Introduction: While the Moon presently lacks a global, internally-generated magnetic field, the lunar crust contains many regions of localized magnetization known as magnetic anomalies, which are strongly correlated with lunar swirls [1,2]. Swirls are a type of lunar surface feature characterized by sinuous patterns of atypical reflectance that show spatial similarities with their associated magnetic anomalies. Among other theories, swirls are hypothesized to be the result of magnetic shielding from solar wind exposure [3,4]. To explore the formation and possible origin of swirls, NASA selected the Lunar Vertex (LVx) mission to investigate the famous swirl Reiner Gamma [5].

In preparation for the launch of LVx in April of 2024, solar wind interactions with the magnetic anomaly associated with Reiner Gamma have been modeled based upon orbital magnetic data and examined relative to ultraviolet (UV) datasets and space weathering byproduct abundance datasets. UV wavelengths are sensitive to submicroscopic iron (SMFe) byproducts of weathering, formed by sputtering and implantation of solar wind ions and micrometeorite impacts [6,7]. However, charged particles such as ions incident on a magnetic field are deflected by the Lorentz force, which is maximized at perpendicular angles, reducing weathering in these regions [8].

Similar to Earth’s magnetosphere, lunar magnetic anomalies are influenced by incident solar wind, and lunar “mini-magnetospheres” form when the magnetic intensity of the anomaly establishes a balance against the solar wind dynamic pressure [9,10,11,12,13]. Thus, studying both the field intensity and morphology of swirl-associated magnetic anomalies is crucial to determining the effects of solar wind weathering.

Methods: A three-dimensional model of the magnetic anomaly at Reiner Gamma was constructed from a derived surface field model [14] interpolated to average spacecraft orbital altitude. This model is coregistered to ultraviolet datasets [15,16] and SMFe abundance datasets [17], and mini-magnetospheres were modeled at several intensity thresholds to explore potential boundary layers at which solar wind deflection may relate to photometric anomaly morphology [18].

Spatial profiles were selected to capture a range of magnetic intensities and surface field morphology. Here UV, bulk SMFe abundances, microsize Fe abundances, and nanosize Fe abundances were sampled along these profiles and compared to the magnetic intensity and geometry along each profile to understand how mini-magnetosphere formation and compression may be expressed in solar wind weathering patterns.

Results: The bright lanes of the Reiner Gamma swirl possess UV signatures that indicate varying levels of reduced weathering, which correspond to similarly varying solar wind weathering byproduct abundances, and are correlated with mini-magnetosphere structures which may act as magnetic mirrors that deflect solar wind particles. Furthermore, the dark lanes inside the swirl do not appear to be “over matured” relative to the background which could be a result of maturity saturation due to local mineralogy [19,20].

Overall, this supports previous work showing that the degree of space weathering decreases as magnetic intensity increases, as more solar wind ions are deflected which limits the formation and abundance of nsFe particles coating lunar soil grains. However, within some regions there may be secondary processes such as dielectric breakdown and charged dust lofting occurring as a result of compression-induced currents and field line connection with the regolith, which may contribute to swirl patterns in currently unquantifiable ways.

Discussion: UV and SMFe abundance profiles suggest uneven amounts of solar wind exposure across Reiner Gamma, perhaps as a result of magnetic field interactions with solar wind. The profile that sampled the targeted LVx landing site predicts that the lander will observe compression from within the highest magnetic intensity region of the anomaly, and the rover will observe increasing degrees of solar wind exposure during its traverse.

Compression of mini-magnetospheres is dependent on the incident solar wind particle velocity and density and angle of incidence of solar wind. This may offer a potential explanation for swirls observed in UV that are not immediately apparent in visible and near-infrared wavelengths as described in [21], as time-varying exposure to solar wind may be creating reduced weathering patterns observable only at certain times and within more sensitive wavelengths. Further analysis is underway to examine this possibility.