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Dual-spacecraft detection of large-scale magnetic flux ropes by Mars Express Ionospheric Sounding and the Mars Global Surveyor Magnetometer

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Abstract

We show here that Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS), on board the Mars Express (MEX) spacecraft, has detected large scale magnetic flux ropes in the Martian ionosphere. Using the electron cyclotron echoes that occur on MARSIS ionograms, we measure the magnetic field strength local to MEX. In regions surrounding intense magnetic fields remanent in the Martian crust, the magnetic field strength measured by MARSIS usually corresponds well with magnetic field models based on measurements by the Mars Global Surveyor magnetometer and electron reflectometer (MGS MAG/ER). In some cases, however, there are large deviations from the model fields. We have catalogued 39 such cases between 2005 and 2009. In two of these cases, we have near simultaneous measurements with MGS MAG/ER. Minimum variance analysis on these two cases shows that the magnetic field rotates in the manner expected for a magnetic flux rope. The structures are quasi-stable over the half-hour between measurements. We estimate an approximate diameter of 700 km for these flux ropes. Both of the flux ropes occur directly downstream from the strongest Martian crustal magnetic arcades, near the Martian south pole. These flux ropes are over an order of magnitude larger in diameter and are distributed differently than the filamentary flux ropes seen at Venus and in the northern hemisphere of Mars.

1. Introduction

The ionospheric sounding mode of MARSIS, in flight around Mars on the Mars Express spacecraft, is designed to be a top-side ionospheric sounder. We have found, however, that when MEX goes below the magnetic pileup boundary, MARSIS can measure the magnetic field strength local to Mars Express (see [4]; [1]). This measurement has been verified by comparison with a model ("the Cain model", see [3]) based on measurements by MGS MAG/ER spacecraft in regions of large crustal magnetic field. Although in most cases the magnetic field strength measured by MARSIS tracks the Cain model very well, occasional large deviations are observed. The top panel of Fig. 1 shows an example of such a deviation, with the MARSIS measurement shown in black and the the Cain model field strength shown in red. The observed deviation starts at about 15:49 UT. The bottom panel shows a pass along a nearly identical ground track that does not show a corresponding deviation, implying that the deviation is transient. Over about four years of observations, 39 such deviations have been observed. The strongest of these events occur near the strong crustal fields in the southern hemisphere of Mars.

2. Dual-spacecraft detection

Two of the magnetic enhancements mentioned above occur nearly simultaneously with similar detections by the MGS magnetometer. We take advantage of these near coincidences to analyze the field components using the minimum variance technique. This analysis shows that the magnetic field rotates, as expected for a magnetic flux rope. The flux rope axis, which can be identified as the axis of intermediate variance, is found to be aligned on the peak field strength points of both MGS and MEX measurements, implying that the structure is quasi-stable over the half-hour between MARSIS and MGS measurements. Furthermore, both of these flux ropes occur directly downstream from the strongest Martian crustal magnetic arcades. Because the path of Mars Express is directed nearly perpendicular to the axis of both of these flux ropes, we can deduce a diameter of approximately 700 km at this location near the south pole of Mars. The orientation for one of these events is shown in Fig. 2.

3. Summary and Conclusions

MARSIS has detected 39 significant transient deviations from the known Martian crustal magnetic field. Two coincidences with enhancements in the MGS MAG magnetic field have been exploited to show that these deviations have the form of large-scale magnetic flux ropes, similar to those reported by [2]. The ground track positions of the peak magnetic field strengths for both MEX and MGS line up along the flux rope axis as determined by minimum variance analysis. Both the large diameter and the geographical position of these flux ropes imply that these are not the same as filamentary flux ropes seen at Venus and in the northern hemisphere of Mars. As do [2], we infer a picture of magnetic flux ropes created by the solar wind stretching and detaching plasma trapped around strong crustal fields.

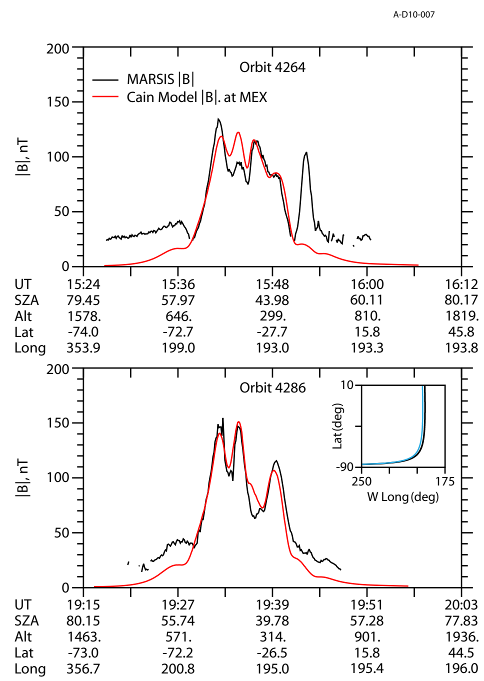

Figure 1: Top: MARSIS detection of flux rope (black), compared with Cain (red). Bottom: Magnetic field along a near-identical track to the top panel but with no flux rope detected. The inset shows the two tracks.

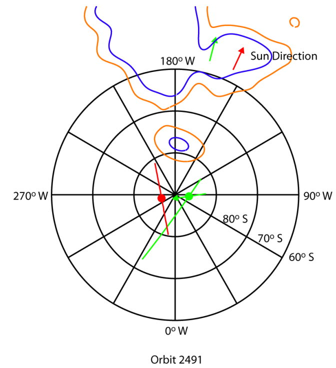

Figure 2: Polar plot around the Martian south pole showing the MEX ground track in red, the MGS ground track in green, and the 50 and 75 nT contours of the crustal magnetic field in orange and blue. The large dots indicate the peak magnetic field and the green arrow shows the flux rope axis inferred from the minimum variance analysis done on the MGS MAG magnetic field components.

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