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Simulation study of Solar Wind interaction with Mercury's magnetosphere

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Abstract

The interaction of the Hermean magnetosphere and the Solar Wind is investigated using a 3-dimensional parallel multi-species hybrid model. In the simulation, it is assumed that Mercury is at its Aphelion and the IMF orientation is the orientation reported by MESSENGER during its first flyby. The principal regions of this interaction are reproduced by the hybrid model and the electromagnetic field spatial variations are described as well. This model represents a strong tool to study Mercury's plasma environment.

1. Introduction

The three flybys of Mariner 10, the numerous terrestrial observations of Mercury's exosphere and the recent flybys of MESSENGER [1] have brought important information about the Hermean environment since the last 40 years. Mercury's intrinsic magnetic field is principally dipolar and its interaction with the Solar Wind (SW) provides a miniature magnetosphere but very dynamic. Mercury's exosphere is very variable [2] and a complex neutral environment made of various neutral constituents have been observed (H, He, O, Na, K, Ca, Mg) [3,4]. The small number of *in situ* observations and the fact that the Hermean magnetospheric activity is not observable from Earth make simulation studies of the Hermean environment a useful tool to understand the global interaction of the SW with Mercury.

1.1 Previous modelling effort

Travnicek et al. ([5]) have presented 3-dimensional hybrid simulation of Mercury's environment for different SW pressure. Their model reproduces the main features of the interaction between the SW and a magnetized planet such as a bow shock, the magnetosheath and the magnetopause. More recently, Wang et al. ([6]) presented a hybrid simulation study of the interaction between Mercury and the SW during the first two flybys of MESSENGER in 2008. It shows that the direction of the Interplanetary Magnetic Field (IMF) strongly controls the global structure of the Hermean magnetosphere.

This study presents simulation results from a 3-dimensional parallel multi-species hybrid model of Mercury's magnetosphere interaction with the SW.

2. A parallelized hybrid model dedicated to Mercury

2.1 The hybrid formalism

In the hybrid frame, only kinetic effects related to ions are taken into account. Ions are considered as macro-particles and electrons are treated as an inertialess fluid ensuring the neutrality of the plasma and contribute to the total current and electronic pressure. The model solves the Maxwell equations to provide the temporal evolution of the electromagnetic field.

2.2 Specificities of the simulation model

In this model, the solar wind plasma is composed of SW protons (95%) and alpha particles (5%). The SW parameters are taken such they are representative of the SW when Mercury is at its Aphelion (0.47AU), as mentioned in Table 1. The simulated IMF is oriented according to the IMF observed during the first flyby of MESSENGER on January 2008 with a cone angle of ~45° [6]. A neutral corona of atomic hydrogen is included in this model and is partly ionized by solar photons, electron impacts and charge exchange between SW ions and neutral H. Two electron fluids with different temperature are implemented to mimic the SW and ionospheric plasma.

This model is an adapted version of the 3D parallel model for the Martian environment [7]. Simulations are performed on a meso-scale computational center dedicated to this project.

Table 1: parameters of the 3D hybrid simulation

Parameter	Value	Unit
IMF X comp.	14.7	nT
IMF Y comp.	8.4	nT
IMF Z comp.	12.6	nT
H+ density	30.4	cm^{-3}
He++ density	1.6	cm^{-3}
Electron density	32	cm^{-3}
H+ temp.	13.e4	K
Alfvén velocity V_A	82	$Km.s^{-1}$
Bulk velocity	5.2	V_A
Inertial length $c/\omega_{p,H}$	40	km
Cyclotron puls. $\omega_{c,H}$	2	$Rad.s^{-1}$
Time step	0.05	$\omega_{c,H}$
Spatial step	3	$c/\omega_{p,H}$

3. Simulation results and conclusion

Simulation results allow describing the ionized environment in the vicinity of Mercury. This model is enabled to reproduce all the different boundaries and region such as the Bow Shock, the magnetopause, the cusp, the plasma sheet, etc… Planetary and SW plasmas are treated separately and the dynamic of each ion species is investigated. Simulations have been performed on a grid of 190×350×350 cells with a spatial resolution of $\Delta x \sim 120$km. Ten macro-particles per cell represent the SW plasma and a total number of about 230 millions particles are present in the simulation. The magnetic field environment, the dynamic of SW ions and planetary protons are presented in this study.

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