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Stéphane Labrosse
Laboratoire de géologie de Lyon
École normale supérieure de Lyon

Report on the habilitation thesis of Marie Běhounková entitled :
Tides in terrestrial planets and icy moons.

Marie Běhounková presents a thesis where she summarises her work for the last twelve years on the topic of tides in terrestrial planets and moons. The forty page long summary is followed by a collection of eleven papers which she co-authored and for which, as she puts it, she has contributed significantly. This collection is only a selection of Marie's publications list which contains three times more papers, including some in which she obviously contributed significantly, but are not directly related to the topic of the thesis, in particular early papers in her career. I have gone through the check of originality of the thesis done by the system Turnitin and it is absolutely clear that the thesis represents an original work with minimum overlap with the existing literature. Before getting in the specifics, I want to state that I am impressed by the work of Marie Běhounková and that **I strongly recommend granting her the habilitation**.

The topic of Marie Běhounková's thesis is important for our understanding of the structure, dynamics and evolution of planets and moons, in our solar system as well as for exoplanets. It is also quite complex and technical since it combines several key ingredients, each of which being worthy of independent studies : mantle convection, tides, rheology and orbital and rotational evolution. In principle, the idea is simple : tides deform planets and moons and because they are not purely elastic (rheology), part of that deformation is dissipated into heat. This process, as it transfers orbital and rotational energy into heat inside the objects, makes the orbits evolve. Since the rheology is temperature dependent, this process depends on the thermal structure of the object, which is controlled mainly by convection, which itself depends on the heat sources, including tides, and the rheology. But to go beyond these simple ideas requires several quite technical skills, first to master the theoretical basis of the various aspect of the problem and then solve it, essentially using numerical models.

The thesis starts with an introduction that presents the role of tides in the dynamics and evolution of planets and moons and how these can be used to infer constraints on their internal structures. This short presentation positions the problem and shortly mentions the past and future space missions relevant to the topic.

The second chapter provides a summary of the theories needed to adress the problem and the numerical tools that Marie Běhounková has developed and used to solve it. The first part concerns tidal forcing and the associated deformation introducing Love numbers. The second part deals with rheology, starting with a purely elastic one and introducing various models of visco-elastic rheology, mainly the Maxwell and Andrade models. The third part presents tidal deformation, various approaches to compute it and the induced dissipation. It starts with normal mode theory, which is the simplest (computationally) but cannot easily solve laterally varying properties or deviations from sphericity. The time domain approach is then introduced as well as the numerical strategies to solve it, finite difference-spherical harmonics or finite elements. The fourth part shortly covers the convective heat transfer theory and numerical models. The fifth part presents the theory for the orbital and rotational evolution of the studied objects and the sixth part shortly discusses the coupling between various models. The time scales of each process are mentioned and the simplifications used in the various studies, in relation with the various papers associated to the thesis. This chapter covers a lot different notions in twenty pages and cannot pretend to provide all the details that one might need to develop his or her own models. However, it provides the basic structure needed to understand the logic behind the various studies that are discussed in the following chapter. Being personally not expert on the tidal deformation part, I enjoyed getting that short introduction on the topic.

The third and last chapter of the thesis discusses the applications to various objects, mostly moons in the solar system (Enceladus, Europa) and exoplanets close to their stars. The first section is general and concerns the tidal heating as function of frequency and choice of rheology and the implications in terms of planetary convective evolution. Depending on the efficiency of convective heat transfer and the amount of tidal heating, two scenarios are possible, a balanced situation or a runaway heating that leads to melting of the object. The second section discusses the applications to Europa, which is an object of primary importance for habitability issues and is the target of planned future missions. This section summarises a recent paper that is provided in the thesis. Tidal dissipation and convection are modeled in the rocky core of Europa and the study shows that at present time, tidal heating is a significant contribution of the surface heat flow, even possibly dominent for periods of large eccentricity. Some possible outcomes from the planned missions might allow testing of this model. The third section discusses studies of Enceladus, which has received an important attention of the community since the discovery of the intense activity at its south pole. This section and the associated papers show the large part Marie Běhounková played in the studies trying to understand this activity, which is challenging owing to the small size of that moon and the limited amount of heat sources that are expected. Interestingly, that topic has shifted significantly with the demonstration in 2016 that the ice crust is in fact quite thin and unlikely to sustain convection. Marie Běhounková has modeled the dynamics and evolution of Enceladus before and after that turning point, with different model assumptions. I was in particular impressed by the various models used to assess the effects of the important ingredients to this problem, like for exemple the tiger stripes and the lateral variations of the ice thickness. The last section of that chapter discusses results on terrestrial exoplanets, their rotational-orbital evolution and implication for their habitability. This topic is quite interesting but also more speculative since it opens new territories for which observations are still scarce.

The research topic presented by Marie Běhounková is quite complex as it combines several processes that each are already rather complex. An additional difficulty comes directly from their coupling, their different time scales and their feedbacks. Being able to produce meaningful results and separate the various effects is a real challenge but the collection of papers shows that Marie Běhounková is one of the very few researchers in the world that can do that. Two of these papers are first-authored by a student supervised by Marie and it is clear to me that she deserve being granted the habilitation.

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Stéphane Labrosse
Professeur
École Normale Supérieure de Lyon
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