MARTIAN CRUSTAL S-WAVE VELOCITIES FROM P-WAVE POLARIZATION – A TEST STUDY FOR INSIGHT.

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Introduction: The InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) mission will place a lander on the surface of Mars in November 2018 to investigate the planet's internal structure and the differentiation of the terrestrial planets with the help of a seismometer (SEIS), a heat flow probe (HP^3), and a precision tracking system (RISE), as well as auxiliary sensors [1]. Crustal thickness and structure of Mars are among the main scientific objectives of InSight. Orbital topography and gravity data can constrain relative variations in Martian crustal thickness, but need to assume the crustal thickness at a specific tie-point, usually a global thickness minimum in the Isidis impact basin. An independent estimate at the InSight landing site could thus help to better constrain crustal thickness all across Mars.

On Earth, receiver functions are a standard, single-station seismological technique to study crustal and upper mantle structure using converted and reflected phases in the coda of distant earthquakes. The method has also previously been applied to Apollo lunar seismograms [2]. However, as a travel-time method, receiver functions generally suffer from a trade-off between the depth to a seismic discontinuity and the velocity above [3], and the interpretation of the Apollo receiver functions in terms of lunar crustal thickness is non-unique [4]. In order to resolve this trade-off, a joint inversion with Rayleigh wave ellipticity measurements is envisioned for InSight [5]. Here, we investigate the alternative option to measure frequency-dependent P-wave polarization from receiver functions and derive crustal S-wave velocity structure from this [6].

Data and Method: A database that allows to quickly calculate synthetic seismograms for 16 different one-dimensional Mars models is available at the Marsquake Service at ETH Zurich [7]. The available family of models results from a combination of two different crustal thicknesses (30 vs. 80 km) with two different sets of crustal velocities and densities, two different mantle compositions, and two different areotherms. We test the method on synthetic seismograms for six of these Mars models that cover the variety in crustal and upper mantle velocities. Additionally, we use a terrestrial data set recorded at five stations in central Europe to allow for a wider range of possible crustal structures and to study the effect of measured vs. noise-free synthetic data. These stations are charactezized by known differences in crustal structure, including thickness (between 24 and 45 km), velocities, and presence of sediments.

We first calculate receiver functions from the teleseismic P-arrivals [8] and then measure the P-wave polarization from the amplitudes of vertical and radial receiver functions at the P-wave onset after band-pass filtering in a range of periods between 1 s and 120 s. The polarization angles are directly related to apparent S-wave velocities, with measurements at increasingly longer periods containing more and more information from larger depths [6]. The apparent S-wave velocities depend on the velocity structure of the subsurface and are inverted for the true S-wave velocity structure via a grid search.

Results: We investigate the distance range likely usable for the calculation of receiver functions on Mars and find that P might be used between 35° and the core shadow (about 107°), and PP for larger distance. PKP is likely not a useful phase for receiver function analysis on Mars, as the absence of a solid inner core leads to polarity reversals of the phase and makes the distance range in which it might be observable rather small. Comparison to models for the spatial distribution of Martian seismicity [9,10] indicate that some seismicity should be occuring within the P distance range from the InSight lander during the nominal mission duration of on Martian year, generating data to which we can apply our method.

The derived apparent S-velocity curves are distinct for the six considered Mars models, even taking into account InSight's maximum event localization uncertainty. They provide information on the crustal, and, in cases with a thin (30 km), fast crust, upper mantle velocity structure. The curves for the terrestrial stations all show clear deviations from the one obtained from synthetics for a global 1-D reference Earth model, and are distinguishable from one another. Inversion results show a close correspondence to the true models for the synthetic Mars data, but also indicate decreasing resolution with depth and the sensitivity of the data to average velocities over some depth interval rather than fine-scale structure. The latter could be provided by the receiver function waveforms themselves.

References: [1] Banerdt W. B. et al. (2018) subm. to *Space Sci. Rev.* [2] Vinnik L. et al. (2001) *GRL*, *28*, 3031–3034. [3] Ammon C. et al. (1990) *JGR*, *95*, 15303–15318. [4] Lognonné P. et al. (2003) *EPSL*, *211*, 27–44. [5] Panning et al. (2017) *Space Sci. Rev.*, *211*, 611–650. [6] Svenningsen L. and Jacobsen B. H (2007) *GJI*, *170*, 1089–1094. [7] Ceylan S. et al. (2017) *Space Sci. Rev.*, *211*, 595–610. [8] Knapmeyer-Endrun et al. (2014) *GJI*, *197*, 1048-1075. [9] Knapmeyer et al. (2006) *JGR*, *111*, E11006. [10] Plesa et al. (2018) subm. to *GRL*.

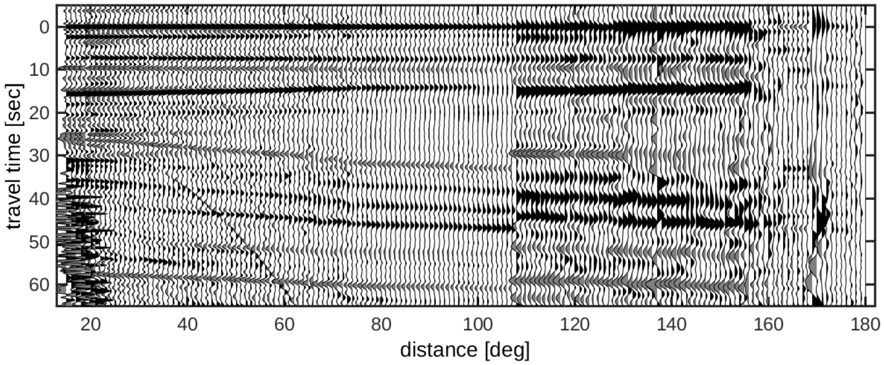

Figure 1: Example of radial receiver function section for a Mars model with an 80 km thick, slow crust, showing a large amount of converted and reflected phases. Until 107° distance, the P-phase has been used to calculate receiver functions, from 107° to 156°, PP, and beyond 156°, PKP.

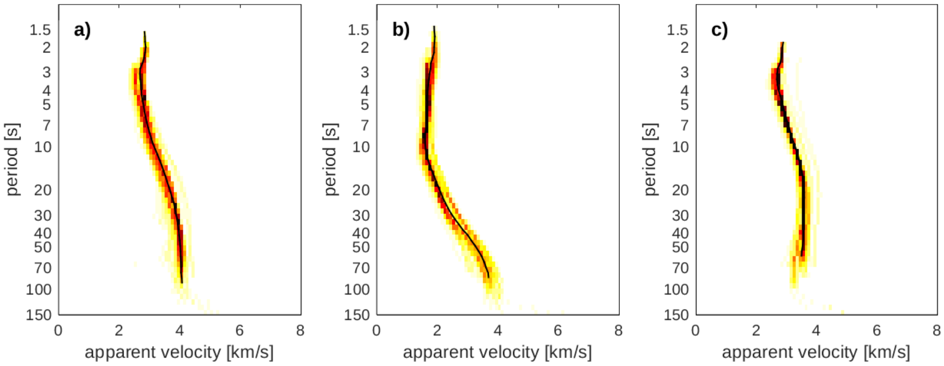

Figure 2: Examples of measured apparent S-wave velocity vs. period for models with **a)** a thin (30km), fast crust, **b)** a thin, slow crust, and **c)** a thick (80km) fast crust. Colored area is data density and black line median curve.

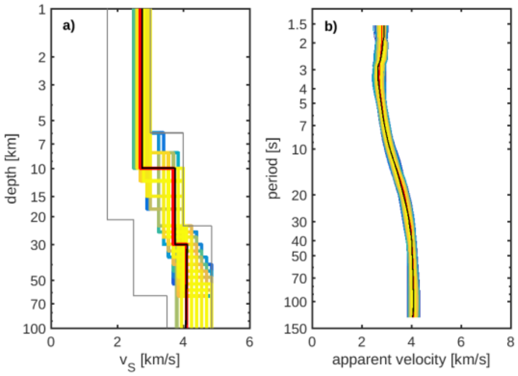

Figure 3: Examplary **a)** inversion results and **b)** fit to the data for model with a thin, fast crust. In **a)**, black indicates true model, red model providing the best fit to the data, and gray lines outline the parameter space covered in the grid search. In **b)**, black is the measured median curve, and red the best fit modeled curve.