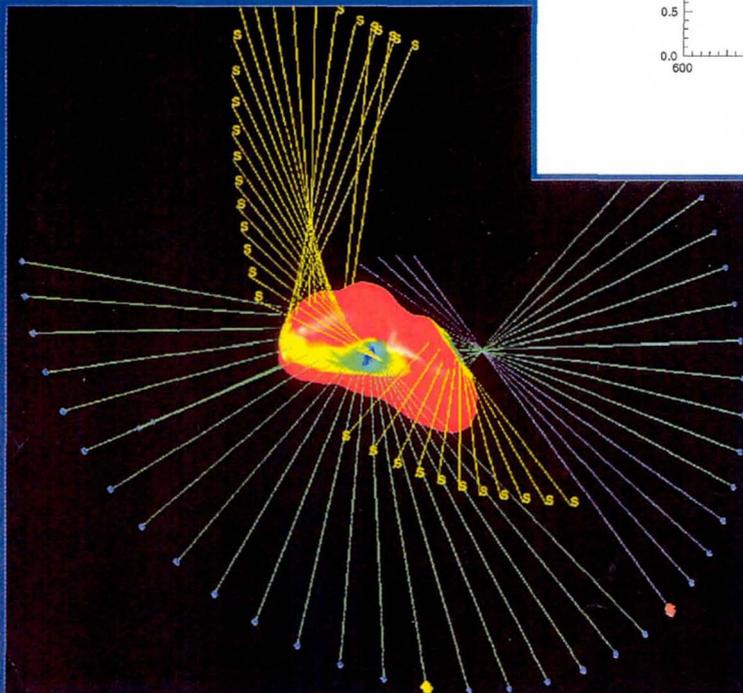
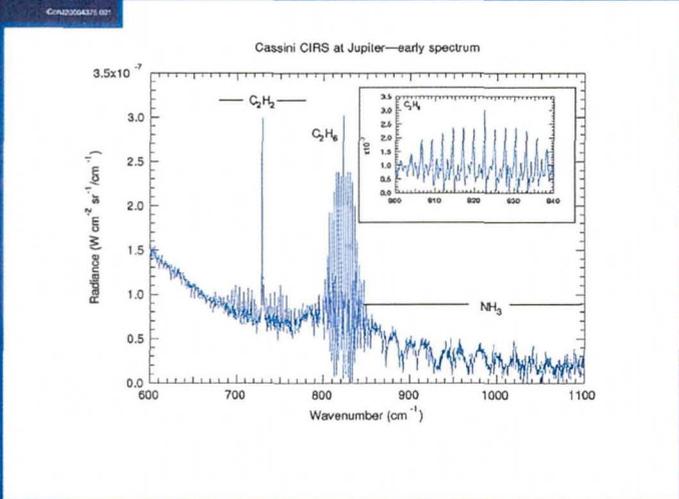
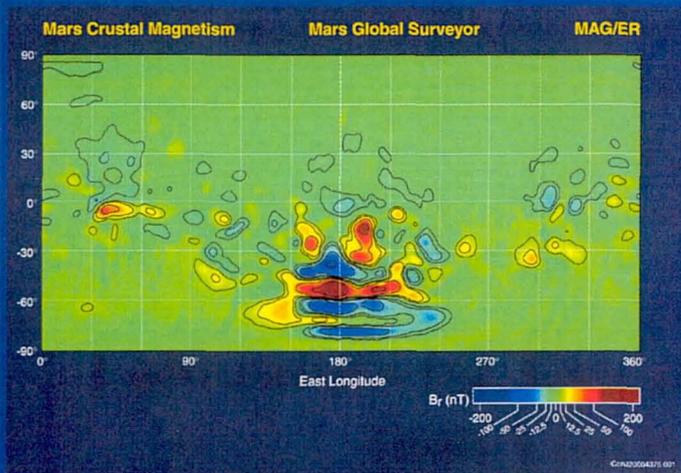


Laboratory for Extraterrestrial Physics 2000 Yearly Report



**2000 Yearly Report
Laboratory for Extraterrestrial Physics**

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PUBLICATIONS LISTING

Editors - Book Lakew, Donald Fairfield, and David Stern

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The NASA Goddard Space Flight Center (GSFC) Laboratory for Extraterrestrial Physics (LEP) performs experimental and theoretical research on the heliosphere, the interstellar medium, and the magnetospheres and upper atmospheres of the planets, including Earth.

LEP space scientists investigate the structure and dynamics of the magnetospheres of the planets including Earth. Their research programs encompass the magnetic fields intrinsic to many planetary bodies as well as their charged-particle environments and plasma-wave emissions. The LEP also conducts research into the nature of planetary ionospheres and their coupling to both the upper atmospheres and their magnetospheres. Finally, the LEP carries out a broad-based research program in heliospheric physics covering the origins of the solar wind, its propagation outward through the solar system all the way to its termination where it encounters the local interstellar medium. Special emphasis is placed on the study of solar coronal mass ejections (CME's), shock waves, and the structure and properties of the fast and slow solar wind.

LEP planetary scientists study the chemistry and physics of planetary stratospheres and tropospheres and of solar system bodies including meteorites, asteroids, comets, and planets. The LEP conducts a focused program in astronomy, particularly in the infrared and in short as well as very long radio wavelengths. We also perform an extensive program of laboratory research, including spectroscopy and physical chemistry related to astronomical objects.

The Laboratory proposes, develops, fabricates, and integrates experiments on Earth-orbiting, planetary, and heliospheric spacecraft to measure the characteristics of planetary atmospheres and magnetic fields, and electromagnetic fields and plasmas in space. We design and develop spectrometric instrumentation for continuum and spectral line observations in the x-ray, gamma-ray, infrared, and radio regimes; these are flown on spacecraft to study the interplanetary medium, asteroids, comets, and planets. Suborbital sounding rockets and ground-based observing platforms form an integral part of these research activities.

This report covers the period from approximately October 1999 through September 2000.

1 Personnel

Dr. Richard Vondrak continues as Chief of the LEP. Mr. Franklin Ottens is Assistant Chief. The Branch Heads are Dr. Joseph Nuth (Astrochemistry); Dr. Thomas Moore (Interplanetary Physics); Dr. Drake Deming (Planetary Systems); Dr. Steven Curtis (Planetary Magnetospheres), and Dr. James Slavin (Elec-

trodynamics). 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. 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. Michael Hesse, Dr. Robert Hoffman, Dr. Donald Jennings, Mr. Michael Kaiser, Dr. John Keller, Dr. Alexander Klimas, Dr. Theodor Kostiuik, Dr. Brook Lakew, Dr. Ronald Lepping, Dr. Robert MacDowall, Dr. William Maguire, Dr. Marla Moore, Dr. David Nava, Dr. Larry Nittler, Dr. Walter Payne, Dr. John Pearl, Dr. Robert Pfaff, Dr. Dennis Reuter, Dr. D. Aaron Roberts, Dr. Paul Romani, Dr. Robert Samuelson, Dr. Edward Sittler, Dr. Michael Smith, Dr. David Stern, Dr. Adam Szabo, Dr. Jacob Trombka, Dr. Adolfo Figueroa-Viñas, and Dr. Peter Wasilewski. The following are National Research Council Associates: Dr. Akimasa Ieda, Dr. Robert Boyle, Dr. Dana Hurlley Crider, Dr. Steven Cummer, Dr. Aharon Eviatar, Dr. Robert Glinski, Dr. Natchimuthuk Gopalswamy, Dr. Cedric Goukenleuque, Dr. Hugh Hill, Dr. Kristi Keller, Dr. Gunther Kletetschka, Dr. Patrick Michael, Dr. Lutz Rastätter, Dr. Frank Schmölling, Dr. Kristine Sigsbee, Dr. Peyton Thorn, Dr. Vadim Uritsky, and Dr. Oleg Vaisberg. The following scientists work at LEP as either contractors to GSFC or as long-term visiting faculty: (Raytheon/ITSS) Dr. Ashraf Ali, Dr. Daniel Berdichevsky, Dr. Scott Boardsen, Dr. Rainer Fettig, Dr. Henry Freudenreich, Dr. Georgi Georgiev, Dr. Roger Hess, Dr. Shrikanth Kanekal, Dr. Masha Kuznetsova, Dr. Nitya Nath, Mr. George McCabe, Dr. Vladimir Osherovich, Dr. Mauricio Peredo, Dr. Michael Reiner, Dr. Pamela Solomon, Dr. Adinarayan Sundaram, and Dr. Nikolai Tsyganenko; (Universities Space Research Association (USRA)) Dr. Mei-Ching Fok, Dr. Venku Jayanti, Dr. Kathleen McClernan, Dr. Dimitris Vassiliadis, and Dr. Hung Kit Wong; (Applied Research Corporation) Dr. Sanjoy Ghosh, and Dr. Edouard Siregar; (Computer Sciences Corporation (CSC)) Dr. Larry Evans; (Catholic University of America) Dr. Dennis Bogan, Dr. Pamela Clark, Dr. Tamara Dickinson, Dr. Michael DiSanti, Dr. Frank Ferguson, Dr. Fred Nesbitt, Dr. Neil Dello Russo, and Dr. Richard

Starr; (Space Science Applications, Inc. (SSAI)) Dr. Richard Achterberg, and Dr. Ronald Carlson; (University of Maryland Baltimore County (UMBC)) Dr. David Steyert; (Georgia Southern University) Dr. Robert Nelson; (University of Maryland, College Park) Dr. Dennis Chornay, Ms. Kelly Fast, Dr. Thejappa Golla, and Mr. Virgil Kunde; (Charles County Community College) Dr. George Kraus; (IONA College) Dr. Robert Novak; (Cornell University) Dr. Barney Conrath and Dr. Paul Schinder; (Challenger Center) Dr. Jeff Goldstein, Dr. Tilak Hewagama, and Dr. Timothy Livenood; (NOMAD Research) Dr. Dean Pesnell; (National Institute of Standards and Technology (NIST)) Dr. Vladimir Orkin; (John's Hopkins Applied Physics Laboratory (APL/IPA)) Dr. Nicola Fox; (Eckerd College) Dr. Reginald Hudson; (University of Colorado) Mr. Jeremy Richardson; (University of Oslo) Dr. Nikolai Ostgaard; (University of Bergen) Dr. Johan Stadsnes.

A large and very capable staff of engineers, technicians, secretaries, and computational personnel also support the work of the LEP scientists.

2 Astrochemistry

2.1 Chemical Kinetics

Outer Planet Hydrocarbon Chemistry. The reaction of D atoms with methyl radicals (CH_3) is important in the chemistry occurring in the thermosphere of Jupiter. *In-situ* measurements of the D/H ratio by the Galileo probe mass spectrometer (Mahaffy, Donahue, Atreya, Owen and Niemann, 1998) have prompted modelers to explain the observations through calculations of the atomic D distribution using a 1-D photochemical diffusion model combined with a radiative transfer model. The major reactions involved in the model include those of H and D atoms with H, HD, H_2 and CH_3 (Parkinson, Griffioen, McConnell, Jaffel, Vidal-Madjar, Clarke and Gladstone, 1999). F. Nesbitt, R. 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, as reported previously, completed an experimental and theoretical study of the limiting high-pressure rate coefficient for the reaction $\text{H} + \text{CH}_3 + \text{M} \rightarrow \text{CH}_4 + \text{M}$. Since this reaction is far from the high-pressure limit under typical experimental conditions, the approach to this study was to measure the rate constant for the isotopic variant $\text{D} + \text{CH}_3 \rightarrow \text{CH}_3\text{D}^* \rightarrow \text{CH}_2\text{D} + \text{H}$ which, with a small isotope correction, mimics the rate at the high-pressure limit. It was clearly established that, at low pressures, the initially formed methane complex CH_3D is not stabilized. Subsequently, these results alerted the modelers of the Galileo observations to the fact that the reaction of D with CH_3 is a rapid two-body reaction leading to CH_2D and not a slow three-body reaction forming CH_3D . Our results on $\text{D} + \text{CH}_3$ turned out to be crucial for the modeling calculations.

Stratospheric Chemistry. Halogen oxides are known to play an important role in atmospheric chemistry, es-

pecially in catalytic reaction cycles involved in stratospheric ozone depletion. The role of bromine oxides has long been established and recently the efficiency of bromine in this regard has been estimated to be about 50 times larger than chlorine. The recent detection of OBrO in the stratosphere has prompted suggestions that this oxide may serve as a nighttime reservoir for bromine. R. Thorn and L. Stief in collaboration with R. Klemm (Brookhaven National Laboratory), and T. Buckley and R. Johnson (both at NIST) measured the heat of formation for OBrO using a discharge flow-photoionization mass spectrometer apparatus coupled to the U-11 beam on the vacuum ultra-violet ring at the National Synchrotron Light Source at Brookhaven National Laboratory. The appearance energy of BrO^+ from the dissociative ionization of OBrO was determined from the measured threshold at $\lambda = 98.65 \pm 0.23$ nm to be $\text{AE}(\text{BrO}^+, \text{OBrO}) = 12.57 \pm 0.03$ eV. Taking known thermodynamic quantities this result yields $\Delta_f H^\circ = 173 \pm 4$ kJ mol $^{-1}$, the first experimental measurement of the heat of formation of OBrO. In addition, our computations yield a theoretical value of 164 ± 8 kJ mol $^{-1}$ which is in good agreement with the experimental result. These results will be useful to both modelers and kineticists when evaluating the viability of potential atmospheric reactions involving this species.

Cosmic Ices. Infrared spectroscopy of cosmic-type ices exposed to both proton bombardment and to UV photolysis within the same experimental setup is now possible in the Cosmic Ice Laboratory at GSFC. This unique facility is used to examine a variety of physical-chemical and radiation-chemical processes in ices. Experiments lead to the formation of many complex organic molecules through processes that are thought to represent those occurring on comets, interstellar icy-grains or on the surfaces of icy satellites. (1) The radiation chemistry of water-methanol ices near 16K was reinvestigated. R. Hudson (Eckerd College) and M. Moore found no evidence for the formation of acetone (previously, a variety of authors hinted that acetone was present). Ethylene glycol is identified in the ice and is also a residual material left after most water is sublimed. (2) P. Gerkakines (NRC), M. Moore and R. Hudson (Eckerd College) have compared the nature of products formed after proton irradiation and UV photolysis of a variety of simple binary and a few ternary mixtures. For $\text{H}_2\text{O} + \text{CO}_2$ we showed that both energy sources form carbonic acid, and CO with similar formation yields. An extension of this work is the direct comparison of photolysis and irradiation of $\text{H}_2\text{O} + \text{CO}_2 + \text{CH}_3\text{OH}$ and $\text{H}_2\text{O} + \text{CO}_2 + \text{CH}_4$ ices at 18K in the same laboratory with ices created under the same conditions. Although the processing methods are not identical, there are many similarities between the results of the experiments, i.e. similar products and yields. However, there are two major differences: the formate ion is only observed for proton irradiated CH_3OH containing ices, and (2) the rate of CO formation is measured to be 2 to 4 times higher in UV-photolyzed ices. (3) R. Hudson and M. Moore

reported on new experiments and interpretations concerning the "XCN" band detected in some interstellar ice spectra. New laboratory spectra of UV-photolyzed and proton-irradiated ices were completed and interpreted using the role of e^- and H^+ scavengers to reveal the photo and radiation chemistries. The idea that XCN is the cyanate ion is presented. An extension of this work leads to the prediction of the chemical precursors required for the synthesis of the "OCN⁻" band. This is possible since most experiments have been performed along with appropriate isotopic substitutions. (4) M. Moore, R. Hudson, and P. Gerakines have posted infrared data to the Cosmic-Ice Laboratory web page (www-691.gsfc.nasa.gov/cosmic_ices). Data serve as reference spectra of molecules in H_2O -dominated ices at 15-20 K measured from 2.5 to 25 microns.

Low-Temperature Thermodynamic Properties.

In collaboration with R. Nelson the vapor pressure of ethane has been measured from 95-k just above the triple point - to 72 K using the low-temperature vapor pressure system at GSFC. New data were also acquired for propane from ~ 250 to 80 K to further refine the preliminary measurements for this molecule that were reported in a paper describing our apparatus. Work has begun to develop the experimental protocols necessary to measure the thermodynamic properties of binary systems by concentrating initially on the nitrogen-methane.

Energy Transfer. J. Allen in collaboration with P. Michael (NAS/NRS Resident Research Associate) has measured the vibrational-to-translational (V-T) rate for the self-relaxation of methane from 300 to 90 K using the infrared non-resonant photoacoustic spectrometer at GSFC. Accurate values for the temperature dependence of this rate are required to correct for methane self-relaxation when measuring the V-T relaxation of methane by other molecules in a gas mixture. Experiments are under way to determine the temperature dependence of the V-T rate for the relaxation of methane by nitrogen.

Intracavity Laser Spectroscopy. J. Allen in collaboration with J. Keller, (who recently transferred to the Astrochemistry Branch) have revived and upgraded the intracavity laser spectrometer. Having completed several improvements, the system is being readied to measure the temperature dependence of overtone absorption by deuterium hydride (HD).

2.2 Cosmic Grains

Nucleation, Growth and Metamorphism of Silicates in Astrophysical Environments. We are conducting experimental studies to understand the nucleation of refractory vapors, the chemical speciation of the condensates and the change in the spectral properties of the dust as a function of thermal annealing and hydration. Each of these three experimental tasks presents its own special challenges. We have recently completed studies of the nucleation of lithium vapors (Ferguson and Nuth, 2000) and have begun to study the nucleation of sodium. These studies have been carried out primarily to test the

applicability of several different models currently used to describe the nucleation of refractory vapors, but also because alkali metal clouds might be important opacity sources in the atmospheres of extrasolar planets orbiting close to their parent stars. We have published several papers on the speciation of magnesium silicate, iron silicate, and magnesium-iron silicate condensates applied to circumstellar environments (Rietmeijer, et al., 1999a,b) and to the ISM (Nuth, Hallenbeck and Rietmeijer, 1998; 2000) that demonstrate the importance of metastable eutectics during the vapor-solid phase transition. In particular, we demonstrated that separate populations of pure magnesium silicate and pure iron silicate smokes condense from an iron-magnesium-silica-rich vapor phase. This observation greatly simplifies prediction of the spectral properties of the initial condensate (Nuth, Rietmeijer, et al., 2000) and the spectral evolution of the smokes as a function of thermal annealing (Hallenbeck et al., 2000).

Experimental studies of the nucleation of dilute iron vapors demonstrated that single magnetic domain iron grains form spontaneously in the complete absence of a magnetic field (Nuth and Withey, 1999). Such grains were observed to be fully magnetized and coagulated extremely efficiently due to magnetically enhanced coagulation. Experimental studies of the catalytic activity of our iron silicate condensates demonstrated that such materials are extremely efficient Fischer-Tropsch type catalysts (Ferrante, et al., 2000) and further studies of both iron and magnesium silicates are in progress. Finally, our measurements of the temperature dependent evolution of magnesium silicate smokes (Hallenbeck et al., 2000) lead us to propose a new method by which the relative formation age of individual comets might be determined based on the relative proportions of crystalline and amorphous grains in their comae (Nuth, Hill, and Kletetschka, 2000). The method could be put on a quantitative footing by dating returned crystalline silicate dust from several comets and can be observationally tested by searching for the predicted correlation between the ratio of the crystalline to amorphous dust fraction and the increasing fraction of volatile organics (versus CO) in the comet as this ratio increases. Older comets contain more amorphous dust and fewer complex organic molecules.

For the first time it has been demonstrated that experimentally produced, amorphous iron silicate smokes act as Fischer-Tropsch-Type catalysts to convert H_2 and CO into simple hydrocarbons. R. Ferrante (US Naval Academy) and M. Moore studied the catalysis for temperatures from 470-670 K and reactant gas mixtures of H_2/CO with a ratio of 2-100. Maximum conversion rates of a few percentage points were achieved over only a 3-h time period. Major products were methane, ethane, ethylene, carbon dioxide, and water. Products were identified by IR spectroscopy.

3 Planetary and Cometary Physics

Laboratory Gas-Phase Spectroscopy. A significant ef-

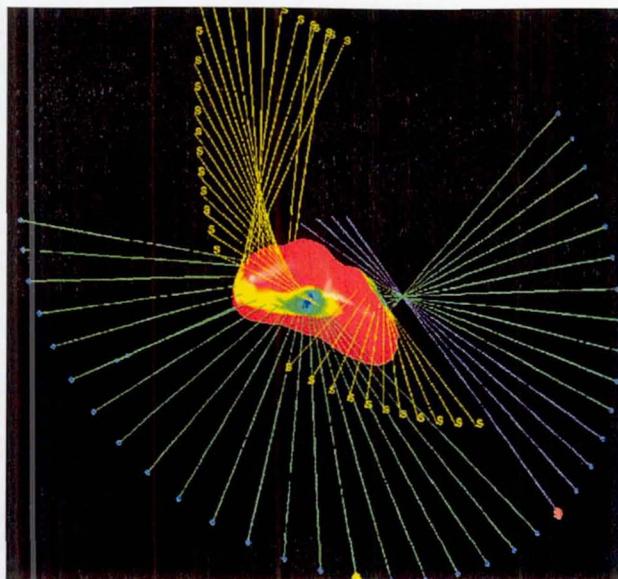


Fig. 1.— Analysis of the x-ray fluorescent emission from the surface of Eros as part of the Shoemaker-NEAR Discovery Mission requires detailed knowledge of both the sun angle illuminating the surface viewed by the instrument and the instrument viewing geometry as the signal is acquired. Simulation of one orbital pass is displayed.

fort in the LEP is high-resolution laboratory infrared spectroscopy of gaseous molecular species. The research by the LEP spectroscopy group composed of D. Reuter, J. Sirota, J. Hillman, and D. Steyert is focused primarily on molecules of planetary and astrophysical interest, and supports NASA flight missions in both these areas. The work also supports ground-based astronomy and terrestrial atmospheric studies. Particular emphasis is placed on obtaining reliable intensities; self- and foreign-gas pressure broadening coefficients and line-mixing effects. There is a vigorous program to measure Tunable Diode Laser (TDL) and Fourier Transform Spectrometer (FTS) spectra at wavelengths greater than $10\ \mu\text{m}$. Supporting laboratory measurements are scarce for these wavelengths, but are crucial for the analysis of data from upcoming space missions such as Cassini, where CIRS will obtain spectra of Saturn and Titan from 7 to $1000\ \mu\text{m}$. Recent activities of the group have included obtaining and/or analyzing spectral data for excited state and fundamental transitions in H_2 , $^{13}\text{C}\ ^{12}\text{CH}_6$, $^{12}\text{C}_2\text{H}_6$, C_2H_4 , C_2H_2 , N_2O , CO_2 , C_3H_4 (both the methylacetylene and allene isomers), $(\text{CH}_3)_2\text{CO}$ and HNO_3 . This work has been carried out in collaboration with personnel at several institutions including W. Blass (U. of Tennessee), N. Donahue (Harvard University), J. Frye (Howard University), J. Johns (NRC, Canada), M. Mickelson (Denison University), A. Perrin (C.N.R.S., Paris), L. Strow (UMBC), C. Suarez (NRC, Argentina) and R. Tipping (U. of Alabama). These measurements have already impacted planetary studies. For example, the ν_{12} ^{13}C ethane ($^{13}\text{C}^{12}\text{CH}_6$) intensities have been used

in conjunction with ground-based observations to infer an essentially terrestrial $^{13}\text{C}/^{12}\text{C}$ ratio on Jupiter and Saturn, while the intensities of the ethylene (C_2H_4) transitions have been used to obtain concentrations of this species in the upper atmosphere of Saturn. The low temperature line intensity and self- and nitrogen broadened measurements of the ν_9 band of allene near $28\ \mu\text{m}$ 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. The group has also developed theoretical models for the infrared spectra of molecules in cometary comae including formaldehyde, methanol and OCS.

As well as obtaining and analyzing spectra, the group places a strong emphasis on improving instrumentation and, among other accomplishments, has developed a unique TDL system for obtaining spectra to $\sim 30\ \mu\text{m}$ employing advanced (Si:As and Si:Sb) BIB detectors, high performance lead-salt lasers, and a long-path White-type sample cell. A very long-path, coolable White-type cell has been developed which allows spectra to be obtained at pathlengths in excess of 500 m and at temperatures as low as 120 K. The group has used the BIB detectors and a CsI beamsplitter to obtain high-resolution, long wavelength, FTS spectra using a Bruker spectrometer at Harvard University. The group also uses the Kitt Peak National Observatory's McMath-Pierce FTS spectrometer to obtain accurately calibrated spectra of molecules of planetary and terrestrial interest, and has developed several techniques (e.g. double-passing the beam to double the spectral resolution) to enhance this spectrometer. An effort is also in place to develop methods for external cavity stabilization of long-wavelength TDLs.

Infrared Heterodyne Spectroscopy of Isotopic Ethylene. T. Kostiuk, W. Blass (U. of Tennessee), T. Livengood, T. Hewagama, and D. Buhl in collaboration with V. Morozhenko and A. Kollyukh (Institute of Semiconductor Physics, Ukraine) completed two papers "Infrared Heterodyne Spectroscopic Measurements of Ethylene and Isotopic Ethylene ($^{13}\text{C}^{12}\text{CH}_4$) Transitions Between $840\ \text{cm}^{-1}$ and $980\ \text{cm}^{-1}$ " and "Self and Nitrogen Broadening of the $\nu_{10}20_{11,10} - 19_{10,9}$ Ethylene Transition at $927.01879\ \text{cm}^{-1}$ " The retrieved molecular parameters are needed for interpreting measurements at high spectral resolution from planetary atmospheres and astrophysical sources. The Infrared Heterodyne Spectroscopy group at GSFC has used a laboratory infrared heterodyne spectrometer to measure the strength, pressure-broadening, and frequency of 168 rotational-vibrational transition lines in the ν_4 , ν_7 , and ν_{10} bands of isotopic ethylene ($^{12}\text{C}_2\text{H}_4$ and $^{13}\text{C}^{12}\text{CH}_4$) at room temperature and at low pressures typical of planetary strato-

spheres. Frequencies and intensities were determined to better than $5 \times 10^{-5} \text{ cm}^{-1}$ and 10% respectively. Pressure broadening coefficients were determined to $\sim 10\%$. Ethylene is a product of methane photochemistry and is a chemically important trace species in the atmosphere of Jupiter, Saturn, and Titan. The two manuscripts have been submitted for publication.

A Model for Beam-Integrated High Resolution Spectral Line Observations. T. Hewagama and K. Fast (U. of Maryland), J. Goldstein and T. Livengood, and T. Kostiuk have developed a numerical algorithm that will accurately model beam integrated spectral lines from molecules in solar system planetary atmospheres. The model employs a vertically inhomogeneous infrared radiative transfer algorithm to calculate the contributions from different portions of the source for a given atmospheric thermal profile, and accurately applies the beam response and manifestations due to atmospheric dynamics. An important feature of the model is the incorporation of a non-linear model parameter optimization algorithm which provides the capability of fitting observational data. The model was used to derive the ethane molecular abundance and direction of the zonal wind field in Titan's stratosphere from IR heterodyne spectroscopy observations. It is also being used in the analysis of IR heterodyne spectroscopy observations of molecular lines in the atmospheres of Jupiter, Venus, and Mars.

3.1 Venus

Data analysis by F. Schmillig (NRC), J. Goldstein, T. Hewagama (U. of Maryland), and T. Kostiuk, of high precision wind measurements of the upper Venus atmosphere is currently in process. Lines in both $^{12}\text{CO}_2$ emission and $^{13}\text{CO}_2$ absorption from the atmosphere of Venus, measured at a resolving power of 6×10^6 using infrared heterodyne spectroscopy, are being analyzed to retrieve high altitude (110 km) horizontal wind velocities for a sub-solar to anti-solar flow and a zonal retrograde component; and a lower altitude (70 km) anti-solar to sub-solar return flow. The accuracy of the results will be on the order of 1 m/s.

3.2 The Moon

Solar Eclipse Predictions. In November 1999, F. Espenak authored NASA TP-1999-209484 titled "Total Solar Eclipse of 2001 June 21." This publication contains complete details for the eclipse including tables, maps, figures, and meteorological statistics for viewing sites. The NASA eclipse bulletins are prepared in cooperation with the IAU Working Group on Eclipses as a public service to both the professional and lay communities, including educators and the media. The publication is also available on the web at: <http://umbra.nascom.nasa.gov/eclipse/010621/rp.html>.

Migration of Hydrogen to the Lunar Poles. D. Crider and R. Vondrak have constructed a Monte Carlo model that simulates the migration of particles in the lunar exosphere. The particles begin at a location consistent

with the expected distribution of particles given the solar wind as the source. The particle then reacts with the surface through sputtering. The particle is assumed to thermalize to the local surface temperature of the Moon. It is released with a velocity taken from the Maxwellian distribution at that local temperature in a random direction. Under the effects of gravity, the trajectory is calculated. If the particle escapes the Moon, it is recorded as lost to the system. While in transit, it has a probability of being ionized by solar photons or solar wind particles. If it is ionized, it is lost from the system. Otherwise, the particle is allowed to land at its new position, thermalize and take another hop. If the particle lands poleward of 85° , we test to see if it arrived in a cold trap by comparing the fraction of cold trap area at that pole to a random number. The trapped particles are counted. If the particle lands on the night side of the Moon, it remains adsorbed in place until the lunation brings it across the terminator. D. Crider and R. Vondrak find that the solar wind can supply enough hydrogen to the polar hydrogen deposits in 36 million years. This amount of time is reasonable considering the stability of the Moon's orbit.

3.3 Mars

Martian Volatiles. Analysis of ground-based Mars spectral mapping data acquired during the April 1999 opposition ($L_s=130$) by D. Glenar and G. Bjoraker, D. Blaney (JPL), and R. Joyce (KPNO) has demonstrated that Martian volatiles can be distinguished, mapped and inventoried at regional scales using ground-based near-IR spectroscopy at moderately high spectral resolution ($R>1000$). S. Polar CO_2 ice has been identified and mapped using "forbidden" 2.28 and 2.32 micron features which are sensitive to grain size. The data set, acquired at roughly the beginning of the Mars Global Surveyor science mapping mission, also reveals the distribution of mid- North latitude H_2O ice clouds, and (tentatively) a N. polar H_2O ice collar. Both of these have been observed independently by MGS/TES (J. Pearl/693). Reduction of the data is continuing and a manuscript summarizing the detection and measured distribution of Martian volatiles is in preparation.

Magnetic Field of Mars. Completion of aerobraking maneuvers by the Mars Global Surveyor allowed the acquisition of close-in magnetic field data by the Magnetometer/Electron Reflectometer (MAG/ER) over a significant portion of the planet covering a broad range of longitudes and latitudes. M. Acuña is the Principal Investigator (P.I.) for the MAG/ER, J. Connerney and P. Wasilewski are Co-investigators (Co-I's). Mapping of the strong crustal magnetic sources previously discovered during the first aerobraking and science phasing orbits revealed the existence of very strongly magnetized areas south of the dichotomy boundary and a very close correlation between the location of the sources and the ancient, cratered highlands of Noachian age. Furthermore, the absence of crustal magnetization in large impact plains such as Hellas and Argyre suggests that the Martian dynamo ceased to operate very early in the his-

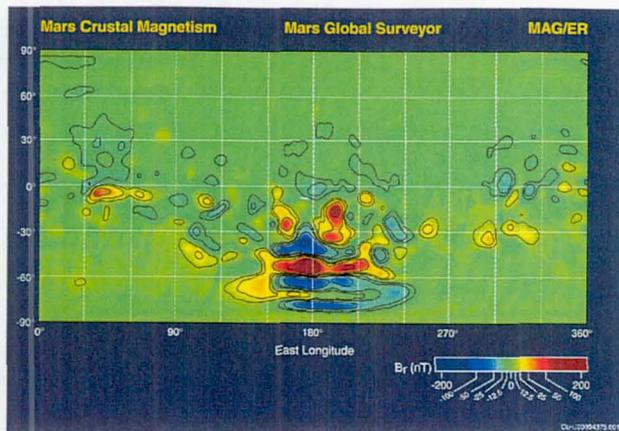


Fig. 2.— Map of the magnetic field of Mars at MGS mapping altitude of 400 (+/-30) km. The radial component of the magnetic field associated with crustal sources is illustrated using the color scale shown. Observations used for this map were obtained while the spacecraft was in the shadow of Mars during mapping cycles 1-3 and 10-12. The median value of all observations for each 3 degree latitude by 3 degree longitude bin is plotted.

tory of the planet, within the first few hundred million years. This important discovery has profound implications for our current understanding of Mars' early history and thermal evolution. Added to these important findings is the discovery of very strongly magnetized linear features extending thousands of Km in Terra Sirenum and Terra Cimmeria has further challenged our understanding of tectonic processes at Mars. The structure of these magnetic lineations suggests the prior existence of tectonic processes at Mars similar to those observed at Earth in connection with seafloor spreading. The alignment of these features follows approximately that of grabens and stress faults associated with the Tharsis rise suggesting that the lineations could have been caused by buckling and fracturing of an ancient, thin magnetized shell rather than a continuous spreading process. The intense magnetization (~ 20 A/m) of the crustal layer, modeled as a 30 Km slab, is another problem that has been addressed by members of the team. Laboratory studies of magnetic susceptibility in meteorites suggest that hematite may play an important role in explaining the high remnant magnetization of the crust.

Analysis of Mars Global Surveyor Magnetic Field and Electron Data to Understand the Solar Wind Interaction with Mars. D. Crider and members of the Magnetometer-Electron Reflectometer (MAG/ER) team have conducted qualitative analyses of the magnetic field morphology in the solar wind interaction with Mars using MAG/ER data. The radial component of the magnetic field on the dayside of Mars, away from the strong crustal fields was investigated. In the draping picture, the solar wind magnetic field is mostly horizontal on the entire dayside of the planet, with a slight downward or upward component that is grouped by east-west hemi-

spheres in a magnetic field aligned coordinate system. It was found that the radial part of the magnetic field has an average that is closer to zero inside the ionosphere than outside of the ionosphere. However, the distribution is much broader inside the ionosphere than outside. This result fits well with those of D. Mitchell (U. of California, Berkeley) who has shown that the ionosphere tends to extend to higher altitudes over the strong crustal magnetic sources. Their results show a broad distribution inside the ionosphere due to contributions from the strongly magnetized regions, even though they tried to avoid those areas.

O₃ in the Atmosphere of Mars. W. Maguire is continuing his characterization of ozone in Mars atmosphere using the IR limb data from the Thermal Emission Spectrometer (TES) instrument on the Mars Global Surveyor (MGS). Photochemical models predict a large seasonal variation in O₃ abundance, in higher abundance as water vapor abundance decreases. In addition, the models predict a significant diurnal variation of O₃ superimposed on this seasonal variation. These models, together with ground- and other spacecraft-based observations, are being used as guides in the analysis of large spectral averages assembled from the TES data. P. Christensen (Arizona State University) is the TES P.I. and J. Pearl is a Co-I. In collaboration with J. Pearl, M. Smith, B. Conrath, M. Kaelberer, E. Winter and E. Guandique, and P. Christensen (P.I., Arizona State Univ.) MGS/TES data analysis is being carried out. Recent results include mapping Mars's water vapor.

Ozone Study by Using Photolysis Product. R. Novak spent his sabbatical year at GSFC working with M. Mumma. R. Novak, M. Mumma, and M. DiSanti conducted the first detailed study of ozone on Mars using emission from its photolysis product, the O₂(¹Δ_g) band system, to probe ozone in the middle atmosphere. They also measured atmospheric water by observing the Δ₁ band of HDO near 3.67 μm (DiSanti and Mumma 1995). Both species were mapped at high spatial resolution, and diurnal and seasonal effects were explored. Enhanced ozone was detected over the dawn terminator, confirming the predicted buildup during the Martian night. Together, these measurements provide a new approach for studies of the water-ozone cycle on Mars.

Infrared Heterodyne Measurements of O₃ in the Atmosphere of Mars. F. Espenak and R. Cortland (National Space Club Summer Scholar) completed basic reduction and preliminary analysis of Mars spectra obtained with the Goddard Infrared Heterodyne Spectrometer (IRHS) to measure ozone in the atmosphere of Mars at 9.66 microns. The observations were performed atop Mauna Kea at the coude focus of the 3 meter NASA Infrared Telescope Facility (IRTF) during March 1999. Terrestrial O₃ normally renders Earth's atmosphere opaque to these frequencies, but Mars' large geocentric radial velocity near quadrature shifts the O₃ lines into the wings of their telluric counterparts where the terrestrial atmosphere is transparent enough to permit the observations. Radiative transfer analysis soft-

ware is being modified for migration onto the SUN workstation.

3.4 Jupiter and Io

Jupiter Observing Program: H₃⁺ Aurora and Io Flux Tube Footprint. J. Connerney and T. Satoh (Science University of Tokyo) continue a program of long-term observations of Jupiter at 3.42 μm wavelength using the NSFCAM infrared camera and NASA's IRTF at Mauna Kea, Hawaii. An image obtained at this wavelength shows H₃⁺ emission from high altitudes (above the methane homopause) against a darkened planetary disc (by absorption due to methane). These images evidence intense and omnipresent auroral emissions at both magnetic poles and emission at the foot of the Io Flux Tube (IFT). The latter often appears as an isolated, sub-arcsecond spot 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. Emission extending well downstream (60 degrees) of the IFT footprint along Io's L shell can be seen at times in both hemispheres. High time resolution imagery of the IFT footprint is used to further our understanding of the electromagnetic interaction between Jupiter and Io.

Recent imagery reveals (over some longitudes) multiple footprints at the foot of the IFT suggesting multiply reflected Alfvén waves passing between Jupiter's ionosphere and the high density torus (Connerney and Satoh, 2000). 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). These images are also used to model the distribution of Jovian H₃⁺ 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 (Satoh and Connerney, 1999). 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. A continued program of observation of the aurora is conducted to monitor the state of the magnetosphere in support of the Galileo Mission.

Spectropolarimetry. In collaboration with Matthew J. Penn (California State University), D. Branstetter (National Solar Observatory - Tucson), and the Staff at the National Solar Observatory at Sacramento Peak, the Dunn Solar Telescope (DST) was used to acquire polarimetric images for sodium line emissions in and near the Io torus during the Galileo's encounter with Io. The data is being reduced to obtain polarization maps of the regions observed.

Composition of the Jovian Atmosphere. G. Bjoraker and T. Hewagama are using spectra of Jupiter acquired with the CSHELL spectrometer at NASA's Infrared Telescope Facility in Hawaii to study the deep atmosphere. Observations of CH₄ and NH₃ were ob-

tained simultaneously with measurements by the Near Infrared Mapping Spectrometer on the Galileo Orbiter. The methane observations are sensitive to the abundance of water vapor between 3 and 7 bars on Jupiter. This technique permits mapping H₂O on Jupiter using ground-based telescopes. Preliminary results show dramatic variations in the abundances of both H₂O and NH₃ near the Great Red Spot. Additional observations are planned to support the Cassini flyby of Jupiter in December 2000.

Jovian Mid-IR Aurora and the Solar Cycle. T. Kostiuik, with Co-I's T. Livengood and J. Goldstein, K. Fast, and T. Hewagama (U. of Maryland), and D. Buhl are continuing their study of the long-term variability of Jupiter's mid-infrared aurora. Evidence for solar cycle-dependent variations in the intensity of 12 μm emissions of the ethane molecule in Jupiter's polar aurorae has been observed since 1977 using infrared heterodyne and Voyager IRIS spectroscopic observations. Ground based measurements were conducted from the NASA Infrared Telescope Facility (IRTF) and along with Voyager IRIS data, span nearly 2 solar cycles, with the most recent observations in November 1999. A solar cycle dependence is significant, as no such dependence has been noted in any other emission from Jupiter's auroral regions. Such dependence may signal changes either in the properties of the impinging particle beams or in the target atmosphere receiving the beam. Additional measurements are planned in December 2000 in coordination with Cassini Composite Infrared Spectrometer (CIRS) during the Cassini flyby of Jupiter. Complementary information on altitude and spatial extent of the emission, hydrocarbon abundances, and temperature will be retrieved by the coordinated measurements.

Comet Shoemaker-Levy 9. D. Deming and J. Harrington (Cornell University) have completed the first phase of their modeling of the infall of the SL9 impact plume. They begin their parameterized models with power-law plume ejecta; a ballistic Monte Carlo method is used to calculate synthetic views of the plumes in flight, infall fluxes, and debris patterns on the Jovian disk. These calculated plume views and debris patterns are compared with observations in order to determine the parameters of the model such as the tilt and opening angle of the ejecta cone, velocity cutoff values in the power law, etc. The infall fluxes from the best-fit ballistic model are then used to initialize a radiative-hydrodynamic (RH) model of the plume infall. The RH model is based on Zeus-3D, modified to include radiative transport in the gray approximation. The RH model follows the interaction of the infalling plume with the atmosphere, and computes infrared light curves versus wavelength. The resultant light curves are in excellent agreement with observations, and have allowed Harrington and Deming to identify the nature of several previously mysterious SL9 phenomena, including "third precursors," "McGregor's ring," the "bounce," and the "flare." The "flare" was observed to occur near 1000 sec post-impact as a sharp spike in the 0.9 μm light curves

observed by several groups, and the models clarify the nature of this and the aforementioned phenomena. It is planned to make the atmospheric models widely available to the community as a resource for SL9 data analysis.

Temporal Study of SL9-Introduced Ammonia in Jupiter's Stratosphere. K. Fast (U. of Maryland), working with LEP members T. Kostiuk, D. Buhl, F. Espe-nak, and P. Romani, and with A. Betz and R. Bor-eiko (U. of Colorado, Boulder) and T. Livengood, are analyzing infrared heterodyne spectra of NH₃ introduced into Jupiter's stratosphere by the impact of Comet Shoemaker-Levy 9. Measured time scales for the removal of ammonia from the stratosphere by solar ultraviolet photolysis will shed light on chemical and dynamical processes in the Jovian stratosphere. Infrared heterodyne ammonia emission line spectra at a resolving power of $\sim 10^7$ were obtained by Betz et al., and are being analyzed using the BEAMINT modeling software to retrieve stratospheric ammonia mole fractions and altitude distributions, and temperature information. Spectra from six different impact regions were acquired from hours to 3 weeks following the impacts on up to 4 different days for each site, enabling an investigation of the tempo-ral behavior of ammonia abundance and temperatures in Jupiter's stratosphere. The combined data set can be used to investigate the long-term behavior of ammo-nia in the stratosphere, as well as provide constraints on current photochemical models.

Jovian Broadband Radio Emissions. C. Barrow (Max Planck Institute), A. Lecacheux (Observatoire de Paris), R. MacDowall, and M. Kaiser studied Jovian broadband radio emission (bKOM) detected by the Ulysses spacecraft during 1994 to 1996 during which time the spacecraft was more than 5 AU from Jupiter. All of the bKOM events observed when Ulysses was at north-ern jovicentric latitudes were predominantly right-hand (RH) polarized while events recorded when the space-craft was at southerly jovicentric latitudes were predom-inantly LH polarized, the change taking place at approx-imately 0 deg jovimagnetic latitude. Compared with previous observations of the bKOM, made by spacecraft considerably closer to Jupiter, the present occurrence probabilities were lower for the LH polarized events al-though the distribution was similar. For the RH po-larized events, however, the distribution was different, the so-called main peak being absent or, perhaps, dis-placed towards a larger central meridian longitude. It was shown that, in a two-dimensional model, if cyclotron maser emission in a dipole magnetic field is assumed for Jupiter, the detection of bKOM at a given frequency by a spacecraft at a specified location, uniquely deter-mines the complete geometry of the emission cone for an assumed value of L (the invariant longitude) and a given field model. Although this is not true for a three-dimensional model, these results raise questions on the application of the cyclotron maser theory to bKOM emis-sion.

M. Reiner, M. Kaiser, and M. Desch reanalyzed the

Ulysses data taken during the Ulysses-Jupiter encounter to look for possible long term periodicities in the Jo-vian radiation. The recurrence of the solar wind two-sector structure at the spacecraft was strongly reflected in the intensities of Jovian bKOM and nKOM radio emis-sions. Furthermore, a repeated pattern was found where a sharp cessation of the bKOM emission was followed, after a short time delay, by an abrupt onset of an nKOM "event," which lasted for some 5 days. This behavior of the bKOM and nKOM emissions was repeated for four consecutive 25-day periods during the Ulysses inbound trajectory.

3.5 Saturn and Titan

IR Spectral Imaging of Saturn and Titan. An obser-vational program to explore the atmosphere of Saturn and the atmosphere/surface interaction of Titan is con-tinuing with N. Chanover (New Mexico State University) as P.I. Scientific Co-I's include D. Glenar and G. Bjo-raker, J. Hillman (U. of Maryland), and D. Kuehn (Pitts-burg State University). We are using three acousto-optic tunable filter (AOTF) cameras developed at GSFC. Analysis of spectral imaging data from this class of cam-era should improve our understanding of the atmospheric dynamics and chemistry of these bodies. User interface software for the new IR camera was developed by D. Kuehn who served as Summer 2000 GSFC Summer Fac-ulty Fellow, in collaboration with GSFC colleague D. Glenar. Saturn was observed at the Apache Point Ob-servatory 3.5 meter telescope in January 2000, and these data are currently being analyzed. Titan was observed in October 1999 using adaptive optics at the Mount Wil-son 100" telescope. These data are being deconvolved and processed at New Mexico State University, and will be analyzed using models that correct for Titan's atmo-sphere. The surface reflectivity that we derive at 0.94 mi-crons, the shortest surface-sounding wavelength that has been used from ground-based telescopes, is being com-pared with other results in the near-IR to gain insight into Titan's surface composition. Titan will be observed again in November 2000 to obtain global coverage of the satellite. The atmospheres of both Saturn and Jupiter will also be observed in November 2000 using VIS and IR AOTF cameras. These observations should reveal the complex interaction between thermal radiation escaping from the planetary interiors and visible cloud structures in the tropospheres of these planets.

Titan Stratospheric Condensates. R. Samuelson and L. Mayo (Raytheon/IBS) have reanalyzed Voyager 1 IRIS data of Titan's north polar hood using a radiative transfer model appropriate for spherical atmospheres that includes scattering and collision induced absorp-tion. Analysis of the spectral continuum between 250 and 600 cm^{-1} suggests thin condensate clouds in the lower stratosphere consisting of particles with effective radii between 1 and 5 micrometers. Composition is un-known, but either condensed hydrocarbons or nitriles are consistent with the data. Some depletion of a coexisting photochemical aerosol (compared with regions not con-

taining condensates) appears to be required, implying a partial sweeping up of the aerosol by precipitating cloud particles.

Rings of Saturn in the mid-IR. T. Livengood, T. Kostiuk, C. Lisse (U. of Maryland and STScI), and H. Käuffl (European Southern Observatory) have imaged Saturn and its rings in the mid-Infrared. Images were obtained in October-December 1996, at the European Southern Observatory using the Thermal Infrared Multi-Mode Instrument (TIMMI) on the 3.6-m telescope. Photometric images were made through filters from 7.7 μm to 13 μm with the TIMMI 64x64 element Ga:Si array at an image scale of 0.5 arcsec/pixel. The ring ansae brightness was modeled as a function of radial distance from Saturn based on the viewing geometry. Analysis of spectrophotometry indicates a peak in the emitted radiance of the rings near 12 μm . A significant difference in the radiance from the East and West ansae was observed, with a maximum ratio W/E of ~ 2 near 11.3 μm . Possible explanations for the difference include thermal heating and cooling, ring geometry, and ring particle properties and composition.

Titan Winds. A paper has been submitted by T. Kostiuk with co-authors T. Livengood, J. Goldstein, T. Hewagama and K. Fast (U. of Maryland), and D. Buhl and F. Espenak describing first direct measurements of the global circulation on Titan using the Goddard Infrared Heterodyne Spectrometer (IRHS). A beam integrated radiative transfer software package (BEAMINT) for beam-integrated high resolution spectral line observations has been developed to model the Doppler-shifted ethane line spectra observed on Titan. Results indicate a globally averaged zonal wind of > 100 m/s in the direction of Titan's rotation. Current results and future measurements are important for the optimization of the Cassini's Huygens Probe science investigation, particularly surface studies. Results will also provide significant constraints on dynamical models of atmospheres of slowly rotating bodies.

3.6 Comets

M. Mumma reviewed tests of cometary origins at the ISSI Cometary Workshop (Zurich). In 1999, the International Astronomical Union named asteroid 8340 "Michael J. Mumma" in recognition of his work on the volatile composition of comets, which provided the first definitive detections of water, methanol, methane, and ethane in comets, and the first infrared detections of carbon monoxide and carbonyl sulfide.

M. Mumma, M. DiSanti, N. Dello Russo, R. Novak, and K. Magee-Sauer (Rowan Univ.) made the first observations of a comet with NIRSPEC, a new facility instrument at the Keck Observatory atop Mauna Kea, HI. NIRSPEC is the first of a new generation of cross-dispersed cryogenic infrared spectrometers, for use in the 1 - 5 μm wavelength spectral range. The observations were conducted in collaboration with the instrument development Team (I. McLean (UCLA), P. I.), during instrument commissioning. The team investigated the

volatile composition of the long-period comet C/1999 H1 (Lee) during June - August 1999. The organics spectral region (2.9 - 3.7 μm) was completely sampled at both moderate - and high - dispersion, along with the CO fundamental region (near 4.67 μm). Global production rates were obtained for seven parent volatiles: water, carbon monoxide, methanol, methane, ethane, acetylene, and hydrogen cyanide. Many new multiplets from OH in the 1-0 band were seen in prompt emission, and numerous new (unidentified) spectral lines were detected. Three hypervolatiles (methane, ethane, and acetylene) had abundances similar to those in comets Hyakutake and Hale-Bopp, but carbon monoxide was strongly depleted in comet Lee. This difference demonstrates that chemical diversity occurred in the giant-planets' nebular region, where these three comets originated.

M. Mumma, M. DiSanti, N. Dello Russo, R. Novak, and K. Magee-Sauer investigated the organic volatile composition of the dynamically new comet C/1999 S4 (Linear), using CSHELL at the NASA IRTF and NIRSPEC at the Keck Observatory during July 2000. They found that CO was present at an abundance of 1% relative to water, the lowest detected to date among the long-period and new comets. The hypervolatiles methane and ethane were detected at levels much lower than found in comets Hyakutake, Hale-Bopp, and Lee. Methanol was searched but was not detected. The comet disrupted in mid-July, terminating the investigation. Analysis is in progress.

V. Krasnopolsky (Catholic University), M. Mumma, and M. J. Abbott (U. of California, Berkeley) investigated soft X-ray emission from comets Borrelly, Encke, Mueller (1993 A1), and Hale-Bopp (post-perihelion). Borrelly and Hale-Bopp were detected and upper limits were obtained for Mueller and Encke, bringing the total to five comets detected of the eight in the EUVE database. The measured signal in these comets is proportional to $r^2 \Delta^2 Q_{gas}$, consistent with excitation by solar wind charge transfer. The outburst detected by BepoSAX in Hale-Bopp and the non-detection by ROSAT remain puzzling, but these are best explained if the BepoSAX detection represents enhanced charge transfer during a gas release. The ROSAT non-detection is puzzling.

V. Krasnopolsky and M. Mumma completed analysis of their EUVE spectrum of comet Hyakutake which covers the spectral range 8.0-70.0 nm with a resolving power of 10. Emission lines of multiply charged ions were detected. These ions are brought to the comet by the solar wind and are excited in charge exchange with cometary neutral species. The detected He II line at 30.4 nm is excited in a similar process involving solar wind alpha particles. The photon luminosity measured at energies below 100 eV exceeds that above 100 eV by a factor of 2. The O II lines at 53.8/53.9 nm, 61.7 nm, and 43.0/44.2 nm are also detected; these lines are formed by photoionization of atomic oxygen similar to the process giving rise to Earth's dayglow. Neon is depleted in Hyakutake by more than a factor of 2600 relative to the solar

abundance, confirming the current view that Oort cloud comets formed in the Jupiter-Neptune region of the solar nebula.

3.7 Meteorites/Asteroids

Database of Bulk Elemental Compositions of Meteorites. The X-ray/Gamma-Ray Spectrometer (XGRS) on the NEAR spacecraft will determine the surface elemental composition (e.g., Mg, Al, Si, Fe, O, and K (possibly Ca, S, Ti, and Th) of the S-class asteroid 433 Eros. These abundances should help elucidate both possible relationships to known classes of meteorites and geological processes that occurred on Eros (e.g., impact processing, partial melting). To aid in the analysis and interpretation of the NEAR XGRS data, J. Trombka and his collaborators are compiling a database of bulk elemental compositions of meteorites. They are limiting their database to those they deem to be the most reliable, specifically selecting analyses of representative samples of falls or unweathered finds. Their initial emphasis is on classes of meteorites most likely related to Eros, including ordinary chondrites and several types of achondrites, and excluding meteorite types which are poor spectral matches for Eros (e.g., carbonaceous and enstatite chondrites, aubrites). These data form the basis for plots of elemental abundances and abundance ratios to distinguish classes of meteorites and identify geological processes on Eros. This database is now on-line and has been successfully applied to the analysis of the NEAR X-ray Spectrometer (XRS) Data.

Surface Composition of 433 Eros. The first results obtained were derived from the NEAR/X-Ray Spectrometer (XRS) observation of 433 Eros surface made during two M-Class flares and quiet sun conditions during the period May to July 2000. These results are compared to compositions of meteorite groups. Statistically significant results from gamma-ray spectrometry require substantially longer integration times than from x-ray spectrometry. Low Aluminum abundances for all regions argue against global differentiation of Eros. Mg/Si, Al/Si, Ca/Si, and Fe/Si elemental ratios have been interpreted as a relatively primitive, chondritic composition. Marked depletions of sulfur and possible aluminum and calcium depletions, relative to ordinary chondrites, may represent signatures of limited partial melting or impact volatilization. These measurements characterize the surface down to about 100 microns and only characterize a small fraction of the surface. Further, more complete elemental composition maps will be obtained over the next months until the end of the mission in February 2001. Elemental mapping of the entire surface should enable documentation of the presence or absence of compositional heterogeneity, which would be an expected result from partial melting. Likewise, compositions derived from gamma-ray results, which sample to depths of 10 cm, should indicate whether the near-surface composition is characteristic of the composition at depth. Results from the NEAR Gamma-ray measurements will be available near the end of the mission. J. Trombka is

the P.I. for the X-ray/Gamma-ray Spectrometer system on NEAR.

3.8 Extra-solar Planets

Extra-solar Planetary Infrared Emissions. D. Deming and G. Bjoraker collaborated with G. Wiedemann (ESO, Garching) to search for a methane signature in the extra-solar planet orbiting Tau Bootis. They use a spectral deconvolution method to search for the signature of methane absorption near $3.28 \mu\text{m}$, using observations from CSHELL on the NASA IRTF. Cross-correlation of the data with a theoretical spectrum of planetary methane shows a significant peak in the cross-correlation near the velocity of the star, which they attribute to a low mass object in a long-period orbit. A second cross-correlation feature, weaker and more diffuse, was found at a velocity amplitude in agreement with the recent claimed detection of the planet in reflected light by Cameron et al. Additional IR observations are needed to confirm the reality of this feature.

U. of Colorado (LASP) graduate student J. Richardson is in residence in the LEP working with D. Deming and C. Goukenleuque, to observe the secondary eclipse of the "transiting planet" orbiting HD209458. L. Esposito (U. of Colorado), J. Harrington (Cornell U.) and G. Wiedemann (ESO) are also collaborating. The observations will utilize a differential spectrophotometric method to observe the subtle change in the "star+planet" spectrum as the planet is eclipsed. According to Goukenleuque's model for the planet, the optimal wavelength is near $3.7 \mu\text{m}$ where a flux peak in the planetary spectrum is produced by a minimum in the opacity. Observations are scheduled for October 2000 on the NASA IRTF, and are proposed for other large telescopes in 2001.

NAS/NRC postdoctoral associate C. Goukenleuque is working on improving his model for irradiated "hot Jupiter" extra-solar planets. These improvements will incorporate the opacity of strong metallic lines in the visible, as well as a convective adjustment.

Extrasolar Planetary Spectroscopic Modeling. T. Kostiuik and his collaborators are developing a spectral synthesis model to calculate the thermal-IR spectra of extra-solar planetary systems. It can be used to study the atmospheric spectra of terrestrial and Jovian type planets as well as the recently discovered hot-Jupiter-like planets. The model will be comprehensive in the sense of including effects such as stellar irradiation and viewing angle. The model can be used to plan observational programs, and eventually to analyze direct-detection data.

4 Sun-Earth Connections

Space Weather Modeling-The Community Coordinated Modeling Center (CCMC). The CCMC is a research and development facility aiming at research in support of the generation of advanced space weather models. New and improved space research models will be created by combining models and modules covering different spatial regions and different physical param-

ters. Models and modules are being developed largely in the scientific community, but also at the CCMC GSFC facility itself. The ultimate goal of the CCMC is the generation of one or more comprehensive space weather models, which cover as completely as possible the entire range from the solar corona to the Earth's upper atmosphere. Models that are developed and successfully applied to scientific test problems are to be transitioned to the Rapid Prototyping Centers of NOAA and the Air Force, for operational testing. These models will also be made source code available to the scientific community, to support the "open model policy," and for the CCMC effort to remain nonexclusive. All initial external computational resources are now on-line. The CCMC has successfully ingested a first, magnetospheric model, the University of Michigan global MHD code. CCMC staff has developed a set of comprehensive visualization tools for this model. CCMC staff is in the process of combining this model with a radiation belt code developed at GSFC. Current status and model results are available via the web page <http://ccmc.gsfc.nasa.gov>. An initial operating capability has been accomplished. M. Hesse is leading this effort in collaboration with L. Rastätter, M. Kuznetsova, P. Reitan, S. Ritter, A. Deane, and K. Keller.

Near-Real-Time Geomagnetic Disturbance

Predictions. In the prediction of the high-latitude electrodynamic ionospheric state, a model of the auroral/polar surface field was developed last year. It has been coupled to the KRM procedure and the Ahn et al. conductance to yield the electric potential and ionospheric and field-aligned currents. The September 1999 SCOSTEP S-RAMP Space Weather Campaign and ISR World Days provided an opportunity to put several of our magnetic field prediction models on line and drive them with real-time solar wind from ACE. Three types of models have been put on line: a) Dst index; b) AL/AU indices and c) high-latitude ground field $B(\phi, \theta)$. The amplitude of the disturbance (e.g. indices) are generally well predicted, but the latitudinal localization is still not satisfactory (the localization error is ~ 7 degrees). The model database has now been enlarged to 3 months of data. Online predictions can be found by selecting "Near Real-Time Predictions" on the NDSPG homepage at <http://lepgst.gsfc.nasa.gov/>. The NDSPG group in Code 692 at GSFC did this work.

4.1 Magnetospheric Physics

ISIS Digital Database. Digital ISIS 2 topside-sounder ionograms are continuing to be produced by a team led by R. Benson of the LEP. The digital ionograms, produced from the original analog telemetry tapes, are being archived at the National Space Science Data Center at GSFC. Nearly 300,000 digital ISIS-2 ionograms from 18 globally distributed telemetry stations, had been processed by the end of July 2000. They correspond to ionospheric topside soundings during the 11-year interval from 1973 through 1983. Since most of these data were never processed into the conventional

35 mm analog film format, they are analogous to the output of a successful new satellite mission covering this earlier solar cycle interval. A search program (to assist in the retrieval of the data based on date, time, geographic or magnetic parameters, status of instruments, etc.) and an analysis program (to invert the ionogram traces to electron-density profiles) are available from <http://nssdc.gsfc.nasa.gov/space/isis/isis-status.html>.

Ionospheric Electrodynamics. R. Hoffman with J. Gjerloev of Denmark continued their study of the electrodynamics of substorms as observed in the ionosphere using data from the two Dynamics Explorer spacecraft. The height-integrated conductivities calculated from precipitating electrons are generally larger than previous models have shown, maximizing in the surge. The technique used attempts to maintain the gradients in the parameters, which are important for field-aligned current calculations. The classical Harang discontinuity is found not to exist during substorms except west of the auroral surge, but to broaden toward midnight into a wide region of very weak convection. A narrow convection channel is coincident with the highest conductances located just poleward of the Harang region. This channel drives the substorm current wedge component of the westward electrojet. The horizontal currents and the field-aligned currents derived from compare favorably with the field-aligned currents determined from the magnetometer measurements, thus confirming the technique used.

Aurora Indices Analysis. R. Hoffman and J. Gjerloev analyzed the characteristics during substorms of the auroral indices AU and AL derived from ground magnetometer stations. In pre-midnight hours (during the expansion phase and very early recovery phase) they found that the station giving the AL index showed an auroral surge. A significant field decrease was observed at post-midnight and morning hours.

Plasma Transport and Energization. A group at GSFC and other institutions, led by T. E. Moore, explored the transport and energization of plasmas in the Earth's magnetosphere, using theoretical tools guided by observations. Studies ranged from the entry of solar wind plasma into the magnetospheric cusp regions, to the transport through the polar caps and lobes into the plasma sheet, to the formation of the ring current and the relativistic radiation belt electrons. A comprehensive ring current model was developed by merger of the Fok model with the Rice Convection Model, substantially improving both models. A provocative hypothesis was put forth suggesting that ionospheric or internal plasmas actually are an essential element of ring current formation.

Geomagnetic Storm/Substorm Relations. The relation between particle injections and storm-time ring current was also investigated by the Nonlinear Dynamics and Space Physics Group at GSFC (A. Klimas and collaborators) using ground magnetometer data, solar wind parameters from ISEE3 and IMP-8, geosynchronous data, and in certain intervals in 1991, ring-

current particle fluxes from CRRES/MICS. During strong storms (6/1991, 9/1998) the geomagnetic effect of the injected particles can be clearly discerned even from the ground magnetometers. The magnetic disturbance due to an injection and its drift echoes can reach as high as 35% of the geomagnetic field power associated with the ring current.

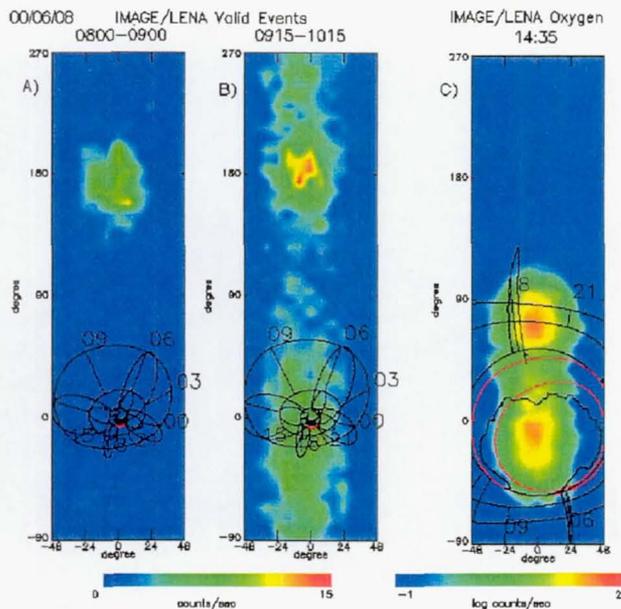


Fig. 3.— Low Energy Neutral Atom (LENA) imager's sequence of images for June 8, 2000, when CME-driven shock passed the Earth's magnetosphere.

4.2 Magnetotail

NENL Onset Time and Location Determined. For the two July 9, 1997, substorms Geotail and IMP 8 measurements and simple plasma sheet flow model have been used to determine that open flux tube reconnection commenced in the tail ~ 1.5 to 3 min prior to the appearance of the traditional onset signatures on the ground and in the ionosphere (Slavin et al., 2000). The location of the near-earth neutral line (NENL) was $X \sim -17 R_e$. This is the first time that plasma and magnetic field observations were taken simultaneously earthward and tailward of the NENL to localize its onset time and location. This result is in excellent agreement with statistical surveys of high-speed flows in the plasma sheet observed by the Geotail spacecraft. It also supports previous IMP 8 traveling compression region analyses indicating that slow, closed, plasma sheet flux tube reconnection begins up to 5-6 min before expansion phase onset. The convective propagation of the earthward flow bursts to the inner magnetosphere at $X \sim -9 R_e$ and the ejection of the plasmoid past $X \sim -30 R_e$ appeared to proceed with the expected flow speeds of several hundreds of kilometers per second. Earthward of Geotail the substorm onset indicators were simultaneous to within $+1$ min indicating that the substorm current wedge develops and transfers energy and momentum on the much faster timescale of

Alfvén waves traveling between the low latitude magnetosphere and the auroral zone. The existence of these two timescales for the development of the substorm expansion phase is one of the most basic predictions of the modern NENL model of magnetospheric substorms. This research was conducted by J. Slavin, D. Fairfield, M. Hesse, R. Lepping and A. Ieda.

Magnetotail Plasmoids and Auroral Brightenings. Magnetotail plasma and magnetic field measurements from the Geotail spacecraft have been compared with ultraviolet auroral images from the Polar spacecraft by A. Ieda and D. Fairfield. It is found that there is virtually a one to one relationship between the tailward release of a plasmoid and an auroral brightening. Sometimes, however, the brightenings are small and not full magnetospheric substorms, even though accompanied by typical plasmoids. The plasmoids typically follow brightenings within 2 minutes, however after considering the likely time delay between the release and the observation of the plasmoid, it seem likely that the release precedes the brightening. This early release of the plasmoid suggests that tail reconnection is the cause of auroral brightenings.

Ideal Ballooning Instabilities in the Plasma Sheet Region. Possible mechanisms for the excitation of ideal ballooning instabilities in the plasma sheet region have been investigated by A. Sundaram and D. Fairfield. The excitation of ideal ballooning modes in the plasma sheet region is investigated using MHD fluid and kinetic descriptions. Two-dimensional equilibrium configurations for the distant tail and the transition regions (dipole-like to tail-like) are used. With the fluid approach, it is shown that both local and non-local ballooning modes are excited in the distant tail region and plasma compressibility effects enhance the growth rates. In the transition region, where a new equilibrium with pressure anisotropy is developed, preliminary calculations show that the pressure anisotropy and compressional mode coupling effects cause the global excitation of new ballooning modes with fast growth rates.

Our analytical model describing the excitation of ballooning modes in the transition region supports recent substorm related observations of shear Alfvén coupled magnetosonic modes. Further numerical work is in progress to determine the growth rates and thresholds for the instability. In the gyro-kinetic description, eigenvalue equation is derived, where the effects associated with the curvature drift and the gradient B resonances are included. This work is still in progress, aiming to derive solutions both analytically and numerically.

Generation of Electrostatic Lower Hybrid Waves in the Central Plasma Sheet Region. A. Sundaram, A. Figueroa-Viñas, and D. Fairfield are working on this project. They investigate the excitation of electrostatic lower hybrid waves in the magnetic field reversal region of the plasma sheet using a gyro-kinetic approach. They consider a two-dimensional tail configuration that includes magnetic field components in x and z directions and study the non-local properties of lower hybrid modes

near the weak field region. We derive a second order differential equation with curvature drift and gradient B resonance effects included. Currently the work is in progress to obtain eigenvalues by employing analytical and numerical techniques. This analysis will confirm the viability of an earlier work (A. Sundaram, D. Fairfield, D. Vassiliadis, JGR, 103, 4649, 1998) on the excitation of electrostatic lower hybrid mode by the magnetic field gradient in the current sheet.

Modeling of Collisionless Magnetic Reconnection. M. Hesse and M. Kuznetsova investigated kinetic processes of relevance to the re-arrangement of magnetotail current systems during the substorm growth and expansion phases. The studies address microphysical processes occurring in the magnetotail current layer with clear macroscopic consequences. They are based on fully self-consistent, electromagnetic, particle-in-cell simulations. The first focus of the analyses is on the pre-onset formation of a thin current sheet. The additional current, brought about by the lobe magnetic field increase associated with solar wind-like driving electric fields, appears to be carried by the electrons, in a thin current sheet of substantially enhanced current density. Thin current sheet formation leads to a reduction in the normal magnetic field, which is shown to be sufficient for magnetic reconnection to initiate. This onset is analyzed in detail. Last, an investigation of the kinetic kink instability, which can lead to strong current sheet warping, and potentially to turbulence, is presented. The results here support earlier analytical results indicating that kinetic kinking growth rates are strongly reduced if realistic ion-electron mass ratios are considered.

Particle-in-cell, modified hybrid, Hall-MHD, and MHD simulations are used by M. Hesse, M. Kuznetsova, and L. Rastätter to investigate collisionless magnetic reconnection in thin current sheets, based on the configuration chosen for the "GEM magnetic reconnection challenge." The emphasis is on the overall evolution, as well as details of the particle dynamics in the diffusion region. Here electron distributions show clear signatures of nongyrotropy, whereas ion distributions are simpler in structure. The investigations are extended to current sheets of different widths. Here we derive a scaling law for the evolution dependence on current sheet width. Finally, we perform a detailed comparison between a kinetic and Hall-magnetohydrodynamic model of the same system. The comparison shows that, although electric fields appear to be quite similar, details of the evolution appear to be considerably different, indicative of the role of further anisotropies in the ion pressures. These models, combined with analytical theory were also used to derive an explicit transport model which represents the essential physics in the ion and electron dissipation regions. This model was included and extensively tested in an MHD model of magnetic reconnection, and recently has been included into a larger scale, regional MHD model of magnetotail dynamics.

Recently, M. Hesse extended studies of magnetic reconnection to fully three-dimensional systems, applying

a fully electromagnetic particle-in-cell model developed in-house. Initial results of these simulations indicate that the basic structure of the dissipation region appears to be similar to the one found in translationally invariant models. In addition, lower-hybrid-drift instabilities tend to broaden the current sheet in the regions of steep density gradients.

Ring Current Formation. An investigation of the effect of ionospheric convection electric fields on ring-current formation was undertaken by M. Hesse. The study consists of a combination of a conceptual analysis of the magnetotail effects of ionospheric convection electric fields, an analytic estimate of the effects of plasma transport from the tail region into the inner magnetosphere, followed by self-consistent magnetohydrodynamic simulations and simulations using a recently improved, self-consistent version of the Rice Convection Model. Supported by the self-consistent models, the conceptual analysis predicts that plasma transport into the inner magnetosphere is impeded by the compressive response of the plasma sheet plasma to the ionospheric convection electric field. An inductive electric field resulting from the self-consistent inner plasma sheet response effectively cancels the applied electric field yielding very little plasma transport on small volume, high magnetic field flux tubes. Instead, the inductive electric field modifies the magnetic configuration by deforming dipolar flux tubes to more tail-like shapes, thereby satisfying the transport constraints applied at the ionospheric boundary. As a conclusion of these analyses, effective plasma transport into the dipolar magnetic field region in the inner magnetosphere and thus, ring current formation, is possible only if the plasma content of tail-like flux tubes is significantly reduced. The most likely mechanism effecting this reduction is magnetic reconnection. It is therefore likely that magnetic reconnection and substorms facilitate, but do not directly cause, the formation of the storm-time ring current.

Multiscale Global Modeling of the Magnetosphere. S. Curtis is leading an effort to develop a three dimensional adaptive mesh MHD code which will include for the first time in any simulation of the terrestrial magnetosphere, a tilted, rotating dipole. His collaborators are D. Spicer of Goddard's Earth and Space Computing Division and staff of GSFC's HPCC team.

Investigation of the Magnetotail Field Response. N. Tsyganenko investigated the dependence of the magnetotail field on the dynamical pressure of the incoming solar wind, the interplanetary magnetic field, and the level of the Dst-field. The study used magnetometer and plasma data from several years of Geotail, AMPTE/IRM, and ISEE-2, between 10 and 60 R_e . Interplanetary parameters were obtained from the IMP 8 and Wind spacecraft. The goal of the work was to identify, for databased magnetosphere models, the input variables that best characterize changes in the cross-tail electric current. The highest value of the multiple correlation coefficient R between the predicted and observed tail lobe field was given by a combination of the solar

wind pressure-and IMF-related quantities. In the near magnetotail, a very good fit ($R=0.967$) was obtained from a simple four-parameter regression relation, and the largest contribution was found to come from the pressure term. In the same study, N. Tsyganenko tried to predict the tail's lobe field even better, using solar wind parameters not only from the time of observation, but also covering the preceding hour. In the inner magnetotail, the contribution from the pressure-dependent term was found to increase with growing time lag, suggesting that the average delay between changes in solar wind pressure and the reaction of the lobe field was significant. At larger distances, the tail field was found to respond with much shorter delays, which implied a greater role of directly driven processes there.

N. Tsyganenko also developed a quantitative model of the inner magnetospheric magnetic field, which combined the asymmetric ring current with field-aligned currents, generated by an azimuthal variation of the plasma pressure. The model ring current and associated Birke-land currents were based on average radial profiles of particle pressure and anisotropy observed by AMPTE/CCE spacecraft. Their fields were calculated by the Biot-Savart integral, the results were fitted to analytical formulas, and the coefficients of those formulas were fitted by least squares to the calculated field. The goal of this work was to devise a realistic and computationally efficient description of the asymmetric ring current, to be included in an advanced model of the external geomagnetic field.

Self-Organized Criticality in the Magnetosphere Plasma Sheet. The Nonlinear Dynamics and Space Physics Group (NDSPPG) in Code 692 (A. Klimas, D. Vassiliadis, V. Uritsky, J. Valdivia, J. Takalo, and R. J. Parks) has focused its research on the stability of the magnetospheric current sheet was examined. Emphasis was placed M. Hesse on evidence for self-organized criticality (SOC). A current sheet model with a magnetic reversal region was examined in continuum (1-D resistive MHD) and discrete (cellular automaton) approximations. Power-law spectra and distributions of system variables were found indicative of SOC in the system. More important, the susceptibility of the modeled current sheet was found consistent with the mean field theory of SOC and, as the SOC limit was approached, the expected expansion of the current sheet interaction region was verified. Currently a 2-D resistive MHD model of a reversal region is being developed and tested.

4.3 Solar and Heliospheric Physics

Halo-Coronal Mass Ejections Near the 23rd Solar Minimum. A statistical analysis of such events during a 1-year period near the last solar minimum (December 1996-December 1997) was performed by an inter-institutional team, focusing on 14 Halo-Coronal Mass Ejections (H-CMEs) with distinct, non-overlapping signatures at the Sun. The team included D. Berdichevsky, C. Farrugia (U. of New Hampshire), B. Thompson, R. Lepping, D. Reames, M. Kaiser, J. Steinberg (Los

Alamos/New Mexico), and S. Plunkett, and D. Mitchels (both NRL/DC), and it focused on solar and interplanetary aspects.

The analysis begins with a typical sample, a Sun-Earth event in which the full range of signatures at the Sun and in the interplanetary medium was identified. After discussing in some detail several individual events, a statistical analysis of the whole set is presented. Tracking of the shock driven by the ejecta, either by MeV energized particles and/or by kilometric slowly-drifting radio emissions, was partially or fully available for $\sim 65\%$ of the cases, and provided further information about the Sun-Earth connection. It is emphasized that while many of the events share common signatures on the solar disk, phenomena both at the Sun and at 1 AU vary widely. It is concluded that no single feature at the Sun determines the magnitude of the energy stored in magnetic field and plasma which is later observed at the Earth. At the end a conceptual model which might account for the diverse observations at 1 AU is put forward.

Stokes Mapping at 12 μm Wavelength. Full Stokes mapping of magnetic fields in active regions has recently become possible in the mid-infrared. The cryogenic spectrometer Celeste on the McMath-Pierce telescope has produced the first 12 μm measurement of all four Stokes parameters (I, V, U, and Q) in sunspots. The magnesium (MgI) line at 12.3 μm wavelength exhibits a large Zeeman splitting that is resolved at field strengths above a few hundred gauss. In general, fields measured with this line originate in the upper photosphere at heights above those measured in the visible and near infrared. The measurements are made by optically selecting each Stokes parameter in sequence using 1/2- and 1/4- wave plates, followed by a chopping linear "polarizer." The spectra are recorded with Celeste, a high resolution liquid helium cooled grating spectrometer built by NASA's GSFC. Individual measurements record the MgI spectrum at each point along a 2.4 arcminute slit. Data cubes (two-dimensions spatial, one-dimension spectral) are created for each Stokes parameter by stepping the slit across the portion of the Sun being imaged. The unique infrared capability of the McMath-Pierce telescope, and its large aperture, makes this work possible. D. Jennings, D. Deming, and G. McCabe, T. Moran (Catholic U.), R. Boyle (Dickinson College), P. Sada (Universidad de Monterrey) are working on this project.

Solar Chromosphere Heating. The solar chromosphere emits 90% of the net radiative loss from the solar atmosphere in quiet and non-flaring active regions. Therefore the problem of understanding solar atmospheric heating is mainly the problem of understanding chromospheric heating. M. Goodman has proposed a mechanism for heating plasma in magnetic flux tubes under solar chromospheric conditions. It is the dissipation of proton Pedersen currents driven by the convection electric field generated by flow of plasma orthogonal to the magnetic field. This flow is driven by slow, longitudinal magnetoacoustic waves. It is proposed that this heating mechanism switches on at the height in a flux

tube at which the protons become magnetized, which offers an explanation for the observation that chromospheric heating begins several hundred kilometers above the photosphere.

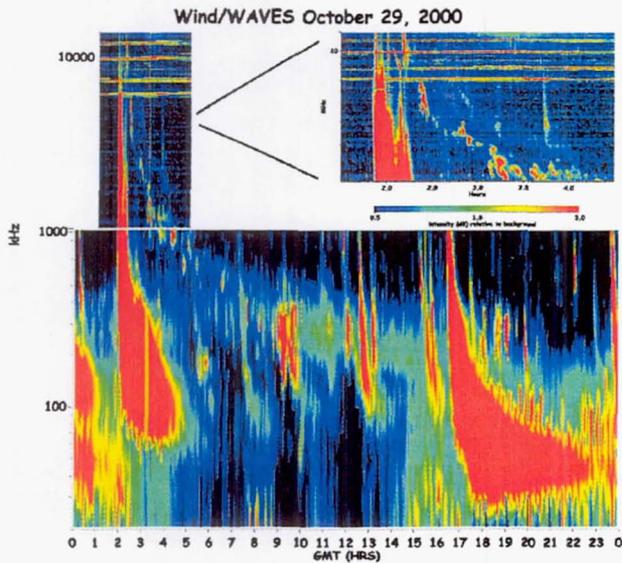


Fig. 4.— Wind/WAVES observes radio emissions from the initial explosion and the subsequent interplanetary shock associated with the October 29, 2000, halo coronal mass ejection (CME).

Low Density Solar Wind Intervals. I. Richardson, D. Berdichevsky, M. Desch, and C. Farrugia conducted a “Survey of low density solar wind during more than three solar cycles” to compare the low density ($< 1 \text{ cm}^{-3}$) solar wind interval of May 1999 to earlier observations. They catalogued and compared other instances of low density solar wind in 1965-1999, using data from the NSSDC OMNI database. Although systematic effects may be present, clear evidence exists of more frequent occurrence of low density plasma around solar activity maxima.

Periods of low mass flux and low dynamic pressure show a similar behavior, previously noted in annual averages. Low density intervals may be more prevalent in weaker sunspot cycles. Around two-thirds of the periods with densities ($< 1 \text{ cm}^{-3}$) are associated with transient solar wind structures, in particular with ejecta and post-shock flows. The majority of other events are associated with corotating streams. The May 1999 event was unusual because it was not clearly associated with an ejecta or a stream, but a similar period was observed in July-August 1979.

The response of the Earth’s magnetosphere to the very tenuous solar wind on May 11, 1999, was investigated by C. Farrugia and co-workers. They studied the Equatorial and Polar regions using observations by multiple spacecrafts. They found the magnetosphere to be quasi-dipolar for approximately 16 hours at six Earth radii.

The Electron Strahl in the Low Density Solar Wind.

A recent occurrence of an interval (May 9-12, 1999) of abnormally low density solar wind has drawn attention to such events. The SWE instrument on WIND observed nine similar events between November 1994 and August 1999, and the occurrence distribution in this period suggests a solar cycle dependence. Three events were studied in detail with SWE observations of the electron strahl (Ogilvie et al., 2000). The strahl is the beam of electrons with energy above 100 eV which move along the magnetic field away from the Sun. In their paper on the solar origin of the polar rain, Fairfield and Scudder [1985] analyzed the evolution of the strahl en route from its coronal origin out to 1AU. They predicted that the strahl should be enhanced due to scatter-free magnetic focussing when the solar wind density is low. SWE observations of the strahl bear out this prediction. During these low density periods, the angular width of the strahl beam, in the absence of collisions, became very small and the overall distribution function extremely anisotropic. The strahl temperature derived from the log slope of the energy spectrum was consistent with a coronal temperature, indicating the similarity between the strahl spectra at 1AU and that of the coronal origin. K. Ogilvie, R. Fitzenreiter, and M. Desch are working on this project.

Survey of the Electron Strahl, 1995-2000. During 1995, when co-rotating streams were regularly observed, the solar wind electron strahl onset was always observed following the stream interface, which marks the separation of the interacting flows. The strahl was not seen before a stream interface, meaning that the strahl does not cross the stream interface. Thus it was shown that the strahl was associated with co-rotating streams and their sources [Ogilvie et al., 1999; Fitzenreiter et al., 1998]. This work will be extended to include all occurrences of the strahl from 1995 through 2000, in order to determine the possible association of the strahl occurrence with magnetic clouds and any possible solar cycle dependence. K. Ogilvie and R. Fitzenreiter are leading this effort.

2-D MHD Solar Corona and Solar Wind Model. As a SOHO Guest Investigator Co-I. (M. Guhathakurta is P.I.) E. Sittler has been developing a semi-empirical 2-D MHD model of the solar corona and solar wind which generates 3-D (spiral pattern built in) maps of the velocity, effective temperature and effective heat flux once empirical 2-D maps of the density and magnetic field are determined. The model uses both white light coronagraph data and Ulysses plasma and magnetic field data. We have published numerous papers based on this model this past year. The model is best representative of solar minimum conditions. We are now in the process of generalizing the model for solar maximum conditions for which we have incorporated up to 5 current sheets and helmet streamers. We have also begun to compare our effective heat flux profiles with other theoretical models that have predicted heat flux profiles. In this area we have begun a collaboration with M. Velli (U. of Florence). We are also working on making the model more self-consistent and using its effective heat flux in the en-

ergy equation of 2-D MHD models and multi-fluid models (L. Offman, Raytheon). So far, the results are very promising.

Type III Radio Bursts as CME Indicators. Considerable progress was made in understanding the solar origin of complex type III-like radio bursts observed in the Wind/WAVES high-frequency receivers that are associated with the solar liftoff of CMEs. M. Reiner and M. Kaiser, in collaboration with researchers in the Czech Republic and in Germany, demonstrated that these bursts most likely originate from the acceleration of electrons very low in the solar corona, contrary to the generally accepted view. In another work, M. Reiner and M. Kaiser showed that these complex type III-like bursts were well correlated with geoeffective CMEs and therefore can be used as a first warning of potential space weather events.

Solar Coronal Shocks. Using the Wind/WAVES radio observations, a concerted effort was made to determine the origin of coronal shocks that produce metric and decametric type II radio signatures. M. Reiner and M. Kaiser, in collaboration with colleagues on LASCO and at the Culgoora radio telescope, provided the most compelling evidence to date for the existence of two distinct coronal shocks; one associated with the flare blast wave that produces metric radio bursts and a second that originates with the CME and produces the decametric radio emissions. In a separate study, M. Reiner, M. Kaiser, N. Gopalswamy, and collaborators provided further evidence by demonstrating that the dynamics of a large sample of decametric-hectometric type II radio bursts are well correlated with the dynamics of the corresponding CMEs, while no significant correlation was found between the dynamics of the associated metric type IIs and either the decametric-hectometric type IIs or CMEs.

Type II Bursts and EUV Transients. N. Gopalswamy, M. Kaiser, J. Sato, and M. Pick studied a metric type II burst and a 'brow' type enhancement in EUV during the hard X-ray flare of 1997 April 15 from a newly emerging region, AR 8032. The position of the type II burst obtained from the Nancay radioheliograph coincided with the EUV transient. The type II burst and the EUV transient were in the equatorial streamer region to the north of the flaring region. This observation suggests that the EUV transient may be the manifestation of the MHD shock responsible for the type II burst.

The CME-Solar Wind Coupling. Using an observed relation between speeds of CMEs near the Sun and in the solar wind, N. Gopalswamy, A. Lara, R. Lepping, M. Kaiser, D. Berdichevsky, and O. St Cyr, determined an "effective" acceleration acting on the CMEs. They found a linear relation between this effective acceleration and the initial speed of the CMEs. The magnitude of the acceleration is similar to that of the slow solar wind. The average solar wind speed naturally divides CMEs into fast and slow ones. Based on the relation between the acceleration and initial speed, they derived an empirical model to predict the arrival of CMEs at 1 AU.

Wind/WAVES Type II Bursts and Solar Eruptions. N. Gopalswamy, M. Kaiser, B. Thompson, L. Burlaga, A. Szabo, A. Lara, and A. Vourlidas analyzed a large number of solar eruptive events that produced radio emission in the decameter-hectometric (DH) radio window (1-14 MHz), newly opened by the Wind/WAVES experiment. The distinguishing characteristics of coronal mass ejections (CMEs) associated with the DH type II radio bursts are larger-than-average width and speed. A majority of the DH type II bursts were associated with IP shocks and kilometric type II bursts.

Coronal Dimming, CMEs and Type II Radio Bursts. N. Gopalswamy, M. Kaiser, R. MacDowall, M. Reiner, B. Thompson, and O. St Cyr revisited the controversial flare-CME-shock relationship using the multiwavelength observations of the 1998 April 27 CME associated with coronal dimming, an X-class flare and type II radio burst. They found that the coronal dimming observed in X-rays and EUV is indeed a CME signature and that the CME clearly precedes the accompanying flare.

Near-Sun and Near-Earth Manifestations of Solar Eruptions. N. Gopalswamy, A. Lara, M. Kaiser and J.-L. Bougeret compared the near-Sun and near-Earth manifestations of solar eruptions that occurred between November 1994 to June 1998. They compared white CMEs, metric type II bursts and EIT waves (near the Sun) with interplanetary (IP) signatures such as decameter-hectometric type II bursts, kilometric type II bursts, IP ejecta and IP shocks. Analysis showed that:

1. Most (93%) of the metric type II bursts did not have IP signatures;
2. Most (80%) of the IP events (IP ejecta and shocks) did not have metric counterparts;
3. A significant fraction (26%) of IP shocks was detected (in-situ) without drivers.

In all these cases, the drivers (CMEs) were ejected transverse to the Sun-Earth line suggesting that the shocks have much larger extent than the drivers do. Shocks originating from both limbs of the Sun arrived at Earth, contradicting earlier claims that shocks from the west limb do not reach Earth.

New Index of Solar Activity Based on Solar Wind Parameters. During the last year, a significant portion of work by V. Osherovich, J. Fainberg, and R. Stone was devoted to research on the solar wind quasi-invariant - which has been recently suggested as a new index of solar activity [Osherovich, Fainberg and Stone, 1999]. The quasi-invariant $[QI = (B^2/8\pi)/(\rho v^2/2)]$ is a combination of magnetic field strength B , plasma density ρ and solar wind speed v . Measured in the solar wind near the Earth, the median value of QI was shown to be a reliable index of solar activity for the 28 year period holding a linear relation with sunspot numbers (SSN) with a high correlation coefficient (cc) of 0.98 [Osherovich, Fainberg and Stone, 1999]. Using hourly data from the Pioneer-Orbiter for the period from 1978 - 1988, it was demonstrated that QI near Venus also closely follows SSN with a correlation coefficient of 0.95 for the yearly mean values. We found that QI_{Venus} and QI_{Earth} are slightly

larger than unity, namely $QI_{Venus} = a^* \cdot QI_{Earth}$, where $a^* = 1.15 \pm 0.006$ [Fainberg, Osherovich and Stone, submitted to GRL 2000]. The relations of B , ρ and v with SSN which we found near Venus (0.7 AU) are qualitatively similar to those at 1 AU. However, out of the three components, ρ has the strongest relation (anti-correlation) with SSN in the solar wind surrounding Venus and in this sense is the leading component of QI. At * 1 AU, B was found to be the leading component.

Electron Suprathermal Tails and Solar Coronal Heating. In the last year A. Viñas in collaboration with H. Wong and A. Klimas investigated the generation of electron suprathermal tails in the solar atmosphere in connection with wave-particle processes by which the solar corona is heated and accelerated outward to form the expanding the solar wind. Our results demonstrated that low frequency obliquely propagating slow, fast and Alfvén mode waves can carry a substantial parallel electric field that drive high frequency plasma turbulence which subsequently can be damped by the background electrons. As a result electrons are accelerated out of the background distribution function forming suprathermal tails. This process is so effective that it occurred on time scales fast compared to the quenching of the low frequency waves by collisional damping. The resultant suprathermal distribution function is characterized by an electron density and temperature typical of that observed in the solar corona.

Heating of O^{+5} Ion and Temperature Anisotropy in the Solar Corona. Velocity distribution of O^{+5} ions derived from the Ultraviolet Coronagraph Spectrometer (UVCS) observations in coronal holes indicate that the O^{+5} ions are highly anisotropic ($T_{\perp} / T_{\parallel} \approx 30 - 300$) at 3.5 solar radii. A. Viñas has investigated the evolution of the temperature anisotropy and the heating of O^{+5} ions by the ion-cyclotron instability using SOHO and TRACE UVCS line-spectral observations in coronal holes. The observations provided empirical values for the electron density and the ion temperatures. The results demonstrate that the electromagnetic ion-cyclotron instability leads to a rapid decrease in the temperature anisotropy and to the transfer of some kinetic energy of the particles into the magnetic field fluctuations, decreasing the anisotropy by an order of magnitude within 300 - 900 proton cyclotron periods (equivalent to about 3 - 9 seconds). Thus the ion-cyclotron instability put constraints to the temperature anisotropy of O^{+5} ions that can be sustained in the solar corona.

Interplanetary Shock Geometry. A. Szabo, in collaboration with C. W. Smith (Bartol Research Institute, U. of Delaware) and R. Skoug (LANL) continued their multi-spacecraft analysis of the interplanetary shock surface curvature. The study was extended to include IMP 8 and Geotail in addition to WIND and ACE observations. The study has confirmed that the interplanetary shock surfaces can have deformations on the scale of 10s of Re.

Low Mach Number Shock Locations. Bow shocks observed by the Wind spacecraft during intervals of un-

usually low solar wind density on April 26-27 and May 10-12, 1999, are the most distant upstream shock locations ever observed. These observations, which corresponded to shock subsolar distances of 45 and 42 RE, along with shock observations by 3 other spacecraft on these days, were used to compare with the predictions of different models. Two recent MHD bow shock models predicted the observed locations quite well when a new Mach-number-dependent shape parameter was used. Bow shock predictions were limited by uncertainties in measurements of the very low solar wind densities and uncertainties in the position and shape of the magnetopause. Asymmetries in the shock shape caused by the interplanetary magnetic field direction and not accounted for by models were another source of uncertainty.

Voyager Solar Wind Electrons. As a heliospheric structure Co-I. (L. Burlaga is P.I.), E. Sittler has been re-analyzing the Voyager electron data out to the orbit of Jupiter including both the core and halo contributions in the analysis. Based on this analysis, we are beginning to study the core-halo relationship for CMEs and ejecta to see how they compare with what we observed for magnetic clouds. In E. Sittler and L. Burlaga, 1998 we showed that because the halo population in magnetic clouds can contribute significantly to the total electron pressure, there was an anti-correlation between the total electron density and total electron temperature.

North-South Solar Wind Flows at 47 AU. North-south variations in the solar wind speed with a period of 26 days, were observed near 47 AU at the most recent solar minimum by L. Burlaga and J. Richardson. Such variations were observed closer to the sun in the distant heliosphere during the previous solar minimum. The amplitude of the fluctuations does not diminish as rapidly with increasing distance as predicted by a model that attributes the fluctuations solely to compressive effects. A MHD model of M. Goldstein, A. Roberts, L. Burlaga, E. Siregar and A. Deane (U. of Maryland) which incorporates shear effects can explain the amplitude variations and other characteristics of the observations such as the depletion of density and magnetic field near the solar equatorial plane.

Statistical Properties of the Solar Wind. L. Burlaga has shown that the magnetic field strength has a log-normal distribution with certain characteristics that are independent of distance from the sun. Recently, L. Burlaga, A. Lazarus, and A. Szabo showed that the solar wind speed, temperature and density have log-normal distributions at 1 AU near solar minimum and during the phase of increasing solar activity. L. Burlaga argued that a statistical model that could explain observations such as these should be needed to supplement the conventional deterministic models of the solar wind.

Solar Wind Properties. Wind data, mostly from the WIND-SWE instrument, is being used by K. Ogilvie and his collaborators to study electron heat flux, strahl, and other distortions of the velocity distribution function, and their relation to plasma waves. Data from the

Faraday cups on WIND-SWE is also used to study disturbances in the solar wind caused by solar events.

Corotating Interaction Regions (CIRs). K. Ogilvie in collaboration with E. Roelof (APL) has shown that a relationship exists between plasma and energetic particle properties in the space between the forward and reverse shocks in CIR's. Their work is based on CIRs in the solar wind as observed by the SWICS and HiScale instruments on Ulysses.

Shock Acceleration. K. Ogilvie studied acceleration of ambient solar wind and pick-up ions at interplanetary shocks in collaboration with M. Baring (GSFC, Code 660).

Correlations Between Plasma Properties at SoHo and Wind. This work by K. Ogilvie has been ongoing for sometime and has formed the subject of a number of meeting presentations.

Wave Particle Interactions. R. MacDowall and P. Kellogg (U. of Minnesota) have contributed a chapter, "Waves And Instabilities in the 3-D Heliosphere," to the monograph "The Heliosphere near Solar Minimum: The Ulysses Perspective," to be published by Springer-Praxis in the near future. Examples of the waves reviewed include the radio waves produced by electrons accelerated by solar flares or by interplanetary (IP) shocks, a variety of wave modes produced at tangential and rotational discontinuities of the magnetic field, and waves associated with variations in the solar wind heat flux. In each case, unstable particle distributions produce oscillations of a subset of the particles in the plasma that are detectable by electric or magnetic field antennas. Such data have been obtained from a number of heliospheric missions, such as Helios-1 and -2, Voyager-1 and -2, ISEE-3, and Wind. Ulysses, which is the first mission to make in-situ observations at the highest heliolatitudes, has provided a new perspective on plasma waves in the interplanetary medium, particularly those in fast solar wind. An example is the discovery of Langmuir waves occurring frequently in magnetic holes, an observation that seems to have escaped all previous missions.

Langmuir Envelope Solitons and Stability of Type III Bursts. T. Golla (U. of Maryland), M. Goldstein, R. MacDowall, K. Papadopoulos (U. of Maryland), and R.G. Stone presented evidence for Langmuir envelope solitons in solar type III burst regions observed by Ulysses. Millisecond time resolution data from the Ulysses Fast Envelope Sampler shows that Langmuir waves causing type III solar radio bursts occur as broad intense peaks with spatial scales of order 10 km at 1-3 AU from the Sun. These structures are identified as one-dimensional Langmuir envelope solitons, which are maintained in quasi-stable equilibrium by the interplanetary magnetic field. Such observations support the conclusion that strong turbulence processes, such as the modulational instability or oscillating two-stream instability, are the means by which type III beams are stabilized.

Origin of Type III Radio Emission. T. Golla and R. MacDowall studied various aspects of interplanetary

type II radio bursts, which are believed to be caused by electrons accelerated at interplanetary shocks. A search for Langmuir wave activity near about 150 interplanetary shocks confirmed that these waves are rare, detected at only 15 percent of the shocks, and almost always occur upstream of the shocks. They were detected at both quasi-perpendicular and quasi-parallel shocks, implying that the type II burst radio emission that they are believed to produce is not correlated with shock normal geometry. T. Golla and R. MacDowall also studied fragmented structure of interplanetary type II radio bursts, which they associated with enhanced emission associated with sharp density gradients. The density gradients increase the efficiency of conversion of Langmuir waves into electromagnetic radiation, leading to bright clumps of radio emission seen on dynamic spectra displays of the bursts.

Modeling of Magnetic Clouds with Heat Flux. For the first time, heat flux has been incorporated in the energy transport equations in order to model the long-term evolution of interplanetary magnetic clouds [Osherovich 2000]. This model utilizes the previously developed self-similar model ($\gamma < 1$) of V. Osherovich, Farrugia, and L. Burlaga (1993), but demonstrates that due to heat flux across the cylindrical walls of the expanding flux rope, the electron temperature after a slow rise has a maximum somewhere between 1 and 2 AU and then exponentially decreases with a typical time scale of 5 - 6 days. This model is based on exact MHD solutions and measurements of the polytropic index γ for electrons which show that $\gamma \sim 0.4 - 0.5$ due to the highly non-Maxwellian electron distribution [J. Fainberg et al., 1996, V. Osherovich, J. Fainberg, and R. Stone, 1998] using Wind data. Fainberg and Osherovich are studying the contribution of fast and slow solar wind to QI and, in general, their role in the solar cycle.

Multi-tube Structure of Some Magnetic Clouds. Measurements of the polytropic index γ inside a magnetic cloud has shown that there are two non-equal tubes inside the cloud [J. Fainberg et al., 1996; Osherovich et al., 1997]. For both tubes, $\gamma < 1$, but each tube has its own polytrope. V. Osherovich, J. Fainberg and R. Stone tested exact MHD equilibrium solutions which are a superposition of solutions with cylindrical and helical symmetry [Krat and V. Osherovich, 1978] as a new paradigm for a multi-tube model. Comparison of magnetic and gas pressure profiles for these bounded MHD states with observations suggests that some complex magnetic clouds can be viewed as multiple helices embedded in a cylindrically symmetric flux rope [V. Osherovich, J. Fainberg and R. Stone, 1999].

Origin of the North-South Oscillations in Solar Wind Velocity Observed in the Outer Heliosphere during Two Solar Minima. Data from the Voyager 2 spacecraft have shown that during the past two solar minima the equatorial heliospheric plasma velocity oscillated perpendicular to the ecliptic plane with an approximately 26-day period. Two explanations have been proposed: compressive interactions between streams, and velocity-shear in-

interactions that produce a Kármán vortex street. We have studied the solar wind conditions that might give rise to those observations using our time-dependent compressible MHD code solved in spherical coordinates in the two-dimensional $r - \theta$ plane. We find that, because the velocity jumps between fast and slow wind are supersonic, the classic Kármán vortex street cannot be excited. Both velocity-shear layers and stream interactions can, however, produce signatures in density, velocity, and magnetic field that resemble the observations. In particular, we find north-south variations of the flow velocity with a period that is approximately half that of the period of the variation in flow speed. This result is insensitive to the thickness of the velocity shear layers. A depletion in density (and magnetic field magnitude) relative to the expected Parker value is predicted by the simulations that generate the north-south flow via velocity shear, similar to that observed by the Voyager spacecraft. When the effective tilt of the plasma sheet is increased, corotating interaction regions produce shock waves and other complex time-dependent evolution. We conclude that at solar minimum the observed north-south oscillations are a robust phenomenon that can form from the interaction of fast and slow solar wind streams or from velocity shear. Which mechanism dominates is a consequence of the degree of tilt of the heliospheric current sheet, the magnitude of the velocity shear, and other physical parameters. However, the depletions seen in density and magnetic flux in the Voyager data, suggest that velocity shear in the outer heliosphere at solar minimum is the origin of the observed north-south flow patterns. This work has been submitted for publication [Goldstein et al., 2000]. M. Goldstein leads this effort in collaboration with D. A. Roberts, L. Burlaga, E. Siregar, and A. Deane (U. of Maryland).

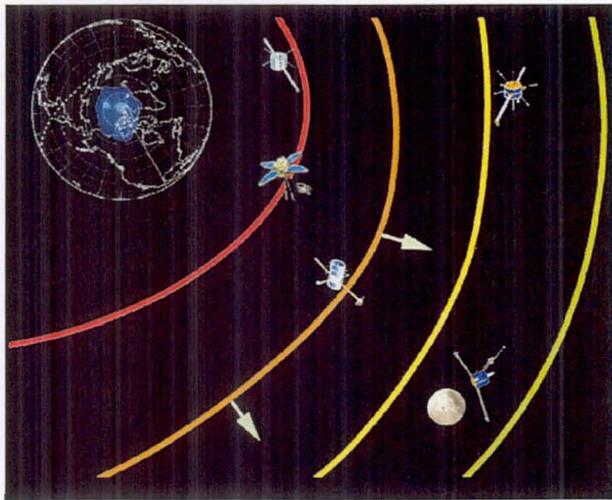


Fig. 5.— On May 11, 1999, when the solar wind “almost disappeared,” five ISTP satellites observed the Earth’s bow shock moving out to an unprecedented distance beyond the orbit of the Moon.

Global Models of the Solar Wind. Our model of the Ulysses fast latitude scan in 1994-1995 observations dur-

ing solar minimum has been published in *Usmanov et al.*, [2000a,b]. The calculation is a steady state two-dimensional MHD calculation in which the energy for fast solar wind comes from an Alfvén wave flux. The WKB approximation is used to describe the Alfvén wave flux. The model is axisymmetric, as was the heliosphere at solar minimum. The observed 40° band of slow wind emerges self-consistently from the model. The calculation reproduces quantitatively the Ulysses observations and describes the transformation of a dipolar magnetic field near the Sun into the configuration observed at Ulysses. This effort is led by M. Goldstein in collaboration with W. Farrell and A. Usmanov (State University of St. Petersburg).

Incorporating the Dissipation Range of MHD Turbulence into Numerical Simulations. As reported last year, our research on the dissipation range of MHD turbulence showed that the turbulent cascade of Alfvén waves leads, via cyclotron interactions, to anisotropic heating of protons. Theoretical and numerical work has shown that coupling between resonant protons, nonresonant protons, and waves leads to strong anticorrelations in time (up to -0.99) between the parallel and perpendicular pressures. The result required developing a theory for the nonlocal behavior in resonant interactions from which was discovered a new nonadiabatic quasi-invariant for low-collisional cyclotron resonant wave-damping processes that had the observed anticorrelation. This work has been summarized in a review by M. Goldstein et al. [1999]. This effort is led by M. Goldstein in collaboration with S. Ghosh, E. Siregar, and V. Jayanti.

Termination Shock Crossing. Based on our models of shocks in the distant heliosphere that include pickup protons and magnetic fields, which predict anti-correlation of the termination shock location and solar activity, Y. Whang and L. Burlaga calculated that the termination shock is probably moving inward toward the sun at the present time. Based on recent observations of the properties of the solar wind, they concluded that Voyager 1 could cross the termination shock within the next few years, and it might cross the termination shock 3 or more times over a period of 4 years.

5 Space Science Missions: Operational

5.1 IMP 8

Magnetic Field Investigation (MAG). The fall of 2000 marks the 27th anniversary of IMP 8’s operation in orbit. The spacecraft has provided valuable solar wind, magnetosheath and magnetospheric fields and particles data over its long lifetime. The magnetometer (A. Szabo, P.I.) has suffered an anomaly on June 10, 2000, preventing the collection of useful data. The analysis of the nature of the anomaly and corrective measures are still being studied. The 15.36 seconds time resolution magnetic field data for the whole duration of the mission has been added to the publicly available CDAWeb interface. This provides a new, user-friendly access to the data set. Also, the highest time resolution (320 msec) data set

for the entire mission are currently being reprocessed to facilitate faster and easier methods of dissemination to the public. On-campus Co-I's of this experiment are R. Lepping and J. Slavin. An off campus Co-I. is N. Ness with the Bartol Research Institute, U. of Delaware.

5.2 Voyagers 1 and 2

Project Status. 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 1 is now at 79 AU at a latitude of $\sim 34.5^\circ$ N, and Voyager 2 is at 62 AU at a latitude of 26° S. 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. L. Burlaga is responsible for the reduction of the data and is active in the analysis of these data.

Voyager-Planetary Radio Astronomy (PRA) Experiment. The PRA instrument continues to operate during the Voyager Interstellar Mission portion of the Voyager program. PRA still detects strong solar radio bursts and monitors the very low radio frequencies for signs of the inner helioshock and the return of the so-called '3 kHz noise' from the heliopause. The PRA investigation is led by M. Kaiser.

5.3 Ulysses/URAPS and SWICS

Project Status. As of September 2000 the Ulysses spacecraft was well on its way to a second overflight of the southern solar pole, having reached a heliographic latitude of more than 70° S at 2.5 AU from the Sun. Contrary to the situation during the solar minimum orbit, the heliosphere at these high latitudes appears similar to that at low latitudes; this is expected because the tilt of the solar current sheet is much larger near solar maximum. Consequently, the spacecraft passes through recurring fast and slow solar wind, even at high latitudes. The GSFC contributions to Ulysses include involvement with two of its instruments: the Unified Radio and Plasma Wave investigation (URAP) and the Solar Wind Ion Composition Spectrometer (SWICS). URAP Co-I's at GSFC are M. Desch, J. Fainberg, M. Goldstein, M. Kaiser, R. MacDowall (P.I.), M. Reiner, and R. Stone (P.I. Emeritus); K. Ogilvie is a Co-I on the SWICS team.

5.4 GEOTAIL

Project Status. The Japanese/NASA Geotail spacecraft remains in good health and continues to provide excellent data from its 9×30 Re equatorial orbit as it begins its ninth year of operation. Geotail survived a 4.5 hour eclipse last February that was more than twice as long as what the spacecraft was designed to withstand. Future eclipses will now become shorter. Much of Geotail's data is now available via the Web, including the Comprehensive Plasma Instrument's plasma data from the solar wind detector and the Low Energy Plasma instrument's plasma data from both the solar wind and energetic plasma detector. The later data along with

the magnetic field data are available via the Japanese DARTS system. Plans are for this system to soon make available both highest resolution magnetic field data (16 vectors/sec) and plasma distribution functions. Geotail continues to make important contributions to the ISTP solar Maximum Mission and advance the knowledge of basic magnetosphere processes such as the entry and redistribution of energy and particles in the magnetosphere. D. Fairfield is NASA's Project Scientist for Geotail and he and M. Acuña are Co-I's on the magnetic field experiment.

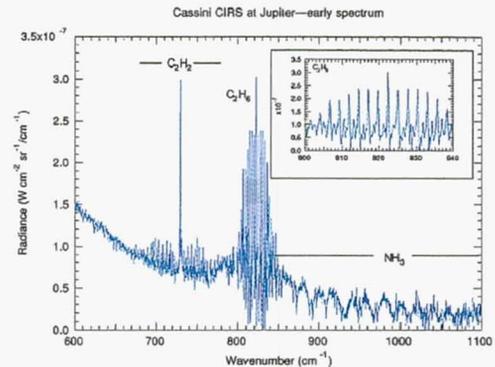


Fig. 6.— Cassini CIRS at Jupiter - early spectrum.

5.5 WIND

Project Status. The WIND spacecraft continues to operate normally, more than 6 years after launch, with only minor problems with the spacecraft and instruments. On May 27 the SWICS portion of the SMS experiment failed. Following the major 14 July solar energetic particle (SEP) event, the telemetry transmitter on WIND lost 25% of its power, dropping from 29W to 22W, corresponding to one amplifier stage. This was subsequently corrected by switching to the backup transmitter resulting in bringing the power back to 32W. SEPs also caused a 1% degradation in the solar array power and a temporary saturation of the sun sensors resulting in a loss of magnetic field and plasma data for about 32 hours. Complete recovery of the data is expected following recreation of the spacecraft spin phase information. On July 27 the fuel tanks were successfully reconfigured from the odd to the even half system. On August 3 a portion of the WAVES 50-m monopole was lost from causes unknown. This resulted in a 3-4 dB loss in gain and induced a small nutation in the spacecraft that damped out in 15-20 minutes. On August 16, WIND completed its petal orbit phase and entered a distant prograde orbit that will take the spacecraft to 255 R_E alternately ahead and behind Earth in its orbit. No other spacecraft has entered such an orbit before. Observations made during this phase of the mission will be used to compare solar wind scale length measurements with ACE and other near-Earth orbiting space-

craft. K. Ogilvie is the Project Scientist and M. Desch is the Deputy Project Scientist.

WIND/Magnetic Field Investigation (MFI) Health and Status. The WIND MFI magnetometer system continues to operate nominally. Its data contributes significantly to many space science studies around the world. Much of the data is also conveniently obtained directly on-line as key parameter data, including relatively high resolution 3 s data. The MFI team collaborates directly in many of these studies when appropriate. Some of the team's research areas are the properties of the interplanetary medium (especially quasi-static and transient events), their comparisons to solar events, the magnetosphere's boundaries, and magnetotail events during active periods. The MFI's Website describes many of these areas and contains a bibliography of over 150 articles and papers on which a team member is either author or coauthor, and it continues to grow rapidly. Making available the highest resolution magnetic field data on a production basis and assisting the space science community with consultation on data at all time scales are in the plans. Continuing to distribute such data expeditiously is also in the plans. The Laboratories' members of the MFI team are M. Acuña, L. Burlaga, M. Collier, W. Farrell, R. Kennon, R. Lepping (P.I.), W. Mish, J. Scheifele, J. Slavin, A. Szabo (Data Production Manager), and E. Worley; there are five off-campus members.

Wind-WAVES Experiment. The WAVES experiment continues to operate perfectly and its data products are being used by many investigators in analysis of solar events and space weather, in conjunction with Cassini in studies of Jupiter's radio emissions, and with ground-based radars to study ionospheric propagation. The Wind/WAVES investigation is an international collaboration with M. Kaiser currently serving as P.I. Besides IP Type II observations, theoretical efforts have been made by W. Farrell to explain the Type II emissions via direct coupling of electron energy to the ordinary mode wave propagation branch via relativistic electron cyclotron harmonic processes.

5.6 FAST

Project Status. NASA's FAST satellite continues to acquire excellent data and provide exciting new observations concerning acceleration processes at the interface of the hot, magnetospheric plasma and the cool, ionospheric plasma. The FAST science team has already reported several major discoveries. 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 P.I. for FAST is C. Carlson (U. of California, Berkeley). R. Pfaff of the LEP is the NASA Project Scientist for the FAST mission.

5.7 POLAR

Project Status. The POLAR orbit continues to evolve with apogee moving into the mid-latitude region. Currently the cuts through the radiation belts are occur-

ring at higher L values, enhancing the value of particles and fields measurements in the radiation belts. All instruments continue to operate properly except for the wave measurements and the mass analysis of thermal particles. More recently the TIMAS instrument (mid-energy mass-angle spectrometer) has suffered a thermally induced data interface problem which causes the loss of all data except during periods of minimum temperature. R. Hoffman is the Project Scientist.

Thermal Ion Dynamics Experiment-Plasma Source Instrument (TIDE-PSI). The investigation team led by T. E. Moore conducted a wide variety of studies this year. Topics ranged from the entry of solar wind plasma into the magnetosphere through the cusp region, to the outflow of ionospheric plasma as influenced by solar wind conditions, to the global transport of plasmas throughout the magnetosphere accessible to POLAR. This work involved extensive collaboration with investigators on other ISTP spacecraft, notably WIND, FAST, and the LANL geosynchronous spacecraft, but also DMSP, Interball, and others; and is continuing through the next solar maximum period in a few years.

5.8 ISTP Theory and Ground-based Experiments

Project Status. The ISTP theory and ground-based experiments teams continue to make fundamental contributions to the success of the ISTP mission. In particular, the theory groups have produced major firsts such as a global magnetospheric simulation under conditions of extremely low solar wind and thus continue to provide a unifying framework for the widely separated spacecraft and ground-based experiments. S. Curtis is the ISTP Project Scientist for Theory and Ground-Based Experiments.

5.9 CASSINI

Composite InfraRed Spectrometer (CIRS). CIRS is a Fourier-transform spectrometer on the Cassini spacecraft that measures radiances in the thermal infrared between 10 cm^{-1} and 1400 cm^{-1} (1 mm and $7\text{ }\mu\text{m}$) with a spectral resolution up to 0.5 cm^{-1} . It will map the temperatures and composition of Saturn, its satellites, and its rings during Cassini's four-year orbital tour that will begin in July 2004. On its way to Saturn, Cassini will fly within 140 R_J of Jupiter at the end of 2000. V. Kunde (P.I.), J. Brasunas, G. Bjoraker, F. Flasar, D. Jennings, J. Pearl, P. Romani, R. Samuelson, R. Achterberg, C. Nixon, R. Carlson, and M. Smith have been planning the CIRS operations and observations of Jupiter during this unique opportunity. Although much further away, CIRS at mid-infrared wavelengths will have the same spatial resolution, 2.5° of latitude at the sub-spacecraft point, that the Voyager thermal infrared spectrometer (IRIS) had when it was only within 10 R_J of Jupiter, by virtue of its small 0.3-mrad detectors. Although IRIS only enjoyed this resolution for a few hours about Jupiter closest approach, CIRS will maintain it for several weeks. The instrument started out the year snug and blind. In

April, the cover of the passive cooler for its mid-infrared detector arrays was successfully ejected. In late September, its telescope cover will be ejected, and shortly afterward CIRS will begin to accumulate an extensive data set on Jupiter's atmosphere, its rings, and its satellites. B. Conrath, P. Schinder, J. Tingley, M. Elliott (SSAI) and F. Carroll (Raytheon/ITSS) are also involved in this effort.

Radio and Plasma Wave Experiment (RPWS). The Cassini Radio and Plasma wave Experiment (RPWS), led by D. Gurnett (U. of Iowa) is actively engaged in observations of Jupiter's radio emissions. Closest approach to Jupiter is December 30, 2000. RPWS investigators from GSFC include M. Kaiser, M. Desch, and W. Farrell.

LEP members (M. Kaiser, W. Farrell, and M. Desch) were recently involved in the search for lightning-related radio emissions from Venus using measurements from the CASSINI RPWS during the two 1999 swingbys. Preliminary analysis indicates that no obvious lightning-related emissions were detected for flash durations exceeding 1 millisecond.

Cassini Plasma Spectrometer (CAPS). As a Cassini CAPS Co-I. (D. Young is P.I.) E. Sittler has been working on a model (with B. Johnson (UVA), J. Richardson (MIT), S. Jurac (MIT), M. McGrath (HST) and D. Young (UM)) on a model that predicts the observation of pickup ions by the CAPS as the spacecraft passes through the co-rotational wake of Dione and Enceladus which are icy satellites (moons) of Saturn. These model predictions will provide the basis for planning such observations during the design of the tour around Saturn. Such observations will provide a direct measurement of the sputtered atmosphere of these icy satellites and thus a direct measure of the global composition of these icy satellites. Knowledge of their composition is important for the understanding of their geological evolution. It may also provide important insights into the composition of the Saturnian system when it originally formed, as well as insights into the initial composition of the solar system when it first formed.

CAPS Co-I, E. Sittler and his collaborators have been supporting CAPS operations, calibration, and the development of Spectrum Analyzer Module group tables that will allow the CAPS ion mass spectrometer to detect both interstellar pickup ions, and Jovian ions coming from Jupiter's magnetosphere during the Cassini flyby of Jupiter which begins October 2000. The team has also developed some new data modes for the flight software to support the Jovian encounter period.

5.10 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, R. Starr, L. Nittler, and D. Nava) is involved in the operation of the X-ray/Gamma-ray Spectrometer System (XGRS) on NEAR during the cruise and orbital phases. The Near Earth Asteroid Rendezvous (NEAR)-Shoemaker mission

began an orbital rendezvous with the S-type asteroid Eros on February 14, 2000. This mission represents a milestone in the understanding of the geologic processes that formed and altered asteroids in the early history of the Solar System. These spectrometers detect 1-10 keV x-rays and 0.3-10 MeV gamma ray emissions. Discrete line x-ray and gamma-ray emissions in these energy domains can be used to determine the surface distribution of many geologically important elements (e.g., Mg, Al, Si, S, Ca, Fe, O, K and possibly Th). In addition, NEAR carries a near-infrared spectrometer and multi-spectral imager allowing direct comparison between the elemental composition measured by the XGRS and the mineralogy inferred from the optical and infrared spectral measurements. These complementary data sets will help elucidate both possible relationships to known classes of meteorites and geological processes that might have occurred on Eros (e.g., impact metamorphism and partial melting). Since May 2, 2000, NEAR has been in a low (35-50 km) orbit about the center of mass of Eros, beginning an extended phase of detailed surface mapping of the asteroid.

The NEAR XGRS has been included in the Inter-Planetary Network (IPN) for the detection of Gamma-Ray Bursts (GRB). The IPN now incorporates GRB information from the NEAR, Ulysses, Compton-GRO, GGS-Wind, and Konus. At least one coincident detection per week is now accomplished a number of source locations for GRB's have already been determined using the IPN and their red-shifts derived.

Magnetic Fields Investigation. The Magnetic Field Experiment on the NEAR spacecraft is designed to characterize the magnetization state of 433 Eros and its interaction with the solar wind. Mario Acuña is the Team Leader for this investigation with C. Russell of UCLA as a Team Member and additional contributions by B. Anderson of the Applied Physics Laboratory. This instrument is fully operational and returning valuable data from orbits ranging from 35 to 100 Km from the center of mass. Initial expectations for S-Class asteroids based on the Galileo inferred magnetization state for Gaspra, suggested that a significant remnant field could be present at 433 Eros. Measurements conducted to date by the NEAR-Shoemaker spacecraft in orbits as close as 35 Km from the center of mass, do not support these conclusions. Instead they suggest that Eros belongs to a class of undifferentiated LL-chondrites with extremely low remnant magnetization.

5.11 Mars Global Surveyor

Project Status. The MGS spacecraft has been orbiting Mars since September 1997 returning a wealth of new data about the planet's atmosphere, topography, gravity, geology, magnetic fields, ionosphere and solar wind interaction among others. The spacecraft and instruments are fully operational. More than 6000 orbits have been completed to date. Data from a variety of instruments including the Magnetometer/Electron Reflectometer (M. Acuña, P.I., J. Connerney and P. Wasilewski, Co-I's)

have been delivered to the Planetary Data System and are available to the broad scientific community. This mission will enter into its extended phase starting February 2001 and continued support of mission operations and data analysis is expected.

Thermal Emission Spectrometer (TES). Atmospheric investigations of Mars by the Goddard TES team continued. J. Pearl is a Co-I. and M. Smith is a Team member. Analysis by B. Conrath, using limb observations, has allowed determination of the planetary vertical temperature field to be extended from 4 to 7 scale heights. M. Smith has obtained first results on the seasonal distribution of water vapor by analysis of the rotational lines of water vapor between 200 and 350 cm^{-1} .

5.12 ACE

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

5.13 Lunar Prospector

Project Status. The Lunar Prospector Spacecraft was crashed on purpose into a lunar crater near the south pole to try to detect the presence of water at this location. This action terminated operations of the Magnetometer/Electron Reflectometer Experiment, a collaborative effort between M. Acuña and R. Lin of the Space Sciences Laboratory (UCB).

Magnetometer-Electron Reflectometer Investigation. This investigation confirmed the early detection of Lunar crustal magnetization by the Apollo sub-satellites and established for the first time an intriguing correlation between the location of magnetized areas on the Moon and the antipodes of large basin-forming impacts. Empirical models developed by the UCB group reproduce the Lunar Prospector data with intriguing accuracy. Explanations for this antipodal relationship in terms of refocusing of magnetic fields associated with impact-generated plasma effects have been proposed but require further study and validation. The Lunar Prospector and Mars Global Surveyor MAG/ER data have contributed new and significant information concerning the fundamental role that large impacts played in the thermal evolution of planets in the early solar system.

5.14 IMAGE

Low Energy Neutral Atom Imager (LENA). Using data from the Low Energy Neutral Atom (LENA) imager, Code 692's instrumental contribution to the recently launched IMAGE spacecraft, a team of GSFC investigators including M. Collier, T. Moore, K. Ogilvie, D. Chornay, J. Keller, B. El Marji, and B. Giles have been studying a June 8, 2000, event during which LENA observed neutral atoms from the solar wind. The fluxes observed by LENA are roughly consistent with the expected flux of neutral solar wind, and the presence of

sputtered oxygen observed in the time-of-flight spectra show that the energy of these neutral particles exceeds one keV. These constitute the first observations of the neutral solar wind.



Fig. 7.— Exterior of the LENA sensor launched on September 25, 2000, on the IMAGE spacecraft.

Magnetospheric Radio Sounding. The Radio Plasma Imager (RPI) is an active sounder on the IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) satellite, which was launched on 25 March 2000. The RPI (Instrument P.I., B. Reinisch, U. of Massachusetts, Lowell) is one of a compliment of remote sensing instruments on IMAGE (Mission P.I.: J. L. Burch, Southwest Research Institute). R. Benson is a member of the RPI team and is participating in the analysis of plasmagrams (apparent range vs. sounder-frequency records) which reveal local plasma resonances and long-range magnetospheric echoes.

5.15 Cluster-II

Magnetic Fields Investigation. The recently launched Cluster-II is 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 the LEP magnetometer Co-I's and they will participate actively in the data analysis effort. For example, while flying in their baseline tetrahedral formation, the magnetic field measurements will be used to calculate the "curl" of the field and infer the electric current passing through 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. In late August 2000, the magnetometers on all four spacecraft were successfully activated and their operation is nominal. Data production is expected to start in January-February 2001. The

NASA Project Scientist for Cluster-II is LEP scientist, M. Goldstein.

6 Space Science Missions: Developmental

6.1 Triana

Solar Wind Plasma and Magnetic Field Investigation (PlasMag). The Triana Earth imaging mission will include a combined high-time resolution magnetometer and plasma instrument to study the solar wind and to provide real-time space weather data. K. Ogilvie is the P.I. of the Development Team. He leads the Electron Electrostatic Analyzer development. A. Lazarus (MIT) is the lead for the Faraday Cup positive ion subsystem and M. Acuña for the magnetometer. A. Szabo is responsible for the ground data system. The instrument is undergoing final checkout before delivery to the spacecraft. Triana is expected to be launched in April 2002.

6.2 New Millennium Program

ST-5/ Constellation of Nanosatellites. The New Millennium Program's Fifth Space Technology Mission, ST-5, will launch three small (~ 20 kg) satellites into geosynchronous transfer orbit in the Spring of 2003. Their objective is to provide flight validation for 8 new technologies critical for the future deployment and operation of constellations of "nanosatellites," spacecraft weighing ~ 10 kg. "Nanosatellites" are intended for the Sun-Earth Connection and Solar System Exploration Themes. Moreover, ST-5 will test deployment and operations strategies necessary to make these future "constellation-class" science missions economically viable. In order to validate the suitability of these small spacecraft as platforms for particles and fields measurements and to exercise the mission's autonomous operations capabilities, the ST-5 spacecraft will each carry a miniaturized magnetometer and energetic particle detector. J. Slavin is the ST-5 Project Scientist and he leads the science validation instrument activities.

Solar Sail Demonstrator. A team, including A. Szabo, has been working in collaboration with JPL to design a mission to demonstrate the deployment and control of a solar sail power craft. The GSFC concept incorporates a ~ 1600 m² solar sail powering a ~ 20 kg spacecraft in near-geosynchronous orbit. Besides proving the viability of the various solar sail technologies, this mission will also characterize the space environment of the sail and determine how much future science observations would be effected by this new mode of propulsion.

6.3 Kuiper Express and EO-1

LEISA Development. D. Reuter, D. Jennings and G. McCabe are developing infrared spectral imagers based on the LEISA (Linear Etalon Imaging Spectral Array) concept. This development is a collaboration with members of the Engineering Directorate. LEISA represents a completely new concept in spectrometer design made possible by large-format detectors and advances in thin-film technology. Originally developed for the Pluto Fast-

Flyby Mission (PFF) under the Advanced Technology Insertion Program, LEISA uses a state-of-the art filter (a linear variable etalon, LVE) in conjunction with a detector array to obtain spectral images. The major innovation of LEISA is its focal plane that is formed by placing a LVE in very close proximity to a two-dimensional detector array. The LVE is a wedged dielectric film etalon whose transmission wavelength varies along one dimension. In operation, a two-dimensional spatial image is formed on the array, with varying spectral information in one of the dimensions. The image is formed by an external optic. Each spatial point is scanned in wavelength across the array, thereby creating a two-dimensional spectral map.

The LEISA/Atmospheric Corrector (LAC) is on the New Millennium Program Earth Orbiter 1 (EO-1) mission to be launched in November 2000. The primary purpose of this atmospheric data is to correct the high spatial resolution, low spectral resolution Landsat-type multispectral images for the spatially and temporally variable effects of the atmosphere. In addition to these satellite programs LEISA was flown in an aircraft in the summers of 1997, 1998, and 1999 as part of the instrument complement in an agricultural sensor program. The program was part of a Space Act Agreement with Boeing Commercial Space Company. The airborne LEISA instrument was also flown in South Africa in March of 1999 as part of the ARREX program.

6.4 Mars Surveyor/01

Project Status/Gamma Ray Spectrometer (GRS). A re-flight of a Mars remote sensing of GRS will be accomplished during the Mars Surveyor 2001 mission. The spacecraft is planned for launch in April 2001 and arrival at Mars in December 2001. The P.I. is W. Boynton of the U. of Arizona and the Co-I's at GSFC are J. Trombka, L. Evans, and R. Starr. The Ge detector is being supplied by URSYS in France. The passive cooler is being supplied by A. D. Little. The analogue electronics are being designed and built at GSFC and U. of Arizona. The digital electronics are being designed and built at the U. of Arizona where flight system integration and test will take place. Calibration of the flight detector system will be a joint responsibility of the U. of Arizona and GSFC. The flight detector system has been completed and is under test. The flight system will be incorporated aboard the spacecraft during the December 2000 or January 2001 in preparation for launch April 2001.

6.5 MESSENGER

Project Status. The Discovery program has selected a Mercury orbiter mission called MESSENGER for development. The purpose of this mission is to collect global information on the surface, interior, exosphere and magnetosphere of this least explored of the terrestrial planets. The P.I. 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 JHU/APL. LEP scien-

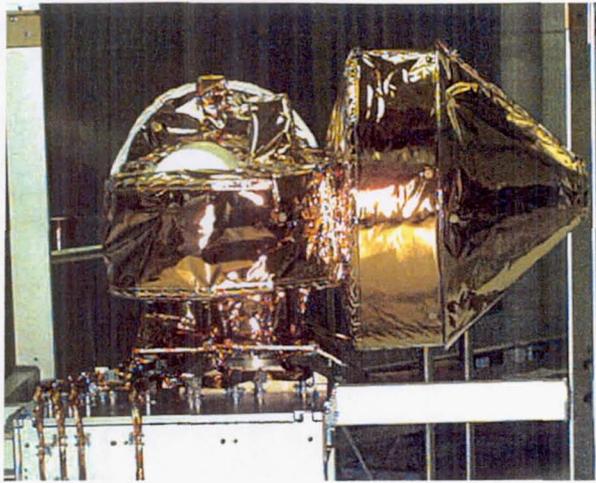


Fig. 8.— CIRIS instrument launched on board the Cassini spacecraft in 1997.

tists will be responsible for the vector magnetometer and the investigation of the planetary magnetic field and the magnetic structure of Mercury's magnetosphere. The LEP magnetic fields Co-I's are M. Acuña and J. Slavin. MESSENGER will be launched in 2004 and go into orbit around Mercury in 2009 following two earlier fly-by encounters.

6.6 GEC

Project Status. The Science and Technology Definition Team are completing the Geospace Electrodynamic Connections (GEC) Mission definition document. The fundamental questions behind the mission are:

1. How does the Ionosphere-Thermosphere (I-T) system respond to magnetosphere forcing?
2. How do these responses of the I-T system dynamically affect the coupling of the upper atmosphere with the magnetosphere?

The underlying processes are multi-scaled and their analysis requires multi-satellite measurements. GEC is a challenging mission, consisting of several spacecraft flying in a high inclination (83°) pearls-on-a-string orbital formation, with inter-spacecraft spacing ranging from 10's of kilometers to 1/4 of the orbit. Each spacecraft carries instruments to measure all relevant local plasma and neutral atmosphere parameters. The nominal orbital configurations are 2000X185 km, but each spacecraft will carry enough propulsion fuel to dip below 130 km, i.e., deep into the Pedersen current closure region, for more than a dozen weeklong campaigns. The capability to vary spacecraft separations and perigee altitudes provides the experimental platform needed to resolve the near-Earth geospace electrodynamic connections.

6.7 IMEX

Project Status. The Inner Magnetosphere Explorer (IMEX), a University-Class Explorer (UNEX) is designed to investigate the physical processes, which rapidly accelerate charged particles in the inner magne-

tosphere to very high energies during major geomagnetic storms. Currently, the IMEX team is awaiting a USAF agreement to fly IMEX on a Titan-IV DSP Mission. A Boeing IUS study has concluded that IMEX technical issues for flying on a Titan-IV are low risk. Launch is anticipated to be about November 2002. M. Collier of the LEP is the Project Scientist.

6.8 MATADOR

Project Status. Lab members (W. Farrell, M. Desch, M. Kaiser, and J. Houser) recently won a Mars instrument proposal through the Human Exploration and Development of Space (HEDS) enterprise to study the fluid and electrical interaction of Dust in the windy Martian atmosphere. The Electrical Charging Hazards Originating from the Surface (ECHOS) proposal was submitted in late 1999, and the electrical portion of the package was merged with the Arizona Camera to form a new meta-instrument called Mars ATmosphere And Dust in the Optical and Radio (MATADOR). The package was originally scheduled to fly on the Mars03 Lander mission. With the loss of Mars Polar Lander and a reexamination of the overall Mars Surveyor Program, MATADOR is currently being funded in an extended definition Phase A until a launch date can be selected.

6.9 ISS/EGM

Project Status. International Space Station Electrostatics of Granular Material (ISS/EGM) Lab members (W. Farrell and J. Houser) are currently designing a charge dust particle sensing system using RF technology for use on the International Space Station (ISS) EGM experiment. The purpose of the experiment is to understand the triboelectrical forces on dust in microgravity, and to quantify individual dust grain's electric monopole and dipole moments. Such information has direct applications to grain motion in various man-made and natural systems. The EGM experiment is slated to fly in 2004.

6.10 STEREO

Project Status/STEREO-WAVES. The WAVES experiment was selected as one of the four instrument complexes for the STEREO Mission. The team is similar to the Wind WAVES experiment and is led by J.-L. Bougeret (Paris Observatory). GSFC team members include M. Kaiser (Deputy P.I.), R. MacDowall, J. Fainberg, and M. Reiner. STEREO is currently in its PHASE-A/B which involves detailed design studies.

Project Status/STEREO-IMPACT. The STEREO IMPACT Investigation is a collaboration of the LEP with the Space Sciences Laboratory (UCB) and other institutions to provide a comprehensive instrument to measure plasmas, particles and fields to the STEREO Project. As STEREO-WAVES above, this project is in Phase A/B involving detailed tradeoff studies and conceptual designs. M. Acuña of the LEP is responsible for the development and manufacture of the magnetic field portion of the experiment.

6.11 AIMS

Project Status. AIMS (Acousto-optic IMaging Spectrometer) is a compact VIS-to-SWIR Mars lander prototype imaging spectrometer being assembled at GSFC, and supported by the Code SM Mars Instrument Development Program (MIDP). The AIMS P.I. is D. Glenar, and engineering support is provided by teams in Code 566 (T. Flatley) and 548 (J. Parker). AIMS operates as a true tunable spectral camera between 0.48 and 2.4 microns wavelength, with [effectively] hundreds of spectral channels. It is designed to rapidly identify, distinguish and map surface mineralogies, as required in a sample return mission. Development of AIMS is now in its third year, and current plans call for field testing of the instrument at Mauna Kea in April 2001 with colleagues at JPL (D. Blaney) and U. of Tennessee (D. Britt).

6.12 Magnetospheric Multiscale (MMS) Mission

Project Status. S. Curtis is P.I. of an effort funded at \$300k per year by the Remote Experimentation and Exploration (REE) program that is part of NASA's High Performance Computing and Communication (HPCC) initiative. The object of this investigation is to examine the use of high performance computing on board the MMS mission spacecraft to increase science return and autonomy. This a continuation of an earlier grant to examine the general application of on-board high performance computing to constellations of spacecraft for greater science return and autonomy. The MMS has had four industry-based design studies that have helped to focus the mission design. In addition, the basis of the industry designs, the report of the MMS Science and Technology Definition Team has been published. S. Curtis is Project Scientist for MMS.

7 Sounding Rockets and Suborbital Programs

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

data along vertical trajectories, their low vehicle speeds (compared to satellites) with long dwell times at apogee, their ability to easily support multiple payload clusters and tethers, their ability to be launched 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 help 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.

7.1 GEODESIC

The GEODESIC Sounding Rocket was designed to explore the fine structure of charged particle acceleration and wave-particle interactions in the topside auroral ionosphere. The mission emphasized high-time-resolution measurements of core electrons and ions, covering 0-10 eV and 0-50 eV respectively, and pitch angle-energy images every 10 ms, or 10 m along the rocket trajectory. The high degree of spatial/temporal resolution was motivated by the increasingly apparent fact that auroral energy dissipation - including localized ion heating, wave generation, and acceleration of auroral electrons - is concentrated on scales of the order of, or less than, 100m. GEODESIC explored the pathways through which electromagnetic fields and accelerated particle populations couple energy into thermal populations, and through which the thermals in turn affect waves. A secondary objective of GEODESIC was to demonstrate the feasibility and utility of electro-optical detection of charged particles in space. This technique was motivated by the desire to improve measurement resolution in time, energy, and pitch angle. The project is funded by the Canadian Space Agency and is the initiative of Professor Dave Knudsen (U. of Calgary). R. Pfaff is a Co-I on this payload and was funded by NASA to provide a vector electric field instrument.

GSFC's instrumentation on GEODESIC measured the DC and AC vector electric field using the double-probe technique. In this case, spherical sensors with embedded pre-amps from DC-MHz were extended on booms in the spin plane. Since the payload spin axis was oriented along the magnetic field direction, the two-dimensional electric field measurement completely parametrized the electric fields perpendicular to the magnetic field vector, B. A third axis, along the payload axis, measured the parallel component. Instrumentation also included multiple baseline measurements of wavelength and phase velocity, as well as onboard FFT's of plasma waves up to several MHz. A high-speed burst memory triggered on intense wave events that were recorded in 4 simultaneous wave channels.

The launch took place on February 26, 2000, from Poker Flat, AK, and achieved an apogee of 990 km. It encountered a series of intense auroral arcs. A variety of plasma waves, including broadband ELF noise, VLF hiss, and discrete emissions at the upper hybrid frequency were observed. The waves and DC electric fields are being analyzed in conjunction with the high resolution particle measurements.

8 Future Missions

8.1 Living With a Star (LWS)

The goal of the Living with a Star (LWS) Program is to develop the scientific understanding necessary to effectively address those aspects of the connected Sun-Earth system that affect life and society. As presently envisioned, LWS has solar, heliospheric, magnetospheric and ionospheric flight elements. It emphasizes a unified systems approach to space weather with a strong theory, modeling and data analysis thrust as a central, cross-cutting element. Furthermore, there will also be a robust technology development and a flight test program to provide new instrumentation and flight test spacecraft subsystems.

Under the direction of the SEC Theme Director, a pre-formulation team for LWS was assembled by the GSFC late in 1999. LEP scientists actively participating in this effort are A. Szabo (Solar Sentinels Project Scientist), R. Hoffman (Radiation Belt Mappers Project Scientist), B. Giles (Radiation Belt Mappers Deputy Project Scientist), R. Pfaff (Ionospheric Mappers Project Scientist), Dean Pesnell/Nomad (Ionospheric Mappers Deputy Project Scientist), M. Hesse (Theory and Modeling Project Scientist), R. Vondrak (Steering Committee), T. Moore (Steering Committee), and J. Slavin (Steering Committee). In addition, B. Thompson (Code 682) is the Project Scientist for the Solar Dynamics Observatory. The Pre-formulation team was led by R. Fisher (Code 680), A. Poland (Code 680) and P. Caruso (Code 740). With collaborations from the space weather science and end-user communities, this team has delivered a preliminary mission concept study to NASA Headquarters. Contingent upon receiving final approval by Congress, an LWS Project Office will be established in the coming year and further mission architecture and implementation planning initiated.

Solar Sentinels (SS). A pre-formulation definition team developed the Sentinels mission scenario for the heliospheric portion of the LWS initiative. The goal of the Sentinels is to study the large-scale structure and evolution of the solar wind near the ecliptic between 0.5 and 1 AU. Specifically it aims to improve our understanding of how transients travel from the Sun to the Earth. Also, by mapping specific solar wind disturbances back to the surface of the Sun, this mission will search for the triggering mechanisms of geoeffective events. Moreover, the location and mechanisms of energetic-particle acceleration will be investigated. The accomplishment of these goals and objectives will allow an increase in the accu-

racy of propagation models and lead to the development of improved space weather forecasts.

The Definition Team recommended that four Inner Heliospheric Sentinels be required to accomplish the objectives. The small spinning spacecraft will be placed in heliocentric orbits ranging from 0.5 to 0.95 AU to make in-situ observations only. In addition, a Far Side Sentinel in a 1 AU orbit nearly out of phase with the Earth will observe the opposite half of the Sun in visible and EUV wavelengths and will make *in-situ* observations. Finally, the definition team recognized that an L1 Sentinel is required by the end-user community, which will complete the near-ecliptic heliospheric constellation.

Radiation Belt Mappers (RBM). A concept study was performed for the LWS Radiation Belt Mappers by an ad-hoc committee composed of scientists knowledgeable of the subject of radiation belts, modelers of radiation belts, and representatives of the user community. This group defined the primary program requirements, both from the science and users perspectives, and prioritized them. This analysis showed the need for multiple, low-inclination satellites, each well instrumented for both fields and particles measurements to acquire the data needed for an understanding of the sources, acceleration, transport, diffusion, and scattering mechanisms in the radiation belts. Specifically, RBM must fulfill the following:

- o Specific science community needs include:
 - Coverage of full particle phase space distributions over local time and altitude.
 - Electric and magnetic fields characterization over frequency domains of interest.
- o Specific user community needs include:
 - Data products for specification and predictive models.
 - Data products for real-time telemetry for the operations community.

The RBM mission is being designed to address the needs of both science and user communities now and into the next decade and will enable systematic long-term characterization of the radiation environment, especially the documentation and understanding of extreme events.

Ionospheric Mappers (IM). The IM mission will address a wide range of fundamental ionospheric and thermospheric problems using an array of spacecraft that will provide unprecedented, coordinated global measurements. The mission concept was developed by an ad hoc committee of scientists and end users. The three main areas of research and their space weather effects include:

- o Variations of the ionosphere and thermosphere, including:
 - Scintillations caused by ionospheric density irregularities, which disrupt communications and navigation systems and impact GPS accuracy;
 - Large-scale variations of ionospheric density and radiation, producing charging effects on satellite systems;

The Integrated Science and Technology Definition Team (ISTDT) has established the primary science objectives of this mission along with the resulting mission requirements and recommended minimum scientific instrumentation. These results have been presented to NASA HQ for further consideration. A. Szabo is a member of the ISTDT.

8.6 Auroral Lites Mission

The Auroral Lites mission is envisioned to be a five identical spacecraft mission to explore the underlying physics of the terrestrial auroral zone. The measurements will be space-time separated on scales down to 500 meters and, using the fifth spacecraft, derived measurements such as current densities will also be space-time separated for the first time in any space mission for a three dimensional plasma. The Auroral Lites mission, with very extensive university and foreign participation, will be submitted for consideration in the next MIDEX round. S. Curtis is the P.I.

8.7 SERAD

The Space Environment Radiation and Debris (SERAD) Mission is a proposed collaboration between the NASA manned spaceflight researchers at Johnson Space Center and GSFC. The SERAD objectives are to map the terrestrial radiation belts as well as the to study the sources and distribution of space debris between low earth orbit and geosynchronous Earth orbit. SERAD will employ 5-6 microspacecraft with heritage from earlier GSFC nanospacecraft technology efforts, including ST-5. In addition, there will be a larger deployer ship which will carry the debris detection experiments. Operationally, the microspacecraft will be deployed along an equatorial geosynchronous transfer orbit which will allow instantaneous radial sections of the radiation belts to be made, which owing to the symmetry properties of the radiation belts, will allow unique space-time separated maps of the belts to be produced. Owing to variations in the radiation and the debris belts with solar cycle, two SERAD deployments are planned: one at solar minimum in 2005 and one at solar maximum in 2010. S. Curtis is leading the study.

8.8 ANTS

The Autonomous Nano Technology Swarm (ANTS) advanced concept envisions the resource-driven exploration of the Solar System's Asteroid Belt by a swarm of totally autonomous robots. The robots would take the form of picospacecraft (mass less than one kilogram) powered by solar sails. The robots would utilize insect hierarchical intelligence and would be specialized workers or sciencecrafts with one instrument defining their functionality. Studies of the ANTS advanced concept provide a long-term vision for nearer term applications of autonomy and advanced on-board computation such as are being studied for the Magnetospheric Multiscale mission. S. Curtis leads this effort.

9 Instrument Development

HIPWAC. F. Schmuelling (NRC), T. Kostiuik, D. Buhl, and F. Minetto, with support from P. Rozmarynowski and F. Hunsaker have completed the development of a transportable, mid-infrared heterodyne receiver, Heterodyne Instrument for Planetary Wind And Composition (HIPWAC) is an advanced infrared heterodyne spectrometer (IRHS) for the measurement of Doppler broadened molecular line shapes and the wind-driven Doppler shifts of molecular lines formed in low-pressure, regions of planetary atmospheres and astrophysical sources. It is designed for use on large 8-10 m telescopes and is easily transportable to any observatory. The instrument design and construction includes a carbon fiber composite laser cavity and system optical bench, yielding a low mass, and highly mechanically and thermally stable system. The instrument has a frequency resolution of better than 106 in the range of 9 to 12 microns and permits remote velocity measurements to $\sim 1m/s$. The instrument is currently being tested and is scheduled for observations of Jupiter in coordination with the Cassini mission flyby of Jupiter in December 2000.

Planetary Bolometers and Spectrometers. J. Brasunas, in concert with B. Lakew, R. Fettig and S. Aslam, has continued the development of moderately cooled infrared bolometers based on thin-films of the high temperature superconductor material YBCO. J. Brasunas and B. Lakew are Co-I's for the Cloud Infrared Radiometer for UNESS (CIRRUS) instrument (S. Ackerman, U. of Wisconsin is the P.I.). It is a 4-channel, far-infrared radiometer employing four high temperature superconducting bolometers to study the radiative properties of cirrus clouds from the International Space Station. The four bolometers will be fabricated and characterized by the LEP. CIRRUS was selected for a study phase in 2000 under NASA's unESS program, and will be re-proposed for a flight instrument build in early 2001. In addition to the bolometer work, J. Brasunas is pursuing development of very broad-band ultraviolet-to-millimeter wavelength beamsplitters based on free-standing, grown films of CVD (chemical vapor deposition) diamond. By combining the bolometer and the CVD beamsplitter, the goal is to produce, for future planetary and earth missions, a smaller, lighter version of the CIRS spectrometer on the Cassini mission.

New Concept for an Energetic Neutral Atom Detector. By detecting, analyzing, and imaging Energetic Neutral-Atom (ENA) fluxes, plasma processes can be studied remotely and globally. Current technology for ENA detection and analysis below 10 keV uses either transmission through a carbon foil or grazing angle collisions with a low work function surface to convert neutral atoms to ions that are subsequently analyzed and detected. Both methods suffer from low conversion efficiencies accompanied by large angle scattering and energy loss. An alternative solution which will improve resolution and efficiency is to ionize the ENA using charge

exchange collisions with low ionization potential atoms (alkali metals) in the gas phase. To confine the alkali metal atoms we exploit the large difference in velocity between the neutrals going through the cell and the thermal alkali metal atoms contained in the cell. The charge exchange cell will be surrounded with rotating blades on a number of concentric circles. The rotational velocity (of order 30,000 rpm) will be sufficiently high to direct alkali metal atoms moving toward the ends of the cell back into the center while at the same time fast neutral atoms and negative ions pass through unimpeded. We have explored the turbotrap concept using a Monte Carlo simulation of particle trajectories. For an arrangement that includes two sets of rotating blades moving at 32,000 rpm we found that over 99% of the particles are returned to the trap. Based on these results, plans for building a prototype instrument are under development. This effort is lead by J. Keller., J. Allen, J. Britt (Code 544) and M. Coplan (U. of Maryland) are Co-I's. A summer undergraduate student is also providing support.

Large Area X-Ray Detectors. Detector areas of 25 cm² or greater are needed for K-shell x-ray planetary remote sensing systems in order to obtain the best spatial resolution. Proportional counters have been developed and flown on space flight missions successfully, but the energy resolution is very poor and cannot resolve, for example, the Mg, Al, and Si lines. The lines can be resolved by using balanced filters. The observations must be made simultaneously because the lines must be resolved from the same area on the planetary surface. Because of the motion of the orbiting satellite, use of a filter wheel cannot achieve this result. Thus separate detectors are needed for each of the filters. Under this program, room temperature silicon strip detector systems are being developed with resolution better than proportional counters. With the improved energy resolution, a balanced filter system may not be needed, thus reducing the weight and volume of the detector system. Furthermore, the room temperature solid state detectors themselves are lighter than the equivalent proportional counter systems. Improved energy resolution will also improve the signal-to-noise response of these detectors because they will reduce the rather significant background under the various detected photopeaks. A silicon PIN detectors is being flown as part of the NEAR mission and results so far indicate that the background due to cosmic ray interactions is considerably reduced as compared with proportional counters. Detector area of about 1 cm² produced with reasonably good energy resolution. Studies have just begun on developing mosaics of these detectors in order to obtain the desired 25 cm² area. A silicon drift has been constructed and will be tested using an Application Specific Integrated Circuit system developed at GSFC.

Lander Gamma-Ray Spectrometer. Elemental analysis by gamma-ray spectroscopy involves the detection of characteristic gamma-rays emitted by the decay of naturally radioactive elements, by means of cosmic ray primary and secondary excitation, or by the use of a

machine or radioactive neutron excitation source. This project will develop a gamma-ray spectrometer and neutron detection system that weighs less than 2 kg for use on rover missions. Major advances have been made to develop a scintillation gamma-ray detector incorporating CsI and a silicon photo-detector. Energy resolutions have been achieved which are as good as those obtained using photo-multiplier tubes with large area scintillators.

Solar Probe Plasma Instrument. E. Sittler continues to lead the effort to develop a nadir viewing capability for Solar Probe, which began with our initially funded proposal for NRA-95-OSS-15. He recently led an international team as P.I. for a proposal for the *in-situ* package of Solar Probe which has recently (July 6, 2000) been submitted to NASA headquarters. The development of the nadir viewing capability has led to a number of technological breakthroughs. We now have a complete design including the booms and heat shield, which can now be launched in a deployed configuration. This significantly reduces the risk in the program with regard to the nadir viewing feature. We have also been able to reduce the thermal input to the spacecraft significantly below the AO specification. The design concept is based on using a pair of electrostatic mirrors, which steer the ions and electrons into the nadir spectrometer. The later is safely confined within the "room temperature" part of the spacecraft. At present we have also developed an ion spectrometer for Solar Probe which we are now in the process of testing.

9.1 Development of IR-VIS-UV Optical Components Produced by Micro- and Nano-Technology

Far IR Imaging Array. With an eye towards future development, efforts to micro-machine sapphire are making progress. With its excellent thermal properties, micro-machined sapphire can be used to fabricate highly sensitive YBCO based bolometer arrays. These would be ideal for long term, moderately cooled ~90 Kelvin planetary instruments. 2-D arrays of these high temperature superconducting bolometers could also be used for imaging in the Far IR. The active pixels' thickness can be of the order of 1 μ m. This effort is led by B. Lakew in collaboration with J. Brasunas, S. Aslam and R. Fetting.

Gold Black Deposition Facility. For the deposition of gold black, a fractal conglomeration of nano-particles, a facility is maintained and further developed by R. Fetting in collaboration with J. Brasunas and B. Lakew. Gold black can be used as an absorber of low heat capacity for radiation from visible wavelength all the way through the infrared, into the submillimeter range. It is applied on HTS bolometers. The gold black is critical to the success of the high Tc bolometers in the proposed CIRRUS instrument.

Electrical Contacts to HTS Thin Films. Work is performed by R. Fetting to improve the electrical contacts to high temperature superconducting thin films by means of focused ion beam milling and ion induced metal organic chemical vapor deposition (MOCVD). J. Brasunas,

B. Lakew, S. Aslam, as well as J. Orloff, and K. Edinger at the U. of Maryland are involved in this effort.

Microshutters. Arrays of shutters for spatially resolved spectroscopy applications are being developed. Shutters of 100 μm opening have been developed. These can be arranged to form large arrays (<1kx1k) where the single shutters can be individually addressed. Photolithography methods are being developed to produce such arrays with appropriate addressing electronics.

Rapid prototyping is done by focused ion beam milling and testing with electron-microscope compatible methods. Facilities to test the optical performance are being developed. Planing has started to incorporate microshutter arrays in a ground based near infrared instrument. R. Fettig, H. Moseley and A. Kutyrev (GSFC code 685); M. Jhabvala, B. Mott and M. Li (GSFC Code 553); J. Orloff and K. Edinger (U. of Maryland) are involved in this project.

Electric Field Experiment Group. The LEP electric field experimental group led by R. Pfaff, designs and builds electric field double probes and Langmuir probes for flights on sounding rockets and satellites in the Earth's ionosphere. On-board processing electronics have been developed to gather burst memory data of significant flight events and onboard FFT processing that extend the measured frequency regime of electric field waves to several MHz. A new digital impedance probe utilizing discrete frequency steps has also been developed to observe resonances in the ionospheric plasma to provide absolute electron density and temperature measurements. This will be flown on a future sounding rocket flight.

10 Educational Outreach and Technology Transfer

Specific Education and Outreach Effort for Advanced High School and College Students. As reported last year, two students in a high school in Tennessee who were interested in mathematical aspects of the solar wind contacted the LEP. R. Lepping "walked" the students through understanding some aspects of the solar wind's interaction with the magnetosphere via the use of the Akasofu epsilon parameter and its comparison with the geomagnetic index Dst for a given interplanetary magnetic cloud event. They wrote analysis and plot programs and displayed the results on the Web with noteworthy success. Since that time the material that was used previously has been expanded and presented at the Conference of the National Council of Teachers of Mathematics in Chicago, in mid-April, as a Space Science teaching tool. Recently the scientist is communicating with a professor (D. Warn, at Boise State College) to help him render the program applicable for his students automatically and for use for multiple events. We hope to make this program as general as possible and are in the process of adding its main elements to the Lab's Education/Outreach Website.

Green Holly School. As a result of classroom interest in NASA's space station and spaceflight missions,

W. Maguire interacted with students at the Green Holly School in suburban Maryland. As part of their science class activities, students wrote letters about constructing models of the Constellation space station. He also met with some of the science class students during their outing to the GSFC Visitors Center. This Fall, in collaboration with the science faculty at the School, we will assess what other joint activities would encourage interest in space-related topics.

National Institute of Justice/NASA's GSFC Program. A Memorandum of Understanding has been signed between the National Institute of Justice (NIJ) and the NASA to develop instruments and communication networks that have application in both NASA's space program and in NIJ programs with state and local forensic laboratories. The objective of the program is to produce instruments and communication networks that have application in both NASA's space program and in NIJ programs with state and local forensic laboratories. The approach taken in this program will be based on the remote sensing and in-situ systems developed by NASA for planetary space exploration. Field testing these systems can contribute significantly to the verification and development of such exploration methods for future planetary missions. The systems to be developed involve the non-destructive measurement of physical evidence at crime scenes. The first phase of the project has had as its objective the development of a x-ray fluorescence system for the measurement of gun shot residues and blood at crime scenes. Preliminary feasibility studies have been completed and have demonstrated that portable x-ray fluorescence systems can have the sensitivity for the detection of gunpowder residues and blood samples in the crime scene environment.

Outreach to Schools. M. Peredo has given a number of talks to school groups, teacher workshops, and other general participation events as part of the ISTP outreach effort.

Visiting Students. For 6 weeks each, covering June and August of 2000, a middle school teacher, Mrs. Kate Terrell and Ms. Katie McClernan, a University of Arizona student who was part of the National Space Scholars Program assisted R. Lepping in the development of parts of the Laboratories' education/outreach website. This year the emphasis was on making the site more consistent and attractive to the public and on adding various activities and tutorials. The student also continued the analysis of large angle directional discontinuities in the solar wind as seen by both the WIND and IMP 8 spacecraft, especially in the examination of the curvature of discontinuity surfaces and their changing thicknesses, which appears to be a common occurrence even on the scale of 50 R_E or less. This project started last year. This year, after the student left, the work was taken over by the teacher. In the process an IDL program that uses 40 input quantities for each discontinuity, and originally written by the student, was slightly modified. The program was tested using reasonable simulated data last year, but now it appears to be successfully working for

actual space data. It is currently in production. Preliminary results show that a broad range of radii of curvature is found. The smaller radii will be difficult to explain. It appears that other natural considerations, other than errors, will have to be invoked to explain them.

10.1 Educational Web Sites

"The Great Magnet, the Earth." The outreach efforts of D. Stern, conducted over the World Wide Web, were focused on the Earth's magnetism, since Y2K marks the 400th anniversary of William Gilbert's book "De Magnete." A non-mathematical website was established: "The Great Magnet, the Earth": (<http://www-spof.gsfc.nasa.gov/earthmag/demagint.htm>) and most of its Spanish translation (by J. Mendez of Algorta, Spain) is already on the web as well, linked to the same home page. The page has 16 main sections. A long historical review "A Millennium of Geomagnetism" was submitted to the Journal of Geodynamics and covers this material on a more professional level. The anniversary was marked by a session on history of geomagnetism at the Spring Meeting of the American Geophysical Union, organized by D. Stern.

Another educational resource, for individual study and for non-calculus courses in high schools and colleges, is "From Stargazers to Starships" with home page at: www-spof.gsfc.nasa.gov/stargaze/Sintro.htm. As reported last year, the site covers elementary astronomy, Newtonian mechanics and spaceflight, plus a self-contained course on the related math. Added this year was a section on the Sun, a set of 42 lesson plans (link from /Lintro.htm) and a Spanish translation by Mr. J. Mendez of Algorta, Spain (link from /Mintro.htm). It now contains 266 text files (plus many images) and single copies on a CD are available from the author, D. Stern. D. Stern also gave a workshop on this material "Space Physics as a Theme in High School Using Web Resources" at the summer meeting of the American Association of Physics Teachers in Guelph, Canada.

Lunar Eclipse. F. Espenak is the webmaster of the NASA Eclipse Home Page at: <http://sunearth.gsfc.nasa.gov/eclipse/eclipse.html>. During January, this web site received up to 1,725,533 hits in one week due to the tremendous interest generated by the total lunar eclipse of January 20. He assisted the Goddard Office of Public Affairs in the development of lunar eclipse animations to distribute to news media nationally for the lunar eclipse. Espenak also gave interviews about the eclipse to the NBC Today Show (10 million viewers) and a number of other television news broadcasts around the country.

F. Espenak also gave three eclipse lectures to general public:

1. MAPS (planetarium educators meeting) - May 2000;
2. MIDCON2000 (Astronomical League Regional Convention) - June 2000;
3. ASTROCON2000 (Astronomical League National Convention) - July 2000.

LEP Educational and Outreach Program. D. Tag-

gart, M. Collier, and R. Lepping are leading an effort, joined by various members of the Laboratory to continue the development of its Education/Outreach Website. It attempts to appeal to a broad audience, but targets high school students in particular. In mid-July of this year it has been accepted by Safexplorer database for families. It is now listed on many other major search engines. It highlights the scope of the Laboratory's research and recently it has had added new tutorials and resources for teachers. A general "business card" and a postcard showing the site's URL (http://lep694.gsfc.nasa.gov/lepedu/lepedu_hp.html) and its front page has been developed to advertise the site.

The publication list includes all papers published or submitted in 1999 by the LEP Staff (or by visitors, if a substantial portion of the work was done at LEP).

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