NASA Goddard Space Flight Center

Laboratory for Extraterrestrial Physics

Greenbelt, Maryland 20771

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 2000 through September 2001.

1 Personnel

Dr. Richard Vondrak continues as Chief of the LEP. Mr. Franklin Ottens is Assistant Chief. The Branch Heads are Dr. Joseph Nuth (Astrochemistry); Dr. Thomas Moore (Interplanetary Physics); Dr. Drake Deming (Planetary Systems); Dr. Steven Curtis (Planetary Magnetospheres), and Dr. James Slavin (Electrodynamics). The Laboratory Senior Scientists are Drs. Richard Goldberg, Michael Mumma, Keith Ogilvie, and Louis Stief. 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. Mei-Ching Fok, 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 Kostiuk, Dr. Brook Lakew, Dr. Guan Le, 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. Amy Simon-Miller, Dr. Edward Sittler, Dr. Michael Smith, Dr. David Stern, Dr. Adam Szabo, Dr. Jacob Trombka, Dr. Adolfo Figueroa-Viñas, and Dr. Peter Wasilewski. Also Co-op students, Mr. Daniel Martinez, Ms. Kelly Fast, and Mr. Walter Allen. The following are National Research Council Associates (NRC): Dr. Akimasa Ieda, Dr. Robert Boyle, Dr. Aharon Eviatar, Dr. Perry Gerakines, Dr. Jesper Gjerloev, Dr. Cedric Goukenleuque, Dr. Hugh Hill, Dr. Kristi Keller, Dr. Gunther Kletetschka, Dr. Alexander Kutepov, Dr. Jan Merka, Dr. Therese Moretto, Dr. Frank Schmülling, Dr. Kristine Sigsbee, Dr. Christian Steigies, Dr. Vadim Uritsky, Dr. Oleg Vaisberg, Dr. Phillip Webb, Dr. Robert Weigel, Dr. Michael Wong, and Dr. Chin-Chun Wu. The following scientists work at LEP as either contractors to GSFC or as long-term visiting faculty: (Emergent Information Technologies, Inc. (EITI)) Dr. Daniel Berdichevsky, Dr. Scott Boardsen, Dr. Henry Freudenreich, Dr. Sanjoy Ghosh, Dr. Roger Hess, Dr. Vladimir Osherovich, Dr. Edouard Siregar, Dr. Pamela Solomon, and Dr. Adinarayan Sundaram; (Raytheon/ITSS) Dr. Ashraf Ali, Dr. Rainer Fettig, Dr. Venku Jayanti, Dr. Maria Kuznetsova, and Dr. Lutz Rastätter; (Universities Space Research Association (USRA)) Dr. Nikolai Tsyganenko and Dr. Dimitris Vassiliadis; (Computer Sciences Corporation (CSC)) Dr. Larry Evans; (Catholic University of America) Dr. Pamela Clark, Dr. Dana Crider, Dr. Tamara Dickinson, Dr. Michael DiSanti, Dr. Frank Ferguson, Dr. Natchimuthuk Gopalswamy, Dr. Patrick Michael, Mr. George McCabe, Dr. Robert Nelson, Dr. Fred Nesbitt, Dr. Michael Reiner, Dr. Neil Dello Russo, and Dr. Richard Starr; (Space Science Applications, Inc. (SSAI)) Dr. Richard Achterberg, Dr. Ronald Carlson, and Dr. Mauricio Peredo; (University of Maryland Baltimore County (UMBC)) Dr. David Steyert; (University of Maryland, College Park) Dr. Dennis Chornay, Dr. Georgi Georgiev, Dr. Thejappa Golla, Dr. Tilak Hewagama, Dr. John Hillman, 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 and Dr. Timothy Livengood; (NOMAD Research) Dr. Dean Pesnell; (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.

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

2 Astrochemistry

Cosmic Ices. Mid-infrared spectroscopy of cosmic-type ices exposed to both proton bombardment and UV-photolysis is used to examine a variety of physical-chemical and radiation-chemical changes in ices. Results show that many complex organic molecules form through processes that are thought to be relevant to comets, interstellar icy-grains, or the surfaces of icy satellites. New results from the Cosmic Ice Laboratory include:

The Formation and Stability of C_3O_2. The formation rate of C_3O_2 was measured in laboratory ices of pure CO and CO_2 and mixtures of these molecules with H_2O at 18K. The most efficient formation occurs in ion irradiated pure CO ices. UV and ion destruction rates were measured along with C_3O_2's IR band strength and vapor pressure. (P. Gerakines and M. Moore)

Formation of Cyanate Ion (OCN^-) in Interstellar (IS) Ice Analogs. Extensive laboratory work investigated the 4.62 micron band formation in proton irradiated ices to simulate energetic processing of IS ice analogs. Results leave no doubt that the 4.62 band is due to the cyanate anion. This extensive work should establish the 4.6 micron band identification with OCN^- and quell a 20 year controversy over its identification. (R. Hudson and M. Moore)

NH_4^+ Matches Two IS Ice Absorption Features. UV-photolyzed or ion-irradiated ices containing H_2O, CO_2, NH_3 and O_2 undergo acid-base reactions involving NH_3 to produce a variety of ions: NH_4^+, NO_2^-, NO_3^- and HCO_3^-. Laboratory results suggest an abundance of NH_4^+ of nearly 10% relative to H_2O in similar IS ices. (M. Moore, R. Hudson, and W. Schutte, Leiden University)

HCN and HNC Formation and Stability in N_2 Rich Ices Relevant to Triton and Pluto. HCN and HNC were identified in ion-irradiated N_2 rich ices containing CH_4 or CH_4 + CO. UV photolysis of the same ices does not produce HCN on HNC. The formation route for these species was examined, showing a connection with diazomethane, CH_2N_2, a molecule also synthesized during processing. When warmed to 35 K, these ice products undergo acid-base reactions forming ammonium cyanide and ammonium azide, two salts, which may similarly form on the surfaces of Triton and Pluto. (M. Moore and R. Hudson)

Complex Organic, Hexamethylenetetramine (HMT), Found in Irradiated Interstellar Ice Analog. HMT has been detected in organic residues resulting from H_2O : CO : CH_3OH : NH_3 ices submitted to UV photolysis or proton irradiation. This is the first time HMT is detected after proton irradiation of an interstellar or cometary ice analog, whereas this molecule was suspected to be a characteristic signature of a UV photolysis process. This result strengthens the probability of HMT presence in the interstellar medium and in comets, where it should eventually be detected with the COSAQ instrument onboard Rosetta mission. (H. S. Cottin, NRC, and M. Moore).

3 Extrasolar Planets.

Radio Search for Extrasolar Planets. LEP members (W. Farrell and M. Desch) obtained radio telescope time on the Very Large Array (VLA) to search for a radio signature from the extrasolar planet about Tau Bootes. While coherent cyclotron emission from these distant planets is expected to be very weak at Earth, Tau Bootes was previously predicted to have the most likely chance of being detected. The data is currently being analyzed. Initial results suggest that a solid detection was not made, but the lack of detection still places upper limits on the planetary magnetic field and stellar winds emitted from the star.

Search for the Secondary Eclipse of Extrasolar Planets. D. Deming and L. J. Richardson are attempting to detect the secondary eclipse in the "transiting planet" system, HD 209458. Other collaborators include L. Esposito (LASP) and J. Harrington (Cornell). The secondary eclipse occurs when the planet passes behind the star. Because the planet-to-star brightness ratio is greater at long wavelengths, the secondary eclipse may be relatively "large" (0.2%) in the infrared. The approach is to look for subtle changes in the infrared spectrum of the system as the planet is eclipsed by the star. They collaborated with G. Wiedemann (Univ. Observatory, Munich) to obtain moderate resolution infrared spectra during two secondary eclipses in July 2001, using the ISAAC spectrometer on the VLT. An additional two eclipses were observed from Mauna Kea at lower spectral resolution, using the SpeX instrument on the NASA Infrared Telescope Facility (IRTF). Analysis of the data is underway, utilizing models for the exoplanet's infrared spectrum computed by NRC postdoctoral associate C. Goukenleuque. He has extended his original (51 Peg) model, by adding visible-region opacities due to strong atomic lines, by improving the water condensation computation, and by improving the convective adjustment.

Transit Spectroscopy of Extrasolar Planets. D. Deming, C. Goukenleuque and L. J. Richardson are collaborating with J. Harrington and K. Matthews (Caltech) in an attempt to detect water absorption in the "transiting planet," HD 209458b. This is being done using "transit spectroscopy," searching for absorption features in the stellar spectrum as the planet transits the star. The observations utilize the HNA spectrometer on the Palomar 5-meter telescope. Extensive data were obtained during two transits in August 2001, and the data analysis is underway.

4 Planetary and Cometary Physics and Chemistry

4.1 Laboratory Studies.

Gas-Phase Spectroscopy. A significant effort in the LEP is high-resolution laboratory infrared spectroscopy of gaseous molecular species. The research by the LEP spectroscopy group (D. Reuter, 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, line-mixing effects and temperature dependent spectra. There is a vigorous program to measure spectra at wavelengths greater than 10 μm using Tuning-Diode-Laser and Fourier-Transform Spectroscopy. Supporting laboratory measurements are scarce for these wavelengths, but are crucial for the analysis of data from upcoming space missions such as Cassini, where CIRS will obtain spectra of Saturn and Titan from 7 to 1000 μm. Recent activities of the group have included obtaining and/or analyzing spectral data for excited state and fundamental transitions in H_2, H_2O, $^{13}C^{12}CH_6$, $^{12}C_2H_6$, C_2H_4, C_2H_2, N_2O, CO_2, C_3H_4 (both the methylacetylene and allene isomers), $(CH_3)_2CO$ and HNO_3. This work has been carried out in collaboration with personnel at several institutions including W. E. Blass (Univ. Tenn.), N. M. Donahue (Harvard Univ.), J. M. Frye (Howard Univ.), J. W. C. Johns (NRC, Canada), A. Perrin (C.N.R.S., Paris), M. Sirota, L. L. Strow and W. Wang (UMBC), C. B. Suarez (NRC, Argentina) and R. H. Tipping (Univ. Alabama). These measurements have already had an effect on planetary studies. For example, the ν_{12} ^{13}C ethane ($^{13}C^{12}CH_6$) intensities have been used in conjunction with ground-based observations to infer an essentially terrestrial $^{13}C/^{12}C$ ratio on Jupiter and Saturn. The intensities of the ethylene (C_2H_4) transitions have been used to obtain this species concentrations in the upper atmosphere of Saturn. The low temperature line intensity and self- and nitrogen broadened measurements of the ν_9 band of allene near 28 μm are the first such measurements of this band, and are among the longest wavelength TDL data ever obtained. The high-pressure long-pathlength CO_2 broadening spectra show the clear effects of line-mixing and far-wing line shapes in this species and may be used to model atmospheric spectra for the Mars Global Surveyor. The parameters obtained from these experiments are crucial to the proper interpretation of the upcoming CIRS measurements of the atmosphere of Titan.

As well as obtaining and analyzing spectra, this group places a strong emphasis on improving instrumentation and, among other accomplishments, has developed a unique tunable diode laser (TDL) system for obtaining spectra to $\sim$30 μm employing advanced (Si:As and Si:Sb) BIB detectors, high performance lead-salt lasers and a long-path White-type sample cell. A very long-path, coolable White-type cell has been assembled which allows pathlengths in excess of 500 m at temperatures as low as 150 K. We have also obtained a CsI beamsplitter which we have used to expand the long-wavelength capability of the Bruker FTS spectrometer at the atmospheric chemistry group at Harvard University, which we use in collaborative spectroscopy experiments.

Kinetics - Outer Planet Hydrocarbon Chemistry. The methyl (CH_3) radical is the first free radical to be detected in the atmospheres of the outer planets. It was observed with ISO in the atmospheres of Saturn and Neptune and recently with Cassini - CIRS in the atmosphere of Jupiter. The observed column densities of CH_3 for Saturn and Neptune are lower than those calculated from atmospheric photochemical models. The major sink for CH_3 radicals is the self-reaction $CH_3 + CH_3 + M \rightarrow C_2H_6 + M$. If the rate constant for this reaction at the low temperatures and pressures of these atmospheres is significantly greater than that estimated from previous measurements in the laboratory at higher temperatures and pressures, then this larger k_1 would resolve the discrepancy between the observed and calculated CH_3 column densities. R. Cody, W. Payne, L. Stief, R. Thorn and F. Nesbitt (Coppin State College, Baltimore, MD), in collaboration with D. Tardy (Univ. Iowa) and M. Iannone (Millersville Univ., Millersville, PA) are measuring the rate constant for this reaction at low temperatures and pressures in helium in a discharge flow - mass spectrometer apparatus. Helium is a more suitable bath gas for the outer planetary models than argon, which has been used in all but a few previous measurements. The measurements for k_1 at $T = 298$ and 202 K are completed. This study represents the first measurements of the pressure dependence of the rate constant at a temperature below 298 K. Studies at $T = 155$ K are in progress. These laboratory values of k_1 are being used to validate a theoretical expression for the decrease of k_1 with pressure. The validated theoretical expression can then be used to determine k_1 at pressures below those studied in the laboratory as required by the planetary models.

Rock Magnetism. The rock magnetism laboratory conducts experimental studies in support of the interpretation of planetary magnetometer missions such as NEAR and the Mars Global Surveyor. In addition experimental studies of the meteorite magnetic record and basic properties of magnetic mineralogies that could be responsible for the long wavelength magnetic anomalies observed with the MAGSAT Earth orbital mission are part of the venue.

The characteristics of TMRM (Transformation Remanent Magnetization) associated with the first-order 13 Gpa shock transition in body-centered cubic (bcc) iron has been evaluated. The magnetization intensity is much reduced compared to cooling through the Curie point and the vector direction is more or less coincident with the field direction acting during the shock event.

The Lodestone is massive iron ore that had been oxidized naturally, imparting microstructure in the massive magnetite ore. This microstructure increases the magnetic coercivity and magnetic retentivity and sets the stage for magnet properties when the sample is struck by a lightning bolt. The critical physical evidence is the REM value (ratio of NRM (natural remanence) to the SIRM (saturation remanence)) which is $\gg 0.1$ compared to cooling through the Curie point which is the most efficient magnetization mechanism but has REM about 0.02. Mother Nature essentially processes the magnetite ore to impart magnet properties and then charges the ore with a lightning bolt. This process was verified with triggered lightning experiments at the Langmuir lab (New Mexico Tech) at South Baldy mountain.

Thermoremanent Magnetization (TRM) is one of the most efficient remanent magnetization mechanism in nature resulting in the largest specific magnetization intensity compared to other mechanisms. Among the magnetic minerals in the Earth's crust: magnetite, hematite, titanomagnetite, titanohematite and pyrrhotite are the ones most frequently encountered. Our results suggest that if the conditions of metamorphism and crystallization allow MD hematite to be formed in the lower and middle crust then these hematite grains may contribute significantly to the magnetic remanence. These unique properties of TRM in MD hematite require a reevaluation of their role in the interpretation of magnetic anomalies on Mars and Earth.

Carbonados are aggregate polycrystalline diamonds and are found in placer deposits of the Central African Republic (CAR) and the Bahia Province of Brazil. Their origin is uncertain. Results reveal that the carbonados contain material with contrasting magnetic hysteresis behavior and magnetization. Acid leaching permitted us to monitor the distribution of magnetic carriers within the samples. The magnetic carriers are distributed at the vitreous surface; including open pores and that the carbonado interior is essentially devoid of the magnetic carriers. The formation of the magnetic carriers is thus closely linked with the origin of the smooth surface, perhaps during the hypervelocity ejection of carbonados into the Earth's atmosphere.

4.2 Planetary Observations

4.2.1 Mars

Martian Volatiles. The properties and diurnal evolution of Martian aphelion clouds are being investigated by D. Glenar, with Co-investigators G. Bjoraker, R. Samuelson, J. Pearl, and D. Blaney (Jet Propulsion Laboratory) using IR mapping data acquired by the KPNO Cryogenic Spectrometer during the '99 opposition. Results show the diurnal evolution of topographically related H_2O ice clouds near L_s=130, which were mapped during the same time period by MGS/TES at fixed (1400 hrs) local time. Comparisons of Mie scattering radiative transfer models with the observed cloud spectral shapes (D. Glenar/R. Samuelson) suggests that cloud particles have multi-modal size distributions, with characteristic radii between 1-4 microns. Additional spectral mapping observations of Mars in K and L-bands were conducted during June and July '01 by D. Glenar and D. Blaney, using the SpeX slit spectrometer at the NASA Infrared Telescope Facility (IRTF). The July measurements at L_s=195 coincided with the onset of a global dust storm, monitored simultaneously by MGS/TES. (J. Pearl, M. Smith)

Mars Global Surveyor Thermal Emission Spectrometer. We have been using MGS/TES infrared spectra to monitor the seasonal and spatial distribution of aerosols and water vapor. In the past year we have completed one full year of MGS mapping and have examined the seasonal and spatial dependence of atmospheric temperature, dust opacity, water ice cloud occurrence, and water vapor column abundance, and looked at the interrelations between those quantities. We have also used TES limb-geometry spectra to study the scattering properties and the vertical distribution of dust and water-ice aerosols and water vapor gas. (M. Smith)

Vertically-Resolved High Altitude CO_2 Hot Bands on Mars. W. Maguire, J. Pearl, M. Smith, B. Conrath, A. A. Kutepov (Munich), M. Kaelberer, E. Winter and P. Christensen (Arizona State), as part of their analysis of MGS/TES spectra, have begun studying the 10 μm CO_2 hot bands first observed from the ground. The energy levels in these bright bands are in non-LTE (non-local thermodynamic equilibrium), pumped by the 2.7 μm via the 4.3 μm CO_2 bands which absorbs solar radiation. The Mars latitude and height of this emission varies with season and approximately tracks the location of solar input. Mars' orbital eccentricity produces a 40% change in the solar radiation input to its atmosphere over a Martian year. By accounting for this in a non-LTE code modified for Mars' atmosphere, we have improved our modeling of the emission.

Physics of Mars Non-LTE CO_2 Emission. T. Kostiuk with Co-investigators T. Livengood, W. Maguire, J. Pearl, F. Espenak, and T. Hewagama are supporting MGS/TES observations that have detected and spatially mapped non-thermal emission by CO_2 in the upper atmosphere of Mars. TES observations lack the requisite spectral resolution to resolve the individual emission lines and thereby derive physical information about the source region. HIPWAC observations conducted in August 2001 sensed non-LTE rovibrational lines of CO_2 with sufficient signal-to-noise to characterize the gas kinetic temperature in the source region from the Doppler line-broadening. Observations were conducted along the ~2PM dayside track of the MGS at high resolution, $\lambda/\Delta\lambda=5\times10^6$. A serendipitous bonus from these measurements was the observation of variable depth in the pressure-broadened CO_2 absorption profile at disc center due to the global dust storm in progress at the time, providing a gauge of the altitude to which dust was circulated.

R. Novak, M. Mumma, M. DiSanti, N. Dello Russo, and K. Magee-Sauer continued their detailed study of ozone on Mars using emission from its photolysis product, the $O_2(^1\Delta_g)$ band system, to probe ozone in the middle atmosphere. They simultaneously measured atmospheric water by observing the ν_1 band of HDO near 3.67 μm. Both species were mapped at high spatial resolution using CSHELL at the NASA IRTF, and diurnal and seasonal effects were explored. Enhanced ozone was detected over the dawn terminator, confirming the predicted buildup during the Martian night. In depth analysis was completed for meridional maps acquired in January 1997 (L_s = 67.3°). Our column burdens for water along the central meridian agree well with those acquired by TES on the MGS at the same season (late northern spring) in the following Mars year. Our ozone column burdens in the middle atmosphere are consistent with (and augment) independent measurements of total column burden returned from FOS on Hubble Space Telescope, providing a first glimpse of the altitude distribution for ozone on Mars. Together, these measurements provide a new approach for studies of the water-ozone cycle on Mars.

Martian Atmosphere Electric Circuit. LEP Members W. Farrell and M. Desch have determined the conditions required for a global atmospheric electric system on Mars, this fed by the electricity from Martian dust storms. Such a system is analogous to the terrestrial global atmospheric electric circuit driven by thunderstorms. In essence, the dust storms act as electrical generators, driving current between the planet surface and planetary ionosphere. As long as the ground conductivity exceeds a specific value, the circuit completes itself through the fair-weather atmosphere away from the dust storms.

4.2.2 Jupiter

Cassini/Radio and Plasma Wave Science (RPWS) and the Jupiter Encounter. As Co-investigators on RPWS, LEP members M. Kaiser, W. Farrell, and M. Desch were active participants in the January 2001 Cassini encounter with Jupiter. Plasma wave measurements were used to identify a number of Jovian bow shock crossings. Radio and plasma emissions also indicated a two day period when the spacecraft made multiple entries into the deep tail of the planetary magnetosphere. The science team found evidence for a boundary layer at the edge of this Jovian magnetotail. These findings are to be presented in a pair of upcoming Nature articles.

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 northern jovicentric latitudes were predominantly right-hand (RH) polarized while events recorded when the spacecraft was at southerly jovicentric latitudes were predominantly LH polarized, the change taking place at approximately 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 although the distribution was similar. For the RH polarized events, however, the distribution was different, the so-called main peak being absent or, perhaps, displaced 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 determines 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 emission.

M. Reiner, M. Kaiser, and M. Desch re-analyzed the Ulysses data taken during the Ulysses-Jupiter encounter to look for possible long term periodicities in the Jovian 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 emissions. 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.

Jovian Mid-IR Aurora During the Cassini Flyby. T. Kostiuk with Co-investigators T. A. Livengood, F. Schmülling, D. Buhl, K. E. Fast, T. Hewagama, and J. J. Goldstein observed Jovian auroral emission of ethane in the HIPWAC instrument's first two runs in December 2000 and in February 2001, during the Cassini spacecraft flyby of Jupiter. Observations complemented spacecraft measurements and contributed to the development of a long-term database to investigate solar-cycle related variations in the activity of Jupiter's aurora. These observations were conducted in concert with scheduled observations of the Jovian auroral region by the Cassini Composite Infrared Spectrometer (CIRS). The measurements complement CIRS' broad spectral coverage, high spatial resolution, and unique vantage point using groundbased spectra at extremely high spectral resolution tied to a history of related measurements.

Temporal Study of SL9-Introduced Ammonia in Jupiter's Stratosphere. K. Fast, with Co-authors T. Hewagama, T. Kostiuk, P. Romani, F. Espenak, A. Betz,

R. Boreiko (Univ. Colorado, Boulder) and T. Livengood, have in press a report on the temporal behavior of introduced ammonia and temperatures in the stratosphere of Jupiter following the impact of Comet Shoemaker-Levy 9 fragments G and K, measured with infrared heterodyne spectroscopy (IRHS) by co-authors Betz and Boreiko. Spectra were acquired from hours to 18 days following the impacts, enabling an investigation of the temporal behavior of ammonia abundance and temperatures in Jupiter's stratosphere. Results are consistent with the work of J. Harrington (Cornell Univ.) and D. Deming for upper atmospheric heating and introduction of material by "splashback" of the material ballistically ejected from Jupiter's atmosphere by the impact. The integrated mass of ammonia suggests that the observed ammonia was excavated from Jupiter's deep atmosphere rather than introduced by the comet fragments' dissolution. Ammonia concentrations after impact decrease significantly faster than the rate expected from photolytic destruction. The last set of observations, however, suggest additional lower-altitude sources of ammonia supporting the concentration in the lower stratosphere.

Jupiter Atmospheric Composition. G. Bjoraker and T. Hewagama are using spectra of Jupiter acquired with the CSHELL spectrometer at NASA's IRTF in Hawaii to study the deep atmosphere. Observations of CH_4 and NH_3 were obtained nearly simultaneously with measurements by the CIRS on the Cassini spacecraft during the Jupiter flyby in December 2000. The methane observations are sensitive to the abundance of water vapor between 3 and 7 bars on Jupiter. This technique permits mapping H_2O on Jupiter using ground-based telescopes. Preliminary results show dramatic variations in the abundances of both H_2O and NH_3 near the Great Red Spot.

4.2.3 Saturn's Satellites

Near-IR Spectral Imaging of Titan. Spectral imaging of Titan has been conducted on two successive years, using a GSFC-built acousto-optic camera at the Mt. Wilson 100 inch natural guide star adaptive optics facility. N. Chanover (New Mexico State) is the Principal Investigator and D. Glenar, G. Bjoraker the GSFC Co-investigators. Other team members include J. Hillman, D. Kuehn (Pittsburg State University) and C. McKay (NASA Ames). The objectives have been to observe Titan in and out of the 0.94 micron methane "window" and at selective wavelengths that are sensitive to absorption and scattering, in order to investigate the temporal nature and spectral shape of the basic bright and dark regions, including the Cassini/Huygens probe landing site. The first-year data set has been processed to remove low-level spectral "streaking" from the AOTF, and has been otherwise deconvolved to enhance spatial contrast. Supporting modeling of the haze contribution is being done at NASA Ames.

Titan Winds and Atmospheric Composition. T. Kostiuk, with Co-authors K. Fast, T. A. Livengood, T. Hewagama, J. Goldstein, F. Espenak and D. Buhl published their analysis of three combined runs at the NASA IRTF using Infrared Heterodyne Spectroscopy (IRHS) to measure the limb-to-limb relative Doppler shift of ethane gas transported by wind in the stratosphere of Titan. The wind direction is found to be prograde with 94% confidence. The existing Titan data set has resulted in an improved value for the concentration of ethane in Titan's stratosphere, shifting the central value to somewhat lower concentration and decreasing the error bars by a factor of several relative to the prior literature [T. A. Livengood et al., 2001]. Anticipated measurements of Titan wind tentatively scheduled for the Gemini North telescope in January-February 2002, potentially may decrease the experimental uncertainty by a factor of about two to five relative to the current results, providing a significant measurement of wind magnitude. The same observations will have a similar effect to improve the retrieved ethane concentration and will provide constraints on Titan's stratospheric thermal profile in advance of the arrival of the Huygens Probe mission.

Modeling Pickup Ions at Icy Satellites. E. Sittler, as Cassini Plasma Spectrometer (CAPS) Co-investigator, is studying pickup ions at Dione and Enceladus. His model includes a sputtered atmosphere for each icy satellite and ion production is produced by photoionization, charge exchange and electron impact ionization. The atmosphere is assumed to be optically thin and finite gyro-radii effects are shown to be small. As a fluid element passes through the atmosphere, ions are accumulated by the ionization mechanisms noted above to yield a pickup ion density at the assumed observation point where the Cassini spacecraft is located. This information is then used to produce simulated data products that would be produced during the separate icy satellite encounters. These data products are in the form of ion distribution functions and energy-TOF spectrograms. The pickup ions are assumed to form ring distributions which can readily be distinguished from ambient ions. The observed ion abundances of pickup ions can be used to determine the composition of the icy satellite surfaces.

4.3 Comets and Meteoroids

M. Mumma, M. DiSanti, N. Dello Russo, K. Magee-Sauer, R. Novak, and D. Reuter reported results from the first observations of an Oort cloud comet (C/1999 H1 Lee) 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), Principal Investigator), during instrument commissioning. 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 (5 - 40 au), where these three comets originated.

M. Mumma, N. Dello Russo, M. DiSanti, K. Magee-Sauer, R. Novak, and D. Reuter, with S. Brittain and T. Rettig (Notre Dame), I.S. McLean (UCLA), and Li-H. Xu (Univ. New Brunswick) investigated the organic volatile composition of the Oort-cloud comet C/1999 S4 (C/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 dynamically-new comets. The hypervolatiles methane and ethane were detected at levels much lower than found in comets Hyakutake, Hale-Bopp, and Lee. Methanol was found to be depleted by a factor of ten or more. HCN was only slightly depleted and H_2S was nearly normal, yet both are more volatile than methanol. M. Mumma et al., advanced the view that C/S4 formed in the relatively warm nebular region near Jupiter (5 - 10 au); they further suggested that C/S4 may be the first comet identified of the kind that delivered water to Earth.

M. Mumma, N. Dello Russo, M. DiSanti, K. Magee-Sauer, and R. Novak, with A. Conrad and F. Chaffee (W. M. Keck Observatory), studied the long period comet C/1999 T1 (McNaught-Hartley) using NIRSPEC at Keck and CSHELL at the NASA IRTF. They found this comet to be rich in CO (∼20%) but "normal" in C_2H_6 (0.65%) and CH_3OH (1.7%) (IAUC 7578). The CO mixing ratio in this comet is similar to that found for native CO in Hyakutake and Hale-Bopp, but it is much higher than that found for comets Lee (∼2%) and C/S4 (LINEAR) (∼1%). Abundances of C_2H_6 and CH_3OH are similar to those in comets Hyakutake, Hale-Bopp, and Lee. Further analysis is in progress.

M. Mumma, M. DiSanti, N. Dello Russo, K. Magee-Sauer, and R. Novak studied the long-period comet C/2001 A2 (LINEAR) using NIRSPEC at Keck and CSHELL at the NASA IRTF. They found this comet to be enriched in ethane by a factor of two relative to four other comets from the Oort cloud. Further analysis is in progress.

N. Dello Russo, M. Mumma, M. DiSanti, K. Magee-Sauer, and R. Novak completed their study of ethane in comet Hale-Bopp during its recent apparition. Ethane (C_2H_6) was detected in C/1995 O1 Hale-Bopp on thirteen dates between UT 1996 September 20.3 ($R_h = 3.01$ AU pre-perihelion) and 1997 September 25.7 ($R_h = 2.83$ AU post-perihelion) using high-resolution infrared spectroscopy. Production rates and rotational temperatures were measured, and the derived heliocentric dependence for ethane production was $Q = (5.52 \pm 0.20) \times 10^{28}$ $[R_h{}^{(-2.43\pm0.13)}]$ molecules s^{-1}. The spatial distribution of C_2H_6 molecules in the coma was consistent with all ethane being released directly from the nucleus, although the possibility that a small fraction was released as a distributed source can not be excluded. When our derived production rates for ethane, water, and acetylene (C_2H_2) are compared, we obtain an average relative abundance of $C_2H_6/H_2O = (6.23 \pm 0.42) \times 10^{-3}$, and $C_2H_6/C_2H_2 = 2.4 \pm 0.7$. The high ethane abundance relative to acetylene in Hale-Bopp suggests its ices were altered by radiation processing and/or hydrogen-atom addition reactions on the surfaces of ice-mantled grains in the natal cloud. These results are not consistent with ices in Hale-Bopp originating in a thermally or chemically equilibrated region of the solar nebula.

M. DiSanti, M. Mumma, N. Dello Russo, and K. Magee-Sauer completed their study of carbon monoxide production in Hale-Bopp during its recent apparition. The release of CO was studied between June 1996 and September 1997 using high-resolution infrared spectroscopy near 4.7 μm. The excitation of CO molecules in the coma was assessed through measurement of the rotational temperature on several dates at an angular resolution of ∼1 arcsecond. An increase in T_{rot} with distance from the nucleus was revealed, most likely due to photolytic heating by fast H-atoms. Observed temperature profiles varied from date to date, but overall the degree of heating was most pronounced near perihelion. Similar rotational temperatures were observed for CO and HCN, perhaps indicating control of rotational populations by collisions with electrons. The spatial distribution of CO molecules in the coma revealed two distinct sources for CO, one being CO ice native to the nucleus, and another being CO released from a progenitor distributed in the coma. Only the native source was seen when the comet was beyond 2 AU from the Sun. Based on pre- and post-perihelion observations on five dates with heliocentric distance R_h between 4.10 and 2.02 AU, a heliocentric dependence $Q_{CO,native} = (1.06 \pm 0.44) \times 10^{30}\ R_h{}^{-1.76\pm0.26}$ molecules s^{-1} was obtained. Within $R_h \sim 1.5$ AU, however, both native and distributed sources were consistently present on all dates of observation. The total CO produced was the sum of the two sources and, based on seven dates, obeyed $Q_{CO,total} = (2.07\pm0.20) \times 10^{30} R_h{}^{-1.66\pm0.22}$ molecules s^{-1}. This heliocentric dependence was consistent with that found for water $Q_{H2O} \alpha\ R_h{}^{-1.88\pm0.18}$ between 0.93 and 1.48 AU and for mm-sized dust ($R_h{}^{-1.7\pm0.2}$ between 0.9 and 2.5 AU). Our derived total mixing ratio for CO was $Q_{CO,total}/Q_{H2O} = 0.241 \pm 0.009$, with native and distributed sources each contributing an abundance of approximately 12% that of water. The distributed source exhibited behavior consistent with thermal destruction of a precursor material. The observed variations in its production rate and spatial distribution along the slit suggested contributions from both a diffuse source in the coma and possibly from one or more jets enriched in CO or CO-containing material, such as CHON grains.

V. Krasnopolsky (Catholic Univ. at GSFC), M. Mumma, and M. J. Abbott (Univ. Cal., 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 data base. 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 BeppoSAX in Hale-Bopp and the non-detection by ROSAT remain puzzling, but these are best explained if the BeppoSAX detection represents enhanced charge transfer during a gas release. The ROSAT non-detection is puzzling.

V. Krasnopolsky and M. Mumma reported the first detection in cometary soft X-rays of spectral lines from highly-charged low-Z species, confirming that charge transfer of solar wind ions is the principal excitation mechanism. Their EUVE spectrum of comet Hyakutake covers the spectral range 8.0-70.0 nm with a resolving power of 10. Emission lines of multiply charged ions were detected, the most prominent of which are O^{4+} λ21.5, $C^{4+}\lambda$24.9, and He^+ λ30.4. O^{5+} and C^{5+} ions are brought to the comet by the solar wind and are excited in charge exchange with cometary neutral species. The detected He^+ 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^+ lines at 53.8/53.9 nm, 61.7 nm, and 43.0/44.2 nm are also detected; these lines are formed by photo-ionization 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.

Comet Shoemaker-Levy 9. D. Deming and J. Harrington (Cornell) published their parameterized models of the collision of comet Shoemaker-Levy 9 with Jupiter [Harrington and Deming 2001, Deming and Harrington 2001]. They modeled the plume "splashback" using a coupled ballistic Monte-Carlo and radiative hydrodynamic approach. Their models are adjusted to reproduce the appearance of the SL9 plumes at the limb and the post-impact disk debris patterns, as imaged by Hubble Space Telescope. They modified the ZEUS-3D hydrodynamic code to include radiative damping (in the grey approximation), and they follow the shock evolution resulting from the splashback of the ballistic plumes onto a model jovian atmosphere. They compute infrared light curves for the "main event," which are found to strongly resemble the observed light curves. Several previously unexplained phenomena ("third precursors" the "0.9-micron flare," "McGregor's ring," and the "bounce") are given physical explanations by comparison with the model output. The researchers expanding the model to include wavelength-dependent opacities in the radiative damping, simple equilibrium shock chemistry, and the formation and transport of dust grains in the plume.

Atmospheric Meteoroid Effects. J. Grebowsky and D. Pesnell have expanded their analyses of the impacts of interplanetary dust particles on the ionospheres of solar system bodies to Venus. Their involvement in previous studies led to models of the meteoroid effects at Earth and Mars, and more recently Jupiter. Models are now available to predict consequences at all the other planets and to provide guidance for the interpretation of planetary spacecraft radio occultation measurements of low altitude ionosphere layers. Also, in collaboration with J. Moses, a review of the ionospheric and neutral atmospheric consequences of meteoroids throughout the solar system has recently been completed, for inclusion in an AGU monograph on comparative planetary aeronomy.

5 SUN-EARTH CONNECTIONS

Space Weather Modeling-The Community Coordinated Modeling Center (CCMC). The CCMC is an interagency activity aiming at research in support of the generation of advanced space weather models. The CCMC's central facility is located within the LEP. New and improved space research models will be created by combining models and modules. Models and modules will be developed mostly in the scientific community, but also at the CCMC GSFC facility itself, if required. 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. Combined models will have switchable modules, covering different regions and different physics. Models, which have been developed and successfully applied to scientific test problems are to be transitioned to the Rapid Prototyping Centers of NOAA and the Air Force, for operational testing. These models will also be made source code available to the scientific community, to support the "open model policy," and for the CCMC effort to remain nonexclusive. The CCMC has now tested the University of Michigan global MHD model, which features dramatically increased numerical stability, and which is now used routinely. CCMC staff is in the process of coupling this model with a radiation belt model developed at GSFC. Results from the Michigan model are available on-line at the CCMC web page (http://ccmc.gsfc.nasa.gov). The CCMC is now, for the first time, offering runs-on-request to the science community at large. The CCMC is also in the process of ingesting new ionospheric and solar models. (M. Hesse, L. Rastätter, M. Kuznetsova, P. Raitan, S. Ritter, A. Falasca, K. Keller, S. Bakshi, T. Vollmer)

5.1 Solar and Heliospheric Physics

Neupert Effect Linked to Solar Flare Hot Plasma Upflow. M. Rilee and G. Doschek (NRL) report a survey of Solar Flare X-ray data obtained with the Yohkoh and Compton GRO spacecraft. In this work they compared the evolution of blue-shifted X-ray emission observed by the Yohkoh Bragg Crystal Spectrometer with hard X-ray burst light curves observed with other Yohkoh instruments and the Compton BATSE instrument. They report that the similarity between impulsive solar flare emissions and the rate of increase of gradual flare emissions (the Neupert Effect) is due to the transfer of material from hot flare upflows to a stationary coronal component of the X-ray flare. Furthermore, the rise in intensity of the stationary coronal X-ray emission seems strongly related to the decay of the impulsive hard X-ray emissions. A power-law relationship between soft and hard X-ray emissions during hard X-ray flare decay was reported.

Solar Vector Magnetometry at 12 μm Wavelength. Vector magnetometry of a large active region on the Sun was performed during late April 2001. This was a period of strong activity. Of particular interest was a flare that occurred during one observation. The field structure and intensity in the flare region was recorded and is being analyzed to determine the field dynamics during the event. The observed 12.3 μm magnesium (MgI) line is the most sensitive to magnetic field strength of any line in the solar spectrum. This line originates in the upper photosphere near the temperature minimum. To record the magnetic field parameters, a cryogenic grating spectrometer was used on the McMath-Pierce telescope of the National Solar Observatory at Kitt Peak. Polarization analyzer optics were attached to the input of the spectrometer to measure Stokes I, Q, U, and V. The grating spectrometer, Celeste, is a high-resolution liquid helium cooled grating spectrometer built by GSFC. The McMath-Pierce solar telescope is the only facility where this work can be done because of its unique infrared capability and large aperture. (D. Jennings and D. Deming)

Modeling the Solar Corona. E. Sittler, in collaboration with M. Guhathakurta have developed a semi-empirical model of the solar corona from which 2D maps of flow speed, effective temperature, and effective heat flux are computed. They modeled Spartan data with a three current sheet model. The Spartan data was acquired while the corona was in transition from solar minimum to solar maximum and there was evidence of multiple current sheets. They also investigated the importance of waves and electron heat conduction in the energy equation within the framework of the model. The model produces estimates of the effective heat flux from the energy equation and can be used as a constraint for future theoretical model development of the corona.

Ion Cyclotron Instability Control of the Coronal Temperature Anisotropy. Velocity distribution of O^{+5} ions derived from the Ultraviolet Coronograph Spectrometer (UVCS) observations in coronal holes indicate that the O^{+5} ions are highly anisotropic ($T_\perp/T_\parallel \approx 30$ to 300) at 3.5 solar radii. L. Ofman, A. Vinas, and S. P. Gary (2001) 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. 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). This result implies that some unknown mechanism must be sustaining the large observed anisotropy.

Wave Particle Interactions on Ulysses. A review of Ulysses wave observations [R. MacDowall and P. Kellogg 2001] includes the radio waves produced by electrons accelerated by solar flares or by interplanetary 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.

Solar Wind Quasi-Invariant as a Heliospheric Index of Solar Activity. During the last year, earlier work of V. Osherovich, J. Fainberg, and R. Stone (2000) on the solar wind quasi-invariant $QI=(B^2/8\pi)/(\rho v^2/2)$ has been extended from 1 AU to 30 AU using Voyager data. This recent work confirmed the earlier finding concerning the global heliospheric nature of QI. Namely, we demonstrated that despite the orders of magnitude change of B and density ρ for distances from 1 AU to 30 AU, QI changes very little and closely follows the solar cycle as it does near the Earth and Venus. (J. Fainberg and V. Osherovich)

Plasma Resonance Spectroscopy as a Diagnostic Tool in the Earth's Magnetosphere. Application of our resonance spectroscopy results to IMAGE/RPI spectra with analyses of magnetospheric response to the arrival of interplanetary magnetic clouds is underway. Using the classification developed earlier [Benson et al., 2001], we found that sounder-stimulated plasma resonances provide us with a means to measure magnetospheric density and magnetic field with accuracies of 1-2%. We are studying the magnetospheric response to high QI events like magnetic clouds, characterizing the state of the magnetospheric plasma in terms of non-dimensional ratio of electron gyro radius to the Debye radius. (J. Fainberg)

Keplerian Oscillations Under the Influence of Coriolis Force. We have applied the recently formulated Two Oscillator Model (TOM) to RXTE observations of the neutron star low mass x-ray binary GX 17+2 [V. Osherovich and J. Fainberg, 2001]. This work is a spin-off of ongoing research on resonances in magnetized plasmas.

Seasonal Variation of Neutral Solar Wind. Using data from the Low Energy Neutral Atom (LENA) imager, an instrumental contribution to the IMAGE spacecraft, a team of Goddard investigators including M. Collier, T. Moore, K. Ogilvie, D. Chornay, and J. Keller, along with investigators from other institutions, have been studying the seasonal variation of solar wind energetic neutral atoms to determine the amount of interstellar gas and dust in the inner solar system. Preliminary estimates place an upper limit of 6×10^{-19} cm^{-1} for the column content of dust at 1 AU.

Solar Wind Transient Flows. The relations between transient flows in the solar wind at 1 AU and solar phenomena were discussed in several papers. L. Burlaga et al. [2001b] showed that two types of transient flow which have been neglected in solar wind studies can be produced by the opening and closing of a near equatorial coronal hole and by the latitudinal motions of equatorial extensions of polar coronal holes, respectively, both on a time scale of the order of a solar rotation. The origin and development of a relatively simple and isolated magnetic cloud was studied by D. Webb et al. [2000], who found that the foot-points of the magnetic cloud were probably associated with twin dimmings at the Sun. The Sun-Earth connections of a magnetic cloud were discussed by C. Farrugia et al. [2001]. L. Burlaga et al. [2001c] showed that half the ejecta at 1 AU during the ascending phase of the solar cycle were not magnetic clouds; they called these ejecta "complex ejecta" because the magnetic field directions are very complex even though the speed profile is relatively simple. L. Burlaga et al. [2001d] showed that successive CMEs observed within a day or so in the corona interact and merge between the Sun and Earth to form complex ejecta at 1 AU.

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 interactions that produce a Kármán vortex street. M. Goldstein, D. Roberts, and L. Burlaga, in collaboration with their colleagues E. Siregar and A. Deane, have studied the solar wind conditions that might give rise to those observations using a time-dependent compressible MHD code solved in spherical coordinates in the two-dimensional $r - \theta$ plane. 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, north-south variations of the flow velocity with a period that is approximately half that of the period of the variation in flow speed are found. 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. 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 [M. Goldstein et al., 2001].

New Connections Between the Heliospheric Magnetic Sectors. D. Roberts and M. Goldstein used three-dimensional MHD simulations in spherical coordinates to show that the sectors of opposite magnetic polarity in the heliosphere are necessarily connected due to solar rotation and the tilt of the magnetic axis. This is not a sporadic reconnection, but rather a steady state condition initiated by nonradial flows caused by inevitable pressure imbalances. The differing constraints on magnetic and thermal pressures imply differing radial evolution of the magnetic and thermal pressures near the heliospheric current sheet. The transverse flows that attempt to enforce pressure balance lead to inductive electric fields that differ for the three magnetic field components. As a result, the radial and tangential fields do not become zero simultaneously, and the there is also a field component induced normal to the current sheet. The result is large field loops. The observational signature of this effect is the offset between the radial and tangential field zeros and the consequent nonzero magnitude of the field magnitude and rotation of the field across the sector boundary. Helios observations are consistent with the time scale and magnitude of the effects.

Microstructure of the Solar Wind. T. Zurbuchen et al. [2001] discussed the composition of microscale magnetic holes observed by ACE at 1 AU, and concluded that magnetic reconnection might play a role in the formation of some of these magnetic holes. M. Forman and L. Burlaga showed that the distribution function of velocity fluctuations associated with turbulence at 1 AU had long tails produced by intermittency, and they showed that the fluctuations could be described by Castaing's model for a distribution function.

Cosmic Ray Modulation. F. McDonald et al. [2001] showed that the onset of modulation in the distant heliosphere in solar cycle 23 was associated with a Merged Interaction Region (MIR), but the MIR had limited latitudinal extent. L. Burlaga et al. [2001e] showed that step-decreases in the cosmic ray intensity in the distant heliosphere near solar maximum were produced by Global MIRs.

A View of the Inner Heliosphere During the May 10-11, 1999, Low Density Anomaly. On May 10 and 11, 1999, near-Earth spacecraft observed the solar wind density drop to below 0.1 particles cm^{-3}. Using those data, W. Farrell, M. Goldstein, and their colleague, Arcadi V. Usmanov have mapped solar wind parameters back to the Sun from 1 AU using two techniques. The first assumed constant-velocity trajectories plus co-rotation, while the second employed MHD-derived magnetofluid parameters. This inverse tracing creates a view of the inner heliosphere useful for identifying the source location on the Sun of the density anomaly. When the two methods were compared, it was found that the source location of the anomaly predicted by MHD mapped to $\sim 20^\circ$ eastward of the constant-velocity result. The coronal magnetic field maps indicate that the low-density event occurred as the polar coronal magnetic field began reversing. A. Usmanov et al., concluded that the event was likely initiated by a latitudinal excursion of the low velocity heliospheric current sheet toward the helioequator. The emergence of this slow flow into the preexisting faster wind produced a strong rarefaction and the anomalously low densities.

Conditions Producing Low Density Solar Wind. I. Richardson, D. Berdichevsky, M. Desch, and C. Farrugia (2000), performed a "Survey of Low Density Solar Wind During More than Three Solar Cycles" to place the May 1999 low density (<1 cm^{-3}) solar wind interval in context. Low-density solar wind in 1965-1999 was investigated using data from the NSSDC OMNI database. Although systematic effects may be present, there is clear evidence of increased occurrence rates 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. The occurrence of low densities may be higher in weaker sunspot cycles. Roughly two-thirds of periods with densities <1 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 is unusual because it is not clearly associated with an ejecta or stream, but it is not unique since a similar period was observed in July-August 1979.

Dynamics of Coronal Mass Ejections (CMEs.) Using the WIND/WAVES radio observations, in conjunction with the LASCO white-light observations and in-situ measurements of shock parameters, M. Reiner and M. Kaiser have made considerable progress in understanding and quantifying the dynamics of CMEs in the solar corona and interplanetary medium. They have shown how by requiring consistency between the observed radio frequency drift of the type II emissions and the plane-of-sky dynamics deduced from the white-light LASCO observations, the true dynamics of a CME in the corona can be determined. Furthermore, by comparison of the radio data with the white-light coronal densities measured by LASCO, they have demonstrated that type II radio emissions are generally generated in enhanced density regions in the corona and have argued that these emissions may be generated when the CME-driven shock propagates through dense streamers in the solar corona. These results were obtained in collaboration with A. Vourlidas and R. Howard (NRL) and O. C. St. Cyr (Catholic Univ.).

Speeds of CMEs. M. Reiner and M. Kaiser have also shown how the measured in-situ shock parameters associated with a CME can be used together with the radio frequency drift of the type II emissions to determine the true speed profile of a CME throughout the heliosphere. Using this technique they have found that normally the acceleration or deceleration of CMEs occur in the high corona, but that in some cases, such as for the Bastille Day event from July 14, 2000, the deceleration of the CME can extend well out into the interplanetary medium.

Sources and Dynamics of CME's. D. Berdichevsky (Raytheon-ITSS), C. Farrugia (Univ. New Hampshire), B. Thompson, R. Lepping, D. Reames, M. Kaiser, J. Steinberg (Los Alamos/New Mexico), S. Plunkett, and D. Mitchels (both NRL/DC) presented a statistical analysis of a 1-year period near the last solar minimum (December 1996-December 1997), focussing on 12 H-CMEs separated at least by three days. Work focused on solar and interplanetary aspects. Findings include a distinction between events related to filament eruptions near and away from active regions. In-situ ejecta contain, in some cases interplanetary magnetic cloud or cloud-like structures. Seven out of eight interplanetary shock velocities are consistent with being locally driven by the ejecta. 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 $\sim 50\%$ of the cases, and further strengthened the Sun-Earth Connection.

Polarization of Type III Emissions. Using the direction-finding analyses on the Wind/WAVES radio data, M. Reiner, M. Kaiser, and J. Fainberg have discovered weak circular polarization in kilometric type III storm emissions at high frequencies. In one case they have also found that the polarization experiences a 1.6 hour oscillation which may be associated with some fundamental oscillation in the corresponding helmet streamer on the Sun.

Polarization of IMAGE Spacecraft Signals. M. Reiner, M. Kaiser, and S. Cummer (Duke Univ.) have used the direction-finding analyses on Wind/WAVES to determine the amplitude and linear polarization of a signal transmitted from the IMAGE spacecraft.

Interplanetary Shock Geometry. A. Szabo, in collaboration with C. Smith (Bartol Research Institute, Univ. Delaware) and R. Skoug (LANL) continued their multi-spacecraft analysis of the interplanetary shock surface curvature. The study focused especially on magnetic cloud driven interplanetary shocks. It was established that the curved surface of the shocks is consistent with the orientation and size of the driving magnetic flux ropes with the largest clouds corresponding to the cleanest signatures.

Magnetic Cloud Model. A model has been developed that describes the topology of a magnetic cloud without assuming the force-free condition. Fitting of the model to experimental magnetic field data from the WIND spacecraft allows us to determine the current density, the attitude of the axis, and the relative closest-approach distance between the spacecraft and the cloud axis. The results of the model indicate that the non force-free topological model of the magnetic field better describes the observations than previous force-free models. (A. F. Viñas)

5.2 Magnetospheric Physics

Magnetic Cloud Triggering Locations of Magnetic Storms: Single/Multi-phase. WIND data was used to study the effects of 34 magnetic cloud "complexes" with respect to their ability to cause magnetic storms. Cloud complexes include the magnetic clouds, their upstream shocks (which occur about half the time), and the intervening sheaths. The leading and trailing parts of the clouds were examined separately. Another study related to this one is underway which examines many decades of magnetic storms and their apparently triggering magnetic cloud-complexes as observed from various spacecraft. Statistics are being gathered to see if the WIND cloud study is supported. (C.-C. Wu and R. Lepping)

Bastille Day Event - Heliospheric Aspects. The Bastille Day 2000 event produced a remarkable magnetic cloud at 1 AU as well as several other flows [C. Smith et al., 2001; R. Lepping et al., 2001]. The Voyager 2 spacecraft was nearly radially aligned with the Sun and Earth at this time. C. Wang et al. [2001] found that the arrival time of the Bastille Day flows at Voyager 2 was in good agreement with the predicted time, and they showed that the magnetic field, and speed profiles were also in agreement with predictions of a model. L. Burlaga et al. [2001a] showed that a MIR was observed by Voyager 2, and Y. Whang et al. [2001] showed how this MIR formed by interactions among shocks and flows.

Bastille Day Event - 1 AU and Magnetosphere. A paper has been written for a special issue of Solar Physics which concentrates on the solar wind aspects at 1 AU of the Bastille Day solar events based mainly on data from WIND but including data from GOES and Geotail. Two magnetic clouds were identified and two interplanetary shocks, the second of which was driven by the second (larger and stronger) magnetic cloud. These were part of a dramatic series of events during which the Earths sub-solar magnetopause was pushed into < 5 Re due to the very fast speed (> 1100 km/s) of the solar wind in the larger cloud; a geosynchronous satellite was observed to go into the magnetosheath at the time. A major magnetic storm of Dst = -300 nT resulted from this magnetic cloud, early in which the IMF was greater than 60 nT and southward. Scientists from NOAA, MIT, Bartol Research Institute, and the Univ. Iowa contributed to this study. (R. Lepping, D. Berdichevsky, L. Burlaga, C.-C. Wu, M. Desch)

Magnetospheric Effects of a Low-density Solar Wind. C. Farrugia and co-workers (including D. Berdichevsky) investigated the response of the Earth's magnetosphere to the very tenuous solar wind on May 11, 1999, using multi-spacecraft observations. They found a quasi-dipolar magnetosphere for approximately 16 hours at six Earth radii during this low-density interval. Their data also strongly supported the ideas of direct entry of the solar wind "strahl" electrons into a preferred hemisphere that is controlled by the IMF magnetic field sector. The fact that these electrons were particularly energetic during times of low solar wind density was also in agreement with theoretical ideas concerning their escape from the sun.

Neutral Atom Emissions from the Magnetosheath on March 31, 2001. Combining simulation, modeling and data analysis efforts, a team of Goddard investigators including M. Collier, T. Moore, M.-C. Fok, L. Rastätter, M. Kuznetsova, and A. Falasca have compared LENA neutral atom imaging data from the March 31, 2001, event with an instrument response model based on results from the CCMC. They find a very good level of agreement which suggests that LENA is observing dramatically enhanced solar wind charge exchange in the magnetosheath during this period.

Plasma Transport and Energization. T. Moore, M.-C. Fok, and B. Giles are exploring the transport and energization of plasmas in the Earth's magnetosphere, using theoretical tools and guided by observations. Studies range from the entry of solar wind and ionospheric plasmas into the magnetospheric cusp regions, including the distribution of dayside reconnection, 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 study of energetic electron acceleration by substorm magnetic field dynamics was completed and published [M.-C. Fok et al., 2001]. A comprehensive ring current model was developed by merging the Fok model with the Rice Convection Model. Methods for deconvolving the energetic plasma distribution from neutral atom images were published [J. Perez et al., 2000]. A provocative hypothesis was put forth suggesting that ionospheric or internal plasmas actually are an essential element of ring current formation [T. Moore et al., 2001]. More recently, an investigation of the distribution of reconnection on the dayside magnetopause has been undertaken, with very interesting first results.

Empirical Modeling of the Solar Influence on Terrestrial Plasma Outflows. B. Giles and T. Moore have continued much earlier studies of the Dynamics Explorer data sets and found that the apparent lack of terrestrial outflow strength to variations in the Interplanetary Magnetic Field (IMF) is a characteristic of low energy ionospheric outflows, even of heavy ions. This result is perplexing in view of the pervasive association of ionospheric outflows with geomagnetic activity, and in turn the association of geomagnetic activity with the interplanetary field direction, especially southward orientations. This result fully merits additional study so that it can be fully understood, but is nevertheless a robust result that has spanned two major NASA space physics mission datasets. Using these datasets, B. Giles has prepared a functional description, useful for global modelers, of the ionosphere supply of particles to the outer magnetosphere. Through this statistical description and trajectory tracings, B. Giles further demonstrated that the terrestrial contribution to the plasma sheet is both mass-dependent and local-time dependent under stretched and compressed magnetic field conditions. A study is nearing completion that demonstrates that the terrestrial outflow source appears to have a minimum, but steady and significant, level even in the absence of normal levels of solar wind influence. Other work includes a comparison of in-situ observations of field-aligned ion outflow with remote images of the charge exchange source of those flows which shows the relative consistency of the two measurement techniques as geophysical conditions vary.

Earth Bow Shock. A. Szabo, in collaboration with J. King (GSFC), K. Paularena (MIT) and J. Merka (GSFC/NRC) have been analyzing all of the Earth bow shock crossings observed by the IMP 8 spacecraft. Five years of the mission have been completely analyzed and the complete compilation is being placed in a publicly searchable database at NSSDC. A surprisingly large number (>20) of multiple bow shock crossings were observed for certain solar wind conditions.

Radiation Belt - Ring Current Forecasting Model. M.-C. Fok and collaborator G. Khazanov at the Marshall Space Flight Center are developing a radiation belt - ring current forecasting model (http://johanna.gsfc.nasa.gov/UPOS/). This is one of the ongoing projects of the University Partnering for Operational Support (UPOS) program sponsored by the US Air Force and the US Army. Our goal is to develop a model that can predict the radiation belt environment and the corresponding radiation doses, 24 hours ahead of time. Special features of this model include: local-time dependence of plasma distributions, self-consistent calculation of particle decay due to wave-particle interactions, and solar wind conditions driving the model. The current version of the model has been tested and validated by comparing model outputs with measurements at the geosynchronous orbit by the Los Alamos satellites.

Neutral Atom Modeling in Support of the IMAGE Mission. Energetic ion fluxes and the associated energetic neutral atom (ENA) emissions during active periods since the launch of the IMAGE mission are simulated. These modeled results are used to understand and interpret the features seen by the IMAGE/ENA instruments. A web site (http://johanna.gsfc.nasa.gov/IMAGE/) is developed by M.-C. Fok to display these results for the use of the IMAGE team and for the broader space science community.

Magnetosphere Magnetic Field Model. N. Tsyganenko developed a new data-based model of the magnetosphere, representing the variable configuration of the inner and near magnetosphere for different interplanetary conditions and ground disturbance levels. The input parameters of the model include the Dst-index (SYM) and the solar wind parameters (speed, proton density, and IMF components), at the time of observation and also during the preceding 1-hour interval. The model output is the predicted magnetospheric B-field vector (in GSM coordinates). The model is based on a new set of data, mostly taken in 1994-1999 by the ISTP spacecraft Polar and Geotail, and complemented by observations from the earlier missions ISEE-2, AMPTE/CCE/IRM, CRRES, and DE-1. The interplanetary medium data for this effort came from solar wind and IMF monitors onboard WIND and IMP 8 spacecraft. The model magnetospheric boundary was specified using a most recent empirical approximation by J. Shue et al. Its size is controlled by the solar wind pressure, and its shape also varies in response to the tilt of the Earth's dipole. The model magnetopause confines the total field inside the boundary, but it also allows an IMF-controlled interconnection field due to a finite normal Bn, resulting in open magnetospheric configurations. The degree of predicted IMF penetration inside the magnetosphere, derived from data, was found to greatly increase as the IMF turned southward. The IMF orientation and magnitude was also confirmed as the major factor controlling the magnitude and spatial extent of the model Birkeland currents: both Region 1 and 2 currents strongly increase and shift equatorward at low altitudes during southward IMF periods. The model replicates the dramatic buildup of the dawn-dusk asymmetry of the inner magnetosphere during storms, associated with the development of the partial ring current, a feature absent in earlier data-based models. Fitting the model to the data revealed a striking predominance of the partial ring current over the axisymmetric ring current during major disturbances, in good agreement with recent particle simulations by the Michigan University group.

Ionospheric Electrodynamics During Substorms. A self-consistent model of the ionospheric electrodynamics during the expansion and early recovery phases of substorms has yielded the three dimensional current system in the nighttime sector. The feeding as well as the drainage of the substorm current wedge component of the westward electrojet is due principally to an imbalance of the downward region 0 and upward region 1 current sheets under which the electrojet is flowing. We do not find evidence of a simple downward current post-midnight and upward current pre-midnight. The wide post-midnight convection electrojet contributes to the narrow pre-midnight wedge current with about 40% of the total wedge current. Almost the entire eastward electrojet originates on the dayside, whereas about 50% of the westward electrojet in the bulge region originates from the dayside. (R. Hoffman and J. Gjerloev)

Plasma Convection and Field-Aligned Currents. Plasma convection in the ionosphere and cusp field-aligned currents are investigated using data from FAST spacecraft and global models from the Assimilative Mapping of Ionospheric Electrodynamics technique (AMIE) during a prolonged interval with large positive IMF-By and northward Bz conditions $By/Bz \gg 1$. The results show that the global plasma convection forms two cells oriented nearly along the Sun-Earth line in the ionosphere. In the northern hemisphere, the dayside cell has a clockwise convection mainly circulating within the polar cap on open field lines. A second cell with counterclockwise convection is located in the nightside circulating across the polar cap boundary. The observed two-cell convection pattern appears to be driven by the reconnection along the anti-parallel merging lines poleward of the cusp extending toward the dusk side when IMF *By/Bz* $\gg$1. The field-aligned currents in the cusp region flow downward into the ionosphere. The return field-aligned currents extend into the polar cap in the center of the dayside convection cell. The field-aligned currents are closed through the Peterson currents in the ionosphere, which flow poleward from the polar cap boundary along the electric field direction. The research was conducted by G. Le and R. Pfaff, Jr., in collaboration with G. Lu of NCAR/High Altitude Observatory and R. Strangeway of UCLA.

Magnetosphere Standing Waves. The inner regions of Earth's geomagnetic tail form one of the most interesting and actively researched areas of the magnetosphere. A survey of several years of Geotail data between 9 and 15 Earth radii revealed two examples of very regular waves in the electric and magnetic field data that are confined to within a few degrees of the equator. The waves are seen near 10 Re and occur during quiet periods following magnetic storms. The waves have periods near one minute with a second harmonic also observed. Indications are that these are standing waves on moderately distorted dipole field lines. (D. Fairfield)

Flux Ropes Discovered in Earthward Bursty Bulk Flows. Examination of Geotail measurements in the near-tail ($X > -30\ R_e$) has revealed the presence of high intensity, twisted magnetic fields embedded within high-speed earthward flows in the plasma sheet. Modeling and analysis has indicated that these signatures are associated with small, $\sim$ 1-2 R_e diameter, magnetic flux ropes being carried earthward with "Bursty Bulk Flows (BBFs)" in the plasma sheet [J. Slavin et al., 2001]. The magnetic fields themselves are well described as force-free magnetic flux ropes. The presence of such structures embedded in BBFs constitutes strong evidence that multiple reconnection X-lines can simultaneously operate in the near tail. In such a situation, the first X-line to begin reconnecting lobe flux tubes becomes the separator for the plasma and magnetic flux ejected tailward as opposed to flowing earthward where the bursty bulk flows heat and compress the inner magnetosphere. This research was conducted by J. Slavin, D. Fairfield, R. Lepping, and M. Hesse.

Relationship of Auroral Brightenings to Magnetotail Plasma Flows. A. Ieda and D. Fairfield have continued to study the relationship between auroral brightenings, magnetotail plasma flows and geomagnetic substorms. They have used substorm auroral brightenings to define a large number of events. Tailward flows are frequently associated with substorm onsets beyond 20 Re when the onset is near the local time of the spacecraft. Earthward flows are predominate earthward of 20 Re but are associated with the substorm onsets less frequently than are the more distant tailward flows. Both tailward and earthward fast flows are observed more often when auroral breakups occur in the duskside.

Magnetotail Current Sheet. We 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. (M. Hesse, M. Kuznetsova)

Reconnection in Current Sheets. Particle-in-cell, modified hybrid, Hall-MHD, and MHD simulations are used 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 a scaling law is derived 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. (M. Hesse, M. Kuznetsova, L. Rastätter)

Reconnection in Three Dimensions. Recently, studies of magnetic reconnection were extended to fully three-dimensional systems, applying a fully electromagnetic particle-in-cell model developed in-house. Results of these simulations indicate that the basic structure of the dissipation region is similar to the one found in translationally invariant models. In addition, lower-hybrid-drift instabilites tend to broaden the current sheet in the regions of steep density gradients. (M. Hesse, M. Kuznetsova)

Electrostatic Lower Hybrid Instability in the Magnetotail Current Sheet. A. Sundaram, A. Vinas, and D. Fairfield are working to understand anomalous dissipation in the tail plasma sheet that might lead to magnetic reconnection. The excitation of electrostatic lower hybrid waves in the magnetic field reversal region is being studied using fluid and kinetic equations. A two-dimensional magnetic field configuration with a magnetic field gradient in the South-North direction is used to study the linear stability theory of lower hybrid waves. In the fluid case, the dispersion relation is shown to be sensitive to the parameters describing the wavelength along y-direction and the ratio of electron gyro-radius to the current sheet width. The long wavelength lower hybrid waves in the fluid limit are found to be unstable due to the magnetic field gradient. In the kinetic limit, the effect of wave particle resonances such as the curvature drift and gradient-B resonances is examined and the analytical estimate shows that the electrostatic waves are excited for a certain wavelength spectrum. The preliminary work initiated here highlights the possibility that lower hybrid waves can indeed play a role in producing the anomalous dissipation for the magnetic reconnection and substorm onset. Extensive numerical work, both in fluid and kinetic limits, is in progress.

Excitation of Electrostatic Electron-ion Hybrid Waves. A. Sundaram, D. Fairfield, and other collaborators are examining the nature and origin of observed low frequency wave activity in the tail plasma sheet. The tail data obtained from the three-dimensional plasma instrument aboard the AMPTE/IRM satellite reveal that there is a gradient in the ion density and the ion beta at the interface between the plasma sheet boundary and the central plasma sheet. There arises an inhomogeneous south-north electric field that is transverse to the earthward directed magnetic field and intensifies during active substorm periods and this can cause large transverse sheared flows. The stability of electron-ion hybrid waves in the presence of such flows is investigated, using the two-fluid description. A preliminary calculation indicates that the electrostatic waves driven by sheared flows are excited in the current sheet layer. Further work involving the numerical solutions of the dispersion relation is in progress.

Observational Evidence for Self-organized Criticality in the Magnetotail Plasma Sheet. Earth's magnetotail plasma sheet is suspected to be in or near self-organized criticality. If so, then spatiotemporally localized reconnection events in the plasma sheet may play the role of dissipation (avalanche) events in mathematical models of self-organized criticality. Observations have shown that these localized reconnection events are strongly correlated with disturbances in the ionosphere. We have investigated some statistical properties of the ionospheric disturbances with the expectation that these disturbances may reflect the dynamics of the plasma sheet. Earlier studies had shown power-law size and duration distributions for bursts in ionospheric electrojet index (AE) time series data. These distributions are generally considered symptomatic of a system in self-organized criticality. These results had been criticized, however, since these distributions might simply reflect the properties of the solar wind impinging on the magnetosphere. In response, the electrojet index and solar wind data have been analyzed to verify a new group of scaling laws that recently has been found associated with self-organized criticality. These scaling laws govern the statistical superposed-epoch evolution of dissipation events in terms of the so-called spreading exponents. Our results show that, for time-scales up to 3-4 hours, the electrojet index data exhibit these scaling laws while the solar wind data do not. The correlation between localized auroral brightening and localized plasma sheet reconnection has been shown particularly strong. The statistical properties of auroral brightening observed by the UVI experiment onboard the POLAR spacecraft have been examined with the expectation that these statistics may also reflect the dynamics of the plasma sheet. We have found a variety of power-law distributions over as much as five decades of scale-size, limited only on the low end of the distributions by experimental resolution and on the high end by the spatial dimensions of the auroral region. These remarkable distributions constitute strong evidence for a system in self-organized criticality. (A. Klimas, V. Uritsky)

Plasma Physical Models of Self-organized Criticality in the Magnetotail Plasma Sheet. Traditionally, self-organized criticality is studied using so-called "sandpile" mathematical/numerical models. While useful for some purposes, the utility of these models for understanding the dynamics of the plasma sheet is limited. A study has begun of plasma physical models of self-organized criticality that are generally composed of a magnetohydrodynamic (MHD) basis, modified by an idealized representation of kinetic phenomena that are activated when and where the MHD approximation fails. The widely divergent natural scales of these two components, when they are strongly coupled, allows for multi-scale behavior in the intervening range and for the possibility of scale-free self-organized criticality. Self-organized criticality has been demonstrated in a one-dimensional version of these models. A two-dimensional model is presently under study. Very long numerical runs that are necessary to allow the model to evolve into a self-organized configuration have been achieved. (A. Klimas, V. Uritsky)

Real-time Prediction of Ground-and Ionospheric-level Electrodynamic Disturbances. Real-time prediction of indices is continuing. The prediction website was moved to the lab-wide webserver (http://lep694.gsfc.nasa.gov/RTSM/). The site contains predictions from the original real-time models of Dst and AL/AU driven by ACE solar wind key parameters. For verification, Kyoto quick-look indices are superposed when available. An early version of the spatiotemporal model for the high-latitude B-field is also included. (A. Klimas, D. Vassiliadis, R. Weigel)

Prediction of Spatiotemporal Ground-level Magnetic Disturbances. The dynamic model of the high-latitude ground magnetic field has been upgraded. The model database has been expanded in temporal length although the model now makes use of only one 25-mag meridional chain (the Finnish IMAGE) whose data are binned by magnetic local time and latitude and then analyzed. The model field is now expressed in geomagnetic coordinates allowing the interpretation in terms of auroral electrojets and other current systems. The main model is parameterized by the polar cap index. A list of activity intervals has been identified for testing. They range from Northward Bz-conditions to a magnetic cloud. Geoeffectiveness is measured by maximum and minimum indices (analogous to AL and AU), polar cap area, and integrated Joule heat. A second model parameterized by solar wind activity level and driven by real-time ACE key parameters is also used. (A. Klimas, D. Vassiliadis, R. Weigel)

Seasonal and Solar-cycle Variability of Relativistic Electron Fluxes in the Inner Magnetosphere. The effect of solar wind speed on the energetic electron fluxes has been known for more than two decades, but the acceleration mechanism is not understood. Seasonal and solar-cycle variation provides indicators for the efficiency of the average coupling. The daily 2-6 MeV electron flux is measured by low-Earth-orbit SAMPEX spacecraft in the range of L=1-10. Linear filter analysis of 8 years of data shows that there are two regions of increased flux coupling, at L=3 and 4.5. The size in L of the linear coupling region and its duration in days are parameterized by season and solar cycle. The coupling is more intense and prolonged during equinoxes than solstices. In the last solar cycle the fall equinox dominates over the spring with a ratio of 1:2 in response duration, although the intensities are not significantly different. The results are consistent with the equinoctial hypothesis and the Russell-McPherron effect. (A. Klimas, D. Vassiliadis, R. Weigel)

Predictability of Spatiotemporal Fluctuations in Ground-level Magnetic Disturbances. A neural network model that directly predicts the level of temporal fluctuations in ground-level magnetic disturbances in a fifteen-minute time interval has been developed. The model is driven by solar wind data from the ACE satellite and has been tested on 30 auroral zone magnetometer stations for nearly all days of 1998. These filters show that the local times that have a large average amplitude of temporal magnetic fluctuations often have a high predictability. The filters are currently being modified to determine how much the amplitude of temporal fluctuations in ground-level magnetic disturbances is influenced by the amplitude of temporal fluctuations in the solar wind velocity and magnetic field (as opposed to the amplitude only). (A. Klimas, D. Vassiliadis, V. Uritsky, R. Weigel)

Ionospheric Activities. Ionospheric thermal plasma measurements from a dozen spacecraft missions over more than one solar cycle were originally compiled by J. Grebowsky and W. Hoegy at GSFC using common data formats on optical CD's. D. Blitza has now merged these data with all other available thermal plasma data from many international satellite missions. Also, J. Grebowsky and A. Aikin undertook a review study of all insitu ion composition experiments from sounding rockets and satellites, which is to be a chapter in a new Cambridge University Book "Meteors in the Earths Atmosphere."

ISIS Digital Database. Digital ISIS 1 topside-sounder ionograms are being produced, from the original analog telemetry tapes, by a team led by R. Benson. They are being archived at the National Space Science Data Center (NSSDC) at GSFC to augment some 300,000 digital ISIS-2 ionograms covering the 12-year interval from the end of 1971 through early 1984. The new ISIS-1 digital topside-sounder data can be used to produce electron-density profiles from the sounder altitude of 550 to 3,500 km down to the altitude of the ionospheric peak electron density. The existing ISIS-2 digital sounder data can be used to produce such profiles from the ISIS-2 altitude of 1400 km down to the peak altitude. Both satellites were in polar orbits. Programs to assist in the retrieval of the data, to produce electron-density profiles from the echo traces, and to help interpret sounder-stimulated ionospheric plasma resonances are available from http://nssdc.gsfc.nasa.gov/space/isis/isis-status.html. R. Benson and colleagues recently provided evidence to support the claim that scaling laws that have been developed to interpret these resonances can be used to determine magnetospheric electron densities from magnetospheric emissions observed between harmonics of the electron cyclotron frequency. R. Benson and J. Grebowsky used ISIS-2 derived electron-density profiles to show that the ionospheric peak altitude can drop to the vicinity of 100 km in the polar-hole region.

6 SPACE SCIENCE MISSIONS: OPERATIONAL

6.1 Cluster

The four spacecraft that comprise the ESA/NASA Cluster mission were launched July 16 and August 9, 2000, on two Russian Soyuz rockets from the Russian cosmodrome in Baikonour. The mission was officially commissioned on February 1, 2001. The main goal of Cluster is to study, in three dimensions, the small-scale plasma structures in key plasma regions such as the solar wind, bow shock, magnetopause, polar cusps, magnetotail and the auroral zones. With its unique capabilities of three-dimensional spatial resolution, Cluster plays a major role in the International Solar Terrestrial Program (ISTP) where Cluster and the Solar and Heliospheric Observatory (SOHO) are the European contributions. Cluster's payload comprises state-of-the-art plasma instrumentation to measure electric and magnetic fields from quasi-static up to high frequencies, and electron and ion distribution functions from energies of nearly 0 eV to a few MeV. The science operations are coordinated by the Joint Science Operations Centre (JSOC) at the Rutherford Appleton Laboratory (UK), and implemented by the European Space Operations Centre, ESOC, in Darmstadt, Germany. A network of eight national data centers has been set up for raw data processing, the production of physical parameters, and their distribution to end users all over the world. The Laboratory for Extraterrestrial Physics has made significant contributions to several of the experiments, including, the Flux Gate Magnetometer (A. Balogh, Imperial College, Principal Investigator), the Plasma Electron And Current Experiment (A. Fazakerley, Mullard Space Science Laboratory, Principal Investigator), the Electric Fields and Waves (M. Andre, Swedish Institute of Space Physics). In addition, W. Mish has played a critical role in designing and operating the U.S. node of the Cluster Science Data Center. The NASA Project Scientist for Cluster-II is LEP scientist, M. Goldstein.

Magnetic Fields Investigation. Cluster-II is now operational with 4 spacecraft flying 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 (MFI) lead by Principal Investigator 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-investigators 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 though their formation. The magnetic field measurements from the four spacecraft can also be used to synthesize a "wave telescope" for the detection and characterization of low-frequency waves.

6.2 IMAGE

Imager for Magnetopause to Aurora Global Exploration (IMAGE). T. Moore continued as Project Scientist for the IMAGE mission as it operated through its first year on orbit and beyond. J. Green of the Space Science Data Operations Office, joined as Deputy Project Scientist soon after operations began. IMAGE has functioned nearly flawlessly and has been providing images of plasma clouds around the Earth and their response to the solar wind buffeting they receive. Both electron and ion aurora are seen to develop in multi-spectral movies, as the solar wind scours the outer boundaries of the magnetosphere and enters into the dayside cusp regions. The ionosphere responds to auroral energy inputs with particles flowing out into space. Clouds of hot plasma form near midnight and drift rapidly around Earth, inflating the geomagnetic field. Cold plasma near the Earth is swept sunward by the return flow through the center of the magnetosphere. Numerous features of the cold plasma are also seen in radio plasma soundings that reveal the origins of wave emission features. Finally, both the galactic gas flowing through the solar system, and the remnant nebular dust disk are seen interacting with the solar wind. These results were featured in the January 26, 2001, issue of Science, the March 15, 2001, issue of Geophysical Research Letters, and in the April 2001 issue of Scientific American. All instruments continue to function as well as or better than expected.

Low Energy Neutral Atom Imager (LENA). T. Moore led the science investigation of LENA data from IMAGE. These investigations have shown that solar wind enhancements produce prompt responsive increases in the outflow of ionospheric plasma from the Earth, through the action of dayside auroral activity. Also, they have shown that the solar wind contains a component of neutral atoms that is created largely by charge exchange of solar wind protons on a combination of solar system dust and associated gas, and interstellar gas passing through the solar system, providing an indirect remote measurement of the presence of these gases in the inner solar system. In addition, LENA directly observed the interstellar neutral gas in the region downstream of the Sun within the flow of interstellar gas through the solar system.

Magnetospheric Radio Sounding. R. Benson and colleagues have applied experience gained from the interpretation of ionospheric topside-sounder data to interpret plasma resonances stimulated by the Radio Plasma Imager (RPI) on the IMAGE satellite. Working with RPI Principal Invetigator, B. W. Reinisch and colleagues at the Univ. Mass., Lowell, these resonances have been used to aid in the determination of magnetospheric electron-density profiles and the in-situ electron density and magnetic-field strength along the IMAGE orbit.

6.3 International Solar Terrestrial Physics (ISTP - Polar, WIND, Geotail Spacecraft)

NASA's ISTP Senior Review. The ISTP project scientists submitted a proposal to NASA's Senior Review Committee advocating the continued operation of Polar, Wind, and Geotail in an era of very restricted data analysis budgets. The panel found that the precession of the Polar orbit toward the equatorial plane offers opportunities for conducting important new scientific investigations. They recommended continued funding for Polar to support this new stand-alone science and to provide support for the IMAGE and Cluster Missions. Wind and Geotail were asked to submit further plans on how to continue operations at reduced cost. Studies of how to maintain all these ISTP spacecraft at reduced cost are underway.

6.3.1 Polar

The Polar spacecraft of the ISTP mission continues to operate with 12 of the 13 instruments. Data acquisition from the TIMAS instrument (a particle imaging spectrograph for ions), which ceased providing data in late 1999, was reestablished by switching the entire spacecraft to a redundant data system. The nine Earth radii apogee of the polar orbit is approaching the equator, yielding new data by skimming the dayside magnetopause during the spring period and crossing the plasmasheet in the tail during the fall period. A strategy for use of the remaining fuel on board for spin direction control will allow the spin axis to switch between orbit normal and ecliptic normal until late 2003, when ecliptic normal operations will be continuous. R. Hoffman is the Polar Project Scientist.

Thermal Ion Dynamics Experiment-Plasma Source Instrument (TIDE-PSI) on Polar. The investigation team led by T. 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. 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.

6.3.2 Geotail

The Geotail spacecraft remains in good health and continues to provide excellent data from its 9×30 Re equatorial orbit as it begins its tenth year of operation. Long Earth shadows are the primary hazard to Geotail's health and this spacecraft has now survived the longest shadows that it will encounter. Much Geotail data is now available via the web, including CPI plasma data from the solar wind detector and LEP plasma data from both the solar wind and energetic plasma detectors. The latter data, along with the MGF magnetic field data, is available via the Japanese DARTS system. 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. Geotail spends roughly half it time in the solar wind and, with the demise of the IMP 8 magnetometer and the extension of the WIND orbit to large distance, Geotail is the only spacecraft providing near-Earth measurements of the interplanetary magnetic field. Planning is underway to enable the continued operation of Geotail under severe budget constraints. D. Fairfield is NASA's Geotail Project Scientist.

6.3.3 WIND

The WIND spacecraft continues to function successfully, returning data on solar events (energetic particles, solar wind plasma, magnetic field, shock direction finding, etc) as well as doing work on predetermined research topics such as shock physics, magnetic reconnection, disturbances in the solar wind, etc. WIND has been the most frequently used source of solar wind quantities during the last 12 months. It remains the only spacecraft which can track CME shocks, and has the largest dynamic range for energetic particles among present spacecraft. It also has two 3-D spectrometers which can measure the electron distribution, enabling coronal observations to be made at all times of low density. K. Ogilvie is the WIND project scientist.

WIND/WAVES: Comparison of the Plasma Wake of the Moon and Space Shuttle. LEP scientists on the Wind team demonstrated the similarities between the lunar wake as observed by the WIND spacecraft and the wake formed by the space shuttle. Plasma conditions reasonably scale between the two different environments, and it is demonstrated that very similar physical processes are occurring in wake replenishment in both the solar wind and ionosphere. A most interesting observation is that both the lunar wake and shuttle wake develop two low density "streamers" in the deep wake region. Predictions regarding the wake of the space station can be made, based on the analogies.

WIND Solar Wind Electron (SWE) Studies. WIND/SWE data from the electron spectrometer and strahl sensor continue to be processed and analyzed. SWE electron moments data are now being archived in the NSSDC and are available on the CDAWEB. The study of the solar wind electron strahl during period of very low density (below 1/cc) has been completed and the results published [Ogilvie et al., 2000]. During the low density periods the strahl was found to be enhanced. This enhancement was interpreted as being due to reduced coulomb collisions in the tenuous plasma in agreement with a previous theoretical study. An unexpected benefit of the strahl sensor came about during the high-flux proton event of July 14, 2000, which disabled the WIND sun sensors. Strahl sensor observations of the Sun enabled recovery of the WIND spacecraft spin period and made possible the analysis of several key experiments during this unique event. Currently, a research study is underway on the analysis of electron distribution functions near interplanetay shocks. Preliminary results suggest similarities with the Earth's bow shock, with both the upstream foreshock region and the downstream region exhibiting typical electron heating. SWE electron moments and distribution functions and their interpretation have been provided for a number of collaborations that have resulted in co-authored publications. These studies include a statistical study of counterstreaming electron events in magnetic clouds [Shodan et al., 2000]; a study of the response of the magnetosphere to the low density solar wind events [Farrugia et al., 2000]; a study of electrostatic noise observed by the WIND/WAVES experiment that was associated with motion of the inner low latitude boundary layer as observed by SWE [Farrell et al., 2001]; an observational study of WIND data, which includes heat flux dropouts in SWE pitch angle distributions, showing signatures of reconnection occurring near the foot points of a magnetic cloud [Collier et al., 2001]. Also ISEE-1 electron plasma data, both moments and distribution function data from 1977-1979, have been archived into common data format files and are available to the community. This archived ISEE-1 data set has been used in a new, collaborative study of the relation between the magnetic field jump and de Hoffman-Teller potential change across the Earth's bow shock [Hull et al., 2000].

Magnetic Field Investigation (MFI). The WIND MFI magnetometer system continues to function nominally. Most of the mission data set is publicly available as both rapidly generated Key Parameter (KP) data and final calibrated, higher time resolution (3 sec) data from either the teams web site or the ISTP CDAWeb. In addition, added value support data, such as bow shock crossing times, list of magnetic clouds and interplanetary shocks are constantly updated on the team's web site. Considerable progress has been made in bringing the very large highest (msec) time resolution data set into publicly accessible format. However, individual requests for this type of data are already regularly supported. Some of the team's research areas are studies of the properties of the interplanetary medium (especially shock waves, and quasi-static and transient events), and their relationship to solar events, the magnetosphere's boundaries, and magnetotail events during active periods. MFI's website also contains a bibliography of over 180 WIND articles and papers on which a team member is either author or co-author. The Laboratories' members of the MFI team are M. Acuña, L. Burlaga, M. Collier, W. Farrell, R. Kennon, R. Lepping (Principal Investigator), W. Mish, J. Scheifele, J. Slavin, A. Szabo (Data Production Manager), and E. Worley.

6.4 IMP 8

Magnetic Field Investigation (MAG). The fall of 2001 marks the 28th 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, Principal Investigator) 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 has been updated for the whole duration of the mission at the publicly available CDAWeb. Also, the highest time resolution (320 msec) data set for the entire mission is currently reprocessed to facilitate faster and easier methods of public dissemination of this data. On-Center Co-investigators of this experiment are R. Lepping and J. Slavin and an off-Center Co-investigator is N. Ness at the Bartol Research Institute, Univ. Delaware.

6.5 FAST

NASA's FAST satellite continues to acquire excellent data and provides an exciting new look on acceleration processes at the interface of the hot, magnetospheric plasma and the cool, ionospheric plasma. 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 Principal Investigator for FAST is Dr. Charles W. Carlson of the Univ. California at Berkeley. R. Pfaff, Jr. is the NASA Project Scientist for the FAST mission.

6.6 ACE

ACE continues its successful operation following its launch in August 1997. L. Burlaga is a Co-investigator on the MFI. M. Acuña built the magnetometer and the experiment is managed by N. Ness with the support of members of his institution.

6.7 Ulysses

As of September 2001, the Ulysses spacecraft has completed its second "fast" latitude scan through perihelion and reached a heliographic latitude of more than 79 deg N. at 1.94 AU from the Sun. The second fast latitude scan found interplanetary conditions very different from the previous fast latitude scan, which occurred in 1994-1995 during solar minimum. This time the solar wind was highly variable in density and velocity from the south pole up to about 75 deg N. In 1994-1995, the variable solar wind was confined to a relatively small range of latitudes around the solar magnetic equator, and high latitude solar wind was a nearly constant high velocity stream from the polar coronal holes. The current situation arises because of the considerable tilt of the solar magnetic equator; nevertheless, it is somewhat surprising to see the variable solar wind extending to the poles of the heliosphere. The GSFC contributions to Ulysses include involvement with two of its instruments: the Unified Radio and Plasma Wave investigation (URAP) and the Solar Wind Ion Composition Spectrometer (SWICS). URAP Co-investigators are M. Desch, J. Fainberg, M. Goldstein, M. Kaiser, R. MacDowall (Principal Investigator), M. Reiner, and R. Stone (Principal Investigator Emeritus); K. Ogilvie is a Co-investigator on the SWICS team.

6.8 SWAS

After a successful launch in December 1998, SWAS has completed its primary objective of mapping dense molecular cloud cores in the submillimeter emission lines of H_2O, O_2, ^{13}CO, and atomic carbon, providing the first glimpse of important chemical processes and cooling needed to initiate the early stages of star formation. The first scientific results of SWAS took up the entire issue of the Ap.J. (Lett) August 2000. In addition, SWAS has successfully observed water in several comets, notably Comet McNaught-Hartly and Comet Lee. SWAS has been funded for a two year extended operation to undertake further detailed observations of the Interstellar Medium. The Principal Investigator for SWAS is G. Melnick of the Smithsonian Astrophysical Observatory. G. Chin is the SWAS Project Scientist.

6.9 Near Earth Asteroid Rendezvous (NEAR)

MFI on NEAR. The NEAR - Shoemaker MFI was designed to characterize the magnetization state of asteroid 433 Eros. M. Acuña is the Team Leader for this investigation with C. Russell of Univ. California, Los Angeles as Team Member and additional critical contributions by B. Anderson of the John's Hopkins Applied Physics Laboratory (JHU/APL). The instrument operated nearly continuously in the 35 and 50 km circular orbits, during close flyby's of the asteroid and for two days after the spacecraft landed on Eros itself in February 2001. No detectable magnetic field of asteroidal origin has been found for this S-Class object, in contrast with expectations based on the results obtained by other investigators at Gaspra and Braille. Eros is in class by itself as one of the most non-magnetic objects explored in the Solar System. It has been classified as an LL-chondrite on the basis of NEAR measurements but the magnetic field observations are causing a complete reassessment of the existing chondrite meteorite magnetization data.

X-Ray/Gamma-Ray Spectrometer (XGRS) on NEAR. The NEAR Shoemaker remote sensing XGRS has completed more than a year of operation in orbit and on the surface of 433 Eros. Elemental compositions for a number of the surface regions of Eros have been derived from analyses of the characteristic x-ray and gamma-ray emission spectra. Results indicate that over the portion of Eros where statistically significant elemental ratios have been obtained, the surface composition is homogeneous to within present statistical errors. These results indicate that Eros is primitive and has not been heated to temperatures sufficiently high to form a crust. There is also an indication that S may be some what depleted compared with ordinary chondrites.

Cosmic Gamma Ray Bursts (GRBs) on NEAR. Since the gamma-ray detector and electronics on NEAR also respond and process gamma-ray transient events, the NEAR XGRS instrument was included as part of the Inter-Planetary Network (IPN) for the detection and localization of GRBs. The IPN localizes gamma-ray bursts by timing their arrival at distant spacecraft. The IPN benefited greatly from the presence of NEAR in the network over a 15-month period from December 1999 to February 2001. During this 15 month period, the network included NEAR, Ulysses, GGS-WIND (the Konus instrument), BeppoSAX (the Gamma-Ray Burst Monitor), and the Rossi X-Ray Timing Explorer (the All Sky Monitor). With NEAR in it, the network detected over 100 GRBs. Of them, 34 were localized rapidly enough and precisely enough to warrant optical and radio follow-up observations. That is, the locations were determined within about 24 hours, and the positions were derived with accuracies of the order of several arcminutes. These radio and optical observations resulted in the discovery of nine new counterparts, and of the nine, distances were obtained for five of them by measuring their redshifts. (These numbers represent increases of about 50% to the database of GRB counterparts). The most interesting result was the detection of a burst originating in the southern constellation Carina which, with a redshift of 4.5, is the most distant GRB yet detected. The gamma-radiation traveled for 12.5 billion years before being detected by the network [Anderson et al. 2000].

6.10 Cassini

Composite InfraRed Spectrometer (CIRS). The Cassini spacecraft's 140-RJ swingby of Jupiter at the end of December 2000 provided a good shakedown of CIRS prior to its arrival at Saturn. It was also an opportunity to acquire unique measurements of Jupiter. CIRS thermal mapping of Jupiter's atmosphere represented an unprecedented combination of spatial resolution (up to 2.5 ° of latitude), spectral coverage (10 to 1400 cm^{-1}, or 1 mm to 7μm), and spectral resolution (up to 0.5 cm^{-1}, apodized). The high spectral and spatial resolution led to the first detection of the methyl radical and diacetylene-two key products in the cycle initiated with the destruction of methane by photolysis and charged particle impacts-in the polar hot spots that have been associated with Jupiter's aurora. The temperatures retrieved from the spectra have also been of interest. The zonal winds inferred from the thermal wind equation exhibit a vertical decay with altitude at the tropopause, but a more complex behavior higher in the stratosphere. There is also evidence of a thermal anomaly at the equator, having a wavelike variation with altitude. This may be related to the equatorial quasi-periodic temporal behavior seen in ground-based observations that is thought to be similar to the quasi-biennial oscillation in Earth's middle atmosphere. In addition to analyzing Jupiter data the international CIRS team, including V. Kunde (Principal Investigator), R. Achterberg, G. Bjoraker, J. Brasunas, R. Carlson, B. Conrath, F. M. Flasar, D. E. Jennings, C. Nixon, J. Pearl, P. Romani, R. Samuelson, A. Simon-Miller, and M. Smith, is planning the 4-year tour of observations of the Saturn system, beginning in 2004.

Cassini Plasma Spectrometer. E. Sittler is a Co-investigator for the Cassini Plasma Spectrometer (CAPS) instrument. CAPS is composed of five major subsystems. As Co-investigator for CAPS, E. Sittler has been in charge of development of certain flight software and scientific analysis of CAPS data at GSFC. The Cassini spacecraft has just completed a successful flyby of the Jupiter system. The CAPS instrument has operated nominally during this whole period. Closest approach with Jupiter occurred on Dec. 30, 2000 when the spacecraft came within about 140 R_J of Jupiter. The spacecraft entered the magnetosheath many times during the encounter and observed a few magnetopause crossings when it entered Jupiter's magnetosphere. This encounter offers an excellent opportunity to test the capabilities of CAPS. In order to support the Cassini flyby of Jupiter, ground software was developed for processing the TOF data. The primary composition observed has been protons and alpha particles over a wide range of energies.

6.11 Mars Global Surveyor (MGS)

Magnetic Field Investigation (MFI). The MGS spacecraft continues to orbit Mars in its Extended Mission phase and the Magnetometer/Electron Reflectometer instrument continues to operate flawlessly. Magnetic field data from more than 10,000 orbits have been acquired and processed resulting in an enormous data set which has been submitted to the PDS. Mario Acuña is the Principal Investigator with J. Connerney and P. Wasilewski as Co-investigators. The MAG/ER Investigation is a collaboration with the Space Sciences Laboratory (UCB), B. Lin of the Space Sciences Laboratory (UCB), and D. Mitchell Co-investigators. This collaboration includes H. Reme, D. Vignes (currently at GSFC) and C. Mazelle of the Centre d'Etudes Spatiales des Rayonnements, Toulouse, France, N. Ness, P. Cloutier, (Rice Univ.), D. Crider, and S. Bauer of the University of Graz, Austria.

Mars Atmosphere. Atmospheric investigations of Mars by the Goddard group of the Mars Global Surveyor (MGS) Thermal Emission Spectrometer Experiment (TES) team continued. More than one full Martian year of infrared spectral data have been obtained from the MGS mapping orbit. These data allow the study of interannual variations in atmospheric phenomena to begin. Further results are described in Section 4.2. (J. Pearl, M. Smith, W. Maguire, B. Conrath)

6.12 Lunar Prospector

Lunar Prospector Magnetic Field Investigation. Although this mission was terminated last year, magnetometer data processing and analysis has continued to expand the data base that has been submitted to the PDS. The Magnetometer/Electron Reflectometer Team, a collaboration between M. Acuña and B. Lin, continues to analyze the data received with the aim of understanding the origin of Lunar magnetization and the role that giant impacts played in its modification. The apparent synergism with Mars crustal magnetization continues to be of high scientific interest for present and future research. In addition to its planetary goals, the Lunar Prospector data has been utilized to diagnose and track significant solar-terrestrial events.

6.13 Voyager 1 and 2

Voyager 1 and 2 Magnetometers. The magnetometers on Voyagers 1 and 2 continue to function as designed and return data from explored regions of the distant heliosphere enroute to the termination shock and heliosheath. Voyager 1 is now at 82 AU at a latitude of $\sim$34.5° N, and Voyager 2 is at 65 AU at a latitude of 27°S. L. Burlaga is responsible for the reduction of the data and is active in the analysis of these data.

6.14 Earth Orbiter-1

The Linear Etalon Imaging Spectral Array (LEISA) Atmospheric Corrector. The LEISA/Atmospheric Corrector (LAC) is on the New Millennium Program Earth Orbiter 1 (EO-1) mission launched in November of 2000. This camera provides 250 meter spatial resolution, 0.89 to 1.6 μm spectral images at a constant spectral resolution of 35 cm^{-1}. The primary purpose of this atmospheric data is to correct the high spatial resolution, low spectral resolution Landsat-type multispectral images (from another instrument on-board) for the spatially and temporally variable effects of the atmosphere. EO-1 flies in formation with the operational Landsat-7 satellite which will allow the operational Landsat data to be corrected as well. Atmospheric correction is expected to improve the accuracy of satellite measured surface reflectances and increase the reliability of data products derived from them. The unique hyperspectral images also provide scientific data in their own right, including water vapor estimates, cloud and aerosol parameters, and surface properties. (D. C. Reuter, D. E. Jennings)

7 SPACE SCIENCE MISSIONS: DEVELOPMENTAL

7.1 New Millennium Program/ST-5 Mission

The New Millennium Program's Fifth Space Technology Mission, ST-5, will launch three small, $\sim$20 kg, satellites into geosynchronous transfer orbit in late 2003 or early 2004. Their objective is to provide flight validation for eight new technologies critical for the future deployment and operation of constellations of "nanosatellites" (i.e., spacecraft weighing $\sim$10 kg) for the Sun-Earth Connection and Solar System Exploration Themes. 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. ST-5 successfully completed its Preliminary Design Review in June and will soon go forward to Confirmation Review by NASA Headquarters. J. Slavin is the ST-5 Project Scientist and G. Le is leading the science validation instrument activities.

7.2 Geospace Electrodynamic Connections Mission

The Science and Technology Definition team completed the Geospace Electrodynamic Connections (GEC) Mission definition document, which has been printed and made available to the science community. The Integrated Mission and Design Center at GSFC provided a preliminary spacecraft design for the mission. The goal of GEC is to advance to a new and deeper level of insight our understanding of the coupling between the ionized and neutral components of the upper atmosphere. Its primary focus is on multipoint in situ measurements of all the important neutral atmospheric and ionospheric plasma parameters at altitudes below 300 km, the region where the direct contribution of the neutral atmosphere to magnetosphere energy dissipation is most important. This will be done by employing up to four identically instrumented satellites in a high inclination, 2000 × 185 km, pearls-on-a-string configuration orbit. The spacecraft will each carry onboard propulsion to vary the spacing between the spacecraft and to perform excursions below the nominal perigee altitude of 185 km. Through multi-spacecraft sampling of the ionosphere-thermosphere (I-T) region over a broad range of latitude and local times and through focused dipping campaigns in the most important coupling zone, GEC will answer two fundamental questions: (1) How does the I-T system respond to magnetospheric forcing? (2) How is the I-T system dynamically coupled to the magnetosphere. J. Grebowsky is the Project Scientist for GEC.

7.3 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 Principal Investigator of the development team and the lead for the electron electrostatic analyzer. 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 spacecraft is undergoing final checkout before being placed in storage where it will await a launch opportunity.

7.4 Discovery Program/MESSENGER Mission

Magnetic Fields Investigation. Following a successful Preliminary Design Review, the MESSENGER mission to Mercury has now been confirmed for development by the Discovery Program. The purpose of this mission is to collect global information on the surface, interior, exosphere, and magnetosphere of this least explored of the terrestrial planets. The Principal Investigator is S. Solomon of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The lead institution for the spacecraft and mission operations will be the Johns Hopkins Univ. Applied Physics Laboratory. LEP scientists will be responsible for the vector magnetometer and the investigation of the planetary magnetic field and the magnetic structure of Mercury's magnetosphere. The LEP magnetic fields Co-investigators are M. Acuña and J. Slavin. MESSENGER will launch in 2004 and go into orbit about Mercury in 2009 following two earlier fly-by encounters.

7.5 STEREO

STEREO Magnetometer. The STEREO IMPACT investigation includes instruments provided by the LEP. M. Acuña is responsible for the provision of the magnetic field experiment portion of IMPACT. Current activities involve definition of spacecraft interfaces and electromagnetic cleanliness requirements to insure accurate measurements.

7.6 Mars Sample Return Mission

Mars ATmosphere And Dust in the Optical and Radio (MATADOR). W. Farrell, M. Desch, J. Houser, and M. Kaiser completed the last year of development on the Mars03 Sample Return Mission MATADOR package, which lost its manifest due to the uncertainties in the Mars Explorer Program and rescheduling of the Sample Return Mission to late in the decade. The MATADOR instrument is lead by P. Smith at Univ. Arizona, and has strong GSFC participation in science management and instrumentation. The team continues their studies of triboelectrified dust, and in mid-June performed a field test in the desert outside Tucson, Arizona where optical, electrical, and fluid measurements were obtained simultaneously during passages of dust devils.

7.7 Communications/Navigation Outage Forecast System (C/NOFS)

Electric Field Investigation. Goddard's Vector Electric Field Investigation (VEFI) is being prepared for inclusion on the Air Force Communications/Navigation Outage Forecast System (C/NOFS) satellite to be launched in late 2003. The main objective of the satellite is to study irregularities in the equatorial ionosphere that disrupt communications and navigation systems. Such irregularities are generally associated with equatorial "spread-F" and are linked to ionospheric plasma depletions and variable DC and AC electric fields. The planned orbit of the C/NOFS satellite is 400 by 700 km with a 13 degree inclination. The VEFI experiment includes instrumentation to measure DC and AC electric fields, and includes a burst memory, on-board signal processing (FFTs), and a filter bank. In addition, the VEFI experiment also includes a magnetometer (to be provided by M. Acuña), a lightning detector, and a fixed-bias Langmuir probe which serves as the trigger input for the burst memory. R. Pfaff, Jr. is the Principal Investigator of the VEFI instrument for C/NOFS.

8 SOUNDING ROCKETS AND SUBORBITAL PROGRAMS

Sounding Rockets Program Status. R. Pfaff is the Project Scientist for NASA's Sounding Rocket program, described briefly here. NASA's Sounding Rockets Program provides a cost effective, rapid means to carry out unique scientific experiments in space, as well as to test new flight instrumentation. Sounding rockets provide the only platforms with which scientists can carry out direct in-situ measurements of the mesosphere and lower ionosphere/thermosphere region (40-120 km) which is too low to be sampled by satellite-borne probes. Furthermore, they provide quick access to high altitudes where astronomy, planetary, and solar observations can be made of radiation at wavelengths absorbed by the Earth's atmosphere, including emissions from objects close to the sun (e.g., comets, Venus, Mercury) which are precluded from observation by large, orbiting telescopes such as the Hubble and EUVE. Sounding rockets also provide an extremely high quality, low "g-jitter" environment, ideal for a variety of microgravity experiments. Unique features of sounding rockets include their ability to gather data along vertical trajectories, their low vehicle speeds (compared to satellites) with long dwell times at apogee, their ability to easily support multiple payload clusters and tethers, the ability to launch rockets into geophysical "targets" (e.g., thunderstorms, aurora, cusp, equatorial electrojet, etc.) when conditions are optimum, including operations at remote launch sites, the recovery and re-flight of instruments and payloads, and the acceptance of a greater degree of risk which helps maintain the low cost aspect of the program. In addition to science and technology, sounding rockets also provide invaluable tools for education and training. Over 350 Ph.D.'s have been awarded to date as part of NASA's sounding rocket program. Missions are selected each year based on peer-reviewed proposals selected by various science discipline offices at NASA Headquarters.

Rocket Study of the Polar Mesosphere. R. Goldberg led an international scientific team in the Distribution and Role of Particles in the Polar Summer mesosphere (DROPPS) Rocket Program, launched in July 1999 to study the polar summer mesosphere. This has already produced a special section of eight papers in the April 15, 2001, issue of Geophysical Research Letters. New findings include the existence of negatively charged particle layers in conjunction with polar mesospheric summer echoes, determination of particle size within noctilucent clouds, and electric field structure and plasma characteristics within both type of events. Additional work is currently in progress concerning the origin of Polar Mesosphere Summer Echoes (PMSE's).

Sporadic-E Experiment from Wallops Island, Virginia. In order to investigate the complex electrodynamics and neutral-plasma coupling inherent to sporadic-E layers in the Earth's mid-latitude ionosphere, a rocket/ radar experiment was launched from Wallops Island, Virginia on June 29, 2001. R. Pfaff was the Principal Investigator of this rocket and the lead scientist for the DC and AC electric field and Langmuir probe experiments. The rocket experiments consisted of a pair of "mother-daughter" payloads with a limited apogee so that the payloads "hovered" in the sporadic-E region (95-125 km). The payload pair included vector DC and AC electric field detectors, a highly accurate flux-gate DC magnetometer, an ionization gauge, and spaced-electric field receivers to measure the wavelength and phase velocity of the unstable plasma waves. In addition to the rocket experiments, continuous VHF backscatter radar operations were carried out from a site at Ft. Macon, North Carolina, where 3-m backscatter echoes were observed associated with sporadic-E layer. An ionosonde at Wallops Island also showed the presence of sporadic-E layers. On June 29, 2001, the rocket was launched into an unstable sporadic-E layer showing the presence of quasi-periodic radar echoes. All of the instruments performed well and detailed analysis is underway.

Future Rocket Programs. A new rocket program (MaCWAVE) with R. Goldberg as Principal Investigator was awarded and is currently scheduled for high latitude launches during summer 2002, and winter 2003. Critical Design Review for the payloads occurred on August 16, 2001. Finally, R. Goldberg, W. Farrell, M. Desch, and J. Houser were part of a team selected to conduct flights on the Uninhabited Aeronautical Vehicle (ALTUS UAV) during summer 2002. The flights will occur in Florida. They are designed to measure the energy generated in the upward direction above thunderstorms. The payload was developed at LEP through earlier studies in partnership with IDEA, Inc. under an SBIR.

9 FUTURE MISSIONS

9.1 Living with a Star (LWS)

Living with a Star, Geospace Missions Network. R. Hoffman and B. Giles were named as Project Study Scientists and assist with the definition of this Sun Earth Connections (SEC) mission. The LWS Geospace Mission Definition Team, named during the summer of this year, has begun meeting and working on its report. Current attention is devoted to the definition of specific mission objectives and measurement parameters. The possibility of hosting geospace instrumentation on the LWS Solar Dynamics Observatory is also being explored.

Sentinels. The goal of the LWS Sentinel element is to gain an understanding of the fundamental physics that connects solar phenomena to geoeffective events. The Pre-formulation team has completed its report recommending a mission composed of four Inner Heliospheric Mappers and a solar far side observatory. The NASA Headquarters-appointed Science Architecture Team has endorsed the concept of the Inner Heliospheric Mappers and has recommended the formation of an official Science Definition Team. The Sentinels are expected to be launched by 2009. A. Szabo is the Sentinels project scientist.

Geospace. The Geospace element of LWS will be moving rapidly towards the definition of an implementation plan with the formation of the Geospace Mission Definition Team by NASA Headquarters. A plan with options and priorities will be completed in the spring of 2002 and will be the basis for an Announcement of Opportunity (AO) for the flight program. The Team of university, industrial, and government laboratory scientists has engineering support from the Applied Physics Laboratory of Johns Hopkins University. Management of the program is within the Solar Terrestrial Probes program of Goddard. R. Hoffman is the Geospace Definition Scientist.

9.2 Frontier Mission

Interstellar Probe. NASA's Interstellar Probe will be the first spacecraft designed to explore the local interstellar medium and its interaction with our solar system. Its unique trajectory from Earth to $\sim$200 AU in $\sim$15 years will enable the first comprehensive measurements of plasma, neutral atoms, magnetic fields, dust, energetic particles, cosmic rays, and infrared emission from the outer solar system, through the boundaries of the heliosphere and on into the local interstellar medium. 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 Headquarters for further consideration. A. Szabo is a member of the ISTDT.

9.3 New Millennium Program

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 $\sim$1600 m^2 solar sail powering a $\sim$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. The solar sail craft is one of the four concepts being proposed for the New Millennium Program ST-7 mission. A. Szabo is a member of the pre-phase A solar sail proposal development team.

9.4 DRACO

T. Moore continued to serve as project study scientist for the Magnetospheric Constellation-DRACO Mission during the definition of this Solar Terrestrial Probe mission. The Science and Technology Definition Team, chaired by H. Spence, completed it's writing of their report. The report was printed in early June 2001, and is now available by request through the SEC web site at http://stp.gsfc.nasa.gov. Attention is currently focusing on technology issues relating to the mission, including the miniaturization of several key spacecraft and instrument components, and the definition of a launch vehicle approach.

9.5 Connections

T. Moore is leading a GSFC team contribution to a proposal for a unique new MIDEX mission mission, "Connections" designed to achieve a new understanding of magnetosphere-ionosphere interactions. It uses an energetic electron beam fired from a high altitude spacecraft, creating a disturbance in the ionosphere which, when detected by radar, reveals the actual linkage between the two regions. Auroral imaging has produced some of the most spectacular and suggestive data about what is going on in geospace, and auroral movies are often regarded as a 2D projection of the dynamics of the magnetosphere. However, the sad truth is that we don't really know what we are looking at in auroral images. This is because the shape of the aurora is an image of the magnetosphere that is turned inside out and highly distorted by the complex geomagnetic field, like an anamorphosis. Anamorphoses are artworks that must be viewed through a distorting lens or mirror to be seen in their true forms. In our case, only the distorted image is seen, and the true form of something that is stubbornly invisible except through this distorting lens must be inferred. Exactly how the geomagnetic field connects auroral features to the responsible magnetospheric plasma regions is not known, so it is difficult to understand the apparent shapes. Indeed, the times when the aurora is brightest and most dynamic are known to be just the times when the magnetic field is changing shape most rapidly. At such times the lens is being zoomed, focused, and even astigmatized in the middle of our observations, which has made such inferences exceedingly difficult. The Connections mission will unravel the auroral-geomagnetic lens transfer function and allow the magnetosphere to be seen in its true form.

Connections Orbit Selection Through Theory and Modeling. Professor J. Sojka at Utah State Univ. is the Principal Investigator of the proposed Connections mission. T. Moore, M. Collier, and M.-C. Fok are Co-investigators, with roles providing the plasma neutralizer, the electron plasma instrument, and participation in the theory and modeling team. Fok has performed theoretical study and field line mapping to established the link between the Connections spacecraft and different regions in the ionosphere and the magnetosphere. This study will guide the selection of the Connection orbit to ensure Connections will cover the important regions and achieve the proposed science goals.

9.6 Submillimeter Infrared Ice Cloud Experiment (SIRICE)

SIRICE is a proposed low-risk mission to improve our knowledge of the amount of ice mass in the Earth atmosphere so that prediction of regional climate change can be substantially improved. This improved characterization will be derived from nadir observations at sub-millimeter wavelengths coupled with infrared images. SIRICE addresses the effects of clouds on climate change and NASA's overarching theme of "Earth System Responses and Feedback Processes." The far IR instrument on SIRICE is the Sub-millimeter radiometer (SMR). LEP's J. Brasunas and B. Lakew are members of the science team for SIRICE. The Principal Investigator is S. Ackerman (Univ. of Wisconsin). The four high temperature superconducting bolometers baselined for the focal plane of the SMR will be developed and characterized by the LEP.

9.7 Autonomous Nano-Technology Swarm (ANTS)

The ANTS Asteroid Survey Mission, an advanced mission concept involving the rendezvous and mapping of thousands of Main Belt Asteroids by 2030 has been proposed by S. Curtis, including the support of M. Rilee, M. Bhat, P. Clark, W. Truszkowski of the Advanced Architectures and Automation Branch, G. Marr of the Flight Dynamics Analysis Branch, J. Nuth, and others.

Based on an insect colony analog and drawing on features of biological systems, the mission concept identifies technologies that with proper development will enable a large number of pico-spacecraft to obtain remote sensing data from many hundreds of asteroids a year. Sensor-specialized worker spacecraft with solar sails and no consumables are to maneuver themselves into optimal vantage points for data acquisition. Data, after some processing, will be transferred to a layer of communication and command spacecraft which in turn manage the operation of the ANTS system. Autonomous operation at the swarm and spacecraft level is to be achieved through a hierarchical bottom up/top-down approach which matches appropriate levels of artificial intelligence to specific operational needs.

10 INSTRUMENT DEVELOPMENT

On-board High Performance Computing for Space Science Missions. M. Rilee, M. Bhat, and S. Boardsen, under S. Curtis have been studying how high performance, commercial-off-the-shelf multi processor computing systems might be utilized on board spacecraft on space science missions. In particular, applications to the Magnetospheric Multi-Scale (MMS) mission are being studied. Moving some computations to the spacecraft promises to reduce downlink communication requirements and provide better coverage and resolution. With the support of NASA's High Performance Computing and Communications Project and in collaboration with Jet Propulsion Laboratory (JPL) researchers, software that models particle detector data reduction and cross-correlative radio interferometry have been developed. Automated data reduction applied to archived Hawkeye spacecraft data have been prototyped. Work has begun towards the development of a flight test of this technology. Research into the implementation of autonomous science instrumentation is being performed.

Miniaturized Analyzers for Plasmas. T. Moore and J. Lobell have initiated a project to develop miniaturized analyzers for plasmas, appropriate to multi-spacecraft missions such as Magnetospheric MultiScale and Magnetospheric Constellation (MC). Initial efforts are focused on new concepts for compact plasma energy-angle analyzers such as that proposed by T. Zurbuchen of the Univ. Michigan, in which nearly an entire hemisphere of angular directions is imaged upon a single circular detection system. This effort is being supported through a Graduate Student Researcher Program grant to P. Koehn, under Zurbuchen's advisorship. In addition, reduction in size of more traditional "top-hat" analyzers is being undertaken as a combined mechanical engineering/packaging/machining challenge, in collaboration with code 500 of GSFC. A dedicated ASIC solution for sweep coordination and data acquisition is being developed, also in collaboration with M. Johnson and other personnel from the Applied Engineering and Technology Directorate.

Onboard Lossy Data Compression. B. Giles and T. Moore have initiated a project to develop data compression methods and algorithms specialized for in-situ particle instrumentation and appropriate for multi-spacecraft missions such as MMS and MC. Efforts are focused on the development of new concepts for the lossy compression of real time data streams via wavelet transforms. Exploration and metric testing of various transform functions, quantizers, interleaving and truncation schemes, and encoder methods should identify optimal algorithms. The ultimate goal is to provide balance between the desired data compression ratios and the ultimate quality of the reconstructed sparse data arrays. The effort is being led by an Applied Engineering and Technology Directorate Professional Internship Program participant, M. Buenfil.

Measuring the Solar Wind Near the Sun. E. Sittler has led the development of nadir viewing technology for solar wind ions for the Solar Probe Mission. Most of the work has concentrated on the thermal input to the spacecraft and the mechanical design of the booms. Development of high temperature thermal blankets has reduced the thermal input to the spacecraft bus to less than a few watts. This technology will allow measurement of the solar wind ions all the way to perihelion which is only 4 solar radii from Sun center. The electrostatic mirrors are now projected to operate below 50C which is considerably cooler than earlier projections. The electrostatic mirrors are composed of parabolically shaped wire meshes. We have also been investigating various coating techniques which will "solder" the wire mesh into the desired shape. Problems have occurred when the mirror is flat and wrinkles tend to form. This is believed to be caused by thermal expansion and contraction of the mandrel during the plating process. One solution to be investigated is using materials with low thermal expansion coefficient and coated with Teflon; the Teflon is needed so that the wire mesh does not bond to the mandrel during plating process. Another approach is to use a photo-etching technique which was successfully used for the CAPS experiment for Cassini and does not have the thermal expansion problems noted above.

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 passing 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. A prototype of the turbotrap is currently being constructed with the aim toward testing and validating the instrument concept. This effort is led by J. Keller and J. Lorenz (Litton Advanced Systems).

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 materials YBCO and GdBCO. J. Brasunas and B. Lakew are Co-invesigators for the SIRICE instrument (S. Ackerman, Univ. Wisconsin is the Principal Investigator). It is a 4-channel, far-infrared radiometer employing four high temperature superconductor 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. SIRICE is being proposed for an Earth System Science Pathfinder mission. In addition to the bolometer work, J. Brasunas is pursuing development of very broad-band, visible-to-millimeter wavelength beamsplitters based on free-standing, grown films of Chemical Vapor Deposition (CVD) diamond. By combining the bolometer and the CVD beamsplitter, the goal is to produce, for future planetary missions, a smaller, lighter version of the CIRS spectrometer on the Cassini mission.

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. Fettig 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 SIRICE instrument.

Acousto-optic Imaging Spectrometer/AIMS. Work has been largely completed on a prototype Acousto-optic IMaging Spectrometer (AIMS), built at GSFC and funded by the Office of Space Science, Mars Instrument Development Program. Principal Investigator is D. Glenar and other team members include D. Blaney, JPL; D. Britt, Univ. Tenn; G. Georgiev, K. Uleck, and J. Hillman, Univ. Maryland; and J. Parker, T. Flatley and W. Powell, GSFC. AIMS is a compact VIS/ near-IR tunable camera which is capable of multi-spectral imagery at arbitrarily chosen wavelengths. This class of instrument can guide the rapid collection of mineralogical samples for future Mars sample return missions. The camera demonstration is a field-deployable unit which consists of: (1) 2 kilogram optics module in an actively cooled environmental shroud which simulates Mars surface temperatures, (2) 2-kilogram electronics module, and (3) AZ-EL pointing mechanism. The opto-mechanical assembly of this instrument has been completed, and breadboard designs for the front-end electronics are currently being tested. A fully-operating breadboard of the camera short wavelength channel has been characterized by UMD postdoctoral fellow G. Georgiev.

Far IR Imaging Array. The development of a 2-D monolithic array using micromachined sapphire as a substrate has made substantial progress. Several masks have been tried including one which promises to withstand the conditions under which micromachining is performed. The sensing element in each pixel will be a high temperature superconducting thin film (YBCO or GdYBCO). The IR absorber will be a low filling factor gold black layer deposited at our LEP's gold black deposition facility. B. Lakew is the Principal Investigator for this DDF funded project. J. Brasunas, S. Aslam (Raytheon ITSS), and R. Fettig are collaborators.

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 which 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. Scanning may be accomplished by a number of methods such as by the orbital motion of the spacecraft, by rotating the spacecraft, as was planned for PFF, or by a steerable mirror. The actual spatial resolution is determined by the spatial resolution of the imaging optic, the image scan speed, and the readout rate of the array. The spectrometer has no moving parts, a minimum of optical elements and only one electronically activated element, the array. Compared to conventional grating, prism, or Fourier transform spectrometers and mechanically or electrically tunable filter systems, it represents a great reduction in optical and mechanical complexity.

Heterodyne Instrument for Planetary Wind And Composition (HIPWAC) Instrument Development. The new HIPWAC has now been commissioned in three observing runs at the NASA Infrared Telescope Facility (IRTF) in December 2000, February 2001, and August 2001, successfully meeting the scientific objectives of each run. HIPWAC development activities in Autumn 2001 will refit the instrument for operation on the Gemini 8m telescope facilities, with the first Gemini run tentatively scheduled for January-February 2002. The HIPWAC effort is led by T. Kostiuk, and until his departure by F. Schmülling, with D. Buhl and K. Fast, T. Livengood and J. Goldstein, and T. Hewagama, with engineering support by F. Minetto and J. Annen. Design support and CAD drafting has been provided by P. Rozmarynowski and F. Hunsaker. Mechanical engineering and composite-materials fabrication of the HIPWAC optical benches, optical mounts, and laser cavities was provided by K. Segal and P. Blake of the Mechanical Engineering Branch (GSFC). Student Juan Delgado (UMD) characterized optical components and subsystems in the laboratory and was able to attend and significantly contribute to the third observing run. HIPWAC is an advanced infrared heterodyne spectrometer (IRHS) for the measurement of molecular lineshapes and the wind-driven Doppler shifts of molecular lines formed in low-pressure, high altitude, regions of planetary atmospheres. Improved performance derives from implementation of new technologies and from the characteristics of large (8-10m) telescopes accessible to a transportable instrument: (1) factor of $\sim$10 improvement in sensitivity on small targets compared to a 3m telescope; (2) improved spatial discrimination; (3) reduced velocity broadening due to range of Doppler shift from planetary rotation across the diffraction-limited FOV; (4) improved system quantum efficiency compared to current components; (5) flexible access to available telescopes; and (6) access to different latitudes from which to observe. The prototype 1 meter-length cavity for the CO_2 laser local oscillator was used in the December 2000 and February 2001 runs. The advanced dual-laser-tube cavity supporting 0.5m tubes was used in August 2001. The IRHS group presently is investigating the replacement of old discrete-filter technology for signal-processing using a modern acousto-optic spectrometer system. Work is beginning on an overall upgrade to mate HIPWAC to any of the general class of 8-10m telescopes now in operation.

ISS/Electrostatics of Granular Material (EGM). W. Farrell is a Co-investigator on EGM, an experiment to examine dust electrodynamics in microgravity. Current efforts include designing an RF system to be incorporated into the dust chamber onboard the International Space Station for examining the electrical nature of the particles. In microgravity and low fluid flows, electrical forces dominate the dust dynamics, with grains forming long filament structures due to dipole dynamics. The LEP-designed RF system would examine grain-grain discharges and directly sample grain charge upon contact with the RF system antenna.

11 EDUCATIONAL OUTREACH AND TECHNOLOGY TRANSFER

Space Weather Center Traveling Museum. Scientists and Education and Public Outreach (EPO) specialists associated with the ISTP program were key participants in the development of the Space Weather Center traveling museum exhibit (http://www-istp.gsfc.nasa.gov/ exhibit). Extensive funding, content, imagery, and technical support (including much of the writing of the exhibit text) were provided.

Maryland Science Center Partnership. In the Fall and Winter of 2000-2001, ISTP staff, including N. Fox, M. Carlowicz, and R. Hoffman, forged a partnership with the Maryland Science Center in Baltimore, Maryland, to offer more than a dozen public events and activities related to the exhibit. In the Spring of 2001, that same staff brought the exhibit to Goddard's Visitor Center, securing the funding, assembling the exhibit, and conducting at least a dozen more public programs in conjunction with the exhibit.

Sun-Earth Days 2001. In the Spring of 2001, ISTP staff served as co-leaders of the Sun-Earth Days 2001 EPO event on April 27-28, 2001. M. Carlowicz worked with staff of the Sun-Earth Connection Education Forum (SECEF) to develop the themes and web site for the exhibit. Partnerships were formed with the Discovery Science television network and the Astronomical League of amateur astronomers. Support was provided to more than 60 scientists who made public presentations around the country on Sun-Earth Days. This event has provoked more than 50 education workshops and at least a hundred public science events attended by tens of thousands of people across the country (for more details, see http://sunearth.gsfc.nasa.gov/SECEF_SunEarthDay).

Mission to Geospace Web Site. On the World Wide Web, ISTP invited the public into our scientific world with the Mission to Geospace web site. The site was designed as a library or portal for journalists, teachers, and space aficionados to find more information and materials about Sun-Earth Connections (SEC) science. Mission to Geospace is best known for its extensive library of articles, releases and photos, its easy-to-read backgrounders on space science, and its "Follow the Sun" window to key space weather imagery and data sets. In the past year, a special section on solar maximum and links to many Spanish-language materials and web sites have been added. In the year 2000, the site received more than 3.5 million "hits," and we project that we will receive 5 million hits in 2001. An external review panel convened by NASA to judge the quality of the agency's web efforts favorably reviewed the site. (http://www-spof.gsfc.nasa.gov:80/istp/outreach/)

Education and Outreach Website. D. Taggart, M. Collier, and R. Lepping lead the development of an Education/Outreach Website. This site attempts to appeal to a broad audience, but targets high school students in particular and highlights the scope of the Laboratory's research. The site is now listed on many major search engines. A postcard showing the sites URL and its frontpage has been developed to advertise the site and it already has had broad distribution. R. Lepping continues to communicate with a professor (D. Warn) at Boise State College to help him in using a previously developed solar wind-magnetosphere education activity. New magnetic cloud events have also been added. We are making this activity as general as possible and are in the process of adding its main elements to the Laboratory's EPO site. (http://lep694.gsfc.nasa.gov/lepedu/FrontPage.html)

ISTP Presentations. ISTP staff, including R. Hoffman, N. Fox, M. Carlowicz, D. Stern, A. Szabo, K. Sigsbee, and M. Acuña, made presentations of scientific and educational materials to teachers and students at the NASA Education Workshops (NEW), the National Science Teachers Association, the ASPIRA Hispanic Education Conference, and several Washington, D.C. and Maryland education meetings. ISTP presentations and publications also obtained a warm response from the press. The central topic was synthesized in the cover page of a special issue of Geophysical Research Letters and featured in the Earth in Space magazine.

Educational Outreach and Students. T. A. Livengood has engaged in numerous classroom visits and public talks presenting planetary and space science to the public, including personal work done with the infrared heterodyne spectroscopy group at GSFC. J. Delgado worked in the heterodyne spectroscopy laboratory during the 2000/2001 academic year, assembling and testing laser systems and contributing to development efforts for the HIPWAC instrument. He gained sufficient expertise to travel to Mauna Kea, Hawaii, to support the third commissioning run for HIPWAC on the NASA IRTF, where he made invaluable contributions to the preparation for, and conduct of, the successful observing run. T. Kostiuk served on the Advisory Committee for the National Air and Space Museum/Challenger Center Voyage Exhibition, a scale model of our solar system on the Washington Mall in front of the Air and Space Museum.

The publication list includes all papers published or submitted in 2000/2001 by the LEP Staff (or by visitors, if a substantial portion of the work was done at LEP).

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