Heat Flow and Physical Properties Package HP$^3$

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What is the energy budget of the planet and how much heat is produced in the planetary interior?

- Heat flow provides \textit{InSight} into the thermal and chemical evolution of the planet by constraining the concentration of radiogenic elements, the thermal history of the planet and the level of its geologic activity.
- Surface heat flow is measured by determining the regolith thermal conductivity, $k$, and the thermal gradient $dT/dz$
  \[ q = k \frac{dT}{dz} \]
- **Key challenges:**
  - Measuring the thermal gradient disturbed by the annual thermal wave.
  - Accurately measuring the thermal conductivity in an extremely low conductivity environment.
Models assuming a Wänke & Dreibus (1994) composition and taking the thermal history as well as crustal contributions to the heat flow into account indicate surface heat flows between 17 and 29 mW/m².

For the same average surface heat flow, larger spatial variability could be caused by mantle plumes.

An Elysium Plume would cause a surface heat flow difference of up to 10 mW/m².
Determine the heat flux at the landing site to within ±5 mW/m².

LVL 1

LVL 2

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
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<tbody>
<tr>
<td>L2-PSRD-196</td>
<td>The InSight Project shall measure the thermal gradient in the subsurface at the landing site to within 7% over the range of 0.1 to 5.0 K/m.</td>
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<tr>
<td>L2-PSRD-197</td>
<td>The InSight Project shall measure the thermal conductivity in the subsurface at the landing site to within 7% over the range of 0.02 to 0.1 W/m·K.</td>
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<tr>
<td>L2-PSRD-xxx</td>
<td>The InSight Mission shall measure the surface brightness temperature at the landing site with an accuracy of better than 1K, and a precision of better than 1 K.</td>
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Subsurface Temperature Variations

- Surface temperature is affected by the diurnal wave to a few 10cm and by the annual temperature wave to several meters depth.

... T range over the entire year
- T on warmest day
- T on coldest day

Need to measure
- thermal gradient below annual wave or
- measure annual wave plus thermal gradient

Credit: InSight Environmental Requirements Document, JPL D-75270, Nov. 15, 2012
- Depth to mole tip of 5 meters allows the science requirements to be met in 235 sols!
- Shallower penetration requires longer measurement: 390 sols for 4 meters; 530 sols for 3 meters; 1 Martian year for 2 meters
**Mole**
- Hammering mechanism
- Heater foils / sensors for active thermal conductivity measurements (TEM-A)
- Static Tilt sensors (STATIL)

**Tether Length Monitor (TLM)**

**Science Tether (TEM-P)**
Embedded T sensors for passive thermal gradient measurements

**Engineering Tether**
Connects to Back End Electronics (BEE) on S/C
Hardware Architecture - Mole

Prototype Mole: Under construction

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

Breadboard mole: Currently used for part 1 of TRL 6 test at JPL
Hardware Architecture - STATIL and TLM

- used together with TLM to reconstruct path of mole. Thereby, depth of the temperature sensors on tether are known to sufficient accuracy to determine heat flow at required accuracy.
- It is protected from the shock of the mole motor by two shock isolation springs

The TLM (together with the tiltmeter)
- is crucial to determine the (absolute) depth of the temperature sensors.
- consists of two strings of markers on the left and right edges of the science tether and of a read-out optoelectronic device to count the passage of the markers.
The science tether is used to measure the temperature gradient as a function of depth in the regolith.

14 PT100 Sensors (4 wire measurements) are soldered onto a 5 m long capton tether and protected by Nusil silicone adhesive.

The tether is 35 mm wide. Its width is slightly larger than the diameter of the borehole to warrant sufficient thermal contact with the borehole wall.
Hardware Architecture – TEM-A

- will measure thermal conductivity by a modified line heat source method
- Combined heaters/temperature sensors glued to outside of mole
- Heaters controlled from backend electronics inside the lander

Prototype accommodation of TEM-A

Breadboard TEM-A
The amount of self-heating when providing a known power to the heaters is a measure of the ambient regolith’s thermal conductivity:

$$\Delta T(t) = C_1 \ln t + C_2$$

- $C_1$ and $C_2$ need to be calibrated by models / experiments
- 2x3 channels to determine the flux in different wavelength bands
- Employs thermopile sensors to measure the temperature of the surface
- To be mounted below the lander deck and measure the surface temperature in an unshadowed region unobstructed by hardware (HP³, SEIS)
Mission Timeline

Launch
March 8, 2016

Instrument Deployment
60 sols

Entry, Descent, and Landing
September 20, 2016

Cruise
(6.5 mo)

Surface Monitoring
(1 martian year, or 687 days, or 23 mo)

End of Surface Monitoring
September 18, 2018

Final Data Deliveries
(7 mo)

End of Mission
February 24, 2019

Roughly to scale

The technical data in this document is controlled under the U.S. Export Regulations; release to foreign persons may require an export authorization.
- HP³ is deployed by the Instrument Deployment System (IDS)
- The penetration phase lasts ~ 30 Sols and incorporates thermal conductivity measurements between hammering cycles.
- During penetration STATIL and TLM are used to determine the mole path
• Bremen has the facilities available needed for environmental testing
  – Pyroshock Test Facility
  – Vibration Test Facility
  – Space Simulation Chamber
  – Miscellaneous Thermo-Vac Chambers
  – Climate Chamber
• Incline Test Bed
  – 2m x 2m x 1m, available

• Deep Penetration Test Bed A
  – 3m x 0.6m diameter, available

• Deep Penetration Test Bed B
  – 5m x 0.8m diameter, integration ongoing, available mid February

• Geothermal testbed (GTB)
  – 2.5m x 0.6m diameter, available

• Mechanical Testbed (MTB)
  – 3m x 0.6m diameter, available
Summary

- HP\textsuperscript{3} will
  - conduct the first extraterrestrial heat flow measurement since Apollo
  - contribute important new science to the exploration of Mars
  - combine thermal conductivity, temperature and surface brightness temperature measurements to determine the planet’s heat flux
  - use penetration progress for soil science
  - improve on mature and well understood technology
  - reach TRL 6 in summer 2013