URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

Fully-kinetic global simulations of Mercury's magnetosphere in support to BepiColombo

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Mercury is the only telluric planet of the solar system, apart from Earth, possessing an intrinsic magnetic field. This magnetic field shapes (and it is shaped by) the plasma dynamics around the planet, defining the Herman magnetosphere, and the interaction with the impinging solar wind forming the bow shock and foreshock. Mercury's magnetosphere has been investigated by multiple space missions in the past, notably the NASA Mariner10 and MESSENGER missions, being today the target of the joint ESA/JAXA BepiColombo mission now cruising to Mercury. BepiColombo's novel instrumental suite will target the electron kinetic physics at Mercury for the first time, providing observations of (i) electron distribution function and (ii) electromagnetic fields with resolution up to the electron plasma frequency. In order to interpret and plan such observations, a fully-kinetic model of the Hermean magnetosphere including self-consistently ion and electron kinetic physics, is needed.

In this work, we present the first fully-kinetic, three-dimensional, global simulations of the interaction between Mercury's magnetic field and the solar wind using the implicit particle-in-cell code iPIC3D. We present two runs using typical solar-wind parameters at Mercury and purely southward (or northward) interplanetary magnetic field (IMF). The plasma parameters resulting from our PIC simulations are then used to characterize the expected instrumental response of the PWI/AM2P experiment onboard BepiColombo.

As a first step, we validate the results of our simulations by comparing the shape and position of the magnetospheric boundaries (bow shock and magnetopause) with the average ones found by MESSENGER magnetic field observations [1]. This benchmark ensures that the scaled-down parameters used in our PIC simulations do not affect the global dynamics of the solar-wind magnetosphere interaction. Our simulations show that magnetic reconnection in the tail accelerates and heats electrons up to energies of few keVs in the case of southward IMF. Such high-energy electrons are ejected from the neutral line in the tail planetward in a substorm-like process, leading to strong particle precipitation in the nightside of Mercury, especially at local time 0-6 h. Finally, the results of our PIC simulations are used to infer the typical plasma density and temperature to be expected by the AM2P instruments, thus characterizing the instrumental response of the PWI/AM2P mutual impedance experiment in the different regions of the Hermean environment. Synthetic mutual impedance spectra of the AM2P experiment are produced.

In summary, we have presented and validated a novel fully-kinetic numerical model of Mercury's magnetosphere [2] to be used in support of the science operations and planning of the BepiColombo mission. As an example of such coordinated efforts between modelling and observations, we were able to produce the expected response of the PWI/AM2P experiment, and derive crucial information concerning the operational mode of the instrument in the different parts of Mercury's environment.

References

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2. Lavorenti, F., "Electron dynamics in small magnetospheres. Insights from global, fully kinetic plasma simulations of the planet Mercury", Astronomy and Astrophysics, vol. 664, 2022. https://doi.org/10.1051/0004-6361/202243911.