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A STUDY OF FLUX TRANSFER EVENTS AT DIFFERENT PLANETS

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ABSTRACT

Flux transfer events are disturbances in and near the magnetopause current layer that cause a characteristic signature in the component of the magnetic field parallel to the average boundary normal. These disturbances have been observed at Mercury, Earth and Jupiter but not at Saturn, Uranus or Neptune. At Earth FTEs last about 1 minute and repeat about every 8 but at Mercury, a much smaller magnetosphere, the events last seconds and are tens of seconds apart. These features have been interpreted in terms of magnetospheric flux ropes connected to the interplanetary magnetic field, arising as the result of reconnection. An analogous phenomenon occurs at Venus where magnetic flux ropes arise at the ionopause, a boundary between a very strongly magnetized plasma and a very weakly magnetized one. However, here the flux ropes do not appear to be due to reconnection.

INTRODUCTION

Transient localized reconnection at the Earth's magnetopause was first reported in 1978 at high latitudes with the HEOS 2 spacecraft /1/ and at low latitudes with the ISEE 1 and 2 spacecraft /2/. Since then these characteristic disturbances have been called flux transfer events or FTEs. They cause compressions and rotations in the magnetospheric and magnetosheath magnetic field that would be expected from a cylindrical object moving across the magnetopause. These disturbances have been interpreted in terms of transient, spatially limited reconnection in which magnetic flux tubes of the magnetosphere and the magnetosheath become interconnected. Many studies have been conducted on FTEs at the terrestrial magnetopause. These studies reveal that FTEs occur about every 8 minutes when the IMF is southward 13, 41, and are detected over about half the magnetopause at any one time /5/. These events are not triggered by changes in the interplanetary field but occur periodically under steady IMF conditions /6/.

Flux transfer events appear to be fairly insensitive to solar wind conditions. For solar wind conditions at 1AU, FTEs occurrence seems mainly dependent on the IMF direction and little else /4/. In order to learn more about what controls the properties of FTEs we need to investigate the behavior of FTEs under very different conditions. Such conditions are provided by the magnetospheres of Mercury and the outer planets. We will also examine the solar wind interaction with Venus to compare with the phenomena that arise in at an unmagnetized planet.

MERCURY

Only one spacecraft, Mariner 10, has visited Mercury. On its first and third encounters with Mercury Mariner 10 flew by on the nightside of Mercury and observed a planetary magnetosphere strongly resembling a miniature version of the terrestrial magnetosphere /7/. One of the phenomena seen was the FTE. Figure 1 shows a crossing of the magnetopause in boundary normal coordinates and the characteristic bipolar signature of the magnetic field, the compressional signature and the strong distortion in the BM component are all seen /8/. The amplitude of the disturbance is similar to that of terrestrial FTEs, but the duration is much less. The duration of the FTE shown is less than 1 second. Clear FTE signatures were seen at 3 of the 4 Mariner 10 crossings of the magnetopause including, one just 46 seconds earlier than the

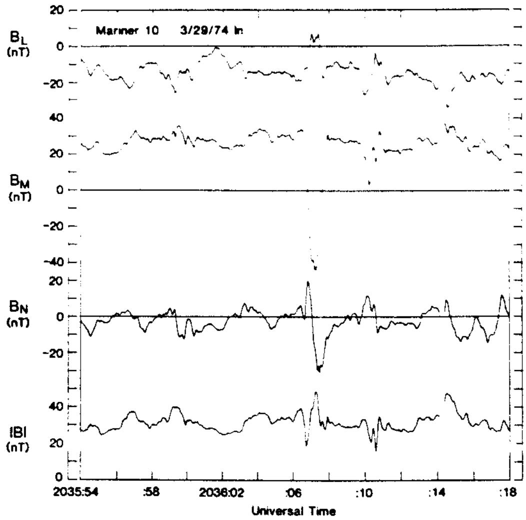

Fig. 1 Flux transfer event seen at the Mercury magnetopause by Mariner 10. Vector magnetic field components displayed in boundary normal coordinates.

one shown in Figure 1. Thus in a magnetosphere that about 1/20 the linear dimension of the terrestrial magnetosphere, FTEs last about 1/20th as long, and occur more rapidly. FTEs also were clearly an important source of fluctuations in the outer magnetosphere /9/ much as they are in the terrestrial magnetosphere.

JUPITER

A magnetosphere of the other extreme in size is that of Jupiter that has been probed by Pioneer 10 and 11, Voyager 1 and 2 and Ulysses. Figure 2 shows an example of a FTE at Jupiter as detected by Pioneer 10/10/. The duration of the FTEs are very similar to terrestrial FTEs about 30s and this separation of 12 minutes is not unlike that of terrestrial FTEs, but their amplitude of less than 1nT peak to peak is about a factor of 4 or more less than that of terrestrial FTEs when scaled by the planetary magnetic field just inside the magnetopause. Thus the large scale of the jovian magnetosphere has not resulted in the growth of giant flux transfer events. Perhaps some counteracting effect such as the solar wind conditions in the jovian magnetosheath has countered the expected growth of these FTEs.

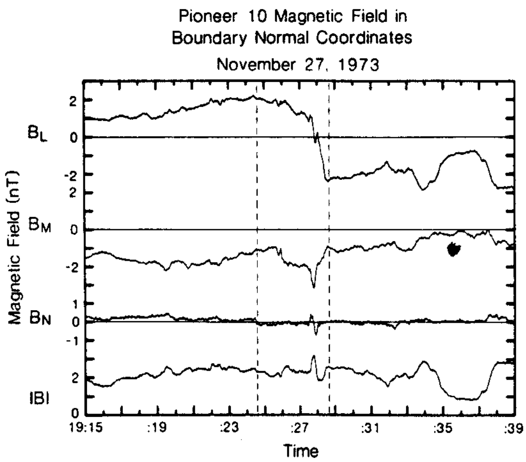

Fig. 2 Flux transfer event seen at the Jupiter magnetopause by Pioneer 10. Vector magnetic field components displayed in boundary normal coordinates.

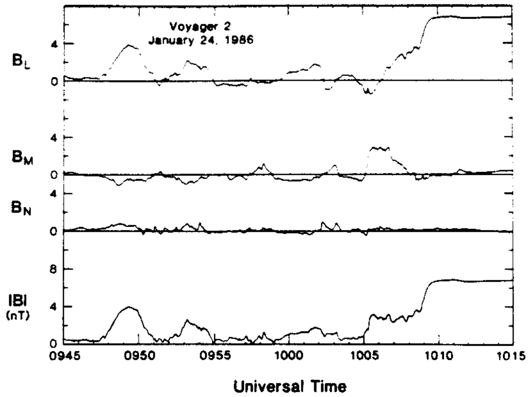

Fig. 3 Uranian magnetopause crossing by Voyager 2. Vector magnetic field components displayed in boundary normal coordinates.

SATURN AND BEYOND

Pioneer 11, Voyager 1 and 2 travelled beyond Jupiter to Saturn and Voyager 2 continued to Uranus and Neptune. These spacecraft encountered quite a different magnetopause at these planets than normally encountered on Earth. This difference is illustrated in Figure 3 for the Voyager 2 crossing of the Uranian magnetopause /11/. Here the magnetosheath magnetic field (on the left) is very weak in comparison with the magnetospheric field on the right. Waves are seen in the total magnetic field but they do not appear to be flux transfer events. This behavior is seen at the terrestrial magnetopause under similar high beta magnetosheath conditions /11,12/. The magnetopause at Saturn is also similar to that at Uranus but it is difficult to say whether the Neptune magnetopause is similar because Voyager 2 entered the Neptune magnetopause through the polar cusp.

VENUS

The solar wind plasma conditions at Venus are similar to those at the Earth and Mercury but there is no detectable planetary magnetic field. Hence the interaction resembles in some sense the magnetopause of Uranus turned inside out with the strong field region on the outside and the high beta region on the inside. Figure 4 shows an example of a crossing of the Venus

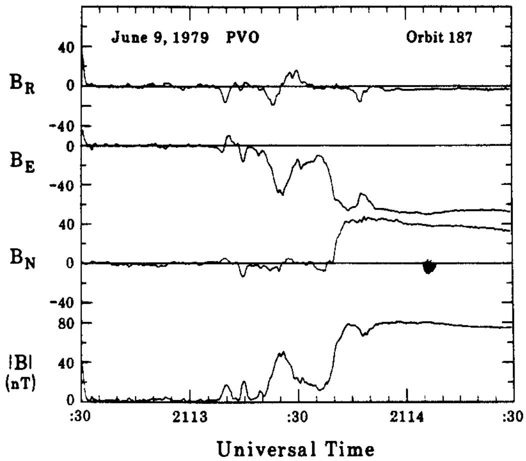

Fig. 4 Venus ionopause as observed by the Pioneer Venus Orbiter near the subsolar point. Vector magnetic field components displayed in radial, east, north coordinates.

"ionopause" close to the subsolar point /13/. The magnetic field is shown in boundary normal coordinates. In some ways the magnetic profile is similar to that of the Uranian magnetopause but one important difference is that there is a radial component to the magnetic field. The magnetic field is not simply draped over the planetary ionosphere but has become twisted. Thus it is possible to produce flux ropes without reconnection. In fact the Venus ionosphere is full of such twisted ropes /14,15/.

SUMMARY AND CONCLUSIONS

This brief trip through the solar system has given us some important insights into the production of flux transfer events. First the observation of short duration FTEs, occurring in rapid succession, very similar to those on the terrestrial magnetopause but scaled in proportion to the linear scale of the magnetosphere suggests that the linear dimension of the magnetosphere affects the duration and separation of FTEs /16/. The relative weakness of FTEs at Jupiter and their apparent absence at Saturn, Uranus and Neptune suggests that the plasma conditions typical of the outer planetary magnetosheath do not promote the growth of FTEs. The most significant change in the solar wind with heliocentric distance is the increase in the magnetosonic Mach number of the solar wind flow relative to the planets. This produces a high beta plasma at the nose of the magnetosphere. High beta plasmas have been observed to decrease the rate of reconnection at the terrestrial magnetopause /17,18/. Thus this decrease in FTE occurrence in the outer heliosphere is consistent with our ideas about the generation of FTEs.

The Venus observations, however, suggest caution in our studies of FTEs because twisted flux ropes can be caused by processes other than reconnection. At Venus we believe that velocity shear rather than magnetic shear is the important process in creating the twist.

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