Ohio University

Astrophysical Institute and Department of Physics and Astronomy

Athens, Ohio 45701

The following report covers the period November 2003 through October 2004.

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. In 2004 the University celebrated its bicentennial. Ohio's Department of Physics & Astronomy has 28 faculty active in research in areas including nuclear physics, biophysics, condensed matter and surface physics, nanoscience, and astrophysics. The Department offers a Ph.D. in physics, with a current graduate enrollment of approximately 70 students. Additional information about the Department can be found at the WWW site `http://www.phy.ohiou.edu`. In September 2004 the Ohio University Board of Trustees approved the establishment of the Astrophysical Institute (ApI) to support the continued growth of research and education in astronomy and astrophysics at the university.

The ApI and the Institute for Nuclear and Particle Physics at Ohio University submitted a joint proposal to the University for the enhancement of research efforts at the intersection of astrophysics and nuclear/particle physics, under the title "The Structure of the Universe from Quarks to Superclusters." The proposal received the highest ranking in an internal University competition, and was approved for funding in October. This program will provide infrastructure enhancements to the University's observational capabilities and laboratory facilities, as well as support for new faculty positions and student research.

2 PERSONNEL

Astrophysics faculty include Markus Böttcher, Brian McNamara, Joseph Shields, Thomas Statler, Emeritus Professor James Dilley, and Instructors George Eberts and Tom O'Grady. Felix (Jay) Lockman of the National Radio Astronomy Observatory, Green Bank, is an Adjunct Professor. Affiliate members of the ApI involved in astrophysics-related research include Carl Brune and Daniel Phillips in the Department of Physics & Astronomy, and Douglas Green and Julie Libarkin in the Department of Geological Sciences. Mangala Sharma continued as a Postdoctoral Research Associate under McNamara's supervision, until her departure in September to join the Department of Astronomy and Astrophysics at the Pennsylvania State University as a Lecturer. Postdoctoral Research Associates in Brune's group are Alexander Voinov, who arrived from the Joint Institute of Nuclear Research in Dubna, Russia, and Michael Hornish. Shields completed a year-long sabbatical in August.

During the past year Böttcher supervised research by graduate students Justin Finke, Swati Gupta, Manasvita Joshi, and Sergey Postnikov, and undergraduate Jon Harvey; Brune supervised research by graduate students Aderemi Adekola, John Bevington, Zachary Heinen, and Catalin Matei, and undergraduate Chris Dodson; McNamara supervised research by graduate students Laura Birzan, David Rafferty, and Rocco Samuele, and undergraduates Jack Steiner and Stephanie Voyles; Shields supervised research by graduate students Anca Constantin, Yurii Pidopryhora, and Sarah Zelechoski; and Statler supervised research by graduate students Steven Diehl and Robert Salow and undergraduates Jess Wilhelm and Tomomi Watanabe. Samuele completed a masters thesis, and has moved to a position with Northrop Grumman Space Technology. Salow completed his Ph.D. in November and has taken a position on the staff of the Institute for Defense Analyses. Constantin completed her Ph.D. in August and has moved to a postdoctoral position at Drexel University. Steiner was named a Goldwater Scholar in the 2004 competition. Pidopryhora was awarded a National Radio Astronomy Observatory Predoctoral Research Fellowship.

Böttcher received new and continuing funding from NASA, including support for INTEGRAL and XMM GO observations. McNamara received new and continuing funding from NASA, the Spitzer Science Center, the Department of Energy, and the *Chandra X-ray Observatory* (*CXO*), including a NASA Long Term Space Astrophysics grant for projects related to X-ray emission in clusters and the optical and radio properties of giant central cluster galaxies. He served on the Telescope Allocation Committee for the National Optical Astronomy Observatory, the VLA/VLBA proposal review committee for the National Radio Astronomy Observatory, and a panel for the *Hubble Space Telescope* (*HST*) Cycle 13 Proposal Review. McNamara continued his service to the Constellation-X Facility Science Team Panel on ISM/IGM.

Shields received new and continuing funding from the Space Telescope Science Institute (STScI) and the *CXO* for studies of active galaxies. He continued his service as Scientific Editor for the *Astrophysical Journal*, and was a panel member for the *HST* Cycle 13 Proposal Review. Statler received new funding from the NSF, supporting work with the international SAURON collaboration on the structure and dynamics of elliptical galaxies. He was elected vice chair of the AAS Division on Dynamical Astronomy, with a term beginning in April 2004.

McNamara and Statler co-chaired the spring meeting of the Ohio Section of the American Physical Society, which had a theme of "Extragalactic Astrophysics and the New Era of X-ray Astronomy." The meeting was held on the Ohio University campus in May, with a total attendance of 200.

3 RESEARCH

3.1 Solar System

Undergraduate student T. Watanabe is beginning senior thesis work, supervised by Statler, on the rotational properties of small near-earth asteroids. The goal is to understand the rotational discontinuity at diameters near 150 meters. Nearly all asteroids larger than this have periods of 2 hours or longer. Since this period corresponds closely to the minimum for self-gravitating objects of typical asteroidal densities, the existence of the limit is widely interpreted as indicating that objects larger than 150 m are not rigid bodies but "rubble piles." In contrast, below 150 m there is a population ($\sim$ 40 known at present) of fast rotators, with periods ranging down to 70 s. These objects are interpreted as monolithic, rigid bodies under centrifugal tension. However, the nature of the transition between the monoliths and the rubble piles is not well understood because of the small number of objects known. The existence of one large rapid rotator (2001 OE_{84}) suggests that there may be at least some large monoliths. Photometric observations on the MDM 2.4 meter telescope are being proposed to target Earth-approaching objects in the few-hundred-meter diameter range (absolute magnitude $H \approx 21.5$) and determine their rotation periods.

3.2 X-Ray Binaries and Ultraluminous X-Ray Sources

Using a coupled Monte-Carlo/Fokker-Planck code for time-dependent radiation transfer and electron dynamics in two spatial dimensions, Böttcher and Finke have done model simulations of the millisecond flaring activity of Cyg X-1. In the source's high/soft state, this flaring activity could be successfully reproduced by a powerful energy release (e.g., through magnetic reconnection) localized in a tenuous, hot corona atop a cool, optically thick accretion disk. Corresponding simulations for the low/hard state of Cyg X-1 are currently underway.

Böttcher and Gupta are currently investigating time-dependent spectral and variability signatures of mildly relativistic jet outflows from X-ray binaries, using a quasi-analytical approach to solve the electron spectrum evolution. First results of this study, focusing on X-ray spectral variability patterns, indicate that X-ray hardness-intensity correlations may be used as a diagnostic of various variability scenarios for microquasar jets.

I. A. Smith [Rice U.] and Böttcher are leading a collaboration to monitor the ultraluminous X-ray sources (ULXs) X-1 and X-2 in the nearby spiral galaxy NGC 1313. A series of 11 pointings by the *XMM-Newton* X-ray observatory has already been carried out in 2003 and 2004, co-ordinated with ground-based radio (ATNF; PI: S. Ryder) and optical (VLT; PI: M. Pakull) observations. These observations are intended to extract X-ray spectra from the individual X-ray sources in NGC 1313, identify their optical and radio counterparts, and to monitor their variability on time scales from weeks to months. First results of the XMM observations confirm the ULX nature and strong variability of X-1 and X-2. Both ULXs are embedded in ionized nebulae, suggesting largely isotropic X-ray emission. The optical counterpart of ULX X-2 has been identified as a faint (23.2 mag.) blue star. No radio source could be identified as the counterpart of X-1 or X-2. The X-ray spectra of both ULXs are consistent with a pure power-law.

3.3 The Milky Way

For his dissertation, Pidopryhora is working with Lockman to study H I clouds in the halo of the Milky Way. Such clouds have motions consistent with Galactic rotation and do not seem to be related to the classic high-velocity clouds. The current investigation makes use of extensive and ongoing observations with the Green Bank Telescope (156 hours) and Very Large Array (64 hours). The project involves a statistical study of clouds in the inner Milky Way, with high-resolution investigation of selected objects. A preliminary analysis indicates that the halo clouds contain much of the H I away from the Galactic plane, with a span of distances ranging from more than 2 kpc from the disk, down to locations where the clouds are blending with the disk gas. A typical cloud has a mass of order 10-100 $M_\odot$ and a size of order 10-100 pc. The spectra of many halo clouds consist of at least two components, one broad and one narrow, indicating that the neutral hydrogen is described by two phases with different temperatures. The first results of a high resolution study suggest that a cloud's mass is equally distributed between its dense compact core and thinner and broader envelope.

Additional scrutiny is being given to a unique coherent structure near Galactic longitude 35° rising higher than 2 kpc above the Galactic plane, dubbed "the Whisker". This object contains $> 10^5$ $M_\odot$ of H I; morphologically its lower regions resemble a "turbulent network," while by about 1 kpc it breaks into clusters of clouds. Clouds from the uppermost part of the Whisker (above 2 kpc) differ from typical halo clouds by not having a narrow spectral component, which may indicate that only warm gas survives at such heights.

Some of the clouds have coincident background continuum sources, which would enable absorption measurements that could reveal the clouds' spin temperature and allow estimation of their pressure. The peak column densities for some clouds are sufficient that molecular gas may be present, a possibility that can be tested with observations in the 18 cm OH line.

3.4 Normal Galaxies

Statler is collaborating with the SAURON team (T. de Zeeuw [Leiden], R. Davies [Oxford], R. Bacon [Lyon], et al.) to model the elliptical galaxies observed using the SAURON integral field spectrograph. The objective is to use the 2-dimensional kinematic maps together with Statler's dynamical modeling approach both to constrain the intrinsic shapes and viewing geometries of the individual objects, as a prelude to more careful modeling by Schwarzschild's Method, and to obtain the intrinsic shape distribution of elliptical galaxies. Results for the "standard elliptical" NGC 3379 are consistent with the previous results obtained from long-slit kinematic data. NGC 4365, a galaxy with skew rotation and a kinematically decoupled core, is found to be highly triaxial and somewhat flatter than it appears. The old age of the stellar population implies that this shape has persisted for many hundreds of dynamical times. This rules out black holes $> 3 \times 10^9$ $M_\odot$, which numerical simulations indicate would either have globally axisymmetrized the galaxy or rendered the inner several arcseconds spherical. It is also possible to constrain the rate of figure rotation (tumbling) about the short axis. The required populations of long-axis tube orbits, combined with the small isophotal twist, places corotation at > 8 effective radii. Work is continuing to model the remaining SAURON ellipticals and to determine the elliptical galaxy shape distribution.

A major systematic uncertainty in modeling elliptical galaxy shapes is the present inability to constrain their internal orbital structure on theoretical grounds. However, a huge archive of N-body merger simulations exists, few of which have ever been carefully analyzed in terms of their internal kinematics. Statler is developing tools to mine this archive and produce a more broad-based, and dynamically oriented, analysis of merger simulations than has been previously attempted, in collaboration with E. Athanassoula [Marseille].

Statler is collaborating with L. Young [New Mexico Tech] to study the stellar and gas kinematics of CO-rich ellipticals and investigate the dynamical connection between the stars, ionized gas, and molecular gas. Multi-position-angle long-slit spectroscopy in V band of the well-behaved galaxy NGC 807 and the young merger remnant NGC 3656 was obtained at the MMT in 2003 January, in clear but not photometric conditions. Data reduction is progressing.

Diehl and Statler are continuing their study of the X-ray emitting interstellar gas in early type galaxies, with a reanalysis of archival Chandra ACIS data on ~ 70 objects. It is well known that stellar sources contribute a significant fraction of the X-ray emission from normal galaxies, and it is necessary to remove resolved point sources. In addition, a new technique has been developed to remove the contribution of unresolved point sources to the diffuse emission. This is done by dividing the data into appropriate hard and soft energy bands, correcting for exposure maps and background, and modeling the unresolved point-source emission by a scaled version of the hard band image. The scale factor is derived by extrapolating the hardness ratio of resolved point sources to low luminosities. Subtracting this model from the soft band reveals the morphology of the hot gas alone. Fits to the gas surface brightness profiles and spectra will provide a means to build a Fundamental Plane relation for elliptical galaxies purely in the X-ray regime. Comparison of the optical and X-ray gas isophotes will uncover the importance of rotational support and/or AGN-related processes for the hot gas. This could have major consequences for dark halo mass estimates, which are mostly based on the common assumption of hydrostatic equilibrium.

The properties of the resolved point sources can also be studied for the entire sample. The point-source luminosity function is analyzed by a new iterative Bayesian technique that takes incompleteness effects into account. A previously reported "knee" at the Eddington luminosity of a 1.4 $M_\odot$ neutron star (e.g. see Sarazin, Irwin & Bregman 2000) is not seen. This break in the luminosity function was mainly caused by selection effects at the low-luminosity end.

Diehl and Statler have also developed a new adaptive binning technique, specifically to study the diffuse X-ray morphology, but applicable to non-X-ray data as well. This method is based on the algorithm of Cappellari & Copin (2003); but unlike that algorithm, the new technique can be used on sparse data and in cases in which the errors are not purely Poissonian. The new approach introduces a generalization of the centroidal Voronoi tesselation, and minimizes the scatter in the signal-to-noise ratio per bin.

Diehl and Statler are collaborating with C. Fryer [LANL] and M. Ruszkowski [Colorado] on hydrodynamical simulations of the formation of giant cooling disks in mergers of early type galaxies. Preliminary 2-D simulations, in which a spherical blob of gas is dumped into a static potential on an eccentric orbit, show that it is possible to create large, slowly cooling, rotationally supported disks of approximately the observed density and temperature. More sophisticated simulations in 3 dimensions are planned for the near future, using both smooth-particle hydrodynamics and adaptive-mesh codes.

3.5 Active Galactic Nuclei

Böttcher continued his work on co-ordinated multiwavelength observations and theoretical modeling of broadband spectra and spectral variability of blazars (= gamma-ray loud quasars and BL Lac objects). Detailed modeling has been carried out using intensive multiwavelength observations of BL Lacertae in 2000, in collaboration with A. Reimer [Bochum]. The results included remarkable spectral variability in both the optical and the X-ray regime. At optical and hard X-ray frequencies, a general trend of spectral hardening during flares was uncovered, while the soft X-ray variability appears to be associated with spectral softening during flares. Both aspects of the spectral variability, along with satisfactory multiwavelength spectral fits, were provided by a time-dependent leptonic model, in which the flaring activity of the source is dominated by a hardening of the spectra of ultrarelativistic electrons in the relativistic plasma jet emanating from BL Lacertae. These leptonic model fits have also been compared to fits with hadronic jet models, which predict a substantial flux of the source at > 100 GeV γ-rays, in contrast to the leptonic models.

A large international collaboration, led by M. Böttcher, has done another intensive co-ordinated multiwavelength monitoring campaign on the BL Lac object 3C 66A, which ended in March 2004. It involved radio monitoring by the University of Michigan and the Metsähovi (Finland) radio observatories, 9 epochs of VLBA observations, optical observations by the Whole Earth Blazar Telescope (WEBT) collaboration (Böttcher is the WEBT campaign manager of this project), 20 monitoring observations by the Rossi X-ray Timing Explorer (RXTE), and ground-based Very-High-Energy (VHE) γ-ray observations by the STACEE and Whipple Atmospheric Cherenkov Telescope facilities. With the assistance of Joshi and Harvey, all data have now been collected and analyzed. The source exhibited significant optical variability on time scales ranging from a few hours to ~ 2 weeks on top of a gradual overall brightening throughout Sept. 2003 – Feb. 2004. Due to the relatively low flux, no significant X-ray variability could be detected. VHE γ-ray observations by STACEE indicated a not significant $\sim 2.5\,\sigma$ excess at photon energies > 50 GeV, while the Whipple > 350 GeV measurements yielded further upper limits. The broadband spectrum of the source indicates a synchrotron spectrum extending into the soft X-ray regime. On short time scales, the optical spectra occasionally showed a spectral softening associated with flaring activity, in striking contrast to the usually opposite trend observed in most other similar objects.

Böttcher has suggested a hadronic synchrotron mirror model for the "orphan" TeV flare of the BL Lac object 1ES 1959+650 (Krawczynski et al. 2004). In this model, the isolated TeV flare (without simultaneous X-ray counterpart) is reproduced via photopion production interactions between relativistic protons ($\gamma_p \approx 10^3 - 10^4$) and external photons from reflected jet synchrotron radiation. Analytical estimates indicate that such a model can explain the "orphan" TeV flare with a reasonable proton number density in a jet which might be dynamically dominated by the kinetic energy carried in their baryon content, though the broadband emission is usually dominated by ultrarelativistic leptons. The details of this model are currently under investigation by Postnikov and Böttcher.

Shields continued his collaboration with H.-W. Rix [MPIA-Heidelberg], L. Ho [OCIW], A. Filippenko [UC-Berkeley], M. Sarzi [Oxford U.], G. Rudnick [MPA-Garching], D. McIntosh [U. Mass.], A. Barth [UC-Irvine], and W. Sargent [Caltech], in studying the spectroscopic properties of nearby, weakly active nuclei as measured through small apertures (median radius ~ 8 pc) with *HST* and STIS. An analysis of the nuclear emission properties has been completed. The results show that sources with stronger AGN signatures exhibit greater concentration of nebular emission; for H II nuclei the nebulosity is often actually circumnuclear on these scales. Nuclei of all spectroscopic classes show significant increases in electron density on small scales, as traced by the [S II] doublet ratio. Gradients in emission line ratios are otherwise modest. Comparison of the results of the *HST* survey with measurements on similar spatial scales for our own Galactic Center demonstrates that the Milky Way has a very typical nucleus, in terms of nebular emission, stellar populations, and other properties.

Constantin, Shields, Ho, Barth, and Filippenko are expanding on this work through analysis of archival *HST* spectra for a large sample of nearby weak emission-line nuclei, with the goal of determining their dominant energy sources. The study employs a quantitative comparison of the nebular line flux ratios in small (*HST*) and large (ground-based) apertures. Although the nuclear emission is resolved by the *HST* data and the contrast with the surrounding starlight is significantly enhanced, only less than 10% of the narrow-lined objects reveal broad Balmer Hα features, changing thus their spectral classification from type 2 to type 1. It is found that in most cases, the nebular line flux ratio measured within the central tens of pc is not much different from that averaged over an order of magnitude larger sizes, containing at least ten times as much emission. This suggests that many nearby emission-line nuclei are not necessarily powered by accretion onto a compact central object, and that the composite model suggested for the LINER/H II transition nuclei (that assumes a geometry in which a central accreting-type nucleus is surrounded by star-forming regions) is not generally supported.

As part of her dissertation research, Constantin also conducted an investigation of potential relationships between reddening, luminosity and the continuum shape in AGNs. This project involves simple Monte Carlo simulations of dust reddening of active nuclei, in a scheme in which the inner radius of the absorbing material scales with the intrinsic luminosity of the central source (a variant of the "receding torus" picture), consistent with expectations that grains will evaporate above a certain radiation density. The results show qualitative agreement with the observed luminosity-continuum slope correlation. Moreover, the resulting numbers of absorbed sources predicted in this framework appear consistent with recent modeling/observations of the X-ray background light and extragalactic point source population.

Shields is collaborating E. Moran [Wesleyan U.] and Penn State researchers H. Flohic, M. Eracleous, and G. Chartas in a study of the X-ray properties of LINERs as revealed by archival Chandra data. The results confirm previous indications that circumnuclear point sources and diffuse emission are often significant contributors to the total X-ray luminosity of the central ~ 200 pc of such objects. Efforts are underway to understand what if any effect the extended X-ray sources have on the nebular emission in these objects.

3.6 Galaxy Clusters

McNamara and colleagues were awarded several *Chandra* Cycle 6 programs to investigate galaxy clusters with bright, X-ray cores ("cooling flows") and cavity systems. The programs address the cycle of cooling, accretion-driven star formation, and reheating of the intracluster gas by radio jets, supernova explosions, and thermal conduction. High resolution *Chandra* images of clusters have revealed complex structures created by interactions between powerful radio sources and the gaseous medium surrounding them. McNamara and colleagues have shown that giant, galaxy-sized cavities or bubbles in the X-ray emission are created during these interactions.

McNamara, P. Nulsen [CfA], M. Wise [MIT] and other collaborators discovered three clusters with powerful shock systems and giant cavity systems. A *Chandra* image of the distant $z = 0.22$ cluster MS0745.6+7421 shows a pair of enormous cavities, each 200 kpc in diameter. The cavities are surrounded by powerful, $\sim 6 \times 10^{61}$ erg shocks, making it the most powerful AGN outburst known in a galaxy cluster. This is enough energy to quench a large cooling flow for several Gyr and to heat the cluster by 2/3 keV per particle, a substantial fraction of the $1 - 3$ keV per particle required to "preheat" the cluster. The blast was fueled by the accretion in only 10^8 yr of $\sim 3 \times 10^8$ $M_\odot$ of gas, corresponding to a substantial fraction of the mass of the host supermassive black hole. McNamara, Nulsen, and colleagues have detected a similarly large shock front with a power approaching 10^{61} erg in the Hydra A cluster. Again, this is enough power to quench the cooling flow and to heat the cluster on large scales. An analysis of the Hercules A cluster, which is similarly powerful, is underway.

Birzan, Rafferty, McNamara, Wise, and Nulsen are investigating the systematic properties of cavities in a large sample of clusters taken from the *Chandra* archive. They found a trend showing that the average cavity power scales in proportion to the luminosity of the cooling gas and central radio power. The energy in the cavities (heating) can balance radiation losses (cooling) in roughly half of the 18 systems with prominent cavities. Birzan, Carilli [NRAO], and McNamara are leading a collaboration to use the VLA to study the radio properties of cavity systems in greater detail.

Rafferty is continuing his thesis work with McNamara attempting to understand feedback and star formation in galaxy cluster cooling cores. The hot, X-ray emitting gas in the core is expected to cool and form stars at rates of hundreds of solar masses per year. However, new X-ray and optical observations show evidence for only a fraction of this cooling gas. Intermittent heating by the active galactic nucleus (AGN) may account for this discrepancy. The trend between the heating and cooling luminosities mentioned above suggests the existence of a feed-back loop governed by the AGN. Star formation should trace the bulk of the gas cooling to low temperatures. Star formation rates for several cooling-core systems with sensitive measurements lie within a factor of a few of the cooling rates. Rafferty is studying the optical and X-ray properties of a large number of both cooling and non-cooling cores to test simple feedback models.

McNamara, Steiner, former undergraduate student R. Ryan [Arizona State U.], and Sharma are conducting a multiwavelength study of the Abell 1835 cluster. The collaboration is testing the new cooling flow feedback paradigm using an excellent optical/UV and X-ray data set. The star formation rate, which exceeds 100 $M_\odot$ yr^{-1}, agrees with the upper limit on residual cooling found with XMM's reflection grating spectrum and a *Chandra* image of the cluster. The star burst is located where the cooling time of the gas is shortest (10^8 yr) and where rapid cooling is expected to occur.

McNamara continued his long-term collaboration on the "160 Square Degree Rosat Cluster Survey" with a team including A. Vikhlinin [CfA] and C. Mullis [ESO]. Samuele and McNamara are leading a search for [O II]λ3727 and Hα emission from 77 brightest cluster galaxies in the 160 degree survey. Nebular emission is a sensitive tracer of accretion onto the galaxies and their supermassive black holes. The clusters lie at redshifts $z = 0.07 - 0.7$, and their X-ray Luminosities range between $L_X = 0.04 - 4.27 \times 10^{44}\,\mathrm{erg\,s^{-1}}\,[0.5 - 2\,\mathrm{keV}]$. Surprisingly, they found no [O II]λ3727 or Hα emission stronger than -15 Å or -5 Å respectively in any galaxy. The team is considering several interpretations of this dearth of emission line galaxies. McNamara and Voyles are examining the radio properties of the 160 Square Degree sources using First and NVSS data. McNamara and a team led by M. Donahue [Michigan State U.] have been allocated *HST* time to obtain images of the distant clusters from the Survey. The goals of the program, which is just getting underway, are to study galaxy evolution and cluster masses through weak lensing.

McNamara and Shields are collaborating with a team from the National Optical Astronomy Observatory, the Harvard Smithsonian Astrophysical Observatory, and Ohio State University on a large area *Chandra* X-ray survey of the NOAO Böotes Deep Wide Field. *Chandra* observations were carried out with a uniform exposure of 5 ksec. Identification of X-ray sources within the field is complete, and identifications of optical counterparts are being finalized. The team is now embarking on an optical spectroscopy program of the X-ray sources in the field. Large-scale stacking analyses to investigate the average X-ray properties of different classes of optical galaxies are also in progress.

Sharma, McNamara, and other collaborators completed their *Chandra* analysis of the cluster Abell 1991. Cool, dense lumps of X-ray emitting gas were found within the halo of the cD galaxy that appear to be unrelated to the central radio source. A possible interpretation is that the lumps of gas are the cool cores of disrupted galaxies or galaxy groups falling into the cluster center for the first time. Sharma, Statler, and R.

Ciardullo [Penn State] are investigating this scenario. A possible problem is that there are no photometric signatures of the starlight that would be associated with these putative galaxies. Seen against the background of the central cD, it is conceivable that this light could be lost in projection. The team is proposing long-slit spectroscopy with the Hobby-Eberly Telescope to test for the presence of starlight from disrupted galaxies in velocity space.

3.7 Nuclear Astrophysics

Brune is pursuing a better understanding of the $^{12}C(\alpha,\gamma)^{16}O$ reaction at low energies. The rate of this reaction determines the $^{12}C/^{16}O$ ratio produced by helium burning in stars, and consequently has very significant effects on the subsequent structure and nucleosynthesis, as well as the final outcome of the evolution. Calculation of the reaction rate in helium-burning conditions requires the cross section be known for energies of $\sim$ 300 keV; unfortunately, at this energy the cross section is too small to be measured with presently available accelerator technology. Work on this project is proceeding on several fronts. Using the 4.5-MV tandem accelerator located at Ohio University's Edwards Accelerator Laboratory, Brune and Matei have measured the γ-ray branching ratios for states in ^{16}O which impact the reaction cross section. A collaboration is also underway with scientists at Argonne National Laboratory to make improved measurements of the ^{16}N β-delayed α particle spectrum which helps to constrain the cross section. A further collaboration with scientists at TRIUMF (Canada's national laboratory for nuclear and particle physics located in Vancouver, BC) will make improved direct measurements of the $^{12}C(\alpha,\gamma)^{16}O$.

Voinov recently completed a study of γ-ray emission by hot iron nuclei. This work found an unexpected enhancement in the low-energy γ-ray strength function (the strength function describes the probability for transitions to various final states). These results are likely to have important implications in many fields of nuclear physics, including the neutron capture reactions which take place in the rapid neutron capture process. Further studies of this new phenomena are planned for the future.

Brune and Hornish are collaborating with scientists at Oak Ridge National Laboratory (ORNL) to utilize radioactive beams to study reactions relevant to nucleosynthesis in stellar explosions. Measurements have been completed of the neutron-transfer reaction $^{18}F(d,p)^{19}F$; this cross section helps to constrain the rate of the proton capture reaction $^{18}F(p,\alpha)^{15}O$ by determining properties of levels in ^{19}F, which is the mirror nucleus of ^{19}Ne. Measurements are planned of the proton transfer reaction $^{18}F(d,n)^{19}Ne$ which will provide more direct information about the reaction of interest. Brune and colleagues are also studying the $^{17}O(^{3}He,n)^{19}Ne$ reaction to better determine the properties of the excited states of ^{19}Ne. The proton-induced reactions on ^{18}F are critical for estimating the production by novae of ^{18}F, an isotope whose β^+ decay may produce an observable flux of γ-rays with energies up to 511 keV. These reactions also have important effects on the yields of heavier nuclei produced in novae and X-ray bursts. Brune's group is also initiating a new program to study the nuclear structure of nuclei far from stability. Experiments are being planned to measure the nuclear level densities in proton-rich isotopes at ORNL. This nuclear structure information is critical for proton- and neutron-capture reactions on unstable nuclei.

PUBLICATIONS

Birzan, L., **Rafferty, D. A.**, **McNamara, B. R.**, Carilli, C. L., Wise, M. W., & Nulsen, P. E. J., "Interactions between Radio Sources and the Intracluster Medium," BAAS, 36, 905, 2004.

Birzan, L., **Rafferty, D. A.**, **McNamara, B. R.**, Wise, M. W., & Nulsen, P. E. J., "A Systematic Study of Radio-induced X-Ray Cavities in Clusters, Groups, and Galaxies," ApJ, 607, 800–809, 2004.

Blanton, E. L., Sarazin, C. L., **McNamara, B. R.**, & Clarke, T. E., "Chandra Observation of the Cooling Flow in Abell 262," BAAS, 35, 1282, 2003.

Blanton, E. L., Sarazin, C. L., **McNamara, B. R.**, & Clarke, T.E., "Chandra Observation of the Central Region of the Cooling Flow Cluster A262: A Radio Source that is a Shadow of Its Former Self?" ApJ, 612, 817–824, 2004.

Böker, T., et al. (11 authors including **J. C. Shields**), "The Nuclei of Late-Type Spiral Galaxies," in *The Formation and Evolution of Massive Young Star Clusters*, ed. H. J. G. L. M. Lamers, A. Nota, & L. J. Smith (San Francisco: ASP), in press, 2004.

Böker, T., Sarzi, M., McLaughlin, D. E., van der Marel, R. P., Rix, H.-W., Ho, L. C., & **Shields, J. C.**, "An HST Census of Nuclear Star Clusters in Late-Type Spiral Galaxies: I. Cluster Sizes and Structural Parameter Correlations," AJ, 127, 105–118, 2004.

Böttcher, M., "Coordinated Multiwavelength Observations and Spectral Variability Modeling of Gamma-ray Blazars," in *The Integral Universe*, Proceedings of the 5th INTEGRAL Workshop, in press, 2004.

Böttcher, M., "Modeling the Broadband Spectra and Variability of Blazars, NewAR, 48, 339–401, 2004.

Böttcher, M., et al., "Multiwavelength Observations of 3C66A in 2003," BAAS, 36, 909, 2004.

Böttcher, M., & **Postnikov, S.**, "Hadronic Synchrotron Mirror Model for Orphan TeV Flares in Blazars," BAAS, in press, 2004.

Böttcher, M., & Reimer, A., "Modeling the multiwavelength spectra and variability of BL Lacertae in 2000," ApJ, 609, 576–588, 2004.

Braizinha, B., et al. (9 authors including **C. R. Brune**), "Resonant and Direct Components in the $^{3}He(d,p)^{4}He$

Reaction at Low Energies," Phys.Rev.C, 69, 024608, 5 pp., 2004.

Brand, K., et al. (18 authors including **B. R. McNamara** & **J. C. Shields**), "Tracing the Accretion History of the Universe using X-rays from the Red Galaxy Population in the Bootes Field," BAAS, 36, 747, 2004.

Brune, C. R., "Nuclear Astrophysics," in *Fundamental Interactions*, Proceedings of the Nineteenth Lake Louise Winter Institute (Singapore: World Scientific), in press, 2004.

Brune, C. R., "Astrophysical Applications of Few-Nucleon Physics," Nucl. Phys. A, 737, 102–109, 2004.

Constantin, A., & **Shields, J. C.**, "The Role of Dust in Modifying Quasar SEDs," BAAS, 35, 1327, 2003.

Constantin, A., & **Shields, J. C.**, "Emission and Absorption in Narrow-Line Seyfert 1 Galaxies," in *AGN Physics with the Sloan Digital Sky Survey*, ed. G. T. Richards & P. B. Hall (San Francisco: ASP), 269–272, 2004.

Crenshaw, D. M., Kraemer, S. B., Gabel, J. R., Schmitt, H. R., Filippenko, A. V., Ho, L. C., **Shields, J. C.**, & Turner, T. J., "High Resolution UV Spectra of the Dwarf Seyfert 1 Galaxy NGC 4395: Evidence for Intrinsic Absorption," ApJ, 612, 152–158, 2004.

Finke, J., & **Böttcher, M.**, "Modeling of a High/Soft State Flare in Cyg X-1," BAAS, 36, 940, 2004.

Flohic, H., Eracleous, M., Chartas, G., Moran, E., & **Shields, J.**, "The Central Engines of LINERs as Viewed by Chandra," BAAS, in press, 2004.

Gupta, S., & **Böttcher, M.**, "Time Dependent Radiation Signatures from Microquasar Jets," BAAS, 36, 939, 2004.

Kenter, A. T., et al. (12 authors including **B. R. McNamara** & **J. C. Shields**), "Chandra Observations of the Bootes 9 Square Degree Field," BAAS, 35, 1351, 2003.

Kenter, A. T., et al. (18 authors including **B. R. McNamara** & **J. C. Shields**), "Chandra Results from the Boötes 9 Square Degree Field," BAAS, 36, 730, 2004.

Lockman, F. J., & **Pidopryhora, Y.**, "Extra-planar H I in the Inner Milky Way," in *Extra-planar Gas*, ed. R. Braun (San Francisco: ASP), in press, 2004.

Matei, C., & **Brune, C. R.**, "Branching Ratio Measurements of the 7.12-MeV State in ^{16}O," Nucl. Phys. A, in press, 2004.

McNamara, B.R., "Magnetic Bubbles in Galaxy Clusters," in Carnegie Observatories Astrophysics Series, Vol. 3: *Clusters of Galaxies: Probes of Cosmological Structure and Galaxy Evolution* ed. J. S. Mulchaey, A. Dressler, & A. Oemler (on-line), 4 pp., 2004.

McNamara, B. R., "Star Formation in Cluster Cooling Flows," in *The Riddle of Cooling Flows in Galaxies and Clusters of Galaxies*, ed. T. H. Reiprich, J. C. Kempner, & N. Soker (on-line), 4 pp., 2004.

McNamara, B. R., Nulsen, P. E. J., Wise, M. W., **Birzan, L.**, & **Rafferty, D.**, "Bubbles and Supercavities in Clusters of Galaxies," BAAS, 36, 902.

McNamara, B. R., Wise, M. W., & Murray, S. S., "The Insignificance of Global Reheating in the A1068 Cluster: Multiwavelength Analysis," ApJ, 601, 173–183, 2004.

Mullis, C. R., **McNamara, B. R.**, Quintana, H., Vikhlinin, A., Henry, J. P., Gioia, I. M., Hornstrup, A., Forman, W., & Jones, C., "The 160 Square Degree *ROSAT* Survey Revised Catalog and Cluster Evolution," in Carnegie Observatories Astrophysics Series, Vol. 3: *Clusters of Galaxies: Probes of Cosmological Structure and Galaxy Evolution* ed. J. S. Mulchaey, A. Dressler, & A. Oemler (on-line), 4 pp., 2004.

Mullis, C. R., Vikhlinin, A., Henry, J. P., Forman, W., Gioia, I. M., Hornstrup, A., Jones, C., **McNamara, B. R.**, & Quintana, H., "Evolution of the Cluster X-Ray Luminosity Function," ApJ, 607, 175–189, 2004.

Murray, S. S., et al. (17 authors including **B. R. McNamara** & **J. C. Shields**), "X-ray Boötes 3 Dimensional Survey (XB3dS)," BAAS, 35, 1307, 2003.

Murray, S. S., et al. (17 authors including **B. R. McNamara** & **J. C. Shields**), "Initial Results from the Chandra Shallow X-ray Survey in the NDWFS in Bootes," BAAS, 36, 745.

Netzer, H., et al. (15 authors including **J. C. Shields**), "The Ionized Gas and Nuclear Environment in NGC 3783. IV. Modeling the 900 kilosecond Chandra Spectrum," ApJ, 599, 933–948, 2003.

Nulsen, P. E. J., **McNamara, B. R.**, Wise, M. W., & David, L. P., "Cluster Scale AGN Shock Outbursts in Hydra A and MS0735.6+7421," BAAS, 36, 903, 2004.

Pidopryhora, Y., & Lockman, F. J., "The Structure of Clouds in the Galactic Halo," BAAS, 36, 811, 2004.

Rafferty, D. A., **Birzan, L.**, **McNamara, B. R.**, Wise, M. W., & Nulsen, P. E. J., "Feedback and Star Formation in Cluster Cores," BAAS, 36, 905, 2004.

Raiteri, C. M., Villata, M., **Böttcher, M.**, & the WEBT Collaboration, "The Ongoing WEBT/ENIGMA Campaigns on AO 0235+16 and 3C66A," in *Proceedings of the Second ENIGMA Meeting*, ed. C. M. Raiteri & M. Villata (Pino Torinese: Osservatorio Astronomico di Torino), 239–244, 2004.

Salow, R. M., & **Statler, T. S.**, "Self-Gravitating Eccentric Disk Models for the Double Nucleus of M31," ApJ, 611, 245–269, 2004.

Sarzi, M., Rix, H.-W., **Shields, J. C.**, Ho, L. C., Barth, A. J., Rudnick, G., Filippenko, A. V., McIntosh, D. H., & Sargent, W. L. W., "The Stellar Populations in the Central Parsecs of Bulges," ApJ, in press, 2005.

Sarzi, M., Rix, H.-W., **Shields, J. C.**, Ho, L. C., Barth, A. J., Rudnick, G., Filippenko, A. V., & Sargent, W. L. W., "The Stellar Populations in the Central Parsecs of Bulges," in *The Interplay among Black Holes, Stars, and ISM in Galactic Nuclei*, ed. T. Storchi Bergmann, L. C. Ho, & H. R. Schmitt (San Francisco: ASP), in press, 2004.

Sharma, M., **McNamara, B. R.**, Nulsen, P. E. J., Owers, M., Wise, M. W. , Blanton, E. L., Sarazin, C. L., Owen, F. N., & David, L. P., "A Chandra X-Ray Observation of A1991: The Late Stages of Infall?" ApJ, 613, 180–188, 2004.

Shields, J. C., & the SUNNS Collaboration, "Nebular Excitation of Low-Luminosity Emission Nuclei," in *The Interplay among Black Holes, Stars, and ISM in Galactic Nuclei*, ed. T. Storchi Bergmann, L. C. Ho, & H. R. Schmitt (San Francisco: ASP), in press, 2004.

Shields, J. C., & **Constantin, A.**, "Quasars and Narrow-Line Seyfert 1s: Trends and Selection Effects," in *AGN Physics with the Sloan Digital Sky Survey*, ed. G. T. Richards & P. B. Hall (San Francisco: ASP), 265–268, 2004.

Shields, J. C., Rix, H.-W., Barth, A. J., Filippenko, A. V., Ho, L. C., McIntosh, D. H., Rudnick, G., Sargent, W. L. W., & Sarzi, M., "Black Holes as Traced by Weak Active Nuclei," in Carnegie Observatories Astrophysics Series, Vol. 1: *Coevolution of Black Holes and Galaxies*, ed. L. C. Ho (on-line), 5 pp., 2003.

Shields, J. C., Rix, H.-W., Sarzi, M., Ho, L. C., Barth, A. J., McIntosh, D. H., Rudnick, G., Filippenko, A. V., & Sargent, W. L. W., "The Survey of Nearby Nuclei with STIS," BAAS, 35, 1296, 2003.

Smith, I. A., **Böttcher, M.**, Ryder, S., & Pakull, M. W., "Multiwavelength Observations of the Ultraluminous X-ray Sources in NGC 1313," BAAS, 36, 918, 2004.

Statler, T. S., Emsellem, E., Peletier, R. F., & Bacon, R., "Long-Lived Triaxiality in the Dynamically Old Elliptical Galaxy NGC 4365: Limits on Chaos and Black Hole Mass," MNRAS, 353, 1–14, 2004.

Statler, T. S., & **Salow, R. M.**, "The Nuclear Disk and Supermassive Black Hole in M31," BAAS, 36, 852, 2004.

Voinov, A., et al. (10 authors), "Large Enhancement of Radiative Strength for Soft Transitions in the Quasicontinuum," Phys Rev Lett, 93, 142504, 4 pp., 2004.

Walcher, C. J., Häring, N., Böker, T., Rix, H.-W., van der Marel, R. P., Gerssen, J., Ho, L. C., & **Shields, J. C.**, "Nuclear Star Clusters in Bulgeless Galaxies," in Carnegie Observatories Astrophysics Series, Vol. 1: *Coevolution of Black Holes and Galaxies*, ed. L. C. Ho (on-line), 7 pp. (on-line), 2004.

Walcher, C. J., van der Marel, R. P., McLaughlin, D., Rix, H.-W., Böker, T., Häring, N., Ho, L. C., Sarzi, M., & **Shields, J. C.**, "Masses of Star Clusters in the Nuclei of Bulgeless Spiral Galaxies," ApJ, in press, 2004.

Watson, C. R., et al. (18 authors including **B. R. McNamara** & **J. C. Shields**), "X-ray Emission from Low Redshift 2MASS-selected galaxies in the Bootes Field and Implications for Star Formation," BAAS, 36, 747, 2004.

Wise, M. W., **McNamara, B. R.**, & Murray, S. S., "The Insignificance of Global Reheating in the A1068 Cluster: X-ray Analysis," ApJ, 601, 184–196, 2004.

Wise, M. W., **McNamara, B. R.**, Nulsen, P. E. J., & David, L. P., "A Detailed Analysis of the AGN/ICM Interaction in Hydra A," BAAS, 36, 903, 2004.

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