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Modelling of the solar wind interaction with the Moon: Magnetic anomaly region and Debye sheath layer near the surface

E. Kallio (1), R. Jarvinen (1), S. Dyadechkin (1), P. Wurz (2), S. Barabash (3), A. Rantala (1) and M. Alho (1)
(1) Finnish Meteorological Institute, Helsinki, Finland (esa.kallio@fmi.fi), (2) Physikalisches Institut, University of Bern, Switzerland (3) Swedish Institute of Space Physics, Kiruna, Sweden

Abstract

The recent lunar missions have shown that the solar wind interaction with the Moon is more complex than anticipated before and scientifically highly interesting, as shown by new in situ plasma, neutral atom and magnetic field observations. Especially, an unexpectedly high fraction of the incident solar wind protons is reflected from the surface, and even larger fraction at the location of lunar magnetic anomalies. This effect has been observed both by measuring deviated solar wind flow near the magnetic anomalies and by observing decreased flux of energetic neutral hydrogen atoms, H-ENAs, from the surface region of strong magnetic anomalies [1, 2, 3]. These global scale processes affect the properties of plasma near the lunar surface. Consequently, also physical processes at much smaller spatial scale, within the Debye sheath layer, where the electric potential of the surface and near surface region are controlled by photoelectrons and solar wind particles, are affected.

In this work we use two numerical kinetic simulation models developed to study the solar wind interaction with the Moon: (1) a local 3-D hybrid model (HYB-Moon) to study a plasma region near lunar magnetic anomaly and (2) a full kinetic 1-D electrostatic Particle–In-Cell PIC model (HYB-es) to study the Debye layer a few meters above the surface. Both models are part of the HYB planetary plasma modelling platform developed at the Finnish Meteorological Institute. In the hybrid model ions are modelled as particles while electrons form a charge neutralizing massless fluid. In the PIC simulation both ions and electrons are modelled as particles. In the presentation we will show results based on these models.

1. Introduction

The properties of the lunar plasma environment are affected by the properties of the Moon, the Sun and the nearby space (Fig. 1). The Moon does not have a noticeable global dipole magnetic field and it does not have an atmosphere. Therefore, charged particles originating from the Sun and outside of the Solar System can hit the lunar surface unimpeded.

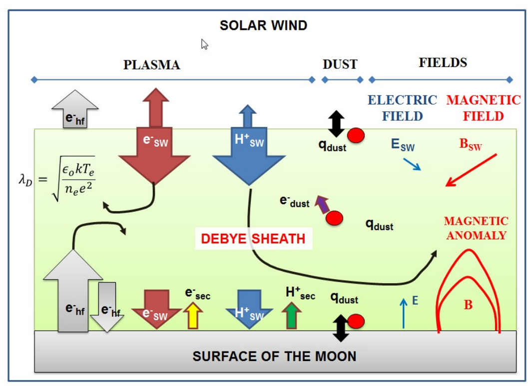

Figure 1. A schematic illustration of plasma populations and fields that affect the lunar dust-plasma environment near the lunar surface: photoelectrons (e^-_{hf}), solar wind electrons (e^-_{sw}) and ions (H^+_{sw}), dust electrons (e^-_{dust}), dust particles (q_{dust}), electric field (**E**) and magnetic field. Because of the non-zero magnetic field associated with the interplanetary magnetic field ($\mathbf{B}_{SW}$), electric currents in the plasma and the lunar magnetic anomalies, the charged particle follow gyromotion around the magnetic field. The electric field consists of the convective electric field of the solar wind ($\mathbf{E}_{sw}$) and the electric field associated with the charge separation within the potential sheath and possibly also within magnetic anomalies. The length scale of the potential sheath is the Debye length (λ_D) [4].

Moreover, micrometeoroids can freely hit and modify the lunar surface due to the lack of an atmosphere. The Sun is the source of the solar wind, a continuous flow of ions (mainly protons, H^+, and alpha particles, He^{++}) and electrons. The Sun is also the source of the interplanetary magnetic field (IMF) and, thus, the solar wind plasma is magnetized. The Sun also emits extreme ultraviolet (EUV) radiation that ionizes both the lunar surface and neutral atoms above the surface.

In this work we focus on study of the finite gyroradius effects near the lunar plasma environments. The solar wind plasma is magnetized and, therefore, ions and electrons rotate around the Interplanetary Magnetic Field (IMF). Moreover, the crustal magnetic field of the lunar magnetic anomalies also affects the motion and velocity of charged particles. We use two kinetic models to study finite gyroradius effects in the lunar plasma environment at two different length scales: (1) the "mesoscale" where the modelled region on the lunar surface includes a magnetic dipole, and (2) the "microscale", which contains a thin photo-electron layer above the lunar surface (typically in sunlight and having thickness of order of a few meters).

2. Description of the models

The kinetic models used in this work are based on the HYB modelling platform. Historically, the HYB platform was created to include several hybrid models to study the solar wind interaction with various Solar System objects, for example the Moon (HYB-Moon) [5]. Later a full 3D electromagnetic PIC code was included in the platform (HYB-em) [6]. More details about the hybrid model, PIC simulations and how they compare to the magnetohydrodynamic (MHD) approach can be found elsewhere (see, e.g. [7]; [8]). The new model in the HYB platform implemented for this paper is a full kinetic 1D electrostatic PIC code (HYB-es).

3. Summary

We have studied the role of finite gyroradius effects in the lunar dust-plasma environments at different length scales. The analysis was based on two kinetic models, where the hybrid model enabled the study of the ion kinetic effects while the full kinetic PIC model included also the kinetic effects of electrons. Although this is only a first step to estimate the role of the crustal magnetic field in the lunar dust-plasma environment, the study suggests that an accurate self-consistent model should include finite gyroradius effects.

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