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Cusp energetic particle events: Implications for a major acceleration region of the magnetosphere

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Abstract. The Charge and Mass Magnetospheric Ion Composition Experiment (CAMMICE) on board the Polar spacecraft observed 75 energetic particle events in 1996 while the satellite was at apogee. All of these events were associated with a decrease in the magnitude of the local magnetic field measured by the Magnetic Field Experiment (MFE) on Polar. These new events showed several unusual features: (1) They were detected in the dayside polar cusp near the apogee of Polar with about 79% of the total events in the afternoonside and 21% in the morningside; (2) an individual event could last for hours; (3) the measured helium ion had energies up to and many times in excess of 2.4 MeV; (4) the intensity of 1-200 KeV/*e* helium was anticorrelated with the magnitude of the local geomagnetic field but correlated with the turbulent magnetic energy density; (5) the events were associated with an enhancement of the low-frequency magnetic noise, the spectrum of which typically extends from a few hertz to a few hundreds of hertz as measured by the Plasma Wave Instrument (PWI) on Polar; and (6) a seasonal variation was found for the occurrence rate of the events with a maximum in September. These characterized a new phenomenon which we are calling cusp energetic particle (CEP) events. The observed high charge state of helium and oxygen ions in the CEP events indicates a solar source for these particles. Furthermore, the measured 0.52-1.15 MeV helium flux was proportional to the difference between the maximum and the minimum magnetic field in the event. A possible explanation is that the energetic helium ions are energized from lower energy helium by a local acceleration mechanism associated with the high-altitude dayside cusp. These observations represent a potential discovery of a major acceleration region of the magnetosphere.

1. Introduction

Since the discovery of the Earth's radiation belt by Van Allen and his colleagues in 1958 [*Van Allen and Frank*, 1959; *Yoshida et al.*, 1960; *Van Allen*, 1963], the studies of the energetic particles have been extended to include the geomagnetic trapped heavy ions [*Krimigis and Van Allen*, 1967; *Fritz and Krimigis*, 1969] and the trapped isotopic species in the radiation belt [*Chen et al.*, 1994, 1996a, b; *Cummings et al.*, 1994]. All of the studies concerning the energetic particles in the radiation belts are limited to either near the equator or at lower altitude.

On February 24, 1996, Polar was launched into a 1.8 × 9 R_E (Earth radius) polar orbit, which has an inclination of 86 deg and a period of 18 hours. Over the first year, the spacecraft sampled high-altitude regions in the north and low altitudes in the south and spins with a period of about 6 s. A special feature of the Polar spacecraft is the onboard interconnection of sensors for electronic communication that the measured magnetic field can be communicated to ion sensors for use in data organization. The Charge and Mass Magnetospheric Ion Composition Experiment (CAMMICE) onboard Polar consists of two sensors, the Heavy Ion Telescope (HIT) and the Magnetospheric Ion Composition Sensor (MICS), designed to measure the charge and mass composition within the geomagnetosphere over the energy range of 1 KeV/*e* to 60 MeV/ion, to de-

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termine the fluxes of various ion species and their relative abundances and to seek to identify mechanisms by which these ions are energized and transported from their source populations within geospace. The HIT sensor uses a three-element solid-state detector telescope to measure the rate of energy loss and the ion's total incident energy, and this permits an unambiguous determination of the ion's nuclear charge, mass, and incident energy over the energy range from 100 KeV/ion to 60 MeV/ion. There are also some discrete discriminators on each detector to create data response channels that can be accumulated in a manner identical to a number of previous instruments of this type flown as part of the science payload of Explorer 45, ATS-6, Viking, and CRRES [*Fritz and Cessna,* 1975; *Fritz et al.,* 1985]. The MICS sensor uses an ogive-shaped electrostatic analyzer, a secondary-electron generation/detection system, and a solid-state detector to measure the energy, time-of-flight, and energy per charge of the incident ions, which permit a unique determination of the ion's incident charge state, mass, and energy over 1 KeV/e to 400 KeV/e energy range and provide important information about the origins of the energetic particles.

The polar orbits of the Polar spacecraft thus provide an excellent opportunity to investigate the energetic particles in the polar cusp regions. By definition, the polar cusps are near zero magnetic field magnitude and funnel-shaped areas between field lines that map to the dayside and nightside of the magnetopause surface. Theoretically, for perfect shielding, the cusps are focal points for the shielding currents confining the magnetosphere [*Chapman and Ferraro,* 1931]; for not perfect shielding, the cusps become open funnels for direct entry of magnetosheath plasma into the magnetosphere [e.g., *Reiff et al.,* 1977; *Reiff,* 1979; *Marklund et al.,* 1990; *Crooker et al.,* 1991; *Yamauchi et al.,* 1996]. In practice, the cusp regions are identified either by minimum local magnetic fields [*Farrell and Van Allen,* 1990] or by a combination of magnetic field, plasma flow, and plasma wave [*Chen et al.,* 1997b; *Fung et al.,* 1997]. Depending upon the interplanetary conditions, the polar cusps can open and close several times with a period of hours and form local magnetic minima and maxima to temporarily confine the MeV ions [*Chen et al.,* 1997a].

On August 27, 1996, Polar/CAMMICE observed an energetic particle event in the polar cusp region, which showed some unusual features [*Chen et al.,* 1997a]. Now, we confirm that the event represents a new magnetospheric phenomenon, and we call it the cusp energetic particle (CEP) event. A total of 75 CEP events were detected during 1996. Section 2 describes the August 27, 1996, event as an example of the CEP events, section 3 lists all of the CEP events measured by CAMMICE in 1996 and displays their positions in the magnetosphere, section 4 shows the seasonal variations of the CEP events, while section 5 discusses the possible relationships of the energetic helium intensities with the local magnetic fields. Section 6 discusses the implications of the results, and section 7 summarizes the discovery of the CEP events and the discovery of a major acceleration region of the magnetosphere.

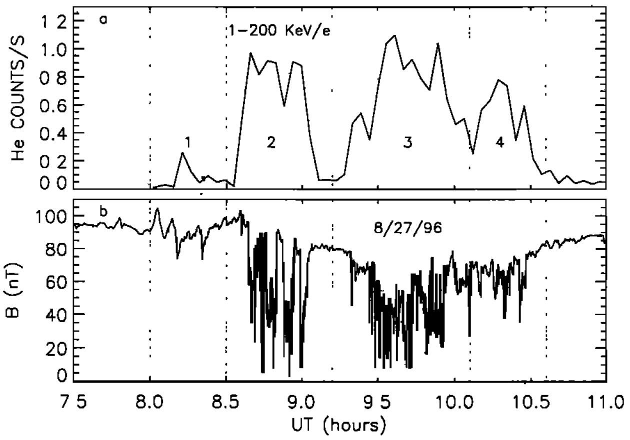

Figure 1. An example of the CEP events on August 27, 1996. (a) The 1-200 KeV/e helium counting rate versus time, (b) the corresponding variation of the local geomagnetic field, where the vertical dashed lines mark the four different regions in the events.

2. CEP Event: An Example

An example of the CEP events is shown in Figure 1. On August 27, 1996, at about 0840 UT when the Polar spacecraft was 9 R_E (Earth's radius) from the Earth at $\simeq 67°$ geomagnetic latitude (MLAT) and $\simeq$ 14.7 hours local time (MLT), the MICS sensor detected a large increase of 1-200 KeV/e helium intensity (Figure 1a) that was corresponding to a large decrease in the magnitude of the local geomagnetic field (GMF) measured by the Magnetic Field Experiment (MFE) [*Russell et al.,* 1995] on Polar (Figure 1b). In other words, Figure 1 suggests qualitatively that the 1-200 KeV/e helium intensity was anticorrelated with the field magnitude. The event lasted more than two hours. A quantitative relationship between the 1-200 KeV/e helium count rate and the field magnitude is plotted in Figure 2 with a 3.3-min average data set during the August 27, 1996, 2-hour event period. Figure 2 indicates that the helium count rate was most clearly anticorrelated with the field magnitude when the GMF was in the range of 50-100 nT.

Plate 1 presents measurements by the Plasma Wave Investigation (PWI) [*Gurnett et al.,* 1995] on Polar of the plasma wave intensities on August 27, 1996, for the same time period as shown in Figure 1. The data are displayed as a frequency-time spectrogram with magnetic power density increasing as colors go from blue to yellow and red. The distance of Polar from the Earth (in R_E), the magnetic latitude, the magnetic local time (MLT), and the L shell values are shown at the bottom of the plate. The important point to be made from Plate 1 is that there are broad bandwidth bursts of magnetic noise extending from below 5.6 Hz up to about 1 kHz which appear to correlate well with the magnetic field decreases and helium count rate increases observed in Figure 1. The low-frequency noise is believed to arise from the turbulent magnetic fields in a plasma and must consist of whistler mode waves, because no other electromagnetic modes of propagation

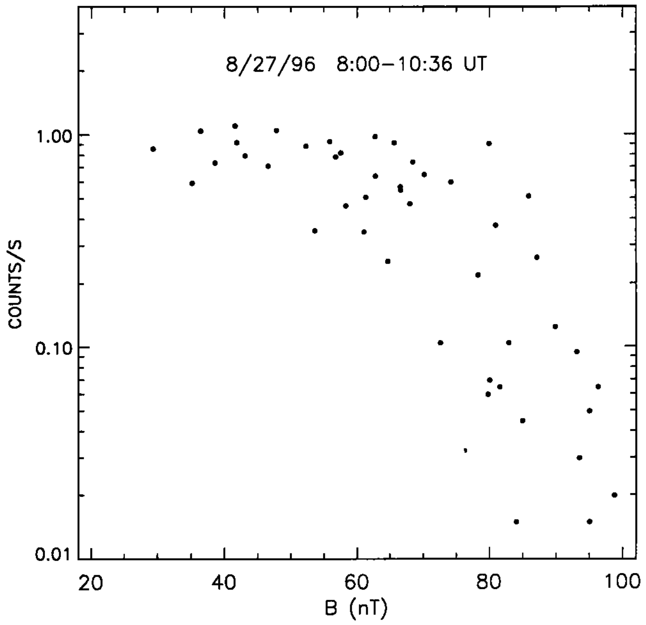

Figure 2. Relationship between the 1-200 KeV/e helium counting rate and the local field magnitude with a 3.3-min average data set during the August 27, 1996, 2-hour event period.

occur in the frequency range in which the turbulence is observed, i.e., between the proton cyclotron frequency and the electron cyclotron frequency. In Plate 1, one feature of the spectrum during the CEP event is the rapid decrease in intensity with increasing frequency; the other feature to note is that the most intense emissions occur at frequencies less than about 200 Hz.

Furthermore, a closer examination of Figure 1 indicates that there were four helium peaks that were associated with four local minima in the field magnitude and corresponded to four different regions: 8.0-8.5 UT, 8.5-9.2 UT, 9.2-10.1 UT and 10.-10.6 UT, and they were designated as four individual CEP events. The numbers of 1, 2, 3, and 4 within the vertical dashed lines in Figure 1a mark the four different regions in this period. The four-peak feature at high latitude was also found both in the 20-200 KeV electron fluxes (Figure 3a) measured by the Imaging Electron Sensor (IES) and in the 20-500 KeV proton fluxes (Figure 3b) by the Imaging Proton Sensor (IPS). The IES and IPS are two sensors in the CEPPAD (Comprehensive Energetic Particle and Pitch Angle Distribution) experiment on Polar spacecraft [*Blake et al.*, 1995]. It is significant to note that the energetic electron intensities are also en-

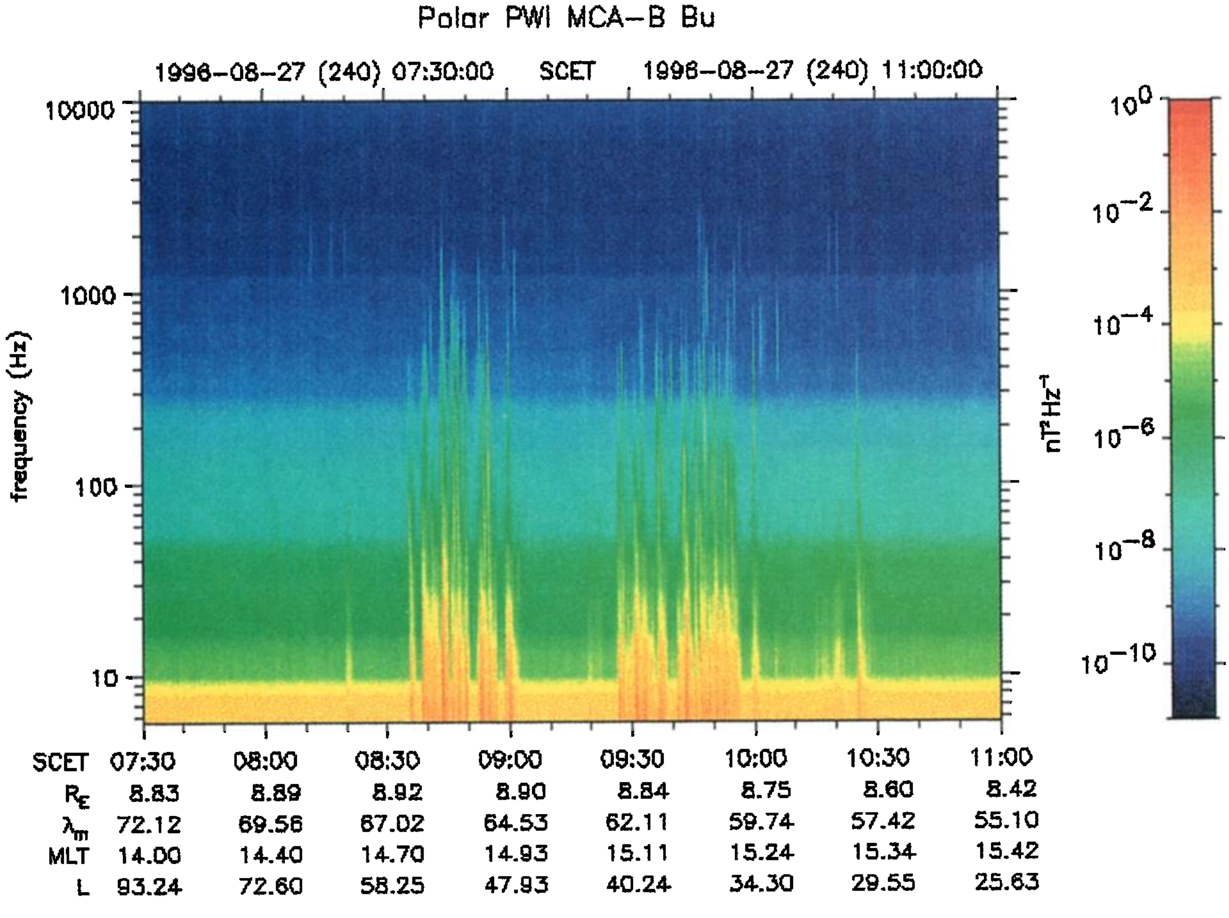

Plate 1. Frequency-time spectrograms of the plasma wave magnetic field intensity on August 27, 1996. The intensities are color coded in blue through red according to the color bar shown to the right. The distance of Polar from the Earth (in R_E), the magnetic latitude, the magnetic local time (MLT), and the L shell values are shown at the bottom. Broadbanded magnetic field turbulence is seen during the four period of interest shown in Figure 1.

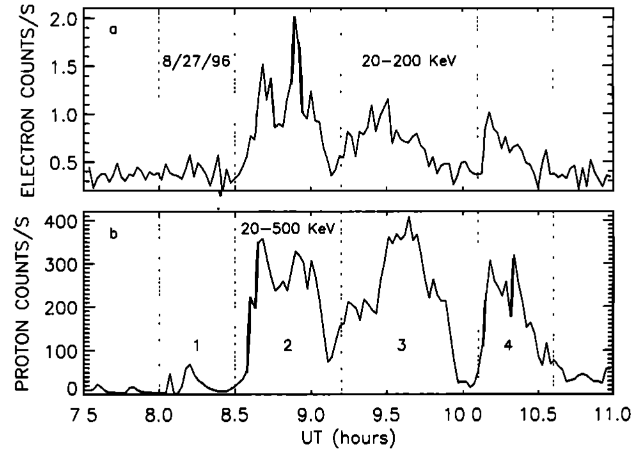

Figure 3. Counting rates versus time for both the (a) 20-200 KeV electrons and (b) 20-500 KeV protons during the same time periods as in Figure 1, where the vertical dashed lines mark the four different regions in the events.

hanced by the same process responsible for producing the CEP events.

The most remarkable feature is that there is an increase of the 0.52-1.15 MeV helium flux of more than 2 orders of magnitude detected by the HIT sensor within the event period [*Chen et al.,* 1997a]. This is indeed very surprising because it is unexpected theoretically [e.g., *Ilyin et al.,* 1986; *Chen et al.,* 1996b]. The aforementioned features for the events on August 27, 1996, are also present in other events during different days.

3. Total CEP Events and Their Positions in Magnetosphere

Table 1 tabulates the 75 CEP events detected by Polar during 1996. The cusp regions, where the CEP events were detected, were identified from MICS plasma flow, MFE magnetic field, and PWI plasma wave by criteria similar to that used by *Chen et al.* [1997b] and *Fung et al.* [1997]. It is not uncommon to observed multievents in a given day, which indicates how dynamic the polar cusp is. Table 1 also shows that all but one of the CEP events were associated with the low-frequency noise enhancements.

Figure 4 exhibits the event-averaged positions of the CEP events in the magnetosphere with plots of MLT versus MLAT (Figure 4a) and MLAT versus R/R_E (Figure 4b) in polar coordinates. In Figure 4a, the four dashed circles from inside to outside indicate the MLAT positions from 80° to 50°, respectively. In Figure 4b, the dashed circles represent the distance of Polar from the Earth (in R_E, Earth's radius). Figure 4a reveals that the CEP events were observed in the dayside and that the event distribution is asymmetric about noon. In the regions of $R > 7$ R_E, 7 hours < MLT < 17 hours, and $45° <$ MLAT $< 80°$, the sample-time of the morningside by the Polar was about 0.87 of that of the afternoonside in 1996, so that after normalized by the sample-time one obtained nearly 79% of the total events in the afternoonside and 21% in the morningside. This result is different from that of the lower energy plasma that enters into ionosphere through the low-altitude cusp where a more symmetric distrubition is expected and found [e.g., *Heikkila and Winningham,* 1971; *Frank,* 1971; *Marklund et al.,* 1990]. Both panels in Figure 4 also reveal that the CEP events spanned more than 20 deg in geomagnetic latitude, which is also different from the expectation of the low-altitude cusp where it is observed to be only about 4 deg or less in latitude [e.g., *Menietti and Burch,* 1988; *Marklund et al.,* 1990; *Yamauchi et al.,* 1996], but is consistent with the high-altitude cusp's result [*Fung et al.,* 1997] where cusp widths of about 30 deg were reported.

Figure 5 displays the same events as Figure 4 by joining the start and end points of each event with a single line in Cartesian coordinates. Figure 5a shows that the position of these CEP events could occur over 6 hours in local time and 30 deg in latitude, much larger than

Table 1. CEP Events in 1996

Date	Universal Time, hours	Number of Events	LFN enhanced
May 29	3.80-7.10	3	Y
June 20	4.80-7.10	2	Y
July 21	0.70-2.00	2	Y
July 26	2.80-5.00	3	Y
July 31	7.50-9.80	2	Y
Aug. 14	3.50-8.00	2	Y
Aug. 16	8.00-10.6	3	Y
Aug. 22	23.5-24.0	1	Y
Aug. 23	0.00-3.60	3	Y
Aug. 24	10.4-13.6	2	Y
Aug. 27	8.00-10.6	4	Y
Aug. 28	2.40-4.00	2	Y
Aug. 28	21.4-23.0	3	Y
Aug. 30	7.00-8.70	1	N
Sept. 8	2.00-4.50	3	Y
Sept. 10	4.50-8.90	2	Y
Sept. 11	0.80-3.60	2	Y
Sept. 11	19.5-22.4	2	Y
Sept. 14	0.30-1.50	2	Y
Sept. 18	7.20-10.1	3	Y
Sept. 19	20.8-22.5	2	Y
Sept. 20	13.8-16.3	3	Y
Sept. 21	5.70-8.80	1	Y
Sept. 22	0.70-3.00	3	Y
Sept. 27	2.00-6.20	2	Y
Sept. 27	22.0-23.5	1	Y
Sept. 29	7.50-9.50	1	Y
Oct. 2	4.20-6.70	3	Y
Oct. 8	2.40-4.00	2	Y
Oct. 8	21.0-23.0	1	Y
Oct. 9	15.6-17.0	1	Y
Oct. 13	5.40-8.40	2	Y
Oct. 13	23.0-24.0	1	Y
Oct. 14	0.00-1.30	2	Y
Nov. 4	5.60-8.80	3	Y

Here LFN is low-frequency noise; N, no; Y, yes.

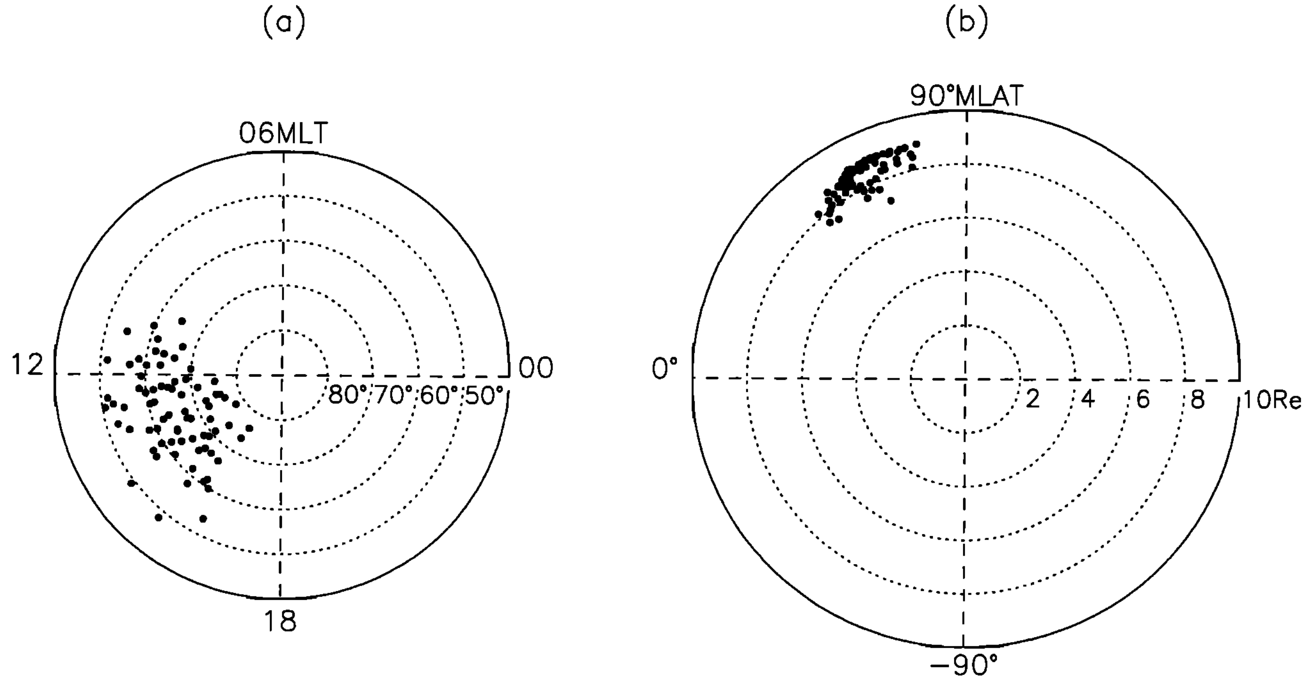

Figure 4. The event-averaged positions of the CEP events in the magnetosphere with (a) MLT versus MLAT and (b) MLAT versus R in polar coordinates. In Figure 4a, the four dashed circles from inside to outside indicate the MLAT positions from 80° to 50°, respectively; while in Figure 4b, the dashed circles represent the distance of Polar from the Earth (in R_E, Earth's radius).

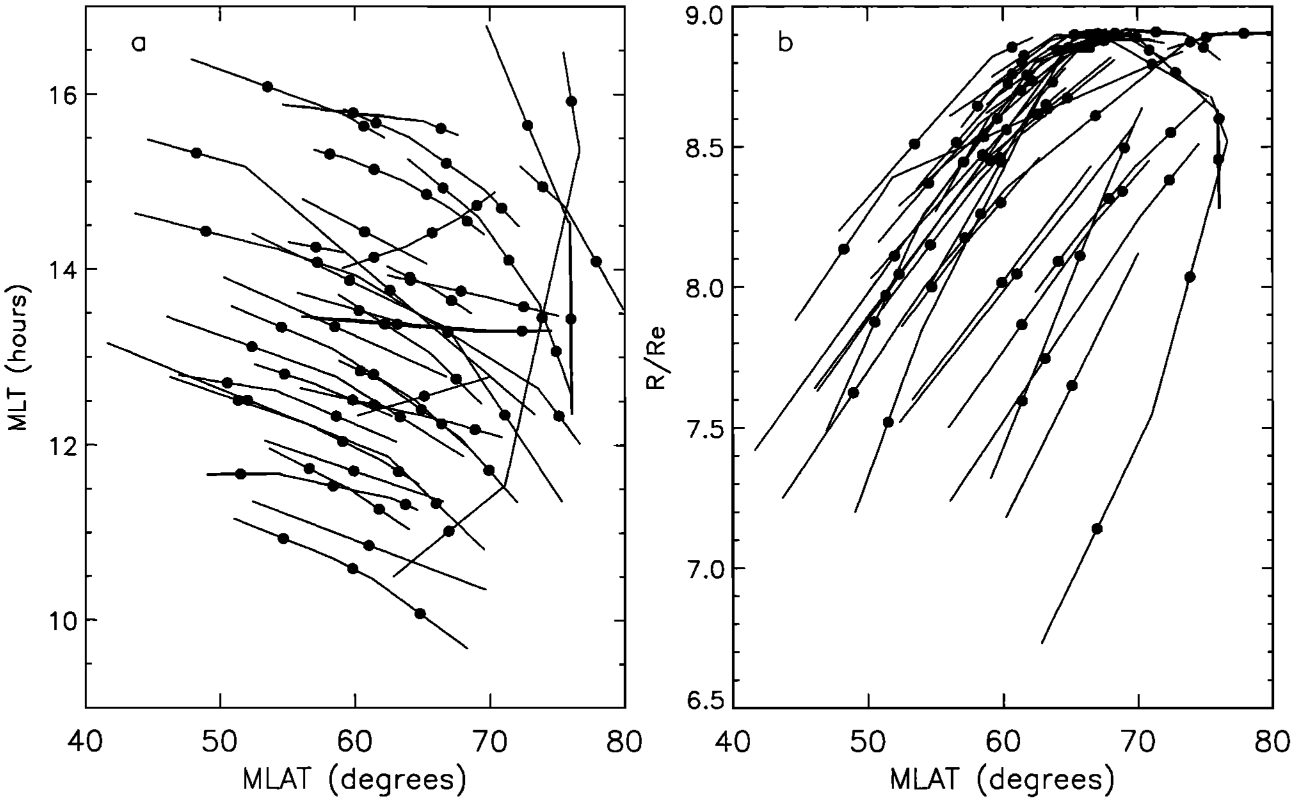

Figure 5. The same events as in Figure 4 with the start and the end points of each event being joined by a single line in Cartesian coordinates.

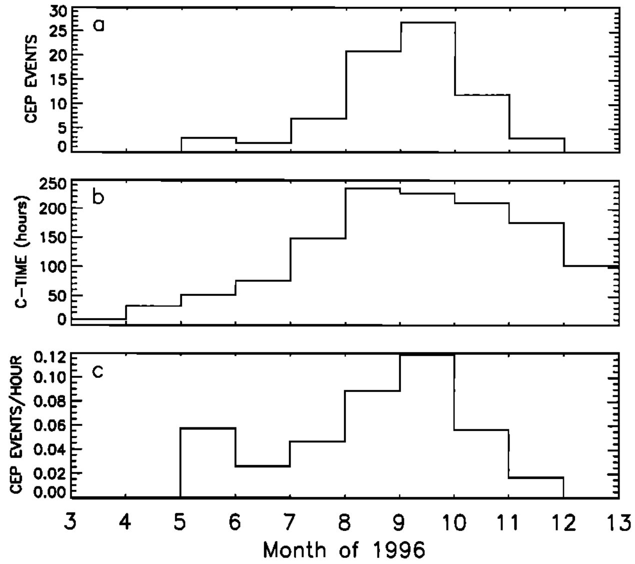

Figure 6. The monthly (a) CEP events, (b) the time (C-time) spent by Polar in the region where the CEP events may be detected, and (c) the occurrence rates of the CEP events (normalized by the C-time) during 1996.

expected, and that the observed CEP events peaked around 60°-70° MLAT. Another interesting feature is that the CEP events extended more degrees in latitude in the afternoonside than that in the morningside. For an individual CEP event at 8.5 R_E, it had a typical value of about 10 deg in latitude (see right panel). All CEP events were observed at radial distances greater than 7 R_E. Figure 5 gives the size of polar cusp regions.

4. Seasonal Variations and Energy Spectrum of CEP Events

The CEP events also exhibit seasonal variations. Figure 6a is a histogram showing the distribution of the monthly CEP events during 1996. A peak value of 27 events was measured in September. Before ascribing this to a seasonal variation, one needs to examine the Polar's orbit effect. As mentioned in the last section, those Polar orbits with $R > 7\ R_E$, 7 hours < MLT < 17 hours, and 45° < MLAT < 80° are chosen as the region where a CEP event may be detected, and the time (C-time) spent by the Polar spacecraft in such a region is shown in Figure 6b. If Polar spends less time in such a region, one would expect to observe fewer events. This is the case before May 1996, which may explain why no CEP events were observed during March and April. However, this is not the case after May 1996. The C-time in Figure 6 indicates that there were ample opportunities for POLAR to pass through the dayside cusp region during June to December periods. Therefore the variation of the CEP event occurrence rate during June to December 1996 was real seasonal effect, as showed in the bottom panel of Figure 6, where the CEP events are normalized by the C-time. A similar seasonal dependence was found by *Newell and Meng* [1988, 1989] in low-altitude study of cusp ion precipitation.

The energy spectrum, presented in Figure 7, shows the helium flux averaged over all of the CEP events when energetic helium data are available. The four HIT energy passbands from top to bottom in Figure 7 are 0.52-1.15 MeV, 1.15-1.8 MeV, 1.8-2.4 MeV, and 2.4-8.2 MeV, respectively. Figure 7 suggests a power law spectrum, and the least squares fit (solid line in Figure 7) gives a spectral index of 4.6±0.9. The important point is that the helium energy in the CEP events can be greater than 2.4 MeV. During aforementioned CEP event times, the D_{st} index showed rather geomagnetically "quiet" periods. No comparable flux was observed by the Wind spacecraft for all of the CEP event periods. This suggests a local acceleration region.

5. Relationships of He Intensity With Local GMF

The local magnetic fields play an important role in organizing the measured energetic helium intensities. Figure 8 associates the event-averaged counting rate of the 1-200 KeV/e helium with four different local GMF parameters in four panels: $< dB^2 >$ (Figure 8a), $< B >$ (Figure 8b), $B_{max}-B_{min}$ (Figure 8c), and B_{min} (Figure 8d), where $< >$ represents event average, $dB = B_{i+1} - B_i$ from 6 s resolution field data, and B_{max} and B_{min} are maximum and minimum field magnitudes during an individual event period, respectively. The four open squares are the four events on August 27, 1996. The event-averaged method was used to reduce the irregular and random fluctuations and to analyze the statistical properties. (Note that because of data gaps, no valid 1-200 KeV/e helium data for the third event period on September 18, 1996, and the event period on September 19, 1996, are available, and no valid GMF data after September 30, 1996, are accessible at this time.) Figure

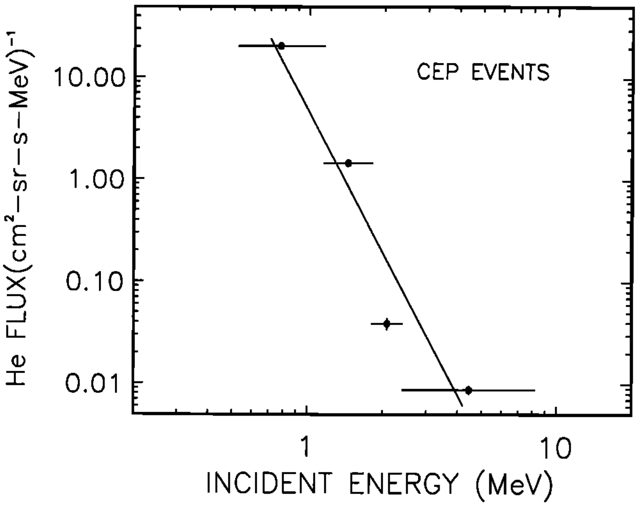

Figure 7. Helium energy spectrum of the CEP events in 1996.

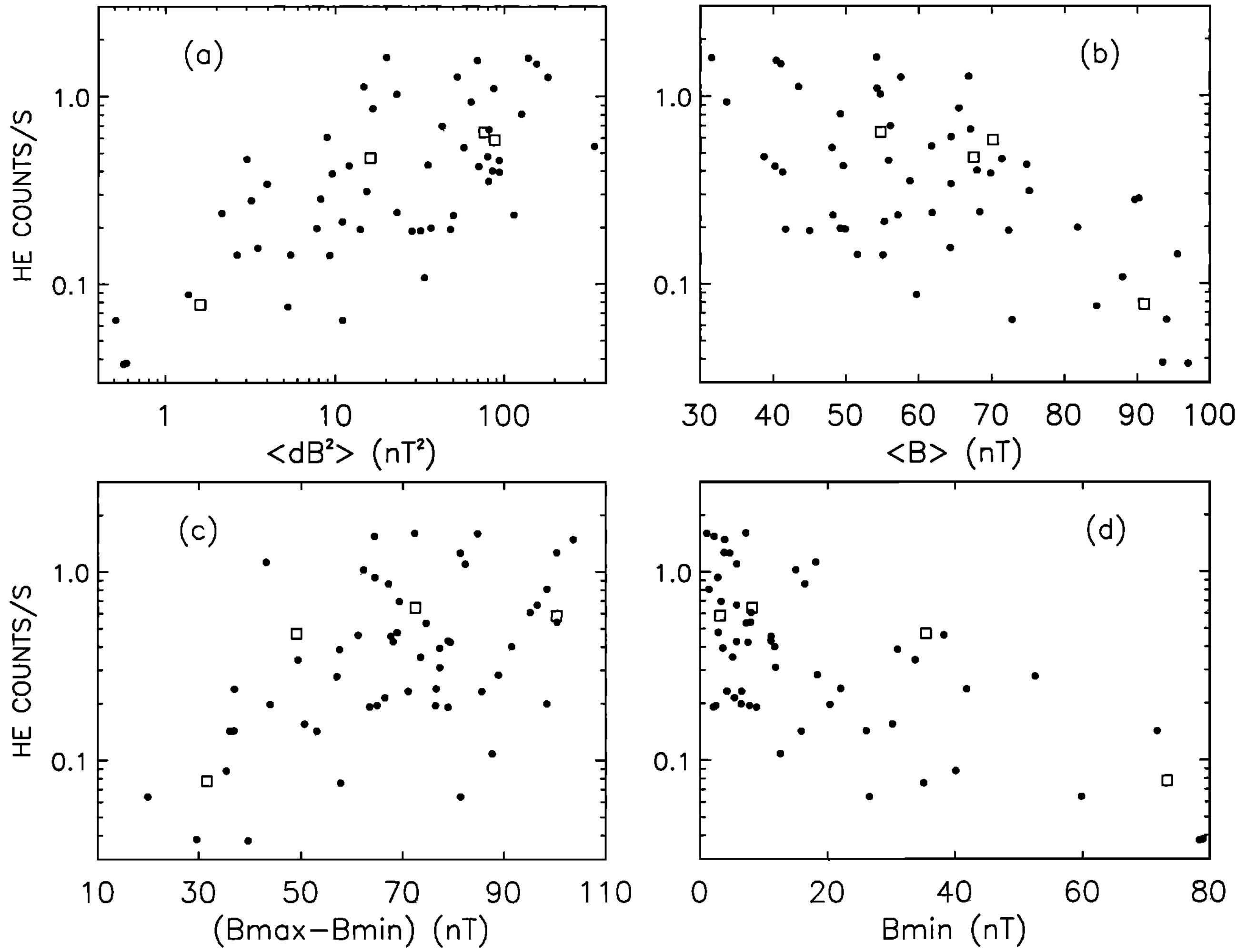

Figure 8. Event-averaged counting rate of the 1-200 KeV/e helium versus four different local GMF parameters in four panels: (a) $< dB^2 >$, (b) $< B >$, (c) $B_{max} - B_{min}$, and (d) B_{min}, where $< >$ represents event average, $dB = B_{i+1}$ - B_i, and B_{max} and B_{min} are maximum and minimum field magnitudes during an individual event period, respectively. The four open squares represent the four events on August 27, 1996.

8 reveals that the 1-200 KeV/e helium intensities were best organized by $< dB^2 >$ (Figure 8a), and that there was an anticorrelation between 1-200 KeV/e helium intensities and the event-averaged (mean) field (Figure 8b). Figure 8d also shows an anticorrelation of 1-200 KeV/e helium intensities with the B_{min} and indicates that most CEP events are concentrated at $B_{min} < 10$ nT. In Figure 8c, a poor correlation of 1-200 KeV/e helium counting rates with $B_{max} - B_{min}$ is found when this difference is less than 50 nT; however, when the field difference is greater than 50 nT, no correlation is found (see also the squares in Figure 8c).

Figure 9 is a plot similar to Figure 8 but for 0.52-1.15 MeV helium ions; in Figure 9c it exhibits a clear linear correlation between the 0.52-1.15 MeV helium flux and the field difference for all events (dots) and for the August 27, 1996, events (squares). Comparing with Figure 8, Figure 9 shows less correlation between the 0.52-1.15 MeV helium intensities and the $< dB^2 >$ in Figure 9a, no correlation of the helium flux with the mean field in Figure 9b, but clearly anticorrelation with B_{min} in Figure 9d.

6. Discussion

It is well known that the dayside magnetosheath is dominated by solar wind plasma with high ion charge states and solar composition [*Gloeckler et al.,* 1986]. *Chen et al.* [1997a] reported that the August 27, 1996, events exhibit large amounts of He^{++} and $O^{>+2}$. Our analysis of all of the CEP events listed in Table 1 has determined that (1) the 1-200 KeV/e helium ions are He^{++}; i.e., compared to He^{++}, the He^{+} is negligible; (2) compared to $O^{>+2}$, the $O^{<+3}$ is negligible; and (3) at 1-200 KeV/e, the helium particles are the dominant heavy ions with an intensity of about 1 order of magnitude larger than the oxygen ions. These facts suggest a solar source for the particle fluxes in the CEP events.

It is generally held that there are two energy storage regions in the magnetosphere with one in the geomag-

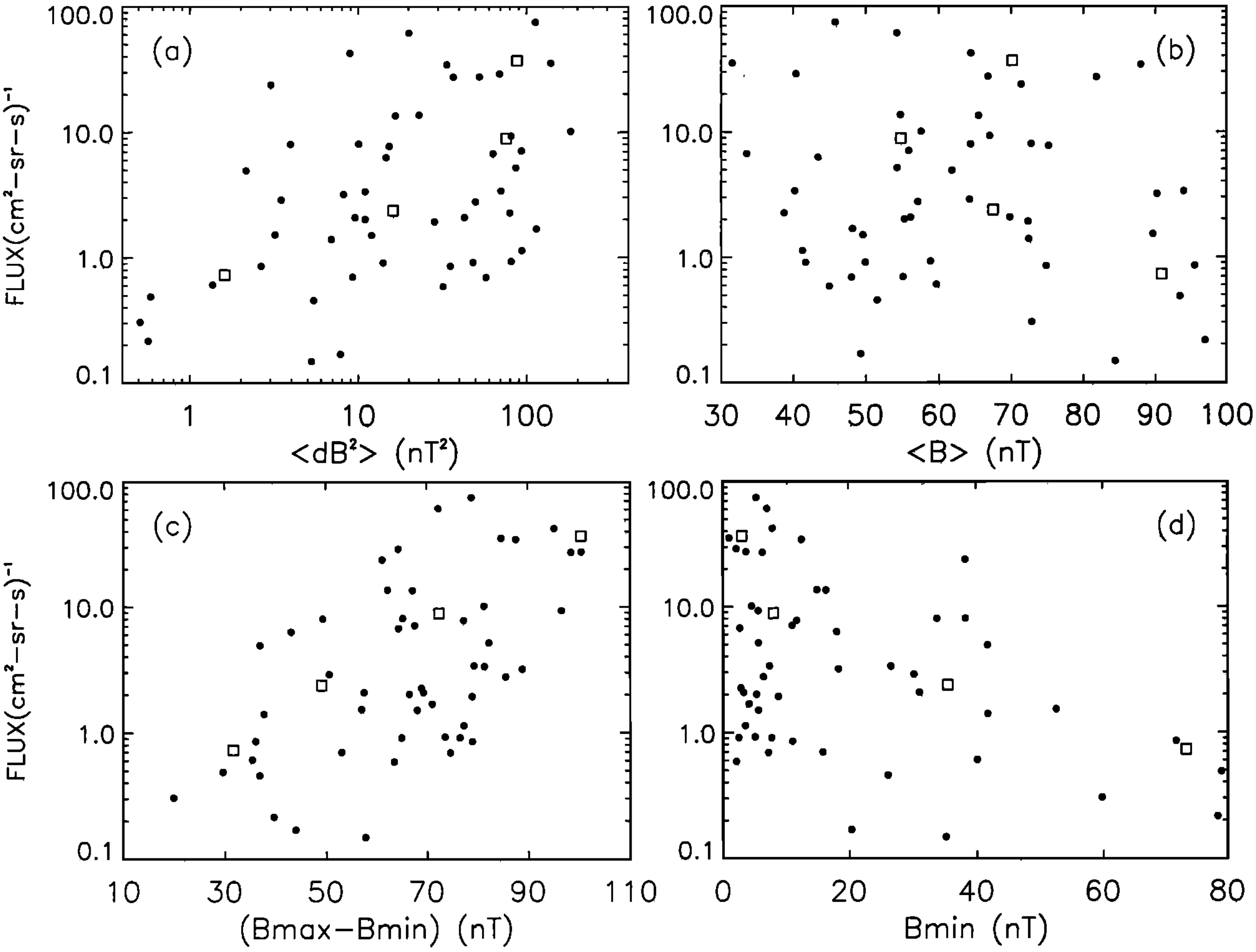

Figure 9. The similar plot as in Figure 8 but for 0.52-1.15 MeV helium ions.

netic tail and the other one in the ring current. However, these Polar observations seem to suggest a third energy storage region. The pitch angle distributions of 0.52-1.15 MeV helium in the August 27, 1996, CEP events were found to be different from an isotropic distribution, and the helium ions showed different energy spectra in different CEP events [*Chen et al.,* 1997a]. This is also a characteristic of other CEP events listed in Table 1 as well. The point here is that the observed helium ions in the CEP events are from the same solar source but that they exhibit different energy spectra in different cusp regions. Therefore the measurements suggest that the CEP events constitute a new temporarily confined heavy ion population that was controlled by some local accelerating and confining mechanism [*Chen et al.,* 1997a]. These results imply an unanticipated energy storage and transfer region associated with the polar cusps. The CEP events may also be related to the large (more than 2 orders of magnitude) increase of the MeV helium flux in the outer radiation belt as observed for the CEP events on August 27, 1996, reported by *Chen et al.* [1997a].

Axford [1970] has suggested that ions can be directly injected into the polar regions from the magnetosheath and subsequently accelerated, and *Bird* [1975] discussed a mechanism for the capture of solar wind ions and their subsequent trapping. While it is clear that the high charge state ions originated from the magnetosheath, the injection and trapping mechanisms for these ions remain unknown. The extremely low frequency electromagnetic waves that are observed during the CEP events are similar to the lion roars observed in the magnetosheath on ISEE and discussed by *Tsurutani et al.* [1982]. Their study concluded that the lion roars that were detected close to the magnetopause were generated by the cyclotron instability of anisotropic thermal electrons when the local plasma critical energy falls to values close to or below the electron thermal energy, 25 eV, as a result of decreases in B, or conversely, in high-beta (10-25) regions. The lion roars are terminated by increases in the ambient magnetic field. In the present study, the magnetic field turbulence, in association with the decreases in magnetic field and increases in helium counts, may be an indication of plasma injection from the magnetosheath through sporadic reconnection. Figure 8d demonstrated that most CEP events are concentrated at B_{min} < 10 nT, which suggests that a strong diamagnetic cavity can be produced at high latitude in the northern polar cusp. The anticorrelation between 1-200 KeV/e helium intensities and the event-averaged (mean) field in Figure 8b is also consistent with the existence of a diamagnetic cavity.

The conversion of magnetic energy to plasma energy through reconnection and acceleration by induction electric fields has been suggested for some time as a means to accelerate particles. There have been no in situ observations to provide the detail information for investigating such energy conversion and acceleration mechanisms at the high altitude polar cap until the launch of the well-instrumented Polar spacecraft. In Figure 8, since the $< dB^2 >$ term is proportional to the turbulent magnetic field energy density, the correlation between 1-200 KeV/e helium counting rates and the $< dB^2 >$ in Figure 8a may be interpreted to mean that the turbulent magnetic energy density is converted into the helium ion's kinetic energy. This seems to point to a resonant or an induction electric field acceleration mechanism for the 1-200 KeV/e helium ions. Furthermore, the fact that the MeV helium ions in the CEP events are controlled by the field difference ($B_{max} - B_{min}$) (Figure 9c) suggests that the acceleration mechanism for MeV helium is either different from that for 1-200 KeV/e helium or greater than that by which the former are energized. These observations represent a potential discovery of a major acceleration region of the magnetosphere.

7. Summary and Conclusions

The Charge and Mass Magnetospheric Ion Composition Experiment (CAMMICE) on board Polar spacecraft observed 75 CEP events in the polar cusp regions in 1996. All of these events were associated with a decrease in the magnitude of the local magnetic field measured by the Magnetic Field Experiment (MFE) on Polar. Our principal conclusions are the following:

1. They were detected in the dayside polar cusp near the apogee of Polar with about 79% of the total events ocurring in the afternoonside and 21% in the morningside.
2. An individual event could last for hours, and the measured helium ion had energies up to and many times in excess of 2.4 MeV.
3. The intensity of 1-200 KeV/e helium was anticorrelated with the magnitude of the local geomagnetic field but correlated with the turbulent magnetic energy density.
4. All but one of the events were associated with magnetic field turbulence in the frequency range between the proton cyclotron frequency and electron cyclotron frequency.
5. A seasonal variation was found for the occurrence rate of the events with a maximum in September. The observed high charge state of helium and oxygen ions in the CEP events indicates a solar source for these particles.
6. At energy range of 0.52-8.2 MeV, the helium energy spectrum in the CEP events can be represented by a power law with an index of 4.6±0.9.
7. The measured 0.52-1.15 MeV helium flux was proportional to the difference between the maximum and the minimum magnetic field in the event.
8. A possible explanation is that the energetic helium ions are energized from lower energy helium by a local acceleration mechanism associated with the high-altitude dayside cusp. These observations represent a potential discovery of a major acceleration region of the magnetosphere.

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