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MESSENGER observations of the plasma environment near Mercury

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Introduction

The Fast Imaging Plasma Spectrometer (FIPS) [1] is part of the Energetic Particle and Plasma Spectrometer instrument on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft. FIPS has a nearly hemispheric field of view (FOV). Part of this FOV is obstructed, however, necessitating the development of a novel algorithm to derive bulk plasma parameters from the observed proton spectra and angular distributions. Plasma ion measurements made by MESSENGER are the first ever to be made at Mercury.

MESSENGER has confirmed and extended the earlier Mariner 10 measurements of Mercury's small, (~200 nT-R_M^3 dipole moment, where R_M is Mercury's radius) intrinsic magnetic field [2,3]. The resulting magnetosphere is much smaller than that of Earth, by about a factor of 8, but qualitatively similar in structure [4-6]. A technical problem prevented the Mariner 10 ion experiment from returning data, so only electron measurements at Mercury were available prior to MESSENGER.

The first MESSENGER flyby measurements revealed that Mercury's magnetosphere is immersed in a cloud of planetary ions that extends beyond the dayside bow shock and also demonstrated the existence of a "boundary layer" of indeterminate origin just inside the dawn magnetopause [2, 7, 8]. The second flyby confirmed the existence of this dayside boundary layer as a permanent feature of Mercury's magnetosphere [2, 9]. Further, the second flyby provided observations of very intense magnetic reconnection at the dayside magnetopause and in the magnetic tail [9].

We first present a summary of the plasma analysis methodology and its applicability within the MESSENGER magnetosphere. We then focus on the recovered proton densities and temperatures, which are the first to be reported from Mercury.

Methodology

Because of the FIPS FOV obstructions, particularly in the sunward direction, it is necessary to interpret FIPS observations with a forward model, i.e., a model for a velocity distribution defined by its moments, and find the best match of the properties of that model for recovery of basic plasma properties (density, bulk velocity, and temperature). This model includes the detailed sensitivity dependence of FIPS as a function of incident particle angle and energy, as well as the precise location and attitude of the MESSENGER spacecraft and orientation of the spacecraft solar panels

In this work, we restrict the application of this forward model to regions where two specific assumptions are likely to hold: (1) the plasma distribution is well represented by a Maxwellian distribution, and (2) bulk plasma speed is low compared with thermal speed, $v << v_{th}$.

Results and Discussion

We have used this methodology to recover plasma density and thermal velocity parameters focused in three regions where magnetospheric flow is likely reduced, perhaps even stagnant, and the above assumptions likely hold: the quiet-time plasma sheet and the dayside and nightside boundary-layer regions.

The recovered values for the Mercury plasma sheet seen during MESSENGER's first flyby of Mercury on 14 January 2008 (M1), along with calculated temperature and pressure, are presented in Figure 1. At Earth, Baumjohann et al. [10] reported average values for density of ~0.2–0.5 cm^{-3}, for temperature of ~30–56 MK, and for velocity of ~50–75 km/s. The reported value of β, the ratio of plasma to magnetic pressure, was found to vary greatly from 20–30 near the inner edge of the plasma sheet to 0.3 at the outer edge. We note first that the above velocity range, if also present at Mercury, would fit within the assumptions of our recovery method. By comparison, the recovered density for the full M1 plasma sheet is considerably larger than the average at Earth, ranging from 1 to 12 cm^{-3}. Because of radial scaling, the solar wind density is expected to be higher by about a factor of 10 at Mercury than at Earth. Since plasma sheet density depends in part on the solar wind density, higher plasma sheet densities at Mercury are not unexpected. The temperature of the Mercury plasma sheet, at ~ 1 MK, is considerably lower than seen at Earth. The proton pressure increased by about a factor of 2 as MESSENGER approached the planet, a trend consistent with observations at Earth [11].

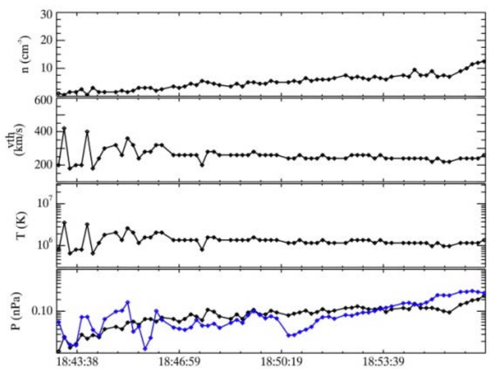

Figure 1. Recovered values of density (*n*), thermal velocity (v_{th}), temperature (*T*), and pressure (*P*) from the plasma sheet traversal during M1. The blue line in the bottom panel shows the magnetic pressure.

We also consider the boundary layers, one nightside and one dayside, encountered during each flyby. In each of these regions, the change in magnetic field intensity leveled off and variation increased substantially, indicating a marked plasma pressure. Average recovered plasma values, by region, are shown in Table 1, along with the drop in magnetic pressure, ΔP_M, seen on entering the dayside boundary layer. Comparison between the two flybys shows little variation in density with time, meaning that there was little spatial variation as MESSENGER flew through the region. During the first flyby, the temperature increased by a factor of 2 with decreasing distance from the planet. During the second flyby (M2) we observed plasma that was hotter and more dense than during the first flyby.

Table 1. Average plasma parameters for boundary layers. Both proton (P_P) and magnetic (P_M) pressure are given. See text for other details.

	Dayside Boundary Layer		Nightside Boundary Layer	
Flyby	M1	M2	M1	M2
$\langle n \rangle$	16	8	4.3	5.2
$\langle T \rangle$	8.7×10^5	4.7×10^6	2.4×10^6	4.1×10^6
$\langle P_P \rangle$	0.19	0.51	0.14	0.28
$\langle P_M \rangle$	1.9	3.01	3.1	2.7
ΔP_M	-1.63	-1.61	n/a	n/a
$\langle \beta \rangle$	0.1	0.2	0.5	0.1
$\langle \lvert B \rvert \rangle$	69.1	91.2	88.4	81.4

Conclusions

The recovered plasma density, temperature, and pressure values show marked differences between the two flybys. We found that density and pressure variations compare favorably with observations at Earth. In particular, the southward interplanetary magnetic field during M2 produced notably higher *T* in the dayside and nightside magnetosphere. Furthermore, we calculated the magnetic pressure drop on entering the dayside boundary layer during each encounter. Stress equilibrium requires that this magnetic pressure drop be balanced by an increase in plasma pressure. However, we found that the proton pressure derived from the new recovery method accounts for only a small fraction of this pressure drop. The remaining pressure may be due in part to heavy planetary ions, not included in this analysis.

References

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