Our ref: Review of Habilitation Thesis "Tides in Terrestrial Planets and Icy Moons" of Dr. Marie Běhounková

Phone: +31 15 27 88272

E-mail: L.L.A.Vermeersen@tudelft.nl

TU Delft
University of Technology Delft

Faculty Aerospace Engineering
Planetary Exploration
Kluyverweg 1
2629 HS DELFT Netherlands

Department for Science and International Relations
Faculty of Mathematics and Physics, Charles University
Ke Karlovu 3
121 16 Prague 2
tel. 951551220

Dear Prof. Málek,

I have read Marie's habilitation thesis on "Tides in Terrestrial Planets and Icy Moons" with great interest and pleasure. It is a fine piece of work that puts together Marie's high-impact publications on an important subject in planetary sciences and astronomy: tides. Although of minor importance for the solid Earth, tides dominate the energy balance and shape many of the moons orbiting the outer planets. Icy moons have been, are, and will be prime targets of space missions of NASA and ESA. They offer the best possibilities for finding extraterrestrial life in their interior oceans and the outer planetary systems in our Solar System are nearby analogue study objects for exoplanetary systems. I especially appreciate that Marie has worked on both: icy moons, especially Jovian Moon Europa and Saturnian moon Enceladus, and exoplanets. The search for earth-like exoplanets and possible extraterrestrial life on them is one of the most important topics in astronomy nowadays and tides might well turn out to be an essential ingredient here.
Marie has especially worked on the theoretical and numerical modelling of signatures resulting from tidal interactions. Notably the coupling between the simulated models was studied, important to get an idea of and a grip on the complicated feedback between tidal heating, thermal evolution and orbital-rotational changes. We are at the beginning of understanding these complicated interactions that require knowledge and numerical skills of many physical and chemical subareas of the natural sciences. Fundamental aspects for this understanding have been investigated and modeled in Marie's papers, with some remarkable and important new results, including:

1. silicate melt production in the interior of Europa and its consequences for the long-term dynamics and internal water ocean chemistry of Europa;
2. heat loss in relation to tidal dissipation for Enceladus leading to the conclusion that Enceladus likely contains a deeper heat source;
3. the possible strong local influence that the four main tiger stripe faults near Enceladus' south pole might have on increasing the effectiveness of tidal heating;
4. constraining the conditions for thermal runaways for exoplanets and triggering large-scale magmatic activity; and
5. strong increase of tidal dissipation when locking into high spin-orbit resonance for low eccentricities.

Undoubtedly, these models and findings will lead to applications when new data become available from planetary missions as JUICE and Europa Clipper and from space-borne astronomical telescopes aimed at exoplanetary systems.

Our ref: Review of Habilitation Thesis "Tides in Terrestrial Planets and Icy Moons" of Dr. Marie Běhounková

Phone: +31 15 27 88272

E-mail: L.L.A.Vermeersen@tudelft.nl

Marie has nicely summarized all important aspects of her work in the Methods & Models and Application chapters, after a clear Introduction chapter on the subject of tides and its many consequences. The Methods & Models chapter testifies of her broad knowledge on such subjects as rheologies, heat transfer, tidal dissipation mechanisms and orbital & rotational changes. The way in which to numerically model these and how to couple them is well described. How all these elements play a role in the 11 publications becomes clear from the nice overview in the Summary section 2.7, which I found particularly helpful in assessing the publications.
The Applications chapter gives a lucid overview of the many implementations of the methods and models. General aspects are treated and discussed on thermal-tidal coupling and the way tidal dissipation affects both icy moons and exoplanets. For the icy moons Europa and Enceladus connections are sought with observable features and whether tidal dissipation could lead to convection in a thermally evolving interior. Also the possible effects of tidal interaction and dissipation on surface features were studied, notably on fault patterns. For exoplanets, of which we have less data than on the icy moons in our Solar System, Marie's numerical models have been applied to terrestrial exoplanets themselves without moons, particularly on the coupling between orbital changes of the exoplanet around its star, rotational variations and tidal dissipation. Resonances play an important role here, and these are well dealt with in this Chapter.
Future work will extend on the models and applications, notably on orbital – thermal evolution modeling including on outer perturber and non-zero obliquity. It is interesting to read that these models will not only be applied to Enceladus, but also to the Jovian and even the Earth-Moon system. Regarding more realistic rheological modeling, effects of melt will be included, which already has been studied to some extent for Io (last December one of my PhD-students, Teresa Steinke, successfully defended her PhD-thesis on this). It is certainly interesting to consider effects of melt in rheological models of Europa and for exoplanets, as is proposed in Section 4. Furthermore, effects of time-dependent stresses and lateral ice crustal thickness variations will likely lead to new insights. All plans as suggested by Marie for further model developments and their applications seem realistic, doable and important to me.

The list of 11 publications reflects and guarantees the high quality of Marie's work. All 11 papers are published in high-impact and high-citation index international journals, including a first-author paper in Nature Geoscience. Furthermore, 7 of these 11 papers are first-author publications, and also for the other 4 publications it is clear from the statements on page 63 of the thesis that Marie made important major contributions.

I have gone through the originality check of the thesis as performed by the system Turnitin. It is clear to me that the thesis represents an original work based on an excellent collection of 11 papers in high-impact international journals. I could not identify any scientific misconduct regarding copying.

To conclude: I am impressed by both quantity and quality of the work as presented in the habilitation thesis. The thesis meets all requirements for a standard habilitation work, in my opinion, and I have no recommendations for further work that should be done for this thesis.

I thus fully and unconditionally recommend the Habilitation degree for Marie.

Delft, The Netherlands, March 31 2022

[redacted]

Prof. Dr. L.L.A. (Bert) Vermeersen
Chairholder Planetary Exploration TU Delft