A Final Report for

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HIGH ALTITUDE PLASMA INSTRUMENT (HAPI) DATA ANALYSIS

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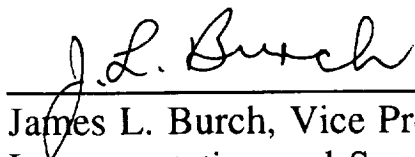Attention: Ms. Cynthia L. Tart
Greenbelt, MD 20771

Submitted by:

J. L. Burch

SwRI Project 15-3320

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APPROVED:

James L. Burch, Vice President
Instrumentation and Space Research Division

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INTRODUCTION

The objectives of the Dynamics Explorer mission are to investigated the coupling of energy, mass and momentum among the Earth's magnetosphere, ionosphere and upper atmosphere. At launch, on August 3, 1981, DE-1 was placed into an elliptical polar orbit having an apogee of 23,130 km to allow global auroral imaging and crossings of auroral field lines at altitudes of several thousand kilometers. At the same time DE-2 was placed into a polar orbit, coplanar with that of DE-1 but with a perigee altitude low enough (309 km) for neutral measurements and an apogee altitude of 1012 km.

The DE-1 High Altitude Plasma Instrument (HAPI) provided data on low and medium energy electrons and ions from August 13, 1981 until December 1, 1981, when a high-voltage failure occurred. Analysis of the HAPI data for the time period of this contract has produced new results on: (1) the source mechanisms for electron conical distributions, (2) particle acceleration phenomena in auroral acceleration regions, (3) Birkeland currents throughout the nightside auroral regions, (4) the source region for auroral kilometric radiation (AKR), and (5) plasma injection phenomena in the polar cusp.

The DE Science Team, at its meeting on March 7 and 8, 1989, identified four Team Science Objectives:

1.   Plasma physics of the auroral acceleration region,

2.   Dynamical interactions between the thermosphere and the magnetosphere,

3.   The ionosphere as a source of plasma for the magnetosphere,

4.   Electrodynamic coupling as a function of substorm phase and IMF direction.

Most of the DE-1 HAPI research that has been done under this contract contributes to the first objective, plasma physics of the auroral acceleration region, although objectives (3) and (4) are also represented in the work.

I. SUMMARY OF ACCOMPLISHMENTS

Discussed below are some of the major accomplishments of the HAPI data analysis effort during the contract period.

A.   *Investigations of Source Mechanisms for Electron Conics*

Electron conics were observed in the DE-1 data by Menietti and Burch [1985], who reported them to be associated with trapped particles and parallel electric fields. The authors suggested perpendicular heating via wave-particle interactions as a source

mechanism, in analogy with ion conic formation. Lundin et al. [1987] and Hultqvist et al. [1988] later reported observations of electron conics in the Viking data and suggested that a parallel potential difference that varies in magnitude over a fraction of an electron bounce period might explain electron conics that were observed to be associated with ion conics. For plasma parameters characteristic of those observed by DE-1 in the mid-altitude nightside auroral region, Wong et al. [1988] have shown that upper hybrid waves generated by a loss-cone distribution in a background cold plasma can preferentially heat the electron population in an magnetically oblique direction by cyclotron resonance. They pointed out that any particle distribution that produces $df/dv_\perp > 0$ might act as the free energy source.

Wong et al. [1988] also pointed out that because of the dependence of the diffusion coefficient on energy and pitch angle, upper hybrid waves will heat the electrons in both the parallel and perpendicular directions. By contrast, for the case of parallel acceleration only, the ratio of upgoing to downgoing electrons at any specific perpendicular energy should always be unity except in the case of lower energy backscattered electrons. For all of the observed electron conical distributions presented by Menietti and Burch [1985], however, more particles were detected moving up the field line than down, with the ratio as large as 1.45.

Recently Menietti et al. [1992] have reported observations by both particle and plasma wave instruments on board DE-1 and the Swedish Viking satellite that demonstrate the presence of intense upper hybrid waves at mid-altitudes of the polar magnetosphere in association with electron conical distributions. This work suggests the possibility that upper hybrid waves heat electrons perpendicular to the magnetic field and are responsible for at least some electron conical distributions. Of 12 DE-1 orbits on which electron conics were observed in the Menietti et al. [1992] study, waves near the upper hybrid frequency were seen (within about 30 seconds of the time of one frequency sweep of the plasma wave instrument, PWI) on 10 of them.

The above studies have thus far demonstrated by theory and simulation that electron conics can be generated by upper hybrid waves (perpendicular heating) although other sources such as, electron acoustic waves, Langmuir waves, and Alfvén-ion cyclotron waves have been suggested by others. More experimental and theoretical research remains to be done before the process or processes responsible for electron conical distributions can be identified with certainty.

B.   *Investigations of Particle Acceleration Phenomena in Auroral Acceleration Regions*

Gurgiolo and Burch [1988] combined HAPI data and computer simulation techniques to determine the altitude profile of parallel potential distributions associated with auroral electron acceleration. An unexpected result was obtained. Agreement between the computer model and the HAPI data could only be found if the potential structure was split into a lower-altitude part and a higher-altitude part, with the spacecraft in a region containing no parallel electric fields. This was the first evidence of a split-type potential

distribution, and it can explain several other features of auroral ion and electron distributions.

The surprising result obtained by Gurgiolo and Burch [1988] raised the questions of what type of electron distribution would be expected to be observed within a region containing a parallel electric field and whether or not such distributions are ever seen in the HAPI data. The paper by Burch et al. [1990] reports the observation of a new type of auroral electron distribution, which has the characteristics of a bi-directional conic and which can be reproduced by test particle simulations. The conclusion of Burch et al. [1990] is that the typical midaltitude auroral electron distribution that has been observed by several different spacecraft is characteristic of a field-free region between parallel potential drops. The electron distribution that is expected within a parallel electric field is quite distinct and is only rarely observed by DE-1.

C. *Observations of Birkeland Currents Throughout the Nightside Auroral Regions*

By means of comparisons of the DE-1 HAPI data with the DE-1 MAG-A data, we have determined that at altitudes of several thousand to 20,000 kilometers upward-moving ionospheric electrons in regions of significant Birkeland currents are accelerated to energies above 5 eV, and hence all the major charge carriers can be observed by the HAPI instrument. This is not true at low altitudes, where upward-moving cold electrons, not observable with contemporary particle detectors, carry most, if not all, of the downward current. The major potential charge carriers are the accelerated cold electron beams (upward and downward), upward ion beams and conics, and precipitating electrons. While all of these populations, and sometimes others, can contribute significant current densities, we have found the cold electron beams to be the most common carriers of downward currents and, along with precipitating electrons, to carry the upward current as well.

In a recent published by Marshall et al. [1991] data from the DE-1 HAPI and MAG-A were used to examine particle acceleration and Birkeland current phenomena in the mid-altitude (10,000-20,000 km) nightside auroral region. Field-aligned current densities as derived from the two instruments were compared, generally resulting in good agreement. Comparisons were then made between the currents predicted by the model of the Knight [1973] for the parallel potential drops inferred from the HAPI data. It was found that large discrepancies resulted unless the full Knight formula (instead of the commonly used approximation) was used, including the temperatures of the observed electron distributions. The conclusion reached by Marshall et al. [1991] was that the Knight formula can predict fairly accurately the observed relationships between the parallel potential drop and the upward field-aligned current. Downward field-aligned currents, on the other hand, appear to be carried by suprathermal electron bursts, which may or may not be associated with parallel potential drops.

D. *Studies of the AKR Source Region*

According to Wu and Lee [1979] the most likely source of free energy for the generation of AKR is the loss-cone distribution within a region of depleted plasma density where the ratio of electron plasma frequency to gyrofrequency (ω_p/ω_g) is less than 0.3. This distribution provides the requirement of the cyclotron maser instability that $df/dv_\perp > 0$, and the theory has had success in explaining the observations to date.

Menietti et al. [1993] recently reported DE-1 particle and wave data for a pass of the nightside auroral region near an AKR source center. They compared their results to those reported by Viking and also to recent numerical simulation studies of Winglee and Pritchett [1986], which show a great similarity to the observations. As noted by Menietti et al. [1993], adjacent to and generally poleward of the AKR region was a region of electron distributions with $t_\perp/t_\parallel >> 1$. Menietti et al. [1993] have presented DE-1 data that could indicate that a mechanism suggested by Winglee and Pritchett [1986] is responsible for producing a distribution with $df/dv_\perp > 0$ outside the forbidden region and that the cyclotron maser instability itself leads to population of the forbidden region as well as to the AKR wave growth.

The simulation studies of Winglee and Pritchett [1986] demonstrated how the competition between the bump-in-tail instability and the cyclotron maser instability can then produce diffusion along both the parallel and perpendicular directions, with the resulting distribution depending on the initial parameters such as the electron density and the wave propagation angle, but much more experimental evidence with data acquired at higher rates will be necessary to confirm this possibility.

E. *Plasma Injection Phenomena in the Polar Cusp*

The polar cusp is the only region of the magnetosphere through which solar-wind plasma has been observed to enter the magnetosphere directly. In addition to the direct penetration of solar-wind plasma, there is also propagation of waves that are excited at the magnetopause by processes such as the Kelvin-Helmholtz instability. Both phenomena carry energy down the polar cusp into the upper ionosphere where it can produce strong heating of ionospheric plasma. As a result of this heating, there is an enhanced outflow of ionospheric plasma known as the cleft ion fountain.

It has been suggested that downflowing ions in the cusp can generate waves around the lower hybrid frequency and multiples of the ion gyrofrequencies, and that such waves can cause ion conics. More recently Viking and DE-1 data have been used to study cyclotron resonance heating and double cyclotron absorption in the cusp. Along these same lines, Winglee et al. [1993a, b] have considered the injection of energetic magnetosheath plasma through the polar cusp and the ion heating and upward ion conics that may result. Their approach was to use Dynamics Explorer plasma measurements to characterize the two mesoscale phenomena that are easily observed in the cusp (the cusp ion flows and the large-scale ion conic population) and to explore the microscale processes responsible for the ion heating with particle simulations.

Observations from Dynamics Explorer 1 have shown that the injected magnetosheath ions have very distinct characteristics, forming a "V" shape on energy/pitch-angle spectrograms [Burch et al., 1982]. This unique spectral feature arises from the fact that the transit time from the injection region to the point of observation in the mid-altitude cusp is a function of ion pitch angle. Both impulsive injection and injection through a restricted region in a convection electric field can lead to the "V" signatures.

Winglee et al. [1993b] have recently shown from DE 1 data that cusp ion injection is subject to short period modulation (of about 10 - 18 seconds with an injection duration of only a few seconds). This modulation is shown to be associated with modulation of the characteristics of the outflowing ionospheric plasma owing to the interaction of magnetosheath and ionospheric plasma. There is clearly an association between these two mesoscale phenomena, which suggests that they are coupled by microscale processes occurring at temporal scales not observable with DE 1. Even with the available data, however, Winglee et al. [1993b] have noted a correlation between the cusp ion injections and the ion conics along with concurrent periodicities in upgoing and downgoing cusp electrons. The possibility that the magnetosheath ions can provide a net downward momentum transfer to the ambient ions as well as enhancing their heating rate was investigated by Winglee et al. [1993b] with electrostatic particle simulations.

The results of the simulations performed by Winglee et al. [1993b] are consistent with the DE-1 data in that the magnetosheath ion injections initially suppress the upward ion conics, as downward momentum is imparted to the ambient ions, but the conics strengthen as the ion injection diminishes as a result of a heating process, which is a slow speed ion-ion drift instability between the outflowing heavy ions and the H^+ ions.

F.   *Support of Studies Led by Other DE Groups*

A number of other DE studies have been supported by our analysis of HAPI data for other groups. Several of these studies have been completed and are represented by publications listed in Section II.

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Southwest Research Institute
Instrumentation and Space Research Division
6220 Culebra Road
San Antonio, TX 78238

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