LARGE-SCALE TOPOGRAPHIC ROUGHNESS OF TERRESTRIAL PLANETS: A COMPARISON.

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Introduction: Global statistical characterization of planetary topography can provide important additional information about geological, geophysical and physical processes shaping planetary surfaces. At the largest scales, the statistical characteristics of topography (usually in the form of power of spherical harmonics) are widely used for basic global geophysical inferences, especially when combined with gravity data at the same scales. On the other hand, small-scale topographic roughness and its scale dependence aids geomorphologic analysis and may give insight into surface processes. Here we focus on intermediate scales of tens to a hundred kilometers. This is the only scale range at which topographic data are presently available for all terrestrial planetary bodies (the Earth, the Moon, Mars, Venus, and Mercury). Presently, Mercury lacks global topographic data, while massive high-resolution data sets suitable for statistical analysis of km and sub-km-scale topography are available for the Earth and Mars only.

Data sets: The nature of available data strongly limit the possible statistical characteristics that can be used for interplanetary comparison. Global statistical inferences demand large homogeneous data sets of comparable characteristics.

The most limiting topographic data are for Mercury. The only data set large enough and homogeneous enough is a collection of 34 Earth-based radar profiles [1]. Profiles have orientations close to east-west in the equatorial region of the planet. Points along profiles have a typical spacing of about 6 km, each point being an average of several radar bursts. The cross-track radar footprint is as wide as ~100 km, but the actual variability of the measured topography, its good correspondence to the observed features [1], and the high correlation of formal scattering of measurements within each point and topographic slopes indicate that the effective footprint is actually smaller, and the data are good for the statistical study of tens of km-scale topography.

For the Moon we used Lunar Prospector Laser LIDAR profiles [2]. Spacing between elevation measurements along profiles is about 2 km, but many points are missing. For Mars, Venus and the Earth available topographic coverage is much better. We used global gridded topographic data (from MGS-MOLA, Magellan Radar Altimeter and SRTM mission, respectively) and extracted a number of randomly selected latitudinal and longitudinal profiles to mimic the nature of the data sets for the Moon and Mercury.

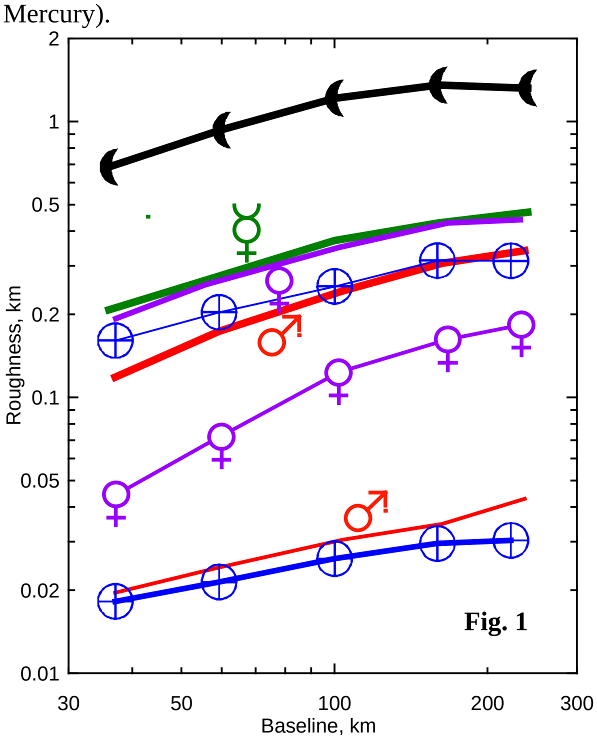
Roughness characterization: The choice of statistics that characterize roughness is not trivial. It should objectively reflect the characteristic vertical scale of topography for a given horizontal scale and should be tolerant to the differences in the nature of the data sets. After several approaches, we chose the following quantity. We consider three points A, B, C along the profiles separated by the half-baseline distance. We obtain three elevations h_A, h_B, h_C by averaging all available elevation measurement data on the profile within half-baseline-long segments around each point. Then we calculate topographic variation at the given baseline as $h_B - (h_A + h_C) / 2$, collect a distribution of this quantity over all the data set and use the interquartile width of this distribution as a measure of roughness at a given scale. Here we deal with baselines from 35 to 250 km.

For different terrains roughness can differ by orders of magnitude. Because of this, a single roughness value for a planet is not an objective characteristic: it strongly depends on the particular method of averaging used to derive it. We need to choose regionally large (because of very large scales used) areas that would be relatively homogeneous geologically. For planets with good topographic coverage, there is a good criterion for the right choice of such regions: for different randomly selected small profile sets from the same region the calculated roughness values should not differ significantly. For example, the whole lunar data set does not possess this property, while its subset for the far side does.

Preliminary results: We chose several regions on these planetary bodies to assess the variability of large-scale roughness. Scale dependences of roughness for these regions are shown in **Fig. 1**; roughness at 80 km baseline plotted against gravity is shown in **Fig. 2** for the roughest terrains. For Mercury we used the whole data set (green curve with Mercury symbol in Fig. 1). For the Moon we used the whole far side (black curve; the roughest in the sample set). For the Earth we arbitrary chose the western one third of the US as an example of a mountainous region (upper blue curve with the Earth signs), and the Russian Plain as an example of plain region (lower blue curve).

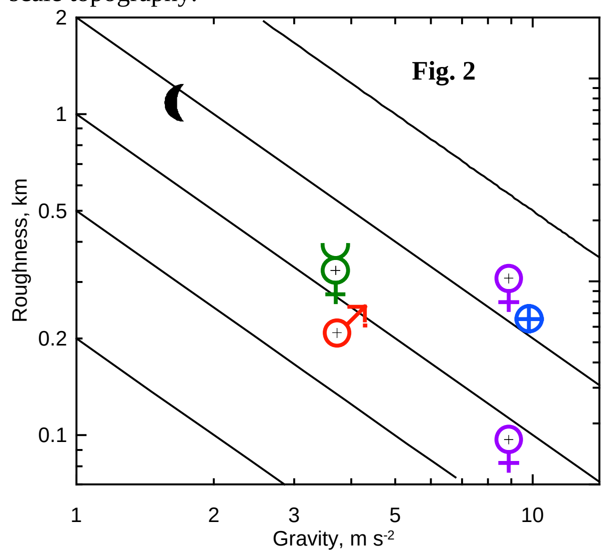
For Mars, we chose three regions in the highlands: Noachis Terra, Arabia Terra, and Terra Cimmeria; the curves for this three regions were remarkably similar, and the average curve (upper red) is shown in Fig. 1. The similarity of highland regions is a little surprising: Arabia Terra is globally smoother at subkilometer scale, has much fewer very steep slopes, is located in the area of much thinner crust and at much lower elevations, and has many unique geological features. However, with respect to the large-scale roughness, it is very similar to other highlands. We suggest that for martian highlands large impact craters are the dominant features responsible for the topographic signature at these large scales, and this explains the observed similarity.

We used Utopia Planitia as a representative of martian lowlands (lower red curve with Mars symbols). It is seen that the flatness of this terrain at these scales corresponds to the terrestrial idea of "plains". The smoothest large regions on Venus (e.g., Sedna Planitia) would reside close to martian and terrestrial plains in Fig. 1 (not shown), while typical venusian plains (Rusalka Planitia, violet curve with Venus symbols) are much rougher due to the presence of coronae, ridge belts, various minor volcanic features, etc. Finally, Ovda Regio represents Venusian highlands, mostly tesserae (upper violet curve, almost coincides with Mercury).



The scale dependence of roughness is characterized by the Hurst exponent *H*. It is related to the power law exponent θ for the dependences in Fig. 1 as $H = (2\theta + 1) / 5$ and changes in a range from 0.2 to 0.6 for our sample.

Cratered terrains: It is interesting to compare heavily cratered terrains, because they are significant on three different bodies: the Moon, Mercury and Mars. All three curves have a very similar shape with *H* =0.4 - 0.5 for shorter baselines and 0.2 - 0.3 for longer baselines. This transition indicates the existence of a characteristic horizontal scale ~100 km of large-scale topography.



Cratered terrains of Mars and Mercury are significantly smoother than the Moon, which is a natural consequence of higher gravity *g*. The simple Bingham-fluid scenario of complex crater formation [e.g., 3] with universal yield stress predicts g^{-1} scaling of topographic amplitude. Scaling considerations in [4] implicitly lead to a gentler dependence $g^{-0.7}$. From Fig. 2 it is clearly seen that the difference between the lunar far side and Mercury and especially Mars is steeper (thin solid lines correspond to g^{-1} scaling). This should be explained by additional smoothing factors of Mercury and Mars, for example, more extensive volcanic resurfacing. The difference between Mars and Mercury can be explained by effective removal of rims and infill of craters by erosion on Mars. Alternatively, one can speculate that effective cohesion is lower on Mars due to higher volatile content in accord with the explanations of the observed smaller simple/complex crater transition diameter [5].

Mountains of tectonic origin on the Earth and Venus are above g^{-1} scaling of cratered terrains on the Moon, Mars and Mercury. Large-scale impacts are obviously unable to produce as high a topographic amplitude as tectonics, because of the effective acoustic fluidization of the material just after the impact [3].

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