EPSC Abstracts
Vol. 5, EPSC2010-904, 2010
European Planetary Science Congress 2010

Spectral representation of the tide-generating potential and the inducing magnetic potential on the Galilean satellites

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Abstract

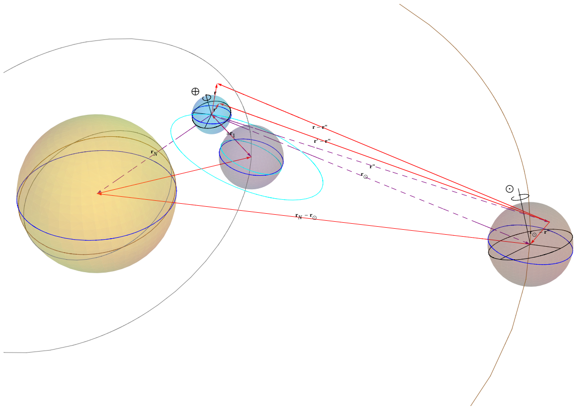

Figure 1: A planet surrounded by celestial bodies.

Celestial bodies in the neighbourhood of a ‘planet’ (in the loose sense of the word, so applying to the Galilean satellites as well) generate, by their gravitational field, gravity field variations, tides and rotation perturbations on the planet, and affect the trajectory of orbiting artificial satellites (figure 1). The magnetic field surrounding some of these neighbours, if time-varying as viewed from the planet, does also induce magnetic field variations on the planet, provided it contains a layer of conductive material. The magnitude of these effects depends on properties of the planet’s interior, yielding a convenient way to study the interior. In planetary sciences, the gravitational and magnetic ‘perturbations’ induced by the neighbours are mathematically represented by a tide-generating potential and an inducing magnetic potential in some planetary reference frame moving with the planet. For theoretical purposes, it is desirable that they be expressed in the form of harmonic (or Poisson) series.

For a limited number of planets, accurate tide-generating potentials have been built, either from analytical ephemerides (such as VSOP87 [2]) in Cartesian or spherical coordinates using Poisson series manipulators (e.g. [6], [9]), or from numerical ephemerides (such as DE405 [8]) along with spectral analysis methods (e.g. [4]).

In general, approximate tide-generating potentials may be readily obtained from the neighbours’ mean orbital elements (e.g. [3]). These orbital elements are usually referred to the planetary reference frame, and may therefore undergo very large variations if a neighbour and the planet do not actually orbit each other. A better way then is to choose intermediate points so as to split the neighbour’s motion into perturbed two-body motions (this is possible if the planetary system is hierarchised). Furthermore, it is common to assume that the planet and its neighbours rotate uniformly and are spherically symmetric (see [1] for a generalisation to extended bodies). These approximations are not always sufficient: for instance, how strong is the influence of Jupiter’s flattening J_2 on the Galilean satellites?

A similar method may be used to determine the spectrum of the inducing magnetic potential (we only address that part of the spectrum which arises from the astronomical motions, so we do not deal with plasma effects, e.g. in the planet’s ionosphere; see [7] for a comprehensive investigation of the spectrum of the Galilean satellites’ magnetic field).

From a restricted set of physical and geometric quantities (planetopotential and magnetic potential multipolar coefficients, and mean orbital and rotational elements), it is thus possible to compute, in a general setting, the approximate spectrum of the tide-generating and inducing magnetic potentials, and we apply this method to the Galilean satellites.

Example: Europa’s gravity

As an example, we computed the tide-generating potential on Europa induced by Jupiter, Io, Ganymede, Callisto, the Sun, and Saturn. The celestial bodies are assumed to be uniformly rotating and we use the mean orbital elements of the two-body systems Jupiter-Europa (mean motion n_{E}), Jupiter-Io (mean motion $n_{\mathrm{I}} \simeq 2n_{\mathrm{E}}$), Jupiter-Ganymede (mean motion $n_{\mathrm{G}} \simeq n_{\mathrm{E}}/2$), Jupiter-Callisto, Sun-Jupiter, and Sun-Saturn.

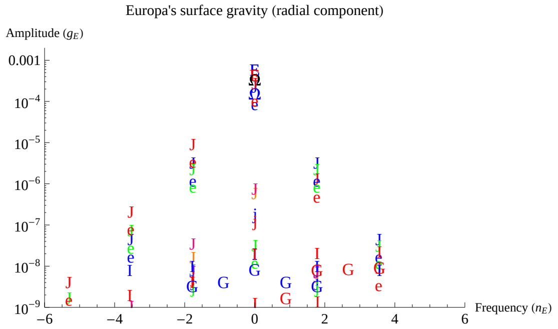

Figure 2: Europa's 'surface' gravity (along the surface of a sphere of radius R_{E}).

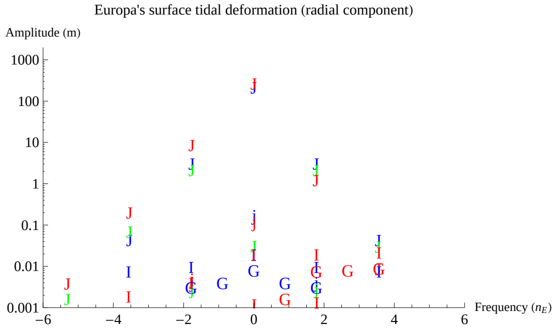

Figure 3: Europa's surface tidal deformation.

(degree ℓ, order m)			
(0, 0)			
(2, 0)	(2, 1)	(2, 2)	
(3, 0)	(3, 1)	(3, 2)	(3, 3)

E ⟶ Europa's mean gravitational field
e ⟶ time-dependent (tidal) part of Europa's gravitational field
Ω ⟶ Europa's centrifugal field
J ⟶ tide-generating field induced by a spherical Jupiter
j ⟶ additional (non-central) contribution of Jupiter
I ⟶ tide-generating field induced by a spherical Io
G ⟶ tide-generating field induced by a spherical Ganymede

For non-zonal components, positive frequencies are prograde oscillations and negative frequencies are retrograde oscillations.

Europa's tidal deformation, mainly resulting from Jupiter's attraction, is responsible for mass redistribution and variations in Europa's gravitational field. Figure 2 shows the amplitude spectrum of the radial component of Europa's surface gravity field (normalised to Europa's mean surface gravity) for a typical value $k_2 = 0.25$ of Europa's surface Love number k_2. Figure 3 shows the amplitude spectrum of the radial component of Europa's (second-degree) surface tidal displacement for a typical value $h_2 = 1.20$ of Europa's surface Love number h_2. The contributions of Callisto, the Sun and Saturn lie out of the plot range (below $10^{-9} g_{\mathrm{E}}$ and 1 mm).

We see that the contribution from the non-central part of Jupiter's gravitational field is comparable to the contributions from Io and Ganymede.

The L1 ephemerides [5] and refined rotation models may be used to improve the accuracy of these results.

Acknowledgements

A. Trinh is Research Fellow ('Aspirant') of the Fonds de la Recherche Scientifique – FNRS (Belgium).

References

[1] Borderies, N.: Mutual gravitational potential of N solid bodies, Celest. Mech., Vol. 18, pp. 295-307, 1978.

[2] Bretagnon, P. and Francou, G.: Planetary theories in rectangular and spherical variables. VSOP 87 solutions, Astron. Astrophys., Vol. 202, pp. 309-315, 1988.

[3] Kaula, W. M.: Tidal dissipation by solid friction and the resulting orbital evolution, Rev. Geophys., Vol. 2, pp. 661-685, 1964.

[4] Kudryavtsev, S.: Harmonic development of tide-generating potential of terrestrial planets, Celest. Mech. Dyn. Astr., Vol. 101, pp. 337-348, 2008.

[5] Lainey, V., Duriez, L., and Vienne, A.: Synthetic representation of the Galilean satellites' orbital motions from L1 ephemerides, Astron. Astrophys., Vol. 456, pp. 783-788, 2006.

[6] Roosbeek, F.: RATGP95: a harmonic development of the tide-generating potential using an analytical method, Geophys. J. Int., Vol. 126, pp. 197-204, 1996.

[7] Seufert, M., Saur, J., and Neubauer, F. M.: Multifrequency electromagnetic sounding of the Galilean satellites' interiors, EGU General Assembly, 2–7 May 2010, Vienna, Austria, 2010.

[8] Standish, E. M.: JPL planetary and lunar ephemerides, DE405/LE405, JPL Interoffice Memorandum, 1998.

[9] Van Hoolst, T. and Jacobs, C.: Mercury's tides and interior structure, J. Geophys. Res., Vol. 108, E11, 2003.