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Constraining the amount of radiogenic elements in the interior of Mars from the HP^3 heat flow measurement

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The InSight mission (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) to be launched in 2016 will carry a seismometer (SEIS) and heat flow probe (HP^3) to the martian surface, and address questions related to the size, physical state, and composition of the core and mantle, the thickness of the crust, and the thermal state of the interior.

The heat flow measured at the surface depends on the amount of heat producing elements (HPE) present in the interior and offers a measurable quantity that can help to constrain the planetary heat budget. If the Urey ratio - the ratio between internal heat production and surface heat loss - is known, the heat production rate in the interior can be determined.

We run thermal evolution models of increasing complexity and compared the obtained present-day Urey ratio for a set of different models/parameters. To this end, we used the 2D-3D mantle convection code Gaia [1], as well as 1D parameterized models [2]. We varied the initial amount of HPE [3, 4,5,6], used various viscosity formulations (temperature-, temperature- and depth-dependent viscosity, viscosity jump in the mid mantle), varied the size of the core, and considered models with and without phase transitions in the mantle. Additionally, we tested the effects of different partitioning of HPE between mantle and a fixed crust, different initial conditions (temperatures and boundary layer thicknesses) and reference viscosities.

Our simulations show that, for a one-plate planet like Mars, the Urey ratio is mainly sensitive to the efficiency of mantle cooling, i.e. the mantle viscosity, and to the mean half-life of long-lived radiogenic isotopes. Given that models of the thermo-chemical evolution of Mars generally indicate reference viscosities below 10^{21} Pa s [3, 7], the martian Urey ratio is likely only a function of the Thorium concentration in the planetary interior. Surface radiogenic abundances determined from gamma-ray spectroscopy [8] are best consistent with the compositional model from [3]. Assuming the bulk Thorium abundance to be known, our simulations indicate that the Urey ratio of Mars can be computed with an uncertainty of likely less than 15%.

If global heat loss can be estimated by the upcoming heat flow measurement with an uncertainty of 20%, and if the InSight seismological investigation can determine the planet's silicate mass fraction to within 20%, error propagation calculations yield an uncertainty of 35% for the heat production rate. Furthermore, the InSight measurement should allow us to distinguish between different proposed compositional models.

References:
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