MESSENGER Observations of Reconnection Ion Diffusion Region Structure at Mercury

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Introduction

Magnetic reconnection is known to be the most important process for plasma transport and energy conversion in space plasma. This process involves the formation of two nested diffusion regions where the frozen-in flux condition no longer holds, first on the ion and then on the electron gyro-scales. In the larger ion diffusion region the inflow ions become de-magnetized and decoupled from the electrons. The differential motion between the ions and electrons results in Hall current that produces a quadrupolar magnetic field normal to the plane of reconnection. Closer to the X-line, the electrons also de-magnetize to form the inner diffusion region. Studies of magnetic reconnection at Earth have observed these Hall quadrupolar magnetic fields in the cross-magnetotail current sheet. MESSENGER observations taken at Mercury have shown that magnetic reconnection is the dominant driver of magnetotail dynamics and that it is significantly more intense than at Earth. Here, we examined 4 years of MESSENGER magnetic field data to study the plasma sheet structure, Near Mercury Neutral Line (NMNL) and quadrupolar magnetic field signatures on ion-scales surrounding bi-polar magnetic fields normal to the magnetopause and magnetotail current sheets. The results are compared with measurements of X-lines and quadrupolar magnetic fields at Earth.

Identification

- Using 4 years of MESSENGER's MAG data, the plasma sheet crossing is identified by hand based on the following criteria:
  - ➢ The diamagnetic decrease in B-field in the plasma sheet must correspond to a reversal of Bx (i.e. crossing the current sheet)
  - ➢ Only plasma sheet crossings with clear boundaries are selected.
  - ➢ The average decrease of B-field inside the plasma sheet must be more than 50% of the average magnetotail lobe field.

- Figure 1 shows an example of a plasma sheet crossings on February 3rd 2013 with each regions of the magnetotail labeled and marked with red dashed lines.

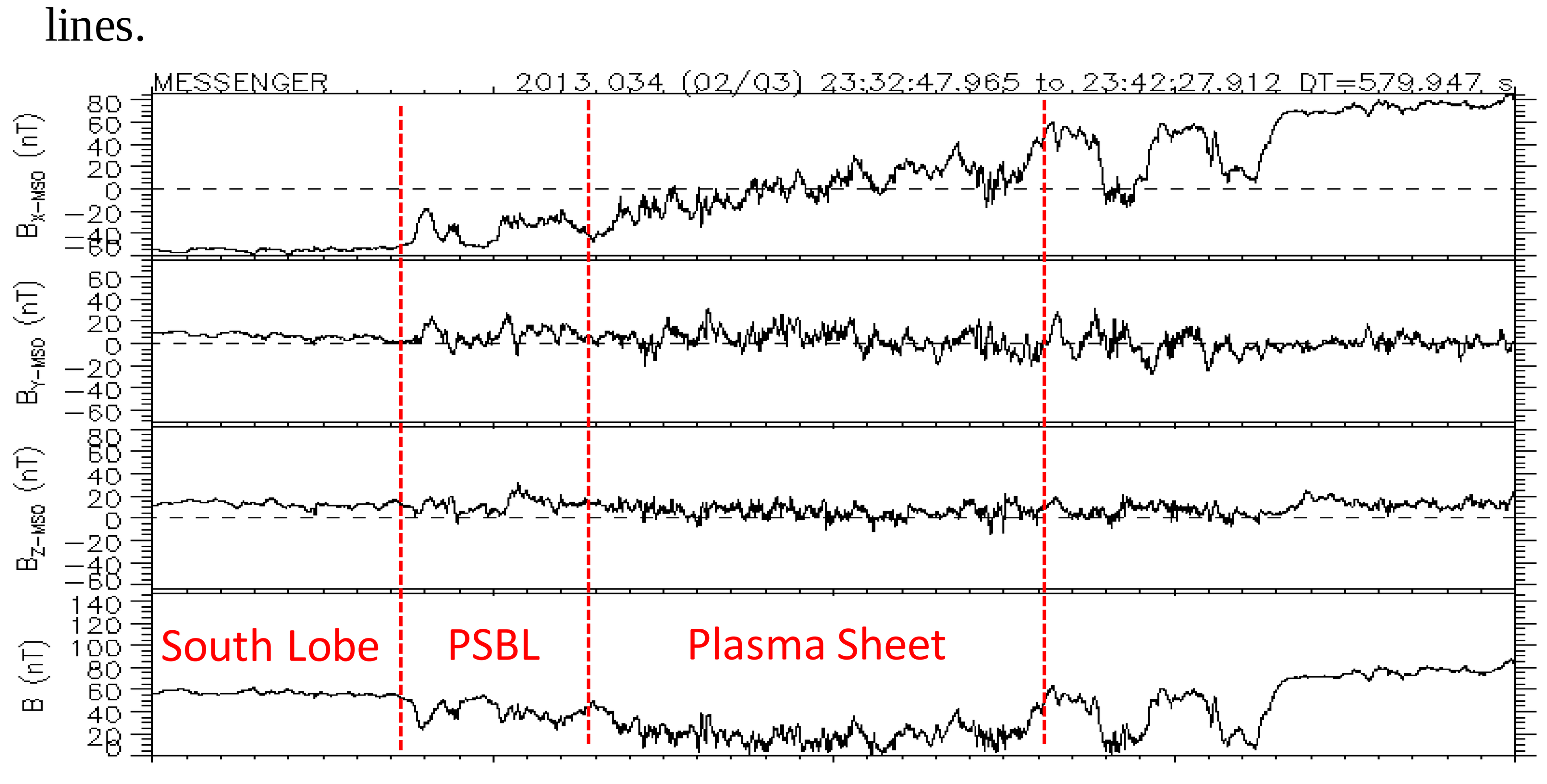


Figure 1. Example of a plasma sheet crossing on February 3rd 2013. MESSENGER first encountered the southern lobe and into the plasma sheet boundary layer (PSBL). MESSENGER entered the plasma sheet where there is a sudden drop in B-field, followed by a increase in B-field as it exits.

- A total of 333 plasma sheet crossings were identified over 4 years of MESSENGER MAG data.

Results

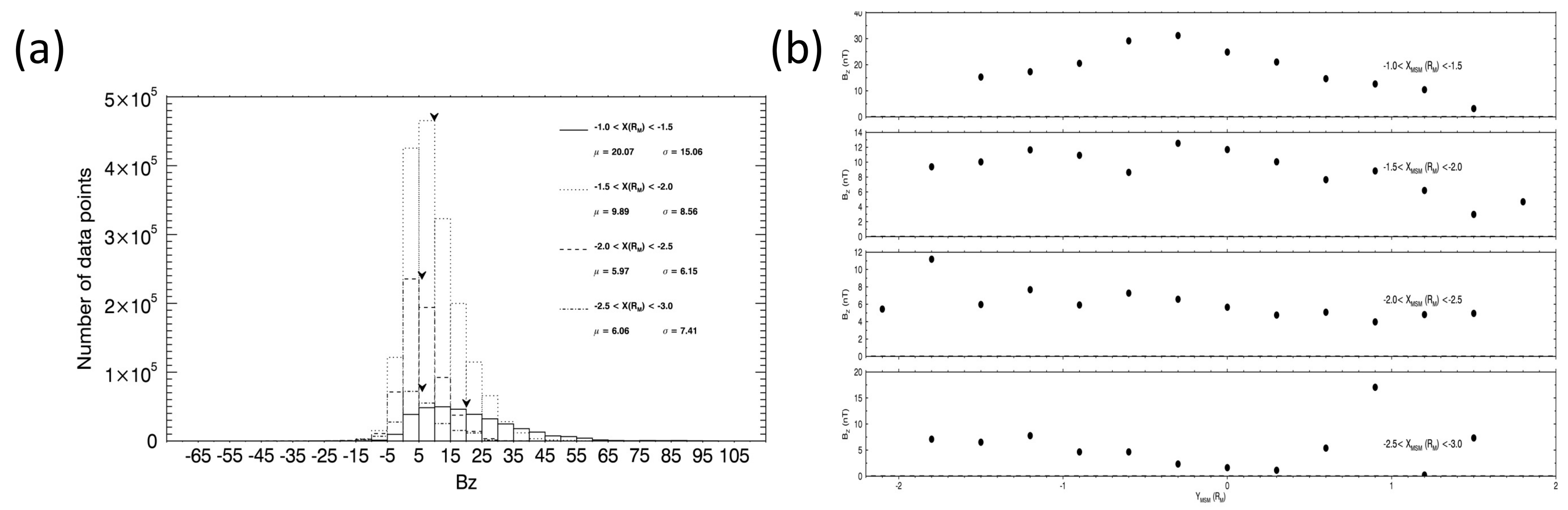


Figure 2(a). Histograms of Bz in the plasma sheet in aberrated MSM coordinate system for 4 distance regions. The mean of each histogram is represented by an arrow. (b) Bz plotted as a function of Y_{MSM} for same downstream X_{MSM} regions as Figure 2(a)

- Figure 2(a) shows the histograms of B_z in the plasma sheet for 4 different downstream distance X_{MSM} regions.
- Result shows that B_z in the plasma sheet is predominantly positive between $-1 > X_{MSM}\ (R_M) > -3.0$ with the average decreasing with downstream distance and the variances remaining nearly constant.
- Variance of the distribution at $|X_{MSM}| > 2.5$ is significantly larger than the mean (i.e. reconnection X-Lines forms most often at distance $|X_{MSM}| < 2.5$), consistent with previous studies [Slavin et al., 2012; Dibraccio et al., 2014].
- Figure 2(b) shows B_z as a function of Y_{MSM} for 4 X_{MSM} regions where B_z near $Y_{MSM} \sim 0$ decreases to near zero between $-2.5 > X_{MSM}\ (R_M) > -3.0$.

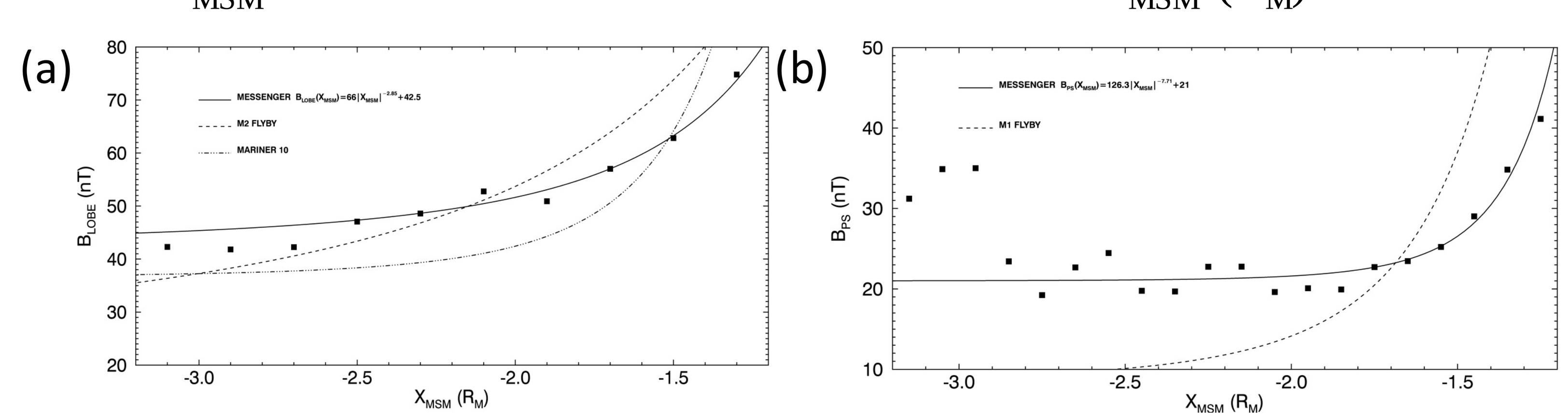


Figure 3. (a) Lobe B-field intensity as a function of X_{MSM}. (b) Plasma Sheet (PS) B-field intensity as a function of X_{MSM}.

- Figure 3a shows the 1-min average lobe B-field intensity as a function of X_{MSM}. A power law relation is fitted to the data as shown by the solid line.
- The lobe B-field intensity falls off with $|X|^{-2.9}$ which is much faster than that of Earth's ($|X|^{-0.5}$) [Slavin et al., 1985].
- This shows that intense reconnection at Mercury's magnetotail closes the open lobe flux closer to the planet.
- The tail magnetopause stop flaring at $\sim |X| > 2.8R_M$ which is consistent with the results by Mariner 10 flyby as shown by the dotted line.
- In Figure 3(b), plasma sheet B-field intensity is also fitted to power law of $|X|^{-7.71}$ which falls off faster than that of the M1 flyby [Slavin et al., 2012].

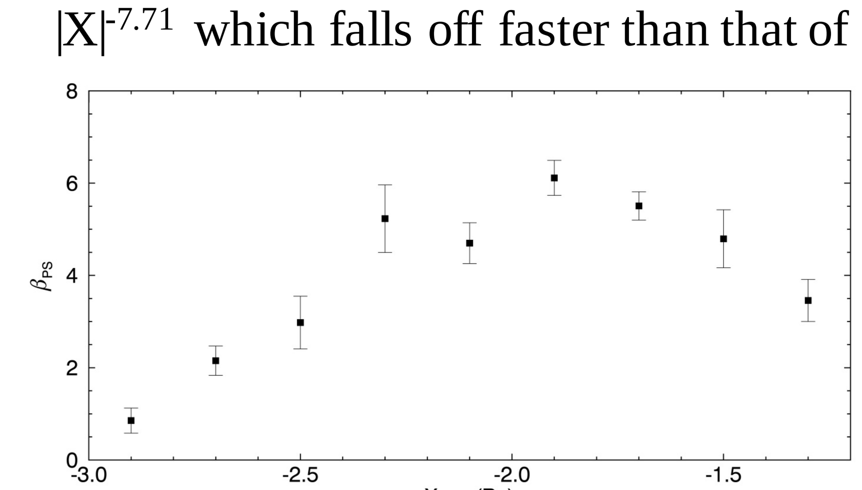


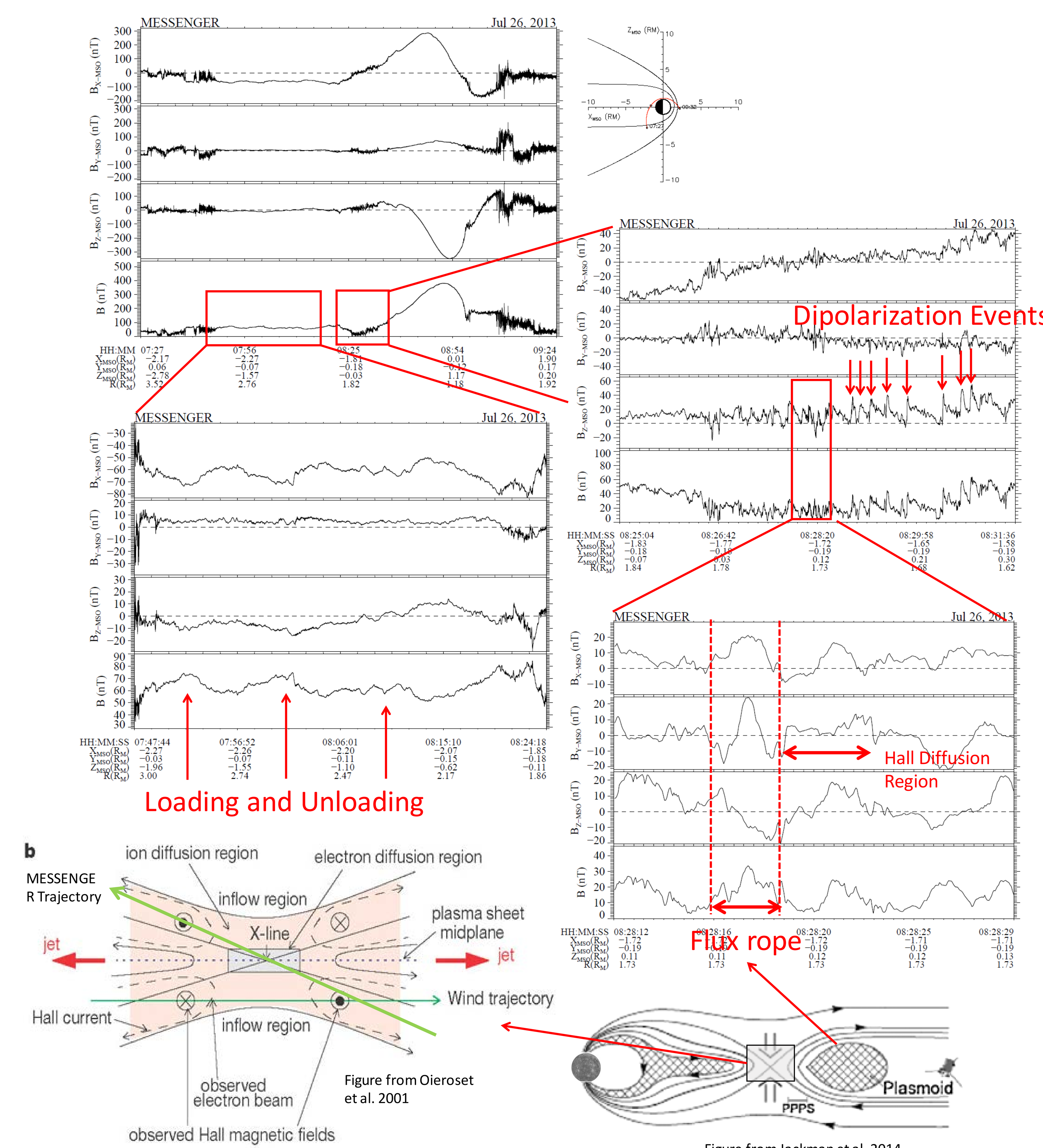
Figure 4. (a) Plasma sheet β as a function of X_{MSM}.

- Figure 4 shows the plasma sheet beta determined from the equation:

$$\beta_{PS} = \left(\frac{B_{Lobe}}{B_{PS}}\right)^2 - 1$$

- Increase in β near region where x-lines usually are found

Observation of Ion Diffusion Region



Conclusions

- Statistical results show that the reconnection X-lines form most often at $|X_{MSM}| < 2.5$ near midnight.
- The lobe and plasma sheet B-field intensity as a function of downstream distance |X| follows a power law relation similar to Earth.
- However, due to intense reconnection, the rate of fall off is much faster than Earth's.
- We also reported the first possible observations of Hall diffusion region at Mercury's magnetotail.
- The bipolar signature in Bx and Bz with corresponding increase in By suggest that MESSENGER encounters the diffusion region diagonally.

References

1. Slavin et al.,1985, An ISEE 3 Study of Average and Substorm Conditions in the Distant Magnetotail.
2. Slavin et al., 2012, MESSENGER and Mariner 10 flyby observations of magnetotail structure and dynamics at Mercury.
3. Dibraccio et al., 2014, MESSENGER observations of flux ropes in Mercury's magnetotail.
4. Oieroset et al., 2001, In situ detection of collisionless reconnections in the Earth's magnetotail.

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