A Narrow Region of Electron Beams at the Poleward Edge of the Cusp

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Viking electron energy spectrogram (ESP) and positive ion energy spectrogram (PISP) data show that there is a thin and faint but distinguishable region at the poleward edge of the cusp-cleft region. This region is characterized by 100- to 300-eV field-aligned electrons with no striking ion feature except for coexisting low-energy upward ions. These faint electron beams are almost always observed unless the interplanetary magnetic field (IMF) is southward, yet they are different from the polar arcs, boundary cusp electrons, and the merging type electron burst on merging field lines for the following reasons. First, the thickness of this region (very thin) and the electron beams' pitch angle distribution of this region are clearly different from those of the boundary cusp or the polar arc region. Second, these electron beams are observed during weak IMF when the ions do not show any merging-associated energy dispersion. This region sometimes exists even when the merging line is located on the other (equatorward) side of the cusp, indicating that these electron beams are not the merging-related electron burst. Third, this region is absent near local noon (1130-1230 MLT). The electron beams are found rather on the morningside and the afternoonside. This special distribution is not expected for polar arcs or merging-related electron bursts. The absence of the thin electron beam region near local noon indicates, together with its latitudinal location (always between the cusp and the polar cap or polar arcs), that the tail boundary layer can be a possible source of these electron beams. Since this newly found region is very thin and it is always located between the cusp and polar cap or polar arcs, we call it the cusp poleward edge, despite its absence near local noon.

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1. Introduction

The cusp-cleft region is a special region in the sense that various regions of the magnetosphere are mapped and condensed into this small area [*Elphinstone et al.*, 1991]. It thus contains much information about the magnetospheric topology and its physics. Following a number of studies [*Lundin et al.*, 1991; *Smith and Lockwood*, 1990; *Newell et al.*, 1991*a,b*; and references therein], the cusp-cleft region may be subdivided into even smaller regions which can be mapped to different regions of the magnetosphere [*Kremser and Lundin*, 1990]. However, it is still an open question how each part of the subdivided cusp-cleft region is mapped to regions of the magnetosphere, especially when the interplanetary magnetic field (IMF) is northward. In this case, the poleward part of the cusp is considered to be the most densely mapped region, but it is not well studied yet. The poleward boundary of the cusp-cleft region can be mapped far into the magnetotail, as *Murphree et al.* [1990] suggested from their UV observations of extraordinary auroral emission when the IMF is northward. Here we focus on this area. We use Viking particle data in the present study.

2. Particle Observation

Figure 1 shows the electron and the ion energy spectrogram for the cusp-cleft traverse of orbit 218. Both the IMF B_y and B_z measured by IMP 8 are zero without disturbances during this period. The particle precipitation pattern agrees with this IMF condition: the mantle cusp is very thin, and no energy dispersion in the ion spectrum nor velocity filter effect [*Burch et al.*, 1982] (see also *Menietti and Burch* [1988]) is recognized in the cusp proper (1244-1251 UT) or in the boundary cusp (1251-1254 UT). There is an isolated electron burst at 1240 UT on the poleward side of the cusp proper. The magnetic field data show that this electron beam does not carry a substantial amount of the large-scale field-aligned current. The characteristic energy is a few hundred electron volts, which is the same energy level as the boundary cusp, but there is no outstanding ion feature distinguishing this region from the boundary cusp. This small electron event is rather commonly observed when the IMF is very weak or northward.

Figure 2 (orbit 967) shows another example of the small electron beam on the boundary between the cleft and the polar cap when the cusp is very quiet without any temporal structure. The IMF is $B_y = -3$ and $B_z = +2$. Again, the mantle cusp is quite thin, and the ion dispersion is absent, which is consistent with the measured IMF B_z. The negative IMF B_y is also confirmed by the magnetic field data, i.e., the polarities of IMF B_y dependent field-aligned currents near local noon (*DPY* field-aligned currents) [*Friis-Christensen et al.*, 1985]. They are upward (1554-1602 UT) on the equatorward side and downward (1603-1612 UT) on the poleward side, corresponding to dawnward IMF. Right on the poleward edge of this large-scale field-aligned current system, there is a faint and narrow electron beam at 1612 UT. Therefore this electron beam is considered to be on the poleward edge of the cusp-cleft region. The particle data also support this because the polar cap starts beyond this electron beam. Again, it is clearly different from the merging-related feature or the boundary cusp. According to our model for the IMF B_y effect on the cusp current system [*Yamauchi et al.*, 1993], one may expect another field-aligned current poleward of the limit of the cusp-cleft region flowing on the prenoon polar arcs, but neither such a field-aligned current nor the polar arc is recognized in the present case. Therefore we interpret that the prenoon polar arc does not extend to this longitude.

The faint electron beam on the poleward boundary of the cusp-cleft region is not always downward oriented although it is so in the above examples. Figure 3 (orbit 1108) shows the same type of electron beam on the poleward boundary of the cusp-cleft region. It is bidirectional rather than downward-oriented in this case. The IMF is $B_y = -3$ and $B_z = +1$, and stable. The boundary cusp extends to 0740 UT, beyond which the bidirectional electrons are observed in 1° width. If the latitudinal extent of this electron beam is as narrow as 0.2° or less, which corresponds to one spin of the satellite, it can be detected as a single downward or upward beam. Therefore we interpret this as the same phenomenon as the electron beam of Figures 1 and 2.

One may question whether the bidirectional beam can be a part of the dayside polar arc. Since it is field-aligned, the electron beam might be related to some sort of optical emission; however, it is at least different from what we traditionally call the polar arc [e.g., *Hardy et al.*, 1986; *Eliasson et al.*, 1987] for three reasons. First, this electron beam is very narrowly distributed (as narrow as 0.1°). Second, its longitudinal distribution is different from that of the polar arc. This point is discussed in section 3, where we perform a statistical analysis. Third, the morphology is different; i.e., the intensity is very low, and the pitch angle distribution is different. Figure 4 (orbit 1148) shows an example of the dayside polar arc. The IMF data are missing for this traverse; however, we may easily infer $B_z > 0$ from the particle energy dispersion (increasing energy toward pole) [*Woch and Lundin*, 1992*b*] and $B_y < 0$ from the polarities of *DPY* field-aligned currents [*Friis-Christensen et al.*, 1985].

The electron and ion data show that the satellite is on the boundary cusp (or the acceleration region of *Woch and Lundin* [1992*a*]) up to 1354 UT. Structured electrons are observed after 1355 UT, corresponding to the traversal of a morningside polar arc for IMF $B_y < 0$ [*Elphinstone et al.*, 1990]. There are clear differences between these structured electrons and the electron beams of the previous figures. The most important one is the pitch angle distribution. The electron lacks the beamlike characteristics in the polar arc. Also, the latitudinal extent is different; i.e., the polar arc is more widespread. Thus the faint electron beams found in Figures 1, 2, and 3 are different from the polar arc. Since they are also different from the merging-related electron burst or the boundary cusp, we may suggest a new name for this small region of electron beams: the cusp poleward edge, indicating it is always found as a thin layer between the cusp and the polar cap or polar arcs.

Near 1354:30 UT between the cleft and the polar arc, one can identify a rather clear electron beam. We can not here distinguish the cusp poleward edge from the merging-related electron burst (J. Woch, private communication, 1991). Since the negative B_y should cause a shift of the merging point toward prenoon, the rather strong electron beam at 1040 MLT could be either of them. We leave this unsolved here. In section 3, we use only clear cusp poleward edge cases for the statistical study and exclude confusing cases like this example.

As is briefly mentioned, the electron beam might be recognized as some sort of optical emission. *Murphree et al.* [1990] recently reported that there is such an emission poleward of the ordinary dayside aurora [e.g., *Lui et al.*, 1987]. A tiny series of discrete aurora is seen mostly at the poleward edge of the cusp-cleft region during northward IMF. Although the observed cusp aurora can be associated with the polar arc rather than the cusp poleward edge, this UV observation still supports the present particle observation of the cusp poleward edge.

3. Statistics

The cusp poleward edge is sometimes observed and sometimes not. What determines it? Let us consider the fact that the cusp poleward edge's electron beam appears on the boundary of the cusp-cleft region and the polar cap or the polar arc. This transition is clear when the IMF is northward because the mantle cusp shrinks [*Sckopke et al.*, 1976; *Woch and Lundin*, 1992*b*]. Such a clear boundary is hardly expected when the southward IMF causes the mantle cusp to be widespread and causes antisunward convection. The electron and ion fluxes in the mantle cusp gradually decrease toward the polar cap in this case [*Woch and Lundin*, 1992*b*], and the transition to the polar cap is very smooth. Therefore we may not expect the cusp poleward edge to exist when the IMF is southward or, more precisely, when the cusp morphology corresponds to the southward IMF with gradual transition between the cusp-cleft region, the mantle, and the polar cap.

Figure 5*a* shows the IMF dependence of the appearance of the cusp poleward edge, i.e., the field-aligned electron beam at the poleward edge of the cusp-cleft region. We employ types of cusp instead of the IMF B_z for the classification. We identify the cusp as a south type when the ion and the electron fluxes in the widespread mantle cusp decrease toward the polar cap [*Newell et al.*, 1991*a*]. The remainder are termed north type cusps. The types of cusp and the actual IMF have a strong correlation [*Woch and Lundin*, 1992*b*].

The figure clearly demonstrates a strong IMF dependence of the cusp poleward edge appearance. It is often observed in the north type cusp, but not in the south type cusp at all. Although there are two exceptional examples of the faint electron burst event for the southward IMF according to Figure 5*a*, the cusp types of these examples are rather marginal between southward IMF and weak IMF (relatively short mantle), and we may still conclude that the cusp poleward edge does not exist for a south type cusp. The appearance of the cusp poleward edge is more dependent on the cusp types than the measured IMF B_z polarity, suggesting that the IMF effect on the cusp poleward edge is related to the cusp morphology rather than to the magnetospheric activity as shown in Figure 5*b*. However, this result does not necessarily mean that the cusp poleward edge's electron beams are coming from the dayside. The cusp-cleft region is a kind of singular region in the magnetosphere-ionosphere mapping, and it can be mapped to a large area of the magnetosphere, i.e., not only to the dayside but also to the nightside.

Figure 5 also shows that the cusp poleward edge does not always exist even in the north type cusp. In other words, there is an unknown factor that controls the cusp poleward edge appearance. One possible candidate for this is the magnetospheric activity. However, as shown in Figure 6, there is no apparent Kp dependence of the cusp poleward edge appearance for the north type cusp. This is reasonable because the cusp poleward edge is related to a northward IMF, which is usually not associated with strong magnetospheric activity. Although the data are not statistically significant for $Kp3$ cases, we may safely conclude that the magnetospheric activity is not controlling the morphology of the cusp poleward edge when the cusp is of the north type.

Let us examine the distribution of the polar cap boundary with and without the cusp poleward edge's electron beam. Figure $7a$ shows the result for the north type cusp. Cusp traversals without cusp poleward edge are clustered near local noon. In order to display this uneven distribution more clearly, we show a histogram of the local time dependence in Figure $7b$. It now becomes obvious, despite rather poor statistics, that the cusp poleward edge disappears near local noon. This is further evidence that the cusp poleward edge is not related to the merging-related electron burst and that the cusp poleward edge is not the same as the polar arc (the distribution of the polar arc is found, for example, in Figure 3 of *Hardy et al.* [1986]). The result is well understood if the cusp poleward edge is mapped somewhere to the boundary layer. Since the cusp is a singular region of the magnetosphere-ionosphere mapping and since the cusp poleward edge is located the most poleward of the cusp-cleft region, it is natural that this region is mapped to the boundary layer in the magnetotail which is quite far from the cusp-cleft region. Note that we are not eliminating the possibility that the cusp poleward edge is the near-cusp part of the polar arc [*Hardy et al.*, 1986], but the present statistics at least indicate that the source region or mechanism should be different from the rest of the ordinary polar arc or the polar rain.

4. Summary and Discussion

We find a small region of faint field-aligned electron beams at the poleward boundary of the cusp-cleft region when the IMF is northward or very weak. The characteristic energy for the electron beam is 100 to 300 eV. Downward-oriented beams are more frequently observed than upward-oriented beams, but this can be understood if the thickness of this layer corresponds to one spin period (20 s) of the satellite or less. This narrow region, which we call the cusp poleward edge, is morphologically (e.g., in pitch angle distribution and thickness) different from both the polar arc and the merging-related electron injection region. The distribution of the cusp poleward edge, based on the result of Figure 7, is schematically illustrated in Figure 8 for northward IMF. The absence of the cusp poleward edge near local noon shown in Figures 7 and 8 indicates that it can be mapped to the boundary layer somewhere in the distant magnetotail. This local time dependence is further evidence that the cusp poleward edge is different from both the polar arc and the merging-related electron injection region.

Although the cusp poleward edge is characterized by electron beams, there is no large-scale field-aligned current according to the magnetic field data. This indicates that the electron beams are bidirectional rather than downward-oriented. Therefore the cusp poleward edge's electron beam is hardly related to the region 0 field-aligned current of *Heikkila* [1984] (see also *Bythrow et al.* [1987]). The cusp-associated large-scale field-aligned currents (cusp region field-aligned current and cusp part region 1 field-aligned current) do not extend beyond the cusp poleward edge, although a substantial amount of the field-aligned current flows on the polar arc when the IMF B_y is strong.

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Fig. 1. Electron and positive ion energy spectrogram for a cusp traversal (orbit 218) when the satellite traveled from the polar cap to the cusp. The magnetic field data are also shown, in which the directions of the field-aligned currents are indicated by open arrows. The IMF is nearly zero. Notice the narrow electron beam at around 1240 UT.

Fig. 2. Electron and positive ion energy spectrogram and magnetic field data for a cusp traversal (orbit 967) when the satellite traveled via the cusp to the polar cap. The IMF condition is $B_y = -3$ and $B_z = +2$. The same type of narrow electron beam as in Figure 1 is recognized around 1612 UT.

Fig. 3. Electron and positive ion energy spectrogram and magnetic field data for a cusp traversal (orbit 1108) when the IMF condition is $B_y = -3$ and $B_z = +1$. Here the region of the electron beam is wider (0741-0742 UT), and it is bidirectional. The electron burst at 0740:20 UT could be related to merging. Although it could be related to the same type of phenomenon as the other electron beams, we did not account for that here.

Fig. 4. Electron and positive ion energy spectrogram and magnetic field data for a cusp traversal (orbit 1148) when the satellite traveled from the cusp to the polar cap. The polar arc is recognized after 1355 UT, and its electron feature is found to be quite different from the electron beams of the previous figures.

Fig. 5. (*a*) IMF dependence of the cusp poleward edge observation. We examined all Viking cusp traversals which also crossed the polar cap. Since Viking cusp traversals are from dusk to dawn for orbits 300-900, we excluded these traversals from the statistics (same in the following figures). We use types of the cusp instead of the IMF B_z polarity. There is a clear dependence: the

cusp poleward edge appears during northward IMF. The correlation is better with the cusp type (direction of the ion energy dispersion, or convection) rather than the IMF itself. (*b*) Therefore the IMF control of the electron beam on the cusp poleward edge is mainly through the cusp morphology rather than through the magnetospheric activity.

Fig. 6. *Kp* dependence of the cusp poleward edge's electron beam for north type cusps. There is no apparent correlation between *Kp* and cusp poleward edge appearance.

Fig. 7. (*a*) The distribution of the cusp poleward edge and (*b*) the local time dependence of the cusp poleward edge when the cusp type is north. The cusp poleward edge's electron beam is absent only near local noon.

Fig. 8. Schematic diagram of the distribution of the cusp poleward edge when the IMF is northward.

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