Ohio State University
Department of Astronomy

Columbus, OH 43210–1106

Abstract

This annual report covers the period September 1997 through August 1998.

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 (chairperson), 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 appointment as Research Scientist. David Ennis and Glenn Tiede were lecturers. 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 included Bruce Atwood (director), S. Ralph Belville, David F. Brewer, Paul L. Byard, Jerry A. Mason, Thomas P. O'Brien, Daniel P. Pappalardo, David Steinbrecher, Robert Stonebreaker, and Edward Teiga. Unreported last year was the resignation of Kevin Duemmel and the appointment of Daniel Pappalardo as Electronic Engineer.

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

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

Postdoctoral researchers in Astronomy during this period included Rupert A. C. Croft, Paul Eskridge, Julia Kennefick, Sultana N. Nahar, Alison Sills, Keven I. Uchida, and Honglin Zhang. Kennefick left in November 1997 for a position at Oxford and Zhang left in March 1998 for a position at Los Alamos National Laboratory.

Graduate students in the Astronomy Department during the academic year included Jin An, Andreas Berlind, Alberto Conti, Mark E. Everett, B. Scott Gaudi, Anita Krishnamurthi, Paul Martini, Vijay Krishna Narayanan, Piotr Popowski, Solange V. Ramírez, Patrizia Romano, Samir Salim, Andrew W. Stephens, and Yongquan Yuan. In addition, Emanuela Pompei was a visiting graduate student and Guo Xin Chen arrived for the Spring quarter, 1998. Nikolay Andronov, Kenneth Sills, and Adam Steed arrived for the Summer quarter, 1998. The M.S. degree was awarded to Gaudi and Martini, and the Ph.D. degree to Everett, Krishnamurthi, and Popowski.

2 Facilities and Instrumentation

In 1998 Ohio State University (OSU) formally joined the MDM Observatory on Kitt Peak, Arizona. OSU now has a one-quarter share of the observing time on its 2.4-m and 1.3-m telescopes effective July 1, 1998. The other MDM partners are Dartmouth University, Columbia University, and University of Michigan.

OSU also has a one-sixth share of the Large Binocular Telescope project (LBT), which is under construction at the Mount Graham International Observatory in Arizona. 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 formally withdrew from its 37-year partnership with Lowell Observatory and Ohio Wesleyan University for the operation of the 1.8-m Perkins Telescope at Lowell because of its entry into the LBT project and MDM. Effective August 1, 1998, Lowell Observatory acquired full ownership of the Perkins telescope by purchasing it and the Perkins Schmidt telescope from Ohio Wesleyan University. OSU 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 June and July, Wagner and Bertram moved their Lowell Observatory offices and households to Tucson, and established office and shared laboratory space at the Steward Observatory, in support of the department's LBT and MDM activities. Support equipment was moved to the MDM Observatory on Kitt Peak and to the Steward Observatory on the University of Arizona campus. The OSU-provided facility instruments at the Perkins Telescope were shipped to Columbus. Two of these instruments, the CCD spectrograph and the Imaging Fabry Perot Spectrograph, are currently being modified for use at MDM. The third instrument, OSIRIS, is being upgraded to a 1024×1024 HgCdTe detector array. This upgrade is funded largely by CTIO. The plan is for OSIRIS to return to CTIO in 1999 for use by the entire community as a facility infrared imager and moderate resolution spectrometer.

The instrumentation program at OSU has built and deployed two CCD imaging systems on 1-m telescopes in Chile and South Africa as part of the contribution to the Probing Lensing Anomalies NETwork (PLANET) collaboration. The CCD systems are the first stage of an instrument that will ultimately take simultaneous optical and infrared images of on-going gravitational microlensing events to find planets and other anomalies. Currently only the 2K×2K CCD channel is operational although the instrument is ready for the full CCD and Aladdin infrared array configuration. The first Aladdin infrared array is expected in early 1999, and the additional infrared channel will be installed in the Chile instrument in April 1999 and in the South African instrument in July 1999.

Work is progressing on optical and preliminary mechanical designs for a high-throughput optical spectrograph to be built by OSU for the LBT. This spectrograph will have moderate resolution and multi-object capability and be capable of taking spectra of the faintest known sources. Work is also continuing on the development and implementation of the aluminizing system for the LBT.

Peterson is the principal investigator on a Medium-Explorer proposal that was submitted to the NASA Office of Space Sciences in 1998 August. The proposed spacecraft, known as *Kronos*, will carry co-aligned and sensitivity-matched ultraviolet/visible and X-ray spectrometers into a high-Earth orbit for temporal monitoring of extragalactic and Galactic accretion-driven sources. The goal of this mission is to determine the inner structure (accretion disks, broad-line regions, and relativistic jets) of active galactic nuclei (AGNs) and to test critically accretion-disk models of stellar-mass binary systems with and without black holes. Major institutional partners are NASA Goddard Space Flight Center, Space Telescope Science Institute, Spectrum Astro, Inc., and the Columbus-based Center of Science and Industry.

3 Solar Systems

3.1 Our solar system

With the publication of the *Hipparcos* catalog, Frogel and Gould realized that a search could be done for stars that might pass close enough to the Sun to trigger a major comet shower. They calculate that a star passing within $\sim 10^4$ AU of the Sun would trigger a comet shower that would reach the inner solar system about 0.18 Myr later. They also calculate an *a priori* probability of $\sim$ 0.4% that a star has passed this close to the Sun but that the comet shower has not yet reached the Earth. Their search of the *Hipparcos* catalog for such recent close-encounter candidates found none. Other papers have reported on similar unsuccessful searches, but Frogel and Gould are the first to estimate the completeness of the search. Because of the relatively bright completeness limit of the catalog itself, $V \sim 8$, the search is sensitive to only about half the stars that could have had such a near encounter. On the other hand, they show that the search is sensitive to nearly all of the *past* encounters that would lead to a *major* shower in the *future* and conclude that it is highly unlikely that one will occur during the next 0.5 Myr.

Wagner, Millis and Buie (Lowell Obs.) and Elliot (MIT) have initiated a program to discover faint Kuiper Belt Objects (KBOs) using the MOSAIC CCD camera at the prime focus of the Mayall 4-m telescope on Kitt Peak. To date, approximately 50 objects have been discovered in this annular region from 30 to at least 130 AU but the surveys have only covered about 25 to 30 deg^2 of the approximately 10,000 spanned by the Belt and are very incomplete fainter than $R = 23.5$. The MOSAIC camera on the 4-m telescope images four times the area per exposure to a limit 1.5 mag fainter ($R \simeq 25$) than the leading current survey. They estimate that in two nights of data with this system, 40 KBOs down to $R = 24.2$ could be discovered. Furthermore, their search could discover Pluto-sized objects out to 300 AU. A new motion detection technique developed by Buie allows discoveries in real time at the telescope based on three images obtained at 2 hr intervals.

3.2 Other solar systems

DePoy, Gaudi, Gould, and Pogge have recently joined PLANET, an international collaboration that makes coordinated observations of on-going gravitational microlensing events from four telescopes in the southern hemisphere. OSU's involvement includes managing all PLANET observations from the Yale 1-m telescope at CTIO and providing observers for observations from the sites in South Africa and Tasmania. OSU also built and deployed CCD cameras for the Chilean and South African sites that were used for the majority of observations this season. PLANET monitored 35 microlensing events during 1998, making an average of more than 220 images per event (combined measurements at V and I). The primary goal of the observations is to assess in a statistically meaningful manner the existence of planets around other stars; the planets can be detected via their gravitational microlensing effect. Analysis of the data is currently underway, but preliminary indications are that the PLANET observations have a higher than expected planet detection probability. In some well-sampled cases the detection probability is nearly 100%.

Gaudi is focusing his efforts on astrophysical applications of microlensing, with an emphasis on using microlensing to discover extra-solar planets. Together with Naber and Sackett (Kapteyn Institute), he has completed a preliminary study of microlensing by multiple planets in high magnification events. Their investigation revealed that the joint probability of two planets having projected separations such that they would both be detected was substantial, 1 – 15% for two planets with the intrinsic separations of Jupiter and Saturn. They illustrated the possible effects of multiple planets on the observed light curves and suggested implications of their result on previously computed detection probabilities. Continuing on the planetary microlensing front, Gaudi has also shown that there exists a degeneracy between planetary microlensing and binary-source perturbations. This degeneracy makes the interpretation of poorly or inaccurately sampled perturbations difficult. He has shown that this degeneracy can be resolved by accurate and densely sampled photometry, by a combination of optical with infrared photometry, and/or by spectroscopic observations. As a member of the PLANET collaboration, Gaudi has made significant contributions to the data acquisition and analysis of microlensing events in the 1998 PLANET observing season. In particular, he was primarily responsible for the modeling of the microlensing event MACHO-SMC-98-1, a binary event towards the SMC for which the PLANET data and analysis indicated that the lens most likely resides in the SMC itself. As part of his thesis work, Gaudi has collaborated with Sackett, DePoy, and Gould to develop a method to calculate the planet detection efficiency of microlensing follow-up collaborations, and he has begun to apply this to the PLANET data set.

4 Stars and Stellar Evolution

Slettebak and Wagner, in collaboration with Maitzen, Paunzen, and Pressberger (Univ. Wien) used *Hipparcos* proper motion data as well as published and their own radial velocity data to identify HIP 60350 (RNS 31250; CBS 463) as the fastest young B-type runaway star. Spectra obtained with the 4.5-m MMT and with the 1.5-m telescope of the L. Figl Observatory, near Vienna, yielded a spectral type of B4–5 V and a mean heliocentric radial velocity of 220 km s^{-1} when combined with a previously published measurement. The radial velocity and proper motion give an overall LSR velocity of 417 km s^{-1}, the largest yet encountered, and suggest that it was ejected 20 Myr ago or slightly less from the galactic plane. The velocity and mass of the star point to dynamical cluster ejection rather than to a supernova event.

Wagner and collaborators identified a new transient X-ray source, XTE J0421+560, with a peculiar variable star called CI Cam. The X-ray source was discovered by the RXTE satellite on 1998 April 1. The source rose rapidly in intensity, reaching nearly 2 Crab on April 1.04. The region was observed with the VLA on April 2.63 by Hjellming and Mioduszewski (NRAO), who found a new radio source within the X-ray error box. Wagner found the new radio source to coincide with CI Cam, a star discovered by Merrill in 1930 during an objective prism survey of the Milky Way. An optical spectrum of CI Cam obtained on April 3 with the Perkins 1.8-m telescope by Wagner and Starrfield (Arizona State Univ.) indicated that the emission lines of the Balmer series, He I, and Fe II were stronger than in previously published spectra. It also exhibited He II emission lines which were not present earlier. Subsequent optical photometry showed that CI Cam was $\sim$3.5 mag brighter than its quiescent magnitude. By April 4, the X-ray outburst had ended, making CI Cam the fastest X-ray nova ever observed. VLA images obtained on April 5.1 and 6.9 by Hjellming and Mioduszewski showed that the radio source had become resolved and exhibited a symmetrical S-shaped twin jet morphology, analogous to that of SS 433, with an inferred tangential speed of $0.15c$. CI Cam might contain either a mass-losing giant star with an extended wind zone blowing over a compact object, similar to GX1+4, or a luminous thick accretion disk from which the jets emanate and an unseen secondary star, as in SS 433.

Gaudi and Gould have completed a feasibility study of the ability of microlensing to resolve stellar atmospheres. They find that, with reasonable observing requirements, it should be possible to coarsely measure radial variation of the surface brightness profile of stars in the bulge to an accuracy of $\sim 10\%$.

Pinsonneault, Narayanan, Steigman, and Walker have studied the primordial lithium abundance in halo star models with rotational mixing. The distribution of initial rotation rates and angular momentum loss law inferred from studies of open clusters were applied to halo star models, and the predicted lithium depletion pattern was then compared with halo star data. The halo star distribution of lithium depletion factors, the ratio of ^{6}Li to ^{7}Li depletion, and the mean lithium trend as a function of effective temperature were found to be consistent with models including rotational mixing. A range of 0.2 – 0.4 dex depletion relative to the observed mean lithium abundance was found in these models. Unfortunately, this exacerbates the "crisis" in BBN (Big Bang Nucleosynthesis) 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).

4.1 Open clusters

Pinsonneault, with Stauffer (CfA), Soderblom and King (STScI), Hanson and Jones (UCSC) and Fischer (SFSU), examined the puzzling discrepancy between the distances to five open clusters inferred from stellar evolution theory and those inferred from *Hipparcos* parallaxes. Multicolor main sequence fitting was performed to test for errors in the assumed open cluster abundance scale. Good agreement between the *Hipparcos* and main sequence fitting distances was found for the Hyades, α Per, and Praesepe clusters. The two distance techniques, however, were found to disagree for the Pleiades cluster at a highly significant level. The Coma Ber cluster was found to be modestly discrepant. The photometric metallicity scale was found to be in good agreement with the metallicity scale from high-resolution spectroscopy. Nearby field stars with accurate parallaxes were studied, and no such stars with solar abundance and thin disk kinematics were found to exhibit the same anomaly as the Pleiades. Evidence for a possible spatially dependent systematic error in the *Hipparcos* parallaxes, at the 1 milli-arcsecond level, was found.

Pinsonneault and Terndrup are completing work to obtain and analyze new data on stellar rotation in young open clusters, in collaboration with Krishnamurthi (JILA) and Stauffer (CfA). They are completing their survey of rotation rates ($v \sin i$) of low-mass stars in the Pleiades, and Hyades, with additional data from Jones (Lick Obs.) and collaborators. These data have provided important constraints on the evolution of angular momentum and of surface lithium depletion in young clusters, as well as revealing information on the initial conditions (angular momentum budget and disk lifetime) for stars of low mass. In the future Terndrup will obtain a few new key observations on rotation rates in intermediate-age clusters of relatively low metallicity, and he will assemble and critically analyze the large and growing database on rotation and mixing on the main sequence and in giants.

4.2 Cool stars

A final revision and extension of the Perkins Catalog of standard MK spectral types is being carried out. Entitled "Revised Catalog of Standard MK Spectral Types for the Cooler Stars," by Keenan and Newsom, it has been completed through the range 0 – 9 hours of RA and has been placed on the OSU Astronomy Department website in order to make the standards available to observers as quickly as possible. It can be accessed at http://www.astronomy.ohio−state.edu/MKCool/. Additional hours of RA will be added as they are completed.

Calibration by the *Hipparcos* parallaxes has led Keenan and Barnbaum (Valdosta State Univ.) to modify slightly the zero point for luminosity classes III and IIIb for spectral types between G5 and K3. This change allows most stars of the clump to be distinguished from the main ridge of giants on surveys carried out at resolutions of 2 to 3 Å in the blue region.

Martini and Osmer completed their study of M dwarfs in the Deep Multicolor Survey (DMS). They developed color criteria to select M dwarfs from point sources found in the DMS and determined that the technique was effective to a limiting magnitude of $V = 22$. They solved for the vertical distribution of the M dwarfs perpendicular to the galactic plane and then derived luminosity and mass functions for the sample. They found that the luminosity function reached a peak at $M_V \approx 12$ and declined toward fainter magnitudes. The resulting mass function is not consistent with a Salpeter function at the 3 σ level and is approximately flat for the interval 0.1 $M_\odot$ to 0.6 $M_\odot$.

Bertram, Wagner, and Hollis (NASA/GSFC) digitized optical photographic plates, obtained from the Lowell Observatory archive, of the nebulosity surrounding the symbiotic Mira variable star R Aquarii. These data, obtained by Lampland using the 1.0-m reflector at Lowell Observatory and which span the period 1921 to 1950, suggest that the R Aqr jet, which was first observed and reported in the 1970s, was already affecting the inner compact nebulosity at earlier epochs. These results are the first observational evidence of an earlier origin for the R Aqr jet and are consistent with an estimated jet age of $\sim$ 100 years as determined from the proper motions of the oldest radio-emitting jet components.

Pinsonneault, Basu, and Bahcall (IAS) have studied both helioseismology and solar neutrino fluxes. The net effect of changes in the nuclear reaction cross-sections was a modest lowering of the predicted event rates for the Kamiokande and Homestake experiments. The agreement between the predicted sound speed from theoretical models and the sound speed inferred from inversions is excellent in the radiative interior. Current work is focusing on the impact of mixing on the seismic properties and neutrino fluxes, as well as the dependence of the inverted sound speed on the reference model which is used.

Wing and Yuan are collaborating with Alvarez (Univ. Libre Bruxelles), Plez (Univ. Montpellier), and Höfner (Univ. Vienna) on a comparison of observed and computed spectra of Mira variables. Hydrodynamical piston-driven pulsating models computed in Vienna are combined with new Uppsala opacities, which are believed to include all significant molecular absorbers in cool stellar atmospheres, to compute spectra at 50 phases covering two pulsational periods. The computed spectra are then compared to near-infrared spectrophotometry of several Miras obtained by Wing at Lick Observatory in 1965–67. The idea is to see if the dynamical models reproduce the loops shown by real stars in diagrams of band strength versus temperature, as well as their observed ranges in these two quantities. It is found that the behavior of the models is qualitatively quite similar to that shown by the stars, and in particular the observed phase lag between the band strength variations of TiO and VO is well reproduced. There are, however, some systematic quantitative differences, e.g. the computed TiO bands are too strong at all phases. They are now examining the effects of changes in the initial conditions of the pulsating model.

Wing and Yuan have explored the wavelength dependence of the amplitudes of Mira variables by comparing near-infrared spectrophotometric scans obtained near the times of maximum and minimum light. The amplitudes of M- and S-type Miras vary with wavelength in a complicated manner due to the presence of temperature-sensitive molecular bands in addition to the smoothly varying effects of changes in effective temperature and continuous opacity sources. On the other hand, the amplitudes of carbon Miras are nearly independent of wavelength throughout the near infrared. It remains to be seen whether synthetic spectra can explain how the carbon Miras can vary in brightness without (apparently) changing in effective temperature or band strength.

Wing is collaborating with Alexander and Ferguson (Wichita State Univ.), Johnson (Indiana Univ.), Hauschildt (Univ. Georgia), and Allard (Lyon) on a comparison of observed and computed spectra of normal giant stars that have been observed on Wing's eight-color near-infrared system of narrow-band filter photometry. Synthetic colors are being calculated for a new grid of model atmospheres computed in spherical geometry with the PHOENIX code. Several applications are planned, the first being to attempt to improve the effective temperature scales for cool stars of both giant and dwarf luminosities. Similar calculations of synthetic spectra, but using the MARCS code and extending to carbon-rich compositions, are underway in collaboration with Jørgensen (Niels Bohr Institute).

5 Interstellar Medium (ISM)

5.1 ISM: observational work

Martini, Sellgren, and DePoy completed a ground-based survey for molecular hydrogen emission from reflection nebulae for which Sellgren has mid-infrared observations with *Infrared Space Observatory (ISO)*. Narrow-band images in the 1–0 S(1) line of H_2 and adjacent continuum were obtained to select nebular positions for the *ISO* observations. They also obtained *JHK* spectra of reflection nebulae with H_2 emission to derive the gas density and ultraviolet (UV) radiation intensity from the H_2 line ratios. Comparison of these observations with current models of photodissociation regions provide an excellent means of determining the physical characteristics of interstellar material in these young, low-mass star-forming regions.

Uchida, Sellgren, and Werner (JPL) have been using *ISO*'s mid-infrared camera and its circular variable filter to obtain imaging spectroscopy of photodissociation regions, where stellar radiation interacts with a nearby molecular cloud. They have obtained spectra of six reflection nebulae whose central stars have temperatures between 3,600 and 19,000 K. They detect the interstellar infrared emission features (IEFs) at 6.2, 7.7, 8.6, 11.3, and 12.7 μm in three nebulae with stellar temperatures of 6,800 to 19,000 K. The relative strengths of the individual IEFs, and of the associated continuum emission, show no dependence on the amount or hardness of the incident UV field. They plan next to convolve laboratory absorption spectra at UV and visible wavelengths with the energy distributions of the stars illuminating different reflection nebulae, to make quantitative tests of different laboratory analogs for the materials which emit the IEFs. These laboratory analogs include neutral and ionized polycyclic aromatic hydrocarbons (PAHs) as well as hydrogenated amorphous carbon.

Sellgren has used *ISO*'s short-wavelength spectrometer to obtain a $2-45$ μm spectrum of the bright reflection nebula NGC 7023, in collaboration with Léger and Verstraete (Institut d'Astrophysique Spatiale) and Moutou (Obs. Haute Provence). The results to date include a sensitive upper limit on the C_{60}^{+} abundance in the ISM; detections of pure rotational transitions of H_2, which are good measures of the gas temperature in the photodissociation region; and the discovery that that the "7.7" μm IEF in fact breaks up into three distinct features, at 7.4, 7.6, and 7.8 μm. The 7.6 and 7.8 μm IEFs were previously observed, but the 7.4 μm IEF is new.

Sellgren and An are comparing the spatial distribution of different molecular and grain components in NGC 7023. They are analyzing images of emission from H_2, the 2 μm continuum, and the 3.3 μm IEF. The H_2 emission traces the photodissociation region, while the 2 μm continuum and the 3.3 μm IEF trace the presence of perhaps separate populations of tiny aromatic grains and/or large aromatic molecules.

Güsten (MPIfR) and Uchida have measured the line-of-sight magnetic field component in the dense gas (10^{5-6} cm^{-3}) in eleven 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 measurements comprise the first major effort to fill a significant gap in the observational data; to date, nearly all Zeeman studies have sampled fields only in low to moderate density gas ($< 10^3$ cm^{-3}). No line-of-sight magnetic field, above an average 3σ limit of 1.9 mG, is detected toward any of these sources. The W3(OH) region, found in a previous study to have a line-of-sight field of 3 mG in its dense gas, is thus unique in this respect. The implication of this study is that the magnetic fields are supercritical in the sense that they are not capable of supporting their host clouds against gravitational collapse. The relatively low average field limit is consistent with those theories predicting the quick onset of and short time scales for ambipolar diffusion.

5.2 ISM: theoretical and laboratory work

In the last year, Herbst's program of research into the gas-phase and grain surface chemistry of interstellar clouds continued unabated. Graduate student Terzieva (OSU Chemistry) and Herbst investigated the global agreement between observed molecular abundances and those calculated via gas-phase models for selected dense cloud cores. They found that a variety of chemical models could account for $\sim$ 80% of the observations with the assumption of constant homogeneous physical conditions. Herbst collaborated with graduate student Lee (OSU Physics) and others to investigate the conditions under which gas-phase models lead to two stable solutions of molecular abundances ("bistability") and determined that such solutions occur for an intermediate band of ionization fractions. Herbst collaborated with Caselli (Arcetri Obs.) and others to use the results of gas-phase chemical models to interpret observations of DCO^+, HCO^+, and CO and to obtain both the degree of ionization and cosmic ray ionization rate in 24 cloud cores. Turner (NRAO) and others collaborated with Herbst to analyze the chemistry of acetylenic-type molecules found in selected small translucent molecular clouds.

Although much of the work of Herbst and co-workers concerns purely gas-phase chemistry, some research has also been accomplished in the chemistry occurring on interstellar grains. Caselli, Herbst, and others proposed a modification of the rate equations used to describe granular chemistry. Unlike the case for gas-phase chemistry, the use of differential "rate" equations for granular chemistry is an approximation to more detailed Monte Carlo procedures. Certain shortcomings of the rate approach can be removed by the modifications introduced by Caselli et al. The actual use of the modified rate equations in gas-grain models of cold interstellar clouds was reported in a paper by Shalabiea (Cairo Univ.), Herbst, and others.

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. Herbst and co-workers have therefore continued to calculate the rates and other assorted details of processes important in the ISM but poorly constrained. One such recent study by graduate student Tomashevsky (OSU Chemistry) and Herbst concerns the vibrational distribution of product CO from the dissociative recombination reaction

$$\mathrm{HCO^+ + e \longrightarrow CO(v) + H};$$

while a second study by Talbi (Ecole Normale Superieure) and Herbst is concerned with the structure of the product ion of the reaction

$$\mathrm{C^+ + NH_3{*} \longrightarrow CH_2N^+ + H}.$$

The product ion was found to have a linear $HCNH^+$ structure exclusively, proving that the above reaction does not lead preferentially to interstellar HNC rather than HCN. Finally, Petrie (Univ. New South Wales) and Herbst studied selected interstellar reactions involving electrons sticking to neutral species and actually causing changes in their structures.

In recent work not yet published, Bettens (Australian National Univ.) and Herbst are investigating whether or not large abundances of negative ions such as C_7^- can be produced in diffuse interstellar clouds to help explain the riddle of the diffuse interstellar bands. In addition, Herbst and Le Page (Univ. Colorado) are investigating whether or not interstellar positive ions of PAHs can be protonated by simply sticking to abundant hydrogen atoms. McEwan (Univ. Canterbury), Herbst, et al. are studying the abundance of benzene (the simplest PAH) that can be produced by gas-phase reactions in dense clouds. Terzieva and Herbst are determining the O_2 abundance from a variety of models in preparation for data from SWAS. Postdoctoral researcher Aikawa (OSU Physics) and Herbst are preparing chemical models of protoplanetary disks that contain deuterium fractionation.

In relevant laboratory work, Bettens et al. have completed a study of the submillimeter-wave spectrum of methyl mercaptan (CH_3SH), and a long study of the similar spectrum of methyl formate is nearing completion.

Bautista (NASA/GSFC) and Pradhan completed their detailed study on the emission spectra and the ionization structure of Fe I through Fe IV in gaseous nebulae. The calculations included new photoionization cross sections, total electron-ion recombination rates, excitation collision strengths, and transition probabilities calculated under the Iron Project by the OSU atomic astrophysics group. They studied in detail the excitation mechanisms for [Fe II], [Fe III], and [Fe IV] emission and carried out spectroscopic analysis of observed infrared, optical, and UV spectra. They also studied the physical structure and kinematics of nebulae and their ionization fronts. Spectral analysis of the well-observed Orion Nebula was carried out as a test case, using extensive collisional-radiative and photoionization models. It is shown that the [Fe II] emission from the Orion Nebula is predominantly excited via electron collisions in high density partially ionized zones; radiative fluorescence is relatively less effective. Further evidence for high density zones is derived from the [O I] and [Ni II] spectral lines, as well as from the kinematic measurements of ionic species in the nebula. The iron ionization in Orion is modeled using the newly calculated atomic data, showing some significant differences from previous models. The new model suggests a fully ionized H II region at densities on the order of 10^3 cm^{-3}, and a dynamic partially ionized H II/H I region at densities of $10^5 - 10^7$ cm^{-3}. Photoionization models also indicate that the optical [O I] and [Fe II] emission originates in high density partially ionized regions within ionization fronts, thereby confirming the general Fe II/O I correlation in H II regions determined in earlier studies. The gas phase iron abundance in Orion is estimated from observed spectra, including recently observed [Fe IV] lines.

6 Our Galaxy

Gould is currently focusing his work on applications of microlensing and on the local distance scale. Microlensing studies include detection of planets, microlensing observations toward M31, developing new methods to extract additional information about individual microlensing events, and investigation of the relation between star counts and microlensing. Local distance-scale work includes measuring the distance to the Galactic Center, R_0, using kinematics and RR Lyrae variables, measuring the distances to the Hyades and Pleiades using kinematics, and determining the spatial correlations in *Hipparcos* parallaxes.

Popowski has completed his Ph.D. thesis on the use of RR Lyrae stars as distance indicators, with the goal of determining different cosmological parameters, in particular the Hubble constant, H_0. This work, done in collaboration with Gould, included a calibration of the absolute magnitude of RR Lyrae stars through statistical parallax and analysis of the systematics of this method, determination of extinction towards Baade's Window and measuring R_0 from RR Lyrae stars. Additionally, Popowski determined the proper motion of the globular cluster NGC 6522 in Baade's Window.

6.1 The bulge of the Milky Way

Frogel, Tiede, and Kuchinski (Caltech) completed a preliminary analysis of K, J–K color-magnitude diagrams (CMDs) for seven different positions, on or close to the minor axis of the Milky Way, at Galactic latitudes between $+0\overset{\circ}{.}1$ and $-2\overset{\circ}{.}8$. With the assumption that the true CMDs of these fields should be similar to that for Baade's Window with no intrinsic dispersion, they derived *average* values for the extinction in the K band (A_K) between 0.27 and 2.15, corresponding to average values of $E(J–K)$ between 0.44 and 3.46. There is a well-defined linear relation between the average extinction for a field and the star-to-star scatter in the extinction for the stars within each field. This finding suggests that the typical apparent angular scale size for an absorbing cloud is small, perhaps not more than a few arcseconds. Frogel et al. showed previously that the slope of the (linear) giant branch in a K, $J–K$ CMD is a good indicator of metallicity and that for stellar populations older than $\sim$ 10 Gyr it is nearly independent of age. In the absence of spectroscopy, this could be the only indicator in heavily reddened fields where optical observations are impossible. Frogel et al. analyzed their new minor-axis CMDs and derive a dependence of $\langle$[Fe/H]$\rangle$ on latitude for $-0.^\circ 8 \leq b \leq -2.^\circ 8$ of -0.085 ± 0.033 dex deg^{-1}. When combined with previous data from Tiede et al., Frogel et al. find for $-0.^\circ 8 \leq b \leq -10.^\circ 3$ that the slope in $\langle$[Fe/H]$\rangle$ is -0.064 ± 0.012 dex deg^{-1}. An extrapolation to the Galactic Center (GC) predicts [Fe/H] = $+0.034 \pm 0.053$ dex. Frogel et al. conclude from an examination of the ratio of the number of stars with $K_0 < 8.0$ to the number of stars with $8.0 \leq K_0 \leq 9.4$ that the young population observed at the GC extends out to about 1° from the GC but quickly falls off in density.

Frogel completed an analysis of surface brightness maps at 12 μm derived from *IRAS* observations. He estimated the integrated 12 μm flux from the Galactic bulge as a function of galactic latitude along the minor axis from these data. A simple model was used to remove Galactic disk emission (e.g. unresolved stars and dust) from the *IRAS* measurements. The resulting estimates were compared with predictions for the 12 μm bulge surface brightness based on observations of complete samples of optically identified M giants in several minor axis bulge fields. He found no evidence for any significant component of 12 μm emission in the bulge other than that expected from the optically identified M star sample plus normal, lower luminosity stars. Known large-amplitude variables and point sources from the *IRAS* catalogue contribute only a small fraction to the total 12 μm flux.

Frogel, Gould, and Stephens are analyzing deep *Hubble Space Telescope (HST)* NICMOS images of one field in the bulge of the Milky Way in an attempt to find the lowest mass stars present in the bulge. This research will constitute part of the Ph.D. thesis for Stephens.

Terndrup, Rich (Columbia) and Sadler (Univ. Sydney) are studying the stellar population and kinematics of K giants in the inner kpc of the bulge. For the first time, the kinematic signature of the Galaxy's bar is seen in the stellar velocities, but only in the metal-rich half of the stellar population – the metal-poor stars are in a hotter system.

With Peterson (Astrophysical Advances), Walker (NOAO/CTIO) and Sadler, Terndrup has continued an extensive survey of horizontal-branch stars in the bulge. Using a small allocation of time on the new Two-degree Field (2dF) instrument at the Anglo-Australian Telescope, they have uncovered a large number of hot horizontal-branch stars, confirming their membership in the bulge through their kinematics. Such stars have been implicated in the longstanding problem of the UV excess (at $\lambda < 2500$ Å) in elliptical galaxies and the bulges of other spirals. Continuing work on the numbers and temperatures of these stars in the bulge will uncover the controlling factors(s), particularly metallicity, for the production of hot, UV-emitting horizontal-branch stars.

Peterson and Terndrup are in the final stages of a paper on the kinematics of ionized gas in the diffuse ISM towards the bulge. This will be the first exploration of this gas along these lines of sight, and will provide more detailed velocity information than is currently available in the literature. Terndrup has also completed a survey of carbon isotopic abundances in bulge stars, in collaboration with Suntzeff (CTIO) and Smith (UTEP).

6.2 The Galactic Center (GC)

Ramírez is working on her Ph.D. thesis on chemical abundances of stars in the central hundred parsecs of the Galaxy. She is collaborating with Sellgren, Carr (NRL), Balachandran (Univ. Maryland), 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 NASA Infrared Telescope Facility. Their measurements of [Fe/H] are the first stellar abundance determinations in the GC. Her sample consists of seven M supergiants and three AGB stars, each with $K < 9$ and low water absorption. Nine of these stars, including the three AGB stars, are located in the central cluster within 2.5 pc of the GC. The remaining M supergiant belongs to the Quintuplet cluster, located 30 pc away from the central cluster. Ramírez et al. have found that [Fe/H] values for the ten GC stars are consistent with the solar Fe abundance. This is surprising because the abundances in H II regions in the Milky Way and other spiral galaxies are observed to reach their highest values at the nucleus. They plan next to measure stellar abundances of α–elements (Ca, Si, Ti) to address the issue of selective enrichment in the GC.

Uchida is continuing his studies of the GC nonthermal "filaments", seven linear radio continuum features believed to be the manifestations of a strong ($\sim$mG), perhaps pervasive, vertical magnetic field in the GC. The filaments are thought to be illuminated by interactions with molecular clouds, which cause magnetic reconnection and subsequent acceleration of electrons to relativistic velocities along the field lines. Also apparently requisite are nearby ionizing sources to provide an ample supply of free electrons. Morris (UCLA), Serabyn (Caltech) and Uchida are exploring and refining this hypothesis, using the VLA to detail the northern tip of the nonthermal filament G359.1−0.2, where a cloud/filament/H II region coincidence is found. Güsten (MPIfR) and Uchida are using *ISO* to observe the portion of the GC radio arch that is interacting with a massive molecular cloud and an H II region. Uchida is part of a collaboration, led by

Staguhn (Univ. Maryland), that has just completed a multi-wavelength study of G359.5+0.18, the nonthermal filament north of the Sgr C complex.

There is mounting evidence of past energetic activity in the GC, 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 byproduct of this activity, the western edge of the GC lobe / AFGL 5376 region, a large-scale (~100 pc) candidate shock feature arising from the GC.

Uchida has developed a 3-D kinematic code to investigate the effects of shear motions on large-scale expanding bubbles in the GC and the possibility that shear is responsible for the longitudinal elongation of the Sgr A East nonthermal bubble toward the GC. In preliminary results, he finds that shear due to differential rotation in the GC causes most expanding bubbles to become noticeably elongated on very short time scales (10^5 years), with all bubbles taking on a characteristic "cashew" shape at later times. Uchida also finds that shearing in the GC slows the outward expansion of a bubble. The ages of GC features, if based on their sizes, may thus have been consistently underestimated in past studies. He also finds that most expanding bubbles in the GC eventually self-intersect or form a major "kink" along their GC-facing surface. Gas is presumably shocked in these kinks, loses its angular momentum and then spirals in toward the GC. This is to be investigated in detail, but preliminary results show that shear motions play a role in mass deposition in the GC.

7 Extragalactic Astronomy

Eskridge and Pogge are continuing their work on the elemental abundances and star-forming properties of polar-ring galaxies. Polar rings tend to have roughly solar oxygen abundances, and steep H II region luminosity functions. These properties resemble those of luminous early-type spirals, despite the typically blue colors, low luminosities, and high M_{HI}/L_B ratios of polar rings. A model for the formation and evolution of polar rings that accounts for all their observed properties remains elusive.

Pogge and Eskridge have completed a study of the abundances of H II regions in a sample of S0 galaxies. Spectroscopy of the bright H II regions reveal solar gas-phase oxygen abundances. These high abundances place the S0s onto the general trend of increasing O/H with increasing galaxy luminosity and earlier Hubble types that has been found for spirals and irregulars. In general, star-forming S0 galaxies have O/H abundances typical of spirals of similar total stellar luminosity. The implications are that S0s appear to be the low end of the Hubble Sequence of spirals, and that their interstellar gas is primarily internal in origin. This contradicts the previous suggestion that S0s only acquire new interstellar gas by accretion of low-mass satellites or primordial gas clouds, both of which should be significantly metal-poor. A surprise of the study is that two counter-rotating S0s, which show direct evidence of a massive infall of gas and stars, also follow these trends. Since currently favored models for the formation of counter-rotating gas/star systems involve retrograde captures of dwarf galaxies (which would be very metal-poor), this presents a quandary as to how to reconcile these two results.

Frogel and Salim are surveying some rich Abell galaxy clusters in the near-infrared in an attempt to determine the stellar content of the member galaxies and to investigate the color-magnitude diagram for different types of clusters. Combined with optical colors, such work will help to understand the evolution of galaxy colors and test whether there are differences that are dependent on environment. They are also collaborating with Rich (UCLA) on a program of deep near-infrared imaging of the Windhorst field, the second deepest field after the Hubble Deep Field (HDF) to be imaged by *HST* in the optical. Given the importance of the results from the HDF, it was felt that having a second field with which to compare the results will be extremely valuable.

With Sung (Korea Astron. Obs.), Han (Chungbuk National Univ.), and other collaborators, Ryden has continued to study the apparent and intrinsic shapes of dwarf galaxies. Analysis of low surface brightness dwarf irregular galaxies (dIs) has shown that the ellipticities of dIs are similar to those of blue compact dwarfs, but slightly flatter, on average, than those of dwarf ellipticals. The shapes of dIs are inconsistent with their being a distribution of randomly oriented oblate or prolate spheroids. In particular, the shapes of dIs are inconsistent with their being flattened disk-like systems.

Ryden has made a study of the apparent shape of elliptical galaxies as a function of radius. In the region where the dynamical time is short (about 1 Myr), core ellipticals are significantly rounder than power law ellipticals. In the outer regions, where the dynamical time is greater than 10 Myr or so, the shape distributions for core ellipticals and power law ellipticals are indistinguishable. The inner isophotes of core ellipticals are consistent with their being randomly oriented oblate objects, but their outer regions must be triaxial in the majority of cases. The difference in shape between the inner and outer regions of core ellipticals may have its origin in the physical process by which the core forms.

DePoy continued working on studies of obscured star formation in the 30 Dor region of the LMC. Images of the region, which is the largest concentration of molecular material in the LMC, were obtained at L (3.5 μm) with a 1024×1024 InSb detector array in a camera on the South Pole Infrared Explorer (SPIREX) telescope by DePoy and Martini as part of the testing of the instrument. Images obtained later in the season were among the most sensitive $L-$band images ever obtained and reached a limiting magnitude of $L \approx 14$ (S/N=5). The images revealed a complex of embedded sources to the north of 30 Dor (coincident with red sources seen with NICMOS on *HST* by Walborn et al.). An $L-$band survey of the entire region that complements previous *JHK* work done by DePoy and Stephens is underway.

7.1 Extragalactic stellar populations

Frogel and collaborators studied the stellar content of four M31 globular clusters and of the cores of six elliptical galaxies. Their observations were made with the Faint Object Spectrograph (FOS) on *HST*. They compared their new data with similar information for the dwarf elliptical M32, Galactic globular clusters, and Galactic stars. Their most general finding was that among the M31 globular clusters, Galactic globular cluster/Galactic stars, and elliptical galaxies there are at least three separate stellar populations. For example, while the M31 globular cluster MIV is as metal-poor as the Galactic globular cluster M92, the former shows a strong NH 3360 feature in its integrated spectrum. Other UV line indices were shown to be significantly different as well. Of the three stellar populations studied, M31 globular clusters and elliptical galaxies are more similar to each other than each is to the Galactic stellar populations defined by globular clusters and nearby stars.

Frogel, Stephens, and DePoy have just obtained *HST* data for two other projects involving M31. The first consists of NICMOS observations of several fields in the bulge of M31 in an attempt to settle the long-standing controversy as to how luminous are the stars in the bulge. This has important implications for determining the age of the bulge and, hence, its formation history. In another *HST* NICMOS project they have obtained images of five M31 globular clusters that appear to be extremely metal rich. Again, determination of the luminosity function of the bright stars on the RGB and AGB will have important implications for the age of the cluster. The data will be compared with similar observations of galactic globular clusters and will further add to our knowledge of star formation when M31 was young.

Pompei has been studying the globular cluster system in an interacting elliptical galaxy. Her goal is to test the bimodal cluster formation theory. Pompei analyzed broad-band (B, V, R) and narrow-band (Hα) images of NGC 5898. No bimodality in color distribution was detected. She found the globular cluster's surface density distribution is well fitted by a power law.

7.2 Spiral galaxies

In collaboration with Fabbiano (SAO) and Shapley (CIT), Eskridge is involved with an analysis of the *Einstein Observatory* sample of spiral galaxies. Highlights of this work include evidence that the well-known $L_B \propto L_H^{0.7}$ correlation breaks down for mid-type spirals (Sb – Sbc), but is obeyed by both the early-type (S0/a – Sab) and late-type (Sc – Irr) samples. There are strong links between radio continuum and infrared emission, with the quirk that for the early-type spirals the link is between radio continuum and 12 μm emission, while for the late-type spirals the link is between radio continuum and far-infrared emission. Also for the late-type spirals the far-infrared and radio continuum are related to the X-ray emission. This interconnection appears to be driven by the increased importance of on-going star formation in the latest-type spirals.

Using *HST*, Kaufman, B. Elmegreen (IBM), D. Elmegreen (Vassar), Brinks (Univ. Guanajuato), Yuan (CCNY), Klarić (Midlands Tech.), Montenegro (CCNY), Struck (Iowa St.), and Thomasson (Onsala) found an irregular network of dust spiral arms in the nucleus of NGC 2207 that are not obviously related to star formation, bar structure, or gravity–driven spiral density waves. They propose that the dust spiral arms result from acoustic instabilities that amplify at small galactic radii.

Kaufman, Brinks, B. Elmegreen, D. Elmegreen, Klarić, Struck, Thomasson, and Vogel (Univ. Maryland) have taken H I, radio continuum, Fabry-Perot Hα, and ^{12}CO observations and broad-band optical and near infrared images of the interacting spiral galaxies NGC 5394/95. In NGC 5395, they find a large ring or pseudo-ring of Hα, radio continuum, and H I emission, noncircular motions, massive H I clouds (10^8 $M_\odot$) along the very broad western arm, a very large shell or caustic feature, and non–planar structures. NGC 5395 has a long H I tidal arm that departs in velocity from the main disk. Its starburst companion, NGC 5394, has bright inner spiral arms and two long, symmetric, outer tidal arms. Only one of the three inner arms is detected in Hα. The tidal arms have a stellar arm/interarm contrast that is large compared to normal spiral arms.

Pompei has pursued an investigation of the existence of possible links between bars and boxy/peanut bulges. Near-infrared (J, H, K') images of 20 spiral galaxies were taken by Pompei at the 2.2-m ESO telescope in La Silla. The isophote shape and the trend of position angle and ellipticity with galactocentric radius were analyzed, searching for bars and/or triaxial bulges. A geometrical model was used to determine the true axis ratio of all objects that revealed a non-axisymmetric shape. Pompei finds that 30% of the galaxies show an asymmetric structure. One galaxy in the sample, NGC 1371, shows a triaxial bulge.

To further investigate the link between boxy/peanut morphology and bars, Pompei and Terndrup analyzed high-resolution spectra of eight edge-on spiral galaxies. They discovered that one galaxy in the sample shows stellar counterrotation, although its gaseous kinematics does not show any sign for counterrotation.

Ryden and Thakar (Johns Hopkins Univ.) are using smoothed particle hydrodynamics (SPH) simulations to study the formation of counterrotating disks and other kinematically distinct subsystems in disk galaxies. Using a sophisticated SPH code, rather than the simple-minded sticky particle scheme that was employed in their preliminary investigations, reveals that the time scale for counterrotating disk formation is shorter than previously thought. Thakar and Ryden are beginning a study of the formation and evolution of counterrotating and skew-rotating bulges in disk galaxies.

7.3 The OSU galaxy survey

With the exception of about one dozen galaxies whose deep BVR images need photometric calibration, all of the observations for the OSU galaxy survey have now been completed. Eskridge, who joined the OSU team in 1998 January, is leading the effort to get through the first level of image reduction. What may be the single most important investigation of the survey is well underway: assigning a Hubble class to the more than 200 galaxies from their $H-$band images. Since galaxies in the survey represent a complete magnitude-limited sample drawn from the RC3, this classification effort will, first of all, reveal the most accurate estimate for the occurrence of bars amongst all types of spiral galaxies to date. Additionally, since the H light is a much closer tracer of the mass distribution of the galaxy than is optical light, this reclassification will be based on the underlying mass distribution rather than being influenced by the presence of dust and young stars.

The collaboration with the galaxy group led by Windhorst (Arizona State Univ.) is continuing. They have obtained 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. With this collaboration, there are more than 400 galaxies in the sample. The combined *UBVRIJHK* sample will allow them to quantify local galaxy parameters in the range 3000 Å to 2.2 μm. They are developing a modeling analysis technique for application to faint field galaxies seen with *HST* to address the relative importance of bulge versus disk dominated galaxies, of late-type versus irregular galaxies, and of low surface brightness galaxies versus subgalactic clumps as a function of redshift.

8 Active Galactic Nuclei and Quasars

8.1 Seyfert galaxies

Pogge and Martini were awarded 23 orbits with *HST* to use NICMOS to make deep J and H images of the nuclei of 23 Seyfert 2s (including types 1.8 and 1.9 which show weak broad lines) selected from the CfA redshift survey. The CfA sample is spectroscopically complete to $m_{Zw} = 14.5$, making it best suited for statistical studies of Seyfert 1s and 2s. These are then combined with archival $V-$band WFPC2 images to form V–H color maps of the central regions to study their dust properties. The results thus far have revealed that all of the Seyfert 1.8 and 1.9 galaxies show strong nuclear point sources dominating the emission from the central $0\farcs5$. The Seyfert 2s, on the other hand, only show nuclear point sources in a minority of objects; most do not show dominant nuclear sources. In a few, the location of the nucleus at 1.6 μm is different from that at 0.5 μm, and it is clearly being hidden at visual wavelengths by dust in the host galaxy proper. Detailed spectroscopic analysis and decomposition of the nuclear and galaxy light is continuing.

Peterson, Pogge, Wagner, and Bertram have transferred their Seyfert 1 galaxy monitoring program from Lowell Observatory to MDM Observatory. After eight years of weekly monitoring, they have decreased their sampling rate to approximately once per month to investigate long-term variability. The goals of this program are to understand broad-line profile variations and to determine the variability power spectrum of the variations with the specific aim of trying to determine the low-frequency turnover, which is expected to be related to the mass of the central black hole.

Wanders (Univ. St. Andrews) and Peterson are continuing their investigation of Hβ line profile variations in AGNs. They find that all profiles they have studied can be plausibly modeled as being comprised of three individual components, one near the systemic redshift of the AGN, plus components that are blueshifted and redshifted relative to systemic. The profiles vary in relative flux in a way that is apparently independent of the continuum variations (i.e., they are not reverberation effects) and also independent of one another. The relative strengths of these components determine the symmetry properties of the profile. Large-scale profile changes appear to persist for dynamical time scales characteristic of the broad-line region (BLR) (i.e., years), although they can first appear rather quickly. The nature of the profile changes points towards stochastic events, which argues against the conventional wisdom that the BLR is comprised of a very large number of individual clouds, and points towards models in which continuum beaming effects are important.

Peterson has completed an International AGN Watch project to extend ground-based optical monitoring of NGC 5548 to eight years. The total AGN Watch data base on NGC 5548 now consists of more than 800 spectra obtained between 1989 December and 1996 October. The Hβ emission-line lag relative to the continuum variations has varied from 10 to 20 days over the course of this program, and there is evidence that the Hβ lag is correlated with the mean continuum luminosity. Thus the most important line variations arise at a distance from the continuum source that changes with the continuum brightness — when the continuum is brighter, the most significant line response occurs at larger distances from the continuum source.

Pogge along with Shields (Ohio Univ.) and DeRobertis (York Univ.) have used integral-field spectroscopy of NGC 1068 obtained at the 3.6-m CFHT to search for [Ca II] emission in an off-nuclear region noted for strong near-infrared [Fe II] emission lines. The strong [Fe II] emission in this region has been suggested as due to release of iron into the gas-phase by destruction of dust grains in shocks associated with the nuclear outflow. If this is true, then calcium, a refractory element also strongly depleted onto grains in the ISM, should be released, with photoionization models predicting strong [Ca II] emission at 7291 Å. They failed to find any evidence of [Ca II] emission, setting a tight upper limit on the amount of gas-phase calcium in this object. This suggests that the grains are still largely intact, and that the strong [Fe II] emission may be due to other excitation mechanisms. They are planning on expanding this study to other Seyfert galaxies that show strong near-infrared [Fe II] to see if these objects also show little or no [Ca II] emission.

Pradhan and Sigut (Univ. Western Ontario) have been studying the anomalously high optical and UV fluxes from Fe II observed in spectra of quasars and AGNs. The phenomenon is commonly known as the "Fe II problem." In a recent study Pradhan and Sigut have calculated Fe II emission line strengths for AGN broad-line regions using precise radiative transfer and Iron Project atomic data. They improved the treatment of all previously considered excitation mechanisms for the Fe II emission: continuum fluorescence, collisional excitation, fluorescence by self-overlap among the iron lines, and fluorescent excitation by Lyα. It was demonstrated that Lyα fluorescence is of fundamental importance in determining the strength of the Fe II emission. In addition to enhancing the UV and optical Fe II flux, Lyα fluorescence also results in significant near-infrared Fe II emission at 8500 − 9500 Å. New observations are suggested to probe this effect in strong Fe II emitting quasars.

8.2 AGN surveys

Osmer, Kennefick, Hall, and Green completed their work on the electronic catalog of stellar objects in the Deep Multicolor Survey (DMS). The catalog is now available at www.astronomy.ohio-state.edu/~posmer/DMS/ on the World Wide Web. The DMS is a CCD survey that covers 0.83 deg^2 at high galactic latitude in U, B, V, R, $I75$, and $I86$ and reaches 5 σ limiting magnitudes ranging from 22.1 in $I86$ to 23.8 in B. The catalog contains 19,494 objects, for which it gives positions, magnitudes, error estimates, and classification codes in the six filter bands. They make available tables of the spectroscopic results for the 55 quasars, 44 compact, narrow, emission-line galaxies, and 135 stars that have been confirmed to date in the DMS. Illustrations of the spectra are also presented.

Conti, Kennefick, Martini, and Osmer completed a search for compact quasar and AGN candidates in the HDF. They used the individual "dither" images to obtain radial profiles that were well sampled on the sub-pixel scale for all objects and developed techniques to select the most compact, i.e., stellar-like, objects in the HDF. In addition they generated synthetic quasar spectra to cover the redshift range $1.0 < z < 5.5$ and used them to compute predicted colors for quasars. They found 8 unresolved objects and 12 slightly resolved objects with colors consistent with quasars. None of these objects had colors consistent with $z > 3.5$ quasars. However, they independently recovered one compact, narrow, emission-line galaxy with a spectroscopic redshift of 3.36 and five spectroscopically confirmed stars, which provide validation for their modeling techniques. Because quasars at some redshifts have colors that overlap with those of stars, Conti et al. estimated that the upper limit of quasars/AGNs in the HDF is 20 objects to a limiting magnitude of $V_{606} = 27$. This upper limit already means that quasar number counts do not rise steeply from the values found from previous ground-based surveys with limiting magnitudes of 20 to 21.

Kennefick, Hall, Osmer, and collaborators are also continuing their work on the BTC40 and BFQS surveys for faint quasars. The BTC40 program has covered 40 deg^2 in B, V, and I with the BTC camera at CTIO in a search for $z > 5$ quasars, gravitational lenses, and distant galaxy clusters. The survey is designed to reach limiting magnitudes of 25 to 26 in B and V and 24 in I. The BFQS survey uses the same camera but longer exposures to reach limits of 26.7, 25.7, and 24.6 magnitudes in B, R, and I over an area of approximately 7 deg^2 to search for quasars with $3.3 < z < 5.0$.

9 Gamma-Ray Bursts

Wagner is collaborating with the Lowell Observatory Near-Object Search (LONEOS) team to use the LONEOS 0.58-m Schmidt telescope and a CCD camera, located on Anderson Mesa near Flagstaff, to identify optical afterglows of the brighter gamma-ray bursts (GRBs) discovered by the BATSE experiment on-board the *Compton Gamma-Ray Observatory*. In its current configuration, the LONEOS telescope images 5.1 deg^2 to $R \simeq 20$ (3σ) in a 5 minute integration at an image scale of $2\overset{''}{.}8$ pixel^{-1}. The field of view of LONEOS is well matched to GRB locations that have been analyzed by NASA/MSFC LOCBURST processing. Improvements to the corrector plate and the addition of a second CCD are planned to increase the sensitivity and field of view.

LONEOS images each event at the first opportunity. The images are transferred over the network from LONEOS to Steward Observatory where they are reduced, combined, and analyzed. The identification of optical afterglows is based on variability and requires the acquisition of frames of the same field 24 to 48 hours after the acquisition of the initial frames. Upon completion of an on-line sky map by LONEOS, to which the initial frames can be compared, they expect that the identification of an optical afterglow associated with a GRB would proceed more quickly. In addition, the large field of view and depth of LONEOS images can be used in an archival fashion to identify an optical counterpart based on subsequent X-ray localizations from BeppoSAX or RXTE/PCA.

LONEOS is still being commissioned, but even in this testing phase it was possible to image GRB 971029 on 1997 October 29.277 UT, only 5.2 hours after the GRB. At a galactic latitude of only 7° the field was very crowded. Several potential afterglows of this burst with $R \approx 20$ are present on these images which include only part of the LOCBURST error box.

10 Cosmology and Large-Scale Structure

10.1 Large-scale structure

Popowski, Weinberg, Ryden, and Osmer quantified the ability of the two giant quasar surveys, the Sloan Digital Sky Survey and 2dF, to establish the geometry of the Universe by predicting the accuracy with which they can constrain the matter density (Ω_M) and cosmological constant (Ω_Λ).

Weinberg, Katz (Univ. Massachusetts), and Hernquist (UC Santa Cruz) used hydrodynamic simulations to predict the clustering of galaxies at $z \approx 2 - 4$. The simulations predict that high redshift galaxies are highly biased tracers of the underlying mass distribution, i.e., they exhibit much stronger clustering. They show that several variants of the cold dark matter (CDM) scenario can account fairly well for current measurements of the clustering of the Lyman-break galaxy population, and that improved measurements may provide good diagnostics of the physics of galaxy formation but rather weak tests of cosmological models.

Owen and Weinberg, in collaboration with Villumsen (Max Planck Institut, Garching), completed a study of "galaxy" formation in 2-dimensional simulations with scale-free initial conditions and cooling laws specially designed to preserve scale-free physics. By comparing the numerical results to analytically derivable scaling laws, they showed that the simulations give reliable results for the fraction of gas that cools and condenses into galaxy-like objects. Extension of this approach to three dimensions will provide an important test for the ability of hydrodynamic simulation codes to correctly model galaxy formation.

Narayanan and Weinberg completed a paper describing and testing their "hybrid" method for recovering the primordial mass density fluctuations from the present-day galaxy density field, which combines earlier approaches based on monotonic mapping and backwards dynamical evolution. Tests on simulations show that this method successfully reproduces the true galaxy density field if the reconstruction incorporates the correct assumptions about the density parameter and the relative bias between galaxies and mass, but that it fails in a systematic manner for wrong assumptions. They are now collaborating with Frenk and Branchini (Univ. Durham) on application of this method to the PSCZ redshift survey of 15,000 galaxies selected from the *IRAS* Point Source Catalog. This study has already made substantial progress; when completed, it should yield significant new constraints on the value of Ω_0 and the bias between galaxies and mass and will also yield detailed, fully non-linear predictions for the galaxy peculiar velocity field. In related work, Narayanan and Croft compared the performance of six different reconstruction schemes, finding that the hybrid method and the Path Interchange Zel'dovich Approximation (PIZA) method gave the most accurate recoveries of the initial density field.

Narayanan, Berlind, and Weinberg have used a combination of large volume N-body simulations and simple prescriptions for biased galaxy formation to examine the sensitivity of various statistical measures of galaxy clustering and galaxy peculiar velocities to detailed assumptions about bias. This study places particular emphasis on the different effects of "local" bias, in which the efficiency of galaxy formation depends only on the local environment, and "non-local" bias, in which galaxy formation is modulated coherently over large scales. Scherrer and Weinberg developed an analytic argument showing that, under quite general assumptions about the properties of mass clustering, a local bias cannot alter the shape of the galaxy correlation function or galaxy power spectrum on large scales. This result implies that measurements of large scale galaxy clustering reveal the true shape of the mass correlation function and power spectrum, unless galaxy formation is modulated by a non-local process. The analytic result is supported and extended by Narayanan et al.'s numerical study. Berlind has begun an investigation of "filling factor" statistics, which may be more robust than traditional clustering measures to the uncertainties in the relation between galaxies and mass.

Weinberg, in collaboration with Cole, Hatton, and Frenk (Univ. Durham), completed a large set of artificial redshift catalogs drawn from N-body simulations, designed to have geometry and selection parameters similar to the planned 2dF and Sloan galaxy redshift surveys. They have made the catalogs publically available for the use of researchers developing techniques to extract cosmological information from these ambitious surveys. Weinberg and Berlind are collaborating with Colley (Harvard Univ.), Gott (Princeton Univ.), and Park (Seoul National Univ.) on topological analysis of a mock Sloan catalog created from a larger volume simulation.

Weinberg continues his participation in the Sloan survey, with particular attention to the issues of galaxy spectroscopic target selection and (through his membership in the survey's Collaboration Council) the more tedious but unavoidable issue of the collaboration's publication policy. The project obtained its first imaging data in May 1998, and the next year will be a busy time for commissioning instruments and testing the software and target selection algorithms.

Walker and graduate student Manoj Kaplinghat (OSU Physics) are examining the background flux of neutrinos from all supernovae. Steigman, Kaplinghat, and Walker have shown that neutrinos from all the supernovae that have ever occurred are not observable using current detectors, contrary to many claims. 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.

10.2 Lyman α forest

Croft and Weinberg, in collaboration with Hernquist, Katz, and Pettini (Royal Greenwich Obs.), measured the power spectrum of mass fluctuations at redshift $z = 2.5$ from Pettini's sample of Lyα forest spectra. The measured slope of the power spectrum agrees with the predictions of models based on inflation and CDM. By combining the measured amplitude with the observed abundance of galaxy clusters, they obtained an estimate of the cosmological density parameter $\Omega_0 \approx 0.45 \pm 0.1$ (open universe) or $\Omega_0 \approx 0.35 \pm 0.1$ (flat universe). In collaboration with graduate student John Phillips (OSU Physics), they combined this measurement with microwave background anisotropy measurements to further constrain the parameters of inflation+CDM models. They have also used simulations to examine the physical information encoded by statistical measures of Lyα forest spectra that treat each spectrum as a continuous 1-dimensional field. In collaboration with Burles (Univ. Chicago) and Kirkman and Tytler (UC San Diego), they have carried out a preliminary comparison between the results of numerical simulations and measurements from Keck HIRES spectra using these statistics.

Croft and Gaztañaga (Univ. Barcelona) have been developing an analytical approach to the theory of the Lyα forest to complement the numerical simulations. Because the physical picture of the forest that emerges from the simulations is well described by simple approximations, it is feasible to predict properties of the forest by combining these approximations with gravitational perturbation theory. This different approach makes it possible to study general questions directly, such as whether the observed Lyα forest is consistent with having evolved under gravitational instability, and whether the primordial density fluctuations were gaussian.

Croft and Weinberg have been investigating the possibility of using Lyα forest spectra of close quasar pairs as a probe of cosmic geometry. The correlation length measured from cross-correlating the flux distribution in such spectra can act as a measuring rod, which when compared with the correlation length along the line of sight can give information on the spacetime metric. Tests on numerical simulations indicate that non-linear peculiar velocity effects need to be modeled and included for the method to work in an unbiased fashion.

Weinberg, Katz, Hernquist, and Davé (UC Santa Cruz) used hydrodynamic cosmological simulations to study the evolution of the Lyα forest at low redshift, showing that the simulation models that are so successful at explaining the properties of the high-redshift Lyα forest also account for the most important observed features of the low-redshift forest, including the sharp change in evolution rate at $z \sim 1.5$ and the correlations between higher equivalent width lines and galaxies. In collaboration with Hellsten (UC Santa Cruz), they searched for signatures of O VI absorption in a Keck HIRES spectrum and compared the results to simulated spectra to conclude that the metallicity of the diffuse intergalactic medium (at $z \sim 3$) declines for densities below the cosmic mean.

10.3 Big Bang Nucleosynthesis

Tosi (Bologna), Steigman, and collaborators have shown that observations of the stellar metallicity distribution and the Galactic gas fraction lead to very nearly model-independent constraints on the destruction of D which, in concert with deuterium observations in the ISM and in the solar system, yield an inferred primordial abundance in agreement with the "low" values from high-redshift QSO absorbers. Along with Hata (OSU and IAS) and Tosi, Steigman is continuing this "generic" approach, using independent observations of D and ^{3}He in the solar system and the local interstellar gas to constrain Galactic astration of D.

Steigman, Viegas and Gruenwald (São Paulo) continue their program of investigating various sources of potential systematic errors in using emission-line observations of extragalactic H II regions to zero in on the primordial abundance of ^{4}He. Currently they are exploring the effect of inhomogeneities on the ionization correction.

In a broad class of non-standard cosmological models the universal scale factor increases as a power of the time, independent of the matter density or its equation of state. Kaplinghat, Tkachev (OSU and Purdue), Walker and Steigman have shown that such models fail the BBN test. Basically, universes described by such models take so long to cool down to BBN temperatures that all neutrons have decayed and no significant nuclear reactions can occur.

10.4 Early universe and cosmological parameters

With Turner (Fermilab/Univ. Chicago), Dodelson (Fermilab), and Lopez (Univ. Chicago), Scherrer investigated the effect of a decaying neutrino on the cosmic microwave background. This work indicated that some neutrino masses and lifetimes can already be ruled out by current observations.

Scherrer completed a paper with Turner and Kaplinghat on constraining variations in the constants of nature using the cosmic microwave background. They were able to show that the next generation of cosmic microwave background experiments may constrain changes in the fine-structure constant to $\sim 10^{-3}$.

With Liddle (Imperial College), Scherrer investigated the behavior of scalar fields in the early universe. They examined scalar fields which may evolve in such a way as to help solve the cosmological constant problem and provided a systematic classification of such fields.

Inspired by the results of a summer REU project, which showed that recent cosmological data on SNeIa could not rule out relativistic particles as a significant component of the Universe, Scherrer, Kaplinghat, and Walker are trying to understand how significant relativistic energy density can affect the observable Universe.

Given the "crisis" in BBN, Steigman, Hata and 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 primordial yields of the light element abundances. Their results favor "low" primordial deuterium in agreement with the Tosi et al. results, but in apparent conflict with (some of) the ^{4}He data. This work continues with an exploration of the consequences of dropping any constraints which derive from observations related to theories of structure formation, such as the "shape" parameter.

Continuing this non-BBN approach, Tkachev and Steigman use observations of MACHOs along with Local Group dynamics to infer the "universal" baryon fraction. Their results favor a high baryon density, consistent with estimates of the baryon density from observations of the Lyα forest.

10.5 Cosmic ray nucleosynthesis

Walker is researching 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. With graduate students Jim Kneller and John Phillips (OSU Physics), Walker completed a cosmic ray nucleosynthesis code which incorporates these new data. Steigman, Kneller, 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 they expect from inhomogeneous cosmic ray nucleosynthesis. It has been long known that the light elements Li, Be and B can be synthesized in collisions between cosmic ray nuclei and interstellar gas nuclei. For near-solar metallicities, collisions between cosmic-ray protons and alphas and interstellar CNO nuclei dominate. If, naively, the complementary reactions are ignored, a quadratic relation between the Li, Be, and B abundances and Fe/H is "predicted", in contrast to the observed, nearly linear relation. Kneller, Steigman and Walker have shown that cosmic-ray CNO nuclei hitting ISM H and ^{4}He dominate Li, Be, and B production below solar metallicities, leading to a nearly linear abundance relation in agreement – quantitatively as well as qualitatively – with the observed data.

11 Atomic Astrophysics

Pradhan leads an atomic astrophysics group at OSU, including Bautista (now at NASA/GSFC), Chen, Nahar, Romano, and Zhang (now at LANL). Considerable progress has been made in the past year in analyzing nebular and AGN spectra, and in theoretical studies of atomic radiative and collisional processes in astrophysical plasmas. The group is involved in accurate calculations, using *ab initio* quantum mechanical methods, of collision strengths, photoionization cross sections, transition probabilities, and electron-ion recombination rates. The results are incorporated into a number of astrophysical applications, such as spectral analysis of ground and space based observations.

11.1 The Iron Project

The analysis of emission spectra reveals the existence of heavy, iron-peak elements such as iron, cobalt, and nickel as end products of stellar nucleosynthesis. The OSU group is part of an international collaboration called the Iron Project. The aim of the project is to compute accurate atomic data for collision strengths, photoionization cross sections and fine structure transition probabilities for iron and iron-peak elements. Other groups in the Iron Project are from the UK, France, Canada, Germany, and Venezuela. The large-scale quantum mechanical calculations are being carried out on the Cray T94 and the massively parallel Cray T3E at the Ohio Supercomputer Center in Columbus.

Under the Iron Project, work has been completed recently or is in progress for calculating accurate data for collision strengths and rates for Fe IV, Ni II and Fe VI. The electron impact excitation collision cross section includes fine structure with allowance for strong coupling and relativistic effects.

11.2 Photoionization, electron-ion recombination and ionization balance

The radiative processes of photoionization and electron-ion recombination are being studied for complex iron ions and other ions along isonuclear sequences. The photoionization cross sections, σ_{PI}, and the total and state specific recombination rate coefficients, $\alpha_R(T)$, are obtained in an *ab initio* manner in the close coupling approximation. The photoionization cross sections of a large number of bound states have been reported for Fe IV. The new features in the photoionization cross sections include the presence of a large resonance in the near threshold region of the ground state.

The total recombination rate coefficients, $\alpha_R(T)$, for the iron ions are being calculated in a detailed manner for the first time. The calculations are carried out in a new treatment developed by Nahar and Pradhan where both the radiative and dielectronic recombinations are incorporated in a self-consistent, unified manner. Their present results differ considerably from the earlier rates obtained with simpler approximations. The recombination rates for Fe IV and Fe V are in press. Application of the new recombination rate coefficients and photoionization cross sections to the ionization structure of iron in planetary nebulae show that under typical conditions the relative fractions of Fe V and Fe VI change by nearly a factor of two.

The astrophysical models involving the inverse processes of photoionization and electron-ion recombination, such as calculations of ionization fractions in plasmas in photoionization equilibrium, require a consistent set of data for these two processes to reduce the uncertainties introduced by different approximations. The method developed by Nahar and Pradhan provides both σ_{PI} and $\alpha_R(T)$ in a self-consistent manner. Calculations are carried out for oxygen ions through all ionization states from O I to O VII, for σ_{PI} and $\alpha_R(T)$.

Application of the unified recombination rates to ionization fractions of oxygen ions in plasmas in coronal equilibrium shows significant differences with the previous abundance calculations at these temperatures. Similar results were obtained for carbon and nitrogen ions last year.

Relativistic photoionization cross sections can also be calculated in full intermediate coupling using the Breit-Pauli approximation. Zhang used the approximation for C IV, C V, and O VII ions, where radiation damping effects were also included. Work is in progress for other highly charged multi-electron systems where relativistic effects are likely to be of importance.

The *ab initio* unified treatment of total electron-ion recombination, as described by Nahar and Pradhan in 1995, subsumes both radiative and di-electronic recombination. Zhang and Pradhan extended this treatment to relativistic calculations for photorecombination spectra including fine structure. Pradhan, Zhang, and Nahar have implemented a perturbative method to include radiation damping of autoionizing resonances in photoionization and recombination of highly charged ions. The calculated recombination spectra are in excellent agreement with *absolute* experimental recombination (DR) cross sections, including resonance structures, measured with synchrotron ion storage rings (CRYRING in Stockholm and 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.

11.3 Radiative transition probabilities and X-ray spectra

Accurate transition probabilities are being calculated using methods for atomic collision theory developed under the Iron Project. The new developments under the Iron Project now enable relativistic fine structure calculations in the Breit-Pauli R-matrix (BPRM) method. The computational methods are efficient and enable large-scale calculations up to the order of 10^6 transitions in complex ions of the iron group elements.

The first large-scale data for the fine-structure transition probabilities for dipole-allowed and intercombination transitions in Fe XXIV and Fe XXV have been reported recently by Nahar and Pradhan. The number of energy levels and oscillator strengths obtained far exceed the existing data. Comparison of oscillator strengths for He-like and Li-like iron with the previously most accurate calculations including relativistic and quantum electrodynamics effects show agreement at the level of a few percent. The Fe XXIV and Fe XXV lines are expected to be seen in the X-ray spectra to be taken by the *AXAF* satellite.

Nahar and Pradhan have completed the BPRM calculations for the fine structure transition probabilities of a complex iron ion, Fe V. An extensive amount of data for the transition probabilities of about 1.43 million transitions are obtained, compared to none available in the NIST compilation. The results are being analyzed.

The new data will be available electronically through the Opacity Project database, TOPbase, and the Iron Project database, TIPbase.

12 Nuclear Astrophysics

The γ-process, thought to synthesize higher mass p-process nuclides, is described with statistical model (γ,p), (γ,α) and (γ,α) cross sections, almost none of which has ever been measured. To test those for (γ,p), Boyd's research group used the University of Notre Dame accelerator facility to measure cross sections for the inverse reactions ^{112,119}Sn(p,γ) and ^{96}Zr(p,γ). In order to circumvent the high backgrounds that would have resulted from the relatively high incident proton energies, reactions were selected that produced radioactive daughters. Cross sections were determined by radiating the targets, then observing β-delayed γ-rays off-line. The results were found to be reasonably consistent with the statistical model predictions.

Boyd, Meyer (Clemson Univ.), and Hencheck (Univ. Wisconsin, Green Bay) have studied the results of repetitive bursts of nucleosynthesis in a hot H-rich environment: the repetitive rp-process, or (rp)^2-process. The results suggest that the nucleosynthesis of the neutron-poor Mo and Ru isotopes, which has long defied explanation, might be consistent with such a processing scenario.

For several years a collaboration that includes several members of Boyd's group has been designing OMNIS, the Observatory for Multiflavor NeutrInos from Supernovae. This relies on interactions of the incident neutrinos with "converter nuclei", e.g., iron or lead, to produce secondary neutrons. Detection of the neutrons thus signals the arrival of the neutrinos. OMNIS would be used to perform diagnostics on the stellar core collapse process and, possibly, to measure neutrino masses at cosmologically interesting levels. Use of different converter nuclei allows the possibility of determining if ν-oscillations have occurred, since oscillations of μ- or τ-neutrinos into e-neutrinos would tend to produce "hot" e-neutrinos that could produce identifiable events. Central to this project are the detectors to be used and the signal to noise of the site in which it will be housed. The OSU group has conducted detector tests, and has also measured the neutron background in a possible site, the Waste Isolation Pilot Plant (WIPP) which is 2000 feet underground in New Mexico. It was found that WIPP has an acceptable signal to noise for a galactic supernova. The possibility that detectors built for other projects, e.g., detection of oscillations from neutrinos from accelerator beams, could be used as possible supernova neutrino observatories is also being studied.

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