Subsurface probing of planetary bodies

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Outline

- Surface and subsurface thermal physics
- Missions with subsurface science
- Thermal sensors
- Models and measurements
- Heat transport in granular media
Why to go under the surface

- To take samples and analyse their chemical & mineralogical composition
- To perform measurements of physical properties (seismometry, thermal properties, mechanical properties, structure)
- To reach deep layers of the body (subsurface ocean on Europe)
- To collect minerals and precious materials (e.g. He3 on the Moon)
Techniques of surface and subsurface exploration

- Taking samples
- Drilling
- Hammering
- Anchoring
- Penetrating mole
- Melting in
Thermal processes in planetary bodies

- **Heat sources**
  - hot interior
  - surface irradiation

- **Thermal transport processes**
  - heat conduction (in solid, liquid and gas phases)
  - radiative transfer
  - advection/convection (mass motion)

**Quantities to be determined:**

- Temperature profile $T(z)$
- Heat flow $K \cdot rT$
- thermal conductivity $K$, thermal diffusivity, thermal inertia
Example: heat transport in comets

Heat transport equation (Prialnik & Podolak)

\[
\frac{\partial u(T)}{\partial t} + (\rho_{c} c_{d} + \rho_{v} c_{v} + \rho_{g} c_{g}) \frac{\partial T}{\partial t} + \nabla \cdot F = \lambda(T) \rho_{a} (1 - f_{g}) H_{ac} - q_{v} H_{v} - q_{g} H_{g}.
\]

Koemle

Conduction

Advection

Amorph. ice <-> cryst. ice

Sublimation
Missions with subsurface thermal experiments

- Apollo 15 & 17
- Mars-Express: Beagle
- Rosetta: MUPUS (Philae)
- Phobos-Grund
- Exo-Mars: HP3

**Apollo**: thermal probes inserted into boreholes 2m deep, but sensors not properly deployed, therefore heat flow values, 28-33 mW/m$^2$ questioned => the uncertainty in the lunar core temperature is 250 - 400º
Penetrators

MUPUS on Philae (Rosetta Lander)
PI – Tilman Spohn (DLR)

Penetrator designed & manufactured in SRC, Warsaw
Penetrators: moles

- HP3 (Exo-Mars) – Beagle heritage
Thermal sensors

- Resistance thermometers

THP sensors
- design for MUPUS 1999

active area = 1 dem²
length = 325 mm

kapton 50μm thick
Titanium thin layer <0.5μm thick
Copper paths 17μm thick
Thermal sensors

- Principle of operation

Hot rod method

**Thermal conductivity measurements:**

\[ T - T_0 = \frac{2Q\alpha^2}{\pi^3\lambda} \int_0^\infty 1 - \exp\left(-\kappa tu^2/r^2\right) \frac{u^3\Delta(u, \alpha)}{\Delta(u, \alpha)} du \]

Where:

- **t** - time
- **T_0** - initial temperature
- **Q** - applied heating power
- **\lambda** - thermal conductivity
- **\kappa** - thermal capacity
- **\alpha** - heat capacity ratio: medium to wire
MUPUS measurements on Earth

The snow setup in vacuum

Graz | Gz_snow_3T.asc

PT100

heated

bottom

surface

T [°C]

time [min]

min
Potential problems

- Conductivity of thin sensors (titanium, copper) is different than the conductivity of the bulk material
- Calibration: precise K(T) dependence should be taken
- Aging effects => recalibration 12 years after sensor manufacturing should be done
- Two wire method used => reference current should be measured before each measurement
- Heating and temperature measurements must be done sequentially
New sensors

(wires to measure- and- power-supply system)

a) b) c)
New sensors

Connection to datalogger using 4 wire resistance measurement method

Electric power supplied and controlled by datalogger.

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**Platinum sensor circuit**

- Copper wires
- Electric power supplied and controlled by datalogger.

**Graphs**

- **Platinum**
  - Line graph showing resistance vs. temperature (T [K])
  - Temperature range from 173 to 473 K
  - Resistance values from 50 to 200 Ω

- **Isotan**
  - Graph showing resistance vs. temperature (T [K])
  - Temperature range from 173 to 473 K
  - Resistance values from 99.4 to 100.2 Ω
Thermal measurements

- Cometary material & asteroid regolith analogues
- Teflon and delrin as reference materials
- Measurements in thermal and thermal-vacuum chambers
Models

- Analytical: applicable for simple geometries and quite complicated
- Semi analytical based on Green functions
- Numerical: FEM
Measurements: calibration

Teflon - thermal chamber

Sensitivity of simulations
Measurements
Measurements

- In thermal chamber => $K$ in the narrow range 0.2 - 0.4 W/m/K
Granular media

- Different transport processes (Slavin et al.)

\[ \dot{Q} = K_{\text{eff}} \frac{4R^2(T_1 - T_2)}{2\alpha_e R} = G(T_1 - T_2) \]

\[ G = G_f + \frac{G_s(G_{\text{par}})}{G_s + G_{\text{par}}} \text{ with } G_{\text{par}} = G_o + G_i + G_c. \]

\[ G_s = K_s \alpha_s \pi R^2 / 2R, \quad G_c = K_s \alpha_c \delta / h_r, \]

\[ G_f = \frac{4\sigma_s}{2/\epsilon - 1} \alpha_f 4R^2 T^3, \quad G_i = K_i \alpha_i \pi B^2 / g, \]

\[ G_o = K_o[1 - \exp(-R/\lambda)] \alpha_o \pi (R^2 - B^2) / R \]

\[ \approx K_o[1 - \exp(-R/\lambda)] \alpha_o \pi R. \]
Granular media (2)

Slavin et al., 1 mm aluminum spheres

When the parameters of cometary/asteroid analogues are used then $K \approx 0.2 \text{ W/m/K}$ at atmospheric pressure
Future research

- Different sensor designs should be tested
- Modeling needs improvement => granularity of medium taken into account
- Thermal resistance between the sensors and the medium is the main experimental problem

- Between not too frequent space missions most of the planetary research will be done in the lab
Thank you for your attention