USING THE INSIGHT MEASUREMENTS TO CONSTRAIN LARGE-SCALE NUMERICAL SIMULATIONS OF THE INTERIOR OF MARS. A.-C. Plesa[1], S. Padovan[1], N. Tosi[1,2], D. Breuer[1], M. Grott[1], M. Knapmeyer[1], M. Wieczorek[3], M. Golombek[4], A. Rivoldini[5], P. Lognonné[6], T. Spohn[1,7], S.E. Smrekar[4] and W.B. Banerdt[4], [1]Institute of Planetary Research, German Aerospace Center, Berlin Germany (ana.plesa@dlr.de), [2]Technische Universität Berlin, Berlin Germany, [3]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, France, [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [5]Royal Observatory of Belgium, Brussels, Belgium, [6]Institut de Physique du Globe de Paris, Université, Paris, France, [7]International Space Science Institute, Bern, Switzerland.

Introduction: The NASA InSight (Interior exploration using Seismic Investigations, Geodesy and Heat Transport) mission will perform seismic and heat flow measurements, as well as measurements of variations of the rotation axis of Mars to determine the present-day thermal state and interior structure of the planet [1]. Measurements recorded at the landing site in the Elysium Planitia region [2], will provide important data that will help constrain the thermal and chemical history of Mars and improve our understanding of how the interiors of terrestrial planets evolve with time.

Large-scale numerical simulations have been applied to model the thermal evolution of the interior of Mars in a 3D spherical geometry [e.g., 3]. The measurements performed by the InSight instruments will provide valuable constraints, which will help select successful models, and, in turn, such calculations will provide a tool to support the overall interpretation of the InSight data.

In this study we discuss how the seismic and heat flow measurements of the InSight mission will improve thermal evolution models of the interior of Mars.

Thermal evolution models: The thermal evolution of the interior of Mars is modeled by solving the conservation equations of mass, momentum and energy [e.g., 4]. The models account for radioactive decay and core cooling during the 4.5 Gyr of thermal evolution and compute the temporal and spatial variations of the temperature, flow velocity, stress and pressure fields.

Crustal thickness: To investigate the effects of a spatially variable crustal thickness on the mantle dynamics and surface heat flow variations, 3D thermal evolution models employed a crust whose thickness is constant in time but varies with location as derived from gravity and topography data (Fig. 1) [3, 5]. The results show a surface heat flow distribution that correlates with crustal thickness variations (i.e., high heat flow values are observed in regions covered by a thick crust, while areas covered by a thin crust exhibit a relatively small heat flow, Fig. 2). In addition, the crustal thickness distribution may affect the location of mantle plumes [3, 6]. However, crustal thickness models are not unique, and differences in crustal thickness between geological locations vary depending on the assumed crustal density and minimum crustal thickness [3, 5]. In addition, the difference in crustal thickness between the northern and southern hemisphere (the so-called crustal

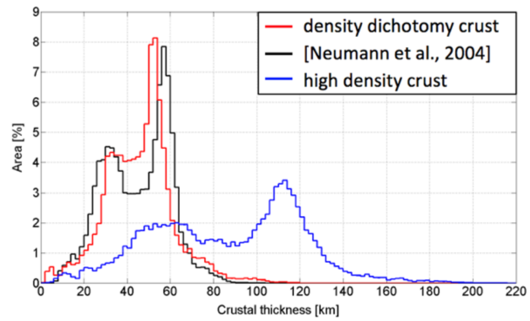

Figure 1: Crustal thickness histograms of crustal thickness models derived from gravity and topography data [3, 7].

thickness dichotomy) can be reduced if the crustal density varies between the two hemispheres [3, 8].

One of the goals of the InSight mission is to determine the crust-mantle boundary depth to within ±10 km at the landing site [e.g., 9]. This can be used to anchor crustal thickness models and constrain crustal thickness variations on a global scale. Hence, a better determination of the crustal thickness variations will help to constrain the variation of the surface heat flow and possibly the location of mantle plumes in the interior. In addition, possible crustal layering that would be observed in the InSight data would provide important constraints for modelling crustal growth processes.

Core radius and chemical state: Up to now only indirect estimates exist for the size of the Martian core. Using the latest estimates of the tidal Love number k_2 [10], the size of the liquid core has been calculated to be larger than 1800 km with a sulfur content of more than 16wt% [6] in agreement with studies about the bulk composition of Mars [e.g., 11]. However, this result is at odds with [12] that suggests a sulfur concentration of only 5wt% [12], which would imply a much smaller core radius (<1500 km) or require other light elements together with sulfur in the core to be compatible with k_2.

InSight's seismic and rotation dynamics measurements will help determine the core radius with

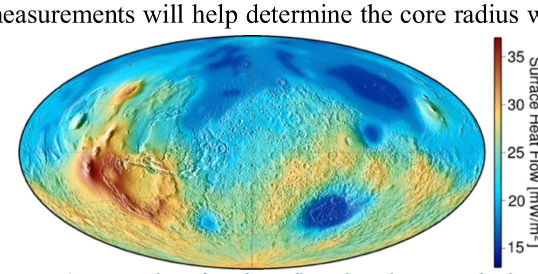

Figure 2: Typical surface heat flow distribution calculated at present day from 3D thermal evolution models [3, 6].

an accuracy of ±200 km [e.g., 9]. The radius of the core is ultimately important to determine whether an endothermic phase transition from ringwoodite to perovskite is present at the base of the mantle, which would affect the core-mantle boundary (CMB) temperature and the interior dynamics. For a core radius < 1700 km, a perovskite layer may exist at least for some time during the evolution, while for a core radius >=1700 km the pressure in the mantle is not sufficient for such a layer to be present.

Whether Mars possesses a solid inner core is not known. Thermal evolution models suggest that the core would most likely be entirely liquid today [e.g., 6, 13]. Nevertheless, an inner core could induce a resonant amplification of Mars' annual prograde nutation [14] large enough to be detectable by InSight [15]. This will provide important constraints for the evolution of the CMB temperature that can be used to improve thermal evolution models of Mars.

Surface heat flow: InSight will determine the heat flow at the landing site to within ±5 mW/m^2 [16]. Thermal evolution models that have assessed the magnitude of surface heat flow variations on Mars suggest that the InSight measurement will return a value representative for the average heat flow of the planet. The average surface heat flow value, can then be used together with an estimate of the planet's Urey ratio, i.e., the heat production rate divided by the total heat loss, to constrain the heat production rate and thus the bulk abundance of heat producing elements (HPE) in the interior of Mars [17]. The latter is an important parameter for thermal evolution models of interior dynamics of Mars, as it controls the amount of volcanic and tectonic activity the planet has experienced over its thermochemical history.

Seismicity: The level of seismicity of Mars is believed to lie between that of the Earth and the Moon So far, indirect estimates for Mars, based on the analysis of surface faults, models of lithospheric cooling and mantle convection, suggest an annual seismic moment between 3.4 x 10^{16} and 3.9 x 10^{19} Nm [7, 18, 19, 20].

The determination of seismic activity of Mars within a factor of 2 for seismicity values >2x10^{18} Nm/yr by

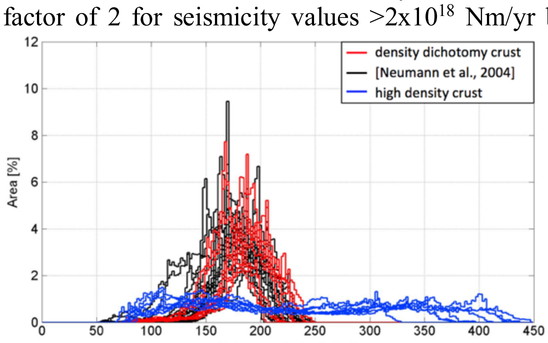

Figure 3: Histograms of the seismogenic layer depth for a suite of simulations employing the crustal thickness models shown in Fig. 1 [7].

InSight would help to constrain the existing seismicity models. In addition, if the depth of seismic events can be estimated from the InSight measurements, this would allow to place constraints on the depth of the seismogenic layer thickness and thus on the thermal state of the lithosphere. Models suggest that the seismogenic layer could extend to depths of about 400 km (Fig. 3), if the crustal thickness is on average 87 km thick and contains about 98% of the bulk abundance of HPE, leading to a cold and stiff lithosphere [7].

Seismic velocities: An important goal of the InSight mission is to determine the seismic velocities in the upper 600 km of the mantle to within ±0.25 km/s [21]. Since seismic velocities are sensitive to thermal and chemical variations, the InSight measurements could help distinguish between various interior models. Models with a thick crust highly enriched in HPE and a large pressure-dependence of the viscosity would lead to larger variations of the lithospheric temperature and a thicker lithosphere compared to a crust poorly enriched in HPE and a weak pressure-dependent viscosity [9].

Mantle viscosity: The viscosity of the mantle is one of the most important parameters in thermal evolution models, as it controls the efficiency of heat transport. Although the InSight measurements will not constrain the viscosity of the mantle directly, they can be used together with thermal evolution models to select parameters that are compatible with the seismic and heat flow data. Hence, the mantle viscosity may be indirectly constrained by selecting representative models.

Conclusions: The Insight mission will provide valuable measurements that can be used to constrain thermal evolution models of the interior of Mars. Surface heat flow and seismic data will help determine the present-day thermal state and interior structure of the planet, and will help select representative models of the interior evolution. In turn, this will provide important implications for the thermal history of terrestrial planets in general.

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