Space Technology

Thermal control

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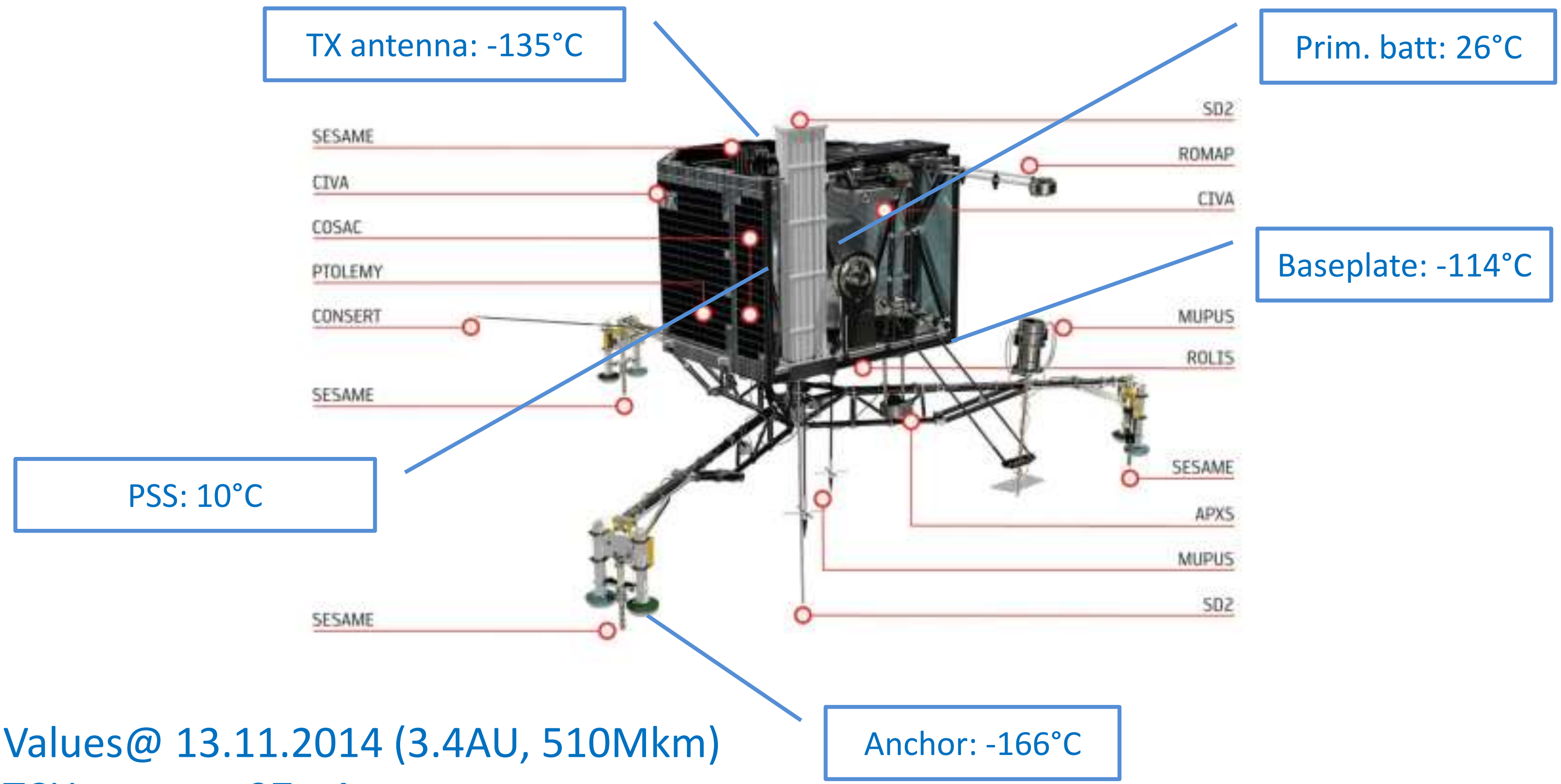
The thermal control system

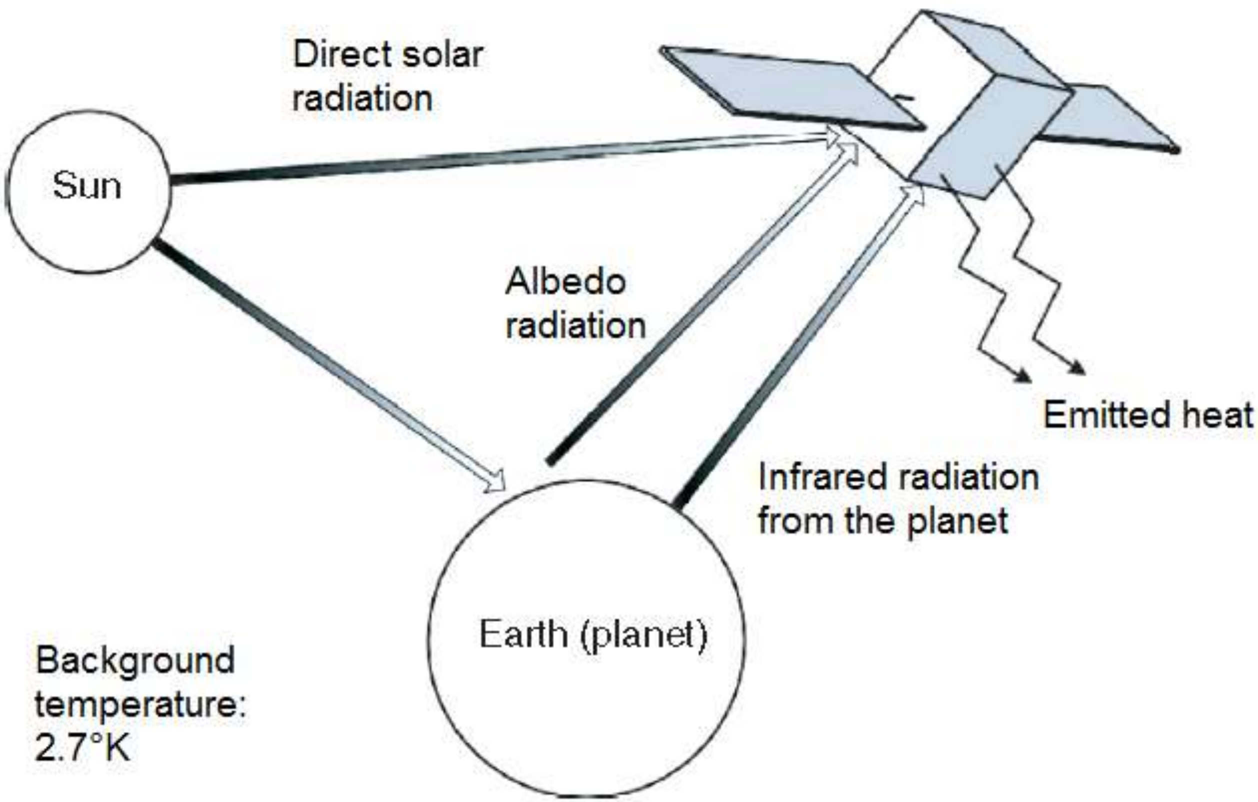
- Keep the mechanical, electrical and electronic units of the spacecraft within the specified operating temperature ranges
  - < 200 K (-73°C) cryogenic range (e.g. optical systems)
  - 200 to 470 K (-73°C-197°C) conventional range (internal units)
  - > 470 K (197°C) high-temperature range (e.g. reentry bodies)



Values@ 13.11.2014 (3.4AU, 510Mkm)
TCU current: 27mA

Environmental conditions

- **Convective** heat transfer be neglected (no atmosphere)
- Only heat **radiation**, **conduction** and **absorption** should be take into account

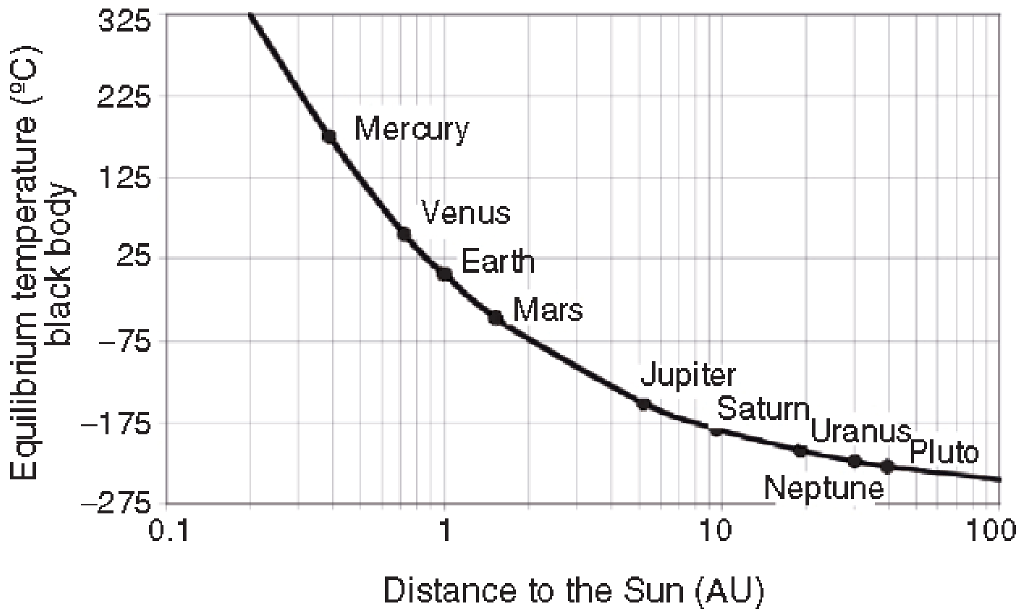


Heat radiation and absorption

- Transport the energy by electromagnetic waves (100 nm -100 μm)
  - Emitted (**radiated**) energy is proportional to the surface size, the temperature and the emissivity
  - **Absorbed** energy depends on the surface size and the solar flux density

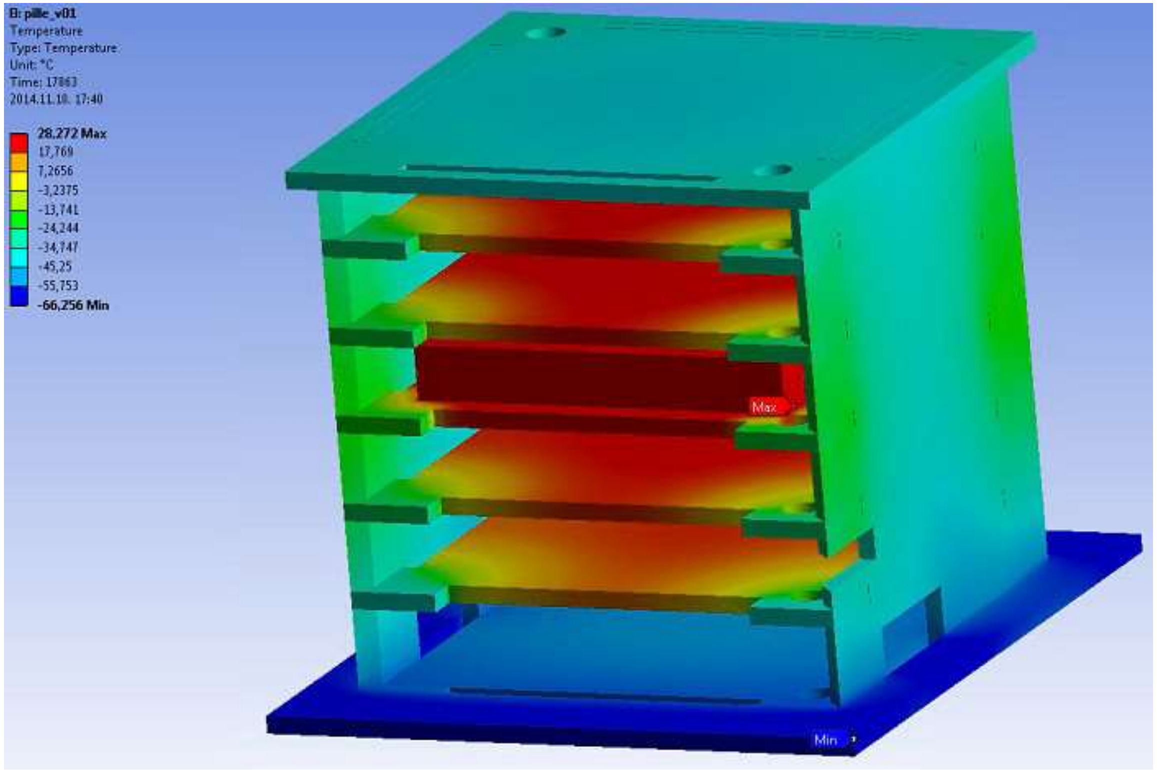
- Surface coating is applied usually
  - Black paint (internal surface to improve heat exchange with radiation)
  - White paint (external surface for low solar heat absorption)
  - Ag/Au/Al coating

The temperature of a black sphere versus the distance to the Sun:



Heat conduction

- Transport of heat between two locations of a solid body due to a temperature gradient
  - Parameters:
    - heat conductivity
    - cross-section of the heat path
    - temperature gradient
    - distance



    - Heat transport is a very complex process!

Basic thermal calculations

- **Heat radiation**

  the radiated power of area A at T temperature is:

  $$P = \varepsilon \cdot \sigma \cdot A \cdot T^4$$

  $0 < \varepsilon < 1$ is the emissivity

  $\sigma = 5.67 \cdot 10^{-8}$ W/m^2K^4 is the Stefan-Boltzmann constant

- **Heat absorption**

  absorbed power of area A is:

  $$P = \alpha \cdot A \cdot S$$

  α is the absorptivity

  S is the solar intensity W/m^2

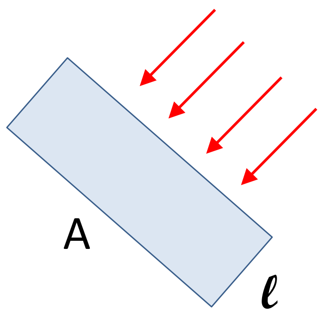
- **Heat conduction**

  heat energy Q transfer in time t:

  $$\frac{dQ}{dt} = \lambda \cdot A \cdot \frac{dT}{\ell}$$

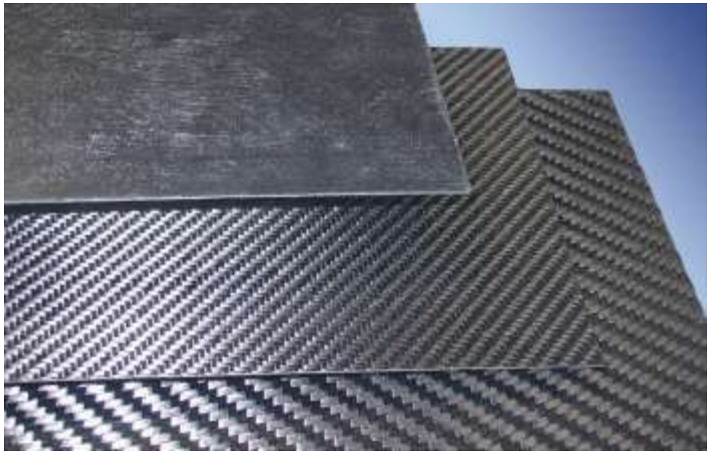
  λ is the heat conductivity W/mK°

  dT/ℓ is the temperature gradient



Design of the thermal control system

- No general theory is existing – engineering practice and tests are needed
- The shape and number of contacts, deforms are influencing the calculation
- Without contacts the heat transfers with radiation or through the enclosed gas
- Convection can be neglected (small dimensions)
- Filler materials are applied to achieve high heat conductivity (e.g. heat transport to base plate) – (graphite-fiber foil)

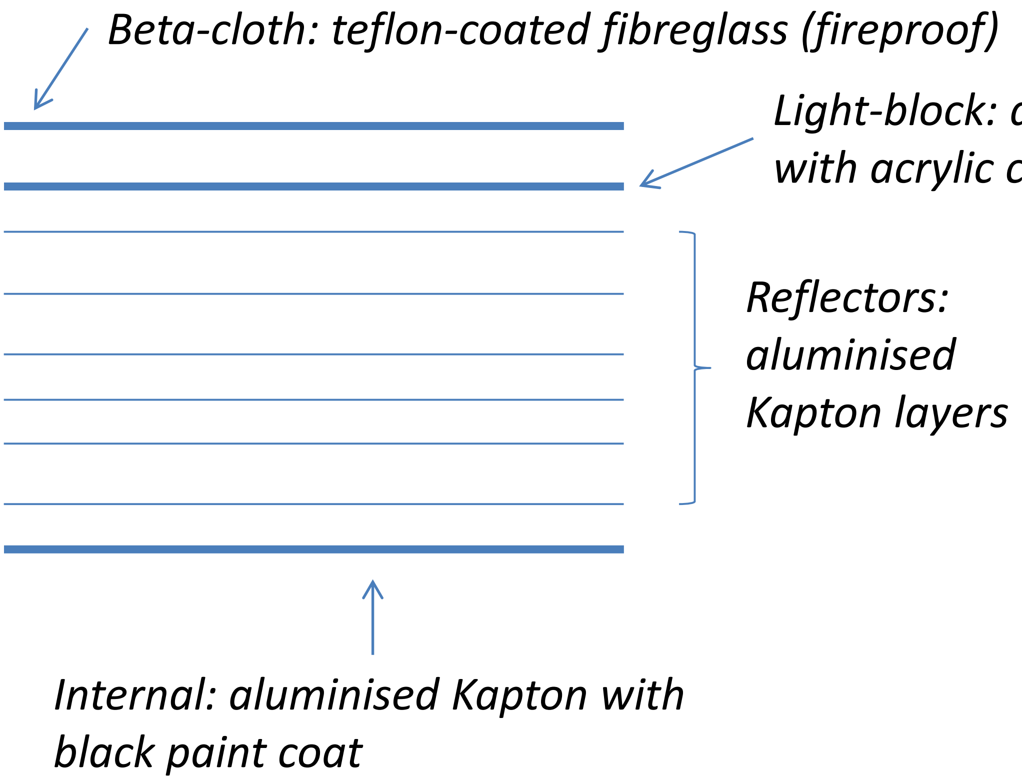


(SIGRAFLEX)

- Mathematical thermal models and simulations (transient and steady-state analysis)
- Testing
  - Development tests
  - Qualification tests
  - Thermal cycle tests
  - Thermal-vacuum tests
  - Thermal balance tests
  - Predictions

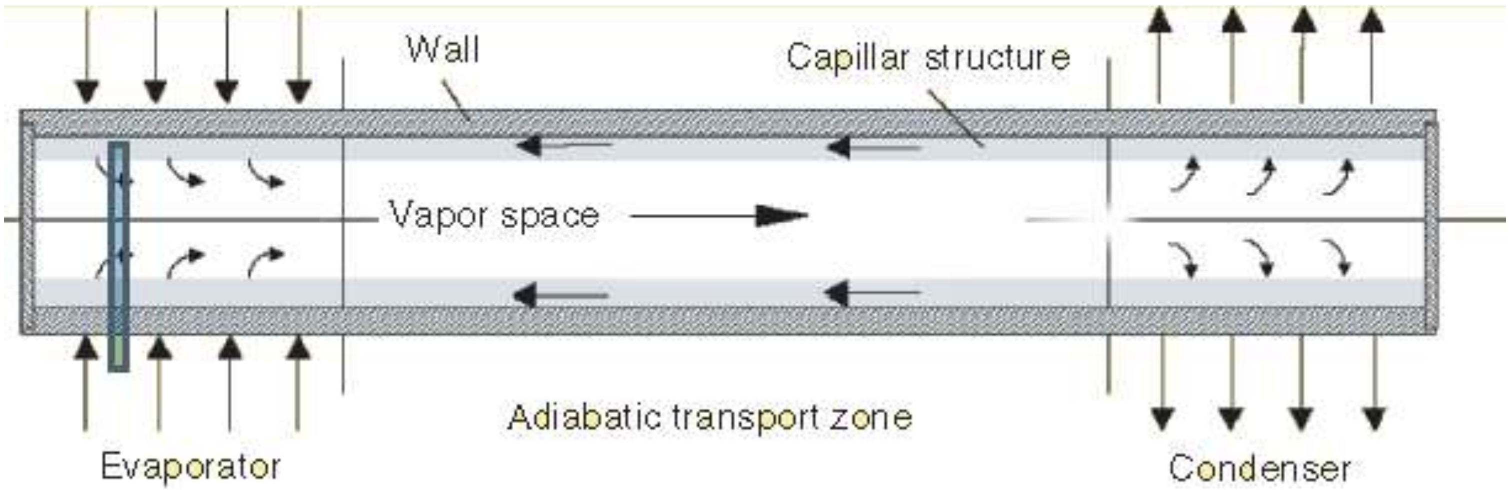
Thermal insulation

- Minimize heat fluxes between two temperature regimes
- MLI (Multi Layer Insulation)
  - several layers of plastic foil (polyester or polyamide) separated by plastic nets to reduce heat conduction
  - Excellent insulation in vacuum
- Multiple 15-50µm foils + 25nm coating

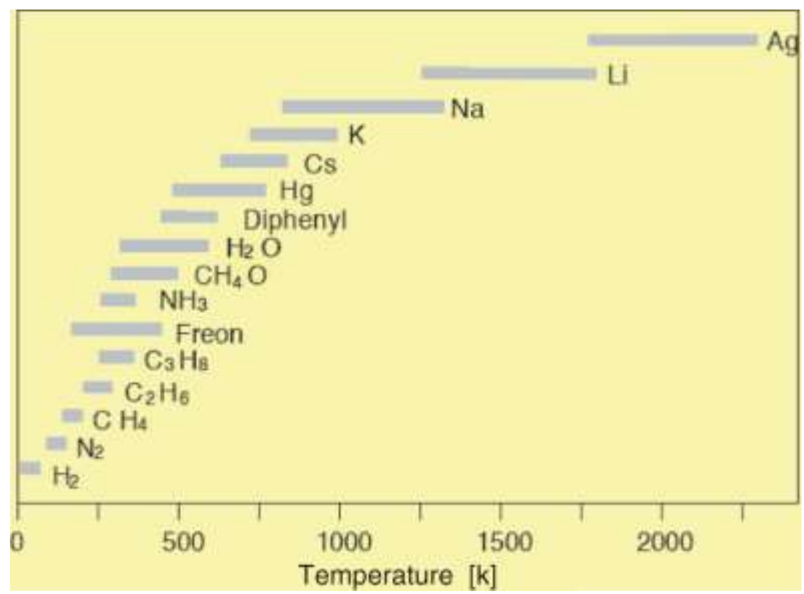


Two-phase cooling loops

- ❑ The heat of vaporization of a liquid is transported between an evaporation and a condensation site (e.g. heat pipe)

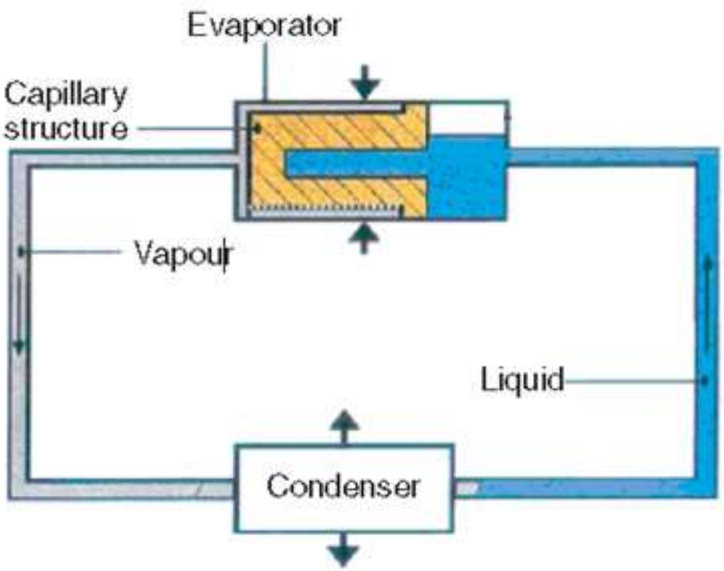


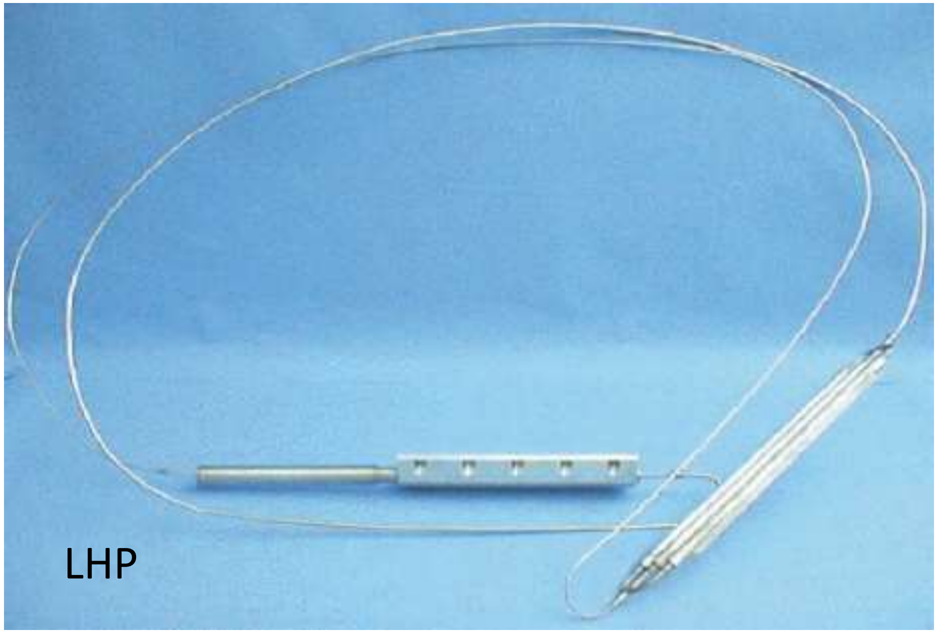
- ❑ Fully passive
- ❑ No outside energy is needed
- ❑ Small temperature differences can be used for heat transport (liquid type determines the heat range)
- ❑ Fluid/wall material compatibility required



Heat pipe examples

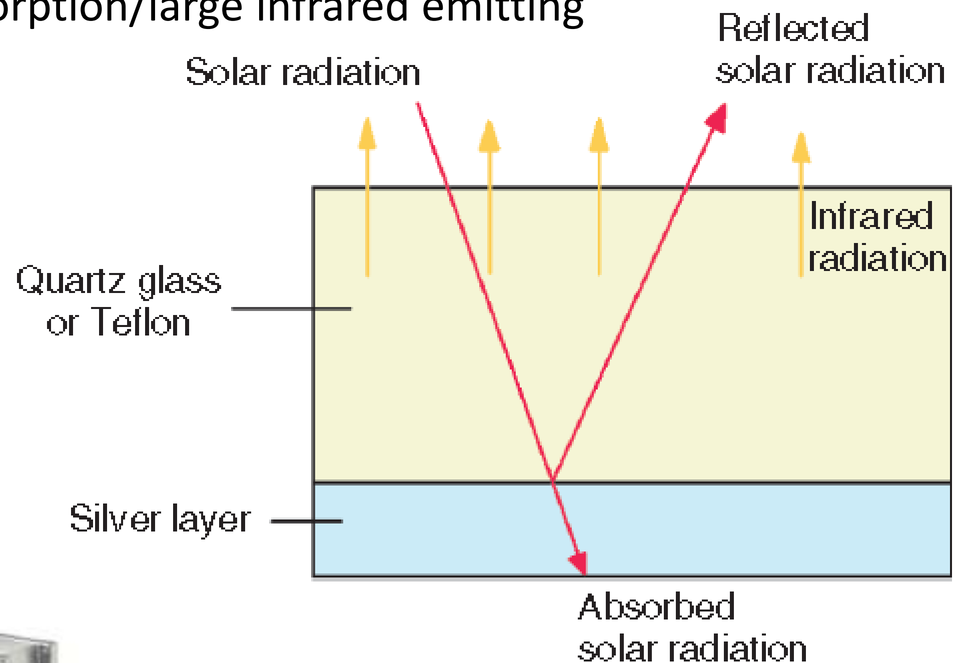

- Capillary structures with high capillary forces are needed
- Operation in Earth’s gravity field is often not possible: the capillary forces are too small against the gravitational force
- The solution: loop heat pipe – LHP
  - The capillary structure exists only in the evaporator
  - 1-2kW heat transport can be achieved





Thermal surfaces

- Visible surfaces absorb or emit thermal energy in the infrared band
- Internal spacecraft surfaces are black coated to achieve good heat exchange
- Radiator-surfaces: low solar energy absorption/large infrared emitting
  - Optical solar reflectors (OSR):



- Thermal louvers:

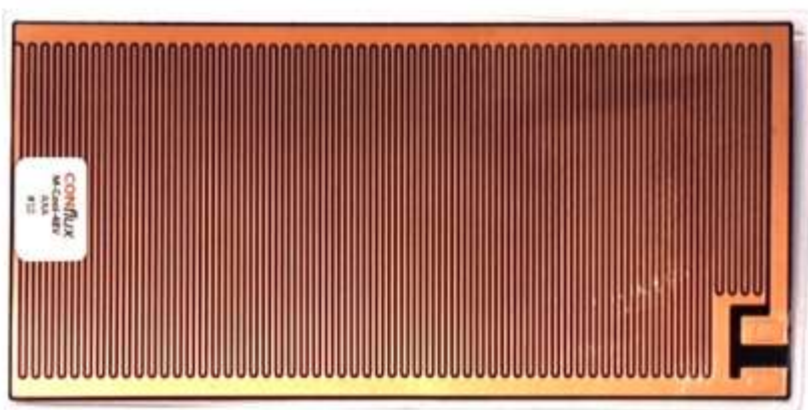
Heaters

- If the absorbed solar radiation is inadequate
- If the internal heat dissipation is too low

- Heater: electrical resistance

- Heating may required for:
  - Payloads
  - External sensors
  - Batteries
  - Propulsion systems

- Heaters are controlled by ground commands or by PCDU (Power Control and Distribution Unit)



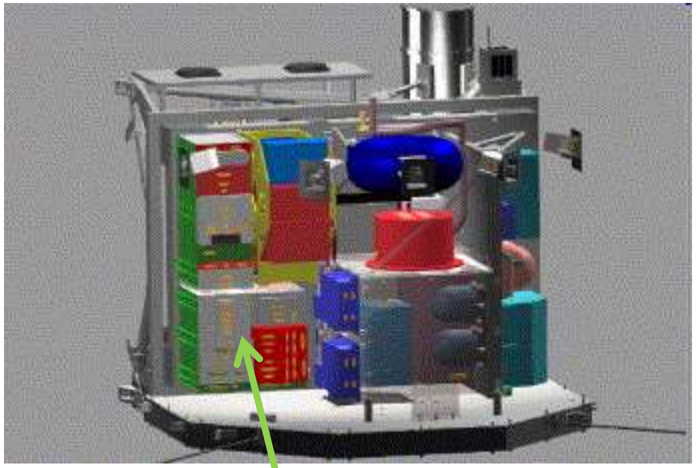
Operation of the thermal system

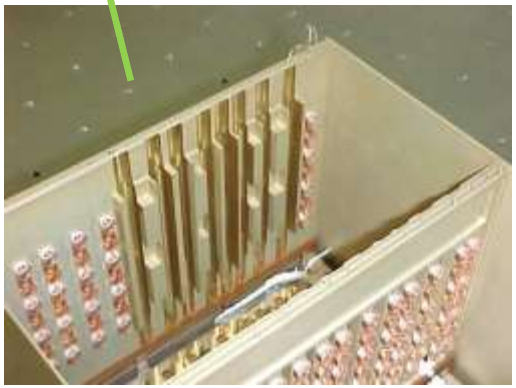
- The operation temperature of system and payload elements must be ensured
  - A warm-up process may required
- Immediate heater switch-on could be dangerous:
  - Battery overload
  - Lost of the energy
  - Heat of instruments could be also utilized

Example: Roland wake-up sequence

- Thermal conditions:
  - Partial operation: -80°C +70°C
  - Full operation -45°C +70°C
  - Accumulator charge above +5 °C

- Wake up circuit checks the thermal and energy conditions
- AUXPS switch on
- PCU and CDMS switch on
- Oscillators, real-time clocks, RX switch on
- CDMS software start





Common e-box

Sources:

- Gary D. Gordon, Walter L. Morgan:
  Principles of Communications Satellites
  Wiley, ISBN: 978-0-471-55796-8
- Wilfried Ley, Klaus Wittmann and Willi Hallmann (ed):
  Handbook of Space Technology
  Wiley, ISBN: 978-0-470-69739-9

Main topics / questions

- The main role of the satellite’s thermal system
- Heat transfer in space and main heat sources
- Special materials to transport and insulate heat
- Heat transfer devices and heaters