REINER GAMMA SWIRL: BRIGHT ALBEDO FEATURES TREND LOWER THAN SURROUNDING TOPOGRAPHY

J. R. Weirich[1], D. L. Domingue[1], F.C. Chuang[1], A.A. Sickafoose[1], M.D. Richardson[1], E.E. Palmer[1], and R.W. Gaskell[1] [1]Planetary Science Institute, 1700 E. Fort Lowell, Suite 106, Tucson, AZ 85719-2395, USA.

Introduction: Lunar swirls are distinctive features on the Moon that have bright albedo patterns. Fig. 1 shows the classic example swirl of Reiner Gamma, the destination of the Lunar Vertex mission launching in 2024. The on-swirl regions have high albedo, while the surrounding off-swirl or dark lanes have low albedo. Lunar swirls are associated with crustal magnetic anomalies [1-2]; however, it has been thought that these albedo patterns tend to drape across the surface unaffected by local topographic changes.

[3] did not find topographic correlations with swirls using a global 100-m raster Digital Terrain Model (DTM) [4]. More recently, topographic investigations at Mare Ingenii swirl, using a DTM with more than 100x greater spatial resolution than [3], found a subtle correlation between swirls and height [5]. The on-swirl locations, when taken as a whole, were 2-3 m lower than the off-swirl locations, a difference that would not have been detectable in previous DTMs.

Elevation differences between on- and off-swirl raise the question of whether height plays a role in swirl formation. The Mare Ingenii elevation difference was an average, and height profiles across the DTM showed portions of the topography that did not follow the average. So, while height may not be a *controlling* factor in swirl formation, the evidence at Mare Ingenii swirl indicates height could be a *contributing* factor to swirl formation. To further the topographic investigation of lunar swirls, we have performed a similar analysis at the Reiner Gamma swirl.

Methods: The DTM of Reiner Gamma, like the one at Mare Ingenii, was generated using Lunar Reconnaissance Orbiter Camera (LROC) images with the Stereophotoclinometry (SPC) software suite [6-7], which can generate DTMs with a resolution equal to the image resolution. The 3D uncertainty of the SPC-generated DTM is the equivalent of one or two vertices (i.e., ground-sample distance) of the DTM [8]. SPC was used to generate DTMs that guided the OSIRIS-REx spacecraft to touch the surface of asteroid Bennu, proving the efficacy of SPC [9].

For this work, we generated a “low” resolution 7 by 7 km DTM at 2.6 m/vertex. Within the low-resolution region, we also generated a “high” resolution DTM subregion that is 0.6 by 2.3 km at 0.8 m/vertex. Following [5], regional slopes were subtracted from the DTM and large craters and other regional topographic features were masked to minimize reflectance changes

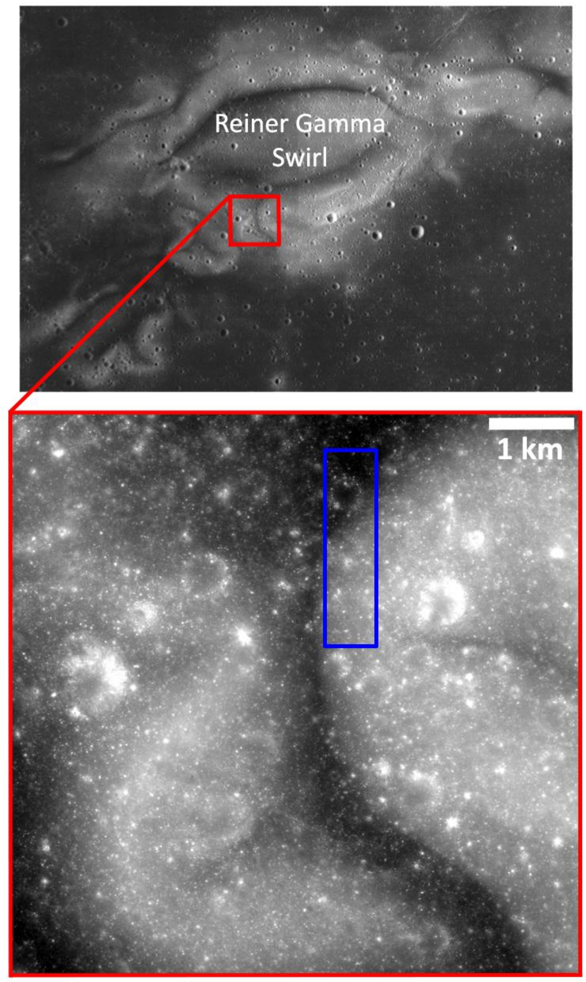

Figure 1. (Top) The Reiner Gamma Lunar swirl center: (7.4° N, 301° E). Red box indicates study region. Image from the LROC WAC mosaic. **(Bottom)** LROC NAC image showing study region. Blue rectangle indicates hi-resolution subregion.

due to extreme topographic changes. Improving upon [5], we mapped the swirl using machine learning tools rather than by human eye [10]. The on- and off-swirl regions of Reiner Gamma were mapped using both the supervised maximum likelihood classification (MLC) method and the unsupervised K-Means method, on images with three different incidence angles. Both methods indicated there is a third region intermediate to on- and off-swirl, which we term as “diffuse”. Further details of these methods can be found in [10].

We performed statistical analyses of the heights in on-swirl, off-swirl, and diffuse regions using three methods; cumulative distributions, mean heights with confidence intervals, and fitting histograms.

Results: An example of the MLC algorithm results are shown in Fig. 2. The K-Means method returned similar results to that of MLC. Note that there was up to an 18% difference in the number of points classified as either on-swirl, off-swirl, or diffuse between the two methods. Full maps and a discussion can be found in [10].

Preliminary statistical results from the low-resolution DTM indicate that, as a whole, the on-swirl regions are on average 1 or 1.5 m lower than diffuse, depending on the machine-learning method used, and are ~0.5 m higher than the off-swirl regions. For the high-resolution DTM, preliminary results indicate that on-swirl regions are approximately 4 m lower than the off-swirl region (Fig. 3). This 4 m elevation difference is ~5 times the vertex spacing of the DTM, indicating the height difference is greater than the height uncertainty. The mean height of the diffuse-swirl region is 0 or 1.7 m lower than the off-swirl region, depending on the machine-learning method used, and thus intermediate in height between on- and off-swirl.

Similar to the DTMs at Mare Ingenii, elevation profiles across the DTM do not always follow the average trend. Statistically, each region is at a different elevation, but there is variability within each region representing macroscale roughness. The profiles are more sensitive to the macroscale roughness. The regional correlations with topography indicate height may be a contributing factor to swirl formation.

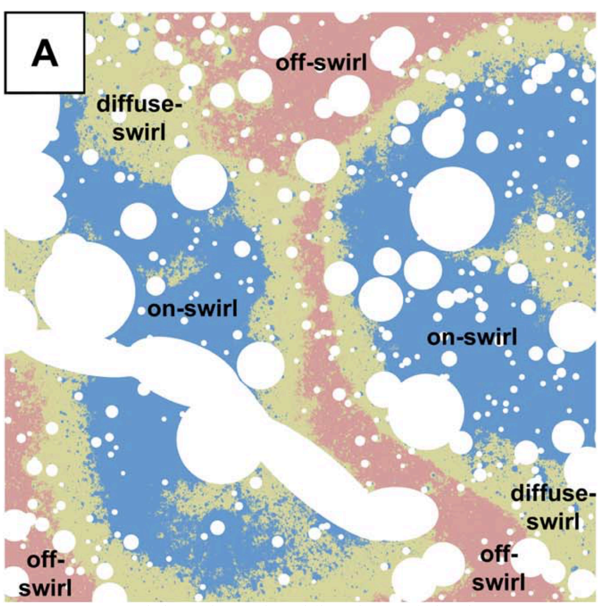

Figure 2. Swirl region classification of the low-resolution DTM using the MLC algorithm. White areas are craters or large regional topographic deviations that have been masked out. From [10].

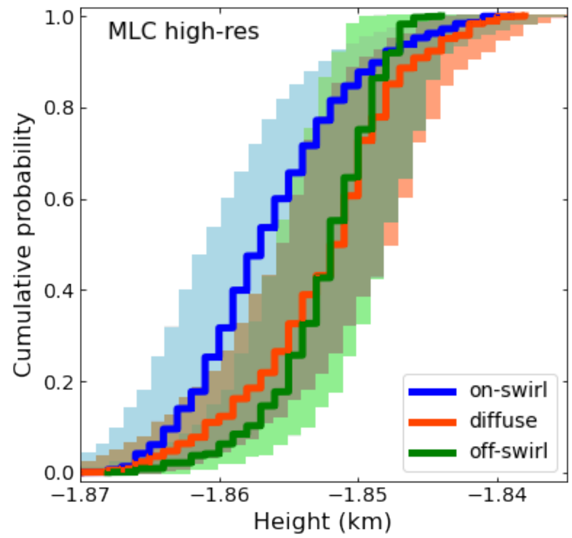

Figure 3. Cumulative distribution of high-res subregion. Shaded areas indicate height uncertainty.

Conclusion: DTMs of small sample areas in two swirls, Mare Ingenii and Reiner Gamma, indicate that on-swirl regions are on average a few meters (1-3 m) lower than the immediate surrounding material. Although height difference has not been thought to play a significant role in swirl formation, there are scenarios that could preferentially form bright swirls in lower "pockets" of topography. One such scenario is dust migration, where sub-micron to micron-sized dust collects in low topographic areas. This dust is the size fraction that affects spectral properties and could explain the bright and dark regions in the swirl. Further details of how dust migration can affect swirl formation can be found in [5,11].

References:

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