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Simulating the Reiner Gamma Swirl and Magnetic Anomaly: The Impact of the Solar Wind Alpha Population

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The Reiner Gamma swirl is one of the most prominent albedo features on the lunar surface. Its modest spatial scales and structure allows fully kinetic modelling. The region therefore presents a prime location to investigate the lunar albedo patterns and their co-location with magnetic anomalies. The precise relationship between the impinging plasma and the swirl, and in particular, how these interactions vary over the course of a lunar day, remains an open issue.

Here we use the fully kinetic particle-in-cell code, iPIC3D, coupled with a magnetic field model based on Kaguya and Lunar Prospector observations, and simulate the interaction with the Reiner Gamma anomaly for all plasma regimes the region is exposed to along a typical orbit, including different solar wind incidence angles and the Moon's crossing through the terrestrial magnetosphere. We focus on the impact of the solar wind alpha population and construct energy and velocity distributions in key locations surrounding the interaction region of the anomaly.

The energy flux profile provides a better match to the albedo pattern only when integrating over the full lunar orbit. Including He²⁺ as a self-consistent plasma species improves the brightness ratios between the inner and outer bright lobes, the dark lanes, and the mare background. However, substantial differences between the observed albedo pattern and the predicted flux remain. For example, the bright outer lobes are substantially brighter than predicted and the central portion of the anomaly is darker than predicted. This is likely due to an incomplete model of the near-surface field structure.

Solar wind standoff can explain the large-scale correlation between the Reiner Gamma swirl and the co-located magnetic anomaly. In particular, the outer bright lobes emerge in the simulated weathering pattern only when integrating over the entire lunar orbit, although they are much weaker than observed. Both the proton and helium energy flux to the surface need to be taken into account to best reproduce the swirl pattern. A complete understanding of the solar wind interaction with lunar magnetic anomalies and swirl formation could be vastly improved by low altitude measurements of the magnetic field and solar wind.