Analysis of Ganymede's gravitational field in support of JUICE mission

ID: 256

Edoardo Santero Mormile[1,2,3], Giuseppe Mitri[2,3]

1 Università degli Studi di Trento, Trento, Italy

2 Dipartimento di Ingegneria e Geologia, Università d'Annunzio, Pescara, Italy

3 International Research School of Planetary Sciences, Pescara, Italy

UNIVERSITY OF TRENTO

PhD SST Space Science and Technology

INTRODUCTION

In the absence of seismic data, the gravity field allows to investigate the internal distribution of mass of a planetary object. The upcoming missions **JUICE** (ESA), **BepiColombo** (ESA-JAXA) and **Veritas** (NASA) will measure the gravitational fields of **Ganymede**, **Mercury**, and **Venus**, respectively, to **constrain their interiors**. In this work, we provide the starting steps for the analysis of Ganymede's gravitational field (in the frame of JUICE mission), using other planetary bodies as benchmarks.

GOALS

- Assessing the actual state of the art of the planetary interior inference;
- Developing a **novel code** (MATLAB) to handle and process the gravity data from space missions (spherical harmonics expansion);
- Evaluating the **gravitational anomalies** maps and the **admittance spectrum**;
- Starting to analyse these results to catch hints of the body's internal structure.

METHODOLOGY

The gravitational field of a body can be measured using a **spherical harmonic expansion** approach [1], exploiting the associated Legendre polynomials P_{nm}. In this case, the gravity data are in the form of "Stokes coefficients" [C_{nm}, S_{nm}]. This subdivision in **degree *n*** (and order *m*) allows a study of direct correlations between the maximum expansion degree n_{max}, the resolution of the models ($\approx \pi R/ n_{max}$) and the depths of the subsurface structure: lower *n*, the deeper the source (and vice versa) [1].

$$\boldsymbol{U(r,\theta,\phi)} = -\frac{GM}{r}\left\{1+\sum_{n=2}^{n_{\max}}\left(\frac{R}{r}\right)^n\sum_{m=0}^{n}\left(\bar{C}_{nm}\cos m\phi+\bar{S}_{nm}\sin m\phi\right)\bar{P}_{nm}(\cos\theta)\right\}$$

•$[\theta,\phi]$ = colatitude, longitude;

•$\overline{C}_{nm}, \overline{S}_{nm}, \overline{P}_{nm}$= 2-pi normalized.

Even the topography of the body can be expressed in spherical harmonics terms, allowing us to **compare and combine the gravitational effects with the planetary shape**. Notice that the n_{max} needs to be matched between gravity and topography models.

$$\boldsymbol{h(\theta,\phi)} = \sum_{n=0}^{n_{\max}}\sum_{m=0}^{n}\left(\bar{C}^t_{nm}\cos m\phi+\bar{S}^t_{nm}\sin m\phi\right)\bar{P}_{nm}(\cos\theta)$$

This results in two quantities to constrain the interiors: from the gravitational acceleration (i.e., Free-Air anomaly) the topography contribution can be subtracted, via **Bouguer correction**, while from the gravity spectrum, it is possible to analyse the **admittance *Z(n)***. In the following, the resulting equations:

- Free-Air anomaly (= $\partial U/\partial r$):

$$\frac{dU}{dr} = \frac{GM}{r^2}\left\{1+\sum_{n=2}^{n_{\max}}\left(\frac{R}{r}\right)^n(n+1)\sum_{m=0}^{n}\left(\bar{C}_{nm}\cos m\phi+\bar{s}_{nm}\sin m\phi\right)\bar{P}_{nm}(\cos\theta)\right\}$$

- Bouguer correction [2]:

$$\begin{Bmatrix}C^T_{nm}\\ S^T_{nm}\end{Bmatrix} = \frac{4\pi R^3}{M(2n+1)}\sum_{i=1}^{i_{\max}}\frac{(\rho^i)\begin{Bmatrix}C^t_{nm}\\ S^t_{nm}\end{Bmatrix}^i_{nm}}{R^i i!}\frac{\prod_{j=1}^{i}(n+4-j)}{(n+3)}$$

- Admittance [3]:

$$Z(n) = \sum_{m=0}^{n}\left(\frac{\bar{C}^g_{nm}\bar{C}^t_{nm}+\bar{S}^g_{nm}\bar{S}^t_{nm}}{\bar{C}^{t\,2}_{nm}+\bar{S}^{t\,2}_{nm}}\right)\left[\frac{\frac{GM}{r^2}(n+1)}{10^{-8}}\right]$$

REFERENCES

[1] Kaula, *Determination of the Earth's gravitational field*, 1963

[2] Wieczorek and Phillips, *Potential anomalies on a sphere*, 1998

[3] Wieczorek, *Gravity and Topography of the Terrestrial Planets*, 2015

Planet	Gravity model	Topography model	n_{max}	km/pxl
Mercury	*HgM009 (Genova, 2015)*	*gtmes_150v05 (Neumann et al., 2016)*	150	51,1
Earth	*XGM2019e_2019 (Zingerle et al., 2019)*	*Earth2014_10800 (Curtin University, WAGG, 2014)*	2190	9,1
Venus	*MGNP180U (Konopliv et al.,1999)*	*VenusTopo719 (Wieczorek, 2015)*	180	105,6
Moon	*GRGM1200C (Goosens et al, 2016)*	*MoonTopo2600p (LRO LOLA Team, NASA, 2024)*	1200	4,6

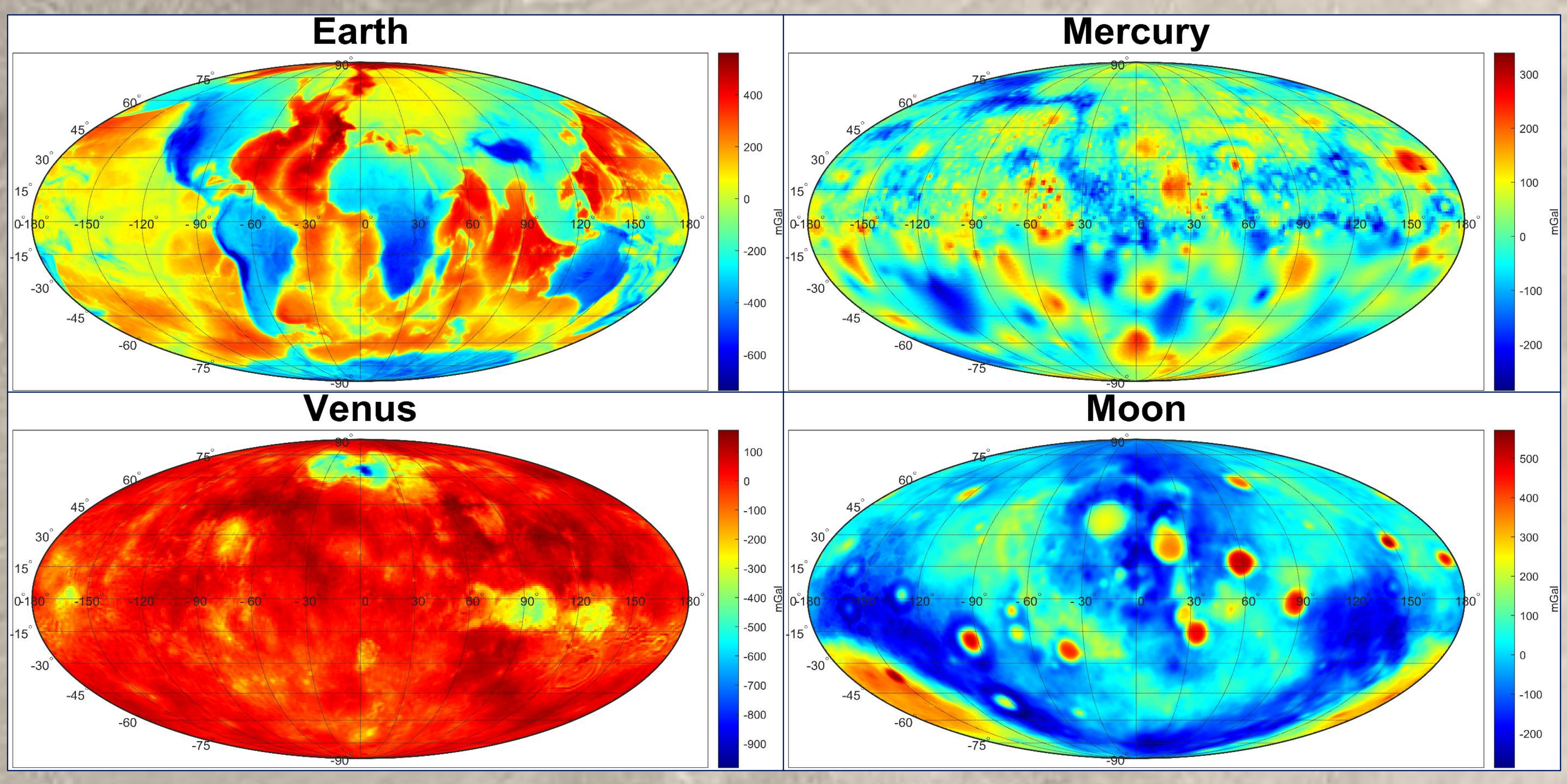
RESULTS

The code was tested on Mercury, Earth, Venus and Moon, calculating the gravitational maps of the field and anomalies, along with the correspondent admittance spectrum. The so-obtained resulting maps are consistent with those reported in the literature, validating both the code and the performed analysis.

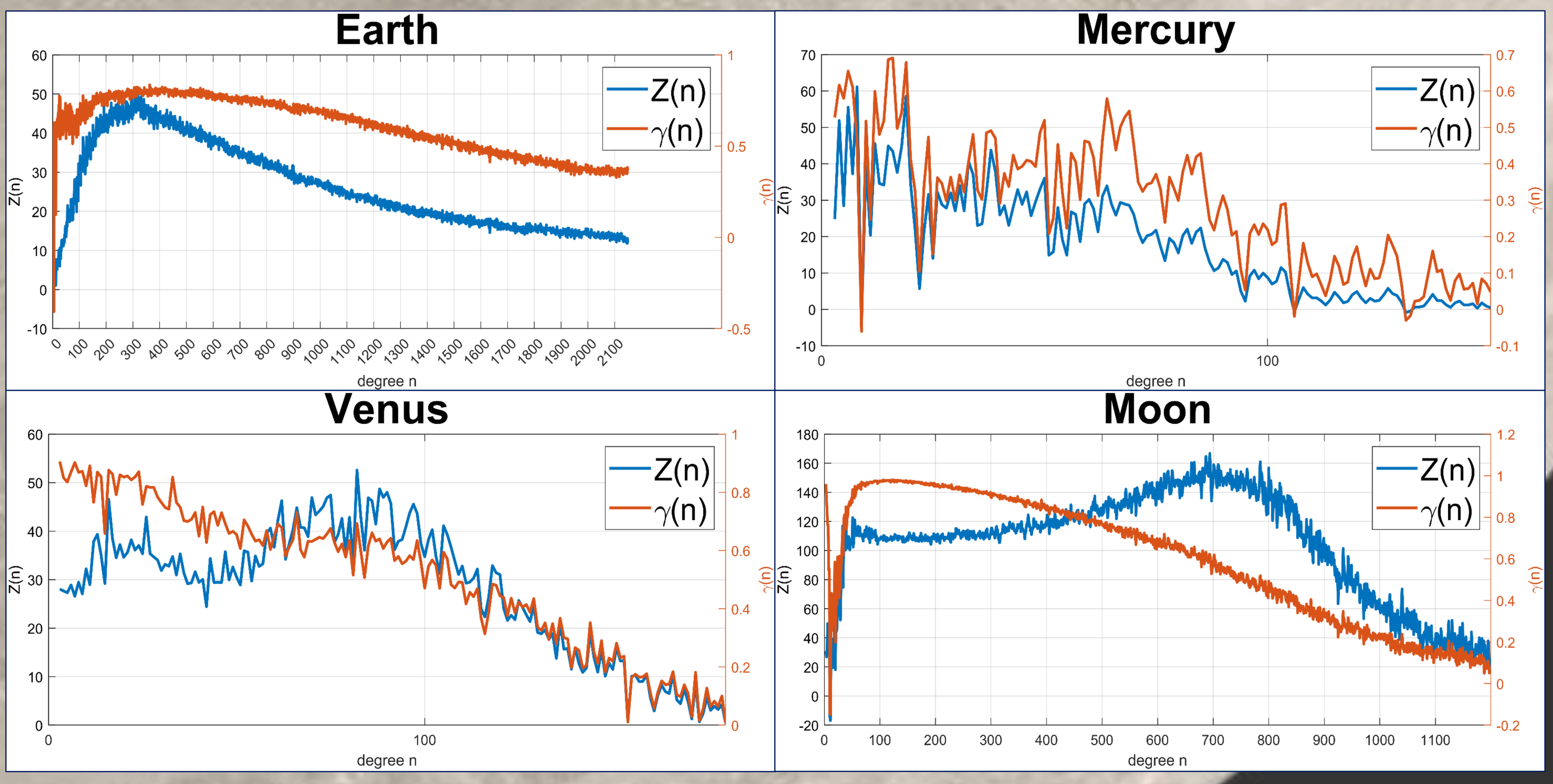
The code is able to handle any gravity data, resulting **numerically stable** up to the highest tested degree (i.e., 2190 for the Earth model).

The analysed data are reported in the table, including the gravity and topography models, the correspondent maximum available expansion degree n_{max} and the resulting global resolution ([*km/pxl*]).

Bouguer anomaly



Admittance *Z(n)* and correlation factor *γ(n)*



FUTURE WORKS

- Enhancing the admittance *Z(n)* and spectrum analyses through the application of a new mathematical tool, called ***Spherical Iterative Filtering***.
- **Synthetic** gravitational field generation: building an artificial planetary body with known interfaces (depth and topography) and generating its gravitational field.
- Development of **inversion methods**.