Ohio University

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The following report covers the period November 1998 through October 1999.

1. INTRODUCTION

Ohio University was the first institution of higher education in the Old Northwest, and is part of the state university system of Ohio, with a current enrollment of approximately 20,000 students. Ohio's Department of Physics & Astronomy has 21 faculty active in research in areas including nuclear physics, biophysics and nonlinear dynamics, condensed matter and surface physics, and astrophysics. The Department offers a Ph.D. in physics, with a current graduate enrollment of approximately 50 students. Additional information about the Department can be found at the WWW site http://www.phy.ohiou.edu.

2. PERSONNEL

Astrophysics faculty in the Department include Joseph Shields and Thomas Statler, Emeritus Professor James Dilley, and Instructors George Eberts and Tom O'Grady. Stephen Vine continued as a Postdoctoral Research Associate under Statler's supervision. Statler was promoted to Associate Professor with tenure. The Physics & Astronomy Department and University have approved the expansion of the Astrophysics Group by hiring an additional tenure-track faculty member, and a search for this position is in progress at the time of writing.

During the past year Statler has supervised research by graduate students Jakob Bak, Michelle Connelly, Heath Lambright, Robert Salow, and undergraduate Megan Krejny. Shields has supervised research by graduate student Bassem Sabra. Connelly completed a masters degree in physics in June, and has since joined the staff of the U.S. Patent Office in Washington, D.C. Bak was awarded a stipend from the AAS Division of Dynamical Astronomy to present his research at their annual meeting in Estes Park, Colorado, in April.

Statler's research on the structure and evolution of elliptical galaxies received continuing support from an NSF Faculty Early Career Development (CAREER) Award. This funding also allowed the continuation of the Science Teachers Active in Real Science (STARS) program into its second year. As part of this program, Kevin McChesney [Marietta High School] spent the summer in the lab of OU Professor Arthur Smith, assisting with calibration of an atomic force microscope and the assembly of a molecular beam epitaxy facility. Shields received new and continuing funding from STScI and NASA for studies of active galaxies. Shields continued as a member of the Publications Committee for the Astronomical Society of the Pacific, and as a member of the Telescope Allocation Committee for the National Optical Astronomy Observatories.

Shields and Statler assisted in the formation of the Southeast Ohio Astronomical Society, an organization committed to promoting interest and public education in astronomy. Shields has been working with the City of Athens to draft a zoning ordinance for control of light trespass and light pollution that adversely affects local observing conditions. If adopted, this ordinance will be the first such law enacted by a city within the state of Ohio.

3. RESEARCH

3.1 Normal Galaxies

Statler is continuing observational and theoretical work to constrain the three dimensional mass distributions and stellar phase-space distribution functions in elliptical galaxies. Observational collaborations with T. Smecker-Hane [UC Irvine] and M. Merrifield [U. Southampton] have resulted in data for NGC 1700, NGC 3379, NGC 2768, and NGC 4472, using the old MMT and the KPNO Mayall 4m. These observations can yield mean velocities with $\sim$ 10 km/s accuracy on four position angles per galaxy out to $>$ 1.5 effective radii, as well as measurements of the dispersion and higher moments. Data reduction and kinematic analysis on NGC 2768 and NGC 4472 are in progress; results for NGC 1700 and NGC 3379 are published. Plans for a comprehensive multi-wavelength dynamical study of an X-ray selected sample of bright ellipticals are being laid by Statler in collaboration with R. Ciardullo [Penn. State U.] and R. Mushotzky [NASA/GSFC]. Chandra data will be obtained through GTO programs; proposals for time on HST and on the rebuilt MMT are pending.

Statler has completed dynamical modeling to determine the intrinsic shape and orientation of NGC 3379, with the addition of further kinematic data provided by K. Gebhardt [Lick Obs.]. The results strongly constrain the galaxy to be nearly axisymmetric and oblate, with a small but non-zero triaxiality. If the galaxy is not intrinsically twisted, the models also indicate a substantial flattening from the inner to the outer parts. In this sense the structure of NGC 3379 is reminiscent of, though not as extreme as, the edge-on S0 galaxy NGC 3115. The inclination of the galaxy is constrained to be in the vicinity of 30° from pole-on, and work is in progress to determine the implications of this result for the nuclear disk structure seen by HST and for the associated radio source.

Connelly completed a Master's degree project under Statler's supervision to measure roughly a dozen line indices defined on the Lick/IDS system from the NGC 3379 data. Just as these spectra give unprecedentedly high-resolution views of the dynamical structure, Connelly's results should provide a comparably clear view of the chemical abundance gradients.

Bak and Statler have completed dynamical modeling of galaxies from the sample of radio ellipticals with multi-position-angle kinematics from Davies & Birkinshaw (1987).

The aim of this work is to derive a dynamically-based estimate of the *parent* distribution of intrinsic shapes. (Most previous work has relied solely on photometry.) The maximal-ignorance estimate indicates two peaks in the parent distribution, consisting of nearly-oblate and nearly-prolate galaxies. However, the relative rarity of triaxial systems is not a robust result, and depends sensitively on the ''dynamical prior'' used in the models. In particular, the results are sensitive to the behavior of the mean streaming velocity away from the principal planes, a property that could, and should, be predicted by galaxy formation models.

Vine and Statler are continuing the work of former post-doc S. Dutta, in collaboration with M. Weil [McGill U.], to perform this analysis for a sample of simulated ellipticals formed by pair mergers, group mergers, and heirarchical collapse. Lambright and Statler are also working with simulated merger remnants provided by Weil to test the robustness of intrinsic shapes and orientations derived by modeling projected shape and kinematics. The simulations are ''observed'' using software developed by Bak and modified by Lambright. A variety of statistical tests are to be performed using multiple orientations of the same galaxy as well as randomly oriented samples of different galaxies, to search for biases in the modeling technique.

Bak is nearing completion of a dissertation under Statler's supervision that addresses the formation of counter rotating cores in elliptical galaxies. A suggested method of formation for such cores posits that dynamical friction causes a compact companion to spiral into the center of a much larger elliptical galaxy on a retrograde orbit relative to the larger galaxy's rotation. If the core of the smaller galaxy is not tidally disrupted, it may carry some of its orbital angular momentum to the center. Bak has completed N-body simulations of counter rotating core formation by satellite accretion. 2D line-of-sight velocity fields, including third and fourth order Gauss-Hermite terms, are created using penalized likelihood methods. The photometric aspects of the simulations are analyzed with IRAF to provide a comparison with observations. The results indicate that dissipationless accretion of a satellite is unable to form counter rotating cores. In the cases where the satellite does not disrupt, tidal torques force the its orbital plane to pivot so that it is oriented at least 90 degrees with respect to the orbital plane of the larger galaxy during the final stages of the merger.

Vine, in collaboration with S. Sigurdsson [Penn. State U.], has investigated the dynamical evolution of high density galactic disks during the late stages of disk galaxy formation. The investigation has confirmed earlier speculation that initial global instabilities in the underlying disk structure can cause a proportion of the mass in the disk to dynamically evolve into central spheroidal structures. Overmassive disks develop an bar instability in their centers, which causes transfer of angular momentum from the central regions of the disk to the dark matter halo. This loss of angular momentum to the halo enables an increase in density in central disk mass and subsequent weakening or destruction of the bar instability. The central disk orbits become more isothermal and a spheroidal structure is formed. This bulge-like structure then acts as a stabilising influence on the disk instabilities and an equilibrium situation is reached. Subsequent disk–bulge decomposition reveals that the central disk surface density, or equivalently, surface brightness falls below the canonical Freeman limit – an observed upper limit on the central surface brightnesses of galaxies. This process also serves us with some insight into the conflict between theoretical cuspy dark matter halo densities and flat-cored isothermal halos consistent with observations. The central halo density in dark matter models with cuspy central density profiles is seen to decrease, reducing the central halo density gradient. This work has been carried out using collisionless N-body simulations utilizing the hybrid SCFTREE code (Vine & Sigurdsson, 1998, MNRAS, 295, 475). This code is in the process of being implemented on the CRAY T3E at the Ohio Supercomputing Center, allowing greater efficiency to search parameter spaces or a significant increase in particle number.

Statler continues a collaboration with D. Terndrup, B. Ryden, and R. Pogge [Ohio State U.] to study the stellar populations of dwarf ellipticals in the Virgo cluster using surface brightness fluctuations. Two runs on the MDM Hiltner 2.4m in 1998 and 1999 were hampered by poor seeing but yielded deep *V*-band images of a number of objects. Five nights in 2000 on the 2.4m are scheduled to continue this program.

A secondary program of multicolor photometry of globular cluster systems in ordinary ellipticals unexpectedly revealed a previously unknown shell system in NGC 2634 during the 1998 2.4m run. Statler and undergraduate student M. Krejny are collaborating with J. van Gorkom and C. Liu [Columbia U.], who have obtained additional images in photometric conditions, to further study this object. Krejny is leading the reduction of the optical data, and VLA D array time will be requested in 2000 to examine the neutral hydrogen distribution in NGC 2634 and its neighbor galaxies, which collectively make up the HG 90 group.

3.2 Galaxy Nuclei

Salow is continuing work on the double nucleus of M31, as part of his dissertation research under Statler's supervision. Salow is exploring the consequences of the eccentric disk model proposed by Tremaine (1995), in which the double nucleus arises from a statistical accumulation of stars near apoapsis in an eccentric stellar disk in dynamical equilibrium. To model the disk, Salow and Statler constructed a model based on work by Goldreich and Tremaine (1979) on the epsilon ring of Uranus; in that model the ring is represented by a set of nested Keplerian wires which precess due to the quadrupole moment of Uranus and the self gravity of the wires. The requirement that the set of wires precess at the same rate defines a system of nonlinear equations in the eccentricities of the wires, which can then be solved by standard techniques. In the case of M31, the model includes only the self-gravity of the wires which are nested around a black hole; the bulge-induced precession is ignored. The results suggest that it is not possible to reproduce the double nucleus of M31 with nested thin wires because the wires are not allowed to cross in the model. The possibility of wire-crossings seems to be necessary for an equilibrium configuration with an off-center density peak.

To investigate the M31 nucleus further, Salow has been working on a finite-dispersion eccentric disk model devised by Statler. This model involves the construction of an approximate phase-space distribution function (DF) in terms of the integrals of motion for Kepler orbits in a co-rotating frame (Statler 1999). This DF is built from a representation of the quasiperiodic orbits (whose parents are numerically integrated closed periodic orbits) as a continuum of nearby Kepler orbits. Approximate self-consistent equilibria are found by iteration: the density is found from the DF, the potential is then computed numerically from the density, closed periodic orbits are then found in the potential, a new density is found from the orbits, and the cycle repeated until convergence is achieved. Vine and Statler have been pursuing complementary N-body simulations of eccentric disks; simulations to study the stability of the self-consistent equilibrium models are also planned.

Shields, in collaboration with H.-W. Rix, [MPIA-Heidelberg], L. Ho [Carnegie Obs.], A. Filippenko [UC-Berkeley], W. Sargent [Caltech], G. Rudnick, and D. McIntosh [Steward Obs.], is studying the emission properties and small-scale kinematics of nearby, weakly active nuclei using HST and STIS. Initial results from this survey have revealed for the first time the presence of broad, double-shouldered emission components in the Balmer lines of two LINERs, NGC 4203 and NGC 4450. These features are reminiscent of the double-peaked emission lines found in broad-line radio galaxies, which can potentially be understood as the signature of a relativistic accretion disk. NGC 4203 additionally has extended gas with a well-behaved rotation curve that can be used to constrain a central mass concentration. The central rotation curve is too steep to be explained with the mass associated with stars, and is consistent with a black hole with a mass of $\sim 10^6 - 10^7$ $M_\odot$. This result and the LINER emission properties and spectral energy distribution can be consistently interpreted in terms of an advection-dominated accretion flow (ADAF), which is predicted for systems with substantially sub-Eddington accretion rates.

The infrared properties of LINERs have been the subject of study by A. Alonso-Herrero, G. Rieke, M. Rieke [Steward Obs.], and Shields. This study utilized *J*-band spectra from the MMT, which reveal that LINERs commonly exhibit [Fe II] 1.2567 μm emission. One scenario for interpreting this emission and other observed characteristics is in terms of a fading starburst in a metal-rich nuclear environment. In this picture, the [Fe II] emission results primarily from shock interactions driven by supernova remnants.

Shields has been working with F. Hamann [U. Florida] and H. Netzer [Wise Obs.] to study the properties of associated absorption in QSOs, using observations from HST. Spectra were obtained of the quasar 3C288.1 at wavelengths spanning 600 – 1600 Å in the source restframe. The data display a wealth of associated absorption lines, with ionization ranging from C III and N III to Ne VIII and Mg X. Analysis reveals that the absorber is described by multiple components in terms of ionization. There has been considerable interest in recent years in drawing a connection between associated UV absorption and X-ray ''warm'' (ionized) absorbers. In the case of 3C288.1, the absorbing medium is consistent with a warm absorber in terms of ionization state, but the column density is sufficiently small that it would not be expected to produce observable X-ray absorption. An abundance analysis of the UV absorber implies that its metallicity is approximately half-solar.

Shields and Hamann are also moving towards completion of a survey of the emission properties of QSOs at $z > 4$. A final observation run for this project was conducted at the Keck Observatory in June. Nitrogen emission-line diagnostics suggest that abundances in the nuclear regions of these sources are already enhanced to levels that may exceed solar metallicity, even at these early times, consistent with normal chemical enrichment driven by high mass stars. Results from this work also demonstrate the potential importance of selection effects in influencing measured emission properties, due to the $(1 + z)$ scaling of emission-line equivalent widths and their influence on broad-band magnitudes.

3.3 Nebular Astrophysics

Shields is collaborating with S. Oey [STScI], M. Dopita [MSSSO], and C. Smith [CTIO] in detailed modeling of H II regions in the Large Magellanic Cloud. An advantage in studying these nebulae is the fact that relatively complete inventories of high mass stars have been compiled, leading to the identification of the spectral types that dominate the ionizing radiation field. Spectra were acquired with the Siding Spring Observatory 2.3-m telescope, and include scanned observations that provide the integrated spectra of these sources, which are valuable for comparing local versus global measures of nebular diagnostics, and for comparison with measurements of unresolved giant H II regions at large distance. The observations and photoionization model predictions are generally in good accord, although the nebular temperatures tend to be *overestimated* by the models (opposite to the trend that would result from temperature fluctuations in the nebula). Nebular diagnostics of the stellar continuum were also examined. The η' parameter appears to have limited utility for constraining stellar temperature for stars hotter than 40,000 K; however, the [Ne III]/Hβ ratio holds some promise as a useful indicator of continuum hardness.

Sabra is continuing dissertation research on the physical properties and energetics of optical filaments associated with the central galaxies in cooling-flow clusters. His work focuses on NGC 1275 and M87, the central galaxies in the Perseus and Virgo clusters, respectively. The ionization source of the filaments is still debated. Optical spectra, acquired by Shields and A. Filippenko [UC-Berkeley] with the Lick Observatory 3-m telescope, show that the filaments of NGC 1275 are in a low ionization state. Shocks and stellar photoionization models have difficulty reproducing the line ratios. The hot intracluster medium (ICM) provides an additional source of energy and ionizing photons. If the nebular gas is photoionized, the forbidden-line spectrum is suggestive of a hard incident continuum , but the absence of He II λ4686 places a strong limit on the number of incident photons above 54 eV. Photoionization simulations were used to investigate the role of the X-rays from the ICM in powering the nebular filaments of NGC 1275. The observed line ratios can be reproduced if the radiation field from the ICM is filtered by an intervening screen of plasma in an intermediate ionization state. M87 filament spectra reveal that the filaments around that galaxy are in a higher ionization state that those of NGC 1275. An analysis program similar to that of the NGC 1275 work is in progress for the M87 nebular filaments.

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