Tidal heating in multilayer planets : application to the Trappist-1 system

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Motivation

The Trappist-1 planets represent good candidates for exobiology studies. Thus, it is important to constrain the system to prepare for future observations (e.g. with the JWST).
For these close-in planets, their orbital, rotational and interior evolution can be strongly driven by tides.

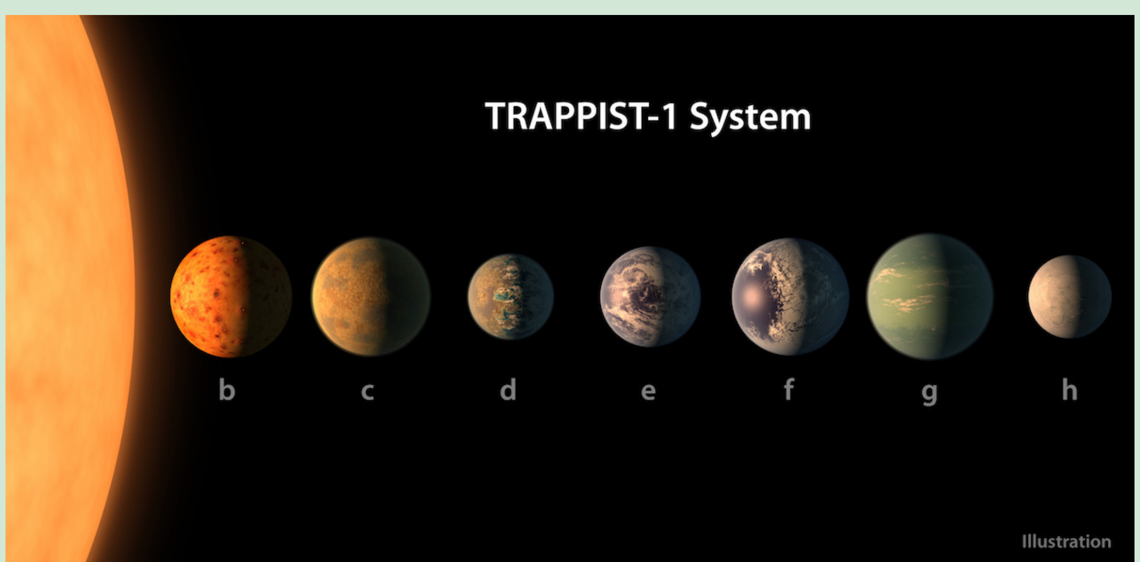
Problem : Most tidal orbital models use only simple tidal description: homogeneous body and simple rheology.

Solution: A multilayer model for planet interiors and Andrade rheology: knowing the mass and radius of the planets, we can infer a possible generic multilayered structure of a planet interior.

How does this multilayer structure impact the tidal response ?

About Trappist-1

- The star: Trappist-1a, only 9% the mass of the Sun
- The planets: 7 Earth-like planets, 4 in the Habitable Zone



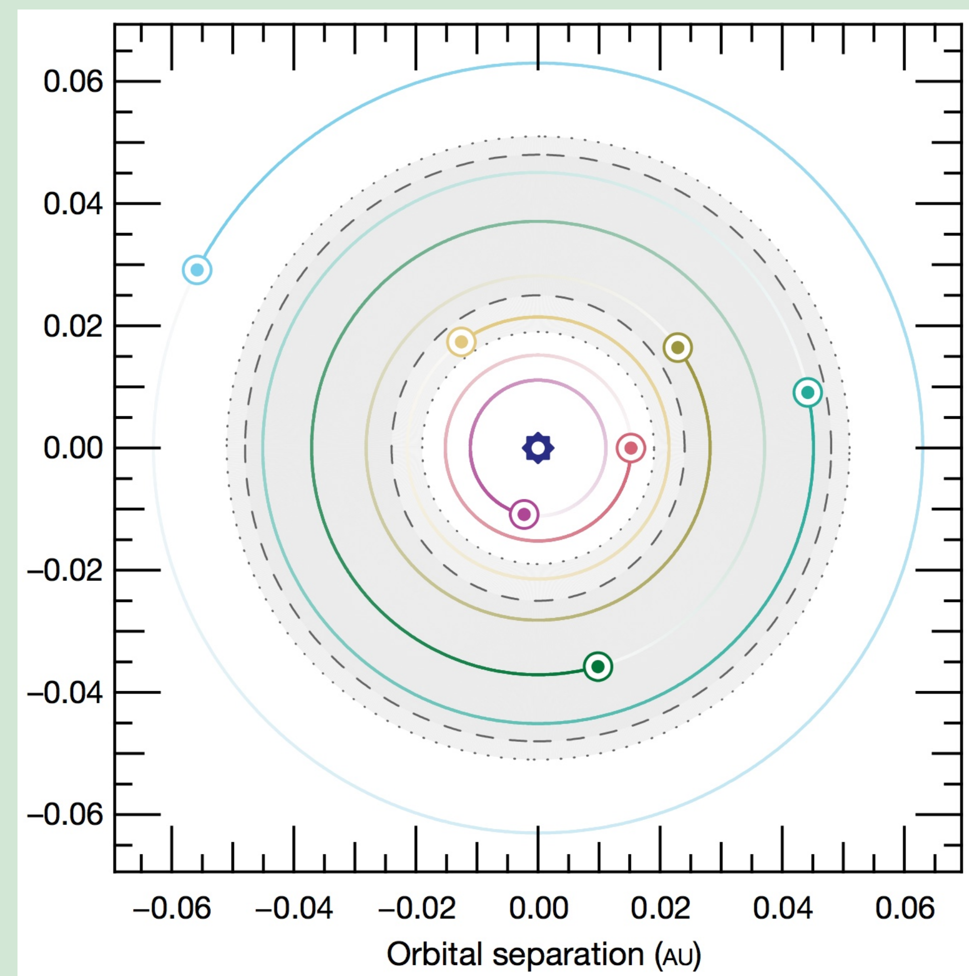


Figure 1: Orbital architecture of TRAPPIST-1 (Gillon et al. 2017). The Habitable Zone is in gray.

Comparison between multilayer and homogeneous models

Structure model from Tobie et al. 2005

3 internal structure profiles for Trappist-1e :

- Homogeneous profile with uniform viscosity and rigidity module
- Multilayer profile 1 with 138% ratio Fe/Si in the mantle with respect to Earth and 0% proportion of ice (Grasset et al. 2000)
- Multilayer profile 2 with 150% Fe /Si ratio in the mantle with respect to the Earth and 5% proportion of ice

The chosen rheology is Andrade's : viscoelastic rheology with memory of the material.

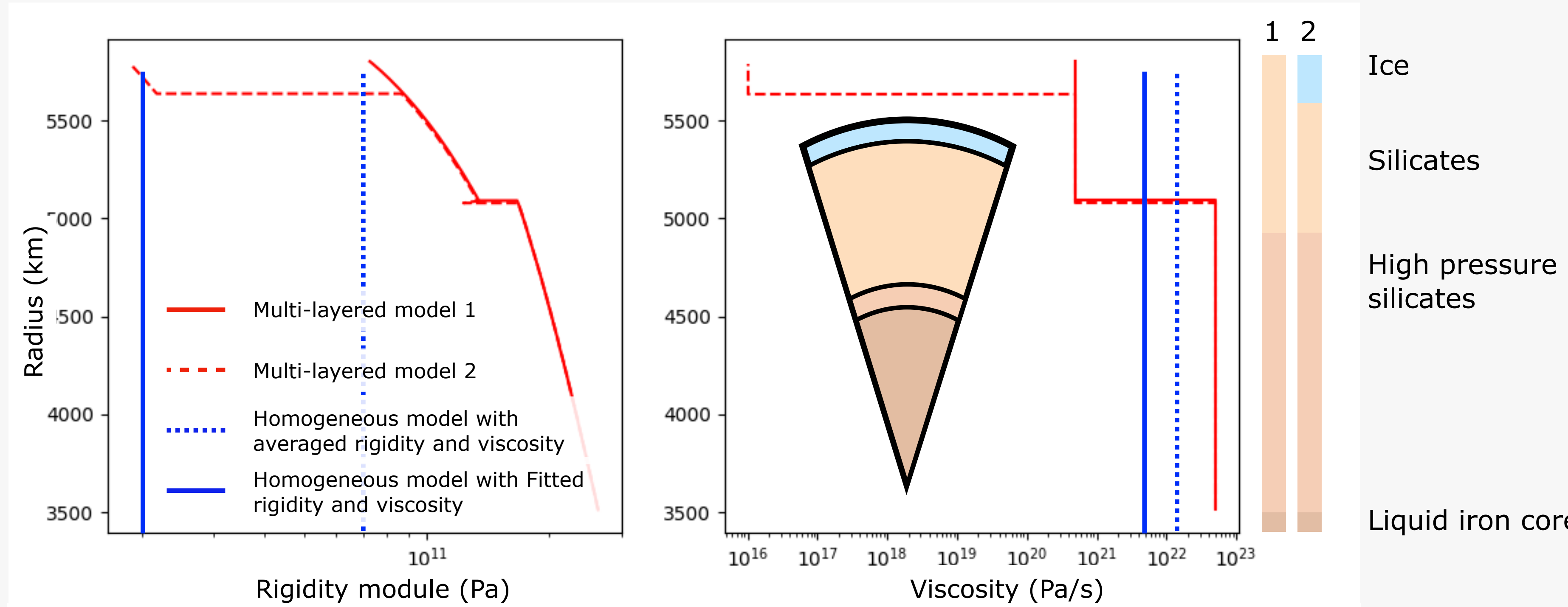
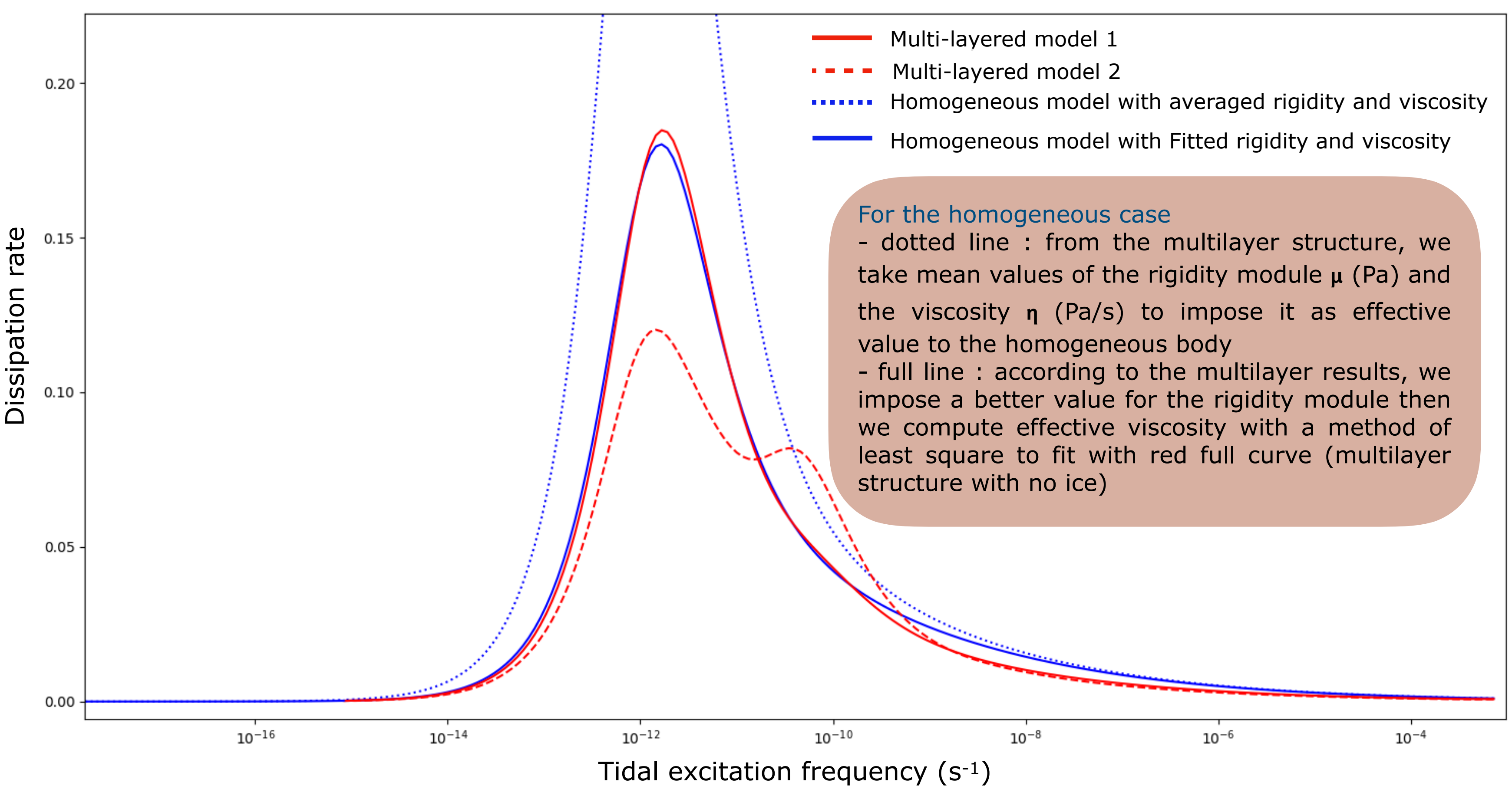


FIGURE 2: Radial profile of the rigidity module and viscosity for a planet of 0.772 $M_\oplus$, 0.910 $R_\oplus$

FIGURE 3 : Comparison between the value of the dissipation (imaginary part of the Love number) for the planet Trappist-1e, computed thanks to Takeuchi and Saito's multilayer approach (1972) and after Efroimsky's proposition for homogeneous spherical bodies (2012)



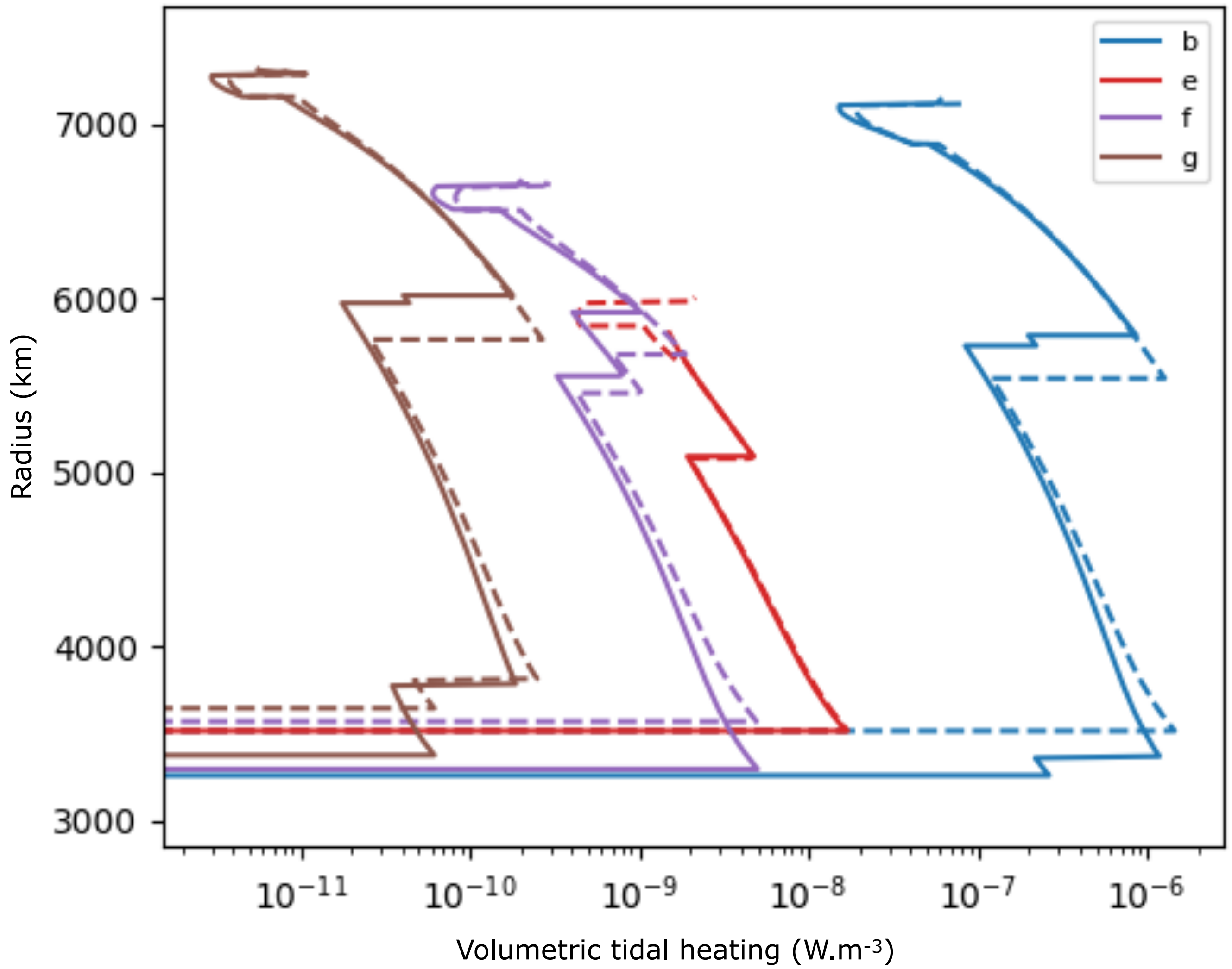
The Love number k_2 of a body describes its response to a tidal potential. Especially, its imaginary part allows to estimate the dissipation due to tides in planet interior.

The curve profile of the homogeneous model does not allow to predict the behavior of planet with ice that we compute with the multilayer model.

We see that with only 5% of ice the behavior is totally different.

TIDAL HEATING OF TRAPPIST-1 PLANETS

FIGURE 4 : profile of tidal heating for Trappist-1b, e, f and g



- Far from the star, contribution from tidal heating effects quickly become less effective.
- But tidal heating may still be one of the effects with no negligible contribution to the total heating processus of the interior of the planet.

Comparison of the tidal heating of the 3 planets within the habitability zone to the case of Trappist-1b

Trappist-1b, very close to the star experiences an extremely important heating rate (see Table 1):

- 4 to 5 times more than for Io, most active telluric body of the Solar system (100 TW).
- 8 to 10 times more important than the total heating on Earth (50 TW).

Planet	Mass ($R_\oplus$) / Radius ($R_\oplus$)	Ice (%)	Ratio Fe/Si (%)	Global tidal heating (TW)
b	1.017 / 1.121	20.5	100	413
		24.0	150	519
e	0.772 / 0.910	0.0	138	2.8
		5.0	150	2.9
f	0.934 / 1.046	11.0	100	1,0
		14.5	150	1,1
g	1.148 / 1.148	19.0	100	0.09
		22.5	150	0.11

TABLE 1 : property of some planets of the system and tidal heating