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Electromagnetic Particle-in-Cell Simulations of the Solar Wind Interaction with Lunar Magnetic Anomalies: Interaction Mechanisms Under Varying Solar Wind Conditions.

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We present three-dimensional fully kinetic and electromagnetic simulations of the solar wind interaction with lunar crustal magnetic anomalies (LMAs). Using the implicit particle-in-cell code iPic3D, we confirm that LMAs may indeed be strong enough to stand off the solar wind from directly impacting the lunar surface forming a mini-magnetosphere, as suggested by spacecraft observations and theory. In contrast to earlier MHD and hybrid simulations, the fully kinetic nature of iPic3D allows to investigate the space charge effects and in particular the electron dynamics dominating the near-surface lunar plasma environment. We describe the general picture of the interaction of a dipole model centered just below the lunar surface under various solar wind and plasma conditions, and focus afterwards on the ion and electron kinetic behavior of the system. It is shown that the configuration is dominated by electron motion, because the LMA scale size is small with respect to the gyroradius of the solar wind ions. We identify a population of backstreaming ions, the deflection of magnetized electrons via the ExB-drift motion and the subsequent formation of a halo region of elevated density around the dipole source. Finally, it is shown that the presence and efficiency of the latter mechanisms are heavily impacted by the upstream plasma conditions and, on their turn, influence the overall structure and evolution of the LMA system. Our work opens new frontiers of research toward a deeper understanding of LMAs and is ideally suited to be compared with field or particle observations from spacecraft such as Kaguya (SELENE), Lunar Prospector or ARTEMIS. The ability to evaluate the implications for future lunar exploration as well as lunar science in general hinges on a better understanding of LMAs.
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