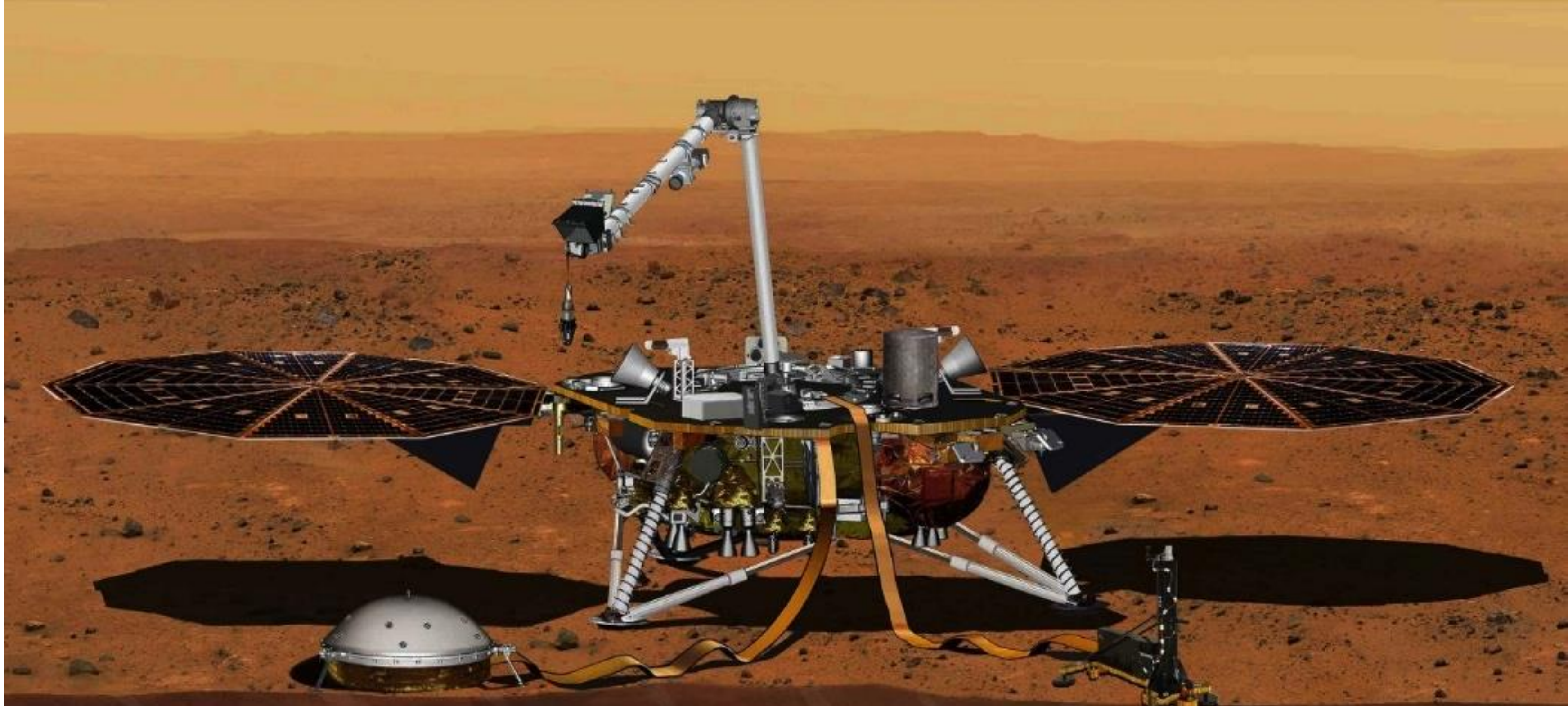
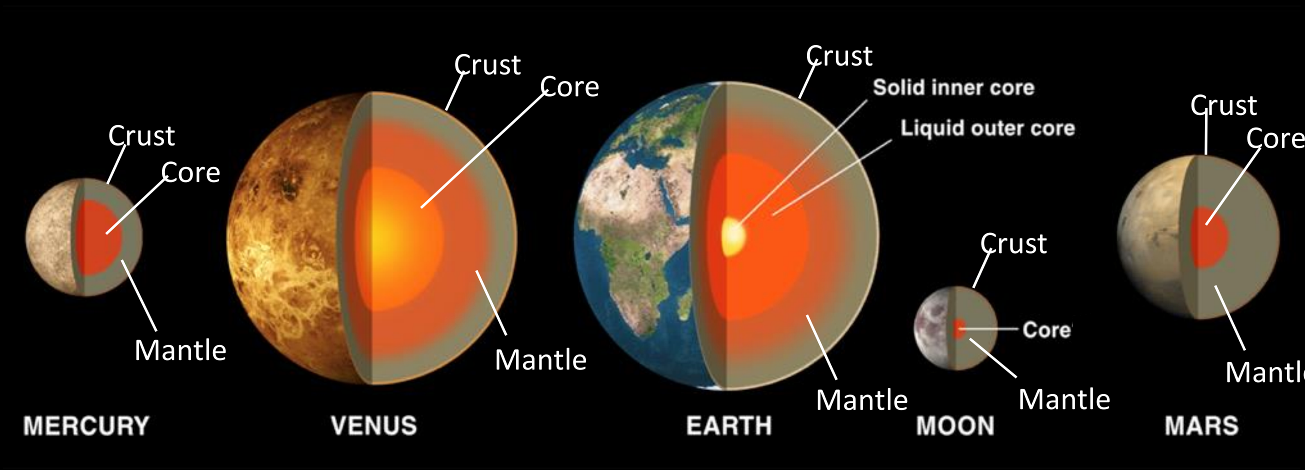


Exploring the Birth of Rocky Planets: The InSight Mission to Mars

Dr. W. Bruce Banerdt
Jet Propulsion Laboratory

19 September, 2017

InSight Mission Science

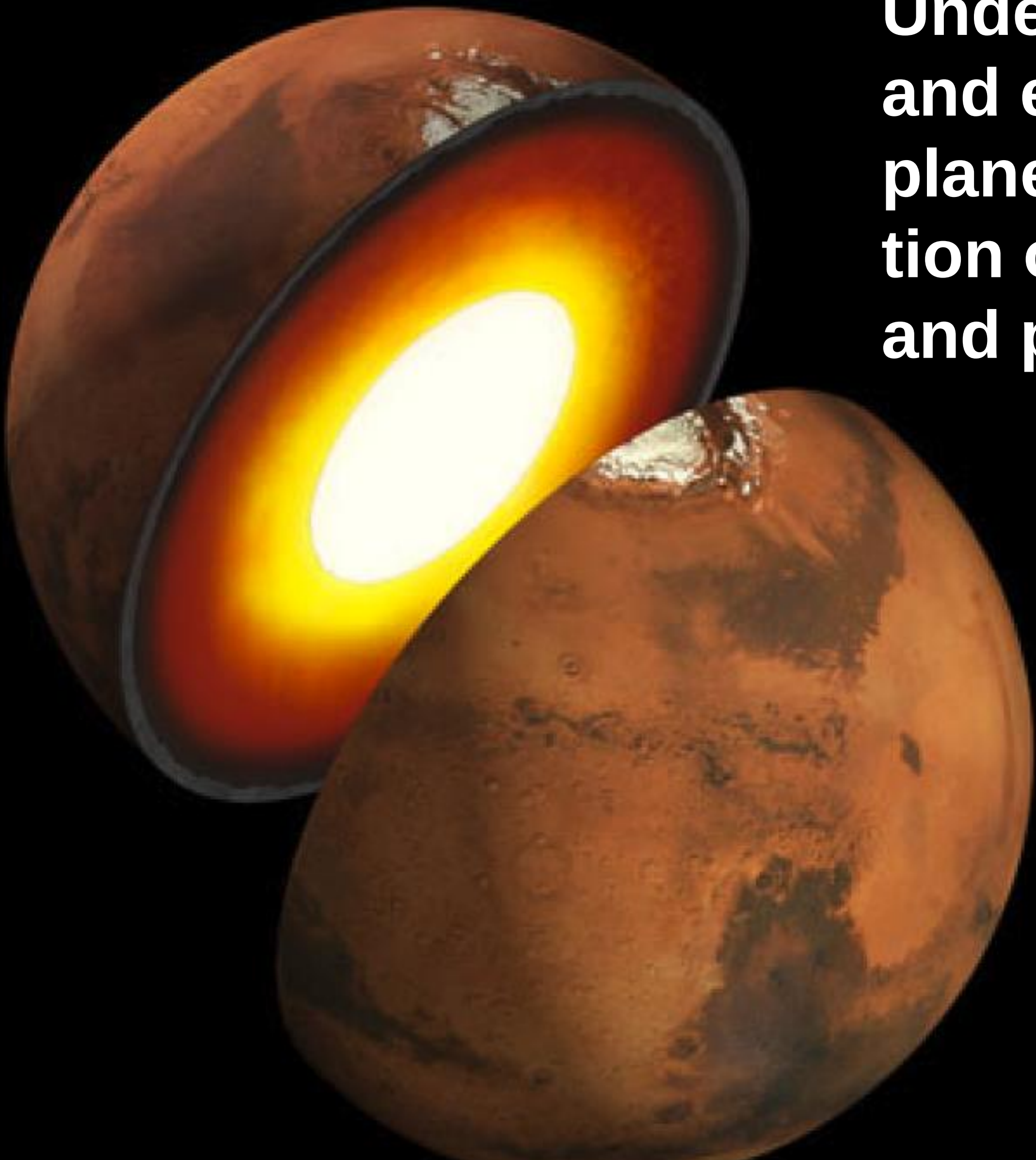


You Can Think of InSight as a Time Machine…

- Its measurement goals travel back in time more than a hundred years, to terrestrial seismology at the turn of the 20th century:
  - 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?

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

InSight Science Goal:

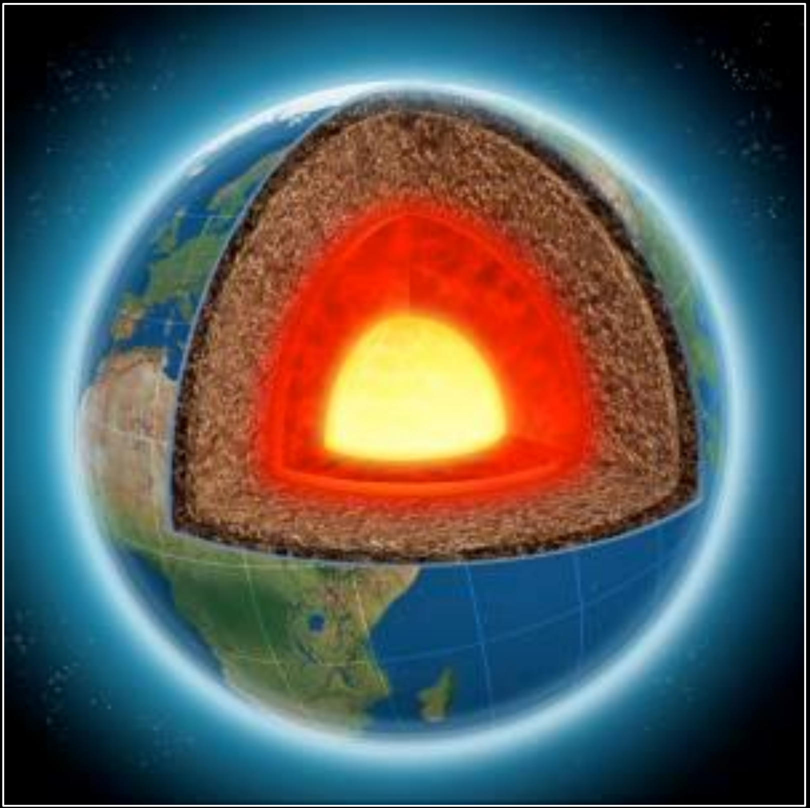


Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars.

- **Seismology**
- **Precision Tracking**
- **Heat Flow**

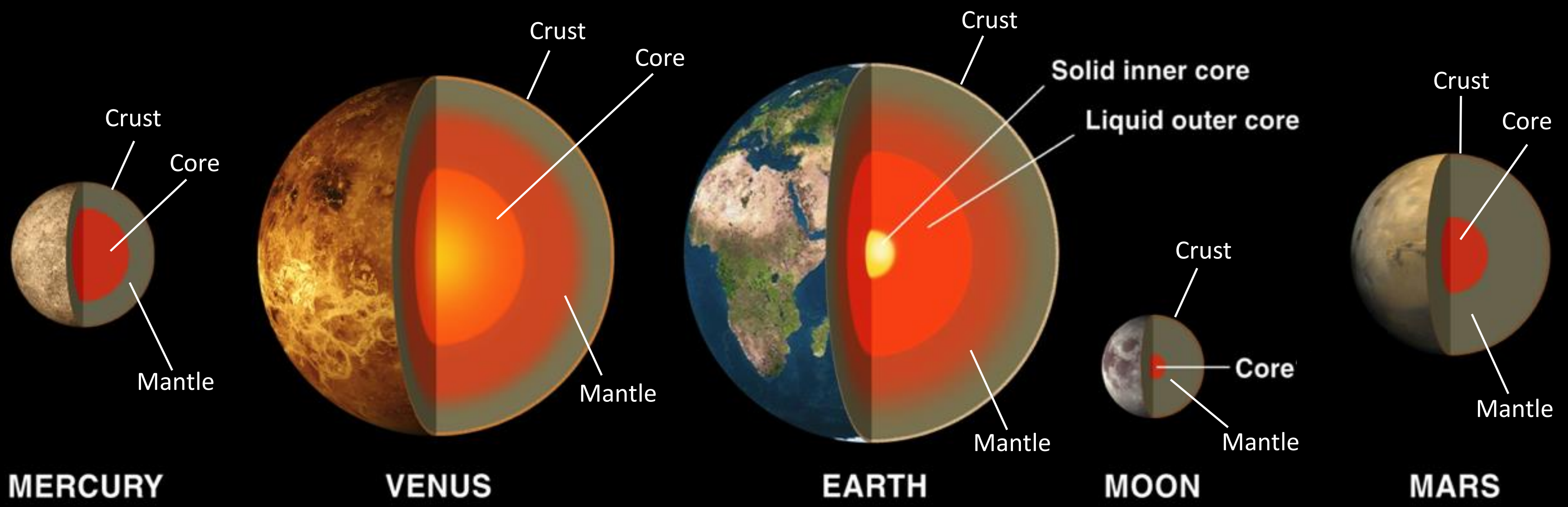
Why is it Important to Understand Planetary Interiors?

- The interior of a planet comprises the heat engine that drives all endogenic processes
- It participates in virtually all dynamic systems of a planet.
  - Interior processes have shaped the surface of the planet we see today.
  - It is a source and/or sink for energy, rocks, atmosphere/hydrosphere
- It provides many of the necessary conditions for a planet to become, and remain, habitable.



- **It retains the fingerprints of the planet's origins, overprinted to some degree by its subsequent evolution.**

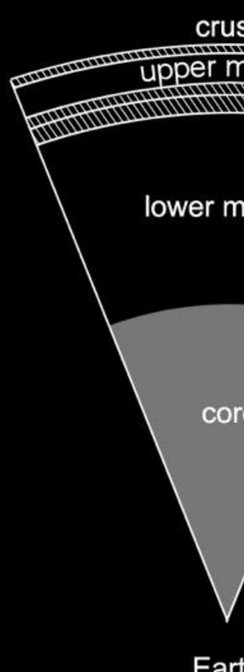
Terrestrial Planet Structure



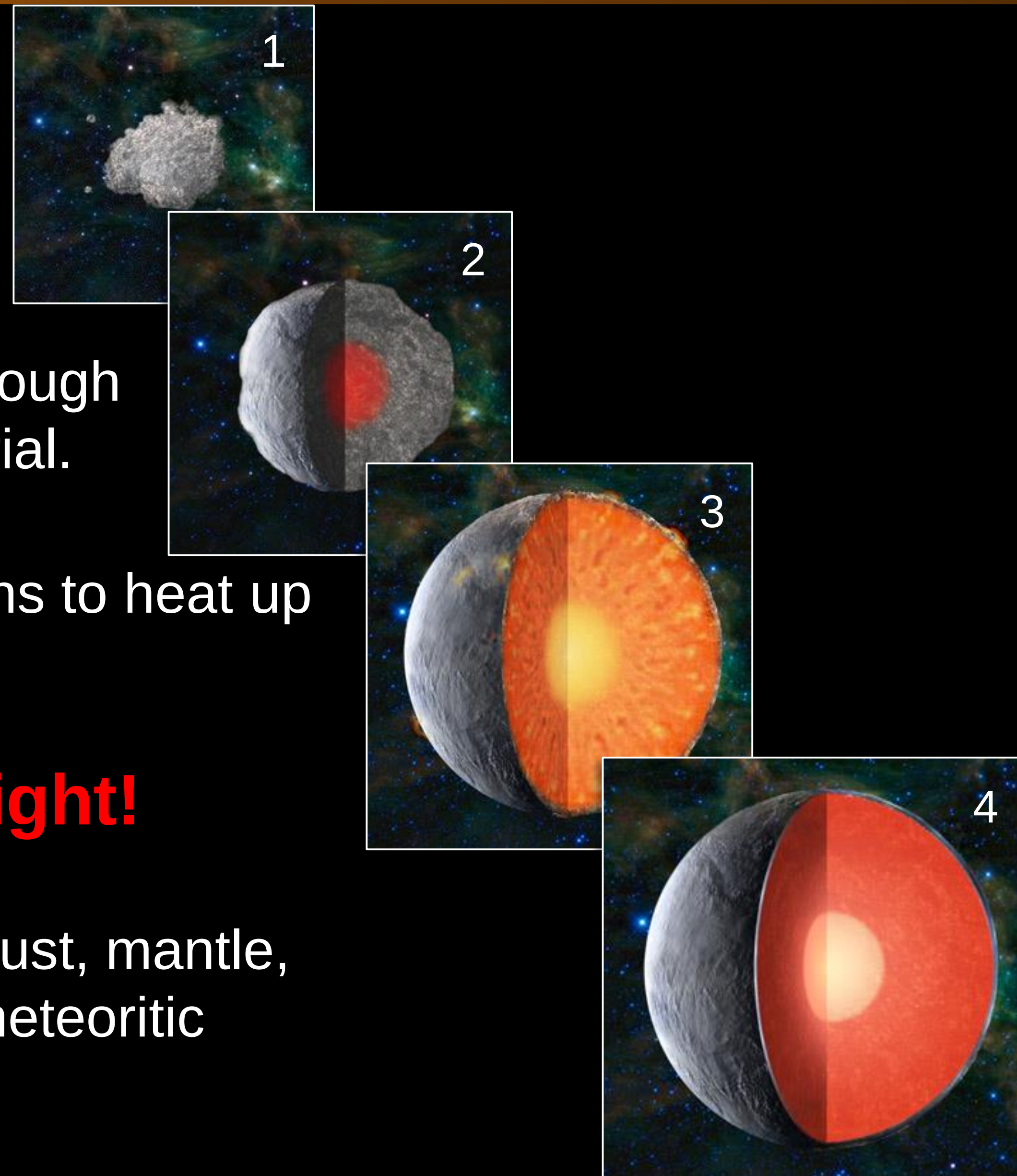
Terrestrial planets all share a common structural framework (crust, mantle, core), which develops very shortly after formation and which determines subsequent evolution.

Why Go to Mars? Because it's Just Right!

- We have information ... related) terrestrial planets, the Earth and ...
  - Much of the Earth's ea... yed by plate tectonics, vigorous ma...
  - The Moon was formed ... a limited range of P-T conditions (<200 ...
- Mars is large enough ... processes, but small enough to have ... y.

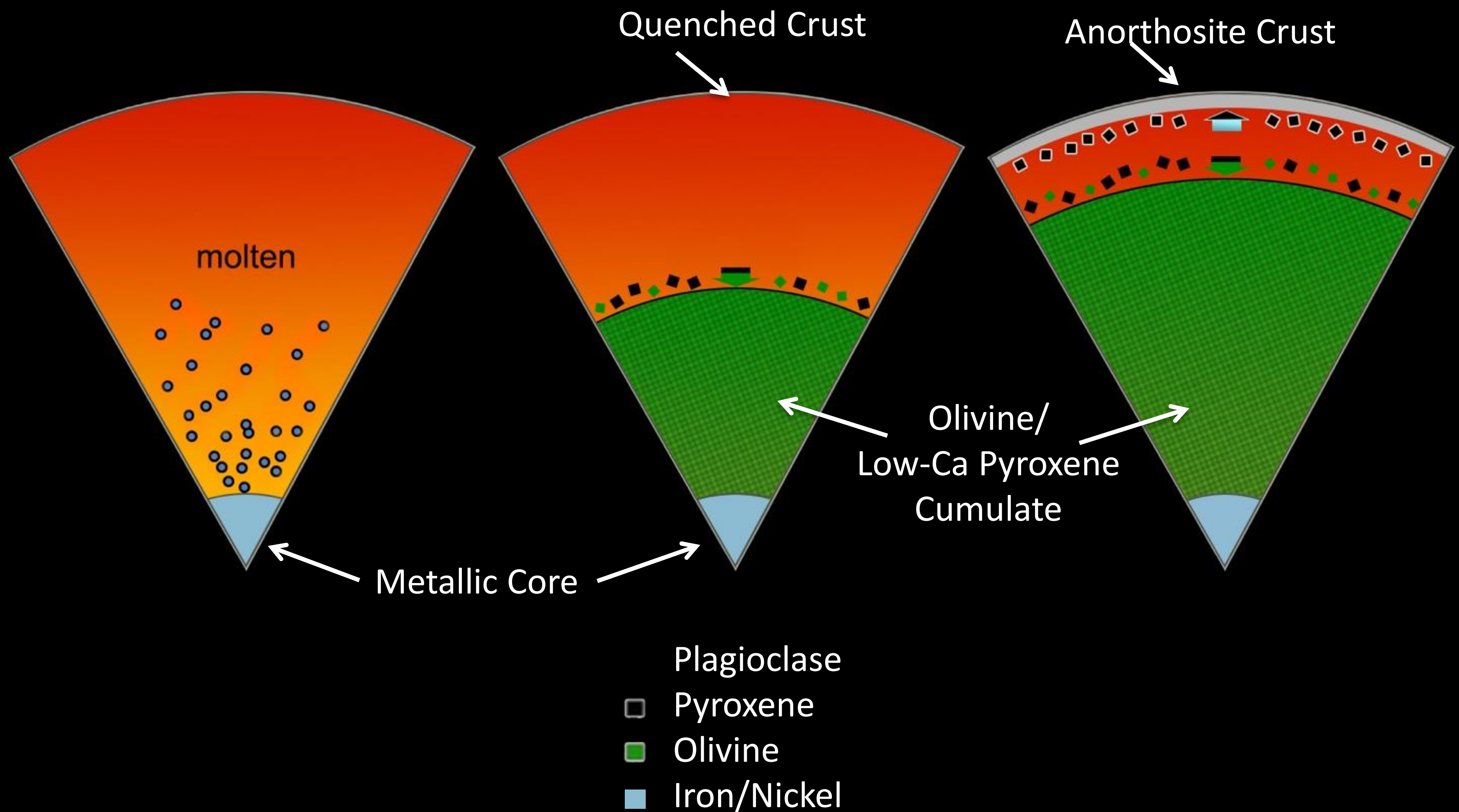


How Does a Terrestrial Planet Form?

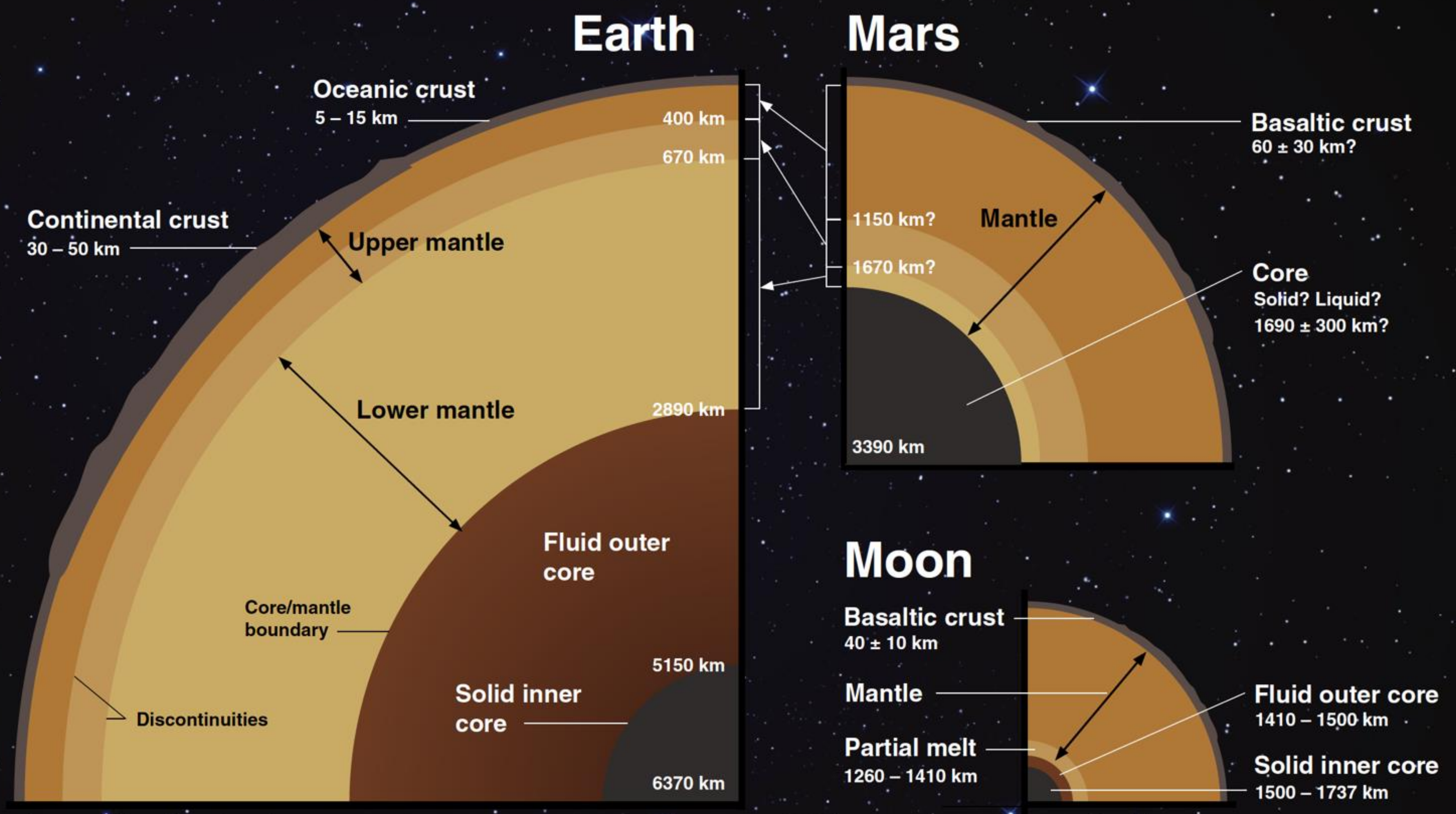


1. The planet starts forming through accretion of meteoritic material.
2. As it grows, the interior begins to heat up and melt.
3. Stuff happens! ← **InSight!**
4. The planet ends up with a crust, mantle, and core with distinct, non-meteoritic compositions.

Lunar Magma Ocean Model



Mars Structure Compared to Earth and Moon



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.

Measures of activity

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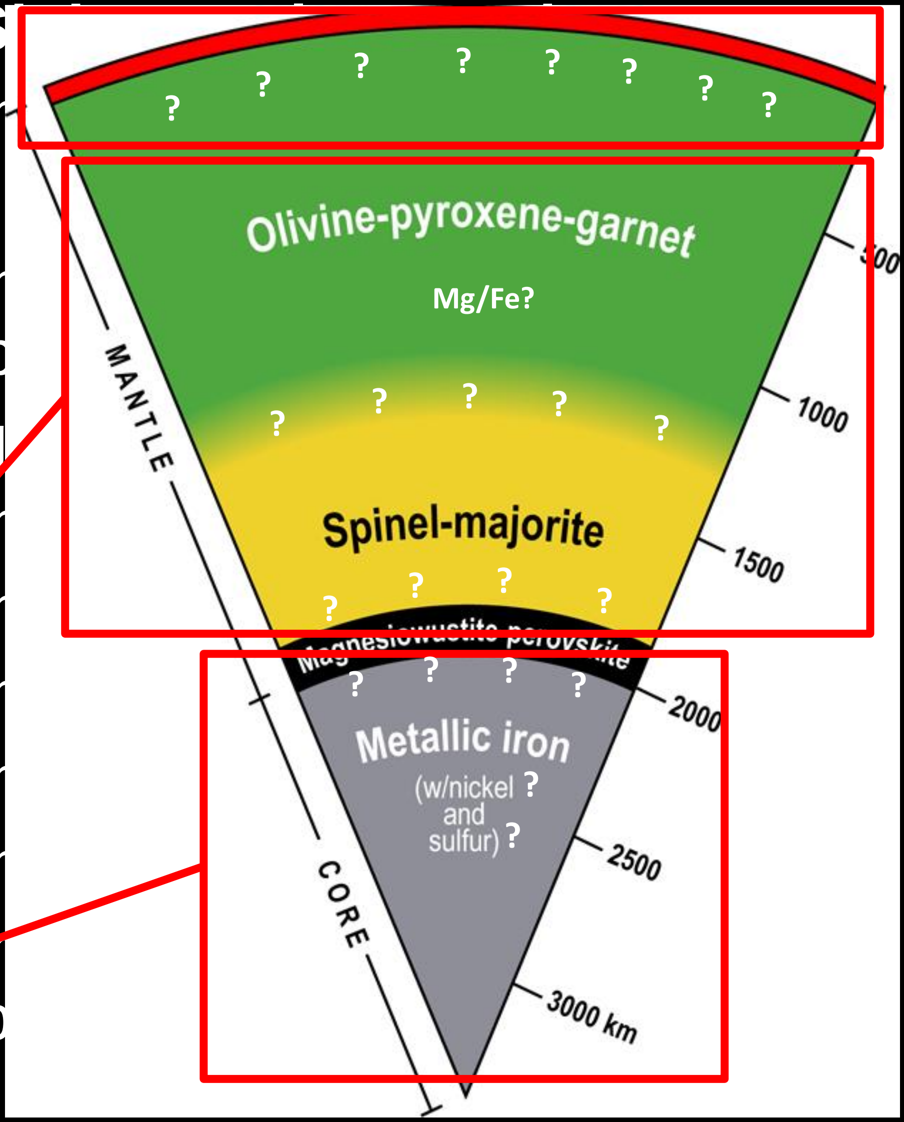
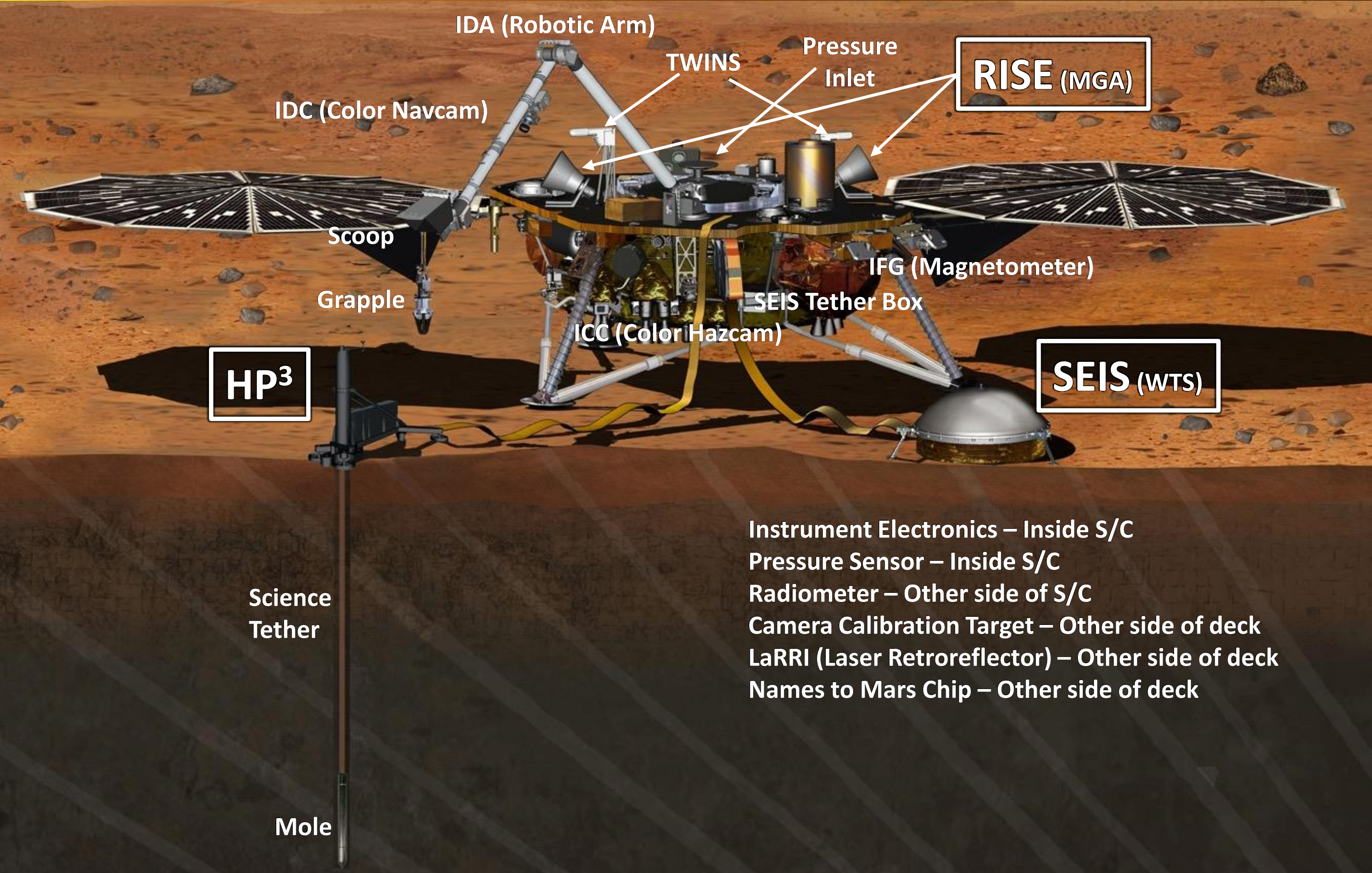


InSight Payload

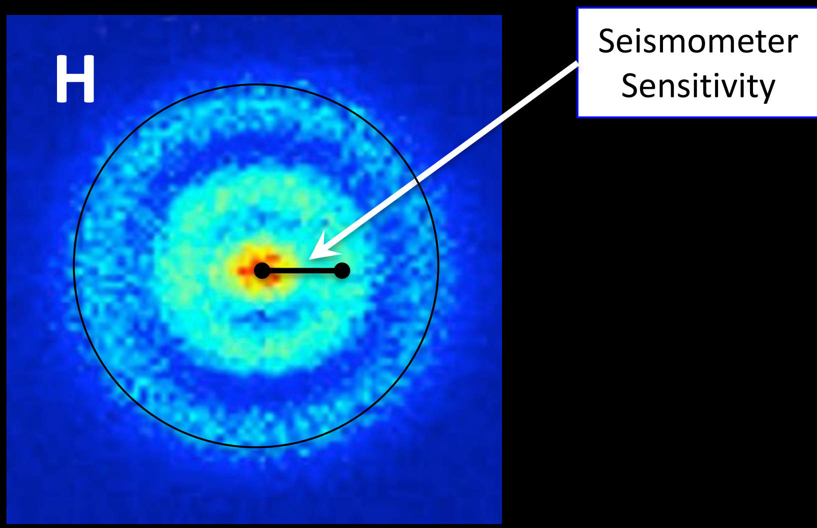
InSight Payload Configuration



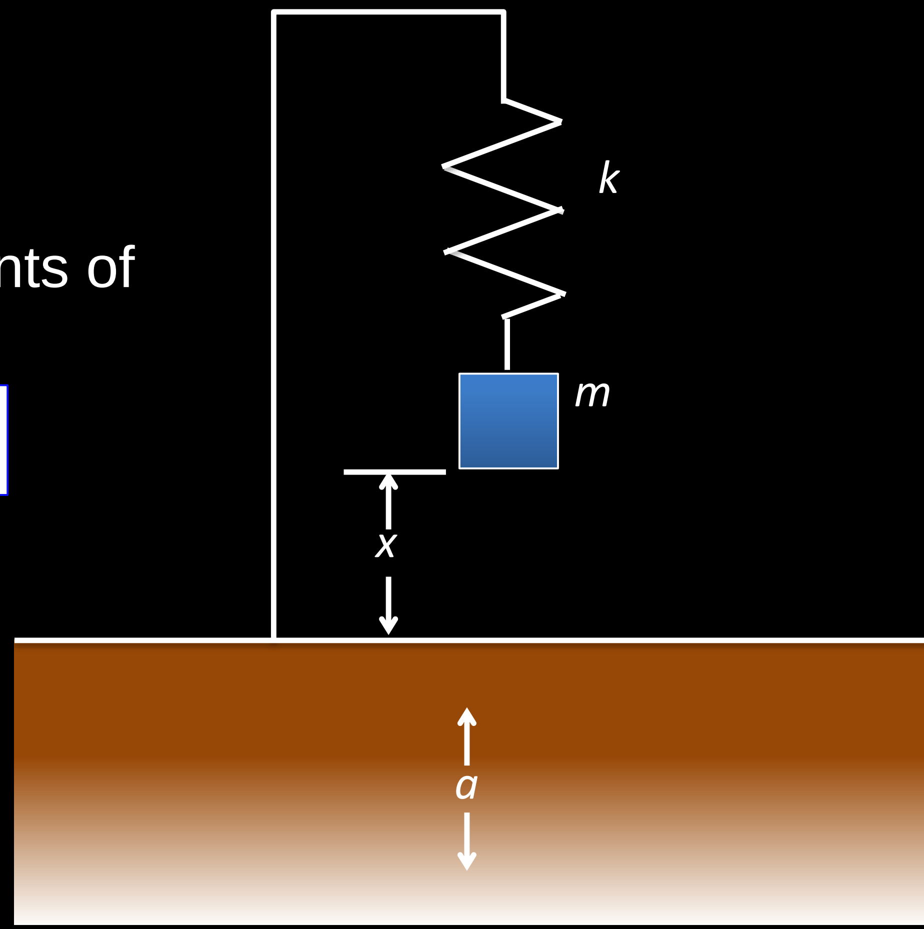
Seismometer Sensitivity

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

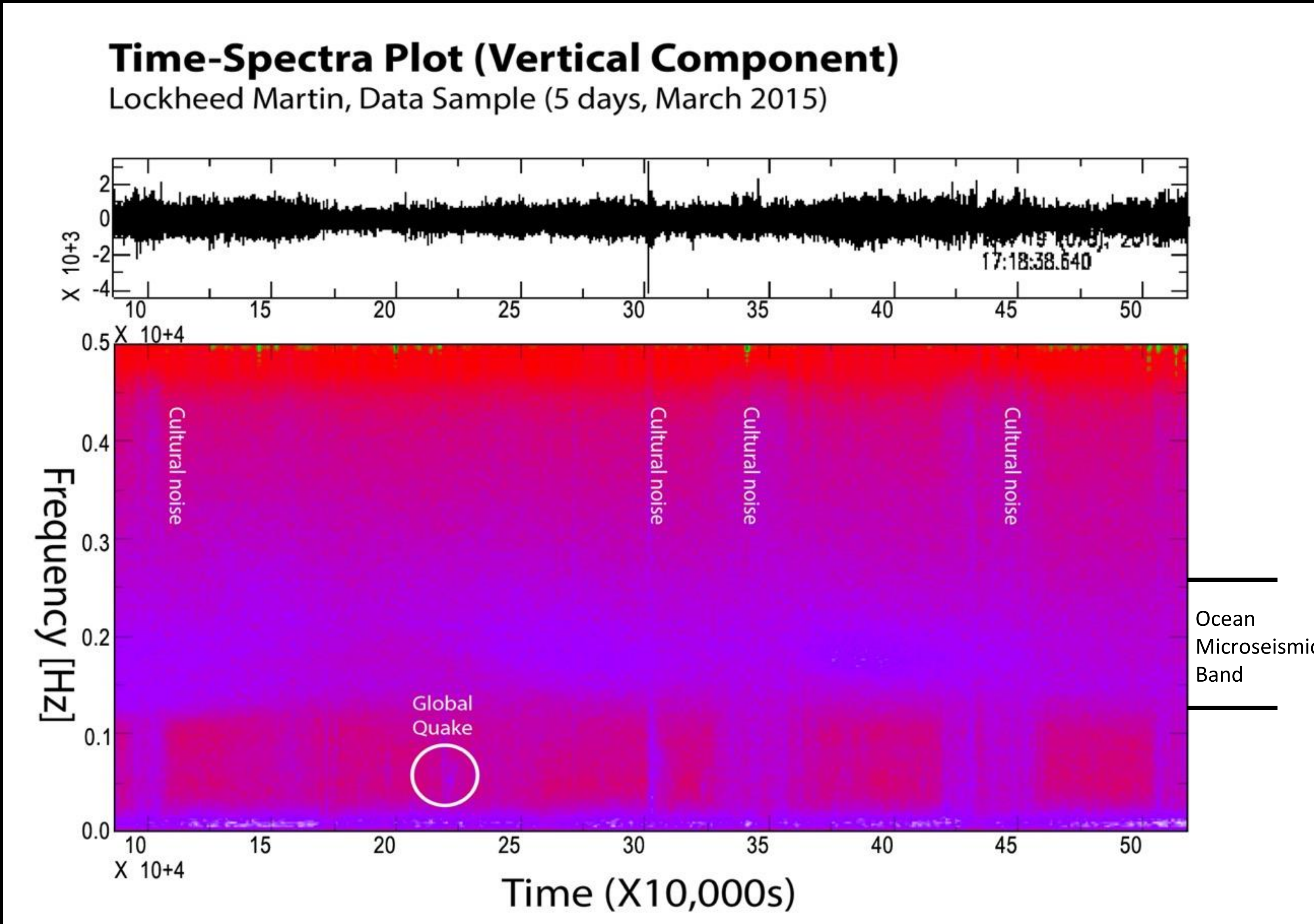
$\Rightarrow$SEIS is sensitive to displacements of ~2.5×10^{-11}m



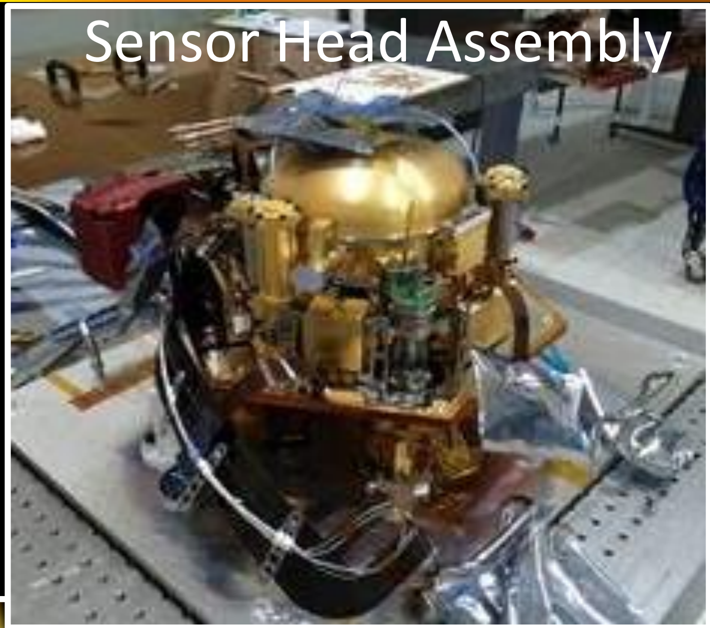
Or half the Bohr radius of a hydrogen atom

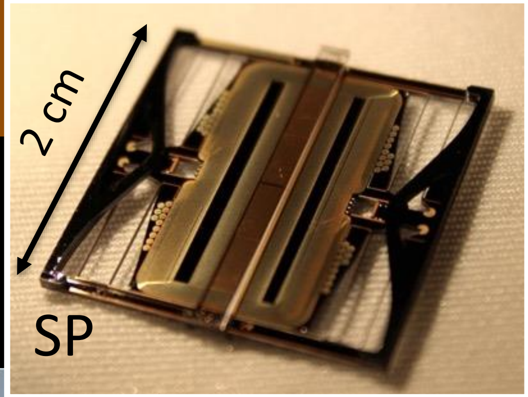


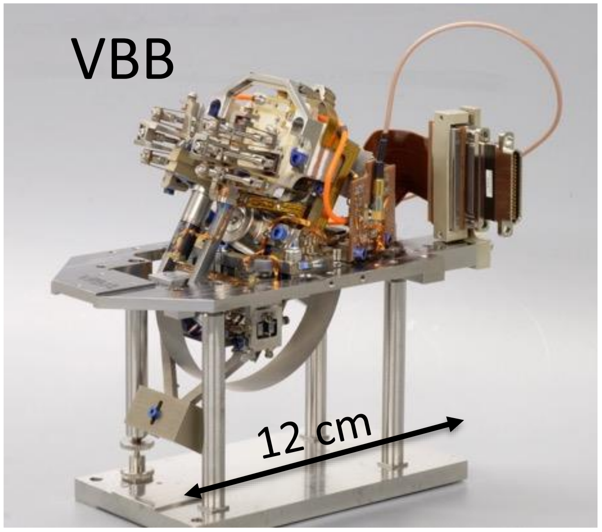
Seismometer Sensitivity – Beach Noise in Denver, CO

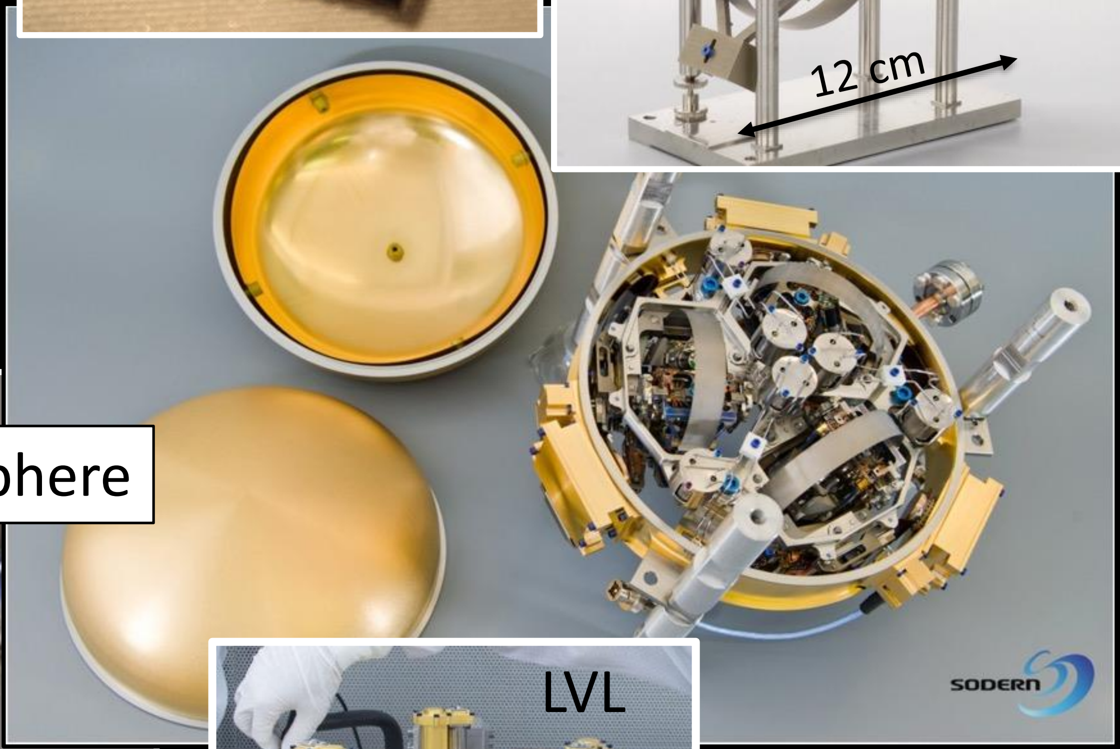


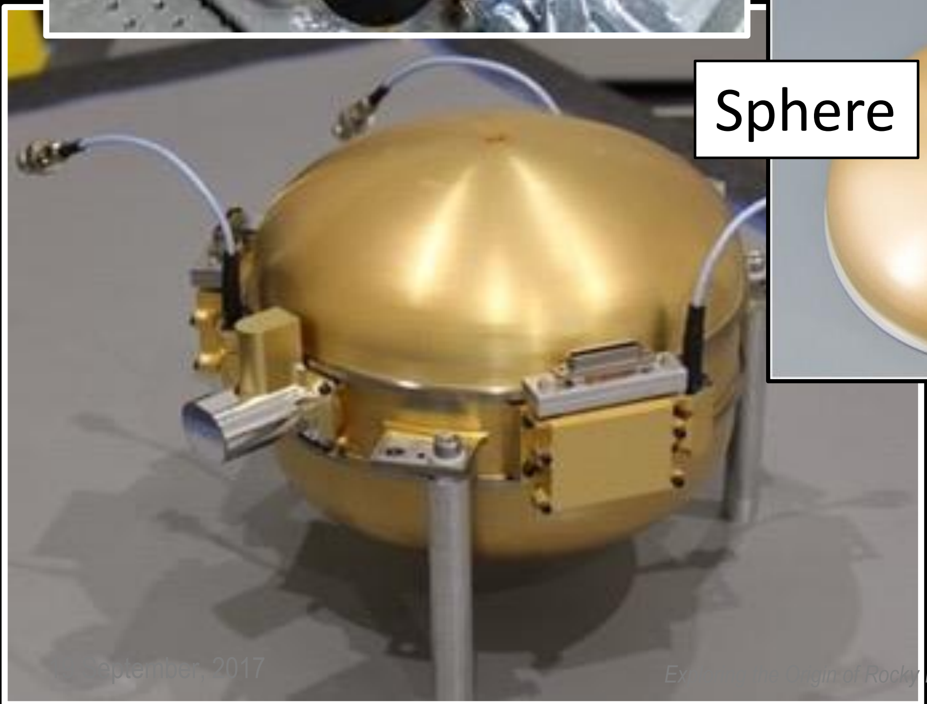
SEIS Sensors





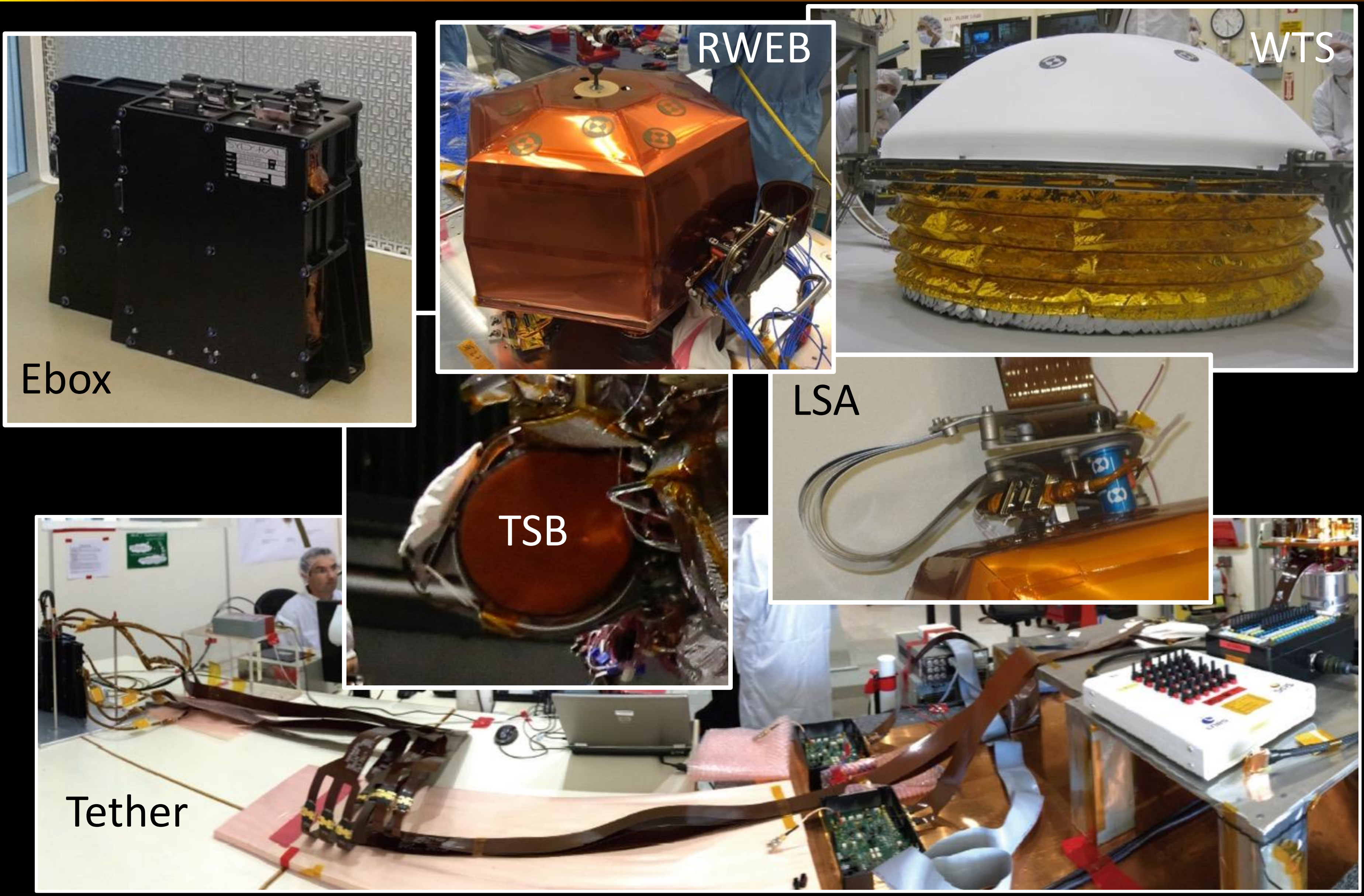




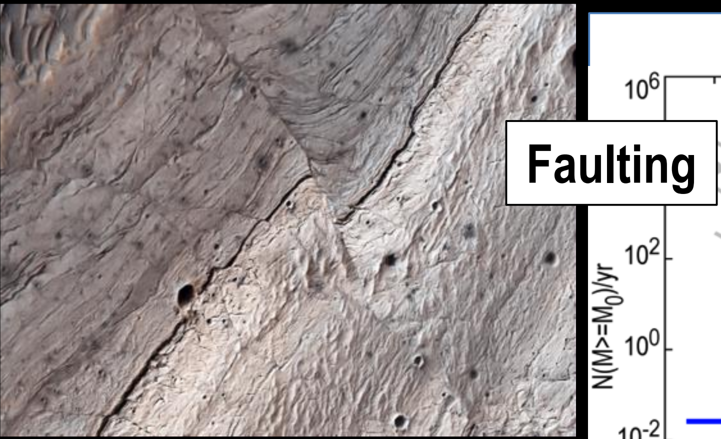


Sphere

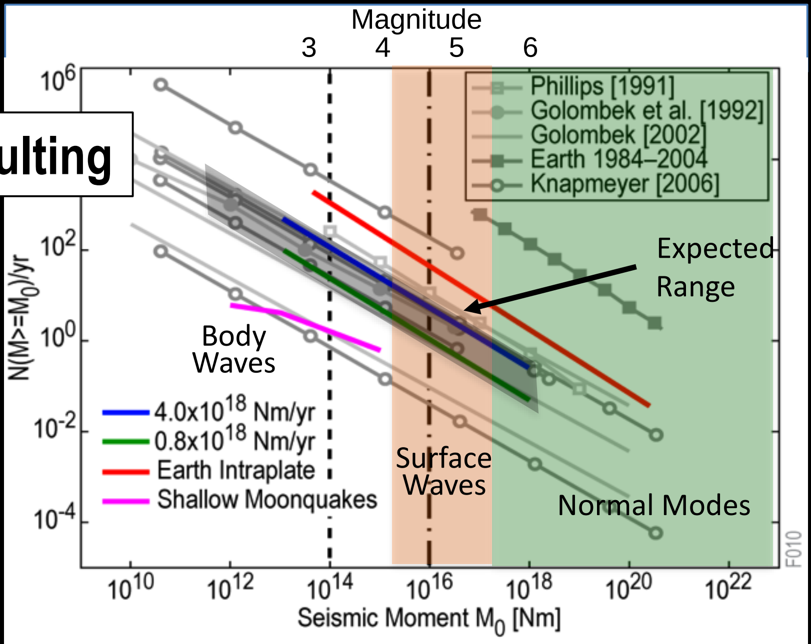
Other SEIS Components

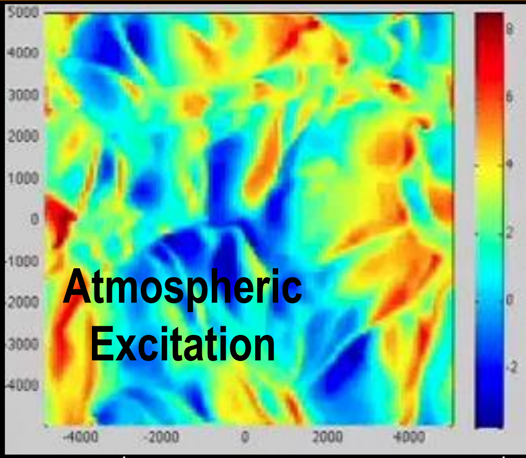


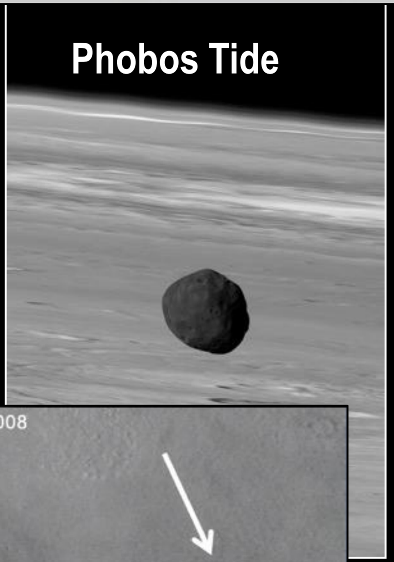
Martian Seismology – Multiple Signal Sources

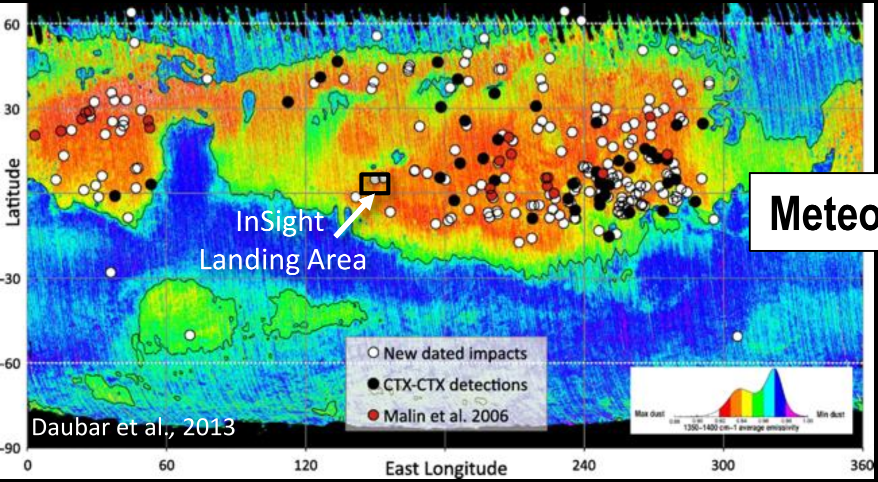


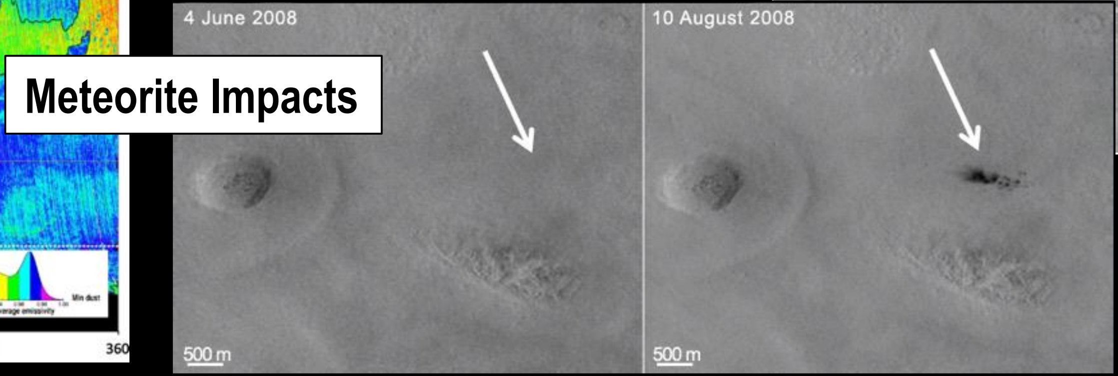
Rate of Seismic Activity



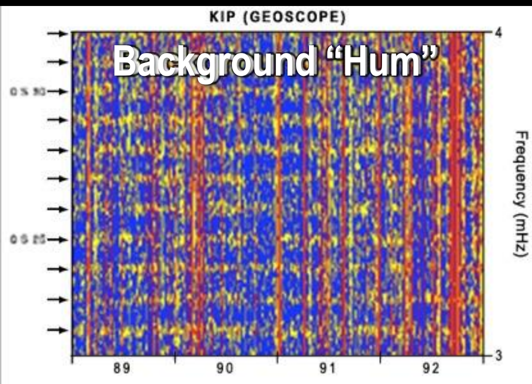


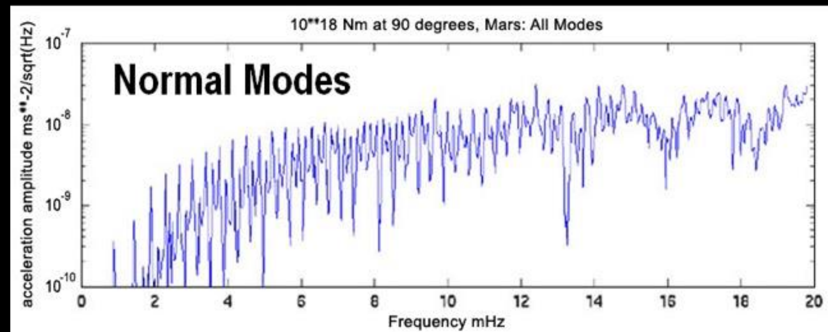


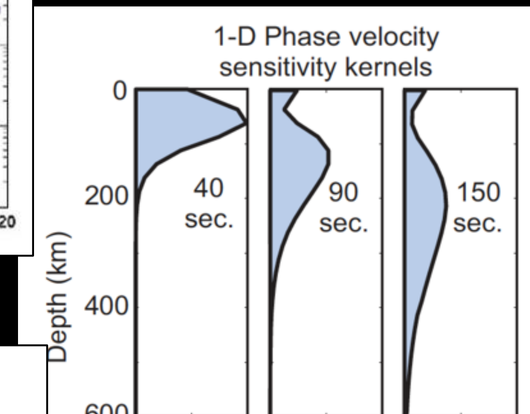




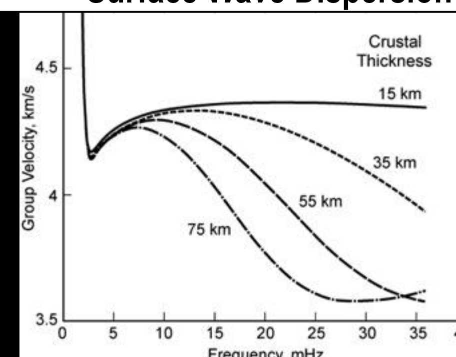
Martian Seismology – Single-Station Analysis Techniques

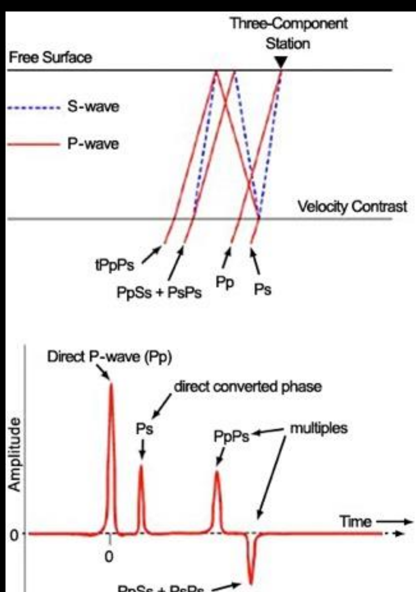




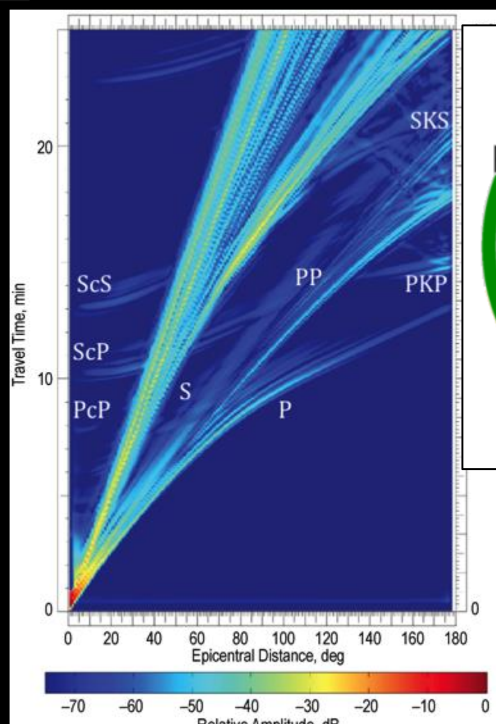


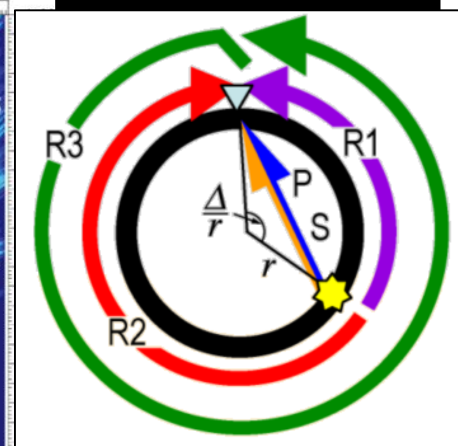
Surface Wave Dispersion





Receiver Function

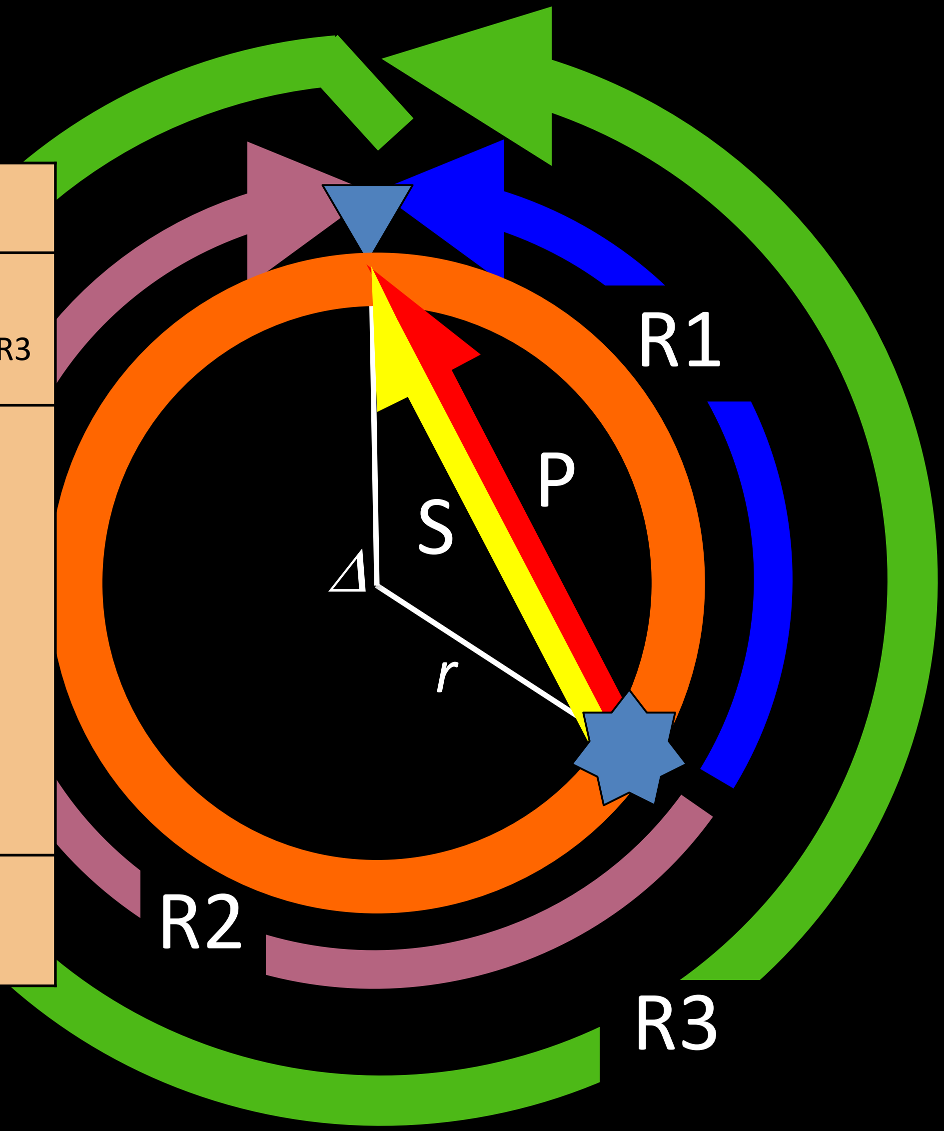




Arrival Time Analysis

Event Location and Seismic Velocities from a Single Record

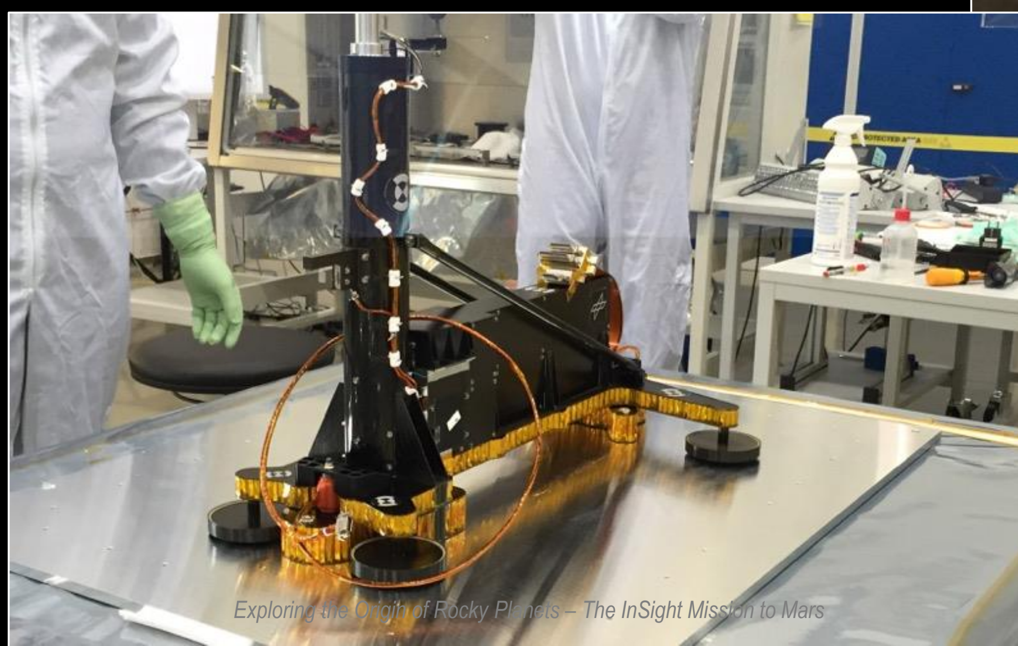
Location and Velocity Determination
Obtain 5 measurements: T_p, T_s, T_{R1}, T_{R2}, T_{R3}
Determine 5 parameters: V_R, Δ, T_0, V_p, V_s • $V_R = 2\pi r/(T_{R3} - T_{R1})$ • $\Delta = \pi r - V_R(T_{R2} - T_{R1})/2$ • $T_0 = T_{R1} - \Delta/V_R$ • $V_p = 2r \sin(\Delta/2r)/(T_p - T_0)$ • $V_s = 2r \sin(\Delta/2r)/(T_s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



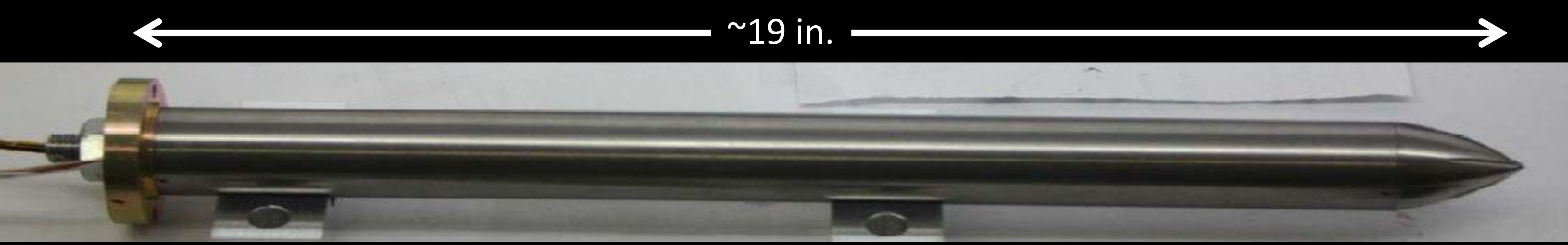
Heat Flow Measurement – HP³

- HP³ (Heat Flow and Physical Properties Probe) has a self-penetrating “mole” that burrows up to 5 meters below the surface.
  - Cable contains precise temperature sensors every 35 cm to measure the temperature changes with depth.

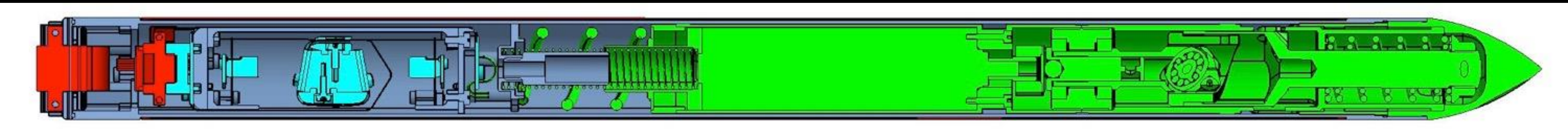
- This will yield the rate of heat flowing from the interior.



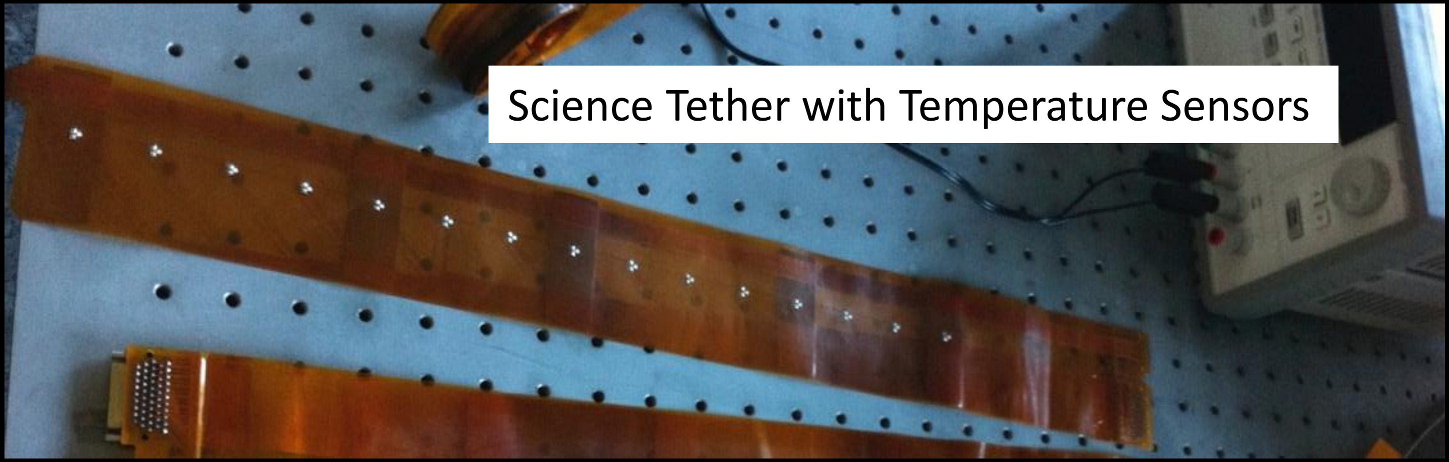
Mole and Science Tether



Tilt meters Motor Hammer Mechanism

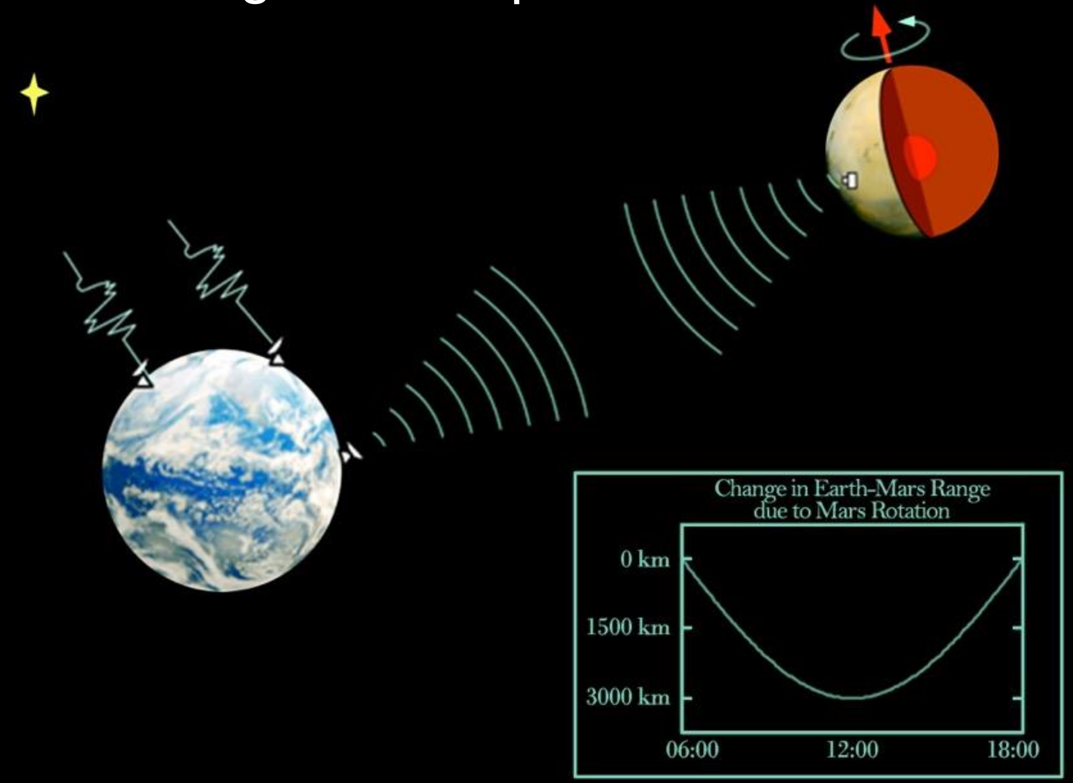


Heater foils within Mole outer hull



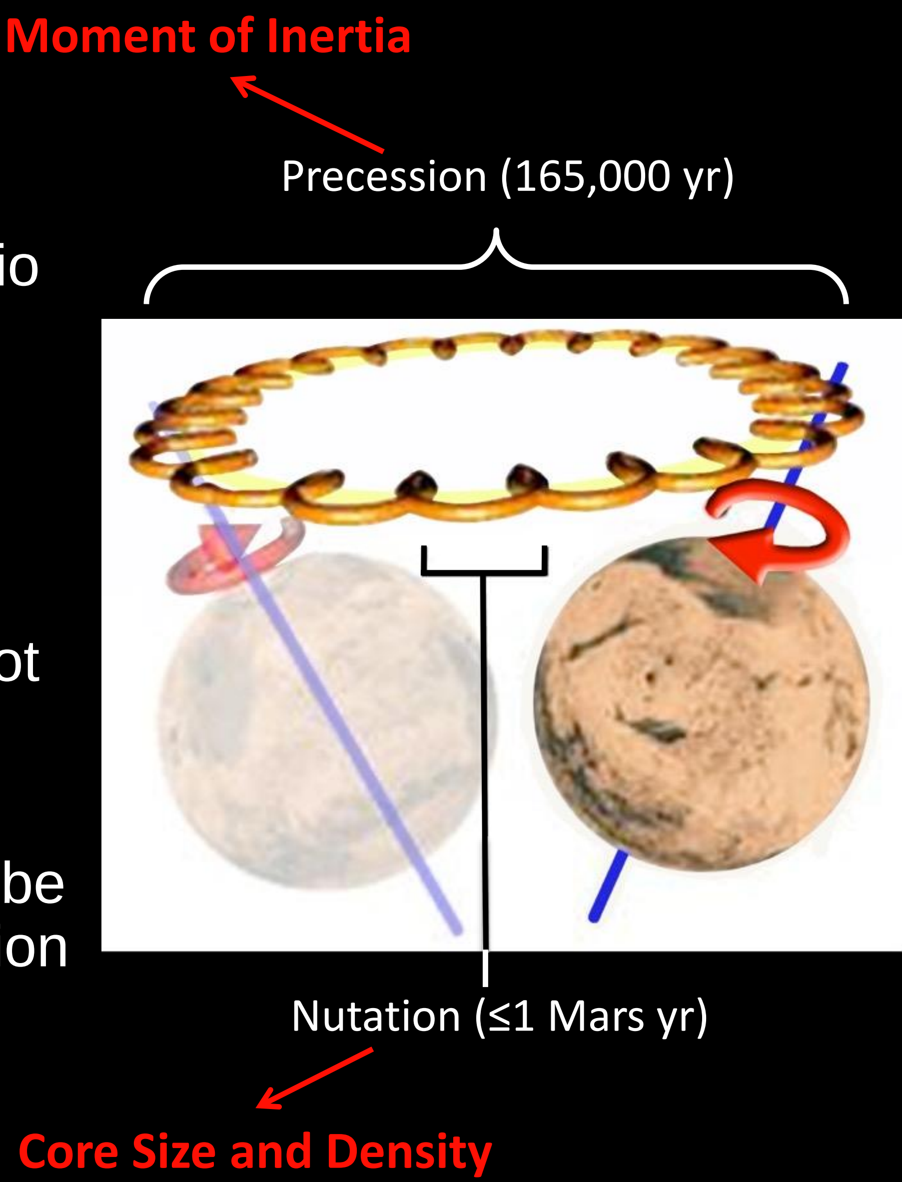
Precision Radio Tracking – RISE

- 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 within **less than 10 cm**.
- By tracking the lander location for about an hour several times a week over the length of the mission, we will be able to determine extremely small changes in the pole direction of Mars.



Precision Radio Tracking – RISE

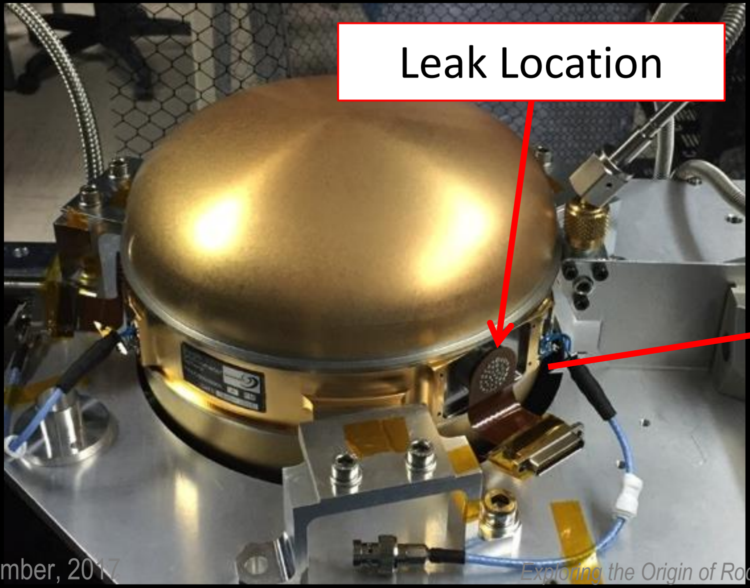
- First measured constraint on Mars' core size came from combining radio Doppler measurements from Viking and Mars Pathfinder, which determined spin axis directions 20 years apart.
- InSight will provide another snapshot of the axis 20 years later still.
- With 2 years of tracking data, it will be also be possible to determine nutation amplitudes and frequencies.

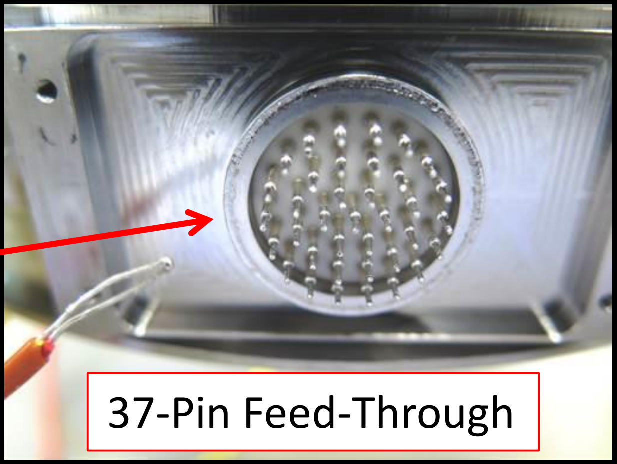


InSight Mission Description

InSight 1.0 Becomes InSight 2.0

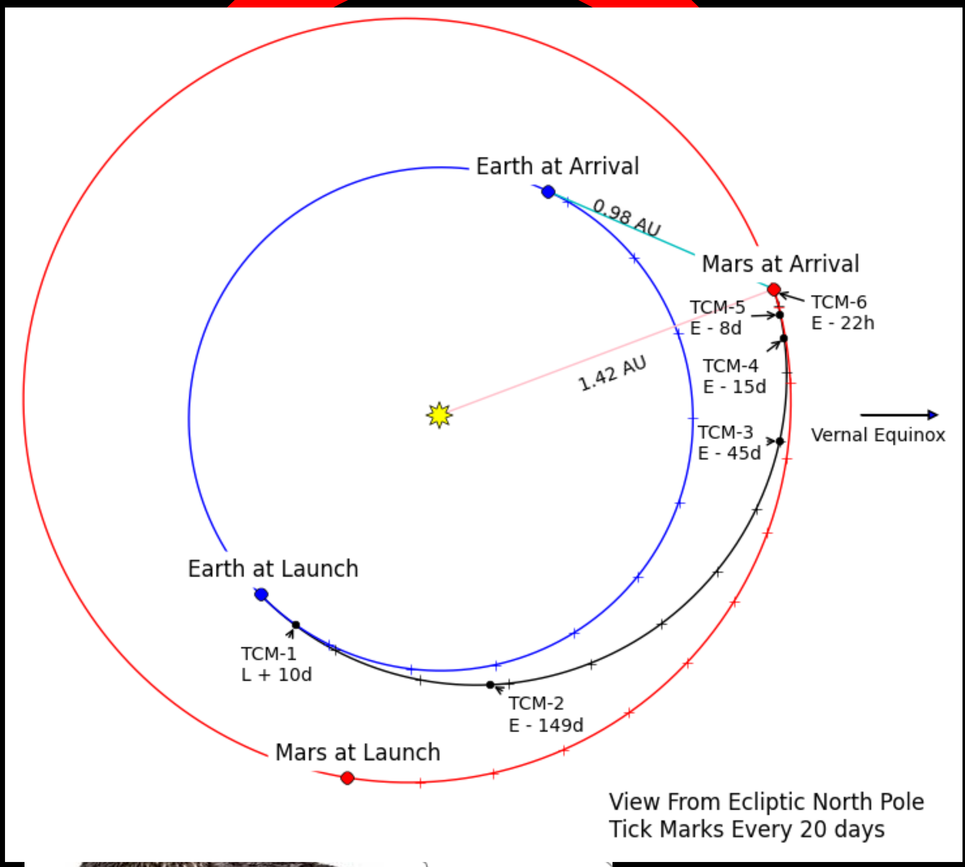
- InSight was originally on a path for a launch in March 2016.
- Due to various development problems, SEIS was about 9 months late on its delivery schedule to the spacecraft.
- About a week before this planned delivery (late August 2015), a tiny leak was detected in the vacuum vessel containing the seismic sensors.
- Despite a crash program to fix this leak, on December 23, 2015 we were forced to abandon the 2016 launch.
- After an intense replanning effort, NASA agreed in March 2016 to extend the InSight project for a launch at the next Mars opportunity in 2018.



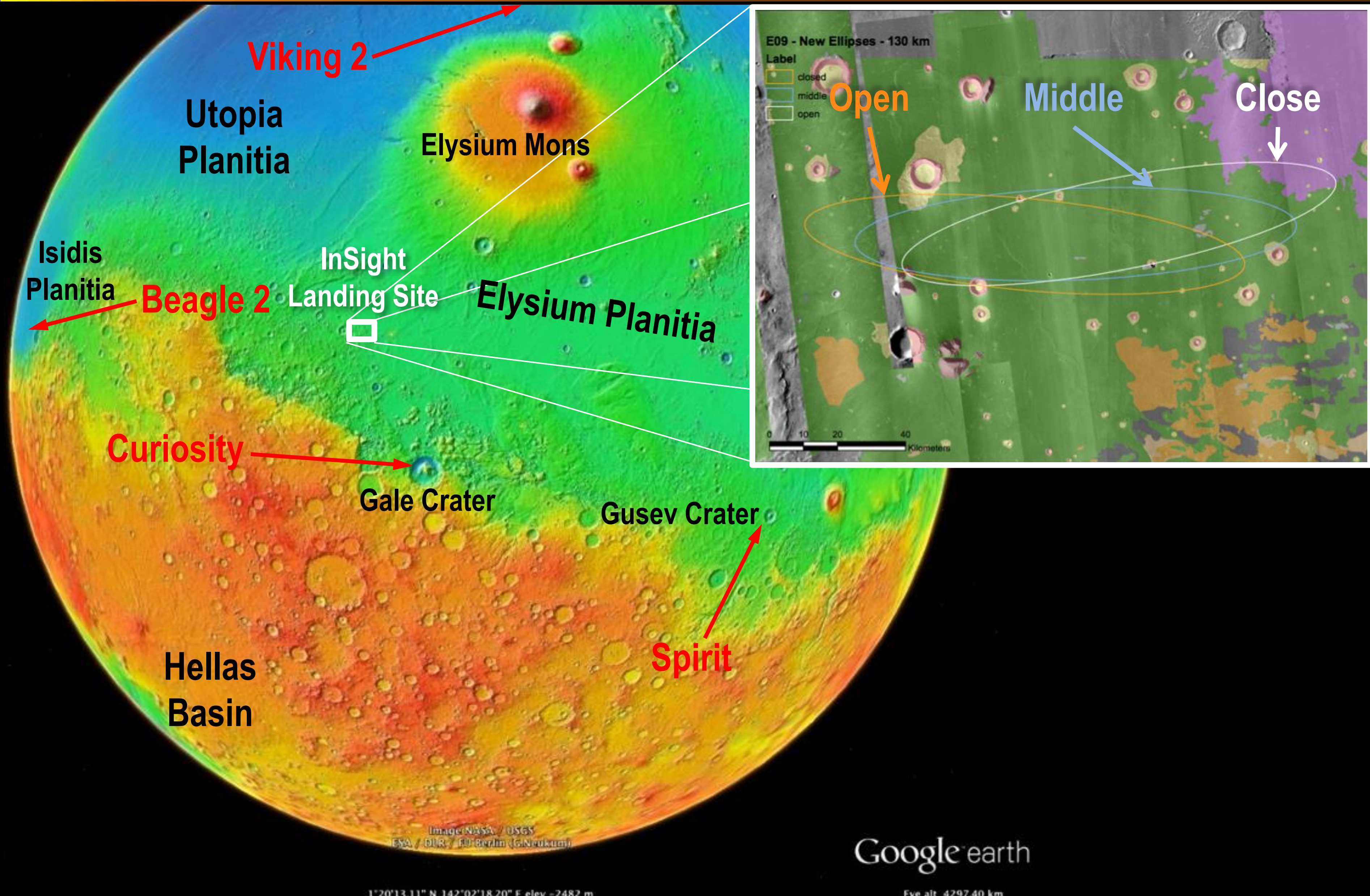


InSight (2.0) Mission Summary

- InSight will fly a near-copy of the successful Phoenix lander
- Launch: May 5-June 8, 2018, Vandenberg AFB, California
- Fast, type-1 trajectory, 6-mo. cruise to Mars
- Landing: November 26, 2018
- Two-month deployment phase
- Two years (one Mars year) science operations on the surface; repetitive operations
- Nominal end-of-mission: November 24, 2020



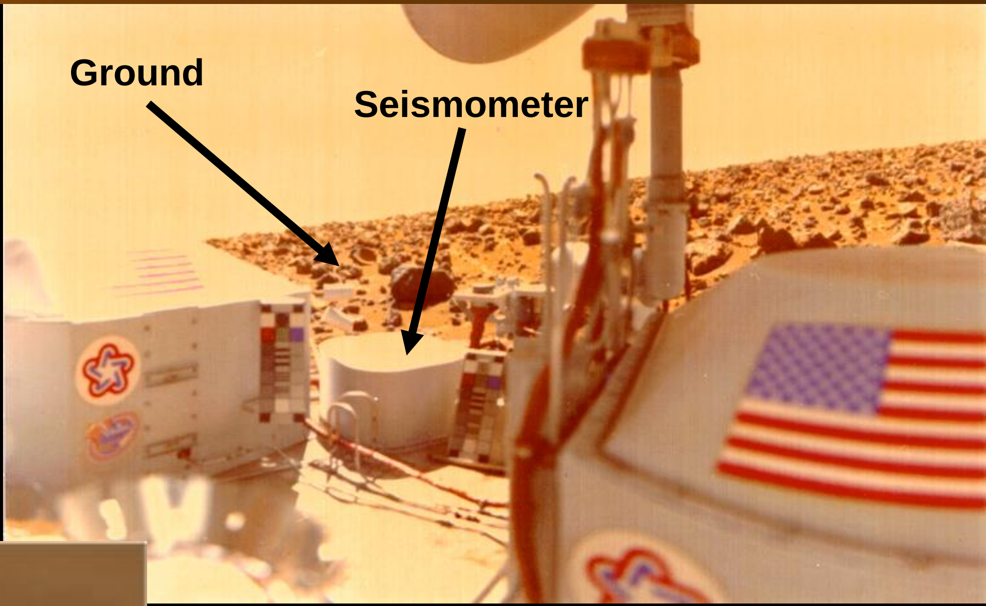
Landing Site – Western Elysium Planitia

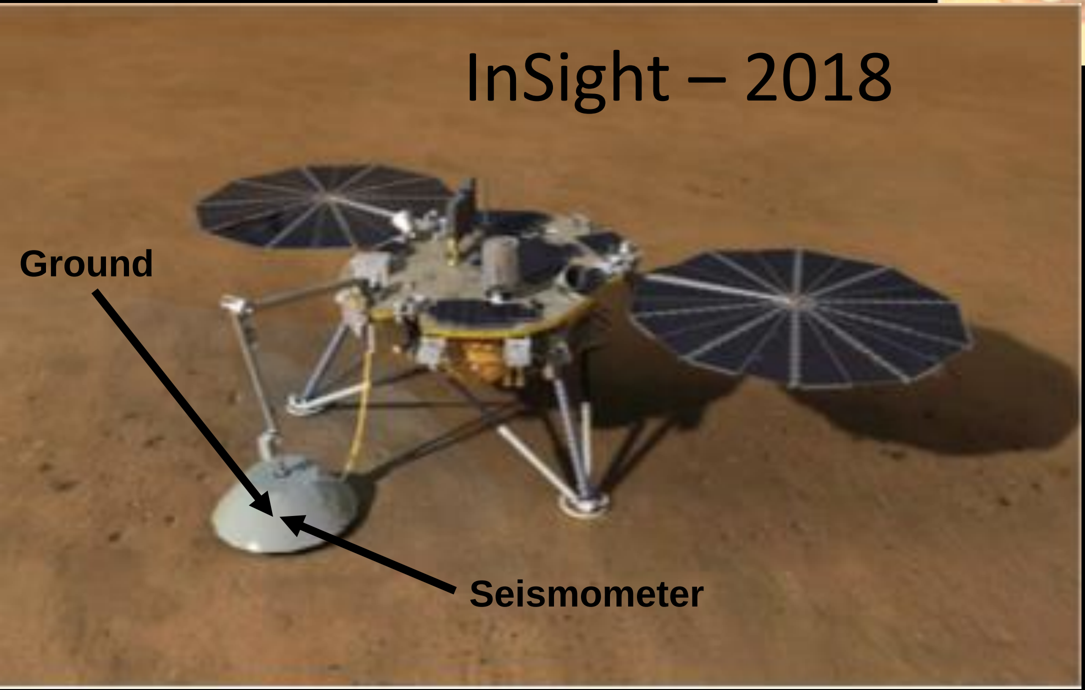


Surface Deployment is Key to InSight Measurements

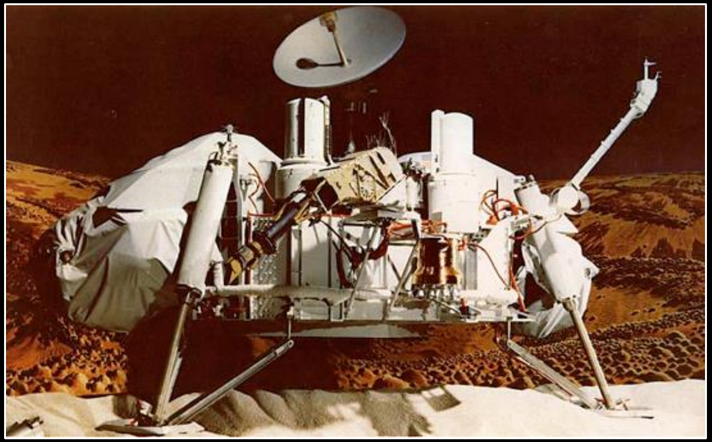
The quality of a seismic station is directly related to the quality of its installation.

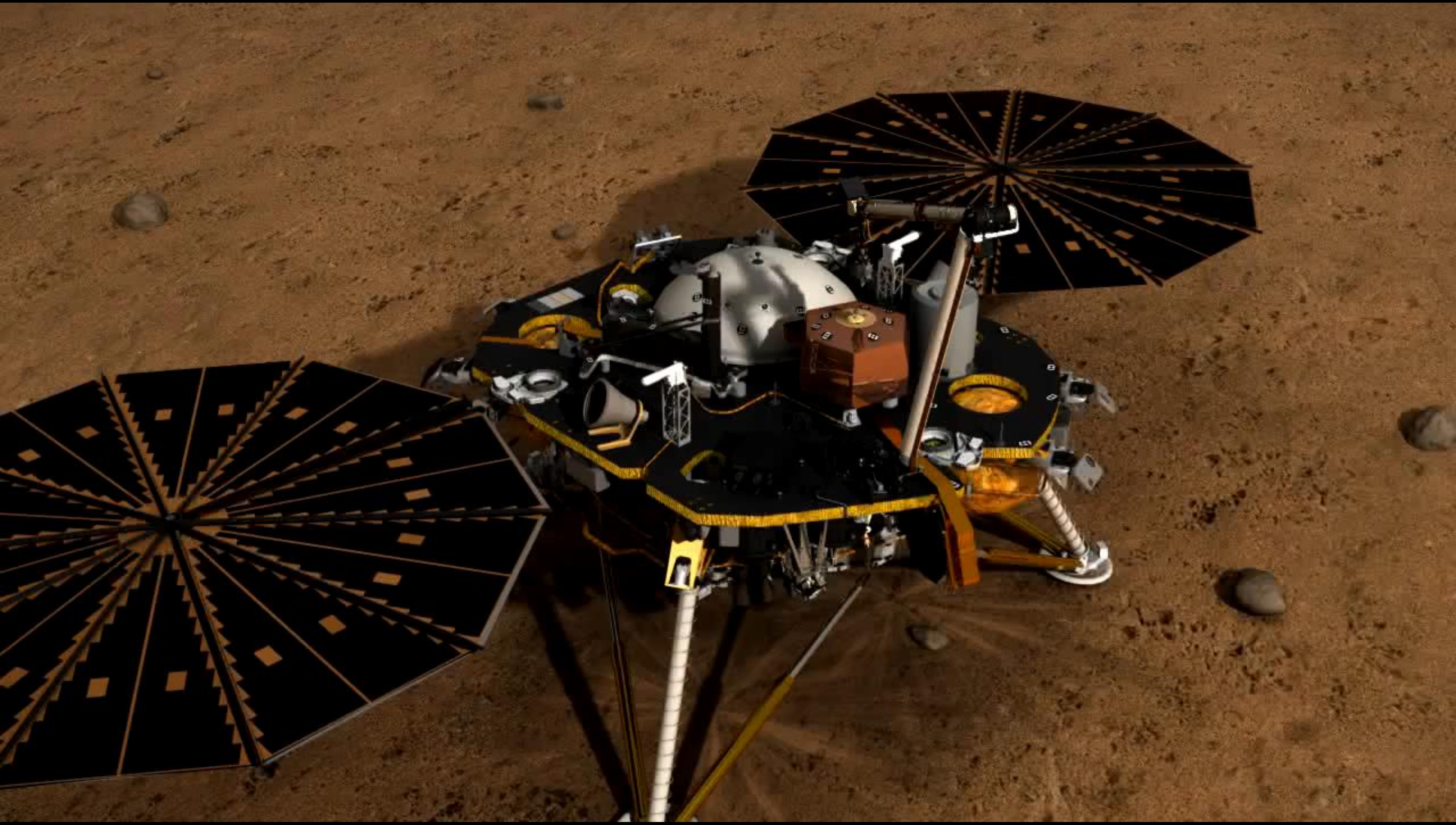
But after traveling 650 million km to Mars, the instruments are still ~1 m from the ground…



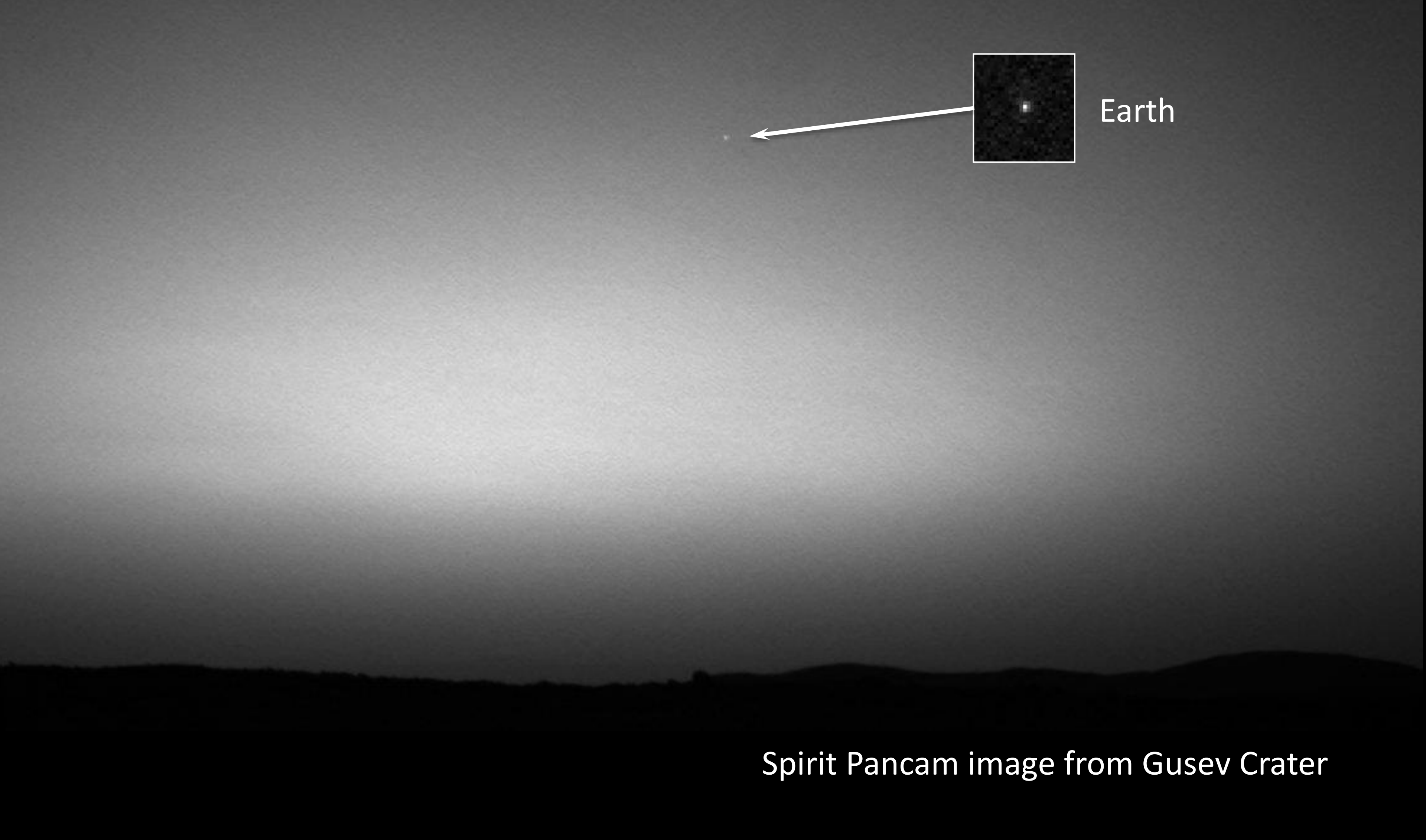


Viking 1 – 1976





Gaining InSight into the Earth, by exploring Mars



Spirit Pancam image from Gusev Crater