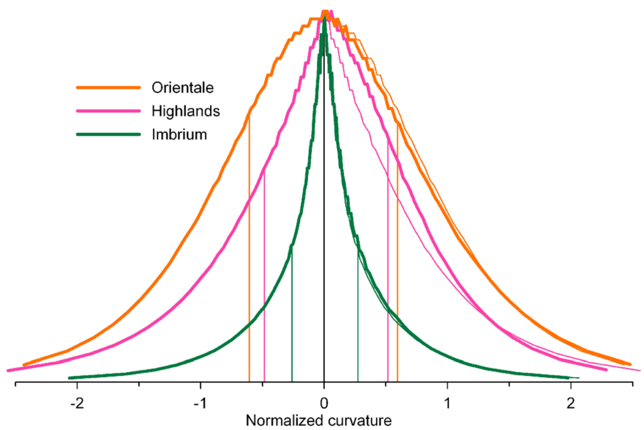

Figure 2. Bold curves, curvature-frequency distributions calculated over large areas: "Orientale," the Hevelius Formation areas marked with arrows in Figure 4a, $\sim 2.8 \times 10^7$ data points; "Highlands," a large area of typical highlands, young large craters excluded, $\sim 10^8$ data points; "Imbrium," the Fra Mauro Formation area marked with arrows in Figure 4b, $\sim 0.7 \times 10^7$ data points. Curvature (equation (1)) is calculated at l = 1.8 km baseline and is normalized by its interquartile range for highlands. Frequencies are normalized by their maximum values. Thin curves show left, negative (convex) branches of the distribution flipped to the right for comparison with the positive (concave) branches. Thin vertical lines show $c_{1/4}$ and $c_{3/4}$ quartiles.

the images. Another example of a good measure of roughness is the median differential slope proposed for Mars by *Kreslavsky and Head* [2000] and applied to LOLA data by *Rosenburg et al.* [2011]. Maps of this measure of roughness at the same baselines, if properly contrasted, are almost indistinguishable from the maps we used in the present work.

[9] Positive values of profile curvature c correspond to concave segments of topographic profiles, while negative values correspond to convex segments. An ideal imaginary surface made of smooth bowl-shaped craters with sharp rims, would be almost entirely concave, except a very small area of rim crests. For typical highlands shaped by numerous impacts and downslope movement of regolith, concave segments are more frequent than convex segments. Figure 2 (middle, bold violet curve) shows the frequency distribution of curvature c/r_0 at l = 1.8 km baseline calculated over a large area of typical highlands ($\sim 10^8$ data points). To illustrate the asymmetry of this distribution its left, negative (convex) branch is duplicated with a thin line flipped to the right. It is seen that the bold line is above the thin line (except for rare high curvature values), which means that the number of concave segments exceeds the number of convex segments; concave segments prevail. The same typically occurs for the curvature-frequency distributions inside the map cells, with the distinction that the total number of data points is much smaller and the distributions are much noisier.

[10] Concavity is a quantitative measure of prevalence of concave topographic forms over convex ones. The rationale for our choice of particular statistical measure of concavity is similar to that of roughness. For example, skewness of the curvature-frequency distribution, like any other measure based on the distribution moments, is not a good measure of concavity because it is badly affected by the heavy tails of the distribution. The median curvature $c_{1/2}$ does characterize the misbalance between segments of profiles with the positive and negative values of c and is little affected by the tails. However, if we imaginarily stretched all topography vertically, all values of c would proportionally increase, and $c_{1/2}$ would also proportionally increase. To obtain a statistics that characterizes the proportion of concave segments regardless of the vertical scale, we normalized the median curvature $c_{1/2}$ by the characteristic scale of the curvature variations. Thus, we used the median curvature normalized by its interquartile range as a measure of concavity v:

$$v = c_{1/2} / \left(c_{3/4} - c_{1/4} \right). \quad (3)$$

Positive concavity values indicate the prevalence of concave segments of topographic profiles; negative concavity indicates the prevalence of convex topographic forms. For the "Highlands" distribution in Figure 2, equation (3) gives v = 0.033. We calculated concavity v for each map cell and obtained a concavity map. (The median value of concavity in cells that belong to the typical highlands is about 0.100, significantly higher than the concavity calculated for the whole distribution over the same area, 0.033; this occurs due to the nonlinear nature of the concavity measure we use.) Because concavity has a high level of inherent noise, we applied additional cosmetic filtering to this map to reduce the noise in exchange for resolution; Figure 1c shows the result.

[11] When we look at the surface images or simulated illuminated topography, our eyes catch the most prominent features; slope breaks associated with these features usually occupy only small proportions of the map cells and hence, due to our choice of statistics, they have a small influence on the roughness and concavity. Our measures r and v characterize the most typical, dominant topography. In a sense, the roughness and concavity maps make visible some variations of topographic properties that are not readily apparent in the images.

[12] Roughness at both baselines and concavity at the longer baseline are shown in Figure 3 as an RGB color composite: roughness at longer (Figure 1a) and shorter (Figure 1b) baselines is coded in the red and green channels, respectively; brighter shades denote rougher surfaces; concavity (Figure 1c) is coded in the blue channel; brighter shades denote higher concavity. The most obvious feature on this composite map is the dichotomy between the smooth (dark) maria and the rough (brighter) highlands. In the RGB color composite, typical highlands have bluish and pinkish shades, which denotes the prevalence of concave topography (high intensity in the blue channel). A few of the largest Copernican (the youngest) craters and proximal ejecta of some of them are light green in the map (Figure 3): they are extremely rough, especially at the shorter baseline, and have reduced (in comparison to typical highlands) concavity. Several of the largest Eratosthenian and Upper Imbrian craters have distinctive orange or yellowish surroundings, which indicates excessive roughness of their proximal ejecta at the longer baseline and reduced concavity.

3. The Roughness and Concavity Signature of Impact Basins

[13] After the mare - highlands dichotomy, the next most striking feature is the 930 km diameter Orientale multiring