ANISOTROPY OF LUNAR GRAVITY AND TOPOGRAPHY. Regan L. Patton, School of the Environment, Washington State University, Pullman, WA 99164-2812, rpatton@wsu.edu

Introduction: Long-wavelength patterns dominate the directional dependencies of lunar gravity (N) and topography models (H). Directional covariance ratios $R_l(N)$, $R_l(H)$, and $R_l(N,H)$, where l is spherical harmonic degree, are sensitive to the position of the coordinate pole [1]. Computing these ratios at 40962 equally-spaced points on the lunar surface produces geographically-referenced spectral estimates, which can be visualized as degree-wise anisotropy maps (Fig. 1). Ratios close to unity indicate isotropy, while those greater or less than unity indicate zonal or sectoral anisotropy, respectively.

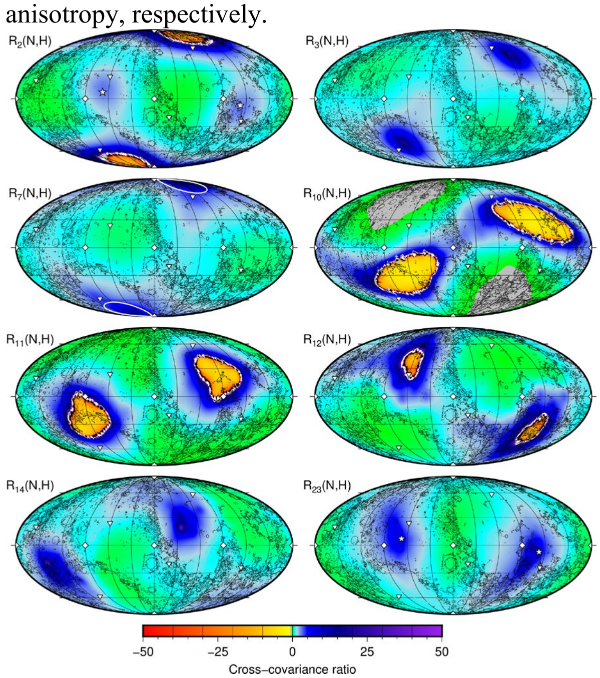

Figure 1: Anisotropy maps for N=JGGRX1500E [2] and H=LOLA2600P [3]. Mollweide projections (central meridian 270°E, nearside-right, farside-left).

Spectral and Spatial Patterns: Topographic anisotropy is found at l = 2, 3-5, 7, 12 and 14. Gravity anisotropy occurs at l = 2, 3, 7, 11, and 21. Degree 2 anisotropy maps depict triaxial ellipsoids aligned with the principal topographic and inertia axes. Gravity-topography anisotropy is found at l = 3, 7, 14, 20, 23, and 29. The appearance of degrees 3 and 7 in all three metrics indicates significant lateral structure with wavelengths of ~3100 km and ~1500 km, respectively.

Spatially the degree 3 zonal maxima coincide with the South Pole-Aitken (SPA) basin, while the degree 7 maxima, at high latitudes, have no obvious physiographic expression. Maxima at degrees 14 and 23 lie in Oceanus Procellarum and the nearside southern/farside northern highlands, respectively.

Anisotropy at short wavelengths is broadband and extremal about the major **a** and minor **c** axes of the topographic ellipsoid (Fig. 2). Axis **a** is subparallel to the offset between the Moon's center-of-figure and center-of-mass, and intersects the highland regions noted above.

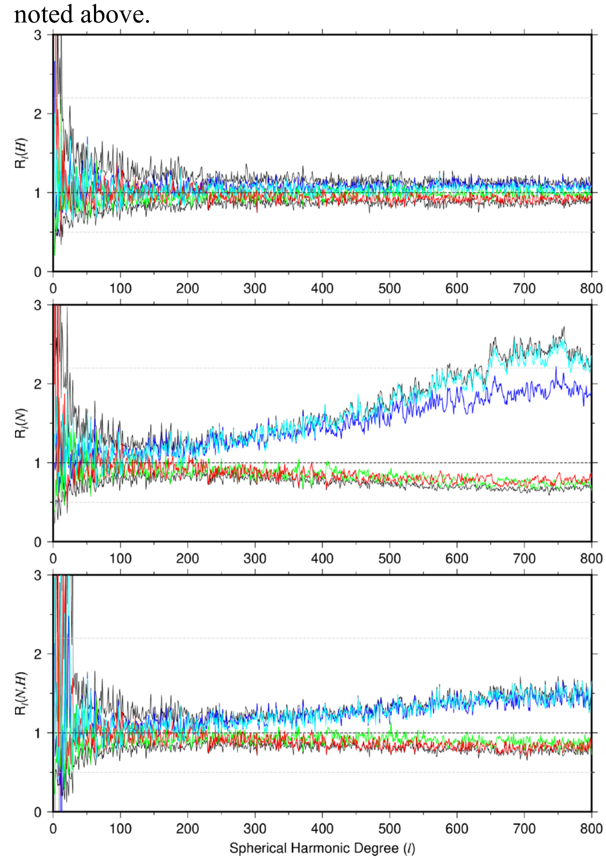

Figure 2: Anisotropy spectra for N=JGGRX1500E and H=LOLA2600P. Topographic ellipsoid axes **a**,**b**,**c** in blue, green, and red. CM-CF axis in cyan.

Probability Distributions: Distributions of $R_l(N)$ and $R_l(H)$ are log-normal at all investigated degrees, consistent with random stochastic processes. The distribution of $R_l(N,H)$ is also log-normal, except at l = 2, 10, 11, and 12, where it is Cauchy-like. Thus, as expected, lunar gravity and topography models are well-correlated stochastic processes, except at wavelengths of ~4400 km and ~870-1040 km. Older models exhibit Cauchy-like distributions at even higher degrees (Fig. 3). Global sampling has reduced these errors to just those noted above. What is the source of these errors?

Modal cross-coupling and orbital mismodeling are likely culprits.

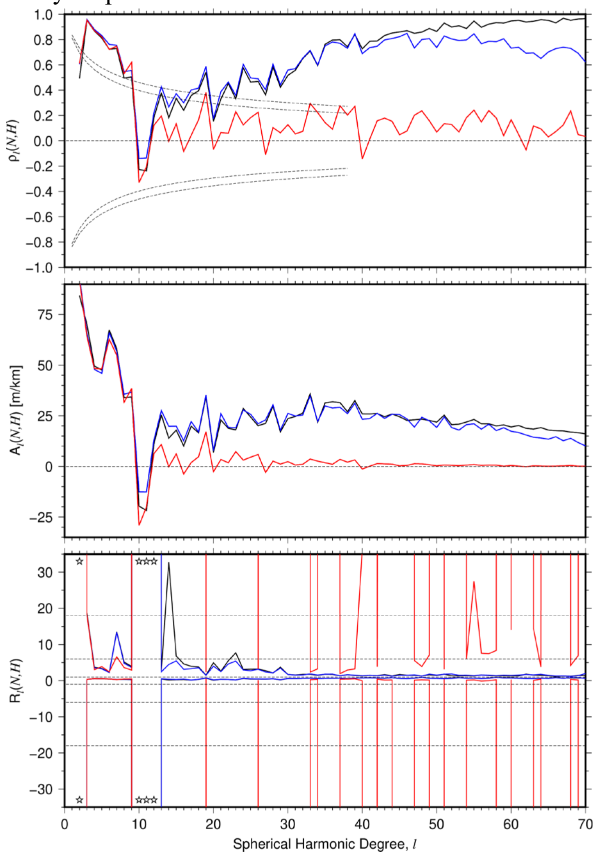

Figure 3: Cross-spectra for models from the Clementine [4] (red), SELENE [5] (blue), and GRAIL[2]-LOLA[3] (black) missions.

Tidal Deformation: Asymptotic extremes at l = 10-12 coincide with zonal maxima at l = 3, 14 and 23 (Fig. 4). Lateral density variations in the SPA basin, Oceanus Procellarum, and lunar highlands are potential sources of tidal torques, and contribute to the misalignment of the principal inertia and topographic axes (Fig. 1). Unexplained degree 3 misfits have long been noted in lunar laser ranging studies [6,7].

Asymptotic extremes at l = 2 coincide with zonal maxima at l = 7. The presence of a fluid core boundary in the depth range 1360-1540 km [6] might result in a degree 7-8 body tide. Coincidentally, radial orbit errors estimated from the LP75G covariance matrix peak in this range [8]. Similarly, mechanical decoupling in the mid-mantle might result in tidal deformation in the l = 10-12 waveband. Deep moonquakes occur at depths ranging from about 800 to 1100 km, with dominantly tidal periods [9]. Localization physics should be included in tidal models. Ultimate resolution of these errors, however, will probably require including altimeters aboard a future GRAIL-like mission.

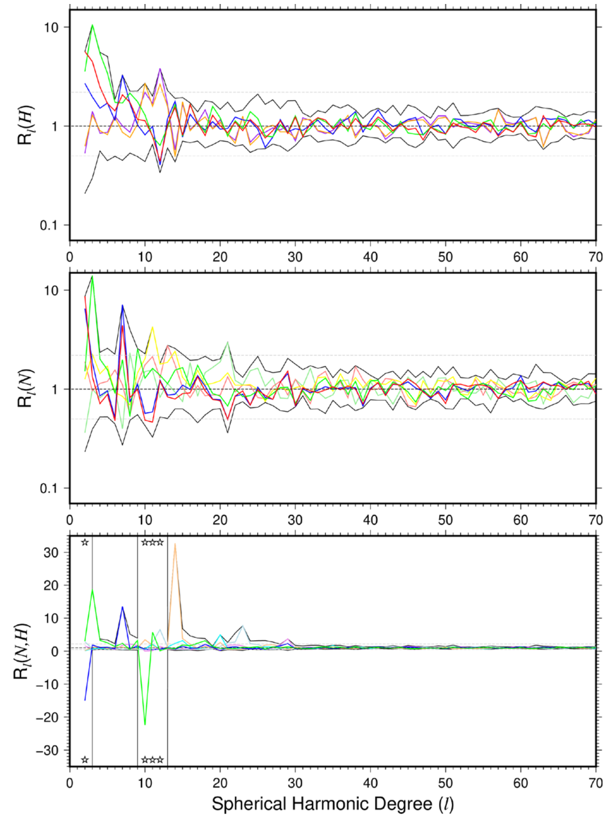

Figure 4: Comparison of anisotropy maxima for N=JGGRX1500E and H=LOLA2600P. Modal cross-coupling occurs between degrees 2-7, 3-10, 10-14, and 12-23.

Acknowledgments: SHTOOLS [10] and GMT [11] were used extensively in this work. Spherical harmonic models for gravity and topography were obtained from the NASA-PDS Geosciences node.

References: [1] Bills, B.G. and Lemoine, F.G. (1995) *JGRE, 100,* 26275–26295. [2] Konopliv, A. et al (2014) *GRL, 41,* 1452–1458. [3] Wieczorek, M.A. (2015) *TOG, 10.05, 153*–193. [4] Zuber, M.T. et al (1994) *Science, 266,* 1839–1843. [5] Namiki, N. et al (2009) *Science, 323,* 900–905. [6] Williams, J.G. et al (2014) *JGRE, 119, 1546*–1578. [7] Viswanathan, V. et al (2019) *AGU Fall Mtg. Abstracts,* G31B-0649. [8] Floberghagen, R. (2002) *Lunar Gravimetry: Revealing the Far-Side, Kluwer, Dordrecht, 286pp.* [9] Lammlein, D.R. et al (1974) *Rev. Geophys. Space Phys.,* 12, 1-21. [10] Wieczorek, M.A. and Meschede, M. (2018) *Geochem. Geophys. Geosys.,* 19, 2574-2592. [11] Wessel, P. et al. (2019) *Geochem. Geophys. Geosys., 20, 5556-5564.*