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What is Cluster telling us about magnetotail dynamics?

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Abstract

In this review, we report on some new aspects of magnetotail dynamics found in the data of the first traversal of the magnetotail by the Cluster quartet in summer and autumn 2001: (1) The electron drift instrument made the first direct measurements of tail lobe convection. The statistical data shows convection toward the center of the plasma sheet, with a clear dependence on the sign of the interplanetary magnetic field B_Z component. Moreover, a dawn–dusk shear (if one compares convection in opposite lobes) for B_Y-dominated interplanetary field hints to an interconnection of open lobe field lines with the interplanetary medium. (2) At times the tail current sheet resembles a one-dimensional Harris sheet, which might get as thin as 500 km and may carry current densities as high as 20–40 nA/m^2. (3) At other times, the current sheet may exhibit rapid kink-type flapping motion with vertical velocities of 50–100 km/s. During these intervals the current sheet clearly exhibits a bifurcated structure, with two current density maxima around a region of much reduced current in the center of the plasma sheet.

Keywords: Cluster; Magnetotail dynamics; Magnetosphere; Current sheet

1. Introduction

The Cluster quartet of satellites allows, for the first time, to separate spatial and temporal variations in arbitrary geometry measurements of space plasma parameters. This is of particular importance in a highly variable and dynamic region like the Earth's magnetotail and provides completely new insight into magnetotail dynamics. Further, new understanding comes from new and improved instrumentation.

The Cluster spacecraft were launched in summer 2000 and put into a polar orbit. They became operational since February 2001, after five months' commissioning phase, and they experienced the first tail passage from July to October 2001. The four satellites had separations ranging from 1500 to 3000 km in the magnetotail region during this period. The orbit of the Cluster quartet is almost fixed in the inertial frame, so that they pass the magnetotail from the dawn side flank to the dusk side flank as the Earth's magnetosphere revolves around the Earth once in a year in the inertial frame centered in the Earth.

Of particular interest is the orientation and shape of the Cluster tetrahedron when it traverses the plasma sheet at its apogee from north to south at a radial distance of about $20R_E$. Fig. 1 shows the typical tetrahedron configuration during current sheet traversals: of particular importance for the current sheet studies will be that spacecraft (s/c) 3 leads the other s/c by about 1500 km on their north-to-south orbit. The east–west and Sun–Earth pairs have been used in other studies (e.g., Nakamura et al., 2002a; Zhang et al., 2002; Petrukovich et al., 2003) not discussed here.

The Cluster data presented in this review stem from three instruments: (1) the Flux-Gate Magnetometer (FGM; Balogh et al., 2001); (2) the Cluster Ion Spectrometry (CIS; Rème et al., 2001) experiment; and (3) the Electron Drift Instrument (EDI; Paschmann et al.,

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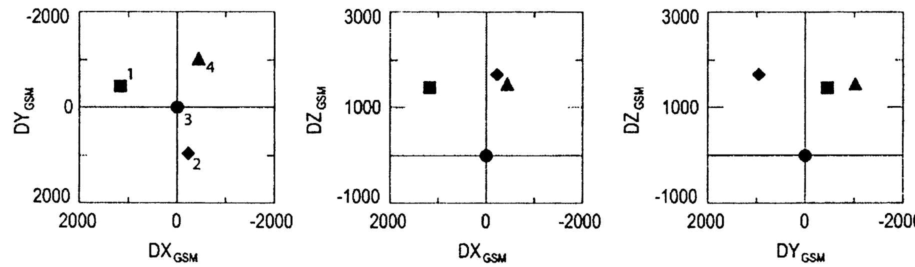

Fig. 1. Typical orientation of the Cluster tetrahedron (s/c 1–4) during plasma sheet traversals in 2001.

2001). EDI is a novel instrument that observes the electric field by measuring the drift velocity of artificially emitted electron beams in the plane perpendicular to the local magnetic field. By using this technique, the drift velocity is measured successfully even in the more tenuous regions of the magnetosphere like the near-Earth tail lobes.

2. Tail lobe convection

The interplanetary magnetic field (IMF) interacts with the Earth's dayside magnetic field through magnetic reconnection. The solar wind drags the reconnected field lines from the dayside to the nightside, stretches the field lines, and stores the energy in the form of magnetic tension. The stored energy is released when the open magnetic field lines reconnect again to form closed field lines, which return toward the Earth. The convection in the lobe is tightly connected to dayside reconnection. The plasma density in the near-Earth lobe is typically lower than 0.01/cc, which makes the observations of lobe convection by particle detectors difficult. Here, we will show observations of the averaged near-Earth tail lobe convection and its relationship to IMF polarity by using the Electron Drift Instrument (EDI) aboard the Cluster spacecraft.

Noda et al. (2003) averaged spin resolution data (4-s values) to a 5-min data set for the comparison with ACE solar wind data. They used EDI data from July to October 2001 from three Cluster spacecraft (on s/c 4 EDI is not operated) within $-15 \leqslant X_{\mathrm{GSM}} \leqslant -5R_E$, $|Y_{\mathrm{GSM}}| \leqslant 12R_E$, $4 \leqslant |Z_{\mathrm{GSM}}| \leqslant 12R_E$. The criterion for Y_{GSM} serves to exclude the low latitude boundary layer. The criterion for Z_{GSM} was chosen to avoid the plasma sheet. They then divided the data into four categories based on 90° IMF clock angle sectors centered on $\pm B_Z$ and $\pm B_Y$. For the IMF, they used the ACE magnetic field data, first shifting the time tags of the magnetic field data by using ACE solar wind velocity data (so that the observation position corresponds to $X = 0$). The EDI data for the four IMF states were then averaged into four different bins. Fig. 2 shows the most prominent features found.

We can draw the following conclusions from this figure. First, the vectors point toward the neutral sheet in both panels. Second, the flow direction in the Y–Z plane (right-hand panel) changes between $+B_Y$ and $-B_Y$ conditions. For $+B_Y$, the vectors in all four quadrants have a counterclockwise component in this Y–Z plane, while for $-B_Y$ a clockwise component appears (that the vector in the northern dawn quadrant in the $-B_Y$ case has a different sense may be caused by the small amount of data for that state/bin). Third, as expected, the velocity becomes larger for IMF $-B_Z$ because for this IMF polarity dayside reconnection occurs most efficiently.

The most notable point is the difference of the velocity in the Y–Z plane under $\pm B_Y$ conditions. For $+B_Y$,

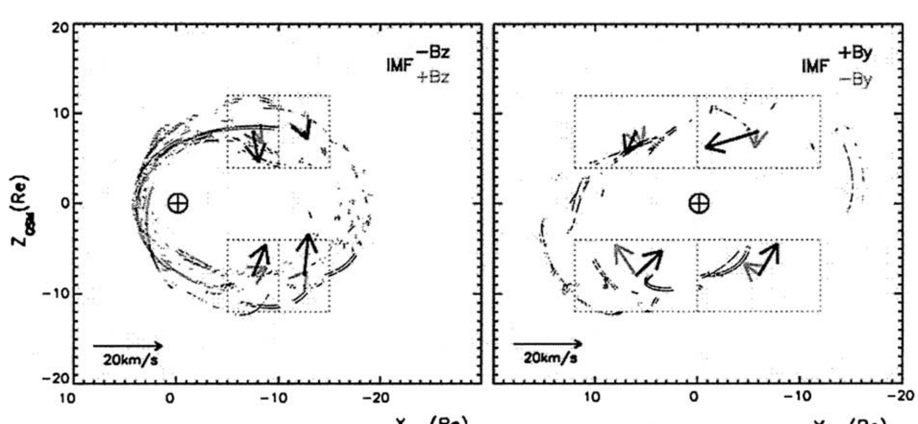

Fig. 2. Average lobe convection for different IMF clock angles (after Noda et al., 2003).