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The global-scale magnetic field of Mercury

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1. Introduction

Mariner 10 [1] and MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) observations [2,3] from flybys of Mercury indicate that the planet's internal field has a significant quadrupole term consistent with an axially aligned dipole displaced northward by ~0.16 R_M, where R_M is Mercury's radius. In models based on these data the dipole and quadrupole coefficients are highly correlated because of limited observation locations, so the solutions are not well constrained [4,5]. In addition, signatures of plasma pressure near the equator raise questions about the fidelity of the field magnitudes recorded near the equator [6].

2. Plasma and the Magnetic Field

In its polar orbit at Mercury the MESSENGER spacecraft passes through the equator at approximately 1000 km altitude on the descending orbit node. Data from orbit confirm the prevalence of plasma pressures near the equator. Figure 1 shows Magnetometer data [7] acquired shortly after instrument turn-on after orbit insertion on 18 March 2011. Signatures of plasma pressure are present from 01:49 to 02:07 UTC. Similar depressions are observed on almost every orbit and prevent direct application of spherical harmonic analysis to the orbital data for latitudes south of ~30°N.

3. The Magnetic Equator

Despite the decrease in field magnitude, the direction of the field near the equator is not highly variable. The steady direction is consistent with a diamagnetic plasma signature that reduces the local field but does not alter the basic field geometry. Because the global magnetic field governs plasma pressure distributions and the locations of external currents, the net magnetic field is symmetric about the magnetic equator. Hence, the location of the magnetic equator can be determined without correcting for local plasma pressures and external currents. We consider the magnetic field in cylindrical MSO coordinates (ρ, φ, z) where z is positive northward. In this system the magnetic equator is indicated by the $B_\rho = 0$ point, and the z coordinate of this point, denoted $Z_{\rho 0}$, indicates the magnetic equator (Figure 2).

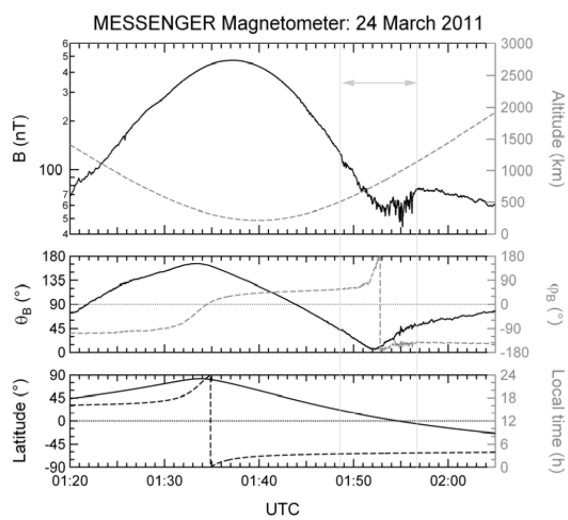

Figure 1. MESSENGER magnetic field data for 24 March 2011 in Mercury solar orbital (MSO) coordinates, where X is sunward, Z is northward, and Y is duskward. From top, panels show field magnitude and spacecraft altitude; magnetic field MSO polar angle, θ_B, and azimuth angle, φ_B; and spacecraft latitude and local time. Vertical lines indicate the depressed magnetic field near the equator.

$Z_{\rho 0}$ was evaluated on each descending node pass by selecting one minute of data centered on the $B_\rho = 0$ point. A linear fit between B_ρ and z from this segment was used to find $Z_{\rho 0}$. Figure 3 shows results for data from 23 March to 9 May 2011, indicating a northward displacement with a mean of 472 ± 14 km (3-standard-error uncertainty).

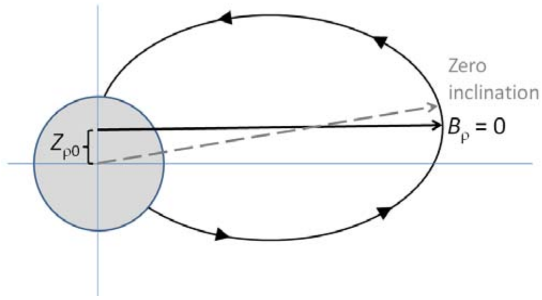

Figure 2. Determining the magnetic equator using the $B_\rho = 0$ point. For an axially aligned dipole offset northward from the planetary center, the point of zero inclination (i.e., the position where the magnetic field is parallel to the local horizontal determined in geographic coordinates) occurs farther from the planetary equator than the true dipole equator.

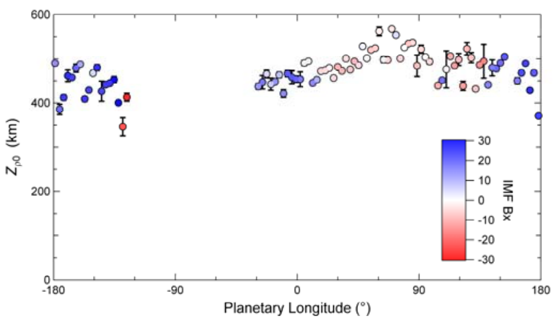

Figure 3. $Z_{\rho 0}$ versus planetary longitude. Color coding indicates the sunward IMF component, B_X, since this may affect $Z_{\rho 0}$ on the nightside. Error bars are 3-standard-error uncertainties.

The variation of magnetic equator relative to the mean offset appears to be predominantly due to interplanetary magnetic field (IMF) B_X. To estimate the magnetic tilt, analysis of the zero inclination point using an origin displaced northward by 472 km yields an upper limit of 2.5° even ignoring the variation from IMF B_X.

4. Summary and Conclusions

Analysis of Mercury's magnetic field from MESSENGER orbital observations shows that despite marked plasma pressures near the equator, magnetic field directions can be used to determine the north-south position of the magnetic equator. Such analysis yields a northward displacement of the planetary dipole of 0.193 ± 0.006 R_M and a maximum tilt of 2.5°. This northward displacement implies a substantial north-south asymmetry in the surface field intensity and presents a challenge for planetary dynamo models to produce a large-scale dipolar field offset from the planetary equator. One possibility is that this asymmetry may reflect the influence of large-scale lateral variations in heat flow at the core-mantle boundary.

Acknowledgements

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