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

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InSight Mission Science

Exploring the Origin of Rocky Planets – The InSight Mission to Mars
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 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 on the interiors of only two (closely related) terrestrial planets, the 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.
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.
Differentiation in a Terrestrial Planet

Lunar Magma Ocean Model

- Molten
- Metallic Core
- Quenched Crust
- Anorthosite Crust
- Olivine/Low-Ca Pyroxene Cumulate

- Plagioclase
- Pyroxene
- Olivine
- Iron/Nickel
Mars Structure Compared to Earth and Moon

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Earth
- Oceanic crust: 5 – 15 km
- Continental crust: 30 – 50 km
- Upper mantle
- Lower mantle
- Fluid outer core
- Solid inner core
- Core/mantle boundary
- Discontinuities

Mars
- Basaltic crust: 60 ± 30 km?
- Mantle
- Core: Solid? Liquid?
- 1690 ± 300 km?

Moon
- Basaltic crust: 40 ± 10 km
- Mantle
- Partial melt: 1260 – 1410 km
- Fluid outer core: 1410 – 1500 km
- Solid inner core: 1500 – 1737 km
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.
<table>
<thead>
<tr>
<th><strong>InSight Level 1 Requirements</strong></th>
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<tbody>
<tr>
<td><strong>Crust</strong></td>
</tr>
<tr>
<td>thickness</td>
</tr>
<tr>
<td>layering</td>
</tr>
<tr>
<td><strong>Mantle</strong></td>
</tr>
<tr>
<td>stratification</td>
</tr>
<tr>
<td><strong>Core</strong></td>
</tr>
<tr>
<td>size</td>
</tr>
<tr>
<td>density</td>
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<tr>
<td><strong>Thermal structure</strong></td>
</tr>
<tr>
<td><strong>Measures of activity</strong></td>
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<tr>
<td>Distinguish liquid vs. solid outer core</td>
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<tr>
<td>Determine the core radius</td>
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<tr>
<td>Determine the core density</td>
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<td>Determine the heat flux</td>
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<td>Determine the rate of seismic activity</td>
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<tr>
<td>Determine epicenter locations</td>
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<tr>
<td>Determine the rate of meteorite impacts</td>
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</tbody>
</table>
InSight Payload
InSight Payload Configuration

In the diagram, the following components are highlighted:

- **SEIS (WTS)**: Sensitive Electronics Instrument Sensitivity (Wide-Template Sensitivity)
- **HP³**: High-Precision Instrument Electronics
- **IDA (Robotic Arm)**
- **Scoop**
- **Grapple**
- **IDC (Color Navcam)**
- **ICG (Color Hazcam)**
- **RISE (MGA)**
- **TWINS**
- **Pressure Inlet**
- **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 Chip – Other side of deck**

The diagram represents the payload configuration of the InSight mission to Mars, exploring the origin of rocky planets.
Seismometer Sensitivity

- Acceleration noise requirement over 1 Hz: \( \leq 10^{-9} \text{ m/s}^2/\text{Hz}^{\frac{1}{2}} \)

  - For oscillatory motion,
    \[ x = \frac{a}{\omega^2} = \frac{a}{4\pi^2f^2} \]

  \( \Rightarrow \) SEIS is sensitive to displacements of \(~2.5\times10^{-11}\text{m}\)

Or half the Bohr radius of a hydrogen atom
Seismometer Sensitivity – Beach Noise in Denver, CO

Time-Spectra Plot (Vertical Component)
Lockheed Martin, Data Sample (5 days, March 2015)

Ocean Microseismic Band

Global Quake

Cultural noise

Frequency [Hz]

Time (X10,000s)
SEIS Sensors

Sensor Head Assembly

Sphere

VBB

LVL

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Other SEIS Components

- Ebox
- RWEB
- WTS
- LSA
- TSB
- Tether
Martian Seismology – Multiple Signal Sources

**Rate of Seismic Activity**

- **Magnitude**
  - 3
  - 4
  - 5
  - 6

- **Expected Range**

**Body Waves**
- 4.0 x 10^18 Nm/yr
- 0.8 x 10^18 Nm/yr
- Earth Intraplate
- Shallow Moonquakes

**Surface Waves**

**Normal Modes**

**Faulting**

**Atmospheric Excitation**

**Phobos Tide**

**Meteorite Impacts**

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Martian Seismology – Single-Station Analysis Techniques

Background “Hum”

Normal Modes

Surface Wave Dispersion

Receiver Function

Arrival Time Analysis

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### Event Location and Seismic Velocities from a Single Record

**Location and Velocity Determination**

<table>
<thead>
<tr>
<th>Obtain 5 measurements: $T_p$, $T_s$, $T_{R1}$, $T_{R2}$, $T_{R3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine 5 parameters: $V_R$, $\Delta$, $T_0$, $V_p$, $V_s$</td>
</tr>
<tr>
<td>- $V_R = 2\pi r / (T_{R3} - T_{R1})$</td>
</tr>
<tr>
<td>- $\Delta = \pi r - V_R (T_{R2} - T_{R1}) / 2$</td>
</tr>
<tr>
<td>- $T_0 = T_{R1} - \Delta / V_R$</td>
</tr>
<tr>
<td>- $V_p = 2r \sin(\Delta/2r) / (T_p - T_0)$</td>
</tr>
<tr>
<td>- $V_s = 2r \sin(\Delta/2r) / (T_s - T_0)$</td>
</tr>
</tbody>
</table>

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

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- Tilt meters
- Motor
- Hammer Mechanism
- Heater foils within Mole outer hull

Science Tether with Temperature Sensors

~19 in.
• 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.
• 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 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

- Elysium Mons
- Gusev Crater
- Gale Crater
- Viking 2
- Beagle 2
- Curiosity
- Isidis Planitia
- Utopia Planitia
- Hellas Basin
- InSight Landing Site

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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…
Gaining InSight into the Earth, by exploring Mars

Spirit Pancam image from Gusev Crater