InSight: A Geophysical Mission to a Terrestrial Planet Interior

Bruce Banerdt, Principal Investigator
Jet Propulsion Laboratory

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InSight Science Team

PI: Bruce Banerdt, JPL
Sami Asmar, JPL
Don Banfield, Cornell
Lapo Boschi, ETH
Ulrich Christensen, MPS
Véronique Dehant, ROB
RISE PI: Bill Folkner, JPL
Domenico Giardini, ETH
Walter Goetz, MPS
Matt Golombek, JPL
Matthias Grott, DLR
Troy Hudson, JPL
Catherine Johnson, UBC
Günter Kargl, IWF

Dep. PI: Sue Smrekar, JPL
Naoki Kobayashi, JAXA
SEIS PI: Philippe Lognonné, IPGP
Justin Maki, JPL
David Mimoun, SUPAERO
Antoine Mocquet, Univ. Nantes
Paul Morgan, Colo. Geol. Surv.
Mark Panning, Univ. Florida
Tom Pike, Imperial College
HP³ PI: Tilman Spohn, DLR
Jeroen Tromp, Princeton
Tim van Zoest, DLR
Renée Weber, MSFC
Mark Wieczorek, IPGP
• The interior of a planet retains the signature of its origin, overprinted to a variable degree by its subsequent evolution.

• It 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.
  – Source and/or sink for energy, materials.

• It provides the geochemical “background” against which biomarkers will be measured.

• 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, mantle convection.
  – The Moon was formed under unique circumstances and with a limited range of P-T conditions (<200 km depth on Earth).
  – Observing another planet (any planet!) will provide enormous advances in our understanding of the history of the solar system and planetary processes in general.
The seismic exploration of Mars’ interior has been a consistent, high-priority planetary science objective for 35 years.
InSight Mission’s Science Goal:

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

Directly addresses NASA, ESA and 2011 Planetary Science Decadal Survey objectives for understanding the origin and diversity of terrestrial planets.
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. We seek to understanding the processes by which this structure is formed.

- There is strong evidence that its basic crust and mantle structure have survived little changed from the first few hundred Myr of formation.
- 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.

Mars is uniquely well-suited to study the common processes that shape all rocky planets and govern their basic habitability.
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.
Our understanding of planetary differentiation is largely based on the lunar magma ocean model, which was developed in response to Apollo geochemical and geophysical data. But…

- This is a complex process; the physics is not well understood and present constraints are limited.
- Lunar P-T conditions are not particularly representative of other terrestrial planets.
**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?

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Current Uncertainty</th>
<th>InSight Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crustal thickness</td>
<td>65±35 km (inferred)</td>
<td>±5 km</td>
</tr>
<tr>
<td>Crustal layering</td>
<td>no information</td>
<td>resolve 5-km layers</td>
</tr>
<tr>
<td>Mantle velocity</td>
<td>8±1 km/s (inferred)</td>
<td>±0.13 km/s</td>
</tr>
<tr>
<td>Core liquid or solid</td>
<td>“likely” liquid</td>
<td>positive determination</td>
</tr>
<tr>
<td>Core radius</td>
<td>1700±300 km</td>
<td>±75 km</td>
</tr>
<tr>
<td>Core density</td>
<td>6.4±1.0 gm/cc</td>
<td>±0.3 gm/cc</td>
</tr>
<tr>
<td>Heat flow</td>
<td>30±25 mW/m² (inferred)</td>
<td>±3 mW/m²</td>
</tr>
<tr>
<td>Seismic activity</td>
<td>factor of 100 (inferred)</td>
<td>factor of 10</td>
</tr>
<tr>
<td>Seismic distribution</td>
<td>no information</td>
<td>locations ≤10 deg.</td>
</tr>
<tr>
<td>Meteorite impact rate</td>
<td>factor of 6</td>
<td>factor of 2</td>
</tr>
</tbody>
</table>
**InSight Payload**

**RISE (S/C Telecom)**
Rotation and Interior Structure Experiment

**HP³ (DLR)**
Heat Flow and Physical Properties Probe

**SEIS (CNES)** (also IPGP, ETH/ESA, MPS/DLR, IC/Oxford/UKSA, JPL/NASA)
Seismic Experiment for Interior Structure

**IDA (JPL)** – Instrument Deployment Arm

**IDC (JPL)** – Instrument Deployment Camera

**ICC (JPL)** – Instrument Context Camera

**Surface Deployment Test Bed**

**Tether Length Monitor**

**Scientific Tether**
- Embedded T sensors for thermal gradient measurements

**Tractor Mole (TM)**
- Hammering mechanism
- Active thermal conductivity measurements
- Static Tilt sensors

**Pressure, Temperature and Wind sensors**

**Electronics**

7 March 2013

CAPS Meeting, Washington, DC
Martian Seismology – SEIS

Multiple Signal Sources

Faulting

Rate of Seismic Activity

Atmospheric Excitation

Phobos Tide

Meteorite Impacts

InSight Landing Area

Daubar et al., 2010
Martian Seismology – SEIS

Single-Station Analysis Techniques

Receiver Function

Background "Hum"

Normal Modes

1-D Phase velocity sensitivity kernels

Surface Wave Dispersion

Arrival Time Analysis
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).

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

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

Free core nutation constrains core MOI directly, allowing separation of radius and density.
HP$^3$ (Heat Flow and Physical Properties Probe) has a self-penetrating “mole” that burrows down 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, these 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.
Prototype Mole is under construction

Breadboard Mole, currently used for part 1 of TRL 6 test at JPL
Auxiliary Payload Elements – To Support Primary Investigations

• Instrument Deployment
  – The Instrument Deployment System (IDS) provides the capability for successfully placing the instruments on the surface of Mars
    • IDA – Robotic arm; left-over hardware from MSP01
    • IDC – Arm-mounted MER/MSL Navcam; modified for color imaging
    • ICC – Under-deck-mounted wide-angle MER/MSL Hazcam

• Environmental monitoring
  – InSight will carry a meteorological package to characterize the atmospheric noise environment for SEIS
    • Pressure (mPa barometer; JPL)
    • Wind speed and direction, air temperature (REMS-based anemometer and thermal sensors; CAB, Spain)
    • Ground temperature (MARA-based 3-filter IR radiometer; DLR)
    • Magnetic field (0.1 nT vector magnetometer; UCLA)

• Note that these can be all be used for Mars research
Seismometer Sensitivity

- A seismometer is essentially an accelerometer consisting of a mass on a spring.
  \[ F = ma = k \Delta x \]
  – Measure \( \Delta x \), get \( a \).
- Instrument noise requirement at 1 Hz: \( \leq 10^{-9} \text{ m/s}^2/\text{Hz}^{1/2} \)
  – For oscillatory motion,
  \[ x = a/\omega^2 = a/4\pi^2f^2 \]

\( \Rightarrow \) SEIS is sensitive to displacements of ~\( 2.5 \times 10^{-11} \text{ m} \)

This is about half the Bohr radius of a hydrogen atom.
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 large payload mass capability of the Phoenix lander to fly a very capable 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 Wind/Thermal Shield Deployment
InSight Mission Summary

- InSight will fly a near-copy of the successful Phoenix (and unsuccessful MPL) lander
- Launch: March 8-27, 2016
- Land: September 20, 2016
- Two years (one Mars year) on the surface
Deployment Test Bed
**HP³ Testbeds at DLR and JPL**

- **Deep Penetration Testbed A**
  - 3 x 0.6 m
  - Bremen

- **Deep Penetration Testbed B**
  - 5 x 0.8 m
  - Bremen

- **Inclined Testbed**
  - 2 x 2 x 1 m
  - Bremen

- **Geothermal Testbed**
  - 2.5 x 0.6 m
  - Pasadena

- **Mechanical Testbed**
  - 3 x 0.6 m
  - Pasadena
Taking the Plunge – August 20, 2012
“Look deep into nature, and then you will understand everything better.” – Albert Einstein