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Hectometre-Scale Roughness of the Moon

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Abstract

Hectometre-scale roughness of the Moon derived from LOLA ranging measurements is used to decipher the age sequence of Copernican craters and detect variability of regolith properties.

1. Rougness map

I use data from laser altimeter LOLA [1] onboard LRO to map statistical parameters of topographic roughness in a way similar to that successfully applied for Mars [2] and to the LOLA data in [3, 4]. Here I present a map of hm-scale roughness (Fig. 1). For this map calculated the second derivative ("curvature") of along-orbit topographic profiles for each triplets of consecutive laser altimeter shots, which gives curvature at 115 m baseline along the orbit. For each map cell, I selected all data points within the cell and calculated the curvature-frequency distribution. I use the interquartile width of this distribution as a measure of roughness. The interquartile curvature of the whole data set is 5.8×10^{-5} m^{-1}. Since absolute value of this roughness measure is not intuitive, I normalize all values listed below by this number, so roughness r = 1 is the typical roughness of the Moon. Except a few extremely rough young craters, r varies within 0.75 – 1.3 range. The roughness map gives essentially new information in comparison to topography and images: (1) it gives a synoptic view of small-scale properties; (2) it characterizes background roughness, while in images we mostly perceive individual features (e.g. craters); (3) it utilizes exceptional precision of LOLA ranging.

2. Inferences

2.1 Nature of roughness

Maps of kilometre-scale roughness [see 3, 4] generated in a similar way clearly show a distinctive dichotomy between smooth maria and rough highlands. Contrarily, as it was first noted in [3], there is no any systematic difference between hectometre-scale roughness (Fig. 1) of maria and highlands; e.g., Mare Crisium is rough (r = 1.1), and Mare Tranquillitatis is smooth (r = 0.8). Geological boundaries of maria usually are not associated with any prominent contrast in hm-scale roughness, with some exceptions. Lunar surface roughness at hm scale results from balance between surface smoothing by regolith gardening processes (micrometeoritic impacts) and roughening by impacts creating 10s m and larger craters.

2.2 Young impact craters

A few craters are distinctively rough. Among craters larger than D = 30 km, sixteen (16) are extremely rough with $r > 2.0$; three (3) of them are rougher than r = 3: Tycho (r = 3.3, D = 82 km), Jackson (r = 3.3, D = 71 km), and Crookes (r = 3.0, D = 49 km). Both walls and floors of these craters are rough. All 16 craters have bright albedo rays and are known to be of Copernican age [5]. Obviously, large impacts create rough topography of newly formed craters; with time, small- and micrometeoritic impacts produce new regolith and smooth the surface down. Of two craters with presumably known age [5], Copernicus is older (0.8 Ga) and smoother (r = 2.2) than Tycho (0.1 Ga, r = 3.3), which is consistent with smoothing with time. (In Fig. 1 both craters are saturated white, and the significant difference in their roughness is not seen). All craters larger than D = 30 km listed in [5] as Copenican or in [6] as rayed can be easily identified in the roughness map (Fig. 1) due to increased roughness either of the whole crater or of its walls only; in many cases, however, this increased roughess is below r = 2. A number of Eratosthenian craters also have a similar weak signature. Thus, more detailed studies of rougness signature of large craters can be used to refine their relative and absolute ages.

Three large rough craters: Tycho, Jackson, and Ohm (r = 2.3, D = 64 km), have prominent planetary-scale systems of roughness rays (Fig. 1). Roughness of the rays is not as high as roughens of the craters themselves, within 1.2 - 1.6. All roughness rays are simultaneously bright albedo rays, but far not all albedo rays of these and other craters have any roughness signature. In addition to these three ray systems, possible roughness rays might be associated with Crookes, Aristarchus (r = 2.4, D = 41 km), and King (r = 2.3, D = 77 km). More detailed analysis is needed to understand, whether all large enough impacts produce roughness rays that fade away with time, or some other conditions (like proper impact velocity) play a role in roughness ray formation. In addition to the mentioned ray systems, there are a few similar moderately rough lineaments not obviously associated with any crater.

2.3 Regolith variability

The "background" roughness away from the youngest craters and rays results from equilibrium between impact-induced roughening and impact-induced smoothing (regolith gardening). Since the balance between smaller and larger projectiles is regionally uniform, the observed variations of the "background" roughness should be attributed to variations of material properties. In several cases roughness contrasts indeed are associated with geological boundaries, e.g., Aristarchus Plateau is anomalously smooth (r = 0.75), which can be related to the known presence of pyroclastic material and smaller regolith grain size in this unit. More enigmatic are, e.g., smoothness (r = 0.8) of SPA basin and roughness of central farside highlands (r = 1.3, rays excluded). These variations indicate that mechanical properties of highland regolith and megaregolith vary widely at the regional scale. There is no any global well-defined correlation between roughness and elevation or composition; in some regions (like in SPA – central farside) lower and more mafic terrains tend to be smoother. Detailed comparison of hm-scale roughness with other data sets promises advance in understanding regolith gardening processes.

References

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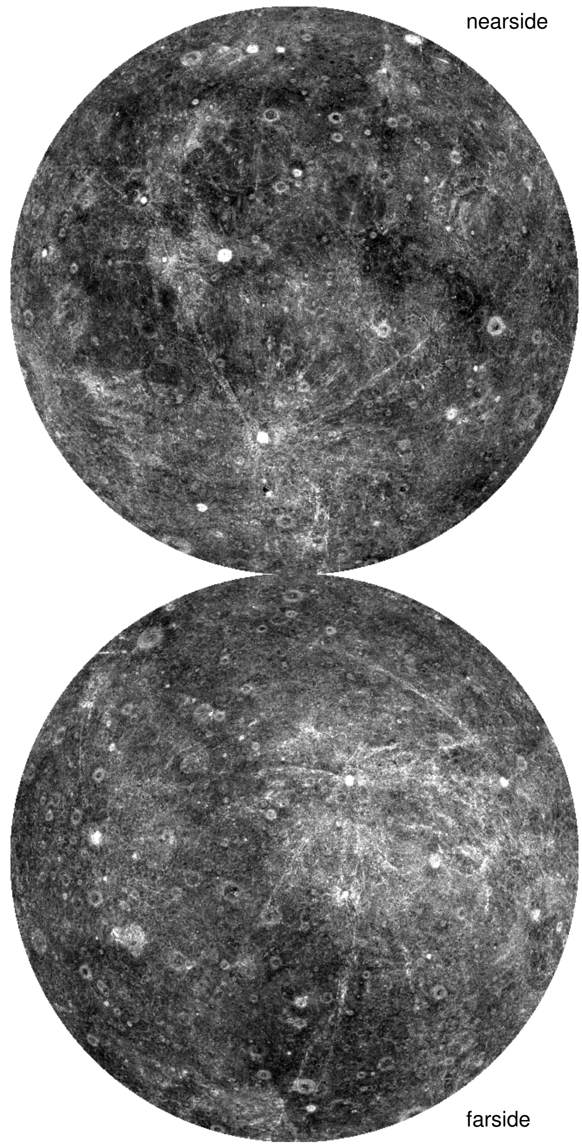

Figure 1: Hectometre-scale roughness of the Moon. Lambert azimuthal equal-area projection. Brighter shades denote rougher surface.