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DOUBLE STAR INITIAL RESULTS OF MAGNETOTAIL CURRENT SHEET

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Abstract. The newly launched DSP (Double Star Program), the first Chinese space science mission, in complement with the highly successful Cluster mission, have improved our current knowledge about the key processes of the energy release and transfer in the Sun-Earth system. In this paper, we present some initial results of magnetotail current sheet observed by DSP in conjunction with Cluster.

1. Introduction

The Double Star Program (DSP) is the first Chinese space science mission. The mission, in cooperation with ESA, consists of two spacecraft with carefully designed orbits to coordinate with the CLUSTER mission for important conjunctions (Liu et al, 2005). The first Double Star satellite, known as TC-1 which comes from Chinese abbreviation of "Explorer 1", was launched on December 29, 2003 into a nearly equatorial orbit with an apogee just about 13 R_E and a perigee altitude of 570 km. The second satellite, TC-2 was launched six months later on July 24, 2004 into a polar orbit with an apogee of 7 R_E. Double Star, together with the CLUSTER spacecraft, enables us to make simultaneous multi-point, multi-scale observations in many key magnetospheric regions (Figure 1). In this paper, we present some initial results of magnetotail current sheet observed by DSP in conjunction with Cluster.

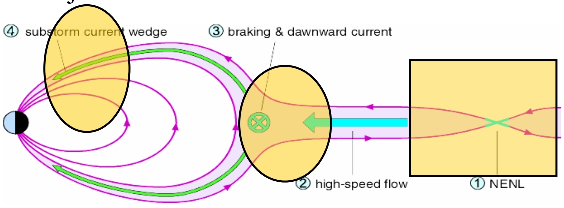

Fig. 1: Nightside magnetosphere dynamic processes. The shaded square is the region covered by Cluster measurement and the shaded circles are the regions covered by TC-1 and TC-2.

2. Current sheet oscillation

Since the first discovery of the magnetotail neutral sheet (Ness, 1965), it has been found that the neutral sheet frequently appears to be in motion due to changing solar wind conditions and geomagnetic activity. Oscillations of the neutral sheet have been identified by multiple crossings of the neutral sheet by the spacecraft. These oscillations are due to flapping motions of the neutral sheet in the north-south direction (Speiser and Ness, 1967), waves traveling along the axis of the magnetotail (Speiser, 1973) or wave motion along the dawn-dusk direction (Lui et al., 1978).

It has been shown in Cluster case studies that a wave moving in the dawn-dusk direction could cause the neutral sheet to be very steeply inclined toward the Y-axis (Zhang et al., 2002; Sergeev et al., 2003). Further statistical studies revealed that this dawn-dusk wave is kink-like and has a preferred propagation direction from the tail center to flank (Sergeev et al., 2004; Runov et al., 2005b). Thus the source of this kink-like wave is localized in the central part of the magnetotail.

Neutral sheet kink-like waves along the Y-axis have been observed at tailward distances of ~ 15 to 30 Re by IMP 5 (Lui et al, 1978) and around ~ 14 to 19 Re by Cluster (Runov et al., 2005b). In addition, Volwerk et al. (2003) found kink-mode waves along the X-axis. However, no observation in the near-Earth neutral sheet is available. In addition, all the observations are made from a single satellite or a cluster of closely spaced spacecraft, i.e., one single location. No simultaneous observations at two different magnetotail locations have been made to date.

Figure 2 top and bottom panels show overviews of the period 1100 – 1700 UT on August 5, 2004, during which both the Cluster and TC-1 satellites were in the magnetotail and had multiple crossings of the neutral sheet, as indicated by the reversal of the Bx polarity. The top panel of Figure 2 shows Cluster FGM magnetic field data at 1-s resolution (Balogh et al., 2001). The data are shown in GSM Cartesian coordinates with a color scheme of black, red, green, and blue for spacecraft 1 to 4, respectively. All Cluster spacecraft are located initially in the northern lobe indicated by Bx > 0. Beginning with the first crossing at ~ 1334 UT, there are nine crossings of the neutral sheet in about two hours, before Cluster is finally situated in the southern hemisphere. All crossings satisfy the common definition of neutral sheet, i.e., Bx = 0 and the magnetic field intensity reaches a minimum. The Cluster tetrahedron moves slowly in the –Z direction. At 1334 UT, the time of the first crossing, Cluster s/c 1 was at GSM position of (-15.4, -8.9, 3.4) Re. At 1500 UT, Cluster s/c 1 was at (-16.1, -9.2, 2.4).

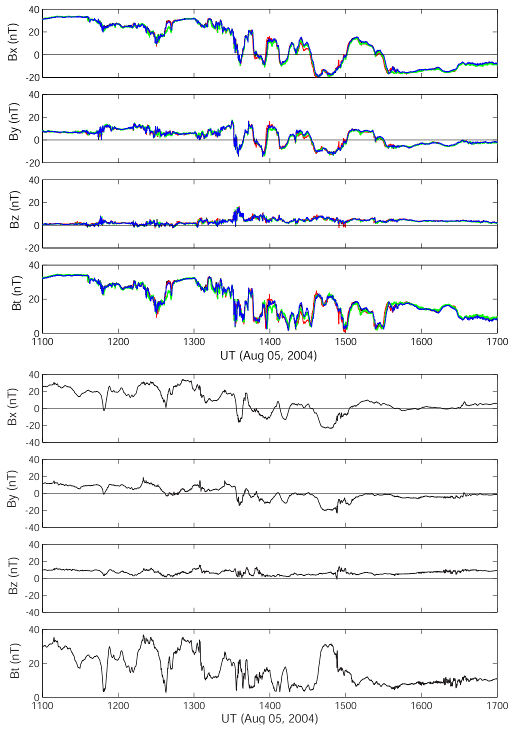

Fig. 2: Magnetic field in GSM coordinates measured by Cluster (top panel) and TC-1 (bottom panel).

The bottom panel of Figure 2 shows TC-1 spin averaged magnetic field measurements with about 4 second resolution in GSM coordinate (Carr et al, 2005). The flapping motion of the neutral sheet can be identified by the multiple crossings of the Bx = 0 line. The TC-1 spacecraft moves towards dawn from a GSM position of (-11.4, -6.2, 2.7) Re at 1333 UT to (-10.7, -6.8, 2.6) Re at 1509 UT. Comparing the two panels of Figure 2, we see that both TC-1 and the Cluster spacecraft, which were situated 5 Re apart, observed very similar magnetic profiles with multiple neutral sheet crossings. We note that both Cluster and TC-1 were located in the same local time sector. To illustrate the similarity of the magnetic profiles for both TC-1 and Cluster, we show in Figure 3 the Bx components of the magnetic field. We identify eight crossings both for TC-1 and Cluster, as shown in Figure 3 by the shaded area. As will be shown, these multiple crossings are due to a dawn-dusk wave propagating across the neutral sheet. Hence, we will study these eight crossings in details in the following.

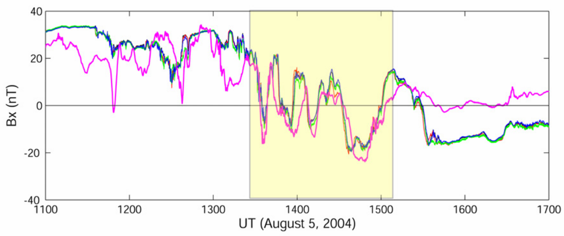

Figure 3. Comparison of the Bx components of the magnetic fields observed by Cluster and TC-1. The thick magenta line is the TC-1. The shaded region indicates the eight neutral crossings to be studied in detail.

Using four Cluster spacecraft magnetic field measurements, we determine the neutral sheet orientation and speed along the neutral sheet normal (Zhang et al., 2002). The first crossing at 1334 UT exhibits a motion different from the other 7 crossings, indicated both by the normal direction and speed along the normal direction. For crossing 2 to 8, we find that all y-components of the neutral sheet normal direction are negative indicating a motion in the dawn direction with a speed about 20 – 50 km/s. Further, we note that the sign of the z-components of the normal direction of crossings 2 to 8 switches between positive and negative in sequence, which implies a wavy profile propagating downwards.

To determine the normal direction of the neutral sheet for TC-1, we apply minimum variance analysis (MVA) (Sonnerup and Cahill, 1967) to determine the normal directions of the TC-1 neutral sheet crossings. Overall the values of the intermediate to the minimum eigenvalues ratio, λ_2/λ_3, are basically well defined. Furthermore, care has been taken to ensure the time stationarity of the normal direction during our MVA determination (Zhang et al., 2005). To do so, we perform MVA on nested sets of data intervals centered at the middle of the neutral sheet crossing. We find that the normal directions for all crossings are rather time stationary since the results from all the different nested segments are similar. We find that the normal direction of neutral sheet crossings clearly indicate a wave motion along the dawn-dusk direction, consistent with Cluster observation. Thus a dawn-dusk propagation wave is observed simultaneously by TC-1 and Cluster on August 5, 2004.

3. Flow channel scale

Bursty bulk flow (BBF), the transient fast plasma flow, is known to play an important role in the magnetotail (Baumjohann et al., 1990; Angelopoulos et al., 1992). Nakamura et al. (2004) have shown statistically that the flow channel has a spatial scale of 2-3 Re in the dawn-dusk direction and 1.5-2 Re in the north-south direction. Applying this flow channel scale, we study a magnetic structure observed by Cluster and TC-1 in the magnetotail.

On 14 August 2004, a large-scale magnetic structure was observed by TC-1 in the southern lobe and by Cluster in the northern lobe of the magnetotail. In Figure 4 we show the magnetic field data from Cluster and TC-1 between 1900 to 2200 UT. Lowpass-filtered (for periods larger than 1.5 min.) has been applied to the data to clearly show the low frequency oscillation. In the different panels, the Cluster spacecraft are labeled with their usual colors (black, red, green and blue), whereas the TC-1 data are plotted in solid line in magenta. The data show a magnetic structure passing by TC-1, starting at ~1915 UT, with the signature of a dipolarizing field or plasma sheet expansion region, i.e., a decrease of Bx combined with an increase in Bz. The spacecraft thus enters the plasma sheet and remains there. Similarly, the Cluster spacecraft see a magnetic structure with the signature of a dipolarization starting ~2000 UT. Visual inspection shows that the data from TC-1 and Cluster can be well lined up by shifting TC-1 by ~29 minutes. To clarify the correspondence between the observations of TC-1 and Cluster we have added a gray line, representing the TC-1 data shifted by 29 minutes, and for Bx and By the sign has been reversed in order to compensate for the different hemispheres that the spacecraft are in. There is a surprisingly good match between the two data sets, both sets show the dipolarization-like structure over approximately the same time interval, and both show the low frequency oscillations of the magnetic field with a period near 5 minutes. However, there are differences in the two data sets from Cluster and TC-1. For example, in Bx one sees that for TC-1 this field component decreases from approximately -18 nT to -8 nT, and does not return to its pre-event value, and thus the spacecraft remains in the plasma sheet. For Cluster one sees that the X-component of the magnetic field first returns again to almost pre-event values after 1 hour, i.e., Cluster enters the plasma sheet and then exits again. Then Bx decreases again, most likely as a result of Cluster nearing the neutral sheet and motion of the magnetotail.

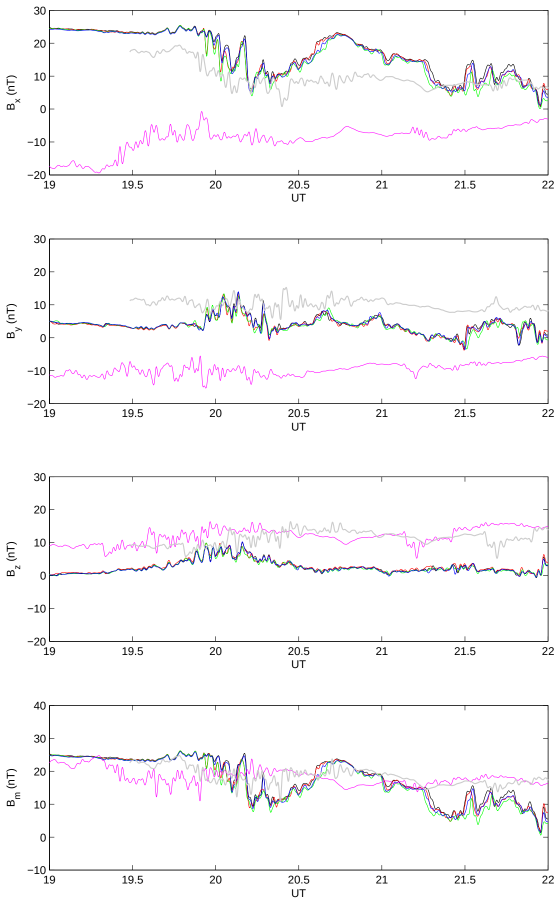

Fig. 4: The low-pass filtered magnetic field data for Cluster (usual colours) and TC-1 (solid magenta line). The gray line shows the TC-1 data shifted by 29 min. and sign-reversed to compensate for the opposite hemispheres.

4. Discussion

The magnetotail neutral sheet is best represented by an arched surface which separates magnetic field lines of opposite polarity. The magnetotail neutral sheet is anchored to the geomagnetic dipole at a hinging distance of 11 Re (Dandouras, 1988). As mentioned in the introduction, the neutral sheet kink-like wave along the Y-axis has been observed at tailward distances of ~14 to 30 Re (Lui et al., 1978; Runov et al., 2005b). The present study shows that this wave can be observed as close to the Earth as 11 Re along the X direction, in the neighbourhood of the magnetotail hinge point. In other words, the whole near-Earth magnetotail neutral sheet (-11 Re > X > -30 Re) likely to oscillate in this kink-like mode, which internally produces in the central part of the tail and propagates toward the tail flanks. A schematic view of this wave is shown in Figure 5 based on this study and earlier observations (Zhang et al., 2002; Sergeev et al., 2004; Runov et al., 2005b).

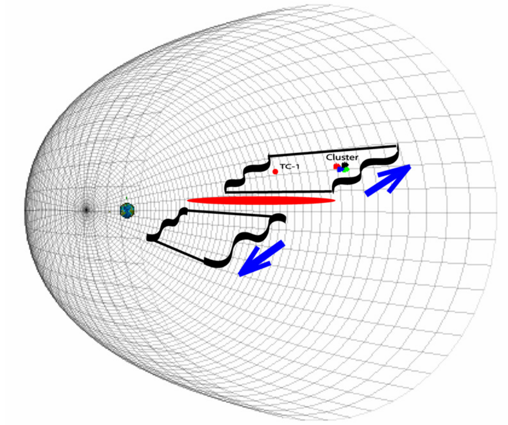

Figure 5. Schematic view of the kink-like wave emitted from the central part of the magnetotail and propagates toward the tail flanks. The TC-1 and Cluster were located 5 Re apart at same local time. For the first time, the wave has been observed at two different magnetotail locations simultaneously. Based on this study and earlier observations, this dawn-dusk wave can be observed at tailward distances of ~ 11 to 30 Re.

In the case of 14 August 2004, we have investigated magnetic structure observed both by TC-1 and Cluster, under the assumption that this structure was a dipolarized field region moving past the spacecraft. It consists of a decrease of the X-component of the magnetic field, combined with an increase in the Z-component and an Earthward plasma flow. A possible interpretation of the observed structure lies on the scale of the flow channel. Nakamura et al. (2004) have shown that the plasma flow channel in the magnetotail is of limited size, i.e., ~3 Re in the y-direction and ~2 Re in the z-direction. Indeed, the vertical separation between TC-1 and Cluster at "onset TC-1" is ~ 3 Re. TC-1 observes Earthward flow at 300 km/s and thereby the creation of a flow channel, whereas Cluster observes unperturbed lobe field. After 29 minutes, when TC-1 still observes the low velocity plasma flow, the Cluster spacecraft have moved approximately 0.4 Re in Zgsm. This will move Cluster to the boundary of the flow channel already observed by TC-1. Here we have to assume that TC-1, which basically does not move in z was located inside the flow channel region already before the flow started. Thus, the structure observed by Cluster is the entry of the spacecraft into the flow channel, which also explains the slow motion of, what we called before, the "local dipolarization" or "flapping". The flow perturbs the magnetic field, bending it from Bx into Bz. A schematic view of this process is shown in Fig. 6.

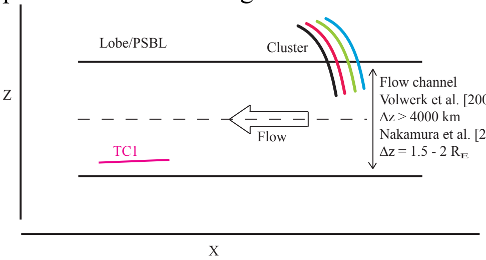

Figure 6. Schematic view of the spacecraft entering the plasma sheet flow channel. TC-1, remaining on near constant Zgsm observes the creation of the flow channel and remains in this channel. The low velocity flow is maintained until after 2000 UT. 29 minutes later, Cluster has moved in Zgsm and enters the flow channel, observing that the magnetic field ``dipolarizes'' and the plasma flow.

5. Summary

Using magnetic field measurements from TC-1 and Cluster we find that the neutral sheet was dominated by a kink-like wave structure propagating from the central sector of the magnetotail toward dawn at tailward distances of both 11 Re and 16 Re. In this study we also investigate the conjunctive observations of a large scale magnetic structure by TC-1 and Cluster in the magentotail. A possible interpretation of the structure by invoking the flow channel scale has been presented.

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