

# 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 1998 through 30 June 1999.

### 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.

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 106deg 40'W, a latitude of 35deg 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 will be augmented by several wide-angle Cerenkov telescopes (WACT, currently under construction) 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) is proceeding with a target completion date of late 1999. 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

Cox (T-6) has worked to develop a stellar model linear theory pulsation code to include the possibility that matter and radiation temperatures may not be equal during pulsations. The J-B term across a computational mass shell is usually ignored with the sweeping assumption that these intensities are equal throughout the entire stellar model. However, even in the static model at the top of a shallow convection zone, mass motions of the matter result in both matter

and radiation luminosity gradients that make the matter temperature somewhat larger than the radiation (photon) temperature. With the usual large stellar matter opacity, matter absorption and emission are high and the matter heats and cools rapidly so that its temperature at the top of the convection zone is usually less than a few percent larger than that for radiation. During pulsations when zones are forced to have temperature variations, those for matter can be smaller than for radiation in ionization layers and larger than radiation in deep adiabatic layers. These variations affect separately matter and radiation pressures to change even the purely adiabatic pulsation eigensolutions. The requirement of separate equations for the matter and radiation entropy variations in the nonadiabatic case, and the fact that the temperature difference (J-B) term is extremely large compared to the usual energy flow terms, makes scaling of the linear theory matrix elements necessary. Preliminary results for nonequilibrium diffusion oscillations of solar models have been presented to the GONG community. Further work for many other kinds of pulsating stars is in progress.

J. Guzik (XTA) and collaborators have continued investigating aspects of helioseismology. Guzik presented an invited review at SOHO6/GONG'98 conference on inferences from helioseismology, highlighting recent work with undergraduate student K. Despain (Brigham Young U.) on implications of the recently revised solar radius determination, and also on the sensitivity of predicted gravity-mode frequencies to the solar core structure.

Guzik, R. Epstein (NIS-2), W. Haxton (Inst. Nucl. Theory), F. Poulin (student, U. Massachusetts), and J. Schissel (student, Iowa State U.) investigated alternative solar models with partially-mixed cores and reduced opacities, and the effects of updated nuclear reaction rates on core structure and the solar neutrino predictions. Guzik and C. Neuforge (XTA) reviewed the sensitivity of solar oscillation frequencies to uncertainties in the chemical element abundances. Guzik presented work with A.N. Cox (T-6) on the effects of nonequilibrium diffusion and time-dependent convection on solar oscillation frequencies at GONG'99.

Guzik reviewed work by Cox, Guzik, and Despain on pulsation-driven outflows in Luminous Blue Variable stars and the extreme LBV star Eta Carinae, at the IAU 169 conference in Heidelberg, Germany, the "Eta Carinae at the Millennium" conference held in Montana, and at a colloquium at U. Minnesota.

P. Bradley (XTA) and J. Guzik attempted to explain the sparse observed frequency spectrum of shell-hydrogen burning  $\delta$  Scuti stars such as  $\delta$  Scuti and 4 CVn. These stars are predicted to have a dense pulsation spectrum of nonradial modes, with many nodes in a gravity-wave propagation cavity in the core. However, only a few (6-12) modes are observed in these stars, and the frequency spacing is reminiscent of a pure pressure-mode spectrum, with no g-mode cavity. Bradley and Guzik performed numerical experiments to restrict the gravity mode propagation region by setting the buoyancy frequency to zero in portions of the core. The predicted frequency spacing increased, but was not as regular as in the observed spectrum for 4CVn; more work needs to be done to examine possible physical justifications, such as

mixing or increased damping, to reduce or eliminate the g-mode propagation cavity. Guzik also reviewed asteroseismology of less-evolved core hydrogen burning  $\delta$  Scuti stars including XX Pyx and FG Vir at the 6th Vienna Workshop in Astrophysics (August 1999), and at the NATO Advanced Study Institute in Cesme, Turkey (September 1998).

W. Dappen (USC) and J. Guzik reviewed available astrophysical equations of state and opacities, including practical recommendations for stellar evolution and pulsation modeling. This review will soon be published in the proceedings of the NATO Advanced Study Institute, Cesme, Turkey, held in September 1998.

Matthew Templeton (XTA), with P. Bradley and J. Guzik (XTA), completed a paper (ApJ, in press) on an asteroseismological analysis of the binary delta Scuti star  $\theta$  Tucanae. Several studies of this system, including Templeton's analysis of IRAS data with Thomas Harrison (NMSU) suggest that the  $\delta$  Scuti star may have undergone mass transfer, and our study was to show whether single-star evolution and pulsation models can adequately describe this object.

Templeton (XTA) completed a study of  $\delta$  Scuti variable stars detected by the MACHO project, in collaboration with the MACHO Project. Templeton has found 90 new  $\delta$  Scuti stars in the MACHO database of variable stars in the Galactic bulge, including at least ten double-mode stars. Detailed analysis of their pulsation spectra will be submitted for publication shortly. A theoretical analysis of these objects is currently under way in collaboration with Guzik and Bernard McNamara (NMSU).

A. B. Kaye (XTA) has been working with collaborators on the observational problems associated with the newly discovered  $\gamma$  Doradus variable stars. In collaboration with Gregory Henry (Tennessee State), Frank Fekel (Tennessee State), and Douglas Hall (Vanderbilt), Kaye continues to photometrically monitor new  $\gamma$  Doradus candidates with the TSU/VU 0.4-meter automatic photoelectric telescope (APT). During the period covered by this report, several new candidates were discovered. Kaye, Fekel, and Richard Gray (Appalachian State) have been investigating the basic properties of these stars, and have found at least one to be chemically peculiar. Kaye and collaborators at the Osservatorio Astronomico di Brera (Merate) have been investigating the binary nature of several  $\gamma$  Doradus and  $\delta$  Scuti binary stars. Guzik (XTA), Kaye, Bradley (XTA), Neuforge (XTA), and Cox (T-6) have discovered the physical mechanism behind the  $\gamma$  Doradus pulsations, which may lead to further insight into the interaction between convection and pulsation.

Kaye and Balona have re-investigated the Be star  $\zeta$  Tauri and have concluded that the rotation of magnetically-suspended density enhancements above the photosphere are likely to be the source of the observed variations. Further observations of Be stars with the goal of better understanding this phenomenon are underway.

Kaye, Henry, Hall and Carolyn Kuranz (CIC-12) have been working on chromospherically active stars discovered with the TSU/VU 0.4-meter APT. Several new candidates have been found, and further observations are planned.

C. Neuforge (XTA) has been working with Guzik (XTA) on seismological tests of the diffusion-mass/loss theory in  $\lambda$

Bootis stars. Two competing theories have been developed to explain the  $\lambda$  Bootis phenomenon: the diffusion/mass-loss theory and the diffusion/accretion theory. The diffusion/mass-loss models require a significant fraction of the star's main-sequence lifetime for the characteristic metal deficiencies to appear at the surface. During this time, the settling of helium can also take place. The gravitational settling time scale is the same for He and the heavy elements. When most heavy elements are depleted by a factor of 3 (the typical depletion factor predicted by the diffusion/mass-loss theory), He should also be depleted by a factor of 3. Moreover, about half of the known  $\lambda$  Bootis stars also exhibit  $\delta$  Scuti-like pulsations. The question to be answered here is: to what extent does helium depletion affect the predicted spectrum of unstable modes in  $\lambda$  Bootis star models?  $\lambda$  Bootis models have been calculated, including diffusion and mass loss. For the mass loss rates typical of  $\lambda$  Bootis stars, we find that our models are still hot enough to be stable against  $\delta$  Scuti-like pulsation when the helium is depleted by a factor of 3. This means that mild  $\lambda$  Bootis stars should not pulsate, unless these stars are sufficiently red. Since  $\lambda$  Bootis stars are found in the whole  $\delta$  Scuti instability strip, this seismological test shows that the diffusion/mass loss theory cannot explain the existence of the blue mild  $\lambda$  Bootis stars. This work has been presented as a poster at the 6th Vienna Workshop in Astrophysics (August 1999).

Pourbaix (University of Brussels - Belgium), Neuforge and Noels (University of Liege - Belgium) revised the masses of the components of the binary system  $\alpha$  Cen and investigated the effects of these revisions on the evolution models of the system.

Goriely (University of Brussels - Belgium), Neuforge and Guzik have been working on the effects of the uncertainties on the nuclear reaction rates on the solar neutrino predictions, using the NACRE compilation for the reaction rates.

Neuforge, Guzik and Swenson (XTA) have been testing the sensitivity of the solar oscillations frequencies to the neon abundance.

Deupree (DX-7) and Neuforge have been investigating hydrodynamic models of 2-D rotating stars, in order to determine the amount of overshooting during the evolution of these stars.

Neuforge has been collaborating with Jehin, Magain, Noels, Parmentier and Thoul (University of Liege - Belgium) in the study of the chemical composition of mildly metal-poor stars and the possible globular cluster origin of these stars.

Deupree has used his fully implicit, two dimensional hydrodynamics code to produce Zero Age Main Sequence (ZAMS) models of non-rotating and rotating stars. Hydrodynamic simulations of these models have been performed to determine the convective core overshoot and the angular momentum distribution inside the convective core. ZAMS models with non-uniform rotation outside the convective core have been constructed as well. These show that there are significant limits on the rotation law allowed before unexpected changes in the core structure occur. Evolution of these models through core hydrogen burning has begun.

### 3.2 Supernovae and Pulsars

After three years of effort, the paper, ‘‘Rapid Photometry of Supernova 1987A: A 2.14 ms Pulsar?’’ of J. Middleditch (CIC-3) and 11 other authors, has been provisionally accepted for publication in *New Astronomy*. The work encompasses three topics: the discovery of the 2.14 ms signature, its unusual  $\sim 1,000$ s modulation and what this implies for supernovae, pulsar formation and neutron star structure; the lack of any ‘‘normal’’ pulsar (i.e., with constant pulse profile and stable timing), and further observations confirming the 2.14 ms signature and its  $\sim 1,000$  s modulation; and further means of recognizing a detection of the unusual signal. A 2 ms rotation period is typical of what would result from a merger of two white dwarf cores and this also explains the BSG nature of the progenitor star, Sk -69° 202, the extreme mixing of the elements within, the ring-like structure surrounding, and the asymmetric expansion of the ejecta from the supernova remnant. Moreover, the unusual 1,000 s modulation of the 2.14 ms signal is consistent with the r-mode instabilities recently postulated for hot young neutron stars by Owen, Lindblom and their colleagues, and there is no need to invoke a non-axisymmetry of 1 part in  $10^6$  in the crust, which most recent models of neutron star structure do not support.

Work by J. Middleditch continues on the timing of the recently discovered 62 Hz pulsar, J0537-6910, in the Large Magellanic Cloud. A large glitch, of order 1 part in  $10^6$ , has already been seen around March-April of 1999, and other smaller and more temporary excursions of the spin frequency from its normal spindown track have been observed.

Middleditch is also attempting to detect a pulsar signal from the recently-discovered X-ray point source in Cas A. The object in Cas A may represent what SN 1987A will look like in 250 years time; according to R. McCray of JILA, there is at least some evidence for polar ejection, similar to what was seen in SN 1987A.

### 3.3 Active Galaxies

During the period from July 1998 to July 1999 V. Pariev worked with S.A. Colgate (T-6) and J.M. Finn (T-15) on simulating magnetic dynamo near accretion disks around supermassive black holes in AGNs. A kinematic dynamo code was designed and used to show that star-disk collisions can cause the necessary  $\alpha$ -effect required for the  $\alpha$ - $\Omega$  dynamo to operate. It was shown that this new mechanism for a dynamo can quickly lead to the amplification of magnetic fields to the equipartition value with the gas pressure in the disk. The same code was used to provide theoretical justification and support for the liquid sodium dynamo experiment, which is being constructed in New Mexico Tech (S.A. Colgate, H. Beckley). Research is underway on investigating possible parametric resonant excitation of the dynamo.

V.I. Pariev and B.C. Bromley (University of Utah) have applied the method of minimum and maximum frequency shifts to the new data on the broad skewed iron emission line from MCG-6-15-30 and found that the data strongly favours the hypothesis of a puffed-up accretion disk in this Seyfert nucleus.

V.I. Pariev, P. Laguna (Pennsylvania State University) and W.A. Miller (T-6) started work investigating hydrodynamic instabilities and accretion rates from a thick torus orbiting a black hole.

### 3.4 Neutron Stars

L. M. Franco (University of Chicago), B. Link (Montana State University), and R. I. Epstein (NIS-2) have been studying quakes in neutron stars. Stresses in an evolving neutron star can arise through gravitational, magnetic and superfluid forces. These stresses can crack the crust, affecting the star’s spin evolution and possibly generating high-energy emission. We study the growth of strain in the crust of a magnetized neutron star as its spin frequency decreases and examine the initiation of cracks or starquakes. In preliminary work (Link, Franco & Epstein 1998), we studied a homogeneous model of a neutron star. This has been extended 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 begins breaking at the rotational equator and matter flows to higher latitudes along a fault line inclined at an angle to the equator. Magnetic stresses favor fault lines directed toward the magnetic poles. We thus expect that our previous conclusions concerning pulsar timing still hold, namely, that the asymmetric redistribution of matter produces damped precession which could ultimately lead to an increase in the spin-down torque exerted on the star. Starquakes could explain the permanent *offsets* in the period derivative that have been observed to follow glitches in at least three pulsars.

Link, Epstein and Lattimer have also studied pulsar constraints on neutron star structure and equation of state. With the aim of constraining the structural properties of neutron stars and the equation of state of dense matter, they studied sudden spin-ups, *glitches*, occurring in the Vela pulsar and in six other pulsars. They present evidence that glitches represent a self-regulating instability for which the star prepares over a waiting time. The angular momentum requirements of glitches in Vela indicate that  $\geq 1.4\%$  of the star’s moment of inertia drives these events. If glitches originate in the liquid of the inner crust, Vela’s ‘radiation radius’  $R_\infty$  must exceed  $\approx 12$  km for a mass of  $1.4M_\odot$ . Observational tests of whether other neutron stars obey this constraint will be possible in the near future.

Epstein and A. V. Olinto (University of Chicago) have studied possible origins of ultra-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 scattering off the cosmic microwave background. We suggest 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 neu-

iron star without suffering significant spallation reactions. For plausible models of the Galactic magnetic field, the trajectories of the iron ions curve sufficiently to be consistent with the observed arrival directions of the highest energy events.

### 3.5 Plasma Astrophysics

Stirling Colgate, Hui Li, (T-6) and others have started a new initiative in Plasma Astrophysics, which draws astrophysicists and plasma physicists from several divisions and groups within the Laboratory. The science goals of this initiative include: the origin of angular momentum transport in accretion disks; the origin of magnetic field in galaxy clusters; the origin of relativistic jets and their emissions; and the nature of magnetic reconnection process. This initiative brings together experts on hydro, MHD, and kinetic plasma theories, as well as experimentalists on magnetic reconnection. The numerical tools available to us include large scale SPH, MHD and PIC (particle-in-cell) codes.

On the angular momentum transport problem, we have identified a new instability in accretion flow: Rossby wave instability in accretion disks (Li *et al.* 1999, ApJ, in press). We are working on 2D and 3D nonlinear simulations of this Rossby vortex instability to understand the transport processes and their efficiency (Li *et al.* 1999, in preparation). 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.

On the origin of magnetic fields in galaxy clusters, we have calculated the magnetic energy and flux of the large, coherent regions of near uniform Faraday rotation measure and find this energy to be of the order of the binding energy of the central black hole of the AGN of the cluster. This suggests that the AGN is the source of these fields. A saturated accretion disk dynamo as previously suggested, (Colgate and Li, 1997, Lindau and Invited talk, IAU, Bozeman, 1999, and ApJ Letters, in preparation) explains this energy and flux. By comparison, a galactic dynamo would be insufficient by  $10^7$ , and if the field pervaded the entire cluster, the magnetic energy required increases to 100 times that of a single AGN black hole.

On the galactic dynamo via star-disk collisions, the dynamo in the accretion disk necessary to explain this energy and flux has been simulated with a kinematic, vector potential code with V. Pariev and exponential gain has been created using plumes that simulate star disk collisions. These collisions are a robust source of driven magnetic helicity (as well as broad emission lines) and so the back reaction saturates the dynamo when all the accretion energy of the black hole appears as magnetic energy and flux.

An experiment with liquid sodium to simulate this alpha omega dynamo in the laboratory has been funded by NSF at New Mexico Inst. of Mining and Technology based upon this theoretical work at LANL.

On the formation of astrophysical jets, we are working on the formation of force-free magnetic helix from shearing the footpoints of magnetic fields on accretion disks. Initial calculations show the formation of collimated structures which mimic the astrophysical jets. This process is the direct con-

sequence of the galactic dynamo as accretion energy is eventually converted into magnetic fields via back-reaction. The transport of these magnetic fields eventually fills up the space around each active galaxy and the whole galaxy cluster.

Together with Prof. Sakai (Toyama Univ.) and his group, we are performing 2D and 3D PIC simulations of drift kink instability in a current sheet. In addition, we are carrying out simulations on lower-hybrid wave instability, which might facilitate an efficient energy conversion between magnetic field and particles.

We continue to work on the particle heating and acceleration in accretion disks and jets. We have been using our fully time-dependent, wave-particle-photon coupled kinetic codes to model the multiwavelength AGN spectra, especially the TeV blazars. We are studying the SSC model in detail using the full Klein-Nishina cross section, which is very important in predicting the TeV flux (Li & Kusunose, 1999, ApJ, submitted; Kusunose, Coppi, & Li 1999, ApJ, submitted).

Together with Curt Michel (Rice), we have written a Physics Report on Electrodynamics of Neutron Stars (Phys. Rep. 318, 227, 1999). A follow-up study on the dynamics of nonneutral plasmas is in progress.

Together with Peter Gary (NIS-1), we have worked on the electron heat flux problem in galaxy cooling flows. Cooling flows models require a severe reduction of electron heat flux whose origin is not understood. We proposed a kinetic microinstability which naturally inhibits the electron heat flux and showed that this instability might be quite relevant in the cluster cooling flows (Gary & Li 1999, ApJ, in press).

Together with Peter Gary and Yoshi Kazimura (LANL), we have performed extensive PIC simulations of electron beam instability, which is applied to the magnetic fluctuation observations near the auroral region of Earth (Gary, Kazimura, Li, Phys. of Plasmas, 1999, in press; Kazimura, Gary, Li, 1999, GRL, submitted). A follow-up paper on the discovery of electron beams using POLAR satellite is being prepared, which confirms our theoretical prediction (Dorelli, Gary, Li, 1999, GRL, in preparation). Another on-going space physics project is to understand the damping of solar wind MHD turbulence by electrons and protons via linear Vlasov theory (Li & Gary, JGR, to be submitted).

We sponsored Prof. Lovelace (Cornell) as our new Anderson Fellow at IGPP/LANL. Lovelace has been collaborating with us on Rossby wave instability and magnetic helix formation.

### 3.6 High-Energy Gamma-Rays

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), W. Benbow, D. G. Coyne, D. E. Dorfan, L. Kelley, J. McCullough, M. Moralez, S. Westerhoff, D. A. Williams (UC Santa Cruz), R. Ellsworth (Geo. Mason U.), L. Fleysher, R. Fleysher, A. Mincer, P. Nemethy (New York U.), B. Shen, A. J. Smith, T. Tumer, K. Wang, M. Wascko (UC Riverside), A. Falcone, M. McConnell, J. Ryan (U. New Hamp-

shire), R. Atkins, B. Dingus, J. McEnery (U. Utah). The Milagro air-shower detector is being commissioned at Fenton Hill 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  $\sim 750$  photomultiplier tubes placed in a  $5000m^2$  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  $1500m^2$ . 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  $\sim 1.5$ -m of water; it had the same energy and angular response as Milagro, although it was smaller and had no muon detection capabilities. High-energy emission from Markarian 501, a blazar, has been detected with Milagrato; this result is discussed in a paper that has been published in *Ap. J. Letters*. In addition, solar energetic particles with energies exceeding 10 GeV from the Nov. 6, 1997 solar flare/coronal mass ejection have been detected by Milagrato. Further analysis of the data acquired with Milagrato is underway.

In spring, 1998, Milagrato was disassembled and the installation of full Milagro detector began. Milagro is now fully installed and test data-taking has begun. Full-scale operations should commence by the end of 1999. Observations with Milagro are expected to continue for 5-10 years.

### 3.7 Gamma-Ray Bursts

ROTSE (Rick Balsano, Jeff Bloch, Don Casperson, Sandy Fletcher, Galen Gisler, Julie McAnallen, Andy Pawl, John Szymanski, Jim Wren (all NIS-2), Jack Hills (T-6), Richard Miller (P-23), Carl Akerlof, Susan Amrose, Bob Kehoe, Tim McKay, Justin Schaefer (U Michigan), Stuart Marshall (Livermore), Brian Lee (FermiLab)). The Robotic Optical Transient Search Experiment with its phase I instrument (consisting of 4 0.11-m aperture lenses and CCD cameras) at the LANSCE site in Los Alamos, achieved the first ever optical observations of a gamma ray burst while the burst was still occurring. Our paper on GRB990123 was published in *Nature* in April 1999. Subsequent observations by other groups established the distance and thereby proved this burst to be the brightest optical flash ever recorded. The ROTSE I telescope continues automated observations, taking routine sky patrols every night while remaining in readiness to respond to alerts from the Gamma Ray Coordinate Network (GCN) and other sources. ROTSE I has responded to 60 alerts, but has detected only the very bright flash from GRB990123 thus far.

The sky patrol data from ROTSE I now amounts to 2.5 Terabytes, archived in the mass store at Los Alamos. This data is presently being utilized in searches for variable stars,

and will soon be exploited for near-earth object searches. The variable star searches are thus far confined to selected fields amounting to just 7% of the ROTSE I sky coverage over a four-month period. The photometry is accurate to 0.1m at 14th magnitude. A total of 600,000 objects were examined, of which 1950 were found to be variable. Only about 200 of these were previously known in the General Catalog of Variable Stars. A paper presenting these results is in preparation, reporting 134 new RR Lyrae stars, 216 new Cepheids, 102 new Miras, 646 new Long Period Variables, 407 new Contact Binaries, 118 new eclipsing systems, and 100 new  $\delta$  Scuti stars. The extension of this variable star search to the entire ROTSE I data (complete coverage of the sky north of declination -30 degrees) should increase these numbers by a factor of about 16.

In November of 1998, ROTSE I was used to observe the Leonid meteor shower, and recorded an extremely bright and persistent meteor burst near the shower radiant. Plans are underway to perform a similar campaign in November 1999, in coordination with meteor observers in other nearby locations. The second phase of our project, ROTSE II, a pair of Torus Optics 0.45-m telescopes, is still being checked out and debugged at the LANSCE site. When these are in automatic operation, they will provide optical counterpart/afterglow coverage down to 17th magnitude. Plans for a third phase telescope, ROTSE III, are now under contract with vendors. Eventually the ROTSE III telescopes will be distributed to a number of sites around the world to increase the coverage for gamma-ray burst responses.

James Terrell (NIS-2) continues to analyze satellite gamma-ray burst data from Air Force DMSP (Defense Meteorological Satellite Program) spacecraft, together with Ray Klebesadel and Jim Griffee (Sandia National Laboratory). Two of these (DMSP13 and DMSP 14) are currently operational in 800-km orbits. The excellent data obtained from the extraordinary burst of 27 August 1998 (from SGR+14) are still being analyzed and it is hoped can be released soon.

### 3.8 Other Observational Astronomy

Beginning in April 1999 a multi-disciplinary team has been involved in the commissioning and operations support for the Sloan Digital Sky Survey (SDSS) located in the Sacramento Mountains of southern New Mexico.

Bryan Laubscher (NIS-4) has been a member of the SDSS photometry team whose mission is to build the SDSS standard star system. The technique uses a dedicated 20 inch telescope to observe bright primary standard stars to define the new photometric system and fainter secondary star fields which will provide the link between the photometric system and the observations taken by the 2.5 meter survey telescope. The 1 degree field of view of the 20 inch telescope is inscribed by a 2048 square CCD which is the heart of the photometry camera system. Bryan has contributed to the photometry mission plans as well as the reduction techniques used in the reduction pipeline along with his collaborators at JHU. He has also performed engineering work on the photometry instrumentation.

Peregrine McGehee (LANSCE-8) is working with the FermiLab-based controls and interlock team to extend the

capabilities of the SDSS telescope control system. The successful integration of the Experimental Physics and Industrial Control System (EPICS) toolkit co-developed at Los Alamos has been described in a paper presented at the Astronomical Data Analysis Software and Systems IX conference.

The Magdalena Ridge Observatory (MRO), situated at an elevation of 10,700 feet near Socorro, NM, is an imaging infrared and optical interferometer that will consist of a trio of 2.4 meter telescopes outfitted with adaptive optics. The MRO primarily operate in the near-infrared at 2.2 microns (astronomical K-band) and have a nominal baseline of 50 meters with one of the collecting apertures optionally moveable along a 100 meter track.

Since July 1998 LANL has become increasingly involved in the international optical interferometry community with travel to the October 1998 Interferometry workshop at Lowell Observatory, Flagstaff, AZ (Galen Gisler, NIS-2 and Peregrine McGehee, LANSCE-8) and the May 1999 "Working on the Fringe" conference hosted by JPL at Dana Point, CA (Peregrine McGehee). In addition interferometry had been featured in the Los Alamos Astrophysics seminar series with talks by Bill Danchi (UCB/ISI), Mark Colavita (JPL/PTI), and Christian Hummel (USNO/NPOI).

In conjunction with a university consortium comprised of New Mexico Institute of Mining and Technology, New Mexico State University, New Mexico Highlands University, and the University of Puerto Rico as well the Air Force Research Laboratory, the Army's Space and Missile Defense Command, and the Office of Naval Research, Los Alamos staff across three groups have been involved in the exploration of technical and scientific design issues. The LANL team includes Peregrine McGehee, Bryan Laubscher (NIS-4), and Galen Gisler, Sandra Fletcher, Don Casperson, and Jim Wren (all NIS-2).

Fenton Hill Observatory (Don Casperson, Galen Gisler, Daryl MacInnes, Jake Parks, Guthrie Partridge, Cathy Plesko, Tim Dolch, Jim Wren (all NIS-2), Phil Lubin (UCSB), Carl Pennypacker (UCB)). Cameras for recording daytime cloud cover have been running since November 1997, and this database is being used to study the astronomical suitability of the Fenton Hill Site, 35 miles west of Los Alamos. A weather station was installed in December 1998. The Research and Education Automatically Controlled Telescope (REACT) has been used since the summer of 1998 for school groups and public nights, but automatic and remote control of the telescope has not yet been achieved. A CCD camera was integrated onto the telescope in June 1999, and is in current use. A better camera for the telescope was received by the UCSB group in the fall of 1998, and software for its use is being prepared there.

Earthwatch Campaign, "Transient Phenomena in Astrophysics" (Don Casperson, Galen Gisler (all NIS-2), Todd Haines (P-23), with the assistance of Donna Powell (Crownpoint, NM Middle School)). For the third year, we hosted a Student Challenge Awards Program from the Earthwatch Institute, funded by the Durfee Foundation, on astronomical transient phenomena. The eight high-school students participating helped with the development of the Fenton Hill Ob-

servatory site, with the debugging of the REACT telescope and dome, and with seeing measurements. In addition they attended a number of cultural events. The first radio astronomical observations at Fenton Hill were done this summer using amateur radio equipment. Decametric observations of Jupiter were accomplished by the students, and they helped prepare a simple 150 MHz interferometer that was used later in the summer to detect fringes from bright radio sources. The 1999 Earthwatch students were: Nathan Bushey, Adam Gerchen, Matt Murray, Jim Patek, Mariana Rodriguez, Andie Sabino, Maria Velazquez, and Kristen Young.

LANL's Center for Space Science and Exploration (CSSE) funded a significant upgrade of the ALEXIS Facility, a soft X-ray/UV reflectometer originally built to support the DOE's ALEXIS EUV/ultrasoft X-ray all-sky monitor mission. The upgraded Facility will be used to characterize experimental optics and detectors.

### 3.9 Workshop

LANL Space and Remote Sensing Sciences Group hosted a workshop entitled "Small Missions for Energetic Astrophysics: Ultraviolet through Gamma-Ray," held February 22-26, 1999, at the J. Robert Oppenheimer Study Center, Los Alamos National Laboratory. W.C. Priedhorsky served as Chairman of the Scientific Organizing Committee, and S.P. Brumby served as Chairman of the Local Organizing Committee and as Editor of the proceedings. The proceedings of the workshop are currently in preparation for publication.

Scientific Session Topics: Active galactic nuclei, Compact objects/ binaries, Extragalactic diffuse background and the intergalactic medium, Gamma ray bursts, Interstellar medium, Supernovae and supernova remnants, Stellar astrophysics, White dwarfs and isolated neutron stars, Emerging technologies for small satellite missions

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