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Electromagnetic particle-in-cell simulations of the solar wind interaction with lunar magnetic anomalies

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We present the first 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 centred just below the lunar surface under various solar wind and plasma conditions and focus on the kinetic effects. 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. Driven by strong pressure anisotropies, the mini-magnetosphere is also unstable over time, leading to only temporal shielding of the surface underneath. 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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