SEISMIC DETECTION OF THE MARTIAN CORE BY INSIGHT. Stähler, S. C.[1], Savas Ceylan[1], Andrea Cecilia Duran[1], Raphaël Garcia[2], Domenico Giardini[1], Quancheng Huang[3], Amir Khan[1,4], Doyeon Kim[3], Philippe Lognonné[5], Ross Ronan Maguire[3], Angela G. Marusiak[6], Ana Catalina Plesa[7], Henri Samuel[5], Nicholas C. Schmerr[3], Martin Schimmel[8], David Sollberger[1], Eleonore Stutzmann[5], Daniele Antonangeli[9], John F. Clinton[1], Martin van Driel[1], Mélanie Drilleau[2], Tamara Gudkova[15] Anna Horleston[10], Jessica Irving[10], Taichi Kawamura[5], Ved Lekic[3], Robert Myhill[10], Francis Nimmo[11], Mark Panning[6], Attilio Rivoldini[12], Cédric Schmelzbach[1], Sabine Stanley[13], Renee C. Weber[14], Zongbo Xu[5], Géraldine Zenhäusern[1], W. Bruce Banerdt[6]
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Introduction: A plethora of geophysical, geochemical, and geodynamical observations indicate that the terrestrial planets have differentiated into silicate crusts and mantles that surround a dense core. The latter consists primarily of Fe and some lighter alloying elements (e.g., S, Si, C, O, and H) [1]. The Martian meteorites show evidence of chalcophile element depletion, suggesting that the otherwise Fe-Ni-rich core likely contains a sulfide component, which influences physical state.

There is strong evidence from measurements of the tidal deformation of the planet that the core of Mars is presently liquid [2–4]. Recent experimental studies of phase relations in the Fe-S and (Fe,Ni)-S systems at conditions of the center of Mars are compatible with an entirely liquid core at present [5, 6]; yet, core size and composition are un-certain [7, 8]. Related hereto is the question of the presence or absence of a lower mantle in Mars, i.e., whether bridgmanite-structure silicates are present, which can possibly exert considerable control over the dynamical evolution of mantle and core [9–13]. A small core will tend to be Fe-rich and favor the presence of a lower mantle whereas large cores will tend to be enriched in light elements and inhibit a lower mantle.

The InSight mission aims at constraining these numbers via the RISE radio tracking experiment [14], and the SEIS seismic package [15]. The results of RISE are presented in a separate abstract in the same issue [25], and here we focus on the results of SEIS.

Data: We used data recorded by SEIS [26] for high SNR marsquakes between March 2019 and July 2020. The InSight Marsquake Service located these events in the distance range 27-40 degrees, based on identification of P- and S-body waves [16–19]. Later studies identified a number of secondary, surface-reflected phases, which were used to constrain the upper mantle (see LPSC abstract by Khan et al. [27]). We build upon the velocity models derived from these phase picks to constrain the time window in which to look for shear waves reflected from the core mantle boundary. Since shear waves cannot propagate in a fluid medium, the core mantle boundary (CMB) acts as a polarization filter, which fully reflects horizontally polarized shear waves back into the mantle. Shear waves reflected from the CMB, called ScS, are therefore expected to have a predominantly horizontal polarization at the receiver, with an azimuth orthogonal to the source direction. In this distance range, ScS is separated in time from any other body wave phase and therefore well-observable.

Methods: We follow a two-step approach: 1. Confirm seismic arrivals as ScS, based on existing mantle velocity models. 2. Pick precise arrival times and invert those for mantle profiles and core size, constrained by mineralogy, moment of inertia and average density of the planet.

To enhance body wave arrivals, we remove elliptically and polarized signal to enhance ScS waves. For the events listed above, we sum the signal power in a suitable frequency band around the predicted arrival time for ScS in a set of 5000 mantle models compatible with the travel times of other phases. The stack confirms that significant energy is present in time windows that correspond to reflection from a strong interface at ~1600 km depth associated with the liquid Fe-rich core with a radius of around 1800 km radius.

We identified these arrivals for each individual event and picked travel times and measured frequency content. Using these updated depths, we invert all the travel times together with moment of inertia and the mean density of the whole planet.

Results: The inversion of travel times constrains the core radius to the upper end of pre-mission geophysics-based estimates [7, 20]. This value is compatible with estimates from the geodetic experiment RISE onboard and implies that a lower mantle is unlikely to be present. Moreover, a large core has important implications for core composition. Average retrieved core density is 6 g/cm^3, which implies that for a (Fe-Ni)-S composition, a sulfur content in excess of 18% is required. This is above the eutectic composition observed experimentally with potentially profound implications for the future crystallization of the Martian core [6, 21], subject to further laboratory research of Fe-S data under core conditions [22].

All ScS candidate phases that were observed show significant seismic energy and a relatively flat spectrum above 0.1 Hz, which implies a low seismic attenuation throughout the mantle. The spectral character of direct S-phases for the distant-most events [16] is consistent with that of the ScS-phases for more nearby events, which supports the identification of the arrivals as core-reflected. As expected from typical rheologies [23], the quality factor at seismic periods is significantly higher than the average value found at the period of the Phobos tide of 5.5h (Q_μ=85, [24]).

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