Rice University
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The following report covers the Department activities from October 1996 through October 1997. Updated research information, as well as course listings and our graduate brochure can be accessed on the Web at http://spacsun.rice.edu.

1. INTRODUCTION

In 1963 Rice University established the first Department of Space Science in the United States to support our country's manned and unmanned exploration of space. Today, as the Department of Space Physics & Astronomy, it strives for excellence in graduate education and research across a broad spectrum of topics in physics & astronomy ranging from the Earth's climate and magnetosphere to observational and theoretical astrophysics.

2. PERSONNEL

2.1 Academic and Research Staff

Seventeen personnel constitute the primary resident academic and research staff. For the 1996/97 academic year, Professors were P. A. Cloutier, R. J. Dufour, A. A. Few, Jr., J. W. Freeman, R. C. Haymes, E. P. Liang, F. C. Michel, C. R. O'Dell, P. H. Reiff (*chair*), J. C. Weisheit, and R. A. Wolf. Assistant Professors were A. A. Chan and P. M. Hartigan. Distinguished Faculty Fellows were T. W. Hill and K. A. Smith. T. S. Ledley was a Senior Faculty Fellow and F. R. Toffoletto is a Faculty Fellow.

Affiliated Faculty (from other University departments) were Professors F. B. Dunning (physics), D. Heymann (geology), and G. K. Walters (physics). Adjunct faculty were Adjunct Professors D. Black (LPI), W. C. Horton, Jr. (U. Texas, Austin), J. D. Winningham (SWRI), and D. T. Young (SWRI); and Adjunct Associate Professors T. F. Stepinski (LPI) and J. H. Newman (NASA-JSC). W. E. Gordon was a Distinguished Professor Emeritus. J. W. Chamberlain, A. J. Dessler, and R. F. Stebbings were Professors Emeritus.

R. W. Spiro was a Senior Research Scientist; C. Law, B. Lindsey, C. Straub, and I. A. Smith were Research Scientists. P. Krisko and M. Böttcher were Postdoctoral Research Associates, with Dr. Böttcher from the Max Planck Institute in Bonn just joining the Department this year to work in the high energy research group headed by E. Liang.

2.2 Students

At the beginning of the 1997/98 academic year, 27 students were enrolled in full-time graduate study. Of these, five joined the department for graduate study in August 1997. In addition, six junior and one senior undergraduate students were enrolled in our ''Space Physics & Astronomy Option'' study program towards obtaining a B.A. degree in Physics.

During our May 1997 Commencement three Ph.D. and three M.S. degrees were awarded. The Ph.D. recipients and dissertation titles were Chuan Luo for ''Radial-Zoned Thermal Accretion Disk Model Around Black Holes,'' Michael J. Moss for ''Gamma Ray Observations of Black Hole Candidates Nova Ophiuchi 1993 and Nova Velorum 1993,'' and Shan Xue for ''Numerical Modeling of the Magnetospheric Cusp: Ion Injection and Number Density Calculations.'' The M.S. recipients were Karsten E. Braaten for ''A Model of Bounce-Averaged Relativistic Protons with Emphasis on the March '91 Magnetospheric Compression,'' Michikazu Hojo for ''Coupling of Two Computational Models of the Earth's Magnetosphere,'' and Karen M. Klamezynski for ''Bounce-Resonant Ion Interaction with Hydromagnetic Waves''

3. FACILITIES

The department is located on the second and third floors of Herman Brown Hall, on the campus of Rice University. Most faculty, staff, and student offices occupy the third floor of the building, which also includes our computational and data analysis facilities. Several standalone Sun sparcstations (including a server, ''spacsun''), a Vax cluster, X-terminals, and Macintosh computers are networked together with other campus-wide systems and the internet. In collaboration with the Computer and Information Technology Institute at Rice and with the help of a generous grant from Digital Equipment Corporation we have recently acquired a 4-processor Alphaserver 4100/400/1gb which has greatly enhanced our capabilities for processor intensive computations. A new multimedia facility in our conference room enables speakers to present movies, slides, Web pages, and do video conferencing during talks. A thorough collection of scientific texts and research journals is maintained in the Department reading room and in Rice's Fondren Library.

Undergraduate and graduate students have the opportunity to use a variety of telescopes in education and research, ranging from small instruments located on the roof of Fondren Library, to computerized 14- and 36-inch telescopes at the George Observatory, located in Brazos Bend State Park, 35 miles southwest of the campus. In addition, students use facilities at the Lunar and Planetary Institute in nearby Clear Lake City, as well as the laboratories for space instrumentation development at the Southwest Research Institute in San Antonio, Texas.

4. RESEARCH

4.1 Space Science

4.1.1 Earth and Atmosphere

Professor A. Few's research interest is in atmospheric physics with a special emphasis on atmospheric electricity and Earth system science. In the experimental area he has data from a suite of instruments that operated at the South Pole for a three-year period; these measurements monitor the total global thunderstorm activity, a parameter strongly influenced by global warming. Few is also active at the national level in global change or Earth system science education. He is an author-participant in the Global Change Instruction Program (NSF and NCAR), and in the Earth System Science Education Program (NASA and USRA). These programs share the goal of developing undergraduate courses and teaching materials in the interdisciplinary areas of global change or Earth system science.

The emphasis of Senior Faculty Fellow Tamara Ledley's recent work has been to understand the role of the polar regions in shaping global climate on a wide range of time scales by examining the possible mechanisms of climate change. The polar regions of the Earth can have a large impact on global climate despite the fact that they occupy a small percentage of its total area. The main feature of the polar regions that make them different from others is the presence of snow and ice. The impact of snow and sea ice on the climate of the polar regions and globally has been examined with a coupled energy balance climate - thermodynamic sea ice model that includes a hydrologic cycle. The modeling studies show that snow and sea ice have a large impact on the energy exchange between the atmosphere and ocean, and that changes in that interaction affect climate.

Ledley's work has led to studies on the shorter time scales, which involve examining the effect of various atmospheric and oceanic processes on the sea ice regime of the Ross Sea and the subsequent impact on the climate system, and the influence of the El Niño on the polar oceans. On the longer time scales she is examining the mechanisms that produce the large scale glacial/interglacial cycles recorded in the geologic record, and has recently incorporated a dynamic ice sheet model into the coupled system in order to study the interactions between the different components of the climate system on the ice age time scales.

4.1.2 Earth's Magnetosphere and Space Weather

Over a period of many years, Professor R. A. Wolf and collaborators have developed a computer code called the Rice Convection Model (RCM), which has proved to be an effective research tool for studying the dynamics of the Earth's inner magnetosphere. The code describes the complex particle populations of the Earth's inner magnetosphere in terms of approximately thirty fluids. It self-consistently computes magnetospheric densities, pressures, and electric fields, as well as ionospheric currents and electric fields and the currents that flow along field lines to connect the two regions.

To investigate how the inner and outer magnetosphere affect each other, Wolf's group is working to couple the RCM to 3D magnetohydrodynamic codes that provide the best available theoretical representation of the outer magnetosphere. One such collaboration, with Joachim Birn of Los Alamos National Lab and Michael Hesse of Goddard Space Flight Center, aims at understanding the magnetospheric substorm, which is the fundamental dynamic process of the Earth's magnetosphere. The new substorm model incorporates the RCM, the Los-Alamos/Goddard MHD model of tail dynamics, and an equilibrium code that has been developed through a Los-Alamos/Goddard/Rice collaboration. Preliminary results with a model that couples the RCM with the equilibrium model suggest that a region conducive to the tearing instability is likely to form in the inner region of the magnetosphere after the system has been driven by the solar wind for several hours (Toffoletto *et al.*, 1996).

Wolf is also collaborating with John Lyon of Dartmouth College and Willard White and colleagues at Mission Research Corporation to incorporate the RCM inner magnetosphere within MHD treatments of the outer magnetosphere and its interaction with the solar wind, thus providing a self-consistent computational representation of the entire system.

In the past, the RCM has used an input data-based magnetic field rather than calculating that field self-consistently. Recently, however, Frank Toffoletto has developed a numerical equilibrium solver that recomputes the magnetic field, time step by time step, keeping it consistent with the RCM. This has produced the first-ever numerical solutions of a complete and reasonable set of physical equations for the inner magnetosphere.

A group led by Professors Freeman, Wolf, and Senior Research Scientist R. W. Spiro developed a streamlined, data-driven version of the Rice Convection Model designed to run from real-time space and ground data. This real-time model, called the Magnetospheric Specification Model, can thus provide an up-to-date picture of the state of the inner magnetosphere. It now runs routinely at the U. S. Air Force's space forecast center, and it is also proving to be a useful tool for the scientific analysis of space data. It was recently used to demonstrate that bursts of enhanced magnetospheric convection are responsible for the injection of new ring current particles in a magnetic storm, and that the magnetic reconfigurations involved in magnetospheric substorms play a relatively minor role.

During the past year, Freeman, with Rice University Senior Paul O'Brien, developed a neural network to predict the amount of energetic electrons in the radiation belt. This component of the radiation belt seems to be responsible for ''deep dielectric'' discharge damage to spacecraft. Freeman and O'Brien determined that the primary spectral feature was a power-law, and were able to model this behavior successfully with a neural network for a major geomagnetic storm. In the process, they discovered that some variations in the electron flux at the geostationary orbit could be attributed to local-time variations. The observed local-time distributions imply that electrons enter the magnetosphere from the geomagnetic tail. A paper has been submitted to the Journal of Geophysical Research discussing the spectra of the energetic electrons, the local-time dependence, the neural networks, and the source of the electrons. Papers were also presented at the Lund Workshop on Applications of Artificial Intelligence to Solar Terrestrial Physics and the 27^{th} IAGA meeting in Uppsala Sweden. This work has been supported by Sterling Software.

Freeman and graduate student Kirt Costello developed neural networks that can be used with the Magnetospheric Specification and Forecast Model (MSFM). These networks will run the MSFM entirely from solar wind data, thereby increasing the forecast period for the model by the solar wind transit time from the L1 point up to an hour. Costello built a neural network that specifies the K_p index with an accuracy comparable to that generated from real-time ground-based data. This neural network was tested successfully with the MSFM and the results were documented in Costello's Ph.D. Thesis, ''Moving the MSFM into a Real-Time Forecast Model Using Solar Wind Driven Forecast Modules.''

Seth Orloff, a Ph.D. candidate student with Freeman, has developed a Solar Energetic Particle Tracer model (SEPTR) for use in conjunction with an Integrated Space Model being developed by Mission Research Corp. The SEPTR computes cut-off energies and spectra for solar protons and electrons from solar flares. In an interesting application this model has demonstrated the existence of a class of trapped electron trajectories that originate at the equator but migrate to the cusp region on the day side of the magnetosphere. These are trapped particles that can mirror in the cusp as well as the equator.

Assistant Professor Anthony Chan is the principal investigator on a project to model the so-called ''killer electrons,'' relativistic electrons which can cause significant damage to scientific and communications spacecraft. The project is part of the National Space Weather Program. Chan and graduate student Hee-Jeong Kim are studying the physical mechanisms for the large flux variations which are observed during magnetic storms. Two main mechanisms are considered: a fully-adiabatic effect and a trapping boundary effect. The fully-adiabatic effect may occur when the magnetic field configuration changes slowly compared to an electron drift period and all three adiabatic invariants of the electron motion are conserved. The trapping boundary effect is a particle loss mechanism which occurs when an initially trapped drift orbit becomes untrapped.

Chan is continuing a theoretical study of the effects of anisotropic plasma pressure and kinetic effects on MHD equilibrium and stability in the Earth's magnetosphere. Anisotropy can significantly lower both the wave eigenfrequency and the instability threshold for ballooning modes (pressure-gradient-driven MHD modes). Resonant wave-particle instabilities are also considered. These studies use linear gyro-kinetic theory (a self-consistent kinetic theory of low-frequency waves and instabilities in plasmas). Theoretical results are compared with spacecraft measurements of wave and particle properties.

Elena Belova, Richard Denton and Mary Hudson at Dartmouth College, with help from Chan, are developing a hybrid MHD-gyrokinetic computer code to calculate the self-consistent nonlinear evolution of magnetospheric hydromagnetic waves and the induced particle transport. Liu Chen at the University of California at Irvine, in collaboration with Chan, is developing general equations for the transport of mass, momentum and energy across the dayside magnetopause due to low frequency waves. Chan and collaborators C. Z. Cheng and Jay Johnson at Princeton University continue studies on kinetic effects on MHD modes in the Earth's magnetosphere.

Faculty Fellows Tom Hill and Frank Toffoletto continue their work on the development of an open magnetosphere model. At the 1996 and 1997 Geospace Environment Modeling Snowmass workshops they participated in the joint session on model comparisons with Synoptic Weather Maps. They used the open magnetosphere model to derive polar cap convection patterns and open/closed boundary locations. A paper discussing the results of this has been submitted (Hill and Toffoletto, J. Geophys. Res., 1997) Graduate student Jinwen Song has prepared a new version of the open magnetosphere model for distribution on the internet (Song, MS Thesis, Rice University, 1997).

Hill, Toffoletto and graduate student Andrew Urquhart are undertaking a study to compare auroral images taken by the polar spacecraft with the theoretical predictions of their open magnetosphere model. This project is supported by NASA as part of their Global Geospace Science Guest Investigator Program.

Hill and Toffoletto, together with G. Erickson and M. Heinemann of the Air Force Research Lab, have begun a concept study supported by the NSF/GEM program to assemble the first comprehensive global model of the magnetosphere that will be used as a community-wide research tool in magnetospheric physics. This global model is analogous to the global climate models that are found in the atmospheric community.

P. Kloucek of the Computational and Applied Mathematics Department at Rice University and Toffoletto are collaborating in a project to adapt an unstructured finite code to solve magnetospheric problems, the first results of which are to be presented at the American Geophysical Union Fall meeting in December, 1997.

Professor Patricia Reiff's research group is active in studies of the Earth's magnetosphere and ''Space Weather.'' As a Co-I on the Polar spacecraft, launched in February 1996, she and graduate students Andrew Urquhart and Vance Henize are investigating the detailed response of the magnetosphere to changes in the Interplanetary Magnetic Field, particularly in times where the IMF is nearly parallel to the Earth's field near the boundary. Reiff is also a Co-Investigator for the IMAGE mission, which will fly in January 1, 2000 as NASA's first MIDEX. Using new techniques such as neutral atom imaging and radio sounding, IMAGE will for the first time be a remote sensing tool for the entire magnetosphere. Her students will be working with the theoretical group as well as with the hardware and spacecraft design. Reiff is also a Co-Investigator on the ESA/Cluster spacecraft, also scheduled for launch in 2000.

In addition, Reiff is Principal Investigator of a NASA outreach program The Public Connection which creates computerized exhibits and planetarium shows for museums and schools.

4.1.3 Solar System Plasmas

Hill and Wolf continued their study of rotationally driven magnetospheric convection at Jupiter. This work involves numerical simulation of the outward transport of plasma from the centrifugally unstable Io plasma torus. They are also developing a simulation model of inner magnetospheric perturbations induced by the July 1994 impacts of the Comet Shoemaker-Levy-9 fragments. The aim of this work is to account for the low-latitude ultraviolet aurora observed by

HST after the K fragment impact, and the frequency-dependent enhancements of decimetric synchrotron emissions observed after the impacts.

Professor Paul Cloutier and his students continued their analysis of 14 years of Pioneer Venus Orbiter data. Accomplishments to date include extensive study of the dayside ionosphere of Venus covering a variety of topics, such as (1) wave-particle mechanisms at the ionopause, including missing pressure in the Venus ionosphere, and a model of superthermal ion behavior; (2) structure and dynamics of the Venus ionopause and ionosphere, including Venus ionopause formation, and magnetic signatures and structure in the dayside Venus ionosphere; and (3) flows and fields in the Venus ionosphere, including refinement of the flow/field models of the ionosphere with comparative applications for other solar system bodies. In addition, progress continues to be made in understanding the dynamics of the nightside ionosphere of Venus, such as the structure, instabilities, and electric field noise in Venus's ion troughs.

Recent work includes the discovery of a magnetic field rotation at the dayside Venus ionopause which correlates with the boundary between post-shock solar wind flow and Venus thermal ions. From these observations a new configuration for the dayside magnetic field draping has been derived. In addition, a new current system to account for this changing field orientation is being explored. These new features of the dayside have instigated a reexamination of the mechanics driving the solar wind interaction at Venus. While the data currently available is specific to Venus, there is a great opportunity for comparative atmospheric studies.

Assuming Mars also represents a non-magnetic obstacle to the flow, as past experimental observations indicate, the field diagnostics established at Venus make it possible to probe the structure of the Martian ionosphere using magnetometer data in the absence of ion mass spectrometer data. This discovery has led to diagnostic tools for interpretation of the Mars Global Surveyor magnetometer experiment data, for which Cloutier serves as a Co-Investigator. Early results from the MGS project indicate a crustal remnant field of surprising variation across the surface of the planet. Already data have shown what appear to be a range of solar wind interactions taking place including one similar to Venus. The next year will be very busy analyzing the vast amounts of data from MGS.

Currently Cloutier and graduate student Dana Crider are working on mapping the electric potential across the dayside of Venus. Cloutier and graduate student Pete Walker have recently finished a current model for the nightside Venus ionosphere and are working on matching it with the dayside ionosphere using the thesis results of Research Scientist Colin Law. Law is now working on Mars Global Surveyor data while extending his Venus research.

4.2 Galactic Astronomy

4.2.1 Young Stellar Objects

Assistant Professor Patrick Hartigan continued his research into the formation of shock waves within stellar jets. As part of a collaboration led by B. Reipurth (ESO), Hartigan completed an extensive study of the shock waves within the stellar jet HH 111 that was published this year in the AJ. Because neutral hydrogen can become collisionally excited at the shock front, one can use it to mark the location of the shocks. By comparing high resolution HST images with ground-based spectroscopy, Hartigan and collaborators found clear evidence for multiple bow shocks, and Mach disk/bow shock structures in several locations along the flow. There is evidence that the medium which surrounds the jet has a much lower density than the jet itself, implying that the surrounding medium plays a negligible role in the jet dynamics once the jet has emerged from the environs of the accretion disk.

Hartigan is PI on two HST projects that involve young stellar objects and jets, and a Co-I on a third such project, each of which should obtain data within the next year. The first project, in collaboration with J. Morse and J. Bally at Colorado, is a narrow band imaging study of HH objects in the Cepheus A outflow. The goal is to examine how the spatial distributions of Hα emission, which outlines the location of shocks, and [S II] emission, which shows where the gas cools, vary across the region. Cepheus A is probably the best example of a simple, extended bubble driven by a high velocity flow, and we hope to understand how energy and momentum propagate in such flows, and the degree to which instabilities affect the observed structures.

Hartigan is PI on a project with S. Kenyon (CfA) to examine spectra of close binary T Tauri stars to determine how material accretes onto very young binary systems when they are still surrounded by their nascent disks of gas and dust. Hartigan is also a Co-I on a team led by B. Reipurth to examine proper motions of HH objects with HST. These new images will be combined with existing HST images to create a 'movie' of the jet as it emerges from its protostellar disk.

As part of his senior thesis, undergraduate Jason Tumlinson analyzed ultraviolet FOS spectra of the bow shock HH 47A, and concluded that multiple shocks were needed to explain the observations. Hartigan continued this analysis over the summer, and has successfully explained the relative fluxes of the many ultraviolet Fe II lines visible in the spectra by a combination of resonance absorption and optically thin spontaneous decay. This work is currently being prepared for publication.

Professor C. R. O'Dell was on sabbatical leave throughout this report period, having been awarded a Humboldt Prize from the Alexander von Humboldt Foundation of Germany, and was resident at the Max Planck Institute for Astronomy in Heidelberg. There he helped to organize a conference at the Ringberg Castle on the Orion Star Formation Region.

O'Dell continued to analyze the circumstellar disks surrounding stars in the Trazpezium Cluster. This work included observations of one such object with the new NICMOS camera of the HST (Chen *et al.* 1997), showing that the inner disks are molecular, and analysis of HST WFPC2 images which shows that the ''proplyds'' are ionization bounded on the sides facing the photoionizing star which produces M42 (θ^1C Ori) and that their atmospheres more closely resemble the exponential density decrease which is a hallmark of an equilibrium situation than the r^{-3} distribution which is expected from an ionization front suffering a high rate of photoablation (O'Dell, 1998). This may explain why the proplyds have been able to survive even though close to θ^1C Ori. O'Dell also co-authored a review paper on star formation (O'Dell & Beckwith 1997).

4.2.2 H II Regions

O'Dell and Hartigan concluded their HST program of imaging of the Herbig Haro objects found near M42 (O'Dell *et al.*, 1997). They found that there are two HH systems, one arising from the OMC-1 embedded source near IRc-2 and another formed of shocks generated in the foreground lid of neutral material which seals the front side of M42.

As a complement to the HST imaging of the Orion nebula, Hartigan, O'Dell, and collaborator J. Morse (Colorado) have been reducing and analyzing an extensive set of Fabry-Perot images of the Orion nebula taken at the CTIO 1.5-m in the lines of Hα, [N II], [S II] and [O III]. These data isolate the high velocity flows from the background photoionized gas clearly for the first time in an H II region. The blue shifted objects are primarily Herbig Haro objects, while the proplyds were found to show jet-type flow to both the blue and red. Results based on the [S II] and [O III] data cubes were published this year (O'Dell *et al.*, 1997), and Hartigan *et al.* are currently working to reduce the remaining data cubes for eventual publication as a CD-ROM which will be made available to the astronomical community. A similar set of data taken by Hartigan, Morse and P. Paliunas (GSFC) in December 1996 at the KPNO 4m telescope for the young stellar outflow L 1551 are currently being analyzed. Two undergraduate students, Shane Bowen and Chris Coco, helped to analyze the FP data with Hartigan last summer.

Professor Reginald Dufour has been pursuing numerous projects related to imagery and spectroscopy of Galactic and extragalactic H II regions, planetary nebulae, and the shells ejected by massive stars. Dufour and O'Dell are collaborators among a group, led by R. H. Rubin of NASA-Ames, which have obtained HST observations (WFPC, WFPC2, FOS, & GHRS) of the Orion Nebula in three observing cycles aimed at detailed model analyses of physical conditions and abundances. Papers on three aspects of the studies: formation of the low-ionization lines of [O I] and [Fe II] (Baldwin *et al.*, 1996), the gaseous-phase Fe abundance from the UV [Fe IV] 2837 Å line (Rubin *et al.* 1996), and the N/O ratio in Orion derived from the UV N II] 2139/43 Å doublet (Rubin *et al.* 1997) have been completed. Additional papers on temperature and density diagnostics (and fluctuations thereof), the UV-optical extinction curve, and abundances of CNONeSiFe in the Orion Nebula are being prepared. New observations of the spatial variation of UV-optical emission lines across ionization fronts, possible wind-shock fronts, and protostellar objects in the Orion Nebula using STIS on HST are being executed in Cycle 7.

In addition to Orion, Dufour has acquired echelle spectroscopy and interference filter imagery of several H II regions using telescopes at San Pedro Martir Observatory in Baja. In collaboration with M. Peimbert and R. Costero of IA/UNAM (Mexico) and D. Walter (South Carolina St.), he is studying O and N abundances from faint recombination lines and the spatial variation of temperature across the nebulae. In 1996, Dufour and H. Castañeda of IAC/VILSPA (Spain) imaged M 8 and M 17 in the nebular and auroral emission lines of [N II] and [O III] with the 1-m telescope at La Palma to extend the T_e-mapping studies. Dufour and Hartigan are collaborators in a group, led by D. Walter, in a HST Cycle 7 program of UV-optical-IR spectroscopy (STIS) and imagery (WFPC2 and NICMOS) of the Perseus Arm H II region and wind-driven bubble nebula, NGC 7635.

4.2.3 Planetary Nebulae

In collaboration with Andreas Burkert of Heidelberg O'Dell extended the analysis of the Cometary Knots found in the Helix planetary nebula (IAU Symposium 180, in press, 1997; ApJ, submitted). It appears that these objects are stable against photoablation by the hot central star, although the confining mechanism remains uncertain.

Dufour has been collaborating with S. Torres-Peimbert, M. Peimbert, and M. Peña of IA/UNAM (Mexico) on HST imagery and spectroscopy of two halo PNe, DDDM-1 and M2-29. HST WFPC1 imagery of M2-29 revealed a jet emanating from the central star, and FOS UV-optical spectra taken in 1995 indicate that the N and O abundances in this PN are higher than previously believed; hence, this star is unlikely to be a member of the halo. He is also collaborating with astronomers in Mexico and Spain in a program of interference imagery of bright PN in the lines of [O III] and [N II] to map the electron temperature distribution across these objects. He is also part of a group, including R. Rubin (NASA-Ames), P. Harrington (U. Maryland), S. Colgan (NASA-Ames), and D. Levine (IPAC) pursuing a comprehensive UV(HST)-optical(SPM)-IR(ISO+HST) spectroscopic study of abundances in bright PN from comparisons of both T_e-sensitive and T_e-insensitive emission lines of identical ions. In early 1997 Dufour also began a collaboration with R. Henry (U. Oklahoma) and K. Kwitter (Williams College) in a UV-optical abundance study of the nearest PN, NGC 7293, based on reprocessed IUE and new KPNO optical spectra.

Dufour is PI on a HST Cycle 5 program of FOS UV-optical spectroscopy of condensations ejected by the supermassive star Eta Carinae last century. Excellent FOS spectra covering the 1150–8500 Å wavelength range were taken of ten locations in the ejecta surrounding Eta Carinae. Graduate student Tim Glover and Dufour have largely completed the analysis for the ''S'' condensations located SW of the central object and the prominent jet to the NW. They found that N/O and C/O are enhanced in these ejecta by factors of >1000 over ISM values near the sun. In addition, the UV emission lines of nitrogen appear in four ionic states (N II, N III, N IV, and N V), indicative of radiative shocks with velocities 120–150 km/s for a gas that is N-rich and correspondingly depleted in C & O. Results on these regions, the homunculus, and recently obtained spectra of the NE jet were presented by Glover and Dufour at the 1996 October Luminous Blue Variables meeting in Kona, HI. Collaborators on this study include J. Hester (Arizona St.), D. Currie (U. Maryland), and D. van Orsow (STScI).

4.2.4 Supernova Remnants

Hartigan and graduate student Parviz Ghavamian have finished a model of the free-free emission expected from radiative shocks at high densities. This work takes into account that the optical depth and orientation angle affects the observed spectral indicies. A paper on this work will be submitted to the ApJ by the end of 1997. Hartigan, J. Raymond (CfA) and C. Smith (Michigan) are working on a project that will become part of Ghavamian's Ph.D. thesis, which is to study the Balmer decrements and line profiles of nonradiative shocks in supernova remnants. They plan to investigate several fundamental aspects of shock physics that can only be studied in nonradiative shocks, such as (1) whether or not the particle energy distribution is Gaussian, (2) the degree to which electron and proton temperatures differ behind the shock, (3) the importance of radiative transfer in resonance lines of H, and (4) the effect of the magnetic field orientation on temperature equilibration.

Professor Edison Liang, with student Katherine Keilty, embarked on a new project at LLNL to explore the use of the big lasers such as *Nova* and the future *NIF* to simulate the interaction of supernova ejecta with the circumstellar matter, particularly the pending impact of SN1987A with its inner ring. With the help of large scale 1-D and 2-D radiation-hydrodynamic codes, they are mapping out the physical parameter space achievable with laser target interaction and its scalability to the astrophysical parameter space. Preliminary results show that the shock velocity, electron temperature and the ratio of Coulomb mean-free-path to the scale size of both cases are very similar. Laboratory experiments are especially useful for studying the evolution of radiative shocks and Rayleigh-Taylor instability of the shock interaction region.

4.2.5 Stellar Plasmas, Neutron Stars

Professor F. Curt Michel continues to be active in theoretical work concerning the properties of neutron stars and their evolution. Within the last year he has begun to work on a model to simulate the particle motion about a rotating neutron star with an *inclined* magnetic field. An extension of earlier work with Jurgen Krauss-Polstorff is now being undertaken with Research Scientist Ian Smith and graduate student Peter Thacker. So far, Michel and collaborators have been able to simulate shut-down pulsars (aligned, with only emission of particles from surface), pair-production configurations (aligned, with pair production if E-fields sufficiently large), and have shown that the entirely filled magnetospheres originally proposed collapse to an inactive dome/torus configuration. Future efforts will attempt to extend this work to the more interesting case of an inclined magnetic field.

Michel is also involved with analysis of HST images of the Crab Nebula which show *major* variations in the so-called ''wisps'' on times scales a short as a *week*, in collaboration with a group headed by Jeff Hester at Arizona State University (see Session 75 of the June 1996 AAS meeting).

Michel is also collaborating with Hui Li (LANL) on numerical calculations directed at simulating winds from pulsars. Of particular interest are the polar regions where the HST images suggests that an enhanced jet of relativistic wind is flowing. Along the same lines, he is developing a way of calculating the interaction of a plasma with large amplitude electromagnetic waves. The assumptions of standard plasma physics preclude such calculations. This work will soon be submitted.

Michel's work with Ben Eastlund and Ben Miller on pulsed gamma rays from pulsars, recently published, shows that pulsed gamma rays need not come from polar caps but rather can be produced by an isotropically filled magnetosphere.

Professor Jon Weisheit and graduate student David Geller have finished their study of how intense (*i.e.*, megagauss) magnetic fields alter the small-angle limit of Rutherford scattering of electrons by ions; this work is described in a forthcoming article in Physics of Plasmas. Deflections tend to be inhibited when the electron cyclotron radius R_e is less than the plasma Debye length D_e. However, unlike the field-free case, there can be both positive and negative changes in the perpendicular component of the electron velocity V. Moreover, in addition to a change in the trajectory pitch angle a, scattering also can result in a rotation of the velocity vector around the cone it traces out in the absence of any scattering. This second possibility does not result in a change of pitch angle, but does contribute to the overall diffusion of V with time. The main effect on transport phenomena is to diminish the Coulomb logarithm, with the uppermost effective impact parameter being well approximated by ($R_e/\sin a$) instead of D_e. In the atmospheres of magnetic white dwarf stars, these modifications can reduce (parallel) electrical and thermal resistivites by an order of magnitude.

Work by Geller and Weisheit now in progress concerns the effects of intense magnetic fields on thermal bremsstrahlung, again, through the modification of collision trajectories; one can also view the general process as interruption of cyclotron emission by (modified) Coulomb collisions. Their goal is to develop convenient formulae for Gaunt factors which include the principal magnetic field effects.

4.2.6 High Energy Astrophysics

Liang, with Research Scientist Ian Smith, Postdoc Markus Böttcher, and graduate students Anthony Crider and Dechun Lin, made major advances in the study of Gamma Ray Burst spectral evolution. Using state-of-art Monte Carlo relativistic radiation transport codes, they constructed spectral evolution models based on the idea of multiple Compton scattering which satisfy most know spectral and temporal properties of BATSE gamma ray bursts. Crider, supported by a NASA GSRP Fellowship, also discovered new properties of gamma ray burst low energy spectral evolution that rule out the popular synchrotron shock model. Motivated by the recent discovery that GB970508 is most likely cosmological, Liang generalized the saturated Compton cooling model to the cosmological context. This requires that the radiating plasma be a Thompson thick, but physically thin, dense spherical shell expanding at a typical bulk Lorentz factor of several hundreds. For bursts with multiple pulses, this model requires that the pulses correspond to multiple ejections from a central engine, rather than a single blast wave interacting with an inhomogeneous ISM. This model predicts that the late time pulse profile should follow a simple power law with decay index close to unity.

Böttcher, in collaboration with H. Li (LANL) and M. Kusunose (Japan), is leading a development of a state-of-the-art, time-dependent, and space-dependent Monte Carlo code for Comptonization with hybrid thermal and nonthermal relativistic leptons. This highly versatile code is being used to simulate a large variety of high energy sources including gamma ray bursters, black holes, neutron stars, and AGNs.

Liang and former student Luo continued to work on transonic accretion disk models of black hole candidates. These solutions complement and generalize the currently popular advection dominated accretion flows. Using such disk models Liang has computed the spectral output and discovered that the spectral state transitions in Galactic black hole candidates can be caused by changes in the viscosity or the sub-Keplerian angular momentum value at the outer disk boundary.

With former Rice student Michael Moss and undergraduate visitors Julia Dobrinskaya and Sameer Sheth, Liang and collaborators continued to analyze and model the spectral and temporal data of black hole candidates from many experiments, including CGRO, RXTE, and ASCA. Liang is a guest observer on CGRO and RXTE. Objects observed this past year include GX339-4, GRS1758 and 1E1740.7.

4.3 Extragalactic Astronomy

Weisheit and undergraduate student Kenneth Rines (now at CfA) are exploring the question of which clusters of galaxies are relaxed, *i.e.*, in dynamical equilibrium. Their analysis is based on comparing the true, two-point spatial autocorrelation function for pairs of galaxies in a given cluster with autocorrelation functions computed for simulated equilibrium systems, modeled as polytropes. Thus far their work shows that, for computer simulations of clusters with relatively large radii, the autocorrelation function generally has a linear form. This contrasts sharply with the power-law form that is well established observationally for loosely correlated objects such as field galaxies, or whole clusters. Next, they intend to construct autocorrelation functions for actual clusters and determine if, in projection, significant differences exist between spiral-rich and spiral-poor clusters. A careful treatment of cluster edge effects is expected to be quite important here.

Dufour continues a collaboration with D. Garnett and E. Skillman (U. Minnesota), and G. Shields (U. Texas) to study the UV spectra of H II regions using FOS (and now, STIS) on HST in several irregular and spiral galaxies. FOS spectra of two H II regions in IZw18 have been acquired during 1995/6 and confirmed earlier suspicions that C/O is higher by about 0.3 dex compared to several other very-metal-poor irregular galaxies (Garnett *et al.*, 1996). HST FOS UV-optical spectra of H II regions in the spiral galaxies M 101 and NGC 2403 have also been obtained are being used to study the C-abundance gradient in spiral galaxies for the first time. Some of their results for NGC 2403 have been accepted for publication (Garnett *et al.*, 1997). Graduate student Cindy Kurt and Dufour have largely completed a comprehensive study of the UV-optical spectrum of the peculiar dusty H II region in the SMC N88A based on FOS and CTIO spectra. They are awaiting the results of HST WFPC2 imagery, scheduled for 1997 October, to complete this project as Kurt's thesis for the M.S. degree. Despite the exceptionally high dust content of this nebula, the CNO abundances are similar to that of the general ISM of the SMC. The basic goal of these studies, taken together, is to obtain a realistic scenario of the evolution of the CNO element group, and potential depletion effects by dust, in the ISM of star-forming galaxies.

Dufour participated in a large collaborative effort, primarily led by E. Skillman (Minnesota), in studies of the star formation history of several nearby irregular galaxies with HST. Observations of Sextans A, Leo A, GR8, and IZw18 with HST have been obtained, or have been scheduled for 1997-1998. Dufour is currently leading the study of the most metal-poor star-forming galaxy known – I Zwicky 18 – using HST imagery and spectroscopy. The results of WFPC2 imagery has been reported in several meetings and conference publications and is currently being written up for publication in the AJ. These HST imagery results showed that IZw18 and a second Im galaxy located 15 arc sec to the NW are both resolved into stars and the second galaxy could be as near as 2 kpc to the starbursting main body. This was confirmed from a long-slit spectrogram of the brightest emission knots in IZw18 and the companion with the 4.2m William Herschel telescope in La Palma in 1996 February (Dufour, Esteban, and Castenada, 1996). The radial velocities of the two galaxies were found to be identical within errors of measurement. Hence, the ionized gas which surrounds IZw18 may have been tidally disturbed by the companion galaxy. This discovery adds a new complication to the peculiarities to the history of this most metal-poor galaxy known. In order to sort out the effects of the interaction between the two galaxies, Dufour and P. Shopbell (Caltech) obtained excellent 15 km/sec resolution Fabry-Perot observations of Halpha emission between IZw18 and the companion with the Palomar 5-m telescope in 1997 February.

Postdoc Böttcher continued his work on AGN spectral models. His results confirm that the spectral peak of gamma ray Blazars can be explained in terms of synchro-compton emission from relativistic jets, and their spectral variability can be caused by changes in the Doppler factor.

4.4 Instrumentation Development

Progress continues on construction of the IRFP, a fully cryogenic high resolution Fabry-Perot interferometer that will operate in the 1 - 2.5 μm range. Partners in this collaboration include P. Hartigan at Rice, G. Cecil at UNC and the staff at CTIO. Optical design for the instrument is complete, and construction of the dewar should begin shortly. The instrument will be installed initially at the 1.5-m and 4-m telescopes at CTIO, and after a checkout period will be made available to the general astronomical community.

PUBLICATIONS

Baldwin, J. A., Crotts, A., **Dufour, R. J.**, Ferland, G. J., Heathcote, S., Hester, J. J., Korista, K. T., Martin, P. G.,

O'Dell, C. R., Rubin, R. H., Tielens, A. G. G. M., Verner, D. A., Verner, E. M., Walter, D. K., and Wen, Z. 1996, *Physical Conditions in Low-Ionization Regions of the Orion Nebula*, ApJ 468, L115.

Belova, E. V, Denton, R. E., and **Chan, A. A.** 1997, *Hybrid Simulations of the Effects of Energetic Particles on Low-Frequency MHD Waves*, Journal of Computational Physics, in press.

Bettison-Varga, L., Berger, R., Creasy, J., Dyar, D., Knight, P., **Ledley, T. S.** and McManus, D., 1997, *How Should We Integrate Research and Education?, Shaping the Future of Undergraduate Earth Science Education*, editors: M.F.W. Ireton, C.A. Manduca, D.W. Mogk, proceedings of the workshop Spheres of Influence: Shaping the Future of Earth Science Education, American Geophysical Union, National Science Foundation and the Keck Geology Consortium, 29.

Boyle, C. B., **Reiff, P. H.** & Hairston, M. R. 1997, *Empirical Polar Cap Potentials*, J. Geophys. Res., 102, 111.

Böttcher, M. and Collmar, W. 1997, *Spectral variability of PKS 0528+134 at gamma-ray energies* A&A Letters, in press.

Chen, C. R., *et al.* [**O'Dell** is 3rd of 8 authors] 1997, *2.12 μm Molecular Hydrogen Emission from Circumstellar Disks in the Orion Nebula*, ApJ Letters, in press.

Crider, A., **Liang, E.**, & **Smith, I.** 1997, *Evidence for Saturated Inverse Compton Scattering in Gamma-Ray Bursts*, Revista Mexicana de Astronomía y Astrofísica (Serie de Conferencias), in press.

Crider, A., **Liang, E. P.**, **Smith, I. A.**, **Lin, D.**, & Kusunose, M. 1997, *A Thermal-Nonthermal Inverse Compton Model for Cyg X-1*, in ''Proceedings of the Fourth Compton Symposium,'' in press.

Crider, A., **Liang, E.**, **Smith, I.**, Preece, R., Briggs, M., Pendleton, G., Paciesas, W., Band, D. and Matteson, J. *Evolution of the Low-Energy Photon Spectra in Gamma-Ray Bursts*, ApJ 479, L39.

Crosas, M., & **Weisheit, J.** 1996, *Spallation in Active Galactic Nuclei*, ApJ 465, 659.

Ding, C., **Hill, T. W.**, and **Toffoletto, F. R.** 1996, *Improvement of the Toffoletto-Hill open magnetosphere model*, in ''Physics of Space Plasmas,'' 14, T. Chang and J. R. Jasperse, eds., (Cambridge: MIT Press), 639.

Dobrinskaya, J., **Liang, E.**, **Luo, C.**, Sheth, S., **Smith, I.** and Murakami, T. 1997, *Timing Analysis of the ASCA Data of Galactic Black Hole Candidates*, in ''X-Ray Imaging and Spectroscopy of Cosmic Hot Plasmas,'' F. Makino and K. Mitsuda eds., (Tokyo: Universal Acad. Press), p. 481.

Dohm-Palmer, R. C., Skillman, E. D., Saha, A., Tolstoy, E., Mateo, M., Gallagher, A., Hoessel, J., Chiosi, C., and **Dufour, R. J.** 1997, *The Dwarf Irregular Galaxy Sextans A. I. HST Photometry of the Resolved Stars*, ApJ in press.

Dohm-Palmer, R. C., Skillman, E. D., Saha, A., Tolstoy, E., Mateo, M., Gallagher, A., Hoessel, J., Chiosi, C., and **Dufour, R. J.** 1997, *The Dwarf Irregular Galaxy Sextans A. II. Recent Star Formation History*, ApJ in press.

Dufour, R. J., Esteban, C., and Castaneda, H. O. 1996, *Evidence for a Physically Associated Companion Galaxy to I Zw 18*, ApJ 471, L87.

Dufour, R. J., Garnett, D. R., Skillman, E. D., and Shields, G. A. 1996, *IZw18: New Results from HST Imagery and Spectroscopy*, in ''From Stars to Galaxies,'' ASP Conference Series, 98, 358; see also 1997, ''Science with the Hubble Space Telescope - II,'' 348.

Eastlund, B. J., Miller, B., & **Michel, F. C.** 1997, *Emission from Closed and Filled Magnetospheric Shells and Its Application to the Crab Pulsar*, ApJ 483, 857.

Garnett, D. R., Skillman, E. D., Shields, G. A., and **Dufour, R. J.** 1997, *Abundances Gradients in NGC 2403*, ApJ in press.

Garnett, D. R., Skillman, E. D., **Dufour, R. J.**, and Shields, G. A., 1996, *High Carbon in I Zwicky 18: New Results from Hubble Space Telescope Spectroscopy*, ApJ 481, 174.

Geller, D. G., & **Weisheit, J. C.** 1997, *Classical Electron-Ion Scattering in Strongly Magnetized Plasmas, I. A Generalized Coulomb Logarithm*, Phys. Plasmas, in press.

Green, J. L., Taylor, W. W. L., Fung, S. F., Benson, R., Calvert, W., Reinisch, B. W., Gallagher, D. L., & **Reiff, P. H.** 1997, *Radio remote sensing of magnetospheric plasmas*, in ''Measurement Techniques for Space Plasmas: What Works and What Doesn't,'' (in press).

Hartigan, P. 1996, *HST Observations of the HH 47 and HH 111 Stellar Jets*, in ''Accretion Phenomena and Associated Outflows,'' IAU Colloquium #163, p536.

Hartigan, P. 1997, *Observations of the Inner Accretion Disk Around Young Stars*, in ''Star Formation Near and Far,'' October Maryland Astrophysics Conference, p153.

Hartigan, P., Carpenter, J., Dougados, C., and Skrutskie, M. 1996, *Jet Bow Shocks and Clumpy Shells of H_2 Emission in the Young Stellar Outflow Cepheus A*, AJ 111, 1278.

Heathcote, S., Morse, J., **Hartigan, P.**, Reipurth, B., Schwartz, R.D., Bally, J., & Stone, J. 1996, *Hubble Space Telescope Observations of the HH47 Jet: Narrow Band Images*, AJ 112, 1141.

Hoogeveen, G. W. and **Cloutier, P. A.** 1996, *The Triton-Neptune plasma interaction*, J. Geophys. Res., 101, 19.

Kim, H. and **Chan, A. A.** 1997, *Fully-Adiabatic Changes in Storm-Time Relativistic Electron Fluxes*, J. Geophys. Res. in press.

Law, C. C., and **Cloutier, P. A.** 1997, *Currents and magnetic field structures in the dayside solar wind interaction with Venus*, J. Geophys. Res. 102, 199.

Ledley, T. S. and S. Chu. 1996, *The Initiation of Ice Sheet Growth, Milakovitch Solar Radiation Variations, and the 100 KYR Ice Age Cycle, Proceedings of the Conference on the Dynamics of the Arctic Climate System, Goteborg, Sweden, Nov 7-10, 1994*, World Climate Research Program, 129.

Ledley, T. S. and Pfirman, S. 1997, *Sediment-Laden Snow and Sea Ice in the Arctic and Its Impact on Climate*, Climatic Change, in press.

Liang, E. 1997, *Multiwavelength Signatures of Galactic Black Holes*, Phys. Report, in press.

Liang, E. 1997, *Saturated Compton Model of Cosmological Gamma-Ray Bursts*, ApJ in press.

Liang, E. 1997, *X-Ray Strategies for Solving the Gamma-Ray Burst Mystery*, Proc. Allsky X-Ray Observation for the Next Decade Conference, ed. A. Yoshida (Tokyo: Universal Acad. Press).

Liang, E., Kusunose, M., **Smith, I.** and **Crider, A.** 1997, *Physical Model of Gamma-Ray Burst Spectral Evolution*, ApJ 479, L35.

Liang, E. and Narayan, R. 1998, *Spectral Signatures and Physics of Black Hole Accretion Disks*, Proc. 4th Compton Symp., C. Dermer *et al.* eds., (New York: AIP).

Murillo, M. S., & **Weisheit, J. C.** 1997, *Dense Plasmas, Screened Interactions, and Atomic Ionization*, Physics Reports, in press.

O'Dell, C. R. 1998, *Observational Properties of the Orion Nebula*, AJ in press.

O'Dell, C. R. and S. V. W. Beckwith 1997, *Young Stars and Their Surroundings*, Science 276, 1355.

O'Dell, C. R., **Hartigan, P.**, Bally, J. & Morse, J. A. 1997, *High Velocity Features in the Orion Nebula*, AJ in press.

O'Dell, C. R., **Hartigan, P.**, **Lane, W.**, **Wong, S.**, Burton, M., Raymond, J., & Axon, D. 1997, *Herbig Haro Objects in the Orion Nebula*, AJ 114, 730.

Raymond, J., Blair, W., Long, K., Vancura, O., Edgar, R., Morse, J., **Hartigan, P.**, & Sanders, W. 1997, *The Ultraviolet Spectrum of a Face-On Shock Wave in the Vela Supernova Remnant*, ApJ 482, 881.

Reiff, P. H., J. L. Green, S. F. Fung, R. F. Benson, W. Calvert, and Taylor, W. L. 1996, *Radio Sounding of Multiscale Plasmas*, in ''Physics of Space Plasmas,'' 14, T. Chang and J. R. Jasperse eds., (Cambridge: MIT Press), p. 415.

Reipurth, B., **Hartigan, P.**, Heathcote, S., Morse, J. and Bally, J. 1997, *Hubble Space Telescope Images of the HH 111 Jet*, AJ 114, 757.

Rubin, R. H., **Dufour, R. J.**, Ferland, G. J., Martin, P. G., **O'Dell, C. R.**, Baldwin, J. A., Hester, J. J., Walter, D. K., and Wen, Z. 1997, *[Fe IV] in the Orion Nebula*, ApJ 474, L131.

Rubin, R. H., Martin, P. G., **Dufour, R. J.**, Ferland, G. J., Baldwin, J. A., Hester, J. J., Walter, D. K., and Wen, Z. 1997, *Temperature Variations and N/O in the Orion Nebula from HST Observations*, ApJ in press.

Smith, I. A. 1996, *Contribution of Galactic Arm Sources to the 3B Catalog*, in ''Gamma-Ray Bursts: Third Huntsville Symposium,'' C. Kouveliotou, M. S. Briggs, & G. J. Fishman eds., (New York: AIP), 536.

Smith I. A. 1997, *The Soft Gamma-Ray Repeaters*, in ''The Gamma-Ray Universe Revealed by CGRO,'' in press.

Smith, I. A., *et al.* 1997, *Infrared, Submillimeter, and Millimeter Observations of the Soft Gamma-Ray Repeaters*, ESA SP-382, C. Winkler, T. J.-L. Courvoisier, & Ph. Durouchoux eds., (Noordwijk: ESA Publications), 191; see also 1996, ''Gamma-Ray Bursts: Third Huntsville Symposium,'' C. Kouveliotou, M. S. Briggs, & G. J. Fishman eds., (New York: AIP), 966; and 1997, Advances in Space Research, in press.

Smith, I. A., **Crider, A.**, **Liang, E. P.**, Dunne, B. C., Fenimore, E. E., & Li, H. 1996, *Hardness Ratio versus Duration for PVO compared to BATSE and PHEBUS*, in ''Gamma-Ray Bursts: Third Huntsville Symposium,'' C. Kouveliotou, M. S. Briggs, & G. J. Fishman eds., (New York: AIP), 101.

Smith, I. A., Gründl, R. A., **Liang, E. P.**, & Lo, K. Y. 1997, *BIMA Observations of Gamma-Ray Bursters GRB 970111 and GRB 970228*, ApJ 487, L5.

Smith, I. A., Gründl, R. A., **Liang, E. P.**, & Lo, K. Y. 1997, *Millimeter-Wave Observations of Gamma-Ray Bursters* Revista Mexicana de Astronomía y Astrofísica (Serie de Conferencias) , in press.

Smith, I. A., **Liang, E. P.**, **Crider, A.**, **Lin, D.**, & Kusunose, M. 1997, *Saturated Compton Scattering Models for the Soft Gamma-Ray Repeater Bursts*, in ''Proceedings of the Fourth Compton Symposium,'' in press.

Smith, I. A., **Liang, E. P.**, **Moss, M.**, Dobrinskaya, J., Fender, R. P., Durouchoux, Ph., Corbel, S., Sood, R., Filippenko, A. V. & Leonard, D. C. 1997, *Multiwavelength Observations of GX 339−4*, in ''Proceedings of the Fourth Compton Symposium,'' in press.

Smith, I. A., Schultz, A. S. B., Hurley, K., Van Paradijs, J., & Waters, L. B. F. M. 1997, *JCMT Observations of Soft Gamma-Ray Repeaters*, A&A, 319, 923.

Steen, R. S. and **Ledley, T. S.** 1997, *Asynchronously Coupling the Cryosphere and Atmosphere in an Energy Balance Climate Model*, Annals of Glaciology, in press.

Toffoletto, F. R., **Spiro, R. W.**, **Wolf, R. A.**, Hesse, M., & Birn, J. 1996, *Self-consistent modeling of inner magnetospheric convection*, in ''Third International Conference on Substorms (ICS-3),'' E. J. Rolfe & B. Kaldeich eds., (Noordwijk: ESA Publications), 223.

Usadi, A., **Wolf, R. A.**, Heinemann, M., & Horton, W. 1996, *Does chaos alter the ensemble averaged drift equations?*, J. Geophys. Res. 101, 491.

Van Paradijs, J. *et al.* [**Smith, I. A.** is 5th of 12 authors] 1996, *Infrared Observations of Soft Gamma Repeaters* A&A, 314, 146.

Wolf, R. A., **Freeman, J. W. Jr.**, Hausman, B. A., Spiro, R. W., Hilmer, R. V., & Lambour, R. L. 1997, *Modeling convection effects in magnetic storms*, in ''Magnetic Storms,'' B. T. Tsurutani, J. K. Arballo, W. D. Gonzalez & Y. Kamide eds., Geophys. Monogr. Series, Series, (Washington: Amer. Geophys. Union) 161.

Wolf, R. A., and **Spiro, R. W.** 1997, *Numerical modeling of ring current and plasmasphere*, Space Sci. Rev. 80, 199.

Xue, S., **Reiff, P. H.**, and Onsager, T. G. 1997, *Modeling Cusp Ion Injection Using Realistic Electric and Magnetic Fields*, Geophys. Res. Lett. 24, 2275.

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