A deep history of the terrestrial planets

Interior dynamics of Mercury, Mars, and the Moon through time

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In Short

- Terrestrial planets are bodies with a solid surface, whose bulk composition is dominated by silicate rocks and metals
- Their evolution is largely controlled by the amount of energy produced and/or available in their interiors as a function of time
- Massive 3D numerical simulations of the interior dynamics of Mercury, Mars, and the Moon can be constrained by spacecraft and telescopic observations
- Improving our understanding of the evolution of the terrestrial planets is key to characterize our own solar system in the context of the thousands of extrasolar planetary systems discovered

In this project, we employ our mantle convection code Gaia [1] to investigate the thermal history of Mercury, the Moon and Mars. Our models are constrained by data from space missions and telescopic observations that help us make robust inferences on the evolutionary paths of these terrestrial bodies. In addition, we focus on coupling large impact simulations with models of interior dynamics to understand how such energetic events, which were common in the first billion of years of the solar system, will affect the subsequent evolution of Mercury, the Moon and Mars [2].

Mars

In-situ heat flow and seismic measurements are ultimately important to understand the thermal state and interior structure of terrestrial bodies, but so far such measurements are available solely for the Moon and the Earth. The NASA InSight mission (http://insight.jpl.nasa.gov), which successfully landed on November 26th 2018 in the Elysium Planitia region, Mars, will perform unprecedented in-situ heat flow and seismic measurements of the red planet that will help constrain its present-day thermal state and interior structure and in turn its thermochemical history.

In preparation of the upcoming seismic and heat flow measurements from InSight, we have developed thermal evolution models of the interior of Mars [3, 4], which will help to interpret the InSight data in a global context. In a recent study, we combined the largest-to-date set of 3D numerical simulations of the thermal evolution of Mars with pre-InSight geological, geophysical, and petrological data sets to constrain the present-day thermal state and interior structure of the planet [3]. Our results suggest that Mars possesses a core with a radius larger than 1800 km and an average crustal thickness between 46 and 87 km, strongly enriched in heat producing elements. The strong depth-dependence of the viscosity leads to the formation of prominent mantle plumes that may produce melt up to the present day below Tharsis, the largest volcanic province on Mars (Fig. 1). In an additional study, we have used our thermal evolution models to predict the present-day seismicity of Mars. Our results suggest that deep seismic events could be expected, if the crust is sufficiently thick and highly enriched in heat producing elements, and consequently the mantle is considerably depleted leading to a stiff lithosphere [4].

The forthcoming heat flow and seismic data of InSight will provide valuable anchor points to further constrain thermal evolution models of Mars and to select the most representative models that are compatible with the present-day heat loss and seismicity of the planet.

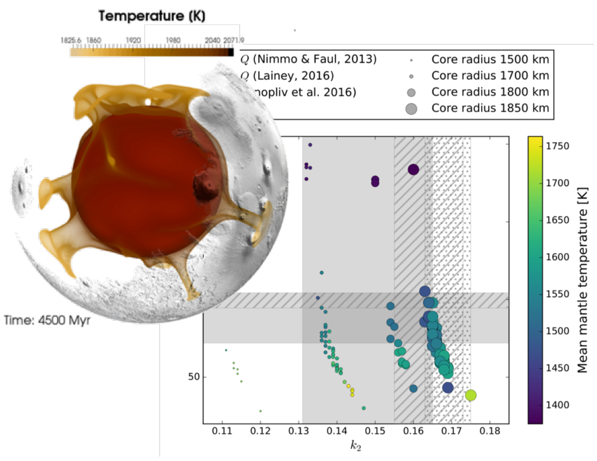

Figure 1: *Thermal evolution models of Mars and their comparison with estimates of the tidal Love number k_2 and tidal quality factor Q (shaded regions) [3]. Each symbol stands for a full 3D thermal evolution model (130 models in total) and the size of each symbol indicates the core radius used in the model. The 3D view shows the location of present-day mantle plumes in the interior of Mars overlain by the MOLA topography for the southern highlands.*

The Moon

We have started to investigate the thermo-chemical history of the Moon by linking its global evolution to the data-sets relative to the large basins, with an approach similar to the one used for Mercury in [5]. The battered lunar surface bears evidence of energetic collisions with asteroids during the early history of the Solar System. Most noticeable is the South Pole Aitken (SPA) basin with a diameter of about 2400 km, which was formed about 4.3 Gyrs ago. The absence of volcanic material in the interior of SPA provides valuable constraints for the magmatic evolution of the Moon, and in particular may help characterize the distribution of heat producing elements in the lunar subsurface [6].

We started collaborating with colleagues at the Museum für Naturkunde in Berlin to more appropriately model the effects of large basins formation on the mantle evolution. Hydrocode simulations obtained with the numerical code iSale [7] are coupled to the thermal evolution models of the Moon by considering the temperature anomaly introduced by large-scale impacts at specific times during the lunar history (Fig. 2).

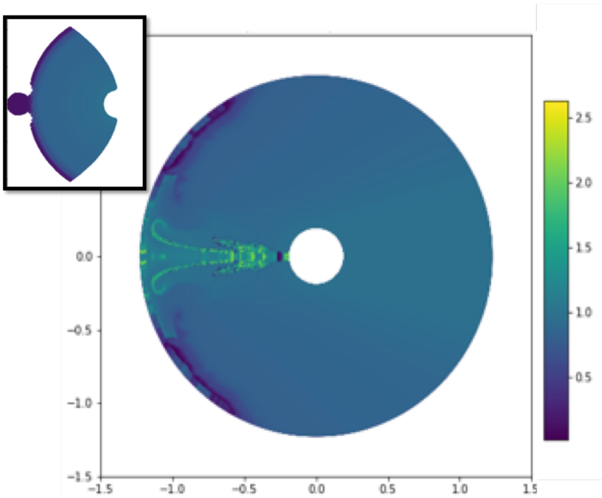

Figure 2: *Non-dimensional thermal anomaly introduced by a large-scale impact obtained running the iSale code and interpolating the data on the Gaia grid using Delaunay triangulation. The inset shows the iSale temperature data right before the impact.*

Outlook

In future studies we will focus on the effects of large scale impacts on the thermo-chemical evolution of stagnant-lid planets. By considering thermal anomalies introduced by large-scale collisions during the early evolution of terrestrial planets, we aim to link surface observations of impact basins to the interior dynamics and thermal history of the Moon. In addition, we will investigate whether chemical heterogeneities formed as a consequence of mantle melting can explain the chemical diversity observed at the surface of terrestrial planets.

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More Information

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