Seismic investigations of the Martian near-surface at the InSight landing site

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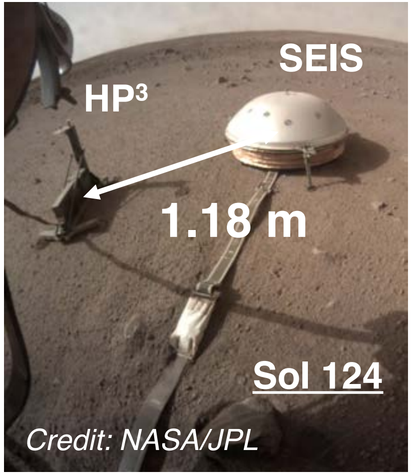
Motivation – “Active-source” near-surface seismic study

- The Heat Flow and Physical Properties Package (HP^3) was deployed close to seismometer package (SEIS) in mid-February 2019
- HP^3 mole is a self hammering device **producing seismic waves** with each hammer stroke
- The seismic signals may allow **infering on the shallow elastic properties** to (Kedar et al., 2017):
  - Study the geological structure, composition and history at the landing site
  - Understand the seismic noise recorded by SEIS
  - Provide regolith properties for future missions



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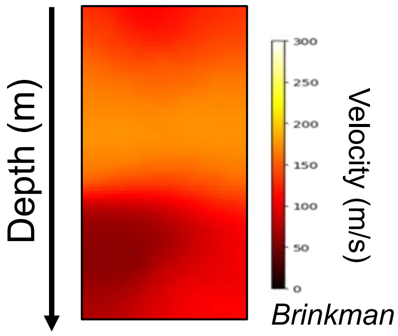
Proposed seismic analyses to study the near-surface

Seismic traveltimes

- The traveltime of the wave arriving first at SEIS can provide information on the subsurface **seismic velocity structure** (Brinkman et al., 2019)

Velocity model
from a synthetic data test

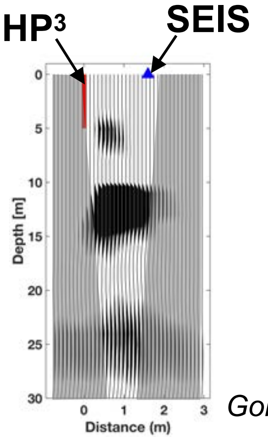


Brinkman et al. (2019)

Subsurface reflection imaging

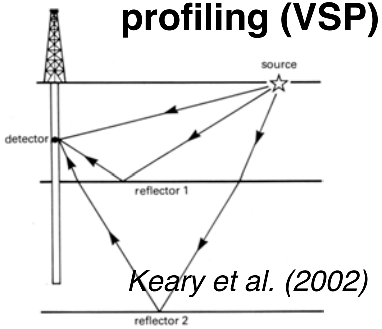
- Reflected waves may be used to image **shallow interfaces** analogoues to vertical seismic profiling (Golombek et al., 2018; Brinkman et al., 2020)
- Requires the mole to penetrate into the subsurface

Seismic reflection imaging illustrated with synthetic data



Golombek et al. (2018)

Vertical-seismic profiling (VSP)



Keary et al. (2002)

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Challenges of this opportunistic experiment

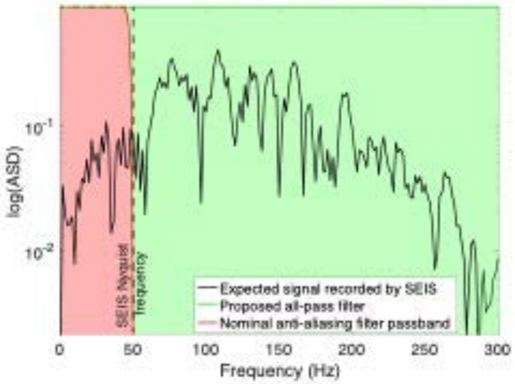
- The analysis of the HP^3 seismic signals is an **opportunistic experiment** that was only conceived after the key hardware decisions were made (Kedar et al. 2017)

- **Time-resolution challenge**: the SEIS acquisition flow is designed for seismic signals with frequencies <50 Hz but the HP^3 mole produces signals with frequencies >100 Hz (Sollberger et al., 2020)

- **Time-correlation challenge**: SEIS and HP^3 operate on independent clocks that need to be correlated to determine the traveltimes of the seismic waves precisely enough for the proposed analyses (Brinkman et al., 2019)

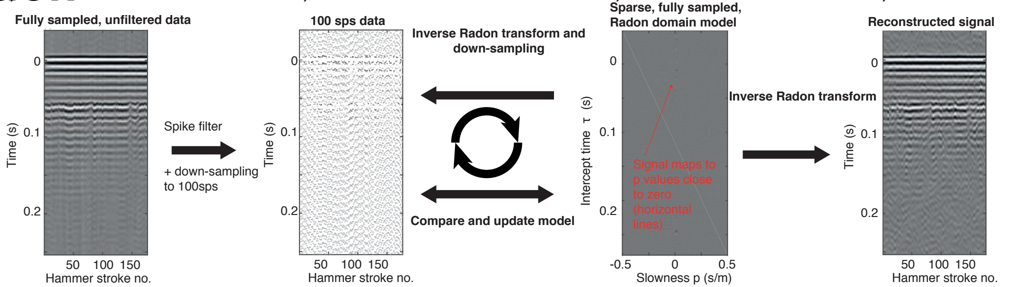
Reconstruction of information beyond Nyquist frequency

The HP3 hammering seismic signals are observed to have a **much broader frequency** content then the nominal SEIS acquisition electronics is designed to record.



Sollberger et al. (2020)

We therefore developed an acquisition and signal reconstruction flow that includes (1) **recording aliased data** by omitting filters when downsampling the data for transfer from Mars to Earth and (2) reconstructing the original signals using a **sparseness-constrained reconstruction algorithm** that exploits the high repeatability of the hammering signals and uncorrelated hammer time and sampling (Sollberger et al., 2020).



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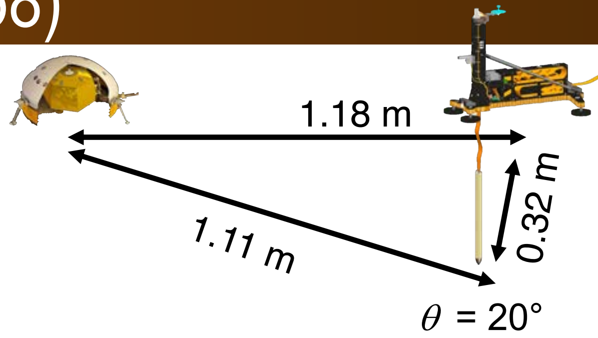
Brinkman et al. (2019)

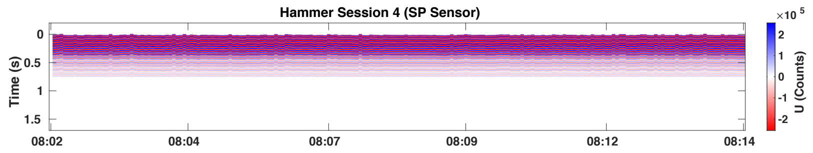
First results – Hammering session 4 (sol 158)

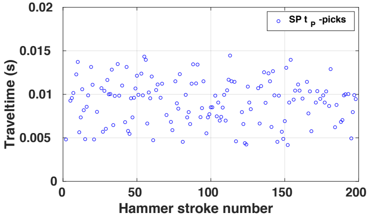
- The seismic data of the SEIS short period (SP) sensor were recorded in aliased fashion for several HP[3] hammering sessions

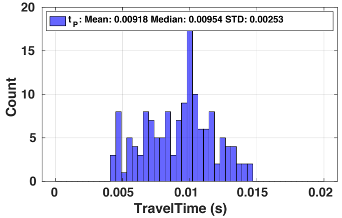
- First-arrival traveltimes were determined from the reconstructed data

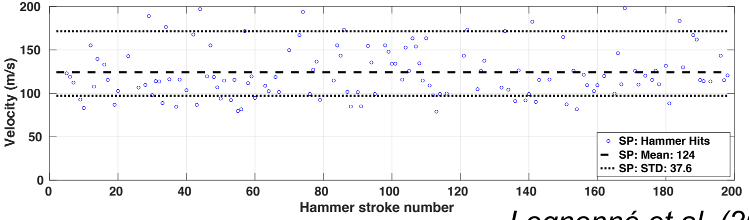
- An apparent velocity of 124 ± 34 m/s was obtained for hammering session 4 (Lognonné et al., 2020)











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Lognonné et al. (2020)

Interpretation

- Observed low (~120 m/s) seismic P-wave velocity interpreted to represent the **bulk velocity of the volume between HP³ mole tip and SEIS**

- Low velocity **consistent with proposed near-surface stratigraphy** (Golombek et al., 2020) of >3 m thick impact-fragmented regolith consisting of poorly sorted unconsolidated sands and rocks

- A **near-surface velocity model** is under construction based on the HP3-SEIS traveltime and compliance inversions using atmospheric pressure signals (Lognonné et al., 2020)

Schmelzbach et al. (2020), EGU2020-20481

Credit: NASA/JPL

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