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# Wave Intensifications Near the Electron Cyclotron Frequency Within the Polar Cusp

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As DE 1 flew through the polar cusp, enhanced narrowband electrostatic waves were sometimes observed just above the electron cyclotron frequency, $f_{ce}$. In this report, we present wave and particle measurements from three representative cusp transits in order to characterize these signals and understand the conditions that favor their generation. In these representative cases, narrowband emission intensifications occurred at frequencies between 1.1 to 1.3 $f_{ce}$. The emission intensities ranged between $5 \times 10^{-14}$ to $10^{-12}$ $V^2/(m^2$ Hz), such waves being 50 to 1000 times greater than the narrowbanded cyclotron-related signal levels detected in adjacent regions. Simultaneously occurring with the wave enhancements were energetic cusp electrons with energies extending up to about 500 eV. It was found that the form of the local cusp electron velocity distribution had a direct influence on the wave spectral character. A preliminary study indicates that electron beams in the cusp can generate the enhanced signals, although generation by an anisotropic warm component cannot be ruled out. Based on an examination of many cusp transits, the occurrence of these enhanced signals appeared to have some dependency on *Kp* index, indicating that increased particle flows (associated with increased geomagnetic activity) seem to affect their generation. Although the exact wave/particle coupling mechanism responsible for these enhancements is difficult to identify, it is evident that the generation is directly related to the energetic cusp electrons.

## INTRODUCTION

It has been known for many years that magnetosheath particles can directly enter into the magnetosphere through the polar cusp [*Frank*, 1971]. These particles are also detected near the Earth at radial distances as low as 1.3 $R_E$ [*Heikkila and Winningham*, 1971]. Due to the presence of these particles, the cusp is an active source of various ULF and VLF waves [*Gurnett and Frank*, 1978]. In this paper, we shall describe Dynamics Explorer (DE) 1 observations of one particular wave mode found in the cusp region, this being a narrowbanded emission near the electron cyclotron frequency, $f_{ce}$. We shall present cases where this emission becomes intensified within the cusp as compared to the narrowband cyclotron-related emission levels observed in adjacent regions. The conditions favoring the generation of these wave enhancements shall also be discussed.

The DE 1 satellite is in a polar orbit around the Earth with a perigee and apogee of 1.1 and 4.9 $R_E$, respectively. On board the spacecraft is the plasma wave instrument (PWI) which consists of two 128-channel sweep frequency receivers capable of sampling in a frequency range from 100 Hz to 410 kHz in 32-s and a wideband receiver [*Shawhan et al.*, 1981]. The two sweep frequency receivers can be connected to any of the following: a 101-m electric antenna ($E_x$), a magnetic loop antenna (B), and a 0.6-m short electric antenna ($E_s$) all measuring wave components in the spin plane, and a 5-m electric antenna ($E_z$) measuring wave components along the spin axis. During the periods of interest, one receiver was always connected to the $E_x$ antenna which is the longest and most sensitive antenna. For further details concerning the PWI experiments, see *Shawhan et al.* [1981].

Another experiment on board the spacecraft is the high altitude plasma instrument (HAPI) which consists of five identical electrostatic analyzers each oriented at different viewing angles ranging from 45° to 135° with respect to the spin axis. These analyzers measure the electron and ion flux at as many as 64 different energy levels varying from 5 eV to 32 keV. Since the spacecraft is spinning, the three-dimensional velocity distribution of the particles can be obtained. More explicit detail about the experiment can be found in *Burch et al.* [1981].

Narrowband electrostatic emissions associated with the electron cyclotron frequency, $f_{ce}$, are commonly detected in the outer magnetosphere at dipole $L$ shell values greater than about 5 [*Kennel et al.*, 1970; *Christiansen et al.*, 1978]. These emissions often appear at odd half-harmonics of the electron cyclotron frequency, $3/2 f_{ce}$, $5/2 f_{ce}$, $\cdots$, $(n + 1/2) f_{ce}$, with harmonics nearest the electron plasma frequency, $f_{pe}$, having the strongest intensities [*Shaw and Gurnett*, 1975]. Just outside the plasmapause, at about $L = 4$ to 5, the spectral form of these emissions is altered, with both a narrowband and diffuse component being detected at frequencies between harmonics of $f_{ce}$ (though no longer exactly at the half-harmonics). Within the plasmasphere, at $L$ values less than about 4 or 5, both the narrowband and diffuse components merge to form a narrowband emission at the upper hybrid resonance frequency, $f_{\text{uhr}} = (f_{ce}^2 + f_{pe}^2)^{1/2}$, that is detected throughout the region [*Shaw and Gurnett*, 1975]. It was speculated by *Shaw and Gurnett* [1975] that the different forms of the narrowband emissions correspond to different

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plasma conditions found throughout the magnetosphere, varying from warm plasma sheet electrons with a cold background in the outer magnetosphere to a high density cold component in the plasmasphere. Near the plasmapause, the narrowband electrostatic wave amplitudes tend to be small, typically a few microvolts per meter [*Shaw and Gurnett*, 1975; *Kurth et al.*, 1979*a*]. However, very significant intensifications of up to 1 to 20 mV $m^{-1}$ have been reported to occur just beyond the plasmapause boundary when $(n + 1/2) f_{ce} \sim f_{uhr}$ [*Kurth et al.*, 1979*a*, *b*]. As demonstrated in *Kurth et al.* [1979*b*], these intensifications result from a nonconvective instability.

The polar cusp is centrally located in the dayside region of the magnetosphere at 1200 hours magnetic local time (MLT) and between 70° to 80° invariant latitude [*Tsyganenko and Usmanov*, 1982]. Magnetosheath particles directly enter into the magnetosphere at this location [*Frank*, 1971; *Paschmann et al.*, 1976], exciting a number of wave modes in the ULF and VLF ranges [*Gurnett and Frank*, 1978]. These emissions include (1) the whistler-mode auroral hiss emissions which are generated by low energy electron beams found near the low-latitude edge of the cusp [*Lin et al.*, 1984], (2) broadband electrostatic noise believed to be driven by field-aligned currents in the cusp [*Fredricks et al.*, 1973], (3) ULF-VLF magnetic noise which has been extensively discussed in the literature [*Russell et al.*, 1971; *D'Angelo*, 1973; *D'Angelo et al.*, 1974; *Hansen et al.*, 1976; *Haerendel et al.*, 1978], and (4) narrowbanded emissions lying just above $f_{ce}$ similar to those found in the outer magnetosphere. *Gurnett and Frank* [1978] report that these narrowbanded emissions occur at frequencies of about 1.1 to $1.2 f_{ce}$, and are relatively weak as compared to the auroral hiss and broadband electrostatic noise found in the region. Also, the emission is more diffuse within the cusp as compared to the narrowbanded cyclotron emissions detected outside.

The main objectives of this report are the following: (1) to describe the intensifications of the narrowband cyclotron emissions detected within the polar cusp by the DE PWI, (2) discuss the relationship between these enhanced signals and the energetic cusp electrons detected by the DE HAPI, and (3) identify the conditions required to generate such wave enhancements.

## OBSERVATIONS

The wave character of the cusp as detected by DE 1 at around 4 $R_E$ is very similar to that observed by Hawkeye 1 [*Gurnett and Frank*, 1978]. Specifically, propagating within and outside the cusp is whistler-mode auroral hiss which is commonly detected from <1 kHz up to the electron cyclotron frequency, $f_{ce}$. The hiss emission can be identified on a frequency-versus-time spectrogram by its funnel-shaped appearance. Also observed within the cusp is intense broadband electrostatic noise similar to that detected by Hawkeye 1. This emission appears from <10 Hz up to as high as 10 kHz. Finally, like the Hawkeye observations, an emission is observed near the electron cyclotron frequency, $f_{ce}$. As we shall demonstrate, these signals can become intensified within the region as compared to their external signal levels.

Observations during a cusp transit occurring on day of year (DOY) 295 of 1981 are presented in Plate 1. In Plate 1*a*, a wave frequency-versus-time spectrogram from the PWI experiment is displayed, while in Plate 1*b*, a particle energy-versus-time spectrogram from the HAPI experiment is shown for both the electrons and ions. In the middle panel of Plate 1*b* the spin phase of the spacecraft relative to the local geomagnetic field is also displayed. During this time period, DE was traveling poleward in the dayside region between hour 0900 to 1000 MLT. This trajectory took the spacecraft through the polar cusp. As indicated in the particle spectrogram (see Plate 1*b*) energetic cusp ions similar to those reported by *Heikkila and Winningham* [1971] were detected between 0940 to 0949 UT, at an invariant latitude of about 71°. As indicated in the top panel of Plate 1*b*, detected during this cusp transit was an energetic electron component extending up to 700 eV. Significant wave activity was also observed in association with the transit (see Plate 1*a*). From about 0925 to 1020 UT, the funnel-shaped auroral hiss emission was detected, extending from about 1 kHz up to the white line in the spectrogram which represents the electron cyclotron frequency, $f_{ce}$. It is evident that the hiss propagates both within and outside the cusp region. Upon entering the cusp at 0940 UT, intense broadband electrostatic noise was detected extending from <10 Hz to about 10 kHz. The bandwidth of this noise remained at about 10 kHz for the next 2–3 min. However, after this time the bandwidth dropped to about 800 Hz, with only an occasional burst above this frequency being detected. Upon entering the polar cap at about 0950 UT, these intense electrostatic emissions ceased completely.

As can be seen in Plate 1*a*, enhanced wave activity just above $f_{ce}$ was observed during the period DE was in the cusp (from 0940 to 0949 UT). However, prior to entry into the region, the narrowbanded electrostatic emissions were relatively weak. At the far left edge of the spectrogram (at 0900 UT), a narrowband emission at about 100 kHz is seen. This emission is identified as the low intensity upper hybrid emission commonly detected in the plasmasphere and plasmapause. Its decreasing frequency is associated with the decreasing plasma density at the edge of the plasmasphere. As noted by *Shaw and Gurnett* [1975], the character of this emission changes outside the plasmasphere, behaving more like an electron cyclotron half-harmonic type. This change in character is consistent with the DE wave measurements. After exiting the plasmasphere at 0910 UT, the weak narrowband emission decreases in intensity and appears to vary as the electron cyclotron frequency, remaining near $1.4 f_{ce}$. Figure 1*a* is a wave electric field spectrum detected between 0935 and 0936 UT showing the weak emission lying above $f_{ce}$ with an intensity of $10^{-15}$ $V^2/(m^2$ Hz) (or about 0.7 $\mu$V/m). However, the narrowband wave character became much different as the spacecraft entered the cusp. As shown in Plate 1*a*, this emission appeared to both broaden in frequency and intensify from 0940 to about 0949 UT. Figure 1*b* indicates that the cusp emission, occurring at about $1.28 f_{ce}$, had a signal strength of about $10^{-12}$ $V^2/(m^2$ Hz) (or ~22 $\mu$V/m), which is nearly a factor of $10^3$ times greater than its strength measured outside the cusp.

During this cusp transit, the second PWI receiver was connected to the magnetic loop antenna. However, a measurable magnetic signal associated with the enhancements was obtained only around 0941–0942 UT when the electric field strength was most intense. This magnetic signal was very weak, being about $10^{-14}$ $\gamma^2$/Hz. Such weak magnetic signals associated with narrowband emissions have been previously reported by *Shaw and Gurnett* [1975]. The cor-

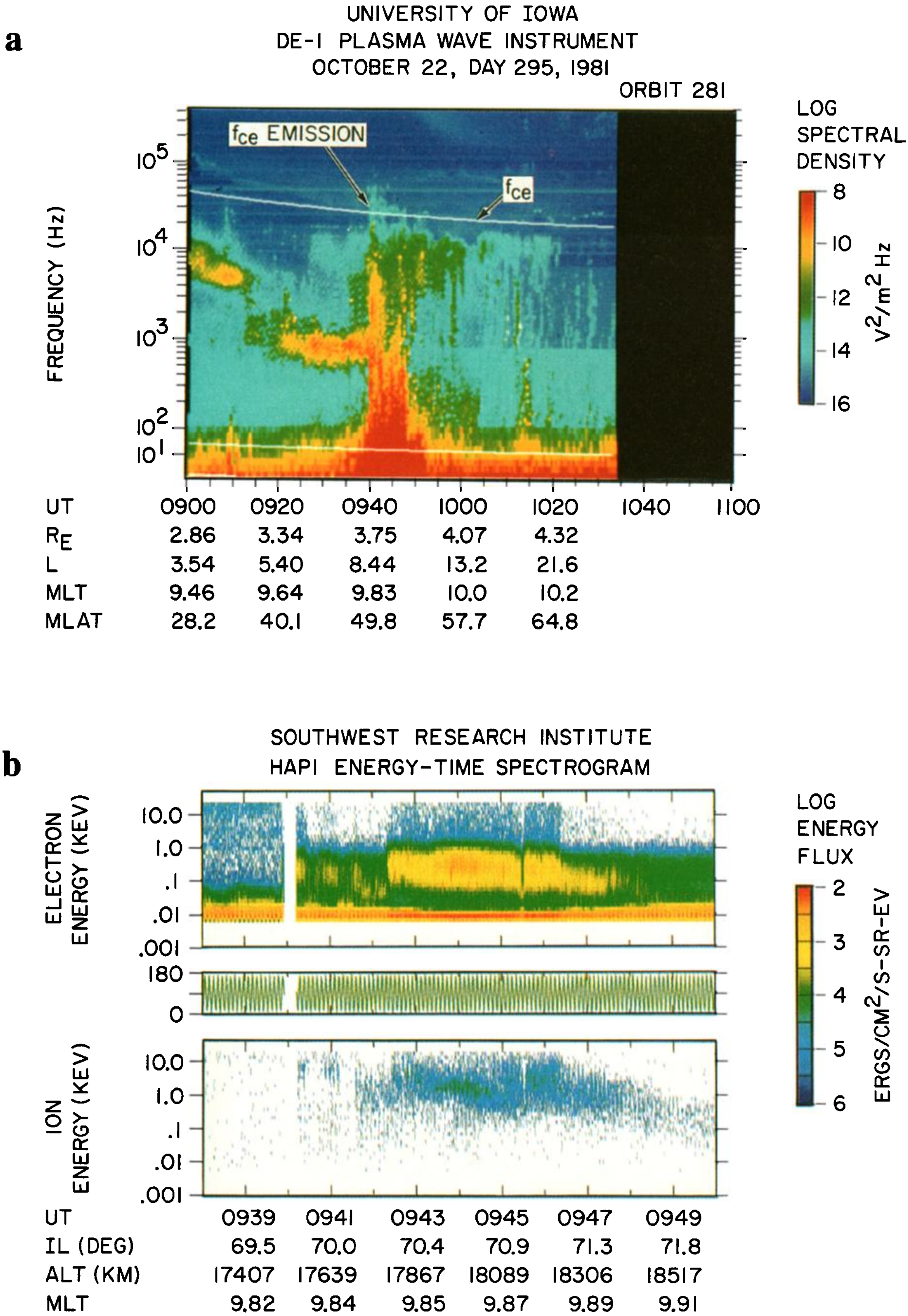


Plate 1. DE 1 (*a*) PWI frequency-versus-time wave spectrogram and (*b*) HAPI energy-versus-time particle spectrogram corresponding to the cusp transmit occurring on DOY 295 of 1981.

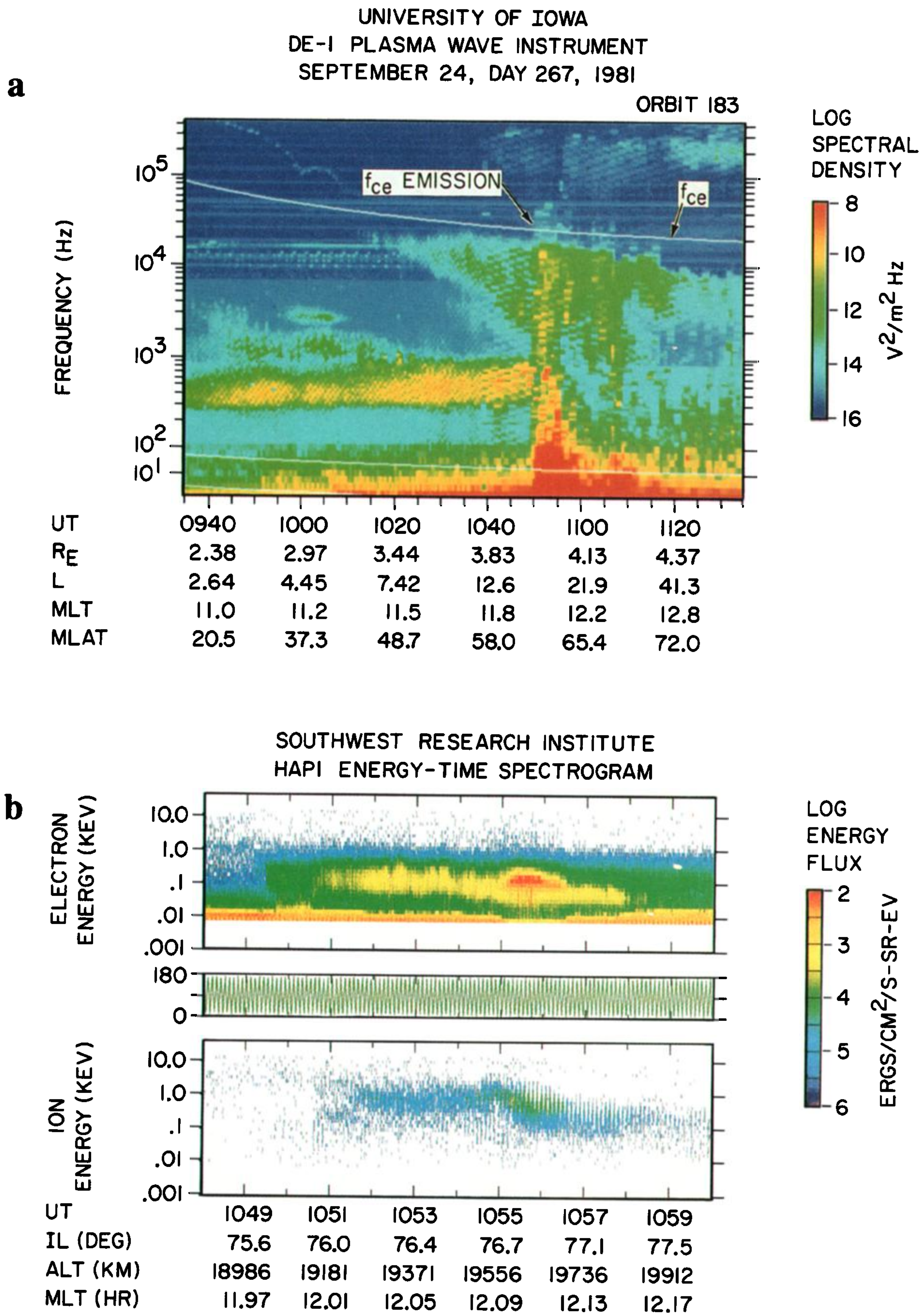


Plate 2. Another DE 1 (*a*) wave and (*b*) particle spectrogram for the cusp transit occurring on DOY 267 of 1981.

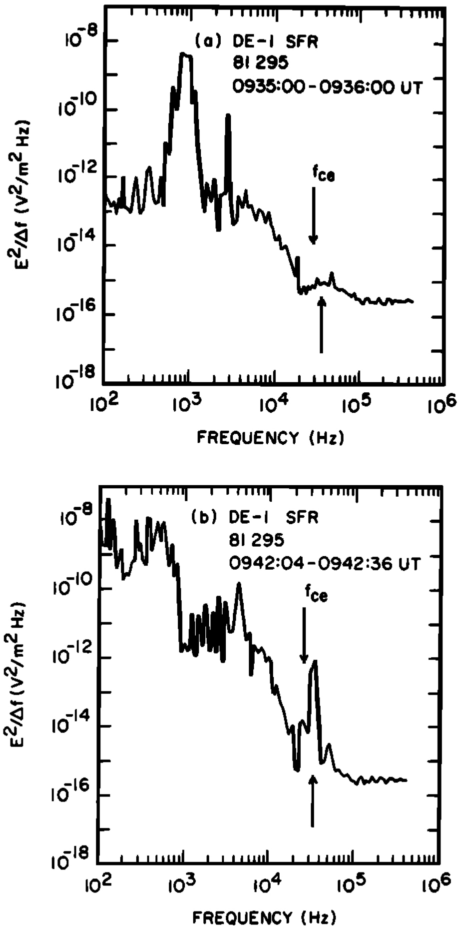


Fig. 1. The PWI wave electric field spectrum (*a*) outside and (*b*) within the cusp on DOY 295. Note the enhanced wave activity just above $f_{ce}$ within the cusp.

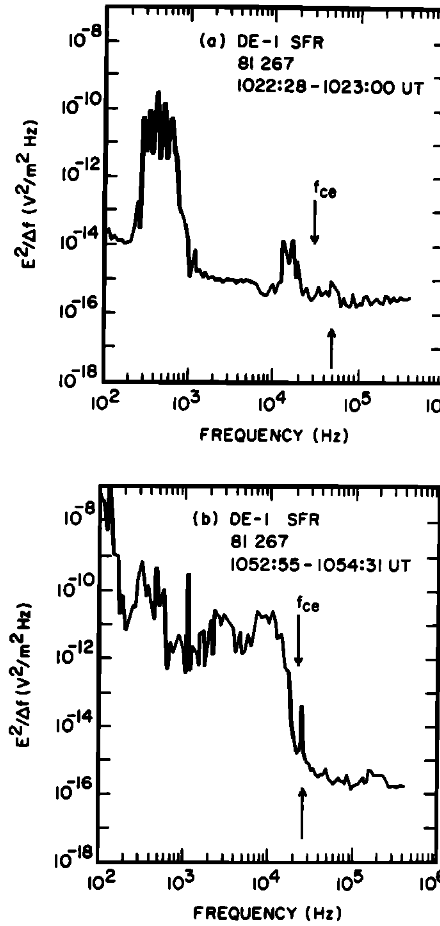


Fig. 2. The PWI wave electric field spectrum (*a*) outside and (*b*) within the cusp on DOY 267. Again, enhanced electron cyclotron emissions were observed with the cusp.

responding $cB/E$ ratio of the emission is small, having a value of about 0.03.

Wave and particle measurements from another cusp transit are presented in Plates 2*a* and 2*b*, which display the PWI and HAPI measurements, respectively, during DOY 267 of 1981. The format of these spectrograms is similar to those of Plate 1. As indicated in Plate 2*b*, energetic cusp ions were detected between 1051 and 1059 UT, when the spacecraft was at an invariant latitude of 76°–77° and MLT of 1200 hours. An energetic electron component extending up to about 400 eV was also detected during this same period. As shown in Plate 1*a*, intense wave activity was associated with this particular cusp transit. In particular, auroral hiss with its distinctive funnel appearance was detected from 1010 to 1105 UT. At 1051 UT, as DE entered the cusp, intense broadband electrostatic noise was detected extending nearly to $f_{ce}$. For the most part, this emission persisted while the spacecraft was in the cusp, but its bandwidth appeared to decrease to about 200 Hz after 1055 UT.

Like the previous case, a complicated emission lying just above $f_{ce}$ was detected within the cusp (from 1050 to 1059 UT). This emission is labeled in Plate 2*a*. However, prior to entry into the cusp, the narrowband emissions were relatively weak. At 0940 UT, an emission near the upper hybrid resonance frequency of 400 kHz was observed within the plasmasphere (this appearing in the left-hand corner of Plate 2*a*). As DE exited the plasmasphere, the electron plasma frequency decreased, causing a corresponding frequency decrease in the emission. This decreasing frequency continued until 1010 UT. At this time the wave character changed, with the emission becoming so weak that it was nearly unobservable on the color spectrogram shown in Plate 2*a*. To observe the emission, one has to examine plots of the wave electric field spectrum like those shown in Figure 1. Figure 2*a* is a spectrum from 1022:28 to 1023:00 UT, showing the weak narrowband emission lying at about 1.5 $f_{ce}$. As DE entered the cusp, the emission's character changed, becoming more intense and complicated. Figure 2*b* shows the electric field spectrum from 1052:55 to 1054:31 UT, when the spacecraft was in the cusp. This spectrum indicates the presence of a signal at about 1.1 $f_{ce}$ having an intensity of $7 \times 10^{-14}$ $V^2/(m^2\ Hz)$ (~6 μV/m). Although relatively weak compared to other cusp emissions, the signal intensity is still 70 times greater than the narrowbanded cyclotron emission levels detected prior to cusp entry. As seen in Plate 2*a*, the wave enhancement persisted while the spacecraft was in the cusp, but then ceased as it exited the region at 1059 UT.

During the transit, the second PWI receiver was again connected to the magnetic loop antenna. However, a magnetic signal associated with the enhancements was not detected. The measured wave electric field strength was about $10^{-13}$ $V^2/(m^2$ Hz). Assuming $cB/E$ was 0.03, as in the previous example, the magnetic field strength would be only about $10^{-15}$ $\gamma^2$/Hz. Such a magnetic field would be undetectable since it is much smaller than the receiver noise level.

As a final example of the low altitude cusp region, we present measurements from DOY 269 of 1981. Plates 3*a* and 3*b* display the PWI and HAPI measurements, respectively, associated with this transit in a similar format as the plates displayed previously. As shown in the lower panel of Plate 3*b*, DE detected energetic cusp-related ions from 1024 to about 1035 UT, at an invariant latitude of 72° and MLT of 1100–1200 hours. Like the previous cases, an energetic electron component extending to about 400–500 eV was also observed during the cusp transit, as indicated in the top panel of Plate 3*b*. As shown in the PWI spectrogram (see Plate 3*a*), auroral hiss was detected both within and outside the cusp, while electrostatic broadband noise was detected and confined within the cusp region. The bandwidth of the electrostatic noise extended as high as 10 kHz during the first 2 min in the cusp, but abruptly dropped to below 700 Hz thereafter.

As indicated in Plate 3*a*, the PWI receiver detected enhanced wave activity near $f_{ce}$ both within and just outside the cusp region. However, distant from the cusp the narrow-banded emissions were relatively weak. At 0940 UT, a narrowband emission near $f_{uhr}$ was detected within the plasmasphere, this emission decreasing in frequency in association with the decreasing electron density. The emission appeared to remain an $f_{uhr}$ emission until the entry into the polar cusp at 1024 UT. However, the distinction between an $f_{uhr}$ emission and one near 3/2 $f_{ce}$ was difficult to make during the 10-min period prior to cusp entry. Figure 3*a* displays the wave electric field spectrum from 1020 to 1021 UT. This spectrum shows a low intensity emission lying just above $f_{ce}$ with a strength of $10^{-15}$ $V^2/(m^2$ Hz). However, from 1021 to 1022 UT, which is about 3 min prior to DE's entrance into the cusp, a very strong narrowband intensification was detected. Figure 3*b* is the electric field spectrum during this time which shows the emission enhancement, occurring at 1.6 $f_{ce}$, with an intensity of $10^{-10}$ $V^2/(m^2$ Hz) (~1 mV/m). Such large amplitudes are similar to those reported by *Kurth et al.* [1979*a*] at the outer edge of the plasmapause when $f_{uhr} \sim (n + 1/2)f_{ce}$. At 1024 UT, when HAPI detected the energetic cusp ions and electron component, an intensified signal near $f_{ce}$ was simultaneously observed (see Plate 3*a*). This signal was detected continuously for about the next 9 min. Figure 3*c* is the wave electric field spectrum from 1027 to 1028 UT which clearly shows the cusp enhancement occurring at 1.1 $f_{ce}$ with an intensity of about 7 × $10^{-14}$ $V^2/(m^2$ Hz) (~6 $\mu$V/m). This intensity represents a factor of 70 increase over the typical narrowband emission strengths detected outside the region.

Again, during the period of interest, the second receiver was connected to the magnetic loop antenna. However, the only detectable magnetic signals from the narrowband emissions were observed during the strong wave enhancement from 1021 to 1022 UT when DE was just outside the cusp. In this case, the magnetic field value was about 2 × $10^{-12}$ $\gamma^2$/Hz. The corresponding $cB/E$ ratio was about 0.04, which is a value similar to the first case presented (and also to those reported by *Shaw and Gurnett* [1975]).

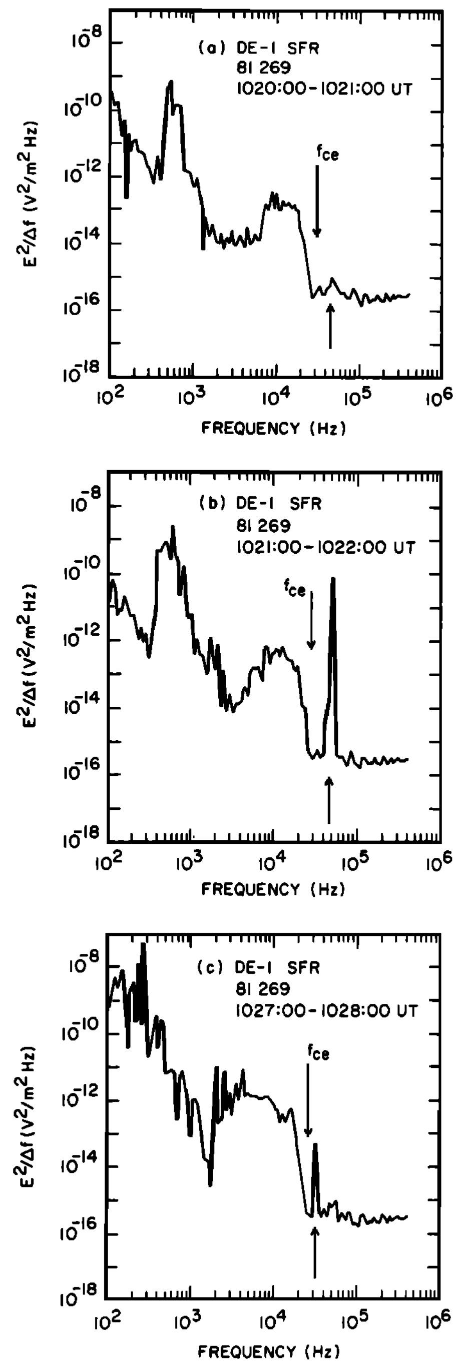


Fig. 3. The PWI wave electric field spectrum (*a*) distant from, (*b*) near, and (*c*) within the cusp. As shown in Figure 3*b*, a very strong narrowband emission enhancement near 1.6$f_{ce}$ was observed about 3 min prior to DE's entry into the cusp. Within the region, electron cyclotron emission enhancements were detected, as indicated in Figure 3*c*.

## Discussion

As illustrated by the cases presented, the narrowband wave intensities in the cusp increased by nearly a factor of 50 to 1000 over levels outside. To determine if these enhancements are a usual feature of the cusp, we examined 30 consecutive DE dayside passes between the MLTs of 1000 and 1400 hours which have been processed into spectrogram form. Transits through the cusp region were identified by the

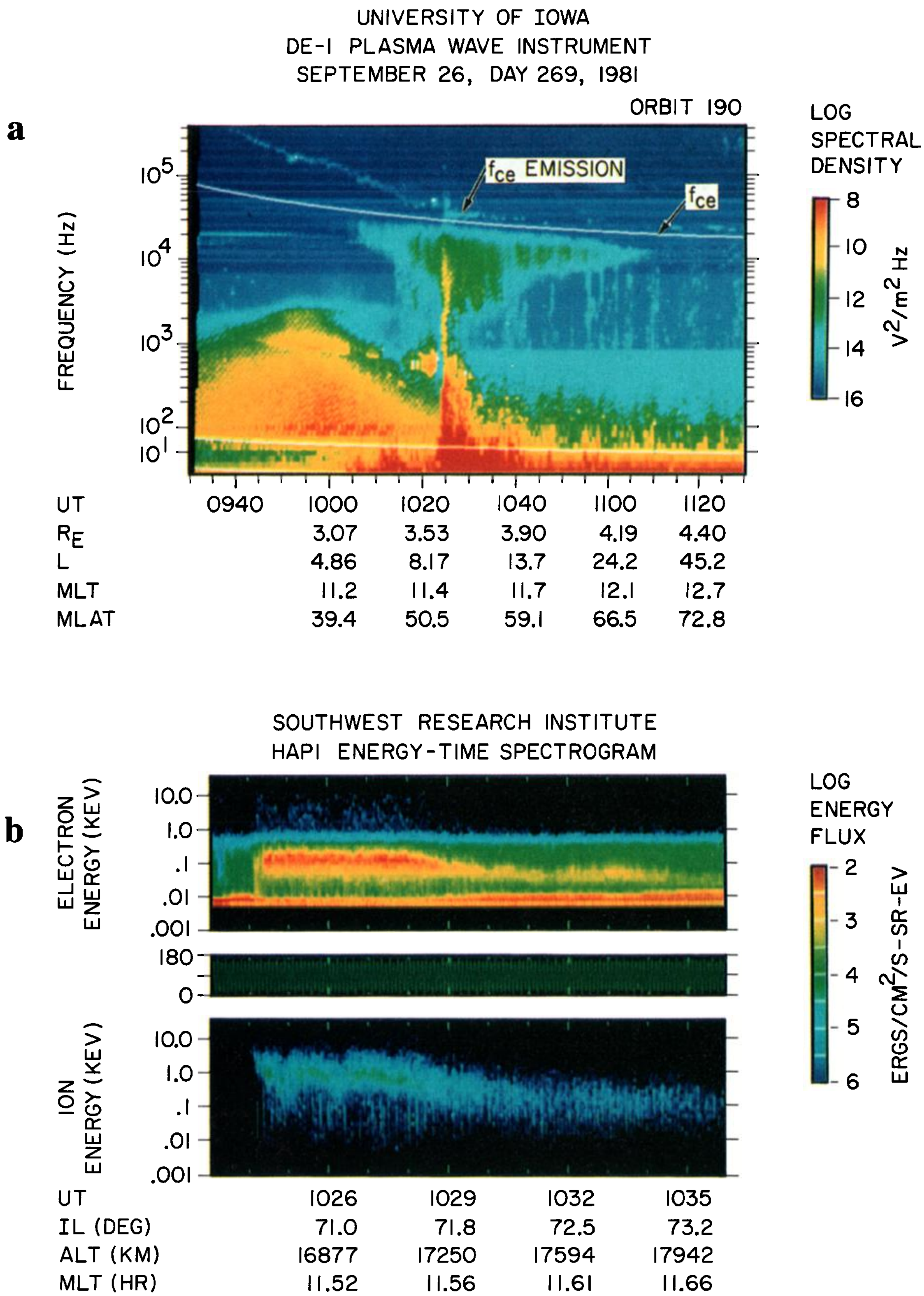


Plate 3. DE 1 (*a*) wave and (*b*) particle spectrogram for the cusp transit occurring on DOY 269 of 1981.

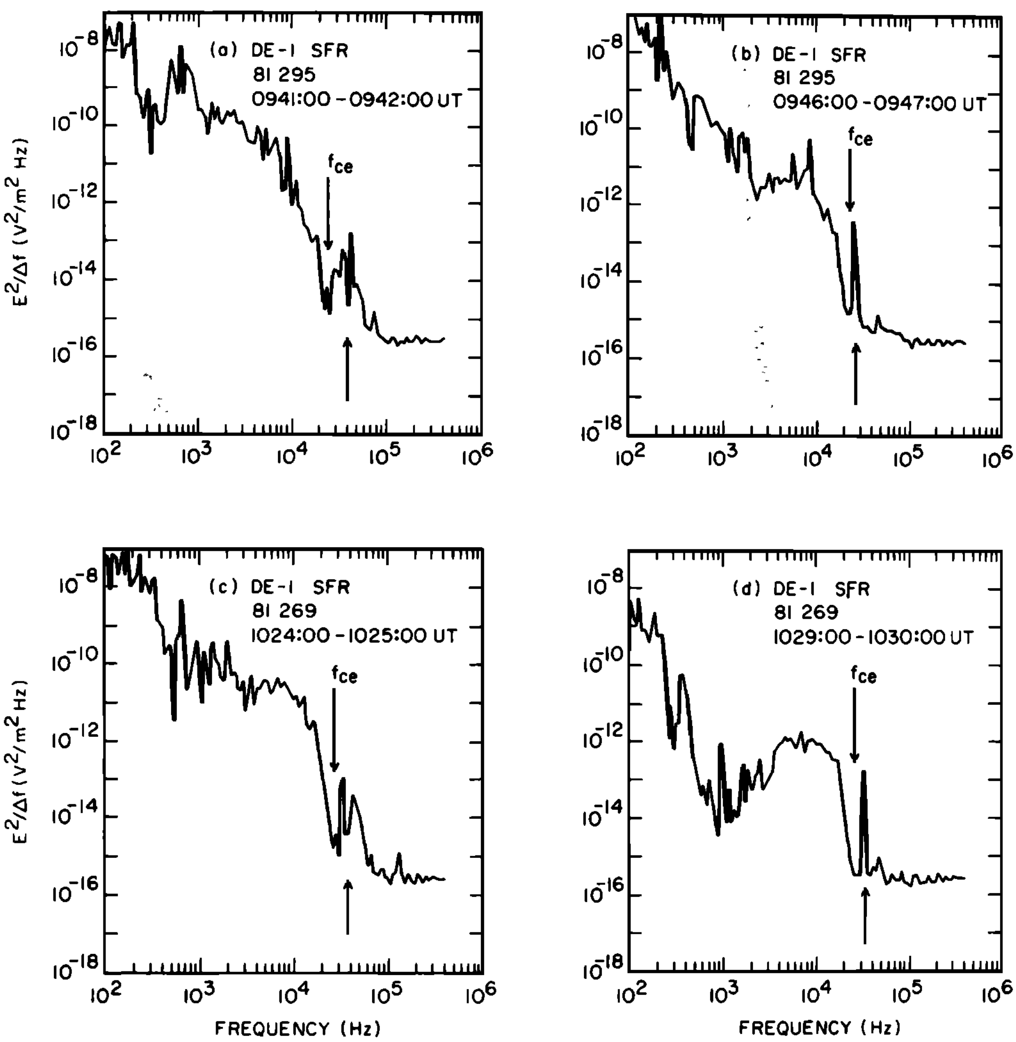


Fig. 4. The PWI wave electric field spectrum during the cusp transit occurring on DOY 295 of 1981 at (*a*) low and (*b*) high cusp latitudes. Spectra during the transit on DOY 269 of 1981 at (*c*) low and (*d*) high cusp latitudes are also displayed. Note that the cyclotron emissions had a larger bandwidth and complicated peak structure at lower cusp latitudes.

VLF wave activity, including the presence of auroral hiss and broadband electrostatic noise. The transits occurred between the magnetic latitudes of 48° and 76°, which is the expected latitude range for the cusp (e.g., Figure 12 of *Gurnett and Frank* [1978]). Out of 30 passes through the cusp region, 20 had wave enhancements lying just above $f_{ce}$ similar those shown in our representative examples. Although these signals appeared quite often, there were cases where the emission was weak or absent within the cusp, and these occurrences will be discussed below.

In the last section, it was mentioned that an energetic electron component extending up to approximately 1 keV was commonly detected within the cusp region. *Heikkila and Winningham* [1971] showed that these electrons have a spectral appearance similar to those observed in the magnetosheath, and thus it is believed that the electrons have penetrated directly to low altitudes through the polar cusp. *Frank and Ackerson* [1971] report that a temperature difference between the electrons and the ions ($T_e > T_i$) also characterizes the cusp particles. *Shaw and Gurnett* [1975] suggest that the character of the narrowband emission changes depending on the nature of the ambient plasma. In our case it appears that the narrowband emissions intensify and broaden in frequency with the advent of the energetic cusp electrons.

Even within the cusp itself, the nature of the signals changed as DE flew from lower to higher latitudes. In all three wave spectrograms (Plates 1*a*, 2*a*, and 3*a*), both the broadband electrostatic noise and emissions near $f_{ce}$ had relatively large bandwidths when DE first entered the cusp region at lower latitudes. However, these bandwidths became smaller as DE flew to higher cusp latitudes. Figure 4 displays electric field spectra at the beginning of the cusp transit and at later periods within the cusp for the crossings occurring on DOY 295 and 269 of 1981. We see in Figure 4*a* that when DE first entered the cusp on DOY 295, the emission lying just above $f_{ce}$ had a very complicated structure, having both a widened bandwidth of about 40 kHz and multiple peaks (in fact, three maximums were observed between $f_{ce}$ and 2 $f_{ce}$ during this time). During the same 3-min period, the broadband electrostatic noise also had its largest bandwidth, extending up to about 10 kHz (see Plate 1*a*). However, after this 3-min period, the bandwidth of both appeared to decrease. As noted in Figure 4*b*, at a later time

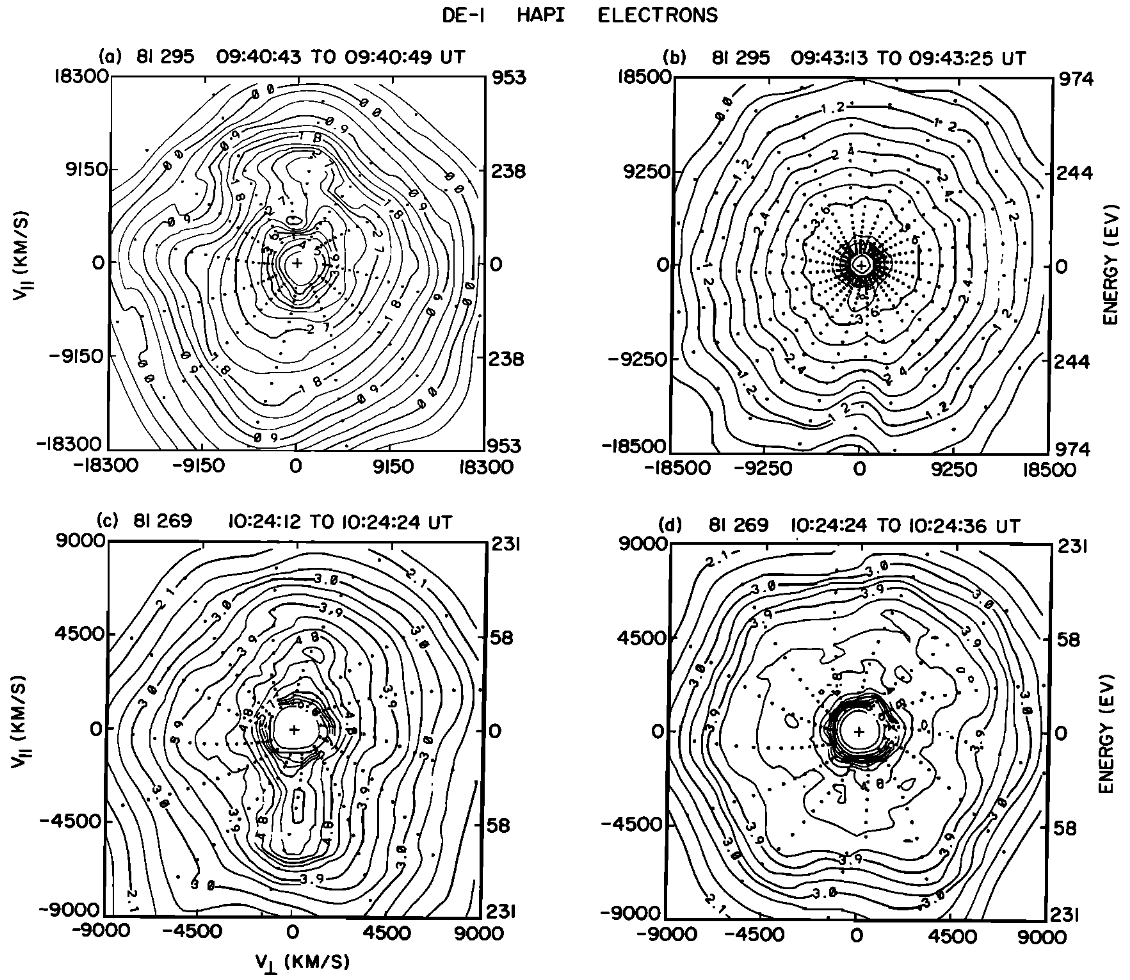


Fig. 5. The HAPI electron distributions within the cusp at (*a*) low and (*b*) high cusp latitudes on DOY 295 and (*c*) low and (*d*) high cusp latitudes on DOY 269.

when DE was at a higher cusp latitude, the cyclotron emission appeared as a single narrow peak of 7–10 kHz bandwidth lying at about 1.1 $f_{ce}$. The bandwidth of the broadband electrostatic noise also decreased to a typical value of about 800 Hz. The behavior of the two wave components during the cusp transit on DOY 269 appeared very similar, with the largest bandwidths occurring at the low latitude edge of the cusp. Figure 4*c* shows the $f_{ce}$ enhancements when the spacecraft first entered the region. Like the previous case, the emission appeared to have a relatively wide bandwidth and multiple peaks. However, at a later time (corresponding to a higher cusp latitude) the emission appeared as a single narrow peak lying just above $f_{ce}$.

It is suspected that the different peak structure and bandwidths of the cusp wave enhancements correspond to a change in the particle distribution in the region. As an example, we see in Plate 1*b* that the electron spectral character within the cusp appeared to change at 0942:15 UT on DOY 295. At relatively low latitudes in the cusp (from 0940 to 0942:15 UT), the energetic particle distribution was dominated by a strong field-aligned component, without the nearly isotropic warm component seen at later times. Figure 5*a* shows the energetic electron distribution during part of this period, which clearly displays the presence of the field-aligned component with an energy of about 244 eV. After 0943 UT, when the spacecraft was at higher latitudes within the cusp, the energetic electrons appeared to have both a low energy (50–100 eV) field-aligned component, along with an isotropic warm component extending to 1 keV (see Figure 5*b*). To identify the warm component in Figure 5*b*, note the expanded contour levels as compared to those shown in Figure 5*a*. Similar electron distributions were observed during the cusp transit of DOY 269. In the electron energy spectrogram shown in Plate 2*b*, a very strong field-aligned component was observed upon entering the cusp (from about 1024:15 to 1024:30 UT) with a warm and very occasional field-aligned component seen thereafter. The electron distribution in Figure 5*c* shows the field-aligned component observed in the first half minute of 1024 UT, while the distribution in Figure 5*d* displays the warmer component seen at higher cusp latitudes. Our observations indicated that the presence of the field-aligned electron component detected at lower latitudes dramatically effects the character of the $f_{ce}$ wave enhancements by increasing their apparent bandwidth and creating multiple maximums. With the advent of the warm component at higher latitudes, a narrowing of the apparent bandwidth occurs and the emission appears as a single maximum.

The process transferring energetic electron energy to the

$f_{ce}$ wave intensifications is particularly difficult to identify in the low altitude cusp. *Young et al.* [1971, 1973] described two types of instabilities capable of generating narrowband emissions between $f_{ce}$ and $2 f_{ce}$. The first type is called the "flutelike" mode which applies to emissions with $k_{\|} = 0$. In this case, the solution to the dispersion relation appears very similar to the Bernstein modes [*Bernstein*, 1958], only now a warm component is included. It was demonstrated [*Young et al.*, 1973] that a dense warm electron distribution with a large positive slope in perpendicular velocity, $df/dv_{\perp} > 0$, can excite waves with $f_{ce} < f < 1.5 f_{ce}$. The second type of instability occurs when $k_{\|} \neq 0$. In this case, a dense warm distribution with either $df/dv_{\perp} > 0$ or a temperature anisotropy ($T_{\perp} > T_{\|}$) can excite waves between $f_{ce}$ and $2 f_{ce}$, the former at frequencies $<1.5 f_{ce}$ (particularly if the thermal speed of the cold background electrons is small) and the latter generally at frequencies $>1.5 f_{ce}$. The orientation of the wave electric field vector in the spacecraft spin plane can be obtained from the antenna spin-modulation pattern. For the narrowband cusp emissions occurring from 0940 to 0947 UT on DOY 295, the electric field was found to be oriented at an angle of 58° (±25°) with respect to the spin plane projection of B. From 1023 to 1032 UT on DOY 269, the orientation was 11° (±8°) with respect to the spin plane projection of B. In both cases, the waves possessed a significant $k_{\|}$ component, ruling out the "flutelike" instability as a possible mechanism. However, the second version of the instability creating modes with $k_{\|} \neq 0$ may still be a viable generation process.

Another possibility is the wave being excited by the observed field-aligned electron component. To test this hypothesis, we have conducted a stability analysis of the electron cyclotron wave using the electron plasma parameters obtained between about 0941:36 and 0941:37 UT of day 295. As determined from analysis of the HAPI electron data, the electrons can be modeled by a beam and background components. The beam has a peak energy of 75 eV with a temperature of 70 eV, and a density of 3.8 $cm^{-3}$; the warm Maxwellian background electrons have a temperature of 69 eV and density of 3.0 $cm^{-3}$. Because of the spacecraft-produced photoelectrons, it is not possible to determine the cold background electron density directly but we have initially assumed a reasonable value of 4 $cm^{-3}$. The growth (or damping) rate of the electron cyclotron wave is very sensitive to the temperature of the cold electrons, for the aforementioned plasma parameters and an electron cyclotron frequency of 23 kHz. The electron cyclotron wave is marginally unstable for a wave normal angle, $\theta \approx 60°$, and the unstable frequency is about $\omega \simeq 1.22\ \Omega_e$ if the temperature of the cold electrons is 0.1 eV. The wave is damped if the temperature of the cold electrons increases. However, if we increase the beam speed to twice the beam thermal speed, the instability can occur even when the temperature of cold electrons is 1 eV. Furthermore, the maximum growth tends to occur at smaller wave normal angles for higher beam speed. A comprehensive survey of electron-beam-generated electron cyclotron waves is beyond the scope of this paper and will be deferred to future work.

About 3 min prior to the cusp crossing on DOY 269, a very intense narrowband emission enhancement was detected for about 1 min (see Figure 3*b*). This emission seems to occur where $f_{\mathrm{uhr}} \sim 3/2 f_{ce}$ and thus it may be generated by the nonconvective instability discussed by *Kurth et al.* [1979*a*, *b*]. Since this process occurs elsewhere near the plasmapause, it is suspected that this particular intensification was independent of the enhancement processes associated with the cusp.

As discussed above, signal intensifications just above $f_{ce}$ were observed in about 67% of the cusp transits. However, they were not always observed, and we should address the possible conditions required for these waves to exist. It has been demonstrated that the cusp configuration varies with the level of geomagnetic activity [*Tsyganenko and Usmanov*, 1982]. At large *Kp* values, the cusp tends to become compressed and shift to lower magnetic latitudes, such effects being caused by enhanced currents flowing in the region. Since the observed wave enhancements occur within the cusp, it is suspected that they are also affected by such enhanced particle flows. To check this assertion, the *Kp* indices during the 30 cusp transits discussed above were catalogued. It was found that the average *Kp* value when no $f_{ce}$ enhancements were observed was 2.2 ± 0.3, while the average *Kp* value when $f_{ce}$ enhancements were present was 3.2 ± 0.6. This trend is quite suggestive, implying that the enhanced current flows associated with increased geomagnetic activity affect the generation of the $f_{ce}$ signal enhancements. In fact, intensifications just above $f_{ce}$ were observed in 11 out of 12 transits occurring when $Kp \geq 4$. Figures 6*a* and 6*b* show the occurrence of enhanced and not enhanced $f_{ce}$ wave activity, respectively, as a function of *Kp*, which summarizes these results.

## CONCLUSIONS

In order to illustrate the narrowband wave character near $f_{ce}$ in the polar cusp region, we have presented wave measurements during three DE 1 transits through the region. It was found that the narrowband emissions can have a different character within the cusp as compared to the adjacent regions outside. In the cases presented, enhanced signal strengths were observed from $f_{ce} < f < 1.5 f_{ce}$ within the cusp, these being as much as 50 to 1000 times greater than the narrowband emissions detected outside but adjacent to the cusp. Simultaneously observed with the wave enhancements was an energetic electron distribution consisting of a field-aligned and nearly isotropic warm electron component.

The $f_{ce}$ intensifications in the cusp were not as large as the narrowband enhancements known to occur at the edge of the plasmapause when $f_{\mathrm{uhr}} \sim (n + 1/2)f_{ce}$, these having amplitudes on the order of 1–20 mV/m [*Kurth et al.*, 1979*a*, *b*]. Such an emission was observed about 3 min prior to the cusp transit on DOY 269 of 1981. The intensifications were also not as large as the hiss and broadband electrostatic emission amplitudes associated with the cusp. Such small signal strengths may explain why the moderate intensifications have been previously overlooked on a DE wave spectrogram of the region.

The enhanced signals within the cusp appeared to change form depending on DE's magnetic latitude. At the equatorial cusp edge, the emission had a relatively large bandwidth and consisted of a multipeaked maximum (see Figure 4*a*). This wave character was observed when the energetic electrons appeared more field-aligned. However, at higher magnetic latitudes in the cusp, the waves became more narrowbanded, possessing a single peak lying near $f_{ce}$ (see Figure

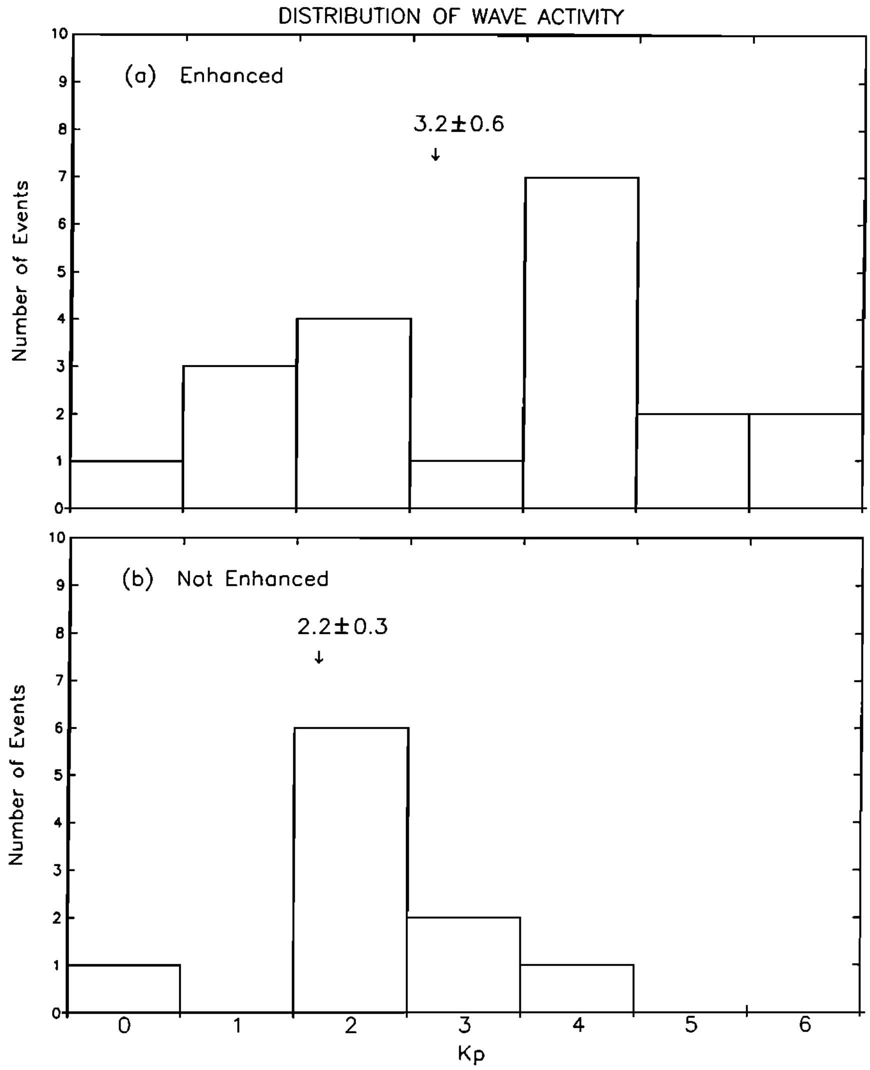


Fig. 6. The occurrence of the $f_{ce}$ waves as a function of geomagnetic activity, *Kp*. Note that the wave enhancements tend to occur at larger *Kp*.

4*b*). This wave character was observed when the warm nearly isotropic electron component dominated the particle energy spectrum (with some field-aligned flows detected simultaneously). We have performed a preliminary stability analysis using measured local plasma parameters and find that electron beams may be responsible for the observed electron cyclotron waves, although processes similar to those described by *Young et al.* [1971, 1973] cannot be ruled out. The occurrence of the $f_{ce}$ cusp intensifications appeared to have some dependency on *Kp* index implying that the enhanced electron flows associated with magnetically active periods influence wave generation. Based on these results, it is evident that the $f_{ce}$ wave intensifications are closely related to the energetic cusp electrons.

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