HINDSIGHT FROM INSIGHT: WHAT SCIENCE COULD HAVE BEEN DONE WITH A SIMPLER MISSION?

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The InSight mission was very successful at producing high quality seismic data to investigate the deep interior of Mars, delivering new estimates of the core size, the first value of the seismicity level and many other results. At the same time, the deployment of a high quality seismometer (very broadband, VBB) shaped the mission profile and required a dedicated robot arm. Future missions to Mars may want to carry a more robust short period seismometer (SP) to monitor the seismicity of the planet or investigate specific questions without shaping the whole mission around the instrument. We therefore investigated, which science results of the InSight mission could have been obtained with a significantly reduced effort.

InSight design considerations: When the seismic experiment was planned on the Viking landers in the late 1970s, it was decided to place the seismometer on the deck of the lander to reduce complexity of the mission [1].The resulting high sensitivity of the seismometer to wind-generated vibrations resulted in a paradigm that seismology on planets with an atmosphere requires separating the seismometer from the lander itself. With the hindsight of a successful InSight mission, we re-evaluate this paradigm.

Seismicity: InSight observed two families of Marsquakes, with dominant energy below 1 Hz (*LF*), or above (*HF*) [2]. The sensitivity of the SP below 1 Hz was too low to observe the flat part of the LF spectra. Above 3 Hz, both sensors have roughly equivalent performance.

Marsquakes: From the above follows that only a small number of *LF* events could be observed with the SP even in the best configuration on ground. The largest Cerberus Fossae event, S0235b has a particularly strong S-wave that clearly shows up on SP, but the P-wave is barely above noise and thus likely not distinguishable from other signals, e.g. from wind.

The HF events make up the wide majority of observed marsquakes (1232 out of 1319), most of which could have been observed with both sensors on ground. However, it must be clearly stated that the scientific insight obtained from a single HF event is quite low. Due to the high scattering in shallow layers, their signal cannot be used for structural inference easily.

Just counting both event types over an extended mission would help constrain the level of seismic activity on Mars and shed some light into the unexpected and unexplained seasonality of *HF* events [3].

Meteoritic Impacts: InSight detected two very large meteoritic impacts by their seismic waves [4] and a number of smaller impacts with shorter distances to the lander [5]. All these signals were observed on the SP sensor as well (if it was active during the event), since impact-generated seismic events were generally found to be dominated by high frequency energy. This means that even an SP-equipped seismic experiment could monitor meteor impacts on Mars continuously.

Near surface-structure: The near surface structure has been investigated mainly by high frequency signals.

Regolith thickness and elastic parameters: The hammering of the HP^3 heat flow probe was used as an active seismic source to investigate the shallowest part of the Martian subsurface [uppermost meter, see 6]. The hammering almost exceeded the dynamic range of both seismometers, even in low-gain mode. A future seismology-equipped mission might consist of a lander platform on which a seismic sensor is placed that observes e.g. the drilling activity on a rover, e.g. the ExoMars mission.

Shallow layering: The uppermost 500 meter below the InSight lander were imaged using the spectra and polarization of Rayleigh waves in the ambient noise [7], as well as in the coda of marsquakes [8]. Both methods agreed that at least two layers of soft material (interpreted as sediments) between more rigid layers (most likely basaltic lava flows) are needed to explain the data. While the analysis of the ambient noise above 1 Hz will be challenging with the SP only, the coda analysis is well possible with a few HF events observed on the SP.

Deep Interior: Investigating the deep interior of Mars was the main motivation of the InSight mission.

Crustal thickness: The strongest evidence for the crustal thickness below InSight came from receiver functions, i.e. seismic waves that are converted into another wave type (e.g. from P to S or vice versa) at a shallow interface [9, 10]. On Earth, these are typically relatively weak signals. Due to a very strong interface at around 8-10 km depth below the lander, S-waves observed by InSight show a very strong pre-cursor a few seconds before the main phase. This signal is well-visible on SP-data and can be stacked when observed on multiple events.

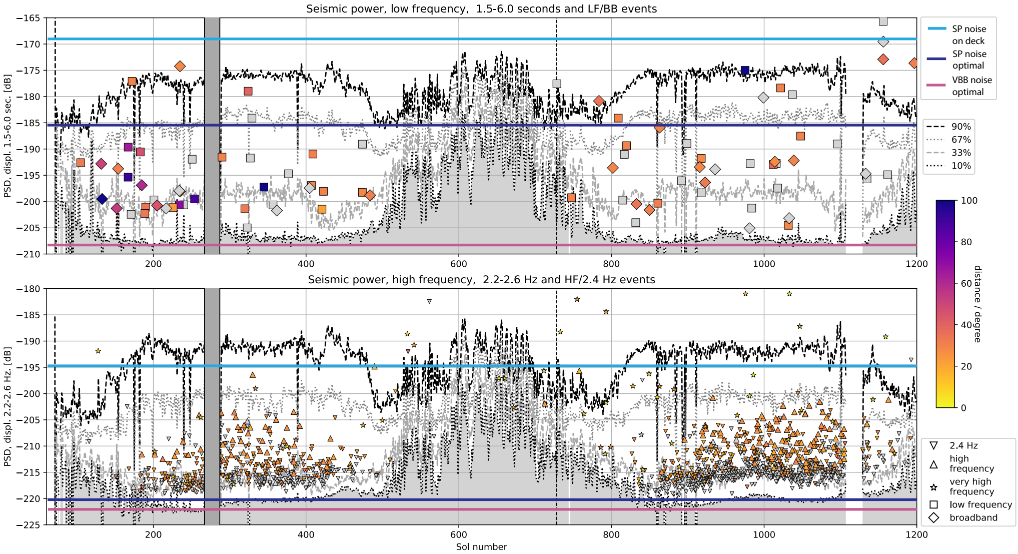

Figure 1: Signal strength of marsquakes observed by InSight (colored markers) compared to the ambient wind noise (black and grey) and the noise level of the SP short period seismometer on ground (dark blue), as well as on deck (light blue).

Crustal profile: The crustal structure away from the InSight landing site was determined using surface waves of large impacts [11, 4]. These signals were restricted to relatively long periods and clearly below the SP observation threshold.

Mantle profile: The seismic estimates on mantle structure [12, 13] relied on surface reflected seismic waves (PP, SS, PPP, SSS). Those were only observed for *LF* events, of which only a few were observed on SP. However, the InSight LF event dataset is dominated by Cerberus Fossae in 28–32° [14]. Even a single good PP/SS observation at a different distance will contribute significantly to our understanding of the Martian mantle.

Core radius and composition: The seismic estimates of the core radius relied on the observation of core-reflected seismic waves [ScS, 15] or core-diffracted P-waves [Pdiff, 16], which are all low-amplitude long period phases and could not have been observed using the SP instrument in any configuration.

Auxiliary Science: The SEIS noise level on all sensors was strongly correlated with wind velocity [17, 18]. No matter the shielding, a seismometer therefore produces an estimate of the wind speed. For the InSight configuration, it was shown that the sensitivity of the seismometer to wind exceeded that of the APSS sensors, specifically for low wind speeds (< 2m/s)[19]. This effect obviously increases for a poorly shielded instrument and is highest for one installed on the lander deck.

Conclusion: We conclude that investigations of the deep interior, specifically the core required all the effort of the InSight mission. Possible results of a mission with a short period seismometer could be the local shallow subsurface, and crustal profile, as well as monitoring of the regional seismicity and the global impact rate. A instrument on a low-profile lander could still obtain some of these goals during times of quiet wind.

References: **[1]** D. L. Anderson et al. (1977). DOI: 10.1029/JS082i028p04524. **[2]** J. F. Clinton et al. (2021). DOI: 10.1016/j.pepi.2020.106595. **[3]** M. Knapmeyer et al. (2021). DOI: 10.1016/j.epsl.2021.117171. **[4]** L. V. Posiolova et al. (2022). DOI: 10.1126/science.abq7704. **[5]** R. F. Garcia et al. (2022). DOI: 10.1038/s41561-022-01014-0. **[6]** N. Brinkman et al. (2022). DOI: 10.1029/2022JE007229. **[7]** M. Hobiger et al. (2021). DOI: 10.1038/s41467-021-26957-7. **[8]** S. Carrasco et al. (2023). DOI: 10.1093/gji/ggac391. **[9]** B. Knapmeyer-Endrun et al. (2021). DOI: 10.1126/science.abf8966. **[10]** D. Kim et al. (2021). DOI: 10.1029/2021JE006983. **[11]** D. Kim et al. (2022). DOI: 10.1126/science.abq7157. **[12]** C. Durán et al. (2022). DOI: 10.1016/j.pepi.2022.106851. **[13]** M. Drilleau et al. (2022). DOI: 10.1029/2021JE007067. **[14]** S. C. Stähler et al. (2022). DOI: 10.1038/s41550-022-01803-y. **[15]** S. C. Stähler et al. (2021). DOI: 10.1126/science.abi7730. **[16]** C. Durán et al. (2022). DOI: 10.1029/2022GL100887. **[17]** P. Lognonné et al. (2020). DOI: 10.1038/s41561-020-0536-y. **[18]** C. Charalambous et al. (2021). DOI: 10.3929/ethz-b-000479669. **[19]** A. Stott et al. 2022. DOI: 10.31223/X58H1F.