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This report summarizes activities during the academic year 2001-2002. For more detail please see the Department's web site at http://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. Stubbs, W. Sullivan and P. Szkody; Associate Professors S. Hawley and T. Quinn; and Assistant Professor J. Dalcanton. W. Baum, K. H. Böhm, E. Böhm-Vitense, T. Jacobsen and G. Wallerstein were faculty emeritus. G. Lake is a Research Professor, presently at Institute of Systems Biology in Seattle. J. Lutz and I. King are Research Professors. A. Larson, S. Palen, and T. Smith were Lecturers. Research Associates and postdocs were C. Rockosi, L. Homer, M. Kress, L. Mayer, and T. Murphy. Research and engineering staff included L. Carey, P. Doherty, J. Morgan, R. Owen, and C. Reschke. Twenty graduate students were registered as members of the Department. Ph.D. degrees were awarded to S. Matt and B. Williams.

Changes occurring this year include these: Prof. C. Hogan became Vice-Provost for Research at U. Washington. King arrived from U.C. Berkeley in spring 2002. V. Woolf came as a postdoc in summer 2002. S. Palen departed in summer 2002 for Weber State U. and L. Meyer left for a research position in Zurich.

2. RESEARCH

2.1 Solar System and Astrobiology

Brownlee, Joswiak, Kress and Matrajt are involved in a variety of laboratory investigations on interplanetary dust particles (IDPs). Recent work has examined the role that these particles have played in delivering carbon and organic material to the early Earth when the flux of cometary particles was orders of magnitude higher that it is a present. In collaboration with J. Bradley, L. Keller and others, Brownlee has participated in a project to identify a 23m feature seen in YSO's. Using synchrotron micro-IR techniques on IDPs and standard minerals they showed that the 23m feature is a signature of iron sulfide and not the previously suggested iron oxide. An interesting implication of this work is that sulfur remains largely in the gas phase in the ISM but forms FeS grains in dense clouds and YSO disks. Also in collaboration with Bradley and others, recent study of nanodiamonds in cometary IDPs showed that the abundance of nanodiamonds is lower than seen in asteroidal materials. This work implies that there was a source of nanodiamonds within the solar nebula and that meteoritic nanodiamonds are not purely presolar as commonly believed.

Brownlee leads STARDUST a NASA Discovery mission that will collect comet samples and return them to Earth. Built as a partnership between JPL, Lockheed Martin and the UW, the mission was launched early in 1999. As of October 2002, it has completed over half of its complex trajectory that involves three loops around the Sun, a comet flyby and return to Earth. In November 2002 Stardust will flyby the 4 km S type asteroid Annefrank, and do a complete encounter rehearsal for its January 2004 flyby of Comet Wild 2. During cruise, 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 and return them to Earth. 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 Peter Ward have written 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. This effort is an extension of the previous collaboration ''Rare Earth- Why complex life is uncommon in the Universe. The previous book explored Earth's place in space while the new effort examines its place in time- how the present state of Earth differs from its past and future.

Tom Murphy and Chris Stubbs, along with Eric Adelberger in the physics department, are pursuing a test of general relativity by means of characterizing the shape of the lunar orbit to millimeter precision. The technique, called lunar laser ranging (LLR), involves launching a short laser pulse 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. LLR provides the very best tests available of several fundamental aspects of gravity: 1) LLR is the only test of the strong equivalence principle, allowing us to answer the question, ''how does gravitational energy itself gravitate;'' 2) LLR provides a competitive test of the weak equivalence principle compared to lab tests, capable of sensing differential accelerations of the earth and moon toward the sun at the level of a part in 10^{14}; 3) LLR performs the best check of the constancy of Newton's gravitational constant, G–currently at the level of less than a part in 10^{12} change per year; 4) LLR measures other relativistic effects such as curvature of space and geodetic precession.

Mayer and Quinn with James Wadsley (McMaster)and Joachim Stadel (Victoria/Zurich) continue to investigate gravitational instabilities in a protoplanetary disks as away to form giant planets. They have performed several SPH simulations at increasingly high resolution and showed that overdensities and self-gravitating clumps that collapse into protoplanets can arise if the disk is cold enough. The highest resolution simulations employ one million particles. This is the first time that long-lasting clumps are observed in high resolution simulations of disk evolution and therefore this work represents a new milestone in the field. Protoplanets are followed for many orbital times and after a thousand years have masses and orbits strikingly similar to those of observed extrasolar planets. This work shows that the disk instability is a viable model for planet formation.

Raymond and Quinn with J. Lunine (University of Arizona) are examining the process of volatile delivery to the forming terrestrial planets. Water is deposited on the forming Earth when it accretes embryos and planetesimals which formed farther out in the solar system and are volatile-enriched. They are examining the dependence of this volatile-delivery mechanism on several parameters, including the position of Jupiter in the Solar System and various conditions in the proto-planetary disk. They find that terrestrial planets which form in systems with Jupiter at significantly smaller or larger semimajor axes are likely to accrete fewer water-rich bodies during their formation.

Barnes, Raymond and Quinn are investigating the possibility of planets existing and forming in known extrasolar planetary (XSP) systems. They are testing the formation of terrestrial planets in between planets in known XSP systems, starting from planetary embryos, and examining the stability of the planets which form.

Barnes and Quinn, with D. Richardson (University of Maryland) and J. Lissaur (NASA Ames) are performing direct simulations a self-gravitating planetesimal disk. Currently they are performing simulations of small patches with high resolution in order to determine the mass distribution of planetesimals in the disk. These will soon be extended to full disk simulations in order to understand the extent of radial mixing, and the interactions with the giant planets.

Lufkin and Quinn are studying the migration of gas giants within a gaseous protoplanetary disk. In a preliminary study of the stability of these gaseous disks, they discovered that some of the theoretical temperature profiles used in the literature are convectively unstable. The plan is to perform full disk simulations of the planet interacting with the disk using the SPH technique with the goal of determine the extent and timescale of radial migration in extra solar planets.

Quinn and W. Rubens (Cambridge) have performed simulations of the formation of Jupiter's Galilean moons. They find that with an initial density profile that is shallower that the standard profile, that they are able to reproduce the masses and positions of the Galilean moons. In contrast, the standard initial density profile produces all the moons at Io's distance.

Quinn continues to lead the working group for Solar System science within the SDSS. With M. Juric (Princeton), Z. Ivezic (Princeton), R. Lupton (Princeton), S. Tabachnik (Princeton), he positionally correlated known asteroids with a sample of 18,000 asteroids detected by the Sloan Digital Sky Survey (SDSS). They found 2641 unique matches, which represent the largest sample of asteroids with both accurate multicolor photometry and known orbital parameters. The matched objects are predominantly bright and demonstrate that the SDSS photometric pipeline recovers 90% of the known asteroids in the observed region.

2.2 Stars and Compact Objects

L. Homer and S. F. Anderson, in collaboration with B. Margon and R. A. Downes (STScI), and E. W. Deutsch (ISB) reported on their Chandra and HST observations to pinpoint the UV/optical counterpart of the luminous, bursting, low-mass X-ray binary in the core of the globular cluster NGC 6441. The superb Chandra imaging provides a new and much smaller X-ray error circle that still includes their previously suggested (based on HST imaging data) optical identification ''star U1''; their newly reported HST STIS time-resolved optical spectra reveal that U1 has a very blue and smooth optical SED that varies in a fashion consistent with the known 5.7h X-ray periodicity, providing strong confirmation of the suggested optical identification.

Homer and Anderson, in collaboration with a group led by W.H.G. Lewin and D. Pooley (MIT), F. Verbunt (Utrecht), Margon, and others reported on their continuing spacebased studies of the burgeoning population of lower luminosity X-ray sources in globular clusters; Chandra observations reveal the faint X-ray sources, and HST data are employed to identify optical/UV counterparts. Nearly a dozen likely CVs are identified in NGC6752, further confirming theoretical expectations for the importance of close binaries in globular cluster dynamical evolution; in NGC6440, a surprisingly large number of likely quiescent LMXBs are also found (along with CVs, etc).

Anderson, in a collaboration led by Margon, reported on the discovery of 40 Faint High Latitude Carbon Stars (FHLCs) from SDSS. Proper motion studies with H.C. Harris (USNO) indicate that the sample is a roughly comparable mixture of distant (100 kpc) halo giants and examples of the recently-recognized exotic class of very nearby dwarf carbon (dC) stars; although selected from only a small fraction of the final survey area, even this initial sample doubles the number of known dCs.

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 Peg, 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 of A), 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) published a large survey paper characterizing M, L and T dwarfs in the Sloan Digital Sky Survey, including follow up observations from the ARC 3.5m telescope at Apache Point Observatory.

Hawley, A. West, S. Raymond, L. Walkowicz and Covey (UW graduate students) began a program to study the magnetic activity properties of the M and L dwarfs in SDSS.

Hawley, N. Silvestri (Florida Inst. Tech.) and T. Oswalt (FIT) finished a paper on the kinematics of M dwarfs in their common proper motion binary sample. This work forms part of Silvestri's PhD thesis. Another paper on the age dependence of M dwarf activity is in preparation.

Hawley and P. Szkody received an NSF grant to continue work on an SDSS project targeting red dwarf/white dwarf binary systems. The goal is to study the evolution of low mass stars in binary environments and the properties of precataclysmic variables. New UW graduate student J. Bochanski and new UW postdoc N. Silvestri are also beginning work on this project, which will include extensive follow up observations at the ARC 3.5m telescope.

Hawley, J. Allred (UW graduate student) and C. Johns-Krull (Rice University) continued work on the March 2000 flare campaign on AD Leo. Allred presented a poster at the June 2001 Albuquerque AAS meeting, and the first paper is ready for submission. This work will be a part of Allred's PhD thesis.

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.

Hawley and Johns-Krull carried out an HST Cycle 10 program to search for transition region emission in very low mass stars. Initial results indicate that these stars maintain persistent emission and do not become active only during flares as has been suggested by some authors.

Hawley, Reid and J. Gizis (U. Delaware) published the fourth paper in the PMSU survey series, investigating the nearby star luminosity and mass functions.

Hawely, Reid, K. Cruz (U. Penn), Covey and O. Fraser (UW graduate student) began a program on the ARC 3.5m telescope to obtain spectroscopic observations of candidate nearby stars.

Balick and A. Frank (U Rochester) completed 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. Mz3 shows clear signs of a scale change suggesting that it is expanding homologously. Structure changes in M2–9 are lateral, as had been found earlier.

S. Matt, Balick, and Winglee (U.Wash.) completed development of a magneto-hydrodynamic code developed to follow fields trapped in the winds of a rotating star. The dynamical effects of these fields on the outflows show that under conditions expected for η Carinae two bipolar lobes and a disk form in the same outflow.

P. Boynton, J. Deeter and J. Swank (GSFC) continue to collaborate on Rossi XTE pulse-timing observations of SMC X-1 to study correlations between accretion torque and X-ray flux in this X-ray binary. They have established that the fluctuations in both torque and flux closely follow 1/f laws (''pink'' or ''flicker'' noise), but that these data alone are not sufficient to clearly establish a correlation between the two variables. They are proposing follow-up RXTE observations of SMC X-1 and possibly Her X-1 as well to try to definitively determine whether there is a torque-flux correlation in either of these X-ray binaries. Moreover, they are evaluating whether data from the RXTE all-sky monitor can be productively used in these torque-flux studies.

E. Böhm-Vitense, K.G. Carpenter (GSFC) and R.D. Robinson (Catholic U.) have continued their studies of transition layers between chromospheres and coronae of main sequence Hyades F stars. FUSE spectra of 22 Hyades stars showed that the layers with electron temperatures around 250,000 K, emitting the OVI lines, are not heated by conductive flux down from the coronae, but rather by the same, as yet unknown, heating mechanisms working in the deeper layers. The OVI and CIII lines are very broad. In addition to rotational and thermal broadening the line profiles are broadened by two different non-thermal velocity fields, one with a Gaussian velocity distribution with average velocities between 40 and 80 km/s, and the other one with velocities twice or three times as large. It is tempting to relate the lower velocity component with acoustic shocks and the high velocity component with magnetohydrodynamic waves.

A. D. Vanture (Everett Comunity college) working with Wallerstein and Gallino (Univ. of Torino) analyzed spectra of the S stars in Omega Centauri. They have turned out to be a heterogeneous bunch with some having had their heavy element excess since birth, some having developed it in their own interiors and one star suspected to be a mass-transfer binary. In cooperation with L. Pompeia (Univ. of Sao Paulo)

Wallerstein is obtaining spectra to derive the ratio of Cu/Zn and Sc/Fe in a wide variety of stellar types. In cooperation with S. Andrievsky (Univ. of Odessa, Ukrane) he is analysing spectra of distance cepheid variables to improve on the corellation of metallicty and various element ratios with distance from the Galactic Center.

S. Matt, A. Goodson (Earth & Space Sciences), R. Winglee (Earth & Space Sciences), and Böhm completed their simulation-based studies of ‘‘jet outflows’’ resulting from the interaction between YSO magnetospheres and the circumstellar accretion disks. They found that the interaction mechanism is robust and self-regulating. That is, the basic outflow properties depend only relatively weakly on the choice of the model parameters. All outflows are episodic with a timescale set by the spin-down time of the disk inner edge.

Böhm and Matt have been studying the properties of HH 255 (also known as ‘‘Burnham’s nebula’’), an essential part of the outflow from T Tauri. This object is enigmatic because, while it shows an integrated spectrum that is identical to a typical HH spectrum, the centroid velocity is nearly zero with respect to T Tauri, and the velocity dispersion is unexpectedly small. Also the line emission stratification is different than in typical HH objects. Böhm and Matt conclude that the peculiar properties of HH 255 can be partially understood by explaining HH 255 as a standing shock wave. This may have a theoretical justification, since Matt found in his thesis that, when a wide-angle wind is collimated by an external magnetic field, there is a tendency to form standing shocks.

2.3 The Galaxy and the Local Group

C. 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 4m telescope at CTIO. This project, with Stubbs as PI, has been awarded 30 half-nights per year as an NOAO long term survey.

King, A. Cool (SFSU), and J. Anderson (UC Berkeley) are studying an 18-day outburst of a dwarf nova, observed by HST in the globular cluster M22.

King, with G. Piotto (Padua) and a long list of collaborators, have completed their HST snapshot study of 74 globular clusters, and a paper giving all the color-magnitude diagrams is in press in A&A.

King and J. Anderson (UC Berkeley) have under way a long list of projects dealing with HST astrometry in globular clusters. For this purpose they have greatly refined the accuracy of distortion corrections for the WFPC2 camera (available from jay@astron.berkeley.edu). Work in progress includes measurement of proper motions of individual stars in 47 Tucanae, Omega Centauri, and 6 other globular clusters, studies of anisotropy of stellar motions, exploration of the luminosity function near the hydrogen-burning limit in 4 clusters, and determination of globular-cluster distances by comparison of the dispersion of proper motions with that of radial velocities.

Hodge, together with former students B. Skelton and J. Ashizawa, published an Identification Atlas of Local Group Galaxies, including 200 charts. Published by Kluwer in 2002, the atlas was prepared during the 1990’s and publication had been delayed by computer failures.

2.4 Galaxies and QSOs

Anderson continued his participation in SDSS collaborations to identify and study high-redshift ($z>4$) quasars. For example Anderson, in collaboration with a group led by W.N. Brandt and D.P. Schneider (PSU), reported on initial Chandra X-ray observations of three quasars at redshifts $z=5.8$ to 6.3; all were detected in X-rays, with X-ray to optical flux ratios similar to those of more modest redshift quasars–indicating that even X-ray spectra should be feasible with current and future X-ray missions.

Anderson, in collaboration with P.B. Hall and M.A. Strauss (Princeton), and many others in SDSS, reported on their confirmation of populations of extreme sub-classes of broad absorption line (BAL) QSOs. Among several dozen such extreme BALQSOs discovered in early SDSS data are: objects with absorption which removes an unprecedented 90% of all flux shortward of MgII; an object in which the BAL absorption has varied with a surprisingly large amplitude and rapidity; numerous highly reddened BALQSOs; and even two luminous objects—perhaps related to BALQSOS—whose nature is not yet definitively understood.

With B. Willman (UW), J. Dalcanton has begun a novel survey for new companions to the Milky Way. 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.

In collaboration with V. Desai (UW), Dalcanton is using the SDSS to study the mass function of galaxies in clusters. They find substantial disagreement with numerical simulations. In particular, they do not find that the mass function is a self-similar function of cluster mass, in contrast to claims in the literature.

Dalcanton and P. Yoachim (UW) 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 are beginning a large program of spectroscopic follow-up to measure the dynamics, ages, and metallicity of the thick disk.

A. West (UW) and Dalcanton are continuing their collaboration with M. Disney (Cardiff) and the HIPASS collaboration to use SDSS to explore the optical properties of gas rich galaxies. They are pursuing follow-up of extremely gas rich galaxies. West has also 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.

B. Williams, working with Hodge, completed an analysis of the star formation histories of different areas of M31 using

HST data. They also published a catalog and discussion of newly-recognized young star clusters in M31, using an automated cluster-finding program developed by Williams.

A. Seth and Hodge used an automated cluster-finding program to identify young star clusters in the galaxy NGC 6822, for which ages were obtained from color-magnitude diagrams using HST images. Hodge and K. Krienke (Seattle Pacific U.) supplemented these data with a survey of intermediate age and old clusters in the galaxy, providing a measure of cluster formation rates and the first data on cluster survival statistics for NGC 6822.

Hodge was a member of a team that obtained two cycles of snapshot images of nearly 200 candidate nearby dwarf galaxies with HST. He was co-author on 7 published papers based on analysis of these images.

Together with B. Elmegreen (IBM), Y. Efremov (Sternberg) and others, Hodge was involved in a study of a remarkably luminous blue globular cluster in the normal Sc galaxy NGC 6946. It is surrounded by a circle of smaller young clusters. Observations were obtained with HST and the 6m telescope of the Special Astrophysical Observatory.

2.5 Particle Astrophysics and Cosmology

L. Mayer, F. Governato, Quinn and Willman with J. Wadsley (McMaster), and J. Gardner(Pittsburgh) have analyzed new high resolution N-Body/SPH simulations of galaxy formation. These runs show for the first time that realistic disk galaxies can form in the currently favored LCDM cosmological models once enough resolution is used. The large galaxies whose evolution is followed to the present time shows at the end many properties in common with observed early-type spiral galaxies, e.g. the presence of a thin disk, thick disk and bulge as well a stellar halo, all with realistic stellar ages and mass distributions. An analysis of the global properties (e.g. orbits) of the satellites formed in the same run is now being carried out.

Mayer, using high resolution numerical simulations, has carried out an extensive study of bar formation in low surface brightness galaxies. Bar-halo interactions has recently been proposed as a mechanism to create a core in a cuspy halo, thus reconciling the predictions of LCDM models with the observation of rotation curves of spiral galaxies. Mayer has built several models of LSB galaxies embedded in LCDM halos, exploring a vast parameter space and including even a gaseous disk; bar formation is thus studied in both a collisionless and fluid disk. Most of the realistic models of LSBs that were built are stable to bar formation; this seems to require an extremely cold, mostly gaseous disk as a starting condition and implies that present-day LSBs should host a dim bulge that results from the secular evolution of the bar. While past bar formation might explain the present structure of red, early-type LSB galaxies, it is not clear whether typical blue LSBs that make up most of the samples used to measure rotation curves might fit in the same scenario.

Quinn with N. Katz (U. Mass) and M. Weinberg (U. Mass) are looking into the detailed dynamics of these 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.

With G. Taffoni (SISSA/ISAS) and M. Colpi (Milano-Bicocca), Governato and Mayer have finished a study of the orbital evolution of satellite galaxies in LCDM models using a combination of simulations and semi-analytical models. These authors have carried out an exhaustive analysis of the parameter space relevant to satellites, deriving useful analytical formulae that should faithfully describe what is observed in cosmological simulations. In the future these recipes will be directly tested with a very high resolution cosmological simulation of a cluster that Mayer has also performed. The final goal is to match the results of such costly simulations given an appropriate initial distribution of satellite orbits, masses and density profiles, doing that orders of magnitude faster.

Mayer has finished running a new, high resolution simulation of a small galaxy cluster that sets a new standard in numerical resolution: objects as small as the dwarf galaxies of the Local Group are resolved for the first time within a cluster-sized potential. This data set is being used by Willman, Governato, Mayer and Quinn to study the evolution of cluster galaxies and intracluster light.

D. Reed and Quinn with G. Lake (ISB) has analyzed the effects of the suppression of initial density fluctuations on the scale of galaxy groups in a series of cosmological simulations. The dynamical states and lower number density of groups in the suppressed power simulation are consistent with a potential under-abundance of virialized galaxy groups in recent X-ray surveys, with the caveat that the X-ray luminosity function for objects of group mass is strongly model dependent.

Reed, Quinn and Governato with L. Verde (Princeton) have used a number of high resolution simulations to provide more quantitative results on the steep inner profiles of dark matter halos. They find that halos consistently have steeper profiles than the standard NFW profile.

Quinn, with E. Hayashi (U. Victoria), J. Navarro(U. Victoria), J. Taylor (U. Victoria), and J. Stadel (U. Victoria) investigated the evolution of substructure in cold dark matter halos using N-body simulations of tidal stripping of substructure halos (subhalos) within a static host potential. They found that halos modeled following the Navarro, Frenk & White (NFW) mass profile lose mass continuously due to tides from the massive host, leading to the total disruption of satellite halos with small tidal radii.

Quinn, with C. Power (Durham), J. Navarro (Victoria), A. Jenkins (Durham), C. Frenk (Durham), S. White (Max-Plank), and V. Springel (Max-Plank) performed a comprehensive set of convergence tests which explore the role of various numerical parameters on the equilibrium structure of a simulated dark matter halo. They obtained results with two independent, state-of-the-art, multi-stepping, parallel N-body codes: PKDGRAV and GADGET. They found that convergent mass profiles can be obtained for suitable choices of the gravitational softening, timestep, force accuracy, initial redshift, and particle number.

C. Stubbs, R. Covarrubias, A. Rest and G. Miknaitis and A. Miceli are members of the ESSENCE team, using the

CTIO 4m 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.

C. Stubbs and C. Hogan are members of the US science team for the Laser Interferometric Space Antenna (LISA), a trio of satellites that will be used to detect gravitational radiation from astrophysical sources.

T. Murphy, J. Strasburg, C. Stubbs and E. Adelberger are pursuing design and implementation of a lunar laser ranging program, with the APO 3.5m telescope. This project is designed to exploit the large aperture of the 3.5m to achieve a hundredfold increase in photon collection, to probe the equivalence principle at a level of sensitivity ten times beyond the present state of the art.

Reed, Stadel and Quinn have performed an 80 million particle simulation of structure in a 100 Megaparsec region. This is sufficient resolution to follow the formation of galactic halos and their substructure. By using the actual halos as tracers of galaxies, they are able to reproduce the spatial and velocity correlation functions seen in the SDSS data. In particular they do not see the ‘‘cold flow’’ problem that has plagued lower resolution simulations. With a crude density-morphology relation they are also able to reproduce the correlations of the individual Hubble types.

Quinn, and Stadel, 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. They find that the distribution of lensing magnifications can be used to put additional constraints on cosmological parameters such as the matter density.

Quinn with Moore (Durham), Calcaneo-Roldan (Durham), Stadel, Lake, Ghigna and Governato (Milan) used their simulation of the Local Group to make quantitative and speculative predictions for direct detection experiments. They find that the singular cores of substructure halos always survive complete tidal disruption although mass loss is continuous and rapid. Extrapolating wildly to earth mass halos with velocity dispersion of 1 m s^{-1} (roughly equal to the free streaming scale for neutralinos) they find that most of the dark matter may remain attached to bound subhalos.

With Font (Victoria), Navarro (Victoria), Quinn and Stadel examined the suggestion that substructure in cold dark matter (CDM) halos may be in conflict with the presence of thin, dynamically fragile stellar disks by performing N-body simulations of a disk/bulge/halo model of the Milky Way that includes several hundred dark matter satellites. These simulations indicate that substructure plays a negligible dynamical role in the heating of the disk over several Gyrs. However, the disruption of disks due to mergers over the history of the galaxy remains a concern.

With Borgani (Trieste), Governato, Wadsley, Menci (Rome), Tozzi (Trieste), Lake and Stadel, Quinn conducted some high resolution simulations of galaxy clusters and groups, aimed at studying the effect of non-gravitational heating on the entropy of the ICM. They use observational results on the excess entropy in central regions of galaxy systems to constrain the amount of extra-heating required. They find that setting the entropy floor $S_f l = 50$ keV cm^2, which corresponds to an extra heating energy of about 1 keV per particle, is able to reproduce the observed excess of ICM entropy.

Wadsley, Stadel, and Quinn are continuing to improve ‘‘GASOLINE,’’ a scalable, parallel N-body and Smooth Particle Hydrodynamics code. A star formation and supernovae feedback recipe has been added. With Babul (Victoria) and Katz (Massachusetts), they will be using this code to study the formation and interaction of galaxies in a cluster environment with the aim of comparing with X-ray observations of clusters.

3. RESEARCH TOOLS

Stubbs continued as Telescope Scientist for the 3.5m telescope project. He is beginning design work on a true color camera for that telescope that uses dichroics and several CCDs for simultaneous imaging in several bands. Planning is starting to utilize the SDSS 2.5-m telescope for time-domains studies 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

George Wallerstein was named Henry Norris Russel Lecturer of the *American Astronomical Society* for 2002. Dalcanton became a Sloan Fellow. I. King received the degree of Laurea Honoris Causa from the University of Padua (24 June 2002). Balick became a Fellow of the AAAS.

Brownlee, Quinn, and Sullivan are a 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 a scientific meeting on η Carinae.

C. Stubbs and C. Hogan serve as members of the US science team for the Laser Interferometric Space Antenna (LISA), a trio of satellites that will be used to detect gravitational radiation from astrophysical sources.

Hodge is the Editor, and Lutz is the Associate Editor, of the *Astronomical Journal*. Szkody began her 3 year term as Scientific Editor of the Astrophysical Journal and serves on the Publication Board of the PASP. She is President of IAU Commission 42 (Close Binaries) and is the UW representative to AURA. Szkody has been elected to the AURA Nominations Committee and to the AURA Solar Observatory Council. She also serves on the MAST Users Committee. She was an invited speaker at Conferences in Germany (Physics of Cataclysmic Variables and Related Objects), Spain (International Conference on Classical Nova Explosions) and Italy (NATO Advanced Workshop on White

Dwarfs) as well as at Summer Schools for Undergraduate students in Ojai, California and for Graduate students in Lithuania.

Hawley continues 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 Astro-Seattle, which has changed into Project AstroBio with the inclusion of a broader range of classroom activities and of more biologists as partners. About 65 teacher/scientist partnerships throughout the Puget Sound region are now supported.

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 fourth year, includes 23 faculty in 9 departments and 18 graduate students. Approval was received for the Certificate in Astrobiology, which a student obtains in addition to his/her own department's Ph.D. Undergraduate courses in Astrobiology were also developed during the past year.

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 fireballs, 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.

J. Lutz received a five year grant from NASA to become an Office of Space Science Education Broker-Facilitator. The new organization, Space Science Network Northwest (S9N2), serves space scientists and educators in Washington, Oregon, Idaho, Hawaii, Alaska, Montana and Wyoming. Lutz served as Director of Manastash Ridge Observatory.

Bruce Balick, Chair