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The global current systems of the Martian induced magnetosphere

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Abstract

We combine over 4 years of magnetic field measurements from the Mars Atmosphere and Volatiles EvolutioN (MAVEN) orbiter to create the first empirical and quantified global map of the current systems in an induced magnetosphere, which we show are driven by a solar wind powered magnetospheric convective electric field. We find ionospheric currents connected to the bow shock, indicating the area coupling the ionosphere and the solar wind is larger than expected. We also find strong asymmetries in sunward currents between the north-south electric hemispheres and a twist in the global system.

1. Introduction

Conductive, non-magnetized planetary objects (e.g. Mars, Venus, Titan, Pluto, comets) form induced magnetospheres shaped solely by currents induced in the interaction with the solar wind. The induced currents enhance the magnetic pressure near the planet to the point that the solar wind is completely deflected around the planet, though they also couple the ionospheric plasma to the solar wind. The associated electrodynamic energy transfer can power atmospheric ion escape inside the induced magnetosphere and drive evolution of atmospheric and volatile contents on geological time scales.

2. Instrumentation and Method

We use measurements from the MAVEN magnetic fields instrument (MAG) to create 3-dimensional maps of the average magnetic vector field near Mars. MAVEN/MAG comprises two 3-axis fluxgate magnetometers mounted on boomlets at the tips of the spacecraft solar arrays and provides magnetic vector measurements in the range 0.015–65,536 nT with an absolute vector accuracy of 0.05%, angular precision <0.05°, and 32 s^{-1} cadence [1]. Two Cartesian grids are defined in the planetcentric Mars-Sun-Electric (MSE) reference frame, in which $X_{\rm MSE}$ is antiparallel to the solar wind flow, $\mathbf{v}_{\rm sw}$, $Z_{\rm MSE}$ points in the direction of the solar wind motional electric field,

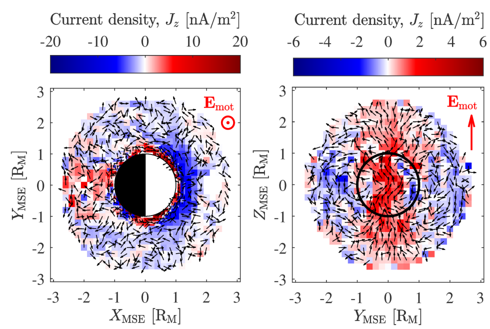

Figure 1: Component of the currents co-aligned with the upstream solar wind motional electric field, $\mathbf{E}_{\rm mot}$, indicated with a red arrow. The left panel shows a slice of the 3D map of currents cut in a plane intersecting the center of the planet, the right panel shows a slice through the induced magnetotail at $X_{\rm MSE} = -1.4\,{\rm R_M}$.

$$\mathbf{E}_{\rm mot} = -\mathbf{v}_{\rm sw} \times \mathbf{B}_{\rm IMF}, \qquad (1)$$

and $Y_{\rm MSE}$ completes the right-handed system in the average direction of the upstream Interplanetary Magnetic Field, $\mathbf{B}_{\rm IMF}$. A grid with resolution 0.1 $\rm R_M$ (Mars radii) is used below 1000 km altitude and another grid with resolution 0.2 $\rm R_M$ is used above 1000 km altitude.

The MSE reference frame is effectively co-oriented with the orientation of the induced magnetosphere. To obtain MAVEN/MAG measurements in MSE, the location and direction of the magnetic field vectors are corrected for solar wind aberration and the varying upstream IMF clock angle, $\phi_{\mathrm{IMF}} = \tan^{-1}(B_z/B_y)$. Measurements from the MAVEN Solar Wind Ion Analyzer (SWIA) [2] and MAG are used to identify measurements in the undisturbed undisturbed solar wind. The clock angle is interpolated throughout the orbit using a low-pass filter with $\times 20$ times the weight given to undisturbed IMF relative measurements of draped magnetic fields in the magnetosheath.

The average current vectors, $\mathbf{J}$, can subsequently be found from the average magnetic vector field using the Maxwell-Ampere law,

$$\mathbf{J} = \frac{1}{\mu_0}(\nabla \times \mathbf{B}). \quad (2)$$

Here magnetic permeability is represented by μ_0 and we neglect the displacement current term, which is assumed to effectively average out over 4 years of measurements.

3. Summary and Conclusions

We find that current layers at the induced magnetosphere boundary and bow show are flowing antiparallel to the motional electric field of the solar wind. In turn, this electric southward flow of charge powers ($\mathbf{E} \cdot \mathbf{J} < 0$) a magnetospheric convective electric field, which drives electric northward load currents ($\mathbf{E} \cdot \mathbf{J} > 0$) in the conductive ionosphere and gyroconductive tail neutral sheet (Figure 1), and the magnetic barrier forms as a result of the intersection of the two opposing current layers.

The cross-tail current sheet is twisted and tilted, owing to sunward currents flowing in the southern electric ($-Z_{\mathrm{MSE}}$) hemisphere, distorting the magnetic neutral sheet and gyroconductive region in the tail. In contrast, sunward/antisunward currents are nearly absent in the northern electric ($+Z_{\mathrm{MSE}}$) hemisphere, likely owing to differences in the electric connections between the ionosphere/tail and the magnetosheath. An illustration of the current systems is shown in Figure 2.

The bow shock currents clearly close in the ionosphere and in the induced magnetotail, therefore the Mars–solar wind coupling area is larger than commonly thought [3, 4] and the derived coupling coefficients are smaller than current estimates.

A paper detailing the findings presented here is currently under review [5]. In addition, we will also discuss expected differences between the current systems of Venus and Mars.

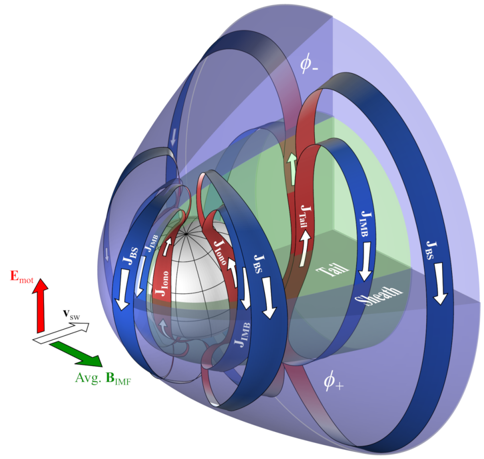

Figure 2: Illustration of the current systems in the Martian induced magnetosphere. Generator/dynamo currents are colored blue and load currents are colored red.

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