INSIGHT AND SINGLE–STATION BROADBAND SEISMOLOGY: FROM SIGNAL AND NOISE TO INTERIOR STRUCTURE DETERMINATION.

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Introduction: The InSight Mission is one of three NASA down-selected projects in competition for the 2010 Discovery AO. The goal of SEIS (a very-broad-band (VBB) seismometer), the mission's core instrument, is to determine the interior structure and seismic activity of the planet. We summarize the requirements flow, from instrument performance to expected science performance in terms of interior structure and activity determination.

SEIS noise requirement: Performance and installation quality of the InSight seismometer are the most critical parameters to ensure success in terms of seismic signal detection, as negatively demonstrated by the Viking Lander seismometer which was dominated by wind during the day and was weakly sensitive to ground motion during the night (due to emplacement on the lander deck) [1]. The InSight seismometer will be not only superior in sensitivity to all previous Mars seismometers (see Figure 1 for comparison), but also much better installed thanks to the unique capacity of the InSight lander, which will provide a robotic installation of the instrument on the ground and include a Wind/Thermal Shield (WTS; see Figure 2.).

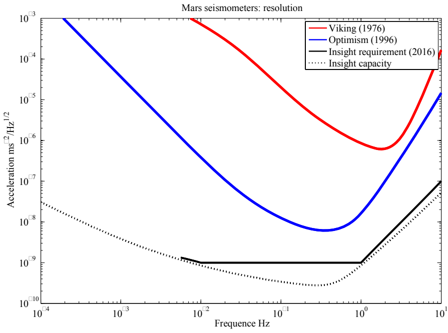

Figure 1. Comparison of the InSight requirement and capability (black solid and dotted lines, respectively) with those of the previous Mars missions (red line, Viking 2, landed in 1976 [1]; blue line, Optimism on Mars96, lost in 1996 [2]). The improvement of the InSight requirement over the Viking capability is 1000× for body waves (1 sec) and 65000× for surface waves (20 sec), equivalent to 2 and 3.2 body wave (m_b) and surface wave (m_s) magnitudes respectively.

Seismic and impact signal amplitude estimation: Theoretical estimates from thermoelastic cooling [3] and calculation of the seismic moment release from observed surface faults [4] predict a level of activity ~100× greater than observed shallow moonquake activity. This level would provide ~50 quakes of seismic moment ≥10^{15} Nm (roughly equivalent to terrestrial magnitude m_b=4) per (Earth) year, and ~5× more quakes for each unit decrease in moment magnitude. A few large quakes with moment in the range 10^{17}– 10^{18} Nm might also be expected during the full Mars year nominal mission duration, enabling the detection of free oscillations on the vertical component [5]. Detection signal to noise are shown in Figure 3.

Figure 2. Wind and Thermal Shield during field tests on Martian analog surface in Réunion Island. By covering and protecting the SEIS instrument, the WTS aims to reduce the instrument thermal and wind generated noise below the expected level of ground noise on Mars (i.e., Mars microseismic noise) and will act as a "portable" seismic vault.

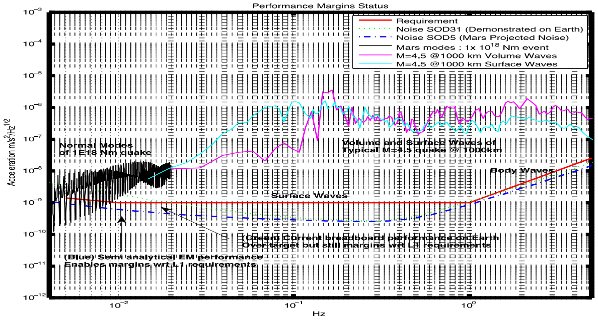

Figure 3. Summary of the SNR for modeled normal modes (black curves) and terrestrial seismic observations (cyan and magenta), compared to the InSight requirement (red) and capability (blue)

Impact-generated signals can be estimated through impact rate modeling, integrating both the impactor flux [5], atmospheric ablation effects [6] and seismic calibration on the Moon [7]. Modeling predicts that about 20 events with a Signal to Noise Ration > 3 (with respect to the requirement instrument noise) should be detected during the nominal mission of InSight, including 5 with SNR > 9 (Figure 4).

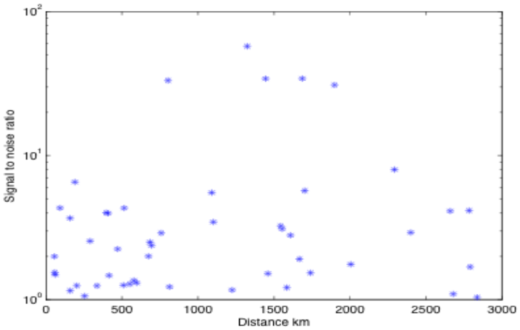

Figure 4 Modeling results of impact SNR with a Monte-Carlo simulation of impactors and seismic amplitude impulse/distance estimates calibrated on the Moon and corrected with the a priori attenuation differences between Mars and the Moon. Large events correspond to impacts of about 1 ton. The InSight L1 requirement is for the detection of an impact of 10^6 Ns impulse at distances less than 400 km with a SNR > 3.

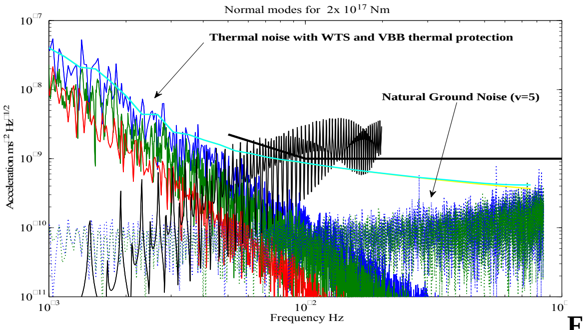

Figure 5: Amplitude of a $3x10^{17}$ Nm marsquake free oscillation signal compared to instrument noise (black curve is SEIS requirement, cyan is expected capability) and environement noise (left, temperature, right, pressure, for day, sol,night in blue, green, red respectivelly). One or two such quakes are expected to occur during the two years of InSight operation and will provide a seismic “grail” of information, comparable to those used on Earth for elaboration of the standard PREM model [9]. Temperature noise and ground pressure noise are shown, the latter for a non-consolidated subsurface with 1 km/s V_p and 500 m/s V_s. The eigenmode frequencies will strongly constrain the lithosphere mean shear velocity.

Environmental noise modeling: Thermal and ground pressure noise estimates have been performed using Pathfinder temperature and pressure data together with the performance of the WTS and VBB Sphere thermal protection. In addition, natural pressure-induced ground acceleration has been modeled by using ground static loading theory [8]. Modeling results for normal modes and surface waves are shown in Figure 5.

Mantle and crust seismic inversion: As only one seismic station is available, structure inversion will be performed using:

- Secondary seismic data which do not depend on the event location: e.g., free oscillation frequencies for the largest quakes constraining the interior down to 200 km and receiver functions constraining the crust-mantle discontinuity below the landing site (see [10] for lunar data);
- Seismic impact data from impacts post-located by a Mars orbiter [11];
- Seismic data associated with events with more than 3 different wave arrival time determinations (for V_s inversion with constant V_p/V_s) or more than 4 (for full V_p, V_s inversions).

Seismic activity levels and wave amplitudes have been used to estimate the number of events with multiple arrivals. We estimate that about 35 events will be detected with both P and S waves, and about 10 with P, S and R1 surface waves and core phases (e.g., PcP, ScP). For about half of the latter, the R2 surface wave will be also be detected, enabling an epicentral distance determination contaminated only by lateral variability, which can be corrected with 3D modeling [12]. These events and associated seismic data set will allow the determination of seismic velocities down to 600 km to within ±0.25 km/sec, enabling the first seismic model of another planet than Earth and exciting constrains in term of planetary formation and evolution.

References: [1] Anderson et al. (1977) J. Geophys. Res., 82, 4524-4546; [2] Lognonné et al. (1998) Planet. Space Sci. 46, 739-747; [3] Phillips (1991) LPI Tech. Rept. 91-02, 35–38; [4] Golombek et al (1992) Science 258, 979–81; [6] Le Feuvre and Wieczorek (2011) Icarus 214, 1-20; [5] Lognonné et al. (1996) Planet. Space Sci. 44, 1237-1249; [6] Lognonné (2005) Ann. Rev. Earth Planet. Sci. 33 :19.1-19.34; [7] Lognonne et al, (2009) J. Geophys. Res. 114, E12003; [8] Sorrels et al. (1971) Geophys. J. RAS 26, 83-98; [9] Dziewonski and Anderson (1981) PEPI 25, 297-356; [10] Vinnik et al. (2001) Geophys. Res. Lett. 28, 3031-3034; [11] Daubar et al. (2011) LPSC XXXXII, abs. #1608, p.2232; [12] Larmat et al. (2008) Icarus 196, 78-89.