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AN ISEE-1/2 SPACECRAFT STUDY OF AN UNUSUAL FLUX TRANSFER EVENT

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ABSTRACT

Using the ISEE–1/2 spacecraft, an unusual FTE was studied. The perturbation in the direction normal to the magnetopause reached a maximum size of 64 nT, exceeding the field amplitude in the adjacent magnetosphere. The observation was made at 1500 Local Time in the southern hemisphere (10° below the magnetic equator). From two point observations, it was found that the structure has a scale length of $2R_E$ in the north-south direction in boundary normal coordinates. The velocity of the structure in that direction was about 50 km/sec. The dimension and the velocity in the east-west direction could not be established. The FTE signature recurred after about 9 minutes.

INTRODUCTION

Flux transfer events (FTEs), typically with duration of about 1 minute, scale size $1R_E$, and peak to peak magnetic perturbation normal to the magnetopause (B_N) of 20nT, are believed to arise from the dayside reconnection /1/. From the correlation between the location of spacecraft observations and the polarization of the B_N perturbation, it is thought that FTEs form in the equatorial regions of the magnetopause /2/.

The structure of FTEs was first interpreted by Russell and Elphic /3/. Alternative theoretical models have been subsequently proposed. The two most popular models at the present time are the multiple x-line reconnection model of Lee and Fu /4/ and the time-varying reconnection models of Southwood et al. /5/ and Scholer /6/. The multiple x-line model postulates that at high Reynolds number, reconnection occurs at multiple locations as a consequence of the tearing-mode instability. The latter models postulate that reconnection occurs at a single location but its rate changes as free energy accumulates and dissipates in the course of reconnection. As the spacecraft makes single point observations and the motion of FTEs tends to mix up spatial and temporal variations, it is hard to judge which model is better from the time series of spacecraft observations. Supporters of the time–varying model claim that it explains the particle signatures better than does the multiple x–line model /5/.

In this report, we used magnetic field and particle data to study an unusual flux transfer event. The normal component of the magnetic perturbation for the event reached 64 nT and the field strength within the structure was enhanced substantially relative to the surrounding field. The duration of the event was about 4 minutes, longer than the typical 1 minute time scale for a typical FTE. ISEE–1 and ISEE–2 at that time were separated by about 1000 km, which was just adequate to resolve the structure and velocity of the event. We attempt to interpret the observations in terms of the above noted models, with only partial success.

OBSERVATIONS

In this study, spacecraft measurements from the UCLA Magnetometer Experiment on ISEE–1/2 and the Los Alamos/Max-Planck-Institut Fast Plasma Experiment on ISEE–2 are used. Magnetic field data are displayed in boundary normal (LMN) coordinates /3/ in which L is approximately parallel to the magnetospheric field just inside the magnetopause, M is roughly azimuthal along the boundary, and N is along the normal to the boundary. The magnetosheath and magnetospheric field components in the GSE coordinates were (-30,35,-40) nT and (18,0,38) nT respectively. The observations were made at 1500 Local time and the spacecraft were located at 10° below the magnetic equator. ISEE–2 led ISEE–1 in their inbound orbit. They were separated by 300 km in L and 1000 km in N. The separation in M was negligibly small.

Figure 1 presents an overview of 45 minutes of magnetic field data in LMN coordinates. In the plot, the thick/thin traces correspond to the ISEE–1/2 observations, respectively. Initially, both spacecraft were in the magnetosheath. As ISEE–2 led ISEE–1 inbound, it encountered the magnetopause first as evidenced by positive turnings of the B_L and B_M traces near 17:53 UT. As a result of rapid magnetopause oscillations, ISEE–2 subsequently passed into and out of the magnetosphere twice. ISEE–1, after grazing the magnetopause twice, entered into the magnetosphere 5 minutes later than the ISEE–2 spacecraft. After

18:12 UT, both spacecraft were well inside the magnetopause. The magnetic signatures that immediately attracted our attentions were three large B_N perturbations (which will be referred to as events 1, 2, and 3, respectively). Event 1, which started at around 18:14 UT, had a -64 nT B_N perturbation as seen by both spacecraft. Following that, at 18:17 UT, ISEE-2 observed event 2 which had a +32 nT B_N perturbation. There was, unfortunately, a gap in the ISEE-1 data during this event. At 18:23 UT ISEE-1, which was closer to the magnetopause, observed a -30 nT B_N disturbance. At that time, ISEE-2 was too far inside the magnetosphere to see the same B_N deviation but it still observed a disturbed ambient field, which is reflected in the total B plot. Figure 2 shows high time resolution (0.25 sec.) data for the three events. We associate the entire interval between 18:14 and 18:18 UT with passage of the first FTE. It is seen that between event 1 and event 2, the magnetic fields fluctuated at high frequencies. After event 2, the magnetic field remained in a quiet magnetospheric field, until event 3 occurred. The spacecraft encountered different plasma regions during the interval of fluctuating magnetic field. Figure 3 plots the moments of the plasma and the magnetic field data observed by ISEE-2. From top to bottom are ion plasma density N, temperature T, pressure P and β (ratio between plasma pressure and magnetic pressure) and magnetic B_T component. By comparing with the magnetosheath moment plots, we found that the ion number density N and the temperature T within the FTE-associated flux tube have values intermediate between the values in the magnetosheath (which are not plotted) and the magnetosphere. Figure 4 presents the phase space particle distribution plots. The top panel shows the electron distribution and the bottom panel shows the proton distribution. From left to right are the particle distributions in the magnetosheath, in an FTE-associated flux tube, and in the magnetosphere, respectively. The proton distribution changes its appearance dramatically between the magnetosphere and the magnetosheath. In the bottom panel one can clearly observe that the distribution in the flux tube appears to be intermediate to the distributions in the magnetosphere and the magnetosheath. Such intermediate distributions have generally been regarded as signatures of reconnection /7/.

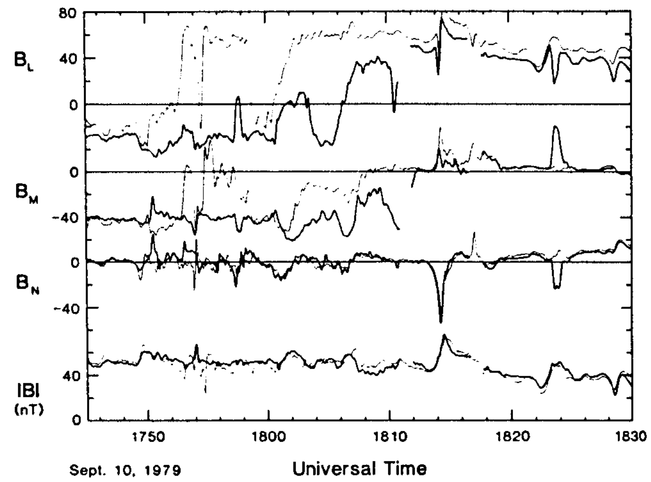

Fig. 1. 45 minutes of magnetic field data in LMN coordinates. In all figures thick traces are for ISEE-1 and thin traces for ISEE-2.

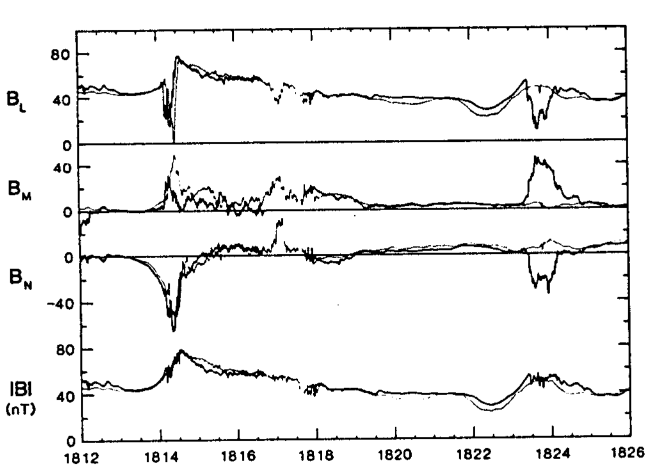

Fig. 2. High time resolution magnetic field to highlight the turbulent nature of the magnetic field in the reconnection region. Thick and thin traces are the same as Fig. 1.

Using two spacecraft, the motion and scale size of the reconnected flux tube can be estimated. Shown in Figure 5 is the high time resolution (0.25 sec.) data for event 1. Between 18:14:00 and 18:14:30, ISEE-1/2 observed a structure sweeping past the spacecraft that encountered ISEE-1 prior to ISEE-2. The fact that B_L remained positive after 18:14:30 excludes the possibility that the FTE moved across the spacecraft because of inward displacement of the magnetopause since the B_L component should be negative for the magnetosheath field. The other possible way in which ISEE-1 would observe the sweeping structure prior to ISEE-2 would be if the flux tube moved downward in the L direction. The spacecraft were separated by 300 km in L and ISEE-1 was closer to the magnetic equator than ISEE-2 in the southern hemisphere. From Figure 5, it is seen that the time delay between ISEE-1 and ISEE-2 was about 6 s. The 300 km separation and 6s delay correspond to a southward velocity of 50 km/sec. From the 260 s duration of the turbulent magnetic field, i.e., the time interval between event 1 and event 2, and from the 50 km/sec estimated velocity, one can constrain the flux tube scale size to be of the order of 2 R_E, a typical scale size for an FTE.

DISCUSSION

We find that the event cannot be fully explained by any existing models of FTEs. The essential anomaly is that the B_N component represented almost the total magnetic field for event 1. One way the Russell and Elphic model could produce a large B_N component would be if the spacecraft were located at a position centered between the magnetosheath and magnetopause sides of the reconnected structure, i.e., at the kink where the reconnected flux tube penetrates the magnetopause boundary. However, within the kink the polarization of the B_N perturbation would have to be positive. This is just opposite to the spacecraft observation. Both the multiple x-line model and the time-varying reconnection model predict a chain of magnetic bubbles, either created spatially or temporally. As spacecraft moves in and out of the bubbles, it will detect different plasma properties as is shown schematically in Figure 6. Owing to reconnection, the magnetic bubbles form a "shish-kebab" structure which moves downward. Equivalently the spacecraft moves upward in a frame fixed in the perturbed field. As we can see from the figure, initially the spacecraft was, close to the magnetopause, located in the magnetosphere. The magnetic field was relatively quiet and in the direction expected for the magnetosphere. As event 1 was encountered, the spacecraft observed a large negative B_N deviation. However these models also have trouble in explaining the large size of the deviation but this deviation is at least in the expected direction. Afterwards, the magnetic field became strongly turbulent and B_N returned to its baseline value. This is just what one expects when the spacecraft is in the center of the flux tube where we expect fluctuations caused by reconnection and a zero B_N component. As the spacecraft moves further up, we would expect it to exit the bubble at a position on the earthward and northward side as shown, since we observed a positive B_N perturbation. This signature should be followed by the disappearance of the high frequency fluctuations of the magnetic field. This was just what spacecraft observed for the event 2 and afterwards. The spacecraft encountered another magnetic bubble which was denoted as event 3. The B_N deviated in the same direction as for event 1. Probably due to the spacecraft's inward motion and the oscillation of the magnetopause, the spacecraft exited the bubble very abruptly and it did not detect a large positive B_N deviation subsequently.

Both the multiple x-line model and the time-varying reconnection model predict similar bubble structures and can explain some of the spacecraft observations. However, these models still have trouble in explaining all the important

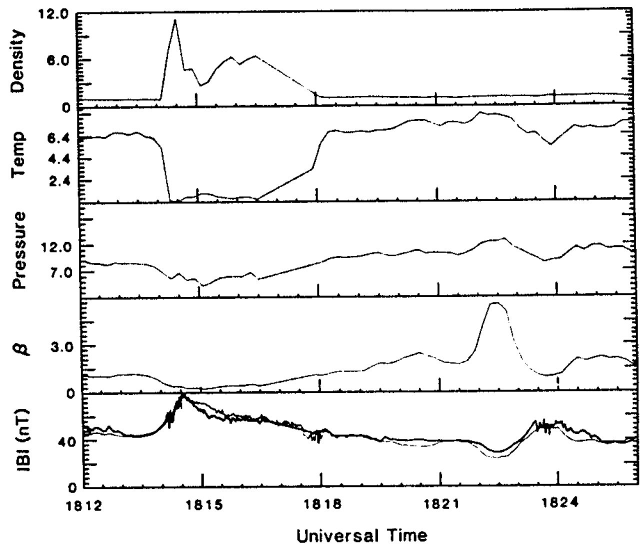

Fig. 3. Moments of the plasma (ISEE–2 only) and the total magnetic field plots (ISEE–1 and –2) on the same time scale as Fig. 2. From the top to bottom are plasma density ($1/cm^3$), temperature (10^7K°), pressure ($10^{-9}dyne/cm^2$), β (ratio between plasma pressure and magnetic pressure) and B_T component. Thick and thin traces are the same as Fig. 1.

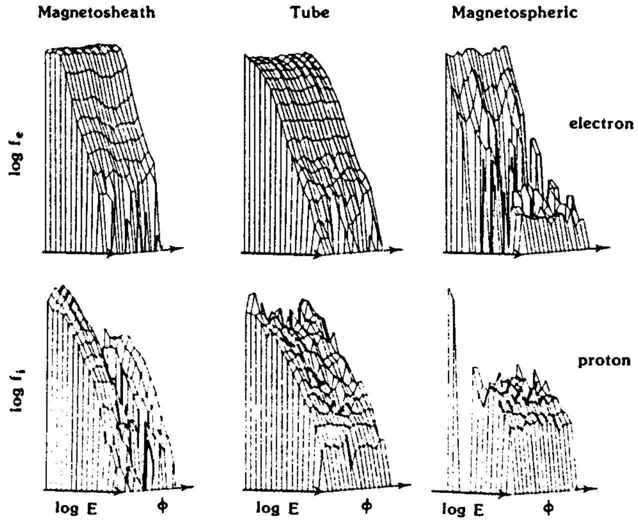

Fig. 4. Electron and proton distributions (logarithmic scale) plotted as the function of energy (logarithmic scale) and look direction in the magnetosheath, in an FTE-associated flux tube, and in the magnetosphere.

features observed by spacecraft. For example, the abrupt changes of all magnetic field components, when the spacecraft entered into or exited the magnetic bubbles, cannot be satisfactorily explained by these models. Neither can these models satisfactorily explain the large B_N deviations. Further work remains to be done.

We believe that the extreme characteristics of this unusual FTE are worth further investigation and will help to refine the present models of FTE formation.

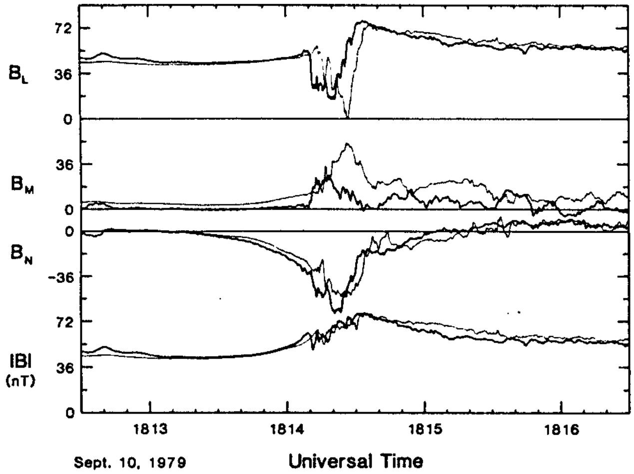

Fig. 5. High time resolution magnetic field data for event 1. The systematic delay as the structure sweeping ISEE–1 and then ISEE–2 observed is readily noted. Thick and thin traces are the same as Fig. 1.

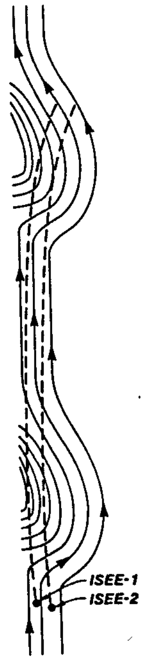

Fig. 6. Schematic drawing for the relative motion of the spacecraft to magnetic bubbles created by either a multiple x–line model or a time–varying reconnection model (in the magnetospheric side only).

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