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OBSERVATIONS OF THE NOTHERN POLAR CUSP WITH THE POLAR SPACECRAFT

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ABSTRACT

This study analyses an extended cusp region on 14th August 1996, where relatively high fluxes of solar wind particles are seen over a period of ~4 hours. This coincided with weak IMF B_Z, with varying orientation. Solar wind particles are identified as having high charge state and low energy (1-10 keV/q). We have concentrated on observations of $O^{>2+}$ and He^{2+}. Using CAMMICE MICS and MFE data from the POLAR spacecraft, together with MFI and SWE data from the WIND spacecraft, it has been shown that the extended cusp regions do not correlate with extended (≥ 3 hours) periods of either northward, anti-sunward, eastward or westward oriented IMF. This suggests that these events are not connected with tail lobe reconnection, as suggested by Grande et al., 1997. The magnetic field measured by POLAR has been compared with the Tsyganenko 1989 (T89) magnetospheric model. The T89 model shows the event occurring on closed field lines in the tail lobe, where solar wind particles are not expected to be present. This disparity is caused by the suppression of open field lines in the T89 model.

1. INTRODUCTION

The Earth's cusps are regions of the magnetosphere where magnetosheath plasma has direct access to the dayside auroral regions. Since material in the magnetosheath is comprised of shocked solar wind plasma, the particle composition and charge state is the same as that found in the solar wind. High charge state ion species, such as He^{2+} and $O^{>2+}$, can only be created in any quantity in the solar corona since temperatures there are sufficiently high to reach the required ionisation energies. Such charge states cannot be created locally in the magnetosphere. A consequence of the magnetosheath plasma being processed by the bow shock is that the magnetic field is highly disturbed, with the orientation changing on short time-scales (minutes or less). On the other hand magnetospheric plasma near the cusp has low density, low charge state (He^{+} and O^{+}) and high energy (accelerated by processes in the magnetosphere). The magnetospheric field in the vicinity of the cusp region is highly ordered and steady. Therefore, when a spacecraft enters the magnetosphere from the cusp, the ion composition is observed to change from high charge state; high density; low energy to low charge state; low density; high energy, as is shown in Figure 1. This is accompanied by a rapid rotation of the magnetic field vector as the spacecraft passes from the ordered magnetospheric field into the shocked magnetosheath field, as shown in Figure 2.

The starting point for this study was an event on 29th May 1996, discussed by Grande et al, (1997) which was described as an extended cusp region. This region was characterised by intense fluxes of solar wind-like ions, which showed evidence of flows and trapping. The solar wind/magnetosheath plasma in this region was typically He^{2+} and $O^{>2+}$ ions with energies from 1 to 10 keV/q. What was even more remarkable was that it coincided with a period where the Interplanetary Magnetic Field (IMF) was exceptionally strong (10 to 15 nT) and northward for several hours. This lead to the conjecture that the extended cusp region had been caused by magnetic reconnection in the tail-lobe (e.g. Gosling et al., 1991; Kessel et al., 1996). An initial study we carried out (Stubbs, 2001) showed no correlation between extended periods (≥ 3 hours) of either northward, anti-sunward, eastward or westward oriented IMF and extended cusp regions. This is supported by the WIND data for 14th August 1996 discussed in section 3.

2. SPACECRAFT

The data for this study has come from the two Global Geospace Science (GGS) spacecraft, POLAR and WIND.

POLAR is in a 1.8×9 Re polar orbit with an inclination of ~86° to the equator (Acuña et al., 1995). Its apogee is at high northern latitudes. POLAR is spin-stabilised at 10 rpm with its spin axis approximately perpendicular to the orbital plane. Data is used from the CAMMICE MICS (Magnetospheric Ion Composition Sensor) and MFE (Magnetic Field Experiment) (Russell et al, 1995). MICS measured the ion flux, mass and charge states for ions with energies of 1-200 keV/q (Wilken et al., 1992).

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MICS is a 2-D instrument viewing perpendicular to the POLAR spin axis.

WIND's orbit takes it from the nightside magnetosphere to the L1 point, though it spends most of its time in the solar wind upstream of the Earth. Data is used from the MFI (Magnetic Fields Investigation) and the SWE (Solar Wind Experiment) (Lepping et al., 1995 and Ogilvie et al., 1995 respectively). The SWE data was used to find the solar wind flow velocity used to calculate IMF propagation time.

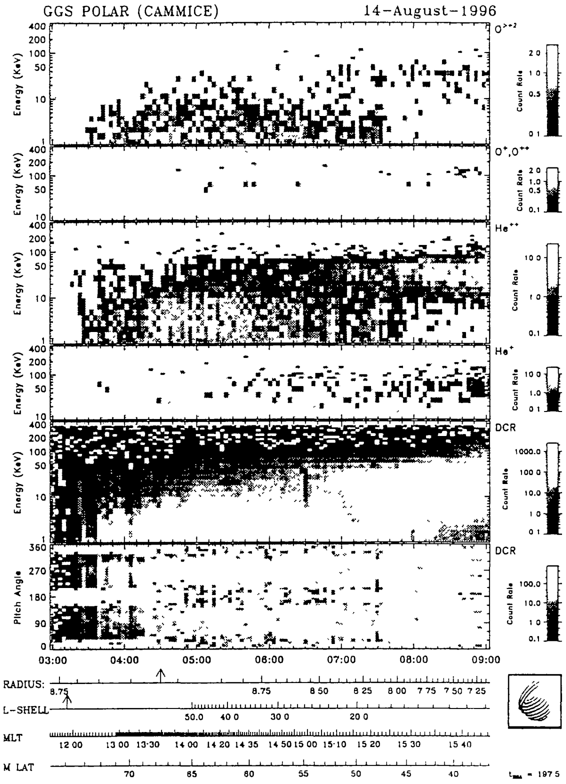


Figure 1: Data from the CAMMICE MICS (Magnetospheric Ion Composition Sensor) showing an extended cusp-like event on the 14th August 1996. The panels show count rates for ions. From the top, these are $O^{>2+}$, O^+ & O^{2+}, He^+, He^{2+}, DCR (Double Coincident Rate – includes all particles, i.e. mainly protons) and Pitch Angle distribution of the DCR relative to the local magnetic field. The Count Rate scale is shown to the right of the relevant panel.

3.OBSERVATIONS

On 14th August 1996, WIND was ~ 87 Re upstream of the Earth and measured a fairly constant solar wind velocity of ~ 360-390 kms^{-1}. The particle density was relatively high ~10-15 cm^{-3}. The IMF, as shown in Figure 3 with a time delay adjustment, varied from ~3-7 nT in magnitude. The GSE z-component was relatively weak varying between –2 nT (southward IMF) to 2 nT (northward IMF). Prior to 0235 UT, the GSE B_Z component had been northward for ~30 minutes.

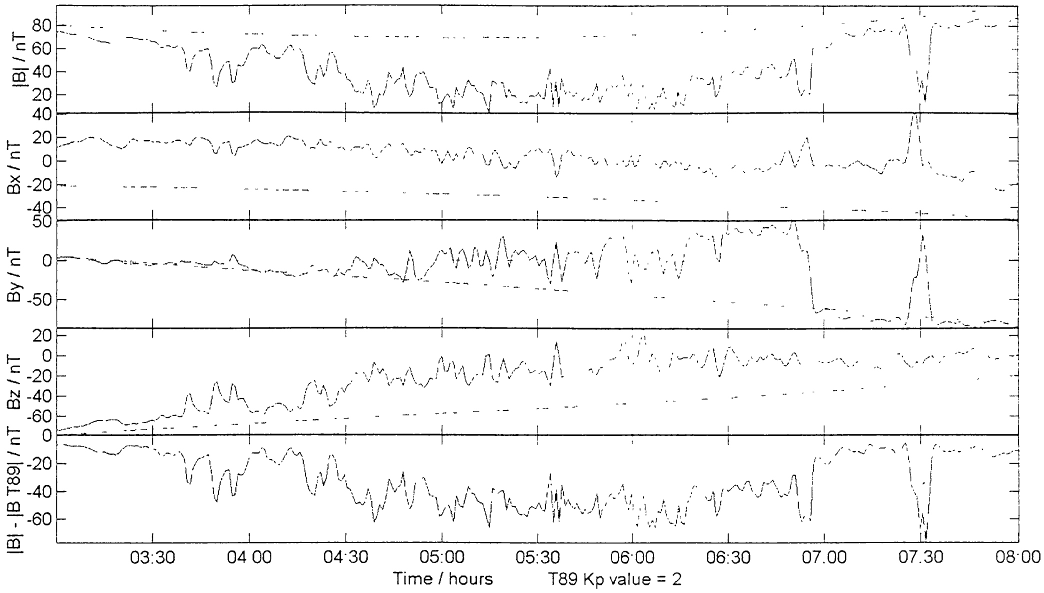
Data plots for the relevant times are shown in Figures 1, 2 and 3. Figure 1 shows ion fluxes from the MICS instrument. Figure 2 is a time series of MFE magnetic field data (solid line) with the prediction from the Tsyganenko 1989 (T89) magnetospheric model (broken line), both in GSM co-ordinates. Figure 3 shows MFI magnetic field data from WIND in GSE co-ordinates. GSE co-ordinates are used for the WIND data as alignment with the magnetosphere at POLAR is better than with GSM.

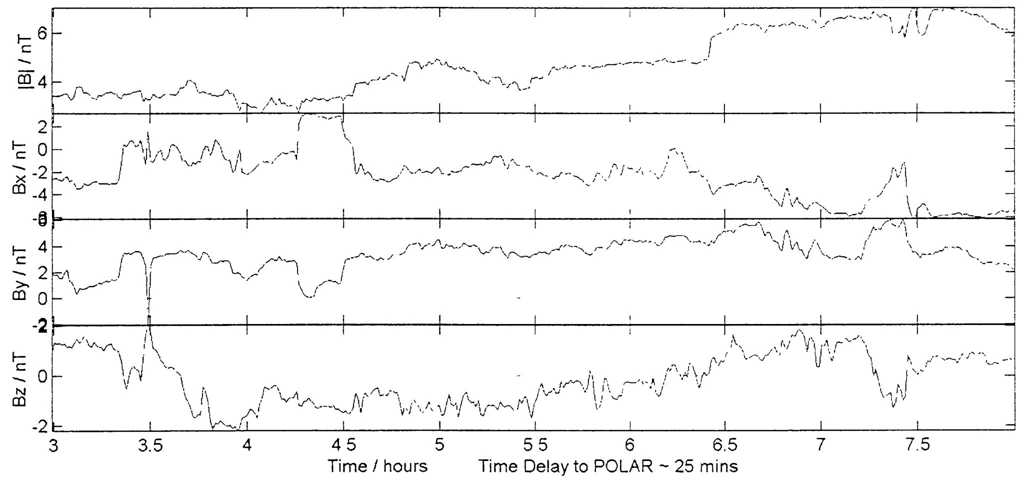
At ~0320 UT, POLAR left the dawnside polar cap and MICS observed an energy dispersion event, presumably associated with tail-lobe reconnection. This tallies with northward IMF as seen at WIND. At ~0340 UT, POLAR entered a boundary layer as indicated by an increase in ion flux (particularly He^{2+} and $O^{>2+}$) and a more disturbed magnetic field. From ~0420 UT to ~0658 UT, MICS observed intense fluxes of He^{2+} and $O^{>2+}$ ions with a peak energy from ~2-3 keV/q (magnetosheath energies). At the end of this period, the ion fluxes show evidence of energy dispersion, with the higher energy particles being lost from the cusp region first. From ~0340 UT until ~0625, the time-adjusted IMF was relatively weak and southward (~-1.5 nT). From ~0658 UT to ~0725 UT, the ion fluxes observed by MICS was reduced and the magnetic field at POLAR increased. From ~0625 UT to ~0715 UT the IMF was northward (~1.5 nT). From ~0720 UT to ~0735 UT, MICS observed an increase in ion fluxes, particularly in the high charge state species. This was accompanied by a decrease in B-field magnitude, mainly due to a fall in the GSM y-component. This coincided with a southward turning of the GSE z-component of the IMF occurring at ~0720 UT. After ~0735, POLAR left the cusp and moved duskward into the dayside magnetosphere. This manifests itself by an increased ordering of the magnetic field and the transition from magnetosheath to magnetospheric particle fluxes.

The IMF B_Z for the main extended cusp region (~0420 UT - ~0658 UT) was relatively weak and southward (~-1.5 nT). This shows that extended cusp regions are not solely associated with strong persistent IMF B_Z. It also highlights that it is not dependent on northward IMF B_Z, as discussed in Grande et al., (1997).

4. T89 MODEL COMPARISON

The Tsyganenko 1989 (T89) model (Tsyganenko, 1989), uses spacecraft data to empirically model the magnetospheric field using statistical techniques. In this study we have used the IGRF (International Geomagnetic Reference Field) with 10 spherical harmonic terms, rather than the dipole approximation. In this version of the model, the only disturbance





parameter used is the K_P index. As K_P is a 3 hour average, this means that events taking place on time-scales ~< 3 hours will not be accounted for: this includes magnetic reconnection.

Figure 2: (top) Time series comparison of magnetic field data with the T89 model. Solid lines show 46 s resolution magnetic field data from the MFE instrument aboard POLAR; broken lines show the T89 model. From the top the panels show the modulus of the magnetic field and the x-,y- and z-components in GSM ço-ordinates. The bottom panel the difference of the observed |B| from that expected from T89.

Figure 3: (bottom) Time series of magnetic field measured by the MFI instrument aboard WIND. Plotted in GSE co-ordinates. The time has been corrected to account for propagation time from WIND to the cusp.

Figure 2 shows a comparison of the magnetic field data (solid line) with the T89 model (broken line). Viewed in conjunction with the time-adjusted IMF data from WIND in Figure 3; it is possible to see a correlation between the IMF z-component and the goodness of the T89 fit with the MFE data. When the IMF is northward, the fit appeared to be better than when it is southward. The bottom panel in Figure 2 shows ΔB, the difference between the magnetic field magnitude and the T89 modelled magnetic field magnitude. ΔB for northward IMF is ~ -10 to -20 nT, whereas ΔB for southward IMF is ~ -40 to -60 nT. The trend in the fit is particularly apparent in the GSM B_Y component. During southward IMF, the fit gradually gets worse, until the IMF settles back to the northward orientation, whereupon the fit improves within ~30 minutes. Of course this effect could also be caused by a boundary moving across the spacecraft. At these altitudes, typically, boundary velocities exceed spacecraft velocities.

To help place the event in the magnetosphere, the portions of the orbit for which POLAR was in the cusp have been plotted with T89 field lines in GSM co-ordinates, as shown in Figure 4. Each field line passes through a point on the orbit for the specific time and K_P. The K_p (model input) was 2, corresponding to a range of K_P indices from 1- to 1+. T89 is a closed magnetospheric model with no open flux. In the model there is a polynomial function which restricts all field lines to within a magnetopause boundary. [Occasionally, the polynomial function fails and a field line is able to escape. An example of this is the gap after ~0600 UT, where the erroneous field lines have not been plotted.] It is likely that many of the field lines are not closed, merely open flux suppressed by the polynomial function. Therefore, it is possible that much of the flux which appears as tail lobe in this figure is actually open flux.

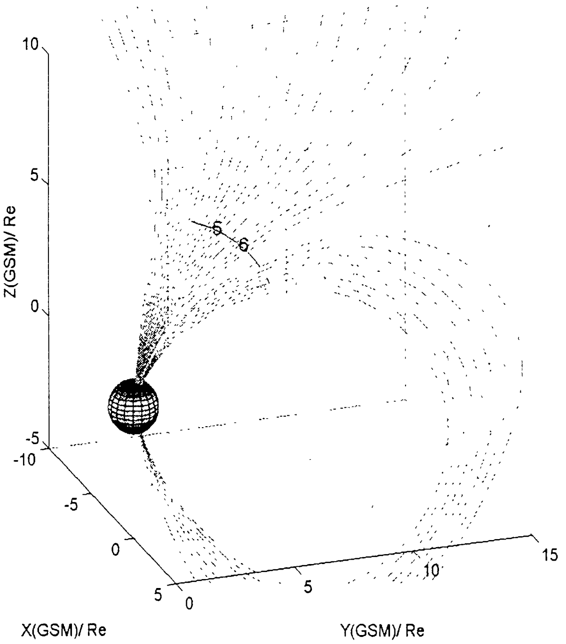


Figure 4: T89 field lines plotted with the POLAR orbit, both plotted in GSM co-ordinates. The portions of the orbits shown are for ~0420 to ~0658 UT and for ~0725 to ~0735 UT. This is when ion species and intensities were cusp-like.

5. CONCLUSIONS AND SUMMARY

The observed energy dispersion at ~0320 UT is possible evidence for tail-lobe reconnection, as the IMF prior to this event had been northward for ~1 hour, suggesting that tail-lobe reconnection would have time to become established. The correlation of WIND magnetic field data with POLAR magnetic field and ion flux data, strongly suggests a high degree of cusp dependence on solar wind conditions on short time scales, in particular IMF B_Z. It also highlights that strong persistent IMF B_Z is not necessary for these events to occur.

As processes around the cusp happen on time scales less than 3 hours, and because of the open flux suppression by the polynomial function, disagreement between data and the T89 model is inevitable. However, these extended cusp regions are vast relative to an average cusp crossing and can differ considerably from T89 predictions.

It is important to remember that the cusp varies both spatially and temporally and it is possible that the cusp is narrow and a single spacecraft moves with the cusp. However, in the case of 29th May 1996 (Grande et al., 1997) two spacecraft measurements make clear that this is not the case. Similarly, on an orbit where MICS observes very low magnetosheath-like ion fluxes, it is possible that the boundary is moving in such a way that the spacecraft spends very little time in the cusp. To resolve the problem of spatial versus temporally variation, multi-point measurements of the cusp are needed to resolve this ambiguity. The ClusterII mission will be invaluable in this respect. Further work in studying these extended cusp regions is planned.

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