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THE DISCOVERY OF A NEW ACCELERATION AND POSSIBLE TRAPPING REGION OF THE MAGNETOSPHERE

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ABSTRACT

A new acceleration and possible trapping region of the magnetosphere has been discovered by the POLAR spacecraft through the observations of the **cusp energetic particle** (CEP) events. The events were detected in the dayside high-altitude cusp and were associated with a dramatic decrease and large fluctuations in the local magnetic field strength. These events could last for hours, in which the measured helium ions had energies up to 8 MeV (Chen *et al.*, 1997a, 1998). A fundamental question to be addressed is the origins of the cusp energetic ions. Simultaneous observations indicated that the ion fluxes in the CEP events were higher than that in both upstream and downstream from the bow shock. We have determined the power spectra of the local magnetic field turbulence calculated over the September 18, 1996 CEP event periods for fluctuations in the ultra-low frequency (ULF) ranges, corresponding to periods of about 0.33-500 seconds. It is found that the mirror parameter, defined as the ratio of the square root of the integration of the parallel turbulent spectral component over the ULF ranges to the local mean field, is correlated with the intensity of the MeV helium flux. A statistical study of the CEP events indicated that the MeV helium flux was also proportional to the difference between the maximum and the minimum magnetic field in the event. These results represent a discovery that the high-altitude dayside cusp is a new acceleration and possible trapping region of the magnetosphere.

INTRODUCTION

The cusp regions are identified by a combination of low magnetic field strength, high plasma intensity, and the presence of broadband plasma wave noise (Fung *et al.*, 1997; Chen *et al.*, 1998). On February 24, 1996, POLAR was launched into a 1.8 × 9 R_e (Earth radius) polar orbit, an inclination of 86 degrees and a period of 18 hours. Such polar orbits provide an excellent and unique opportunity to investigate the energetic ions in the cusp regions. The Charge and Mass Magnetospheric Ion Composition Experiment (CAMMICE) onboard POLAR was designed to measure the charge and mass composition within the magnetosphere over the energy range of 1 keV/e to 60 MeV, to determine the fluxes of various ion species and their relative abundances and incident charge state, to provide important information about the origins of the energetic ions, and to identify mechanisms by which these ions are energized and transported from their source populations within geospace.

CEP EVENTS

Figure 1 is an example. On September 18, 1996, at about 7:00 UT when the POLAR spacecraft was about 8.9 R_e from the Earth at $\simeq$ 70 deg geomagnetic latitude (MLAT) and $\simeq$ 13.4 hours local time (MLT), the CAMMICE detected an increase of 0.52-1.15 MeV helium intensity (top panel of Fig. 1) that corresponded to a dramatic decrease and large fluctuations in the magnitude of the local geomagnetic field (GMF) measured by the Magnetic Field Experiment (Russell *et al.*, 1995) on POLAR (bottom panel of Fig. 1). In other words, Figure 1 suggests that the MeV helium intensity was anticorrelated with the field magnitude. The event lasted more than three hours (about 7.0-10.1 UT). The numbers of 1, 2, 3, and 4 within the vertical dashed lines in Figure 1 mark four different time periods: 7.0-7.8 UT, 7.8-8.6 UT, 8.6-9.1 UT, and 9.1-10.1 UT. It is noticed that there was an increase of more than two orders of magnitude of the 0.52-1.15 MeV helium flux within period 4. Figure 1 represents a new magnetospheric phenomenon called cusp energetic particle (CEP) events (Chen *et al.*, 1998). A total of 75 CEP events in 1996 has been reported (Chen *et al.*, 1998).

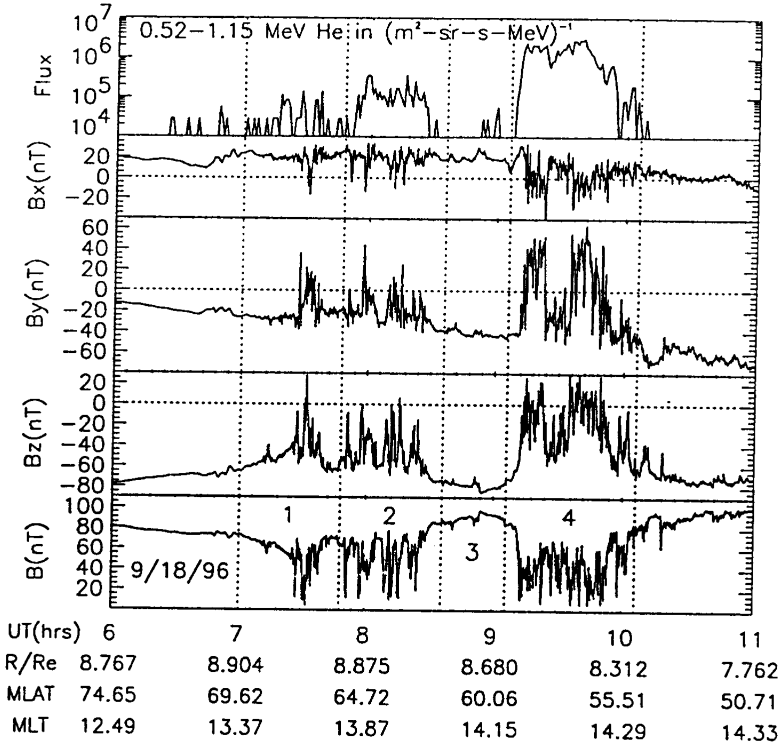

Fig. 1. The CEP event on September 18, 1996, where the panels from top to bottom are the spin-averaged flux of the 0.52-1.15 MeV Helium versus time, the corresponding variation of the local GMF Bx, By, Bz, and B, respectively. The distance of POLAR from the Earth (in Re), the magnetic latitude (MLAT), and the magnetic local time (MLT) are shown at the bottom of the figure.

SOURCE OF CUSP ENERGETIC IONS

Recent reports (Chen *et al.*, 1997a, 1998) indicated that the observed helium and oxygen ions in the CEP events had high charge states. Since solar ions have higher charge states than that of ionospheric particles (Gloeckler *et al.*, 1986), a solar source for the ion fluxes in the CEP events is required. It is well known that the typical energy of the solar wind plasma is about 1 keV, much less than MeV, and a natural question to be addressed is the origin of these cusp MeV ions.

Chen *et al.* (1997a) have discussed the possibility of the solar energetic particle events as a direct and transient source of the particles in the August 27, 1996 CEP events, and have ruled it out due to a lack of simultaneous comparable flux being observed by the WIND spacecraft. This result is also true for all of the other CEP events observed in 1996. During the September 18, 1996 CEP event times, the D_{st} index was about -17 nT, indicating a rather geomagnetically "quiet" period. Since D_{st} is a measure of the mechanism that drives magnetic storms, and the CEP events are not correlated to D_{st}, the storm-time ring current mechanism is not the one that energizes these particles.

The other possibility is that the bow shock accelerates the low energy solar wind particles to a higher energy. Previous observations indicated that at energies larger than 60 keV the ion fluxes were almost the same either before the bow shock in the upstream or after the bow shock in the magnetosheath (West and Buck, 1976; Krimigis *et al.*, 1978). At 9:15-9:45 UT on September 18, 1996, GEOTAIL was in the upstream region from the bow shock and on the dawn side of the Earth, and POLAR was in the cusp; simultaneous observations indicated that the ion fluxes in the cusp were higher than that in the upstream from the bow shock. On September 11, 1996 at 2:30-3:00 UT, GEOTAIL was in the downstream region from the bow shock in the magnetosheath and POLAR was in the cusp. The ion flux in the CEP events, as shown in Figure 2, were higher than that in the magnetosheath. Therefore, the bow shock acceleration alone cannot explain the observed high flux in the CEP event.

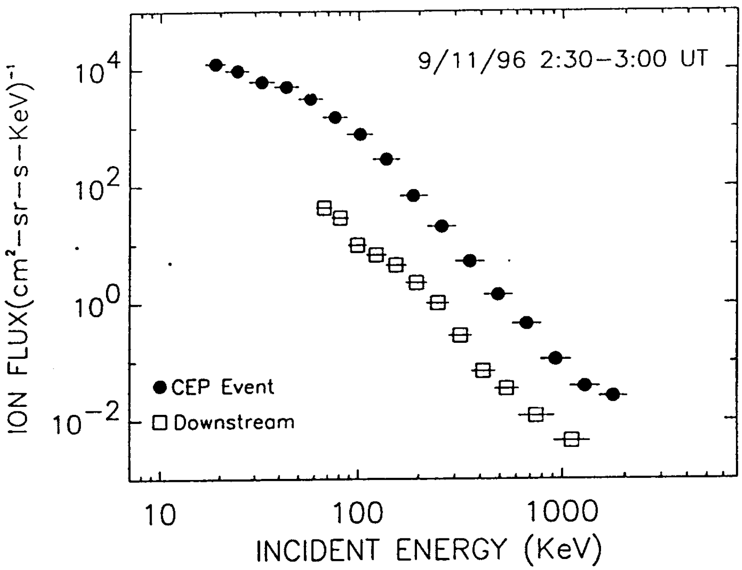

Fig. 2. Ion energy spectra observed by the GEOTAIL in the downstream (open squares) and by the POLAR in the cusp (solid circles) at 2:30-3:00 UT on September 11, 1996.

CORRELATIONS OF MEV HE FLUX WITH LOCAL GMF PARAMETERS

Figure 1 suggests that the local turbulent magnetic fields play an important role in organizing the measured energetic helium intensities. For further understanding the quantitative relationship between the MeV helium flux and the turbulent field, the turbulent magnetic energy spectra have been calculated for the four time intervals (see Fig. 1) during the 9/18/96 CEP event periods. The spectrum analysis method developed by Chen (1989) is used to determine the power spectra of the local GMF turbulence for fluctuations in the ultra low frequency (ULF) range of about 0.002 to 3 Hz, corresponding to periods of about 0.33-500 seconds that cover the calculated bounce and drift periods of the tens of keV to MeV charged particles in the cusp (Chen *et al.*, 1997b; Sheldon *et al.*, 1998) and the ion gyroperiod in the CEP events. Integrating the spectral component parallel to the mean field over the ULF ranges, one obtains a term that is proportional to the ULF parallel turbulent magnetic energy. The mirror parameter was defined as the ratio of the square root of the integration of the parallel turbulent spectral component over the ULF ranges to the local mean field (Bieber *et al.*, 1993). Figure 3 plots the mirror papameter versus the MeV helium fluxes for the four time periods showed in Figure 1. A remarkable feature of Figure 3 is that there is a clear correlation between the MeV helium flux and the mirror parameter. Since the mirror parameter provides a measure of the influence of mirroring interactions, indicating a local effect, and is proportional to the turbulent magnetic energy that will produce the induced electric field to accelerate the charged particles, Figure 3 gave a direct observational evidence that the high-altitude dayside cusp is an acceleration region.

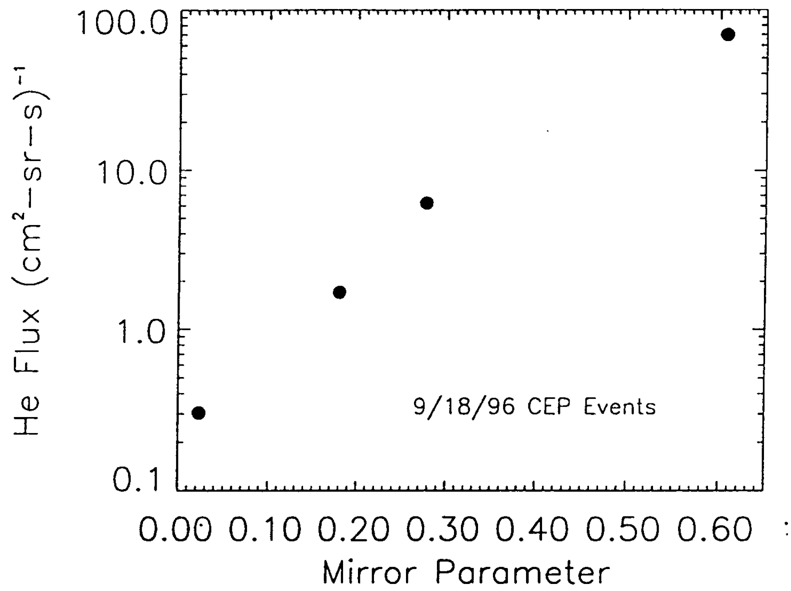

Fig. 3. The mirror paramter versus the MeV He fluxes for the four time periods showed in Fig. 1.

Another GMF parameter that indicates a local effect is the difference between the maximum and the minimum magnetic field in the event (Bmax-Bmin). Figure 4 associates the event-averaged 0.52-1.15 MeV helium flux with the local GMF parameter (Bmax-Bmin) when the GMF data were available during the CEP event periods. The four open squares are the four events on September 18, 1996, and the four open triangles are the four events on August 27, 1996. Figure 4 exhibits a clear correlation between the 0.52-1.15 MeV helium flux and the field difference, suggesting that the cusp is a possible trapping region of the magnetosphere.

SUMMARY AND CONCLUSIONS

The main differences between bow shock acceleration and cusp acceleration are: (1) the turbulent magnetic energy is in order of (4 nT)^2 (=16 nT^2) for bow shock but is in order of (30 nT)^2 (=900 nT^2) for high-altitude cusp, and (2) the time for ions to stay in the acceleration region is seconds to minutes for bow shock but is tens of minutes to hours for cusp. Data from CAMMICE reveal that the energetic ion population is always present in the cusp regions, what varies is its intensity (Chen *et al.*, 1998). Subsequent radial diffusion from the cusp or other transport/entry processes may deposit particles in the outer radiation belts (Fritz *et al.*, 1998). In summary, (1) the ion flux in the CEP events was higher than that in both upstream and downstream from bow shock so that the bow shock acceleration alone cannot explain the measured ion flux in the CEP events, (2) there is a clear correlation between the MeV helium flux and the mirror parameter, (3) the MeV helium flux was proportional to the difference between the maximum and the minimum magnetic field in the event. These observations represent a discovery that the high-altitude day-side cusp is a new acceleration and possible trapping region of the magnetosphere. This discovery may open an avenue for understanding the source of energetic particles within the magnetosphere.

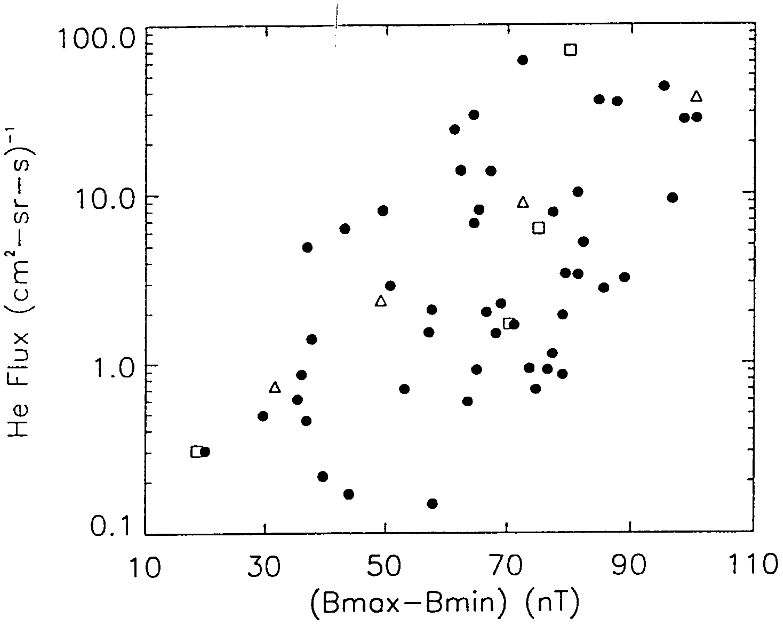

Fig. 4. The local GMF parameter (Bmax-Bmin) versus the event-averaged 0.52-1.15 MeV helium flux, where Bmax and Bmin are maximum and minimum field magnitudes during an individual event period, respectively. The four open squares are the four events on September 18, 1996, and the four open triangles are the four events on August 27, 1996.

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REFERENCES

Bieber, J. W., J. Chen, W. H. Matthaeus, C. W. Smith, and M. A. Pomerantz, Long-Term Variations of Interplanetary Magnetic Field Spectra With Implications for Cosmic Ray Modulation, *J. Geophys. Res.*, **98**, 3585 (1993).

Chen, J., Long-Term Modulation of Cosmic Rays in Interplanetary Magnetic Turbulence, Ph.D.

thesis, Univ. of Del., Newark (1989).
Chen, J., T. A. Fritz, R. B. Sheldon, H. E. Spence, W. N. Spjeldvik, *et al.*, A New, Temporarily Confined Population in the Polar Cap During the August 27, 1996 Geomagnetic Field Distortion Period. *Geophys. Res. Lett.*, **24**, 1447 (1997a).
Chen, J., T. A. Fritz, R. B. Sheldon, and H. E. Spence, The High Altitude Dayside Cusp: A New Trapping and Acceleration Region of the Magnetosphere (abstract), *Eos Trans. AGU*, **78**, F592 (1997b).
Chen, J., T. A. Fritz, R. B. Sheldon, H. E. Spence, W. N. Spjeldvik, *et al.*, Cusp Energetic Particle Events: Implications for a Major Acceleration Region of the Magnetosphere, *J. Geophys. Res.*, **103**, 69 (1998).
Fritz, T. A., Chen, J., and R. B. Sheldon, The Role of the Cusp as a Source for Magnetospheric Particles: A New Paradigm? *Adv. Space Res.*, **25**, No. 7-8, 1445 (2000).
Fung, S. F., T. E. Eastman, S. A. Boardsen, and S.-H. Chen, High-Altitude Cusp Positions Sampled by the Hawkeye Satellite, *Phys. Chem. Earth*, **22**, No. 7-8, 653 (1997).
Gloeckler, G., F. M. Ipavich, D. C. Hamilton, B. Wilken, W. Stüdemann, *et al.*, Solar Wind Carbon, Nitrogen and Oxygen Abundances Measured in the Earth's Magnetosheath With AMPTE/CCE, *Geophys. Res. Lett.*, **13**, 793 (1986).
Krimigis, S. M., D. Venkatesan, J. C. Barichello, and E. T. Sarris, Simultaneous Measurements of Energetic Protons and Electrons in the Distant Magnetosheath, Magnetotail, and Upstream in the Solar Wind, *Geophys. Res. Lett.*, **5**, 961 (1978).
Russell, C. T., R. C. Snare, J. D. Means, D. Pierce, D. Dearborn, *et al.* The GGS/POLAR Magnetic Fields Investigation. *Space Sci. Rev.*, **71**, 563 (1995).
Sheldon, R. B., H. E. Spence, J. D. Sullivan, T. A. Fritz, and J. Chen, The Discovery of Trapped Energetic Electrons in the Outer Cusp, *Geophys. Res. Lett.*, **25**, 1825 (1998).
West, Jr., H. I., and R. M. Buck, Observations of $>$ 100-keV Protons in the Earth's Magnetosheath, *J. Geophys. Res.*, **81**, 569 (1976).