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This report summarizes activities during the academic year 1996-1997. For more detail please see the Department's web site at www.astro.washington.edu.

1. STAFF AND STUDENTS

During the Academic Year 1996-1997, the teaching faculty of the Department included Professors B. Balick, K. H. Böhm, P. Boynton, D. Brownlee, P. Hodge, C. Hogan, G. Lake, B. Margon, C. Stubbs, W. Sullivan, P. Szkody and G. Wallerstein. T. Jacobsen and E. Böhm-Vitense were faculty emeritus and G. Nelson was on leave. The research faculty included S. Anderson, W. Baum, and T. Quinn. Twenty-four graduate students were registered as members of the Department. T. Smith (UW), F. Governato (U. Rome), E. Magnier (MIT), D. Richardson (U. Virginia), A. Tomaney (Columbia), M. Rugers (UW), G. Gonzalez (U. Texas), V. Dwarkadas (U. Virginia) and F. van den Bosch (Leiden) were Research Associates. J. Hughes continued as Lecturer Part-Time, C. Impey (U. Arizona) as Visiting Professor, and H. Kang (Pusan U., Korea) as Visiting Scientist.

2. RESEARCH

2.1 Solar System

D. Brownlee and D. Joswiak are involved in a variety of laboratory investigations of interplanetary dust. This work ranges from isotopic measurements on micron-size grains to mineralogical studies at the 10 nm scale. Along with J. Bradley (MVA Inc, Georgia Tech.) and R. Pepin and D. Schlutter (U. Minnesota) they are studying the form and origin of He which is found at extraordinarily high concentrations in 10 micron interplanetary particles. It is likely the He was implanted by both recent solar wind and ancient processes.

Brownlee is the PI of the STARDUST Discovery mission to collect cometary and interstellar particles and return them to Earth. This mission is now in the assembly and test phase and is scheduled for launch in February 1999. In addition to returned samples, the mission will also provide high resolution images of comet Wild 2, dust flux measurements and time-of-flight mass spectrometer data on both cometary and contemporary interstellar dust grains.

D. Richardson is continuing work with G. Lake, T. Quinn, and J. Stadel on direct N-body simulations of the formation of the Solar System. They have modified a parallel kd-tree cosmology code to handle the unique demands of planetesimal dynamics simulation, namely collision detection and sensitive hierarchical time-steps. Preliminary tests of a single-stepping version on a local cluster of five 400-MHz DEC Alphas were in good agreement with state-of-the-art computations performed by a group in Japan using the HARP architecture. The goal is to run the code on a 512-node T3E, which will allow for practical simulations with $N \sim 10^6$, several orders of magnitude better than has ever been achieved in direct Solar System formation simulations. This project matches the broad goals of the NASA Origins initiative to study the origin of solar systems. It will help answer many long-standing questions regarding our own Solar System: (1) whether the planets grew from a uniformly-evolving mass distribution of planetesimals or from the runaway growth of just a handful of bodies; (2) whether planetary rotations and obliquities are the result of a gradual spin-up process or are simply determined by the last giant impact; (3) the nature and extent of radial mixing of rocky material in the mid to late stages of planet formation; and (4) the primordial surface density distribution. The study will also help determine the role giant planets play in the formation of terrestrial planets, which may serve as a guide for future searches for planets like our own.

Richardson is continuing to study the dynamics of asteroid-sized rubble-piles, with collaborators W. Bottke (Cornell) and S. Love (NASA/JPL). There is mounting evidence that small bodies in the Solar System, particularly comets and Earth-crossing asteroids (ECAs), are fragile rubble-piles: comet Shoemaker-Levy 9 (SL9) was tidally disrupted near Jupiter; C-class asteroid 253 Mathilde has a remarkably low density (1.3 g cm^{-3}); of 107 asteroids smaller than 10 km, none has a rotation period shorter than 2.27 h, suggesting they lack strength; and numerical hydrocode simulations, used to model large crater-forming events on Phobos, Gaspra, and Ida, suggest that rubble-piles survive impacts better than solid rock. Using a numerical code that has been successfully applied to studies of planetesimals and planetary rings, Richardson and his colleagues have found that planetary tides play a significant role in the evolution of rubble-piles in the terrestrial planet region. Depending primarily on the close-approach distance, encounter velocity, and net spin, and less importantly on bulk density, spin orientation, and overall shape, such bodies encountering a planet can: (1) undergo catastrophic SL9-type disruption, which could lead to the formation of crater chains on the planet's moon(s); (2) suffer a fission event, leading to formation of binary asteroids and doublet craters; (3) experience milder mass loss but with significant body reshaping, which could explain the strange shapes of asteroids such as 1620 Geographos; or (4) suffer a mild change of shape and/or spin without mass loss, making the body more susceptible to tidal disruption on a subsequent pass. This is a rich field of study and there is much more work to be done. For example, it is possible that the Martian moons were formed by tidal stripping of a large asteroid on a near parabolic trajectory. This and other ideas are being investigated.

Quinn *et al.* are integrating the orbits of the planets over the lifetime of the Solar System. This is 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, they will gain insight into fundamental questions of non-linear dynamics. In particular, the Solar System displays a small instability with a time-

scale of 5 Myr. What this means for the evolution of the system over 5 Byr is not clear, but is something they can answer with this integration. Additional products of their 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 to the massive planets that can be detected in other planetary systems. At this time, the integration has completed 200 million years backward in time, and 20 million years forward. This is about 30 times longer than previous accurate integrations of the planets.

Stadel and Quinn are looking at methods for integrating the Solar System on a massively parallel machine. The obvious problem is how to put thousands of processors to work on only 9 planets. One solution is to parallelize the problem over time using a waveform relaxation technique. Each processor is given planet positions at different times as predicted by Keplerian orbits. The planetary perturbations are then calculated in parallel and accumulated across the processors.

Quinn is investigating the stability of the outer planets of the Solar System over billion year timescales. Of particular interest is the sensitivity of stability to the planetary orbital parameters such as eccentricity and inclination. He has found that by increasing the initial eccentricities of the outer planets by only 50%, Uranus will be ejected on a 100 million year timescale. Large scale chaos is evident in the outer planets if the eccentricities are increased by only 30%. These results have implications for the significance of the recent discoveries of planets around other solar-like stars.

Quinn continues to lead the working group for Solar System science within the Sloan Digital Sky Survey. This group 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 5 color photometry of the SDSS will bring new light to the orbital dynamics, taxonomy, and origins of these objects. M. Hammergren has chosen a set of well known ''standard'' asteroids to be used as taxonomic calibrators for the Sloan color set. A program has been initiated to obtain Sloan photometry for these objects so that Sloan colors can be tied into other asteroid classification systems.

T. Smith and P. Hodge continued their terrestrial impact crater sampling program by completing an extensive sampling of the Dalgaranga impact crater in Western Australia. A total of 260 samples were collected from the crater. The Dalgaranga crater is unique in that it is the only terrestrial impact crater known to be caused by a stony-iron meteorite. Preliminary analysis of the samples shows they contain large numbers of microscopic meteoritic fragments. Laboratory work is also continuing on samples collected from the Odessa craters in Texas. Impactite particles first discovered near the main crater rim have now been found in samples at distances of up to 1 km from the crater. Microscopic meteoritic particles are found in nearly all the soil samples within 700 meters of the main crater. The meteoritic material's integrated mass is at least 1000 kg.

2.2 Stars and Compact Objects

A. Layden (U. Mich.) and S. Wachter obtained extensive photometry of the suspected cataclysmic variable CG Muscae and find that it is in fact an RR Lyrae star. From measurements of its light curve, physical parameters such as metal abundance, reddening and distance are derived. They also report on the discovery of three new variables in the nearby field.

E. Deutsch, B. Margon, and S. Anderson continued their work on optical identifications of intense X-ray sources in the cores of globular clusters. A large fraction of all sources not significantly obscured by extinction are now identified. The candidate identification in NGC 6441, originally suggested on the grounds of position and peculiar colors in HST photometry, has now also been found to be time-variable in HST photometric data. Thus despite the rather high incidence of faint UV-excess objects in this cluster, the NGC 6441 source is probably correctly identified. A candidate has now also been found for the central X-ray source in NGC 6552; it will require further study, as although its unusual UV colors and magnitude agree well with identifications in other clusters, the position of this object is just at the limit permitted by the ROSAT HRI X-ray data.

Anderson and Margon obtained Rossi X-ray Timing Explorer observations of the intense central X-ray source in NGC 6624, the shortest known period binary star. Most of the data were obtained simultaneously with HST observations, which they have already reported to mirror in UV light the 11-minute orbital oscillation first seen in X-rays. Analysis of this unique simultaneous observation may permit comparison of the X-ray and UV phases, spectral changes, etc.

Margon, Anderson, and Wachter obtained HST NICMOS infrared imaging of the field of the intense galactic X-ray source GX17+2 (=X1813-14). Although for decades the 17th mag G star NP Ser has been suggested as the possible optical counterpart of this prototypical low-mass X-ray binary, that object shows no optical anomalies. As Deutsch *et al.* have also demonstrated that the variable radio source probably associated with the X-ray object agrees only poorly in position with NP Ser, contrary to previous conclusions, the possibility that NP Ser is an unrelated superposition now seems quite attractive. The NICMOS data may reveal other, obscured candidates quite close to the brighter star.

Margon and Deutsch, with J. Bland-Hawthorn (AAO), obtained time-resolved photometry of V2116 Oph, the unusual optical counterpart of the 120-second X-ray pulsar GX1+4, in the strong O I λ8446 emission line of the symbiotic-like primary star. The objective is to search for synchronous optical pulsations reprocessed from the incident pulsed X-ray flux. An innovative use of the AAT Taurus Tunable Filter in charge-shuffle mode permitted very high throughput photometry in a narrow band which isolates the emission line. Preliminary analysis indicates, despite very poor observing conditions, an upper limit of a few percent on these pulsations.

Wachter obtained extensive VRI photometry of the low mass X-ray binary and Z-source GX 349+2. The data reveal a period of 22.5 ± 0.1 h and half-amplitude 0.2 mag. This result confirms and extends the 22 h period previously re-

ported by Wachter & Margon. No color change is detected over the orbit, although the limits are modest. In order to measure the mass function of GX 349+2 and determine its emission region geometry, Wachter and D. Hoard obtained simultaneous photometry and spectroscopy with the CTIO 0.9m and 4m telescopes.

Wachter reported observations of the intense persistent X-ray burst source Ser X-1. The faint blue optical counterpart MM Ser has long been known to have a companion 2.1″ distant. The new images indicate that MM Ser is itself a further superposition of two stars, separated by only 1″. At the very least, the ratio of inferred burst to quiescent optical flux is affected by the discovery of this additional component. In the worst case, the wrong object may have previously been assumed as the optical counterpart.

A. Smale (NASA/GSFC) and Wachter performed simultaneous optical/IR and X-ray studies of the three X-ray dipping sources X1254-690, X1323-619, and X1624-490, utilizing the CTIO 1.5m telescope and the Rossi X-ray Timing Explorer. The goal of the campaign is to determine the energy budgets of each system, test current models of the optical reprocessing regions, and measure the size of the emitting/obscuring regions. Monitoring of the field of X1624-490 also revealed an optical/IR candidate counterpart.

E. Böhm-Vitense, together with B. Beck-Winchatz, N. Evans (CfA), K. Carpenter (GSFC), R. Robinson (CSC), P. Cottrell (Mt. John U. Obs.), and M. Albrow (S. African Astron. Obs.), has used HST/GHRS spectra to determine the dynamical mass for the Cepheid V636 Sco, which was previously observed with IUE and found to have a B9.5 V companion. The derived dynamical mass for the Cepheid came out to be $3.1 \pm 0.4\ M_{\odot}$, which is surprisingly low for its pulsation period of 6.8 days. They therefore suspect that the companion may itself be a binary, in which case the analysis gives the wrong result.

Together with the above mentioned collaborators and S. Morgan (U. of N. Iowa) Böhm-Vitense also determined the dynamical mass of the beat Cepheid Y Carinae, which is the only beat Cepheid known to have a companion. The beat mass, determined from the ratio of the beat periods, (using models calculated by Morgan, incorporating the OPAL opacities), comes out to be $3.85 \pm 0.05\ M_{\odot}$ in agreement with the dynamical mass, thereby arguing for the validity of the OPAL opacities.

Böhm-Vitense, Carpenter, Robinson, T. Ake and J. Brown (Washington State U.) continue their investigation of short wavelength HST/GHRS spectra of Ba and CH peculiar stars in order to study the suspected white dwarf companions. If the ''subgiant CH'' star HD 89948 has a white dwarf companion it is too faint to be observed. The Hipparcos parallaxes of this ''subgiant'' CH star and the comparison ''G5IV'' star HD 157347 show that both stars are actually main sequence stars. Böhm-Vitense and collaborators also study the ultraviolet emission line spectra of the Ba and CH peculiar stars in comparison with those of non-peculiar stars. The ratios of the carbon and silicon emission line fluxes confirm the carbon abundance peculiarities.

P. Szkody continued collaborations with E. Sion (Villanova) on the heating of white dwarfs in disk and magnetic cataclysmic variables under support from the NASA LTSA program. Using Hubble Space Telescope GHRS observations of the dwarf nova VW Hyi taken one month after the end of an outburst, Szkody with F.H. Cheng and M. Huang (Villanova), W. Sparks (LANL) and I. Hubeny (GSFC) found a surprisingly strong line of phosphorus at 1250A. The high P abundance (900 solar!) required to fit this line, together with elevated Al abundances from previous observations, suggest a hot thermonuclear runaway in the past. This provides the first spectroscopic link between a dwarf nova and a classical nova. Quiescent GHRS spectra of the ultrashort period (81 min) dwarf nova WZ Sge showed a rapidly rotating white dwarf (V sin i of 1200 km/s), which is an order of magnitude larger than the rotational velocity of the 4 hr period dwarf nova U Gem. This is contrary to the expectations that the fastest rotation would occur in the oldest (shortest period) systems from spinup by accretion. Analysis of FOS observations of AL Com from 10-14 months past outburst with Sion, Sparks, Cheng, Hoard and S. Howell (U. Wyoming) indicate a cooling sequence about half as long as WZ Sge, consistent with non-spherical accretion via an equatorial belt. Spectral line variations were apparent in both the UV and ground-based optical data, indicating changing visibility of a non-uniform disk or of a secondary star irradiated by the white dwarf.

IUE and Voyager observations of the cataclysmic variable S193 by Szkody with P. Garnavich (CfA), A. Silber, L. Pastwick, and J. Holberg (U. Az.) showed peculiarities of the line spectrum both at high and low states which provide further circumstantial evidence for the existence of a disk and a magnetic white dwarf in an intermediate polar system.

A coordinated EUVE, RXTE, and ground-based campaign of the highest field magnetic cataclysmic variable (AR UMa) during a high state took place by Szkody, G. Schmidt (U. Az.) and M. Wagner (OSU). The large increase in flux over previous low state observations will be used to study the accretion characteristics under the high field regime.

Analysis of data on a coordinated RXTE, ROSAT, EUVE, IUE and ground campaign covering the 45 day supercycle of the dwarf nova system V1159 Ori by Szkody, Hoard, Silber, Pastwick, Hubeny, K. Honeycutt and J. Robertson (Indiana U.), J. Cannizzo (GSFC), J. Drew (Oxford), and C. la Dous (Sonneborg) showed an inverse correlation between the soft and hard X-ray and optical-UV fluxes during each outburst cycle. There was no evidence of the EUV component expected to originate from the boundary layer during outburst.

Coordinated RXTE and ground-based APO and WIYN observations of the old novae V841 Oph and DI Lac by Szkody, Honeycutt and Robertson were accomplished over 40 day intervals to monitor the quasi-periodic cycles evident from long term optical photometry. These data will provide information to understand this behavior in comparison to the accretion cycles of dwarf novae.

Optical spectra of the magnetic cataclysmics RXJ0757 +6306 and RXJ0719+6557 and the disk systems EG Cnc were obtained by Szkody and G. Tovmassian (UNAM) with the 3.5m APO telescope to study the location of emission

zones in magnetic systems and in disks following long, extended outbursts. RXJ0757+6306 showed a very strong s-wave with an orbital period close to the limit for H secondaries (81 min). EG Cnc showed a strong emission line flux modulation throughout its 85 min orbit and different spectral characteristics from quiescence, indicating the system was greatly affected for months past its superoutburst.

CCD photometry at MRO by Szkody and Hoard was combined with photometry from Israel by E. Liebowitz and A. Retter (Wise Observatory) to obtain continuous 20 hrs of coverage for several nights. These data showed a repeatable sinusoidal 5.5 hr variation in this nova 3 yrs past outburst. Further data will be obtained during the decline to study how the irradiated secondary changes as the nova returns to quiescence.

Hoard and Szkody continued their investigation of the SW Sextantis subclass of cataclysmic variables. With M. Still (U. St. Andrews), R. Smith (Sussex), and D. A. H. Buckley (SAAO), they studied the SW Sex star UU Aquarii, and suggest a relation between the orbital phase at which the transient absorption feature appears in the emission lines of the SW Sex stars and their mass accretion rates. With A. Linnell (MSU/UW) Hoard and Szkody developed a software suite that will be used to calculate orbital-phase-resolved model light curves and spectra of cataclysmic variables.

Hoard, B. Rodgers, and D. Alves (LLNL) obtained the first infrared image of IRAS 06562-0337 and showed that this object, which was previously thought to be a protoplanetary nebula in the short-lived evolutionary zone between the post-asymptotic giant branch and planetary nebula stages, is actually an embedded cluster of approximately $>$50-100 young stars with an extended central object which is likely a massive Herbig Be star.

Hoard, Szkody, R. Baptista (UFSC), M. Eracleous (UC Berkeley), K. Horne (U. St. Andrews), K. Misselt (LSU), A. Shafter (SDSU), and J. Wood (Keele) used high time resolution HST Faint Object Spectrograph ultraviolet spectra of the dwarf nova IP Pegasi to study the relation between flickering in the spectral lines and continuum. Their findings show that flickering is not coupled between the UV lines and continuum, nor between some UV emission lines of different excitation, suggesting a multiple emission zone model.

Hoard, Rodgers, T. Burdullis, L. Machado-Pelaez, M. O'Toole, and S. Reed investigated the photometric flickering behavior of the hot component in the symbiotic star CH Cygni. They find variability at timescales suggestive of disk-accreting systems, and a cessation of flickering during the optical minimum of 1996.

During the past year G. Wallerstein has completed two major abundance analyses. He and C. Abia (U. Grenada, Spain) have completed the analysis of heavy elements in 7 SC stars. For most of the heavy, s-process, elements the enhancement is about a factor of 10. They studied the 5924 Å line of Tc very carefully. It seems to be present but so heavily blended that quantitative Tc abundances could not be derived. The Rb/Zr ratio showed that the neutron density during s-processing ranged from 10^6 to $\lesssim 10^8$ cm^{-3} for the SC stars. These neutron densities favor the ^{13}C source for the neutrons as compared with the ^{22}Ne source.

G. Gonzalez and Wallerstein, with four other authors, completed an analysis of the light and spectral variations of the unique variable, FG Sge. The star appears to now be an R CrB star that shows obscuration events as large as seven magnitudes. The C_2 bands are quite strong and go into emission during minimum light. The excess of rare earths over iron is a factor of 1000, which is larger than for any known evolved stars. The Na D-lines show that mass-loss is occurring at a velocity of about 200 km/sec. A spectrum of the possibly similar star discovered by Sakarai was obtained with the 4-m echelle at CTIO. Wavelength measurements revealed the presence of 125 lines of CI. The data are being combined with spectra obtained by M. Shetrone (ESO) and M. Keane (CTIO).

Gonzalez and D. Lambert (U. Texas) completed an abundance analysis of five luminous Cepheids in globular clusters. In M5 V84, 19 elements were studied. That star shows a deficiency of O and an excess of Na and Al as seen in many globular cluster red giants. The stars with RV Tau-like light curves do not show evidence of element separation due to grain explusion, which is seen in RT Tau stars of the general field.

Wallerstein and Gonzalez have completed the acquisition of high resolution spectra of M supergiants in the young open cluster h and χ Persei. Wallerstein has been assigned observing time to obtain spectra of similar stars, but with a significantly lower metal content in the SMC cluster, NGC 330.

P. Boynton, in collaboration with J. Deeter and J. Swank (GSFC), has observed SMC X-1 with Rossi XTE, and is currently engaged in analyzing these data to see whether there is a correlation between X-ray luminosity and mass-accretion torque on the pulsar. Boynton and Deeter are also revisiting the optical observations of HZ Her (Her X-1), with the goal of placing limits on the obliquity of the pulsar with respect to the orbit axis of this system.

2.3 Interstellar Material and Ejecta

V. Dwarkadas and R. Chevalier (U. Va.) completed research on the interaction of Type Ia supernova remnants (SNRs) with their surroundings. They find that the ejecta density profile is exponential in the free expansion stage. The interaction of a SNR with this ejecta density profile running into the ambient medium has been modelled and successfully applied to two historical SNe, SN 1006 and SN 1572.

Dwarkadas and B. Balick submitted their work on the evolution of proto planetary nebulae (PPNe) in which the evolution of the wind properties is incorporated. The nebula first goes through a radiative momentum-conserving stage before entering the more familiar energy-conserving stage. The formation and growth of instabilities in both stages is studied and compared to the observed small-scale structure in PNe.

Balick, Y. Terzian (Cornell), A. Hajian (U.S. Naval Obs.) and M. Perinotto continue to analyze images of FLIERs in planetary nebulae obtained with narrow band images on the HST. The morphological properties, coupled with ionization and kinematic studies from the ground, cannot be explained by standard paradigms of outflows or shocks.

Balick, V. Icke (U. Leiden) and G. Mellema (Stockholm Obs.) have begun analyzing narrowband images of selected bipolar planetary nebulae, hoping to understand how the collimation of the outflowing gas can be understood hydrodynamically.

Balick, A. Riera (Barcelona), K. Xilouri (NAIC) and Terzian are investigating the abundances in large planetary nebulae with very low ionization. They cannot confirm earlier reports of large abundance gradients in some of these objects. Observations will continue through much of 1998.

Balick, along with Mellema and A. Raga (UNAM) are modelling the evaporation flows from dense neutral knots bathed in ionizing radiation. They find a complex set of morphological changes occur inside the knot as well as in the evaporated gas. They hope to develop the model to account for the observed ionizations and velocities of FLIERs.

Balick, with Hajian and Terzian, completed their spectroscopic studies of abundances in additional PNe with FLIERs. They found that pairs of adjacent FLIERs have radically different velocities, a completely unexplainable result unless unlikely projection effects or very complex hydrodynamical processes are highly significant.

Dwarkadas and Balick with K. Davidson (U. Minnesota) and a larger team are studying the luminous blue variable star Eta Carinae. They are exploring the formation of the Homunculus Nebula around Eta through numerical simulations. These simulations are meant to reproduce both the large-scale morphology and kinematics as well as the small-scale surface structure.

Dwarkadas, A. Frank (U. Rochester) and Balick are studying the formation of jets and collimated outflows in PNe. Following up on an earlier suggestion by Frank *et al.* (1995), their simulations explore whether such collimated outflows can indeed form in the proto-PN phase, and if so trace their subsequent evolution.

Dwarkadas is working on models of the formation of nebulae around massive stars, using data provided by N. Langer. The explosion of the star as a SN and the subsequent interaction of the resultant blast wave with the circumstellar medium are being investigated.

Dwarkadas, along with P. Lundqvist (Sweden), is working on obtaining spectra of Type Ia SNe in the first 100 days after the explosion, using an exponential ejecta density profile for the SN ejecta.

A. Goodson, R. Winglee (Geophysics, U. of Wash.) and K.H. Böhm have been studying a time-dependent jet launching and collimating mechanism for YSO. They have obtained numerical simulations of the interaction between an aligned dipole rotator and a conducting circumstellar accretion disk which is initially threaded by the dipole field of the star. A hot, well collimated outflow is generated by the flow towards the rotation axis, while a cool slower outflow is produced near the disk. Episodic magnetic reconnection allows the process to repeat.

Garnavich, A. Noriega-Crespo (IPAC), Raga and Böhm have been studying the 2.121μ narrow band H_2 images and the H_2 spectra of a highly collimated bipolar jet near the IRAS 05487 + 0255 source. The jet extends over 40″. It is visible only in H_2, not in any atomic or ionic HH lines.

Böhm and J. Solf (Tautenburg, Germany) are extending their detailed position-velocity diagram studies of the environment of T Tauri. The purpose is to obtain additional information about the kinematics and the ionization and excitation state covering extended regions of this area in the atomic and ionic lines, and relating this new information to the results obtained from H_2 emission (see Herbst *et al.*, AJ, 114, 744, 1997).

2.4 The Galaxy

Baum and Hammergren have continued their work on the stellar population in Baade's Window, which is a field of relatively low obscuration only about 4 degrees from the direction to the Galactic center, and which is important for studying the stellar population of the Milky Way bulge. They have revised their map of interstellar extinction in that field. They find the V-band extinction to be 1.27 mag at the position of the deepest HST-WFPC2 observation, where the luminosity function is being derived in collaboration with WFPC team colleagues. The extinction analysis is based on groundbased CCD frames kindly made available by the OGLE group.

Kang, D. Ryu (on leave from Chungnam National U.) and Lake examined the dynamics of thermal instabilities in protogalaxies. Such instabilities have been proposed as a formation mechanism for globular clusters, but the characteristic masses found by earlier calculations were roughly 30 times too large. The new calculations found that clouds which cool isobarically to produce classic two-phase media are too small to be Jeans unstable. Clouds that cool isochorically experience shocks in their late stages of evolution that reduce the Jeans mass to a value that matches present-day globular clusters. They have begun a follow-on study of the enrichment of the clouds by supernovae.

The University of Washington continues its significant participation in the MACHO project, a search for Galactic dark matter via gravitational microlensing. C. Stubbs is one of the project's Principal Investigators, and graduate students M. Pratt and A. Becker work with D. Reynolds of the UW technical staff as members of the MACHO team. This year they were joined by A. Tomaney who will be working to extract more events from the MACHO dataset using the techniques of frame subtraction photometry. The project uses a dedicated telescope at the Mount Stromlo Observatory in Australia and a dual color 32 Mpixel mosaic CCD camera to monitor over 20 million stars per night to search for the transient brightening that is the signature of gravitational microlensing.

They continue to detect ongoing microlensing events well before peak amplification. This past year they detected many instances where the point-source, point-lens approximation to lensing broke down, introducing fine structure into the light curves. Coordinated from the University of Washington (by Becker), they obtained frequent coverage of ongoing microlensing events from a variety of telescopes in the Southern hemisphere.

The MACHO project is in the process of reducing a data set spanning 4 years of observations in the Magellanic Clouds, which should reduce the uncertainties in the optical

depth determination to the LMC. They have recently reported the first observation of lensing towards the SMC, and this will help constrain models of the lensing population(s) they have detected.

2.5 External Galaxies and QSOs

Beck-Winchatz and Anderson are analyzing multicolor CCD images obtained from the ARC 3.5m, and WFPC2 images from HST, to establish a new sample of ultrafaint ($m<24$) quasars. Their approach significantly reduces morphological contamination by faint galaxies, a prominent difficulty encountered by most other surveys for ultrafaint QSOs. The sample ultimately will be used to probe the faint end of the logN-logS curve and the luminosity function, constraining global models for the evolution of the QSO population.

Margon and Deutsch discovered that the poorly-studied, $m\sim19$ variable star CC Boötis, which has been noted in the literature as a candidate for a halo red giant, proves instead to be a quasi-stellar object of redshift $z=0.172$, and thus is 10^{10} more luminous than its cataloged classification. It is also detected as an X-ray source by ROSAT. In addition to its odd heritage, CC Boo exhibits unusually high amplitude optical variability for an optically-selected QSO.

Margon and Deutsch, collaborating with D. Lamb and F. Castander (Chicago), used the ARC 3.5m telescope to successfully image the optical transient associated with the gamma-ray burst GRB 970228. This detection of the fading fireball at $m\sim23$, made 3 days after the burst, was one of the few ground-based detections of the event. If this case was typical, 4m-class telescopes can reach at least some bursts even after a delay of several days, an important tactical issue when deciding how to follow future events.

Baum and Hammergren, together with some colleagues on the HST-WFPC team, derived the distance of the Coma Cluster and the associated value for the Hubble Constant, based on deep WFPC2 exposures of the bright Coma elliptical, IC 4051. They compared the turnover magnitude of the globular cluster luminosity function (GCLF) in IC 4041 with GCLFs in the Milky Way, in M31, and in the Virgo elliptical M87. Absolute magnitudes therefore rest ultimately on the zero-points of RR Lyraes and of classical Cepheids. Assuming pre-Hipparcos values for those, they inferred a Coma distance of 105 $\pm$ 6 Mpc and an associated Hubble Constant of 68 $\pm$ 6 km/s per Mpc, consistent with their earlier paper on the GCLF in NGC 4881.

Baum and Hammergren collaborated on a project headed by B. Thomsen (U. Aarhus, Denmark) using deep HST-WFPC2 observations of the bright Coma elliptical NGC 4881 to derive the distance of the Coma Cluster from I-band surface brightness fluctuations (SBF) by comparing them with SBF data in the much nearer Leo elliptical NGC 3379. They obtained a Coma distance of 102 $\pm$ 14 Mpc, which is very similar to their GCLF value.

Baum collaborated with S. Sakai (IPAC, Caltech) and several others on the detection of the tip of the red-giant branch (TRGB) in deep HST-WFPC2 frames in the halo of the Leo-Group elliptical NGC 3379. The bright end of the luminosity function in NGC 3379 is found to have a slope consistent with that for Population II red giants, and the TRGB implies a distance of 11.5 $\pm$ 1.6 Mpc. Taking Virgo infall into account and stepping out from Leo to the Coma Cluster, these results yield a Hubble Constant of 68 $\pm$ 13 km/s per Mpc.

Baum participated in a WFPC-team study headed by C. Grillmair (JPL, Caltech) on the V-I color-magnitude diagram of the stellar population in M32, the elliptical companion of M31, derived from deep HST-WFPC2 exposures. The color-luminosity distribution of the red giants argues for a very broad spread of metallicity, namely [Fe/H] from -1.5 to $+0.1$, but it cannot be interpreted unambiguously regarding the distribution in ages.

Hodge, B. Skelton and J. Ashizawa completed their ''Atlas of Local Group Galaxies,'' to be published both as a book on paper and electronically. It identifies most recognized components (variable stars, star clusters, HII regions, etc.) in 27 Local Group galaxies, all of those for which identification atlases have not previously been published.

Hodge, J. Balsley, T. Wyder and Skelton prepared a catalog of 1246 new HII regions in M33, bringing the total number of cataloged HII regions in the galaxy to near 2000. The luminosity function of these objects is now complete to values as faint as 10^{34} ergs/sec.

Skelton, with Hodge, is continuing her study of the energetics of giant HII regions in M33. Her sample includes seven of the brightest HII regions imaged in the emission lines of Hα, Hβ, [SII]6717,6731, and [OIII]5007. The data include not only the bright cores of these objects, but also the extended halos which contribute to the diffuse ionized gas seen throughout the galaxy. In collaboration with W. Waller, S. Heap, and E. Malumuth (all of GSFC), the radial distribution of nebular properties is being correlated with the stellar population of the ionizing cluster as well as with models of the diffuse emission.

Skelton and E. Magnier have recently begun a collaboration with R. Bontekoe and L. Waters (U. of Amsterdam) to study deconvolved IRAS images of M33.

K. Olsen and Hodge, in collaboration with N. Suntzeff, A. Walker, R. Schommer (CTIO), E. Olszewski (U. Az.), and M. Mateo (U. Mich.), produced and analyzed V-I,V color-magnitude diagrams from HST WFPC2 data of six red globular clusters in the Large Magellanic Cloud. They find that the clusters are indeed old, having very similar color-magnitude diagrams to those of the Milky Way globular clusters M3, M5, M13, and M55, in particular. Fitting of model stellar isochrones, while not as accurate as comparing to fiducials, also yields ages as old as those of the Milky Way globulars.

Olsen, working with Hodge, continued using the LMC cluster HST data to study the star formation history of the field stars. In a poster paper presented at the AAS meeting in Winston Salem, NC, they, along with collaborators A. Dolphin, Suntzeff, and Walker, showed that a model incorporating a recent burst in the star formation rate 10 times above average, as has been measured in other studies, does not fit the color-magnitude diagram of field stars near NGC 1754. Rather, a model using a constant star formation rate over the age of the LMC seems to provide a better fit.

Olsen, Hodge, E. Wilcots (U. Wisc), and L. Pastwick (U. Wyom.) published a paper on the age of the association LH72, which lies at the geometric center of Constellation III in the LMC. Using IUE spectra and CTIO photometry of seven stars, they find a progression in age N-S along the association, with the oldest stars at the northern end of the association having an age of $\sim$15 Myr and the youngest stars at the southern end $\sim$5 Myr, suggesting propagating star formation. They interpret their results in light of the model of M. Dopita (MSSSO) and others, in which Constellation III, a supershell with a diameter of $\sim$1.5 kpc, is suggested to be a region of self-propagating star formation with an expansion age of $\sim$15 Myr.

Wyder, D. Zucker, and Hodge are studying a supernova remnant that is coincident with an X-ray source in the Local Group galaxy NGC 6822. They have obtained low- and moderate-resolution long-slit spectra of the object with the APO 3.5m telescope, and are analyzing the spatial dependence of emission-line ratios within the remnant.

Zucker, Hodge, and Wilcots are engaged in a multiwavelength study of star formation, stellar populations, and gas dynamics in the Local Group starburst galaxy IC 10. As part of the study, they have used the APO 3.5m to obtain low-resolution spectra and broad-band photometry of a number of peculiar variables in the galaxy.

Wyder, Dolphin and Hodge used archival HST data in two colors to study the stellar populations in a spiral arm of the Virgo Sc galaxy NGC 4321. Using Dolphin's program to solve for the star formation histories in the arm and interarm regions separately, it was found that the data are consistent with a constant star formation rate in the interarm regions while the stars in the spiral arm show a star formation rate in the last 5 million years that is four times larger than in the adjacent interarm regions.

Dolphin continued work on a new method for determining star formation histories in nearby galaxies, which uses a numerical fitting algorithm to determine the most likely star formation history. This project is in an early stage, and will be continued this year by applying the method to observed data. In collaboration with D. Hunter (Lowell), Dolphin obtained UBV photometry of seven fields in and outside Shapley Constellation III in the LMC. Initial analysis has been done, and this project is also continuing.

2.6 Cosmology

Quinn, Stadel, and Lake continue to analyze their large simulations of the Sloan Digital Sky Survey 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). Quinn, Lake, I. Szapudi (Fermilab) and A. Stebbins (Fermilab) are analyzing the large scale structure statistics of these simulations, such as counts-in-cells, high order correlation functions and weak lensing.

J. Gardner and Quinn with N. Katz (U. Mass.), D. Weinberg (OSU), and L. Hernquist (UCSC) are using simulations to calculate the amount of Lyα absorption predicted by various cosmological models. By comparison with absorption seen in observed QSO spectra, they are able to rule out certain models for structure formation.

Quinn, Stadel, and Lake with B. Moore and F. Governato (Durham) have examined the effects of mass resolution and force softening on the density profiles of cold dark matter (CDM) halos that form within cosmological N-body simulations. As the mass and force resolution are increased, the halo profiles become steeper and denser in the central regions and do not converge to a unique result. These steep inner density profiles, $\rho(r) \sim r^{-1.4}$, will prove problematic for the CDM model when compared with the observed properties of halos on galactic and cluster scales.

C. Hogan continued studies of the observational tests of Big Bang Nucleosynthesis. With K. Olive and S. Scully (U. Minnesota) he developed a new Bayesian approach to discounting the stellar helium enrichment in extragalactic HII regions to get general model independent bounds on the primordial abundance of helium. With M. Rugers and Y. Levin (Yeshiva U.) he continued statistical studies of deuterium abundances in quasar absorption systems, especially statistical measures of the effect of hydrogen contamination on measured abundances. Current studies include calibration of errors and biases using TreeSPH simulations.

Hogan and Anderson continued study of high redshift helium absorption, including limits on abundances and on the density of the diffuse gas. Their cycle 7 HST program will address the optical depth of the absorption in the bulk of velocity space at higher resolution and better background subtraction than previous programs, which will determine not only the density of the gas but the homogeneity of its early ionization history.

Hogan, M. Fukugita (Tokyo) and P. J. E. Peebles (Princeton) elaborated on their earlier study of the global density of baryons in various states. The bulk of observed baryons appear to be in hot gas with stars and their remnants being only a minor contribution.

D. Reiss, A. Diercks, Stubbs and Hogan continued their participation in an international team studying high redshift supernovae and using them to constrain cosmological models. The first results of a successful campaign including HST produced a Hubble diagram extending to $z = 1$.

Reiss, Hogan and Stubbs are continuing their work with B. Schmidt and L. Germany (Mt. Stromlo Observatory) to search for supernovae in Abell clusters. The objectives of the project are to measure the luminosity function of SNe, to explore the correlation of spectral characteristics and light curve shape with their absolute luminosity, to measure the bulk motion of the Local Group using SNe Ia as distance indicators, and to directly compare SN Ia distances with brightest cluster galaxy distances.

3. MISCELLANEOUS

The Department continued to host the editorial office of the Astronomical Journal, with Hodge continuing as Editor.

Szkody served as AAS Councilor, Vice President of IAU Commission 42 (Close Binaries), AAAS Member-At-Large, and member of the HEAD Executive Committee.

Margon continues as Chair of the Board of Directors of the Association of Universities for Research in Astronomy

(AURA), and was also elected by that body as the first Chair of its Member Representatives.

As Chair of the AAS Historical Astronomy Division, Sullivan led the effort to establish the new LeRoy E. Doggett Prize for Historical Astronomy. Sullivan became President of IAU Commission 50 (Protection of Observatory Sites). Sullivan is director of Project ASTRO in Seattle; in its first year it has matched and trained 25 professional and amateur astronomers with grades 4-9 teachers to enhance science education in the Seattle area. Sullivan is leading a campus interdisciplinary effort on the topic of ''Planets and Life,'' designed to foster research on the origin and development of life on Earth and on extraterrestrial sites.

Hogan completed a primer on modern cosmology which will be published in 1998 by Springer-Verlag. He was elected as a Trustee of the Aspen Center for Physics.

4. RESEARCH TOOLS

The UW Telescope Engineering Group (P. Waddell, W. Siegmund, E. Mannery, R. Owen, M. Evans, S. Limmongkol, R. Leger, F. Toevs, L. Carey) continues its work on the Sloan Digital Sky Survey. The focus is now on integration of the optics and control system of the 2.5m telescope.

Margon and Anderson continued their participation on the High Throughput X-ray Spectroscopy (HTXS) mission study team, lead by H. Tananbaum (CfA) and N. White (GSFC). HTXS is now on NASA's Space Science Strategic Plan as one of a handful of missions under consideration for possible new near-term starts, and features a very large collecting area (obtained by launching six identical modest-sized satellites) across a broad X-ray bandpass, along with sophisticated instrumentation for high resolution X-ray spectroscopy.

Margon was selected by NASA as a member of the Next Generation Space Telescope Ad Hoc Science Working Group.

P. Doherty, Diercks, Magnier and Stubbs delivered a novel wide field drift scanning camera (dual 2K x 4K CCD's) to the Lowell Observatory for use in the Lowell Observatory Near Earth Object Survey. The system is being integrated into the telescope control system and test images are being obtained. They hope to be in full operation, generating over 20 GBytes of data per night, by the end of calendar 1997.

Craig J. Hogan, Chair