The InSight Mission
Exploring the Interior of Mars

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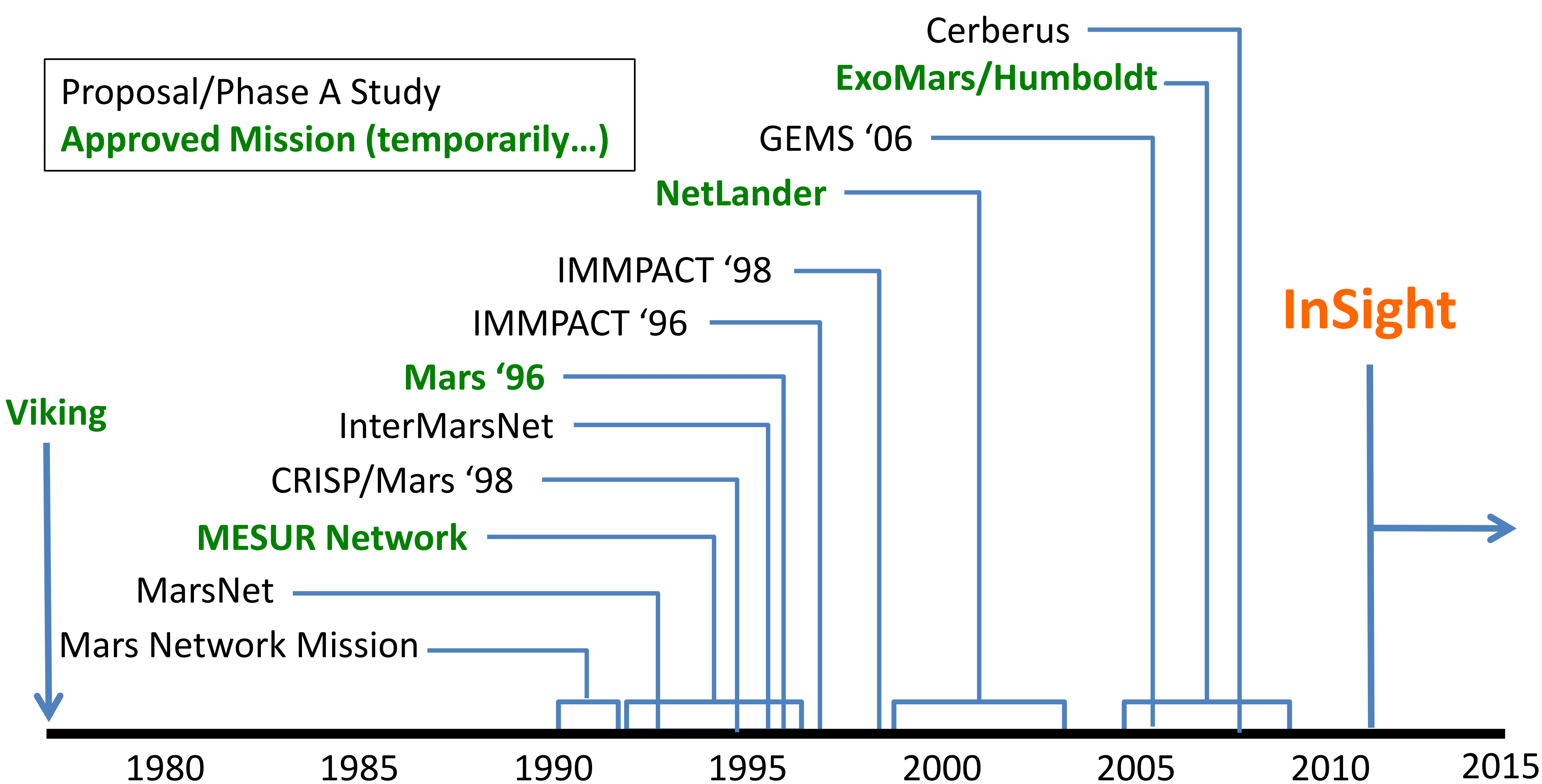
Early Planetary Seismology

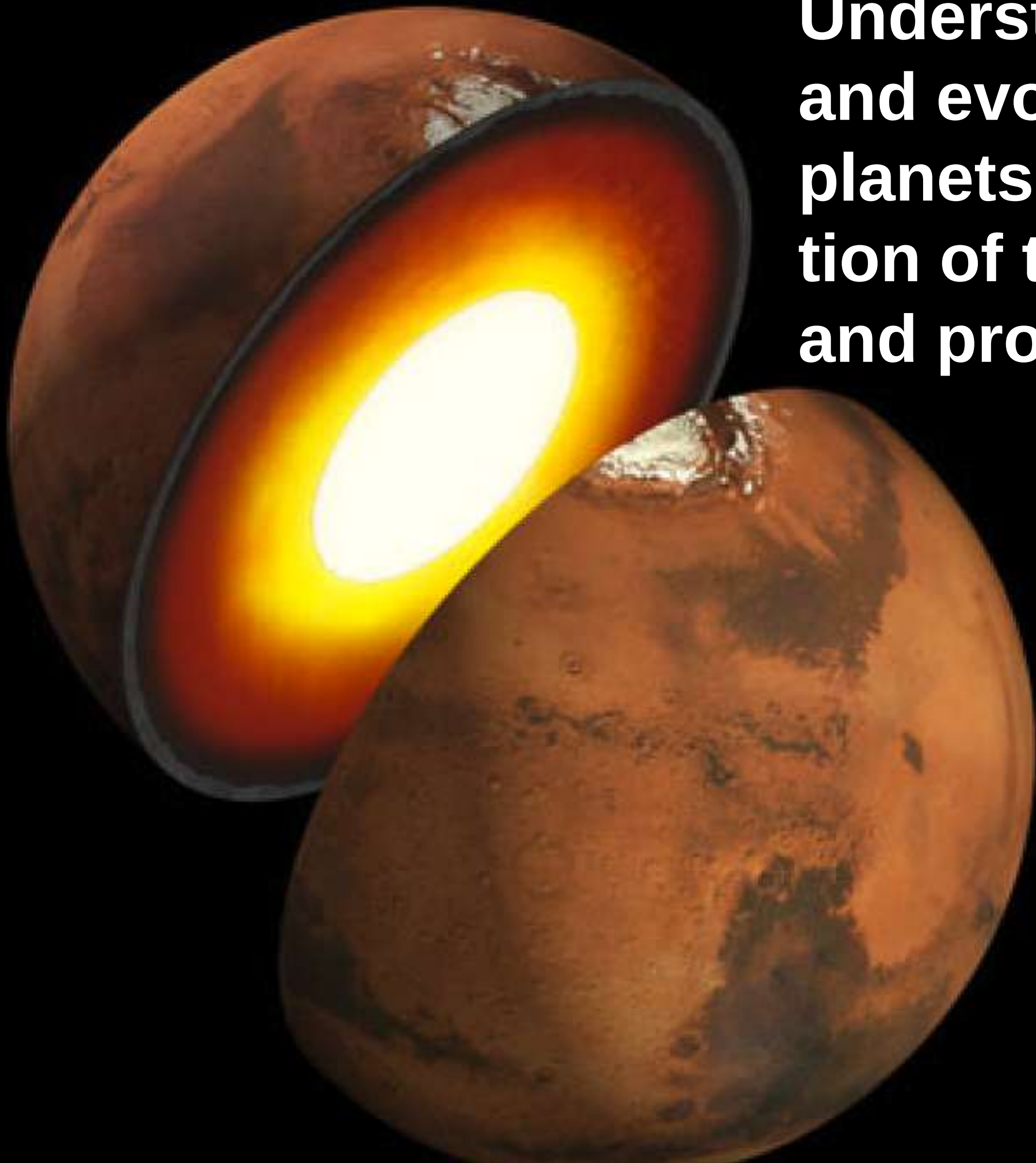
- At the dawn of the age of planetary exploration, seismology was considered a key technique for understanding a planet and its interior.
  - The first instruments sent to the surface of another planet were seismometers.
    - Rangers 3–5; 1962
  - The two highest scientific priorities of the Apollo program were sample return and seismology.
    - Apollos 11, 12, 14, 15, 16; 1969–1977
  - The first landers sent to Mars carried seismometers.
    - Vikings 1, 2; 1975–1977

Mars Seismology, 1977 – Present

- Over the 35 years since Viking and Apollo, despite many proposals and several mission starts, there have been no further seismic investigations of the interior of any planet… until now!



InSight Science Goal:

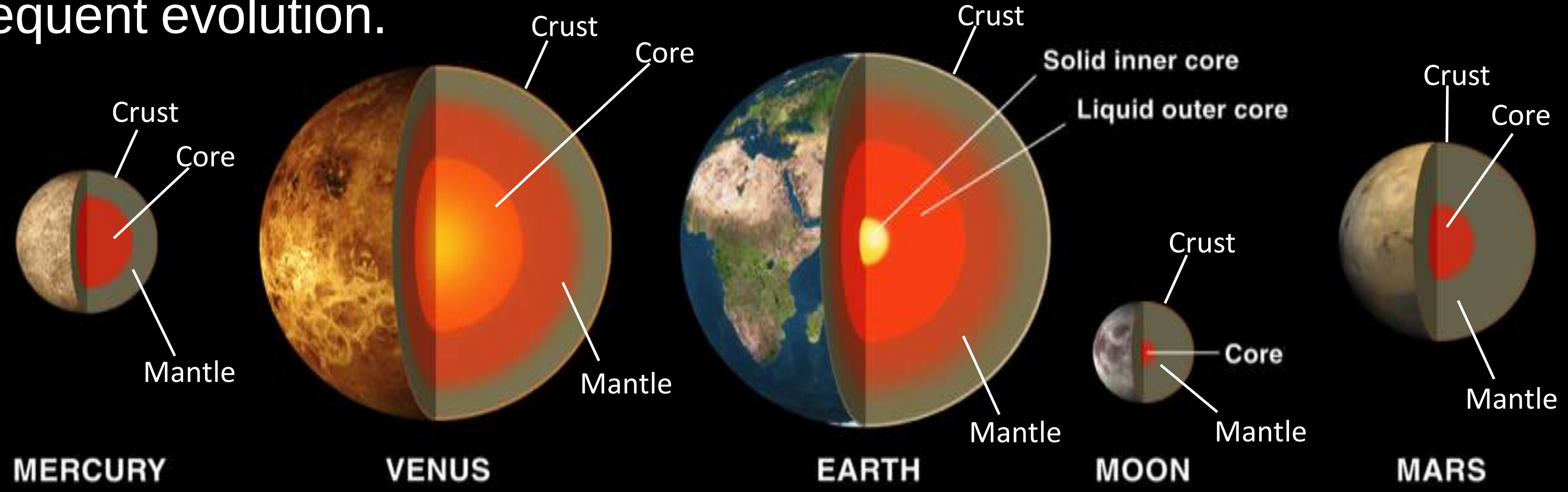


Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars.

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

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.

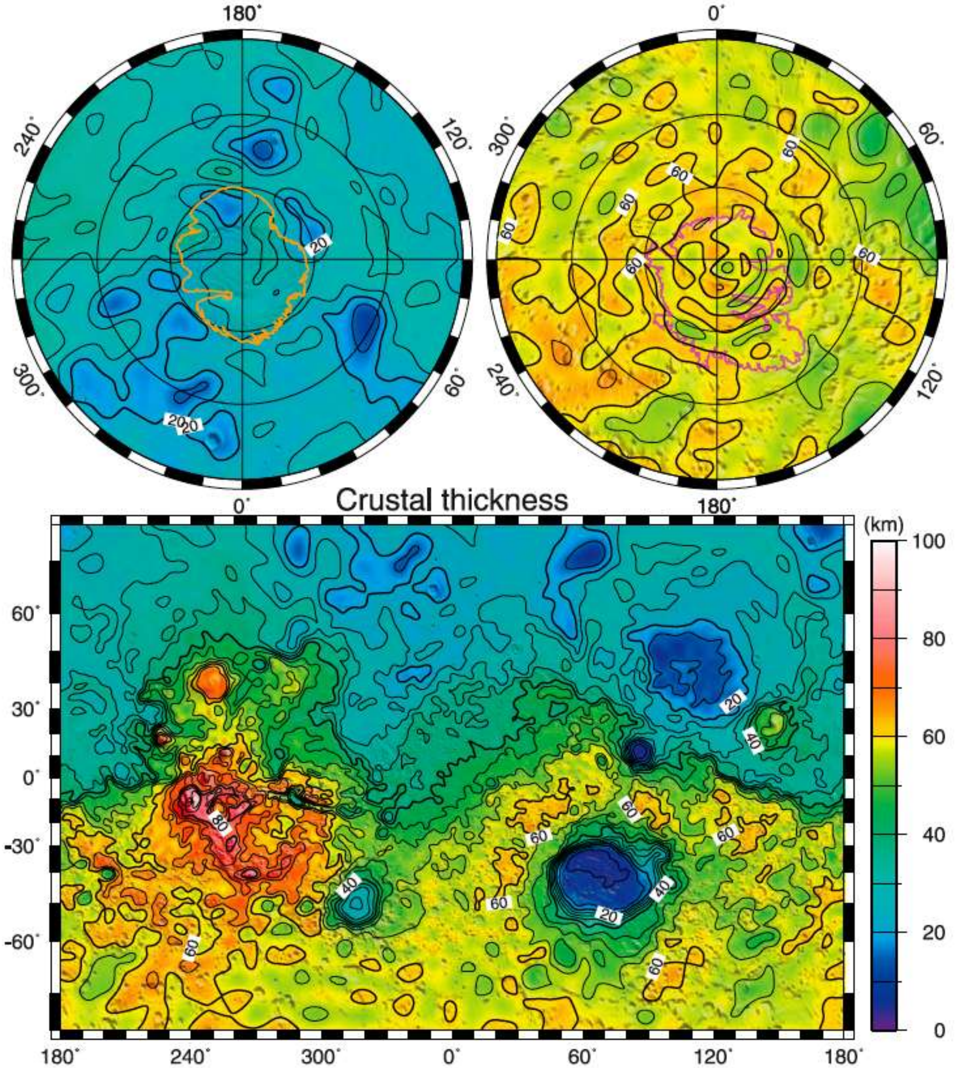


Mars is uniquely well-suited to study the common processes that shape all rocky planets and govern their basic habitability.

- 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.

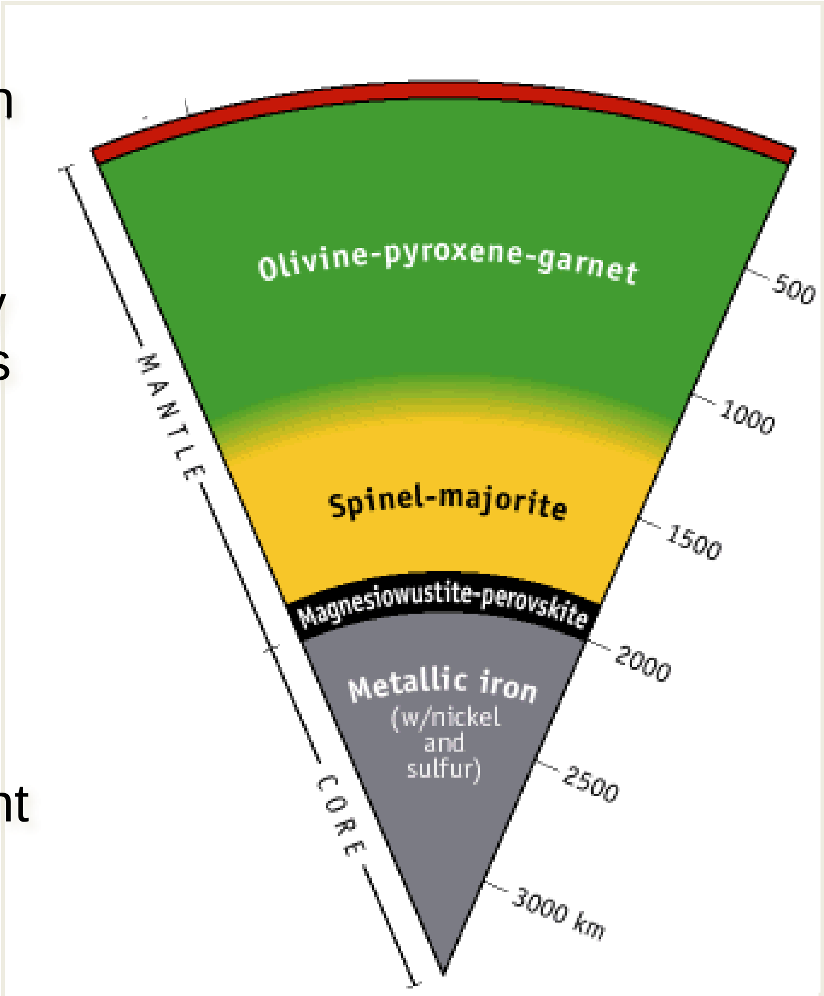
Crust Questions

- 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.



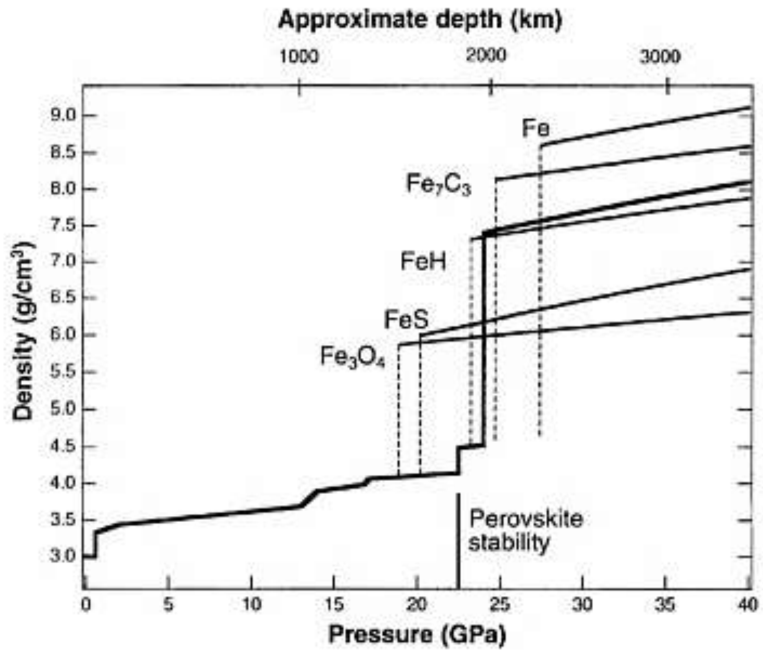
Mantle Questions

- What is the actual 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, but what are the lighter alloying elements?
- At least the outer part appears to be liquid; is there a solid inner core?
- How do these parameters relate to 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 Mars' origin and history.

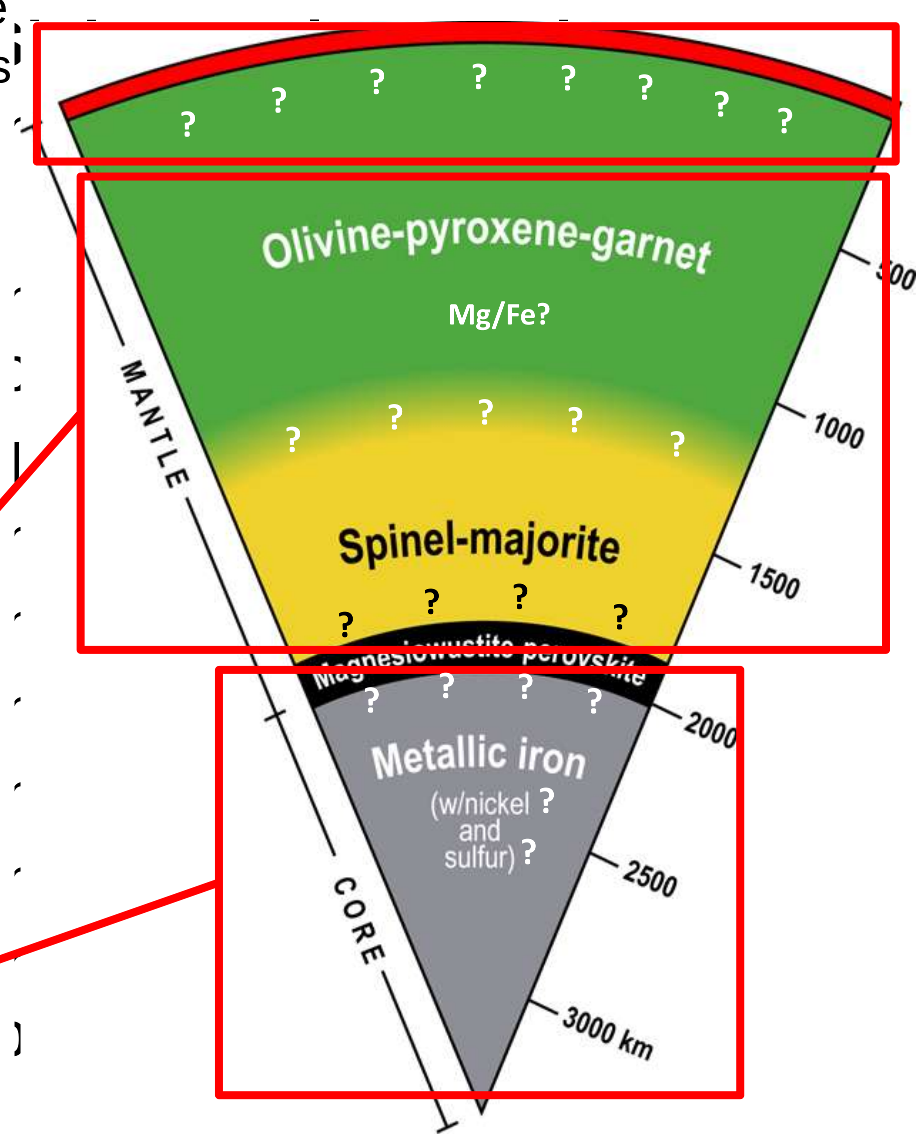


Basic Structure Provides Key Information about Formation and Evolution
Direct Linkage Between Science Objectives and L1 Requirements

- **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.



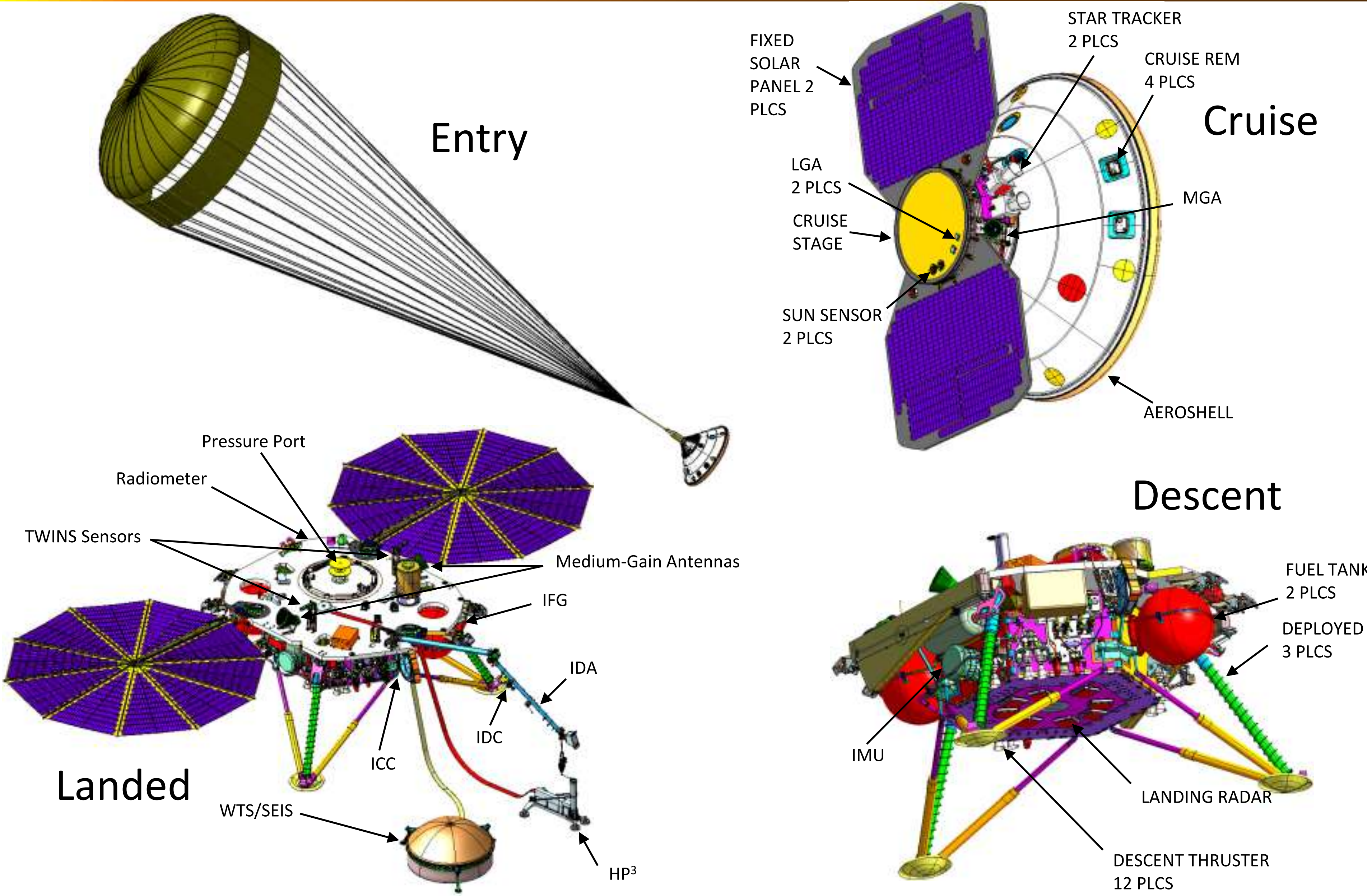
What Do We Know About the Interior of Mars?

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

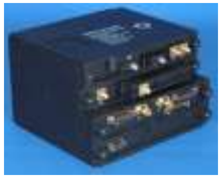
InSight Mission Summary

- 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

InSight Spacecraft Configurations



InSight Payload



Small Deep Space Transponder

RISE (S/C Telecom)

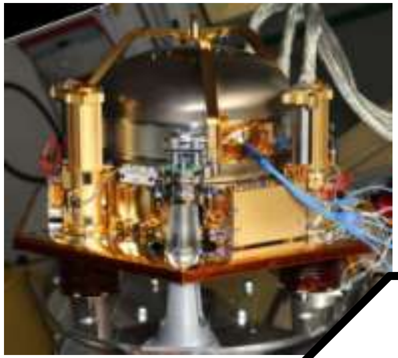
Rotation and Interior Structure Experiment

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

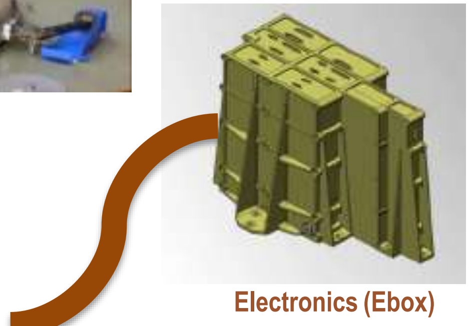
Seismic Experiment for Interior Structure

Wind and Thermal Shield (WTS)

Thermal Enclosure (RWEB)



Sensor Head: VBB, SP, LVL

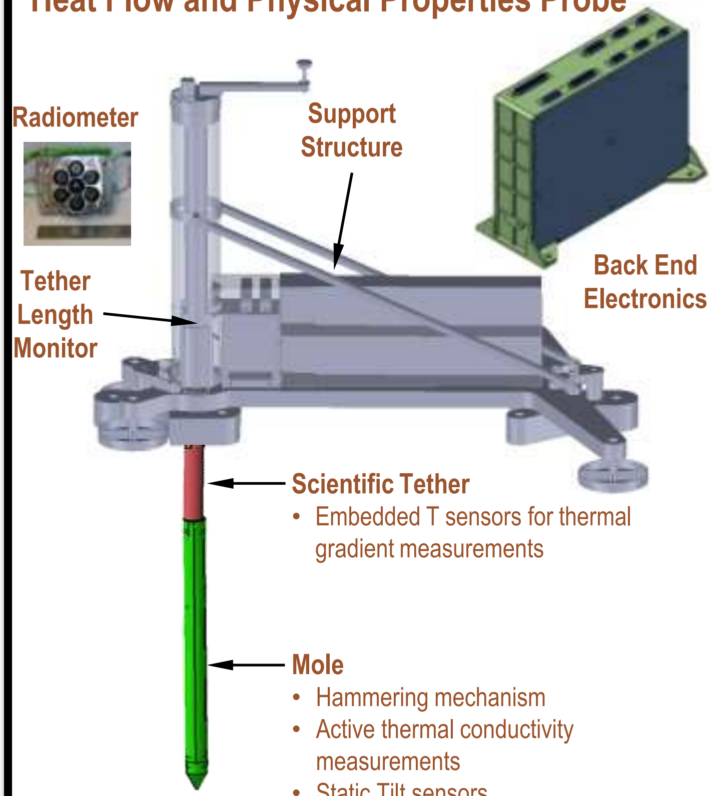


Electronics (Ebox)

Tether (THR)

HP^3 (DLR)

Heat Flow and Physical Properties Probe



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)

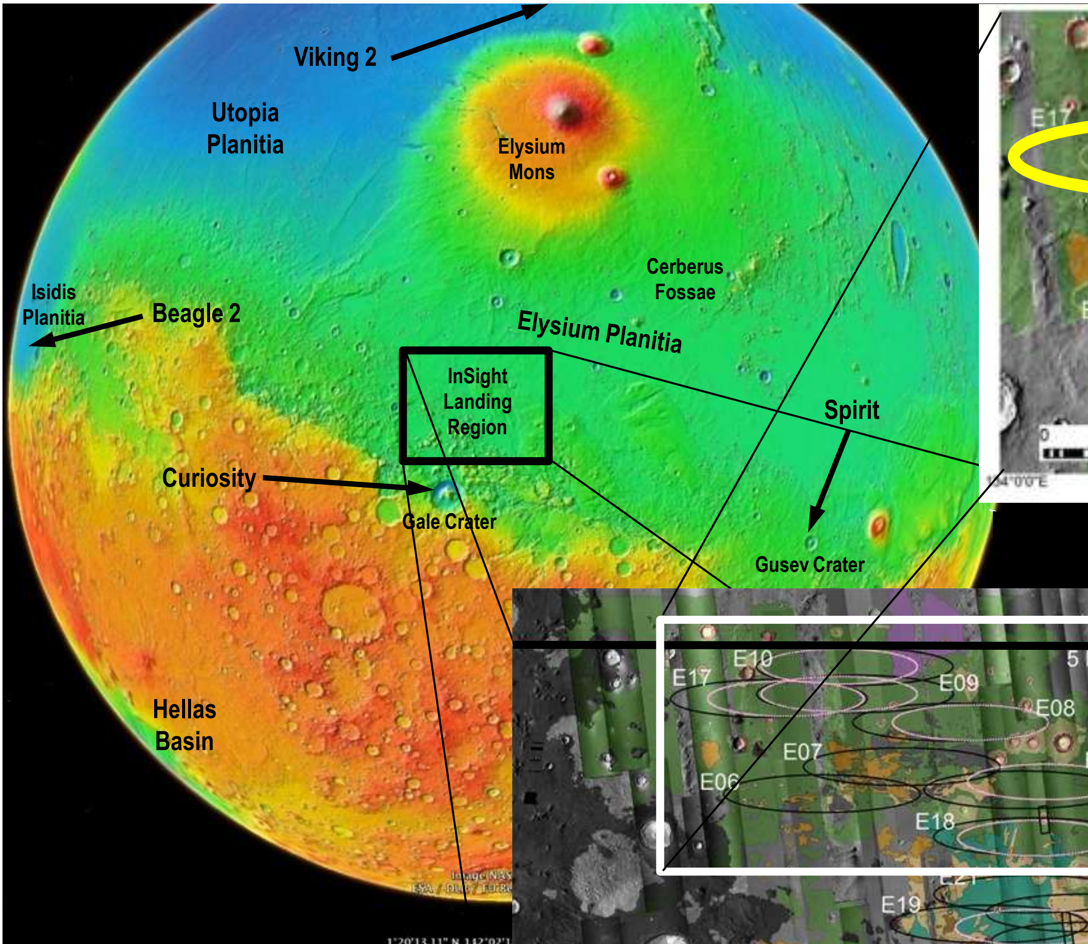
Instrument Deployment System

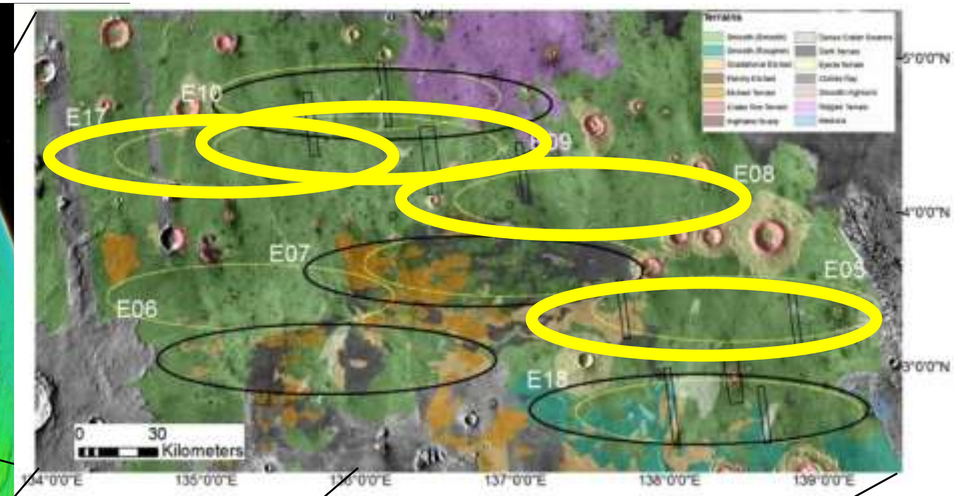
IDA – Instrument Deployment Arm

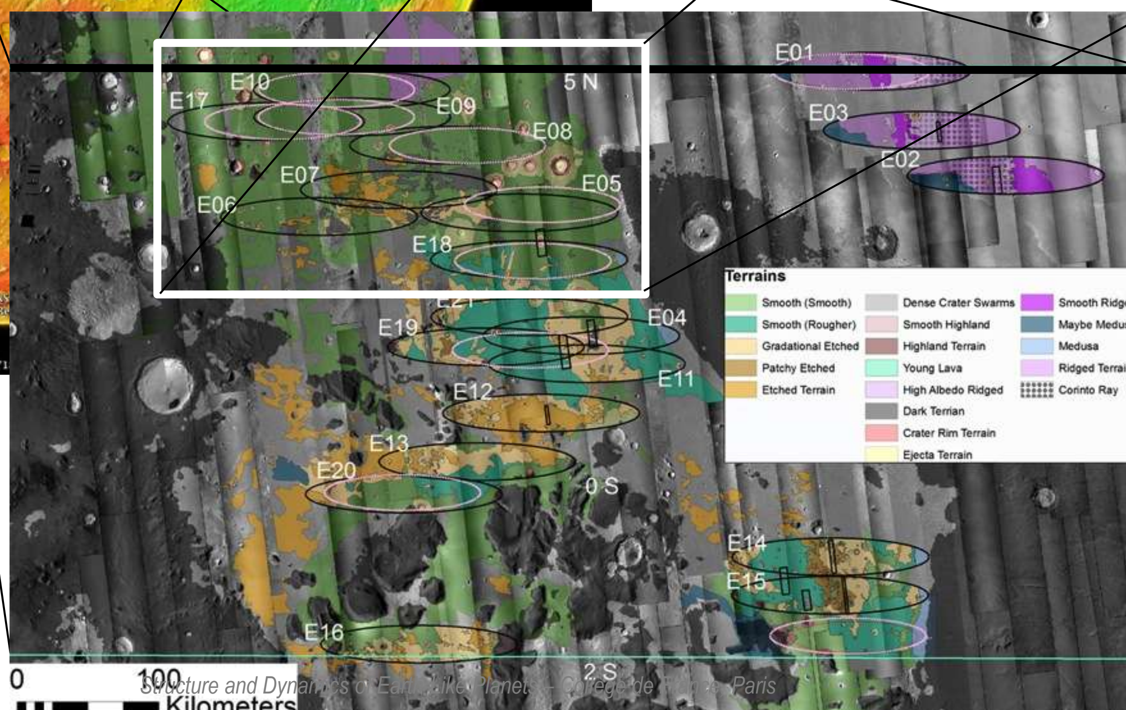
IDC – Instrument Deployment Camera

ICC – Instrument Context Camera

Landing Site Selection Status

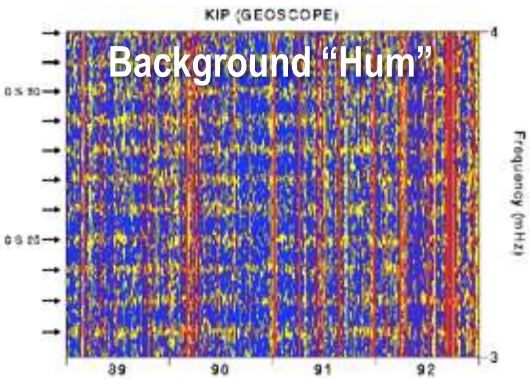


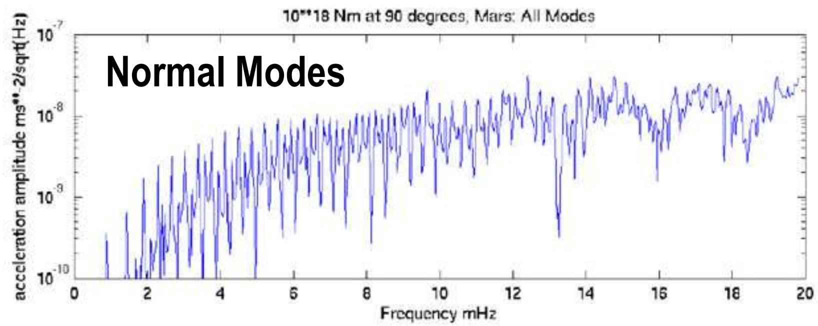


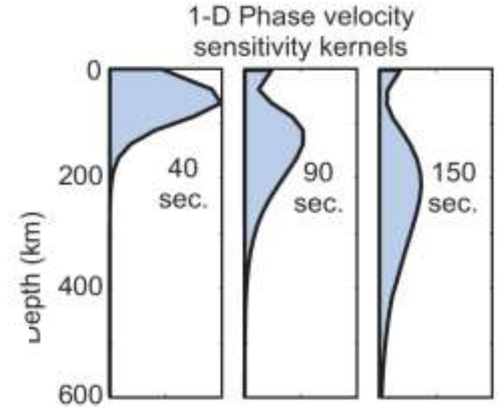


Ellipse	Lon.	Lat.
E05	138.2	3.3
E08	137.3	4.1
E09	136.0	4.4
E17	135.1	4.3

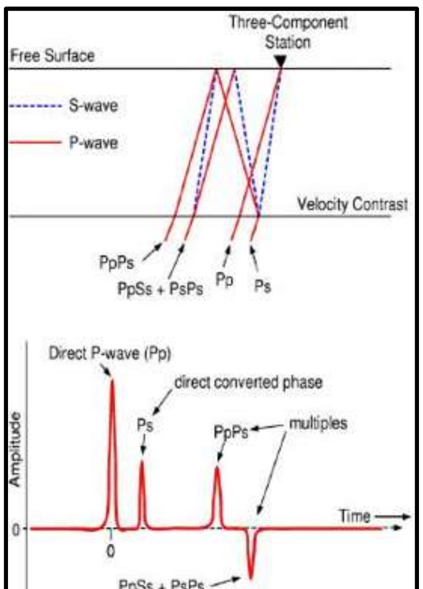
Martian Seismology – Single-Station Analysis Techniques



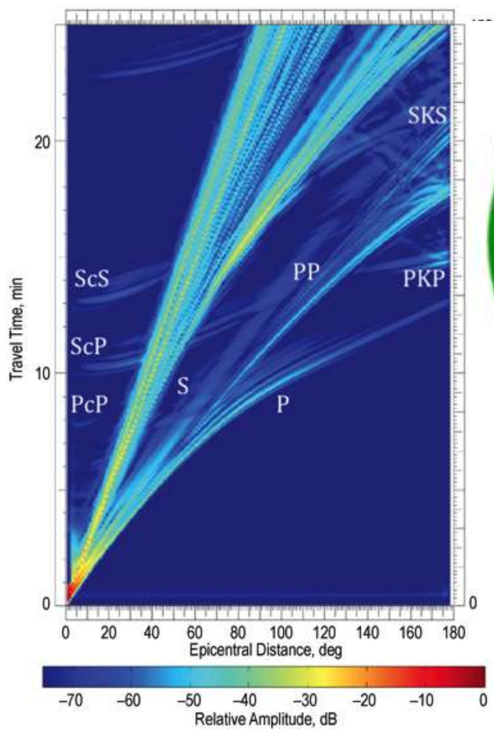


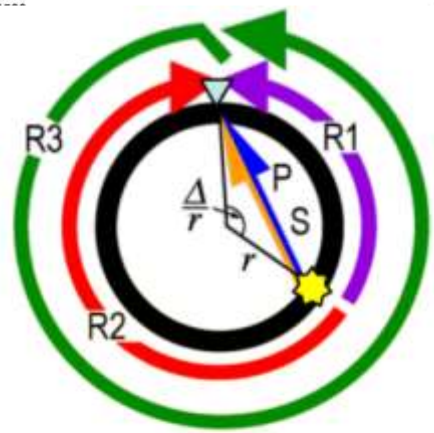


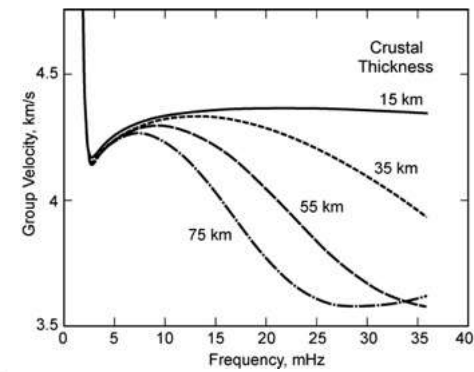
Surface Wave Dispersion



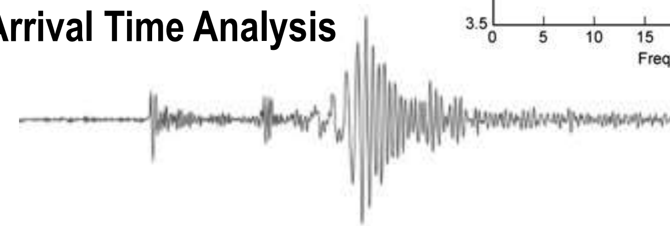
Receiver Function





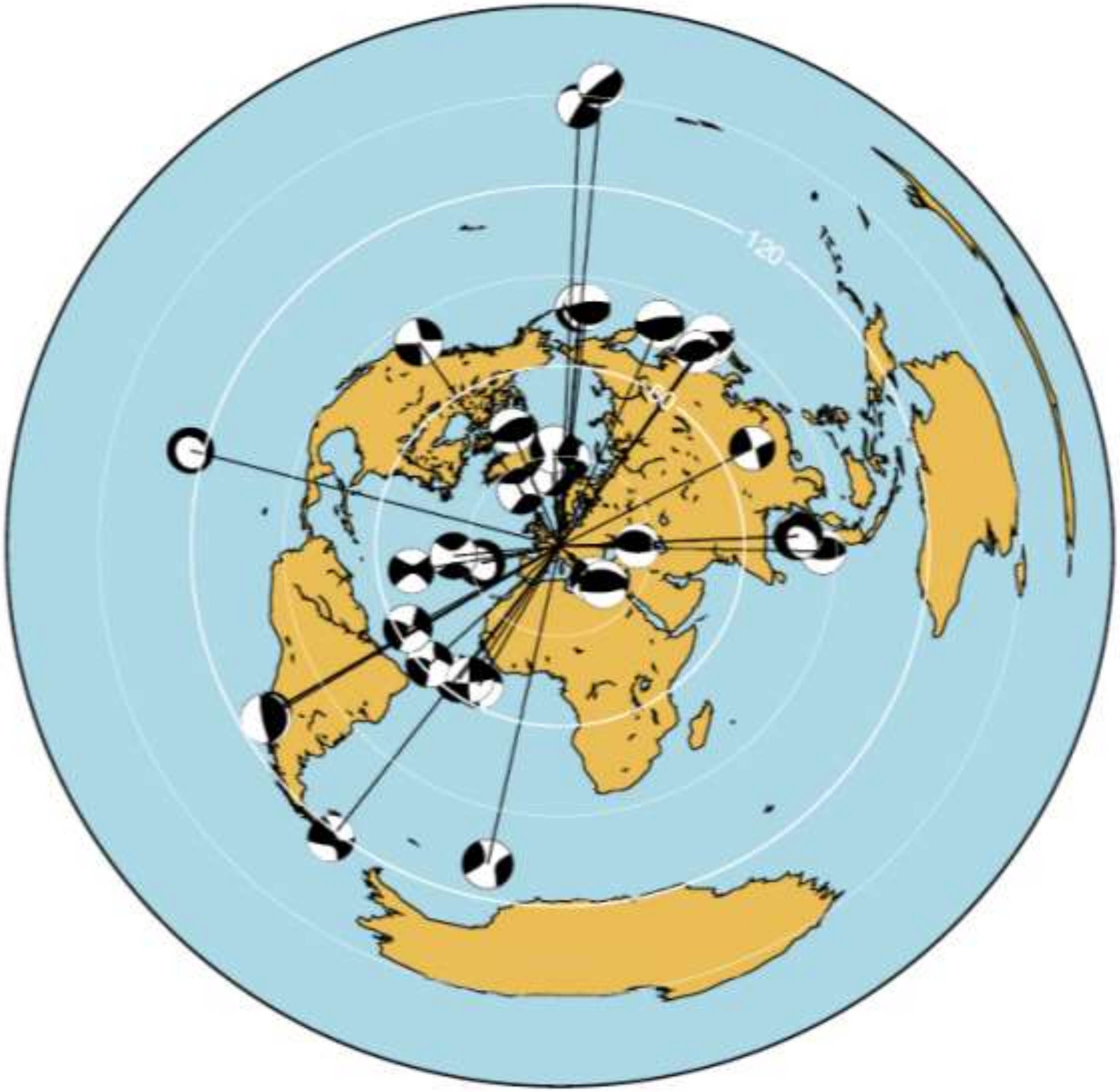


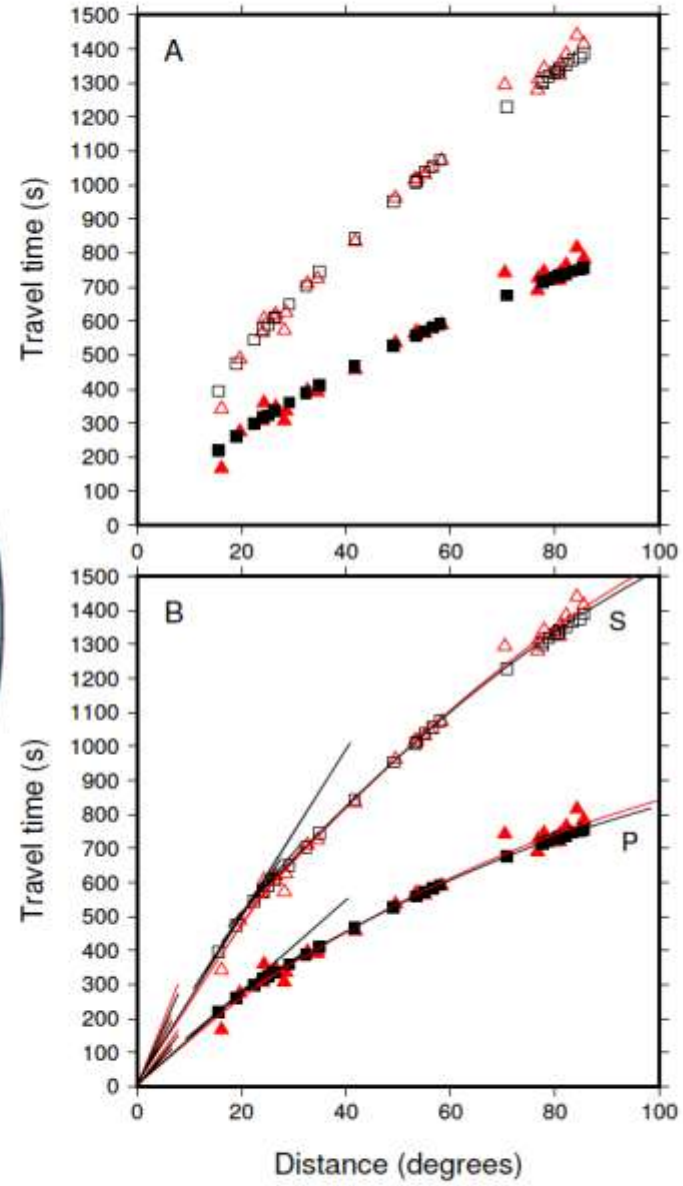
Arrival Time Analysis



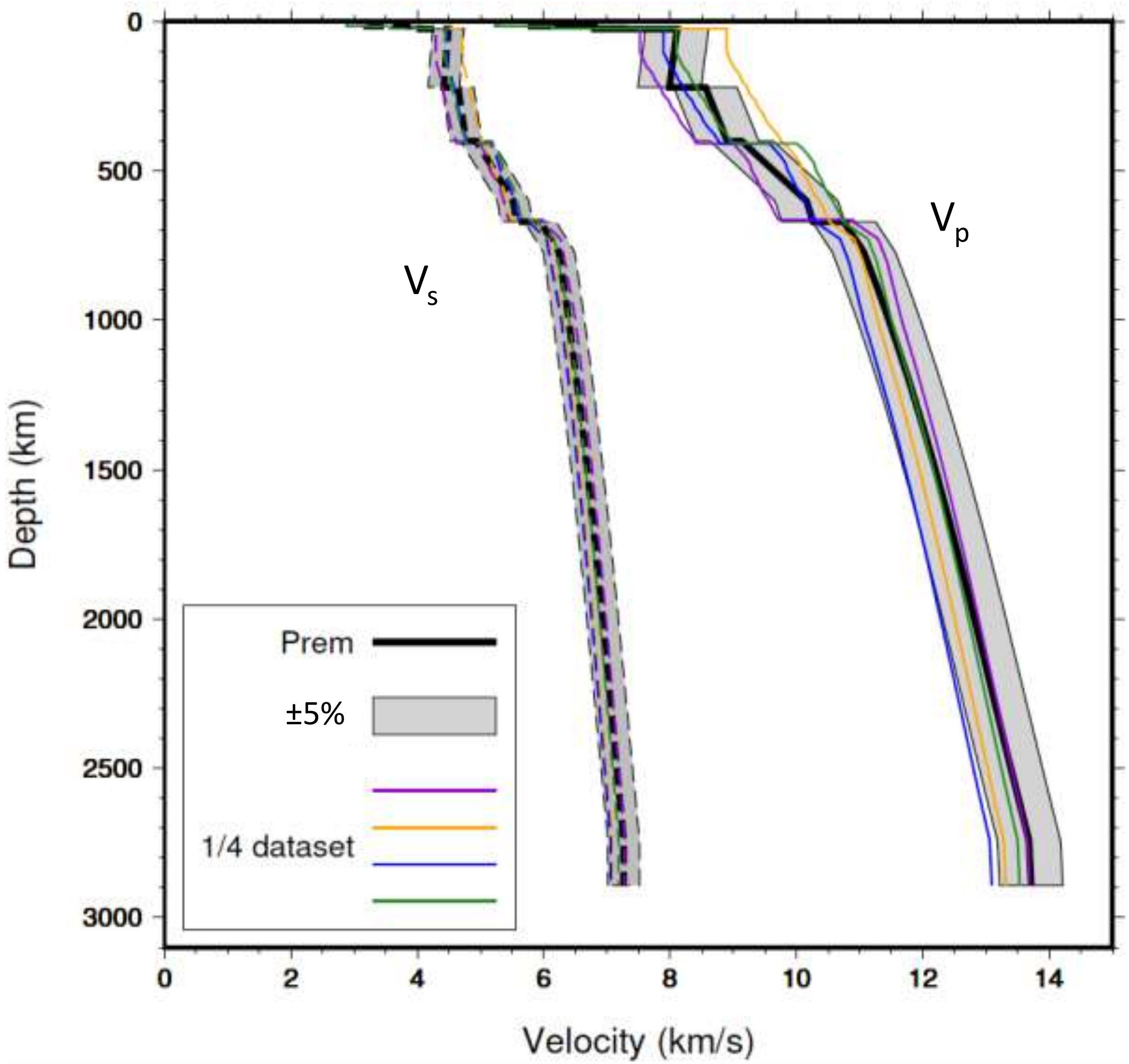
36 Earthquakes Used to Simulate Single-Station Analyses

M. Panning et al., Icarus, in press

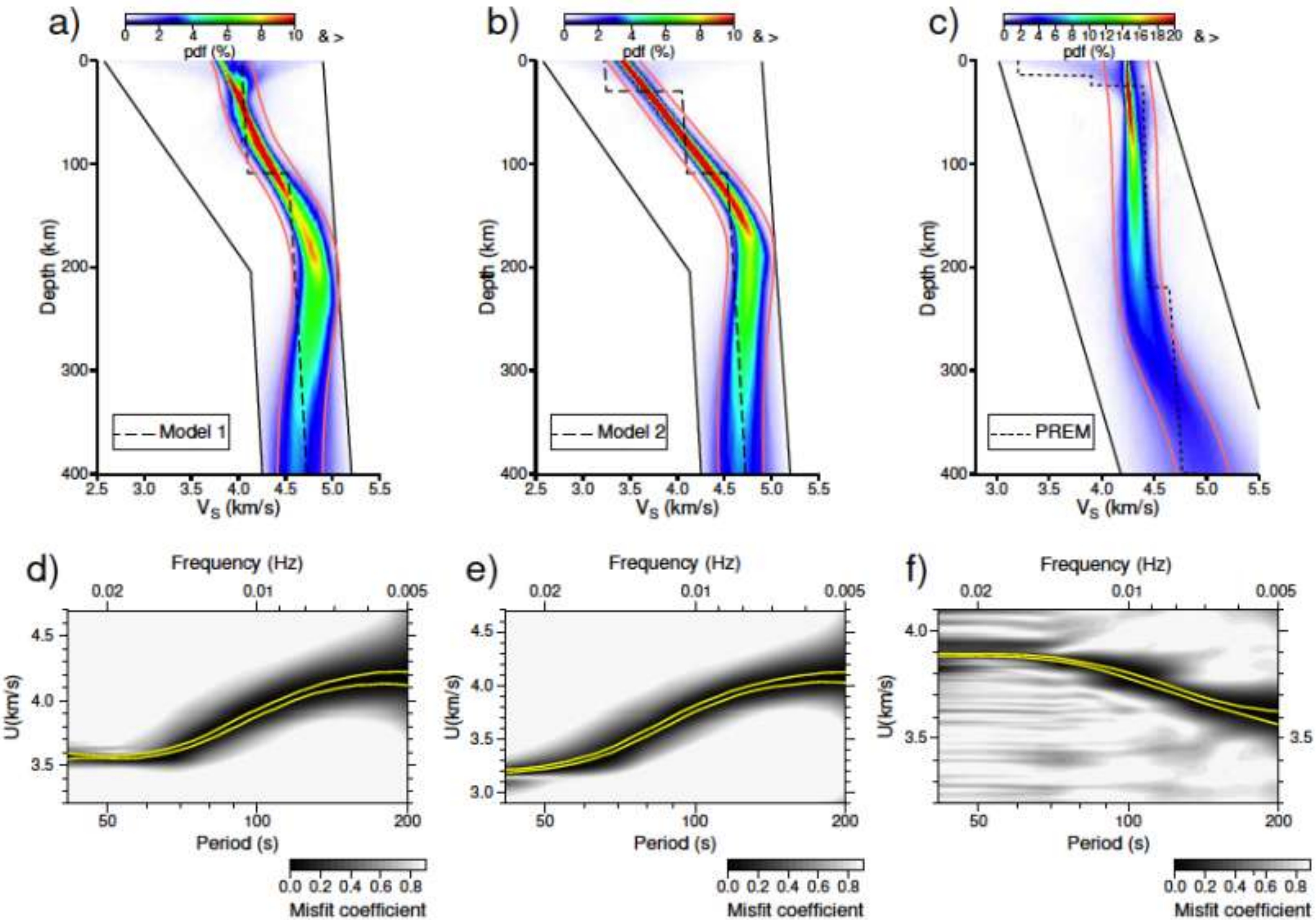




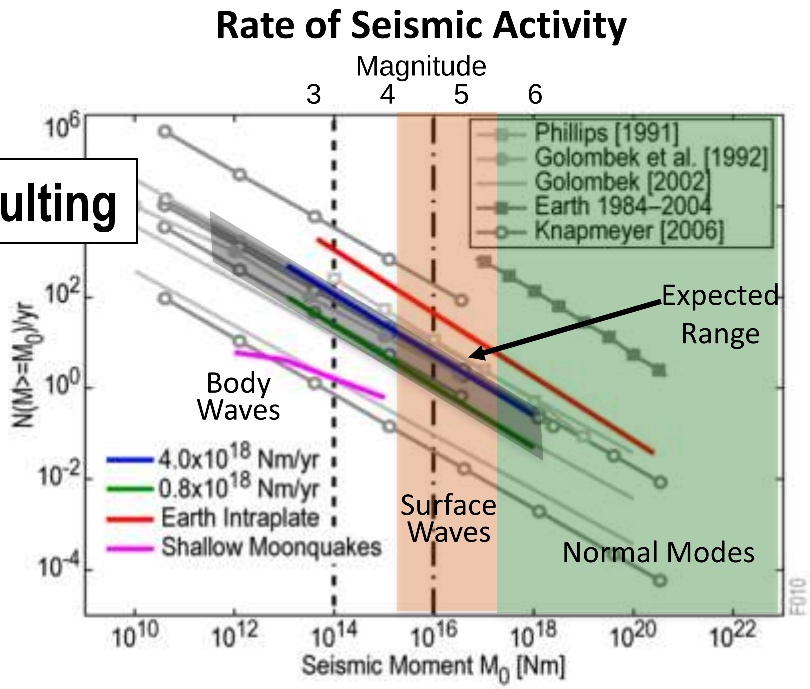
Recovery of Earth Structure Using 7-Event Subsets

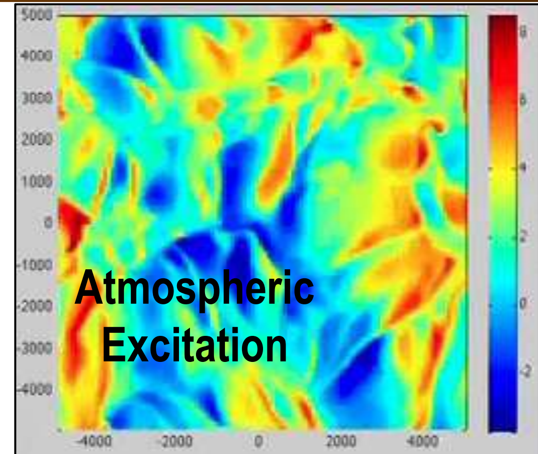


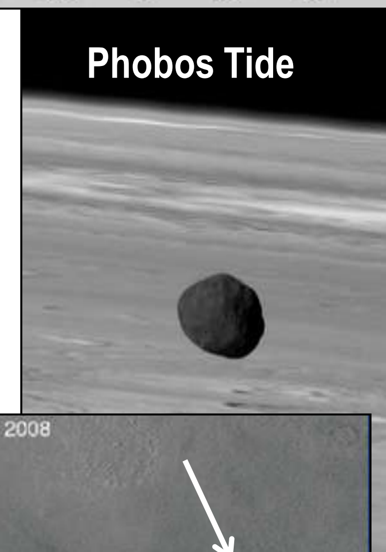
Inversion of Surface Wave Dispersion Data

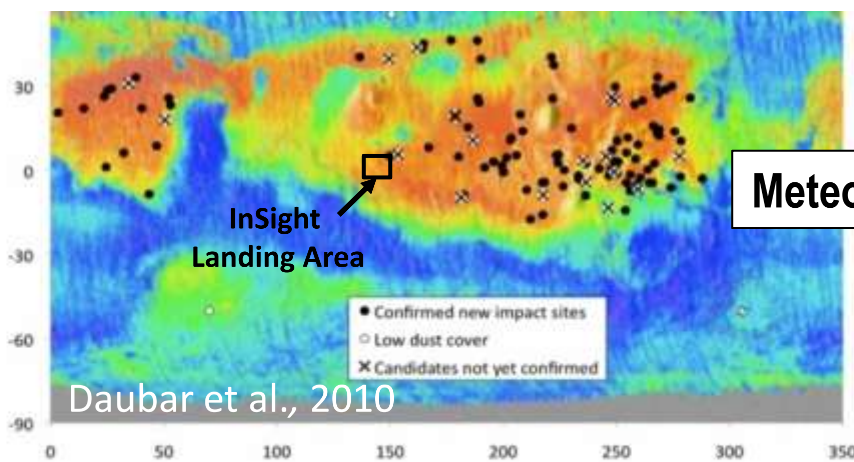


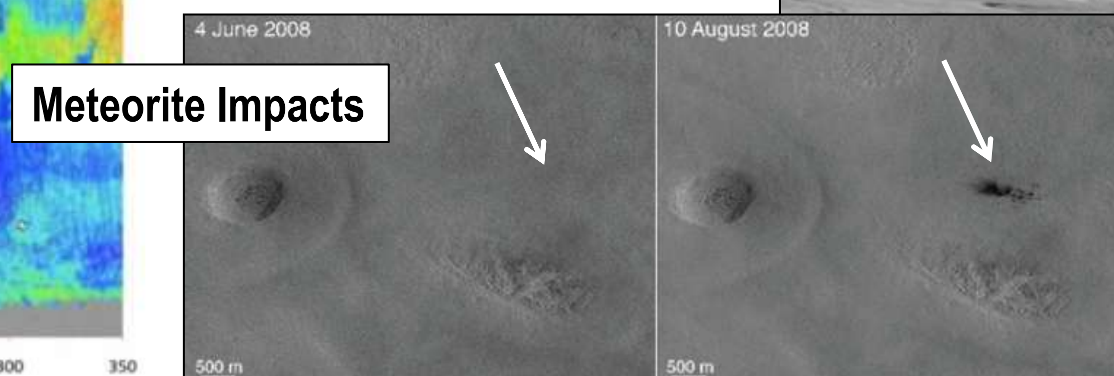
Martian Seismology – Multiple Signal Sources







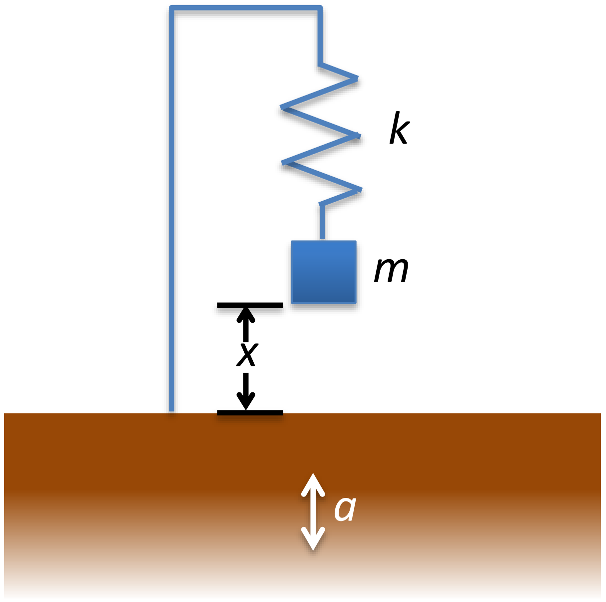




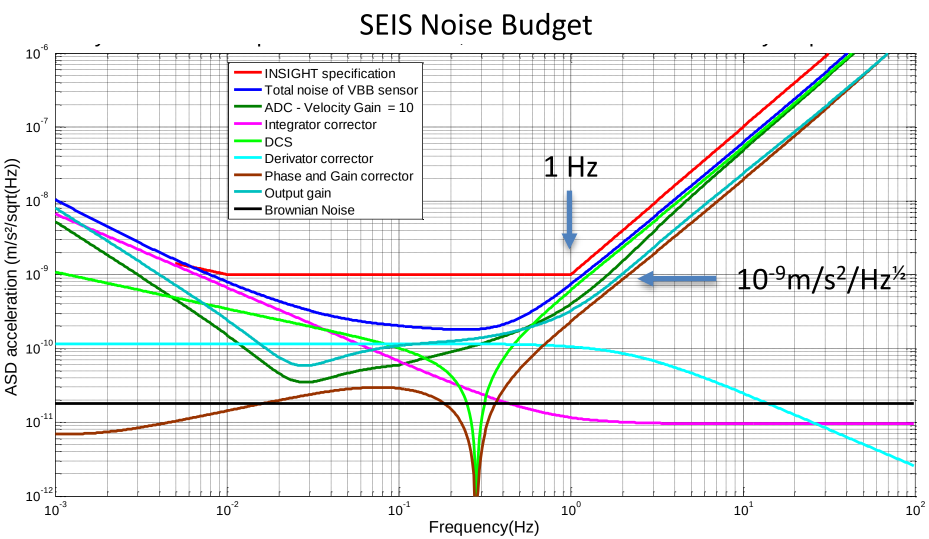
Seismometer Sensitivity

- Acceleration noise req. over 1 Hz: $\leq 10^{-9}$ m/s²/Hz½
  - For oscillatory motion, $x = a/\omega^2 = a/4\pi^2 f^{\,2}$

  ⇒SEIS is sensitive to displace-ments of ~2.5×10^{-11}m



This is about half the Bohr radius of a hydrogen atom

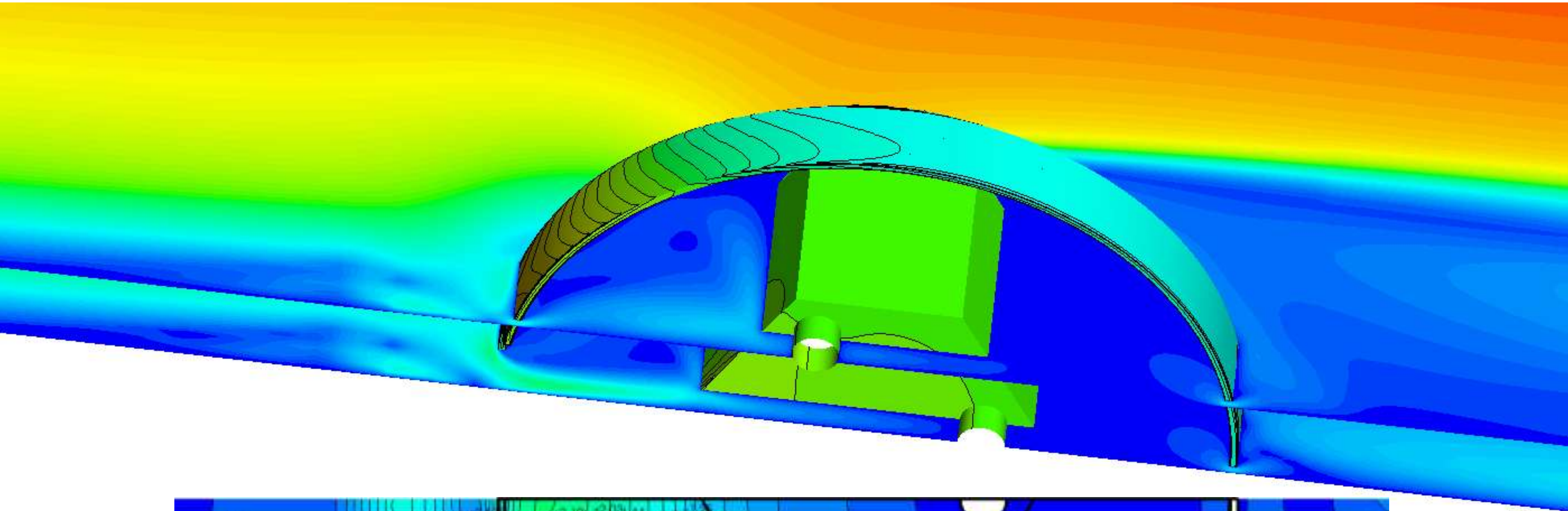


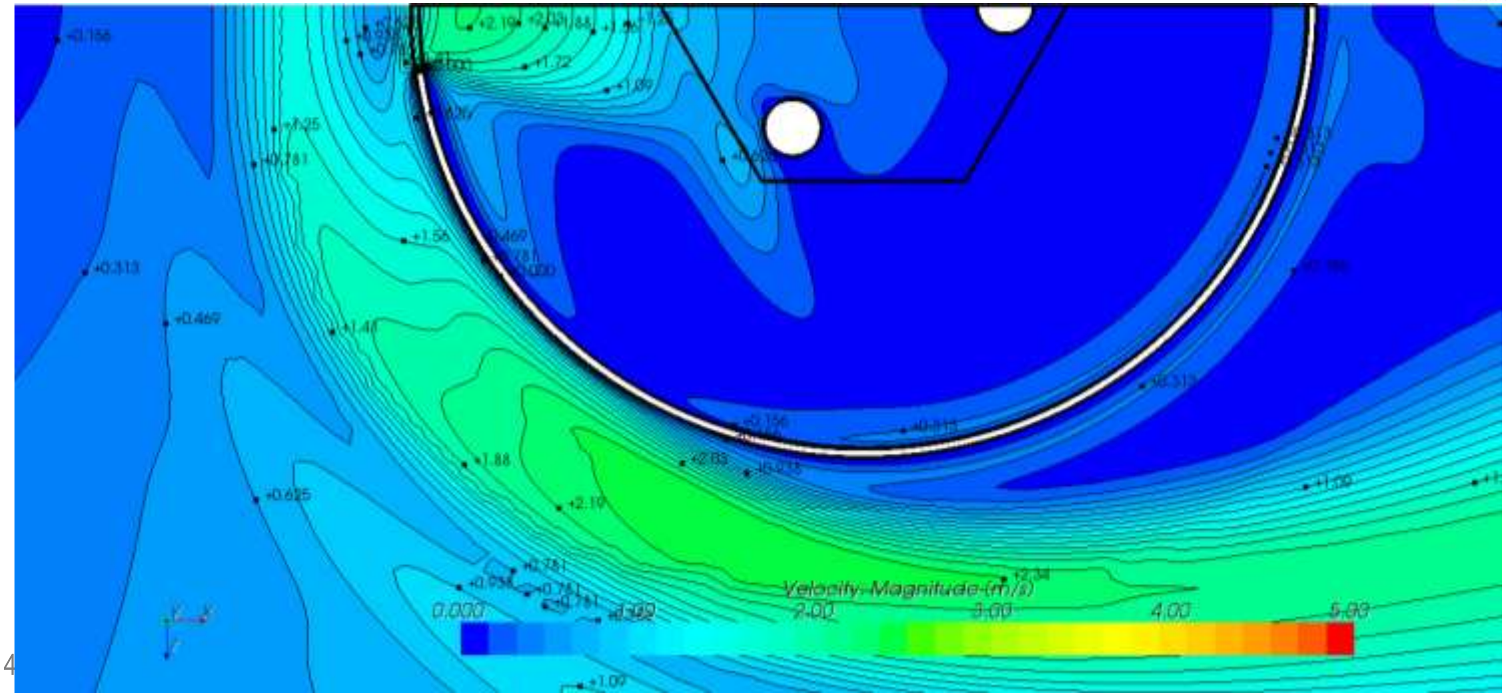
APSS – Auxiliary Payload Sensor Subsystem

- **Environmental monitoring**
  - A seismometer measures almost everything in its vicinity better than it measures seismic waves.
    - Could sense the flapping wings of a butterfly on top of the instrument!
  - 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

“Stealth” instruments

CFD Modeling of SEIS Wind and Thermal Shield

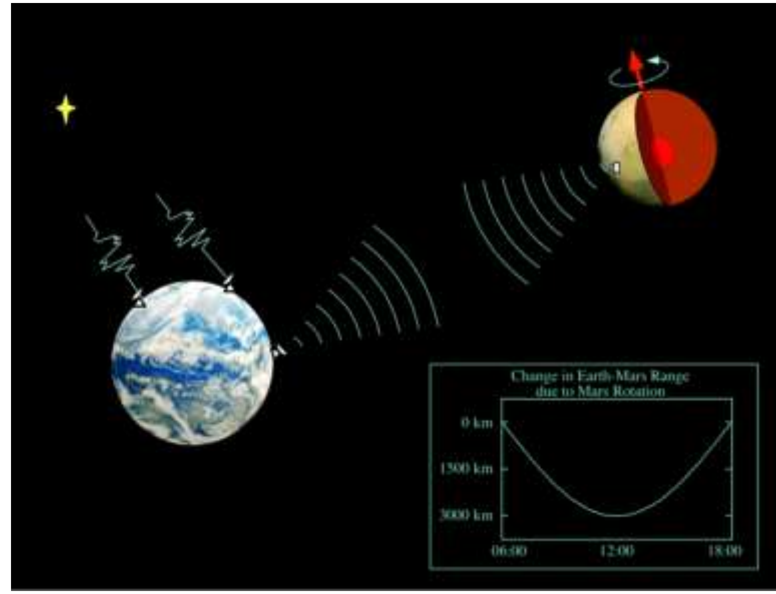




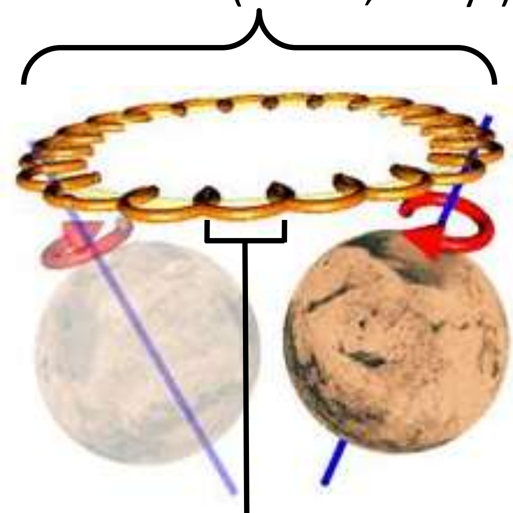
InSight

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-decameter precision
  - Free core nutation constrains core MOI directly, allowing separation of radius and density.

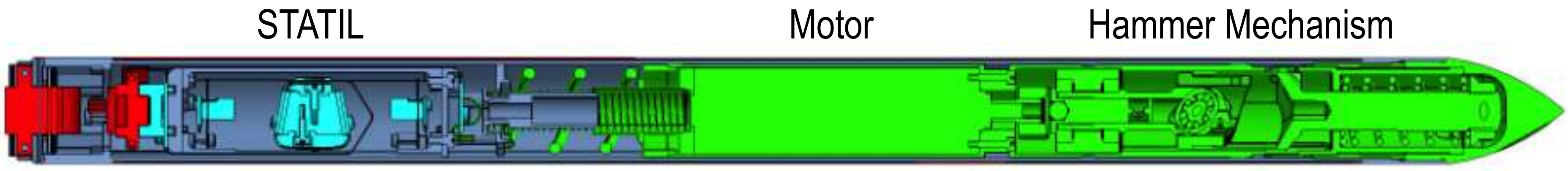


Precession (T=165,000 yr)

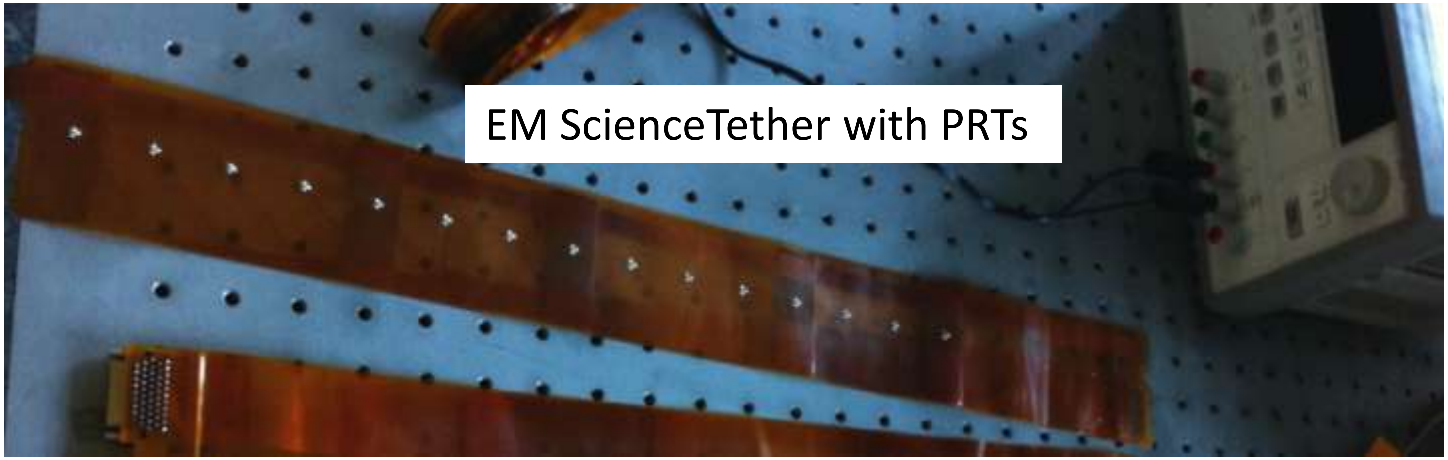


Nutation (T≤1 Mars yr)

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

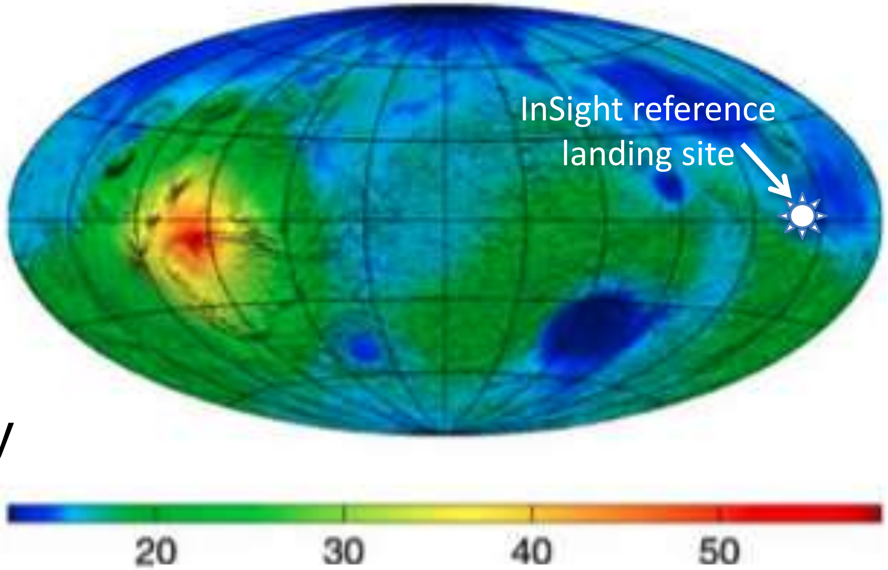


TEM-A: foils within Mole outer hull)



Heat Flow Measurement – HP^3

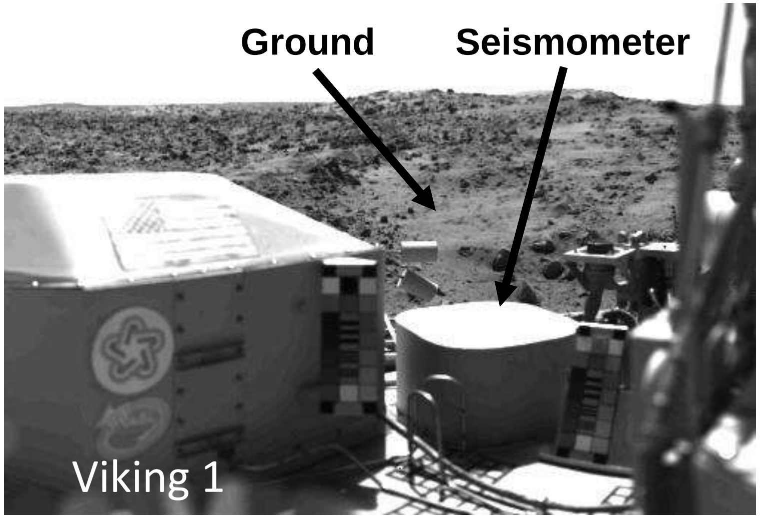
- HP^3 (Heat Flow and Physical Properties Probe) has a self-penetrating "mole" that burrows down 3 to 5 meters below the surface.
  - It trails a tether containing precise temperature sensors every 35 cm to measure the temperature gradient of the subsurface.
  - It also contains a heater to supply a 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.

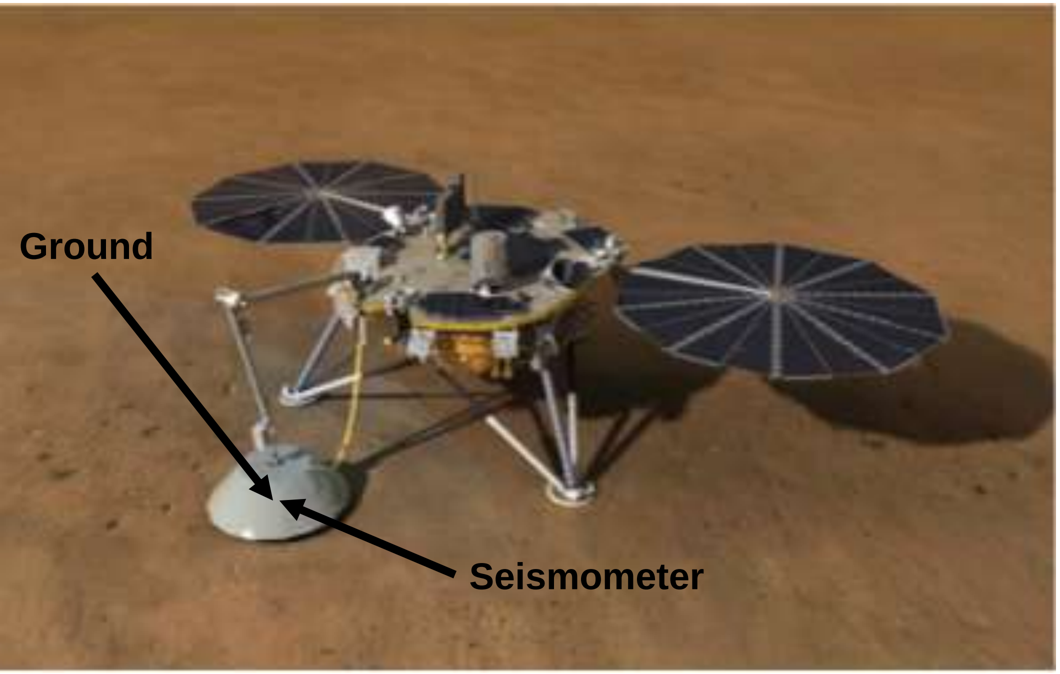


Surface Heat Flow Model (mW/m^2)
Grott and Breuer, 2010.

Surface Deployment is Key to InSight Measurements

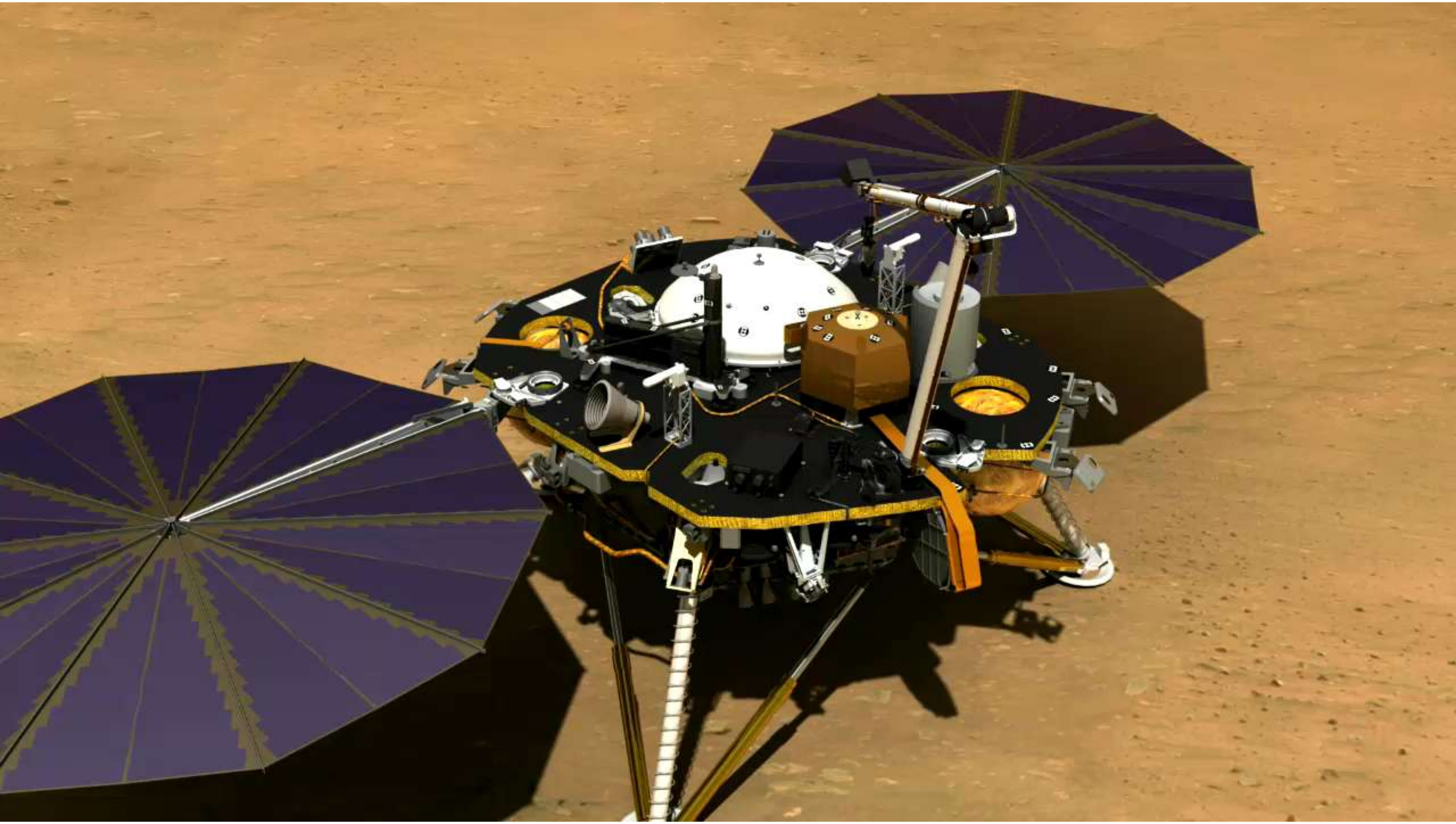
- The quality of a seismic station is directly related to the quality of its installation.
  - Installation couples the instrument to the ground and isolates it from the rest of the environment.
- But after landing, the instruments are still ~1 m from the ground…



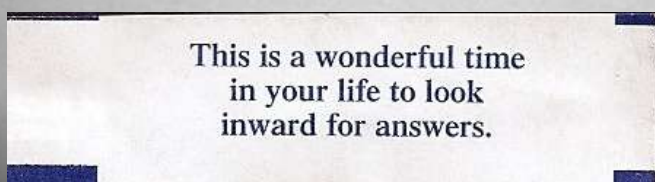


- InSight takes advantage of the payload mass capability of the Phoenix lander to fly an unpre-cedented deployment system.
- It will place the seismometer on the surface and cover it with an effective wind and thermal shield
- This will allow the seismometer sensitivity to reach the micro-seismic noise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

Seismometer and HP^3 Deployment



"Look deep into nature, and then you will understand everything better." – Albert Einstein



– Chinese Fortune Cookie

Gusev Crater