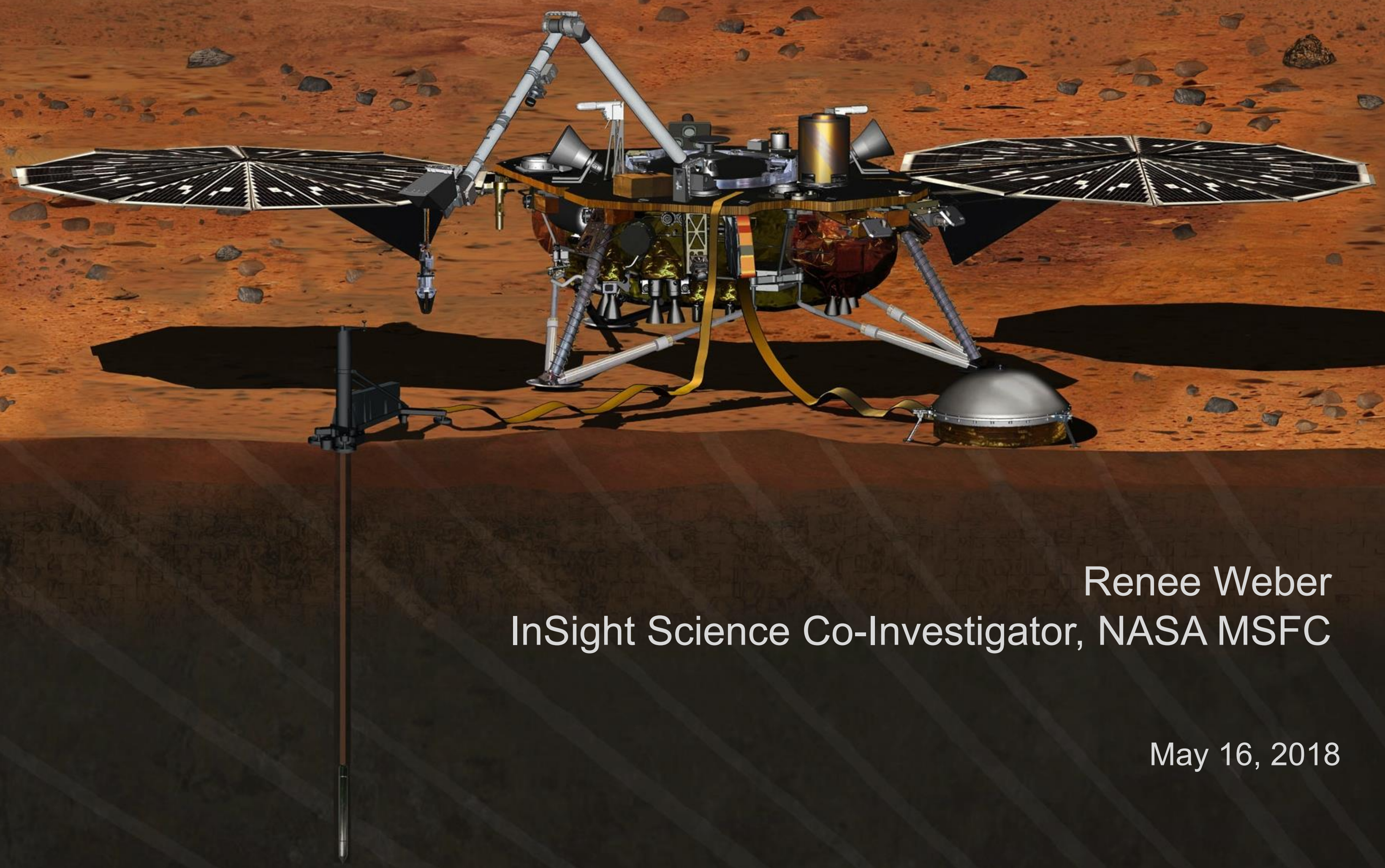
The InSight Mission
Exploring the Interior of Mars

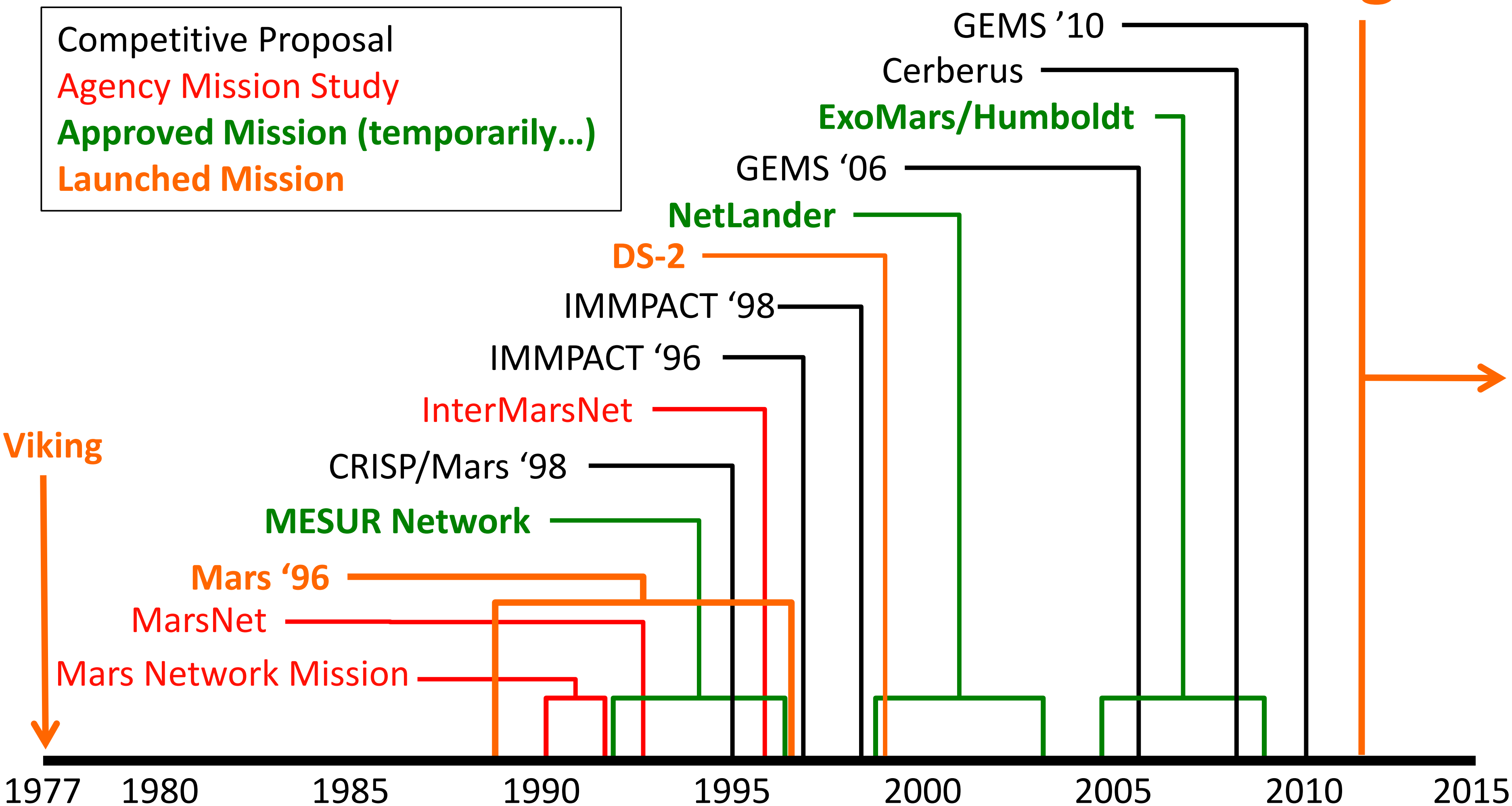


Renee Weber
InSight Science Co-Investigator, NASA MSFC

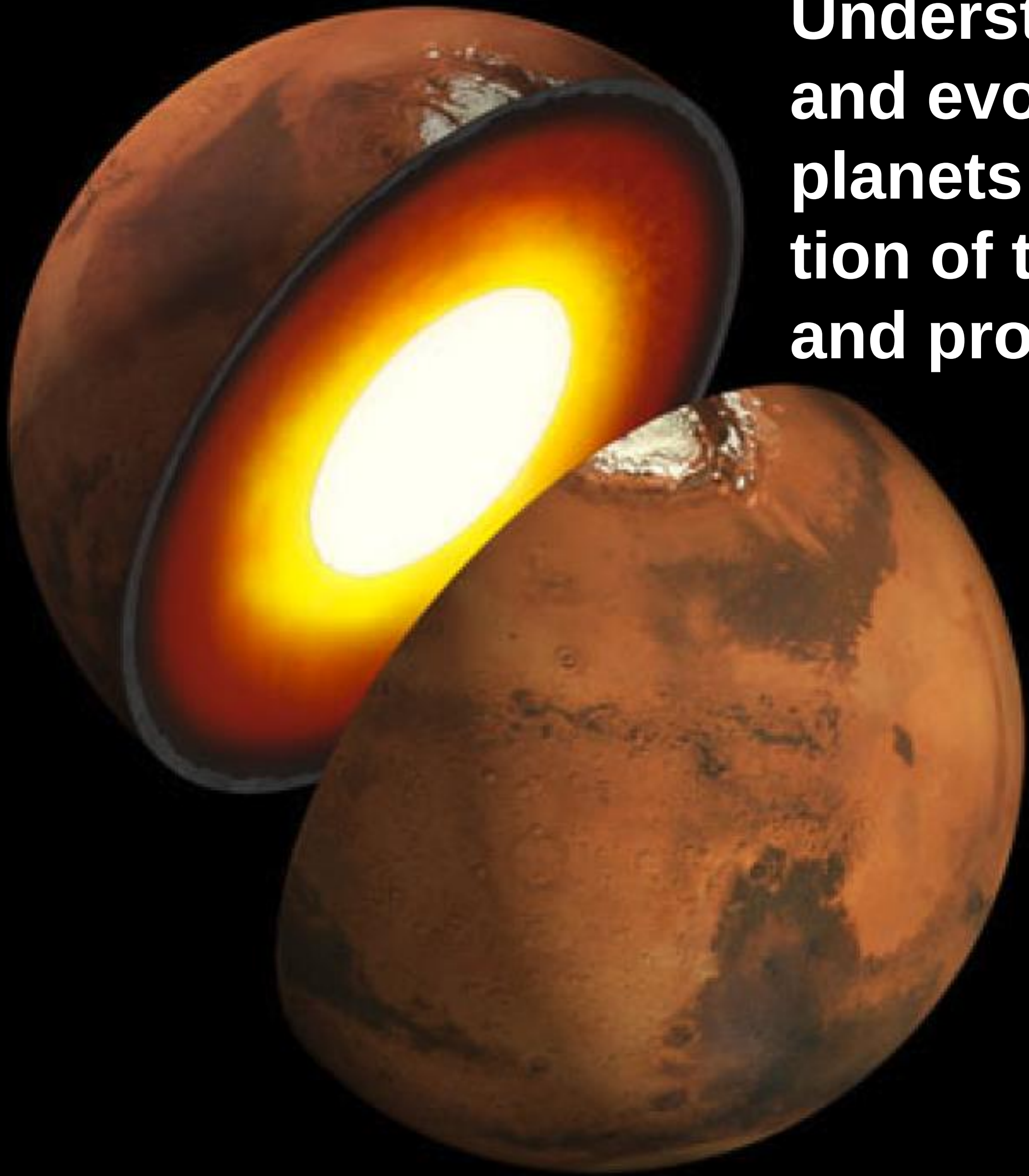
May 16, 2018

A Mission 35 Years in the Making…

Over the 35 years since Viking and Apollo, despite many proposals, several mission starts, and even a couple of launches, there have been no further geophysical investigations of the interior of any planet… **InSight!**



InSight Science Goal:

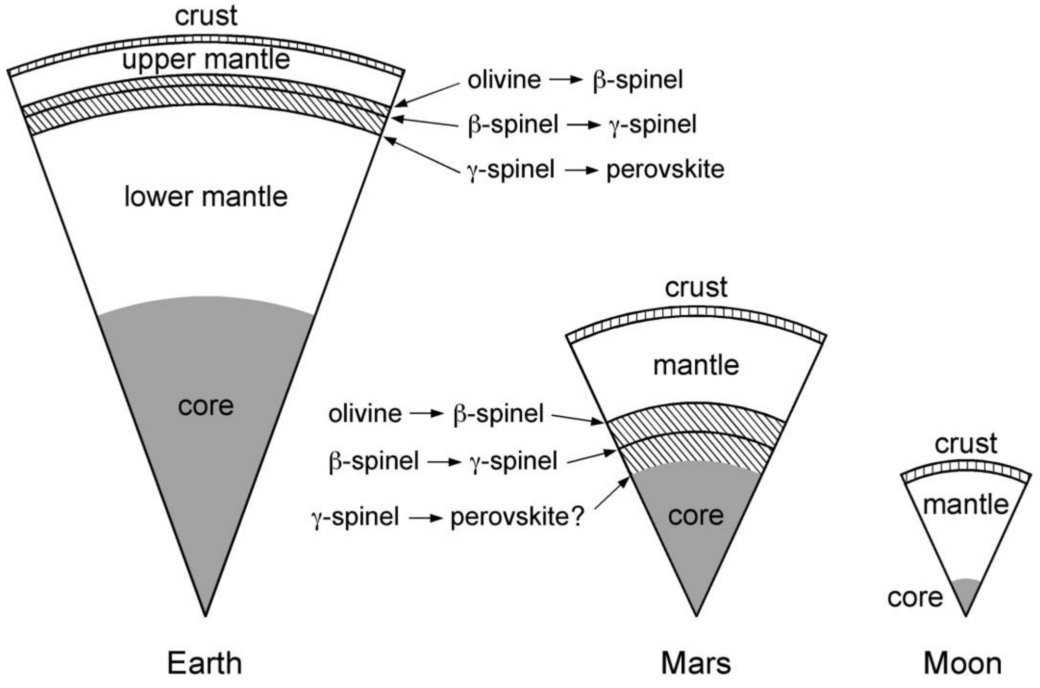


Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars.

- **Seismology**
- **Geodesy**
- **Heat Flow**
  - **Magnetics**

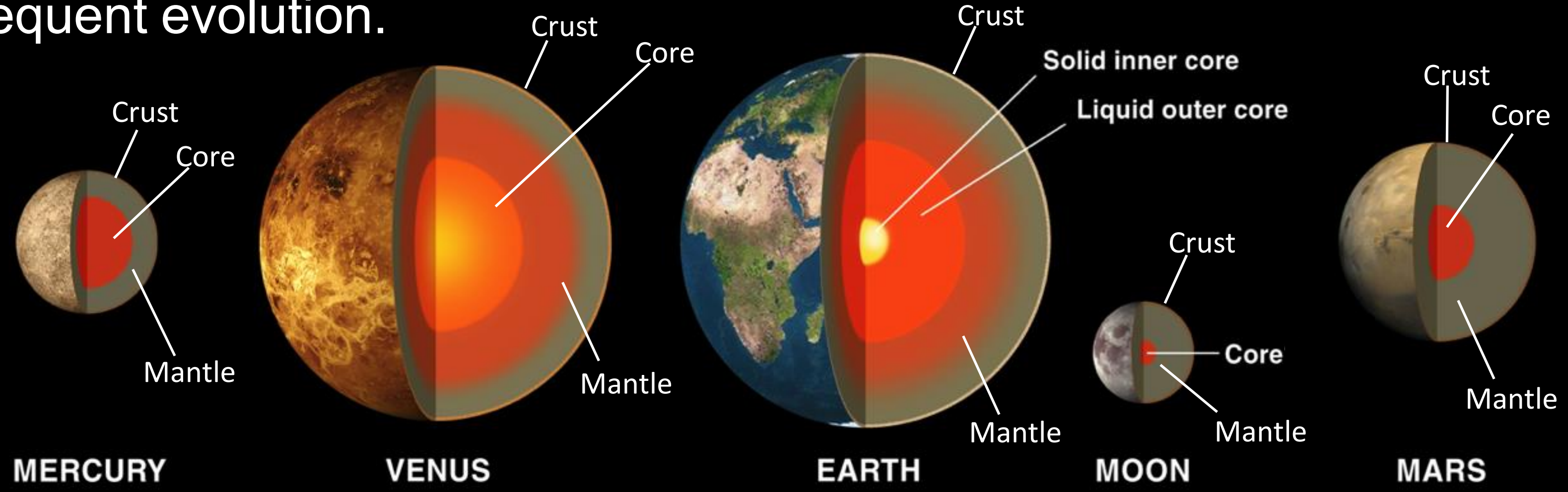
Why Mars?

- We have information on the interiors of only two (closely related) terrestrial planets, Earth and its Moon.
  - Much of the Earth's early structural evidence has been destroyed by plate tectonics, vigorous mantle convection.
  - The Moon was formed under unique circumstances and with a limited range of P-T conditions (<200 km depth on Earth)
- Mars is large enough to have undergone most terrestrial processes, but small enough to have retained evidence of its early activity.



Mars is Key to Understanding Early Formation of Terrestrial Planets, Including Rocky Exoplanets

Terrestrial planets all share a common structural framework (crust, mantle, core), which is developed very shortly after formation and which determines subsequent evolution.



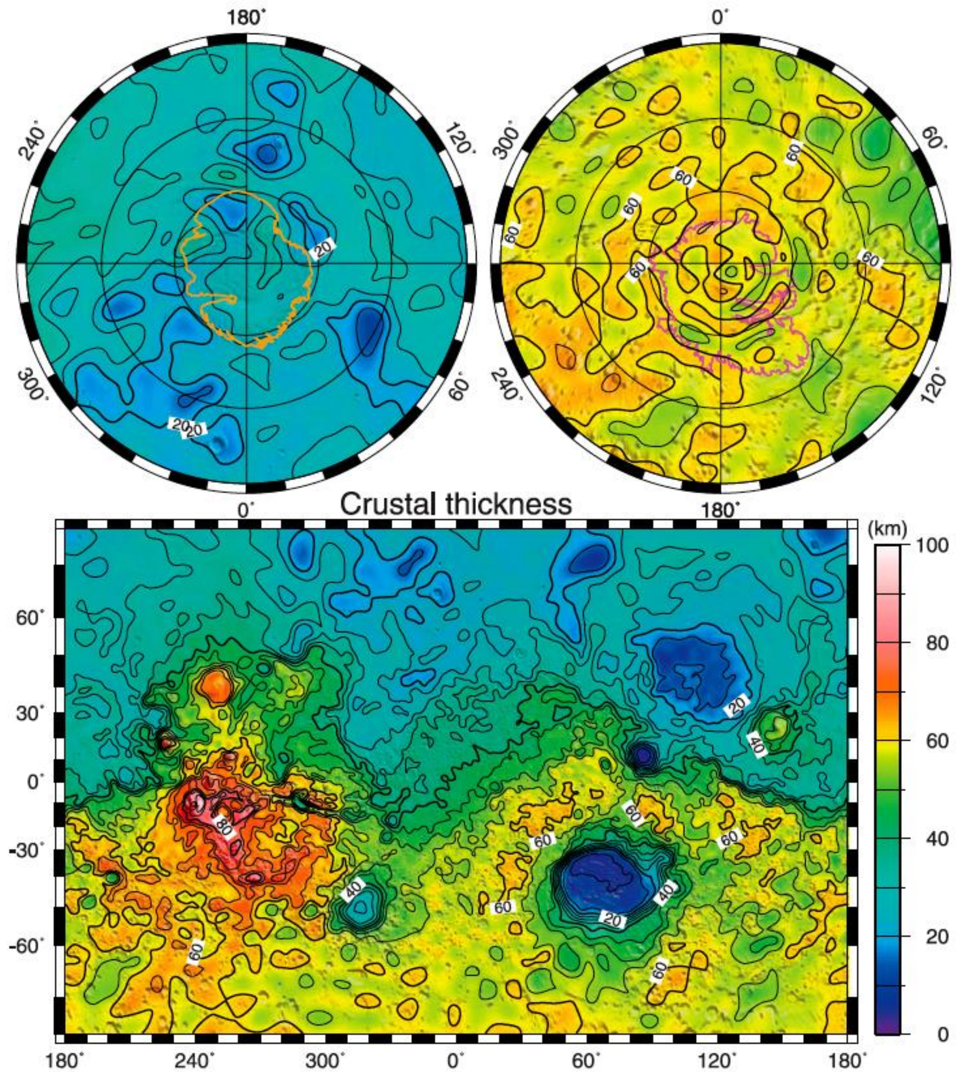
Mars is uniquely well-suited to study the common processes that shape all rocky planets and govern their basic habitability.

- There is strong evidence that its basic crust and mantle structure have survived little changed from the first few hundred Myr of formation.
  - Ancient crustal surface age from crater and QCD density
  - SNC evidence for persistent distinct mantle reservoirs, Ar isotope ratios
- Its surface is much more accessible than Mercury, Venus.
- Our knowledge of its geology, chemistry, climate history provides a rich scientific context for using interior information to increase our understanding of the solar system.

InSight

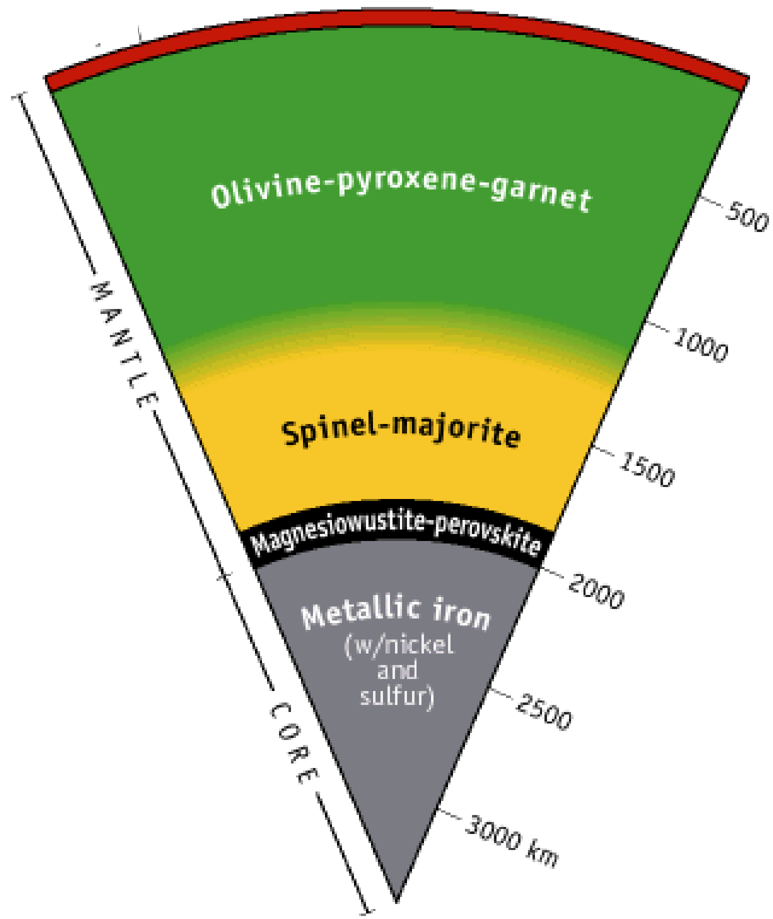
Crust Questions

- 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?
- These questions and more can be addressed by a simple thickness measurement.



Mantle Questions

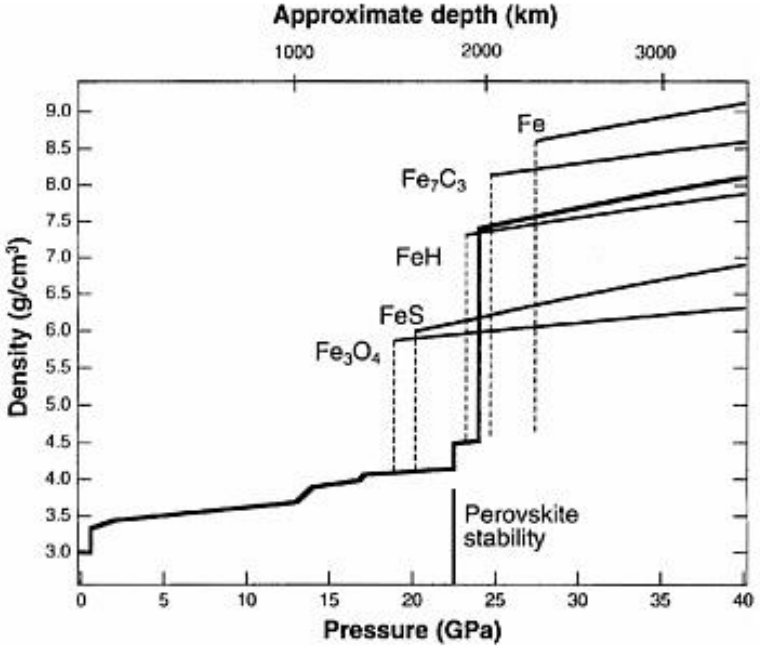
- What is the mantle density, which can be related to composition (e.g., Mg#, mineralogy, volatile content)?
- To what degree is it compositionally stratified? What are the implications for mantle convection?
- Are there polymorphic phase transitions?
- What is the thermal state of the mantle?
- All can be addressed to some extent by basic seismic observations.



Core Questions

- Radius is 1600±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?
- Without radius and shear measurements we are stuck with a family of possible core structures, each with significantly different implications for the origin and history of Mars .

Density Profiles Allowed by Moment of Inertia Constraint

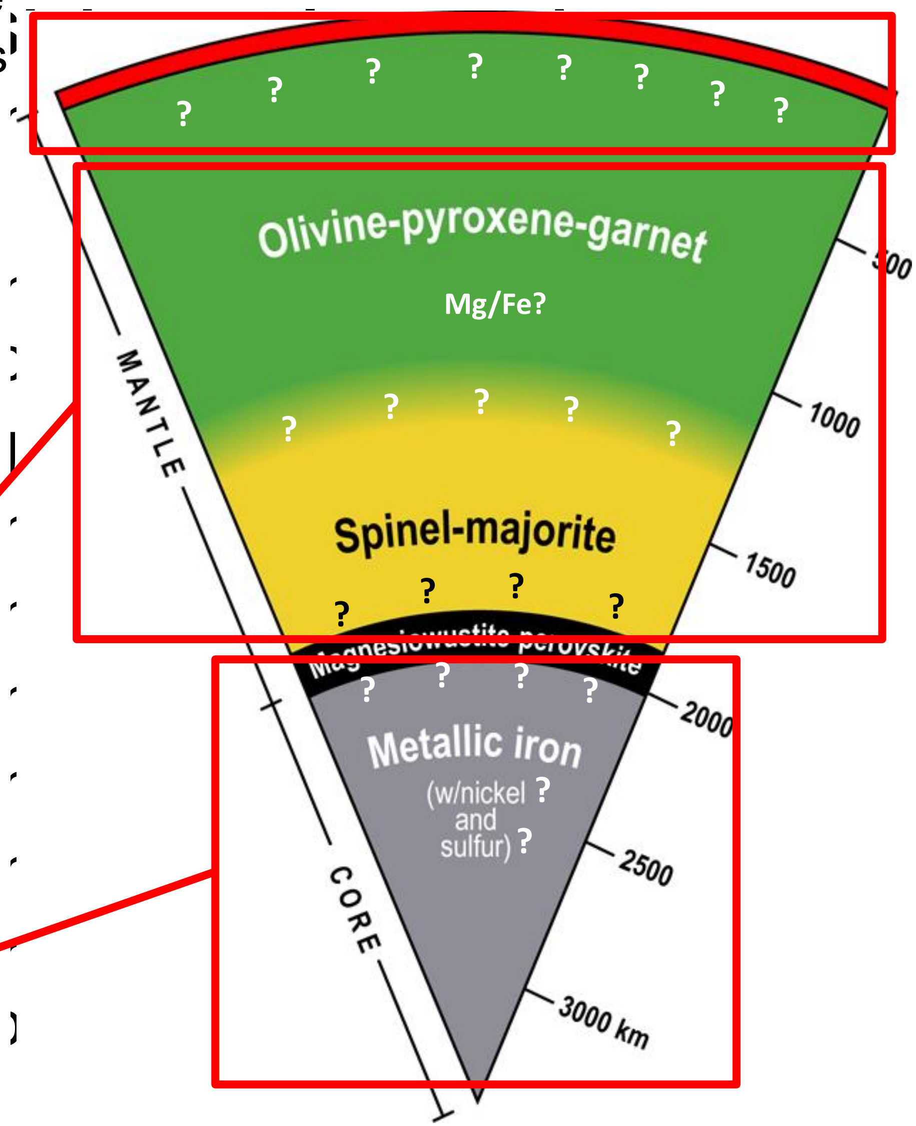


Basic Structure Provides Key Information about Formation and Evolution

- **Crust:** Its **thickness** and vertical structure (**layering** of different compositions) reflects the depth and crystallization processes of the magma ocean and the early post-differentiation evolution of the planet (plate tectonics vs. crustal overturn vs. immobile crust vs. …).

- **Mantle:** Its behavior (e.g., convection, partial melt generation) determines the manifestation of the thermal history on a planet's surface; depends directly on its **thermal structure** and **stratification**.

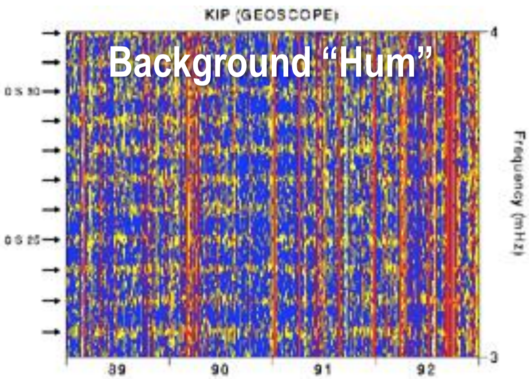
- **Core:** Its **size** and composition (**density**) reflect conditions of accretion and early differentiation; its **state** (liquid vs. solid) reflects its composition and the thermal history of the planet.

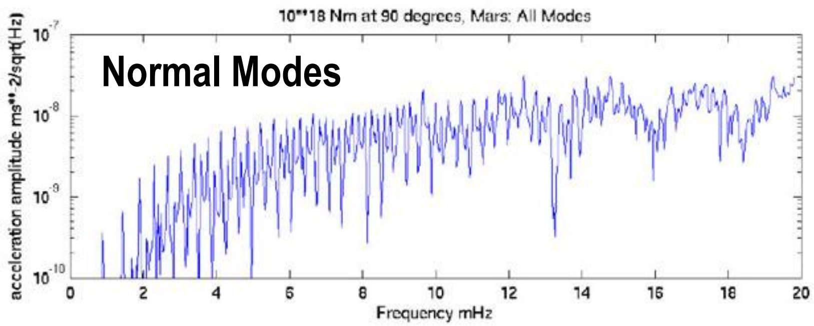


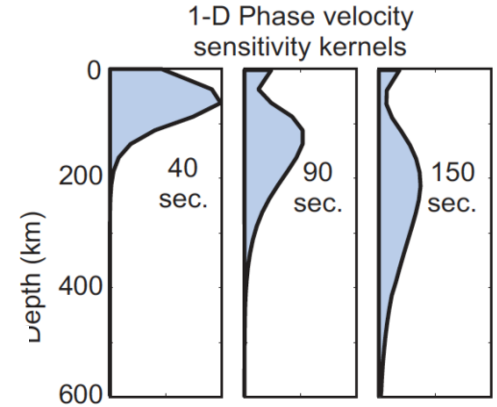
What Do We Know About the Interior of Mars?

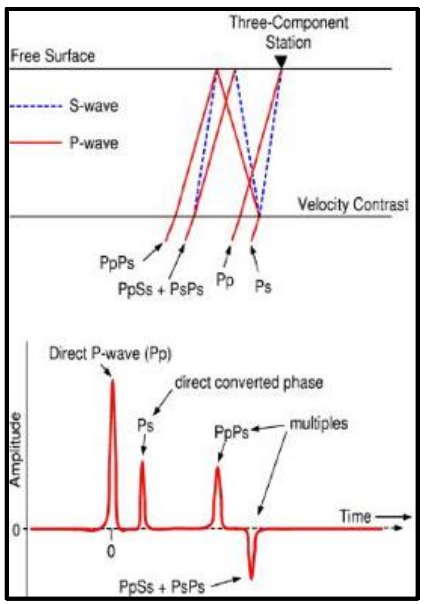
Measurement	Current Uncertainty	InSight Capability	Improvement
Crustal thickness	65±35 km (inferred)	±5 km	7X
Crustal layering	no information	resolve 5-km layers	New
Mantle velocity	8±1 km/s (inferred)	±0.13 km/s	7.5X
Core liquid or solid	“likely” liquid	positive determination	New
Core radius	1700±300 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	factor of 100 (inferred)	factor of 10	10X
Seismic distribution	no information	locations ≤10 deg.	New
Meteorite impact rate	factor of 6	factor of 2	3X

Martian Seismology – Single-Station Analysis Techniques

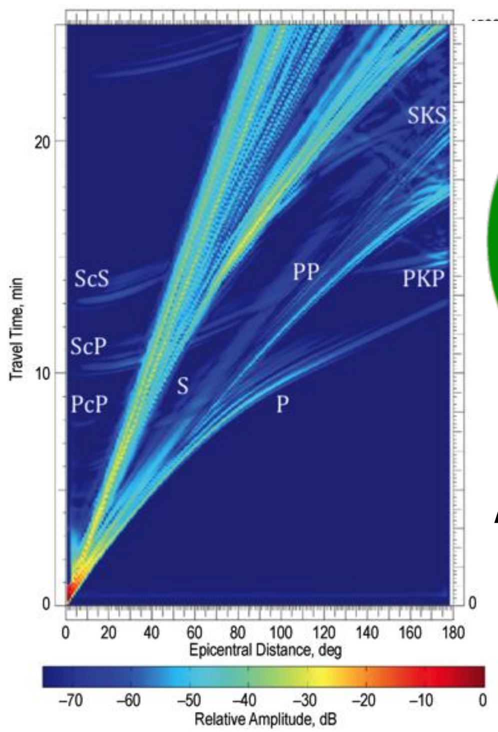


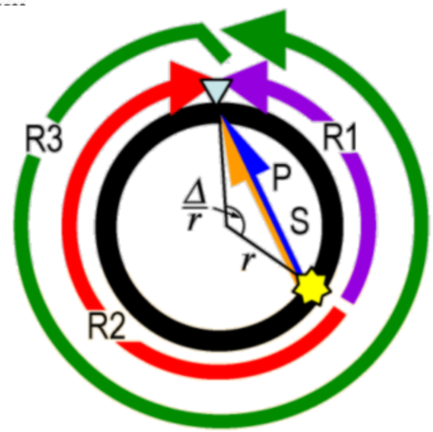




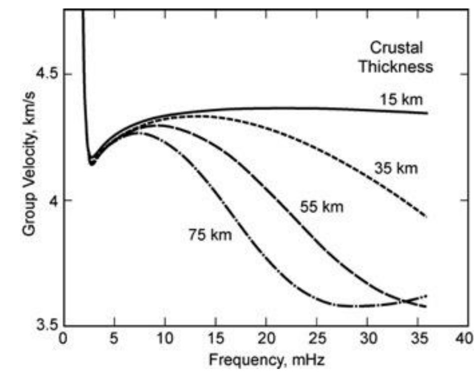


Receiver Function

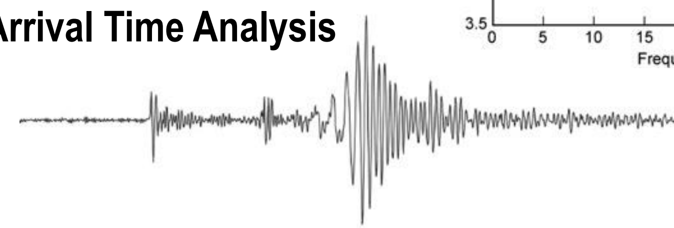




Surface Wave Dispersion

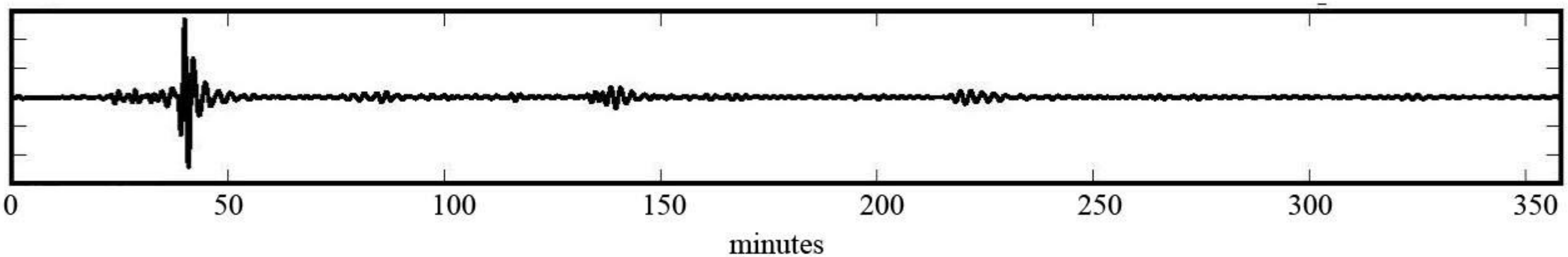


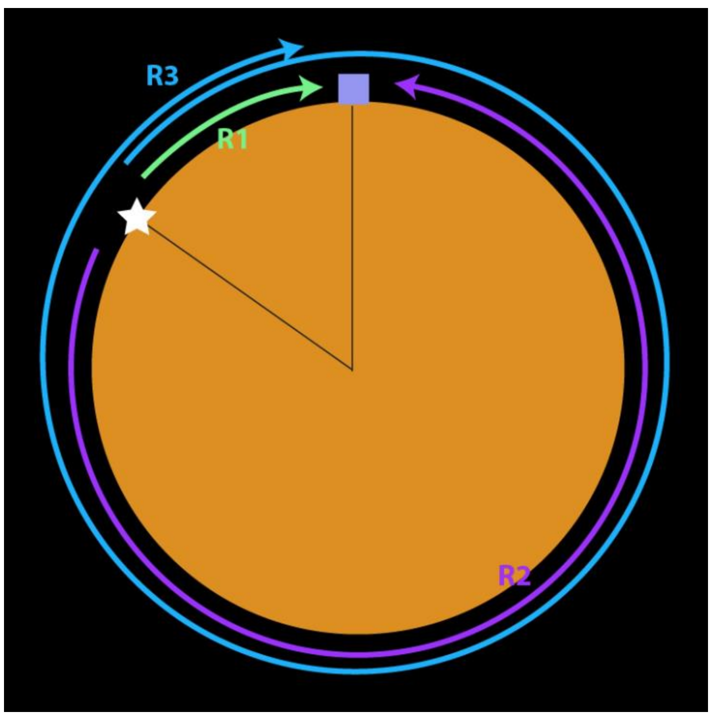
Arrival Time Analysis



epicentral distance from Rayleigh waves

vertical component





angular group velocity

$$U = \frac{2p}{R3 - R1}$$

epicentral distance

$$D = p - \frac{1}{2}U(R2 - R1)$$

origin time

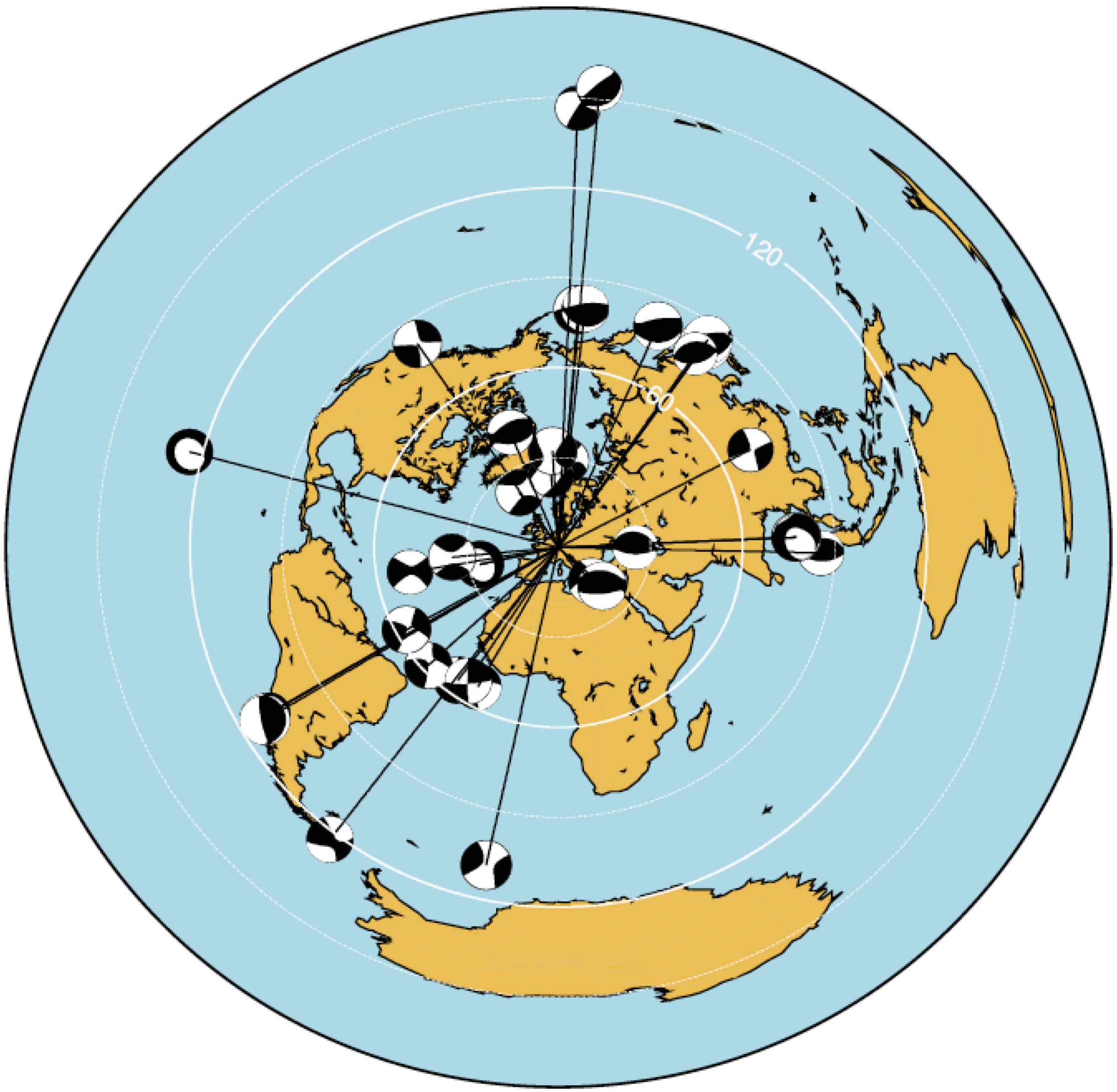
$$t_0 = R1 - \frac{D}{U}$$

combined with body-wave arrivals, can invert for 1D mantle velocity profiles

Panning et al., 2015

36 Earthquakes Used to Simulate Single-Station Analyses

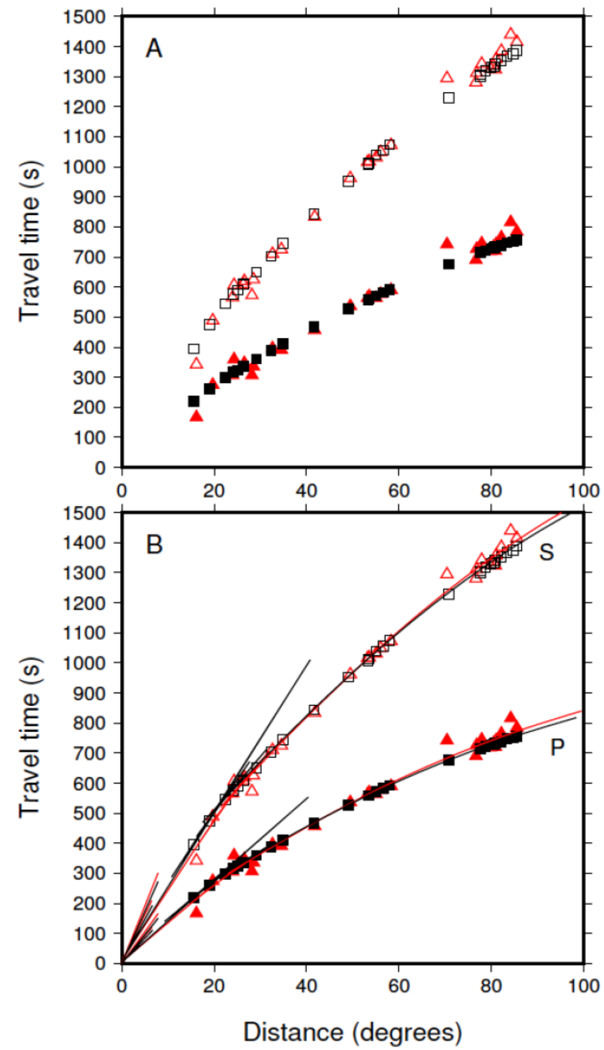
M. Panning et al., Icarus, 2005



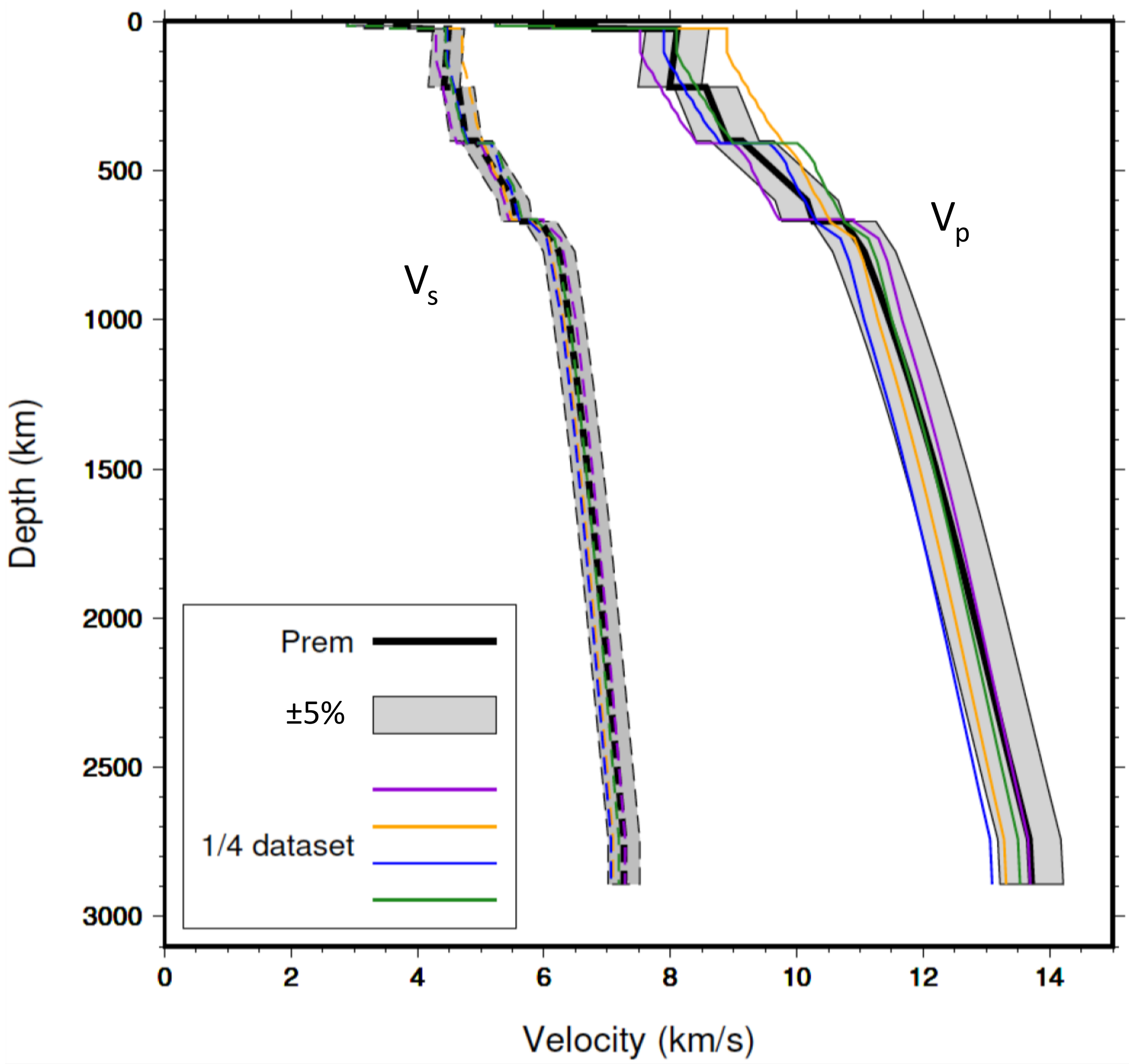
Travel Time Picks

Black – catalog distance

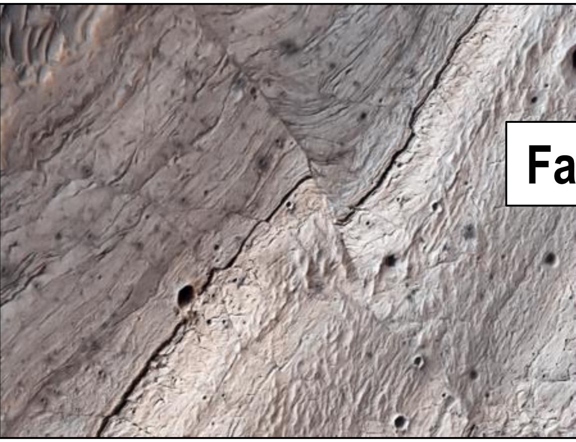
Red – surface wave estimate

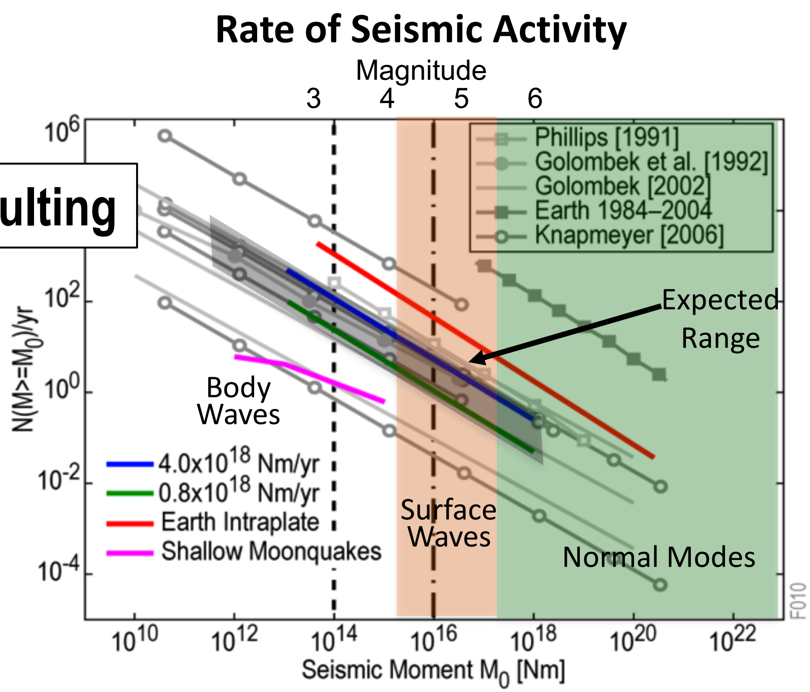


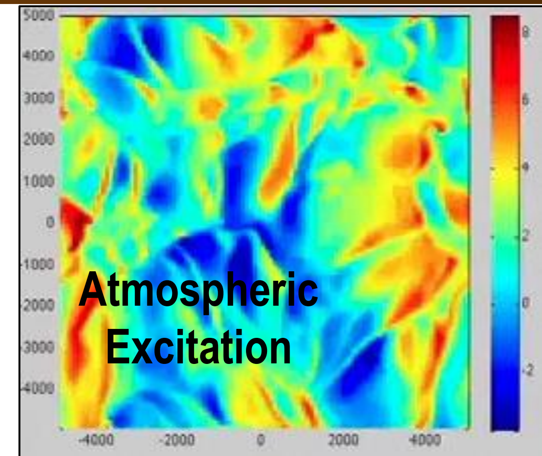
Recovery of Earth Structure Using 7-Event Subsets

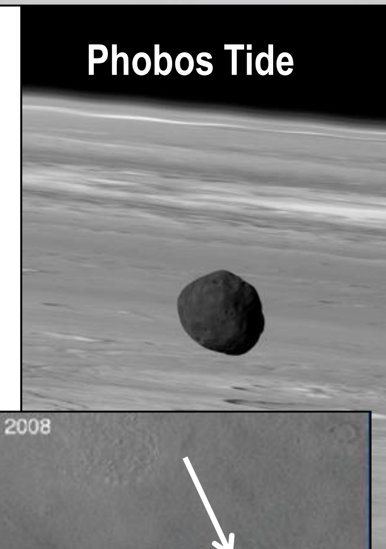


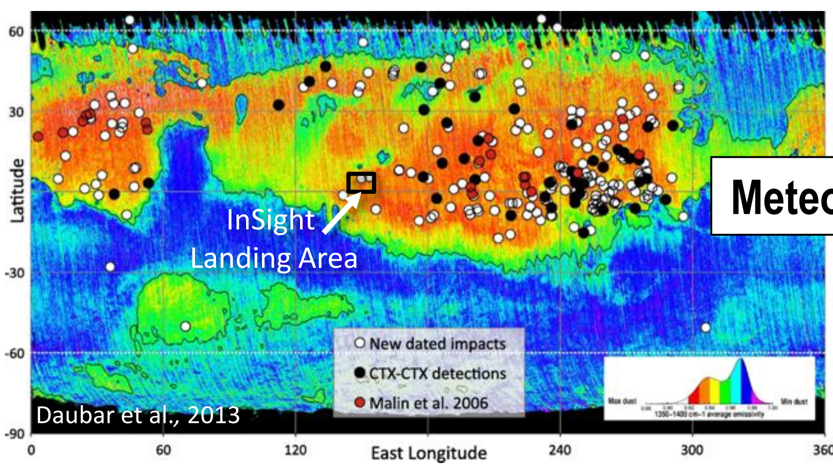
Martian Seismology – Multiple Signal Sources

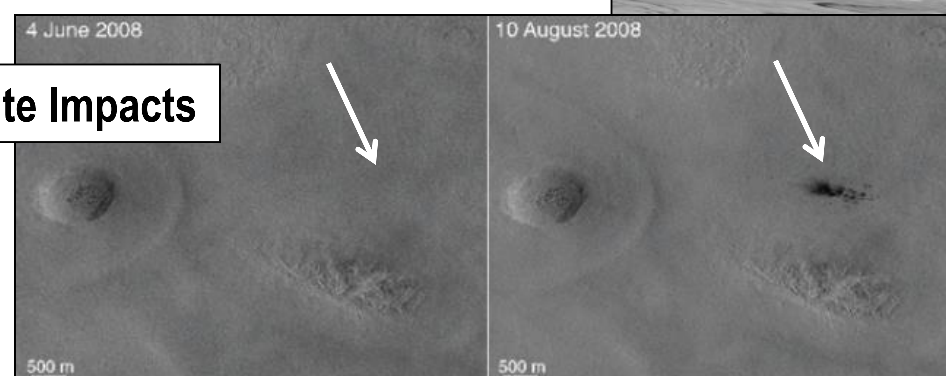








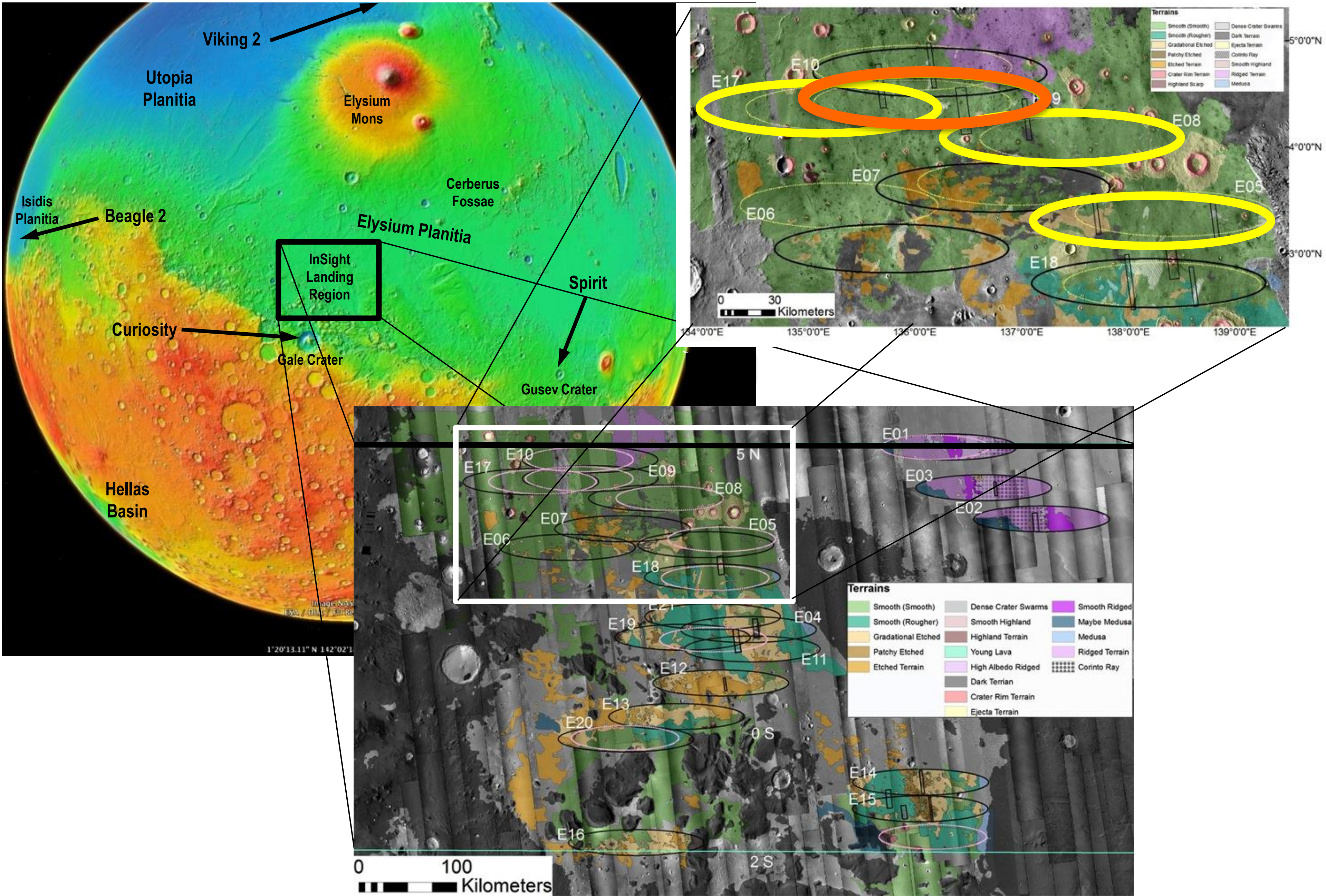




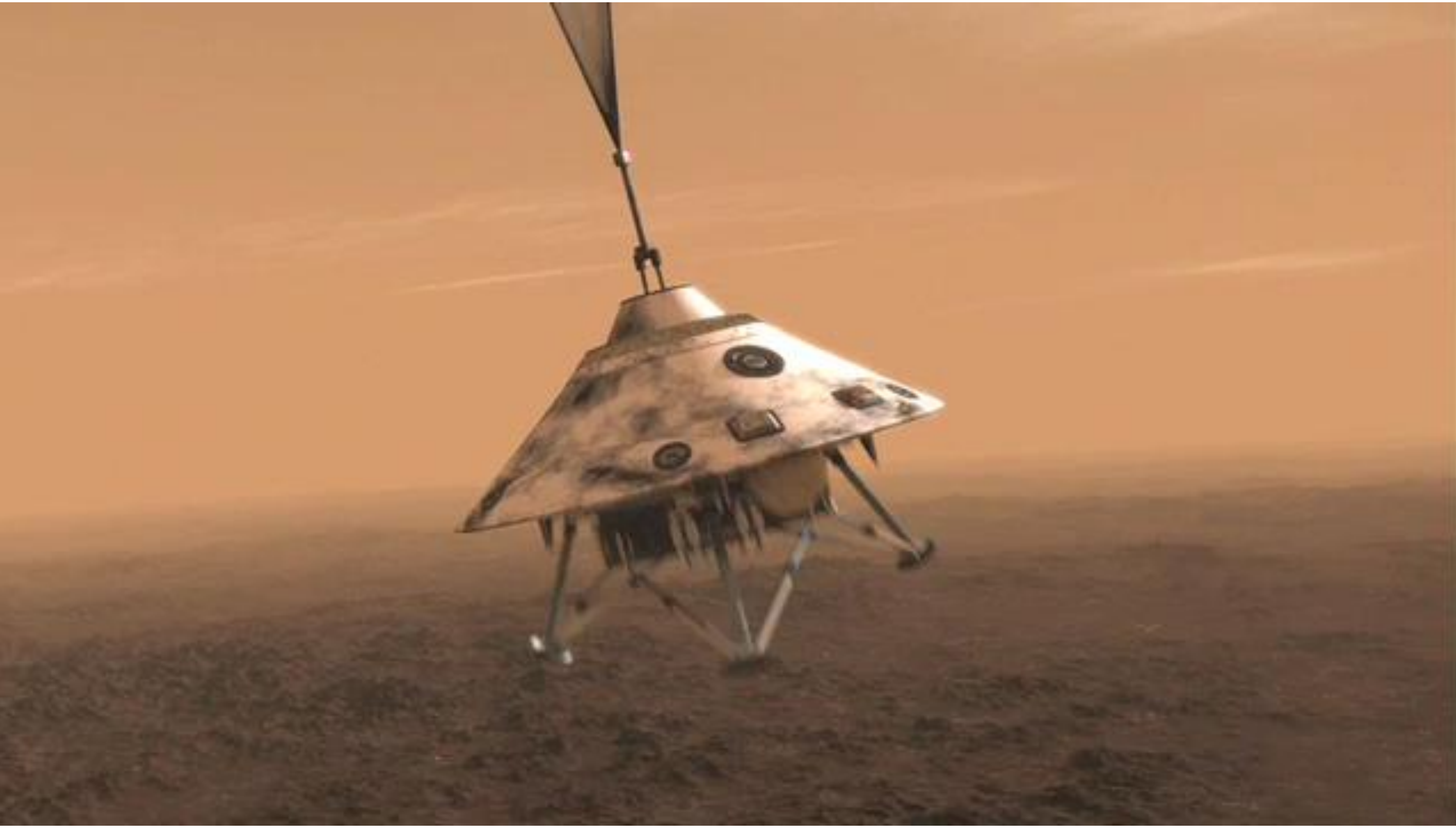
InSight Mission Summary

- InSight will fly a near-copy of the successful Phoenix lander
- Launch: March 4-24, 2016 from Vandenberg AFB, California
- Fast, type-1 trajectory, 6.5-mo. cruise to Mars
- Landing: September 28, 2016
- 67-sol deployment phase
- Two years (one Mars year) science operations on the surface; repetitive operations
- Nominal end-of-mission: October 6, 2018

Landing Site – Western Elysium Planitia



InSight Mission Animation (well, actually Phoenix…)



InSight Payload

Small Deep Space Transponder

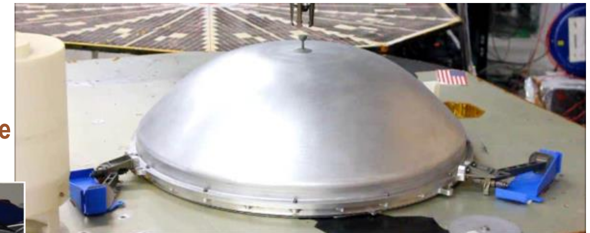
RISE (S/C Telecom)

Rotation and Interior Structure Experiment

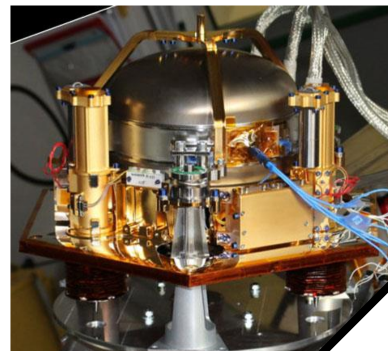
SEIS (CNES) (also IPGP, ETH/SSA, MPS/DLR, IC/Oxford/UKSA, JPL/NASA)

Seismic Experiment for Interior Structure

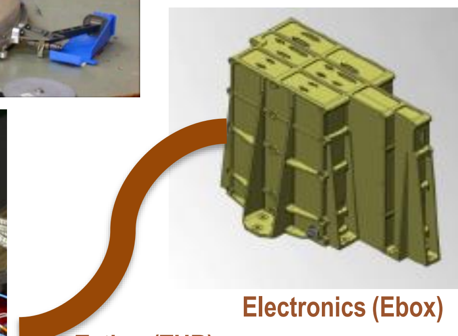
Wind and Thermal Shield (WTS)



Thermal Enclosure (RWEB)



Sensor Head: VBB, SP, LVL



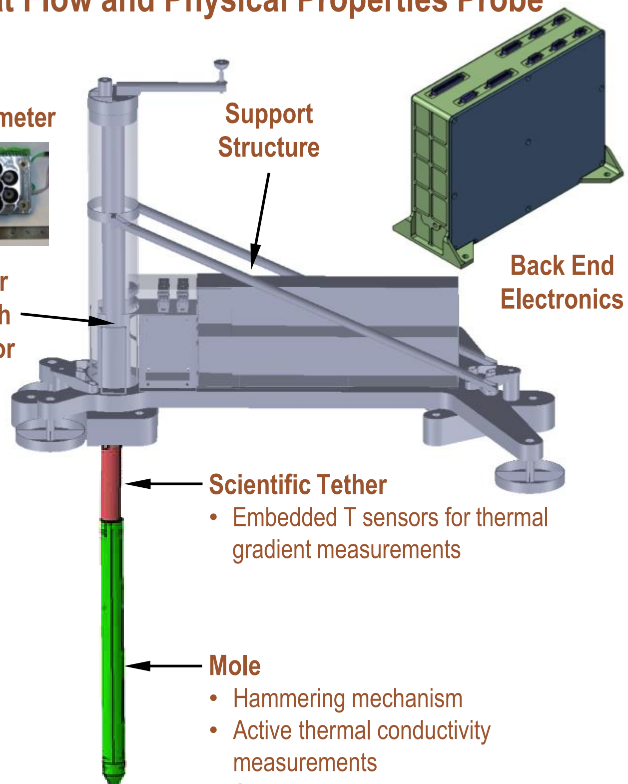
Electronics (Ebox)

Tether (THR)

HP³ (DLR)

Heat Flow and Physical Properties Probe

Radiometer



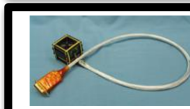
Support Structure

Back End Electronics

Tether Length Monitor

Scientific Tether
- Embedded T sensors for thermal gradient measurements

Mole
- Hammering mechanism
- Active thermal conductivity measurements
- Static Tilt sensors



IFG (UCLA) – InSight FluxGate

Pressure Sensor

TWINS (CAB) – Temp. and Wind for INSight

APSS (JPL)

Auxiliary Payload Sensor Suite

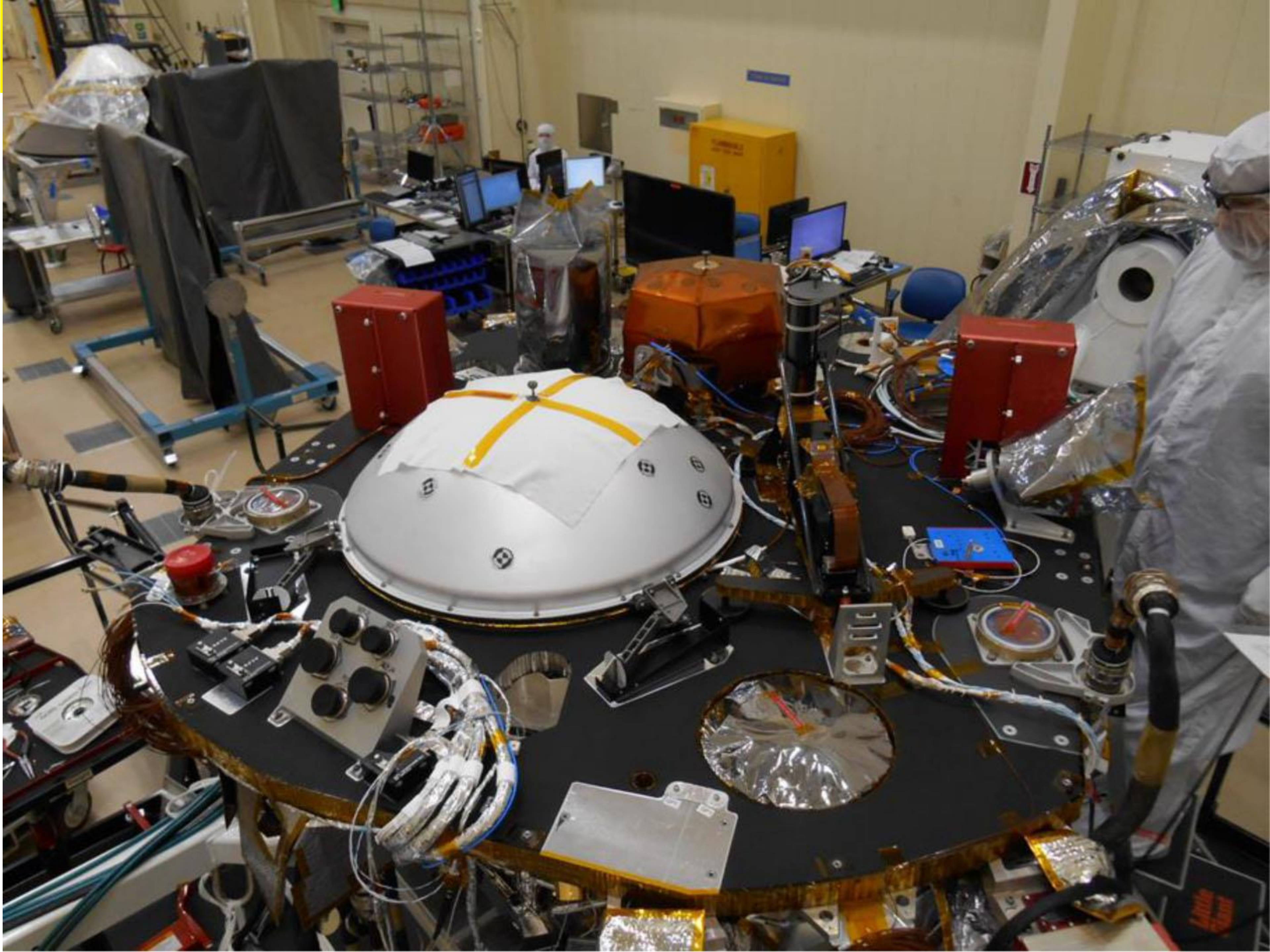
IDS (JPL)

Instrument Deployment System

IDA – Instrument Deployment Arm

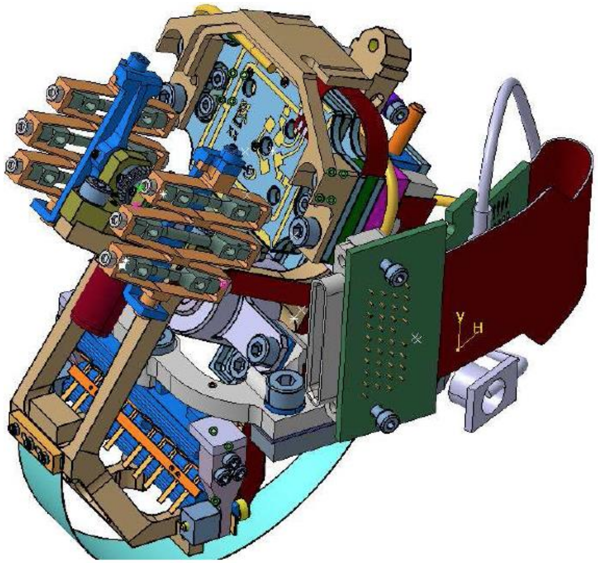
IDC – Instrument Deployment Camera

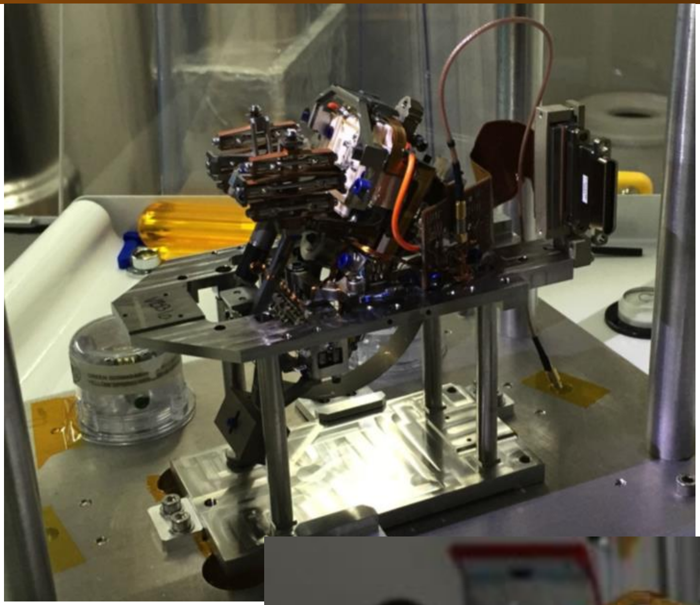
ICC – Instrument Context Camera

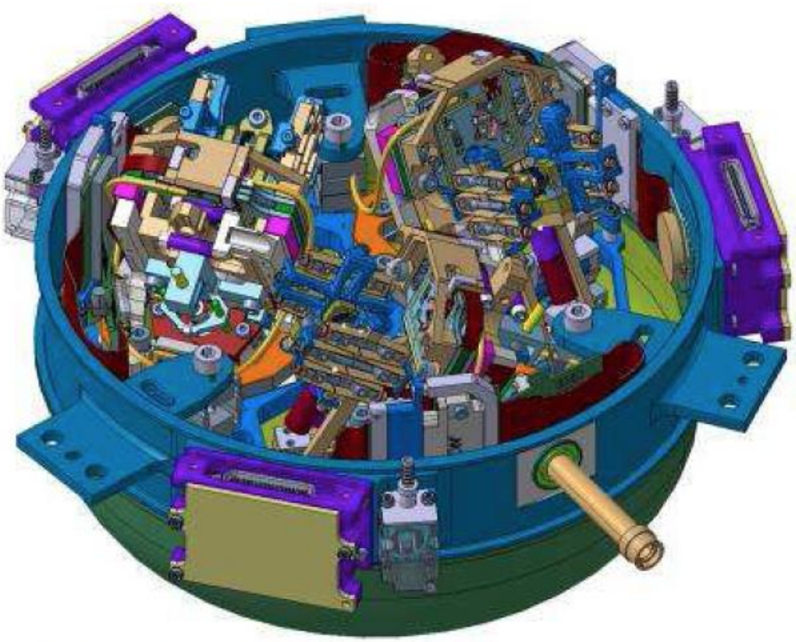


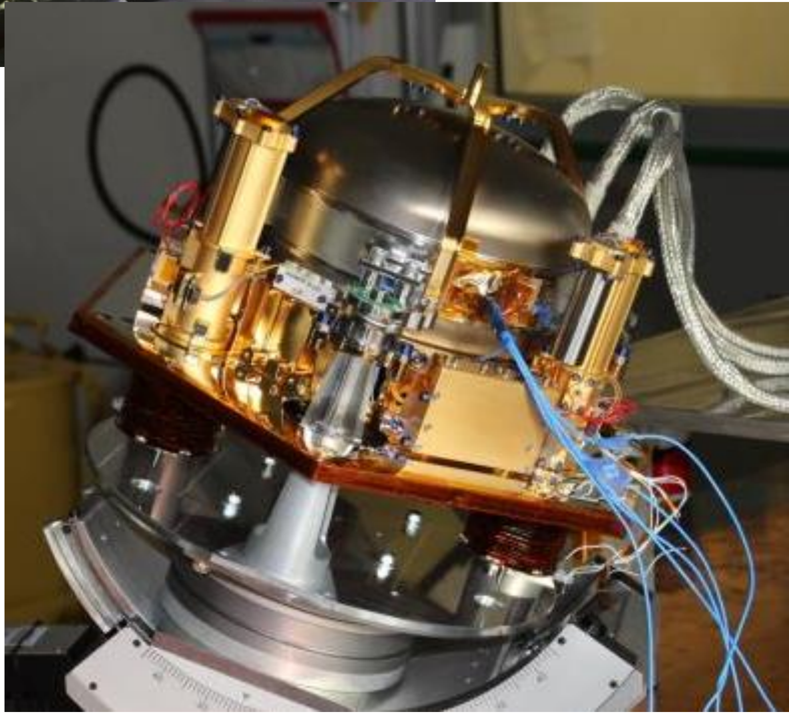
InSight

SEIS: A Little More Complicated Than a Mass on a Spring…









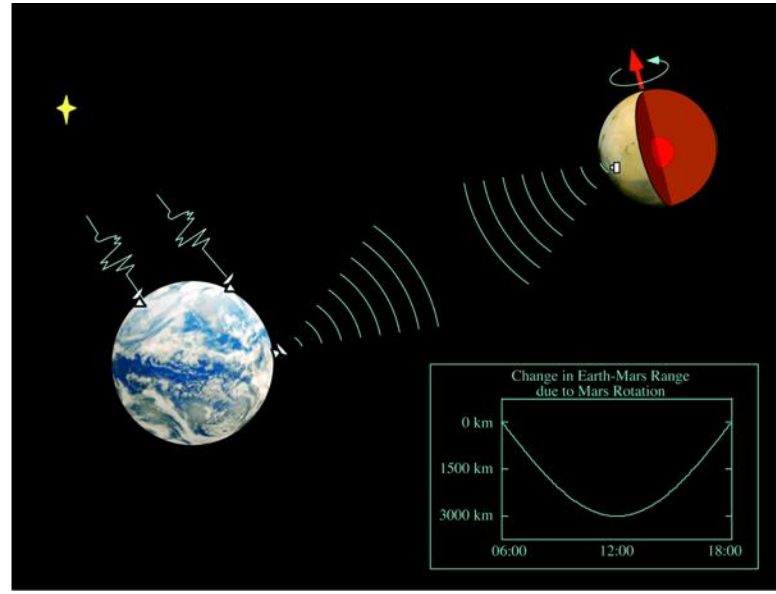
APSS – Auxiliary Payload Sensor Subsystem

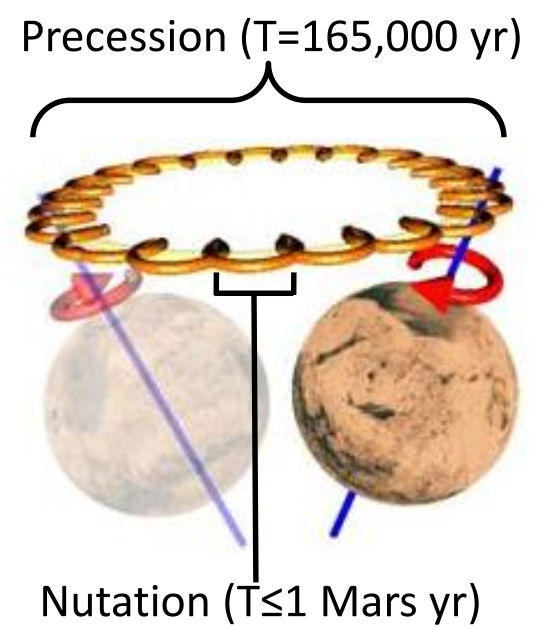
- **Environmental monitoring**
  - A seismometer measures almost everything in its vicinity better than it measures seismic waves.
  - InSight will carry a sensor package to characterize the atmospheric and electromagnetic noise environment for SEIS
    - **Pressure** – 10 mPa barometer, DC-10 Hz
    - **TWINS** (Temperature and Wind for INSight) – Wind speed and direction, air temperature, twice per second
    - **Radiometer** – Ground temperature from IR emission
    - **IFG** (Insight FluxGate) – Magnetic field to 0.1 nT, DC-10 Hz
- **These can all be use for other science!**

“Stealth” instruments

Precision Radio Tracking – RISE

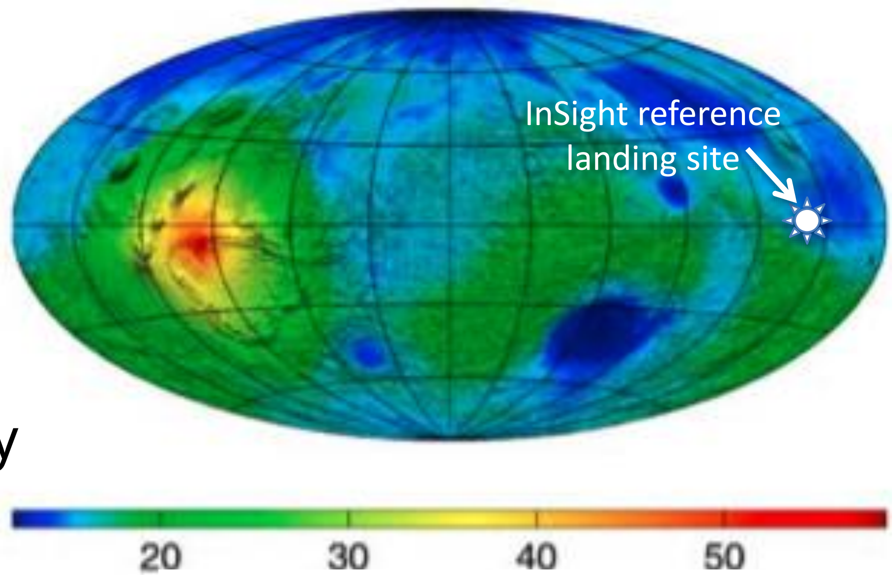
- First measured constraint on Mars core size came from combining radio Doppler measurements from Viking and Mars Pathfinder, which determined spin axis directions 20 years apart
  - Difference of spin axis direction gives precession rate and hence planet's moment of inertia
  - Constrains mean mantle density, core radius and density, although only 2 parameters are independent.
- InSight will provide another snapshot of the axis 20 years later still, providing stronger constraints on precession.
- In addition, nutation amplitudes can be determined after 2 years of tracking with sub-decimeter precision
  - Free core nutation constrains core MOI directly, allowing separation of radius and density.





Heat Flow Measurement – HP³

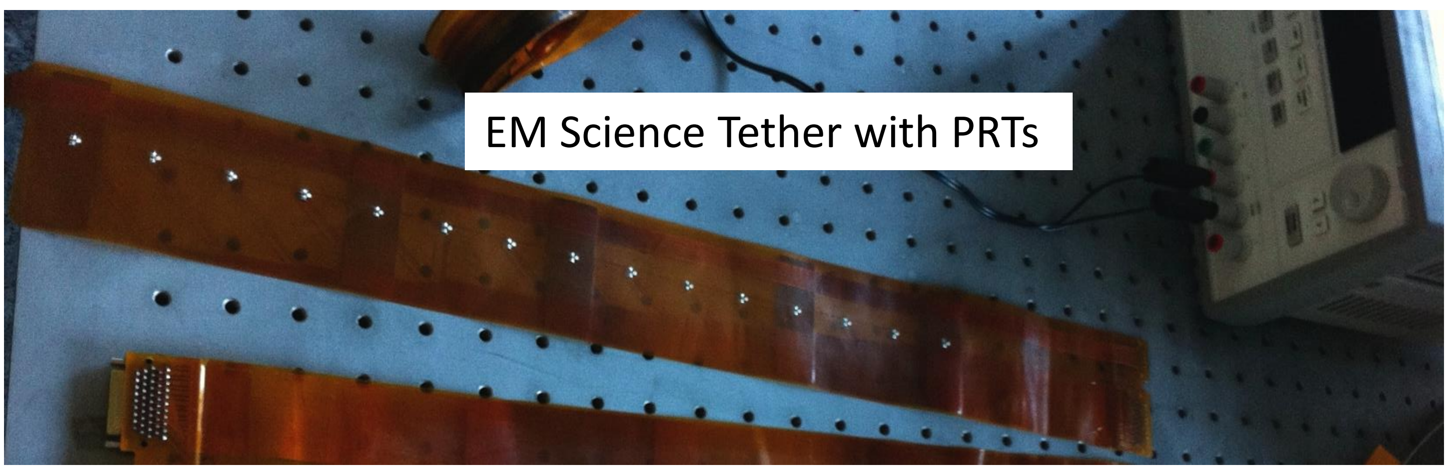
- HP³ (Heat Flow and Physical Properties Probe) has a self-penetrating “mole” that burrows down 3 to 5 meters below the surface.
  - It trails a tether containing precise temperature sensors every 35 cm to measure the temperature gradient of the subsurface.
  - It also contains a heater to supply a heat pulse for an active determination of thermal conductivity every 50 cm.
- Together, gradient and conductivity yield the rate of heat flowing from the interior.
- Present-day heat flow at a given location provides a critical boundary condition on models of planetary thermal history.



Surface Heat Flow Model (mW/m²)
Grott and Breuer, 2010.

Self-Hammering Mole, Thermal Sensors in 5-m Tether

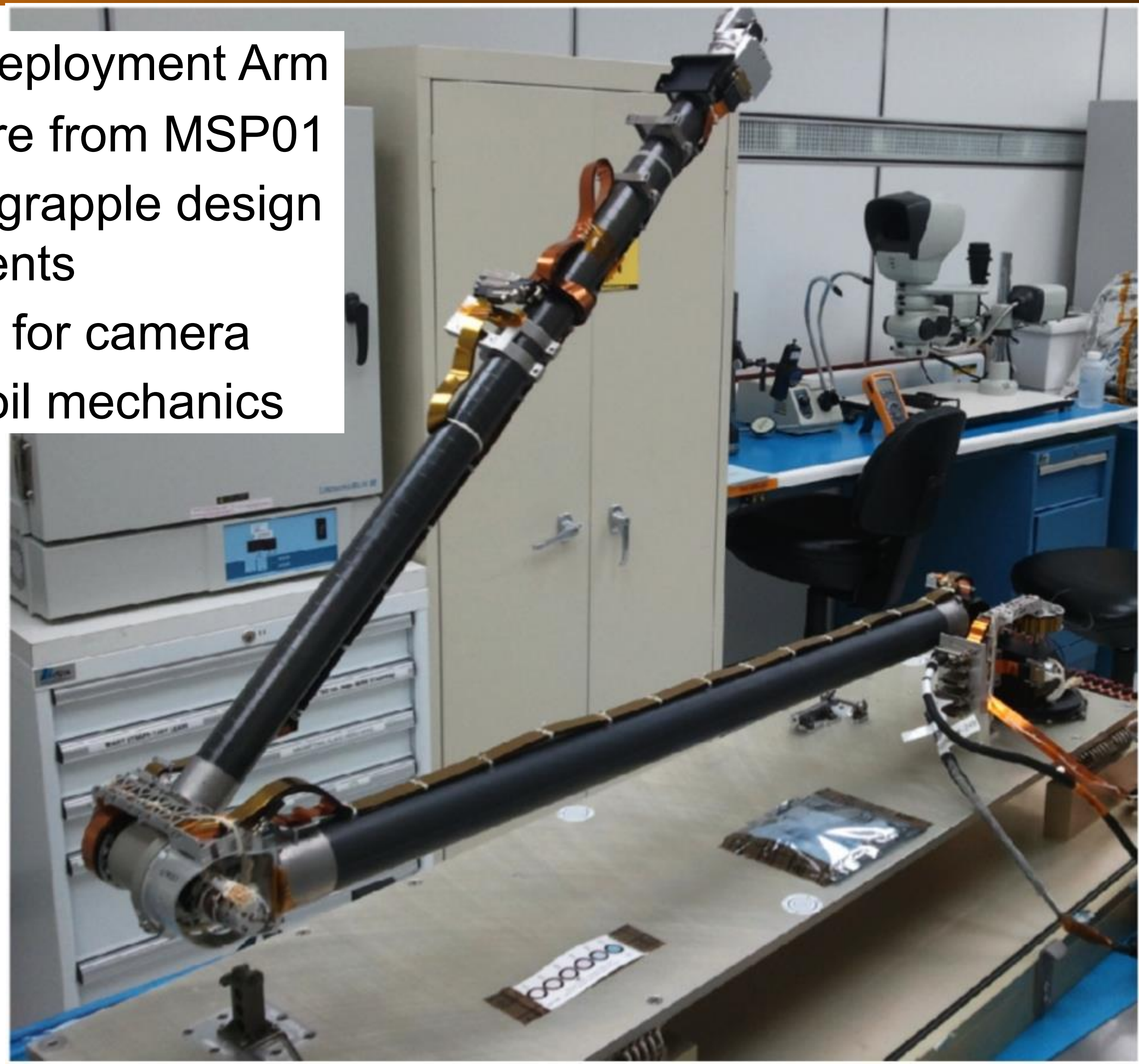
TEM-A: foils within Mole outer hull)



Mole Movie

Instrument Deployment System – Robotic Arm

- IDA – Instrument Deployment Arm
  - Left-over hardware from MSP01
  - New mechanical grapple design for lifting instruments
  - Provides pointing for camera
  - Can be use for soil mechanics investigations

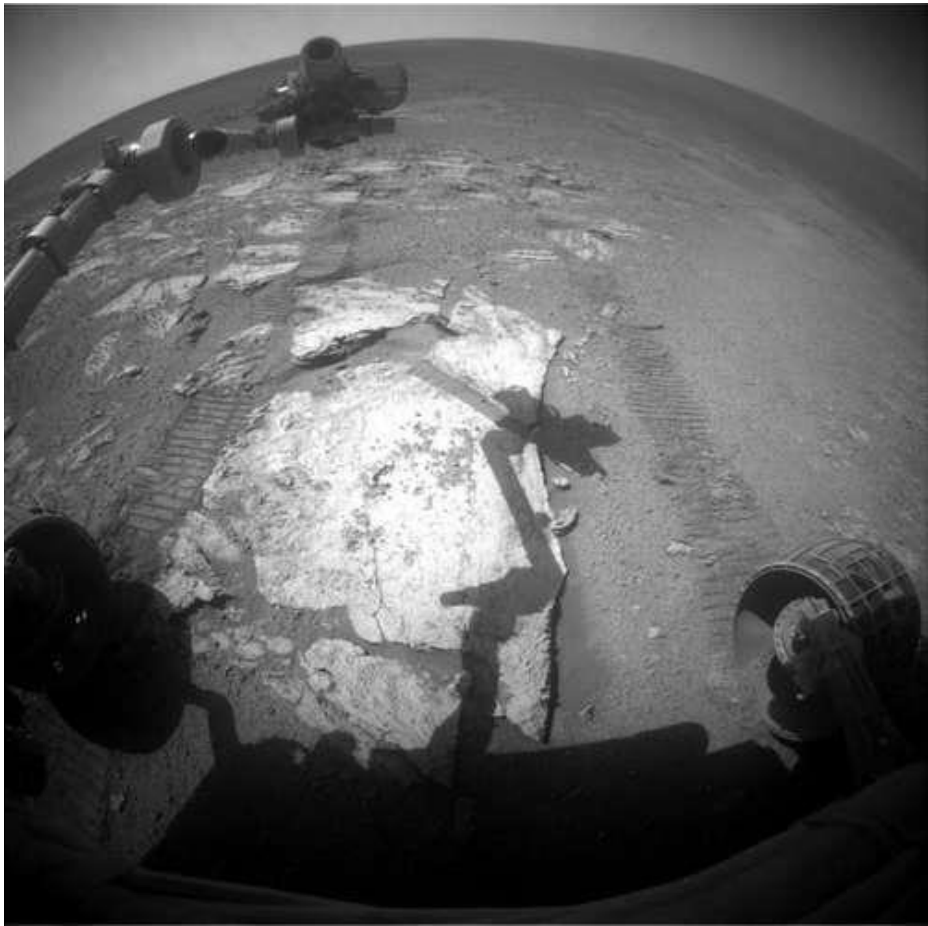


Instrument Deployment System – Cameras

- IDC – Instrument Deployment Camera
  - Left-over hardware from MSL
  - Moderate resolution
  - Same as MSL/MER Navcam, except…
  - Color!

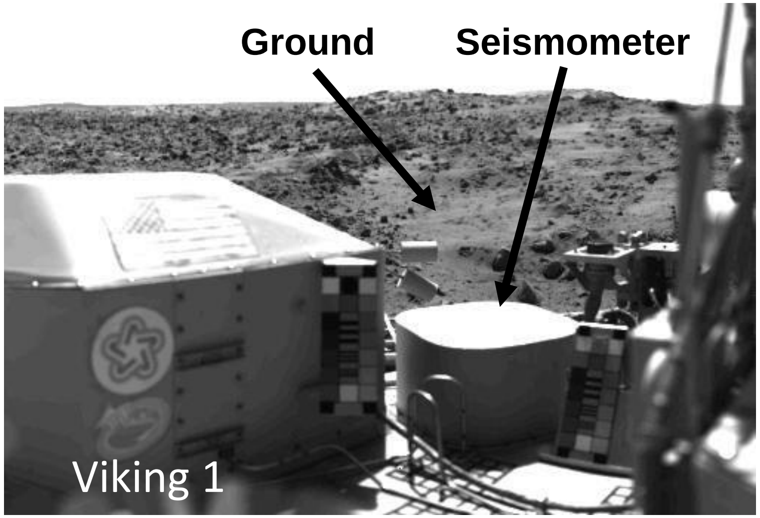
ICC – Instrument Context Camera

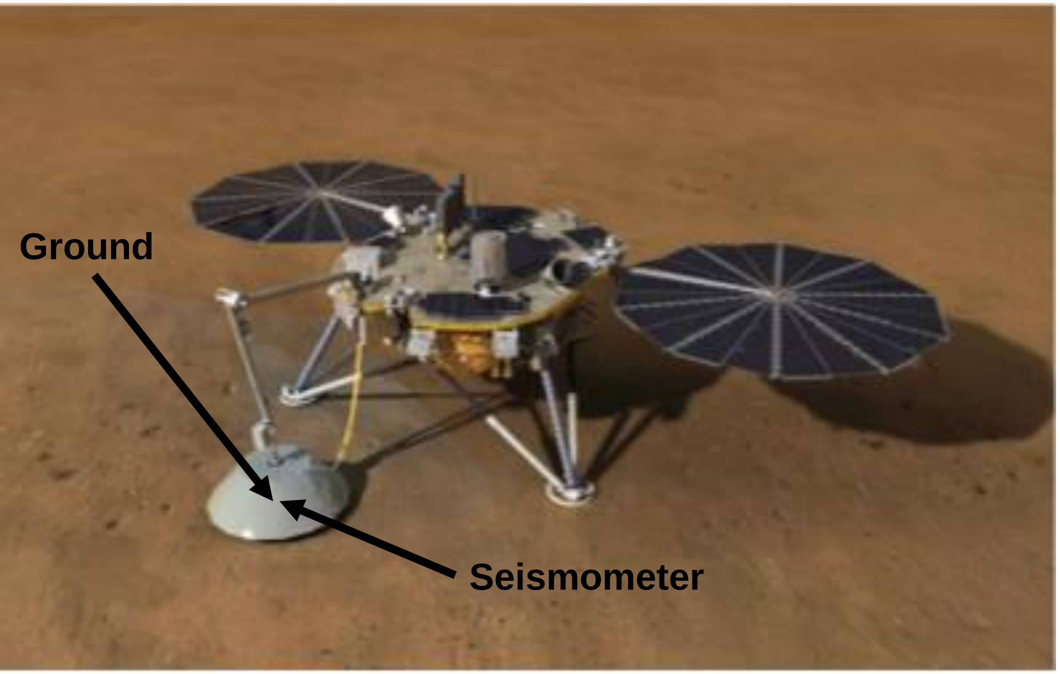
- Left-over hardware from MSL
- Same as MSL/MER Hazcam
- Fixed to lander, fisheye FOV covers entire workspace (again, in color)



Surface Deployment is Key to InSight Measurements

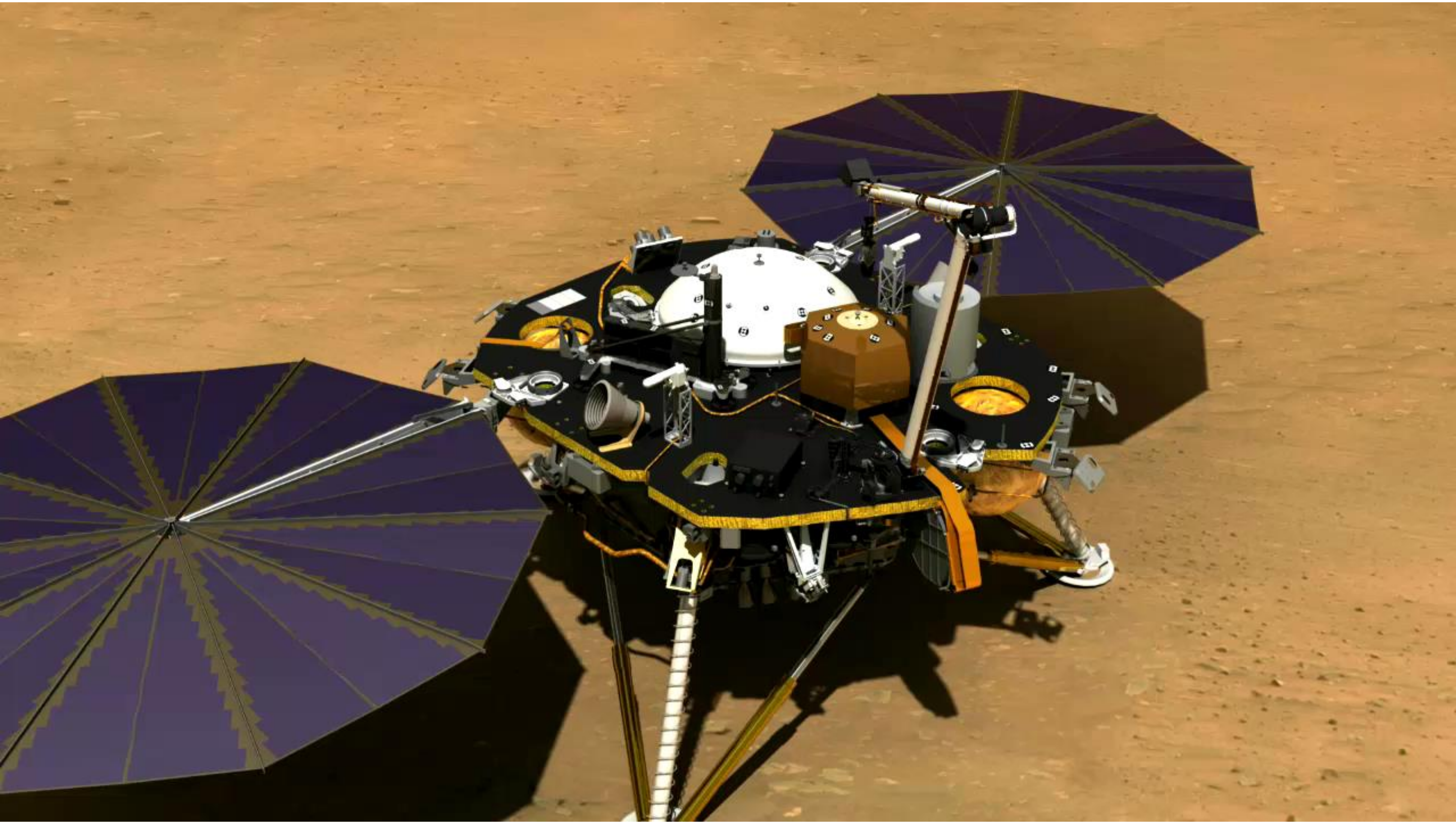
- The quality of a seismic station is directly related to the quality of its installation.
  - Installation couples the instrument to the ground and isolates it from the rest of the environment.
- But after landing, the instruments are still ~1 m from the ground…





- InSight takes advantage of the payload mass capability of the Phoenix lander to fly an unprecedented deployment system.
- It will place the seismometer on the surface and cover it with an effective wind and thermal shield
- This will allow the seismometer sensitivity to reach the micro-seismic noise level of the planet

Seismometer and HP^3 Deployment



Spirit Pancam image from Gusev Crater