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 1996 through 30 June 1997.

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 there follows a list of 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. The Central Computing Facility and the Advanced Computing Laboratory have several Cray computers, Connection Machines, and clusters of advanced workstations. Most technical Laboratory Divisions and Groups have their own computing resources in addition, from minisupercomputers to desktop machines.

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 high 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, whose research aims chiefly involve the detection and monitoring of transient astronomical sources, but which will also serve 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 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, is visible from Fenton Hill, some 60 miles away.

The site was used for many years by the Los Alamos geothermal project known as Hot Dry Rock. 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 asked Los Alamos to terminate Hot Dry Rock, and the site is potentially available to other users.

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 use agreement that will specifically permit the development of an astronomical observatory is in process.

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. 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. Plans for the installation of an automated 14-inch optical telescope, the Research and Education Automatically Controlled Telescope (REACT) are proceeding with a target completion date of spring 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

Art Cox has considered how yellow giant pulsators such as Cepheids and RR Lyrae variable stars can exhibit period changes that are both positive and negative and are much faster than expected from evolution changes of the stellar radius. A small settling of helium through both the shallow hydrogen convection zone and the deeper helium convection zone can give a helium composition gradient that slightly changes the surface layer structure and the natural period of oscillation. Some mixing processes, like tidal motions during a close stellar encounter, can homogenize these layers and change periods over time. Rapid rotation will keep the composition the same throughout, and no period change other than that induced by evolution can occur. Mass loss and the process of diffusive settling are much too slow to give the observed period changes by themselves. But a dredge-up of the helium or a slow temporary deepening of a helium gradient by mass accretion from a companion star will produce period changes of both the fundamental and overtone radial modes much as is observed. The observed period change in Polaris and period changes in opposite directions of the globular cluster double-mode RR Lyrae variable V53 in the globular cluster M15 are explained by this means.

Cox, **Joyce Guzik**, **Mike Soukup**, and **K. Despain** have further studied the hydrodynamic outbursts of the luminous blue variables in our galaxy and other nearby ones. The outburst mechanism that seems to occur for these most massive (up to 100 $M_\odot$) and luminous stars in the universe is radial and nonradial pulsations that periodically make the radiation luminosity exceed its maximum allowed Eddington limit in deep layers. Thus the loosely-bound overlying mass is gently pushed off, since the mean gamma of its matter is almost as low as the pure radiation value. Considerable work has been done to investigate the role of time-dependent convection. In hydrostatic models, convection can carry an almost unlimited amount of luminosity. In the low density envelopes of these stars it is difficult, though, for the chaotic matter flow to transport much luminosity. But the radiation luminosity still may never exceed the Eddington limit. When a star pulsates, convection has its own time-dependent behavior, and its phasing actually aids in letting the radiation luminosity periodically increase above the Eddington limit. The most massive stars in our galaxy display deep seated iron line opacity layer outbursts. But stars with masses near 20 to 30 $M_\odot$ have rather gentle outward pushes from only the helium ionization opacity layers and only mild outbursts. They display outbursts that are more like enhanced mass loss episodes. It is very possible that a large number of outbursts for the most massive of these luminous blue variables cause enough total mass loss that they never evolve very far red before they eventually become Wolf-Rayet stars that die near or even below the main sequence. These results were presented in two international conferences at Hawaii and Los Alamos this year.

Paul Bradley is working on seismology of the hydrogen atmosphere (DAV) white dwarfs. Bradley is using 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. Two of the pulsation periods for these two stars are near 215s and 270s, while G 117-B15A has an extra mode at 304s. If the similar periods of the two stars is the result of their having nearly identical internal structures, then both must have a hydrogen layer mass of $\sim 10^{-7} M_\star$ or $\sim 10^{-4} M_\star$. Both stars have a helium layer mass near $10^{-2} M_\star$ and the C/O core is oxygen rich. The hydrogen layer mass uncertainty for both stars occurs because we do not know if the mode near 215s is the first or second overtone $\ell = 1$ gravity mode. Determining the hydrogen layer masses for these and other ZZ Ceti stars will help us determine if there is a preferred hydrogen layer mass (or mass range) for the hydrogen atmosphere white dwarfs. Bradley presented this work at the conference ''A Half Century of Stellar Pulsation Interpretations: A Tribute to Arthur N. Cox'' held at Los Alamos in June.

Joyce Guzik and **Bradley** are continuing their work on the evolutionary and pulsation properties of stellar models appropriate for δ Scuti stars as part of a NASA Astrophysics Theory Program grant. Most of the work this year is focussed on the effect of changing the heavy element (Z) mass fraction on the seismologically inferred structure. They used the star FG Virginis as an example and find that they can fit most of the 21 observed frequencies reasonably well with a $1.82 M_{\odot}$ $Z=0.02$ model or a $1.95 M_{\odot}$ $Z=0.03$ model. To the observer, the two models would appear identical, but the internal structure, and hence the predicted pulsation frequencies, are slightly different. Guzik and Bradley reported their results at IAU Symposium #181 ''Sounding Solar and Stellar Interiors'' at Nice, France in October 1996 and at the ''A Half Century of Stellar Pulsation Interpretations: A Tribute to Arthur N. Cox'' stellar pulsation meeting held at Los Alamos in June.

Matt Templeton and **Guzik** reanalyzed a large data set of the archetype δ Scuti star, δ Scuti itself, taken in the 1980's. They find eight frequencies with confidence. Based on the six linearly independent observed modes, Templeton and Guzik computed evolutionary models and determined the theoretical pulsation frequencies. Their analysis shows that only the radial modes are useful for constraining the structure of δ Scuti, because there are several $\ell=1$ or 2 nonradial modes within 1 to 2 μHz of each observed frequency, making mode identification difficult. They conclude that δ Scuti is in the hydrogen shell burning phase and has a mass near $2.1 M_{\odot}$. The results of this work are in a paper to be published in the October 1997 Astronomical Journal.

Guzik and **Robert Deupree** are continuing to improve and validate a 2- dimensional stellar evolution code (ROTORC) that includes the ability to handle the effects of rotation and other hydrodynamical features. As part of the validation effort, they constructed a non-rotating ''standard'' solar model with ROTORC for comparison to nominally equivalent ones from a 1-dimensional code. They then computed rotating models that duplicate the rotation rate of the present Sun and analyzed them for instabilities at the convection zone base. They find that flows due to small differential rotation rates develop at the convection zone base with velocities of a few cm s^{-1} and they decay away rapidly. Their conclusion is that angular momentum transport and mixing must occur over longer timescales, or at very small (non-resolved) spatial scales. Guzik and Deupree reported different aspects of their results at IAU Symposium #181 ''Sounding Solar and Stellar Interiors'' at Nice, France in October 1996 and at the AAS meeting at Toronto in January 1997. Some of Deupree's results will appear in the Astrophysical Journal.

Robert Deupree performed hydrodynamic and stellar evolution calculations of rotating stars, finding that the hydrodynamic simulations produce convective core overshooting of about one-third of a pressure scale height for an 8.75 solar mass core hydrogen burning model. Deupree and Guzik also calculated evolutionary and hydrodynamic models for the sun. There is a hint of some very modest convective overshooting at the interior of the solar convective zone, but the angular resolution is too coarse to make any firm statements.

Guzik and **Bradley** hosted the stellar pulsation meeting ''A Half-Century of Stellar Pulsation Interpretations: A Tribute to Arthur N. Cox'' at Los Alamos National Laboratory on June 16-20, 1997. Over 150 people from 28 different countries attended; both are records for this series of meetings, originated by Arthur Cox in 1971. Rather than focus on the different variable star classes, this meeting was organized around physics themes to emphasize the unifying physical principals underlying the disparate activity of the different variable stars. The proceedings are being edited by Bradley and Guzik and will be published as part of the Astronomical Society of the Pacific Conference Proceedings series in 1998.

3.2 Supernovae

As a representative of Carnegie Observatories, in lieu of the death of collaborator Jerome Kristian, **J. Middleditch** traveled to La Serena, Chile during Feb. '97 to attend the ''Supernova 1987A: Ten Years After'' conference to present the results on the 2.14 ms candidate optical pulsar. W. Kunkel of Carnegie Observatories, and about a dozen others from elsewhere are also collaborators on this work. Briefly, the 2.14 ms signal is consistent with a neutron star which precesses with a $\sim$1,000 s period *and* is rapidly spinning down because of the same non- axisymmetric oblateness of order 1 part in a million. The results presented in this talk, which included data from the HSP of the HST, were challenged in a rebuttal talk by Joe Dolan of the HSP team. However, upon cross examination by Middleditch, the discrepancy in the quoted sensitivity of the HSP results was revealed as being due to the large difference between the backgrounds of PSR0540-69 and SN1987A. The latest monitoring observations of SN1987A had been made by Middleditch during the preceding December at Carnegie's Las Campanas Observatory (LCO).

In the months following the conference, Middleditch worked on merging the two separate papers on SN1987A into one coherent work, in accordance with the wishes of the referee and *New Astronomy* editor. After considerable further analysis, in particular of the signals seen during Feb. and Oct./Nov. of '95, and Feb. '96, including over 50 simulations using actual data, the now 59-page long merged work was resubmitted to *New Astronomy* in mid-June of '97. As of Oct. 24 '97 the referee had not responded.

Middleditch also traveled to Cerro Tololo Inter-American Observatory (CTIO) during November of '96 with John Finley of Purdue University in order to make simultaneous observations (with the X-ray Timing Explorer – XTE) of the 50 ms pulsar in the Large Magellanic Cloud, PSR0540-69, with the 1.5-m telescope. Middleditch made a similar trip to CTIO during Sep. '97 with Kent Wood of the Naval Research Lab. to make simultaneous observations (with XTE) of the strong 2-s Quasi-Periodic Oscillator

(QPO) from the AM Herculis star, BL Hydri, which had been discovered by him at LCO during a November 1994 monitoring run of SN1987A. AM Her stars are cataclysmic binary systems that consist of a strongly magnetic white dwarf whose field enforces synchronous rotation with the orbital motion of a low-mass companion star. These QPO have now been observed, sometimes sporadically, in no less than five AM Her stars: AN UMa, 1E1405-451, EF Eri, VV Pup, and now BL Hyi. These systems are becoming increasingly important because their QPOs originate from the polar caps of the compact star, as do the ~ 1-kHz QPOs recently discovered by XTE in neutron stars accreting from a binary companion. In the AM Her systems, stand-off shocks form in the field-aligned accretion flows near one or both of the white dwarf's magnetic poles. By making simultaneous optical and X-ray observations of either accreting neutron stars with kHz QPOs, or of AM Her systems with 0.5-Hz QPOs, one can hope to unravel the physical mechanism by which these QPOs form. Unfortunately, in the neutron star systems, kHz optical QPOs have never been seen. Thus the AM Her systems, already known to have optical QPOs, provide the only target in which simultaneous optical and X-ray QPOs might be observed. Some simultaneous data was gathered during this observing run, but the prevalent El Niño prevented it from being as successful as had been hoped. In consequence, a similar proposal for time on the LCO 2.5-m during Jan. '98 was submitted. Such a run would also be used to continue the monitoring of SN1987A.

3.3 Neutron Stars

Richard Epstein, Bennett Link (Montana State Univ.), Gordon Baym (University of Illinois), and Lucia Munoz Franco (University of Chicago) are modeling starquakes on neutron stars. Evolving neutron stars are expected to undergo cracking and faulting of their crusts that could drive or modulate a host of interesting high-energy phenomena. The researchers are developing a quantitative picture of neutron-star crust dynamics in the presence of magnetic fields and its relation to observable phenomena. The crusts of both isolated and accreting neutron stars undergo strain accumulation and repeated cracking as the stars evolve. They are examining the sources of crust straining and the changes they induce in the stellar structure, rotation, and magnetic field. Variations in the star's rotation frequency alter its equilibrium oblateness, thereby straining the star's crust. The magnetic field frozen in the star also produces straining. The crusts of accreting neutron stars are additionally strained as mounds of material accumulate. Their study follows the build up of strain in isolated and accreting neutron stars. They are calculating the response of magnetic fields to the crustal displacements, the cracking and faulting of the stellar surface, and the resulting changes in the structure of the crusts and magnetic fields. An important part of this investigation is the mechanical properties of neutron star crusts, including the possible existence of a brittle-plastic transitions region.

Together with Curt Michel (Rice), **Hui Li** has written a Physics Report on Electrodynamics of Neutron Stars (submitted). By studying the particle trajectories in the wind zone, they have made progress in understanding the knots seen by HST in Crab Nebula (ApJL, to be submitted). An invited talk on this subject was presented in the 6th Tex-Mex Conference on Astrophysics.

3.4 Gamma-Ray Bursts and Transient Searches

James Terrell has continued analyzing satellite gamma-ray burst data, together with Ray Klebesadel, John Laros (U Az), and Kevin Hurley (UC Berkeley). Gamma-ray burst detectors are aboard seven U.S. Air Force Defense Meteorological Satellite Program (DMSP) spacecraft, two of which are currently in use. Their 800-km altitude orbits give a field of view to 117 degrees from the zenith. A great many bursts have been detected, usually in coincidence with detections by GRO or other satellites such as PVO or Ulysses. The directions of the sources can be determined with considerable accuracy from such correlated observations, even when neither GRO nor Beppo-SAX is involved. Results obtained from the most recently launched satellites (DMSP 13 and DMSP 14) were given at the 1997 Huntsville Gamma-Ray Burst conference.

Hui Li continues to work on gamma-ray bursts, both in data analysis and theory. A comprehensive study on the comparison between BATSE data and Halo Beaming model is published in ApJ 484, 720. He has also started the search for soft x-ray transients from nearby galaxies using ROSAT PSPC data. He discovered an excess of x-ray flashes with duration around 1000 sec from nearby galaxies and is performing detailed analyses of the events we found (ApJL, to be submitted). Together with **Stirling Colgate**, he has been working on the physical processes associated with high velocity neutron stars and how they evolve from soft gamma-ray repeater phase to gamma-ray bursters (ApJL, to be submitted).

Galen Gisler, **Todd Haines**, **Don Casperson**, **Michelle Beaver**, **Heather Pickett**, and **Guthrie Partridge**, with the assistance of Donna Powell (Crownpoint NM Middle School), hosted a Student Challenge Awards Program from the Earthwatch Institute, funded by the Durfee Foundation, on an astronomical site characterization study for an observatory dedicated to the detection and monitoring of astronomical transients. Despite poor weather, the eight high-school students who participated in the expedition managed to perform visual and CCD measurements of seeing and sky brightness at the Fenton Hill site and also at the Pajarito Peak site on Zia Pueblo land. The students who participated were: Lauren Baylor, Rumman Chowdhuri, Nicole Detorie, Tim Dolch, Jim Miller, Cathy Plesko, Leo Salom, and Ed Takashima.

Jeff Bloch, **Casperson**, **Jim Wren**, **John Szymanski**, and **Gisler**, together with Carl Akerlof, Tim McKay, Bob Kehoe, Brian Lee (U. Mich), and Stuart Marshall (LLNL) have been working on the Robotic Optical Transient Search Experiment (ROTSE) to provide automatic search and detection capabilities for optical counterparts of gamma-ray bursts and other high-energy transient sources. The first component of ROTSE consists of four co-mounted small telescopes with CCD cameras, which together cover a 16.5deg field of view to a depth of 16^{th} magnitude in 15 seconds. This system has been assembled for debugging at the LANSCE site in Los

Alamos, for eventual installation at Fenton Hill. Routine hands-on operation of the system occurs every clear dark night with repeated exposures of selected fields to check the optical and electronic characteristics of the system and to develop and test the data-handling and transient detection programs. Software for rapidly responding to coordinate alerts, and for remote operation, including weather monitoring, is currently under construction. The system will eventually be capable of performing a complete survey of the accessible sky every clear night, while awaiting, and responding to, transient alerts. The second stage of the ROTSE system consists of two 0.45m telescopes presently being built at Torus Optics in Iowa, and expected for delivery in the winter of 1997/1998.

Gisler, **Kirsten Boudreau**, and **Partridge**, together with Phil Lubin (UC Santa Barbara) and Suzanna Deustua (LBNL) have been working towards the installation of the Research and Education Automatically Controlled Telescope (REACT) at Fenton Hill. This telescope, with a narrower field and greater depth than the ROTSE systems, will be used for follow-on studies of detected transients, and for continued monitoring of known sources. Its field of view is well matched to the resolution of the Milagro ultra-high-energy gamma-ray detector. The 0.4m telescope is presently being fitted for automatic operation by Epoch Instruments of San Leandro CA. The automated dome, with its control system and weather station, has been received, and will be assembled on site as soon as the concrete pad for the observatory is in place, expected in autumn 1997.

Todd Haines, **Casperson**, **Beaver**, **Partridge**, **Gisler** and **Mayra Alana**, together with Mark Vagins (UC Irvine), have begun design studies for an all-sky optical monitor for the detection of bright transients. An inexpensive way of achieving all-sky coverage is an array of off-the-shelf camera lenses and CCD cameras (Astrophysical Transient Observatory Multiple Imaging Cameras - ATOMIC), similar to the approach taken by Tom Droege and The Amateur Sky Survey (TASS), but unitary designs are also under consideration. It is relatively straightforward, with ATOMIC arrays installed at several locations, to achieve continuous coverage of the entire sky down to $\sim 12^{\text{th}}$ magnitude.

3.5 Particle Acceleration

Hui Li continues to work on wave-particle resonant acceleration processes. The transient-time damping between electrons and oblique magnetohydrodynamic waves can accelerate electrons out of the thermal bath and form nonthermal tails that give rise to gamma-ray emissions in accretion disks around black hole candidates. The work done together with J.A. Miller (UAl) is published in ApJL 478, 67. He gave the invited review talk on the stochastic particle acceleration in the Relativistic Jets Workshop in Cracow, Poland. **Li** and **Peter Gary** finished a paper on proton firehose instability and its role in solar wind which has been submitted to JGR. Together with M. Kusunose (Japan), they have finished a massive time-dependent wave-particle-photon coupled kinetic code which will be used to model the multiwavelength spectra from black hole accretion disks, jets and possibly gamma-ray bursts (ApJ, to be submitted).

Hui Li, **Stirling Colgate** and Richard Lovelace (Cornell), have (almost) finished a paper on Rossby wave instability in Non-Barotropic accretion disks (ApJL, to be submitted). They discovered that this instability is likely responsible for the onset of viscosity in accretion disks and may explain the transient phenomena seen in many x-ray binaries.

3.6 Ultra-high-energy astrophysics

The Milagro Air Shower Detector: **Todd J. Haines**, **Richard S. Miller**, **Gus Sinnis**, **Cyrus M. Hoffman**, **Galen Gisler**, D. Berley, M.-L. Chen, 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. Autonoma Barcelona), A. Lu (UC Santa Barbara), 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), M. McConnell, J. Ryan, (U. New Hampshire), B. Dingus, (U. Utah).

The Milagro air-shower detector is under construction at Fenton Hill 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 m^2 covered pond located at an elevation of 2640 m. Milagro will have an energy threshold below 500 GeV and a muon detection area of 1500 m^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, and Markarian 501 and 421) will be studied.

In 1995, the site was prepared for Milagro: a new pond liner and cover were installed as were a water circulation and filtration system and a cover-inflation system to permit work underneath the cover. During the summer of 1996, the entire structure used to position all of the photomultiplier tubes in the pond was installed. In the late summer of 1996, a prototype detector, called Milagrito, was installed. Milagrito has 228 photomultiplier tubes sitting on the pond bottom covered with $\sim$ 1 meter of water; it has the same energy and angular response as Milagro, although it is smaller and has no muon detection capabilities. Milagrito began taking data in February, 1997. The primary purpose is to test the Milagro hardware and to perfect reconstruction and analysis techniques. In addition, Milagrito can perform 1-TeV observations of transient and steady sources. To date, over 4 billion events have been recorded.

In the spring of 1998, Milagrito will be disassembled and the full Milagro detector will be installed; completion is expected by fall 1998 with data taking beginning soon thereafter. Observations with Milagro are expected to continue for 5-10 years.

3.7 Solar energetic particles

Robert C. Reedy (NIS-2) has continued his work on studying ancient solar energetic particles using the lunar nuclide fossil record. Recently measured cross sections have been used to unfold measurements of 5730-year ^{14}C in lunar rock 68815 and 0.10-Myr ^{41}Ca, 0.72-Myr ^{26}Al, and 1.5-Myr ^{10}Be in lunar rock 74275. Average solar proton fluxes inferred for the past 10^4 year (from ^{14}C) and 10^5 years (from ^{41}Ca) are higher by about 40% and $\sim$100%, respectively, than those over the last 10^6 years (from the other two radionuclides), although the ^{41}Ca results have large uncertainties because several key cross sections have not been measured. These and additional (e.g., 0.30-Myr ^{36}Cl and stable ^{21}Ne) nuclides in other lunar samples are now being studied to confirm and extend these results for fluxes of solar protons for various time periods during the last few million years.

3.8 Near-Earth Objects

Jack Hills, and **M. Patrick Goda** studied the meteoroid of October 3, 1996 that entered the atmosphere over New Mexico and Texas. This object grazed the atmosphere and then returned to space. It had been suggested that it went into a bound orbit around the Earth and entered the atmosphere in California one orbit later. Hills and Goda used a spherical atmospheric model to integrate the passage of the object through the atmosphere. They found that if it were iron its initial radius was 0.5-0.8 meter while if it were stone its radius was 1-2 meters. There are problems with the capture hypothesis for this object: The length of arc that it traveled in the atmosphere from its closest approach to Earth to the point where it left the atmosphere at a height of 100 km was about 1700 km, which is longer than observed. It is also hard to see how the orbiter could have landed as far north as California. Because of the much smaller velocity of the object and its smaller radius due to ablation, they find that the object is much more strongly affected by the atmosphere on its second return. It should have plunged to ground well before reaching California.

3.9 Nuclear Physics

J.B. Wilhelmy, **R.S. Rundberg**, **M.M. Fowler**, **G.G. Miller**, **K. Ullmann**, **J.L. Ullmann**, and **R.C. Haight** measured neutron capture gamma rays for neutrons incident on radioactive ^{171}Tm, as part of a new program to study neutron capture cross sections on radioactive nuclides. A target consisting of about 2.7 Ci (2.5 mg) of the 1.9 year ^{171}Tm was prepared by irradiation of ^{171}Er in the INEL reactor. The Tm was chemically separated from the Er source and electrodeposited on a 0.5 mil Be foil that had been coated with about 700 angstroms of Ti. A cover foil of 0.5 mil Be was placed on top of the target. The target sandwich was irradiated at the Lujan Center pulsed neutron facility at LANSCE. Prompt gamma rays were measured using two deuterated benzene liquid scintillators. Neutron energies were determined by time of flight techniques. The useful range was from 1 eV to more than 100 keV incident neutron energy. To verify the procedure, several stable species were measured using the same chemical techniques and experimental set up. These consisted of ^{169}Tm, ^{165}Ho, ^{171}Yb, blank Be backings, and Au foils. The on-line analysis showed very distinctive structure that could be identified with capture reactions on ^{171}Tm. Data reduction is currently in progress to convert the results into neutron energy-dependent capture cross sections. These data are of interest in s-process astrophysical applications.

3.10 Neutrinos

Terry Goldman, with G.J. Stephenson (UNM), and B.H.J. McKellar (U Melbourne) studied neutrino clouds. They consider the possibility that neutrinos (but no other light fermions) are coupled very weakly to an extremely light scalar boson. They first analyzed the simple problem of one neutrino generation and show that, for ranges of parameters that are allowed by existing data, such a system can have serious consequences for the evolution of stars and could impact precision laboratory measurements. They discussed the extension to more generations and showed that the general conclusion remains viable. Finally, should such a scalar field be present, experiments would give information about effective masses, not the masses that arise in unified field theories.

They also studied MSW-like enhancements without matter. A scalar field, coupled only to neutrinos, has an effect on oscillations among weak interaction current eigenstates. The effect of a real scalar field appears as effective masses for the neutrino mass eigenstates, the same for the antineutrino as for the neutrino. Under some conditions, this can lead to a vanishing of δm^2, which maximizes mixing independently of the vacuum mixing angles, as in the MSW effect. They discuss some examples and show that it is possible to resolve an apparent discrepancy in spectra required by r-process nucleosynthesis in the mantles of supernovae and by solar neutrino solutions.

Thomas Bowles supplied the following report from the SAGE experiment, in which **J.S. Nico**, **W.A. Teasdale**, and **D.L. Wark** also participated.

SAGE has reported a result for the integral flux of solar neutrinos of $74\ ^{+11+5}_{-10-7}$ SNU, which is only 55% of that predicted by the Bahcall- Pinsonneault standard solar model. Taken together with the results from the other solar neutrino experiments (chlorine, Kamiokande and SuperKamiokande, and GALLEX) it appears likely that the observed deficit of solar neutrinos is due to neutrino oscillations. If true, this would require that neutrinos have mass and would constitute the first definite evidence of new physics beyond the standard electroweak model which is predicted to exist by most Grand Unified Field Theories.

To check the overall efficiency of SAGE, a calibration of the Gallium- Germanium Neutrino Telescope was carried out in 1995 using an artificial ^{51}Cr neutrino source with the activity of about 520 kCi. They published the results in Phys. Rev. Lett. 77 (1996) 4708 with a quoted ratio of the measured production rate to that predicted from the source activity of 0.95 ± 0.12. This verifies that the SAGE experimental operation is correct and provides considerable evidence for the reliability of the SAGE solar neutrino measurements.

Several hypotheses have been developed to explain the observed solar neutrino deficit, based on proposed neutrino properties, particularly neutrino oscillations. However, the combined uncertainties due to statistics and systematics in solar neutrino measurements can not completely exclude an astrophysical solution of the solar neutrino problem. It has recently been pointed out by Robertson and Heeger that the confidence level with which one can rule out astrophysical solutions of the solar neutrino problem is highly sensitive to the central value and uncertainty in the gallium results. Thus, it is very important to continue to improve the accuracy of the SAGE results.

To increase measurement accuracy, SAGE started a program in 1996 of further data taking, which includes carrying out measurements at intervals of 1.5 months during the period of 1996 through at least 1998. During early 1997 additional equipment was installed that further automated the extraction process with a consequent improvement in the stability and reliability of operations. Extractions continue to be carried out on this schedule with the last extraction being made in late September 1997.

It should be noted that measurements made in this period are of the highest importance as data will be taken simultaneously with measurements of the very large neutrino telescopes SuperKamiokande and SNO, which are only sensitive to the higher energy part of solar neutrinos and do not provide any information on the dominant p-p solar neutrino flux that is measured by SAGE.

It is also obvious, in spite of the exceptional importance of measurements using existing telescopes, that a new generation of active neutrino telescopes with a low energy threshold of about 100 keV and resolution of about 2 keV would provide significant progress in understanding the processes inside the Sun as well as new neutrino properties. Telescopes based on GaAs crystalline detectors can provide the ability to independently study solar neutrino properties as well as solar physics. The ability to measure p-p solar neutrinos as well as ^{7}Be and pep neutrinos could enable the measurement of the parameters of possible MSW neutrino oscillations with unprecedented accuracy. It would also be possible to directly measure the temperature in the center of the Sun as well as to observe interactions of neutral currents. Such detectors could also address a wide variety of other interesting problems in physics. Of particular interest is the ability of small detectors of GaAs to provide significant improvement in the ability to search for dark matter in the form of Weakly Interacting Massive Particles (WIMPs).

In 1997 the SAGE collaboration began investigations of the technical possibilities of development of crystalline detectors based on GaAs. Large (1 kg) GaAs crystals were produced under special conditions. These crystals have substantially improved electronic characteristics compared to most commercially available GaAs. They are now working to make small detectors out of these crystals and to measure their performance as photon and charged particle detectors.

3.11 General Relativity and Cosmology

Wojciech H. Zurek continued to work on problems in cosmology and black hole astrophysics. In the first category are the efforts to understand the gravitational origins of the galactic and large scale structure, and ways to infer cosmological parameters (such as Ω) from observations (collaborative efforts with **M.S. Warren** and postdocs). In much earlier stages of the evolution of the Universe, second-order phase transitions, such as those observed in ^{3}He experiments, are relevant. These recently allowed two groups to test basic understanding of cosmological phase transitions in the laboratory, mentioned in the justification of the 1996 Nobel prize. This resulted in a collaboration with Pablo Laguna and others to simulate phase transitions. Star-disk collisions, a joint project with **S.A. Colgate** and A. Siemiginowska, led to a better (and much more optimistic) estimates of the broad-line regions resulting from this phenomenon. It has also resulted in a joint project with P.J. Armitage and M.B. Davies on fuelling active galactic nuclei.

Dharam Ahluwalia and C. Burgard introduced a new effect of gravitationally induced quantum mechanical phases in neutrino oscillations. In the neighborhood of a neutron star, gravitationally induced quantum mechanical phases are roughly 15% of their kinematical counterparts. When this information is coupled with the mass square differences implied by the existing neutrino–oscillation data they find that the new effect may have profound consequences for type-II supernova evolution.

Ahluwalia introduced a generalized notion of flavor–oscillation clocks. The generalization contains the element that various superimposed mass eigenstates may have different relative orientation of the component of their spin with respect to the rotational axis of the gravitational source. It is found that these quantum mechanical clocks do not always redshift identically when moved from the gravitational environment of a non–rotating source to the field of a rotating source. The non–geometric contributions to the redshifts may be interpreted as quantum mechanically induced fluctuations over a geometric structure of space–time.

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The publication list includes all papers published or submitted between July 1996 and June 1997 by LANL staff and their collaborators.

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Galen Gisler
Cyrus Hoffman