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Interpretation of measurements with novel thermal conductivity sensors suitable for space applications

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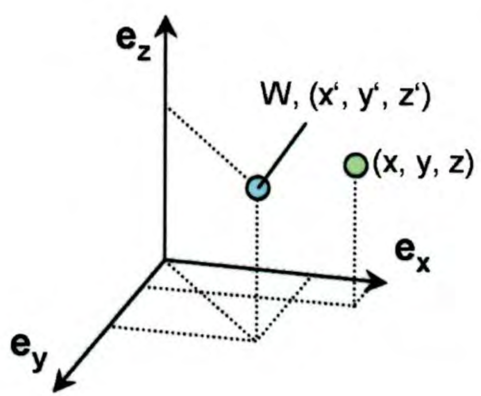
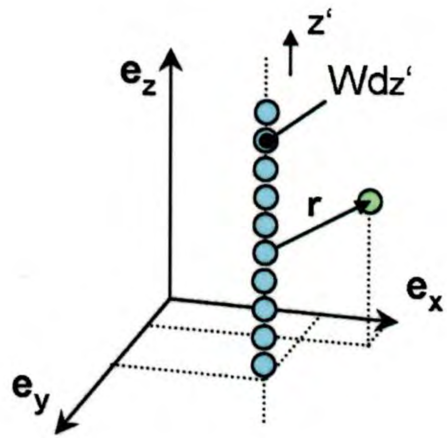
Outline

- Thermal conductivity sensors
- Space applications – ESA Rosetta mission – MUPUS instrument
- Influence of heat loss though wires
- Influence of thermal resistance
- Influence of probe‘s thermal properties and geometry
- Measurements versus modeling
- Summary

Theory of thermal conductivity sensors

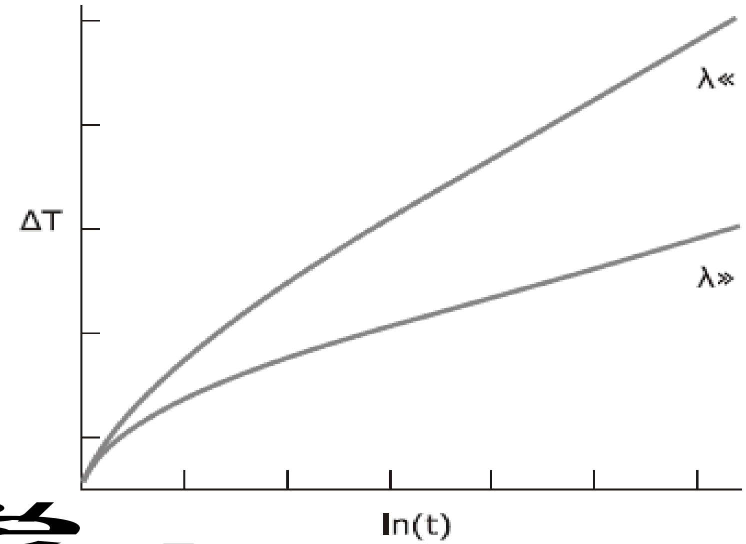




Approximation for

- Thin and long sensor
- Long heating time:

$$\vartheta = \frac{q}{4\pi\lambda}\ln\left(\frac{4at}{r^2}\right) - \frac{\gamma q}{4\pi\lambda}$$



Point heat source:

$$\vartheta = \frac{Q}{8(\pi a t)^{3/2}} e^{-\frac{\left[(x-x')^2+(y-y')^2+(z-z')^2\right]}{4at}}$$

Line heat source:

$$\vartheta = \frac{q}{4\pi\lambda} E_1\left(\frac{r^2}{4at}\right) \qquad E_1(x) = \int_x^\infty \frac{e^{-u}}{u}\,du$$

Transient Thermal Conductivity Sensors

TP08	TP02	LNP03	LNP02	LNP01
D= 1.3mm	D=1.5mm	D=3.5mm	D=4.3mm	D_i= 10mm D_a= 16mm
L= 70mm	L=150mm	L= 100mm	L= 100mm	L= 300mm

Left:

Commercial (standard) needles

Middle:

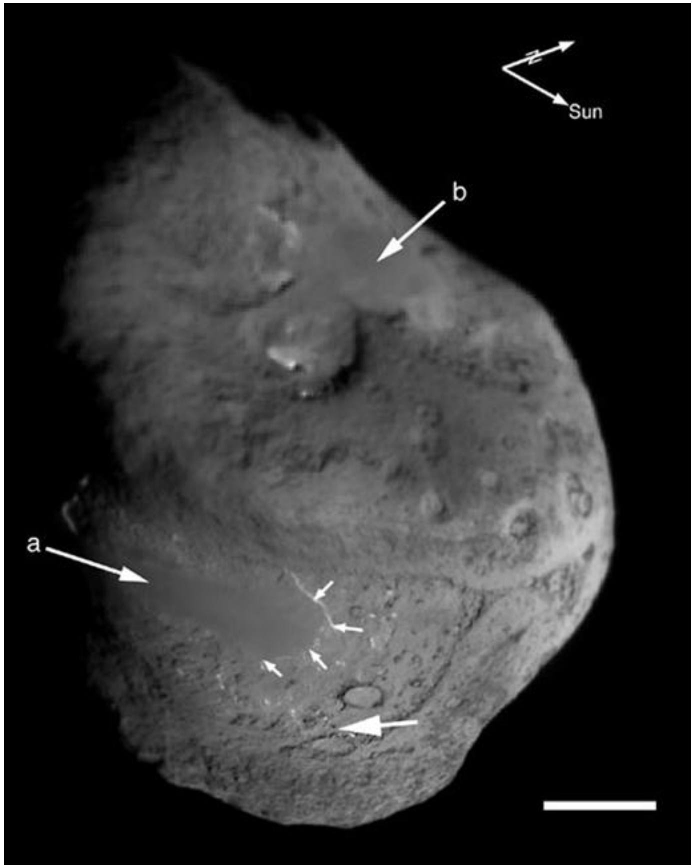
Custom-made (short) needles

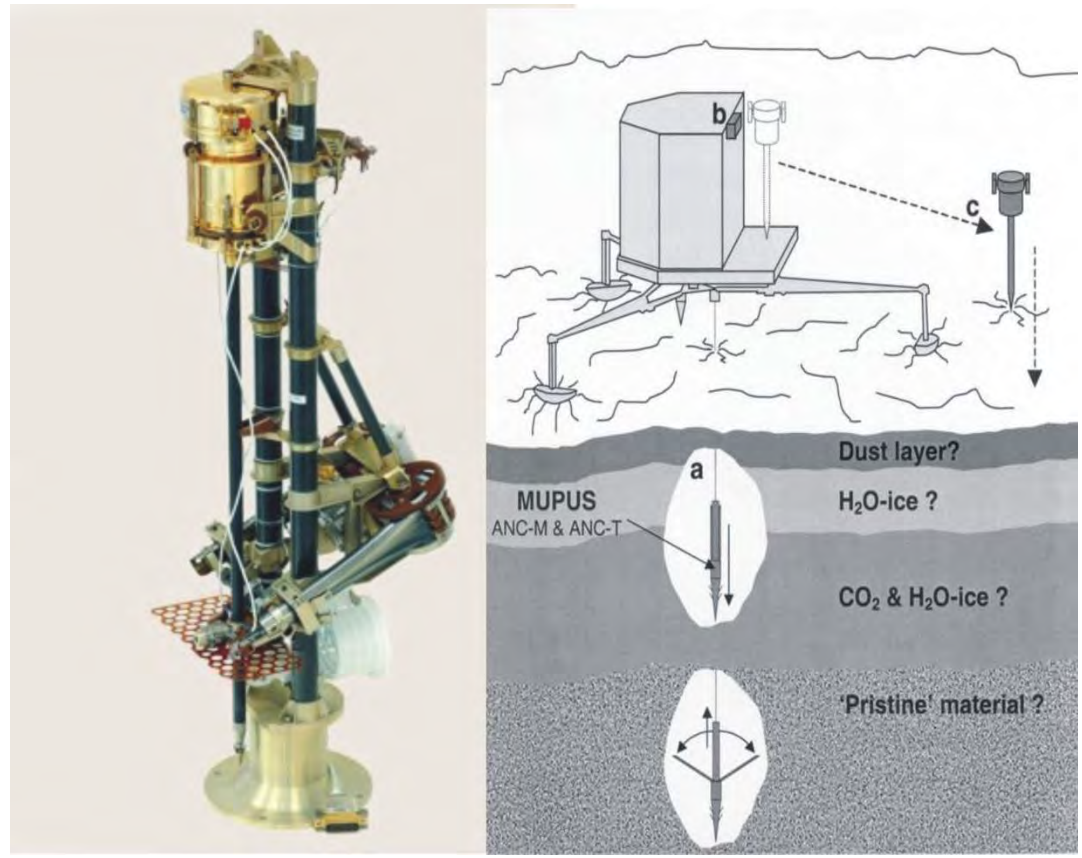
Right:

Custom-made hollow cylindrical sensor

Manufacurer:
HUKSEFLUX Thermal Sensors, Holland

MUPUS on Rosetta-Philae Mission

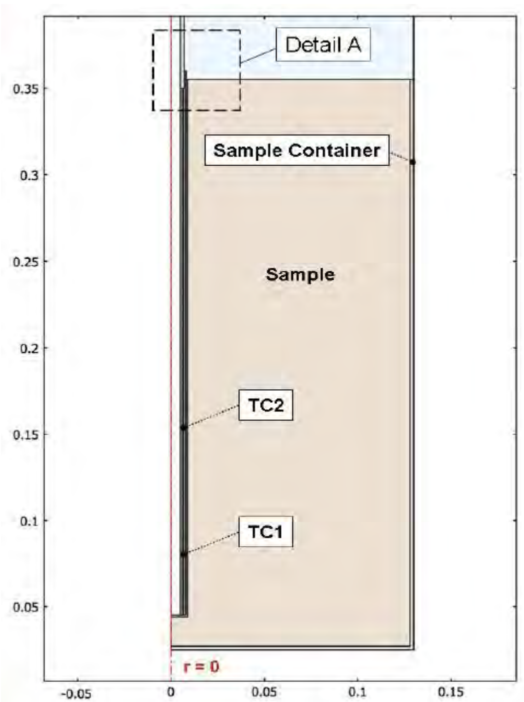


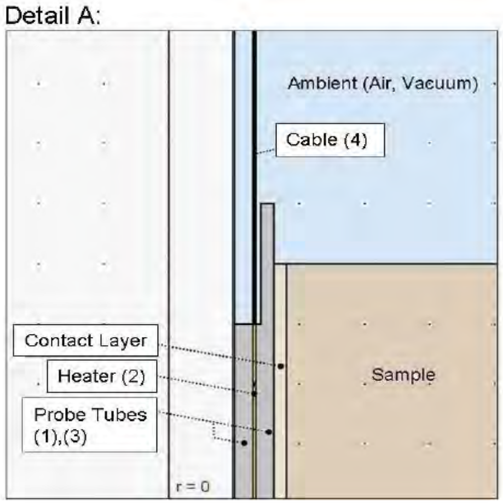


Comet Tempel 1 as seen by the NASA Spacecraft DEEP IMPACT in July 2005

Comet Lander Philae and its Thermal Conductivity Experiment MUPUS - comet landing in November 2014

COMSOL model for short sensors

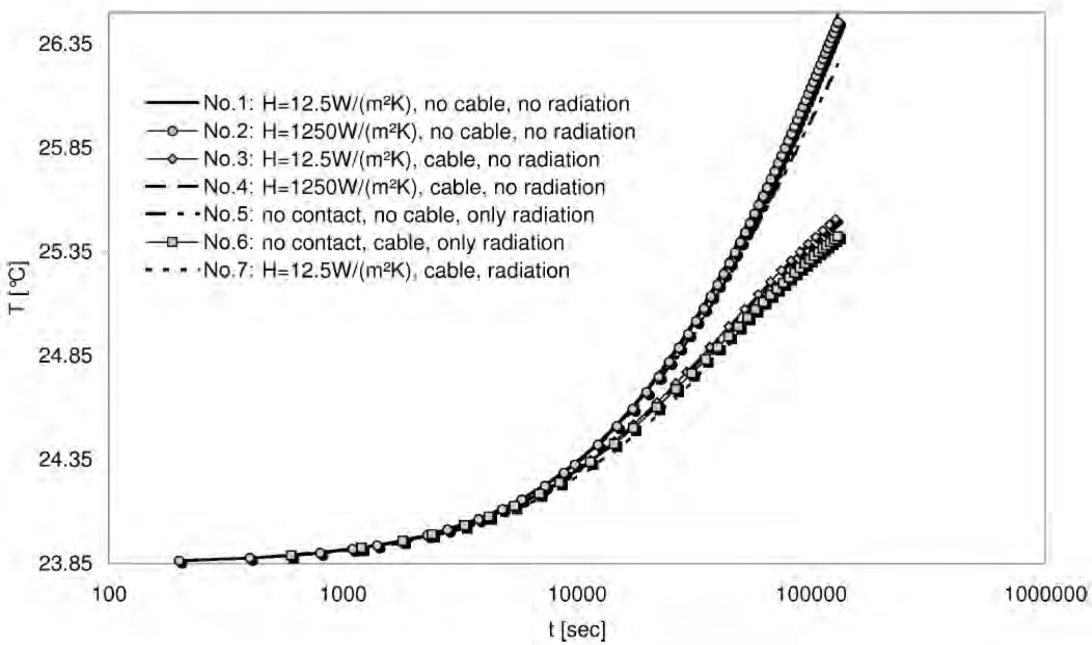




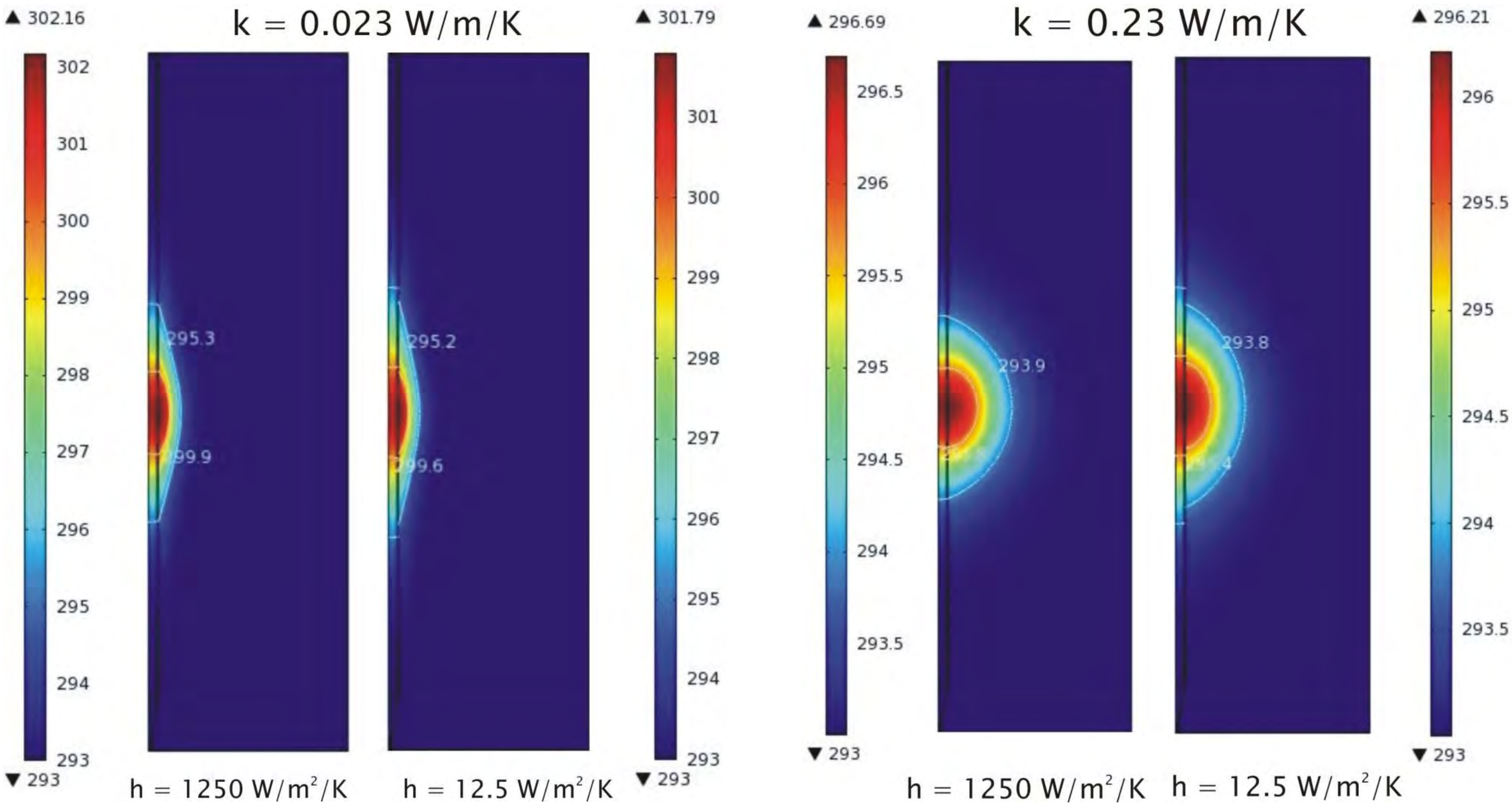
Modelled temperature increase of the thethermal probe for different cases:

- **-Axial heat loss by cables**
- **-Radiative heat loss**
- **-Thermal resistance**

Geometry of the COMSOL Heat Transfer Model for the custom –made *short and thick* transient thermal conductivity probes



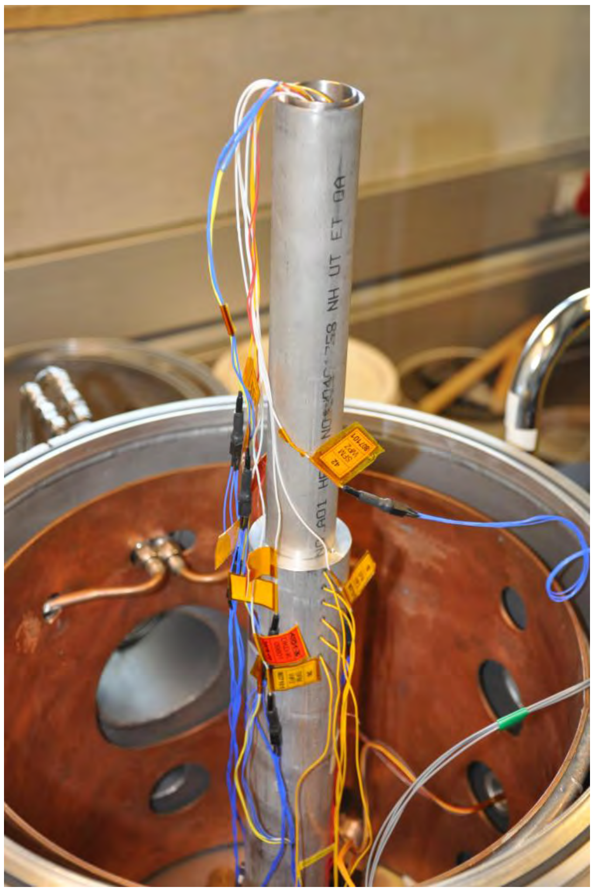
Influence of thermal resistivity



Low thermal conductivity sample
(regolith under vacuum)

High thermal conductivity sample
(regolth under normal air pressure)

Experimental setup and COMSOL model

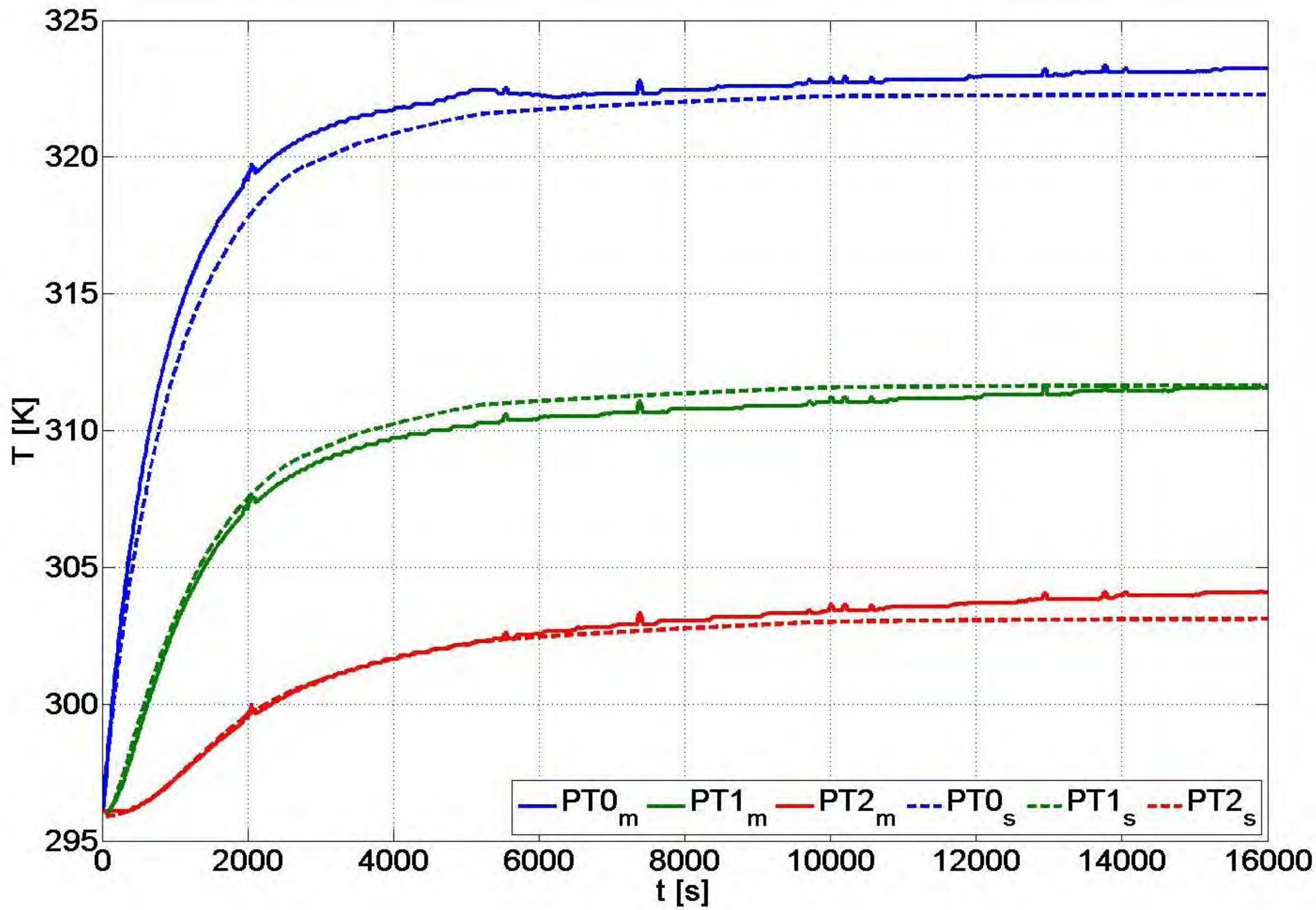


Shielded configuration
(*surface-to surface* radiation)

Unshielded configuration
(*surface-to ambient* radiation

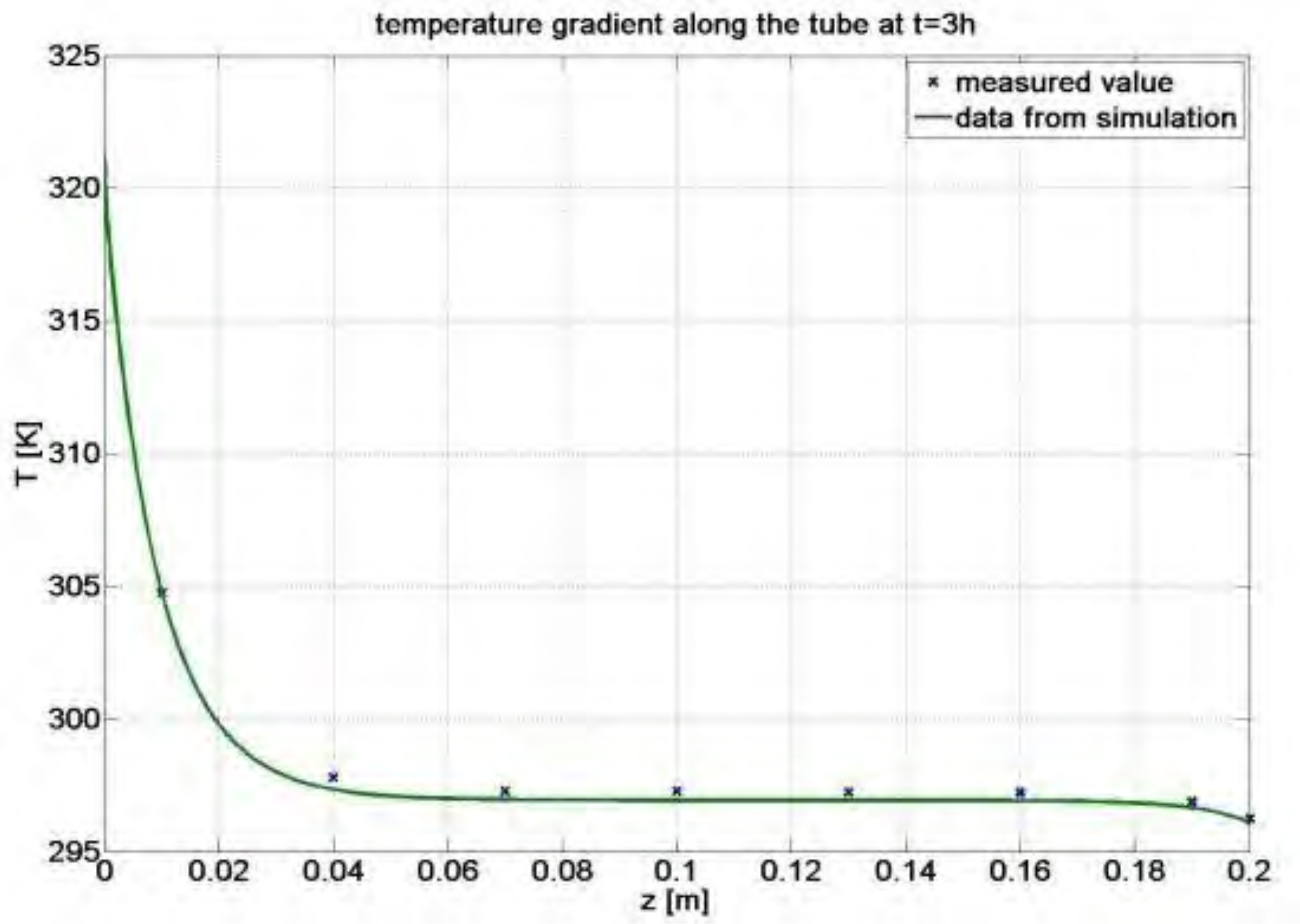
COMSOL model for
shielded configuration

Comparison of model and experiment 1



Measured temperature increase of heated tube (solid lines) in comparison with the temperature rise predicted by the COMSOL model (dashed lines) – *surface-to-surface radiation* case.

Comparison of model and experiment 2



Temperature profile along the tube after 3 h of heating -- *surface-to-ambient* radiation case.

Summary

Data from thermal conductivity sensors used on planetary missions need a more sophisticated evaluation than standard hot needle sensors because:

- **Sensor thermal properties affect the result**
- **Sensor geometry has a larger influence**

A *COMSOL Multiphysics* model using the full possibilities of the Heat Transfer Module (thermal resistance, thermal radiation,realistic geometry) is necessary and useful to evaluate realistic values for the thermal conductivity and the heat flux at planetary surface and subsurface layers, as the shown examples illustrate.