sizes inferred from the time delays, this unique, homogeneous data base can be used to study profile variability in AGNs. An early, clear result is that unlike the flux variations, the broad-line profile variations are not reverberation effects, i.e., they are not due to changes in the luminosity of the central source. The data will also be used to study the long-term continuum variability of radio-quiet AGNs.

Wanders and Peterson completed an International AGN Watch project based on *International Ultraviolet Explorer* data obtained during the summer of 1996. The ultraviolet spectrum of NGC 7469 was monitored continuously for 49 days, producing over 200 individual spectra. A major result of this campaign was the detection of wavelength-dependent continuum lags: the variations at longer wavelengths follow those at shorter wavelengths, with a time delay that increases with wavelength. The trend detected in the ultraviolet spectra extends into the optical, as demonstrated through analysis of concurrent optical spectra. With collaborators K. Horne, S. Collier (St. Andrews), S. Kaspi, D. Maoz (Wise Observatory), and T. Alexander (Garching), Peterson and Wanders developed a model-independent Monte Carlo method for evaluating uncertainties in cross-correlation lags. This method, applied to NGC 7469, confirms the existence of wavelength-dependent continuum lags. The lags between variations at 1315 Å and those at 1825 Å, 4845 Å, and 6962 Å are found to be $0.22^{+0.12}_{-0.13}$ days, $1.25^{+0.48}_{-0.35}$ days, and $1.84^{+0.93}_{-0.94}$ days, respectively. The uncertainties quoted are conservative (in the sense that they might be slightly overestimated). These observations are consistent with a standard accretion disk model for the continuum source if the variability signal is propagated radially at the speed of light.

The UV/optical monitoring program on NGC 7469 was complemented by 30 days of virtually continuous monitoring with the *Rossi X-Ray Timing Explorer*. Peterson participated in this experiment, which was led by K. Nandra (Goddard Space Flight Center). Significant variations were found in both the soft X-rays and UV continuum, but the variations seem to be poorly correlated at zero lag.

Pogge and Martini have gathered flux calibrated broadband WFPC2 images of 41 of the 48 CfA Seyfert galaxies from the HST Data Archives. The CfA sample is spectroscopically complete to $m_{Zw}=14.5$ mag, making it best suited for statistical studies of Seyfert 1s and 2s. The HST images reveal a striking difference between the general appearances of Seyfert 1s and Seyfert 2s at subarcsecond scales. In particular, the Seyfert 1 nuclei are all very bright and saturated, while the Seyfert 2s are faint and embedded in complex nuclear surroundings. A few of the Seyfert 2s are clearly being obscured by circumnuclear dust in the host galaxies on scales of 10s of parsecs. This confirms a trend seen in less well-defined samples of Seyfert galaxies, but has important implications for interpretation of the differences between Seyfert 1s and 2s in the context of the Unified picture, as some of the obscuration may be intrinsic to the host galaxy, rather than a property of the unresolved central engine (e.g., a thick accretion torus). Follow-up studies using NICMOS and ground-based near-IR spectrophotometry are in progress for the coming year.

Pogge, D. Maoz (Tel Aviv), M. Eracleous (U.C. Berkeley), and L. Ho (CfA) are using the WFPC2 to obtain Hα and [O III] emission-line imaging of three UV-bright and three UV-dark LINER galaxies. Most of the images were acquired by HST between April and July 1997 and were analyzed and flux-calibrated at OSU with the help of Ohio Wesleyan University undergraduate S. Benfer. Combining the new data with archival broad-band imaging, they made maps of nuclear emission-line gas and dust on the scales of 10s of parsecs in the immediate vicinity of the LINER nuclei. One galaxy remains to be observed with HST during the coming year. The images will be combined with coordinated UV spectrophotometry and ground-based images to try to understand the nature of the line-emitting gas and to probe the nature of the central engine. A key mystery is why UV-dark LINERs have approximately the same optical emission-line strengths, but are completely undetected at wavelengths shortward of 3000 Å, while the UV-bright LINERs show strong point UV sources in their nuclei.

The Ph.D. dissertation of J. Vandegriff (OSU Physics) dealt with the nucleosynthesis that might result if clumps of matter were hit by jets of high energy particles, the sort of situation that might well exist near the central engine of quasars (Vandegriff *et al.* 1997). It was found that appreciable amounts of ^{2}H and ^{3}He can be made if the jets intersect cool clumps, whereas synthesis of nuclides beyond oxygen might be expected if the process occurs in a clump of matter that is close enough to the central engine to be heated to several hundred million K. Both possibilities might have implications for the observations of high deuterium abundance reported recently.

In a sub-class of quasars, anomalously high optical and UV fluxes are observed, particularly from Fe II spectra — the so called ''Fe II problem.'' A. Sigut (U. of Western Ontario) and Pradhan have developed a new code, based on extensive atomic models of iron with exact radiative transfer, that would test various physical mechanisms potentially responsible for the Fe II problem. X-ray spectra from highly ionized iron ions are also being studied, with a view to understanding the gravitational redshifts of the Kα lines to test the paradigm of a supermassive black hole with an accretion disk.

8. ATOMIC ASTROPHYSICS

Pradhan's group, which includes two senior research associates (Nahar and Zhang) and two graduate students (Bautista and Romano), is involved in the spectral analysis of H II regions, active galactic nuclei (AGN), and hot, young white dwarfs, as well as in theoretical atomic studies of radiative and collisional processes in astrophysical plasmas. A comprehensive program is under way to compute the basic atomic parameters required in astrophysical models. The processes include electron collisions, photoionization and recombination. The data are then employed to determine the physical conditions in the sources. Details of the program may be obtained from the Website
http://www.astronomy.ohio-state.edu/~pradhan/

The group is also part of an international collaboration called the Iron Project, with members in U.K., U.S., France, Germany, and Venezuela. The large-scale quantum mechanical calculations are being done on the Cray Y-MP 8/128 and the massively parallel Cray T3E and IBM SP2 at the Ohio Supercomputer Center in Columbus.

8.1 The Iron Project

Heavy elements of the iron-peak group such as iron, cobalt, nickel are of great importance as end-products of stellar nucleosynthesis. The main emphasis is on the *ab initio* calculation of electron impact excitation cross sections, including fine structure, with allowance for strong coupling and relativistic effects. In addition, radiative data for some of the heavier atomic systems are also calculated with improved accuracy. As a part of the Iron Project work, within the past year electron impact excitation collision strengths for Fe III and Fe XXII were published and the results for Fe IV are in press. The work on Fe XXII was an improved calculation with relativistic effects and radiation damping included.

8.2 Electron-Ion Recombination

The *ab initio* unified treatment of total electron-ion recombination (e.g. Nahar & Pradhan 1995), subsuming both radiative and di-electronic recombination, was extended to relativistic calculations for photorecombination spectra including fine structure (Zhang & Pradhan 1997). A perturbative method was implemented to include radiation damping of autoionizing resonances in photoionization and recombination of highly charged ions (Pradhan & Zhang 1997). These papers report *ab initio* R-matrix close-coupling calculations for unified (electron+ion) recombination cross sections that are in excellent agreement with *absolute* experimental recombination (DR) cross sections, including resonance structures, measured on synchrotron ion storage rings (CRYRING in Stockholm and the Test Storage Ring in Heidelberg) for Ar XIV, C V, C VI, and O VIII, and DR resonance intensities for Fe XXV measured on the Livermore Electron-Ion Beam Trap (EBIT).

8.3 Photoionization, recombination and ionization balance

The group continues large-scale computations for photoionization cross sections for large, complex ions such as iron ions. Results on Fe I, Fe IV and Fe V have been reported while work on Cr I is in progrss. The extensive resonance structures and enhanced background cross sections for these ions differ considerably from the previous values carried out in much less elaborate manner. The recombination cross sections and rate coefficients for these ions have also been carried out in a detailed manner for the first time. The recombination rate coefficients for Fe I and Fe II have been reported and the calculations for Fe IV and Fe V have also been completed. Calculations are carried out using a new, unified treatment developed by Nahar and Pradhan. In addition to the heavy ions, the recombination rate coefficients for astrophysically abundant atoms and ions are obtained along the isonuclear sequences, such as carbon ions C I–VI, nitrogen ions N I–VII, and oxygen ions O I–VIII, which are then used for determination of ionization fractions in thin, coronal plasmas. The new results differ significantly from the ealier values. However, the main point of this work is to provide, for the first time, completely self-consistent rates for photoionization and recombination for photoionization models. The rates are calculated using an identical set of atomic eigenfunctions for both photoionization and recombination and are therefore self-consistent in an *ab initio* manner.

We now also have the capabilities to calculate photoionization cross sections for high energies and for highly-charged ions, including relativistic effects, using either the Breit-Pauli R-matrix or the relativistic distorted wave codes.

8.4 Radiative transition probabilities

Nahar and Pradhan have calculated an extensive set of fine structure radiative transition probabilites for both dipole allowed and forbidden transitions in Fe III. Transition quantities for fine structure dipole allowed transitions in S II have also been calculated by Nahar. Astrophysical models use the transition probabilites of a large number of transitions, usually for fine structure levels. Additionally, a large number of oscillator strengths in LS coupling have been reported for Fe I, Fe IV and Fe V.

8.5 Atomic Data

Bautista, Romano, and Pradhan have computed new resonance-averaged photoionization cross sections from the Opacity Project database TOPbase for most astrophysically abundant elements. C. Mendoza (Caracas) and Pradhan have made TOPbase electronically available for general users from a dedicated server at NASA/GSFC (Laboratory of High Energy Astrophysics).

9. NUCLEAR ASTROPHYSICS

The premier conference on Nuclear Astrophysics, Nuclei in the Cosmos, was held at the University of Notre Dame in the summer of 1996. The summary talk for the conference was given by Boyd (1997).

9.1 rp-Process

Two papers dealt with rp-process nucleosynthesis, the high temperature process that occurs in a hydrogen-rich environment (Hellstrom *et al.* 1997, Raimann *et al.* 1997). Both concerned experimental efforts aimed at determining the properties of some of the short-lived proton-rich nuclei involved in the rp-process. These included ^{96,98}Ag and ^{98}Cd, all three of which are at or close to the proton drip-line, and could be progenitors of stable nuclei with the same baryon number. Boyd's group measured the half lives of all three nuclei. They also found that β-delayed proton emission is not highly probable for any of those nuclides, preventing abundance shifts due to that mechanism.

9.2 Stellar Nucleosynthesis

The effort (King *et al.* 1997) to determine the low-energy cross section for the $^{12}C(\alpha,\gamma)^{16}O$ reaction, being conducted at the medium energy nuclear physics facility TRIUMF, concentrated this past year on use of β-delayed proton emission from ^{17}Ne to obtain the required information. This cross section directly affects the size of the iron core during stellar collapse, and, hence, the ease or difficulty the star has exploding as a supernova. Two states in ^{16}O, a 1- state at 7.12 MeV and a 2+ state at 6.92 MeV, produce resonances that dominate the low-energy cross section for this reaction. Unfortunately, since both of those states are just below the $\alpha+{}^{12}C$ threshold, their effects on the cross section cannot be observed at laboratory energies at which observable yields can be measured. Thus indirect techniques are required to determine the $^{12}C(\alpha,\gamma)^{16}O$ cross section at energies relevant to helium burning. It was found that an isobaric analogue state in ^{17}F does have a small but adequate branch to the 2+, 6.92 MeV state of ^{16}O, making it possible to determine the impact of that ^{16}O state on the low energy $^{12}C(\alpha,\gamma)^{16}O$ cross section.

9.3 Neutrino Astrophysics

The efforts of Boyd's group to develop an observatory for supernova neutrinos have progressed to the point of designing detectors and measuring neutron backgrounds in a possible underground site (Boyd *et al.* 1997). This observatory would rely on the interactions between the neutrinos and nuclei, either in the rock surrounding the observatory or in panels of converter nuclei of, e.g., lead or iron, to produce neutrons. Detection of the neutrons would then provide the signal from the supernova. This observatory would hope to detect a sufficient number of events to do statistically significant diagnostics of the supernova collapse. It also has the potential to measure neutrino masses at cosmologically interesting levels.

The background measurements, conducted at the Waste Isolation Pilot Plant near Carlsbad, New Mexico, were found to provide an excellent signal-to-noise for the signal expected from a galactic supernova. The detector efforts are aimed at developing detectors that will be stable over long periods of time, and that will readily provide discrimination between the neutrons of interest and the much-more-numerous background γ-rays.

10. COSMOLOGY AND LARGE-SCALE STRUCTURE

10.1 Large-Scale Structure

Croft, Weinberg, N. Katz (U. Massachusetts) and L. Hernquist (U.C. Santa Cruz) have devised a method for estimating the power spectrum of mass flucuations from observations of the Lyα ''forest'' of absorption features seen in quasar spectra. The method makes use of the fact that in gravitational instability models for structure formation, variations in the optical depth to Lyα absorption caused by intergalactic gas along the line of sight to a quasar can be simply related to fluctuations in the underlying matter density. The power spectrum of the absorbed flux has the same shape on large scales as the matter power spectrum, and the amplitude can be simply normalized by requiring that the predicted mean amount of flux absorbed is the same as in an observed spectrum. The matter power spectrum obtained after this procedure is free of the uncertain ''bias parameters'' which complicate measurements made from the galaxy distribution. The method has been tested using the cosmological hydrodynamic simulations of Weinberg, Katz, and Hernquist. A preliminary application to a Keck HIRES spectrum of Q1422+231 provided by A. Songaila and L. Cowie (U. Hawaii) yields results compatible with low amplitude cold dark matter models, but with a large statistical uncertainty. An application to a much larger sample of observational data is underway.

Weinberg, Croft, Gaudi, Katz, Hernquist, U. Hellsten (U.C. Santa Cruz), J. Miralda-Escudé (U. Pennsylvania), R. Davé (U.C. Santa Cruz), and M. Rauch (Caltech) have pursued a number of other issues related to the model of the Ly α forest that emerges from hydrodynamic cosmological simulations. Key results from the past year include a demonstration that the ''standard'' cold dark matter model reproduces the observed distribution function of Lyα flux decrements, a demonstration that the argument for a high baryon density associated with the Lyα forest can be cast in very general terms that are independent of the details of the simulations or the cosmological model, and a demonstration that the simulation models can explain recent observations of metal lines associated with the Lyα forest if the intergalactic medium is enriched to $\sim 10^{-2.5}$ solar metallicity, as predicted in recent theoretical studies of enrichment from the earliest stellar systems. The current focus of the research program is on developing the most powerful statistical tools for testing cosmological models against Lyα forest data; Croft, Weinberg, Katz, and Hernquist carried out a preliminary comparison between simulations and the Q1422+231 spectrum using some of these statistics.

Weinberg, Katz, Hernquist, J. Gardner (U. Washington), C. Ma (U. Pennsylvania), and E. Bertschinger (MIT) examined theoretical predictions for the abundance of damped Ly α and Lyman limit absorbers in different cosmological scenarios, using a combination of numerical simulations and numerically calibrated semi-analytic techniques. They showed that the standard cold dark matter model reproduces the observed abundance of damped systems but that variants of this model that have significantly less small-scale power at high redshift are likely to fail this cosmological test. Even the standard model underproduces the observed abundance of Lyman limit systems, though the dependence of this result on the assumed baryon density has not yet been examined.

Narayanan and Weinberg have completed the development of their ''hybrid'' method for reconstruction analysis of galaxy redshift surveys and tested it on N-body simulations and artificial redshift catalogs. They showed that this hybrid scheme improves substantially on the Gaussianization method developed earlier by Weinberg and that application to the Point Source Catalog Redshift Survey (PSCZ) should yield significant new constraints on the value of Ω_o and the bias between galaxies and mass.

Narayanan and Croft have been testing different schemes for evolving the large-scale distribution of matter in the Universe backwards in time. Seven different schemes have been tested against the results of full gravitational N-body simulations. Various statistical measures, including the cross-correlation of the true and reconstructed initial density fields, have been applied. The majority of tests seem to indicate that both the ''hybrid'' scheme of Narayanan and Weinberg and the Lagrangian method of Croft and E. Gaztañaga (Barcelona) are significantly more accurate than the methods which have been applied to observational data so far.

Croft, together with G. Dalton (Oxford) and G. Efstathiou (Cambridge), has been studying the pattern of galaxy clustering around galaxy clusters. The strong infall motions expected in gravitational instability models cause distortions in the cross-correlation function of galaxies and clusters in redshift space. These can be quantified and used to constrain the density parameter Ω_o as well as the relationship between the galaxy and mass distributions. Direct comparisons of observations with the predictions of specific cosmologies reveal how the efficiency of galaxy formation may vary with scale. The APM galaxy and cluster redshift surveys have been used to show how, in popular cold dark matter cosmological models, the galaxy distribution is expected to be less clustered than the mass on small scales, and the value of Ω_o is constrained to be significantly less than unity.

Weinberg gave the conference summary talk at the Sesto meeting on ''Dark and Visible Matter in Galaxies and Cosmological Implications.'' His contribution to the conference proceedings reviews recent observational and theoretical progress on these topics, describes highlights of the results presented at the conference, and discusses the implications of these and other results for current understanding of the structure of galaxies, the nature of dark matter, the mechanisms of galaxy formation, and the origin of the Tully-Fisher relation. An appendix to the article lists the lyrics of ''The Dark Matter Rap: A Cosmological History for the MTV Generation.''

10.2 Big Bang Nucleosynthesis

In a paper by Orito *et al.* (1997), Boyd and his co-workers studied the possible effects of different geometries for the high-density regions in inhomogeneous models of big-bang nucleosynthesis. Both spheres and cylinders were assumed, and both uniform densities and hollow objects were studied. Each might result from some structure in the early universe. It was found that hollow cylinders, as might result from cosmic strings, gave the best representation of the big-bang abundances and also allowed the highest baryon-to-photon ratio. However, the representations of the big-bang abundances are only slightly better than they are for other geometries, and they do not do much better at resolving the well-known low-helium/high-deuterium crisis of the standard model.

The confrontation between the predictions of primordial nucleosynthesis in the context of the standard hot big-bang cosmology and the primordial abundances of the light elements (D, ^{3}He, ^{4}He, ^{7}Li) inferred from observational data is the focus of Steigman's research program. As in the past, Steigman and collaborators have continued to pursue a vigorous many-pronged program aimed at exploiting observational data to derive better estimates of the primordial abundances for each of the cosmologically interesting light elements with the goal of using these data to challenge and test the standard hot big-bang model. This effort has resulted in the OSU group's identifying an apparent ''crisis'' for standard big-bang nucleosynthesis (SBBN) as a result, mainly, of the ''tension'' between the inferred primordial abundances of deuterium and ^{4}He and their SBBN predicted yields.

In the last year Steigman has continued to direct his efforts towards using observations of D ''here and now'' (in the ISM and/or the solar system) and of ^{4}He in extragalactic H II regions as a basis for inferring the primordial abundances of D and ^{4}He. New data on possibly nearly primordial ''there and then'' deuterium observed in several QSO absorption-line systems excited the expectation that uncertain corrections for galactic evolution could be avoided, but contradictory results (''high-D'' in some absorbers, ''low-D'' in others) have left this hope unfulfilled. Steigman and colleagues (Hata *et al.* 1996) have explored the implications of this deuterium dichotomy and have proposed an alternative approach to identifying which – if either – value for the primordial abundance of D is correct. The high-D claimed for some QSO absorbing systems is fully consistent with the predictions of SBBN (and with the inferred primordial abundances of ^{4}He and ^{7}Li) but implies a very low nucleon density, in conflict with other observational constraints. In particular, high-D challenges models of galactic evolution (has 90% or more of the present ISM been cycled through stars without overproducing the heavy elements and/or tying up the interstellar gas in low-mass stars and stellar remnants?). In contrast, the low-D claimed for other absorbers is in conflict with the predictions of SBBN and the inferred primordial abundances of ^{4}He and ^{7}Li, but it suggests a more reasonable nucleon density and is consistent with ''normal'' galactic evolution.

To investigate this conundrum in more detail, Steigman, in collaboration with M. Tosi (Bologna) and D. Dearborn (Lawrence Livermore Laboratory), used a new grid of stellar models by Dearborn which track both D and ^{3}He, in concert with Tosi's chemical evolution models to follow the galactic evolution (with time and location in the Galaxy) of D and ^{3}He (Dearborn, Steigman & Tosi 1996; DST). The stellar models confirm the production of significant amounts of new ^{3}He by low-mass stars. Indeed, DST found that stellar ^{3}He production is so overwhelming that, even in the absence of any primordial D or ^{3}He, all evolution models predict ^{3}He abundances in excess of those observed in the solar system and in galactic H II regions. To reconcile this apparent contradiction, DST explored a series of non-standard stellar models in which the ^{3}He yields were modified. Even so, their conclusions reinforced the already stringent upper bound on the primordial abundance of deuterium inferred from the observed solar or ISM values. To pursue this further, Steigman, along with Tosi, F. Matteucci (Trieste), and C. Chiappini (Trieste & São Paulo), ignored the ^{3}He information and explored a wide variety of chemical evolution models to see if those capable of destroying deuterium efficiently were consistent with observational data (e.g. time-evolution of the heavy element abundances, abundance ratios, G-dwarf distribution, etc.). Tosi *et al.* (1997) have found that those models which permit large D-destruction are inconsistent with the observational data and those models consistent with the data permit only modest D-destruction (by no more than a factor of 2–3 at present). All these results point towards a relatively low primordial abundance of deuterium, tightening the noose on the universal density of baryons and exacerbating the conflict between the predicted (''high'') and observed (''low'') helium abundance.

As the second-most abundant nuclide in the Universe, ^{4}He plays a key role in testing the standard hot big-bang cosmology and in probing for new physics beyond the standard model. K. Olive and E. Skillman (U. of Minnesota) and Steigman have included new data on ^{4}He in low-metallicity extragalactic H II regions to infer the primordial helium abundance which they find to be ''low.'' The large number of independent measurements of high statistical accuracy is responsible for the very small *statistical* uncertainty in Y_P. Olive, Steigman & Skillman have also used the data in a semi-empirical approach to bounding a large class of possible contributions to *systematic* offsets in Y_P. The relatively low value derived for Y_P exacerbates the challenge to SBBN.

In an effort to explore sources of possible systematic errors, Steigman collaborated with S.M. Viegas and R. Gruenwald (IAG/USP Brazil) in modelling the low-metallicity extragalactic H II regions. They have studied the effect of temperature fluctuations on the determination of the helium abundance. In the absence of observations constraining such temperature fluctuations they found (Steigman, Viegas & Gruenwald 1997) that the systematic errors could be large, and they suggested that to minimize such uncertainty, only the very lowest metallicity regions should be used. This collaboration is continuing, extending the search for systematic errors to ionization corrections and underlying stellar absorption.

Walker is supervising a project with A. Linn (a first-year Fowler Fellow) on the primordial abundance of ^{4}He. Along with Scherrer and Steigman, they are trying to use statistical tests to bound the primordial ^{4}He abundance from observations of ^{4}He in metal-poor extragalactic H II regions.

Given the ''crisis'' in SBBN, Steigman, N. Hata (IAS) and J. Felten (NASA/GSFC) have set aside the BBN path to the baryon density and explored non-BBN constraints on the key cosmological parameters such as the age, expansion rate (Hubble parameter) and overall density of the Universe. In this manner they have been able to ''predict'' the baryon density and, consequently, the expected yields of the light element abundances from SBBN. Their results favor a Universe of modest density (0.5 – 0.6 critical), a relativity low Hubble parameter (60 km s^{-1} Mpc^{-1}), an age of 13 Gyr, and a ''high'' baryon density (0.08 – 0.10 critical). This favors ''low'' primordial deuterium in agreement with some observational data but predicts ''high'' primordial helium in conflict with the data taken at face value. Continuing work with I. Tkachev (OSU & Purdue Univ.) using observations of MACHOs and Local Group dynamics supports this high baryon density which is also consistent with estimates of the baryon density from observations of the Lyα forest.

Walker, Steigman, Pinsonneault, and Narayanan examined the cosmological implications of new stellar evolution calculations for the primordial ^{7}Li abundance. They showed that the stellar models which best fit the open cluster lithium abundances also provide the best description of halo star lithium abundances. Using several independent constraints they bounded the lithium depletion in halo stars to be between 0.2 and 0.4 dex. Unfortunately, this exacerbates the BBN crisis since the primordial lithium abundance inferred from their analysis lends equal support to the ^{4}He data and to the deuterium data (some of which is in conflict with the ^{4}He data). Additional work which examines the role of rotational mixing in globular clusters (where new data shows large lithium abundance variations) is in progress.

A second research direction by Walker centers on the production of Li, Be, and B. Walker co-authored a mainly experimental paper on the $\alpha+\alpha \rightarrow {}^{6,7}$Li cross section which finds that the production of ^{6}Li is half as large as previously thought. Walker is now completing a cosmic ray nucleosynthesis code which incorporates these new data. Steigman and Walker are examining variations in the Be and B halo star abundances at low metallicity. There appears to be a self-consistent picture emerging that these variations are exactly what one would expect from inhomogeneous cosmic ray nucleosynthesis.

Walker is finishing work on two other projects: (1) the background flux of neutrinos from all supernovae, and (2) constraints on power-law universes. Steigman, M. Kaplinghat (OSU Physics) and Walker have shown that neutrinos from all the supernovae that have ever occurred are not observable using current detectors. The neutrino flux is bounded by the redshift distribution of star formation and, even in scenarios where neutrinos mix from one type to another, the flux is too low. Also, Steigman, Walker, and Tkachev are completing work that examines the properties of cosmologies that expand as a constant power law in time.

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