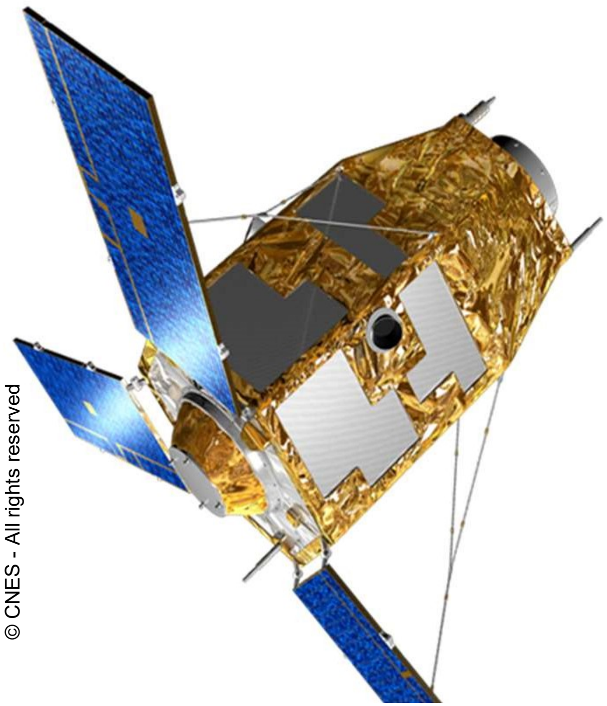
Ecole Technologique du RT Vide

Choix des matériaux pour le contrôle thermique



CENTRE NATIONAL D'ÉTUDES SPATIALES

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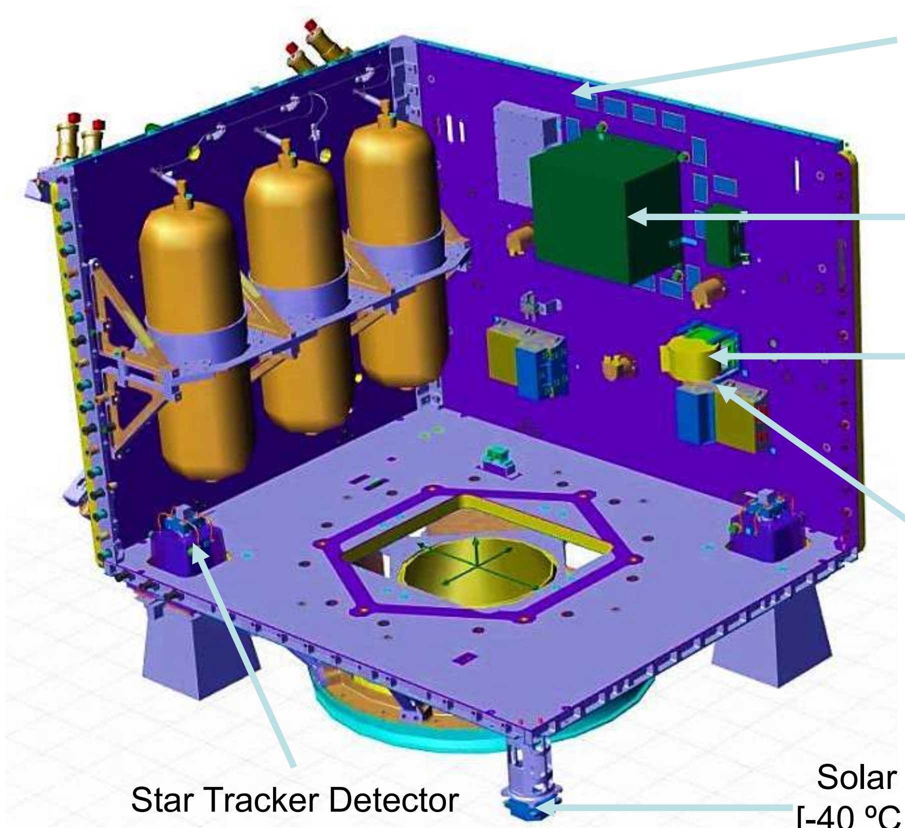
1. TCS Objectives and Constraints
2. Heat Transfer and Heat Storage
3. TCS Main Functions

TCS Objectives

- Temperature Range
  - Keep a structure, an equipment unit, an EEE component, a material, a mechanical part or a process within a temperature range which insures its nominal behaviour and its integrity

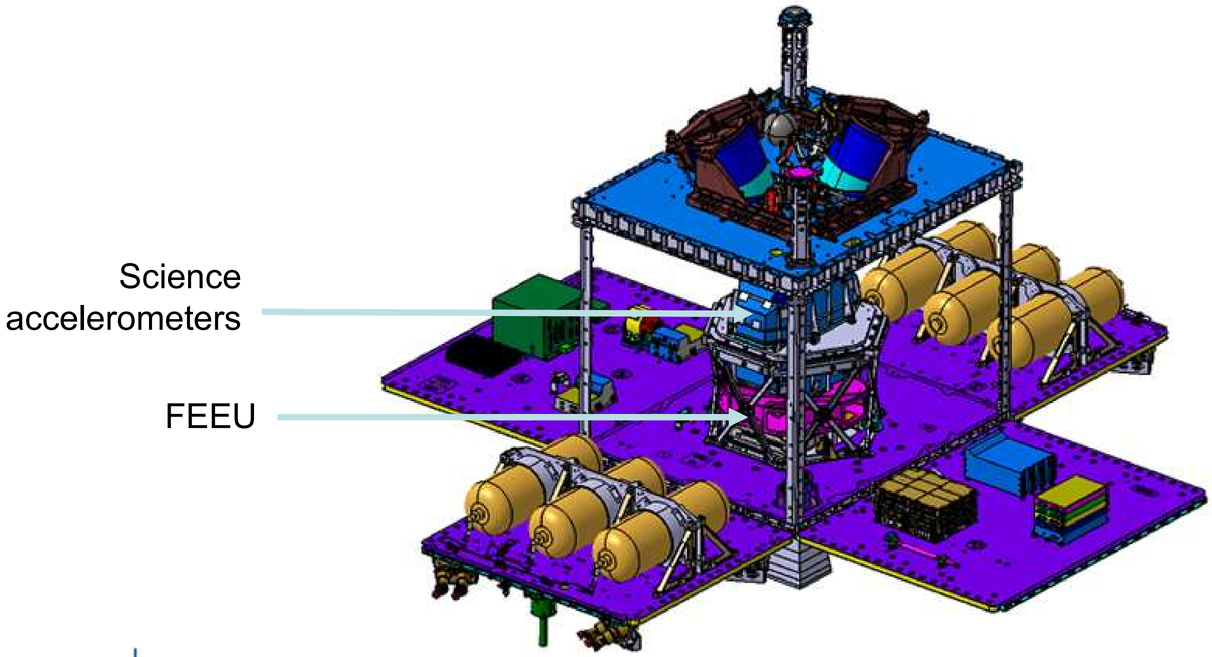
Example Microscope



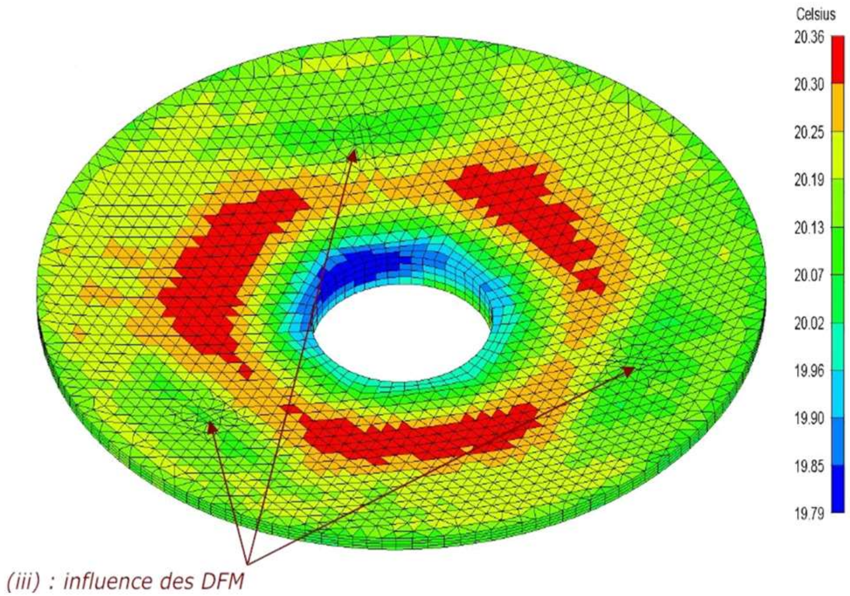
TCS Objectives

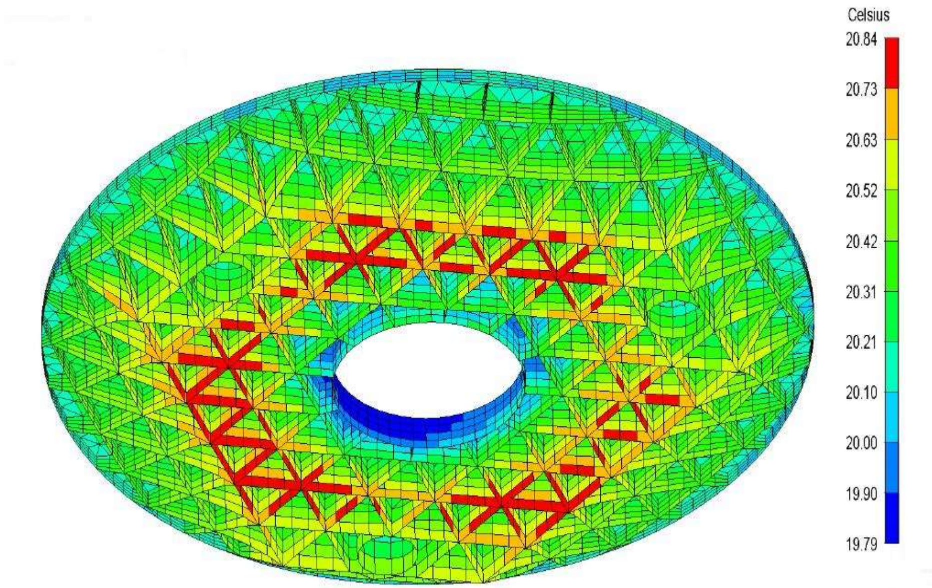
- Temperature stability
  - Keep stable in time a temperature level (ºC), difference (ºC) or gradient (ºC/m)

- Example Microscope
  - Science accelerometers: dT < 1 mK peak-to-peak during an orbit
  - FEEU (electronic unit):   dT < 10 mK peak-to-peak during an orbit



- Temperature homogeneity
  - Reduce a spatial temperature difference in an area or at an interface
- Example: Optical Telescope Primary Mirror
  - Radial ΔT (from center to edge): ΔT < 1 ºC
  - Axial ΔT (from bottom to top): ΔT < 0.5 ºC
  - Radial and axial ΔT temporal stabilities: d(ΔT) < 0.5 ºC peak-to-peak during an orbit





TCS Constraints
Vacuum

- Space: an unfavourable thermal environment
  - Vacuum: no atmosphere available as an efficient heat sink, no convective heat transfer
  - Only IR radiation towards the deep space at 3 K

TCS
Challenges and functions

Objectives

- Temperature ranges
- Temperature stabilities
- Temperature homogeneities

Constraints

- Vacuum
- Environmental heat radiation
- Orbits and attitudes
- Material degradation
- Microgravity
- And some planetary harsh environments

Thermal Control Functions

- Thermal Insulation (in particular Multi Layer Insulation)
- Heat Rejection (from radiators towards Space Environment)
- Heat Spreading&Transport (without or with fluids)
- Heating
- Cooling (passive and active coolers; in particular at cryogenic levels)
- Temperature Regulation (by heater, by cooler or by fluid)

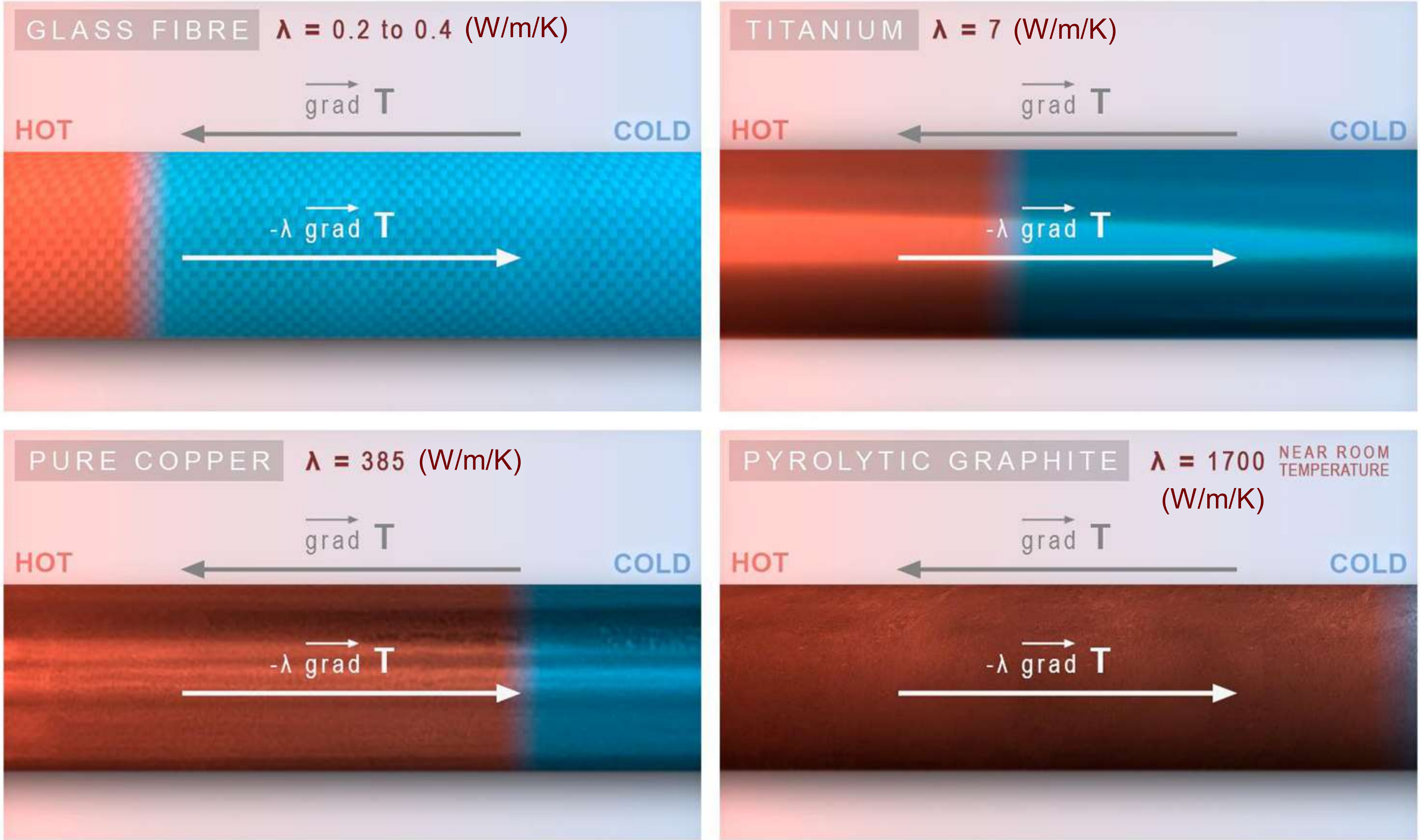
1. TCS Objectives and Constraints

2. Heat Transfer and Heat Storage

3. TCS Main Functions

Heat exchanges

By conduction



By conduction

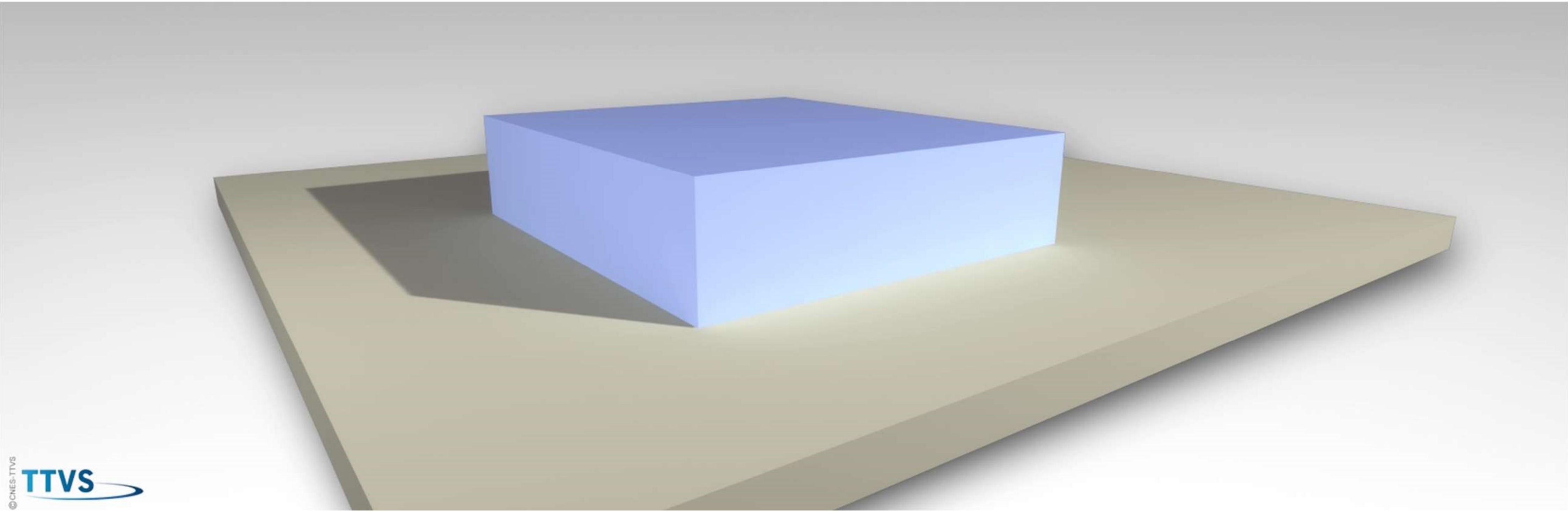
Matériau/Fluide	Conductivité thermique λ (W.m^{-1}.K^{-1})
Fibre de carbone (sens fibre)	de 100 jusqu'à 1100
Cuivre pur	385
Magnésium	160
Aluminium pur	210
AG5 ou AU4G	120
Acier inoxydable 18.8	16.3
Invar	13.5
Alliage titane Ta6V	≈7.0
Silice	1 à 1.4
Téflon	0.24
Fibre de verre / époxy	0.2 à 0.4
Feutre de silice	0.03
Polystyrène expansé	0.03 à 0.06
Régolite lunaire (premier centimètre)	≈0.0015
Régolite lunaire (sous les premiers centimètres)	[0.015 ; 0.030]
Air	≈0.0260

By conduction

- Conduction through thermal contact between two solids
  - Unit mounting classical example
  - Heat transfer efficiency (h, W/(m²*K)) depends on surface contact quality on area S

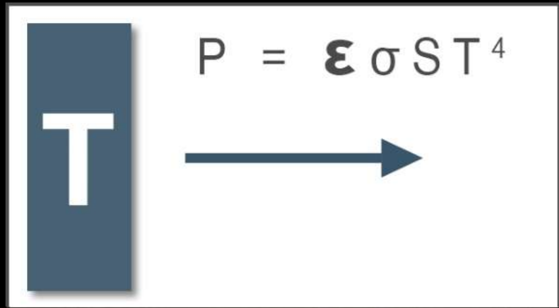
$$P = h*S*(T_{solid1}-T_{solid2})$$

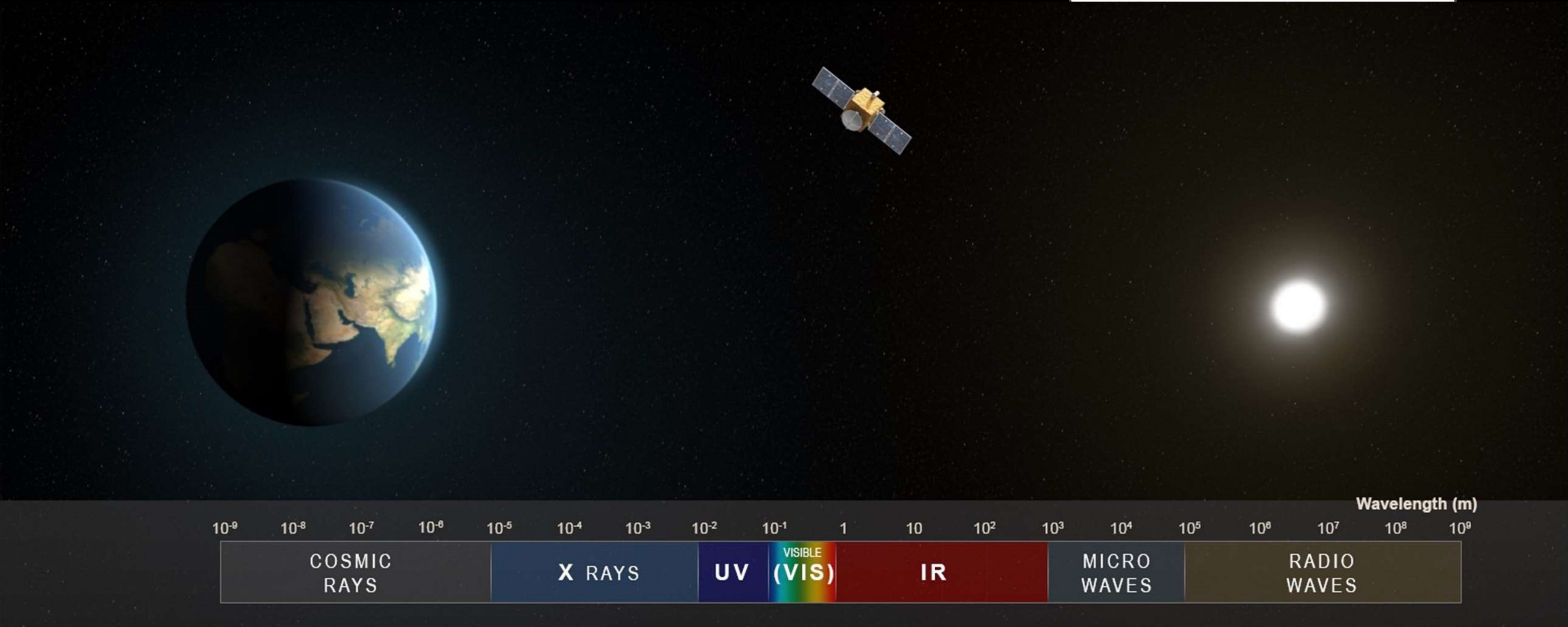
h = 100 W/(m²*K) for rough contacts, h = 10000 W/(m²*K) for good contacts



By radiation under space vacuum and near Earth

- Definition
  - An exchange of heat by absorption and emission of photons energy
  - Emission is proportional to T^4





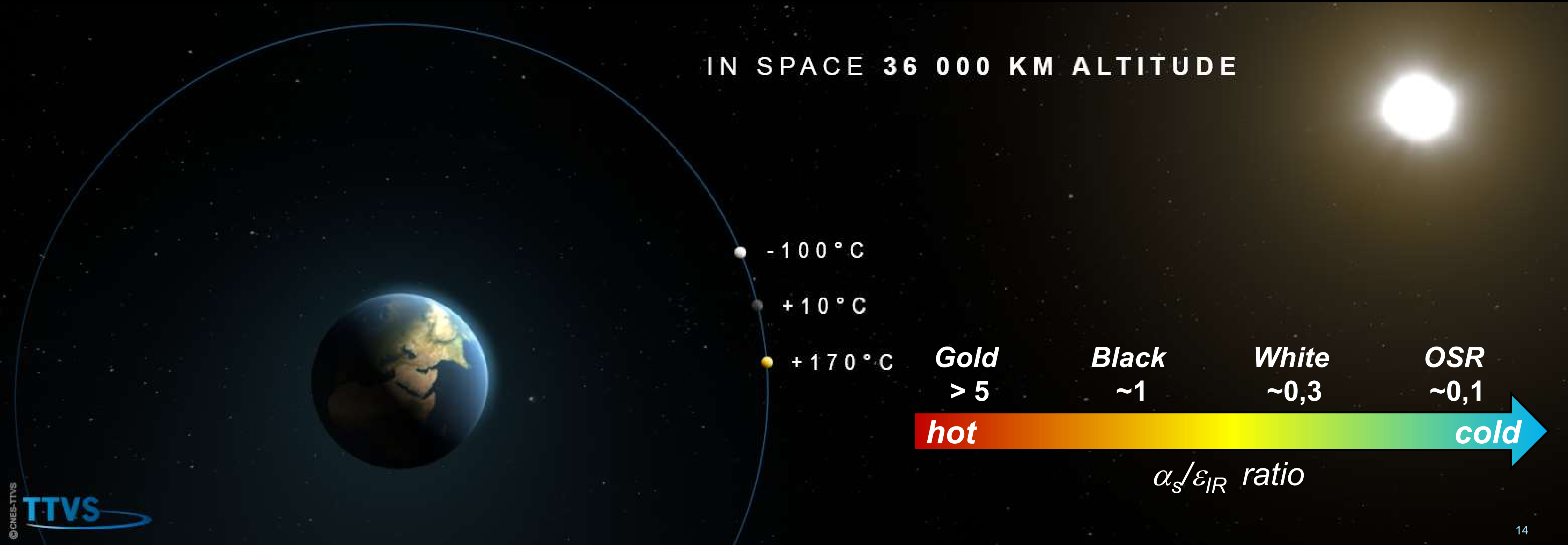
TTVS

Radiation: a surface phenomenon

- Surface thermo-optical properties (all wavelengths and all directions)
  - Sun spectrum ➔ total absorption ➔ solar absorptivity = α_s
  - IR spectrum ➔ total absorption = total emission ➔ IR emissivity = ε_{IR}
    - At each wavelength, emission coefficient = absorption coefficient
    - Grey surface hypothesis: emission and absorption coefficients are not temperature dependent

$\alpha_s/\varepsilon_{IR}$ ratio defines “hot" and "cold" coatings

Under space vacuum, very high sensitivity to surface thermo-optical properties



By radiation under space vacuum

Applications

- Efficient heat rejection to environment by radiators (high ε_{IR} by SSM or OSR ≈ 0.80; $\alpha_s/\varepsilon_{IR}$ ≈ 0.25)

Pleiades spacecraft

Inmarsat

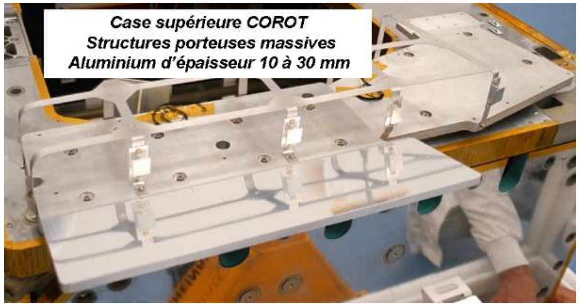
By radiation under space vacuum

- Typical values
  - Attention au vieillissement des revêtements (notamment absorptivité solaire)

Matériau	Absorptivité solaire α_S	Emissivité infrarouge ε_{IR}
Nickel noir	0,92	0,4
Or poli	0,23	0,03
Aluminium poli	0,12	0,04
Peinture noire PU1	0,96	0,89
Peinture blanche PSB	0,22	0,88
OSR OCLI	0,08	0,81

Heat storage and recovery

- Heat capacity (J/K) or thermal inertia
  - Heat required to increase by 1 K the temperature of a given physical medium
  - Equal to Mass (kg) * Specific heat (J/K/kg) = M.Cp



- General application : $M.C_p.dT/dt = \Sigma$ Heat Transfers

- Application: COROT radiator
  - For Video Electronic temporal stability: dT < 0.3 ºC peak-to-peak during one orbit

Matériaux	Capacité thermique massique ($J.Kg^{-1}.K^{-1}$)	Masse volumique ($Kg.m^{-3}$)
Acier inoxydable	502	790
Alliage Aluminium AU4G	920	2 650
Cuivre	389	8 900
Alliage TA6V	540	450
Béryllium	1 780	1 850
Fibre de carbone / époxy	804	140
Polystyrène	1 340	25
Verre (Silice)	750	2 400
Cartes électriques	900	1 300

Heat transfer and storage

- 3 heat transfer modes
  - Conduction
  - Convection
  - Radiation
- Heat storage and recovery

- Physical phenomena driving thermal control development
- To choose best materials/coatings for a Thermal Control System

TCS = Thermal Control System = Système de Contrôle Thermique

1. TCS Objectives and Constraints
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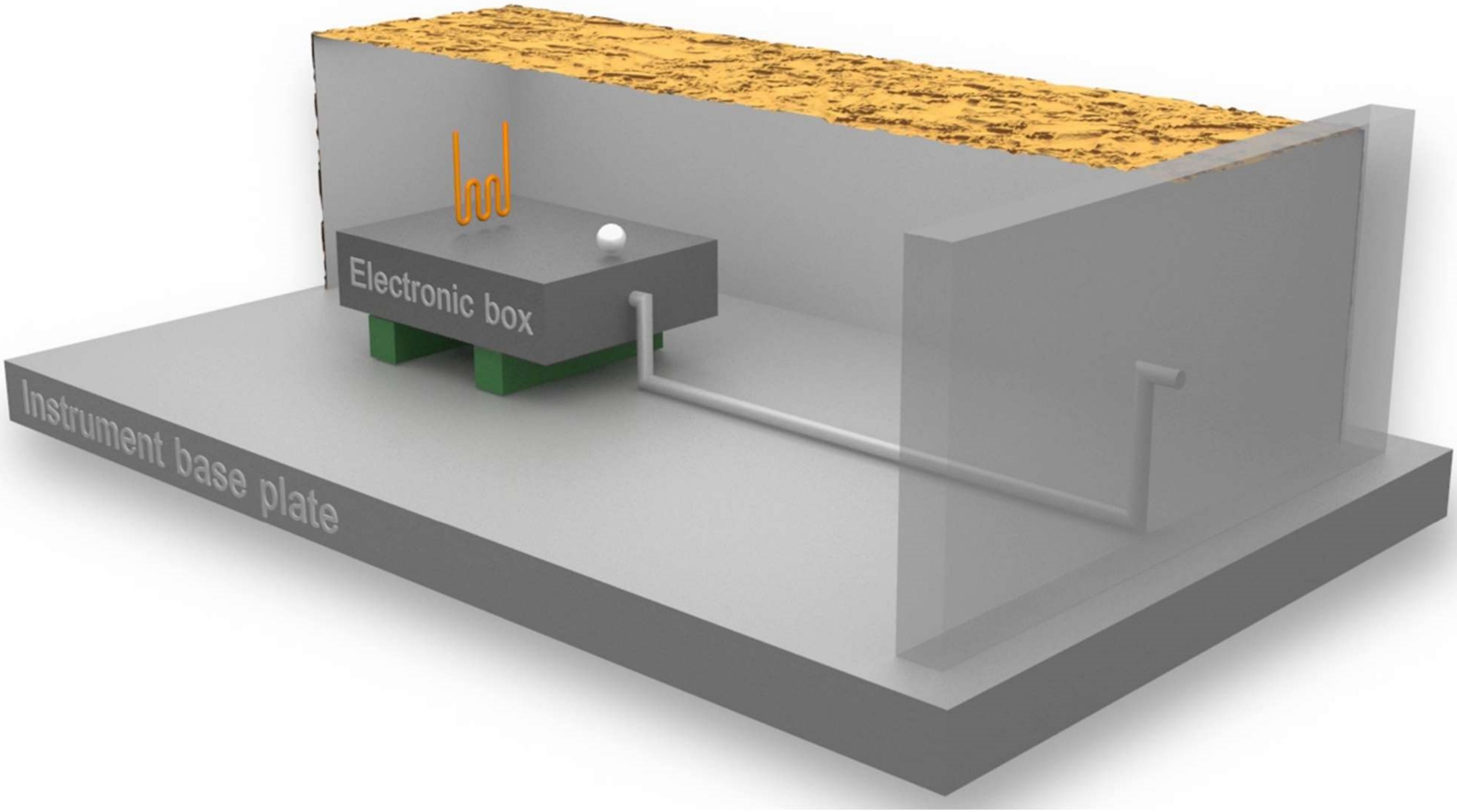
TCS design
6 main functions

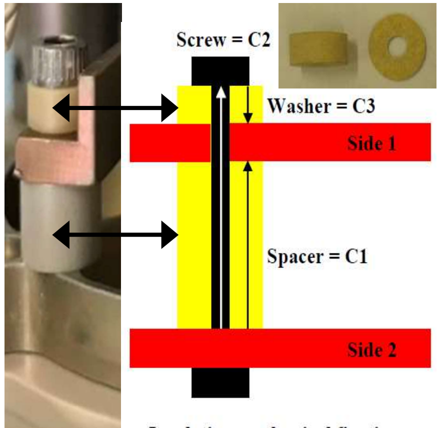
- Insulation
- Rejection
- Heat transport
- Heating
- Cooling (see dedicated slides)
- Regulation



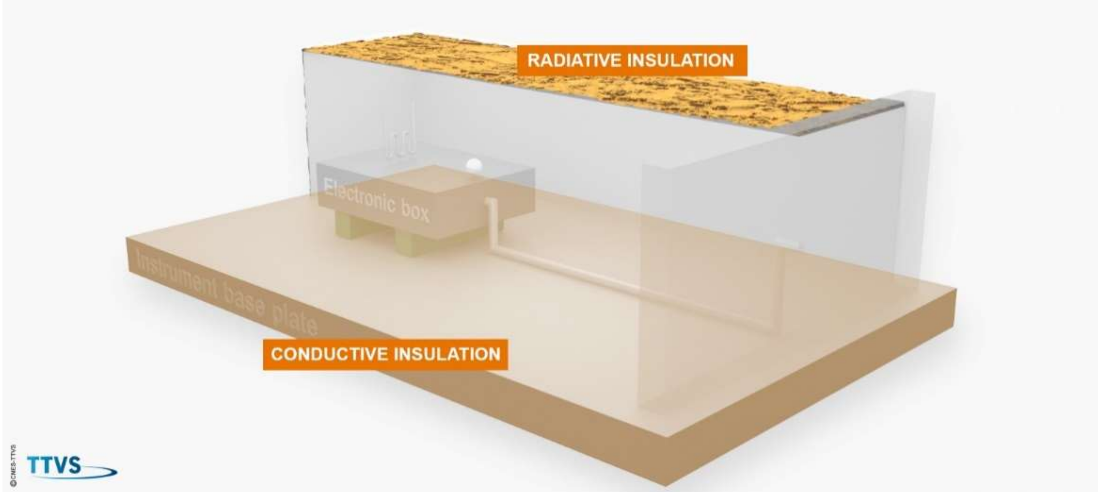
TTVS

- Mainly passive solutions
  - Conductive insulation

    Ex : Washers & Spacers

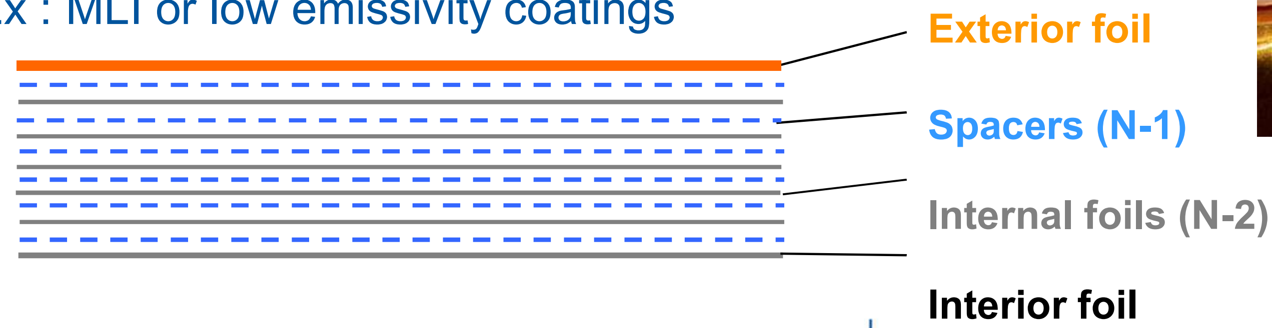


Insulating mechanical fixation



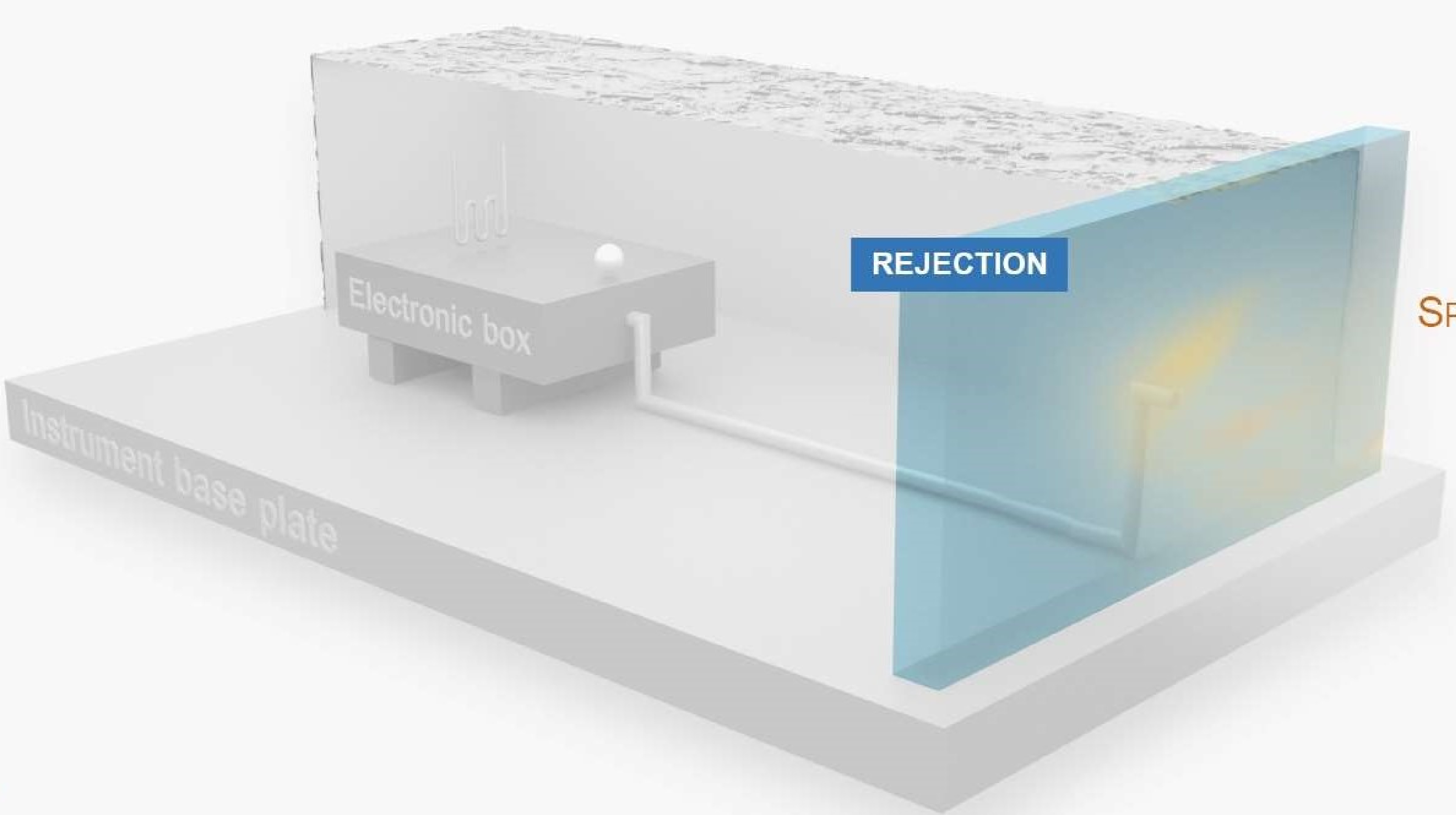
  - Radiative insulation

    Ex : MLI or low emissivity coatings



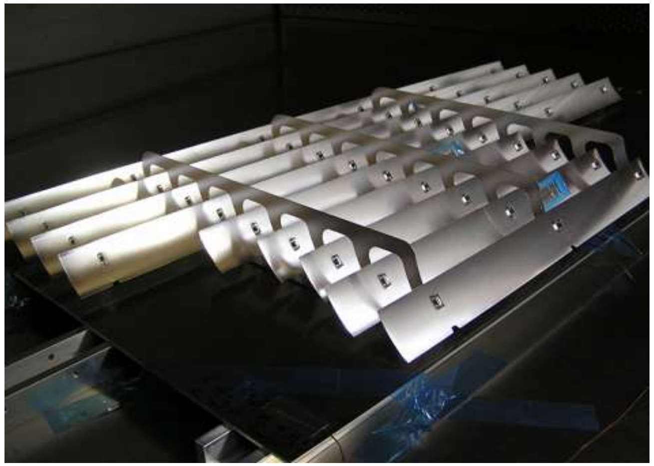
TCS design
Radiative Heat Rejection

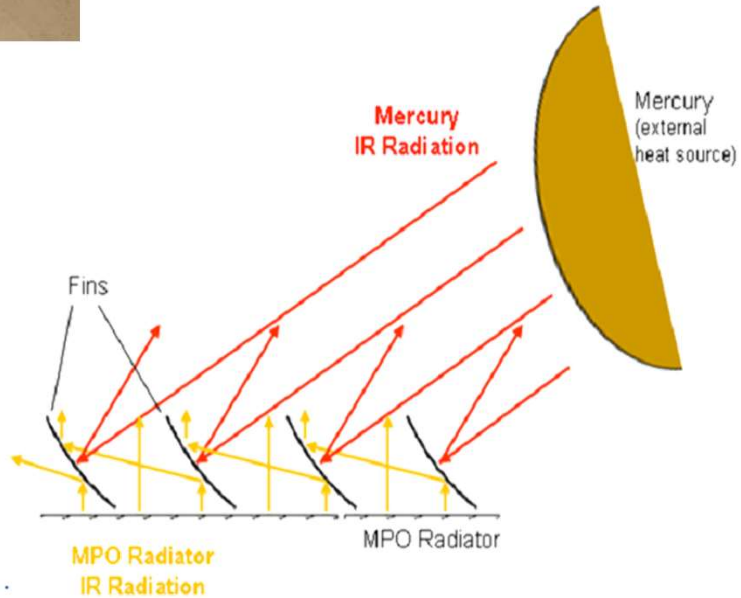
- Objective
  - Reject heat from dissipative equipment towards heat sink (deep space in general)
- General method
  - Use of radiative areas with large fields of view towards heat sink
  - Use coatings/paints with high IR emissivity



TCS design
Rejection means

- External radiators: high IR emissivity coatings + low solar absorptivity coatings
- Thermal baffles: to increase radiators fields of view towards deep space and to protect radiators against external heat sources (Sunshield, Earthshield, Mercuryshield…)





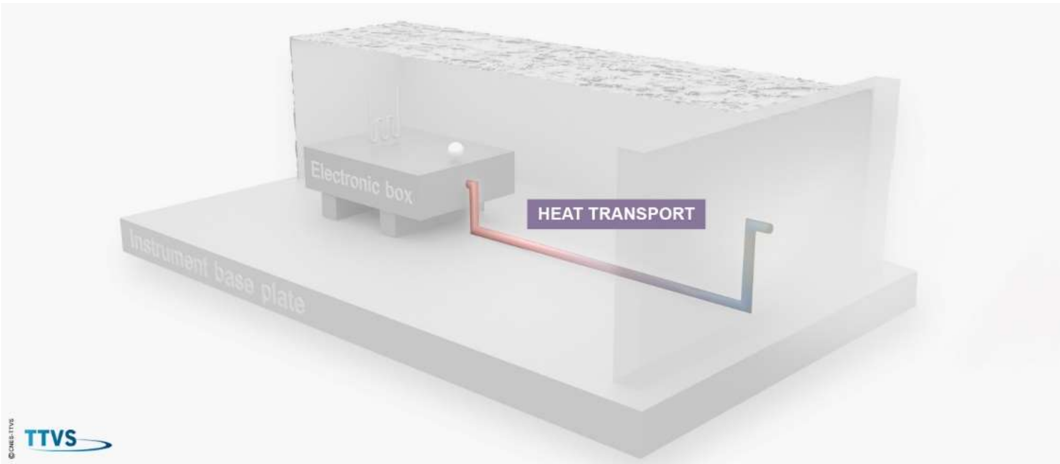
TCS design
Heat transport

Objective

- Connect dissipative equipment and radiator with a temperature difference as low as possible

Means = thermal buses

- Rigid or flexible conductive links for moderate transport needs
- Thermo-hydraulic technologies allow more powerful thermal buses



Advantages

- Thermal coupling + Mechanical decoupling
- "Low cost" technology
- Reliability

Drawbacks

- Small distances (typically < 5 cm)
- Mass

TCS design
Heating with regulation

Objectives

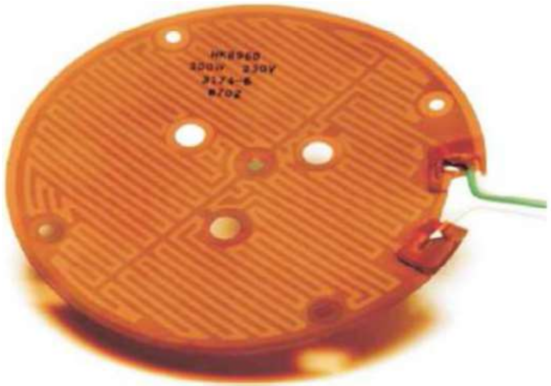
- Integrity of equipment during operational or non operational modes
- Performances of equipment during operational modes

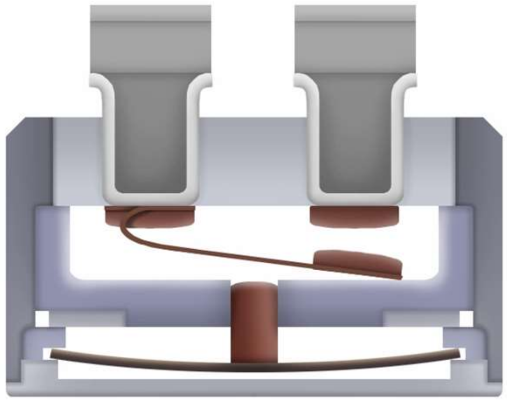
Means

Heaters with many possible regulation control laws

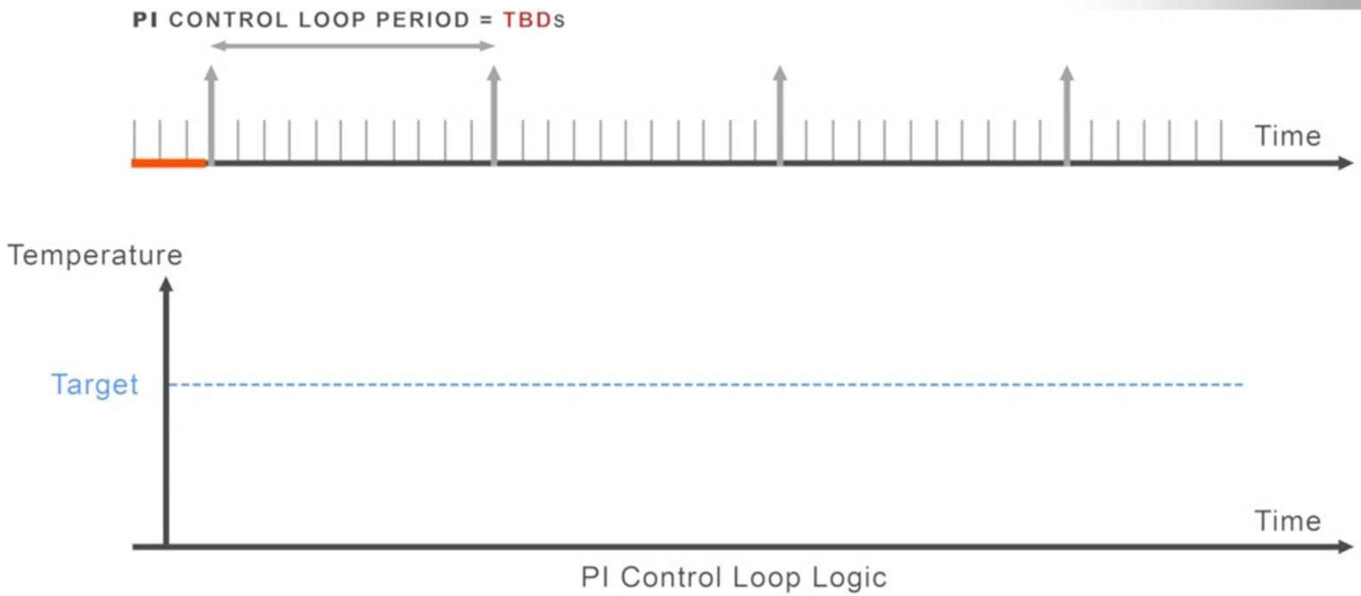
- ON/OFF: mechanical thermostat or thermistors coupled with on-board software
- Sharp regulation: thermistors + PI control law through on-board software

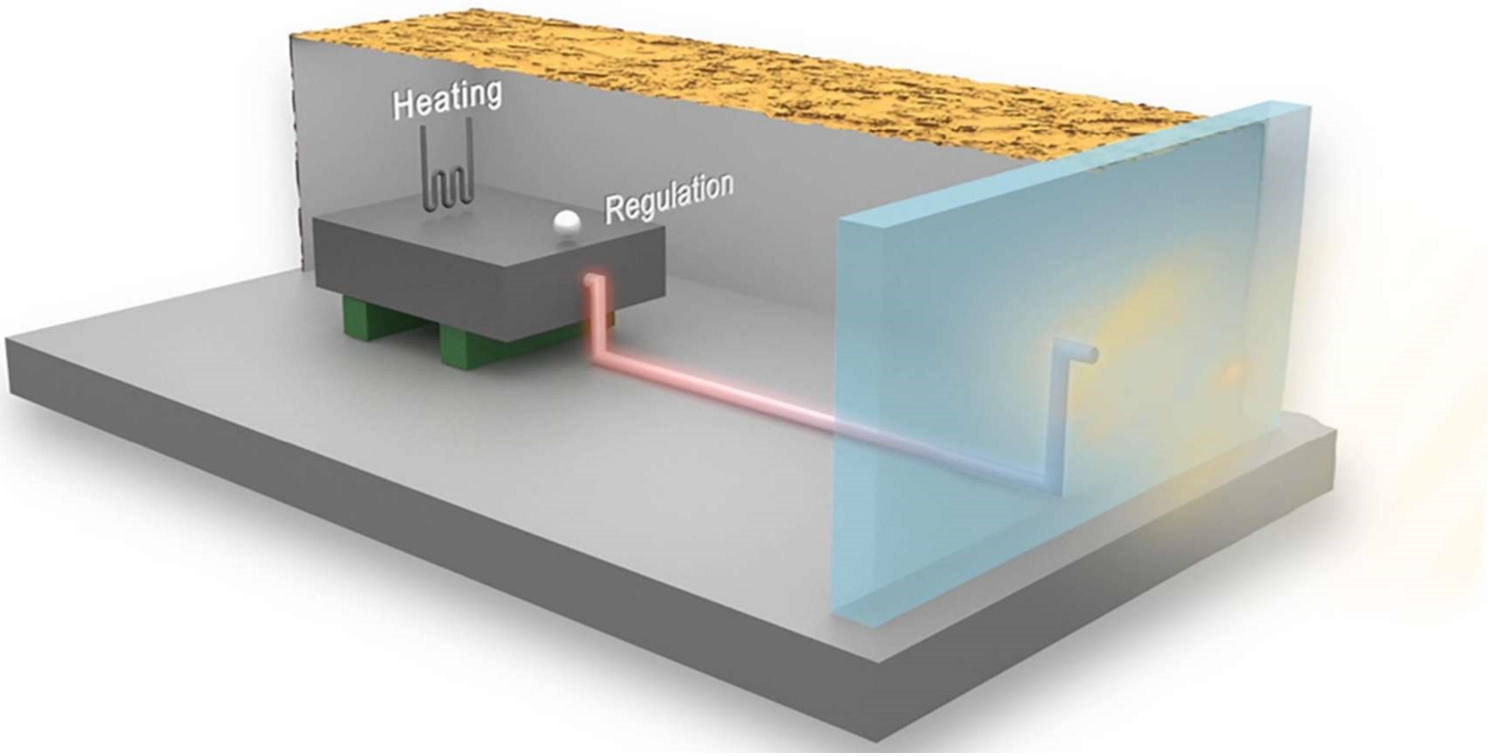
Heaters, mechanical thermostats and temperature sensors
Heating line = two heating circuits (N+R) and three temperature sensors for redundancy purpose



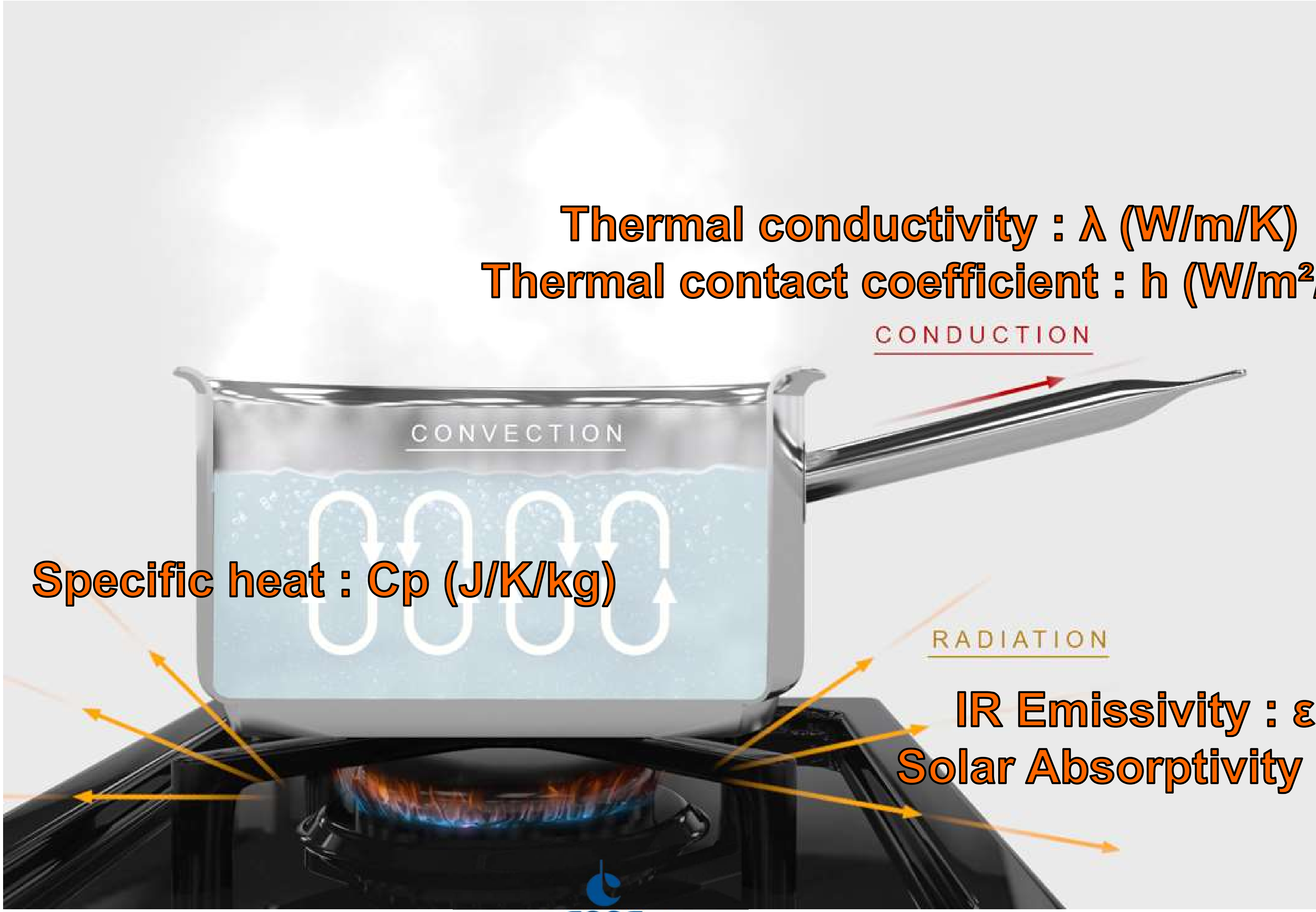


Heating with Regulation by On-Board Computer (OBC)





Conclusion



Thermal conductivity : λ (W/m/K)
Thermal contact coefficient : h (W/m²/K)
CONDUCTION
CONVECTION
Specific heat : Cp (J/K/kg)
RADIATION
IR Emissivity : ε
Solar Absorptivity : α

1. TCS Objectives and Constraints

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MERCI !