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OCCURRENCE DISTRIBUTION OF PREFERENTIAL HEATING EVENTS IN THE AURORA

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ABSTRACT

The FAST satellite has detected a class of ion conic events in which He^+ is more strongly accelerated than H^+ or O^+. The helium ions in these events typically have 3–30 times the energy of simultaneously observed protons, unlike most conics, in which no strong preferential acceleration occurs. These events are well correlated with the occurrence of electromagnetic ion cyclotron (EMIC) waves and are associated with inverted-V electron distributions. The acceleration mechanism is similar to a mechanism which has been proposed for the acceleration and enrichment of ^3He in impulsive solar flares. We present a statistical study of such events in the FAST data set. We show that these events are found primarily in the pre-midnight sector and that their occurrence distribution is similar to the distributions previously found for inverted-V electron events and for EMIC waves. ©1999 COSPAR. Published by Elsevier Science Ltd.

INTRODUCTION

Transverse acceleration of ions, which leads to the formation of ion conics, is a ubiquitous feature of the aurora. Although lower hybrid waves and ULF waves have been suggested as candidates for heating ions, the heating is much more efficient when part of the wave energy is at the ion cyclotron frequency since the waves and particles can then interact resonantly (e.g., Chang *et al.*, 1986).

Three types of wave emissions are associated with ion conics in the aurora (André *et al.*, 1998). The most common is a broad-band ELF (BBELF) emission, but electromangetic ion cyclotron (EMIC) waves are found in a sizeable number of cases, particularly in the pre-midnight sector. Some less spectacular ion conics are associated with lower hybrid waves.

When EMIC waves accompany an ion conic, He^+ is found to be energized more efficiently than other species (Lund *et al.*, 1998). Such a preferential acceleration is needed to explain upflowing He^+ fluxes in a sizeable fraction of the cases studied by Collin *et al.* (1988). The He^+ is apparently accelerated by a cyclotron resonant interaction with the waves near the altitude where their frequency equals the helium gyrofrequency f_{cHe^+}. Such an interaction is believed to be responsible for producing X-type distributions of He^+ in the equatorial magnetosphere (Anderson and Fuselier, 1994), and this mechanism is similar to a mechanism that has been proposed to account for anomalously high ^3He abundances in impulsive solar flares (Temerin and Roth, 1992).

SAMPLE DATA

The Fast Auroral Snapshot Explorer (FAST) was launched 21 August 1996 into a 4200 × 350 km orbit with 83° inclination. FAST carries the Time-of-flight Energy Angle Mass Spectrograph (TEAMS), which simultaneously measures 3-D distributions of H^+, He^{2+}, He^+, and O^+ at 0.001–12 keV and also provides a mass spectrum over the range 1–60 amu/q (Möbius *et al.*, 1998). Other instruments aboard include electrostatic analyzers for electrons and ions, electric field sensors, and fluxgate and search coil magnetometers.

An example of an ion conic with preferential acceleration is shown in Figure 1, which shows electron, ion, TEAMS, and wave data from an auroral pass taken near 23 MLT on 24 January 1997. FAST is near apogee during this pass. The preferential heating event occurs at 12:46:10–30 UT, during an inverted-V electron event. Note that the He^+ is heated to an energy of about 1700 eV, compared with 100 eV for O^+ and 200 eV for H^+. A conic associated with BBELF emissions is also seen during this pass at 12:45:30–50. (The low flux levels for H^+ and O^+ at 12:46:35, during the beam, are due to a data dropout.)

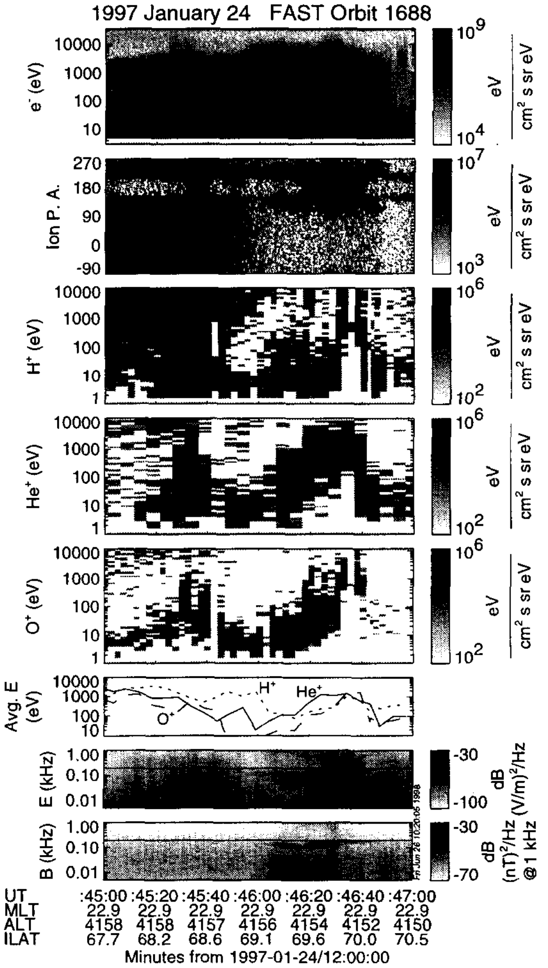

Fig. 1. Electron energy, ion pitch angle, and H^+, He^+, and O^+ energy spectrograms; characteristic energy for the three major ion species; and ELF electric and magnetic field spectrograms from a preferential acceleration event seen by FAST on 24 January 1997. The lines across the wave spectrograms denote the local proton gyrofrequency.

STATISTICAL RESULTS

A statistical survey of data from September 1996 to February 1997 has identified 714 ion conics, of which 106 are associated with EMIC waves. Figure 2 shows the locations of the events associated with EMIC waves. The majority of these events are in the pre-midnight sector; only a handful occur between 03–12 MLT. BBELF ion conics, by contrast, are found at all local times with comparable probability (not shown).

The association between EMIC waves and preferential He^+ heating in conics is illustrated in Figure 3, which shows a histogram of the energy ratios between He^+ and H^+ for the EMIC events identified in the FAST data. The median value of this energy ratio is about 5. A similar histogram for ion conics associated with BBELF emissions (not shown) shows that this energy ratio is nearly 1 for 85% of BBELF events and in the range 0.4–2.5 for 95% of BBELF events.

Figure 4 shows how the occurrence distribution of preferential He^+ heating events with respect to magnetic local time compares with a previous statistical study of the occurrence of EMIC waves in the aurora with the ISIS data sets (Saito *et al.*, 1987). Figure 5 shows a similar comparison for the distribution over invariant latitude. A recent survey of Freja data (Erlandson and Zanetti, 1998) shows a similar distribution to the ISIS study. Our results agree qualitatively with both previous studies, although our distributions are more

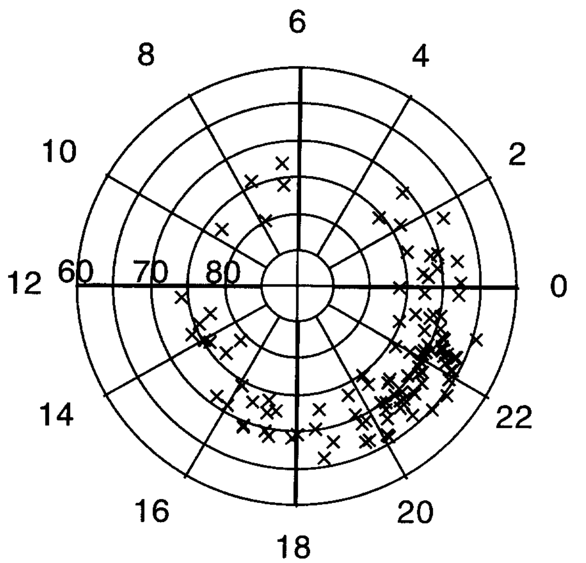

Fig. 2. Locations of preferential He^+ acceleration events in invariant latitude and magnetic local time.

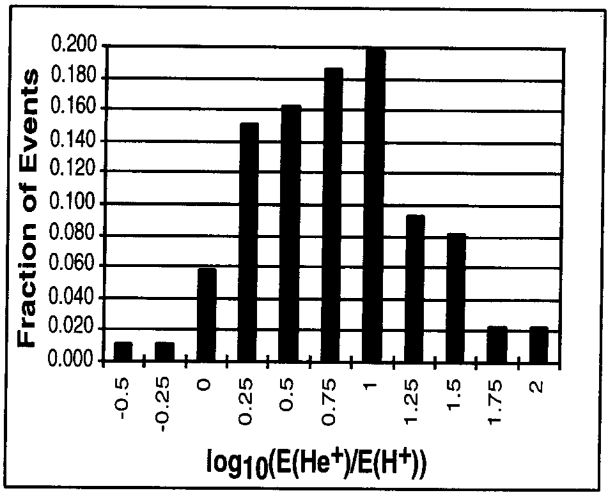

Fig. 3. Histogram of energy ratios between He^+ and H^+ for ion conic events coincident with EMIC waves.

sharply peaked than those of Saito *et al.* (1987). The difference could result from EMIC wave propagation effects (see Lund and LaBelle, 1997, for a discussion) or from variations with the solar cycle.

The distribution of electron acceleration events in the DMSP data (Newell *et al.*, 1996) is also similar to our distribution. This association also holds for individual events as well: preferential He^+ acceleration events almost always occur within "inverted-V" structures. This association suggests that downgoing electrons are necessary but not sufficient for generating the EMIC waves that produce the preferential acceleration. Erlandson and Zanetti (1998) made a similar conclusion in their study.

We have also detected a seasonal variation in the occurrence of these events. During September–October 1996, FAST crossed the southern hemisphere aurora near apogee around 20–24 MLT; during January–February 1997, FAST covered the same local time range near apogee in the northern hemisphere. We find more preferential He^+ acceleration events in the northern winter than in the southern spring. This variation is consistent with the previously established seasonal dependence of EMIC emissions (Saito *et al.*, 1987; Erlandson and Zanetti, 1998) and of intense "inverted-V" electron events (Newell *et al.*, 1996).

SUMMARY

The results of this study reinforce the association noted previously between EMIC waves and transverse heating of He^+ (Anderson and Fuselier, 1994; Lund *et al.*, 1998). In addition to the correlation of preferential He^+ heating in ion conics with EMIC waves, we have shown that the distribution of these ion conics is similar to the distribution previously found in statistical studies of EMIC waves (Saito *et al.*, 1987; Erlandson and Zanetti, 1998). Preferential acceleration events are also well-correlated with so-called inverted-V electrons. The relative importance of EMIC and BBELF waves in transverse ion acceleration will be addressed in a future paper.

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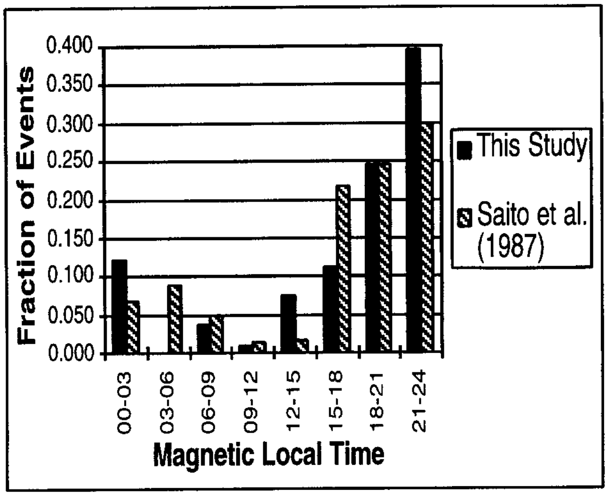

Fig. 4. Distribution of preferential heating events (this study) compared with EMIC occurrence (Saito *et al.*, 1987) over magnetic local time.

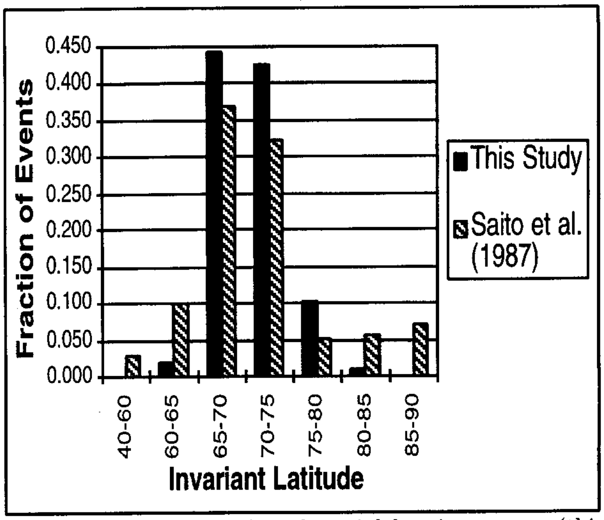

Fig. 5. Distribution of preferential heating events (this study) compared with EMIC occurrence (Saito *et al.*, 1987) over invariant latitude.

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