NIGHTSIDE POLAR CAP BOUNDARY AURORAL ION OUTFLOW DURING SUBSTORMS

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ABSTRACT

We present observations of ion conic outflow on the nightside auroral polar cap boundary from the FAST satellite during January/February 1997. Our statistical study reveals that these high ion outflow events occur preferentially near magnetic midnight, where magnetic field lines map directly to the nightside plasma sheet. Furthermore, by identifying substorm onsets through Polar UVI images, we find that events are associated with substorm expansion phase, though not exclusively. We estimate the total outflow due to an average event to be in the 10^{23} ions/sec range, and conclude that during substorms and active aurora, the polar cap boundary ion conic outflows are an important contributor of ionospheric plasma to the nightside plasma sheet.

Key words: ion conics; polar cap boundary; ion outflow.

1. INTRODUCTION

Ion conic distributions were first observed by *Sharp et al.* [1972] on 1976-65B and have since been observed by many other satellites such as S3-3 [*Gorney et al.*, 1981], DE-1 [*Peterson et al.*, 1992], ISIS-1 and ISIS-2 [*Klumpar*, 1979]. As the ionosphere is considered by some [*Chappell et al.*, 1987] to be a fully adequate source of plasma for the earth's magnetosphere, ion outflow due to ion conics, as an important component of the ionospheric outflow, is important to characterize, particularly during active times.

In the current study, we observe high flux ($> 10^8$ cm^{-2} s^{-1}) ion conic outflow on the nightside auroral polar cap boundary on 168 of 606 FAST auroral crossings. These outflows take place on the nightside, where magnetic field lines are directly connected to the magnetotail. In addition, in more than half of the cases where a polar cap boundary is observed, the ion outflow on the polar cap boundary accounts for the majority of ion outflow over the entire auroral pass. In this study, we find that the ion outflow is correlated with substorm expansion phase, but also occurs during other active aurora.

We present statistics to show that the ion conic outflow occurs near midnight, and is higher after a substorm onset. In addition, we calculate the total ion outflow associated with those events near substorms, when the MLT extent of the outflow can be estimated from UVI data.

2. DATA

In this study, we present data from the FAST and Polar satellites. FAST was launched in August 1996 and has an orbit inclination of 83 degrees, with an apogee of 4180 km and a perigee of 350 km. Polar was launched in 1996 and has an inclination of 86 degrees with an apogee of 8 R_E and a perigee of 0.8 R_E. The Ultraviolet Imager (UVI) images used in this study were taken near Polar apogee over the northern hemisphere.

Figure 1 shows FAST particle data from orbit 1809, during which an ion conic event occurred from 07:25:40 UT to 07:26:40 UT. The event is most clearly seen in panels 3 (ion pitch angle spectrogram) and 4 (ion energy spectrogram) as an enhancement in energy flux at pitch angles near 120 and 250 degrees and at energies from a few eV to hundreds of eV. The ion number flux (> 20 eV) is integrated over all pitch angles and is plotted in panel 7. Note that panel 7 is plotted on a logarithmic scale so that the ion outflow number flux is an order of magnitude higher at the polar cap boundary than elsewhere in the auroral pass. It is evident that the outflow from the polar cap boundary ion conic dominates the total ion outflow of the entire auroral pass. Panel 8 is an integral of the curve in panel 7, and makes this more apparent. From the TEAMS ion composition

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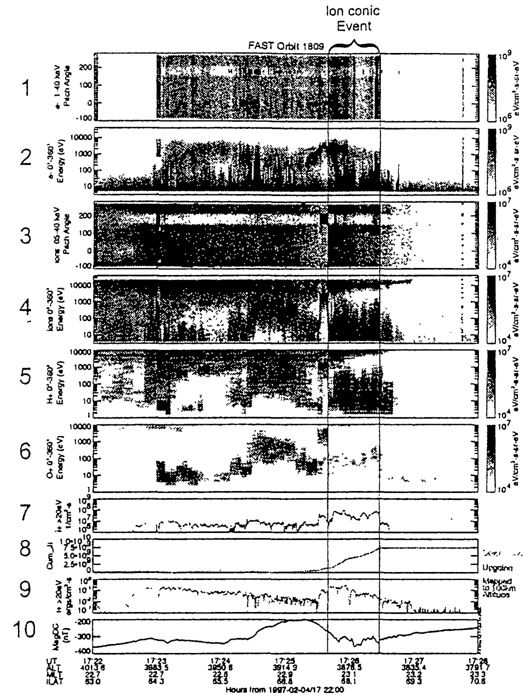

Figure 1. FAST Orbit 1809 summary data. Panels 1 and 2 show electron pitch angle and energy spectrograms. Panels 3 and 4 show ion pitch angle and energy spectrograms from the ion electrostatic analyzer. Panels 5 and 6 show H+ and O+ pitch angle spectrograms from the mass-resolving TEAMS instrument. Panel 7 shows integrated ion number flux over all pitch angles and energies > 20 eV. Panel 8 is the integral of the curve in panel 7. Panel 9 shows integrated ion energy flux over all pitch angles and energies > 20 eV. Panel 10 shows east-west magnetic field, where a positive slope indicates a downward current region.

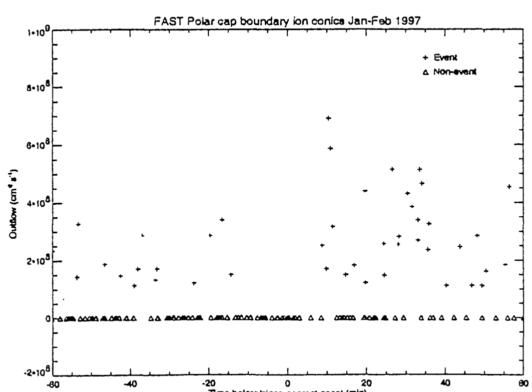

Figure 2. Peak ion outflow flux plotted versus time since or before substorm onset time. Events are plotted as plus signs while non-events are plotted with zero outflow as triangles.

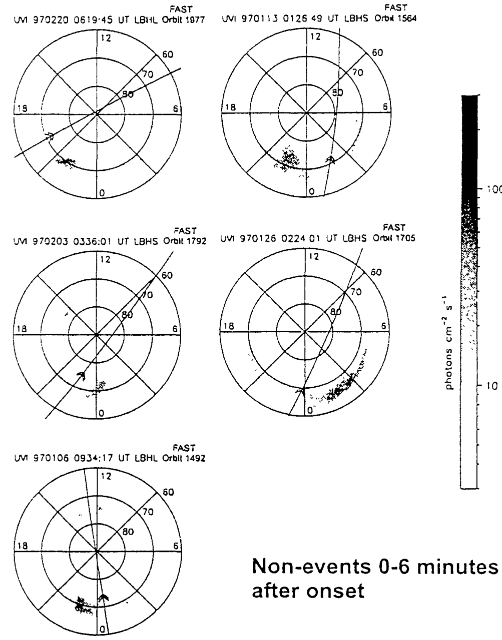

Figure 3. Polar UVI images of non-events 0-6 minutes after onset. Images are plotted in MLT/ILAT coordinates and are viewed either through Lyman-Birge-Hopfield Long (LBHL) or Short (LBHS). The two arrows show the direction and location of the FAST satellite at the start and end of the integration period of each image.

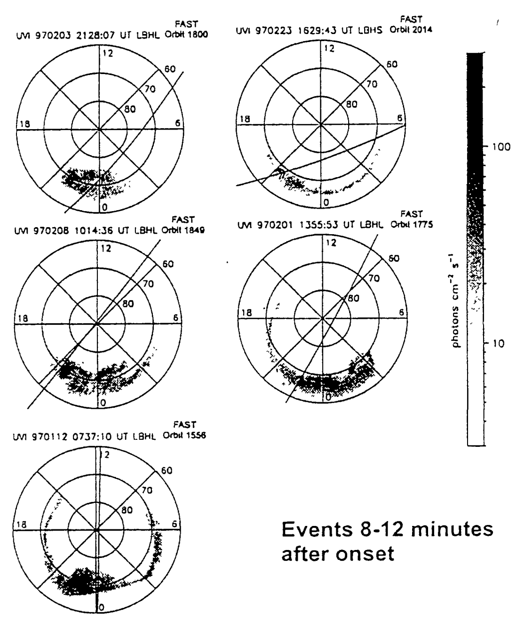

Figure 4. Polar UVI images of events 8-12 minutes after onset

data in panels 5 and 6, we see that the ion conics are composed of more H+ than O+.

3. STATISTICAL STUDY

In order to explore the conditions under which these polar cap boundary ion conics occur, a statistical study was done using FAST orbits during January/February 1997 to characterize their occurrence in MLT, their relation to substorms, and the magnitude of the outflow.

Ion conic events were identified through viewing of FAST ion summary plots, which are 5-second (spin period) averaged IESA data. An ion conic was classified as an event if:

1. It exhibited outflow number flux $> 10^{8} cm^{-2}s^{-1}$ when integrated over all pitch angles and energies > 20 eV, mapped to 100 km altitude, and
2. It occurred on the polar cap boundary.

In order to normalize the statistics, non-events were recorded for all FAST nightside auroral polar cap boundary crossings during which no outflow $> 10^{8}$ cm^{-2} s^{-1} was seen.

By examining a histogram of the MLT distribution of events, we found that the polar cap boundary ion conics are centered near midnight, with the peak occurrence falling in the hour before midnight.

We also analyzed the ion conic outflow relative to substorm phase. Substorm onset times were determined using Polar UVI images to identify times when a clear auroral breakup was followed by an expansion phase.

A delay and prior time relative to the nearest identified substorm onset was then calculated for each ion conic event. Figure 2 shows the plot of ion conic event outflow flux versus the time since/before substorm onset. We note that in our study of 606 FAST orbits, many events were outside the limits of -60 to +60 minutes, but we consider points falling beyond this range as due to the lack of identified substorm onset times, rather than to a true long delay. That is, we do not believe there is a direct physical mechanism that relates an ion conic event to the substorm onset identified 4000 minutes earlier. Rather, such a long delay time is due to an extended period of disturbed auroral activity during which no clear substorm structure is evident.

We make two statements from figure 2: 1) because there are 14% events before and 45% events after onset, the likelihood of observing an event after onset is higher, and 2) because the average outflow flux is 1.98×10^{8} cm^{-2} s^{-1} before an onset and 3.01×10^{8} cm^{-2} s^{-1} after an onset, the outflow flux is higher

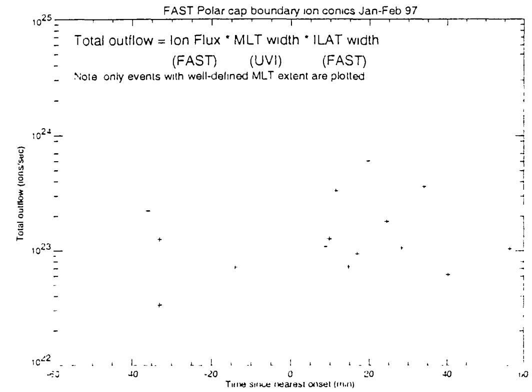

Figure 5. Total ion outflow rate for events within one hour of substorm onset

after substorm onset. For comparison, the average outflow of all 168 events is 2.46×10^{8} cm^{-2} s^{-1}.

In addition, we note that non-events that are recorded near substorm onset are due to the FAST satellite not passing through the localized substorm onset location. We show Polar UVI images with the FAST trajectory overlaid in figures 3 and 4 to demonstrate this. Figure 3 is a series of non-events that occur 0-6 minutes after a substorm onset, and figure 4 is a series of events that occur 8-12 minutes after substorm onset. It is clear in these cases that in all the events FAST passes through the localized enhancement in the aurora, whereas in all the non-events FAST does not pass through the enhancement. We also mention that the correlation of the onset "spot" with the observation of an ion conic event becomes less clear farther away from onset.

4. TOTAL OUTFLOW

In order to estimate the total ion outflow due to an ion conic event, we multiply the observed fluxes by an area, where the ILAT extent is determined from FAST data and the MLT extent is determined by Polar UVI data. Only in 27 select events was it possible to estimate the MLT extent of the ion outflow. We plot in figure 5 the events falling within one hour of identified substorm onsets. Most events fall in the 10^{23} ions/sec range. We estimate our results to have an uncertainty of a factor of 2.

5. DISCUSSION

Based on individual FAST passes, the ion conic outflow on the polar cap boundary appears to dominate the total ion outflow on many nightside auroral passes. Indeed, the flux values observed of several times 10^{8} cm^{-2} s^{-1} is greater than average fluxes in the 10^{7} cm^{-2} s^{-1} range reported by *Yau et al.* [1985] in the 21-03 MLT sector.

However, when we compare the total ion outflow (in ions/sec) due to the nightside polar cap boundary conics on the order of 10^{23} ions/sec with values of 10^{25} ions/sec ion outflow over the total auroral oval reported by *Yau et al.* [1985], it appears that the outflow contribution of the polar cap boundary ion conic is small. Several factors exist to explain this apparent discrepancy.

First, *Yau et al.* [1985] obtain their 10^{25} ions/sec value by integrating over all magnetic local times, including the cusp (09-15 MLT), which, according to their figures, has fluxes higher by a factor of 2-5. Therefore, only 1/3 to 1/6 of the 10^{25} ions/sec can be attributed to outflow from the 21-03 MLT sector.

Our values are integrated over 1 or 2 hours of MLT, for those events which we are able to estimate a MLT extent. From UVI images, there is evidence to indicate that the polar cap boundary ion conics occur over a much broader range of MLT, possibly 8-10 hours.

Our data were taken in January and February 1997, during solar minimum, when $F_{10.7}$ was approximately 70. For comparison, *Yau et al.* [1985] used data from 1983-1984, when $F_{10.7}$ was approximately 90-140. It is uncertain based on *Yau et al.*'s [1985] discussion what factor to assign to account for the difference in $F_{10.7}$ but it does not seem unreasonable to use a factor of 1.5 to 2.

Based on these uncertainties, our values of polar cap boundary ion conic outflow in the 10^{23} ions/sec range should be adjusted by a factor of 35 to 120 before comparison with *Yau et al.*'s [1985] figures. Our results would then be consistent with *Yau et al.* [1985].

We have observed higher average ion outflow fluxes after substorm onset, during substorm expansion phase, than before substorm onset, during substorm growth phase. This association is clear for the well-structured substorms for which onsets were identified. However, because of the dynamic nature of the aurora, it is not possible to classify all events into phases of a substorm and we observed many ion outflow events during generally active aurora. The ion outflow is probably due to a feature, though present during substorm expansion phase, is not unique to the expansion phase.

The simultaneous observation of high energy dispersed precipitating ions (see figure 1 panel 4), a signature of ion injections from the X-line, with the polar cap boundary ion conics provides evidence that the outflows occur on closed magnetic field lines. This means that the outflow has a direct magnetic path to the magnetotail and does not flow out along open magnetic lines out of the earth's magnetosphere, thus strengthening our argument that polar cap boundary ion conic outflow is an important contributor of ionospheric plasma to the earth's magnetotail.

6. CONCLUSION

We have observed ion outflow in the form of polar cap boundary ion conics on the nightside auroral oval. The outflow at the polar cap boundary dominates the outflow over the entire nightside aurora on over half of all FAST nightside auroral passes during January/February 1997 for which a polar cap boundary ion conic is observed. The ion conic is generally composed of light ions and has energies ranging from a few to a few hundred eV. Polar cap boundary ion conic events occur near midnight, where magnetic field lines connect to the magnetotail. In addition, these polar cap boundary ion conic events are associated with substorm expansion phase, though not exclusively. The correlation of an ion conic event with an enhancement in UV emissions is clear near substorm onset but decreases farther away from substorm onset. Calculation of the total ion outflow rate for polar cap boundary ion conics results in values of 10^{23} ions/sec, which, when differences in method of analysis are taken into account, is consistent with *Yau et al.* [1985] values of 10^{25} ions/sec over the entire oval. Ion outflow in the midnight sector, though on average may be lower than cusp ion outflow, has bursts of high ion fluxes that occur on the polar cap boundary during substorm expansion phase and during active aurora. Because these occur on the nightside on closed magnetic field lines, we view the polar cap boundary ion conic outflow as an important contributor of ions to the nightside plasma sheet and magnetotail, particularly during substorms and active aurora.

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