# Bulletin of the American Astronomical Society

# Observatory report: LEP



## INTRODUCTION

The Laboratory for Extraterrestrial Physics (LEP) performs experimental and theoretical research on the physical properties and dynamical processes of the interplanetary and interstellar media, and the magnetospheres and upper atmospheres of the planets, including the Earth. Research related to the chemistry and physics of planetary stratospheres and tropospheres, and condensed solar system matter including meteorites, asteroids, comets and planets also forms an important component of the LEP research. A focused program in astronomy is conducted, particularly in the infrared and in short as well as very long radio wavelengths. An extensive program of laboratory research, including spectroscopy and physical chemistry related to astronomical objects, is also performed.

The Laboratory proposes, develops, fabricates and integrates experiments on Earth-orbiting, planetary and interplanetary spacecraft and sounding rockets to measure the characteristics of magnetic fields, electric fields and plasmas in space using both direct and indirect methods. Spectrometric instrumentation required for continuum and spectral line observations in the X-ray and gamma-ray regime, infrared and radio regions are designed and developed within the Laboratory, and flown on spacecraft to study the interplanetary medium, asteroids, comets, and planets. Studies are conducted to investigate electric and magnetic fields and plasma-dynamic phenomena in the near-Earth space environment. These studies concern temporal and spatial variations influencing the motion and composition of plasma and neutral gases in the Earth's atmosphere and magnetosphere. Suborbital and ground based observing platforms form an integral part of these research activities.

This report will cover the period from July 1, 1994 to August 31, 1995, to include new launches as well as new significant recent work.

# I. PERSONNEL

NASA is pleased to announce the appointment of Dr. Richard Vondrak as Chief of the Laboratory for Extraterrestrial Physics. Before deciding to join the LEP, he was Director of Space Physics, Lockheed Palo Alto Research Laboratory, Lockheed Research and Development Division. Mr. Franklin Ottens is Assistant Chief. The Laboratory Senior Scientists are Drs. Richard Goldberg, John Hillman, Michael Mumma, Louis Stief, and Robert Stone; Dr. Joseph Nuth is Head of the Astrochemistry Branch; Dr. Keith Ogilvie is Head of the Interplanetary Physics Branch; Dr. Drake Deming is Head of the Planetary Systems Branch; Dr. Steven Curtis is Head of the Planetary Magnetospheres Branch, and Dr. James Slavin is Head of the Electrodynamics Branch. The Information Analysis and Display Office is headed by Mr. William Mish.

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

*National Research Council Associates:* Dr. Richard Achterberg, Dr. James Clemmons, Dr. Frank T. Fergusson, Dr. Nicola Fox, Dr. Robert Glinski, Joseph Harrington, Dr. Vladimir Krasnopolsky, Dr. Masha Kuznetsova, Dr. Gerald Lehmacher, Dr. Giovanni Laneve, Dr. Thomas Moran, Dr. Neal Dello Russo, Dr. Pedro Sada, Dr. Adam Szabo, Dr. Satoshi Taguchi, Dr. Peyton Thorn, Dr. Eugene Ustinov, Dr. Mark Weber, and Dr. Xingfa Xie

*University Space Research Association Scientists:* Dr. Tamara Dickeson, Dr. Michael DiSanti, Dr. Michael Goodman, Dr. Marcos Sirota, Dr. Nikolai Tsyganenko, Dr. Dimitris Vassiliadis, and Dr. Hung Kit Wong. During this reporting period Dr. Marcos Sirota won the USRA Excellence in Technology Award.

*Personnel on University Grants, University of Maryland:* Drs. Casey Lisse, Timothy Livengood, Thejappa Golla, Denise Lengyl-Frey, Ms. Kelly Fast; Catholic University of America: Dr. Paul Schindler; Cornell University: Dr. Michael DiSanti.

*Visiting Faculty:* Drs. William Blass, Robert Boyle, Edward Chang, Pamela Clark, Yaara L. Dickerson, Bertram Donn, Robert F. Ferrante, Joan Frye, George Kraus, Lembit Lilleleht, Karen Magee-Sauer, Robert Nelson, Fred I. Nesbitt, Richard Starr, David Steyert, Fred Volkening, and Paul Withey.

*Graduate Students Working on Ph.D. or M.S Thesis Research in the LEP:* Patricia Daukantas, Andrew Korb, Miska Le Louarn and B. Patrick Michael.

*Undergraduate Students Working in the LEP:* Kim Ennico, Gene Fujii, Nikolay Ivchenko, Lori Fenton, Todd Krygier, James Ramsey, Kyle Rice, and Christine Whelman. During this period, Kim Ennico was named as a British Marshall Scholar. Leonard Boyd.

*Contractor Associate Scientists:* From Hughes-STX (HSTX), Drs. Daniel Berdichevsky, Scott Boardsen, Mr. Mark Cushman, Drs. Michael Goodman, Sanjoy Ghosh, Roger Hess, Shrikanth Kanekal, Brooke Lakew, Paul Marionni, Nitya Nath, Mr. George McCabe, Drs. Vladimir Osherovich, Mauricio Peredo, Michael Reiner, Pamela Solomon, K. Edouard Siregar, Nikolai Tsyganenko; from Science Systems Applications, Inc. (SSA, Inc.): Drs. Richard Achterberg, Ronald Carlson, Mr. Lawrence Herath, Mr. James Tingley, Ms. Carolyn Martin; from Computer Sciences Corporation (CSC): Drs. Larry Evans, Ashraf Ali, Rangasayi Halththore. Dr. Robert Nelson is on a one year IPA appointment from Georgia Southern University.

*NASA Headquarters Detailees:* Joseph Nuth and David Nava are part-time detailees in the Solar System Exploration Division managing the Planetary Materials and Astrochemistry Program. Theodor Kostiuk continues as a detailee in the Solar System Exploration Division. He manages the Planetary Instrument and Development Program (PIDDP). Joseph Grebowsky and Mark Smith are detailees to the Space Science Division. Robert Hoffman completed his tenure at Headquarters this year.

Thomas Birmingham is the Project Scientist for the NASA Space Physics Theory Program (SPTP), which provides support for 15 autonomous groups located at universities and other research centers throughout the U.S. He maintains scientific and management oversight.

# II. PLANETARY & COMETARY RESEARCH

## Mars

F. Espenak and colleagues T. Kostiuk, T. Livengood, and T. Hewagama (NASM) used the Goddard Infrared Heterodyne Spectrometer (IRHS) to measure ozone in the atmosphere of Mars at 9.66 μm. The observations were performed atop Mauna Kea, Hawaii, at the coude focus of the 3-meter NASA Infrared Telescope Facility (IRTF) during March 1995. Terrestrial $O_3$ normally renders Earth's atmosphere opaque to these frequencies, but Mars' large geocentric radial velocity near quadrature shifted the $O_3$ lines into the wings of their telluric counterparts where the terrestrial atmosphere was transparent enough to permit the observations. The spectra show an enhanced ozone abundance over a range of latitudes. Analysis of the entire data set is currently in progress, but preliminary results indicate higher levels of ozone than predicted by the models of Liu and Donahue, and Shimazaki.

V. Krasnopolsky examined a problem of uniqueness of a solution for photochemical modeling and established a rule that the number of boundary conditions given by densities and/or non-zero velocities should be equal to the number of chemical elements in the system. He calculated two models of Mars' photochemistry, with and without nitrogen chemistry, which fit the observations of $O_2$, CO, $O_3$, and the $O_2$ 1.27 μm airglow close to the uncertainties of the measured values. The importance of nitrogen chemistry in the lower atmosphere depends on a fine balance between N and NO in the upper atmosphere which is not known within the required accuracy.

M. Acuña continued his Principal Investigator (PI) activities on the Mars Global Surveyor Magnetometer and an Electron Reflectometer, a joint effort with the University of California at Berkeley and the University of Toulouse, France.

J. Pearl continued his activities as a Co-Investigator (Co-I) on the Mars Global Surveyor Thermal Emission Spectrometer (TES) experiment; Dr. Philip Christensen (Arizona State Univ) is the TES PI. Further work on the Mariner 9 Infrared Interferometer Spectrometer (IRIS) data, with L. Fenton and T. Martin (JPL), has provided quantitative values of dust opacity in the Martian atmosphere during the decline of the great 1971 dust storm. S. Dason and B. Conrath have developed a scheme for the inversion of limb infrared radiances that is capable of measuring vertical temperature perturbations due to propagating gravity waves. Efforts have been initiated with D. Reuter to make new laboratory transmission measurements of the far wings of the 15 mm $CO_2$ band; these measurements are required to permit accurate atmospheric temperature retrievals over the very long, low pressure paths to be encountered in the TES limb observations. In preparation for possible upward-looking infrared vertical sounding from a Martian lander, M. Smith devised an inversion scheme for probing the diurnal boundary layer using measurements in the $CO_2$ 15 mm band. The method appears able to sound the lower scale height of the atmosphere, with a vertical resolution on the order of 100 m.

The Atmospheres Node of the Planetary Data System was terminated in the past year. As closeout activities of the Infrared Subnode, the Palomar Spectrogram observations of the comet Shoemaker-Levy 9 (SL9) impact with Jupiter are being prepared for archiving.

T. Livengood continues his work on high resolution infrared spectroscopy and imaging of planets and on International Ultraviolet Explorer (IUE) studies at the Laboratory, as a Research Associate of the University of Maryland under a cooperative agreement with the LEP.

V. Krasnopolsky (NAS-NRC), M. Mumma, and G. Bjoraker obtained isotopic ratios in Martian carbon dioxide from spectra taken at 3.7 mm and 8 mm; they find that heavy oxygen ($^{18}O$) is depleted on Mars, relative to Earth. They interpret this in terms of atmospheric evolution, and argue that an initial atmospheric abundance of 5 bars $CO_2$ is implied at the beginning of the heavy bombardment, and about 0.3 bars $CO_2$ at the end. V. Krasnopolsky, G. Bjoraker, M. Mumma, and D. Jennings extracted upper limits to abundances for $CH_4$, $H_2O2$, $H_2CO$, and HCl from the same spectra. The methane abundance (70 ⊥ 50 ppb) is not significantly different from the Mariner 9 IRIS result, but the upper limit for formaldehyde (

## Jupiter

*Thermal Waves on Jupiter:* D. Deming and collaborators completed an analysis of infrared observations of planetary-scale thermal waves on Jupiter. They concluded that these low-amplitude ( 0.3 K) waves are likely to be Rossby-gravity waves, represented by small (0.1 degree) latitude excursions in the zonal winds. These latitude excursions produce temperature fluctuations via "vortex stretching," wherein changes in the derivative of pressure with respect to potential temperature must occur in order to conserve Ertel's potential vorticity. Additional observations of these waves are planned to be made in support of the entry of the Galileo probe into Jupiter's atmosphere. Since Jupiter is near conjunction at the time of probe entry (December 7, 1995), the observations will utilize the McMath-Pierce solar telescope on Kitt Peak.

*Jupiter and Io:* J. Connerney and colleagues T. Satoh, and R. Baron (Univ. Hawaii) have imaged Jupiter at 3.40 mm wavelength using the NSFCAM infrared camera and NASA's IRTF at Mauna Kea, Hawaii. The technique exploits a set of emission lines of the $H_3^+$ ion (3.40 mm) within a strong absorption band of methane, to image the distribution of $H_3^+$ with high spatial resolution (subarcsec), time resolution (minute), and signal to noise ratio (hundreds). These images, like those obtained previously with ProtoCAM, evidence intense and omnipresent auroral emissions at both magnetic poles and emission at the foot of the Io Flux Tube (IFT). The latter appears as an isolated, sub-arcsec spot which moves across Jupiter's disc in concert with the orbital motion of Io; it is excited by the electrodynamic interaction of Jupiter's magnetic field with Io. The IFT footprint has subsequently been identified in Hubble Space Telescope (HST) ultraviolet images obtained with the WFPC2 and FOC instruments. The June 1995 and July 1995 NSFCAM images captured Io's signature in both POLAR regions with greatly improved spatial and time resolution. Analysis of these images is expected to improve our understanding of Io's interaction with Jupiter's magnetic field. A complete map of the IFT footprint on the planet's surface ("ground truth") is now being assembled; when complete, it will constrain models of Jupiter's magnetic field.

*Jupiter $H_3^+$ Aurorae:* T. Satoh (Hughes/STX, GSFC) and colleagues J. Connerney (GSFC) and R. Baron (Univ. Hawaii) used many ProtoCAM infrared images of Jupiter to model the distribution of Jovian $H_3^+$ emissions in the auroral regions. A linearized inverse method has been developed which allows many images of the aurora, obtained at different central meridian longitudes, to be inverted, modifying a source model in such a way as to minimize the difference between the observed and simulated images, pixel by image pixel. A simple model consisting of uniformly illuminated, washer-shaped emission regions centered near the magnetic poles does a reasonably good job in modeling the observations, but additional emissions are required to fully explain the observed intensities. Evidence is found for enhanced emissions at longitudes marked by weaker surface magnetic field magnitudes, and there appears to be a local time enhancement in emissions poleward of the auroral oval in the dusk sector. On the basis of the distribution in longitude along the auroral oval, the $H_3^+$ auroral emissions can be associated with the precipitation of electrons drifting (towards higher system III longitudes) in longitude about Jupiter.

*Solar Wind Control of Jupiter's $H_3^+$ Aurorae*: Auroral intensities obtained on 15 observing dates in early 1992 have been compared with a time series of solar wind ram pressures measured in-situ by the Ulysses spacecraft (S. Bame, PI; R. Stone, PI). The auroral intensity has two principal components of time variability: A short-term variability (days) which correlates well with the solar wind ram pressure arriving at Jupiter, and a longer-term variability (months) which is believed to be related to the energization and transport of magnetospheric plasma in Jupiter's magnetosphere. The solar wind correlation supports the view that Jovian $H_3^+$ aurorae occur on field lines that map to the distant magnetosphere, where small variations in ambient magnetic field magnitude, driven by the solar wind fluctuations, can effectively "pump" energy into the charged particle population and increase precipitation on a short time scale. In addition, a method of analysis of photometric observations of auroral emissions (auroral "light curves") has been devised and illustrated with reference to the Jupiter observations. Continued observations are planned to monitor the state of the Jovian magnetosphere and to provide further insight into the Io interaction and the generation of decameter wave radio emission.

## Saturn

P. Sada, D. Jennings, G. McCabe, G. Bjoraker, and D. Deming performed mid-infrared (8 to 20 μm) observations of Jupiter and Saturn with CELESTE, a GSFC-developed cryogenic large grating echelle spectrometer, in conjunction with the McMath-Pierce Solar Telescope (KPNO/NSO). These observations were used to retrieve the stratospheric temperature structure and the abundance distribution of various molecular species of astrophysical importance. The general objective of this project is to monitor changes in the status of the atmospheres of these planets, and to map the spatial distribution of the vertical temperature profile and the chemical abundance. The Jupiter observations concerned the characterization of the atmosphere of Jupiter one year before the Galileo mission reaches the planet in preparation for additional observations planned to be carried out simultaneously with the probe's entry and sampling of the atmosphere. Through these observations the feasibility and usefulness of ground-based thermal-infrared daytime observations of Jupiter obtained when the planet is close to the sun, and unavailable for most observers, has been demonstrated.

## Titan

*Investigation of the Circulation of Titan's Stratosphere:* Earlier direct measurements of the mean zonal wind velocity from the difference of Doppler shifts of 12 μm ethane emission lines from the eastern and western hemispheres of Titan were consistent with prograde winds of 100 m/sec with a comparable sized uncertainty. Infrared heterodyne measurements are underway by T. Kostiuk, T. Livengood, K. Fast, D. Buhl and F. Espenak in collaboration with T. Hewegama and J. Goldstein (National Air and Space Museum) to improve on the results and establish velocity uncertainties of better than 35 m/sec. Analysis software is also being developed that will allow improved interpretation of the measurements including comparison to wind field models for Titan. These investigations are not only of scientific interest, but also important for planning the release of the Huygens probe into Titan's atmosphere as part of the Cassini mission and for interpretation of resultant measurements.

*Algorithms for the Retrieval of Temperature and Para-Hydrogen Fraction:* These algorithms, developed by B. Conrath and E. Ustinov (NRC/RRA) in collaboration with P. Gierasch (Cornell), have been applied to Voyager IRIS thermal spectra to obtain zonal mean temperature and para-hydrogen profiles for Jupiter, Saturn, Uranus, and Neptune. Estimates of the zonal mean, upper tropospheric circulation for each planet have been obtained by applying diagnostic models to the temperature and para-hydrogen fields.

*Atmospheres of the outer planets:* W. Maguire collaborated with J. Hillman, D. Glenar, G. Chin, W. Blass and M. Le Louarn to identify the composition of hazes in the upper atmosphere at the SL9 impact sites on Jupiter, developing an atmospheric model to fit absolute reflectivity (I/F) variations in the methane and ammonia bands. In other work, he worked with E. Ustinov, J. Pearl, B. Conrath, M. Smith, C. Martin, S. Dason and L. Fenton to develop atmospheric model parameters to be used in an analytical study of weighting functions for Jupiter. In another area, he continued his analysis of Voyager 2 Neptune spectra, recently identifying a new atmospheric minor constituent, dicyanoacetylene ($C_4N_2$) in an average of IR spectra. Finally, he performed theoretical calculations relevant to gases in planetary atmospheres using Lie algebraic methods to calculate parameters for molecules containing a small number of atoms.

*Global Winds on Saturn's Moon Titan:* M. Flasar, M. Allison (NASA GISS) and J. Lunine (U. of Arizona ) have completed a review of what is known about the global winds on Titan, and provide a wind profile that forms the basis of the wind model currently used in planning by the Cassini/Huygens mission. R. Achterberg and M. Flasar have completed their analysis of thermal waves in Saturn's atmosphere, as detected in Voyager IRIS data.

They have identified a wave with zonal wavenumber 2, which they interpret as a Rossby wave excited by a critical-layer instability in the zonal mean flow. M. Flasar and R. Killen (Southwest Research Institute) have completed their study of the information content of microwave observations of the giant planets. They find that microwave fluxes at centimeter wavelengths probe the relative humidities of condensible species, e.g., ammonia, and are fairly insensitive to the atmospheric temperature-pressure profile.

*Photochemistry of Titan's Atmosphere and Ionosphere:* V. Krasnopolsky and Cruikshank (ARC) considered the photochemistry of Titan's atmosphere and ionosphere. Their model included vertical profiles of 32 neutral and 21 ionized species. It established sublimation rates of parent species $N_2$, $CH_4$, and CO from the ice, precipitation rates of photochemical hydrocarbons and HCN, and escape rates of N, $H_2$, H, O, and C. Some new processes are discussed. A variety of the models were checked, and four basic unknown values and their plausible ranges were determined: the CO mixing ratio, the magnetospheric electron energy input, the rate coefficient of reaction between $N_2$ ion and C, and the ion escape velocity.

## Comets

*Evolution of Comet SL9 After Break-up:* K. Olson (930/George Mason Univ.) and M. Mumma applied an N-Body dynamic code to argue that the nucleus of comet SL9 split into about 100,000 cometesimals, rather than 21 discrete chunks, and that the cometesimal cloud then re-grouped into the several dozen 'fragments' observed. They examined the effect of dissipative collisions between cometesimals and showed that re-accreted clumps can form at the core of individual swarms under some conditions. Starting with a cloud of cometesimals (each 40 m or 80 m in size) at break-up, they showed that up to several dozen swarms form as the body recedes from Jupiter. T. Rettig (Notre Dame), J. Hahn (Notre Dame), and M. Mumma showed that the number of 'fragments' found in SL9 is consistent with a simple analytical treatment of the process. Using HST images, they examined the behavior of fragments that dissipated; dissipation is expected for low mass 'fragments.' M. Mumma et al. showed that the wings of material seen at discovery are consistent with regolith stripping prior to tidal disruption of the nucleus itself. X. Xie, K. Olson, and M. Mumma examined the dynamical evolution of 'fragments' from apojove to impact, and showed that the predicted entry light curves agree with those observed by the Galileo spacecraft.

M. DiSanti and M. Mumma showed that the organic emission feature (3.23.6μm) seen in comet P/Swift-Tuttle was contributed by two species: Methanol and another volatile (X-organic). They showed that the new emission tracks the volatile production rate, not the dust intensity, and they suggest that the progenitor is a new form of volatile carbon having an abundance comparable to methanol (~5%, relative to water). They discovered a sharp spectral feature at the center (3.425 mm) of the X-organic feature and its width (~1.2-1.7 cm-1), but were not able to identify it.

N. Dello Russo and M. Mumma examined photo-chemical processing of cometary and interstellar ice analogues at low temperatures, emphasizing nuclear spin conversion in molecules with equivalent hydrogensparticularly those species that have been detected or are expected to be present in comets. Following EUV irradiation at low temperature, the ices are warmed and gas phase spectra are taken. Individual ro-vibrational spectral lines are examined and the ortho to para ratio (OPR) is measured. The goal of the study is to determine whether the OPR varies with the temperature at which the sample was last processed. Comparison with the OPR's measured for comets P/Halley and Wilson 1987 VII may constrain the temperature and environment of cometary formation.

X. Xie and M. Mumma developed a Monte Carlo model for the cometary coma, and applied it to spacecraft measurements of comet 1P/Halley. The models were evaluated using both hard-sphere and more realistic (semi-classical) molecular collision cross-sections. They first explored spherically symmetric uniform outflow from the nucleus, and showed that the predicted outflow velocities and their variation with cometocentric distance agree with measurements obtained by the NMS instrument on Giotto. All previous attempts to model the Giotto outflow velocities failed. They showed that the success of a spherically symmetric model successfully explains the physics of a coma with severe departure from spherical symmetry largely because the approach geometry of the spacecraft remained in a particular azimuthal sector of the coma. However, the derived global production rate bares an uncertain relationship to the true value. They then developed a model for axisymmetric outflow, and again achieved good agreement with Giotto outflow velocities using an appropriate 'sector' production rate. The global production rate (integrated over all sectors) depends on the assumed degree of asymmetry, and a reasonable range of asymmetry parameters was used to evaluate the possible systematic error introduced into the Giotto production rates by this effect. The axisymmetric model is now being evaluated for use at other heliocentric distances, and for interpretation of remote spectroscopic observations.

## Shoemaker-Levy 9 Jupiter Event

*Water Detection Following Impact of SL9:* G. Bjoraker and colleagues at Cornell University used the Kuiper Airborne Observatory deployed out of Melbourne, Australia, to detect water immediately following the impact of several fragments of Comet Shoemaker-Levy (SL9) with Jupiter. They obtained spectra at 7.7 mm showing emission lines of $H_2O$ and $CH_4$. The peak infrared signal occurred during the fallback phase in which ejecta from the initial explosion re-entered Jupiter's atmosphere and was heated to 1000 to 1200 K near the 3-microbar level. The mass of $H_2O$ in the G fragment was estimated to be $3 \times 10^{12}$ g, equivalent to a sphere of ice 180 m in diameter. The observed water was probably not excavated from below Jupiter's water cloud. Instead, the initial explosion reduced the cometary material into component atoms, including oxygen and carbon, which were mixed with Jovian hydrogen to produce CO and $H_2O$.

In collaboration with D. Banfield, P. Gierasch, and P. Nicholson (Cornell), B. Conrath developed a retrieval algorithm to obtain vertical profiles of particulates from near-infrared spectral measurements. The algorithm was applied to Palomar spectral measurements of SL9 impact sites in the 2.35 $\mu$m methane absorption band. In all cases, maxima in the profiles were found to be located at pressures less than or equal to 10 mbar.

D. Deming and J. Harrington are conducting a radiative hydrodynamic simulation of the plume infall from the collision of comet SL9 with Jupiter. It is currently believed that fall-back of the plume ejecta produced large shock-heating of the upper Jovian atmosphere over an extended region on Jupiter. This heating over an extended area was responsible for the very bright infrared emission seen by terrestrial observers and referred to as the "main event." Deming and Harrington's computations of this fall-back process define the height profile of the atmospheric heating, and enable them to account for many features of the observed infrared light curves. Specifically, they find that the series of secondary maxima following the main peak of the light curve is produced by a rebound ("bounce") of the infalling plume material and the upper atmospheric layers. Both the amplitude, and to a lesser extent the period, of this bounce are influenced by the opacity of the plume material because of radiative damping. They plan to collaborate with G. Bjoraker and W. Maguire in order to include a large number of molecular emission lines in the radiative opacities.

Stratospheric ammonia and ethane emission lines were measured from Jupiter at the NASA Infrared Telescope Facility (IRTF) using the GSFC Infrared Heterodyne Spectrometer (IRHS), on Mauna Kea, Hawaii, as part of the IRTF Comet Crash Observing Program. T. Kostiuk was on the IRTF Comet Collision Science Team. The abundance and altitude distribution of ammonia injected into the Jovian stratosphere by the collisions were determined. Ammonia was found to exist primarily at high stratospheric altitudes above the 10 mbar pressure level. The total mass of ammonia derived corresponds significantly to a greater amount than can be delivered by cometary nitrogen, supporting the hypothesis that the source material for the stratospheric ammonia came primarily from the deep Jovian atmosphere. The data are also being used to study temporal changes of stratospheric ammonia using subsequent observation up to 8 months after collision, thus testing photochemical models.

T. Livengood, T. Kostiuk, G. Bjoraker, and P. Romani also participated in the European Southern Observatory campaign to observe the SL9 impacts, at ESO in La Silla, Chile. Observations were made using the facility thermal-infrared camera TIMMI on the ESO 3.6 m telescope. The team collaborated with scientists from the European Southern Observatory, H.U. Käufl and G. Wiedemann. Data from these observations include the light curve of two impact events, spectrophotometry of many impact sites during the week following the impacts, absolute intensity measurements of the IR excess from each impact site, and the morphology of the stratospheric impact ejecta.

LEP staff were involved with observations of the SL9 impact events using the IUE (T. Livengood, T. Kostiuk, and F. Espenak) as part of the IUE SL9 International Science Team, with particular responsibility for the planning and analysis of measurements of the ultraviolet aurora. Spectra were acquired of the aurorae, the atmospheric albedo at the impact sites, the plasma torus, and of aurora-like emission from several of the actual impact plume events. Atmospheric data collected from several impact sites by the IUE include the entirety of each impact region considered, complementing the time-series of data acquired in the core of the G impact site by HST.

# III. ASTROCHEMISTRY

*Reactions of the vinyl radical* are potentially important in determining the abundances of such molecules as $C_2H_2$, $C_2H_4$, and $C_2H_6$ in the atmospheres of Jupiter, Saturn, Titan and Neptune. The most important reaction is that with atomic hydrogen. The temperature dependence of the rate constant and the product branching ratios of the reaction of H atoms with vinyl radicals ($C_2H_3$) have been determined. In a collaborative effort with D. Shallcross of Cambridge University, QRRK calculations and Troe analysis were also performed using the experimental data. Calculations were made to investigate the relationship between the observed kinetics, products, possible reaction mechanisms and finally to suggest a value for the limiting low pressure rate constant. The important results for models of the outer planets and satellites are: (1) the measured rate constant is substantially larger than that used in present models, and (2) the first evidence for a significant yield of $C_2H_4$ at low pressure and temperature. Also of importance to models of the outer planets, measurements of the collisional deactivation of the $nu^4$ mode of methane by He, $H_2$ and $CH_4$ were made over the temperature range from 205 to 295 K.

*Cosmic-Type Ices Before and After Proton Irradiation:* Laboratory studies of the spectral properties of cosmic-type ices before and after proton irradiation are conducted using a unique set-up designed specifically for the ion bombardment of thin films of low temperature ices. The focus of these investigations is to understand mechanisms and products in irradiated icy materials thought to exist in cometary ices, interstellar icy grain mantles, and in some cases the surfaces of icy satellites. The results provide information on appropriate physical-chemical and radiation-chemical processes as well as the optical properties of both simple and complex cosmic-type ices. Experimental studies on the spectral identification of new species synthesized in irradiated $CH_3OH$ and $H_2O$+$CH_3OH$ ices have been completed. Mass spectroscopy of volatile species released during slow warming gives supporting information on identifications. $H_2CO$ is the dominant volatile species identified in the irradiated ices; $CH_4$, CO and $CO_2$ are also formed. During warming, the ice evolves into a residual film near 200 K whose features are similar to those of ethylene glycol along with a C=O bonded molecular group. Irradiation simulates expected cosmic ray processing of ices in comets stored in the Oort cloud region for 4.6 billion years. Results support the idea that a comet originally containing an $H_2O$+$CH_3OH$ ice component has a decreasing concentration of $CH_3OH$ towards its outer, most heavily irradiated layers (if independent of all other sources and sinks). Infrared spectra of $CH_3OH$ at $T<20$ K on amorphous silicate smokes show a predominantly crystalline phase ice.

*Far-infrared (20-100 μm) spectral data on $H_2O$* have been obtained. Measurements were made in transmission using a silicon substrate. Three sets of data were collected. Spectra of $H_2O$ ice formed at 15, 40, 80, 100, 120, 140, and 160 K. Spectra of $H_2O$ ice formed at 15 K and warmed to 40, 80, 100, 120, 140, and 160 K. Spectra of $H_2O$ ice formed at 160 K and cooled to 140, 120, 100, 80, 40, and 15 K. These data are part of a collaborative effort in which laboratory reference data will be used to help identify the phase and possibly the temperature of any $H_2O$ ice detected in nebulae around evolved stars observed using ISO.

*Spectral emission features in the Red Rectangle (HD44179):* Efforts to understand and correlate such emissions to absorption features making up the Diffuse Interstellar Bands (DIBs) have resulted in the proposal that thioformaldehyde ($CH_2S$) may be responsible for a number of prominent DIBs between 677-686 nm. Additional work on DIBs at 579.7 and 585 nm has lead to a more thorough analysis of similar bands in the Red Rectangle and the conclusion that the most prominent emission features between 570 and 698 nm (other than Na lines) may be due to the $C_3$ molecule.

*Silicate Grain Formation and Metamorphism:* A recent review has identified several key parameters for further study: the nucleation process itself, metamorphism of the initial condensates and grain coagulation mechanisms. Experimental studies of the nucleation of magnesium metal continue to add support to the applicability of Scaled Nucleation Theory to laboratory conditions; extension of this theory to circumstellar environments will be more difficult. Experimental studies of additional refractory vapors will continue in order to test the predictions of Scaled Nucleation Theory. Because annealing of freshly condensed Mg-Fe Silicates will result in the formation of a population of single magnetic domain iron grains, an initial theoretical examination of the enhanced coagulation cross-section of such materials has recently been completed that demonstrated enhancements of as much as seven orders of magnitude over the geometric cross-section. It was also argued that this process would produce very low dimension fractal grains having greatly enhanced absorption cross-sections that could significantly affect interpretations of protostellar continuum flux measurements in the submillimeter range.

The morphology, distribution, and composition of metallic particles in individual chondrules from the Bjurbole meteorite have been investigated using a scanning electron microscope with energy dispersive X-ray spectrometer, to determine what correlations may exist between the metallic particles' petrographic characteristics and the magnetic properties of the individual chondrules. This research provides information concerning nebular conditions and processes responsible for imprinting the observed magnetic characteristics of chondrules. These measurements may be the first definitive proof that lightning discharges occurred in the primitive solar nebula.

*A 1-D methane photochemical model* was used to analyze the significance of recent rate constant measurements. Two different photochemical scenarios to convert $C_2H_2$ to $C_2H_6$ can be constructed, depending upon whether R1 or R2 is used. But both involve the same sequence of hydrocarbons ($C_2H_2$, $C_2H_3$, $C_2H_4$, $C_2H_5$, $CH_3$, $C_2H_6$). The rate constant for R2 was found to be a factor of 18,000 times slower than used in previous studies. The new rate measurement for R2 is consistent with previous measurements but $C_2H_4$ was found to be a significant product in addition to $C_2H_2 + H_2$. Only the latter product channel had been used in prior methane photochemical models. Thus, the new product channel in R2 has the potential to negate the effect of the reduction in ethylene formation via R1. However, the reaction scenario using R2 is less efficient in converting $C_2H_2$ to $C_2H_6$ than the one using R1. This is because it depends upon H, which is in scarce supply in the lower stratosphere where the ethylene channel is important.

*The 1993 Sir Harold Thompson Memorial Award* was presented to M. Weber, W. Blass, S. Nadler, G. Halsey, W. Maguire, and J. Hillman. It was presented by the Editors of Spectrochimica Acta Part A, for the most significant contribution to spectroscopy published in the journal in 1993. The paper is entitled, "L-Resonance effects in $C_2H_2$ near 13.7 $\mu$m. Part II: The two quantum hotbands" and represents the culmination of a decade-long quest aimed at understanding vibrational resonance effects in linear polyatomic molecules.

## Gas-Phase Spectroscopy:

A significant effort in the LEP is high-resolution laboratory infrared spectroscopy of gaseous molecular species. The research effort (D. Reuter, J. Sirota, J. Hillman, M. Weber, and D. Jennings) is focused primarily on molecules of planetary and astrophysical interest, and supports NASA flight missions in both these areas. The work also supports ground-based astronomy and terrestrial atmospheric studies. The group has begun a vigorous program to measure TDL and FTS spectra at wavelengths greater than 10 mm. Measurements are scarce at these wavelengths, but are crucial for the analysis of data from upcoming missions such as Cassini, where Composite Infrared Spectrometer (CIRS) will obtain spectra of Saturn and Titan from 7 to 1000 mm. Recent work includes analyzing spectral data for excited state and fundamental transitions in $H_2$, $^{13}C_1{}^2CH_6$, $C_2H_4$, $C_2H_2$, $N_2O$, $CO_2$, $C_3H_4$ and $HNO_3$. This work has been carried out with W. Blass (Univ. of Tenn.), J. Frye (Howard Univ.), J. Johns (NRC, Canada), A. Perrin (C.N.R.S., Paris), D. Steyert (Wabash College), and L. Strow (UMBC). These measurements have already impacted planetary studies. For example, the $^{13}C$ 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, while the intensities of the ethylene ($C_2H_4$) transitions have been used to obtain concentrations of this species in the upper atmosphere of Saturn.

The group has developed a unique tunable diode laser (TDL) system for obtaining spectra to ~ 30 mm employing advanced (Si:Sb) BIB detectors, high performance lead-salt lasers and a long-path White-type sample cell. A very long-path, coolable White-type cell is currently in fabrication which will allow path lengths in excess of 500 m at temperatures as low as 120 K. They are also planning to enhance the long-wavelength capability of the Kitt Peak National Observatory McMath FTS spectrometer by employing a series of long-wavelength beamsplitters, and are developing methods for external cavity stabilization of long-wavelength TDLs.

# IV. SOLAR AND STELLAR RESEARCH

## Solar

Summer Faculty Fellow E. Chang (U. of Mass.) collaborated with D. Deming to analyze the first infrared spectrum taken of a solar prominence in the 1 to 5 mm spectral region. The spectrum was taken by D. Deming using the Fourier transform spectrometer at the McMath-Pierce solar telescope on Kitt Peak. It was found to contain numerous emission lines due to hydrogen and helium. Analyses of the line widths and intensities are consistent with a scenario wherein helium emission is formed in the cooler central regions of the prominence, whereas hydrogen emission is formed at the edges, which are heated by coronal EUV radiation. Infrared observations of prominences are planned to be made simultaneously with SOHO observations of UV emission lines.

## Stellar

M. DiSanti with A. Schultz (CSC) and collaborators imaged the southwest extension of the dust disk in b Pictoris, using the WFPC on HST in a novel configuration. The disk was imaged in PC1, while the core of the stellar PSF was positioned in WF4, thereby eliminating stellar 'bleeding' in the disk image. A Pic was observed in identical fashion, and was used to model both the PSF and light scatter for scaled subtraction from the corresponding b Pic image. Preliminary analysis indicates the disk is more edge-on than implied from ground-based imagery. The PC1 images clearly show a narrow disk with a thickness of ~0.2-0.4 arcsec extending out to a distance greater than 20 arcsec (300 AU) from the star. This bright inner core is surrounded by an outer, fainter envelope of material (width~80 AU), which may be less dense, or may be composed of grains with a strikingly different size distribution.

P. Sada (LEP NRC), D. Jennings, G. McCabe (LEP Hughes/STX), and D. Deming, in collaboration with R. Loewenstein (U. Chicago/Yerkes) and R. Boyle (Dickinson Coll.), performed mid-infrared stellar observations with CELESTE, a Goddard-developed cryogenic large grating echelle spectrometer, in conjunction with the Apache Point Observatory 3.5m telescope. The purpose was to search for Zeeman splitting in the 12.32 µm MgI 7i-6h line (extensively observed in the Sun) in a sample of late-type stars that are likely to have significant magnetic fields in an attempt to make sensitive and direct model-independent measurements of stellar magnetic fields. Initial observations consisted of high-resolution spectra of a-Ori and a-Tau, and subsequent observations of fainter strong-field stars are planned.

# V. SOLAR WIND AND HELIOSPHERE

## The International Solar-Terrestrial Program (ISTP)

The LEP has a leading role in the ISTP program, a comprehensive trilateral (U.S., Japan, European Space Agency) effort to study the plasma, energetics, and flow through the solar terrestrial system. M. Acuña of the LEP is the Project Scientist for ISTP coordinated three spacecraft, Wind, Geotail, and POLAR, to perform a study solar wind-magnetosphere coupling. LEP scientists have been chosen to participate in nine different experiments, of which they serve as PI on four. The Wind spacecraft, part of the GGS mission, was placed in distant Earth orbit on November 1, 1994. Wind contains eight instruments covering the measurements of waves, fields, plasma, and particles. The Radio and Plasma Wave Experiment (WAVES) is a combined effort of the Paris Observatory, the University of Minnesota, and GSFC. In addition to a variety of in-situ plasma waves, it covers the low frequency radio astronomy spectrum from the solar wind plasma frequency cutoff near 20-30 kHz up to nearly 14 MHz. In this frequency range, WAVES measures all four Stokes polarization parameters as well as the direction of arrival of the emission.

The laboratory contributed several instruments which were successfully launched on the Wind spacecraft. K. Ogilvie is PI os the solar wind instrument, R. Lepping is PI of the magnetic field instrument, and M. Kaiser is PI of the WAVES investigation.

The ISTP Program is now providing simultaneous coordinated scientific measurements from many of the key areas of Geospace. The ISTP Central Data Handling Facility (CDHF) and the associated Science Planning and Operations Facility (SPOF) provide the space physics community with a set of integrated science products and associated tools to enable the planning and conduct of solar-terrestrial physics. The data activities are under the direction of W. Mish, the Deputy Project Scientist for Data Systems. The set of products produced spans real-time telemetry and science from several spacecraft and ground-based instruments. This data set is continuously updated with the most recent measurements and is available to the space physics community both electronically and on CD-ROM in standard formats. Contributing data are four different ground-based investigations, instrumentation from multiple geostationary spacecraft, Geotail, Wind, and IMP-8 spacecraft, as well instruments on the soon to be launched POLAR, FAST, SOHO and Cluster spacecraft.

The ISTP SPOF provides products and science planning tools that range from generic KP display software, spacecraft ephemeris, field models, long and short range science plans, customized trajectory and KP summary plots for individual spacecraft, to a catalog of preliminary solar wind events, science coordination and public outreachthese products and tools are available electronically through the CDHF and the World Wide Web (WWW).

Data analysis programs for both the "key parameters" and the full data stream of the Wind instruments are operative, and work on the analysis of the data from the Wind instrument is underway.

## The Solar Wind

*Observations of Solar Wind Turbulence:* Access to the data from spacecraft sampling the regions from 0.3 to 20 or more AU from the Sun has given us the opportunity to study the evolution of the interplanetary fields (magnetic, velocity, density, temperature) over a wide range of conditions. M. Goldstein and A. Roberts have led efforts to determine the nature of the fluctuations, and in particular the degree to which they represent actively evolving turbulence. During the past year, much of this effort has focused on the structure and evolution of the region near the solar equator known as the "streamer belt" located above large helmet streamers on the Sun. It has been shown that this region is highly striated, even near the orbit of the Earth, and that this structure is almost certainly a remnant of conditions near the Sun. The structure is gradually eroded, apparently due to shear and compressive interactions between the filaments. With Ulysses data, M. Goldstein and A. Roberts along with their co-workers, have been able to confirm their previous predictions of how solar wind fluctuations evolve in relatively structureless flows. Studies of the evolution of Alfvénic fluctuations have further elucidated the role of Alfvén waves in solar wind acceleration, indicating that the observed properties of the fluctuations are probably not consistent with the wave driven model. A. Roberts has studied a fast and a slow Alfvénic wind, finding that they have very similar properties, consistent with their both having experienced a similar evolution despite the great difference in their speeds.

*Magnetohydrodynamic (MHD) Simulations of Heliospheric Phenomena:* A substantial number of scientists have been supported by a NASA Space Physics Theory Program grant (PI, M. Goldstein) to use a variety of simulation methods to study heliospheric phenomena. The group uses a variety of numerical algorithms to solve the compressible and incompressible MHD turbulence in one to three dimensions (A. Roberts, M. Goldstein, S. Ghosh, E. Siregar, and A. Deane), but also use hybrid codes (A. Figueroa-Viñas) and Vlasov-Maxwell simulations (A. Klimas). The situations have more and more closely approximated the real heliosphere. In the most recent simulations, a new code using a Flux Corrected Transport algorithm has been developed with time dependent and non periodic boundary conditions to study highly nonlinear situations at high Mach numbers. The code solves the inviscid compressible MHD equations in conservation form with all (effective) dissipation localized in steep structures. A simulation has also been constructed which contains two shear layers with periodic conditions in the directions transverse to the flow and supersonic and super Alfvénic inflow which is the first to demonstrate true spatial evolution of Alfvénicity instead of using time as a proxy for the radial coordinate. The evolution observed appears very similar to that seen by spacecraft, both in its evolution in time and in where the evolution is the strongest.

*Instabilities of Alfvenic Fluctuations:* M. Goldstein, A. Figueroa-Viñas, S. Ghosh, and A. Roberts have investigated instabilities of Alfvénic fluctuations due to coupling with compressive fluctuations. This has led to a very complete characterization of the problem, and an application to the excitation of waves upstream of interplanetary shocks. A. Roberts has shown that compressive couplings do not limit the amplitude of MHD waves to be near the value of the mean magnetic field ("saturation"). The lack of evidence for this effect in the simulations provides further strong constraints on the role of Alfvén waves in the acceleration of the solar wind. S. Siregar and S. Ghosh, along with A. Roberts and M. Goldstein, have extended their investigation of vortex streets in the outer heliosphere at solar minimum to include compressible two- and three-dimensional effects that can be compared with the observed properties of the density, and magnetic and velocity fields.

*Theoretical Studies of Solar Wind Turbulence:* M. Verma (IIT, Kanpur), working with A. Roberts and M. Goldstein, has applied turbulence phenomenologies to the question of how much heating of the solar wind can arise from turbulence. These models suggest that turbulent heating is likely to be significant throughout much of the heliosphere, and to be dominant in the inner heliosphere. When combined with simulations, these results will enable us to have more confidence in applying turbulence models to situations where no in-situ observations are available such as in the open solar corona, in coronal loops, and over the solar poles. We also tested the validity of the two "standard" turbulence phenomenologys using MHD simulations. Both the Kolmogoroff and Kraichnan models appear to have significant limitations, especially for highly Alfvénic flows, although the Kolmogoroff-like model does work better for non-Alfvénic regimes.

*Pickup Protons in the Distant Heliosphere:* Pressure balanced structures are small-scale structures across which the total pressure is constant, as discussed in the recent book of L. Burlaga 1995. Using observations of pressure balanced structures near 35 AU, in the distant heliosphere (the region between 30 AU and the termination shock), the pickup proton pressure, density and temperature were determined by L. Burlaga et al. The results are consistent with the model of V. Vasyliunas and G. Siscoe and the boundary conditions determined by the Ulysses experiment of G. Gloeckler et al. The pickup proton pressure was found to be much greater than the solar wind pressure at 35 AU, so L. Burlaga et al. concluded that the pickup protons must be included in any MHD model of the distant heliosphere and the interaction of the solar wind with the interstellar medium.

*Merged Interaction Regions and Cosmic Ray Modulation:* Global Merged Interaction Regions (GMIR's) were observed in the Voyager 2 magnetic field data during 1990 and 1991 by L. Burlaga, N. Ness, and F. McDonald et al. These two GMIR's caused major step-decreases in the cosmic ray intensity. The relation between the change in the cosmic ray intensity and the magnetic field strength is the same at 35 AU as it was at 11 AU. The GMIR observed during 1991 was preceded by a relatively strong shock discussed by L. Burlaga. This shock could have been related to the one that D. Gurnett et al., proposed as the cause of the radio emissions observed during 1992.

*Interaction of the Solar Wind with the Termination Shock and Heliopause:* C. Whang and L. Burlaga developed a model of the interaction of the GMIR shock discussed above with the termination shock and heliopause. They showed that the GMIR shock would produce both a reflected shock and a transmitted shock when it interacted with the heliopause, and they suggested that the two bands of radio emissions were produced in the two regions behind these shocks. In view of the conclusion of L. Burlaga et al., that pick-up protons play a major role in the dynamics of the distant heliosphere, C. Whang developed a two-fluid model that considers both the solar wind protons and the pickup protons. Using this model, C. Whang, L. Burlaga and N. Ness confirmed the qualitative conclusions of C. Whang and L. Burlaga, and they estimated that during 1991-1992 the termination shock and heliopause were at 66 AU and 150 AU, respectively.

*Radio "Snapshot" of the Interplanetary Field:* A major goal of the Ulysses URAP is to track suprarthermal electrons which stream away along the spiral interplanetary mgnetic field from the Sun after a solar flare. These electrons produce radio waves, which can be observed remotely by URAP. In particular, the directional observations of these bursts from high heliographic latitudes provides a unique perspective of the exciter electrons, which usually follow magnetic field lines near the ecliptic plane. This is the first direct "snapshot" view of the spiral structure of the field structure out to distances of the order of 1 AU. The technique also shows large changes in the fields due to coronal disturbances such as Coronal Mass Ejections. M. Reiner, J. Fainberg, and R. Stone have demonstrated the application of the Ulysses observations to the detection of large scale distrubances in the interplanetary magnetic field. In conjunction with the Wind WAVES experiment, this technique will be extended, to three dimensions resulting in, the triangulation of radio source positions.

*WAVES- Preliminary radio and Plasma Observations:* M. Kaiser is currently PI for this experiment. Co-I's from LEP include M. Desch, M. Reiner, R. Stone, J. Fainberg, R. MacDowell, and W. Farrell. To date, emissions from the sun (type II and type III bursts), from the Earth (auroral kilometric, myriametric, and man-made noise), from Jupiter (decametric and hectometric components), and the cosmic background radiation have been measured. Simultaneous observations between WAVES and the Ulysses URAP experiment in solar orbit will permit triangulation of solar type III source regions. Similar observations between WAVES and URAP are providing detailed two-dimensional mapping of Jupiter's hectometric wavelength radiation pattern. Simultaneous observations between WAVES and the Nancay Observatory in France are providing complete spectral coverage of the Jovian decametric spectrum for the first time. Finally, radar transmissions from the SURA facility in Vasil'sursk, Russia, have been detected near 9 MHz by WAVES, demonstrating that ionospheric propagation reasearch can be achieved with only a few kw of radiated power. Observations of noise free regions in the spectrum at low frequencies will help in the planning of future space low frequency radio astronomical missions.

*The Electron Foreshock:* A survey of the electron foreshock using observations from the Wind Solar Wind Experiment (SWE) is in progress by R. Fitzenreiter. The Wind spacecraft was well situated in its early orbits for a foreshock study, since variations in the solar wind magnetic field about its average direction brought the spacecraft into repeated magnetic contact with the Earth's bow shock. The 3-D electron velocity distribution measurements of SWE are providing information about the source of the backstreaming electrons originating at the point of magnetic contact with the shock. The measurements do in fact distinguish between upstream electrons which are due to magnetic reflection of solar wind electrons incident on the bow shock and those which originate in the magnetosheath and move upstream through the shock. The measurements also provide unprecedented resolution of the velocity dispersed leading edge of the foreshock boundary, the region in which bump-on-tail reduced electron velocity distributions are observed as well as intense Langmuir waves generated by the electrons. These observations are being used in conjunction with simulations (A. Klimas) to study the plasma wave generation process, specifically the balance between plasma wave generation and maintenance of the unstable electron velocity distribution due to replenishment by upstream electrons from the bow shock.

*Particles Accelerated by Many Collisionless Shocks:* Using data from the ULYSSES SWICS experiment in collaboration with G. Gloeckler, K. Ogilvie and scientists from Code 660 have studied particles accelerated by the many collisionless shocks, both forward and reverse, observed beyond 1 AU These shocks are mostly quasiperpendicular and have Mach numbers in the range 1.5 5. It can be shown that both particles from the solar wind and particles from the pickup distributions are accelerated into a phase space distribution which joins up to the distribution observed at higher energies. The shape and the normalization of these distributions can be accurately simulated by using Monte Carlo methods. Because of the low background and complete mass discrimination of the SWICS instrument, these studies are now possible.

*Jupiter, a Source of Oxygen in the Interplanetary Medium:* Using SWICS-Ulysses observations, K. Ogilvie has determined the strength of Jupiter as a source of neutral oxygen in the interplanetary medium. It can be shown that Jupiter is a rather weak source of oxygen in the heliosphere when compared to the interstellar medium.

*Interplanetary Magnetic Clouds:* Magnetic clouds are interplanetary structures with enhanced magnetic field characterized by a smooth rotation of the magnetic field vector and a low proton temperature $T_p$ and were first identified by L. Burlaga and coworkers at GSFC in 1981. Work has continued here on the modeling of magnetic clouds using theoretical ideas based on the nonlinear evolution of magnetic flux ropes.

V. Osherovich, C. Farrugia and L. Burlaga have studied the effects of gas pressure. They assumed the energy transport is described by a polytropic relationship and reduced the set of ideal MHD equations to a single second order nonlinear ordinary differential equation for the evolution function. This equation led to the interpretation of the system in terms of a mechanical analog of a one dimensional nonlinear oscillator.

The theoretical analysis shows that the self-similar expansion of a magnetic flux tube requires the polytropic index gamma to be less than unity. These workers have also compared and contrasted two models which have been proposed for the global magnetic field line topology of magnetic clouds: one being a magnetic flux tube geometry and the other being a spheromak geometry (including possible higher multiples). Because the duration of typical magnetic cloud encounters at 1 AU (1 to 2 days) is comparable to their travel time from the Sun to 1 AU, the clouds should be treated as strongly non stationary objects. By treating magnetic clouds as self-similar evolving MHD configurations and solving rigorously the full set of MHD equations, it was demonstrated that the asymmetry in the magnetic signature may arise solely as a result of expansion. It was found that the magnetic structure of the cloud is modeled better by the magnetic flux tube. For the spheromak, however, self-similar radially expanding solutions are known only for gamma equal to 4/3. From work done earlier, Osherovich et al., showed that the polytropic relationship is applicable to magnetic clouds and that the corresponding polytropic index is ~ 0.5. This observational result is consistent with the self-similar model of the magnetic flux rope, but is in conflict with the self-similar spheromak model. In addition, the self-similar nonlinear evolution of rotating magnetic flux ropes was studied and presented in a paper in press by C. Farrugia, V. Osherovich, and L. Burlaga along with observational evidence of magnetic cloud rotation.

Ulysses provided an opportunity to study of a cloud observed at 4.6 AU from the Sun during the period 10-12 June 1993. J. Fainberg, V. Osherovich, R. Stone R. MacDowall, J. Phillips (LANL) and A. Balogh (Imperial College) conducted a thorough study of the wave, thermodynamic and magnetic properties of this cloud. The traversal of this cloud took three days (~ 2 AU across), and there was a sheath region on each side of the cloud extending in time for about 1 day. The boundaries of the cloud and the sheath were well delineated in the magnetic, thermodynamic, as well as wave characteristics. Within the cloud, the electron to proton temperature ratio was ~10-20, which is larger than typical for clouds at 1 AU. As predicted by the modeling work at GSFC, this increase should lead to a great decrease in Landau damping, which would permit excitation of ion-acoustic like waves. Such waves Doppler-shifted were observed by the URAP experiment in this cloud at times directly corresponding to large temperature ratios. Within the cloud the polytropic index of the electrons which formed the dominant plasma pressure term was ~ 0.35-0.37, which is less than unity and which according to the models of Osherovich et al., will lead to expansion of the cloud. In the sheath region, the polytropic index was found to be close to adiabatic, which indicates that the cloud was isolated from the solar wind by its sheath. The analysis of this cloud at 4.6 AU has added to our confidence in the applicability of this MHD solution to interplanetary magnetic clouds.

*Theoretical Analysis of Resonance Conditions in Magnetized Plasmas:* V. Osherovich and J. Fainberg have studied cylindrical oscillations of electrons in a plasma where the background magnetic field is parallel to the axis of a cylinder and the ion background is taken to have a constant positive density. Assuming self-similarity, they reduced the problem to two second order nonlinear differential equations, relating fluctuations of electron density and fluctuations of magnetic field. The system studied is shown to have two fundamental frequencies. In the linear domain, these frequencies correspond to the Z and X cold plasma wave cutoff frequencies(R = 0 and L = 0 conditions in the notation of Stix, respectively). Thus, they differ by the gyro frequency. In the nonlinear domain, these frequencies change and resonances at harmonics and at the sum and difference frequencies appear. When the plasma/gyro frequency ratio is close to an integer, these results indicate special resonance conditions which are characterized by a steepening of the fundamental resonances and an intensification of the higher-order harmonics.

# VI. PLANETARY MAGNETOSPHERES AND LOWER ATMOSPHERE

Although very detailed in-situ measurements are possible by flying spacecraft through the magnetosphere, it is a very difficult problem to map these zero dimensional point measurements into an overall three dimensional view of the Earth's magnetosphere. To assist in these mapping, increasingly realistic and sophisticated global MHD simulations of the magnetosphere have been developed. Under the auspices of the ISTP program, Deputy Project Scientist for Theory and Ground-based Experiments, S. Curtis, major advances have been made in this area during the last year. First, existing simulations which have been developed at two institutions (UCLA and UMD) have been for the first time quantitatively inter calibrated and benchmarked against a set of well defined satellite observations. The results of this study have yielded not only an excellent case study of the ability of present simulations to "images" of the global magnetosphere, but, also illuminates those areas where advances in simulation technique are required. Second, in anticipation of the increasingly quantitative demands which programs such as ISTP will place on the simulations, development has progressed on a new generation of simulations which can dynamically adjust the mesh used in the simulation to the level of resolution required to describe the processes to within the limits of the MHD approximation. S. Curtis and associates at GSFC's

Space Data Computing Division have been developing concepts and specific mission designs involving multi spaccraft with controlled separation. These next generation simulations will also be able to naturally incorporate kinetic processes on length and time scales in which the MHD approximation fails.

In addition, due to engineering and design breakthroughs resulting from a partnership with private industry, magnetospheric multiprobes in the form of four spacecraft flying in a tetrahedral array are now in the NASA MIDEX price range. Two concepts that have been developed and are presently being refined under the direction of S. Curtis are Grand Tour Cluster Lite, which will tour the boundary regions of the magnetosphere and Auroral Lites which will study the filamentry plasmas of the auroral zones. Both sets of multiprobes will separate space and time scales down to 1 km for the first time in an astrophysical plasma.

## Theoretical Studies

*Dynamic formations of the current sheet:* M. Hesse's research focused on the dynamical formation of thin current sheets in the magnetotail, and their breakup at the onset of substorm activity. Thin current sheet formation was modeled by means of both particle and MHD type numerical methods. In both cases it was found that driving electric fields as expected from southward IMF conditions lead to the formation of new thin current sheets embedded in the plasma sheet. The driving electric field, however, did not penetrate into the plasma sheet region, such that driven convection appeared to be largely absent. Further studies involved particle acceleration in self-consistent particle models of magnetotail dynamics, reconnection related acceleration mechanisms in astrophysical plasmas, formation processes of field-aligned current systems, neutral atom fluxes from charge exchange in the plasma sheet, and flux rope formation from bubble-like plasmoids. Associated code development was required for three-dimensional MHD and MHD-equilibrium codes, as well as for hybrid codes.

*Magnetospheric Modeling:* The LEP magnetospheric modeling group, D. Stern, N. Tsyganenko, M. Peredo, and T.Sotirelis continued deriving modules and tools, and assembling them into global magnetospheric models. N. Tsyganenko has derived a global model with realistic magnetopause shapes and behavior, and is extending it to include Birkeland currents. Both he and Stern have developed Birkeland modules and Stern has also published a comprehensive review of modeling, a guide to the field. T. Sotirelis modified an existing Tsyganenko model to approximately satisfy force balance with the solar wind. He and M. Peredo also successfully applied scalar potentials expanded in tangent sphere harmonics (the closest thing to dipole hammonics) to the representation of the fields of Birkelandlike currents.

## Jovian Magnetosphere

A new component of Jovian low frequency radio emission was identified in the Ulysses high Jovian latitude data. This new emission component, called bursty high latitude (BHL), differs from well-known kilometric Jovian radio emissions in that it is very bursty and elliptically Polarized. It is the only known example of elliptically Polarized Jovian radio emission at kilometric wavelengths (Jovian DAM emission has also been observed to be elliptically Polarized). The discovery of the BHL emission is significant because it may lead to a better understanding of the effects of wave coupling with the medium. It is believed that the observed circular Polarization of the well-known Jovian kilometric emissions is a consequence of this mode coupling. Ray tracing calclulations which include the mode coupling may lead to a understanding of why BHL is elliptically Polarized while the other kilometric components are circularly Polarized. The BHL emission may be generated by a mechanism proposed by K. Wong and M. Goldstein. Additional work on the jovian magnetosphere and Io are included in the section on Planetary and Cometary research.

## Ionospheres

R. Benson has recently employed ISIS data to emphasize that caution must be used when applying conclusions based on terrestrial auroral kilometric radiation observations to radiation processes in planetary magnetospheres since source-region conditions can be quite different in the extraterrestrial environment. R. Benson also used his ionospheric topside sounder experience as a member of the Radio Plasma Imager (RPI) team to help develop the concept of magnetospheric radio sounding. The RPI was one of the instruments in the Imager for Magnetopause-to-Aurora Global Exploration (PI, J. Burch/Southwest Research Institute) (IMAGE) that passed the first part (science and instrumentation) of a two part evaluation process in the current MIDEX competition.

R. Benson is heading an effort to convert data from the International Satellites for Ionospheric Studies (ISIS) into a digital format. This unique ionospheric topside sounder data set is in danger of being lost because of problems with media deterioration and availability of sufficient storage space for the tapesmost of which have never been processed to yield ionograms on 35 mm film. The ISIS satellites have produced the only global mapping of the topside ionosphere over more than an entire solar cycle. The data are also ideal for investigating stimulated plasma emissions and natural radio emissions. The goal is to convert the ISIS topside sounder data from the original analog telemetry tapes directly into digital ionograms.

## Venus Lightning/Ionospheric Waves

More than a decade after discrete narrow band low frequency (100 Hz) electric field bursts were first detected by the electric field waves detector on Pioneer Venus, there is still some argument as to the source of these signals. They could be whistler mode signals resulting from lightning within the Venusian atmosphere, or perhaps simply ionospheric induced plasma waves signatures. In the latest overview, J. Grebowsky et al. break down all the evidence, optical and electric, to show that there is strong evidence optically for the presence of lightning and that a subset of the low frequency waves detected in the ionosphere have properties that are best attributed to whistler mode radiation from atmospheric electrical discharges. However, not all the 100 Hz signals satisfy the whistler mode propagation criteria, indicating that other non-lightning mechanisms are coincidentally present. It is difficult to surmise any reasonable occurrence rates of lightning from the E field observations. Optical measurements are also sparse. More measurements are required to determine the lightning mechanism from the global distributions and occurrence rates of the flashes.

## Equatorial Electrojet and Spread-F Electrodynamics

The LEP carried out comprehensive rocket/radar plasma physics experiments in Brazil as part of the Guará campaign from September-October 1995. These experiments included instrumentation to measure the driving DC electric fields, current density, plasma density, and plasma waves (including wavenumber and phase velocity) in the unstable daytime equatorial electrojet. The data provided the first complete picture of the electrojet electrodynamics including the two-stream and gradient drift waves which are driven by this unstable system. In addition, instrumentation was prepared for another rocker payload developed by J. LaBelle at Dartmouth College, which, for the first time, investigated the detailed instability physics of the very high altitude (900 km) "plume" structures associated with equatorial plasma depletions.

## Mesospheric Atmospheric Dynamics

The first phase of the program Mesosphere and Lower Thermosphere Equatorial Dynamics (MALTED) was concerned with the interaction of large and moderate scale waves with small scale instabilities and turbulence. The tropical dynamical structure of the mesosphere is thought to be quite different from that observed at other latitudes. Twenty meteorological rocket flights were coordinated with 4 large Nike-Orion flights to provide a ten day sequence in the meteorology of the region. Preliminary results have already been presented at several national and international meetings, and will shortly be available in published form. These results demonstrate the apparent presence of turbulence in narrow layers between 85-90 km altitude, with features similar to but weaker than those seen in the POLAR summer mesosphere. The electrojet was also sounded with these same Nike-Orion payloads and is yielding information about both two stream and gradient drift instabilities in the daytime and the less-well-known nighttime electrojet.

*Highly relativistic electron precipitation (HREP) during HREP events:* These events usually increase in frequency and intensity during the downward side of the solar cycle. From data acquired from rockets launched at Poker Flat, Alaska, during an HREP event in May, 1990, R. Goldberg has estimated that depletions in mesospheric ozone could exceed 20-30%. Such depletions can reduce the heating of regions near maximum energy deposition by as much as 4 K/day, which is large enough to affect local winds and other dynamics. Furthermore, the impact of these relativistic electrons might cause Joule heating of the lower mesosphere by 1-2 K/day, depending on the magnitude of the local electric field. A new study with Upper Atmosphere Research Satellite (UARS) is just underway to seek out these effects and determine their magnitude. F. Herrero in collaboration with J. Meriwether (Clemson U.) and F. Biondi (U. of Pittsburgh) discovered a new heat source in the equatorial thermosphere such that the thermosphere east of the Andean mountain range is consistently hotter than the thermosphere to the west, and the zonal neutral winds are consistently slower in the east. The observations were performed using the Fabry-Perot interferometer in Arequipa, Perú. The heat source is preliminary understood in terms of tropospheric waves generated at the Andean barrier with vertical wavelengths in excess of about 40 km.

Fourier analysis of the thermospheric density variations measured by the San Marco satellite, uncovered reflection of tidal modes from the 300 km altitude region. Possible causes involving ion-drag and/or viscous dissipation under investigation. This activity is being carried out by F. Herrero in collaboration with the University of Rome investigators of the Progetto San Marco. G. Laneve is currently a visiting scientist under the NRC program. A new LEP project has been funded to study vertical velocity distribution in the low-latitude thermosphere and corresponding electrodynamic effects. F. Herrero is project leader for this program.

# VII. SPACE FLIGHT PROGRAMS

This section provides a brief description of currently operational satellites, space probes, and rocket programs in which the LEP contributed operations, hardware, data analysis and scientific research. Other sections provide a more detailed discussion of some of the scientific results obtained from these missions.

M. Acuña is the Project Scientist for the entire International Solar Teresstrial Program (ISTP) which includes the following spacecraft: Wind, Geotail, POLAR, Cluster, and SOHO. A brief discription of these and other spacecraft follows:

## Voyager

Data are still being received from Voyagers 1 and 2 experiments. These data include magnetic field, radio wave, electron and ion plasma observations in the outer planet magnetospheres and the Io plasma torus. Comprehensive infrared spectra of the outer planets acquired with the Voyager Infrared Interferometer Spectrometer (IRIS) instrument provide information on gaseous abundances, temperature profiles, winds, and net energy balances in the atmospheres of the outer planets. In addition, the interplanetary data from the magnetometer and plasma instruments are being intensively studied.

## IMP-8

The multi-decade old IMP-8 spacecraft continues to provide valuable information on solar energy input into the terrestrial magnetosphere and measurements of the Earth's magnetotail dynamics with coverage extending over a complete solar cycle. R. Lepping is the magnetometer PI.

## Ulysses

Observations from the Ulysses spacecraft, the first mission to explore heliospheric space above the poles of the Sun, are providing new information on the structure and content of the interplanetary medium. R. MacDowall is the PI for the Ulysses Unified Radio and Plasma Wave investigation (URAP). The Ulysses spacecraft reached 80 S. heliographic latitude in September 1994 and subsequently made a rapid transit of the heliographic equator, reaching the highest northern heliographic latitudes in July 1995. The first URAP results from high latitudes have been published by R. Stone and colleagues. The URAP observes radio emissions from the Sun, interplanetary medium and planets. A wide variety of in-situ plasma waves, which result from unstable particle distributions in the solar wind are measured. Since the Ulysses went from the high southern to high northern latitudes in only a few months, it has provided an unprecedented opportunity to study the latitude gradients of the various plasma wave modes populating interplanetary space. LEP scientists play a leading role in the study of solar radio phenomena in the frequency range of 30 kHz to 2 MHz. Instruments are designed for a comprehensive analysis of radio waves in the interplanetary medium originating from solar electrons traveling along the interplanetary magnetic field and from large interplanetary shocks.

## Geotail (ISAS Japan)

The Geotail spacecraft, launched as part of the ISTP was launched successfully in July 1992. Its continuing objective is to explore and understand the Earth's geomagnetic tail. Two LEP investigators on this mission are M. Acuña and D. Fairfield whose research is basically the study of magnetic fields. D. Fairfield is also Deputy Project Scientist for Geotail.

## Wind

The Wind spacecraft, is part of the Global Geoscience Mission (GGS) of the ISTP program. Its mission objective is to measure the magnetosphere energy deposition into the Earth's atmosphere. The LEP has a large number of PI's and Co-I's on this spacecraft. K. Olgilvie is Deputy Project Scientist for this mission.

## Sounding Rocket Program

The LEP played a major role in the Guará Rocket Campaign, a NASA/Brazilian joint scientific program conducted at Alcântara, Brazil, from August-October, 1995. This site was selected because of its proximity to the magnetic and geographic equators. PI's from the LEP (R. Pfaff, R. Goldberg), Dartmouth (J. LaBelle) and Clemson (M. Larsen) were responsible for the launch of 33 rocket payloads designed to investigate several equatorial phenomena including the electrojet, spread F, and mesospheric-atmospheric dynamics. The first phase of the program Mesosphere and Lower Thermosphere Equatorial Dynamics (MALTED) was concerned with the interaction of large and moderate scale waves with small scale instabilities and turbulence. R. Pfaff of the LEP is the Project Scientist for the sounding rocket program.

The following missions are expected to be launched in the next year:

## POLAR

POLAR is a part of the ISTP Program. This spacecraft will be placed in a 90 inclination, elliptical orbit with a 9 RE apogee and a 8 RE perigee orbit. It is expected to be launched in early 1996. R. Hoffman is the Deputy Project Scientist. The Laboratory has a number of Co-I's on this spacecraft.

## Cluster

The Cluster mission consists of four identical spacecraft that are to be launched into a POLAR orbit (90 inclination) with 4 RE perigee and 22 RE apogee. The mission, which is also part of the ISTP, is designed to separate spatial from temporal structures in the Earth's magnetosphere and in the solar wind. At a scale larger than 1000 km, the four Cluster spacecraft are equipped with fuel sufficient to change the spacecraft separation from several hundred km to several RE and back during the two year nominal lifetime of the mission. The spacecraft will be launched on an Ariane 5 in the Spring of 1996. Members of the laboratory are Co-I's on the magnetometer, electron plasma, and electric field experiments, and M. Goldstein is the Deputy Project Scientist.

## NEAR

M. Acuña continues as the Near Earth Asteroid Rendezvous (NEAR) magnetometer lead investigator

The NEAR mission has a February 1996 launch date. b M. Acuña is the Team Leader for the Magnetometer Facility instrument and J. Trombka is the Team Leader for the X-Ray/Gamma-Ray Spectrometer (XGRS) Facility Instrument. The major activities presently underway involve the calibration and verification of operation of the flight instruments. Present indications are that both flight system are operating properly and meeting specifications.

## Mars '96 Mission (Russian)

The X-ray/Gamma ray spectrometer group activities are as Co-I's on the Russian Mars '96 mission and the Joint NASA/FBI Technology Sharing project.

## Clark

Flight x-ray spectrometers systems utilizing room temperature detectors for the observation of solar transient events has been constructed and will be launched in 1996 aboard the Clark mission. The results of these Earth orbital flights will also be useful for possible application to future (XGRS) systems to be flown on Discovery planetary exploration missions. The PI for this X-ray Spectrometer is R. Starr. M. Acuña and J. Trombka are Co-I's. This project is being carried out in cooperation with investigators in the Laboratory for Astronomy and Solar Physics (Code 680).

## FAST

The objective of the Fast Auroral Snapshot Explorer, (FAST) is to examine the physical processes that produce the Earth's aurora at the highest temporal resolution yet obtained. Instruments for FAST will study the type of particles that stream down along magnetic field lines that causes the spectacular aurora displays, and the electric and magnetic fields in the POLAR regions of the Earth. The FAST instruments are provided by the PI, C. Carlson at the University of California, Berkeley, with Co-I's from numerous U.S. and European institutions. R. Pfaff of the LEP is the NASA Project Scientist.

## SWAS

The Submillimeter Wave Satellite, (SWAS) is a pioneering astrophysics mission in which a submillimeter-wave radio observatory has been built to study the interstellar chemistry and the processes of star formation in interstellar clouds. It will perform its mission by obtaining high resolution heterodyne spectra from transitions of $H_2O$, $^{13}CO$, CI, and $O_2$. Study of the emission from these key transitions provide insight to the chemical nature, cooling, dynamics, and physical conditions of star forming regions. The Prime Investigator for SWAS is G. Melnick from the Smithsonian Astrophysical Observatory with Co-I's from the U.S. and Germany providing the SWAS instrument. G. Chin is the NASA Project Scientist for SWAS.

FAST and SWAS are the second and third members of the original Small Explorer (SMEX) set of missions. The first SMEX satellite, Solar, Anomalous, and Magnetospheric Explorer (SAMPEX) was launched by a Scout rocket on July 3, 1992, and is still operational on an extended mission mode. The aim of the SMEX program is to provide frequent and inexpensive access to space for astrophysics and space physics satellites. Both the FAST and SWAS spacecraft were designed and constructed in-house at the Goddard Space Flight Center by the Engineering Directorate. The FAST and SWAS satellites have completed all of their integration and environmental testing successfully. FAST and SWAS are now slated to be launched in the late Spring of 1996 pending a successful qualification flight of the Pegasus XL rocket.

# VIII. SPACE FLIGHT INSTRUMENTATION DEVELOPMENT

## Cassini Composite Infrared Spectrometer

A major current effort in the LEP is the development of the CIRS for the Cassini orbiter. V. Kunde is PI, and D. Jennings, J. Brasunas, L Herath, M. Flasar, P. Romani, are Co-I's. The CIRS science team includes Co-I's from other U.S. institutions, as well as Co-I's from England, France, and Germany. CIRS consists of a pair of Fourier transform spectrometers which cover the 101400 $cm^{-1}$ range with a spectral resolution up to 0.5 $cm^{-1}$. The 10-600 $cm^{-1}$ range is covered by a POLARizing interferometer with two thermopile detectors and a 4.3 mrad field of view. The 600-1400 $cm^{-1}$ range is covered by a conventional Michelson interferometer with two 1 x 10 HgCdTe arrays, each pixel having a 0.3 mrad field of view which allows limb sounding to be carried out. The Engineering Model is presently in System Integration and Test. The experiment addresses a wide variety of scientific objectives for atmospheres, satellites, and rings, including composition and thermal state. CIRS is versatile and sensitive, and is expected to make many new discoveries as well as systematically extending knowledge of the Saturn system.

## Cassini Plasma Spectrometer

The LEP is also collaborating with the Southwest Research Institute and Los Alamos National Laboratory in the construction and testing of the plasma spectrometer Cassini Plasma Spectrometer (CAPS) experiment for the Cassini orbiter. This is a graded field spectrometer of high resolution and geometric factor, which will be used to measure the composition and velocity distribution functions of ions in the magnetosphere of Saturn. E. Sittler has been directing the development of several subsystems for CAPS. They include a Spectrum Analyzer Module (SAM) which receives time-of-flight (TOF) data from the Ion Mass Spectrometer (IMS), builds TOF spectra, and processes the TOF spectra to compute ion counts for a preselected set of ions. In addition, the HVU-1, a $\perp$16 kV high voltage power supply provides the high voltages needed by the IS to operate properly. This power supply is a novel design to provide a floating 1200 volt regulated supply. Flight software for SAM and a subsystem of the DPU is also under development.

## LEISA Development

D. Jennings, D. Reuter, and G. McCabe are developing an infrared spectral imager based on the Linear Etalon Imaging Spectral Array (LEISA) concept as one of the major scientific instruments to be included in the payload of the TRW Small Satellite Technology Program (SSTP) satellite, LEWIS, to be launched in the summer of 1996. This development is a collaboration with Codes 718 and 752 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 optical system. 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 the orbital motion of the spacecraft, as in the SSTP application, 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.

For the Earth-viewing LEISA application the imager will operate in the 1 to 2.5 mm spectral region with a resolving power (l/Dl) of about 250. Under day-light conditions the spectral images obtained will provide maps of spectrally dependent surface and atmospheric reflectances and atmospheric transmittances. These may be analyzed to yield: 1) surface information including soil and vegetation types, extent of vegetation, snow and ice fields, zones of fire damage and pollution etc. and 2) atmospheric information including areal cloud fractions, cloud heights, cloud particle sizes, cloud particle phases, aerosol properties, large fire smoke extents, volcanic dust and aerosol production, etc.

## X-ray and Gamma-ray Planetary Instrument Design and Development Program

The X-Ray/Gamma Ray (XGRS) Team which was established as part of the Planetary Instrument Definition and Development Program (PIDDP) has as its goal the development of x-ray and gamma-ray remote sensing and in-situ technologies for future planetary exploration missions. This team is under the direction of J. Trombka and represents groups having active programs with NASA, the Department of Energy (DOE), the Department of Defense (DOD), and a number of Universities and private companies. Studies undertaken by this groups include: x-ray and gamma- ray detectors; cryogenic cooling systems; x-ray and particle excitation sources; mission geochemical research requirements; detector space radiation damage problems; field simulation studies; theoretical calculations and x-ray and nuclear cross-sections requirements; and preliminary design of flight systems. Results obtained in this program were used to develop the designs specifications for the x-ray/gamma-ray remote sensing systems for the NEAR mission. The results of the XGRS facility program studies were also made available to a number of investigators to assist in their development of proposals for the Discovery and Rosetta programs. Studies of the radiation damage effects carried out with partial funding from the XGRS facility program funding has contributed significantly to our understanding of the data obtained during the cruise phase of the Mars Observer mission. These studies also contributed to our capability of determining the timing protocol for annealing Ge detectors in space and thus influenced the design of the Mars Observer Gamma-Ray Spectrometer system. These studies have also been used to help in the design and development of the Mars '96 Ge Precision Gamma-Ray Spectrometer (PGS). Furthermore, the calibration and test protocols have been developed for the PGS using results obtained in the XGRS Program. Facilities being developed under this program will be used to calibrate the NEAR and Mars '96 remote sensing X-ray and Gamma-ray Spectrometers.

Mars Observer (MO) data is also being used to correlate the degradation in resolution produced by space cosmic radiation with ground based ~1GeV proton beam radiation damage studies of high purity germanium detectors. These data are essential for verifying theoretical models used to predict the performance and induced activities in gamma-ray detectors flown on long duration planetary exploration missions. This work is also very important in the design considerations of future mission detectors.

## Sounding Rocket Program

The position sensitive detector for the Temperature And Wind Rocket Spectrometer (TAWRS) and the IMS instrument is now operational, and calibration of the instruments has begun. This work supports the Ionospheric Descending Plasma Layers Rocket Experiment in collaboration with SAIC, Inc. Launch is scheduled for Spring 1996. A new project has been funded for Sudden Atom Layers study in collaboration with Cornell University. Construction of a negative/positive ion mass spectrometer pair has begun. Launch is scheduled from Puerto Rico, late in 1997 to early in 1998. F. Herrero of the LEP is the project scientist for these Rocket programs

### Electric Field Instruments

The electric field experimental group, led by R. Pfaff, designs and builds electric field double probes for flights on sounding rockets in the earth's ionosphere. In the past year, these instruments were flown on nine payloads and included electronics to measure both the DC and AC vector electric field components. For example, experiments launched on sounding rockets off the coast of Brazil last year included double probe instruments designed, built, and tested at Goddard that returned the first measurements of the DC Polarization (vertical) electric field that drives the equatorial electrojet. On-board processing electronics have also been developed and flown to compute cross-spectral information real-time and on-board FFT processing was developed that extended the measured frequency regime to 8 MHz.

### Spherics VLF Receiver Stations

VLF receivers have been designed by W. Farrell, J. Houser, and M. Desch to detect, timetag, and return spheric emissions generated by lightning events. Timeofarrival information can then be used to determine the source location of the lighting event, and thus identify distant weather features via their electrical activity. The receivers are custombuilt digital radios that can incorporate timing information from the global positioning satellite (GPS) system. It is planned that the receiver system will be in formal operation in the spring of 1996. The Mars Observer (MO) gamma-ray spectrometer data, obtained during the cruise phase of the mission, is being analyzed for solar and galactic cosmic ray induced activity within the germanium detector.

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