National Aeronautics and Space Administration

Operating Modes and Cooling Capabilities of the Flight ADR for the SXS Instrument on Astro-H

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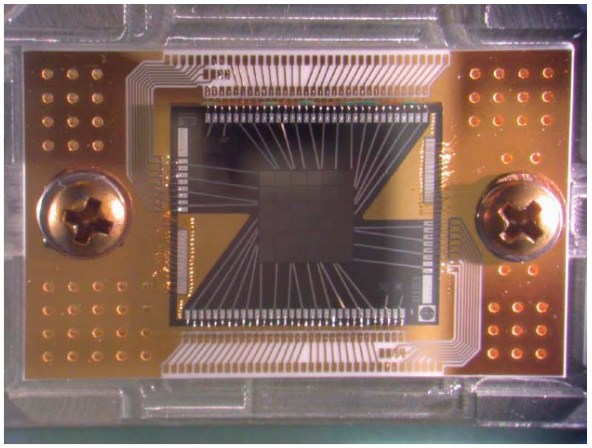
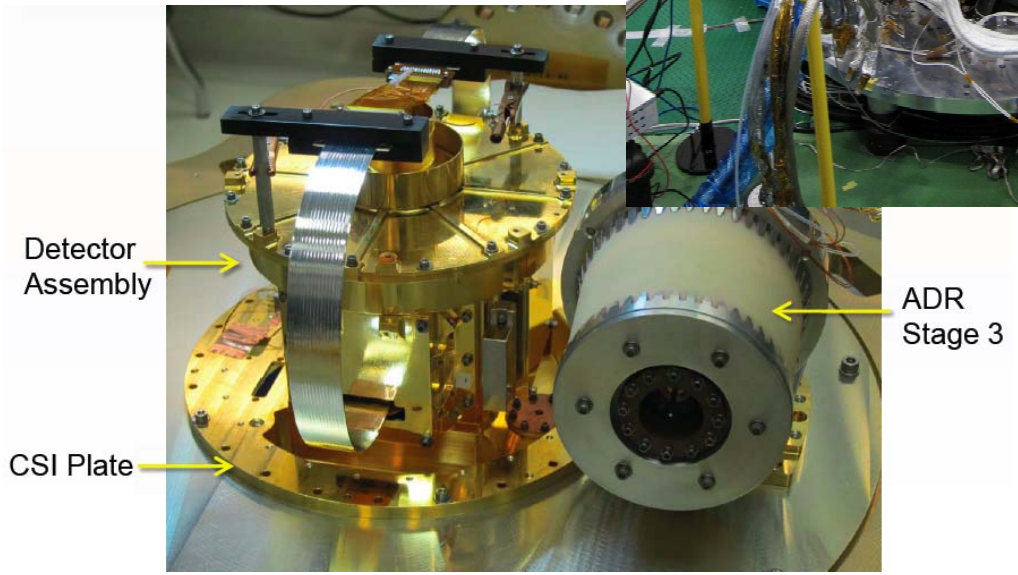
Key ADR team members: Mark Kimball, Michael DiPirro

Astro-H Soft X-ray Spectrometer

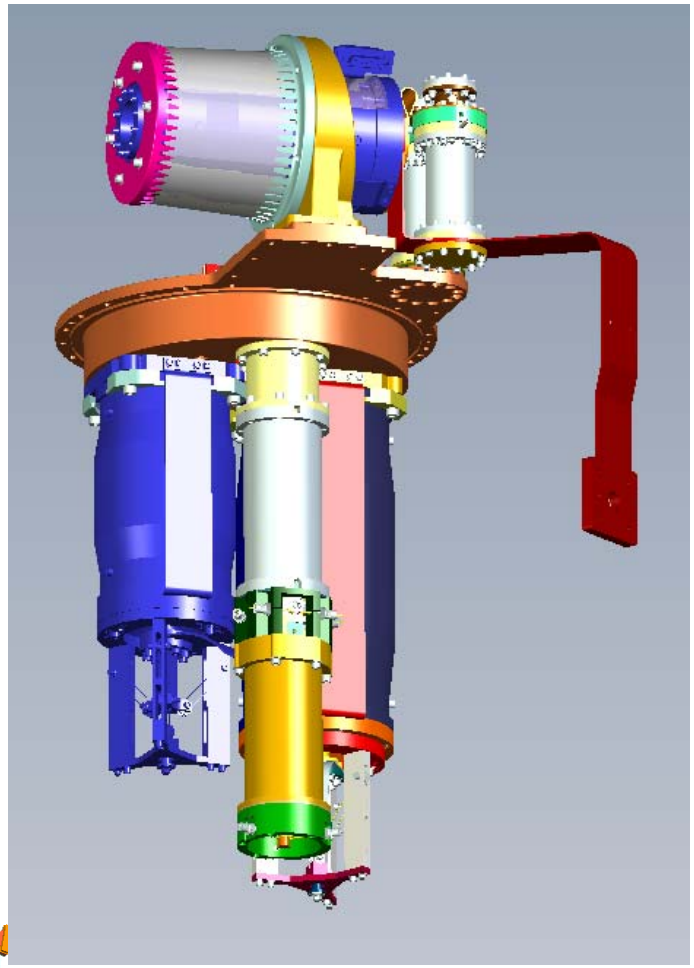
- 6x6 array of x-ray microcalorimeters cooled to 50 mK

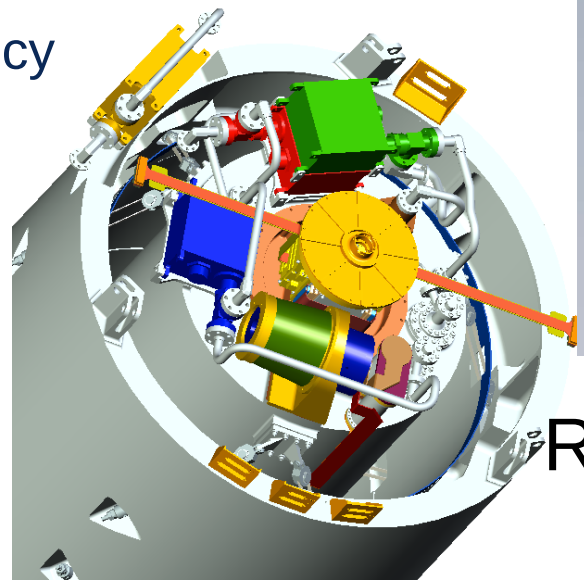




ADR Driving Requirements

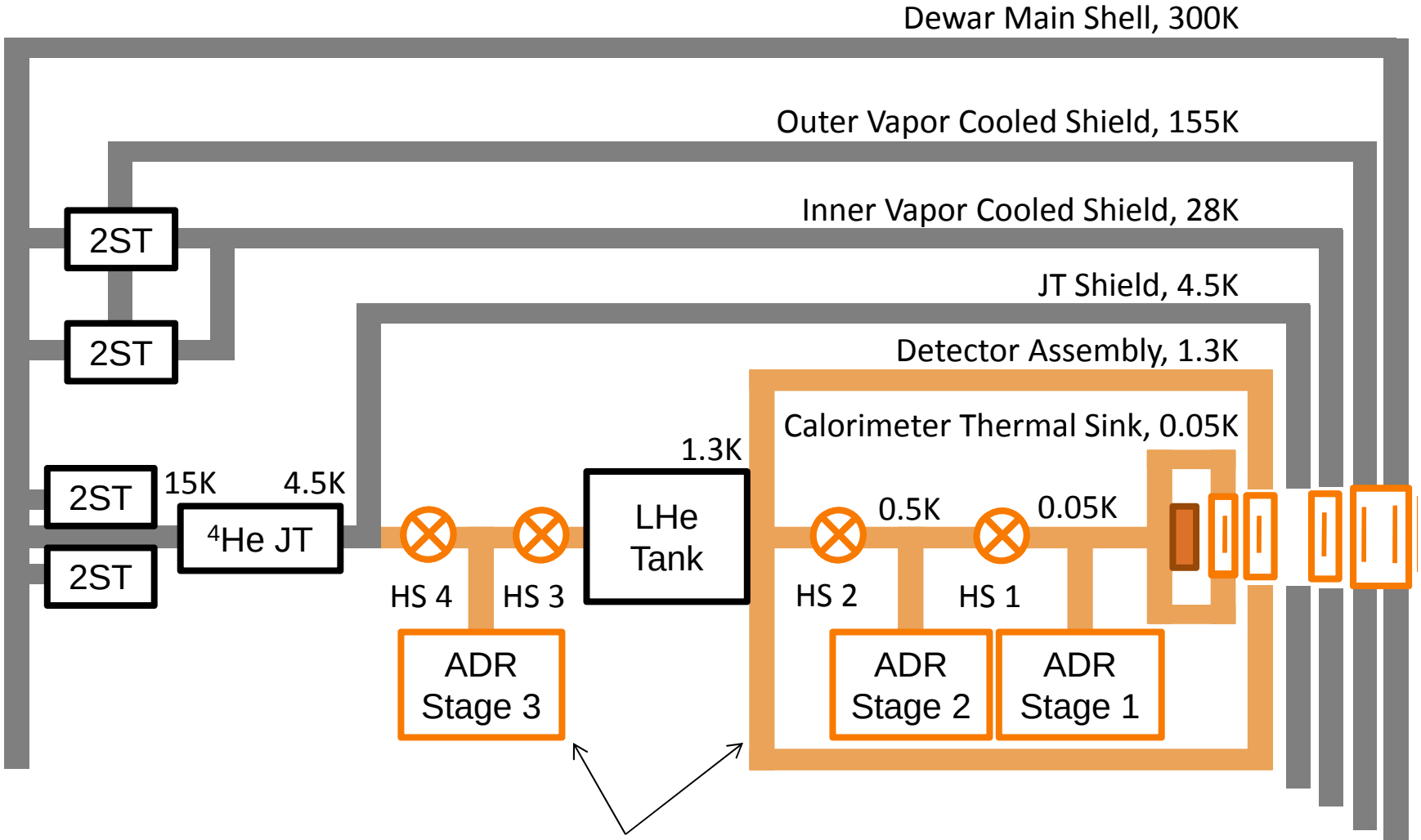
- ADR is used to cool the detectors to 50 mK
  - 0.25-0.40 μW of conducted heat (leads)
- ADR rejects heat to either:
  - Superfluid helium at <1.3 K
    - <0.23 mW average (4 year lifetime)
  - Joule-Thomson cooler at ~4.5 K
    - <18 mW peak
- Detector housing stable to 1 mK (time scales of 02 sec to 10 min)
- 90% observing efficiency





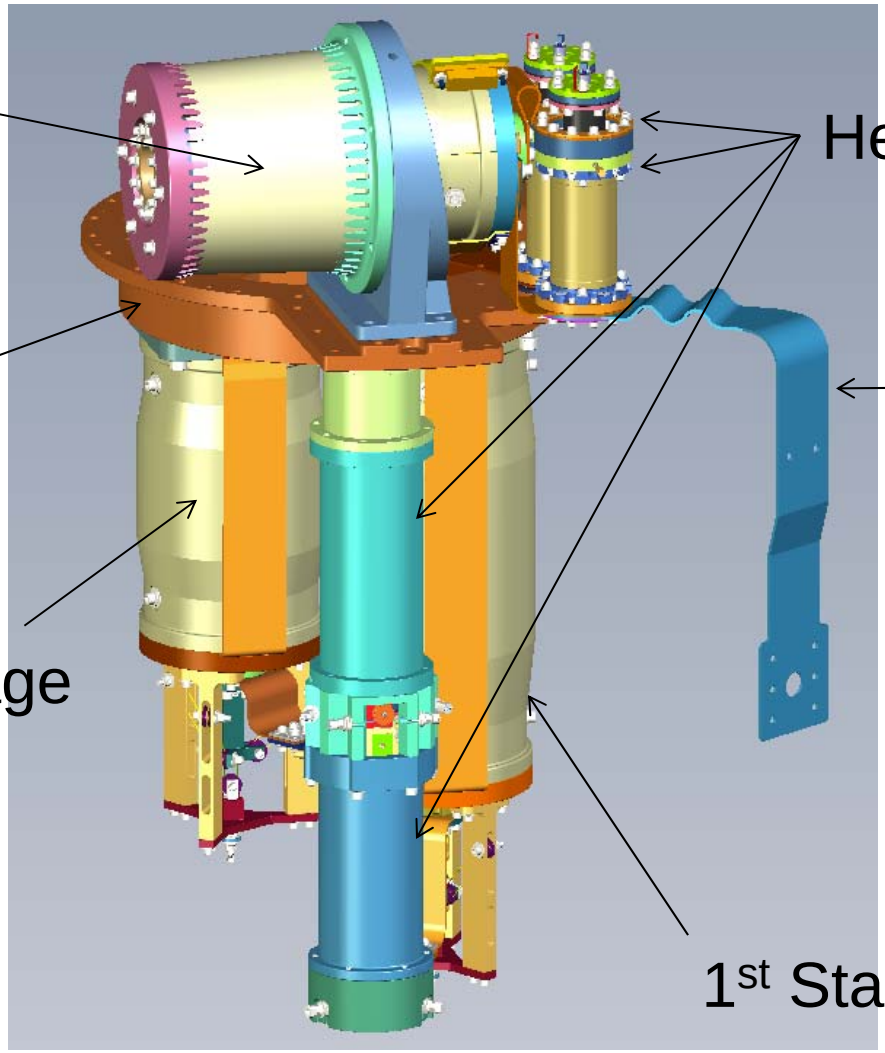
Requires 3-stage ADR

Astro-H Cryogenic System



NASA/GSFC hardware

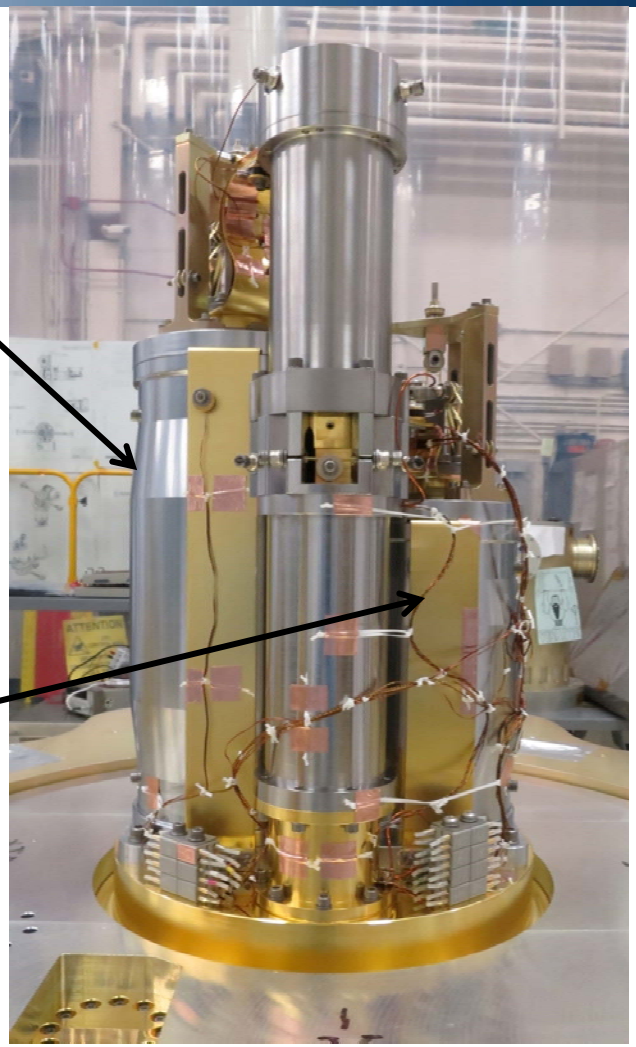
ADR Layout

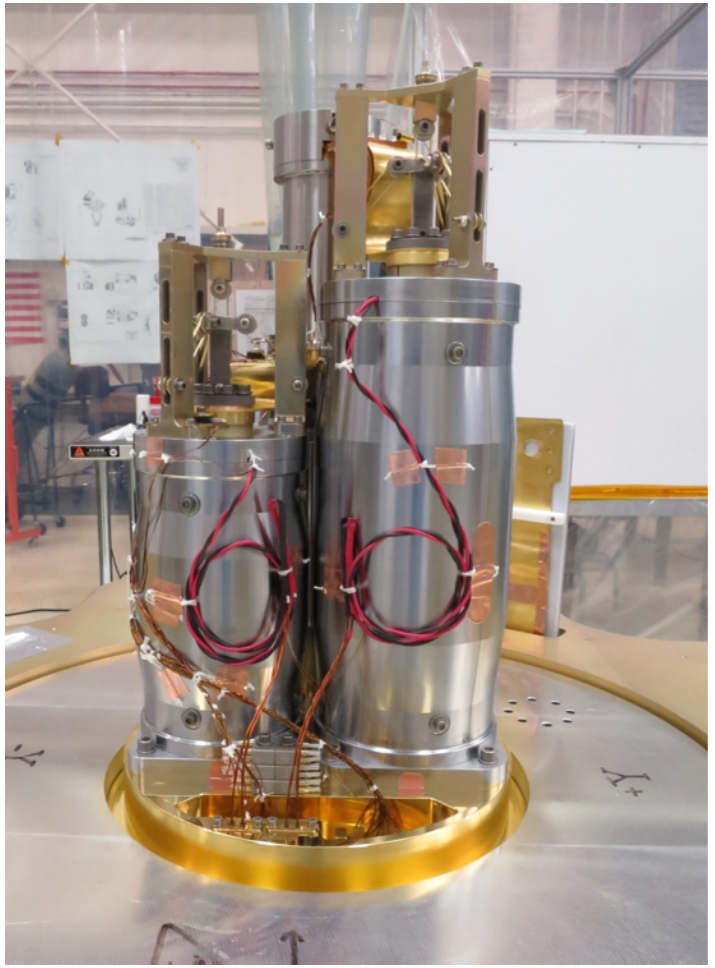

3rd Stage
Heat switches
Mounting plate – mechanical and thermal I/F to He Tank
Thermal strap To JT cooler
2nd Stage
1st Stage

2-Stage ADR

Stage 1:
- 270 g CPA
- 2 T, 2 amp magnet

Stage 2:
- 150 g GLF
- 3 T, 2 amp magnet

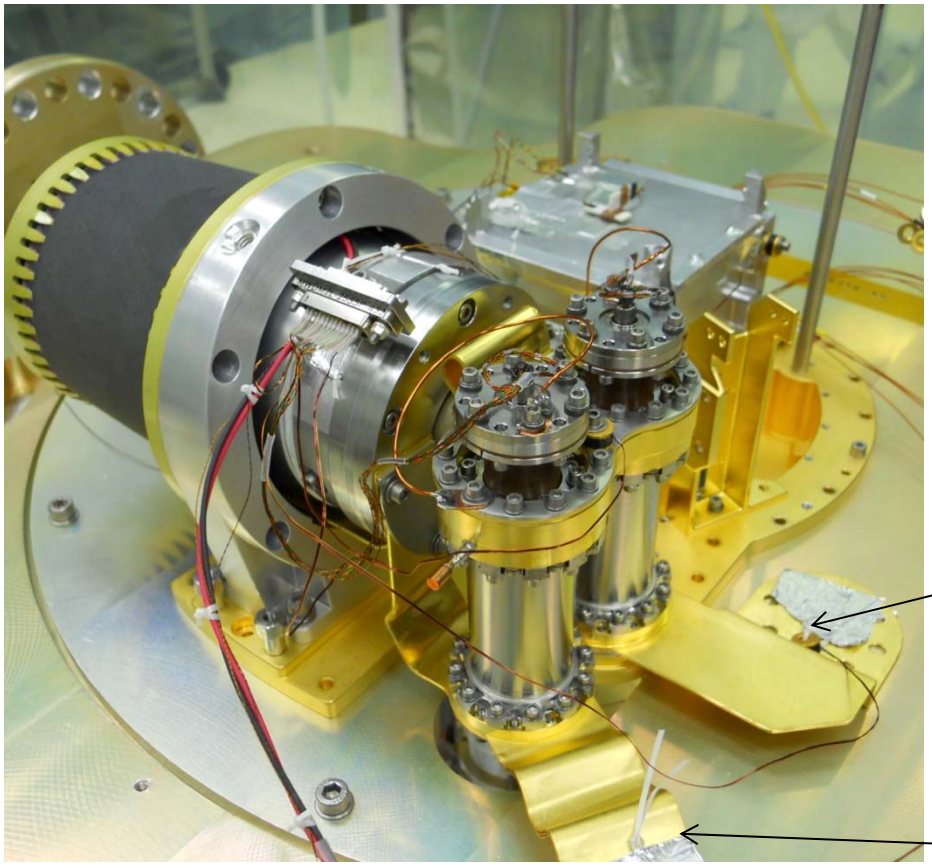




Heat switches are active gas-gap

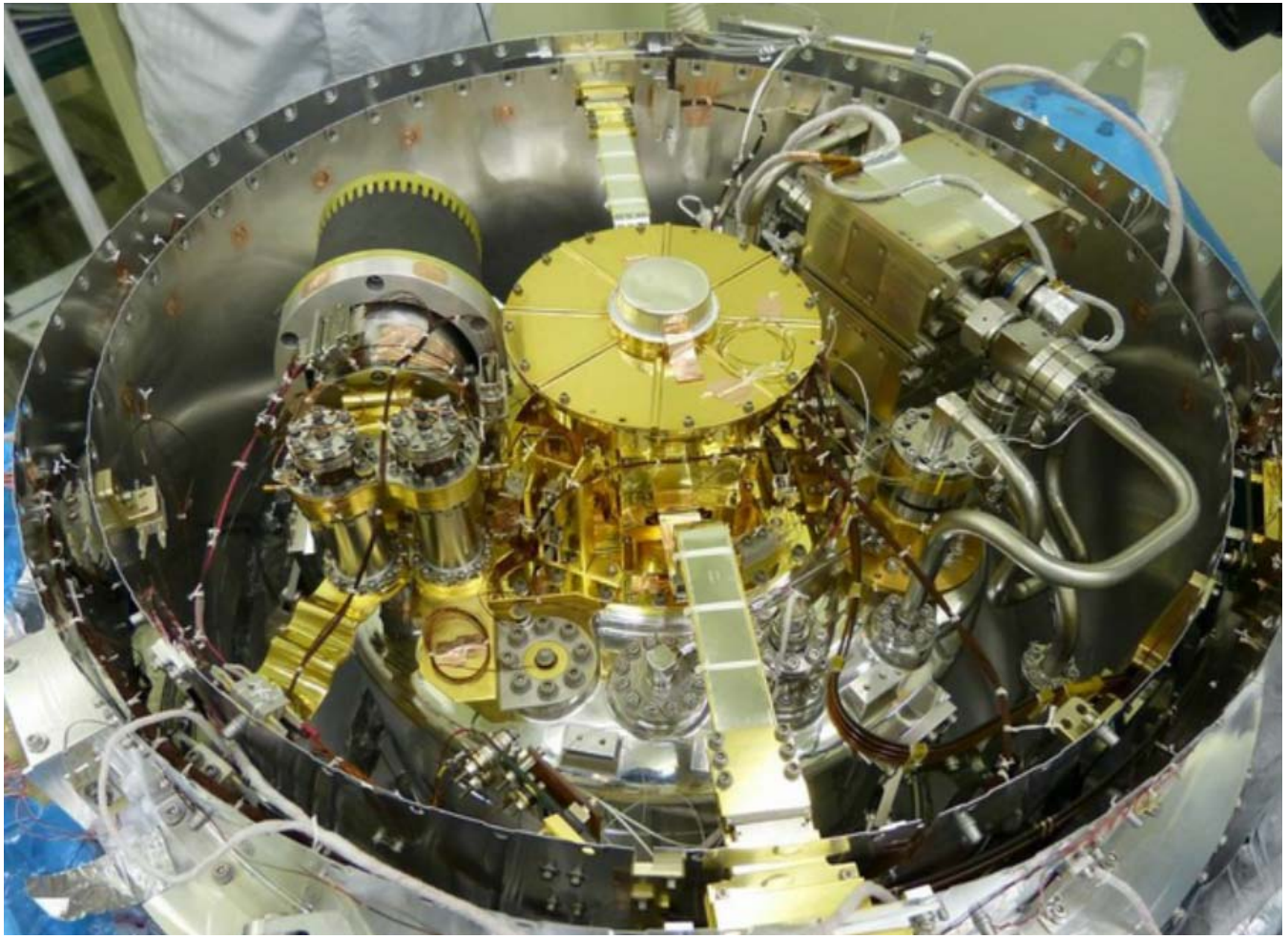
3rd Stage ADR

Stage 3:
- 150 g GLF
- 3 T, 2 amp magnet

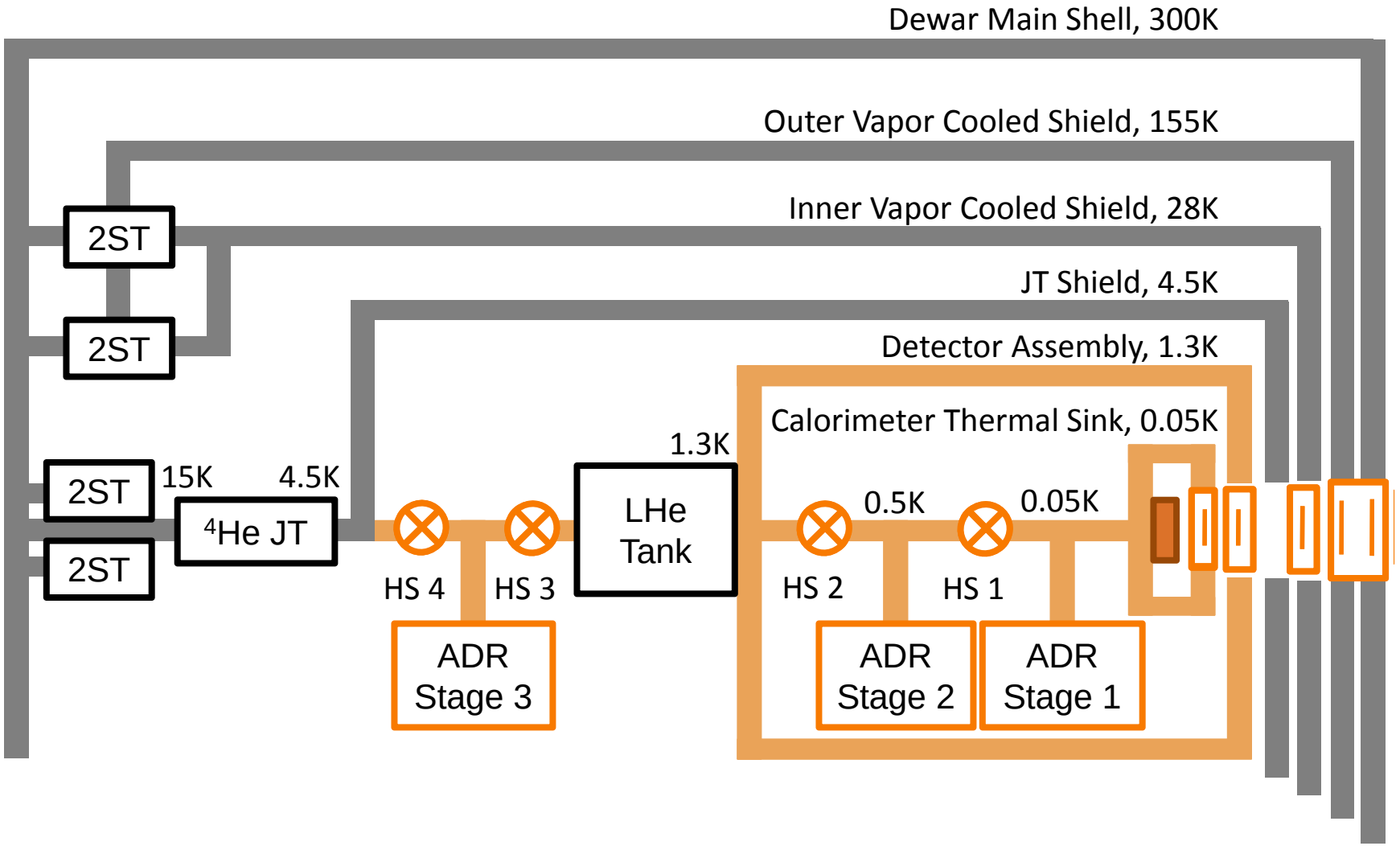


Heat switches are active gas-gap

Flight ADR, Detector and Dewar (April ‘14)

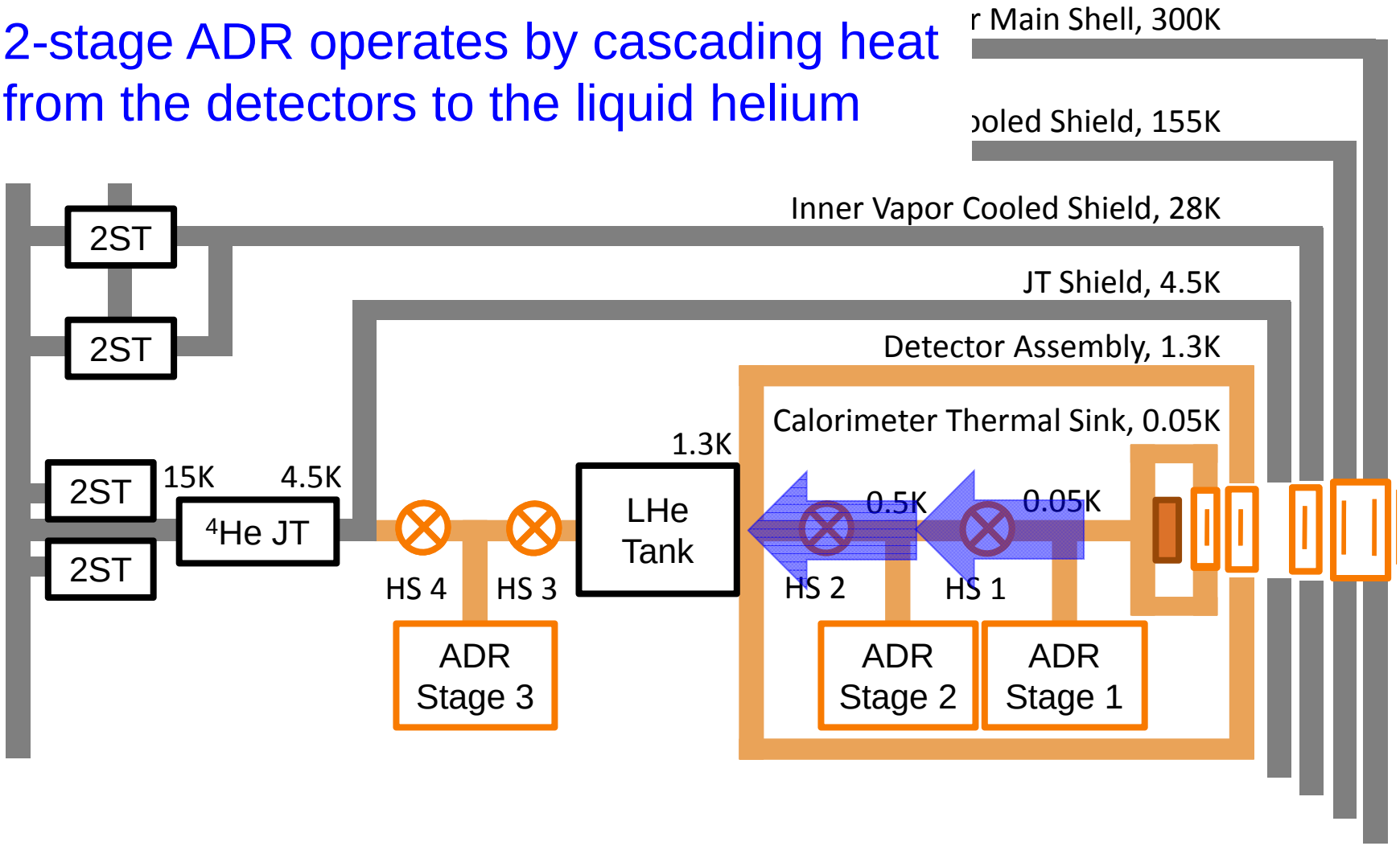


Astro-H Cryogenic System



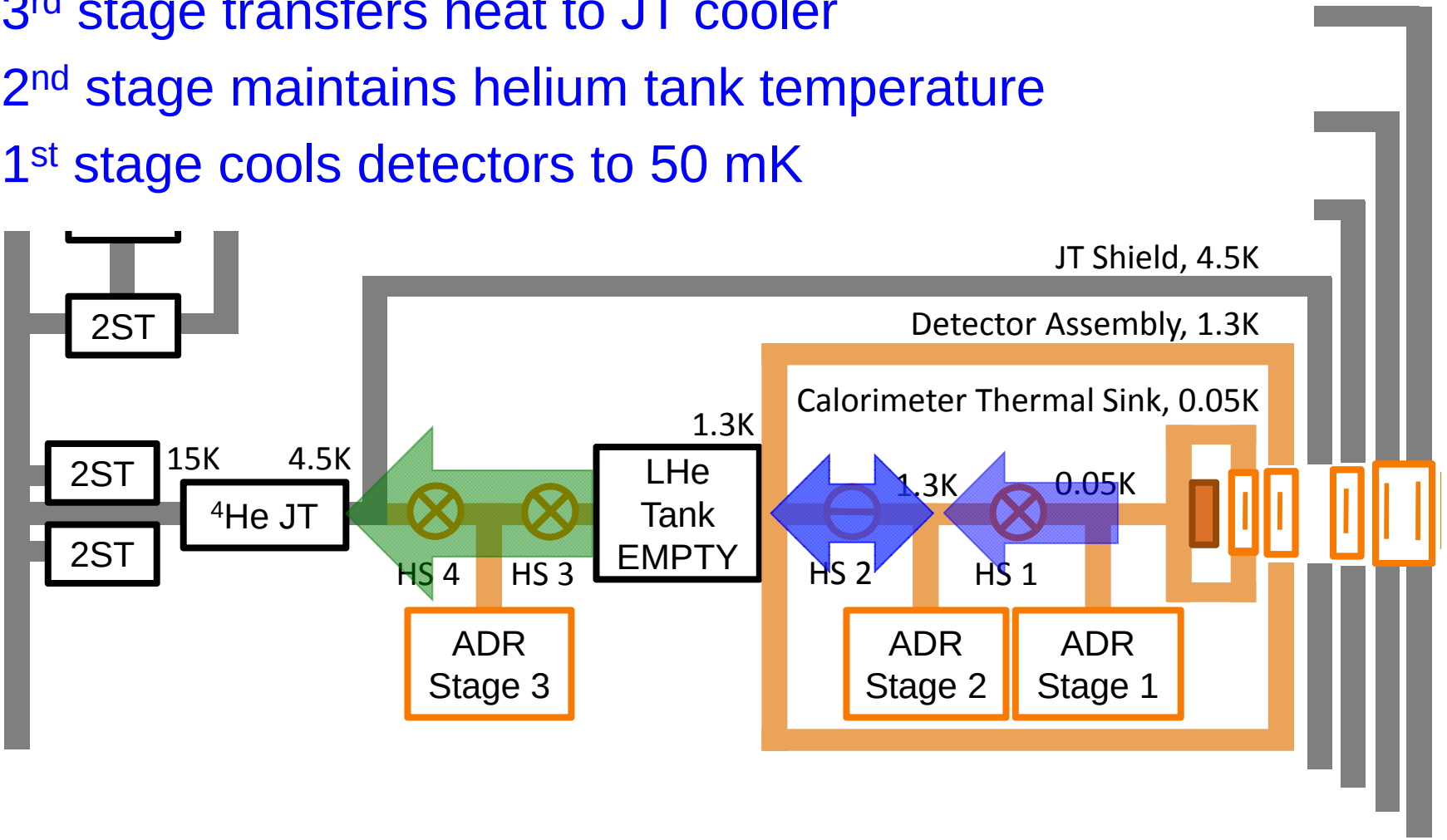
ADR Operation with Helium

- 2-stage ADR operates by cascading heat from the detectors to the liquid helium



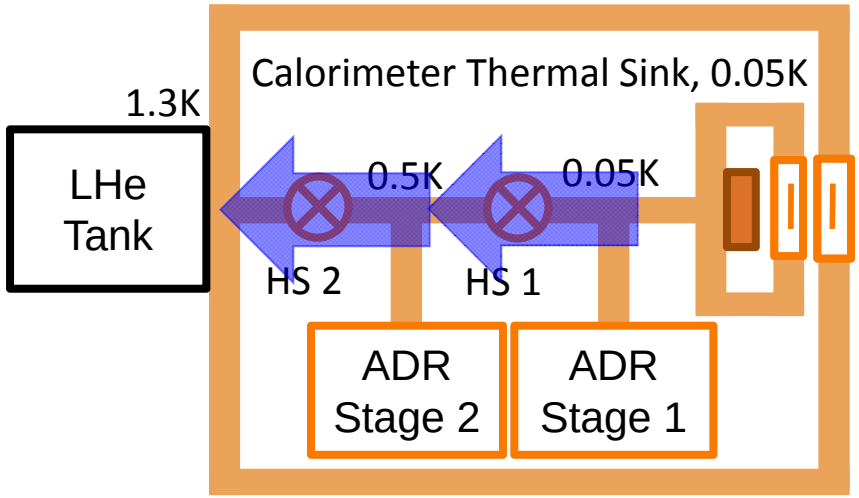
Operation in Cryogen-Free Mode

- 3rd stage transfers heat to JT cooler
- 2nd stage maintains helium tank temperature
- 1st stage cools detectors to 50 mK



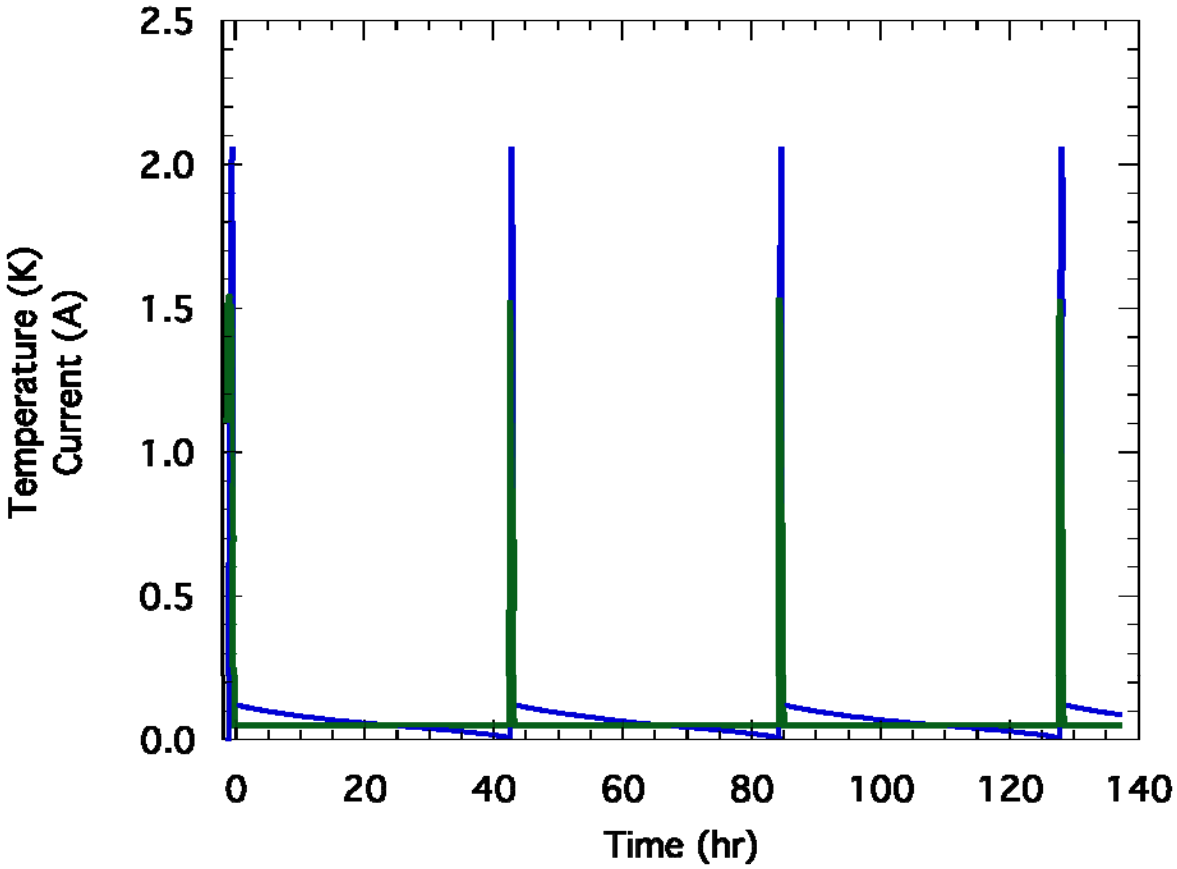
Operation with Liquid Helium

- Recycling sequence
  - Stage 1 and 2 are warmed to ~10% above the He bath
    - HS1 and HS2 turned ON
  - Stages 1 and 2 charge to full field (2 T and 3 T)
    - HS2 is turned off
  - Stage 2 cools Stage 1 (still at 2 T) to <0.8 K
    - HS1 is turned off
  - Stage 1 is demagnetized to 50 mK, and Stage 2 to 0.5 K



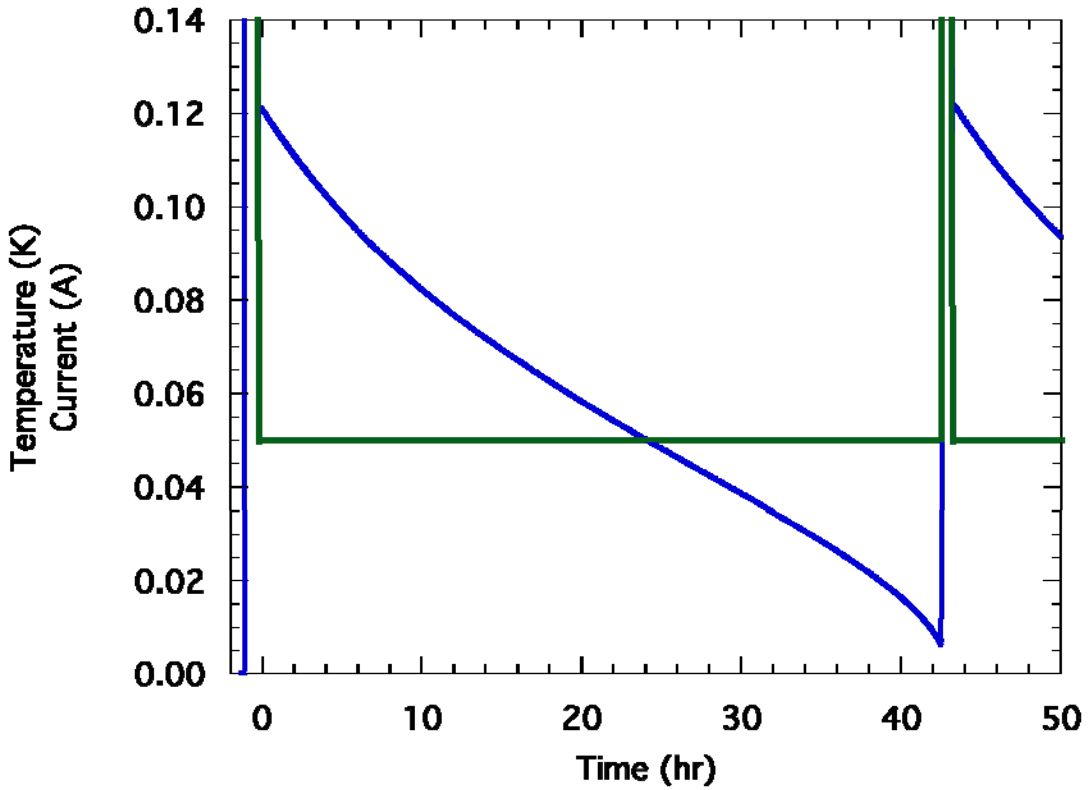
50 mK Stage Operation

- 2-stage ADR is automatically recycled when the first stage current falls below 5 mA
  - Temperature control becomes less stable



Stage 1 Performance

- Demagnetized from 0.75 K and 2 T (0.16 J max cooling capacity)
- Hold time with He bath at 1.20 K is ~43 hours
  - On orbit expect ~1.10 K and 38 hour hold time
- Heat load is 0.87 μW
  - Measured 84% heat absorption efficiency

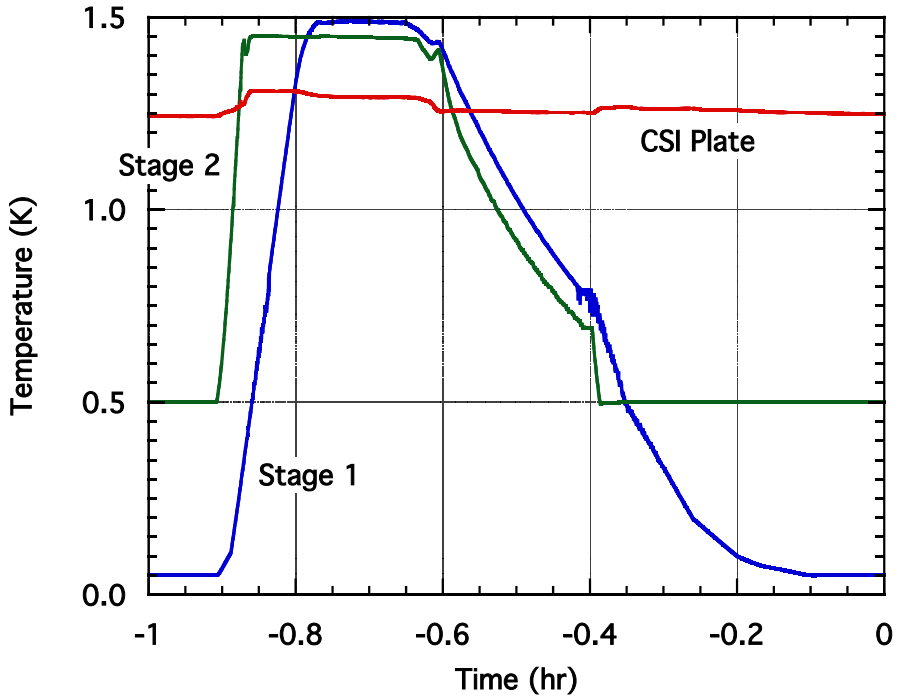


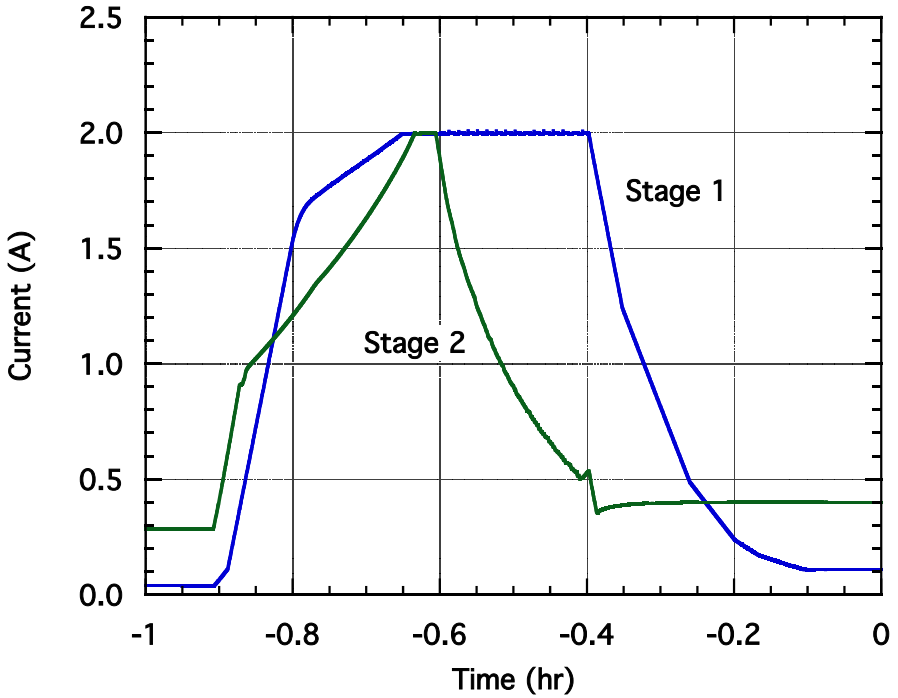
Heat loads to 50 mK

Heat switch:	0.015 μW
Detector assy:	0.27 μW
Kevlar susp:	0.58 μW

2-Stage ADR Recycling

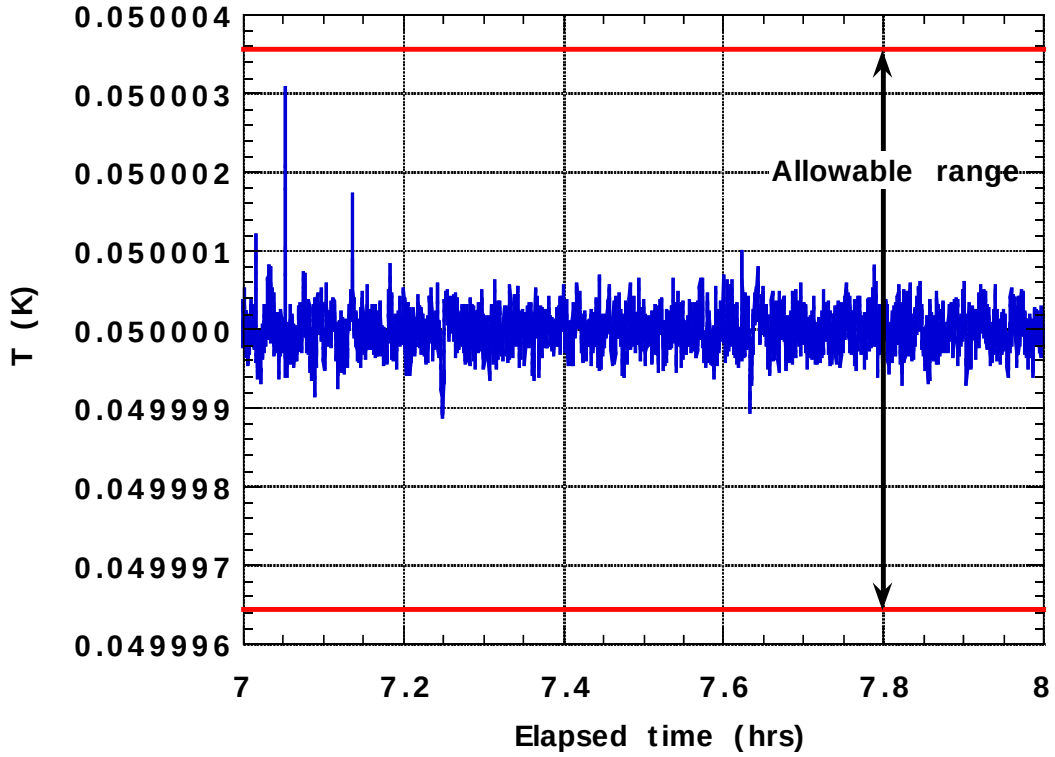
- Recycle time <1 hour, including recovery time
  - Detector response stabilizes as detector and ADR components equilibrate
- Control setpoints are based on the He tank temperature (uses mounting plate T)
  - Control system automatically adjusts to conditions during flight





Temperature Stability

- Required stability: 2.5 μK rms
- Actual: 0.37 μK rms



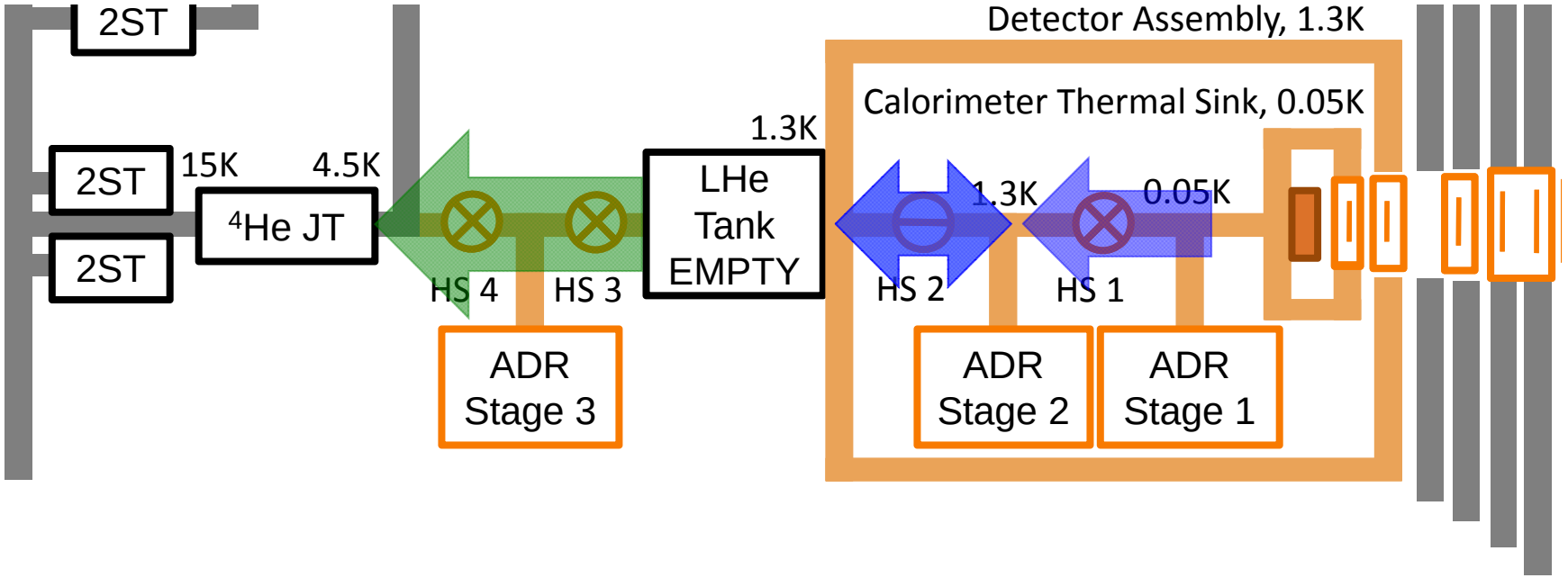
2-Stage ADR Operation Summary

- Recycle time, including detector equilibration: ~1 hour
- Hold time: 43 hours
- Instrument observing efficiency (duty cycle): >97%
- Temperature stability <1 μK rms

- Integrated heat flow to helium tank
  - Hysteresis from S1 and S2 magnets 3.42 J
  - HS1/HS2 getter power 0.76 J
  - Heat from salt pills 7.84 J
  - Total 12.02 J
- Time average load to He tank is 0.077 mW
  - Requirement is <0.2 mW
  - If ADR is recycled every day, heat per cycle is ~10 J, avg is 0.115 mW

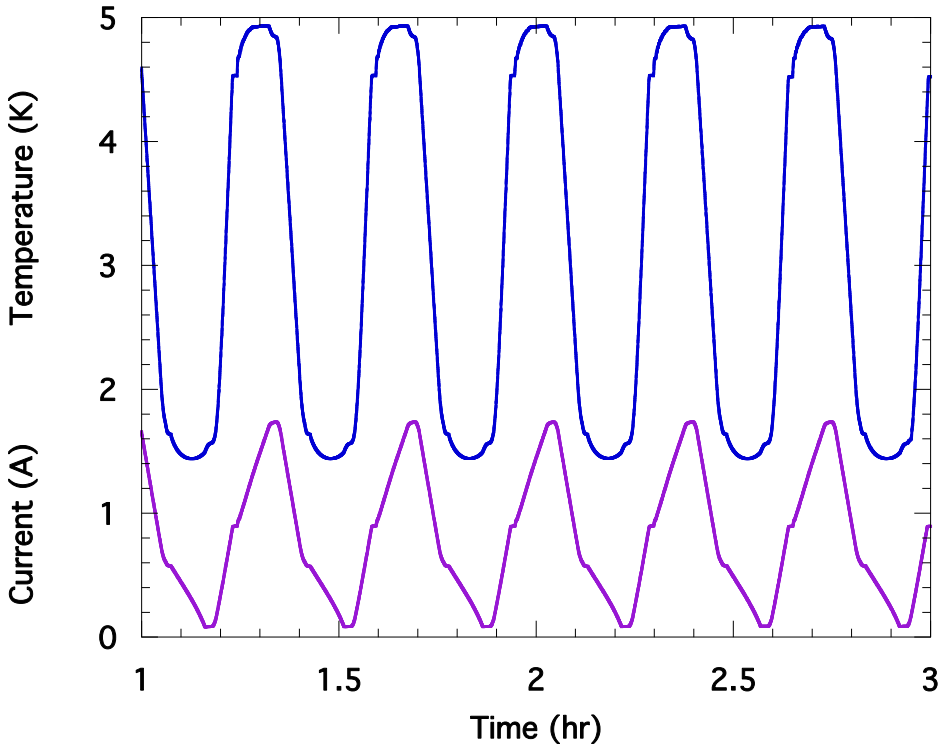
Cryogen-Free Operation

- 3rd stage transfers heat to JT cooler
- 2nd stage maintains helium tank temperature (goal <1.5 K)
  - Builds up cooling capacity during hold time
- 1st stage cools detectors to 50 mK, rejects heat to 2nd stage



3rd Stage Cycling

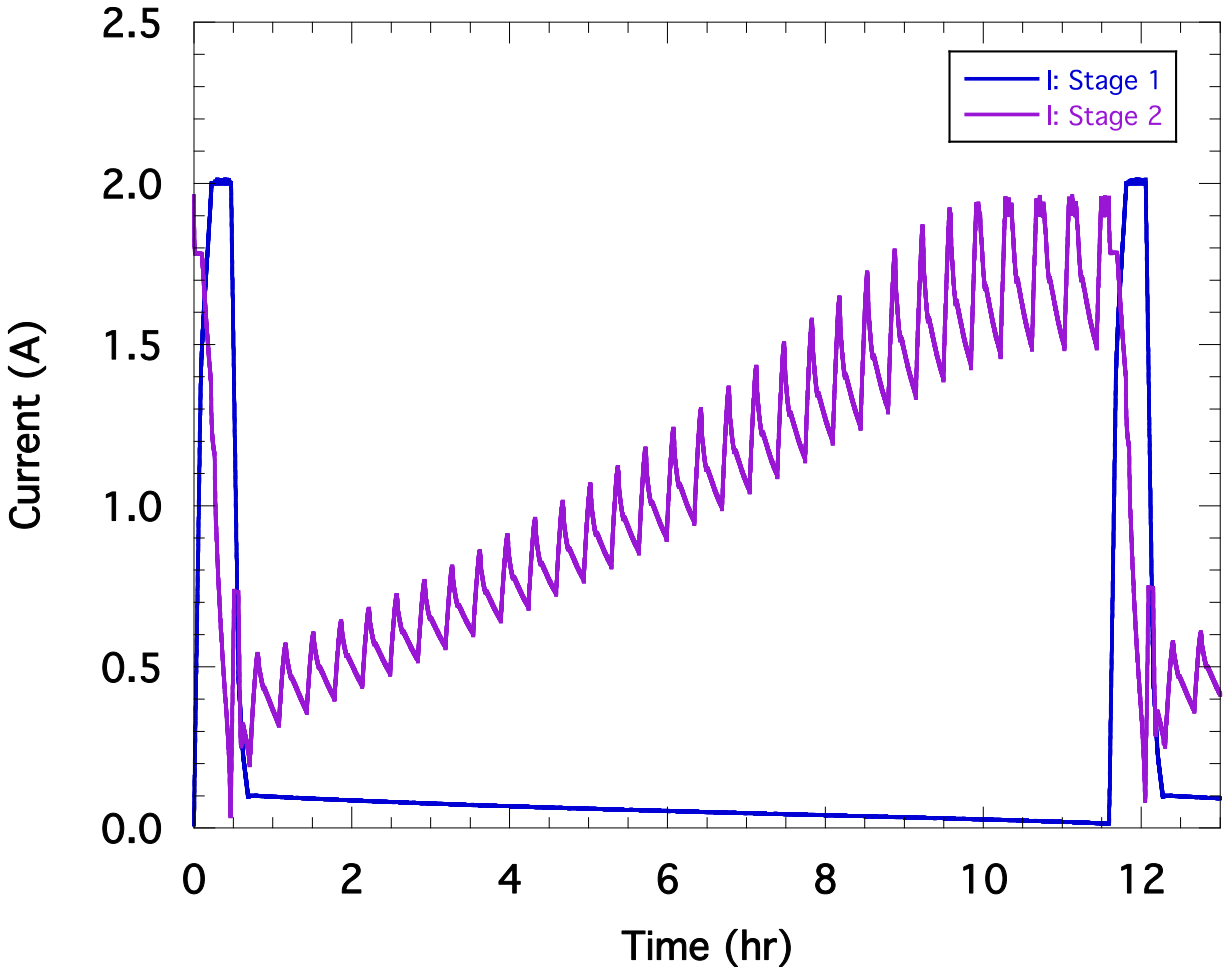
- Cycle period ~21 minutes
- Low temperature setpoint is continuously adjusted to match helium tank T
- Time average heat lift of 2-3 mW in range of 1.4-1.8 K
  - Helium tank parasitic load is ~0.6 mW
  - ADR internal heat generation is ~1.2 mW



Full Cycle with He tank at 1.625 K

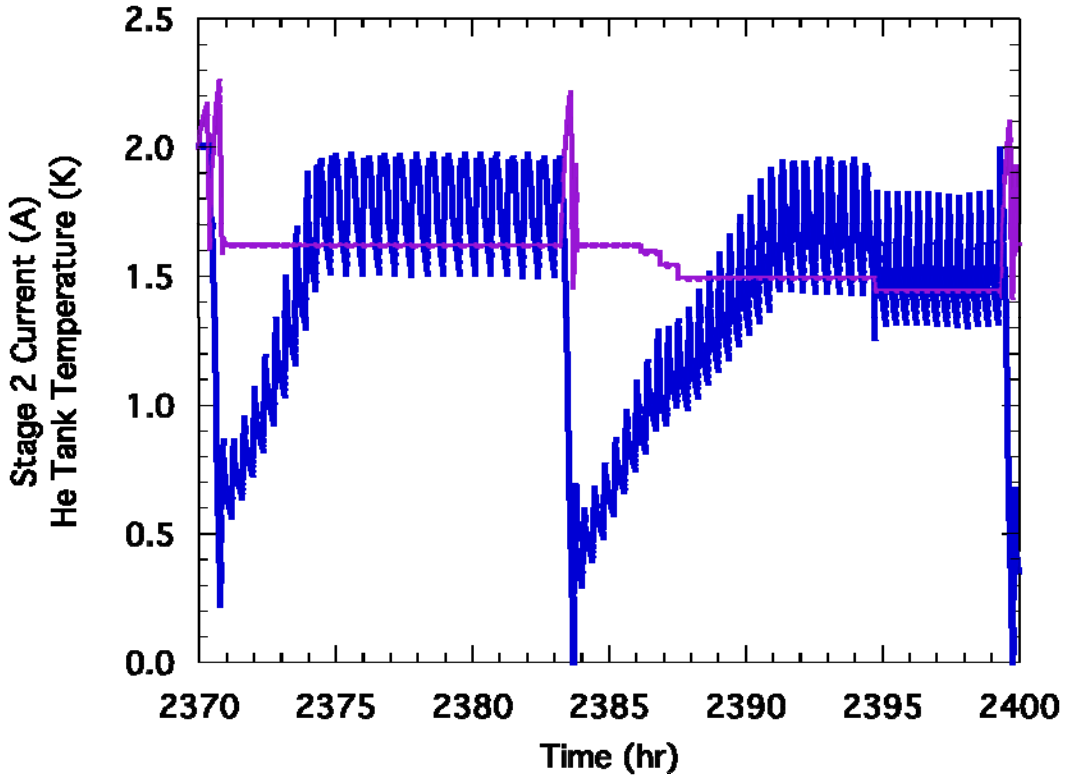
- S2 charges during S1 hold time
- S1 is automatically recycled when current falls below 20 mA

- 40 minute recycle
- 11.0 hour hold
- >94% observing efficiency



He Tank Control

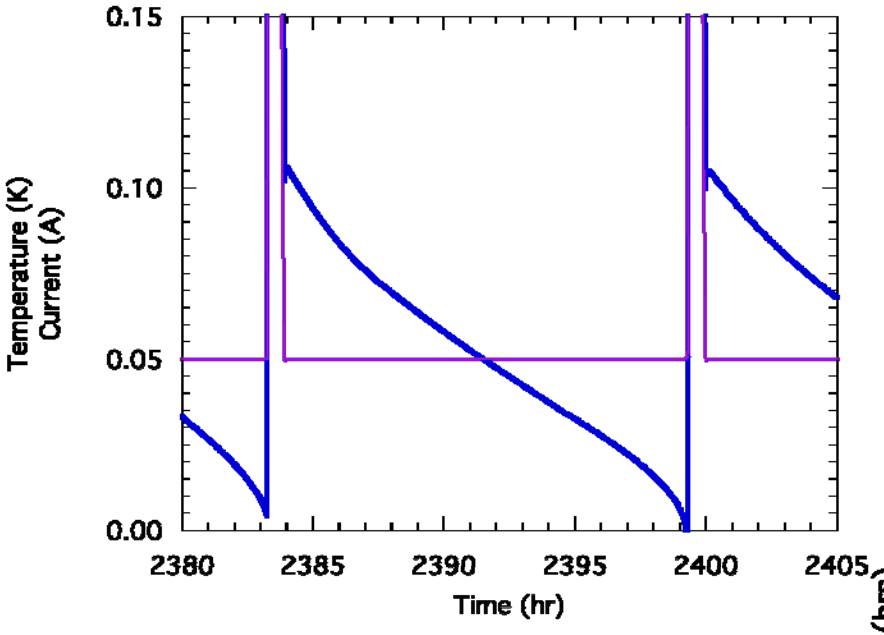
- Lower He tank temperature = slower charging rate of Stage 2

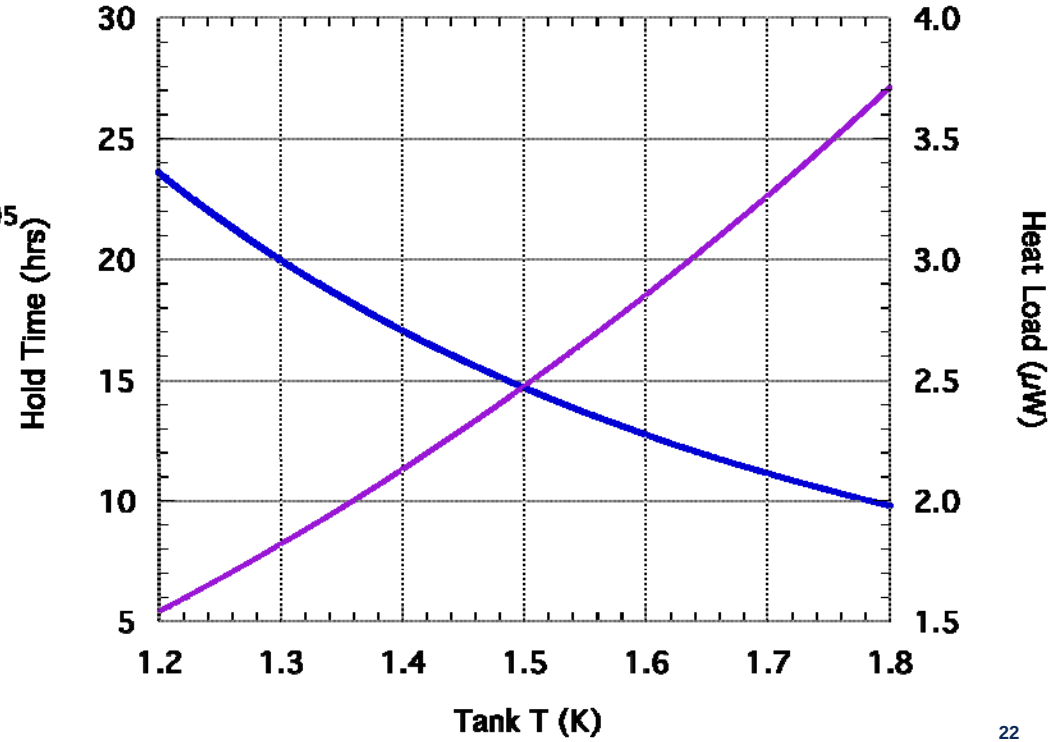


- On orbit, tank will be regulated at lowest temperature at which Stage 2 charges completely during Stage 1 hold time
  - 1.5-1.55 K, based on current test conditions
  - Will change if cryocooler performance degrades over time

Stage 1 Cycling

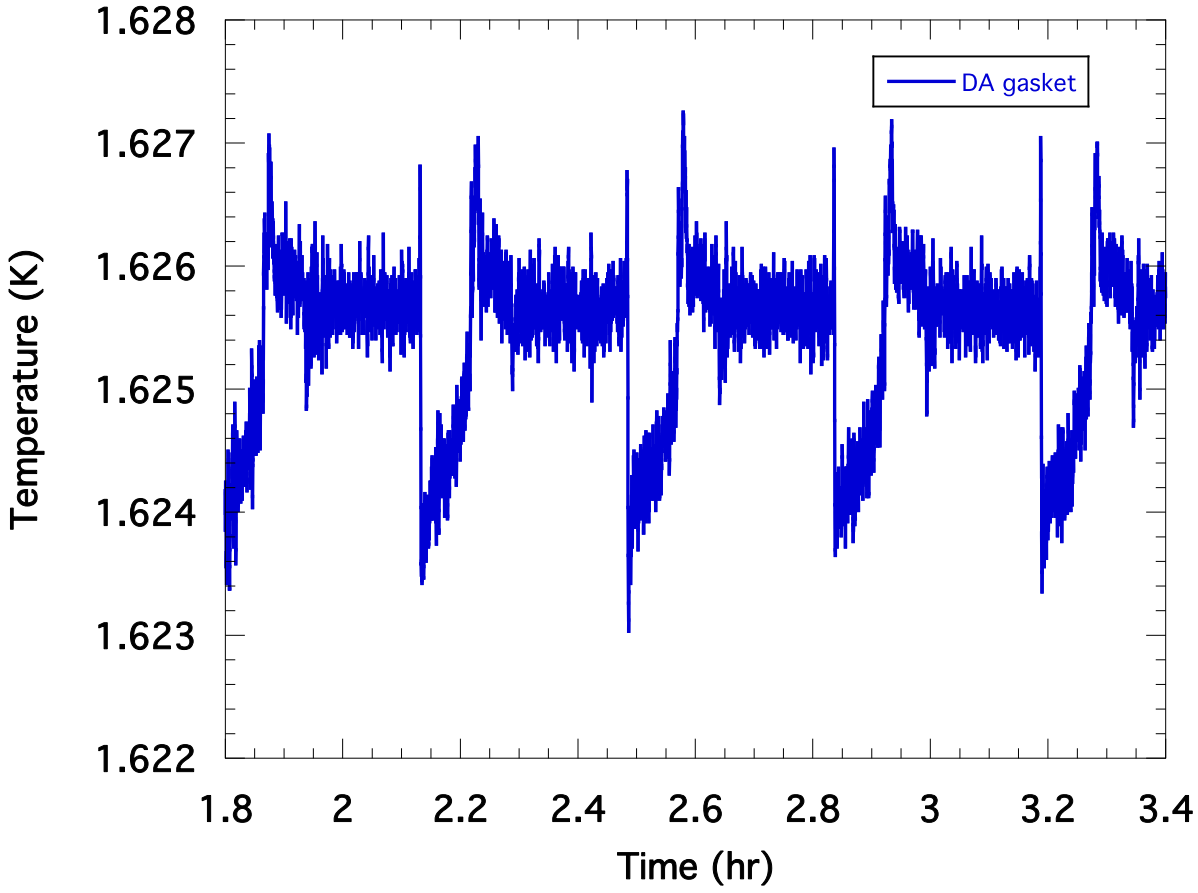
- Stage 1 automatically recycles at 10 mA current





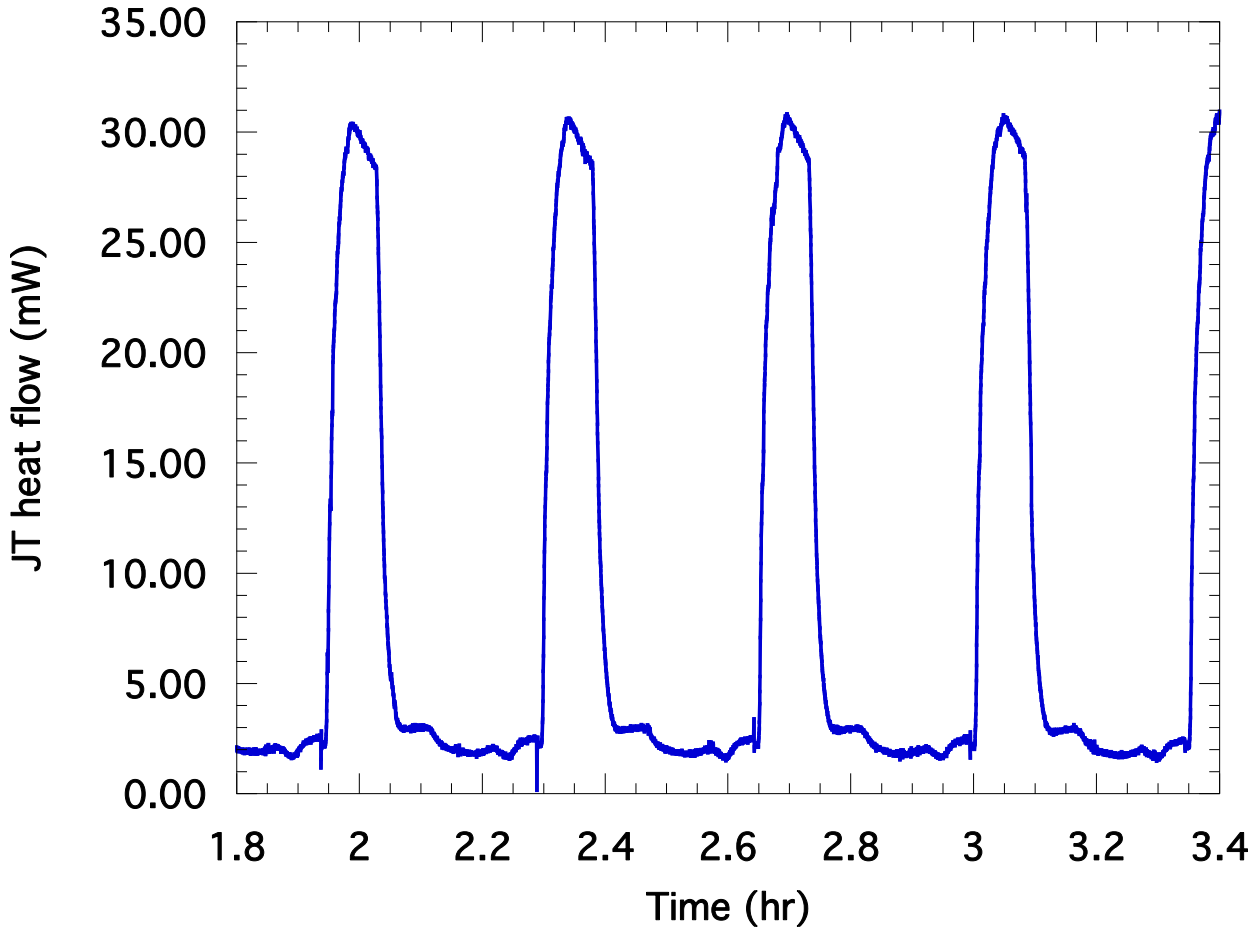
Detector Housing Temperature Stability

- Required stability is 1 mK over time scales of 0.2 s – 10 min
  - Brief periods in which fluctuation is ~2 mK
  - With current detector performance, this is acceptable



Heat Flow to the JT Cooler

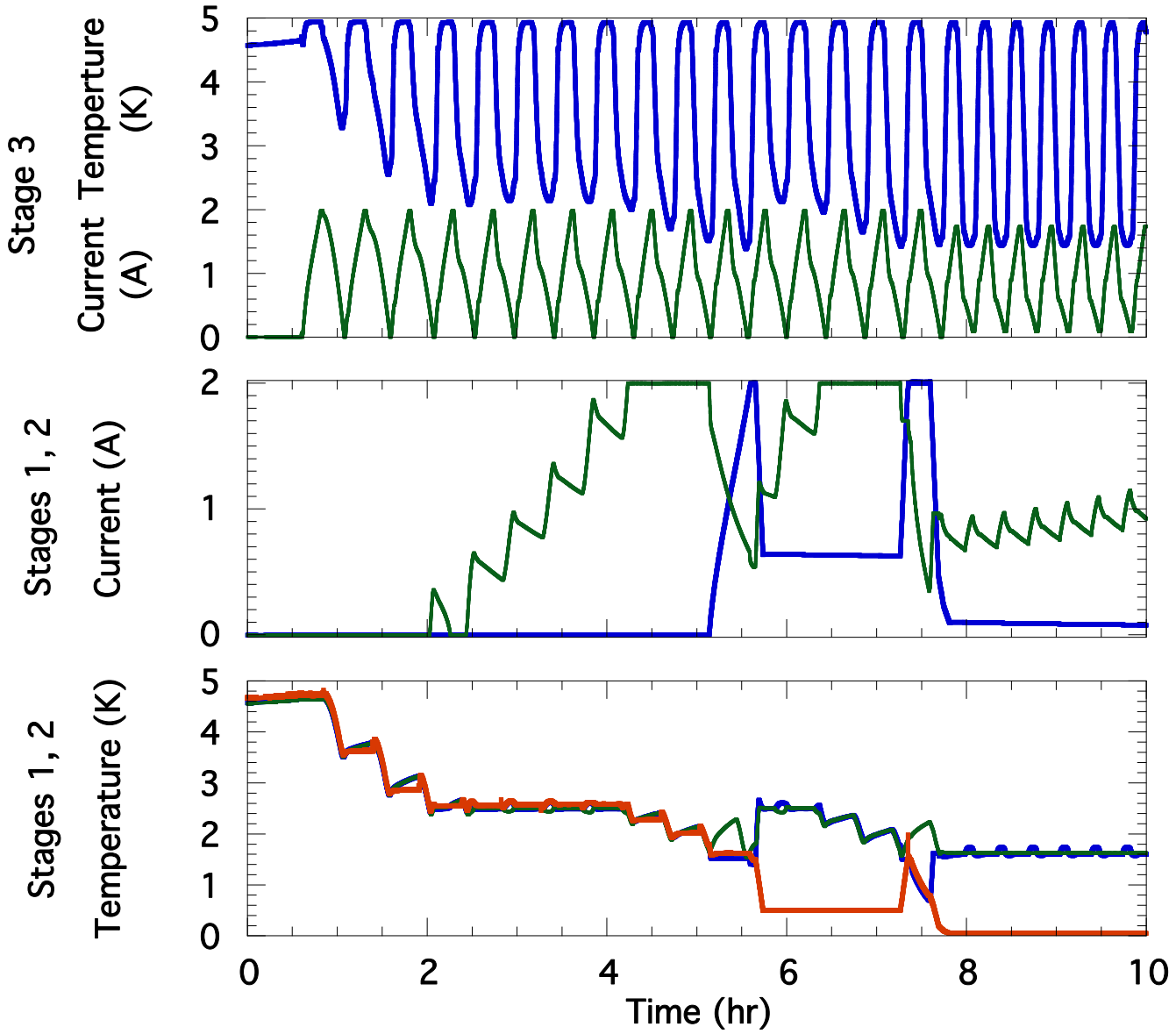
- Cycling was adjusted to give max heat flow of 30 mW
  - Maximum flow tolerable at nominal input power



Warm Start

- ADR must handle the case of a warm start
  - He tank, ADR and detectors starting at 4.5 K
  - May be necessary after catastrophic warmup
    - Due to loss of cryocooler operation for long period
    - Due to issues with guard vacuum
- Control must be autonomous
  - No intervention via ground control

Cooldown from 4.5 K



Summary

- ADR operates successfully with 2 very different heat sinks
- Demonstrated autonomous control in all operating modes
  - 2-stage with helium
  - 3-stage in cryogen-free mode
    - Warm start, automatic recycling
  - Pre-launch (maintain He temperature during launch hold)
- Meets all instrument requirements
  - Cooling power
  - Temperature stability
  - Instrument observing efficiency
  - Heat rejection to He bath or JT cryocooler