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1998 Annual BAAS Observatory Report

Goddard Space Flight Center

Laboratory for Extraterrestrial Physics

Greenbelt, MD 20771

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INTRODUCTION

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 1997 through September 1998.

I. 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 Deputy 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, Mr. Virgil Kunde, Dr. Ronald Lepping, Dr. Robert MacDowall, Dr. William Maguire, Dr. Marla Moore, Dr. David Nava, 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. Mark 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. Nancy Charnover, Dr. Steven Cummer, Dr. Robert Glinski, Dr. Susan Hallenbeck, Dr. Vasyl Morozhenko, Dr. Lutz Rastätter, Dr. Michael Smith, Dr. Carlos Suarez, Dr. Peyton Thorn, and Dr. Juan Valdivia.

The following scientists work at LEP as either contractors to GSFC or as long-term visiting faculty: (Raytheon/STX) 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. Brook Lakew, Dr. Carey Lisse, Dr. Nitya Nath, Mr. George McCabe, Dr. Vladimir Osherovich, Dr. Mauricio Peredo, Dr. Michael Reiner, Dr. Pamela Solomon, Dr. Adinarayan Sundaram, Dr. Nikolai Tsyganenko, Mr. Sarabjit Bakshi, Mr. Frank Carroll, Ms. Karen Horrocks, Mr. Monte Kaelberer, and Mr. Eric Winter; (Universities Space Research Association) Dr. Mei-Ching Fok, Dr. Jesper Gjerloev, Dr. Venku Jayanti, Dr. Valeriia Troitskaia, 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. Nat Gopalswamy, Dr. Vladimir Krasnopolsky, Dr. Fred Nesbitt, Dr. Neil Dello Russo, and Dr. Richard Starr; (SSAI) Dr. Richard Achterberg, Dr. Ronald Carlson, Mr. James Tingley, and Mr. Matt Elliott; (Space Applications Corporation) Dr. Hemant Davé; (Univ. of Maryland Baltimore County) Dr. Marcos Sirota; (Georgia Southern Univ.) Dr. Robert Nelson; (Univ. of Maryland College Park) Dr. Dennis Chornay, Ms. Kelly Fast, Dr. Thejappa Golla, and Dr. Timothy Livengood; (Charles County Community College) Dr. George Kraus; (Cornell Univ.) Dr. Barney Conrath and Dr. Paul Schinder; (Rowan College) Dr. Karen Magee-Sauer; (Univ. of Virginia) Dr. Lembit Lilleleht and Dr. Patrick Michael; and (Challenger Center) Dr. Jeff Goldstein and Dr. Tilak Hewagama, (NOMAD Research) Dr. Dean Pesnell, (National Institute of Standards & Technology) Dr. Vladimir Orkin.

II. ASTROCHEMISTRY

Ozone. Hypochlorous acid, HOCl, is a temporary chloride reservoir species in the Earth's stratosphere. As such, it sequesters atomic chlorine which catalyzes ozone depletion. Knowledge of thermochemical properties such as ionization energy (IE) and heat of formation (• H_f) of atmospheric species such as HOCl are valuable for both laboratory experiments and atmospheric models. The photoionization efficiency spectrum of HOCl was measured for the first time in photoionization-mass spectrometry (PIMS) experiments at the National Synchrotron Light Source located at Brookhaven National Laboratory. From an analysis of the step-like threshold in the spectrum, P. Thorn, L. Stief, S. Kuo (BNL) and R. Klemm (BNL) obtained a value of 11.12 ± 0.01 eV for the adiabatic IE of HOCl. This agrees well with the only previous experimental measurement which employed photoelectron spectroscopy (PES). However, in the absence of mass resolution, this PES measurement was severely complicated by the presence of features due to Cl_2O, Cl_2, and H_2O in addition to HOCl. A value for the heat of formation of HOCl was obtained from our recent value for • $H_f(Cl_2O)$ along with literature values for the equilibrium constant for the reaction $Cl_2O + H_2O \leftrightarrow 2\ HOCl$ and for • $H_f(H_2O)$. This yields ΔH_f (HOCl) = -18.4 ± 0.8 kcal/mol which is in excellent agreement with the value -18.2 kcal/mol from a very recent *ab initio* calculation.

Hydrocarbon Chemistry. In photochemical models of the atmospheres of the giant planets Jupiter and Saturn, an important reaction in the hydrocarbon chemistry is that between H, the dominant atomic species, and CH_3, a significant hydrocarbon radical species. Recent ISO satellite observations have lead to the first detection of CH_3 in the atmospheres of both Saturn and Neptune. The reaction of atomic hydrogen with methyl radicals is a pressure-dependent recombination process: $H + CH_3 + M \rightarrow CH_4 + M$. This reaction is difficult to study in the laboratory; the limited data available is at T=300K and above due to its importance in combustion chemistry. For atmospheric models, values of the molecular rate constant k_o and the limiting high pressure limit k are needed at low temperatures. Even though the high pressure limit is not approached in the atmospheric systems, the pressure ranges involved are such that an analytical expression involving k_o and *k* is required as a model input in order to generate rate coefficient values as a function of altitude (i.e., as a function of pressure and temperature). F. Nesbitt (Coppin State College), P. Thorn, W. Payne and L. Stief, in collaboration with D. Wardlaw (Queen's Univ., Kingston, Ontario), P. Seakins, S. Robertson, and M. Pilling (all at Univ. of Leeds) have completed an experimental and theoretical study of this reaction at T=298K and 200K. Different isotopic variants of the reactants were employed (D, CH_3, CH_2D, CHD_2) to obtain a measure of *k* for the $H + CH_3$ reaction. The average of three individual sets of data for each of the three methyl isotopomers yields, after correction for isotopic substitution, $k = (2.9 \pm 0.7) \times 10^{-10} cm^3\ molecule^{-1}\ s^{-1}$ at T=298K; this means that, at the high pressure limit, the reaction occurs on essentially every collision at T=298K. The result at T=200K is $k = (1.5 \pm 0.4) \times 10^{-10} cm^3\ molecule^{-1}\ s^{-1}$. This decrease in rate constant with decreasing temperature confirms recent theoretical predictions for the $H + CH_3$ reaction. The T=200K result is more appropriate for atmospheric models of outer planet atmospheres than the previously employed higher temperature results.

Hydrocarbon-Nitrogen Chemistry. For planets or satellites with a predominantly N_2/CH_4 atmosphere (Titan, Neptune and Triton), reactions of atomic nitrogen with small hydrocarbon free radicals such as CH_3, C_2H_5 and $C_2H_3$are expected to be important processes in the atmosphere which couple the separate hydrocarbon and nitrogen chemistries and lead to the formation of nitrile compounds such as HCN and CH_3CN. In previous studies at GSFC of the N

+ C_2H_3 reaction, it was established that one or more isomers of the C_2H_2N radical and the C_2H_3N adduct molecule are primary products of the reaction. In order to aid in the identification of the product isomers, high resolution photoionization-mass spectrometry (PIMS) studies were performed at the National Synchrotron Light Source located at Brookhaven National Laboratory by R. Thorn, P. Monks, and L. Stief with S. Kuo, Z. Zhang, S. Ross and R. Klemm (all at BNL). The C_2H_2N radical product exhibits a photoionization efficiency (PIE) spectrum and threshold quite different from that of CH_2CN, the lowest energy isomer. The absence of PIE spectra for the five other isomers and ionization energies (IE) for three of the isomers makes a unique identification impossible but it is clear that the product is not exclusively or even principally the lowest energy isomer CH_2CN. By way of contrast, the C_2H_3N adduct molecule product exhibits a PIE spectrum and threshold identical to that of the lowest energy isomer CH_3CN. While CH_3CN has recently been detected in the atmosphere of Titan by Bézard, Marten and Paubert, and in laboratory N_2/CH_4 plasma discharge experiments by Thompson et al., potential sources of CH_3CN are not limited to the N + C_2H_3 reaction.

Cosmic Ices. Studies of infrared spectra of cosmic-type ices are conducted using a unique setup designed specifically for the ion bombardment of ice films. The focus of these investigations is to understand physical-chemical and radiation-chemical processes and identify products in irradiated icy materials thought to exist in cometary ices, interstellar icy grain mantles, and ices on the surfaces of some satellites and planets. Two types of processes are currently under investigation: (1) H and OH addition reactions, and (2) acid-base reactions in low-temperature ices. (1) M. H. Moore and R. L. Hudson (Eckerd College) have studied addition reactions and calculated yields for the synthesis of C_2H_4, C_2H_6 and C_2H_5OH in irradiated H_2O + C_2H_2 ices, and C_2H_6 and CH_3OH in irradiated H_2O + CH_4 ices. This work was suggested after abundant C_2H_6, CH_4, and C_2H_2 were identified in comets Hyakutake and Hale-Bopp. Addition reactions resulting in the synthesis of H_2CO, CH_3OH and HCOOH in irradiated H_2O + CO ices have been completed and yields of products are to be determined. Since most of these molecules have been detected in comets and interstellar ices, their yields are of interest for chemical modeling. (2) Acid-base reactions in irradiated ices is one scheme suggested for the formation of species which might exist in planetary ices and for the formation of candidate molecules whose spectra could match the unidentified 6.8 micron interstellar ice feature. The formation of carbonic acid, H_2CO_3, is unique to the ion processing of H_2O + CO_2 ice. M. H. Moore and R. K. Khanna (Univ. of Maryland) have studied its reaction with NH_3 during warming near 120K and have identified carbamic acid, $NH_3^+COO^-$, as a major product. Current acid-base ice experiments on Fe- and Mg-silicates will search for the formation of carbonates and carbamates during reactions with the carbonic and carbamic acids.

III. PLANETARY AND COMETARY 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 (D. C. Reuter, J. M. Sirota, J. J. Hillman and D. E. Jennings) 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 microns. 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 7-1000 microns. 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) and HNO_3. This recent work has been carried out in collaboration with personnel at several institutions including W. E. Blass (Univ. of Tenn.), J. M. Frye (Howard Univ.), J. W. C. Johns (NRC, Canada), A. Perrin (C.N.R.S., Paris), D. W. Steyert (Wabash College), L. L. Strow (Univ. of Maryland Baltimore Campus), C. B. Suarez (NRC, Argentina) and R. H. Tipping (Univ. of Alabama). These measurements have already impacted planetary studies. For example, the $_{12}{}^{13}C$ 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 $_{9}$ band of allene near 28 microns 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 ~ 30 microns employing advanced (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.

High Resolution Infrared Heterodyne Spectroscopy of Isotopic Ethylene at 10.5 m. The Infrared Heterodyne Spectroscopy group at GSFC requires molecular transition measurements at extremely high spectral resolution to interpret the information content of planetary and astrophysical spectra. A laboratory infrared heterodyne spectrometer has been used by V. Morozhenko (NRC), T. Kostiuk, D. Buhl (GSFC), T. Hewagama (Challenger Ctr.), T.A. Livengood (GSFC and Univ. of Maryland), and A. Kollyukh (Institute of Semiconductor Physics, Ukraine) to measure the strength, pressure-broadening, and frequency of more than 150 rotational-vibrational transition lines in the $_{4}$, $_{7}$, and $_{10}$ 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. Absolute frequencies of the stronger lines have been determined to $\pm 5.3\times10^{-5}$ cm^{-1}. Intensities were determined to ~ 10% accuracy. Ethylene is an important hydrocarbon species present in the atmosphere of Jupiter, Saturn, and Titan. It is a product of methane chemistry in the stratospheres of these planets and has a complicated spectrum in the middle IR region, which makes it an effective probe of physical-dynamical properties of these atmospheres.

Theoretical Molecular Spectra. W. Maguire and coworkers continued modeling higher IR vibrational states of a number of molecules with low numbers of constituent atoms. By including appropriate perturbation terms, model accuracy has been improved for line positions and intensities for a suite of test molecules: CO_2, H_2O and HCN. Mixing coefficients needed to improve intensities have been calculated for CO_2 states. The models for CO_2 and H_2O will be useful in interpreting the IR spectra of Mars, Venus and Earth.

Wind Dynamics in the Venus Mesosphere. D. Buhl (GSFC), with J. J. Goldstein (Challenger Ctr.) and G. Chin (GSFC) have completed an analysis of wind velocities measured in the mesosphere of Venus using the Doppler shift of carbon monoxide (CO) lines formed in the upper mesosphere. The atmosphere of Venus contains a large amount of CO in the upper mesosphere. The millimeter rotational lines of CO at 115 and at 230 GHz have been used to study the abundance and time variations of the Venus upper atmosphere. At the center of the CO line is a narrow Doppler core which can be used to measure the velocity of the mesospheric winds, first noted by this research group in 1991. The millimeter CO lines arise from an altitude of 100 km in the Venus mesosphere. In modeling the mesospheric winds, the line of sight velocity components across the disc are convolved with the telescope beam. Observations with the NRAO 12 m telescope were made of this line during the inferior conjunctions of Venus in January 1990 and April 1993. Wind velocities of approximately 100 m/s were measured and two distinct flows were observed. Each observation showed a retrograde zonal wind flow of ~ 100 m/s at the equator. The second component of the global wind is a subsolar to antisolar flow driven by solar heating of the upper atmosphere. This flow was first observed by Goldstein in 1989 at altitudes above 100 km. Our observations showed a return flow of gas coming from the dark side of the planet during the pre-inferior conjunction periods of December 1989 (-120 m/s) and March 1993 (-90 m/s). In April 1993, the wind flow reversed and we measured a direct flow of 240 m/s in the equatorial region. These dramatic changes in the subsolar wind patterns suggest strong dynamical changes in the Venus mesosphere.

Multi-Band Spectral Imaging of Mars. D. Glenar, J. Hillman, G. Bjoraker and F. Espenak (GSFC), N. Chanover (New Mexico State Univ.), D. Blaney (JPL) and R. Joyce (KPNO) are planning an observational campaign for the 1999 opposition of Mars. The objective is to assemble a photometrically calibrated, spectrally complete ground-based image cube within the telluric "windows," at the highest possible spatial resolution. These measurements will employ new observing technologies and will be concurrent both with spacecraft measurements and supporting observations by the upgraded HST. Three observing teams will conduct the investigations with three instruments spanning 0.65-5.0 micron. Instruments and planned observing facilities are: (a) Visible/NIR AOTF camera and auxiliary camera with 600-1050 nm interference filter wheel, at the USAF/Phillips Lab 1.5m, laser-beacon adaptive optics telescope. Spatial resolution ~ 0.3 arcsec (125 km). Science targets: Fe_2^+, Fe_3^+ mineralogy and coarse grain hematite search. (b) SWIR (1.7-3.4 micron) AOTF camera at the Apache Point Observatory, 3.5m, f/10, Nasymth focus telescope. Spatial resolution ~ 0.8 arcsec (340 km). Science targets: 3 micron water-of-hydration feature and CO_2, H_2O ice (polar regions and clouds). (c) KPNO cryogenic grating/slit spectrometer (CRSP) at the KPNO 2.1 m, f/15 Cass. focus. Selected 3-5 micron (L, M band) with multiple grating settings. Spatial resolution ~ 0.8 arcsec (340 km). Science targets: water-of-hydration (3-4 micron long wave extension) and sulfate mineralogy.

Martian Dust Storm Electric Discharges. LEP scientists (Farrell, Cummer, Kaiser, Desch, 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. In collaboration with J. Marshall of NASA Ames Research Center, they are also performing a series of laboratory experiments to understand the microscopic nature of the Martian dust-charging and radiation process.

Composition of the Deep Jovian Atmosphere. G. Bjoraker, G. Orton (Jet Propulsion Laboratory), A. Collard (UK Meteorological Office), and L. Sromovsky (Univ. of Wisconsin) acquired spectra of Jupiter using the CSHELL cryogenic grating spectrometer at NASA's Infrared Telescope Facility in Hawaii. A new technique was tested to study the physical conditions near the 5-bar level on Jupiter. Observations of CH_4, NH_3, and PH_3 were obtained to complement in situ measurements by the Galileo Entry Probe. The methane observations are sensitive to the abundance of water vapor as well as to water ice clouds. Data are being analyzed to determine the O/H ratio and to measure the abundance and distribution of gaseous and condensed water on Jupiter.

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.

Jupiter and Io. Dr. J. E. P. Connerney (GSFC) and T. Satoh (Science Univ. of Tokyo) continue a program of long-term observations of Jupiter at 3.40 m 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 (3.40 m) within a strong absorption band of methane, to image the distribution of H_3^+ with high spatial and time resolution. 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 appears as an isolated, sub-arcsecond spot which moves across Jupiter's disc in concert with the orbital motion of Io (Connerney et al., 1993); it is excited by the electrodynamic interaction of Jupiter's magnetic field with Io. June 1995 and July 1995 NSFCAM images captured Io's signature in both polar regions with greatly improved spatial and time resolution. Additional improvement in imaging H_3^+ emissions resulted from the introduction of a custom filter set on the NSFCAM filterwheel (3.4265 m, 3.54 m, and 3.49 m null) in July 1998. Emission extending well downstream (60 degrees) of the IFT footprint along Io's L shell can be seen in the southern hemisphere. High time resolution imagery of the IFT footprint is used to further our understanding of the electromagnetic interaction between Jupiter and Io. A catalog of observed surface locations of the IFT footprint has been used to greatly improve models of Jupiter's magnetic field (Connerney et al., 1998).

Jovian Mid-IR Aurora and the Solar Cycle. T. Kostiuk, D. Buhl, and F. Espenak (GSFC), with T. A. Livengood, K. E. Fast (Univ. of Maryland and GSFC), J. Goldstein, T. Hewagama, and K. H. Ro (Challenger Ctr.) observed thermal infrared emission lines of ethane (12 m) in Jupiter's north polar auroral stratosphere in August 1998, using the Goddard Infrared Heterodyne Spectrometer (IRHS) at the NASA InfraRed Telescope Facility. These observations will be used as probes of both short-term (<days) and long-term (years) behavior of the Jovian infrared aurora. Measurements will provide additional information on apparent correlation of ethane variability with solar activity, which is suggested by Voyager and IR heterodyne data obtained since 1979. Results supporting a correlation will have significant impact on theories on the Jovian magnetosphere/ionosphere and their interaction with the lower atmosphere.

First Equatorial Observations of Winds in Jupiter's Stratosphere. In addition to mid-IR auroral observations, the Goddard IRHS was used in August 1998 by J. Goldstein, T. Hewagama, K. H. Ro (Challenger Ctr.), T. Kostiuk, D. Buhl, F. Espenak (GSFC), T. A. Livengood, and K. E. Fast (Univ. of Maryland and GSFC) to measure the Doppler-shifted emission of ethane (C_2H_6) at 12 m in order to measure wind velocities in the stratosphere. The only previous measurement in this pressure regime used the injection of dust and aerosols from Comet Shoemaker-Levy 9 as a tracer in visible light, in a narrow interval at 43 south latitude. Measurements at the equator touch on a new area not yet measured and inaccessible to theory due to intrinsic limitations in the calculation of winds from thermal balance.

Jupiter's H_3^+ Aurorae. Dr. T. Satoh (Science Univ. of Tokyo) and J. Connerney (GSFC) used 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. A linearized inverse method is used to extract an emission model from many images of the aurora, obtained at different Central Meridian Longitudes. Evidence is 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.

Jovian Radio Emissions. M. Kaiser and R. MacDowall have discovered a rare and quite unusual form of Jupiter's low-frequency radio emissions in the Ulysses/URAP data. Dubbed "radio bulls-eyes" because of their appearance on dynamic spectral displays, these events are 100% correlated with high solar wind-ram pressure. They also, at times, exhibit a periodicity between events of 10.5 hrs, suggesting a possible influence or even cause by Ganymede.

IR Spectral Imaging of Saturn. J. Hillman, D. Glenar, G. Bjoraker (GSFC) and N. Chanover (New Mexico State Univ.) investigated the near-IR spectrum of Saturn using an IR AOTF (acousto-optic tunable filter) camera. Key objectives are to obtain a photometrically calibrated spectral image cube of Saturn between 1.7–5.2 microns. 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-micron "hot spots" and characterize spatial variations in trace molecular species.

Rings of Saturn. T. Kostiuk (GSFC), T. A. Livengood (GSFC and Univ. of Maryland), C. M. Lisse (Raytheon/STX and Univ. of Maryland), and H. U. Käufl (European Southern Observatory) have imaged Saturn and its rings in the mid-infrared. Images were obtained October–December 1996 at the European Southern Observatory using the Thermal Infrared MultiMode Instrument (TIMMI) on the 3.6 m telescope. Photometric images were made through filters from 7.7 m to 13 m with the TIMMI 64×64 element Ga:Si array at an image scale of 0.5 arcsec/pixel. Preliminary analysis of the photometry indicates a peak in the emitted radiance of the rings near 12 m. A significant difference in the radiance from the East and West ansae was observed, with a maximum ratio W/E of ~ 2 near 11.3 m. Possible explanations for the difference include thermal heating and cooling, ring geometry, and ring particle properties and composition.

Detection of H_2O on Titan. G. Bjoraker and R. Samuelson are members of an international team led by A. Coustenis (Meudon Observatory, France) that used the Infrared Space Observatory (ISO) to detect H_2O in Titan's stratosphere. The Short Wavelength Spectrometer was used in the grating mode to detect two emission lines of water vapor at 39.4 and 43.9 m. These observations must be performed above the Earth's atmosphere to avoid interference from terrestrial water. Coustenis and coworkers fitted the emission lines with an H_2O profile increasing from 0.1 ppb at 1 mbar to 8 ppb at 10 bars in the stratosphere. The observations can be explained by a model in which dust particles from both the Saturnian system and the interplanetary medium ablate in the upper atmosphere, thus introducing H_2O into Titan's reducing atmosphere. Subsequent photochemistry produces CO_2, which was detected by Voyager and confirmed by ISO. The H_2O influx rate is estimated to be about 1.8×10^{6} molecules $cm^{-2} sec^{-1}$. These results will provide guidance for mapping sequences planned when GSFC's Composite Infrared Spectrometer aboard the Cassini spacecraft reaches the Saturnian system in 2004.

Titan Winds. Work has continued, led by J. Goldstein and T. Hewagama (Challenger Ctr.) with T. Kostiuk, D. Buhl, F. Espenak (GSFC), T. A. Livengood, and K. E. Fast (GSFC and Univ. of Maryland), in measuring and interpreting stratospheric winds on Titan. A software package called BEAMINT has been developed to model the range of Doppler-shifted spectra contributing to an observation of Titan using the Goddard Infrared Heterodyne Spectrometer. A BEAMINT-based analysis is being conducted to estimate the globally-averaged zonal wind speed using data obtained in 1993, 1995, and 1996. The package also will be applied to test specific theoretical wind field models for Titan's atmosphere, such as those developed by F. M. Flasar (GSFC), against observed spectra.

CH_3 Detected in Neptune's Atmosphere. P. Romani collaborated with B. Bézard, T. Encrenaz (Observatoire de Paris, Section de Meudon, France) and H. Feuchtgruber (ISO Science Op. Center, ESA, Madrid, Spain) to acquire the first detection of the methyl radical (CH_3) in the atmosphere of Neptune. Spectra were recorded on 12 November 1997 using the Short Wavelength Spectrometer (SWS) of the Infrared Space Observatory (ISO) in the grating mode. The spectral range 16.44–16.56 µm was observed during 50 min of integration at a resolving power $\lambda/\Delta\lambda \approx$ 1500. The final spectrum shows prominent emission from the ν_2 band of CH_3 centered at 16.497 µm (with an S/N ratio of about 30). This emission feature can be reproduced with a CH_3 column density of about 2×10^{13} cm^{-2} in the upper atmosphere. Observations were then used to constrain a one-dimensional hydrocarbon photochemical model. Model output, (CH_3) mixing ratio vs. altitude, was used to generate synthetic spectra that were then compared

to the observed spectrum. Initial results favor an eddy diffusion coefficient lower than that had been inferred from analysis of Voyager UVIS and IRIS observations. There is little, if any, sensitivity to the H flux from the ionosphere, while there is a noticeable sensitivity to the solar flux (solar maximum vs. solar minimum). Presently we are focusing on quantifying how uncertainties in the photochemical reaction scheme effect our results.

Comet Shoemaker-Levy 9. D. Deming is collaborating with Dr. Joseph Harrington (Cornell Univ.) in a theoretical modeling study of the plume-infall phase of the 1994 collision of comet Shoemaker-Levy 9 with Jupiter. The modeling takes place in two phases. In the first phase, the ejecta plumes are modeled by J. Harrington using a ballistic Monte-Carlo technique to "throw" large numbers of plume particles, and track their infall. The plume particles are randomly selected so as to represent a power-law in velocity distribution. Several free parameters are adjusted so as to give optimal agreement with the profiles of the ejecta plumes at the Jovian limb, and the debris patterns on the disk, as observed by the Hubble Space Telescope. In the second phase, the infalling mass and momentum densities from the ballistic plume simulations are coupled to a Zeus 3-D hydrodynamic model of the Jovian atmosphere. The Zeus 3-D code was modified by D. Deming to include radiative transport and damping in the gray approximation. Initial results from the Zeus calculations give infrared light curves for the "main event" which agree with the observed light curves in several significant respects, including the production of secondary maxima, or "bounces."

Temporal Study of SL9-Introduced Ammonia in Jupiter's Stratosphere. Working with LEP members T. Kostiuk, D. Buhl, F. Espenak, and P. N. Romani (GSFC), K. E. Fast (GSFC and Univ. of Maryland) has taken the lead in analysis of high-resolution spectra of NH_3 introduced into Jupiter's stratosphere after the impacts of fragments of Comet Shoemaker-Levy 9. Other collaborators on this work are A. L. Betz and R. T. Boreiko (Univ. of Colorado, Boulder) and T. A. Livengood (GSFC and Univ. of Maryland). Ammonia is destroyed by solar UV radiation, and knowledge of the time scales involved in its removal would shed light on processes in the Jovian stratosphere. Infrared heterodyne ammonia emission line spectra at a resolving power of ~ 10^7were obtained by Betz et al. and were analyzed using the GSFC heterodyne group's radiative transfer 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 4 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.

Lunar Wake Studies. Although the main mission of WIND involves Sun/Earth connection, one interesting secondary science topic has been the study of the lunar wake during the numerous WIND lunar swingbys. LEP scientists Farrell, Kaiser, and Owen have been involved in this study with investigators John Steinberg from LANL and Stuart Bale from Berkley, demonstrating that the wake has a substantial kinetic nature, possessing counter-streaming ion flows and a strong electrostatic turbulent tail that extends over a length much greater than that expected from previous MHD theory. Recently, they performed a kinetic simulation of the wake dynamics which closely match the observations. Results from the simulation can be found on

http://lepmfi.gsfc.nasa.gov/mfi/lunar.html.

Extrasolar Planetary Radio Emissions. Recently, LEP scientists Farrell and Desch and French colleague Philippe Zarka applied planetary magnetic and radio scaling laws to the known extrasolar planets to determine the possibility of detecting coherent cyclotron emissions from the extrasolar planetary magnetospheres. The study concluded that such emission is nominally below the limit of detectability by the largest ground-based radio telescopes. However, if the local stellar wind about the extrasolar planet increases, cyclotron radiation power levels from the planet will also increase in an exponential fashion. Thus, the highest probability for detection occurs for short periods during anomalous, fast-flow stellar winds at the extrasolar planet. Such periods cannot be predicted a priori, but some consistent monitoring in the HF band of planets about tau Boötes and rho CrB might be performed in case of a serendipitous detection.

Extrasolar Planetary Infrared Emissions. D. Deming and G. Bjoraker are collaborating with Dr. Guenter Wiedemann (ESO) in a project to detect infrared spectral emissions from the planetary companions of 51 Peg, Ups And, and Tau Boo. The planets in these systems orbit very close to the parent stars and their atmospheric spectral emissions may therefore be enhanced by heating and re-emission of the intense stellar radiative flux. They calculate that the planetary spectral structure should be detectable at the level of 0.01% of the stellar continuum, and more than 2000 spectra have been acquired near 3 and 5 microns to search for planetary methane and carbon monoxide emissions and/or absorptions. The observations used the NASA Infrared Telescope Facility (CSHELL spectrometer) and the Kitt Peak 4-meter telescope with the Phoenix spectrometer.

Terrestrial Differential Refraction. T. A. Livengood (GSFC and Univ. of Maryland), with T. Kostiuk, D. Buhl, F. Espenak (GSFC), K. E. Fast (GSFC and Univ. of Maryland), T. Hewagama, J. Goldstein, and K. H. Ro (Challenger Ctr.) have determined that the index of refraction of the Earth's atmosphere at $12\mu m$ differs significantly from the reference literature. Astronomical instruments at mid-IR wavelengths, which are significant for solar system temperatures and molecular composition, generally are guided with a visible-light imaging system. Refraction in the Earth's atmosphere may displace the visible and infrared images by up to several arcseconds. To point accurately at the desired source and to register accurately multiwavelength phenomena, it is necessary to account for the different atmospheric refraction between the guiding wavelength and the wavelength(s) of interest. We have measured the differential refraction between visible wavelengths and 12 μm and have found the refraction to differ significantly from the dispersion relation accepted in the astronomical and metrological literature. Newly-derived values have been used with success in astronomical observations requiring high pointing precision.

IV. SUN-EARTH CONNECTIONS

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. The analysis showed that high energy (>3 keV) precipitation occurs briefly (on the order of 5-10 min) in the substorm onset bulge and the westward-traveling surge, while dawn sector energetic precipitation lasts from shortly after onset to up to 2 hrs after substorm onset. Quantitative comparisons with FAST electron data revealed that most of the morningside x-rays are generated by diffuse plasma sheet precipitation at the equatorward edge of the ultraviolet and visible emissions. In a collaboration with N. Østgaard, J. Bjordal, and J. Stadsnes at the Univ. of Bergen in Norway and with other POLAR experimenters, PIXIE x-ray images have shown large-scale patchy morningside energetic precipitation whose timing indicates a source of drifting electrons originating at substorm onset. An investigation of possible mechanisms for the spatial patchiness of this precipitation is ongoing.

Ionosphere Conductivity Models. J. Gjerloev and R. Hoffman have created a self-consistent model of the auroral electrodynamics including height-integrated Hall and Pedersen conductivity, electric fields, ionospheric Hall and Pedersen currents and field-aligned currents. Global auroral images were used to select as well as organize individual events in order to prevent mixing of different geophysical conditions and thereby minimize undesirable smearing. The model was used to explain a characteristic westward jump in the auroral electrojet indices associated with the onset of the substorm and a similar eastward jump during the recovery phase (Gjerloev et al., 1998).

ISIS 2 Ionograms. Digital ISIS 2 topside-sounder ionograms are being produced by a team at GSFC, led by R. F. Benson of the LEP, directly from a collection of the original analog telemetry tapes that have been preserved. The digital ionograms are being archived at the National Space Science Data Center at GSFC. Since most of the data selected for digitization were not processed into the conventional 35 mm analog film format, the new data base (approximately 100,000 digital ISIS-2 ionograms, as of mid-July 1998, and still growing) is analogous to a new satellite mission with high-quality ionospheric data covering an earlier solar cycle. The time interval of the digital data includes the large 1981 solar maximum. For information about the project and how to obtain the available data, see http://nssdc.gsfc.nasa.gov/space/isis/isis-status.html.

Effects of Energetic Electron Precipitation on Mesospheric Ozone. Earlier studies from rocket data and a GSFC 2-D model prediction had concluded that highly relativistic electron events (HRE's) could induce up to 30% depletions of daytime ozone near 65 km altitude at high latitude. Current studies of UARS data by D. Pesnell and R. Goldberg during the intense HRE during May 1992, using electron data from PEM/HEPS and ozone data from CLAES and MLS show that the ozone depletion during that event was significantly lower; (i.e., below 10%) which is the minimum signal that could be detected by these instruments near 60 km (Pesnell et al., 1998). Unfortunately the S/N level deteriorates even further with increasing altitude making extraction of useable data above 60 km nearly impossible. However, newly developed algorithms for HALOE and HRDI may make mesospheric ozone data available there. This is the subject of an ongoing study.

Power Line ELF Emissions. LEP investigators Farrell, Desch and Houser considered the effect of power line ELF radiation on the upper atmosphere and lower ionosphere. Specifically, they demonstrated that D-region electron heating was extremely small, but displayed some variation based upon the conductivity of the underlying ground. In a quantitative way, it was demonstrated that a more conducting ground tended to draw ELF power flux Earthward, and thus was less effective in topside heating.

Magnetospheric Physics

Substorm Predictions. The nonlinear dynamics modeling group, Klimas, Vassiliadis and Valdivia, continued the prediction and modeling of magnetospheric activity. The analyses correlate solar wind and geomagnetic data measuring the rate of decay for the ring current, and the coupling efficiency between solar wind VxB electric field and the mid-latitude Dst index. A modeling technique to construct nonlinear ordinary differential equations from the nonlinear filters was developed and applied to mid-latitude Dst (Klimas et al., 1998) and high-latitude AL indices. In the case of substorm expansions, prediction directly from the solar wind variables or polar geomagnetic data reproduces their amplitude, but there are still uncertainties in the time profile (incorrect onset timing and duration, see Vassiliadis et al., 1998). Perhaps the most important development was the modeling of individual magnetometer disturbances (both in mid- and high latitude) replacing the prediction of magnetic indices (Valdivia et al., 1998).

Space Weather Session at Western Pacific AGU. R. Lepping chaired a session on space weather at the Western Pacific Geophysical Meeting in Taipei, Taiwan, in July 1998 and gave an invited talk, at that session, on the role and importance of magnetic clouds in space weather. It was pointed out that the magnetic field is always intense within a magnetic cloud, and most often it is pointed nearly southward for about half of a cloud's extent, meaning often for 12 or so hrs, giving the most important conditions for the cause of a major geomagnetic storm. Various examples of "normal" and unusual magnetic cloud structures were shown supporting the case for their importance.

Effect of Sudden Impulse on the Tail. The ISTP program allows investigators the opportunity to study the effect of solar wind pressure discontinuities on the magnetospheric system routinely using multiple spacecraft. This represents the magnetospheric response to a step function impulse. M. R. Collier, J. A. Slavin, R. P. Lepping, K. Ogilvie, and A. Szabo are investigating the effect of pressure discontinuities in the solar wind on the magnetotail using data from the WIND and IMP 8 spacecraft. Two events have been analyzed in detail to date. It has been shown that a simple model in which a uniform field is compressed by a step function constriction accurately predicts characteristic time scales, which are on the order of minutes, and the magnetic field profiles. The results of this study indicate that the magnetotail maintains an approximate MHD equilibrium as it responds rapidly to interplanetary pressure discontinuities.

Magnetospheric Magnetic Field Modeling. Kolja Tsyganenko has developed a quantitative model of the effects of the seasonal/diurnal wobbling of the Earth's magnetic moment and of the interplanetary magnetic field upon the shape of the magnetotail current sheet, based on data of GEOTAIL and ISEE-1/2 spacecraft. For the first time, he found the effect of the Earth's dipole tilt upon the shape of the magnetotail boundary using a multispacecraft data set of the magnetopause crossings. Tsyganenko also developed a new mathematical method for the modeling of these effects, making it possible to model a wide variety of realistic magnetospheric configurations.

Terrestrial Plasma Energization. M.-C. Fok and T. E. Moore explored the physics of geomagnetic storms and the ring current plasma that is associated with them, using comparisons of model and simulation results with published data sets. This work is also being used as the basis for simulations that anticipate the neutral atom fluxes that will be seen by the Imager for Magnetopause to Aurora Global Exploration (IMAGE) mission neutral atom instruments. Collaborating with G. Khazanov of the Univ. of Alabama in Huntsville, 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 in diverse contexts.

Substorm Injection of Ring Current Ions. M.-C. Fok and T. Moore have been working on modeling the inner plasma sheet and the ring current during substorm injections. A particle code developed by D. Delcourt, one of their collaborators, was run to trace particles backward in time to form a time-dependent ion distribution on the nightside inner plasma sheet. These simulated ion fluxes are served as boundary conditions to our ring current model, which calculates the adiabatic acceleration and deceleration of particles during substorms. The simulation generates most of the known qualitative features of substorm injection events including initial formation in the evening sector, Earthward and tailward expansion, azimuthal spreading both dawnward and duskward, production of a sharp inner "injection boundary," and creation of characteristic ion dispersion patterns in the geosynchronous orbit region.

Flow Bursts and Substorms. D. H. Fairfield, with data contributed by numerous national and international colleagues, studied high-velocity magnetotail flow bursts in the Earth's magnetotail that were measured by the Japanese plasma experiment and the Japanese/GSFC magnetic field experiment on the GEOTAIL spacecraft. Events seen in the premidnight equatorial region between 10 and 15 R_e were compared with other magnetospheric phenomena. These bursts are characterized by Earthward velocities approaching 1000 km/s and they last for times of the order of one minute. The supporting ISTP measurements show that the flow bursts are closely associated with auroral brightenings, auroral kilometric radiation (AKR) onsets, geosynchronous particle increases and ground magnetic activity. Flow bursts for which Polar UVI images are available showed auroral brightenings that developed near the footpoint of the GEOTAIL field line. AKR intensifications usually accompanied the flow bursts in close time coincidence whereas dispersionless geosynchronous particle injections tended to be delayed by 1-3 mins. Since flow bursts often exhibit the earliest onsets of these various phenomena, it seems likely that this chain of events is initiated in the tail beyond 15 R_e, presumably by magnetic reconnection. It is concluded that flow bursts are a fundamental magnetotail process of limited spacial extent that are important in energy and magnetic flux transport in the magnetosphere. Magnetotail flow bursts are intimately connected to auroral acceleration processes and AKR generation at several thousand km altitude.

Plasmoid Ejection. J. A. Slavin, D. H. Fairfield, and R. P. Lepping have collaborated with ground-based and GEOTAIL investigators to investigate plasmoid formation and ejection. One year of IMP 8 magnetometer measurements taken during the distant tail phase of the GEOTAIL mission were searched for traveling compression regions (TCR) which signal the release of plasmoids down the tail. A total of 10 such intervals were identified. Examination of the GEOTAIL measurements showed that this spacecraft was in the magnetotail for only three of the events. However, in all three cases clear plasmoid signatures were observed at GEOTAIL. These plasmoids were observed at distances of X = -170 to -197 R_e. The in situ plasma velocities in these plasmoids are found to exceed the time-of-flight speeds between IMP 8 and GEOTAIL suggesting that some further acceleration may have taken place following release. The inferred lengths of these plasmoids, ~ 27–40 R_e, are comparable to the downtail distance of IMP 8. This indicates that TCR's at IMP 8 can be caused by plasmoids forming not only Earthward, but also adjacent to or just tailward of the spacecraft. The closeness of IMP 8 to the point of plasmoid formation is confirmed by the small, ~ 0–3 min, time delays between the TCR perturbation and substorm onset. In two of the plasmoid events high-speed Earthward plasma flows and streaming energetic particles were measured in the plasma sheet boundary layer surrounding the plasmoid along with large positive B_z at the leading edge of the plasmoid suggesting that the core of the plasmoid was "snow plowing" into flux tubes recently closed at an active distant neutral line. In summary, these unique two-point measurements clearly show plasmoid ejection near substorm onset, their rapid movement to the distant tail and their further evolution as they encounter preexisting X-lines in the distant tail (Slavin et al., 1998).

Reconnection at the High-Latitude Magnetopause. Using observations by the HYDRA instrument on WIND, Scudder and Ogilvie have examined the nature of the magnetopause using the Walen relation. In particular, they show that a test of the validity of the relation at a particular crossing can be performed closer to the discontinuity using electrons rather than ions, leading to better determination of magnetopause normal directions for test of the presence of reconnection.

Particle Acceleration During CME Events. Several magnetic cloud/CME events have been observed during the 1997–98 time period, as we approach the maximum of the next solar cycle. Multiple spacecraft have observed for the first time the evolution of these events from their origin to passage over the magnetosphere. S. Kanekal and collaborators at the Univ. of Colorado have studied the magnetospheric outer zone energetic electron response to these cloud/CME events using data from sensors onboard POLAR and SAMPEX. POLAR and SAMPEX measure electrons in energy range of several keV to MeV over all L shells at 2–9 R_E and 600 km altitudes respectively. Data from the WIND spacecraft were used to identify the cloud/CME events. Comparison was made of the energetic electron responses at different L shells, energies and altitudes. Superposed epoch analyses were done to examine the common features of the outer zone electron response. These results demonstrate a remarkable coherence of energetic electron enhancements throughout the entire outer radiation zone.

Ground-based Radar Observations of the Magnetopause. LEP scientist W. Farrell and NRL scientist Paul Rodriguez are currently involved in an international collaboration with Russian and Ukrainian scientists with the goal of detecting radar echoes from the magnetopause. The large Russian SURA radar facility is the transmission site and the world's largest decametric radio telescope at the Kharkov, Ukraine, site is used for receiving. Preliminary tests of the experiment are ongoing in the summer and fall of 1998. If successful, such radar diagnostics of the magnetopause could be used to localize this boundary during magnetospheric quiescent and active periods. The location measurements might potentially supplement the IMAGE data product by providing magnetopause position during periods when the spacecraft's radio plasma imaging system is out of range.

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 (Hesse and Winske, 1998; Kuznetsova et al., 1998a,b).

Bursty Bulk Flows. M. Hesse (LEP) with J. Birn and D. Winske (both Los Alamos National Laboratory) undertook a study of ion kinetic effects in bursty bulk flows (BBF's). Using a hybrid model, they could prove that the interaction between magnetic flux and particles ejected from the reconnection region and the stationary plasma ahead of the perturbation can generate strongly nongyrotropic ion distributions. These distributions decay by means of ion cyclotron turbulence. The resulting magnetic field fluctuations strongly resemble the observed signatures of "current disruption" (Hesse et al., 1998a).

Plasma Sheet Kinking. M. Hesse and M. Kuznetsova (LEP) with J. Birn, D. Winske (both 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 which 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 (Hesse et al., 1998b).

Magnetohydrodynamic Simulations of Magnetospheric Dynamics. J. Birn (Los Alamos National Laboratory), M. Hesse (LEP), 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 focussed 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 (Birn et al., 1998a,b).

MHD Simulations of Reconnection. L. Rastätter and M. Hesse have investigated the formation and structure of thin current sheets which develop in the near-Earth magnetotail during pre-substorm compression of the tail. This work was carried out with high spatial resolution in two-dimensional (2D) and three-dimensional (3D) Hall-MHD simulations to find the influence of the current carriers (electrons or ions) on the dynamics. It was confirmed that electrons carry most of the current in the thin sheets as had been concluded in the literature from particle or hybrid simulations. This result was obtained with near-Earth boundary conditions associated with a rigid inner magnetosphere which limits the magnitude of the cross-tail magnetic field component (in 2D) and allows the approach to a new equilibrium in 2D. The thickness of the evolving current sheet was found to be consistent with observations and other theoretical work as well. The 3-D simulations confirm the formation of the thin sheets as well, however, with reduced current amplitudes. Those reductions in current intensity arises from the lateral redistribution of magnetic flux evading the compression, which was assumed to be strongest in the midnight plane. In Hall-MHD, the magnetic flux is carried by the electron velocity. Thus, the electron current becomes asymmetric and is concentrated on one side of the magnetotail cross section as magnetic flux is swept to one side after it enters from the tail lobes.

MHD Modeling of Astrophysical Accretion Disks. The interaction between an accretion disk and the magnetosphere of a compact star was investigated by L. Rastätter (LEP) and K. Schindler to study the role of hydromagnetic instabilities in two- and three-dimensional MHD simulations. To accomplish this, equilibria in a poloidal plane in cylindrical coordinates were computed including varying rotation rates between rigid (magnetosphere) and Keplerian (disk) as well as different disk-mass densities. Through dynamical simulations after perturbations of different wavelengths along the invariant (toroidal) direction of the equilibria, the magnetosphere accretion disk interaction was found to be determined primarily by instabilities of the exchange type which occur as part of the disk matter supported by the magnetic field against gravity. Magnetic line-tying effects in the thin magnetopause sheet at the inner disk edge effectively reduce instability and lead to larger structures in the magnetopause evolving from small-scale initial perturbations.

Global MHD Simulations of the Magnetosphere. S. Curtis, D. Spicer, C. Mobarry, K. Olsen, and P. MacNeice have developed a fully operational, adaptively refined global simulation code of the terrestrial magnetosphere which can be easily modified to simulate other planetary magnetospheres as well. A unique aspect of this code is that is incorporates the correct magnetic dipole seasonal tilt and its daily variations. These variations have already been shown to have major impacts on magnetospheric structure and must be incorporated to allow quantitative agreement with observations on large scales. The role of the temporal variations in dipole tilt in magnetospheric dynamics as compared to the external solar wind forcing is presently being investigated. Additionally, the code is being extended beyond the limits of the MHD approximation to include finite ion gyroradii effects and Hall effects through a collaboration with J. Huba at the Naval Research Laboratory. Also, to better treat the dynamics of the inner magnetosphere, a partnership has been formed with a team lead by C. Cheng (Princeton Univ.) to incorporate the more important kinetic aspects of processes in this region, in particular with respect to the ring current. The power of global magnetosphere simulations to self-consistently treat the entire magnetosphere as a system make them a natural backbone for space weather prediction efforts. During the next year, the code will be modularized into five components which will allow the treatment of all regions of geospace at all relevant scales: kinetic, hybrid, and MHD. These components will be the bow shock region, the inner magnetosphere, the magnetotail, the ionosphere, and the rest of the magnetosphere.

Lower Hybrid Waves in the Field Reversal Region. D. Fairfield, A. Sundaram and A. Viñas have investigated in detail the excitation of electrostatic and electromagnetic lower hybrid waves in the magnetic field reversal region of the plasma sheet using a kinetic theory. This work is an extension of their earlier results which demonstrated that long wavelength electromagnetic and short wavelength electrostatic lower hybrid waves are excited in the field reversal region by the magnetic field gradient. For a two-dimensional magnetotail configuration, the dispersive properties of lower hybrid waves near the weak field region are examined for all wavelengths by considering kinetic effects such as curvature drift and gradient-B resonances. An exhaustive study incorporating the nonlocal effects shows that unstable wave characteristics near the lower hybrid frequency persist and the theory developed here supports the GEOTAIL observations of lower hybrid waves in the entire plasma sheet region. The waves generated in the field reversal region may provide anomalous dissipation and these waves may therefore be the source for causing substorms.

Heliospheric and Solar Physics

Solar Prominence Observations. E. S. Chang (Univ. Massachusetts) and D. Deming have analyzed several high spectral resolution spectra of solar prominences made in the infrared spectral region using the McMath-Pierce Fourier transform spectrometer on Kitt Peak. They find that the infrared lines of hydrogen and helium can be exploited to give improved temperatures and electron densities for prominences. The large Stark broadening which is seen for infrared lines, in combination with the lack of line-blending, allowed them to derive accurate and model-independent electron densities.

Radio Emissions From Dual Shock Waves. M. Kaiser and coworkers have reported the first case of dual solar shock waves causing type II radio emissions. During the 7 April 1997, CME event, they observed two different type II emissions, one attributed to the CME-driven shock and the other to the flare-associated blast wave shock. Long speculated, this represents the first observation of this phenomenon.

Radio Emissions From CME's. M. Reiner and coworkers measured the radio emissions associated with the 6-10 January 1997 CME and magnetic cloud and deduced that the emission was generated at the localized intersection point between the CME-driven shock wave and a preexisting fast corotating stream. They also showed that this emission was quite atypical as most other interplanetary type II bursts come from a very broad region immediately in front of the CME-driven shock.

Solar Radio Bursts. Radio observations from the Ulysses spacecraft in combination with in situ data and/or radio observations from other spacecraft improved our understanding of low-frequency solar radio emissions. M. Reiner M. Kaiser, J. Fainberg, and R. Stone published the first dual-spacecraft, 3-D triangulation of the trajectory of a solar type III radio burst, using WIND and Ulysses radio observations, leading to the unambiguous determination of a density-distance scale in the solar wind. 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. R. MacDowall, A. Klimas, D. Lengyel-Frey, R. Stone, and G. Thejappa compared the observations of type II bursts from Ulysses, WIND, and ISEE-3, showing why the different receivers, trajectories, etc., yield type II bursts that appear to have different morphologies; nevertheless, all such observations are useful for prediction of geoeffective space weather events. 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.

Solar Transition Region Modeling. M. Goodman developed an electrically driven, steady-state, dissipative MHD model with flow to study the structure and heating mechanisms of the solar transition region (TR). The model includes the complete Ohm's law for a collision-dominated plasma. The model makes several important predictions. First, the thermoelectric current density, which is almost always neglected in MHD modeling of the solar atmosphere, can nearly cancel the conduction current density. Second, the electron pressure gradient, which is also usually neglected, can make the dominant contribution to the generalized electric field that drives the conduction current density. Third, the contribution to TR heating of the dissipation of electric currents on spatial scales greater than or on the order of 10 km is insignificant. Fourth, the electron heat flux from the corona can provide all of the energy required to heat the TR. Fifth, the thermoelectric component of the electron heat flux, which is driven by the generalized electric field, flows from lower to higher temperatures, and can cancel a large fraction of the familiar temperature gradient-driven electron heat flux which flows from higher to lower temperatures. The total heat flux flows from higher to lower temperatures, as required by the second law of thermodynamics.

Solar MHD Theory. M. Goodman developed a cylindrically symmetric, electrically driven, steady-state MHD model with flow and an energy equation to study the effects of classical transport processes on MHD equilibria. The solutions studied demonstrate that the thermoelectric current density, driven by the temperature gradient, can make the main contribution to the current density by one or more orders of magnitude, and that the thermoelectric component of the electron heat flux, driven by an effective electric field, can make a large contribution to the total heat flux. These solutions also demonstrate that the electron pressure gradient and Hall terms in Ohm's law can make dominant contributions to the radial electric field. These results indicate that the common practice of neglecting thermoelectric effects, and the Hall and electron pressure gradient terms in Ohm's law is not always justified, and can lead to large errors. The model may be applied to any fully ionized, two-component, electron-ion, collision-dominated plasma for which the ion cyclotron frequency is much larger than the ion-ion Coulomb collision frequency, such as the plasma in magnetic flux tubes in the solar interior, transition region, and possibly the lower corona.

MHD Model of the Solar Corona and Solar Wind. E. Sittler has been developing an empirical 2-D MHD steady- state model of the solar corona and solar wind. The model uses empirically derived electron density profiles from white light coronagraph observations from Skylab and SOHO and empirically derived models of the magnetic field which is fit to observed streamer topologies which also come from white light coronagraph data. The equations are solved in the rotating frame of the Sun for which conservation of mass, momentum and energy is imposed. The model requires an estimate of solar wind speed as a function of latitude at 1 AU, for which Ulysses plasma data is used, and an estimate of the radial component of the magnetic field at 1 AU for which Ulysses magnetometer data is used. The model makes 2-D maps of the flow velocity, effective temperature and effective heat flux as a function of radial distance and latitude. The magnetic field model shows that the octopole term dominates the global surface magnetic field of the Sun.

Heating of the Solar Corona. One theory for the hot solar corona is that the coronal plasma is not heated in situ at all, but rather results from the "velocity filtration" of nonthermal electron distributions in the transition region and below. Roberts and Miller proposed that a cascade of MHD fast mode waves, generated at large scales by an unspecified mechanism (but possibly related to microflares), will readily accomplish the required tail formation just as it produces flare particles under other conditions. Low levels of turbulence $(\delta B/B\ 0.1)$ injected at large scales necessarily lead to strong tail formation in the transition region and upper chromosphere and may also account for tails in the interplanetary distributions.

Proton Heating. The turbulent cascade of Alfvén waves leads, via cyclotron interactions, to anisotropic heating of protons. Siregar, Viñas, and Goldstein developed a model of a limited closure for parallel-propagating proton cyclotron waves using kinetic information from hybrid simulations and tested and completed it. The simulations showed 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 β dependence for the quasi-steady anisotropic state, as observed.

Heating by Fluctuating Electric Fields. In another approach to the heating problem, Viñas, Klimas, and Wong investigated the role of fluctuating electric fields. It is known that all three MHD wave modes can possess significant parallel electric field components in high β plasmas. They showed, using several numerical simulation techniques, that such fluctuating fields generate high frequency electron plasma oscillations and ion acoustic waves, which then drive electron plasma turbulence. The high-frequency waves are later damped by the background electrons, resulting in electron acceleration and the generation of non-Maxwellian suprathermal tails.

Heating by "Phase Mixing." Using our FCT-based MHD code, Ruderman (Russian Academy of Sciences), Goldstein, Roberts, Deane, and Ofman (GSFC, Code 682) also investigated the role of "phase mixing" as a heating mechanism in an expanding medium. They found that the FCT code reproduced, at least qualitatively, the linear prediction that velocity shear will damp Alfvén waves.

Acceleration Mechanisms in Solar Flares. As part of their research on acceleration mechanisms in solar flares, Viñas and Miller (Univ. of Alabama at Huntsville) employed a 1-1/2-D electromagnetic hybrid code to determine the role of nonlinear Landau damping of Alfvén waves under flare conditions in accelerating ions. In this process, two Alfvén waves form a beat wave with a parallel electric field, which is then Landau-damped on the background particles. They found that nonlinear Landau damping needs to be included when studying ion acceleration by Alfvén waves.

Evolution of Solar Wind Turbulence. To address some of the fundamental problems about the evolution of solar wind turbulence that cannot be addressed by two- and three-dimensional spectral simulations in Cartesian geometry (e.g., the role of spherical expansion), Goldstein, Roberts, Ghosh and Deane (Univ. of Maryland College Park) developed a new simulation code that solves the compressible MHD equations in three dimensions in spherical coordinates. The code solves the ideal or resistive MHD equations in spherical coordinates and in conservation form (to the extent possible). The underlying algorithm is Flux Corrected Transport (FCT). FCT is a shock-capturing scheme that obtains a high-order solution from a combination of a low-order solution and a high-order flux. The new results confirmed the basic idea that velocity shear, especially when associated with magnetic shear, leads to strong evolution in the Alfvénicity of the initial population.

Two-Dimensional Turbulence. In a related study, nearly two-dimensional MHD turbulence was studied using three-dimensional simulations in which a 2-D state was held fixed at the inflow end of the box and the flow evolved with distance. The relevance and importance of two-dimensional turbulence in which both the **k** and δB are nearly orthogonal to $\mathbf{B}_0$, to solar wind structure and evolution has been the subject of considerable discussion. Cartesian cases were found to evolve very similarly to the pure 2-D expectation, but spherical expansion leads 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. Our results suggest further that the 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. Ghosh, Roberts, Goldstein and Matthaeus (Bartol Research Institute) conducted MHD spectral code simulation studies of the interaction of parallel-propagating Alfvén waves with pressure-balanced 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.

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. G. Thejappa, R. MacDowall, and A. Viñas reviewed the in situ wave phenomena associated with interplanetary shocks and identified the implications for type II solar radio burst emission.

Solar Wind Plasma Composition. Oxygen isotopic composition provides invaluable information on the formation and evolution of a variety of astrophysical systems. In particular, solar isotopic abundances establish a basis for interpreting isotopic abundances and their variations in meteorites and planetary reservoirs and provide constraints on and input for solar and stellar atmosphere models. M. R. Collier, along with a team of scientists at the Univ. of Maryland College Park, and the Univ. of Bern, Switzerland, using data from the MASS instrument on the

WIND spacecraft, a high-resolution mass spectrometer, have observed the isotope oxygen-18 in the core solar wind for the first time. The results indicate an oxygen-16 to oxygen-18 isotopic abundance of 450+/-130, consistent with previous measurements of this ratio from solar energetic particles and solar spectra as well as with the terrestrial value of about 500. With more data, the oxygen-16/oxygen-18 as well as other isotopic ratios, will be even more tightly constrained and, with corresponding refinements in SEP results, will provide a sound basis for comparison.

Electron Strahl. The WIND Solar Wind instrument (SWE) includes a sensor especially configured to measure the solar wind strahl. The strahl is the part of the suprathermal (> 100 eV) halo component of the solar wind electron velocity distribution that is most closely aligned with the interplanetary magnetic field. Strahl electrons are believed to originate in the inner corona and move relatively freely out to 1 AU, and thus, should be able to provide information on the state of the corona. As a result of our examination of electron data during seven solar rotations in 1995, R. J. Fitzenreiter and K. W. Ogilvie found that, when compared with the interplanetary magnetic sector and corotating stream structure, the electron velocity distributions are most anisotropic and the strahl flux most intense during high-speed streams. The strahl angular width is smallest when the solar wind velocity is largest, approximately 5 at 600 eV, and becomes much wider when the velocity is low. A significant flux of electrons coming from the anti-strahl direction, while only about 10% of the strahl flux, does not however form a beam but is spread over the entire field of view. This variability of the flux and angular distribution of the strahl and anti-strahl suggests that a pitch angle scattering process may be acting to broaden the strahl and that the anti-strahl may be due to backscattering of the strahl.

Source Regions of Strahl Electrons. Continuing interpretation of the observations made with the WIND strahl instrument, K. W. Ogilvie and R. J. Fitzenreiter completed a study of the whole of 1995, which confirms and extends that of Fitzenreiter et al., 1998. For the strahl to be seen at the Earth, it must be possible for a direct magnetic connection to exist from its source to the Earth. The new study shows that the strahl closely confined to the magnetic field, came from the Northern coronal hole until about July 1995, and then switched to the Southern coronal hole for the balance of the year. This resulted from the motion and warping of the heliospheric current sheet, and the fact that the strahl cannot cross the current sheet.

The Interplanetary Magnetic Field at Large Distances. Voyagers 1 and 2 are now in the distant heliosphere, where the pressure of the pickup ions greatly exceeds that of the magnetic field and solar wind plasma. Voyager 2 has moved beyond 55 AU and is at a latitude of ~ 19 S, while Voyager 1 is beyond 71 AU at a latitude of ~ 33 N. L. F. Burlaga has shown that the magnetic field strength between 1 AU and 66 AU follows the prediction of Parker's spiral field model, when solar cycle variations and latitude variations are considered. The magnetic field strength in the distant heliosphere decreases inversely with increasing distance from the Sun. It also is proportional to the strength of the magnetic field at the Earth (a measure of the strength of the solar magnetic field) which varies with the solar cycle being strongest at solar maximum and weakest at solar minimum. The speed increases with heliographic latitude (more so near solar minimum than at solar maximum), which has the effect of decreasing the interplanetary magnetic field strength for a given source strength. L. F. Burlaga has also shown that the distribution of hour averages of the magnetic field strength measured by Voyager 1 for each year is lognormal to very good approximation throughout the solar cycle and from 1 AU to 66 AU. The ratio of the standard deviation to the mean magnetic field strength for each is a constant, independent of the solar cycle and the distance from the Sun. This implies that when the magnetic field is strong, as at solar maximum, the standard deviation of hour averages of B is large, consistent with the observations when the Global Merged Interaction Regions (large regions containing unusually intense magnetic fields) are observed near solar maximum. Likewise, near solar minimum (when the mean magnetic field strength is relatively small) the merged interactions are either weak or absent.

Electron Polytrope Index in Magnetic Clouds. A major controversy has arisen concerning the relation between the moment electron temperature and the density of the plasma. The observations show an inverse relation between the electron temperature and density, which implies an adiabatic exponent less than one if the relation reflects a polytropic law. Most people argue that the polytropic exponent must be greater than unity everywhere in the solar wind as it is in air and other neutral gases in thermal equilibrium on Earth. However, magnetic clouds in the solar wind must be treated as a two-component plasma with the electrons having a significantly higher temperature than the protons. Analysis of the Voyager data for magnetic clouds between 1 AU and 5 AU showed that the electron distribution is non-Maxwellian and that the nonthermal tail is smaller when the density is larger. Thus, the moment temperature is smaller when the density is larger, explaining why the effective adiabatic exponent is less than one.

The first measurements (ISEE-3 and IMP 8) of the polytropic index in a magnetic cloud (Osherovich et al., 1993) confirm this unusual thermodynamics, namely, polytropic index below unity, suggested by the self-similar model. Further measurements of the polytropic index γ inside the clouds have been done using Ulysses and WIND data. V. Osherovich, J. Fainberg and R. G. Stone have analyzed the WIND data for the 10 January 1997, cloud confirming $\gamma = 1/2$ and the dominant role of electrons over protons in their contribution to the total gas pressure. E. Sittler and L. Burlaga have recently published a paper on electron temperatures within magnetic clouds using Voyager data. They support the developing viewpoint that solar wind electrons within magnetic clouds are highly non-Maxwellian and that they tend to obey a polytrope relationship with index $\gamma \sim 0.5$. Here the electron temperature anticorrelates with the electron density. They show that the core electron temperature and halo electron temperature individually do not anticorrelate with the density. Rather, because the halo population within magnetic clouds can contribute to more than 50% of the electron pressure an anticorrelation between the total electron temperature and electron density can occur as the density of the core electron density varies relative to the halo electron density. They plan to investigate this issue within other solar ejecta events.

Geometry of Magnetic Clouds. Much attention has been given to the comparison of predictions of the self-similar model for the evolution of the total magnetic field. Using multispacecraft observations of the 10 January 1997 cloud, V. Osherovich, J. Fainberg and R. G. Stone have found that the self-similar model adequately describes both amplitude and profile of the magnetic field. Specifically, the flattening of the magnetic field profile predicted by the model is found in many old clouds. Such flat profiles cannot be modeled by any cylindrical force-free field. The presence of different polytropic indices inside the same cloud are interpreted within the framework of a multitube model. This model is based on bounded MHD solutions which describe interacting helical tubes embedded in a cylindrical flux rope. Therefore, the model constitutes a major deviation from cylindrical symmetry.

R. Lepping, D. Berdichevsky, and A. Szabo, have initiated a study of the errors expected for magnetic cloud cylindrical symmetric, force-free model fit-parameters in terms of (1) the level of the "noise" in the cloud's magnetic field and (2) how far the spacecraft passed from the axis of the cloud. The early stages of the study entailed examining the difference between the observed field and the best-fit model, where a force-free flux rope of cylindrical shape was used and where 25 cases from WIND magnetic field data were considered. These difference fields were used to investigate the degree of anisotropy of the noise and how the difference field depends on how far the observation is from the cloud's axis. On average the answer is no for both questions. The level of the noise in terms of a typical difference field, based on the first part of the study, was used to guide how to "noise up" simulated magnetic clouds of exactly known characteristics. These were then fitted with the cylindrical model to see how well they replicated the known input characteristics as a function of noise level and distance from the cloud axis. As expected, the derived fit-parameters became less certain for higher levels of noise and for greater distances, but now a quantitative understanding is being obtained. The study is being extended to include how well a magnetic cloud of elliptical cross-section is fitted by this simple earlier model that was developed for the circular cross-section, and a new model-scheme considering this new feature is underway.

Magnetic Flux in Magnetic Clouds. R. Lepping and A. Szabo, joined by GSFC solar physicists C. DeForest and B. Thompson, completed a study of the magnetic fluxes characteristic of a large set (30) of interplanetary magnetic clouds (flux ropes) observed over many decades primarily by the IMP 8 and WIND spacecraft and categorized according to their occurrence during either solar max or min. They employed a model that assumes a force-free magnetic structure and focused on 12 cases which occurred during the SOHO time-frame. The magnetic fluxes for a few select magnetic clouds were estimated, in order to compare their flux content to apparently related solar photospheric magnetic flux. For the two most reliable cases the ratio of magnetic flux at the Sun to that estimated in the magnetic cloud at 1 AU was on average 0.4. The solar flux estimates were derived from SOHO/MDI measurements guided by SOHO/EIT and Yohkoh/SXT observations.

Unusual Magnetic Clouds. R. Lepping, A. Szabo, and L. Burlaga have identified and presented a model description of a magnetic cloud seen in the February 1998 WIND field and plasma data that has a unique flux rope structure. That is, it satisfies the usual force-free model constraints but requires different boundary conditions: in this case the axial field changes sign at an internal "cylindrical shell" where usually the outer boundary was assumed to be located. This is contrary to all other examples of magnetic clouds yet observed. The apparent solar origin of such a structure is under review.

The WIND events of 7-8 January 1998, are interpreted in terms of observations of adjacent magnetic clouds, or large flux ropes. R. Lepping, A. Szabo, and L. Burlaga were joined by solar physicists D. Webb (Boston College) and B. Thompson and plasma physicists A. Lazarus (MIT) and J. Steinberg (LANL) in a research effort describing these events and their model characteristics. The first flux rope was shown to have about three times the diameter of the second one. These structures apparently can be related to separate events on the Sun's surface occurring about 4 days earlier which may help to explain why they arrive in their time-order and with their estimated axial-attitudes.

Shock Inside a Magnetic Cloud. Using high time resolution data from the WIND MFI experiment, in conjunction with data from the WIND/3DP and WIND/MASS instruments, M. R. Collier, W. Farrell, J. A. Slavin, A. Szabo, and R. P. Lepping in association with other investigators have assembled observations of an unusual "shock in formation" inside the 19 October 1995 magnetic cloud. The results indicate a complex internal structure to the magnetic cloud suggesting that magnetic clouds may be highly structured dynamic phenomena and that current whistler models based on parallel propagating waves may be inadequate.

The Heliospheric Current Sheet. A. Szabo, R. Lepping, working with D. Larson (Univ. of California, Berkeley), studying multispacecraft observations of the heliospheric current sheet (HCS), found that many large 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 Re). The generation mechanisms of these extreme magnetic field shears are not well understood but suspected to be the remains of solar coronal dynamic activity.

The Heliospheric Current Sheath in the Magnetosheath. A. Szabo has also demonstrated that the discontinuities associated with the HCS can be reliably observed in the Earth's magnetosheath. A statistical study of these discontinuities observed first in the interplanetary medium then in the magnetosheath showed a systematic deviation of the discontinuity surface normals towards the local bow shock normal direction. Also, it has been shown that the type of the discontinuity can undergo modification as it passes through the bow shock.

Interplanetary Shocks. A. Szabo and D. Berdichevsky have fitted all WIND-observed interplanetary (IP) shocks from the launch of the spacecraft (November 1994) until June 1997. They have used a variety of techniques, among them a complete MHD Rankine-Hugoniot nonlinear least squares method, to obtain shock normals and speeds with reliable estimates of the uncertainties in these parameters.

Geometry of Interplanetary Shocks. Using WIND and IMP 8 observations of the same IP shocks, A. Szabo has demonstrated that nonnegligible deviations between the corresponding shock normals exist. The deviations have a slight correlation with the S/C separation perpendicular to the Sun-Earth line, but no radial separation dependence. S/C separation effects alone appear to be insufficient to explain the shock normal deviations. It is suggested that the IP shock surfaces have waves or deformations on the scale of 10s of R_E which result in the observed shock normal direction deviations.

Corotating Interaction Regions. K. Ogilvie and E. C. Roelof (APL) have been interpreting the series of corotating interaction regions (CIR's) observed by Ulysses in 1992 and 1993, using SWICS and HI-SCALE particle data with use of plasma and magnetic field data in a supplementary capacity. In a paper, Ogilvie, Roelof, and Forsyth (1998), describe the relationship between CIR interfaces defined by local maxima in the argument of specific entropy and by observations of solar wind ionization state and composition. This study served to draw attention to inconsistencies in the present understanding of the behavior of energetic particles at CIR's. Specific entropy appears not to order the flux of energetic particles.

Relationship Between Energetic Particles and Plasma Temperature. Another paper by Ogilvie and Roelof (in preparation) shows the relationship between energetic particle fluxes and plasma moment temperature is normally very close across the energy range 60 keV to ~ 1 MeV. Observations, which can interpret this finding, were reported by Gloeckler et al., 1995, concerning the phase space densities derived from SWICS and HI SCALE observations. This work will continue.

Correlation of Interplanetary Structures. The emphasis on multipoint measurements resulting from the plethora of

spacecraft currently operational raises important questions, including the degree of accuracy expected in extrapolating upstream solar wind measurements downstream to points on the Earth's magnetosphere. A team of investigators at GSFC, including M. R. Collier, J. A. Slavin, R. P. Lepping, A. Szabo, and K. Ogilvie, using data from the WIND and IMP 8 spacecraft, have evaluated using a cross-correlation analysis the timing accuracy expected from multipoint measurements. Given the WIND and IMP 8 trajectories, about 88% of the time the timing accuracy will be good to within 25%.

As collaboration between GSFC (K. Ogilvie), MIT (A. J. Lazarus), and the Univ. of Maryland (Coplan), studies are being made of the correlation between plasma measurements at L1 (SOHO) and WIND in its double lunar-swingby orbit. The ranges of separation are up to 240 R_E in the Xse direction, < 100 R_E in Yse, and < 20 R_E in the Z direction. With a time resolution of ~ 1 min it has been possible to separate the advective delay of the solar wind from the corotational delay. Calculated correlations, between fluxes, densities and velocities observed at the two spacecraft are usually greater than 0.75, but clear intervals exist when this is not so. If we interpret the corotational delay in terms of an angle of a corotating disturbance, these fronts are frequently aligned with the interplanetary magnetic field.

Geometry of IMF Structures. Using interplanetary magnetic field data from three spacecraft, WIND, IMP 8, and GEOTAIL, M. R. Collier, A. Szabo, J. A. Slavin, R. P. Lepping, and D. Fairfield have determined the characteristic radius of curvature of interplanetary magnetic field structures. Preliminary results indicate that, with some variation, the typical radius of curvature is of the order of 100 or so AU. These results indicate that structures may be assumed approximately planar over scale sizes of the order of tens of Earth radii.

Ion Foreshock of Earth. D. Berdichevsky (Raytheon-STX), G. Thejappa (Univ. of Maryland), R. Fitzenreiter, and R. Lepping (both NASA/GSFC), the late T. Yamamoto, and S. Kokubun (both Japan), R. McEntire and D. Williams (both APL/Johns Hopkins Univ.), and R. P. Lin (Univ. of California, Berkeley) developed and presented a simple method which allows the determination of intervals of magnetic conjunction between far-located spacecraft in the ion foreshock region. This method allowed the authors to present observations at locations approximately magnetically conjugated (in space and time, near and far upstream [70 to 230 R_E] of the Earth's bow shock) where there were simultaneous and in one case sequential occurrence of enhancements of ultra low frequency (ULF) waves, (i.e., waves below the proton cyclotron frequency), while strongly scattered ions were present. These new observations of distant ion foreshocks, similar in many ways to the near ion foreshock, may help to shed light on the important process of wave-energetic particle coupling observed in the vicinity of planetary and interplanetary shocks.

V. SPACE SCIENCE MISSIONS: OPERATIONAL

IMP 8

Magnetic Field Investigation. The fall of 1998 marks the 25th 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 functions as upstream solar wind monitor, along with ACE and WIND, and increasingly as a source of useful magnetospheric data, especially in the magnetotail. 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 and by helping to form various positional constellations for ISTP correlative studies. The magnetometer team (R. Lepping, P.I.) continues to enhance the magnetometer investigation's home page, which provides IMP 8 magnetic field data in a useful form to the public. Major areas of study by the team are large-scale interplanetary structures, the bow shock and magnetosheath (A. Szabo and R. Lepping) as well as the magnetotail (J. Slavin). Recently a major effort has been initiated to produce very high-resolution IMP 8 magnetic field data for the entire mission (J. Slavin). After proper editing these data will be free to the public, and their availability will be well advertised on the Web.

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 70 AU while Voyager 2 is approaching 60 AU. L. Burlaga is responsible for the reduction of the data and is active in the analysis of these data, which are now the weakest magnetic fields ever measured, approximately 0.02 nT.

Ulysses

URAPS and SWICS. The Ulysses spacecraft is now in the second orbit of its exploration of the high-latitude heliosphere. In late 1998, 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 P.I. R. MacDowall is at GSFC as are co-investigators M. Desch, J. Fainberg, M. Goldstein, M. Kaiser, M. Reiner, and R. Stone (P.I., Emeritus); K. Ogilvie is a co-investigator on the SWICS team.

GEOTAIL

Magnetic Field Investigations. The GEOTAIL magnetic fields investigation is a collaborative effort between the LEP and various institutions in Japan. Prof. S. Kokubun (Solar Terrestrial Environment Laboratory) is the P.I. and D. H. Fairfield and M. H. Acuña are co-investigators. After 6 years of operation the GEOTAIL magnetic field measurements continue to play a major role in studies of the dynamics of the nightside magnetosphere including plasmoids, reconnection, and the formation of the substorm current wedge.

WIND

Project Status. The WIND spacecraft spent the early part of 1998 in a partial halo orbit at the L1 libration point tracking Earth-directed coronal mass ejections at radio wavelengths, monitoring the solar wind input to Earth as part of ISTP, cross-calibrating instrument response with ACE spacecraft instrumentation, and measuring solar wind structures in conjunction with ACE and IMP 8. In early May, WIND began a return to double-lunar swingby orbits and phasing loops in order to initiate a unique series of petal orbits that will begin 17 November. The 14-day petal orbits ($5R_E$ x 80 R_E) will take WIND to high inclinations on the dawn side of the magnetosphere and around to the nightside magnetotail region. The petals will terminate 1 April 1999 when a backflip maneuver will be executed to return the spacecraft to the dayside once again. During this latter phase of the mission, WIND will continue to monitor the solar wind about 80% of the time, will continue to track CME's, and will continue to measure energetic particles from active solar regions. WIND continues to operate with a single data tape recorder having lost the primary tape recorder in December 1997. This loss has not materially affected data coverage. All of WIND's eight instruments continue to operate normally with no major problems. The WIND Project Scientist is K. W. Ogilvie and the Deputy Project Scientist is M. Desch.

Magnetic Fields Investigation. The WIND Magnetic Fields Investigation (MFI-R. Lepping, P.I.) continues to operate properly. Its data contributes to many space science studies around the world, and the MFI team often collaborates directly in a large number of these studies. The MFI investigation's web page has been augmented over the last year, especially in the areas of magnetic clouds, the magnetosphere, and the lunar wake. The web page's extensive bibliography of over 90 papers continues to grow bearing witness to value of the MFI data. The team has assisted an NRL team, lead by J. Chen, to display the results of their successful solar wind prediction algorithm, whose purpose is to estimate the probability of an observed (by WIND) solar wind feature being geoeffective. Plans are underway to produce the highest resolution magnetic field data on a production basis. Other Lab members of the MFI team are M. Acuña, L. Burlaga, M. Collier, W. Farrell, R. Kennon, J. Scheifele, J. Slavin, A. Szabo, and E. Worley; there are five off -campus members also.

Solar Wind Experiment. 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. W. Ogilvie.

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. In 1998, a second campaign period was conducted in Alaska that brought together concentrated satellite, airplane, and ground-based observations. 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 Dr. Charles W. Carlson (Univ. of California at Berkeley). Dr. Robert F. Pfaff Jr. of the LEP is the NASA Project Scientist for the FAST mission.

POLAR

Project Status. Polar operations, especially in conjunction with ground-based facilities, continues to provide multispectral images of the Earth's aurorae and comprehensive particles and fields observations in the high-latitude magnetosphere. Currently, some short-period anomalies between the planned pointing direction of the despun platform that contains the three auroral imagers and telemetered position data for the platform are being investigated. No significant instrument problems have occurred for some time. The first ISTP workshop was held in Europe in late September at the Rutherford Appelton Laboratory, with over 160 attendees. Contract and grant activities for the Polar extended mission are significant because all the old contracts and grants stemming from the development phase of the program are being closed. An important new issue arising from the public availability of Polar data has been raised regarding the publication of data obtained from the web and explicitly uncertified. The editor of *GRL* requested a Project opinion on two particular cases where the authors of manuscripts did not request certification by the data provider. While there appear to be violations of the Data Rights Rules of the ISTP Project, the Project office is not in a position to prevent publication. The authors have agreed to add specific comments regarding the data used. The editor of *GRL* has subsequently requested general policy statements from the Project.

Thermal Ion Dynamics Experiment-Plasma Source Instrument (TIDE-PSI). Based on operations of the PSI, B. L. Giles and T. E. Moore, collaborating with Dr. J. L. Horwitz and Y.-J. Su of the Univ. of Alabama in Huntsville, completed the first ever survey of the high-altitude polar wind throughout the polar cap region, and a complementary survey of the polar wind at 1 Earth radius altitude. They found that the polar wind is faster and hotter than anticipated by theories, and richer in heavy O^+ ions. In addition, they found that the polar wind density and therefore flux is strongly controlled by the solar zenith angle on the conjugate ionosphere, and that the source of the O^+ is in the dayside auroral zone or magnetospheric cleft region. With M. Hirahara, they also made new observations of plasma heating in the auroral zones, shown responsible for the escape of the heavier atmospheric components including oxygen. Comparison with auroral imagery allowed definitive association with bright auroral features. With D. Dempsey (Rice Univ.) and C. Russell (UCLA) they also reported observations of solar wind plasma interactions with ionospheric plasma in the dayside cleft region.

Polar Electric Field Instrument. NASA's Polar satellite continues to acquire unprecedented data in the Earth's inner and outer magnetosphere, polar cap, and cusp regions. The payload includes the first vector electric field instrument to be flown in the Earth's magnetosphere. In-depth studies of electric fields in the cusp are among the projects undertaken by LEP scientists during 1998. The principal investigator for the Polar Electric Field instrument on Polar is Prof. Forrest

Mozer (Univ. of California at Berkeley). At the LEP, the electric field team consists of Drs. Robert Pfaff and Michael Hesse.

Galileo

Radio-Science. F. M. Flasar and P. J. Schinder, with colleagues D. P. Hinson (Stanford Univ.) and A. J. Kliore (JPL) have analyzed Earth occultations of the Galileo spacecraft by Io. Refraction in Io's ionosphere of the transmitted monochromatic 13-cm signal from the spacecraft to tracking stations on Earth produced additional Doppler-shifts in the received signal frequency that were inverted to obtain vertical profiles of electron density. The Galileo occultations were unusual in that five usable occultations occurred, each with an immersion and emersion leg, sampling a far greater number of locations on Io than available before. The measured ionosphere is highly variable with peak electron densities and their altitudes varying markedly with position. Highest densities are near the sub-Jupiter and anti-Jupiter points of Io. Evidence is seen of a wake on the downstream side of Io relative to the magnetosphere corotating with Jupiter. Cross-correlation of data from two receiving stations indicate that the wake plasma velocities in the downstream direction increase from small values near Io's surface to the corotating velocity (57 km/s) about 7 Io radii downstream.

Cassini

Composite InfraRed Spectrometer. Launched on the Cassini spacecraft in October 1997, CIRS is an infrared spectrometer that measures planetary radiation from 1 mm to 7 µm. It is a combination of a standard Michelson interferometer operating at wavelengths shortward of 16 µm and a polarizing Martin-Puplett interferometer operating at longer wavelengths. Shortly after launch, the interferometers' common moving-mirror scan mechanism was successfully unlatched. In the ensuing months, CIRS has undergone several health checks and appears to be functioning normally. Because of potential damage to its sensitive infrared detectors from sunlight, both the telescope cover and passive radiator cooler cover remain in place. The latter is to be released near the end of 1999, after the spacecraft is at a distance of 2 AU from the Sun. The telescope cover will be released shortly before the Jupiter flyby, which occurs in late 2000. Observations of Jupiter are tentatively planned, but the primary target is the Saturn system. V. Kunde leads an international science team that includes LEP scientists G. Bjoraker, J. Brasunas, F. M. Flasar, D. Jennings, P. Romani, J. Pearl, R. Samuelson, D. Glenar, R. K. Achterberg, and R. Fettig.

Plasma Investigation. Under the direction of E. Sittler, the LEP delivered several key subsystems to Southwest Research Institute which were then integrated with the Cassini Plasma Spectrometer (CAPS) instrument, tested and then integrated with the spacecraft which was then successfully launched in October 1997. The subsystems delivered by the LEP included a Spectrum Analyzer Module (SAM) and a ± 16 kV high-voltage power supply called HVU-1. SAM acquires time-of-flight (TOF) data from the Ion Mass Spectrometer (IMS) from which it builds TOF spectra, and processes the TOF spectra to produce ion counts for a pre-selected group of ions. HVU-1 provides a total of 30 kV across the linear electric field section of the IMS.

This power supply uses a novel design to provide a regulated 1200 volts to a microchannel plate floating at -15 kV. We also provided flight software for SAM and the CPU2 processor of the DPU. Preparations are now made for a flight software load in October 1998 and instrument checkout in January 1999.

Radio and Plasma Wave Investigation. LEP has scientific co-investigator involvement in the Cassini RPWS radio and plasma wave experiment (Kaiser, Desch, and Farrell). Specifically, the Cassini radio receiver was turned on very shortly after launch, and immediately made remote measurements of Jovian decametric and hectometric radio emissions which are currently being used to supplement ground-based observations of the planet. The spacecraft has since made a close encounter with Venus, and the RPWS experiment made critical and unique determinations of the various magnetoplasma boundary layers based upon their plasma wave signatures.

NEAR

X-Ray/Gamma-Ray Investigation. The NEAR x-ray/gamma-ray team (led by J. Trombka and including P. Clark, L. Evans, S. Floyd, T. McClanahan, and R. Star) is involved in the operation of the NEAR XGRS and system during the cruise phase of the mission. Instrument operations 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. A program for observing gamma-ray bursts has been initiated and three to five bursts per week have been observed during the period of XGRS operations. The very strong gamma-ray bursts which occurred on 15 December 1997, was observed in coincidence with observations made on the Ulysses and Compton Gamma-Ray Observatory. Effects of long-term radiation exposure have been observed in the gamma-ray/x-ray detectors and the mechanism producing this degradation is understood. The results of these studies are presently being prepared for publication. A number of students from both universities and high schools have participated in developing significant parts of the NEAR XGRS data management acquisition analysis processing system.

Magnetic Fields Investigation. The NEAR spacecraft recently executed a close Earth fly-by on its way to a rendez-vous with asteroid Eros 433 in January 1999. This spacecraft is instrumented with a Magnetic Field Experiment which was developed jointly by GSFC and JHU/APL with scientific participation by UCLA-IGPP. The Team Leader is an LEP scientist, M. H. Acuña.

Due to cost and schedule limitations the NEAR spacecraft was built with minimal magnetic constraints. This results in significant spacecraft generated magnetic signatures being detected by the magnetometer which require careful characterization and removal. This activity has been conducted at JHU/APL by Dr. B. Anderson with excellent results as evidenced by the close agreement between the data obtained during the Earth fly-by and that acquired by the WIND spacecraft. This validation will result in excellent data acquisition at Eros with an estimated RMS error approaching 1 nT in magnitude.

NEAR will arrive at Eros 433 on 10 January 1999, and will remain in orbit around the asteroid for 1 year. Prepeparations are underway to process the magnetic field data into physical frameworks taking into account different shape models and coordinate systems. The magnetometer was reactivated on 17 July 1998, and has been providing continuous data since that time. Several Eros possible magnetization models are being developed taking into account the latest observations of planetary magnetism in the solar system. Magnetic field measurements are

crucial in providing data about the nature of the interior of

Eros.

Mars Global Surveyor

Magnetometer-Electron Reflectometer Investigation. The Mars Global Surveyor spacecraft, in a highly elliptical and nearly polar orbit about Mars since September 1997, 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. H. 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. The MAG/ER investigation aboard MGS acquires measurements of the vector magnetic field and electron fluxes in the Mars environment, extending well below the altitude of the ionosphere near periapsis.

The present-day Mars lacks an appreciable global magnetic field, but numerous and surprizingly strong magnetic sources have been identified in the outer shell, or crust, of the planet. Each periapsis pass samples the crustal field at low altitudes over a narrow range of latitudes and longitudes within a few minutes of periapsis. Through the early phase of the mission, the latitude of periapsis has drifted northward from about 31.7 N (Sept. 1997) to a maximum of 86.3 N (June 1998). Magnetic anomalies are found with magnetic moments of up to 1.6×10^{16} A-m^2, indicating the presence of permanent magnetic sources with both large volume and high iron content. Unconstrained, best fitting dipole models place the sources within the upper 50 km of the Mars crust. Mid-latitude sources appear to be associated with the older, heavily cratered terrain, but a few large high-latitude sources have also been detected to date.

The magnetometer and electron reflectometer experiment (MAG/ER) on the Mars Global Surveyor spacecraft has obtained evidence from many orbits that a magnetic "pile-up" boundary is formed above the planetary ionopause as has also been observed at Venus and comets. The high-resolution studies of plasma characteristics and magnetic field structure are used to delineate the relative roles of the various physical processes believed responsible for the formation of the "pile-up" boundary. These include photoionization, charge exchange, electron impact and mass loading. The direct interaction of the solar wind and the Mars atmosphere may help explain the loss of an early Mars atmosphere and water ocean.

Thermal Emission Spectrometer. Investigations by J. Pearl and his coworkers of the Martian atmosphere continue, based on data obtained by the Thermal Emission Spectrometer on the orbiting Mars Global Surveyor spacecraft. Excellent datasets covering the planetary vertical temperature field to 4 scale heights for 1/2 Martian year, the vertical distribution of ice and dust aerosols, and the complete life cycle of the regional Noachis dust storm of Nov.-Dec. 1997, have been obtained. Analysis continues in cooperation with B. J. Conrath (Cornell Univ.) and M. D. Smith (Catholic Univ. of America). Preliminary results have been published (Christensen, et al., 1998; Keating, et al., 1998).

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.

Lunar Prospector

Magnetometer-Electron Reflectometer Investigation. The Lunar Prospector Magnetometer-Electron Reflectometer (MAG-ER) Investigation is a joint venture between the LEP, the Univ. of California at Berkeley and the Univ. of Toulouse. Its objective is to provide the first global mapping of the Moon's permanent crustal magnetic fields. Arriving at the Moon in January 1998, MAG-ER is detecting these magnetic fields either directly by the magnetometer, if they are sufficiently strong, or indirectly through the observation of electrons which have been caused to "mirror" before impacting the lunar surface and are reflected back to Lunar Prospector. Initial results have already provided support for the Apollo-era hypothesis that many crustal regions of magnetization are associated with large impact features. The MAG-ER team has also discovered one region with a diameter of over a 100 km of sufficiently strong magnetic fields to shield the lunar surface from the solar wind (Lin et al., 1998).

VI. SPACE SCIENCE MISSIONS: DEVELOPMENTAL

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.

New Millenium DS-4

CIRCLE. The Champollion Infrared Comet Lander Experiment (CIRCLE, P.I. R. Yelle, Boston Univ.) is one of two instruments being developed for the New Millenium DS-4 rendezvous mission with comet Tempel-1, with a planned 2003 launch. D. Glenar participates as a member of the science definition team for this instrument, which incorporates a 1-4 micron AOTF spectrometer channel. This instrument is being developed jointly by Boston Univ., JPL and GSFC. A breadboard of the CIRCLE spectrometer source will be developed in the LEP Planetary Systems Branch and then exercised by making spectroscopic measurements of cryogenic ices, in coordination with M. Moore of the Astrochemistry Branch.

Pluto Fast Flyby and EO-1

LEISA Development. D. C. Reuter, D. E. Jennings and G. H. McCabe (LEP, Raytheon/STX) 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 which is formed by placing an 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. Scanning may be accomplished by a number of methods such as by the orbital motion of the spacecraft, by rotating the spacecraft, as was planned for PFF, or by a steerable mirror. The actual spatial resolution is determined by the spatial resolution of the imaging optic, the image scan speed, and the readout rate of the array. The spectrometer has no moving parts, a minimum of optical elements and only one electronically activated element, the array. Compared to conventional grating, prism, or Fourier transform spectrometers and mechanically or electrically tunable filter systems, it represents a great reduction in optical and mechanical complexity.

LEISA was flown as one of the major scientific instruments on the TRW Small Satellite Technology Program (SSTP) satellite NASA Lewis Research Center launched in August 1997. Unfortunately, this satellite re-entered prematurely in September 1997 before any data were obtained. The LEISA/Atmospheric Corrector (LAC) will fly on the New Millennium Program Earth Orbiter 1 (EO-1) mission to be launched in December 1999. In this case the camera will provide 250-meter spatial resolution, 0.89 to 1.6 micron spectral images at a constant spectral resolution of ~ 35 cm^{-1}. The primary purpose of this atmospheric data is to correct the high spatial resolution, low spectral resolution Landsat-type multispectral images (from another instrument on board) for the spatially and temporally variable effects of the atmosphere. Planned formation flying encounters with the operational Landsat satellite will allow the operational Landsat data to be corrected for atmospheric effects as well. Atmospheric correction is expected to improve the accuracy of satellite-measured surface reflectances and increase the reliability of data products derived from them. The unique hyperspectral images will also provide scientific data in their own right, including water vapor estimates, cloud and aerosol parameters, and surface properties. In addition to these satellite programs, LEISA was flown in an aircraft in the summers of 1997 and 1998 as part of the instrument complement in an agricultural sensor program. The flights were over agricultural areas near Lubbock, Texas. The purpose of the program is to transfer a GSFC-developed instrument and to develop software to perform atmospheric correction of remotely sensed high spatial resolution multispectral VNIR measurements. This activity was part of a Space Act Agreement with Boeing Commercial Space Company.

Mars 2003 Lander

Acousto-Optic Imaging Spectrometer (AImS). The NASA Mars Instrument Development Program (MIDP) has approved an AOTF-based brassboard demonstration lander camera for Mars surface composition and mineralogy studies, with LEP scientist D. Glenar as Principal Investigator. The instrument is by its nature electronically programmable and will provide high spatial and spectral resolution imaging within its 0.50 to 2.2 micron tuning range. This development activity is a logical extension of previous activities under the PIDDP and SBIR awards and is on timeline to be proposed for consideration in the Mars 2003 Lander opportunity.

SWAS Mission

Project Status. After a 3-year storage period the Submillimeter Wave Astronomy Satellite (SWAS), the third approved Small Explorer Program mission, is currently undergoing tests in preparation for an early December 1998 launch with the Pegasus XL aircraft-borne rocket. SWAS will observe 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 P.I. for SWAS is Gary Melnick of the Smithsonian Astrophysical Observatory. Gordon Chin is the SWAS Project Scientist.

IMAGE

Project Status. T. Moore continues to serve as mission scientist for the Imager for Magnetopause to Aurora Global Exploration (IMAGE) mission as it progressed through fabrication to environmental testing this year. 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. L. Giles, who joined LEP in February, J. Green, M.-C. Fok, D. L. Gallagher (NASA Marshall Space Flight Center) and with G. Wilson (MRC, Nashua, New Hampshire) and J. Perez (Auburn Univ., Auburn, Alabama).

Low Energy Neutral Atom Imager. As lead co-investigator, T. Moore directs the development of LENA. Science support for LENA includes K. Ogilvie, F. Herrero, J. Keller, D. Chornay and M. Collier, who joined LEP in June. Engineering support from Code 600 included S. Gray (Code 660) as resource analyst, J. Lobell (Code 692) as systems engineer, M. Johnson (Code 695) as control electronics and power engineer, J. Johnson (Code 696) as software engineer, P. Rozmarynowski (Code 690) as mechanical designer, and F. Hunsaker (Code 690) as mechanical engineer and fabrication coordinator. The LENA team in Code 600 was also supported by J. Laudadio (Code 700) as instrument manager, and by a number of Codes 300, 500 and 700 engineering staff members. LENA technical challenges were reduced by descoping to a passive (unheated) conversion surface, based on test results obtained at the Univ. of Denver atomic beam facility. Fabrication is nearing completion with assembly and functional testing beginning as this is written. Calibration and environmental testing will take place in early FY 1999, with delivery to the s/c by 16 February 1999.

Radio Sounder. A radio-sounder known as the Radio Plasma Imager (RPI) will be one of the instruments flown on the IMAGE satellite scheduled for launch on 1 January 2000. The RPI (Instrument P.I.: B. Reinisch, U. Mass., Lowell) is one of a complement of remote sensing instruments on IMAGE (Mission P.I.: J. L. Burch/Southwest Research Institute). R. F. Benson is a member of the RPI team and recently published a tutorial-type paper, with the RPI team, on the capabilities of magnetospheric radio sounding.

VII. SOUNDING ROCKETS AND SUBORBITAL PROGRAMS

Program Status. A member of the LEP staff (Dr. Robert 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) which 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 Earth's atmosphere, including emissions from objects close to the Sun (e.g., comets, Venus, Mercury) which 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.

VLF Emissions From Sporadic E Layer. LEP scientists Cummer, Farrell, and Pfaff have performed a more detailed analysis of VLF electric and magnetic field data from a 1992 rocket flight over Arecibo and found evidence of enhancement of both the electric and magnetic field magnitudes of the signal from the VLF transmitter in Puerto Rico (NAU, 28.5 kHz) inside a high-density sporadic E ionization layer. In contrast, one-dimensional propagation simulations predict an electric field decrease along with a magnetic field increase. Simulation studies will continue in an effort to explain these anomalies.

Cleft Accelerated Plasma Experimental Rocket. The CAPER payload is scheduled for launch in Jan.–Feb. 1999, with final integration during Sep.–Dec. 1998. T. Moore guided the final design of the Thermal Ion Capped Hemisphere Spectrometer (TICHS), which complements the Thermal Electron Capped Hemisphere Spectrometer of C. Pollock (SwRI) to provide comprehensive core plasma observations for this payload. Mechanical fabrication for the pair of instruments was completed at MSFC, while electronics systems have been designed and fabricated at SwRI. The instruments have been functionally tested at MSFC and SwRI, and will be integrated on the payload beginning 24 August. The objective of this mission is to observe and diagnose the mechanisms of plasma heating in the topside ionosphere of the polar cleft region. Analysis has continued on the data set obtained from a previous and closely related rocket payload called Sounding the Cleft Ion Fountain Energization Region (SCIFER). M. Adrian (Univ. of Alabama in Huntsville and MSFC) has completed dissertation work at UAH on the thermal plasma observations from SCIFER, while assisting in the preparations of TECHS and TICHS for the CAPER flight. The focus of analysis is currently on the measurement of electron heat fluxes and core drifts in the plasma heating regions.

Dark Cusp Campaign. In December 1997, NASA carried out a very successful sounding rocket campaign from Spitzbergen, Norway, in which two Black Brant IX sounding rocket payloads were launched into the dayside cusp during darkness. Two unique data sets are now in hand, each containing a treasure trove of particles and fields measurements concerning the dayside cusp. An important set of simultaneous ground-based and satellite data is also available, adding to the richness of the data. One rocket was flown during Bz North and the other during Bz South conditions. Each payload returned DC electric and magnetic fields, plasma waves, energetic particles, photometer data, and thermal plasma data. The GSFC effort, led by Dr. Robert Pfaff, concerns the analysis of the measurements of electrodynamic parameters on the two payloads gathered with instruments built at the Center.

DROPPS Campaign. A new program, DROPPS (The **D**istribution and **R**ole **o**f **P**articles in the **P**olar **S**ummer Mesosphere) involving rockets, radars and lidars has been approved by NASA and is scheduled for launch in July 1999 from Andøya, Norway. This program is expected to investigate the importance of submicroscopic particles to induce the polar mesospheric summer echoes (PMSE's) first seen by 50 MHz radars about 20 years ago.

DROPPS is a focused, international rocket, radar, and lidar program 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 and noctilucent clouds. The P.I. is Dr. Richard Goldberg of the LEP.

As a co-investigator, Dr. Robert Pfaff is preparing electric field instrumentation to measure both the DC and wave electric field environment within the altitude region of 80–88 km where these effects are 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 will be obtained.

Guara Campaign. In August 1994, the MALTED (**M**esospheric **A**nd **L**ower **T**hermospheric **E**quatorial **D**ynamics) Program was conducted from the Alcântara rocket site in Brazil as part of the International Guará Rocket Campaign (Pfaff et al., 1997) to study equatorial dynamics, irregularities and instabilities in the ionosphere. Analysis of these data has provided the first experimental evidence for gravity-wave breaking in the mesosphere (Lehmacher et al., 1997; Goldberg et al., 1997; Fritts et al., 1997).

Sporadic-E Experiment in Conjunction with Arecibo Observatory. In order to investigate the complex electrodynamics and neutral-plasma coupling inherent to sporadic-E layers in the Earth's mid-latitude ionosphere, a series of rocket/radar experiments was planned as part of the NASA El Coqui II Campaign from Tortuguero Launch Range, Puerto Rico, in March–April, 1998. Dr. Robert F. 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 ion mass spectrometer, an ionization gauge, and spaced-electric field receivers to measure the wavelength and phase velocity of the unstable plasma waves. Separate 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, incoherent scatter radar measurements of plasma density and drift velocity were gathered almost every night during the 3-week campaign. Continuous VHF backscatter radar operations were carried out from a site near Salinas, Puerto Rico, where 3-m backscatter echoes were observed associated with sporadic-E and other types of low-altitude ionospheric layers. On 24 March 1998, one of the instrumented rockets was launched, attaining an apogee of 129 km. The payloads successfully pierced an intense sporadic-E layer observed by both the Arecibo radar and the in situ density and ion mass spectrometer probes. In situ DC electric fields revealed very low (~ 1–2 mV/m) ambient fields with small amplitude structures of the same order. No high-frequency (short-scale) waves were observed, consistent with the VHF backscatter observations at the time of the launch.

Metallic Layers From Meteor Showers. In light of the recent high interest on the upcoming strong Leonids meteor shower, we have reviewed all previous mass spectrometer sampling of metallic ions in the meteoric ablation belt (90-110 km altitude) to determine if the influence of specific meteor showers could make a significant and observable difference in the density and composition of metallic ions seen in this belt during meteor showers. Our conclusion based on these data is positive (Grebowsky et al., 1998). As a result, we have proposed a rocket program to study the abundance of ionic debris introduced during meteor showers.

GEODESIC. The GEODESIC mission is designed to uncover the microphysical processes which 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). Dr. Robert Pfaff is a co-investigator on this payload.

Under Dr. Pfaff's supervision at the LEP, 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 Ft. Churchill, Canada.

APEX. The LEP at GSFC is providing a suite of vector DC and wave electric field, DC magnetic field, and thermal plasma instruments to be flown on a sounding rocket experiment in the high-latitude ionosphere, as part of the Active Plasma Experiment (APEX). GSFC's science contributions are led by Dr. Robert Pfaff of the LEP. The payloads are primarily being built by the NASA/Wallops Flight Facility.

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 is scheduled for January 1999 from Poker Flat, Alaska.

Electrodynamics Research From a Remotely Piloted Aircraft. LEP Investigators Houser, Goldberg, Farrell, Desch and Cummer, along with scientists from Penn State and NRL, are investigating transient and steady-state electrical currents above thunderstorms using instrumentation on board aerial remotely piloted vehicles. The Navy's Swallow RPV has a potential altitude capability in excess of 30,000 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. Wallops Flight Facility will provide full operational support including range, TM, and weather services. A 3-day test flight is scheduled for early fall to assure operational readiness prior to the science campaign scheduled for late summer 1998 or early spring 1999.

Finally, in a conceptual study, it is attempted to develop an instrumental package to be flown on a remotely piloted aircraft (RPA) 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 RPA 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 (Goldberg et al., 1997).

VIII. FUTURE MISSIONS

Solar Terrestrial Probes

Magnetospheric Multiscale (MMS). The second new mission in the Solar Terrestrial Probe line after the solar mission, STEREO, is MMS. MMS will utilize advanced commercial off-the-shelf technology to fly a seven- spacecraft mission to explore virtually the entire magnetosphere at unprecedented resolution. The dynamics of the magnetosphere system from the kinetic scales through MHD scales will be examined by a next-generation cluster of five spacecraft. Four spacecraft in a quasi-tetrahedral array suffice to uniquely separate space and time which is required for quantitative closure between observations and theory. However a fifth spacecraft may be used to generate an additional three tetrahedra. This will allow the advanced cluster to uniquely separate space and time for quantities such as current density which are derived from the curl of the magnetic field for which a single cluster acts as a point measurement. The individual spacecraft will be instrumented with particle and field detectors to fully characterize the ambient plasma. The separations of the spacecraft will vary from kilometers to several Earth radii depending on location and will allow the first look at the magnetosphere at variable resolution from micro to meso scales over this vast range. In addition to the five spacecraft advanced cluster, there are two spacecraft placed in orbits to image the global inner magnetosphere and hence to place the smaller scale advanced cluster measurements in context. The instruments on the imaging spacecraft will utilize the energetic neutral imaging technology which is being pioneered for Earth usage on the IMAGE MIDEX mission. The Science Technology Definition Team (STDT) is chaired by J. Burch of SWRI. The Project Scientist is S. Curtis of GSFC, and J. Gervin of GSFC is the Project Formulation Manager. GSFC participants on the STDT include R. Vondrak, M. Hesse, and J. Slavin.

Global Electrodynamics. The science and technology implementation planning for the GED spacecraft mission, one of NASA's Solar Terrestrial Probe missions, has begun with the selection (by NASA Headquarters) of its Science and Technology Definition team (STDT) which held its first meeting at GSFC in late August. This mission will consist of multiple spacecraft potentially dipping to altitudes lower than any previous spacecraft and is scheduled for launch in approximately 2007. It will bring closure to our understanding of the key electrodynamic roles that the ionosphere and lower thermosphere play in the Sun-Earth connection. Multiple spacecraft are required to resolve the many spatial and temporal scales that characterize the underlying physics. The STDT is chaired by R. A. Heelis, U. Texas at Dallas. GSFC involvement includes R. F. Pfaff as a member of the STDT, J. M. Grebowsky as the GED Project Scientist, and J. C. Gervin as the Project Formulation Manager for the mission.

Magnetospheric Constellation. The fourth mission identified in the Solar Terrestrial Probe line is Magnetospheric Constellation (MagCon). The MagCon mission concept involves the dispersal of 10's to 100 small--1 to10 kg--spacecraft within the magnetosphere through the use of a "mothership" with propulsion. The scientific objective of MagCon is the mapping of magnetospheric structure and the observation of plasma- dynamic processes involving broad regions of the magnetosphere. Instrumented for particles and fields measurements, such a constellation is presently the only manner in which the temporal and spatial development of such fundamental phenomena as magnetospheric substorms can be resolved in a definitive manner. Technology development in support of the necessary "nanosatellites" is underway at GSFC under the direction of the MagCon Project Manager, P. Panetta. In the coming year an LEP scientist will be appointed as MagCon Study Scientist and a Science and Technology Definition Team will be selected by NASA Headquarters to support the mission development. The launch of the MagCon Mission is scheduled for late 2008.

MIDEX

Dipper Mission. Scientists in the LEP also prepared a MIDEX proposal for a satellite called "Dipper" which was submitted in August 1998 to NASA. The P.I. of the Dipper project is Dr. Robert F. Pfaff Jr. The Dipper satellite will carry out an unprecedented, systematic, and focused in situ exploration of the Earth's lower ionosphere and thermosphere below 200 km that will produce a pivotal base of knowledge from which we will understand how our near-space environment works. It will carry, for the first time, comprehensive instruments to the Earth's critical boundary region where the ionized gases of space and the neutral gases of the atmosphere are coupled, and where impinging forces and momentum are deposited from the magnetosphere above and from the troposphere, stratosphere, and mesosphere below. The Dipper includes a comprehensive suite of well-proven scientific instruments and a very experienced science team from world-class laboratories. The Dipper will be launched on a Delta 7320 and includes propulsion to provide over 10,000 excursions to altitudes below 200 km with over 3000 dips to altitudes below 150 km during its 2-year lifetime.

Electrodynamics Explorer. A joint GSFC-Univ. of Michigan-Univ. of Texas proposal for an ionospheric Electrodynamics Explorer (EFEX) was submitted to NASA Headquarters in response to the latest Small Explorer (MIDEX) Announcement of Opportunity. T. L Killeen of the Univ. of Michigan is the principal investigator and the GSFC co-investigators are J. A. Slavin and M. H. Acuña. GSFC will have responsibility for the vector magnetometer and electric field double probe flight hardware. The primary science objective of EFEX is to obtain global images of the high-latitude ionospheric convection pattern and, together with in situ measurements, quantitatively determine the energy input from the magnetosphere to the high-latitude upper atmosphere under a variety of interplanetary conditions.

DISCOVERY

VESPER Mission. The VEnus Sounder for Planetary ExploRation (VESPER) is a proposed Discovery Mission. 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 allow 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 microns. 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 P.I. is Gordon Chin of GSFC. The science team comprises investigators from the Univ. of Arizona, Cal Tech, Univ. of Cologne, Cornell Univ., GSFC, JPL, Univ. of Massachusetts, Space Science Institute, SUNY Stony Brook, Univ. of Virginia, and Washington Univ. Lockheed Martin Astronautics in Denver, Colorado, will develop the spacecraft and perform mission operations. GSFC will manage the project and develop the VESPER instrument suite.

Janus. A Discovery Step 1 proposal for an extremely fast, relatively inexpensive mission to complete the initial exploration of the inner solar system called Janus has been submitted to NASA Headquarters. The mission takes only 115 days to reach Mercury and only about 1.8 years from launch to fully execute the three Mercury encounters which will allow the first complete geophysical and geochemical mapping of both faces of Mercury and the search for polar water. The mission also features a total of four well-instrumented spacecraft which will permit the first multipoint measurements of a planetary magnetosphere simultaneously at low latitudes, at both poles, and in the magnetotail. The robust instrument complements allow the study of Mercury as an interacting system composed of its interior, surface, atmosphere, and magnetosphere. The mission is a natural Discovery-class precursor to the multiple international orbiter missions which may occur well after the Janus mission is complete. Janus is a partnership among GSFC, JPL, and the Orbital Sciences Corporation. It has a large, critical-mass international science team made possible by the mission's short duration and low expenses that place it far below the Discovery cost cap. The data analysis facility will be run by Bowie State University, a historically black university with an extensive history of partnering with GSFC on advanced data handling, visualization, and analysis techniques. Bowie State University has also run the flight operations for the SAMPEX SMex spacecaft. The P.I. is S. Curtis of GSFC. The LEP scientists will be responsible for the magnetometers, search coils, and the visible/infrared imager. LEP co-investigators on the Janus team are B. Giles, M. Acuña, J. Connerney, M. Desch, R. Macdowall, T. Moore, J. Nuth, D. Reuter, and K. Ogilvie.

MESSENGER Mission. A Discovery program stage 1 proposal for a Mercury orbiter mission called MESSENGER has been submitted to NASA Headquarters. 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. H. Acuña, J. A. Slavin and J. I. Trombka.

Triana Mission. K. Ogilvie has submitted a proposal for a combined high-time resolution magnetometer and plasma instrument for inclusion in the Triana payload in collaboration with Acuña and Lazarus (MIT). The proposal combines solar weather studies with novel solar wind science investigations.

Solar Probe Mission. The Solar Probe Science Working Team (SWT), chartered to define the science objectives for this mission, suggest a strawman science payload, support spacecraft engineering studies and mission design efforts at the Jet Propulsion Laboratory and to contribute to NASA Headquarters' Space Science Strategic Plan development. T. E. Moore and J. A. Slavin serve on this SWT representing plasma and magnetometer instrumentation, respectively.

IX. INSTRUMENT DEVELOPMENT

HIPWAC. The Heterodyne Instrument for Planetary Wind And Composition measurement is being developed by T. Kostiuk, D. Buhl, F. Hunsaker (GSFC) with T. A. Livengood (GSFC and Univ. of Maryland), T. Hewagama, J. Goldstein (Challenger Ctr.), and H. Davé (Raytheon/STX). It will be 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 a variety of telescopes. Substantial improvements will be made in sensitivity and operational capability over the current Coudé-focus IRHS, permanently mounted at the NASA IRTF, enhancing current studies and enabling new studies not now possible. Improved performance will derive from new technologies within the instrument itself and from the characteristics of telescopes that will be accessible to a transportable instrument: (1) improved sensitivity on small targets with large (8-10 m) telescopes, with a factor of ~ 10 increase for pointlike sources; (2) improved spatial discrimination on large telescopes; (3) reduced velocity broadening on large telescopes due to the range of Doppler shifts across the instrument FOV from the planet's rotation, increasing the effective spectral resolution and information content in spectra; (4) improved system quantum efficiency from current components; (5) improved frequency determination due to all factors but especially the improved telescope tracking stability and accuracy from Cassegrain focus vs. Coudé focus; (6) flexible access to telescopes, since large (8-10 m) telescopes are not needed for all tasks; and (7) access to different latitudes, such as observatories in the Southern Hemisphere or at high northern latitudes. A prototype laser cavity for the CO_2 laser local oscillator has been constructed using advanced composite materials by K. Segal and P. Blake (GSFC, 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.

Superconducting Bolometer. J. Brasunas and B. Lakew are preparing a high Tc superconductor (HTS) bolometer for flight aboard the space shuttle in October 1998. Its resistive transition will be measured in space, to determine if this device is robust with respect to launch and to the space environment.

New Planetary Astronomy Observational Program. The near-IR spectrum (1.7-5.2 micron) of Saturn will be investigated using a new AOTF camera. The key objective is to obtain a photometrically calibrated spectral image cube of Saturn between 1.7-5.2 micron. With these data we will identify the 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-micron "hot spots" and characterize the spatial variations in trace molecular species. Investigators include John Hillman, Dave Glenar, Gordon Bjoraker and Nancy Chanover.

Mars Observing Campaign. An observing campaign is being formed for the Mars opposition which occurs in late April 1999. Our objective is to assemble a photometrically calibrated, spectrally complete ground-based image cube at the highest possible spatial resolution. These measurements will employ new observing technologies and will be concurrent both with spacecraft measurements and supporting observations by the upgraded Hubble Space Telescope. Three observing teams will conduct the investigations with three instruments spanning 0.6-5.0 micron. The instruments and planned observing facilities are: (a) Visible/NIR AOTF camera will be employed at USAF/Phillips Lab 1.5m, laser-beacon adaptive optics telescope. Auxiliary camera with interference filter wheel. 600-1050 nm. ~ 0.3 arcsec (125 km). Science targets: Fe_2^+, Fe_3^+ mineralogy and coarse grain hematite search. (b) SWIR AOTF camera at Apache Point Observatory, 3.5m, f/10, Nasymth focus. 1.7-3.4 micron (AOTF limited). 0.8 arcsec (340 km). Science targets: 3 micron water-of- hydration feature and CO_2, H_2O ice (polar regions and clouds). (c) KPNO cryogenic grating/slit spectrometer (CRSP/SALLY) at KPNO 2.1 m, f/15 Cass. focus. Selected 3-5 micron (L, M band). ~ 1.2 arcsec Nyquist (500 km). Science targets: water-of-hydration (3-4 micron long wave extension) and sulfate mineralogy. Observers participating in this campaign include Dave Glenar, John Hillman, Gordon Bjoraker and Fred Espenak from GSFC, Nancy Chanover from NMSU, Diana Blaney from JPL and Dick Joyce from KPNO.

Global Distribution of Ozone in the Atmosphere of Mars. F. Espenak is leading the team of T. Kostiuk, D. Buhl (GSFC), T. A. Livengood, K. E. Fast (GSFC and Univ. of Maryland) T. Hewagama, and J. Goldstein (Challenger Ctr.) in observations of the O_3 molecule in the atmosphere of Mars planned for March 1999, using the Goddard Infrared Heterodyne Spectrometer. The global distribution of O_3 in Mars' atmosphere will be 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.

Champollion Lander. D. Glenar is participating in the science definition team for the Champollion Infrared Comet Lander Experiment, (CIRCLE, P.I. Yelle, Boston Univ.). This instrument uses a 1-4 micron AOTF spectrometer channel and will fly on the New Millenium DS-4 rendezvous mission with comet Tempel-1, with planned 2003 launch. A breadboard of the CIRCLE spectrometer source will be developed in GSFC Code 693 and then exercised by making spectroscopic measurements of cryogenic ices, in coordination with GSFC Code 691 (M. Moore).

Mars Instrument Development Program. NASA Headquarters has approved a brassboard demonstration lander camera for Mars surface composition/mineralogy studies (P.I. D. Glenar). AImS, (for acousto-optic imaging spectrometer) is by its nature electronically programmable and will provide high spatial and spectral resolution imaging within its 0.5 to 2.2 micron tuning range. This development activity is a logical extension of previous activities under the PIDDP and SBIR awards and is on timeline to be proposed for consideration in the Mars 2003 Lander opportunity.

Solar Probe Plasma Instrument. Recently the LEP has been developing a plasma spectrometer capability that will allow one to look in the solar direction (nadir viewing) as close as 3 solar radii from the Sun's surface. At these distances the solar input is more than 2000 times that at 1

AU. The design concept being developed by E. Sittler, J. Keller, K. W. Ogilvie and F. Hunsaker is composed of a dual parabolic electrostatic mirror system with one of the electrostatic mirrors located behind a miniature heat shield. The design of the miniature heat shield is being done in collaboration with NASA Langley Research Center. With this design concept the plasma spectrometer can be safely located behind the primary heat shield of the spacecraft. We have been successful in our design of the miniature heat shield so that the thermal input to the spacecraft bus is less than 12 watts while simultaneously meeting all physical constraints on the miniature heat shield and FOV requirements. A prototype of the miniature heat shield has recently been completed. Preliminary testing of the electrostatic mirror concept is now being performed. We are now in the process of designing and building the spectrometer itself.

Electric Field Experiment Group. The LEP includes an active electric field experimental group, led by Dr. Robert F. Pfaff, that designs and builds electric field double probes for flights on sounding rockets and satellites in the Earth's ionosphere. Onboard processing electronics have also 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.

In the past year, instruments were flown on four payloads, which include electric field probes and electronics to measure both the DC and AC vector electric field components as well as Langmuir probes. These experiments were launched on sounding rockets into the cusp from Spitzbergen, Norway, in December 1997, and into a sporadic-E layer from Puerto Rico in March 1998.

X. EDUCATIONAL OUTREACH

Education Outreach Committee. The Laboratory's Education and Outreach Committee, chaired by R. Lepping, continues to extend itself to the public by assisting teachers and students of nearby schools, and in particular by judging grade 7-12 science fairs. Other members of the committee are R. Benson, P. Clark, M. Collier, F. Espenak, J. Kalb, M. Moore, F. Ottens, A. Roberts, D. Stern, and J. Trombka. Its main purpose is to help provide the public with a better understanding of the role of space scientists, and of our Lab's work in particular, in the nation's science program. The committee continues to develop a home page which includes the work of the Lab, especially aimed at young people.

Visiting Teacher. As part of the NASA-Prince Georges County Teacher Intern program, Mrs. L. Newsome, from Benjamin Tasker Middle School in Bowie, Maryland, returned to visit the Laboratory again for 6 weeks. She assisted in the further development of the Lab's education and outreach home page, in particular on the Lab's "Missions" section and on a new introductory welcome page. She also consulted, as last year, on the further extension and improvement of the web page's glossary. She worked with A. Szabo and her mentor, R. Lepping.

Visiting Student. Rachana Oza, a student from Montgomery Blair High School, Silver Spring, Maryland, also visited our Laboratory for 6 weeks, and participated in research aimed at understanding the source of errors in the position of the IMP 8 spacecraft and analytically determining them using magnetic field data from IMP 8 and the WIND spacecraft in a novel approach. She also contributed to the Lab's education web page, especially with advice on how to make it more appealing to students. She was part of a competitive program called National

Space Scholars Club of gifted high school students. She was given guidance by A. Szabo and her mentor, R. Lepping.

Greg Bilyk and Andrew Rankin of T. C. Williams High School in Alexandria, Virginia, visited the heterodyne laboratory throughout June and July and part of August, with the guidance of T. Kostiuk as well as F. Hunsaker (GSFC) and T. A. Livengood (GSFC and Univ. of Maryland). They constructed mock-ups of the HIPWAC heterodyne instrument and its laser cavity, and assisted in the design and implementation of a light baffle for use with the new optical guide system installed this summer on the Infrared Heterodyne Spectrometer at the NASA Infrared Telescope Facility in Hawaii. Greg additionally assisted with the archiving of field data collected over 1993-1997. Both students had previously been associated with our laboratory while working on a science fair project on the prospects for remote detection of extraterrestrial life within or outside the solar system.

Elementary School Outreach. P. Romani collaborated with teachers and their students at Glenarden Woods Elementary School in Glenarden, Maryland, and at Wildwood Elementary School in Amherst, Massachusetts, to duplicate Eratosthenes's measurement of the circumference of the Earth. Eratosthenes was a Greek who lived and experimented in Egypt in the Ptolemaic era. His determination of the Earth's circumference was within 15% of the modern day value. The project was funded by an IDEAS grant that was cowritten with the teachers. Lesson plans were developed and tested and the students' work was videotaped along with interviews of the teachers and P. Romani. This fall there will be a workshop for teachers at Amherst, Massachusetts, to explain how this hands-on experiment can be integrated into elementary school science curriculum.

LENA Poster. In conjunction with the LENA instrument team under the direction of T. Moore, a LENA instrument poster emphasizing flight hardware was assembled and mounted on the second floor of Building 2, GSFC. We intend to use this poster as a basis for creating products suitable for general audiences, as well as one suitable for the space physics community and for inclusion in a web page.

New Educational Web Sites. Following the successful educational web site "The Exploration of the Earth's Magnetosphere" (http://www-spof.gsfc.nasa.gov/

Education/Intro.html) a new educational site of comparable size, "From Stargazers to Starships," was produced (http://www-spof.gsfc.nasa.gov/stargaze/Sintro.htm). In "Exploration" the first third of the site overlapped the standard high school curriculum (magnetism, ions, electrons, the Sun) but later sections were more specialized. "Stargazers," in contrast, devotes about equal length to naked-eye astronomy, Newtonian mechanics and space flight, and can provide the framework for a 1-year course in high school. It aims to integrate NASA-related topics into the high school curriculum, e.g., illustrating the concept of inertial mass with mass measurements of astronauts in zero-g aboard Skylab. As in "Exploration," the material follows a historical thread, but unlike "Exploration," some mathematics is included, along with a "mathematical refresher" which describes the tools used and makes the site self-contained.

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