NASA's Goddard Space Flight Center
Laboratory for Extraterrestrial Physics

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The NASA Goddard Space Flight Center (GSFC) Laboratory for Extraterrestrial Physics (LEP) performs experimental and theoretical research on the heliosphere, the interstellar medium, and the magnetospheres and upper atmospheres of the planets, including Earth. LEP space scientists investigate the structure and dynamics of the magnetospheres of the planets including Earth. Their research programs encompass the magnetic fields intrinsic to many planetary bodies as well as their charged-particle environments and plasma-wave emissions. The LEP also conducts research into the nature of planetary ionospheres and their coupling to both the upper atmospheres and their magnetospheres. Finally, the LEP carries out a broad-based research program in heliospheric physics covering the origins of the solar wind, its propagation outward through the solar system all the way to its termination where it encounters the local interstellar medium. Special emphasis is placed on the study of solar coronal mass ejections (CME's), shock waves, and the structure and properties of the fast and slow solar wind. LEP planetary scientists study the chemistry and physics of planetary stratospheres and tropospheres and of solar system bodies including meteorites, asteroids, comets and planets. The LEP conducts a focused program in astronomy, particularly in the infrared and in short as well as very long radio wavelengths. We also perform an extensive program of laboratory research, including spectroscopy and physical chemistry related to astronomical objects. The Laboratory proposes, develops, fabricates, and integrates experiments on Earth-orbiting, planetary, and heliospheric spacecraft to measure the characteristics of planetary atmospheres and magnetic fields, and electromagnetic fields and plasmas in space. We design and develop spectrometric instrumentation for continuum and spectral line observations in the x-ray, gamma-ray, infrared, and radio regimes; these are flown on spacecraft to study the interplanetary medium, asteroids, comets, and planets. Suborbital sounding rockets and ground-based observing platforms form an integral part of these research activities. This report covers the period from approximately October 1998 through September 1999.

1. PERSONNEL

Dr. Richard Vondrak continues as Chief of the LEP. Mr. Franklin Ottens is Assistant Chief. The Branch Heads are Dr. Joseph Nuth (Astrochemistry); Dr. Thomas Moore (Interplanetary Physics); Dr. Drake Deming (Planetary Systems); Dr. Steven Curtis (Planetary Magnetospheres), and Dr. James Slavin (Electrodynamics). The Laboratory Senior Scientists are Drs. Richard Goldberg, John Hillman, Michael Mumma, Keith Ogilvie, Louis Stief, and Robert Stone. Mr. William Mish (ISTP Project Scientist for Data Systems) is also a member of the Laboratory senior staff.

The civil service scientific staff consists of Dr. Mario Acuña, Dr. John Allen, Dr. Robert Benson, Dr. Thomas Birmingham, Dr. Gordon Bjoraker, Dr. John Brasunas, Dr. David Buhl, Dr. Leonard Burlaga, Dr. Gordon Chin, Dr. Regina Cody, Dr. Michael Collier, Dr. John Connerney, Dr. Michael Desch, Mr. Fred Espenak, Dr. Joseph Fainberg, Dr. Donald Fairfield, Dr. William Farrell, Dr. Richard Fitzenreiter, Dr. Michael Flasar, Dr. Barbara Giles, Dr. David Glenar, Dr. Melvyn Goldstein, Dr. Joseph Grebowsky, Dr. Fred Herrero, Dr. Michael Hesse, Dr. Robert Hoffman, Dr. Donald Jennings, Mr. Michael Kaiser, Dr. John Keller, Dr. Alexander Klimas, Dr. Theodor Kostiuk, Dr. Brook Lakew, Dr. Ronald Lepping, Dr. Robert MacDowall, Dr. William Maguire, Dr. Marla Moore, Dr. David Nava, Dr. Larry Nittler, Dr. Walter Payne, Dr. John Pearl, Dr. Robert Pfaff, Dr. Dennis Reuter, Dr. D. Aaron Roberts, Dr. Paul Romani, Dr. Robert Samuelson, Dr. Edward Sittler, Dr. Michael Smith, Dr. David Stern, Dr. Adam Szabo, Dr. Jacob Trombka, Dr. Adolfo Figueroa-Viñas, and Dr. Peter Wasilewski.

The following are National Research Council Associates: Dr. Scott Bounds, Dr. Robert Boyle, Dr. Nancy Chanover, Dr. Dana Crider, Dr. Steven Cummer, Dr. Perry Gerakines, Dr. Natchimuthuk Gopalswamy, Dr. Hugh G. M. Hill, Dr. Gunther Kletetschka, Dr. Patrick Michael, Dr. Vasyl Morozhenko, Dr. Lutz Rastätter, Dr. Frank Schmuelling, Dr. Roch Smets, Dr. Carlos Suarez, Dr. Peyton Thorn, Dr. Vadim Uritsky, and Dr. Juan Valdivia.

The following scientists work at LEP as either contractors to GSFC or as long-term visiting faculty: (Raytheon/ITSS) Dr. Ashraf Ali, Dr. Daniel Berdichevsky, Dr. Scott Boardsen, Dr. Rainer Fettig, Dr. Nicola Fox, Dr. Henry Freudenreich, Dr. Emily Greene, Dr. Roger Hess, Dr. Shrikanth Kanekal, Dr. Masha Kuznetsova, Dr. Carey Lisse, Dr. Nitya Nath, Mr. George McCabe, Dr. Vladimir Osherovich, Dr. Mauricio Peredo, Dr. Michael Reiner, Dr. Pamela Solomon, Dr. Adinarayan Sundaram, and Dr. Nikolai Tsyganenko; (Universities Space Research Association) Dr. Mei-Ching Fok, Dr. Venku Jayanti, Dr. Jouni Takalo, Dr. Dimitris Vassiliadis, and Dr. Hung Kit Wong; (Applied Research Corporation) Dr. Sanjoy Ghosh, Dr. Michael Goodman, and Dr. Edouard Siregar; (Computer Sciences Corporation) Dr. Larry Evans; (Catholic Univ. of America) Dr. Dennis Bogan, Dr. Pamela Clark, Dr. Tamara Dickinson, Dr. Michael DiSanti, Dr. Frank Ferguson, Dr. Vladimir Krasnopolsky, Dr. Fred Nesbitt, Dr. Neil Dello Russo, and Dr. Richard Starr; (SSAI) Dr. Richard Achterberg, and Dr. Ronald Carlson; (Space Applications Corporation) Dr. Hemant Davé; (Univ. of Maryland Baltimore County) Dr. Marcos Sirota and Dr. David Steyert; (Georgia Southern Univ.) Dr. Robert Nelson; (Univ. of Maryland College Park) Dr. Dennis Chornay, Ms. Kelly Fast, Dr. Thejappa Golla, Mr. Virgil Kunde, and Dr. Timothy Livengood; (Charles County Community College) Dr. George Kraus; (IONA College) Dr. Robert Novac; (Cornell Univ.) Dr. Barney Conrath and Dr. Paul Schinder; (Rowan

College) Dr. Karen Magee-Sauer; (Univ. of Virginia) Dr. Lembit Lilleleht; (Challenger Center) Dr. Jeffrey Goldstein and Dr. Tilak Hewagama; (NOMAD Research) Dr. Dean Pesnell; (National Institute of Standards & Technology) Dr. Vladimir Orkin.

A large and very capable engineering and computational staff also supports the work of the LEP scientists.

2. ASTROCHEMISTRY

Ozone. Halogen oxides play an important role in reaction cycles involved in stratospheric ozone depletion. One such species, the metastable molecule OClO, has been detected in the stratosphere over Antarctica. The chemical and spectroscopic properties of OClO have been well characterized in the laboratory but much less is known about the bromine analogue. Recently OBrO has been tentatively detected in the stratosphere but model calculations indicate much smaller concentrations than those suggested by the atmospheric measurements. Knowledge of properties such as ionization energy (IE) and heat of formation (ΔH_f) of atmospheric species are valuable for laboratory experiments and atmospheric models. The photoionization efficiency spectrum of OBrO was measured for the first time in photoionization-mass spectrometry experiments at beamline U-11 of the National Synchrotron Light Source located at Brookhaven National Laboratories (BNL). From an analysis of the step-like threshold at $\lambda = 120.5$ nm, R. Thorn and L. Stief, T. Buckley, R. Johnson (NIST), P. Monks (University of Leicester), and R. Klemm (BNL) obtained a value of 10.29 ± 0.03 eV for the adiabatic IE of OBrO. This is the first experimental determination of IE(OBrO). In addition, an *ab initio* calculation using the CCSD(T)-311-G(3df)//CCD/6-311+G(3df) level of theory gives a value of 10.26 eV which is in excellent agreement with the experimental result. These methods would be expected to yield good results for other bromine oxides. Species present in addition to OBrO detected mass spectrometrically included the BrO and Br_2O. Signal from BrO^+ at $m/z = 95$ and 97 amu is due to the presence of the BrO free radical and to dissociative ionization of the molecules OBrO and Br_2O. Further study of the BrO^+ formation process is underway with the objective of determining ΔH_f (OBrO) from the appearance energy of BrO^+ from OBrO. An *ab initio* calculation of ΔH_f (OBrO) is also underway.

Hydrocarbon Chemistry. In photochemical models of the atmospheres of the outer planets and satellites, reactions of the C_2H_3 free radical are poorly understood. Since reactions of C_2H_3 with stable molecules are very slow, the loss of C_2H_3 in planetary atmospheres is mostly *via* rapid reaction with reactive atomic and free radical species. Such atom-radical and radical-radical reactions are considerably more difficult to study in the laboratory than atom-molecule or radical-molecule reactions. In many of the models, the most important loss process for C_2H_3, other than the atom-radical reaction $H + C_2H_3$ previously studied in our laboratory, is the radical-radical reaction $CH_3 + C_2H_3$. R. Thorn, W. Payne, X. Chillier, L. Stief and F. Nesbitt (Coppin State College) have now completed a discharge flow-mass spectrometric (DF-MS) study of this reaction to provide the first data at low pressure (1.3 mbar He) more appropriate for atmospheric models. The average value of the total rate constant at $T = 298$ K is $k = (1.0 \pm 0.5) \times 10^{-10}$ cm^3 molecule^{-1} s^{-1} indicating that the reaction occurs on about every other collision. At $T = 200$ K complications in the observed decay of the C_2H_3 signal prevented a quantitative determination of k at this temperature but little or no temperature dependence is expected for such a fast reaction. Also, the present value of $k(CH_3 + C_2H_3)$ is nearly identical to that for $k(H + C_2H_3)$ which we have previously shown to be temperature independent from $T = 298$ K to 200 K. Product studies at $T = 298$ K and 200 K provided evidence for the occurrence of three primary processes: disproportionation ($CH_4 + C_2H_2$), combination-stabilization (C_3H_6) and combination-decomposition ($C_3H_5 + H$). This study provides the first evidence for the combination-decomposition channel yielding $C_3H_5 + H$. Since the relative importance of the reaction channels will be pressure dependent, the occurrence of these three channels has important consequences for the chemical composition of planetary atmospheres as a function of altitude. The disproportionation channel regenerates methane and acetylene, which are the parent molecules for CH_3 and C_2H_3 respectively. The combination-stabilization channel leads to the formation of propylene, a C_3 hydrocarbon molecule, while the combination-decomposition channel leads to formation of butene, a C_4 hydrocarbon molecule, *via* the formation of the C_3H_5 radical and its subsequent reaction with CH_3.

Cosmic Ices. Laboratory facilities have been expanded to include infrared spectra of cosmic-type ices exposed to both proton and UV photolysis within the same experimental setup. This is a unique capability not possible elsewhere. The focus of the IR investigations is to understand the physical-chemical and radiation-chemical processes in ices leading to the formation of complex organics on comets, interstellar icy-grains and the surfaces of some icy satellites. (1) M. H. Moore and R. L. Hudson (Eckerd College) examined solid-phase reactions in proton irradiated ices in which H-atom addition to CO formed $HCO \rightarrow H_2CO \rightarrow CH_3OH$, and OH-addition formed formic acid. Abundances were greater than in similar reactions from UV photolysis. In addition a comprehensive picture of the formation of organics in cosmic-type ices has been developed. It is based on results from many proton irradiation experiments involving H_2O + carbon oxides, hydrocarbons, and other organics (such as alcohols, aldehydes, ketones, ethers, esters and acids). (2) M. H. Moore and R. L. Hudson (Eckerd College) studied the conditions under which the IR absorption band of H_2O_2 at 3.5 μm could be detected in irradiated H_2O. Contrary to expectations, H_2O_2 was not detected when pure H_2O was bombarded with protons at 80 K (temperatures relevant to ices on Europa). H_2O_2 was formed at 80 K when the H_2O contained either O_2 or CO_2. These results show that molecules such as O_2 or CO_2 in the ice on Europa play a crucial role in its H_2O_2 formation. (3) P. Gerakines, M. Moore, and R. Hudson (Eckerd College) studied the formation of carbonic acid (H_2CO_3) in $H_2O + CO_2$ ices, contrasting the differences between proton bombardment and UV photolysis. The major distinctions between the two cases were found to be the lack of penetration of the UV photons into an ice more than about 0.5 μm thick, and the production/deposition of ions in the ice by the proton beam. Intrinsic band strengths for H_2CO_3 were also measured.

Low-Temperature Thermodynamic Properties. Experimentally determined low-temperature thermodynamic data, particularly vapor pressures, are important for atmospheric models of the outer planets and their satellites. However, these data are often not available over the required temperature range and modelers must rely on approximations or extrapolations of higher temperature data. In a collaborative effort between J. Allen, Jr. and R. Nelson (Georgia Southern University), an apparatus has been constructed to measure thermodynamic properties of single species and mixtures at low temperatures. Details of the system, which is capable of covering a temperature range of 325 to 62 K and a pressure range of 1000 to $\sim 10^{-6}$ Torr, have been presented in an article to Review of Scientific Instruments (accepted). To date we have used our apparatus to measure the low-temperature vapor pressures for a variety of planetary molecules: methane, monodeuterated methane, acetylene, ethylene, ethane, propane, and carbon dioxide. For most of these molecules our experimental results, which are being prepared for publication, differ significantly from the extrapolations of commonly used representations. Protocols are currently being developed to acquire data for binary mixtures such as the methane-nitrogen system.

Circumstellar, Interstellar and Interplanetary Grain Formation. Our understanding of the vapor-phase nucleation and growth of refractory oxide grains has increased considerably over the past several years with the realization that grain growth is controlled by metastable eutectic regions in the phase diagrams of the condensing systems. This realization grew from the detailed analysis of individual, experimentally produced, refractory smokes condensed from a wide range of vapor compositions in our laboratory and analyzed via analytical electron microscopy at the University of New Mexico by Rietmeijer (University of New Mexico) and J. Nuth in 1999 and by J. Nuth *et al.* again in 1999. The new model predicts the formation of a small number of amorphous grain components centered around metastable eutectic compositions predictable from well-known chemical phase diagrams. In related experiments, we also demonstrated that single-magnetic-domain iron grains can be formed spontaneously from the vapor phase even in the complete absence of an ambient magnetic field (Withey and Nuth, 1999). These grains form as fully magnetized dipoles and could serve as the catalysts for the aggregation of nebular dust into chondrule precursors and refractory planetesimals.

Grain Metamorphism. Measurements of the temperature dependent thermal annealing rate for initially amorphous magnesium silicate and iron silicate smokes made by Hallenbeck (University of New Mexico) and J. Nuth in 1998 have led to the development of a Silicate Annealing Index (Hallenbeck *et al.*, 1999) that can predict the infrared spectra of amorphous silicate condensates as a function of the time-temperature history of the material. Preliminary analysis of the predicted behavior of such materials are qualitatively consistent with observations of the mass-loss-rate dependent appearance of crystalline magnesium silicates in AGB stars recently uncovered by ISO. Detailed models of grain formation (based on the metastable eutectic model to predict speciation and Scaled Nucleation Theory to predict nucleation rate) and thermal metamorphism are being tested against ISO observations of the spectral properties of the grains in AGB outflows to see if a more quantitative model of grain formation and evolution in circumstellar outflows can be constructed.

Organic Particles. Small organic particles can be generated in the laboratory from photodissociation combined with chemical reactions of gas mixtures containing the initial organic compounds in mixing ratios of 10^{-4} – 10^{-5} by volume. A reducing atmosphere is needed for the particulate generation. Thus far, the particles are characterized by their infrared spectra measured in an FTIR spectrometer. Measurement of the volatility, thermal stability, and chemical composition of these particles will be attempted. The objective is to generate the particles under known laboratory conditions and characterize them as completely as possible. Then the infrared signatures of these particles can be compared with the infrared spectra observed of particles/grains in circumstellar shells, nebula, and interstellar clouds. R. Cody, M. Iannone (Millersville University), and Fred L. Nesbitt (Coppin State College) are using the small aromatic hydrocarbons of benzene, toluene, ethylbenzene, and xylenes as the precursor organic compounds. These compounds have been used either as a mixture or singly. The major gas component has been either nitrogen, argon, or helium. The effect of the small addition of an oxidizer, i.e. water, to the gas mixture is under study. Dr. Iannone was a participant in the 1999 NASA/ASEE Summer Faculty Fellowship Program.

3. PLANETARY PHYSICS

Laboratory Gas-Phase Spectroscopy. A significant effort in the LEP is high-resolution laboratory infrared spectroscopy of gaseous molecular species. The research by the LEP spectroscopy group composed of D. C. Reuter, J. M. Sirota, J. J. Hillman and D. W. Steyert is focused primarily on molecules of planetary and astrophysical interest, and supports NASA flight missions in both these areas. The work also supports ground-based astronomy and terrestrial atmospheric studies. Particular emphasis is placed on obtaining reliable intensities, self- and foreign-gas pressure broadening coefficients and line-mixing effects. There is a vigorous program to measure TDL and FTS spectra at wavelengths greater than 10 μm. Supporting laboratory measurements are scarce for these wavelengths, but are crucial for the analysis of data from upcoming space missions such as Cassini, where CIRS will obtain spectra of Saturn and Titan from 7 to 1000 μm. Recent activities of the group have included obtaining and/or analyzing spectral data for excited state and fundamental transitions in H_2, $^{13}C^{12}CH_6$, $^{12}C_2H_6$, C_2H_4, C_2H_2, N_2O, CO_2, C_3H_4 (both the methylacetylene and allene isomers), $(CH_3)_2CO$ and HNO_3. This work has been carried out in collaboration with personnel at several institutions including W. Blass (Univ. of Tenn.), J. Frye (Howard Univ.), J. Johns (NRC, Canada), A. Perrin (C.N.R.S., Paris), L. Strow (UMBC), C. Suarez (NRC, Argentina), R. Tipping (Univ. of

Alabama) and W. Wang (UMBC). These measurements have already impacted planetary studies. For example, the ν_{12} ^{13}C ethane ($^{13}C^{12}CH_6$) intensities have been used in conjunction with ground-based observations to infer an essentially terrestrial $^{13}C/^{12}C$ ratio on Jupiter and Saturn, while the intensities of the ethylene (C_2H_4) transitions have been used to obtain concentrations of this species in the upper atmosphere of Saturn. The low temperature line intensity and self- and nitrogen broadened measurements of the ν_9 band of allene near 28 μm are the first such measurements of this band, and are among the longest wavelength TDL data ever obtained. The high-pressure long-pathlength CO_2 broadening spectra show the clear effects of line-mixing and far-wing line shapes in this species and may be used to model atmospheric spectra for the Mars Global Surveyor. The parameters obtained from these experiments are crucial to the proper interpretation of the upcoming CIRS measurements of the atmosphere of Titan.

As well as obtaining and analyzing spectra, the group places a strong emphasis on improving instrumentation and, among other accomplishments, has developed a unique tunable diode laser (TDL) system for obtaining spectra to $\sim$ 30 μm employing advanced (Si:As and Si:Sb) BIB detectors, high performance lead-salt lasers and a long-path White-type sample cell. A very long-path, coolable White-type cell is currently in assembly which will allow pathlengths in excess of 500 m at temperatures as low as 120 K. Work is proceeding to expand the long-wavelength capability of the Kitt Peak National Observatory McMath FTS spectrometer by employing a series of long-wavelength beamsplitters, and to develop methods for external cavity stabilization of long-wavelength TDLs.

Infrared Heterodyne Spectroscopy of Isotopic Ethylene at 10.5 μm. To support a need for accurate molecular transition measurements at high spectral resolution to analyze remote-sensing spectroscopic data from planetary atmospheres, the Infrared Heterodyne Spectroscopy group in the LEP has used a laboratory infrared heterodyne spectrometer to measure the strength, pressure-broadening, and frequency of more than 150 rotational-vibrational transition lines in the ν_4, ν_7, and ν_{10} bands of isotopic ethylene ($^{12}C_2H_4$ and $^{13}C^{12}CH_4$) at room temperature and at low pressures typical of planetary stratospheres. Ethylene is a product of methane photochemistry and is a chemically important trace species in the atmosphere of Jupiter, Saturn, and Titan. A manuscript reporting measurements on ethylene is being submitted by V. Morozhenko (NRC) and T. Kostiuk supported by D. Buhl, T. Hewagama, T. Livengood, and A. Kollyukh (Institute of Semiconductor Physics, Ukraine). Absolute frequencies of the stronger lines of ethylene have been determined to $\pm$ 5.3 $\times$ $10^{-5}cm^{-1}$. Intensities were determined to $\sim$ 10% accuracy.

3.1 Mars

Visible and Near-IR Spectral Imaging of Mars. A very successful observing campaign was executed by D. Glenar and collaborators for the Mars opposition that occurred in late April ’99. The objective was to assemble a photometrically calibrated, spectrally complete ground-based image cube over the visible and near-IR spectral region. These measurements used several instruments and were concurrent both with spacecraft measurements and observations by the upgraded HST. Four observing teams conducted the investigations with 4 instruments spanning 0.4 to 5.0 μm. The instruments and observing facilities were (a) Visible/NIR interference filter (24 filters) camera at the Lowell Observatory 72‘‘ (1.8m) telescope, 430-1050 nm. Science targets were Fe^{2+}, Fe^{3+} mineralogy and coarse grain hematite search. (b) Filter photometer with similar filter set to Lowell at the NMSU Tortugas Mountain Observatory 60-cm telescope, 430-1050 nm. Science targets were Fe^{2+}, Fe^{3+} mineralogy and coarse grain hematite search. (c) SWIR AOTF camera at the Apache Point Observatory, 3.5m, f/10, Nasymth focus. Spectral coverage was 1.7–3.5 μm (AOTF limited), and 0.8-1.0 arcsec ($<$ 430 km) seeing. Science targets: 3 μm water of hydration feature and CO_2, H_2O ice in polar regions and clouds. (d) KPNO cryogenic grating/slit spectrometer (CRSP/SALLY) at the KPNO 2.1 m, f/15 Cassegrain focus. Selected wavelength bands between 2 and 4.7 μm (K, L, M bands), 1.0-1.2 arcsec ($\sim$ 500 km). Science targets: Water-of-hydration (3–4 μm long wave extension) and sulfate mineralogy. Participating observers were D. Glenar, J. Hillman, G. Bjoraker and F. Espenak, N. Chanover, J. Murphy A. Murrell (NMSU), L. Young (Boston University), D. Blaney (JPL) and D. Joyce (KPNO). Preliminary interpretations of these results will be presented at the fall AAS/DPS meeting.

Martian Dust Storm Electric Discharges. LEP scientists W. Farrell, S. Cummer, M. Kaiser, M. Desch, and J. Houser investigated the possibility of detecting radiation from glow and filamentary discharges suspected to be occurring within Martian dust storms. The situation is analogous to the electrification of terrestrial volcanic plumes and terrestrial sand storms. Calculations of the magnitude of charge separation that could be supported by dust storms of a given size indicate that terrestrial-size discharges could exist on Mars, along with microscopic ‘‘glow-like’’ discharges. Further, the LEP scientists modeled the long-distance propagation on Mars of the very low frequency (VLF) electromagnetic radiation from the filamentary discharges to demonstrate their potential detectability on the Martian surface thousands of kilometers from their source. The calculations suggest that these VLF signals could be used not only to locate and track dust storms but also to remotely sense the large scale martian ground conductivity averaged over a depth of a kilometer or more, thereby revealing subsurface geologic features (such as water or highly conductive rock) difficult to detect by other means.

O_3 in the Atmosphere of Mars. F. Espenak, and colleagues T. Kostiuk, T. Livengood, T. Hewagama and F. Schmuelling (NRC) used the Goddard Infrared Heterodyne Spectrometer (IRHS) to measure ozone in the atmosphere of Mars at 9.66 μm in March 1999. The observations were performed atop Mauna Kea at the coude focus of the 3 m NASA Infrared Telescope Facility (IRTF) during March 1999. Terrestrial O_3 normally renders Earth’s atmosphere opaque to these frequencies, but Mars’ large geocentric radial velocity near quadrature shifts the O_3 lines into the wings of their telluric

counterparts where the terrestrial atmosphere is transparent enough to permit the observations. The global distribution of O_3 in Mars' atmosphere was mapped during its northern hemisphere early summer ($L_S = 115°$). Photochemical models suggest that ozone abundances should be rapidly approaching maximum levels in the southern hemisphere; furthermore, Mariner 9 observed high levels of O_3 during this season. These data will be used to test the models and will be compared with previous observations to study the seasonal variability of O_3. The data will also assist Mars Global Surveyor by establishing baseline measurements as the spacecraft orbits Mars. Data reduction and early analysis are now in progress.

Martian Ionosphere. Metallic ions are probably very significant components of the Martian ionosphere. A thorough modeling of the altitude profile of meteoritic ionization in the Martian ionosphere by W. Pesnell (Nomad Research Inc.) and J. M. Grebowsky showed that a persistent layer of Mg ions should exist near an altitude of 70 km. Based on best current estimates of the incident meteoroid mass flux density, a peak Mg ion density of more than 10^4 cm^{-3} is predicted. At these concentrations, the metallic ions should be the dominant ion species in some regions of the nightside Martian ionosphere.

3.2 Jupiter and Io

Stereoscopic Radio Observations of Jupiter by Cassini and Wind. During two intervals in 1999, simultaneous observations of Jupiter's decametric and hectometric radio emissions were made with the Cassini radio and plasma wave instrument (RPWS) and the radio and plasma wave instrument (WAVES) on the Wind spacecraft in Earth orbit. During January, the Jovian longitude difference between the two spacecraft was about 5°, whereas for the August-September Earth flyby of Cassini, the angle ranged from 0° to about 2.5°. With these separations, the instantaneous widths of the walls of the hollow conical radiation beams of some of the decametric arcs were measured suggesting that the typical width is approximately 2°. The conical beams seem to move at Io's revolution rate rather than with Jupiter's rotation rate. Additionally, some of the non-arc emissions have very narrow and quite peculiar beam widths. The observations were carried out by M. Kaiser, W. Kurth, Hospordarsky and D. Gurnett (U of Iowa), and Zarka (Paris Observatory).

Jovian Lightning. LEP investigators W. Farrell, M. Kaiser, and M. Desch presented a model of the Jovian lightning discharge that explains the signal observations by the Galileo probe and the Voyagers. In essence, the discharge is slow (about 2–3 milliseconds), and has a spectral peak below 1 kHz. This ''slow'' discharge, about a factor of 10 times slower than the terrestrial discharge also explains the lack of intense HF emissions from the events.

Thermal Waves on Jupiter. Jovian thermal waves are believed to be Rossby waves, forced by internal convection. They are visible as longitudinal temperature perturbations in thermal infrared images. D. Deming and J. Harrington (Cornell) have been conducting observations and analysis of large-scale thermal waves on Jupiter. Observations of the waves were conducted at the NASA IRTF in October 1998, and additional observations will be acquired in the fall of 1999.

Composition of the Jovian Atmosphere. Methane observations are sensitive to the abundance of water vapor between 3 and 7 bars on Jupiter. G. Bjoraker and G. Orton (JPL) acquired spectra of Jupiter using the CSHELL cryogenic grating spectrometer at NASA's Infrared Telescope Facility in Hawaii. Observations of CH_4 and NH_3 were obtained simultaneously with measurements by the Near Infrared Mapping Spectrometer on the Galileo Orbiter. This technique permits mapping H_2O on Jupiter using ground-based telescopes. Preliminary results show dramatic variations in the abundances of both H_2O and NH_3 near the Great Red Spot and in portions of the North Equatorial Belt. These results were presented at the 1998 meeting of the Division of Planetary Sciences. The abundance of volatiles does not correlate well with belts and zones but ''wet'' regions do coincide with features identified as water clouds by the Galileo imaging team.

Jovian Mid-IR Aurora and the Solar Cycle. Evidence for solar cycle-dependent variations in the intensity of mid-infrared emissions of the ethane molecule in Jupiter's polar aurora was reported by T. Kostiuk with co-authors T.A. Livengood, K.E. Fast, and T. Hewagama, D. Buhl, and J. Goldstein (Challenger Ctr.) in a paper presented at the Magnetospheres of the Outer Planets Conference in August 1999. Data for the analysis come from infrared heterodyne spectroscopic observations of 12 μm ethane emission from Jovian aurora conducted from the NASA Infrared Telescope Facility (IRTF) and from Voyager IRIS observations, spanning nearly 2 solar cycles, with the most recent observations in August 1998. A solar cycle dependence is significant, as no such dependence has been noted in any other emission from Jupiter's auroral regions. Such a dependence may signal changes either in the properties of the impinging particle beams or in the target atmosphere receiving the beam. Further investigation will be required to establish the distinction. T.A. Livengood (UMD), with co-authors T. Kostiuk and H. Käufl (ESO Headquarters, Garching, Germany) reported at the same conference on the spatial distribution of auroral hydrocarbon emissions on Jupiter, derived from mid-IR imaging observations conducted in 1994 and 1996 from the European Southern Observatory using the facility instrument TIMMI. Hydrocarbon auroral emissions are confined to latitudes greater than 50–60°, consistent with the general properties of auroral morphology observed in other wavelengths. Hydrocarbon aurora differs in several particulars, having a distinct ''hot spot'' of emission within the northern auroral oval, and occasional broad distributions of emission spanning a very wide range of longitude. T.A. Livengood was a co-author to R. Prangé's (IAS, Orsay, France) report at this conference on long-term variations of Jupiter's UV auroral activity observed with the (now-deactivated) IUE satellite observatory in 1994 and 1996.

Jupiter's H_3^+ Aurora. A linearized inverse method is used to extract an emission model from many images of the aurora, obtained at different Central Meridian Longitudes. Dr. T. Satoh (Science University of Tokyo) and J. Connerney use NSFCAM infrared images of Jupiter to model the distribution of Jovian H_3^+ emissions in the auroral regions and to monitor the dynamic state of the Jovian magnetosphere. Evidence was found for enhanced emissions at longitudes marked by weaker surface magnetic field magnitudes, and there appears to be a local time enhancement in emissions poleward of the auroral oval in the dusk sector. The auroral intensity has two principal components of time variability: a short-term variability (days) which correlates well with the solar wind ram pressure arriving at Jupiter, and a longer-term variability (months) which is believed to be related to the energization and transport of magnetospheric plasma in Jupiter's magnetosphere. A continued program of observation of the aurora is conducted to monitor the state of the magnetosphere in support of the Galileo Mission.

First Equatorial Observations of Winds in Jupiter's Stratosphere. The Doppler-shifted emission of ethane (C_2H_6) at 12 μm helps measure wind velocities in the equatorial stratosphere. The Goddard IRHS field instrument at the NASA Infrared Telescope Facility was used in August 1998 by J. Goldstein and K. Ro (Challenger Ctr.), T. Kostiuk, D. Buhl, F. Espenak, T. Livengood, K. Fast, and T. Hewagama to make the measurements. The only previous measurements in this pressure regime profited from the injection of dust and aerosols by Comet Shoemaker-Levy 9 to trace winds by feature-tracking in visible light, in a narrow interval at 43° south latitude. Measurements at the equator explore a new region not yet measured and inaccessible to theoretical extrapolation due to intrinsic limitations in the calculation of winds from thermal balance. Data reduction and initial analyses are under way.

Comet Shoemaker-Levy 9. A ballistic Monte-Carlo method to simulate SL9 ejecta plumes has been used to develop a radiative-hydrodynamic model of the SL9 splashback phase by D. Deming and J. Harrington (Cornell). As the ballistic plumes fall back onto the Jovian atmosphere, the resulting shock-heating is modeled using a version of the Zeus-3D hydrocode, modified to include radiative damping in the gray approximation. Synthetic infrared light curves produced by the model are in substantial agreement with observations, including the presence of secondary maxima or ''bounces'' following the main peak. The model also accounts for several other phenomena for which a complete explanation has been lacking to date.

Temporal Study of SL9-Introduced Ammonia in Jupiter's Stratosphere. Measured time scales for the removal of ammonia from the stratosphere by solar ultraviolet photolysis will shed light on chemical and dynamical processes in the Jovian stratosphere. K. Fast, working with LEP members T. Kostiuk, D. Buhl, F. Espenak, and P. Romani, A. Betz, R. Boreiko (U. of CO, Boulder) and T. Livengood, is analyzing infrared heterodyne spectra of NH_3 introduced into Jupiter's stratosphere by the impact of Comet Shoemaker-Levy 9. Infrared heterodyne ammonia emission line spectra at a resolving power of $\sim 10^7$ were obtained by Betz *et al.* and are being analyzed using the BEAMINT modeling software to retrieve stratospheric ammonia mole fractions and altitude distributions, and temperature information. Spectra from six different impact regions were acquired from hours to 3 weeks following the impacts on up to four different days for each site, enabling an investigation of the temporal behavior of ammonia abundance and temperatures in Jupiter's stratosphere. These results will be combined with previous ammonia retrievals from the Goddard IR heterodyne spectrometer, as well as retrievals from other investigators, using the same radiative transfer analysis. The combined data set can be used to investigate the long-term behavior of ammonia in the stratosphere, as well as provide constraints on current photochemical models.

H_3^+ Emissions from Jupiter and Io. J. E. P. Connerney and T. Satoh (Science University of Tokyo) continue a program of long-term observations of Jupiter at 3.40 μm wavelength using the NSFCAM infrared camera and NASA's IRTF at Mauna Kea, Hawaii. The technique exploits a set of emission lines of the H_3^+ ion (3.40μm) within a strong absorption band of methane, to image the distribution of H_3^+ with high spatial and time resolution and extraordinary signal to noise. H_3^+ is a major topside ion in Jupiter's ionosphere. An image obtained at 3.40 μm shows emission from high altitudes (above the methane homopause) against a darkened planetary disc (by absorption). These images evidence intense and omnipresent auroral emissions at both magnetic poles and emission at the foot of the Io Flux Tube (IFT). The latter often appears as an isolated, sub-arcsecond spot that moves across Jupiter's disc in concert with the orbital motion of Io; it is excited by the electrodynamic interaction of Jupiter's magnetic field with Io. Additional improvement in imaging H_3^+ emissions resulted from the introduction of a custom filter set on the NSFCAM filter-wheel (3.4265 μm, 3.54 μm, and 3.49 μm null) in July of 1998. Emission extending well downstream (60°) of the IFT footprint along Io's L shell can be seen at times in both hemispheres. High time resolution imagery of the IFT footprint is used to further our understanding of the electromagnetic interaction between Jupiter and Io. Recent imagery reveals (over some longitudes) multiple footprints at the foot of the IFT suggesting multiply reflected Alfvén waves passing between Jupiter's ionosphere and the high density torus. A catalog of observed surface locations of the IFT footprint has been used to greatly improve models of Jupiter's magnetic field.

Io Torus Radio Emissions. W. Farrell, R. Hess, and R. MacDowall examined O-mode emission in the Io torus and showed that intensifications were likely due to reflection and trapping in density cavities, rather than being signatures of the emission location.

Jovian Radio Emissions. Inspired by recent reports of long term periodicities in the Jovian nKOM and bKOM radio emissions observed by Galileo, M. Reiner, M. Kaiser, and M. Desch reanalyzed the Ulysses data taken during the Ulysses-Jupiter encounter to look for possible long term periodicities in the Jovian radiation. Realizing that the Ulysses-Jupiter encounter occurred during the maximum of the solar cycle, they found that the solar wind was well represented by a simple two-sector structure, and that this (12) 25 day sector structure was strongly reflected in the Jovian bKOM and nKOM radio emissions. That the solar wind sector structure had a profound influence on the intensity of the Jovian bKOM emissions was not new, but what was found very surprising was that there was a sharp cessation of the bKOM emission which was followed by an abrupt onset of an nKOM ''event,'' which lasted for some 5 days. This behavior of the bKOM and nKOM emissions was repeated for four consecutive 25-day periods during the Ulysses inbound trajectory. These observations are rather different from the Galileo observations and suggest that the nKOM periodicities observed by Galileo may ultimately be related to the solar wind structure at Jupiter at the time of the Galileo observations. These new results were presented at the Magnetospheres of the Outer Planets conference in Paris.

3.3 Saturn and Titan

IR Spectral Imaging of Saturn. J. Hillman, D. Glenar, and G. Bjoraker and N. Chanover (NMSU) investigated the near-IR spectrum (1.7–5.2 μm) of Saturn using new AOTF cameras. Key objective is to obtain a photometrically calibrated spectral image cube of Saturn between 1.7–5.2 μm. These data will identify wavelengths most sensitive to convective disturbances in Saturn's atmosphere, observe center-to-limb reflectivity changes that can be interpreted in the context of a vertical structure model, search for Saturnian analogs to Jovian 5 μm ''hot spots'' and characterize spatial variations in trace molecular species.

Rings of Saturn in the mid IR. T. Kostiuk, T. Livengood, C. Lisse and H. U. Käufl (European Southern Observatory) have imaged Saturn and its rings in the mid-Infrared. Images were obtained in October-December 1996 at the European Southern Observatory using the Thermal Infrared Multi-Mode Instrument (TIMMI) on the 3.6 m telescope. Photometric images were made through filters from 7.7 μm to 13 μm with the TIMMI 64$\times$ 64 element Ga:Si array at an image scale of 0.5 arcsec/pixel. Preliminary analysis of spectrophotometry indicates a peak in the emitted radiance of the rings near 12 μm. A significant difference in the radiance from the East and West ansae was observed, with a maximum ratio W/E of $\sim$ 2 near 11.3 μm. Possible explanations for the difference include thermal heating and cooling, ring geometry, and ring particle properties and composition. Results will be reported by T. Livengood at the 1999 Division for Planetary Sciences meeting in Padova, Italy. Additional measurements are planned with the new TIMMI 2 camera coming on line at ESO.

Titan Winds. A beam integrated radiative transfer software package called BEAMINT has been developed to model the Doppler-shifted ethane line spectra contributing to an observation of Titan. A BEAMINT-based analysis has confirmed the earlier zero-order calculations that the globally-averaged wind direction is prograde to high statistical certainty. A report is being submitted by T. Kostiuk with co-authors J. Goldstein and K. Ro (Challenger Ctr.), T. Hewagama, D. Buhl, F. Espenak, T. Livengood and K. Fast, summing up direct measurements of the global circulation on Titan using the Goddard Infrared Heterodyne Spectrometer (IRHS). Further data collection on Titan will be conducted using the portable heterodyne instrument HIPWAC, presently under fabrication. Current results and future measurements are important for final Cassini Huygens Probe release configuration and thus for the optimization of the science investigation, particularly surface studies. Results will also provide significant constraints on dynamical models of atmospheres of slowly rotating bodies.

3.4 Neptune

Neptune's Stratosphere. P. Romani collaborated with B. Schulz (ISO Data Center, ESA, Madrid, Spain), Th. Encrenaz, B. Bézard, E. Lellouch (Observatoire de Paris, Section de Meudon) and S. K. Atreya (The University of Michigan) on the first firm detection of ethylene (C_2H_4) in the stratosphere of Neptune. The detection was made in 6–12 μm spectra of Neptune recorded by Infrared Space Observatory (ISO) PHT-S instrument at a resolution of 0.095 μm. To reproduce the observed emission feature, a column density in the range $1.1 - 3 \times 10^{14}$ molecules cm^{-2} is needed. This abundance of ethylene is consistent with a previous tentative detection of the same band in ground-based low-resolution spectral measurements and upper limits from Voyager UVIS and ISO Short Wavelength Spectrometer observations. We then used the observations to constrain a one-dimensional hydrocarbon photochemical model. To produce this low amount of ethylene, previous photochemical models invoked rapid mixing between the source and sink regions of C_2H_4. However, if recent laboratory measurements of CH_4 photolysis branching ratios at Lyman-α are used this requirement can be relaxed. A paper based on these results has been submitted to *Astronomy and Astrophysics*.

3.5 Meteorites

Meteorite Elemental Composition Studies. The x-ray/gamma-ray spectrometer (XGRS) on the NEAR spacecraft will determine the surface elemental composition (e.g., Mg, Al, Si, Fe, O, and K (possibly Ca, S, Ti, and Th) of the S-class asteroid 433 Eros [1]. These abundances should help elucidate both possible relationships to known classes of meteorites and geological processes that occurred on Eros (e.g., impact processing, partial melting). To aid in the analysis and interpretation of the NEAR XGRS data J. Trombka *et al.* are compiling a database of bulk elemental compositions of meteorites. They are limiting their database to those they deem to be the most reliable, specifically selecting analyses of representative samples of falls or unweathered finds. Initial emphasis is on classes of meteorites most likely related to Eros, including ordinary chondrites and several types of achondrites, and excluding meteorite types which are poor spectral matches for Eros (e.g., carbonaceous and enstatite chondrites, aubrites). These data form the basis for plots of elemental abundances and abundance ratios to distinguish classes of meteorites and identify geological processes on Eros. Initial efforts will be on obtaining accurate abundance ratios, rather than absolute abundances, since ratioing eliminates many of the geometrical factors, which affect the production of x-rays and gamma rays from the asteroid's surface. Given the set of elements measurable by the XGRS, there should be several ratios that will distinguish meteorite classes and geologic processes. Plots of Al/Mg vs. Fe/Mg might track the removal of basaltic and Fe-Ni, FeS melts from a Mg-enriched residue. Plotting Fe/Si from the x-ray spectrometer vs. Fe/Si from the gamma-ray spectrometer might track the preferential enrichment of metallic iron in the surface regolith, given the different penetration depths of X-rays and gamma-rays. The ratio of trace elements K/Th will be a measure of volatile depletion, reflecting the thermal history of Eros.

3.6 Extrasolar Planets

Extrasolar Planetary Infrared Emissions. D. Deming and G. Bjoraker are collaborating with G. Wiedemann (ESO) in an attempt to detect spectral emission features in the extrasolar planetary systems 51 Peg, Ups And, and Tau Boo. A large quantity of high-resolution spectra has been obtained in the 3.3 μm band of methane and the 4.6 μm band of carbon monoxide. The planetary spectral features are expected to be present in these data at a level of approximately 2×10^{-4} of the stellar continuum. Preliminary analysis of the data has achieved sensitivity about one order of magnitude less than is required to detect the planetary spectra. However, planned improvements to the data analysis algorithms are expected to increase the sensitivity significantly.

Extrasolar Planetary Spectroscopic Modeling. An effort to develop quantitative numerical models for mid-infrared spectra of extrasolar planets under a variety of credible circumstances has been initiated by T. Kostiuk, J. Goldstein (Challenger Ctr.), T. Hewagama, T.A. Livengood, and K.E. Fast (UMD), with scientific collaborators J. Lunine (U of Arizona) and J. Kasting (Penn. State U.). T. Kostiuk presented a tutorial on the topic at the March 1999 Pale Blue Dot II conference in Palo Alto California. The BEAMINT package developed to model the spectra of solar-system objects is being adapted to construct spectra at arbitrary spectral resolution with accurate radiative-transfer modeling, to determine constraints. These constraints will affect efforts to directly detect and characterize extrasolar planets of terrestrial and gas-giant type. The initial effort will be to construct synthetic spectra of the known solar system as viewed from an extrasolar perspective. The calculational effort is led by T. Hewagama.

Extrasolar Planetary Radio Emissions. LEP investigators Farrell and Desch along with P. Zarka (Meudon Observatory, Paris) have recently predicted MF and HF radio fluxes from extrasolar planetary cyclotron emission sources. They applied known planetary magnetic fields and radiometric models to obtain the estimate, these models already derived from studies of our own solar system. Based on this work, they were given telescope time on the Very Large Array in New Mexico to search for cyclotron emission from tau Bootes.

4. SUN-EARTH CONNECTIONS

4.1 Ionospheric, Thermospheric and Mesospheric Physics

Auroral Physics. S. Cummer and R. Vondrak have analyzed simultaneous x-ray, ultraviolet, and visible images from the PIXIE, UVI, and VIS instruments on the Polar satellite in an effort to understand auroral substorm dynamics as viewed simultaneously at multiple wavelengths. Quantitative analysis of images of an isolated substorm has revealed strong differences between the morphology of x-ray and ultraviolet/visible emissions during substorm recovery phase. The high-energy electron precipitation responsible for these differences comes from both a continuing injection of high-energy particles near local midnight and preferential precipitation near local dawn of gradient-curvature drifting electrons.

S. Cummer and R. Vondrak also studied the ionospheric electrodynamics of the auroral surge using FAST *in situ* particle and field observations and Polar/VIS high resolution images of the large-scale auroral oval. The analysis indicated the presence of strong upward field aligned currents associated with the surge, which, when combined with an electrodynamic analysis of the region east of the surge head, demonstrate that these upward currents are not locally closed, in contrast to some previous studies.

Sprites and Ionosphere. S. Cummer, in collaboration with researchers at Stanford University and New Mexico Tech, has studied the use of low frequency radiation from lightning discharges to remotely sense both D region electron density profiles and the current variation in lightning discharges associated with transient mesospheric optical emissions (sprites). A study of current waveforms and high speed video images of sprites has shown that present models do not explain either the temporal dynamics or the low altitude extent of the observed emissions.

ISIS Digital Database. Digital ISIS-2 topside-sounder ionograms are continuing to be produced by a team led by R. Benson of the LEP. The digital ionograms, produced from the original analog telemetry tapes, are being archived at the National Space Science Data Center at GSFC. More than 239,000 digital ISIS-2 ionograms from 18 globally distributed telemetry stations had been processed by the end of August 1999. They correspond to ionospheric topside soundings during the 11-year interval from 1973 through 1983. Since most of these data were never processed into the conventional 35 mm analog film format, they are analogous to the output of a successful new satellite mission covering this earlier solar cycle interval. A search program to assist in the retrieval of the data based on date, time, geographic or magnetic parameters, status of instruments, etc., has been written. A program to analyze the digital ionograms has also been prepared. Information on how to access and use both is available from http://nssdc.gsfc.nasa.gov/space/isis/isis-status.html.

Ionospheric Polar Holes. R. Benson and J. Grebowsky analyzed vertical electron-density (N_e) profiles, deduced from newly available ISIS-2 digital ionospheric topside-sounder data. The investigation's focus was the ‘‘polar-hole’’ region within the winter, nighttime polar cap ionosphere during solar minimum. This region is located around 0200 magnetic local time near the poleward side of the auroral oval. Earlier investigations had revealed very low Ne values in this region (down to 200 cm^{-3} near 300 km). The ISIS-2 investigation only found low N_e values ($\approx$ 100 cm^{-3}) near the satellite altitude of 1400 km. The peak ionospheric concentration below the spacecraft remained fairly constant ($\sim 10^5$ cm^{-3}) across the hole region but the altitude of the peak dropped dramatically (to the vicinity of 100 km) in the depletion region. These observations suggest that the earlier satellite *in situ* measurements, interpreted as deep holes in the ionospheric F-region concentration, may have reflected the extreme lowering of the altitude of the ionospheric N_e peak.

4.2 Magnetospheric Physics

Flow Bursts and Substorms. A study by D. Fairfield and coworkers of high velocity earthward plasma flow bursts observed by Geotail in the inner magnetotail (13-15 R_E) has found a close relationship with other magnetospheric phenomena. The bursts are associated with magnetic field dipolarizations, geosynchronous particle injections, auroral kilometric radiation onsets and auroral brightenings as observed by the polar spacecraft. Since the flow bursts often exhibit the earliest onset of these phenomena, it seems likely that reconnection beyond 15 R_E initiate the chain of events. A further study with A. Ieda confirms that associated tailward moving plasmoids are closely associated with auroral brightenings near the meridian of the plasmoid observation. Together these studies reveal a dynamic magnetotail with numerous localized reconnection events occurring. Under still unknown conditions, these flow bursts collectively develop into a global geomagnetic substorm.

A pair of papers about to be submitted for publication report the study of a several hour interval on March 24, 1995 when the Geotail spacecraft made more than 100 quasi periodic crossings of the dusk equatorial magnetotail boundary 14 R_E tailward of the dawn/dusk meridian when then the interplanetary magnetic field was very northward. A MHD simulation of the Kelvin Helmholtz instability using measured upstream parameters reproduces the observations with good clarity. Large observed magnetic field fluctuations are shown to be due to twisting of the field by the vortical flow when there is a small field component in the equatorial plane. Magnetic reconnection occurs within the vortex that allow particles to enter the magnetosphere. This instability is probably an important way that energy, momentum and particles enter the magnetotail, at least when the interplanetary field is very northward.

Plasmoid Ejection. J. Slavin, D. Fairfield, M. Hesse, and R. Lepping have collaborated with ground-based and GEOTAIL investigators to investigate plasmoid formation and ejection. In a new multi-spacecraft study (Slavin *et al.*, 1999) they examined a unique data set returned by IMP 8 and Geotail on January 29, 1995 during a substorm that resulted in the ejection of a plasmoid. The two spacecraft were situated in the north lobe of the tail and both observed a traveling compression region (TCR). From single s/c observations only the length of the plasmoid in X and an estimate of its height in Z can be determined. However, they showed that dual s/c measurements of TCRs can be used to model all three dimensions of the underlying plasmoid and to estimate of its rate of expansion. For this event plasmoid dimensions of $\Delta X \sim 18$, $\Delta Y \sim 30$, and $\Delta Z \sim 10$ R_E are determined from the IMP 8 and Geotail lobe magnetic field measurements. The earthward end of the plasmoid was inferred to be near the mean location of the near-earth neutral line, X $\sim$ -26 R_E. Its center was underneath IMP 8 at X $\sim$ -34 R_E and its tailward end appeared to be near X $\sim$ -44 R_E. Furthermore, a factor of $\sim$ 2 increase in the amplitude of the TCR occurred in the 1.5 min it took to move from IMP 8 to Geotail. Modeled using conservation of the magnetic flux, this increase in lobe compression implies that the underlying plasmoid was expanding at a rate of $\sim$ 140 km/s. Such an expansion is comparable to recently reported V_Y speeds in ''young'' plasmoids in this region of the tail. Finally, the Geotail measurements indicated that a reconfiguration of the lobe magnetic field closely followed the ejection of the plasmoid that moved magnetic flux tubes into the wake behind the plasmoid where they would convect into the near-earth neutral line and become available to feed the reconnection region.

South-North Traveling Compression Regions. The ISTP program allows investigators the opportunity to study the effect of solar wind pressure impulses on the magnetospheric system routinely using multiple spacecraft. M. Collier, J. Slavin, and A. Szabo along with M. Moldwin (Florida Institute of Technology) have studied reverse polarity or south-then-north (SN) bipolar traveling compression regions in the Earth's magnetotail using IMP 8 in the tail lobe and WIND as an upstream monitor. They found that many of the SN TCR's are explained by solar wind pressure pulses.

Substorm Modeling and Prediction. The nonlinear dynamics and plasma physics group of A. Klimas, J. Valdivia, D. Vassiliadis, and visitor J. Takalo (Univ. of Jyvaskyla) expanded their activities from the temporal aspects of geomagnetic and global magnetospheric activity to spatiotemporal modeling and prediction.

Valdivia *et al.* (1998) modeled the ring-current related magnetic disturbances from a set of midlatitude magnetometers. Their modeling procedure clearly shows the ring current longitudinal asymmetry and can be inverted to yield estimates of the local energy density of the current-carriers. They have been developing a mapping procedure that will identify the major disturbance sources: the symmetric and asymmetric ring current, the substorm current wedge, and the effects of solar wind pressure on the dayside magnetopause current.

Similarly, for the high-latitude geomagnetic disturbances the nonlinear dynamics group has developed a spatiotemporal model of the activity from four magnetometer chains. The model is driven by solar wind electric field data and/or the polar cap geomagnetic index. This dynamic, nonlinear model is an advance over present statistical models of the high-latitude geomagnetic disturbances. At its early stage the model reproduces qualitative features of each substorm phase, and there is very good quantitative agreement between conventional indices and those produced by the model.

The nonlinear dynamics group also continued to model the AL/AU indices for geomagnetic activity and the Dst index identifying nonlinear features that correspond to distinct physical processes.

One of the major sources for the nonlinear response of the magnetosphere to the solar wind driving is the stability of the tail current sheet. While conventional theories advocate near-Earth neutral line formation or current disruption at a single or a few sites along the magnetotail, it is more probable that multiple reconnection or current disruption regions exist, and that their interaction produces the irregular magnetospheric response. By using 1-D and 2-D models of the magnetic configuration in the tail the nonlinear dynamics group has found power-law (fractal) distributions and power spectra that are similar to those observed in situ, or on the ground. The statistics of the observations can thus be accounted for by self-organized criticality (SOC), a property of many externally driven complex systems composed of interacting nonlinear elements.

Terrestrial Plasma Energization. M.-C. Fok, B. Giles, and T. Moore explored the transport and energization of terrestrial plasma in the Earth's magnetosphere, using theoretical tools guided by observations. They found that the observed features of magnetospheric substorms are well reproduced by the action of magnetotail dipolarizations (the opposite of tail stretching), acting mainly on plasmas emanating from the Earth through the polar cap regions. Also, they found that the substorm dipolarizations greatly amplify the injection of plasma into the inner magnetosphere, above what would be produced by enhanced circulation. This result indicates that substorms do contribute to the development of global magnetospheric storms and their effects. This work was also the basis for studies of the expected neutral atom flux expected from magnetospheric storms, led by J. D. Perez of Auburn Univ. Collaborating with G. Khazanov of the Univ. of Alaska, and D. Delcourt of the CETP in St. Maur, France, they also explored the outflow of ionospheric plasmas through the auroral zones and polar cap regions, and the energization of plasmas of terrestrial origin, including electrons, in other diverse contexts.

The Role of Ideal Ballooning Instabilities During the Substorm Growth Phase. The stability characteristics of an ideal ballooning mode for tail and transitional (tail-like to dipolar-like) field configurations, using the MHD fluid description were investigated by A. Sundaram and D. Fairfield. A two-dimensional equilibrium model for the tail as well as the transition region between dipole-like to tail-like fields was developed. Both local and non-local excitation of ballooning modes in these two regions were studied by including effects associated with the plasma compressibility and the pressure anisotropy. In the near-equatorial region, it was shown that the ballooning instability characteristics are sensitive to compressibility and pressure anisotropy effects. It was found that, in the tail region, a non-local ballooning mode is excited with a fast growth time of 20 ms. In the transition region where tail-like and dipole-like field characteristics prevail, it was demonstrated that the pressure anisotropy and compressional mode coupling effects cause the excitation of new ballooning modes that grow in a ms. Their analytical model describing the dominance of ballooning modes in the transition region supports recent substorm related observations of shear Alfvén coupled magnetosonic modes.

Magnetospheric Fields During Substorms. N. Tsyganenko made a first attempt to quantitatively represent the dynamics of the magnetospheric magnetic field during the substorm expansion phase, using the data of simultaneous observations from Geotail and GOES spacecraft and a global model of the field, including the contribution from the electric current wedge on the night side.

Storm-substorm Relation. M.-C. Fok and T. Moore have been studying the storm-substorm relation using a test-particle code and a kinetic model of the ring current. The equatorial flux at 12 R_E is established by tracking particles backward in time to their sources. The subsequent transport and energization of this boundary flux are calculated using the ring current model. Various storm and substorm conditions are simulated. They found that substorms occurring during quiet times produce mainly enhancements in the plasma sheet. However, substorms together with storm-time convection bring particles well inside the geosynchronous orbit and form a robust ring current.

Comprehensive Computational Model of the Earth's Ring Current. M.-C. Fok and R. Wolf (Rice University) have been working on combining the Rice Convection Model (RCM) and the Fok's ring current model to form a comprehensive model of the Earth's ring current. Before the merging, the two models were used individually to simulate the same magnetic storm and results from the two models were compared. There was a very good agreement between the models. The model merging is now taking place. RCM is modified to be a module to supply electric field information to Fok's model. In turn, particle distributions calculated using Fok's model will be fed to RCM to update its electric field calculation.

Simulations of Magnetotail Reconnection. L. Rastätter and M. Hesse have studied the interaction of multiple reconnection sites in a three-dimensional semi-global simulation of the Earth's magnetotail. The effects of the (relative) location of the reconnection sites triggered by localized resistivity on the near-Earth current system were extensively investigated. Although the amplitudes of the currents parallel to the magnetic field (field-aligned currents) at the near-Earth boundary (tail cross-section at -5 R_E) decline rapidly with the distance to the reconnection site in downtail direction the total current generated remains fairly constant due to the widening of the current system originating from reconnection at larger distance. In a series of simulations competing reconnection events were studied. A localized increase of the cross-tail current, such as found in a thin current sheet of the pre-substorm magnetotail, can enable the reconnection site further downtail to dominate the appearance of the near-Earth current system. As the evolving plasmoids expand, they interact and merge rapidly on their downtail travel while a single large-scale system of field-aligned currents near the Earth develops.

Collisionless Dissipation and Magnetic Reconnection. M. Kuznetsova and M. Hesse applied their modified hybrid model to the problem of collisionless dissipation in the magnetic reconnection problem. This comprehensive hybrid model includes both electron inertial and thermal, i.e., pressure-based, effects. For current sheet widths of the order of ion inertial lengths, they determined the dominance of electron pressure-based dissipation processes over inertial dissipation. This result was verified and extended using an electromagnetic particle-in-cell code, newly developed by M. Hesse. Using both explicit and implicit versions of this new tool, M. Hesse and D. Winske (Los Alamos National Laboratory) were able to show that inertia-based dissipation can be dominant if reconnection occurs in sheets of electron-scale width. They also performed a step toward a transport-model representation of the pressure-based dissipation process. This effort was continued by M. Kuznetsova and M. Hesse, who used both the hybrid and electromagnetic simulation codes for a detailed comparison. They showed that small modifications are readily introduced into the modified hybrid model such that hybrid simulation results resemble closely the baseline fully kinetic model. They carried this analysis further to devise a new physics-based transport model for electron pressure effects. This relatively simple model shows great promise for the correct inclusion of kinetic dissipation processes in large-scale magnetospheric models.

Electron Dynamics at Reconnection. M. Hesse and co-workers investigated the electron dynamics in the dissipation region of collisionless magnetic reconnection. They found that kinetic electron effects generate substantial deviations form MHD behavior, with electron inertia playing a major role. Using their simulation model, they found the scaling of the electron dissipation region for different electron masses. They were therefore able to make an accurate prediction of the scale sizes to be found in reality.

Magnetohydrodynamic Simulations of Magnetospheric Dynamics. J. Birn (Los Alamos National Laboratory), M. Hesse, and G. Haerendel, W. Baumjohann, and K. Shiokawa (all Max-Planck Institute für Extraterrestrische Physik) extended earlier simulations of magnetospheric dynamics in order to perform a detailed study of magnetotail current disruption. This study demonstrated that current disruption and magnetic reconnection are intimately linked and part of the same large-scale magnetotail instability. The investigation also focused on the exact way the cross-tail current becomes diverted to the ionosphere. Here they found that current diversion relies to a lesser degree on the braking of fast flows then on pressure and magnetic field configurational changes during the course of substorm expansion.

Ion Distributions During Bursty Bulk Flows. M. Kuznetsova and M. Hesse have adapted and applied their new hybrid code that includes electron inertia to investigate ion distributions during bursty bulk flows. They found the generation of a localized burst of earthward flow that envelops an earthward propagating enhancement of the north-south magnetic field component. Distribution functions obtained near the propagating flux enhancement exhibit strong nongyrotropic anisotropies. The magnetic field evolution shows the presence of fluctuations that resemble strongly actual spacecraft observations. The simulation results indicate that magnetic field fluctuations during dipolarization and bursty bulk flows might be due to anisotropies in the ion distributions.

Electron Acceleration in the Outer Zone. Using energetic particle sensors aboard SAMPEX, POLAR and HEO satellites, S. Kanekal and collaborators have studied the electron enhancement events in the outer zone of the magnetosphere. These enhancement events provide information regarding the underlying acceleration mechanisms that are yet to be fully understood. SAMPEX has provided continuous coverage of most of the entire outer zone beginning from a time just after the previous solar maximum to present times. Comparison of flux enhancement events using data from widely separated spacecraft covering an energy range from hundreds of keV to several MeV and a broad range of pitch angles have demonstrated the global and coherent nature of these events.

Plasma Sheet Kinking. M. Hesse and M. Kuznetsova with J. Birn and D. Winske (Los Alamos National Laboratory), used fully kinetic electromagnetic particle-in-cell and Hall-MHD simulations to study the causes of plasma sheet kinking in both two- and three-dimensional models. They found two contributors to the kinking process: 1. a kinetic mode, which operates independent of the velocity distribution, and 2. a velocity shear driven mode, similar to the Kelvin-Helmholtz instability. The latter forms through the action of a lower-hybrid drift mode that serves to generate shears in the plasma flow velocity. Other mechanisms yielding similar results are easily envisioned. A fluid instability grows in the so-established flow shear and propagates in the current direction.

New 3D Particle-in-cell Code. M. Hesse developed a new, fully electromagnetic, three-dimensional particle-in-cell code to study a variety of magnetospheric phenomena, ranging from collisionless magnetic reconnection to current driven instabilities in the current layer of the magnetotail, with a new implicit solver for the electromagnetic fields.

Magnetospheric Magnetic Field Modeling. N. Tsyganenko has performed a statistical study of the near-Earth equatorial magnetic field depression, based on a set of data from 20 months of POLAR magnetometer experiment in 1996–1998, supported by simultaneous information on the solar wind state by WIND and IMP 8 spacecraft. The work addressed the spatial distribution of the magnetic field, produced by the magnetospheric currents near the dipole equator at radial distances between 2.0 and 4.5 R_E, and its dependence on the ground Dst index, solar wind pressure, and the interplanetary magnetic field. The inner field was found to have a significant noon-midnight and dawn-dusk asymmetry, sensitive to the Dst and the solar wind pressure. Tsyganenko also completed a study of the magnetic field depression associated with the dayside magnetospheric polar cusps. In the noon sector, the cusp depression was found from the data of POLAR spacecraft in a relatively narrow latitudinal interval, but extending over a wide range of the geocentric distance. At closer distances the cusp depression was found to fade out due to a rapid increase of the geomagnetic field towards Earth. The study has also shown that the cusp depression becomes significantly shallower as one moves away from the noon meridian. A mathematical method was developed for representing the observed polar cusp depression in quantitative magnetic field models of the geomagnetic field, making it possible to incorporate the realistic structure of the polar cusps in the global models.

Adaptively Refined Global MHD Magnetosphere Simulations. Together with D. Spicer of Goddard's Earth and Space Data Computing Facility and P. MacNeice of Drexel University, S. Curtis is developing the first global MHD simulation code of the terrestrial magnetosphere that rigorously keeps the divergence of the magnetic filed zero. Present efforts are focused on developing very fast parallel versions of the code. A near term simulation objective of the code is to examine the dynamics of the terrestrial radiation belts under extreme interplanetary conditions in the context of a highly resolved global magnetosphere structure.

Magnetopause Model. N. Tsyganenko devised a new model of the magnetopause taking into account the effects of the dipole tilt angle upon its global shape and the observed deformation of the magnetospheric boundary in the vicinity of the polar cusps. All previous data-based models ignored that effect, although its existence was predicted by theory and was confirmed by observations.

Modeling of Astrophysical Accretion Disks. L. Rastätter and K. Schindler finished the investigation of ideal (non-resistive) instabilities of the magnetosphere accretion disk interface region by three-dimensional cylindrical MHD simulations. It was found that gravitationally driven Rayleigh-Taylor modes of instability dominate the shear-driven Kelvin-Helmholtz instability, even with the presence of a large difference between magnetospheric and disk rotation rates at the interface.

4.3 Heliospheric and Solar Physics

Solar Active Regions. Measurements of solar active-region magnetic fields using the 12.32 μm infrared emission line has been carried out by D. Jennings, G. McCabe, T. Moran, D. Deming and P. Sada (University of Monterey, Mexico). The observations use the Goddard ''Celeste'' cryogenic grating spectrometer and the ''Athena'' cryogenic Fabry-Perot system, both at the McMath-Pierce telescope of the National Solar Observatory on Kitt Peak. Celeste observations in October 1998 produced the first large-format sunspot polarization (Stokes-V) maps. Preliminary analysis of these data reveals features of the magnetic field morphology (such as a prominent superpenumbral canopy) that are not easily seen in conventional visible magnetograms.

MHD Model of the Solar Corona and Solar Wind. A semi-empirical 2-D MHD model of the solar corona and solar wind has been developed by E. Sittler and L. Guhathakurta (CUA). The model makes 2-D maps of velocity, effective temperature and effective heat flux. The model calculations are based on white light coronagraph observations from Skylab and SOHO and *in situ* plasma and magnetic field observations from Ulysses. This effort is supported under the SOHO Guest Investigator program. The model calculations applied to solar minimum conditions show the presence of a multipole field with the dominant term being the octupole term. The surface magnetic field strength over the poles is estimated to be 12–15 Gauss. Over the poles the flow accelerates quite fast near the Sun and there are significant non-radial terms at the boundary of the polar coronal hole. Over the poles the temperature is at a minimum near the Sun ($r < 2\ R_S$) while there is a large scale maximum over the poles farther from the Sun ($r \sim 7\ R_S$). The heat flux shows a maximum over the poles with $\sim 2 \times 10^5$ erg/cm^2/sec at the base of the corona. The model compares well with in situ observations at 1 AU. Improvements to the magnetic field model have been implemented by introducing multiple current sheets. This has improved our results near the Sun and close to the equatorial plane.

Heating the Solar Corona. One theory of coronal heating states that the plasma is not heated *in situ* at all. The apparent high temperatures result from a ''velocity filtration'' of non-thermal electron distributions in the transition region and below. This theory requires the formation of a non-Maxwellian electron distribution somewhere in the corona. A. Viñas, A. Klimas, and H.-K. Wong have investigated the role of low-frequency fluctuating electric fields in producing nonthermal coronal electron distributions. It is known that MHD waves can possess significant electric field components parallel to the background magnetic field in high β plasmas. Numerical simulations indicate that these fluctuating fields generate electron plasma oscillations and ion acoustic waves that then drive electron plasma turbulence. As the plasma waves are damped by the background electrons, non-Maxwellian suprathermal tails are formed. An alternative approach is being investigated by D. A. Roberts, M. Goldstein and S. Kainer using 1-D particle-in-cell simulations to determine whether small electric fields produced by the tendency of electrons to ''run away'' from ions can also generate non-Maxwellian electron distributions.

''Phase Mixing.'' Phase mixing by velocity shear generates sharp gradients that enhance the dissipation of Alfvén waves. The formation of these gradients produces a significant component of fluctuation wave vectors transverse to the shear. M. Ruderman (Russian Academy of Sciences), M. Goldstein, D. A. Roberts, A. Deane, and L. Ofman (GSFC, Code 682) found that a fully nonlinear, spherical MHD code based on the Flux-Corrected-Transport (FCT) algorithm reproduced the linear prediction that velocity shear will phase mix Alfvén waves and enhance their damping. As velocity shear refracts wave vectors from parallel propagating to oblique directions, the symmetry of magnetic fluctuations will evolve from transverse fluctuations having a ''slab'' symmetry to one that resembles the mixture of slab plus quasi-two-dimensional symmetry that has been observed. The relevance and importance of quasi-two-dimensional turbulence, in which both the wave numbers and the magnetic fluctuations are nearly orthogonal to the background magnetic field, to solar wind structure and evolution has been the subject of considerable discussion.

Two-Dimensional Turbulence. In related research, D. A. Roberts, M. Goldstein, A. Deane, and S. Ghosh studied quasi-two-dimensional MHD turbulence using three-dimensional simulations in which a two-dimensional state was held fixed at the inflow end of the box and the flow evolved with distance. Cartesian cases were found to evolve very similarly to the pure two-dimensional expectation, but spherical expansion led to a strong suppression of the nonlinear cascades, mainly due to the changing transverse time scales. These results suggest that an initial distribution of quasi-two-dimensional turbulence in the inner corona could not maintain highly Alfvénic correlations as it convects into the solar wind. The results also suggest that significant fraction of solar wind fluctuations observed to be comprised of wave numbers transverse to the local Parker magnetic field probably arises from velocity shear.

Alfvén Wave Interactions. S. Ghosh, D. A. Roberts, M. Goldstein and W. H. Matthaeus (Bartol Research Institute) conducted MHD spectral code simulation studies of the interaction of parallel-propagating Alfvén waves with pressure-balanced (PB) structures, velocity shears, and velocity microstreams. They found that refractive effects in the case of PB structures (fluctuations with vector components parallel to the mean magnetic field), and convection in the case of velocity shears, rapidly diverted parallel-propagating waves to turbulent Alfvénic fluctuations with highly oblique wave vectors. The magnetic variance ratios show a minimum variance in the mean magnetic field direction, although the wave vectors are primarily oblique. This work suggests that only a small fraction of solar wind observations with high velocity-magnetic field correlations may be due to field-aligned Alfvén waves.

Evolution of Solar Wind Turbulence. D. A. Roberts, M. Goldstein, and A. Deane using the FCT simulation code, have shown that turbulent cascades can occur in spherically expanding winds. The rate of cascade decreases as the rate of expansion increases. In the most rapidly expanding cases, no appreciable cascade occurs, although the original mode spectrum still relaxed to a -5/3 power law. These results will help to elucidate the role of turbulence in heating heliospheric plasmas and in assessing the importance of cascades in accelerating and heating the solar corona. The FCT code also confirmed the basic idea that velocity shear, especially when associated with magnetic shear, leads to strong evolution in the Alfvénicity of the initial population.

Evidence for a ''Vortex Street'' in the Outer Heliosphere. Further work with the same MHD code by D. A. Roberts, M. Goldstein, and E. Siregar, showed that the ''vortex street'' interpretation of regular oscillations in the heliospheric plasma in the outer heliosphere at solar minimum remains viable. One recent objection was that Kelvin-Helmholtz instabilities are suppressed by the supersonic velocity jumps observed, but nonlinear simulations show that although the flow becomes more turbulent, the interaction of nearby vortex layers still leads to the alternating flows, as observed.

Incorporating the Dissipation Range of MHD Turbulence into Numerical Simulations. The turbulent cascade of Alfvén waves leads, via cyclotron interactions, to anisotropic heating of protons. E. Siregar, A. Viñas, and M. Goldstein developed a model of a limited closure for parallel-propagating proton cyclotron waves using kinetic information from hybrid simulations. The simulations showed that coupling between resonant protons, nonresonant protons, and waves leads to strong anticorrelations in time (up to -0.99) between the parallel and perpendicular pressures when proper account was taken of nonlocal behavior in resonant interactions. A new nonadiabatic quasi-invariant was discovered for low-collisional cyclotron resonant wave-damping processes. The quasi-invariant predicted an inverse plasma dependence for the quasi-steady anisotropic state, as observed in simulations.

Wave Particle Interactions. Ulysses observations were used to explore a number of the wave particle interactions that occur in the heliosphere. R. Hess, R. MacDowall, and others presented ion-acoustic wave observations near interplanetary shocks, showing that the probability of wave occurrence is highly correlated with the ratio of electron to ion temperatures. N. Lin, P. Kellogg, R. MacDowall, and others also studied Ulysses VLF wave observations to understand the mechanisms that regulate electron heat flux. It is found that VLF electrostatic waves are enhanced during periods of reduced heat flux, suggesting that these waves are involved in heat flux regulation.

R. Hess and R. MacDowall studied the scattering of radio waves due to fluctuations in electron density in the interplanetary medium. Measurements were made of the apparent angular size of the source of Jovian narrow-band kilometric radiation using the URAP instrument on the Ulysses spacecraft. The results gave a large angular size, which approached 35° (half-angle) when Ulysses was approximately 1 AU from Jupiter. Since the geometric source size should be very small at that distance, scattering of the radio waves from density fluctuations in the interplanetary medium is presumed responsible for the large apparent size. These results were presented at a Chapman Conference in Paris.

Correlation of Interplanetary Structures. A study of the correlation between plasma measurements by SOHO at L1 and by WIND in its double lunar swingby orbit was carried out by a collaboration of K. Ogilvie, A. J. Lazarus (MIT) and M. Coplan (UMCP). The ranges of spacecraft separation are up to 240 R_E in the Xse direction, < 100 R_E in Yse, and < 20 R_E in the Zse direction. With time resolutions of 5 minutes and 96 seconds it has been possible to separate the advective delay of the solar wind from the corotational delay. Calculated correlation coefficients between fluxes, densities and velocities observed at the two spacecraft are often greater than 0.75, but clear intervals exists when this is not so. The corotational delay, if interpreted in terms of an angle of a corotating disturbance propagating radially, such fronts are frequently aligned at a smaller angle than the interplanetary magnetic field when the correlation coefficient exceeds 0.8. These studies are being extended to three dimensions.

Large Scale Curvature of Interplanetary Magnetic Field Structures. Using interplanetary magnetic field data from three spacecraft, WIND, IMP 8, and Geotail, M. Collier, A. Szabo, J. Slavin, and R. Lepping have determined the characteristic radius of curvature of interplanetary magnetic field structures. Results indicate that the typical radius of curvature is greater than 100 R_E with values frequently in the range of many hundreds of Earth radii. The investigators have proposed a two scale-length model for interplanetary magnetic field structures: one scale-length on the order of many tens of Earth radii representing structure coherency and another scale-length on the order of many hundreds of Earth radii representing large-scale structure geometry.

Global Models of the Solar Wind. Ulysses observations during the fast latitude scan in 1994–1995 showed that during that period of minimum solar activity, the heliosphere was nearly axisymmetric, steady, and was dominated by fast solar wind except for an equatorial band $\sim 40°$ wide. The fast flows in each hemisphere were relatively structure-free, unipolar and had opposite magnetic field polarities, resembling those of polar coronal holes. An important finding of

Ulysses was the observed lack of dependence on heliolatitude of the radial component of the heliospheric magnetic field in fast solar wind, implying the existence of a concentration of current in the heliospheric current sheet. A. Usmanov (Institute of Physics, St. Petersburg) and M. Goldstein used a steady-state global axisymmetric MHD model to reproduce quantitatively the Ulysses observations and, in particular, to account for the transformation of a dipolar magnetic field near the Sun into the configuration observed at large heliocentric distances.

The Heliospheric Current Sheet. The heliospheric current sheet (HCS), the largest coherent heliospheric structure, separates the two opposite polarity sectors of the heliosphere. A. Szabo, R. Lepping and D. Larson (University of California at Berkeley), studying multispacecraft observations of the HCS, found that many local field reversals are not marking actual crossings from one sector polarity to another. Moreover, some of these ''fake'' current sheet crossings are quite local in nature, smaller than some of the interspacecraft separations ($<$ 50 R_E). The generation mechanisms of these extreme magnetic field shears are not well understood but are suspected to be the remains of solar coronal dynamic activity.

Solar Radio Bursts. Considerable progress was made in the analysis of type II solar bursts and their correlation with CMEs including the first-ever encounter with a type II source region (Bale *et al.*, 1999). Much of the solar effort was aimed toward showing that often two shocks are associated with a CME, namely the shock driven by the CME and the blast wave shock associated with flares occurring during the CME. The driven shocks sometimes cause interplanetary type II radio bursts at decameter and longer wavelengths observed by the WAVES radio and plasma wave instrument onboard the WIND spacecraft. The blast wave shocks are associated with metric wavelength type II bursts observed by ground-based radio telescopes and these shocks rarely, if ever, propagate into interplanetary space (Gopalswamy *et al.*, 1999; Reiner and Kaiser, 1999; and Reiner *et al.*, 1999). Also, a very rare ''U'' burst associated with a CME was observed (Leblanc *et al.*, 1998).

G. Thejappa and R. MacDowall analyzed the wave activity associated with a local type III event, which shows evidence for near simultaneous occurrence of ion-acoustic, whistler, and Langmuir waves, suggesting the coexistence of weak and strong turbulence processes. G. Thejappa, M. Goldstein, R. MacDowall, K. Papadopoulos, and R. Stone presented evidence for Ulysses observations of Langmuir envelope solitons associated with solar type III bursts. Such observations confirm that strong turbulence processes are responsible for stabilizing the type III electron beam.

Magnetic Clouds during Solar Minimum. A summary of the properties of magnetic clouds based on a long term study of WIND events from launch to late 1998 has been prepared by R. Lepping, D. Berdichevsky, A. Szabo, L. Burlaga, and A. Lazarus (MIT). The cloud parameters are from the ongoing list of magnetic clouds and their model fitted values contained in the WIND/MFI Website. The study encompassed the magnetic cloud profiles of the field, density, bulk speed, proton thermal speed, proton plasma β, as well as various statistical properties, such as sizes, field strengths on the axes of the clouds, and vector quantities such as the attitude of the axes and spacecraft impact parameters.

Comparison of Magnetic Clouds: Solar Maximum vs. Solar Minimum. The characteristics of magnetic clouds, based primarily on force free model fitting, have been compared by D. Berdichevsky and R. Lepping for the active vs. quiet parts of the solar cycle. The data used is from the IMP 8 spacecraft in the years 1967–72 and 1978–82 for solar max. and mainly from WIND for solar min. for the years 1995 through 1998. Many quantities are being compared, but so far the cloud's axial field (Bo), the size in terms of the rope's diameter (Do), and the resulting estimated magnetic flux (F) have been examined, revealing that, as we go from solar min. to max, Bo shifts slightly to higher values and is more broadly distributed, similarly for Do, and even more dramatically so for F. Most prominent is the increase in the spread of the values (the standard deviations), compared to the averages, in this progression.

Examples of Fast Interplanetary Transients. D. Berdichevsky, I.G. Richardson (UMCP), B. Thompson, D. Reames, R. MacDowall, M. Kaiser, R. Lepping, K. Ogilvie, and R. Stone, with S. P. Plunkett, and D. J. Michels (NRL/DC) presented past and current ''Examples of fast solar wind transients, their sources and the forecast of possible geomagnetic activity'' at the fifth Latin-American conference of Geophysics in Costa Rica, November, 1998. The presented examples of transients at the Sun tracked to the Earth and explored similarities between these solar ejecta, including possible interplanetary magnetic clouds observed in 1982 during the decreasing part of the 21 solar cycle and in 1998 during the rising phase of the 23 solar cycle. The space-weather significance of the observations and the possibility to forecast these most disruptive occurrences of the geomagnetic environment were discussed.

Error Study in Magnetic Cloud Model Fitting: Effects of an Elliptical Cross-Section. The study of the errors expected for magnetic cloud model fit-parameters in terms of the level of the ''noise'' in the cloud's magnetic field has been continued by R. Lepping, D. Berdichevsky, and A. Szabo. The study uses a force free flux rope of cylindrical shape as applied to WIND magnetic field data. The new part of the study entails simulating various magnetic clouds with elliptical cross-sections and subsequently fitting them by a simple earlier model, developed for the circular cross-section, and then examining the difference between the ''observations'' (simulations) and the model results. Preliminary results, from a small number of cases (about 10) indicate that deviation from a circular cross-section is very slight. If this slight deviation is real, and more cases will be needed to prove it, the short axis of the ellipse is approximately in the ecliptic plane. This may indicate that some flux ropes may be squeezed from back to front in the ecliptic plane, which is what one would expect, if there were any compression of external plasma on the magnetic cloud as it plows through the solar wind and/or occasionally experiences stream compression at the rear. Difference fields between the two kinds of simulated clouds, circular vs. elliptical cross-sectional cases, were generated and put on the WIND/MFI's Website to describe the differences in their profiles.

Reconnection Remnants Inside a Magnetic Cloud. Using data from WIND/MFI, WIND/SWE, WIND/3DP, and WIND/Mass, M. Collier, W. Farrell, A. Szabo, J. Slavin, R. Lepping, R. Fitzenreiter, and L. Ofman in collaboration with other investigators have assembled observations of an unusual ''shock in formation'' inside the 18–20 October 1995 magnetic cloud. The investigators interpret the particle and field observations as resulting from the footpoints of the magnetic cloud reconnecting at low altitude, between 2 and 5 solar radii.

Discovery of a Dual-Axial Polarity Flux Rope-Magnetic Cloud. An unusual interplanetary magnetic cloud observed by WIND on February 4 and 5, 1998 has been shown by R. Lepping, D. Berdichevsky, A. Szabo, and L. Burlaga to be a magnetic flux rope with one axial field polarity in an inner region (called the ''core'') just outside of which (in an ''annular'' region) is an opposite axial field polarity. This overall field structure satisfies the model of a cylindrically symmetric linear force free flux rope, as most solar wind magnetic clouds do, but has this peculiar aspect of this dual axial polarity. It also had a relatively large diameter of about 0.3 AU. All other observed magnetic clouds have a single axial polarity. The linear force free formulation, generally used for studying these interplanetary magnetic clouds, had always allowed for this complex structure, but there were physical reasons to restrict the analysis interval to a smaller radial value, i.e., to where the axial field goes to zero. In this peculiar case the symmetric profile allowed a significantly larger cross-section than the standard one, and it still satisfied the same mathematical formulation; hence, it allowed for a more complex flux rope structure, suggesting an extraordinary solar birth condition.

Electrons in Magnetic Clouds. Voyager electron plasma observations inside of 5 AU were analyzed by E. Sittler and L. Burlaga under the support of the Heliospheric Structure and Dynamics program. This work has resulted in a paper on electron thermal properties within magnetic clouds. Future plans include the study of their properties for CMEs in general.

Small Flux Ropes Discovered in the Solar Wind. Small-scale magnetic flux ropes have been discovered in the solar wind data at 1 AU based on WIND and IMP 8 observations by M. Moldwin, R. Lepping, J. Slavin, and A. Szabo. These small-scale structures (average diameter of 270 R_E) have some similar properties to interplanetary magnetic clouds, but are much smaller and have much shorter durations of 10s of minutes, as compared to large fractions of a day or more for clouds. Also they have typical proton temperatures distinctly lower than the average temperatures for clouds. The small flux ropes have been very successfully fitted with the same force free model used for the magnetic clouds, with usually even better success for fitting the magnitude of the field.

Interplanetary Shocks During the First 2.5 Years of WIND. A comprehensive list of interplanetary shocks covering the first 2.5 years of the WIND mission has been compiled by D. Berdichevsky, A. Szabo, R. Lepping, A.-F. Viñas and F. Mariani (University of Rome). The shocks were analyzed using two independent techniques (various coplanarity methods vs. the more modern Rankine-Hugoniot least-squares fitting method), and the results compared including shock surface normals, shock speeds and Mach numbers. For most events there was surprisingly good agreement between the methods. The shocks were separated according to those driven by transients or those by quasi-periodic structures and some not determined to be either. The statistical analysis of the orientations of the shock normals suggests that interplanetary shocks would in general have an orientation of propagation in longitude from almost nearly eastward to close to normal to a tightly winding Parker spiral. The winding angle of this Parker spiral would be $\sim 36°$, close to the theoretically derived value at 1 AU.

Interplanetary Shock Geometry. Using WIND and ACE observations of the same interplanetary (IP) shocks A. Szabo, in collaboration with C. W. Smith (Bartol), and R. Tokar and R. Skoug (LANL), has demonstrated that non-negligible deviations between the corresponding shock normals exist. It is suggested that the IP shock surfaces have deformations on the scale of 10s of R_E.

The Outer Heliosphere. Merged interactions were identified in both Voyager 1 (V1) and Voyager 2 (V2) data by L. Burlaga in the period of calendar day 260–315. The magnetic polarities at V1 were uniformly positive, indicating that it was above the sector zone in the northern hemisphere. The polarities at V2 were mixed, indicating that V2 was within the sector zone. The different polarity distributions observed by V1 and V2 indicate that they were observing separate Merged Interaction Regions (MIRs) rather than two parts of a single Global Merged Interaction Region. The MIRs did not cause a net modulation effect, but they did sweep up and act as barriers to low energy particle.

The propagation of shocks in the distant heliosphere, where the pressure of pickup protons greatly exceeds the pressure of the magnetic field and solar wind, was investigated in a series of papers by L. Burlaga. Shocks become weaker between approximately 30 AU and the termination shock by $\approx 20\%$. When an interplanetary shock interacts with the termination shock both shocks become weaker. The termination shock moves toward and away from the Sun roughly in phase with the solar cycle. All of these shock related effects were evaluated quantitatively using Voyager data as inputs.

5. SPACE SCIENCE MISSIONS: OPERATIONAL

5.1 IMP 8

Magnetic Field Investigation (MAG). The fall of 1999 marks the 26th anniversary of IMP 8's operation in orbit. This spacecraft has provided useful fields and particles data over that lifetime, and it continues in its role as an important participant in the ISTP program. It still functions as upstream solar wind monitor, along with ACE and WIND, especially when it has a very favorable position, and increasingly it acts as a source of useful magnetospheric data, especially magnetotail data. Because of its longevity, IMP 8 has contributed valuable data to solar, solar wind, magnetospheric, and cosmic ray physics for over a complete solar cycle (i.e., 22 years), and is unique in that regard. IMP 8's role has been enhanced by assuming a partnership with many other spacecraft by helping to form various positional constellations with them for ISTP correlative studies. The magnetometer team (R. Lepping, P.I.) continues to develop the MAG's Website, which provides IMP 8 magnetic field data in a useful form to the public, as well as a description of the investigation. A major effort is underway to produce very high resolution IMP 8 magnetic field data for the entire mission. Other on-campus co-investigators are A. Szabo and J. Slavin and an off campus co-investigator is N. Ness, at Bartol Research Institute at the Univ. of Delaware.

5.2 Voyagers 1 and 2

Magnetic Fields Investigation. The magnetometers on Voyagers 1 and 2 continue to function as designed and return data from unexplored regions of the distant heliosphere en route to the termination shock and heliosheath. Voyager 1 is now beyond 72 AU at a latitude of $\sim$ 33°N while Voyager 2 is approaching 57 AU at a latitude of $\sim$ 20°S. L. Burlaga is responsible for the reduction of the data and is active in the analysis of these data.

5.3 Ulysses

URAPS and SWICS. The Ulysses spacecraft is now in the second orbit of its exploration of the high-latitude heliosphere. In 1999, the spacecraft was well on its way to a second overflight of the southern solar pole. With the approach of solar maximum, it is expected that the high latitude heliosphere will appear more similar to that at low latitudes than was the case for the first Ulysses orbit. The GSFC contributions to Ulysses include involvement with two of its instruments: the Unified Radio and Plasma Wave investigation (URAP) and the Solar Wind Ion Composition Spectrometer (SWICS). URAP co-investigators in the LEP are M. Desch, J. Fainberg, M. Goldstein, M. Kaiser, R. MacDowall (Principal Investigator), M. Reiner, and R. Stone (PI Emeritus); K. Ogilvie is a co-investigator on the SWICS team.

5.4 GEOTAIL

Project Status. The Geotail spacecraft continues to provide excellent data from its 9 x 30 R_E equatorial orbit as it begins its eighth year of operation. Although lack of onboard fuel precludes any further orbit changes to avoid the low temperatures associated with long apogee eclipses, Geotail survived a four-hour eclipse last February that was twice as long as the spacecraft was designed to withstand. After an equally long eclipse next year the eclipses will become shorter. Much Geotail data is now available via the web, particularly CPI plasma data from the solar wind detector and LEP plasma data from both the solar wind and energetic plasma detector. The later data along with the MGF magnetic field data is available via the Japanese DARTS system. Within the last year problems with the MGF experiment have necessitated placing the outboard sensor permanently in the 64 nT range, but this should not have a serious impact on the mission science.

Geotail continues to advance knowledge of basic magnetospheric issues such as the entry and redistribution of energy and particles in the magnetotail. Several studies comparing high velocity flows and auroral images have revealed a close correspondence between these phenomena. The flows are rather localized and studies of simultaneous measurements with Interball and WIND in the tail continue to help determine the relevant scales. Most Geotail studies support reconnection as the important mechanism producing substorms, but the role of the inner magnetosphere remains controversial. Particle beams are seen flowing down the tail in the lobe/mantle region. Sometimes ionospheric oxygen and helium are observed that have apparently been accelerated by the same energy. Other ions seem to enter the tail directly across the tail boundary.

5.5 WIND

Project Status. The WIND spacecraft completed its first series of high-inclination petal orbits on April 1, 1999. From 1–15 April, WIND executed a backflip maneuver that took the spacecraft, with the assistance of two close lunar flybys, from the nightside to the dayside of Earth, rotating the orbit line of apsides by 180°. Although this maneuver was known to be theoretically possible, WIND was the first spacecraft ever to execute a backflip. WIND's current planned trajectory design, which takes it through 2002, includes low-inclination petals, dayside double-lunar swingby orbits, and several Earth-return trajectories that will take the spacecraft out to about 275 R_E above the dawn and dusk terminators of Earth. The eight instruments on WIND continue to function normally and are returning excellent data from the solar wind and magnetosphere. Details of the overall WIND program through 2000 are described by Desch *et al.* (1999). K. Ogilvie is the Project Scientist and M. Desch is the Deputy Project Scientist for WIND.

Magnetic Fields Investigation (MFI). The WIND MFI magnetometer system continues to operate nominally, its data significantly contributes to many space science studies around the world (much of which is conveniently obtained directly on line as key parameter or in-house produced data), and the MFI team often collaborates directly in many of these studies. The MFI investigation's Website has been augmented over the last year, especially in the areas of magnetic clouds and the magnetotail. MFI's Website contains an extensive bibliography of over 110 items (almost all of which are in refereed journals), which continues to grow rapidly baring witness to the value of the MFI data and the industry of the team. Plans continue to produce the highest resolution magnetic field data on a production basis. The LEP members of the MFI team are M. Acuña, L. Burlaga, M. Collier, W. Farrell, R. Kennon, R. Lepping (P.I), J. Scheifele, J. Slavin, A. Szabo, and E. Worley; there are five off campus members also.

Solar Wind Experiment (SWE). The WIND Solar Wind Experiment (SWE) continues to operate successfully, yielding Key Parameters for the solar wind, and electron moment quantities at 6-sec time resolution. The P.I. is K. Ogilvie.

5.6 FAST

Project Status. NASA's FAST satellite continues to acquire excellent data and provides an exciting new look on acceleration processes at the interface of the hot, magnetospheric plasma and the cool, ionospheric plasma. Several major discoveries have already been reported by the FAST science team. Instruments on FAST include fast energetic electron and ion spectrometers, vector DC and AC electric and magnetic field detectors, and an energetic ion composition instrument. The principal investigator for FAST is C. W. Carlson (Univ. of California at Berkeley). R. Pfaff of the LEP is the NASA Project Scientist for the FAST mission.

5.7 POLAR

Project Status. Polar operations, especially in conjunction with ground-based facilities, continue to provide valuable data pertaining to the passage of energy from the solar wind through the polar magnetosphere. Comprehensive particles and fields observations are acquired in the high-latitude magnetosphere, low altitude polar magnetosphere and during trajectories through the radiation belts. Multispectral images of the aurora are obtained at latitudes over the polar regions. The line of apogees is slowly precessing towards the equator at a rate of about 16° per year, with apogee at the end of FY99 at about 50°. Twice each year the spin axis of the satellite is inverted for thermal and power reasons. Sufficient fuel remains on-board to continue the maneuvers until spring of 2002. No significant instrument or spacecraft anomalies of a permanent nature occurred during the past year. On August 2, the ground stations lost telemetry from the satellite for a number of hours. The problem manifested itself in the inability of the spacecraft to respond to normal ground commands. Evaluation of spacecraft and instrument telemetry showed that main power had not been interrupted to spacecraft subsystems or instruments. However, normal operation of the despun platform was interrupted, and the clock was reset to 1995. Instruments were brought back into normal operations after several days with no apparent permanent effect. The cause of the anomaly is being investigated, but at this point cannot be related to solar activity. Other spacecraft experienced anomalous operations at about the same time. This fall the spacecraft will experience long eclipse periods. Attempts will be made to obtain data from the Plasma Wave Instrument, which failed in September 1997 due to a low voltage power supply malfunction, by cooling the instrument during the eclipses and operating immediately following exit. Previously indications were received that the power supply, when very cold, may be able to increase its voltage output sufficiently to operate the low rate processor that operates the Multichannel Analyzer and the Step Frequency Receiver.

Thermal Ion Dynamics Experiment-Plasma Source Instrument (TIDE-PSI). B. Giles and T. Moore noticed that a very clearly-observed solar coronal mass ejection event produced a sympathetic ionospheric mass ejection from the Earth. The mass flux from the Earth increased by over two orders of magnitude in this event. Placing this result in the context of long term statistical observations extending back to the solar maximum in 1981, they found that it is the fluctuations in intensity of the solar wind that appear to control ionospheric outflows. Current theories suggest that the orientation of the interplanetary magnetic field should be more important, but this was found to have negligible observational effect on ionospheric outflow flux. This work involved extensive collaboration with investigators on other ISTP spacecraft and is continuing through the next solar maximum period in a few years.

Polar Electric Field Instrument (EFI). The payload of POLAR includes the first vector electric field instrument to be flown in the Earth's magnetosphere. In-depth studies undertaken by LEP scientists continue investigating electric fields in the cusp. The principal investigator of EFI is F. Mozer (University of California at Berkeley). At the LEP, the electric field team consists of R. Pfaff and M. Hesse.

5.8 Galileo

Radio Science. F. Flasar and P. Schinder have continued their analysis of Jupiter's ionosphere from radio occultations that occurred during the orbital tour. The Galileo mission thus far has provided 15 usable occultation entry and exit soundings, far more than from all previous spacecraft missions combined. The individual retrieved profiles of electron density attest to an active and heterogeneous ionosphere. Several of the profiles exhibit a series of sharp peaks at altitudes below 750 km (above the 1-bar level) that may be indicative of forcing by internal gravity waves, propagating upward from lower in the atmosphere. The dispersion relation of gravity waves links the vertical wavelength, horizontal phase velocity relative to the horizontal winds, and the vertical gradient in temperature. The vertical wavelengths implied by separation of the electron density peaks, together with knowledge of the vertical profile of temperature from Galileo probe measurements, can thus serve as a probe of the horizontal winds in Jupiter's ionosphere, where they are virtually unconstrained at present.

5.9 Cassini

Composite InfraRed Spectrometer (CIRS). V. Kunde (PI), J. Brasunas, G. Bjoraker, F. Flasar, D. Jennings, J. Pearl, P. Romani, R. Samuelson, R. Achterberg, and M. Smith have been active in monitoring the CIRS instrument operation on the spacecraft, and in planning the science observations of Saturn, its rings, and its satellites, including Titan, during the 75-orbit, 4-year tour that begins in July, 2004. CIRS is a Fourier-transform spectrometer that measures radiances in the thermal infrared between 10 cm^{-1} and 1400 cm^{-1} (1 mm and 7 μm) with a spectral resolution up to 0.5 cm^{-1}. A spacecraft-wide instrument checkout in January, 1999 indicated that the instrument is operating well, and preparations are underway for a second checkout, beginning in the summer of 2000. CIRS is currently ''closed up tight,'' in that both the covers of the telescope and of the passive cooler for its mid-infrared detector arrays are in place. These will be ejected over the coming year, with the cooler cover ejecting in April 2000, and the telescope cover later, in early October. The passage by Jupiter at the end of 2000 presents the opportunity of observing that planetary system, providing a more thorough checkout of the Cassini orbiter instruments and the acquisition of some unique measurements of scientific value.

Radio and Plasma Wave Experiment (RPWS). With the RPWS team lead by D. Gurnett (University of Iowa), LEP investigators M. Kaiser, M. Desch, and W. Farrell have been involved in the search for lightning on Venus using the VLF and HF receivers. Presentations from the RPWS team have been made regarding this search. LEP team members are also using the RPWS to examine planetary emissions from Jupiter.

Radio Science. The first instrument checkout also went well for the radio science experiment, which uses the spacecraft's high-gain antenna and the ground receiving stations to transmit monochromatic radiation at the S- (13 cm), X- (3.6 cm) and Ka (1 cm) bands to study atmospheric and ionospheric structure, the structure of Saturn's rings, the gravity fields of Saturn and its satellites, and general relativistic phenomena. During the first checkout, the spacecraft pointing was limited, using only thrusters for attitude control, so the tests for the Ka band, which has the narrowest beamwidth (2 mrad) were relatively crude. These will be repeated during the second checkout in the summer of 2000, when the spacecraft will operate on reaction wheels and have more accurate attitude control. F. Flasar has been active in planning radio occultations of Titan's atmosphere. The occultations will provide the only capability of retrieving atmospheric temperatures in the lowest 30 km of Titan's atmosphere by the orbiter instruments, and the science team has been working with mission planners to ensure that there is a good latitude distribution of occultations on Titan.

Plasma Spectrometer (CAPS). E. Sittler has been leading the effort at GSFC as co-investigator for the Cassini Plasma Spectrometer (CAPS). The LEP team has delivered flight software for the second processor (CPU2) of the Data Processing Unit (DPU) and the Spectrum Analyzer Module (SAM). This software effort primarily supports the operation of the Ion Mass Spectrometer (IMS). SAM, that deconvolves the time-of-flight mass spectra of the IMS, was developed at GSFC. The team has also supported checkout (ICO-1) and is now preparing for Earth swingby. E. Sittler has been collaborating with R. Hartle on the interaction with Titan with special emphasis on pickup ions and what CAPS would see. Here a model is being developed of the interaction and following the trajectories of pickup ions in the complex electric and magnetic fields of the interaction. The model is not self-consistent but is rather guided by *in situ* observations of the interaction. Presently Voyager 1 observations are used as a guide with anticipation of improvement once Cassini gets to Saturn.

5.10 NEAR

X-Ray/Gamma Ray Investigation (XGRS). The NEAR x-ray/gamma-ray team led by J. Trombka (includes team members: S. Squyers (Cornell U.), W. Boyuton (U. of Arizona), J. Bruckner (Max Planck Inst.); participating scientists: J. Arnold (U. of Cal. San Diego), L. Evans (CSC), R. Reedy (Los Alamos Nat. Lab), P. Gorenstein (Harvard Smithsonian), and K. Hurley (UCLA)), working with P. Clark, S. Floyd, T. McClanahan, R. Starr, L. Nittler, and D. Nava, is involved in the operation of the NEAR XGRS and system during the cruise and orbital phases of the mission. Instrument operations were verified. Observations of solar spectra during high activity periods have been obtained. These spectra show both continuum and discrete line calcium and iron emissions. Information on gamma-ray detector activation due to cosmic rays has been obtained. XGRS has been included in the Inter-Planetary Network (IPN) for the detection of Gamma-Ray Bursts (GRB). The IPN now incorporates GRB information from NEAR, Ulysses, Compton-GRO, GGS-WIND, and Konus. The precision of the timing of the NEAR XGRS GRB detection system has been determined by using the detection of the GRB-associated optical transient GRB 990510. The arrival time at Eros is now February 2000. The XGRS data acquisition, management, and analysis are now ready to handle to thousands of spectra that are expected to be measured in orbit around Eros. These observations will be used to obtain elemental composition maps of the surface of Eros. These mapped compositions will be compared to known meteorite compositions in order to ascertain whether Eros has the characteristics of any of these meteorite types. These maps will also be of importance in determining the nature of formation and evolution of the Eros.

Magnetic Fields Experiment (MFE). The NEAR spacecraft is expected to arrive at Eros 433 in February 2000, and will remain in orbit around the asteroid for 1 year. The rendezvous was delayed because of a failed rendezvous burn maneuver on December 20, 1998. The mission was recovered and a successful rendezvous burn maneuver was accomplished on January 3,1999. This spacecraft is instrumented with a Magnetic Field Experiment that was developed jointly by GSFC and JHU/APL with scientific participation by UCLA-IGPP. The team leader is an LEP scientist, M. Acuña. Magnetic field measurements will be crucial in providing data about the nature of the interior of Eros.

5.11 Mars Global Surveyor

Magnetometer-Electron Reflectometer Investigation (MAG/ER). The Mars Global Surveyor spacecraft, in its final mapping orbit since April 1999, is instrumented with a magnetometer and electron spectrometer designed to make accurate measurements of the magnetic fields and plasmas in the near Mars environment. The investigation is a collaborative effort with major hardware responsibilities shared by GSFC, the University of California at Berkeley, and the University of Toulouse. The principal investigator is M. Acuña of the LEP. He is supported by two other in-house co-investigators, J. E. P. Connerney and P. Wasilewski in addition to the team members at the other participating institutions. Vector magnetic field observations of the Martian crust were acquired by MAG/ER during the aerobreaking and science phasing orbits, at altitudes between ~ 100 and 200 km. Magnetic field sources of multiple sources, strength, and geometry were observed. There is a correlation between the location of the sources and the ancient cratered terrain of the Martian highlands. The absence of crustal magnetism near large impact basins such as Hellas and Argyre implies cessation of internal dynamo action during the early Naochian epoch (4 billion years ago). Sources with equivalent magnetic moments as large as 1.3×10^{17} Am^2 in the Terra Sirenum region contribute to the development of an asymmetrical, time-variable obstacle to solar wind flow around Mars.

J. E. P. Connerney and coworkers also found that Martian crustal magnetization is frequently organized in east-west-trending linear features, the longest extending over 2000 km. Crustal remanent magnetization exceeds that of terrestrial crust by more than an order of magnitude. Groups of quasi-parallel linear features of alternating magnetic polarity were found. They are reminiscent of similar magnetic features associated with sea floor spreading and crustal genesis on Earth but with a much larger spatial scale. They may be a relic of an era of plate tectonics on Mars.

Radio Science. F. Flasar, with D. Hinson (Stanford University), has analyzed the vertical profiles of temperature that have been retrieved from the first 88 occultation soundings of the Martian atmosphere, covering latitudes 29° N to 64° S. The profiles exhibit undulations that indicate the presence of vertically propagating waves. This wavelike behavior is most pronounced in regions of ''interesting'' topography, such as the Tharsis region, suggesting a topographical forcing. Several of the temperature profiles, particularly within 30° of the equator, exhibit lapse rates in temperature that are locally superadiabatic approximately 30 km above the surface. This implies that the waves are ''breaking'' and depositing momentum into the atmosphere. Such deposition may play an important role in modulating the atmospheric winds on Mars, and characterizing the spatial and temporal distribution of these momentum transfers can provide important clues to understanding how its global circulation is maintained.

Thermal Emission Spectrometer (TES). Investigations of J. Pearl, W. Maguire and coworkers of the Martian atmosphere continue. They are based on data obtained by the Mars Global Surveyor/Thermal Emission Spectrometer (MGS/TES). The Mapping Mission of the Mars Global Surveyor began in April 1999, with the spacecraft in a 2AM-2PM sun synchronous, nearly polar orbit. Excellent datasets yielding the planetary vertical temperature field to 4 scale heights, and the vertical distribution of ice and dust have been obtained from the Thermal Emission Spectrometer experiment. P. Christensen (Arizona State Univ.) is the TES Principal Investigator and J. Pearl is a co-investigator. In collaboration with J. Pearl, P. Christensen, B. Conrath, K. Horrocks, M. Kaelberer, M. Smith, R. Thompson and E. Winter, W. Maguire is working with the extensive database (generated since MGS arrival at Mars in September 1997) of nadir- and limb-viewing TES spectra to characterize selected Martian minor gaseous atmospheric constituents. In related work, he has made preliminary estimates of the uncertainty in the retrieved temperature profile due to uncertainties in the 15 μm CO_2 band absorption coefficients. The temperature profile derived from TES data is the starting point for analyzing atmosphere and surface properties using the observed IR spectra.

5.12 ACE

Magnetic Fields Experiment. ACE was successfully launched in August 1997. L. Burlaga is a co-investigator on the magnetic field experiment. M. Acuña built the magnetometer at GSFC, and the experiment is managed by N. Ness at Bartol Research Institute, with the support of members of his institution.

5.13 Lunar Prospector

Magnetometer-Electron Reflectometer Investigation (MAG-ER). The Lunar Prospector has been circling the Moon at an altitude of about 30 kilometers (19 miles), gathering geological data through its array of instruments. For July 31, 1999, one last dramatic experiment was planned: a controlled crash into a permanently shadowed crater in the hope of liberating a water vapor plume that could be viewed from Earth and establish definitively that water ice exists on the lunar surface. The impact energy was high, equivalent to a 4000 lb car crash at 1,100mph. The hope is that the crash would liberate perhaps 40 lbs. of water vapor that may be detected by ground- and space-based observatories. A positive spectral detection of water vapor or its photo-dissociated byproduct, OH, would give definite proof of the presence of water ice in the regolith. The Lunar Prospector Magnetometer-Electron Reflectometer (MAG-ER) Investigation was a joint venture between the LEP, the University of California at Berkeley and the University of Toulouse. MAG-ER results provided support for the Apollo-era hypothesis that many crustal regions of magnetization are associated with large impact features.

5.14 SWAS

Project Status. After a successful launch in December 1998, SWAS has proceeded to undertake its primary objective of mapping dense molecular cloud cores in the submillimeter emission lines of H_2O, O_2, ^{13}CO, and atomic carbon, providing the first glimpse of important chemical processes and cooling needed to initiate the early stages of star formation. The PI for SWAS is G. Melnick (Smithsonian Astrophysical Observatory). G. Chin is the SWAS Project Scientist.

5.15 ISTP Science Planning and Operations Facility (SPOF)

Project Status. The ISTP Program, since 1992, has been providing simultaneous coordinated scientific measurements from many of the key areas of Geospace. The ISTP Central Data Handling Facility (CDHF) and the associated Science Planning and Operations Facility (SPOF) provide the space physics community and the public with a set of integrated science products and associated tools to enable the planning and conduct of solar-terrestrial physics. The data activities and ground system are under the direction of the ISTP Project Scientist for Data Systems, W. Mish, a member of the LEP. The set of products produced spans real-time and non real-time telemetry, orbit, attitude, and science products called Key Parameters (KPs) from a number of spacecraft and ground-based instruments. This data set is continuously updated with the most recent measurements and is available to the community both electronically and on CD-ROM in standard formats. Contributing data are four different ground-based investigations, instrumentation from multiple geostationary spacecraft (LANL and GOES), Geotail, WIND, POLAR, SOHO, IMP 8, FAST, SAMPEX, Equator-S, Interball Aurora and Tail, ACE and the soon to be launched Cluster II mission. This Key Parameter scientific data base is now well over 100 Gbytes in size.

The ISTP SPOF provides products and science planning tools that range from generic Key Parameter display software, spacecraft ephemeris, field models, long and short range science plans, customized trajectory and KP summary plots for individual spacecraft, to a catalog of preliminary solar wind events, science coordination and public outreach - there products and tools are available electronically through the CDHF and through the extensive ISTP Web site (http://www-istp.gsfc.nasa.gov).

5.16 ISTP Theory

Project Status. Global MHD simulations of the terrestrial magnetosphere continue to play the leading role in unifying the observations of the ISTP spacecraft in a global context. The continuing success of the global MHD codes in providing a detailed description of the global magnetospheric dynamics underlies the great strength of global self consistent simulations as opposed to more local simulations which attempt to put a part of the magnetosphere in a box and have difficulty owing to dynamic boundary conditions in comparing to data. A major finding of these studies is that although the simulations do not capture the correct microscale (non-MHD) physics, the self-consistency on global scales yields what, by comparison with data, are realistic global dynamics. Major efforts by the research groups this year have focused on the simulation of the magnetosphere at very low solar wind densities. A major continuing topic has been the assimilation of spacecraft and ground-based observations into the codes inner (ionospheric/atmospheric) boundary conditions. A major concern is the availability of adequate funds to make full use of these demonstrated capabilities. S. Curtis is the Project Scientist.

5.17 ISTP Ground-based Experiments

Project Status. ISTP has no spacecraft instrumentation to sample the final link in the solar terrestrial chain (the upper atmosphere and ionosphere) save for the remote imagers on POLAR. There are however ground-based experiments that provide valuable information in this low altitude region. The experiments consist principally of incoherent and incoherent radars. They have provided complementary data for the POLAR spacecraft, as well as perhaps more importantly quantitative polar ionospheric convection patterns to compare with those of the global MHD simulations of the magnetosphere. All sites remain operational, however some will require refurbishment owing to extreme climate conditions in the near future. S. Curtis is the Project Scientist.

6. SPACE SCIENCE MISSIONS: DEVELOPMENTAL

6.1 Cluster-II

Magnetic Fields Investigation. Cluster-II will be the first flight of 4 spacecraft in a controlled formation for the purposes of making coordinated magnetospheric particles and fields measurements. Central to achieving the scientific objectives of this mission is the magnetic fields investigation lead by P.I. A. Balogh (Imperial College). The flight hardware for this investigation was designed and fabricated at several institutions with LEP providing the magnetometer sensors and analogue electronics. M. Acuña, D. Fairfield and J. Slavin are co-investigators and will participate in the data analysis effort. While flying in their baseline tetrahedron, the magnetic field measurements will be used to calculate the ‘‘curl’’ of the field and infer the electric current passing though their formation. The magnetic field measurements from the 4 spacecraft can also be used to synthesize a ‘‘wave telescope’’ for the detection and characterization of low-frequency waves. The NASA Project Scientist for Cluster-II is LEP scientist, M. Goldstein.

6.2 Triana

Solar Wind Plasma and Magnetic Field Investigation (PlasMag). The Triana Earth imaging mission will include a combined high-time resolution magnetometer and plasma instrument to study the solar wind and to provide real-time space weather data. K. Ogilvie is the P.I. of the development team and the lead for the electron electrostatic analyzer. A. J. Lazarus (MIT) is the lead for the Faraday Cup and M. Acuña for the magnetometer. A. Szabo is responsible for the ground data system. Triana is expected to be launched on a Space Shuttle mission early in 2001.

6.3 New Millenium Program ST-5/Nanosatellite Constellation Trailblazer

Project Status. NASA Headquarters has selected the Nanosatellite Constellation Trailblazer (NCT) to be its fifth Space Test Mission, ST-5. NCT will consist of three small, $\sim$ 20 kg, satellites which will be launched into geosynchronous transfer orbit in 2003. They will provide flight validation for 8 new technologies and 2 science instruments critical for the future deployment and operation of constellations of ‘‘nanosatellites’’ (i.e., spacecraft weighing $\sim$ 10 kg) for the Sun-Earth Connection and Solar System Exploration Themes as well as Earth Sciences. Furthermore, NCT will test deployment and operations strategies essential for these future ‘‘constellation-class’’ missions. The Solar Terrestrial Probes/Magnetotail Constellation mission is intended to be NCT’s primary technology infusion recipient. Magnetotail Constellation will build, deploy and operate $\sim$ 100 nanosatellites in the Earth’s magnetotail late in the next decade to determine the nature and origins of geomagnetic storms and substorms. J. Slavin is the NCT Project Scientist.

6.4 Pluto Fast Flyby and EO-1

LEISA Development. D. Reuter, D. Jennings and G. McCabe are developing infrared spectral imagers based on the

LEISA (Linear Etalon Imaging Spectral Array) concept. This development is a collaboration with members of the Engineering Directorate. LEISA represents a completely new concept in spectrometer design made possible by large-format detectors and advances in thin-film technology. Originally developed for the Pluto Fast-Flyby Mission (PFF) under the Advanced Technology Insertion Program, LEISA uses a state-of-the art filter (a linear variable etalon, LVE) in conjunction with a detector array to obtain spectral images. The major innovation of LEISA is its focal plane that is formed by placing a LVE in very close proximity to a two-dimensional detector array. The LVE is a wedged dielectric film etalon whose transmission wavelength varies along one dimension. In operation, a two-dimensional spatial image is formed on the array, with varying spectral information in one of the dimensions. The image is formed by an external optic. Each spatial point is scanned in wavelength across the array, thereby creating a two-dimensional spectral map.

The LEISA/Atmospheric Corrector (LAC) is on the New Millennium Program Earth Orbiter 1 (EO-1) mission to be launched in December of 1999. The primary purpose of this atmospheric experiment is to correct the high spatial resolution, low spectral resolution Landsat-type multispectral images for the spatially and temporally variable effects of the atmosphere. In addition to these satellite programs LEISA was flown in an aircraft in the summers of 1997, 1998 and 1999 as part of the instrument complement in an agricultural sensor program. The program was part of a Space Act Agreement with Boeing Commercial Space Company. The airborne LEISA instrument was also flown in South Africa in March of 1999 as part of the ARREX program.

6.5 Mars Surveyor/01

Project Status. A re-flight of a Mars remote sensing gamma-ray spectrometer will be accomplished during the Mars Surveyor 2001 mission. The spacecraft is planned for launch in March 2001 and arrival at Mars in December 2001. The principal investigator is W. Boynton (University of Arizona) and the co-investigators at the LEP are J. Trombka, L. Evans (CSC) and R. Starr (CUA). The Ge detector is being supplied by URSYS in France. A. D. Little is supplying the passive cooler. The analogue electronics are being designed and built at GSFC (Code 660). The digital electronics are being designed and built at the University of Arizona where flight system integration and test will take place. Calibration of the detector system will be a joint responsibility of the University of Arizona and GSFC. Prototype models have been constructed and are under test. The flight systems are now being constructed.

6.6 IMAGE

Project Status. T. Moore continued to serve as mission scientist as the Imager for Magnetopause to Aurora Global Exploration (IMAGE) mission progressed through instrument deliveries and observatory environmental testing this year. The IMAGE spacecraft is currently in storage awaiting a Feb. 2000 launch. An active theory and modeling effort continues in support of the analysis and quantitative physical interpretation of the images to be obtained from IMAGE. T. Moore has been participating in this effort in collaboration with B. Giles, J. Green (Code 630), M.-C. Fok, D. L. Gallagher (NASA/MSFC), G. Wilson (MRC, Nashua, NH) and J. Perez (Auburn Univ.).

Low Energy Neutral Atom Imager (LENA). As lead coinvestigator, T. Moore led the completion, calibration, and delivery of the Low Energy Neutral Atom imager (LENA). Science support for LENA included M. Collier, K. Ogilvie, F. Herrero, J. Keller, and B. Giles. Engineering support included S. Gray (Code 660) as resource analyst, J. Lobell as systems engineer, J. Johnson as software engineer, P. Rozmarynowski as mechanical designer, and F. Hunsaker as mechanical engineer and fabrication coordinator. The LENA team was also supported by J. Laudadio (Code 700) as instrument manager, and by a number of code 300, 500 and 700 engineering staff members. LENA was calibrated in Feb. 1999, and delivered to the spacecraft in March 1999. A paper describing LENA and its calibration was accepted in June 1999.

Magnetospheric Radio Sounding. The Radio Plasma Imager (RPI) has been integrated into the IMAGE satellite which is scheduled for launch on 15 February 2000. The RPI (Instrument PI: B. Reinisch, U. Mass., Lowell) is one of a complement of remote sensing instruments on IMAGE (Mission PI: J. L. Burch/Southwest Research Institute). R. Benson is a member of the RPI team and has participated in the preparation of several papers concerning magnetospheric radio sounding, with the RPI team, for a Special Issue of Space Science Reviews dedicated to the IMAGE mission.

6.7 MESSENGER

Project Status. A Discovery proposal for a Mercury orbiter mission called MESSENGER has been selected by NASA Headquarters for development. The purpose of this mission is to collect global information on the surface, interior, exosphere and magnetosphere of this least explored of the terrestrial planets. The principal investigator is S. Solomon of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The lead institution for the spacecraft and mission operations will be the Johns Hopkins Univ. Applied Physics Laboratory. LEP scientists will be responsible for the vector magnetometer and the geochemistry package. The LEP co-investigators on the MESSENGER team are M. Acuña, J. Slavin and J. Trombka. MESSENGER will launch in 2004 and go into orbit about Mercury in 2009 following two earlier fly-by encounters.

6.8 GEC

Project Status. The Science and Technology Definition Team for the Geospace Electrodynamics Connections Mission (GEC) is in the final phase of writing the mission definition report. The theme of GEC is ''To discover the important temporal and spatial scales for electromagnetic energy coupling and dissipation in the magnetosphere-thermosphere-ionosphere (MTI) system.'' The mission consists of 4 identical spacecraft carrying a full complement of plasma and neutral particle detectors each carrying hundreds of kilogram of propulsion fuel. All four spacecraft will be initially placed, like pearls-on-a-string, in 200 x 2000 km high inclination parking orbits, but will use their propulsion capability to dip below 130 km and to change orbital parameters so that all the important coupling spatial and temporal scales in the MTI can be resolved. The Project Scientist for GEC is J. Grebowsky.

6.9 IMEX

Project Status. The Inner Magnetosphere Explorer (IMEX), a University-Class Explorer (UNEX), is designed to investigate the physical processes that rapidly accelerate charged particles in the inner magnetosphere to very high energies during major geomagnetic storms. Its complement of four major experiments based on pre-existing designs includes field instruments, a fluxgate magnetometer, 3-D plasma instrumentation, and high-energy particle detectors. Currently, the IMEX team is completing its Phase A, Concept Study, and obtaining a launch endorsement from the USAF for a Titan-IVb/DSP mission launch in mid 2002. The team is also investigating other launch options. The Project Scientist for IMEX is M. Collier.

6.10 The Community Coordinated Modeling Center (CCMC)

Project Status. The Community Coordinated Modeling Center (CCMC), a research and development facility aims at research in support of the generation of advanced space weather models. New and improved space research models will be created by combining models and modules covering different spatial regions and different physical parameters. Models and modules will be developed largely in the scientific community, but also at the CCMC GSFC facility itself (directed by M. Hesse). The ultimate goal of the CCMC is the generation of one or more comprehensive space weather models, which cover as completely as possible the entire range from the solar corona to the Earth's upper atmosphere. Models that have been developed and successfully applied to scientific test problems are to be transitioned to the Rapid Prototyping Centers of NOAA and the Air Force, for operational testing. These models will also be made source code available to the scientific community, to support the ''open model policy,'' and for the CCMC effort to remain nonexclusive.

7. SOUNDING ROCKETS AND SUBORBITAL PROGRAMS

Program Status. A member of the LEP staff R. Pfaff is the Project Scientist for NASA's Sounding Rocket program. NASA's Sounding Rocket Program provides a cost effective, rapid means to carry out unique scientific experiments in space, as well as to test new flight instrumentation. Sounding rockets provide the only platforms with which scientists can carry out direct *in situ* measurements of the mesosphere and lower ionosphere/thermosphere region (40-120 km) that is too low to be sampled by satellite-borne probes. Furthermore, they provide quick access to high altitudes where astronomy, planetary, and solar observations can be made of radiation at wavelengths absorbed by the atmosphere of Earth, including emissions from objects close to the Sun (e.g., comets, Venus, Mercury) that are precluded from observation by large, orbiting telescopes such as the Hubble and EUVE. Sounding rockets also provide an extremely high quality, low ''g-jitter'' environment, ideal for a variety of microgravity experiments.

Unique features of sounding rockets include their ability to gather data along vertical trajectories, their low vehicle speeds (compared to satellites) with long dwell times at apogee, their ability to easily support multiple payload clusters and tethers, the ability to launch rockets into geophysical ''targets'' (e.g., thunderstorms, aurora, cusp, equatorial electrojet, etc.) when conditions are optimum, including operations at remote launch sites, the recovery and reflight of instruments and payloads, and the acceptance of a greater degree of risk which helps maintain the low cost aspect of the program.

In addition to science and technology, sounding rockets also provide invaluable tools for education and training. Over 350 Ph.D.'s have been awarded to date as part of NASA's sounding rocket program. Missions are selected each year based on peer-reviewed proposals selected by various science discipline offices at NASA Headquarters.

DROPPS Campaign. A new program, DROPPS (The Distribution and Role of Particles in the Polar Summer Mesosphere) involving rockets, radars and lidars was launched in July, 1999 from Andøy, Norway in collaboration with the European MIDAS Program. DROPPS consisted of two Black Brant rocket flights plus an array of Meteorological rockets by F. Schmidlin of the GSFC/Wallops Flight Facility. The Black Brant payloads consisted of detectors designed to measure the mass distribution of submicroscopic particles in both a charged and neutral state (Taylor Univ. and Univ. of Chicago), sensors to measure 3-D AC and DC electric fields (GSFC and the Univ. of Washington), Gerdien and blunt probes (Penn State Univ.) to measure the plasma environment, radio propagation experiments to measure absolute electron density (Technical Univ. of Graz, Austria), and photometers (Univ. of Stockholm, Sweden) to detect the presence and thickness of noctilucent clouds (NLCs). The flights were also coordinated with ground based lidar and radar measurements at Andøy (ALOMAR Observatory) and the EISCAT Radar Observatory at Tromsø, Norway. Co-Is from five U.S. and four European Laboratories and Universities participated in the study.

DROPPS is a focused, international rocket, radar, and lidar program designed to study the mass distribution of dust and aerosol particles in the high-latitude summer mesosphere, the electrodynamic environment, and their complex relationship with polar mesospheric summer echoes (PMSEs) and NLCs. To meet this objective, the first rocket sequence was launched into a strong PMSE (polar mesospheric summer echo) display with a weak NLC also present. The second sequence, launched one week later, passed through a strong NLC with no PMSEs present. This successful program is expected to evaluate the importance of submicroscopic particles to induce the PMSEs first seen by 50 MHz radars about 20 years ago, and provide direct information about the role of electric fields in the observed processes. The P.I. is R. Goldberg of the LEP.

As a co-investigator, R. Pfaff prepared and flew electric field instrumentation to measure both the DC and wave electric field environment within the altitude region of 80-90 km where these effects were observed to be most prevalent. Since there is very little plasma present at these altitudes, the double probe technique requires additional considerations in order to ensure that accurate measurements would be obtained there.

Sporadic-E Experiment in Conjunction with the University of Illinois VHF Backscatter Radar. In order to investigate the complex electrodynamics and neutral-plasma coupling inherent to sporadic-E layers in the Earth's midlatitude ionosphere, a series of rocket/radar experiments were conducted at the Wallops Flight Facility, Wallops Island, VA. R. Pfaff was the P.I. of these rockets and the lead scientist for the DC and AC electric field experiments. The rocket experiments consisted of two pairs of ''mother-daughter'' payloads with limited apogees so that the payloads ''hovered'' in the sporadic-E region (95–125 km). Each payload pair included vector DC and AC electric field detectors, a highly accurate flux-gate DC magnetometer, an ionization gauge, and spaced-electric field receivers to measure the wavelength and phase velocity of the unstable plasma waves. One payload also included an ion mass spectrometer from the University of Texas at Dallas. Other rockets were included to simultaneously carry aloft TMA trails to measure the neutral wind and its velocity shear, believed responsible for the sporadic-E layer formation. In addition to the rocket experiments, continuous VHF backscatter radar operations were carried out from a site at Ft. Macon, NC, where 3-m backscatter echoes were observed associated with sporadic-E and other types of low-altitude ionospheric layers. On 4 July 1999, one of the instrumented rockets was launched alongwith one TMA rocket, the former attaining an apogee of 119 km. The payloads successfully pierced an intense sporadic-E layer observed by the radar, digisonde, and the in situ density and ion mass spectrometer probes. In situ DC electric fields revealed very low ($\sim$ 1–2 mV/m) ambient fields with small amplitude structures of the same order. However, no strong wave modes (10 mV/m) and large wind shears were detected.

APEX. The LEP provided a suite of vector DC and wave electric field, DC magnetic field, and thermal plasma instruments that were flown on a sounding rocket experiment in the high-latitude ionosphere, as part of the Active Plasma Experiment (APEX). R. Pfaff leads GSFC's science contributions. NASA/Wallops Flight Facility was primarily building the payloads.

APEX is a joint project involving the Johns Hopkins University Applied Physics Laboratory and the Russian Academy of Sciences Institute for the Dynamics of Geospheres. The science objectives include understanding the electrodynamic interactions between a burst of neutral gas undergoing ionization that is released near 400 km altitude and about 1 km away from the instrumented payload, as well as parametrizing the geophysical plasma conditions in which the release is conducted. To this end, measurements of DC and AC electric fields, field-aligned currents, Alfvén waves, plasma density and temperature, spacecraft potential, and higher frequency plasma waves are essential. When the data gathered from the instruments described herein are analyzed in conjunction with the onboard photometer, energetic particle, and other measurements, our understanding of the spatial and temporal structure inherent to the partially ionized beam in space will be enhanced by a large degree. The launch of the APEX payload occurred during January 1999 from Poker Flat, Alaska.

GEODESIC. The GEODESIC mission is designed to uncover the microphysical processes that govern the interaction between cool, dense ionospheric plasma and magnetospheric energy sources, hot tenuous plasma, and plasma waves. The project is funded by the Canadian Space Agency and is the initiative of Prof. Dave Knudsen (Univ. of Calgary). R. Pfaff is a co-investigator on this payload.

Under R. Pfaff's supervision, instrumentation is being prepared that will measure the DC and AC vector electric field using the double-probe technique. In this case, spherical sensors with embedded pre-amps will be extended on booms in the spin plane. Since the payload spin axis will be oriented along the magnetic field direction, the two-dimensional electric field measurement will completely parametrize the DC and AC electric fields perpendicular to the magnetic field vector, B, expected to be encountered during this experiment. A third axis, along the payload axis, will measure the parallel component. Instrumentation will also be included to carry out multiple baseline measurements of wavelength and phase velocity, as well as onboard FFT's of plasma waves up to several MHz. The launch is scheduled for January 2000 from Poker Flat, AK.

Electrodynamics Research From a Remotely Piloted Aircraft. LEP Investigators R. Goldberg, J. Houser, W. Farrell, M. Desch and S. Cummer, along with scientists from Penn State and NASA/MSFC, are planning to investigate transient and steady-state electrical currents above thunderstorms using instrumentation on board unmanned aeronautical vehicles (UAVs). The General Atomic UAV, ALTUS, has a potential altitude capability in excess of 60,000 feet and can easily carry electric and magnetic sensors for determining the nature of the upward-directed currents during both quiescent and active periods directly over an active thundercell. By teaming with a small company, IDEA, an electromagnetic payload is in development to make such measurements and will be flown on test flights for the first time during the Spring 2000 from El Mirage, CA, primarily to gain insight on the EMI environment aboard the aircraft.

It is planned to follow the above test flights with flights in an electromagnetically active environment by summer 2000, particularly to measure electrodynamic quantities in the vicinity of thunderstorms. The recent high interest in upward lightning caused by the discovery of red sprites and blue jets provides the first direct evidence that there is a strong AC component of current contributed to the global electric circuit by such processes. The UAV provides an ideal platform from which to measure the necessary parameters to determine the importance of this energy input to the circuit by measuring the required parameters in an in situ environment.

8. FUTURE MISSIONS

Radiation and Technology Demonstration (RTD) Project. S. Curtis is the Project Scientist for RTD Project, a joint effort between the Glenn, Johnson, and Goddard NASA Field Centers. This spacecraft that is funded by the NASA HEDS (Human Exploration and Development of Space) Office has several principal objectives: the demonstration of advanced large scale (10 kW) ion propulsion engines, the characterization of the local spacecraft environment modifications owing to ion propulsion, the characterization of the cosmic ray environment, and the mapping of the radiation belts using 8 nanospacecraft to be launched from the ion propelled mothership. Goddard will focus on the radiation belt mapping by the nanospacecraft that has the potential for revolutionizing our understanding of the radiation belt structure and dynamics with direct applications to both manned spaceflight and commercial satellites. The mission has had a preliminary design study this year. Next year the Technology and Science Definition Team, which is chaired by the Project Scientist, will begin to refine the science and technology objectives. Launch is projected for 2004.

REE. JPL's Remote Exploration and Experiment (REE) program is aimed at examining the ramifications of on-board super computing capabilities for the next generation of spacecraft (2002+). S. Curtis has been a Principal Investigator in REE for the past two years and during that time has examined the computational requirements for both in situ and remote sensing instruments for future space physics missions. In particular, on-board moment calculations for plasma detectors and on-board radio image synthesis have been shown to reduce data volumes by more than three orders of magnitude and to hence open the door for much greater autonomy. Algorithms to perform these functions are presently being tested on the REE testbed facility at JPL. In the next several years, the role of supercomputing in enhancing autonomy through intelligent spacecraft subsystems will be examined.

8.1 Solar Terrestrial Probes

The Magnetotail Constellation Draco Mission. T. Moore assumed the role of mission study scientist for this exciting new mission being planned as part of the Sun Earth Connections Solar Terrestrial Probes program. A science and technology definition team was selected and appointed in cooperation with NASA HQ in March 1999. It will hold five meetings during FY99, and will issue a report on the status of this mission by the end of FY99, under the leadership of chair H. Spence (Boston University). There has been strong interaction with the SEC Roadmap process, with the refinement of the original ''Magnetospheric Constellation'' mission into a specific Magnetotail ''Dynamics, Reconnection And Configuration Observatories'' (DRACO) mission. A follow-on mission was also defined for the future roadmap, the Inner Magnetosphere Constellation, whose main objective would be the study of magnetospheric storm development and its relationship to auroral substorm activity.

Magnetospheric Multiscale (MMS) Mission. S. Curtis is the Project Scientist for the MMS mission whose objective is to study the underlying physics of the magnetosphere on micro and mesoscales using a complete set of plasma measurements (AC and DC electric and magnetic fields, complete high time resolution ion and electron distribution functions), during a voyage through the magnetosphere consisting of four distinct orbital phases from latitudes to high latitudes and from near earth to deep space. Fundamental physics questions, of relevance to all astrophysical plasmas, involving reconnection, particle acceleration, and turbulence will be addressed. The 5 spacecraft mission will maintain a tetrahedron formed by 4 spacecraft in the regions of scientific interest. The fifth spacecraft will be centered in the tetrahedron. This geometry will allow not only the unique space time separation of directly measured quantities, but also derived quantities such as the current density from the curl of the magnetic field. The spacecraft separations will vary from less than 10 to more than 10,000 km. using active propulsion. The spacecraft will be highly autonomous, intercommunicating, and self-ranging. The Science Technology Definition Team has completed its work and will soon issue its report. Preliminary designs of the spacecraft have been made and a Request for Information has gotten 7 responses from potential industrial partners, one of whom will be selected competitively to build the spacecraft. The MMS mission is the second multi-platform Solar Terrestrial Probe Mission. Launch is projected for 2006. A very strong interaction between MMS results, the future development of global magnetospheric simulation codes and space weather predictability is expected.

8.2 Frontier Mission

Interstellar Probe. NASA's Interstellar probe will be the first spacecraft designed to explore the nearby interstellar medium and its interaction with our solar system. Its unique trajectory from Earth to $\sim$ 200 AU in $\sim$ 15 years will enable the first comprehensive measurements of plasma, neutral atoms, magnetic fields, dust, energetic particles, cosmic rays and infrared emission from the outer solar system, through the boundaries of the heliosphere and on into the interstellar medium. The Integrated Science and Technology Definition Team has established the primary science objectives of this mission along with the resulting mission requirements and minimum scientific instrumentation. The principal scientific objectives of this mission are: 1. Explore the nature of the interstellar medium and its implications for the origin and evolution of matter in our Galaxy and the Universe. 2. Explore the influence of the interstellar medium on the solar system, its dynamics, and its evolution. 3. Explore the impact of the solar system on the interstellar medium as an example of the interaction of a stellar system with its environment. 4. Explore the outer solar system in search of clues to its origin, and to the nature of other planetary systems. A. Szabo is a member of the ISTDT.

8.3 MIDEX

Auroral Lites Mission. The Auroral Lites (AL) mission, a joint venture with Sweden government, is planned to be a 5 spacecraft mission in an elliptical polar orbit. The spacecraft will uniquely separate space and time not only for direct measurements such as magnetic and electric fields, but also current densities through a unique configuration that can generate 4 effective tetrahedra using 5 spacecraft. The tetrahedra size will be controlled by on-board propulsion and will be capable of typical separations ranging from 500 meters to greater than 100 km. Complete measurements of fields and particles will be made together with multispectral stereo auroral imaging of the aurora. There is also a global, international ground-based segment that will provide context measurements for the microscale AL in situ measurements. Theory tools on all scales, ranging from simulated aurora using global MHD codes to kinetic simulations of microscale processes will be included. AL will reveal the dynamical processes underlying the filamentary plasmas of the terrestrial auroral zone and, by extension, an entire class of astrophysical plasmas that are not directly measurable. The Principal Investigator is S. Curtis.

8.4 Discovery

VESPER. The VEnus Sounder for Planetary ExploRation (VESPER) is a proposed Discovery Mission. The mission was selected as one of five finalists by NASA HQ to proceed to a Concept Study.

The VESPER mission will provide the first comprehensive and synoptic study of Venus with sufficient sensitivity and duration to test major models of the dynamics, chemistry and circulation throughout the Venus atmosphere. The VESPER Orbiter employs a state-of-the-art heterodyne spectrometer originally developed for astrophysical study of interstellar clouds. The primary instrument is a heterodyne receiver, the Submillimeter Limb Sounder (SLS), whose extremely high gas constituent sensitivity and high spectral resolution allows the detection of trace gases while simultaneously measuring wind velocities above the clouds. The Deep Atmosphere Spectral Camera (DASC) will make measurements below the clouds to the surface with spectral and spatial images of upwelling thermal emission taken from 1.0 to 2.5 μm. A two-color Near UltraViolet Imager (NUVI) will track the dynamics of the upper cloud deck. X-band radio occultation using the spacecraft transponder will attain high spatial resolution temperature profiles covering a wide range of Venus latitudes and local hours.

VESPER Principal Investigator is G. Chin of GSFC. The science team is comprised of investigators from the University of Arizona, Cal Tech, University of Cologne, Cornell University, GSFC, JPL, University of Massachusetts, Space Science Institute, SUNY Stony Brook, University of Virginia, and Washington University. Lockheed Martin Astronautics in Denver, CO will develop the spacecraft and perform mission operations. GSFC will manage the project and develop the VESPER instrument suite.

Mercury Express Mission. The Mercury Express (MEX) mission is a faster, better, cheaper precursor mission to Mercury. The mission takes only slightly more than one year to execute and reaches Mercury 115 days after launch. The three platform mission would determine the internal field of Mercury far better than any single orbiter. It would image the entire surface of Mercury for the first time while performing a global survey of its chemical composition. MEX will also provide the best survey of the ion composition and electric field structure of the Mercury magnetosphere in the near future and also yield detailed gravity moments of the planet. It has an enormous data volume of nearly 100 Gbits and uses its highly eccentric orbit to deliver that data volume to Earth. Taken together, MEX would provide an excellent foundation for future orbiters by completing the initial survey of Mercury and allowing the future orbiters to do what they do best: conduct detailed surveys. If MEX were launched in 2006, its mission would be complete in 2007. The Principal Investigator is S. Curtis.

9. INSTRUMENT DEVELOPMENT

HIPWAC. F. Schmuelling (NRC) has taken the lead in optomechanical design of the new Heterodyne Instrument for Planetary Wind And Composition (HIPWAC), an effort led by T. Kostiuk and D. Buhl, with T. Livengood, K. Fast, and T. Hewagama, and J. Goldstein (Challenger Ctr.). Design support and CAD drafting has been provided by P. Rozmarynowski and F. Hunsaker. The final design is near completion with fabrication to begin in Fall 1999. HIPWAC is an advanced infrared heterodyne spectrometer (IRHS) for the measurement of molecular lineshapes and the wind-driven Doppler shifts of molecular lines formed in low-pressure, high altitude, regions of planetary atmospheres. The instrument will be transportable to the Cassegrain or Nasmyth focus of large telescopes, providing improved sensitivity and operational capability over the current Coudé focus IRHS, permanently mounted at the NASA IRTF. Improved performance will derive from implementation of new technologies and from the characteristics of large (8-10m) telescopes accessible to a transportable instrument: (1) factor of $\sim$ 10 improvement in sensitivity on small targets compared to the present instrument on a 3m telescope; (2) improved spatial discrimination; (3) reduced velocity broadening due to the range of Doppler shifts from planetary rotation across the diffraction-limited FOV, increasing effective spectral resolution; (4) improved system quantum efficiency compared to current components; (5) improved frequency determination due to all factors but especially improved telescope tracking at the Cassegrain or Nasmyth foci vs. Coudé focus; (6) flexible access to available telescopes; and (7) access to different latitudes from which to observe. A prototype laser cavity for the CO_2 laser local oscillator has been constructed using advanced composite materials by K. Segal and P. Blake (Code 548.2). The instrument optical bench will be constructed similarly, in order to conserve weight and to achieve superior stiffness and resistance to thermal expansion or contraction on a scale of order 0.001% under variable thermal loads. A flight-spare acousto-optic spectrometer from the SWAS satellite is on loan from the University of Köln to experiment with improved back-end electronics to fully modernize the heterodyne spectroscopy system.

Planetary Bolometers. J. Brasunas, in concert with B. Lakew and R. Fettig, has continued the development of moderately cooled infrared bolometers based on thin-films of high temperature superconductor material (YBCO). Recent efforts have succeeded in reducing the sapphire membrane material to 8 μm thickness, to improve speed of response. Also successful was the attempt to replace 17 μm diameter gold-wire leads with 10 μm diameter gold wire, utilizing a welding technique instead of the conventional gold-wire bonding. The thinner wire enables better thermal isolation, improving sensitivity. In addition to the bolometer work, J. Brasunas is pursuing development of very broad-band (ultraviolet to millimeter wavelengths) beamsplitters based on free-standing, grown films of CVD (chemical vapor deposition) diamond. By combining the bolometer and the CVD beasmplitter, the goal is to produce for future planetary and earth missions a smaller, lighter version of the CIRS spectrometer on the Cassini mission.

Efforts to micro-machine sapphire are making progress. With excellent thermal properties, micro-machined sapphire can be used to fabricate highly sensitive YBCO based bolometer arrays. These would be ideal for long term, moderately cooled (90 Kelvin) planetary instruments. B. Lakew, J. Brasunas, I. Aslam, M. Cushman (both with Raytheon/ITSS) and R. Fettig are involved in this effort.

Instrument for Line Integral Measurements of Electron Distributions. A team led by M. Collier and including J. Keller, F. Herrero, P. Rozmarynowski and D. Chornay as well as participants outside Goddard is building a laboratory prototype of an electron spectrometer which obtains the electron velocity distribution in space plasmas using a two-dimensional tomographic method. The advantages of this design over previous techniques used to measure electron distributions include: (1) simplicity – the instrument eliminates hardware complexity instead relying on well-established but computationally intensive, mathematical techniques to deconvolve the data. (2) passivity – there are no stepping voltages or look angles. The instrument acquires all angles and all energies all the time. (3) inexpensive and robust – the simple design makes this instrument the ideal candidate for multi-spacecraft missions where many copies of a single instrument will be required. (4) versatility – the deconvolution technique employed may be tailored to fit the end: simple methods for browse or KP data and much more sophisticated methods for specific event data.

Planetary X-Ray/Gamma-Ray Remote Sensing. Remote sensing gamma-ray spectrometers aboard either orbital or flyby spacecraft can be used to measure line emissions in the energy region $\sim$ 100 keV to $\sim$ 10 MeV. These elemental characteristic excitations can be attributed to a number of processes such as natural radioactivity, and cosmic ray primary and secondary induced activity. Determination of the composition of O, Si, Fe, Mg, Ti, H, Ca, K, Th, and U can be expected. Global elemental composition maps can be obtained using such spectrometer systems. This is a PIDDP funded program. The P.I. is J. Trombka.

A number of factors have to be considered in the development X-ray and gamma-ray remote sensing spectrometers for use on future planetary exploration missions. These factors can be derived from the constraints imposed by the requirements of such programs as Discovery. This program requires low cost and short times between program initiation and spacecraft launch. The flight instruments must be significantly reduced in weight from those previously flown (e.g. Apollo, Mars Observer, and NEAR).

Large Area X-Ray Detectors. From the calculations of solar induced x-ray emission from planetary surfaces, detector areas of 25 cm^2 or greater are needed for K-shell x-ray planetary remote sensing systems in order to obtain the best spatial resolution. Proportional counters have been developed and flown on space flight missions successfully, but the energy resolution is very poor and cannot resolve, for example, the Mg, Al, and Si lines. The room temperature solid state detectors themselves are lighter than the equivalent proportional counter systems. They are being developed by J. Trombka and S. Floyd in collaboration with C. Stahle (Code 553), R. Starr (CUA) and C. Tull (Photo-Imaging Co.).

Lander Gamma-Ray Spectrometer. Elemental analysis by gamma-ray spectroscopy involves the detection of characteristic gamma-rays emitted by the decay of naturally radioactive elements, by means of cosmic ray primary and secondary excitation, or by the use of a machine or radioactive neutron excitation source. This project will develop a gamma-ray spectrometer and neutron detection system that weighs less than 2 kg for use on rover missions.

Solar Probe Plasma Instrument. E. Sittler leads a GSFC effort on Solar Probe to develop a capability of nadir viewing of the solar wind at distances as close as 4 solar radii from the Sun. The problem of energy input to the spacecraft from an electrostatic mirror system was largely solved with a miniature heat shield. The properties of high voltages at high temperatures were studied and found to pose no problems. Presently a prototype of the mirror system with an ion spectrometer is being built.

Development of IR-VIS-UV Optical Components Produced by Micro- and Nano-Technology. R. Fettig, in collaboration with people from Code 693, 685, 553 (DDL), 551 and the University of Maryland at College Park, worked on several projects applying micro- and nano-structures to astronomy relevant subjects:

Gold Black Deposition Facility And High Temperature Superconducting Bolometers. For the deposition of gold black, a fractal conglomeration of nano-particles, a facility is maintained and further developed by R. Fettig in collaboration with J. Brasunas, B. Lakew and M. Cushmann. Gold black can be used as an absorber of low heat capacity for radiation from visible wavelength all the way through the infrared, into the submillimeter range. It is applied on HTS bolometers. The same team has also performed work to improve the electrical contacts to high temperature superconducting bolometers by means of focused ion beam milling and ion induced metal organic chemical vapor deposition.

Microshutters. R. Fettig, in collaboration with H. Moseley, A. Kutyrev, M. Jhabvala, J. Orloff (UMCP) and K. Edinger (UMCP), developed arrays of shutters for spatially resolved spectroscopy applications. Shutters of 100 micrometer opening are developed which can be arranged to form large ($>$ 1kx1k) arrays where the single shutters can be individually addressed. Rapid prototyping is done by focused ion beam milling and testing with electron-microscope compatible methods.

Nanohole Filters. R. Fettig, in collaboration with J. Orloff and K. Edinger (UMCP), developed UV-transmissive filters with a sharp cutoff for visible light. Densely packed arrays of holes of the size of the cutoff wavelength are produced applying nano-technology methods in thin foils. Such filters will allow the use of large CCD arrays for UV applications.

Mars Lander Camera. The NASA Mars Instrument Development Program (MIDP) has approved a brassboard demonstration lander camera for Mars surface composition/mineralogy studies. The P.I. is D. Glenar. AImS, (for acousto-optic imaging spectrometer) is now in its second year of development. The camera is electronically programmable and will provide high spatial and spectral resolution imaging within its 0.50 to 2.3 μm tuning range. This development activity is a logical extension of previous activities under the PIDDP and SBIR awards and is on a timeline to be proposed for consideration in the Mars 2005 Lander opportunity, or future Mars Micromissions.

AOTF Light Source. An AOTF light source has been designed and breadboarded by Dave Glenar and lab team as part of the Champollion Infrared Comet Lander Experiment (CIRCLE), in collaboration with R.Yelle (P.I., Boston U.) and JPL. CIRCLE was a payload instrument in the recently cancelled New Millenium ST-4 mission to Comet Temple I. However, this breadboard will be being completed with the balance of FY'99 funds and delivered to JPL for demonstration of the overall instrument operation.

Electric Field Experiment Group. The LEP electric field experimental group, led by R. Pfaff, designs and builds electric field double probes for flights on sounding rockets and satellites in the Earth's ionosphere. Onboard processing electronics have been developed to gather burst memory data of significant flight events and onboard FFT processing that extend the measured frequency regime of electric field waves to several MHz.

Dust Detection via Contact Electrification. LEP personnel W. Farrell, J. Houser, S. Cummer and M. Desch are developing a sensitive charged dust detector that will be capable of measuring charge levels of a few 100 electrons per grain. The system is more sensitive than electrometers. This instrument was recently proposed for an upcoming Mars mission.

10. EDUCATIONAL OUTREACH AND TECHNOLOGY TRANSFER

The Spectrum of the Star Spangled Banner. J. Hillman and coworkers have used their near-IR AOTF Camera to explore the near-IR reflection spectrum of the Star Spangled Banner Flag while it hung on the wall at the National Museum of American History. This activity is one phase of the 3-year Preservation Program for this historical artifact. They generated a mosaic of 72 image-cubes (20-25 images deep in wavelength) of the entire surface of the flag at a spatial resolution of approximately 0.2 inches/pixel. They are currently using false color techniques and band-depth maps to visualize the various states of the Flag, pre-restoration. The Team consisted of J. Hillman and D. Glenar, N. J. Chanover (Department of Astronomy, New Mexico State University), W. E. Blass (Department of Physics, University of Tennessee) and J. Goldstein (Challenger Center for Space Science Education).

The results of this research are expected to include the non-invasive estimation and image maps of the Flag in absorption bands corresponding to residual non-polar stain levels (over entire surface), moisture content over entire surface (2.09 μm water band), state of oxidation, the characterization of dyes used from spectral differences. These data will provide an archival data set for placing the current state of the flag into an historical context. Even if we don't completely understand the data now ''We'' may do this again in 100 years. These data may provide a baseline for the characterization of the state of this artifact.

For public outreach, the use of space exploration technology as part of the restoration effort has successfully made the connection between American History and Space Science. As part of NASA's effort to bring the thrill and excitement of Space Science to the public, we participated in a NASM Family Science Night presentation on the 2005 Mars Mission, which may be using the same AOTF camera technology.

Duplicating Eratosthenes's Measurement. P. Romani visited several schools and attended a teachers' workshop in Massachusetts as a wrap up to a project to duplicate Eratosthenes's measurement of the circumference of the Earth that was funded by an IDEAS grant. The project was also the subject of a presentation at the National Science Teachers Conference. He worked with teachers and their students at Glenarden Woods Elementary School in Glenarden, Maryland. The students studied ancient China in a yearlong thematic unit that involved language arts, social studies, and art. To this program a week-long unit on rockets, in honor of the Chinese discovery of gunpowder, was added. The students learned about the numerous ''firsts'' in rocketry that the ancient Chinese accomplished (multiple rocket launchers, multi-stage rockets, etc.) and worked on several hands-on rocket projects that cumulated with students building and launching their own model rockets. He also did a presentation at career day Martin Luther King Middle School in Beltsville, Maryland.

''From Stargazers to Starships'' An extensive course at the high-school level (also non-calculus undergraduate), titled ''From Stargazers to Starships,'' has been written by D. Stern and is on the web at http://www-spof.gsfc.nasa.gov/stargaze/Sintro.htm. It covers (at about equal length) elementary astronomy, Newtonian mechanics and spaceflight, in about 70 web files with many illustrations; a new 7-unit section on the Sun has been recently added and is being expanded. The course follows a historical threads and incorporates many space-related applications.

This material is currently tried out in Wilde Lake High School, Columbia Md. (by Glenn Bock) and at Lower Cape may HS (by Jerry Roth). Its ideas are described in ''Using Space to teach Physics'' in The Physics Teacher, February 1999. In addition to the above it includes a 12-section math course, guidance to the teacher, 35 lesson plans (more in preparation), a cross-linked glossary, timelines, problems (solutions sent by mail to requesting teachers), a Q&A section and more. Hits are currently around 130,000/month and a Spanish translation by J. Mendez in Spain is underway; the sections on astronomy and Newtonian mechanics have all been translated and are on the web.

National Institute of Justice/NASA GSFC Program. A memo of understanding has been signed between the National Institute of Justice and NASA to develop instruments and communication networks that have application in both NASA's space program and in NIJ programs with state and local forensic laboratories. These systems would be connected to central crime laboratories so forensic experts can view crime scenes remotely and help direct the investigation at these sites in real time. The approach taken in this program will be based on the remote sensing and *in situ* systems developed by NASA for planetary space exploration. Field testing these systems can contribute significantly to the verification and development of such exploration methods for future planetary missions. The first year of the project will involve the use of a number of already developed prototype detector systems including both hardware and software to demonstrate the principals of this approach. The feasibility demonstration will concentrate on the detection of gunpowder residue at crime scenes. The P.I. is J. Trombka. Also involved are S. Floyd and T. McClanahan.

NEAR Mission Outreach Program. Since the launch of the NEAR mission in February 1996, the XGRS staff has been involved in many Education and Public Outreach activities. J. Trombka and coworkers have made presentations to numerous teacher and student groups that have been at Goddard attending various conferences and workshops. These have included the annual Lunar Sample/Meteorite Education Conference, the MathCounts Workshop, and NEWMAST (NASA Education Workshop for Mathematics, Science and Technology Teachers) program. A number of students from Madeira HS, E. Roosevelt HS, Hebrew Academy of Greater Washington and Jewish Day school have been introduced to planetary science and have assisted in the development of XRGS data reduction package. L. Evans, Pam Solomon, Pamela Clark and Sister Mary Ellen Murphy have played a major role in these outreach activities.

Outreach to Schools. In May, Pamela Clark participated in the VITS (Videoconferencing Interaction for Teaching Science) program sponsored by the Educational Outreach office at Goddard. This was the first videoconference in this pilot interactive outreach program for high school students. Clark and two other women scientists representing other parts of Goddard participated in an hour long question and answer session on the nature and manner in which NASA scientists do their work. The program received rave reviews from student, faculty, administrators, and the local media.

N. Fox and A. Szabo participated in the ''Live From The Sun'' program, a live presentation of Sun-Earth connection research at Goddard broadcasted on public TV channels. Students watching in their classrooms the description of various research results could ask questions from the participating scientists on the air. Phone lines were also kept open two hours after the presentation. Based on the highly positive feedback from students and teachers, a follow-on program is planned.

Development of Lesson Plans. Working with two Madeira High School students, Merritt Johnson and Lisa deGorter, Evans and Solomon supervised the preparation of two lesson plans designed for middle school teachers for posting on the WWW. The lesson plans, developed by a previous year's Teacher Intern Martha West, use NEAR Mission science to teach about meteorites and asteroids. The lesson plans were placed on the NEAR-XGRS web site (http://leptpm.gsfc.nasa.gov/near.html) and are linked to the NEAR mission website at the Applied Physics Laboratory.

In May, L. Evans and P. Solomon led a class of middle school teachers through the lesson plan on meteorites, using clay models in a demonstration using basic math and statistical prediction methods to determine asteroid composition. The teachers were participants in GSFC's 1999 Education Showcase.

Mrs. Linda Newsome, a visiting middle school teacher, is assisting in developing a teaching activity for advanced high school students based on a recent successful collaboration between R. Lepping and two students in a high school in Tennessee who were interested in the solar wind and the application of mathematics to it. R. Lepping ''walked'' the students through understanding some aspects of the solar wind's interaction with the magnetosphere via the use of the Akasofu ϵ parameter and its comparison with the geomagnetic index Dst. Files of the needed WIND solar wind data and Dst were provided to the students electronically. They wrote an analysis and plot program in C and displayed the results on the Web, all along being advised by R. Lepping and a high school counselor. They did an excellent job in general, which included writing a report and preparing a poster for a contest. Mrs. Newsome is using the resulting materials, including the various correspondences, to render it applicable for many students as automatically as possible for the purpose of leveraging the benefits of the collaboration.

Visiting Teachers. L. Evans and P. Solomon participated with teacher Sarah Brown in the Students United with NASA becoming Exited about Math and Science (SUNBEAMS) program. They served as mentors over the summer, and presented the basics of NEAR-XGRS science to her middle school class when it spent a week at GSFC in February. In addition to talking with students about asteroids and the NEAR mission, they assisted with a hands-on activity on impact cratering, and were interviewed by individual members of the class about their professional backgrounds and experiences.

L. Evans and P. Solomon also served as co-mentors to Willie Taylor, a Prince Georges County high school teacher participating in the GSFC Education Office summer intern program. Mr. Taylor is currently working on a web site that will allow teachers and students to access NEAR science data in close to real time during the 2000 encounter of the NEAR spacecraft with the asteroid Eros.

In August, P. Clark, Sister Mary Ellen Murphy, P. Solomon, and L. Evans put together and taught a program on the NEAR mission for the Educational Outreach office summer public school teachers program. The program included presentation of background material on the NEAR mission, and the role of meteorites in providing ground truth for asteroids, as well as teacher participation in a laboratory involving characterizing meteorite analogues using readily available material. Contextual and teaching tool materials were made available to teachers.

Visiting Students. P. Clark and Sister Mary Ellen Murphy worked with two high school students, Merritt Johnson and Lisa deGorter, to cross-calibrate and characterize the solar monitors on the NEAR mission using the GOES solar spacecraft data by comparing GOES and NEAR solar monitor output during periods of enhanced solar activity.

Gregory Bilyk of T.C. Williams High School in Alexandria, Virginia worked in the heterodyne laboratory during the summer, with the guidance of T. Kostiuk, T. Livengood, T. Hewagama, and F. Schmuelling (NRC). Greg reduced and analyzed measurements of infrared star IRC10216 to determine the point spread function and true focus of the IRTF and IRHS system. Results will be used in the analysis of present data and in the final detailed design of the HIPWAC instrument. Greg, with Andrew Rankin, competed in the past year in the Northern Virginia Regional Science Fair, receiving first place in the Earth and Space Science Division on a project exploring strategies for the detection of extrasolar planets, with guidance from T. Livengood and T. Kostiuk. The National Space Club also honored them for their award.

Ms. Katie McClernan, a recent high school graduate, assisted in the identification of directional discontinuities in the solar wind as observed by both the WIND and IMP 8 spacecraft. She then assisted in developing an IDL program that uses 40 input quantities for each discontinuity, including timing, positional, and spacecraft information, to process the data in order to estimate the degree of curvature of the discontinuity surfaces. The program was successfully tested using reasonable simulated data so far.

Educational Web Sites. F. Espenak is the webmaster of the NASA Eclipse Home Page at http://sunearth.gsfc.nasa.gov/eclipse/eclipse.html. During August 1999, this web site received up to 3,624,546 hits in one week due to the tremendous interested generated by the total solar eclipse of August 11. In 1997, Espenak authored NASA RP 1398 titled ''Total Solar Eclipse of August 11, 1999.'' By June 1999, all 4,000 hard copies of this publication had been distributed with requests for more copies arriving daily. This publication is also available on the web at: http://umbra.nascom.nasa.gov/eclipse/990811/rp.html. This web site received a maximum of 238,284 hits during the week of the eclipse.

D. Taggart and R. Lepping are leading an effort, joined by various members of the Lab, to continue the development of its Education/Outreach Website. On June 24, 1999 it was announced to the scientific community through American Geophysical Union's SPA newsletter. It attempts to appeal to a broad audience, but targets middle and high school students in particular and has been given a SafeSurf rating of ''ALL AGES.'' It highlights the scope of research undertaken by the Laboratory, e.g., studies on Sun's atmosphere, solar wind, magnetospheres, ionospheres, and atmospheres of the planets (especially Earth), other solar system physics, including comets and asteroids, and the interstellar medium. An original glossary, tailored to the Lab's research, has been produced to help the students or their parents navigate the Website. Extensive coverage is given to the many missions that the Lab has been involved in. Plans are to proceed to the interactive stage.

For six weeks in July-August 1999 a middle school teacher (Mrs. Linda Newsome) and a recent high school graduate (Ms. Katie McClernan) were assisting R. Lepping in the further development of parts of the Laboratories education/outreach website with emphasis on making the site more appealing to middle and high school students. This was done by the addition of various puzzles to ''hook'' the students into understanding the Lab's research. The puzzles include the use of scientific glossary terms and scientific pictures and sketches.

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