

Los Alamos National Laboratory

Los Alamos, New Mexico 87545

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This report is for astronomy-related research at Los Alamos National Laboratory covering the period 1 July 1997 through 30 June 1998.

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. In Section 3 are the research contributions, ordered roughly by subject matter. 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 already in the late 1950's in order 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.

Astrophysics, starting with stellar structure and violent activity in stars, 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.

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 ultra-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° 40W, a latitude of 35° 53N, 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 is now 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 under construction on Fenton Hill in a 5-million gallon pond used by the Hot Dry Rock project in its early days. Milagro will be augmented by several wide-angle Cerenkov telescopes (WACT) to study the composition of cosmic rays. The Robotic Optical Transient Search Experiment (ROTSE) telescopes will be installed at Fenton Hill when their debugging, in their 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) are proceeding with a target completion date of fall 1998. Other instruments are expected to be installed subsequently as a result of other collaborations with the University of California, and New Mexico institutions. Eventually the site may become a University of California Research Station under the auspices of INPAC.

3. RESEARCH

3.1 Structure of the Sun and Stars

Many intrinsic variable stars display period changes that seem to be too rapid or of the wrong sign to be attributed to a radius change caused by normal stellar evolution. Cox (T-6) has investigated whether these period changes could be due to a changing composition structure in the outer stellar envelope where pulsation periods strongly sense the stellar structure. A composition gradient in hydrostatic equilibrium will cause a density gradient different from that for an envelope with a homogeneous composition. The Cepheid variable star Polaris and a double mode RR Lyrae variable star (V53)

in the globular cluster M15 have been investigated assuming in the first case that slow convective overshoot and in the second case slow accretion of interstellar matter can change the composition structure of these two stars enough to completely explain their observed period changes. A particular problem with the RR Lyrae variable is that the two modes change periods in opposite directions, almost surely ruling out a simple, but unreasonably rapid radius change. The mechanisms discussed in an *Astrophysical Journal* paper include the slow gravitational settling of helium over the life of a star, dredge-up of helium by convection overshoot, mass loss, the accretion of a similar composition interstellar matter to deepen a preexisting composition gradient, tidal distortions and composition mixing by stellar encounters, and rotation mixing if a star spins rapidly enough.

For almost eight years, Cox (T-6) has been revising the famous handbook *Astrophysical Quantities* by C. W. Allen. The manuscript is now finished for 27 chapters, 706 text pages, 411 tables, and 86 line drawing figures. There are 91 authors for entire chapters or just short sections. Springer in New York will publish the book near the end of 1998. The American Astronomical Society sponsored the creation of this fourth edition.

J.A. Guzik (XTA) continued her work on solar structure and helioseismology, and presented an invited review at the SOHO-5/GONG'98 workshop in Boston in June 1998. Guzik also worked with GRA Matthew Templeton (New Mexico State U.) on pulsations of delta Scuti variable stars; with XTA postdoc Anthony Kaye on determining the pulsation mechanism for gamma Doradus variable stars; and with Arthur N. Cox (T-6) and UGS Kate Despain (Brigham Young U.) on hydrodynamic modeling of the envelopes of Luminous Blue Variables. The luminous blue variable results were presented in invited talks at IAU 169 in Heidelberg, Germany in June 1998, and at a workshop on Eta Carinae in Montana in July, 1998 (proceedings in preparation).

Robert Deupree (DX-7) performed both 2D evolutionary and 2D hydrodynamic simulations of rotating stars, focusing on the amount of convective core overshooting and the angular momentum distribution in the convective cores of massive core hydrogen burning stars. The conclusions to date indicate that all models show convective core overshooting, with more overshooting for slower rotation. The amount of overshooting ranges from about 0.2 to 0.5 pressure scale heights beyond the formal boundary of the convective core. The angular momentum distribution in the convective core appears to fit a power law in the distance from the rotation axis, as long as a cutoff at small distances from the rotation axis is imposed. Deupree received a NASA Theory Program grant this year to continue this work.

Paul Bradley (XTA) is working on seismology of the hydrogen atmosphere (DAV) white dwarfs. Bradley used his recently published grid of pulsation periods for evolutionary DA models to fit the observed periods of the white dwarfs G 117-B15A and R 548 (1998, *ApJS*, 116, 307). These two white dwarfs have masses between 0.55 and $0.60M_{\odot}$, consistent with the spectroscopic mean mass of white dwarfs in general. The favored hydrogen layer mass for both stars is about $10^{-4}M_{\star}$, but masses near $10^{-7}M_{\star}$ cannot be ruled

out. He is presently applying this grid of models to two more white dwarfs, L 19–2 and GD 165. Adding these two stars will help decide if there is a hydrogen layer mass common to all DAV white dwarfs or if there is a range of hydrogen layer masses. Answering this question is important, because it affects the cooling history of white dwarfs and also how white dwarf progenitors lose mass in the planetary nebula phase of their evolution.

3.2 Supernovae

In collaboration with F. Marshall, W. Zhang, & E. Gotthelf of GSFC, and D. Q. Wang of Northwestern U., J. Middleditch (CIC-19) took a look at XTE data from SN1987A with his Los Alamos-based software, just to make sure nothing was being missed prior to the data being made public. A 62.055 Hz signal with higher harmonics consistent with a very sharply-peaked pulse was found in 6 hours of XTE data from October, 1997. The signal was then found in other XTE PCA data taken just earlier in December.

Subsequent analysis of ASCA data by Gotthelf and Wang pinpointed the source of the pulsed X-rays to the LMC SNR N157B (although the XTE PCA was centered on SN1987A, its 1° FOV admitted several other SNR's). Thus the pulsed X-ray source is likely the neutron star remnant of a supernova which Gotthelf and Wang estimated to be some 4,000 years old, based on their previous study using ROSAT data. The timing age of the pulsar, derived from the ratio of its period to twice the period derivative, was about 5,000 years, meaning that the pulsar had been born with a spin period of only 7 milliseconds. Previously, “traditional” theories had said that no pulsar could be born spinning faster than ~ 100 Hz, and that the pulsars with millisecond periods were *all* spun up via accretion from material donated by a “normal” binary companion star. A recent twist on this picture advanced by B. Owen, L. Lindblom and their collaborators has hot young neutron stars, perhaps born spinning rapidly, “sloshing” inside and thus producing copious amounts of gravitational radiation in order to slow to ~ 100 Hz by one year of age.

Cracks in the traditional theory had already been apparent for a decade, ever since Middleditch and collaborators discovered a 3 ms pulsar in the globular cluster, M28, to be followed by the discovery of several dozen more pulsars in globular clusters (10 in 47 Tuc alone). The great abundance of ms pulsars in the globulars, coupled with the scarcity of their supposed progenitors, the X-ray binaries, in the same set of clusters, was difficult to reconcile. Still, many astrophysicists clung stubbornly to the traditional theory, in spite of this growing disparity and the mounting evidence for the *lack* of any strongly-magnetized, moderately rapidly spinning (~ 60 Hz) pulsar in the remnant of Supernova 1987A.

With a magnetic field of just under a teragauss, the pulsar J0537-6910 in N157B now clearly indicated that the weaker the magnetic field at birth, the more rapidly spinning the pulsar at birth – a very simple and obvious notion which academia had long rejected in favor of more complicated scenarios. Thus, in light of this “new” understanding of pulsar formation, if there was a way to produce a neutron star with a very weak magnetic field at birth, then the very

rapidly-spinning pulsars – those with true millisecond periods – could be produced in a supernova explosion, rather than by being recycled through a binary system possibly billions of years later.

SN1987A and the stellar dynamics of the globular clusters offered the clue necessary to solve this puzzle. It is now thought, thanks to Phillippe Podsiadlowski and others, that SN1987A was produced by the merger of the white dwarf cores of two massive stars. This would certainly explain the blue supergiant progenitor, the extreme mixing of the elements, the rings, and, finally the [implied] very fast, but weakly magnetized pulsar remnant. Certainly, the 2.14 ms pulsar candidate discovered by Middleditch and his collaborators in SN1987A is consistent with this picture, since the pair of progenitor white dwarf cores would not contain much Fe due to the timescale of the binary coalescence and core merger, and would thus not be strongly magnetized, in spite of their high specific angular momentum. The timing irregularities associated with the 2.14 ms signal are also consistent with more moderate and longer-persisting “sloshing” of Owen and Lindblom. Meanwhile the mechanism by which the globulars produce their overabundance of ms pulsars is clearly via white dwarf-white dwarf mergers resulting from the binary-binary collisions of late-type, low mass stars, resulting in Type IB supernovae. This scenario is further corroborated by the absence of pulsars in globular clusters with spin periods shorter than 2 ms (determined, according to S. Colgate, by the branching of the Maclaurin-Jacoby instability in the white dwarf-white dwarf merger process).

So now the picture of ms pulsar formation is nearly complete. There are probably some instances in which ms pulsars are produced via recycling of old neutron stars through binary systems, but clearly, most of the ms pulsars in globulars, and the pulsar remnant in SN1987A were born in “original spin” – with ms periods – through the core merger process.

The paper on the 2.14 ms candidate in SN1987A is undergoing final revision for *New Astronomy*.

3.3 Neutron Stars

Richard Epstein (NIS-2) worked with Bennett Link (Montana State University) and Lucia M. Franco (University of Chicago) to investigate starquake-induced magnetic field changes in neutron stars and the resulting and torque evolution. The persistent increases in spin-down rate (*offsets*) seen to accompany glitches in the Crab and other pulsars suggest increases in the spin-down torque. They interpret these offsets as due to *starquakes* occurring as the star spins down and the rigid crust becomes less oblate. They studied the evolution of strain in the crust, the initiation of starquakes, and possible consequences for magnetic field and torque evolution. Crust cracking occurs as equatorial material shears under the compressive forces arising from the star's decreasing circumference, and matter moves to higher latitudes along a fault inclined to the equator. They found that a starquake is most likely to originate near one of the two points on the rotational equator farthest from the magnetic poles. The material breaks along a fault approximately aligned with the magnetic poles. They suggested that the

observed offsets come about when a starquake perturbs the star's mass distribution, producing a misalignment of the angular momentum and spin axes. Subsequently, damped precession to a new rotational state increases the angle α between the rotation and magnetic axes. The resulting increase in external torque appears as a permanent increase in the spin-down rate. Repeated starquakes would continue to increase α , making the pulsar more of an orthogonal rotator.

3.4 Interstellar Medium

Anthony. L. Peratt (XPA) and Gerrit L. Verschuur, University of Memphis, are working on the critical-ionization-velocity effect in the interstellar medium. Observations of neutral hydrogen (HI) emission profiles produced by gas in the local interstellar medium are found to be characterized by four linewidth regimes. A striking coincidence exists between these linewidths and the magnitudes of the critical ionization velocities of the most abundant atomic species in interstellar space. The data relate to observations near neutral hydrogen clouds that are filamentary in morphology, the geometry most often associated with magnetic fields in critical ionization velocity theory.

3.5 Gamma-Ray Bursts and Other Transients

James Terrell (NIS-2) has continued analyzing satellite gamma-ray burst data from seven Air Force DMSP (Defense Meteorological Satellite Program) spacecraft, together with Ray Klebesadel, John Laros (University of Arizona), and Jim Griffiee (Sandia National Laboratory). Two of these (DMSP 13 and DMSP 14) are currently in use, in 800-km altitude orbits. Many bursts have been detected and analyzed, usually in coincidence with other satellites such as GRO, Ulysses, BeppoSax, or Konus/Wind.

Especially good data have been obtained from the recent very powerful gamma-ray burst on 27 August 1998 (GRB980827), which saturated both counters on DMSP 13 and DMSP 14, and also triggered the high-time-resolution circuits. The periodicity of 5.15 seconds was obvious, as were two peaks in the counting rate and a long (\sim 200 sec) tail. Analysis of this burst is continuing and will result in a published paper if possible.

ROTSE (Susan Amrose, Jeff Bloch, Don Casperson, Sandy Fletcher, Galen Gisler, Donglai Gong, Dan Kocevski, John Szymanski, Jim Wren (all NIS-2), Carl Akerlof (U Mich), Bob Kehoe (U Mich), Brian Lee (U Mich), Stuart Marshall (Livermore), Tim McKay (U Mich)). The Robotic Optical Transient Search Experiment installed its phase I instrument (consisting of 4 0.11-m aperture lenses and CCD cameras) at the LANSCE site in Los Alamos in the summer of 1997, and began routine automated observations in March 1998. Several automated responses to gamma-ray burst alerts have been performed, and routine sky patrols of the entire overhead sky down to 15th magnitude are carried out every clear night. Over 1 Terabyte of data from this instrument has now been archived at Los Alamos. The phase II instrument, a pair of Torus Optics 0.45-m telescopes, is presently being checked out and debugged at the LANSCE site.

Fenton Hill Observatory (Don Casperson (NIS-2), Galen Gisler (NIS-2), Todd Haines (P-23), Guthrie Partridge (NIS-2), Cathy Plesko (NIS-2), Jim Wren (NIS-2), Chad Young (P-23)). Astronomical surveys for the new observing site at Fenton Hill (106 degrees, 40 minutes, 23 seconds West longitude, 35 degrees, 52 minutes, 50 seconds North longitude, 2641 meters elevation) were performed, and a concrete pad with telescope piers was installed in the spring of 1998. Power and ethernet were run to the pad, and a small building to house electronics was placed. A camera for recording day-time cloud cover has been running on the site since November 1997, saving images every half hour to the website <http://laastro.lanl.gov/fho/>.

REACT (Don Casperson, Galen Gisler, Guthrie Partridge, Cathy Plesko, Jim Wren (all NIS-2), Chad Young (P-23), Phil Lubin (UCSB), Carl Pennypacker (UCB)). The Research and Education Automatically Controlled Telescope (REACT) was installed at the Fenton Hill Observatory site in June 1998. A remotely operable dome from Technical Innovations was erected on the new FHO pad and the telescope, a beefed-up and refurbished Celestron C-14 from Epoch Instruments, was installed. First light with the telescope was June 18th, during an Earthwatch Institute Student Challenge Awards Program campaign, with eight high school students from around the US participating. Software integration of the telescope and dome continues, with the goal of performing routine automated and remote operations, and supplying images to schools via the Hands-On Universe program.

Earthwatch Campaign, "Transient Phenomena in Astrophysics (Don Casperson, Galen Gisler, Guthrie Partridge, Cathy Plesko (all NIS-2), Todd Haines (P-23), with the assistance of Donna Powell (Crownpoint, NM Middle School)). For the second year, we hosted a Student Challenge Awards Program from the Earthwatch Institute, funded by the Durfee Foundation, on astronomical transient phenomena. The students helped with the development of the Fenton Hill Observatory site, with the debugging of the REACT telescope and dome, and with seeing measurements. In addition they participated in a number of cultural events. The 1998 Earthwatch students were: Beth Brown, Jon Darvill, David Hamner, Matt Jones, Elyne Kahn, Corrie Lambrecht, Dana Sadava, and Megan Wernke.

Konstantin Borozdin (NIS-2), Mikhail Revnivtsev, Sergey Trudolyubov, Chris Shrader and Lev Titarchuk are working on an X-ray spectra analysis of black-hole transients using RXTE data in terms of bulk motion comptonization model.

We present an analysis of the high-energy radiation from black hole (BH) transients, using archival data obtained primarily with the Rossi X-ray Timing Explorer (RXTE), and a comprehensive test of the bulk motion Comptonization (BMC) model for the high-soft state continuum. The emergent spectra of over 30 separate measurements of GRO J1655-40, GRS 1915+105, GRS 1739-278, 4U 1630-47 XTE J1755-32, and EXO 1846- 031 X-ray sources are successfully fit by the BMC model, which has been derived from basic physical principles in previous work. This in turn provides direct physical insight into the innermost observable regions where matter impinging upon the event horizon

can effectively be directly viewed. The BMC model is characterized by three parameters: the disk color temperature, a geometric factor related to the illumination of the black hole site by the disk and a spectral index related to the efficiency of the bulk motion upscattering. For the case of GRO J1655-40, where there are distance and mass determinations, a self consistency check of the BMC model has been made, in particular, the assumption regarding the dominance of gravitational forces over the pressure forces within the inner few Schwarzschild radii. We have also examined the time behavior of these parameters which can provide information on the source structure. Using our inferred model parameters: color temperature, spectral index and an absolute normalization we present new, independently derived, constraints on the black hole mass, mass accretion rate and the distance for the aforementioned sources. Also notable is the relationship between the color temperature and flux, which for GRO J1655-40 is entirely distinct from a simple T^4 dependence, and strikingly consistent with the disk model we have invoked - standard Shakura-Sunyaev's disk with the modification to the electron scattering. This provides insight into the origin of the seed soft photons, and allows us to impose an important estimation of the hardness parameter, T_h , which is the ratio of the color temperature to the effective temperature - we find $T_h \approx 2.6$, higher than previous estimates used in the literature.

Revnivtsev, M., Emelyanov, A. and Borozdin, K studied the RXTE observation of an X-ray outburst from CI Cam/XTE J0421+560 system. The observations of X-ray transient XTE J0421+560, which is an X-ray counterpart of symbiotic binary CI Cam, by RXTE experiments give a set of important and unexpected results. The source attracted attention because of the unusually fast rise of its X-ray flux, which was followed by an unusually fast decline after the maximum passage. During 10 days of observations by PCA and HEXTE experiments the flux from the source decreased by more than two orders of magnitude. One interesting result is the detection of a soft X-ray flare, which was not correlated with the flux change in harder energy range. The source spectrum in 3-150 keV band can be approximated by power-law with an exponential cut-off at higher energies. The spectrum of this shape can be generated in the cloud of non-thermalized optically thin plasma. The softening of the spectrum (or decrease of the effective temperature) with the decrease of flux has been mentioned. The emission lines have been detected at energies 6.5-6.7 keV and around 8 keV. The discovered shift of the 6.7-keV line to lower energies can be explained either as Doppler-effect for moving media, or as generation of another, 6.4-keV emission line in a cold cloud, the density of which evolved with time. If this is due to the Doppler-effect, then this is the second time, after SS433, when X-ray emission generated by relativistic jet plasma has been observed in our Galaxy. In this case the cloud is observed at an angle $\sim 80^\circ$ to the line of sight. The appearance of the line near 8 keV is probably due to the emission of highly ionized Ni or Fe K_β line, and, as far as we know, is detected for the first time for Galactic sources.

3.6 X-Ray Astronomy

Konstantin N. Borozdin, Steven P. Brumby, William C. Priedhorsky (all NIS-2) performed long-term X-ray observations of Cyg X-3. For this study we have used publicly available data from the all-sky monitor aboard Rossi X-ray Timing Explorer satellite. We found that the shape of the lightcurve for Cyg X-3 is quite stable against flux variations and can be satisfactorily described by the classical EXOSAT lightcurve. However, the hardness dependence is different for high and low fluxes. These results provide some restrictions on the existing models of the system.

W. Priedhorsky, S. Brandt, K. Borozdin, (all NIS-2) are working on implementing an All-sky X-ray Camera on the International Space Station. A pinhole camera is an elegant but effective approach to an x-ray all-sky monitor. It is an ideal astrophysical instrument for the Space Station, because it does not require pointing, is robust against contamination, and requires modest resources (120 kg, 50 Watts, 10 kpbs). Nonetheless, it would be more sensitive than any previous all-sky x-ray monitor. By continuously monitoring the entire unocculted sky, this instrument would be sensitive to changes at all timescales. Besides monitoring the brightest few hundred x-ray sources, including about a dozen active galactic nuclei, this instrument would be uniquely sensitive to fast transients, unlike any scanning instrument. We would expect to detect several hundred events per year with timescales from a minute to a day, and better understand their correlation with magnetic activity on nearby stars. We would also expect to detect about 50 gamma-ray bursts per year and locate them to 1 square degree, independently verifying the BATSE sky distribution. Issues involved in flying this instrument on the Space Station include the management of image data from a continuously scanning 2-dimensional field, autonomous determination of aspect using x-ray image data, the detection and exclusion of solar panel occultation from the data, the optimum integration of a very wide-field instrument onto an EXPRESS pallet, safety validation of already-built hardware, and thermal considerations for a very low-power instrument. We conclude that Space Station is an attractive platform to conduct wide-field x-ray astronomy.

3.7 Ultra-high-energy astrophysics

The Milagro Air Shower Detector: Cyrus M. Hoffman, Todd J. Haines, Richard S. Miller & Gus Sinnis (all P-23), Galen Gisler (NIS-2), D. Berley, M.-L. Chen, D. Evans, J. A. Goodman, G. W. Sullivan (U. Maryland, College Park), S. Hugenberger, I. Leonor, A. Shoup, G. B. Yodh (UC Irvine), M. Cavalli-Sforza (U. Autonomia Barcelona), W. Benbow, D. G. Coyne, D. E. Dorfan, L. Kelley, J. McCollough, M. Moralez, D. A. Williams, T. Yang (UC Santa Cruz), R. Ellsworth (Geo. Mason U.), L. Fleysher, R. Fleysher, A. Mincer, P. Nemethy (New York U.) B. Shen, A. Smith, T. Tumer, K. Wang, M. Wascko (UC Riverside), A. Falcone, M. McConnell, J. Ryan, (U. New Hampshire), B. Dingus, J. McEnery (U. Utah). The Milagro air-shower detector is under construction in the Jemez Mountains, about 35 miles west of Los Alamos, NM. Milagro will be the world's first high-duty-factor, large-aperture telescope for cosmic

gamma rays around 1 TeV. The detector will consist of 750 photomultiplier tubes placed in a 5000 m² covered pond located at an elevation of 2640 m. Milagro will have an energy threshold below 500 GeV and a muon detection area of greater than 1500 m². Major objectives include searches 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. In the late summer, 1996, a prototype detector, called Milagrito, was installed in the pond.

Milagrito had 228 photomultiplier tubes sitting on the pond bottom covered with 1.5-m of water; it had the same energy and angular response as Milagro, although it was smaller and had no muon detection capabilities. Milagrito took data from February, 1997 to April, 1998. The primary purpose was to perform prototype tests of the Milagro hardware and to perfect reconstruction and analysis techniques. In addition, the data from Milagrito can be analyzed for evidence of transient and steady emission above 500 GeV: over 9 billion events were recorded. Preliminary analysis indicates that emission from Markarian 501 has been observed.

In spring, 1998, Milagrito was disassembled and the installation of full Milagro detector began. At this writing, nearly 700 photomultiplier tubes are deployed and the pond contains over 2.5 million gallons of water: completion is expected by fall, 1998 with data taking beginning soon thereafter. Observations with Milagro are expected to continue for 5-10 years.

Cosmic-Ray Composition

The WACT (Wide-Angle Cerenkov Telescope) collaboration (Gus Sinnis, Todd Haines, Cyrus M. Hoffman (LANL), Jordan Goodman (University of Maryland, College Park), Steve Stochaj, Tom Stephens (New Mexico State University), Guarang Yodh (University of California, Irvine), Don Coyne, David Williams (University of California, Santa Cruz), Brenda Dingus, Julie McEnery, Robert Atkins (University of Utah)) is studying the composition of high-energy cosmic rays.

Discovered at the turn of the century the origin and nature of the cosmic radiation is still a source of debate. Due to a steeply falling energy spectrum, the composition has been directly measured up to ~ 100 TeV. Above that energy the flux is too low to measure from high-altitude balloons or space craft. To date no ground-based measurement has been performed within the energy range of these direct measurements. The necessarily indirect nature of the ground-based measurements (measuring properties of the extensive air shower after ~ 20 radiation lengths) and the lack of a direct confirmation of the validity of any ground-based technique has led to continuing uncertainty in the cosmic-ray composition above 100 TeV. However, it is just at these energies where knowledge of the cosmic-ray composition is most useful. At energies near 5 PeV (PeV = 10^{15} eV) the all particle cosmic-ray flux steepens. Knowledge of the composition across this feature (the "knee") will help determine the origin of the high-energy cosmic rays. If the composition tends

to get lighter (protons) above the knee then these cosmic rays probably have an extra-galactic origin, while if the composition gets heavier (iron), the source of the cosmic rays is most certainly within our own galaxy.

The WACT collaboration will build an array of six Cerenkov telescopes to measure the lateral distribution of Cerenkov light in extensive air showers. With additional information from the Milagro detector (muon content and electromagnetic shower size) the array will be quite sensitive to cosmic-ray composition. By using a "camera" made of ~ 30 photomultiplier tubes to image the sky, WACT will achieve the twin goals of a low energy threshold (necessary to make a directly compare with the balloon and satellite measurements) and a large aperture (necessary to make a measurement at higher energies where the flux is very low). Over the past year we have obtained the mirrors for the telescopes, begun manufacturing of the telescope mounts, and designed the electronics. We will begin civil construction this year and hope to have our first camera installed in 1999.

3.8 Solar energetic particles

Robert C. Reedy (NIS-2) has studied solar energetic particles (SEPs) using both modern measurements and the lunar-nuclide fossil record. Analyses of several sets of results determined from the nuclides made in lunar samples by SEPs indicate that the average fluxes of SEPs for energies integrated above 30 and 60 MeV are fairly well determined. The lowest integral fluxes above these energies are those determined for the last 1–5 million years from stable ²¹Ne (in a 2-Myr-old rock), 3.7-Myr ⁵³Mn, 1.5-Myr ¹⁰Be, and 0.72-Myr ²⁶Al. The average fluxes increase with decreasing half-lives for 0.30-Myr ³⁶Cl, 0.10-Myr ⁴¹Ca, and 5730-year ¹⁴C. The highest fluxes of SEPs above 30 and 60 MeV are the average of those measured from 1954 to 1997.

3.9 Active Galactic Nuclei

Stirling Colgate, Hui Li (both of T-6), John Finn (T-15), Howard Beckley (NMT), Vladimir Pariev, Andy Nelson (Univ. of Az) have proposed the hydrodynamic mechanism by which angular momentum is transported in accretion disks, based on initial calculations and laboratory modeling. This depends upon the excitation of Rossby vortices by large radial gradients in entropy. The entropy gradient is created by the trapping of heat as the thickness builds up before the instability. This leads to a critical condition on thickness above which the non-linear transport will take place. The formation of such disks in the formation of black holes in galaxies leads to a natural circumstance for producing an $\alpha - \Omega$ dynamo with near infinite gain. Helicity is generated by star-disk collisions. The saturation or back reaction of this dynamo produces the AGN/quasar phenomena. The generated magnetic flux explains the magnetic fields of the universe. We have proven the helicity generation of plumes in the laboratory. We have shown with a kinematic dynamo code proof of principle of the $\alpha - \Omega$ dynamo.

Colgate (T-6) and Li (T-6 and NIS-2) have proposed a paradigm for the energy flow in AGN accretion disks by dynamo dominated accretion. The picture consists of: using

star-disk collisions in accretion disk around supermassive black holes as the basic flow structure for $\alpha - \Omega$ dynamo; the back reaction of this dynamo removes the angular momentum of matter near the black hole; and the formation of force-free helix whose dissipation is the ultimate origin of intense radiation from AGNs. This is written up as an invited lecture (Colgate & Li 1998) in an International Conference and Lindau Workshop on Plasma Astrophysics and Space Physics, Lindau, Germany.

Li and others have identified a new instability in accretion flow: Rossby wave instability in Non-Barotropic accretion disks (ApJ, in press). We are working on a more complete theory of this instability by both solving the linearized equations and fully 3D hydro simulations using a parallelized SPH solver developed by M. Warren (T-6). The preliminary linear theory has been worked out (Li *et al.*, APJL, to be submitted). We envision that this instability plays an important role in the angular momentum transport and generating QPO's that are commonly seen in stellar mass black hole systems.

Li and Kusunose continue to work on the particle heating and acceleration in accretion disks. Most of our recent work is summarized in an invited review at the meeting High Energy Processes in Accreting Black Holes, Graftavallen, Sweden, (Li 1998, PASP, in press). We have been using our fully time-dependent, wave-particle-photon coupled kinetic codes to model the multiwavelength observations of galactic x-ray binaries (Li & Kusunose, ApJ, submitted). We have also performed extensive comparisons between our kinetic code and Monte Carlo simulations (Kusunose & Li, ApJ, submitted).

Li and Dermer also use the same kinetic code to model the time-dependent multiwavelength AGN spectra, especially the TeV blazars (Dermer & Li, invited talk at INTEGRAL Workshop; also Li & Dermer, ApJL, to be submitted). We are studying the synchrotron-self-Compton (SSC) model in detail using the full Klein-Nishina cross section, which is very important in predicting the TeV flux. We find that a large Doppler factor (> 30) is required in general for the SSC model.

Sun (NIS-2), Fenimore (NIS-2) and Li have nearly completed a project searching for x-ray flares using data from ROSAT/PSPC. We are submitting a paper which describes our discovery of an x-ray superflare from a dM7e star (Sun, Fenimore & Li, ApJ, submitted). This result is surprising and has potentially important implication for stellar dynamo process since x-rays are generally not expected from such late type of stars. Several papers on our overall search results are also in preparation.

Li and Curt Michel (Rice), have written a review paper on Physics Report on Electrodynamics of Neutron Stars (in press). By studying the charge distributions around an active pulsar, we are making progress in understanding the dynamics of nonneutral plasmas.

Li is also working on understanding the damping of solar wind MHD turbulence by electrons and protons (Li & Gary, JGR, to be submitted); the reconnection process in accretion disk and astrophysical jets.

3.10 Numerical Modeling

Advances in the simulation of astrophysical and cosmic plasmas are the direct result of advances in computational capabilities, today consisting of new techniques such as multilevel concurrent simulation, multi-teraflop computational platforms and experimental facilities for producing and diagnosing plasmas under extreme conditions for the benchmarking of simulations. Examples of these are the treatment of mesoscale plasma and the scaling to astrophysical and cosmic dimensions and the Accelerated Strategic Computing Initiative whose goal is to construct petaflop (10^{15} floating operations per second) computers, and pulsed power and laser inertial confinement plasmas where megajoules of energy are delivered to highly-diagnosed plasmas. Recent work by Anthony L. Peratt (XPA) concentrates on the achievements to date in simulating and experimentally producing plasmas scaled to both astrophysical and cosmic plasma dimensions.

Plasma science is rich in distinguishable scales ranging from the atomic to the galactic to the meta-galactic, i.e., the mesoscale. Thus plasma science has an important contribution to make in understanding the connection between microscopic and macroscopic phenomena. Plasma is a system composed of a large number of particles which interact primarily, but not exclusively, through the electromagnetic field. The problem of understanding the linkages and couplings in multi-scale processes is a frontier problem of modern science involving fields as diverse as plasma phenomena in the laboratory to galactic dynamics.

Unlike the first three states of matter, plasma, often called the fourth state of matter, involves the mesoscale and its interdisciplinary founding have drawn upon various subfields of physics including engineering, astronomy, and chemistry. Basic plasma research is now posed to provide, with major developments in instrumentation and large-scale computational resources, fundamental insights into the properties of matter on scales ranging from the atomic to the galactic. In all cases, these are treated as mesoscale systems. Thus, basic plasma research, when applied to the study of astrophysical and space plasmas, recognizes that the behavior of the near-earth plasma environment may depend to some extent on the behavior of the stellar plasma, that may in turn be governed by galactic plasmas. However, unlike laboratory plasmas, astrophysical plasmas will forever be inaccessible to in situ observation. The inability to test concepts and theories of large-scale plasmas leaves only virtual testing as a means to understand the universe. Advances in computer technology and the capability of performing physics first principles, fully three-dimensional, particle-in-cell simulations, are making virtual testing a viable alternative to verify our predictions about the far universe.

A recent paper on this work explores the dynamical and fluid properties of the plasma state, plasma kinetics, and the radiation emitted from plasmas. It also outlines the formulations for the particle-in-cell simulation of astrophysical plasmas and advances in simulational techniques and algorithms, as-well-as the advances that may be expected as the computational resource grows to petaflop speed/memory capabilities.

PUBLICATIONS

The publication list includes all papers published or submitted between July 1997 and June 1998 by LANL staff and their collaborators.

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