University of Virginia Department of Astronomy Leander McCormick Observatory

Charlottesville, Virginia, 22903-0818

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This report covers the period 1 September 1998 to 31 August 1999.

1. PERSONNEL

During this time the departmental faculty consisted of Steven A. Balbus, Roger A. Chevalier, John F. Hawley, Philip A. Ianna, Zhi-Yun 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.

Postdocs in residence included Dana Dinescu, Richard deGrijs, and Paul Ricker.

Robert Rood took over the Chairmanship in July, replacing Robert O'Connell who has served the Department so well for many years. Eric W. Weisstein resigned as Research Scientist to take a position at Wolfram Researrch. Richard Patterson was promoted to Research Scientist for Astrometric Support. Michael Begam also held an astrometric support position and 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 20 enrolled graduate students at the end of this period. Eric Richards completed his Ph.D. during the year and received a Hubble Fellowship.

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. Visitors included Chris Moss (Arizona), Rich Gelderman (Western Kentucky), Yuri Izotov (Kiev), Doris Neumann (Saclay), Claes Fransson (Stockholm), and P. Koubský (Prague).

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 was installed and the mirror resilvered for the 1-m . 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.

Majewski and Crane (grad student) began construction of a student speckle interferometry camera for use on the 26‘‘ refractor.

3. RESEARCH

3.1 Stars and Stellar Evolution

Balbus has carried through a study of turbulent transport in disks based on the close analogy between thermally stratified and and rotating fluids. The effect of MHD turbulence on *heat* transport in a convectively stable disk is to produce a downward (i.e., toward the midplane), against the large scale temperature gradient. This is the analogue behavior of inward angular momentum transport found when convective turbulence is imposed in Rayleigh-stable disks. The heat transport is likely to be small, and thus dominated by the conventional upward diffusive heat transport.

The analogy between rotating and stratified flows also suggests that a counterpart to the magnetorotational instability may exist, which would affect the transport of entropy in a convectively stable thermal layer. Balbus has discovered such an instability, which is based on thermal conduction along magnetic lines of force. It appears to be a type of double-diffusive instability, depending upon the combination of a small resistivity and a large thermal conductivity. The astrophysical implications of the finding are currently under investigation.

Balbus, in collaboration with J. Papaloizou (Queen Mary-Westfield College) has completed a study of the foundations of alpha disk theory via a time dependent nonlinear analysis. Conditions under which turbulent transport in accretion disks may properly be described by an alpha formalism have been elucidated. While magnetic fields can rigorously be incorporated within this formalism, it can be shown that self-gravity may not. Viscous models of such disks are likely to be qualitatively incorrect.

Balbus, in collaboration with C. Terquem (IAP), is developing models of magnetized protostellar disks. The focus of the research is upon the effect of Hall currents on the stability properties of the disk for general magnetic field geometries. The transition between a magnetized inner disk zone and a nonmagnetized adjacent zone is important to understand for models of the dynamical evolution of the solar nebula and protostellar disks more generally.

Chevalier and Li investigated models for GRB (gamma-ray burst) afterglows involving the interaction of a relativistic blast wave with the wind from a Wolf-Rayet star. These studies were motivated by the association of GRBs with star-forming region and with supernova-like events, which suggest that GRBs have massive star progenitors. The wind interaction models show that the sources can have similar luminosities and spectra as in interstellar interaction models, but that the evolution is different. A number of observed afterglows are compatible with wind interaction, including the ones that have been identified with supernova-like emission. The radio evolution of GRB 970508 is especially suggestive of wind interaction However, wind interaction models do not appear to be appropriate for all observed afterglows. For example, the bright source GRB 990123 is

better modeled as an interstellar interactor. The implication is that there are two progenitor types among the observed sources: in one case the progenitors are massive stars and in the other they are compact binary mergers.

Chevalier, together with Lundqvist and others, used the *HST* to obtain an ultraviolet spectrum of the Crab pulsar. The spectrum showed a blueshifted C IV absorption line with velocities extending to at least 3,000 km s^{-1}. This absorption feature may be due to freely expanding supernova ejecta that extend around the commonly observed Crab Nebula. However, the observations do not imply that there is sufficient energy in the ejecta to bring the energy of SN 1054 up to a normal supernova energy. Because of the power law spectrum of the Crab pulsar, the spectrum also gives an excellent estimate of the dust extinction curve in this direction.

Chevalier, together with Fransson, Fesen, Filippenko and others, is analyzing *HST* and ground-based spectra of the Type IIn supernova SN 1995N taken at an age of 2–3 years. They have found at least 3 types of line emission: unresolved lines that appear to be from circumstellar clumps of gas photoionized by the hard supernova radiation, lines with a ''boxy'' profile that are probably from freely expanding ejecta, and lines of intermediate width, some of which (Hα and Mg II) have broad wings. The second type of emission is not present in H lines, which suggests that the emission is from heavy element enriched ejecta. This component is seen in the UV lines of Si IV, C IV, Si III], and C III]. The circumstellar interaction is complex; the strong, broad Mg II doublet is indicative of shock interaction over a broad range of velocities, as might be expected if clumps are present.

Dinescu has completed the measurement of five Selected Areas fields for the purpose of star and galaxy counts to faint magnitudes ($V \approx 22$). The fields are located toward the Galactic anticenter, at various Galactic latitudes. The measurement was carried out with the UVa PDS microdensitometer used in the photometry mode, and for each field, six Mayall 4-m photographic plates were scanned. The reduction procedure consists of obtaining catalogues of classified objects with calibrated magnitudes. While catalogues were derived for all fields, the photographic magnitude calibration awaits for deep CCD standard photometry in order to obtain calibrated photographic photometry down to $V = 22$. The derived positions in these catalogues will be used as input for the following astrometric measurement which has the purpose of deriving proper motions for kinematic studies at the Galactic anticenter.

Dinescu, Majewski and Girard (at Yale University) have started a proper-motion study of the globular cluster Pal 12. The aim is to obtain the absolute proper motion of the cluster to an accuracy of 0.3 mas yr^{-1}, and therefore its orbit. The orbit will clarify whether this cluster was part of the Large Magellanic Cloud as proposed by Lin & Richer (1992). Proper-motion membership probabilities will help better define the color magnitude diagram of this cluster, and also investigate its structural parameters, and possible tidal tails. About thirty photographic plates have been measured with the precise Yale PDS micordensitometer, and the reduction is almost complete. A similar study was also started for globular cluster NGC 7006, and, so far, all eighteen plates for this cluster were measured at Yale.

Hawley and Balbus continue to investigate the nature of the angular momentum transport mechanisms, MHD turbu-

laboration with I.N. Reid (U. Penn) and I.B. Thompson (OCIW). They are currently attempting to derive density laws of the Galactic populations by photometric parallax with *RI* photometry in seven 2 deg^2 fields observed with the Swope 1-m. *VI* photometry from SASSY also reveals a possible extension of the tidal stellar tail of the Sagittarius (Sgr) dwarf galaxy 25° south of the Sgr nucleus. These and all other available Sgr data are reanalyzed in contributions in a collaboration with K. Johnston (IAS), W. Kunkel (Las Campanas Obs.), and C. Palma (graduate student), which conclude that the best fit model has the tidal arms of Sgr multiply wrapped around the Milky Way.

Majewski and Palma have been collaborating with R. Peterson (Lick) and E. Green (Steward) to investigate radial velocity clumping at the 2 km s^{-1} level among the non-cluster members in the field of the open cluster NGC 6791. The clumping is reminiscent of tight radial velocity clumping predicted by Helmi & White (1999) when the debris of tidally disrupted satellites become multiply-wrapped around the Milky Way.

Majewski, Dinescu, W.Y. Johnson (undergraduate), Patterson, Ostheimer, and Palma have been studying internal stellar population and bulk kinematical properties of the Galactic globular cluster ω Centauri, which lend support to the idea that this globular may actually be the nucleus of a massively disrupted dwarf galaxy.

Richards and T. Butler (undergraduate student) studied the periodicities derived from radio flare data of two nearby binary star systems: V711 Tau (HR 1099) and β Per (Algol). These systems are within 35 pc of the Sun. Richards and Butler used 2.3 GHz and 8.3 GHz observations from the Green Bank Interferomenter database. They used two techniques, namely Fast Fourier Transforms and the Phase Dispersion Minimization (PDM) technique, to determine the frequency of radio flaring activity. Based on data collected from 1996 November to 1999 April, they found that the dominant periods were 49 days for β Per and 120 days for HR 1099.

Richards and P. Koubský (Ondřejov Observatory, Czech Republic), have completed their study of multiwavelength spectra of CX Dra in collaboration with V. Šimon and P. Skoda of Ondřejov Observatory (Czech Republic), G. J. Peters of Univ. of Southern California, and also, R. Hirata and S. Masuda of Kyoto University (Japan). They used the spectra to study the distribution of circumstellar gas in CX Dra, a non-eclipsing Algol binary. Their results were derived from several hundred Hα, He I (6678.15 Å), Hβ, and Si II λ6371 spectra of CX Dra which were obtained over 23 years from 1975 to 1998 at six observatories in five countries. This study has resulted in the refinement of the orbital solution of CX Dra; equivalent width measurements which showed short-, medium-, and long-term behavior of the difference profiles; calculation of the Balmer decrement; velocity maps based on the velocity curves of the Hα and He I difference emission peaks; trailed spectrograms of the Hα, Hβ, He I, and Si II lines; and Doppler tomograms at these four wavelengths.

Rood, Ferraro (Bologna), Fusi Pecci (Bologna), Paltrinieri (Roma), 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. Several papers were completed during the year.

Sarazin, Rood, J. Irwin (U. Michigan), F. Ferraro (Bologna Obs.), and B. Paltrinieri (U. La Sapienza) detected a Low Luminosity Globular Cluster X-ray source (LLGCX) in the globular cluster NGC 288 using ROSAT. There is evidence for X-ray variability on a time scale of $\sim$ 1 day. The presence of this LLGCX in such a diffuse cluster suggests that dense stellar systems with high interaction rates are not needed to form LLGCXs. They also set a strong upper limit on any diffuse X-ray emission. This upper limits was lower than the values observed for X-ray faint early-type galaxies. This indicates that the soft X-ray emission in these galaxies is due either to a component which is not present in globular clusters (e.g., interstellar gas, or a stellar component which is not found in low metallicity Population II systems), or to a relatively small number of bright low mass X-ray binaries.

Along with graduate student Wayne Winters, Balbus and Hawley are carrying out local three-dimensional simulations of MHD in Keplerian differential rotation, and have examined the chaotic nature of the resulting turbulence. They find that the Lyapunov exponent is on order Ω. Characteristic time-averaged values for the net stress appear to be well-defined only when averaged over many orbits. This issue bears directly on the traditional Shakura-Sunyaev parameterized viscosity formalism, which is predicated upon the existence of well-defined local Reynolds and Maxwell stresses within the disk.

3.2 Interstellar Medium

Chevalier, in collaboration with Bykov, Ellison, and Uvarov, investigated the acceleration and nonthermal emission from relativistic particles that are accelerated by supernova shock waves in a molecular cloud. The cloud model allowed for the clumpy structure that is known to exist in these objects. The shock wave becomes radiative in the interclump gas and a dense, magnetically supported shell forms. Both diffusive shock acceleration and compression of ambient cosmic rays were considered in modeling the γ-ray emission observed from supernova remnants such as IC 443. The ambient cosmic rays can provide an acceptable source only if their spectrum extends to quite low energy. Shock acceleration is a possibility, although the efficiency must be high in order to overcome strong Coulomb losses. The emission from the interclump shock wave is capable of explaining the synchrotron radio emission and the γ-ray emission observed from remnants like IC 443. Shock waves in molecular clumps produce a particle spectrum extending to lower energies, so they do not contribute to this emission. However, the clump shocks are possible sources of nonthermal, X-ray bremsstrahlung emission. Future X-ray and γ-ray observations will provide tests for this model.

Rood, Bania (BU), Balser (NRAO-GB) & Wilson (MPIfR) are continuing their project to determine the cosmic

abundance of ^{3}He. Observations of H II regions continued at the Green Bank 140 Foot. The 3.5 cm hyperfine line of $^3He^+$ was detected in a large number of low density H II regions which should be easy to model (a necessary step in getting the abundances). Amusingly the continuum in some of these regions is so weak that an accurate measure of the hydrogen has not been made, so the $^3He^+$/H abundance ratio has yet to be determined. The 140 Foot Radio Telescope ceased operation in July. The 3-Helium project was the last outside observing proposal scheduled on the telescope. The last scan ended at 08:12:20 EDT, 19 July, 1999 having managed to sneak 12 minutes past the scheduled shutdown.

3.3 Galaxies and Active Galactic Nuclei

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 (Univ. Wisconsin) analyzed high-resolution optical and near-infrared *HST* observations of two adjacent regions in the fossil starburst region, ''B,'' in M82, M82 B1 and B2. These observations allow them to study the evolved young cluster population associated with the fossil starburst.

The main results of this analysis are:

(1) The star cluster population in B2 is more heavily affected by internal extinction than that in B1, amounting to an excess extinction in B2 of $A_{V,\mathrm{excess}} \simeq 1.1 \pm 0.3$ mag.

(2) Age estimates based on theoretical modeling date the cluster population in the fossil starburst between $\sim 2 \times 10^8$ and $\sim 10^9$ years, assuming solar metallicity, with a peak in the distribution near the upper age limit. This implies that $M/L_V \sim 1.0$, which leads to cluster mass estimates of $\sim 10^4 - 10^5 M_\odot$, peaking near $\sim 10^4 M_\odot$.

(3) The majority of the more extended sources in the M82 B regions are characterized by $2.34 \leqslant R_{\mathrm{eff}} \lesssim 8.4$ pc, or $0.5 \lesssim R_{\mathrm{core}} \lesssim 1.6$ pc (with $\langle R_{\mathrm{core}} \rangle \simeq 1.2$ pc), with a wing extending to larger sizes, consistent with the Galactic globular cluster size distribution. It thus appears that the population of star cluster candidates in the M82 B regions resembles the Galactic globular cluster population at a younger age. The radial luminosity profiles of the brightest clusters are more closely approximated by power laws than by a Gaussian model, in particular in their wings, which favors a slow star formation scenario.

Based on archival *HST* Hα observations, de Grijs, O'Connell, Becker, Chevalier, and Gallagher (Univ. Wisconsin) discovered ten compact Hα-bright sources in the post-starburst region that are significantly brighter than average. The Hα luminosities, surface brightnesses and sizes of these compact sources are entirely consistent with those of the populations of Hα supernova remnants (SNRs) in similar late-type galaxies; their size distribution is also in agreement with their older ages compared to the young radio SNRs previously found in the active starburst in the center of M82. If these sources are old SNRs, we can set an upper age limit to the starburst in M82 B2 of $\sim 50 - 100$ Myr; B1 would be slightly older. This may hint at propagating star formation in the disk of M82.

For the first time, they present a composite Hα surface brightness–diameter ($\Sigma - D$) relation for SNRs in M82 B and similar comparison galaxies. Despite the large differences among intrinsic SNR properties, the composite H$\alpha\Sigma - D$ relation is well defined. The small scatter in the $\Sigma - D$ relation for the M82 B SNRs indicates that they are in the radiative phase of evolution. For such a small remnant to enter the radiative phase, this implies a high ambient density, > 50 cm^{-3}, which might be present in this unusually dense region. However, more information is needed to determine whether the emission is from shock waves in SNRs or from photoionized nebulae.

De Grijs and Peletier (Univ. Durham, UK) used optical observations of a statistically complete sample of edge-on disk-dominated galaxies to study the intrinsic vertical color gradients in galactic disks, to constrain the effects of population gradients, residual dust extinction and gradients in the galaxies' metal abundance. For the majority of their sample galaxies, the colors and color gradients in the range $1.0h_z \leqslant |z| \leqslant 3.0h_z$ most likely reflect the intrinsic galactic properties (where h_z is the vertical scale height).

It appears that the intrinsic vertical color gradients are either non-existent, or small and relatively constant as a function of position along the galaxies' major axes. On average, the earlier-type galaxies exhibit smaller vertical ($B - I$) gradients than the later types; the results are consistent with the absence of any vertical colour gradient in the disks of the early-type galaxies. In most galaxies small-scale variations in the magnitude and even the direction of the vertical gradient are observed: at larger galactocentric distances they generally display redder colors with increasing z height, whereas the opposite is often observed in and near the galactic centers.

For a significant fraction of the sample galaxies another mechanism in addition to the effects of stellar population gradients is required to explain the magnitude of the observed gradients. The non-zero color gradients in a significant fraction of the sample galaxies are likely (at least) partially due to residual dust extinction at these z heights, as is also evidenced from the sometimes significant differences between the gradients measured on either side of the galactic planes.

Majewski and Ostheimer (graduate student), in collaboration with W. Kunkel (Las Campanas), have calibrated a technique for finding distant halo giant stars. Together with K. Johnston (IAS) and Patterson, they have discovered moving groups of giant stars in fields around the Magellanic Clouds. These stars have properties similar to model expectations for debris from a tidally disrupted Magellanic system. With D. Geisler (U. Concepcion), this group has applied the same technique to the Carina dwarf spheroidal galaxy, and identified an extended distribution of giant stars well beyond Carina's nominal tidal radius which could be tidal debris. If so, a large fractional mass loss rate for Carina of 27% Gyr^{-1} is implied.

Majewski, Siegel (graduate student), Patterson and Rood have analyzed the distribution of red giant and horizontal branch stars in the Sculptor dwarf galaxy, and conclude that it contains two populations of stars with different metallicity, radial distributions, and horizontal branch types. Hence,

Sculptor exhibits an *internal* second parameter problem.

O'Connell, Rood, Burstein (ASU), Landsman (Raytheon-STX/GSFC), Bohlin (STScI) & Wu (CSC/STScI), with graduate students J. Crane and I. Freedman, are using HST/STIS to study spatial gradients in the far-UV ''upturn'' component in nearby E/S0 galaxies. The upturn is produced primarily by metal-rich extreme horizontal branch stars and their descendents. Observations of 5 E/S0 galaxies were completed during the year. The far-UV data (centered at 1500 Å) are excellent and allow them to determine the spectral shape and radial dependence of the UV light to $r = 12''$ in these objects. No spectral features are evident in the data, although the resolution in most cases was only 40Å in order to provide good S/N. Several objects exhibit asymmetric profiles (larger than at optical wavelengths), which may be related to internal extinction. The spectra of M32 reveal the presence of about a dozen extranuclear point sources, all of which must have $T > 10000$K to be UV-bright. These appear to be the population of post-HB stars detected in HST/FOC UV images by Brown *et al.* (1998).

On the far-UV spectral image of the normal giant elliptical galaxy NGC 1399, O'Connell's group discovered a faint, far-UV point source lying within $\sim 0.04''$ (4 pc) of the center of the galaxy as defined by the stellar background light. The nuclear source stands out clearly from the interpolation of the smooth stellar background. The source is also detected on the UV end ($<$ 3800 Å) of an optical-band CCD spectrum of NGC 1399, but it becomes submerged in the bright stellar background at longer wavelengths. The source has $m_\lambda(1500\text{Å}) = 22.1$ in the STMAG system. Renzini et al. (1995) and Cappellari *et al.* 1999 had scrutinized earlier HST/FOC UV images of NGC 1399 and did not detect a source of this brightness. It appears to be variable and is probably an AGN associated with the known compact radio source and X-ray source in NGC 1399. With a luminosity of $\nu L_\nu \sim 4 \times 10^{38}$ ergs s^{-1}, this is the faintest AGN so far detected in the UV-optical region. The variability of the closest analogue, a UV source detected in NGC 4552 by the Renzini and Cappellari groups, was best interpreted as a flare produced by the partial stripping of a single stellar atmosphere by a central black hole.

With their photometric giant identification technique Ostheimer and Majewski are using the Mayall 4m with the 8 CCD MOSAIC detector to examine M31's halo to determine it's extent, flattening, and density law to low surface brightnesses. They are also searching for tidal debris from M31 dSph galaxies that may have been disrupted in M31's past.

C. Palma (graduate student), Majewski, and K. Johnston have completed an analysis of orbital poles of Milky Way satellite galaxies and globular clusters to search for dynamical families. Among the globulars, those of Zinn Young type (i.e., second parameter) are most likely to be following orbits similar to ''Magellanic Plane'' and ''Fornax–Leo–Sculptor'' stream dwarf galaxies. Published proper motions for 39 globular clusters and 6 dwarf satellite galaxies yield five groups of satellite galaxies and globular clusters with similar orbital parameters, however, observational errors are still too large to make definitive associations.

C. Palma, F. Bauer (graduate student), Majewski, Sarazin, W. Cotton (NRAO), and A. Bridle (NRAO) have completed their multiwavelength study of the giant FR II radio galaxy NVSS J214530+815455. Apart from some odd spectral index features in the radio lobes, this $\sim$ 4 Mpc FR II is very much like a typical radio galaxy, but with the lobes $\sim$ 10 times larger. Optical observations reveal the host galaxy to be typical of FR II hosts, while galaxy counts and WIYN HYDRA spectroscopy show it to be a member of a ''rich group'' of galaxies. However ROSAT HRI observations find no X-ray gas associated with this group.

Sarazin and Irwin 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.

W. Saslaw and W. Cotton 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, possible motion of the star could provide a rough estimate of the mass of our Galaxy out to the star's distance. 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.

Thuan, in collaboration with Izotov (Kiev), is pursuing a long-range program to check the conclusion obtained by Izotov & Thuan (ApJ,511, 639, 1999) based on chemical evolution arguments that all galaxies with a metallicity less than 1/20 solar are young, with age $\leqslant$ 100 Myr. The aim is to obtain ground and space-based photometric images of the handful of known BCDs with $Z \leqslant Z_\odot/20$ to study their stellar populations and put constraints on their ages. Together with Izotov and Foltz (MMT), Thuan has obtained MMT spectrophotometry and HST WFPC2 *V* and *I* images of the BCD SBS 1415+437 with $Z = Z_\odot/21$. We found that chemical abundances, color profiles and spectral energy distributions all say that SBS 1415+437 is a truly young galaxy that did not start to make stars until $\sim$ 100 Myr ago. Together with Papaderos and Fricke (Gottingen) and Izotov, Thuan has obtained VLT/FORS *U*, *B* and *R* images of the BCD Tol 65 with $Z = Z_\odot/24$. The age of the underlying low-intensity stellar component as inferred from radially averaged color profiles is well below 1 Gyr.

Thuan, in collaboration with Guseva (Kiev) and Izotov, has analyzed long-slit spectral observations of 39 Wolf-Rayet (WR) galaxies with heavy element mass fraction ranging over 2 orders of magnitude, from $Z_\odot/50$ to $2Z_\odot$. We derive the numbers of early WC (WCE) and late WN (WNL) stars from the luminosities of the red and blue bumps, and the number of O stars from the luminosity of the Hβ emission line. Additionally, we propose a new technique for deriving the numbers of WNL stars from the N III λ4512 and

Si III λ4565 emission lines. It is found that the relative number of WR stars $N(\mathrm{WR})/N(\mathrm{O}+\mathrm{WR})$ decreases with decreasing metallicity, in agreement with predictions of evolutionary synthesis models. The relative number ratios $N(\mathrm{WC})/N(\mathrm{WN})$ and the equivalent widths of the blue bump EW (λ4650) and of the red bump EW(λ5808) derived from observations are also in satisfactory agreement with theoretical predictions, except for the most metal-deficient WR galaxies. A possible source of disagreement is too low a line emission luminosity adopted for a single WCE star in low-metallicity models. We assemble a sample of 30 H II regions with detected He II λ4686 nebular emission to analyze the possible connection of this emission with the hard UV radiation of the WR stars. The theoretical predictions satisfactorily reproduce the observed intensities and equivalent widths of the He II λ4686 nebular emission line. However, galaxies with nebular He II λ4686 emission do not always show WR emission. Therefore, in addition to the ionization of He^+ in the H II region by WR stars, other mechanisms for the origin of He II λ4686 such as radiative shocks probably need to be invoked.

Thuan, in collaboration with Izotov and Guseva (Kiev), Papaderos and Fricke (Gottingen) and Foltz (MMT), has analyzed archival HST and ground-based observations to put constraints on the distance to the most metal-deficient blue compact dwarf galaxy known, I Zw 18. We argue that the distance to I Zw 18 should be as high as 20 Mpc, twice the previously accepted distance, to reconcile the properties of the massive stellar population inferred from colour-magnitude diagrams with the ionization state of the C component, as well as the detection of WR stars and high excitation of the gas in the main body.

Thuan, in collaboration with Noeske, Papaderos and Fricke (Gottingen), Izotov and Guseva (Kiev) has studied the nature of two ''cometary'' blue compact dwarf (BCD) galaxies, Mrk 59 and Mrk 71, using ground-based and HST images. These are characterized by an off-center starburst at one end of their elongated stellar body. Spectral population synthesis models, broad-band colors and color-magnitude diagrams give an age of $\sim$ 2 Gyr for the underlying low-intensity component in both cometary BCDs, significantly younger than the age of several Gyr derived for this component in BCDs with more central starbursts.

Whittle (PI), Silverman (graduate student), Nelson (U. Nevada), and Wilson (U. Maryland) have continued to work on their cycle 7 HST STIS data on the Seyfert 2 galaxy Markarian 78. STIS spectral images from four slits each with four spectral ranges were re-reduced and calibrated, improving on the pipeline reduction. [O III] λ5007 line profile parameters have been measured for all spectra as well as line strengths and reddening corrections for all optical and red lines (blue and UV lines have yet to be measured). The aim is a thorough investigation of the ionization and dynamical conditions in this archetypal jet dominated Seyfert galaxy.

This same group (Whittle, PI) were awarded cycle 8 HST STIS time to study a further 8 Seyfert galaxies thought to have strong jet-gas interactions in their narrow line regions. The aim is to extend the detailed case study of Markarian 78 with a simpler kinematic analysis of 8 similar galaxies, establishing the full range of jet-gas interactions. The first data have just been taken.

Whittle was awarded cycle 8 HST WFPC and STIS time to make a detailed study of two Seyfert galaxies with exceptionally strong blue wing asymmetries. The aim is to find out whether the blue wings originate from outflowing gas or inflowing gas. The ambiguity in direction of flow has been recognised but not solved for nearly 15 years. It is hoped that this study will finally solve the flow direction ambiguity. The first data set is about to be taken.

Whittle and Gelderman (WKU) have continued their work on Compact Steep Spectrum (CSS) radio galaxies, presenting the first detailed optical study of this relatively understudied class of radio galaxy. Their findings include the discovery of exceptionally luminous broad and structured [O III] profiles, suggesting the presence of strong jet-gas interactions. However, the correlation between line luminosity and radio power, the ionization state of the gas, and the limits found for jet-induced star formation all suggest little or no jet-gas interactions. A paper discussing these results is close to completion and will be submitted to ApJ.

Whittle wrote a 10,000 word invited review article on ''Seyfert Galaxies'' for the upcoming ''Encyclopedia of Astrophysics'' published by the Institute of Physics (IoP). The review is written at the advanced undergraduate, graduate and professional non-specialist level and considers a number of themes : discovery, classification, detection, structure and geometry, relation to other AGNs, black holes, continuum emission, broad line region, narrow line region, hosts, environment, triggering, and future prospects.

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 (U. Sidney) 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 the Westerbork Northern Sky Survey (WENSS) to search for undiscovered cluster radio halos and radio relics in Abell clusters. These diffuse radio sources are believed to arise from a population of relativistic electrons accelerated in cluster merger shocks. The low frequency (327 MHz) covered by WENSS is ideal for observing radio halos and relics since they characteristically have very steep spectra.

Kempner and Sarazin also used the WENSS and NVSS radio surveys to determine an upper limit to the diffuse radio flux from Abell 2199. This limit was used to constrain the cluster magnetic field by requiring that the radio flux be con-

sistent with the hard X-ray flux observed by BeppoSAX, assuming that the observed hard X-rays excess were due to inverse Compton emission. They find that the magnetic field must be very weak ($< 0.073\,\mu$G) in order to avoid producing an observable radio halo. They suggest that the hard X-ray radiation is due to nonthermal bremsstrahlung by a population of suprathermal electrons which are being accelerated to higher energies.

S. Randall (graduate student) and Sarazin are calculating the effect of extreme ultraviolet emission from clusters of galaxies on the diffuse ionizing radiation field in the universe.

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 and Kempner have calculated nonthermal bremsstrahlung (NTB) models for the hard X-ray (HXR) tails recently observed by BeppoSAX in clusters of galaxies. In these models, the HXR emission is due to suprathermal electrons with energies of $\sim$ 10–200 keV. They consider models in which these transrelativistic suprathermal particles are the low energy end of a population of electrons which are being accelerated to high energies by shocks or turbulence. They also consider a model in which these electrons are the remnant of an older nonthermal population which is losing energy and rejoining the thermal distribution. They compared these NTB models to the observed HXR tails in Coma and Abell 2199. The NTB models require a nonthermal electron population which contains about 3% of the number of electrons in the thermal ICM.

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.

Sarazin, M. Markevitch, A. Vikhlinin, and W. Forman (all CfA) have derived temperature profiles and maps for the nearby galaxy clusters A2199 and A496, which have the most accurate ASCA spectral data for all hot clusters. X-ray images, temperature maps, and the presence of moderate cooling flows indicate that these clusters are relaxed and therefore can provide reliable X-ray mass measurements under the assumption of hydrostatic equilibrium and thermal pressure support. The measured total mass profiles within are well approximated by the Navarro, Frenk, and White ''universal'' profile.

Sarazin and Wise are calculating models for the X-ray emission in cluster cooling flows in which a fraction of the cooled gas is stored as cold, X-ray absorbing gas. The spectra of these models agree with recent observations of excess X-ray absorption in cluster cooling flows. Sarazin and Wise find that the spectra are distinguishable from foreground absorption in ways that should be detectable in ASCA spectra. Also, the absorption effects the X-ray surface brightness profiles, from which the local rates of gas cooling have been derived.

Whittle, and Moss (Steward) have completed their Objective Prism Survey of Hα emitting galaxies in 8 nearby Abell clusters. Last year, Paper III was published in MNRAS, while this year Paper IV has been prepared for publication. In this work, they have investigated how the environmental influence on star formation itself depends on the cluster richness. For clusters spanning a significant range from loose (eg Abell 262) to dense (eg Coma) there is a very significant increase in the incidence of triggering star formation. This dependence is distinct from the relation between triggered star formation and local galaxy surface density.

Whittle, Moss (Steward), and Kennicutt (Steward) have continued their program to take deep Hα images of four nearby clusters of galaxies using the Kitt Peak 0.9 meter telescope with CCD mosaic. They had a successful run of 7 nights generating 32 Giga-bytes of data. Data reduction and initial analysis have begun. This projects aims to define the local Hα luminosity function in cluster galaxies, with the ultimate goal of providing a current epoch star formation census with which to compare with higher redshift star formation rates and so study the cosmological evolution of star formation. The project also allows a detailed look at cluster environmental influence on star formation. A first result is the discovery of an interacting pair of galaxies which appear to have spawned about 10 dwarf galaxies in the tidal tails, raising a possible creation mechanism for the large number of dwarf galaxies found both in clusters and the field.

3.5 Cosmology

W. Saslaw's 520 page monograph ''The Distribution of the Galaxies: Gravitational Clustering in Cosmology'' has been completed and is scheduled to be published by Cambridge University Press in late 1999. It is the first book that describes observations, computer simulations, and the gravitational many-body theory of galaxy distribution functions. It also discusses correlation functions, fractals, bound clusters, topology, percolation, and minimal spanning trees, as well as giving a historical introduction to the subject. Emphasis is on the gravitational physics of clustering and nearly all the relevant theory is derived from first principles.

W. Saslaw and J. Edgar are calculating the evolution of galaxy clustering at high redshifts for cosmological many-body clustering. Using recently discovered groups of galaxies at redshifts of about three, this can constrain the amount and distribution of dark matter in our universe.

W. Saslaw has calculated the probability that overdense superclusters of galaxies can form in the expanding universe

as a result of gravitational quasi-equilibrium clustering. The results depend quite sensitively on the properties of the superclusters, and seem to be consistent with observations.

Thuan, in collaboration with Izotov (Kiev), is pursuing a long-term program to improve the determination of the primordial ^{4}He abundance using blue compact dwarf (BCD) galaxies. Together with Izotov, Chaffee (Keck), Foltz (MMT), Green (NOAO) and Guseva (Kiev), he has obtained high-quality spectroscopic observations of the two most metal deficient BCDs known, I Zw 18 and SBS 0335−052. Underlying stellar absorption strongly influences the observed intensities of He I emission lines in the brightest NW component of I Zw 18, and hence this component should not be used for primordial He abundance determination. The effect of underlying stellar absorption, though present, is much smaller in the SE component. Assuming all systematic uncertainties are negligible, the He mass fraction $Y = 0.243 \pm 0.007$ derived in this component is in excellent agreement with recent measurements by Izotov & Thuan, suggesting the robustness of the technique applied in measurements of the helium abundance in low-metallicity blue compact galaxies. They show that, while underlying stellar absorption in SBS 0335−052 is important only for the He I λ4471 emission line, other mechanisms such as collisional and fluorescent enhancements are influencing the intensities of all He I emission lines and should be properly taken into account. They use a self-consistent method based on the five strongest He I emission lines in the optical spectrum for correction for collisional and fluorescent enhancements. Assuming all systematic uncertainties are negligible, the weighted mean He mass fraction in SBS 0335−052 is $Y = 0.2437 \pm 0.0014$ when the three He I λ4471, λ5876 and λ6678 emission lines are used, and is 0.2463 ± 0.0015 when the He I λ4471 emission line is excluded. The weighted mean helium mass fraction in the two most metal-deficient BCGs I Zw 18 and SBS 0335−052, $Y = 0.2462 \pm 0.0015$, after correction for the stellar He production results in a primordial He mass fraction $Y_p = 0.2452 \pm 0.0015$. The derived Y_p leads to a baryon-to-photon ratio of $(4.7^{+1.0}_{-0.8}) \times 10^{-10}$ and to a baryon mass fraction in the Universe $\Omega_b h^2_{50} = 0.068^{+0.015}_{-0.012}$, consistent with the values derived from the primordial D and ^{7}Li abundances, and supporting the standard big bang nucleosynthesis theory. For the most consistent set of primordial D, ^{4}He, and ^{7}Li abundances we derive an equivalent number of light neutrino species $N_\nu = 3.0 \pm 0.3\,(2\sigma)$.

3.6 Astrometry

Dinescu and undergraduate C. Knez have investigated classification of objects and centroiding accuracies for HST WFPC2 data. This project aims at deriving absolute proper motions of globular clusters and Galactic satellites using archived HST data.

Dinescu, Patterson and Majewski are investigating the astrometric performance of the UVa PDS microdensitometer for the long scans required by the proper-motion studies of the Selected Areas. This involves a new computer control of the PDS which will replace the old VAX system with a UNIX computer, and the development of the software to measure these large catalogs. Also a significant number of comparison tests will be done in order to understand the performance of this new system. Thus similar photographic plates will be measured on both the Yale and the UVa PDS microdensitometers, and the Yale PDS will be used as a standard since its capabilities are well understood.

Dinescu, Majewski and Siegel (graduate student), in collaboration with K. Cudworth (Yerkes Obs.) have continued their work on the proper motions of satellite galaxies and globular clusters of the Milky Way. Using thirty photographic plates measured with the Yale PDS microdensitometer, Dinescu, Majewski, Girard (Yale) and Cudworth have almost completed a proper-motion study (to an accuracy of 0.3 mas yr^{-1}) of the globular cluster Pal 12 with the aim of determining its orbit. This will clarify whether this cluster was once part of the Large Magellanic Cloud as has been proposed by Lin & Richer (1992), better define the cluster color magnitude diagram, and improve knowledge of its structural parameters. A similar study was also started for globular cluster NGC 7006, with eighteen plates measured at Yale. For Siegel's thesis project on the proper motion of the Leo II dwarf spheroidal, 10 orbits of HST snapshot time have been granted to provide a new epoch of data to add to first epoch, archival 200'' plates from Baade, and some newer KPNO 4-m data. The Leo II CCD data has also been used to produce a variable star catalogue and revised Leo II structural parameters, including possible evidence for tidal arms seen in the distribution of Leo II giant stars.

Using their photometric giant search technique, Majewski, Patterson, Kunkel (Las Campanas Obs.), Kundu, and D. Geisler and W. Gieren (both U. Concepcion) have begin a large survey of the southern ($\delta < +25$) sky to find bright ($V < 13$), metal-poor giant stars suitable for the Space Interferometry Mission (SIM) Astrometric Grid. In the first year of the survey, conducted with the Las Campanas 1-m Swope telescope, $\sim$ 60% of approximately 2,000 evenly spaced survey fields have been imaged with the Swope 1-m telescope at Las Campanas. The spectroscopic phase of the survey will begin shortly.

Majewski is nearly finished the observing 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 turn of the century Mt. Wilson 60'' telescope, for proper motions of exquisite ($<$ 0.1 arcsec/century) precision to $V \approx$ 19.

Ianna, Patterson, and Begam are continuing the CCD parallax program at the Mount Stromlo and Siding Spring Observatories using the 1 m reflector. The program support was renewed this year by NSF. 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.

Ianna, T. Henry and others (P. Seitzer, C. Anguita, R. Mendez, and M.T. Ruiz) have begun a nearby star parallax program at CTIO on the 0.9m and 1.5m telescopes through a NOAO Survey award. The observing, about six nights per month, began in August 1999. The aims of this program are similar to the Australian program: to identify new nearby star candidates in new southern proper motion catalogs through photometry and to obtain parallaxes of those objects likely to be within 20 pc. Precision will be limited to about 3 mas in

order to more quickly have results for a larger number of stars with the goal of filling in the nearby star data base in support of the NASA NStars Project.

Patterson, Ianna and Begam have continued to obtain Cousins *VRI* photometry for additional nearby star candidates such as the new Scholz southern APM stars and 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 to one of the southern parallax programs.

4. MISCELLANY

Balbus was a participant at the ISSI workshop ''From Dust to Terrestrial Planets,'' held at the University of Bern in February 1999. Balbus was a visitor at the Université de Grenoble during May 1999, and at Queen Mary–Westfield College during July 1999. Chevalier served on the NRC/NAS Committee on Astronomy and Astrophysics and on the scientific organizing committee for the Young Supernova Remnant Workshop in Boulder, CO, and began a term on the NOAO Observatories Visiting Committee. Richard DeGrijs received the ''Van Swinderen'' award of the Royal Netherlands Physical Society for the most comprehensible summary in Dutch (for non-experts) of a Ph.D. thesis in the natural sciences published in the preceeding academic year. Hawley was a participant in the program on Black Hole Astrophysics at the Institute for Theoretical Physics during June 1999. Hawley served on the National Computational Science Alliance User Advisory Panel. Ianna serves as a technical consultant to CSICOP, a member of the Executive Board of the International Dark-Sky Association, Chair of the Virginia Section of IDA, a member of the NASA Keck Time Allocation Committee, on the Scientific Working Group of the NASA NStars Project, IAU Technical Working Group of Commission 51 on Extrasolar Planets.

Majewski served on the Space Interferometry Mission Science Working Group and remained a Visiting Associate of the Carnegie Observatories. O'Connell is chair of the Scientific Oversight Committee for the Hubble Space Telescope Wide Field Camera 3, a two-channel UV-visible-infrared imager scheduled for installation during the 2003 servicing mission. He also served as chair of the HST Cycle 8 Time Allocation Committee panel on Galaxy Populations and Interactions. Richards gave 14 lectures on Close Binary Stars

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