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

This report covers the period 1 September 2002 to 31 August 2003.

1. PERSONNEL

During this time the departmental faculty consisted of Steven A. Balbus, Gregory J. Black, Roger A. Chevalier, Wesley N. Colley, John F. Hawley, Zhi-Yun Li, Steven R. Majewski, Edward M. Murphy Robert W. O'Connell, Richard J. Patterson, Robert T. Rood, Craig L. Sarazin, William C. Saslaw, P. Kenneth Seidelmann, Michael F. Skrutskie, Trinh X. Thuan, Charles R. Tolbert, Anne J. Veribiscer, D. Mark Whittle, and Kiriaki M. Xilouris.

Robert E. Johnson from Materials Science has his research group in planetary astronomy located within the department. In retirement both Laurence W. Fredrick and Philip A. Ianna remained active members of the Department. Ianna was serving as a rotator at the NSF.

John C. Wilson joined the Department in October as a Research Scientist. Mercedes Richards resigned in April taking a position at Penn State.

Postdocs in residence included Elizabeth L. Blanton, Tracy Clark, Jean-Pierre de Villiers, David McDavid, Kristen Menou, Thomas H. Reiprich, Jaehyon Rhee & Helio Rocha-Pinto. Mary Kutty Michael from Robert Johnson's planetary astronomy group was also in residence. Blanton was a Chandra Fellow. McDavid, Menou, Rocha-Pinto & Reiprich all received support from the Celerity Foundation.

Other personnel included Data Analyst Cameron Hummels, Instrument Maker Charles Lam, Electronics Design Technician James Barr, Office Manager Barbara Nicholson, & Secretary Jacquelynn Harding. Howard Powell joined the Department as a computer hardware/ software assistant.

At the end of this period there were 25 resident graduate students, 3 non-resident graduate students, 2 planetary astronomy graduate students, and one visiting graduate student.

Long term visitors included Tony Allen, Franz Bauer, Ben Dorman, Rick Fisher, Eileen Friel, Yukata Fujita, Yuri Izotov, Melanie Johnson-Hollitt, Josh Kempner, Ruben Kransnopolsky, Bill Kunkel, Jean-Pierre Lasota, Fumitaka Nakamura, Ruth Peterson, Steve Reynolds, Valery Shematovich, Tim Slater, Noam Soker, & Caroline Terquiem.

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-in Clark refractor on Mount Jefferson is now used exclusively for education and public outreach. It is heavily used for both our graduate and undergraduate courses. The Public Night program has been expanded. During the year a plan to greatly expand the education and public outreach program was initiated. This is described in §4.

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. A major upgrade of instrumentation is underway and is described in §3.7.

A gift from the Celerity Foundation of Frank and Wynnette Levinson has made it possible for the Department to initiate several programs. Skrutskie and John Wilson have initiated a program in near-IR instrumentation. The Department has recently joined the Large Binocular Telescope consortium and Steward Observatory in an agreement made through the Research Corporation. Observations at Steward facilities began during the year.

3. RESEARCH

3.1 Stars and Stellar Evolution

Chevalier has a program to investigate young core collapse supernova remnants, especially Cas A. Using recent information on the expansion and positions of the forward and reverse shock waves in Cas A, Chevalier & Oishi (graduate student) modeled Cas A as interaction with the dense wind from a red supergiant star. In this picture, Cas A might have been a Type IIn or IIb supernova, rather than the Type Ib or Ic as typically thought. The scenario provides a context to study other aspects of the remnant, including the one-sided asymmetry of the remnant and the cellular structure observed at X-ray and radio wavelengths. The site of the explosion as determined from the motion of fast knots is displaced for the center of the bright ring of emission. With Mellon (graduate student), Chevalier is finding that the observed asymmetry is more likely to be due to an asymmetric wind than to an asymmetric supernova. Blondin (NCSU) & Chevalier find that the cellular structure can be reproduced by considering 3-dimensional simulations of the interaction of the supernova with the surrounding medium. The hydrodynamic instability of the reverse shocked gas being decelerated by the surrounding medium gives rise to the structure.

In view of the recent discovery of many PWNe (pulsar wind nebulae) and observations of their surroundings, Chevalier is investigating the interaction of PWNe with realistic supernova models in order to relate these objects to the known properties of supernovae. In addition, cases where there are observations of the surroundings allow a more detailed check on the nature of the event. These studies indicate that 3C58 may be older than the historical supernova SN 1181, but that MSH 15-52 and G11.2+0.8 are consistent with identifications with historical supernovae. There are

also indications that PWNe are associated with a variety of supernova types. The Crab Nebula may be associated with a Type IIP supernova, but G292.0–0.3 is more likely to be associated with the Type IIn or IIb supernova. In these cases, the PWN is trapped in the inner, flat part of the supernova density distribution. Chevalier is also examining the case where the PWN might break out from this inner part of the supernova.

Chevalier, in collaboration with Li and Fransson (Stockholm), is continuing a program to investigate GRBs (gamma-ray bursts) and their surroundings as a means of providing constraints on their progenitors. The recent discovery of SN 2003dh in connection with GRB 030329 shows that at least some long duration GRBs are associated with massive stars. Chevalier and collaborators thus examined what circumstances would be necessary for all long duration bursts to have massive star progenitors. The problem with constant density environments inferred around some GRBs would most plausibly be accomodated by interaction with a region of shocked interstellar wind. However, this can require a high surrounding pressure and/or a low mass loss density. One way of producing a high pressure is by having the burst in a high pressure starburst region, so that the location of the burst may be related to afterglow properties.

Chevalier and Fransson are also modeling the X-ray properties of Type Ib and Ic supernovae, which are of special interest because of their relation to gamma-ray bursts (e.g., SN 1998bw and SN 2003dh). The expected radiation mechanisms are synchrotron, inverse Compton, and thermal, and they are making estimates of which operate in different regions of parameter space. The present number of observed sources is small, but these estimates should enable a strategy for X-ray observations of this important class of supernovae.

De Villiers and Hawley have begun a collaboration with J. Krolik and S. Hirose (Johns Hopkins University) to analyze GRMHD simulation data as part of a detailed study of the inner regions of black hole accretion disks. The emphasis of this work is on the dynamical structures of disks in the near hole region, and the possibility of energy extraction from spinning black holes. Several high resolution simulations were carried out for a variety of black hole spins.

Hawley, Balbus, and De Villiers continue to investigate, through combined analytical and numerical studies, the nature of the magnetorotational instability in disks, and its implications for angular momentum transport, MHD turbulence, and global dynamics of astrophysical disk systems.

While the magnetorotational instability has been extensively studied and applied in the context of standard accretion disks, its behavior in a self-gravitating disk has not yet been fully elucidated. To this end Balbus, De Villiers, and graduate student S. Fromang (IAP, Université de Paris) are conducting studies of three-dimensional MHD disks including self-gravity.

Hawley continued as part of an collaborative effort to develop an astrophysical magnetohydrodynamic (MHD) simulation code as a successor to the popular ZEUS code, The effort is headed by J. Stone (Princeton). During the past year the one-dimensional version was released for use. Both C and Fortran 95 version of the code, dubbed ATHENA, have now been released, and full two- and three-dimensional versions are in development.

Li started a new project with F. Nakamura (Niigata University, Japan) on star formation in magnetized, turbulent clouds. The goal is to extend the standard model of low-mass star formation to include the supersonic turbulence observed in molecular clouds. They find that the turbulence can speed up star formation through enhanced ambipolar diffusion in shock compressed regions. The magnetic field, on the other hand, can prevent the cloud from being converted into stars too rapidly, in one turbulence crossing time or less. The interplay of strong magnetic fields and turbulence may lead to different modes of star formation.

Li explored the role of magnetic fields in defining the masses of forming stars with F. Shu (NTHU, Taiwan) and A. Allen (ASIAA, Taiwan). They find that the magnetic fields trapped by the collapsing cloud material can reduce the rate of mass accretion onto the central object, making it easier for the protostellar winds to reverse the infall. They obtained a characteristic stellar mass that depends on the magnetic field strength and velocity dispersion of the cloud, and used it as the base for a simple model of initial mass function (IMF).

Li continued his collaboration with a research group in Moscow led by V. Shematovich in developing a coupled dynamical and chemical model for starless cores of molecular clouds, which are sites for isolated low-mass star formation. They are incorporating detailed radiative transfer into their models, in an effort to generate synthetic molecular line profiles for direct comparison with observations. A preliminary result is that the motions in the well-studied starless core L1544 appears to be dominated by rotation rather than infall.

Li and Anderson (graduate student) continued their investigation of the structure of magnetocentrifugal outflows launched from accretion disks, together with R. Krasnopolsky (UIUC) and R. Blandford (Stanford). They find a simple relation between the flow speeds at large, observable distances and the rotation rate at the wind launching surface. Applying the relation to the famous classical T Tau system DG Tau, they were able to determine that the low-velocity component of its wind originates from a region extending from $\sim$0.3 to $\sim$4 AU on the disk. The origin of the high-velocity component remains unclear.

Majewski, Patterson, Rhee, Hummels and graduate student Polak, with collaborators Kunkel (LCO), Geisler (Concepción), Gieren (Concepción), and others have completed the photometric portion of the Grid Giant Star Survey (GGSS), which is designed to find $V<13$ metal poor giants to be used as Astrometric Reference Grid stars for the Space Interferometry Mission (SIM). Follow-up 2 Å resolution spectroscopy for SIM Grid candidates in the Southern Hemisphere has been completed, and Northern Hemisphere spectroscopy will commence soon with the new fiber-fed spectrograph at Fan Mountain Observatory. High resolution spectroscopy of these stars is being obtained in collaboration with Smith (UTEP) and Geisler to derive accurate stellar parameters and for velocity monitoring. Meanwhile, Rhee, Patterson and Majewski explored the application of artificial neural networks (ANN's) for the estimation of stellar param-

eters ($T_{\rm eff}$, log g, and [Fe/H]) from the moderate resolution spectroscopy. Preliminary results indicate that the ANN's are able to estimate the parameters with an accuracy of: $\sigma(T_{\rm eff})=225$ K, $\sigma(\log g)=0.48$, and $\sigma([{\rm Fe/H}])=0.32$ dex. Polak, Ciardi (IPAC), Patterson and Majewski used the 2MASS catalog to compute proper motions for the stars in the GGSS. Combining these data with photometric parallaxes, full spatial motions have been computed for the stars, and are being used in conjunction with the photometric metallicities to study the kinematics of the Milky Way disk and nearby halo.

Rood, Ferraro, and others from Bologna continue work on globular cluster stars. Current projects include blue stragglers, circumstellar gas around globular cluster giants, and hot horizontal branch stars.

A number of new studies have begun to exploit the 2MASS point source catalogue for studies of Milky Way Structure. Majewski, Skrutskie, Weinberg (UMASS) and Ostheimer (graduate student) have been using the 2MASS catalogue to search for M giants in the halo. Among the significant findings are the $>360°$, wrapped tidal tails of the Sagittarius (Sgr) dwarf galaxy. These extensive tidal tails are being used by Majewski, Law (undergraduate student) and Johnston (Wesleyan) to constrain the Sgr orbit and mass as well as the strength, flattening and lumpiness of the Galactic halo. This work is greatly assisted by the addition of numerous 5–10 km s^{-1} precision radial velocities for Sgr M giants being obtained with the KPNO 2.1-m, YALO 1.5-m, Bok 2.3-m and Swope 1-m telescopes by Majewski, Skrutskie, Patterson, Law, Kunkel, Johnston, Weinberg (U. Mass), and graduate students Crane and Frinchaboy. In addition, higher resolution ($\sim$1 km s^{-1}) spectra of the Sgr core are being obtained with the DuPont 2.5-m and Blanco 4-m + Hydra system to explore whether and how tidal disruption affects the velocity characteristics of a dwarf galaxy like Sgr. Meanwhile, Majewski, Vivas (Yale), and Ivezić (Princeton) are comparing the Sgr M giant distribution with the distribution of likely Sgr RR Lyrae stars in the halo. Complementing this work, Frinchaboy, Majewski, Patterson, Kunkel, Garvin (graduate student) and Polak have been using data from the GGSS to trace the extent of the Sagittarius dwarf galaxy. Approximately 6000 spectra have been obtained with the CTIO 4-m + HYDRA spectrograph; the radial velocities will be used to search for Sgr and other tidal streams in the halo.

Another tidal stream in the direction of the Galactic anticenter (recently discovered by the SSDS) was investigated using M giants from the 2MASS catalogue by Rocha-Pinto, Majewski, Skrutskie & Crane. A number of lines-of-sight over Galactic latitudes between $-36°$ and $+36°$, in the Galactic longitude range from 100° to 270°, show evidence for the existence of this structure in the outer Galaxy. Crane, Majewski, Rocha-Pinto, Frinchaboy, Skrutskie, and Law carried out a spectroscopic study of M giant constituents of the coherent stellar structure at the Galactic anticenter and uncovered evidence suggesting that the structure is the remnant of a tidally disrupted dwarf galaxy. On the other hand, Law, Majewski, Skrutskie, Carpenter (Caltech) and Ayub (undergraduate student) have studied how differential reddening might have overemphasized the significance of previously reported tails detected around the globular cluster Omega Centauri.

Graduate students Muñoz and Chatzikos, guided by Majewski and Skrutskie, are leading a project (involving all the current second and third year graduate students) to use 2MASS data to trace the Galactic metallicity gradient towards both the North and South Galactic poles exploiting the color dependence in red clump stars on metallicity and analyzing the color magnitude diagram for two regions near the Galactic polar caps. The study shows a clear metallicity gradient extending continuously to $|z|\sim3.5$, where an apparent break in the gradient is observed. In an exploration of the other dimensions of the Galactic Plane, Frinchaboy, Kunkel, Skrutskie, and Majewski have begun a project to measure carbon stars (isolated using 2MASS) in the bar of the Milky Way. These data will be used to investigate kinematics along the entire length of the bar.

Frinchaboy, Phelps (CSUS), Majewski, Dinescu (Yale), and Friel (NSF) have continued to investigate the ages, distances, and dynamics of old open star clusters. Photometry analysis is being continued and preparatory work for astrometry and spectroscopic work has begun. Frinchaboy, Majewski and Friel are continuing a project to determine the orbits and metallicities of a number of Galactic clusters using absolute proper motions and spectroscopic radial velocities. This will yield cluster orbits that can be used as a probe of Galactic disk dynamics with ''test particles'' of known ages, distances and metallicities.

Majewski and collaborators have continued to explore the extended structure of dSph galaxies using Washington +DDO51 imaging to isolate associated giant stars. With Sohn (graduate student) and Siegel (STScI), work has continued on the galaxies Leo I and II. The giant candidate list of Leo I was used to derive new structural parameters and to generate radial profile. The radial profile of Leo I, like other dSphs such as Carina and Ursa Minor, shows a clear departure from the best fit King profile. Spectroscopic follow-up of both galaxies with the Gemini and Keck telescopes has begun. Muñoz, Majewski, Patterson and Crane have been working on a photometric search for extratidal K giant candidates in the Carina dSph using data from the CTIO 4-m + Mosaic camera. This survey covers $\sim$12 square degrees and is a follow-up of the previous study of Carina over a smaller area. Preliminary results confirm the existence of a significant number of extratidal giants extending well beyond the nominal tidal radius. A separate survey of the Sculptor dwarf, in collaboration with former UVa undergraduate Westfall (Wisconsin) shows similar results. Spectroscopic follow-up is planned to both confirm the membership of candidates and to study the velocity dispersion outside the tidal radius. In a Washington+DDO51 search around the Magellanic Clouds, Majewski, Patterson, Ostheimer and Kunkel have identified numerous tidal debris structures, some that may be parts of the Magellanic Clouds.

Using the same Washington+DDO51 technique, Siegel, Majewski, Gallart (IAC) and Braun (NFRA) have been searching for giant stars in high velocity clouds (HVC's) as a means to check whether they are nascent galaxies. While a number of faint giant star candidates were detected in four

clouds studied in detail, these are consistent with the numbers in adjacent control fields, suggesting that there does not appear to be any association with the HVC's.

Crane, Majewski, Patterson, and Bahcall (IAS) continued the analysis of spectra of K giants at the Galactic Pole as a means to improve upon previous estimates of the Oort limit and the amount of local dark matter in the Galactic disk. These stars were selected in a large Washington+DDO51 survey of the North Galactic Cap. Following upon the published study of kinematics of F-K stars in a much deeper, but much smaller area North Galactic Pole survey by Polak and Majewski have produced a complementary study of K-M stars in the same field to study the disk populations of the Galaxy.

McDavid analyzed optical polarization observations of the bright Be star Achernar (α Eri, B3Vpe) obtained at CTIO in September 1995 during a coordinated campaign with simultaneous ultraviolet spectroscopy by G. Peters (USC) and optical spectroscopy by D. Gies (CHARA). The data are being used to investigate recent ESO VLT interferometry results which have been interpreted to indicate that the photosphere of this star is extremely oblate.

McDavid continued his program of CCD photometry of open clusters to study the evolutionary status of Be stars. Using the GenI CCD camera on the FMO 1-m telescope, *UBVRI* and narrow band Hα/red continuum exposures reaching the latest main sequence B-type stars in several clusters were obtained, toward the goal of characterizing the relative abundances of Be stars as a function of cluster parameters.

Oishi and K. Tomisaka (NAOJ) began investigations into the collapse of a rotating, magnetized cloud core for the purpose of investigating binary fragmentation.

Rhee and T.C. Beers (Michigan S.) continued to survey candidate very metal-poor ([Fe/H] $\leqslant -2.0$) giants from the HK-II survey, over the magnitude range $11.0 \leqslant B \leqslant 16.0$, covering some 7000 deg^2 of intermediate to high Galactic-latitudes. Ongoing medium-resolution ($\sim 1-2$ Å) spectroscopic follow-up using NOAO observing facilities has allowed to obtain, to date, some 1000 spectra (400, 450, and 150 spectra for red giants, subgiants near the main-sequence turnoff, and FHB/A stars, respectively) for the HK-II metal-poor star candidates. In particular, the detection rate of *bona fide* very metal-poor *giants* ([Fe/H] $\leqslant -2.0$) is about 45%, which is quite encouraging. Kinematics of these stars will be studied with proper-motions obtained from the recently released UCAC2 astrometric survey catalog. They continued also large international high- and medium-resolution spectroscopic follow-up of metal-poor stars and Carbon stars selected from the Hamburg/ESO survey and HK survey in collaboration with N. Christlieb (Hamburger) and colleagues. Of particular importance, they find that the upper envelope of carbon enhancement observed for the Carbon stars is nearly constant, at [C/H] $= -1.0$, over the metallicity range $-4.0 < [\mathrm{Fe/H}] < -2.0$. Implications of these results will be further studied.

Continuing research on the chemical enrichment and evolution of the local Milky Way disk, Rocha-Pinto, J. Scalo (Austin) and G. Hensler (Kiel) have used data for nearly 424 dwarfs to readdress the problem of explaining the observed age–velocity dispersion relation among stars of the solar neighborhood. Although heating scenarios are commonly adopted in the literature as the cause of this relation, the authors argue that the data could more easily be understood as resulting mainly from the cooling of a primordially hot collapsing disk.

Skrutskie is investigating the spatial distribution of high-proper motion sources revealed by 2MASS astrometry with the aim of detecting bulk streaming motions in the vicinity of the Sun.

Wilson and Skrutskie continued their multi-year study of the local luminosity function of late-M and L-dwarfs in the field by conducting spectroscopic follow-up observations of 2MASS color-selected late-M and early-L type stars/brown dwarfs with the CorMASS spectrograph at the 1.8m Vatican Advanced Technology Telescope. Wilson, in collaboration with Michael Liu (IfA) and Jennifer Pope (graduate student), has also been studying the low-mass luminosity function within the Pleiades Cluster through deep wide-field near-infrared imaging conducted at the Palomar 200-inch telescope. Wilson, a member of a Space Infrared Telescope Facility (SIRTF) guaranteed-time observation (GTO) team, also prepared for upcoming spectral observations of a sample of low-mass stars and brown dwarfs with this recently launched space telescope.

Since early 2002, Lorimer (Jodrell), Xilouris, Fruchter (STScI), Stairs (UBC), and Camilo (Columbia) have been carrying out high-precision timing observations with the Arecibo 300-m radio-telescope of the binary millisecond pulsar, J0407+1607. This is a 25.7-msec pulsar in a 669-day orbit about a low-mass star($a \approx 0.2\ M_\odot$ white dwarf). Extending the current baseline of the timing observations will make J0407+1607 an excellent test of general relativity and in particular the strong equivalence principle. Deep broad-band CCD images with the Bok 2.3-m telescope were recently obtained aiming at an optical identification of the companion star.

Lorimer, McLaughlin (Jodrell), Arzoumanian (GSFC), Xilouris, Cordes (Cornell), Backer (Berkeley), Lommen (Franklin & Marshall), and Fruchter are currying out timing observations of new pulsars discovered during the Arecibo upgrade period. Highlights of the results include a 55.7-ms isolated pulsar, thought to be the relic of a disrupted double neutron-star binary system, two recycled millisecond pulsars currently under investigations, and several other bright long-period pulsars. Among the long-period pulsars PSR J0815+09 has a very unusual pulse profile morphology with four components defying well established classification schemes. Careful analysis of its single pulses revealed that all four components exhibit regular drifting with the sense of the drift changing among components.

Bobroswski, Xilouris, Soker & Rood have been studying the departure from axisymmetry in the structures of six planetary nebulae and proto-planetary nebulae observed with the Hubble Space Telescope. The aim of this work is to demonstrate that the departure from axisymmetry can be quantified, despite its complicated nature. With our limited data sample we have so far demonstrated that indeed the departure from

axisymmetry can be used to constrain the formation mechanism of the axisymmetrical structure itself, and in particular, favors a binary model.

Following an upgrade of the pointing model of the 1-m astrometric reflector at Fan Mt, Xilouris and Soker have been obtaining deep narrow-band CCD images to investigate the mechanism responsible for the present shaping of planetary nebulae with large angular size.

3.2 Interstellar Medium

Murphy, B. Otte (JHU), J.C. Howk (JHU), Q.D. Wang (U. Mass.), W.R. Oegerle (NASA/GSFC), and K.R. Sembach (STScI) continue their study of the galactic fountain in the edge-on spiral galaxy NGC 4631. Initial observations with the Far Ultraviolet Spectroscopic Explorer revealed the presence of emission from O VI ions in the hot halo of NGC 4631. Additional observations show O VI emission at every observed position in the halo which indicates that the fountain covers a large fraction of the disk of the galaxy. NGC 4631 represents the first, and only, galaxy in which a true galactic wide fountain has been detected. 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.

Murphy and O'Connell have obtained FUSE observations to search for O VI absorption from high velocity gas in the halo of the face-on spiral galaxy M 101. Any rising or escaping galactic fountain gas in the halo should be seen in absorption against the bright H II regions in the disk. A detection of the outflowing gas would allow them to determine the rate at which material flows from the disk into the halo.

Along with M. Mac Low (AMNH), Oishi has begun implementing ambipolar diffusion into the parallel magnetohydrodynamics code ZEUS-MP. Once complete, this will be used to study the effects of magnetic field diffusion in cold molecular cloud regions and on the magnetorotational instability in disks. Preliminary testing has begun at the Pittsburgh Supercomputing Center and the American Museum of Natural History.

Graduate student Quireza Campos (Sao Paolo) and Rood are using high precision radio recombination line and continuum data to determine electron temperatures of a very large sample of Galactic H II regions. This will lead to an estimate of metallicity. The large sample scattered throughout the Galaxy can show for example whether abundance trends are azimuthally symmetric.

3.3 Galaxies and Active Galactic Nuclei

Colley has joined a project with Heather Welch and Mike Skrutskie to measure the two-point correlation function of color-redshift selected galaxies in the 2MASS catalog. Colley developed a highly efficient tree algorithm to carry out the two-point analysis, and reduced computing times from weeks to hours. The measured two-point function's slope is slightly shallower than the canonical Peeble's value of -0.8, though work remains on refining our color-selection criteria.

Hawley and De Villiers are part of an on-going effort to develop next generation of fully general relativistic MHD simulation code. Co-Investigators in this project include C. Gammie and S. Shapiro (U. Illinois). The ultimate aim is to develop simulations of such energetic events as neutron star collisions and gamma ray bursts, although at the present their effort is focused on accretion in the Kerr spacetime with an application to AGN and the Galactic center.

Hampton (undergraduate student), with Majewski and Bershady (Wisconsin) are producing synthetic color-color diagrams to age date starburst clusters within the galaxy 52W036 to map out the evolutionary history of this possible high redshift analogue of the ''antennae'' galaxy pair.

O'Connell, Rood, and S. Sohn (graduate student) are analyzing a sample of over 50 globular clusters in the elliptical galaxy M87 selected from deep far-UV imaging with the STIS/FAR-UV MAMA camera in 4 fields. Clusters are detected to a limit of $m(FUV)\sim 24.5$ and cover a range in $(FUV-V)$ color of 0.5 to 3.0 mags. They are significantly bluer than typical Milky Way globular clusters and represent an extension of the continuum of clusters in this regard. However, they do not appear to overlap with the UV properties of elliptical galaxies. A significant number of UV detections in all four fields have no counterparts on deep *V*-band images. Only about 30% of these could be from the same cluster population described above. These could be young clusters, background starburst galaxies, or transient sources.

O'Connell, with collaborators J. Gallagher (U. Wisc.), L. Smith (UColLond), and R. deGrijs (Sheffield) have obtained high resolution ($0.1''$) optical spectra of super star clusters and their environment in the nearby starburst galaxy M82. These include strong emission lines in the starburst core as well as blue absorption features sensitive to stellar populations. The spectra are being analyzed for evidence of outflows from clusters, ionization levels, abundance variations, population ages, and spatial structure in the complex central regions of the galaxy.

O'Connell and Rood are both Co-Investigators on the Hubble Treasury Program ''Mid-Ultraviolet Spectral Templates for Old Stellar Systems'' (R. Peterson, Lick Observatory, PI), which aims to develop a grid of high fidelity 2000–3500 Å spectra of stars that can be used to interpret the integrated light of galaxies. This spectral region is critical for studies of the ages of quiescent populations at high redshifts as a means of determining their formation epochs. The program involves both new HST spectroscopy and extensive theoretical modeling of atmospheres.

Clarke, Sarazin, Blanton, and J. Uson (NRAO) discovered an X-ray absorption feature in the image of the central region of the galaxy cluster Abell 2029 which is due to UZC J151054.6+054313, a foreground spiral galaxy. The absorption allows one to constrain the total interstellar gas content of the galaxy and the possibility that dark matter in galaxies is baryonic.

The X-ray group at U. Va. has an ongoing project to image X-ray-bright early-type galaxies to study the physics of the hot interstellar gas. S. Randall (graduate student), Sarazin, and J. Irwin (U. Michigan) have analyzed Chandra and

XMM observations of the X-ray bright elliptical galaxy NGC 4649. This galaxy has a large number of Low Mass X-ray Binaries (LMXBs), and very bright X-ray emission by interstellar gas. The gas emission shows radial fingers which my be due to convection. J. Carlin (graduate student) and Sarazin are working on a Chandra observations of NGC 533 and G. Sivakoff (graduate student) and Sarazin are working on the observation of NGC 1600. Sarazin is reducing an XMM/Newton observation of NGC 5846. Cycle 2 XMM/Newton observations of NGC 4552 and NGC 4125 are scheduled as well.

The LMXB populations and hot gas in X-ray-faint early-type galaxies are being studied by the X-ray group at U. Va. G. Sivakoff, Sarazin, and Irwin have studied the LMXB populations in two X-ray faint early-type galaxies (NGC 4365 and NGC 4382) with Chandra observations. A Chandra observation of NGC 5866 is being analyzed, Sarazin, Sivakoff, and L. Angelini (GSFC) are studying the competing roles of age and metallicity in determining the occurrence of LMXBs in GCs in NGC 4365.

The X-ray group at U. Va. has a large project to determine the properties of the LMXB populations and hot gas in a complete sample of Virgo cluster ellipticals. Sivakoff, Sarazin, Irwin, P. Coté, and A. Jordan (Rutgers) are using both archive and new Chandra observations. Coté is the PI of an HST large project to image all these galaxies with the ACS, and this will provide globular cluster (GC) populations to compare to the LMXBs.

Sarazin, Sivakoff, Irwin, Coté, and Jordan are observing NGC 4697, the nearest optically-bright, X-ray faint elliptical galaxies 4 times with Chandra to detect much fainter LMXBs and to determine the variability of sources. A Hubble Space Telescope observation will be used to construct a globular cluster catalog and determine the relation between the GCs and LMXBs.

Thuan in collaboration with Izotov (Kiev), Stasińska (Meudon) and Guseva (Kiev) have derived element abundances in 310 emission-line galaxies from the Early Data Release of the Sloan Digital Sky Survey (SDSS) for which the [O III] λ4363 emission line was detected. No extremely metal-deficient galaxy was found. The metallicity lies in the range from $Z_\odot/12$ to $Z_\odot/2$. The Fe/O abundance ratio is smaller than the solar value, which can be interpreted as an indication that type Ia supernovae have not yet appeared in these galaxies, implying an age of less than 1 – 2 Gyr. The N/O abundance ratio ranges from log N/O= –1.6 to –0.8. The fact that no galaxy with log N/O $\leqslant$ –1.6 was discovered implies that local low-metallicity emission-line galaxies are of a different nature than high-redshift damped Lyα systems with log N/O of $\sim$ –2.3 and that their ages are probably larger than 100 – 300 Myr.

Thuan in collaboration with Hibbard (NRAO) and Lévrier (Meudon) have obtained VLA H I observations of the Blue Compact Dwarf (BCD) galaxies NGC 2366, NGC 4861, VII Zw 403 and Haro 2. These galaxies span a range of BCD morphological types. The cometary-like BCDs NGC 2366 and NGC 4861 have regular rotational kinematics with a V/σ of 8.7 and 6.4, respectively. On the other hand, the velocity fields of the iE BCD VII Zw 403 and of the nE BCD Haro 2 lack regularity and their rotational motion is around the major, not the minor axis. The H I distribution is centrally peaked in VII Zw 403 and Haro 2, a general feature of all iE and nE-type BCDs, the most common ones. By contrast, cometary-type BCDs have multiple H I peaks which are scattered over the disk. The active regions of star formation are associated with regions of high H I column densities, with slight displacements between the H I and stellar peaks. NGC 2366 shows many H I holes, resulting from the disruptive influence of massive star formation and supernovae on the interstellar medium (ISM). In all BCDs, there is a tendency for H I gas with higher velocity dispersion to be associated with regions of lower H I column density. This anti-correlation can be understood in the context of a two-phase model of the ISM. In all BCDs, the radio continuum emission is associated with the star-forming regions and is predominantly thermal in nature. H I clouds with no optical counterparts have been found in the vicinity of NGC 4861 and Haro 2.

Whittle (PI), Rosario (graduate student), Nelson (Drake), and Wilson (U. Maryland) have continued to work on HST STIS observations of Seyfert galaxies which show strong jet-gas interactions. They completed a detailed study of Markarian 78, an archetype for this class of object. The results focus on two aspects: ionization mechanisms and the properties of the jet flow. A careful analysis effectively rules out shock ionization as a significant contributor to the line emission, while photoionization models which include an optically thin component are needed to match some of the high ionization lines. The spectral data provide a complete map of mass, momentum and kinetic energy of the ionized gas across the region which, when combined with estimates of energy stored in the relativistic plasma, allow constraints to be placed on the jet's momentum and kinetic energy. This analysis shows the jet to be dominated by thermal gas moving transonically (Mach numbers $\sim 1-$ few) at $1-$ few times the emission line velocity ($\sim$1000 km s^{-1}) with mean density ~ 1 cm^{-3}. The estimated luminosity and momentum of the jet are significantly lower than previous estimates which assumed emission line luminosity traces jet power, and a single shock accelerates the ionized gas.

3.4 Clusters of Galaxies

Blanton, Sarazin, B. McNamara (Ohio U.), and Clarke are studying the cooling flow cluster Abell 262 using X-ray data from *Chandra* and radio data from the VLA. The central cD galaxy has a double-lobed radio source associated with it, and the eastern lobe has clearly evacuated a cavity in the X-ray-emitting ICM. Unlike other well-studied cooling flow clusters, the energy output from the radio source is not sufficient to balance the luminosity of the cooling gas. The current outburst of the radio source may be less powerful than average for this AGN.

Blanton, Sarazin, D. Helfand (Columbia U.), M. Gregg (UC Davis / LLNL), R. Becker (UC Davis / LLNL), and R. White (STScI) are analyzing *Chandra* data of a high-redshift ($z\approx 1$) cluster that was discovered using a bent-double-lobed radio source as a cluster signpost. The X-ray emission is elongated and traces the galaxy distribution as seen in the

optical and NIR. The cluster may be undergoing a merger. This is one of only a handful of X-ray-emitting clusters known at $z \gtrsim 1$.

Blanton, Sarazin, and Clarke are studying the formation of wide-angle tailed radio sources by observing their cluster environments in the X-ray at low redshift. An observation of Abell 1446 is scheduled in *Chandra*'s Cycle 5.

Blanton, Sarazin, Clarke, D. Helfand, M. Gregg and R. Becker are investigating the formation of wide-angle tailed radio sources in poor environments that may be ''fossil groups'' (former groups of galaxies, whose members have been cannabalized by the central, bright, elliptical galaxy). Two of these objects are scheduled for observation in Cycle 5 with *Chandra*.

Clarke, Blanton, and Sarazin are studying the cluster Abell 2029 using X-ray data from *Chandra* and radio observations from the VLA. The cD galaxy is host to a steep-spectrum, distorted radio source which appears to be interacting with the surrounding thermal X-ray gas. In contrast to other cluster center radio/X-ray interactions, this cluster does not show clear larger scale X-ray cavities. Deep *Chandra* observations are scheduled in Cycle 5.

Clarke and J. Kempner (CFA) are investigating the correlation between the X-ray luminosity of the ICM and the 1.4 GHz radio halo power in a sample of high-luminosity galaxy clusters. Using the VLA to search for new radio halos, they will be able to investigate the influences of environment on the formation of cluster-wide radio halos.

Clarke and Sarazin are studying the complex merging cluster Abell 520 in order to investigate the connection between the diffuse radio emission and X-ray structure in the core of the cluster. XMM/Newton observations of the cluster are scheduled in Cycle 3.

Clarke, J. Bagchi (IUCAA), T. Ensslin (MPA), and N. Kassim (NRL) are using the GMRT to study large scale structure formation at the intersection of galaxy filaments. The radio observations will be combined with optical and X-ray data of the systems.

Reiprich, Sarazin, and Sivakoff analyze Chandra observations of nine clusters from a statistical sample of the 63 X-ray brightest galaxy clusters in the sky. Due to further successfully proposed Chandra observations and archival data the full set of 63 clusters will have been observed by the end of 2004. The main aim of the analysis of the complete sample is to reduce systematic uncertainties which dominate the overall uncertainty in the use of clusters as cosmological probes.

Reiprich, Blanton, Carlin, Chatzikos (graduate student), Clarke, Kempner, Randall, Sarazin, Skrutskie, and Sivakoff investigate the multiwavelength properties of a statistical sample of about 800 galaxy clusters selected from the ROSAT All-Sky Survey in collaboration with MPE (Garching). The collaboration is based on the telescope time available to UVa through the agreement with the University of Arizona made possible by the Celerity foundation.

Blanton, Sarazin, K.-W. Wong (graduate student) and B. McNamara (Ohio U.) are using a Chandra images to study the cooling flow clusters Abell 262 and Abell 2626, both of which show evidence for radio/cooling flow interactions. XMM/Newton observations of Abell 2626 and Abell 2063 are being obtained to study the X-ray spectra of the radio bubbles detected with Chandra. Blanton, Sarazin, McNamara, M. Wise (MIT), P. Nulsen (Wollongong), and L. David (CfA) have obtained a Chandra image of Abell 1991 as part of the same project.

Chandra observations of Abell 1446 are being used by Blanton, Sarazin, Clarke, and Reiprich to study the formation of wide-angle-tailed radio sources in clusters.

Blanton, Sarazin, and N. Soker (Univ. Haifa) have studied the possible effects of thermal conduction on cluster cooling flows.

A high redshift cluster, BD1137+3000, was detected in X-rays with Chandra by Blanton, Sarazin, D. Helfand, M. Gregg (IGPP), and R. Becker; they are planning to observe it with XMM/Newton. The cluster comes from a sample selected by searching the FIRST radio survey for distorted radio galaxies, and was confirmed with optical/IR observations. This group is also observing the region around two moderate redshift bent double (BD) radio sources, BD1249+3038 and BD0853+2324, which appear to be isolated in order to find the ambient gas which is producing the distortion.

M. Chatzikos, Sarazin, J. Kempner, M. Markevitch (CfA), and P. Ricker (U. Illinois) observed the merging cluster Abell 2065 in X-rays with Chandra. These observations provide a strong test of the destruction of cooling cores by mergers; in previous ROSAT and ASCA observations, this cluster appeared to have two cool cores which survived the merger. Sarazin, Clarke, Blanton, and Y. Fujita (NAO Japan) have approved observations of Abell 115N/S and A1664/3541, two hybrid merging/cooling flow clusters with radio relics.

An interaction between the radio source and the X-ray gas in Abell 2029 has been found by Clarke, Sarazin, and Blanton using a short archived Chandra observation. They also find a spiral feature of enhanced cool emission which may be due to a subcluster merger. A very deep observation of Abell 2029 with Chandra is being made in order to further study these features and the absorption feature due to the foreground galaxy.

Clarke and Sarazin are observing the complex merging cluster Abell 520 with XMM/Newton; this cluster has an unusual radio halo.

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

The merging cluster Abell 1644 was observed with XMM/Newton by Reiprich, Sarazin, and Kempner, who found that a tail of cool gas in the cluster trailing the smaller subcluster. They are also observing the merging clusters Abell 1240, and Abell 725 with XMM-Newton.

Reiprich, Sarazin, Blanton, Randall, Sivakoff, H. Böhringer, P. Schuecker (MPE), Y. Ikebe (GSFC), and E. Pierpaoli (Princeton) are obtaining new and archived Chandra observations of a complete sample of the brightest clusters in the sky. This HIFLUGCS sample is being used to provide a low redshift sample for cosmological studies. Archived XMM/Newton observations of the sample are also

being analyzed. Reiprich, Blanton, Clarke, Carlin, Chatzikos, Randall, Sarazin, and Sivakoff are working with a large group at MPE and elsewhere to study a very large sample of more distant clusters, the NORAS II sample. Observations by the X-ray group at U. Va. with the Bok telescope are being used to provide images and spectra to confirm the identifications and determine the redshifts of the clusters. With Skrutskie, 2MASS is being used for statistical studies of the galactic populations of the clusters.

Sarazin reviewed the observations and theory of mergers and nonthermal processes in clusters of galaxies at the Sydney IAU JD 10.

Abell 2107 and Abell 2670 are two clusters containing cD galaxies with relatively high velocities. Chandra observations are being make by Sarazin, Blanton, Y. Fujita, and I. Tanaka (NAO Japan) to try and understand the dynamics of these clusters.

Sarazin, Kempner, and L. Rudnick (U. Minnesota) 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 which allows measurements of the cluster magnetic fields and the spectral aging of this population of cosmic ray particles, and polarization maps which 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.

The cluster Abell 133 was observed with XMM/Newton by Sarazin, Reiprich, Fujita (NAO Japan), Kempner, H. Andernach (U. de Guanajuato), M. Ehle (XMM-Newton SOC), A. Roy (MPIfR), Rudnick, and B. Slee (ATNF). They discovered a cold front and weak shock near the cluster center, providing more evidence for a cluster merger. The unusual spidery radio relic near the cluster center is believed to be a detached old radio bubble from the central AGN. Chandra and XMM/Newton observations are also being obtained for A13, a cluster with a similar filamentary radio relic.

W. Saslaw and B. Leong (Cambridge, U.K.) have used a gravitational statistical mechanical calculation to estimate the density of small clusters of galaxies such as our local group. Such groups are quite common and therefore it is not surprising that the flow around the local group is only mildly perturbed from the Hubble expansion.

3.5 Cosmology

Recently, a somewhat surprising phenomenon has been discovered in QSO lens systems, particularly in HE 1104-1805. The light in one image appears to ''flicker'' more than in the other on short timescales (of order a month) at the level of a few percent. Since the stellar mass Einstein ring crossing time for such systems is much longer than that, the phenomenon seems to require that either the lens galaxy have a significant population of small, planetary mass dark matter ''particles,'' and/or that the QSO has structures on very small scales. Some suggestions have been that the QSO has dark, absorbing clouds, or bright emitting clouds racing around the interior of the accretion disc, which, when magnified caustically create the flickering. However, Schild has shown that the flickering in Q0957+561 is neither preferentially ''up'' nor ''down,'' but more akin to true power-law flickering. Colley and Schild have therefore undertaken to simulate the HE 1104-1805 system under the assumptions of fairly normal accretion disc, but a lens galaxy with a range of possible dark matter masses. While the MACHO program apparently ruled out Jupiter-mass type dark matter, the focus here would be more on Earth-mass type dark matter. The QSO lens regime is much more favorable for detecting such matter, since the optical depth is near unity (rather than a part in a million).

The WMAP results have provided the deepest full-sky view to date of the Cosmic Microwave Background. Colley and J. Richard Gott, III, have begun a search for large cosmic strings in the survey. Such a string would be most visible if it were moving tangentially to the sky at relativistic speeds. In that case, it should leave a tell-tale signature on the CMB: a step function in temperature along a latitude line at roughly 60 degrees from the direction of its motion. Colley has found that such a massive cosmic string would be apparent to the eye in the WMAP results if the string were about three times more massive than seems theoretically plausible. As WMAP results continue to improve, however, plausible cosmic strings should become just detectable. Colley has also begun work on a statistical method to detect such strings even when the eye cannot.

W. Saslaw with D. Baumann (Princeton) and B. Leong (Cambridge, U.K.) have developed and explored a hybrid metric for an Einstein-deSitter Universe in which a single cluster of galaxies grows to fill the particle horizon. This is the only known example so far of a universe which can change its global symmetry because of its evolving equation of state.

W. Saslaw and F. Ahmad (University of Kashmir, Srinagar) are examining the detailed nature of phase transitions in the cosmological many-body problem from a statistical mechanical viewpoint.

W. Saslaw and B. Leong are examining implications of the peculiar velocity distribution function of galaxies for the nature of dark haloes. Their conclusion is that galaxies generally have individual haloes, rather than many galaxies belonging to large communal haloes.

Thuan in collaboration with Izotov (Kiev) have redetermined the primordial helium abundance Y_p and the slope dY/dZ using a sample of 82 H II regions in blue compact galaxies, including new spectrophotometric observations of 33 H II regions which span a large metallicity range, with oxygen abundance $12 + \log(\mathrm{O/H})$ varying between 7.43 and 8.30 ($Z_\odot/30 \leqslant Z \leqslant Z_\odot/4$). For a subsample of 7 H II regions, they derive the He mass fraction taking into account known systematic effects, including collisional and fluorescent enhancements of He I emission lines, collisional excitation of hydrogen emission, underlying stellar He I absorption and the difference between the temperatures T_e(He II) in the He^+ zone and T_e(O III) derived from the collisionally excited [O III] lines. By extrapolating the Y vs. O/H linear regression to $\mathrm{O/H} = 0$ for 7 H II regions of this subsample, they obtain $Y_p = 0.2421 \pm 0.0021$ and $dY/dZ = 3.7 \pm 1.2$. In the framework

of the standard Big Bang nucleosynthesis theory, this Y_p corresponds to $\Omega_b h^2 = 0.013^{+0.003}_{-0.002}$, where h is the Hubble constant in units of 100 km s^{-1} Mpc^{-1}. This is smaller at the 2σ level than the value obtained from recent deuterium abundance and microwave background radiation measurements. The linear regression slope $dY/dZ = 2.8 \pm 0.5$ for the whole sample of 82 H II regions is similar to that derived for the subsample of 7 H II regions, although it has a considerably smaller uncertainty.

3.6 Astrometry

Based on an earlier time-series analysis of selected regions from the southern hemisphere parallax program, Bartlett (graduate student), Ianna, and Begam continued their investigation of LHS 288. Ianna and Begam (Steward Observatory) continue their analysis of the CCD parallax work from the Mount Stromlo and Siding Spring Observatories. Ianna and T. Henry (GSU) are continuing and expanding the successful three-year CTIOPI parallax program at CTIO on the 0.9-m, which began in August 1999 under the auspices of a NOAO Survey award. In collaboration with D. Koerner (NAU), the observing list is being doubled, and a new aspect — a comprehensive search for low mass companions to red and white dwarfs — is underway. Via the SMARTS Consortium, the CTIOPI team now has about 100 nights/year using four telescopes at CTIO to study nearby stars. 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. So far, they have discovered 18 new stars within 10 parsecs and an additional 112 new stars within 25 parsecs of our Sun.

Seidelmann and J. Kovalevsky are proofreading and indexing their book ''Fundamentals of Astrometry'' for publication by Cambridge University Press.

3.7 Astronomical Instrumentation

Crane, Lam, and Barr completed construction of a fiber-fed spectrograph for the Fan Mountain Observatory 40-inch telescope. After a period of successful laboratory testing, the instrument was relocated to the observatory. Instrument installation and observatory upgrade work have recently been completed with first light expected in September.

Crane, McDavid, Barr, and Lam finished the installation of a weather station and 40-inch telescope environment monitoring system at the Fan Mountain Observatory. Software development and testing of the system are currently underway.

McDavid implemented a mount model which reduced the RMS pointing error of the FMO 1-m telescope from 6 arcmin to 1 arcmin and is continuing efforts together with Barr and Lam to resolve the problem of intermittent sticks and slips on the order of a few arcmin due to mechanical instabilities of the declination bearing, drive train, and encoder assembly.

McDavid made improvements in the functionality of the computer control programs for the two ARC CCD camera systems in use at the FMO 1-m telescope, including the addition of a serial link to the telescope control system which may be used to automatically record essential data to the image headers in FITS format and integration of the GenII camera with the fiber-fed spectrograph designed by Crane and Majewski. He also worked in collaboration with Barr and Crane to develop a computer system to monitor an array of temperature and humidity sensors in the 1-m observatory building and a weather station which was installed on the rooftop of the station house.

Skrutskie and Wilson have established a laboratory for the development of infrared instrumentation in new laboratory space renovated by the Department during the previous summer. The infrared laboratory's active instrument, CorMASS – a cross-dispersed low-resolution ($R = 300$) infrared spectrograph, successfully moved from the Palomar 60″ to the Vatican Observatory 1.8-meter telescope at Mt. Graham seeing first light there in December. CorMASS has been scheduled for nearly 30 nights since that time. The Laboratory received a NSF/MRI grant to have students design and build a state-of-the-art 1024×1024 HgCdTe infrared camera for the University's Fan Mountain 30″ telescope. The students have finalized an optical design for the system have begun fabrication of the dewar and optical mounts. Restoration and upgrade of the 30″ telescope is underway. Students also fabricated a DIMM seeing monitor and have been regularly characterizing the seeing at the site. Wilson is leading the optical design effort for a new infrared spectrograph. Three nearly-identical copies of this cross-dispersed $R = 3000$ near-infrared spectrograph are planned. One, fabricated at Cornell, is destined for the Palomar 200″ telescope. Another, fabricated at Caltech, will operate at the Keck 10-meter telescope. The University of Virginia will fabricate a third instrument capable of traveling to 4–10-meter host telescopes. The Laboratory has recently provided a 2MASS camera to the Center for Astrophysics for use at the 1.3-meter 2MASS telescope at Mt. Hopkins to carry out gamma-ray burst and supernova follow-up under the supervision of Josh Bloom at the Center for Astrophysics. The Laboratory is also engaged in a test and characterization program to evaluate the suitability of commercial InGaAs arrays for astronomical applications.

3.8 Space Astronomy

Ianna is a co-investigator with a MASSIF Effort to Determine the Mass-Luminosity Relation for Stars of Various Ages, Metallicities, and Evolution States, which is a key project for the NASA's Space Interferometry Mission (SIM). MASSIF seek s precise mass measurements for stellar and substellar using astrometry and spectroscopy. SIM is currently scheduled for launch in 2009.

A proposal, ''Astrometric Mapping Explorer (AMEX),'' was submitted to NASA. This is a combination of the previous FAME and DIVA projects, and would be funded by NASA and the DLR in Germany. Seidelmann is the chairman of the AMEX Science Team and prepared the science portion of the proposal. In preparation for Phase A, research on charge transfer efficiency using time delay integration readout is underway. Studies are being done on the use and

analysis of spectral observations for determining astrophysical parameters. Also, the optical design and the data reduction methods are being investigated.

3.9 Solar System

Balbus and Hawley continue to investigate, through combined analytical and numerical studies, the influence of MHD turbulence on gap formation and planet migration.

As chairman of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements, Seidelmann drafted the next triennial report of the working group and chaired their meeting at the IAU General Assembly in Sydney, Australia. He also presented a paper on the history of the Working Group at the AGU Fall Meeting 2002 in San Francisco. This session was in memory of the original chairman of the working group, Merton Davies.

Skrutskie is conducting high-precision low-resolution ($R = 300$) 0.8-2.5 μm spectroscopy of Enceladus using the CorMASS instrument at the Vatican Advanced Technology Telescope to characterize ice temperature and morphology differences between the leading and trailing hemispheres. He is also conducting long-term synoptic observations of Titan in the same configuration to monitor tropospheric cloud formation.

Verbiscer continues to investigate the photometric properties of Saturnian satellites. She has produced mutually consistent rotational and solar phase curves using broadband UVBRI HST WFPC2 data in collaboration with R. French and C. McGhee (Wellesley). Solar phase curves of Enceladus, Mimas, and Tethys all have sharp, narrow opposition surges which become apparent only through observations made at phase angles of less than one degree. She has applied the Hapke (Icarus 157, 523, 2002) photometric model, which includes coherent backscattering, to solar phase curves for Mimas and Enceladus in each UVBRI filter in order to determine physical characteristics of each satellite regolith as well as to investigate any wavelength dependence of photometric parameters. Rotational lightcurves produced from HST data show that while both Mimas and Enceladus have brighter trailing hemispheres than leading, the albedo difference between the two hemispheres is greater for Mimas.

3.10 Astronomical Surveys

The 2MASS project (Skrutskie, P.I.) delivered all-sky catalogs containing 470 million point sources and 1.3 million extended source to the public concluding the original project. Skrutskie is now participating in the 2MASS ''Extended Mission'' which will, over the next two years, deliver the full content of the 1.4 billion 2MASS source extractions, repeated calibration observations, and special deep observations of 400 square degrees covering the LMC/SMC and other regions of astrophysical interest.

4. EDUCATION AND PUBLIC OUTREACH

During the year there were about 4000 visitors to the McCormick and Fan Mountain Observatories as part of our continuing public outreach program. In August 2003, the Astronomy Department offered a series of special public programs to coincide with the perihelic opposition of Mars. Nearly 1500 visitors attended the four ''Mars Mania'' events.

Thuan and Murphy assisted in the production of the ''Dark Matter'' planetarium show at the Science Museum of Virginia in Richmond. The show, which ran from February to June 2003, was funded with a Hubble Space Telescope education and public outreach supplemental grant to Thuan.

Murphy, Rood, Tolbert and Patterson have proposed developing a University of Virginia science outreach center around the McCormick Observatory. The center will combine the education and public outreach programs from all science departments at the University. An architectural study of the Observatory and the former director's residence is underway to determine how to renovate the structures to accommodate a science center.

The Astronomy Department has formed the Friends of the Leander McCormick Observatory to provide financial and volunteer support for the education and public outreach program.

Murphy was a University of Virginia Teaching and Technology Initiative Fellow for the 2002-2003 academic year. He used to fellowship to prototype a series of problem solving tutorials for use in the introductory astronomy classes for non-science majors.

5. MISCELLANY

Bartlett completed the first of a three-year teaching technology fellowship. During this time, her work concentrated on digitizing the Department's collection of approximately 5,000 slides.

Blanton was a member of the local organizing committee for the conference *The Riddle of Cooling Flows in Galaxies and Clusters of Galaxies* in Charlottesville, VA.

Chevalier served on the AURA/NOAO Observatories Visiting Committee (Chair), the USRA Board of Trustees, and the AAS Heineman Prize Committee (2003 Chair). He was on the Scientific Organizing Committees for the IAU Colloquium 192 on Supernovae (April 2003), IAU Symposium 218 on Young Neutron Stars and Their Environments (July 2003), and the meeting X-Ray and Radio Connections (Feb. 2004).

Clarke was a member of the local organizing committee for the conference *The Riddle of Cooling Flows in Galaxies and Clusters of Galaxies* in Charlottesville, VA.

Hawley served on the National Computational Science Alliance (NCSA) User Advisory Committee.

Ianna serves as a technical consultant to CSICOP, a member of the Executive Board of the International Dark-Sky Association, the 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, on the IAU Working Group on Extrasolar Planets, and on the Roadway Lighting Design Study Advisory Committee for VDOT.

Majewski continues to serve as a member of the NASA Space Interferometry Mission Science Team and, together with Patterson, heads the SIM Key Project ''Taking Measure of the Milky Way.''

McDavid was re-elected to the Organizing Committee of the IAU Working Group on Active B Stars and continued as webmaster for the Be Star Newsletter, which is now hosted on the departmental web site.

Murphy served as a reviewer for proposals to the National Radio Astronomy Observatory's Green Bank Telescope.

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 next HST servicing mission.

Patterson and Frinchaboy have continued as Cooperative Observers for the National Weather Service Station that has operated continously at McCormick Observatory since the 1890's.

Reiprich was chair of the Local Organizing Committee of the international conference ''The Riddle of Cooling Flows in Galaxies and Clusters of Galaxies'' attended by 100 participants from ten countries in June 2003 in Charlottesville.

Sarazin was a member of the Astronomy and Space Physics Science Council of Universities for Space Research Association, the XMM/Newton Cycle 3 Proposal Review Panel, and the scientific organizing committees for the the Soft X-ray Emission from Clusters of Galaxies and Related Phenomena meeting in Huntsville, AL, Riddle of Cooling Flows Meeting in Charlottesville, VA, the Cosmic Rays and Magnetic Fields in Large Scale Structure meeting in Busan, Korea, and the meeting of the Southeastern Section of the American Physical Society in Auburn, AL.

W. Saslaw gave ten invited lectures, about half of which were popular public talks and half were technical university lectures, in Mumbai, Pune, Kolkata and Delhi during a three week visit to India in November 2002 at the invitation of the National Council of Science Museums.

W. Saslaw and P. Murdin have discovered an astronomical interpretation of a previously mysterious symbol on an ancient coin.

Seidelmann continues as president of Celestial Mechanics Institute, the organization responsible for the scientific oversight of the ''Celestial Mechanics and Dynamical Astronomy'' journal.

The organization and arrangements were made for the 5th US Russian Space Surveillance Workshop to be held in St. Petersburg, Russia in September, 2003. Seidelmann will lead the US delegation and chair the workshop again.

Tolbert, Fredrick, and Rood all served as AAS Shapley Lecturers.

Wilson attended the Science-Engineering-Technology Congressional Visits Day in Washington, DC, in April, 2003. Sponsored by the AAS and numerous other professional societies, the event allowed participants an introduction to various actors in the science policy stage as well as meetings with Members of Congress.

6. PRIZES AND AWARDS

Crane and Frinchaboy were awarded Aerospace Graduate Research Fellowships by the Virginia Space Grant Consortium.

Oishi was the recipient of a 2003 NSF East Asian Summer Institutes Fellowship to study at the National Astronomical Observatory of Japan in Mitaka, Tokyo. In addition, he received Graduate Student support from a NASA Education Grant (NAG5-13028) to the American Museum of Natural History to complete his thesis research under the direction of M. Mac Low.

Rhee received a Small Research Grant of the American Astronomical Society (AAS) in support of his research entitled ''New Metal-Poor Giants and Horizontal-Branch Stars from the HK-II Survey.''

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Robert T. Rood, Chairman