Abstract

The past few decades have seen a dramatic expansion of our knowledge on planets not only thanks to the numerous planetary missions and exoplanet surveys, but also our advances in understanding the physics inside planets from the theoretical side, and being able to simulate our hypotheses thanks to the breakthroughs in scientific computing. Regrettably, due to their far away distance from Earth, Uranus and Neptune were mostly neglected in terms of visitors (unlike their bigger siblings Jupiter and Saturn), and our only *in situ* measurements come from the *Voyager 2* flybys from the late 1980s. This is quite unfortunate, as our far away giants are as interesting as the other two, if not more. Until new data is available, we are bound to push our understanding of Uranus and Neptune further by theoretical modelling of the physics that might be present inside them.

Probing planetary phenomena and the properties of the involved materials were and still are very challenging topics due to the complexities within planets. Fortunately, with the advances in both computational power and experimental setups, we are slowly reaching a point where we are able to simulate or emulate planetary conditions here on Earth, be it inside a computer or a laboratory. However, since there are still many uncertainties regarding the interiors of Uranus and Neptune (mostly due to lack of data), *generalizable* theoretical models of any kind of physical property are powerful tools for interpreting the implications of interior structure models that were generated with varying physics in consideration. Planets being complex systems with various different aspects of physics all influencing each other, getting a better understanding of a certain phenomenon will eventually help us constrain and interpret the behavior of other kind of physics better.

Our work addresses *(i)* the lack of information regarding *the electrical properties inside Uranus and Neptune, especially between their atmospheres and their dynamos.* Data on this region of *rapidly increasing electrical conductivity* (as we have discovered it to be) is very scarce in the literature, and we start this work by presenting our generalizable models for ionically conducting H_2–He–H_2O mixtures that might be present in Uranus and Neptune. We then move on to *(ii)* understanding the inevitable *coupling between zonal winds and the background magnetic fields* of Uranus and Neptune; the implications of this coupling on *zonal wind depths*, and the possible existence of *detectable poloidal magnetic field perturbations* that are induced via this coupling. Lastly, we present our work on *(iii)* the *dynamical implications of zonal winds* on Uranus and Neptune with regards to *zonal gravitational harmonic measurements*, *planetary shapes and rotations.*

The work presented in this thesis is a first step towards generalizing the electrical properties inside Uranus and Neptune and the coupling of zonal flows with the magnetic fields due to it. However, there are still many different configurations of material mixtures that needs to be modelled, and various 3D coupling simulations that needs to be run to be able to get a more complete understanding of this intricate and important interaction within Uranus and Neptune. Having these models available will pave the way for correctly interpreting any *in situ* magnetic field measurement that will be done on a future mission. Same is true for the investigation done on the implications of dynamics of zonal winds in this work. These models are needed to correctly interpret data from future orbiter missions, and will eventually reveal the truth of our hypotheses and the shortcomings of our models.

During my PhD, in addition to my research on understanding the magnetic field–zonal field interplay in Uranus and Neptune, I have worked on exploring the non-Uranian science potential of a prospective mission to Uranus. An interplanetary mission to Uranus would be in contact with Earth via its radio link, and this setup would provide an exceptional opportunity to detect gravitational waves passing through the solar system, potentially constrain the local dark matter content, and also localize the hypothesized “Planet 9”. Thus, we were able to show that a prospective mission to Uranus is not only necessary and important for understanding the Uranian system better, but also an exceptionally opportunity to conduct non-planetary science in an efficient and cheap way. In the end of this thesis work, we will briefly mention these possibilities in detail, and in the respective published papers will be listed in the Appendices.