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 [1], coupled with a magnetic field model based on orbital-altitude observations from Kaguya and Lunar Prospector observations [2,3], 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.

Consistent with the hypothesis that swirls form as a result of plasma interactions with near-surface magnetic fields, we show that the energy flux profile produces a pattern similar to Reiner Gamma’s alternating bright and darkly coloured bands, but only when integrating over the full lunar orbit. Including He$^+$ as a self-consistent plasma species improves the match [4,5].

Our simulations suggest that the albedo patterns may be used to inform models of the finely structured near-surface magnetic fields where swirls are present [6].

An improved understanding of the plasma environment at the Reiner Gamma swirl is particularly valuable, as this is likely to be a prime target for future low-orbiting spacecraft or even landers.

Maps of the magnetic (B) and electric field (E) at increasing altitudes above the lunar surface, centred on Reiner Gamma, for runs A-F. The middle column shows the difference between the magnetic field magnitude at steady-state and the initial magnetic field model $B_0$. $|B - B_0|$ reveals variations up to 10 nT, which are caused by the impinging solar wind plasma compressing and deforming the input magnetic field. The highest electric field magnitudes range up to 100 mV m$^{-1}$, with larger values found for decreasing incidence angles with respect to the surface normal.

Comparison of the relative brightness of Reiner Gamma with the simulated energy flux to the surface integrated over one lunar orbit.

(a) Inverse of the LRO-WAC empirically normalised reflectance image [7]. A smaller number indicates a brighter surface. The brightness values are normalised to the mare background averaged over the illustrated region. Equivalently, a larger value indicates more darkening assuming an initially bright surface prior to weathering. (b-d) Integrated, combined, normalised energy flux profile to the surface combining $p^+$ and He$^+$, $p^+$, and He$^+$, respectively.

Conclusions

- The major albedo features of the Reiner Gamma swirl - namely, its alternating bright lobes and dark lanes - can be explained in terms of the integrated energy flux at the lunar surface.
- He$^+$ might be a key factor required to obtain a one-to-one correlation between the observed albedo patterns and the plasma weathering pattern.
- Fully kinetic modelling can provide essential information to help guide the development of future lunar missions and exploration endeavours that depend on an improved understanding of the local and global plasma environment.