

University of Virginia
Department of Astronomy
Leander McCormick Observatory
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This report covers the period 1 September 2003 to 31 August 2004.

1. PERSONNEL

During this time the departmental teaching faculty consisted of Steven A. Balbus, Roger A. Chevalier, John F. Hawley, Zhi-Yun Li, Steven R. Majewski, Edward M. Murphy, Robert W. O'Connell, Robert T. Rood, Craig L. Sarazin, William C. Saslaw, Michael F. Skrutskie, Trinh X. Thuan, Charles R. Tolbert, and D. Mark Whittle.

Research scientists associated with the department were Gregory J. Black, Richard J. Patterson, P. Kenneth Seidelmann, Anne J. Verbiscer, John C. Wilson, 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.

Matthew J. Nelson joined the Department in June as a Research Scientist. Francisca Kemper will join the department in January, 2005 as an Assistant professor. Kelsey Johnson joined the department in September 2004 as a Hubble Fellow. She will become an Assistant Professor in 2005. Wesley N. Colley departed in May taking a position in the private sector.

Postdocs in residence included Jeffrey S. Bary, Elizabeth L. Blanton, Matthew H. Burger, Tracy Clark, Jean-Pierre de Villiers, David A. McDavid, Thomas H. Reiprich, Helio Rocha-Pinto and Ricardo P. Schiavon. Mary Kutty Michael from Robert Johnson's planetary astronomy group was also in residence. Blanton was a Chandra Fellow. McDavid, Rocha-Pinto & Reiprich all received support from the Levinson Fund of the Peninsula Community Foundation.

Other personnel included Instrument Maker Charles Lam, Electronics Design Technician James Barr, Office Manager Barbara Nicholson, & Secretary Jacquelynn Harding and computer hardware/software assistant Howard Powell.

At the end of this period there were 27 resident graduate students, 3 non-resident graduate students, 2 planetary astronomy graduate students, and one visiting graduate student.

Jeffrey Crane, John Silverman & Tony Sohn completed their Ph.D.s during the year.

Long term visitors included Nicolai Chugai, Ben Dorman, Eileen Friel, Yukata Fujita, Yuri Izotov, Bill Kunkel, Francesco Sylos Labini, Kristen Menou, Fumitaka Nakamura, Ruth Peterson, Valery Shematovich, & Caroline Terquem.

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 Frank Levinson Fund of the Peninsula Community Foundation has made it possible for the Department to initiate several programs. Skrutskie and John Wilson have initiated a program in near-IR instrumentation. Matt Nelson has recently joined that effort. 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 (including the 2.3-m Bok, 1.8-m Vatican Advanced Technology, MMT, and Magellan telescopes) were made during the year.

3. RESEARCH

3.1 Stars and Stellar Evolution

Balbus supervised the work of graduate student S. Fromang (IAP, Université de Paris) who developed a three-dimensional magnetohydrodynamics code including self-gravity. With this computational tool, it is now possible to investigate the simultaneous development of the magnetorotational and Jeans instabilities in star formation processes. This work, which comprises the bulk of Fromang's PhD thesis, showed that the two instabilities interfere with another, rather than mutually enhance transport. This contributes to inefficiency in the star formation process. Dr. Fromang successfully defended his thesis in June 2004.

Balbus supervised the BS degree of M. Kunz, who carried out a calculation of the stability of a magnetized, rotating gas in the presence of ambipolar diffusion. Such a gas has complex stability behavior, and the calculation involved novel technical features. Most importantly, ambipolar diffusion was found to have a significantly destabilizing role, a result of some significance for galactic molecular disks.

Balbus and Hawley 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.

Balbus, K. Menou, and H. Spruit (MPI), completed a study of the stability of stellar differential rotation. The diffusive effects of thermal conduction, viscosity, and electrical resistivity were included in the calculation. Interestingly, it was found that all of these processes must be included for a truly self-consistent calculation. The resulting stability analysis indicates that the observed solid body rotation of the solar radiative zone (and by inference other stellar radiative zones) may have been driven to this minimum energy configuration by magnetorotational and related instabilities.

Chevalier has continued to explore the relation between various types of core collapse supernova and the observed properties of young supernova remnants with ages $\sim 10^3$ years. Massive star supernovae can be divided into four categories depending on the amount of mass loss from the progenitor star and the star's radius: red supergiant stars with most of the H envelope intact (SN IIP), stars with some H but most lost (III, IIb), stars with all H lost (Ib, Ic), and blue supergiant stars with a massive H envelope (SN 1987A-like). Various aspects of the immediate aftermath of the supernova are expected to develop in different ways depending on the supernova category: mixing in the supernova, fallback on the central compact object, expansion of any pulsar wind nebula, interaction with circumstellar matter, and photoionization by shock breakout radiation. The observed properties of young supernova remnants allow many of them to be placed in one of the supernova categories; all the categories are represented except for the SN 1987A-like type. Of the remnants with central pulsars, the pulsar properties do not appear to be related to the supernova category. There is no evidence that the supernova categories form a mass sequence, as would be expected in a single star scenario for the evolution. Models for young pulsar wind nebulae expanding into supernova ejecta indicate initial pulsar periods of 10 – 100 ms and approximate equipartition between particle and magnetic energies. Ages are obtained for pulsar nebulae, including an age of 2400 ± 500 yr for 3C58, which is not consistent with an origin in SN 1181. There is no evidence that mass fallback plays a role in neutron star properties. In collaboration with J. Blondin (NCSU), Chevalier is following up this work by computing the evolution of supernovae in red supergiant winds in more detail. This work will show the evolutionary status of young remnants and the extent to which a pulsar wind nebula can be crushed by a reverse shock front in the case of wind interaction.

Chevalier and C. Fransson (Stockholm) are modeling the emission from Type IIP (plateau) supernovae as a way of investigating the mass loss properties of red supergiants at the end of their lives. The supernovae are thought to come from stars with initial mass $\sim 8 - 25 M_{\odot}$. The expected stellar end points can be found from evolutionary calculations and the corresponding mass loss properties at this point can be estimated from typical values for Galactic stars. The mass loss densities of observed supernovae can be estimated from

observations of the thermal X-ray and radio synchrotron emission that result from the interaction of the supernova with the surrounding wind. Both the X-ray and radio luminosities are sensitive to the mass loss and initial masses of the progenitor stars. Both the mass loss density and the variation of density with stellar mass are consistent with expectations for the progenitor stars deduced from direct observations of 4 supernovae. Current observations are consistent with mass being the only parameter; observations of a supernova in a metal poor region might show how the mass loss depends on metallicity.

Chevalier, with N. Chugai (Institute of Astronomy, Moscow) and P. Lundqvist (Stockholm), proposed a model to account for both the bolometric light curve and the Ca II emission features of the peculiar Type Ia supernova (SN) 2002ic, which exploded in a dense circumstellar envelope. The model suggests that the SN Ia had the maximum explosion energy expected for a CO white dwarf detonation and that the ejecta expand in the approximately spherically symmetric (possibly clumpy) circumstellar environment. The Ca II features are emitted by the shocked SN ejecta that underwent deformation and fragmentation in the intershock layer. The scattering of line photons by the unshocked SN ejecta explains a strong skewing towards the blue seen in the Ca II doublet. The Ca II triplet modeling implies the fraction of the O I 8446 Å line is about 25% of the 8500 Å feature on day 222, which is consistent with the observed flux in the Ca II 8550 Å triplet from the flux of 8500 Å blend. The Ca II doublet and triplet fluxes are used to derive the electron temperature (≈ 4430 K) of the dense fragments of the shocked ejecta and the ratio of their cumulative area to the area of undisturbed shell. In this model, the large luminosity of the Ca II 8550 Å triplet is related to the large area ratio of the shocked ejecta material in the intershock zone.

Hawley is part of an on-going collaboration to develop the next generation of fully general relativistic MHD simulation codes. Co-Investigators in this project include C. Gammie and S. Shapiro (U. Illinois). At present this project is focused on accretion into Kerr black holes.

Combining both numerical and analytic approaches, Hawley, Balbus, and De Villiers explored the properties of the magnetorotational instability, and its implications for angular momentum transport, energy transport, and global dynamics of astrophysical disk systems.

Hawley is part of an collaborative effort to develop an astrophysical magnetohydrodynamic (MHD) simulation code based on a conservative Godunov-type algorithm. The project aims at producing a publicly-available, well documented code as a successor to the popular ZEUS code. The effort is headed by J. Stone (Princeton). Both C and Fortran 95 version of the code, dubbed ATHENA, have now been released for both one- and two-dimensional simulations. A three-dimensional version remains in development.

Bary has continued a high-resolution near-infrared spectroscopic survey of T Tauri stars located in nearby star forming regions in an attempt to detect H₂ emission from disks around young stars that possess no other disk tracer emission. Observations of emission from H₂ gas tracers are typically used to infer the presence and physical characteristics

of circumstellar disks encircling young stars. However, emission from these disk tracers is seen to disappear before planets are predicted to form. If the absence of disks tracers means the absence of a disk, then there is a real problem for the current timescale for planet formation predicted by the core accretion model. Bary has analyzed the spectra of T Tauri stars and Herbig AeBe stars in the Chamaeleon I star forming region as part of a larger survey for quiescent H_2 emission using Phoenix on Gemini South. Several new detections of the $2.1218 \mu\text{m } v=1 \rightarrow 0 \text{ S}(1)$ line have been made towards both classical and weak-lined T Tauri stars, including one detection towards a Herbig Ae star.

Li continued his collaboration with F. Nakamura (Niigata University, Japan) on numerical simulations of star formation in magnetized, turbulent clouds. Their latest simulations include both dynamically important magnetic fields and supersonic turbulence, as well as the newly formed stars and their outflows. For turbulent clouds that are initially magnetically subcritical, they find relatively low efficiencies of star formation of a few percent over several cloud collapse times; these are similar to the values inferred in regions such as the Taurus molecular clouds that form dispersed low-mass stars. Magnetically supercritical clouds are found to have higher star formation efficiencies and may correspond to cluster-forming regions. Their evolution is affected to a larger extent by protostellar outflows.

Li and Anderson continued their investigation of the structure of magnetocentrifugal outflows launched from accretion disks, together with R. Krasnopolsky (UIUC) and R. Blandford (Stanford). They are able to numerically obtain wind solutions over a wide range of mass loading, including a new type of “heavily loaded” winds whose magnetic fields are completely dominated by the toroidal component. The stability of this new class of wind solutions remains to be determined. They find that magnetocentrifugal winds are approximately self-similar in mass loading. A simple analytic formula is obtained for the terminal wind speed in terms of the conditions at the launching surface.

Li and Mellon initiated a new project with A. Allen (ASIAA, Taiwan) on disk formation in magnetic clouds. The project is motivated by their earlier finding that the strong magnetic field envisioned in the standard picture of low-mass star formation can remove almost all of the angular momentum of the collapsing protostellar envelope, thereby inhibiting disk formation in the ideal MHD limit. They have begun to incorporate non-ideal effects into the protostellar collapse calculations, starting with a treatment of ambipolar diffusion. The goal is to determine the conditions under which the all important disks can reappear in the problem of star formation in magnetized clouds.

Li started a collaboration with S. Shang (ASIAA, Taiwan) and her group on the interaction of magnetocentrifugal winds with ambient medium. The motivation is to unify the two competing (jet-driven vs wind-driven) theories for molecular outflows, which are thought to be the ambient material swept up by protostellar winds. The unification is possible because magnetocentrifugal winds are intrinsically anisotropic, with a dense axial jet surrounded by a more tenuous, wide-angle wind. They find that at early times the interaction is domi-

nated by the dense jet, producing molecular outflows expected in the jet-driven scenario. The outflows widen at later times, driven by the wide-angle component. They predict that those narrow outflows that appear to be driven by jets are relatively young; they will evolve into wider outflows that appear to be wind-driven.

A photometric search for tidal streams around a number of Galactic globular clusters has led to promising signs of extratidal stars for eight of these clusters (NGC6397, NGC1904, NGC3201, NGC5824, NGC288, NGC5634, Pal5, and Arp2). Follow-up spectra are needed to confirm the extratidal candidates in these clusters. Photometric work on additional clusters (including Pal 11 and 15) is also underway. This work is being carried out by Muñoz (graduate student), Moskowitz (undergraduate student, Wesleyan), Beaton (undergraduate student) Frinchaboy (graduate student), Majewski, Patterson, Kunkel, Chou (graduate student), and Carl Grillmair (SIRTF).

Frinchaboy, Majewski and Friel (NSF) are continuing a project to determine the orbits and metallicities of a number of Galactic open 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 to investigate the outer Galactic rotation curve and the Galactic abundance gradient. Together with Muñoz, Phelps (CSUS & UC Davis), Kunkel (LCO) and Patterson, this research group continues to survey the ages, distances, and dynamics of old open star clusters. Work continues to confirm cluster association with the Galactic Anticenter Stellar Structure or Monoceros “Ring.”

Frinchaboy, Kunkel (Las Campanas), Skrutskie, and Majewski are continuing a project to measure radial velocities carbon stars in the bar of the Milky Way, using the 2MASS survey. These data will be used for investigation of bar kinematics along the entire length and to determine the influence of the bar on the carbon stars in the outer Milky Way disk.

Crane (graduate student), Majewski, Rhee (CalTech), Rocha-Pinto, Skrutskie, Patterson, and Bahcall (IAS), continued the analysis of photometry and spectroscopy of K and M giants at the North Galactic Pole as a means to both measure the vertical density law of the Galaxy and to improve upon estimates of the Oort limit and the amount of dark matter in the Galactic disk. Additional work on understanding stellar populations, especially halo substructure, at the North Galactic Pole is being undertaken by Polak (graduate student) and Rocha-Pinto, in collaboration with Hanson and Klemola (UCO/Lick).

The spatial distribution of 2MASS M giant candidates have been analyzed by Rocha-Pinto, Majewski and Skrutskie, in a search for tidal streams around the Milky Way. A very large concentration of M giants has been found close to the Galactic plane between Galactic longitudes 270° and 290° , which seems to mark the core of the recently discovered Monoceros stellar stream. Other less conspicuous concentrations of M giants have been found towards the constellations of Triangulum-Andromeda, Perseus, Chamaeleon, Musca and Cancer. They have obtained spectroscopic con-

firmation for the M giants in the Triangulum-Andromeda and Perseus overdensities. The main sequence turn-off of the Triangulum-Andromeda feature has also been found in previous imaging by Ostheimer, Majewski and Patterson.

The tidal disruption of the Sagittarius dwarf galaxy has been a continuing focus of research by the Majewski-Patterson research group. They are working with Pakzad (graduate student), Frinchaboy, Skrutskie, Prada (IAA-Granada), Ivezić (Princeton), Johnston (Wesleyan), Hummels (graduate student, Wesleyan), Law (graduate student, Caltech) and Kunkel to map and understand the trailing arm beyond the previously published 150° length using M giant candidates from 2MASS. Further mapping of the Sgr leading arm in the inner Galaxy is being done by Polak. In addition, Chou and Majewski are working with Smith (UTEP), and Bizyaev (UTEP) to analyze echelle spectra of M giants in the tails as a means to characterize the ‘‘chemical fingerprint’’ of Sgr stars. This will help in the verification of candidate Sgr debris stars in the crowded solar neighborhood. N-body modeling of the Sgr tidal arms, and the constraints they place on the shape of the Galactic potential, has been undertaken by Law, Johnston and Majewski.

Majewski and Patterson continue work with Geisler (Concepcion), Smith (UTEP) and Bizyaev (UTEP) to explore stars within the Grid Giant Star Survey, a photometric survey of bright giant stars to serve as astrometric reference stars for the Space Interferometry Mission (SIM) created by a collaboration led by UVA. Giants are identified to Washington $M \sim 17$ in 1300 fields over the entire sky. Current work includes both high resolution spectroscopy and photometric monitoring of bright giants suitable for SIM, and these data have been used to guide and provide input for the selection of SIM grid stars. Reduction of the last fields in the photometric catalogue is now nearly complete.

In an effort to uncover and trace additional halo substructure, Majewski, Patterson, Kunkel, Frinchaboy, Muñoz, Nidever (graduate student), and Polak are using data from their Grid Giant Star Survey to identify giants to Washington $M \sim 17$ in 1300 fields over the entire sky. Approximately 7000 spectra have been obtained through long-term status on the CTIO 4-m and WIYN 3.5-m Hydra spectrographs; initial work has focused on fields positioned to find debris from Sgr and the Magellanic Clouds.

The mapping of extended population of giants around a number of Galactic dwarf spheroidal galaxies continues. Sohn (graduate student), Majewski, Guhathakurta (UCO/Lick), Kunkel (LCO) and Cooper (UC Berkeley) have used Keck radial velocities of 49 Leo I stars, including 16 Leo I giants near and to either side of the King limiting radius, to measure the dynamical profile of this dSph. The spectroscopic results show that their Leo I giant selection technique, which makes use of the Washington $M, T_2 + DDO51$ photometry, is 100% reliable in this dSph, and that Leo I shows signs of rotation. They also find non-virialized clump of stars just outside the King limiting radius showing evidence that this galaxy has been tidally stripped by Galactic potential. Combining these results, they conclude Leo I is (1) a galaxy in a transitional state between dIrr and dSph, and (2) a galaxy in an early stage of tidal disruption. Similar work on the

Ursa Minor, Carina and Sculptor dwarf spheroidals is being pursued by Muñoz, Frinchaboy, Chou and Kuhn (Hawaii), working with Majewski, Patterson and Kunkel to obtain follow-up echelle spectroscopy with Keck and Magellan. N-body modeling of these systems is being undertaken by Majewski, Muñoz and Johnston (Wesleyan).

Chou continued work with Shang (ASIAA, Taiwan), Allen (ASIAA) and Liu (ASIAA), on a unified model for bipolar outflows from young stars.

An analysis of the kinematical data for 425 solar neighborhood dwarfs was undertaken by Rocha-Pinto, Flynn (Turku), Scalo (Texas), Hänninen (Turku), Maciel (São Paulo) and Hensler (Viena). They have shown that the age-velocity dispersion among solar neighborhood stars is still very uncertain and how current estimates of this relation is affected by the use of corrections and data binning. The existence of this relation is commonly interpreted as a result of secular disk heating caused by collision of stars with giant molecular clouds and/or massive black holes. The authors argue that none of the heating mechanisms proposed to date can explain the large values of the velocity dispersion presented by the oldest disk stars.

Rood, Bania (BU), Balsaer (NRAO-GB), & Quireza (graduate student, São Paulo) had their first successful observations searching for the 3.5 cm hyperfine line $^3\text{He}^+$ in planetary nebulae (PNe) using the Robert C. Byrd Green Bank Telescope. Early indications are that because of much reduced systematic errors, results can be obtained roughly four times faster than with the MPIfR 100 m radio telescope. The abundances eventually obtained will be used to address the paradox that while some PNe add substantial ^3He to the interstellar medium (ISM), the ISM as observed via H II regions shows no evidence for increasing ^3He .

As part of the HST/Treasury program (GO-9455/ 9974) a new set of stellar evolutionary tracks are being computed by Schiavon. These tracks are combined with state-of-the-art synthetic spectra computed from first principles in order to produce synthetic single stellar population integrated spectra in the UV. This project is being developed in collaboration with B. Dorman, R. Peterson (Lick Observatory), Rood, O’Connell, and other members of the HST-Treasury team. Preliminary predictions were produced for a small set of metallicities and abundance ratios, for a range of stellar masses. The evolutionary tracks are currently being checked through comparison with computations from other groups and with color-magnitude data of Galactic globular clusters.

A library of high quality integrated spectra of Galactic globular clusters has been collected with the 4m Blanco telescope at CTIO/Chile. This is the largest homogeneous library of Galactic GC spectra ever produced at the involved resolution, spectral coverage and S/N. The spectra are being used to constrain models of stellar population synthesis. The first of a series of papers, presenting the spectral library, is going to be submitted before the end of the year. This work is being done in collaboration with J. Rose (North Carolina), S. Courteau (Queens University), and L. MacArthur (British Columbia).

A proposal to obtain deep UV photometry of 30 Galactic globular clusters with Galex has been approved. These data

will make possible an unprecedented characterization of the UV properties of old stellar populations. The data will be collected and analyzed throughout the upcoming academic year. This project is being undertaken in collaboration with O'Connell, Rood, R. Peterson and the rest of the aforementioned HST/Treasury team.

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.

Skrutskie and Bary are carrying out long-term synoptic spectrophotometric observations of accreting T-Tauri stars using the CorMASS spectrograph at VATT in order to study the time-dependent line and continuum signatures of magnetospheric accretion of disk material onto young stars.

Wilson is supporting Spitzer Space Telescope spectral observations of low-mass stars and brown dwarfs as a member of a guaranteed-time observation (GTO) team. He and Pope determined proper motions of Spitzer targets through two-epoch imaging. Wilson and programmer M. Crane also developed a database for managing literature information and reduced data for the Spitzer targets.

Wilson and Xilouris, in collaboration with M. Liu (IfA) and J. Pope (graduate student), have been observing the Pleiades Cluster through deep wide-field near-infrared imaging conducted at the Palomar 200-inch telescope to study the cluster low-mass luminosity function.

Wilson and Skrutskie also 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.

Almost four years of timing with the Arecibo radiotelescope (Lorimer (Jodrell), Xilouris, Fruchter (STScI), Stairs (UBC), Camilo (Columbia)) have established that pulsar J0407+1607 is in a 669-day binary system about a low-mass ($0.2 M_{\odot}$) companion, most likely a white dwarf with a helium-core. The system belongs to a rare category of binaries with relatively long orbital periods but circular orbits ($e \approx 0.001$). The Palomar 200-inch telescope will soon be used to search via deep BVRI imaging and astrometry for the companion white dwarf and obtain a photometric temperature. This will provide an estimate of its cooling age and mass in order to begin addressing the evolution of the system.

Xilouris, Kramer (UV Manchester), Chatzikos, Cole performed 327-MHz polarimetric observations of a selected sample of millisecond pulsars using the Arecibo 300-m radiotelescope aiming at investigating the spectral behavior, intensity-profile complexity and polarization of millisecond pulsars (MSPs) at low frequencies. Investigations conducted so far, primarily at high frequencies, have demonstrated that the properties of the MSP pulse components do not fit easily into successful classification schemes proposed for slower pulsars. Extending these studies to the lower end of the spectrum, where pulsars are brighter and the emission is inherently strongly polarized, are promising in providing a better means of determining the viewing geometry as well as the

location of the emission region in pulsar magnetospheres.

Xilouris, Despande (NAIC) and Kramer (UV Manchester) have been carrying out quasi-simultaneous multi-frequency single-pulse polarimetric observations of pulsars in the frequency range between 330 MHz to 10 GHz with the Arecibo radiotelescope. The frequency agility and broad-bandwidth backends now available at Arecibo, provide a unique opportunity to probe pulsar magnetospheric emission in a unique manner not possible before. Once the instrumental properties are well understood, this data will be used to investigate the origin of the decay of the polarized component of pulsar radio emission with frequency as well as explore the dynamic properties of the pulsed emission with frequency.

Following the refurbishing of the drive system of the 1-m astrometric reflector at Fan Mt, Xilouris and Soker (UV Haifa) are in the process of obtaining deep narrow-band CCD images of a selected sample of large angular size Planetary Nebulae, to investigate the mechanisms responsible for their present shaping.

3.2 Interstellar Medium

Bary and Murphy continue to analyze spectra of the hot halo of NGC 4631 obtained with the NASA Far Ultraviolet Spectroscopic Explorer. They are using OVI 1031.926 Å emission to trace the extent and kinematics of hot, cooling galactic fountain gas. Analysis of these spectra suggest that the cooling halo gas corotates with atomic hydrogen halo gas. Additional *FUSE* pointings have been requested to determine the full extent of the cooling halo and its relationship with the X-ray emission mapped by the Chandra X-ray Observatory.

Along with M. Mac Low (AMNH), J. Oishi (graduate student) has continued a numerical study of the effects of ambipolar diffusion (AD) on the turbulent interstellar medium using a modified version of the ZEUS-MP hydrodynamics code. They have found that AD does not act as a classical diffusion source for magnetic energy. The astrophysical implication is that AD does not set a characteristic scale for the mass spectrum in molecular clouds.

3.3 Galaxies and Active Galactic Nuclei

Balbus developed a formalism for quantifying turbulent transport, both energy and angular momentum, in accretion flows. The formalism lends itself well to numerical diagnostics, and will allow one to study the validity of classical viscous disk theory.

Balbus developed a theory for a new type of viscous instability in a dilute plasma. It is present when the angular momentum is transported along the magnetic field lines. Growth rates are large, and the instability appears to be important for field amplification in protogalaxies, and in accretion processes involving radiatively inefficient flows near black holes.

De Villiers and Hawley continued their collaboration with J. Krolik and S. Hirose (Johns Hopkins University) to investigate detailed properties 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 possi-

bility of energy extraction from spinning black holes. Several high resolution three-dimensional simulations have been carried out for a different black hole spins. The major findings include: 1. A strongly spin-dependent outward flux of angular momentum conveyed electromagnetically from the hole to the accretion disk can retard the effective accretion rate for Kerr holes. 2. Contrary to the expectations of traditional accretion disk theory, there is no general surface within which the stress in the inflow vanishes. 3. Spinning black holes can lose energy by Poynting flux at a rate that strongly increases with black hole spin. Much of this flux is directed outward as an axial jet which can have a luminosity comparable with that of the disk itself. 4. A net loss of angular momentum from a Kerr hole indicates that black holes cannot sustain spin rates much in excess of $a/M = 0.9$.

Found in a large, deep redshift survey of faint galaxies, 52W036's enormous size, high surface brightness, and extreme color, combined with a change in morphology from a horseshoe in the ultraviolet to an apparent source pair in the infrared, make it a very unusual galaxy. Hampton (data analyst), Majewski and Bershad (UWisc) are using HST images to study its structure and evolutionary history in hopes of gaining a better understanding this dynamic system.

Majewski, Ostheimer and Patterson are working with Guhathakurta (UCO/Lick), Reitzel (UCLA), Rich (UCLA), Johnston (Wesleyan), Font (Wesleyan) and others are undertaking a Keck spectroscopic survey of giant stars in the halo of M31, with a specific focus on its halo substructure. The work includes N-body modeling of M31 halo streams.

In collaboration with Bureau (Columbia) and Cress (UKZN, South Africa), Pakzad is finishing up her MSc. thesis entitled "Kinematics and Dynamics of the Elliptical Galaxy NGC 5266."

O'Connell, Rood, and postdoc R. Schiavon are continuing their work 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, mid-UV (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. Good progress has been made in modeling populations with sub-solar abundances. Work is now concentrating on models with non-solar α/Fe and abundances of solar and higher. Unfortunately, the failure of STIS on HST will hamper comparison of the models to high resolution observations of standard stars. Experiments are planned using the lower dispersion grism instrument on ACS as a substitute.

Using HST/STIS, O'Connell, Rood, and graduate students J. Martin, J. Crane, and I. Freedman, together with colleagues at other institutions, have detected a far-ultraviolet nuclear flare in the giant elliptical galaxy NGC 1399, the central and brightest galaxy in the Fornax I cluster. The flare reached a maximum observed far-UV luminosity of $\sim 8.9 \times 10^{38}$ ergs s^{-1} in January 1999. It was detectable in earlier HST archival optical-band images in 1996 but not in 1991 or 1993. It faded by a factor of $\sim 4 \times$ by mid-2000.

The flare is almost certainly associated with the low luminosity AGN responsible for the radio emission in NGC 1399. The properties of the outburst are remarkably similar to the UV-bright nuclear transient discovered earlier in NGC 4552 by Renzini *et al.* (1995). The source is much fainter than expected from its Bondi accretion rate (estimated from *Chandra* high resolution X-ray images), but its UV/optical variability appears to be incompatible with "radiatively inefficient accretion flow" models.

Graduate student J. Martin, under the direction of O'Connell and J. Hibbard (NRAO), and with R. van der Marel and S. Ravindranath of STScI, has begun a combined archival/observational program with HST to study merger signatures in the profiles and colors of the cores of nearby early-type galaxies. Hierarchical formation models predict that such galaxies are built up over an extended period from mergers of smaller systems. Merger events should have continued up to relatively recent times (the last 1-5 Gyr), and many ellipticals and spiral bulges should therefore show evidence of multiple, discrete, intermediate-age populations. Existing searches have primarily been monochromatic or at long wavelengths. The archival program will emphasize multi-color imaging and short wavelengths (down to 3300 Å) for a sample of over 160 galaxies. New high resolution, broad-band, vacuum-ultraviolet (2500-3400 Å) imaging of the cores of 12 bright early-type galaxies will also be obtained with ACS/HRC. This is the most sensitive probe available for the detection of spatially-segregated, multiple population components with ages in the range 1-5 Gyr.

Oishi (graduate student) is collaborating with J. Maron (AMNH/Columbia) and Mac Low (AMNH) on an ongoing project investigating the origin of Galactic magnetic field. The operation of Galactic dynamo is a controversial subject, with most of the contention surrounding the ability of dynamos to create the large-scale, coherent fields observed. This work will continue the study of an idealized problem, that of dynamo activity in a periodic turbulent box, including more realistic dissipation processes than previous simulations.

The X-ray group has an ongoing project to image X-ray-bright early-type galaxies with *Chandra* and XMM/Newton to study the physics of the hot interstellar gas. S. Randall (graduate student), Sarazin, and J. Irwin (U. Michigan) have analyzed 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 may be due to convection. Sivakoff (graduate student), Sarazin, and Carlin (graduate student) recently completed work on a *Chandra* image of NGC 1600, which shows diffuse emission from the galaxy and group and the possible detection of many Ultra-Luminous X-ray sources. Carlin, Sivakoff, and Sarazin are also working on the *Chandra* observation of NGC 533. XMM/Newton observations of NGC 4552, and NGC 5846 and *Chandra* data on NGC 5813 are also being analyzed.

The LMXB populations and hot gas in X-ray-faint early-type galaxies are being studied by the X-ray group. *Chandra* observations of NGC 4526 and NGC 5866 are being analyzed.

The X-ray group 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 which imaged all these galaxies with the ACS, and this is providing globular cluster (GC) populations to compare to the LMXBs.

Sarazin is calculating models for the spatial distribution of X-ray binaries and globular clusters in elliptical galaxies. A high fraction ($\sim 50\%$) of LMXBs in ellipticals are in globular clusters. By comparing the spatial distributions of globular clusters, GC LMXBs, and field LMXBs, one can constrain the fraction of LMXBs made in GCs and the fraction of GCs destroyed during the history of the galaxy.

Sarazin, Sivakoff, Irwin, Coté, and Jordan have observed NGC 4697, the nearest optically-bright, X-ray faint elliptical galaxies five times with Chandra to detect much fainter LMXBs and to determine the variability of sources. A Hubble Space Telescope observation is being used to construct a globular cluster catalog and determine the relation between the GCs and LMXBs. A similar observational campaign will be done this year for NGC 4365.

A new set of stellar population synthesis models in the optical has been developed by Schiavon that predict UV magnitudes and absorption line strengths of single stellar populations. These models are currently being applied to interpret the integrated light of galaxies and globular clusters. The paper presenting the models will be submitted before the end of the year.

Schiavon is studying the evolution of early-type galaxies at $z \sim 1$ on the basis of a large survey of integrated spectra of distant galaxies collected with the Keck telescope under the DEEP survey (<http://deep.ucolick.org>). The major conclusion of this work is that field early-type galaxies half the age of the Universe ago were suffering small amounts of star formation, as indicated by the strength of their Balmer lines (in absorption) and the [OII] λ 3727 line (in emission). This research is being conducted in collaboration with Sandy Faber, David Koo (Lick Observatory) and the DEEP group.

A proposal to obtain long slit integrated spectra of the nuclei of Local Group galaxies in the UV and optical with HST/STIS has been approved (GO-10224). The proposal involved 30 orbits, but it has been rendered undoable by the recent demise STIS. This project was being pursued by Schiavon in collaboration with O'Connell, Rood, R. Peterson and the rest of the HST/Treasury team.

Sivakoff (graduate student), D. Homan (Denison U.), and J. Wardle (Brandeis U.) are examining the brightness temperatures of the milli-arcsecond radio-jet cores found in some AGN. By modeling the radio-jet and using baselines from a synthesis-imaging array to image the modeled jet, one can investigate how accurately synthesis-imaging measures the brightness temperatures of radio-jet cores. Accurate measurements of brightness temperatures are crucial in estimating jet Doppler factors, determining which physical mechanisms limit physical brightness temperatures, and exploring the distinctions between the various AGN classes. They find that the brightness temperatures are generally underestimated

and that the extent of the underestimate depends heavily on effective resolution. Since effective resolution depends on distance and on orientation to the line of sight, understanding this effect is important for studies exploring the physical distinction between AGN classes using estimated brightness temperatures or Doppler factors.

The question of whether there are young galaxies in the local universe forming stars for the first time is of considerable interest for galaxy formation and cosmological studies. The blue compact dwarf (BCD) galaxy I Zw 18, the most metal-deficient star-forming galaxy known, is one of the best candidates for being a truly young galaxy. To determine its age, Thuan, in collaboration with Izotov (Kiev) have obtained very deep Hubble Space Telescope/Advanced Camera for Surveys (ACS) *V* and *I* images (limiting magnitudes $V = I = 29$ mag) to resolve the stars in the BCD and construct its color-magnitude diagram (CMD). It reveals a young stellar population of blue main-sequence (MS) stars (age ≤ 30 Myr) and blue and red supergiants ($10 \text{ Myr} \leq \text{age} \leq 100$ Myr), but also an older evolved population of asymptotic giant branch (AGB) stars ($100 \text{ Myr} \leq \text{age} \leq 500$ Myr). A distance was derived to I Zw 18 in the range 12.6 Mpc – 15 Mpc from the brightness of its AGB stars, with preferred values in the higher range. The red giant branch (RGB) stars are conspicuous by their absence, although, for a distance of I Zw 18 ≤ 15 Mpc, the imaging data go $\sim 1 - 2$ mag below the tip of the RGB. Thus, the most evolved stars in the galaxy are not older than 500 Myr and I Zw 18 is a bona fide young local galaxy. Several star formation episodes can be inferred from the CMDs of the main body and the C component. There have been respectively three and two episodes in these two parts, separated by periods of $\sim 100 - 200$ Myr. In the main body, the younger MS and massive post-MS stars are distributed over a larger area than the older AGB stars, suggesting that I Zw 18 is still forming from the inside out. In the C component, different star formation episodes are spatially distinct, with stellar population ages decreasing from the northwest to the southeast, also suggesting the ongoing build-up of a young galaxy.

Thuan, in collaboration with Izotov (Kiev) have obtained HST/WFPC2 *V* and *I* images of the cometary dwarf irregular galaxy NGC 2366. The resulting color-magnitude diagram reaches down to about $I = 26.0$ mag. It reveals not only a young population of blue main-sequence stars (age ≤ 30 Myr) but also an intermediate-age population of blue and red supergiants ($20 \text{ Myr} \leq \text{age} \leq 100$ Myr), and an older evolved populations of asymptotic giant branch (AGB) stars (age ≥ 100 Myr) and red giant branch (RGB) stars (age ≥ 1 Gyr). The measured magnitude $I = 23.60 \pm 0.10$ mag of the RGB tip results in a distance modulus $m - M = 27.60 \pm 0.11$, which corresponds to a distance of 3.3 ± 0.3 Mpc, in agreement with previous distance determinations. As a consequence of the diffusion and relaxation processes of stellar ensembles, the older the stellar population is, the smoother and more extended is its spatial distribution. An underlying population of older stars is found throughout the body of NGC 2366. The most notable feature of this older population is the presence of numerous relatively bright AGB stars, indicating that in addition to the present burst of age ≤ 100

Myr, there has been strong star formation activity in the past, from ~ 100 Myr to ≤ 2 Gyr ago.

FUSE spectroscopy of SBS 0335–052, the second most metal-deficient blue compact dwarf (BCD) galaxy known ($\log O/H = -4.70$), has been obtained by Thuan in collaboration with Lecavelier (Paris) and Izotov (Kiev). In addition to the H I Lyman series, C II, N I, N II, O I, Si II, Ar I and Fe II absorption lines, mainly arising from the extended H I envelope in which the BCD is embedded, are detected. No H₂ absorption lines are seen. The absence of diffuse H₂ implies that the warm H₂ detected through infrared emission must be very clumpy and associated with the star-forming regions. The clumps should be denser than $\sim 1000 \text{ cm}^{-3}$ and hotter than ~ 1000 K and account for $\geq 5\%$ of the total H I mass. Although SBS 0335–052 is a probable young galaxy, its neutral gas is not pristine. The metallicity of its neutral gas is similar to that of its ionized gas and is equal $\log O/H \sim -5$. This metallicity is comparable to those found in the H I envelopes of three other BCDs with ionized gas metallicities spanning the wide range from $\log O/H = -4.8$ to $\log O/H = -4.0$, and in Ly α absorbers, fueling the speculation that there may have been previous enrichment of the primordial neutral gas to a common metallicity level of $\log O/H \sim -5$, possibly by Population III stars.

Whittle, 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 ~ 1 –few) at 1–few times the emission line velocity ($\sim 1000 \text{ km s}^{-1}$) with mean density $\sim 1 \text{ cm}^{-3}$. 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.

This method of analysis is now being applied to other objects in their sample, of which Mkn 34 is the most spectacular, exhibiting velocities in excess of 1000 km s^{-1} .

3.4 Clusters of Galaxies

O'Connell, with postdoc R. Schiavon, graduate students D. Rosario and G. Demessieres, and collaborators at other institutions, have begun observing programs with GALEX and the Spitzer Space Telescope to obtain deep, vacuum UV imaging and mid-infrared spectroscopy, respectively, of clusters of galaxies hosting large cooling flows.

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.

A high redshift cluster, BD1137+3000, was detected in X-rays with Chandra by Blanton, Sarazin, D. Helfand (Columbia), M. Gregg (IGPP), and R. Becker (UC Davis). 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.

Blanton, Sarazin, Clarke, and B. McNamara (Ohio U.) are doing a very long Chandra observation of Abell 2052 to study the ripples seen in the shorter Chandra image of this cooling flow, radio bubble cluster. This group is also analyzing a Chandra image of Abell 262, which also shows radio bubbles.

M. Chatzikos (graduate student), 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 XMM/Newton observations of Abell 115 N/S and A1664/3541, two hybrid merging/cooling flow clusters with radio relics.

Clarke and Sarazin have a project to image cooling flow radio bubbles and “ghost” bubbles (those without known radio emission) at low frequencies in the radio with the VLA and GMRT. They find that low frequency radio emission fills in the “ghost” radio bubbles in Abell 2597 and Abell 4059.

An interaction between the radio source and the X-ray gas in Abell 2029 has been found by Clarke, Blanton, and Sarazin 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 was 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 strong lensing cross-sections of clusters of galaxies. D. Wik (graduate student), Sarazin, and Randall are using similar techniques to study the effects of mergers on the Sunyaev-Zel'dovich (SZ) effect in clusters.

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 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. Weak lensing observations of moderately distant clusters with the MMT are being used to determine their masses.

Sarazin, Blanton, McNamara, P. Nulsen (CfA), M. Wise (MIT), D. Rafferty (U. Ohio), and C. Carilli (NRAO) have discovered a pair of supergiant radio bubbles surrounded by shocks in the distant cooling core cluster MS0735.6+7421. These represent an extreme example of radio bubbles.

Abell 2107 and Abell 2670 are two clusters containing cD galaxies with relatively high velocities. Chandra observations were made by Sarazin, Blanton, 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.

X-ray and radio studies of radio sources at the centers of cooling core cluster show that the pressures of the radio sources are typically at least an order of magnitude larger than the equipartition pressures. One possibility is that the radio lobes may actually be dominated by very hot thermal or mildly relativistic plasma. Sarazin, C. Pfrommer, and T. Ensslin (MPA) show that SZ images of such radio bubbles with the GBT or ALMA can be used to determine if the pressure support is due to hot thermal plasma, mildly relativistic nonthermal plasma, or very relativistic materials.

The cluster Abell 133 was observed with XMM/Newton by Sarazin, Reiprich, Fujita, 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.

K.-W. Wong (graduate student), Blanton, Sarazin, and B. McNamara (Ohio U.) are using a Chandra images and XMM/Newton spectra to study the cooling flow cluster Abell 2626, which shows evidence for a radio/cooling flow interaction. Chandra observations of Abell 2063 will be taken for similar purposes.

3.5 Cosmology

Saslaw and B. Leong (Cambridge, U.K.) have developed the energy distribution function for gravitational many-body clustering in the expanding universe. They are examining the probability that any given configuration of galaxies in space constitutes a gravitationally bound cluster. If it is bound, they can find the conditional probability that it is also virialized.

Saslaw and F. Ahmad (University of Kashmir, Srinagar) are developing the theory of macroscopic critical variables for second order phase transitions in the gravitational cosmological many-body problem.

Sivakoff and Saslaw have determined the spatial distribution function of galaxies from a wide range of samples in the 2MASS survey. The results agree very well with the form of the distribution predicted by the theory of cosmological gravitational many-body galaxy clustering. They imply that when galaxies clustered they were usually surrounded by individual, rather than communal halos. The observed clustering of magnitude limited subsamples contains a luminosity bias.

3.6 Astrometry

Beaton (undergraduate student), Patterson, Majewski, Boss (DTM), Gatewood (Pitt), Thompson (OCIW) and Weinberger (DTM) are working on the astrometric calibration of imaging data of the open cluster M7 taken at the DuPont Telescope. The goal is to characterize the astrometric stability of the system in preparation for an astrometric extrasolar planet search.

Majewski, Patterson and Dinescu (Yale) have begun a program to measure the proper motions of stars in about 50 Kapteyn Selected Areas to $V \sim 19$. The plate material, spanning nearly a century, includes Kapteyn's original plates from the Mt. Wilson 60-inch, which were matched with a new epoch of plates taken by Majewski on the Du Pont 100-inch telescope. The expected proper motion precision of 1-2 mas/yr will allow study of the Galactic stellar populations and a search for substructure in the Galactic halo.

The book "Fundamentals of Astrometry" by J. Kovalevsky and Seidelmann was published by Cambridge University Press.

Preparation has begun on a revised version of the "Explanatory Supplement to the Astronomical Almanac." This will be edited by Seidelmann along with John Bangert and Sean Urban of the U. S. Naval Observatory.

3.7 Astronomical Instrumentation

Crane, Majewski, Patterson, Skrutskie, and Frinchaboy achieved first light with the Fan Observatory Bench Optical Spectrograph (FOBOS) in September 2003. The instrument's performance exceeds the original design specifications. FOBOS will be used to measure moderate resolution stellar radial velocities for a number of research programs involving the study of Galactic structure. Scientific observing commenced in Spring 2004, and nearly continuous use is expected in the future.

The Infrared Laboratory's active instrument, CorMASS – a cross-dispersed low-resolution ($R=300$) infrared spec-

trograph, has operated as a facility instrument at the Vatican Observatory 1.8-m telescope at Mt. Graham during the past year where it was scheduled for 41 nights. In addition, COR-MASS traveled to the 3.5-m Apache Point Observatory telescope in May for a successful 5-night engineering run. An NSF-funded 1024x1024 HgCdTe infrared camera, whose development has been led by graduate students Kanneganti and Park, is nearing completion and will be installed at the University's Fan Mountain 31-inch telescope in the Fall. Restoration and upgrade of the 31-inch telescope in anticipation of the instrument is underway. The Laboratory has begun fabrication of a new infrared spectrograph to be completed in early 2006. Three nearly-identical copies of this cross-dispersed $R=3000$ near-infrared spectrograph, known as TripleSpec, are planned. One, fabricated at Cornell, is destined for the Palomar 200-inch telescope. Another, fabricated at Caltech, will operate at the Keck 10-m telescope. The Department is seeking a partner for shared use of this new instrument. The Laboratory has provided a 2MASS camera to the Center for Astrophysics for use at the 1.3-m 2MASS telescope at Mt. Hopkins to carry out gamma-ray burst and supernova follow-up. The camera has been installed and the automated facility has been commissioned in anticipation of the launch of SWIFT in the Fall. The second 2MASS camera will be modified by incoming Spitzer Fellow R. Indebetouw to carry out a narrow-band wide-field near-infrared Galactic Plane survey. This Summer the Laboratory received an NSF ATI grant to support a collaboration with industrial partner Sensors Unlimited to develop long-wavelength InGaAs detector material suitable for ground-based background limited observation in the astronomical Ks-band.

3.8 Space Astronomy

Patterson and Majewski undertook a study of the effects of temperature, metallicity and age on the binary frequency and magnitude difference in giant stars of the type to be used as input for the Space Interferometry Mission (SIM) astrometric reference grid. Their analysis showed the importance of avoiding high metallicity, young giant stars, which will introduce a high level of photometric bias in fringe centering with SIM. They have worked with JPL to create a ranked order metric for the selection of the best grid stars for SIM.

A proposal for a concept study, "Origins Billion Star Survey (OBSS)," was submitted to NASA. This is a larger project than the previous FAME project. The concept study was one of eight selected for funding by NASA. Seidelmann prepared the science portion of the proposal and is leading the science part of the concept study. For the concept study research is being done on CCD charge transfer efficiency using time delay integration readout. Studies are being done on the use and analysis of spectral observations for determining astrophysical parameters. The instrument and spacecraft conceptual designs 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 properties of pro-

toplanetary disks, including the influence of MHD turbulence on gap formation and planet migration.

Balbus has shown that solutions of the shearing box equations of motion have a scale symmetry that is relevant for understanding numerical simulations of simple Keplerian shear flows. Such flows are nonlinearly stable on computationally accessible scales. This work shows that any solution on small scales has an exact inflated counterpart on large scales. If large scales are stable, then small scales are as well.

With J. Papaloizou (Queen Mary-University of London), Balbus is computing the three-dimensional response of a protostellar disk to an embedded planet. The nature of the disk's response near the corotation resonance may be important in determining the course of the planet's migration through the disk.

Black is continuing a program aimed at understanding the surface properties of the icy satellites in the outer solar system. A collaboration with D. Campbell (Cornell), S. Ostro (JPL), and L. Carter (Cornell) has been observing Saturn's largest moon Titan over several oppositions with the 13 cm radar system at the Arecibo Observatory. In addition to probing surface roughness and dielectric constant, that work has provided the best evidence to date for liquids on its surface by observing specular echoes which may result from areas of 100 km extent or less and flat to as low as 0.5° . The implied dielectric constants of these areas are consistent with liquid hydrocarbons which have long been postulated to exist on the surface as a by-product of Titan's atmospheric chemistry. With the same group, Black has made radar observations of Iapetus, another enigmatic moon of Saturn, and shown that to the radar the surface's reflectivity is very homogeneous and dark, whereas at optical wavelengths one hemisphere is as much as ten times as reflective as the other. A likely explanation is the presence of buried ammonia compounds which would significantly raise the absorption in the otherwise radar-transparent water ice, while remaining largely hidden at optical and infrared wavelengths. Ammonia compounds are expected to be present in substantial quantity on moons in the Saturn system, but direct evidence for them is lacking.

Black continues to probe the Saturnian ring system with ground-based radio and radar techniques. He has been collaborating with groups from Cornell and Wellesley to obtain radar maps of the rings at various opening angles. These types of observations can map the large particle size distribution in the main rings. In particular, these observations have probed the "azimuthal asymmetry" which was first seen at optical wavelengths but has a larger than expected amplitude at radio wavelengths. This asymmetry is thought to result from gravitational "wakes" generated by individual large ring particles, which become distorted by Keplerian shear into elongated trailing structures.

Imaging of near Earth objects by a radar-interferometer has been an ongoing project by Black and D. Campbell (Cornell). Using the Arecibo 13 cm radar system with the Very Long Baseline Array (VLBA) as the receiving instrument, an observation of the 350 m diameter asteroid Itokawa was made in the summer of 2003 during its close approach to the Earth. This asteroid is also the target of the Japanese sample

return mission, Hayabusa. The technique can achieve plane-of-sky information at resolutions orders of magnitude better than ground-based optical techniques and comparable but orthogonal to standard radar measurements. The primary goals of this project are improved astrometry and absolute orientation of the target's figure and rotation. The main obstacle has been bypassing the hardware VLBA correlator which has difficulty with such near-field, narrowband targets, but that issue has largely been resolved by obtaining the raw datastreams for correlation in software.

Irradiation effects in materials in the outer solar system, ISM, and young stellar objects (YSOs) is the continuing research area of the Johnson group. A principal goal is to relate the composition of the solids in these astrophysical environments to the composition of ambient neutrals and plasma or vice versa. A quantitative description of the physical process relating surface composition of grains and small bodies to the ambient plasma and neutral composition is essential in order to describe these connections quantitatively. The focus is on the physics and chemistry of the radiation effects and desorption processes produced on astrophysical surfaces by energetic ions and electrons, UV photons, and x-rays; and describing sputtering, desorption, radiolysis and photolysis of such surfaces.

Johnson and collaborators are striving to obtain a quantitative understanding of the radiation effects in relevant low temperature materials. The O_2 atmospheres on Ganymede and Europa, and the recently discovered O_2 atmosphere over Saturn's main rings, are produced by radiolysis and/or photolysis of ice. Radiolysis, photolysis and sputtering also produce the alkali atmosphere of Europa, the O_2 , SO_2 and CO_2 trapped in the ices on Europa and Ganymede, the CO_2 trapped in the ice at Callisto and, very likely, its CO_2 atmosphere, the O_3 -like feature seen on Dione, Rhea and Ganymede, and the peroxide present on many of the icy satellites. In addition, toroidal atmospheres have been seen in Saturn's magnetosphere (produced by sputtering of the ring materials), and at the orbit of Europa (produced by radiolysis on its surface). Stimulated desorption is also required to produce gas phase species in molecular clouds in the ISM and above the discs of YSOs. Recent emphasis has been on the dusty plasma disc at Saturn because of their participation with the Plasma Instrument on the Cassini Spacecraft.

Gravitationally bound clouds of neutral gas forming complete or partial tori are ubiquitous in the outer solar system and are associated with one or more satellites. These clouds are produced by the interaction of magnetospheric plasma with satellites and rings within giant planet magnetospheres. Burger, collaborating with Johnson, has adapted his model for Io's neutral clouds to the general study of neutral clouds, with emphasis on those formed at Europa and near Saturn's icy satellites and rings. At Europa, it was shown that the sodium cloud formed from material sputtered off Europa's surface exhibits significant morphological differences from the well observed cloud at Io. Due to the radial variations in density and temperature of the plasma in Jupiter's inner magnetosphere, sodium ejected into the trailing portion of Io's neutral cloud is preferentially ionized over sodium ejected into the leading portion, resulting in a cloud which extends

ahead of Io in its orbit. At Europa, the opposite is true: the leading portion of the cloud is preferentially ionized and a denser trailing cloud expanding radially outward from Jupiter is formed. Similar studies of the atomic and molecular oxygen and hydrogen clouds at Europa have been developed and the initial analysis of these simulations indicate that neutrals escaping from Europa form a longitudinally asymmetric torus exterior to Europa's orbit. This appears to be consistent with Galileo and Cassini spacecrafts observations of high energy ions and fast protons, respectively. Application of the neutral cloud model to Saturn's neutral system is dependent on upcoming observations of plasma in Saturn's magnetosphere by the Cassini Plasma Spectrometer (CAPS). These data will be used in conjunction with the numerical model to determine the distribution of neutral gas near Saturn's icy satellites.

Cassidy (graduate student) and Johnson wrote a Monte Carlo model of the interaction of planetary surfaces and energetic particles. The ejection of atoms and molecules from a surface due to a flux of ions, electrons or UV photons has been studied experimentally and computationally for a variety of target materials and radiation types. Applying this knowledge to airless bodies in the solar system is complicated by the fine-grained regoliths that cover them. The results obtained show that the ejected particle yield is little altered by change in regolith grain shape. Also, the distribution in angles at which the ejected particles leave the regolith is remarkably independent of grain shape and ejection process. The presence of a regolith has implications in modeling processes such as Jupiter's radiation belt and the supply of thin atmospheres on bodies throughout the solar system.

Michael and Johnson have been studying nitrogen escape and heating of the atmosphere of Titan. The flow of plasma onto the atmosphere of a planet or planetary satellite produces a series of energy transfer events that can lead to atmospheric loss, a process often called atmospheric sputtering. The incident plasma consists of deflected Saturn's magnetospheric atomic nitrogen ions and pick up molecular nitrogen ions of energies less than 1.25 keV. The energy distribution of the escaping atomic and molecular nitrogen had been studied and found that the majority of the particles escaped are of energies less than 2 eV. Though the distribution is dominated by low energy atoms and molecules a high energy tail was observed which is typical of atmospheric sputtering. Most of the sputtered particles are backward scattered or scattered to the trailing side of the satellite. The charge exchange of the incident atomic nitrogen ions were studied and found that these charge exchanged incident ions are also escaping to the trailing side. The escaping molecular nitrogen showed a peak at 1400 km above the surface of Titan near the exobase at 1500 km. The escaping atomic nitrogen showed a wider peak at 1350–1450 km. The total escape calculated was more than that estimated by corotating plasma or that of solar origin. The altitude distribution of the energy deposition by the deflected magnetospheric and the pick up ions is calculated and found that these ions deposit more energy close to the exobase where sputtering takes place. Solar photons travel deeper into the atmosphere and deposit energy at a lower altitude. Heating by the incident

plasma is found to increase the temperature of the exobase by about 8K. This work has been carried out in anticipation of new data from the Cassini spacecraft.

Smith and Johnson are completing three-dimensional computational modeling in conjunction with analysis of CAPS instrument data to study Saturn's magnetosphere. The goals are to determine if nitrogen is present and if so, its origins which could be from the moon Titan or other inner satellites of Saturn. The latter may be primordial nitrogen, likely as ammonia in ice or nitrogen ions that have been implanted in the surface and thus give more insight into surface compositions. Two potential Titan sources have been identified: energetic nitrogen ions formed near Titan and energized as they diffused inward, and neutrals in small perigee orbits that became ionized in the inner magnetosphere. These potential Titanogenic nitrogen sources are input into the 3-D computational model to generate the spatial distribution of the nitrogen neutrals and the production of nitrogen ions in Saturn's magnetosphere. The Cassini spacecraft will make many passes through this magnetosphere and these results will be used to help plan future instrument measurement sequences and to rapidly interpret new Cassini data, including the spatial distribution of other species that might be detected by the plasma instruments. The data analysis primarily utilizes results collected from the CAPS, as well as from the Cassini Ion Neutral Mass Spectrometer (INMS), which can detect ions as well as neutrals if the neutral densities are sufficiently large.

Skrutskie is conducting high-precision low-resolution ($R = 300$) $0.8\text{--}2.5\mu\text{m}$ 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. Skrutskie, in collaboration with Black, is conducting long-term observations of Titan in the same configuration to monitor tropospheric cloud formation and map surface composition.

Verbiscer demonstrated that the opposition surge of Enceladus is best described by a model which combines both moderate shadow-hiding and narrow coherent backscattering components. She has begun the analysis of the spectrophotometric properties of Saturn's small, coorbital satellites, Janus and Epimetheus, derived from HST WFPC2 images at broadband UVBRI wavelengths. While the albedo of both satellites increases at longer wavelengths, Epimetheus exhibits a strong wavelength-dependent opposition surge as its albedo increases dramatically at longer wavelengths near opposition, suggesting the presence of the coherent backscatter opposition effect. In collaboration with R. French (Wellesley) she is coordinating a world-wide campaign to observe the saturnian satellites at opposition in 2005 with HST and ground-based telescopes. The 2005 opposition of Saturn presents the extraordinary opportunity to observe its satellites as the Earth transits the disk of the Sun, an alignment which will not occur again until 2020.

3.10 Astronomical Surveys

Skrutskie is participating in developing data products and documentation for the 2MASS "Extended Mission" data re-

lease which will shortly deliver the full content of the 1.4 billion 2MASS source extractions, repeated calibration and Survey observations, and special deep observations of 600 square degrees covering the LMC/SMC and other regions of astrophysical interest.

4. EDUCATION AND PUBLIC OUTREACH

During the year there were about 3000 visitors to the McCormick and Fan Mountain Observatories as part of our continuing public outreach program.

Murphy and R. Bell (U.Va. Curry School of Education) were co-directors of a two-week professional development program for teachers in grades 4-9 from June 27 to July 9, 2004. During the workshop, the teachers learned astronomical concepts using hands-on, inquiry based activities, discussed the nature of science, and saw innovative techniques for using instructional technology to teach astronomy. Twenty-four teachers from across Virginia participated in the program funded by the State Council for Higher Education in Virginia through the No Child Left Behind Improving Teacher Quality program.

Using a Chandra X-ray Observatory Education and Public Outreach Grant, Sarazin and his research group helped to produce a planetarium show at the Science Museum of Virginia in Richmond. The "Black Holes" show ran from February 2004 to June 2004 with a total attendance of 11,895 people. The show, featured "Stella, a black hole of a certain age who used to be a Big Star! Her press agent Irving scrambles to help her combat the inaccurate portrayal of black holes in the news media." The Science Museum of Virginia will offer the script, images, and soundtrack available to other planetariums.

The children's Virginia Discovery Museum and the Leander McCormick Observatory jointly hosted a two-part exhibit on patterns and cycles in astronomy from January to May, 2004. The Discovery Museum hands-on exhibits covered concepts such as the day night cycle, seasons, phases of the moon, water cycle, and planetary orbits. The McCormick Observatory displays covered the life cycles of stars and the galactic fountain. The two part exhibit was funded with a *FUSE* Education and Public Outreach Supplemental grant to Murphy and O'Connell.

The Leander McCormick Observatory and Alden House, the former director's residence, were added to the Virginia Landmarks Register and their nomination to the National Register of Historic Places is pending.

Murphy, Rood, Tolbert and Patterson continue their efforts to establish a regional science education center around McCormick Observatory and Alden House. Architect D. Gilpin of Dalgliesh, Eichman, Gilpin, and Paxton has completed a preliminary site study of Alden House and McCormick Observatory in an effort to estimate the cost to renovate the buildings to host the science center.

5. MISCELLANY

Balbus spent a sabbatical year during academic 2003-04 in the Physics Department of the Ecole Normale Supérieure in Paris, France.

Chevalier served on the USRA Board of Trustees, the AAS Heineman Prize Committee (2003 Chair), and the U. S. National Committee for the IAU (elected Vice-Chair 2004). He was on the Scientific Organizing Committee for the meeting X-Ray and Radio Connections (Feb. 2004).

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

Majewski and Patterson continued to serve on the Science Team for the Space Interferometry Mission, and have worked in particular on the Astrometric Reference Grid in the past year. Majewski continues to serve on the NOAO User's Committee and is also serving on the Science Working Group for the Gemini Wide-Field Multiobject Spectrograph. Majewski and Skrutskie's work on exploring the Sagittarius dwarf spheroidal galaxy with the 2MASS database was recognized by a joint Commemorative Resolution of the Virginia General Assembly.

Murphy served as a reviewer for Cycle 5 education and public outreach proposals to the NASA Chandra X-ray Observatory.

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 that was scheduled for installation during Servicing Mission 4. Progress on the camera has been excellent, and it recently successfully completed thermal-vacuum testing at Goddard SFC. A feasibility study for a robot servicing mission to install WFC3 and COS in lieu of a Space Shuttle mission is presently under way.

Rood was a member of the Galactic Proposal Review Panel for Hubble Space Telescope Cycle 13. He served as UVa's member representative to AURA and was elected to AURA's Observatory Council.

Sarazin was the chair of the Astronomy and Space Physics Science Council of Universities for Space Research Association, a member of the Extragalactic Proposal Review Panel for Hubble Space Telescope Cycle 13 and the panel for the Westerbork Synthesis Radio Telescope, and a member of the scientific organizing committees for the Galaxies Viewed with Chandra meeting in Cambridge, MA, the Pan-Chromatic View of Clusters of Galaxies and the Large-Scale Structure meeting in Tonantzintla, Mexico, and the Cosmic Rays and Magnetic Fields in Large Scale Structure meeting in Busan, Korea,

Saslaw and P. Murdin (Cambridge, UK) have solved the archaeological puzzle of an ancient coin of Istrus, a Greek city on the western shore of the Black Sea. This coin shows two identical heads, inverted top to bottom with respect to each other. This appears to be a unique graphic image, which can be identified with the Sun-God Apollo. The coins are undated, but from their style were thought to have been minted between 450-300 BC. The authors interpret the inversion as symbolizing a major solar eclipse visible in the classical world mainly at Istrus in 434 BC.

Seidelmann continues as president of Celestial Mechanics Institute, the organization responsible for the scientific oversight of the "Celestial Mechanics and Dynamical Astronomy" journal. The 5th US Russian Space Surveillance Workshop was held in St Petersburg, Russia in September,

2003. Seidelmann lead the U. S. delegation and chaired the workshop again.

As chairman of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements, Seidelmann completed the triennial report of the working group and submitted it for publication in *Celestial Mechanics & Dynamical Astronomy*.

Verbiscer served on the HST Cycle 13 TAC Solar System Panel.

6. PRIZES AND AWARDS

Sivakoff was awarded an Achievement Reward for College Scientists Fellowship and a Virginia Space Grant Consortium Aerospace Graduate Research Fellowship.

Pakzad received a Sigma Xi Grant-in-Aid of Research to study the figure rotation in triaxial elliptical galaxies.

Crane was awarded a Dissertation Year Fellowship by the University of Virginia Graduate School of Arts and Sciences, and received a Shannon Award from the University of Virginia Z Society.

Frinchaboy was awarded an Aerospace Graduate Research Fellowship by the Virginia Space Grant Consortium, and was elected to the University of Virginia Raven Society.

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