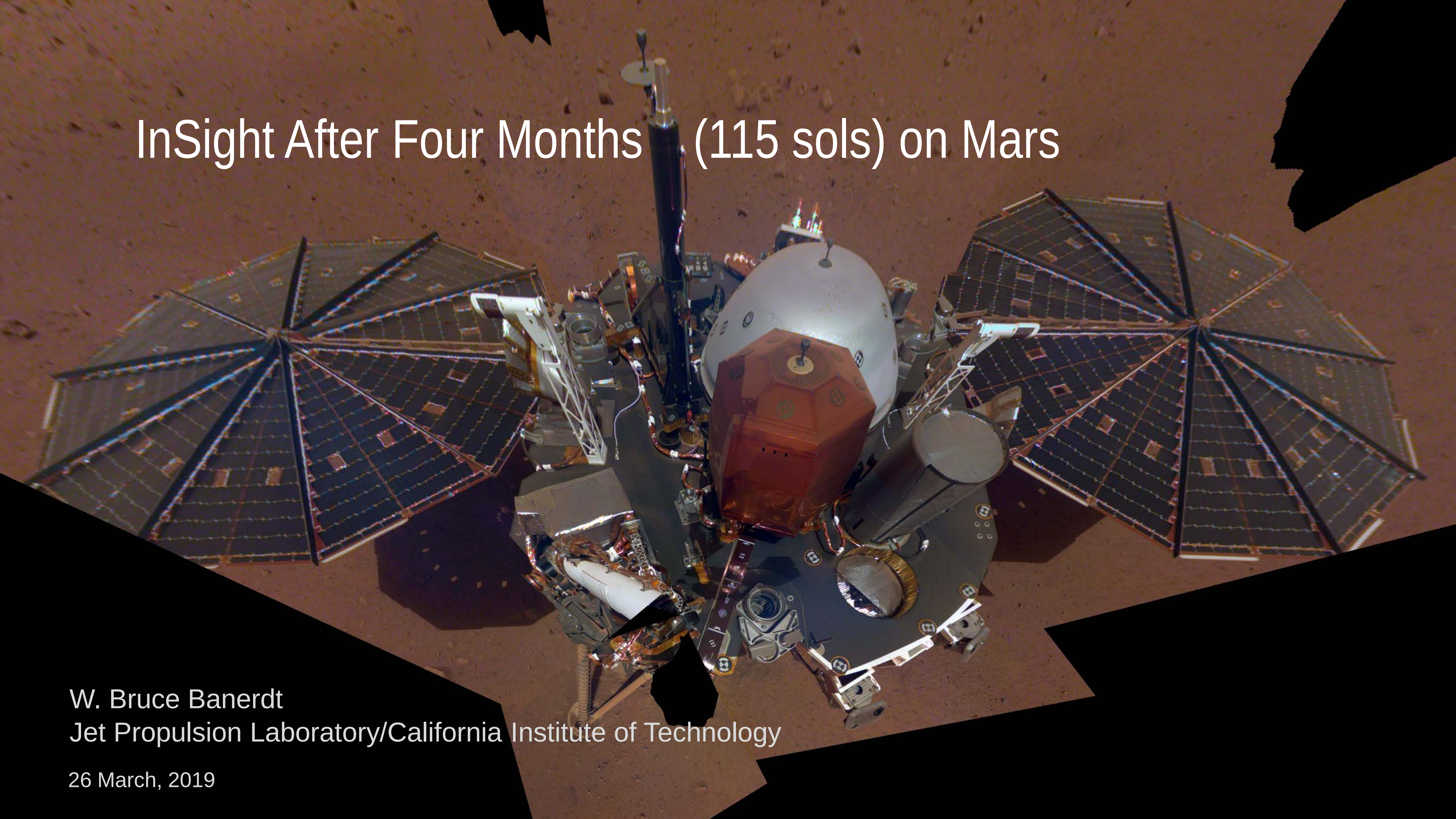
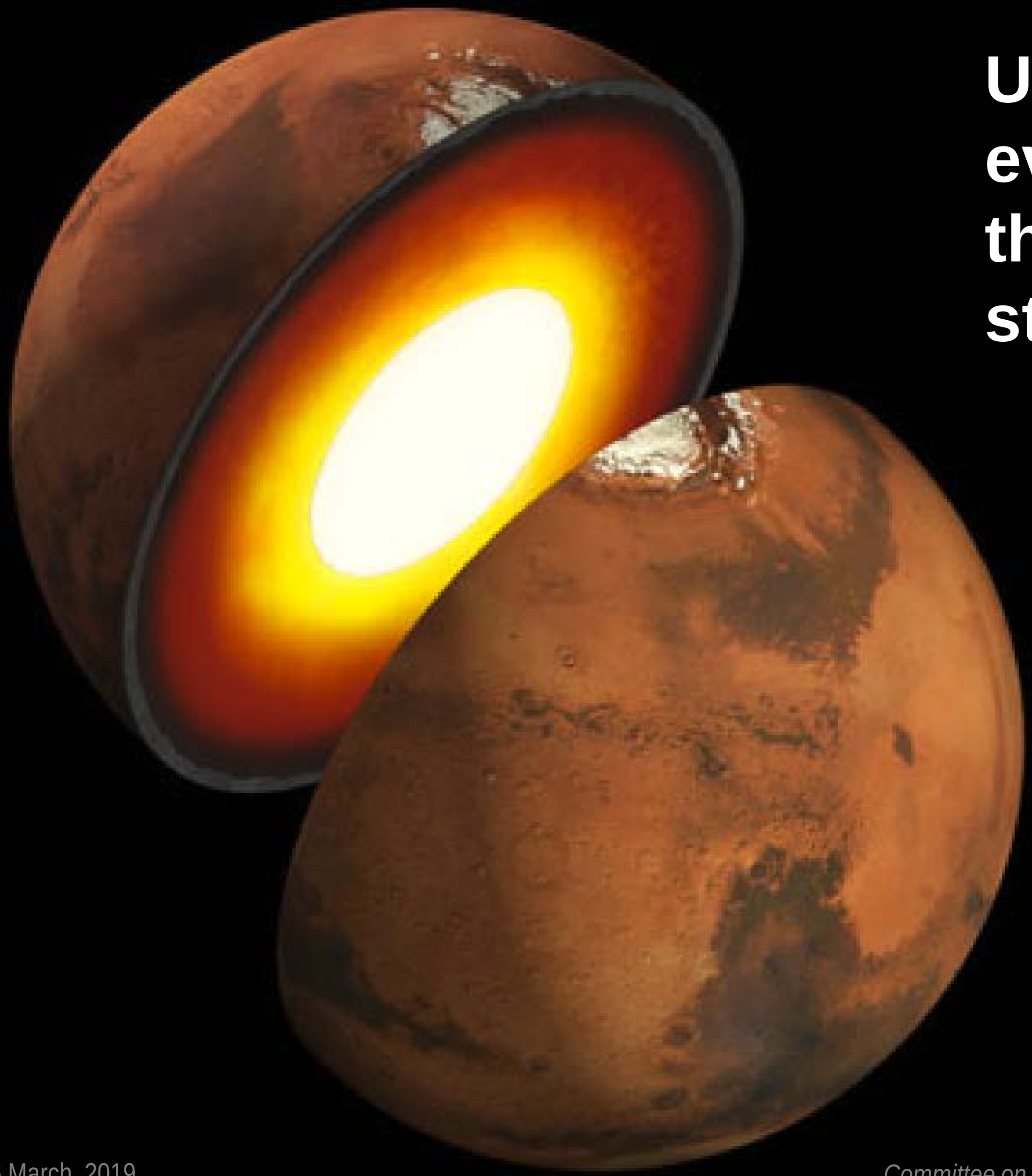
InSight After Four Months (115 sols) on Mars



W. Bruce Banerdt
Jet Propulsion Laboratory/California Institute of Technology

26 March, 2019

InSight Science Goal:



Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars.

- **Seismology**
- **Geodesy**
- **Heat Flow**
  - **Magnetics**
- **While we're here, we might as well do:**
  - **Meteorology**
  - **Geology**

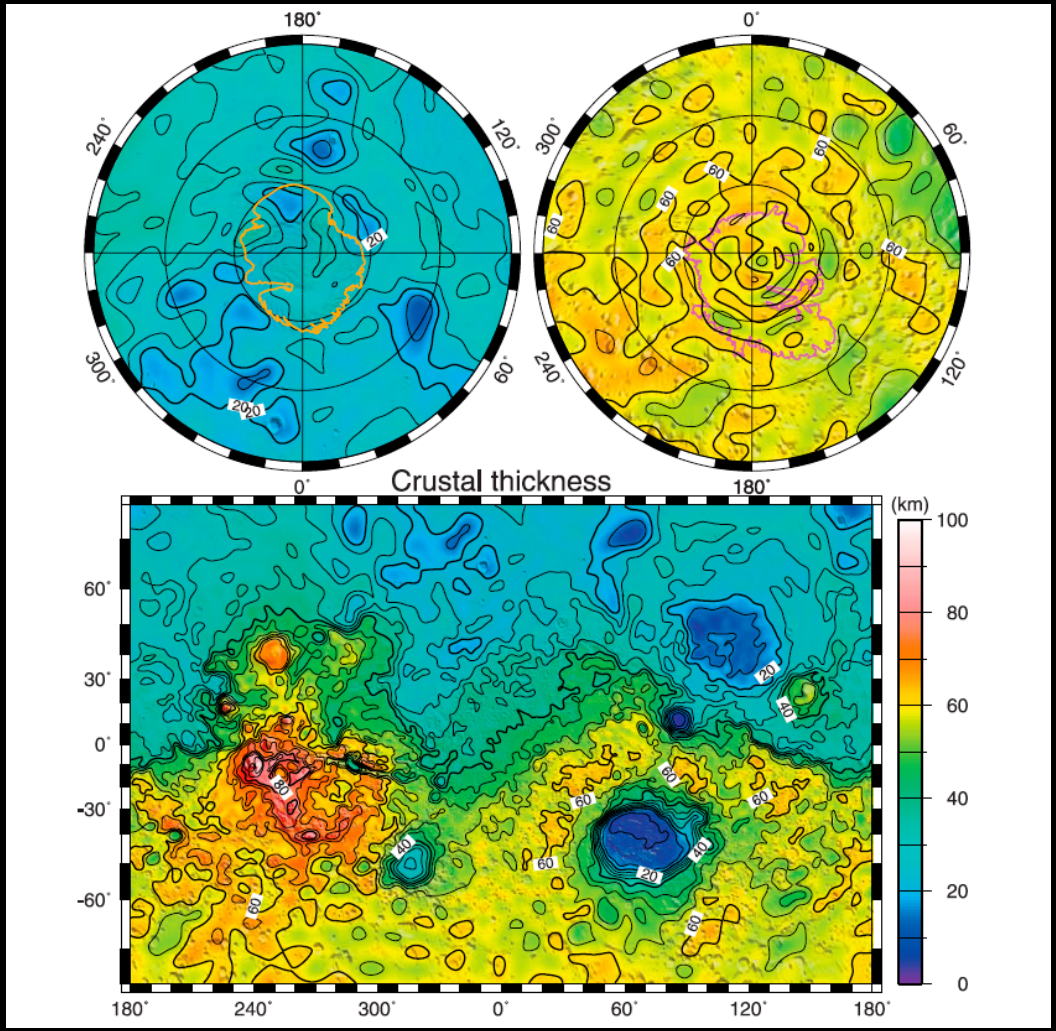
InSight as a Time Machine…

- We travel back in time more than a hundred years, to terrestrial seismology at the dawn of the 20th century, 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?

- We also travel back in time 4.5 billion years, to the beginnings of our solar system, to understand:
  - What were the processes of planetary differentiation that formed the planets, and the processes of thermal evolution that modify them?

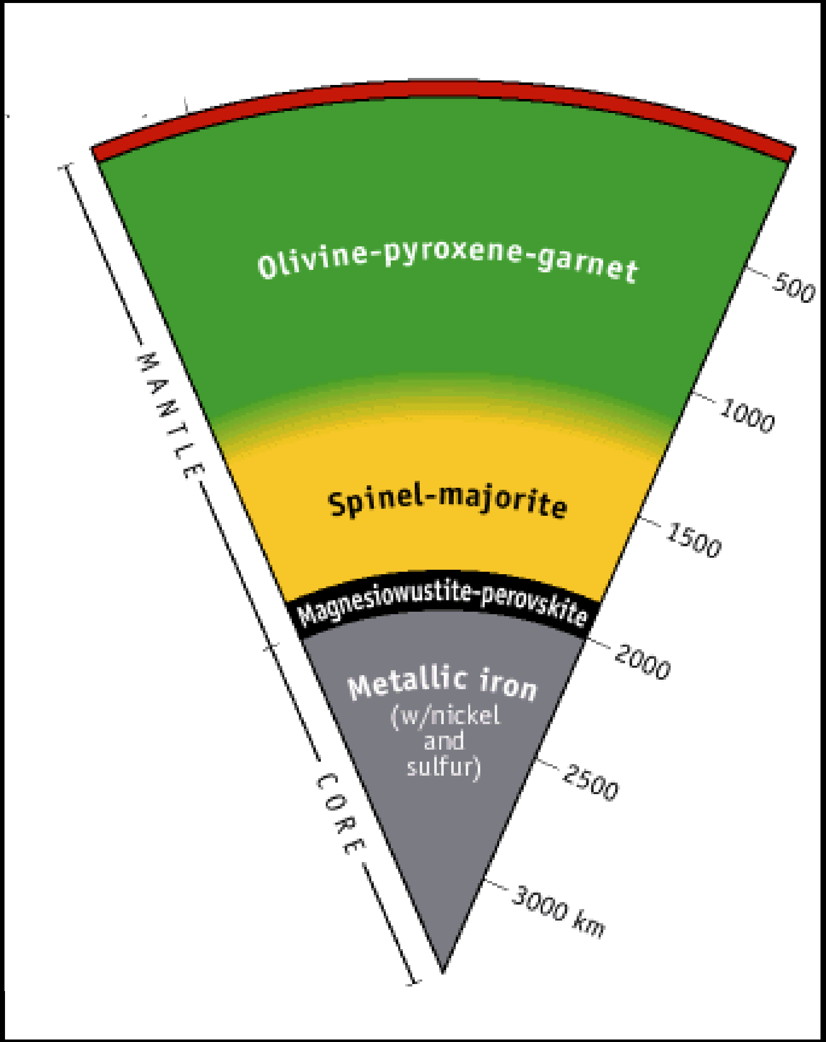
Crust Questions

- From orbital measurements we have detailed information on variations in crustal thickness (assumes uniform density).
- But we don't know the volume of the crust to within a factor of 2.
- Does Mars have a layered crust? Is there a primary crust beneath the secondary veneer of basalt?
- Is the crust a result of primary differentiation or of late-stage overturn?



Mantle Questions

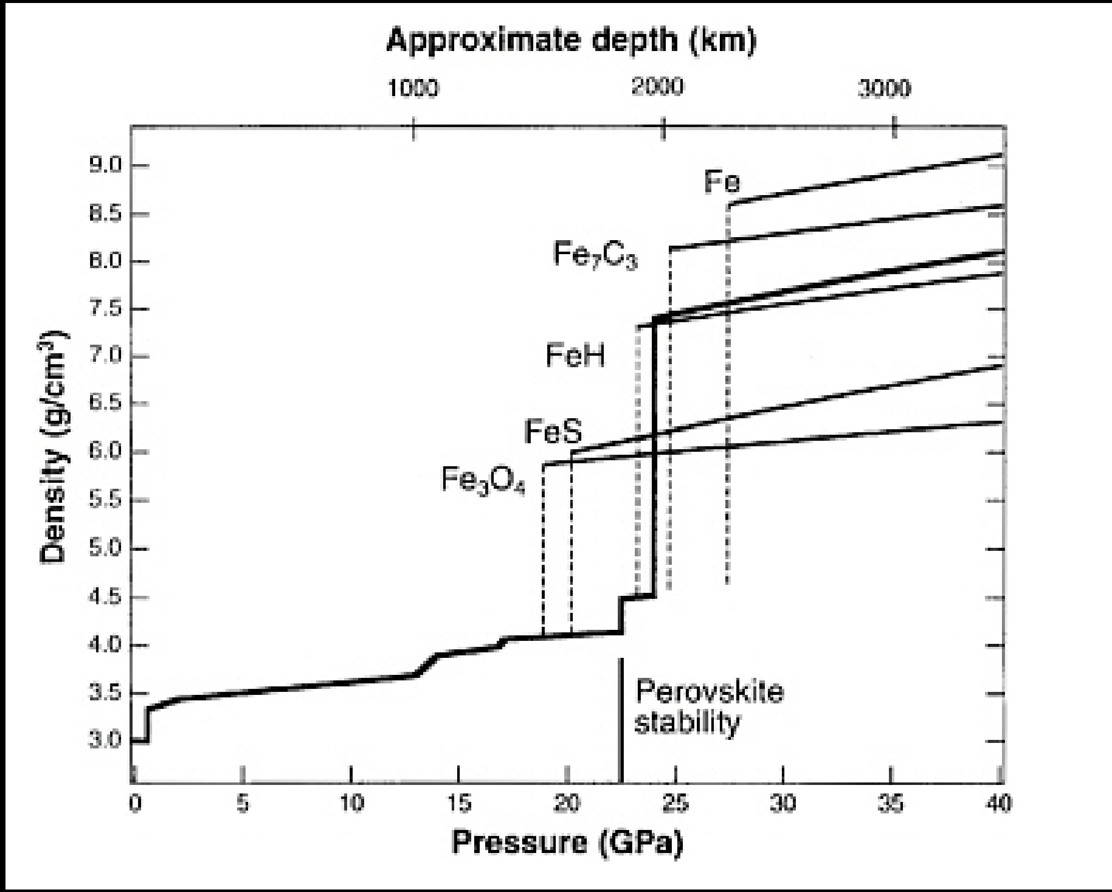
- What is the mantle density? This can be related to composition (e.g., Mg#, mineralogy, volatile content).
- To what degree is it compositionally stratified? What are the implications for mantle convection?
- Are there polymorphic phase transitions (specifically, the perovskite transition around 1800 km)?
- What is the thermal state of the mantle?.



Core Questions

- Radius is 1700±300 km, density is uncertain to ±15%
- Composed primarily of iron, are there lighter alloying elements?
- At least the outer part appears to be liquid; is there a solid inner core?
- How do these parameters relate to core formation and the initiation and shut down of the dynamo?
- Does the core radius preclude a lower mantle perovskite transition?

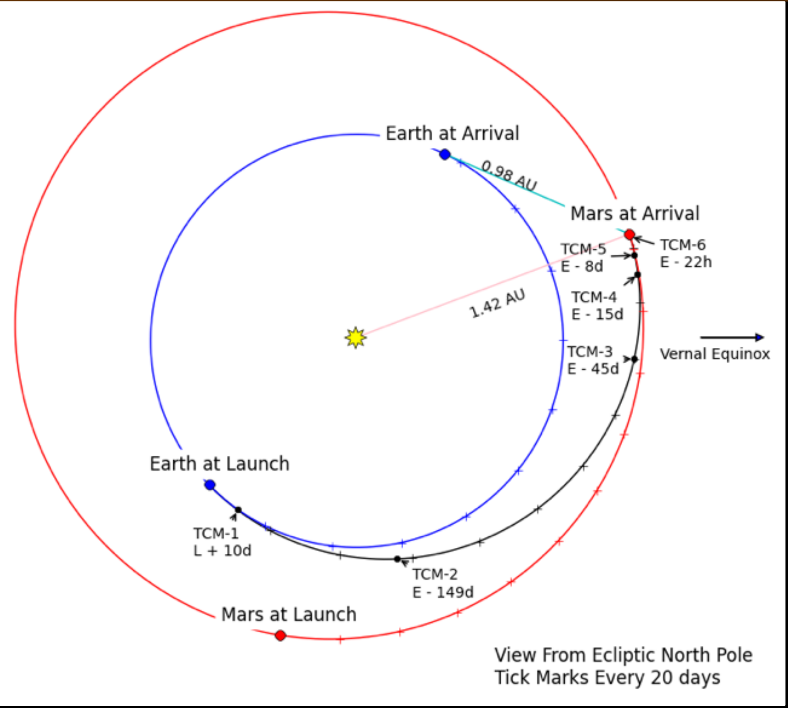
Density Profiles Allowed by Moment of Inertia Constraint



InSight's Contribution to Knowledge of the Interior of Mars

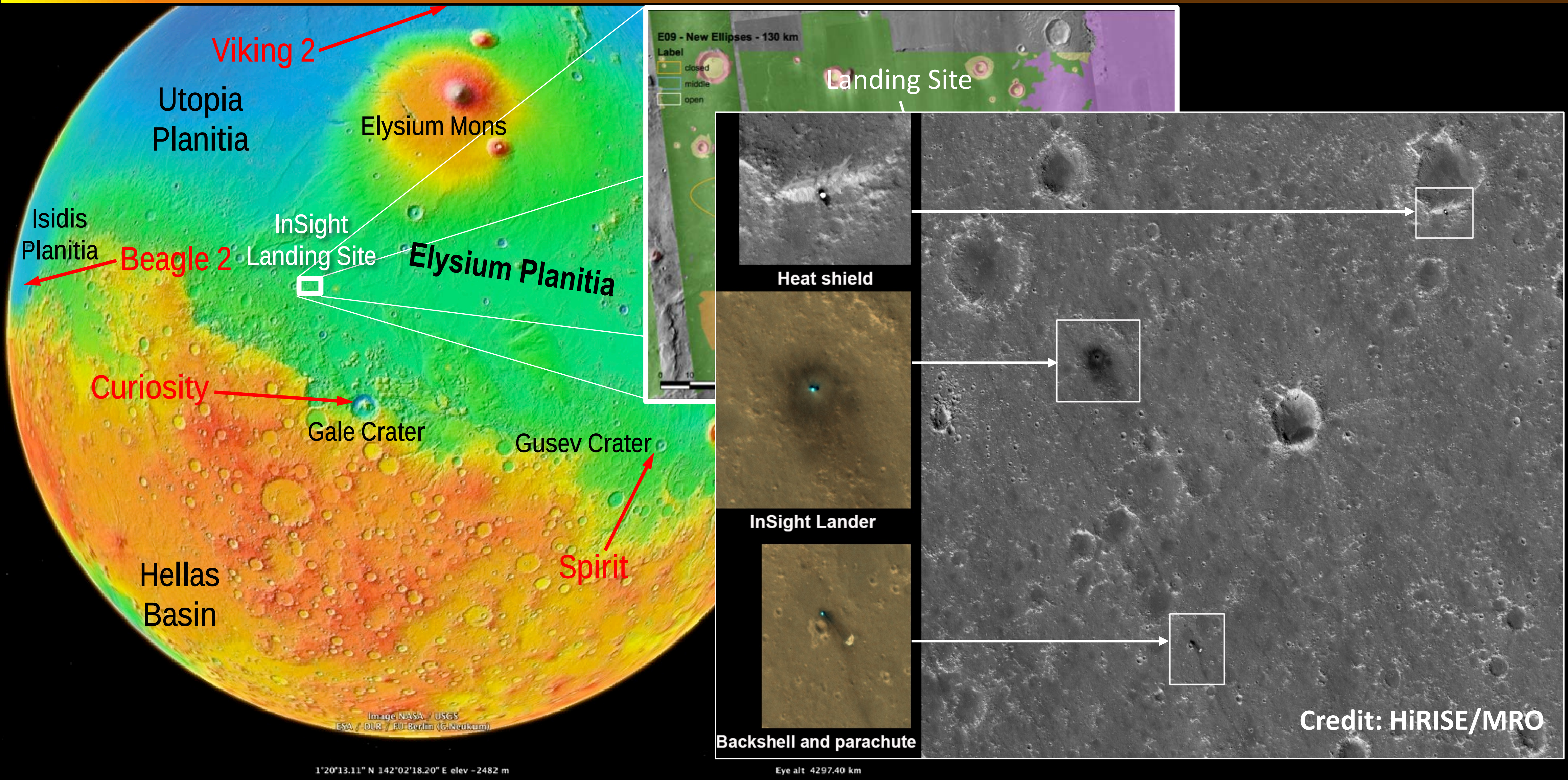
Measurement	Current Uncertainty	InSight Capability	Improvement
Crustal thickness	65±35 km (inferred)	±5 km	7X
Crustal layering	no information	resolve 5-km layers	New
Mantle velocity	8±1 km/s (inferred)	±0.13 km/s	7.5X
Core liquid or solid	"likely" liquid	positive determination	New
Core radius	1700±300 km	±75 km	4X
Core density	6.4±1.0 gm/cc	±0.3 gm/cc	3X
Heat flow	30±25 mW/m^2 (inferred)	±3 mW/m^2	8X
Seismic activity	no information	factor of 10	New
Seismic distribution	no information	locations ≤10 deg.	New
Meteorite impact rate	factor of 6	factor of 2	3X

Mission Summary

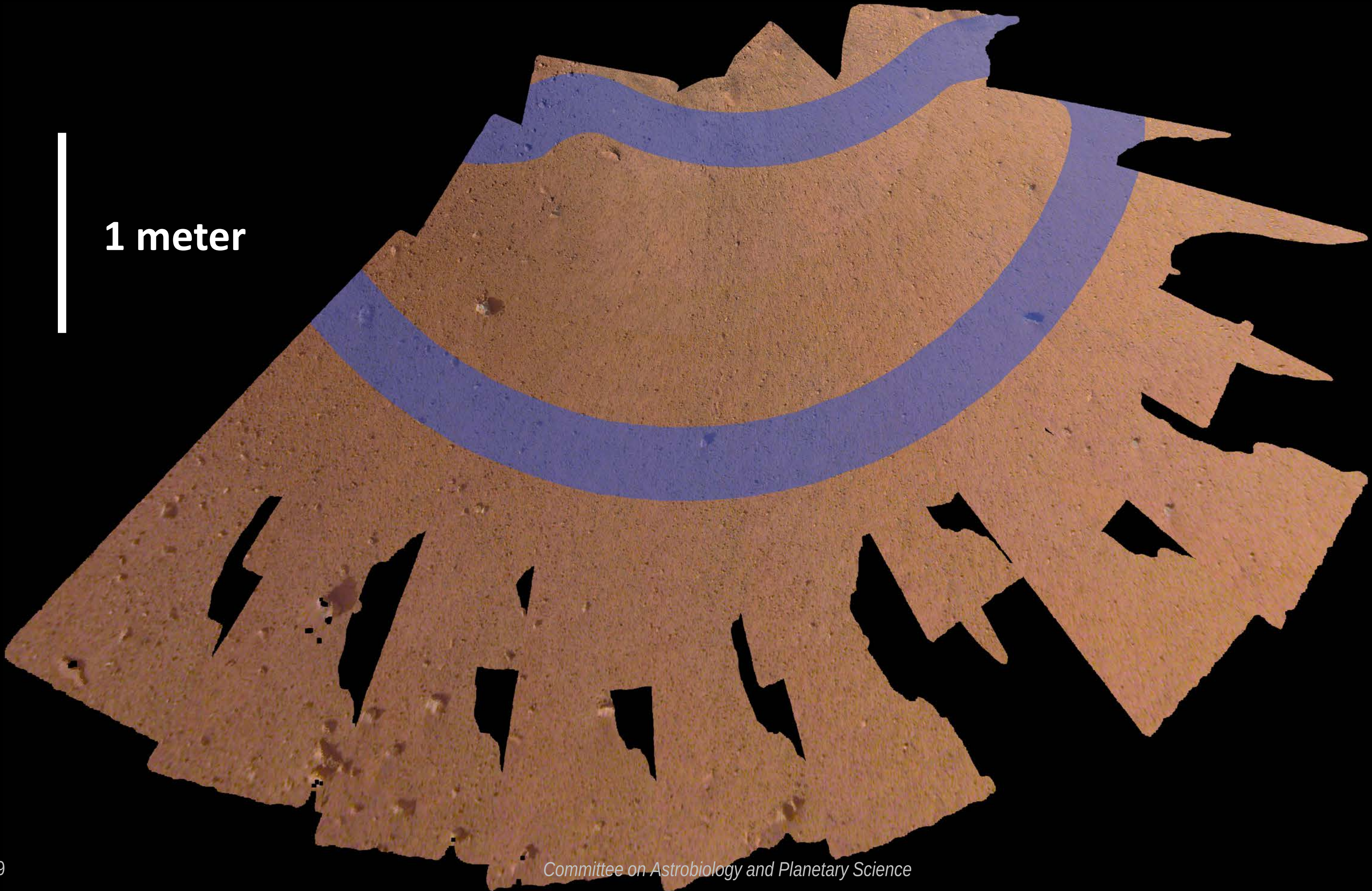


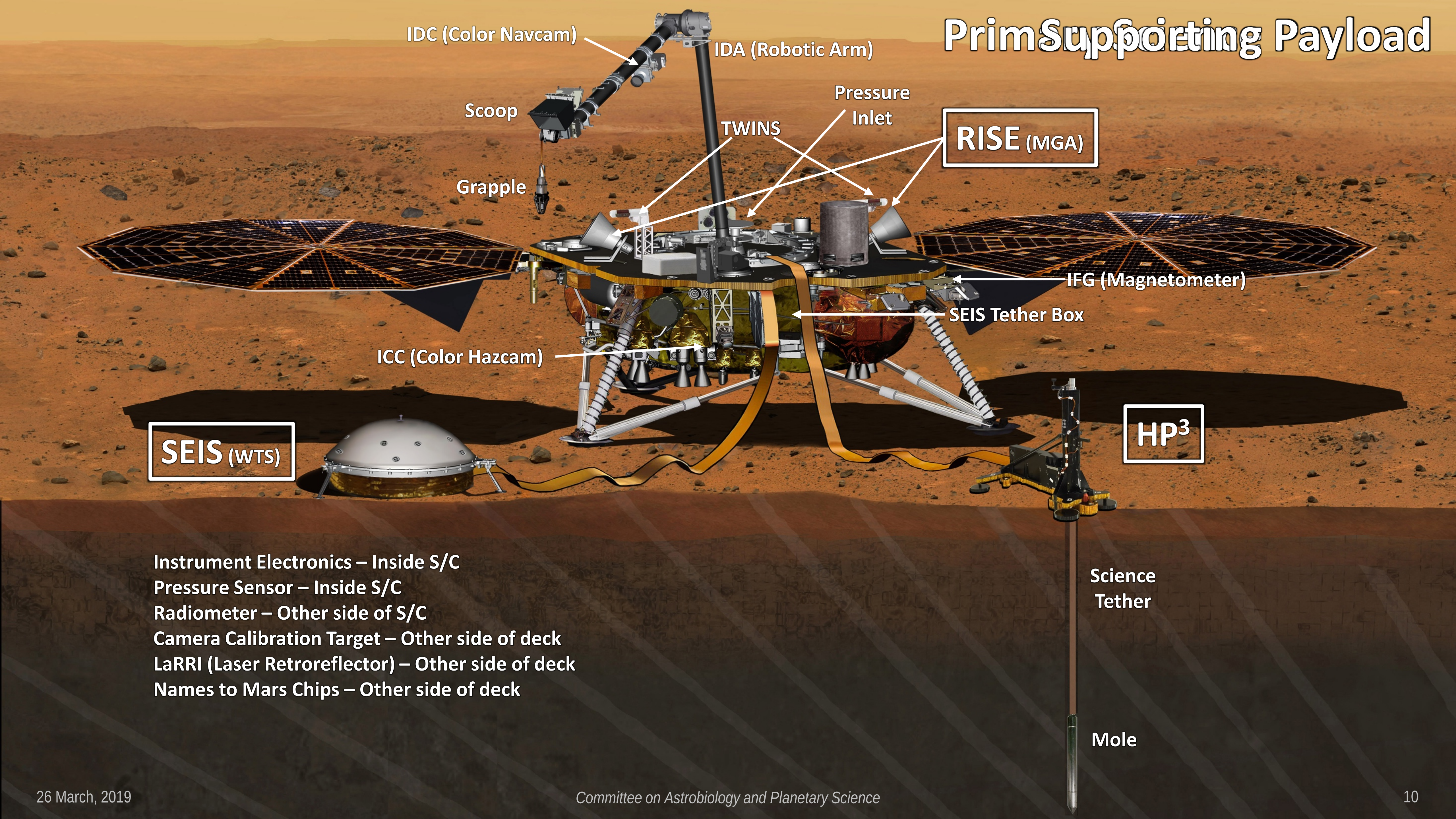
- Launch: 4:05 PDT May 5, 2018, Vandenberg AFB, California
- Type-1 trajectory, 6.5-month cruise
- Landing: 12:00 PDT November 26, 2018, Elysium Planitia
- 3-month deployment phase, 1 Mars year (~2 Earth years) science operations
- Nominal end-of-mission: November 24, 2020

Landing Site, Western Elysium Planitia



IDA (Instrument Deployment Arm) Workspace

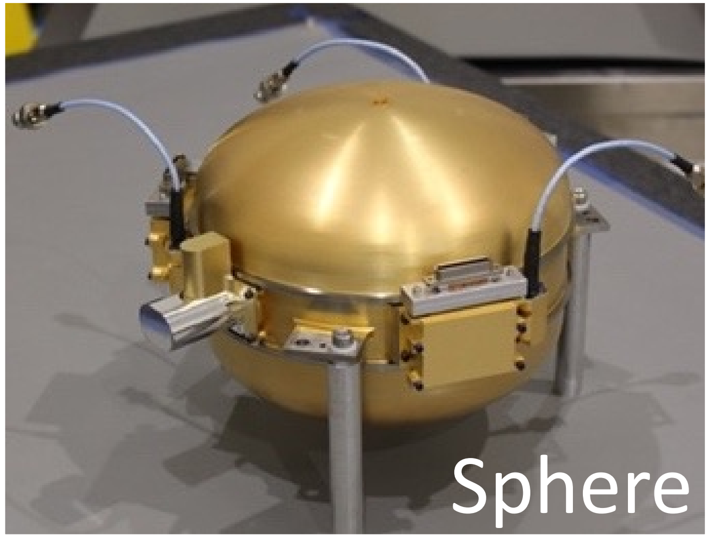


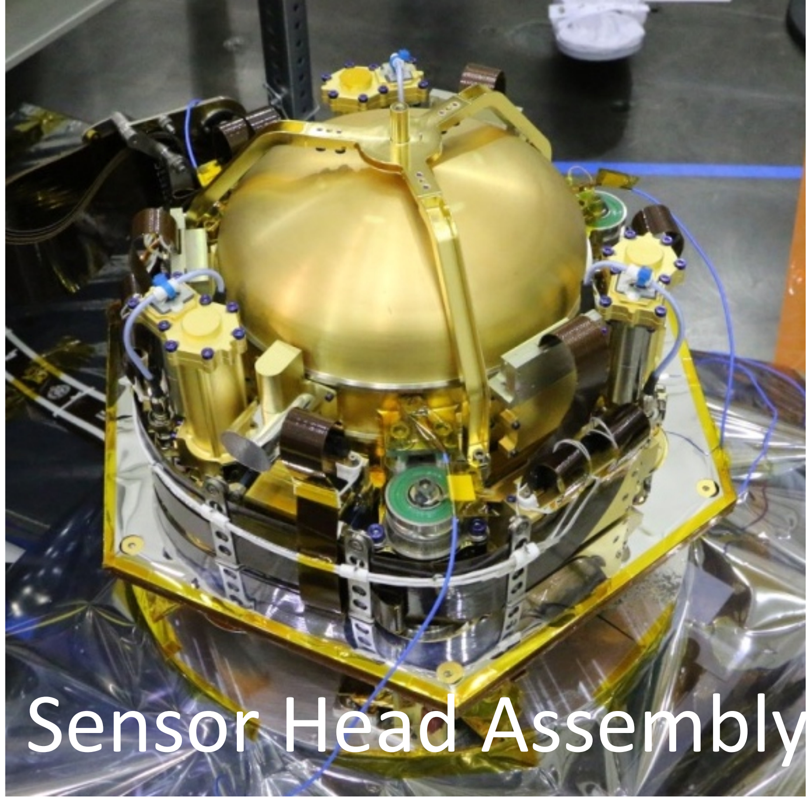


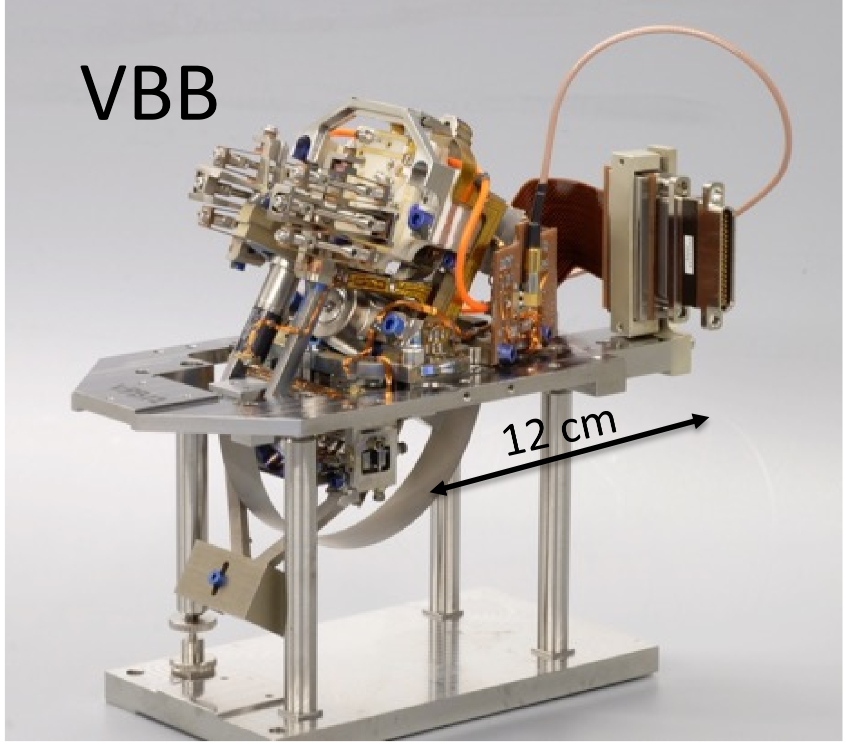
Supporting Payload
IDC (Color Navcam)
IDA (Robotic Arm)
Scoop
Grapple
TWINS
Pressure Inlet
RISE (MGA)
IFG (Magnetometer)
SEIS Tether Box
ICC (Color Hazcam)
SEIS (WTS)
HP3
Science Tether
Mole
Instrument Electronics – Inside S/C
Pressure Sensor – Inside S/C
Radiometer – Other side of S/C
Camera Calibration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

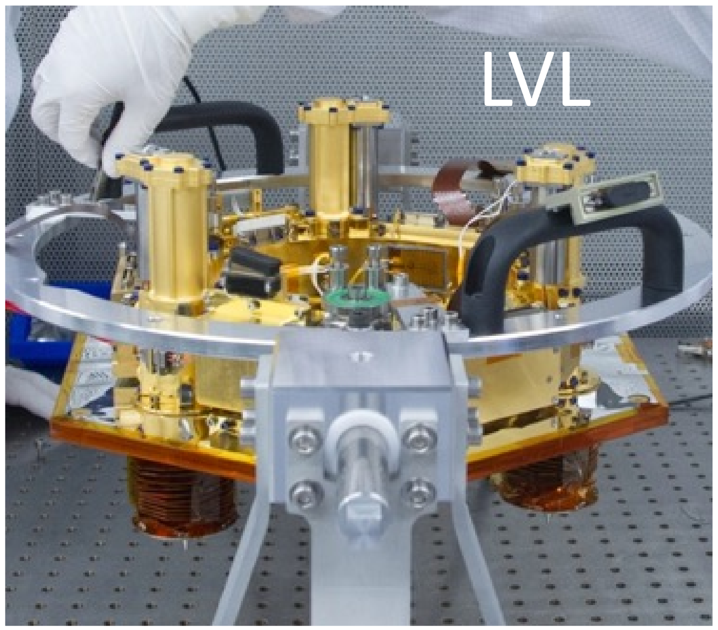
SEIS

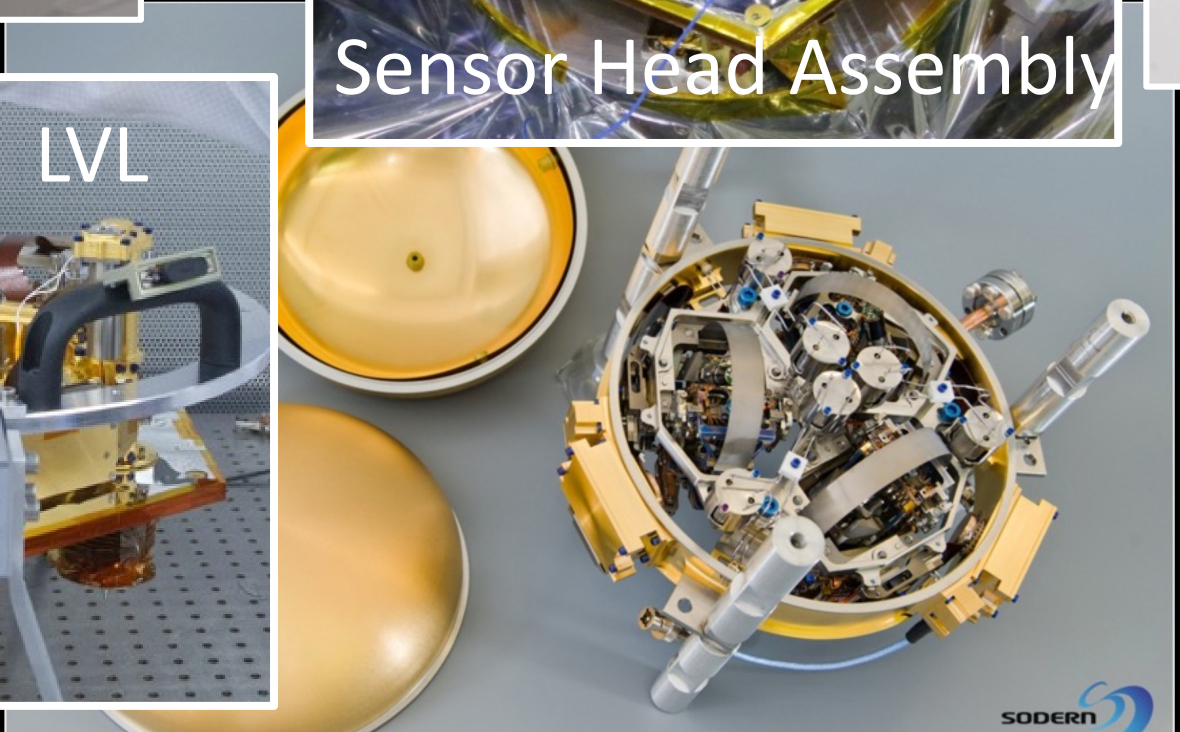
SEIS Sensors

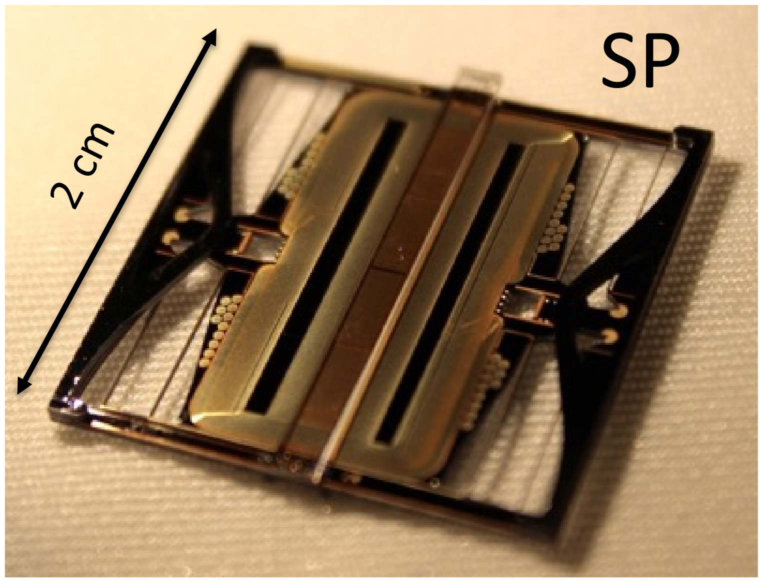




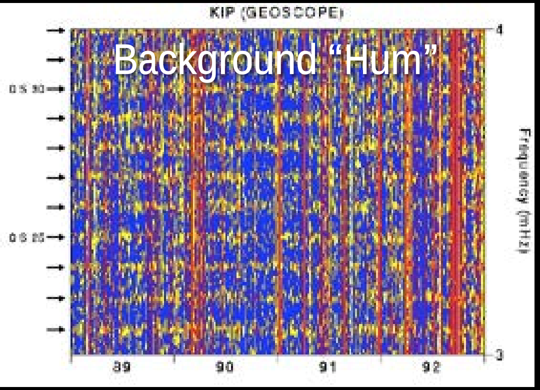


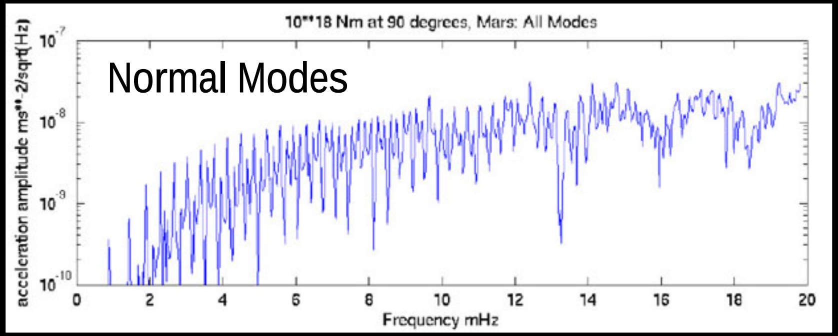


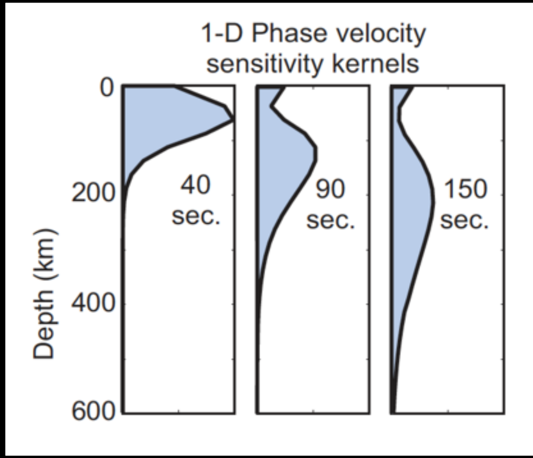




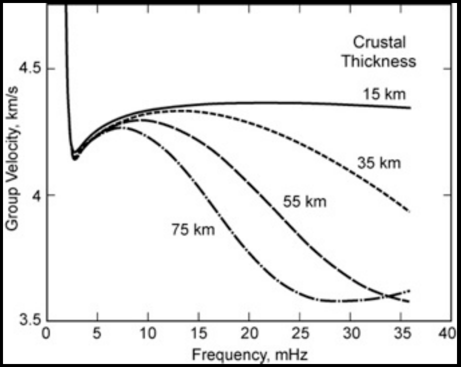
Martian Seismology – Single-Station Analysis Techniques

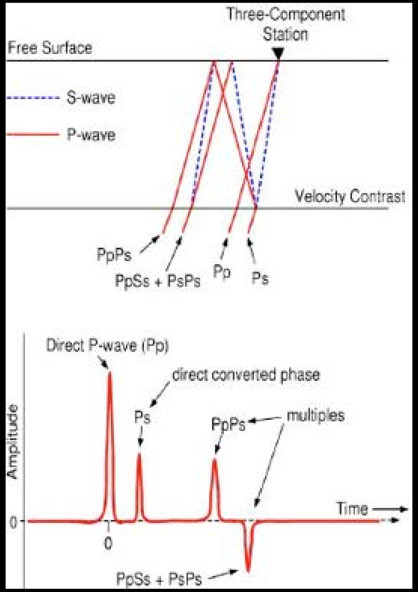




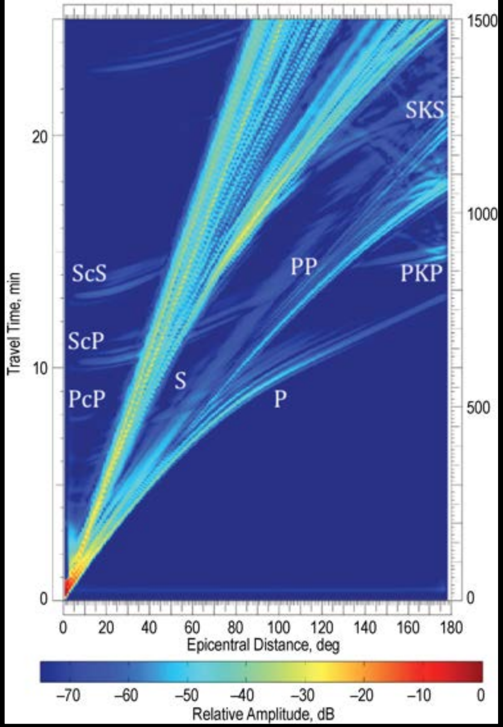


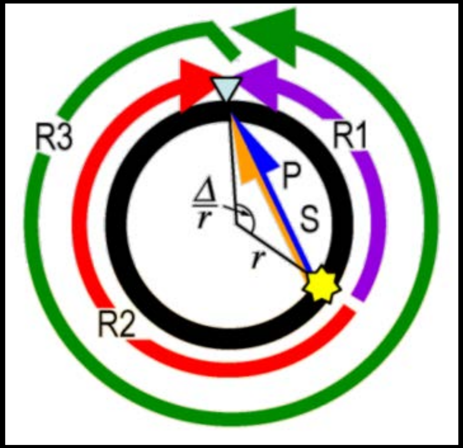
Surface Wave Dispersion



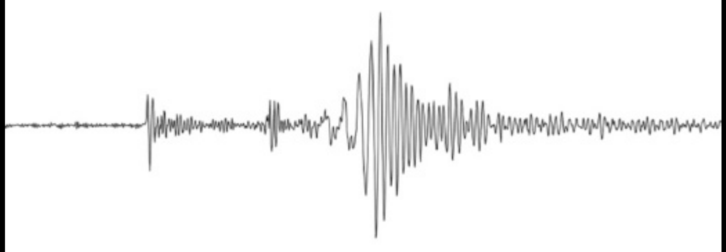


Receiver Function



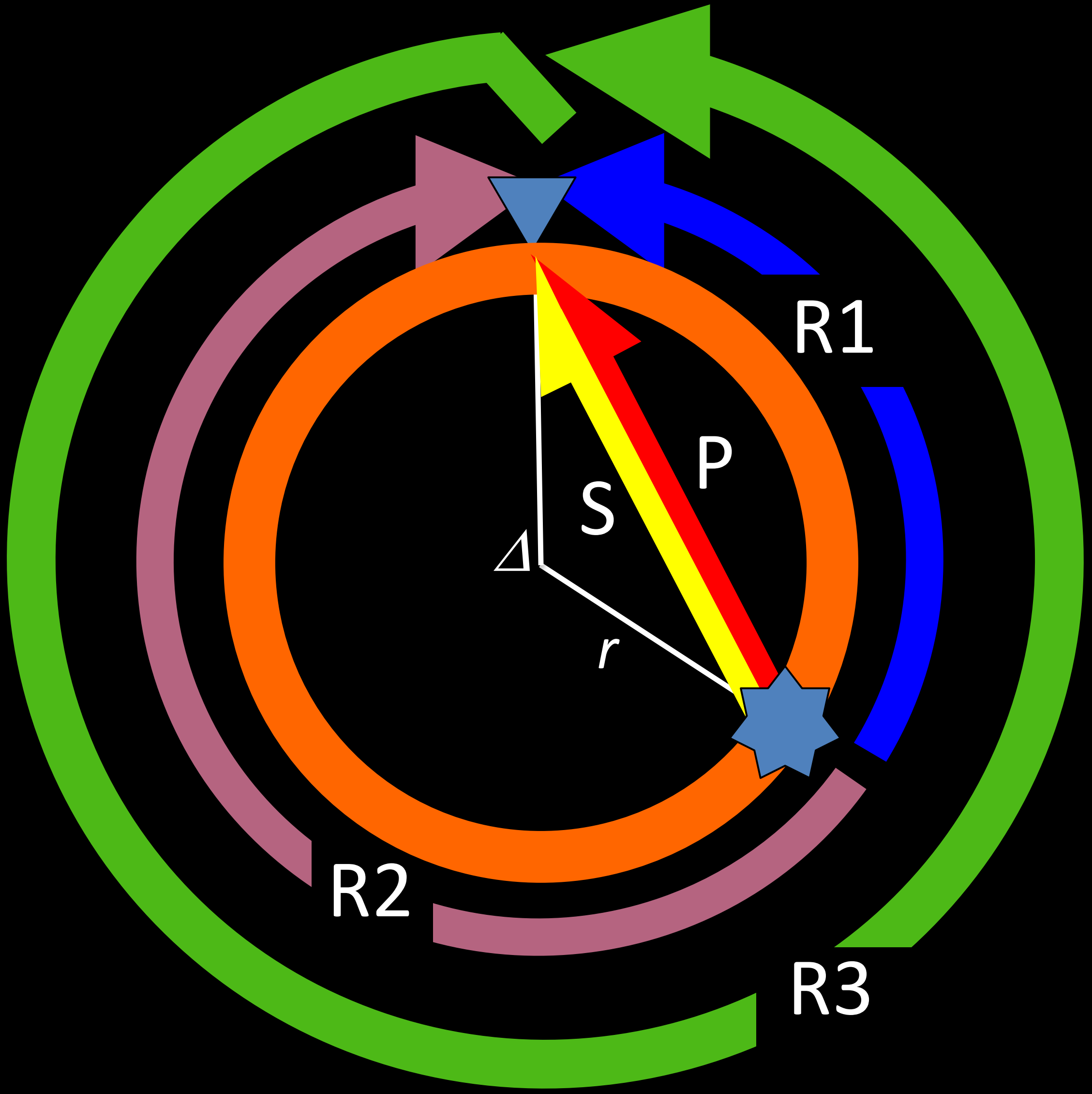


Arrival Time Analysis

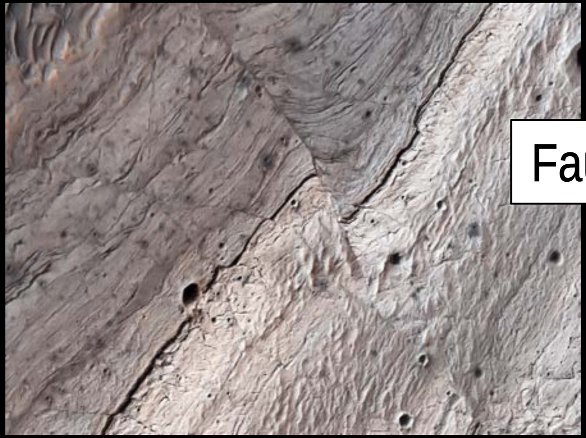


Event Location and Seismic Velocities from a Single Record

Location and Velocity Determination
Obtain 5 measurements: T_p , T_s , T_{R1} , T_{R2} , T_{R3}
Determine 5 parameters: V_R , Δ ,T_0 ,V_p ,V_s From 5 independent relationships: • $V_R = 2\pi r/(T_{R3} - T_{R1})$ • $\Delta = \pi r - V_R(T_{R2} - T_{R1})/2$ • $T_0 = T_{R1} - \Delta/V_R$ • $V_p = 2r\sin(\Delta/2r)/(T_p - T_0)$ • $V_s = 2r\sin(\Delta/2r)/(T_s - T_0)$
Obtain azimuth from Rayleigh wave polarization, P first motion

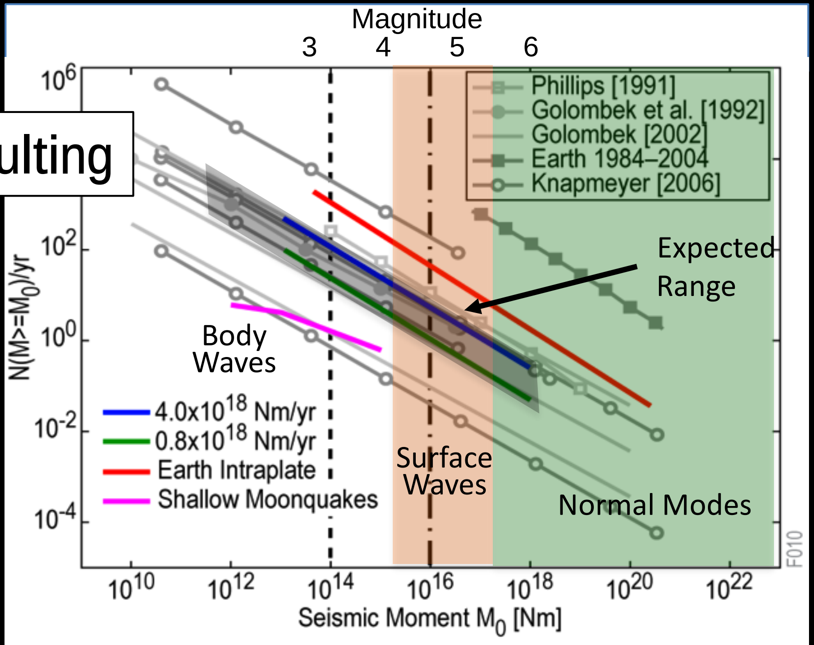


Martian Seismology – Multiple Signal Sources

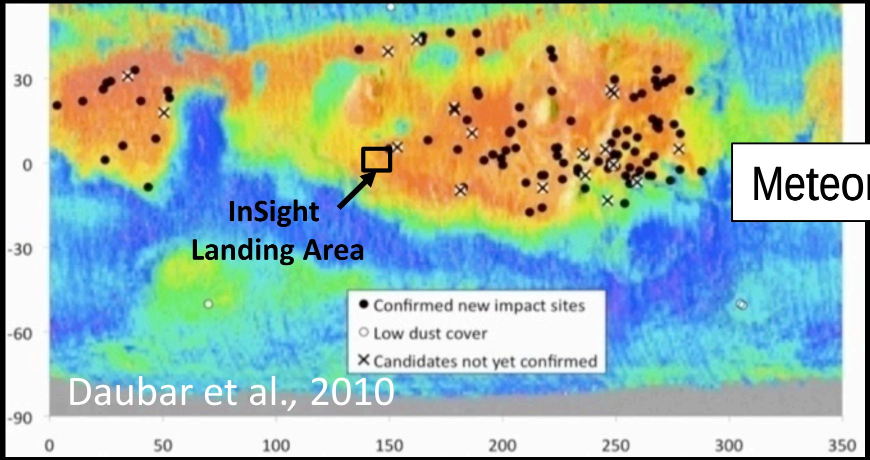


Faulting

Rate of Seismic Activity

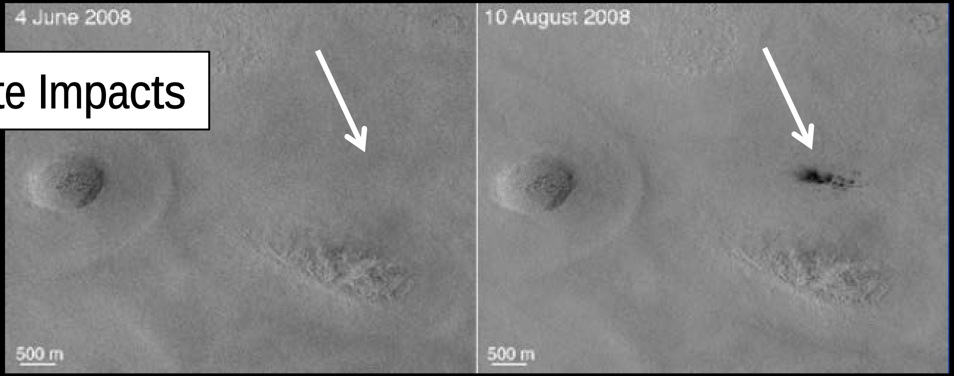


Phobos Tide

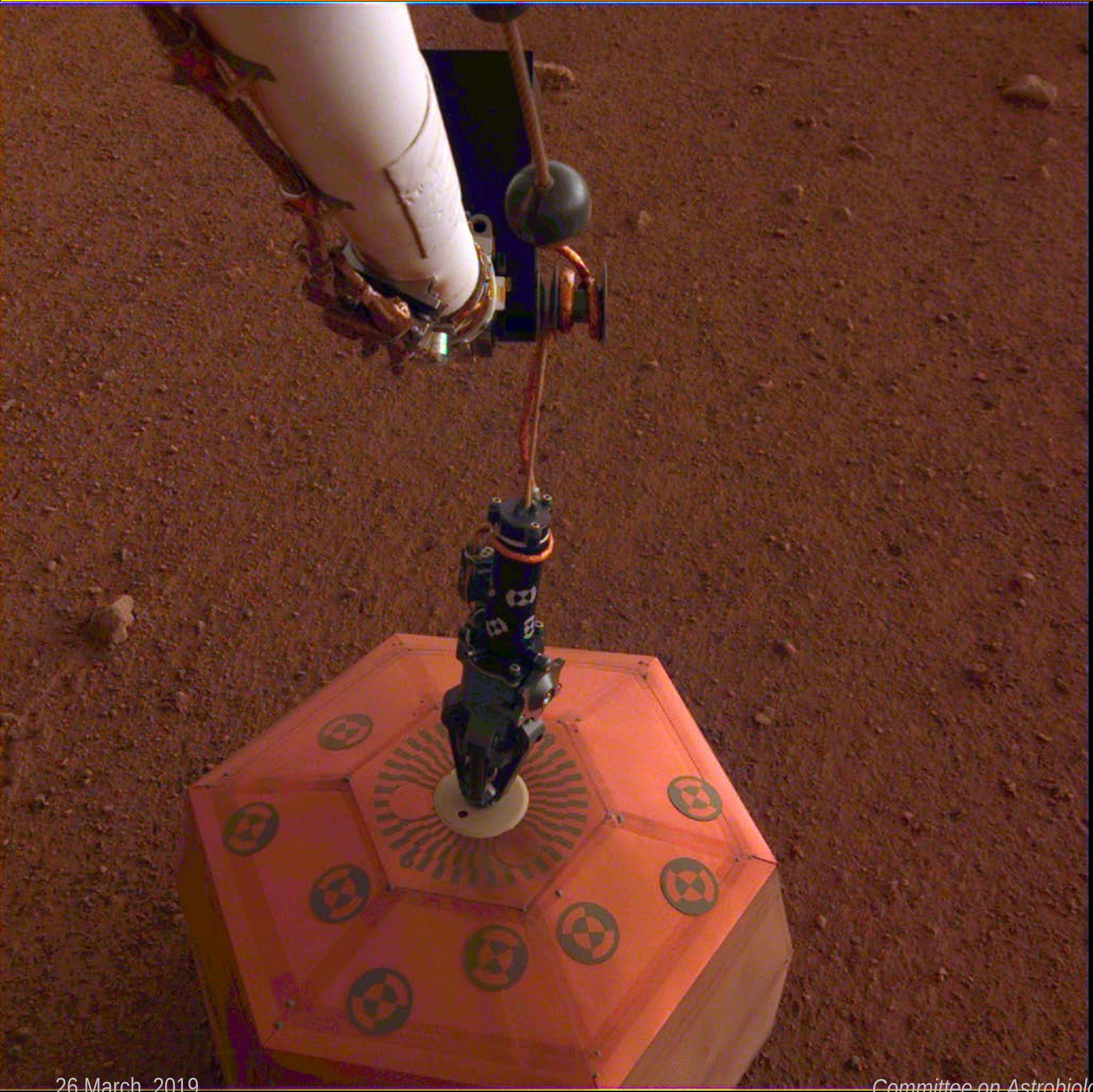


Daubar et al., 2010

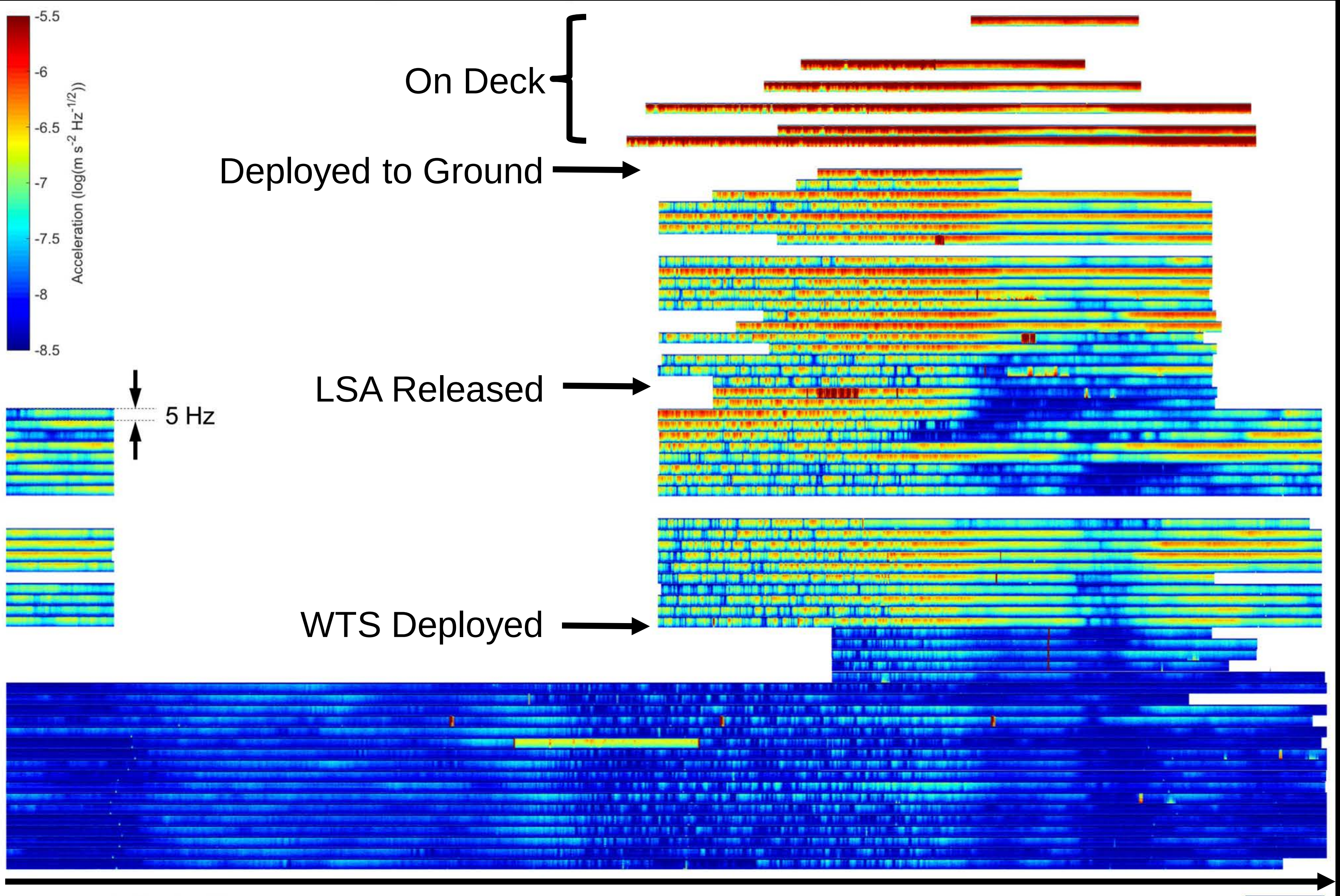
Meteorite Impacts



Sol 22-70: SEIS Deployment

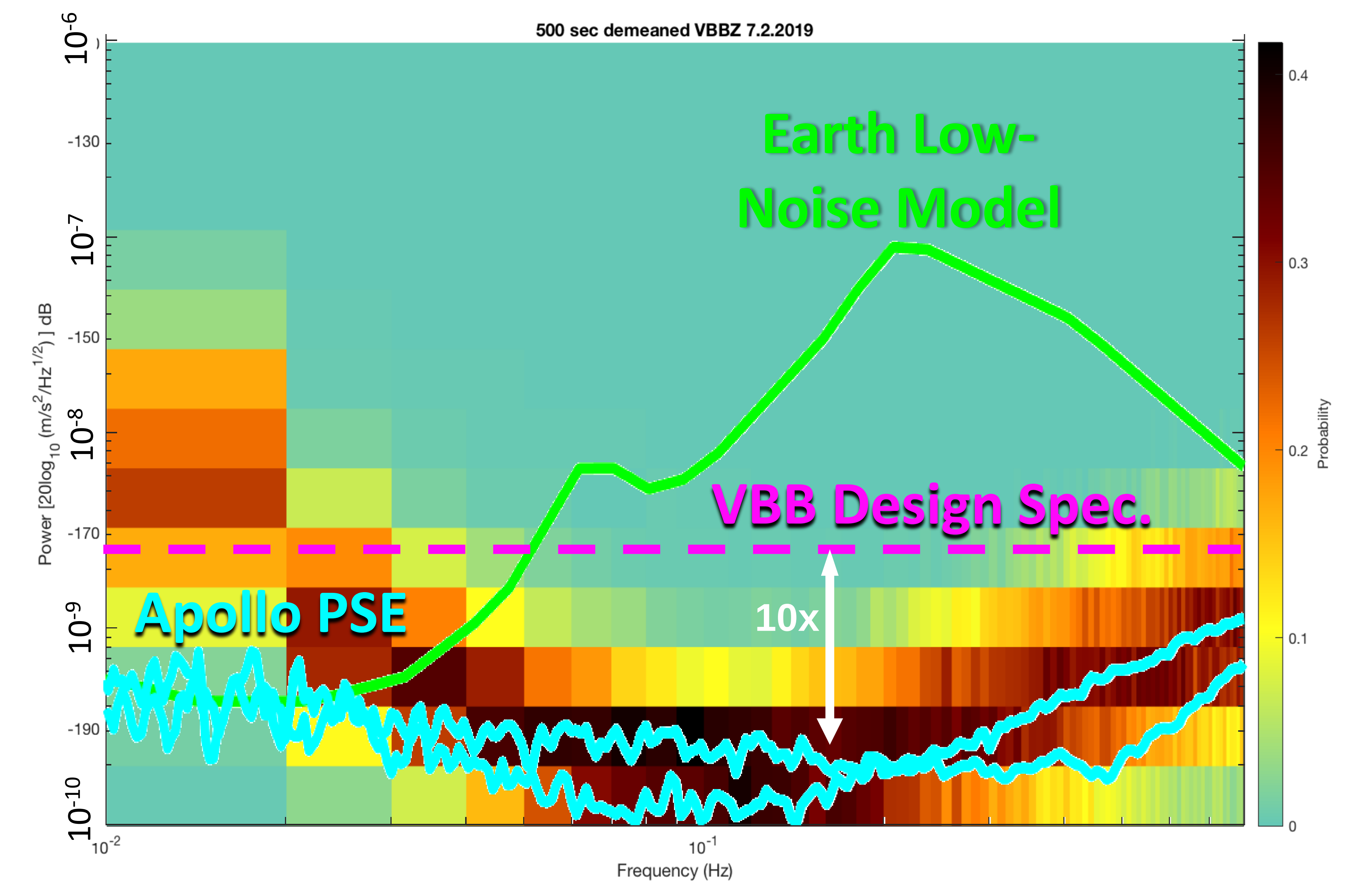


SEIS Noise Evolution: Vertical SP Data Through Sol 87



VBB Acceleration Noise Statistics

For scale, the indicated displacement sensitivity at the bottom of this plot is of order 25 pm, or ~20% the diameter of a hydrogen atom.



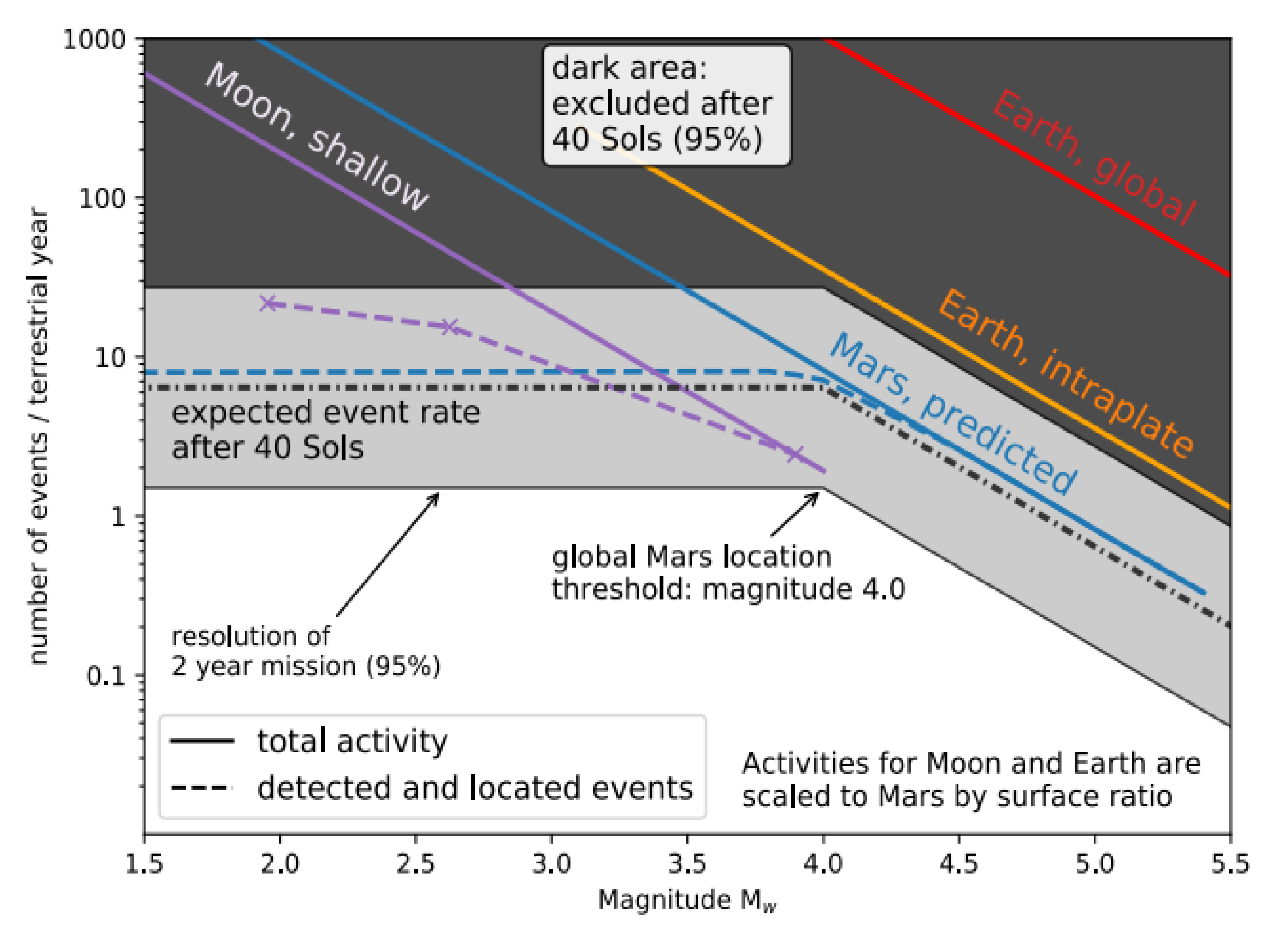
Mars Seismic Activity – The Statistics of Zero

Out of the first 100 Sols on Mars, we had ~40 sols with excellent SEIS data quality.

During this time observed NO signal identified as a marsquake.

This excludes Earth-like activity levels.

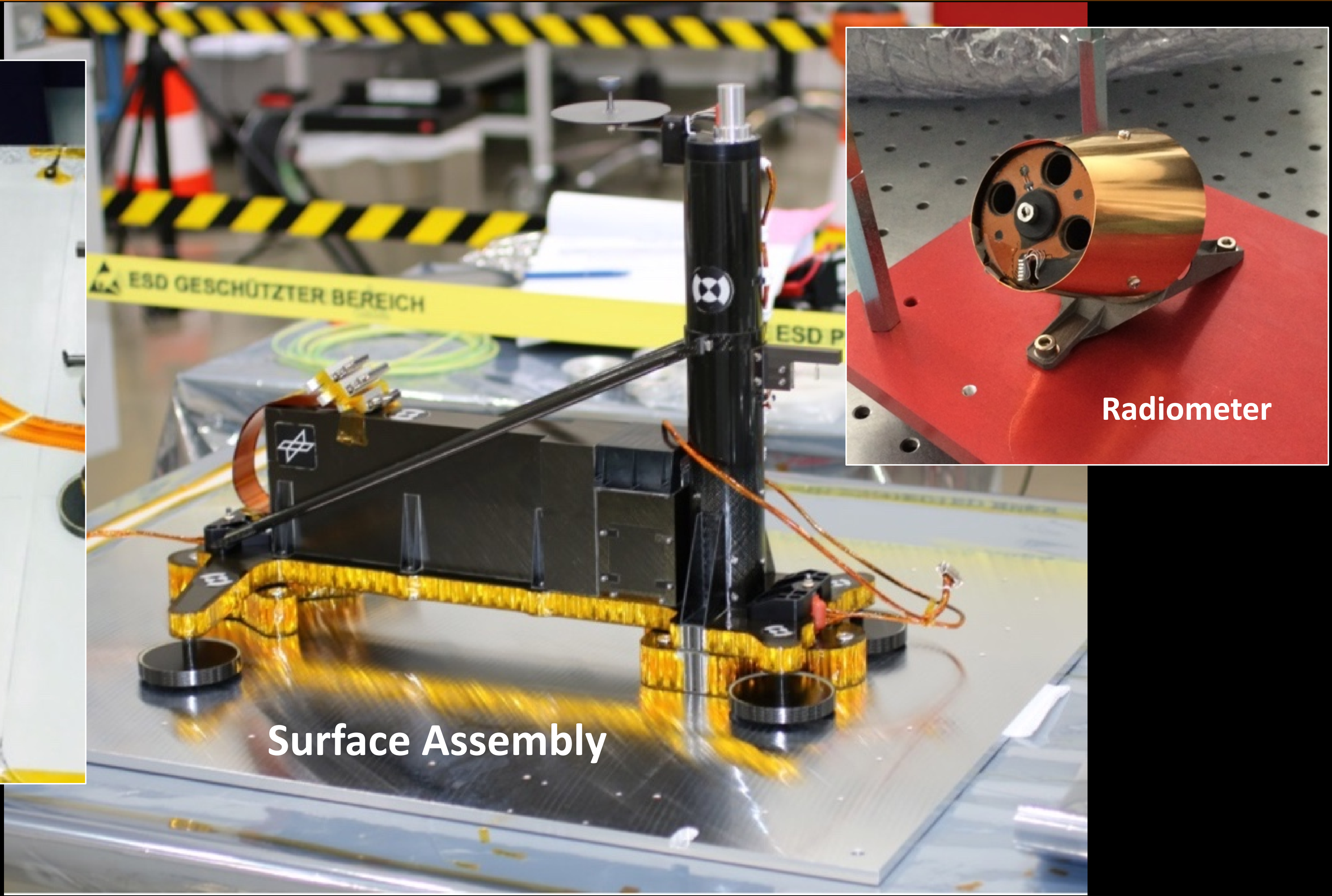
For activity equivalent to our pre-landing estimates, we have an ~50% likelihood of seeing a marsquake.



HP^3

HP^3 Instrument

Mole and Science Tether



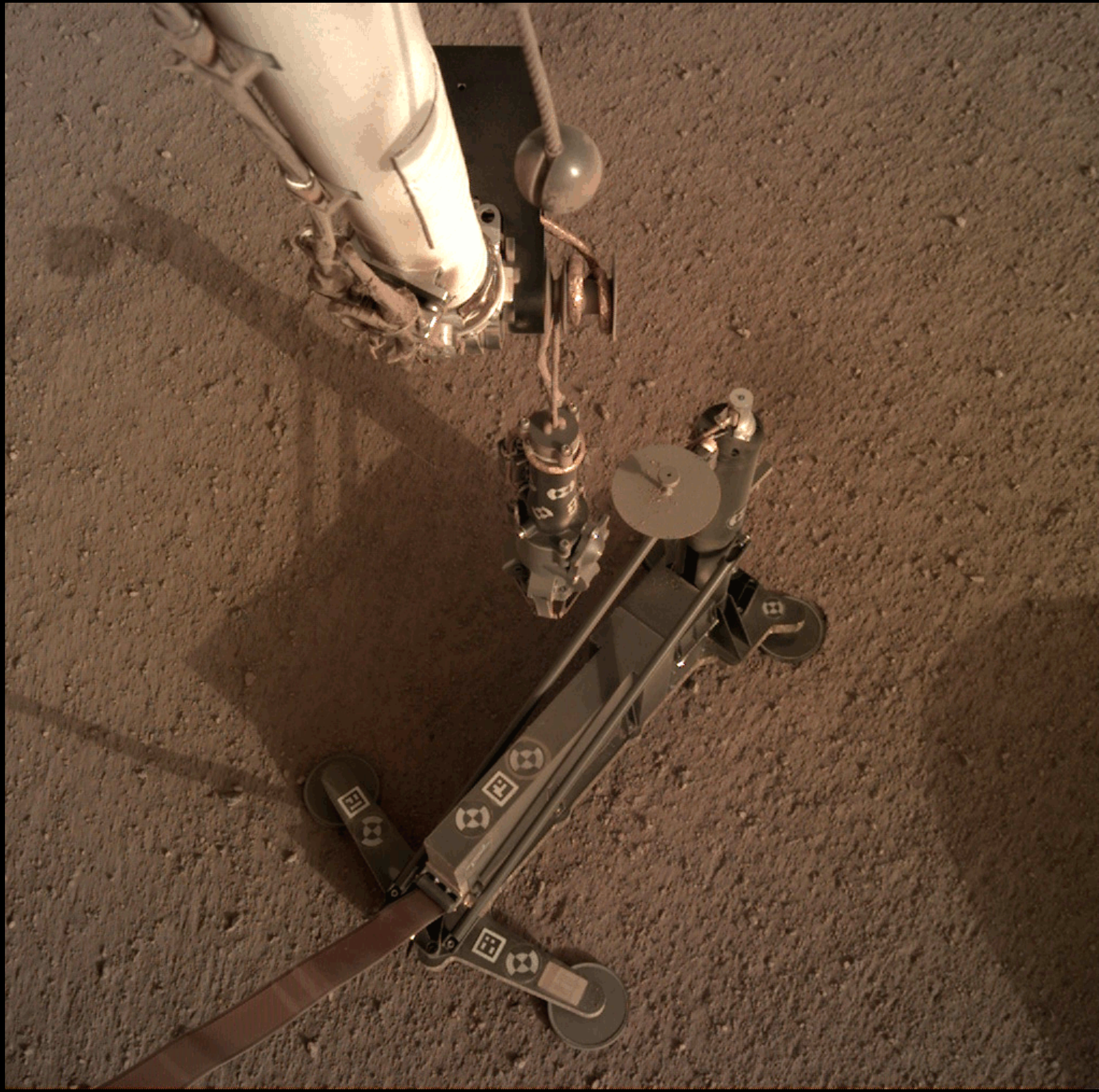
Surface Assembly

Radiometer

HP^3 Operation

HP^3 Status

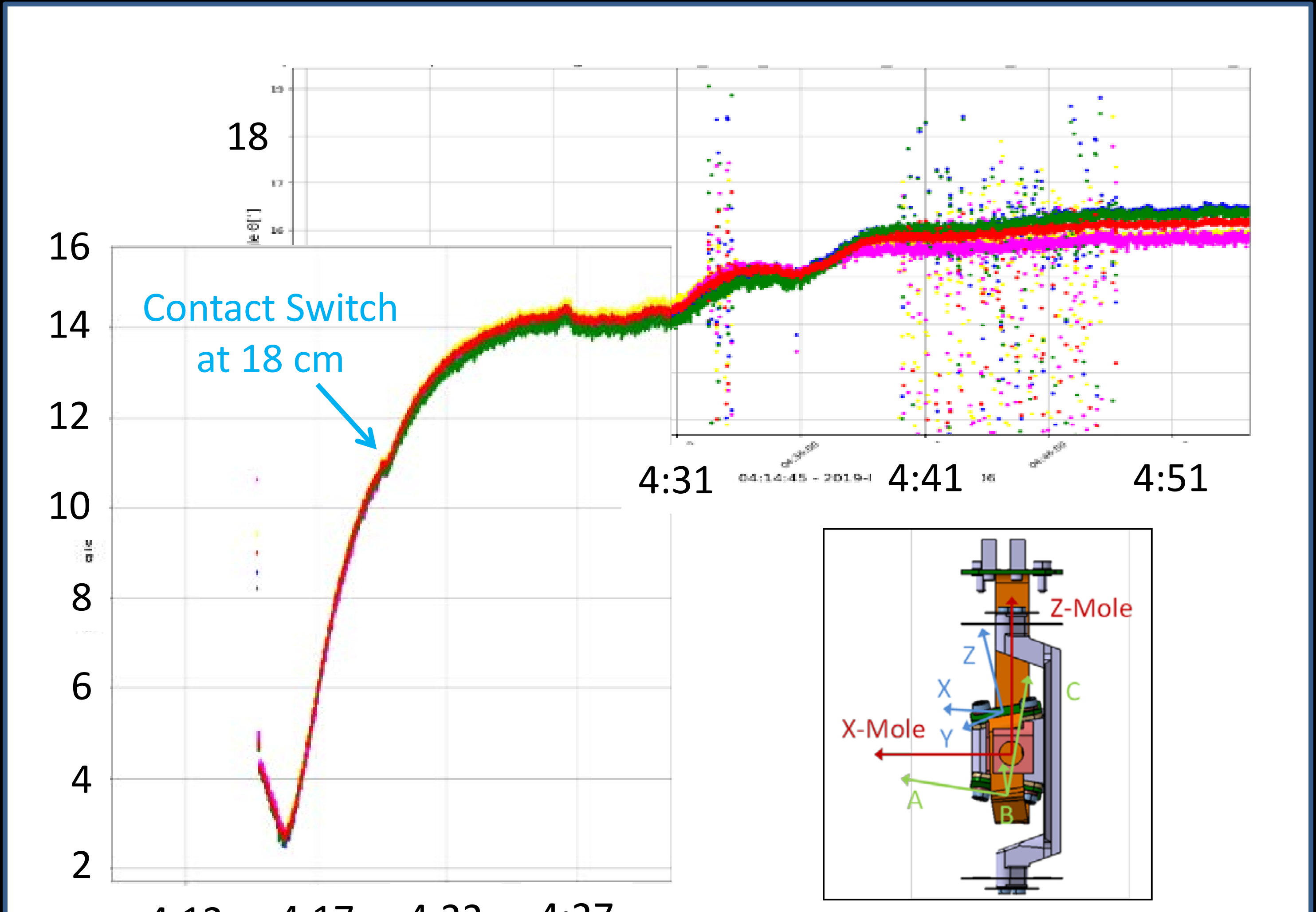
- First hammering session occurred on 2/28 for 4 hours (~4000 strokes)
  - Reached a depth of 18-55 cm; likely ~30 cm
- Second hammering session on 3/4 for 5 hours resulted in no apparent further progress.
- Since then we have paused for further analysis of imaging, seismic, tilt and thermal data, along with dynamic CAD modeling and testing using spare hardware.



Mole Tilt Data

- Tilt meter data gives mole orientation with respect to vertical, plus axial rotation.
  - Approaches vertical for first minute of hammering (~20 strokes/minute)
  - Then angle increases to 14˚ over next 10 minutes.
  - Small (~1˚) increases in angle about 5 and 10 minutes later.
  - Angle remains steady for remainder of 4-hour session.
  - Angle stays near 16˚ for second 5-hour session as well.

Mole Tilt (deg.) vs. Time (h:m)



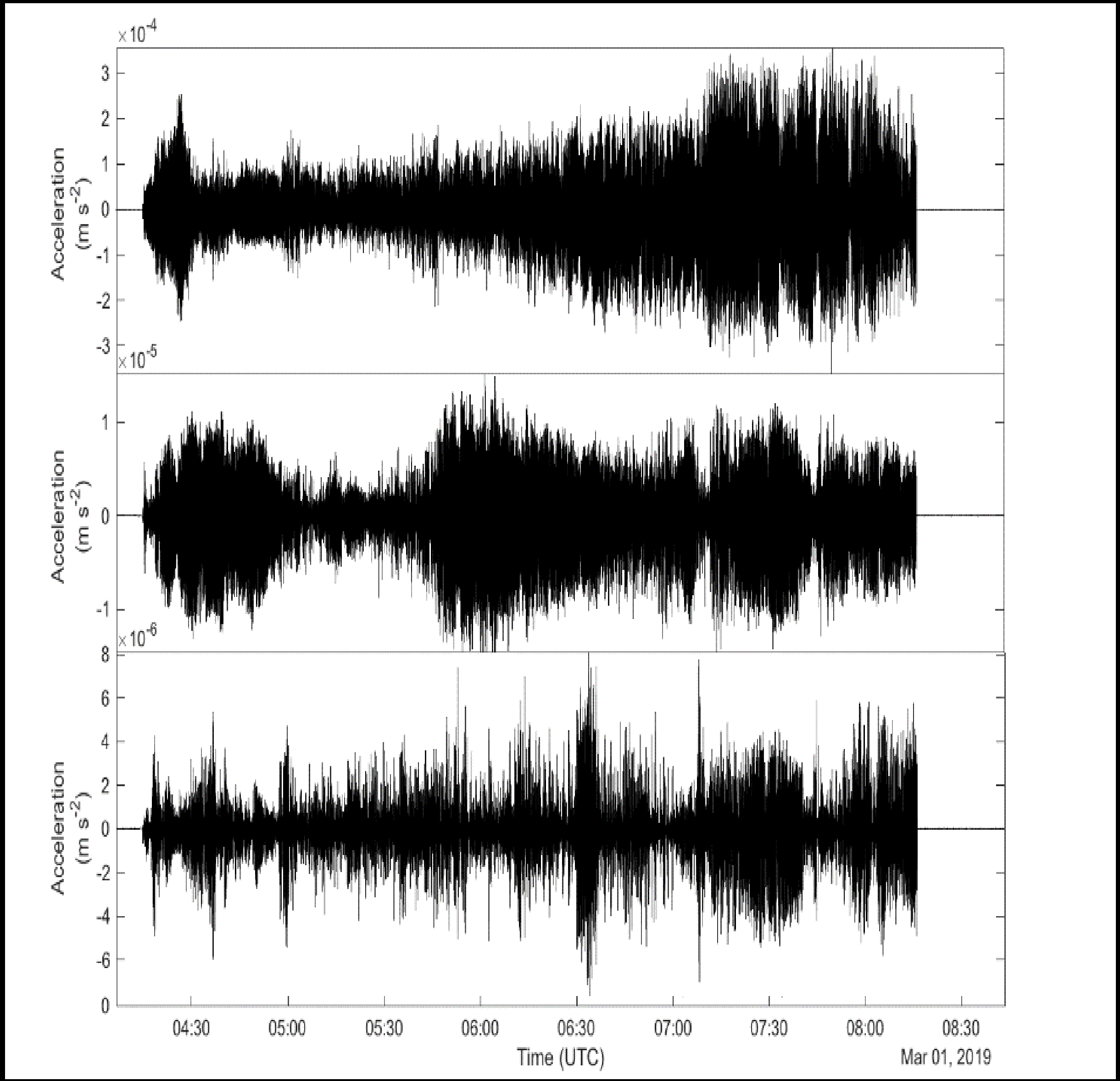
Tilt meter geometry

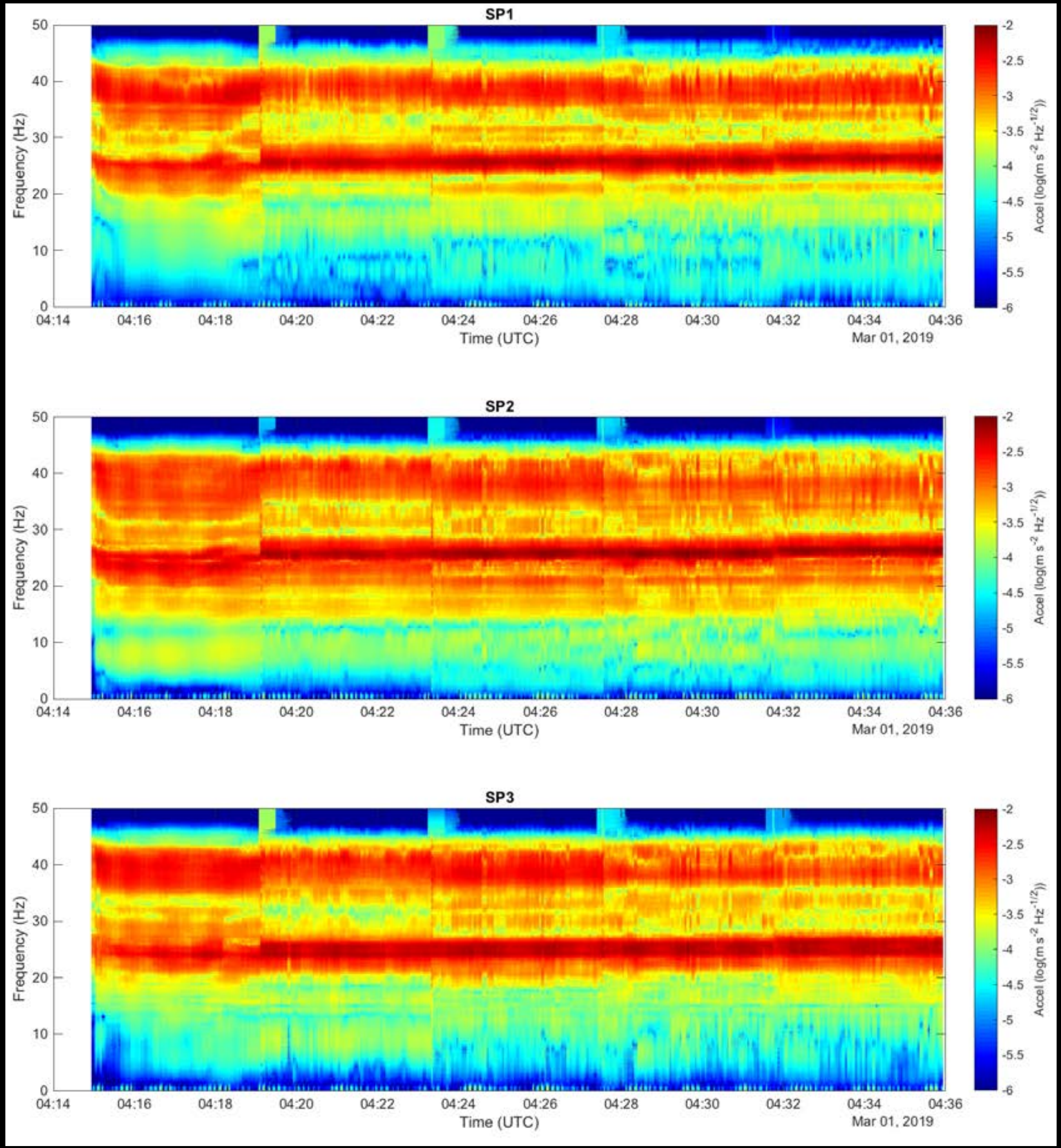
Seismic Data

SP1

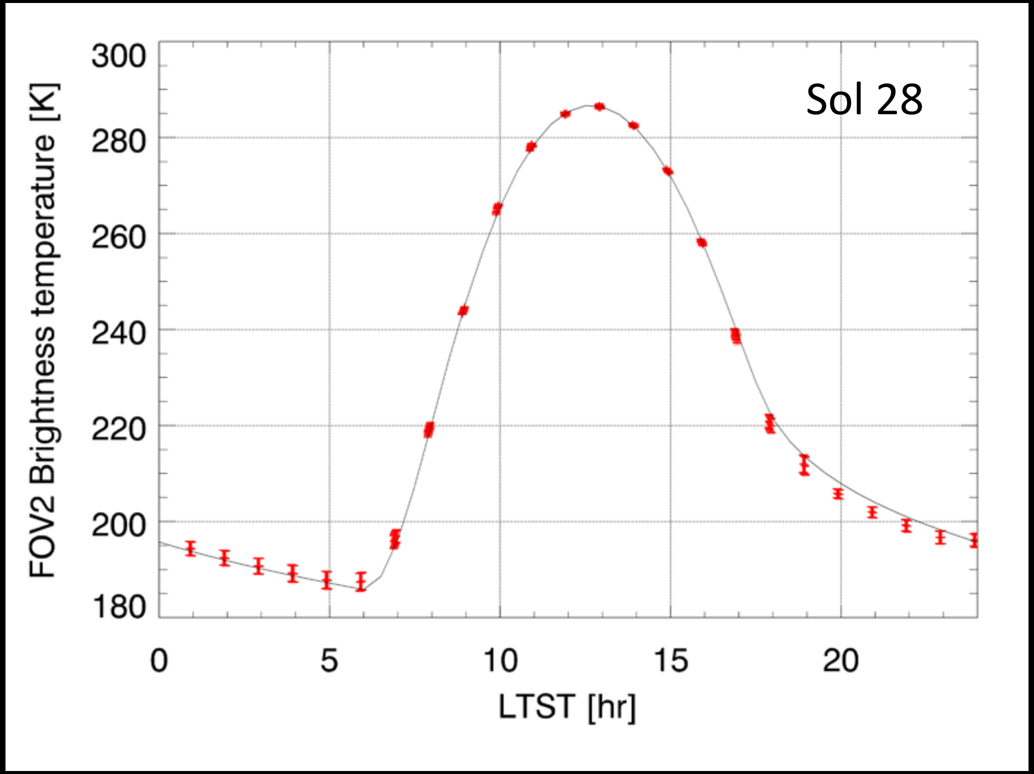
SP2

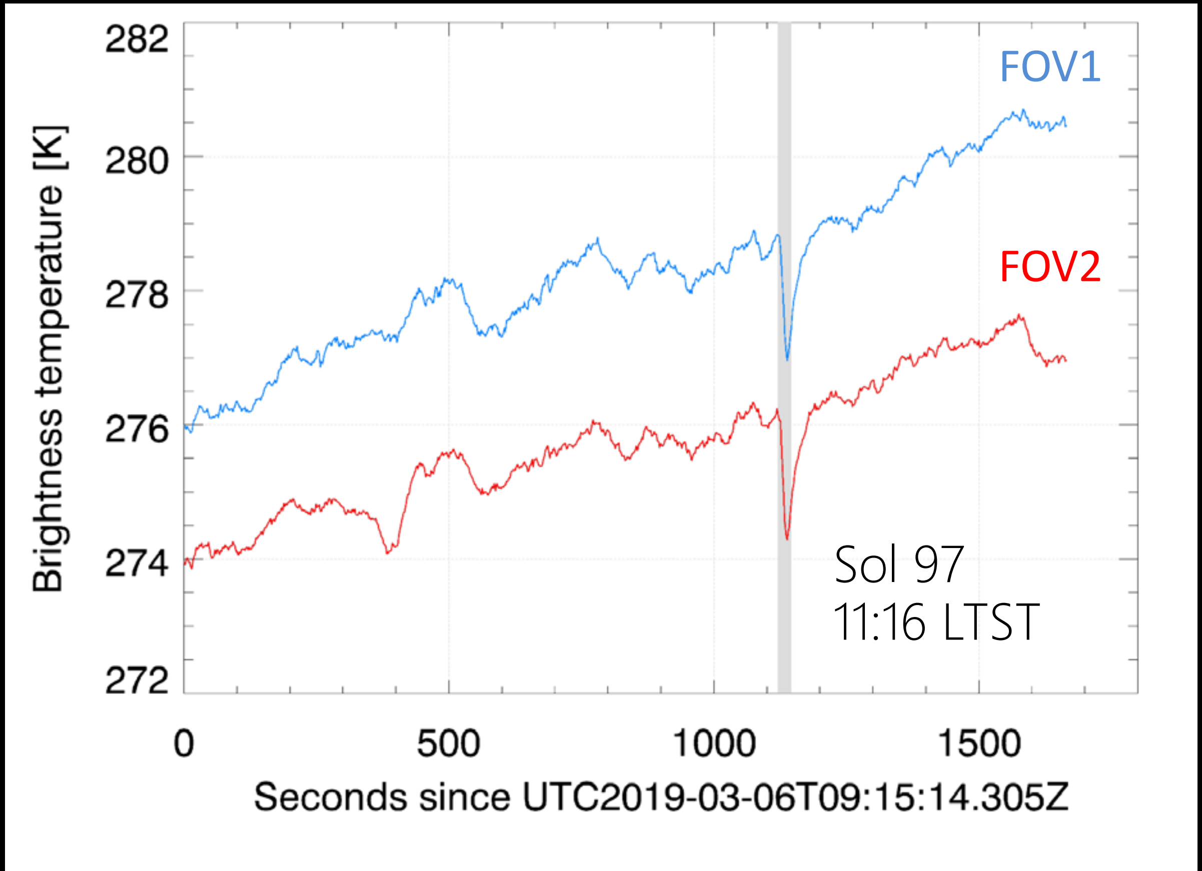
SP3





Radiometer: Daily Brightness Temperature and Phobos Eclipse



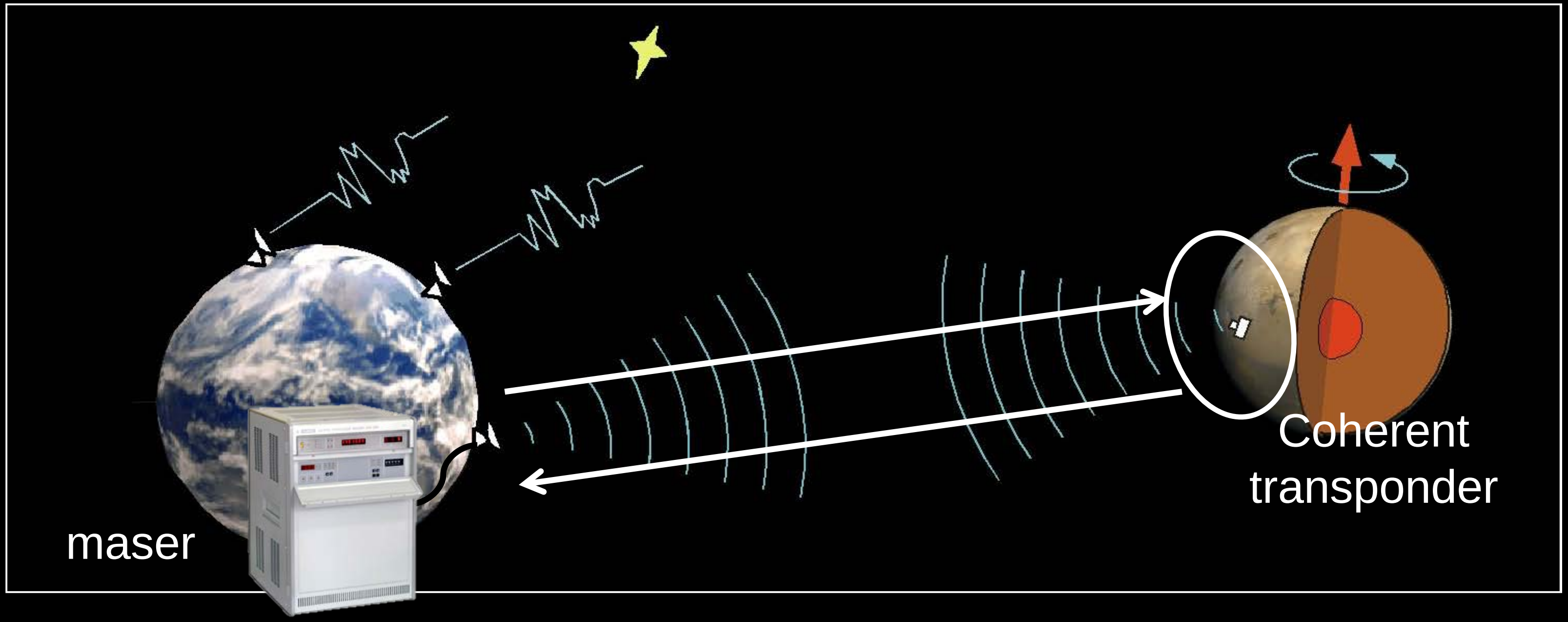


- Both the diurnal and Phobos measurements are consistent with a thermal inertia of 190 J m^{-2} $s^{-1/2}K^{-1}$.
- This is also consistent with both orbiter observations and direct conductivity measurements by the mole in the regolith

RISE

Precision Radio Tracking – RISE

- 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.
- By tracking the lander location for about an hour each day, we will be able to determine the direction and motion of the rotation vector of Mars.

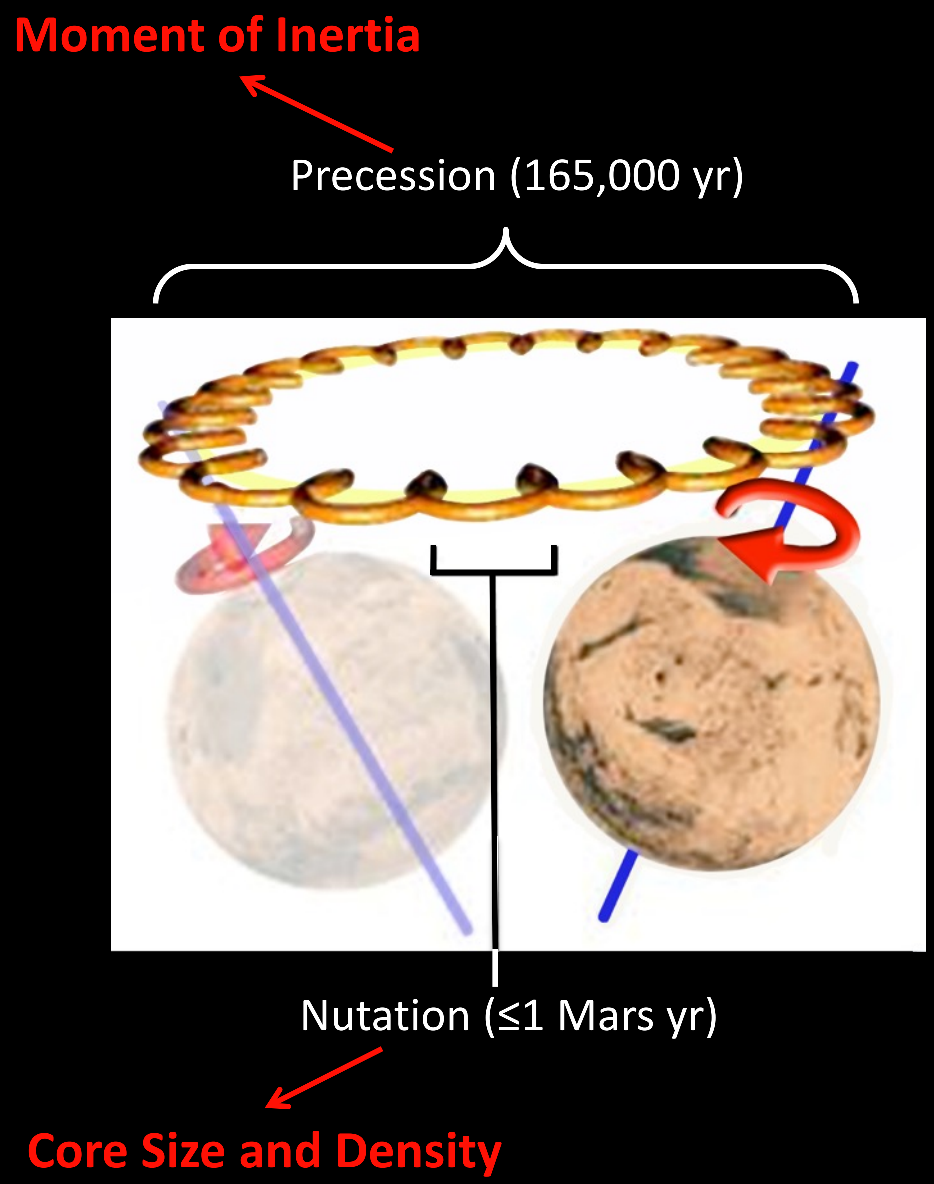


Precision Radio Tracking – RISE

- First measured constraint on Mars' core size came from combining radio Doppler measurements from Viking and Mars Pathfinder, which determined spin axis directions 20 years apart.

- InSight will provide another snapshot of the axis 20 years later still.

- With 2 years of tracking data, it will be also be possible to determine nutation amplitudes and frequencies.



Environmental Sensors

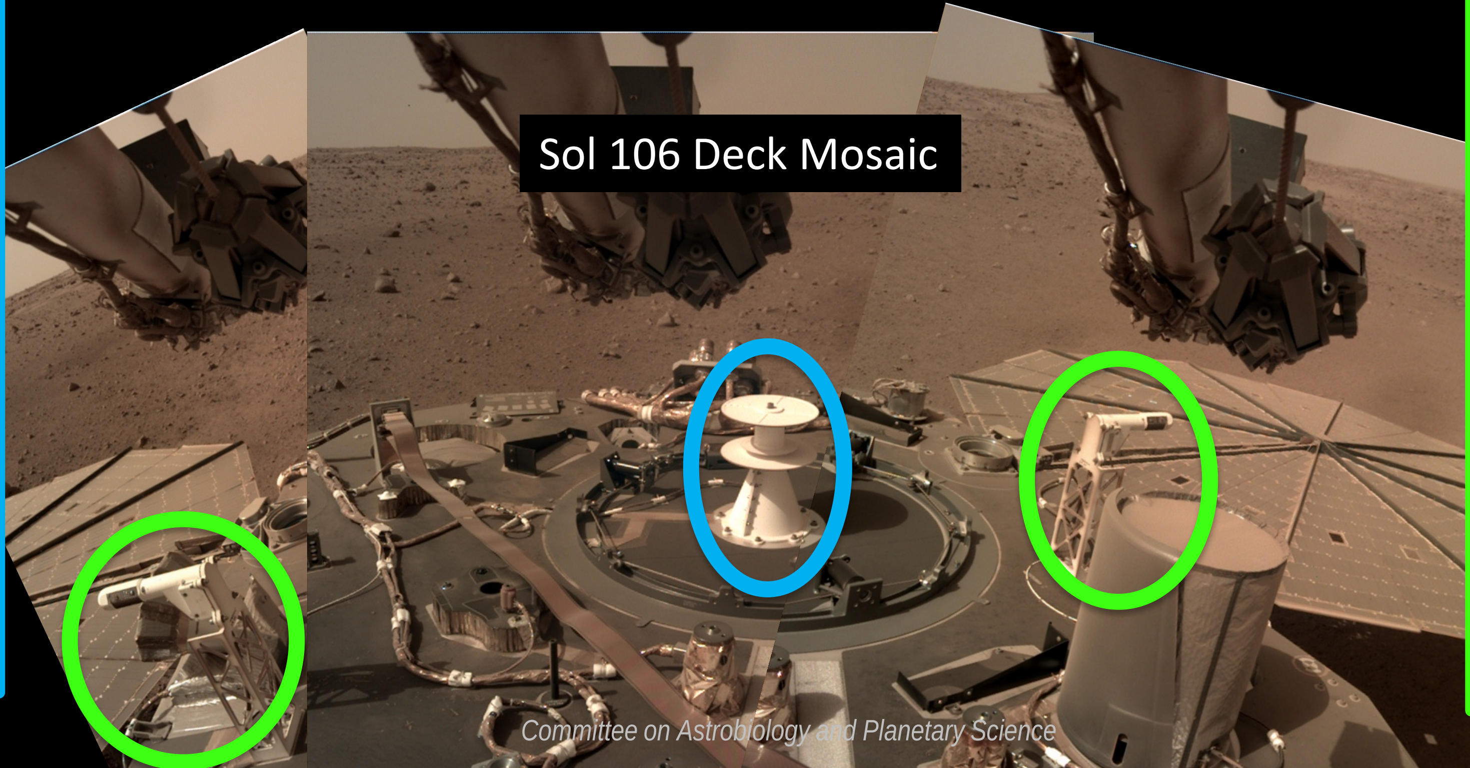
InSight Atmospheric Sensors

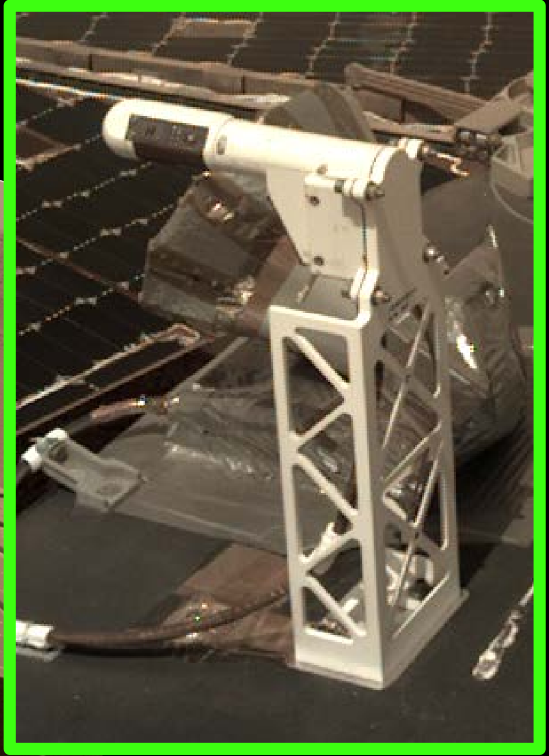
Pressure Sensor

- 20 Hz Sampling
- 10 mPa noise floor
- Quad-disc inlet to reduce wind noise
- Absolute calibration & drift <~1.5 Pa

TWINS (Temperature & Wind for InSight)

- Two outward facing booms
- Each with wind and air temperature
- 1Hz sampling (Wind response ~1s, Temperature ~30s)
- ~1m/s speed, <22˚ direction for wind
- ~5K accuracy, 0.1K resolution for temperature

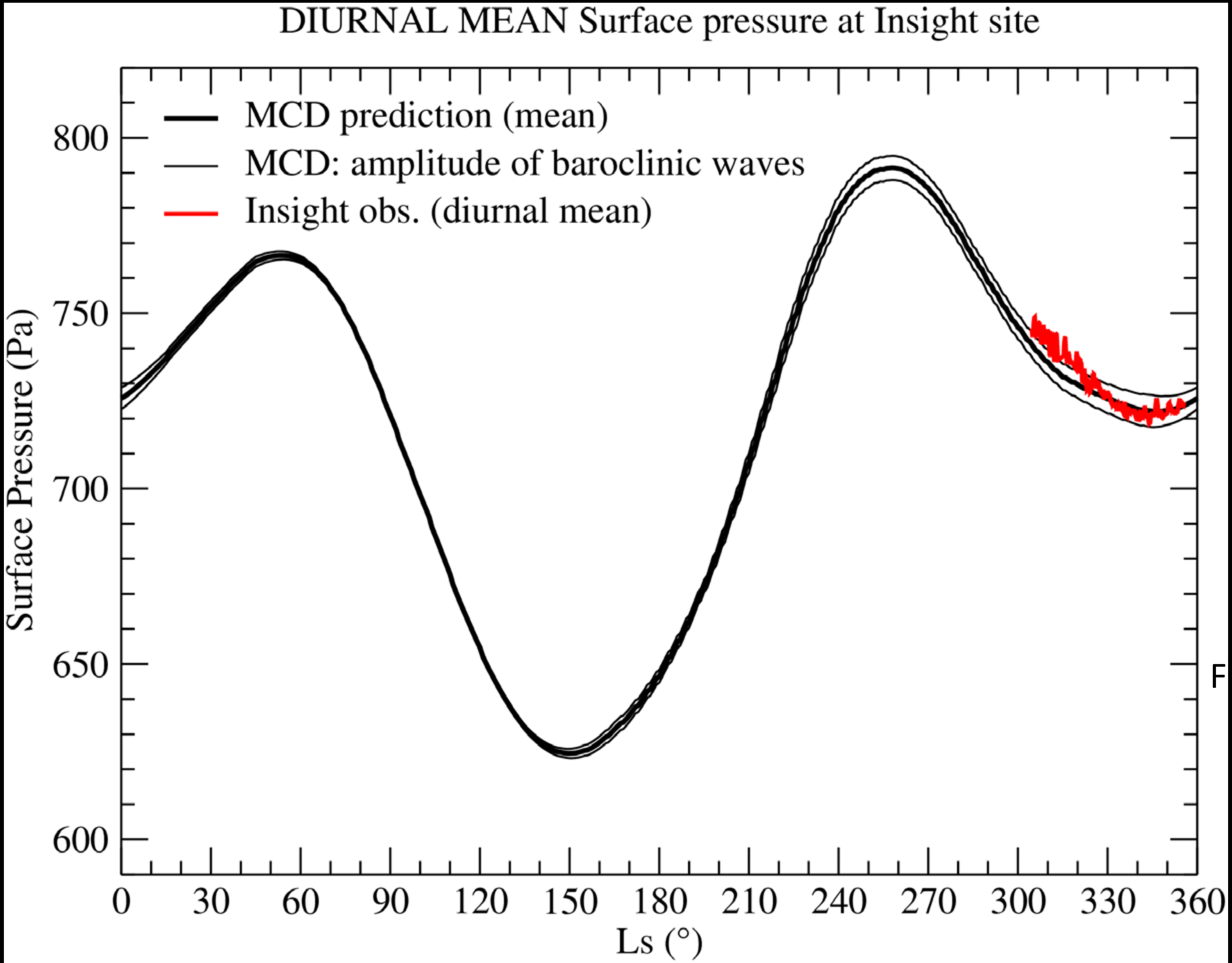




Atmospheric Timescales Investigated by InSight

Timescale	Associated Phenomena	Status
Secular	CO2 cap mass budget	Coming Soon
Interannual	Global dust storms	Coming Soon
Seasonal	CO_2 cycle, atmospheric dynamics	Started…
Synoptic	Regional dust storms	✓
Day-to-day	Baroclinic waves	✓
Diurnal	Thermal tides, slope winds	✓
Hour-to-hour	Gravity waves, slope winds	✓
Minute-to-minute	Boundary layer convection	✓
Second-to-second	Convective vortices & cells	✓
Sub-second	Infrasound, small-scale turbulence	✓

Atmospheric Timescales – Seasonal



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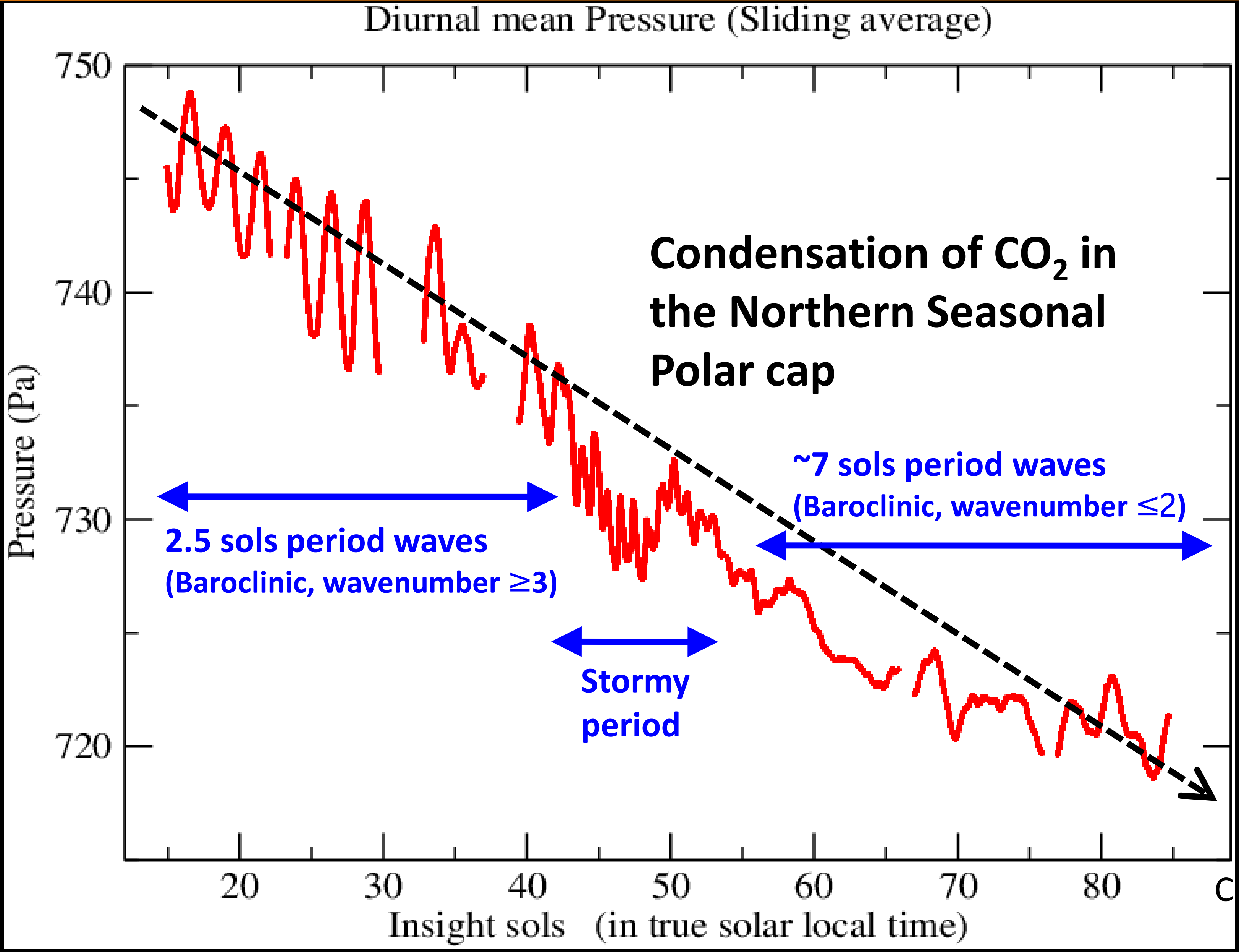
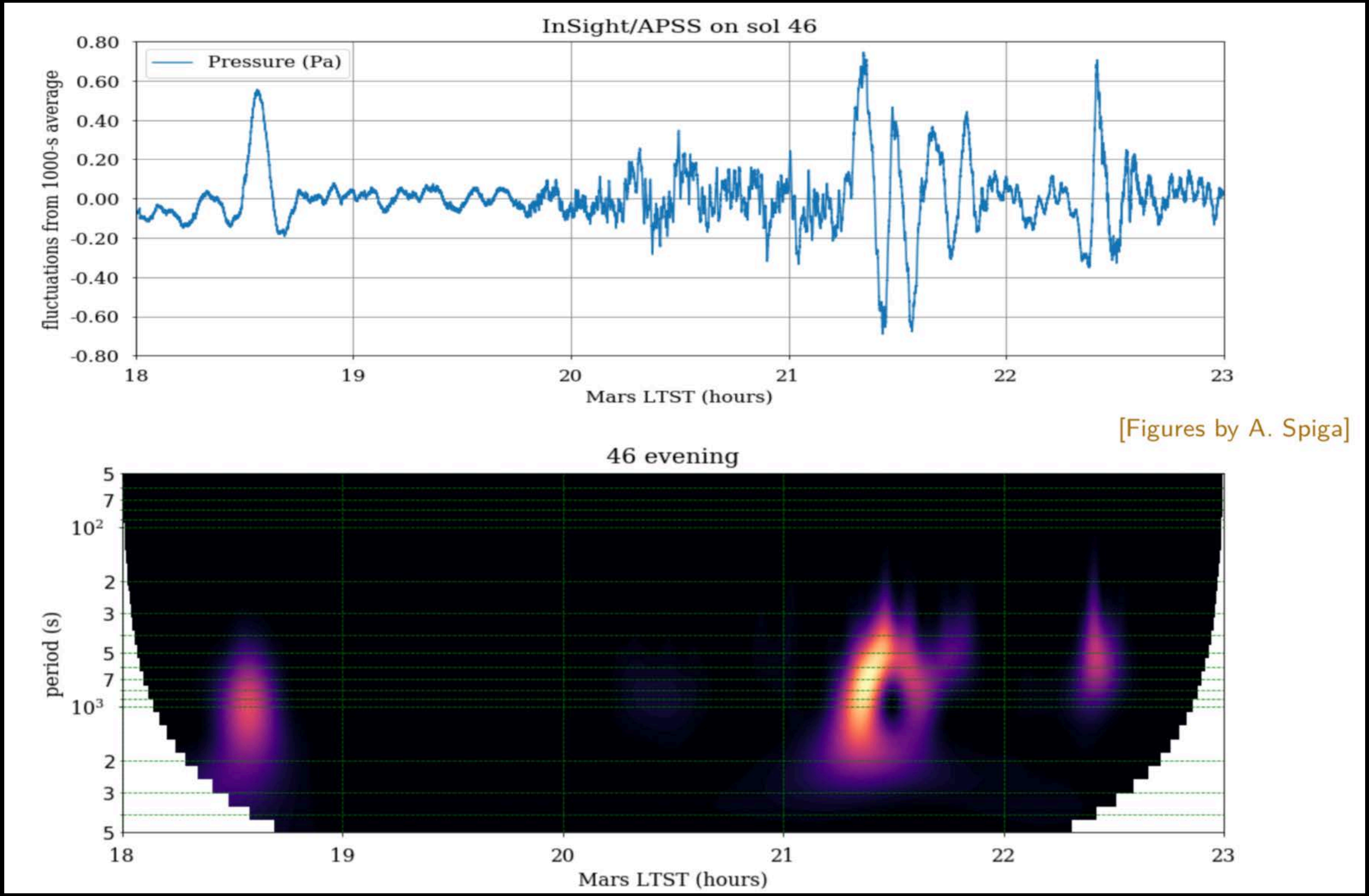
Atmospheric Timescales – Synoptic



Atmospheric Timescales – Hours

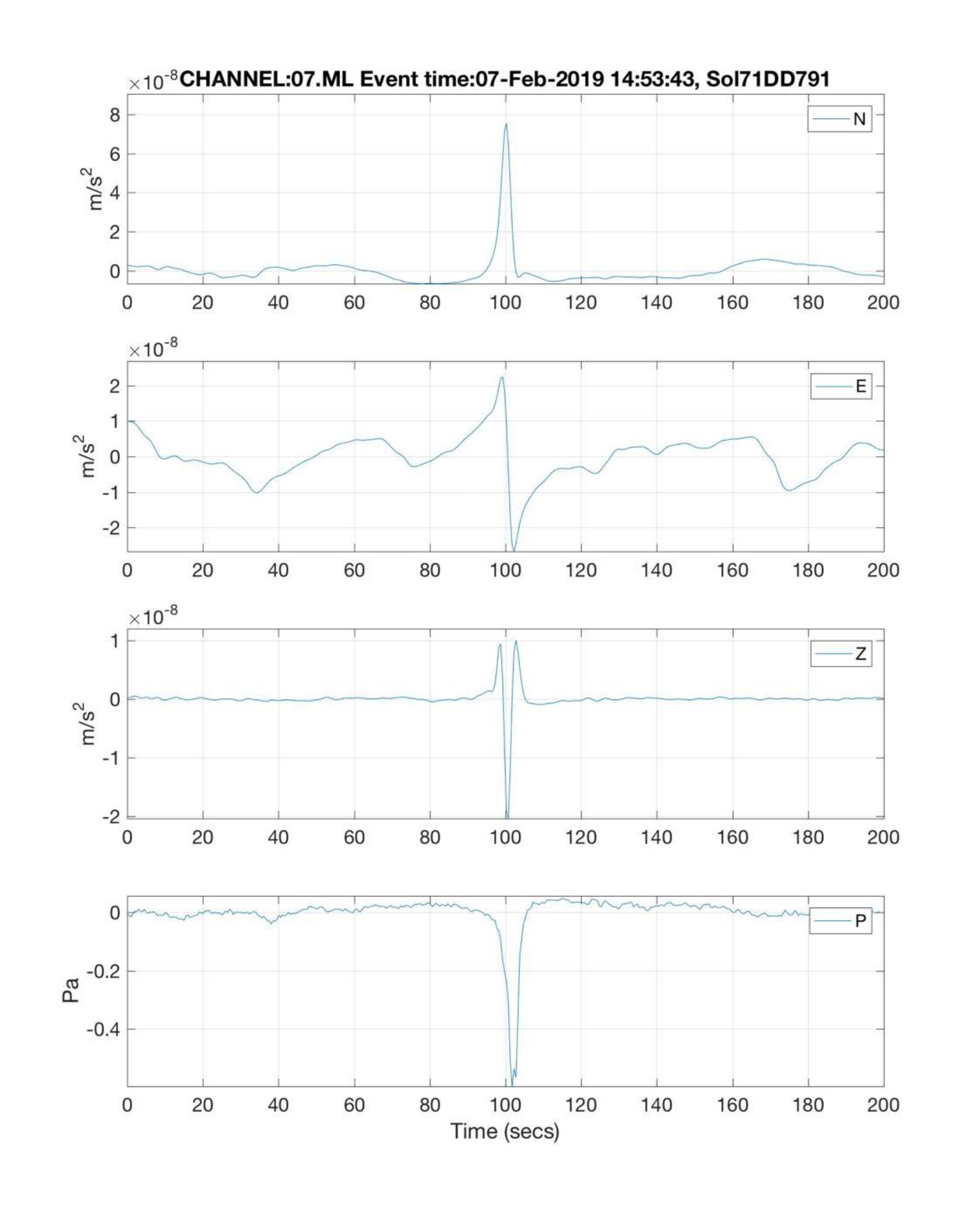


Gravity Waves:

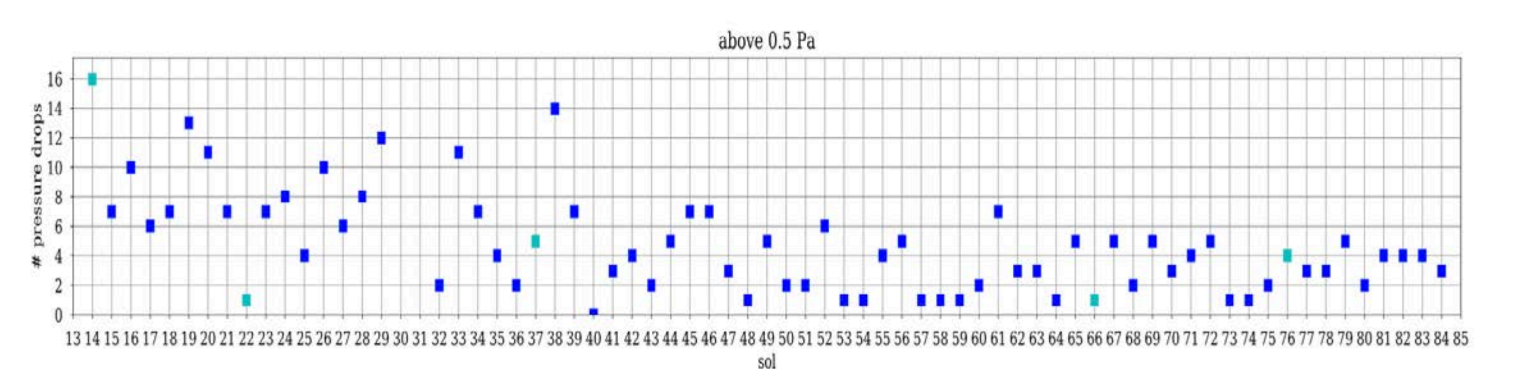
Large event, Sol 46 evening (600-800s period).

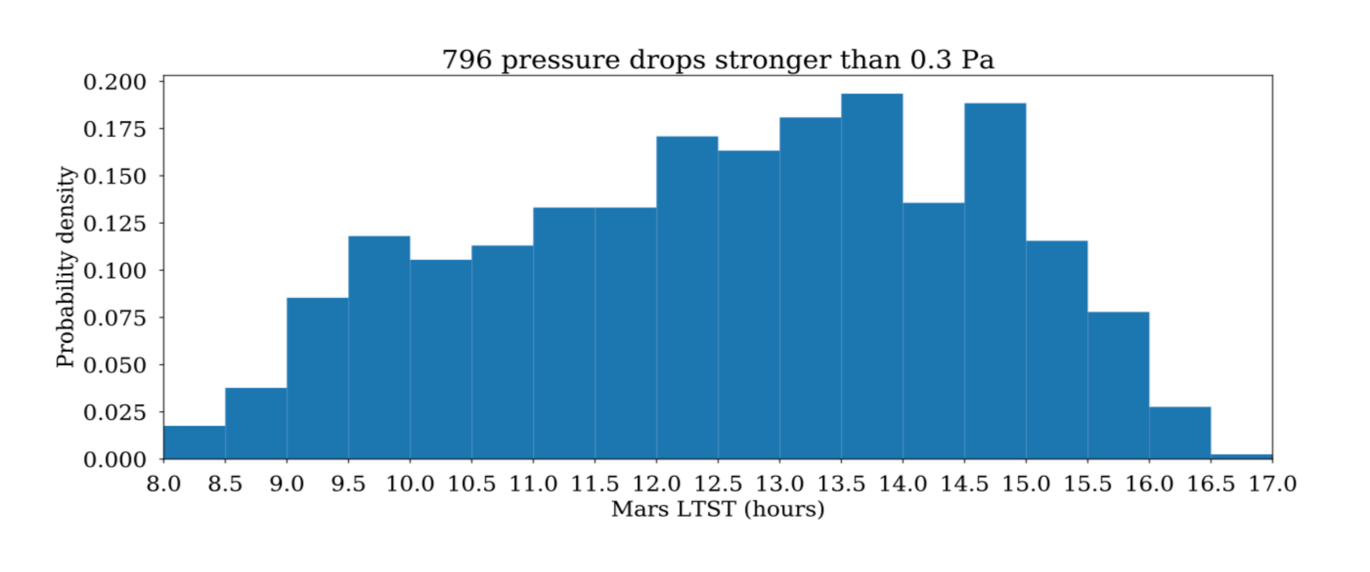
Largest seen to date (~1Pa), but common most nights, several times a night.

Atmospheric Timescales – Seconds

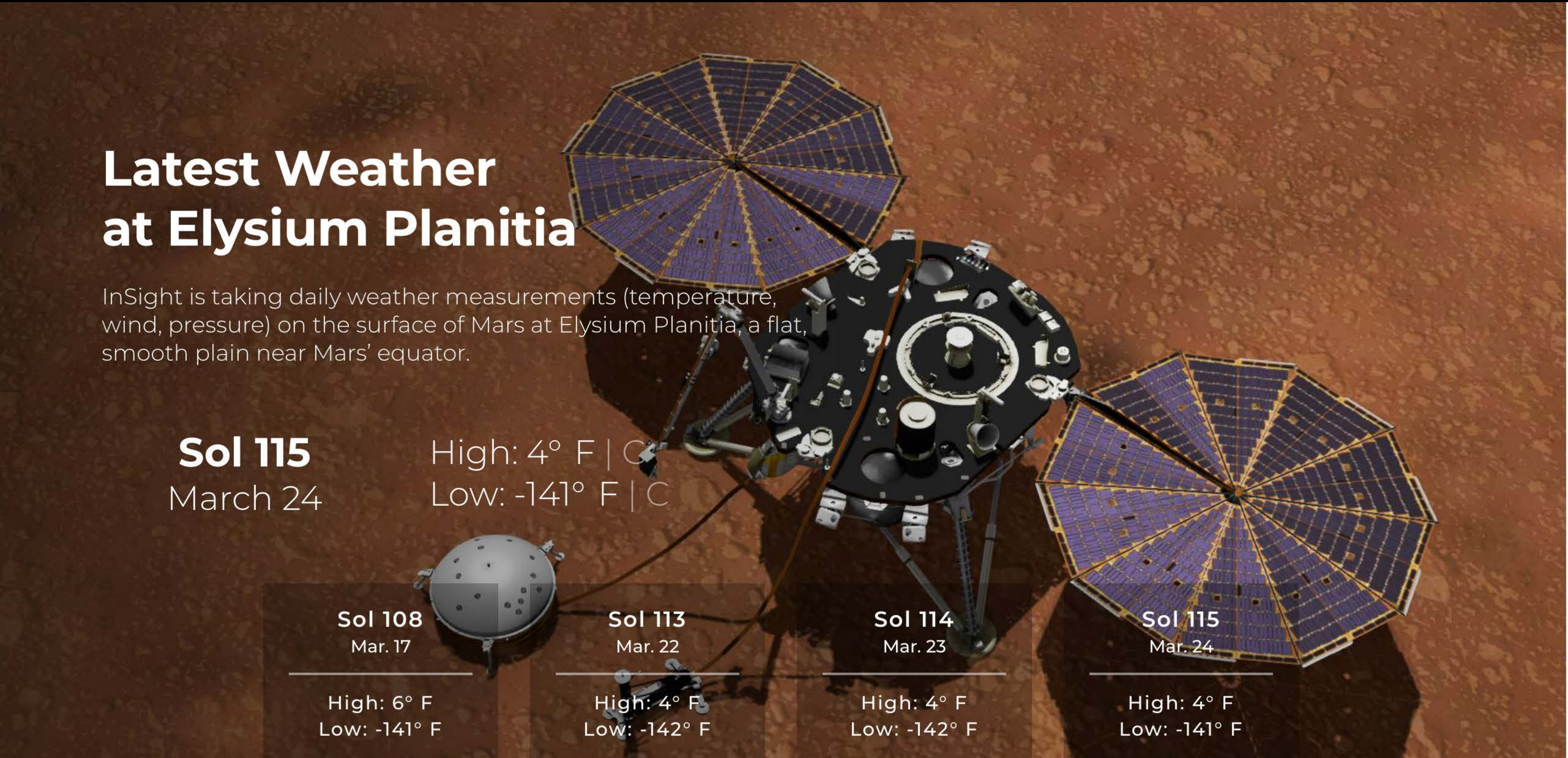


Convective Vortices (Dust Devils)



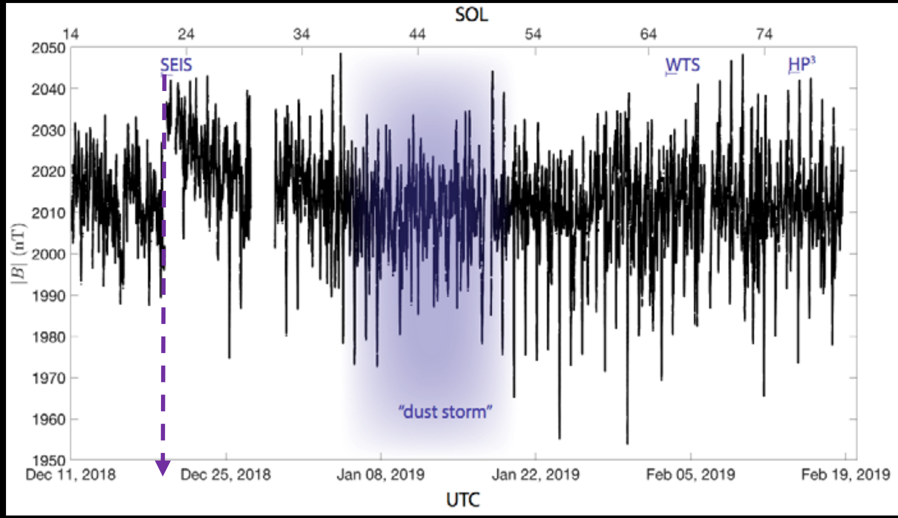


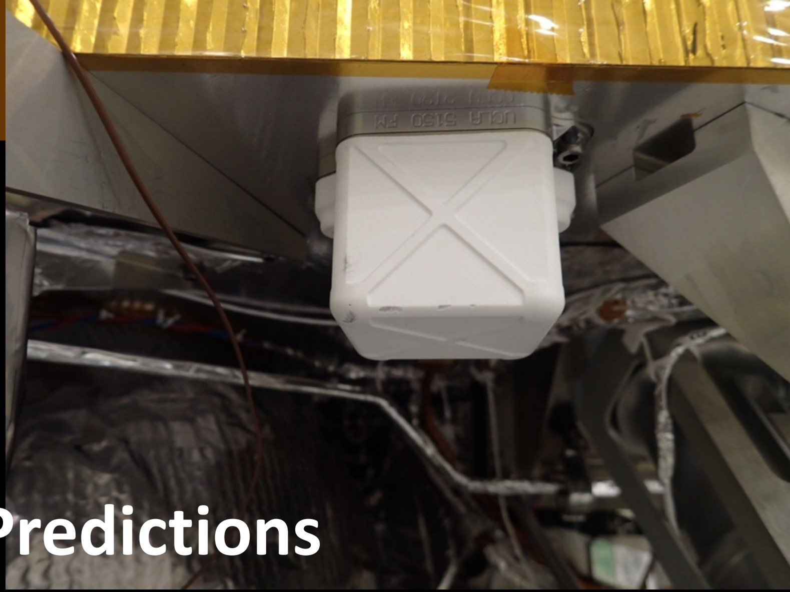
Daily Weather Report Page



IFG: 1st Magnetometer on Mars' Surface

IFG Data: Sols 14 – 82

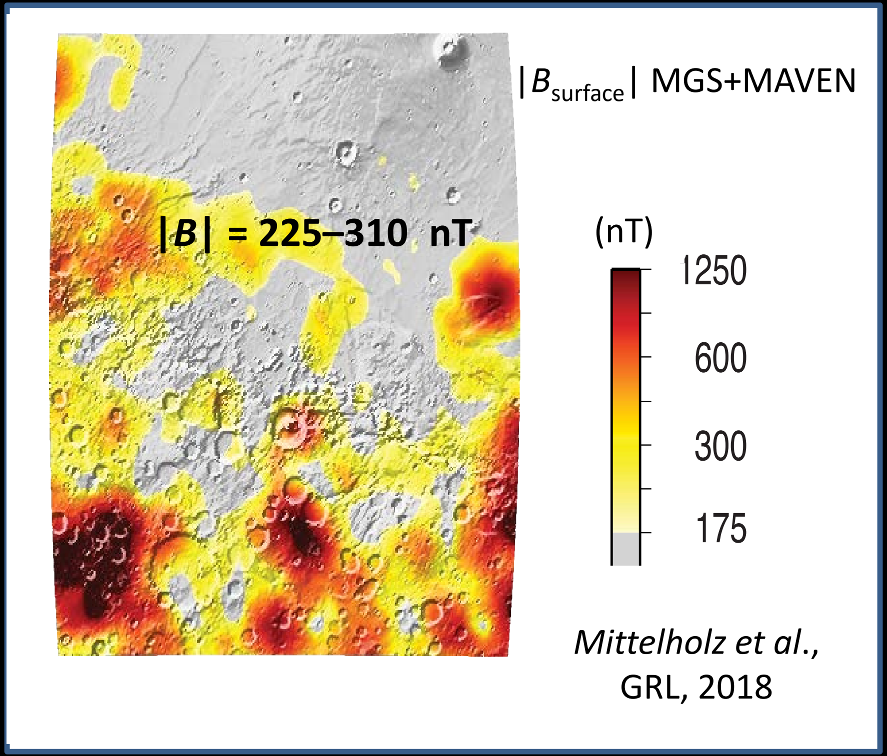




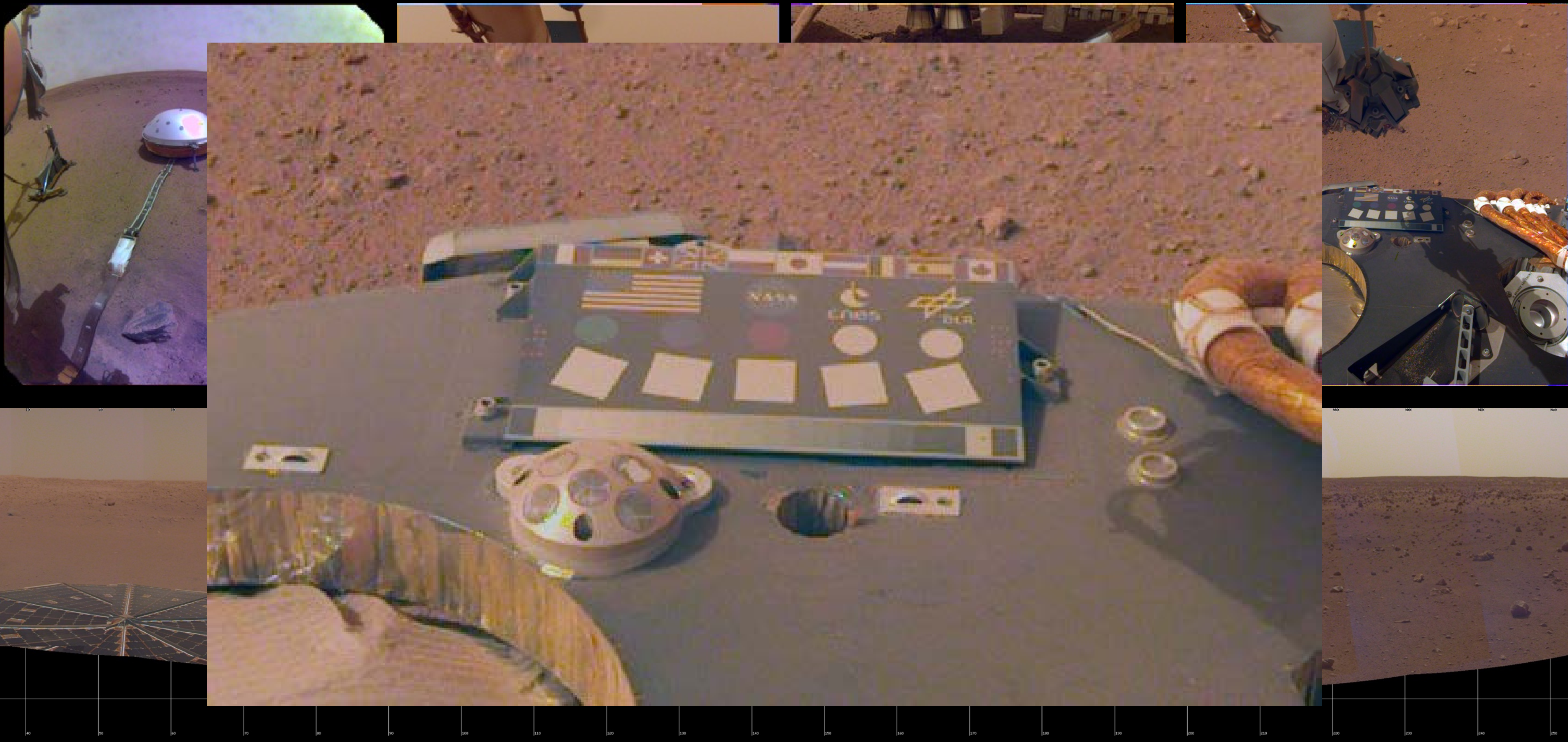
DC field → estimate of crustal field
- **|*B*| = 2013 ± 13 nT**
- Declination = 138°, Inclination = -28°, i.e., SE and upward pointing

Ground-based estimate ~ 10x satellite estimate
→ contributions from magnetizations with scale lengths < ~150 km

Satellite Predictions



Geology and Imaging (1583 Images as of Sol 113, 3/23/19)



Summary

Sunset, sol 101

- InSight landed safely and has completed instrument deployment and SEIS commissioning activities.
- The InSight lander is operating virtually perfectly, and ground operations are proceeding smoothly.
- SEIS is working remarkably well and is exceeding its pre-launch performance goals.
  - No marsquakes have yet been detected; this is consistent with pre-landing estimates.
- HP^3 has encountered an obstruction after ~30 cm of penetration.
  - We are in the process of evaluating the next steps to continue penetration.
- The environmental sensors are making continuous, around-clock observations of the atmosphere and magnetic field, and the geological characterization of the landing area is well underway.