This report covers the period 1 September 1992 to 31 August 1993.

I. PERSONNEL

During this time the departmental faculty consisted of Steven A. Balbus, Roger A. Chevalier, Laurence W. Fredrick, Samuel J. Goldstein, John F. Hawley, Philip A. Ianna, Shiv S. Kumar, Robert W. O'Connell, Mercedes T. Richards, Robert T. Rood, Craig L. Sarazin, William C. Saslaw, Trinh X. Thuan, Charles R. Tolbert, and D. Mark Whittle. Hawley and Richards were promoted to the rank of Associate Professor with tenure effective 1 September 1993.

The Virginia Institute for Theoretical Astronomy (VITA) continued operations during this period with support from the University of Virginia and a NASA Astrophysical Theory Program Grant. Postdoctoral fellows in the theory group were Dimitris Christodoulou, Ben Dorman, Charles Gammie, and Ding Luo. Shlomi Pistinner arrived as a Fulbright Fellow at the end of this period. Suketu Bhavsar, Roger Blandford, John Blondin, Andrei Bykov, Alex Filippenko, Chanda Jog, Valentin Lipovetsky, Bohdan Paczynski, James Stone, Vadim Urpin, and Lifan Wang were VITA Visitors.

Jonathan V. Brinkmann continued as Research Scientist. The two full-time astrometric support positions were held by Jon C. Lingel (McCormick) and Michael C. Begam (Mt. Stromlo). Linda Justice resigned in April as a part-time measurer at the Observatory, and Jon Lingel resigned his full-time position at the end of July, but continued on a half-time basis. James Barr and Cliff Mawyer continued as electronics technician and instrument maker, respectively.

There were 21 graduate students in residence at the end of this period.

II. FACILITIES

The 1 m reflector on Fan Mountain and the 67 cm Leander McCormick refractor on Mount Jefferson were used during the year for our astrometric programs, and for student research and training. Observing time on the 1 m is divided about equally between photographic and CCD programs. Construction of a warm room attached to the 30-inch reflector's dome was completed in August. In the southern hemisphere, the 66 cm Yale-Columbia refractor at Mount Stromlo Observatory continues to be available to the parallax program on a full time basis. During the year there were approximately 1700 visitors to the McCormick and Fan Mountain Observatories as part of our continuing public night programs.

The Perkin-Elmer PDS 1010GM microdensitometer was used for scanning parallax plates. David Stokes (UVA Medical

School) and Ricky Smart (UFL) visited during the year to use the machine.

III. RESEARCH

a. Stars and Stellar Evolution

G. Albright (graduate student) and Richards have continued their investigation of the relative spectroscopic contribution of the chromospheres of the cool Algol secondaries. It is normally assumed that the chromospheric Hα emission from the cool secondary is insignificant compared to that from the circumstellar material associated with the hotter A5–B5 primary. However, based on radio and X-ray data, it is likely that the Hα "difference profiles" contain a chromospheric component. The full-orbit Hα spectra of 9 short-period Algols obtained within the last year show no convincing evidence of flare activity at this wavelength. An observing campaign is now underway to examine the orbital variation of the Ca II infrared triplet (8500–8700 Å). As with the photometry, the relative contribution of the cool secondary is at its highest in the infrared part of the spectrum, and it is hoped that evidence of emission or excess absorption will be found in the Ca II lines at these wavelengths.

Balbus completed a study which showed that currents produced in disks by radiative or other types of drag forces must quite generally give to rise to extremely small magnetic fields. Ion-electron self-induction limits the growth of magnetic fields to have an associated Larmor radius greater than or of order the size of the disk. This was shown by invoking conservation of canonical angular momentum for the ions, which must hold regardless of the nature of the inductive forces on the ions. Using this principle, the derivation of the field limit is considerably simpler than previous treatments of similar problems. Difficulties in understanding the origin of ordered magnetic fields are made more acute by the directness and simplicity of this approach.

Balbus and O. Blaes (CITA) have concluded their study of the development of the magnetic shear instability in weakly ionized disks. They have calculated the criterion for the ion and neutral fluids to be sufficiently well-coupled to allow the instability to proceed unaltered in the disk. Both the cases of strict ion conservation and of ionization equilibrium were studied. Although the most important requirement for good coupling is that the ion-neutral collision rate be larger than the disk rotation frequency, in general the physics of multi-fluid disks is very complex, and some unexpected results were found. The most important of these is the role of a weak azimuthal field in stabilizing the axisymmetric instability when the ion-neutral coupling is marginal, and ionization-recombination physics is important.

Balbus, Gammie and Hawley have investigated the nonlinear behavior of the instability in a Keplerian shearing-sheet system using a three-dimensional MHD computer code developed by

Hawley. This study includes the evolution of initially purely toroidal field geometries, a case that could not be addressed by earlier two-dimensional simulations. As expected from the linear analysis, these toroidal fields prove to be unstable, with a growth time of several orbital periods. Also, the studies have shown that the two-dimensional streaming motions found in earlier simulations tend to break down in three dimensions into a much more turbulent flow. Power spectrum analyses of the non-Keplerian fluctuations show that large-scale anisotropy is important at all wavenumbers, with different cartesian components exhibiting different power laws in their respective fluctuation spectra. Taken as a whole, these models demonstrate that the instability leads to field amplification, turbulence, and angular momentum transport.

Balbus and Hawley completed a study of the behavior of the weak field MHD instability in stellar interiors. They have found that differential rotation within radiative zones is dynamically unstable over a wide range of magnetic field strengths. Angular momentum is transferred within spherical shells from regions near the axis of rotation outward. Helioseismology data indicates that the solar radiative zone is in solid body rotation. The MHD instability is a natural explanation for why this may be expected to be a generic nonlinear outcome of the instability. Dissipation of nonlinear turbulence transfers and deposits angular momentum between fluid elements. Previous explanations based upon hydromagnetic waves required some dissipative mechanism to extract angular momentum form the waves. The MHD instability is both an economical explanation of the transport, as well as an inevitable consequence of differential rotation and a weak magnetic field.

C. Fransson, P. Lundqvist (Stockholm Obs.), and Chevalier are modeling multiwavelength observations of SN 1993J in M81. The radio and X-ray observations of SN 1993J during the first three months can be consistently explained as a result of interaction of the expanding ejecta with a circumstellar medium. Both sets of observations indicate a mass loss rate of $\sim (2\text{–}6)\times 10^{-5}\, M_\odot\ \mathrm{yr}^{-1}$ for a wind velocity of $10\,\mathrm{km\,s^{-1}}$, higher than earlier estimates. The radio observations show evidence for a variation of the mass loss rate from the progenitor system. To explain the properties of the X-ray emission a fairly shallow density gradient in the ejecta are needed. Most of the observed X-ray emission originates from the reverse shock, which is adiabatic. The observed γ-rays come from both the circumstellar and reverse shocks. The ionization and temperature structures of the circumstellar gas are calculated, and they find that the temperature is in excess of 10^5 K, and the medium is completely ionized by the shock radiation. They also find that pre-acceleration of the circumstellar gas by the radiation from the outbreak can explain the observed high velocity for the circumstellar N V and Hα lines.

Chevalier and Luo examined magnetic effects in the shaping of stellar wind bubbles. The magnetic field in the wind from a magnetized, rotating star becomes increasingly toroidal with distance from the star. The strength of the magnetic field can be characterized by σ, the ratio of toroidal magnetic energy density to kinetic energy density in the equatorial plane of the wind. A fast wind shocks against the external medium and creates a bubble whose volume is dominated by shocked gas. The toroidal magnetic field increases in the shocked bubble and can dominate the thermal pressure. The pressure is asymmetric because magnetic tension constrains the flow in the equatorial direction and there are no magnetic effects in the polar direction. The total pressure drives a shell into the surrounding medium. They considered interaction with a slow wind from a previous evolutionary phase, as is thought to occur in planetary nebulae. The structure, which is axisymmetric and extended in the polar direction, depends on 2 parameters: $\sigma v_w/w_o$, where v_w is the wind velocity and w_o is the shell velocity in the polar direction, and $\lambda = v_a/w_o$, where v_a is the velocity of the slow wind. For small values of λ, there is a cusp in the shell in the equatorial plane, i.e. there is an equatorial ring. For larger values of λ, the maximum of the surface density moves away from the equator, i.e. a double ring structure.

Using a multidimensional magnetohydrodynamics code, Christodoulou and Hawley are studying the dynamical evolution of weakly magnetized tori and annuli orbiting around a central potential. These systems represent idealized global models of accretion disks around stars. The models suffer from the magnetorotational instability of Balbus and Hawley that transports large amounts of angular momentum outwards and matter inwards in just a few orbits. The magnetic field and the orbiting fluid develop loops and eddies leading to large-scale turbulence while the field energy increases by about two orders of magnitude.

W. Dalton (graduate student) and Sarazin have constructed a number of models for the high mass X-ray binary (HMXRB) population of our Galaxy. These models are based on a grid of 5544 evolutionary histories for massive binaries. These numerical evolutions utilize recent stellar evolution models for massive stars. The binaries are combined assuming a rate of formation of massive stars, an initial mass function, a binary fraction, a binary mass distribution, and a binary separation distribution. These are constrained by optical observations of massive stars and star formation. The statistics of the resulting HMXRB population are compared to the observed populations of X-ray sources in our Galaxy. X-ray binary sources with evolved comparisons and Be-type X-ray binaries are treated separately. The observed populations can be reproduced by models in which mass transfer in the binaries is significantly nonconservative ($\approx 50\%$ of the gas is lost), the initial masses of stars in massive binaries are correlated, and the high mass end of the IMF agrees with recent optical studies.

Dorman, Rood and O'Connell have been studying the ultraviolet properties in evolved stellar populations. The object of the exercise has been to quantify the circumstances under which very low mass helium burning stars can give rise to the observed ultraviolet properties in elliptical galaxies and spiral galaxy bulges—the "UVX" phenomenon. They have computed a large grid of theoretical models of Extreme Horizontal Branch (EHB) stars (those that do not reach the AGB after core helium-burning evolution) for a wide range in stellar abundance. These models, referred to as Post-Early AGB and AGB-manqué ("failed AGB") models are formed from red giant stars if nearly the entire envelope is lost before the core helium flash takes place. They are identified with the hot subdwarf population of the Galactic halo as well as the hot end of the extreme blue tail seen in some globular cluster horizontal branches. They have computed synthetic fluxes from populations of these stars per unit V luminosity. The model UV colors agree well with integrated photometry of Galactic globular clusters. The comparison of these results with observed $15 - V$ colors will indicate the fraction of the red giant population suffering high degrees of mass loss required to produce the ultraviolet radiation observed in metal-rich galaxies. Preliminary conclusions are that 20–25% of red giants in the galaxies with the strongest UV upturns become hot blue subdwarfs, consistent with enhanced mass loss with metallicity from stars in evolved populations.

Dorman has been collaborating with M. Tripicco and R. Bell (U. Maryland) with work on population synthesis models for metal-rich galaxies and also for globular clusters. Application of early results from this work produced a study of the old Galactic open cluster M 67, in which they found it was necessary to invoke large degrees of mass loss on the giant branch in order to explain the magnitude and color of the red clump stars.

Dorman has also collaborated with V. Dixon (Johns Hopkins) on the interpretation of the spectrum of the Galactic globular cluster NGC 1904 taken from the Hopkins Ultraviolet Telescope. They have been able to synthesize the far-UV spectrum of this cluster using distributions of EHB stars. The results indicate that the stellar mass distribution is non-Gaussian, implying that other factors than age must separate the HB morphology of clusters with extreme blue tails from "redder" HB morphologies.

Gammie and Balbus have been studying the global linear modes of magnetized, stratified disks. Exact solutions for the modes were obtained in some special cases. The global analysis confirms earlier estimates that the disk is stable to the magnetorotational instability of Balbus and Hawley when the critical wavelength obtained from an entirely local analysis is smaller than a disk scale height.

Hawley and J. Stone (U. Maryland) have been investigating improvements to their numerical technique for multi-dimensional MHD. They have also developed a computer code suitable for the highly parallel Connection Machine architecture and have begun extending the MHD simulations to stratified accretion disks.

Kumar is investigating the significance of very-low-mass black dwarfs ($M \lesssim 0.08\,M_\odot$) for the dark matter problem. He is concentrating on the nature of the dark matter in the halo of the Galaxy and his tentative conclusion is that the halo is populated by a very large number ($\sim 1 \times 10^{12}$) of very-low-mass black dwarfs. It is very likely that dark matter observed in other galaxies is also due to the presence of very-low-mass black dwarfs.

P. Plait (graduate student), P. Lundqvist (Stockholm) and Chevalier continue their work using Hubble Space Telescope (HST) images to analyze the circumstellar material around SN 1987A. Continuing HST observations through May 1993 show that the narrow line emission of the circumstellar ring around SN 1987A has faded substantially since the first images were made in August 1990, but has not changed substantially in structure. They have used images in [O III] λ5007Å, Hβ, and [N II] λ6583Å to determine some of the physical parameters of the ring, such as size, inclination angle and geometric shape. Assuming the gas was initially excited by the UV burst from the supernova and has been undergoing recombination, they modeled the spatially resolved electron density of the ring, and found the maximum electron density from the [O III] λ5007Å emission line to be $1.2 \times 10^4\,\mathrm{cm}^{-3}$ on average, and thus an upper limit to the total mass of the ring from the [O III] emitting gas to be $0.9\,M_\odot$, assuming a distance of 50 kpc and a toroidal geometry for the emission. They found that the physical morphology of the ring is significantly different when imaged in different lines, providing a method of mapping different density regions. Knowledge of the velocity field of the ring allows the structure to be remapped into a velocity profile, and they have modeled the appearance of high resolution line profiles. By assuming the currently observed structure in optical lines applies to the early structure in ultraviolet lines, they constructed UV line light curve models to be compared to the early IUE observations. The clumpy structure of the ring has relatively little effect on the light curves. The [O III] images also show extensive nebulosity associated with the bipolar nebula around SN 1987A, which may affect the observations of the ring. They also analyzed the properties of a star superposed on the ring, which they found to be consistent with a main sequence A type dwarf ($V_{\mathrm{mag}} = 20.2$) at the approximate distance of the supernova.

Richards and G. Albright (graduate student) have continued their long-term program to obtain full-orbit Hα spectra of short-period Algols in which direct-impact accretion occurs. In these semi-detached binaries with orbital periods less than 5–6 days, the gas stream from the Roche-lobe filling secondary is predicted to strike the mass-gaining primary. From October 1992 to May 1993, Richards and Albright had 4 visitor runs and 3 nighttime synoptic runs on the 1.5 m McMath-Pierce telescope at the National Solar Observatory (NSO), and 2 visitor runs with the 0.9 m Coudé Feed Telescope at Kitt Peak National Observatory (KPNO). They now have full-orbit Hα spectra of 9 short-period systems (V505 Sgr, δ Lib, TW Dra, β Per, TX UMa, U Sge, S Equ, U CrB, and RS Vul), with some Hβ spectra at key phases to enable calculation of electron densities of the plasma. These systems are all predicted to undergo direct-impact accretion but, except for Algol and TX UMa, there has been sparse evidence of circumstellar material in the visible or ultraviolet spectra. The spectra were obtained at positions around the entire orbit of each binary within 3 to 4 weeks in an attempt to minimize the secular variability that is apparently characteristic of these binaries. The preliminary analysis indicates evidence of circumstellar material in the form of a transient accretion disk in the difference profiles of each binary. Moreover, there are similarities between binaries, with the strength of the emission and absorption in the difference profiles typically dependent on the location of the binary in the primary radius vs. mass ratio diagram. The difference profiles of each binary at a given orbital phase are also time-dependent; suggesting variability in the circumstellar material.

During the past year, Richards continued her study of magnetic activity on the cool components in short-period Algol-type binaries. Richards' work on magnetic activity in the Algols was recently described in a new book entitled "The Realm of Interacting Binary Stars," 1993, edited by J. Sahade, G. E. McCluskey, and Y. Kondo (Dordrecht: Kluwer). The need for new infrared photometry of the Algols was emphasized in this book, as has been done by Richards for several years. The limiting factors are the large amounts of observing time required on an infrared photometer or spectrograph. Moreover, any evidence of magnetic activity would appear as weak features in the light curve or spectrum. As part of a new observing campaign to obtain infrared light curves, Richards and Albright applied for time to use the infrared photometer on the 1.5m Carlos Sanchez Telescope at Tenerife in the Canary Islands. They will observe up to 15 systems with this telescope beginning in 1994 February.

Richards, Albright, and E. Guinan (Villanova University) have submitted a proposal to the NASA IUE Guest Observer Program to obtain ultraviolet spectra of 8 Algol-type binaries. A complementary proposal was submitted to KPNO to obtain "Simultaneous Balmer-line and IUE Spectroscopy of Short-Period Algols." The IUE spectra should arise primarily from the mass transfer process, but the Hα spectra could also arise from the chromosphere of the secondary. The relationship between the IUE and Balmer-line profiles should therefore shed light on the relative contribution of the chromosphere.

The sources of Hα emission can also be distinguished by using the technique of Doppler Tomography. In earlier work, Richards and D. Jones (undergraduate student) found that the source of the Hα emission in β Per was concentrated near the inner Lagrangian point between the stars. However, Richards and M. Swain (graduate student) found that if the data are separated into symmetric halves or quarters and analyzed separately, the Doppler images contain multiple Hα sources. The strongest source is found along the gas stream between the two stars, a consequence of the mass transfer process. Weaker sources are in a semi-circular arc of a disk around the mass gaining star, and in a region close to the cool secondary.

Richards and J. Blondin (NCSU) have continued their study of direct-impact accretion using a modified version of the two-dimensional PPM hydrodynamics code developed by Blondin and the Virginia Numerical Astrophysics Group. The current code includes optically thin radiative cooling. Numerous runs of the code were made over the past year with different stream velocities, injection angle, boundary conditions at the accreting star, and stream density. The results are sensitive to the cooling rate, and very steady disks could be formed in many situations. They will be examining the dynamical role of radiative cooling in future runs.

Rood, in collaboration with F. Ferraro and F. Fusi Pecci (U. Bologna), continues his work to quantify HB morphology and to determine what factors govern the mass loss process(es) which strongly affect the late stages of evolution. In an observational test of the hypothesis that stars in globular clusters with dense cores have enhanced mass loss, Rood and R. Peterson (Lick) have obtained spectra (CTIO-Argus) of HB stars in NGC 2808. If the hypothesis is true the blue HB stars in this cluster with a strongly bimodal HB should have orbits more likely to carry them through the cluster center than the red HB stars. The distribution of measured radial velocities with cluster radius should reveal whether this is the case.

Rood and T. Bania (BU) have embarked on a small scale *SETI* project using the Green Bank 140-ft. telescope. It is a targeted, magic frequency, beacon search. The targets are nearby "oldish" stars with IR excess (candidate Dyson civilizations). The frequencies are those of the hyperfine transitions of muonium and $^3He^+$ observed in the rest frame of the cosmic background radiation. They haven't found anything.

J. Whitney (graduate student), O'Connell, Rood, Dorman, and the UIT team (GSFC) are analyzing far-UV photometry of the globular cluster ω Cen, obtained with the UIT/Astro-1 instrument. The limiting magnitude at 1620Å is ~ 16.9. The images cover a $40'$ diameter field, and hot stars can be resolved throughout the cluster core, owing to the absence of crowding from cool stars. The UIT photometry is matched to a ground-based Strömgren u-band frame to produce an FUV-u color-magnitude diagram. 1900 stars with $T_e \gtrsim 10,000\,K$ are detected on the FUV frame, and 1400 are matched to u-band counterparts. Most of the stars are located near the ZAHB, but about 100 are significantly above it and appear to be in post-HB evolutionary phases. When fitted to Dorman's theoretical models, the hottest stars appear to have envelope masses $\lesssim 0.003\,M_\odot$. The cooler HB stars match the ZAHB well; hotter objects tend to be fainter; reasons for this are being explored. At radii $> 5'$, bluer HB objects tend to be more centrally concentrated than redder objects, in agreement with a ground-based study by Bailyn et al. (1992). However, at smaller radii, bluer objects are less centrally concentrated; implications for mass segregation and binary formation are being studied.

b. Interstellar Medium

Rood, T. Bania (BU), D. Balser (BU) and T. Wilson (MPIfR) are continuing their project to determine the cosmic abundance of ^3He. Further observations of planetary nebulae were carried out at the 100 m radio telescope in Effelsberg. Continuum parameters in H II regions with previously measured ^3He lines were also measured at Effelsberg. These, along with VLA maps and radio recombination line data, are being used to make models for the H II regions. These are necessary for deriving accurate abundance ratios. Observations at Green Bank concentrated on outer galaxy H II regions where the ^{3}He abundance should be closer to the primordial value and on obtaining more accurate line parameters by having observations scattered throughout the year.

K. Borkowski (U. Maryland), Sarazin, and J. Blondin (NCSU) have developed an efficient technique for calculating the fully time dependent non-equilibrium ionization, electron heating, and X-ray emission for very detailed numerical hydrodynamic models of supernova remnants. This technique is being used to determine the X-ray emission for their model of Kepler's SNR. In this model, the progenitor of Kepler's SN is assumed to have been a massive runaway star ejected from the Galactic plane. In its red supergiant stage, its dense stellar wind was distorted and compressed into a bow shock by the ram pressure of the tenuous interstellar medium. The subsequent interaction of the supernova ejecta with this asymmetric circumstellar matter produced a strongly asymmetric SNR. A comparison of the model X-ray spectra with observations implies a moderate overabundance of Fe in Kepler's SNR (only 50% larger than its cosmic value), in contrast to a large (6–15) Fe overabundance derived previously. However, they do find that Si and S abundances are 2–3 times solar. These modest enhancements of Si, S, and Fe may be attributed either to heavy-element enriched SN ejecta or to the initial chemical abundances of the SN progenitor, which originated in the metal-rich inner Galaxy. The comparison of these models with the observed spectra confirm theoretical predictions that moderate electron heating occurs at strong collisionless shock fronts, with the implied electron/mean temperature ratio of $\sim$ 0.5.

Sarazin, C. Wu, M. Crenshaw (CSC), R. Fesen (Dartmouth), and A. Hamilton (U. Col.) have obtained a UV spectrum of the SM star located behind the remnant of the SN1006 supernova with the HST. The spectrum shows broad Fe II absorption lines due to supernova ejecta. The ejecta is moving with speeds of up to $\pm 9000\,\mathrm{km\,s^{-1}}$. The angular size and age of the remnant imply a lower limit on its distance of 1.9 kpc. The mass of Fe^{+} in the ejecta is only $0.014\,M_{\odot}$, presumably because the bulk of the iron is more highly ionized.

c. Galaxies and Active Galactic Nuclei

Brinkmann and O'Connell studied the spatial distribution of near UV photons from the edge-on normal spiral galaxy NGC 891. These photons originated in hot stars in the disk. These photons were scattered dust grains by the interstellar medium of the disk and halo. They found that the scale height of the intensity of these scattered photons was similar to the scale height of the Hα emission in the disk. The UV scale height was about twice that of the Hα scale height in the bulge.

Christodoulou and Sarazin have implemented radiative cooling in a magnetohydrodynamics code and have constructed an initial model of a cylindrical, isothermal gas in hydrostatic equilibrium. They are preparing to study the influence of weak magnetic fields and of nonaxisymmetric perturbations when this model is allowed to cool.

R. Peletier, M. Balcells (both at U. Groningen), and Christodoulou have applied for observing time to use the WHT at La Palma. They hope to obtain both absorption and emission spectra of three galaxies with peculiar structure and kinematics: NGC 2685, 3718, and 4753. In a related study, Christodoulou, Y. Taniguchi (Tohoku U.), A. Habe (Hokkaido U.), R. Peletier (U. Groningen), and P. Eskridge (CfA) have applied for observing time at the Nobeyama Millimeter Array. They hope to resolve the location of the CO gas discovered by Taniguchi et al. in NGC 2685. Hα images obtained independently by Peletier and Eskridge already indicate the presence of yet another ring in the central region of this double-ring galaxy. Such observations of the kinematics will clarify the dynamical evolution of gas accreted by these galaxies and/or inflowing toward the nuclear regions.

W. Dalton (graduate student) and Sarazin are studying the population of massive binary X-ray sources in normal and starburst galaxies. For a given initial mass function (IMF), they have constructed a "parent population" of massive (early B–O type) stars that are expected to evolve to high mass X-ray binary (HMXRB) systems. Each pair is evolved from a series of initial separations, with each scenario weighted by the probability of occurrence, as deduced from observed binary statistics. Mass and angular momentum loss via stellar winds are included in the models, with each pair evolved through the first mass transfer episode, and common envelope phase, should it occur. The first supernova explosion, in general, leaves a bound system, and the orbital parameters of the resulting massive main sequence star + compact object system are calculated. Accretion onto the compact object occurs in one of two ways. For systems with a relatively wide final separation, accretion from the main sequence star's wind may result in a relatively weak X-ray source. For systems with a relatively small final separation, overflow of the main sequence star's critical potential surface results in substantial accretion onto the compact object, and yields a powerful (near Eddington) X-ray source. In both cases, the X-ray lifetime of the source is determined by the evolutionary state of the mass donor. The actual emission from a given system is derived from observations of representative HMXRBs.

V. Dwarkadas (graduate student) and Balbus have completed their investigation into the dynamical stability of the gas flow in the spiral arms of disk galaxies. Their model assumes an isothermal, non self-gravitating equilibrium flow satisfying the equations for tightly wound spiral arms. Their simulations fully take into account the density and velocity structure present in the background flow. Using a linear, finite-difference hydrodynamic code, they have studied the growth of dynamical perturbations with arbitrary initial conditions on the rapidly varying shear flow which occurs in the vicinity of spiral galactic shocks. Despite the presence of a number of features which are associated with instability (changing shear, reflecting boundary condition, co-rotation radii), the investigators have found that any small perturbations introduced in the flow are quickly damped out. Hence, in the absence of self-gravity, interstellar gas flow near spiral arms is dynamically stable to linear perturbations.

R. Gelderman (graduate student) and Whittle have continued their study of Compact Steep Spectrum (CSS) radio galaxies. These galaxies have powerful sub-galactic radio structure, and constitute prime candidates for a strong interaction between radio jets and the interstellar medium of the host galaxy. Presentation of the spectroscopic data has been accepted for publication, and includes detailed line strength and profile information for the sample of about 30 CSS and related objects. These measurements support the picture of a strong jet/gas interaction.

Hawley and G. Lindahl (graduate student) are continuing to develop a three-dimensional, general-relativistic hydrodynamic computer code for simulations of black hole accretion. They are studying several scenarios for the flow of gas with angular momentum around a black hole, including the three-dimensional stability of such flows.

G. Hennessy (graduate student) and O'Connell, with the UIT team (GSFC), are analyzing mid-UV (2500 Å) images of M82 obtained with the UIT during the Astro-1 mission. The limiting surface brightness is $\sim 26\,\mathrm{mag\,arcsec^{-2}}$. The UV light is detectable to radii of 4.1 kpc. Large variations in (MUV−V) colors, up to 3.5 mag, are present. The colors are predominantly driven by extinction differences, and color maps permit the dust distribution within the galaxy to be traced. The well-known plume, or "filamentary region," which is related to the outflow of hot gas along the minor axis, is particularly bright in the MUV on the south side of the galaxy. If light in the plume is mainly scattered from bright sources in the disk, this asymmetry can be explained by the preferential forward scattering of dust grains in the UV. The implication is that the southern plume is on the near side of the galaxy.

Z. Huang (graduate student), Q.-F. Yin (NRAO), Saslaw and D. Heeschen (NRAO) have observed the peculiar pair of galaxies NGC 3395 and NGC 3396 with the VLA in several configurations at four frequencies: X, C, L and P bands. They discovered a radio bridge between the two galaxies. Moreover, the radio emission of each galaxy is not centered on the optical, but is much stronger in the half of each galaxy nearer its companion. This contradicts standard models in which tidal interactions cause gas to flow into the center of a galaxy and produce starbursts only there. In NGC 3395, the tidal interaction is more likely to produce shocks and star formation over much of the galaxy.

C. Nelson (graduate student) and Whittle have continued their study of the stellar velocity dispersions for a sample of about 75 Seyfert galaxies. An extensive data set has been gathered, including a number of quantities relating to the properties of the host galaxies. These data are now ready for publication. Initial analysis confirms the virial nature of the [O III] emission line widths, but also identifies a number of additional relevant processes. An offset from the Faber-Jackson relation for normal spiral bulges suggests that Seyferts have low mass to light ratios, while disturbed Seyferts have systematically broader lines, suggesting the external perturbations penetrate to the galaxy core. A more complete interpretation awaits full analysis of B and I surface photometry.

O'Connell, with J. Gallagher (U. Wisconsin), and D. Hunter (Lowell Observatory), has obtained HST PC images of "super star clusters" in the nearby galaxies NGC 1569 and 1705. These are luminous ($M_V \sim -13.5$), extremely compact, high surface brightness star forming regions which are essentially unresolved from the ground. Excellent imagery in the V and I bands was obtained. From deconvolved V-band images they find that the clusters have very compact cores with extended halos that are partially resolved into individual red supergiants. The half-light radii are $\sim$ 3 pc. The clusters in NGC 1569 show considerable substructure beyond the core and ellipticities that are comparable to the flattenings seen in young clusters in the Large Magellanic Cloud (LMC). Their properties are similar to those of the luminous star cluster R136 in the LMC except that R136 has a lower central surface brightness. The half-light surface brightnesses of the clusters average $7 \times 10^5 L_{V,\odot}\,\mathrm{pc}^{-2}$, which is over 800 times higher than the mean rich LMC star cluster other than R136. The super star clusters represent an extreme but uncommon mode of star formation.

O'Connell, Gallagher, and Hunter, with W. Colley (undergraduate student), also obtained HST/PC imagery of the prototype starburst galaxy M 82. The bright object M 82 A, which appears as 3 barely resolved knots from the ground, is resolved into about 20 individual compact subclusters on the HST deconvolutions. The maximum intrinsic surface brightnesses are comparable to those of NGC 1569 and 1705, described above. It is likely that M 82 A is representative of the hidden starburst region of M 82, which has a bolometric luminosity $\lesssim$ 10 times larger. Remarkably large $(V-I)$ color variations occur within the A complex. The redder subclusters either contain larger amounts of dust or a brighter red supergiant population. The objects also have distorted morphologies, resembling the "champagne" structures of H II regions. They may be influenced by strong wind-like or ionization disturbances originating in the A complex or perhaps by the large-scale superwind which is driving material outward along M 82's minor axis.

Sarazin and R. Saglia (Scuola Normale, Italy) are analyzing a deep ROSAT PSPC X-ray image of the bright elliptical galaxy NGC7144. This galaxy has excellent optical kinematic data, which indicate that it has a halo of dark matter. The X-ray spectra and surface brightness profile should allow the mass determination of the galaxy to be extended to even larger radii.

Sarazin and M. Wise (Kitt Peak) are analyzing the ROSAT High Resolution Imager X-ray observations of a sample of elliptical galaxies. They will determine whether the X-ray emission originates from stars or diffuse gas. The density and temperature of the gas will be derived, and the roles of supernova heating and thermal conduction will be assessed. The dynamical state of the gas (steady or non-steady, inflow or wind) will be determined. The location and amounts of cooling gas will be derived. The possible role of stripping of gas from ellipticals will be studied. The distribution of the total mass of the galaxy will be determined, and the possible existence of halos of dark matter will be investigated. A comparison of the shapes of the X-ray and optical isophotes will allow limits to be placed of the shape of the mass distribution of the galaxy.

Saslaw, B. Boyle (Cambridge, UK), M. Valtonen (Turku, Finland) and R. McMahon (Cambridge, UK) have obtained spectra of a compact optical object in the X-ray emitting region of a radio lobe of Cygnus A to determine its nature.

R. Spiker (graduate student) and Balbus have completed an N-body study of the interstellar gas in the vicinity of a spiral arm. The simulation is local in nature to focus on the small-scale structures found in spiral arm galaxies. The simulations include the shearing of the galactic disk, the self-gravity of the gas, and the gravity of the stellar spiral arm. They have found that the presence of the spiral arm and self-gravity dynamically heats the gas to point at which internal bound structures cannot form. This is consistent with earlier large-scale disk simulations for the spiral structure itself, which found that either gaseous infall or a cooling mechanism is required to maintain spiral structure in the disk. When a collisional drag term is added to the equations, extended structures form on scales of about 1 kpc, which appears to be the preferred wavelength of maximum growth of density waves for typical ISM parameters. Thus, the restriction that the cloud velocity dispersion not greatly exceed observed values implies a minimum energy dissipation rate, which must ultimately be radiated away.

Thuan, in collaboration with Z. Huang (graduate student), Chevalier, J. Condon (NRAO) and Q.-F. Yin (NRAO) has studied with the VLA compact radio sources in the starburst galaxy M 82. Comparison with previous observations shows that most sources are declining in flux. These compact radio sources are attributed to a population of bright, small supernova remnants. The birth rate of the compact radio sources is estimated to be $0.11 \pm 0.05\,\mathrm{yr}^{-1}$. They obey a Σ–D (radio surface brightness–diameter) relation which is remarkably similar to that followed by supernova remnants in the Galaxy and the Magellanic Clouds and by two of the strongest known extragalactic radio supernovae: SN1986J and SN1979C. A least-squares fit to the SNR data gives: $\Sigma_{8.4\,\mathrm{GHz}}\,(\mathrm{W\,Hz^{-1}\,m^{-2}\,sr^{-1}}) = 4.4 \times 10^{-16} D_{\mathrm{pc}}^{-3.5\pm0.1}$, covering 7 orders of magnitude in Σ.

Thuan, in collaboration with M. Sauvage (Saclay, France) has analyzed the far-infrared properties of non-infrared-bright galaxies along the Hubble Sequence, using a complete sample of galaxies in the magnitude limited ($m_{pg} < 14.8$) CfA sample detected in the IRAS Faint Source Survey, a total of 1544 galaxies. It is found that the short-wavelength FIR emission is best explained as having mainly an interstellar origin, and not as coming mostly from non-thermal sources or from circumstellar or photospheric emission from evolved stars. The FIR colors of galaxies from type E–S0 to type Sbc, are mainly controlled by the spatial distribution of the dust relative to the stars. The dust in elliptical is as hot as in magellanic irregulars, because it is concentrated in their central regions ($r \lesssim 1\,\mathrm{kpc}$) where the UV energy density from post-AGB stars is the highest. The dust in Sbc galaxies is the coolest because it is most spread out in the disk where the UV energy density is the lowest. From type Sbc to type Sdm, the FIR colors are controlled by an increasing star formation efficiency (SFE), modulated by a change in dust composition. The metallicity decrease in Sdm galaxies leads to a deficiency of small grains relative to large grains and a reduction of the dust and H_2 masses relative to the H I masses. Conversely, in elliptical galaxies, the larger metallicity may increase the abundance of small grains relative to large grains. Most of the FIR color trends as a function of galaxian morphological type can be reproduced by dust models with three components (PAHs, intermediate-size and large grains), combined with the appropriate dust heating spectral energy distribution.

Thuan, in collaboration with A. Lancon and B. Rocca-Volmerange (Institut d'Astrophysique, France) has studied H + K (1.428 to $2.5\,\mu$m) spectroscopy of 10 luminous infrared galaxies. It is shown how this critical wavelength range, on the boundary between spectral regions dominated by emission from stars or from dust and non-thermal sources, constrains the relative contributions of these components and the star-formation parameters. Because of the large spectral range covered, non-stellar contributions can be identified from their effect on the continuum. The stellar energy distribution contains molecular features (of essentially CO and H_2O) which permit to distinguish red giant stars from supergiants. The near-IR emission lines (Br_γ, He I, H_2, and [Fe II]) provide additional constraints on the rates of ionization and SN explosions. A first analysis is presented using a template evolved galaxy spectrum to represent the underlying galaxies and a population synthesis model based on a library of near-IR stellar spectra to follow the evolution of starbursts. All spectra can be reproduced by models with three main components: stars, hot dust and non-thermal emission. The galaxy spectra can be ordered into a sequence with various mixes of these components. Eight spectra are consistent with essentially stellar but highly obscured emission, and two clearly show an additional non-stellar contribution.

Thuan and D. Frayer (graduate student) have finished analyzing the spectra of 30 Blue Compact Dwarf galaxies selected from the list of Thuan and Martin (1981). The mean metallicity of the sample is $\sim Z_\odot/10$. Neon, argon and sulfur abundances correlate with the oxygen abundance, indicating the primary origin of these elements. There appears to be a trend of increasing N/O ratio for lower metallicity BCDs.

Whittle and A. Wilson (U. Maryland and STScI) have studied the emission line region of the Seyfert galaxy Markarian 78, using HST Planetary Camera images in both line and continuum, as well as using the VLA images at 3.6 cm. The emission region shows a number of knots whose morphology suggest entrainment and acceleration by an outflowing jet or wind. The relation between the radio structure and emission line structure is not straightforward, with some direct correspondence at small radii but an apparent anti-correlation of knot locations at larger radii. It seems that the standard model of a bow shock with accelerated and compressed gas is too simple in this case. Possible alternative models are being explored. A further allocation of cycle 4 HST time has been awarded to obtain spectra of a number of the emission line knots using the Faint Object Spectrograph. The intention is to ascertain the velocity field of the knots and their principle source of ionization.

Whittle and C. Mullis (undergraduate) took astrometric plates of the Markarian 78 region using the 26 inch McCormick telescope in order to obtain an accurate position for the galaxy nucleus. This is important when comparing the HST images (which do not have good absolute coordinates) and the VLA radio images (which do have good absolute coordinates). Between 8 and 10 primary and secondary astrometric stars were used to measure the location of a 13th magnitude star which appeared in the HST images, with an accuracy of 0.1 arcsec.

Whittle, Mullis and R. Gelderman (graduate student) have begun analyzing the Extended Narrow Line Region (ENLR) of Markarian 78, using low resolution long slit data obtained on the KPNO 4 m telescope, and [O III] λ5007 and Hα images obtained on the KPNO 2.1 m telescope. The aim is to use diagnostic line ratios to interpret the radiation field falling on this extended region. Since the ENLR subtends a significant angle to the nuclear source, it may be possible to derive the so-called "polar diagram"—i.e. the UV continuum intensity and spectral shape emerging from the nucleus as a function of angle from the primary axis. Such information provides insight into the various possible "beaming" mechanisms which force the radiation to emerge anisotropically.

Whittle, Sarazin, and Gelderman have used the KPNO 4 m to observe the emission line regions of the cD galaxy 2A0335+096. This galaxy lies at the center of a cooling flow and shows a number of X-ray filaments. Their initial data were compromised by poor observing conditions and a second observing run is scheduled this fall. The aim of the project is to ascertain, from long slit optical spectroscopy, the kinematic and physical state of the warm ionized gas and interpret this in the context of the cooling flow and/or an ongoing merger.

d. Clusters of Galaxies

N. D'Cruz (graduate student) and Sarazin continued their work on the expected emission from the hyperfine radio line of the stable iron isotope ^{57}Fe in cluster cooling flows. This line at a wavelength of 3.07 mm comes from the lithium-like ion Fe^{+23}. In 1984, Sunyaev and Churazov suggested that it might be observable in clusters of galaxies. Cluster cooling flows seem to be promising because, firstly, they have cooler temperatures, which means that the ion Fe^{+23} is more abundant and secondly, they have large columns and emission measures. Another factor affecting the detectability of the line is the chemical history of the intracluster gas. If most of the iron in this gas was produced by Type II supernovae from an early generation of massive stars, ^{57}Fe will be more abundant (relative to ^{56}Fe) than in the solar system. If the line can be detected, its strength can be compared to the strength of X-ray lines from the same element and ionization, which come mainly from the more abundant isotope ^{56}Fe. The comparison would determine the primary nucleosynthetic source of the intracluster gas. Also if the line can be detected the velocity structure of the gas can be determined since spectral resolution in the radio region is much better than that of the current X-ray spectrometers. Integrated surface brightness profiles for a homogeneous and an inhomogeneous cooling flow models have been obtained. Line profiles were also calculated for pure thermal and transonically turbulent broadening in both the models. A few cooling flow clusters possess bright radio sources, hence the effect of a radio source was also studied. A radio source is important because if one tries to detect the line by looking along the line of sight of the radio source then the line should appear in absorption, otherwise it will be in emission. This will be very useful when looking for the line with arrays. The luminosity of the line in both models is of the order of $10^{36}\,\mathrm{ergs\,s^{-1}}$.

P. Foster (graduate student) and Chevalier are studying radiatively cooling self-gravitating flows. The early transitional stage of cooling flows, from a static medium to a steady state inflow, as well as the very central regions of cooling flows, are being considered with this analysis. They have found a self-similar solution to describe this inflow, and are performing numerical modeling to test the breadth of initial conditions which will follow the analytical solutions. The self-similar solution incorporates a power law cooling term which is $\propto \rho^2 T^\lambda$; if $\lambda < 1$ the central temperature increases with time. The paradoxical result of the temperature of cooling gas increasing with time is due to strong gravitational compression. This is confirmed with numerical simulations for $\lambda \leq -0.5$ that have moderately long central cooling times. Shorter cooling times lead to a central thermal runaway. They are examining the observational consequences of the large luminosities seen in the these flows.

Sarazin, O'Connell, and B. McNamara (SAO) are analyzing the ROSAT X-ray images of a sample of cooling flow clusters. Previous X-ray observations suggest that large quantities of gas are cooling at the centers of many clusters, although the final deposition of this gas is still uncertain. They clusters in which there is evidence for recent star formation and/or cooler gas. Evidence for star formation in these galaxies includes blue stellar continua or stellar absorption lines of O–F stars. Cool gas is detected through line emission from gas at 10^4 K, 21 cm line emission or absorption, molecular line emission, or far infrared emission. High resolution X-ray images will be compared to the star formation and cool gas tracers, and the rates of formation of cool gas and stars will be compared to the rates of cooling of the hot, X-ray emitting gas.

Sarazin and M. Wise (Kitt Peak) are examining the effects of optical depth, departures from ionization equilibrium, and radiative transfer on X-ray emission from cluster cooling flows. Previous studies of X-ray emission from clusters have assumed the cluster to be optically thin; however, recent work has shown that resonance lines in clusters may be significantly optically thick. This opacity might significantly affect the emergent spectrum. X–ray spectra provide a rich source of information on the nature of the plasma in clusters. Measurements of line intensities can provide estimates for the gas temperature, density, ionization state, and elemental abundances. Optically thick lines could complicate the determination of such estimates. Wise and Sarazin will examine the accuracy of such spectral diagnostics in the presence of these effects. In addition, the resulting model spectra will be used to study the idea of using X-ray absorption lines to determine an independent estimate of the distance to the cluster.

Sarazin, E. Lufkin, and R. White (UA) are using hydrodynamical models to determine the time-dependence of the mass accretion rate and cooling rate in cluster cooling flows. Detailed agreement is found between previous steady-state models and time-dependent models at fixed times in the simulations. The mass accretion rate $\dot{M}$ is found either to increase or remain nearly constant once the flows reach a steady state.

Sarazin, S. Baum, and C. O'Dea (STScI) have made high dynamic range VLA radio observations of the cooling flow cluster 2A0335+096. They have found radio emission associated with the central D galaxies, with the companion nucleus of the central D galaxies, with a cluster galaxy projected near the nucleus, with the very long NAT radio galaxy, and with several other sources. The central radio emission has an unusually disrupted jet structure with filaments of radio emission which coincide with filaments of X-ray and optical line emission discovered by Sarazin, O'Connell, and McNamara. Both the galaxy radio source near the cluster center and the NAT show X-ray evidence for ram pressure effects. Sarazin, Baum, and O'Dea are considering the possibilities that the radio–optical–X-ray structures are due to the effect of the cooling flow on the (passive) radio source, are due to the effect of the MHD plasma in the radio source on the cooling flow, or are the result of a recent cluster merger.

Sarazin, O'Connell, and B. McNamara (SAO) are using high resolution ROSAT X-ray images to search for aligned radio, optical, and X-ray structures in the central galaxies of moderate redshift clusters. Similar structures have been seen in nearby and very distant clusters.

Sarazin, B. McNamara (SAO), and J. Burns (NMSU) are studying the optical, radio, and X-ray structure of the cD galaxy at the center of the cooling flow cluster A2597. This cluster shows elongated UV/blue continuum lobes, which are roughly aligned with the radio structure. This lobes may be due to either jet induced star formation in the cooling flow gas, or electron scattering of beamed emission from the active nucleus.

Sarazin and Pistinner are studying the hydrodynamical stability and structure of cold clouds immersed in cluster cooling flows. They hope to understand the origin of the excess soft X-ray absorption seen in the X-ray spectra of many clusters of galaxies.

Sarazin and Z. Huang (graduate student) are studying the X-ray structure of a sample of cooling flow clusters of galaxies, using ROSAT and *Einstein* data.

Sarazin and M. Wise (Kitt Peak) are measuring the X-ray spectra of clusters of galaxies with cooling flows using the U.S./Japanese ASCA satellite. They are particularly interested in studying the spectrum of the cooling gas, and the possible spectral effects of cold gas in these systems.

Sarazin, H. Ford (JHU), S. Baum (STScI), and C. O'Dea (STScI) are using HST UV spectra of the nucleus and jet knots in M87 to search for absorption lines from cold gas in the Virgo cluster. This technique should reveal the nature of the cold gas which has been observed in X-ray absorption in this and other cooling flows clusters.

Sarazin and J. Irwin (graduate student) are analyzing the distribution of the hot gas, dark matter, and cold gas in the cooling flow clusters 2A0335+096 using PSPC data from ROSAT.

Sarazin and J. Breen (graduate student) are analyzing the structure of the hot gas in the cooling flow cluster A1795. They have a deep ROSAT observation of this system.

Saslaw and S. Inagaki (Kyoto) are developing an analytical statistical theory for the evolution of accelerations of galaxies in clusters, and are testing the theory with N-body experiments.

Saslaw, R. Sheth (Cambridge, UK) and H. Mo (Cambridge, UK) have determined and analyzed the galaxy distribution functions for the IRAS catalog. Angular diameter scales, the largest probed to date, range from 0.5° to 30°, corresponding to linear diameters $\leq 40h^{-1}$ Mpc. The analysis develops a new technique which has no free parameters. On all scales, the results agree closely with the predictions of simple galaxy clustering. The value of b pattern for the IRAS galaxies at a cell diameter of 30° is 0.62 ± 0.03. It is nearly independent of scale for angular diameters $\geq 20^\circ$.

e. Cosmology

F. Fang (graduate student) and Saslaw are examining the modifications of the galaxy velocity distribution function caused by large concentrations of dark matter in the universe. They derive limits to the amount and forms of these concentrations.

S. Bhavsar (Kentucky) and Saslaw have quantified the study of filamentary structure which arises from the gravitational clustering of galaxies in the universe.

Saslaw, R. Sheth (Cambridge, UK) and H. Mo (Cambridge, UK) have developed a new method for using the projected distribution functions of galaxies to measure the average amplitude and scale where the spatial two-point galaxy correlation function, ξ_2, becomes negative. This technique is sensitive to the negative range of ξ_2 and is independent of the peculiar velocity effects which make direct measurements of ξ_2 uncertain on some scales. It shows that a large class of CDM models, with linear biasing, appears to be inconsistent with the distribution of IRAS galaxies.

Thuan, in collaboration with V. Lipovetsky and L. Pustilnik (Special Astrophysical Observatory, Russia) and Yu. Izotov (Main Astronomical Observatory, Kiev, Ukraine), is pursuing his investigations of the new sample of blue compact galaxies (BCGs) from the Second Byurakan objective prism Survey (SBS). This sample, because it goes 2–3 magnitudes deeper than the Markarian Survey, contains half a dozen BCGs as nearly as metal-deficient as I Zw18 ($Z \sim Z_\odot/50$) and ~ 25 BCGs with $Z_\odot/50 \lesssim Z \lesssim Z_\odot/10$. High S/N KPNO 4 m spectra have been obtained for ~ 10 BCGs with $Z \lesssim Z_\odot/10$, and a primordial helium abundance $Y_\mathrm{p} = 0.232 \pm 0.005$ has been derived. This is close to and consistent with the lower limit of $Y_\mathrm{p} = 0.236$ predicted by standard Big Bang nucleosynthesis theory, with a number of neutrino families equal to 3, and a neutron lifetime of 14.8 min. A study of the large-scale clustering properties of the BCGs in the SBS has been carried out. A two-point correlation analysis yields $\xi(r) = (r/2.0\,\mathrm{Mpc})^{-1.22}$, with a ~ 30 percent smaller amplitude than that of bright CFA galaxies in the same region of the sky: BCGs appear to be slightly less clustered than bright galaxies. About 10% of the BCGs in the SBS sample lie in voids delineated by bright galaxies. With the high S/N 4 m KPNO spectra, it was found that ~ 30 percent of the very low metallicity ($Z_\odot/50 < Z < Z_\odot/10$) SBS BCGs possess a low intensity (≤ 2 percent of the peak intensity) broad component in the Hα and [O III] lines. The FWHM of the broad component translates into $\Delta v \sim 3000\,\mathrm{km\,s^{-1}}$. The broad emission cannot be attributed to Wolf-Rayet stars, because there are galaxies with strong W-R bumps but with no broad component. A superwind driven by supernovae is the most likely explanation for the broad emission. The kinetic energy associated with the broad component is $\sim 10^{54}$ ergs, about 10 times larger than that associated with supershells in the Galaxy, and equivalent to the energy of 1000 supernovae, not unreasonable numbers given the large rate of star formation in BCGs.

f. Solar System

In view of the expected collision of comet Shoemaker-Levy 9 (1993e) with Jupiter in July 1994, Chevalier and Sarazin are calculating basic properties of the initial interaction for a simplified Jovian atmosphere. The shock wave generated by the bolide should be optically thick once once it has penetrated to an atmospheric density $\sim 10^{-6}$ g cm^{-3} and they calculate the postshock conditions assuming LTE for shock velocities v_{sh} in the range 10–60 km s^{-1} and preshock densities $\rho_a = 10^{-6}$–10^{-2} g cm^{-3}. Even at the highest shock velocity, the gas is only partially ionized and the postshock temperature rises with preshock density in order to maintain the ionization. If the ablation rate is limited by the radiative flux, ablation is the dominant energy loss of the bolide for ambient densities $> 10^{-3}$ g cm^{-3}, and the complete ablation of bolides 0.25 km in length can occur. They argue that the ablated gas does not efficiently transfer its kinetic energy to the atmosphere and it ultimately slows in a similar fashion to the comet material. As the bolide initially falls through through the atmosphere, the character of the shock emission changes. At $\rho_a \sim 10^{-8}$ g cm^{-3}, the gas is optically thin and line emission is expected. At $\rho_a \sim 10^{-6}$ g cm^{-3}, the shocked gas is optically thick and the shock front near the bolide produces a blackbody spectrum. The temperature is favorable for ultraviolet (1000–3000 Å) emission and the luminosity may be $\sim 5 \times 10^{23}$ ergs s^{-1} for $\sim$ 0.6 s for a bolide 1 km in radius. At $\rho_a \sim 10^{-4}$ g cm^{-3}, the bolide has passed below the ultraviolet photosphere. The bolometric correction for the optical luminosity is large and they expect a 3000–8000 Å luminosity of $\sim 3 \times 10^{23}$ ergs s^{-1} for $\sim$1 s. The optical emission is strongly peaked in the vicinity of the bolide. The bolide does have an optically thick trail extending $\sim$ 6 km, but it is primarily a source of red and infrared radiation. ¿From the fragmentation model of Chyba, Thomas, & Zahnle (1993), the bolide deposits most of its kinetic energy at $\rho_a \sim 10^{-3}$ g cm^{-3} and this is the effective explosion site. The shock wave from such an explosion can move up about one density scale height. They examined the breakout of the shock front from the Jovian atmosphere and find that the shock acceleration in the decreasing density region is slow, so that the energy flux in the shock front is small. Hot gas created by the explosion ultimately rises due to buoyancy, but the large optical depths at optical and ultraviolet wavelengths suggest that radiative losses will be primarily in the infrared.

Goldstein described the evolution of heliocentric current loops in the solar wind. The pinch force of parallel current filaments is balanced by gas pressure of the conducting electrons and protons in this model. An alternate model with motion of the current filaments providing the outward force may have longer lifetimes.

Goldstein and C. Rogers (undergraduate student) searched for pairs of space debris particles from JPL radar observations at 8510 MHz with the same elliptical orbits. Orbital elements can be calculated for such pairs. Comparison of the most likely pairs (determined by near coincidence of two calculations of the arguments of perigee) with Monte Carlo simulations led us to conclude that the results are not significant. Rogers searched for terrestrial origin for some of the space debris, also on the assumption that some pairs of particles have the same orbit. Again the results were inconclusive.

Goldstein and R. Goldstein (JPL) used the method of least squares to calculate the semi major axis and eccentricity that best fits a three-hour observation of 39 space debris particles in the range 2–11 mm diameter, on the assumption that they are metallic spheres. The results, $a = 7450 \pm 98$ km and $e = 0.039 \pm 0.016$, are well defined, and a paper on the work has been accepted by the Astronomical Journal.

Goldstein has found a series of observations of eclipses of Io made by Thomas Cotton from 1797 to 1830 and published by G. B. Airy in 1853. This material and the general improvement in our computers makes it possible to reanalyze the acceleration of Io detected by Goldstein and Jacobs (AJ, 92, 1986). There is a previously unconsidered theoretical argument by Kumar (Ap&SS, 28,173) that is relevant to Io's acceleration. If Jupiter is to form in the presence of the sun's tidal force, there must be a long-term inflow to a much smaller and more dense protoplanet. A constant mass inflow of $\dot{M}/M = 2 \times 10^{-10}\,\mathrm{yr}^{-1}$ will form the planet and accelerate Io.

C. Finney (U. Tenn., Knoxville) and Goldstein are analyzing Richer's observations of transits of stars and of Mars and of the sun. These observations led to Cassini's determination of the solar parallax and to Isaac Newton's calculation of the earth's oblateness. Finney and Goldstein intend to evaluate the deceleration of the earth's rotation from these observations. The earth's deceleration, if it can be found, will benefit the new calculation of Io's acceleration above. ¿From 35 observations of the meridian height of the sun at transit all within 8 degrees of the zenith, we find with the Bretagnon Simon theory for the sun that the rms deviation of the observed minus calculated meridian heights is less than 10 arcseconds.

H. Bailey (Rose-Hulman) and Goldstein have begun a study of commensurate minor planets to see if Mars has exactly commensurable companions, analogs to the Jovian Hildas (3:2) and Thule (4:3). This work follows the announcement by E. Bowell et al. (BAAS, 22, 1357) that the minor planet 1990 MB is the first Mars Trojan.

Kumar is continuing his work on the structure and evolution of Jupiter. He is investigating the possibility that Jupiter's mass at the time of formation was considerably smaller than its present mass. Since its formation, Jupiter has been accreting mass and Kumar is investigating various accretion processes, including the accretion of matter from the ISM.

J. Miller (graduate student), working on his Ph.D. thesis, has used numerical methods to study the geometry in phase space of minor planets near and at the 2:1, 3:2, and 4:3 commensurability with Jupiter. Miller will compare the objects in the Minor Planet Ephemeris (Saint Petersburg, 1993) with the results of his numerical calculations to separate librators from non librators.

Tolbert and Sarazin suggest that the existence of nearly exact solar eclipses as observed from the Earth may not be a complete coincidence. These nearly perfect eclipses occur because the angular size of the Sun and of the Moon are nearly identical, despite the fact that their actual sizes differ by a factor of nearly

400. They show that this coincidence is approximately physically equivalent to the statement that the Sun and Moon have very similar tidal effects. When a planet is subject to two (or more) similarly sized tidal fields with differing periods, it will experience a periodic variation in the sizes of the tides which results from the beating of the two (or more) periods. The period of this variation will generally be much longer than the periods of the tides produced by the bodies individually. On Earth, these periodic variations are the spring and neap tides. They argue that these long term tidal variations may aid in the evolution of life on a planet, by producing long-lived, isolated tidal pools. These large tides with longer periods may also promote the expansion of life from oceans onto the land. They argue that the latter process may be essential for the development of technological life forms.

g. Astrometry

The photographic parallax programs continued at a reduced rate on the McCormick and Yale-Columbia refractors in Virginia and Australia respectively. Most brighter stars have been deleted from the active observing programs in view of the success of Hipparcos and the elimination by Kodak of the spectroscopic plate types we have most commonly used.

Two lists of parallaxes from plates scanned with the PDS microdensitometer at McCormick for northern and southern stars are in preparation. The precision of the parallaxes from the PDS scans is slightly higher than those from the Grant comparator with half the number of images.

W. Colley (undergraduate student) and Ianna developed an elliptical contouring routine for image location with our PDS scans and measured a plate series for the southern nearby star CD-49° 13515 (Gl 832). Examination of the parallax solution residuals spanning a period of about 15 years showed no evidence for an astrometric perturbation.

Experiments are underway to test the astrometric accuracy of Kodak 4415 Estar-based film in comparison with the IIIaF plate. Observations have been obtained with the McCormick refractor and the Fan 1-meter reflector for both materials under identical conditions, and they will be scanned with the McCormick PDS microdensitometer. The 4415 film offers advantages over plates in lower cost, finer grain, better keeping properties for the unexposed hypersensitized film, and better prospects for long term availability.

The southern hemisphere CCD parallax observations have continued at Siding Spring Observatory on the 1 m telescope with the Astromed camera system and uncoated GEC 8603 chip as the detector; a few observations have been made with an engineering grade Tek 1K by 1K chip.

For the most part the CCD observing program consists of late-type high proper motion stars. A number of white dwarfs in the magnitude range 13–15 are being transferred from the photographic program to the CCD program in consideration of the demise of the Kodak IIa-type plates, the termination of most photographic observations with the Yale-Columbia refractor in the near future, and the higher data acquisition rates at SSO. Formal errors in the CCD parallaxes for several of the best observed stars with 50–60 frames are between one and two milliarcseconds.

Several of the lowest luminosity objects with CCD parallaxes have K band absolute magnitudes fainter than 10, and thus appear to be field brown dwarfs. These are HB2047-34, HB2115-45, RG0050-27, and ESO207-61. This interpretation is based in part on the empirical MLR for low mass stars in the solar neighborhood recently published by Henry and McCarthy (AJ 106, 773, 1993), where they suggest the hydrogen burning cutoff mass occurs at that absolute K magnitude. These four objects are fainter than other low luminosity main sequence stars of the same color, and likely are so because they are substellar and unable to sustain nuclear burning.

h. Space Astronomy

O'Connell continues as a Co-Investigator for the Ultraviolet Imaging Telescope of the *Astro* Spacelab missions. The *Astro-2* mission, half of which will be devoted to Guest Observer programs, is currently planned for December 1994.

IV. MISCELLANY

Hawley was awarded the Helen B. Warner Prize by the American Astronomical Society. He was cited for his work in numerical astrophysics. Thuan won the Henri Chrétien International Research Award from the American Astronomical Society. This award will support an international collaborative research project.

Balbus served as a member of the NASA Kuiper Airborne Observatory Peer Review Committee and the Hubble Fellowship Review Panel. Chevalier served on ACAST (Advisory Committee to the NSF Astronomy Division) and on the Committee of Visitors to the NSF Astronomy Division. O'Connell served as a member of the AURA Observatories Visiting Committee, as chair of the NASA rocket astrophysics program peer review, and as a member of the NASA Astrophysics Mission Operations and Data Analysis working group. Richards served on an NSF peer review committee for the Research Experience for Undergraduates. Sarazin was a member of the NASA Working Group on X-ray Astronomy and the NASA AXAF Users Committee, chaired the NASA ASCA Extragalactic Review panel, and was Visiting Professor of Physics at the Scuola Normale in Pisa in November and December 1992. Saslaw has been elected a member of the Cambridge Committee of the Cambridge Society of Bombay, an international organization for the exchange of academics in all subjects between Britain and India. Whittle has served on the NOAO dark time TAC, as well as the HST Cycle 4 TAC.

Tolbert's term as Executive Vice President of the Society for Scientific Exploration ended after three years of service, but he continues to serve as Treasurer of the Society. Tolbert also continued his participation in the AAS Shapley Lectureships Program. Tolbert served on a panel of the Geophysical Society of America on the Teaching of Earth Science in the U.S.

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Craig L. Sarazin