# The Search for Magnetotail Twisting at Mercury: Comparing MESSENGER Observations with the Terrestrial Case

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## Abstract

Previous studies reported that the terrestrial and Martian magnetotails can become twisted due to the solar wind-planetary interaction; however, the associated physical processes proper of intrinsic and induced magnetospheres are still under debate. In particular, there is evidence that the Interplanetary Magnetic Field (IMF) dawn-dusk component (By) plays a major role in both environments, affecting the sense of twist. Here, we analyze all MESSENGER Magnetometer observations to investigate the IMF By influence on Mercury's magnetotail. We find that Mercury's tail twist is very small ($\leq$ **3** degrees), for a median downtail distance of $\sim$2 Mercury radii. We also identify a correlation between the IMF By and the local By component around the magnetotail current sheet. These results suggest the small (or lack of) twist may be explained by the dipolar field strength in the near-magnetotail. We examine this hypothesis by putting these observations into context with studies on the terrestrial magnetotail.

## 1. MESSENGER Magnetometer Selection Criteria

The presence of a non-zero IMF By component generates asymmetric dayside magnetopause reconnection, affecting the magnetic flux loading in the magnetotail lobes [Cowley, 1981]. According to this model, the deflecting open magnetic field lines exert tangential stresses on the magnetotail lobes that are responsible for the rotation of the current sheet.

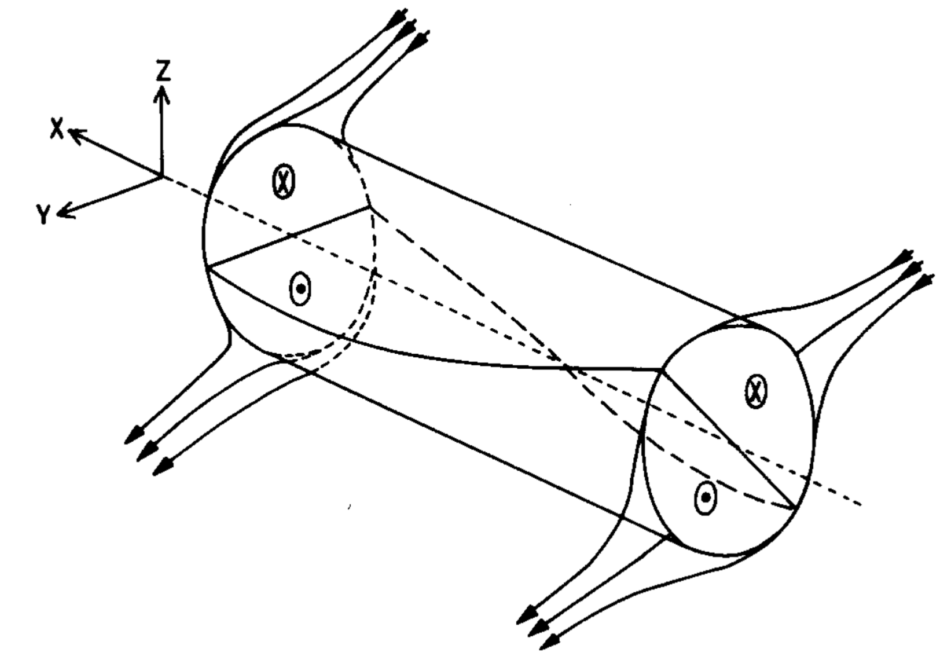


Figure 1. Schematic representation of the tail lobes and current sheet twist due to the IMF torque on the magnetotail for ***By*** $>$ **0** [The Figure is taken from Cowley et al., 1981]

We analyze all MESSENGER Magnetometer (MAG) data:

- We compute 10 s magnetic field averages

-We identify and select MESSENGER's orbits that sampled both the region upstream from Mercury's bow shock and the Hermean magnetotail [Philpott et al., 2020].

- Throughout the mission, the spacecraft mostly explored the southern magnetotail lobe, but also sampled the current sheet and the near northern lobe.

- The distributions of the IMF properties (Figure 2d-f) are consistent with nominal values along Mercury's orbit around the Sun.

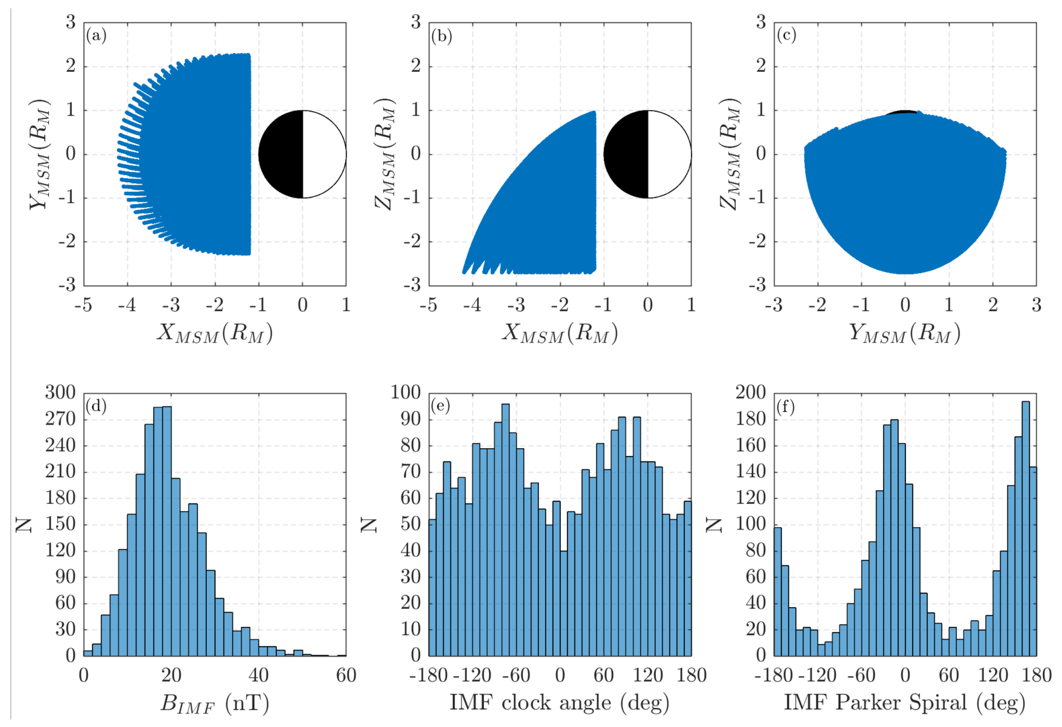


Figure 2. (a-c) MESSENGER position in Mercury's magnetotail (d-f) Distributions of MESSENGER magnetic field observations [Romanelli et al., 2022]

## 2. Results

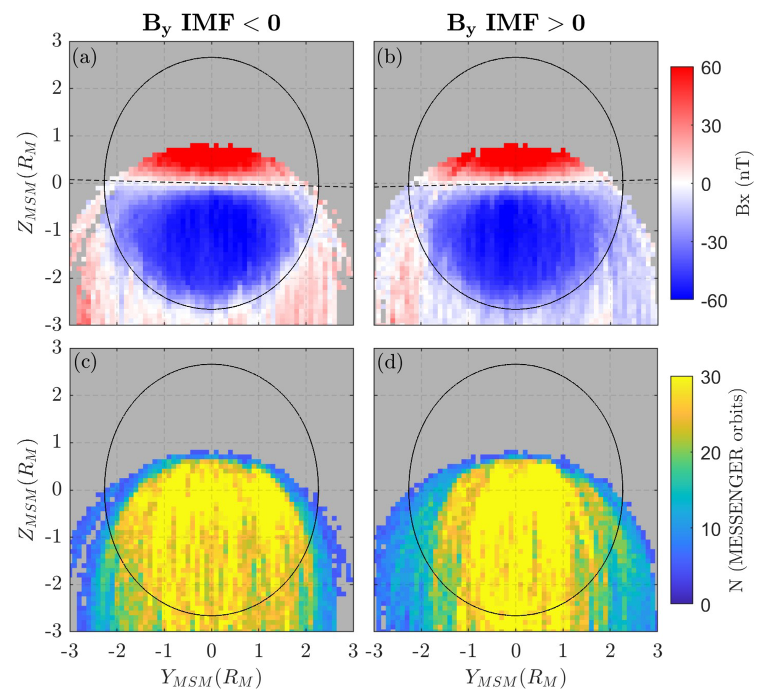


Figure 3. (a-b) Cross-tail projections of the mean Bx component in the Hermean magnetotail as a function of the aberrated YMSM and ZMSM coordinates. (c-d) Number of MESSENGER orbits per bin associated with the magnetic maps shown in panels (a) and (b) [Romanelli et al., 2022].

These results suggest Mercury's tail may be twisted up to $\sim$3 degrees clockwise (counterclockwise) for negative (positive) IMF By (seen from the planet towards the magnetotail tail).

Figure 4a indicates there is a linear correlation (R$\sim$0.33) between By around Mercury's tail current sheet (MAG data with $|\boldsymbol{Bx}| < \mathbf{0.01}\boldsymbol{B}$ and $|\boldsymbol{ZMSM}| < \mathbf{0.2}\boldsymbol{RM}$), and the associated IMF By component for the same MESSENGER orbit. These observations suggest the IMF is able to affect Mercury's magnetotail structure to some extent.

Figure 4b suggests the dipole magnetic field is strong enough to reduce/prevent tail twisting in the near-magnetotail of Mercury.

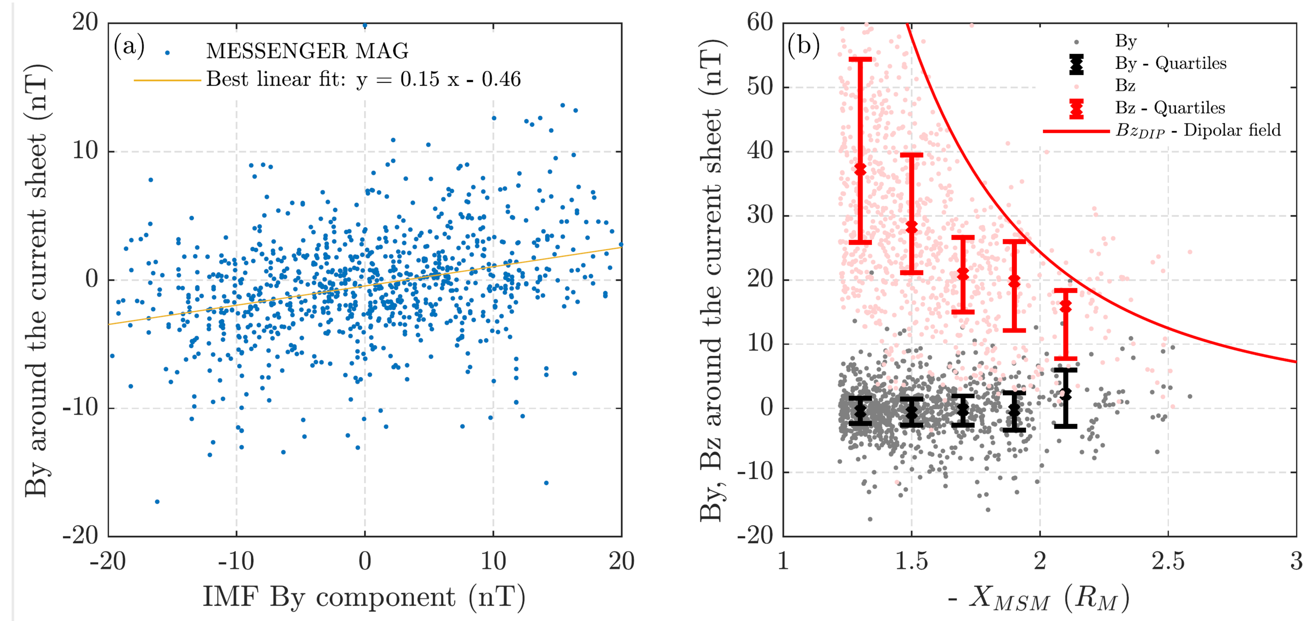


Figure 4. (a) By around Mercury's magnetotail current sheet as a function of the average IMF By component for the same MESSENGER orbit. (b) By and Bz around Mercury's magnetotail current sheet as a function of the downtail distance [Romanelli et al., 2022].

## 3. Discussion

Figure 5 presents a comparison between our tail twist estimation at Mercury and several statistical studies using magnetic field data from observations at Earth. These results suggest the terrestrial twist is appreciable when the influence of the IMF By in the current sheet is on the order of the local planetary dipole field strength (BzDIP).

In the case of the Hermean magnetotail, we find the dipolar field Bz component at the current sheet (BzDIP) is on the order of 4 nT for X $\sim$3.6 RM.

The computed critical distance is $\sim$ 1 Mercury radii further downstream than most of the MESSENGER data available for this study, providing an explanation for the relatively small observed (or lack of) tail twist.

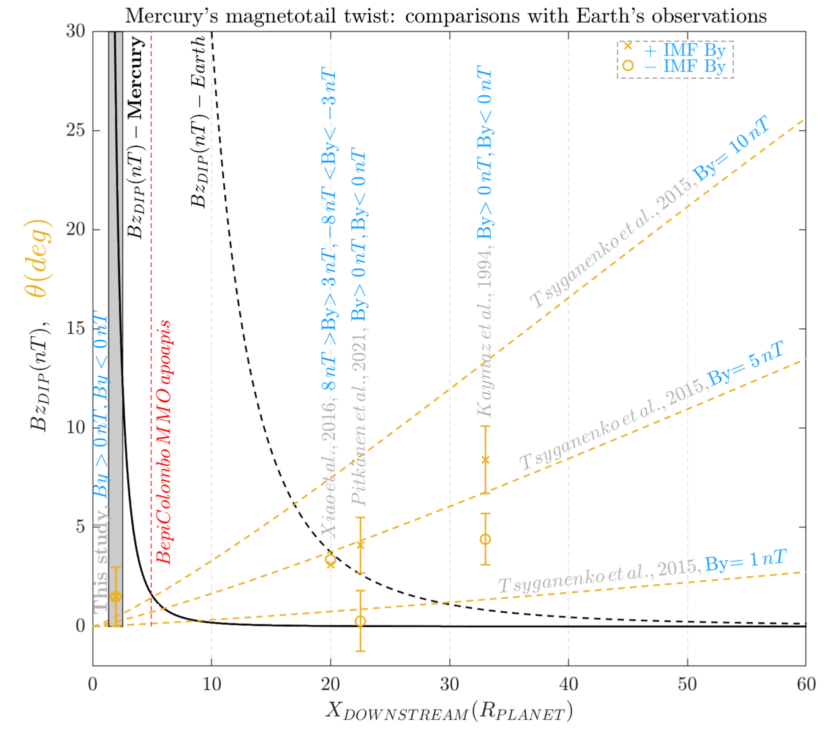


Figure 5. Comparison of our results with observations at the terrestrial magnetotail. Vertical axis shows the Bz component associated with Mercury's and Earth's magnetic dipoles at the respective magnetotail current sheet (black solid and dashed curves, respectively) and the observed tail twist (in yellow) for positive (cross) and negative (circle) IMF By (in light blue), as a function of the distance downstream from the planet (normalized with the planet's radii) [Romanelli et al., 2022].

## 4. Conclusions

Main takeaways: [Romanelli et al., 2022, Geophysical Research Letters, doi: 10.1029/2022GL101643]

- We find an upper bound for Mercury's near tail twist of $\sim$3 degrees, in association with the IMF dawn-dusk (By) component.

- The IMF By is able to affect Mercury's magnetotail current sheet and the local dipolar field can partly explain the small twist.

- Comparisons with observations from Earth suggest the tail twist could be detectable by Bepi-Colombo further downstream of Mercury.