SCIFER — Structure of the cleft ion fountain at 1400 km altitude

R. L. Arnoldy and K. A. Lynch
Institute for the Study of Earth Oceans and Space, University of New Hampshire, Durham

P. M. Kintner and J. Bommel
School of Electrical Engineering, Cornell University, Ithaca, NY

T. E. Moore and C. J. Pollock
NASA MSFC, Huntsville, AL

Abstract. The SCIFER sounding rocket intersected the cleft ion fountain (CIF) at an altitude of about 1400 km revealing the structure of upward flows and ion acceleration. This altitude range is intermediate, between lower altitude studies using DE-2 and HILAT data and higher altitude studies using DE-1 and EXOS-D data. Within the observed intense ion heating region the ions are consistent with satellite measurements of the cleft ion fountain of DE-1, or the “ion wall” of EXOS-D obtained at much higher altitudes. We conclude from the SCIFER data set that the accelerated ion flux levels at 1400 km altitude are similar to the TAI fluxes measured at higher altitudes. Furthermore the transversely accelerated ions are found within separate “events” of 30-40 km latitudinal width and have well-defined boundaries. The ion distribution function within an event indicates transverse-heating up to about 40 eV, occurring a few tens of km below the rocket. The SCIFER data set serves to demonstrate that the cleft ion fountain is composed of discrete structures originating poleward of the electron trapping boundary in regions of depleted ionospheric density.

Introduction

A primary goal of the SCIFER sounding rocket flight was the investigation of the structure and physics of the cleft ion fountain (CIF) at an altitude between previous spacecraft studies, which focused on observations below 1000 km [Loranc et al., 1991, Tsunoda et al., 1989] and observations above 3000 km [Lockwood et al., 1985, Knudsen et al., 1994, Miyake et al., 1993, Moore et al., 1986, Moore et al., 1996]. In this paper we examine the details of the observed ion acceleration structures and their relationship to both large-scale particle boundaries and local ionospheric density. We find that the observed acceleration structures (in the measured energy range of 6 800 eV) are composed primarily of transversely accelerated ions (TAI). The temporal resolution of our ion instruments in this energy range is 166 ms (six 2-d distributions per second) corresponding to a spatial resolution of a few hundred meters. Measurements of thermal ions are discussed separately in Moore et al., 1996 (this issue).

We find that the observed acceleration structures are the low altitude equivalent of the polar cusp heating wall seen on EXOS-D [Knudsen et al., 1994], and the upwelling ions/cleft ion fountain of DE-1 [Lockwood et al., 1985]. The measured ion distribution functions vary in shape through the TAI region, changing from a narrow, 110 degree pitch angle tall at the edge of the region, to a wider, almost trapped-looking (isotropic with a loss cone) distribution in the middle of the region.

Data and Discussion

Figure 1 shows a survey figure of electrons, ions, oxygen, and protons during a segment of the SCIFER flight. This figure demonstrates the overall structure of the particle populations. The measurement ranges of the different instruments are given in the figure labels. The geometry factors of the particle instruments are: electrons, $1.2 \times 10^{-4} \text{cm}^2 \text{srkeV/keV}$ per 10-degree bin, ions, $1.3 \times 10^{-3} \text{cm}^2 \text{srkeV/keV}$ per 5-degree bin, oxygen and protons, $2.3 \times 10^{-4} \text{cm}^2 \text{srkeV/keV}$ per 9-degree bin.

The electron spectrogram in panel A indicates a boundary at about 700 s. At earlier times, equatorward of the 700 s boundary, the electrons were characteristic of a trapped plasma sheet distribution that was drifting and convecting sunward [Newell et al., 1991]. That is, before T+700 s, the electron population was composed of approximately 2 keV electrons which were isotropic in pitch angle except for a loss cone. At times after
Figure 1. Survey plots of the SCIFER data set.

700 s, poleward of the 700 s trapping boundary, the electrons were characteristic of prenoon cleft observations [Newell et al., 1991]. In this case, a series of inverted-V’s and field-aligned suprathermal bursts were observed with energies reaching several keV.

The ion spectrogram in panel B shows that no significant accelerated ion structures were observed equatorward of the trapping boundary. Poleward of the trapping boundary there were two discrete structures of accelerated ions in the time intervals 700-725 s and 765-800 s followed by a broader structured region of lower fluxes from 850-960 s. The mass resolved proton and O+ fluxes are displayed in panels C and D. These mass data are presented to demonstrate that both protons and O+ are comparably accelerated in the 1400 km altitude range and apparently are accelerated by the same or similar mechanisms within the same structures. A more detailed study must await further analysis.

Figure 2. Ion distribution functions from the intense ion event at T+765-800 (see Figure 1 of Kintner et al., this issue, for an expanded energy - time spectrogram.) Panels (a), (b), and (c) show the entrance into the region, and panel (d) is taken from the middle of the region. Each panel shows f(v||, v⊥) in [sec⁻³/km⁶], assuming an oxygen mass. Precipitating particles are shown in the lower half of each panel. Note that data are only shown from detector bins which do not look into the wake, to avoid contamination at low energies; that is why some of the panels do not cover all pitch angles.

Figure 3. Example of fine structure in the relationship of accelerated ions to plasma density. Ions from 6 eV to 750 eV are plotted in the top panel and electric fields from 5 kHz to 0.5 MHz are plotted in the bottom panel.
An accompanying paper demonstrates a precise correlation between the accelerated ion structures, measured wave activity and ionospheric density levels [Kintner et al., 1996]. It concludes that the waves are likely to be current driven electrostatic waves generated in regions of low ionospheric density. In this paper, let us examine the features of the ion data themselves in more detail. From Figure 1 alone we can make a number of observations. The events start abruptly at the T+700 s boundary, and continue intermittently for about 300 s (300 km) in regions several tens of km wide.

To examine the relationship of the accelerated ion structures to precipitating electrons we first discuss the electron populations measured. They consist of (a) suprathermal bursts, and (b) inverted-V events. The suprathermal bursts are characterized by strong field alignment over a broad energy range, from the instrumental threshold of 5 eV to a few keV [Johnstone and Winningham, 1982]. The most obvious suprathermal bursts distinct from inverted-V’s are located approximately at T+735 s, T+720-735 s, T+772-800 s, and T+900-920 s (see panel A of Figure 1). The observed inverted-Vs reach energies of several keV. They can be seen approximately at T+385-870 s and T+950-1000 s.

From our observations of accelerated ion structures on the dayside as shown in Figure 1 we conclude that they are loosely correlated with superthermal bursts of electrons but not with inverted-V’s unless the inverted-V is accompanied by suprathermal bursts. This relationship is consistent with the early research on transversely accelerated ions. [Klumper, 1979].

Figure 2 shows ion distribution functions during the strongest of the accelerated ion structures. The first three panels show the development of the ion acceleration as the spacecraft moves into the structure: 2.5 km before the border of the structure, right at the border, and 2.5 km after the border (assuming a spacecraft motion of 1 km/sec). The acceleration is confined in pitch angle to a narrow region near 104 degrees, indicating a heating region approximately 30 km below the spacecraft. (At this time, the spacecraft is at an altitude of 144 km.) The acceleration has a “bowl” shape, since the lowest energies measured do not appear to be raised in pitch angle as is the higher energy tail. The temperature of the tail at T+768.7 s (panel b of Figure 2) is 42 eV. The levels of f within the event are comparable to satellite measurements as discussed below.

The last panel of Figure 2 shows the distribution deep within the center of the event, at T+785.6 s. (The region extends from T+765 s to T+800 s, and so is about 35 km wide.) By this time the distribution of accelerated ions has spread in pitch angle suggesting an enhancement of downward flow. Such downward flow has been noted in a previous flight when transverse ion acceleration was measured in close proximity to auroral electrons. [Garbe et al., 1992].

Data from the Suprathermal Ion Mass Spectrometer aboard the EXOS-D (Akebono) spacecraft [Knudsen et al., 1994] show a sudden commencement of ion conics at the sharp equatorward boundary of the Cusp/Cleft region between altitudes of 2000 to 8000 km. Knudsen et al. [1994] show that most of the heating takes place within a region less than 30 km wide as ionospheric plasma is convected through the heating slab. The SCIFER TAI in general confirm this scenario. The SCIFER TAI occupy open field lines and commence at the boundary between closed and open field lines [Lorentzen et al., 1996] at T+700 s in Figure 1. Presumably this is the equatorward boundary of the Cleft as discussed by other papers in this issue. Three periods of ion acceleration were measured between T+700 s and T+900 s and the width of the region with the most intense TAI fluxes was 30-40 km wide.

A very extensive data set on dayside ion conics has been collected by the EXOS-D Low Energy Particle experiment [Miyake et al., 1993]. Miyake et al. [1993] report temperatures between 10 and 100 eV for the dayside conics over an altitude range of 3000 and 9000 km, with the higher temperatures occurring at the higher altitudes. The temperature for the SCIFER TAI event at 768.7 s FT (see panel b of Figure 2) is 42 eV.

A comparison of satellite and rocket ion intensities can best be made by comparing the value of the distribution function measured at the two locations. To the best of our knowledge there is only one published quantitative phase space distribution of transversely accelerated ions in the C1F. The phase space plots obtained by the RIMS DE-1 instrument, at an altitude of about 1 Re, can best be used for this comparison [Moore et al., 1986]. At 20 km/s, the RIMS instrument measured a O+ distribution function level of 1 x 1013 sec^-2/km^6 for a conic that was folded such that it would have originated near the rocket altitude of 1000 km. The SCIFER f-value at 20 km/s is 3 x 1012 sec^-2/km^6. We believe this difference to be within that expected from natural variations. For example the SCIFER measurements were made during Kp of 2+, near solar minimum while the RIMS measurement was made during Kp of 3-, near solar maximum.

The relationship of ionospheric density to accelerated ion structures and the steep gradient in ion fluxes at the edges of these structures is remarkable. Kintner et al. [1996, this issue] show some examples of this correlation. We show another example here which demonstrates that the degree of correlation between reduced plasma density and accelerated ions is at the level of the instrumental resolution. The bottom panel of Figure 3 demonstrates that there was a narrow region of increased Langmuir frequency from T+788-790 s corresponding to increased plasma density. The accelerated ion fluxes in the top panel decreased and then increased again in synchronism with the plasma density changes. At T+788 s the ion fluxes decreased below threshold in one energy sweep (166 ms) at the same time that the Langmuir frequency increased. From this example we conclude that the ion acceleration and reduced plasma densities are collocated within about 166 ms or about 166 m across geomagnetic field lines. These re-
sults set specific criteria for the heating of ions by electrostatic ion cyclotron waves as simulated by Ganguli et al. [1988] in that the mechanism is very closely correlated with density drop-outs and sharp gradients in the ambient density.

This correlation is so obvious that it leads to two conclusions. First the accelerated ion structures must be spatial since the ionospheric density structure should be relatively long lived. Conversely the accelerated ions may be producing the ionospheric density structure by eroding ionospheric plasma. Second the ion acceleration mechanism must prefer regions of lower plasma density and be capable of producing very sharp gradients at the edges of the accelerated ion structures. It is tempting to speculate that the ion acceleration mechanism is density dependent and by eroding ionospheric plasma it forces itself into density channels.

Conclusions and Plans for Further Analysis

The ion data in the TAI events on SCIFER are consistent with measurements of the “heating wall” seen in Akebono data, and the cleft ion fountain seen in DE-1 at much higher altitudes. Although we can not directly compare our measurements with the results from DE-2 and HILAT, they certainly support their conclusions that the prenoon cleft is an active region of ion outflows.

The high time resolution of the SCIFER data set reveals the physical details of transverse ion acceleration within the dayside auroral region. Our initial examination of the data set demonstrates that cleft transversely accelerated ions originate at altitudes at least as low as 1200 km, that the TAI can be found in narrow regions (30-40 km) with well defined boundaries, and that the accelerated ions are found coincident with and poleward of the trapping boundary. Furthermore the acceleration mechanism must prefer regions of lower density and be capable of producing structure at the level of a few hundred meters. From our data set we note that the accelerated ion structures were found in regions of ionospheric density of $10^3/\text{cc}$ or less. This may explain the lack of similar observations from other sounding rockets. It will be interesting to compare this dayside mechanism to the similar event measured by the AMICIST rocket in the nightside aurora.

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References


R. L. Arnoldy and K. A. Lynch, Institute for the Study of Earth Oceans and Space, University of New Hampshire, Durham NH 03834. (email: roger.arnoldy@unh.edu; lyucc@unh.edu)

P. M. Kintner and J. Bonnoll, School of Engineering, Cornell University, Ithaca, NY 14853

T. E. Moore and C. J. Pollock, Space Sciences Laboratory, NASA Marshall Space Flight Center, Huntsville, AL 35812

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