Final Report
NASA GRANT NAGW-4176

Local and Global Studies of Ion Outflow from the High Latitude Ionosphere

W. K. Peterson
Lockheed Martin Space Sciences Laboratory
Dept. H1-11 Building 252
3251 Hanover Street
Palo Alto, California 94304
(415)-424-3269

Temporarily at LASP
1234 Innovation Drive
Boulder, Colorado 80309
(303) 492-0686

September 30, 1997

Programmatic Information:

This Grant was awarded as result of a competitive selection under the NASA Space Physics Science Research and Technology (SR&T) program in early 1993. Delays in the Grant/Contracts relationship between NASA and the then Lockheed Corporation delayed funding to 1994.

During 1995, the original expiration date of this grant was extended from October 31, 1996 to December 31, 1997 and a NASA Space Physics Educational Outreach (SPEO) supplement of $5,000 awarded. The period of performance was extended because the Principal Investigator, Dr. Peterson, was heavily involved in the pre- and post -launch software development associated with the TIMAS instrument on the POLAR Satellite and because the new data from the NASA ISTP program were expected to be significantly better than the DE-1/2 that was available at the time this Grant was made. Because of a NASA reorganization, the expiration data was changed again in 1996 to October 31, 1997.

Overview: Ion outflow from the ionosphere plays a fundamental but poorly defined role in magnetospheric processes. The purpose of the research is to better understand the mass coupling between the Earth's ionosphere and Magnetosphere. The work performed under this grant falls in three areas: 1) Event studies using archived data from the DE-1/2 satellites, 2) Investigations using Data from the ISTP satellites, and 3) work supporting a Space Physics Educational Outreach (SPEO) grant supplement.

Event Studies Using Archived data from the DE satellites:

In the first year of this grant, we directly demonstrated that ion cyclotron resonance heating (ICRH) is not a major source of the energy responsible for extracting heavy ions from the ionosphere. This result contradicts a suggestion made by Heppner et al. [*J. Geophys. Res, 98,* 1629, 1993] based on a statistical study of the low frequency wave spectrum obtained from the DE -2 satellite. Our analysis was presented at the Fall 1995 meeting of the American Geophysical Union and published with the title "On the Energy Sources Responsible for the Escape of Heavy Ions from the Ionosphere" in the book *Physics of Space Plasmas (1995), Number 14,* T. Chang and J.R. Jasperse, eds, (MIT) Center for Theoretical Geo/Cosmo Plasma Physics, Cambridge, MA. in 1996, starting on page 395.

Previous investigations have shown that escape of heavy ions involves many processes acting at different altitudes. In particular transfer of energies on the order of 10 eV to oxygen at altitudes near and above the region where collisions no longer dominate ionospheric processes (i.e. about 250 km) is required to support the observed magnitude of escaping heavy ions. Data from the suite of instruments on the Dynamics Explorer satellites were used to infer plasma wave energy input in the oxygen ion cyclotron resonance frequency range into the ionosphere and heavy ion outflow from the ionosphere. The analysis showed that, while ion cyclotron resonance heating can energize some oxygen ions to escape velocity, the input power is too low to account for the flux of escaping ions routinely observed.

As part of the investigation of ICRH heating we also investigated the relative importance of Joule heating (i.e. ion-neutral collisions) in providing the required escape energy to oxygen ions at ionospheric altitudes. Ion-neutral collisions are most effective in collision dominated regions of the ionosphere. The heating rate from this source maximizes at about 130 km. However the escaping flux of heavy ions originates in the transition region between collisionally dominated and free molecular flow in the altitude range between 300 and 500 km. To directly evaluate the importance of the Joule heating mechanism in providing energy to account for the escaping fluxes of O^+ observed we need to estimate or determine the O^+ temperature and, density as well as the rate of energy transfer from ion neutral collisions in the 300 to 500 km altitude range. The data available from the Dynamics Explorer, POLAR or FAST satellites do not directly provide this information. However the extensive ground based data available on the web in support of the ISTP project (of which POLAR is a part), and the active participation of the modeling community provide a mush more effective basis on which to obtain or build models of the O^+ temperature, density and Joule heating rate in the 300 to 500 km altitude range

Investigations using Data from the ISTP satellites.

POLAR was launched in February 1996 and FAST in August 1996. POLAR was put in a 9 x 2 R/Re polar orbit and FAST into a 4,000 x 350 km near polar (83 degree inclination) orbit. Data from the state-of-the-art instruments on both satellites are excellent. The high/low configuration of the two satellites is similar to that available with the DE 1/2 pair. Data from instruments on these satellites provide higher energy, mass, time, angle, and frequency coverage than comparable instruments on the Dynamics Explorer satellites. A systematic search of the POLAR and FAST data sets was performed to identify intervals when outflowing ions observed POLAR could be shown to have come from a region sampled by FAST. A web page identifying such intervals have been prepared. It can be found at the URL ftp://sierra.space.lockheed.com/DATA/fast/polar_fast_selected_events/master.html. It is important to also note that there is an extensive array of ground based data from the SuperDarn and other raders, magnetometer arrays, and ground based imagers (i.e. CANOPUS) that are generally available to support most POLAR and FAST intervals of interest.

In the early phase of the FAST mission, the orbital characteristics of the two satellite favored dayside, cusp/boundary layer studies and a report was recently submitted to *Geophysical Research Letters* on plasma entry into the magnetosphere from the solar wind. (Simultaneous Observations of Solar Wind Plasma Entry from FAST and POLAR, by W.K. Peterson, Y-K. Tung, C.W. Carlson, J. H. Clemmons, H.L. Collin, R.E. Ergun, S.A. Fuselier, C.A. Kletzing, D.M. Klumpar, O.W. Lennartsson, R.P. Lepping, N.C. Maynard, J.P. McFadden, T.G. Onsager, W.J. Peria, C.T. Russell, E.G. Shelley, L. Tang, and J. Wygant, Submitted September 1997).

More recently the orbit has favored nightside auroral region conjunctions where upflowing energetic H^+, O^+, and He^+ are routinely observed. Three papers using the high time resolution FAST and POLAR data to illustrate this point were recently submitted for publication: Species dependent energies in upward directed ion beams over auroral arcs as observed with FAST TEAMS, E. Moebius, L. Tang, L.M. Kistler, M. Popecki, E.J. Lund, D. Klumpar, W. Peterson, E.G. Shelley, B. Klecker, D. Hovestadt, C.W. Carlson R. Ergun, J.P. McFadden, F. Mozer, M. Temerin, C. Cattell, R. Elphic, R. Strangeway, and R. Pfaff, submitted to *Geophys. Res. Lett.* August, 1997, and FAST observations of preferentially accelerated He^+ in association with auroral electromagnetic ion cyclotron waves, E.J. Lund, E. Moebius, L. Tang, L. M. Kistler, M.A. Popecki, D.M. Klumpar, W.K. Peterson, E.G. Shelley, B. Klecker, D. Hovestadt, M. Temerin, R.E. Ergun, J.P. McFadden, C.W. Carlson, F.S. Mozer, R.C. Elphic, R.J. Strangeway, C.A. Cattell, and R.F. Pfaff, submitted to *Geophys. Res. Lett.,* August, 1997, and Relationship of topside ionospheric ion outflows to auroral forms and precipitation, plasma waves, and convection observed by POLAR, M. Hirahara, J.L. Horwitz, T.E. Moore, G.A. Germany, J.F. Spann, W.K. Peterson, E.G. Shelley, M.O. Chandler, B.L. Giles, P.D. Craven, C.J. Pollock, D.A. Gurnett, J.S. Pickett, A.M. Persoon, J.D. Scudder, N.C. Maynard, F.S. Mozer, M.J. Brittnacher, and T. Nagai, submitted to J. *Geophys Res.*, May, 1997.

There are several requirements for conjunction events to be useful in the investigation of outflowing ions: 1) The conjunction should be in the evening or pre-midnight region where the bulk of energetic upflowing ions are encountered. 2) The time of conjunction should correspond to an interval of upflowing energetic ions on the high altitude POLAR satellite and either low energy upflowing ions or downflowing energetic electrons on the lower altitude FAST satellite, and 3) Supporting ground based images and magnetometers and observations of the interplanetary magnetic field (IMF) are available to document the global state of the magnetosphere at the time of conjunction should be available. Preliminary analysis of the conjunction events in the June-August 1997 epoch revealed several conjunctions of potentially the quality of the DE -1/2 conjunctions discussed above. Detailed analysis of the events is pending until a systematic evaluation of all potential conjunctions in the June/August 97 time frame is complete. Evaluation of events requires summary POLAR spectrograms which are generally not available for all intervals until 4 or 5 months after acquisition. The higher resolution data available on POLAR and FAST instruments will provide an opportunity to examine energy transfer mechanisms in more detail than was possible with the suite of instruments available on DE 1/2. This analysis will come after the end of this grant. Fortunately there are presently adequate funds in the POLAR and FAST data analysis budgets to continue support of this research.

Coordinated multi-satellite, observations of molecular ions (i.e. O_2^+, NO^+, and N_2^+) provide an alternative method for investigating energization processes involved in ion escape not requiring magnetically conjugate measurements from two satellites. (See, for example, On the sources of energization of molecular ions at ionospheric altitudes, W.K. Peterson, T. Abe, H. Fukunishi, M.G. Greffen, H. Hayakawa, Y. Kasahara, I. Kimura, A. Matsuoka, T. Mukai, T. Nagatsuma, K. Tsuruda, B.A. Whalen, and A. W. Yau, *J. Geophys. Res., 99*, 23257, 1994). Molecular ions normally have a short lifetime in the ionosphere and are normally not observed above E region (~130 km) altitude. As noted by Peterson et al. [1994] during intervals of high magnetic activity measurable fluxes of molecular ions are observed both on auroral field lines and in the magnetosphere. In particular the molecular ions in the magnetosphere are typically have characteristic energies of many 10's of keV.

Since March 1997, Dr. Peterson has been identifying intervals in which data from instruments on the ISTP satellites and ground based facilities can be effectively used to address the global nature of molecular ion energization and outflow from the high latitude ionosphere. He has been concentrating on obtaining intervals when molecular ions are seen from more two or more of the four satellites capable of detecting low energy outflowing molecular ions (POLAR/TIMAS, FAST/TEAMS, and Akebono/SMS) or molecular ions energized to 10's of keV in the magnetosphere (Geotail/EPIC). The WIND/EPACT instrument is also capable of detecting molecular ions to 10's of keV, but WIND is seldom in the magnetosphere. As noted in Peterson et al. (1994) the conditions for energization and escape of molecular ions can be effectively compared and contrasted to those of O^+ and H^+ to gain more insight into the conditions that are responsible for ion outflow. The chance to observe and characterize the energy input and molecular ion outflow and/or the energized molecular ion component in the plasma sheet and ring current regions at widely separated locations, will give us new insights into the global nature of ion outflow, transport, and energization. The January 1997 CME event appears to be a good candidate for this study. Molecular ions were observed on POLAR/TIMAS, and Geotail/EPIC. Analysis of the data from this event has begun and a preliminary report of the POLAR/TIMAS outflowing molecular ion observations given at the Spring 1997, AGU Meeting (Monitoring Earth's Emission of Heavy Molecular Ions by the TIMAS Instrument on GGS/Polar: O W Lennartsson, J F Drake, H L Collin, A G Ghielmetti, WK Peterson, E G Shelley, H Balsiger , Paper # SM41B-08)

Work supporting a Space Physics Educational Outreach (SPEO) grant supplement.

Mr. Robert Zafran, A middle school teacher in Santa Clara County, and Dr. Peterson, were awarded a SPEO Grant Supplement in 1995. The grant was used to support development and implementation of "The Auroral Project", a web-based, study guide to the aurora and auroral phenomena. The web pages are at ftp://sierra.space.lockheed.com/DATA/speo/home.html

The Aurora Project, a step-by-step, space physics lesson assignment, outlines a research oriented, internet\world wide web (WWW) based, "science project" style lesson. Teachers, parents, relatives, and class or schoolmates can serve as "Project Mentors" to help students complete the Aurora Project learning experience. The earth's aurora is explored by de-emphasizing the importance placed on the written report and the table-top display which are normally the focus of science project oriented tasks. Instead, the Aurora Project develops a sequenced, interlinked learning method that reinforces the student's usage of WWW resources. Such WWW-based resources include other space physics lessons, simulations, real-time data and images, video clips and movies, and scientifically oriented, text-based materials. As students, either individually or with a partner, progress through the lesson, they repetitively integrate and associate the individual steps in a connective fashion utilizing text, graphics, models, and visually oriented displays. The culmination of the project, The Auroral Learning Center (either a table-top or WWW-based page presentation) allows other students to learn about the earth's aurora by experiencing the research and experimentation results.

In addition to the study guide, guidelines for the project mentor are provide that include information on how to obtain relevant videos and books as well as assess the effectiveness to the project.

The auroral project has been used in several Bay Area class rooms in the past two years and has been presented to several meetings of local science teachers.