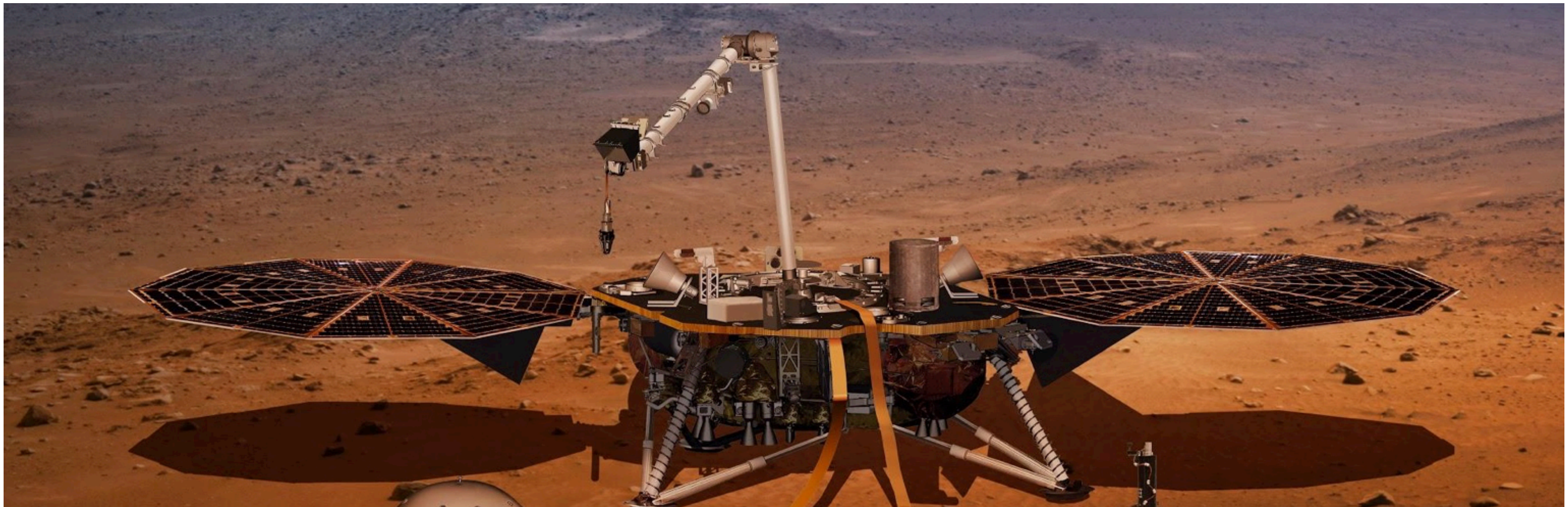

Extraterrestrial Seismology: The perspective after nearly 1 year of InSight on Mars

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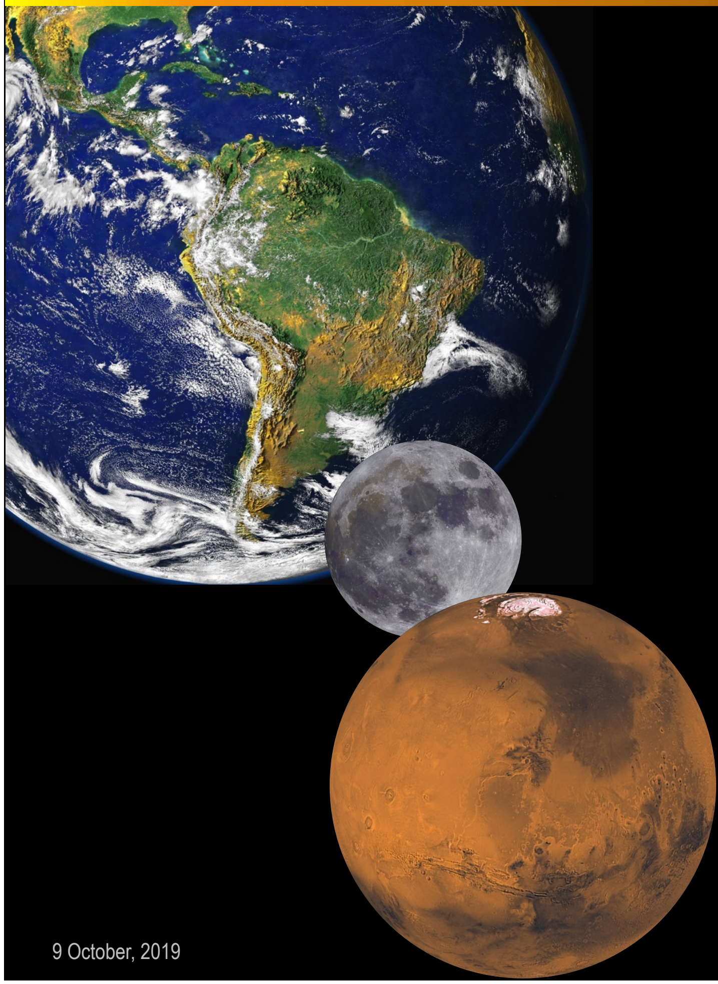
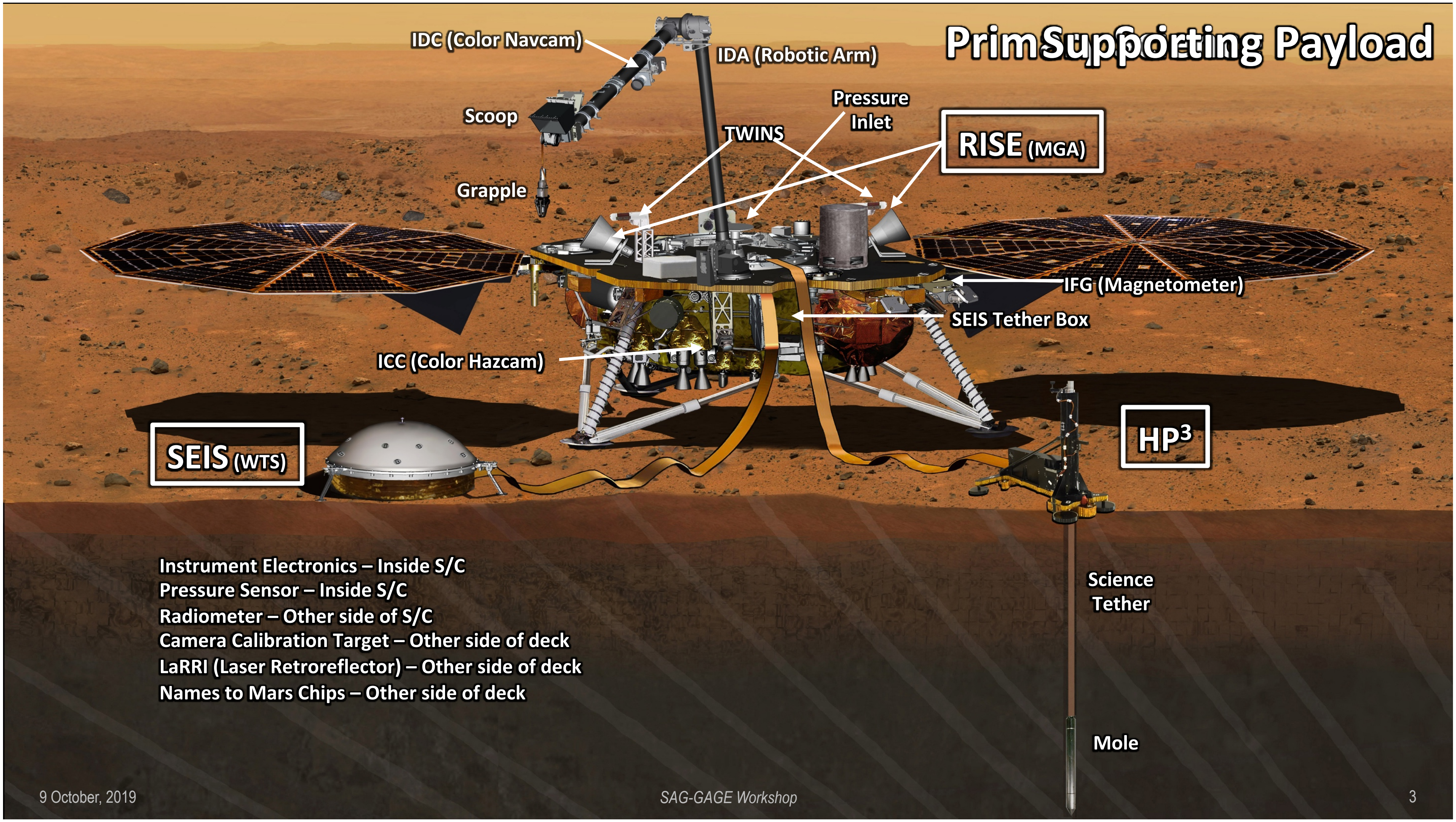
Mars is Only the Third Planetary Interior to be Investigated in Detail



- InSight follows in the footsteps of terrestrial geophysics at the dawn of the 20th century, attempting to answer basic questions about the planet:
  - What is the thickness of the crust?
  - What is the structure of the mantle?
  - What is the size and density of the core?
  - What is the distribution of seismicity?
  - What is the planetary heat flow?

- It also follows a similar path taken a half-century ago on the Moon, when Apollo put in place a lunar seismic/heat flow/laser retroreflector network.

- The overarching goal motivating this mission is to better understand the processes of planetary differentiation that formed the terrestrial planets, and the global processes that subsequently modify them.


Supporting Payload
IDC (Color Navcam)
IDA (Robotic Arm)
Scoop
Grapple
TWINS
Pressure Inlet
RISE (MGA)
IFG (Magnetometer)
SEIS Tether Box
ICC (Color Hazcam)
SEIS (WTS)
HP3
Science Tether
Mole
Instrument Electronics – Inside S/C
Pressure Sensor – Inside S/C
Radiometer – Other side of S/C
Camera Calibration Target – Other side of deck
LaRRI (Laser Retroreflector) – Other side of deck
Names to Mars Chips – Other side of deck

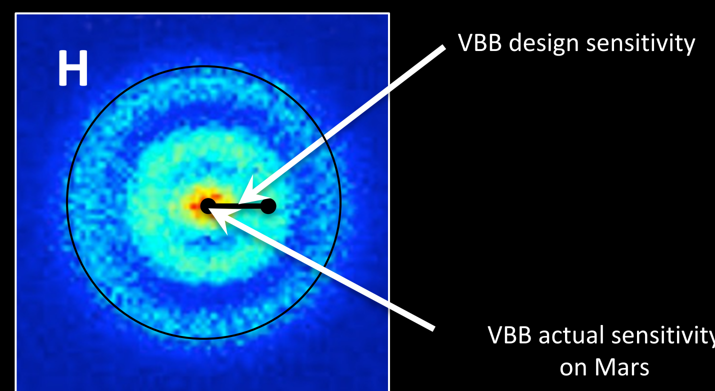
HP3 status

- The HP^3 was deployed to the surface in mid-February and immediately began penetration.
- A depth of 35 cm was reached relatively rapidly (within a few hundred strokes); repeated subsequent hammering (~9000 strokes) resulted in no measurable further progress.
- Our conclusion is that the mole has either encountered an obstacle (e.g., a rock) or, more likely, has lost sufficient hull friction to maintain downward progress.
- As of today, we have new images down which appear to show progress of the mole

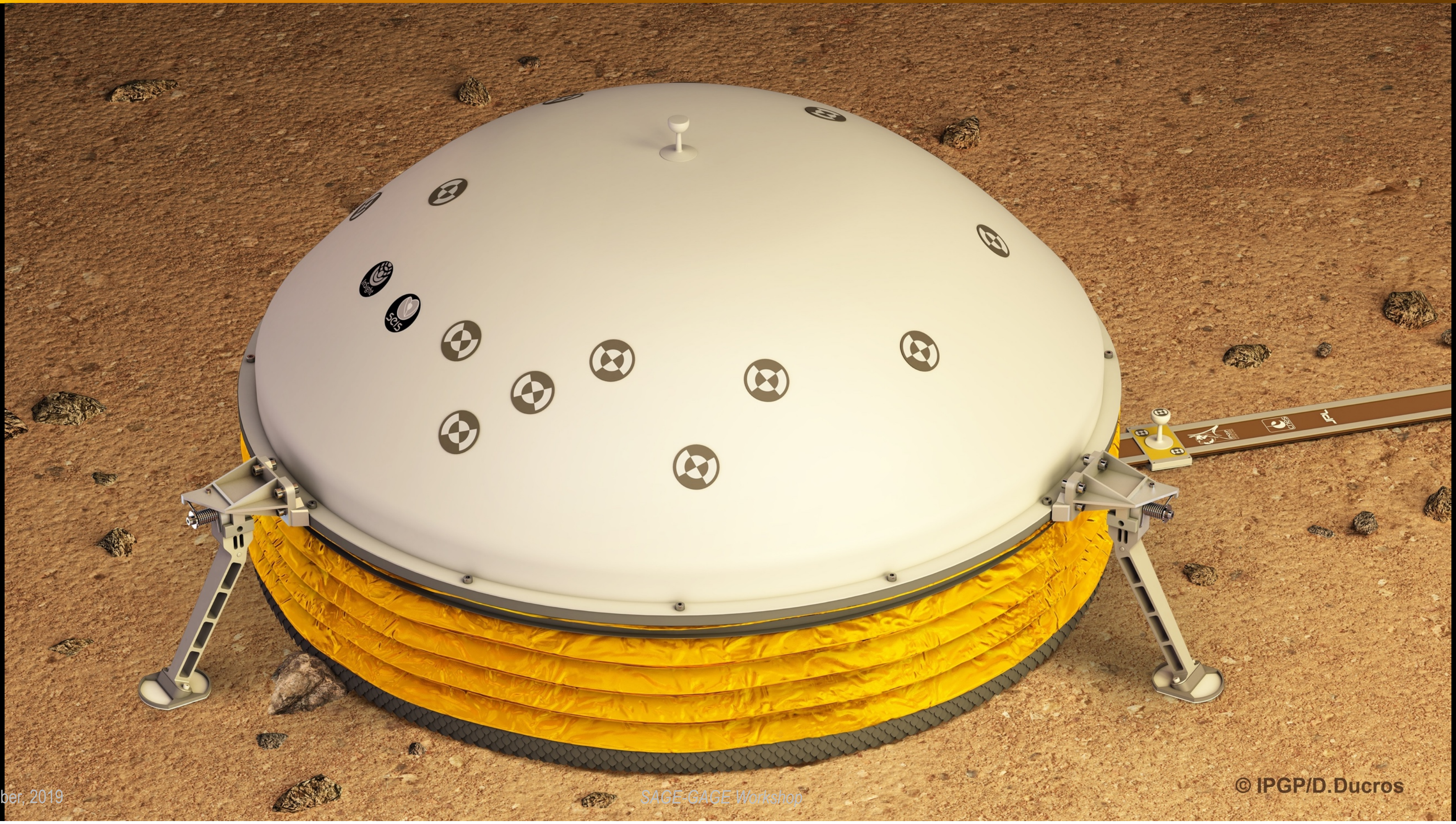
The Challenge of Operating a Seismometer on Mars
It's All About the Noise!

- Need extremely high sensitivity – expect fewer and smaller quakes than on the Earth
  - Sensitivity target: 2.5x10^{-9}m/sec^2/Hz$^{1/2}$
  - This is equivalent to displacement amplitudes smaller than a hydrogen atom

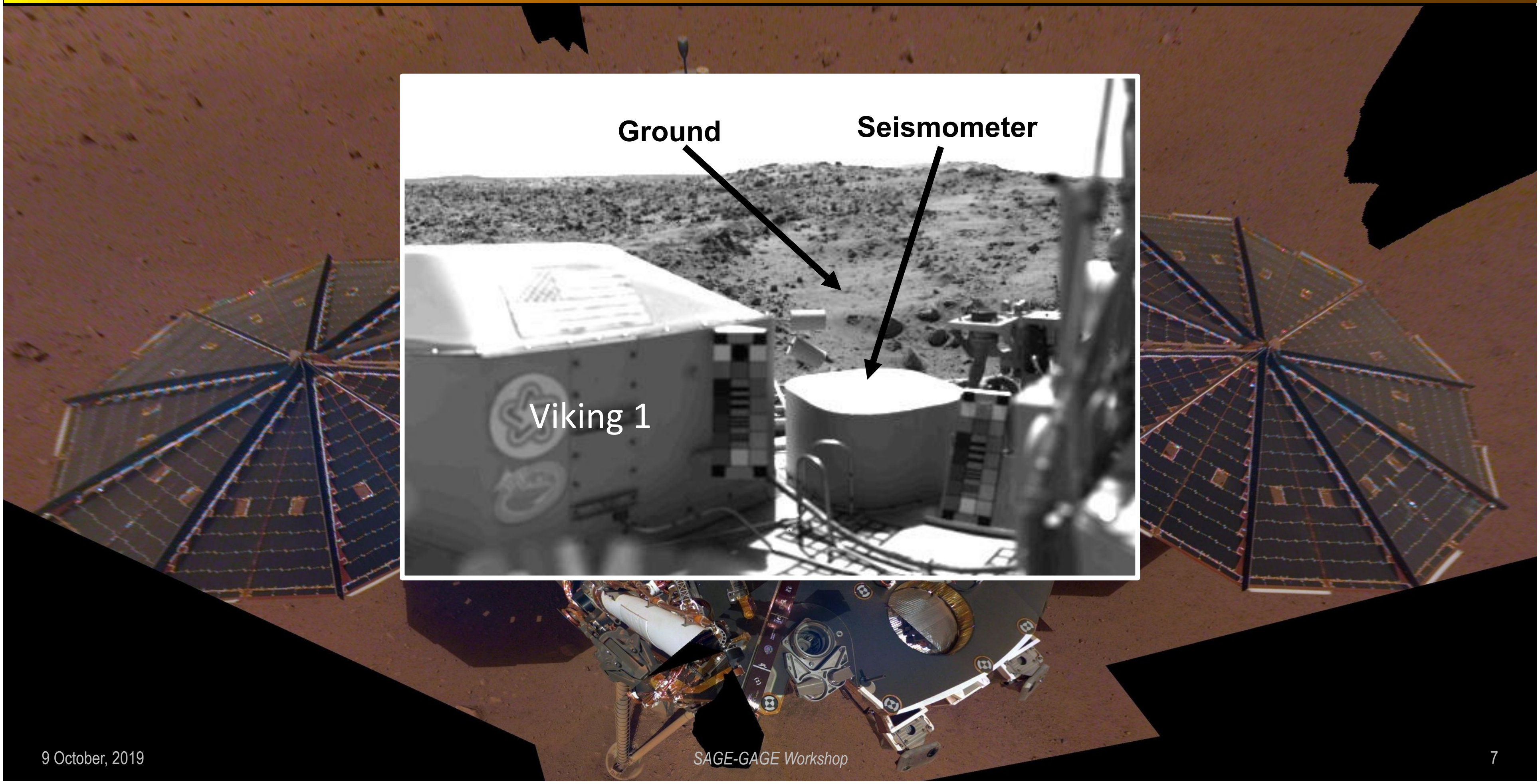
- Therefore one must minimize/compensate for all noise sources:
  - Instrument intrinsic noise
  - Temperature variations
  - Wind
  - Atmospheric pressure variations
  - Magnetic field variations
  - Lander vibrations



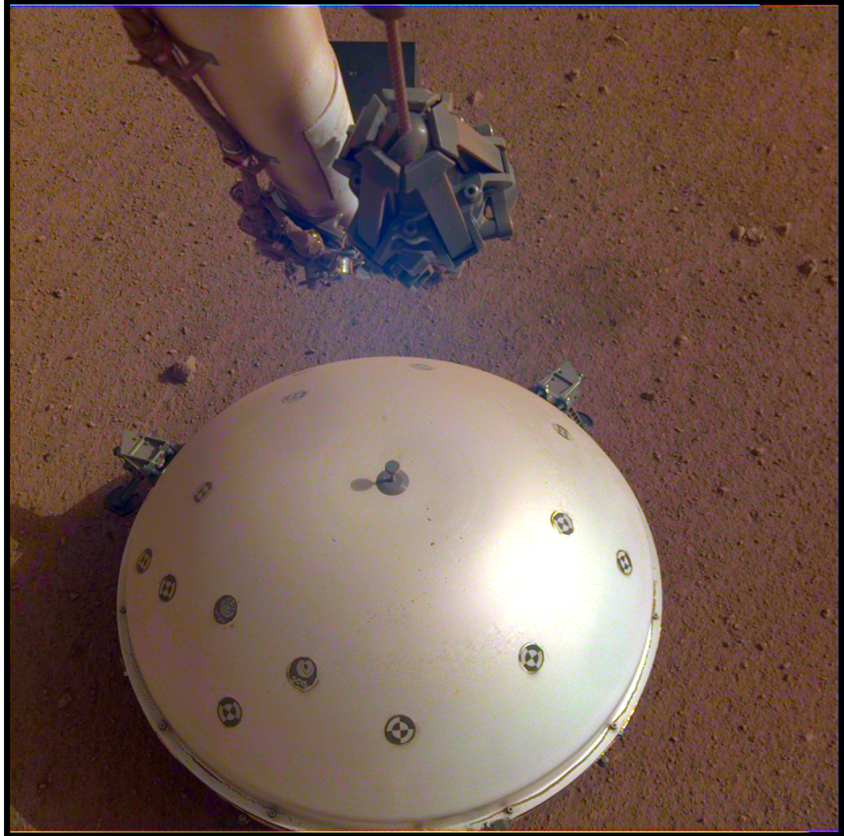
Isolate, Isolate, Then Isolate Again...



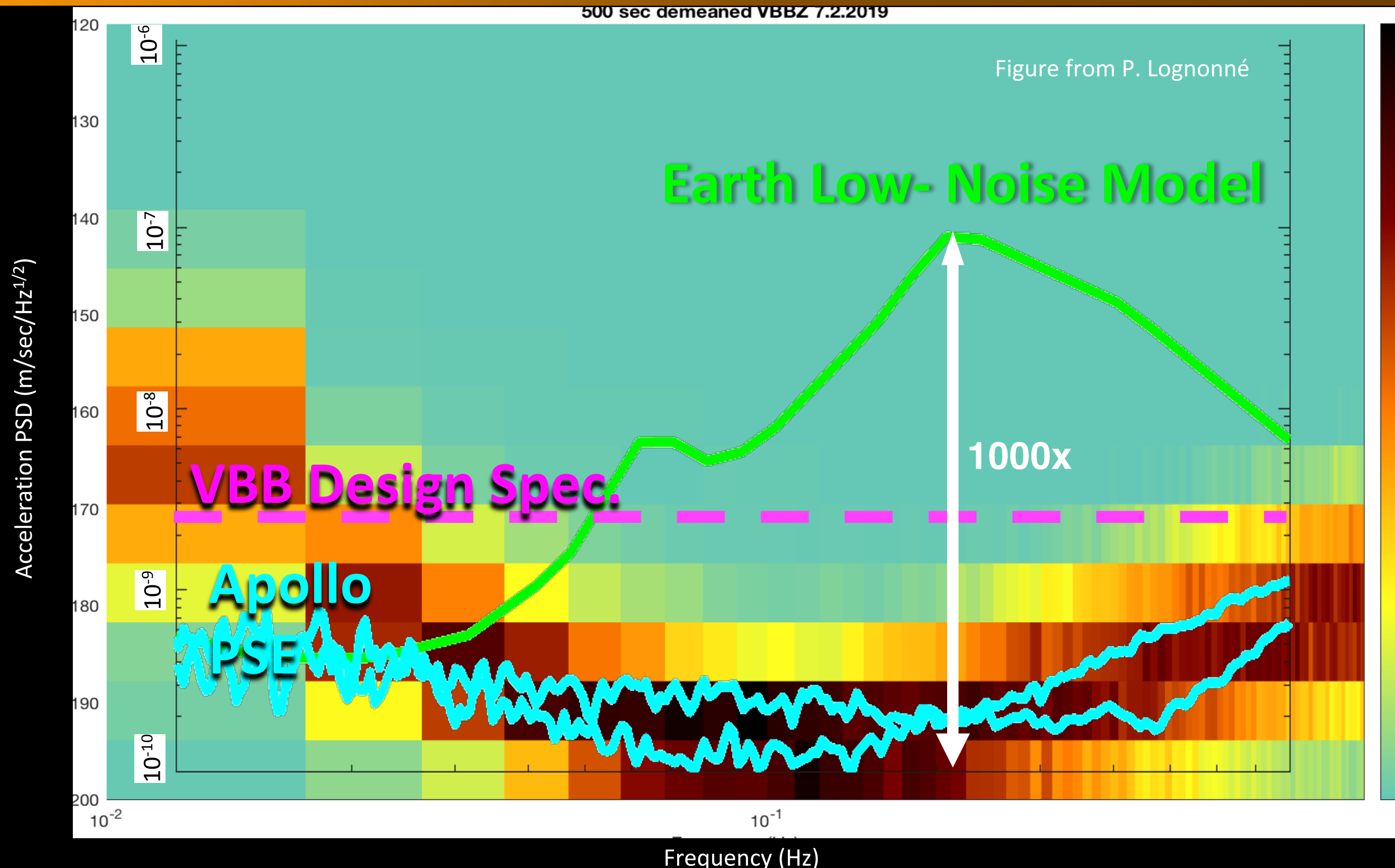
SEIS on Mars – Almost



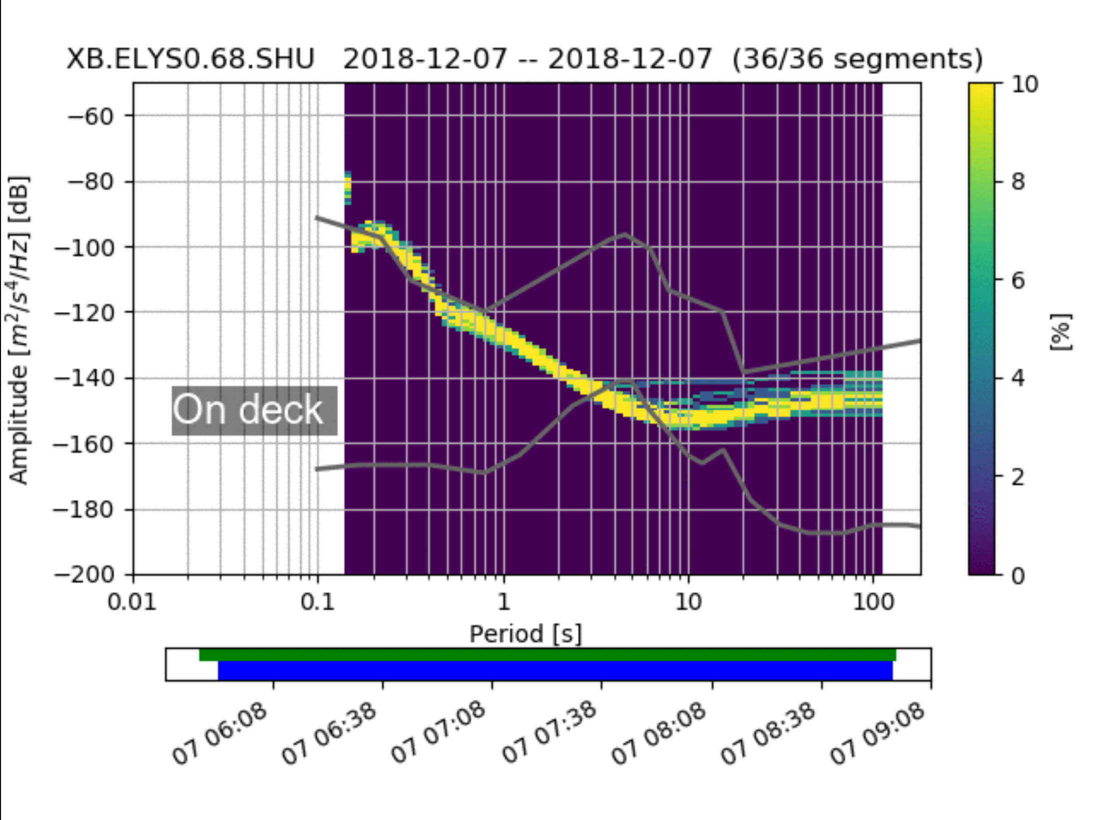
SEIS Deployment



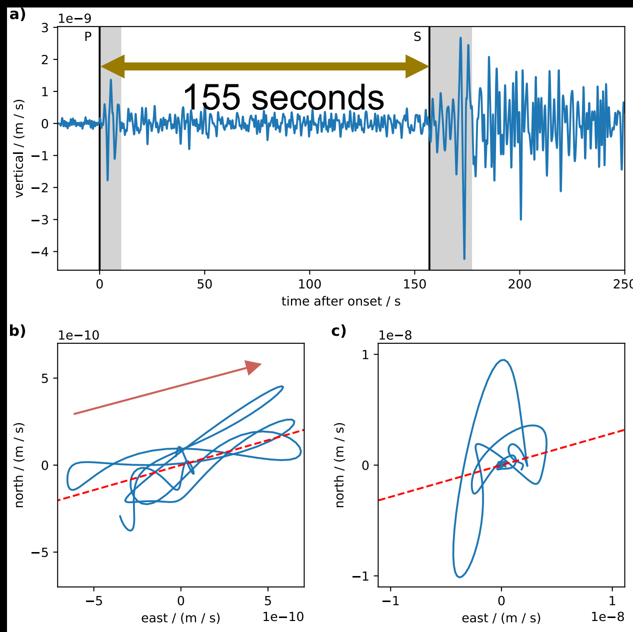
VBB Acceleration Noise Statistics



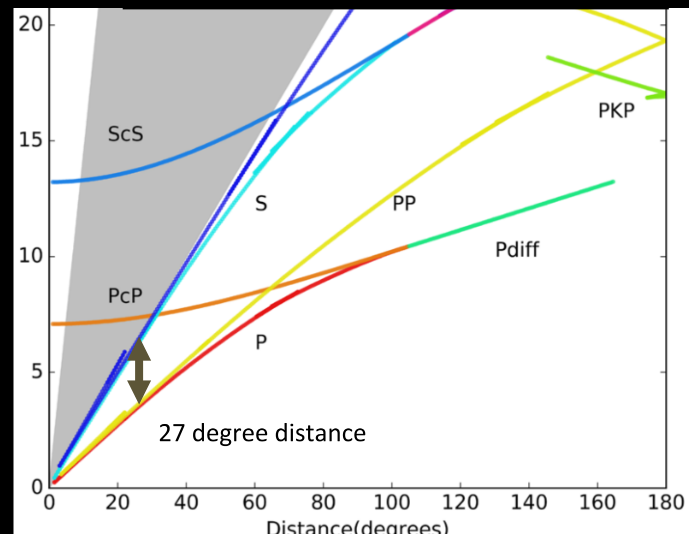
Noise evolution



Locating marsquakes with a single station



M. van Driel

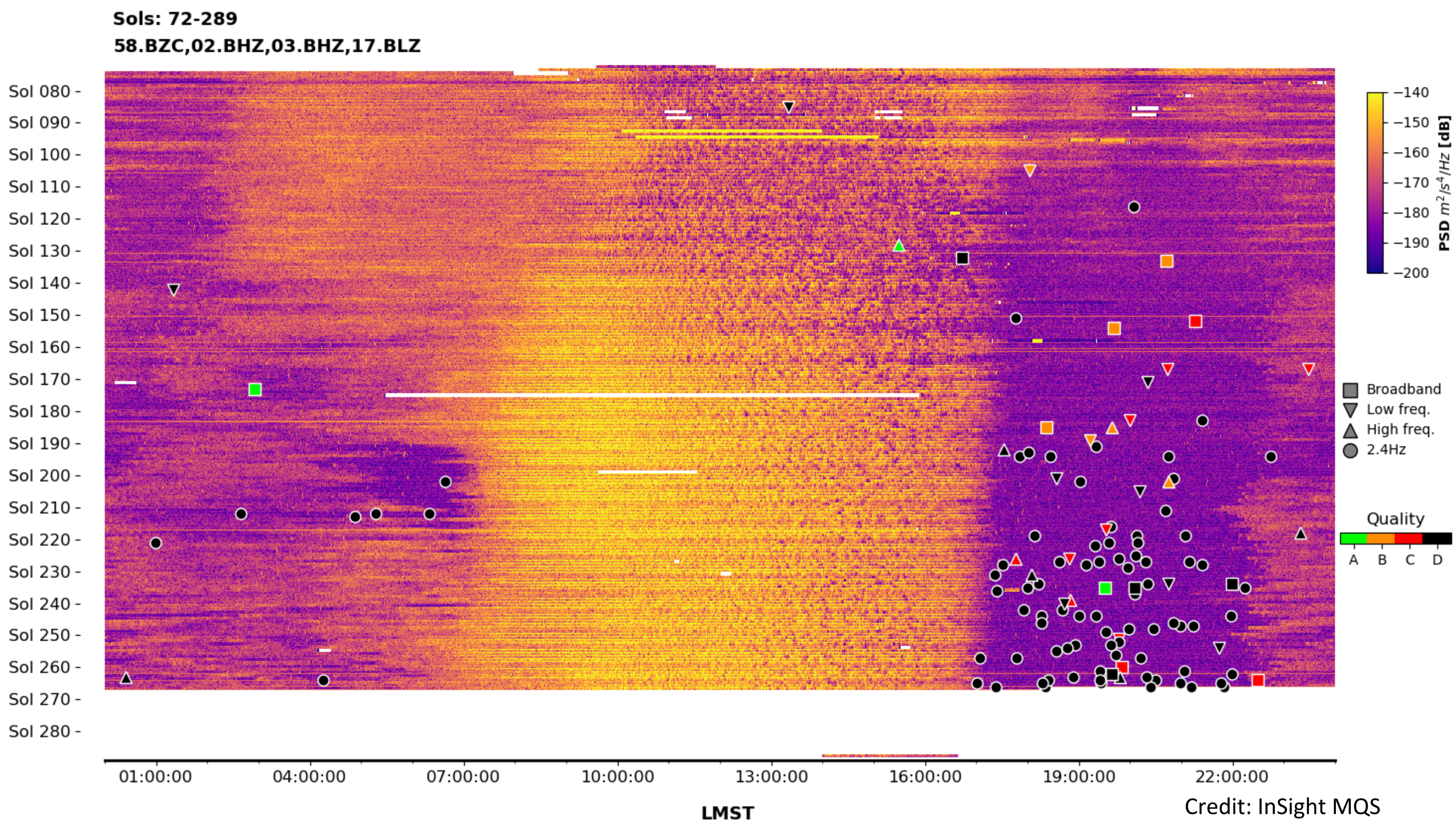


Ceylan et al. (2017)

Direction

Distance

All Seismic Data Through Sol 289 (about 3 weeks ago)

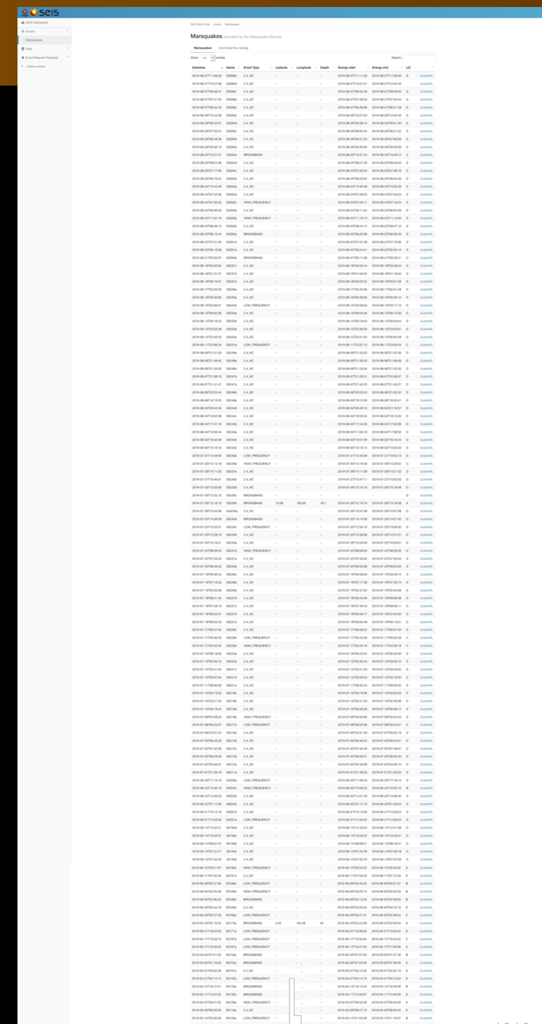


Credit: InSight MQS

InSight Seismic Event Catalog (10/9/2019)

- Currently there are 162 events in the InSight catalog.
  - 3 Quality A
    - » Clear seismic phases and polarization, or SNR>10
  - 5 Quality B
    - » Signal clearly observed, clear seismic phases, but no polarization
  - 94 Quality C
    - » Signal clearly observed, but no clear phases
  - 60 Quality D
    - » Signal only weakly observed
    - » OR likely not a seismic event
    - » OR signal possibly contaminated by environmental conditions

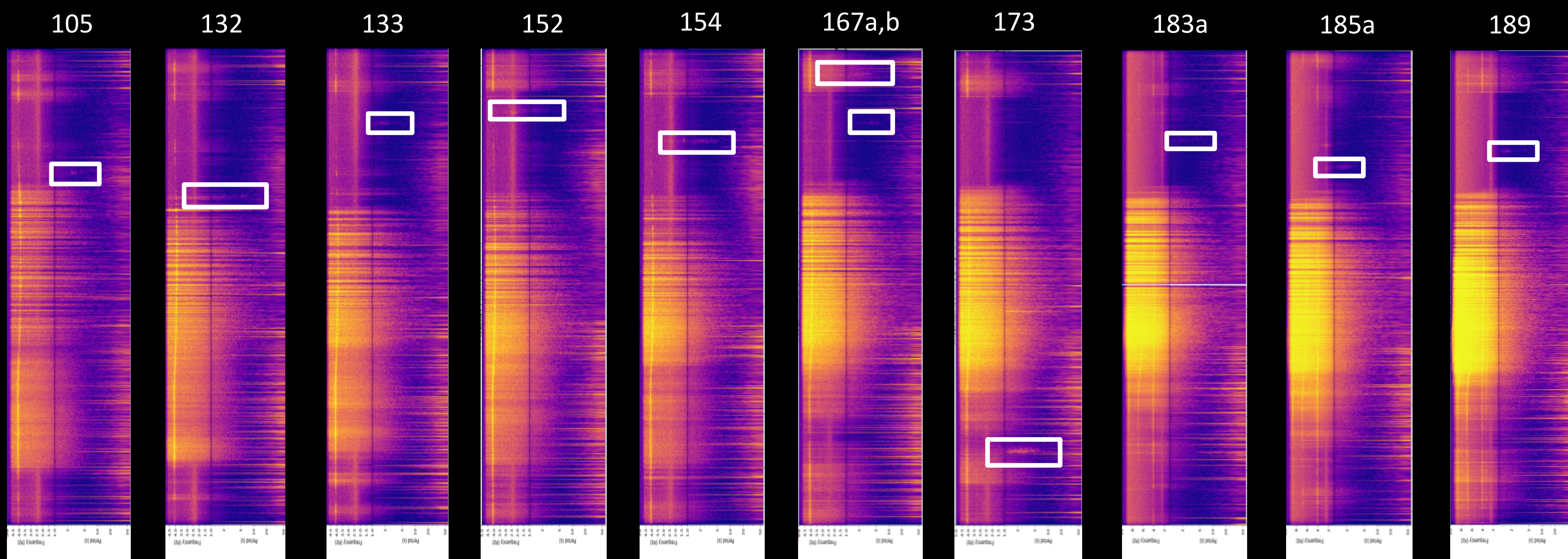
- Preliminary classification scheme:
  - Low frequency (energy only below 1 Hz) – 17 events
  - High frequency (energy only above 1 Hz) – 22 events
  - Broad-Band – 9 events
  - 2.4 Hz – 114 events



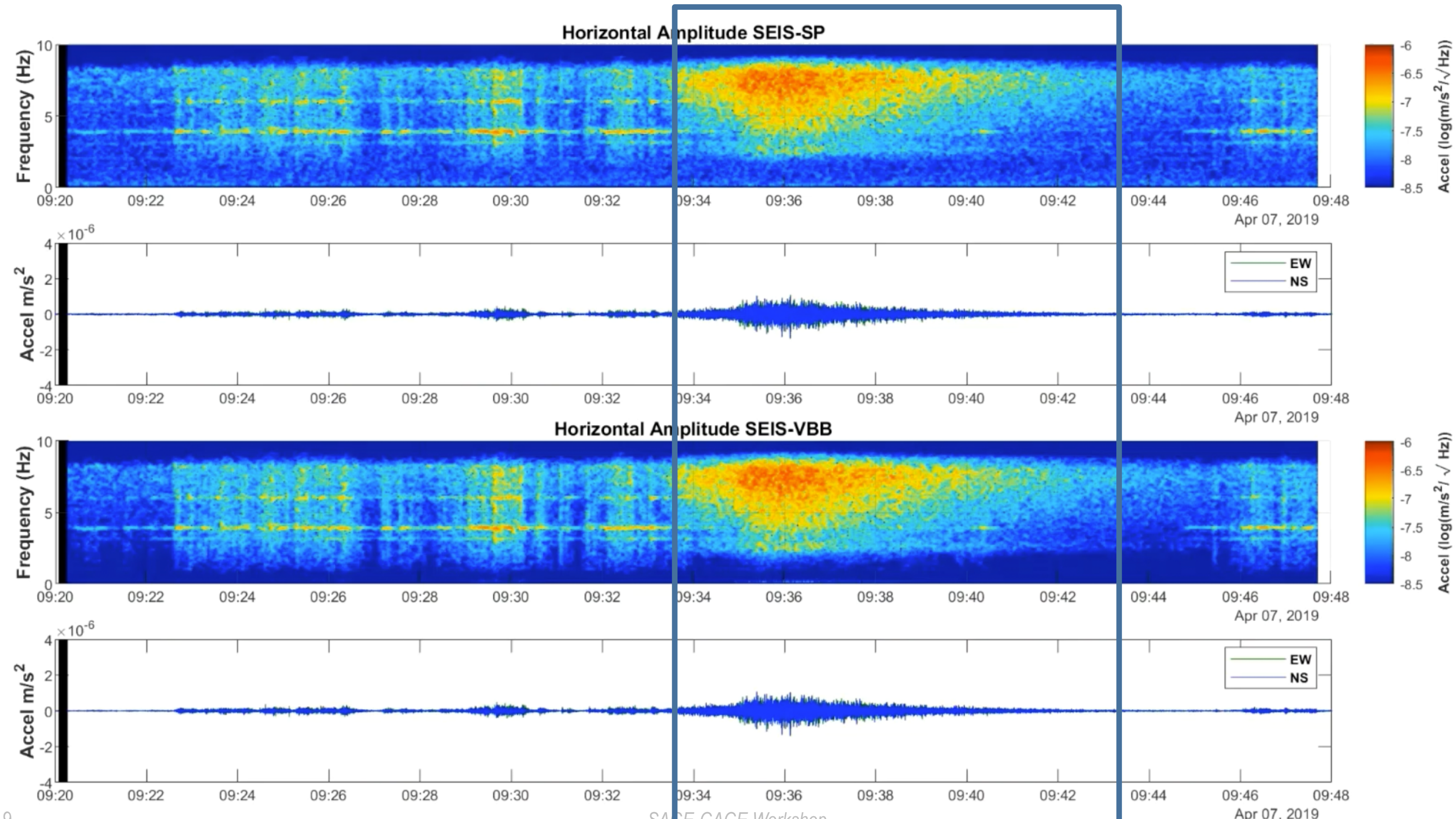
SEIS Continues to Detect Several New Events/Week

Detecting ~2 “significant” events/month

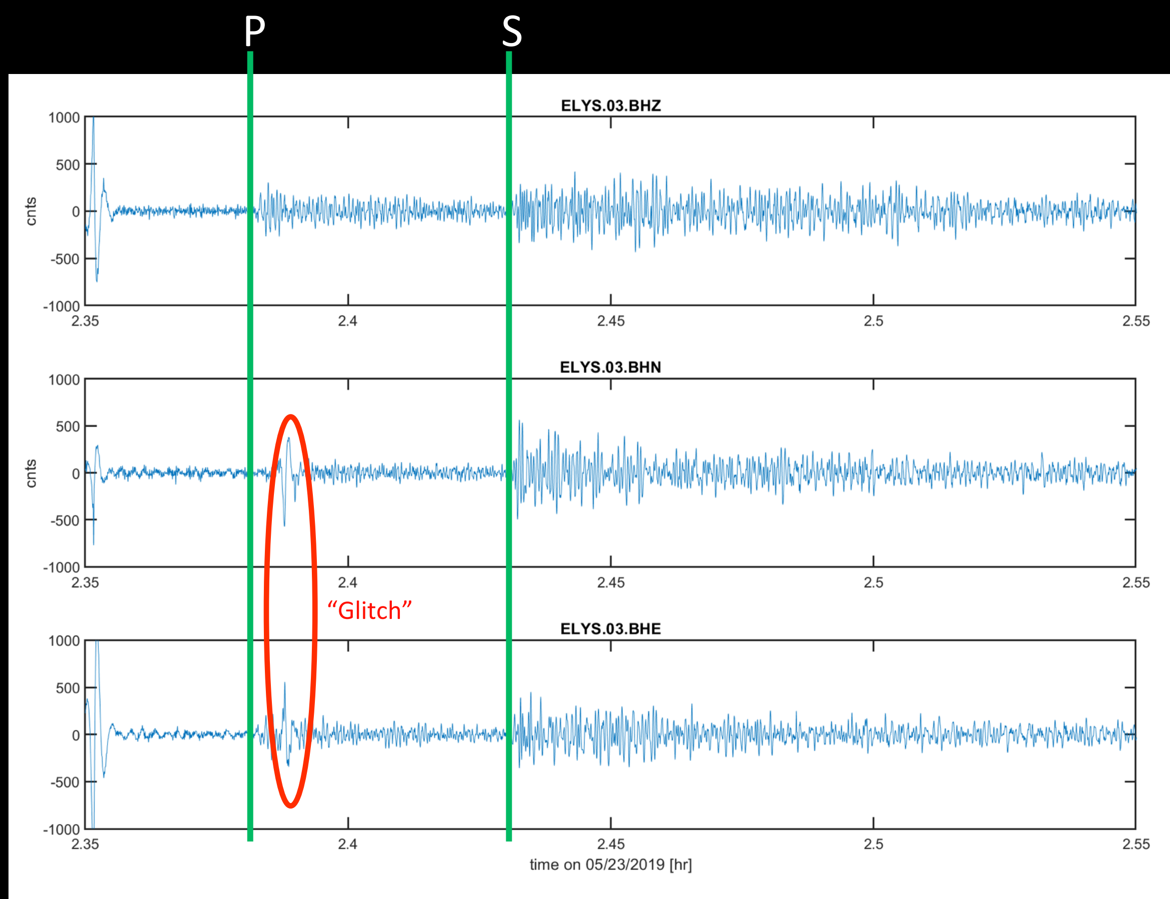
Sol-Long Images – Long Period and Broad Band
Events through sol 200



First Identified Marsquake: S0128a (HA)



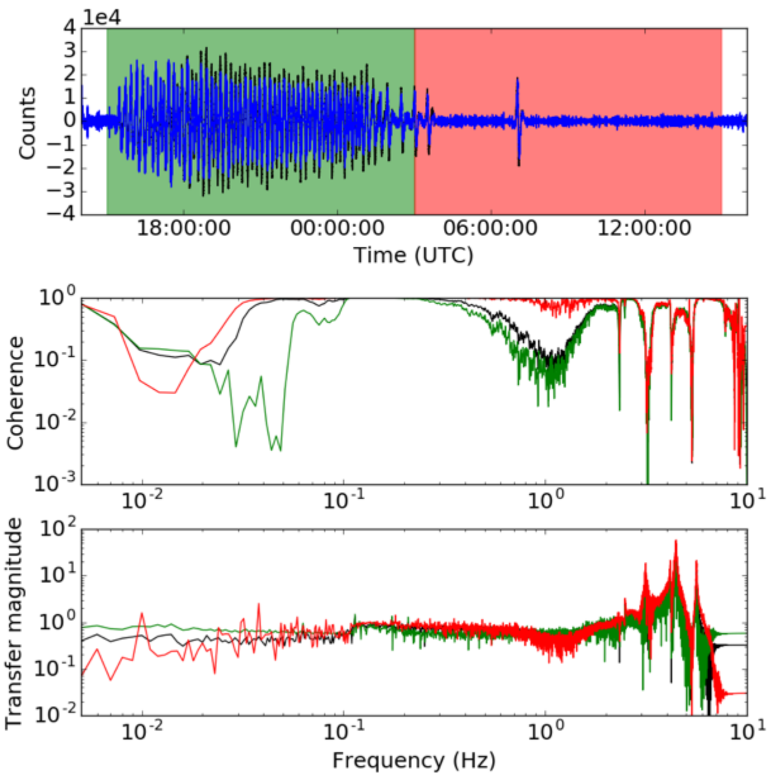
Largest Marsquake to Date: S0173a (BA), Magnitude 3.7

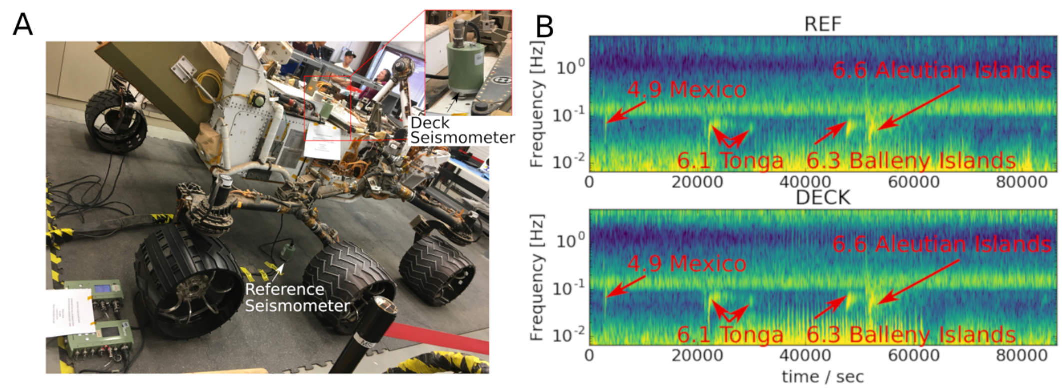


Future deployments on deck?

- The deployment process was critical for achieving target noise levels
- It was also the most expensive part of the mission (building a robotic arm and staffing people to work it for deployment for months!)
- Can we do things on future missions more cheaply if not as high perormance?

On MSL

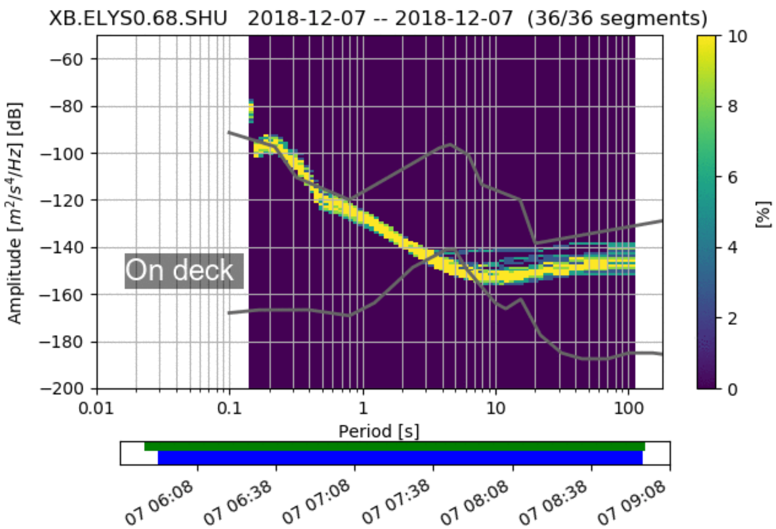


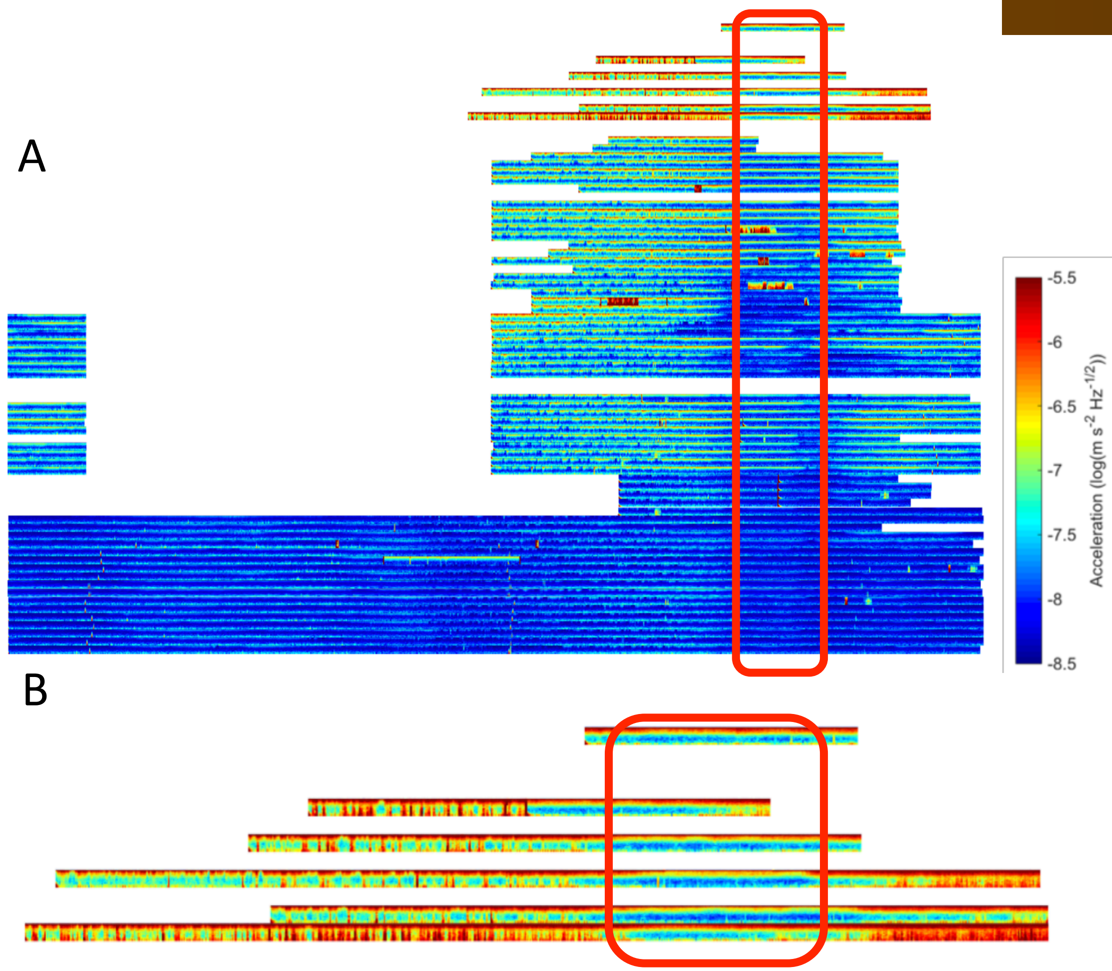


On deck operation on MSL engineering model shows clean recording of teleseismic events and simple transfer function from ground motion. Air motion causes decoherence. Lander activity not considered here (measurements were taken over a weekend, and engineering model does not require active thermal management used on Mars).

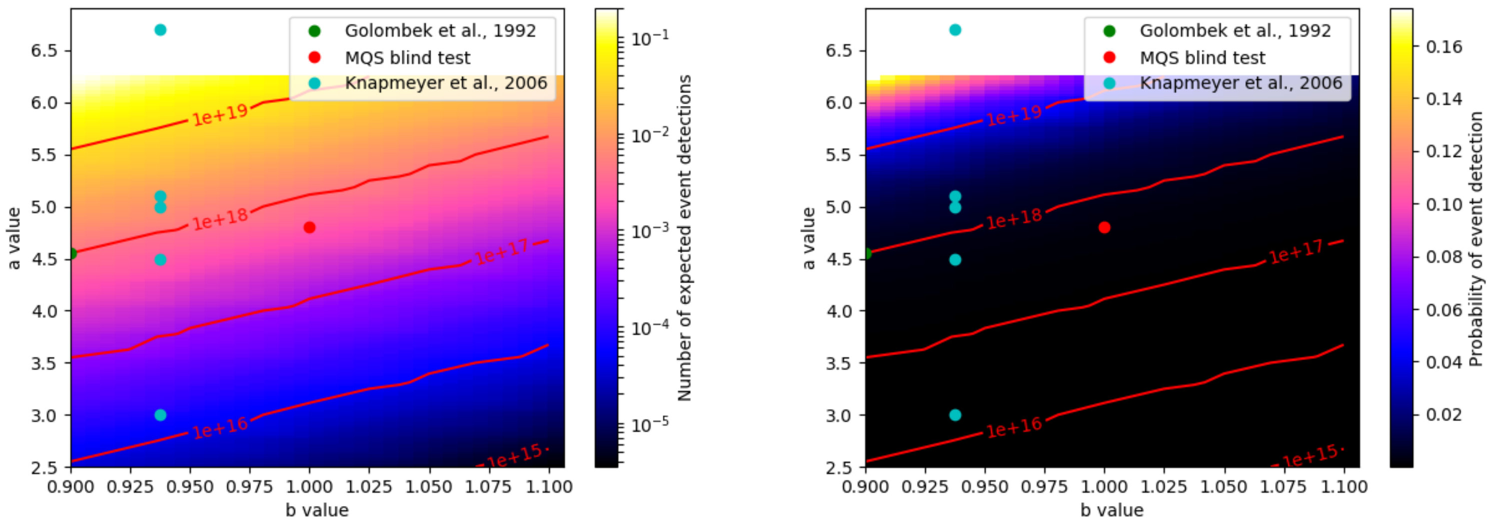
InSight on deck

SP instrument noisier on deck, but still sees significant quiet times during evenings, specifically between 19:00 and 22:00 LMST





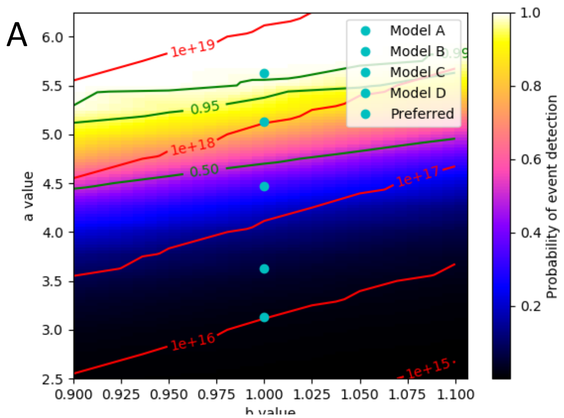
Detection probability on Mars for 48 hours of on-deck observation



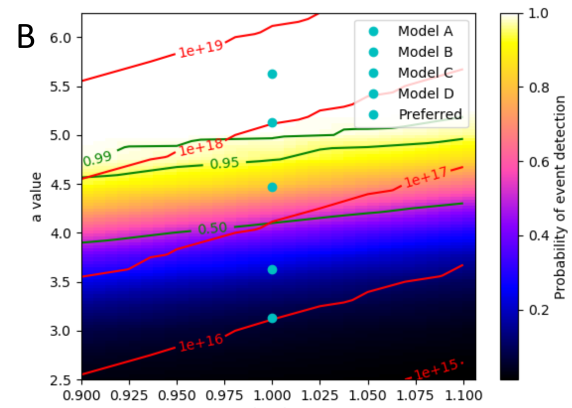
Using synthetic martian seismograms to model detection threshold, it looks like likely years of on-deck operation would be required on Mars.

Simulated 48 hour detection probabilities on Europa!

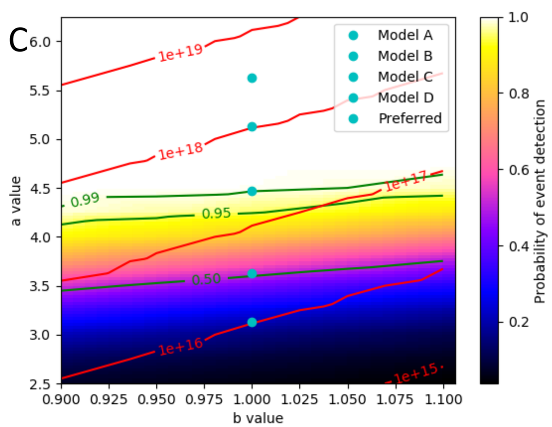
Using observed Mars noise

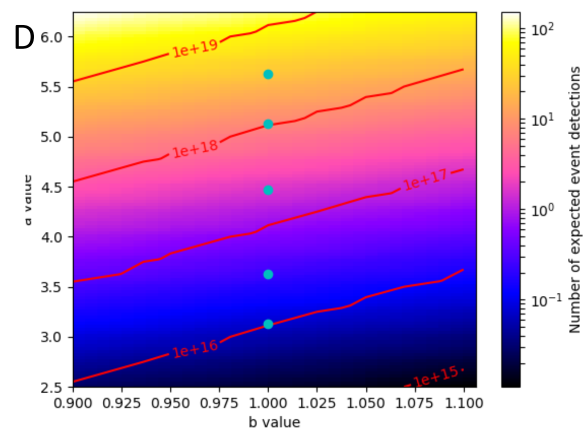


Using minimum Mars noise



Using SP self-noise





Expected number of observation with minimum Mars noise

Summary

- Deploying a seismometer on Mars is a long, slow process.
- The data, though, is quieter than anywhere on Earth in some frequency bands
- We have detected many events and located several of them
- Future deployment on airless bodies may be able to be done without deployment with more modeling of the specific mission design

Sunset over Elysium, sol 145

Raw images are available at mars.nasa.gov/insight essentially as soon as they hit the ground.

All InSight science data through the end of June (sol 210) is currently available in the PDS.

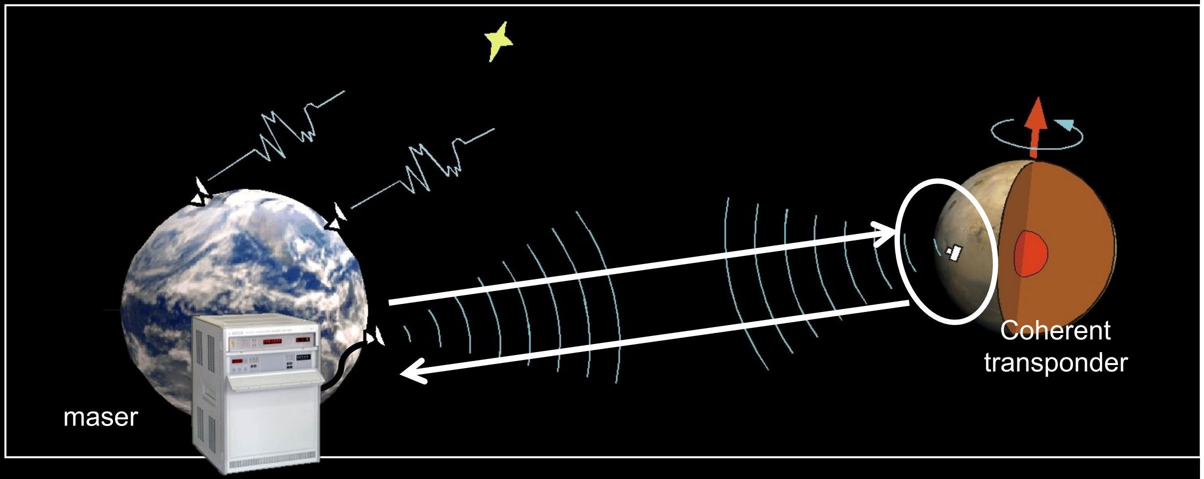
HP3 status

- The HP^3 was deployed to the surface in mid-February and immediately began penetration.
- A depth of 35 cm was reached relatively rapidly (within a few hundred strokes); repeated subsequent hammering (~9000 strokes) resulted in no measurable further progress.
- Our conclusion is that the mole has either encountered an obstacle (e.g., a rock) or, more likely, has lost sufficient hull friction to maintain downward progress.
- We have been developing and testing a recovery plan and are preparing to use the robotic arm to increase the hull friction.

RISE Status

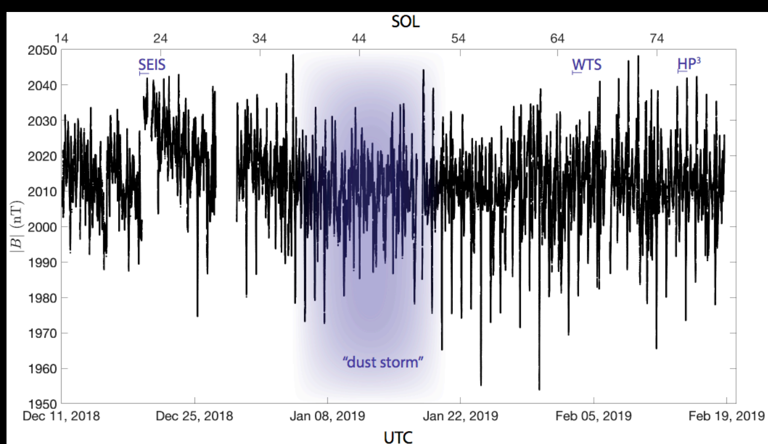
- Measurement of the timing and Doppler shift of the X-band radio signal between the Earth and InSight allow us to track the location and motion of the lander to an accuracy of better than 10 cm in inertial space.
- We are tracking the lander location for about an hour, several sols/week, allowing us to measure the motion of the rotation vector of Mars.
- We expect to have an improved precession measurement, yielding an improved Mars MOI, within a few months.

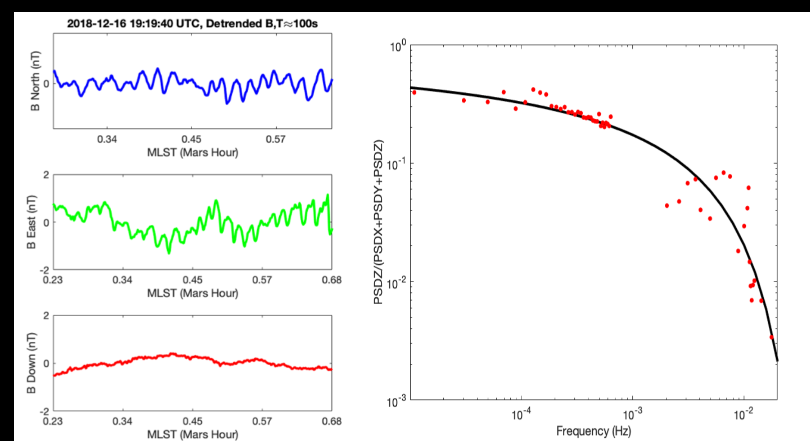
- Measurement of the nutation to a precision that will allow the separation of core radius and density is expected to require an additional year.



Magnetometer (IFG)

- InSight is providing the first magnetic measurements from the surface of Mars. Notable early results include:
  - The DC field at the landing site is roughly an order of magnitude stronger than measured from orbit, evidence of significant crustal field variations at spatial scales less than ~150 km.
  - Vertical field oscillations are observed to be attenuated at higher frequencies relative to horizontal components, possibly suggesting high conductivity at depth.



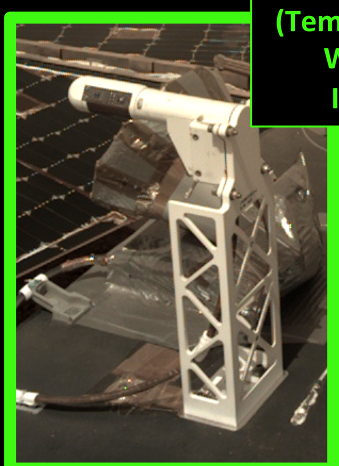


Credit: C. Russell

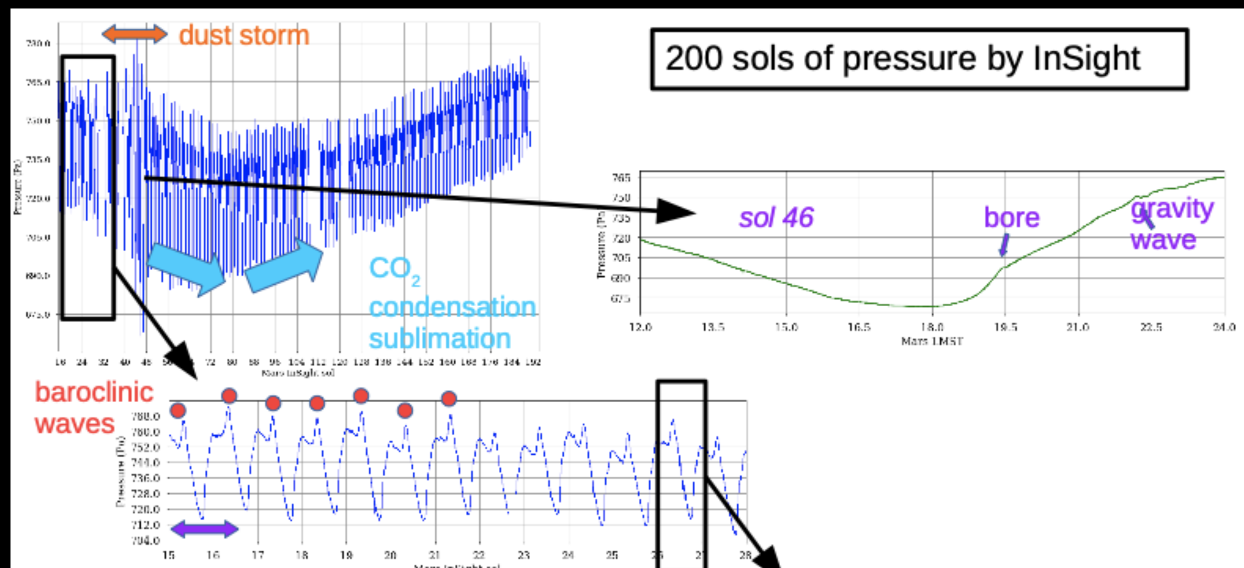
InSight Meteorology

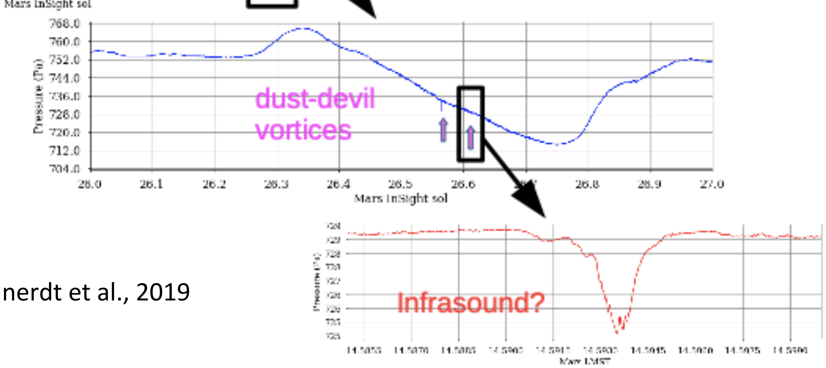
InSight is returning continuous high-rate pressure, temperature, and wind measurements, providing an unprecedented view of atmospheric behavior at time scales from less than a second to months and seasons.

TWINS (Temperature & Wind for InSight)



Pressure Sensor





Banerdt et al., 2019

InSight Cameras (2967 Images as of Sol 293, 9/23/2019)