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)

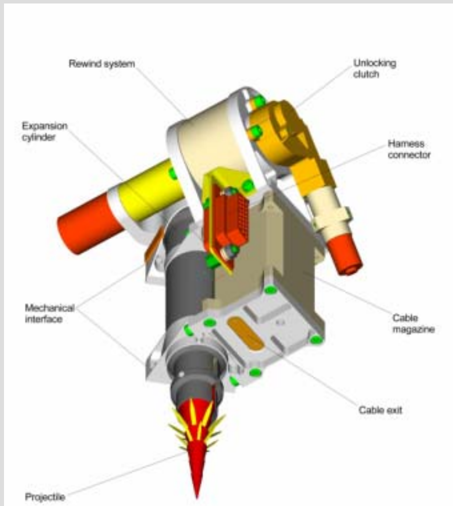
Techniques of surface and subsurface exploration

Taking samples

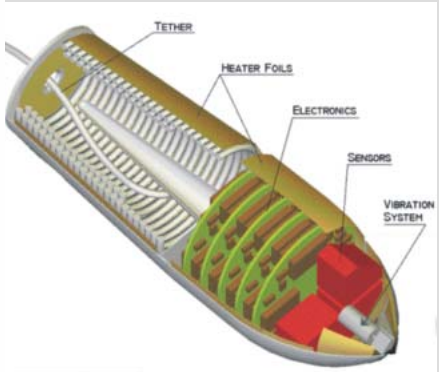
Hammering

Penetrating mole

Drilling



Anchoring



Melting in

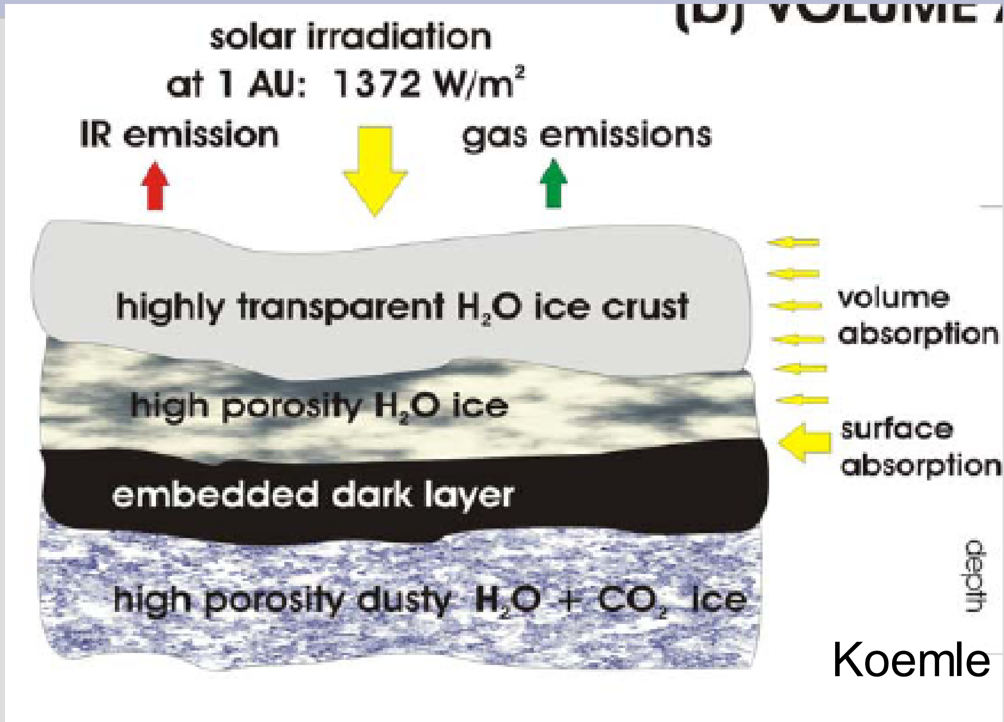
Thermal processes in planetary bodies

- 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 rT**
- **thermal conductivity K, thermal diffusivity, thermal inertia**

Example: heat transport in comets



Heat transport equation
(Prialnik & Podolak)

Conduction

$$(\rho_a+\rho_c+\rho_s)\frac{\partial u(T)}{\partial t}+(\rho_d c_d+\rho_v c_v+\rho_g c_g)\frac{\partial T}{\partial t}+\nabla\cdot\mathbf{F}$$
$$+(c_v\mathbf{J}_v+c_g\mathbf{J}_g)\cdot\nabla T=\lambda(T)\rho_a(1-f_g)H_{ac}-q_vH_v-q_gH_g.$$

Advection

Amorph. ice
<=> cryst. ice

Sublimation

Missions with subsurface thermal experiments

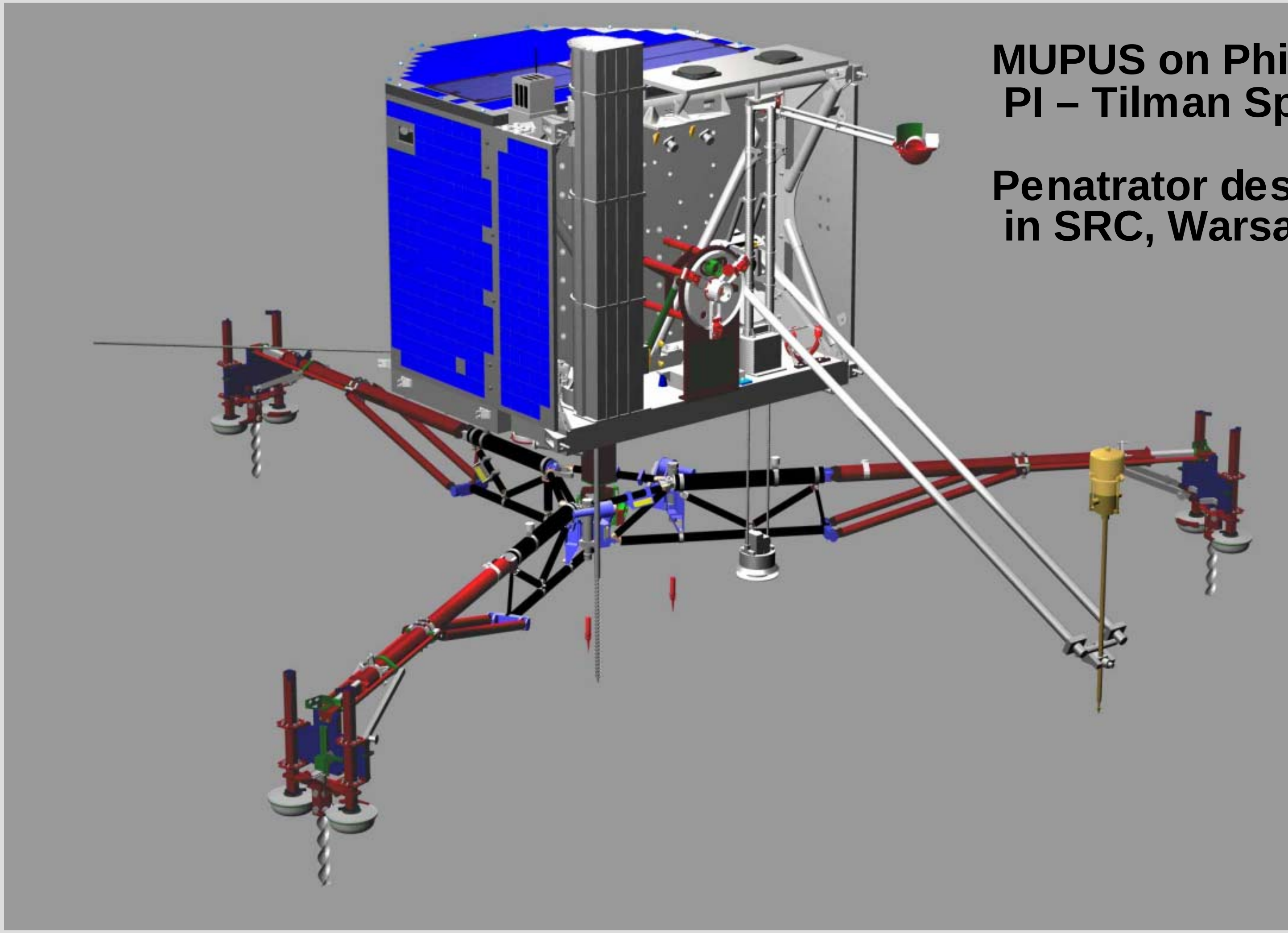
- Apollo 15 & 17
- Mars-Express: Beagle
- Rosetta: MUPUS (Philae)
- Phobos-Grund
- Exo-Mars: HP3

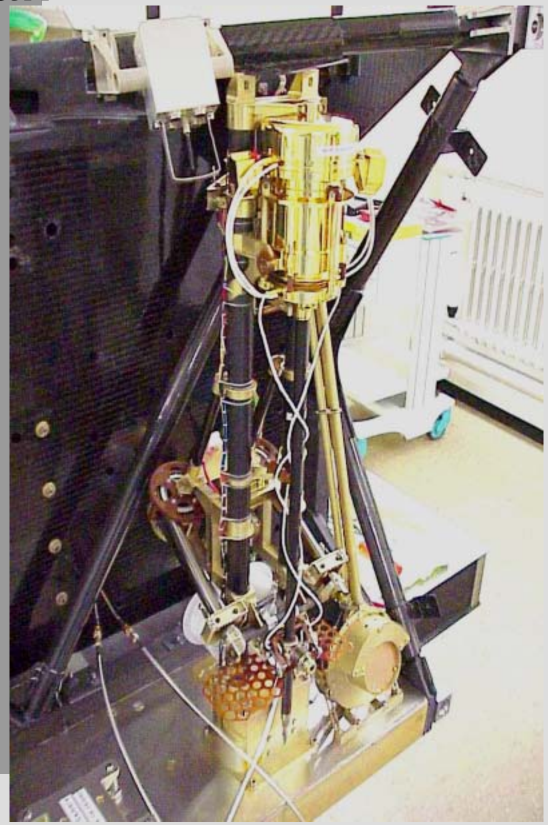
Apollo: thermal probes inserted into boreholes 2m deep, but sensors not properly deployed, therefore heat flow values, 28-33 mW / m^2 questioned => the uncertainty in the lunar core temperature is 250 - 400º

Penetrators

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

Penatrator designed & manufactured in SRC, Warsaw

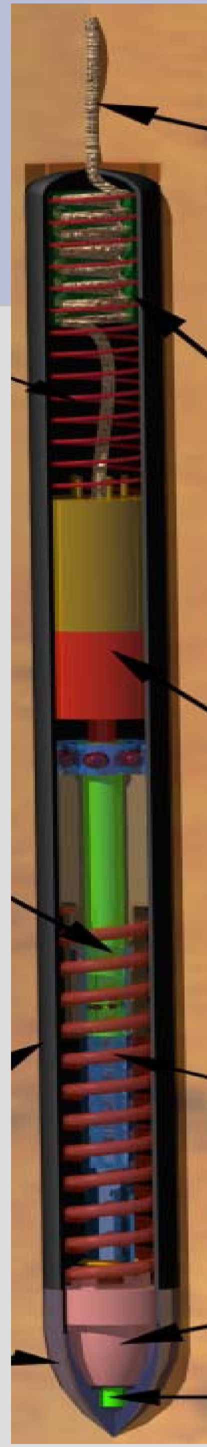




Penetrators: moles

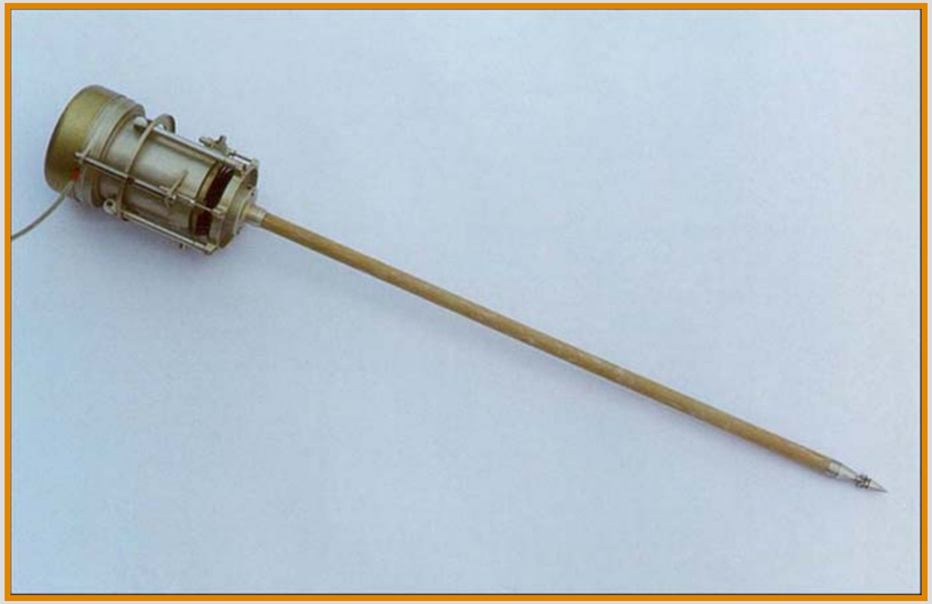
- HP3 (Exo-Mars) – Beagle heritage

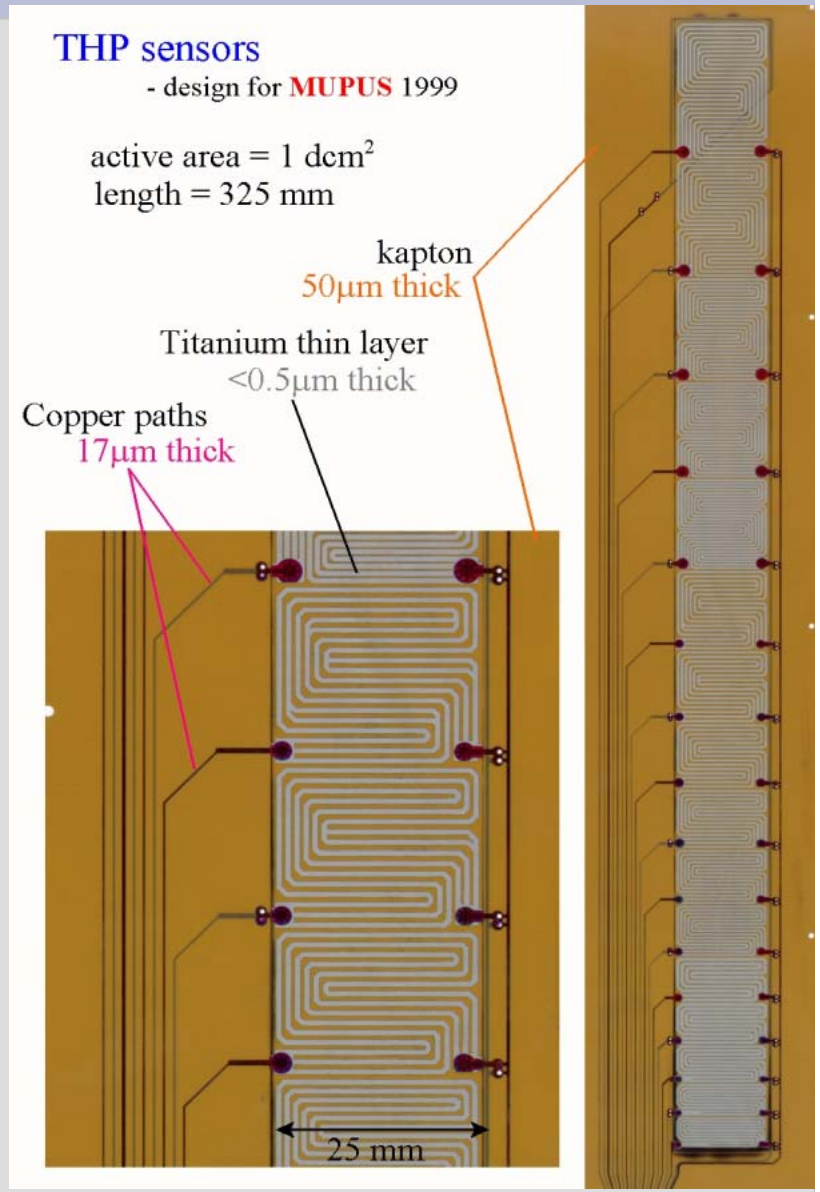
SRC Design



Thermal sensors

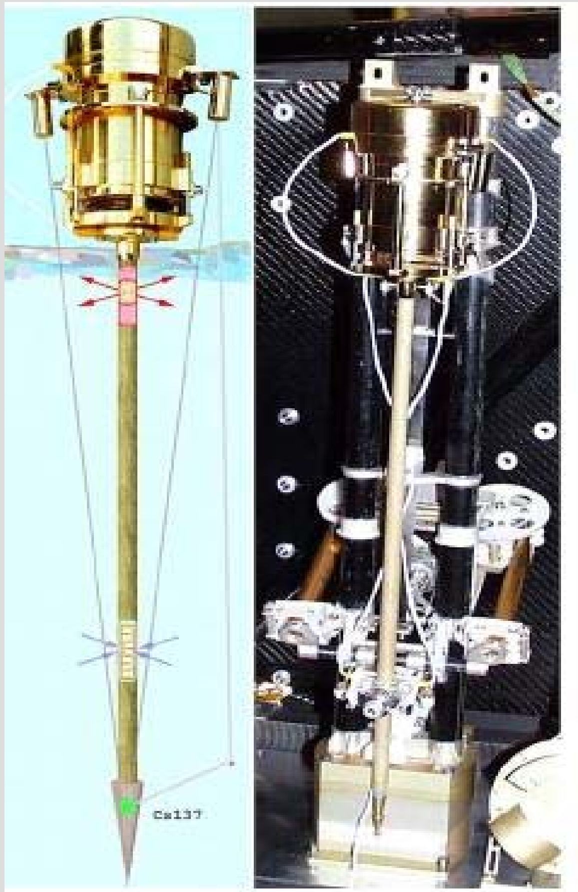
- Resistance thermometers





Thermal sensors

- Principle of operation



Hot rod method

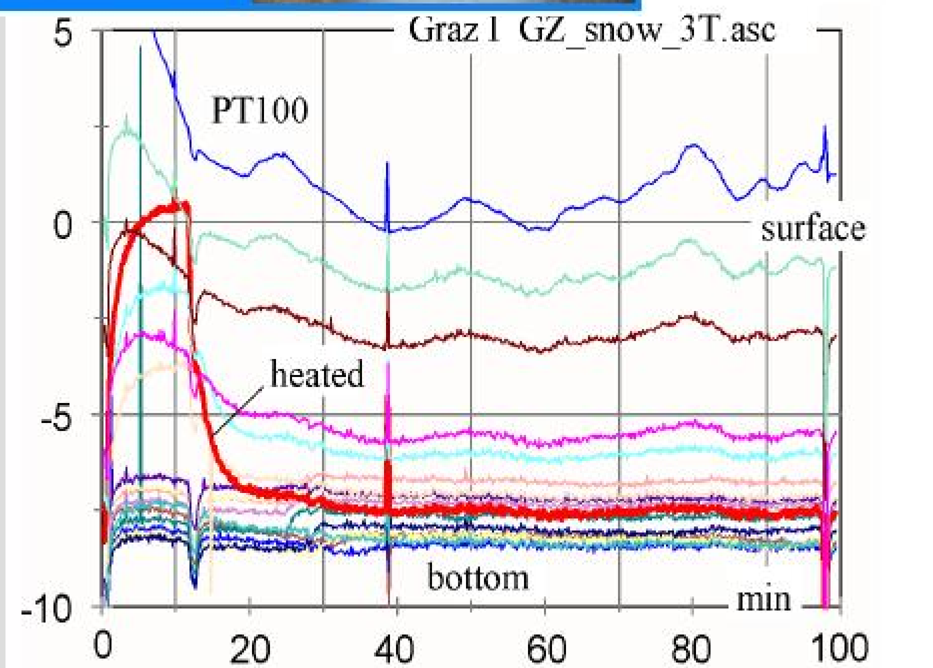
<u>Thermal conductivity measurements:</u>

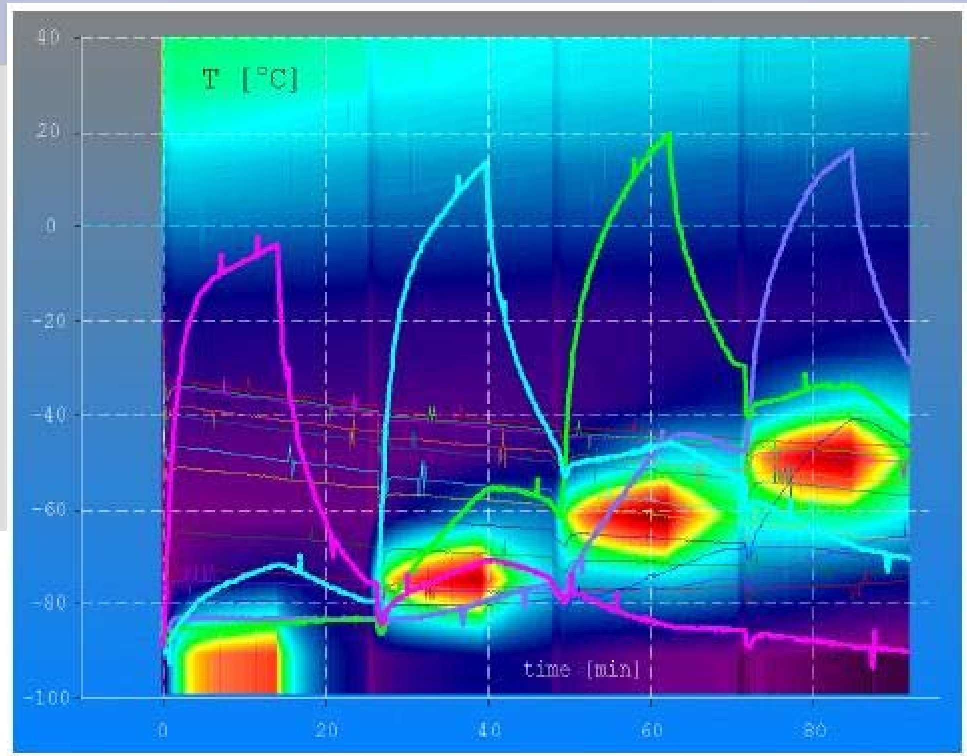
$$T - T_0 = \frac{2Q\alpha^2}{\pi^3\lambda} \int_0^\infty \frac{1 - \exp(-\kappa t u^2 / r^2)}{u^3 \Delta(u, \alpha)} du$$

Where:

t - time
T_0 - initial temperature
Q - applied heating power
λ - thermal conductivity
κ - thermal capacity
α - heat capacity ration: medium to wire

MUPUS measurements on Earth

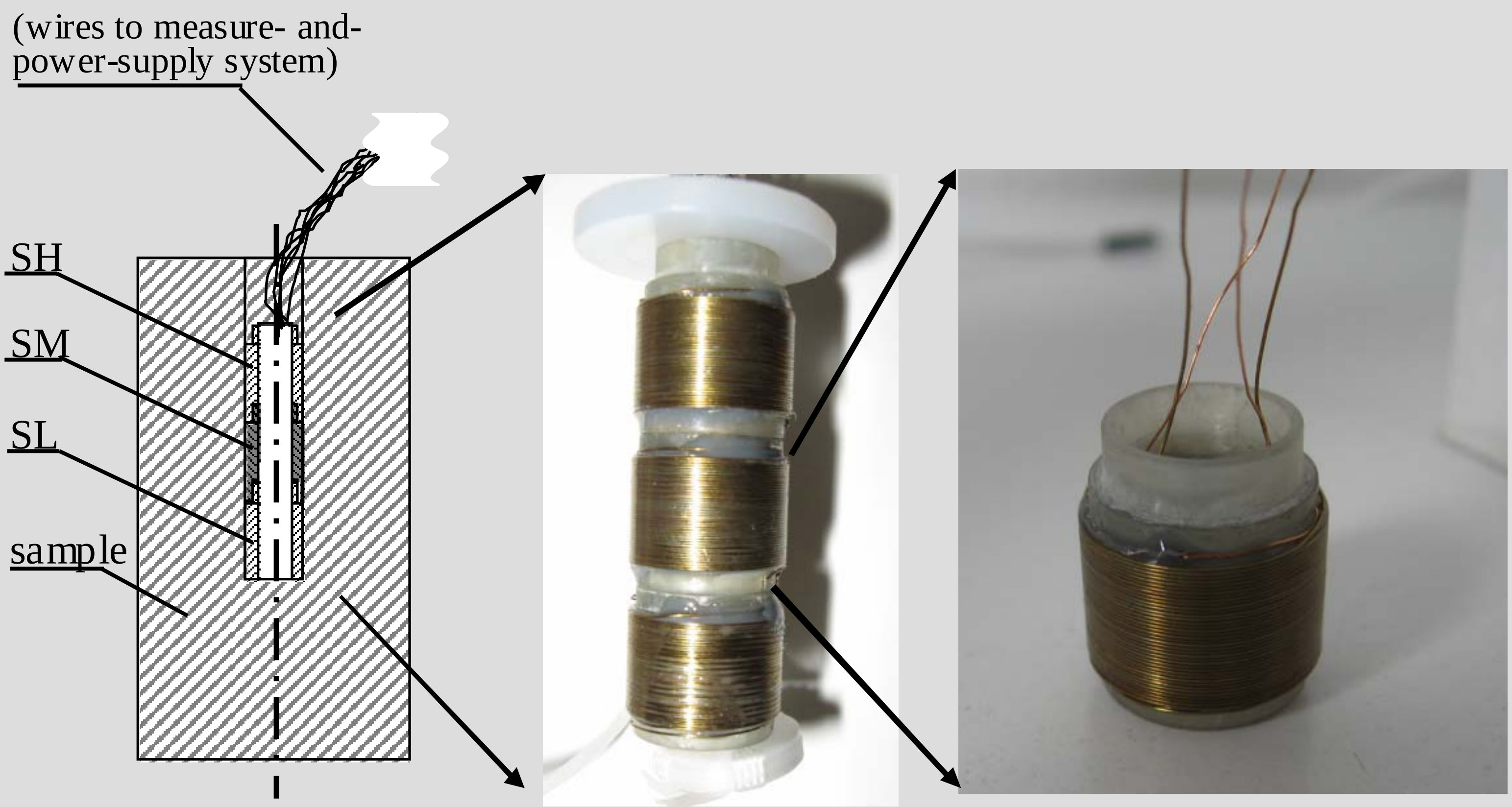




Potential problems

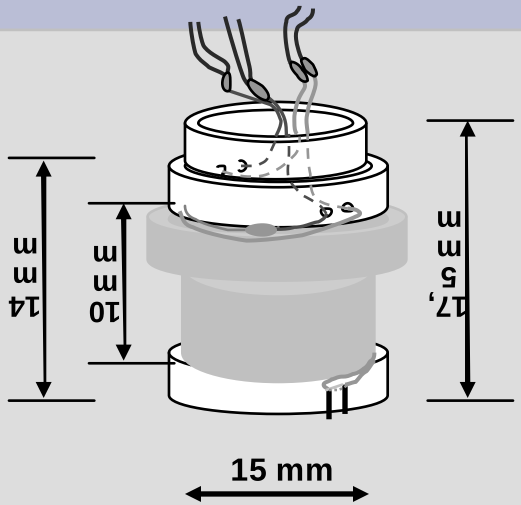
- Conductivity of thin sensors (titanium, copper) is different than the conductivity of the bulk material
- Calibration: precise K(T) dependence should be taken
- Aging effects => recalibration 12 years after sensor manufacturing should be done
- Two wire method used => reference current should be measured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

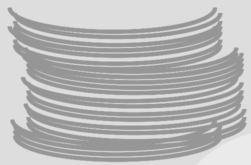
New sensors

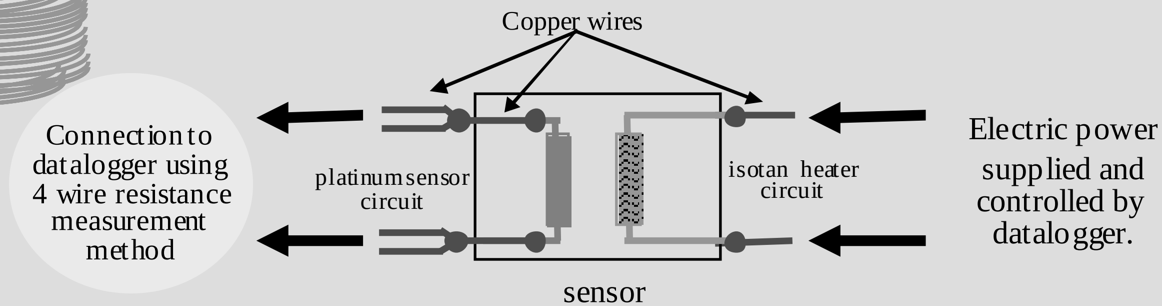


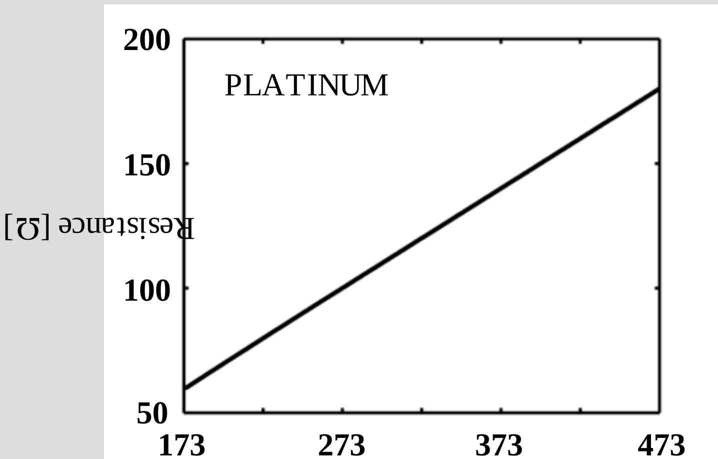
a) b) c)

New sensors

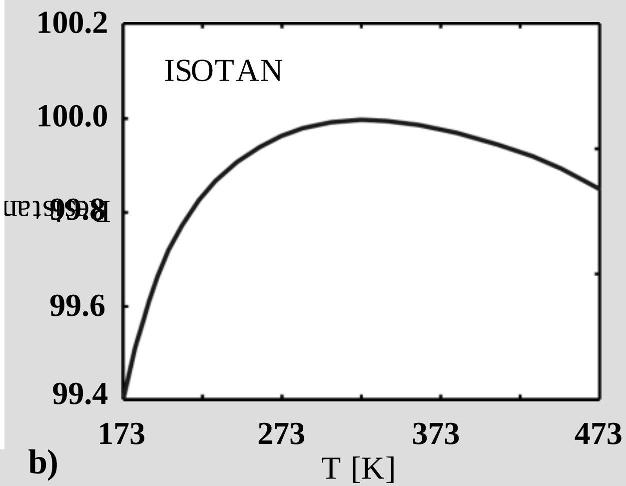








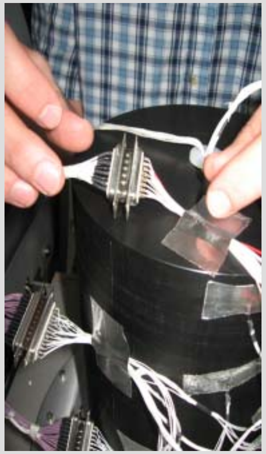
a)



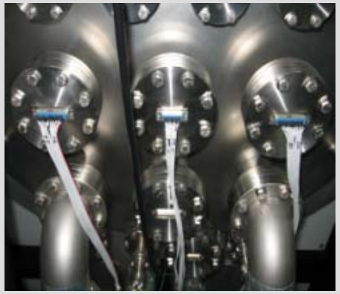
b)

Thermal measurements

- Cometary material & asteroid regolith analogues
- Teflon and delrin as reference materials

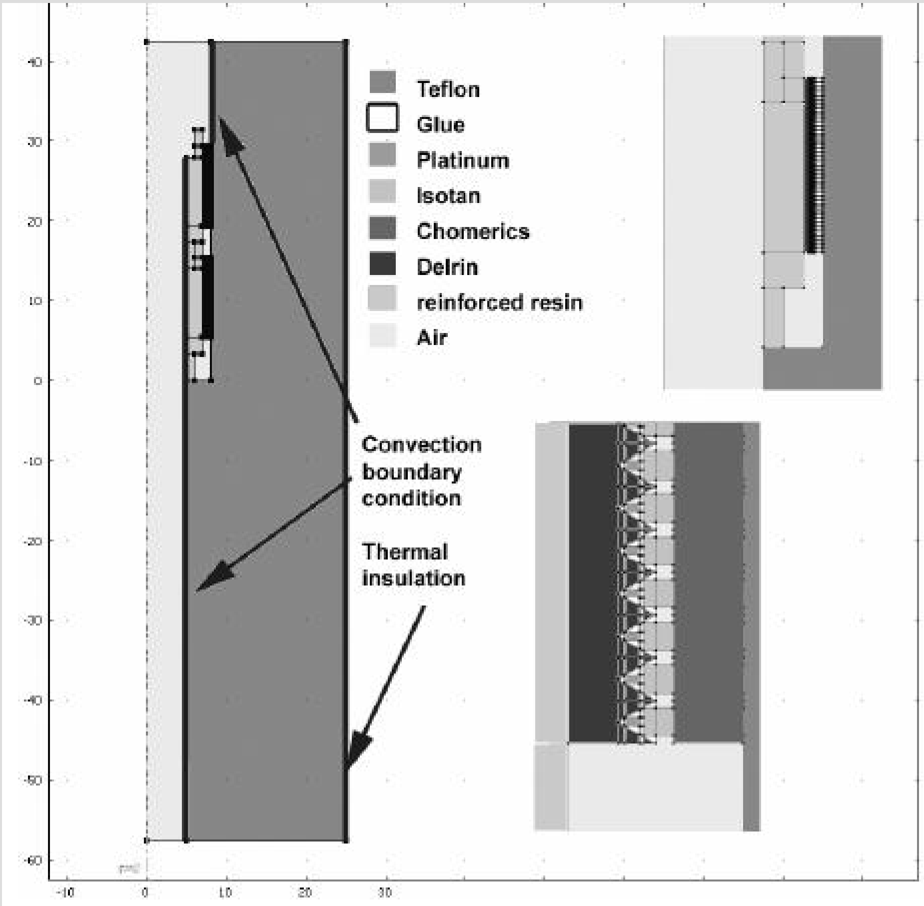




- Measurements in thermal and thermal-vacuum chambers

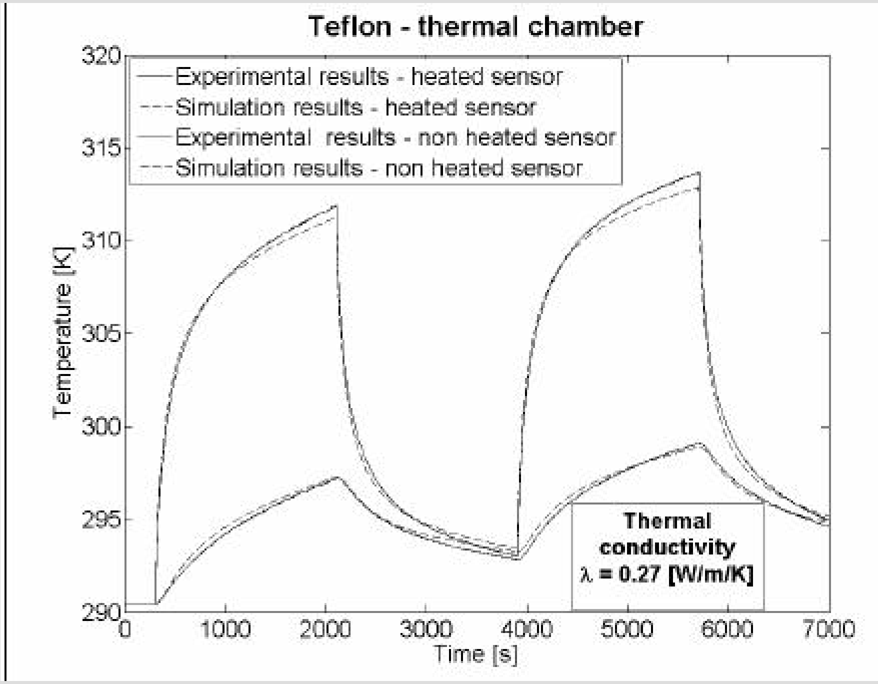



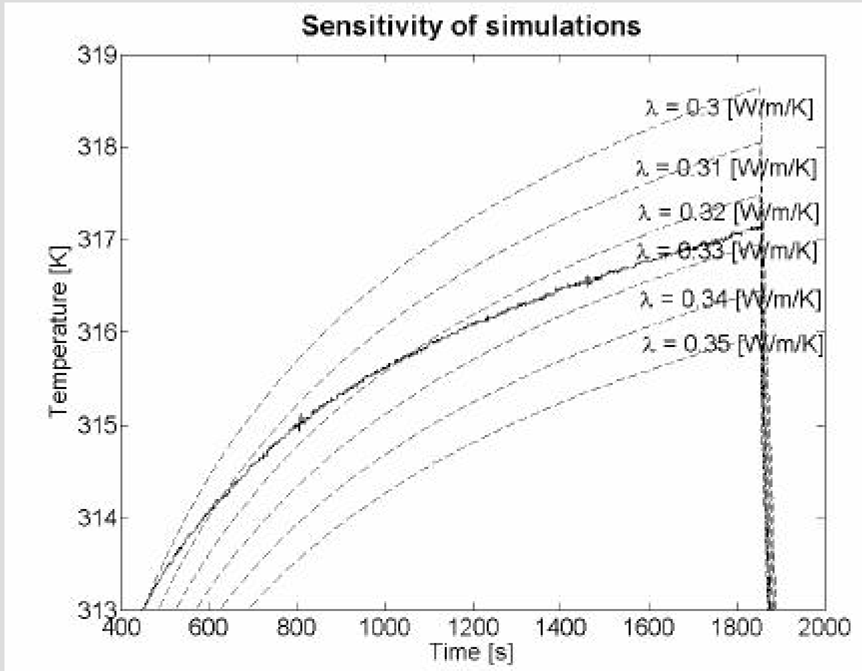
Models

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

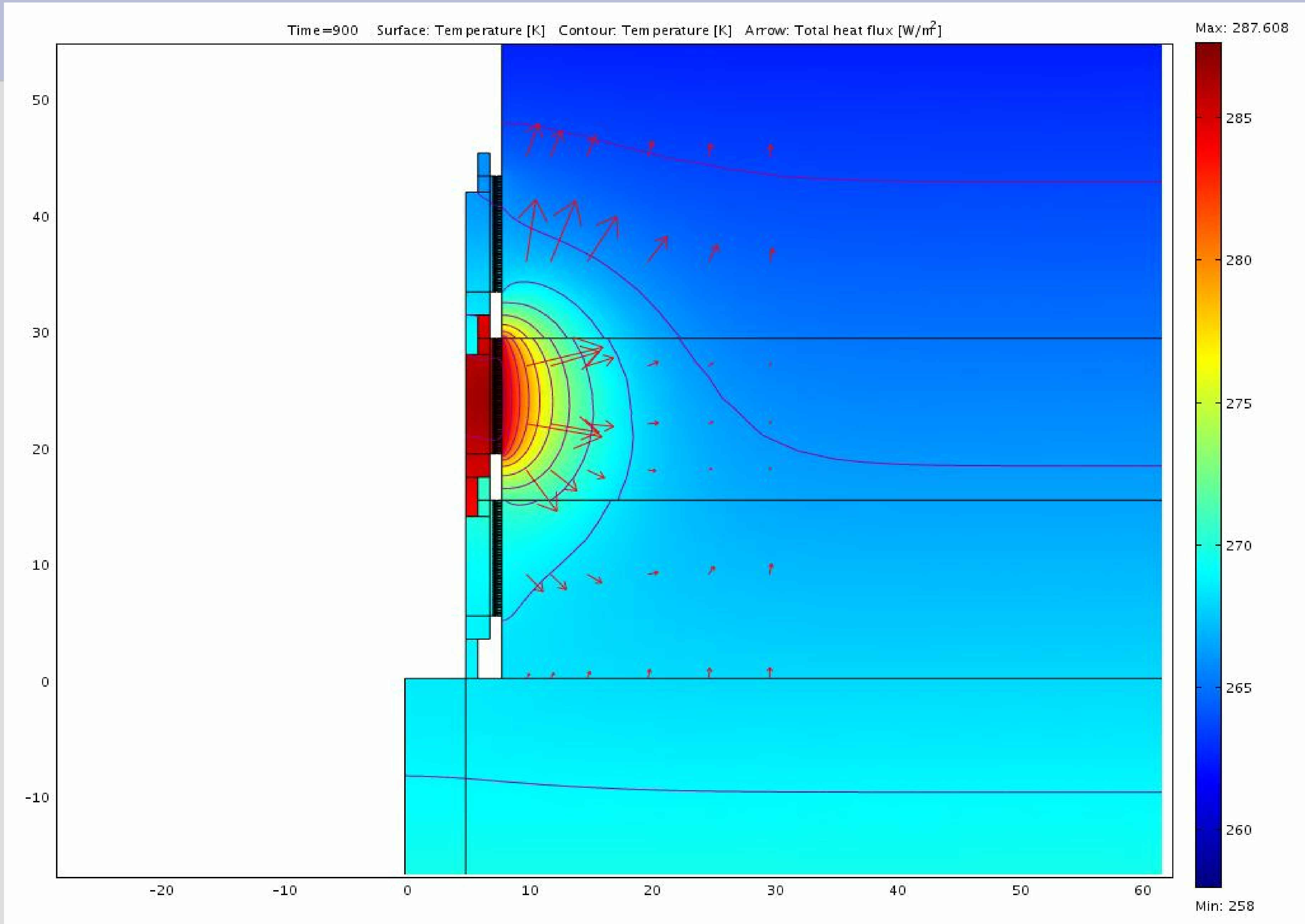


Measurements: calibration



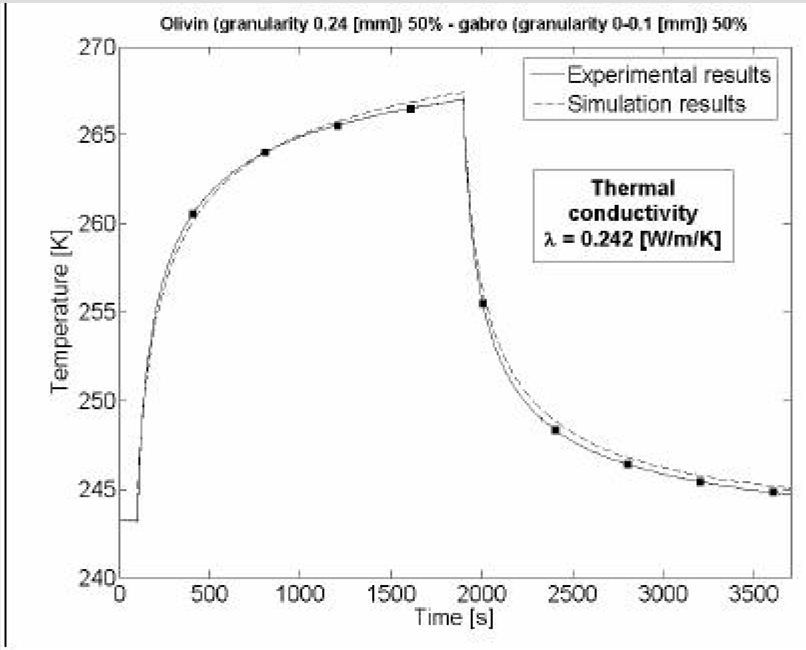


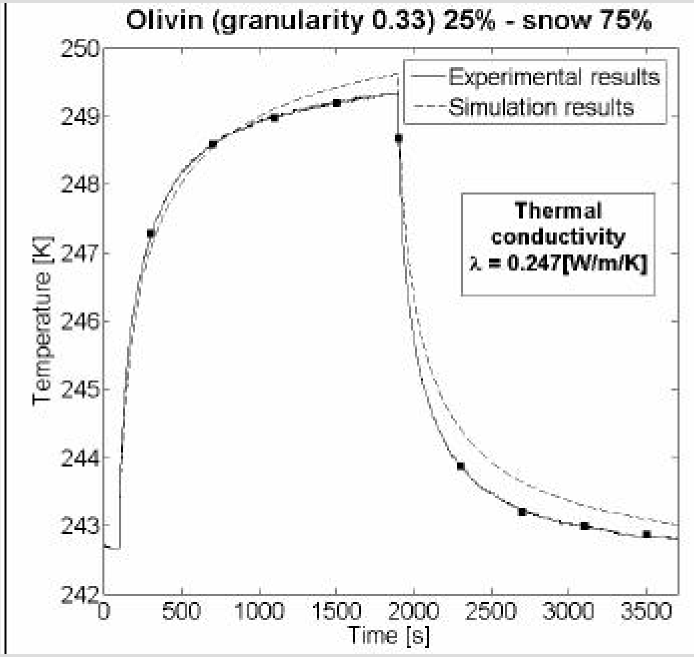
Measurements



Measurements

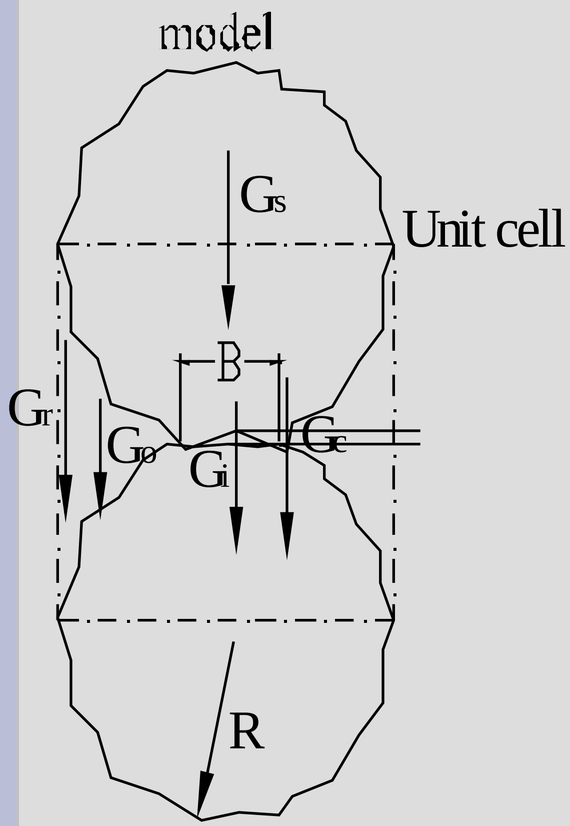
- In thermal chamber => K in the narrow range 0.2 -0.4 W/m/K





Granular media

- Different transport processes (Slavin etal.)



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

$$G = G_r + \frac{G_s(G_{par})}{G_s + G_{par}} \text{ with } G_{par} = G_o + G_i + G_c.$$

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

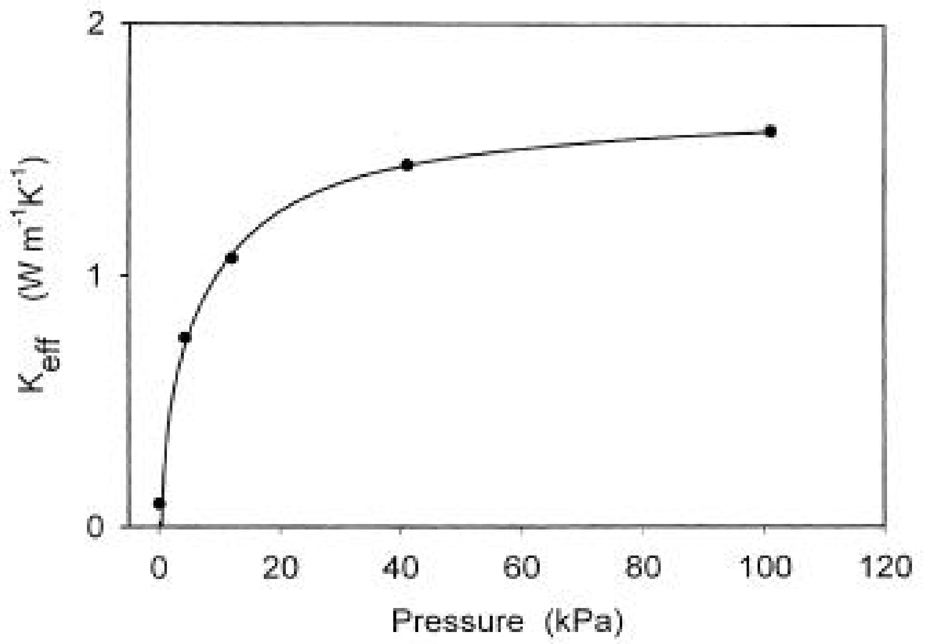
$$G_r = \frac{4\sigma_s}{2/\epsilon - 1} \alpha_r 4R^2 T^3, \quad G_i = K_{gi} \alpha_i \pi B^2 / g,$$

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

$$\approx K_g [1 - \exp(-R/\lambda)] \alpha_o \pi R.$$

Granular media (2)

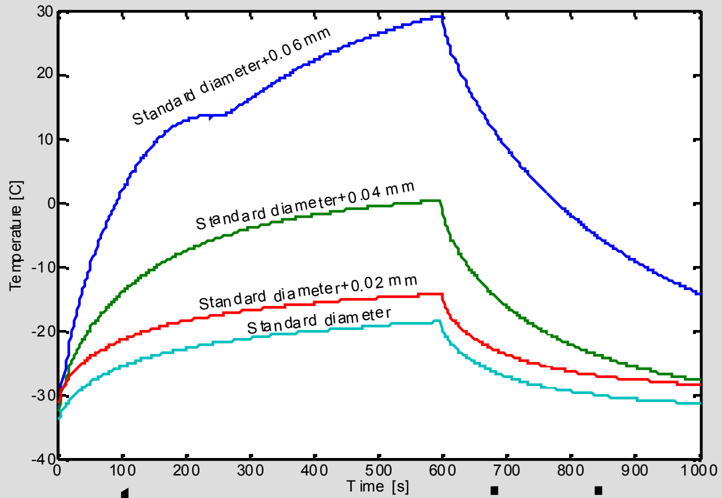
Slavin et al., 1 mm aluminum spheres

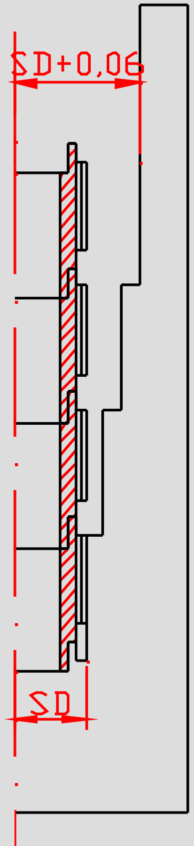


When the parameters of cometary/asteroid analogues are used then K ≈ 0.2 W/m/K at atmospheric pressure

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