Gravimetry and stresses of Mars and its Moons

Planetary missions to the planets and small bodies of the solar system are now aimed at determining the internal structure of planetary objects by deploying on their surfaces geophysical instruments. These measures stem from the scientific need to better understand the formation and evolution of planetary systems, to understand the long-term interactions between internal and external dynamics that control the habitability of planets, and to determine the mechanical properties of small bodies in order to protect ourselves against near-Earth asteroids.

Symbol of this revival of planetary geophysics, the INSIGHT mission deployed at the beginning of 2019 on the surface of Mars a high-precision seismometer (SEIS). This instrument will allow to constrain the structure of the Martian crust and to estimate the Martian seismicity in its tectonic context. But missions to the small bodies of the solar system will also deploy surface geophysical sensors in the coming years.

The main objective of this PhD thesis is to set up tools to model the gravity and stress fields of Mars, its moons and the small bodies of the solar system, in order to prepare the scientific return of INSIGHT and MMX missions, but also HERA and PSYCHE missions. The tools will be validated on the data already acquired by the missions NEAR, HAYABUSA, HAYABUSA-2 and OSIRIS-REX.

A numerical tool has been developed at ISAE-SUPAERO for the modeling of the gravity and deformation fields of an object that does not have spherical symmetry (Pou, 2019). Such a tool can be applied either to volcanic structures on the surface of Mars (by principle of superposition of the gravimetric field of the structure on a global model), or to small bodies such as Phobos or Didymos.

As a first step, the modeling tool will be applied to the modeling of the Phobos gravity field in order to determine the local variations of the gravity field on the surface of Phobos. Indeed, unlike other simulation tools that calculate only the variations of the gravity field outside a sphere including the object or above the surface, our tool allows to calculate the gravity field in the whole domain. These modelings will allow a better understand of the deployment of the rover of the MMX mission. Then a strategy of inversion of density variations inside the object will be set up for simple models and applied to data from previous missions to Eros, Itokawa, Bennu and Ryugu. In particular, we will analyze the differences in data fit between homogeneous models and models that include lateral variations in density.

In parallel with these applications, the modeling tool will be extended to the determination of the stress fields inside the considered object. This extension will be realized using the same numerical tools and will benefit from the capacity of the current code to model the gravity field inside the objects.

Finally, the modeling of the stress field will allow several different scientific studies. First of all, the stress field in the Martian crust will be modeled for the volcanic structure of the Elysium volcano and the Cerberus fossae tectonic system in order to connect the seismicity measured by INSIGHT in this region to the Martian tectonics. The stresses and deformations generated by the Mars tide on Phobos will also be modeled to estimate the non spherical body's love numbers and to predict the potential seismicity of Phobos under the effect of the Martian tides (Murdoch et al., 2017).

References:

- Pou, S. L. (2019). *Contraintes sur la structure interne de Mars et mesures de la marée de Phobos pour la mission INSIGHT* (Doctoral dissertation, Toulouse, ISAE).
- Murdoch, N., Hempel, S., Pou, L., Cadu, A., Garcia, R. F., Mimoun, D., ... & Karatekin, O. (2017). Probing the internal structure of the asteriod Didymoon with a passive seismic investigation. *Planetary and Space Science*, *144*, 89-105.