

University of Virginia
Department of Astronomy
Leander McCormick Observatory
Charlottesville, Virginia, 22903-0818

This report covers the period 1 September 2000 to 31 August 2001.

1 Personnel

During this time the departmental faculty consisted of Steven A. Balbus, Roger A. Chevalier, John F. Hawley, Philip A. Ianna, Zhi-Yun Li, Steven R. Majewski, Robert W. O'Connell, Richard J. Patterson, Mercedes T. Richards, Robert T. Rood, Craig L. Sarazin, William C. Saslaw, Trinh X. Thuan, Charles R. Tolbert, D. Mark Whittle, and Kiriaki Xiluri.

Edward M. Murphy joined the faculty in October as an Assistant Professor. His position is directly tied to education and public outreach. P. Kenneth Seidelmann arrived in November as Research Professor. Michael F. Skrutskie joined the faculty as Professor in August. Philip A. Ianna retired in May—he will remain active in the Department after spending two years at the NSF.

Postdocs in residence included Elizabeth Blanton, Márcio Catelan, Jean-Pierre de Villiers, Dana Dinescu, Yutaka Fujita, Richard de Grijs, Robert Link, Thomas Reiprich, Jaehyon Rhee & Motokazu Takizawa. Eduardo Bringa and Catherine Tully from Robert Johnson's planetary astronomy group were also in residence. During the year Blanton was awarded a Chandra Fellowship which she will take working with Sarazin. Catelan held a Hubble Fellowship working with Rood. Fujita & Takizawa both held Overseas Researcher Fellowships from the Japanese Ministry of Science and are working with Sarazin. Reiprich was the first Celerity Foundation Fellow.

Other personnel included Data Analyst Catherine Slesnick, Instrument Maker Charles Lam, Electronics Design Technician James Barr, Office Manager Virginia Bossong, & Secretary Jacquelynn Harding.

There were 19 enrolled graduate students at the end of this period. Christopher Palma, Michael Siegel, and Chi-Yueh Wang completed their Ph.D.s during the year.

Long term visitors included Lars Bildsten, Yuri Izotov, Bill Kunkel, and Valery Shematovich.

The Virginia Institute for Theoretical Astronomy (VITA) continued operations during this period with support from the University of Virginia and NASA's Astrophysical Theory, Long Term Space Astrophysics, Origins of Solar Systems, and XMM programs, JPL, Chandra, Space Telescope Science Institute, and the NSF Stars/Stellar Systems and Gravitational Physics Programs.

2 Facilities

The Leander McCormick Observatory with its 26-inch Clark refractor on Mount Jefferson is now used almost exclusively for education and public outreach. It is heavily used for both our graduate and undergraduate courses. The Public Night program has been expanded. Several rooms in the observatory are being remodeled and converted into a museum.

The 0.7-m and the 1-m reflectors on Fan Mountain were used during the year for our undergraduate majors and graduate observational astronomy courses. An auxiliary guider was installed by Kiriaki Xiluri on the 1-m telescope. Because of the tailpiece design, guiding is controlled through an 8-inch Meade telescope equipped with a CCD camera. Subarcsecond corrections to the guiding are possible with this setup, but work is already underway to achieve even better guiding with the goal being to achieve 0.36 arcsec resolution; this resolution is a better match for the image scale of the main CCD used for scientific exposures. Jeff Crane and Steven Majewski continue work on a fiber-fed spectrograph for the FMO 1-m telescope. The spectrograph will be used to do the northern hemisphere spectroscopy for Majewski's Grid Giant Star Survey. When complete, the GGSS will provide much of the ground-based pre-launch support for NASA's Space Interferometry Mission (SIM). In Australia, the 1-m reflector at Siding Spring Observatory has continued to be made available for the southern parallax program under a cooperative agreement with Mount Stromlo and Siding Spring Observatories.

In the summer of 2000 the Department received a 10 million dollar gift from the Celerity Foundation of Frank and Wynnette Levinson. Frank received his Ph.D. in Astronomy from UVa in 1980. The gift will in part be used to initiate a program in optical/IR instrumentation headed by Skrutskie, to provide a lead-in to a major telescope project, to enhance our education and public outreach (Murphy), to fund postdoctoral fellowships (Reiprich), graduate fellowships, visitors (Dan Jaffe [Texas], Hal McAlister [Ga. St.], Pat Osmer [OSU], Noam Soker [on sabbatical from Haifa]), and in general to provide broad support to aid in the advancement of the Department.

3 Research

3.1 Stars and Stellar Evolution

Balbus has completed a study of the local stability of a rotating, magnetized, thermally conducting, hot dilute plasma. The study is relevant for the behavior of gas accreting onto a black hole, or in clusters of galaxies. He

found that the stability of this type of system is not governed by the classical Høiland criteria, as many investigators had assumed, but by very different criteria. They are, however, just as simple as the Høiland criteria, but involve temperature and angular velocity gradients instead of entropy and angular momentum gradients. The magnetic field and thermal conduction allow these free energy gradients to be accessed. Numerical simulations by J. Stone (Maryland) has verified the fundamental linear properties of the instability, and extended it into the moderately nonlinear regime.

Balbus, in collaboration with S. Fromang and C. Terquem (IAP, Université de Paris) has completed a study of the self-consistent ionization structure of protostellar disks. The ionization source was taken to be the X-rays from the central young stellar object (YSO). In contrast to previous studies, which used disk models incompatible with steady accretion, the present investigation adopted density profiles taken from α disk calculations. Ionization calculations included the effects of heavy metal ions. A very broad radial range of ionized disk gas was found depending on the parameters adopted, but no model was fully ionized over the entire extent of the disk. The study also indicated that the distribution of the X-ray emissivity in disk-YSO systems (central source, distributed throughout a corona, etc.) is critical to understanding the MHD behavior of the disk.

Balbus, in collaboration with S. Fromang and C. Terquem (IAP, Université de Paris) is studying the stability of rotating magnetized clouds against gravitational collapse. The role of the magnetic field is of particular importance here, because a rapidly rotating core loses angular momentum via MHD torques, contracting further and rotating yet more rapidly. Thus, the magnetic field promotes, not inhibits, gravitational collapse.

Chevalier, Fransson (Stockholm), and collaborators analyzed optical and ultraviolet observations of the Type II_n supernova 1995N at epochs between 321 and 1799 days after the explosion. The spectra show three distinct velocity components. The narrow lines come from circumstellar gas and show both low and high ionization. This component has a low filling factor, and is photoionized by X-rays from the shock. The intermediate component, which is dominated by newly processed oxygen, originates in a shell with velocity of 2500–5000 km s⁻¹, and most likely comes from the ejecta. The hydrogen- and helium-dominated gas has a low ionization, a high density, and velocities that extend out to > 10,000 km s⁻¹. Strong signatures of Ly α -pumped fluorescence lines of Fe II are seen in the near-infrared and ultraviolet. The He/H ratio, ~ 0.3 by number, and the nitrogen overabundance provide strong evidence for CNO burning products. The H α line profile shows strong evolution, with the red wing decreasing faster than the blue. Scenarios involving either a clumpy circumstellar medium, or an aspherical distribution of the surrounding gas, are possible based on the line profiles and physical conditions.

Chevalier, along with Blondin and Frierson (NCSU),

investigated the late evolution of pulsar wind nebulae. For pulsars similar to the one in the Crab Nebula, most of the energy input to the surrounding wind nebula occurs on a timescale $\lesssim 10^3$ years; during this time, the nebula expands into freely expanding supernova ejecta. On a timescale $\sim 10^4$ years, the interaction of the supernova with the surrounding medium drives a reverse shock front toward the center of the remnant, where it crushes the PWN (pulsar wind nebula). One- and two-dimensional, two-fluid simulations of the crushing and re-expansion phases of a PWN show that (1) these phases are subject to Rayleigh-Taylor instabilities that result in the mixing of thermal and nonthermal fluids, and (2) asymmetries in the surrounding interstellar medium give rise to asymmetries in the position of the PWN relative to the pulsar and explosion site. These effects are expected to be observable in the radio emission from evolved PWN because of the long lifetimes of radio emitting electrons. The scenario can explain the chaotic and asymmetric appearance of the Vela X PWN relative to the Vela pulsar without recourse to a directed flow from the vicinity of the pulsar. The displacement of the radio nebulae in G327.1–1.1, MSH15–56 (G326.3–1.8), G0.9+0.1, and W44 relative to the X-ray nebulae may be due to this mechanism.

Post doctoral researcher Jean-Pierre de Villiers is working on developing the next generation of general relativistic simulation code. He is studying schemes for MHD and the addition of a stress term to the existing hydrodynamic GR code. Simulations using this stress are currently underway to map out broad categories of dynamical response in black hole accretion flows.

Hawley and Balbus continue to investigate, through combined analytical and numerical studies, the nature of the angular momentum transport mechanisms, MHD turbulence, and global dynamics of astrophysical disk systems, including protoplanetary systems.

During the past year Hawley has been performing a series global three-dimensional accretion torus simulations. These simulations demonstrate that, quite generally, such tori are strongly unstable to the magnetorotational instability. Turbulence is rapidly produced which drives the angular momentum to a Keplerian profile, regardless of its initial distribution. The instability acts as a dynamo, regenerating poloidal field, and thereby sustaining the turbulence. Work continues with global disk simulations, for a range of initial disk configurations, magnetic field strengths and orientations, and spatial domains.

Along with graduate student Wayne Winters, Balbus and Hawley have completed a three-dimensional global simulations of protostellar disks. They are modeling disks subject to MHD turbulence in which a planet is embedded, to investigate the influence of the turbulence on gap formation and planet migration. They find that the planet itself can influence the turbulence, and hence the angular momentum transport, a behavior that cannot be captured with the standard α -disk modeling. The standard criterion for when a gap can form in a viscous

disk does not appear to reproduce the findings of this more complete numerical MHD study.

Hawley, in collaboration with J. Krolik (JHU) has carried out a detailed three dimensional magnetohydrodynamic (MHD) simulation describing the inner region of a disk accreting onto a black hole with a particular focus on the inflow through the marginally stable orbit. They find that the Maxwell stress is continuous across the marginally stable orbit, in contradiction with the widely-held assumption that the stress should go to zero there. As a consequence, the specific angular momentum of the matter accreted into the hole is smaller than the specific angular momentum at the marginally stable orbit.

Hawley and Stone (Maryland) have begun a study of linearized Riemann schemes as a possible algorithm for MHD studies. The first efforts are directed at Newtonian MHD.

Li started a new project with F. Shu (Berkeley) on oscillations of molecular cloud cores, with an eye on probing the core structure and the properties of waves propagating in the cores. The investigation was motivated by infrared observations of the Bok globule B68, which provide a high-resolution contour map of the column density through the globule. The contours show regular distortions superposed on a smooth background, which could be due to acoustic oscillations. He has carried out an eigenmode analysis for simple equilibrium cloud configurations, and found that the amplitude of oscillation increases with radius away from the core center, and could become quite large in the low density envelope. It was concluded that the oscillations could be detectable most easily in channel maps, especially with ALMA.

Li continued his study of the collapse of magnetized molecular cloud cores leading to star formation. He incorporated rotation into the self-similar solutions of magnetically and thermally supported cores he developed previously with F. Shu for cores on the brink of star formation. The collapse of such magnetized, rotating cores leads to disk formation, which is a new frontier in star formation in magnetized clouds. In collaboration with A. Allen (ASIAA, Taiwan) and F. Shu, he is investigating the processes of core collapse and disk formation numerically. They found that a new type of outflow is produced, with a speed comparable to the sound speed of the cloud. The outflow could carry away a substantial fraction of the angular momentum from the collapsing material, and thus play a role in disk formation. It is too slow, however, to explain the molecular outflow or optical jet often detected around forming stars.

Li and F. Nakamura (Berkeley) have begun a long-term program aiming at understanding the fragmentation of strongly magnetized molecular clouds. Magnetic support allows a cloud to have more than one Jeans mass and still be in static equilibrium. The super-Jeans mass promotes fragmentation. Using a 2D MHD code with mesh refinement, they are able to show, as a first step, that $m = 2$ bar mode can grow during the dynamic col-

lapse phase of the evolution of a disk-like cloud once the cloud has become magnetically supercritical through ambipolar diffusion. The bars developed during the isothermal collapse may subsequently break up into small fragments at higher densities when the dust opacity exceeds unity. The fragments could seed the formation of binaries, multiple stellar systems, and small clusters. The calculations may also have applications to a scenario of extrasolar giant planet formation around protostars that Li is pursuing.

Li continued his collaboration with a research group in Moscow led by V. Shematovich in developing coupled dynamic and chemical models for molecular cloud cores prior to star formation. These models are aimed at explaining the velocity field and chemical abundance data of starless cores that are becoming increasingly available. They modeled the well-observed core L1544 in detail and found a reasonably good match between the abundances and spatial distributions of CO, CCS, N_2H^+ and HCO^+ predicted for a strongly magnetized cloud and inferred from observations. Models involving promptly-collapsing, non-magnetic clouds provide a worse overall fit to the data. This result provides some support to the standard picture of low-mass star formation which envisions core condensation quasi-statically over a relatively long, ambipolar diffusion timescale.

Graduate student Crane, in collaboration with Majewski and Kunkel (LCO) has been working on the calibration of 1 Å resolution spectra from $H\alpha$ to $H\beta$ data through the use of spectral indices and principal component analysis. This work is in support of his work on the Galactic K_z law as a means to determine the amount of local dark matter in the Galactic disk (the Oort limit), in collaboration with J. Bahcall (IAS). To this end, Crane has collected almost 200 square degrees of multicolor imaging data at the North Galactic Pole using the McDonald 0.8-m telescope in order to find a homogeneous sample of K giants at different heights above the Galactic plane. With the selection of K giants underway, plans are being made for the needed follow-up spectroscopic observations.

Graduate student Siegel, Majewski, Reid (STScI) and Thompson (OCIW) continued their work on star counts in Kapteyn Selected Areas. As part of Siegel's Ph.D. thesis, they determined that the density distribution of the stars in the Milky Way (using photometric parallaxes) is best described by a thin disk, a moderate scale height (750 pc) thick disk, a flattened inner halo and a spherical outer halo. However, there is evidence from their fits to seven fields that this global model imperfectly accounts for what appears to be substructure (field to field variations) in the outer halo.

Majewski's group has continued its search for extratidal giant stars torn from Galactic satellites using the Washington M and T_2 filters in combination with the DDO51 filter. The first study of the extended distribution of giants around the Carina dSph produced evidence of a substantial extended giant population, beyond the limiting radius of a King profile fit to the core, around

the dSph. Extensive work to confirm this population has been ongoing. Graduate students Palma and Ostheimer, with Majewski and Link have developed a new statistical algorithm to calculate the probability that stars identified as giants using the Washington + DDO51 system are classified correctly. Both the newly estimated contamination level as well as a growing number of spectra of the previously identified Carina giant candidates show that that extended population of stars associated with this dSph is real.

Meanwhile, photometric surveys around other satellites have been made. Kyle Westfall (undergraduate student), Ostheimer, Frinchaboy, Patterson, Majewski, and Kunkel, have surveyed a wide field around the Sculptor dSph galaxy and find a population of stars beyond its canonical tidal radius. Palma, Majewski and Patterson have completed a similar survey of the Ursa Minor dSph and find extended populations of both red giant and blue horizontal branch stars outside the canonical tidal radius of this system. Within the tidal radius, isodensity contours show that the galaxy has an S-shaped morphology, similar to the tidally disrupting globular cluster Pal 5. Using the Mosaic cameras on both the NOAO 4-m telescopes, Siegel has mapped the Leo II dSph and finds some evidence for an apparent extratidal extension in one direction, while grad student Sohn finds rather clear evidence of a pair of tails on Leo I. Considering the Galactocentric distances to Leo I and Leo II (> 200 kpc), our result is expected to help estimate the dark matter content of the Galaxy. Future observations, to extend the area of the survey, and for spectroscopic follow-up, are planned. These studies are not limited to the Milky Way: Ostheimer, with Jennifer Alltop (undergraduate), has carried out similar studies on the Andromeda dSphs and finds a similar extension around And I (extensions around And II and And III are less certain).

Using spectrographs on the NOAO 4-m telescopes, the DuPont 2.5-m, and the Keck telescopes (in collaboration with R. Guhathakurta, Lick) Majewski et al. are presently undertaking or planning spectroscopic observations of all of the dSphs we have mapped in order to confirm association of the identified extratidal giant candidates and to determine the velocity dispersion as a function of radius. The latter will determine whether these systems are dark matter dominated or affected by tidal disruption. In all cases, the existence of substantial extratidal debris would be hard to understand if these dSphs are heavily dark matter dominated, as suggested by their central velocity dispersions.

Similar searches for extratidal stars around globular clusters are under way. Undergraduate students Alexis Johnson, Amy Forestell, and Veronica Ponce have conducted studies of the globulars Arp 2, NGC 288, and Pyxis, respectively. Spectra of extratidal stars of each cluster are being reduced.

Ostheimer and Link have completed a maximum likelihood algorithm to fit surface densities of globular clusters and dwarf galaxies. This program has been used extensively by Ostheimer to fit models to M31 dwarf

galaxies. Ostheimer has developed a kernel discriminant technique to separate globular cluster and dwarf galaxy stars from the field in the Washington photometry system.

Majewski, Ostheimer and Patterson have continued their study of the halo of M31. The aim is to accurately determine the extent, flattening, metallicity, and metallicity spread of M31. Additionally this survey allows the identification of substructure in the halo of M31 that could be present due to the disruption of dwarf galaxies around M31.

Using the extensive photometric catalogue being generated by the Grid Giant Star Survey (GGSS), Majewski, Patterson, Rhee, and grad students Frinchaboy and Polak have been collaborating with W. Kunkel (LCO), A. Kundu (MSU) and K. Johnston (Wesleyan) to search for phase space structure in the Galactic halo. Thus far over 5000 spectra of GGSS stars as faint as $V = 17.5$ have been obtained using the CTIO 4-m and Hydra multifiber system. Data analyzed so far indicate the presence of a previously undiscovered, but model-predicted, inner tidal arm from the Sgr dwarf galaxy.

Slesnick, Rhee, Patterson and F. Benedict (McDonald) have determined luminosity classes (using photometric techniques used for the GGSS) for reference stars used in the determination of parallaxes for astrophysically interesting stars obtained with the Fine Guidance Sensor interferometer on the Hubble Space Telescope, including: the central star of the planetary nebula NGC 6853, the cataclysmic variable TV Columbae, and the distance scale calibrators RR Lyrae and Delta Cephei.

Majewski, Dinescu, Frinchaboy, Patterson, Ostheimer, Rhee, and Palma have been studying internal stellar population and bulk kinematical properties of the Galactic globular cluster ω Centauri. The metallicity distribution function (MDF) of ω Centauri was determined through the use of the Washington M, T_2 and $DDO51$ photometry to derive photometric metallicities, and construct a metallicity distribution function. The data reveal that ω Centauri has four metallicity peaks; this combined with published work on the age spread in ω Centauri lends support to the idea that this globular may actually be the nucleus of a disrupted, previously more massive dwarf galaxy. With this in mind, and given the retrograde, small size orbit of ω Cen, Dinescu has searched for a kinematical signature left by a hypothetical parent galaxy in the Solar neighborhood. Within the largest sample of metal poor stars to date (Beers *et al.* 2000), she finds a retrograde signature among stars in the metallicity range $-2.0 < [\text{Fe}/\text{H}] \leq -1.5$ that departs from the characteristics of the inner halo, and that in fact resembles ω Cen's orbit.

Rhee and T.C. Beers (Michigan State) have refined metal-poor star selection methodology based on Artificial Neural Network techniques to analyze some 1.5 million *digital* spectra scanned using the Automatic Plate Measuring machine (in collaboration with M.J. Irwin, IoA, Cambridge), in combination with released 2MASS *JHK* photometry (the HK-II Survey). Of particular im-

portance, the new analysis technique developed by Rhee has avoided the introduction of temperature-related bias in the identification of metal-deficient stars, an avoidable troublesome with the *visual* inspection approach employed in the original HK survey (HK-I). Rhee was able to reveal that the “effective yield” of HK-II for stars with $[\text{Fe}/\text{H}] \leq -2.0$ is roughly 60–70%, and recent spectroscopic observations support this higher detection rate of *bona-fide* metal-deficient giant stars among HK-II candidates. From the HK-II survey it is expected to obtain a *new* database of some 5000 cooler metal-poor candidates, consisting mainly of giant stars, over $\sim 7000 \text{ deg}^2$ in the thick disk and halo of the Milky Way Galaxy (to date, some 2000 candidates have already been selected).

Rhee is a participant in large international spectroscopic follow-up observations of metal-poor star candidates identified from the HK-II survey, as well as from the Hamburg/ESO prism survey (in collaboration with N. Christlieb, Hamburg). This effort is aiming to find $N \sim 500 - 1000$ stars with $[\text{Fe}/\text{H}] \leq -3.0$ over the course of the next 3–5 years, and on the order of 5000 – 10000 stars with $[\text{Fe}/\text{H}] \leq -2.0$ in the same period, using KPNO/CTIO telescopes, UVES at the VLT, HDS at SUBARU, or the newly commissioned 6dF facility on the UK Schmidt telescope. Metallicities and radial velocities determined from the medium-resolution spectroscopy, combined with proper motions from ongoing and future astrometric surveys (such as the Yale/San-Juan SPM, USNO survey, and NASA’s FAME and SIM), will provide full space motions for numerous extremely old stars. The HK-II survey will also provide a large sample of giant candidates to be searched for stars with highly enhanced r-process elements by high-resolution spectroscopic follow-up which is already underway for the HK-I stars with VLT, KECK, and SUBARU. The results will help unravel the chemical and dynamical history of the Milky Way.

Richards, Waltman (NRL), and Ghigo (NRAO) completed their program to monitor radio flaring activity in Algol-type and RS CVn binaries with the Green Bank Interferometer. The systems studied were β Per, δ Lib, and V711 Tau. Data were collected at 2.3 GHz and 8.3 GHz for each system from 1995 January to 2000 October. During that time, the data collection was interrupted twice because of temporary closings of the interferometer. The entire campaign lasted for 2096 days and detected numerous strong flares with fluxes as high as 1.17 Jy in β Per, 1.44 Jy in V711 Tau at 8.3 GHz. The 2.3 GHz and 8.3 GHz flux from δ Lib was typically less than 0.02 Jy at 8.3 GHz for more than three years, then we detected the flares with fluxes of ~ 0.03 Jy at 8.3 GHz; the strongest flares observed from this system during our campaign. Two independent techniques, namely power spectrum analysis and the Phase Dispersion Minimization (PDM) technique, were used to determine the frequency of radio flaring activity. Based on data collected from 1996 November to 2000 August, the dominant flaring frequencies were found to be ~ 49 days for β Per, ~ 120 days for V711 Tau. These values

have not changed significantly since the earliest stages of the campaign.

Richards also studied the Radon Transform and its applications to image reconstruction techniques in medicine, geophysics, and astronomy. This transform can be used to reconstruct the image of an object from projections along lines that pass through the object. The Radon Transform is the mathematical projection of the object, while the reconstructed object is the inverse 2-dimensional Fourier Transform of the 1-dimensional Fourier Transform of the projection. This simple process of reconstruction is called back-projection, and the overall procedure is known more widely as “tomography.” In medicine, X-rays are used to produce to “Computerized Axial Tomography” (or CAT) scans, while magnetic fields produce “Magnetic Resonance Imaging” (or MRI) scans. The scanning machines used in the hospital construct the scans from X-rays or magnetic fields that pass along lines through the body. In geophysics, seismic waves are used to produce images of the internal structure of the Earth based on data collected at positions around the Earth. The arrival times of primary (P), shear (S), Raleigh (R), and Love (L) waves at locations around an earthquake have resulted in structural information about earthquakes. In astronomy, tomography has been used to produce images of spot distributions on rotating stars (single or in RS CVn binaries), accretion disks in cataclysmic variables, and the entire mass transfer process in Algol binaries. The simple mathematical formulation of the Radon Transform or the projection of an object along a line is the root of all of these reconstructed images.

Rood, Origlia, Ferraro, & Fusi Pecci (Bologna) have found mid-IR emission from dusty winds surrounding red giants in several globular clusters. The derived mass loss rates show surprisingly little variation with cluster metallicity. Bellazzini, Montegriffo, (Bologna) et al have found a substantial binary population in the globular cluster NGC 288. In addition there is a large centrally concentrated population of Blue Stragglers despite the low cluster density.

The work of Márcio Catelan currently in progress focuses mainly on stellar evolution in globular clusters (GCs). In collaboration with J. Borissova (Bulgarian Acad. Sc.) and F. R. Ferraro (Bologna) he has obtained a color-magnitude diagram for M75 (NGC 6864). They have found M75 to be another rare instance of a “bimodal horizontal branch” cluster. N. Soker (Haifa), Catelan, R. T. Rood (UVA) and A. Harpaz (Haifa), have proposed that first-ascent red giant stars may undergo a “superwind” phase similar to that in AGB stars, and explored the possibility that such a “superwind” might be related to a “gap” at about 20,000 K, separating the blue horizontal branch from the extreme horizontal branch in globular cluster CMDs.

Catelan, W. B. Landsman (GSFC) and F. Grundahl (Aarhus) are studying Hot, UV-bright stars in GCs. The analysis includes ground-based and space-based (UIT and HST-STIS) data, as well as theoretical modeling.

Catelan, T. M. Corwin (UNC) and H. A. Smith (Michigan State) are analyzing the bright variable star population in M75. In collaboration with B. J. Pritzl (NOAO), H. A. Smith and A. V. Sweigart (GSFC), he has obtained snapshot HST-WFPC2 observations of the massive globular cluster NGC 6441 located towards the Galactic bulge. They are currently working on the resulting light curves for variable stars in the most crowded central regions of this very dense globular. This work has shown that HST snapshots provide a means of observing variable stars in the cores of crowded globular clusters. One particularly tantalizing by-product of this investigation is the indication that NGC 6441 may be a metal-rich analogue of ω Centauri, also presenting an internal metallicity spread. This possibility is being investigated on the basis of Hydra spectra of the variables. Time-series photometry for M15 has been obtained last summer by Catelan and J. Borissova at the Bulgarian National Observatory “Rozhen” 2m telescope. With over 150 frames taken in each of B,V,I, this will clearly provide the best CCD light curves for M15’s bright variables to date. The bright variable star population in the outer-halo GC Palomar 3 is being investigated by Catelan, J. Borissova, V. D. Ivanov (Steward Obs.), and S. Ortolani (Padova). The variable star populations in the GCs Arp 2 and NGC 6304 are being investigated by Catelan C. Cacciari (Bologna), C. E. Corsi (Rome), and M. Bellazzini (Bologna).

W. C. Saslaw and D. Valls-Gabaud (Toulouse) are continuing their new theoretical approach to star formation and have completed an extensive grid of models using the Cambridge, U.K., supercomputer.

Sohn (graduate student), Rey (CSA, Yonsei, Korea), and Lee (CSA, Yonsei, Korea) are performing analysis of the RR Lyrae variables in the Oosterhoff type II globular cluster M53 using high-quality light curves obtained in 1995 and 2000. The aim is to understand the Sandage period-shift effect of RR Lyrae variables among clusters of different Oosterhoff types.

Lorimer (Jodrell Bank), Xilouris, Fruchter (STScI), Stairs (NRAO), Eder (NAIC) have used high precision timing observations with the Arecibo 300-m radiotelescope, to obtain phase-coherent timing solutions for eight of the nine new pulsars discovered in a joint STScI/NAIC drift-scan search. Most of the pulsars in this survey are slow, low-luminosity objects with periods ranging between 0.4 and 2.2 sec. Their spin and astrometric parameters as well as the flux densities and emission properties have now been safely established. These ephemerides will be essential to any follow-up studies of these pulsars at other frequencies, as well as in studies of the interstellar medium.

A dedicated campaign of timing observations is currently underway for a 25.7-ms pulsar discovered in the aforementioned Arecibo drift-scan search. Observations obtained so far show that this pulsar is in a 655.7-day binary system about a low-mass ($\geq 0.2 M_{\odot}$) companion star. The on going measurements promise to provide a more accurate measure of the spin and orbital param-

eters, as well as the position, proper motion and possibly parallax of this pulsar. These results will provide valuable insights into the formation and evolution of neutron stars in long-period binary systems. An accurate solution is essential to any follow-up studies of the pulsar and its companion at higher wavelengths, e.g. cm-radio, X-ray, optical etc.

In addition, phase-coherent timing solutions obtained for the first time for 17 pulsars discovered at Arecibo by Hulse & Taylor (1975) in a 430-MHz survey of the Galactic plane are reported in a recently submitted paper by Lorimer, Camilo and Xilouris. In addition to the solutions they present scatter-broadening measurements for two pulsars and pulse nulling and mode-changing properties of two others.

Kramer (Jodrell Bank), Stairs (NRAO) and Xilouris (UVa) have been investigating the emission properties of millisecond pulsars using multifrequency data taken with the Arecibo radiotelescope. In particular the authors have been investigating the stability of the polarization features with time.

3.2 Interstellar Medium

C.-Y. Wang (graduate student) and Chevalier carried out two-dimensional numerical simulations to investigate the properties of dense ejecta clumps (bullets) in a core collapse supernova remnant, motivated by the observation of protrusions probably caused by clumps in the Vela supernova remnant. The ejecta, with an inner flat and an outer steep power law density distribution, were assumed to freely expand into an ambient medium with a constant density. At an age of 10^4 yr, the reverse shock front is expected to have moved back to the center of the remnant. In order to cause a pronounced protrusion on the blast wave, as observed in the Vela remnant, an initial clump density contrast $\chi \sim 1000$ may be required. The clump should be near the inflection point in the ejecta density profile, at an ejecta velocity $\sim 3000 \text{ km s}^{-1}$. These results apply to moderately large clumps; smaller clumps would require an even larger density contrast. Clumps can create ring structure in the shell of the Vela remnant and Wang and Chevalier investigated the possibility that RX J0852-4622, an apparent supernova remnant superposed on Vela, is actually part of the Vela shell. Radio observations support this picture, but the possible presence of a compact object argues against it. The Ni bubble effect or compression in a pulsar wind nebula are possible mechanisms to produce the clumping.

Majewski, Patterson, grad students Crane and Siegel, in collaboration with C. Gallart (Yale) and R. Braun (Dwingeloo) have performed a deep search for stars associated with several compact high velocity clouds (CHVCs) as a means to determine whether the CHVC’s are extragalactic, proto-galactic fragments, rather than Milky Way gas. With the ability to detect and identify any giant stars within ~ 1 Mpc, this program finds no significant population of stars in three CHVC’s.

F. J. Lockman (NRAO/GB), Murphy, S. Petty-

Powell (Evergreen State) and V. J. Urick (Bloomsburg) have completed a very deep 21 cm survey of high-velocity clouds in 860 directions at moderate and high galactic latitudes. The survey should be complete to a column density limit of $N_{\text{HI}} \geq 8 \times 10^{17} \text{ cm}^{-2}$ averaged over the beam. Emission lines are seen down to the limit of the survey implying that there are lines at still lower column densities. Altogether, they find that high-velocity H I covers 37% of the sky. The distribution and kinematics of the weak lines are similar to those of the strong lines and thus do not appear to be a new population. In fact, most of the lines can be associated with one of the large high-velocity cloud complexes. The number of weak lines indicates that most of the mass in the high-velocity clouds resides in the bright complexes and not their thin halos. They see no evidence for a population of weak HVCs at positive velocities that are participating in the Hubble flow, possibly indicating a Galactic origin for the HVC phenomena.

Murphy, B. Otte (JHU), J. C. Howk (JHU), Q. D. Wang (UMass), W. R. Oegerle (NASA/GSFC), and K. R. Sembach (STScI) have obtained observations with the Far Ultraviolet Spectroscopic Explorer that have revealed the presence of emission from O VI ions in the hot halo of the edge-on spiral galaxy NGC 4631. This is the first detection of O VI in emission in a spiral galaxy other than the Milky Way. This detection represents the best evidence yet for a “galactic fountain” operating in a spiral galaxy. A comparison with Chandra and ROSAT X-ray data will allow them to estimate the total mass flux and luminosity of cooling gas for comparison with the input energy from supernovae. They have also obtained Cycle 2 Guest Investigator FUSE observations of the edge on galaxy NGC 891 to search for O VI emission in that galaxy and to act as a comparison with NGC 4631.

Sarazin, K. Borkowski (NCSU), B. Dorman (GSFC), J. Hughes (Rutgers), and R. Smith (CfA) have developed a software package for the analysis of the thermal X-ray spectra of supernova remnants and other nonequilibrium shocks.

3.3 Galaxies and Active Galactic Nuclei

Hawley and Balbus are investigating the dynamics of non-radiative accretion flows around black holes with the specific application to the Galactic center. Most of the prior work on this topic was handicapped by the need to specify the disk stress as an input parameter using the so-called “alpha” formalism. With direct MHD simulations disk stress and evolution emerges self-consistently; this is a significant step forward.

O’Connell, Rood, Catelan, and graduate students J. Martin and S. Sohn analyzed HST/STIS high S/N spectra of the far-UV “upturn” component in nearby early-type galaxies. This is produced in old stellar populations by low mass stars with very thin envelopes on the Extreme Horizontal Branch and later phases of evolution. It is a potentially sensitive probe of the ages of old stellar populations which can be applied to galaxies at high

redshift. The far-UV data (centered at 1500 Å) are excellent and allow them to determine the spectral shape and radial dependence of the UV light to $r = 12''$ in these objects. Although most of the spectra have low spectral resolution, they detect Si IV (1400 Å) and C IV (1550 Å) in all the objects and weaker features of Si II (1260 Å) and C II (1335 Å) in the case of NGC 3115.

In a related program, they are obtaining HST far-ultraviolet photometry of the metal rich globular cluster system of the elliptical galaxy M87 using the STIS/FAR-UV MAMA camera. About 40% of the data were obtained before the STIS electronic failure in May 2001. Observations will continue during the next observing season.

O’Connell, with T. Brown and H. Ferguson (STScI) and R. Ohl (GSFC) completed a first analysis of FUSE far-UV spectra of the giant elliptical galaxy NGC 1399, which has the strongest known “UV upturn.” The 900-1200 Å spectra clearly show photospheric absorption lines from the hot HB stars. The abundance of N is nearly solar, while Si and C are at 30% and 4% of solar, respectively. The data indicate that the stellar population producing the UV upturn is metal-rich but that gravitational diffusion occurs in the atmospheres of the hot stars. There is no evidence for O VI emission from the Fornax cluster cooling flow in which NGC 1399 is immersed; the limit on cooling gas capable of producing O VI is $0.1 M_{\odot}/\text{yr}$.

O’Connell, Sarazin, and R. White (UAI) obtained Chandra X-ray Observatory imaging of the nearby elliptical galaxy M32. M32’s core is the densest known stellar system, which makes it an obvious candidate for nuclear activity. M32 is also the nearest elliptical, and its constituents can be probed to luminosities 400 times fainter than in Virgo Cluster galaxies. The observations were the deepest yet attempted in X-rays of M32, intended to reach $L_x \sim 10^{35} \text{ erg/s}$. Data obtained in July show that CXO has resolved the single known X-ray source near the center of M32 into 3 discrete sources. None of the three is coincident with the nucleus of the galaxy. There is some evidence of a diffuse component as well. Reduction and analysis of the data will continue over the next year.

Rood and O’Connell have joined with R. Peterson (UCSC) and B. Dorman (GSFC) in an ambitious program to make realistic synthetic spectra for cool stars in the mid-UV region. Earlier modeling has been hampered by the very large number of absorption lines for which basic atomic data are not available. Using a combined empirical/theoretical approach, they have produced the most realistic mid-UV spectra yet for F-G main sequence stars. This project is aimed at interpreting the composite mid-UV spectra of old stellar populations, especially the “Extremely Red Objects” now being discovered in large numbers by HST and other large telescopes. Ages for the ERO’s are basic constraints on the epoch at which large structures first formed in the universe.

S. Randall (graduate student), Sarazin, and J. Irwin (Michigan) are analyzing the Chandra observations

of the X-ray bright elliptical galaxy NGC 4649. This galaxy has extended emission line filaments and dust, and the X-ray data be used to study the interaction between the hot, X-ray emitting gas and cooler interstellar material. They will determine whether heat conduction into the cooler gas or energy losses to grains affect the thermal state of the gas. The elemental abundances and gradients in the hot gas will be derived and compared to the stellar values.

Sarazin, Randall, and Irwin are also observing X-ray bright ellipticals with optical emission line and dust filaments. These include NGC 4649 and NGC 5846 with XMM-Newton. They are also observing NGC 533 and NGC 1600 with Chandra.

Sarazin, Irwin, and Bregman analyzed a Chandra X-ray observation of the nearby, bulge-dominated Sa galaxy NGC 1291. Much like the Chandra observation of the X-ray faint elliptical galaxy NGC 4697, their observation of NGC 1291 reveals that a majority of the X-ray emission is resolved into discrete point sources, which appear to be low-mass X-ray binaries (LMXBs). Unlike elliptical and S0 galaxies, the LMXB luminosities in this spiral bulge appear to have an upper cutoff, which is approximately the Eddington luminosity of a neutron star. Some of the emission is truly diffuse and gaseous.

Sarazin, Irwin, and Bregman are observing the very X-ray faint S0 galaxy NGC 3115 with Chandra to determine the nature of its LMXB population, and to try to understand why it is fainter than similar elliptical galaxies.

Sarazin, G. Sivakoff (graduate student), and Irwin are using Chandra X-ray observations to resolve the X-ray binary population in the X-ray faint early-type galaxies NGC 4365, NGC 4382 (M85), and NGC 5866 (M102). They will determine the luminosity functions of the LMXBs, which provide direct evidence of the history of massive star formation, and a measure of the relative numbers of NS and BH binaries.

Sarazin, R. White (Alabama), and S. Kulkarni (Caltech) showed that the LMXB X-ray emission from early-type galaxies is more closely related to the globular cluster population than the field star population. They argued that all LMXBs may be produced in globular clusters.

W. C. Saslaw and W. Cotton are continuing their VLBA observations of a Milky Way star superimposed on the nucleus of an extragalactic radio source to determine if it produces a gravitational lens.

Thuan in collaboration with Izotov (Kiev) is exploring methods to constrain the age of the stellar populations in extremely metal-deficient Blue Compact Dwarf (BCD) Galaxies, those with a metallicity less than 5% solar and suggested by Izotov & Thuan (ApJ, 511, 639, 1999) to be younger than ~ 1 Gyr on the basis of chemical evolution arguments. They have studied the faint C component of the nearby BCD I Zw 18 ($Z_{\odot}/50$). Several techniques are used to constrain the age of the stellar population in I Zw 18C. Ages derived from two different methods, one based on the equivalent widths of the $H\alpha$,

$H\beta$ emission lines and the other on $H\gamma$, $H\delta$ absorption lines are consistent with a 15 Myr instantaneous burst model. We find that a small extinction in the range $A_V = 0.20 - 0.65$ mag is needed to fit the observed spectral energy distribution of I Zw 18C with that model. In the case of constant star formation, all observed properties are consistent with stars forming continuously between ~ 10 Myr and ≤ 100 Myr ago.

They have put constraints on the age of the BCD SBS 0940+544 ($Z_{\odot}/28$) using the equivalent widths of the emission and absorption lines and the shape of the spectral energy distributions (SED). Several scenarios of star formation have been considered. Models with single instantaneous bursts cannot reproduce the observed SEDs implying that star formation in the main body of SBS 0940+544 was continuous. The observed properties in the main body can be reproduced by a continuous star formation process which started not earlier than 100 Myr ago, if a small extinction is assumed. However, the observations can be reproduced equally well by a stellar population forming continuously since 10 Gyr ago, if the star formation rate has increased during the last 100 Myr in the main body of SBS 0940+544 by at least a factor of five. There is no compelling evidence which favors either a young or an old age of SBS 0940+544.

For relatively nearby BCDs that can be resolved with the Hubble Space Telescope, color-magnitude diagrams (CMD) can be used to constrain ages. Thuan & Izotov have obtained the I vs. $(V - I)$ CMD of the BCD UGC 4483 ($Z_{\odot}/23$) which reveals not only a young stellar population of blue main-sequence stars and blue and red supergiants, but also an older evolved population of red giant and asymptotic giant branch stars. The measured magnitude $I = 23.65 \pm 0.10$ mag of the red giant branch tip results in a distance modulus $(m - M) = 27.63 \pm 0.12$, corresponding to a distance of 3.4 ± 0.2 Mpc. The most striking characteristics are the very blue colors of the red giant stars and the high luminosity of the asymptotic giant branch stars. Both of these characteristics are consistent with either: 1) a very low metallicity ($[Fe/H] = -2.4$ like the most metal-deficient globular clusters) and an old age of 10 Gyr, or 2) a higher metallicity ($[Fe/H] = -1.4$ as derived from the ionized gas emission lines) and a relatively young age of the oldest stellar population in UGC 4483, not exceeding ~ 2 Gyr. Thus our data do not exclude the possibility that UGC 4483 is a relatively young galaxy having formed its first stars only ~ 2 Gyr ago.

Thuan in collaboration with Lecavelier (IAP, Paris) and Izotov have used the *FUSE* satellite to investigate element abundances in the interstellar medium of the nearby metal-deficient ($Z_{\odot}/8$) cometary BCD Markarian (Mrk) 59. The mean interstellar H I column density is $\sim 7 \times 10^{20} \text{ cm}^{-2}$ in Mrk 59. No H_2 lines are seen and $N(H_2)$ is $\leq 10^{15} \text{ cm}^{-2}$ at the 10σ level. The lack of diffuse H_2 is due to the combined effect of a strong UV radiation field which destroys the H_2 molecules and a low metallicity which leads to a scarcity of dust grains necessary for H_2 formation. Concerning the heavy ele-

ment abundances in the neutral gas, they find $\log N(\text{O I})/N(\text{H I}) = -5.0 \pm 0.3$ or $[\text{O I}/\text{H I}] = -1.5$ for the neutral gas, about a factor of 10 below the oxygen abundance of the supergiant H II region or $Z_{\odot}/80$.

Whittle (PI), Rosario (graduate student), Nelson (Nevada), and Wilson (Maryland) have continued to work on HST STIS observations of the Seyfert 2 galaxy Markarian 78. Following recalibration, all kinematic and line flux measurements have now been completed. An optimization approach was developed to fit galaxy template spectra to the continuum which resulted in cleaner extraction of the weaker lines. Initial results suggest ionization conditions are essentially unrelated to the kinematic state of the gas, arguing against the prevailing view that shocks are an important energy input.

This same group (Whittle, PI) has continued to work on further HST STIS observations of 8 Seyfert galaxies thought to have strong jet-gas interactions in their narrow line regions. Following recalibration, initial analysis has begun, measuring kinematic and line strength information along the slits. The sample exhibits wide variation in kinematic state, with some extreme examples of highly accelerated gas.

Both imaging and spectra have now been acquired in a third HST project (Whittle, PI) to study in detail two Seyfert galaxies with exceptionally extended blue-asymmetric emission line profile. The imaging data has been fully analyzed and the spectra are currently being analyzed. These data provide possibly the most extreme examples known of highly accelerated off-nuclear gas. Further analysis should establish the distribution and velocity field of the gas, and so establish the physical origin of the blue wings on all Seyferts.

3.4 Clusters of Galaxies

Blanton, Sarazin, B. McNamara (Ohio), and M. Wise (MIT) are using a Chandra image to study the interaction of the central radio galaxy with the cooling flow gas in the cluster Abell 2052. The X-ray image shows that the radio source is blowing bubbles in the X-ray gas.

Y. Fujita (postdoc) and Sarazin calculated models for the effects of minor mergers and accretion on the nonthermal emission from clusters of galaxies. They along with Kempner, H. Andernach (de Guanajuato), M. Ehle (XMM-Newton SOC), A. Roy (MPIfR), L. Rudnick (Minnesota), and B. Slee (ATNF) also analyzed a Chandra X-ray observation of Abell 133, a merging cluster which has a filamentary radio relic. The data show a “tongue” of cool X-ray emitting gas, which may be the disrupted cooling core of one of the merging subclusters.

Kempner, Sarazin, and Rudnick are making follow-up observations of three newly discovered radio relics using the VLA. They have gotten high resolution total intensity maps of the relics at multiple frequencies would enable measurements of the cluster magnetic fields and the spectral aging of this population of cosmic ray particles, while polarization maps would provide details about the magnetic field structure and shock amplification of

the field. Comparison with X-ray observations would also provide an opportunity to study the efficiency of shock acceleration of relativistic electrons and the contributions of nonthermal effects to pressure support in the ICM.

Kempner, Sarazin, and P. Ricker (Chicago) are studying Abell 85 using observations from the Chandra X-ray Observatory. The cluster has a significant cooling flow, but also shows interesting structure associated with the merger of two small subclusters with the main cluster, one of which also has a radio relic. The observations will provide information about thermal and nonthermal effects in the merger process and about the effect of mergers on cooling flows.

Kempner, Sarazin, M. Markevitch (CfA), and P. Ricker (Chicago) are observing the clusters Abell 2034 and Abell 2065 in X-rays with Chandra. These are merging clusters with radio relics, one newly discovered by Kempner and Sarazin. They are also observing the merging clusters Abell 3395 and Abell 1644 in X-rays with XMM-Newton. They will obtain high resolution temperature and entropy maps of the clusters, as well as providing kinematic information about the mergers. Abell 3395 is a well behaved off-center merger which will be compared in detail to hydrodynamic simulations by Ricker.

O’Connell, Sarazin, McNamara, Wise, P. Nulsen (Wollongong), L. David (CfA), C. Carilli (NRAO), C. O’Dea, S. Baum, M. Donahue, M. Voit, A. Koekemoer (STScI), and J. Houck (MIT) are analyzing Chandra observations of the cooling flow cluster Abell 2597. This system shows “ghost bubbles,” which are holes in the X-ray gas produced by nonthermal plasma due to a previous radio outburst.

Randall and Sarazin are using merger trees to determine the effects of cluster mergers on the thermal and nonthermal properties of clusters of galaxies.

Sarazin summarized the physical theory of merger shocks in clusters of galaxies in a chapter entitled “The Physics of Cluster Mergers” in the book *Merging Processes in Clusters of Galaxies*.

Sarazin and Ricker are simulated offset mergers between virialized clusters of galaxies, using the Eulerian hydrodynamics/ N -body code COSMOS. They find that the cluster X-ray luminosity and temperature can increase significantly during the merger. They study the development of turbulent flows during mergers, and compare the survival of distinct pressure peaks in the different simulations. They also study the generation and redistribution of entropy by merger shocks, finding that turbulent mixing and fluid instabilities play a significant role in raising the core entropy of the intracluster medium over a period of several Gyr following a merger.

Sarazin, P. Goldoni, A. Goldwurm, P. Laurent, J. Paul (Saclay), and M. Cassé (IAP) have calculated models for the hard X-ray and soft gamma-ray fluxes, spectra, and images of clusters of galaxies. These have been used to simulate INTEGRAL observations of clusters; the simulations show that INTEGRAL should provide

key information about the nonthermal content of clusters.

Sarazin and Wise calculated models for the X-ray emission in cluster cooling flows in which a fraction of the cooled gas is stored as cold, X-ray absorbing gas. The spectra of these models agree with recent observations of excess X-ray absorption in cluster cooling flows. Sarazin and Wise find that the spectra are distinguishable from foreground absorption in ways that should be detectable in ASCA spectra. Also, the absorption effects the X-ray surface brightness profiles, from which the local rates of gas cooling have been derived.

Sarazin, Blanton, M. Takizawa (postdoc), Wise, and McNamara have observed the clusters of galaxies Abell 262, Abell 2626, and Abell 3112 with Chandra to study the interaction of the radio source and cooling flow.

Sarazin, Wise, McNamara, Houck, and D. Davis (MIT) are using the Chandra spectrum of the distant cooling flow cluster MS2137.3-2353 to study the origin of excess soft X-ray absorption in the spectra of cooling flows.

Sarazin, McNamara, Wise, P. Nulsen, and L. David (CfA) will observe MS0839.9+2938, a moderate redshift cluster which may be a cooling flow cluster in formation.

3.5 Cosmology

W. C. Saslaw has calculated analytically how the rate of galaxy clustering is affected at redshifts between about 0.1 and 0.5 by a cosmological constant and by quintessence. These analytic predictions may be compared with results from recent catalogs.

W. C. Saslaw, D. Baumann and B. Leong are developing models of universes which can change their global symmetry.

W. C. Saslaw, F. Ahmad and N. Bhat are deriving a statistical mechanical description of the cosmological many-body problem.

Thuan in collaboration with Izotov (Kiev) is examining the systematic effects on the primordial ^4He abundance determination. The current best value of the primordial $^4\text{Helium}$ mass fraction determined by extrapolating to $\text{O}/\text{H} = \text{N}/\text{H} = 0$ the empirical correlations $Y-\text{O}/\text{H}$ and $Y-\text{N}/\text{H}$ defined by a large sample of Blue Compact Dwarf (BCD) galaxies, is $Y_p = 0.2443 \pm 0.0015$ with $dY/dZ = 2.4 \pm 1.0$. This result is in excellent agreement with the average $Y_p = 0.2452 \pm 0.0015$ determined in the two most metal-deficient BCDs known, I Zw 18 ($Z_\odot/50$) and SBS 0335-052 ($Z_\odot/41$), where the correction for He production is smallest. The quoted error (1σ) of $\leq 1\%$ is statistical and does not include systematic effects. We study various systematic effects including collisional excitation of Hydrogen lines, ionization structure and temperature fluctuation effects, and underlying stellar He I absorption, and conclude that combining all systematic effects, our Y_p may be underestimated by $\sim 2\%$. Taken at face value, our Y_p implies a baryon-to-photon number ratio $\eta = (4.7_{-0.8}^{+1.0}) \times 10^{-10}$ and a baryon mass fraction $\Omega_b h_{100}^2 = 0.017 \pm 0.005$ (2σ), consistent with the values

obtained from deuterium and Cosmic Microwave Background measurements. Correcting Y_p upward by $\sim 2\%$ would make the agreement even better.

3.6 Astrometry

Bartlett (graduate student) and Ianna completed a time-series analysis of 294 photographic plates taken of Barnard's Star at the Leander McCormick Observatory since 1969, which revealed no evidence of periodic perturbations indicative of a planetary companion. The study included 924 images taken on 105 nights with 103aG plates using a Wratten #12 filter. These observations indicate a parallax of 548.2 ± 1.7 milliarcseconds (mas) and a proper motion of 10332.4 ± 0.2 mas year $^{-1}$ for Barnard's Star. Bartlett and Ianna calculated and analyzed separate periodograms for the annual residuals in right ascension and declination. In neither case does the power at any frequency indicate a signal at a significance level of 50 percent or better. However, their work does not absolutely rule out the possibility that Barnard's Star may have planets.

Ianna and Begam are continuing the CCD parallax work at the Mount Stromlo and Siding Spring Observatories using the 1 m reflector with the expectation of completing the observational part of the program in early 2002. Ianna, T. Henry (GSU), and R. Mendez (ESO) are into the third year of a parallax program at CTIO on the 0.9m and 1.5m telescopes through a NOAO Survey award. The observing, about six nights per month, began in August 1999. The aims of this program are similar to the Australian program: to identify new nearby star candidates in new southern proper motion catalogs through photometry as well as other sources and to obtain parallaxes of those objects likely to be within 20 pc. Preliminary results have found five new objects within 10 pc out of twelve stars reduced.

On the basis of a high quality reduced proper motion diagram for stars in Kapteyn's SA 57 as faint as $B = 22.5$ in combination with variability data to remove a large sample of contaminating QSOs, Majewski and grad student Siegel have found a density of white dwarfs on the sky an order of magnitude larger than found in the previously most complete surveys to these depths. However, most of these stars appear to be part of a faint, low velocity disk population with a scale height only slightly larger (400-600 pc) than the old disk scaleheight from non-degenerate dwarfs. Grad students Crane and Polak are working with Majewski to reduce deep $UBVI$ CCD observations in this same North Galactic Pole field (SA 57) in order to determine photometric parallaxes for the stars in Majewski's deep proper motion sample. The data will be used to study the dynamics of late stars in the disk and to search for further evidence of Local Group tidal cannibalism in the nearby Galactic halo.

Dinescu, Majewski and Sandage (OCIW) continue their deep ($B = 22.5$), multicolor photographic and proper-motion study of other Kapteyn SAs along the Galactic anticenter meridian. So far the ($B - V$) color counts in SA's 29, 45, 71, 118 have been analyzed and the

data agree very well with standard Galactic starcount models for three of the fields. Field SA 71 however, located at $(l, b) = (167, -35)$, shows a remarkable excess of starcounts at $0.0 \leq B - V \leq 1$ and $18 \leq V \leq 19$. This starcount excess can be most plausibly explained within the framework of recent disruption models of the Sgr dSph galaxy which predict the largest densities of debris away from the main body of Sgr to occur rather near this field. In collaboration with T. Girard (Yale), proper motions and radial velocities are being obtained to get kinematical proof of this interpretation for the excess stars.

Grad student Frinchaboy and Majewski, in collaboration with W. Kunkel, have begun a project to determine the orbits of a number of Galactic clusters using absolute proper motions and radial velocities. These data will be used to investigate the outer Galactic rotation curve and the Galactic abundance gradient.

After recently completing work on the orbits of the globular clusters Pal 12, Pal 13, and NGC 7006, Majewski, Dinescu, Cudworth (Yerkes) and collaborators continue their work to measure proper motions for distant Galactic satellites. B. Keeney (undergraduate student), Dinescu and Majewski have measured a preliminary absolute proper motion of the Fornax dwarf spheroidal galaxy from an analysis of combined photographic plate material and HST archived images. So far, the link to absolute proper motion is based on two QSOs located in the background of a small region of the galaxy. First results indicate the Fornax dSph is moving along its major axis, in a low eccentricity orbit. Future plans include analyzing a larger area of Fornax with more extragalactic reference objects to verify the preliminary results. Grad student Siegel and Majewski also completed a first analysis of the proper motion of the Leo II dSph galaxy based on a combination of archive photographic plates and snapshot HST data. Unfortunately, the proper motion of Leo II is poorly defined due to the lack of centroidable background objects. However, the data so far indicate a high energy orbit for Leo II that is only a few σ away from possible membership in the proposed Fornax-Leo-Sculptor stream. Siegel and Majewski have also revised the previously measured proper motion of the Sculptor dSph by incorporating data on newly identified background QSO's to provide a new inertial reference; however, even after this improvement it appears that systematic problems may still dominate the result. Observations to correct these deficiencies are planned.

3.7 Space Astronomy

Majewski is the Principal Investigator and Patterson is a Co-I on a Key Project selected to be carried out with NASA's Space Interferometry Mission (SIM), scheduled for launch in 2009. The goal of the Key Project is to measure the gravitational potential (mass distribution) and dynamical structure of the Galaxy with unprecedented precision. Majewski and Patterson have been part of a successful effort over the past year to de-scope the SIM mission to fit under the mandated cost cap, while retain-

ing the maximum amount of mission-achievable science.

Majewski and Patterson's group, including Rhee, Slesnick, Crane, Polak, W. Kunkel (LCO), and F. Benedict (McDonald) continued the Grid Giant Star Survey (GGSS). The GGSS is designed to find stars needed for the Astrometric Grid of SIM, with a strategy to identify the most distant, $V < 13$, metal-poor K giants in 1302 "bricks", each covering $\sim 0.5 \text{ deg}^2$ at a mean separation of $\sim 6^\circ$, distributed over the entire sky. To date, photometric observations with the Washington M, T_2 and the (gravity sensitive) *DDO51* filters have been performed in 1137 bricks at the Las Campanas 1-m Swope telescope and the 0.8-m telescope of McDonald Observatory. Reduction pipelines have been developed to generate a sample of giant candidates, along with photometric parallaxes and metallicities derived from the three-filter system. Preliminary results show that 93% of bricks have at least one Grid candidate with $M < 13.5$. The median photometric parallax of the most distant Grid candidate per brick is just under 4 kpc. Low-resolution spectroscopic follow-up observations on the Swope 1-m of over 1800 Grid giant candidates (to date) have been carried out to verify the luminosity class and determine spectroscopic abundances and radial velocities. Crane continues to work with Majewski on the design and construction of a fiber-fed spectrograph for the Fan Mountain Observatory, to complete the northern part of the survey. Several components of this instrument are now complete and first light is expected in the Spring of 2002. Graduate student Polak has matched the GGSS to proper motion catalogs to construct Reduced Proper Motion Diagrams as another check on the luminosity class of the candidates. Polak has designed and implemented a dynamic web page for the GGSS catalog to be used by NASA contracted follow-up observations on potential SIM Grid candidates.

Seidemann continued as Chairman of the Full-sky Astrometric Mapping Explorer (FAME) Science Team. FAME is a NASA Midex project planned for launch in October 2004. The FAME team has been preparing for the preliminary design review in October 2001. Due to budget limitations a major rescoping effort has been pursued to reduce mass and cost, while retaining the primary science capabilities.

4 Education and Public Outreach

Murphy and Gauthier (graduate student) organized the University of Virginia's annual Science Day event. Murphy was a member of the Calibration Working Group for the Hubble Space Telescope Cosmic Origins Spectrograph and the NRAO Green Bank Telescope Beam Forming Array Working Group.

During the year there were about 4000 visitors to the McCormick and Fan Mountain Observatories as part of our continuing public outreach program.

Fredrick, Rood, & Tolbert all served as Shapley Lecturers.

5 Miscellany

Balbus was a visitor at the Institut d'Astrophysique de Paris, and at the Institute for Advanced Study in Princeton NJ.

Bartlett (graduate student) accepted an appointment as Visiting Assistant Professor of Physics and Astronomy at Hampden-Sydney College. She was an invited speaker on light pollution ordinances at the annual meeting of the International Dark-Sky Association and at a regional conference hosted by the Virginia Section of IDA.

M. Catelan has participated as a reviewer in one of the HST Cycle 10 Review Panels (Galactic). He has also recently been appointed Associate Professor of Physics and Astronomy at the Pontificia Universidad Católica de Chile in Santiago, Chile.

Chevalier served on the NRC/NAS Committee on Astronomy and Astrophysics, the AURA/NOAO Observatories Visiting Committee, and the USRA Board of Trustees.

Hawley served on the National Computational Science Alliance User Advisory Panel.

Ianna serves as a technical consultant to CSICOP, a member of the Executive Board of the International Dark-Sky Association, Chair of the Virginia Section of IDA, on the Scientific Working Group of the NASA NStars Project, on the Outdoor Environmental Lighting Committee of the IESNA, and the IAU Working Group on Extrasolar Planets.

Majewski has been selected as a Science Team member for NASA's Space Interferometry Mission. Dana Diniescu won the Dirk Brouwer Memorial Prize from Yale University for a contribution to astronomy of unusual merit.

O'Connell is chair of the Scientific Oversight Committee for the Hubble Space Telescope Wide Field Camera 3, a two-channel UV-visible-infrared imager scheduled for installation during the 2004 servicing mission. He also served as a member of the stellar populations panel for the Giant Segmented Mirror Telescope project (NOAO) and of the UV/Optical Detector Working Group (NASA HQ).

Richards was a Visiting Scientist at the Institute for Advanced Study, Princeton, this year. She completed her 3-year term as a member of the AAS Committee on Minorities in Astronomy. Richards was Panel Chair and reviewer for Division of Astronomy, NSF Faculty Early Career Development (CAREER) Program and Presidential Early Career Awards for Scientists and Engineers (PECASE). Richards is a member of the Scientific Organizing Committee for the conference titled "3-Dimensional Stellar Structure" to be held at Lawrence Livermore National Laboratory in July 2002. Richards also contributed articles and research results to the NASA Space Science Education and Outreach Program; the Exhibit Museum of Natural History, University of Michigan; and a new science textbook called "The Energetic Universe" to be published by the Open University,

England. Richards gave a lecture on the "Magic of Tomography" on Sonya Kovalevsky Day: a one-day science workshop for high school students and their teachers at the University of Albany-SUNY, New York, in April, 2001.

Rood served on the NOAO TAC, a TNG review panel, and the NRAO Users Committee.

Sarazin was chair of the Chandra Users' Committee, and a member of the Astronomy and Space Physics Council of Universities for Space Research Association, the Chandra Cycle-3 Review Panel, and the scientific organizing committee for the X-rays at Sharp Focus meeting.

Seidemann completed the triennial report of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites for 2000. He continues as president of the Celestial Mechanics Institute, the corporation overseeing the journal *Celestial Mechanics and Dynamical Astronomy*.

In collaboration with Jean Kovalevsky, Seidemann is writing a book, "Fundamentals of Astrometry." The book will develop the new methods of astrometry with the International Celestial Reference System at the microarcsecond accuracy level.

Thuan served as a TAC member of the extragalactic panel in the HST Cycle 10 proposal review.

6 Prizes and Awards

Bartlett received the Laurence W. Fredrick Teaching Assistant award.

Elizabeth Blanton was the recipient of a Chandra Fellowship.

During the 2000-2001 School year Chris Palma was elected to the U.Va. Raven Society during the Fall, and Wayne Winters was elected to the Raven Society in the Spring. This is an honor society that selects members based on service to the University. At graduation in May 2001, Chris Palma won the Edgar F. Shannon Award (presented by the Z society) for "Contributing to the Academic Excellence of the Graduate School"

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