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# The tidal response of super-Earths and large icy worlds

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The number of detected Super-earths is now growing. Most of the Super-earth candidates orbit at relatively close distance from their central star and therefore are likely subjected to large tidal forcing. Low mass planets ($2 - 10M_E$) with short orbital periods ($< 10 - 20$ days) seem especially abundant around M-dwarf stars (e.g.[1]). Owing to strong tidal interaction, planets with such short orbiting periods get rapidly tidally locked, with important consequences for their thermal state and habitability. Tidal friction in the interior of such planets during tidal despinning as well as once the planet is tidally locked on an eccentric orbit should significantly contribute to the internal heat budget. In the present study, we model the interior structure of super-Earths and large icy worlds, we compute their viscoelastic response to tidal forcing, and evaluate the impact of tidal dissipation on their thermal evolution.

## 1. Interior structure and rheology

We consider planet mass varying between 1 and 10 $M_E$, having a $H_2O$ mass fraction up to 50 %. The interior is assumed to be differentiated in an iron-rich core, a silicate mantle, divided in an upper and lower mantle, and a thick ice layer, possibly liquid in the upper part. For sake of simplicity, the iron-rich core is assumed to be entirely liquid. The interior structure is modeled using the approach of Sotin et al. [2]. The input parameter are Fe/Si, Mg/Si, the Mg content of the silicate mantle, the amount of $H_2O$ and the total mass of the planet. The elastic bulk isentropic modulus, $K$, are derived from the density and pressure profiles. The shear modulus, $\mu$ in the silicate mantle is estimated from the bulk modulus using the following relationship : $\frac{\mu}{K} = 0.631 - 0.899\frac{P}{K}$, which reproduces well the shear modulus profile in the Earth's mantle. For the ice layer, it is computed from the bulk modulus profile assuming a constant Poisson coefficient equal to 0.3. For the viscoelastic response, we use an Andrade model [3, 4], assuming a constant viscosity in each layer. More realistic viscosity and shear modulus profiles will be considered in the future.

## 2. Viscoelastic tidal response

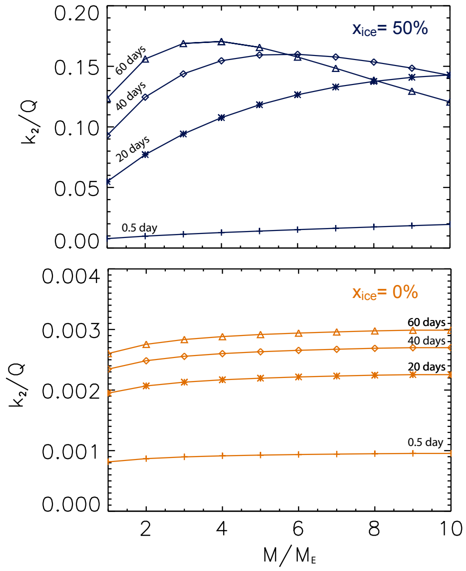

Figure 1: *Variations of the* $k_2/Q$ *ratio as a function of planet mass for Earth-like planets (bottom) and ice-rich planets (top) at four different tidal (orbital) periods, assuming a viscosity of* $5.10^{22}$ *Pa.s,* $10^{21}$*Pa.s,* $10^{16}$*Pa.s, for the lower silicate mantle, upper silicate mantle, high-pressure ice mantle, respectively.*

The viscoelastic deformation of the planet interior under the action of periodic tidal forces are computed following the method of Tobie et al. [5]. We solve the Poisson equation and the equation of motion for small perturbations in the frequency domain using a compressible viscoelastic rheology, as defined above. By integrating the radial functions associated with the radial and tangential displacements ($y_1$ and $y_3$, respectively), the radial and tangential stresses ($y_2$ and $y_4$), and the gravitational potential ($y_5$), we determine the Love number $k_2$, the dissipation function, $Q^{-1}$

and the radial distribution of tidal heating, $H_{tide}(r)$.

As displayed on Figure 1, the $k_2/Q$ ratio (characterizing the global dissipation power) in water-rich planets is much larger than in Earth-like planets. For the parameters considered here, we reproduce the $k_2$ and Q values of the solid Earth ($k_2 \simeq 0.3$, $Q \simeq 350$). For Earth-like planets, this ratio is weakly sensitive to the planet mass and depends primarily on tidal periods (mostly due to the frequency dependence of the Q function). For water-rich planets, the frequency and mass dependencies are more complex.

## 3. Impact of tidal heating on thermal evolution

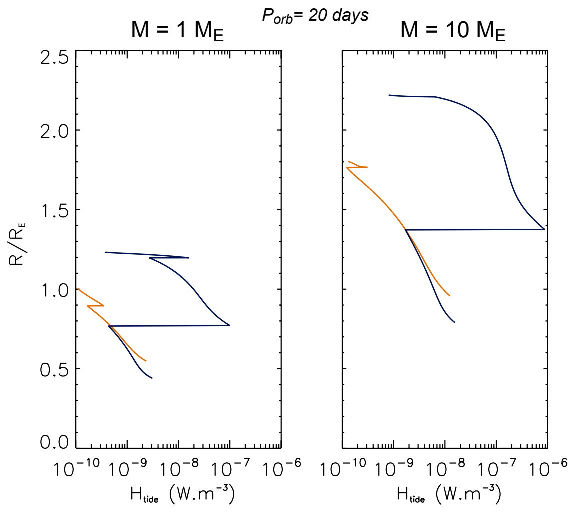

Figure 2: *Tidal heating profiles in Earth-like (orange) and water-rich (dark blue) planets for an orbital period of 20 days and an eccentricity of 1 % and for 1 and 10* $M_E$

Figure 2 presents the radial distribution of tidal heating in two types of planets considered here. In both silicate and ice layers, the maximum heating rate is located at the base of the layer. For the silicate part, the heating rate is comparable to radiogenic heating rate only in the bottom part of the mantle. In the ice mantle, the heating rate is more than two order of magnitude larger, and it is comparable to the values expected in Europa and Enceladus. Such heating rates are expected to have a strong impact of the convective heat transfer in water-rich planets. For the results displayed here, the global dissipation power reach $\sim$ 100 and $\sim$ 300 TW for water-rich planets with a mass of 1 and 10 $M_E$, respectively. As a comparison, the radiogenic heating power of the Earth is of the order of 20-25 TW. Rocky planets may also reach similar dissipation rate but for significantly shorter orbital periods ($\sim$ 6 days).

Using a 3D coupled model, Běhounková et al. [6] showed that tidally-induced thermal runaways are likely in the interior of Earth-size planets orbiting at orbital periods lower than 6-7 days and for eccentricities above 0.01. Here we propose to extent this analysis to larger planetary bodies by combining 3D and 2D approach [7]. The final objective is to develop a general scaling that will be used to assess the possible thermal states of detected exoplanets from their mass, radius and orbital configuration.

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## References

[1] Bonfils, X., Delfosse, X., Udry, S., et al. (2011), ArXiv e-prints

[2] Sotin, C., Grasset, O. and Mocquet, A. (2007). Icarus, 191, 337-351.

[3] Castillo-Rogez, J. C., Efroimsky, M., Lainey, V. (2011). J. Geophys. Res., 116, E9, CiteID E09008.

[4] Efroimsky, M. (2012). Astroph. J., 746, article id. 150.

[5] Tobie, G., Mocquet, A., Sotin, C. (2005). Icarus, 177, 534-549.

[6] Běhounková, M., Tobie, G., Choblet, G., Čadek, O. (2011). Astroph. J., 728, article id. 89

[7] Besserer, J.; Mocquet, A.; Tobie, G.; Choblet, G.; Behounkova, M.; Cadek, O. (2011). EPSC-DPS Joint Meeting 2011, p. 927.