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Fully kinetic 3D simulations of the Hermean magnetosphere under realistic conditions: a new approach

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Simulations of the magnetosphere of planets are usually performed using the MHD and the hybrid approaches. However, these two methods still rely on approximations for the computation of the pressure tensor, and require the neutrality of the plasma at every point of the domain by construction. These approximations undermine the role of electrons on the emergence of plasma features in the magnetosphere of planets. The high mobility of electrons, their characteristic time and space scales, and the lack of perfect neutrality, are the source of many observed phenomena in the magnetospheres, including the turbulence energy cascade, the magnetic reconnection, the particle acceleration in the shock front and the formation of current systems around the magnetosphere.

Fully kinetic codes are extremely demanding of computing time, and have been unable to perform simulations of the full magnetosphere at the real scales of a planet with realistic plasma conditions. This is caused by two main reasons: 1) explicit codes must resolve the electron scales limiting the time and space discretisation, and 2) current versions of semi-implicit codes are unstable for cell sizes larger than a few Debye lengths. In this work we present new simulations performed with ECsim, an Energy Conserving semi-implicit method [1], that can overcome these two barriers. We compare the solutions obtained with ECsim with the solutions obtained by the classic semi-implicit code iPic3D [2]. The new simulations with ECsim demand a larger computational effort, but the time and space discretisations are larger than those in iPic3D allowing for a faster simulation time of the full planetary environment.

The new code, ECsim, can reach a resolution allowing the capture of significant large scale physics without loosing kinetic electron information, such as wave-electron interaction and non-Maxwellian electron velocity distributions [3]. The code is able to better capture the thickness of the different boundary layers of the magnetosphere of Mercury. Electron kinetics are consistent with the spatial and temporal scale resolutions. Simulations are compared with measurements from the MESSENGER spacecraft showing a better fit when compared against the classic fully kinetic code iPic3D. These results show that the new generation of Energy Conserving semi-implicit codes can be used for an accurate analysis and interpretation of particle data from magnetospheric missions like BepiColombo and MMS, including electron velocity distributions and electron temperature anisotropies.

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