**University of Washington**
**Astronomy Department**
*Seattle, Washington 98195-1580*

This report summarizes activities during the academic year 2002-2003. For more detail please see the Department's web site at www.astro.washington.edu.

## 1. STAFF AND STUDENTS

The teaching faculty of the Department were Professors S. Anderson, B. Balick, P. Boynton, D. Brownlee, P. Hodge, C. Hogan, C. Stubbs, W. Sullivan and P. Szkody; Associate Professors S. Hawley and T. Quinn; and Assistant Professor J. Dalcanton. Dalcanton was approved for Associate Professor, and Hawley and Quinn were approved for Full Professor, all starting in the 2003-4 academic year. Stubbs resigned his position at the end of the year to take a faculty position at Harvard.

J. Lutz and I. King are Research Professors. A. Larson and T. Smith are Lecturers. W. Baum, K. H. Böhm, E. Böhm-Vitense, T. Jacobsen and G. Wallerstein are faculty emeritus. Research Associates and postdocs are F. Governato, C. Rockosi, L. Homer, M. Kress, T. Murphy, N. Silvestri, and V. Woolf. Research and engineering staff include L. Carey, P. Doherty, J. Morgan, R. Owen, and C. Reschke. Twenty-two graduate students were in residence in 2002-3.

## 2. RESEARCH

### 2.1 Solar System and Astrobiology

D. Brownlee and Joswiak are working on laboratory analysis of interplanetary dust and developing techniques for cometary dust samples to be returned by the NASA Stardust mission. They have just installed a new Tecnai F20 transmission electron microscope in their laboratory. The microscope is optimized for fine scale compositional imaging and it will be used to investigate the nature of cometary and interstellar materials collected in the stratosphere and on the Stardust mission. A particular emphasis will be the relationship between organic and silicate phases.

Stardust will complete its main goal, sampling of comet Wild2, on January 2, 2004. The mission will return thousands of comet particles to Earth in 2006. A meeting of 65 scientists was held at Crystal Mountain Lodge (Mt Rainier) in August 10-15 to support this effort.

Brownlee, and paleontologist Peter Ward published a new book ''Life and Death of Planet Earth; How the New Science of Astrobiology Charts the Ultimate Fate of Our World.'' This work describes Earth's long term future including decline of CO2, loss of plants and animals, loss of oceans, the end of plate tectonics and, finally, the effects of the red giant sun.

T. Murphy and C. Stubbs, along with E. Adelberger in U.W. Physics, are pursuing a test of general relativity by means of characterizing the shape of the lunar orbit to millimeter precision using short laser pulses to the retroreflector arrays placed on the lunar surface by the Apollo astronauts. By initiating an LLR effort on the 3.5 meter Apache Point telescope, order-of-magnitude gains in statistical measurement error.

J. Armstrong, Quinn and Leovy analyzed a 1 Gyr orbital integration of the Martian orbit together with a seasonally resolved 1-D energy balance model to illuminate the gross characteristics of the long-term atmospheric pressure evolution. They analyzed the statistical variation of the Martian spin axis tilt and precession both prior to and subsequent to the formation of the Tharsis uplift, and explore the long term effects on the Martian climate. Contrary to expectations, the Marian atmospheric pressure is remarkably static over time, and decreases at both high and low obliquity.

L. Mayer (Zurich) and T. Quinn with J. Wadsley (McMaster)and J. Stadel (Victoria/Zurich) continue to investigate gravitational instabilities in protoplanetary disks as a way to form giant planets. They have performed several SPH simulations with p to a million particles and showed that overdensities and self-gravitating clumps that collapse into protoplanets can arise if the disk is cold enough. Protoplanets are followed for many orbital times and after a thousand years have masses and orbits strikingly similar to those of observed extrasolar planets.

S. Raymond and Quinn with J. Lunine (U. Arizona) are examining the process of volatile delivery to the forming terrestrial planets. They investigate volatile delivery as a function of Jupiter's mass, position and eccentricity, the position of the snow line, and the density (in solids) of the solar nebula using numerical simulations. In 42 simulations they have formed 43 planets between 0.8 and 1.5 AU, including 11 ''habitable'' planets between 0.9 and 1.1 AU that vary in mass between 0.23 and 3.85 Earth masses.

R. Barnes, and Quinn are examining the dynamics of the known extra-solar planetary systems. They determine regions of phase space which produce stable planetary configurations. They find that the resonant systems have very narrow zones of stability. Furthermore they find that the best fits to the coupled and resonant systems place them very close to unstable regions.

Barnes and Quinn, with D. Richardson (U. Maryland) and J. Lissaur (NASA Ames) are performing direct simulations with a self-gravitating planetesimal disk. Their technique will soon be extended to full disk simulations in order to understand the extent of radial mixing, and the interactions with the giant planets.

G. Lufkin, Quinn and F. Governato, with Wadsley and Stadel (Zurich) performed three-dimensional self-gravitating smoothed-particle hydrodynamics (SPH) simulations of an isothermal gaseous disc interacting with an embedded planet. They find four regions in parameter space: low-mass planets undergo Type I migration; higher-mass planets can form a gap; the gravitational instability mode of planet formation in marginally stable discs can be triggered by embedded planets; discs that are completely unstable can fragment to form

many planets. For the stable disc cases, our migration and accretion time-scales are shorter and scale differently than previously suggested.

### 2.2 Stars and Compact Objects

M.A. Agueros, in collaboration with D.J. Helfand and E.V. Gotthelf (both Columbia) reported on the first X-ray observations of the Galactic supernova remnant G16.7+0.1. Their XMM-Newton observations strongly detect the remnant's synchrotron core, and place constraints on remnant's distance, age and the central pulsar properties.

L. Homer and S.F. Anderson, in collaboration with a group led by W.H.G. Lewin, D. Pooley (MIT), and others reported on their expanded findings of sensitive Chandra X-ray observations of a number of globular clusters. A dozen clusters spanning a range of physical properties (central concentration, mass, etc.), provide the first conclusive observational evidence for a link between the number of close (X-ray) binaries in clusters and the expected rate of stellar encounters in the globular cluster cores.

Homer, in collaboration with C.G. Bassa (Utrecht), F. Verbunt (Utrecht), and M.H. van Kerkwijk (Toronto), also reported the optical identification for a binary millisecond radio pulsar in the globular cluster NGC 6752. Comparison of ESO and HST photometry with models shows that the optical light probably originates from a white dwarf companion to the pulsar.

Homer, Anderson, S. Wachter, and B. Margon (STScI) reported on their HST/STIS ultraviolet study of the ultrashort binary period (41 min), and remarkably low mass-function, X-ray pulsar 4U 1626-67. They find evidence for absorbing gas in C local to the system, and unusually strong O emission, thus providing independent support for the recent suggestion that the mass donor is the chemically fractionated core of either a C-O-Ne or O-Ne-Mg white dwarf. Moreover the velocity profiles of the UV emission lines are in all cases broad and/or flat-topped, or perhaps even double-peaked, and plausibly formed in (or in a corona just above) a Keplerian accretion disk.

Anderson, Hawley, N. Silvestri, and Szkody, in two collaborations led by H. C. Harris (USNO) and G. D. Schmidt (U. Az) reported further on white dwarfs found in the SDSS. Of special interest are the many white dwarfs with rare spectral types. These include blue DQ stars with atomic carbon, red DQ's with molecular C2 bands, and many unusual DZ white dwarfs. They also find 53 new magnetic white dwarfs with polar field strengths up to $>500$ MG, nearly doubling the number of known magnetics.

P. Szkody continued collaborations with E. M. Sion (Villanova), B. Gänsicke (Germany/UK) and S. Howell (PSI) on HST programs involving observations of white dwarfs in cataclysmic variables (CVs) to determine temperatures, rotation rates and compositions. Five papers were completed on the results for the coolest white dwarfs (EG Cnc and HV Vir), those in the shortest orbital period systems (LL And, EF Peg, VY Aqr, WX Cet), one in a hot old nova (DI Lac) and the only pulsating white dwarf in a CV (GW Lib). In several cases, two temperature models implying cool, slowly rotating white dwarfs combined with hotter, faster rotating zones were required to fit the data.

Szkody, Sion, K. Nishikida (SSL), J. Raymond (CfA), A. Seth and D.W. Hoard (UW), and K.S. Long (STScI) completed the analysis of Chandra data on U Gem, which showed that the X-ray emission arises from a range of temperatures in high density gas which is moving at low velocity. Further data on V426 Oph have been obtained and are being analyzed with L. Homer (UW).

Szkody, Hoard, Sion, Long, A. Linnell (UW) and M. Mouchet (France) analyzed FUSE data on a variety of magnetic and disk CVs (VV Pup, YY Dra, DW UMa, MV Lyr, LS PP. Szkody continued collaborations with E.M. Sion (Villanova), B. Gänsicke (Germany/UK), S. Howell (UC Riverside) and K.S. Long (STScI) on HST programs involving observations of white dwarfs in cataclysmic variables (CVs) to determine temperatures, rotation rates and compositions. Papers were completed on the results for AL Com 5.5 years past outburst, which showed that the UV flux decreased by a factor of 2 over 4 yrs while the distribution remained the same, implying the size of the emission region was changing, rather than the temperature. A study of the extreme outburst amplitude system WZ Sge following its prolonged outburst showed a cooling white dwarf that was veiled by curtain material. Results from a snapshot survey revealed several new systems with inverted C/N ratios, implying a different evolutionary path from most CVs.

Szkody, Homer, J. Raymond (CfA), and D.W. Hoard (IPAC) analyzed Chandra data on V426 Oph, which showed that the X-ray emission arises from a range of temperatures in high density gas which is consistent with a cooling flow after a shock. A spin period of 4.2 hrs was identified. Further work with C. W. Mauche (LLNL) and Long on Chandra data on U Gem after outburst showed a large change from the past quiescent data and large differences with the higher accretion rate system SS Cyg. Szkody, Homer, Schmidt and B. Chen (Spain) also obtained and analyzed XMM data on several of the new CVs identified in the SDSS. All sources showed large variations consistent with a magnetic nature.

Szkody, Hoard, Sion, Long, A. Linnell (UW), P. Godon (STScI) and M. Mouchet (France) continued analysis of FUSE data on a variety of magnetic and disk CVs (WZ Sge, YY Dra, DW UMa, MV Lyr, LS Peg, AE Aqr, VW Hyi, SS Aur and RU Peg). The data show a wide variety of spectra, including absorption lines from the hottest white dwarfs in CVs (MV Lyr, RU Peg), anomolous C and N lines in AE Aqr, time-resolved variation in the emission lines of YY Dra and DW UMa and large changes showing cooling of the white dwarf in the spectra of WZ Sge following its outburst.

Szkody, T. Harrison and J. Johnson (NMSU) completed the HST parallax measurements obtained over 3 years of the CVs WZ Sge, YZ Cnc and RU Peg. These results gave definitive distances for these systems, allowing their true luminosities to be determined. The results, combined with the past set of parallaxes allowed a refinement of the Warner relation between accretion rate and orbital period.

Szkody, together with S. Anderson, S. Hawley, N. Silvestri, A. Henden (USNO), UW grad students O. Fraser, K. Covey, J. Bochanski, L. Walkowicz and undergrad students

M. Wolfe, J. Frith, B. Lawton and E. Owens continued followup studies of CVs found in the SDSS using MRO photometry to obtain light curves and APO spectra for velocity curves. Over 100 CVs have been identified with followup observations on more than 25. With the help of polarimetry provided by G. Schmidt, 5 systems have been identified as magnetic CVs, with 2 having the lowest accretion rates and coolest white dwarfs yet known. Other SDSS collaborative work on single white dwarfs was accomplished with Schmidt on magnetic white dwarfs, J. Liebert (U of A) on peculiar C, O white dwarfs, S. Kleinman (APO) and H. Harris (USNO) on a white dwarf catalog and summary paper. This work has demonstrated the large range of white dwarfs found in SDSS and will greatly add to the total number of known white dwarfs by the end of the survey. e.g., WZ Sge). The data help pinpoint the white dwarf temperature, point out abundance anomalies in these systems compared to single white dwarfs and show interesting narrow component structures in the emission lines that are likely originating in the magnetic accretion streams and columns.

Szkody, Howell, E. Mason (ESO) and T. Harrison and J. Holtzman (NMSU) completed analysis of MMT data of the eclipsing dwarf nova OU Vir which show that the eclipse is that of a hot spot, not the white dwarf, and the hot spot is an optically thick region that does not produce strong emission lines.

Szkody, together with grad students S. Raymond, O. Fraser and undergrad students B. Lawton, J. Frith, M. Wolfe and S. Skinner continued followup studies of CVs found in the SDSS using MRO photometry to obtain light curves and APO spectra for velocity curves. Close to 100 CVs have been identified with follow up observations on more than 25. With the help of polarimetry provided by G. Schmidt (U Az), two of these have been identified as magnetic CVs with the lowest accretion rates and coolest white dwarfs yet known.

Raymond, Szkody, S. Hawley, S. Anderson, K. Covey and A. West have completed the analysis of 109 white dwarf-M dwarf pairs in SDSS, determining the white dwarf temperatures and the spectral types and chromospheric activity of the M dwarfs. A slightly higher fraction of early M stars are seen to be active compared to field dwarfs.

Hawley and K. Covey (UW graduate student) received a NASA ADP grant to investigate the luminosity function and mass function of low mass stars and brown dwarfs using photometric data from 2MASS and SDSS. Spectroscopic observations to assess contamination and bias in the photometric sample are ongoing at the ARC 3.5 m telescope at Apache Point Observatory.

Hawley, A. West, S. Raymond, L. Walkowicz and Covey continued their program to study the magnetic activity properties of the M and L dwarfs in SDSS.

Hawley, N. Silvestri and P. Szkody continued work on an NSF-funded project targeting red dwarf/white dwarf binary systems discovered with SDSS. The goal is to study the evolution of low mass stars in binary environments and the properties of pre-cataclysmic variables.

Hawley, J. Allred (UW graduate student), C. Johns-Krull (Rice University), W. Abbett (U.C. Berkeley) and G. Fisher (U.C. Berkeley) together with several other co-authors, published a major paper on the March 2000 flare campaign on AD Leo. Allred presented posters on this work at the Jan. 2003 (Seattle) AAS meeting and at IAU Symposium 219 (Australia).

Hawley, Johns-Krull, R. Osten (U. Colorado) and A. Brown (U. Colorado) continued work on the September 2001 flare observations on the M dwarf EV Lac. Osten gave a talk on these data at IAU Symposium 219.

Hawley and Johns-Krull published the results of their successful HST Cycle 10 program to detect persistent transition region emission in very low mass stars. Hawley gave an invited talk on this work at IAU Symposium 219.

Hawley, Reid, K. Cruz (U. Penn), Covey and O. Fraser (UW graduate student) continued their program on the ARC 3.5 m telescope to obtain spectroscopic observations of candidate nearby stars. This work forms part of Cruz's PhD thesis.

Hawley, Walkowicz and Reid completed a project to determine the conversion of the H alpha emission line equivalent width to a luminosity ratio that serves as an indicator of magnetic activity.

Hawley, J. Bochanski (UW graduate student), Covey and several co-authors continued their investigation of the 100-parsec M dwarf sample, including activity properties and kinematics.

Hawley, Bochanski, Walkowicz, West and J. Munn (USNO) began a project using SDSS observations of M dwarfs out to 2 kpc to investigate the thin and thick disk components of the Galaxy.

B. Balick and A. Frank (U. Rochester) published a large review article for *Annual Reviews of Astronomy & Astrophysics* that describes the scientific results extracted from studies of the morphologies and kinematics of planetary nebulae.

Balick, Corradi, and Frank are analyzing HST WFPC2 and STIS observations of regions in the immediate vicinity of the central stars in highly bipolar nebulae. Their goal is to determine how the outflowing gas is so symmetrically and highly collimated. The images from WFPC2 were compared with those of the same objects from the HST Archive. Structure changes in M2–9 are lateral, as had been found earlier.

Balick, with R. Henry (Oklahoma) and K. Kwitter (Williams College) completed work on the measurement of chemical abundances in Type-I Planetary Nebulae. Their work was combined with similar studies of H II regions in the Milky Way and elsewhere. The goal was to see whether the stellar production of nuclei has evolved linearly, with each heavy element tracking the production of oxygen. Ne Ar, and Cl track well; however S does not. The authors reached the conclusion that the reason for the S anomalies is likely to be some sort of a problem in the analysis of S/O data.

Balick and A. Hajian (USNO) analyzed WFPC2 images of the planetary nebula NGC 6543 spanning six years. They found that the growth NGC 6543 deviates strongly from uniform expansion. Some parts of the nebula expand as expected from the theory of wind-heated bubbles, whereas the

expansion of other parts of the nebula is difficult to understand within any extant physical context.

E. Böhm-Vitense, K.G. Carpenter (GSFC) and R.D. Robinson (Catholic University) continued their studies of the outer atmospheric layers of Hyades F stars. A comparison of CIV(1548 Å) and OVI(1032 Å) surface line fluxes with x-ray surface fluxes (data from Stern *et al*. 1995) shows very different B-V and v sini dependences for the transition layer lines and x-ray surface fluxes of single stars. A paper showing their results has been submitted to the ApJ.

As part of a large consortium spectra of the globular cluster, M22 were obtained in cooperation with I. Ivans (Caltech) and five others to test the reported metallicity spread. A total of twenty-six stars were observed. During the past year postdoc Woolf and G. Wallerstein have been obtaining high resolution echelle spectra of dm, sdm and sdk stars for abundance analysis. The analysis of Kapteyn's star has shown that its metallicity is given by [Fe/H = −1.0 about half-way between the range of −0.5 to −1.5 by prior investigators using a variety of methods.

Wallerstein has been obtaining spectra of type II cepheids and RR Lyrae stars of periods greater than 0.8 days for abundance analysis. Such long period RR Lyrae stars are very rare but are found in substantial numbers in the unusual globular clusters NGC 6388 and NGC 6441. The spectra will be analysed by S. Andriesky and colleagues of the University of Odessa, Ukraine (not Texas).

Julie Lutz has been doing studies of emission line variability in yellow symbiotic stars and planetary nebula central stars with the echelle spectrograph on the Apache Point telescope. She presentented the results of a MACHO galactic center database study looking for photometric variability in the central stars of planetary nebulae at the Asymmetric Planetary Nebulae conference at Mount Ranier.

K.-H. Böhm participated in an attempt to explain the somewhat enigmatic position-velocity diagrams of the well-known Herbig-Haro object HH 32. This study was initiated by A. Raga (UNAM) and his collaorators (A. Riera, Masciadri, S. Beck and L. Binette). It is concluded (from a 3D-hydrodynamic simulation) that a variable velocity, precessing jet can best explain the observed spatial distribution, the kinematical properties, and the excitation of emission from HH 32.

S. Matt (McMaster Univ., formerly UW), R. Winglee (Earth & Space Sci.) and Böhm studied the ''additional'' collimation of the outflow from a YSO by a ''disk associated magnetic field''. Their numerical simulation is based on the original generation of the outflow by the coupling of the stellar magnetosphere and the inner edge of the disk. These authors now show, that the very weak disk-associated magnetic field ($\ll$ 0.1 G) leads to signficant collimation.

### 2.3 The Galaxy and the Local Group

Stubbs, G. Miknaitis, R. Covarrubias and A. Rest are working with a consortium to continue their next generation microlensing survey of the LMC, using the MOSAIC imager on the 4 m telescope at CTIO. This project, with Stubbs as PI, has been awarded 30 half-nights per year as an NOAO long term survey.

I. King and J. Anderson (Rice U.) continued their study of high-precision proper motions with HST. They published a greatly improved distortion correction for WFPC2, and are completing the task of deriving distortion corrections for the Wide Field Camera and High Resolution Camera of ACS. They have in press a paper showing the plane-of-the-sky rotation of 47 Tucanae, and in collaboration with L. Bedin and G. Piotto (Padua), a paper that uses Galactic bulge stars behind M4, along with a QSO in the background, to measure the absolute proper motion of the cluster and a value for the Oort $A-B$.

### 2.4 Galaxies and QSOs

S. Anderson, Agueros, Homer, and G. Stinson, in collaboration with Margon, W. Voges (MPE), and others presented an initial catalog of more than 1200 quasar/AGN identifications for X-ray sources in the ROSAT All-Sky Survey (RASS). Optical objects from the SDSS imaging catalogs are automatically cross-correlated with RASS X-ray source positions; then priorities for follow-on SDSS optical spectra of candidate counterparts are automatically assigned using an algorithm based on the known fx/fopt ratios for various classes of X-ray emitters. The already very large sample size yields substantial numbers among various rather rare AGN subclasses, e.g., with more than 130 narrow-line Seyfert 1s and 45 BL Lac candidates.

Anderson, in a collaboration led by C. Vignali, W.N. Brandt, and D.P. Schneider (Penn State) reported on their Chandra and XMM-Newton observations of a sample of 13 quasars at $z>4.8$ (most from SDSS). Only 2 of the are not detected in X-rays, doubling the number of X-ray detected quasars at such high redshift. They find X-ray to optical luminosity ratios and composite X-ray spectra consistent with lower redshift quasars, suggesting that the central engines in the high-redshift quasars are quite similar to those in much more recent/nearby quasars.

Anderson, collaborating with a large SDSS group led by D.P. Schneider (Penn State) presented the 2nd edition of the SDSS Quasar Catalog, which includes more than 16,000 spectroscopically confirmed quasars from the SDSS First Data Release (DR1). The catalog includes accurate astrometry, optical photometry, optical spectra, as well as radio, near-IR, and X-ray data from other surveys where available. About 94% of the quasars were first identified by SDSS, e.g., including 5 previously uncataloged quasars brighter than $i<16$, and 17 previously uncataloged quasars with $z>4.5$.

Anderson, in collaboration with P.B. Hall (Princeton), D. Hutsemekers (Liege) and others continued work on the extreme sub-classes of broad absorption line (BAL) QSOs now being found routinely in SDSS. They reported on their ESO VLT high-resolution spectra of the extreme CaII overlapping-trough low-ionization BAL, SDSS J030000.56 +004828.0. Their observations constrain the CaII BAL region to be extremely cool versus that inferred for many BAL flows: $T<1000$ K, and perhaps even $T<550$ K.

J. Dalcanton and B. Willman (UW graduate student) continued their survey for new companions to the Milky Way, using the latest SDSS data release. The survey searches for spatial overdensities of resolved stars, and can find galaxies

with surface brightnesses over a factor of 10 times lower than any known galaxy. They have used this technique to place limits on the stars associated with compact high velocity clouds.

V. Desai (UW graduate student), Dalcanton, Quinn, Governato, D. Reed, and L. Mayer used the SDSS to study the velocity function of galaxies in clusters. They find substantial disagreement with numerical simulations, in that the mass function is not a self-similar function of cluster mass, in contrast to claims in the literature. However, no low mass discrepancy is found, unlike similar data in the Local Group.

V. Desai and Dalcanton, as part of the EDisCS collaboration, are reducing and analyzing 80 orbits of HST-ACS imaging data on 10 high redshift clusters. This data is being used to constrain galaxy evolution in cluster environments out to a redshift of $z \sim 0.8$.

Dalcanton and P. Yoachim (UW graduate student) are continuing the study of thick disks. Yoachim has developed 2-dimensional fitting algorithms to measure the structural parameters of the thick and thin disks. They find that in spite of its low surface brightness, the thick disk is the dominant component in terms of stellar mass and luminosity. The ratio of thick disk to thin disk luminosity increases for lower mass galaxies. They have built a large 5″ slit for use with the APO 3.5 m Double-Imaging Spectrograph to measure Lick indices for nearby thick disks.

A. West and Dalcanton are continuing their collaboration with Mike Disney (Cardiff) and the HIPASS collaboration to use SDSS to explore the optical properties of gas rich galaxies. West has carried out long-slit spectroscopy of many of these systems in order to constrain their dynamics, and thus the density profiles of dark matter halos. He is also using the SDSS database to explore the metallicity and star formation history of the HIPASS equatorial sample of galaxies. He and his HIPASS collaborators have also engaged in a large program of HI follow-up observations with the VLA, Parkes, and Arecibo radio telescopes.

Dalcanton and A. Seth (UW graduate student) have begun analysis of an HST-ACS snapshot program to observe nearby edge-on disk galaxies, in collaboration with R. de Jong (STScI), E. Bell (MPA-Heidelberg), and S. Bianchi (Atreci). These data will be used to characterize the distribution of dust within, the distance to, and the thick disk stellar populations of the galaxies.

Dalcanton and E. Rosolowski (UC Berkeley graduate student) are continuing their collaboration to study the correlations between dust lane morphology and molecular gas content. They have completed a BIMA survey of a large sample of galaxies, and are now pursuing VLA synthesis imaging of the sample, in collaboration with J. Hibbard (NRAO) and M. Tavarez (U. Mich).

Dalcanton has continued her work on the theory of dust lane formation in galaxies. This work has implications for the generation of interstellar turbulence and star formation.

Dalcanton has continued to collaborate with M. Tavarez and M. Mateo (U. Mich) on Tavarez's project to constrain the mass density profiles of dark matter halos using an optimal sample of nearby dwarf galaxies. This has led to an interesting follow-up project on the possibility of detecting baryon-free dark matter halos.

C. Rockosi in collaboration with Dalcanton has undertaken a systematic analysis of Galactic structure using stellar color-magnitude diagrams generated from SDSS data. The analysis is being used to place new constraints on the structure of the Milky Way's thick disk and stellar halo.

Baum gave an invited review of ''Spectral Energy Distributions and Diversity Among Galaxies'' at an August 23rd symposium in Madison Wisconsin honoring the career of Professor Arthur D. Code.

Hodge, working with graduate student Anil Seth and colleague Karl Krienke of Seattle Pacific University, carried out two surveys of the star cluster population of NGC 6822 using HST images. One was an automated search for young clusters based on overdensities of resolved blue stars, yielding 50 new young open cluster candidates. The other was a photometric study of clusters of all ages to determine the cluster age distribution. Working with B. Williams of Harvard-Smithsonian, they continued a similar study of the star clusters of M31.

Hodge continued his study of Local Group dwarf galaxies using HST data and multicolor images of the NOAO Local Group Wide Field Survey. He made a comparison of the star formation histories of these galaxies with their cluster formation history, which is in some cases markedly different.

Hodge continued participation in the work of a group that is publishing results of an HST survey of dwarf galaxies near the Local Group and in nearby groups. Together with former students B. Skelton and J. Ashizawa, he published an ATLAS OF LOCAL GROUP GALAXIES (Kluwer Academic Publishers).

Seth completed an alaysis of the globular clusters of a sample of spiral galaxies, based on data obtained by K. Olsen (CTIO) and B. Miller (Gemini Telescope) and by him at the Apache Point Observatory. They submitted a paper on the results.

### 2.5 Particle Astrophysics and Cosmology

Quinn with Wadsley and Stadel continued to develop the Gasoline code for parallel hydrodynamics with self-gravity. Gasoline is an extension of the efficient Pkdgrav parallel *N*-body code using smoothed particle hydrodynamics. Recent successful Gasoline applications cover a diverse set of areas in astrophysics including galaxy clusters, galaxy formation and gas-giant planets.

Quinn with N. Katz (U. Mass) and M. Weinberg (U. Mass) continue to look into the detailed dynamics of galactic bar-core interactions. In particular, they are determining the relative importance of the resonances seen in analytic theory and idealized simulations for the evolution of more realistic galaxy models.

Reed, Quinn, and Governato, with Gardner (U. Pittsburgh), Fardel (U. Victoria) and G. Lake (WSU) used a high resolution $\Lambda$CDM numerical simulation to calculate the mass function of dark matter halos down to the scale of dwarf galaxies, back to a redshift of fifteen, in a 50 $h^{-1}$Mpc volume containing 80 million particles. The low redshift results allowed them to probe low $\sigma$ density fluctuations signifi-

cantly beyond the range of previous cosmological simulations. They provide an empirical fit to their data that corrects for the overprediction of extremely rare objects by the Sheth and Tormen mass function.

Reed, Quinn and Governato used cosmological numerical simulations to model density profiles in a set of sixteen dark matter halos with resolutions of up to seven million particles. The cosmological scatter of the central slope parameter in the full set of halos is as large as any trends with power spectral index, $n$, or $M/M_*$ for our halos. None of our simulated halos have inner slopes flatter than the NFW central slope of $r^{-1}$ down to our minimum resolved radii of 0.5% to 2%.

Quinn with E. Hayashi (U. Victoria), J. Navarro (U. Victoria) A. Jenkins (Durham), C. Frenk (Durham), S. White (Max-Plank), V. Springel (Max-Plank) and J. Stadel (U. Zurich) have used a set of high resolution cosmological N-body simulations to investigate the inner mass profile of galaxy-sized cold dark matter (CDM) halos. They performed a direct comparison of the spherically-averaged dark matter circular velocity ($V_c$) profiles with rotation curves of low surface brightness (LSB) galaxies from the samples of de Blok *et al.* (2001), de Blok and Bosma (2002), and Swaters *et al.* (2003). Most (about two-thirds) LSB galaxies in this dataset are roughly consistent with CDM halo $V_c$ profiles. However, about one third of LSBs in these samples feature a sharp transition between the rising and flat part of the rotation curve that is not seen in the $V_c$ profiles of CDM halos.

C. Stubbs, R. Covarrubias, A. Rest and G. Miknaitis and A. Miceli are members of the ESSENCE team, using the CTIO 4 m telescope to detect and monitor hundreds of supernovae to determine the equation of state parameter of the Dark energy. G. Miknaitis has led a companion effort that has successfully extracted supernovae from the SDSS Southern Survey data.

Hogan continued his work on the effect of holographic entropy bounds on inflationary perturbations. The likely effect of quantizing gravity is to introduce a discrete spectrum to cosmic perturbations, an effect not apparent in the standard field theory treatments of inflation. This might explain the anomalies in the low order CMB multipoles seen in the WMAP data.

B. Williams, Hogan, Stubbs and other members of the High-z Supernova Search Team completed their study of the host galaxies of high-redshift supernovae, using deep HST images from the archive. A demographic analysis showed no evidence that high redshift supernovae are biased indicators of distance, confirming the ''Dark Energy'' interpretation of the data.

## 3. RESEARCH TOOLS

Stubbs ended his term as Telescope Scientist for the 3.5 m telescope project. Rockosi, Dalcanton and Hawley are developing plans to utilize the SDSS 2.5-m telescope for studies of galactic structure after the sky survey is completed. Internal planning began for participation in a large telescope for a deep sky survey and monitoring to continue where the SDSS project leaves off.

## 4. SERVICE AND OTHER ACTIVITIES

Hodge continued as the Editor, and Lutz and T. Smith are the Associate Editor and Assistant Editor for Electronic Publishing, respectively, of the *Astronomical Journal*. Szkody continued her 3 yr term as one of the Scientific Editors of the Astrophysical Journal.

George Wallerstein presented the Henry Norris Russel Lecture at the January 2003 meeting of the *American Astronomical Society* for 2002. Dalcanton continues as a Sloan Fellow. Böhm-Vitense was awarded the Karl-Schwarzschild Medal by the Astronomische Gesellschaft of Germany.

Brownlee, Quinn, and Sullivan are co-investigators in the UW Center for Astrobiology and Early Evolution, ''Habitable Planets and the Evolution of Biological Complexity'' for which five-year funding was obtained from NASA. These funds and others are supporting the UW's Center for Astrobiology and Early Evolution which was housed in the Department. Balick organized the third scientific meeting on asymmetrical planetary nebulae in July.

Hogan finished his service with NASA's Office of Space Science Roadmap team, and started as a member of their Structure and Evolution of the Universe Subcommittee. He continued as a member of the LISA International Science Team. Hogan continues to serve as the University's Vice Provost for Research.

Szkody serves on the Publication Board of the PASP. She completed her last year as President of IAU Commission 42 (Close Binaries) and is the UW representative to AURA and also serves on the Solar Obervatory Council. She also serves on the MAST Users Committee. She was an invited speaker at Conferences in South Africa (Magnetic Cataclysmic Variables), Australia (IAU) and the AAS (Seattle).

Hawley ended her term on the STScI User's Committee. Balick served on the Scientific Overview Committee for the replacement camera of the Hubble Space Telescope known as Wide Field Camera 3, scheduled for launch in 2004. Anderson continued to serve as chair of the SDSS Serendipity Working Group. Anderson, Balick, Dalcanton and Hawley serve on various management committees for ARC telescopes. Lutz served as Director of Manastash Ridge Observatory.

Sullivan continued as Director of Project AstroBio, a K-12 outreach activity funded by NASA and a private donor. About 60 teacher/scientist partnerships are now trained and supported throughout the Puget Sound region.

Sullivan continued as Chair of the Steering Group for the Center for Astrobiology and Early Evolution, the entity that tries to make a coherent whole out of the UW Astrobiology Program, which, now starting its fifth year, includes 22 faculty in 9 departments and 21 graduate students.

The open houses held at the UW Campus Observatory for public viewing under Larson's supervision. 4000 people visited this past year, hearing short talks on astronomical topics (given by undergraduate astronomy majors) as well as viewing the night sky through the 110-year-old telescope. An open house for the general public was held in May 2003.

The Undergraduate Astronomy Institute continues its work to complete a student radio telescope under C. Rockosi. The UAI continues as a monitoring facility for regional fire-

balls, with undergrads operating an all-sky camera and recording system. Undergraduates led by Larson have restored the old campus observatory where they hold public open houses twice per month. Almost 1000 people visited the campus observatory during the academic year. UAI volunteers also ran planetarium shows for K-12 classes on Friday afternoons to 3500 visiting K-12 students and their teachers. The Department held a public open house in April which was attended by over 500 people.

Julie Lutz is a NASA Office of Space Science (OSS) Education Broker/Facilitator. She directs Space Science Network Northwest which serves as a matchmaker for space scientists and OSS missions and regional schools, community groups, museums, science centers and others. Highlights of the year that involved activities at the University of Washington in Seattle included a 40 hour workshop on astronomy for middle and high school teachers from Washington and Oregon, several half-day educator workshops on astronomical topics (Structure and Evolution of the Universe, Simply Stars, Mars Madness), a special exhibit at the AAS meeting (African American Space Scientists) and working with several programs that encourage students from underrepresented groups to major in science, mathematics and engineering.

Bruce Balick, Chair