SEISMIC CONSTRAINTS ON THE CRUSTAL STRUCTURE OF MARS FROM INSIGHT RECEIVER FUNCTIONS. B. Knapmeyer-Endrun[1], F. Bissig[2], N. Compaire[3,4], R. Joshi[5], R. Garcia[3], A. Khan[2], D. Kim[6], V. Lekić[6], L. Margerine[4], M. Panning[7], M. Schimmel[8], N. Schmerr[6], E. Stutzmann[9], B. Tauzin[10], S. Tharimena[7], E. Bozdağ[11], D. Peter[12], A.-C. Plesa[13], P. Lognonné[9], S. Smrekar[7], W. B. Banerdt[7] and the InSight Crustal Working Group, [1]Bensberg Observatory, University of Cologne, Germany (bknapmey@uni-koeln.de), [2]ETH Zurich, Switzerland, [3]ISAE-SUPAERO, Toulouse, France, [4]IRAP, Toulouse, France, [5]MPS, Göttingen, Germany, [6]University of Maryland, USA, [7]JPL, CalTech, USA, [8]ICTJA-CSIC, Barcelona, Spain, [9]IPGP, Paris, France, [10]Université de Lyon, France, [11]Colorado School of Mines, USA, [12]KAUST, Saudi Arabia, [13]DLR, Berlin, Germany

Introduction: NASA's InSight mission has for the first time placed a very broad-band seismometer on the surface of Mars. The Seismic Experiment for Interior Structure (SEIS) has been collecting continuous data since early February 2019. The main focus of InSight is to enhance our understanding of the internal structure and dynamics of Mars, which includes the goal to better constrain the crustal thickness of the planet [1]. Knowing the present-day crustal thickness of Mars has important implications for its thermal evolution [2] as well as for the partitioning of silicates and heat-producing elements between the different layers of Mars. Current estimates for the crustal thickness of Mars are based on modeling the relationship between topography and gravity [3,4], but these studies rely on different assumptions, e.g. on the density of the crust and upper mantle, or the bulk silicate composition of the planet and the crust. The resulting values for the average crustal thickness differ by more than 100%, from 30 km to more than 100 km [5].

New constraints from InSight will be based on seismically determining the crustal thickness at the landing site. This single firm measurement of crustal thickness at one point on the planet will allow to constrain both the average crustal thickness of Mars as well as thickness variations across the planet when combined with constraints from gravity and topography [6]. Here we describe the first constraints on the crustal structure and thickness at the InSight landing site based on seismic receiver functions for four marsquakes [7].

Methodology: For more than 40 years, receiver functions have become a powerful tool to study the crustal and upper mantle structure in terrestrial seismology [8-10]. The method isolates converted phases, either P-to-S conversions in the P-wave coda or S-to-P precursors to the S-wave, from teleseismic earthquakes by rotation into the ray coordinate system and removal of the source-time-function, distant path effects, and the instrument response (Fig. 1). The relative travel-time of these phases in relation to the parent phase contains information on the depth of the layer where the conversion originates and the seismic velocities above. The receiver functions method has also been applied to data from one station of the Apollo lunar seismic network, though with different interpretations in terms of crustal thickness [11,12].

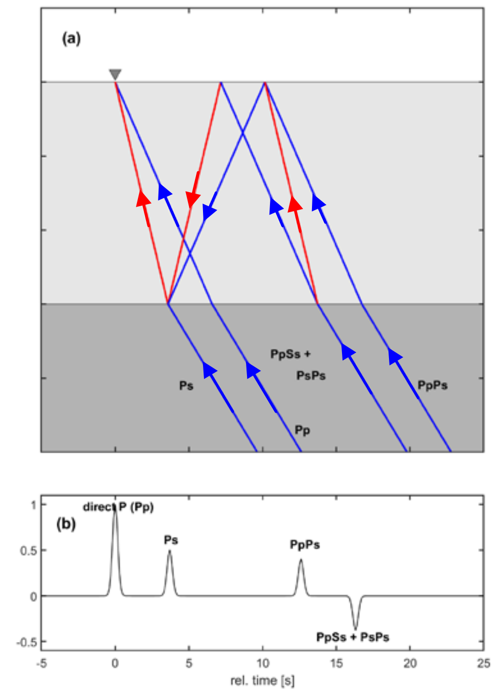

Figure 1: Schematic illustration of P-to-S phase conversions at a discontinuity (a) and corresponding receiver function (b)

We have calculated P-to-S receiver functions for four marsquakes and S-to-P receiver functions for three marsquakes so far. Out of all of the marsquakes recorded to date, these are the only ones with clear enough P- or S-arrivals not dominated by scattering to make them suitable for further analysis. All of these quakes are located at comparatively small epicentral distances, between 25° and 40°. Results for different processing schemes (i.e. filtering, determination of rotation angles, deconvolution method) applied by different teams lead to similar results. As one of the quake recordings was also contaminated by a prominent glitch in the P-wave coda, we also compared results for different deglitching methods for this event to make sure we only interpret reliable phases [13].

One weakness of the receiver function method is that, as a travel-time method, it suffers from a trade-off between layer velocity and layer thickness. To resolve this trade-off, we investigated the use of apparent S-wave velocities determined from the frequency-dependent P-wave polarization measured on the receiver function waveforms [14].

Results: We observe three consistent phases within the first 10 seconds of the P-to-S receiver functions. Within this time window, the energy level on the transverse component is low, indicating a minor role of anisotropy or scattering. At later times, consistency between different events and analysts is decreasing. The S-to-P receiver functions also show a consistent first phase. Later arrivals are harder to pinpoint, which could be due to the comparatively shallow incidence of the S-waves at the considered distances, which prevents the generation of converted waves.

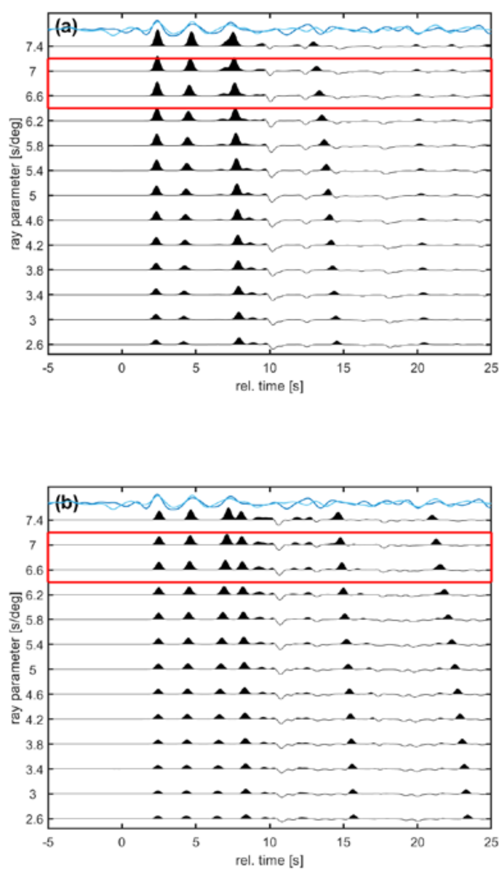

Figure 2: Examples for synthetic P-to-S receiver functions (Q-component) for models with a crustal thickness of (a) 25 km or (b) 39.5 km, arranged by ray parameter. Stacks of the measured receiver functions using two different processing schemes are drawn in blue. The ray parameter range shown corresponds to distances from about 20° to the beginning of the core shadow. The ray parameter range covered by the currently available data is outlined by the red rectangle.

Apparent S-wave velocities could only be determined for one event, which might be related to the close distance of the events and the uncertainty in their ray parameters, and implies that the uncertainty in the apparent S-wave velocities is large. They are compatible with an upper crustal layer of S-wave velocities between 1.75 and 2.15 km/s, and a thickness of 7 to 12 km [13]. Using this result, the crust at the landing site could either consist of two layers with a total thickness of around 25 to 30 km or three layers with a total thickness of around 40 to 45 km (Fig. 2). Within the limited distance range covered by the marsquakes, and the uncertainty in identifying later multiples, these two models cannot be distinguished based on the receiver functions collected so far. However, this model range already improves the constraints on the martian crust by providing a new maximum value of less than 70 km for the average crustal thickness [6].

Outlook: To resolve the depth-velocity trade-off in the receiver functions, information from other complementary methods, specifically noise autocorrelations, will be considered. In addition, more extensive modeling, ultimately including 3D effects [15], will be performed and also be compared to possible P-wave reverberations and S-precursors directly visible in the marsquake seismograms.

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Data from InSight SEIS are available via the Planetary Data System (PDS) Geoscience Node and IRIS-DMC.

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