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# Slow modes in the Hermean magnetosphere: Effect of the solar wind hydrodynamic parameters and IMF orientation

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ABSTRACT

The aim of this study is to simulate the slow mode structures in the Hermean magnetosphere. We use a single fluid MHD model and a multipolar expansion of the Northward displaced Hermean magnetic field, to perform simulations with different solar wind parameters to foreseen the most favorable configuration for the formation of slow modes, attending to the solar wind density, velocity, temperature and the interplanetary magnetic field orientation. If the interplanetary magnetic field is aligned with the Mercury-Sun direction, the magnetic axis of Mercury in the Northward direction or the planet orbital plane, slow mode structures are observed nearby the South pole. If the orientation is in the Sun-Mercury or Northward directions, slow mode structures are observed nearby the North pole, but smaller compared with the structures near the South pole. Increasing the density or the solar wind velocity avoids the formation of slow modes structures, not observed for a dynamic pressure larger than $6.25 \cdot 10^{-9}$ Pa in the case of a Northward interplanetary magnetic field orientation, due to the enhancement of the bow shock compression. If the solar wind temperature increases, the slow mode structures are wider because the sonic Mach number is smaller and the bow shock is less compressed.



## 1. Introduction

MESSENGER spacecraft observations revealed several characteristics of the Hermean magnetosphere as a northward shift of its dipolar field by 0.2 of the planetary radius ($R_M$), a dipolar moment of 95 nT$*R_M^3$ and a tilt of the magnetic axis relative to the planetary spin axis smaller than 0.8° (Anderson et al., 2011). With the data of more than thousand of orbits in the North hemisphere, the Hermean magnetic field can be modeled by an axisymmetric multipolar expansion (Richer et al., 2012; Anderson et al., 2012a).

MESSENGER observations show a variable Hermean magnetosphere due to the wide range of possible configurations of the solar wind (SW), leading to the formation of different magnetospheric structures (Baker et al., 2009, 2011, 2013; Anderson et al., 2008; Johnson et al., 2012). Among these structures this study is focussed on the slow modes. The slow modes are standing structures in the magnetosheath, extensively analyzed in the Earth magnetosphere (Zwan et al., 1976; Southwood et al., 1992; Wang et al., 2004) and recently in the Hermean magnetosphere (Pantellini, 2015). Numerical analysis of slow modes in Mercury predicts the existence of slow modes fronts and eventually slow mode shocks just upstream of the magnetopause, particularly strong in the regions with large magnetic shear near the reconnection points. The presence of slow mode rarefaction fronts are also foretold forming standing structures in the magnetosheath as subproduct of the slow mode expansion (Taylor et al., 2001). The magnetic field lines in the compressional fronts turn connecting the IMF with the planetary magnetic field while in the rarefaction front the plasma flow and the magnetic field are diverted around the planet.

The aim of the present research is to simulate the interaction of the SW with the magnetic field of Mercury and the formation of slow modes in the Hermean magnetosphere for different configurations of the SW. First we fix the solar wind density, velocity and temperature to study the effect of the IMF orientation (for IMF module of 30 nT): in the Mercury-Sun (Bx) and Sun-Mercury (Bxneg) directions, aligned with the Hermean magnetic field in the Northward (Bz) and Southward (Bzneg) direction, as well as in the planet orbital plane perpendicular to the previous directions oriented to the East (By) and to the West (Byneg). In the second part we study the effect of the hydrodynamic parameters (density, velocity and temperature) for a fixed IMF orientation (a Northward IMF orientation with module 30 nT).

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We use the MHD version of the single fluid code PLUTO in the ideal and inviscid limit for spherical 3D coordinates (Mignone et al., 2007). The Northward displacement of the Hermean magnetic field is represented by a multipolar expansion (Anderson et al., 2012b).

**Table 1**
Multipolar coefficients $g_{l0}$ for Mercury's internal field.

| Coeff | $g_{01}$ (nT) | $g_{02}/g_{01}$ | $g_{03}/g_{01}$ | $g_{04}/g_{01}$ |
|---|---|---|---|---|
| | −182 | 0.4096 | 0.1265 | 0.0301 |

**Table 2**
Fixed parameters in the simulations.

| n ($cm^{-3}$) | $T$ (K) | $V$ (km/s) | $M_s$ | IMF (nT) |
|---|---|---|---|---|
| 60 | 58,000 | 250 | 6.25 | 30 |

This paper is structured as follows. Section 2, model description. Section 3, effect of the IMF orientation. Section 4, effect of the hydrodynamic parameters. Section 5, conclusion.

## 2. Numerical model

We use the MHD version of the code PLUTO in the ideal and inviscid limit for a single polytrophic fluid in 3D spherical coordinates. The code is freely available online (http://plutocode.ph.unito.it/).

The simulation domain is confined within two spherical shells, representing the inner (planet) and outer (solar wind) boundaries of the system. Between the inner shell and the planet surface (at radius unity in the domain) there is a "soft coupling region" where special

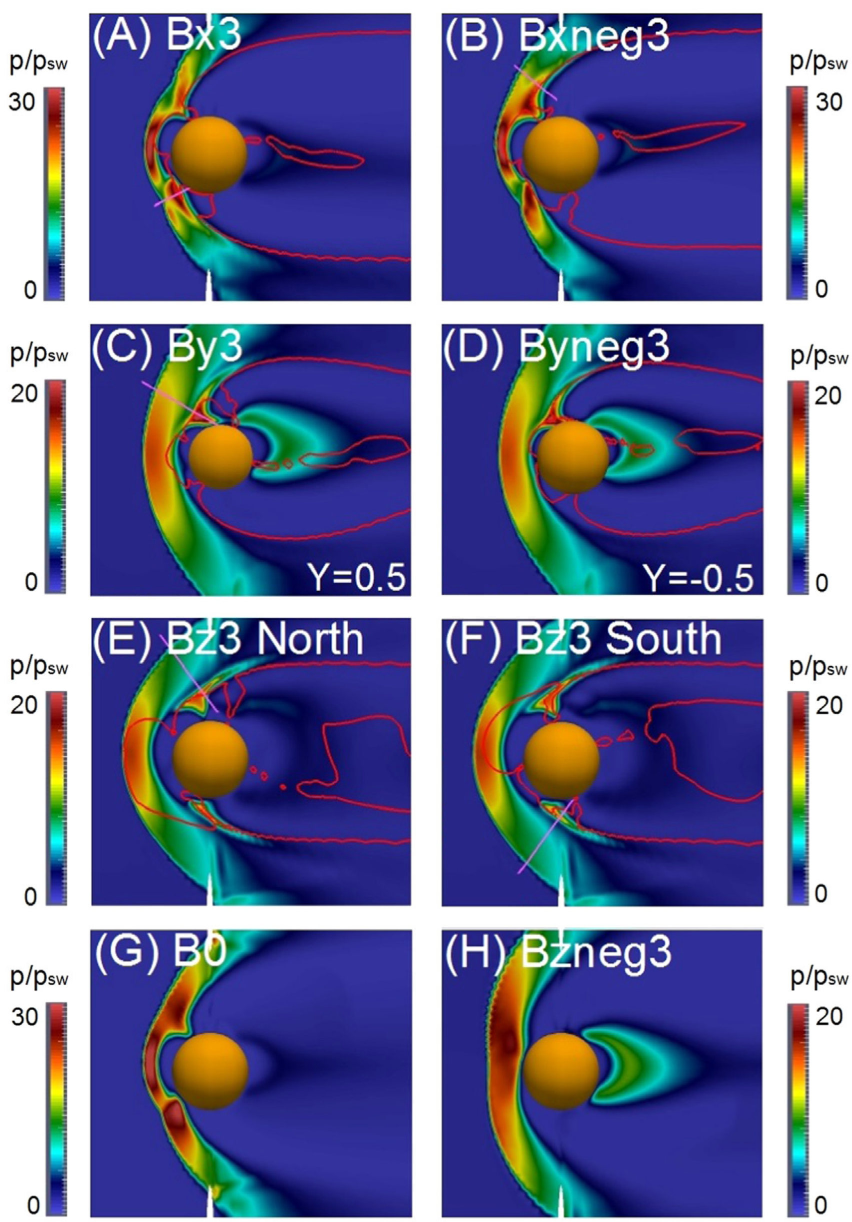


**Fig. 1.** Polar cut of the pressure distribution normalized to the solar wind pressure for the IMF orientations Bx (A), Bxneg (B), By (C), Byneg (D), Bz North pole (E), Bz South pole (F), reference case (G) and Bzneg orientation (H). The red line shows the region where $v/v_\phi \le 1$. The profiles in Fig. 2 are calculated along the solid pink lines. The plots are displaced $0.1R_M$ in $Y$ direction except the By and Byneg cases that are displaced $\pm 0.5R_M$ in $Y$ direction. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)