ELIXIR Course

Thermal Control

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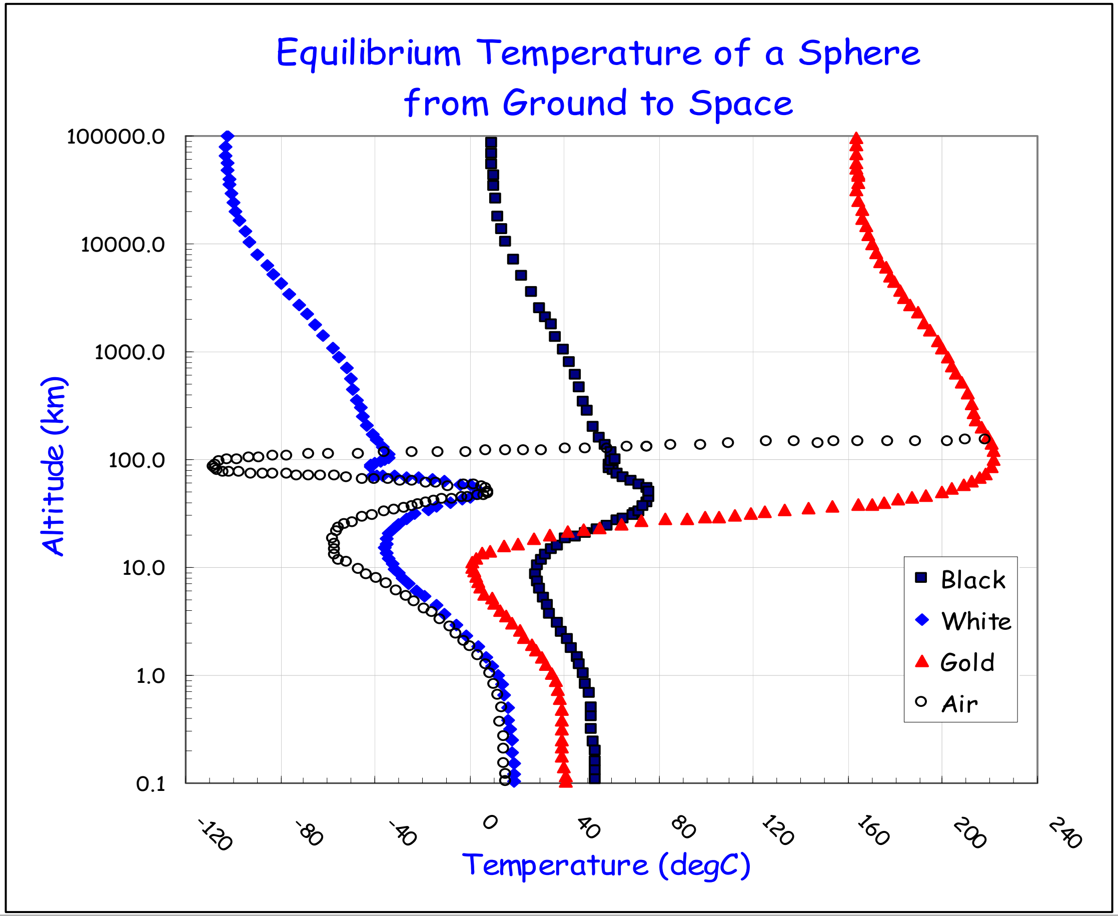
Thermal Control

- from Ground to Space – the Space Environment
- Requirements & Design Drivers
- Why thermal control is required?
- Thermal Control Means: the Engineer’s Toolbox
- Modelling & Analyses
- Verification & Testing

Thermal Control

– from Ground to Space –

- Ultra-high Vacuum, $10^{-14} < p < 10^{-17}$ bar => no convection/cooling

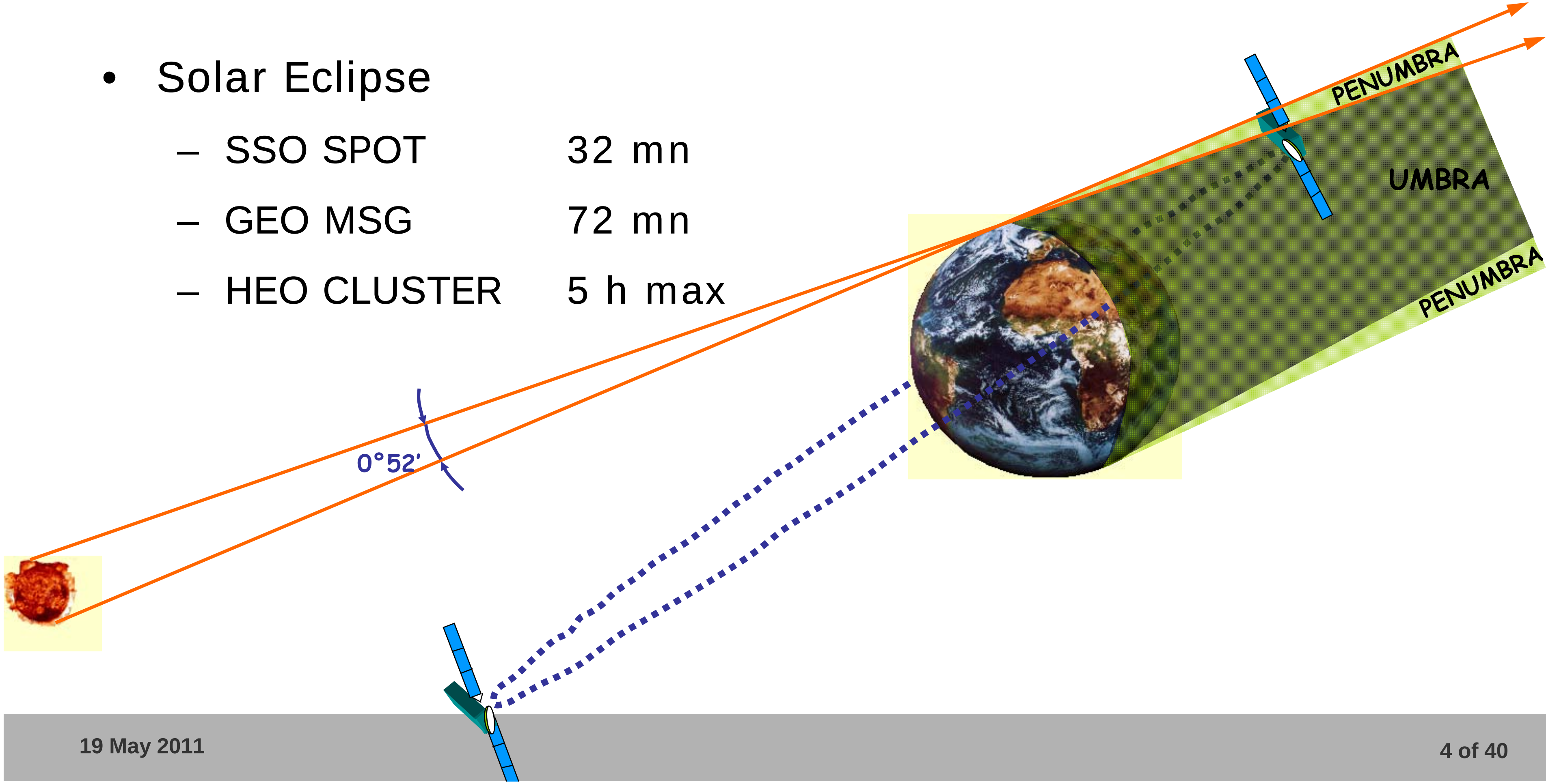


Thermal Control

– the Space Environment –

- Deep Space, @ 2.7 K

- Solar Eclipse
  - SSO SPOT 32 mn
  - GEO MSG 72 mn
  - HEO CLUSTER 5 h max

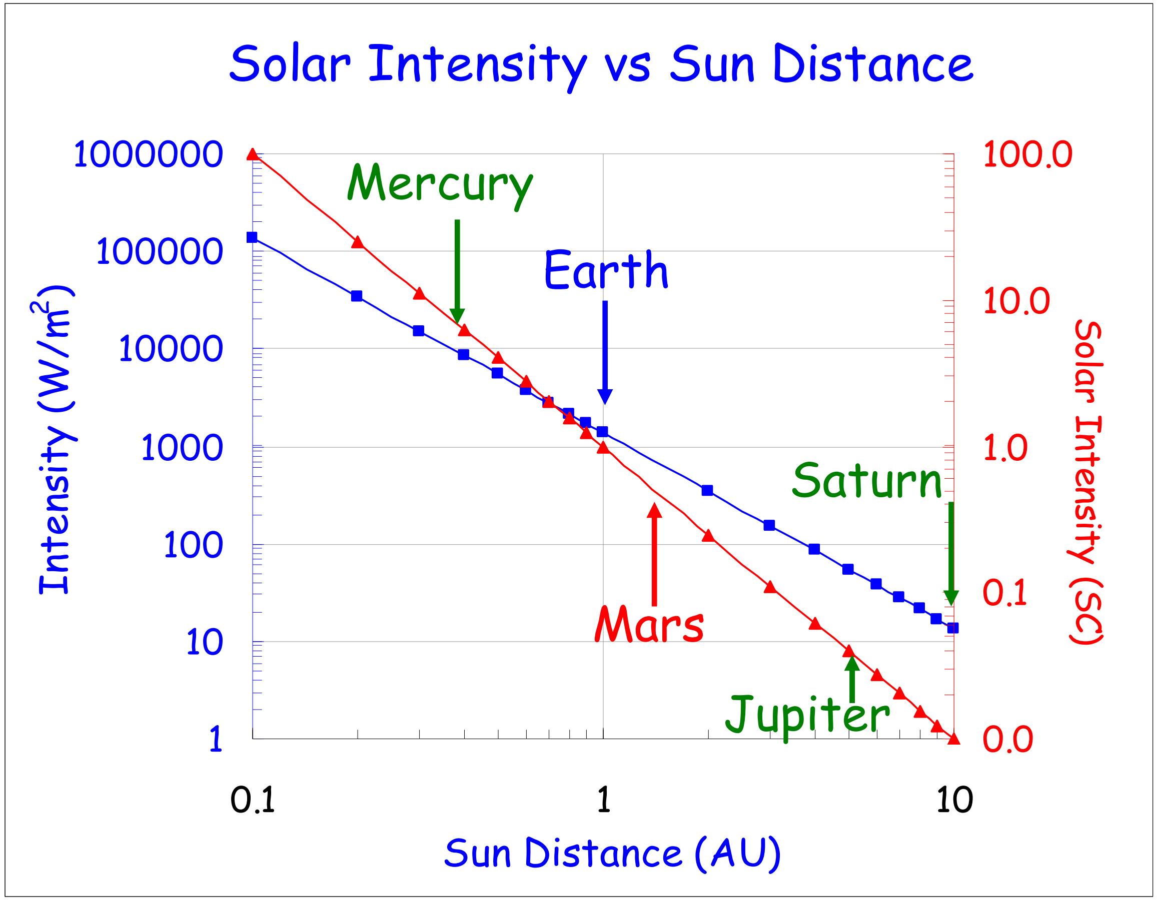


Thermal Control

– the Space Environment –

- Solar Flux, SC=1367 W/m2 @ 1AU=Earth distance

$$q_S = \frac{SC}{d_S^{\,2}}$$

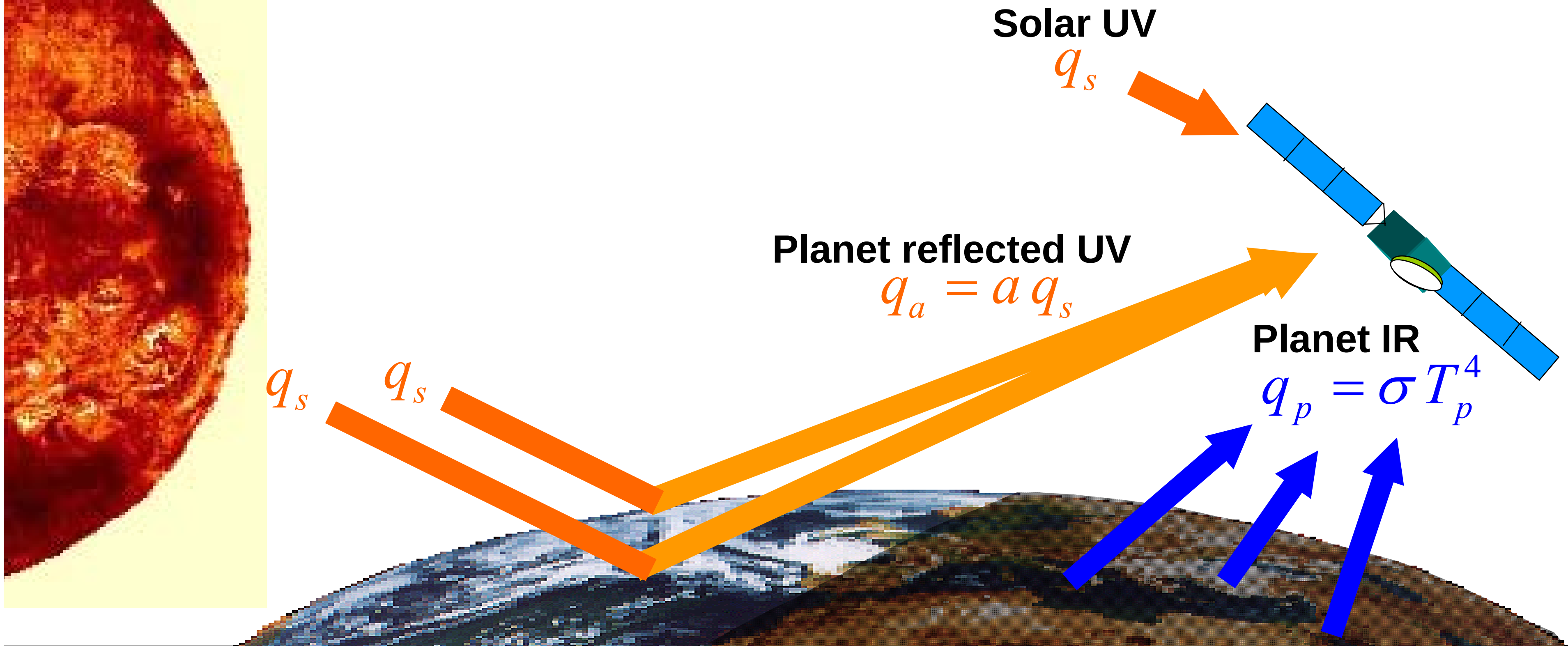


Thermal Control

– Satellite Environmental Loads –

environmental loads Q_i^e at node i

absorbed solar flux		absorbed albedo flux		absorbed planet flux
$q_s \; F_{s,i} \; A_i \; \alpha_i$	+	$q_a \; F_{a,i} \; A_i \; \alpha_i$	+	$q_p \; F_{p,i} \; A_i \; \varepsilon_i$
solar UV		planet reflected UV		planet IR



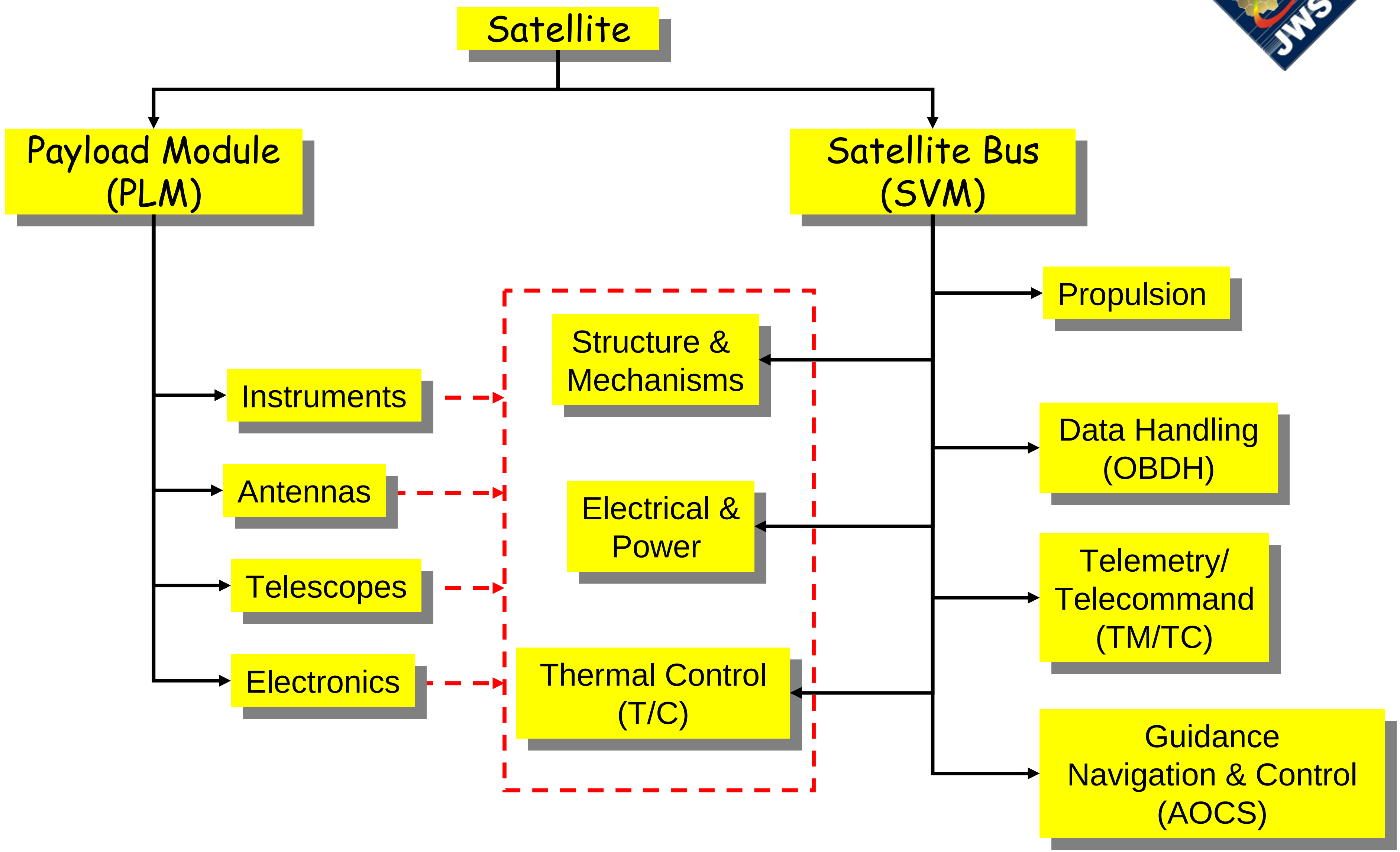
Thermal Control

– Why Thermal Control? –

- Low Temperatures — <u>to ↑ sensitivity of detectors</u>
  - <80 K — detectors
- Narrow Temperature Ranges — <u>to ↑ reliability of components</u>
  - -10 / +40°C — classical equipment
  - 0 / +20°C — battery
- Small Temperature Gradients — <u>to ↑ pointing acc. of opt unit</u>
  - $\Delta T < 5$°C — across 1.5 m optical instrument
- Stable Temperatures — <u>to ↑ pointing acc. of opt unit</u>
  - $\Delta T/\Delta t < 5$ K/h — for typical electronic unit
  - $\Delta T/\Delta t < 0.1$ K/mn — for CCD camera

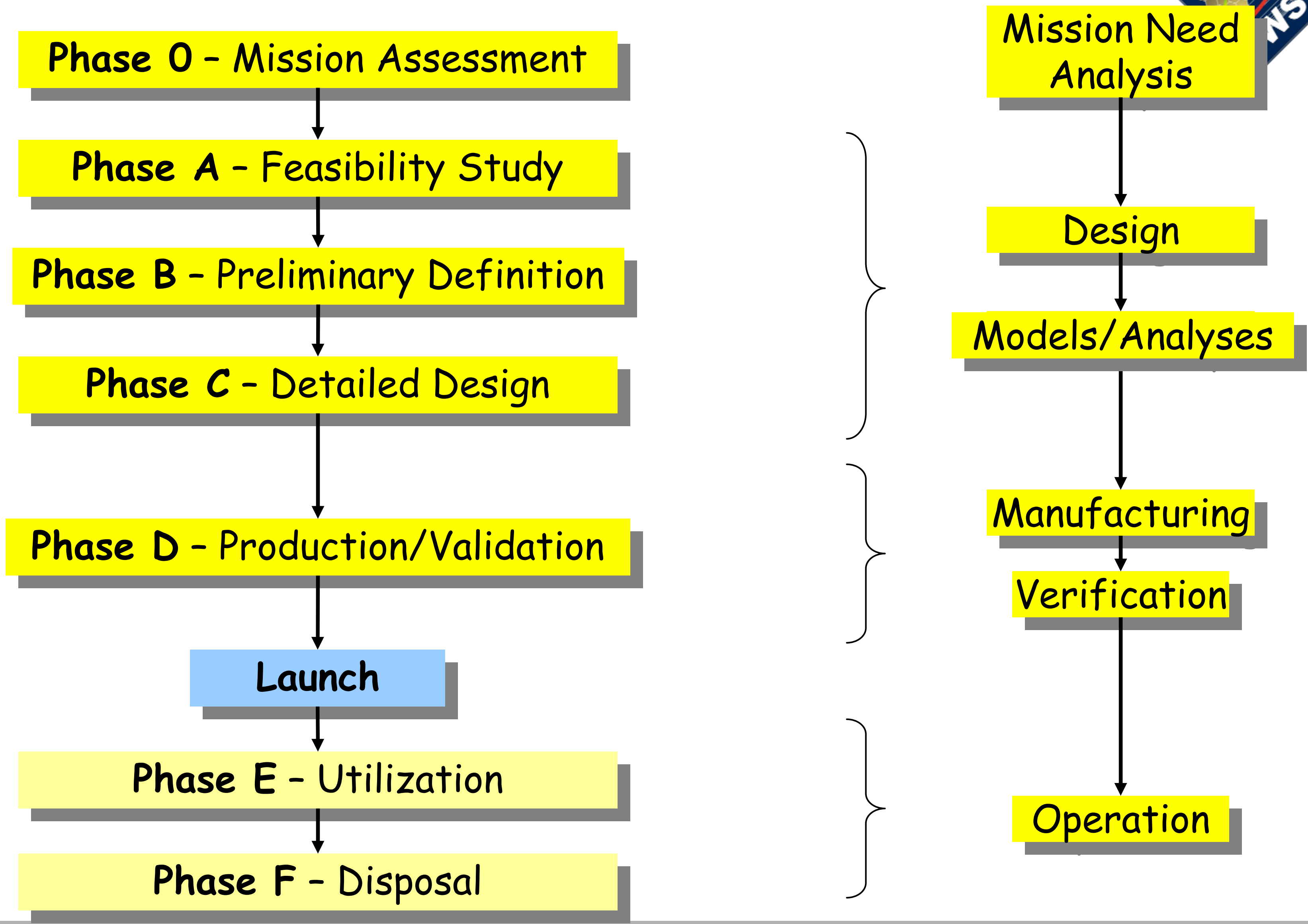
Thermal Control

– Satellite Sub-Systems –



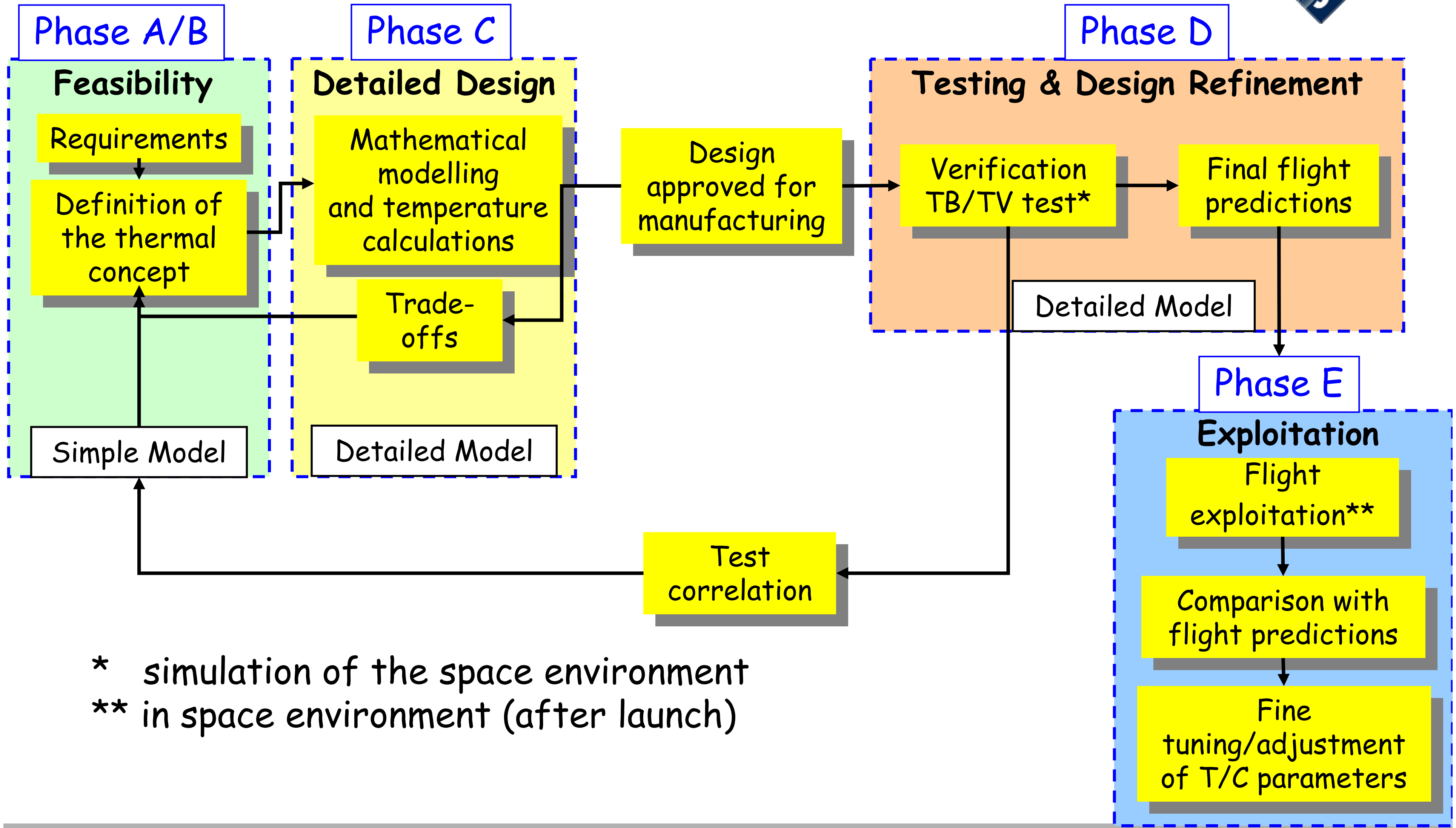
Thermal Control

– Satellite Development –



Thermal Control

– TCS Development –



* simulation of the space environment
** in space environment (after launch)

Thermal Control

– Role of the Thermal Control Sub-System –

- TCS is required to maintain
  - electronics, payload instruments e.g. spectrometer, ToF…
  - S/C structure, interface between satellite modules

- within Specified Ranges
  - temperatures, temperature gradients (K/m) or stability (K/hr)

- within allocated budget by the system: mass, power…

time and €

Balance HEAT FLOWS

to fulfil

REQUIREMENTS

results in

TEMPERATURES

Balance HEAT FLOWS

- through Heating
  - absorb from external sources (solar, albedo, planet IR)
  - use the internal sources
  - dissipate heat internally
  - transfer heat from hot area
- through Cooling
  - reject to deep space (3 K)
  - transfer heat to colder area
  - with cryogenic techniques
    - cryostats, coolers (Peltier, Joule-Thomson...)
  - ablation
- or through Energy Storing
  - latent heat of solidification/melting
  - additional mass -> heat capacity mCp

Thermal Control

– Design Concept: Non-insulated –

- Principle
  - when internal dissipation small w.r.t. environmental fluxes
  - equilibrium temperature results from:
    - internally dissipated power
    - absorbed environmental fluxes (solar, albedo…)
    - emitted radiant energy (σT^4)
- Characteristics
  - no insulation
  - average temperature driven by
    - environmental loads
  - local temperature hot spots still poss
- Example: PROBA1

PROBA1 FM

Thermal Control

– Design Concept: Insulated –

- Principle
  - when environmental sources irradiate few sides
    - Sun, planet IR (Mercury, Mars, Moon…)
  - equilibrium temperature results from:
    - internally dissipated power
    - absorbed environmental fluxes (solar, albedo…)
    - emitted radiant energy (σT^4)
- Characteristics
  - insulation of Sun illuminated sides
  - shadow sides
    - radiate to deep space => **RADIATORS**
  - S/C attitude control to avoid Sun
- Example: XMM and JWST

XMM FM 1999

esa SCIENCE

Thermal Control

– Design Concept: Insulated –

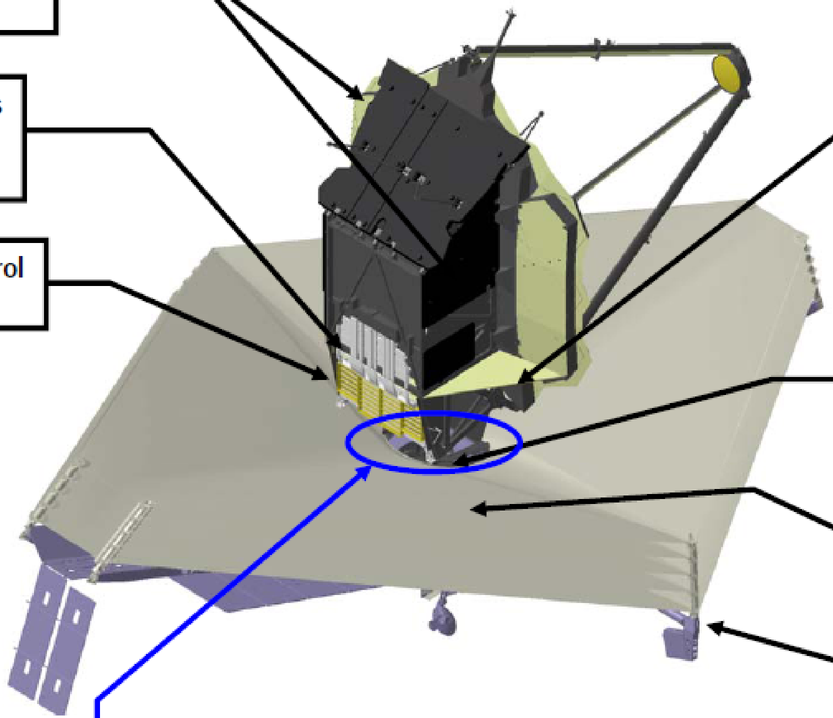
JWST TELESCOPE

• Thermal design is described in Section 24, Thermal Analysis

Cryogenic radiators strapped to each science instrument for passive cooling

Harness radiator to cool wires that connect the IEC to the Region 1 instruments

Directional radiator baffles to control the region 2 thermal dissipations



Thermal shields control heat transfer and stray light

Deployable Tower Assembly for separation of thermal regions

Sunshield Core-Hub assemblies control sunshield shape to optimize performance

Multiple design changes to the CORE region to improve thermal performance
- Close outs between the Sunshield and Deployed Tower Assembly
- Thermal shielding of the IEC

5 Layer Sunshield provides thermal isolation of Region 1 from solar heat loads
- Sun facing layer (Layer 1) reflects solar load.
- Cold Side Layer (Layer 5) reflects IR load.

Thermal Control

– Toolbox –

$\alpha\, \phi_s\, A$

$\varepsilon\, A\, \sigma\, T^4$

RADIATION
- selective coating
- absorber
- MLI blanket
- radiator

LATENT HEAT-ABLATION
- TPS
- PCM

CONDUCTION
- structural material
- doubler, filler, adhesive
- washer, strap, bolt, tyrap, stand-off
- foam

$k\,\frac{A}{l}\,\Delta T$

PASSIVE

ACTIVE

HEATERS
- thermostat control
- electronic control
- ground control

HEAT PIPES - FLOOPS
- fixed/variable conductance
- loop heat pipe
- monophasic/diphasic fluid

LOUVRES

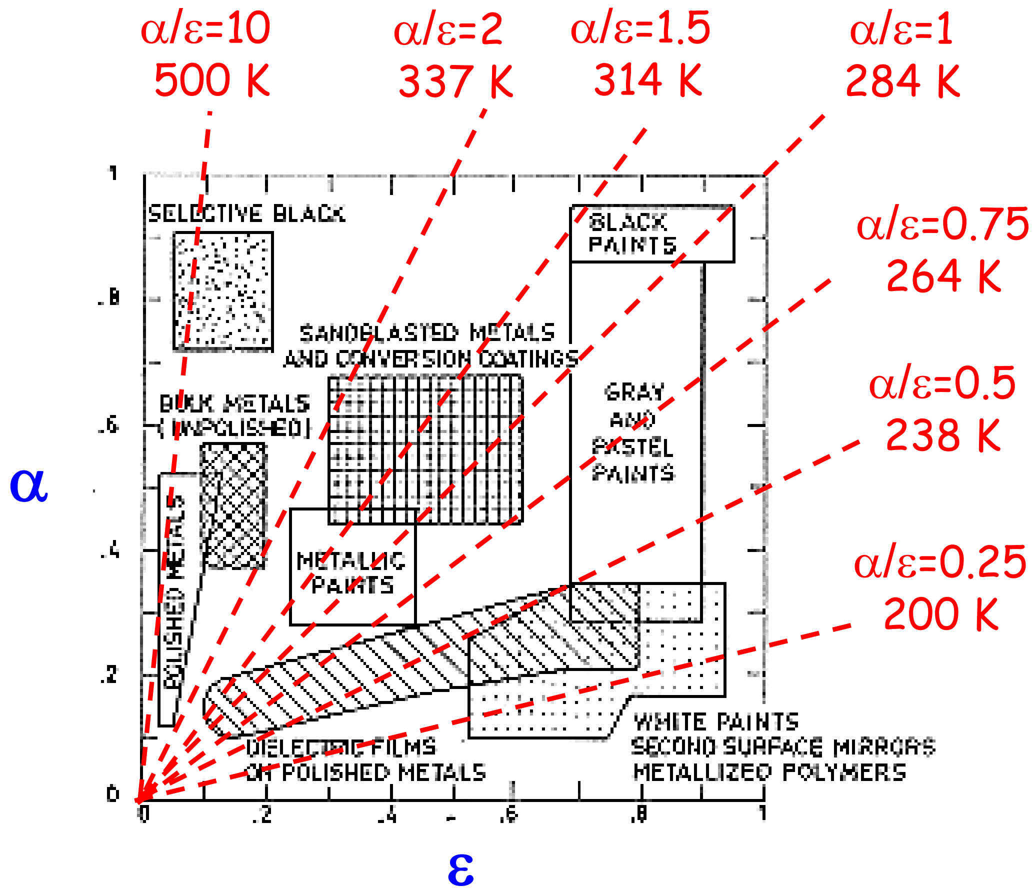
COOLERS
- mechanical
- electrical

ENERGY CONTRIBUTION

ENERGY TRANSFER

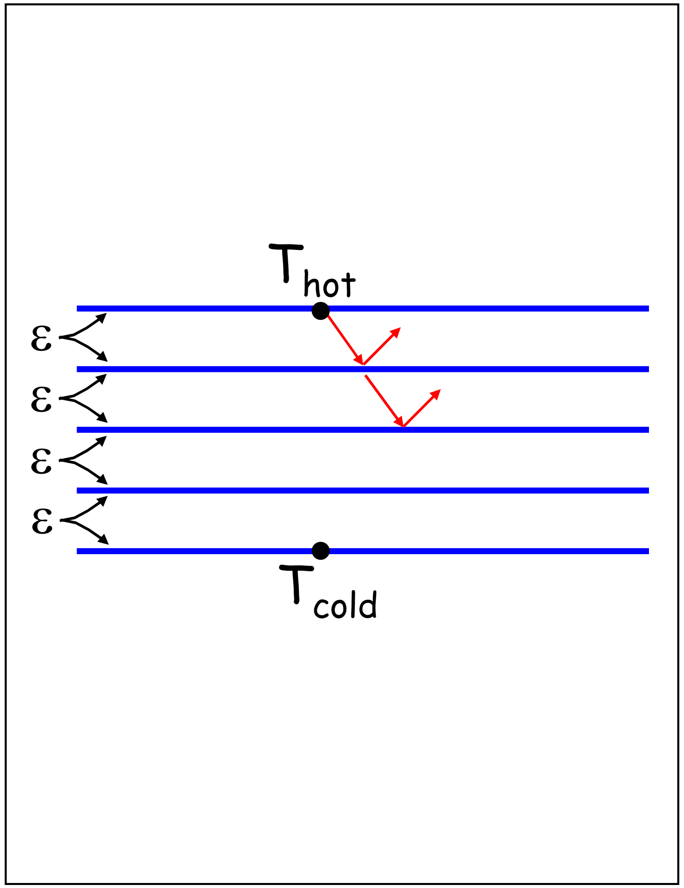
– Toolbox: Selective Coatings –

Coated Sphere Equilibrium Temperature in Sun



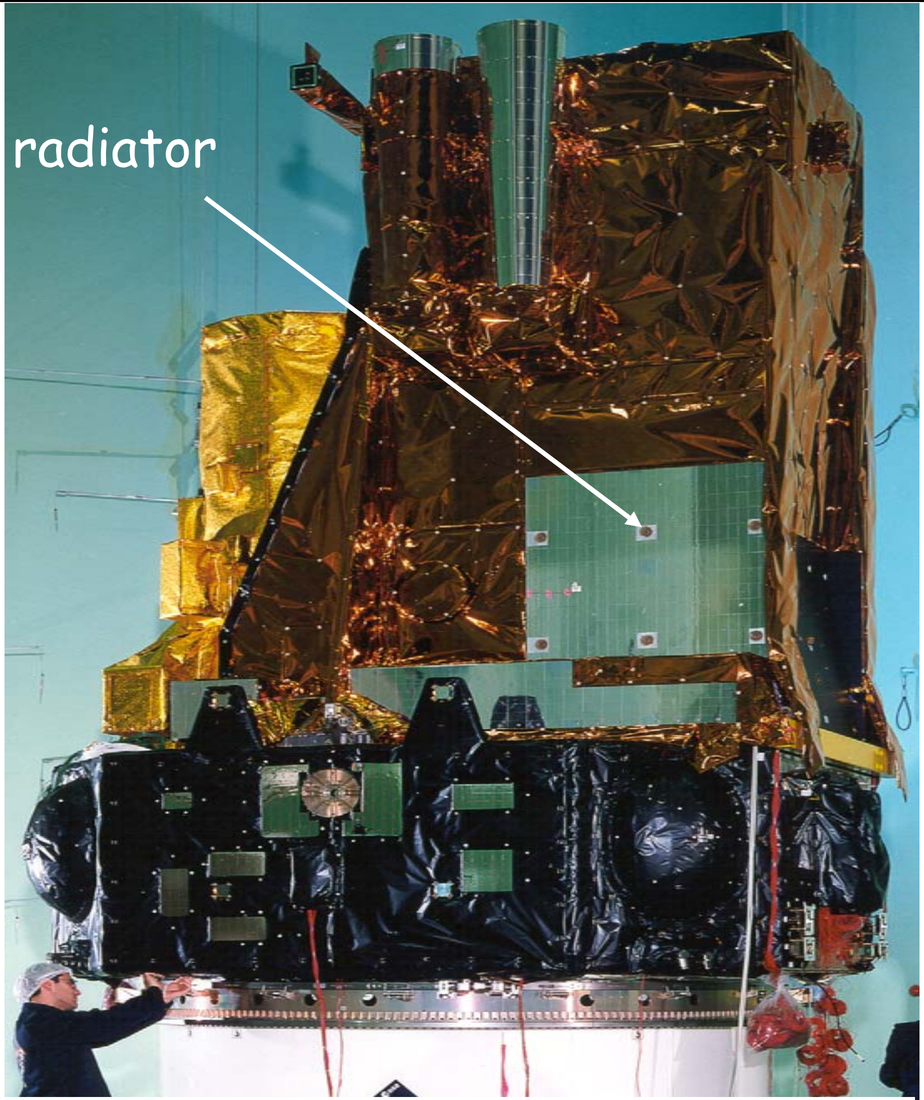
Thermal Control

– Toolbox: MLI Blankets –



Thermal Control

– Toolbox: Radiators –



INTEGRAL STM

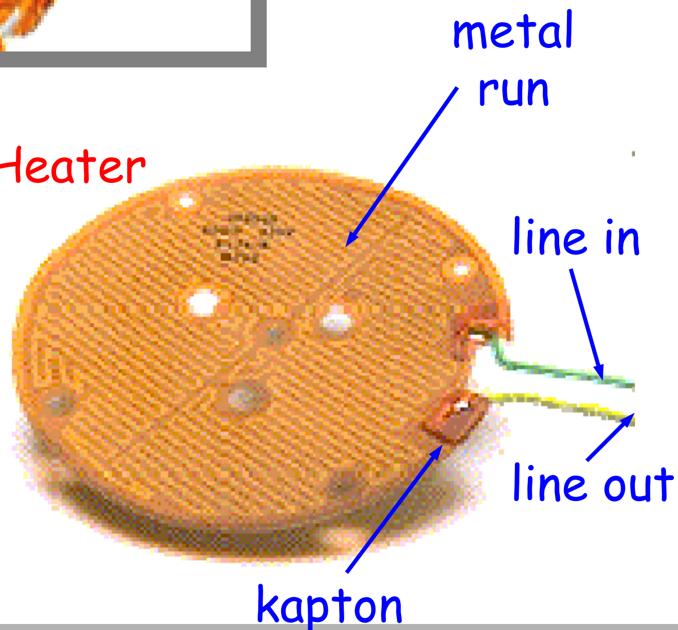
Thermal Control

– Toolbox: Heaters –

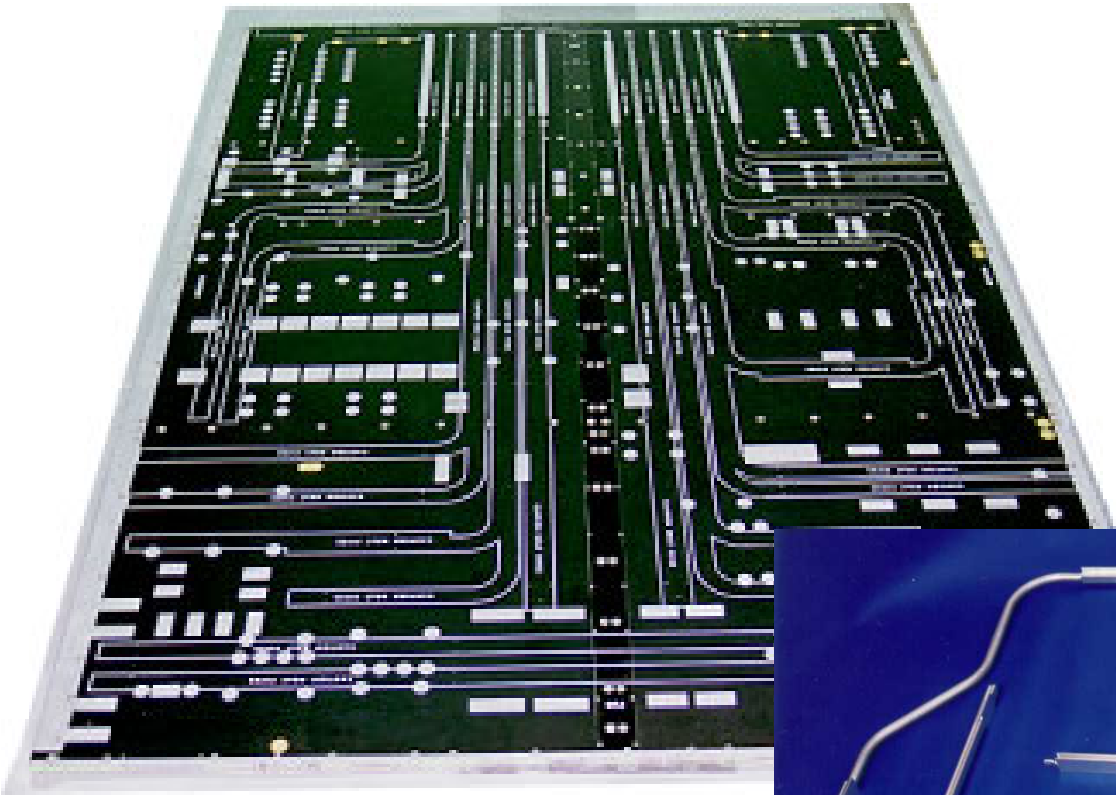
Flat Heater

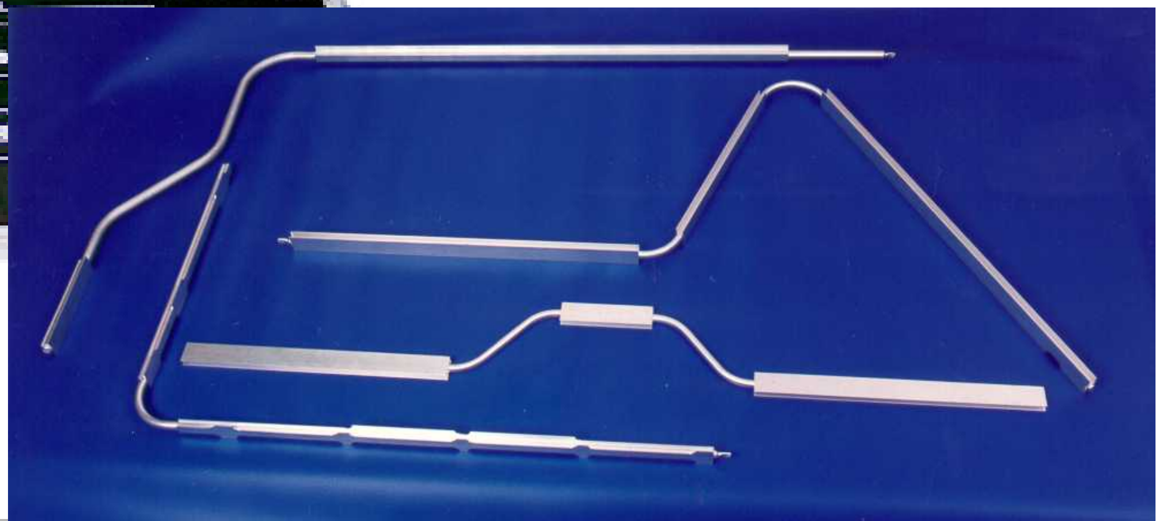
Ribbon Heater

Custom Heater



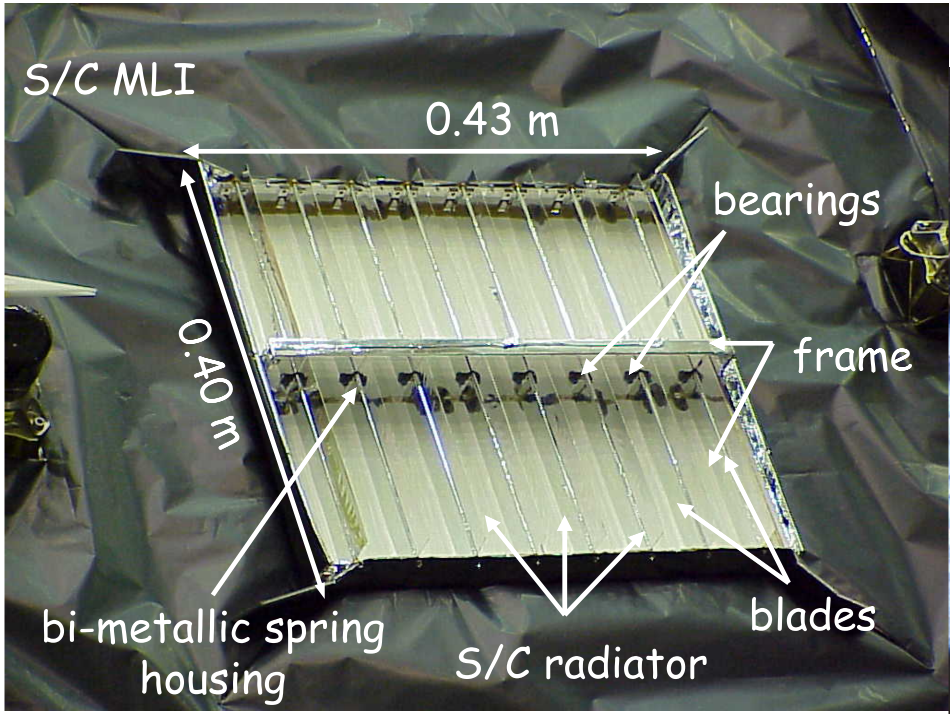
Telecom Panel Heat Pipe (Swales)



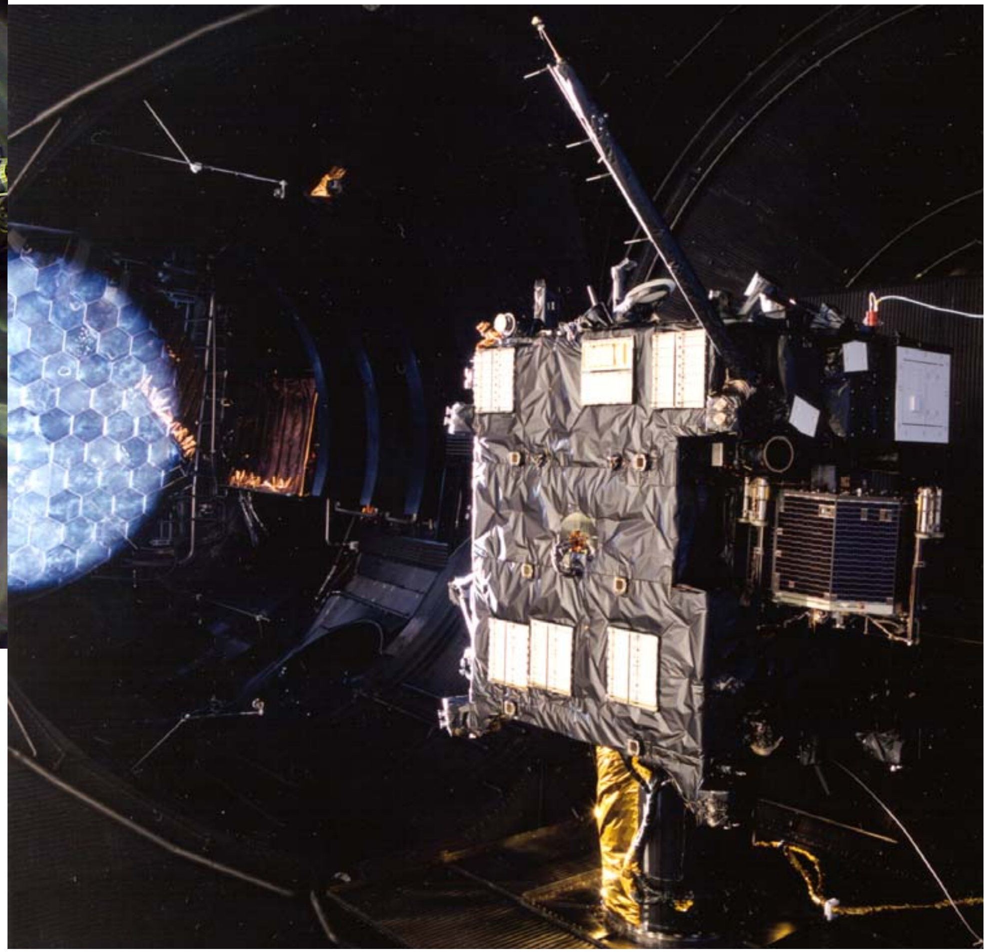


Thermal Control

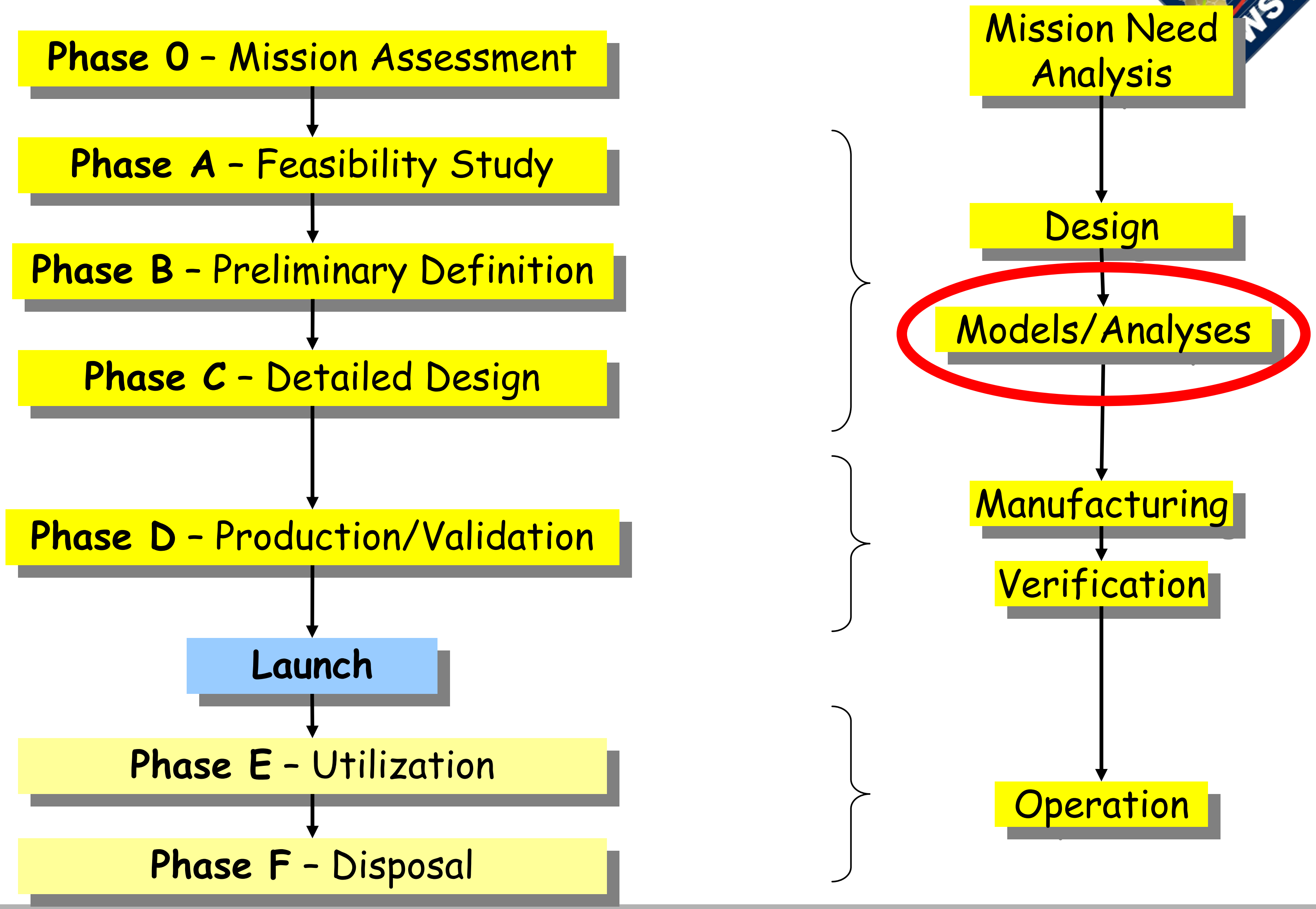
– Toolbox: Louvres –



Louvre on ROSETTA PFM



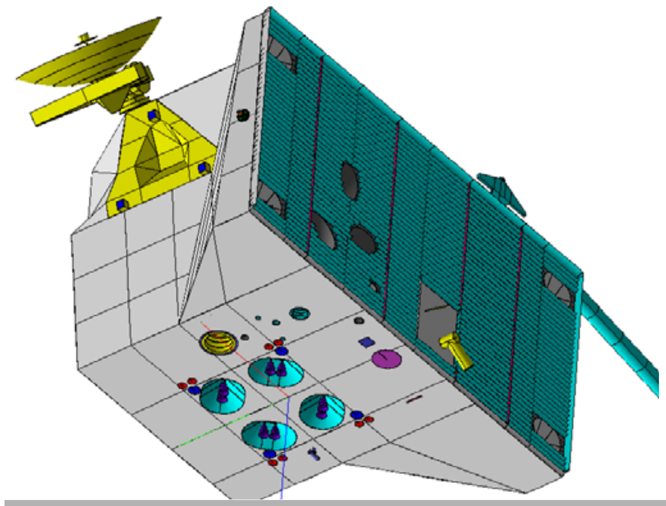
Thermal Control



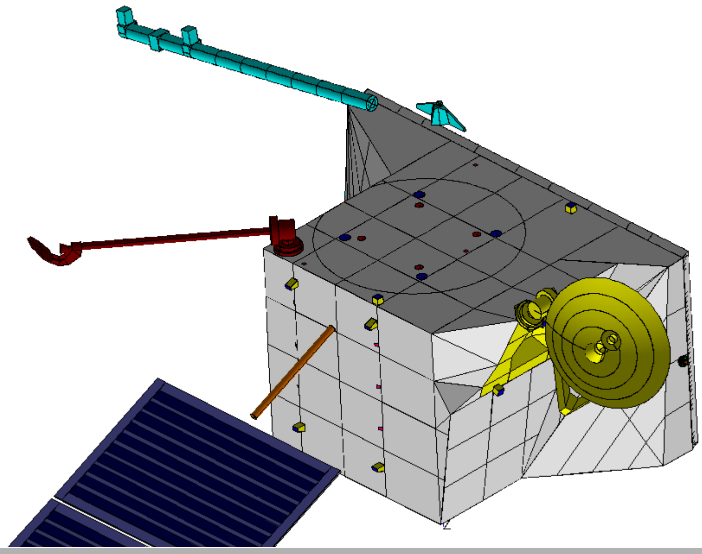
Thermal Control

– Thermal Models –

- Geometrical Mathematical Model (GMM)
  - mathematical representation
    - of satellite geometry i.e. radiating surfaces
  - to compute
    - view-factors (VF) or radiative exchange factors (REF)
    - environmental heat fluxes e.g. from Sun or Planet



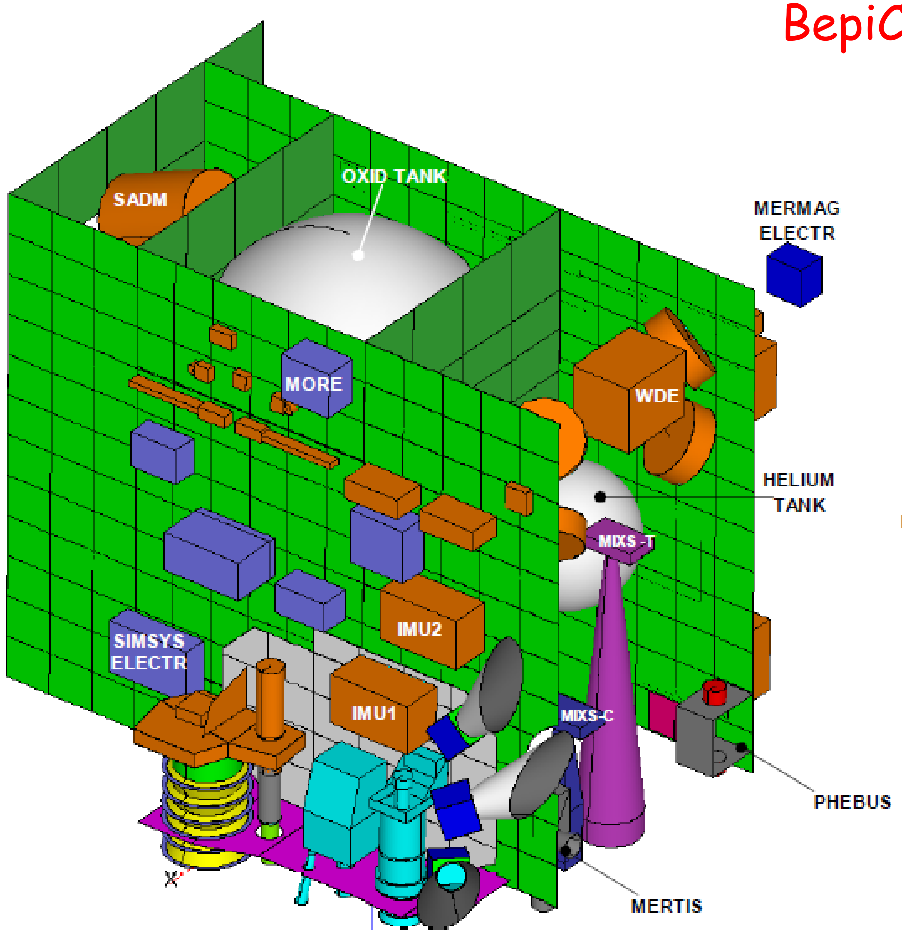
BepiColombo

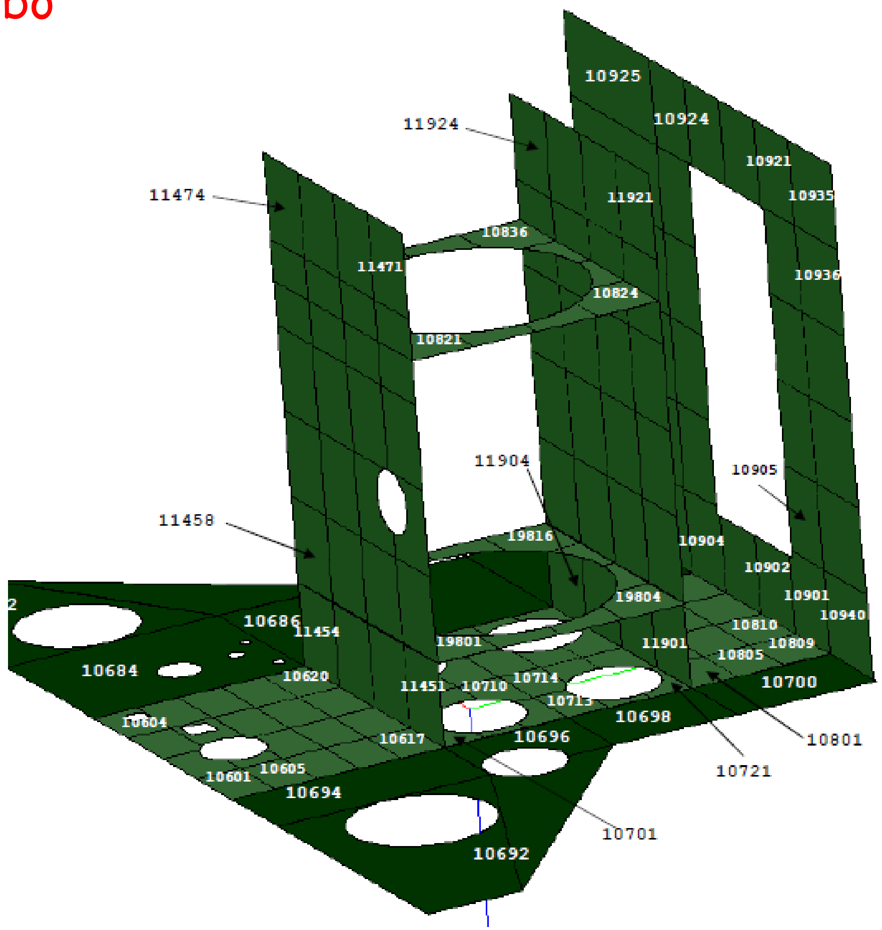


Thermal Control

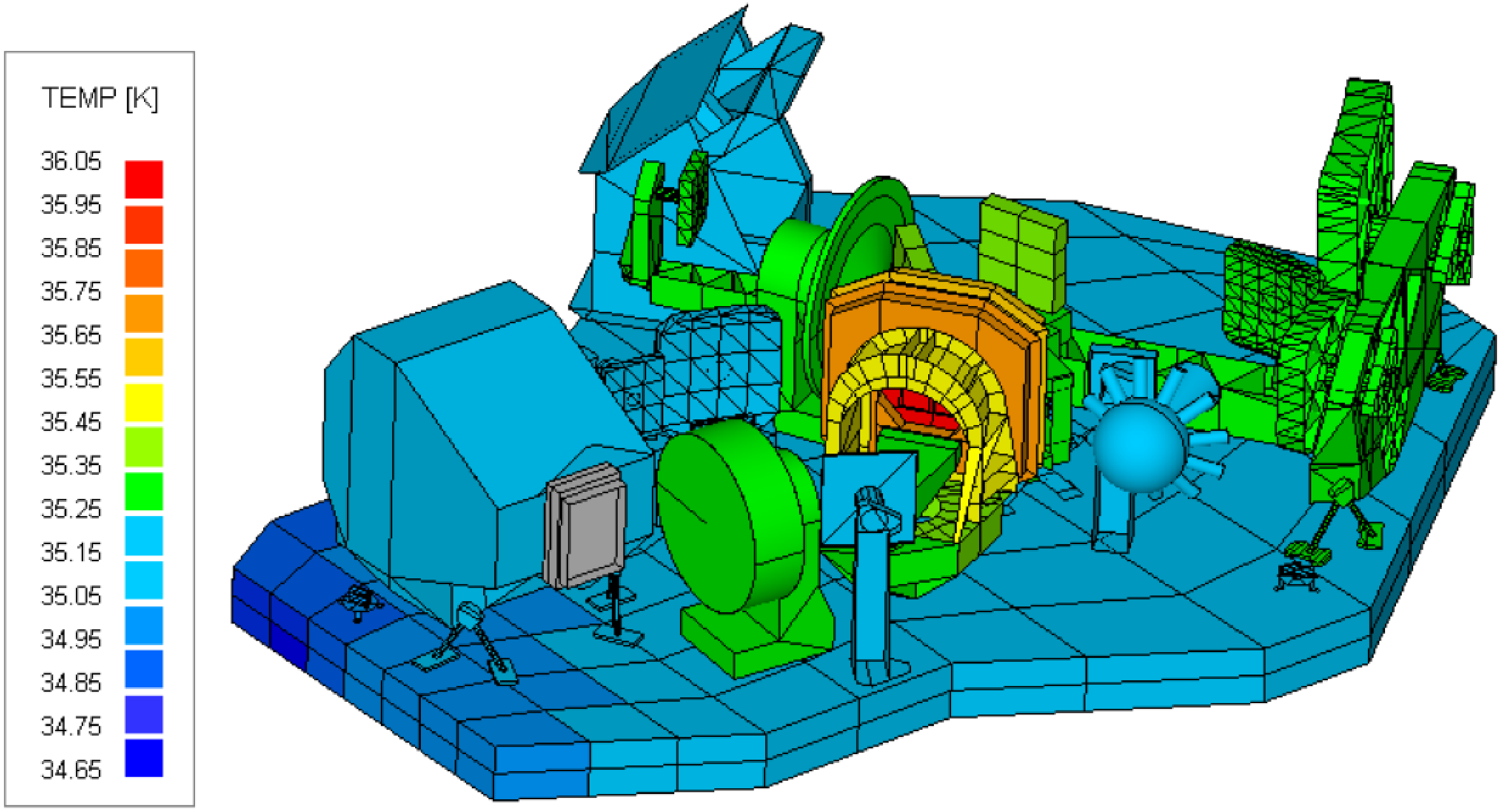
– Thermal Models –

BepiColombo





NEARSPEC GEOMETRICAL MATHEMATICAL MODEL



Thermal Control

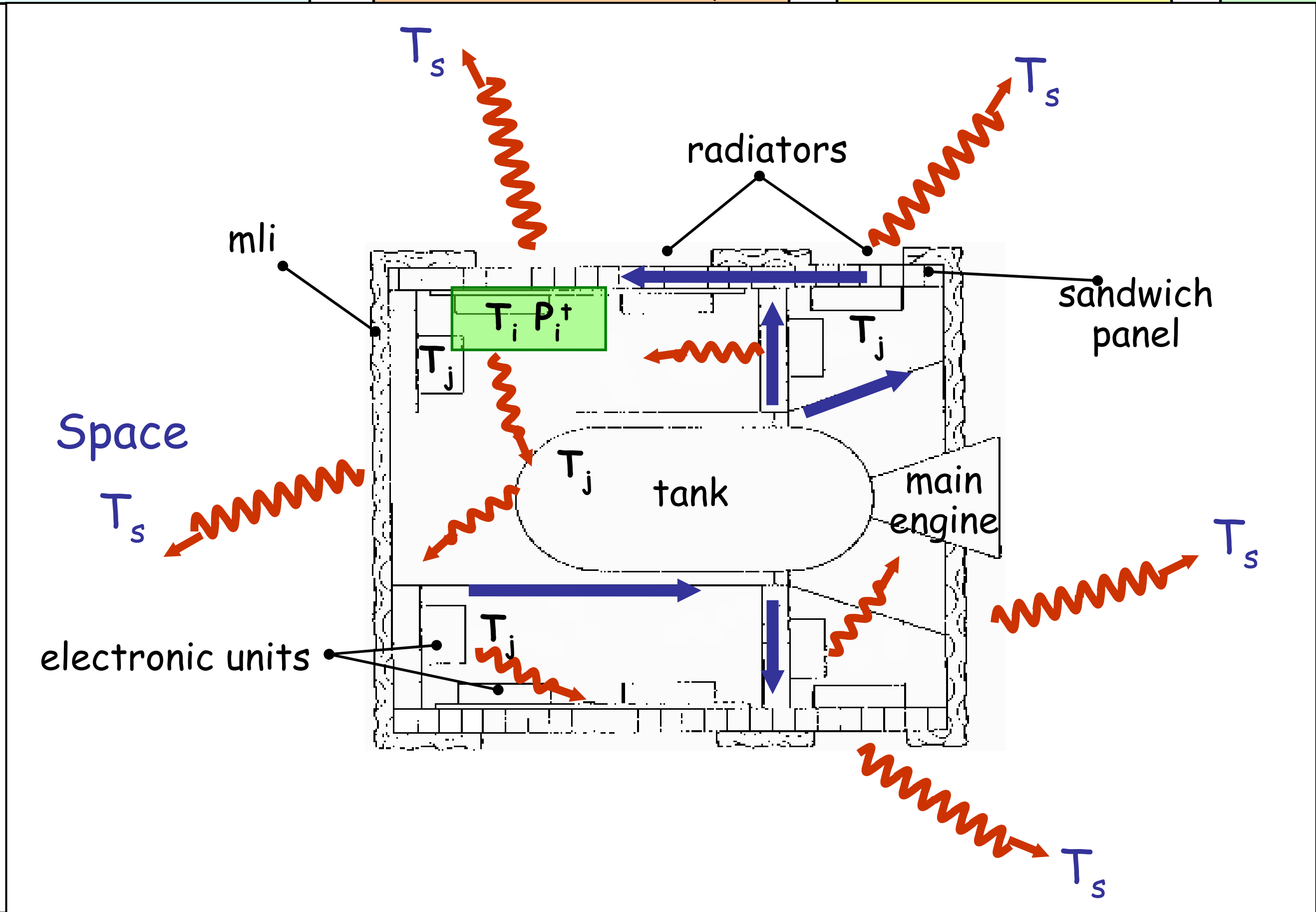
– Thermal Models –

- Thermal Mathematical Model (TMM)
  - mathematical representation
    - of satellite, equipments, structural parts, payloads…
    - of physical phenomena: power generation, mode of heat transfer…
  - to compute
    - <u>temperatures, heat flow</u>
  - set of differential equations to be solved by S/W

Thermal Control

– Differential Equations to be solved –

stored energy		conducted flux		radiated flux		fluid flow (not visualised)		internal loads	external loads
$(mC_P)_i \frac{dT_i}{dt}$	$=$	$\sum_j C_{ij}(T_j - T_i)$	$+$	$\sum_j R_{ij}\,\sigma(T_j^4 - T_i^4)$ *incl. to space	$+$	$\sum_j F_{ij}(T_j - T_i)$	$+$	Q_i^i	$+ \; Q_i^e$



Thermal Control

– Thermal Analyses –

combines the thermal parameters (fluxes, power, thermo-optical…) yielding the worst cases

- Extreme Cases with at least
  - one hot case
  - one cold case

- Result: temperature map and heat flows budgets

- + uncertainties

Thermal Control

– Satellite Development: Verification & Test –

- Phase 0 – Mission Assessment
- Phase A – Feasibility Study
- Phase B – Preliminary Definition
- Phase C – Detailed Design
- Phase D – Production/Validation
- Launch
- Phase E – Utilization
- Phase F – Disposal

- Mission Need Analysis
- Design
- Models/Analyses
- Manufacturing
- Verification
- Operation

Thermal Control

– Satellite Development: Verification & Test –

- Thermal Control main tasks: not specific to thermal engineering
  - list all requirements and resources
  - make the design and implement thermal control hardware
  - verify the design against the requirements → **is the design right?**
    - review of design
    - inspection
    - similarity
    - analysis
  - validate the design → **is it the right design?**
    - by test

done at UNIT or SPACECRAFT LEVELS

Thermal Control

– Verification: Thermal Tests –

- Thermal Cycling Test (TCT) → **System test**
- Thermal Vacuum Test (TVT) → **System test**
- Thermal Balance Test (TBT) → **Thermal test**

done at UNIT or SPACECRAFT LEVELS

Thermal Control

– Thermal Cycling Test –

- Thermal Cycling Test (TCT) → **System test**
  - demonstrates the system ability to fulfil all functional requirements over the required temperature range
  - at ambient pressure
  - in general combined with TVT
  - in more details, TCT aims at:
    - verifying the satellite design w.r.t. mechanical stress
    - the design implementation
      - the manufacturing/integration methods
      - the workmanship

Thermal Control

– Thermal Vacuum Test –

- Thermal Vacuum Test (TVT) → **System test**
  - demonstrates the system (electrical, optical, thermal…) ability to fulfil all functional and performance requirements over the required temperature range
  - in vacuum
  - in general combined with TCT
  - in more details, TVT aims at:
    - verifying the satellite design including the TCS
    - the design implementation
      - the manufacturing/integration methods
      - the workmanship

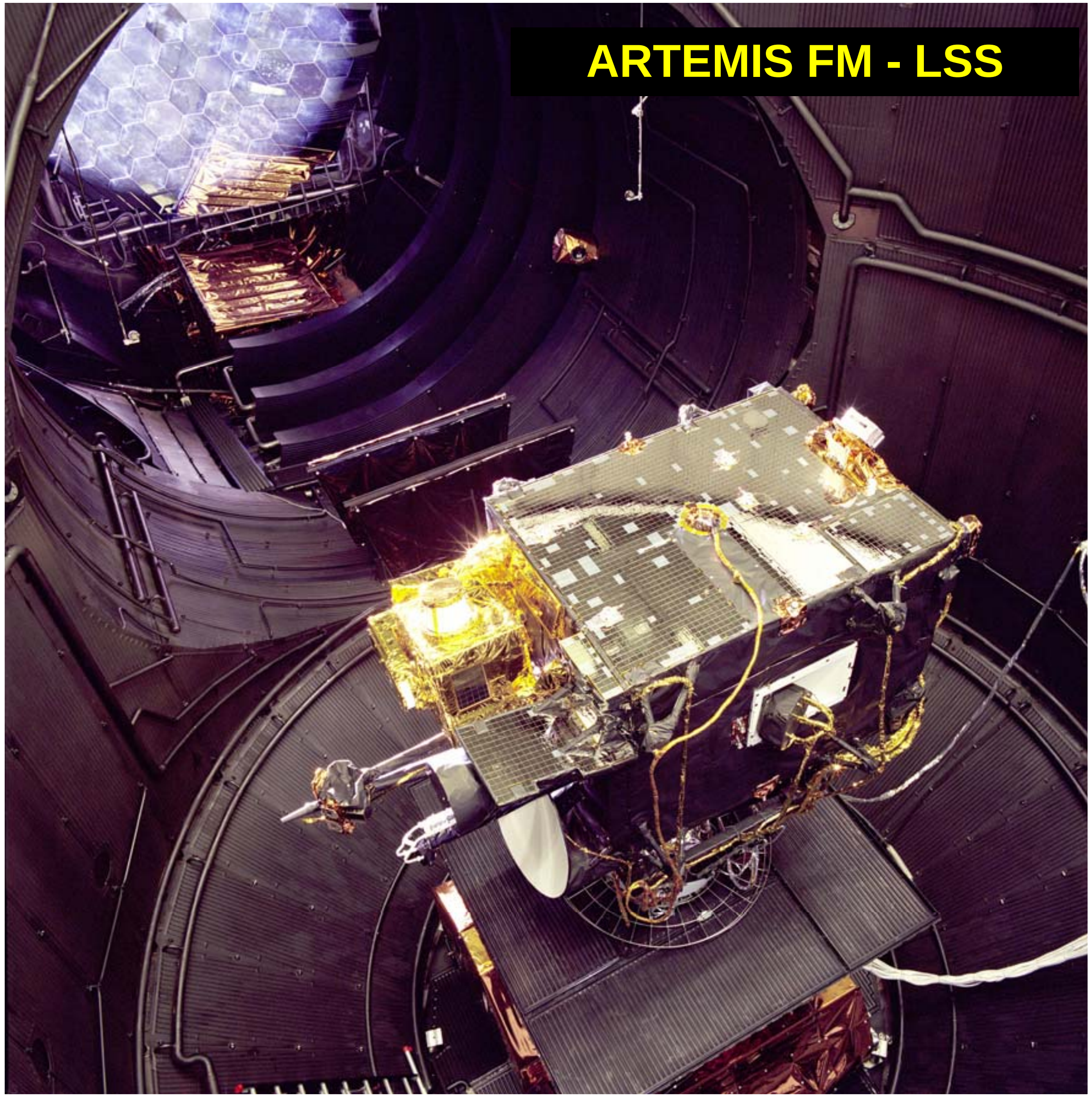
Thermal Control

– Thermal Balance Test –

- Thermal Balance Test (TBT) → **Thermal test**
  - verifies the adequacy of the thermal control design
  - and the mathematical models → **Correlation**
  - <u>in vacuum</u>
  - in more details, TBT aims at:
    - verifying the functionality and performance of thermal H/W and S/W laws
    - correlating the mathematical models
      - in steady-state
      - in transient
    - assessing the thermal design temperature sensitivity (bonus)

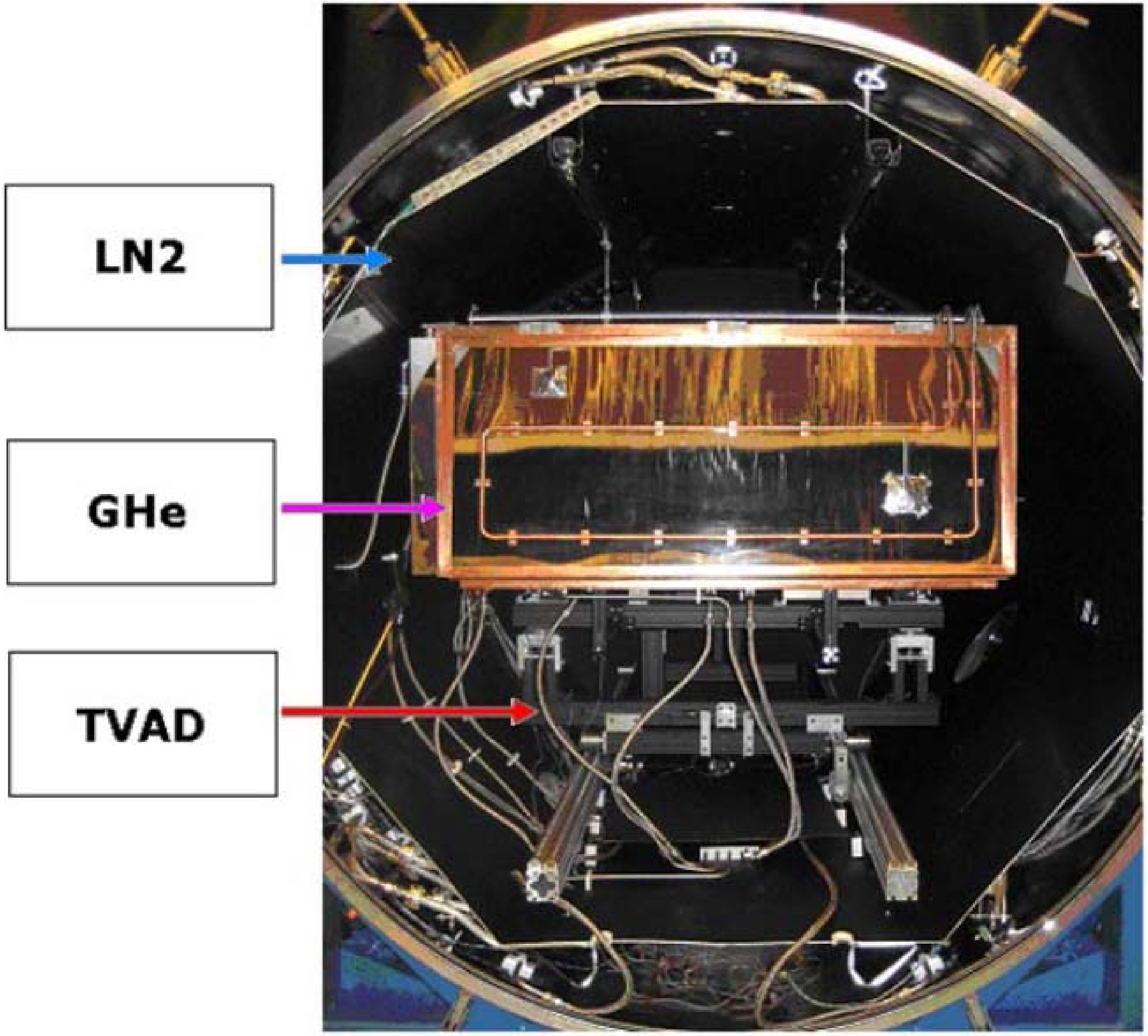
Thermal Control

– Facility: LSS –



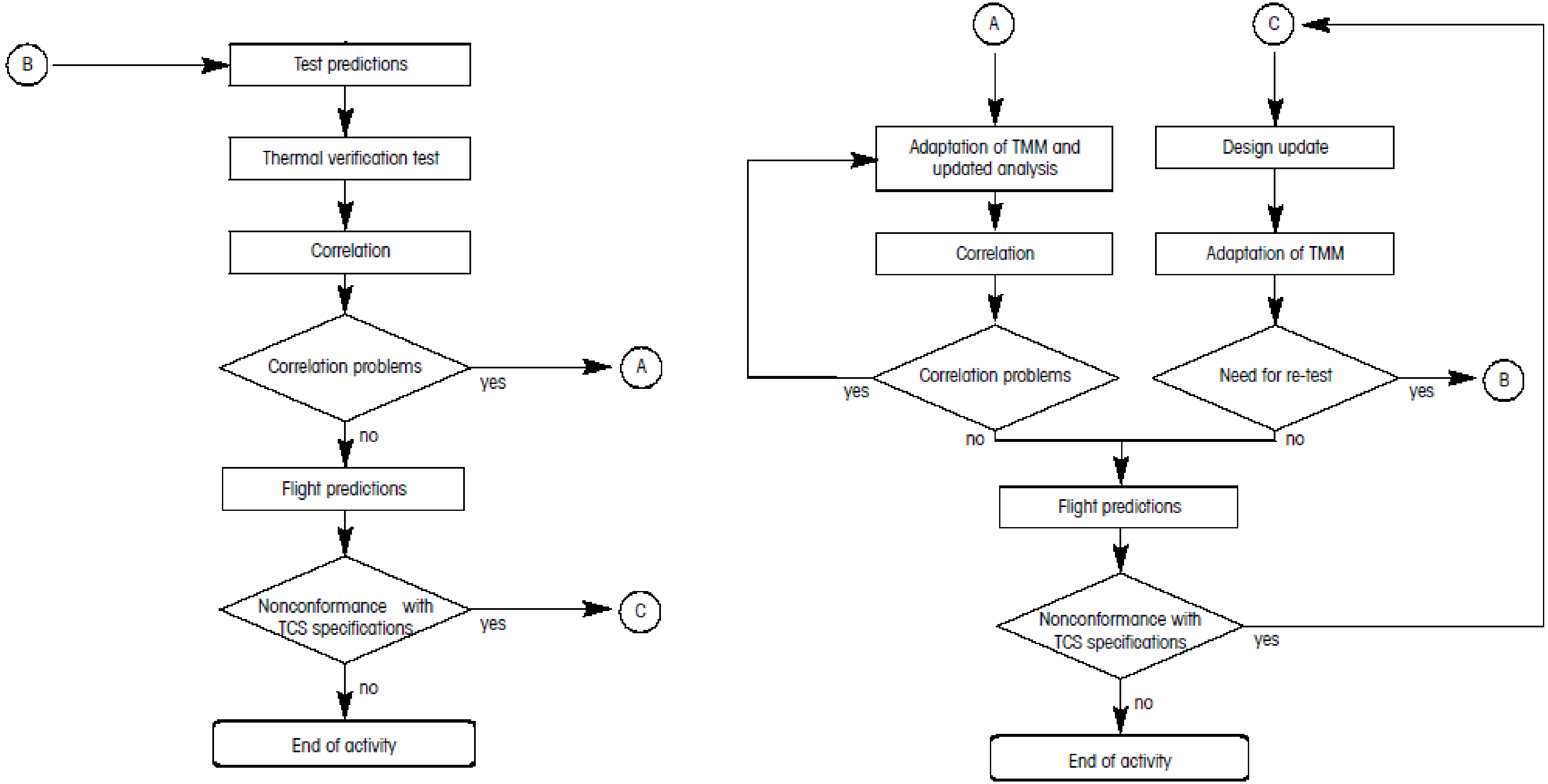
Thermal Control

– Facility: LSS –



Test Chamber Setup (without NIRSpec FM)

- **After TB Test**



Questions ?