

**Ohio University**  
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The following report covers the period November 2001 through October 2002.

## 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 25 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 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 Brian McNamara, Joseph Shields, Thomas Statler, Emeritus Professor James Dilley, and Instructors George Eberts and Tom O'Grady. Additional faculty in the Department engaged in astrophysics-related research include Carl Brune and Daniel Phillips. Markus Böttcher arrived in August from Rice University to join the department as an Assistant Professor. Mangala Sharma, formerly at the Indian Institute of Astrophysics, joined the department in August as a Postdoctoral Research Associate working with McNamara. Statler began a year-long sabbatical in September.

During the past year McNamara supervised research by graduate students John Dulka, David Rafferty, and Laura Rafferty, and undergraduate Russell Ryan; Phillips supervised research by graduate student Yurii Pidopryhora; Shields supervised research by graduate students Anca Constantin and Deepashri Thatte; and Statler supervised research by graduate students Steven Diehl and Robert Salow and undergraduate Daniel Wik. Wik was named a Goldwater Scholar in the 2002 competition, and held a summer research position at the Harvard-Smithsonian Center for Astrophysics. Ryan completed a bachelors degree in physics in June, and entered the graduate program in physics and astronomy at Arizona State University in August. Constantin was awarded a John Cady Graduate Fellowship for the 2002-2003 academic year, one of five named fellowships awarded on a university-wide basis. Thatte completed a masters degree in physics in June, and has since moved to the University of South Carolina.

McNamara received new and continuing funding from NASA, STScI, 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. McNamara continued as a member of the Telescope Allocation Committee for the National Optical Astronomy Observatories. Shields received continuing

funding from STScI and the CXO for studies of active galaxies. He was awarded an Outstanding Teacher Award from the College of Arts and Sciences in September. Shields continued his service as Scientific Editor for the *Astrophysical Journal*. Statler's research on the structure and evolution of elliptical galaxies received continuing support from the CXO and an NSF Faculty Early Career Development (CAREER) Award. Statler continued as a member of the Committee of the AAS Division on Dynamical Astronomy.

## 3. RESEARCH

### 3.1 Normal Galaxies

Salow is continuing work on the Double Nucleus of M31, as part of his dissertation research under Statler's supervision. Radially truncated eccentric disk models with self-gravity and a realistic velocity dispersion have been constructed, and are shown to give rise to kinematic and photometric profiles that resemble those seen in *Hubble Space Telescope* (HST) data for M31. Additionally, these models show distinctive multi-peaked line-of-sight velocity distributions along lines of sight near the central black hole that can be used to identify the eccentric nuclear disk in M31 (Salow & Statler 2001). Salow has extended his published work to include models with the proper radial extent to fully model the nucleus of M31. A multi-dimensional Downhill Simplex Method (see Press *et al.* 1992) is used to minimize the reduced  $\chi^2$  value between a given model and the best-available photometric and kinematic nuclear data for M31. The key result of this modeling will be an accurate, statistically valid mass for the supermassive black hole at the center of M31. Once a best-fit model is found, the stability of a particle realization of the eccentric disk will be examined using an n-body code developed by Salow and Statler.

Statler is investigating the spontaneous generation of eccentric modes in disks, using the same special-purpose N-body code. The code is designed to treat nearly Keplerian disks with particle orbits of high eccentricity, and uses an efficient Hermite integrator that allows individual time steps. Early results indicate that large-amplitude eccentric modes, similar to that present in M31, can be self excited in cold disks with certain density profiles. This work will be pursued further in collaboration with F. Combes [Obs. de Paris], E. Emsellem, and R. Bacon [Observatoire de Lyon].

Statler has begun a collaboration with members of the SAURON group (T. de Zeeuw [Leiden], R. Davies [Oxford], R. Bacon, E. Emsellem, *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. Initial results for the "stan-

standard elliptical” NGC 3379 are consistent with the previous results obtained from long-slit kinematic data. Work on the kinematically complex galaxy NGC 4365 is commencing.

The nucleus of NGC 3379 is also the subject of work by K. Gebhardt [U. Texas] and Statler using *HST* with WFPC2 and STIS to resolve the inner arcsecond of the stellar and gas distribution and kinematic fields. Imaging and spectroscopic data are in hand and are being reduced by Gebhardt.

*Chandra*/ACIS-I observations of two young elliptical galaxies by Statler and McNamara were completed in 2000 and 2001. The results for NGC 1700 are particularly surprising. The X-ray isophotes are highly flattened, reaching a maximum ellipticity  $\epsilon_x \approx 0.65$  at radii where the optical ellipticity  $\epsilon_{\text{opt}} \approx 0.3$ . The X-ray surface brightness profile is shallower than that of the starlight, indicating that the emission comes from hot gas. The flattening is so extreme that the gas cannot be in hydrostatic equilibrium in any plausible potential. A likely alternative is that the gas has significant rotational support. A model representing isothermal gas distributed about a particular angular momentum can reproduce the observed flattening. The cooling time of the gas in the best fit model matches the time since the last major merger. The gas was thus likely acquired in that merger, which involved a pre-existing elliptical galaxy with a hot ISM. The hot gas carried the angular momentum of the encounter, and has since gradually settled into a rotationally flattened, cooling disk.

A search for further signs of rotational support in the hot ISM of elliptical galaxies is being conducted by Diehl and Statler, using archival *Chandra* data. This work includes an analysis of the spectral properties of resolved point sources in the galaxies, in order to model unresolved point sources below *Chandra*’s detection limit that contribute to the diffuse emission. Removal of this contribution will reveal the emission from the hot gas, whose flattening, relative to that of the starlight, will be used to constrain the degree of rotational support. If angular momentum is found to play an important role for the gas, it could have a major impact on dark halo masses that have been derived from the standard assumption of hydrostatic equilibrium.

Statler continues a collaboration with D. Terndrup, B. Ryden, and R. Pogge [Ohio State U.] to study the stellar populations and morphologies of dwarf ellipticals in the Virgo cluster. Observations on this project are completed, after three runs on the MDM Hiltner 2.4m in 1998, 1999, and 2000. Statler has also started a collaboration 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. Two nights of long-slit spectroscopy have been approved for the MMT in the first semester of 2003.

Wik and Statler are investigating the applicability of Fisher information to stellar dynamics, as an alternative to the Boltzmann entropy. Fisher information ( $I$ ) is a measure of the average local smoothness of a distribution, whereas entropy in effect measures the global variation. It is already known that under the same assumptions that underlie the Boltzmann  $H$  theorem ( $dH/dt > 0$ ), one can prove an equivalent theorem for Fisher information ( $dI/dt < 0$ ). How either of these results pertains to violent relaxation, however,

is still not known, though it has been argued that various entropy-like functionals should increase during galaxy formation. Wik is extending existing results on mixing and casting them in terms of Fisher information, and performing N-body experiments on violent relaxation in order to investigate the time evolution of  $I$  numerically.

Shields is collaborating with a team led by T. Böker [STScI] in a study of nuclei in late-type galaxies. This work includes an imaging snapshot survey of 77 objects with *HST*, which has revealed a distinct, compact, and dominant source at or very close to the centers of most of these galaxies. The central sources are spatially resolved in the majority of cases, and evidently represent compact star clusters. Follow-on *HST* spectra of a subset of these clusters provide indications that many of these sources are relatively young.

### 3.2 Active Galactic Nuclei

Time-dependent spectral models for the broadband emission and spectral variability of blazars (i.e., gamma-ray-loud quasars and BL Lac objects) were investigated by Böttcher and collaborators. Intermediate- and low-frequency-peaked BL Lac objects (IBLs and LBLs, respectively) are particularly interesting targets for studies at X-ray energies. In these sources, the synchrotron emission component of their broadband continuum spectra is overlapping with the high-energy (X-ray –  $\gamma$ -ray) component in the frequency range of far-UV to medium-energy X-rays. Consequently, soft X-ray spectral variability studies of IBLs and LBLs reveal the high-frequency end of the synchrotron emission, and thus probe the dynamics of acceleration and cooling of the highest-energy electrons in the jets of these types of blazars.

In two recent studies, Böttcher and collaborators first obtained analytic estimates of the importance of significant synchrotron-self-Compton cooling in the jets of BL Lac objects, and then did a numerical parameter study of various leptonic model configurations, resulting in specific predictions for the soft X-ray spectral variability, depending on the dominant electron cooling mechanism. In their parameter study, Böttcher and J. Chiang [SLAC] focused on a range of parameters particularly relevant to IBLs and LBLs, and investigated especially the X-ray spectral variability. The study focused on the influence of the relative strength of external-inverse-Compton (EIC) vs. synchrotron-self-Compton (SSC) cooling of relativistic electrons in the jet. Remarkable differences between the X-ray spectral variability patterns (spectral hysteresis phenomena) for those two scenarios were identified. These patterns were found to be very weakly dependent on several poorly determined, free parameters of the model. Consequently, the different X-ray spectral variability patterns predicted in that study can be used to probe the dominant high-energy radiation mechanism in this still enigmatic intermediate class of blazars, even without a detailed measurement of the high-energy  $\gamma$ -ray emission, which will not be possible at least until the launch of GLAST. The predicted X-ray spectral variability patterns should be clearly detectable with *Chandra* and/or *XMM-Newton*.

The predictions of Böttcher and Chiang were confronted with existing broadband spectra and soft X-ray spectral variability information from recent *BeppoSAX* observations of

BL Lacertae and W Comae. Böttcher and a large international collaboration of observers previously carried out a multiwavelength campaign to observe BL Lacertae in the second half of 2000. The results of that campaign clearly showed that the high-energy end of the synchrotron component extends far into the X-ray range, and the preliminary variability analysis seems to confirm that a non-negligible amount of external-Compton emission is necessary in order to explain the broadband spectrum and variability of BL Lacertae.

Böttcher, R. Mukherjee [Columbia U.], and O. Reimer [U. Bochum] performed a careful analysis of the broadband spectrum and *BeppoSAX* soft X-ray spectral variability of the LBL W Comae from May 1998. This analysis included detailed modeling with both leptonic and hadronic scenarios. They found that both leptonic and hadronic models could provide acceptable fits to the broadband spectrum of this object. In the case of leptonic models, they also found that the nearly simultaneous EGRET spectrum could only be modelled satisfactorily with a non-negligible external-Compton component. This result, in turn, was found to be consistent with the roughly symmetric flaring patterns in the *BeppoSAX* X-ray light curves. Böttcher and collaborators found a clear discrepancy between leptonic and hadronic models in terms of their predicted high-energy emission above  $\sim 100$  GeV. While leptonic models predicted virtually no  $\geq 100$  GeV emission, hadronic models predict a significant level of high-energy emission out to more than 1 TeV, which should be observable with future atmospheric Čerenkov telescope facilities, such as VERITAS.

Shields is continuing 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.], and A. Barth and W. Sargent [Caltech], in a study of the emission properties and small-scale kinematics for a sample of nearby, weakly active nuclei using *HST* and STIS. Emission-line fluxes and ratios measured in ground-based apertures sampling  $\sim 200$  pc scales were recently compared with the *HST* measurements employing apertures an order of magnitude smaller. While the nuclear emission is clearly resolved, resulting in fluxes that are much smaller in the *HST* aperture, the line ratios often show little difference between the two measurements. This finding is surprising, particularly for “transition” sources that are often assumed to be weak AGNs blended with circumnuclear H II regions, and suggests that additional, distributed sources of ionization are important in many nuclei.

In a related study, R. Pogge and D. Fields [Ohio State U.], Shields, and P. Martini [OCIW] are continuing their analysis of *HST* STIS spectra for a sample of 18 nearby Seyfert 2 nuclei. This project takes advantage of *HST*'s spatial resolution to study the emission-line and continuum properties of these systems on small scales, with minimal circumnuclear contamination. Preliminary findings include the discovery of broad H $\alpha$  emission in approximately half of the sources, and very sensitive upper limits to such emission in the remaining objects.

B. M. Sabra [U. Florida], Shields, Ho, Barth, and Filippenko completed an analysis of *HST* UV/optical spectra of the nucleus of M87. Previous observations of the nuclear gas disk, offset from the central point source, have revealed emission-line spectra that are strongly indicative of shock ionization; however, the line ratios seen directly on the nucleus are different. The current study demonstrates that the nebulosity at the nucleus is best understood as photoionized plasma characterized by a range of densities. The spectra also display absorption lines from material that is evidently associated with the nucleus. Measurements indicate that the absorbing gas may be a low-ionization, low-velocity ( $\sim 100$  km s $^{-1}$ ) analog of the outflows increasingly seen in Seyfert galaxies and QSOs.

Constantin and Shields have initiated a study of spectroscopic properties of Narrow Line Seyfert 1 (NLS1) galaxies. This work is motivated by suggestions that these objects share several attributes with high-redshift QSOs, specifically high accretion rate and high metallicity. This investigation follows on Constantin *et al.*'s analysis of spectra for  $z > 4$  QSOs completed last year. The new study addresses statistical aspects of NLS1 spectral features. Preliminary results indicate that NLS1s and high- $z$  QSOs are in fact rather distinct populations in their physical characteristics. Comparisons between these sources are complicated by the different restframe bandpasses typically observed for nearby NLS1s (optical) and for high- $z$  quasars (UV).

Constantin and Shields are also collaborating with M. Dietrich [Georgia State U.] and F. Hamann [U. Florida] in several statistical studies of quasar emission properties. This work makes use of spectra for a very large sample of quasars that allows separation of redshift and luminosity dependencies. A major result of this effort has been a detailed investigation of the Baldwin Effect, the negative correlation between luminosity and emission-line equivalent width. Dietrich *et al.* are able to demonstrate unambiguously that the equivalent width dependence is on luminosity rather than redshift, and also confirm in detail previous suggestions that the slope of the correlation is a function of the ionization state for the emitting species. Additional detailed analyses of the spectra are being used to probe metallicity in the sample sources.

Shields is part of a large team investigating the nature of UV and X-ray absorption in the Seyfert 1 galaxy NGC 3783. As part of this collaboration, a study led by S. Kaspi [Tel-Aviv U.] has been completed for the absorber as measured in a time-averaged 900 kilosecond *CXO* grating observation. The X-ray absorber shows a substantial velocity width (FWHM  $\approx 800$  km s $^{-1}$ ), with a net blueshift of  $\sim 600$  km s $^{-1}$ , indicative of outflow. Analysis of *FUSE* observations led by J. Gabel [Catholic U.] reveals additional complexity in the absorber, with multiple components displaying velocity-dependent coverage of the continuum source. Future efforts by the team will include investigation of variability in the UV and X-ray absorption features and integration of multi-wavelength constraints into an overall physical description of the absorber in this galaxy.

Shields and McNamara, along with investigators at SAO and NOAO, are part of team awarded *Chandra* time in Cycle

4 to observe the 9 square-degree Bootes field of the NOAO Deep Wide-Field Survey. This program will focus on studying AGN activity in relation to large-scale structure.

### 3.3 Galaxy Clusters

McNamara and colleagues were awarded several *Chandra* Cycle 4 programs designed to probe the relationships between cooling flows, radio sources, and star formation. One of the areas of investigation concerns the origin of large-scale cavities in the thermal cluster X-ray emission, and the cycles of cooling, heating, and star formation in the X-ray emitting gas. The cavities, seen in many clusters observed with high resolution *Chandra* imaging, are usually filled with radio synchrotron emission associated with the lobes of powerful radio galaxies. The cavities appear to be in pressure balance with the hot ICM supported by cosmic rays, magnetic fields, and possibly a very hot, dilute gas. McNamara, colleagues, and students are investigating the systematic properties of cavities over a large sample of clusters with the goal of understanding the life cycles and composition of galactic radio sources, and the transfer of energy and momentum from the radio sources to the keV gas. Sharma is working on the X-ray and radio aspects of the project. McNamara continues his collaboration with H. Li, S. Colgate, and others from Los Alamos National Laboratory studying the origin and dynamical significance of magnetic fields in clusters and on galaxy formation.

McNamara, S. Murray [SAO], M. Wise [MIT], C. Sarazin [U. Virginia], and others have continued their studies of cluster X-ray emission in several clusters, including Abell 1068. Abell 1068 is luminous in X-rays and has been reported to contain a  $400 M_{\odot} \text{ yr}^{-1}$  cooling flow. The central galaxy in the Abell 1068 cluster is remarkable in several respects. It is experiencing a vigorous episode of star formation at a rate of  $80 M_{\odot} \text{ yr}^{-1}$ . In addition, it is a luminous infrared source that would nearly qualify as an “ultraluminous infrared galaxy.” McNamara, Murray, and Wise are analyzing a new *Chandra* image of Abell 1068 that has revealed a remarkable degree of structure in the center of the cluster. The team is investigating whether the X-ray cooling rate and star formation rates match, as would be expected if star formation is fueled by the cooling flow.

An analysis of *Chandra* observations of the Abell 2052 cluster was completed by E. Blanton and C. Sarazin (U. Virginia), working with McNamara. This study presents a detailed treatment of the state of the X-ray plasma surrounding the radio lobes, and a comparison of the much reduced cooling rate to the central star formation rate in the cD galaxy.

McNamara and Ryan are studying several cD galaxies in rich clusters that are undergoing massive starbursts. The optical images were taken through *U* and *R* band wide filters, and narrow  $H\alpha$  filters to study the relationship between star formation, nebular emission, and gas cooling from the intracluster medium. Two clusters in the sample are to be observed with *Chandra* in Cycle 4.

Sharma is continuing a program to investigate properties of poor clusters of galaxies. Such systems are the most common environments for galaxies, but have received limited attention in the literature. Sharma has performed optical pho-

tometry of moderate redshift poor clusters selected as luminous, extended X-ray sources identified with poor galaxy systems in the EMSS Catalog of clusters of galaxies. In terms of the statistical properties of their member galaxies, poor clusters appear to be lower-mass extensions of their rich counterparts. Their early-type galaxy populations are clearly evolved, as traced by the tightness of the color-magnitude relations. The accordance of the latter with those of the Virgo cluster implies that there is little luminosity or color evolution of the bright galaxies over the small redshift range under consideration. However, the blue galaxy fraction for the poor clusters is higher than those of richer clusters at similar redshifts, and similar to those of low redshift Richness 0 clusters. Most of these blue galaxies are disk galaxies while fewer than 20% are interacting. The luminosity functions (LFs) of the individual clusters are not significantly different from each other. Composite LFs in B, V, and R bands (to  $M_V = -18$  mag) are flat, similar to V-band LF of other poor clusters, but steeper than the R-band field LF, implying a significant dwarf population but one that is not so large as in richer clusters.

Each of the poor clusters in Sharma’s sample harbors a gigantic galaxy at its center. Multicolor surface photometry from her study shows that these galaxies have de Vaucouleurs surface brightness profiles with no clear signatures of envelopes characteristic of cD galaxies. One of the galaxies has a color profile that reddens with increasing galactocentric distance; the observed color gradients for the other two galaxies imply a decrease in the metallicity by a factor of about 2 per decade in radius. Sharma also finds that the first-ranked cluster member is frequently aligned with the distributions of member galaxies and the intracluster gas. This trend follows the statistical behavior of the brightest galaxies in rich clusters and in much poorer groups, indicating that the alignment effect is insensitive to system richness.

### 3.4 High Energy Astrophysics Theory

Using a coupled Monte-Carlo/Fokker-Planck code for time-dependent radiation transfer and electron dynamics in two spatial dimensions, Böttcher and his collaborators at Rice University, led by E. P. Liang, studied the energy-dependent rapid X-ray variability resulting from various flaring scenarios in an accretion-disk corona configuration with a realistic radial and vertical profile of the corona and a Shakura-Sunyaev-type radial profile of the accretion disk emission. They investigated two different flaring scenarios in a generic accretion-disk corona configuration with parameters appropriate to reproduce spectral characteristics typically observed in the Galactic microquasar source GRS 1915 +105. In the first scenario, accretion disk flares were simulated as an enhancement of the local accretion-disk temperature over a limited time and at a specified annulus. This resulted in soft X-ray flares narrowly restricted in energy. Most notably, the pronounced spectral pivoting which had been observed in previous simulations using a 1-D plane-parallel geometry did not appear in the 2-D simulations. Flaring activity appeared at  $E \lesssim 10$  keV without a significant effect on the hard X-ray emission. Both hard and soft lags were found in different parameter regimes, and the analysis

showed a slight hardening of the power spectra with increasing photon energies. In a second simulation, Böttcher and collaborators examined a coronal-flaring scenario, in which the local heat input (due to Coulomb heating from a thermal pool of hot protons) was increased over a limited range in time and space (annulus and height). Hard X-ray flares restricted to  $E \gtrsim 10$  keV were found. The variability at  $\sim 10$  keV is predicted to lead the variability at all other photon energies, and no significant energy-dependence of the power spectra was found.

Using realistic 3-D hydrodynamic simulations of supernovae as a guideline, Böttcher, C. Fryer [Los Alamos] and C. Dermer [Naval Research Lab] have recently contrasted the implications of the transient absorption feature (most likely an iron K absorption edge) in the prompt X-ray emission of GRB 990705, with specific predictions of various Gamma-Ray Burst (GRB) progenitor models. They find that the supernova model would be the primary candidate for producing the required GRB environment, although there is still some concern about its actual viability to produce GRBs. Alternatively, a fast-merger version of the He-merger GRB model could be marginally consistent with the observed transient absorption feature, although there is only a very small chance probability of observing such a feature in this model. Consequently, the latter explanation would be in jeopardy if future observations of prompt X-ray emission from GRBs found a significant number of examples of this kind.

### 3.5 Nuclear Astrophysics

Brune is pursuing a better understanding of the  $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$  reaction at low energies. The rate of this reaction determines the  $^{12}\text{C}/^{16}\text{O}$  ratio produced by helium burning in stars, and consequently has very significant effects on the resultant structure and nucleosynthesis, as well as the final outcome of the evolution. Calculation of the reaction rate in helium-burning conditions requires that 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. The alternative is to employ indirect methods and extrapolations of measurements performed at higher energies. Brune and collaborators are planning measurements of the  $\gamma$ -ray branching ratios for states in  $^{16}\text{O}$  which impact the reaction cross section. Research is also underway to improve the methods of data fitting for the different types of data available for this reaction, which will improve the reliability of extrapolations to astrophysical energies.

Brune is continuing his collaboration with scientists at Oak Ridge National Laboratory (ORNL) to utilize radioactive beams to study reactions relevant to nucleosynthesis in stellar explosions. The proton-transfer reaction  $^{14}\text{N}(^{17}\text{F}, ^{18}\text{Ne})$  has recently been measured, which helps to constrain the rate of the proton capture reaction  $^{17}\text{F}(p, \gamma)^{18}\text{Ne}$ . In the future it is hoped that sufficient  $^{17}\text{F}$  beam intensity can be developed so that the  $^{17}\text{F}(p, \gamma)$  reaction can be measured directly. The proton-capture reactions on  $^{17}\text{F}$  are critical for estimating the quantity of  $^{18}\text{F}$  produced by novae, an isotope whose  $\beta^+$  decay may produce an observable flux of  $\gamma$  rays with energies up to 511 keV. These reactions also have important ef-

fects on the yields of heavier nuclei produced in novae and X-ray bursts. Future experiments are being planned at ORNL to study the structure of nuclei far from stability. This information will in turn help to determine nuclear reaction rates in the rapid neutron capture process (R process).

Phillips has investigated properties of neutralinos, which are particles that appear in some supersymmetric extensions of the standard model of particle physics. Neutralinos have not been observed directly, but bounds on their mass and coupling can be derived by an examination of the neutrino pulse from Type-II supernovae. Raffelt (1996) has proposed a simple analytic that allows bounds to be placed on supernova energy-loss mechanisms, like this one, which are “beyond the standard model”: if any energy-loss mechanism has an emissivity (evaluated at  $T=30$  MeV and at nuclear matter density) greater than  $10^{19}$  ergs  $\text{gm}^{-1} \text{s}^{-1}$  then it will remove sufficient energy from the explosion to invalidate the current understanding of the neutrino signal from Type-II supernovae. Using their previously developed soft-radiation theorem, Phillips and collaborators have computed the rate for the process  $NN \rightarrow NN\chi\chi$  (“neutralinostrahlung”) and then applied the “Raffelt criterion” to infer which regions of the neutralino parameter space are inconsistent with the SN1987A signal.

Phillips and co-workers have also investigated the domain of validity for the soft-radiation theorem approach. Estimates indicate that this approach is no longer valid once the emitted energy of the radiation is of order 150 MeV. At that energy there is analytic structure in the amplitude for the emission process which is not well-reproduced in the soft-radiation approximation. However, a detailed test of the breakdown of the soft-radiation approximation would be useful, both for this application to neutralino-property bounds, and for work on neutron-star cooling and related bounds on the size of large, compact, extra dimensions. Phillips and Pidopryhora have developed a simple model within which the breakdown of the soft-radiation approximation can be carefully assessed; within their model the “exact” answer for the amplitude for the emission of radiation can be compared with the soft-radiation approximation result for the same quantity. Detailed comparison of these two results is just beginning and final results of the study are expected soon.

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