How strongly is dissipation affected by the anisotropic tidal response of ocean planets

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Problem

The climate and atmospheric properties of **rocky planets in habitable zones** result from their long-term tidal evolution, which is primarily controlled by **energy dissipation in oceans**. Unlike solid bodies, fluid tides are strongly affected by rotation through Coriolis forces, which breaks the commonly assumed **isotropic assumption**. In this work, we present a **new formalism** to compute energy and angular momentum transfer in **non-isotropic cases** and we use it to characterise quantitatively the validity domain of the isotropic assumption.

Isotropic assumption

- **invariance of properties by rotation** about the center of mass;
- Love numbers k_l **depending solely on the degrees** l.

Physical setup

- idealised Earth-Moon system (Fig. 1);
- thin global ocean of uniform depth $H \ll R$;
- linear drag of coefficient $\sigma_{\rm R}$;
- visco-elastic solid regions (Andrade model);
- point-mass tidal perturber;
- **non-zero obliquity and inclination**.

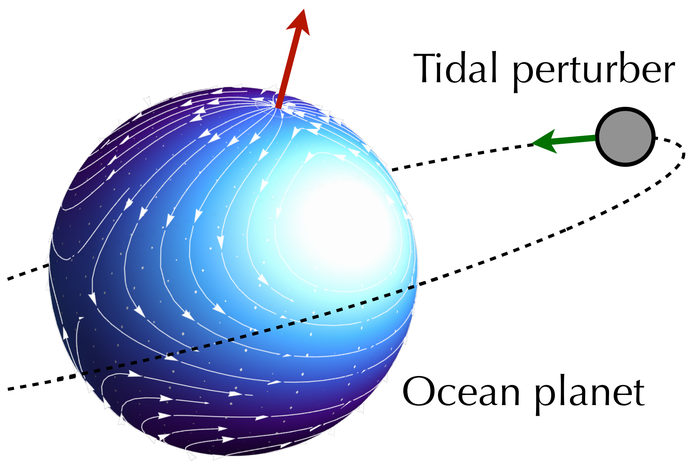

Figure 1: Studied planet-perturber system.

Conclusions

The isotropic assumption:

- holds in the low-frequency range in general;
- **holds for obliquities less than** 10° (quasi-aligned planet-perturber systems);
- leads to **overestimate tidal dissipation** by several orders of magnitude when tidal modes are resonantly excited;
- may induce **significant errors in reconstructing orbital and rotational histories** of fast-rotating planets and **fluid bodies**.

Reference

[1] Pierre Auclair-Desrotour, Gwenaël Boué, Baptiste Loire, *Anisotropic tidal dissipation in misaligned planetary systems*, 2025, A&A, 694, A53

More about this work! →

Method

- **Laplace's tidal equations (LTEs):**

$$\partial_t \boldsymbol{V} + \sigma_{\rm R}\boldsymbol{V} + \boldsymbol{f}\times\boldsymbol{V} + g\nabla\left(\Gamma_{\rm D}\zeta - \Gamma_{\rm T}\zeta_{\rm eq}\right) = 0,$$
$$\partial_t \zeta + \nabla\cdot(H\boldsymbol{V}) = 0.$$

- LTEs solved using a **spectral method**.
- **Spherical harmonic expansion** of the gravitational potentials associated with the forcing and the tidal response (Fig. 2).

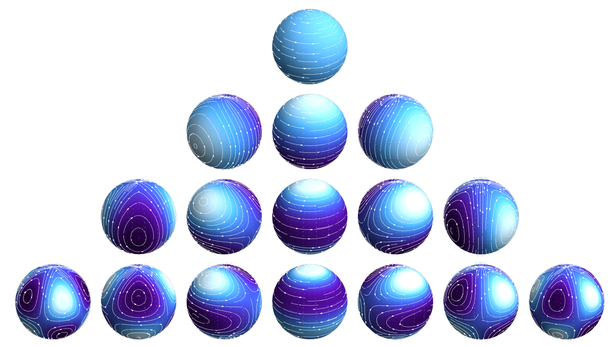

Figure 2: Spherical harmonic expansion of tides.

Comparison between dry and ocean planets

- Calculations performed **with** (Approx) and **without** (Full) the isotropic assumption for **dry and ocean planets**.
- **Spurious resonant tidal modes** appearing in misaligned ocean planets when using the Approx formulation (Figs. 3 and 4).

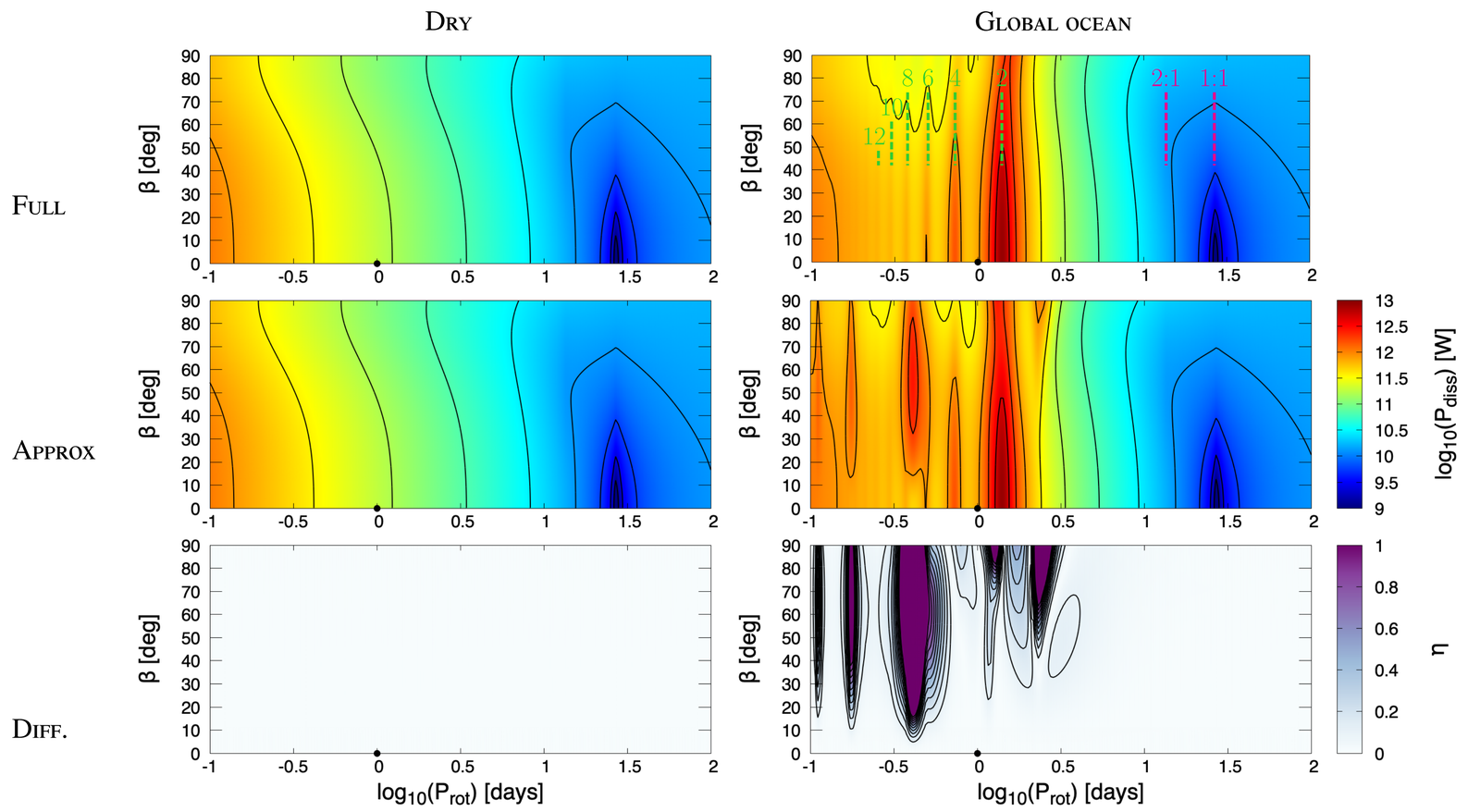

Figure 3: **Tidally dissipated power** as a function of the planet's spin rotation period ($P_{\rm rot}$; horizontal axis) and obliquity (β; vertical axis) for Earth-sized dry (left panel) and global-ocean (right panels) planets. *Top:* full, non-isotropic tidal response (Full). *Middle:* response computed using, for all tidal forcing terms, the degree-2 Love number evaluated in the equatorial plane for the coplanar-circular configuration (Approx). *Bottom:* relative difference between the Full and Approx results (Diff.). Dashed green lines mark resonances associated with oceanic surface gravity modes, while dashed magenta lines indicate the 1:1 and 2:1 spin-orbit resonances.

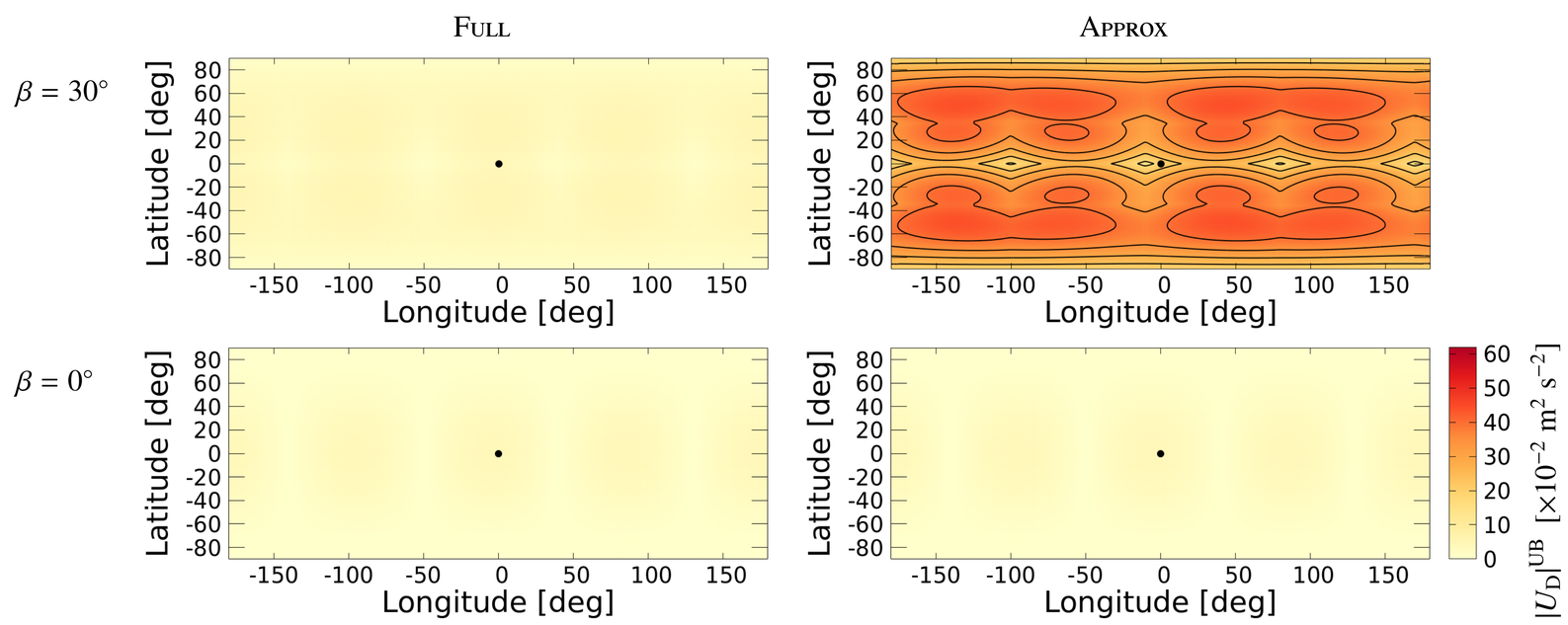

Figure 4: **Latitude-longitude maps of the gravitational potential** induced by the oceanic tidal response, shown in the reference frame corotating with the perturber, for $P_{\rm rot} = 10$ h and two obliquities: $\beta = 30^\circ$ (top) and $\beta = 0^\circ$ (bottom). *Left:* full, non-isotropic tidal response (Full). *Right:* response computed using, for all tidal forcing terms, the degree-2 Love number evaluated in the equatorial plane for the coplanar-circular configuration (Approx). The black dot marks the sub-perturber point.