National Aeronautics and Space Administration

3-Stage ADR for the SXS Instrument on the Astro-H Mission

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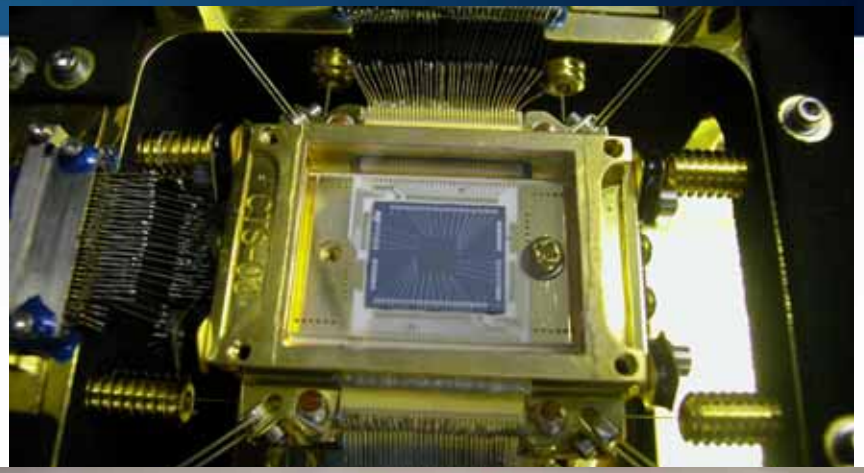
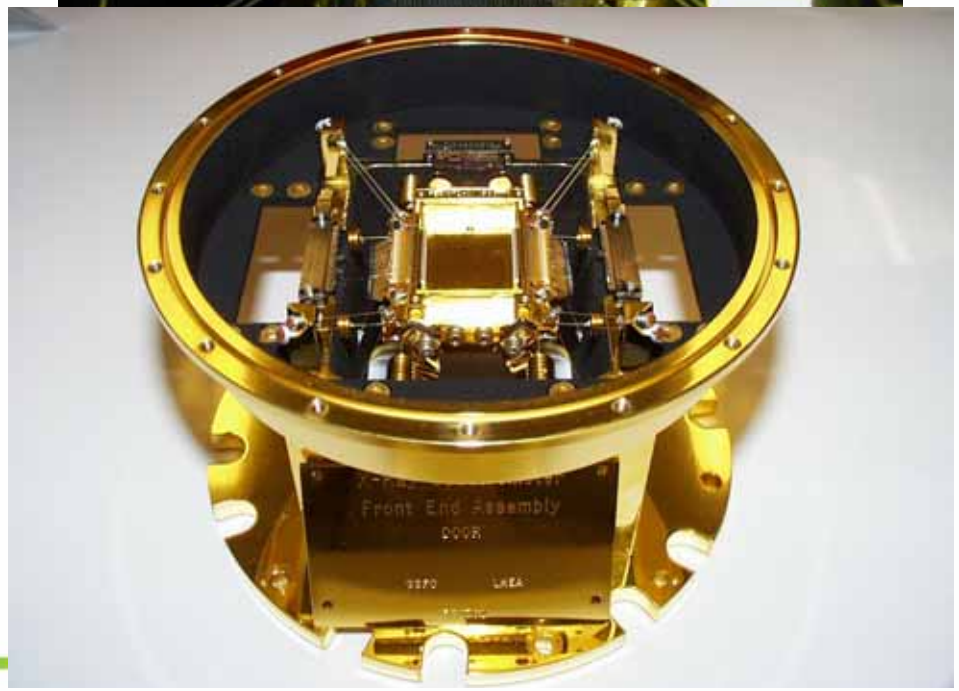
Astro-H Detector Subsystem

- 6x6 array of x-ray microcalorimeters
  - Cooled to 50 mK
  - Dissipation of 0.25 μW (1.3 K housing temperature)
- Adiabatic Demagnetization Refrigerator
  - Rejects heat to a redundant cryogenic system
    - Superfluid helium, 1.3 K
    - Joule-Thomson cooler, 4.5 K

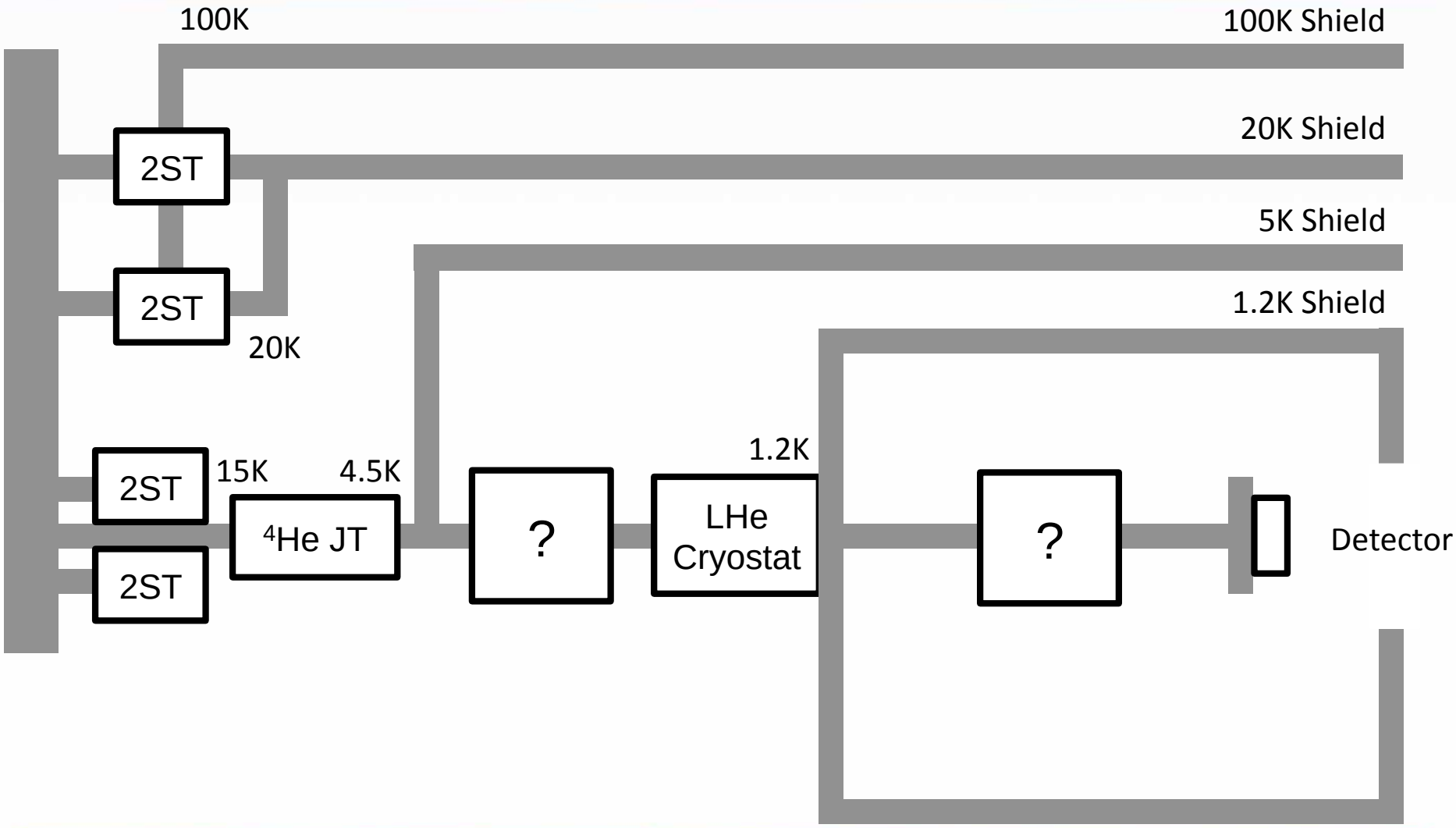




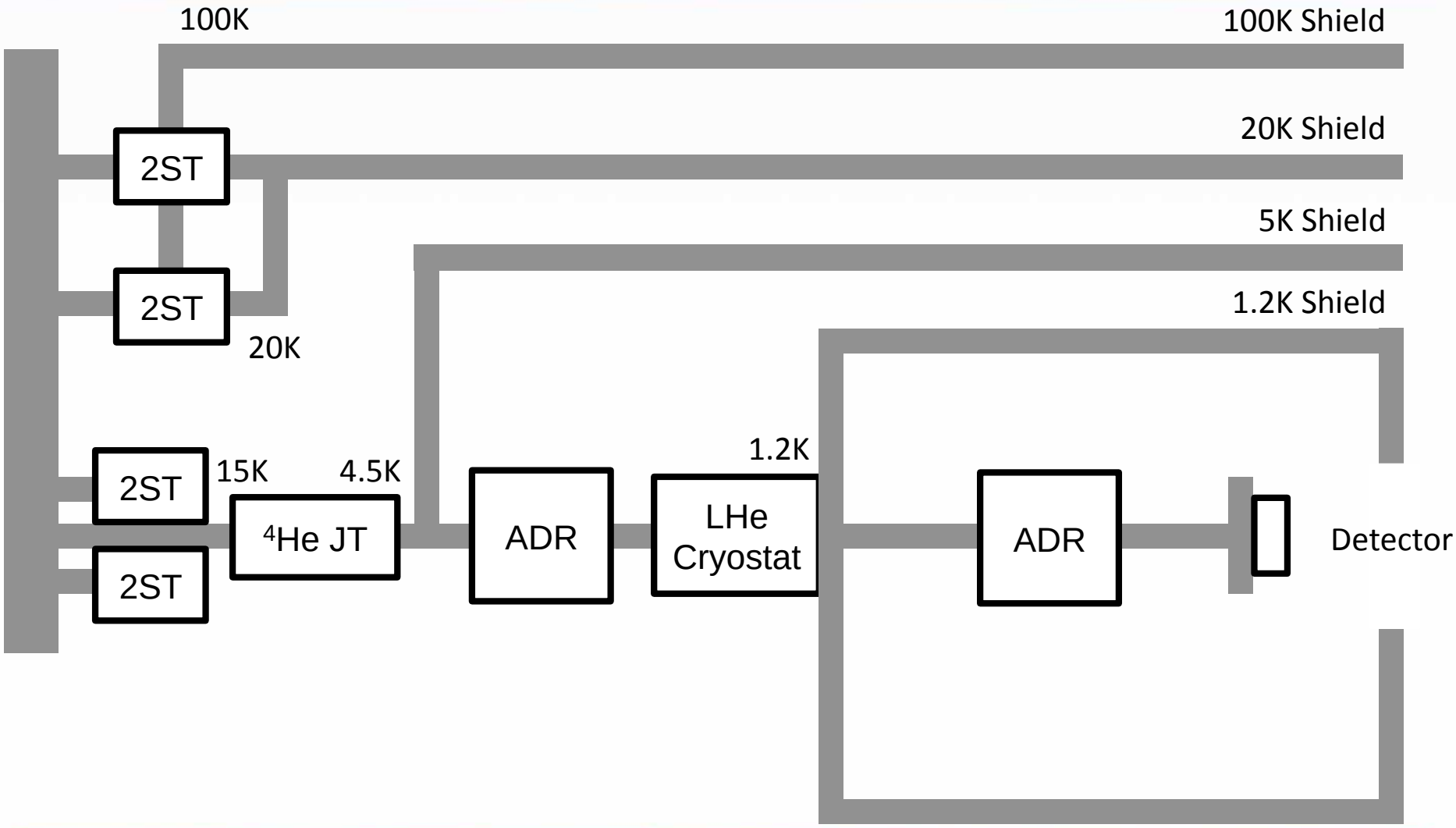
Performance and Functional Requirements

Parameter	Liquid Helium Heat Sink	JT Heat Sink
Detector T	50 mK	50 mK
Detector T Stability	2.5 μK rms	2.5 μK rms
Hold Time	24 hours	24 hours
ADR Heat Sink T	1.3 K	<5.2 K
ADR Heat Rejection	0.23 mW average	20 mW peak
Detector heat load	≤0.5 μW	≤0.5 μW
Recycle time	1 hour	2 hour
Failure tolerance	Failure of JT cooler	Failure of shield cooler (goal)
Detector assembly T stability (1.3 K)	<1 mK/10 min	<1 mK/10 min

Cryogenic System Block Diagram

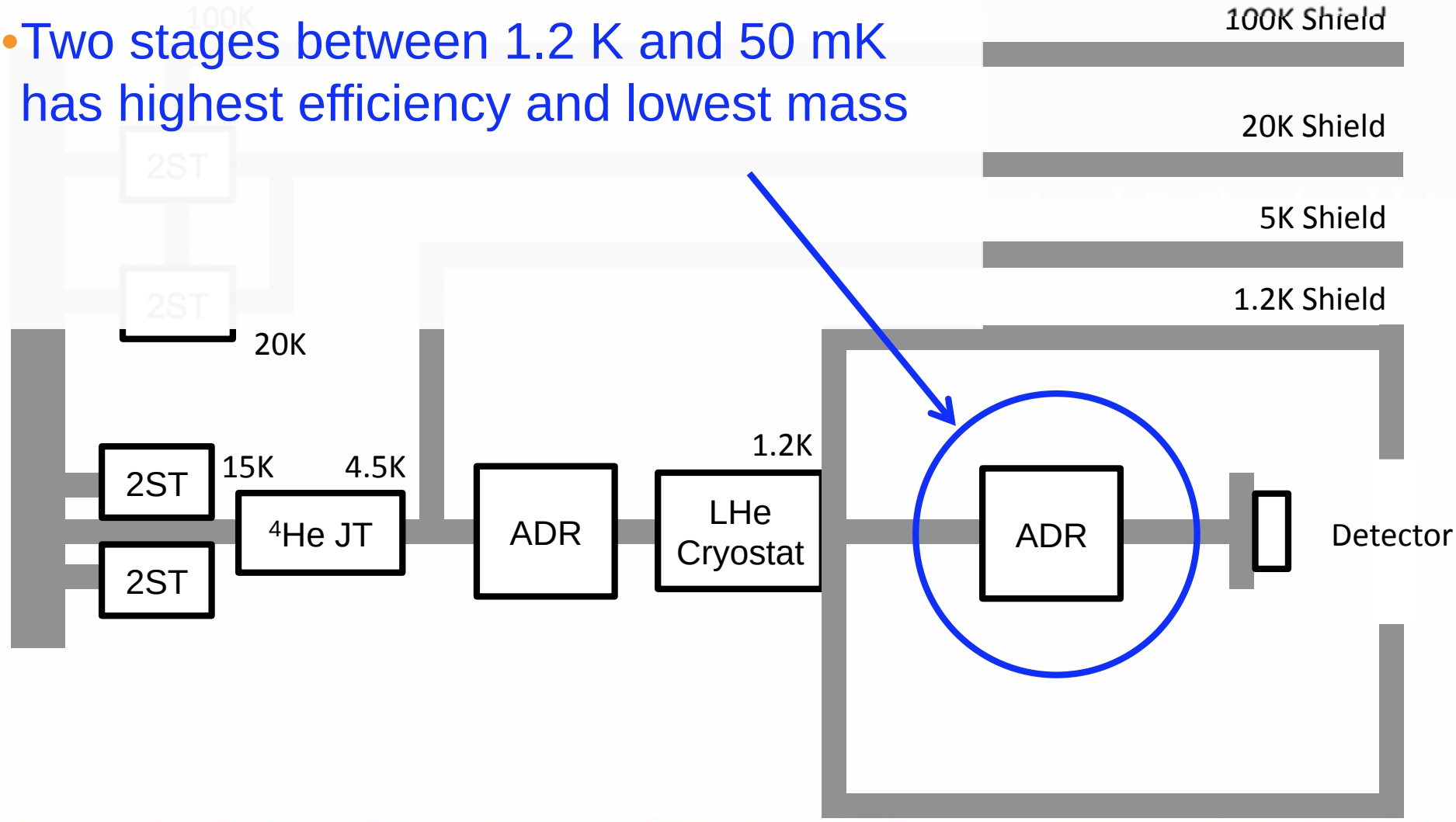


Cryogenic System Block Diagram



Cryogenic System Block Diagram

- Two stages between 1.2 K and 50 mK has highest efficiency and lowest mass



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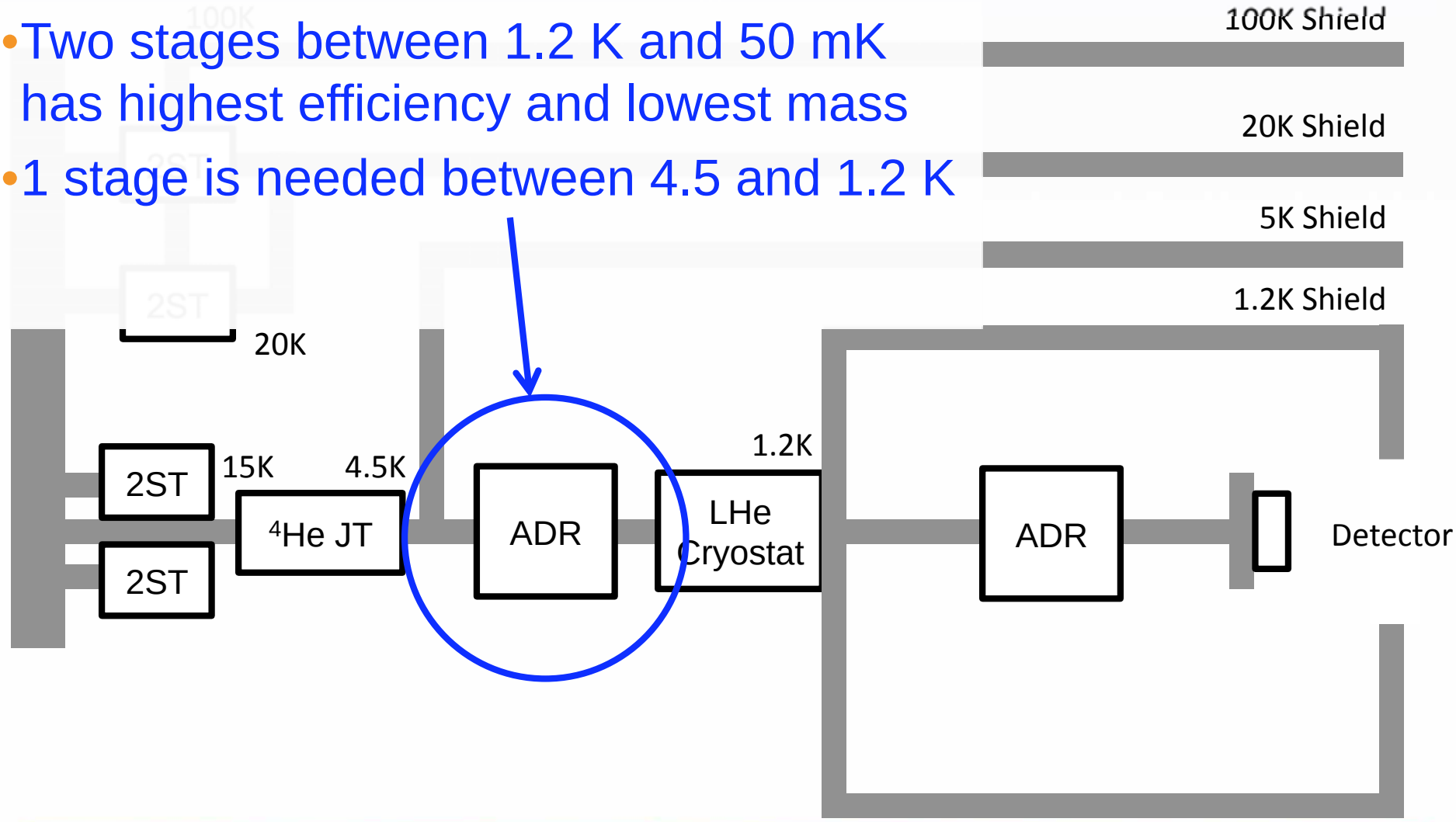
- 1 stage is needed between 4.5 and 1.2 K



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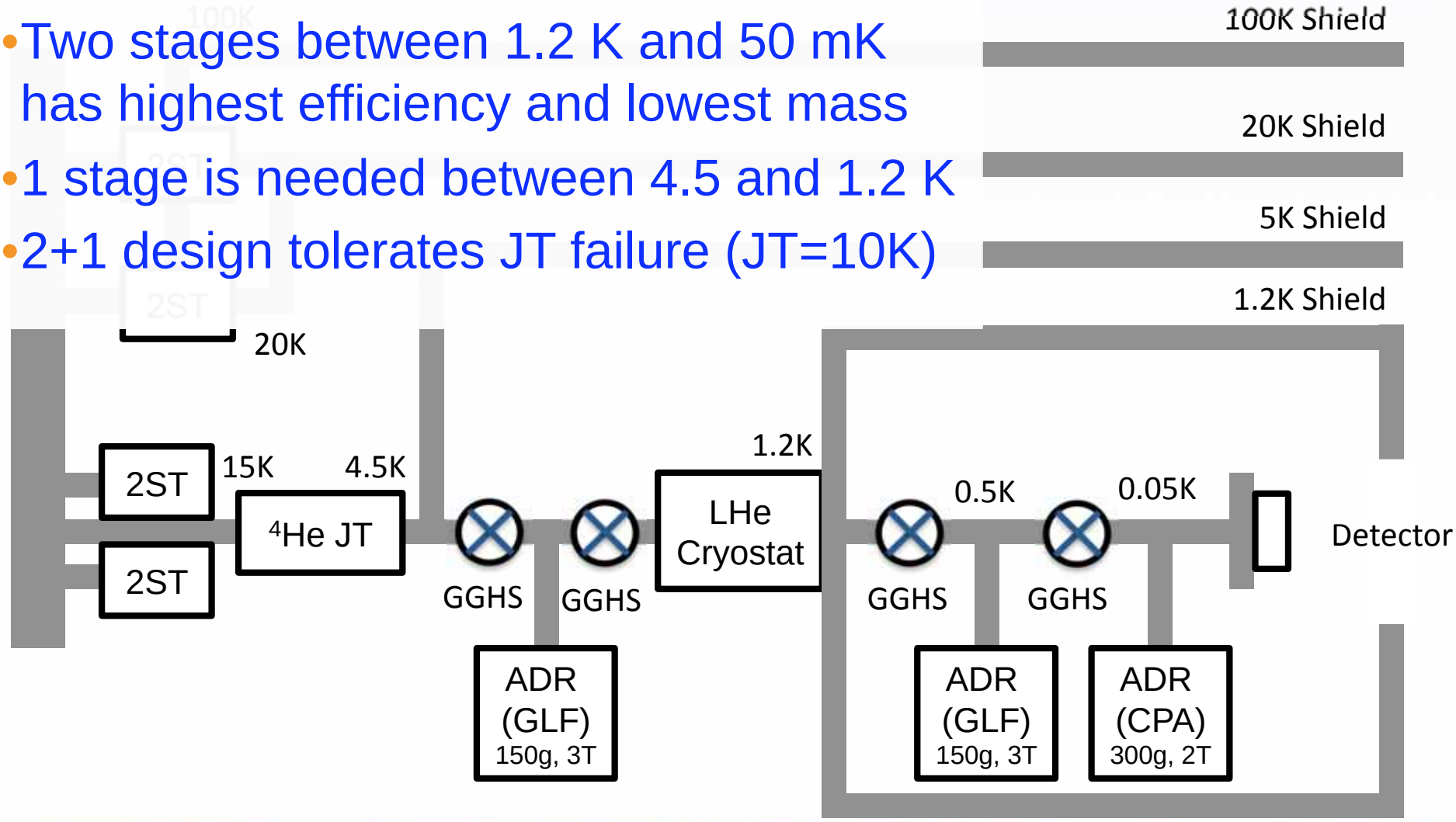
- 1 stage is needed between 4.5 and 1.2 K
- 2+1 design tolerates JT failure (JT=10K)



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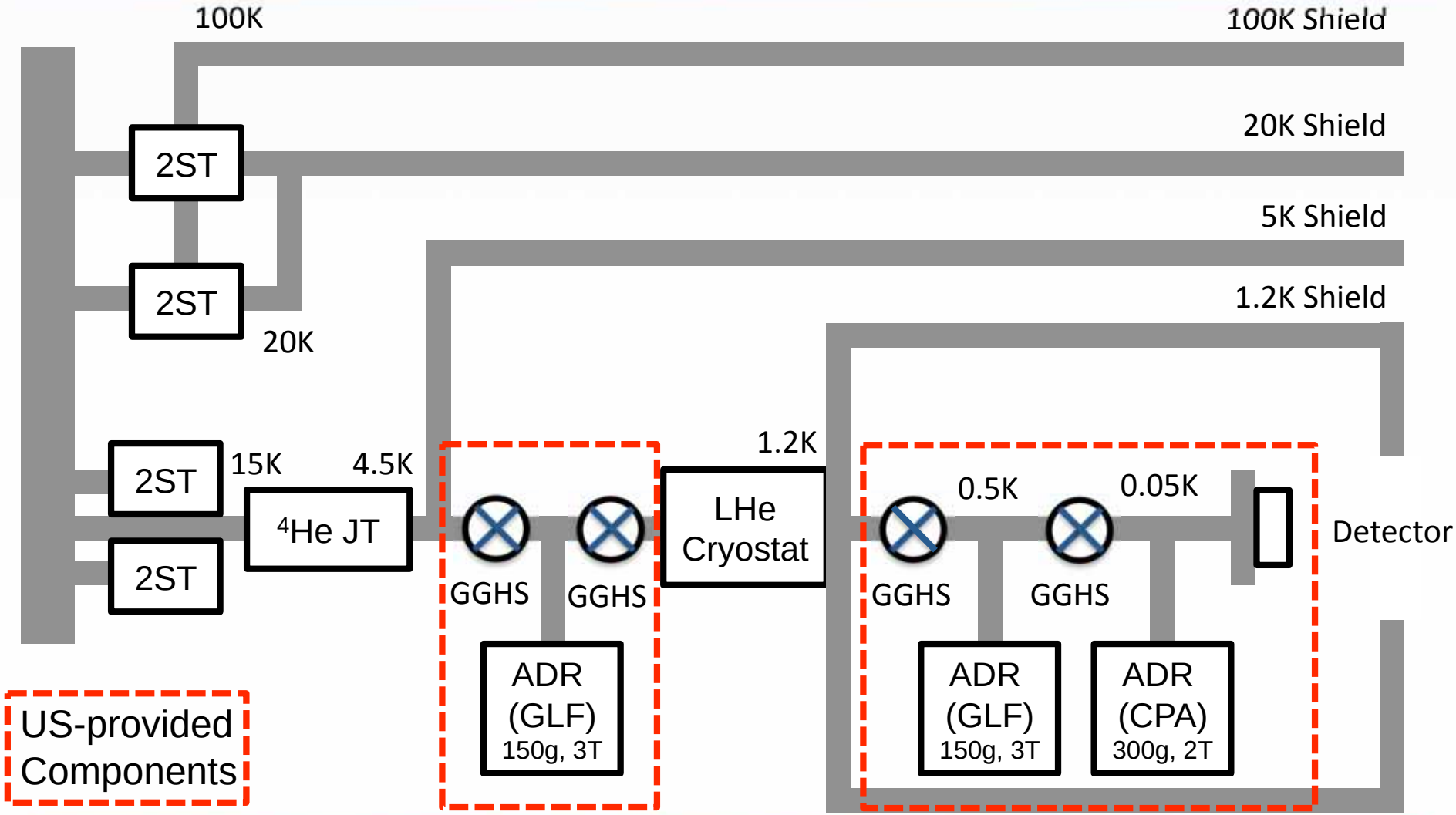
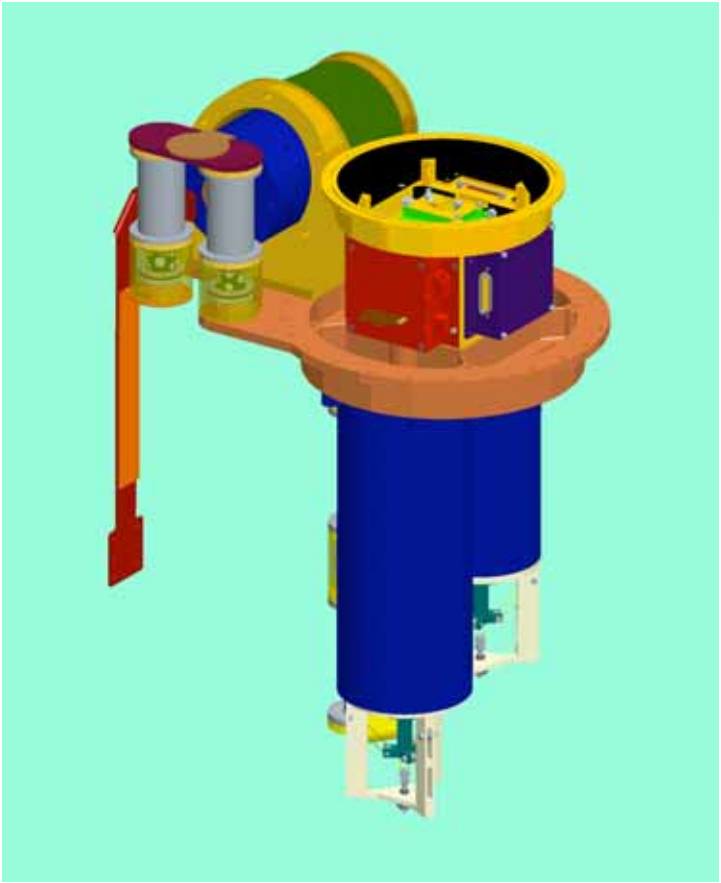


ADR Layout

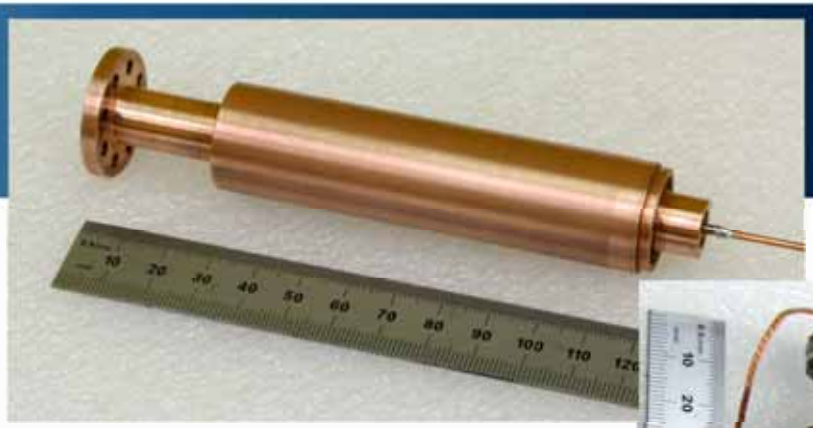
- ADR and detector assembly is an integrated assembly
  - Minimize interfaces with Japanese cryo system

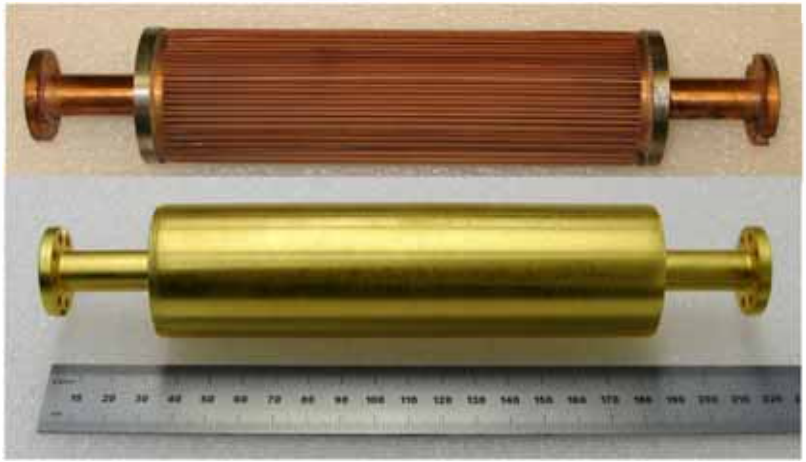


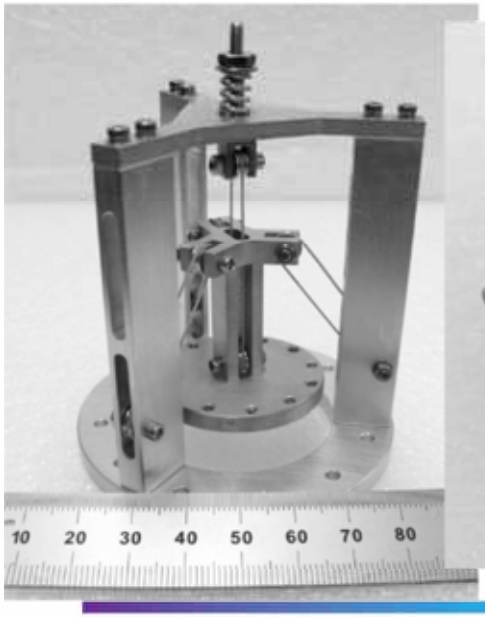
ADR Design Summary

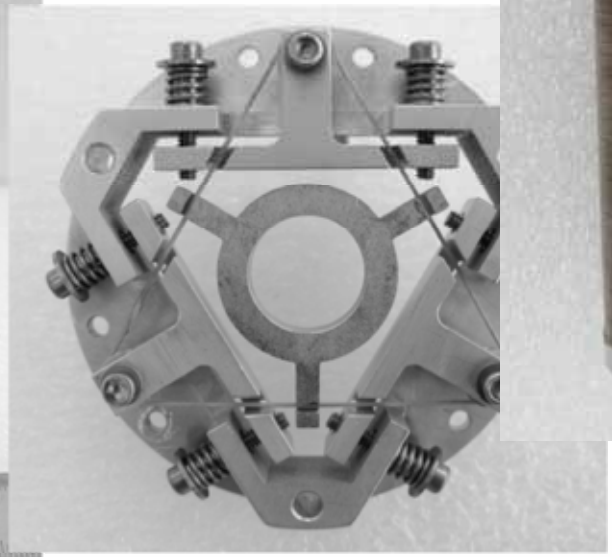
	Stage 1	Stage 2	Stage 3
Refrigerant type	CPA	GLF	GLF
Refrigerant mass	270 g	150 g	150 g
Magnetic field	2 T	3 T	3 T
Hold temperature, T_{op}	0.05 K	0.5 K	1.2 - 4.5 K
Demagnetization temperature	0.8 K	1.4 K	4.5 K
Cooling capacity at T_{op}	0.165 J	0.76 J@0.5 K +2.91 J@0.8 K	~2 J
Mass	5.98 kg	3.95 kg	3.95 kg
Mass total		13.88 kg	

ADR Components



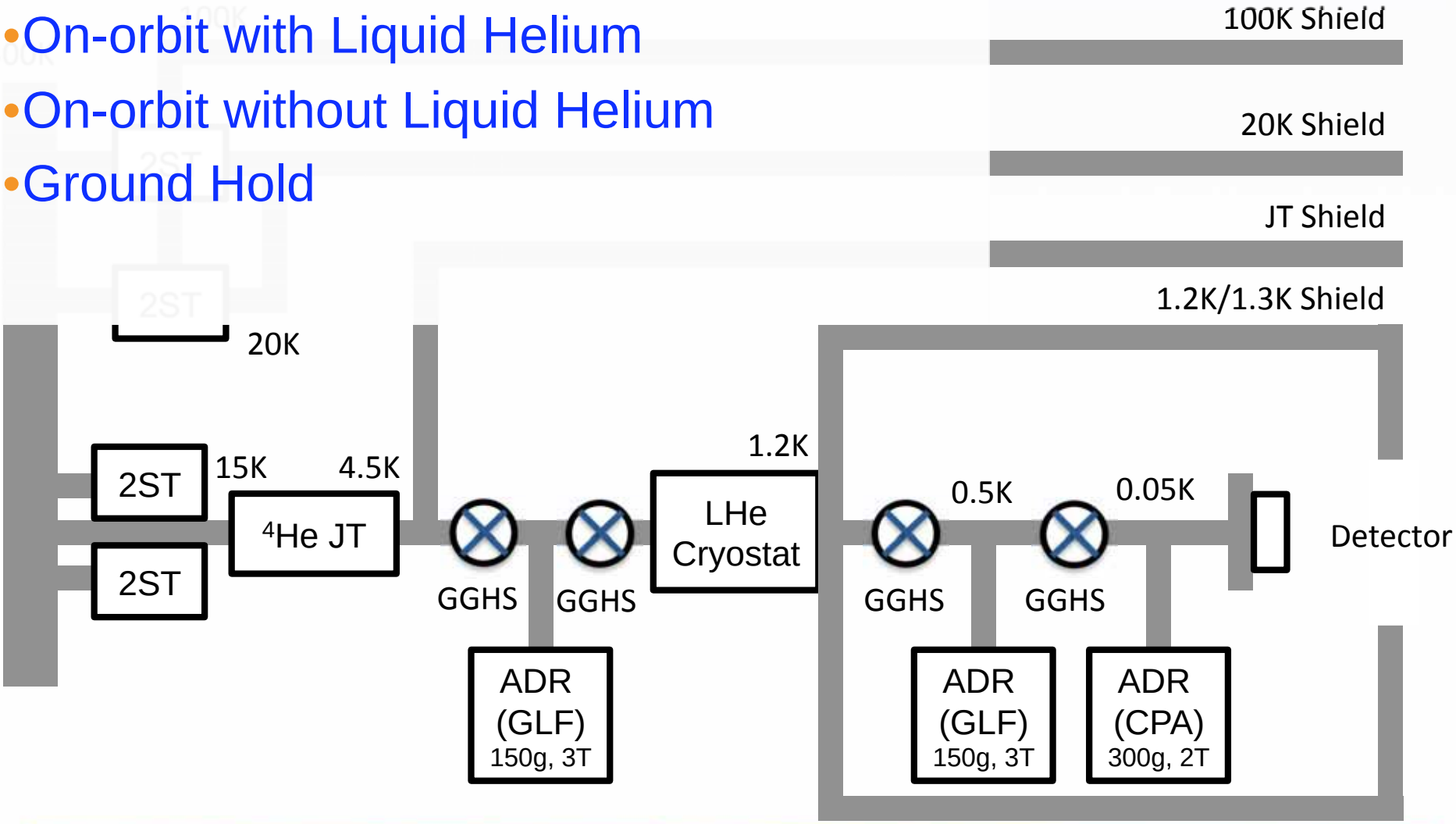






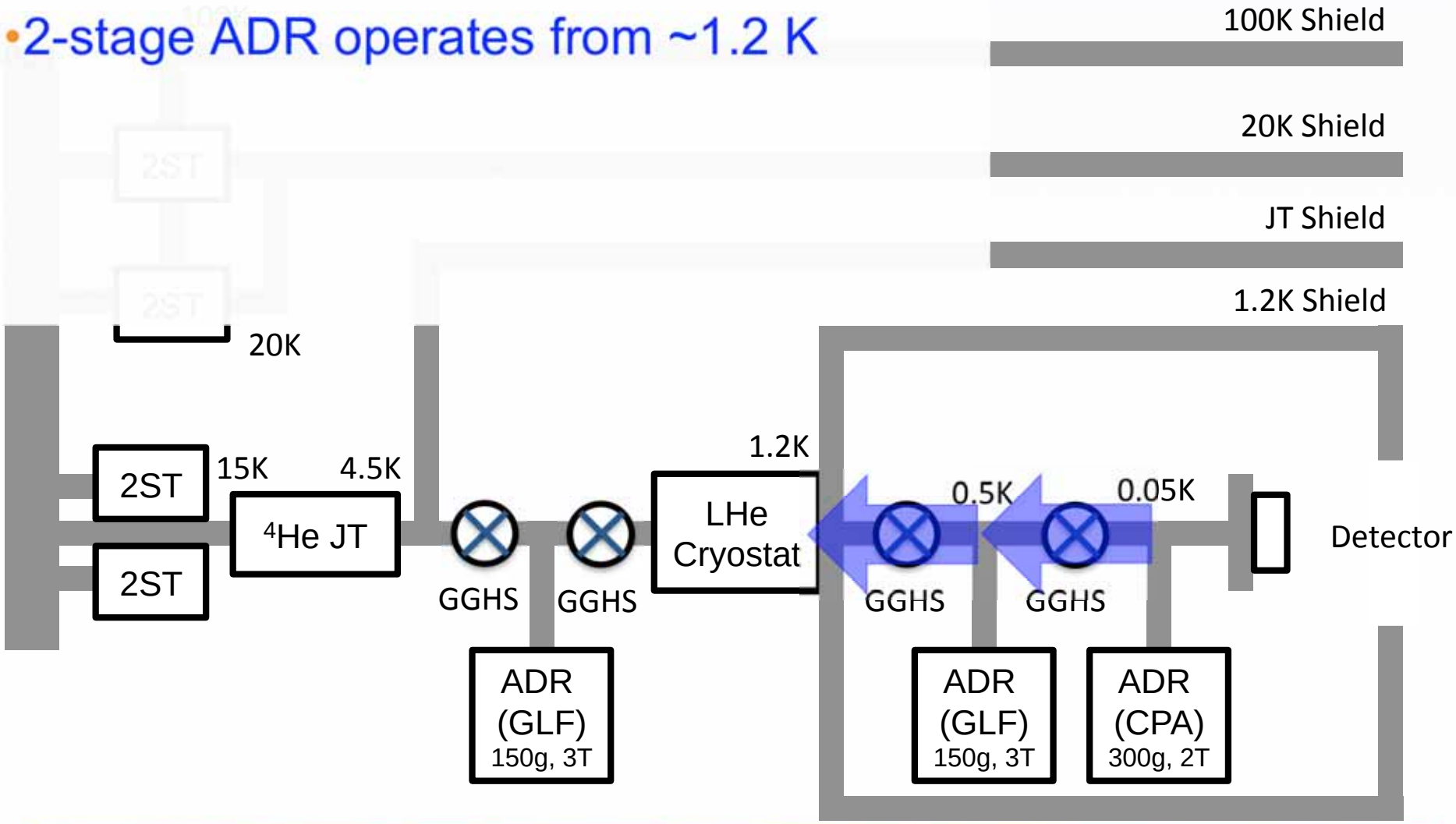
Operating Modes

- On-orbit with Liquid Helium
- On-orbit without Liquid Helium
- Ground Hold



On-Orbit With Liquid Helium

- 2-stage ADR operates from ~1.2 K



2-Stage ADR Operation

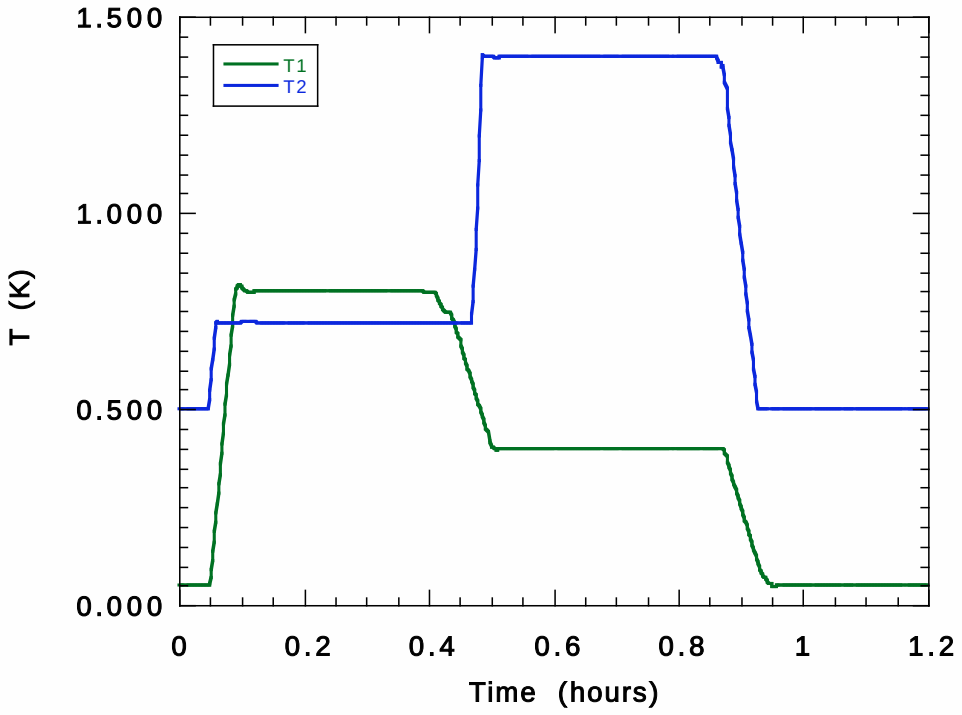
- 2nd stage has two main functions
  - Pre-cool 1st stage before demagnetization
  - Reduce parasitic heat load on 1st stage

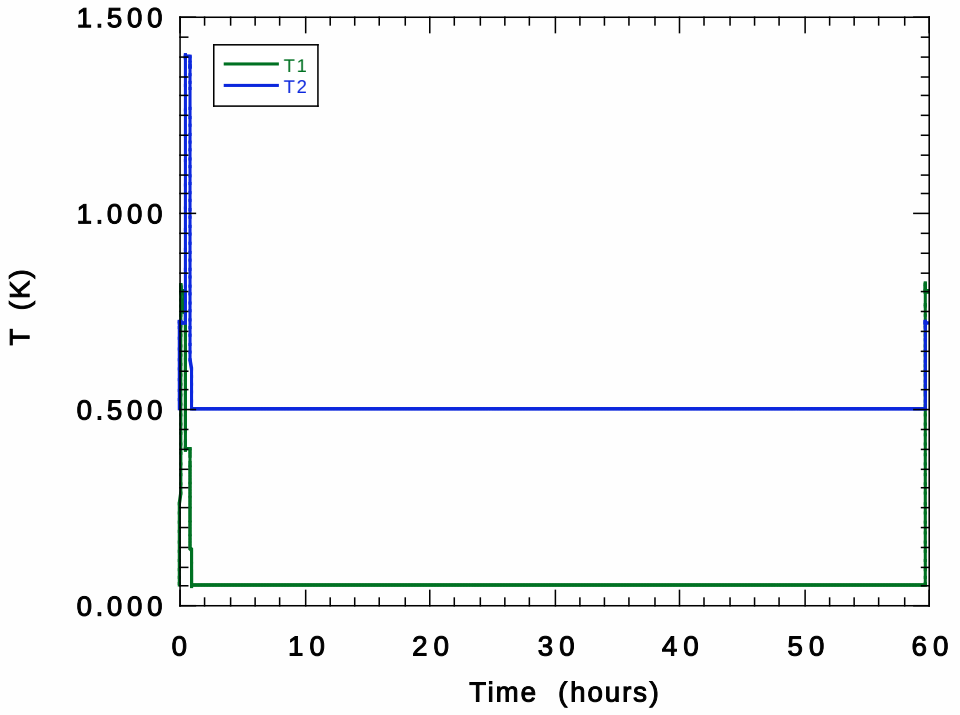
- Heat loads
  - 1st stage: 0.25 μW detector
    0.05 μW Kevlar suspension
    0.09 μW heat switch (0.5 K)
    0.39 μW total
  - 2nd stage: 0.05 μW Kevlar suspension
    0.85 μW heat switch (1.2 K)
    0.90 μW total

Development Unit ADR

Recycling and Hold Time

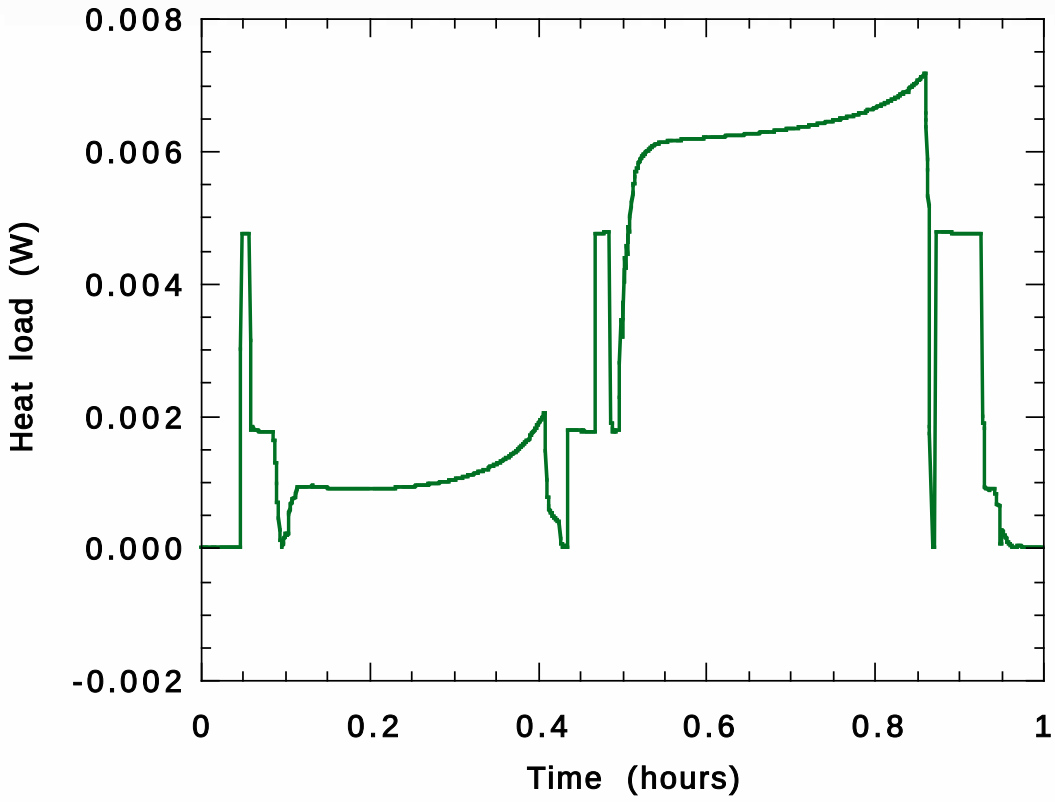
- Modeled performance with 2x heat loads
- <1 hour recycle time
- Nominal hold time >100 hours





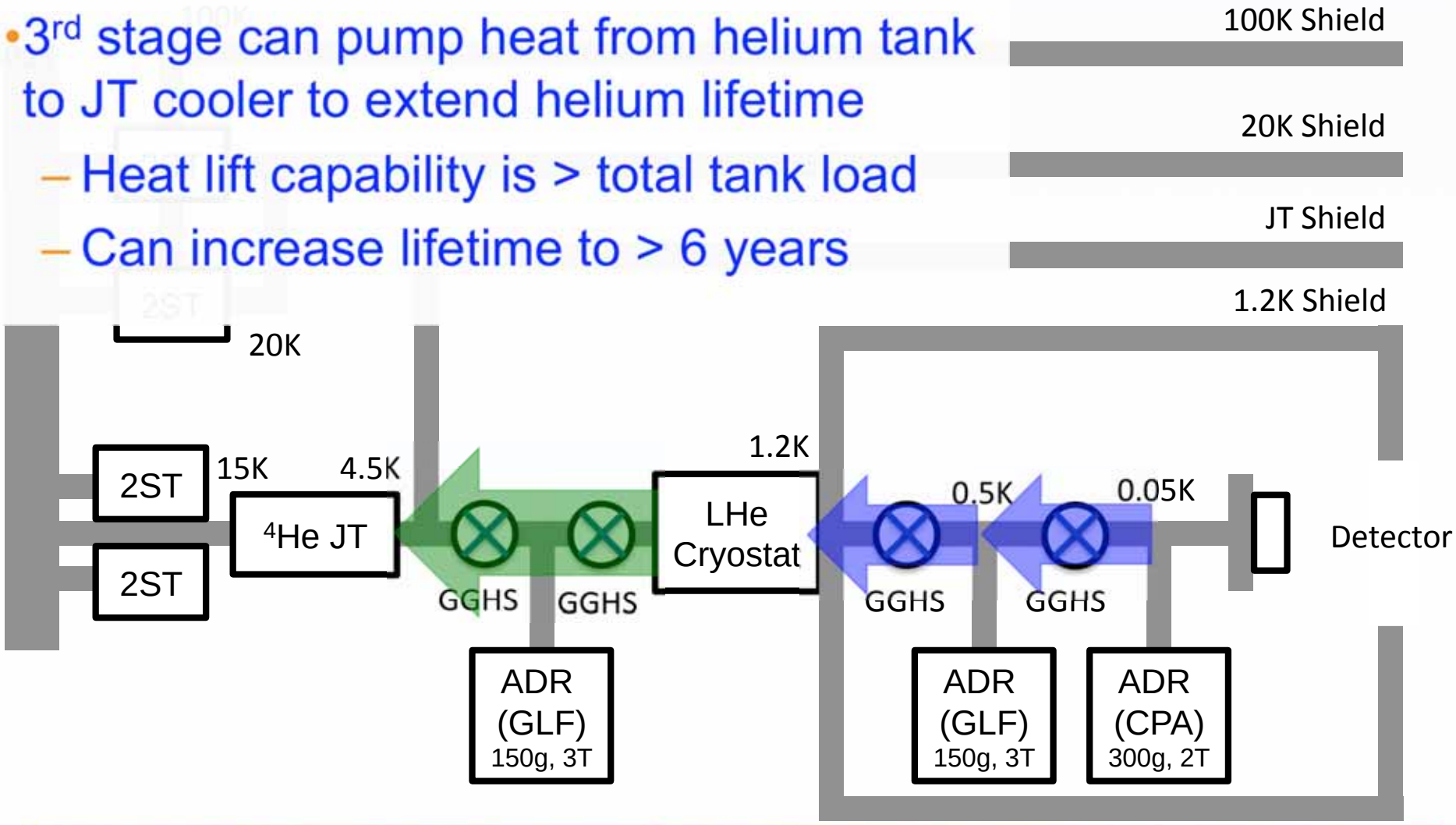
Heat Rejection to Helium Tank

- Total heat rejected is <10 J per ADR cycle
- For >100 hour hold time, average reject rate is 27 μW
- Worst case is 24 hour cycle period, giving average rate of 0.12 mW
  - Reqm't is <0.23 mW



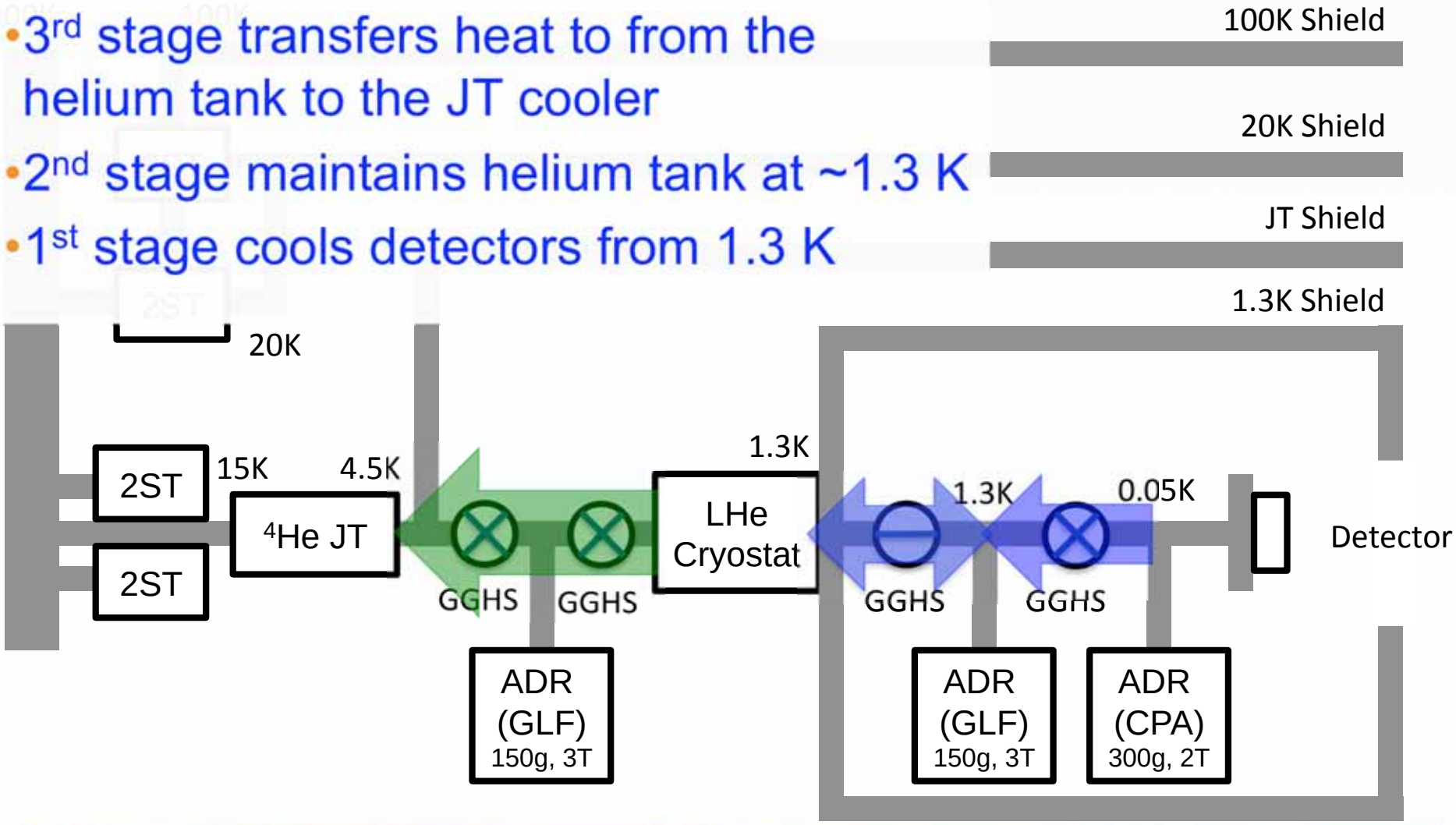
On-Orbit With Liquid Helium

- 3rd stage can pump heat from helium tank to JT cooler to extend helium lifetime
  - Heat lift capability is > total tank load
  - Can increase lifetime to > 6 years



On-Orbit Without Liquid Helium

- 3rd stage transfers heat to from the helium tank to the JT cooler
- 2nd stage maintains helium tank at ~1.3 K
- 1st stage cools detectors from 1.3 K



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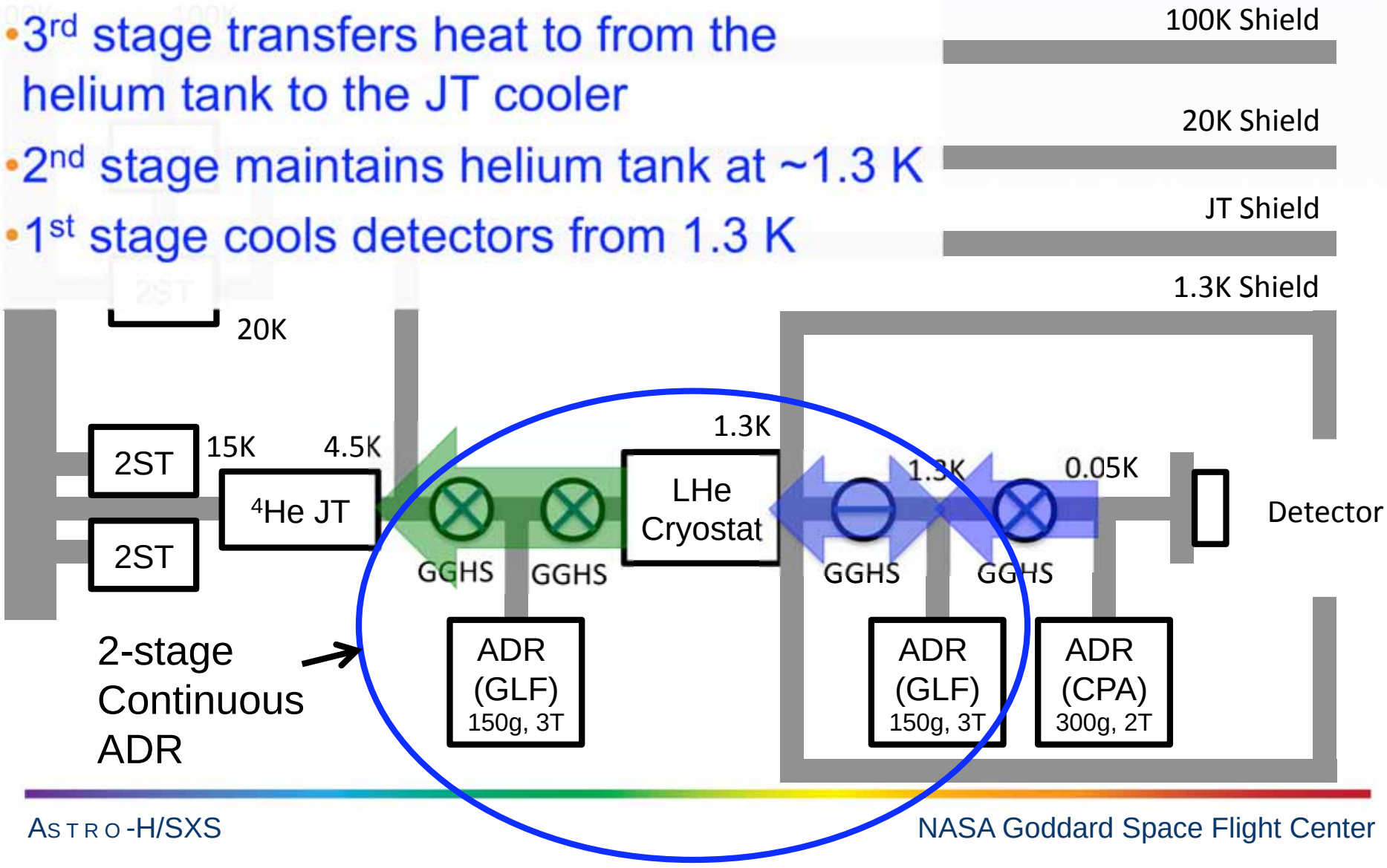
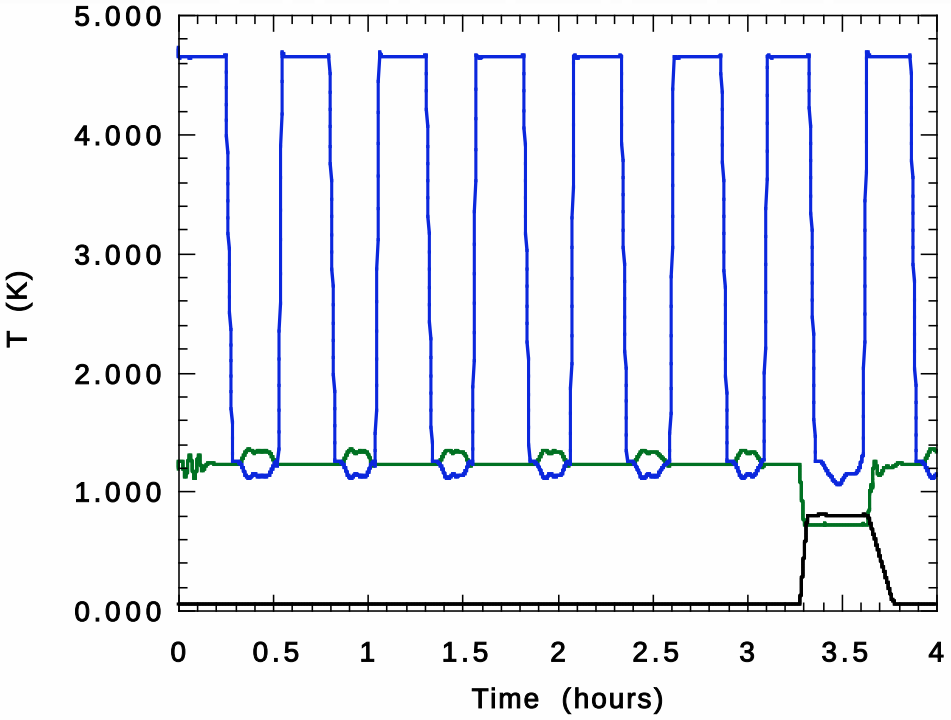


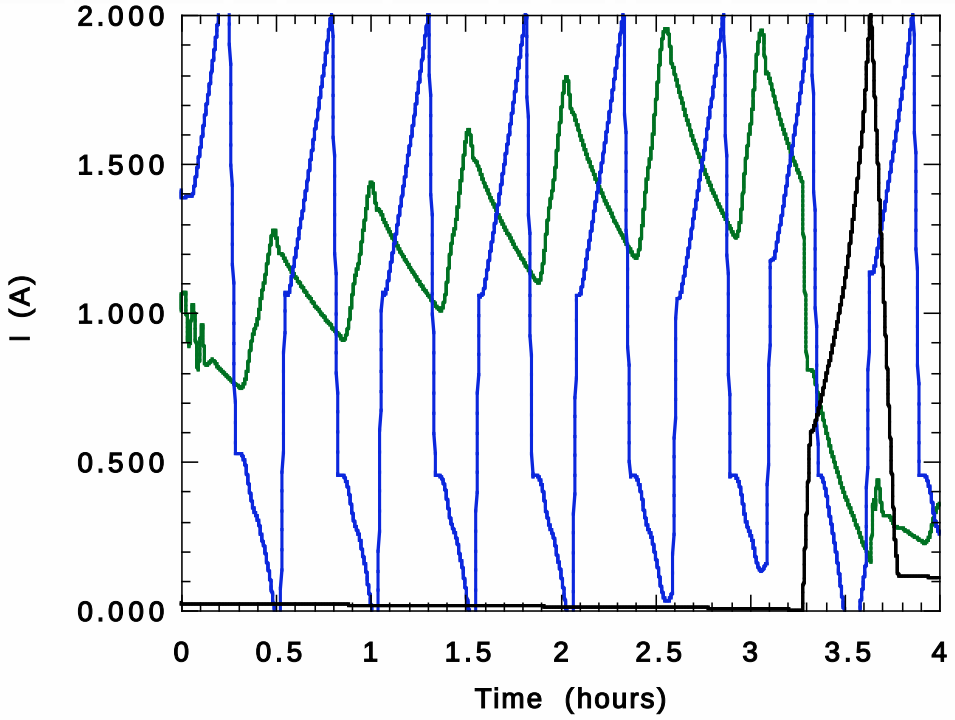
ADR Cycle

- 2nd and 3rd stages maintain helium tank at lowest possible temperature
  - Tank heat load
  - Available JT cooling power
    - Nominally >20 mW (EOL)
    - <6 mW if one shield cooler fails
- 1st stage recycling
  - 2nd stage will decouple from helium tank and cool to <0.8 K to recycle 1st stage
  - 2nd stage will then resume regulating tank at ~1.2 K
    - Higher parasitic load from heat switch to 1st stage
    - Predict 33 hour hold time

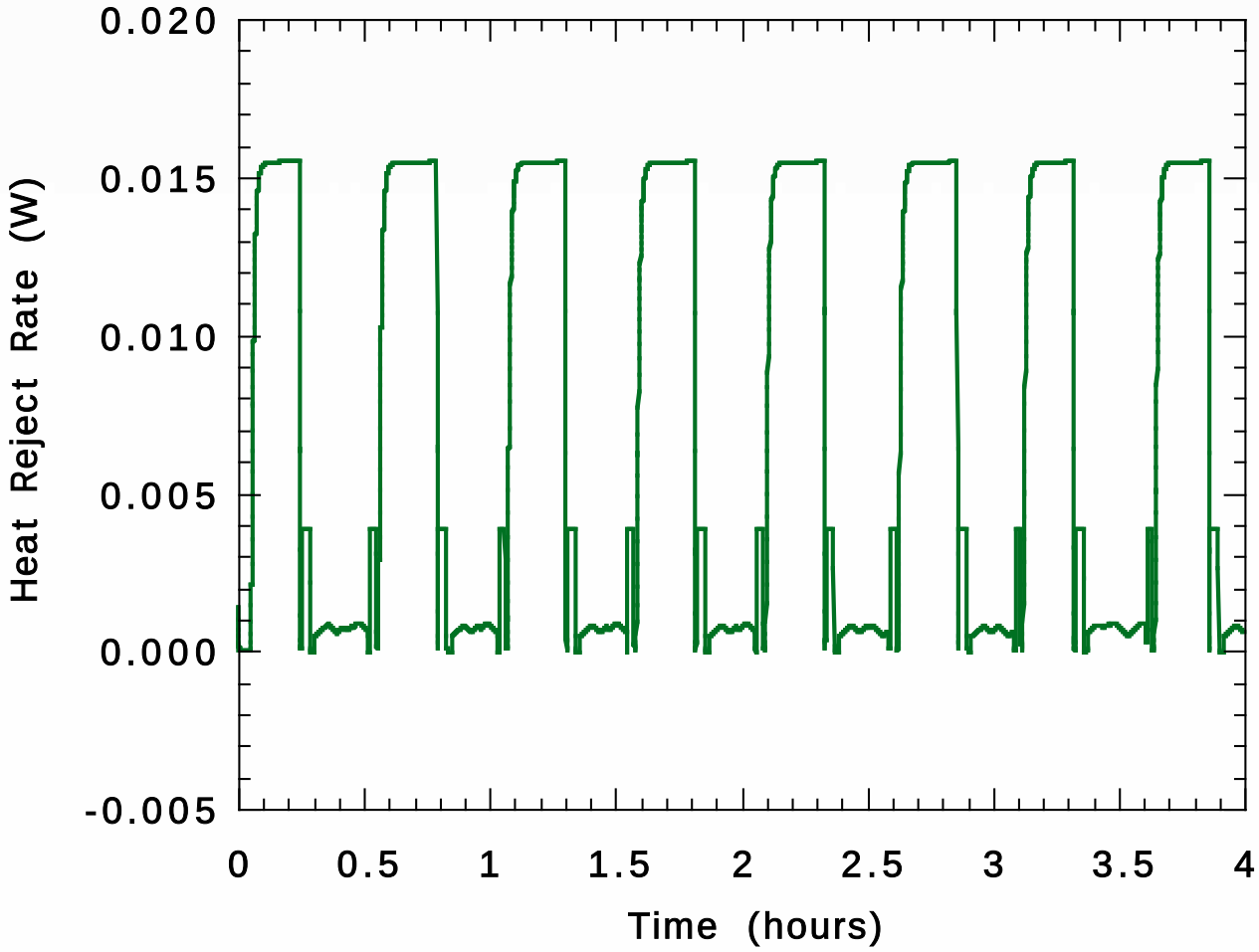
Cycle Details

- 3rd stage cycling builds up cooling capacity of 2nd stage needed to recycle 1st stage





Heat Rejection to the JT Cooler



Summary

- 3-stage ADR allows operation from 2 different heat sink temperatures
  - Redundant operation with stored cryogen and cryocoolers
  - Failure tolerance
    - Depletion of liquid helium
    - Failure of JT cooler
- Performance
  - With liquid helium: >100 hours of hold time
  - With JT cooler: 33 hours
- 3-stage ADR has flexibility to adapt to wide variety of off-nominal conditions on orbit