The Penetrating Mole of the InSight Mars Mission

ROBEX Sensorworkshop
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27/04/2017, Vienna
Interior exploration using Seismic Investigations, Geodesy and Heat Transport

Source: NASA/JPL
InSight: Science goals and objectives:

1. Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars by:
   • Determining the size, composition and physical state (liquid/solid) of the core
   • Determining the thickness and structure of the crust
   • Determining the composition and structure of the mantle
   • Determining the thermal state of the interior

2. Determine the present level of tectonic activity and meteoroid impact rate on Mars.
   • Measure the magnitude, rate and geographical distribution of internal seismic activity
   • Measure the rate of meteorite impacts on the surface
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   P/L: **HP3** (by DLR)

   SEIS (by CNES)

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Heat Flow

- 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 $dT/dz$:

$$ F = k \frac{dT}{dz} $$

- Key challenges:
  - Measuring the thermal gradient undisturbed by the annual thermal wave.
  - Accurately measuring the thermal conductivity in an extremely low conductivity environment.
HP³: Operational Concept
HP³: Operational Concept (BACKUP)
HP³: System Assembly Overview

- Tether Storage compartment
- 2x Tether Length Monitor (TLM)
- Electronic Box
- Penetrating Mole
- Science Tether
- Engineering Tether
- Lightweight CFRP structure
HP³: Science Tether

• Kapton based flex cable including PT100 sensors to determine thermal gradient
• Potted for mechanical protection
HP³: Mole Subsystems

- Development started in late 2012 from ~TRL 3-4
- No sampling/retraction capability (as had PLUTO@Beagle 2)

- **DLR Bremen**
  - Outer Hull, Back Cap, Motor, Payload Compartment

- **CBK Warsaw**
  - Hammering mechanism, tip, locking mechanism

- **DLR Cologne**
  - STATIL (tilt/inclination meter)

- **DLR Berlin**
  - TEM-A, TEM-P (thermal measurement suite)
HP³: Mole Mechanism
HP³: Mole Mechanism (BACKUP)

Diagram showing the steps of the mole mechanism:

a) Start of force spring compression
b) Continue force spring compression
c) Force spring max. compression
d) Force spring release and fwd. shock
e) Backwards motion of sliding mechanism
f) Sliding mechanism fall-back (2nd fwd. shock)

Labels:
- Brake spring
- Actuator
- Force spring
- Shaft
- Roller
- Cylindrical cam
- Hammer

Developed view of cylindrical cam with position of roller, relative to soil:
Lichtenheldt, Schäfer, Krömer
Hammering beneath the surface of Mars – Modeling and simulation of the impact-driven locomotion of the HP3-Mole by coupling enhanced multi-body dynamics and discrete element method
urn:nbn:de:gbv:ilm1-2014iwk-155:2
HP³: Mole Mechanism (MBS & Thermal Sim)

Shock wave propagation through soil
HP³: Deep Penetration Tests

- Stroke rate: 1 stroke per 4 seconds,
- Penetration rate: 5m in ~27h
- Rates primarily determined by available power/voltage from lander
HP³: Flight Unit Ready!
**Aqua- / Cryo-Mole**

**Aqua-Mole**

- Small mole systems – water / pressure tight
- In-situ characterization of underwater sediments with respect to mechanical properties (*recoverable instrumented mole*)
- Sampling of underwater (*recoverable sampling mole*)
- Geophysical measurements from moles embedded in underwater sediments, e.g. for seismicity and heat flow investigations (*non-recoverable instrumented mole* or a *recoverable instrumented mole*)

**Cryo-Mole**

- Sub-variant of the Aqua-Mole
- Equipped with additional heaters for use in snowy or icy environments.

* Krömer, Richter / Oceans09
Aqua- / Cryo-Mole: Early proof-of-concept tests and results

- Heating/melting cycles in ice-soil mix
- Tip heating essential in case of very cold ice
- Combined melting and hammering allows intrusion (rough calculation of speed: 3 cm/h)
## Aqua- / Cryo-Mole: Potential destinations

<table>
<thead>
<tr>
<th>Body</th>
<th>Surface Material</th>
<th>Operating Temperature</th>
<th>Surface Pressure</th>
<th>Intrusion Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td>Sediment or ice/snow</td>
<td>273K +/-?</td>
<td>&gt;1 bar</td>
<td>?</td>
</tr>
<tr>
<td>Mars</td>
<td>dust layer and ice with soil</td>
<td>210 K</td>
<td>6 mbar</td>
<td>1-10 m</td>
</tr>
<tr>
<td>Europa</td>
<td>ice with dust and salt inclusions</td>
<td>110 K</td>
<td>1x10^{-11} bar</td>
<td>3 m</td>
</tr>
<tr>
<td>Europa (ice with methane/ethane)</td>
<td>ice with methane/ethane</td>
<td>95 K</td>
<td>1.5 bar</td>
<td>?</td>
</tr>
</tbody>
</table>
Conclusions

HP3 Status

• The InSight mission awaits launch in May 2018 and landing in September October/November 2018

• It carries DLR’s Heat Flow & Physical Properties Package (HP3) which uses a penetrating mole to dig 5m into the Martian soil

• Opportunities for an Aqua-Mole
  • The Aqua-Mole could be a transfer from space to deep sea
  • It could be a transfer from deep sea / arctic environment into space (e.g. our long term perspective for exploration)

Way forward

• Define / formulate science cases and payload options
• (re-) do technical feasibility studies (water/sediments, snow, ice)