

DEEP VS. SHALLOW ORIGIN OF GRAVITY ANOMALIES AND TOPOGRAPHY ON THE MOON. B. Steinberger^{1,2,3}, S. C. Werner² and T. Kohout⁴, ¹GFZ-Potsdam, Germany (bstein@gfz-potsdam.de), ²PGP-University of Oslo, Norway (Stephanie.Werner@fys.uio.no), ³NGU, Trondheim, Norway, ⁴Division of Geophysics, University of Helsinki, Finland (tomas.kohout@helsinki.fi).

Introduction: Recent release of the new Kaguya (SELENE) lunar gravity [1] and topography [2] data motivates us to analyze lunar gravity and topography spectra, in order to investigate which part of the spectra may possibly be due to density variations in the deep interior of the moon, and what they can tell us about the moon's internal density structure. The new gravity data provide improved information for the lunar far-side, overcoming the earlier lack of tracking data due to the Moon's synchronous rotation.

Method: We follow here a strategy that we have previously in a similar fashion successfully applied to the Earth, Venus and Mars [3],[4]: we assume that both in the mantle and in the lithosphere density anomalies can be modelled as random, with a white noise spectral distribution. We then use a combination of elastic lithosphere and viscous mantle beneath with approximately constant viscosity to compute the "expected" geoid (or more appropriately "selenoid", but we will use here the term "geoid" also for the moon) and topography spectra, as well as their expected ratios and correlations for (i) density anomalies within the lithosphere (ii) density anomalies within the mantle, and (iii) a combination of both.

Results: Our model explains the gravity spectrum for degrees 2-5 as mainly caused by mantle density anomalies (dashed line higher than dotted line in the top panel of Fig. 1), with the combination matching observations well. We note that the gravity spectrum also includes the large degree two - order zero term (flattening), which is, to its largest part non-equilibrium, as the moon is rotating very slowly. This deviation previously has been suggested to represent a fossil shape frozen into the lithosphere early in its orbital evolution [e.g. 5, 6]. Hence it appears that the excess flattening is merely a consequence of mantle density anomalies, and the fact that any planetary body always orients itself relative to its spin axis such that geoid highs are close to its equator. (The minimum energy configuration for a synchronously rotating satellite [e.g. 7]). However, the geoid-topography ratio is under-predicted for degrees 2-5, thus indicating that long-wavelength ($l=2-5$) topography has a large component that is compensated at shallow depth, thus yielding a small geoid signal that is highly correlated with the topography itself. Such an additional topogra-

phy component would also explain that the observed correlation at low degrees is substantially higher than predicted from the mantle density model, while observation and model of the correlation show the same spectral shape. Low correlations around degrees 10-11 are usually related to the presence of 'mascon' impact basins [e.g. 8]. Our model under-predicts gravity power in the mid-degree range 6-13, likely due to crustal thickness variations, which can hence be modelled from gravity and topography data [e.g. 8].

Above degree 30, gravity can be explained as caused by essentially uncompensated topography loaded on an elastic lithosphere: Under this assumption, residual gravity (green in Fig. 1, top) is substantially smaller, than both actual (purple line) and modelled (brown) gravity, which are very similar to each other. Also, the observed geoid-topography ratio follows the model very closely above degree 30 and geoid-topography correlation is high, as expected. We find large lateral variations in both geoid-topography correlation and ratio (Fig.2; Fig. 1, red and blue curves). In particular, the near side shows much higher geoid/topography ratios and much lower correlations, likely related to the positive gravity anomaly over low elevation of the 'mascon' impact basins found only at the near-side.

Discussion: The difference is largest in the degree range from about 9 to 30. The smaller differences for lower degrees could again be an indication that gravity sources in the mantle become dominant, and the mantle shows less of a distinction between near and far side, which is largely a "shallow" feature. Our model can be used to infer tentative depth-averaged density anomalies of the lunar mantle. Like for the Earth and Mars, it appears to be dominated by a strong degree-two signal.

References: [1] Namiki, N. (2009) *Science* 323, 900-905. [2] Araki, H. (2009) *Science* 323, 897-900. [3] Steinberger B. and Holme (2002) *GRL* 29(21), 2019. [4] Steinberger B. et al., *Icarus* in revision. [5] Jeffreys (1976) *The Earth: Its Origin History and Physical Constitution* 6th ed. Cambridge University Press. [6] Lambeck K. and Pullan S. (1980) *PEPI* 22, 29-35. [7] Lambeck K. (1988) *Geophysical Geodesy*. Oxford University Press. [8] Wiczeorek M. A. (2007) In: *Treatise on Geophysics* 10, 165-206.

Figure 1: Geoid spectrum (top), geoid-topography ratio (middle) and correlation (bottom). Purple line with black dots: observed. Dashed black line: Expected curves from random mantle density anomalies. Dotted: Expected from random lithosphere density anomalies. Continuous: Expected from a combination of both. Thin continuous lines in the top panel indicate the expected standard deviation. The brown line in the top panel shows the modelled gravity due to observed topography loading an elastic lithosphere, the green line is residual gravity (observed minus modelled). Density contrast of the topography is 2837 kg/m^3 and transition from partial compensation at long wavelength to no compensation at short wavelength occurs around degree 13, corresponding to an elastic lithosphere thickness of about 34 km. The blue and red lines in the bottom two panels show the observations restricted to the near side (red) and far side (blue) of the moon. However, for each spherical harmonic degree 1, we consider a spectral window from 1-5 to 1+5. The dashed purple line is the corresponding curve for the whole moon.

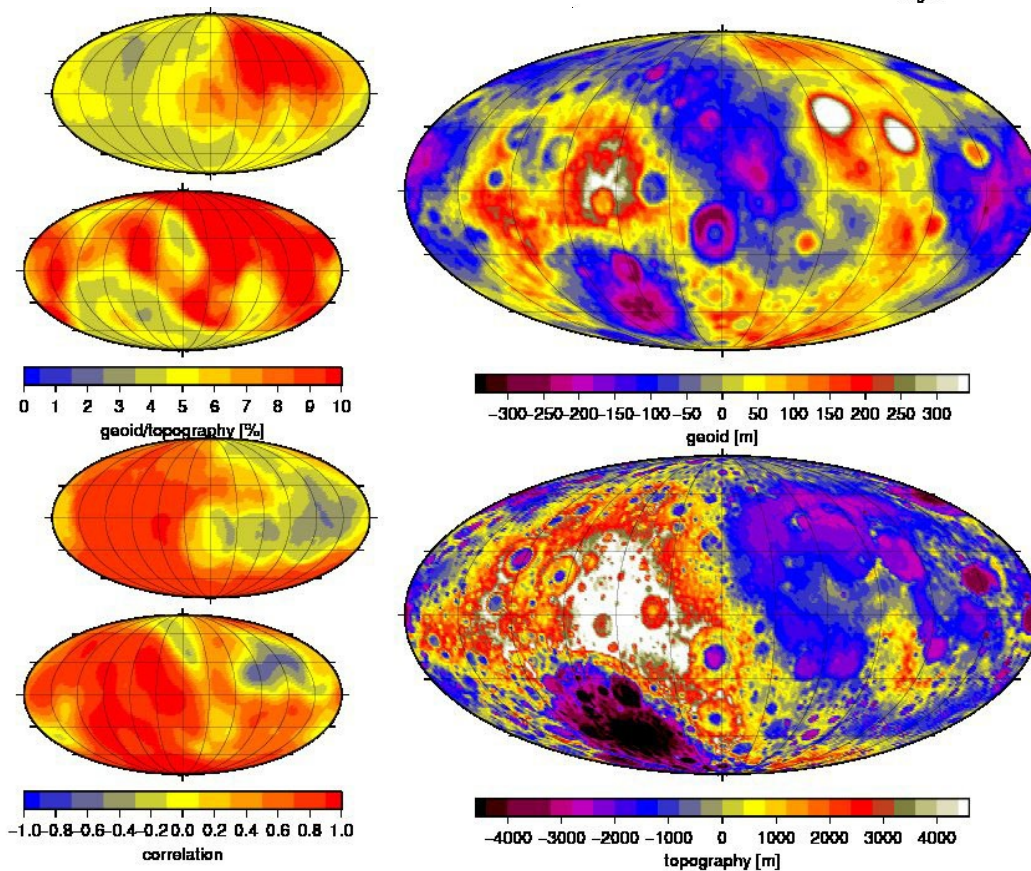
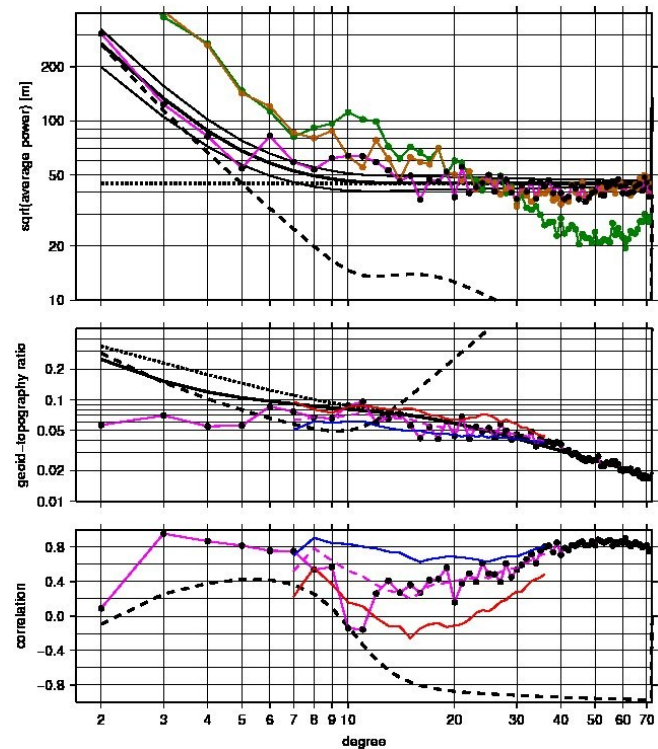


Figure 2: Geoid (top right; flattening excluded) and topography (bottom right) of the moon, and their correlations and ratios, averaged over 30-degree caps.

For each, the top panel is for the degree range 13-31, the bottom panel for 2-12. Near side of the moon on right, far side on left.