University of Washington
Astronomy Department

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This report summarizes research activities during the academic year 1998-1999. For more detail please see the Department's web site at http://www.astro.washington.edu.

1. STAFF AND STUDENTS

During the Academic Year 1998-1999, the teaching faculty of the Department included Professors Bruce Balick, Paul Boynton, Donald Brownlee, Julianne Dalcanton, Paul Hodge, Craig Hogan, George Lake, Bruce Margon, Christopher Stubbs, Woodruff Sullivan, and Paula Szkody. Theodor Jacobsen, Karl-Heinz Böhm, Erika Böhm-Vitense, William Baum, and George Wallerstein were faculty emeritus. Spring quarter marked the last quarter of teaching by Prof. Böhm, capping the end of an illustrious teaching career spanning more than three decades in the department. The research faculty included Scott Anderson, Eugene Magnier, and Thomas Quinn; Prof. Magnier departed to take up an appointment at CFHT. In addition, Suzanne Hawley (Michigan State) was newly appointed Research Associate Professor, and Guillermo Gonzalez (UW) and Derek Richardson (Cambridge) were appointed Research Assistant Professors. Eric Deutsch (UW), Austin Tomaney (Columbia), Vikram Dwarkadas (U. Virginia), Frank van den Bosch (Leiden), Geraint Lewis (Cambridge), James Wadsley (U. of Toronto), and Noella D'Cruz (U. of Virginia) were Research Associates. Eva Grebel (Lick Obs.), a new Hubble Fellow, was appointed Research Associate. Stacy Palen was appointed as a Research Associate and Acting Instructor. Ana Larson was Acting Instructor, and Julie Lutz (WSU) was Visiting Professor. Twenty-three graduate students were registered as members of the Department. Ph.D. degrees were awarded to Bernhard Beck-Winchatz, Brooke Skelton, Mark Hammergren, Andrew Dolphin, Stephanie Wachter and Eric Deutsch.

There were 20 classified and professional staff, including office staff, publication staff for the *Astronomical Journal*, outreach staff for Project ASTRO, and a technical engineering group providing support for the Manastash Ridge Observatory, the Apache Point 3.5m telescope, astronomical instrumentation design and construction, and the construction, commissioning and operation of the Sloan Digital Sky Survey (SDSS).

2. RESEARCH

2.1 Solar System

Brownlee and D. Joswiak are involved in a variety of laboratory investigations of interplanetary dust particles (IDPs). In collaboration with J. Bradley (MVA Inc. and Georgia Tech.) and many others, they have continued detailed work on a component of these particles called GEMS (glass with embedded metal and sulfides). Many lines of evidence suggest that GEMS are preserved interstellar silicate grains. Recent IR spectroscopy of GEMS with the Brookhaven synchrotron has shown that the shape of the 10 micron silicate feature of GEMS is an excellent nearly unique match with the ISM ''astronomical silicate.'' Mixtures of GEMS and crystalline silicates also provide an excellent spectral match with fine structure (11.2 micron bump) observed in Hale Bopp, β Pic, and certain circumstellar regions. In continuing efforts to study the small structure of GEMS Joswiak developed techniques for preparing slices of IDPs that are as thin as 10 nm.

Brownlee leads STARDUST, a NASA Discovery mission built as a partnership between JPL, Lockheed Martin and the UW. The mission (http://stardust.jpl.nasa.gov) was spectacularly launched from Cape Canaveral on February 7, 1999 and is now on a complex trajectory that involves three loops around the Sun, a comet flyby and return to Earth. On the outbound leg of the first orbital loop, the German mass spectrometer CIDA has collected mass spectra of what are believed to be interstellar dust grains. The primary mission goal is to collect dust particles from comet Wild 2 during a close 6 km/s flyby in 2004. Thousands of particles will be captured by impact into low density silica aerogel. The spacecraft will also take high resolution nucleus images and mass spectrometer data during the encounter. The collected samples will return to Earth in January 2006 inside a small atmospheric entry capsule that will land at the Utah Test and Training Range near Salt Lake City.

Brownlee and paleontologist P. Ward (Zoology) have written a new popular book, *Rare Earth: Why Complex Life is Uncommon in the Universe*. This popular astrobiology book explores the hypothesis that while microbial life may be relatively common in extra-solar planetary systems the advance to animal life and long term survival is rare. Many factors such as the Moon, a large Jupiter, a molten/solid core and plate tectonics play major roles in providing Earth with its highly unusual Garden of Eden environment.

Z. Leinhardt, Richardson, and Quinn performed direct numerical simulations of low-speed collisions between rubble piles to study the collisional evolution of km-sized planetesimals in the early Solar System. Various values of impact speed, impact angle, rotation, mass, and restitution coefficient were tested. They found that the dependence on impact angle (often neglected in simple prescriptions) is as important as the dependence on impact speed. They also found that rubble piles are relatively easy to disperse, even at low impact speed, which could strongly hamper planetesimal growth in the early Solar System.

Richardson, C. Porco (LPL), and Quinn are performing high-resolution direct numerical simulations of the dynamics of Saturn's bright A and B rings, where the surface density is high enough for the collective gravity of the ring particles to form transient features such as wakes and aggregates. The output from the simulations will be used as input for a sophisticated light-scattering code that can determine the optical effects of the transient density structures under solar illumination. These simulations represent more than an order of magnitude jump in resolution over previous studies, yielding a realistic particle size range in a patch large enough to adequately sample the fundamental instability modes.

Richardson, Quinn, Stadel, and Lake conducted numerical experiments to test the feasibility of direct (not statistical) simulation of a self-gravitating planetesimal disk. The largest simulation evolved 1 million planetesimals for 1,000 years, several orders of magnitude more particles than any previous direct method could handle. The giant planets were added as a perturbing force to study the development of resonance zones in the asteroid belt region. The strongest mean-motion resonances gave rise to large density peaks and troughs at the appropriate orbital distances. Meanwhile, planet formation proceeded unimpeded in the inner regions. Their goal is to extend these simulations at least 1,000-fold in timescale, well past the runaway growth stage and into the late giant-impacts stage of planet formation.

Quinn is integrating the orbits of the planets over the lifetime of the Solar System, 1000 times longer than any previous accurate integration including general relativity. As well as answering once and for all the question of the stability of the planetary orbits, these integrations will illuminate fundamental questions of non-linear dynamics. In particular, the Solar System displays a small instability with a time-scale of 5 Myr whose effects over 5 Byr will be classified with this integration. Additional products of this research will include a time history of the Earth's orbital elements to be used in investigation of Milankovitch climate cycles and a first look at the generic stability of other planetary systems with an eye toward the relationship of the formation and stability of the Earth with the massive planets that can be detected in other planetary systems. At this time, the integration has completed 900 million years backward in time, and 40 million years forward. This is 100 times longer than previous accurate integrations of the planets.

With R. Barnes, Quinn is also looking at the stability of extra-solar planetary systems. The only known system for which this is an issue is the recently discovered three planet system around Upsilon Andromedae. Barnes has developed a program that explores the parameter space of planetary orbits consistent with the observations and determines their stability over million year time periods.

Quinn continues to lead the working group for Solar System science within the SDSS. With J. Armstrong and R. Lupton (Princeton) he is investigating techniques for detecting Solar System objects in the survey. It is expected that the survey will discover thousands of small bodies including Kuiper belt objects, Centaur asteroids, main belt asteroids, near-earth objects and long period comets. The large sky coverage and five color photometry of the SDSS will bring new light to the orbital dynamics, taxonomy, and origins of these objects. Already a large number of main belt asteroids have been observed as well as a new comet: 1999 Dalcanton.

2.2 Stars and Compact Objects

J. Bardeen (UW Physics) and L. Buchman, in collaboration with D. Bale and R. LeVeque (UW Applied Math), are developing hyperbolic formalisms for the Einstein equations and numerically testing them in one- and two-dimensional cases. Their aim is to contribute toward the Grand Challenge goal of stably evolving colliding black holes.

Utilizing HST and VLA observations, Deutsch, Margon, and Anderson, in collaboration with S. Wachter (CTIO) and W. M. Goss (NRAO), suggested a new candidate infrared counterpart for the intense galactic X-ray source GX17+2 (X1813-14), one of the brightest unidentified X-ray sources on the celestial sphere. The H=20 object is located only 1 arcsec from the far brighter star NP Ser, which was thought for years to be the counterpart. Later observations of dramatic variability confirm the identification of the new candidate. At least in the faint state, the object is far less luminous than would have been predicted, given the observed X-ray properties.

Deutsch, Margon, and Anderson completed their study of the ultraviolet and optical spectral energy distributions of five counterparts of luminous X-ray sources in the cores of globular clusters. Simple accretion disk models with X-ray reprocessing components fit most of the data remarkably well, and allow interesting inferences on the geometry and properties of the disks. The models lead to the prediction that the as yet unknown orbital period of the source in NGC 1851 will be less than one hour, i.e., another member of the recently identified ultrashort period, double-degenerate systems.

Böhm-Vitense, K. Carpenter(GSFC) and R. Robinson (Catholic U.) continued their studies of HST/GHRS Ba II star spectra. In comparison with non-peculiar giants they found excess continuum flux in the ultraviolet for most of them, indicating a contribution from the white dwarf companion. For the two remaining peculiar stars the white dwarfs appear to be too cool to be observable. The chromospheric and transition layer emission of the target Ba stars is lower than for non-peculiar giants, consistent with the assertion that they are older than the normal giants because they lived on the main sequence as lower mass stars with longer lifetimes before collecting additional mass from the (now white dwarf) companions.

Böhm-Vitense, Carpenter and Robinson also studied Hyades main sequence F stars by means of HST/STIS spectra. They found a very steep decrease of the transition layer emission line fluxes for spectral types F5, parallel with the very steep decrease of the rotational velocities, and at the same B-V value at which the Li abundance dip and the CaII emission dips occur.

P. Szkody continued collaborations with E. M. Sion and F.H. Cheng (Villanova) amd B. Gansicke (Germany) to understand the heating of accreting white dwarfs in cataclysmic variables. Hubble Space Telescope GHRS observations of the dwarf nova RX And during 3 different parts of its outburst cycle (near the end of an unusually long quiescence, during the rise to outburst and during the decline from outburst) reveal a slowly rotating (150 km/s) white dwarf with a temperature of 35,000K and subsolar C,Si abundances. Inverse P Cyg profiles during the decline from outburst indicate gas infall onto the white dwarf. These results follow in the trend of slower white dwarf rotation with increasing orbital period.

Continued collaboration between Szkody, G. Schmidt (U of A) and D.W. Hoard (CTIO) on AR UMa (the cataclysmic variable with the highest magnetic field) involved the first STIS observations throughout the orbit during a low state (which clearly show Zeeman effects which will lead to an improved field strength) and ground-based spectroscopy and polarimetry at both high and low states. This led to a model of twin funnels perpendicular to the line of centers and a ballistic gas stream 30-50% of the distance between the stars, as well as an additional high velocity stream.

Szkody obtained HST STIS observations of the usually bright novalike DW UMa in a collaboration with C. Knigge (Columbia), Hoard and K. Long (STScI). Unfortunately, the system entered an unusual low state of mass transfer just at the time of observation, preventing the analysis of expected wind features. However, the observations will lead to a determination of the white dwarf characteristics. Contemporaneous ground based optical spectra and IR photometry obtained at APO will provide values of the accretion rate and distance.

Szkody analyzed HST astrometric parallaxes with T. Harrison (New Mexico State) to provide improved distances for SS Cyg (166 pc), U Gem (96 pc) and SS Aur (200 pc).

Analysis of a coordinated EUVE and ground-based campaign of the magnetic cataclysmic variables V405 Aur and RXJ101.5+0904 by Szkody, J. Armstrong and R. Fried (Braeside Obs) showed that heating operates efficiently even at low accretion rates onto cool white dwarfs and that the location of the emitting zone can change on yearly timescales. Optical photometry, spectroscopy and spectropolarimetry of the optical counterpart of the ROSAT discovered AM Her systemRXJ2157.3+0855 by Szkody, G. Tovmassian (Mexico), Schmidt, J. Greiner and A. Schwope (Germany) revealed a 3.38 hr period system that is very similar to AM Her in overall properties.

Optical photometry and spectroscopy of the M33 star B416 by Szkody, O. Shemmer and E. Leibowitz (Wise Obs) revealed that this object is a LBV, the fifth to be identified in that galaxy. It is also the first LBV to show microvariations that are periodic and coherent over at least 10 yrs.

Szkody, Leibowitz, Hoard, L. Formiggini (Wise Obs), A. Retter (Keele Univ) and T. Burdullis (U of New Mex) analyzed 42 nights of CCD photometry and 2 nights of spectroscopy of the classical nova V705 Cas to prove that the binary period is 5.5 hrs and there are bright spots that are fading with time since outburst.

Using APO and MDM spectra, Szkody, Hoard, and J. Thorstensen (Dartmouth) were able to break the 1-day alias problem on V442 Oph and determine its period to be 0.1243d. Doppler tomograms show a high velocity component and other features identifying it as a high inclination SW Sex star.

Szkody, V. Desai and Hoard also used APO spectra to determine that the orbital period of the extreme amplitude dwarf nova (and the only one with a ZZ Cet pulsing primary) GW Lib is only 79 min. Its spectra are consistent with a white dwarf of temperature 11000K and distance of 114 pc.

Analysis of APO spectra of other large amplitude dwarf novae systems (SW UMa, EG Cnc and USNO1425) by Szkody, Hoard, Desai, Fried and Burdullis show that SW UMa exhibits unusual disk structure with 3 zones of emission persisting over days and that EG Cnc and USNO1425 show orbital modulations of the Balmer emission line strengths for many months past superoutburst.

G. Wallerstein and J. Hughes Clark (Everett Community College) have analyzed Strömgren vgy photometry of stars near the main-sequence turnoff in the globular cluster Omega Centauri. They find a correlation of age and metallicity, with the most metal-poor stars about 3 Gyrs older than the most metal-rich stars. Evidently, the cluster had been self-enriching for a prolonged period. To retain metals ejected from its early generation of stars it must not have interacted with the gas in our Galaxy during its enrichment period.

S. Matt, with Wallerstein and Gonzalez, has analysed high dispersion spectra of the carbon-rich Cepheid RT TrA. He finds that the total CNO abundances are enhanced, presumably by He-burning, and that the ^{12}C so-produced has been reprocessed into ^{13}C and ^{14}N by proton capture. The s-process elements are not enhanced.

Wallerstein and Gonzalez have obtained high resolution spectra of 10 giants in the open cluster M11 obtained at CTIO and APO to look for evolutionary changes in their surface compositions. As of this writing the spectra are being analyzed with model atmospheres and the line-formation program MOOG.

As part of a large program that includes astronomers at the University of Texas and the Lick Observatory, Wallerstein and Gonzalez obtained high resolution spectra with the echelle spectrograph on the APO 3.5-m telescope of giant stars in the globular cluster M22.

Gonzalez and Wallerstein are analysing spectra of the M supergiants in h and χ Per obtained at the Dominion Astrophysical Observatory and McDonald Observatory for chemical composition. The purpose of the program is to compare the h and χ Per cluster with the SMC cluster NGC 330.

Gonzalez continues his research on field RV Tauri stars with D. Lambert (U of Texas at Austin) and S. Giridha (Indian Institute of Astrophyiscs). The latest results continue to uncover new examples of RV Tauri stars with strong depletion of high condensation temperature elements in their atmospheres.

Gonzalez, in a large collaboration with researchers from India and Texas, has completed a spectroscopic campaign of the star, R CrB, during a recent fading event.

Gonzalez and C. Laws have completed the fifth paper in an on-going effort to characterize the parent stars of extrasolar planets via high-resolution spectroscopy. The most significant finding so far has been the high metallicities of these stars relative to the field star population. Spectroscopic observations of the most recently announced systems are planned in coming months.

Gonzalez has started several projects with undergraduate students, which make use of the Manastash Ridge Observatory. Eight students are working on three projects: 1) photometric calibration of the North Polar Sequence, 2) survey of supernova remnants in the nearby face-on spiral, IC 342, and 3) search for transit events by the planet orbiting HD 187123. Chris Laws is also involved with the search for transits.

Boynton, J. Deeter and J. Swank (GSFC) continue to collaborate on Rossi XTE pulse-timing observations of SMC X-1 to detect correlations between fluctuations in accretion torque and in X-ray luminosity. Although there are large variations in both pulsar angular acceleration (torque) and X-ray flux, they find little (if any) correlation between the two. They have, however, detected a significant decrease in the orbital semimajor axis, consistent with a previously detected decrease in orbital period. Motivated by X-ray observations of Her X-1, Boynton and Deeter are investigating the observational consequences of neutron star obliquity in this object. This consideration has prompted a re-examination of the optical light curve of the heated companion, HZ Her, using models that incorporate X-ray beaming and limb brightening of the heated face in addition to the geometrical shadowing and occultation provided by a precessing accretion disk.

2.3 Interstellar Material and Ejecta

Böhm and J. Solf (Tautenburg Obs.,Germany) have continued their study of deep long slit spectra of the two bipolar outflows from the T Tauri binary system. They determine the position-velocity diagrams of [O I], [N II], and [S II] out to a distance of 40$''$from the binary and they find a large number of new condensations in the outflows. In the 270 degrees outflow they detect (in addition to the well-known blue shifted jet) indications of a red shifted counter-jet. The relation between the ionic-atomic outflow (in [O I], [N II], and [S II]) and the molecular (H2) outflow agrees with theoretical expectations except for the core of ''Burnham's nebula'' ($5'' - 10''$S of T Tauri).

A.Goodson, R.Winglee (UW, Geophys.) and Böhm continued their simulation studies of the magnetohydrodynamic launching of jets from accreting young stellar objects. They paid special attention to the (tentative) comparison of the simulation results to observations. As especially important in this context they consider the formation of optical condensations, the episodic behavior of the jet and the formation of a 2-component outflow in the simulation. Velocity spectra are predicted in the simulation and compared to the observations. They show satisfactory agreement.

During the last year Matt has joined the group. Winglee, Matt and Goodson are presently extending the available 2(1/2)- dimensional simulation code to a fully 3- dimensional code.

A. Raga (UNAM), Böhm, and L.Binette (UNAM) are developing a ''shocked cloudlet'' model of HH 43. While most Herbig-Haro objects are certainly due to ''working surfaces'' of jets (with spectra in most cases due to bow shocks) there has been a strong suspicion for a long time that HH 43 is a ''shocked cloudlet'' (i.e., a cloudlet hit by a supersonic stellar wind). Raga, Böhm, and Binette are developing a hydrodynamic model of such an object and are making predictions of their expected emission line spectra.

Balick and D. Reed, along with Hajian (USNO) and four others, compared HST images of the Cat's Eye nebula, NGC6543, obtained in 1994 and 1997. The nebula is seen to be expanding at a rate of about 4 mas y^{-1}. From this and the expansion velocity of the gas a distance of 1.0 kpc and a kinematic age of 1000 y are derived. Deviations from uniform expansion were observed. These were used to constrain the dynamic models of the historical evolution of the nebula.

Balick and undergraduate J. Wilson used HST calibrated images of the Cat's Eye Nebula in order to study its morphology and ionization structure in detail. The results are complex and, in view of the simplicity of basic photoionization theory, rather puzzling. A concentric set of 11 rings was discovered to surround the bright core of the nebula. Their simplicity suggests that mass loss from the star consisted of regular isotropic pulses of gas every 1500 y. However, the bright core of the nebula seems to represent a major mass loss mode change which occurred 1000 y ago.

Balick and undergraduate S. Doyle collected deep CCD images of the bipolar nebula M2-9 obtained from the ground since 1985. After alignment, the sequence of images shows substantial changes in the nebular structure. Since mass loss originates at the star they expected to find radial motions. Instead all motions appear to be lateral. They hypothesize that twin particle beams with outflow velocities of 3000 km s^{-1}, one per lobe, precess with a period of about 120 y and inscribe spirals on the edges of the bipolar lobes.

Balick, With G. Mellema (Stockholm Obs) and V. Icke (Leiden Univ.) continue their analysis of HST images and ground-based high-dispersion spectroscopy of bipolar planetary nebulae. One goal was to locate the gas collimation nozzle and to characterize its dynamical effects on the collimated outflow. This was successful. Another goal was to use the observed properties of the nozzle in order to constrain the models of bipolars; however, the results fail both qualitatively and quantitatively to fit any extant physical models.

Balick and M. Fich (Univ. Waterloo) completed their observational study of a little known LBV in the galactic anticenter. Using the distance of 9.8 kpc that they derive, the star's bolometric luminosity is -11, close to that of η Carinae (-12). The morphology and kinematics of the gas also resembles that in the Homunculus of η Car.

Balick and undergraduate T. Tavenner began work on an analysis of HST images of Hubble 5, a large, energetic, and largely unstudied planetary nebula. The images were photometrically calibrated and divided in order to obtain ''images'' of the line ratios. These suggest that loop-like and ragged ionization fronts permeate the nebula and that the lobes are mottled with strong shear instabilities. They are combining their images with ground based spectroscopy to study the abundances and their gradients in this object.

Balick and Hajian observed the kinematic expansion patterns of two dozen southern planetary nebulae for which they are obtaining multi-epoch HST images. These data will be used to determine the so-called expansion distances to these objects. Accurate distances to planetaries are generally unavailable, so this study will vastly increase our understanding of distances, luminosities, and masses of these objects. Work will continue this year.

2.4 The Galaxy

As the MACHO project, a search for gravitational microlensing by objects in the Galactic halo, enters its final year, the UW team (Stubbs, A. Becker, Tomaney) is working on a mounting second-generation microlensing survey, ''SuperMACHO,'' with a tenfold increase in sensitivity.

The MACHO collaboration is in the final stages of analyzing 5.7 years of archived images of the LMC, SMC and Galactic center. Over 400 microlensing events have been detected to date, the majority reported in real time to the commmunity through a web site at the UW (http://www.darkstar.astro.washington.edu).

Margon, Anderson, and Deutsch, working with the SDSS Consortium, identified the first faint high latitude carbon star from SDSS photometric data, using spectroscopy from the ARC 3.5m to confirm the nature of the object. At $R \sim 19$ it is one of the faintest C stars known, and if a giant is at a galactocentric distance of ~ 100 kpc. The successful identification of this object, which lies not very distant from the normal stellar locus in SDSS color space, is a tribute to the excellent internal precision of SDSS photometry, and indicates that the entire Survey will probably yield hundreds or even thousands of such objects.

Despite indications that classical cataclysmic variable (CV) stars are rare in globular clusters in general, and in the cluster NGC 6624 in particular, Deutsch, Margon, Anderson, and R. Downes (STScI) have serendipitously discovered such a star $\sim 6''$ from the cluster center. An HST spectrum of the $m \sim 22$ object shows strong, broad emission lines typical of numerous field CVs, and the inferred optical and UV luminosity are also similar. Their accidental observation also provides the first high-quality ultraviolet spectrum of a globular cluster CV. That they have detected such an object in an observation that includes just a few percent of the central area of the cluster may indicate that cluster CVs are more common than previously thought, at least near the core.

Gonzalez has started a collaboration to write a paper on the ''Galactic Habitable Zone.'' This is intended as a major review of phenomena related to the habitability of the Earth that occur on a Galactic scale.

2.5 External Galaxies and QSOs

B. Beck-Winchatz (DePaul) and Anderson reported on their analysis of a survey for ultrafaint quasars in the ''Groth Strip''; their survey combines morphology information from HST images with multicolor CCD photometry (from the ARC 3.5m and HST) to obtain a sample with low contamination. Their counts to $B < 24.5$ confirm that deep ground-based QSO surveys suffer severe $> 85\%$ contamination by faint galaxies, while their new ultrafaint counts are in excellent accord with the predictions of several popular pure luminosity evolution models.

Anderson and Margon joined the SDSS collaboration project, lead by X. Fan and M. Strauss (Princeton), on the identification of very high redshift QSOs. Even at this very early stage of the program, SDSS has doubled the number of known high-z QSOs, and is responsible for the majority of all QSOs known at $z > 4.5$, as well as the two most distant known QSOs. These are typically bright ($i < 20$) objects with luminosities similar to 3C273. Individually odd objects such as very high-z BALs are also being found.

Anderson, Margon, and W. Voges (MPE Garching) are leading an SDSS project to provide a very large number of optical identifications and spectra of X-ray sources in the ROSAT All Sky Survey. The goal is to increase the number of known optical counterparts of each subclass by at least an order of magnitude, while providing an exceptionally homogeneous set of data on each, including positions, accurate five color photometry, and spectra for more than 10^4 identifications.

Lewis, with collaborators in both the United States and Europe, has continued his study of APM 08279+5255, the most luminous object in the Universe. This has included radio observations with the Very Large Array and infrared imaging with NICMOS on the Hubble Space Telescope. This study has clearly revealed the gravitational lens nature of this system and uncovered a previously unobserved third image. Taking advantage of the lensing amplification, the Keck 10-m telescope was used to observe the Lyman-alpha forest in APM 08279+5255, providing clues to the distributrion of metals in the early Universe. This high quality spectrum has been released to the general astronomical community for further analysis.

With Belle (Wyoming), Lewis has continued his investigation of how high optical depth microlensing can shed light on the inner regions of Broad Absorption Line quasars. Exploring its influence on polarization properties, this study has demonstrated that spectropolarimetric monitoring programs can reveal the underlying details of the scattering regions, providing clues to the nature of these rare quasar systems at a resolution well below traditional observational techniques.

Lewis has been involved in a number of collaborations which have employed the Very Large Telescope (VLT) to probe the details of Optical Einstein Rings, probed magnetically driven accretion streams in young stellar objects and examined the role of gravitational lensing in several cosmological objects.

Van den Bosch, Dalcanton, and a summer student (B. Robertson) investigated the effects of beam smearing on the HI rotation curves of low surface brightness (LSB) disk galaxies. They found that LSB galaxies with maximum rotation velocities larger than 80 km/s are consistent with dark matter halos with a steep central cusp. This suggests that the inconsistencies between the density profiles of dark halos expected from N-body simulations and those inferred from disk rotation curves are limited to low-mass systems.

Dalcanton, in collaboration with R. Bernstein (Carnegie Observatories) is finishing analysis of the dynamical and photometric properties of a sample of edge-on LSBs. These results are calling into question theories of dark matter which predict strong central cusps. In collaboration with B. Willman and van den Bosch, she has begun a series of calculations to understand the trends seen in the vertical scale heights of disks as a function of Hubble type. This calculation should place constraints on the origin of galaxies' vertical velocity dispersion and the relative mass contribution of disks and dark halos.

With undergraduate J. Murphy, Dalcanton has begun to study the colors and structure of face-on LSBs from the Sloan Digital Sky Survey. She is also working on the derivation of the LSB luminosity function, in close collaboration with Desai.

Dalcanton and Willman have begun a large project to identify new local group dwarfs and stars associated with high velocity HI clouds, through searching for clumps of red giant stars in the Sloan Digital Sky Survey database.

With undergraduates S. Doyle, X. Lam, and D. Schoeler, and collaborator S. Trager at Carnegie Observatories, Dalcanton has been working on a large imaging program of nearby, face-on spirals. The data from this program will be used to understand the relative contributions of disks and bulges, as part of a larger program to study the stellar populations of these two components of spiral galaxies.

Van den Bosch constructed new semi-analytical models for the formation of disk galaxies. These models were used to investigate the origin of the Tully-Fisher (TF) relation. When tuned to the ''slop'' of the TF relation, the model reproduces the correct amount of TF scatter, and yields gas mass fractions, mass-to-light ratios, and characteristic accelerations that are all in excellent agreement with observations. With Dalcanton, he used these models to compare the structure of disk galaxies in the cold dark matter (CDM) model with the theory that mean relations arise from changing the nature of gravity (modified Newtonian dynamics, or MOND). Both paradigms reproduce a large amount of independent observations remarkably well. Whereas the CDM model has problems fitting the shallow rotation curves in low mass systems, MOND has difficulties in simultaneously reproducing the Tully-Fisher relation and the absence of high surface brightness dwarf galaxies with small deficits.

Van den Bosch, A. Rest, Jaffe (Leiden), and H. Ford (JHU) analyzed Hubble Space Telescope images from a snapshot survey of the central regions of 68 early-type galaxies. These images will be used to examine central parameter relations.

Skelton completed her comprehensive study of the giant HII regions of M33. Her observations, taken with the APO 3.5m, HST and ISO, covered the wavelength range from the UV to 16 micrometers and included measurements of emission lines and continuum emission for the gas and photometry and spectroscopy of the exciting stars. The result is a determination of the energy budget for the stars, gas and dust for each of the HII regions, which ranged in distance from the center of M33 from near the nucleus to the far outer regions.

T. Wyder continued his work with P. Battinelli (Obs. of Rome), R. Capuzzo Dolcetta (U. of Rome) and P. Hodge, using APO 3.5m observations to determine the characteristics of OB associations selected in an automated, unbiased way. He also continued his study, with Hodge, of the use of photometry of background galaxies to determine the total extinction and reddening in nearby galaxies, especially in the Local Group.

Dolphin developed a new photometry program for HST WFPC2 images, called HSTPhot, and used it to determine CMDs for a number of external galaxies. With Hodge, he measured the CMD for the WLM dwarf irregular galaxy and its globular cluster, determining the age and abundance distribution of the galaxy's stars and measuring the age, abundance and distance of the globular cluster, using his newly-developed SFR analysis technique. Working with D. Hunter (Lowell Observatory), he also determined the SFH for a portion of the LMC. With Hodge, B. Miller (Leiden Obs.) and M. G. Lee (U. of Seoul), he performed a similar analysis on HST observations of the LGS 3 dwarf galaxy.

Hodge studied the specific cluster frequency for low-mass (non-globular) star clusters in several Local Group galaxies, finding a surprisingly-large range that is apparently environment-related. The capacity to form stars in clusters that are dynamically stable ranges from the extreme cases of the LMC, where the specific frequency is very high, to IC 1613, a galaxy that has almost no stable clusters. Using HST and WIYN telescope data, he, Wyder and A. Cole (U. Wisconsin) found only one significant star cluster in IC 1613, previously known as candidate cluster C32, which has an age near 20 million years and an absolute magnitude of M(V) =-6.

Hodge and Magnier used HST WFPC2 images of M31 to detect and study 15 open clusters in a section of that galaxy. Color-magnitude diagrams for them showed most to be young objects, with ages less than 1 Gyr.

D. Zucker continued to obtain a comprehensive optical data set to study the stars and interstellar matter in the dwarf starburst galaxy IC 10, primarily using the APO 3.5m telescope.

Hodge, working with C.R. O'Dell (Rice), R. Kennicutt (U Arizona) and Wyder, obtained HST-based color-magnitude diagrams and ages of the central clusters of two giant HII regions in NGC 6822 (Hubble V and Hubble X) and analyzed the astrophysics of the gas and stars in these objects.

Grebel and P. Guhathakurta (UCSC/Lick) analyzed the stellar populations in three newly discovered dwarf spheroidal (dSph) companions of M31. In contrast to Galactic dwarfs at similar Galactocentric distances, the three new M31 dwarfs were found to have predominantly old stellar populations and to follow the general relationship between mean metallicity, absolute magnitude, and central surface brightness. Grebel and Guhathakurta obtained radial velocities with Keck for all six known M31 dSph satellites. These data will constrain, for the first time, the kinematics of dSph satellites other than those of the Milky Way.

Grebel, Dolphin, and Guhathakurta identified a new globular cluster in the M31 dSph companion Andromeda I. This cluster resembles Galactic outer halo globular clusters and is the first one ever to have been found in an M31 dSph satellite. And I is the least luminous galaxy known to contain a globular cluster.

Grebel, P. Stetson (HIA), Holtzman (NMSU), D. Geisler (Universidad de Concepcion), A. Sarajedini (Wesleyan Univ.), P. Hurley-Keller and M. Mateo (both U Michigan) are studying the large-scale star formation histories of dSph galaxies. Clear evidence of second-parameter horizontal branch variations was found in Sculptor. Strong evidence for spatially varying star formation was detected in Fornax, where also the youngest population ever found in a dSph (200 Myr) has been identified.

Grebel, Hodge, Dolphin, Zucker, P. Seitzer (U Michigan), I.Karachentsev (SAO), K. Karachentseva (U Kiev), Guhathakurta, Geisler (U de Concepcion), and Sarajedini are carrying out a ground-based (APO, MDM, Keck) and HST snapshot survey of nearby dwarf galaxy candidates. This survey has resulted in the confirmation of many dwarf galaxies as members of nearby groups and in the detection of one possible isolated dSph galaxy.

Grebel and Y. H. Chu (U of Illinois) completed the analysis of HST/WFPC2 data of Hodge 301, a cluster in the 30 Doradus region. Hodge 301 is 20 Myr old, contains many Be stars, has a normal, Salpeter-like initial mass function, and belongs to the oldest generation of star formation in this starburst region.

Grebel, W. Brandner (U of Hawaii), and Chu obtained HST/WFPC2 data of NGC 3603, a Galactic giant HII region. Near the central starburst cluster in this region they detected giant gaseous pillars, Bok globules, and partially ionized globules with forming young stars, which are also being referred to as ‘‘proplyds.’’ The proplyds are the most massive ones ever to have been found. Model calculations indicate that they contain stars of 1-2 solar masses. With L. Drissen (U Laval) and A. Moffat (U Montreal) Grebel found a slope of 0.7 for the initial mass function of NGC 3603, significantly different from the usual Salpeter-like slope. Pre-main-sequence stars were identified as well.

2.6 Cosmology

Using the ARC 3.5m telescope, Deutsch and Margon joined a consortium headed by T. Galama (U. Amsterdam) to report extensive calibrated, multi-band photometry of GRB 970228. In the late stages of the decline, the light curve provides evidence for the presence of a Type Ic supernova, furthering the arguments for the association of at least some gamma ray bursts with this rare supernova subtype.

With R. Ibata (ESO), Lewis has investigated the nature of dark matter in the Universe by examining the impact that stellar mass black holes have on our view of distant galaxies. The results of this study show that if dark matter was comprised of such compact objects then they will reveal themselves with a year long monitoring campaign, similar to the current MACHO projects.

Reed, Quinn and Lake have been studying the formation of structure in non-conventional cosmological models, specifically models missing power on scales between galaxies and clusters. These models were chosen in an attempt to solve the ‘‘cold flow’’ and ‘‘missing groups’’ problems that more conventional models produce.

Quinn, Stadel, and Lake continue to analyze their large simulations of the SDSS volume. The dynamic range of these simulations is large enough to study the formation and structure of clusters (100 kpc) in a volume large enough to contain a fair sample of the Universe (1000 Mpc). With Lewis and A. Babul (Victoria), the weak lensing properties are being studied to see their effect on large scale structure measurements and supernovae distance determinations.

Lake, Quinn, and Stadel with S. Ghigna (Durham), B. Moore (Durham), and F. Governato (Milan) are looking at the properties of dark matter halos within clusters, using the first simulations with enough resolution to look at this problem in a cosmological context. They find two severe problems with the standard CDM model: 1) CDM predicts much more substructure than is seen or inferred to be in galactic halos and 2) the central density profiles of galaxies are much steeper than observed in HI observations of low surface brightness galaxies.

Wadsley, Stadel, and Quinn have added Smooth Particle Hydrodynamics to the scalable, parallel N-body code. The resulting code ‘‘GASOLINE’’ will be used initially to study the gas dynamics in clusters of galaxies.

Gardner, with Quinn, Babul (Victoria) and Governato (Milan) is comparing the evolution of structure in voids. He finds a significant difference in the merger histories of halos that form in voids compared to the average.

D. Reiss, Stubbs, and B. Schmidt and L. Germany (MSSSO) completed a supernova search in Abell cluster fields using the MACHO camera system. Reiss completed analyzing supernova rates at low and high redshifts for his thesis.

Tomaney and others ported MACHO software to compare multiple epochs of SDSS photometry for application to supernova searches and other variability studies with the multiple scans of the SDSS Equatorial Survey. Prototype software was demonstrated on the SDSS first light data.

A. Diercks, Reiss, Stubbs and Hogan continued their participation in the High-Z Team, an international collaboration using distant Type Ia supernovae to study the Hubble diagram at large distance to measure cosmological parameters. The early results continue to be confirmed, showing that supernovae at a redshift of about 0.5 are fainter than expected compared to those nearby, strongly ruling out an Einstein-deSitter cosmology and suggesting that the expansion may be accelerated by a cosmological constant. This discovery of an ‘‘accelerating universe’’ by HZT and SCP (Berkeley) was declared by Science magazine the most important breakthrough in science for 1998. A popular article by Hogan, R. Kirshner (CfA) and N. Suntzeff (CTIO) led the January 1999 issue of Scientific American, the best-selling issue ever.

In addition to the High-z and Mount Stromlo Supernova searches, Apache Point 3.5m telescope is being used to acquire both infrared and optical wavelength photometry of ongoing type Ia supernovae. In particular, Stubbs and others are focusing on understanding the sources of systematic errors that might mask or mimic the effect of a cosmological constant. This work formed the Ph.D. thesis of A. Diercks (now at Caltech) and is being presently pursued by K. Krisciunas.

B. Williams, Hogan, Anderson, Stubbs, and members of HZT have started a study of HST archival images of the host galaxies of distant supernovae. The correlations with residuals from the Hubble diagram will be used to test possible evolutionary effects or other systematics which might affect the ‘‘accelerating-universe’’ interpretation.

Hogan studied the gravitational lensing produced by projected folds in the phase space sheet of cold dark matter.

Projected caustics lead to discontinuous edges in surface density, which for various dark matter candidates lead to angular structure from microarcseconds to picoarcseconds and time variability down to timescales of hours. In principle this technique allows an observational probe of the nature of the dark matter.

D. Norman and C. Impey (U. Arizona) completed her thesis work, a new survey which confirmed previous claims of lens-induced correlations between radio sources and foreground galaxies. Norman also pursued investigations of lens-induced correlations with L. Williams (U. Victoria).

Hogan studied the sensitivity of nuclear properties to variations in the masses of the light quarks, and other apparent ''fine tunings'' in the context of Grand Unification. He concluded that the Yukawa couplings in the Standard Model Lagrangian are unlikely to be predictable by derivation from any symmetry.

Wadsley and J. Bond (U. Toronto) continued their numerical simulations of QSO Lyα front absorption associated with galaxy formation. Wadsley and Hogan have started simulations using GASOLINE to investigate ''hierarchical heating'' of gas as a possible explanation of the fact that the dominant form of cosmic baryons is diffuse $\sim 10^6$K gas around galaxies. Wadsley, Hogan, Anderson and Williams used collected data from QSO HeII absorption to constrain detailed models of cosmic reionization and estimate the total density of baryons.

Mendoza and Hogan developed a Java applet for calculating the predictions, with errors, of Standard Big Bang nucleosynthesis for the abundances of the light elements. The work was featured in Science magazine as an example of innovative research application of web technology.

Anderson, Hogan and Williams completed their HST STIS studies of the $z = 3.18$ quasar PKS 1935-692, covering the region shortwards of rest frame 304 Å to study foreground HeII Lyman-α absorption. In accord with previous results on two other quasars at similar redshift, they demonstrate a correlation with the HI Lyman-α forest, but also find that much of the helium absorption is caused by more diffuse IGM gas with $\Omega_g \sim 10^{-2}$, that is not detected in HI.

Hogan, Anderson, and Williams are also participating in SDSS collaborative efforts to identify bright quasars suitable for high-quality follow-on spectroscopic absorption line studies in the optical and ultraviolet. Their specific interest is on the selection from SDSS data of two rare subsets of quasars: those suitable for measuring the primordial deuterium abundance, and those suitable for He II studies of intergalactic gas.

Hogan's primer on cosmology, *The Little Book of the Big Bang*, is appearing in translations: Dutch, German, Portuguese, Italian, and Polish.

3. MISCELLANEOUS

After his retirement in 1971, Theodor Jacobsen worked for many years on a detailed study of the methods used by ancient astronomers to interpret and model the motions of celestial bodies. Led by Boynton and Brownlee, the Department and the University of Washington Press published the work this year under the title ''Planetary Systems from the Ancient Greeks to Kepler.'' The extraordinary explanatory figures are available at the Department's web site, and profits from its sale will go to the Theodor Jacobsen Fund for graduate student support.

The Department held its first annual Open House in March. Thousands of fans thronged the A building for about five hours, with department volunteers providing astronomical entertainment including kids' activities (e.g., edible comets) and planetarium shows, posters of student research and Project ASTRO classrooms, physics demonstrations, astronomy songfest, astro web surfing, and faculty research lectures, capped with a keynote address by former astronaut and faculty member (and Department alumnus) Pinky Nelson.

Anderson chaired a committee, including faculty, staff and students, to review the technical course offerings of the department, especially the 400-level courses for the undergraduate majors and entering graduate students. The recommendations led to a restructuring of the spring and summer observing courses, a successful proposal to the Kenilworth Foundation for support, and new university support under the Tools for Transformation program. A capstone research experience is now a central part of the undergraduate major.

After four years of development and raising money, Sullivan (together with D. Werthimer and D. Anderson of Berkeley) participated in the launch of ''seti@home'' (setiathome.ssl.berkeley.edu), an innovative project that involves massively parallel computation on desktop computers scattered around the world. Less than six months after launch, 1.5 million persons have requested to participate, and about one-fourth of them are still active. A subsample of SETI data, as continuously being collected by Berkeley's Project Serendip at Arecibo, is taped and broken down into small chunks for distribution over the Internet to whomever wishes to sign up. Individuals download a screensaver program that not only provides the usual attractive graphics when their computer is idle, but also performs sophisticated analysis of SETI data.

As President of IAU Commission 50 (Protection of Observatory Sites), Sullivan was a main organizer of IAU Symposium 196, ''Preserving the Astronomical Sky,'' held in Vienna in conjunjction with a UN space meeting in July 1999. Besides technical discussions of problems of light pollution and radio interference, the symposium reached a much broader audience through press releases and an official statement that was adopted by the UN meeting.

Sullivan continued as one of the leaders of the new interdisciplinary UW Astrobiology Graduate Program, which accepted its first cohort of seven students for entry in the autumn of 1999. Students are accepted to a specific department, but spend about one-third of their effort outside, involved in others of the ten participating departments. The program was selected as a winner of a University Initiatives Fund award which will lead to new faculty appointments.

Sullivan continued as Director of Project Astro/Seattle, which established 45 year-long partnerships between astronomers (both professional and amateur) and grades 4-12 teachers in the Puget Sound region. After participating in a two-day workshop, each astronomer visits his or her class a minimum of 5 times.

Together with J. Bell and S. Squyres (Cornell) and J. Lomberg (Hawaii) Sullivan transformed a photometric calibration target to be placed on NASA's Mars '01 lander spacecraft into the first extraterrestrial sundial. The dial and its associated Web site are a part of K-12/Public Outreach, and will allow those remaining on Earth to know the time on Mars.

Diercks completed his Ph.D. at UCSB and departed UW; he was awarded a Millikan Fellowship at Caltech.

Lake continues to serve as Project Scientist for NASA's High Performance Computing and Communication Project in Earth and Space Sciences (HPCC/ESS). Quinn and Lake are taking the lead for a project to build an integrated framework for Particle Simulation and Visualization.

Margon has been appointed Chair of the NASA Structure and Evolution of the Universe Subcommittee (SEUS), and concurrently a member of the Space Science Advisory Committee (SScAC). He also continues as a member of the AURA Board of Directors, the AURA Member Representatives, the Next Generation Space Telescope (NGST) Ad Hoc Science Working Group, and the Constellation-X Facility Science Team.

Szkody served as AAS Councilor, Vice President of IAU Commission 42 (Close Binaries), AAAS Member-At-Large, and member of the RXTE Users Committee and of the KPNO Telescope Allocation Committee.

Hogan was awarded a Humboldt Research Award by the Alexander von Humboldt Foundation, and initiated a series of associated visits to the Max Planck Institute für Astrophysik in Garching.

Stubbs was named a McDonnell Centennial Fellow, with an award of one million dollars to construct a wide field CCD camera for the ''SuperMACHO'' project. This was one of only two such awards worldwide in astronomy and cosmology.

Hodge completed his 15th year as Editor of the *Astronomical Journal*. A special celebratory conference was held in honor of his 65th birthday at Friday Harbor Labs in September, organized by his many former students and postdocs.

4. RESEARCH TOOLS

J. Morgan took the lead in automating the rotation of the tertiary mirror on the Apache Point 3.5m telescope. This project, which was completed in the summer of 1999, allows us to rapidly change the instrument port being fed the optical beam from the telescope, taking full advantage of the multi-instrument configuration of the telescope, enabling in particular remote use of the new echelle spectrograph.

Rest developed and deployed a Differential Image Motion seeing monitor, now in routine use at Apache Point. A 10-arcminute field spectrograph optimized for the O[III] line at 5007 A is being designed by Rest and Mannery. The camera system at the Manashtash Ridge Observatory was converted to a liquid-nitrogen free cryogenic system, and a fiber-fed spectrograph was put through an initial shakedown run.

The UW Telescope Engineering Group (Pat Waddell, Walt Siegmund, Ed Mannery, Russell Owen, Michael Evans, Siri Limmongkol, Roger Leger, Frederick Toevs, and Larry Carey) completed the construction of the 2.5m telescope and spectroscopic systems for the Sloan Digital Sky Survey. Several hundred square degrees of survey-quality imaging data, and thousands of spectra via a successful test run of the spectroscopic system, have been obtained at the time of this writing, and the first science results from the survey have started to emerge, including a number of projects described above. The commissioning and operations phases of the project are underway, with UW providing engineering support for the drilling of the plug plates for fiber spectroscopy and the construction of the spectrograph fiber cartridges. The end of the construction phase of SDSS led to the restructuring of the Telescope Engineering Group, including the departure of several key contributors to the 2.5m and 3.5m projects after many years of creative and productive service to our department and Astrophysical Research Consortium telescope projects.

Craig J. Hogan, Chair

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