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1. PERSONNEL

This report covers the period 15 August 1997 through 15 August 1999. Staff active in astronomical research and education during this period included: Professors R. J. Buta, G. G. Byrd, P. E. Hardee, W. C. Keel, J. W. Sulentic and R. E. White III and Associate Research Professor D. A. Crocker. Postdoctoral Research Associates were P. Eskridge (end 9/97) and A. Rosen (from 8/95). There are currently seven physics graduate students specializing in astrophysics.

The major research focus of the astronomy group at U. Alabama is on extragalactic theory and observation. We summarize current results and activities by subtopic in the following two sections.

2. THEORETICAL RESEARCH

2.1 Galaxy Dynamics

Buta and F. Combes (Paris Observatory) carried out detailed numerical simulations of three resonance ring galaxies: NGC 1433, NGC 3081, and NGC 6300. Buta reduced detailed optical Hα interferometry of NGC 1433 obtained in collaboration with S. Ryder (UKIRT) and of NGC 6300 obtained in collaboration with G. Madsen (U. Wisconsin). Combined with published HI data, these observations provided well-defined rotation curves for these galaxies. Using *H*-band images, the gravitational potentials in the three galaxies were derived and a cloud-particle disk was evolved in this potential in response to the nonaxisymmetric components. The method was used to derive the pattern speeds in the three galaxies by matching cloud-particle distributions to the gaseous and young star morphologies of the galaxies.

In a theoretical study of the hot gas in elliptical galaxies M. Loewenstein (U Maryland & NASA/GSFC) & White assessed how the gas could be observed to be systematically hotter than the dynamical temperature of the visible stars. D. Davis (MIT) and White previously proposed that the dark matter in ellipticals must be dynamically hotter than the visible stars (see below). Loewenstein and White performed detailed numerical hydrodynamical and stellar dynamical calculations and confirmed that the observed disparity in gaseous and stellar temperatures in ellipticals implies that dark matter is indeed dynamically hotter than the stellar component.

Byrd worked with undergraduates D. Ousley, C. Dalla Piazza, and graduate student D. Domingue to develop a quantitative model for the inner and two outer rings of NGC3081. Here the ring shapes permit a calculation of the perturbation potential even in the outer disk. Use of the perturbation with disk photometry permits determination of disk surface density, mass/light ratios, and halo/disk ratios. A preliminary calculation for NGC 3081 beyond the outer rings (4 exponential scale lengths) indicates substantial dark matter in the disk with a comparatively small amount of the mass in any spherical halo. Byrd, Ousley, and T. Freeman (Bevill State) used their analytic/computer model to demonstrate that the resonance rings in NGC3081 can serve as star formation laboratories for the study of time changes in stellar associations after their formation. The difference in the orbital angular speed and the bar pattern speed serve to separate associations in position angle around the ring according to their age since formation near the ends of the bar. The observed color variation qualitatively matches expectations subject to expected problems of contamination by the light of old disk stars. This model was also used to study the one-armed spiral galaxy, NGC 4622. Previously, Byrd, Freeman, and Howard (NSF) found that the single leading arm in the inner disk can be created by tidal effects of a small companion. Byrd and Freeman have subsequently found that the ring in NGC4622 is an $m = 1$ resonance feature of dissipative periodic orbits of gas clouds. This represents an additional type of resonance ring which should preferentially be the long term result of close passages by small companions.

Models for explaining nuclear activity in disk galaxies (such as Seyfert or Markarian galaxies) range from intrinsic (e.g. bars) to external (tidal perturbation by passing companions). Byrd and collaborators have followed up their work in the late 80's to explore possible links between perturbations and nuclear activity. Their simulations show a several 10^8 yr. delay in the appearance of activity after perturbation and a similar duration which can explain the equivocal observational evidence. Byrd and Valtonen (Turku) predict from the tidal hypothesis that: 1) there should be an excess of pairs where both components are active, 2) nuclear activity will be preferentially excluded in pairs which are unequal and favorably distributed in pairs where the members are equal, 3) smaller pair members can induce activity if they are equal in size than if they are very unequal and 4) pairs where one or both members are active should have a smaller velocity difference times separation normal. These predictions are borne out in observations of Markarian galaxies.

Graduate student R. Mohr (advisor G. Byrd) is studying the gravitational effects of M31 on its smaller companion M32 using computer codes developed by B. Smith (NASA Ames) and R. Miller (U. Chicago). Mohr has also simulated the gravitational effect of the giant association NGC206 on the disk of M31. Finally, Mohr is investigating via simulations the origin of filaments found near giant ellipticals in the cores of galaxy clusters and near non-cluster ellipticals. Mohr finds that tidal disruption and inelastic collision of the disk gas clouds can produce narrow, dust rich and comparatively massive filaments near the E-galaxies.

2.2 Magnetohydrodynamics

Hardee's work involves study of the dynamics and emission from the highly collimated jet outflows observed in extragalactic radio sources, quasars, galactic superluminals, and protostellar outflows. The work includes analytical analysis of the magnetohydrodynamic fluid equations, numerical simulation and modeling of the dynamics and the emission from the jets and comparison with observations of individual objects. In this work relativistic and nonrelativistic adiabatic and radiatively cooling magnetized jets are studied and modeled. Analytical theory is used to establish model dependence on parameters and for its predictive abilities. The numerical simulations are used to study nonlinear processes, e.g., mass entrainment and mixing of jet material with the external environment, and to study applicability of the analytical theory. Modeling work is of particular importance to extragalactic jets or to the galactic jets where the continuum nature of synchrotron or inverse Compton emission provides no direct measure of velocity, density and magnetic field strength, and whose observed apparent motions may reflect a wave pattern or shock speed different from the speed of the underlying flow. Protostellar outflows where line emission serves as a velocity indicator, will allow exploration of the relationship between line emission, entrainment, boundary layer velocity shear and shock structures, and the underlying outflow dynamics. Objectives of this research are (1) to learn how analytical theory with input from numerical simulations can be applied to these objects, (2) to directly apply three dimensional numerical simulations to understanding the outflow dynamics of these objects, (3) to use the results to learn how outflow morphology is influenced by the external environment, by the presence of dynamically significant magnetic fields, and by radiative cooling, and (4) to model the emission from jets and understand the relationship between observed emission and the underlying flow.

Rosen continued the ongoing analysis of simulation data. Studies of the differences between non-relativistic and relativistic jets where performed. Additional work involved analysis of simulations designed to study the effect of magnetic fields on mass entrainment and mixing of an ambient medium with magnetized jet material. Jet toroidal equipartition magnetic fields are found to significantly decrease the rate of mixing between jet and ambient fluid. Poloidal magnetic fields of comparable strength do not provide a similar reduction in mixing. The difference is largely the result of a suppression of jet filamentation by the toroidal magnetic fields. The rate of mixing is found to be related to the growth of surface structures associated with the Kelvin-Helmholtz instability. In the sub-Alfvenic very strong magnetic field regime mixing of jet and ambient fluids is almost entirely suppressed. This suppression coincides with suppression of the Kelvin-Helmholtz instability. However, at the Alfven point the jet becomes very unstable and significant mixing and mass entrainment are found to occur for both poloidal and helical magnetic field configurations. This result has serious implications for jet acceleration and collimation schemes requiring jet acceleration from sub-Alfvenic through the Alfven point to super-Alfvenic speeds.

Hardee continued his collaborative effort with J. Stone (U. Maryland) through analysis of numerical studies on the effect of magnetic fields on the dynamics of radiatively cooling protostellar jets. This work has involved numerical and theoretical study of the effects of radiative cooling on the dynamics and stability properties of 3D protostellar jets. Hardee served as co-advisor for J. Xu (U. Maryland) who completed his dissertation in June 1998 on 3D simulations of protostellar jets. In addition to this work Hardee also performed a theoretical analysis of the bending effect of magnetic fields in the ISM on protostellar jet outflows. This theoretical work was incorporated into a simulation study of jet bending by magnetic fields performed by J. Hurka and J. Schmidt Burgk (MP-Radioastronomie-Bonn). It was found that the observed deflection of some stellar jet outflows probably cannot be the result of interaction with magnetic fields in the ISM as the magnetic fields would have to be too high. On the other hand, a low speed wind outflow could be deflected by moderate ambient magnetic fields. A 2D ram pressure theoretical treatment was found to satisfactorily represent the jet bending observed in the numerical simulations.

3. OBSERVATIONAL RESEARCH

3.1 Normal Galaxies

G. Purcell completed his dissertation study (advisor: R. Buta) of the photometric and kinematic properties of a sample of ''Milky Way Galaxies,'' a set of galaxies chosen to be similar in Hubble type and likely morphology to the Milky Way. Purcell analyzed optical *BI* images and Hα Fabry-Perot interferometry of 27 galaxies near stage Sbc covering the full range of families (barred versus nonbarred) and varieties (inner-ringed versus non-inner-ringed). The main objective of Purcell's study was to determine what physical factors underlie the spread in morphologies at a given Hubble type along the Hubble sequence by measuring photometric profiles and rotation curves of these 27 galaxies. The stage Sbc was chosen because galaxies still cover the full range of families and varieties at this stage, there is significant diffuse Hα emission in the disks for kinematic coverage, and the galaxies provide a well-defined comparison sample for Galactic studies. Purcell's thesis represents the first attempt to apply the Canzian geometric method for estimating pattern speeds in galactic disks to a significant, homogeneously-observed sample of galaxies. With this method, Purcell determined that the inner rings in several of his sample galaxies extend to corotation, and that the outer Lindblad resonance lies within the area covered by the outer spiral arms.

White and D. Davis (MIT) compiled and analyzed the first X-ray complete sample of elliptical galaxies. The X-ray emission from these ellipticals is dominated by gas, presumably accumulated stellar mass loss, with cooling times much less than a Hubble time; the gas is therefore slumping radially inward in subsonic ''cooling flows,'' since it is radiating its pressure support. Temperatures, elemental abundances and X-ray luminosities were determined from ROSAT spectra of 43 ellipticals. They found that the X-ray emitting gas in these galaxies is generally hotter than the dynamical tem-

perature of the stars (as indicated by stellar velocity dispersions). They also found very subsolar elemental abundances in the X-ray emitting gas, so supernovae energy input (and metal contamination) must be negligible. They therefore proposed that the gas is hotter than the stars because the cooling flow gas is traversing dark matter halo potentials which are characterized by larger velocity dispersions than in the associated stellar components. Thus, the dark matter is dynamically hotter than the stars.

3.2 Dwarf Galaxies

Graduate student S. Gessner Stewart completed a dissertation (advisor G. Byrd) using images of dwarf galaxies obtained on the Astro2 mission aboard *Endeavour*. She processed Ultraviolet Imaging Telescope (UIT) data for Holmberg II, Sextans A and IC 2574 to characterize the star formation process in these intrinsically simple systems. This work centered on a test for the origins of HI holes in the ISM of these systems, which have been interpreted as the result of energy input from star-forming regions. UV data offer the potential to find young stars long after they cease to contain ionizing OB stars, and indeed the UIT images show young associations in the centers of many H I holes. Gessner Stewart estimated their ages and energy output, and found these to be comparable to the estimated ages of the expanding holes and the energy required to create them, which supports an origin from energy input by previous generations of star formation.

Eskridge & White analysed archival ROSAT PSPC and Einstein HRI data for an X-ray point source in the bar of NGC 6822, the nearest dwarf irregular beyond the Galactic halo. The source is spectrally very soft and strongly X-ray variable. Spectral uncertainty allows the source to be interpreted either as Super-Soft source or as a black hole binary candidate.

3.3 Resonance Ring Galaxies

Buta continued his studies of resonance ring galaxies via observations and numerical simulations. With graduate student G. Purcell, Buta carried out a detailed photometric and kinematic study of the well-known Seyfert 2 galaxy NGC 3081, a classic resonance ring galaxy with four well-defined ring features. The galaxy has a bright nuclear ring, an intense inner ring, and a characteristic double outer ring/pseudoring structure, all of which are easily linked to specific orbital resonances with the bar. All four rings are sites of active star formation, and there is little star formation away from the rings. Buta and Purcell determined that the that the shape, size, and orientation of the inner ring are the same in *B*, *I*, H α, and *H* passbands, implying a close coupling between the stellar and gaseous rings. The *H*-band image was used by Buta and Purcell to derive the gravitational potential in NGC 3081, using codes written by A. Quillen. From this analysis, Buta and Purcell determined the maximum relative amplitude of the bar and the bar pattern speed.

In a similar study, Buta, Purcell, D. A. Crocker, and REU students A. Alpert and M. Cobb carried out photometric and kinematic analyses of four other classic early-type resonance ring galaxies: NGC 1326, IC 4290, ESO 509 − 98, and ESO 566 − 24. Using *H*-band images to derive the gravitational potentials, and assuming outer rings and pseudorings in the outer regions of each galaxy are linked to the outer Lindblad resonance, these authors estimated pattern speeds and showed that the inner rings are likely to be linked to the inner 4:1 resonance in these galaxies. Optical rotation curves of ringed galaxies were shown to be relatively normal, and that dark matter is required to account for the nearly flat rotation profiles at large radii just as for nonringed galaxies.

Buta, Purcell, and J. Higdon (U. Groningen) carried out a detailed optical and HI study of the interacting ringed barred spiral NGC 5850. VLA observations showed that the HI in NGC 5850 follows the optical blue light spiral structure very closely and shows the same kind of asymmetry. The asymmetry is likely to be due to an interaction with the nearby giant elliptical galaxy NGC 5846, and the authors propose that NGC 5850 is a victim of a high speed encounter with this object. The degree of asymmetry of NGC 5850 depends on the wavelength, being much less significant in the *I*-band than in *B* or Hα, indicating that the gas disk is more disturbed than the stellar disk.

With H. Salo, P. Rautiainen, and E. Laurikainen (U. Oulu), and Purcell, Crocker, and Cobb, Buta carried out a detailed observational and dynamical study of the multiringed southern galaxy IC 4214. IC 4214 has only a weak bar and three strong rings: an inner, outer, and a nuclear ring. Fabry-Perot interferometry reveals the presence of diffuse ionized gas in the region of the bar, inner ring, and nuclear ring, and clear noncircular motions are detected in this region. Analysis of the velocity field under the assumption of pure circular motion gives a value of the inclination which differs by 10° from the inclination inferred from outer isophote shapes. Using two-dimensional sticky particle simulations, this discrepancy is easily accounted for by the effect of the noncircular motions. The simulations led to an accurate estimate of the pattern speed in IC 4214 and showed that all three rings can be linked to standard orbit resonances. The simulations also showed that the visible mass dominates over the unseen halo mass over the main part of the visible disk.

Buta, Crocker, and G. Byrd obtained HST time to observe the detailed structure in the bright nuclear rings in two barred spirals. Nuclear rings are often the sites of starbursts in barred galaxies, and have been linked to the dynamics of an inner Lindblad resonance. The two rings observed are in ESO 565 − 11 and NGC 1326. The former object has the largest known example of a nuclear ring. From multi-band HST WFPC2 images, Buta, Crocker, and Byrd showed that the nuclear ring of ESO 565 − 11 is lined by more than 700 point sources, the brightest of which are ‘‘super star clusters’’ of the type seen in other nuclear rings and in merging systems. The clusters are mostly in the age range 4-6 Myr, although some are old enough to have red supergiants detectable in the *H*-band. An analysis of the gravitational potential inferred from an *H*-band image suggests that the nuclear ring is related to an inner Lindblad resonance and is in an early phase of development. The data for the nuclear ring of NGC 1326 are currently being analyzed by Buta and graduate student P. Treuthardt.

Buta, Treuthardt, and former REU student Madsen are engaged in analysis of optical images of a large sample of ringed galaxies. The goals of the analysis are to derive accurate orientation parameters to allow approximate deprojection of the galaxies, an evaluation of the alignments between bars and rings, and also to derive the average light profiles, disk, and bulge properties of these galaxies. The analysis has so far verified much of what was learned from statistical studies of the projected shapes, position angles, and relative sizes of rings, and has revealed interesting characteristics of individual ringed galaxies.

3.4 Galaxy Opacity Studies

Keel and White continued their use of overlapping galaxies to measure the dust extinction within spirals. They have analyzed a set of new HST WFPC2 of elliptical/spiral overlaps specifically to measure the fine-scale dust structure. At a resolution of order 50 pc, the dust behaves very much like a screen with typical Galactic reddening law. They find scale-free (fractal-like) behavior in the extinction maps over a range of about 1.5 dex in scale. The arm-interarm distinction is more pronounced than seen from the ground, with what earlier appeared as interarm dust sometimes now appearing as discrete spurs crossing between arms.

HST imaging of the spectacular spiral/spiral superposition NGC 3314 offers a unique opportunity to measure the opacity in the inner parts of an Sc galaxy. These data indicate that the dust in some of the arms has a larger scale height than the stars. Seeing the nucleus of the background galaxy within 2″ of the foreground nucleus (300 parsecs) gives a direct estimate of the extinction at this small radius, about $A_I = 4$ magnitudes between the dust arms.

Keel, White and graduate student D. Domingue used spectroscopy to measure the extinction in spiral/spiral pairs, with the redshift difference allowing a separation of foreground and background light in the overlapping regions. This technique requires less precise symmetry than their purely image-based approach. The results of this study tell the same story as the earlier imaging survey – spiral arms can have large optical depth at almost any radius, while interarm regions have a roughly exponential radial distribution of opacity, reaching $A_B = 1$ only well inside $0.4R_{25}$. Keel and White have been extending work on backlit galaxies to the near-infrared bands, in collaboration with P. Eskridge, K. Sellgren, and D. Terndrup (OSU). This work uses the large-format TIFKAM system at the 2.4m Hiltner telescope of MDM Observatory. Domingue, Keel, White, and S. Ryder (JAC Hilo) combined opacity measures with ISO and JCMT far-IR and submillimeter measurements to limit the role of very opaque or very cold dust in three backlit spirals. Adopting an empirical exponential model for the dust distributions allow an estimate of total dust mass from the absorption measures, which agrees with the thermally emitting grain mass calculated from Galactic grain mixes at the 30% level. Thus suggests that we are now seeing most of the grain mass in typical spirals, with little role for either extensive cold dust or small, opaque clumps.

Keel has developed an algorithm to retrieve the three-dimensional distribution of dust in galactic nuclei from images in multiple passbands, solving an integral equation for the amount of starlight in front of and behind dust structures. Tests show that it retrieves planar disks in such systems as NGC 4261. Further application to HST archival images will be used to investigate that apparently large *z*-extent of dust features, to see what level of energy input and plausible mechanisms are required to keep these features so far from the inner disk plane. This approach may also shed light on the difference in dust environments between Seyfert 1 and 2 nuclei reported by Malkan and collaborators.

3.5 Zone of Avoidance Studies

Buta and M. McCall (York U.) completed a detailed photometric study of 14 members of the IC 342/Maffei Group, a nearby small group of galaxies located in the Zone of Avoidance in the Perseus-Cassiopeia border region. The group includes some of the most massive galaxies within 5 Mpc of the Local Group, but has been poorly studied because of the heavy foreground Galactic extinction and star contamination of several of its members. The group includes the nearest massive elliptical galaxy, Maffei 1, the giant Scd spiral IC 342, and the very heavily obscured massive late-type spirals Maffei 2 and Dwingeloo 1. Buta and McCall derived accurate total *V*- and *I*-band magnitudes of these and 10 other mostly dwarf members of the group, to set the stage for deriving distances and to evaluate what impact, if any, this group may have had on Local Group history.

3.6 Active Galactic Nuclei

Sulentic continues a collaboration with P. Marziani and M. Calvani (Padova), D. Dultzin-Hacyan (UNAM) and T. Zwitter (U. Ljubljana) on broad emission line properties of AGN. This work involves comparison of high and low ionization lines using HST archival UV and matching ground based optical spectra. This comparative study has focussed on Hβ and CIVλ1549 which are the most tractable broad lines for a comparison in sources with z$\leqslant$ 1.0. A new sample of about 50 sources is being prepared for publication and will bring the total sample with matching Hβ and CIV to $\sim$ 100. The new sample so far confirms the main results reported in 1996: 1) radio-loud (RL) and quiet (RQ) sources show significantly different broad line properties and 2) the high (HIL) and low (LIL) ionization lines in RQ sources are also significantly different; favoring models where the two lines arise from different BLR clouds. The most striking result involves an apparently ubiquitous blueshift (relative to the local rest frame) of CIV (and other HIL) in RQ sources. This is most easily explained if CIV is produced in an accretion disk wind whose far side component is obscured by the optically thick disk. CIV shows a range of blueshifts from zero to 5000 km/s suggesting that the amplitude of the shift depends upon source orientation. The systematic blueshift disappears in RL sources and is replaced by small stochastically distributed red and blue shifts about the rest frame. Hβ in RL sources shows an average redshift but with large blue and redshifts (up to $\sim$ 4-5000 km/s. This emission is most

easily explained if the line arises in a biconical outflow where an optically thin disk allows us to see both red and blueshifted clouds.

Sulentic and Marziani have investigated the apparent confusion over the frequency and amplitude of the CIV blueshift in the literature. They find that the shift is muted or erased in samples where no narrow line components is subtracted from CIV. Confusion over this component arises because a) the UV NLR lines are expected to be heavily reddened and b) the narrow component of the UV lines is usually broader than the narrow lines observed in the optical (e.g. [OIII] λ5007). Marziani and Sulentic find that the narrow component of CIV shows properties similar to the narrower NLR lines including lack of intensity variations and no line shifts. They ran simple models using CLOUDY that show broader NLR emission lines arising naturally near the inner edge of the NLR where the density is higher. They conclude that there is no strong justification for treating it as BLR gas and that failure to correct for its presence leads to erroneous conclusions about the basic properties of the broad lines.

Working with Keel and P. Allan (Rutherford Appleton Lab. UK), graduate student J. Castro-Ceron finished his master's thesis on the variability of PG quasars. He found that the structure functions of the most and least luminous objects are essentially identical, arguing that previous claims to the contrary were misled by neglect of the transformation into the objects' emitted time frames. There is some evidence that objects with relatively stronger X-ray emission are more strongly variable, while there is essentially no trend with absolute magnitude.

3.7 Galaxy Evolution

Keel continued studies of the rich environment of the radio galaxy 53W002 at $z = 2.4$, working with R. Windhorst and his group at Arizona State. Imaging at the KPNO 4m telescope using medium-bandwidth filters identified additional Lyman α emission candidates in a structure 7 arcminutes ($\approx 5Mpc$) across, of which three have now been spectroscopically confirmed as AGN at this redshift. This grouping is more extended than a King distribution (of any core radius), and its velocity dispersion is comparable to the Hubble flow across its diameter at this early epoch. These data, plus the relative isolation of the structure, suggest that we are seeing it close to turnaround from the general Hubble expansion.

They studied the nature of the faint star-forming objects previously detected in this field, using NICMOS and IRTF data to measure the emitted-optical regime. These results are a close fit to low-metallicity starbursts, changing the interpretation from preliminary data of much lower S/N ratio. ISO data at 7 μ (emitted K band) are still being processed, in hopes of either a mean flux detection or significant limits on the older stars in these objects.

Wu is completing his Ph.D. dissertation on the history of galaxy merging and formation timescales, extending his modelling code to the near-IR passbands. He has used new counts from deep NICMOS and IRTF imagery in the 53W002 field as constraints, explicitly accounting for surface-brightness selection effects.

Pursuing the comparison of deep-UV properties of nearby galaxies with those observed for high-redshift systems, Keel was a coinvestigator on the Starlite payload carried on STS-95 (P.I. Jay Holberg, University of Arizona). This consists of a 0.4m SiC primary mirror feeding a double-pass spectrograph to suppress geocoronal Lyman α emission. A failure in one of the mount bearings meant that they could not improve on the Voyager measurement of M33, but surveys of several 1° regions were carried out, as well as a long strip scan enabled by a specially altered orbiter attitude during one of the final orbits. Reflight of the system (with a dedicated far-UV imager) has been proposed.

3.8 Groups and Clusters of Galaxies

Davis & White used spatially resolved ROSAT X-ray spectroscopy to look for evidence of a recent merger in the radio halo cluster Abell 2255. Cluster radio halos are thought to be associated with recent cluster mergers, with mergers driving shocks which create a pool of relativistic particles, which then radiate via synchrotron radiation. Davis & White find that Abell 2255 indeed has relatively hot patches associated with the radio halo, supporting the merger origin for radio halos.

Graduate student R. Dupke completed a dissertation (advisor R. White) that involved spatially resolved X-ray spectral analysis of intracluster gas. In particular, Dupke used elemental abundance gradients to constrain the metal enrichment mechanisms in intracluster gas. Possible enrichment mechanisms include galactic winds, ram-pressure stripping of galactic gas by intracluster gas and, at the centers of cD clusters, stellar mass loss from the cDs. Dupke discovered and/or confirmed that abundances are centrally enhanced in several clusters. More importantly, spatial gradients in abundance *ratios* were discovered in several clusters, which implies that the dominant metal enrichment mechanism is different near the cluster centers than in their outer parts. Using an ensemble of abundance ratios, the proportion of iron due to SN Ia (as opposed to SN II) was found to be $\sim$ 50% in the bulk of the clusters, increasing to $\sim$ 75% at their centers. Dupke & White showed that ram pressure stripping cannot be the dominant enrichment mechanism anywhere in these clusters. They proposed instead a two stage wind scenario to account for intracluster metal enrichment: a SN II-driven protogalactic wind phase, followed by a less energetic SN Ia-driven wind phase. Dupke also used X-ray spectroscopy of intracluster gas to constrain theoretical models for SN Ia explosions. He showed that so-called ''delayed-detonation'' models do not produce the Ni/Fe ratios observed in the SN Ia component of enrichment in intracluster gas, while the nucleosynthetic yields of older ''convective-deflagration'' numerical models are consistent with the cluster observations. Dupke & K. Arnaud (U. Maryland, NASA/GSFC) used the results of Dupke & White on SN Ia enrichment in clusters to show that the resonant scattering of the Fe K line alleged to occur in the Perseus cluster by Molendi *et al.* is more likely an artifact of a blend with Ni lines, due to SN Ia ejecta.

With P. Godon (STScI) and N. Soker (Technion, Israel), White proposed a couple of magnetic amplification mechanisms which may operate in cluster cooling flows which are

rotationally supported. The twisting of magnetic flux tubes and the operation of a fast $\alpha - \omega$ dynamo will both promote magnetic reconnection, driving activity in the inner 10 kpc of cooling flows and possibly powering the optical filaments seen in the central regions.

Andersen completed his Ph.D. dissertation (advisor W. Keel) on star formation in the nearby clusters of galaxies Hercules (Abell 2151) and Abell 1367. These spiral-rich clusters are sometimes taken as analogues to higher-redshift Butcher-Oemler clusters, but only recently have large-format CCDs made complete studies of their populations feasible. Using broadband and Hα data from KPNO and Lowell, Andersen found that the relation between star formation and cluster location is not as simple as infall models would suggest. Most of the blue galaxies must be blue for long periods (rather than briefly bursting), since there are too few objects of intermediate color to accommodate a fading population that would accompany such starbursts. Hercules also contains a population of compact emission-line galaxies, some hitherto uncatalogued.

Working with Owen (NRAO), Ledlow (UNM), and Andersen, Keel continued work on the rich cluster Abell 2125 at $z = 0.25$. This cluster attracted attention through a combination of richness, blue fraction, and an extraordinary radio-source population. The radio sources and galaxy distribution have been attributed to a cluster merger. They have obtained multiobject spectra and HST imagery to clarify the nature of the radio sources and the cluster dynamics. Some parts of the cluster contain discrete, compact galaxy aggregates, some so compact that their constituents were undercounted in ground-based data. The radio galaxies include traditional red, elliptical systems and spirals; there is morphological evidence that some AGN seen very close to the cD core have been tidally disrupted by either the general cluster field orthe triple cD galaxy itself.

3.9 Interacting Galaxies

D. Domingue is completing a dissertation project (advisor J. Sulentic) on the star formation properties of 20 mixed morphology galaxy pairs. The data includes ISOCAM, ISOPHT and matching Hα images. Isolated E/S0+S/I pairs provide a unique opportunity to study the gravitational effects of a massive perturber on the gas and dust content of a spiral disk. This is the only kind of binary galaxy where one can unambiguously search for evidence of cross-fueling between the components. All of the pairs show self-consistent structure in the ISOCAM LW3, LW8 and Hα images which provides a general confirmation that warm dust is heated most in sites of star formation. There is no evidence for a decrease in the 11.3/15 μm ratio with equivalent width excess, as was seen for extreme starburst knots in the Antennae. The NGC 7752/3 system is of particular interest because the companion shows an unusually high gas mass and dynamical models point to evidence for a continuous fueling of the companion from the spiral disk of the more massive component. A comparative morphology of Hα and ISOCAM images indicates that the two strongest mid-IR 'hotspots' are giant HII regions at the edge of spiral arms involved in disk-wide star formation. The companion with the largest Hα equivalent width in our sample shows a warmer 60/100 Hα emission color than NGC 7753 the dominant spiral.

Keel and Borne (Raytheon) have obtained WFPC2 images of the interacting pairs NGC 6621/2 and NGC 5754/Arp 297C. These were selected as especially good nearby examples of weak advanced interactions (NGC 5754) and of strong but still young interactions (NGC 6621), to see whether and when massive star clusters form during these kinds of interactions (neither of which has been well probed by the pairs studies to date). NGC 6621 in particular is rich in luminous clusters, and shows heliacal dust structure suggesting mass transfer to the earlier-type companion.

Sulentic is studying star formation activity in the compact group known as Stephan's Quintet (SQ). Multiwavelength data and collaborators include: 1) ISOCAM and ISOPHT and matching Hα images with C. Xu (IPAC) and R. Tuffs (M.P. Kernphysik), 2) ROSAT HRI with G. Trinchieri (Brera) and W. Pietsch (M.P.E. Garching) and 3) Hα Fabry Perot images with M. Rosado and D. Dultzin-Hacyan (UNAM). Overall the star formation activity is depressed with the two strongest IR sources involved with athe foreground galaxy NGC7320 and the Seyfert 2 nucleus of NGC7319. If SQ is typical of compact groups then the earlier claim that IRAS data overestimates the level of star formation in compact groups is confirmed. An unusual starburst was found in the tidal debris of SQ with an estimated star formation rate of 0.8 $M_{\odot}$/yr and a burst age of 1-2$\times$ 10^7 years. This is consistent with the age of the X-ray shock that is associated with an ongoing collision in SQ.

Sulentic with Marziani, M. D'Onofrio (Padova) and D. Dultzin-Hacyan have investigated the close pair of spiral galaxies known as UGC3995. This pair shows apparently interacting disks and a zero velocity difference. This appeared to be an excellent candidate pair for investigating possible cross fuelling that might have given rise to the Seyfert nucleus in the brighter component. Older images suggested a luminous filament connecting the nuclei. Unfortunately new images (including archival WFPC2) and spectra reveal little evidence that the spirals are interacting thus illustrating the difficult in proving interaction even when circumstances (i.e. proximity and relative velocity) appear to favor it. The overlapping and near face-on spiral patterns are so well defined that it was possible to estimate the opacity of the foreground companion. The visual extinction was found to vary from 0.15 magnitudes in intra-arm regions to 1.0-1.5 magnitudes in the arms.

Sulentic was co-advisor for H. Toledo (UNAM) who completed a dissertation in November 1998 on the optical and FIR emission properties of mixed morphology pairs of galaxies. This work found evidence for both optical and FIR enhancement in the spiral components of mixed pairs. The level of enhancement appears to be similar to that found for samples of more common spiral-spiral pairs. This suggests that mass of a perturber is more important, in most cases, that the presence and relative orientation of a disk component in the perturber. The FIR results show the largest enhancement signal at 25μm. This aspect could not be studied in previous surveys because the IRAS 25 μm detection fraction was too small. Toledo used coaddition and deconvolu-

tion techniques to both increase the detection fraction in his sample of $\sim$ 130 pairs and to resolve the components in a few cases.

4. OTHER ACTIVITIES

4.1 Equipment

The astronomy group uses a network of 11 Sun and three Silicon Graphics workstations. Through these machines there is access to several 600 dpi B/W Postscript printers, both high and low density 8mm tape drives, 4mm DAT drives, a 1/2-inch high-density tape drive and a color Postscript printer. The computer network shares a capacity of approximately 13 Gbytes of group-accessible disk space as well as another 18 Gbytes of reserved disk space. All the major astronomical software reduction packages are supported and several IDL licenses are available. The new SRC Equatorial Sky Survey and Palomar II survey have been acquired and are gradually moving towards completion. An extensive collection of data has been collected on CDRoms, including the digitized sky survey (north and south).

4.2 Education

Keel prepared a slide set and explanatory booklet on quasars and active galactic nuclei for distribution by the Astronomical Society of the Pacific. The contents may be viewed at the group's WWW site.

Driven by the simultaneous growth of local light pollution and interest both in courses and among the public, the group has acquired a 0.4m Newtonian telescope which will be sited at nearby Moundville Archaeological Park.

4.3 Other

UA physicist R. Tipping and collaborators are involved in NASA sponsored theoretical molecular physics research. Their work on spectral line shapes is important for the analysis of planetary spectroscopic data. It is particularly relevant for radiation emitted in spectral windows between the strong vibration-rotation bands where the absorption is saturated. Collision-induced absorption dominates the FIR spectra of the outer planets, brown dwarfs and newly discovered ''methane stars.''

Graduate student A. Johnson (advisor P. Hardee) is currently working in cooperation with NASA/Marshall Space Flight Center to study BATSE trigger biases. Johnson has written computer algorithms to quantify separately the Peak Counts Bias, which arises from statistical fluctuations, and the Slow Riser Bias, which results from burst flux being included in the on-board background calculation. Johnson, with supervisor C. Meegan (NASA/MSFC) and collaborator J. Hakkila (Mankato State University, Minnesota) is currently working to simulate the action of both biases acting on a burst.

Buta spent 1 month during the summer of 1998 as a visiting astronomer at the Paris Observatory. During this visit he collaborated with Dr. F. Combes on numerical simulations of ringed disk galaxies using a sticky particle dynamics code and other programs. The results were presented at the meeting, ''Galaxy Dynamics: From the Early Universe to the Present,'' held in Paris in July 1999. Buta also presented an invited (keynote) review on ''Resonance Rings and Galaxy Morphology'' at the meeting ''Towards a New Millennium in Galaxy Morphology,'' held in Johannesburg, South Africa in September 1999. This review supplements and updates the more thorough review on the subject published in Fundamentals of Cosmic Physics, vol. 17, p. 95, 1996.

Byrd spent 01-06/99 on a sabbatical visit to Tuorla Observatory (Turku, Finland). While there with collaborators A. Chernin (Moscow State University, Russia), I. Karachentsev (Special Astrophysical Observatory, Russia) and M. Valtonen (Tuorla), he completed a review on triple galaxies for *Fundamentals of Cosmic Physics*. Byrd also served on the scientific and local organizing committees of IAU Colloquium 174 *Small Galaxy Groups* held in Turku, Finland in June 1999.

Hardee was on sabbatical at U. Michigan and STScI during part of the 9/98-6/99 period. He was in residence at NRAO (Socorro) during part of summer '99. Results of some of this work were presented at the Texas Symposium on Relativistic Astrophysics (Paris)held in December '98. Other related work was presented by C. Smith (graduate student at the U. Michigan) at the AAS meeting in January 1999. Additional work was presented by Hardee at the ''Lifecycles of Radio Galaxies'' workshop held at STScI in July 1999.

Sulentic, Marziani and Dultzin-Hacyan completed a review titled ''The Phenomenology of Broad Emission Lines in AGN'' for the 2000 edition of *Annual Reviews of Astronomy and Astrophysics*. Sulentic was a visiting scientist at Osservatorio Astronomico di Padova from 6/99-8/99. He presented the invited review ''Stephan's Quintet: Implications for Compact Groups'' at IAU Colloquium 174 *Small Galaxy Groups* in June 1999, Turku, Finland.

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The UA Astronomy Group maintains a World-Wide Web site (http://www.astr.ua.edu/). It includes information on the graduate program. An extensive collection of deep-sky images obtained by group members, and instructional material including lab exercises. The web site also hosts the popular ''4000 Years of Women in Science'' online exhibit.

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