Constraints on the interior structure and composition of Mars from geodesy. Attilio Rivoldini[1,2], Tim Van Hoolst[1], Olivier Verhoeven[3], Antoine Mocquet[3] and Véronique Dehant[1]. [1]Royal Observatory of Belgium, Avenue Circulaire 3, B-1180 Brussels, Belgium (Attilio.Rivoldini@oma.be), [2] Université Catholique de Louvain, Earth and Live Institute, Georges Lemaître Centre for Earth and Climate Research, [3]Université de Nantes, Nantes Atlantique Universités, CNRS, UMR 6112, Laboratoire de Planétologie et Géodynamique, France

Introduction: By measuring Mars' deformational response to the tidal forcing of the Sun it has been deduced that Mars has at least a partially liquid core [1]. Whether at this stage of Mars' evolution the core is completely molten or whether it contains a solid inner core depends mainly on the thermal state of the mantle and on the concentration of light elements in the core like sulfur that reduce the melting temperature of iron. Unfortunately, we have a poor knowledge of the thermal state of the mantle and the core's concentration of light elements. One important clue is the absence of a planetary magnetic field what suggests a completely molten core. Tidal deformations are not only dependent on the state of the core but are also a strong function of the outer core's radius and depend on the planet's composition through its density and elastic properties. In this work, we use geodesy data about Mars to infer knowledge about its interior structure. As data we use the mass and the most recent estimates of the normalized average moment of inertia ($MOI = 0.3645 \pm 0.0005$) and tidal Love number ($k_2 = 0.159 \pm 0.009$) [2].

Method: The aim of our study is to constrain with geodesy data the thickness and density of the crust, the mineralogical composition of the mantle, and the radius, and sulfur concentration of the core. We do not infer the temperature of the mantle from the data since very different pairs of mantle composition and temperature result in almost identical geodesy data. Therefore, we use two end-member temperature profiles that have been deduced from studies dedicated to the thermal evolution of Mars [3]. In our model the mineralogical composition of the whole mantle is determined by the mantle temperature, the bulk mantle iron concentration, and by the volume fractions of upper mantle minerals (olivine, orthopyroxene, Ca-pyroxene, and garnet). The depth dependent mineralogy is computed by using experimentally determined phase diagrams [4, 5]. The thermoelastic properties at each depth inside the mantle are calculated by using equations of state [6]. We calculate the pressure- and temperature-dependent thermoelastic properties of the core constituents by using equations of state and recent data about reference thermoelastic properties of liquid iron, liquid iron-sulfur, and solid iron [7, 8, 9, 10]. To determine the size of a possible inner core we use recent data on the melting temperature of iron-sulfur [11, 12, 13, 14, 15, 16, 17, 18].

In order to infer knowledge about the model parameters from the geodesy data we use a Bayesian inversion method [19]. The result of this method is a probability density functions on the parameters of the model. From the probability density function we calculate marginal densities and estimate parameter values and regions of occurrence.

Results: Fig.[1] represents the inferred relation between k_2 and the core radius if only the mass and the MOI are used as data and the core sulfur concentration is below $25\mathrm{wt}\%$. Within our model assumptions this result shows that for the k_2 value of [2] Mars has no inner core (at 3σ). A result that is in agreement with the absence of a global magnetic field. For the full geodesy data set we estimate the radius of the core to be $1794 \pm 65\mathrm{km}$ and its sulfur concentration to be $16 \pm 2\mathrm{wt}\%$ (uncertainties are at 0.683). The correlation between core radius and core sulfur concentration is made explicit in Fig.[2].

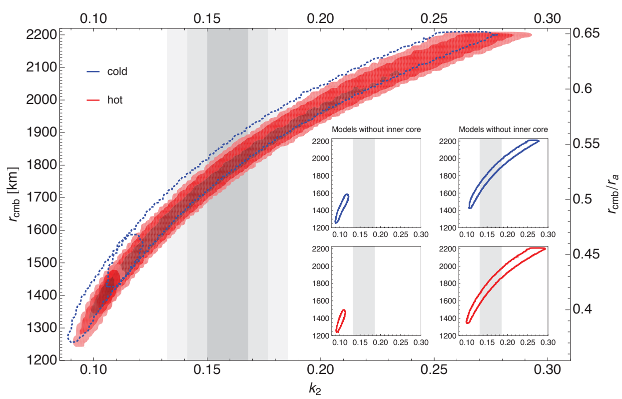

Figure 1: Inferred probability density function on core radius r_{cmb} and tidal Love number k_2 from mass and MOI. The red colored areas delimit 0.997, 0.955, and 0.683 regions of occurrence for hot mantle models. The blue dotted contours delimit the 0.997 regions of occurrence for cold mantle models. The gray bands represent the k_2 value of [2] at 1, 2, and 3σ. The insets correspond to the individual 0.997 contours of the models and the gray bands represent k_2 at 3σ .

The data is compatible with Mars's having a thin layer of perovskite at the bottom of the mantle if the mantle follows a hot temperature profile. Moreover, a chondritic $\mathrm{Fe/Si}$ ratio is shown to be consistent with the geodesy data, although significantly different values are also possible.

Our results demonstrate that geodesy data alone give few constraints on the mineralogy of the mantle and the density and thickness of the crust. In order to obtain stronger constraints on the mantle mineralogy bulk properties, like a fixed Fe/Si ratio, have to be assumed.

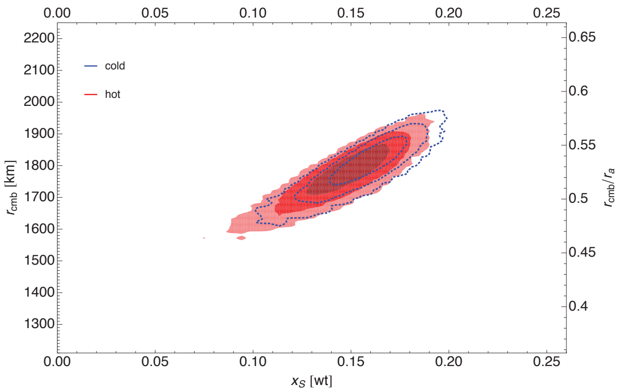

Figure 2: Inferred probability density function on core radius r_{cmb} and core sulfur concentration x_{S} from mass, MOI, and k_2. The red colored areas (blue dotted contours) delimit 0.997, 0.955, and 0.683 regions of occurrence for hot (cold) mantle models.

References: [1] C. F. Yoder, et al. (2003) *Science* 300:299 doi. [2] A. S. Konopliv, et al. (2010) *Icarus* doi. [3] D. Breuer, et al. (2003) *J Geophys Res (Planets)* 108:8 doi. [4] P. Vacher, et al. (1998) *Phys Earth Planet Inter* 106:275. [5] O. Verhoeven, et al. (2005) *J Geophys Res (Planets)* 110(E9):E04009 doi. [6] L. Stixrude, et al. (2005) *Geophys J Int* 162:610 doi. [7] W. W. Anderson, et al. (1994) *J Geophys Res* 99:4273. [8] G. H. Kaiura, et al. (1979) *Canadian Metallurgical Quarterly* 18(2):155. [9] P. S. Balog, et al. (2003) *J Geophys Res (Solid Earth)* 108 doi. [10] T. J. Ahrens, et al. (2002) *Geophys Res Lett* 29:54 doi. [11] R. Boehler (1993) *Nature* 363:534. [12] G. Shen, et al. (1998) *Geophys Res Lett* 25:373 doi. [13] Y. Fei, et al. (2000) *American Mineralogist* 85(11-12):1830. [14] J. Li, et al. (2001) *Earth Planet Sci Lett* 193:509. [15] A. J. Stewart, et al. (2007) *Science* 316:1323 doi. [16] L. Chudinovskikh, et al. (2007) *Earth Planet Sci Lett* 257(1-2):97 doi. [17] B. Chen, et al. (2008) *High Pressure Research: An International Journal* 28(3):315 doi. [18] G. Morard, et al. (2008) *Earth Planet Sci Lett* 272(3-4):620 doi. [19] A. Tarantola (2005) *Inverse Problem Theory and Methods for Model Parameter Estimation* Society for Industrial Mathematics ISBN 978-0898715729.

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