RESULTS FROM THE SHORT-PERIOD (SP) SEISMOMETERS ON THE MARS INSIGHT MISSION: FROM LAUNCH TO SOL 40.

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Introduction: The Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission landed successfully on Mars on 26 November, 2018 at 4.51°N, 135.97°E in Elysium Planitia. InSight's seismic payload, SEIS, includes the short-period (SP) sensors (fig. 1) optimized to investigate the martian seismic signal above a few Hz [1]. The two horizontal SPs acquired data during the cruise to Mars on 16 and 19 July and 29-30 August with the free-fall environment allowing the performance of the sensors to be determined and validating their noise requirements. Details of the results from cruise can be found in the companion abstract. The SP sensors on board the lander have been used to make an initial assessment of site dynamics prior to the full deployment of SEIS on a levelling platform, LVL allowing operation of its very-broad-band (VBB) sensors [2]. Both the SP and VBB sensors were controlled and their signals digitized using the SEIS acquisition and control electronics of SEIS-AC [2]. As the three axes of the SPs can function without levelling, they were able to start observations on the deck from sol 4 of the mission.

Operation: The SPs operated for a total of 210 hours from landing to sol 40. The first data was acquired on Sol 4, with six additional sols of on-deck observations. SEIS was deployed on to the surface of Mars on Sol 24. Further SP data was recorded on the ground, with the VBB joining SP operations after SEIS levelling on sol 35.

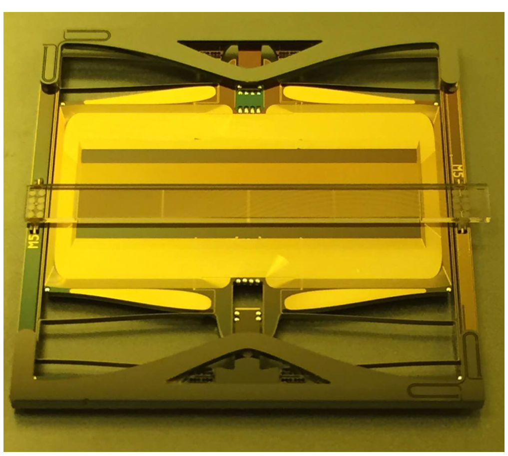

Figure 1. The SEIS SP sensors, 25 mm square, are fabricated from through-wafer etching of single-crystal silicon, with a noise floor of 3 nm/s^2/rtHz

The two main constraints on SP operation were thermal, SEIS is qualified to -65 C, and initial avoidance of UHF passes. Due to thermal constraints, the SPs were operated in the second half of each sol. After observation of the UHF-induced currents in the tether between SEIS and SEIS-AC, the SPs were assessed as safe to operate during the UHF passes after sol 14. The SPs experienced temperatures from -5C to -60 C while operating, a first pyroshock to separate SEIS from the lander, and a second pyroshock to release the tether from the SEIS enclosure.

Although the SPs are seismic instruments, they are fundamentally accelerometers and as such are sensitive to all the dynamics that affect the lander in a 100 sps acquisition bandwidth with a peak sensitivity below 3 nm/s^2/rtHz. While on the deck, the SPs monitored the dynamics in response to three direct influences:

- coupling of the atmosphere to the lander structure
- motion of the regolith under the lander
- internal lander activity, particularly motion of the robot arm.

On-deck observations: Fig. 2 shows the spectrograms from the first operation of the two horizontal SP sensors, the first seismic sensor recordings on Mars since Viking in 1979 [3]. The full bandwidth is shown, with attenuation from the anti-alias filters evident above 40 Hz, but still containing power at the bottom of the audible spectrum. The horizontal features are the excited modes of the lander, at a range of frequencies from 3 to 38 Hz, while the vertical features are broadband excitations from atmospheric activity. The signal represents low frequency acoustic pickup by the lander structure of the Mars environment and can be considered the first sound recording from Mars, albeit at only a 45 Hz bandwidth.

The SPs further characterised the expected seismic environment of the lander [4, 5] with extended

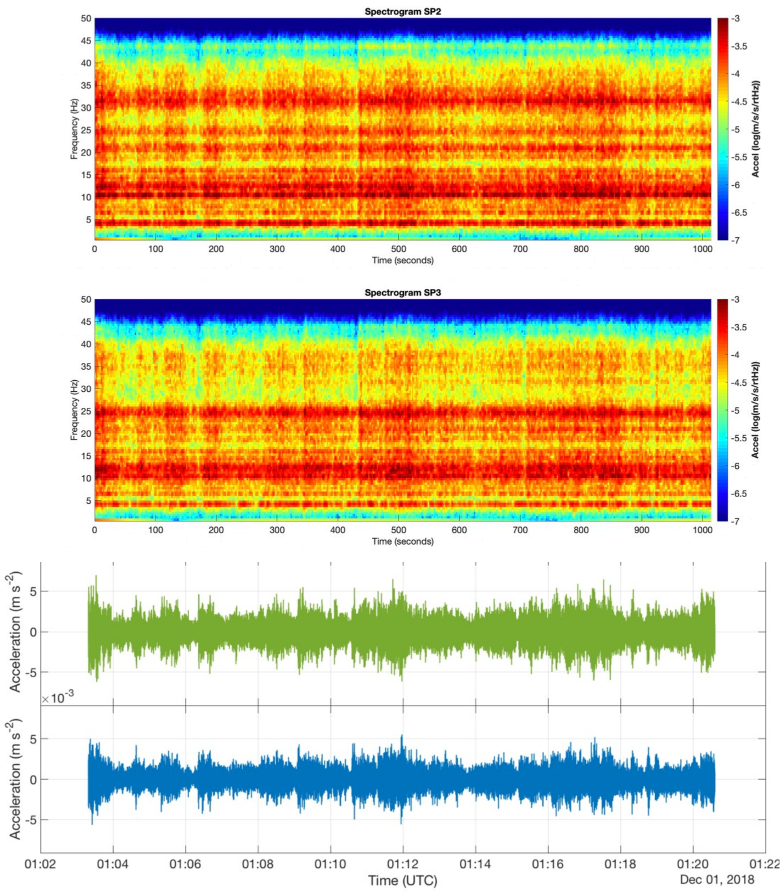

Figure 2. Spectrograms and time series of the acceleration signals from the two horizontal-axis SPs seismic sensors taken on Mars from Sol 4, 16:06:47 LTST showing both atmospheric excitation and the lander response for InSight.

observations, including the amplitude of the lander modes and the detection of lander activity such as Instrument Deployment Arm movements and UHF passes. In addition, the SPs characterised the dynamical environment from about noon to 22:00 LTST, observing consistent patterns in the transduced atmospheric environment, with sustained quiet periods approaching the noise floor of the SP sensors. As well as environmental signals across the full seismic bandwidth, the SPs also were able to determine the tilt variation of the lander by tracking the position of the sensors' proof mass over several sols indicating a very stable attitude of InSight up to SEIS deployment.

Off-deck observations: SEIS was lifted off the deck and lowered onto the surface of Mars on sol 24 at a site chosen to minimise as far as possible the seismic noise injection from the lander [6]. The introduced response from LVL [7], as well as transmission of the lander modes were subsequently observed allowing estimation of the transmission of seismic and aseismic signals though the regolith. During continuation of the deployment phase, the SPs continued to track SEIS tilt in response to levelling operations and the ambient wind forcing. This allowed daily comparative site assessment of the achieved noise floor, including at the quietest periods, as the tether to the lander was slackened.

On sol 35 the very-broad band VBB sensors were first operated in low-gain engineering mode, and the noise of both sensors estimated using coherence between the two sets of seismic sensors. Subsequent simultaneous observations of the SP and VBB signals allowed sensor noise approaching the SP's performance floor to be estimated as further mitigation of aseismic environmental signals was implemented. The observed level of seismic activity to date can be used to place an upper limit on martian seismicity.

Conclusions: The dynamic environment at the InSight landing site has been observed during the deployment of a seismic payload on to the surface of Mars, with over 200 hours of seismic data from InSight's SPs returned. As well as characterising the response of the lander, the SPs have recorded the atmospheric dynamics and provided a profile of the aseismic activity over the second half of a sol at Elysium Planitia. This initial data provides an assessment of the first on-the-ground planetary seismic installation, as well as estimates of the performance on Mars that can be expected from on-the-deck and on-the-ground deployments, with and without additional wind and thermal shielding.

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