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Seismic detection of the Martian core by InSight

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Introduction: A plethora of geophysical, geo-chemical, 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). There is strong evidence from measurements of the tidal deformation of the planet that the core of Mars is presently liquid.

The InSight mission aims at constraining these numbers via the RISE radio tracking experiment, and the SEIS seismic package. We used data recorded by SEIS 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. Later studies identified a number of secondary, surface-reflected phases, which were used to constrain the upper mantle. 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.

Results: The inversion of travel times constrains the core radius to the upper end of pre-mission geophysics-based estimates. 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, subject to further laboratory research of Fe-S data under core conditions.

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 is consistent with that of the ScS-phases for more nearby events, which supports the identification of the arrivals as core-reflected.

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