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BBSI mperial College

InSight: A Geophysical Mission to a Terrestrial Planet Interior

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- 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.



Strategy for Exploration of the Inner Planets: 1977-1987

Committee on Planetary and Lunar Exploration Space Science Board Assembly of Mathematical and Physical Sciences National Research Council

NATIONAL ACADEMY OF SCIENCES Washington, D.C. 1978



NASA-ESA 1998





NASA SSEC 2003

COMPLEX 2003





"Determination of the internal structure of

SPACE SCIENCE IN TH

mposition, structure, s is fundamental to solar system as a providing context for the ses of our own planet."

es for Planetary Science 13-2022

IATIONAL RESEARCH COUNCIL

for Planetary Science in the Decade 2013-2022

The seismic exploration of Mars' interior has been a consistent, high-priority planetary science objective for 35 years.



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



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.



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.
- 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.



- 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.





3

Differentiation in a Terrestrial Planet

Lunar Magma Ocean Model



- 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.



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- **Crust:** Its **thickness** and vertical structure (layering of different compositions) reflects the depth and crystallization processes of the magma ocean and the early postdifferentiation 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
Crustal thickness	65±35 km (inferred)	±5 km
Crustal layering	no information	resolve 5-km layers
Mantle velocity	8±1 km/s (inferred)	±0.13 km/s
Core liquid or solid	"likely" liquid	positive determination
Core radius	1700±300 km	±75 km
Core density	6.4±1.0 gm/cc	±0.3 gm/cc
Heat flow	30±25 mW/m ² (inferred)	±3 mW/m ²
Seismic activity	factor of 100 (inferred)	factor of 10
Seismic distribution	no information	locations ≤10 deg.
Meteorite impact rate	factor of 6	factor of 2





Martian Seismology – SEIS



7 March 2013

InSight

CAPS Meeting, Washington, DC



KIP (GEOSCOPE)

Single-Station Analysis Techniques





- 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.





Nutation (≤ 1 Mars yr)







- HP³ (Heat Flow and Physical Properties Probe) has a selfpenetrating "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
- Togettrenination pielbermaacood unclatity every 50 cm.
 flowing from the interior.
- Present-day heat flow at a given location provides a critical boundary condition on models of planetary thermal history.

InSight reference landing site











TEM foils (TEM-A: foils within Mole outer hull)

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



• A seismometer is essentially an accelerometer consisting of a mass on a spring.

 $F = ma = k \Delta x$

- Measure Δx , get a.
- Instrument noise requirement at 1 Hz: ≤10⁻⁹ m/s²/Hz^{1/2}
 - For oscillatory motion, $x = a/\omega^2 = a/4\pi^2 f^2$
 - ⇒SEIS is sensitive to displacements of ~2.5x10⁻¹¹m

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

7 March 2013



Seismometer and Wind/Thermal Shield Deployment





- InSight will fly a near-copy of the successful Phoenix (and unsuccessful MPL) lander
- Launch: March 8-27, 2016
- Land: September 20, 2016

Surface Configuration

SEIS

 Two years (one Mars year) on the surface





















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

SEIS – SOD4 Prototype, Seismic Vault, St. Maur



CAPS Meeting, Washington, DC

Discovery Announcement – August 20, 2012







The Earth, seen from Mars



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

Gusev Crater