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Formation and Transport of Flux Transfer Events at Mercury

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1. Introduction

Prior to the arrival of MESSENGER, the structure and dynamics of Mercury's magnetosphere were not well understood. Observations from the three MESSENGER flybys have provided evidence that reconnection at Mercury is taking place on a much grander scale than is observed at Earth; giant bundles of reconnected flux, known as flux transfer events (FTEs), were observed at the magnetopause, indicative of very high rates of reconnection between the dayside planetary field and the interplanetary magnetic field [1]. FTEs observed during MESSENGER's second flyby were substantially larger than their terrestrial counterparts [1,2], and recent observations suggest that they can also occur at a far higher repetition rate. Intervals with >50 FTEs, which are termed “FTE showers”, are frequently observed and appear to be a phenomenon unique to Mercury. We have developed a modified version of the Cooling model [3] to trace the motion of flux tubes generated by reconnection at Mercury, and in this paper we compare the model FTEs with observations of FTEs made by MESSENGER. We use these comparisons to determine the most likely location and orientation of the magnetic X-lines at Mercury's magnetopause during a variety of solar wind conditions.

2. The Cooling Model

The Cooling model was first developed to predict the motion of flux tubes formed by reconnection either at low latitudes or just poleward of the cusp at Earth [3]. The magnetosheath magnetic field and the paraboloid shape of the magnetopause are defined using the model of Kobel and Flückiger [4]. The magnetosheath flow and density are derived from the gas dynamic models of Spreiter et al. [5]. Geomagnetic field lines just inside the magnetopause map from the southern to the northern cusp to encompass the surface of the magnetopause. The probability of reconnection taking place at a given location on the magnetopause is calculated as a function of solar wind input conditions using a component reconnection model proposed by Crooker [6]. The reconnected flux tubes are then traced along the magnetopause according to Cowley and Owen [7], on the basis of the stress on the flux tube due to the sheath flow and the magnetic tension on the field line. We have adapted this model to Mercury within the constraints of the MESSENGER data set. For this reason, mean values of solar wind parameters are assigned, but the IMF values are estimated from magnetosheath data. We predict the location, orientation, and velocity of FTEs generated by reconnection at the magnetopause.

3. Case Study: 10 April 2011

The location of MESSENGER during an outbound pass on 10 April 2011 is shown in Figure 1. The spacecraft traversed the southern tail lobe and crossed the magnetopause at ~1704 UTC. The magnetic field measured by the spacecraft is presented below, with vertical dashed lines marking the centers of FTE signatures; there are 21 FTEs during the 11 minute interval. The red line corresponds to the FTE that is subsequently modelled.

The modified Cooling model was run for 100 s under the assumptions that the magnetic field direction in the sheath is representative of the upstream IMF, and that the solar wind velocity and density values are average values at 0.3 AU. The results are projected to the *Y*-*Z* plane in Figure 2. Dotted lines display cuts through the magnetopause at X_{MSO}= +1, 0, -1, -2 and -3 R_M, where R_M is Mercury’s radius. The magnetosheath magnetic field was northward and duskward with positive B_X. Under these conditions (B_Z>0), no reconnection is expected at low latitudes, so the FTEs in Figure 1 must be due to reconnection between the IMF and the

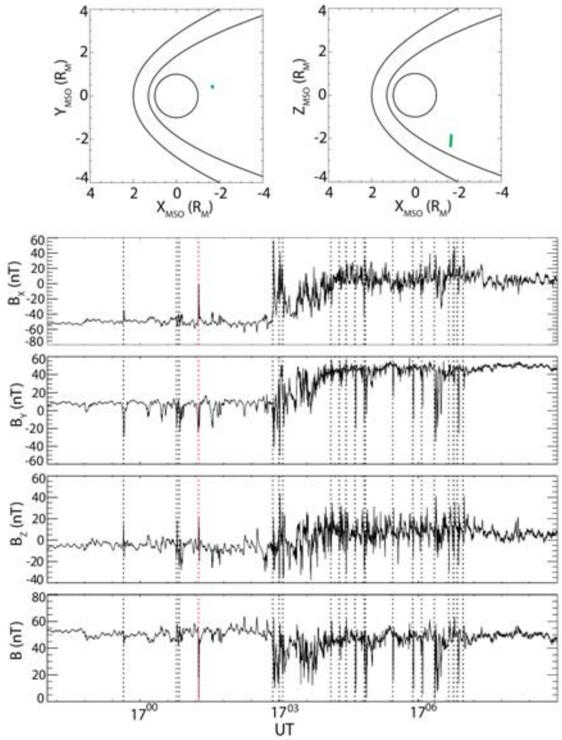

Figure 1: (a, b) Location of MESSENGER during an 11 minute interval on 10 April 2011. A model magnetopause and bowshock are also plotted in black. (c-f) Magnetic field data during the interval, in MSO coordinates. X_{MSO} is directed from the center of the planet toward the Sun, Z_{MSO} is normal to Mercury's orbital plane and positive toward the north celestial pole, and Y_{MSO} completes the right-handed orthogonal system.

lobe flux just tailward of the cusp. Here an X-line of length 2 R_M is extended from a central point tailward of the cusp according to the maximum shear between the planetary and magnetosheath fields [6], and is shown in green in Figure 2. Five flux tubes which have undergone reconnection tailward of the cusp were launched along this X-line. The motion of these flux tubes is calculated according to the model described above, and the point at which each one intersects the magnetopause is traced as a dashed red line. The model predicts that the reconnected flux tube (FTE) labelled "*c*" will cross the location of MESSENGER 15 s after being formed. The X-line geometry predicted by the model was therefore in excellent agreement with the data in this case. Placing the initial X-line in a different location or making it substantially shorter results in no flux tubes intersecting the spacecraft location. Modelling FTEs observed at many different locations on the magnetopause during a variety of IMF directions will enable us to determine the reconnection geometries that characterize the solar wind-magnetosphere interaction at Mercury.

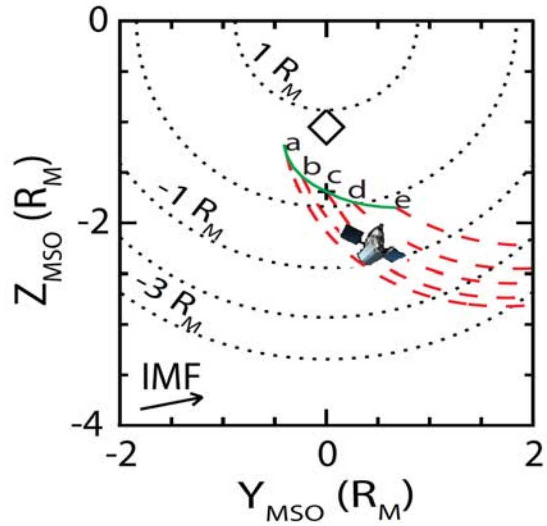

Figure 2: Trajectories of reconnected flux tubes in the *Y-Z* plane; the circles cut through the magnetopause at constant *X*, diamonds mark the cusps, and the location of MESSENGER at the time of the FTE observation is also shown.

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