ROTATION OF A VISCOELASTIC, SYNCHRONOUS CRUST

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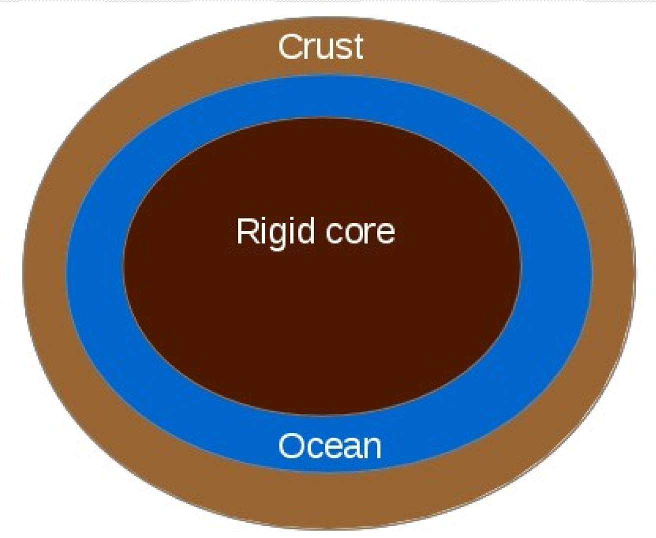
Context

- A global ocean has been detected / hinted for Titan, Europa, Callisto, Ganymede, Enceladus…
- The thin crust enshrouding it is viscoelastic, hence subject to deformations
- The rotational quantities are affected

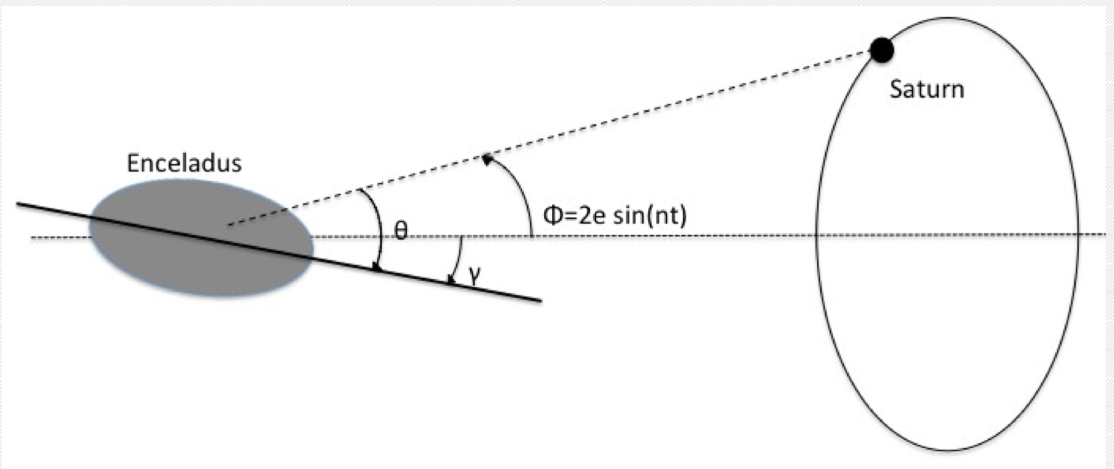


Goal

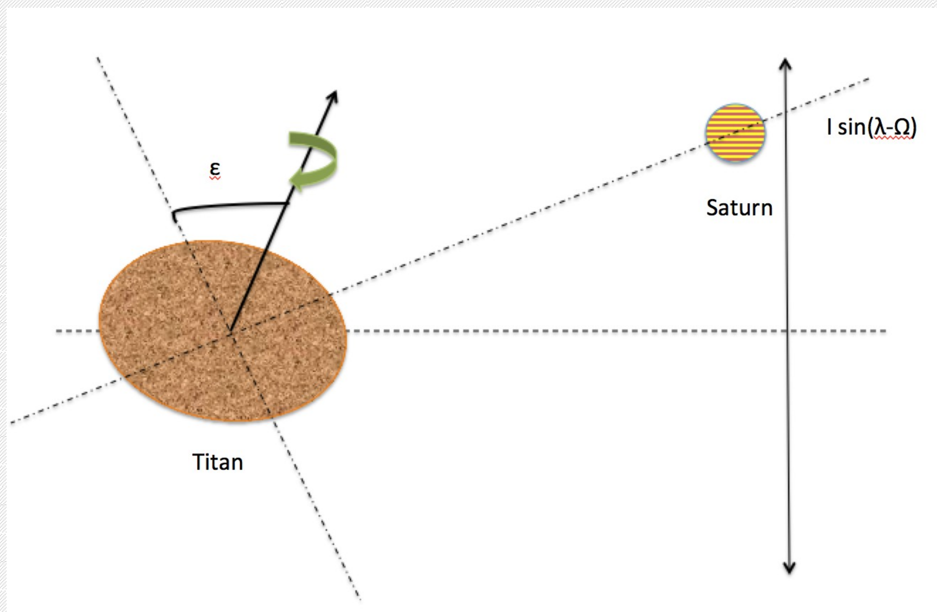
Modeling simultaneously the rotation of a viscoelastic body and the deformations of the crust, for future inversion of the space data.

The rotational quantities

Librations



Obliquity



These quantities are signatures of the interior

Altering the shape enhances the rotational quantities

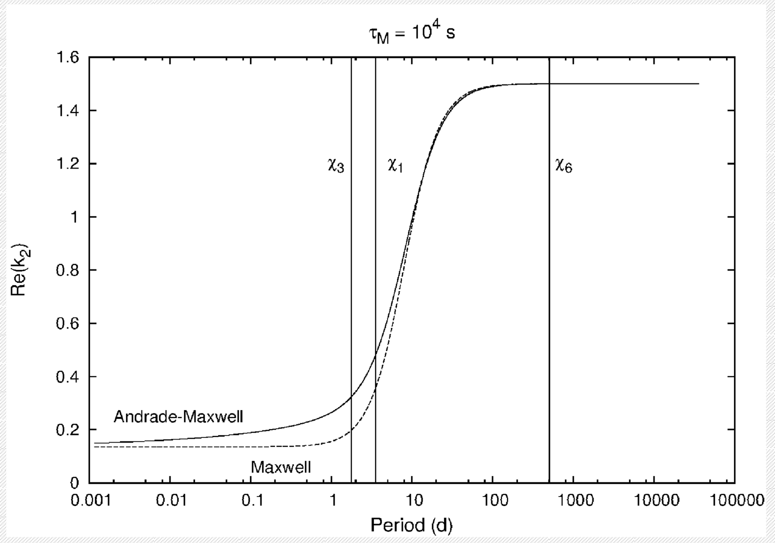
The tensor of inertia

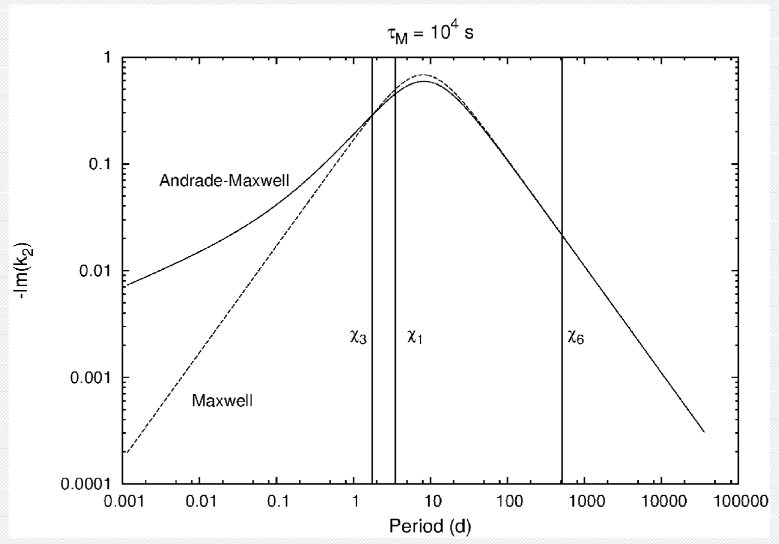
$$(\mathcal{I}) \propto \begin{pmatrix} <I_{11}> & e & \varepsilon \\ e & <I_{22}> & e\varepsilon \\ \varepsilon & e\varepsilon & <I_{33}> \end{pmatrix}$$

This tensor of inertia is time-dependent, because of the variations of the gravitational torque of the parent planet.

The tidal models

- The Love numbers h_2, k_2 depend on the tidal frequency
- The Maxwell time τ_M has a critical role (limit elasticity/anelasticity)
- Andrade model more realistic at high frequencies for ices





χ_1: diurnal frequency, χ_3: semi-diurnal, χ_6: nodal

The algorithm of resolution

This is an iterative algorithm, based on numerical simulations and Fourier decomposition of the solutions.

1) Clever choice of initial conditions: synchronous rotation, Cassini States, + appropriate tensor of inertia
2) Propagation of the equations (10^{th} order Adams-Bashforth-Moulton scheme)
3) Digital filtering (Fourier decomposition) to express the frequency-dependent tidal coefficients
4) New iteration

An example of output

I_{11} (kg.m^2)

Period			Analytical	Numerical
∞			1.9948×10^{26}	1.9948×10^{26}
3.525 d	$\mathcal{M}$	$\propto e$	9.40368×10^{20}	9.39044×10^{20}
3.551 d			–	2.15698×10^{19}
1.763 d	$2\mathcal{M}$	$\propto e^2$	1.55492×10^{19}	1.53731×10^{19}
1.769 d			–	7.08836×10^{17}
1.775 d	$2\mathcal{M}+2\omega$	$\propto \varepsilon^2$	1.75023×10^{15}	–

$\mathcal{M}$: mean anomaly ω: pericenter

The numerical algorithm also gives the influence of the planetary perturbations.

The resulting libration

$$\sigma(t) = \sigma_0 + \sigma_1 \sin(\mathcal{M} + \phi_1) + \sigma_2 \sin(2\mathcal{M} + \phi_2)$$

Conclusions and perspectives

- The viscoelasticity raises the rotational response of the body.
- The dissipative tide ($Im(k_2)$) induces phase-shifts in the librations.
- No supersynchronous rotation obtained from this theory (have to relax the spin-orbit resonance?)
- How could the measurement of the rotational quantities affect the tides?

To know more...

- Goldreich P.M. & Mitchell J.L., 2010, *Elastic ice shells of synchronous moons: Implications for cracks on Europa and non-synchronous rotation of Titan*, Icarus
- Karato S.-i., 2008, *Deformation of Earth materials*, Cambridge University Press
- Laskar J., 1995, *Introduction to frequency analysis*, Proceedings of 3DHAM95
- Noyelles B., *Interpreting the librations of a synchronous satellite*, submitted, arXiV:1605.05919
- Richard et al., 2014, *Librational response of a 3-layer Titan perturbed by non-Keplerian orbit and atmospheric couplings*, PSS
- Van Hoolst et al., 2013, *On the librations and tides of large icy satellites*, Icarus