Institute of Geophysics and Planetary Physics
Los Alamos National Laboratory
2006 Annual Report

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IGPP Scholars

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LA-UR 07-2528

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Mission of IGPP and Insitutional Goals

The Institute of Geophysics and Planetary Physics (IGPP) at Los Alamos National Laboratory (LANL) is a branch of the IGPP systemwide multicampus research unit (MRU) of the University of California (UC). As such, the science mission of IGPP is to *"promote and coordinate basic research on the understanding of the origin, structure, and evolution of the earth, the solar system, and the universe, and on the prediction of future changes, as they affect human life."*

In addition to its role as part of a UC MRU, IGPP at Los Alamos is also a Laboratory institutional center. The institutional goals of IGPP are as follows:

(a) To enhance University-Laboratory relations by fostering collaborations between UC campus faculty, staff, students, and LANL staff

(b) To provide LANL programs with the input of new ideas, people, and contact with the university community at-large

(c) To foster top-quality research at LANL in the more "basic" or "fundamental" aspects of fields that can be mapped to LANL mission thrust areas

(d) To provide a stimulating venue for LANL scientists to broaden their research horizons

Organization of this report

- IGPP: philosophy, leadership, budget, and scope of activities
- Collaborative research activities supported by IGPP during FY06
- Scholar program: scholars during FY06
- Scientific output reported during FY06
- Workshops supported during FY06
- IGPP Summer Schools during FY06

1. IGPP: an organizational summary

IGPP philosophy, leadership, and budget

As part of LANL's mission to conduct the most creative mission-relevant scientific research, IGPP seeks to assure that the Laboratory adopts the highest quality talent in developing new scientific areas. The Laboratory recognizes that the best science in new areas is best facilitated if a strong University presence exists in IGPP sponsored projects. For this reason, IGPP promotes collaboration with universities, and a strong preference is given to collaborations that involves graduate students and postdocs.

Because LANL's line organizations (e.g., divisions) emphasize programmatic research typically supported on 1-3 year time scales, IGPP emphasizes scientific research that has not yet secured programmatic support. Therefore, IGPP favors support to "emerging" scientific research, in stark contrast to applied research that is present in most line organizations.

IGPP performance metrics

- University collaborations: research projects, that involve co-PI's from both the Laboratory and University, including graduate students and/or postdocs.
- Scientific output, e.g., journal publications.
- Revitalization of science: workshops dedicated to summarizing state of the art and/or scientific priorities.
- Extending scientific investments into Laboratory programs.
- Recruitment and retention of LANL staff.

IGPP/LANL is a dynamic organization, and portfolios are adjusted according to changes in the scientific landscape and anticipated new directions within LANL. At present, its leadership consists of a director, managers of four scientific focus areas, an administrative officer, and a secretary.

- Director: Gary Geernaert
    - Operations administrative specialist: Debra Saiz
    - Administrative assistant: Deb Rivera
- Astrophysics focus area: Richard Epstein
- Space physics focus area: Reiner Friedel
- Geophysics focus area: Claudia Lewis
- Climate focus area: Manvendra Dubey
- Summer schools
    - Geophysics (SAGE): Scott Baldridge
    - Cosmology: Salman Habib

An external advisory board meets annually, typically in June. Their tasks are to review the quality of the IGPP investments during the previous year, recommend the selection of collaborative projects to be conducted during the following year, and recommend any improvements and/or changes to IGPP's business practices. The IGPP advisory board meeting typically includes presentations from key client line organizations (e.g., EES, ISR, and X divisions; LDRD program office; and PADSTE) where scientific long term needs and challenges are summarized. During FY06, the advisory board was chaired by Professor Jerry Schubert, UCLA; and members represent the disciplines that are governed by IGPP's portfolios:

- Astrophysics and cosmology
  - Bob Rosner, Argonne National Laboratory
  - George Fuller, University of California, San Diego
  - Gary Zank, University of California, Riverside
- Space physics
  - Chris Russell, University of California, Los Angeles
  - Mike Liemohn, University of Michigan
- Geoscience, including climate and atmospheric sciences
  - Jerry Schubert, University of California, Los Angeles
  - John Roads, University of California, San Diego
  - Freeman Gilbert (UCSD)

IGPP's budget during FY06 included: \$1.6M from the LDRD program office; \$780K of Laboratory G&A, and \$250K from Univesity of California Office of the President. The LDRD Office supports collaborative research as well as the Orson Anderson scholar (see below), while UCOP funds are dedicated to collaborative projects that involve UC campuses. G&A supports IGPP administrative activities, program development directly related to IGPP portfolios, and workshops.

The Orson Anderson Scholar and the Visitor Program

The Laboratory supports the IGPP Orson Anderson scholar with funding from the Laboratory Directed Research and Development program. The Orson Anderson scholar is selected each year, based on Laboratory science challenges and opportunities for collaboration with external institutions. The Orson Anderson Scholar typically is in resident during a period from six months to one year, depending on the availability of the scholar. In addition to the Orson Anderson Scholar, IGPP hosts visiting scholars, with terms lasting up to six months.

During FY06, IGPP's scholars included the following:
(a)Tuija Pulkkinen, OA Scholar from the Space Research Finnish Meteorological Institute. Resident for one year.

(b)Visiting scholar: Phil Kronberg, University of Toronto, resident since 2002.

IGPP activities

IGPP's collaborative research projects and workshops are distributed into each of the four portfolios: astrophysics, space physics, geoscience, and climate/environment. The IGPP collaborative minigrant program, with a co-PI from the Laboratory and a co-PI from a university, presently supports about 40 graduate students and postdoctorial fellows, who spend a substantial fraction of their research time on-site at the Laboratory. Minigrants are also dedicated to support to LANL postdocs. Minigrants are selected via a peer review process, with input from the external advisory committee that meets at LANL in June each year. Minigrants normally cover a three-year period.

IGPP normally supports between 15 and 30 workshops, annually. Topics are recommended by LANL scientists and/or the IGPP systemwide within the University of California.

IGPP also supports summer schools in areas of scientific interest to the Laboratory. Summer schools are supported in order to provide the necessary training to university graduate students so that they are well qualified to start a career on research topics critical to the Department of Energy immediately upon graduation. During FY06, IGPP provided support to the Summer Applied Geophysics Experience (SAGE) summer school, and the annual cosmology workshop.

2. Collaborative research activities during FY06

2.1 Astrophysics research overview: Focus Leader Richard I. Epstein

The Astrophysics focus has supported research in gamma-ray astronomy, neutron star physics, supernova simulations and cosmological structure formation. High-energy gamma rays represent special probes of the universe because they indicate nonthermal activities, i.e. cosmic particle accelerators. The Milagro wide-field high-energy gamma-ray telescope at LANL may be able to see the high-energy tail of gamma-ray burst spectra. A large data sample from a known source of high-energy gamma rays, the Crab Nebula, has been accumulated by Milagro, and a first generation of analysis tools has been developed. The current research project increased the sensitivity of Milagro by improving its background rejection capabilities. In addition to Milagro, IGPP supports research that exploits other facilities, e.g., the Sloan Digital Sky Survey. As is becoming widely appreciated in many fields, we are now entering an age of sophisticated data analysis of observations matched to theory via very large scale computer simulations. This is the age of "predictive science." In almost no other field has this strategy for scientific discovery become as widely important as in cosmology and astrophysics.

The IGPP-supported work on multiphase hydrodynamic simulations addresses formation, distribution, evolution, and interactions of galaxies and the dynamics of clusters. Although radio pulsars can be exceptionally stable clocks, imperfections in the rotation of some pulsars, most notably glitches, have been monitored for some time. Most work has focused on observations of glitches and timing noise, but there is also evidence, in some cases, for long-term, cyclical, but not precisely oscillatory, variations in pulsar spin on timescales of months to years. Such long-timescale variations are reminiscent of free precession; however, this explanation does not work if superfluid vortices are pinned to nuclei in the inner neutron star crust, as is supported by theories of the glitch phenomenon. Investigators have approached this question by producing a multicomponent model for a rotating neutron star that includes the effects of crust-core couplings, vortex drag in the crust as well as in the core, imperfect rigidity of the crust, and magnetic field effects.

***Astrophysics collaborative project reports*:**

Migration of Pro-planets in Gaseous Disks

Principle Investigators:

Hui Li, Los Alamos National Laboratory

Douglas Lin, University of California Santa Cruz

Ian Dubbs-Dixon, Graduate Student, University of California Santa Cruz

There are now about 150 extrasolar planetary systems discovered but major surprises have emerged. One is that very massive planets (up to 10 Jupiter masses) are found to orbit their central stars very closely (at a fraction of Mercury's orbit). One popular theory is to postulate that giant planets were indeed formed farther out in the disks (several AUs) but have migrated inwards to the central star. But theoretical and some numerical studies

have suggested that the migration might occur so rapidly that smaller planets do not have enough time to grow into giant planets before they have migrated all the way to the star (the Type I migration problem). We have proposed to study this problem using high-resolution hydro simulations of gaseous disks with embedded proto-planets. One key aspect is that we want to explore the role of vortices and how they affect the overall torque exerted on the proto-planet. The proposed research forms the part of the PhD research of I. Dubbs-Dixon from UC-Santa Cruz.
Link to: Migration of Pro-planets in Gaseous Disks

Cosmological Hydrodynamics with Adaptive Mesh Refinement
Principle Investigators:
- Salman Habib, Los Alamos National Laboratory
- Dr. Katrin Heitmann, Los Alamos National Laboratory
- Paul Ricker, University of Illinois
- Zarija Lukic, Graduate Student, University of Illinois

Multi-physics hydrodynamics simulations represent the frontier of cosmological and astrophysical simulation. These efforts address science problems of the first rank, such as the formation, distribution, evolution, and interaction of galaxies and the dynamics of clusters. Our research program targets simulation of cosmological flows including gravity, plasma physics, and gas dynamics via adaptive mesh refinement (AMR) codes combining both mesh-based and particle-mesh based solvers. We are applying this capability to the analysis of galaxy clusters and the distribution of matter on scales from hundreds of megaparsecs down to kiloparsecs. Our work is aimed at interpreting observational data from the Sloan Digital Sky Survey (SDSS), Chandra, XMM, and planned near-future observations such as the Constellation-X mission and the South Pole Telescope.
Link to: Cosmological Hydrodynamics with Adaptive Mesh Refinement

Background Characterization for Advanced Gamma-Ray Telescopes
Principle Investigators:
- Marc Kippen, Los Alamos National Laboratory
- Derek Taurnear, Los Alamos National Laboratory
- Mark McConnell, University of New Hampshire
- Pete Bloser, Postdoc, University of New Hampshire

The inability to accurately simulate space background is currently limiting progress in the fledgling field of observational nuclear gamma-ray astronomy. We propose to improve this situation by performing a detailed study of the near-Earth space environment that the next-generation advanced gamma-ray telescopes will occupy. In particular, we propose to model the effects this environment will have on the background for gamma-ray telescopes being developed at LANL, UNH and elsewhere. Completion of a comprehensive background simulation system for this class of telescopes will be extremely important to all researchers in this field. Results will be used to predict science goals for future missions, and to allow useful analysis of the data once they are collected. Additionally, completion of these studies will place our collaboration in a strong position to compete for funding from NASA for the development of one or more proposed missions. Link to: Background Characterization for Advanced Gamma-Ray Telescopes

Improvement of Background Rejection in Milagro Using the Outrigger Array
Principle Investigators:
Gus Sinnis, Los Alamos National Laboratory
Aous Abdo, Michigan State University
Jim Linnemann, Michigan State University

The Milagro gamma-ray observatory is a new type of TeV gamma-ray telescope, using the water Cherenkov technique to detect the extensive air showers produced by energetic gamma rays and cosmic rays. Here we report the results of the first year of effort in using the outrigger tank array to improve the ability of Milagro to reject events initiated by cosmic rays while retaining those initiated by gamma rays. The results of this effort will be an increased sensitivity for the Milagro instrument. This increased sensitivity will enhance all aspects of the physics goals of Milagro.

Channeling Optics for High-Resolution Gamma-Ray Astronomy
Principle Investigators:
Richard Epstein, Los Alamos National Laboratory
James Matteson, University of California San Diego
Slawomir Suchy, Graduate Student, University of California San Diego
Andy Chen, Graduate Student, University of California San Diego
Derek Tournear, Postdoc, Los Alamos National Laboratory

We are using the innovative gamma-ray optics developed at Los Alamos together with sensitive position and energy-resolved gamma-ray detectors developed at UCSD to create revolutionary, new astronomical gamma-ray telescopes that have far superior angular resolution. The successful completion of this work would put the LANL/UCSD collaboration in a strong position to compete for funding from NASA. Additionally, gamma-ray imaging and concentrating has potential importance for medical and homeland security applications; we would also seek programmatic funding from those sources.
Link to: Channeling Optics for High-Resolution Gamma-Ray Astronomy

How Violent is the IGM at High Redshift? The effect of feedback on the Lyman Alpha Forest
Principle Investigators:
Katrin Heitmann, Los Alamos National Laboratory
Matias Zaldarriaga, Harvard University
Adam Lidz, Postdoc, Harvard University

The inter-galactic medium (IGM) seen in Lyman-alpha absorption towards distant quasars plays a very important role in cosmology. It offers a probe of matter clustering in the quasi-linear regime at redshift, $z\sim3$, as well as a window on the extent to which

galaxy formation impacts subsequent structure formation. We propose to study the impact of galactic outflows on the statistics of the Lyman-alpha forest using state-of-the-art numerical simulations, providing insights into galaxy formation and constraining any effect on cosmological parameter determination.
Link to: How Violent is the IGM at High Redshift?

Very High Energy Observations of Gamma-Ray Bursts in the Swift Era
Principal Investigators:

Brenda Dingus Los Alamos National Laboratory
David A. Williams, University of California, Santa Cruz
Postdoctoral Researcher: Pablo Saz Parkinson, University of California, Santa Cruz

The Milagro gamma-ray observatory is a TeV gamma-ray telescope operating at the Fenton Hill site of LANL. Milagro uses the water Cherenkov technique to detect the extensive air showers produced by energetic gamma rays and cosmic rays. Milagro is the first instrument capable of continuously monitoring the entire overhead sky at TeV energies and is therefore ideally suited for the study of transient phenomena, such as gamma-ray bursts (GRBs).

In the first year of this project (September 1, 2005 – August 30, 2006), we have intensified our efforts to detect very high energy emission from GRBs. We have searched the data corresponding to the 27 GRBs which were detected by satellites in this period and which were visible to Milagro. We analyzed the Milagro data for each new burst almost immediately and informed the community of our results in a timely fashion by sending out GCN Circulars (five in the aforementioned period) for the most interesting candidates. In addition, we also undertook an archival search of the BeppoSAX and IPN catalogs, adding another 25 possible candidates. We have presented the results of our searches at three international conferences and are preparing an article for submission to the Astrophysical Journal. The launch of the Swift satellite in late 2004 with its high rate of detection of GRBs, along with the improvements made in both the experiment and our analysis techniques make this an exciting and promising time to be working on the detection of the highest energy photons from GRBs.
Link to: Very High Energy Observations of Gamma-Ray Bursts in the Swift Era

An Optimal Large Scale Structure Weak Lensing Survey to Measure Dark Energy Properties
Principal Investigators:

Daniel Holz Los Alamos National Laboratory
Asantha Cooray, University of California, Irvine
Postdoctoral Researcher: Dr. Naoki Seto, University of California, Irvine
Graduate Student: Hao Gao, University of California, Irvine

There is now overwhelming observational evidence that the universe is undergoing a period of rapid expansion, though the dark energy density component that is responsible for this acceleration is less understood. With the acceleration well established, the focus

is now on trying to understand and develop observational methods that can further elucidate underlying physics related to dark energy, and to distinguish between competing models that involve vacuum energy (cosmological constant), scalar fields, modifications to gravity, among others. We propose to study several potentially interesting methods that can be used to extract additional details, such as the dark energy equation of state (the ratio of pressure to density), and the dependence of the density and equation of state on cosmic epoch. The approaches include weak gravitational lensing of background galaxies by foreground large-scale structure, Type Ia supernova distances out to redshifts of a few, and the signature of baryon oscillations in the large-scale structure clustering. We will optimize a large-scale structure survey to establish the depth and the sky-area that is required to extract the most information related to dark energy. The goal here is to understand whether large-scale structure imaging surveys should be designed to image narrow fields down to fainter magnitudes, or whether it is best to cover larger areas but to shallower depths (for a fixed amount of imaging time). Our study has direct applications to all the proposed surveys that are planned to study dark energy over the next decade.
Link to: An Optimal Large Scale Structure Weak Lensing Survey to Measure Dark Energy Properties

2.2 ***Space Physics Research Overview:*** *Focus Leader Reiner Friedel*

This IGPP focus area supports theoretical research, computational research, and/or observational research into the plasma environment of the Earth's atmosphere and into processes that affect this environment. Research on the transport of plasma and energy from the Sun through interplanetary space to the Earth is also encouraged. Included are the interaction of various plasma populations and the coupling of microscopic and macroscopic phenomena.

Leveraging against Los Alamos National Laboratory (LANL) facilities and databases, e.g., linkage to multi-cluster satellite experiments or computer simulation codes, is strongly encouraged. In particular, use of the extensive measurements from the LANL geosynchronous instruments and GPS instruments, which are unique LANL assets, is encouraged.

Collaborative project reports:

Full Particle Simulations of Magnetic Reconnection at the Magnetopause
Project Investigators:
Gianni Lapenta, Los Alamos National Laboratory
William Daughton, Los Alamos National Laboratory
Homa Karimabadi, University of California San Diego
Jonathan Driscoll, Graduate Student, University of California San Diego

Our goal was to start a systematic study of collisionless magnetic reconnection process at the dayside magnetopause. Many important details of reconnection at the magnetopause remain poorly understood (steady versus non-steady reconnection, preferred location of onset, etc.). During this cycle, we attacked this problem by reconsidering the problem of reconnection onset and its subsequent evolution as a function of guide field. Our approach was based on a combination of nonlocal Vlasov linear theory, analytical theory, and full particle simulations. Our results were surprising: (i) In the linear regime, we demonstrated the existence of a new "intermediate" regime as a function of guide field. (ii) We found no support for any of the previous nonlinear theories. In particular, the prediction that tearing would saturate at minute amplitudes in the presence of a guide field turned out to be incorrect. Our finding suggests that both anti-parallel and component merging can occur at the magnetopause.
Link to: Full Particle Simulations of Magnetic Reconnection at the Magnetopause

Thin Current Sheet Instabilities and Collisionless Magnetic Reconnection
Project Investigators:
Giovanni Lapenta, Los Alamos National Laboratory
Peter Yoon, University of Maryland

We developed a technique for solving the linearized Vlasov-Maxwell set of equations, in which the perturbed distribution function is described as an infinite series of orthogonal

functions, chosen as Hermite-Grad polynomials. The orthogonality properties of such functions allow us to decompose the Vlasov equation into a set of infinite coupled equations. This technique is based on solid but easy concepts, not attempting to evaluate the integration over the unperturbed trajectories and can be applied on any equilibrium. Although the solutions are approximate, because they neglect contributions of higher order coefficients of the series, the physical meaning of the low-order coefficients is clear. This allows us to know exactly on which assumptions the approximation is made and gives a snapshot on which quantities are dominant in the equilibrium. Furthermore the accuracy of solution, which depends on the number of terms taken in account in the Hermite series, appears to be merely a problem of computational power. The method has been tested setting an initial 1-D Harris equilibrium that is known to give rise to several instabilities, like tearing, drift-kink, lower-hybrid. To compare, the same problem has also been studied using particle-in-cell simulations.
Link to: Thin Current Sheet Instabilities and Collisionless Magnetic Reconnection

A Study of Precipitation Losses of MeV Electrons Using Multiple Balloon and Multiple Satellite Observations

Project Investigators:

Reiner Friedel, Los Alamos National Laboratory
Robert Lin, University of California Berkeley

During the first year of this IGPP grant we have thus far conducted the balloon campaign to acquire the unique MINIS data set. The campaign was an overall success with six balloons making a total of twenty-four days of observation. Three balloons, two southern and one northern, were aloft and making observations during the magnetic storm, and MeV precipitation events of January 21st. Data from that day, in particular, is well suited to perform the satellite-balloon correlation study that this IGPP mini-grant set out to do. Since the completion of the campaign, John Sample, the graduate student involved in the project, has begun to process the data into a form that can be connected to in situ satellite measurements. First results of the campaign have been presented at the Spring AGU and the 2nd Annual AOGS meetings. John Sample and Reiner Friedel, the LANL PI also discussed the necessary steps in processing the data during a week-long workshop following the successful balloon campaign. Revised Work Plan for FY 06: The second year of the IGPP mini-grant will be dedicated to performing the correlation work with LANL satellite data. Thus far no visits by the graduate student to LANL have occurred, but such a visit is being planned for FY 05. The second year should involve significant time with the graduate student visiting LANL to bring the data sets together and work with the LANL PI in constructing any models necessary to connect the data sets. Changes to the budget: The most significant change to the budget is the dropping of the graduate student salary, in its entirety, from the mini-grant. This is possible because John Sample is the recent recipient of an NSF Graduate Research Fellowship. The second year s budget thus supports travel for the graduate student to LANL, and support for the LANL PI.
Link to: A Study of Precipitation Losses of MeV Electrons Using Multiple Balloon and Multiple Satellite Observations

Observing the Heliosphere in Energetic Neutral Atoms

Project Investigators:

Herb Funsten, Los Alamos National Laboratory
Gary Zank, University of California Riverside

Nicolai Pogorelov, Vladimir Florinski, Jacob Heerikhuisen, University Co-Investigators:
The main goal of this proposal is to understand the passage of interstellar hydrogen through the heliosphere. While the solar wind plasma contains a large fraction of neutral atoms, the source of these is not the Sun; rather, these neutrals have propagated into the heliosphere from interstellar space. Through the process of charge-exchange, interstellar neutrals affect the bulk dynamics of the outer solar wind, generating pick-up ions as well as energetic neutral atoms. Any model of the heliosphere therefore requires a detailed neutral atom component.
Link to: Observing the Heliosphere in Energetic Neutral Atoms

Radial Evolution of Solar Wind Structure

Project Investigators:

Ruth Skoug, Los Alamos National Laboratory
Christopher Russell, University of California Los Angeles
Lan Jian, Graduate Student, University of California Los Angeles

A key element of successful solar terrestrial predictions is to be able to predict how solar wind structure evolves radially as it propagates from the sun. This effort examines available solar wind data over a variable range of radial separations, examining both stream interactions and interplanetary coronal mass ejections, both to gather empirical understanding of their evolutions and to provide constraints for existing MHD models. The major results in year 1 concerned establishing baseline conditions at 1AU as a function of the phase of the solar cycle. Preparations were also made for the second year's effort exploring the heliocentric radial gradient in the structure and dynamics of the solar wind.
Link to: Radial Evolution of Solar Wind Structure

The Formation of the Cold Dense Plasma Sheet

Project Investigators:

Michelle Thomsen, Los Alamos National Laboratory
Joachim Raeder, University of New Hampshire
Wenhui Li, Graduate Student, University of New Hampshire

Earth's geomagnetic tail consists of the tail lobes and the plasma sheet that separates the lobes. During most times the plasma of the plasma sheet is hot (~5 keV) and tenuous (<~0.1 cm^{-3}), which we call the Hot Tenuous Plasma Sheet (HTPS.) Since the plasma of the plasma sheet is supplied either by reconnection at the dayside magnetopause or by ionospheric outflow, and because these processes subside during times of geomagnetic quiet, one would assume that during such times the plasma sheet would become even less dense. However, often the opposite is observed. During times of several hours of northward Interplanetary Magnetic Field (IMF), and when geomagnetic activity ceases, oftentimes a Cold Dense Plasma Sheet (CDPS) is observed. The density of the CDPS can be as high as several cm^{-3} and the plasma temperature drops well below 1 keV. The CDPS is observed more often near the flanks, but at times extends throughout the plasma sheet. Several mechanisms have been proposed to explain the CDPS, in particular plasma diffusion across the magnetopause, plasma mixing due to Kelvin-Helmholtz vortices, and dual lobe magnetic reconnection. Understanding the CDPS formation is important because the plasma sheet provides the seed populations for the Ring Current and the Radiation Belts, which can become substantially enhanced when the IMF turns southward after a CDPS episode, and when the ensuing magnetic storm pushes the plasma into the inner magnetosphere.

The objective of this project is to establish the physical processes that lead to the formation of the CDPS and to investigate their dependence on the solar wind and IMF parameters.
Link to: The Formation of the Cold Dense Plasma Sheet

Radial Diffusion Modeling with Data Assimilation
Project Investigators:
Geoffrey Reeves, Los Alamos National Laboratory
Richard M. Thorne, University of California, Los Angeles
Yuri Shpirts, Graduate Student, University of California Los Angeles

In this study we propose to incorporate data assimilation techniques into a radial diffusion model of relativistic electrons in the outer radiation belt. The model parameters responsible for stochastic processes will be adjusted first empirically and later by means of data assimilation procedures to give the best fit to observations. We will also perform validation of our results by solving the inverse problem and thus obtain stochastic parameters from the measurements. We propose to assimilate LANL data into computer simulation code using parameter estimation techniques to understand the processes that influence space weather. The techniques and tools developed in this study may in future be applied to more comprehensive global models.
Link to: Radial Diffusion Modeling with Data Assimilation

Multi-Satellite Observation of Substorm Expansion Onset in the Geosynchronous and Mid-tail Regions
Project Investigators:
Joseph Borovsky, Los Alamos National Laboratory
Robert McPherron, University of California Los Angeles
Tung-Shin Hsu, Post Graduate Researcher, University of California Los Angeles

Substorms are so complex that many issues related to them remain very controversial. Many models have been proposed to explain substorm activity. These models can be broadly classified into two categories depending on the cause of the expansion onset. The first invokes processes in the near-Earth region ($|X| \leq \sim 15$ Re) or some feed back instabilities near the ionosphere. The other invokes mid-tail magnetic reconnection

beyond |X| ≈ 15 Re as a source of plasma flowing earthward. Deceleration of this earthward flowing plasma and pileup of magnetic flux pileup close to the Earth is then the cause of near-Earth disturbances. A possible way to distinguish the cause of substorm expansion onset is to examine the relative timing of magnetotail disturbances. If the near-Earth region is the source region of substorm onset, a disturbance should be first observed in the near-Earth region and later in the midtail. Similarly, the opposite time delay should be observed if the mid-tail reconnection is the source of substorm expansion onset. Our project proposes to use magnetic data from multiple spacecraft in the tail to make a statistical examination of the relative timing of phenomena at different distances. Chance conjunctions of GOES, WIND, Geotail, Cluster, INTERBALL, and possibly Double Star will be used to find the statistical patterns of delay between different regions. Data from auroral imagers, ground magnetometers, Pi 2 pulsation detectors, and synchronous particle detectors will be used to establish accurate onset times.
Link to: Multi-Satellite Observation of Substorm Expansion Onset in the Geosynchronous and Mid-tail Regions

Examining Mechanisms for the Low-Latitude Water Equivalent Hydrogen Regions on Mars via the Ames General Circulation Model

Project Investigators:

William Feldman, Los Alamos National Laboratory
Jim Murphy, New Mexico State University
Steven Nelli, Graduate Student, New Mexico State University

The Neutron Spectrometer (NS) of the Gamma Ray Spectrometer (GRS) instrument suite on board Mars Odyssey has measured copious quantities of water equivalent hydrogen (WEH) at several low-latitude locations on Mars (Feldman et al., 2002, 2004a; Boynton et al., 2002; Mitrofanov et al., 2002; Prettyman et al., 2004). Since current environmental conditions are not conducive to WEH stability at these latitudes and locations (Mellon and Jakosky, 1993), a mechanism for their existence is yet to be determined. Local maxima in WEH correlate well with local maxima in topography (figure 1) in these low-latitude regions on Mars (Feldman et al., 2005). Water ice is unstable equatorward of 45˚ latitude (Feldman et al., 2004b; Mellon and Jakosky, 1993), but these low-latitude WEH regions are rich in hydratable minerals (Bish et al., 2003; Möhlmann, 2004). Certain heterogeneous mixtures of these minerals are enough to capture the current amount of WEH seen by the neutron spectrometer (Feldman et al., 2004b). Using the NASA Ames General Circulation Model (GCM), this proposal intends to study mechanisms for hydration of the low-latitude WEH regions. One mechanism to be tested is upslope Hadley cell return flow during perihelion. Preliminary results from the current model already show some correlation between the deposition pattern of water in the model and the WEH-rich regions seen by GRS (figure 2).
Link to: Examining Mechanisms for the Low-Latitude Water Equivalent Hydrogen Regions on Mars via the Ames General Circulation Model

2.3 *Solid Earth Geoscience Overview:* *Focus Leader: Claudia Lewis*

This focus area supports a breadth of basic research concerning planetary surfaces and interiors, including numerical, experimental, and field studies of the structure, properties, processes, and dynamics of terrestrial and giant planets.

The range of topics is broad, including the following:

- Geochemistry (planetary evolution, hydrothermal alteration)
- Geomaterials (elastic behavior)
- Human origins
- Hydrogeology (reaction kinetics; flow, transport, and reactions in porous media; hydrostratigraphy)
- Mantle convection and supercontinent cycles
- Seismology (free oscillations, fluid migration in volcanoes)
- Spatial geostatistics

Many of these projects take advantage of Los Alamos National Laboratory (LANL) facilities (neutron scattering, remote sensing, high-resolution microscopy, high-performance computing, Lunar Prospector) or LANL capabilities (computational fluid dynamics, finite-element modeling, clay mineralogy, and nonlinear acoustics). Nearly all of these projects represent the principal research of graduate students or postdoctoral fellows.

Projects for FY05 included innovative research in areas of current, strong international scientific interest:

- Elastic strain measured by GPS and InSAR for applications in Earth lithospheric processes
- Earthquake seismology and seismotectonics—rupture processes
- Planetary origins

Collaborative solid earth project reports:

Nonlinear Response of Granular and other Materials

Project Investigators:

Paul Johnson, Los Alamos National Laboratory
Robert Guyer, University of Massachusetts

Seminal laboratory studies show that a broad class of materials exhibit *Nonlinear Nonequilibrium Dynamics (NND)*. NND is comprised of modulus softening and markedly increased dissipation induced by large dynamic strains, the *nonlinear fast dynamics*. This is followed by memory of softening after wave forcing—an extended recovery to the equilibrium modulus, the *slow dynamics*. Recently, we have shown that granular media exhibit significant NND in the laboratory[1]. This past year, we have observed NND for granular media *in the Earth* using an active source. We induced the

NND by applying a large vibrator to layered granular media (sediments) at a site near Austin, Texas. While the NND regime has major implications for probing the physics of granular media, it also has significant consequences to predicting sediment response during earthquake strong ground motions, the cause of damage and injury during a large earthquake.
Link to: Nonlinear Response of Granular and other Materials

Using Pressure Interference Tests to Infer Large-Scale Spatial Statistics of Randomly Heterogeneous Geologic Media

Project Investigators:

Daniel Tartakovsky, Los Alamos National Laboratory
Shlomo Neuman, University of Arizona
Ayelet Blattstein, Graduate Student, University of Arizona

Our **goal** is to develop a way to infer the spatial statistics of permeability and storage capacity or porosity in multiscale, randomly heterogeneous geologic media on the basis of large-scale pressure interference tests. To achieve this goal, we pursue the following **objectives:**

(1) Develop analytical or, where necessary, numerical ensemble moment solutions for the stochastic equations that govern groundwater flow to a well in two- and three-dimensional domains, having properties that behave as random fractals with truncated power variograms, based on nonlocal recursive moment equations in spatially bounded and infinite real and/or Laplace-transformed time domains. Test the solutions against numerical Monte Carlo simulations.

(2) Develop methods to infer the spatial statistics of medium permeability and specific storage (or, equivalently, porosity) from pressure interference tests graphically or by inversion based on our newly developed analytical and/or numerical solutions, as well as Monte Carlo results.

(3) Test our novel methods of inference on synthetically generated data.

(4) Use our new methods to infer the spatial statistics of fractured tuffs on the basis of existing pressure interference data from a University of Arizona experimental site near Superior, Arizona.

Link to: Using Pressure Interference Tests to Infer Large-Scale Spatial Statistics of Randomly Heterogeneous Geologic Media

Hydrothermal Activity in Carbonaceous Parent Bodies

Project Investigators:

Bryan Travis, Los Alamos National Laboratory
Gerald Shubert, University of California Los Angeles

Jennifer Palguta, Graduate Student Researcher, University of California Los Angeles
I visited Los Alamos from June 27 – July 8 during which time I worked directly with Bryan Travis. Over the course of my stay, I began familiarizing myself with the code MAGHNUM so that I could begin modifying it to model hydrothermal alteration on carbonaceous chondrite parent bodies. In my meetings with Dr. Travis, he explained the structure and capabilities of MAGHNUM. By understanding MAGHNUM’s setup, I have

been able to determine the best way to couple MAGHNUM with the code PHREEQC which will be responsible for calculating the change of anhydrous minerals to hydrous minerals during fluid transport.
Link to: Hydrothermal Activity in Carbonaceous Parent Bodies

Deep Structure and Processes of the Colorado Plateau and its Margins
Project Investigators:
Scott Baldridge, Los Alamos National Laboratory
James Ni, New Mexico State University
Richard Aster, New Mexico Institute of Mining and Technology
Stephen Grand, University of Texas Austin

This project completed a multiyear, multidisciplinary study, conducted in two phases, whose main focus was a seismic transect from west Texas across the Rio Grande rift and Colorado Plateau to the Great Basin of central Utah. The transect spanned several major tectonic provinces of the southwestern United States from the Great Plains, part of the North American craton, to the basin-and-range extensional province. The purpose of the experiment was to image the entire thickness of the Earth's crust and the upper several hundred kilometers of the mantle in this geologically active region of the world. One important goal was to determine whether small-scale convection and pure-shear deformation, observed near the rift by RISTRA 1.0, may also be the cause of recent extension and volcanism along the western edge of the CP. This would suggest that these processes are ubiquitous and inseparable from western U.S. tectonics. Ancillary goals were to test the hypothesis of lower-crustal thickening of the CP during the Laramide orogeny, to determine mechanisms by which the high topography of the Colorado Plateau is supported, and to search for foundered remnants of Farallon slab
Link to: Deep Structure and Processes of the Colorado Plateau and its Margins

Heterogeneity of Stress in the Crust and its Effect on Earthquake Rupture
Project Investigators:
Michael Fehler, Los Alamos National Laboratory
Ralph Archuleta, University of California Santa Barbara
Daniel Lavallee, Associate Researcher, University of California Santa Barbara
Shuo Ma, Graduate Student, University of California Santa Barbara

This research project is based on the premise that one can capture heterogeneous features of the slip (or stress) on a fault with a stochastic model. The stochastic model can then be used to generate equivalent synthetic distributions of the stress on the fault as input to dynamic modeling of the earthquake rupture. We have made significant progress in areas related to the validation of the stochastic model and its consequences on the ground motions (Lavallée and Archuleta, 2003; and Lavallée *et al*. 2005). Based on the superposition of seismic waves and the Central Limit Theorem, we have laid the basis for a unified picture of earthquake variability from its recording in the ground motions to its inference in source models. This theory stipulates that the random properties of the

ground motions and the source for a single earthquake should be both distributed according to a Lévy law. Our investigation of the random properties of the source model and peak ground acceleration (PGA) of the 1999 Chi Chi earthquake confirms this theory (Lavallée and Archuleta, 2005). As predicted by the theory, we found that the tails of the probability density functions (PDF) characterizing the slip and the PGA are governed by a parameter, the Lévy index, with almost the same values close to 1. The PDF tail controls the frequency at which extreme large events can occur.
These events are the large stress drops—or asperities—distributed over the fault surface and the large PGA observed in the ground motion. Our results suggest that the frequency of these events is coupled: the PDF of the PGA is a direct consequence of the PDF of the asperities.
Link to: Heterogeneity of Stress in the Crust and its Effect on Earthquake Rupture

Geometry, Kinematics and Dynamics f Relay Zones in Extensional/Transtensional Settings
Project Investigators:

Aviva Sussman, and Claudia Leweis Los Alamos National Laboratory
Gautam Mitra, University of Rochester
Rajesh Goteti, Graduate Student, University of Rochester

The presence of relay zones in extensional/transtensional settings pose substantial complexities for understanding fluid-fault interactions. Relay ramps transfer displacement between two overlapping faults by tilting and vertical-axis rotation. The primary objective of our investigation is to work out the dynamics of extensional/transtensional relay zones by integrating three-dimensional fault geometries, kinematics determined from paleomagnetic and structural techniques, and overall stress distributions from finite element modeling. A secondary objective is to develop more accurate geological frameworks such that hydrologists can better model fluid flow in the shallow crust. Our investigation will represent a significant advance in understanding the effects of displacement transfer structures on fluid flow.

One of the best contexts in which to study fault relays in extensional settings is the Rio Grande Rift of the southwestern United States. In addition to accessibility, good exposures due to the semi-arid climate, and a strong foundation of stratigraphic and tectonic relationships from previous investigations, the fact that Rio Grande Rift tip structures are still preserved at the surface provide us with a high probability of success. We propose to incorporate field and laboratory techniques using both stepwise and iterative approaches. Using detailed field observations, we will establish the three-dimensional geometry of the structures of the Rio Grande Rift. Also, meso- and micro-structural studies together with paleomagnetic data will allow us to determine the kinematics of the rift system. Finally, we will use finite element modeling to work out temporal and spatial variation in stress magnitudes and directions.
Link to: Geometry, Kinematics and Dynamics f Relay Zones in Extensional/Transtensional Settings

2.4 *Complex Dynamical Climate and Environmental Systems Overview:*
Focus Leader: Manvendra Dubey

The Earth system represents one of the more complex and challenging systems to observe, simulate, and predict. The importance of understanding it is underscored by the fact that human activities, such as energy production and its emission of carbon dioxide, can potentially impact our climate. This focus area encompasses the dynamical, physical, and biogeochemical processes that regulate our climate system. A particular goal is to elucidate nonlinear interactions between the atmosphere, ocean, biosphere, and cryosphere. This is achieved by integrating the following research elements: coupled-climate modeling, carbon cycle science, carbon sequestration, aerosols, clouds, remote sensing, biogeochemistry, eco-hydrology, uncertainty analysis, paleoclimate records, hydrogen economy, and other energy infrastructure issues.

This focus area contributes to an improved understanding of the change in the Earth's energy balance by anthropogenic greenhouse gases and aerosols, their effects on our climate, and implications for future energy policies. It integrates small collaborative projects between Los Alamos National Laboratory (LANL) scientific staff and academic groups to support LANL's energy security goal, which is aimed at helping the world meet its growing energy demands while managing risks to our environment. In addition, scientific advances in process-level knowledge, systems theory, and uncertainty in this project will contribute to improved methods for assessing uncertainties in nuclear weapon simulations that address weapon design and safety, and it will aid our understanding of Homeland Security issues involving the fate and transport of chemical, biological, and nuclear agents.

Complex Dynamical Minigrant reports:

The Middle Awash Region Structural Transition Zone: Age constraints on volcanotectonic and sedimentation processes and paleontalogical resources

Project Investigators:
Giday WoldeGabriel, Los Alamos National Laboratory
Tim White, University of California Berkeley

The IGPP/LDRD minigrant supported geological investigation in the northern part of the Middle Awash project study area. The National Science Foundation primarily funds the multidisciplinary international geological and paleoanthropological research. The purpose of the geological investigation is to document the complex tectonic and volcanic processes that led to the development of the Middle Awash region of the southern Afar Rift. The Middle Awash region is located within a tectonic and volcanic transition zone from the continental Main Ethiopian Rift to the proto-oceanic rift segment of the Afar Rift. Distinct tectonic, volcanic, and geomorphic features manifested along both rift margins and the intervening rift floor characterizes the Middle Awash region. The trend of the western margin was modified from NE to NS, whereas the southeastern escarpment changed from NE to EW directions. These changes are also reflected in the intervening rift floor. The rift floor is funnel-shaped and more than150 km wide within the transition zone compared with the narrower (80 km) floor of the adjacent northern Main Ethiopian Rift. This is also true for the Quaternary axial rift zone that widens northward into the central Afar Rift. All of these structural modifications are attributed to the tectonic interactions among the

boundary faults of the two oceanic rift basins of the Red Sea and the Gulf of Aden with the continental Main Ethiopian Rift.
Link to: The Middle Awash Region Structural Transition Zone:

Improved Combustion Physics of the LANL Wildland Fire Prediction Model (FIRETEC)
Project Investigators:
Rod Linn, Los Alamos National Laboratory
Thomas Fletcher, Brigham Young University
Michael Clark, Graduate Student, Brigham Young University

The objective of this research is to continue to improve the combustion model used in the LANL Wildland Fire Prediction Model (FIRETEC), which was developed to predict the spread of wildland fires. In the development of FIRETEC, a simple heuristic formulation was used, based on an assumed probability density function, to account for the combined reactions of solid and gas phase. This research seeks to improve the modeling of the physics of solid and gas phase combustion, as well as turbulence-chemistry interactions, without significant increases in computational requirements. We anticipate that an improved model can become a useful tool in predicting wildfire behavior including fire spread rate, ground-to-crown transitions, and flare-ups.
Link to: Improved Combustion Physics of the LANL Wildland Fire Prediction Model (FIRETEC)

Mixed Phase Clouds: Remote Sensing and Climate Change
Project Investigators:
Petr Chylek, Los Alamos National Laboratory
Qiang Fu, University of Washington
Steve Robinson, Graduate Student, University of Washington

Study of the noise in individual MODIS long-wave infrared spectral bands noise estimates for the MODIS instruments mounted on the Terra and Aqua satellites have been performed at the detector level during prelaunch testing as well as during on-orbit analysis. Practical use of satellite data often requires large spatial sampling, which consists of radiation reflected from both sides of the scan mirror and quantified by multiple detectors. Differences in detector sensitivities and inconsistencies in response versus scan angle properties of both sides of the scan mirror add to the apparent error of the calibrated data.
Link to: Mixed Phase Clouds: Remote Sensing and Climate Change

An Upper-Ocean Model for Climate Sensitivity and Variability Simulations
Project Investigators:
Philip Jones, Los Alamos National Laboratory
James McWilliams, University of California Los Angeles

This purpose of this project is the development and application of an upper-ocean model (UOM) for use in global climate simulations in the framework of the national Community Climate System Model (CCSM). The development objective is to implement the UOM algorithm in LANL's Parallel Ocean Program, version 2 (POP2) that will soon become the standard (full-depth) oceanic component in CCSM. The prototype application will use the POP2 UOM coupled to the CCSM atmosphere, sea ice, and land surface components to demonstrate an alternative and more

physically meaningful measure of "climate sensitivity" to greenhouse gas changes. Auxiliary applications to natural variability and biogeochemical coupling will ensue through several collaborations.
Link to: An Upper-Ocean Model for Climate Sensitivity and Variability Simulations

Dissecting the Critical Lings between Ecology and Hydrology: Quantifying spatial and temporal variability of water fluxes and nutrient distributions in environmentally sensitive woodlands

Project Investigators:

Brent Newman, Los Alamos National Laboratory
Andrew Campbell, New Mexico Tech
Daniel Slattery, Graduate Student, New Mexico Tech

Recent research has shown that natural tracer modeling based on the analyses of soil water content, pore water stable isotopes (δD and $\delta^{18}O$), and pore water anion concentrations can produce information about the spatially and temporally variable dynamics of arid and semiarid near-surface environmental systems that have previously not been obtainable. Understanding such complex, nonlinear dynamics is a critical part of U.S. environmental and climate change science priorities. An existing piñon-juniper, paired watershed study site at Bandelier National Monument and a long-term piñon-juniper woodland study site at Los Alamos National Laboratory provide a unique experimental basis to implement these underutilized, but powerful modeling and analysis techniques with the goal of understanding the spatial and temporal variations in water content and nutrient (nitrogen) distributions, and evaporation and percolation fluxes. We expect these results to be a significant contribution to our understanding of complex linkages between ecological and hydrological processes and will provide critical information on basic and applied science questions in semiarid environments.
Link to: Dissecting the Critical Lings between Ecology and Hydrology:

A high resolution record of climatic changes in Northern New Mexico over the last 50,000 years

Project Investigators:

Julianna Fessenden-Rahn, Los Alamos National Laboratory
Susan Trumbore, University of California, Irvine
Luz Maria Cisneros-Dozal, Post Doc, University of California, Irvine

Early paleolimnological studies have suggested precipitation, vegetation and temperature changes in New Mexico although no specific information on the degree or the timing of these changes was provided. Tree-ring based reconstructions over the last 300 years in North America have identified climatic shifts that suggest anthropogenic influence. Yet, longer tree-ring based reconstructions of precipitation patterns in New Mexico over the past 1000 years suggest large natural variability may obscure an anthropogenic signal. The study proposed here in combination with ongoing paleoclimate studies at LANL can provide high resolution temperature, precipitation, vegetation and aerosols deposition records over the past 50,000 years in the Valles Caldera (southwestern United States) and thus help to discern natural from anthropogenic forcing on climatic changes. In addition, we will help with longer (500,000 years) records by testing the utility of cosmogenic isotopes to provide chronologies for a lake core. Climate modelers could use the results generated from this multidisciplinary project to improve weather forecasting for the region. Accurate future

predictions of drought frequency and intensity are critical for implementing preventing strategies to deal with impacts on water supplies, agriculture and fire occurrence.
Link to: A high resolution record of climatic changes in Northern New Mexico over the last 50,000 years

3. IGPP Scholar Program

The general responsibilities of a scholar at IGPP Los Alamos are to conduct his/her own research while in residence at LANL and to participate in the development of new initiatives within LANL and the broader scientific community. The Orson Anderson scholar during FY06 was Tuija Pulkkinen, from Finnish Meteorological Institute Tuija's area of expertise is in computational space physics and experimental validation. In addition, Professor Phil Kronberg, the FY03 Orson Anderson scholar and currently our visiting scholar, continues his affiliation in IGPP as a resident scholar, on an appointment funded from programmatic sources in LANL's ISR, D, and T Divisions.

3.1 Orson Anderson Scholar: Tuija Pulkkinen

During her tenure as an Anderson Scholar 200, Tuija worked on collaborative research with ISR and T divisions, most notably in theoretical and computational research concerning magnetospheric reconnections, magnetospheric substorms, and solar-earth interactions. She produced eight manuscripts, each described with weblinks below.

1: Magnetosphere preconditioning under northward IMF: Evidence from the study of CME and CIR geoeffectiveness
B. Lavraud, M. F. Thomsen, J. E. Borovsky, M. H. Denton and T. I. Pulkkinen Space Science and Applications, Los Alamos National Laboratory, Los Alamos, New Mexico, USA
lavraud_jgr20061.pdf

2: Hysteresis in solar wind power input to the magnetosphere
Minna Palmroth,1 Pekka Janhunen,2,3 and Tuija I. Pulkkinen4,5
palmroth_grl20061.pdf

3: Time history effects at the magnetopause: Hysteresis in power input and its implications to substorm processes
M. Palmroth, T. I. Pulkkinen, T. V. Laitinen, H. E. J. Koskinen, and P. Janhunen
palmroth_ics81.pdf

4: Strong stretching in dusk sector: stormtime activations and sawtooth events compared
N. Partamies, T. I. Pulkkinen, E. F. Donovan, H. J. Singer, E. I. Tanskanen, R. L. McPherron, M. G. Henderson, and G. D. Reeves
partamies_ics81.pdf

5: New interpretation of magnetospheric energy circulation
T. I. Pulkkinen,1,2 M. Palmroth,3 E. I. Tanskanen,3 P. Janhunen,3,4 H. E. J. Koskinen,3,4 and T. V. Laitinen3,4
pulkkinen_grl20061.pdf

6: Thin current sheets as part of the substorm process
T. I. Pulkkinen, C. C. Goodrich, J. G. Lyon, and H. J. Singer
pulkkinen_ics81.pdf

7: Solar wind {magnetosphere coupling: A review of recent results
T. I. Pulkkinen a_, M. Palmrothb, E. I. Tanskanenb N. Yu. Ganushkinab M. A. Shukhtinac, N. P. Dmitrievac
pulkkinen_jastp20061.pdf

8: Magnetospheric current systems during stormtime sawtooth events
T. I. Pulkkinen,1,2 N. Y. Ganushkina,2 E. I. Tanskanen,2 M. Kubyshkina,3 G. D. Reeves,1 M. F. Thomsen,1 C. T. Russell,4 H. J. Singer,5 J. A. Slavin,6 and J. Gjerloev7
pulkkinen_jgr20061.pdf

3.2 Resident Scholar: Phil Kronberg

Summary:

Much of the reported research is connected to, or constitutes extensions of, the LDRD and LDRD/ER "Magnetic Universe/Life Cycles of Galaxies" programs, of which have been a member since coming to LANL as an IGPP Orson Anderson Scholar in 2002/3.

A common scientific motivation for many of the projects listed here is to explore the role of magneto-plasmas and magnetic fields in many astrophysical contexts on large scales. A companion aim is to provide data and insights for plasma and fusion science using large scale astrophysical systems as plasma "laboratories," taking advantage of the enormous scalability of many magneto-plasma phenomena. In our work over my last 4 years in EES/IGPP, we have also shown how cosmic-ray acceleration processes in the Universe can be illuminated by studies of some largest-scale astrophysical systems. Work on the above is ongoing with S.A. Colgate (T-6) and H. Li (X-1), and on other projects with G. Lapenta (T15), D. Higdon (CCS5), X. Tang, and some other colleagues involved with laboratory plasma experiments relevant to astrophysics.

Honors and Awards 2006

Elected to Fellow of the American Physical Society

Citation: *For leading the growing appreciation of the importance of astrophysical magnetic fields. His work has helped to define this area of astrophysics and plasma physics.*

Specific activities:

1. Kronberg has led several interrelated projects to probe diffuse synchrotron radiation on intergalactic scales within the local universe out to 150 megaparsecs. Most prominent of these programs has involved a novel combination of the Arecibo telecope in Puerto Rico and the NRC-DRAO Interferometer at Penticton, BC. A paper describing the first phase analysis has been accepted for publication in the Astrophysical Journal, March 2007 issue. It reports a new discovery of diffuse extragalactic radiation. This has important implications for the acceleration and diffusion of cosmic rays in intergalactic space and introduces a potential new tracer of large-scale structure in the universe, which appears weighted more to distributed energy than to baryonic mass (e.g., galaxies).

2. In 2005/2006 a sequel project was launched to similarly image two additional galaxy supercluster areas. As of December 2006, all of the Arecibo and DRAO observations are complete. Collaborators in 1 and 2, are C.J. Salter and . Perillat,Cornell/Arecibo, and R. Kothes at NRC-DRAO, Canada.

3. Related diffuse synchrotron radiation searches are continuing with collaborators at NRAO, Socorro, NRL (Washington, DC), and Max-Planck-Institut für Astrophysik at Garching (MPA). Collaborators are R. Perley (NRAO), N. Kassim, and A. Cohen (NRL), and T.A. Ensslin (MPA-Garching) and G. Giovannini (Bologna, Italy. These searches involve analysis of data, now collected, from the Green Bank Telescope, the VLA (New Mexico), the Westerbork Synthesis Radio telescope (Netherlands). A key aim of the projects, on which P. Kronberg is P.I., is to press the detection limits of magnetic fields on the largest physical scales observable down towards $\sim 10^{-8}$ G, lower than anything detected thus far. This is the best direct method for measuring the magnetic energy that galactic black holes have deposited into the IGM outside of clusters over cosmic time. The wider aim has been to explore plasma conditions in intergalactic space in the régimes of very low particle and magnetic energy density.

4. Kronberg's Faraday rotation measure data have been combined with galaxy count data in a joint project undertaken in 2004/5 with S. Habib (T-8) and Y-Z. Zhu (T-8). This work was published in the Jan. 20, 2006, issue of the *Astrophysical Journal*.

5. In a new cross-disciplinary project using all-sky astrophysical data, P. Kronberg (IGPP), D. Higdon (CCS-6), and M.B. Short (CCS-6) are co-developing statistical methods to optimally extract information from Faraday rotation measure data that Kronberg brought from the University of Toronto to LANL. Postdoc Short has made several conference presentations of this effort, and acceptance of the first major paper is anticipated in early 2007.

6. Supervision of a doctoral student, Martin Bernet at the ETH in Zürich, Switzerland, was begun in 2006. The first paper, based partly on Bernet's preceding Diploma (M.Sc) is, at yearend 2006, ready for submission. In addition to first author Kronberg at LANL, it involves Miniati, Bernet, and Lilly (ETH) and also LANL scientists Margaret Short and

David Higdon of CCS-6 Division. That is, this ongoing project is now connected to project 5 above.

7. Bernet's Ph.D. thesis will deal with recently acquired spectroscopic data from the European Southern Observatory's VLT optical telescope by combining these with Kronberg's Faraday rotation data for selected quasars. These state-of-the-art, high resolution optical spectra will enable new probes for magnetic fields at cosmologically large redshifts. Such results, hitherto almost non-existent, are needed to provide "hard" data for simulation studies of galaxy and structure evolution. They will help elucidate the mysterious origin of cosmological magnetic fields.

8. Related to items 4 – 7, Kronberg,B. Gaensler, and student S-A. Mao (Harvard/Sydney) and others were awarded time on 2 of the world's most powerful radio telescopes (in the Netherlands and Australia) to produce unprecedented large numbers of new Faraday rotation measures. The data are being analysed by grad. Student S-A. Mao.

9. Kronberg is leading a new analysis using radio and X-ray data of extragalactic jets, whose aim is to determine for the first time the *electric current* structure in jets that are several hundred thousand light years in extent. This will hopefully illuminate the decades-old puzzle of the nature of these enormous energy-transmiting ``pipes'' on the largest scales known. The □nvestigation also involves G. Lapenta (T-15), and a new postdoc, Robert Reid, at the NRAO in Charlottesville VA. This project, begun in 2006, is part of a new effort to combine plasma experiment and theory at LANL with new, high quality radio images made with the NRAO's VLA radio telescope in New Mexico.

10. Other, related combinations of plasma theory, simulation, and radio observation are being explored with X. Tang (T-15), and T. Intrator and S. Hsu (P-24).

11. In 1996, Kronberg was elected to the executive committee of the APS Topical Group on Plasma Astrophysics.

Students and Postdocs supervised in 2006

- Martin Bernet, M.Sc., now Ph.D. student at the ETH-Zürich, Switzerland. Co-supervising.
- Dr. Yongzhong Xu, Los Alamos National Laboratory. Co-supervised.
- Dr. Roland Kothes, Postdoc at the Dominion Radio Astrophysical Observatory, NRC Canada, Penticton, Canada.

- Dr. Margaret B. Short, CCS-6 Div., Los Alamos National Laboratory. Co-supervised.

- Eric Heisler, URA student. Los Alamos National Laboratory. Co-supervised with P-24 Division.

- Sui-Ann Mao, Ph.D. student. Harvard University. New. Co-supervision begun with Prof. B.M Gaensler.

2006 Refereed Journal Publications (omitting conference abstracts)

1. Xu, Y., Kronberg, P.P., Habib, S., & Dufton, Q.W. ``A Faraday Rotation Search for Magnetic Fields in Large Scale Structure'' *Astrophysical Journal*, **637,** 19 – 26, 2006.

2. Kronberg, P.P. ``Extragalactic Radio Sources, IGM Magnetic Fields, and AGN-based Energy Flows'' *AN-Astronomical Notes*, **327**, 517 – 522, 2006.

3. Reid, R.I. (supervised by P.P. Kronberg) ``Smear Fitting: a new image deconvolution method for interferometric data'' *Monthly Notices of the Royal Astronomical Society*, **367**, 1766-1780, 2006.

4. Kronberg, P.P., Kothes, R., Salter, C.J., & Perillat, P. ``Discovery of new faint radio emission on 8 to 3 scales in the Coma field, and some Galactic and extragalactic implications'' *Astrophysical Journal* **658** (in press, 12 pages) 2007.

5. Short, M.B., Higdon, D.M., & Kronberg, P.P. ``Application of Gaussian Process to the Rotation Measures of the near-Galactic Sky.'' Submitted to *Bayesian Analysis* in 2006.

6. Kronberg, P.P., Bernet, M., Miniati, F., Lilly, S. J., Short, M.B., & Higdon, D.M. ``A Global Probe of Cosmic Magnetic Fields to Large Redshifts'' to be submitted to the *Astrophysical Journal*, December 2006.

7. Short, M.B., Higdon, D.M., & Kronberg, P.P. ``Estimating Rotation Measures on the Near-Galactic Sky''. *Proceedings of Bayesian Statistics 8, Valencia 2006*. Oxford University Press, Ed. Jose Bernardo, (6 pages, in press) 2007.

2006 Invited Talks

1. Dominion Radio Astrophysical Observatory, Penticton BC Canada. February 16th ``The High Energy Intergalactic Medium: New probes and techniques''

2. Cosmoday Symposium, Los Alamos National Laboratory. May 5th,

   ``New radio clues on the high-Energy component of the IGM''

3. NASA Goddard Space Flight Center. Tuesday May 16th
   ``Where do intergalactic CR's and magnetic fields come from? Implications of recent discoveries for coming generations of space- an ground-based instruments.''

4. 11th Triennial Marcel Grossmann Meeting, Berlin. July 24th, 2006
   ``Interconnections between Black holes, magnetic fields, CR's in the Universe: A Review ''

5. 11th Triennial Marcel Grossmann Meeting, Berlin. July 26th
   ``Magnetic fields in the high redshift universe''

6. Max-Planck-Institut für Radioastronomie,Bonn. 1st August ``The High Energy Intergalactic Medium: New probes and techniques''

7. LANL Plasma Physics Summer School Lecture, P-Div., Los Alamos NM 17th August. ``Measuring magnetic fields in the Universe''

8. LANL T-6/T-8 Div. Joint Seminar, Los Alamos NM, September 25th. ``Results of new deep radiometry in the Great Wall supercluster, and some astrophysical implications.''

4. IGPP Publications reported during the FY06 period:

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5. Workshops supported by IGPP during FY06:

SDSS Workshop	Mar 2006	POC: Salman Habib
Magnetopheric Workshop	July 2006	POC: Reiner Friedel
HAWK-Super Milagro	July 2006	POC: Reiner Friedel
Seismology	July 2006	POC: Claudia Lewis
Dyn elastic materials	July 2006	POC: Paul Johnson
Cosmology Workshop	July 2006	POC: Salman Habib
Aerosols & Global Warming	July 2006	POC: Manvendra Dubey
Western US Geodynamics	Aug 2006	POC: Claudia Lewis
Supernovae Workshop	Aug 2006	POC: Richard Epstein
Solar Earth Connections	Nov 2006	POC: Joseph Borovosky

6. IGPP Summer Schools

IGPP hosted two summer schools in FY06: the Summer Applied Geophysics Experience (SAGE), the Carbon Sequestration Summer School, and the Cosmology Summer Workshop. These in turn are described in more detail in the following pages.

6.1 Summer Applied Geophysics Experience

IGPP hosted three summer schools in FY06: the Summer Applied Geophysical Experience (SAGE), the Carbon Sequestration Summer School, and the Cosmology Summer Workshop. These in turn are described in more detail in the following pages.

Description

Imagine an educational program in which (1) a small number of the best, highly motivated undergraduate and graduate students from around the world participate; (2) students with diverse educational and professional experience work together in small teams, learning from each other; (3) students work closely every day with faculty and industry professionals; (4) students gain experience in both applied and basic research; and (5) students gather, process, and interpret their own data and present oral and written reports. SAGE, the Summer of Applied Geophysical Experience, *is* that program in geophysics. SAGE, sponsored by the University of California's (UC's) branch of the Institute of Geophysics and Planetary Physics at Los Alamos National Laboratory, is a four-week-long intensive, field-based geophysics course for upper-level undergraduate students, graduate students, and selected professionals. The program is held in June and July of each year. Students apply geophysical methods to basic and applied earth-science problems, such as characterization of unexcavated archaeological sites, evaluation of groundwater resources, and structure of sedimentary basins. Because of its emphasis on "hands on" training in field techniques and on processing and interpretation of data gathered by the students, SAGE significantly augments the standard classroom educational experience. SAGE, the only course of its kind in the world, attracts students internationally. The faculty consists of instructors from Los Alamos and five educational institutions, the U. S. Geological Survey, and a private company (Table 1). They are augmented by other company personnel. SAGE mobilizes an extensive array of geophysical equipment and expertise from universities and the private sector.

Over its 24-year history, SAGE has trained over 600 students, many of whom are now faculty members or prominent in companies.

The goals of SAGE are (1) to encourage undergraduate students to continue with graduate education in geophysics or other earth-science-related fields, (2) to assist graduate students in establishing careers in geophysics in the public and private sectors, and (3) to offer educational opportunities beyond those provided by individual educational institutions.

SAGE has been recognized by the American Geophysical Union (1998) and the Society of Exploration Geophysicists (2000) for its important role in fostering education in geophysics.

Major funding for SAGE 2006 came from the U. S. National Science Foundation, U. S. Department of Energy, Los Alamos National Laboratory, Society of Exploration Geophysicists, and a consortium of companies.

Importance

SAGE addresses critical needs in attracting students to the geophysical sciences, in enhancing students' education in geophysics, and in promoting professional employment of students. SAGE relates directly to detection of buried military structures, treaty-verification and nuclear-explosion monitoring, environmental cleanup, reservoir characterization for hydrocarbon resources, CO_2-sequestration, and groundwater resources. After completing their graduate education, SAGE students are employed typically by energy, geotechnical, and environmental companies and by the national laboratories. SAGE assists in recruiting personnel for employment at Los Alamos.

Accomplishments and Progress

Over its 24-year history, SAGE has worked at many sites in the Santa Fe-Española area on a variety of geophysical problems. For the last several years, work has concentrated in the rapidly developing Eldorado area south of Santa Fe, and on Cochiti and Santo Domingo Pueblos to the west. We are working closely with the Office of the State Engineer, the U.S. Geological Survey, and other governmental agencies, and with the Environmental Offices of Cochiti and Santo Domingo Pueblos. This collaboration is exciting for two reasons. First, it provides geophysical and geological data that address issues related to groundwater resources, in some cases providing direct detection of shallow groundwater. The data are actively sought by agencies mentioned above. Second, it demonstrates to students how geophysics applies to important societal issues. This application of geophysics has been very popular with the SAGE students.

The recent SAGE 2006 was held in Santa Fe, New Mexico, from June 19 through July 14. Twenty four new students, comprising 12 U.S undergraduate, 10 U.S. and foreign graduate students, and two professionals, attended, altogether representing 19 institutions. As usual, techniques taught and used in the field included ground-penetrating radar, magnetics and several electromagnetic methods, seismic refraction and reflection, gravity, and global-positioning surveying. Projects included the following:

A) Geophysical surveys of an unexcavated archaeological site near Santa Fe, New Mexico. Although interesting *per se* and an important applications of geophysics, the purpose of this site was as a proxy for a LANL environmental-restoration site. Recently, SAGE has had to forego working directly on Laboratory sites because of the difficulty of getting access by foreign students.

Nevertheless, these small-scale surveys teach methods relevant to waste-disposal and related investigations. Surveys conducted during SAGE were able to determine the thickness and extent of collapsed domiciles beneath a cover of rubble and soil and to locate a buried kiva.
B) Investigation of fault zones bounding a major structural basin of the Rio Grande rift west of Santa Fe. This was part of a continuing study of the tectonics of the region, investigating fault lengths, fault linkages, and subsurface stratigraphy. In addition, the surveys helped to characterize groundwater resources adjacent to Cochiti and Santo Domingo Pueblos, including the depth to the water table and water quality. Seismic surveys were able more precisely to determine the location of a major basin-bounding (La Bajada) fault zone and the amount of vertical offset (~350 m) (which varies by location), and to locate and evaluate subsidiary faults. In this effort we have been working closely with personnel from the New Mexico Bureau of Geology in Socorro.

Although students work in teams for field work and for interpretion of results, they complete the program by individually presenting their research results in both oral and written form.

In addition to the main, four-week-long program, a follow-up workshop for the SAGE undergraduate students is held during the first week of January. This workshop typically allows the students to continue their work from the main summer SAGE program, providing a more in-depth opportunity to process and interpret their results.

For further information, visit the SAGE website at www.sage.lanl.gov.

Table 1. Teaching personnel for SAGE 2006

NAME	INSTITUTION
W. Scott Baldridge, Co-director	Los Alamos National Laboratory
Shawn Biehler	University of California at Riverside (Emeritus)
Lawrence W. Braile	Purdue University
John Ferguson	University of Texas at Dallas
Bernard Gilpin	Golden West College
George R. Jiracek, Co-director	San Diego State University
Darcy McPhee	U. S. Geological Survey
Louise Pellerin	Green Engineering, Inc.
Aviva Sussman	Los Alamos National Laboratory

6.2 Cosmology Summer Workshop

The Santa Fe topical workshop for 2006 [July 3-21, 2006, http://t8web.lanl.gov/people/salman/sf05/] concentrated on recent developments in cosmology, especially those related to current and expected observational advances, including the cosmic microwave background, large-scale structure, and dark matter and energy/early universe. The workshop was held at St. John's College. There were approximately 75 participants, including 25 graduate students and a similar number of postdocs. As always, discussion was emphasized, with the workshop organization centered on review talks, short technical talks, and discussion sessions. There were review talks on the microwave background, dark energy observations, galaxy clusters, neutrino physics, globular clusters, inflation, the Lyman-alpha forest, and the formation and evolution of galaxies.