Cryogenics overview for LiteBIRD

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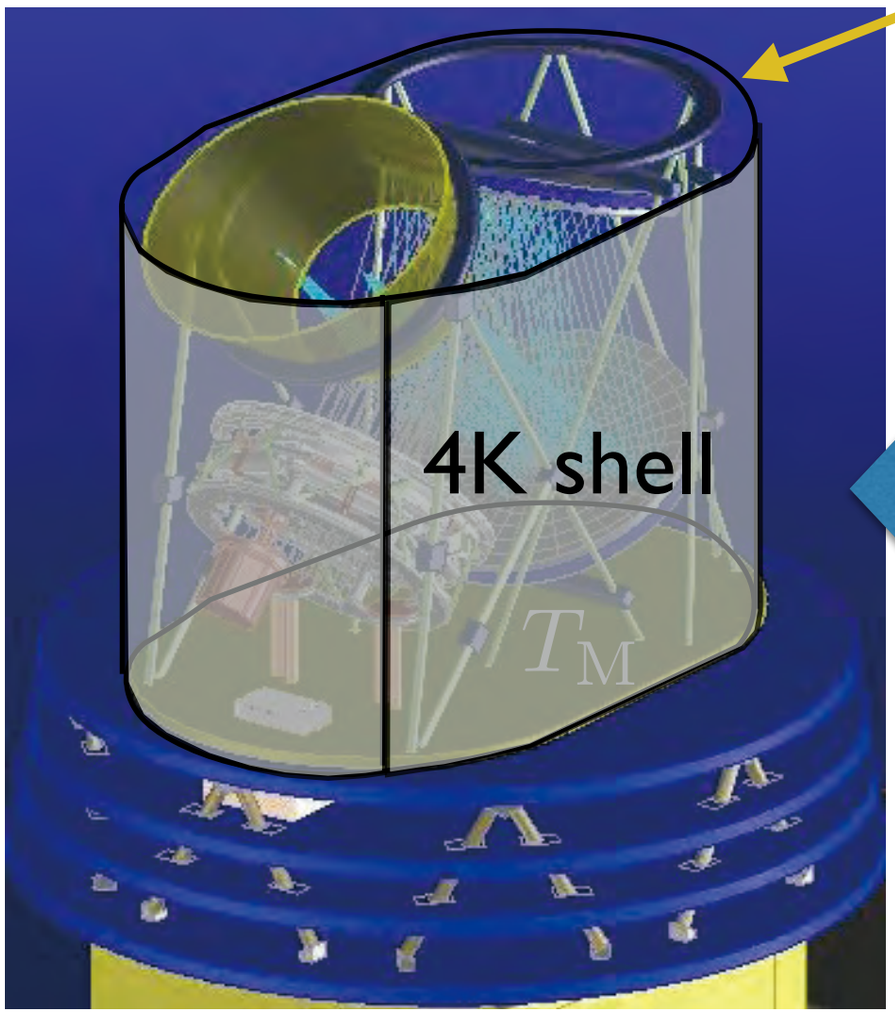
Outline

- Requirements to cooling system from the instruments.
- Preliminary thermal analysis
  - Baseline Model
    - Assumptions
      - How many last stage coolers (LSC)?
      - Radiative cooling or mechanical coolers?
      - Heat dissipation from < 4K
      - Spacecraft configuration
  - Thermal analysis results
  - Design margin as a function of mass(≤ 4K)
- Phase-A1 study

Requirements from instruments

1. To provide ~4 K environment for the telescope system(s)



must be surrounded by ~4 K shield or 3K sky

Sun

Requirements for

- temperature upper limit,
- temperature gradient,
- temperature stability,
- and emissivity of inner surface

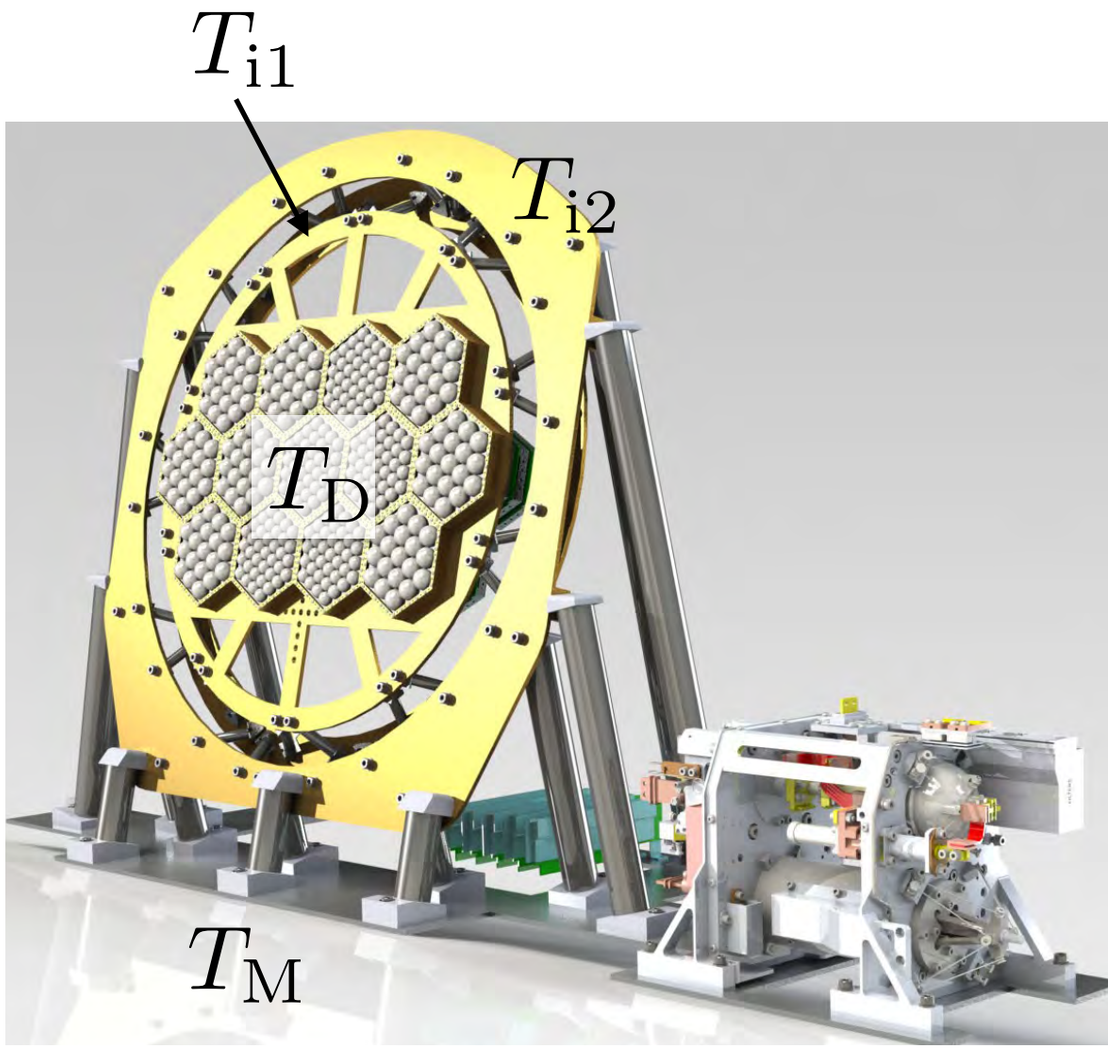
Requirements from instruments

2. To provide ~100m K heat sink(s) for detectors

Requirements for
- temperature,
- temperature stability,

- If there are intermediate temperature stage(s) T_{i1} T_{i2}
  - temperature stability of them.

- Observation efficiency
- Temperature excursion in non-observation duration
- Magnetic moment
  - during observation
  - non observation



more Requirements

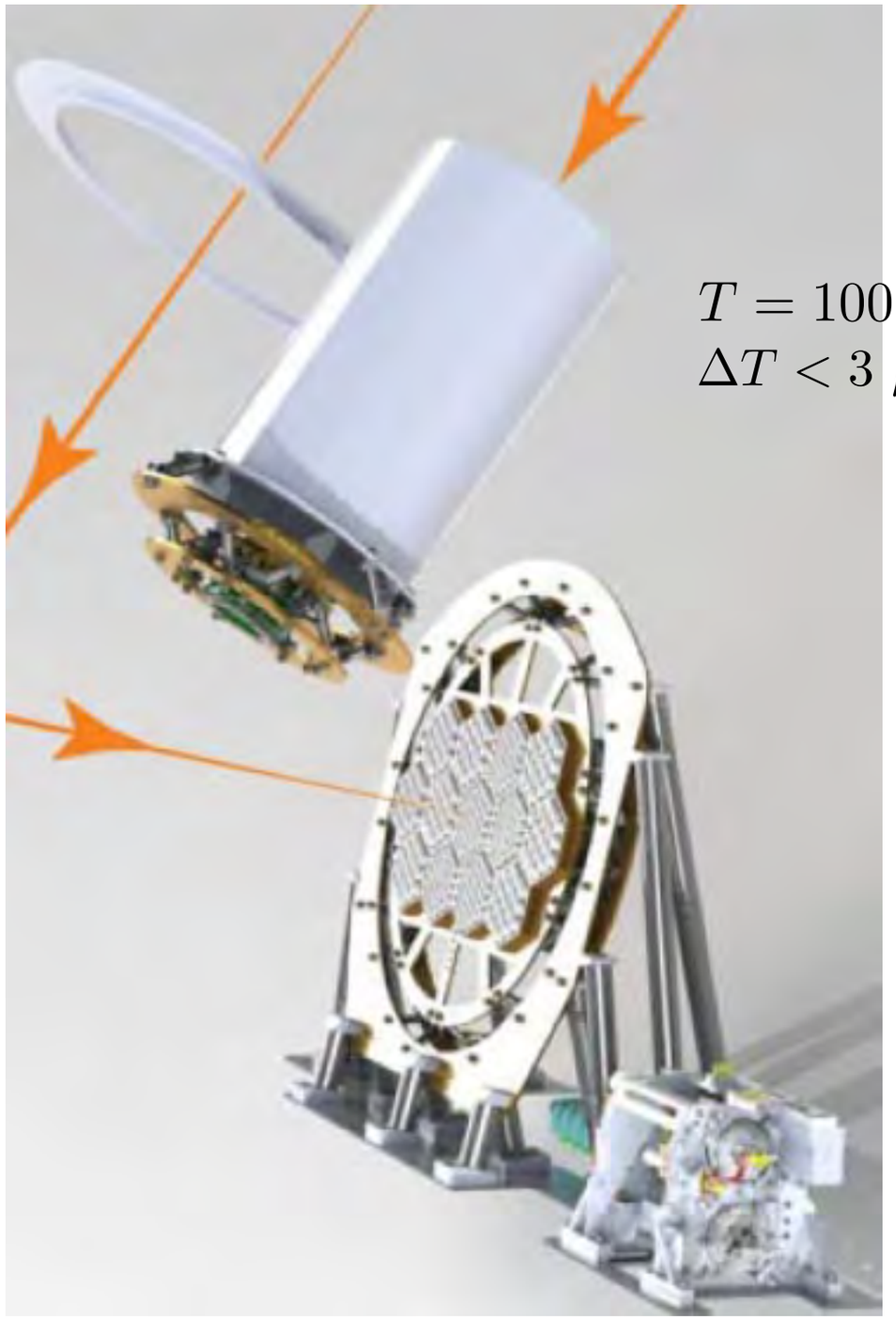
- Hold time of detector stage temperature
- Time efficiency of detector stage temperature
- Maximum excursion temperature of detector and intermediate stages.
- Wire harnesses requirements from room temperature electronics to cold stage(s)
  - impedance and/or length requirements

- Total mass of 4K shell + its interior

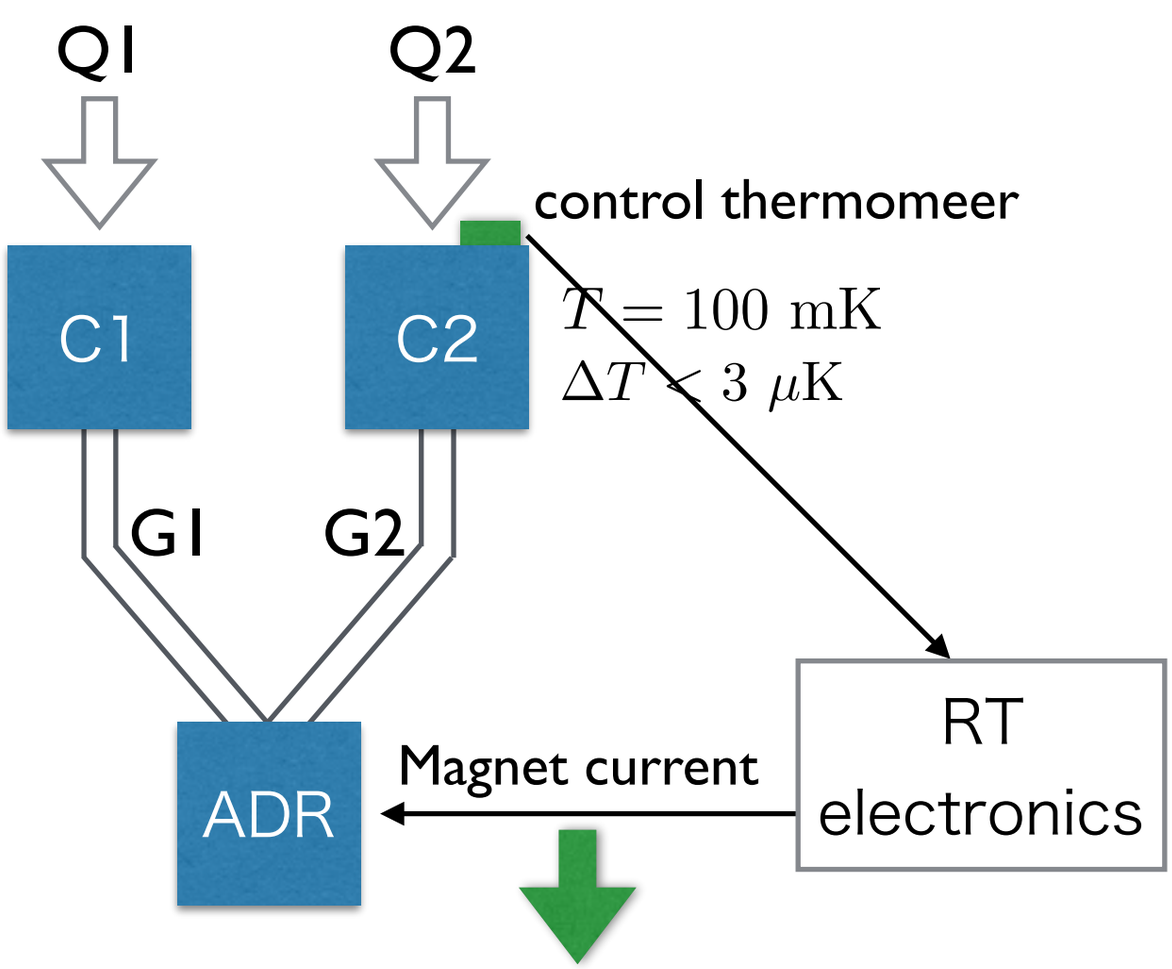
Design conditions

- Launch load condition (static and dynamic)
- Orbit and attitude of spacecraft
- Uncertainties
  - Material properties
- Design margins
- ….

Requirement: Two or more detector units

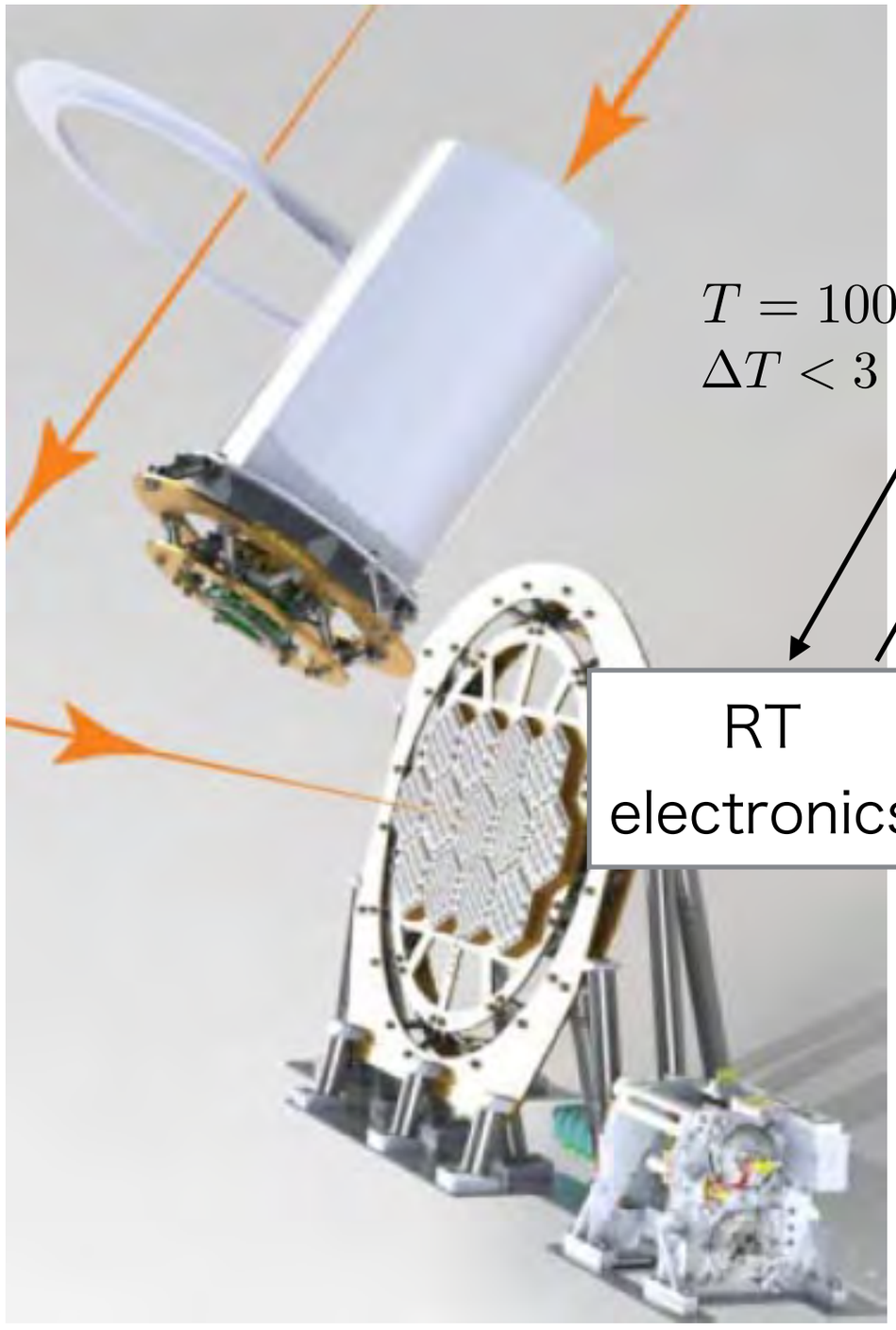


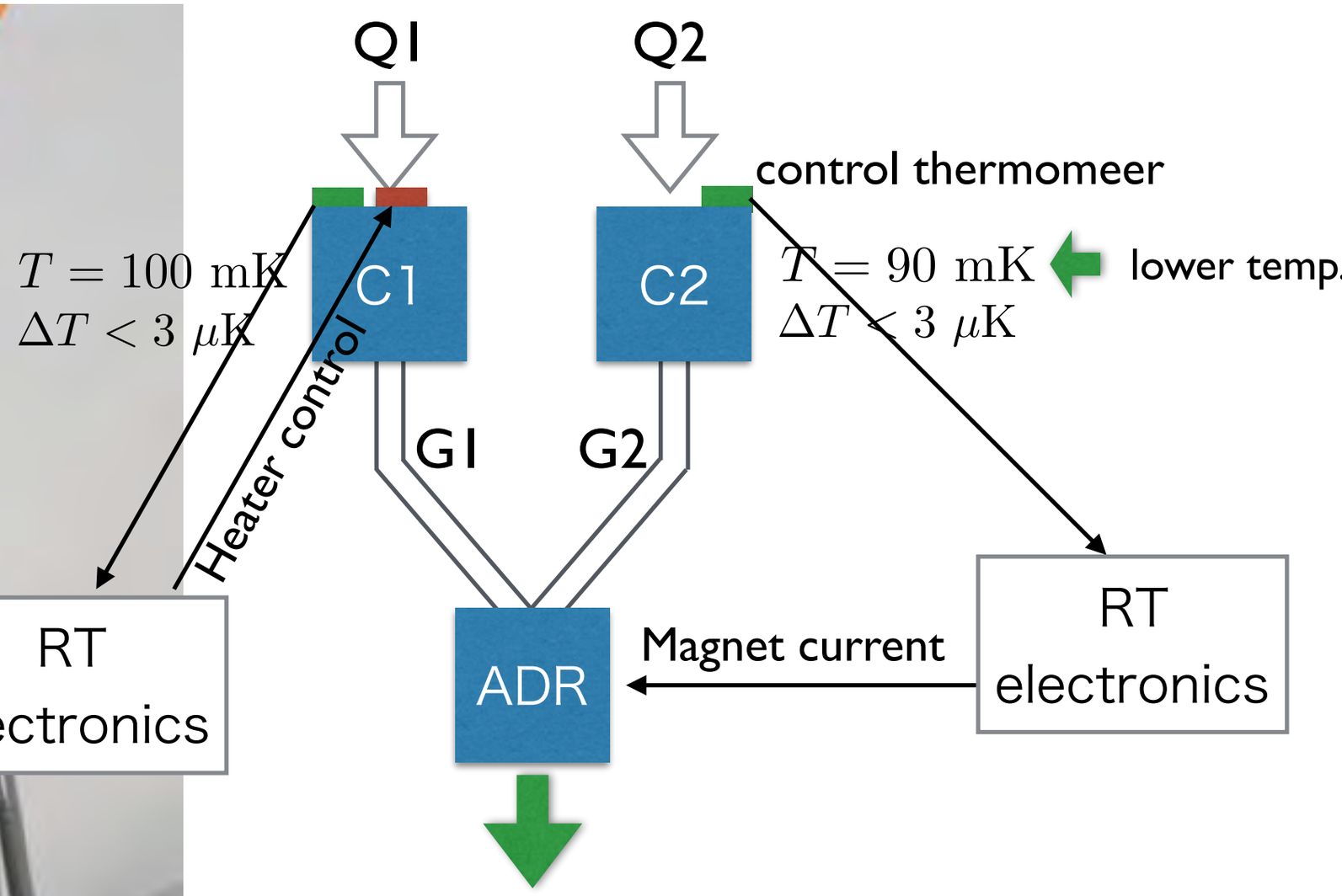
$T = 100$ mK
$\Delta T < 3$ μK



Temp. control by ADR current:
may not work for unit 1.

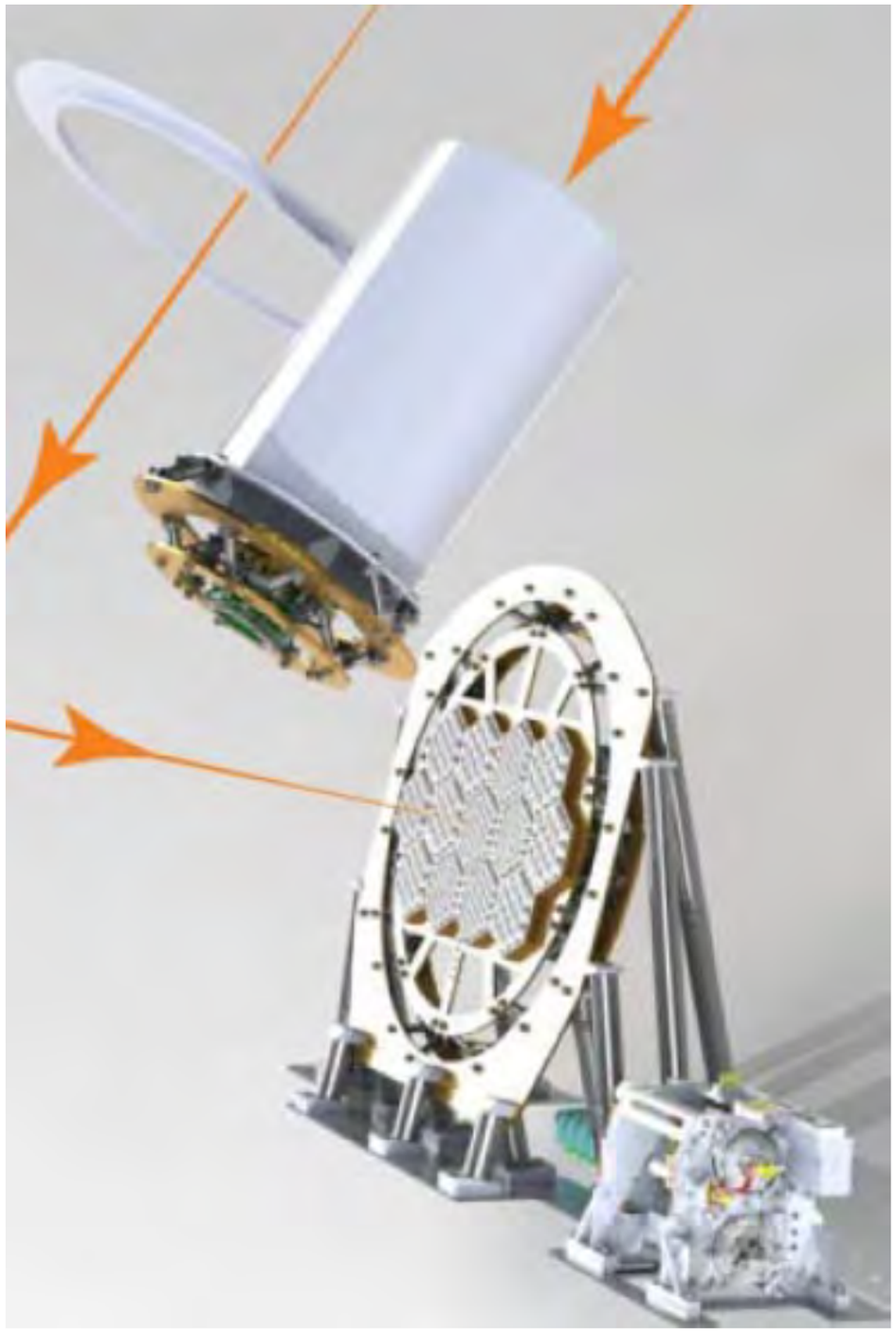
Two or more detector units

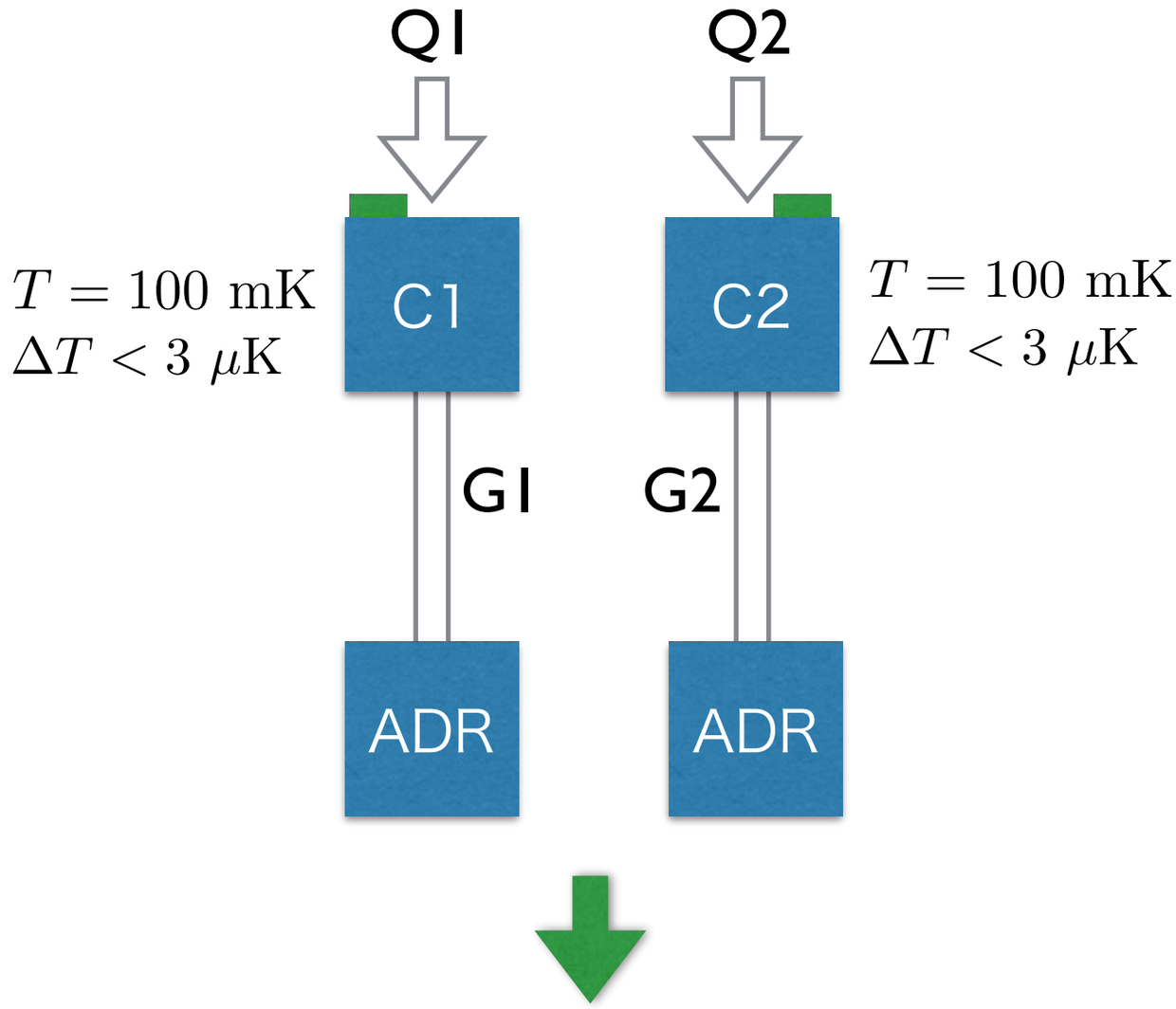




Extra heat from heater control.
Lower observation efficiency

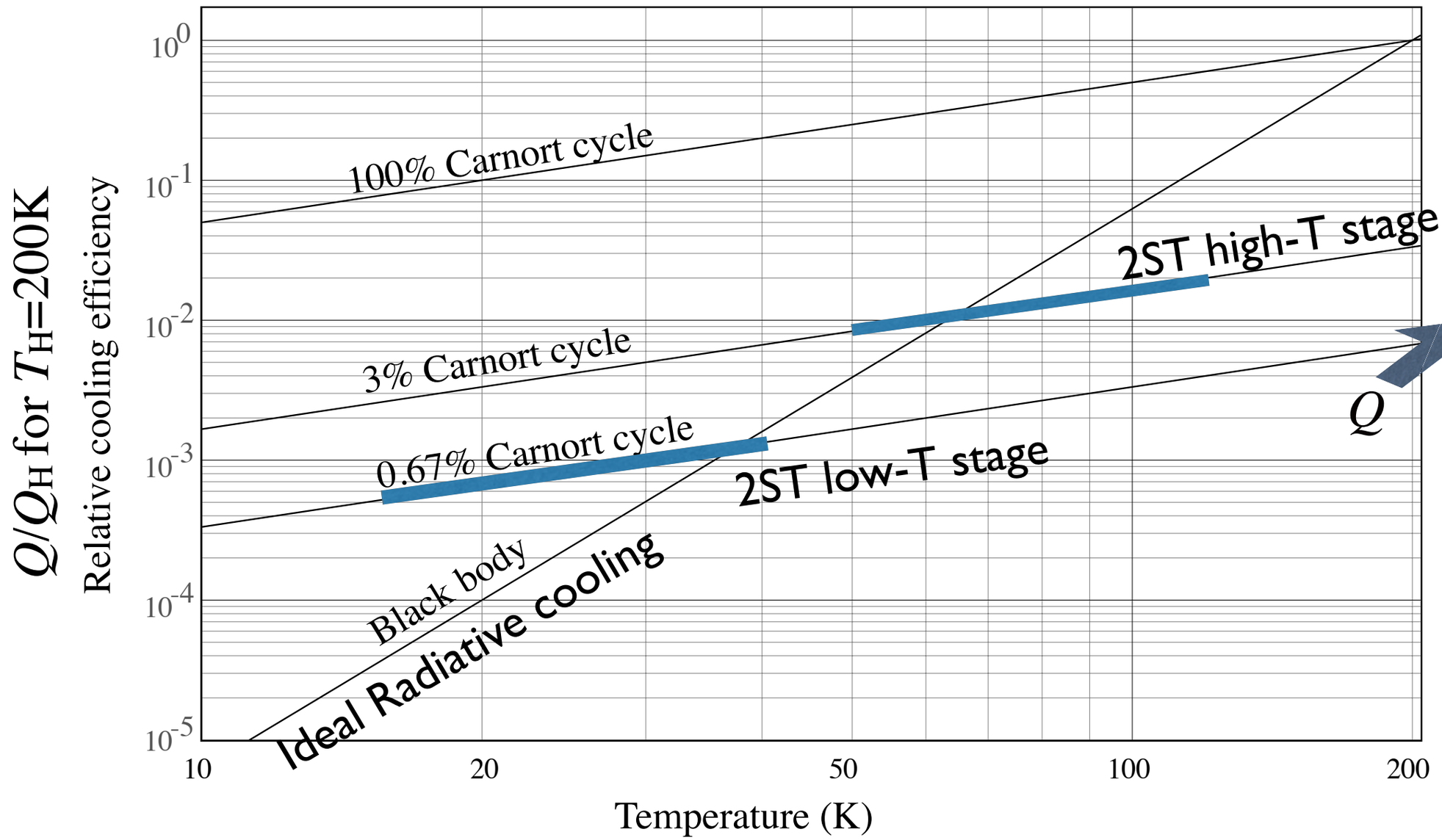
Two or more detector units

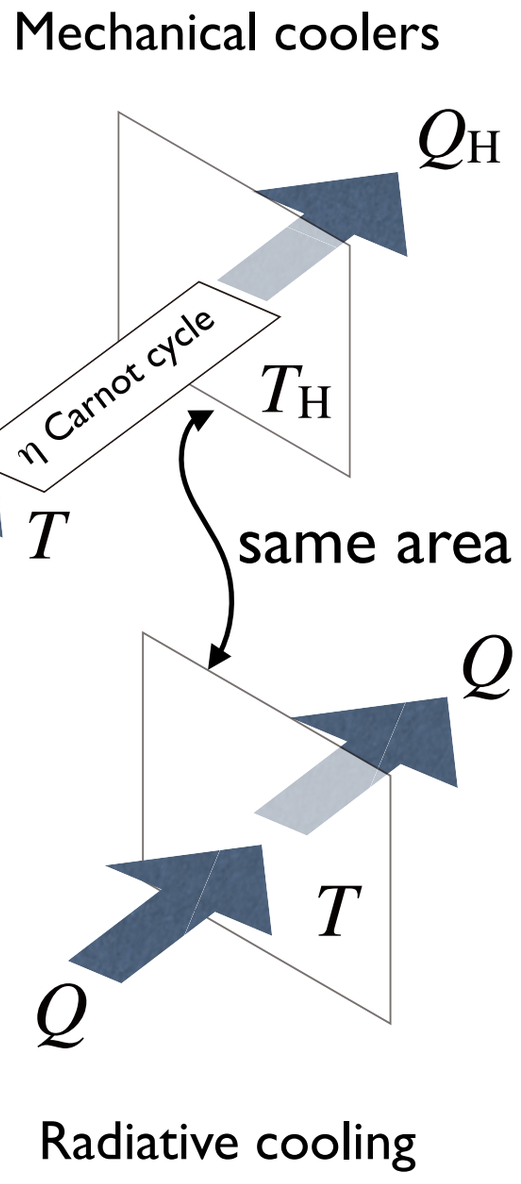




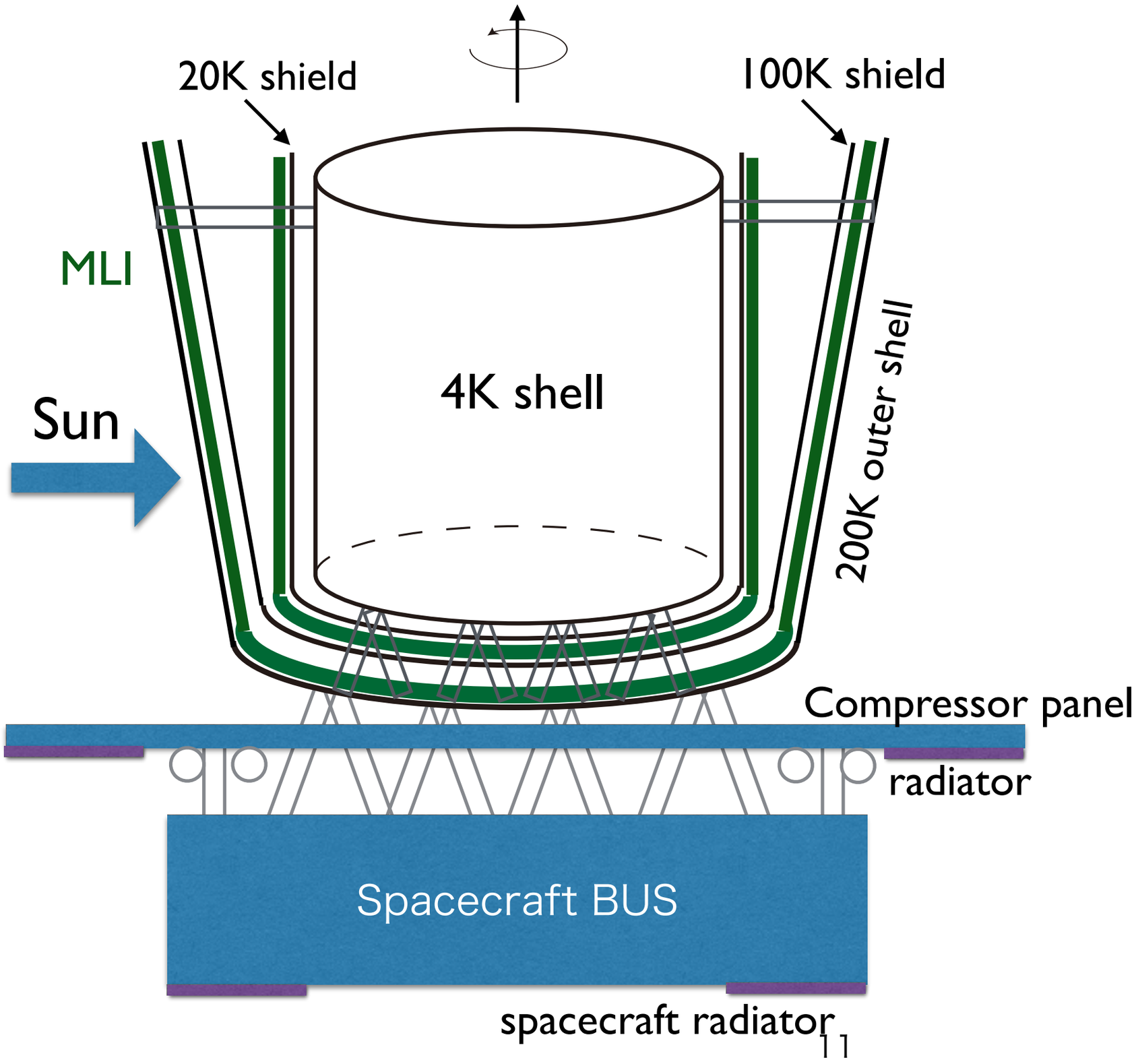
Straightforward, thus maybe better

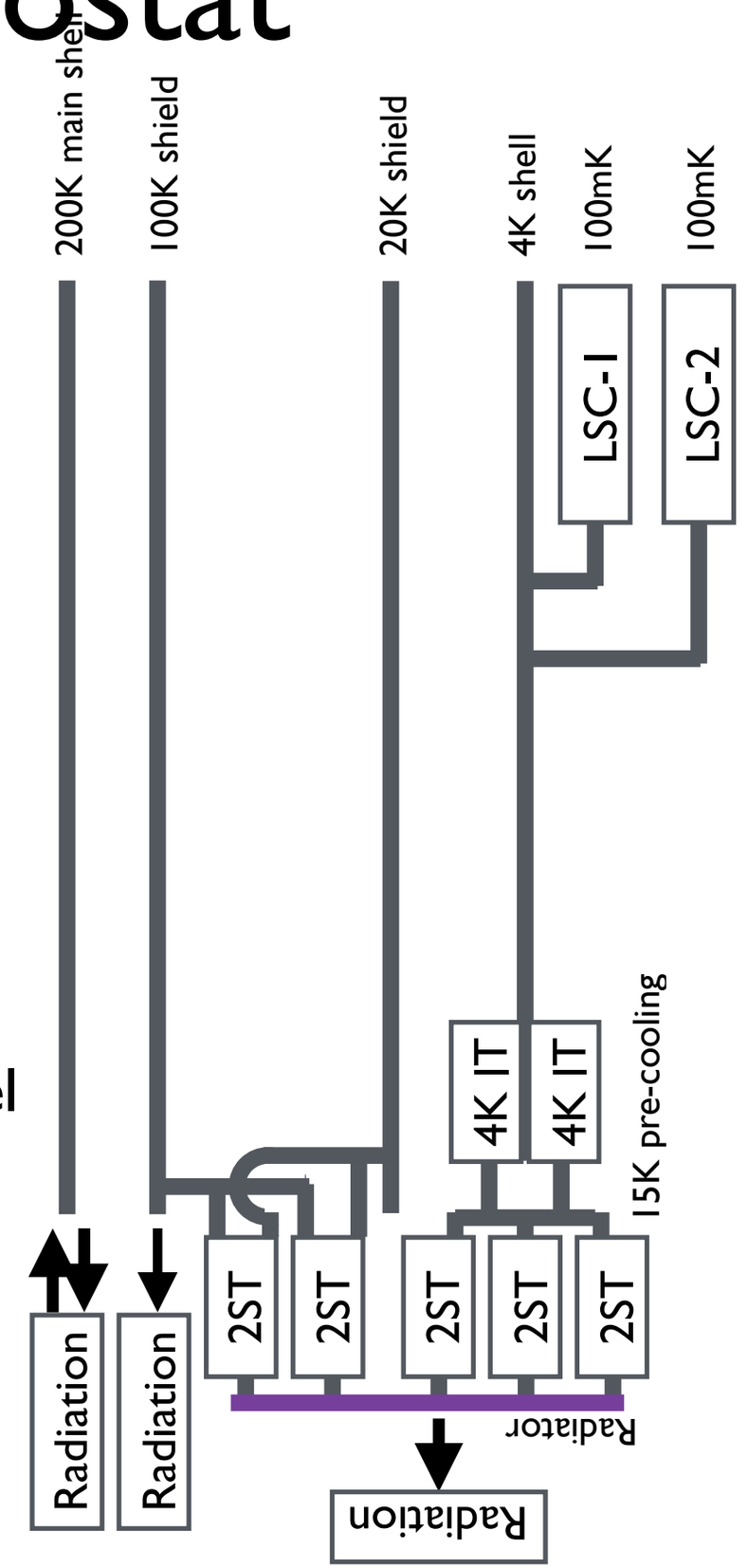
Radiative cooling or mechanical cooler?





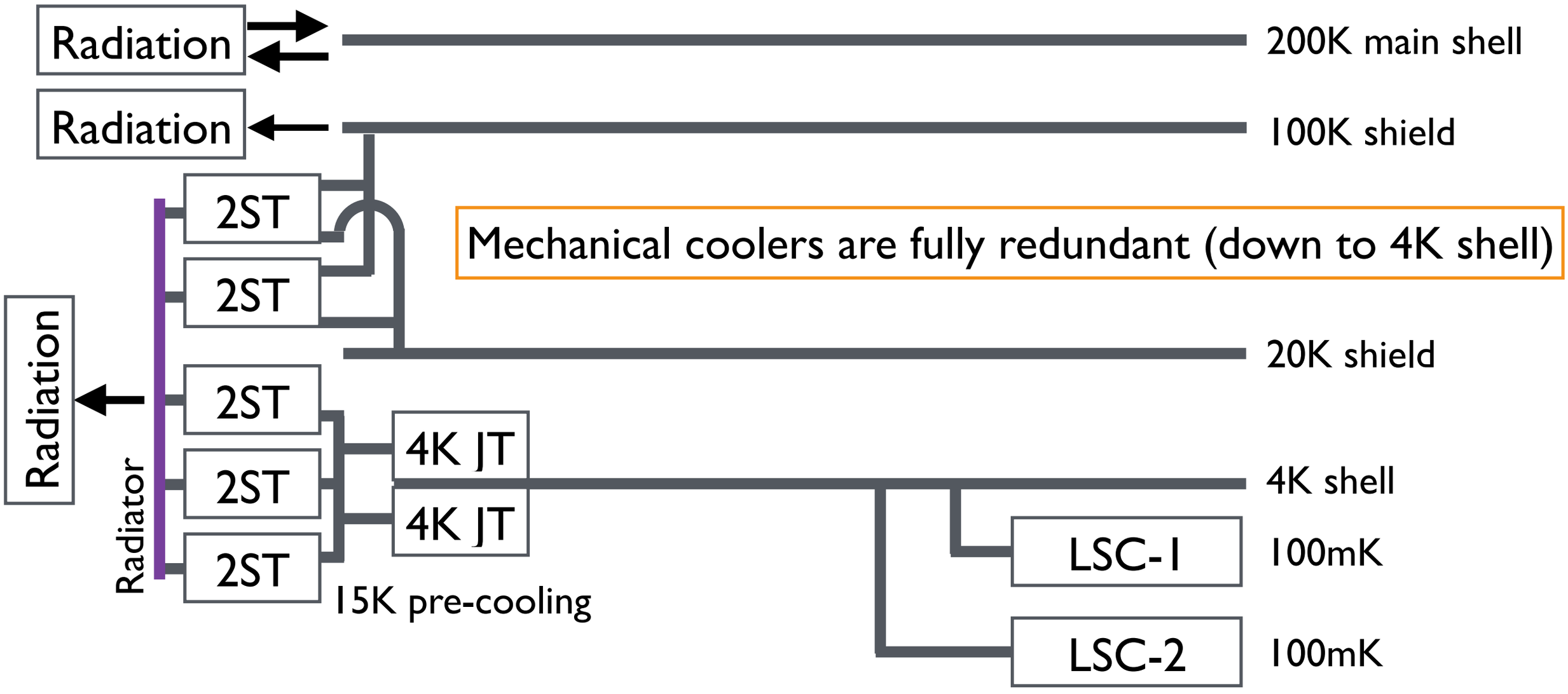
Baseline model cryostat





Preliminary thermal analysis

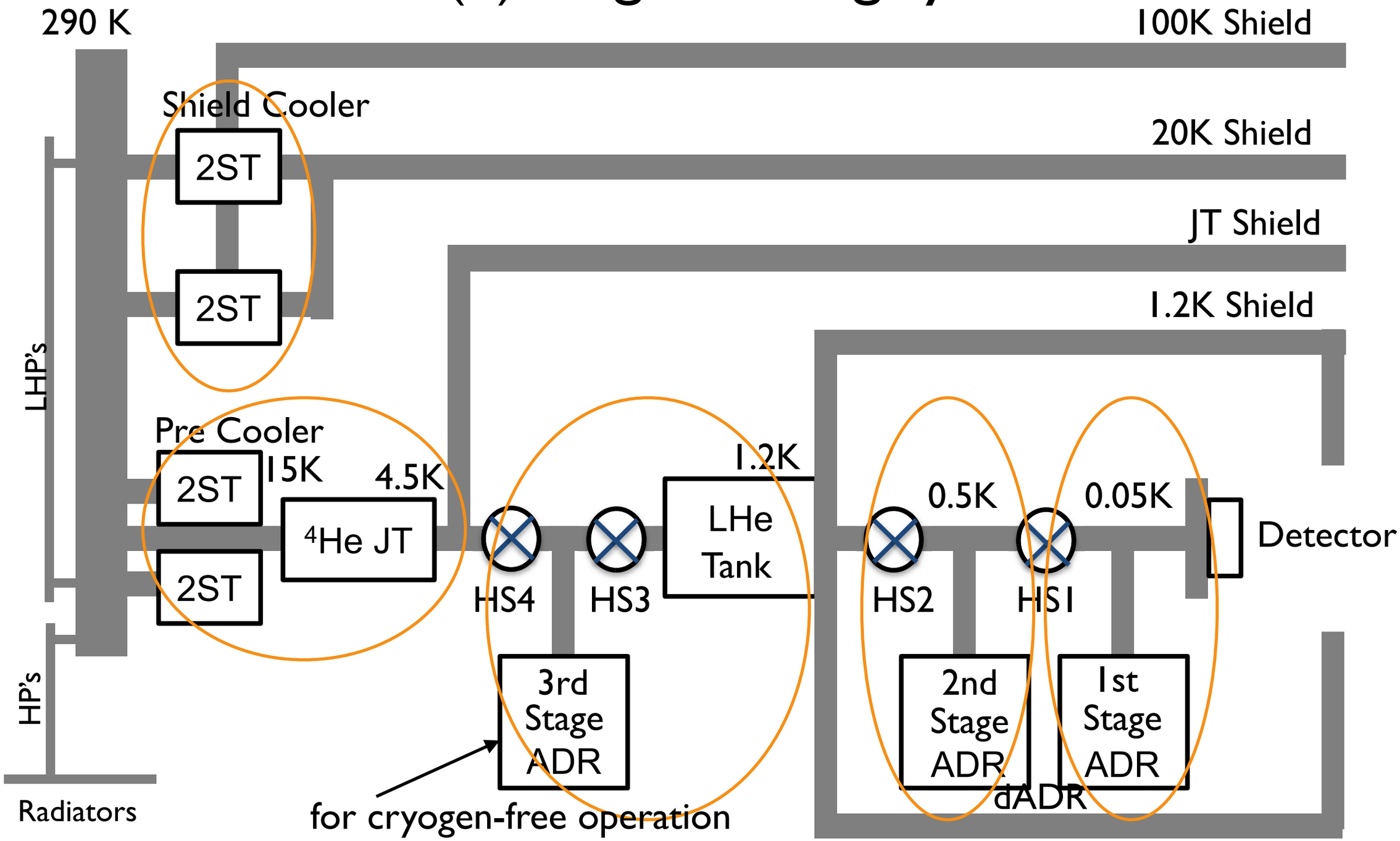
Baseline model cooling chain



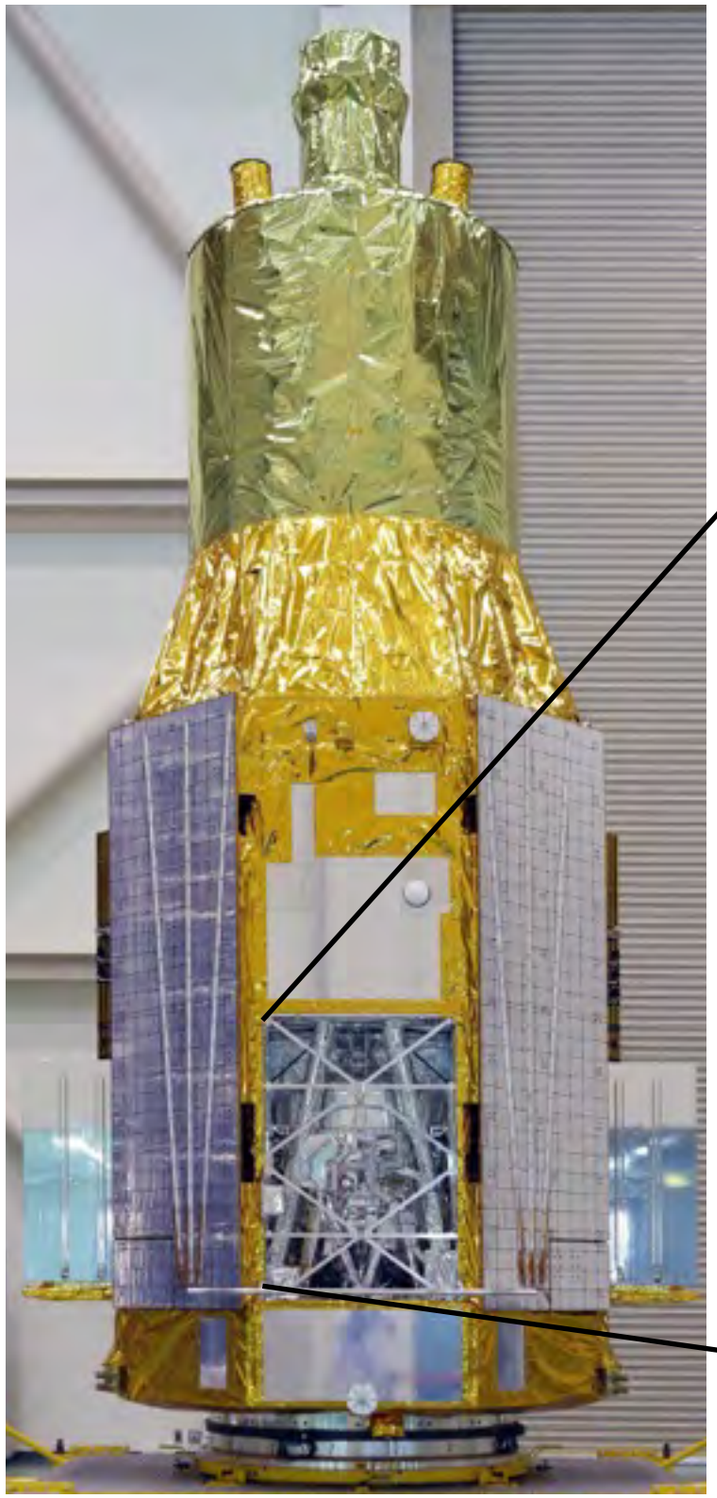
High TRL from ASTRO-H heritage

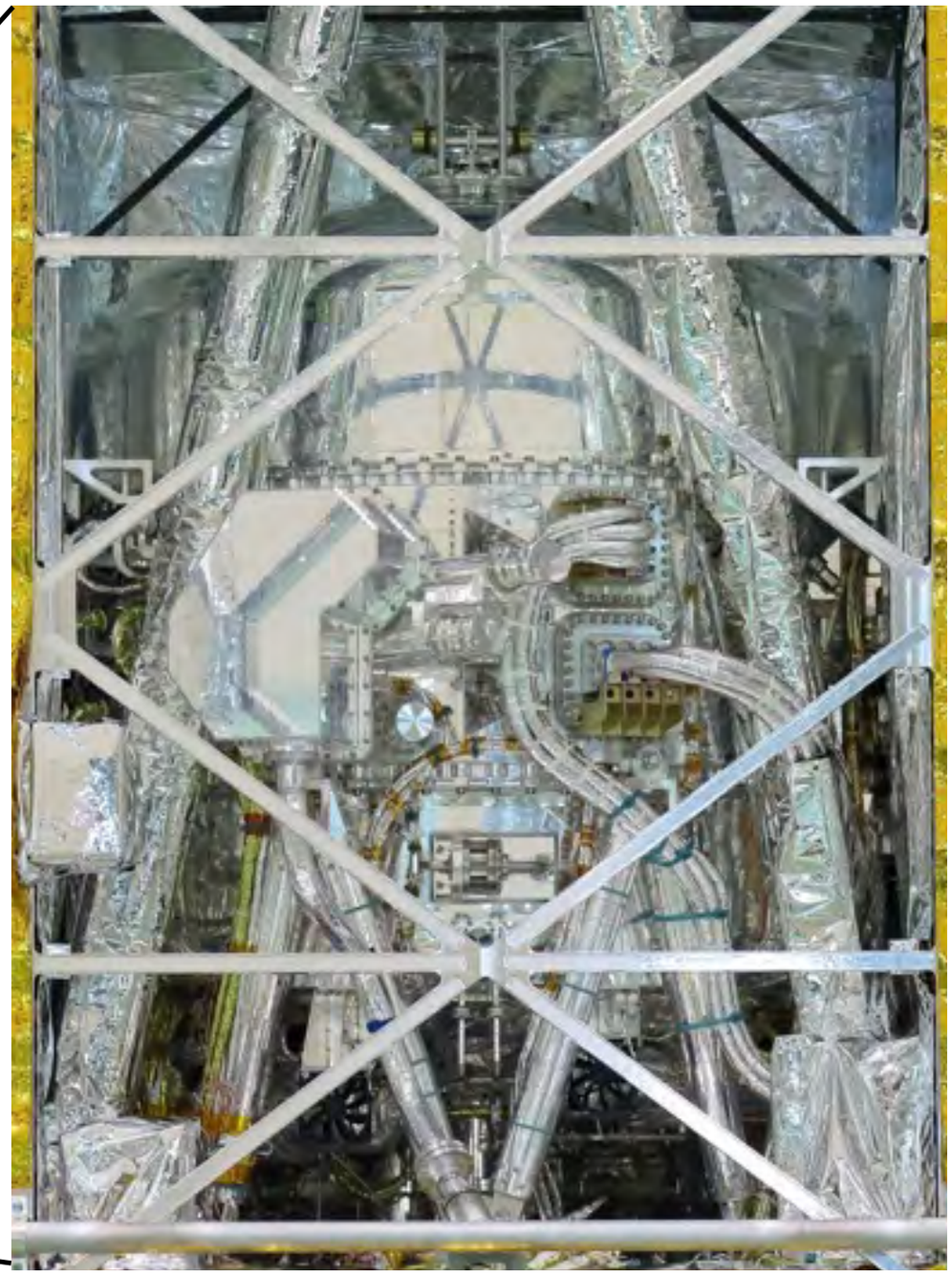
ASTRO-H SXS cooling chain

multi (5)-stage cooling system

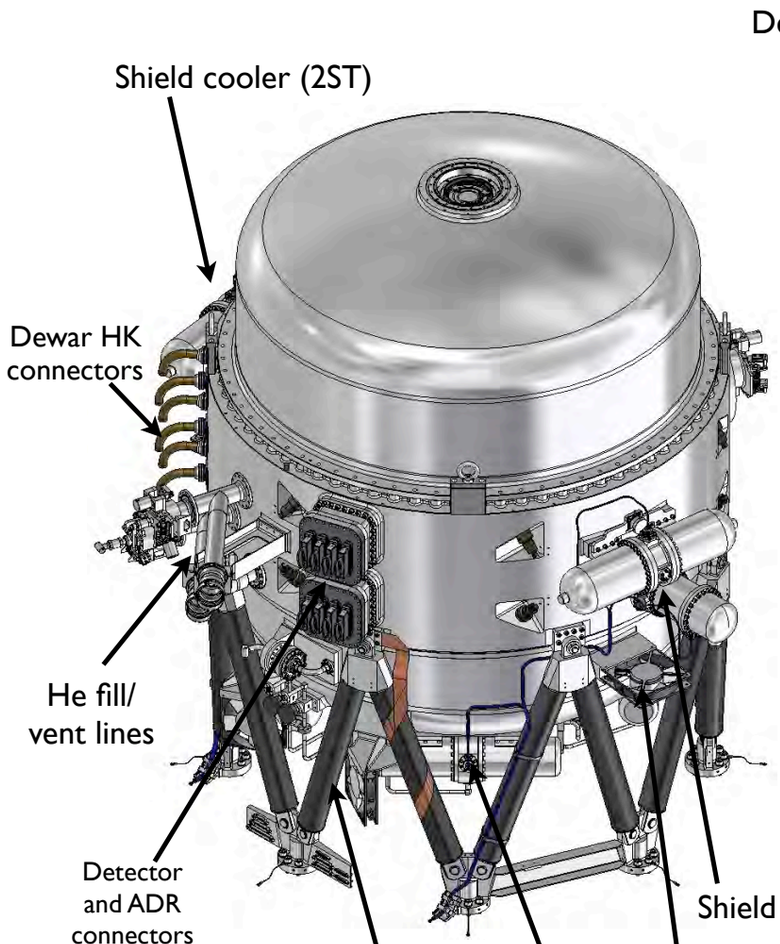


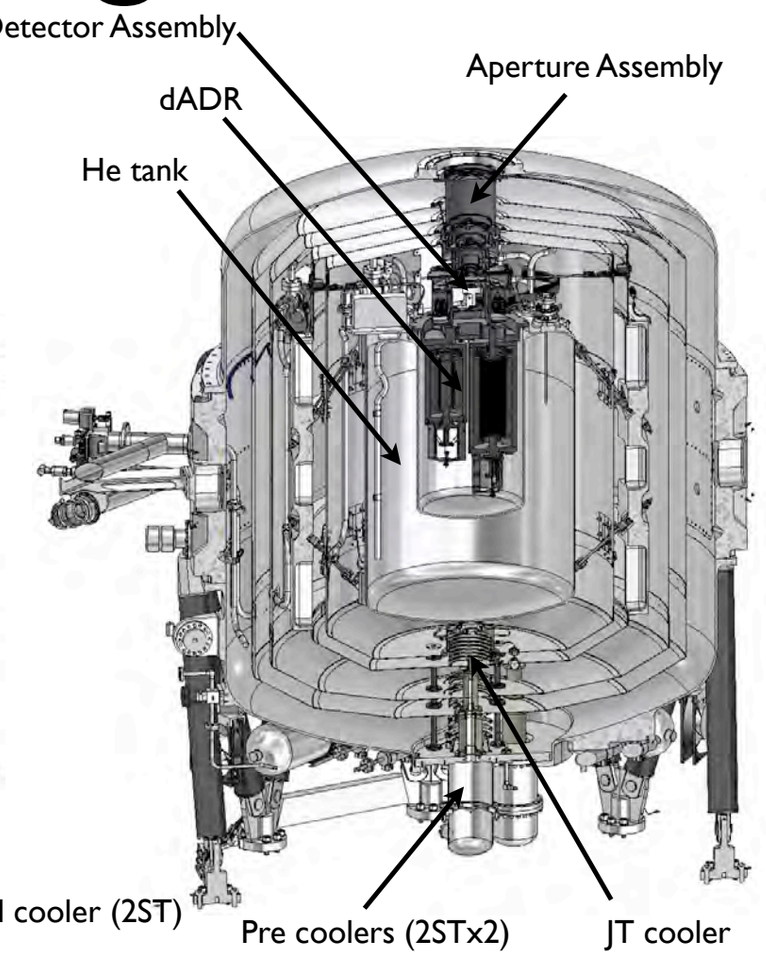
ASTRO-H SXS cooling chain

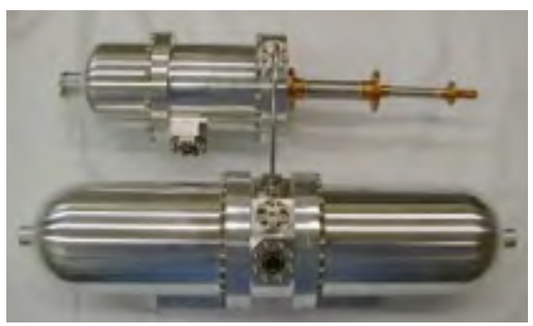




ASTRO-H SXS cooling chain



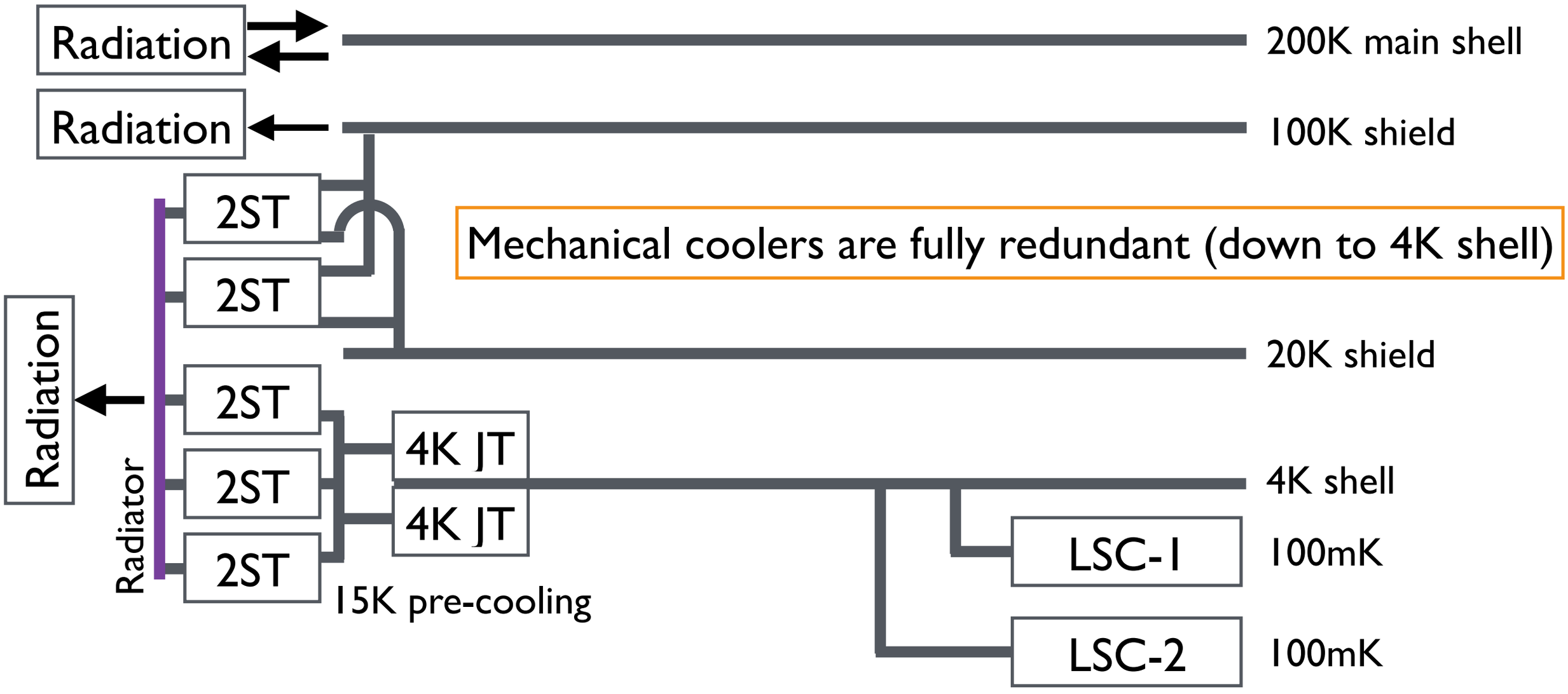




Double-stage Stirling-Cycle Cooler (2ST)

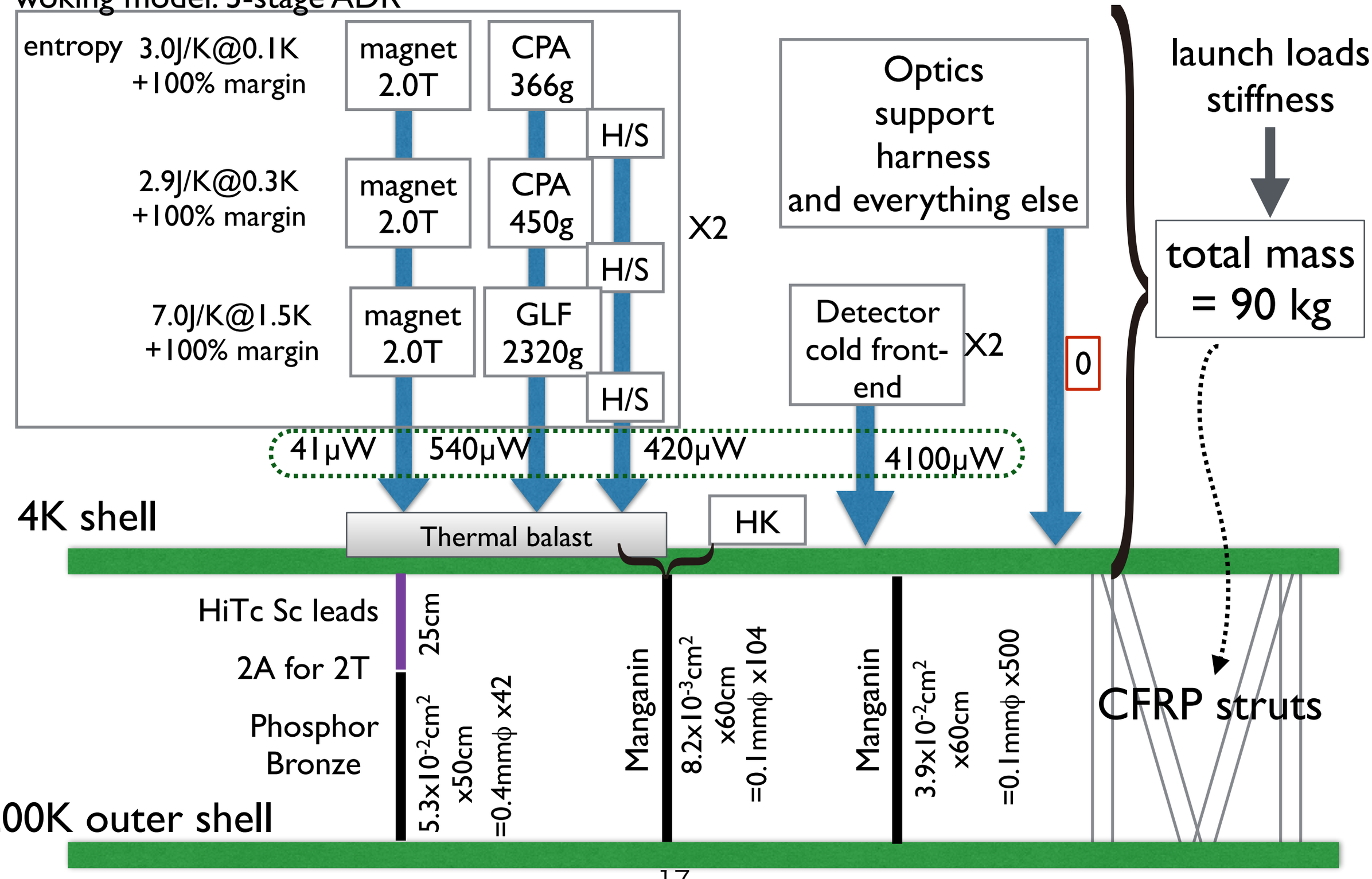
4K Joule-Thomson Cooler (4K JT)

Cooling chain of the model design

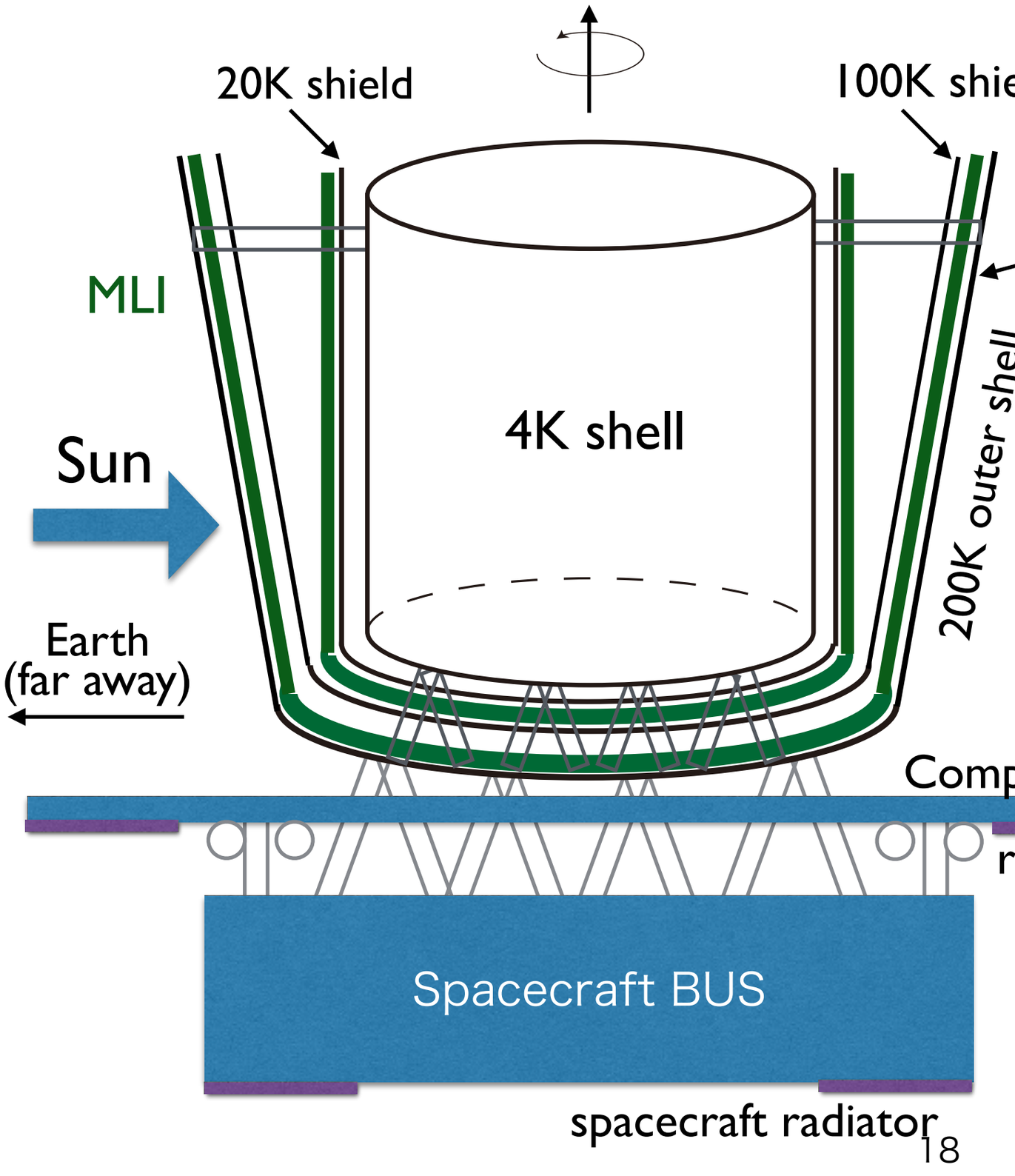


To perform preliminary thermal analysis, we need a model cold stage and wire harness requirements from cold to warm stages.

Working assumptions: cold stage

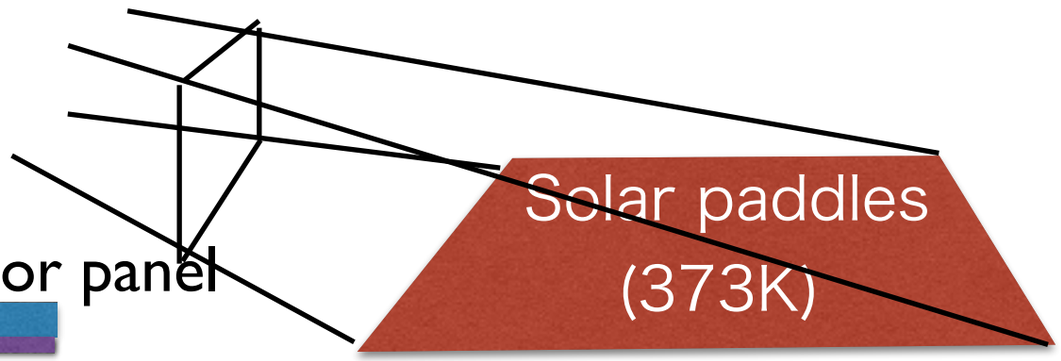


Assumptions: Spacecraft configuration



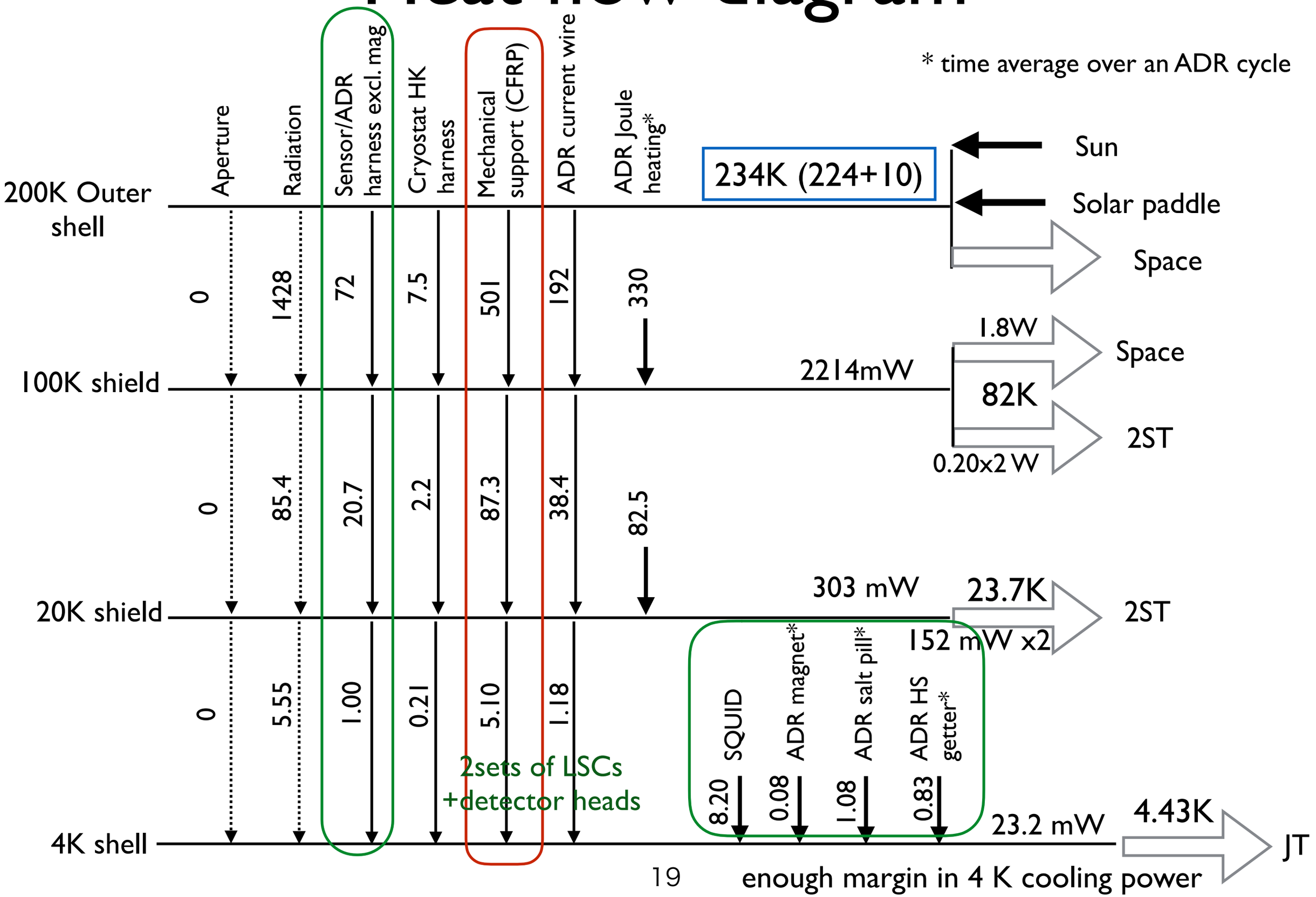
Optical absorption coefficient = 0.2
IR emissivity = 0.8

total area x cos θ =2m^2
distance = 3m
emissivity = 0.8



Heat flow diagram

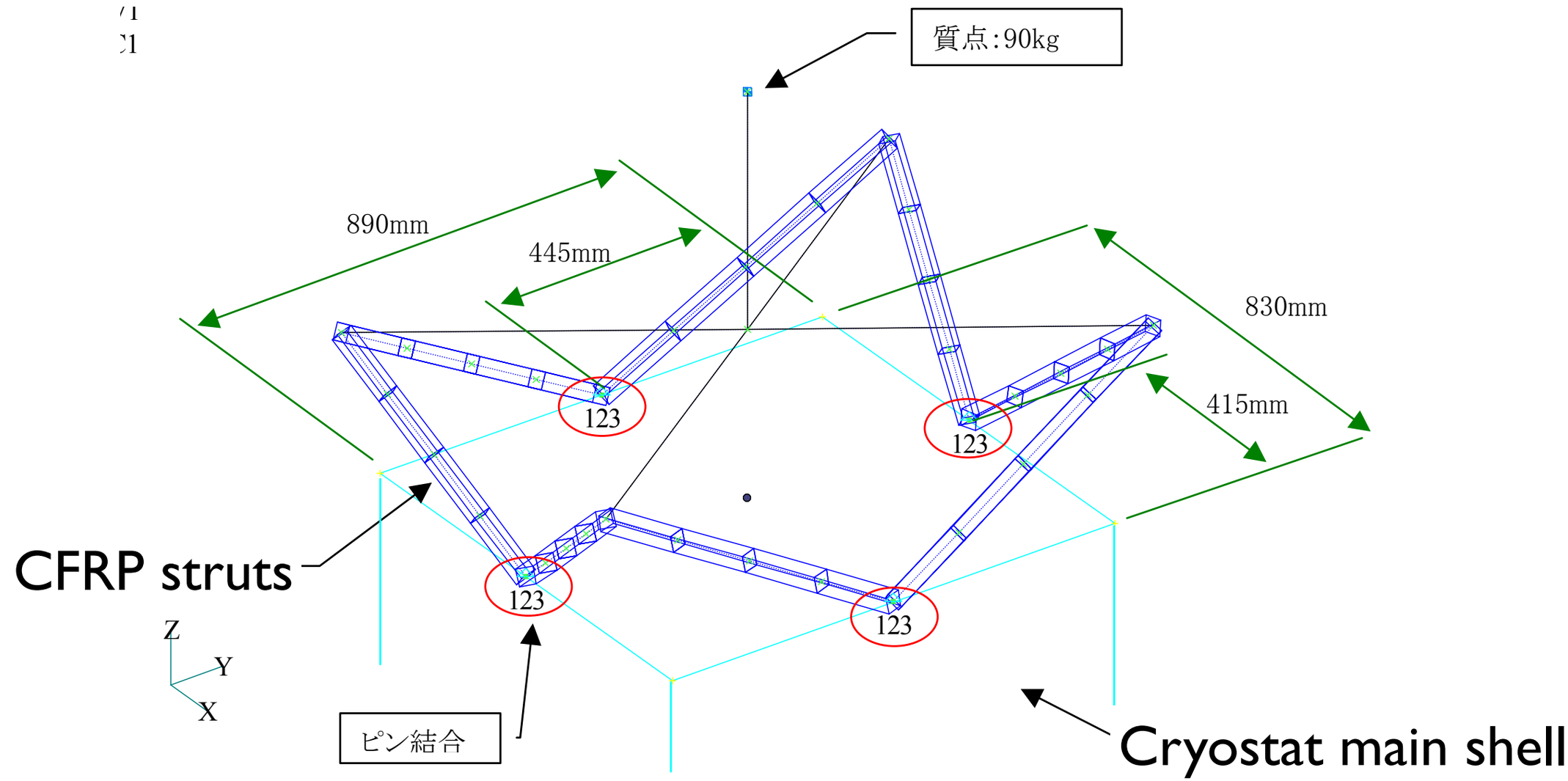
* time average over an ADR cycle



enough margin in 4 K cooling power

CFRP truss

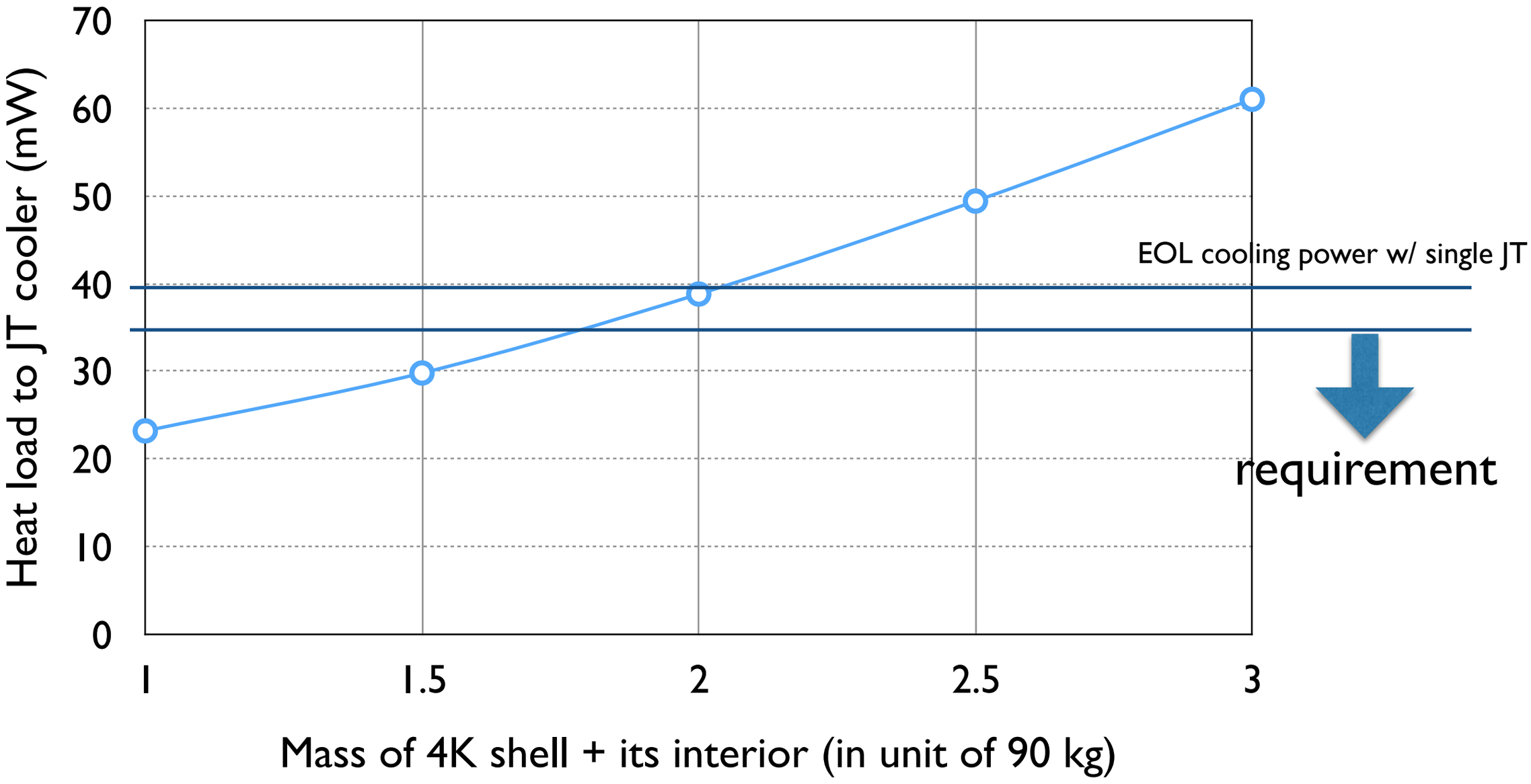
Mechanical analysis model



20G launch load and stiffness requirements (>30Hz lateral, >70Hz axial)

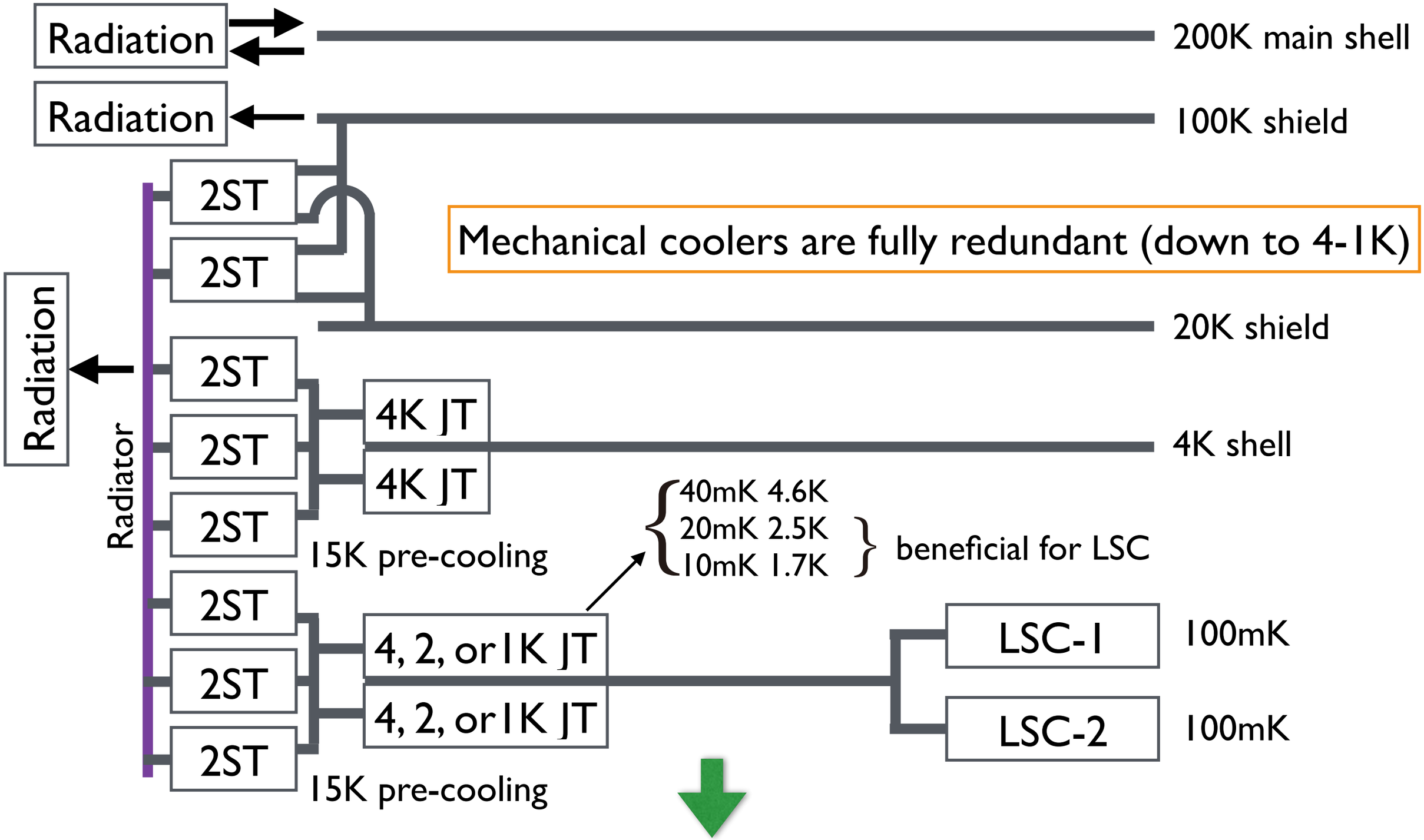
Preliminary thermal analysis

Heat load to 4K JT cooler



The present best estimate is ~3x90 kg.
Then cooling power at 4K has a large minus margin.

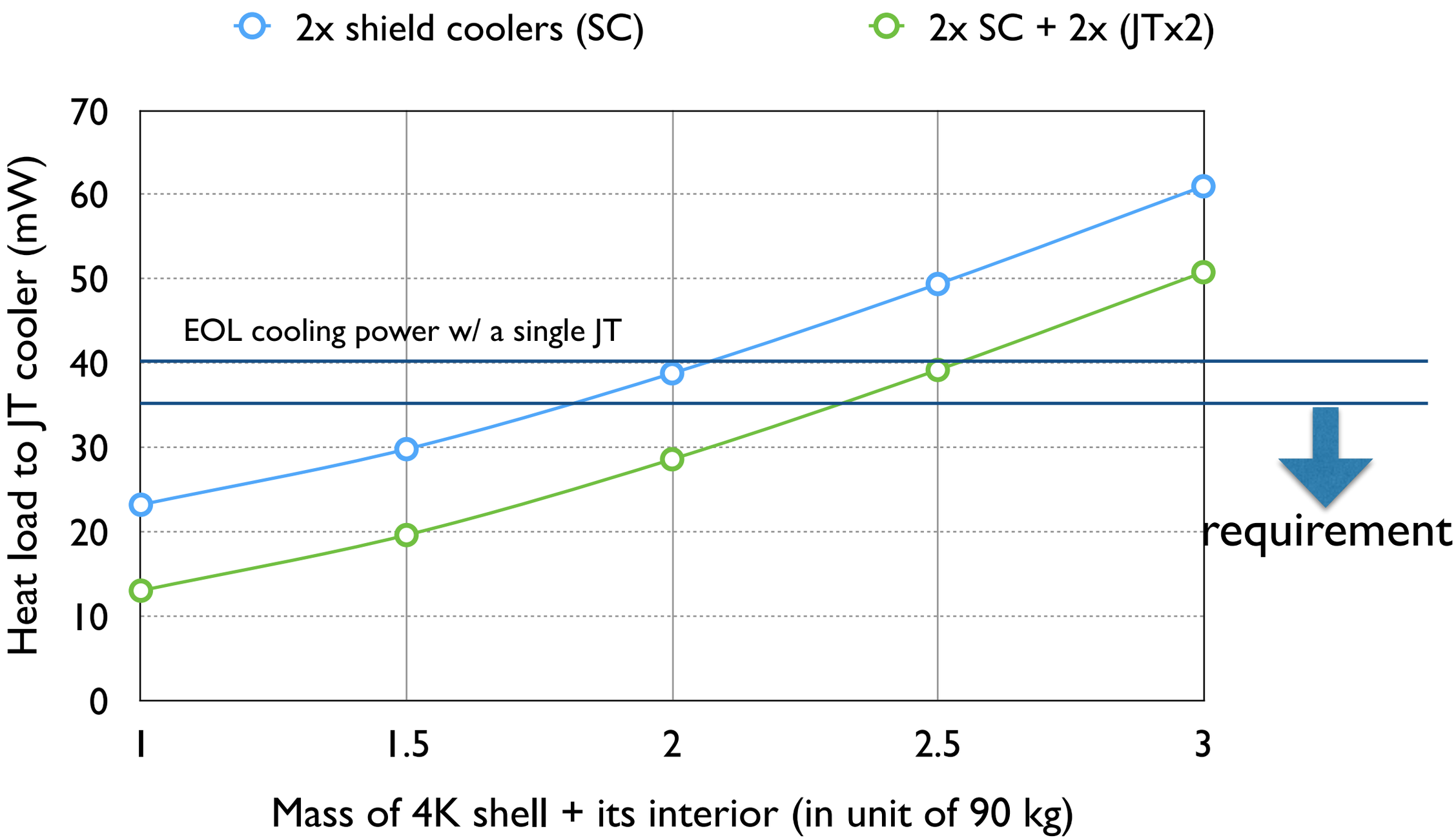
Cooling chain: additional JT



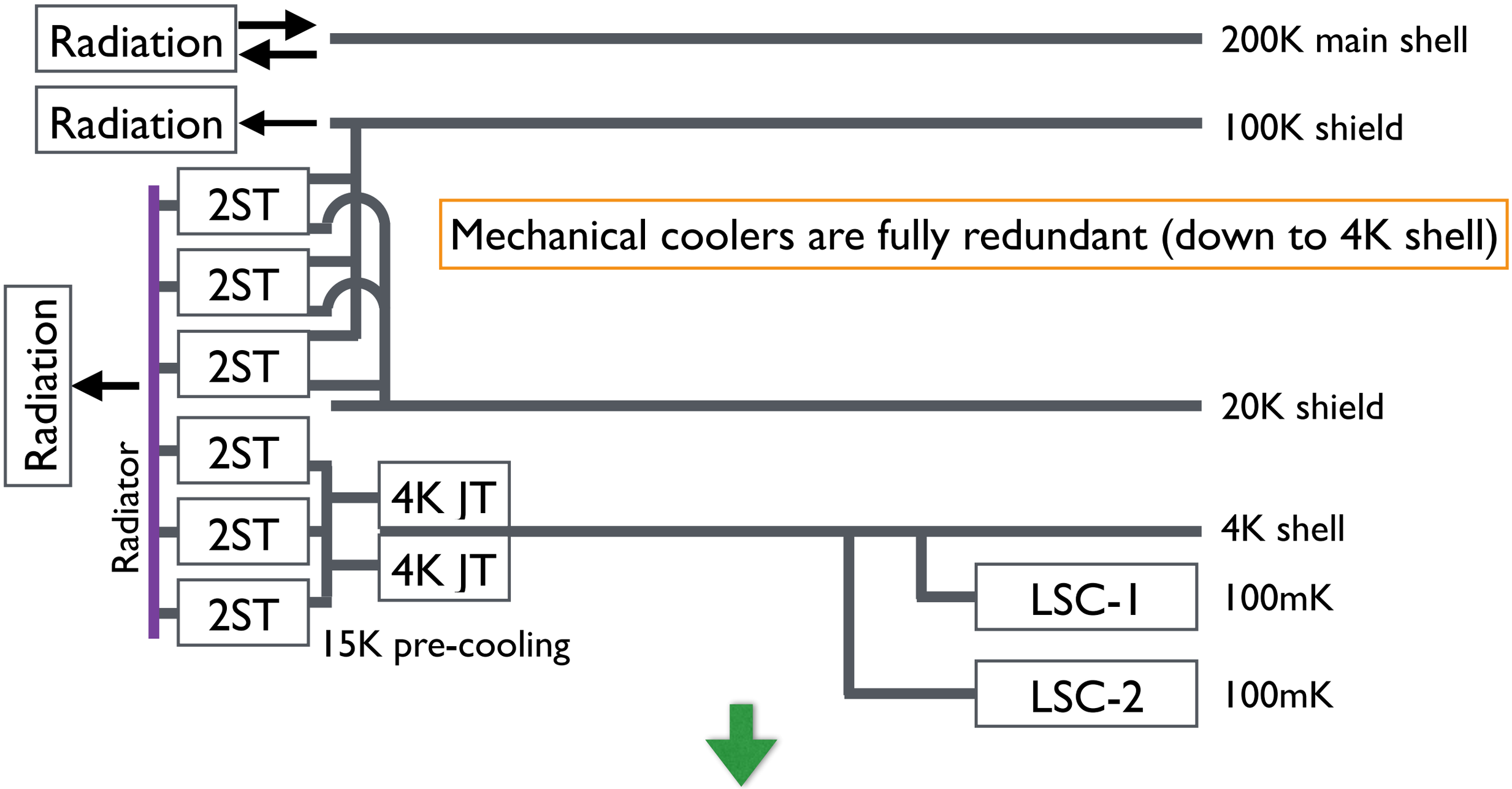
Similar to Athena X-IFU baseline, except that X-IFU does not utilize radiative cooling at 100K.
Still minus margin at 4 K stage if mass is 3x90kg

Preliminary thermal analysis

Heat load to 4K JT cooler



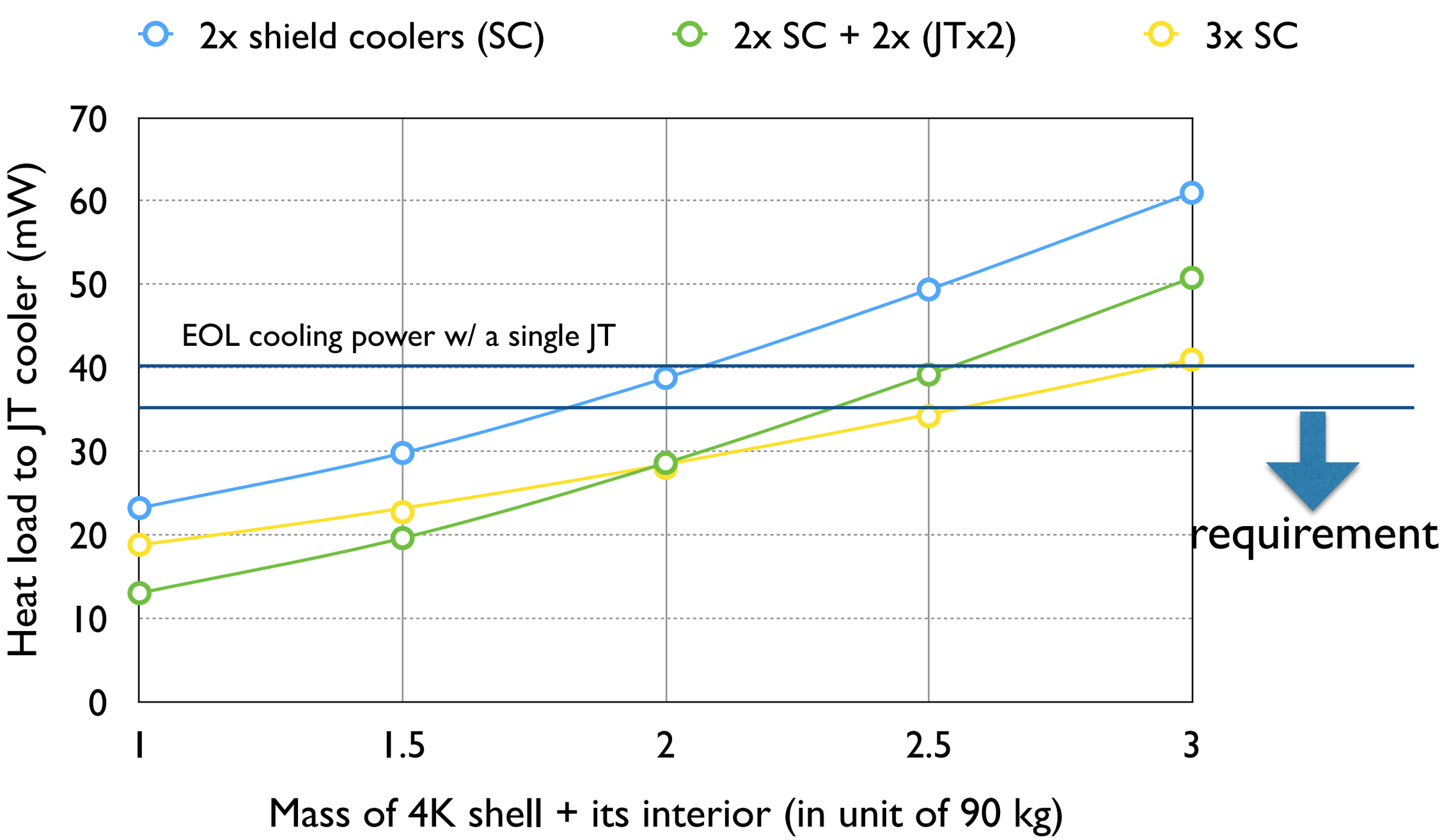
Cooling chain: additional shield cooler



Plus margin at 4K cooling power, for ~ 220kg 4K shell mass.

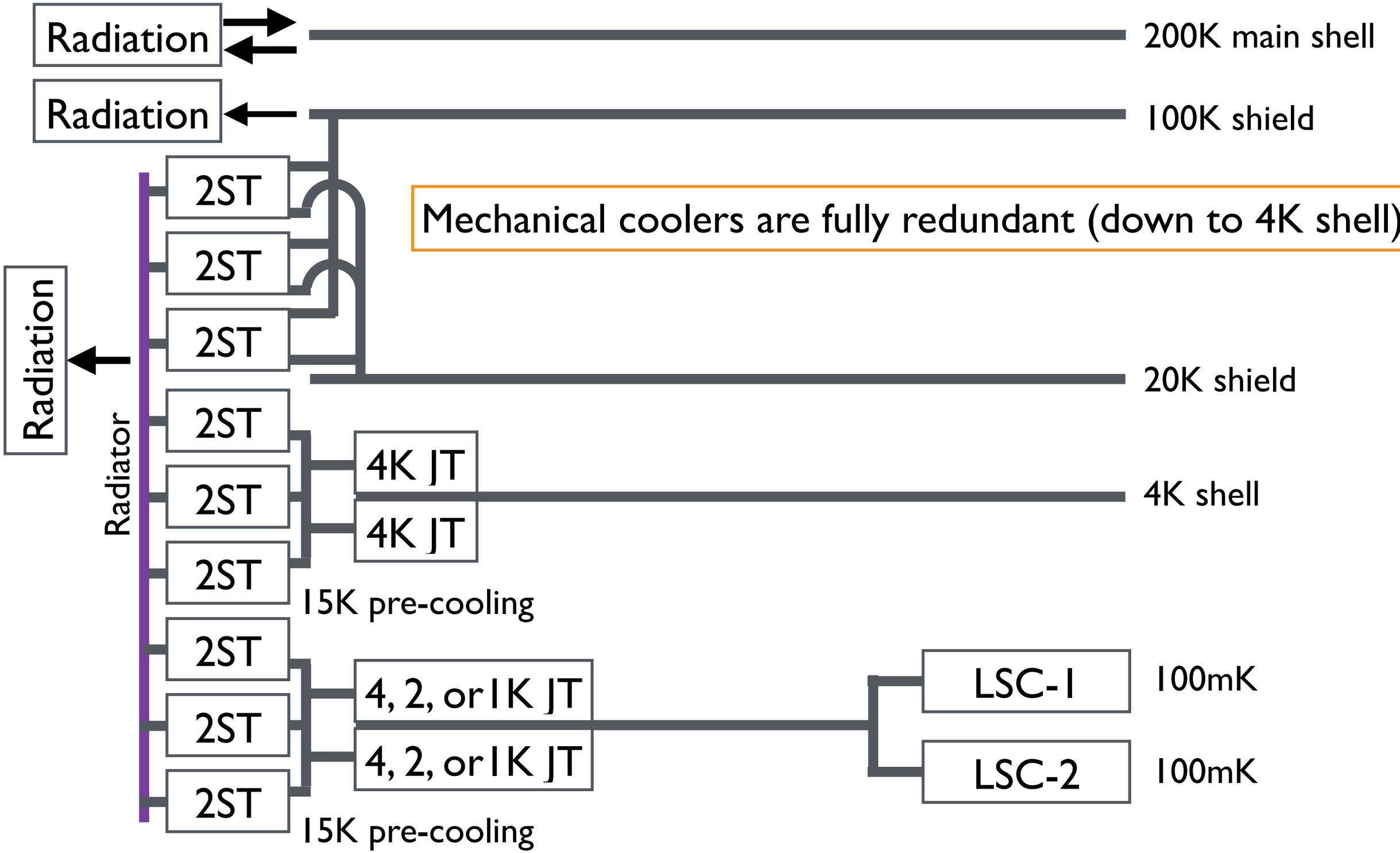
Preliminary thermal analysis

Heat load to 4K JT cooler



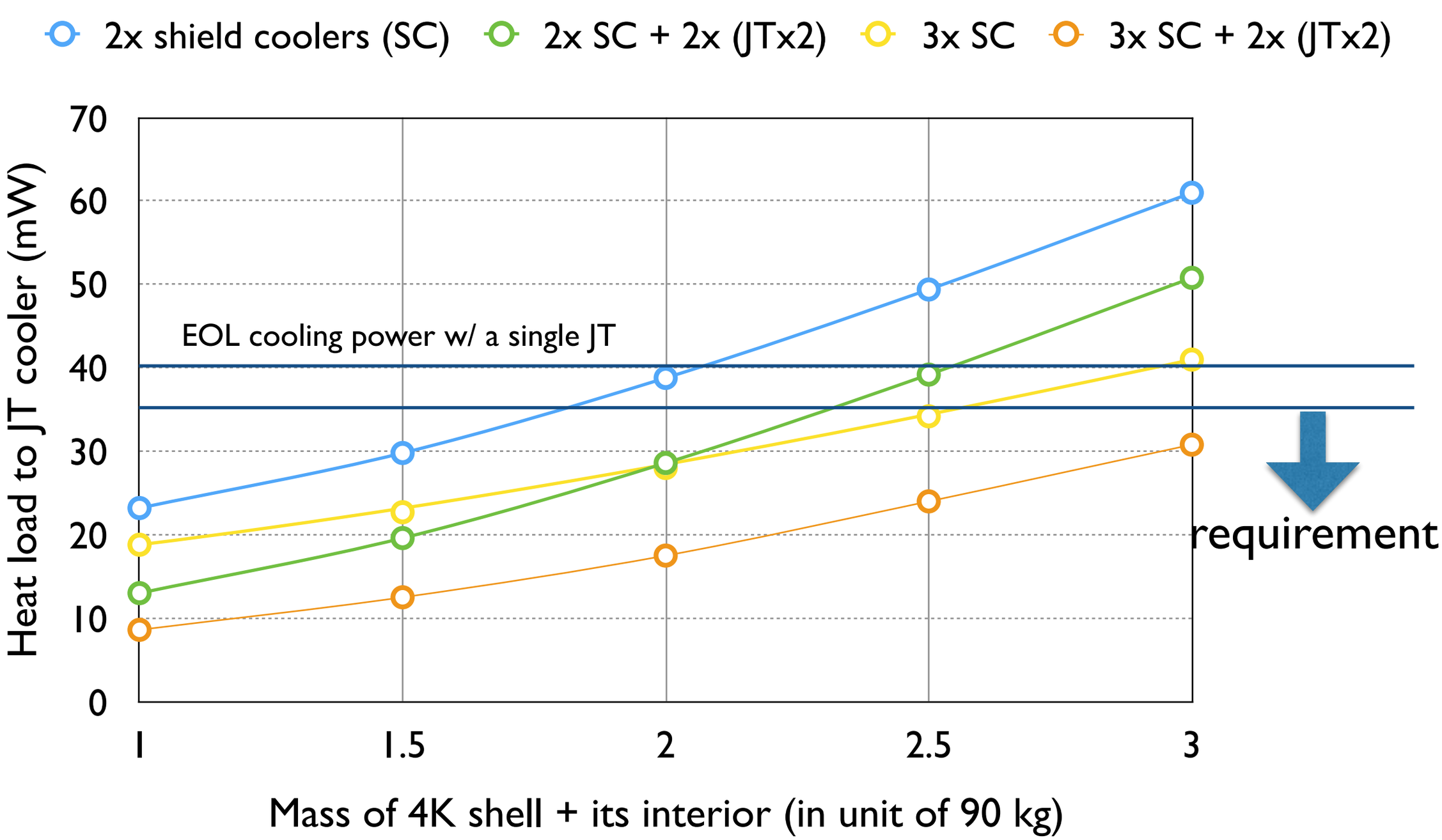
Preliminary thermal analysis

Cooling chain: 3SC+2x (2JT)



Preliminary thermal analysis

Heat load to 4K JT cooler



Phase-A1 study

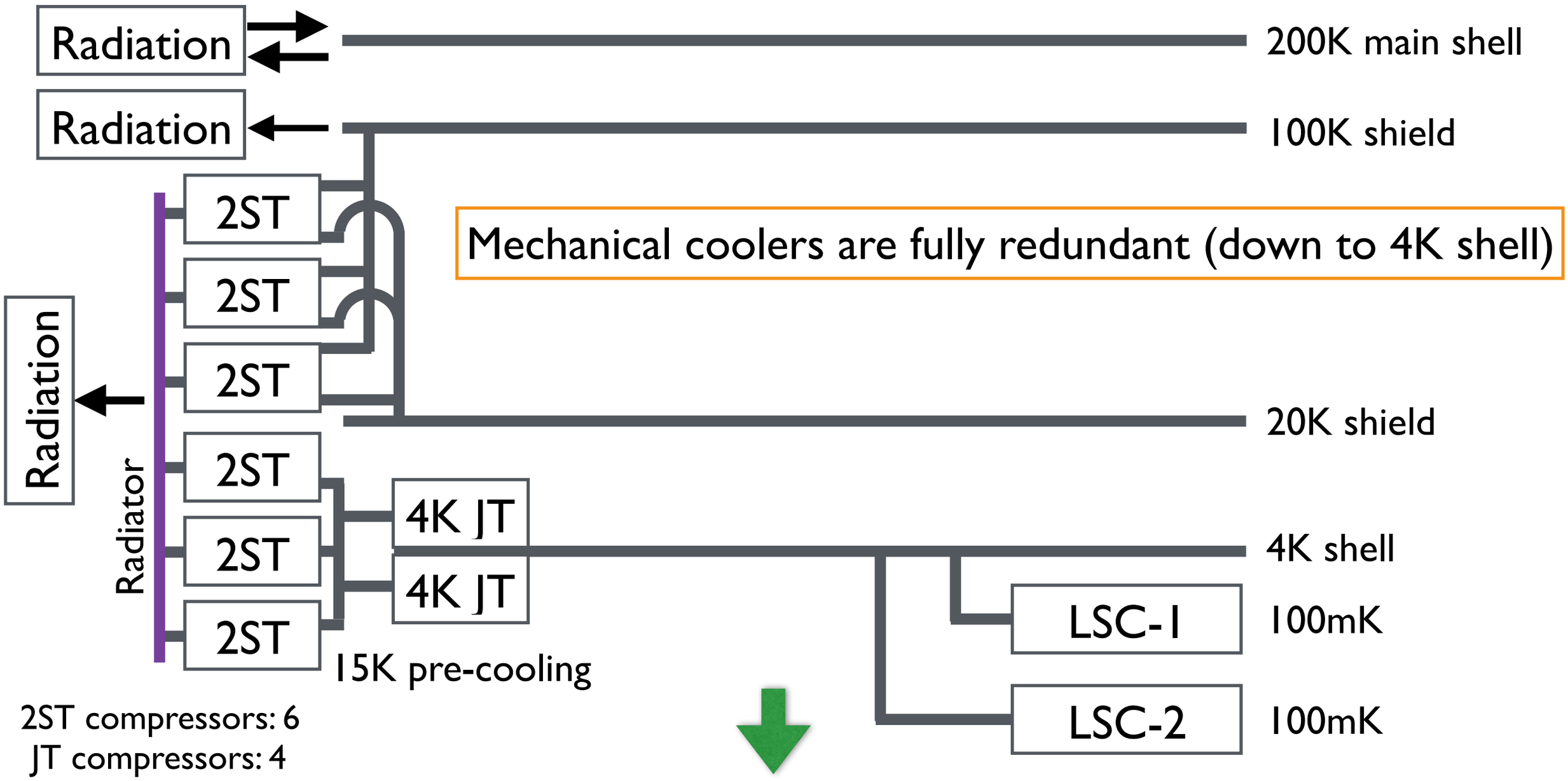
- Identify and list up (all) top-level requirement items from instrument.
- Fill them with (TBR) values as much as possible.
  - (max) mass of 4K shell and its interior
- Determine sensible interface values between cooling system and the instrument (all other interiors of 4K shell).

- Perform trade-off studies among different options, and select a baseline design.
  - # of LSC and interface temperature
- Then perform more detailed mechanical and thermal designs.

Summary

- We have performed a preliminary thermal analysis of the LiteBIRD cryogenic system, using working models for detector and last-stage cooler heat dissipation.
  - Mechanical coolers are required to have redundancy.
  - The solution depends on the total mass supported at 4K. Some of the solutions may be beneficial for the last-stage cooler.
  - If mass (≤4K) is heavier by a factor of 3 than that of the working model (i.e. 90kg -> 270kg), number of cryocoolers increases by a factor of ~2.

Cooling chain: my personal preference



Reasonable number of compressors (10) and
Reasonable design margin if mass(≤4K) < 200 kg.
High TRL from Astro-H heritage