

Los Alamos National Laboratory

Los Alamos, New Mexico 87545

This report is for astronomy-related research at Los Alamos National Laboratory covering the period 1 July 1999 through 30 June 2000.

1 FOREWORD

The Los Alamos National Laboratory is operated by the University of California for the U.S. Department of Energy under contract No. W-74105-ENG-36. The Laboratory is located in northern New Mexico, in the Jemez Mountains at altitudes ranging between 6400 and 8700 feet above sea level, and occupies roughly one hundred square miles of surface area, most of which is a forest of piñon, juniper, and ponderosa pine, divided by rocky canyons. It lies adjacent to the western district of the Santa Fe National Forest.

More than 100 scientists at the Laboratory have an astrophysics background or maintain an active research interest in astrophysics. Much of the astrophysical research reported here was done by staff members whose primary work is in various programmatic areas. The Laboratory encourages scientists to continue doing basic research in their areas of specialty in addition to their programmatic responsibilities.

Section 2 describes the development of astrophysics at Los Alamos and the resources presently available to Los Alamos researchers. The research contributions, ordered roughly by subject matter appear in Section 3. Finally Section 4 lists Los Alamos astrophysics publications appearing during the year under review.

More current information on astrophysics at Los Alamos, including INPAC, Fenton Hill Observatory, and the various groups in which astrophysics is done, may be obtained from the Los Alamos Astrophysics web site, <<http://laastro.lanl.gov/>>.

2 LABORATORY FACILITIES AND BACKGROUND

The primary mission of the Los Alamos National Laboratory has been the development and testing of nuclear weapons, and the subsequent evolution and maintenance of the stockpile. The Laboratory began expanding beyond that primary mission in the late 1950's to maintain the diversity and vigor of the scientific talent here and to ensure the ability to recruit new researchers. The computational power available here has since been applied to scientific endeavors of more academic or civilian interest, in fields ranging from biology to information sciences.

Starting with stellar structure and violent activity in stars, astrophysics has always been a natural interest for Los Alamos scientists because weapons designers were well acquainted with the energy source for the stars, and the associated opacities and equations of state. Explosions in stars (novae and supernovae) challenged the physics in the bomb codes, and the resulting advances in computational methods served the interests of both civilian and defense science.

With the Limited Test Ban Treaty of the early 1960's, the weapons laboratories were called on to provide means to

prove that no weapons would be tested in space. Los Alamos thus got a space mission—the Vela satellites—which carried sensors for energetic particles and gamma-rays into earth orbit. These satellites discovered the still-enigmatic gamma-ray burst sources, and have led to a series of ever more sophisticated sensors and satellite missions. The ALEXIS satellite, designed, built, and operated at Los Alamos, continues to monitor the sky in ultrasoft X-rays or the extreme ultraviolet. LANL scientists helped design and construct the recently-launched HETE-2 satellite, which will detect and locate gamma-ray bursts.

Other descendants of Vela include scientific instruments on missions throughout the solar system, and suites of satellites that have studied and thoroughly characterized the magnetosphere and solar wind. High energy astrophysics at Los Alamos has also developed a ground-based component in the CYGNUS and Milagro high energy gamma-ray telescopes. These detectors extend traditional Los Alamos capabilities in nuclear and particle physics into an area of increasing astrophysical importance.

Los Alamos has an impressive array of scientific computers. State-of-the-art laboratory facilities in a wide variety of fields are also available to Los Alamos scientists. These include, for example, vacuum plasma chambers for simulating spacecraft charging processes and laboratories for fabricating spaceflight-qualified hardware for particle, field, and photon detection. Advanced pulsed power devices can also be used to simulate extreme conditions of matter in certain astronomical objects.

The broad diversity of expertise of the Laboratory's scientific staff is a very important resource. Astrophysicists at the Laboratory can get state-of-the-art information in hydrodynamics, nonlinear dynamics, particle physics, nuclear physics, numerical analysis, and many other disciplines.

2.1 INPAC and Fenton Hill Observatory

In June 1995, the University of California established the Institute for Nuclear and Particle Astrophysics and Cosmology (INPAC), involving seven campuses and the three national laboratories operated by the University (Lawrence Livermore National Laboratory and Lawrence Berkeley National Laboratory, in addition to Los Alamos), with the aim of establishing campus-laboratory collaborations in the field of astro-particle physics. Many of the research projects reported on here are subjects of great interest to INPAC.

With the help of UC collaborators, the Los Alamos branch of INPAC has begun a project to establish a modest astronomical observatory on Forest Service land at Fenton Hill in the Jemez Mountains, with research aimed chiefly at the detection and monitoring of transient astronomical sources; it will also serve as the focus for the development of educational programs targeted to secondary schools in New Mexico and elsewhere.

The site, about 35 miles west of Los Alamos, is at a

longitude of $106^{\circ} 40''$ W, a latitude of $35^{\circ} 53''$ N, and an altitude of 8680 feet, relatively dry, and very dark. There is no line of sight to any city. Between Fenton Hill and Los Alamos are the peaks of the Valle Caldera, most over 10000 feet. Sandia Crest, the mountain overlooking Albuquerque some 60 miles away, is visible from Fenton Hill,

The site was used for many years by the Los Alamos Hot Dry Rock geothermal project. Very deep wells conducted water down to a source of heat, through it, and then back up to the surface for a significant energy gain. The heated water was then passed to heat exchangers for the extraction of power. The Department of Energy has terminated the Hot Dry Rock project, and the site has become available for other uses.

There is a good quality paved road to the edge of the site (an hour's travel from Los Alamos), and graded roads within the site. The developed area consists of about 30 acres, fairly flat, part of a triangular thinly forested ridge about half a mile wide at its base and extending to the southwest a distance of about 3 miles. Los Alamos National Laboratory has had a long-term use agreement with the Forest Service for the developed 30 acres, and could potentially acquire the rights to use some other portions of the ridge, which has a graded Forest Service road along its length. A new inter-agency use agreement that specifically permits the development of an astronomical observatory was formalized in late 1997.

The developed site has power, water, phone, and an ethernet (T1) link to Los Alamos. There are several buildings, including conference rooms, a well-equipped machine shop, a heavy-equipment shop, a warehouse, dormitory trailers and data acquisition trailers. In addition there are some towers that may be useful for instrument deployment platforms.

The Milagro gamma-ray telescope is already in operation on Fenton Hill in a 5-million gallon pond previously used by the Hot Dry Rock project. Milagro is being augmented by several wide-angle Cerenkov telescopes (WACT) to study the composition of cosmic rays. The Robotic Optical Transient Search Experiment (ROTSE II) telescopes will be installed at Fenton Hill when the debugging in the present site at the Los Alamos Neutron Science Center (LANSCE), is complete. An automated 14-inch optical telescope, the Research and Education Automatically Controlled Telescope (REACT) (Galen Gisler, Don Casperson) now has a prototype web interface, and is seeing more use. A new shelter for this 14-inch has been designed, and should be constructed in the fall of 2000. The goal of automating the data taking has been deferred until the new shelter is in place. The telescope is still primarily used by on-site outreach and education efforts.

3 RESEARCH

3.1 Structure of the Sun and Stars

Deupree (DX-7) continued work on the hydrodynamics and evolution of rotating stars with a 2D fully implicit finite difference code. The picture of convective core hydrodynamics is somewhat different than that fostered by mixing length concepts: at any given place and time, the local gradient may

be substantially superadiabatic or subadiabatic, and the convective flow speeds are significantly higher (some tens of kilometers per second) than mixing length concepts would suggest. However, the gradient, when averaged over both space and time, is essentially adiabatic (Deupree, ApJ, 542, 2000). The addition of rotation in convective cores changes the hydrodynamic motion from primarily radial to primarily parallel to the rotation axis. For large enough rotation, the rotation rate resulting from the convective motion may be fit by a power law with a negative exponent of about one half. All models show an appreciable amount of overshooting, typically corresponding to about 0.3-0.5 pressure scale heights.

Peregrine McGehee (LANSCE-8) and collaborators Gillian Knapp, Zeljko Ivezic, and Hao Lei (Princeton) have been conducting a research program on T Tauri stars utilizing Sloan Digital Sky Survey (SDSS) multi-color photometric data. T Tauris are young pre-main sequence stars having spectral types of late G through M, with bright emission lines and a blue continuum. These features originate from an accretion shock driven by the infall of inner circumstellar disk material disrupted by the stellar magnetosphere.

There are known cases of isolated T Tauri stars, such as those in the nearby TW Hydrae association, that are far from any nursery cloud and not particularly fast moving. The program objective is to identify and catalog analogs of the TW Hydrae association in an effort to further understand the mechanisms of low mass star formation.

A series of follow up observations of candidates selected from the SDSS data has begun, commencing with spectroscopy of the brighter targets using the Astrophysical Research Corporation's 3.5 meter telescope located at Apache Point, NM. Additional programs have been proposed elsewhere for faint object spectroscopy and IR circumstellar disk surveys. We expect this study to continue over the five-year lifetime of the Sloan survey.

3.2 Supernovae and Pulsars

John Middleditch (CCS-3) continued his work with collaborators Frank Marshall and Will Zhang (NASA-GSFC), Eric Gotthelf of Columbia, and Daniel Wang of U. Mass., on the unique 62 Hz (16 ms) pulsar, J0537-6910, in supernova remnant, N157B, in the Large Magellanic Cloud (LMC). This pulsar is the fastest known pulsar any supernova remnant. Their timing study of this pulsar is now only 21 months years old and already reveals three major "glitches," each resulting in a sudden increase of the pulsar's spin of about 0.5 parts per million. Following each glitch there is almost no "recovery" of the pulsar's spin back to the lower level extrapolated from data taken previous to each glitch. All of the intra-glitch observations have been successfully timed by "counting cycles," except for one point taken on Jan. 17, 2000, which occurred near the time of the second glitch. Thus there is probably some recovery after the glitches, but the amount can only be a small fraction of the frequency change of the glitch.

Middleditch and 11 collaborators studied the possible 2.14 ms signal apparently associated with SN1987A. The signal was not seen during the last observation in December

of 1996, and the campaign of observations ended afterward, partially owing to collaborator J. Kristian's untimely death in June of 1996. Collaborators from Galway will likely continue to observe SN1987A as well as PSR J0537-6910 in the optical. Chandra observers will observe the source in time series mode when it actually does appear as a source. It may take decades for the 2.14 ms signal to be seen again, but perhaps one or more of the VLT, Magellan and Gemini South will be able to detect a signal.

Since SN1987A is now nearly universally accepted as the result of a core merger, and very likely to be spinning fast (even without knowing for absolute certain about the 2.14 ms signal), and since J0537-6910 was born spinning near 140 Hz some 4,000 years ago, the scales are now tilting toward many pulsars, and nearly all pulsars in globular clusters, having been "born in original spin." The point X-ray source in Cas A is another piece of evidence: its period would likely have already been discovered if it were spinning slowly or only moderately fast

3.3 Active Galaxies

V.I. Pariev (T-6), B.C. Bromley (University of Utah) and W.A. Miller (T-6) worked on using extreme frequency shift method to estimate the parameters of accretion disks in AGNs. The observed iron $K\alpha$ fluorescence lines in Seyfert I galaxies provide strong evidence for an accretion disk near a supermassive black hole as a source of the emission. We present an analysis of the geometric and kinematic properties of the disk based on the extreme frequency shifts of a line profile as determined by measurable flux in both the red and blue wings. The edges of the line are insensitive to the distribution of the X-ray flux over the disk, and hence provide a robust alternative to profile fitting for disk parameters. Our approach yields new, strong bounds on the inclination angle of the disk and the location of the emitting region. We applied our method to interpret observational data from MCG-6-30-15 and find that the commonly assumed inclination 30° for the accretion disk in MCG-6-30-15 is inconsistent with the position of the blue edge of the line at a 3σ level. A thick turbulent disk model or the presence of highly ionized iron may reconcile the bounds on inclination from the line edges with the full line profile fits based on simple, geometrically thin disk models. When applied to data from NGC 4151, our method gives bounds of the inclination angle of X-ray emitting inner disk of $50 \pm 10^\circ$, consistent with the model of the ionization cone grazing the disk by Pedlar et al. (1993). The frequency extrema analysis also provides limits to the innermost disk radius in another Seyfert 1 galaxy, NGC 3516, and is suggestive of a thick disk model.

V.I. Pariev continued work with S.A. Colgate (T-6) and J.M. Finn (T-15) on modelling magnetic dynamo produced by passages of stars through accretion disks in AGNs and the origin of magnetic fields in AGNs.

3.4 Neutron Stars

Gravitational, magnetic and superfluid forces can stress the crust of an evolving neutron star. Fracture of the crust under these stresses could affect the star's spin evolution and

generate high-energy emission. Epstein (NIS-2) and collaborators have studied the growth of strain in the crust of a spinning down, magnetized neutron star and examine the initiation of crust cracking (a *starquake*). A preliminary work (Link, Franco and Epstein 1998) studied a homogeneous model of a neutron star. Recently they extended this work by considering a more realistic model of a solid, homogeneous crust afloat on a liquid core. In the limits of astrophysical interest, our new results qualitatively agree with those from the simpler model: the stellar crust fractures under shear stress at the rotational equator, matter moves to higher latitudes and the star's oblateness is reduced. Magnetic stresses favor faults directed toward the magnetic poles. Thus the previous conclusions concerning the star's spin response still hold; namely, asymmetric redistribution of matter excites damped precession which could ultimately lead to an increase in the spin-down torque. Starquakes associated with glitches could explain the permanent *offsets* in period derivative observed to follow glitches in at least three pulsars.

K. New (X-2), L. Lowe, and D. Brown, have carried out hydrodynamics simulations of rapidly rotating stars whose collapse to neutron star densities has been halted by centrifugal force. Such objects are called "fizzlers." This work indicates that such objects may encounter several modes of dynamical instability. These results are of importance to the gravitational wave detection community and may also shed light on the pulsar kick mechanism. A paper stemming from this work is in preparation.

3.5 High-Energy Gamma-Rays

The Milagro Air Shower Detector: Todd J. Haines, Cyrus M. Hoffman, Frank Samuelson and Gus Sinnis (all P-23), Galen Gisler (NIS-2), D. Berley, J. A. Goodman, E. Hays, D. Noyes, A. J. Smith, G. W. Sullivan (U. Maryland, College Park), R. S. Delay, S. Hugenberger, I. Leonor, A. Shoup, G. B. Yodh (UC Irvine), W. Benbow, D. G. Coyne, D. E. Dorfan, L. Kelley, J. McCullough, M. Moralez, D. A. Williams (UC Santa Cruz), R. Ellsworth (Geo. Mason U.), L. Fleysher, R. Fleysher, A. Mincer, P. Nemethy (New York U.) B. Shen, T. Tumer, K. Wang, M. Wascko (UC Riverside), A. Falcone, M. McConnell, R. S. Miller, J. Ryan, (U. New Hampshire), R. Atkins, B. Dingus, J. McEnery (U. Wisconsin). The Milagro air-shower detector is taking data in the Jemez Mountains, about 35 miles west of Los Alamos, NM. Milagro is the world's first high-duty - factor, large-aperture telescope for cosmic gamma rays around 1 TeV. The detector consists of 750 photomultiplier tubes placed in a 5000 m² covered pond located at an elevation of 2640 m. Milagro has an energy threshold of below 500 GeV and a muon detection area of greater than 1500 m². Major objectives include search for DC and transient point source emission of 1-TeV photons, and studies of solar phenomena such as energetic particle emission. Potential transient sources include gamma-ray bursts, active galaxies and evaporating primordial black holes. In addition, the energy spectrum of known TeV sources (such as the Crab, Markarian 421, and Markarian 501) will be studied. A prototype detector, called Milagrato, took data from February, 1997 to April, 1998: over 9 billion events were recorded. Milagrato had 228 photomultiplier

tubes sitting on the pond bottom covered with 1.5-m of water; its energy and angular response were similar to Milagro, although it was smaller and had no muon detection capabilities. High-energy emission from Markarian 501, a blazar, has been detected with Milagrito. In addition, evidence for emission of TeV particles by a gamma-ray burst has been obtained with Milagrito. These results have been published in *Ap. J. Letters*. Solar energetic particles with energies exceeding 10 GeV from the Nov. 6, 1997 solar flare/coronal mass ejection have also been detected by Milagrito. Further analysis of the data acquired with Milagrito is underway.

In spring, 1998, Milagrito was disassembled and the installation of full Milagro detector began. Milagro is now fully installed and data-taking is underway. Over 33 billion events have been collected, to date. Observations with Milagro are expected to continue for 5-10 years.

3.6 High-Energy Cosmic Rays

The long-held notion that the highest-energy cosmic rays are of distant extragalactic origin is challenged by observations that events above $\sim 10^{20}$ eV do not exhibit the expected high-energy cutoff from photopion production off the cosmic microwave background. Epstein and collaborators have suggested that these unexpected ultra-high-energy events are due to iron nuclei accelerated from young strongly magnetized neutron stars through relativistic MHD winds. We find that neutron stars whose initial spin periods are shorter than $\sim 4(B_S/10^{13}\text{G})^{1/2}$ ms, where B_S is the surface magnetic field, can accelerate iron cosmic rays to greater than $\sim 10^{20}$ eV. These ions can pass through the remnant of the supernova explosion that produced the neutron star without suffering significant spallation reactions or energy loss. For plausible models of the Galactic magnetic field, the trajectories of the iron ions curve sufficiently to be consistent with the observed, largely isotropic arrival directions of the highest energy events.

The WACT collaboration (LANL, NMSU, University of Wisconsin) in conjunction with the Milagro collaboration is building an array of 6 air Cherenkov telescopes to measure the lateral distribution of Cherenkov light in extensive air showers. The goal of this project is to measure the cosmic-ray composition between 50 TeV and 1 PeV. This will be the first ground-based instrument capable of measuring the cosmic-ray composition in an energy band where it has been directly measured with balloon and satellite detectors.

3.7 X-Rays

Scientists at LANL are actively involved with the major X-ray observatories: XMM-Newton and Chandra. Konstantin Borozdin, Cheng Ho, Bill Priedhorsky, Sergey Trudolyubov, and Tom Vestrand (all NIS-2) are members of the Optical Monitor Instrument Team for XMM-Newton. As such, they have access to exciting new guaranteed-time and performance verification observations from all the instruments aboard XMM-Newton.

Borozdin and Priedhorsky, in collaboration with R. Shirey of UCSB and representatives from other XMM instrumental teams, analyzed the observations of the central 30 arc min of

the nearby spiral galaxy M31. In the 34-ksec observation they detected 116 X-ray sources down to a limiting luminosity of 6×10^{35} erg s^{-1} (0.3 – 12 keV, $d = 760$ kpc). They made use of hardness ratios for the detected sources in order to distinguish between classes of objects such as super-soft sources and intrinsically hard or highly absorbed sources. They showed the extent of diffuse emission in the bulge of M31, and they demonstrated that it clearly contained a ~ 0.3 keV thermal plasma component distinct from the composite point-source spectrum.

Borozdin, in collaboration with W. Pietsch (MPE, Germany) and representatives from other XMM instrumental teams, analyzed the first XMM-Newton observations of the starburst galaxy NGC 253. As known from previous X-ray observations, NGC 253 shows a mixture of extended (disk and halo) and point-source emission. The high XMM-Newton throughput allows for the first time a detailed investigation of the spatial, spectral and variability properties of these components simultaneously. A bright X-ray transient was detected near the nucleus. Spectra and light curves for the brightest point sources have been obtained.

Vestrand is part of an international team that is studying new XMM observations of the Coma cluster which are, by an order of magnitude, the deepest X-ray observations ever made of the cluster. These imaging spectroscopy observations are having a profound impact on our understanding of Coma, which is considered by many to be the archetypical rich cluster of clusters. Contrary to previous ASCA results, the temperature distribution around the two central galaxies is homogeneous, suggesting that the core is actually in a relaxed state. However, the galaxy group around NGC 4839 shows a complex temperature structure consistent with an ongoing merger of the group with the main cluster. Since the NGC 4839 group is known to be located along the large scale filament that connects Coma and A1367, the XMM observations support the idea that clusters form preferentially through accretion of sub-clusters along large scale filaments.

Vestrand is also working with the XMM team that is studying deep observations of the giant elliptical galaxy M87. The very high sensitivity of the instruments on XMM-Newton has allowed the team to image X-ray emission that is spatially coincident with non-thermal radio emission and to establish unambiguously that it is thermal X-ray emission from a hot plasma. A study of the radial abundance and temperature distribution of the plasma is currently underway. The preliminary results show a sharp drop of metal abundances in the central regions. An interesting possibility is that the observed decrease in line strength is due to resonant line scattering.

Vestrand is also leading an effort to use the Chandra observatory to make the first high-resolution spectroscopic measurements of X-ray emission from comets. The origin of X-ray is still a subject of heated debate. There are two leading candidates for generating the emission: (1) charge exchange interactions between heavy solar wind ions and neutral atoms in the coma and (2) scattering and fluorescence of solar X-rays by cometary dust grains. The charge exchange model predicts an X-ray spectrum that is dominated by line emission. In contrast, cometary X-ray emission generated by

dust scattering will be dominated by continuum emission. High resolution spectral observations are therefore the key to understanding the origin of cometary X-ray emission.

A collaboration led by D. Band (X-2) observed the Galactic jet-producing binary SS 433 with the X-ray satellite RXTE over three campaigns with simultaneous optical, radio and mm-band coverage. The observations support the model of thermal X-ray emission from the jets where the temperature decreases with distance from the compact object.

K. Borozdin and W. Priedhorsky studied point sources and diffuse X-ray emission from the bulge of the Andromeda galaxy (M31). Using *ROSAT* PSPC data, they performed several tests aimed at understanding the origin of the soft X-ray spectral component detected from the bulge of M31. They found that a significant soft component in the spectrum of the bulge is spatially correlated with the unresolved X-ray emission near the core of M31, which is probably a hot interstellar medium or perhaps a population of multiple faint sources. For the first time, they extracted the spectrum of this unresolved emission, by removing point sources dominating the integral spectrum of the bulge, and found it to be responsible for the most of soft excess. A soft spectral component is not at all needed to fit the point source spectrum that remains after subtracting the unresolved emission. The integral spectra of bright point sources, both inside and outside of the M31 bulge, can be fitted with a single power-law in the *ROSAT* band. Their analysis rules out the previous suggestion that all bulge emission in M31 may be generated by low mass X-ray binaries (Irwin & Bregman, 1999).

K. Borozdin and S. Trudolyubov reported the detection of a 5-Hz QPO from X-ray Nova GRS 1739-278. The X-ray nova GRS 1739-278 flared up near the Galactic center in the spring of 1996. The authors detected ~ 5 -Hz quasi-periodic oscillations (QPO) in RXTE/PCA observations of GRS 1739-278. The QPO were only present when the source was in its very high state, and disappeared later, when it made a transition down into the high state. They presented the energy spectra of this black hole candidate measured in both high and very high states, and discussed the similarities between this system and other X-ray transients.

S. Trudolyubov, K. Borozdin and W. Priedhorsky analyzed RXTE observations of 4U 1630-47 during the peak of its 1998 outburst. The light curve and the spectral evolution of the outburst were distinctly different from the outbursts of the same source in 1996 and in 1999. Special emphasis of their analysis was on the observations taken during the initial rise of the flux and during the maximum of the outburst. The maximum of the outburst was divided into three plateaus, with almost constant flux within each plateau, and fast jumps between them. The spectral and timing parameters were stable for each individual plateau, but distinctly different between the plateaus. The variability detected on the first plateau was of special interest. During these observations the source exhibits quasi-regular modulations with period of $\sim 10-20$ s. The analysis revealed significant differences in spectral and temporal behavior of the source at high and low fluxes during this period of time. The source behavior could be generally explained in the framework of the two-phase model of the accretion flow, involving a hot inner compton-

ization region and surrounding optically thick disk.

K. Borozdin, in collaboration with M. Revnivtsev and R. Sunyaev (IKI, Moscow, Russia; and MPA, Garching, Germany) found a strong QPO feature at 0.085 ± 0.002 Hz in the power spectrum of X-ray transient XTE J1118+480. The QPO was detected in PCA/RXTE data with an amplitude close to 10% rms, and the width 0.034 ± 0.006 Hz. The shape of the power spectrum was typical for black hole candidates: almost flat at frequencies lower than 0.03 Hz, roughly power law with slope ~ 1.2 from 0.03 to 1 Hz, with a following steepening to ~ 1.6 at higher frequencies. The hard energy spectrum detected up to ~ 150 keV and the absence of significant X-ray variability at the high frequencies above 100 Hz strongly supported the identification of XTE J1118+480 as black hole transient.

K. Borozdin and W. Priedhorsky, in collaboration with M. Revnivtsev (IKI, Moscow, Russia), A. Vikhlinin (CfA, Harvard) analyzed Rossi X-ray Timing Explorer observations of GS 1354-644 during a modest outburst in 1997-1998. The source is one of a handful of black hole X-ray transients that are confirmed to be recurrent in X-rays. A 1987 outburst of the same source observed by Ginga was much brighter, and showed a high/soft spectral state. In contrast the 1997-1998 outburst showed a low/hard spectral state. Both states are typical for black hole binaries. The RXTE All Sky Monitor observed an outburst duration of 150 to 200 days. PCA and HEXTE observations covered ~ 70 days near the maximum of the light curve and during the flux decline. Throughout the observations, the spectrum can be approximated by Compton upscattering of soft photons by energetic electrons. The hot electron cloud has a temperature $kT \sim 30$ keV and optical depth $\tau \sim 4-5$. Dramatic fast variability was observed, and has been analyzed in the context of a shot noise model. They noted a qualitative difference in the shape of the dependence of fractional variability on energy, when they compared systems with black holes and with neutron stars. Since it is difficult to discriminate these systems on spectral grounds, at least in their low/hard states, this new difference might be important.

S. Trudolyubov and K. Borozdin, in collaboration with M. Revnivtsev, analyzed the RXTE observations of the recently discovered Galactic microquasar XTE J1748-288 during its 1998 outburst. The spectral evolution of the source during the outburst can be considered a sequence of qualitatively distinct states. During the first observations, corresponding to the maximum of X-ray flux, the spectrum of the source consisted of a dominating hard power law component and a soft thermal component, which can be described by the model of multicolor disk emission. The hard component contributed $>80\%$ to the X-ray luminosity in the 3-25 keV energy band. Later on, as the X-ray source faded, its energy spectrum qualitatively changed, showing High (HS) and then Low (LS) states, both typical for black hole binaries. As the energy spectrum changed, the fast variability also evolved dramatically. Initially the power density spectrum was formed by a dominating band-limited noise component, QPO features at 20-30 Hz and at ~ 0.5 Hz, and a very low frequency noise component. After a significant decrease of the contribution of the hard spectral component the amplitude of the

fractional variability decreased by an order of magnitude and the PDS spectrum adopted a power-law shape with a broad QPO peak around 0.03 Hz. A clear correlation between QPO parameters and X-ray flux was seen.

K. Borozdin, W. Priedhorsky and S. Trudolyubov, in collaboration with co-authors from IKI, Moscow; CfA, Harvard; and GSFC/NASA presented their analysis of RXTE observations of X-ray transients XTE J1748-288, GS 1354-64, 2S1803-245 and CI Cam. Light curves of the outbursts and spectra were discussed in comparison with earlier observations. Unique features for each system were mentioned. Special attention was paid to CI Cam as possible legate for new class of X-ray transients. The results were presented at the Fifth Compton Symposium, Portsmouth, NH, Sep 15–17, 1999.

K. Borozdin and W. Priedhorsky, in collaboration with V. Arefiev (IKI, Moscow, Russia), presented their studies of fast X-ray transients. Fast X-ray Transients (FXTs) are short duration X-ray sources that have timescales of minutes to hours. They have been observed by many instruments, from HEAO-1 to BeppoSAX, however, are still unexplained. Due to their wide range of observational characteristics, it is suspected that FXTs are a heterogeneous collection of objects involving different emission mechanisms. The relationship between FXTs and gamma-ray bursts (GRBs) is particularly intriguing. The results of BeppoSAX observations confirm that some but not all fast X-ray transients are counterparts of gamma-ray bursts. A fraction of 'classical' FXT are believed to be counterparts of GRB's, based largely on time coincidences with GRB events. Other FXTs might be "gamma-ray silent" GRB. The authors discussed the statistics and distribution of FXTs, and compared their characteristics with GRB prompt counterparts and afterglows. The results were presented at the Fifth Huntsville GRB Symp., Huntsville, AL, Oct 18–22, 1999.

W. Priedhorsky (PI), K. Borozdin, T. Vestrand and E. Fenimore, in collaboration with GSFC/NASA, CalTech, IKI (Moscow, Russia) developed a concept for a sensitive all-sky monitor (ASM). ASMs are indispensable for tracking changes in the highly variable X-ray sky. Past monitors have given us hints of rich variability on very fast timescales. With new technology we can explore this window in detail. Wide-field X-ray cameras and collimated hard X-ray detectors are able to continuously monitor the X-ray sky from 2 keV to 1 MeV. The X-ray cameras are four times more sensitive than the best previous ASM, and can locate bright sources in real time with accuracy down to arc minutes. The ASM is able, for the first time, comprehensively study the dynamic X-ray sky on timescales from seconds to years. Extensive simulations of the experiment performance have been carried out.

3.8 Gamma-Ray Bursts

The Robotic Optical Transient Search Experiment (ROTSE) is a collaboration between LANL (Rick Balsano, Jeff Bloch, Don Casperson, Sandy Fletcher, Galen Gisler, Bill Priedhorsky, John Szymanski, Tom Vestrand, Jim Wren (all NIS-2), Jack Hills (T-6)), the University of Michigan (Carl Akerlof, Bob Kehoe, Tim McKay), and LLNL (Stuart

Marshall) which has as its primary objective the rapid optical follow-up of Gamma Ray Burst (GRB) alerts from the Gamma Ray Coordinate Network (GCN). To catch these cosmic explosions, the ROTSE telescopes have to be standing by at all hours, ready to re-point to a gamma ray burst position at a moment's notice. In January 1999 ROTSE proved itself by being the first, and still only, telescope to catch a gamma ray burst in visible light while still flaring in gamma rays. While ROTSE was designed to respond to GRB alerts, in the past year we began a program to search for "orphan" gamma-ray bursts — optical transients from gamma-ray bursts that are not detected in gamma rays. In some theoretical scenarios the number of orphans should far exceed the number of GRBs detected at high energy.

ROTSE science is not limited to just studies of gamma-ray bursts. To ensure readiness and monitor data quality, the ROTSE telescopes also perform nightly automatic surveys of the entire overhead sky. The sky patrol data archived in Los Alamos from ROTSE I now amounts to nearly 4 Terabytes. Our pilot study of this sky patrol data, which was published in the *Astronomical Journal*, shows that ROTSE will have an important impact on stellar astronomy by increasing the number of known variable stars by an order of magnitude. The utility of the sky patrol data was also demonstrated this year by our observations of a new transient X-ray source, XTE J1118+480. While an armada of major observatories studied this remarkable black-hole candidate, our ROTSE data provided unique pre-discovery observations that show the entire development of an optical outburst that began before the X-ray outburst, placing important constraints on models of the system.

D. Band (X-2), T. Piran (Hebrew U.) and R. Jimenez (Rutgers) are determining the distribution function of the total energy emitted by a gamma-ray burst, as well as of the peak gamma-ray luminosity and the energy emitted in the X-ray afterglow. To expand the sample of bursts with spectroscopic redshifts, they have developed a methodology of estimating a burst's redshift from the observed brightness of the host galaxy. This methodology requires a model of the host galaxy population. Determined from burst data, their preferred model shows that the burst rate is proportional to a galaxy's luminosity. They find that the average burst energy is $\sim 10^{53}$ ergs, if radiated isotropically.

The "spikiness" of the burst light curve and the time lag between different energy bands have both been proposed as measures of the burst luminosity. B. Schaefer, M. Deng (Yale) and D. Band (X-2) are testing the consistency between these two correlations using time lags calculated by Band.

James Terrell (NIS-2), together with Ray Klebesadel (NIS-1) and Jim Griffiee (Sandia National Laboratory), is continuing the analysis of gamma-ray burst data produced by the Air Force Defense Meteorological Satellite Program. Satellites DMSP-13 and DMSP-14 are currently in operation in 800-km altitude orbits, producing time histories and spectral data on numerous gamma-ray bursts with 2-second resolution, as well as high-resolution time histories of stronger bursts which meet the trigger criteria.

D. Band (X-2) is also part of collaborations led by R.

Preece (MSFC), B. Schaefer (Yale) and M. Tavani (Columbia) studying various aspects of the spectral evolution of gamma-ray bursts.

D. Band (X-2) is a member of the LOTIS collaboration. Similar to the ROTSE project, LOTIS develops robotic telescopes to catch optical emission during or immediately after a gamma-ray burst; unfortunately, LOTIS I has only provided upper-limits thus far. Band relates the gamma-ray data to the optical upper limits.

D. Band (X-2) is a member of the MARGIE collaboration among the high energy astrophysics groups of UCSD, UCR, LSU, UNH, and Washington U. to design a coded mask-Cadmium-Zinc-Telluride detector system for a ~ 100 day balloon flight. Detecting ~ 40 gamma-ray bursts is the primary objective, but MARGIE will survey the sky in the ~ 50 – 500 keV band while waiting for a burst to occur. Band models the detector system to determine the number of bursts which will be observed.

3.9 Other Observational Astronomy

Robert C. Reedy (NIS-2) has worked on mapping the elemental composition of planetary surfaces using gamma rays, x rays, and neutrons. Sources of gamma-ray lines and backgrounds observed in spectra measured by Lunar Prospector are being identified and used to map the abundances of several elements over the Moon's surface. The x rays measured from the asteroid 433/Eros by the Near Earth Asteroid Rendezvous Shoemaker spacecraft indicate that Eros is relative primitive with roughly a chondritic composition. Work is being done modeling gamma-ray and neutron emission from Mars in preparation for the Mars 2001 orbiter.

This summer marked the fourth consecutive year in which we hosted a group of eight high school students through the Earthwatch Institute's Student Challenge Awards Program. Funded by the Durfee Foundation, this program provides an opportunity for these gifted students to spend two weeks at LANL in an astronomy and astrophysics based curriculum, with an emphasis towards "hands-on" learning at Fenton Hill Observatory. The agenda was coordinated with the Bradbury Science Museum's annual "Astronomy Days" lecture series. At FHO, the students collected images with the REACT telescope and its CCD camera, and viewed the night skies directly with several Schmidt-Cassegrain and Maksutov telescopes.

In addition to optical astronomy, the Earthwatch students learned about radio astronomy, highlighted by a trip to the VLA near Magdalena, NM. They directly participated in some radio background measurements at FHO with an rf spectrum analyzer, and were present for the earliest construction stages of a 151-MHz phased array radio telescope at Fenton Hill.

The Magdalena Ridge Observatory project (Galen Gisler, Peregrine McGehee, Bryan Laubscher, Sandy Fletcher) is being designed by a consortium of universities (New Mexico State University, New Mexico Institute of Mining and Technology, New Mexico Highlands University, and the University of Puerto Rico) to consist of 2 or 3 moderate aperture (2.5m) optical/infrared telescopes atop the 10000 ft Magdalena Ridge west of Socorro, New Mexico. Scientists

at LANL have interacted extensively with the consortium members with respect to the science drivers and the design of these telescopes. It is likely that LANL will be admitted to the consortium in the fall of 2000.

The University of Puerto Rico Interferometer (Galen Gisler, Peregrine McGehee) is a 3 to 4 element infrared interferometer being built at the Los Alamos site at Fenton Hill Observatory in conjunction with scientists at the University of Puerto Rico, New Mexico Institute of Mining and Technology, and the Air Force Research Laboratory. This interferometer is designed to be a prototype for a substantially larger interferometer that will be part of the Magdalena Ridge Observatory. Construction began at Fenton Hill in the summer of 2000 on the telescope support pads and on a walkway to support the beam line. The control building for the former Hot Dry Rock experiment is being refurbished as a beam combining building. The individual telescopes are being assembled at NMIMT, and are planned to be installed at Fenton Hill in spring 2001.

Together with researchers and administrators from UC Berkeley, Rensselaer Polytechnic Institute, the University of New Mexico, and Diné College, we have formed a consortium to build an innovative wide-field telescope on the Navajo Reservation near Tsaile Arizona. This telescope will achieve goals of enhancing communications infrastructure on the Navajo Reservation and educating Navajo youth in high-tech science and engineering, while providing the international scientific community a world-class facility for wide-field surveys and transient monitoring. The first-rate nature of this facility will additionally provide a source of pride among Navajo youth and encourage aspirations to pursue science or engineering careers. The Navajo culture accommodates well to the character of astronomy as a science that passively observes Nature and integrates other disciplines. The facility we will build, tentatively called the Din International Research Center (DIRC), will eventually house other scientific endeavors also, especially including biology and geosciences, using astronomy as the central core. Din College administrators are on board with these plans and are presently setting up meetings for us with tribal medicine men and the tribal government.

P. McGehee (LANSCE-8) continues to support controls engineering and operations at the Sloan Digital Sky Survey 2.5 meter telescope at Apache Point Observatory, NM. He is the architect of the EPICS (Experimental Physics and Industrial Control System) based Telescope Performance Monitor which is responsible for real-time display and archival of telescope engineering status and performance.

Los Alamos National Laboratory expanded its efforts this past year to assist the SDSS in its challenging goal of mapping the North Galactic Cap. Our efforts include carrying out survey observations, troubleshooting instrumentation and software problems as well as creating engineering solutions to the issues of telescope controls, operations and instrumentation.

Anders Jorgensen joined the effort this year to assume the photometry telescope observing duties from Bryan Laubscher and has contributed to the numerical analysis of the

SDSS Photometric System as well as the software that controls the photometry telescope.

Peregrine McGehee has built upon his past telescope controls engineering efforts of the last years by completing and updating the Telescope Performance Monitor (TPM) in addition to providing engineering solutions to problems that have arisen throughout the year. Peregrine has begun research on T Tauri stars by searching the SDSS data and carrying out follow-up observations of these candidates.

Bryan Laubscher has moved from performing observations using the photometry telescope to carrying out survey observations with 2.5 meter survey telescope. In addition he performed engineering work on the photometry telescope. Bryan has begun research on large scale structure and astrophysical transients with the SDSS data.

In conjunction with Gary Loos (Air Force Research Lab.), Peregrine McGehee (LANSCE-8) co-authored an interferometry design paper that was presented at the SPIE conference on Optical Interferometry in Garching. This work examined the effective PSFs (point spread functions) and sensitivity of large aperture near-infrared arrays for configurations similar to the MRO as part of a design study for aperture synthesis imaging.

3.10 Workshops

The Los Alamos Branch of the Institute for Nuclear and Particle Astrophysics and Cosmology helped to host a workshop in Carlsbad, New Mexico, on future underground physics and astrophysics experiments in June 2000. The workshop was very well attended, and included a tour of the underground facilities available at the Waste Isolation Pilot Project. A number of important new initiatives are likely to arise from the discussions held at this event, taking advantage of the low-background and seismic stability that are characteristic of the WIPP site. Significant among these new initiatives are a planned detector for multi-flavor neutrinos from supernovae, and a massive proton decay detector.

A Workshop on the Origin of the Heavy Elements: Astrophysical Models and Experimental Challenges was held in Santa Fe, New Mexico on September 3-4, 1999. Approximately 50 scientists participated in this Workshop, and presentations were made by 14 speakers, 6 from the US and 8 from other countries. The focus was on s-, r- and rp-process nucleosynthesis. Laboratory experiments, both present and planned, and astrophysical observations were represented as were astrophysical models. The proceedings are available as a Los Alamos National Laboratory report, LA-13686-C by sending e-mail to haight@lanl.gov.

PUBLICATIONS

The publication list includes all papers published or submitted between July, 1999 and June, 2000 by LANL staff and their collaborators.

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