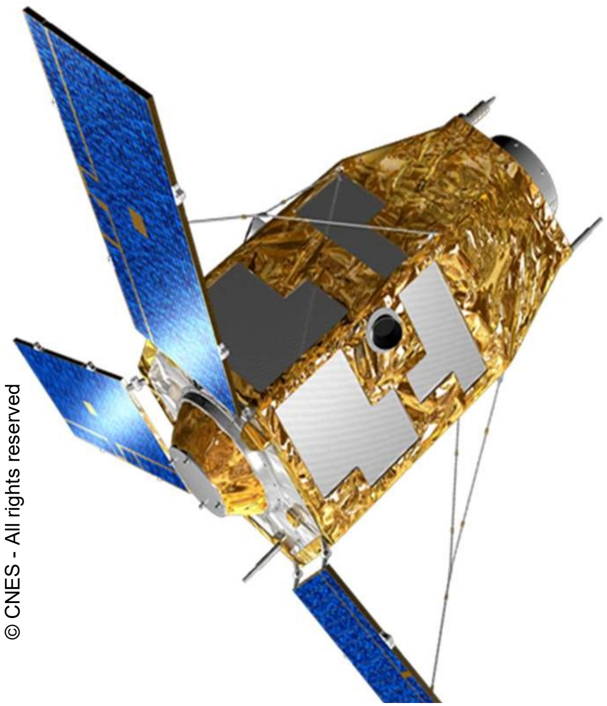
# Ecole Technologique du RT Vide

## Transferts de chaleur





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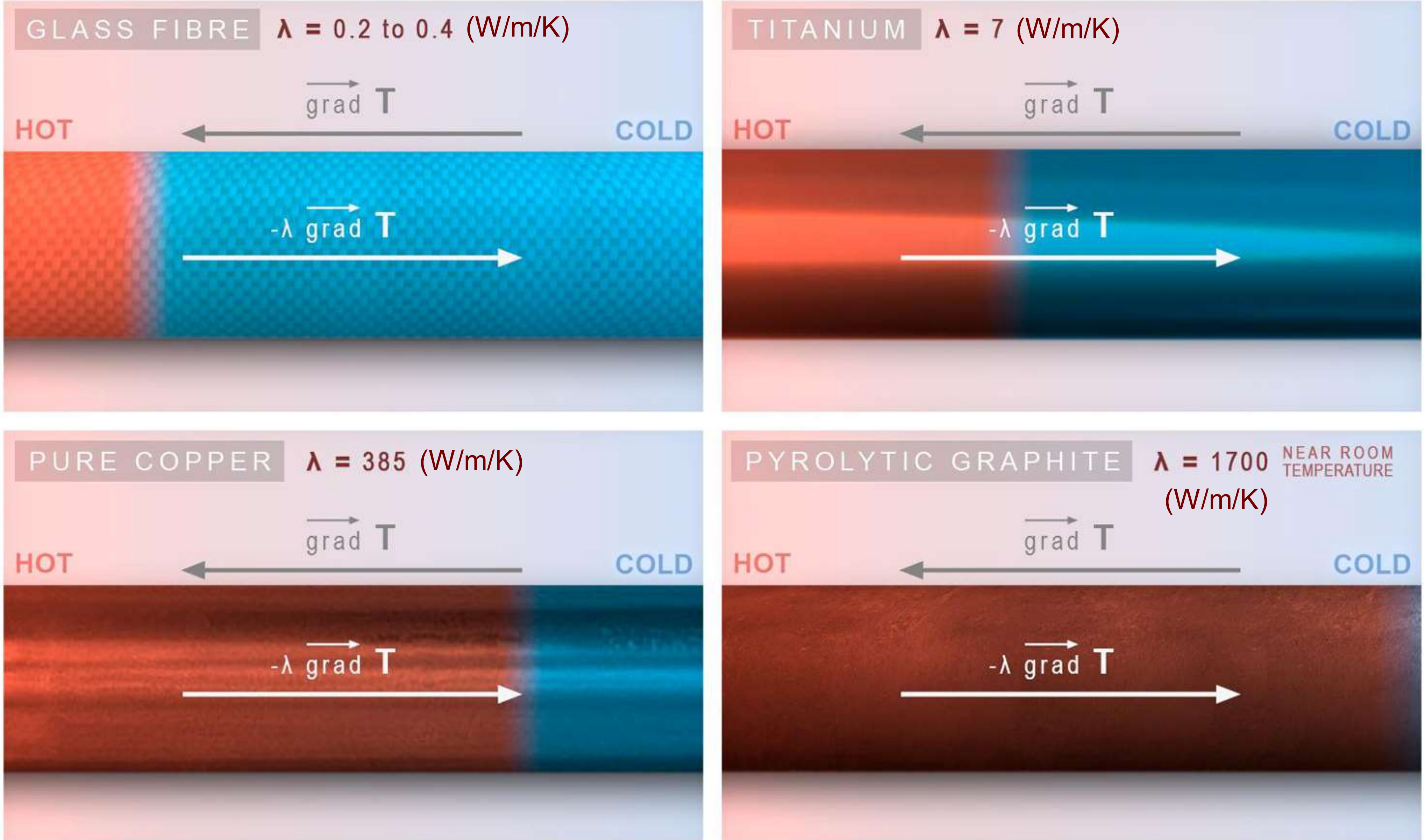
CONDUCTION
CONVECTION
RADIATION

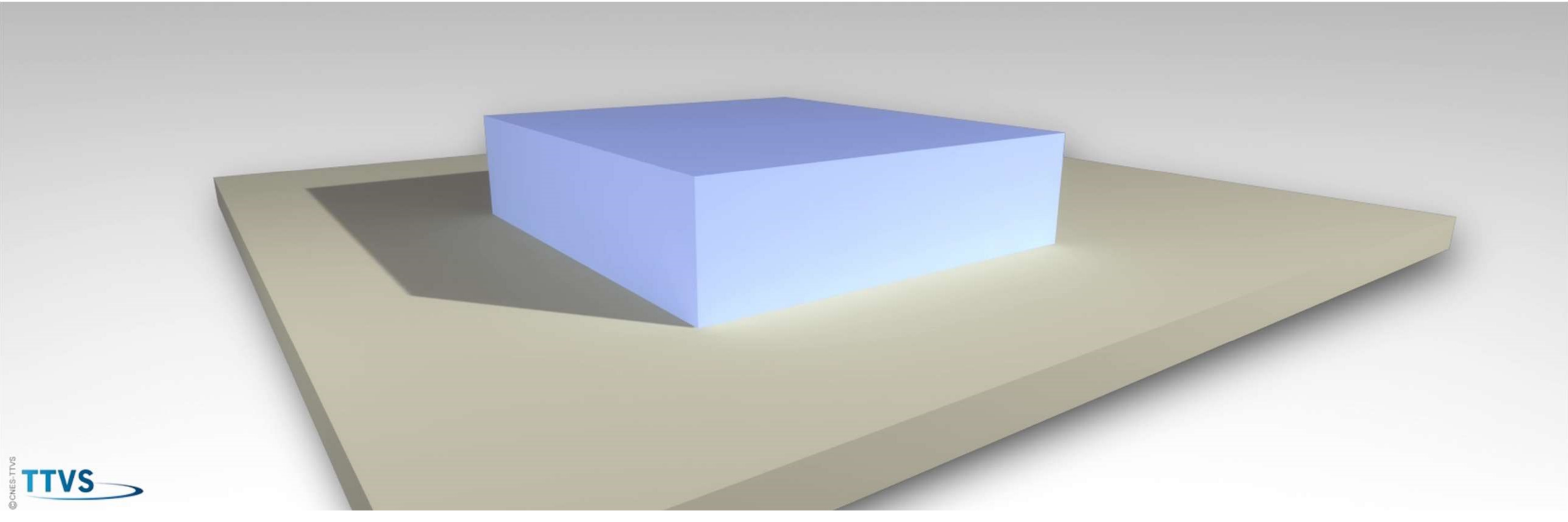
# By conduction



# 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*(Tsolid1-Tsolid2)



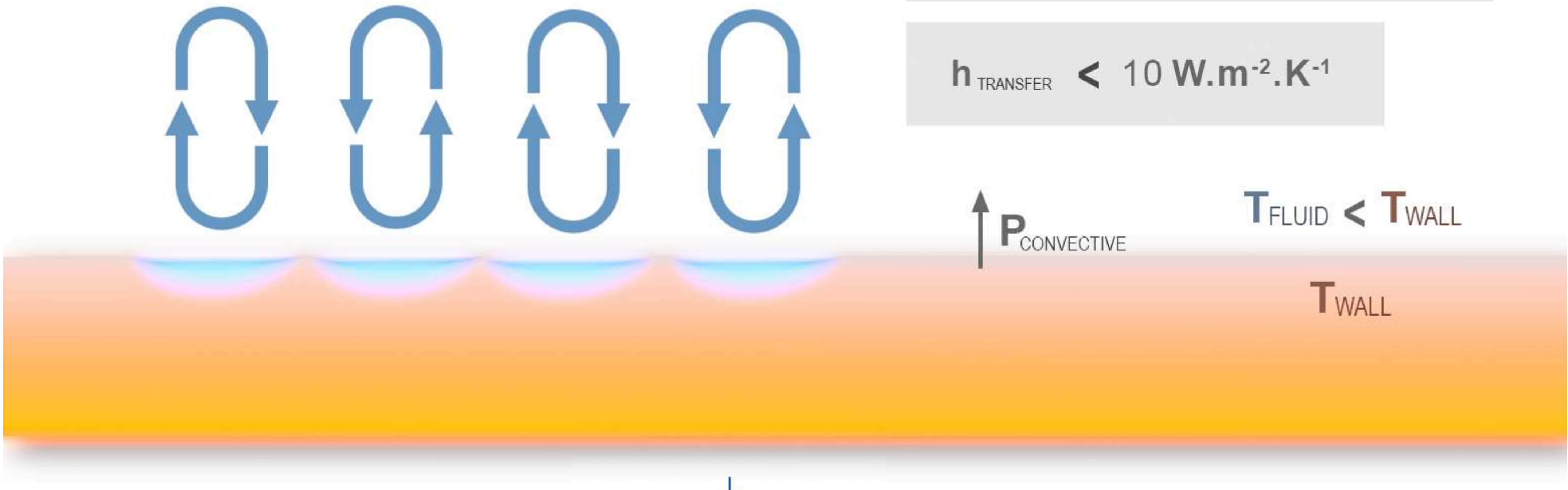
# By convection

## Free convection

- Archimedes force induces fluid motion by density variation with temperature

$$P_{CONVECTIVE} = h_{TRANSFER} \cdot S \cdot \left(T_{FLUID} - T_{WALL}\right)$$

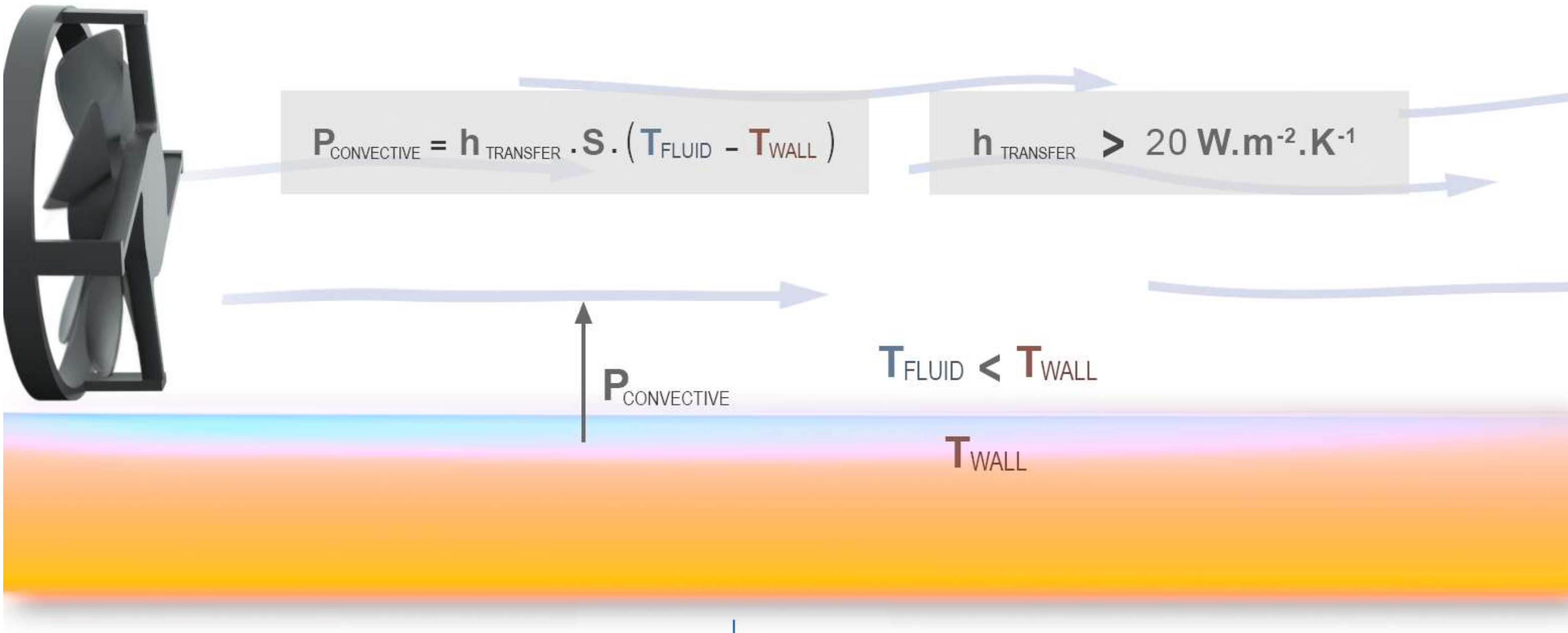
$$h_{TRANSFER} < 10\ W.m^{-2}.K^{-1}$$



# By convection

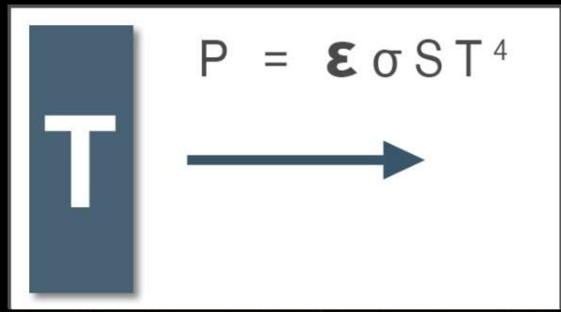
## Forced convection

- Fluid motion is forced to extract heat



# By radiation under space vacuum and near Earth

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

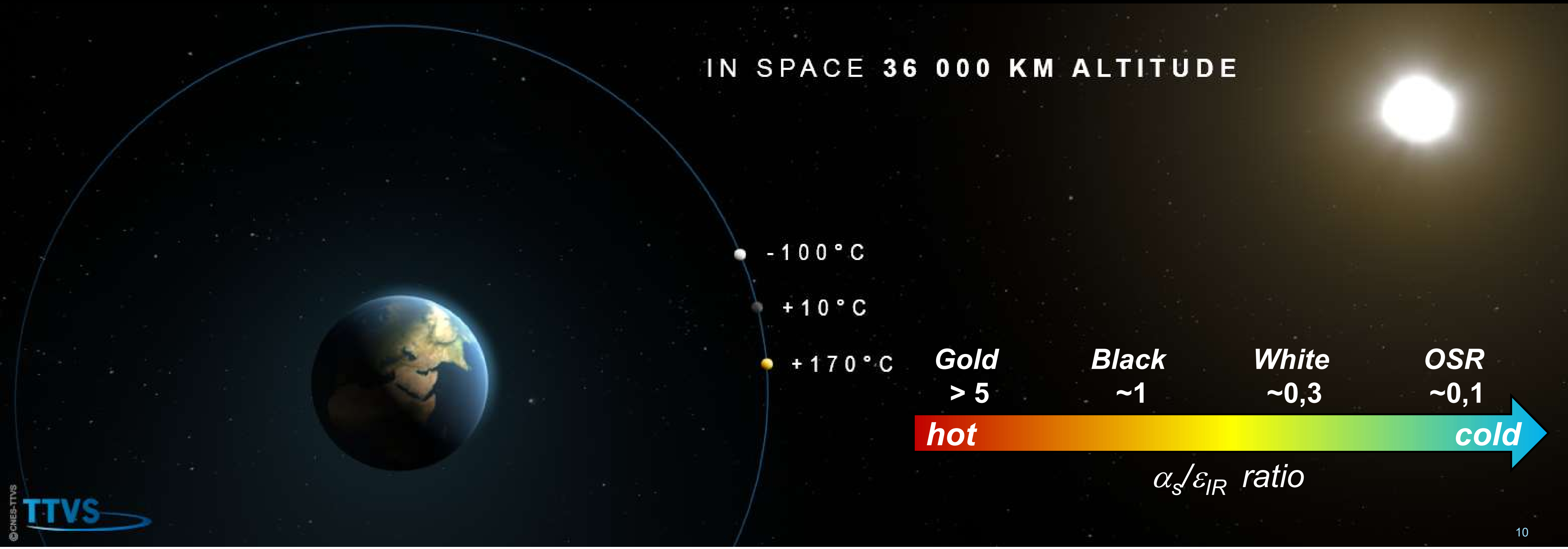



# Radiation: a surface phenomenon

- Surface thermo-optical properties (all wavelengths and all directions)
  - Sun spectrum ➔ total absorption ➔ solar absorptivity = $\alpha_s$
  - IR spectrum ➔ total absorption = total emission ➔ IR emissivity = $\varepsilon_{IR}$
    - 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

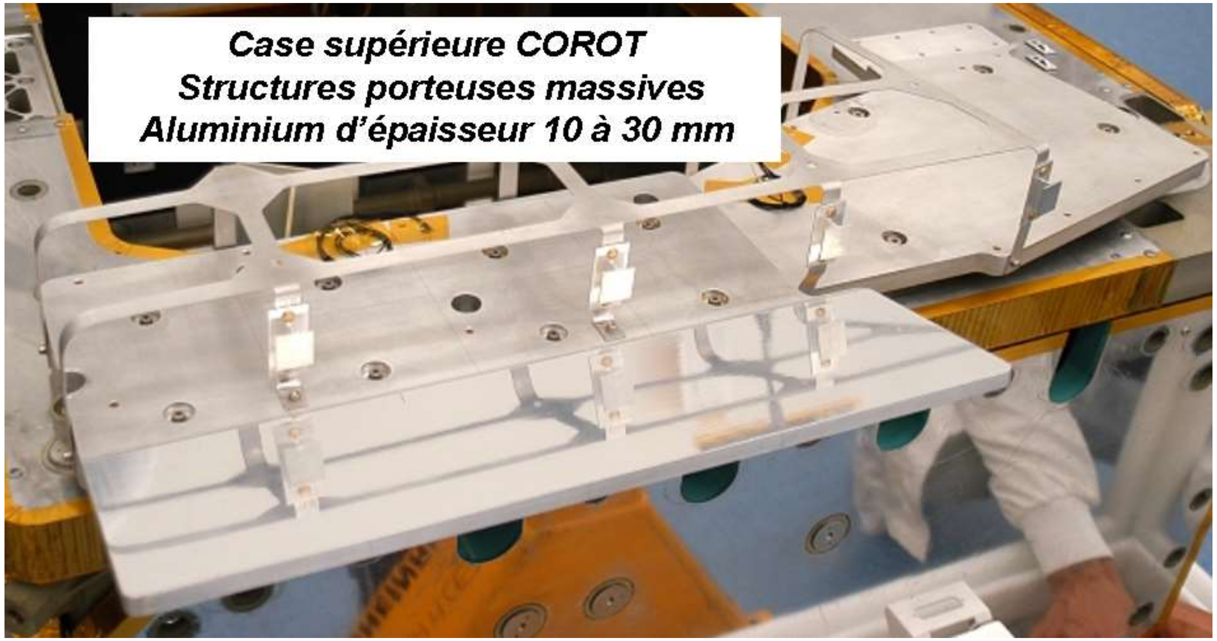


# Heat storage and recovery

- 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



# Heat transfer and storage

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

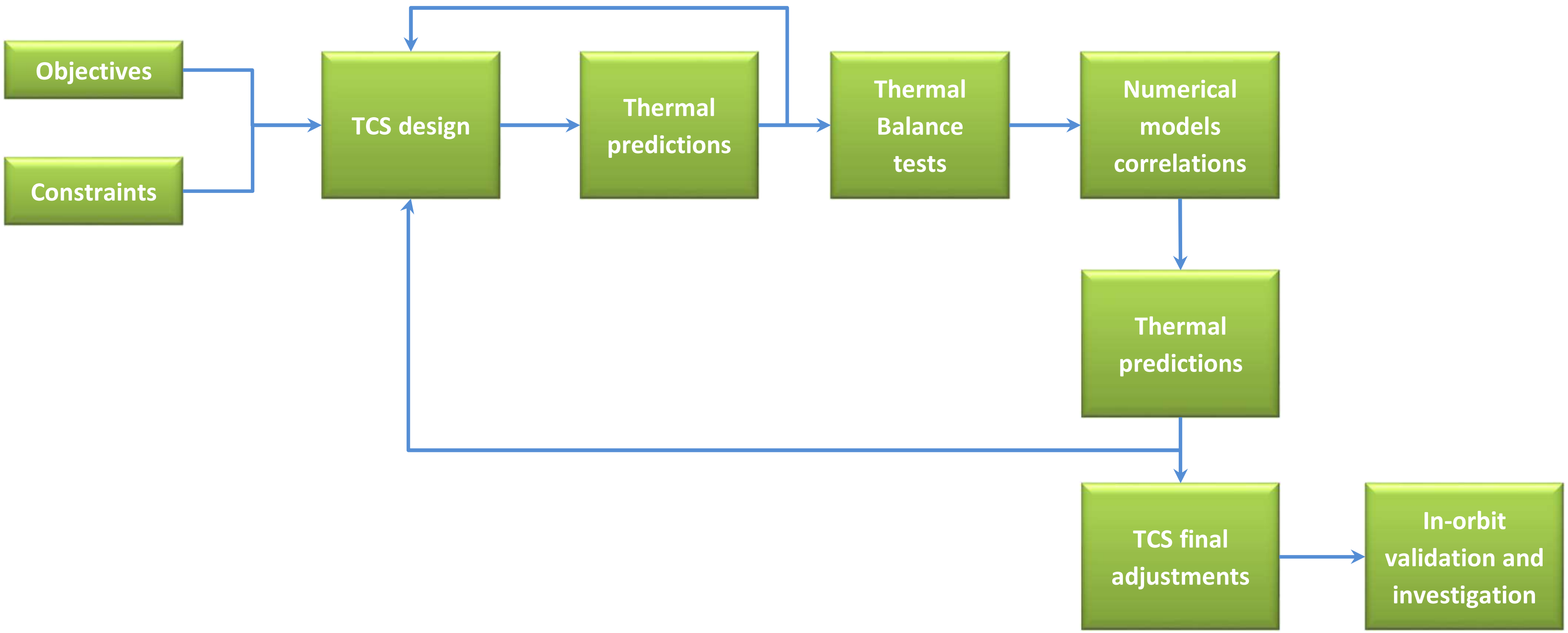
- Physical phenomena driving Thermal Control System development

TCS = Thermal Control System = Système de Contrôle Thermique

1. Transfert et stockage de chaleur
2. Développement et verification d’un système de contrôle thermique
3. La thermohydraulique
4. Les technologies cryogéniques

# TCS development philosophy

- Iterative process during the whole development sequence (constraints  evolutions, design updates…)



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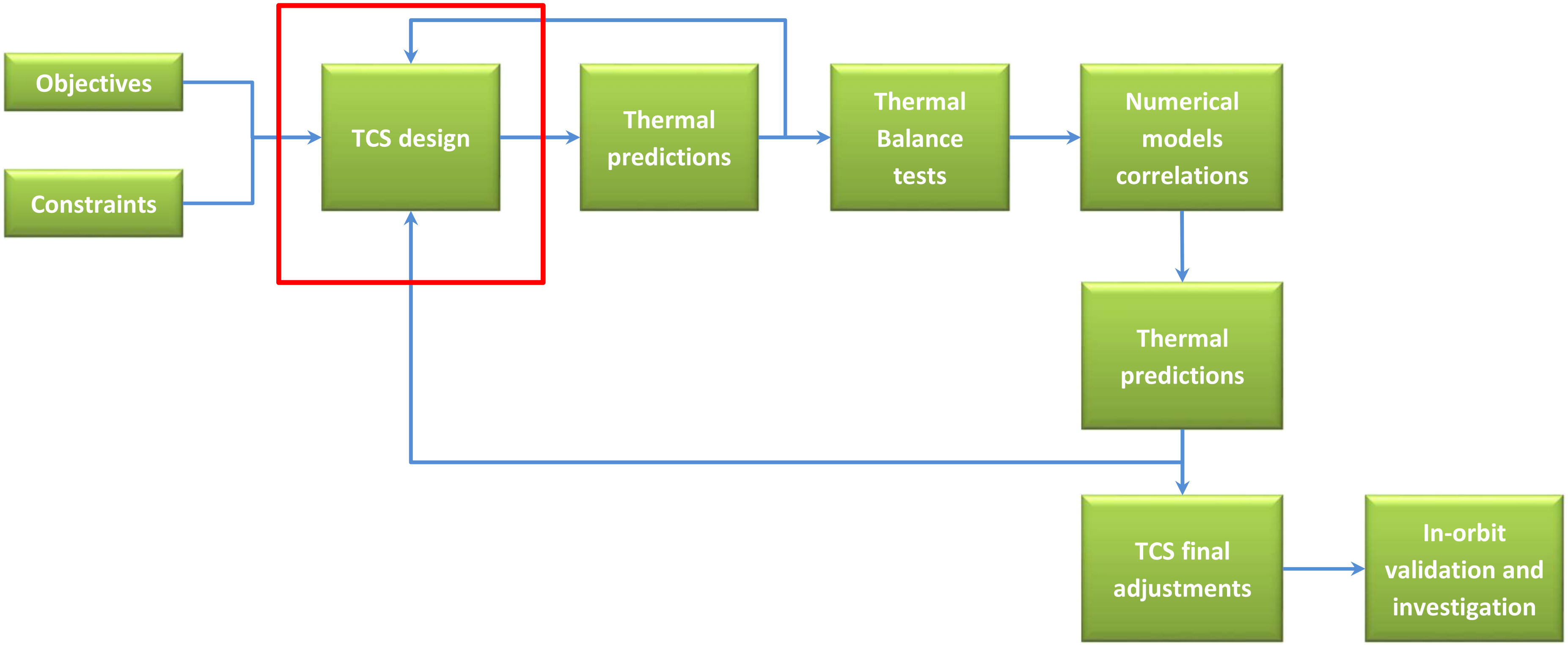
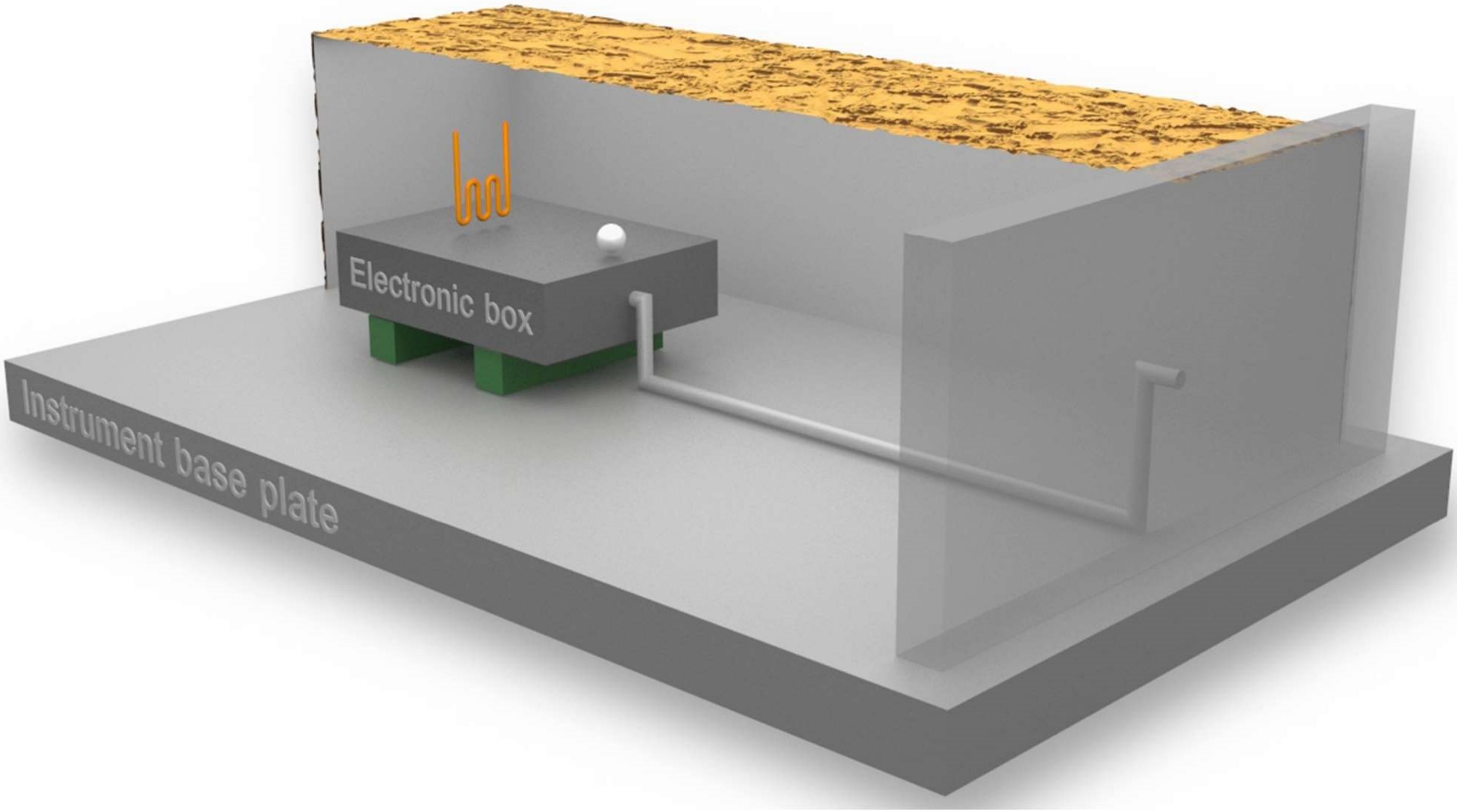


# TCS design
# 6 main functions

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





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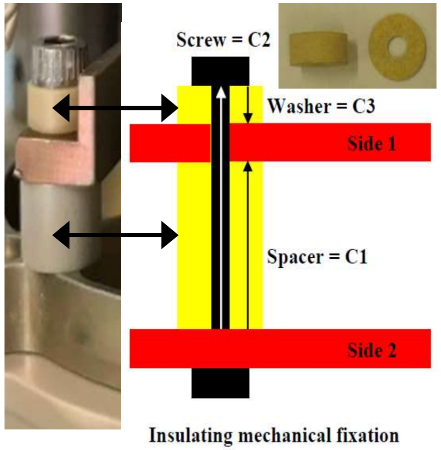
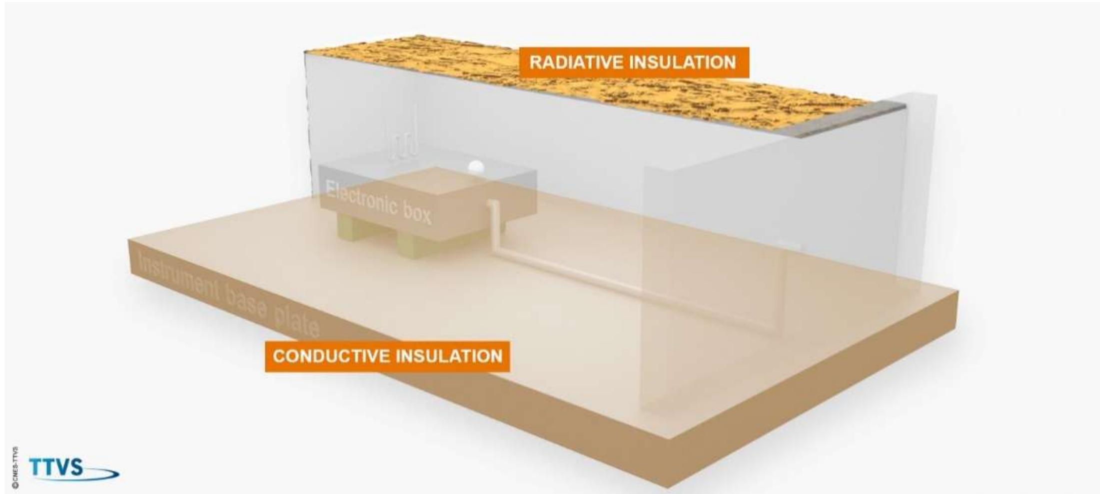
## Mainly passive solutions

- Conductive insulation

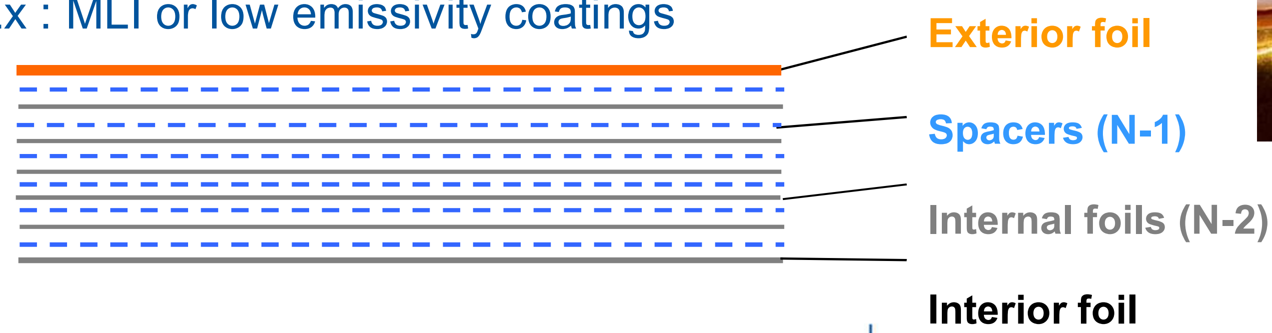
Ex : Washers & Spacers



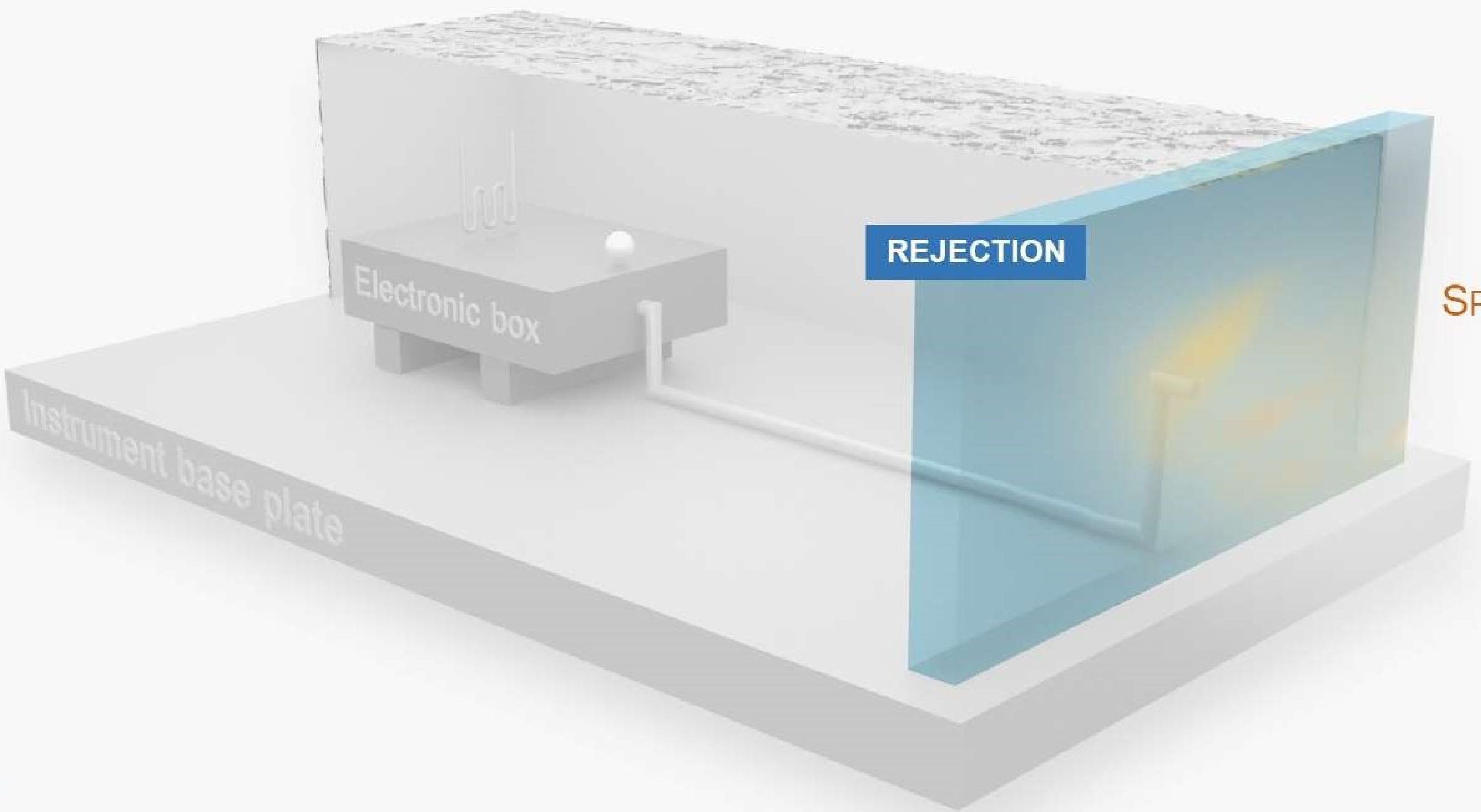

- Radiative insulation

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



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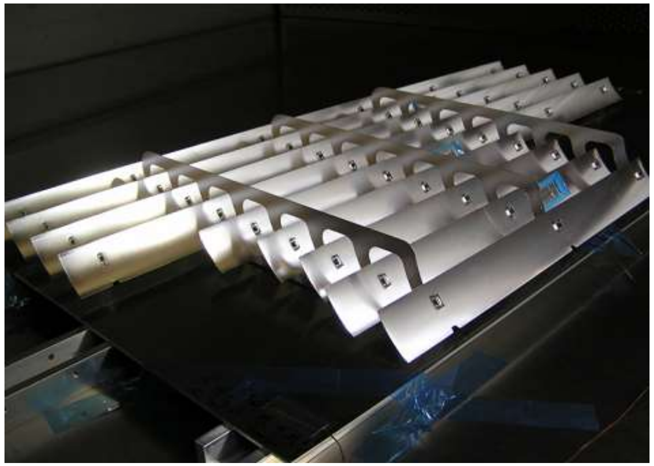
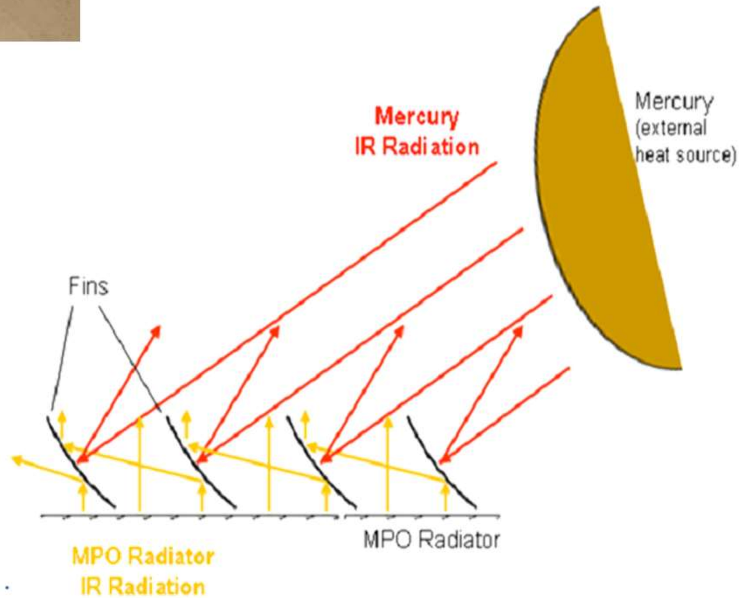
# TCS design
# Rejection means

- 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…)





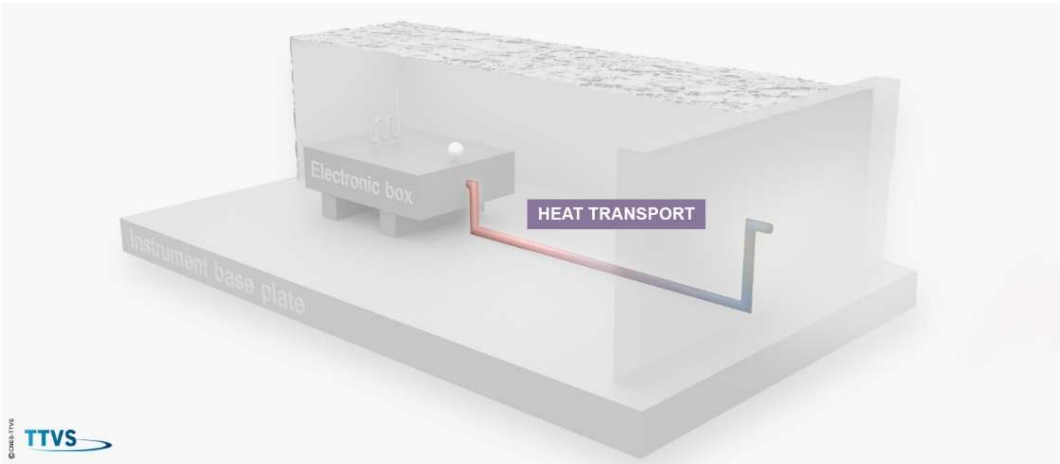
# TCS design
# Heat transport

## 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

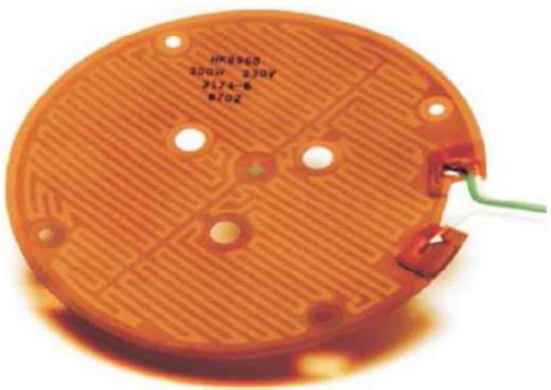
# TCS design
# Heating with regulation

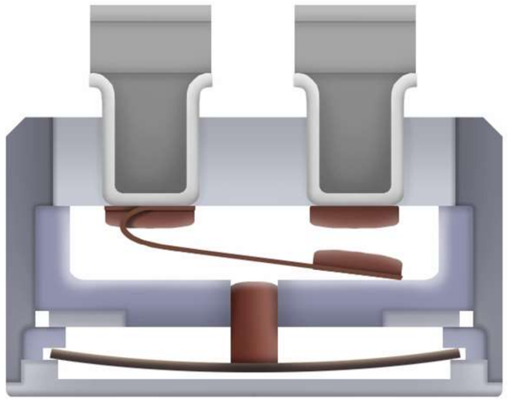
- Objectives
  - Integrity of equipment during operational or non operational modes
  - Performances of equipment during operational modes

- 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





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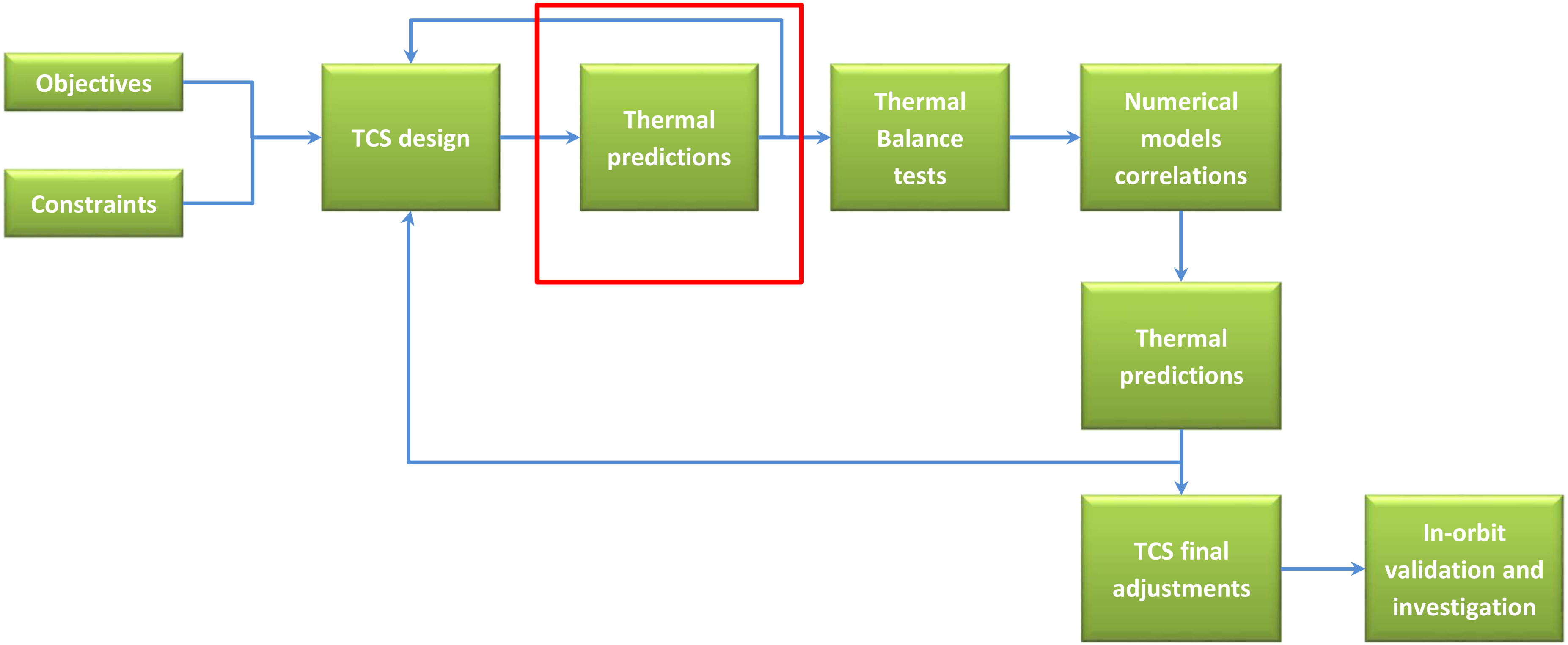
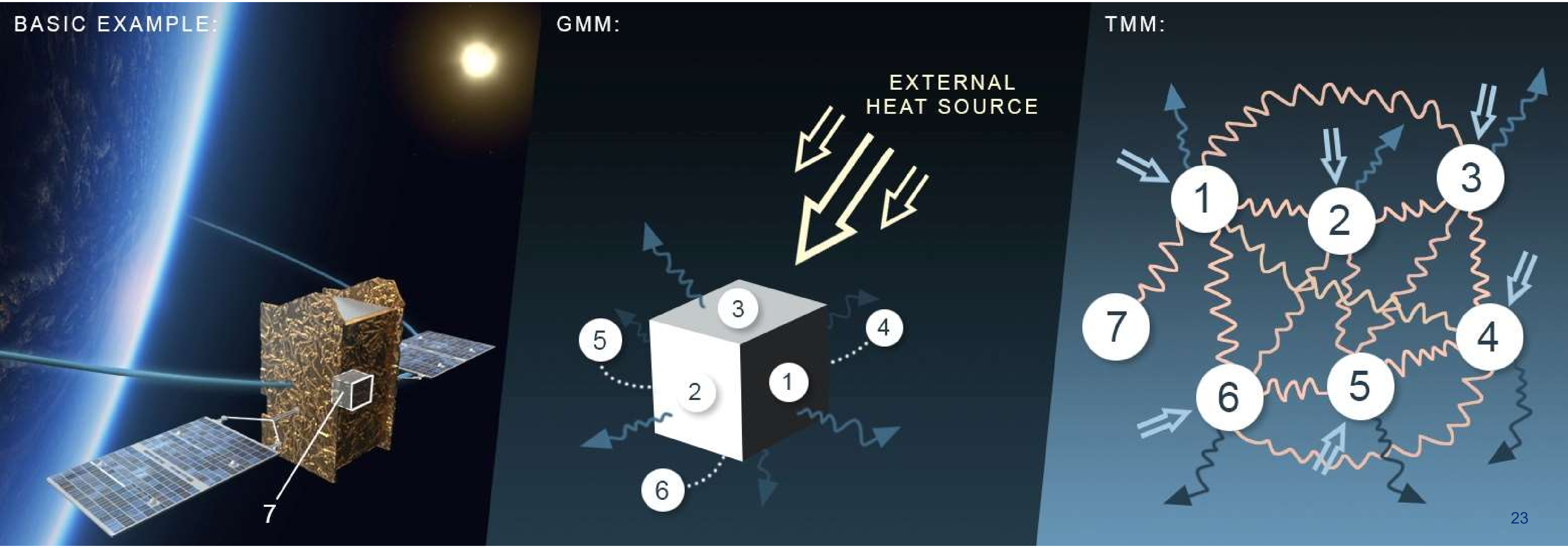


# Thermal predictions
## A cost effective way to predict in-flight thermal behaviour

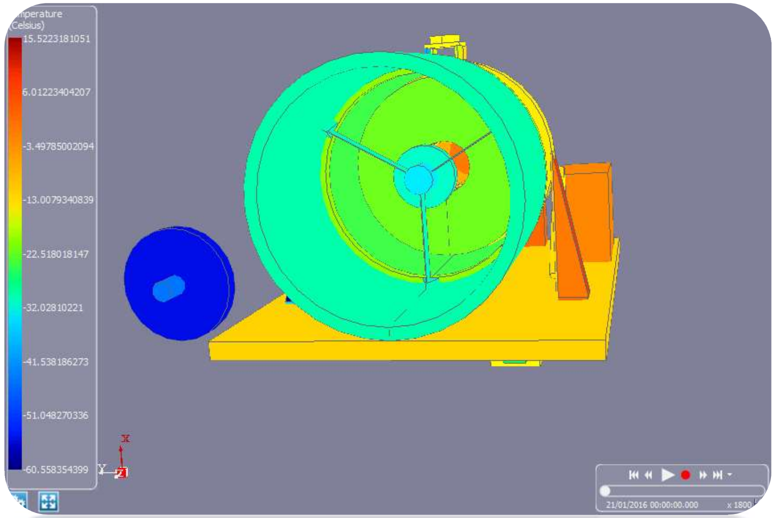
- Numerical models based on CAD models+simplifications/assumptions
- "Nodal Method" : Composed of two distinct entities
  - Geometrical Mathematical Model (GMM) → for radiative exchanges and external heat sources (Sun, Earth…)
  - Thermal Mathematical Model (TMM) → for temperature evolutions and heat exchanges between nodes
- Space environment simulation : Sun, Earth, mission and link with TCS sizing scenario

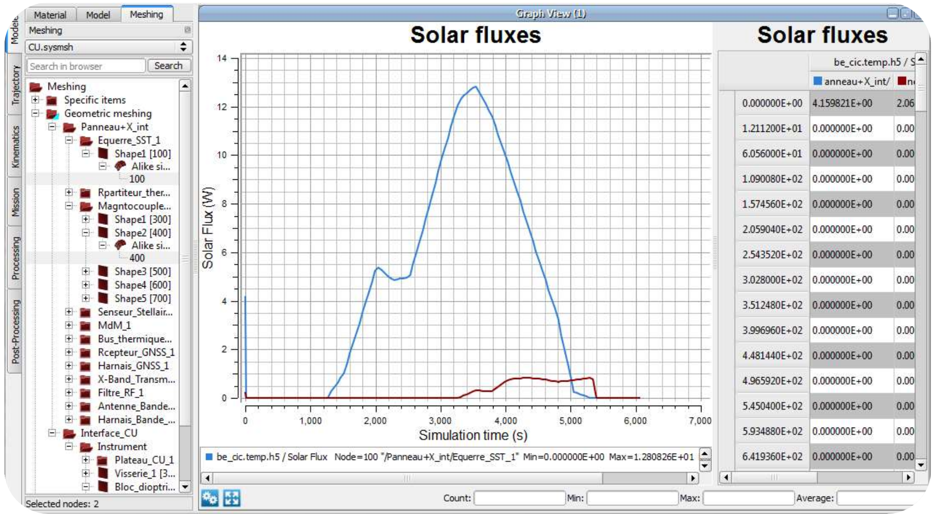


# Thermal predictions

## A cost effective way to predict in-flight thermal behaviour

- Thermal predictions results
  - Temperature evolutions over an orbit and over the whole mission duration → minimum and maximum temperatures versus allowable or design temperature ranges
  - Heat exchanges balances → representative of the global thermal behaviour
  - Temperature mappings → thermo-elastic analyses





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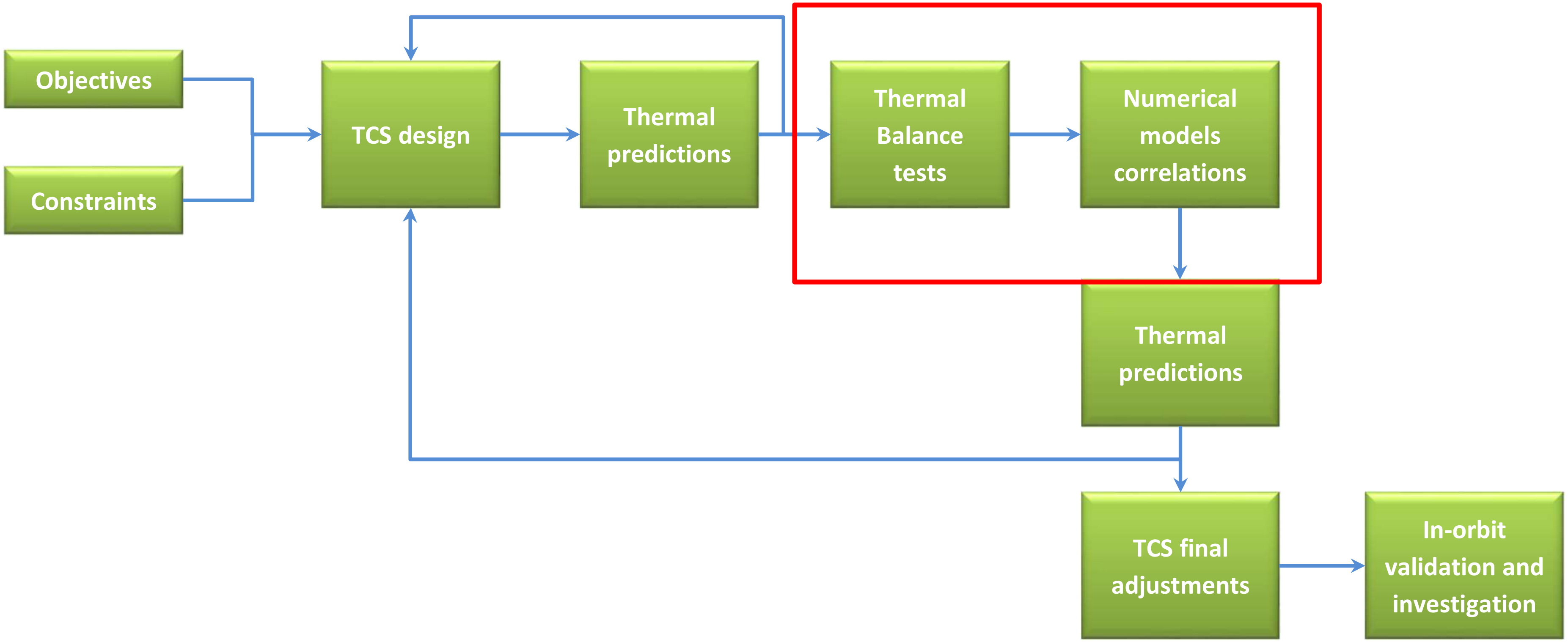
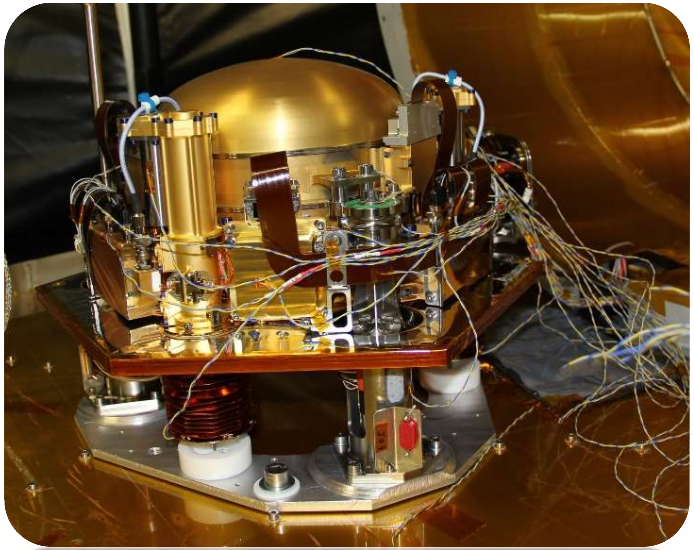
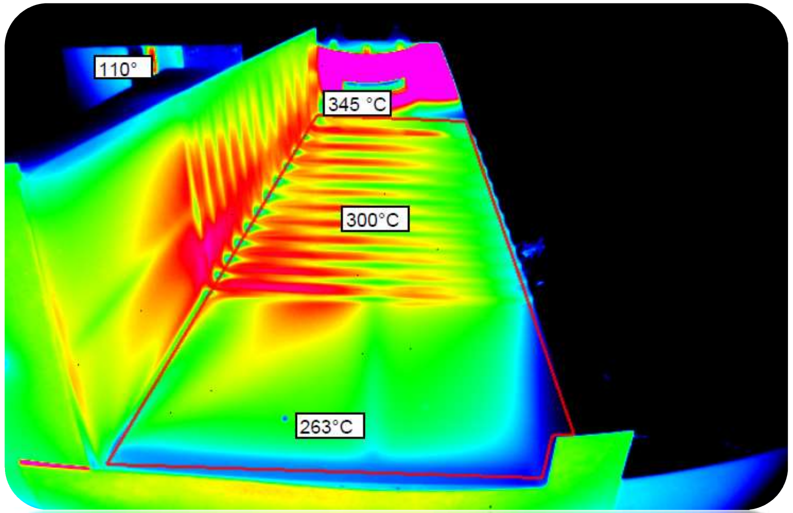


# Thermal Balance (TB) tests

- Thermal Balance test is dedicated to thermal engineer to verify TCS performances and validate numerical models
- Thermal Balance test principles
  - Simulate environmental sizing conditions
  - Reach temperature equilibrium for thermal coupling verification
  - Heat capacities correlated during transient phases for dynamic behaviour representativeness
- Test setup developed to reduce uncontrolled heat leaks
- TB test correlation done after : fine tuning of parameters, but other methods using optimisation based on genetic algorithms





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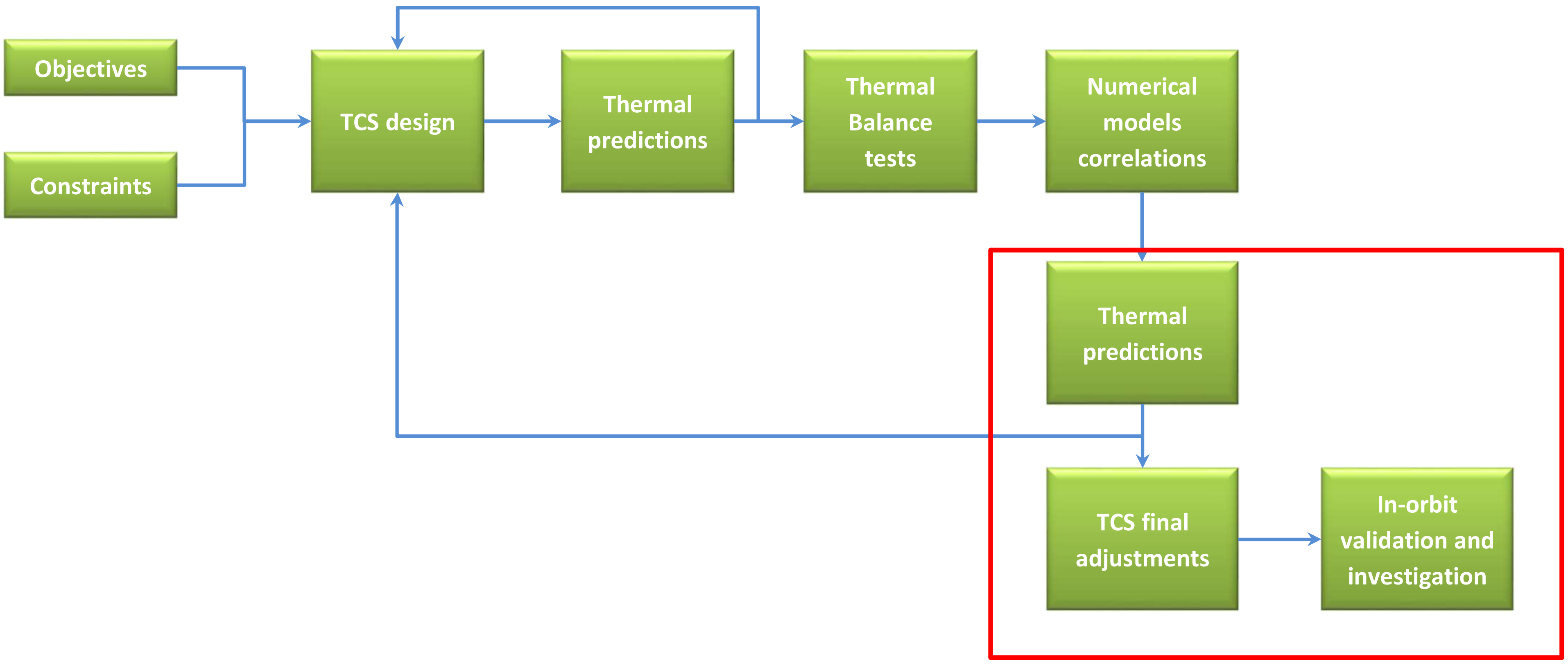

1. Transfert et stockage de chaleur

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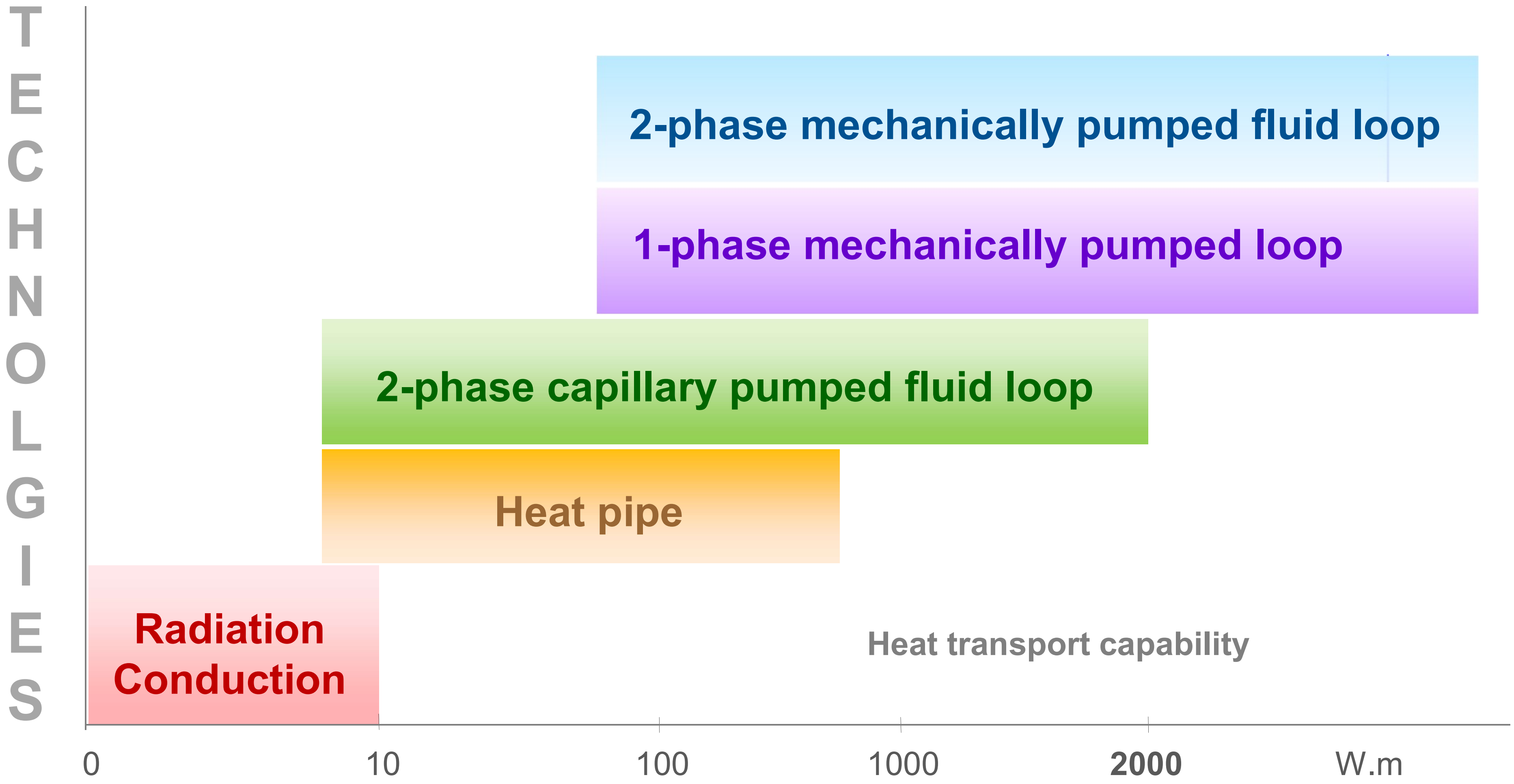
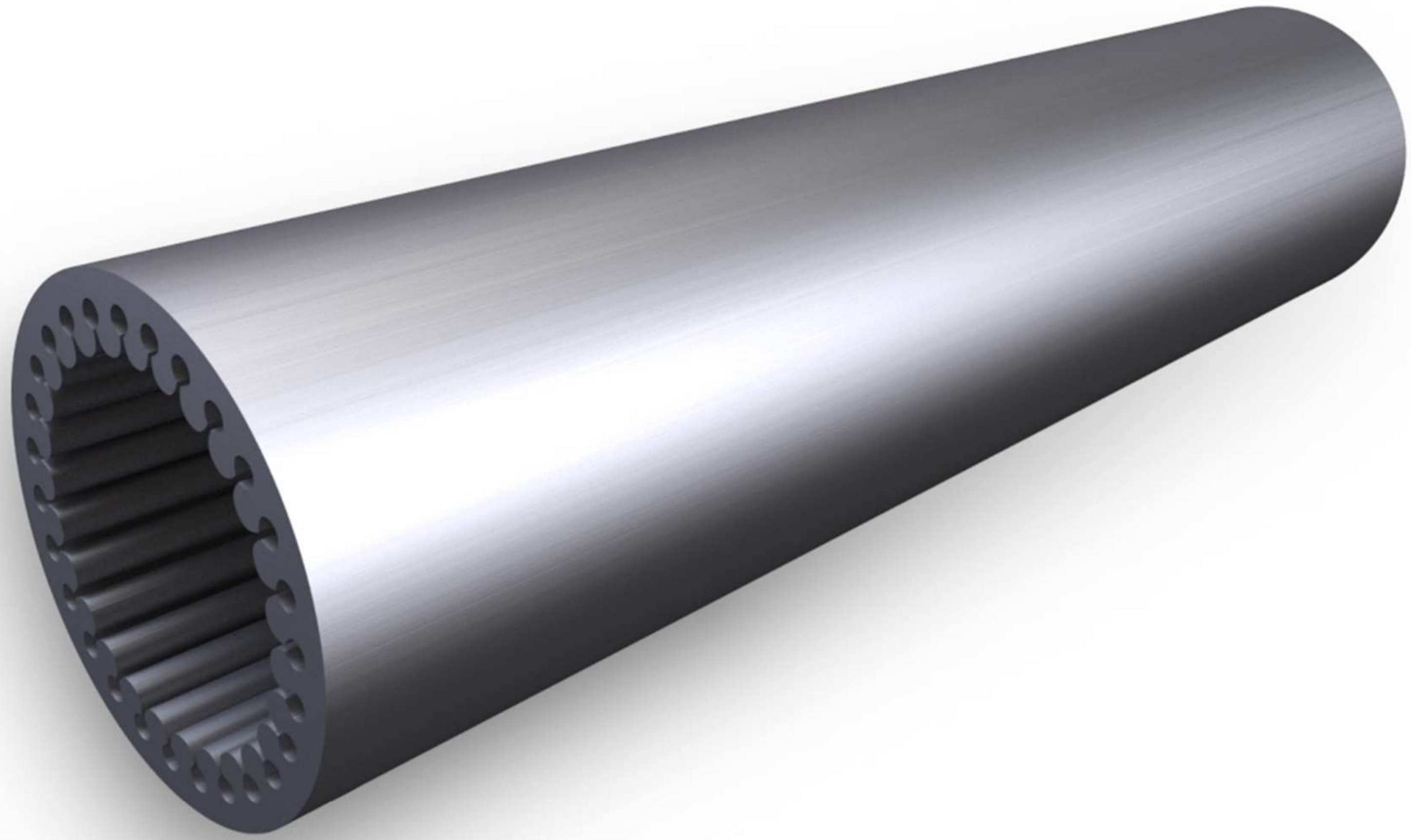
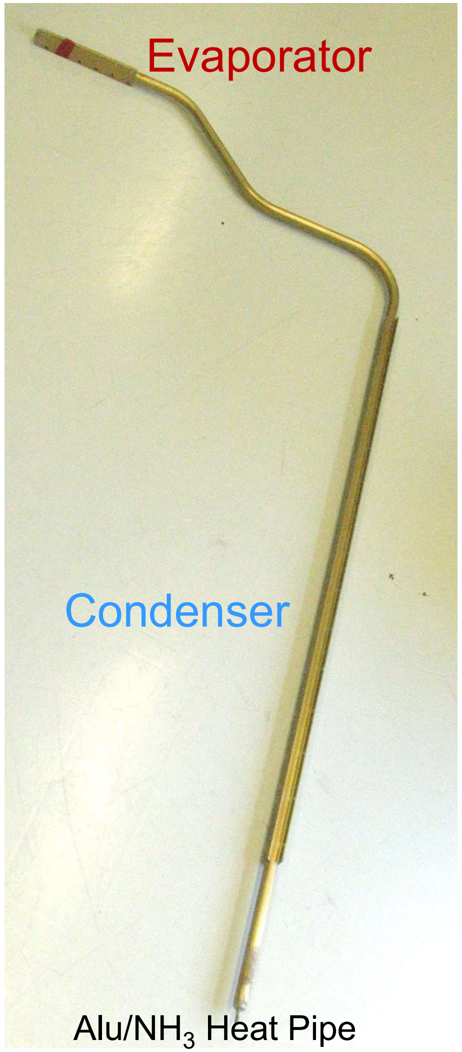
# WHY?

…Since conduction and radiation heat transfers are limited

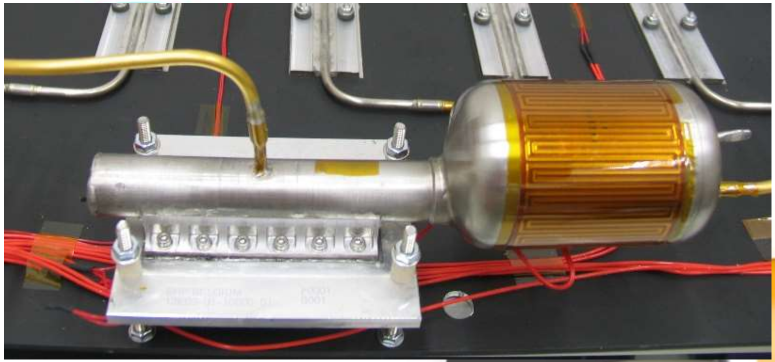


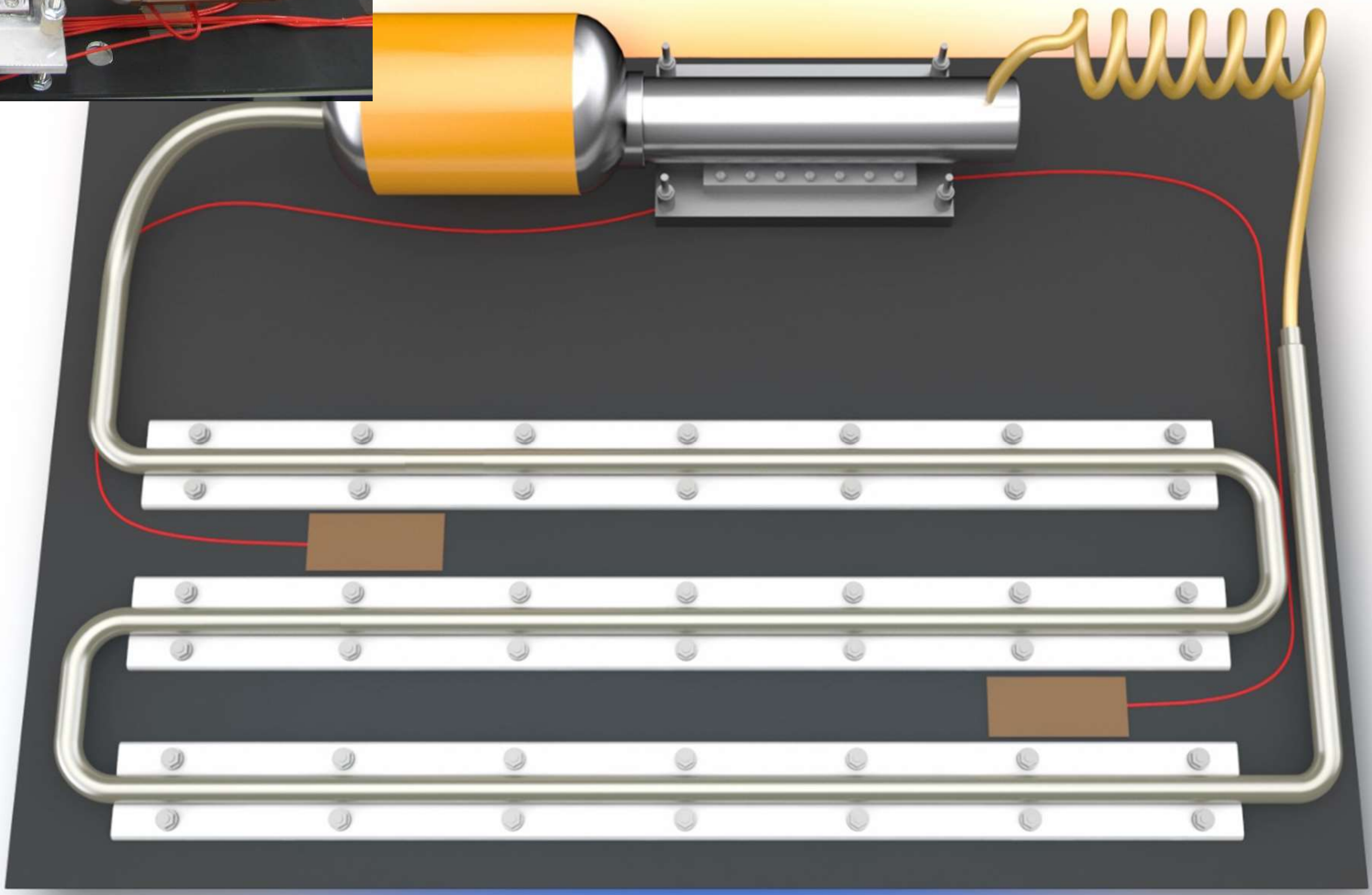
# Heat Pipes



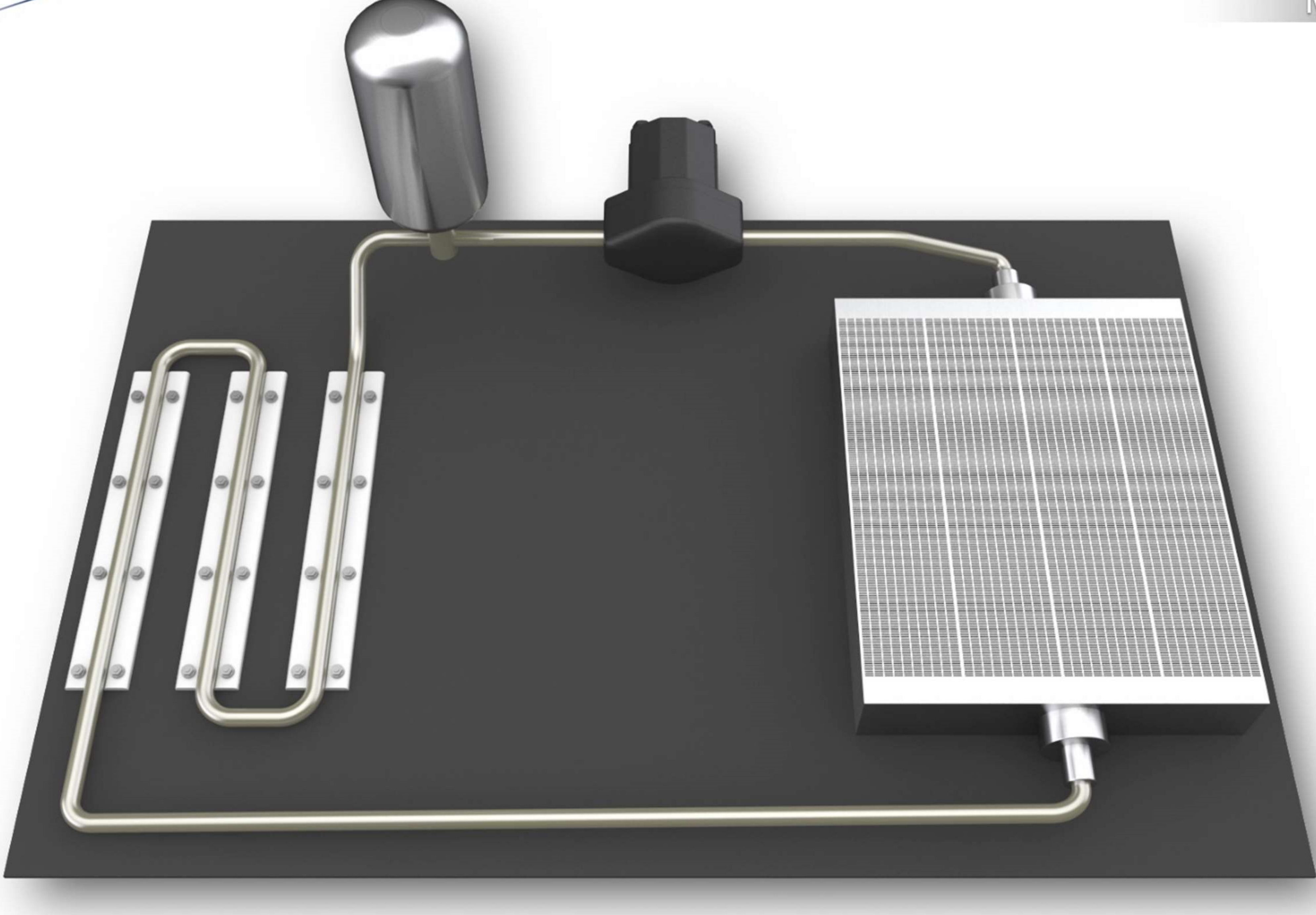



Alu/$NH_3$ Heat Pipe





# MPL



# MPL

(Mechanical Pumped Loop)

## Advantages

- Best option due to use of Latent Heat
- Just limited in providing needed pump flow rate and $\Delta P$
- Accurate temperature control of equipment units (better than 1 ºC)
- Homogeneous equipment units temperatures

## Drawbacks

- Complex system (modelling, operation)
- Pump life time (mechanism)
- Microgravity performances of large loop?

## Operational use

- Large loop: SES17 (Thales Alenia Space) since 2022
- Lots of development in progress: US, EU (NEOSAT).

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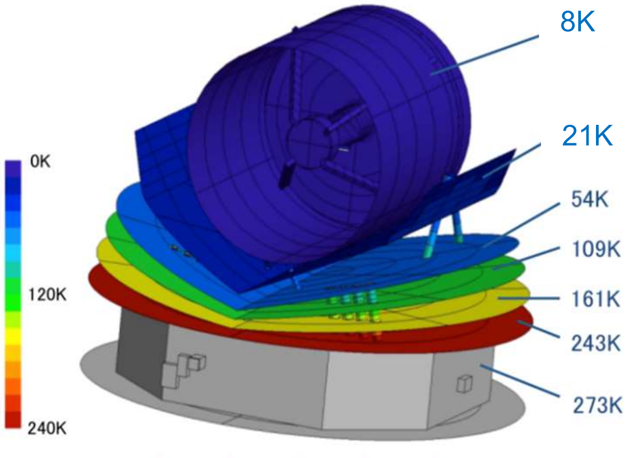
# Cryogenic Technologies
# Why?

- Objective: cooling to cryogenic temperature (below 200 K)
- To reduce the "thermal" noise of detectors
  - Gamma Rays Detection: from 85 K to 100 K
  - SWIR Detection: from 120 K to 180 K
  - IR Detection: from 50 K to 100 K
  - FAR IR Detection: from 0.05 K to 0.3 K
- To reach superconductive state of material (electrical resistance ≈ 0)
  - Superconductive IMUX/OMUX (Telecoms)
- Biological samples storage (e.g. ISS experiment)

# Cryogenic Technologies
# How?

## Passive Technologies

- Passive radiators only = cooling by heat radiation towards external sinks
- Example: IASI first generation, SPICA



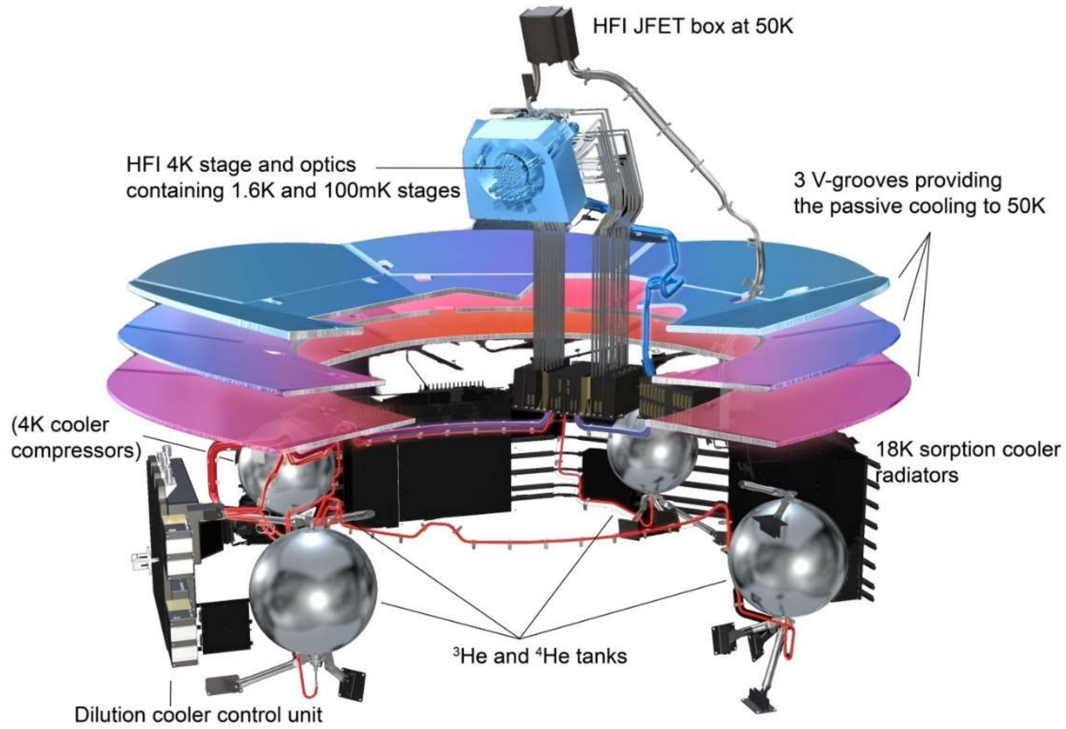

## Cryogens (Helium, Solid Hydrogen…)

- Examples: HERSCHEL


He tank – 1.7 K – lifetime: 3.5 years

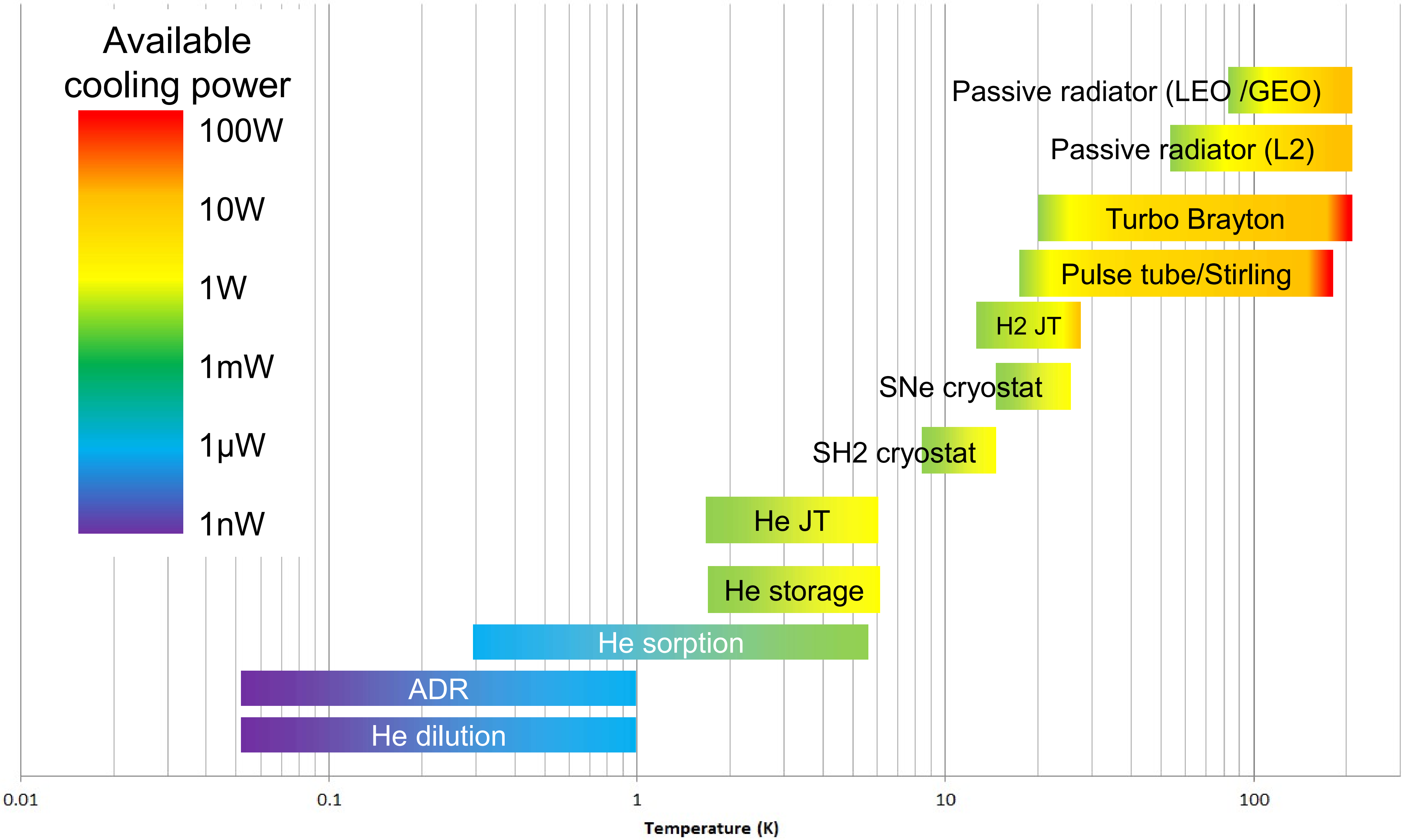
## Active Technologies

- Mechanical coolers (Joule-Thomson, Pulse Tube, Stirling…)
  Examples: IASI-NG, MTG, ASTRO-H
- Sub-kelvin coolers (ADR, Dilution…)



# Panorama

Cryogenic technologies versus temperature



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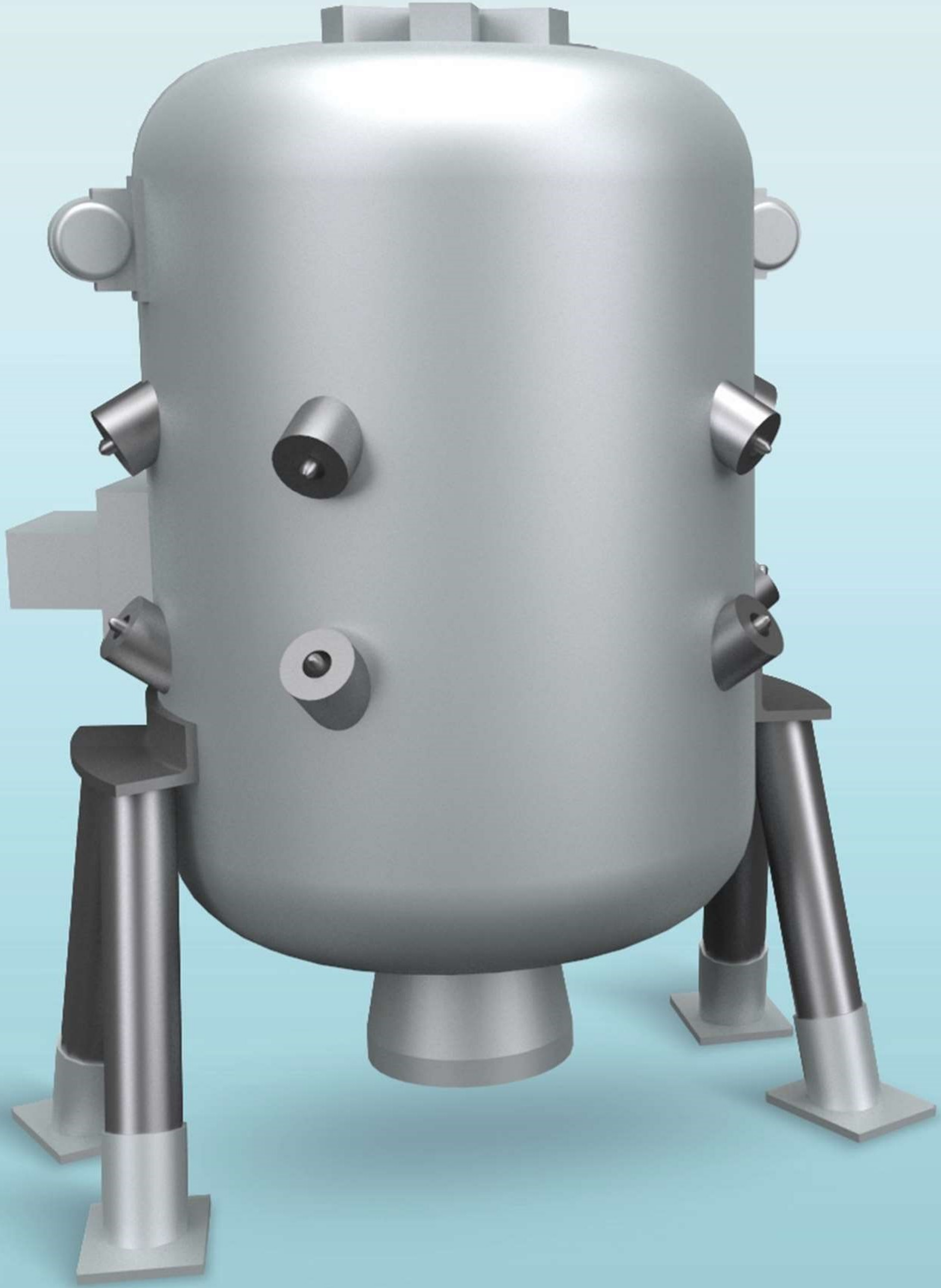
# Cryogenic Architecture
## EXAMPLE AT VERY LOW TEMPERATURE



**TEMPERATURE**

300K
100K
30K
15K
4K
2K

0.3K
0.05K

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# MERCI !