Družicové metody v geodézii a katastru
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Crustal density and global gravitational field estimation on the Moon from GRAIL and LOLA satellite data

Šprlák M.[(1)], *Han S.-C.*[(2)], *Featherstone W.E.*[(3)], *Novák P.*[(1)], *Pitoňák M.*[(1)]

(1) – NTIS – *New Technologies for the Information Society, Faculty of Applied Sciences, University of West Bohemia, Plzeň, Czech Republic*

(2) – *School of Engineering, Faculty of Engineering and Built Environment, University of Newcastle, Callaghan, NSW, Australia*

(3) – *School of Earth and Planetary Sciences, Curtin University of Technology, Perth, WA, Australia*

1. Motivation:

- GRAIL (Gravity Recovery and Interior Laboratory),
- Mapping the gravitational field of the Moon in 2012,
- Altitude: ~10-90 km above the lunar surface,
- Maximum spherical harmonic degree/order (d/o): 1500,
- Spatial resolution of the gravitational field: ~3.6 km.

- ARC Discovery Project (2017 – 2019): "*Lunar crustal structure from high-res gravity, topography, and seismic data*",
- Two geodetic/geophysical tasks important for many applications in geodesy, geophysics, and planetary sciences solved:

  A) Determination of crustal density (inverse problem),

  B) Calculation of global gravitational fields inferred by crustal masses (forward problem).
- Priority: application of independent mathematical methods.

2. Determination of crustal density:

$$\bar{C}_{n,m} = \frac{1}{R^n M(2n+1)} \int_{\Omega} \int_{r} \varrho(r,\Omega)\, \bar{Y}_{n,m}(\Omega)\, r^{n+2}\, \mathrm{d}r\, \mathrm{d}\Omega$$

GRAIL-derived GGFM

LOLA topography

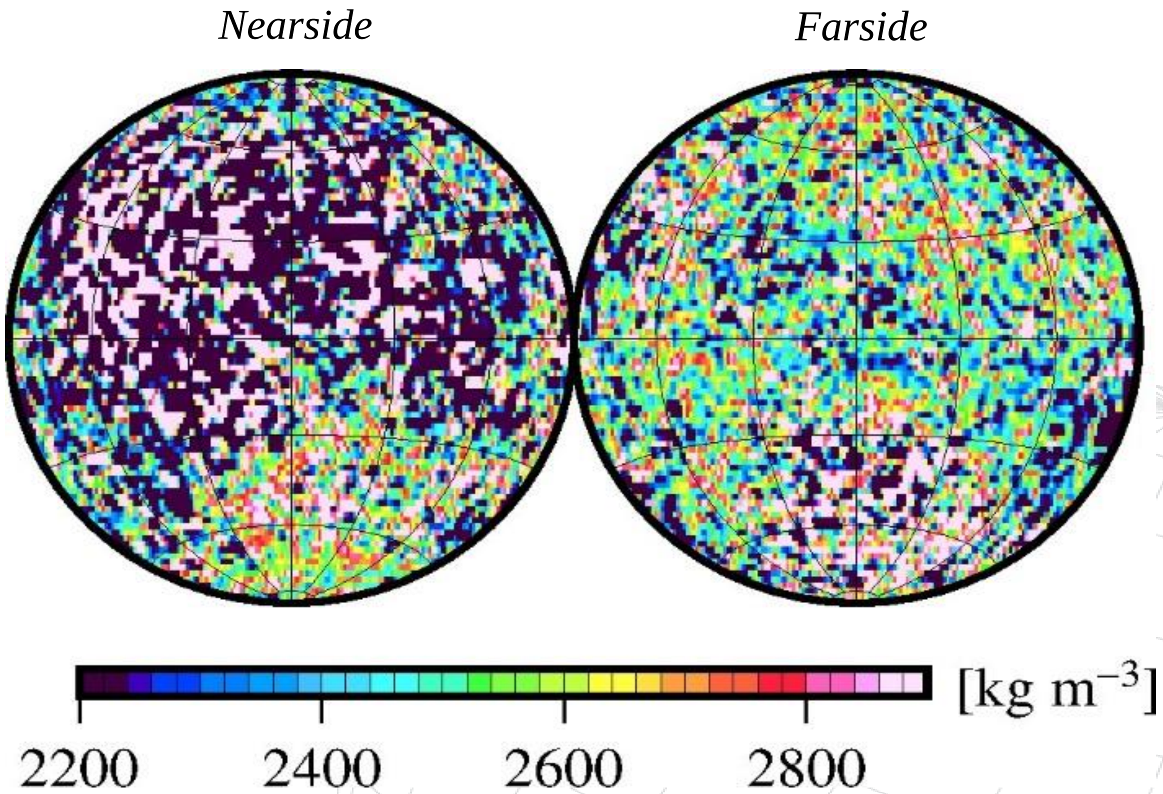
Unknown

- Mathematical model: global, spherical, and linear,
- Horizontal density variations parametrised by surface spherical harmonics,
- Crustal density estimates: 1) constant, 2) horizontally variable, and 3) spatially variable.

Horizontally variable crustal density

Least-squares solution:

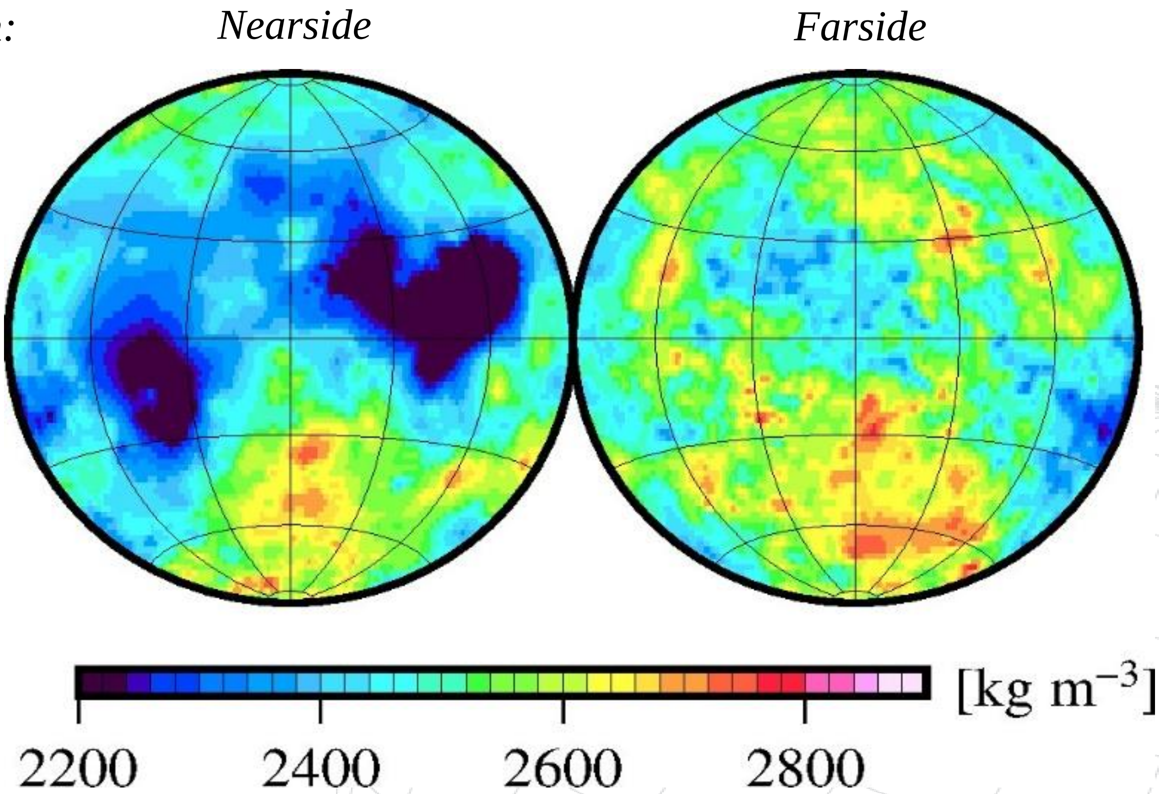
$$\hat{\mathbf{x}} = \left(\mathbf{A}^{T}\,\mathbf{A}\right)^{-1}\,\mathbf{A}^{T}\,\hat{\mathbf{l}}$$



Horizontally variable crustal density

Regularised least-squares solution:

$$\hat{\mathbf{x}} = \left(\mathbf{A}^{\mathrm{T}}\,\mathbf{A} + \mathbf{K}\right)^{-1}\mathbf{A}^{\mathrm{T}}\,\hat{\mathbf{l}}$$



Available at http://icgem.gfz-potsdam.de/tom_celestial

3. Global gravitational field models:

$$\bar{C}_{n,m} = \frac{1}{R^n M(2n+1)} \int_{\Omega} \int_{r} \varrho(r,\Omega)\, \bar{Y}_{n,m}(\Omega)\, r^{n+2}\, \mathrm{d}r\, \mathrm{d}\Omega$$

Unknown

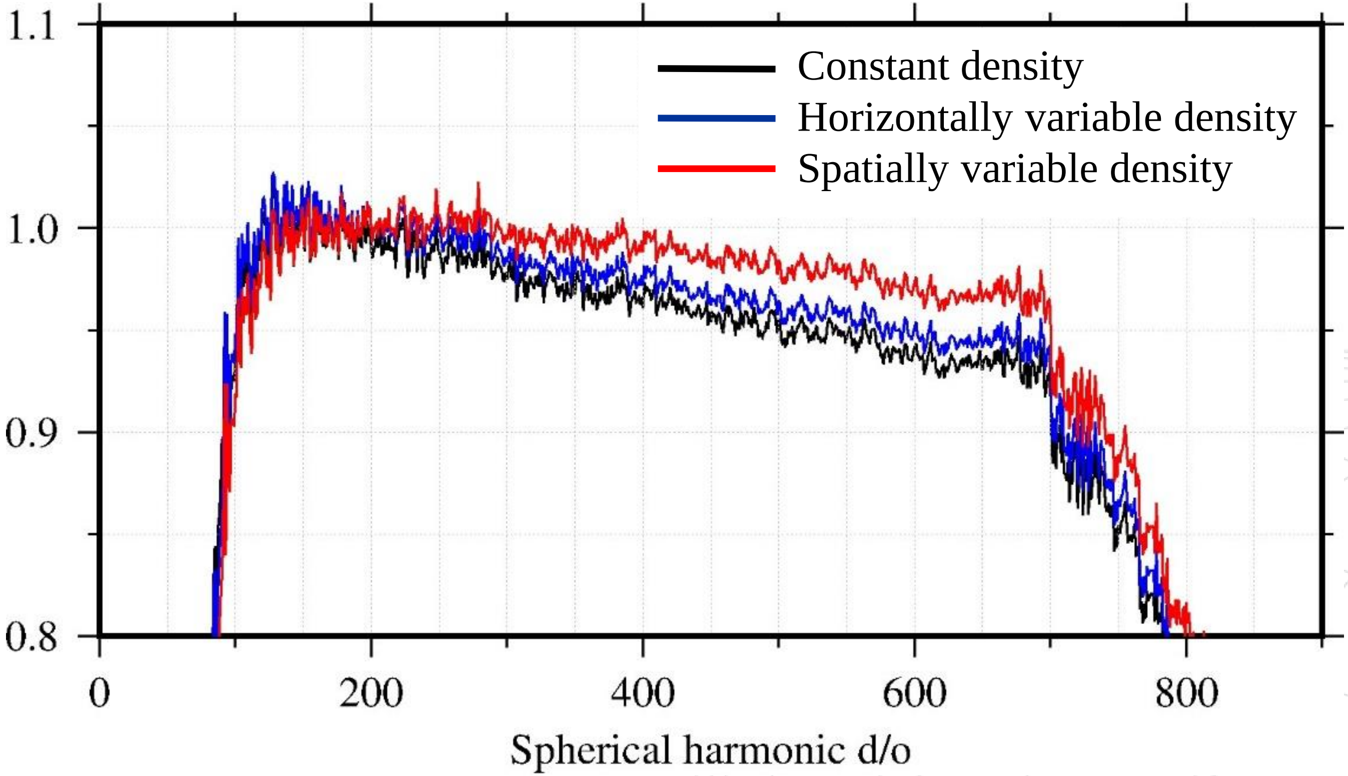
LOLA topography

Our estimates

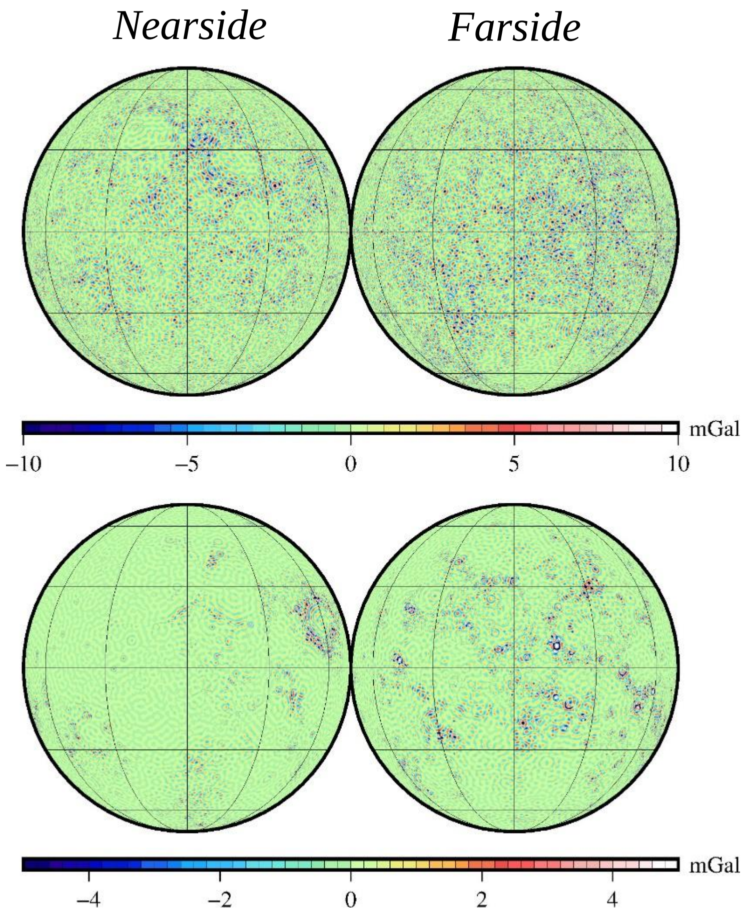
- Forward calculation of 3 GGFMs by the Rigorous Forward Modelling method (Šprlák et al. 2018),
- Maximum spherical harmonic d/o 2519 (spatial resolution ~2.2 km),
- Extensive assessment of the 3 GGFMs in spectral and spatial domains.

Available at https://www.researchgate.net/project/Understanding-the-Moons-crustal-structure-from-analysis-of-new-high-resolution-gravity-topography-and-seismic-data

Admittance (our forward GGFMs vs. GL1500E)



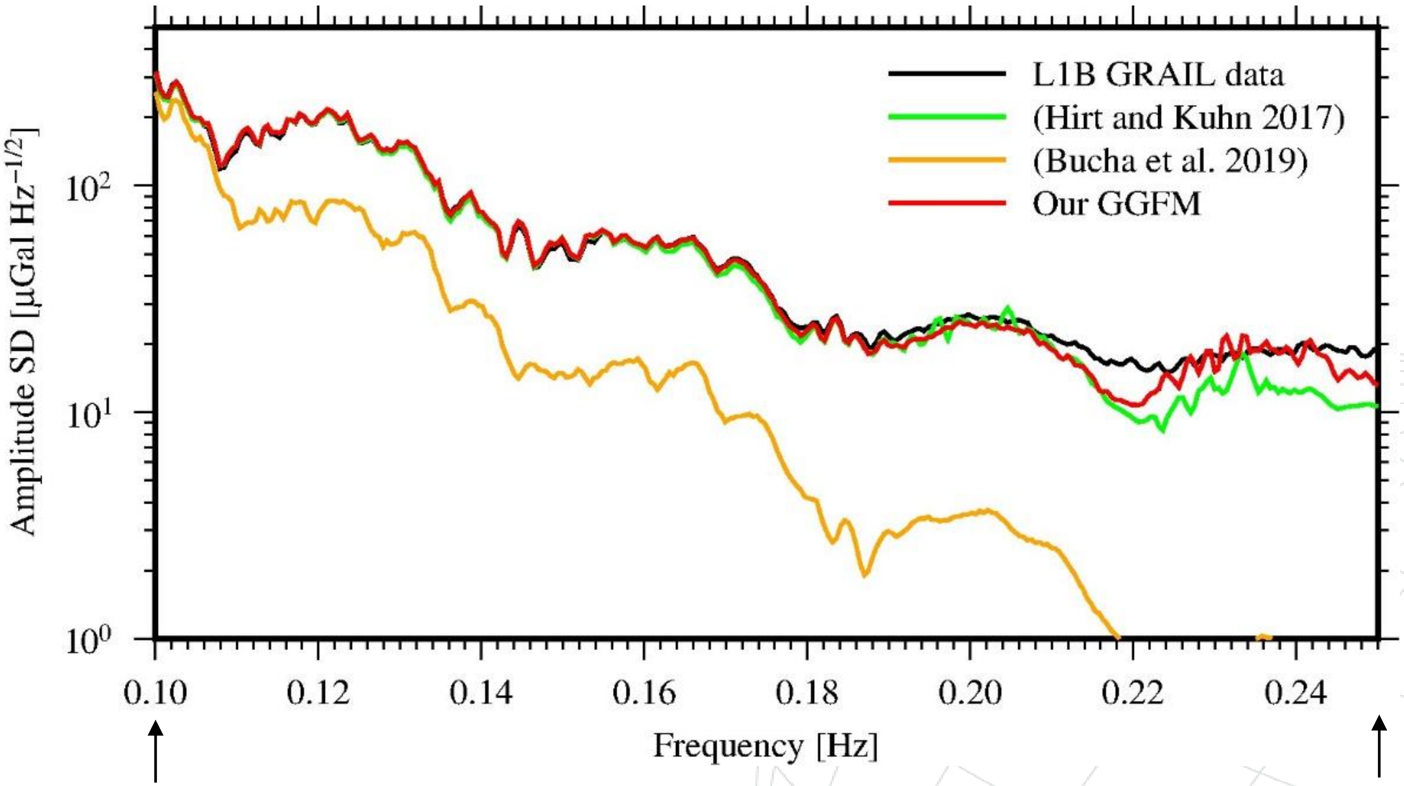
Maps of (Bouguer) radial gravitations



GL1500E minus constant density

Spatially variable density vs. constant density

Along-track analysis (recent forward GGFMs vs. L1B GRAIL)



d/o 650

d/o 1623

4. Conclusions:

- Employment of Newton's integral in the spectral domain and solution of two geodetic/geophysical tasks,
- Formulation of a global, spherical, and linear mathematical model for crustal density estimation,
- Determination of constant, horizontally variable, and spatially variable crustal densities,
- Calculation of 3 forward GGFMs and their extensive testing in spatial and spectral domains,
- The estimated models will find applications in geodesy, geophysics, planetary sciences, navigation, etc.

Published article:

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M. Šprlák [a,b,*], S.-C. Han [a], W.E. Featherstone [c]

[a] School of Engineering, Faculty of Engineering and Built Environment, University of Newcastle, University Drive, Callaghan, NSW, 2308, Australia
[b] NTIS–New Technologies for the Information Society, Faculty of Applied Sciences, University of West Bohemia, Technická 8, 306 14, Plzeň, Czech Republic
[c] School of Earth and Planetary Sciences, Curtin University of Technology, GPO Box U1987, Perth, WA, 6845, Australia

Thank you for your attention!!!

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