The following report covers the period November 1999 through October 2000.

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 23 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 60 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. Brian McNamara arrived in August from the Harvard-Smithsonian Center for Astrophysics to join the department as an Associate Professor. Shields was promoted to Associate Professor with tenure. Postdoctoral Research Associate Stephen Vine departed in February to return to England.

During the past year Statler has supervised research by graduate students Jakob Bak, Heath Lambright, and Robert Salow, and undergraduates Megan Krejny and Daniel Wik. Lambright graduated with an M.S. degree. Bak completed his Ph.D. and has joined Pareto Partners in Los Angeles. Shields has supervised research by graduate students Anca Constantin and Bassem Sabra. Sabra completed his Ph.D. and has moved to a postdoctoral position at the University of Florida. Salow was awarded a stipend from the AAS Division of Dynamical Astronomy to present his research at their annual meeting in Wyoming 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 third year. As part of this program, Millie Gwilym [Nelsonville-York High School] spent the summer working with Statler, testing a small telescope and CCD to be used for student projects. Gwilym obtained a partial relative light curve for the asteroid 433 Eros, with internal errors ≈1%.

McNamara received new and continuing funding from NASA and STScI for projects related to X-ray emission in clusters, and the optical properties of giant central cluster galaxies. He has been heavily involved with the development of the Chandra X-ray Observatory, particularly with the calibration of its focal plane detectors. Shields received new and continuing funding from STScI and the Chandra X-ray Observatory 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.

3 RESEARCH
3.1 Normal Galaxies
Statler completed dynamical modeling to determine the intrinsic shape and orientation of NGC 3379, the “standard elliptical.” The galaxy is most probably axisymmetric and oblate in the inner parts, with an outward triaxiality gradient. This statistical result holds regardless of whether or not the angular momentum is aligned with the short axis. The short-to-long axis ratio of the luminosity distribution is approximately 0.8 inside 0.82 kpc, flattening to approximately 0.65 at 1.9 kpc. The flattening estimate is robust, but that for the triaxiality is dependent on whether the internal rotation field is assumed disklike or spheroid-like. Short-axis inclinations between 30° and 50° are preferred for nearly axisymmetric models; but triaxial models in high inclination are also allowed, which can affect central black hole mass estimates. The models rule out the possibility that the nuclear dust ring at $R=1.5$ is in a stable equilibrium in one of the galaxy’s principal planes. The ring is thus a decoupled nuclear component not linked to the main body of the galaxy. It may be connected with ionized gas that extends to larger radii, with both part of a strongly warped disk; however, if caused by differential precession, the warp will rapidly wind up on itself.

Statler, Lambright, and Bak performed a set of statistical tests to assess the robustness of intrinsic shape and orientation determinations for galaxies. Simulated merger remnants from Weil & Hernquist (1996) were “observed” using software developed by Bak, and then modeled exactly as real systems. The shapes of individual objects are found to be correctly reproduced to within the statistical errors, but with a small systematic bias in the sense of underestimating both the triaxiality and short-to-long axis ratio. Parent shape distributions estimated from samples of independent, randomly oriented objects are also statistically accurate, but on average slightly biased in the same sense. The magnitude of the bias is smaller than 0.1 in either shape parameter, supporting the continued use of these methods on real systems.

Chandra/ACIS observations of the young ellipticals NGC 1700 and NGC 5018 are scheduled for Cycle 2, in a program proposed by Statler and McNamara. These galaxies are part of a sample defining an age sequence at the same optical luminosity and in similar environments. The objectives are to obtain accurate X-ray surface brightness profiles, to derive radial profiles of gas density, temperature, and metallicity...
within the optical radii, and to search for substructure related to inhomogeneous gas flows, tidal debris, and interactions with neighboring systems.

Bak completed his dissertation research on 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 carried out 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, were created using penalized likelihood methods. The photometric aspects of the simulations were 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 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.

Statler is continuing a collaboration with D. Terndrup, B. Ryden, and R. Pogge [Ohio State] to study the stellar populations of dwarf ellipticals in the Virgo cluster using surface brightness fluctuations. Data have been obtained during three observing runs in 1998 – 2000 at the MDM Hiltner 2.4m telescope, and have been reduced by Krejny and Wik. The shell system in the normal elliptical NGC 2634 was discovered serendipitously during the 1998 2.4m run. Krejny has handled the reduction of these data and additional calibration snapshots obtained in photometric conditions by J. van Gorkom and C. Liu [Columbia U.]. Statler, van Gorkom, and Terndrup observed NGC 2634 and its neighbors (which collectively make up the HG 90 group) in H I using the VLA in D array in September 2000, and the data are currently being reduced.

3.2 Galaxy Nuclei

Following up on Statler's findings for NGC 3379 (§ 3.1), further work on the nucleus of this source is planned by K. Gebhardt [U. Texas] and Statler using HST/STIS to resolve the inner arcsecond of the stellar and gas kinematic fields. The observations will be carried out in Cycle 9. Statler is also PI on a Cycle 10 proposal (with R. Ciardullo [Penn State] and R. Mushotzky [NASA/GSFC]) to map the stellar kinematics in the central regions of NGC 1399 and NGC 4472 using STIS. The goal is to obtain two dimensional coverage of the mean velocity and dispersion. The 2-D coverage will allow (1) constraints on triaxiality, thought to be destroyed by central black holes; (2) determination of the rotation axis inside the black hole's radius of influence; and (3) independent constraints on velocity anisotropy. The data will allow black hole masses to be measured with ~30% accuracy.

Salow is continuing work on the double nucleus of M31, as part of his dissertation research under Statler’s supervision. Using a self-consistent iteration scheme with an approximate phase space distribution function (DF), he has constructed equilibrium models of self-gravitating eccentric disks with a finite velocity dispersion. Results show that these models have rotation, dispersion, and surface brightness profiles similar to those seen in M31, as revealed by HST. Furthermore, the models are found to possess characteristic line of sight velocity distribution (LOSVD) features for certain lines of sight. These LOSVD features should be observable, and can thus be used to determine if an eccentric disk of stars is truly present in the nucleus of M31. The soon-to-be-released STIS observations on M31 should have enough signal-to-noise to resolve these features.

Shields is continuing his collaboration with H.-W. Rix [MPIA-Heidelberg], L. Ho [OCIW], A. Filippenko [UC-Berkeley], M. Sarzi [Padova], W. Sargent [Caltech], G. Rudnick, and D. McIntosh [Steward Obs.] for the study of the emission properties and small-scale kinematics of nearby, weakly active nuclei using HST and STIS. Analysis has recently been completed of the gas kinematics for the centers of 24 galaxies. While the majority show spatially resolved nebular emission, only ~25% of the sample exhibits regular kinematics consistent with motions dominated by gravity. The data were acquired at a single position angle. A careful analysis for the sources with regular gas motions demonstrates that such measurements are generally only able to provide an upper limit to a black hole mass, unless additional information is available on the orientation of the central gas disk. A promising means of constraining the disk orientation is from the morphology of dust absorption in unsharp-masked images of the nucleus. Resulting estimates of black hole masses in four objects, and additional upper limits obtained from the velocity widths of spatially unresolved nuclear emission, support an extension to disk galaxies of the recently discovered correlation between black hole mass and stellar velocity dispersion, and also a revision downward of the typical black hole/bulge mass ratio to ~0.002.

Constantin and Shields, in collaboration with F. Hamann [Florida], are analyzing the emission properties of QSOs at z>4, using spectra obtained over multiple observing runs at the MMT and Keck Observatories. A part of this analysis includes a careful consideration of possible selection effects that may propagate into the emission-line properties in existing samples. A comparison of emission equivalent width distributions for color-selected and grim-selected samples indicates that the two are distinct at a statistically significant level. A bias resulting from the influence of the emission lines on broad-band magnitudes may be responsible for much of this difference.

As part of a team led by J. Bechtold [Arizona], Shields is studying the X-ray properties of QSOs at z>4 using Chandra. Seven objects were observed in Cycle 1, and an additional seven are scheduled for Cycle 2. Preliminary results indicate that these sources show UV/X-ray spectral energy distributions (SED) that are similar to QSOs at lower redshift. Efforts are underway to integrate these results into a broader study of the SEDs for the z>4 sources, including the relationship between continuum and emission-line behavior.

Shields is collaborating with M. Eracleous [Penn State]
3.3 Galaxy Clusters

McNamara is continuing his work on the near ultraviolet and optical properties of brightest clusters galaxies in cluster cooling flows. This work attempts to understand the relationships between star formation and the X-ray and radio properties of central cluster galaxies.

One focus of this effort has been Abell 1068, which was identified in the Rosat All Sky Survey as a luminous X-ray cluster at redshift \( z = 0.14 \) with a \( 400 \, M_\odot \, yr^{-1} \) cooling flow. The central galaxy in the Abell 1068 cluster is remarkable in several respects. McNamara found that the galaxy is experiencing a vigorous episode of star formation. Stars are forming at a rate of \( 80 \, M_\odot \, yr^{-1} \) concentrated in the nucleus, but extending in wisps and filaments over a 50 kpc region. Abell 1068’s central galaxy is a luminous infrared source that is centered in a rich cluster of galaxies. High resolution Chandra X-ray imaging was used to disentangle the cluster emission from nonthermal X-rays emitted from 3C295’s prominent radio hot spots. Optical emission from the hotspots was measured using archival HST images. The emission mechanism for the radio, optical, and X-ray emission is still somewhat uncertain; the data favor a synchrotron self-Compton emission model.

McNamara is continuing his work on the 160 Square Degree X-ray Cluster Survey in collaboration with the CfA group, headed by A. Vikhlinin, and the Hawaii group (P. Henry, I. Gioia, and C. Mullis). McNamara and colleagues have completed an optical imaging program designed to confirm the association of extended X-ray emission with distant galaxy concentrations. The results indicate that most clusters detected beyond \( z = 0.5 \) are Abell richness class 1 and 2. The distribution of richnesses is similar to that of nearby clusters identified using similar X-ray criteria. The comparison sample includes automated galaxy counts in nearby clusters by McNamara and SAO summer student K. Whitman [Cornell] using digitized Palomar Sky Survey plates. In addition, the survey team has nearly completed the follow-up redshift survey, and expects to measure the luminosity function in the near future.

McNamara is part of a team led by A. Hornstrup [SAO] that recently completed a study dealing with strong lensing in a \( z = 0.5 \) cluster, RXJ0030+2618, discovered in the 160 degree survey. Early Chandra observations of the cluster are
being combined with ultra-deep optical observations taken with the Nordic Optical Telescope to measure the mass profile of the cluster.

As part of his dissertation research, Sabra completed an analysis of the emission spectra of the optical filaments associated with NGC 1275 and M87, the central galaxies in the Perseus and Virgo cooling-flow clusters respectively. 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 λ 4686 places a strong limit on the number of incident photons above 54 eV. Photoionization simulations indicate that 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, although it remains unclear whether such a screen is consistent with other observational constraints. A variety of arguments suggest an important role for reconnection of the intracluster magnetic field in powering the filaments in NGC 1275 and other clusters. Analysis of spectra of the filaments in M87 show that these nebulae can potentially be described by a mixing-layers model wherein the ionizing continuum impinging on the filaments results from a turbulent boundary that forms at the interface of the cold gas and the hot ICM.

PUBLICATIONS


Joseph Shields