CHARACTERIZATION OF THE InSight NEAR SURFACE SEISMIC PROPERTIES USING THE HEAT FLOW AND PHYSICAL PROPERTIES PROBE (HP³) MOLE AS A SEISMIC SOURCE

S. Kedar[1], W. B. Banerdt[1], N. Brinkman[7], P. Delage[10], L. Fayon[2], M. Grott[3], A. Horleston[4], T. Hudson[1], K. Hurst[1], A. Kiely[1], B. Knapmeyer-Endrun[5], C. Krause[3], P. Lognonné[2], W. T. Pike[6], J. Robertsson[7], C. Schmelzbach[7], N. Schmerr[8], T. Spohn[3], D. Solberger[7], S. Stahler[7], N. Teanby[4], M. Van Driel[7], C. Vrettos[9]
[1]Jet Propulsion Laboratory, California Institute of Technology; [2]Institut de Physique du Globe, Paris; [3]Deutsches Zentrum für Luft und Raumfahrt (DLR); [4]University of Bristol, Bristol, UK; [5]University of Cologne; [6]Imperial College, London; [7]ETH, Zurich; [8]University of Maryland; [9]Technical University Kaiserslautern; [10]École Nationale des Ponts et Chaussées

Introduction: The InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) mission is the first Mars lander to place an ultra-sensitive broadband seismometer on the planet's surface. About a meter away from the seismometer, a Heat Flow and Physical Properties Probe (HP³) experiment will hammer a probe up to 5 m into the Martian subsurface to measure the heat coming from Mars' interior and reveal the planet's thermal history (Figure 1). The probe, which uses a self-hammering mechanism, will generate thousands of seismic signals that can be used to analyze the shallow (several meters) subsurface and shed new light on the mechanical properties of Martian regolith. The descent will progress in ~0.5 m hammering intervals, each interval taking between 0.5−4 hours, and each interval being separated by several days of thermal measurements. Each hammering interval consists of several hundred to several thousand strokes ~4 s apart.

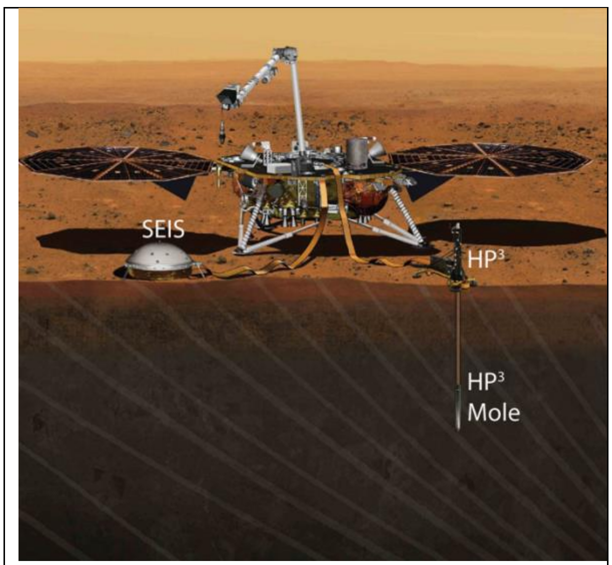

Figure 1: An illustration of the InSight lander in its final configuration on the Martian surface. A Very Broad-band triaxial seismometer is deployed ~1-2 m away from heat probe with a self-hammering mole that will gradually penetrate down to 5m below the surface. [Figure adapted from Kedar et al. 2017]

The mission's level-1 science objectives focus on planetary-scale seismic and tectonic processes and their implications to rocky planet formation. Nevertheless the proximity of a repeating hammer source to a sensitive seismometer presents a unique opportunity to study the physical properties of the shallow subsurface of the landing site. Understanding the seismic properties of Martian regolith, determining its thickness, and resolving the internal structure of the shallow subsurface will help reduce InSight's seismic measurement errors, with the added benefit of carrying out the first geotechnical study of the shallow Martian subsurface.

The HP³ Hammering Mechanism: As described in Spohn at al [2012] and Kedar et al [2017] the HP³ mole internal hammering mechanism produces a double-stroke every ~4 s. In the hammering mechanism, a motor provides rotational motion that is converted by a gearbox into translational motion of a piston to compress the drive-spring. When the drive spring is released, its expansion accelerates the hammer that hits an anvil connected to the casing and transfers the momentum forward. At the time of release of the drive-spring a counter-mass is accelerated and moves upward against the resistance of the brake-spring. This motion transfers momentum backward to the casing that is absorbed by a second spring, which then accelerates the suppressor-mass forward to provide a second hit to the casing.

The HP³ seismic signal: The HP³ mole hammering mechanism produces a distinct seismic signals (Figure 2).

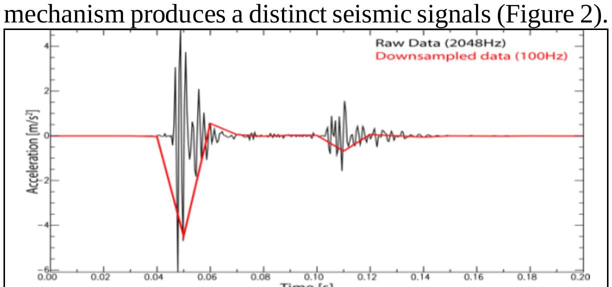

Figure 2: The HP³ hammering mechanism produces a double-strike, that is anticipated to be clearly observed by the InSight seismometers. Shown here is a single double strike recorded by an accelerometer 0.25m from an HP3 engineering-model mole during a field experiment.

However, using these signals for a geotechnical (shallow subsurface, high resolution) seismic profiling presents several challenges:

- Resolution: The InSight Seismic Experiment for Interior Structure (SEIS) requires 100 samples-per-second data that results in under-sampling the HP^3 signal (Figure 2).
- Repeatability of the hammering signal: Although each HP3 penetration session produces several hundred hammer strokes, the ~4 s interval between them varies slightly depending on the regolith properties and on the temperature of the mole.
- The second stroke, ~0.06s following the initial stroke, also varies in time, and may obscure a reflection from an anticipated basalt layer several meters below the surface at the InSight landing site.

In preparation for the InSIght mission, the team has devised several strategies to address these and other challenges. The various data processing and signal reconstruction approaches developed by the team and tested on simulated data are summarized in Kedar et al. [2017] and Golombek et al. [2018].

Field Simulation of the HP^3-SEIS experiment: In 2018, the team has conducted a field experiment in order to test the efficiency of the algorithms developed by the team in a real-world setting. To do that, a site whose geological setting were intended to mimic the anticipated landing site was selected. The site, known as The Harper Hills, in the California Mojave desert was selected since it provides a sharp contact between sedimentary and an igneous rock layer. The hills expose a hard and fast (several km/s) crystalline bedrock composed of gneiss and granitoid, which underlays unconsolidated alluvium (several 100m/s). Prior to carrying out a simulated HP^3-SEIS experiment, a seismic survey of the shallow subsurface was conducted and a model of the underlying shallow geology was constructed (Figure 3).

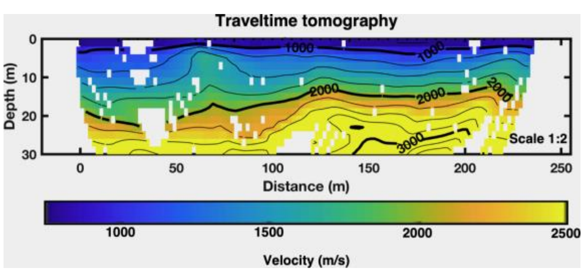

Figure 3: A preliminary seismic model derived from the Harper Hills refraction lines was constructed.

Subsequently, a simulation of the HP3-SEIS experiment was carried out (Figure 4), whose data was used to asses our ability to recover the seismic velocity in the vicinity of the InSight lander and the thickness of the regolith layer.

Figure 4: Two broad band seismometers simulating InSight's Very Broad Band (VBB) and Short Period (SP) seismometers were placed 1m away from a HP^3 mole, and were recording continuously during ~1 hour of hammering.

Recovery the Seismic Properties of the InSight Landing Site: We will report details of the analysis conducted by the team, a summary of the key conclusions is listed below:

- The seismic velocity of the shallow (top 1-2m) of the subsurface was recovered with a high degree of confidence. This information will be useful in understanding and constraining some of the anticipated and observed atmosphere-induced signal that is prevalent in the landing site especially during the Martian day.
- Retrieving the thickness of the regolith down to the crystalline rock proved more challenging, and the team is exploring additional methods, such as identifying local resonances in the subsurface structure to help reduce the uncertainty in the structure down to depth of several tens of meters.

References:

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[2] T. Spohn, M. Grott, J. Knollenberg, T. van Zoest, G. Kargl, S. Smrekar, W. Banerdt, T. Hudson, Insight: measuring the Martian heat flow using the heat flow and physical properties package (HP3). LPI Contrib. 1683, 1124 (2012)

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