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Simulating the Reiner Gamma Lunar Swirl: Solar Wind Standoff Works!

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Discovered by early astronomers during the Renaissance, the Reiner Gamma formation is a prominent lunar surface feature. Observations have shown that the tadpole-shaped albedo marking, or swirl, is co-located with one of the strongest crustal magnetic anomalies on the Moon. The region therefore presents an ideal test case to constrain the kinetic solar wind interaction with lunar magnetic anomalies and its possible consequences for lunar swirl formation. All known swirls have been associated with magnetic anomalies, but the opposite does not hold. The evolutionary scenario of the lunar albedo markings has been under debate since the Apollo era. By coupling fully kinetic simulations with a surface vector mapping model based on Kaguya and Lunar Prospector magnetic field measurements, we show that solar wind standoff is the dominant process to have formed the lunar swirls. It is an ion-electron kinetic interaction mechanism that locally prevents weathering by solar wind ions and the subsequent formation of nanophase iron. The correlation between the surface weathering process and the surface reflectance is optimal when evaluating the proton energy flux, rather than the proton density or number flux. This is an important result to characterise the primary process for surface darkening. In addition, the simulated proton reflection rate is for the first time directly compared with in-orbit flux measurements from the SARA:SWIM ion sensor onboard the Chandrayaan-1 spacecraft. The agreement is found excellent. Understanding the relation between the lunar surface albedo features and the co-located magnetic anomaly is essential for our interpretation of the Moon's geological history, space weathering, and to evaluate future lunar exploration opportunities.

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