Tidal dissipation in stars and fluid planetary layers: impact of rotation, stratification and thermal diffusivity

P. Auclair-Desrotour[1,2], S. Mathis[2], C. Le Poncin-Lafitte[3]

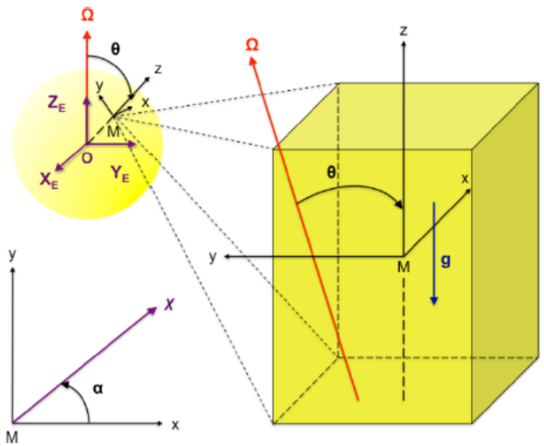
1: IMCCE, Observatoire de Paris, CNRS UMR 8028
2: Laboratoire AIM Paris-Saclay; CEA/DSM/IRFU/SAp
3: SYRTE, Observatoire de Paris, CNRS UMR 8630

Abstract:

Tidal dissipation in stars and planets is one of the key physical mechanisms driving the evolution of planetary systems. Its properties inside the fluid layers of celestial bodies are intrinsically linked to the internal physics of these layers.

We compute the energy dissipated by viscous friction and thermal diffusion in a local fluid section of a star/fluid planet submitted to tidal-like periodic forcing. The properties of gravito-inertial waves excited by tides are analytically derived from its expression, as explicit functions of the tidal frequency and local fluid parameters. The sensitivity of dissipation to a parameter of the fluid is either important either negligible depending on the different asymptotic regimes of the waves, and scaling laws are derived to describe these variations. We thus unravel the strong impact of the internal physics on the tidal energy dissipated inside the fluid layer of a celestial body. It underlines the fluids' parameters that really play a role in dissipation for a given regime.

The studied local set-up:



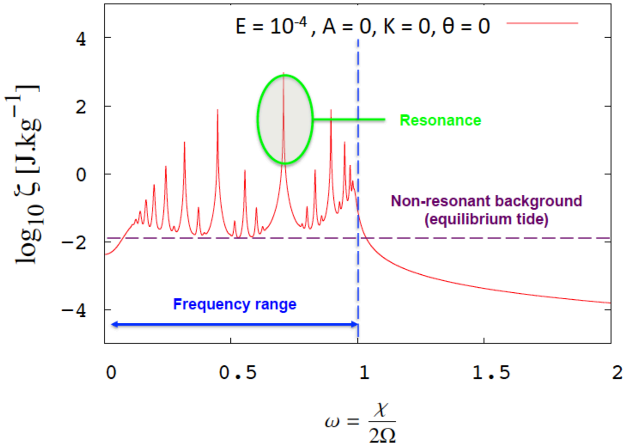


Fig 1: Left: Local section of the studied star/fluid planet. **Right:** Example of the frequency-spectrum of the viscous dissipation of tidal inertial waves (per unit mass and rotation period) in the case where the box is in a convective region.

Complete scaling laws

Domain		$A \ll A_{11}$		$A \gg A_{11}$
$P_r \gg P_{r;11}^{\mathrm{reg}}$		$l_{mn} \propto E$, $\omega_{mn} \propto \frac{n}{\sqrt{m^2+n^2}} \cos\theta$ $H_{mn} \propto E^{-1}$, $N_{\mathrm{kc}} \propto E^{-1/2}$ $H_{\mathrm{bg}} \propto E$, $\Xi \propto E^{-2}$		$l_{mn} \propto E$, $\omega_{mn} \propto \frac{m}{\sqrt{m^2+n^2}} \sqrt{A}$ $H_{mn} \propto E^{-1}$, $N_{\mathrm{kc}} \propto A^{1/4} E^{-1/2}$ $H_{\mathrm{bg}} \propto A^{-1} E$, $\Xi \propto A E^{-2}$
$P_r \ll P_{r;11}^{\mathrm{reg}}$	$P_r \gg P_{r;11}$	$l_{mn} \propto E$, $\omega_{mn} \propto \frac{n}{\sqrt{m^2+n^2}} \cos\theta$ $H_{mn} \propto E^{-1} P_r^{-1}$, $N_{\mathrm{kc}} \propto E^{-1/2}$ $H_{\mathrm{bg}} \propto E P_r^{-1}$, $\Xi \propto E^{-2}$	$P_r \gg P_{r;11}^{\mathrm{diss}}$	$l_{mn} \propto E P_r^{-1}$, $\omega_{mn} \propto \frac{m}{\sqrt{m^2+n^2}} \sqrt{A}$ $H_{mn} \propto E^{-1} P_r^2$, $N_{\mathrm{kc}} \propto A^{1/4} E^{-1/2} P_r^{1/2}$ $H_{\mathrm{bg}} \propto A^{-1} E$, $\Xi \propto A E^{-2} P_r^2$
	$P_r \ll P_{r;11}$	$l_{mn} \propto A E P_r^{-1}$, $\omega_{mn} \propto \frac{n}{\sqrt{m^2+n^2}} \cos\theta$ $H_{mn} \propto A^{-2} E^{-1} P_r$, $N_{\mathrm{kc}} \propto A^{-1/2} E^{-1/2} P_r^{1/2}$ $H_{\mathrm{bg}} \propto E P_r^{-1}$, $\Xi \propto A^{-2} E^{-2} P_r^2$	$P_r \ll P_{r;11}^{\mathrm{diss}}$	$l_{mn} \propto E P_r^{-1}$, $\omega_{mn} \propto \frac{m}{\sqrt{m^2+n^2}} \sqrt{A}$ $H_{mn} \propto A^{-1} E^{-1} P_r$, $N_{\mathrm{kc}} \propto A^{1/4} E^{-1/2} P_r^{1/2}$ $H_{\mathrm{bg}} \propto A^{-2} E P_r^{-1}$, $\Xi \propto A E^{-2} P_r^2$

Control parameters

Ekman number

$$E = \frac{2\pi^2 \nu}{\Omega L^2}$$

Froude number

$$A = \left(\frac{N}{2\Omega}\right)^2$$

Prandtl number

$$P_r = \frac{\nu}{\kappa}$$

Table 1: Scaling laws for the width (l), the height (H), the eigenfrequencies (ω) and the number (N_{kc}) of resonances and for the non-resonant background (H_{bg} that corresponds to the so-called equilibrium tide) and the sharpness (Ξ) that gives the contrast between this later and the main resonance.

Conclusion:
- Tidal dissipation in stars and fluid planetary layers is controlled by rotation, stratification and viscous and thermal diffusivities;
- It cannot be restricted to a parameterized/calibrated tidal quality factor.

Bibliography:

Auclair-Desrotour et al. 2015, A&A
Ogilvie & Lin 2004, ApJ, 610, 477