Indiana University
Department of Astronomy
Bloomington, Indiana 47405

This report covers research activities in the Department of Astronomy and the High Energy Astrophysics group for the period September 2002 through August 2003 inclusive.

1. INTRODUCTION

The Astronomy Faculty at Indiana University consisted of Professors: Haldan N. Cohn, Richard H. Durisen (Chair), R. Kent Honeycutt, Phyllis M. Lugger, Stuart L. Mufson, and Catherine A. Pilachowski; Associate Professor: Constantine P. Deliyannis; Assistant Professor: Liese van Zee; Professors Emeriti: Martin S. Burkhead, Frank K. Edmondson, and Hollis R. Johnson. Other department members included Research Associate Thomas Y. Steiman-Cameron. Brice R. Adams and Eric Ost were members of the professional staff; William R. Kopp, Christina M. Lirot, and Brenda S. Records were members of the support staff. Graduate Students in the Department during the year were: Aaron Boley, Brian Brondel, Jeffrey Burkett, Kai Cai, Janet Casperson, Kevin Croxell, Jeffrey Cummings, David Herrick, Heather Jacobson, Styliani Kafka, Ryan Maderak, Steven J. Margheim, Scott Michael, Annie C. Mejia, Nicholas J. Mostek, Talawanda Monroe, Prasanth Nair, Brian J. Rebel, Adam W. Rengstorf, Allen B. Rogel, Brian Sands, Angela Sarrizine, and Aaron J.B. Steinhauer.

The High Energy Astrophysics group at Indiana University is an interdepartmental (Astronomy and Physics) research group with faculty: Mark Messier (Physics), Stuart L. Mufson (Astronomy), and James Musser (Physics); Senior Scientist: Charles Bower; Graduate Students: Nicholas J. Mostek and Brian J. Rebel; Technical Staff: Art Cohee, Mark Gebhard, Richard LeBeau, James Lovell, Michael Simpson, and John Wildman; Support Staff: Christina Lirot, Debbie McKinney, and Brenda Records.

The Bachelor of Science Degree in Astronomy and Astrophysics was received by Jean Brigham, Jason Ten Barge, and Eric Thompson. The Masters of Arts Degree was received by Janet Capserson, David Herrick, Angela Sarrazine, and Heidi Tebbe. Ph.D. degree was received by Adam Rengstorf, Shawn Slavin, and Aaron Steinhauer.

2. RESEARCH

2.1 Instrumentation and Facilities

The High Energy Astrophysics Group (HEAP) continues its participation in the MINOS experimental search for neutrino oscillations. The experiment sends muon neutrinos toward northern Minnesota from Fermilab in Chicago. The signature of neutrino oscillations is the disapperence of these neutrinos (flavor-changing) along the route. The experiment will explore the neutrino mass region below 10^{-2} eV^2. Neutrinos in this mass range can account for some fraction of the nonbaryonic dark matter in the universe as well as the hot dark matter postulated to explain large scale structure. Construction of the far detector in Soudan, MN is now complete; civil construction of the beam line and the near detector hall is complete and near detector installation will start in late 2003. The NuMI beam will turn on in 2005. At the present time the far MINOS detector is studying neutrino physics and muon physics initiated by cosmic rays in the atmosphere. The Indiana HEAP group had responsible for the construction of the far detector multiplexing boxes (MUX boxes) that route the fiber optic readout cables to the multipixel PMTs and the far detector fiber optic cables.

Work on the QUEST II CCD camera controller, a collaboration between the Physics Department at Yale University and the Astronomy and Physics Departments at Indiana University, has been completed. This camera consists of 112 CCDs, each having 600×2400 13-micron pixels. The camera controller, Indiana's responsibiliity, uses the MFront interface board set with the control logic implemented in Xilinx field programmable gate arrays. The camera has been installed on the Palomar Schmidt Telescope and is currently taking data.

2.2 Solar System Formation

Durisen, Mejía, Cai, Boley, and M.K. Pickett (Purdue U. Calumet) are continuing numerical 3D hydrodynamics studies of gravitational instabilites in protostellar disks as a mechanism for gas giant planet formation. The lifetimes of disks around young stars seem too short for the standard core-accretion mechanism to explain the common occurrence of super-Jupiter exosolar planets. Under conditions of high effective cooling, dense clumps do form in disks, but it is still not clear whether the clumps eventually lead to permanent bound objects. In one particularly long calculation, which has been carried now beyond twenty outer disk rotations, long-lived dense rings develop. Solids of sizes between centimeters and many meters will drift radially toward the centers of these rings on time scales of only hundreds to thousands of years. This suggests a hybrid scenario in which rings produced by gravitational instabilities may drastically shorten the time scales for core accretion.

Contrary to expectations from the work by A. Boss (Carniegie Inst. Washington), the introduction of realistic radiative cooling does not seem to facilitate clump formation in the simulations of the IU-PUC group. This is under further intensive investigation (see Section 2.3).

Clump formation in 3D disk simulations is a difficult numerical problem, requiring high resolution and algorithmic accuracy. Simulations with more physics and more refined numerical techniques are required. Even for a simple isothermal equation of state, the situation remains unclear. A collaboration has been initiated with T.W. Hartquist and S. Falle (U. Leeds) to pursue this problem using adaptive mesh refinement techniques. A recent breakthrough by Durisen and Hartquist is the derivation of an approximate analytic criterion for fragmentation in isothermal disks. This offers insight into how, where, and under what conditions fragmentation will occur. Together with Pickett, they will compare numerical results with the predicitons of the approximate analysis. Extension to the case of a disk with cooling will also be attempted.

Over many years, Durisen and various graduate and undergraduate students have developed a code which calculates the effects of ballistic transport in planetary ring systems. Ballistic transport is the net transport of mass and angular momentum due to exchanges of ejecta from hypervelocity meteoroid impacts onto ring particles. This mechanism can, in principle, explain the production and maintenance of features seen near the inner-edges of Saturn's A and B Rings. However, the best simulations published to date do not agree with the observed rings in important details. Durisen and Herrick have modified the code to handle two independent ejecta distributions at once – the high speed, primarily prograde ejecta from nondisruptive cratering events and the lower speed, retrograde ejecta from meteoroid impacts which catastrophically disrupt ring particles. For his Master's research, Herrick ran a suite of simulations for the B Ring inner edge under different assumptions about the nature of the two ejecta distributions. Future work will involve the inclusion of a more realistic treatment of ring opacity and kinematic viscosity.

2.3 Stars

Rotational fission as a theory of binary star formation supposes that, if a star rotates fast enough, instabilities or bifurcations of nonaxisymmteric surface distortions ultimately lead to splitting of the star into two or more objects. Using 3D hydrodynamics codes, Durisen and coworkers in the 1980's demonstrated that rotating polytropic stars which are dynamically unstable to barlike modes develop strong two-armed spirals. Gravitational torques in the sprial arms transport angular momentum outward and abort the nascent fissioning of the central regions. Until recently, however, there have been few calculations which tested the case where an object evolves quasistatically from stable to unstable conditions. N. Lebovitz (U. Chicago) has maintained that fission will occur under these conditions. As a follow up to detailed studies of finitely unstable polytropes, J.N. Imamura (U. Oregon), Pickett, and Durisen have been using their 3D hydrodynamics code to simulate polytropes in which the entropy per gram is slowly decreased. The polytropic stars are started with slow enough rotation that they are dynamically stable. As they contract due to decreasing entropy, they spin up and surpass the stability limit. Results indicate that the instability proceeds in the same way as calculated earlier, and binary fission is avoided. However, there are suggestions of weak but ineffective instabilities that set in prior to the two-armed dynamic instability.

Imamura, Durisen, and Pickett are continuing their study of ‘‘fizzlers,’’ equilibrium objects with densities between those of white dwarfs and neutron stars. In this density regime, a nonrotating star would collapse due to the softness of the equation of state, but rapid rotation can stabilize the radial collapse modes. So, when the iron core of a massive star collapses with finite angular momentum, a supernova event can be substantially delayed, or prevented altogether, by the formation of such an object, hence the term ‘‘fizzler,’’ for ‘‘fizzled supernova.’’ By incorporating a hot, lepton-rich, high-density equation of state into their 3D hydrodynamics code, Imamura, Pickett, and Durisen have shown that dynamic rather than secular instabilities dominate the evolution of a fizzler and that these instabilities are reached on a deleptonization time scale of a few seconds or less. The gravitational waves emitted during the dynamic instability are, in principle, detectable by LIGO I at Virgo Cluster distances provided that the resultant bar is long-lived. Calculations following fizzlers from dynamically stable to unstable states by deleptonization show extremely interesting oscillatory behavior and may include fission of the central region if nuclear density is attained. The difference between this and the purely polytropic case in the preceding paragraph is the very different equation of state.

Durisen, Mejía, Pickett, Cai, Boley, D. Berry (IU's UITS), and J. Rosheck (free-lance software engineer) are continuing their research on gravitational instabilities (GI's) in disks around young stars using 3D hydrodynamics simulations. In addition to the gas giant planet formation projects mentioned in Section 2.2 above, this work includes the following (names in parentheses are those with primary responsibility): (1) simulations of externally forced spiral waves in disks (Pickett, Cai, Durisen), (2) introduction of progressively more realistic treatments of heating and cooling, energy transport, and shear viscosity (Mejía, Pickett, Durisen), (3) analysis of the asymptotic steady-state equilibrium between heating and cooling (Cai, Boley, Mejía, and Durisen), (4) investigation of the effects of initial conditions and boundary conditions (Cai, Boley, Durisen), (5) computation of SED's (Mejía, Durisen), (6) adaptive mesh treatment of isothermal disks (Pickett, Falle, and Hartquist; see Section 2.2), (7) analytic fragmentation criteria (Durisen, Hartquist, Pickett; see Section 2.2), (8) 2D and 3D visualization of results (Rosheck), (9) increasingly parallelized and portable versions of the 3D hydro code (Berry), and (10) an improved Poisson solver (Berry).

The ultimate goal of this long-term collaboration is to understand the behavior of gravitational instabilities in protostellar disks. In particular, under what conditions do they produce significant mass and angular momentum transport? Is such transport sustained or episodic? What are the observational consequences? Can planets or brown dwarfs ever form from a disk by direct gravitational condensation?

Recent progress has been made in developing realistic treatments of radiative cooling and in performing very long simulations with idealized heating and cooling. The latter are useful for testing the asymptotic behavior of disks evolving under the influence of GI's. As predicted in earlier work, the disk seems to settle into a state of roughly constant Toomre Q after a strong dynamic transient as the GI's first kick in. Mass transport in the GI active region can be as large as about 10^{-5} $M_\odot$/yr during burst-like behavior, comparable to FU Ori peak accretion rates, and is roughly steady in the asymptotic state at about a few times 10^{-7} $M_\odot$/yr, sufficient to sustain T Tauri accretion rates. By varying the cooling time, we have verified an analytic prediction about the relationship of cooling time to the formation of dense fragments.

Radiative cooling algorithms that resolve and treat both the optically thin upper disk layers and the optically thick midplane regions has been completed by Mejía. Large differences in cooling time are found depending on how the optically thick to thin boundary conditions are handled. Claims of very short disk radiative cooling times in the literature may be incorrect. Careful comparisons of radiative cooling by our methods and by those of other researchers will be made by Cai and Durisen.

A major effort is continuing by Mejía and Durisen to include irradiation by the central star. It appears that irradiation tends to suppress the growth of GI's by preferentially heating the star-facing side of spiral corrugations of the disk surface. More rigorous tests of this preliminary result are underway.

A new direction in star/disk modeling has been launched by Durisen, Michael, and Boley. During FU Ori outbursts, there is evidence that the stellar surface and disk meet and that the stellar surface is swollen to two or three times its normal radius. The 3D hydro group has begun an effort to model the response of a star to an encroaching disk. Because this has just begun, only crude test runs with polytropic disk material falling onto a polytropic star are currently planned. If all goes well, the problem will be treated with greater sophistication in coming year.

Durisen and M.F. Sterzik (ESO-Chile) are continuing their investigations of multiple star formation by small cluster decay, particularly its effects on the observable properties of the resultant binaries and multiples . Their schemes are highly successful in reproducing the observed trend in the multiplicity fraction with stellar primary mass. This work has now been extended by including objects with brown dwarf masses in the clusters. The rather high fraction of brown dwarf binaries claimed by some observers seems to require some dissipation in the cluster dynamics or a very large number of brown dwarfs. By relatively simple scaling arguments, devised in collaboration with H. Zinnecker (Ap. Inst. Potsdam), cluster decay modeling in conjunction with collapse and fragmentation seems to be able to explain the typical separations of binaries of different primary masses.

Durisen participated in two observational projects concerning young stars that involved large collaborations. For the first effort, led by J. Alcala (Osservatorio Astronomico de Capodimonte), a star forming region in Orion near L1616 was selected for study because it contained a high density of X-ray selected ROSAT young star candidates. WIYN Hydra observations combined with photometric data confirm that this is indeed an association of young stars. The other project was a coordinated effort, led by B. Stelzer (La Palma), to obtain simultaneous observations in the optical and X-rays for V410 Tau, a strongly flaring T Tauri star. Although no simultaneous observations were obtained due to scheduling problems with Chandra, flare events were captured over many days of monitoring.

Pilachowski, in collaboration with graduate student H. Jacobson, is examining the spectra of A stars in eight young clusters varying in ages from 3 to 100 million years to identify stars showing the presence of infalling material similar to what is seen in β Pic. Infalling material into a central star, manifested through transient absorptions in strong absorption lines such as the Ca II K line, provides an approach to study both the composition and dynamics of planetesimals in young star systems. Clusters, which offer the opportunity for simultaneous observation of multiple stars, were selected to cover the age range over which the frequency of infalling material might be expected to decline.

The multi-object Hydra spectrometers at the WIYN 3.5-m and Blanco 4-m telescopes were used in echelle-mode (resolving power $\sim$15,000) to obtain first epoch Ca II K line profiles for typically 10 stars per cluster. Target stars were selected for observation using on published photometry. Second epoch observations will be obtained during 2004.

Undergraduate REU student Kurt Soto (UC Berkeley), in collaboration with C. Pilachowski, examined spectra of 80 later type stars also obtained in the same young clusters, to obtain estimates of chromospheric activity, projected rotation velocity, radial velocity and spectral type. The clusters ranged in age from the youngest, NGC 2264, at an age of about 3 million years, to the oldest, IC 4664, at an age of about 100 million years.

The stars included in the study were selected to have dereddened B-V colors between 0.4 and 0.9. Chromospheric activity was estimated using indices measuring the emission in the cores of the Ca II lines compared to nearby continuum. Radial velocities were determined by cross-correlation with the solar spectrum. Projected rotation velocities were estimated by comparison with an artificially spun-up solar spectrum. No correlation was found between projected rotation speed and the degree of chromospheric activity, and stars the oldest cluster of our sample, IC 4665, showed the greatest degree of chromospheric activity. This research was carried out as part of the Astronomy REU program at Indiana University with funding from the National Science Foundation.

Pilachowski, in collaboration with V. Smith (UTEP) and numerous other authors, participated in the Gemini Observatory Demonstration Science Program for the Phoenix spectrometer on Gemini South. High-resolution infrared spectra were obtained for twelve red-giant members of the Large Magellanic Cloud (LMC) with the Gemini South 8.3m telescope plus Phoenix spectrometer. Two wavelength regions, at 15540 Å and 23400 Å, were observed. Quantitative chemical abundances of carbon (both ^{12}C and ^{13}C), nitrogen, and oxygen were derived from molecular lines of CO, CN, and OH, while sodium, scandium, titanium, and iron abundances were obtained from neutral atomic lines. The twelve LMC red giants span a metallicity range from [Fe/H]= –1.1 to –0.3. Values for both [Na/Fe] and [Ti/Fe] in the LMC giants fall below their corresponding Galactic values (at these same [Fe/H] abundances) by about $\sim$0.1 to 0.5 dex; this effect is similar to abundance patterns found in the few dwarf spheroidal galaxies with published abundances. The program red giants all show evidence of first dredge-up mixing of material exposed to the CN-cycle, i.e. low ^{12}C/^{13}C ratios, and lower ^{12}C- with higher ^{14}N-abundances. The carbon and nitrogen trends are similar to what is observed in samples of Galactic red giants, although the LMC red giants seem to show smaller $^{12}C/^{13}C$ ratios for a given stellar mass. This relatively small difference in the carbon isotope ratios between LMC and Galactic red giants could be due to increased extra mixing in stars of lower metallicity, as suggested previously in the literature. Comparisons of the oxygen to iron ratios in the LMC and the Galaxy indicate that the trend of [O/Fe] versus [Fe/H] in the LMC falls about 0.2 dex below the Galactic trend. Such an offset can be modeled as due to an overall lower rate of supernovae per unit mass in the LMC relative to the Galaxy, as well as a slightly lower ratio of supernovae of type II to supernovae of type Ia.

Pilachowski is continuing a collaboration with Deliyannis, S. Barden (NOAO), D. Harmer (NOAO), R. Mathieu (U. Wisconsin) and S. Meiborn to search for planets in open clusters of a variety of ages using the Hydra fiber spectrograph on the 3.5-m WIYN telescope. Radial velocities for cluster members are determined relative the average velocity of the ensemble of stars observed. Velocity precision of at 100 m s^{-1} or better has been demonstrated. Additional observations of NGC 752 and Praesepe were been obtained during 2003 and new observations of stars in the young cluster Trumpler 37 were also obtained.

E. Friel (NSF), H. Jacobson (UT Austin), Pilachowski and others investigated the composition of giant stars, including oxygen abundances, in the very old open cluster Cr 261. The data were obtained with the echelle spectrograph at the Blanco 4-m telescope at the Cerro Tololo Interamerican Observatory. Cr 261 was found to have a mean metallicity of [Fe/H]=–0.22, with roughly solar oxygen abundance.

Oxygen abundances for unevolved metal-poor stars were determined by C. R. James, in collaboration with C. Pilachowski, T. Beers, C. Sneden, and R. Cavallo, using moderate resolution spectra obtained with the Mayall 4-m telescope's RC spectrograph at Kitt Peak. At moderate resolution, the high excitation O I triplet lines are blended into a single feature that can be measured and analyzed as a spectroscopic blend. Because the lines are separated by only 3.4 Å, the blended feature is more easily detected than the individual features; thus reliable oxygen measurements can be made in much fainter stars. Also, the immediate vicinity of the oxygen triplet is free of atmospheric absorption line contamination, and the feature is unblended with other stellar lines from additional elements. Approximately half of the sample had been previously studied at high spectral resolution, allowing for a thorough assessment of the feasibility of applying the lower resolution method to this population of stars. Employing a spectrum synthesis analysis to these low-dispersion spectra does sometimes yield meaningful results, and those results are consistent with high-resolution studies. However, in many cases, the weakness of the triplet allows for determinations of upper limits only, most of which are unenlightening.

Undergraduate REU students TalaWanda Monroe and Stacy Sidle completed an LTE spectroscopic analysis of tau Boo, rho CrB, and 51 Peg, three stars reported to have planetary mass companions, in collaboration with C. Pilachowski. From high-resolution (R=200,000), high signal-to-noise ratio (S/N ratio = 250) spectra obtained with the coude feed telescope at the Kitt Peak National Observatory, [Fe/H] values 0.17 +/− 0.13, −0.32 +/− 0.12, and 0.11 +/− 0.05 were determined for the three stars, respectively. Spectral synthesis was employed to derive log epsilon(Li) values for rho CrB and 51 Peg, 1.06 and 1.11 respectively. The compositions of these stars were compared with the abundances of three stars which are not known to harbor Jovian-mass planets, gamma Ser, 110 Her, and beta Aql. Stars with planets were found to have higher metal abundances in lighter elements such as Mg, Al, and Si; supporting the planet-SMR star connection. This research was carried out as part of the Astronomy REU program at Indiana University with funding from the National Science Foundation.

2.4 WIYN Open Cluster Study (WOCS)

Cai, Deliyannis, and Durisen have developed a way to detect binaries in clusters by photometric means only. With accurate enough photometry and a good fit of the color-magnitude diagram to an isochrone, comparison of the observed U-I and B-I versus V of stars with theoretical binaries constructed from model stars in the isochrone main sequence can, in principle, be used to determine the primary mass (M_1) and mass ratio (q) of an observed system. So far, over 200 proper motion members of the WOCS open cluster M35 have been analyzed in this way. For most stars, we can reliably place them into three bins $q<0.4$, $0.4<q<0.7$, and $q>0.7$ for M_1 between one and three solar masses. The distribution tends to be more peaked at middle q-values than the distribution observed for nearby solar-type stars. At higher masses in the cluster, the method fails. This suggests that some additional parameter, like stellar rotation, significantly alters the main sequence UBVRI magnitudes from the Yale values. This effect is currently being quantified.

Despite limitations, the method does allow some measure of the binary fractions and q-distributions in clusters without time-consuming spectroscopy, which picks up only close binaries. The method will be refined and extended to other WOCS clusters to examine possible trends with cluster age and metallicity.

2.5 Globular Clusters

Pilachowski, graduate student J. Casperson, and undergraduate student E. Freeland, with C. Sneden (UT Austin), have determined carbon isotope ratios in three giants in the globular cluster M3 from high dispersion infrared spectra obtained at the Keck Observatory, and in a fourth M3 giant observed with the Phoenix infrared spectrometer on NOAO's Mayall 4-m Telescope at Kitt Peak National Observatory. Abundances of iron, silicon, and titanium were also derived for the three stars with NIRSPEC data. The derived atomic abundances are consistent with values in the literature for these stars. While three of the giants have isotope ratios of approximately 6, typical of globular cluster giants, the carbon isotope ratio in the lithium-rich giant IV-101 is approximately 11, higher than what is found in most other globular cluster giants of similar temperature. The Li and carbon isotope ratio of IV-101 is consistent with a recent suggestion of anomalously energetic hydrogen shell fusion and mixing events in low mass, low metallicity stars on the first-ascent red giant branch.

A. Saha (NOAO) and Pilachowski are conducting a Baade-Wesselink analysis of 29 RR Lyrae variables in the globular cluster M3 with velocities from moderate resolution spectra taken with the Hydra multi-fiber spectrograph on the 3.5-meter WIYN telescope. Light curves in the Gunn *uvgri* system were obtained with the Kitt Peak 0.9-meter telescope.

Pilachowski, in collaboration with R. Cavallo (LLNL) and N. Suntzeff (CTIO), has participated in the investigation of the chemical abundance of aluminum and other metal in 21 red giants in the globular clusters NGC 6752 and M 80 as part of a larger study to determine whether the aluminum distribution on the red giant branch is related to the second parameter effect that causes clusters of similar metallicity to display different horizontal branch morphologies. The observations were obtained of the Al I lines near 6700 Å with the CTIO Blanco 4-m telescope and Hydra multi-object spectrograph. The spectra have a resolving power of 18000 or 9400, with typical S/N ratios of 100-200. Mean [Fe/H] values obtained from the spectra are –1.58 for NGC 6751 and –1.73 for M 80; this represents the spectroscopic abundance determination for M80. Both NGC 6752 and M 80 display a spread in aluminum abundance, with mean [Al/Fe] ratios of +0.51 and +0.37, respectively. No trend in the variation of the mean Al abundance with position on the giant branch is discernible in either cluster with the small sample of stars available.

Undergraduate student Eric Thompson completed an Honors thesis in collaboration with C. Pilachowski to analyze spectra of 35 red giants in the globular cluster M4 to determine chemical composition. The spectra were obtained as part of a survey to look for lithium in globular cluster red giants. The Hydra multi-fiber spectrograph at the 3.5m WIYN telescope on Kitt Peak was used for observations from 6470-6850 Å with the echelle mode. The stars cover a four magnitude range along the red giant branch. Elemental abundances including Mg, Al, several iron group metals, La, and Eu were determined for each star. Some giants exhibited detectable abundances of lithium. The abundances of lithium and other elements were examined as a function of evolutionary phase along the red giant branch.

Undergraduate major Matt Wimmer, guided by C. Pilachowski, analyzed the chemical compositions of two globular cluster giants. The spectra of the stars M71 1-113 and M13 L353 were obtained with the High Resolution Spectrograph on the Hobby-Eberly Telescope using Public Access time available through the NOAO. The spectra cover the wavelength range of 6000 to 7750 Å with a spectral resolving power of about 30,000. The stars were identified from low resolution spectra as possibly showing lithium features, and the presence of lithium was confirmed in one of the spectra. The abundances of more than fifteen elements in each giant were determined using detailed analysis techniques.

Slavin completed a Ph.D. dissertation, under the supervision of Cohn and Lugger, on the structure of two candidate collapsed-core globular clusters NGC 6284 and NGC 6293. He fit analytic models to the star count profiles of these clusters, derived from a careful photometric analysis of HST WFPC2 imaging of the central regions. The maximum-likelihood fits of models with and without cores incorporates completeness information from a large set of artificial star experiments. For both clusters, the structure was found to be consistent with core-collapse models. The inferred surface density slopes for the turnoff-mass stars suggest that these two clusters have smaller populations of 1.4 solar mass degenerate remnants than do some other collapsed-core clusters such as M15.

Lugger and Cohn continued their participation in a collaboration with J. Grindlay, P. Edmonds, and C. Heinke (Harvard) to study the X-ray source populations in globular clusters using HST and Chandra. In the past year, this collaboration has published an analysis of the source population in Terzan 5 (Heinke *et al.* 2003a), a complete millisecond pulsar X-ray survey for 47 Tucanae and NGC 6397 (Grindlay *et al.* 2002), and a survey of quiescent low-mass X-ray binaries (qLMXBs) in nine clusters (Heinke *et al.* 2003b). In these studies, maximum-likelihood fits of generalized King model profiles to the spatial distribution of Chandra sources were used to estimate the source mass. Values consistent with the expected range for CVs, single neutron stars, and LMXBs are obtained.

2.6 Galactic Astronomy

Lugger, Cohn, and graduate student Rogel are participating in the ChaMPlane survey, which is being carried out by a group led by J. Grindlay. The objective is to identify a large sample of serendipitous X-ray sources in deep galactic plane Chandra fields, in order to identify and measure the populations of accretion-powered X-ray binaries in the Galaxy. The primary goal is to identify cataclysmic variables and quiescent low-mass X-ray binaries, in order to determine the luminosity functions of these objects. The secondary goal is to determine the distributions in the Galaxy of Be X-ray binaries and stellar coronal sources. Deep Chandra field observations have sufficient sensitivity to reach such objects over a substantial fraction of the Galactic disk. Each of about 100 Chandra fields is being imaged in Hα, *R*, *V*, and *I* using the mosaic cameras on the CTIO and KPNO 4m telescopes; approximately 30 fields have been imaged to date. Objects are selected for spectroscopic follow-up based on Chandra detection and/or Hα excess. Rogel's Ph.D. dissertation involves WIYN/Hydra spectroscopy of northern hemisphere ChaMPlane fields and development of a model for the Galactic CV distribution for comparison with the spectroscopic results. Spectroscopy has been obtained for 12 northern hemisphere ChaMPlane fields, producing spectra for a total of approximately 1000 objects and identifications for the generally brighter 60% of this sample. The classified objects include a least 4 CVs (detected through Hα excess), several T Tauri stars, a large number of M stars (about half of which are dMe type), and about 30 quasars with redshift z ranging up to 4.2.

2.7 Galaxies and Cosmology

L. van Zee, L. M. Young (NMIMT), R. Dohm-Palmer (Minnesota), and K. Y. Lo (NRAO) completed a study of the velocity dispersion of the neutral hydrogen gas in a small sample of dwarf irregular galaxies. H I velocity dispersions and line shapes in 3 of the dIs show evidence of both warm and cool H I phases. Contrary to initial expectations, there was no trend found between the incidence of the low-dispersion (colder) phase and the star formation rate in dwarf irregular galaxies. The colder H I phase may be a necessary ingredient for star formation, but it is clearly not sufficient. However, there is a global trend between the star formation rate of a galaxy and the incidence of asymmetric H I profiles, as expected from kinetic energy input by young massive stars.

van Zee, Dohm-Palmer, and Young completed a study of the resolved stellar population of UGCA 292, one of the nearest extremely low metallicity galaxies known. The HST observations revealed an old stellar population, at least 3 Gyr old, in this gas-rich, metal-poor galaxy. Thus, despite its blue colors and low metallicity, this galaxy is not undergoing its first episode of star formation. These observations illustrate that it is possible for a galaxy to remain both gas-rich and metal-poor following several star formation episodes.

In collaboration with J. J. Salzer (Wesleyan) and E. D. Skillman (Minnesota), van Zee and undergraduate J. Ten Barge analyzed stellar rotation curves of a small sample of starbursting dwarf galaxies. The majority of the galaxies in this sample are rotation dominated; the optical spectra indicated that the gaseous and stellar components are kinematically coupled in most systems. Interestingly, a few of the galaxies did have decoupled kinematics, suggesting that their high star formation rate may have been induced by a catastrophic event. In these cases, the gaseous component has a significant velocity gradient while the stellar component has no evidence of rotation. These latter cases are particularly intriguing because the optical images and HI data cubes for these galaxies show no evidence of perturbed isophotes or other obvious signatures of interaction.

In collaboration with E. Barton Gillespie (U. Arizona), van Zee obtained UBVRI images of dwarf elliptical galaxies to search for correlations between star formation history and kinematic properties. Preliminary analysis indicates that the observed optical colors are similar regardless of galaxy kinematics, but there is a suggestive trend that rotating dwarf elliptical galaxies may be slightly redder than their non-rotating counterparts. While further analysis of the metallicity and age of the dominant stellar populations are necessary to confirm the significance of this trend, this result suggests that rotating dwarf elliptical galaxies may be both older and more metal-rich than non-rotating dwarf elliptical galaxies in the Virgo Cluster.

van Zee is continuing her study of dwarf galaxy counts in a variety of environments. In hierarchical cosmologies, dwarf galaxies are not only the building blocks of L* galaxies, but the current dwarf galaxy population may provide important constraints on the distribution and abundance of dark matter halos. In collaboration with D. Schade (HIA) and graduate student J. Casperson, van Zee continued observations for the SMUDGES (Systematic Multiwavelength Unbiased catalog of Dwarf Galaxies and Evolution of Structure) survey. The primary goal of the SMUDGES survey is to determine the fraction of dwarf galaxies that undergo a starburst phase. The SMUDGES survey will be the first with both the depth and volume to identify a statistically significant sample of dwarf galaxies that is unbiased by the current star formation activity in each galaxy. To date, approximately half of the survey area has been imaged in BVI; the first spectroscopic observations were obtained in early 2003 with the MMT 6.5m and the WIYN 3.5m telescopes.

In collaboration with E. Barton Gillespie (U. Arizona), van Zee is continuing a study of the morphological evolution of spiral galaxies at intermediate and high redshift. Observations are underway with the CFHT 3.6-meter and the WIYN 3.5-meter for this project. The superb image quality of these two telescopes will enable accurate morphological measurements of galaxies at high and intermediate redshift. This project will focus on the bulge formation process in spiral galaxies.

A. Rengstorf completed his dissertation with Mufson on a search for quasars with the QUEST 1 survey data at high galactic latitudes. The search concentrated on finding quasars with varability criteria alone. During this dissertation research, 30 quasars were found, 9 of which were new discoveries. The plan is to continue searching for quasars using variability criteria with the recently installed QUEST 2 camera on the Mt.Palomar 48-inch Schmidt telescope.

2.8 High Energy Astrophysics

Mufson, J.L. Miller (James Madison U.), and A. Habig (U. MN, Duluth) have finished their cosmic ray studies using MACRO. Their final results appear in papers on the Compton-Getting Effect (Sidereal and Solar Diurnal Waves), point sources of astrophysical muons, the diffuse neutrino flux from AGN, and the shadow of the sun and moon observed using underground muons.

Rebel and Mufson are searching for atmospheric neutrino-induced muons coming from the rock below the MINOS detector as a probe of neutrino oscillations. The far MINOS detector is the first underground detector with a magnetic field so that it can separate positively-charged and negatively-charged muons. This charge separation will enable Rebel and Mufson to search for CPT violation.

The Indiana HEAP group has joined the SNAP experiment (SuperNova Acceleration Probe), a satellite experiment that seeks to confirm the acceleration of the universal expansion and to explore the nature of the dark energy that is driving this acceleration. The launch is currently scheduled for 2010. Bower and Musser are responsible for the design of the interference filters. Mostek and Mufson are working on calibration issues and the development of methods to measure the quantum efficiency of the near infrared HgCdTe detectors.

2.9 Education

Pilachowski, in collaboration with Travis Rector (University of Alaska at Anchorage), H. Tebbe (Indiana University), and F. Morris (Indiana University) successfully implemented a new education website which allows introductory astronomy students access to astronomical data to search for novae in the Andromeda Galaxy. Students participated in observing on the WIYN 0.9-m telescope in Arizona using remote video technology, and then examined the data over the Web to make new discoveries. The website is available at www.astro.indiana.edu/novasearch/.

G. Simonelli (Indiana University) and Pilachowski evaluated student understanding of basic concepts in astronomy by surveying students in an introductory astronomy class at the beginning of a semester. The results are appearing as a Letter in Astronomy Education Review.

2.10 Miscellaneous

Edmondson continued to have a heavy load of professional correspondence. Much of it was in connection with the effect of the restructing of the IAU on Commission 20 and the Minor Planet Center.

All of Edmondson's archived files related to his book (AURA and Its US National Observatories) were transferred to the Indiana University Archive. These filled 54 standard archive boxes. 6 boxes of correspondence files were also tranferred. 20-30 boxes will be reqiured for material to be transferred later.

Edmondson started to use a cane during the late winter and early Spring. A blood sample on April 24 had a low hemoglobin level, and another on April 28 was lower. This was followed by a trip to the Emergency Room on April 29. A bleeding ucler was found and a blood transfer (2 units) followed. He spent 6 weeks in a Health and Living Center while the ulcer was treated medically. He returned home the middle of June, and has home health care (1 hour in the morning and 3 hours in the afternoon).

He kept up with his professional correspondence at the Health and Living Center using their fax service to send long hand letters to the Astronomy Department for Brenda Records to type. He has a fax machine at home now to continue this. His health is good, but he is no longer able to drive. He comes to the office when someone is available to drive him, and health care aides are not scheduled at home.

The Indiana University hosted a meeting in October, 2003, of institutions interested in partnerships to build the next generation of large telescopes, with apertures of 15-30 meters. In attendance were representatives from the Center for Astrophysics, the University of Arizona, the Observatories of the Carnegie Institution of Washington, Cornell University, the University of Texas, the University of Illinois, the National Optical Astronomy Observatory, the University of Chicago, the University of Virginia, Universidad Autonomica de Mexico, the Gemini Observatory, and the University of Toronto, as well as members of the IU Astronomy Department. There were presentations by several of the Working Groups for science, optics, adaptive optics, operations, cost estimates, site, and telescope design, and representatives reviewed their institutions' intentions and resources toward construction of a large telescope.

On October 25, 2002, Indiana hosted ''AstroFest,'' a rededication of the Kirkwood Observatory which was originally dedicated in May, 1901. Brief comments were given by Kent Honeycutt, Martin Burkhead, and Dean of the College Kumble Subbaswamy. Dick Durisen formally rededicated the observatory. On October 26, 2002, several talks were delivered about the uses of the WIYN Observatory for science and teaching by IU faculty Caty Pilachowski, Haldan Cohn, Phyllis Lugger, and Con Deliyannis, who had behind the scenes help from Liese van Zee. Additional talks were given by George Jacoby (Director of the WIYN Observatory), Eric Wilcotts (University of Wisconsin), and distinguished alumna Martha Haynes (Cornell Univeristy).

On the evening of October 26, 2002, a dinner was held in honor of Professor Emeritus Frank K. Edmondson's 90th birthday. Over 100 people attended. Many famous astronomers who could not attend sent letters to be read at the dinner. Most notable among these was Robert Kraft (D. Sci. IU 1995). Many astronomical organizations sent official acknowledgements, including the American Astronomical Society, AURA, the IU Foundation, and the Center for the History of Physics of the AIP.

On August 27, 2003, the Department held ''MarsFest,'' a public outreach program to celebrate Mars' perihelic opposition. Three talks were given in the largest lecture hall in Swain West to standing-room only crowds. Caty Pilachowski talked on the ''Exploration of Mars''; Martin and Barbara Burkhead discussed ''Life on Mars''; and Dick Durisen addressed the question ''Why is Mars so Close?.'' Afterwards, approximately 2,000 people viewed Mars from Kirkwood Observatory or through telescopes set up by the Stonebelt Stargazers from Bedford, Indiana.

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Stuart Mufson
Christina M. Lirot