STEM

The STructure and Evolution of Mercury's core

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SUMMARY

Context and objectives

Mercury, the smallest and innermost planet in the Solar System, has several unique characteristics that can help to improve our understanding of planetary formation, structure, evolution, and habitability. The first mission ever to fly by Mercury, Mariner 10 in 1974, showed that Mercury is much more massive than its size suggests compared to the other terrestrial planets. This indicates an unusually high metal to silicate ratio and an iron core that is relatively to the size of the planet much larger than that of the Earth, Mars and Venus. Mercury has by far the most elliptical orbit around the Sun of any other Solar System planet and is the only Solar System body in a 3:2 spin-orbit resonance -- meaning that Mercury spins on average exactly three times during the time it needs to complete two full orbits around the Sun. This unique property leads to small periodic variations in Mercury's rotation rate that can be used to probe the deep interior, the central topic of this research project.

Observations of these librations, by Earth-based radar and by radio tracking and laser altimeter measurements of the NASA MESSENGER spacecraft, revealed that the core is mechanically detached from the solid mantle and therefore must be liquid close to the core-mantle interface. Mercury also features a relatively weak, global magnetic field generated most likely by fluid flows in its molten and electrically conducting core, not unlike Earth's geomagnetic field. Mercury is the only other example of a terrestrial planet with a self-sustained magnetic field, apart from Earth, which makes it invaluable in order to test and develop planetary magnetism theories.

The aim of this project was to improve and refine our understanding of the formation and evolution of Mercury's interior from current and future rotation data, complemented by other geophysical data, by developing two separate but closely related pathways, building upon the expertise within the planetary research group at the Royal Observatory of Belgium. We planned to extend libration theory to include flow in the outer liquid core and to develop a new thermal modelling of Mercury's core to aid and improve the interpretation of geodesy data in terms of interior properties. Planetary geodesy - the study of the rotation, gravity field and shape of a planet – currently constitutes the main source of information on Mercury's interior.

Results

We describe the main results of the STEM project organized according to the two principal research themes.

Interior structure and evolution (WP1 and WP3)

We developed two methods to model the evolution of the core of Mercury, and take for the first time the growth of a solid inner core and the evolution of a stably stratified layer at the top of the core into account. We coupled the evolution of the core to that of the mantle and discovered that there is a significant feedback between the evolution of the core and that of the mantle, in contrast to for example the evolution of the Earth. Because convective energy transport may not be the dominant

heat transport mechanism in the mantle during Mercury's entire history and the transition from a convective to a conductive state is not captured well in existing parametrized mantle evolution models, we also developed a new parameterized model of the evolution of the mantle that smoothly transitions from convection to conduction.

We calculated a large number of evolution scenarios for Mercury in order to assess the dependence of the evolution on the composition of the core and on properties of the mantle. This study allows to put constraints on Mercury's interior. We showed that a stable layer in the core delays cessation of mantle convection and allows for a past and present-day dynamo, in accordance with observations. We demonstrated that Mercury's core must likely have other light elements than silicon otherwise Mercury could not have a dynamo operating at present time. Models with a small fraction of sulfur as additional light element generate sufficient ohmic dissipation to drive a past and present-day dynamo. They have a present-day inner core with a radius of ~1000km and a ~600km thick thermal boundary layer. Our results also show that the cessation of mantle convection decreases the thickness of the thermally stratified layer and increases ohmic dissipation.

Core flow

We developed a method to determine the flow in the core of Mercury due to the libration of the mantle. The set of governing equations and boundary conditions was solved by an analytical method coupled to a numerical calculation with the KORE code. We considered coupling between the core and the mantle through viscous and electromagnetic torques. They were shown, for realistic parameter values, to be several orders of magnitude smaller than the total torque needed to drive Mercury's observed mantle libration. Given the limited precision of the observed libration amplitude of several percent, we could therefore conclude that the flow in the core due to core mantle coupling can be neglected in studies that interpret the observed amplitude of the libration of Mercury in terms of the interior structure of the planet.

Since Mercury is expected to have a stably stratified layer at the top of the core, we specifically considered how such a layer can affect the core flow. We showed that stable stratification strongly suppresses radial motion and that flow in the core is therefore restricted to the layer close to the core-mantle boundary when the top of the core is stably stratified. In that case, libration leads to a strong tangential flow near the top of the core. This flow induces a non-axisymmetric magnetic field that might explain certain features of the observed magnetic field of Mercury.

Keywords: terrestrial planets, Mercury, interior structure, evolution