University of Virginia

Department of Astronomy
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This report covers the period 1 September 1997 to 31 August 1998.

1 Personnel

During this time the departmental faculty consisted of Steven A. Balbus, Roger A. Chevalier, John F. Hawley, Philip A. Ianna, Z.-Y. Li, Steven R. Majewski 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. Shiv S. Kumar retired from the faculty in June 1998.

The Virginia Institute for Theoretical Astronomy (VITA) continued operations during this period with support from the University of Virginia and NASA Astrophysical Theory Program grants and hosted a number of visitors for brief periods. P. Koubský (Ondřejov Observatory, Czech Republic) was a visitor for two months with support from an NSF Division of International Programs grant to Richards.

Postdocs in residence included Carolyn Cox, Dana Dinescu, Richard deGrijs, Ben Dorman, Richard Patterson and Paul Ricker.

Eric W. Weisstein continued as Research Scientist. Astrometric support positions were held by Michael Begam and Richard Patterson, who spent part of the year at Mount Stromlo Observatory. James Barr continued as electronics technician, and Charles Lam continued as instrument maker. Virginia Bossong and Jacquelynn Harding continued as our secretaries. Nick Nichols is the resident caretaker at the Fan Mountain Station.

There were 19 enrolled graduate students at the end of this period. Noella D'Cruz completed her Ph.D. during the year.

2 Facilities

The 67-cm Leander McCormick refractor on Mount Jefferson and the 0.7-m and the 1-m reflectors on Fan Mountain were used during the year for education in both graduate and undergraduate courses. A new automated tailpiece for the 1-m is in the final stages of construction. In Australia, the 1-m reflector at Siding Spring Observatory has continued to be made available for the southern parallax program under a cooperative agreement with Mount Stromlo and Siding Spring Observatories.

The department moved to new and larger quarters at 530 McCormick Road in June 1998.

The PDS 1010GM microdensitometer was given a major maintenance overhaul by Orbital Sciences and continues to be heavily used for our galactic structure and other astrometric programs. It is also used several times a month by University researchers from the Department of Biology. A second PDS 1010 was acquired from Goddard Space Flight Center and has been installed in a new laboratory in the Astronomy Building; it is currently undergoing testing and new PC-based control software is under development.

3 Research

3.1 Stars and Stellar Evolution

Balbus is carrying through a time dependent nonlinear analysis of the foundations of alpha disk theory, with the intent of elucidating conditions under which turbulent transport in accretion disks may properly be described by an alpha formalism. While magnetic fields can rigorously be incorporated within the this formalism, it can be shown from first principles that self-gravity may not. Viscous models of such disks are likely to be qualitatively incorrect.

With H. Spruit (MPI-Garching), Balbus is investigating the effects of the magnetorotational instability in stars, generalizing earlier studies by allowing for the effects of thermal and resistive diffusivities. Whereas an adiabatic gas is stabilized by radially displaced buoyant oscillations, small wavelength disturbances in a thermally diffusive gas may be destabilized. The effects of this on radial mixing in a star is being explored.

With graduate student Wayne Winters, Balbus and Hawley have carried out further three-dimensional simulations of Keplerian shear flows at high resolution and with different numerical algorithms. These simulations are consistent with complete nonlinear stability of Keplerian disks; self-generated hydrodynamical turbulence is not a source of anomalous viscosity.

Chevalier studied models for pulsar nebulae like 3C58 (SN 1181) that are different from the Crab Nebula in that they have low values of X-ray to radio luminosity. An explanation of this property as due to synchrotron energy losses of the high energy particles has problems with the high magnetic energy that is required and with the observed sharp break in the synchrotron spectrum. An alternative model is one in which the observed spectral break is due to the particle energies at shock injection and the synchrotron energy losses are small. The nebulae are then strongly particle dominated and the pulsars are more powerful than in previous estimates. This model makes predictions for the infrared flux from the nebulae and for the distribution of X-ray and radio emission in the nebulae.

In collaboration with R. Fesen (Dartmouth) and oth-

ers, Chevalier analyzed spectra of SN 1979C and SN 1980K at an age of about 15 years. The data included *HST* ultraviolet spectra of SN 1979C. The spectra show broad emission lines that are those predicted by circumstellar interaction models. Emission from both a cooling reverse shock front and photoionized supernova ejecta can be identified. The emission appears to be from gas that is at a higher density than that in the specific interaction models that are available.

Hawley and Balbus continue to investigate the nature of the angular momentum transport mechanism in astrophysical disk systems through combined analytical and numerical studies. During the past year they have developed and tested a global three-dimensional MHD code for large-scale accretion disk simulations.

Hawley, in collaboration with T. Fleming and J. Stone of the University of Maryland, is investigating the evolution of the magnetorotational instability in the presence of finite resistivity in the local model. Simulations find that in the absence of a mean field, turbulence generated by the instability dies away due to field dissipation below a critical magnetic Reynolds number between 10^4 and 10^3. This suggests that angular momentum transport by MHD turbulence in protostellar disks can be inhibited by Ohmic dissipation at larger magnetic Reynolds numbers than expected from the linear analysis.

Li and Chevalier are analyzing the radio emission from the supernova SN 1998bw, which is likely to be associated with a gamma-ray burst (GRB 980425). It was the most luminous radio supernova ever observed. They are assuming a model in which a mildly relativistic shock front accelerates electrons to a power law energy distribution and find that the data are consistent with expansion into the expected stellar wind of the progenitor star.

Li has extended early work on evolution of magnetized molecular cloud cores to include dust grains. He found that dust grains enhance the coupling between the magnetic field and the cloud matter by up to an order of magnitude. This enhancement significantly modifies the cloud dynamics. In particular, he showed that "starless" cores - those dense cores of molecular clouds that are yet to harbor protostellar objects - must have a substantial infall motion. Such a motion may have been detected recently around L1544. It explains why typical "starless" cores only last a few dynamic times.

Li, F. Bertoldi (MPI-Garching) and C. McKee (Berkeley) are investigating star formation in "elephant trunks" of M16. From the number of the evaporating gaseous globules (EGGs) off the wall of the trunks and the absence of a star cluster in that region, they deduced that stars formed in the EGGs must be induced by radiative implosion. To explain the typical size (of order 10^3 AU) and lifespan (of order 10^4 years) of the EGGs, they proposed that the EGGs are formed when ionization shock fronts strip away the low density envelope of forming stars, exposing the dense region bounded by hydromagnetic shocks. Such shocks were previously studied by Li and McKee.

Li, T. Chiueh (Taiwan) and M. Begelman (JILA), studied the dynamics of Crab-like pulsar winds, which have much more energy in the ultra-relativistic bulk motion than in magnetic fields. From the conservation of energy and momentum, they concluded that strong matter-domination is difficult to achieve in an ideal magnetohydrodynamic (MHD) wind. The reason is that it is hard to open up a flow channel to allow efficient conversion of magnetic energy into kinetic energy while maintaining an exact force balance across the channel. This difficulty points to a non-ideal MHD means to convert magnetic energy into kinetic energy in pulsar winds, perhaps near the light cylinder.

Li, R. Krasnopolsky (CalTech) and R. Blandford (CalTech) examined the launching and the propagation of cold MHD winds/jets from accretion disks. They rewrote the ZEUS2D MHD code, paying special attention to the conditions on the disk boundary where magnetic fields are anchored and the wind material is injected. Their simulations last many Keplerian orbits, and steady states are achieved. They found that, in steady state, disk winds quickly collimate into jets around the rotation axis (even before reaching the Alfvén surface), with density contours more jet-like than streamlines. They are exploring various parameter regimes and will try to extend the simulation to 3D to study, among other things, the stabilities of MHD winds/jets.

Majewski and grad student M. Siegel continued their work on the Selected Areas Starcounts Survey (SASSY), a systematic CCD starcounts survey of the Milky Way, in collaboration with I.N. Reid (Caltech) and I.B. Thompson (OCIW). BVRI photometric and object classification reductions are complete in five of fourteen 2 deg^2 fields observed with the Swope 1-m telescope at Las Campanas. Analysis of the Galactic disk density distribution is now underway. The SASSY also revealed what appears to be an extension of the tidal stellar tail of the Sagittarius dwarf spheroidal galaxy to $b = -40°$ (25° south of the Sgr nucleus), more than double the previously reported size of the Sgr stream.

Additional starcount data to fainter (V=22) magnitudes are being generated by Majewski, Dinescu, and former UVa undergraduate student Jamie Ostheimer in collaboration with Allan Sandage (OCIW) from sky-limited Mayall 4-m photographic plates scanned on the UVa PDS microdensitometer. Catalogues generated with these plates are input to the deep, magnitude-limited, proper motion and multifiber spectroscopic survey of the Galaxy with J. Munn (Yerkes) and S. Hawley (MSU). Radial velocities have been measured for some 1000 survey stars in various fields. UVa undergraduate W. Johnson has been calibrating UBV and Washington photometry for several of the fields in this NSF supported survey of the abundance, density, and kinematical distributions of Galactic stellar populations.

Majewski and UVa undergraduate J. Ostheimer, in collaboration with W. Kunkel (Las Campanas), have calibrated a technique for finding distant halo giant stars.

Together with K. Johnston (IAS) and R. Patterson, they have discovered moving groups of giant stars near the Magellanic Clouds, and with properties suggesting they may be extended tidal debris from the Magellanic system. If true, this would be the first definitive evidence for *tidal* disruption of the Magellanic Clouds.

O'Connell, Rood, and graduate students J. Crane and I. Freedman are analyzing HST spectra of 5 of the unusual, very hot stars in the globular cluster ω Centauri discovered with UIT far-UV observations. One more object remains to be observed by HST/STIS.

Richards and Kempner (graduate student) have completed their study of the Si IV lines in the ultraviolet spectra of U Sge. They used archival IUE spectra of U Sge to study hot ($\sim 10^5$ K) circumstellar gas in this system. The observed spectra contained several UV resonance lines, of which the Si IV lines (λ1394, λ1405) were the strongest. The observed spectra display variations in the line profiles and line centers with orbital phase that suggests the presence of circumstellar gas. The residual emission seen in the difference spectra, after the photospheric contribution was removed from the observed spectra, was strongest between phases $\phi = 0.3$ and $\phi = 0.7$, with a strength of up to 0.2 of the continuum flux. A Doppler tomogram produced from the Si IV λ1394 difference profiles showed that the emission source was located behind the mass gaining star, in the direction away from its mass losing companion. The location of the Si IV emission source is consistent with that of the Hα "absorption zone" seen in tomograms of U Sge and U CrB.

Richards and P. Koubský (Ondřejov Observatory, Czech Republic) have continued their project on eclipsing and non-eclipsing Algols with the aim of obtaining the 3-D structure of the accretion regions in these systems. They and several collaborators have now completed a multiwavelength analysis of 22 years of spectroscopic observations from 1975 to 1997, which were collected at six observatories in five countries: Ondřejov Observatory (Czech Republic), McDonald Observatory (U.S.A.), Kitt Peak National Observatory (U.S.A.), Observatoire de Haute Provence (France), David Dunlap Observatory (Canada), and Okayama Observatory (Japan). They found that the circumstellar gas in CX Dra changes in cycles of hundreds of days. However, these cycles may be part of a longer 4000-day cycle. The emission in the Hα and He I λ6678 lines seems to be permanent, and the changes in the equivalent widths of the difference Hα and He I λ6678 profiles are modulated with the 6.696-day orbital period. Finally, the radial velocities of the dominant Hα emission peak follow an S-wave. The resulting velocity map shows that the source of the single-peaked emission lies close to the L_1 point but away from the line of centers.

Rood, Dorman (GSFC/UVa), Fusi Pecci, Ferraro, Paltrinieri, and others in Bologna continue their project on HST observations of globular cluster stars. The project has two major components. The first is to achieve the largest possible photometric samples of Galactic globular clusters (GGCs). This will allow the most stringent possible tests of stellar model calculations and the assumptions required to make these calculations. The second part involves observations of UV bright objects in globular cluster. Highlights for the year include: (1) *Horizontal Branch (HB) Stars*—the GGCs M13 and M80 have extremely long blue HB tails. Further, groups of stars along the HB are separated by gaps. Since the UV colors are excellent indicators of temperature for such hot stars this showed for for the first time that (at least some) gaps occur at similar temperatures in different clusters. (2) *Blue Straggler Stars (BSS)*—Mid-UV observations have been found to be the ideal tool for obtaining *complete* samples of BSS even in the most crowed region of high density clusters. Only with complete samples can one make a meaningful comparison of BSS content in GGCs with different structural parameters. The discovery in M80 of the largest and most concentrated population of BSS ever observed in a GGC is especially interesting. (3) *Cataclysmic Variables*—In most of the surveyed GGCs a few faint objects with a strong UV excess have been found to lie significantly outside the main loci defined by other cluster stars. Most of these objects are within the error boxes of low luminosity GGC X-ray sources and are good candidates to be the long sought GGC CVs.

Sarazin and W. Dalton (former grad student) are constructing models for the high mass X-ray binary (HMXRB) populations in the Large Magellanic Cloud (LMC) and Small Magellanic Cloud (SMC). In particular, they investigate the effects which the lower stellar metallicities of the Magellanic Clouds (MCs) have on the evolution and properties of HMXRBs. From the observed properties of the relatively small number of identified HMXRBs in the MCs, it has been suggested that MC sources have very high X-ray luminosities, and may contain a higher proportion of black holes than HMXRBs in our Galaxy.

Saslaw and W. Cotton (NRAO) are using the VLBA in an attempt to detect gravitational microlensing of the core of a double radio galaxy by a foreground star in the Milky Way. If successful, this would provide a new test of the mass-luminosity relation for the star. Moreover, motion of the star could alter the image on a time scale of order one year. This would provide additional independent measurements of the star's mass and distance, as well as providing a rough estimate of the mass of our Galaxy out to the star's distance. Furthermore, the image shape would provide information about the structure of the core of the radiogalaxy, possibly related to very small-scale variations of its jet.

3.2 Interstellar Medium

Chevalier investigated the interaction of supernova remnants with molecular clouds. Massive stars may end their lives in the molecular clouds in which they were born. O-type stars probably have sufficient photoionizing radiation and wind power to clear a region > 15 pc in radius of molecular material, but early B stars do

not and may interact directly with molecular gas when they explode. Molecular clouds are known to be clumpy, with dense molecular clumps occupying only a few percent of the volume. A supernova remnant then evolves primarily in the interclump medium. The remnant becomes radiative at a radius of ~ 6 pc, forming a shell that is magnetically supported. The structure of the shell can be described by a self-similar solution. When this shell interacts with the dense clumps, the molecular shock fronts are driven by a considerable overpressure compared to the pressure in the rest of the remnant. Observations of the remnants W44 and IC 443 can be understood in this model. W44 has a shell expanding at ~ 150 km s^{-1} expanding into a medium with density $4 - 5$ cm^{-3}. The shock emission expected in such a model is consistent with the observed Hα surface brightness and the [OI] 63μm line luminosity. IC 443 appears to be expanding at a lower velocity, 100 km s^{-1}, into an interclump medium with a higher density, ~ 15 cm^{-3}. The interaction of the radiative shell with molecular clumps can produce the molecular emission that is observed from IC 443. Both remnants are shell sources of radio synchrotron emission, which can be attributed to relativistic electrons in the cool radiative shell. If ambient cosmic ray electrons are further accelerated by the shock front and by the postshock compression, the radio fluxes and the flat spectral indices of W44 and IC 443 can be explained. The energetic electrons are in a high density shell and their bremsstrahlung emission can approximately produce the γ-ray fluxes observed by *EGRET*.

3.3 Galaxies and Active Galactic Nuclei

Balbus and Hawley are studying the evolution of a magnetic field in a massive halo potential appropriate to a galaxy, both globally and locally in the shearing box approximation.

Balbus and Massimo Ricotti (Colorado) have found exact, local, nonlinear magnetic equilibrium solutions within a differentially rotating background. The solutions consist of rigidly rotating ellipses in the orbital plane with coincident elliptical streamlines of velocity and magnetic field; the net sum of the Coriolis and Lorentz forces compel fluid elements to follow exactly elliptical paths. Because the fields that emerge from these solutions are typically thermal strength, galactic disks may be a natural venue for them. If these confining magnetic structures are sufficiently stable, and can be embedded in a background of shear flow, they are interesting candidate for a large scale confinement mechanism for molecular cloud complexes.

With J. Sellwood (Rutgers), Balbus has offered a detailed, MHD-based explanation for the origin of the broad 21 cm linewidths seen in the extended H I disks of spiral galaxies, based on the magnetorotational instability (Sellwood & Balbus 1999). Stellar sources of cloud motions are nearly absent in such environments. The results were applied to observations of NGC 1058. An MHD explanation for cloud turbulence in nearly star-free gas disks explains why residual random cloud velocities may be a ubiquitous feature of these gaseous galactic disks. Furthermore, under a wide variety of rather standard phenomenological magnetic field scaling laws, the cloud velocity dispersion (of order the Alfven speed) should be nearly constant across a given disk, as indeed observed. Finally, the investigators argue that the latter implies star formation should cut off sharply in disks, which also seems to be a general phenomenon.

Cox and Sarazin are analyzing the ROSAT HRI image of the Virgo elliptical galaxy NGC 4636.

J. Crane (graduate student) and Sarazin are studying the ASCA X-ray spectrum of the elliptical galaxy NGC 1395.

De Grijs, O'Connell and Gallagher (Wisconsin) obtained optical and near-infrared HST observations of a high-luminosity region 700 pc from the nucleus of M82. This region, "M82 B," is believed to be in a post-starburst state, since it has exactly the properties one would predict for a fossil starburst with a similar amplitude to the active burst. It is expected that M82 B originally contained a complement of luminous star clusters similar to that now observed in the region of the active starburst. The combination of observations of both the active and the fossil starburst sites in M82 therefore provides a unique physical environment for the study of the stellar and dynamical evolution of star cluster systems. Several thousand resolved sources are detectable. The first results indicate that the majority of the luminous, compact sources detected are more extended than expected from stellar profiles, although not as bright as (evolved) "super star clusters" that have been detected in many other interacting and starburst galaxies. Another major difference between the star cluster candidates in M82 B and these super star clusters is the shape of their luminosity function (LF): although the LFs of super star cluster populations are often best represented by power laws, the LFs of the star cluster candidates in M82 B show a clear turnover, similar to globular cluster LFs. Preliminary analysis shows that the detected candidate young clusters in M82 B may have been forming continuously since the main starburst, which is believed to have occurred about 200 Myr ago. Even in this time interval evolutionary effects might be detectable because of the dense environment of the starburst. O'Connell and undergraduate student G. Becker are also using the HST data to study the distribution of young star clusters and H II regions in the outer disk of M82.

De Grijs and Peletier (Durham) improved the use of the optical/near-infrared color-magnitude (CM) relation as a distance indicator for spiral galaxies: by avoiding contamination by dust one can reduce the scatter in the spiral galaxy CM relation significantly, thus making this relation feasible as a distance indicator for *field* galaxies with $-25.5 < M_K \leq -20$, and possibly even fainter. Its accuracy can be comparable to that of the widely used Tully-Fisher relation, $\sim 25\%$. High-resolution HST observations can provide a powerful tool to extend the useful distance range and calibrate the relation.

De Grijs and van der Kruit (Groningen) showed that the ratio of the radial and vertical scale parameters in galactic disks contains information about the axis ratio of the stellar velocity ellipsoid. From the analysis of a statistically complete sample of edge-on disk-dominated galaxies, it was found that this axis ratio at one I-band exponential scale length is 0.6 ± 0.2, independent of the amplitude of the rotation curve, or of morphological type. The ratio of the velocity dispersions relates to the scale parameter ratio only through Toomre's Q parameter for local stability in galactic disks.

Majewski and C. Palma (graduate student) are searching for evidence of fossil accretion events in the Milky Way's halo through alignments of possible orbital poles. A statistical cluster analysis algorithm applied to poles derived from published proper motion data for 38 globular clusters and six satellite galaxies indicates at least one significant dynamical family that may be fossil evidence for a prior Galactic accretion event. A two-point correlation function analysis also indicates that the orbital poles of Zinn Young halo globular clusters have a larger clustering amplitude than that of Zinn Old halo globular clusters.

O'Connell, Rood, and colleagues at other institutions are using HST/STIS to study spatial gradients in the far-UV "upturn" component in nearby E/S0 galaxies, which is now thought to be produced mainly by metal-rich extreme horizontal branch stars and their descendents. Although earlier observations with UIT demonstrated the existence of surprisingly large gradients in the FUV/optical flux ratio with radius in E galaxies and spiral bulges, no instrument before STIS had the capability of measuring radial changes in far-UV spectral shape or spectral features. O'Connell has also used the Lick Observatory spectral survey recently published by Trager et al. to show that the far-UV upturn strength is well correlated with Na I and CN features as well as with Mg. However, it does not correlate with Fe line strengths. Other recent studies have shown that the abundances of certain light elements (e.g. N, Mg, Na) are decoupled from those of the iron peak in more luminous E galaxies, and the behavior of the extreme HB stars in old populations is evidently linked to that of the lighter elements.

O'Connell and graduate student Z. Liu are studying the relationship between HI surface density and far-UV luminosity, derived from UIT images, in the rapidly star-forming galaxy NGC 4449.

C. Palma (graduate student) and Majewski have completed WIYN HYDRA observations of an apparent cluster of companion galaxy candidates to the host of the giant FR II radio galaxy NVSS J214530+815455. Redshifts determined for these galaxies from the HYDRA spectra will determine whether the FR II's host is embedded in a surprisingly dense galaxy cluster, or if the FR II is simply seen in projection. Palma, graduate student F. Bauer, and Sarazin have obtained 30,000 seconds of ROSAT HRI exposure in the same field to determine the properties of the IGM in which the radio galaxy is embedded.

Rood, Bania (BU), Balser (NRAO) & Wilson (MPIfR) are continuing their project to determine the cosmic abundance of ^{3}He. Observations of H II regions continued at the Green Bank 140ft. These include a survey of low density H II regions which should be easy to model (a necessary step in getting the abundances).

Sarazin and J. Irwin (Michigan) are studying the X-ray properties of X-ray–faint elliptical galaxies, spiral bulges, and low mass X-ray binaries. The X-ray emission from the faintest X-ray elliptical and S0 galaxies is characterized by a hard $\sim$5 keV component, and a very soft $\sim$0.2 keV component. The hard component has generally been regarded as the integrated emission from low mass X-ray binaries (LMXBs), but the origin of the soft component is uncertain. Irwin and Sarazin suggest that LMXBs also exhibit a soft component, which is responsible for the very soft X-ray emission in the faintest early-type galaxies. They show that AXAF observations of nearby elliptical and spiral bulges should resolve the X-ray emission, at both hard and soft energies. Sarazin and Irwin are also studying the ASCA X-ray spectrum of the elliptical galaxy NGC 499.

Thuan in collaboration with Izotov (Kiev Observatory), have analyzed high-quality spectra for a large sample of 54 supergiant HII regions in 50 low-metallicity blue compact galaxies (BCGs) with $Z_\odot/50 \leq Z \leq Z_\odot/4$. They have derived abundances for the elements N, O, Ne, S, Ar and Fe. They have also analyzed HST/FOS archival spectra of 10 supergiant H II regions to derive C and Si abundances in a subsample of 7 BCGs. The main result is that none of the heavy element-to-oxygen abundance ratios studied (for C, N, Ne, Si, S, Ar, and Fe) depend on oxygen abundance for BCGs with 12 + log O/H $\leq$ 7.6 ($Z \leq Z_\odot/20$). This constancy implies that all these heavy elements have a primary origin and are produced by the same massive (M $\geq$ 10 $M_\odot$) stars responsible for O production. The dispersion of the C/O and N/O ratios in these galaxies is found to be remarkably small, being only $\pm$ 0.3 dex and $\pm$ 0.02 dex respectively. This very small dispersion is strong evidence against any time-delayed production of C and primary N in the lowest-metallicity BCGs. The absence of a time-delayed production of C and N is consistent with the scenario that all galaxies with Z $\leq Z_\odot/20$ are now undergoing their first burst of star formation and that they therefore have ages not exceeding 40 Myr. If so, this would argue against the commonly held belief that C and N are produced by intermediate-mass (3 $M_\odot \leq$ M $\leq$ 9 $M_\odot$) stars at very low metallicities, as these stars would not have yet completed their evolution in these lowest metallicity galaxies. In higher metallicity BCGs (Z $> Z_\odot/20$), there is an increase of the C/O and N/O ratios along with their dispersions at a given O. This is interpreted as due to the additional contribution of C and primary N production from intermediate-mass stars.

These results lead Thuan and Izotov to propose the following timeline for galaxy evolution: a) all objects with Z $\leq Z_\odot/20$ began to form stars less than 40 Myr

ago; b) after 40 Myr, all galaxies have evolved so that Z > $Z_\odot/20$; c) by the time intermediate-mass stars have evolved and released their nucleosynthetic products (10-500 Myr), all galaxies have become enriched $Z_\odot/20$ < Z < $Z_\odot/4$. The delayed release of primary N at these metallicities greatly increase the scatter in the N/O abundance ratio; d) later, when galaxies get enriched to $Z_\odot/4$, secondary N production becomes important. BCGs show the same O/Fe overabundance with respect to the Sun (∼0.4 dex) as galactic halo stars, suggesting the same chemical enrichment history.

Thuan and Izotov, in order to test their proposal, have started a program to derive the age of the stellar populations in all such extremely metal-deficient blue compact galaxies (BCGs). There is only a handful known, as chemical enrichment occurs very fast. After the detailed analysis of SBS 0335-052 ($Z_\odot/41$), which was found to be indeed young, they have embarked on a study of the BCG SBS 1415 + 437 ($Z_\odot/20$). They find an upper limit of ∼100 Myr on the age of SBS 1415 + 437. The (V-I) color of its underlying extended low-surface brightness component is very blue (≤ 0.4 mag), indicative of an age for the stellar component less than 100 Myr. HST images resolve the BCG into stars, and color-magnitude diagram analysis also implies an age less than 100 Myr.

Thuan and Izotov discuss the apparent discrepancy between N/O abundance ratios measured in BCGs and those in high-redshift damped Lyα galaxies, which are up to one order of magnitude smaller. They argue that this large discrepancy may arise from the unknown physical conditions of the gas responsible for the metallic absorption lines in high-redshift samples Lyα systems. While it is widely assumed that the absorbing gas is neutral, they propose that it could be ionized. In this case, ionization corrections factors can boost the N/O ratios in damped Lyα galaxies into the range of those measured in BCGs.

Thuan, in collaboration with Martin (Meudon) and Pustilnik (Special Astrophysical Observatory, Russia), has carried out a neutral hydrogen survey of 80 Blue Compact Galaxies selected from the First and Second Byurakan objective prism surveys to have a HII region-like spectrum, an equivalent width of the OIII λ=5007 line larger than ∼50 Å, and a velocity ≤ 6000 km s^{-1}. The overall detection rate is 69%. HI masses range between 2×10^7 $M_\odot$ and 5×10^9 $M_\odot$ with the HI mass distribution peaking at 4×10^8 $M_\odot$. The full width at half-maximum of the HI profile varies between 30 and 250 km s^{-1}, with a mean at ∼100 km s^{-1}.

Thuan, Sauvage and Madden (Saclay) have used the ISO satellite to observe the metal deficient BCD galaxy SBS 0335-052 between 5 and 17 μm. With a $L_{12\mu m}/L_B$ ratio of 2.15, the galaxy is unexpectedly bright in the mid-infrared for such a low-metallicity object. The mid-infrared spectrum shows no sign of the Unidentified Infrared Bands, possibly due to the destruction of their carriers by the very high UV energy density. From 5 to 17 μm the energy distribution can be fit with a grey-body spectrum, modified by an extinction law similar to that observed toward the Galactic Center, with an optical depth of A_V ∼19-21. Such a large optical depth implies that as much as ∼75% of the current star-formation activity is hidden by silicate dust with a mass up to 5×10^5 $M_\odot$. It is remarkable that such a nearly primordial environment contains as much dust as galaxies which are 10 times more metal-rich. If the hidden star formation in SBS 0335-052 is typical of young galaxies at high redshifts, then the cosmic star formation rate derived from UV/optical fluxes would be underestimated.

C.-Y. Wang (graduate student) and Sarazin are analyzing the ROSAT HRI observation of the elliptical galaxy NGC 1404 in the Fornax cluster.

Whittle, Nelson (Nevada), and Wilson (Maryland) obtained cycle 7 HST STIS spectroscopic data on the Seyfert 2 galaxy Markarian 78. The aim is a thorough investigation of the ionization and dynamical conditions in this archetypal jet dominated Seyfert galaxy, using four slit positions each with four grating settings covering both optical and UV. Initial analysis has recently begun. This project extends their earlier project which used HST PC and FOC images and FOS spectra in a more limited study of ionization and kinematics in the same galaxy. That study, recently completed, identified a number of physical processes manifest in the interaction of the radio jet and the line emitting gas (ablation, flow deflection, gas sweep up, cloud shocks, lack of detailed mixing). Careful comparison of kinematic and ionization conditions across the emission regions shows little correlation, undermining the currently popular speculation that jet shocks play a significant role in ionizing the line emitting gas. They have also studied the extended blue continuum, commonly seen in AGN but currently poorly understood. The remarkable similarity in structure between this blue continuum and the [OIII] line emission argues for nebular continuum emission either directly from the line emitting gas or from ionizing shocks. Preliminary calculations find the shock contribution to be too weak to be important.

Whittle and undergraduate student G. Becker analysed a STIS slitless image of the emission region in Markarian 78. Combining this with a direct [OIII] line image, they were able to derive the velocity pattern of the eight major knots, although inherent ambiguities in the slitless image prevented a more detailed analysis. They explored the possibility of using tomography to reconstruct the full velocity field using several slitless images. Considering only the efficient strategy of two oppositely directed slitless spectra and a direct image, they found that the data were too sparse to usefully reconstruct the velocity field. With more slitless angles, however, the tomographic reconstruction problem is possible.

3.4 Clusters of Galaxies

R. Audano (graduate student) and Sarazin are calculating the gamma ray emission expected from the population of cosmic ray particles in clusters of galaxies.

F. Bauer (graduate student) and Sarazin are analyzing a new ASCA observation and an archival ROSAT PSPC observation of the X-ray cluster Abell 644. It seems to be undergoing a minor merger. The combination of a moderate cooling flow and evidence for a merger make this cluster an interesting case to test the fragility of cooling flows in mergers and/or the speed with which cooling is restored following the merger.

N. D'Cruz (Washington) and Sarazin have determined the predicted luminosities, surface brightness profiles, and spectral line profiles for the 3.071 mm hyperfine line from Li-like ^{57}Fe in cooling flow and non-cooling flow clusters.

J. Kempner (graduate student) and Sarazin are using X-ray and radio observations to determine the importance of thermal and nonthermal shock energy input to clusters.

S. Randall (graduate student) and Sarazin are calculating the history of shock energy input to clusters of galaxies. This result should be useful for determining the efficiency of shock particle acceleration in clusters. They are also determining the contribution of EUV emission from clusters of galaxies to the diffuse extragalactic ionizing background.

Ricker and Sarazin are studying the evolution of merging clusters of galaxies via three-dimensional N-body/hydrodynamics simulations. By simulating pairs of idealized colliding clusters, varying merger parameters such as relative mass and impact parameter, they ascertain the effects of individual mergers on the dynamical state of clusters. One objective of this program is to determine the evolution of observable quantities such as X-ray luminosities, X-ray spectra, and gas and galaxy velocities during mergers. Of particular interest is the evolution of correlations between observables, such as X-ray luminosity and temperature. In addition to providing evidence that additional physics beyond dark matter, gravity, and gasdynamics is required to explain these correlations, the simulations suggest that individual deviations from the observed relationships may be used to derive the amount of time elapsed since a cluster's last major merger. This may be of use in analyzing phenomena such as cooling flows, which show an anticorrelation with merging activity in observations and appear to be disrupted in some simulations. The simulations may also enable the development of 'broad-beam' indicators of merging activity which can be applied to clusters at high redshift, where obtaining high-resolution X-ray images and spatially resolved spectra is not feasible.

Ricker and Sarazin also use simulations to understand the structure of just-relaxed clusters. One problem of interest is the survival of cooling flows during mergers and its dependence on collision parameters. Another is the degree to which the intracluster medium is turbulent as a result of off-center mergers. Turbulent motions may provide support for the constant-density cores seen in intracluster gas. They may also affect the structure of the magnetic fields in cluster cores (with consequences for cooling flows) and accelerate the stripping and destruction of galaxies orbiting near the center of a cluster. A final problem of interest is the acceleration of cosmic rays by merger shocks. These may play a role in producing the diffuse radio halos and hard X-ray and extreme UV emission (thought to be due to inverse Compton scattering) which appear to be correlated with merging activity.

Sarazin is calculating the energy spectrum of relativistic electrons and ions expected in clusters of galaxies, given likely sources for the particles and their rates of energy loss. The resulting energy spectra are used to predict the emission of extreme UV light, soft X-ray, hard X-ray, and diffuse radio synchrotron emission.

Sarazin is working with a large group of scientists associated with the SIGMA hard X-ray detector to analyze the observations of the region of the Coma cluster. Over the last two decades (most recently with BeppoSAX), there have been claims of detections of hard X-ray emission from Coma, which is attributed to inverse Compton (IC) emission from relativistic electrons. But there have also been observations which set upper limits below the detections. Coma has a radio halo, and the combination of the radio synchrotron and hard X-ray IC emission would allow the cluster magnetic field to be determined. Thus, it is important to confirm the hard X-ray detections. The SIGMA detector has much better resolution than earlier experiments. SIGMA does indeed detect hard X-ray emission from the Coma region, but the image shows that the emission comes from the background AGN X Comae and not from the cluster. This emission is highly variable. The combination of varying fields of view of the detectors used in previous measurements and the variation of the X Comae can explain the contradictory results of the earlier observations.

The quasar B2 1028+313 is located in the central dominant galaxy of the cluster Abell 1030 ($z = 0.177$). Sarazin, A. Koekemoer (STScI), O'Dea, Baum, F. Owen (NRAO), and M. Ledlow, (NMSU) obtained HST UV spectra of the quasar to search for absorption due to cool material in the cluster. They detected Lyα and C IV absorption lines at the redshift of the quasar, and derived constraints on the nature of the absorbing material. They also place stringent upper limits on other absorption lines from the intracluster medium. They have also acquired ROSAT PSPC and HRI X-ray images and ASCA X-ray spectra of the quasar. They are trying to use the images and spectra to separate the cluster emission from the brighter quasar. They found that the X-ray emission is strongly dominated by the quasar. The emission varied by a factor of about two between the ROSAT HRI and ASCA observations, which were about one year apart. There was evidence for extended X-ray emission, which contributed about 25% of the total flux. However, this emission does not appear to be normal X-ray emission from intracluster gas, based on its temperature and spatial structure. It appears likely that the extended X-ray emission is associated with the radio source rather than the cluster. The X-ray spectrum of the quasar is fit by a single power-law, except at low energies where there is a soft excess.

Abell 2597 is one of the archetypal "blue-lobed" cooling flow radio elliptical galaxies, also displaying a luminous emission-line nebula, a compact radio source, and a significant dust lane and evidence of atomic and molecular gas in its center. Sarazin, Koekemoer, O'Dea, B. McNamara (CfA), M. Donahue (STScI), M. Voit (STScI), and J. Gallimore (MPA) have imaged the central continuum and emission line regions with WFPC2 on HST. They show that the radio source is surrounded by a complex network of emission-line filaments, some of which display a close spatial association with the outer boundary of the radio lobes. They show that the physical properties of ionized and neutral gas are strongly suggestive of direct interactions between the radio plasma and ambient gas. They resolve the blue continuum emission into a series of knots and clumps, and present evidence that these are most likely due to regions of recent star-formation. U-band polarimetry of the cD galaxy by Sarazin, McNamara, B. Jannuzi (NOAO), R. Elston (U.Florida), and Wise has set an upper limit on the polarized fraction of the blue lobe emission of 6%. This rules out scattering of synchrotron emission as the source of the blue light and is consistent with the blue light being due to star formation. The lack of scattered light suggests that this FR I radio galaxy does not contain a hidden BL Lac object. On the other hand, the limit is consistent with a model in which the alignment effect in both high redshift and low redshift radio galaxies is due to a mixture of scattered light from the AGN and star light, and in which the scatter flux is proportional to the radio flux.

Sarazin and Markevitch are studying the cluster A2065, which shows structure and spectral evidence for both a merger and weak cooling flows associated with both of the central galaxies. The ASCA spectra allow one to determine the strength of the merger shock. This cluster is a very good laboratory to study the effects of mergers on cluster cooling flows.

Saslaw and S. Haque-Copilah have completed their analysis of the velocities and spatial distribution function for 4501 galaxies in the Pisces-Perseus supercluster, based on data by Giovanelli, Haynes and their collaborators. Three-dimensional spatial-velocity distribution functions for counts-in-cells have been determined for the total sample, for a subset containing the most conspicuous galaxies (brightest members with large intrinsic linear diameters), and for a subset containing the least conspicuous galaxies (faintest members with small intrinsic linear diameters). Subsets limited by absolute magnitude as well as by volume are examined. The counts-in-cells distribution functions for all these samples are described remarkably well by the gravitational quasi-equilibrium distribution which was previously found to fit the more statistically homogeneous Zwicky, CfA, ESO, and IRAS catalogs. For the complete Pisces-Perseus sample, the value of b, representing the ratio of gravitational correlation energy to twice the kinetic energy of peculiar motions is 0.8. The most conspicuous galaxies are somewhat more uniformly distributed than the least conspicuous ones, which tend to follow the overall distribution. A dendrogram analysis shows that groups of the most conspicuous galaxies tend to be located near groups of the least conspicuous ones. About 10^3 galaxies around the central region appear to form a fair sample, with the wide range of structures characteristic of gravitational clustering. These results appear to be consistent with the supercluster forming gravitationally by the accumulation of smaller clusters.

Whittle, Moss (Steward), and Kennicutt (Steward) have begun a program to take deep Hα images of four nearby clusters of galaxies. This extends the Hα objective prism work of Moss and Whittle, achieving much deeper detection levels and introducing several new themes. In addition to investigating the cluster environmental impact on star formation in galaxies, the project also aims to determine the distribution of star formation across a wide variety of galaxy types and luminosities. This will provide a current epoch star formation inventory which is necessary in the interpretation of higher redshift studies which target evolutionary processes over large lookback times.

3.5 Cosmology

Saslaw has completed writing his book *The Distribution of the Galaxies: Gravitational Clustering in Cosmology*. This is a monograph of about 450 pages scheduled to be published by Cambridge University Press in summer 1999. It is the first book to describe gravitational theory, computer simulations, and observations related to galaxy distribution functions (a general method for characterizing the clustering and velocities of galaxies). The discussions embed distribution functions in a broader astronomical context which includes correlation functions, fractals, bound clusters, topology, percolation and minimal spanning trees. It also shows how future observations can test theoretical models for the evolution of galaxy clustering at earlier times in our Universe.

Thuan, in collaboration with Hammer and Flores (Meudon) and other colleagues has carried out a deep ISO imaging survey at 6.75 and 15 μm of the Canada-France redshift survey field 1415+52. Careful data analysis and comparison to deep optical (BVI), near-IR (K) and radio (1.4 and 5 Ghz) data have yielded a catalog of 78 15 μm sources with optical identifications, 22 of which with I $<$ 22.5 mag have redshifts. They have a median redshift of $\sim$ 0.7. Almost all the star-forming galaxies present evidence for an A star population. Star-forming objects contribute respectively 50%, 73% and 26% of the extragalactic source counts at 6.75 μm, 15 μm and 5 Ghz, suggesting that the 60 μm luminosity density is strong dominated by emission related to star formation. The group has derived energy distributions for the sources with redshifts and compared them to well-known local galaxy templates in order to classify the galaxies. The classification scheme allows removal of the AGN contribution when deriving the cosmic star formation rate (SFR) density. They find that the SFR density derived by far-infrared fluxes is $\sim$ 2.3 higher than that previ-

ously estimated from UV fluxes. No apparent changes with redshift are found within the range $0 < Z < 1$. The corresponding global extinction is $A_V = 0.55 \pm 0.12$, similar to the average value for local irregulars. About 1% of the CRFS galaxies are strong and heavily reddened starbursts with SFR ranging from 120 to 330 $M_\odot yr^{-1}$, contributing ~25% of the SFR density for $Z \lesssim 1$.

3.6 Astrometry

Ianna, Patterson, and Begam are continuing the CCD parallax program at the Mount Stromlo and Siding Spring Observatories using the 1-m reflector. A paper presenting results for about 25 stars, mostly within 25 pc, is nearing completion; the brighter objects in the list have precisions of 1–2 mas.

Majewski is finishing observations for his program on the DuPont 100" telescope at Las Campanas to repeat photographs of the mid-declination (-15 to +15 degree) Kapteyn Selected Areas. The goal is to match the original plates taken by Seares, Kapteyn and van Rhijn at the turn of the century on the Mt. Wilson 60" telescope, for proper motions of exquisite (< 0.1 arcsec/century) precision to $V \approx 19$, tied to the extragalactic absolute reference frame. CCD photometry of these fields commenced this year on the Swope 1-m telescope.

Majewski and Patterson, in collaboration with W. Kunkel (Las Campanas), W. Gieren (Concepcion) and Johnston (IAS) are beginning their all-sky survey for $V < 13$ giant stars to be used for the Space Interferometry Mission Astrometric Grid.

Patterson and Ianna have continued a limited program to obtain parallaxes for a small sample of very low luminosity objects in the K band of the near infrared using CASPIR on the 2.3 m telescope at Siding Spring, in collaboration with Hugh Jones and M. Hawkins (ROE). Of special interest here is the brown dwarf candidate SERC 296A, shown to have Li in its spectrum.

Patterson, Ianna and Begam have continued to obtain Cousins VRI photometry for additional nearby star candidates such as the Wroblewski and Torres proper motion stars using the Siding Spring 1-m. Stars which have photometric parallaxes showing them to be nearby will be added added to the southern parallax program.

Siegel and Majewski, in collaboration with K. Cudworth (Yerkes) have continued their work on the proper motions of satellite galaxies and globular clusters of the Milky Way. In the past year, second epoch observations of Leo II and Carina were taken at KPNO and CTIO respectively and sufficient material has been obtained for a preliminary study. A CCD photometric study of Leo II is ongoing and a catalogue of member variable stars has been produced. Scanning of plates for both objects, as well as the Sagittarius galaxy cluster Terzan 8, commenced this year on the refurbished McCormick PDS microdensitometer.

4 Miscellany

Balbus was an invited participant at the Isaac Newton Institute of Mathematical Studies at Cambridge University. He attended the workshop "Dynamics of Accretion Disks," with support by a Sesquicentennial Fellowship from the University of Virginia. Chevalier served on the NRC/NAS Committee on Astronomy and Astrophysics and on the scientific organizing committee for the Young Supernova Remnant Workshop to be held in Boulder, CO. Fredrick (emeritus professor) continued his membership on the Hubble Space Telescope Astrometry Team. Hawley served on the scientific organizing committee for the workshop on "Numerical Astrophysics 1998" held in Tokyo, Japan, March 1998 Hawley served on the NCSA User Advisory Panel. Ianna served as local host for the 1998 meeting of the Division on Dynamical Astronomy, is a technical consultant to CSICOP, and is a member of the Board of Directors of the International Dark-Sky Association. O'Connell is chair of the Scientific Oversight Committee for the Hubble Space Telescope Wide Field Camera 3, scheduled for installation during the 2003 servicing mission. He also continues as a Co-Investigator for the Ultraviolet Imaging Telescope (UIT) of the *Astro-2* Spacelab payload and for the Hot Universe Background Explorer (HUBE) and IRIS. R. Ohl (graduate student) continues his work with the Far Ultraviolet Spectroscopic Explorer (FUSE), with responsibility for alignment and testing of the primary optics. C. Palma (graduate student) and J. Ostheimer (undergraduate) won Sigma Xi Grants-in-Aid of Research for their research. Ostheimer spent a summer at Kitt Peak National Observatory under their Research Experience for Undergraduates program. Majewski was named a Cottrell Scholar of the Research Corporation, and served on the Space Interferometry Mission Science Working Group. Richards continued to serve as a member of the AAS Committee on Minorities in Astronomy. She also served as a panel reviewer for the NSF Division of Astronomy. Richards and Kempner (graduate student) were visitors at Ondřejov Observatory, Czech Republic, in June and July 1998. Sarazin was chair of the the AXAF Users Committee, and a member of the ASCA Users Committee, the Heineman Prize Committee of the American Astronomical Society, the High Energy Astrophysics panel for National Academy of Sciences Decadal Report, and the scientific organizing committee for the Ringberg Workshop on Diffuse Thermal and Relativistic Plasma in Galaxy Clusters. Thuan with Balkowski and Cayatte (Meudon) organized the Moriond 98 meeting on "Dwarf Galaxies and Cosmology" in March 1998 at Les Arcs, France. He also organized with Guiderdoni and Bouchet (Institut d'Astrophysique de Paris) thae meeting on "The Birth of Galaxies" in July 1998 at Blois, France. Whittle was an NSF Panel member for the Extragalactic Observing Program, and a Cycle 1 AXAF Panel member for the Clusters and Galaxies panel.

UVa undergraduate Janet Wescott and graduate student Alison Schirmer have been working with Majewski to research the history of McCormick Observatory and the science of astrometry for a planned museum in the Observatory.

The department hosted the March 1998 meeting of

the Division on Dynamical Astronomy of the American Astronomical Society, with Ianna as chair of the local organizing committee.

During the year there were 2680 visitors to the McCormick and Fan Mountain Observatories as part of our continuing public outreach program.

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PUBLICATIONS

Balbus, S.A. and Hawley, J.F. 1998, "Instability, Turbulence, and Enhanced Transport in Accretion Disks," Rev. Mod. Phys., 70, 1

Balbus, S. A. and Ricotti, M. 1998, "On Nonshearing Magnetic Configurations in Differentially Rotating Disks," submitted to ApJS, astro-ph 9809333

Balser, D. S., Bania, T. M., Rood, R. T., & Wilson, T. L. 1998, "^{3}He in the Milky Way Interstellar Medium: Abundance Determinations," ApJ, in press

Bania, T. M., Balser, D. S., Rood, R. T., Wilson, T. L., & Wilson, T. J. 1997, "^{3}He in the Milky Way Interstellar Medium: Summary of Relevant Observations," ApJS, 113, 353

Bershady, M. A., Majewski, S. R., Koo, D. C., Kron, R. G., & Munn, J. A. 1997, "The Luminosity Function for $L > L^*$ Galaxies at $z > 3$," ApJ, 490, L41

Chevalier, R. A. 1997, "Expansion of a Photoionized Stellar Wind," ApJ, 488, 263

Chevalier, R. A. 1998, "Synchrotron Self-Absorption in Radio Supernovae," ApJ, 499, 810

Chevalier, R. A. 1998, "SN 1987A and Circumstellar Interaction," in SN 1987A: 10 Years Later, eds. M. Phillips & N. Suntzeff (San Francisco: ASP Conf. Series), in press

Chevalier, R. A. 1998, "Supernova Remnants in Molecular Clouds," ApJ, in press

Chevalier, R. A. 1998, "Pulsar Nebulae in Supernovae," Memorie Soc. Astr. Ital., in press

Chiueh, T., Li, Z.-Y. & Begelman, M. C. 1998, "Critical Analysis of Ideal MHD Winds as Pulsar Wind Model," ApJ, in press

Cornett, R. H., Dorman, B., Smith, E. P., Fanelli, M. N., Oegerle, W. R., Bohlin, R. C., Neff, S. G., O'Connell, R. W., Roberts, M. S., Smith, A. M., & Stecher, T. P. 1998, "Ultraviolet Imaging of the $z = 0.23$ Cluster Abell 2246", AJ, 116, 44

D'Cruz, N. L., Sarazin, C. L., & Dubau, J. 1998, "Excitation of the 3.071 mm Hyperfine Line in Li-like ^{57}Fe in Astrophysical Plasmas," ApJ, 501, 414

Dalton, W. W., & Sarazin, C. L. 1998, "High Mass X-ray Binary Modeling: The Magellanic Cloud Populations," ApJ, submitted

Dawson, D.W., & Ianna, P.A., 1998, "Collinder 110: An Old Open Cluster in Monoceros," AJ, 115, 1076

Dorman, B., & O'Connell, R. W. 1997, "Constraining the Abundances and Ages of Early-Type Galaxies", in The Ultraviolet Universe at Low and High Redshift, ed. W. H. Waller (AIP Press), 175

Dwarkadas, V. V., & Chevalier, R. A. 1998, "Interaction of Type Ia Supernovae with their Surroundings," ApJ, 497, 807

Ferraro, F. R., Paltrinieri, B., Fusi Pecci, F., Rood, R. T., Dorman, B. 1998, "Faint UV Objects in the Core of Galactic Globular Clusters: A New Sub-class of Cataclysmic Variable?," in Ultraviolet Astrophysics—Beyond the IUE Final Archive, eds. R. González-Riestra, W. Wamsteker, & R. A. Harris (ESA: Noordwijk), 561

Ferraro, F. R., Paltrinieri, B., Fusi Pecci, F., Rood, R. T., Dorman, B., 1998, "Multimodal Distributions along the Horizontal Branch," ApJ, 500, 311

Fang, F. and Saslaw, W. C. 1997, "Constraints on Galaxy Mergers at Moderate Redshifts from their Observed Luminosity and Spatial Distribution Function," in HST and the High Redshift Universe, ed. by N. Tanvir, A. Aragon-Salamanca and J. V. Wall (Singapore: World Scientific), 135

Fang, F. and Saslaw, W. C. 1997. "Effects of Galaxy Mergers on their Spatial Distribution and Luminosity Function," ApJ, 476, 534

Ferraro, F. R., Paltrinieri, B., Fusi Pecci, F., Dorman, B., Rood, R. T. 1997, "Optical counterpart to the X-ray source in M13," MNRAS, 292, L45

Flores, H., Hammer, F., Desert, F. X., Cesarsky, C., Thuan, T. X., Crampton, D., Eales, S., Le Fevre, O., Lilly, S., Omont, A. & Elbaz, . 1998, "Deep Survey at 7m with the ISO Satellite," A&A, in press

Flores, H., Hammer, F., Thuan, T. X., Cesarsky, C., Desert, F. X., Omont, A., Lilly, S. J., Eales, S., Crampton, D., & Le Fevre, O. 1998, "15 microns ISO observations of the 1415+51 CFRS Field: The Cosmic Star Formation Rate as Derived from the FIR Luminosity Density," ApJ, submitted

Franz, O.G., Henry, T.J., Wasserman, L.H., Benedict, G.F., Ianna, P.A., Kirkpatrick, J.D., McCarthy, Jr., D.W., Bradley, A.J., Duncombe, R.L., Fredrick, L.W., Heminway, P.D., Jefferys, W.H., McArthur, B.E., Nelan, E.P., Sheulus, P.J., Story, D.B., van Altena, W.F., and Whipple, A.L., 1998, "The First Definitive binary Orbit Determined with the HST fine Guidance Sensors: Wolf 1062 (Gliese 748)," AJ, 116, 1432

Frayer, D. T., Seaquist, E. R., Thuan, T. X. & A. Sievers 1998, "Molecular Gas in Mrk 109: Constraining the

O2/CO ratio in Chemically Young Galaxies," ApJ, 503, 231

Goldoni, P., Vargas, M., Goldwurm, A., Paul, J., Sarazin, C. L., Laurent, P., Roques, J.-P., Jourdain, E., Malzac, J., Vedrenne, G., Revnivtsev, M., Churazov, E., Gilfanov, M., Sunyaev, R., Dyachkov, A., Khavenson, N., Tserenin, I., & Kuleshova, N. 1998, "SIGMA Hard X-ray Detection of a Background AGN near the Center of the Coma Cluster," ApJ, submitted

de Grijs, R., 1998, "The Global Structure of Galactic Discs," MNRAS, 299, 595

Hawley, J. F. & Balbus, S. A. 1998, "Anomalous Viscosity in Accretion Disks," in Proceedings of the 13th North American Workshop on CVs, S. Howell, E. Kuulkers, C. Woodward (eds), in press

Hawley, J. F. & Balbus, S. A. 1998, "Anomalous Viscosity in Accretion Disks," Wild Stars in the Old West: Proceedings of the 13th North American Workshop on Cataclysmic Variables and Related Objects, S. Howell, E. Kuulkers, C. Woodward (eds), 273

Hawley, J. F. and Stone, J. M. 1998, "Nonlinear Evolution of the Magnetorotational Instability in Ion-Neutral Disks," ApJ, 501, 758

Henry, T.J., Franz, O.G., Wasserman, L.H., Benedict, G.F., Shelus, P.J., Ianna, P.A., Kirkpatrick, J.D., and McCarth, Jr., D.W., 1998, "The Optical Mass-Luminosity Relation at the End of the Main Sequence (0.08 to 0.20 Solar Mass)," ApJ, in press

Hill, R. S., Fanelli, M. N., Smith, D. A., Bohlin, R. C., Neff, S. G., O'Connell, R. W., Roberts, M. S., Smith, A. M., & Stecher, T. P. 1998, "Ultraviolet Imaging of the Irregular Galaxy NGC 4449 with UIT: Photometry and Recent Star Formation History," ApJ, in press

Houck, J. C., Bregman, J. N., Chevalier, R. A., & Tomisaka, K. 1998, "Recent X-Ray Observations of SN1986J with *ASCA*, and *ROSAT*," ApJ, 493, 431

Huang, Z., & Sarazin, C. L. 1998, "A High Resolution ROSAT X-Ray Study of Abell 4059," ApJ, 496, 728

Irwin, J. A., & Sarazin, C. L. 1998, "Low Mass X-ray Binaries As the Source of the Very Soft X-ray Emission in the X-ray Faintest Early-Type Galaxies," ApJ, 494, L33

Irwin, J. A., & Sarazin, C. L. 1998, "ROSAT X-ray Colors and Emission Mechanisms in Early-Type Galaxies," ApJ, 499, 650

Irwin, J., & Sarazin, C. L. 1998, "Resolving Nearby X-ray–Faint Early-Type Galaxies into Low-Mass X-ray Binaries with AXAF at Hard and Soft X-ray Energies," ApJ, submitted

Izotov, Yu. I. & Thuan, T. X. 1998, "Chemical Abundances in Star-Forming Dwarf Galaxies," in Dwarf Galaxies and Cosmology, ed. by T. X. Thuan, C. Balkowski, V. Cayatte, and J. T. Thanh Van (Paris: Editions Frontieres), in press

Izotov, Yu. I., &Thuan, T. X. 1998, "Heavy Element Abundances in Blue Compact Galaxies," ApJ, in press

Izotov, Yu. I. & Thuan, T. X. 1998, "The Primordial Abundance of ^{4}He Revisited," ApJ, 500, 188

Izotov, Yu. I. & Thuan, T. X. 1998, "Reexamining the Helium Abundance of IZw18," ApJ, 497, 227

Kempner, J. C., & Richards, M.T. 1998, "Analysis of the Si IV Ultraviolet Spectra of U Sagittae," ApJ, 512, in press

Koekemoer, A. M., O'Dea, C. P., Baum, S. A., Sarazin, C. L., Owen, F. N., & Ledlow, M. J. 1998, "A Study of UV Absorption in the Intracluster Medium of Abell 1030," ApJ, 508, in press (astro-ph/9806386)

Koekemoer, A. M., O'Dea, C. P., Sarazin, C. L., McNamara, B. R., Donahue, M., Voit, G. M., Baum, S. A., & Gallimore, J. F. 1998, "The Blue Continuum Excess, Line-Emitting Filaments, and Radio Source in the Central Dominant Galaxy of the Cooling Flow Cluster Abell 2597," ApJ, submitted

Koubský, P., Harmanec, P., Božic, H., Percy, J. R., Žižňovsky, J., Huang, L., Richards, M. T., Hadrava, P., & Šimon, V. 1998, "Spectroscopy and Photometry of the Interacting Binary CX Draconis – Evidence for Circumstellar Matter," Hvar Obs. Bull., 22, 17

Koubský, P., Richards, M. T., & Šimon, V. 1998, "Circumstellar Matter in the Interacting Binary CX Draconis," in Proceedings of the 20th Stellar Conference of the Czech and Slovak Astronomical Institutes, Brno, Czech Republic, eds. J. Dušek and M. Zejda, 64

Landsman, W., Bohlin, R. C., Neff, S. G., O'Connell, R. W., Roberts, M. S., Smith, A. M., & Stecher, T. P. 1998, "The Hot Stars of Old Open Clusters: M67, NGC 188, and NGC 6791," AJ, 116, 789

Li, Z.-Y. 1998a, "Formation and Collapse of Magnetized Spherical Molecular Cloud Cores," ApJ, 493, 230

Li, Z.-Y. 1998b, "Self-Similar Collapse of Magnetized Molecular Cloud Cores with Ambipolar Diffusion and the "Magnetic Flux Problem" in Star Formation," ApJ, 497, 850

Li, Z.-Y. 1998c. "A Spherical Model for "Starless" Cores of Magnetic Molecular Clouds: Dynamical Effects of Dust Grains," ApJ, submitted

Linsky, J. L., Wilson, T. L., & Rood, R. T. 1998, "Local Interstellar Medium," in The Primordial Nuclei and Their Galactic Evolution, eds. N. Prantzos, M. Tosi, R. von Steiger, Space Science Reviews, 84, 309

Lufkin, E. A., White, R. E., III, & Sarazin, C. L. 1998, "Time-Dependence of the Mass Accretion Rate in Cluster Cooling Flows," ApJ, submitted

Majewski, S. R. 1997, "Formation and Evolution of the Milky Way," in IAU Symp. 179: Wide Field Surveys, eds. B.J. McClean et al. (Kluwer: Dordrecht), 199

Majewski, S. R., Ostheimer, J. C. & Kunkel, W. E. 1998, "Exploring Halo Substructure with Giant Stars: I. Calibration of the Photometric Search Technique," AJ, submitted

Majewski, S. R., Ostheimer, J. C., Kunkel, W. E., Johnston, K. V., Patterson, R. J. & Palma, C. 1998, "A Search for Tidal Stellar Debris from the Magellanic Clouds: Survey Results from the First Two Years," in IAU Symposium 190: New Views of the Magellanic Clouds, eds. Chu et al., ASP Conf. Ser., in press

Mamon, G. A., Thuan, T. X. & Thanh Van, J. T. (eds.) 1998, "Extragalactic Astronomy in the Infrared," (Paris: Editions Frontieres)

Markevitch, M., Forman, W. R., Sarazin, C. L., & Vikhlinin, A. 1998, "The Temperature Structure of 26 Nearby Clusters Observed with ASCA: Similarity of Temperature Profiles," ApJ, 503, 77

McNamara, B. R., Jannuzi, B. T., Sarazin, C. L., Elston, R., & Wise, M. W. 1998, "An Alignment Effect in FR I Radio Galaxies: U-Band Polarimetry of the Abell 2597 Cluster Central Galaxy," ApJ, submitted

Mendez, R. A., Rich, R. M., van Altena, W. F., Girard, T. M., van den Bergh, S., & Majewski, S. R. 1997, "Proper Motions in the Bulge: Looking Through Plaut's Low Extinction Window," in IAU Symp. 179: Wide Field Surveys, eds. B. McClean et al. (Kluwer: Dordrecht), 223

Moss, C., Whittle, M., & Pesce, J.E., 1998, "Tidally-Induced Star Formation in Abell 1367," MNRAS, 300, 205

Munn, J. A., Koo, D. C., Kron, R. G., Majewski, S. R., Bershady, M. A., & Smetanka, J. J. 1997, "The Kitt Peak Galaxy Redshift Survey (KPGRS) with Multicolor Photometry: Basic Data," ApJS, 109, 45

Nilsson, K., M. J. Valtonen, Jones, L. R., Saslaw, W. C., & Lehto, H. J. 1997, "Optical Emission in the Radio Lobes of Cygnus A," A&A, 324, 888

O'Connell, R. W., 1997, "The Ultraviolet Morphology of Galaxies," in The Ultraviolet Universe at Low and High Redshift, ed. W. H. Waller (AIP Press), 11

O'Connell, R. W., "Far-Ultraviolet Radiation From Elliptical Galaxies," ARAA, in press

O'Connell, R. W., Dorman, B., Shah, R. Y., Rood, R. T., Landsman, W. B., Bohlin, R. C., Neff, S. G., Roberts, M. S., Smith, A. M., & Stecher, T. P. 1997, "Ultraviolet Imaging of the Globular Cluster 47 Tucanae," AJ, 114, 1982

O'Connell, R. W., & Ohl, R. G. 1998, "Far-UV Color and Abundance Gradients in Elliptical Galaxies," in Abundance Profiles: Diagnostic Tools for Galaxy History, ed. D. Friedli, M. G. Edmunds, C. Robert, & L. Drissen (ASP Press), 21

Ohl, R. G., O'Connell, R. W., Bohlin, R. C., Collins, N. R., Dorman, B., Fanelli, M. N., Neff, S. G., Roberts, M. S., Smith, A. M., & Stecher, T. P. 1997, "Far-Ultraviolet Imaging of Early-Type Galaxies," in The Ultraviolet Universe at Low and High Redshift, ed. W. H. Waller (AIP Press), 181

Ohl, R. G., O'Connell, R. W., Bohlin, R. C., Collins, N. R., Dorman, B., Fanelli, M. N., Neff, S. G., Roberts, M. S., Smith, A. M., & Stecher, T. P. 1998, "Far-Ultraviolet Color Gradients in Early-Type Galaxies," ApJ, 505, L110

Paltrinieri, B., Ferraro, F. R., Fusi Pecci, F., Rood, R. T., & Dorman, B. 1998, "UV-CMDs: Searching for Blue Straggler Stars in the Cores of Galactic Globular Clusters," in Ultraviolet Astrophysics—Beyond the IUE Final Archive, eds. R. González-Riestra, W. Wamsteker, & R. A. Harris (ESA: Noordwijk), 565

Papaderos, P., Izotov, Y. I., Fricke, K. J., Thuan, T. X. & Guseva, N. G. 1998, "On the Age of the Nearby Dwarf Galaxy SBS 0335-052," A&A, 338, 43

Parise, R. A., Bohlin, R. C., Neff, S. G., O'Connell, R. W., Roberts, M. S., Maran, S. P., Smith, A. M., & Stecher, T. P. 1998, "Ultraviolet Imaging Telescope Observations of the Horizontal Branch in M13," ApJ, 501, L67

Parker, J. W., Hill, J. K., Cornett, R., Hollis, J., Zamkoff, E., Bohlin, R. C., O'Connell, R. W., Neff, S. G., Roberts, M. S., Smith, A. M., & Stecher, T. P. 1998, "Ultraviolet Imaging Telescope Observations of the Magellanic Clouds," AJ, 116, 180

Patterson, R.J., Ianna, P.A., & Begam, M. C., 1998, "The Solar Neighborhood. V. VRI Photometry of Southern Nearby Star Candidates," AJ, 115, 1648

Peletier, R.F., & de Grijs, R., 1998, "The Scatter in the Near-Infrared Colour-Magnitude Relation in Spiral Galaxies," MNRAS, in press

Ponder, J. M., Burstein, D., O'Connell, R. W., Rose, J., Frogel, J. A., Wu, C.-C., Crenshaw, D. M., Rieke, M., & Tripicco, M. 1998, "Integrated UV Spectra and Line Indices of M31 Globular Clusters and the Cores of Elliptical Galaxies," AJ, in press

Reid, I. N., Majewski, S. R., & Siegel, M. H. 1997, "Star-counts and the Galactic Halo," in Galactic Haloes, ed. D. Zaritsky, ASP Conf. Ser. Vol. 136, (ASP: San Francisco), 3

Richards, E. A., Kellermann, K. I, Fomalong, E. B., Windhorst, R. A., & Partridge, R. B. 1998, "Radio Emission from Galaxies in the Hubble Deep Field", AJ, 116, 1039

Richards, M. T., & Albright, G. E. 1998, "Morphologies of Hα Accretion Regions in Algol Binaries," ApJ, submitted

Richards, M. T., & Ratliff, M. A. 1998, "Hydrodynamic Simulations of Hα Emission in Algol Binaries," ApJ, 493, 326

Richards, M.T., & Rosolowsky, E. W. 1998, "Doppler Tomography of Ultraviolet Spectra of HR 1099," in Tenth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, eds. R.A. Donahue & J.A. Bookbinder, ASP Conf. Ser., Vol. 154 (San Francisco: ASP), CD 2038

Richards, M.T., & Rosolowsky, E. W. 1998, "Doppler Tomograms of HR 1099 from Ultraviolet Spectra," ApJ, submitted

Richards, M. T., & Russell, S. 1998, "Dependence of Radio Flaring Activity on Orbital Phase in Archival Observations of Algol-type and RS CVn Binaries," in Tenth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, eds. R.A. Donahue & J.A. Bookbinder, ASP Conf. Ser., Vol. 154 (San Francisco: ASP), CD 1551

Richards, M. T., Waltman, E. B., Foster, R. S., & Ghigo, F. 1998, "Flaring Activity Cycles in β Per and HR 1099 from a 2GHz and 8GHz Radio Survey," in Tenth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, eds. R.A. Donahue & J.A. Bookbinder, ASP Conf. Ser., Vol. 154 (San Francisco: ASP), CD 1546

Ricker, P. M. 1998, "Off-Center Collisions between Clusters of Galaxies," ApJ, 496, 670

Rood, R. T., Bania, T. M., Balser, D. S., Wilson, T. L. 1998, "3-Helium: Status and Prospects," in The Primordial Nuclei and Their Galactic Evolution, eds. N. Prantzos, M. Tosi, R. von Steiger, Space Science Reviews, 84, 185

Rood, R. T., Dorman, B., Ferraro, F. R., Paltrinieri, B., Fusi Pecci, F., 1998, "UV Bright Stars in Globular Clusters," in Ultraviolet Astrophysics—Beyond the IUE Final Archive, eds. R. González-Riestra, W. Wamsteker, & R. A. Harris (ESA: Noordwijk), 515

Sarajedini, A., Claver, C. F., & Ostheimer, J. C. 1998, "The Properties of the Antlia Dwarf Galaxy," AJ, 114, 2505

Sarazin, C. L. 1997, "Extreme Ultraviolet Emission from Clusters of Galaxies: Inverse Compton Radiation from a Relic Population of Cosmic Ray Electrons?," Proceedings of the Ringberg Workshop on Clusters of Galaxies as Cosmological Probes, ed. H. Böhringer (Munich: MPE), 1

Sarazin, C. L., Koekemoer, A. M., O'Dea, C. P., Baum, S. A., Owen, F. N., & Wise, M. W. 1998, "X-ray Properties of B2 1028+313: A Quasar at the Center of the Abell Cluster A1030," ApJ, 510, in press (astro-ph/9806372)

Sarazin, C. L., & Lieu, R. 1998, "Extreme Ultraviolet Emission from Clusters of Galaxies: Inverse Compton Radiation from a Relic Population of Cosmic Ray Electrons?," ApJ, 494, L177

Sarazin, C. L., Wise, M. W., & Markevitch, M. L. 1998, "X-ray Spectral Properties of the Cluster Abell 2029," ApJ, 498, 606

Saslaw, W. C. 1997, "The Cosmological Many-Body Problem," in Dedication Symposium of the Inter-University Center for Astronomy and Astrophysics: New Challenges in Astrophysics, ed. T. Padmanabhan, (New Delhi: New Age International), 125

Saslaw, W. C. and Haque-Copilah, S. 1998, "The Pisces-Perseus Supercluster and Gravitational Quasi Equilibrium Clustering," ApJ, in press

Schweitzer, A. E., Cudworth, K. M., & Majewski, S. R. 1997, "The Proper Motion of the Ursa Minor Dwarf Spheroidal Galaxy," in Proper Motion Surveys and Galactic Astronomy, ed. R. Humphries, ASP Conf. Ser. Vol. 127, (ASP: San Francisco), 103

Schweitzer, A. E., Cudworth, K. M., & Majewski, S. R. 1998, "The Absolute Proper Motion and a Membership Study of the Ursa Minor Dwarf Spheroidal Galaxy," AJ, submitted

Sellwood, J.A., and Balbus, S.A. 1998, "Differential Rotation and Turbulence in Extended H I Disks," ApJ, in press, astro-ph/9806307.

Shu, F. H., Najita, J., Shang, S. & Li, Z.-Y. 1998, "X-Winds," in Protostars and Planets IV, ed. V. Mannings, A. Boss & S. Russell (Univ. Arizona Press: Arizona), in press

Siegel, M. H., Majewski, S. R., Reid, I. N., & Thompson, I. 1997, "First Results of a CCD Starcount Survey of Selected Areas with the Swope 1-m Telescope," in Proper Motion Surveys and Galactic Astronomy, ed. R. Humphries, ASP Conf. Ser. Vol. 127, (ASP: San Francisco), 175

Stone, J. M., Gammie, C. F., Balbus, S. A., and Hawley, J. F. 1998, "Transport Processes in Protostellar Disks," in Protostars and Planets IV, in press.

Thuan, T. X. 1998, "Le Chaos et l'Harmonie," (Paris: Fayard)

Thuan, T. X. & Izotov, Yu. I. 1998, "Nearby Young Dwarf Galaxies," in the Magellanic Clouds and Other Dwarf Galaxies, ed. by J. M. Braun and T. Richtler (Bonn: Shaker Verlag), in press

Thuan, T. X. & Izotov, Yu. I. 1998, "Nearby Young Dwarf Galaxies: Primordial Gas and Lyman-alpha Emission," ApJ, 489, 623

Thuan, T. X. & Izotov, Yu. I. 1998, "The Primordial Helium-4 Abundance from Observations of a Large Sample of Blue Compact Dwarf Galaxies," Space Science Reviews, 84, 83

Thuan, T. X. & Izotov, Yu. I. 1998, "Young Star-Forming Dwarf Galaxies: Laboratories for Galaxy Formation and Evolution Studies," ed. by T. X. Thuan, C. Balkowski, V. Cayatte, and J. T. Thanh Van (Paris: Editions Frontieres), in press

Thuan, T. X., Lipovetsky, V. A., Martin, J.-M., & Pustinik, S. A. 1998, "HI Observations of Blue Compact Galaxies from the First and Second Byurakan Surveys," A&AS, submitted

Thuan, T. X., Sauvage, M., & Madden, S. 1998, "Dust in an Extremely Metal-Poor Galaxy: Mid-Infrared Observations of SBS 0335-052," ApJ, submitted

Tolbert, C. R., & Sarazin, C. L. 1998, "Solar Eclipses, Tides, and the Evolution of Life on the Earth," Comments on Astrophysics, submitted

Whitney, J. H., Rood, R. T., O'Connell, R. W., D'Cruz, N. L., Dorman, B., Landsman, W. B., Bohlin, R. C., Roberts, M. S., Smith, A. M., Stecher, T. P. 1998, "Analysis of the Hot Stellar Population of the Globular Cluster ω Centauri," ApJ, 495, 284

Wise, M. W., & Sarazin, C. L. 1998, "X–ray Absorption Due to Cold Gas in Cluster Cooling Cores," ApJ, submitted

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