



National Aeronautics and Space Administration



Performance Testing of the Astro-H Flight Model 3-stage ADR

Peter Shirron

Key ADR team members: Mark Kimball, Michael DiPirro, Tom Bialas

Astro-H/SXS

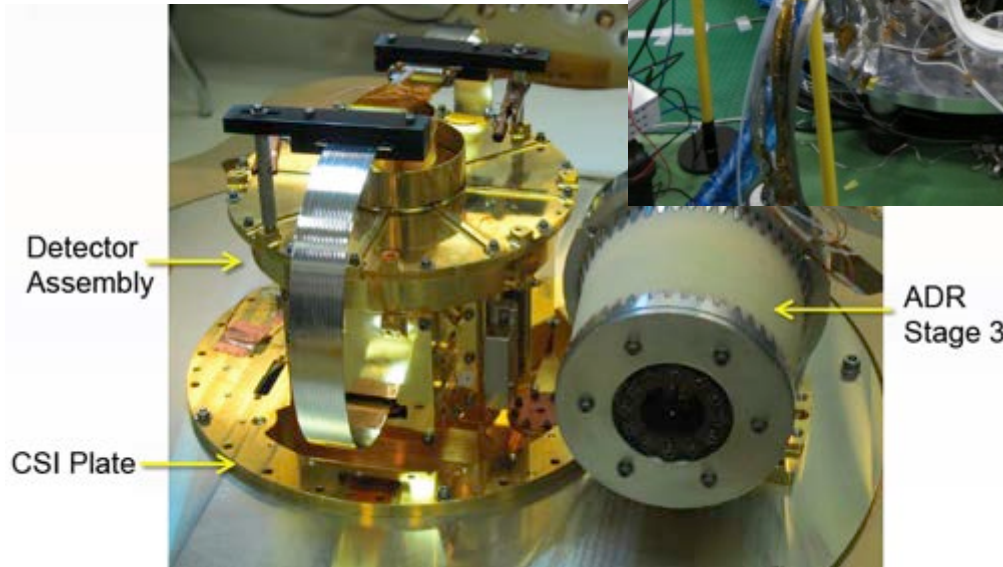
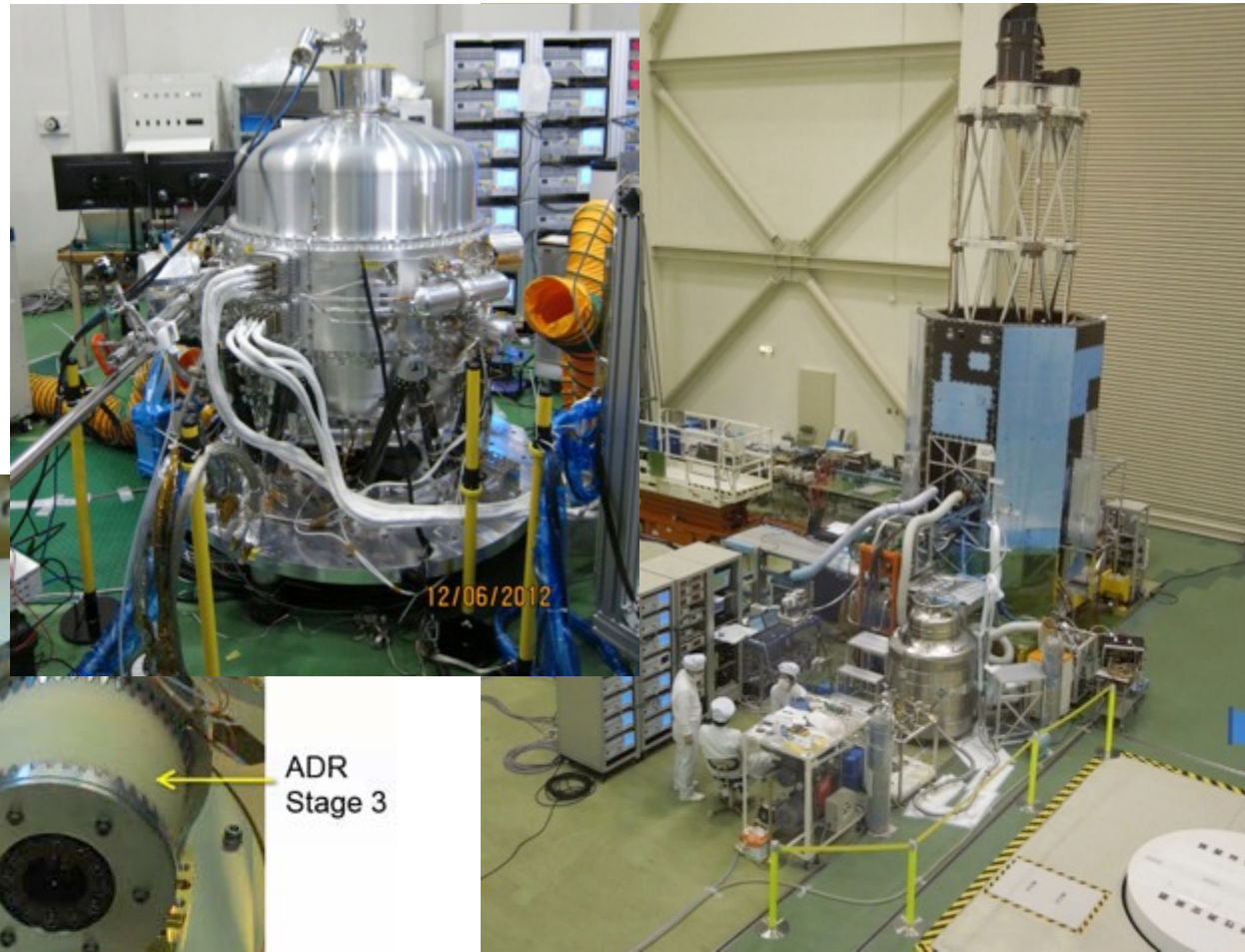
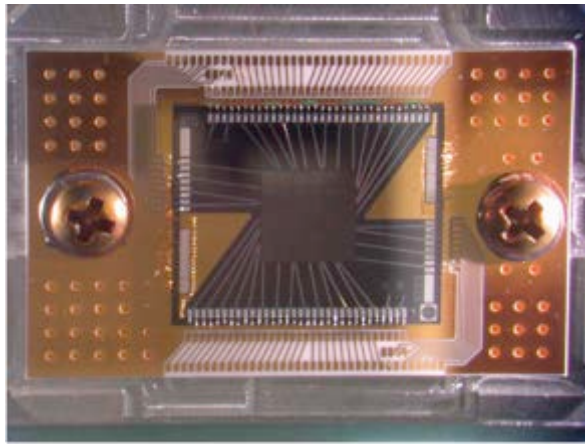
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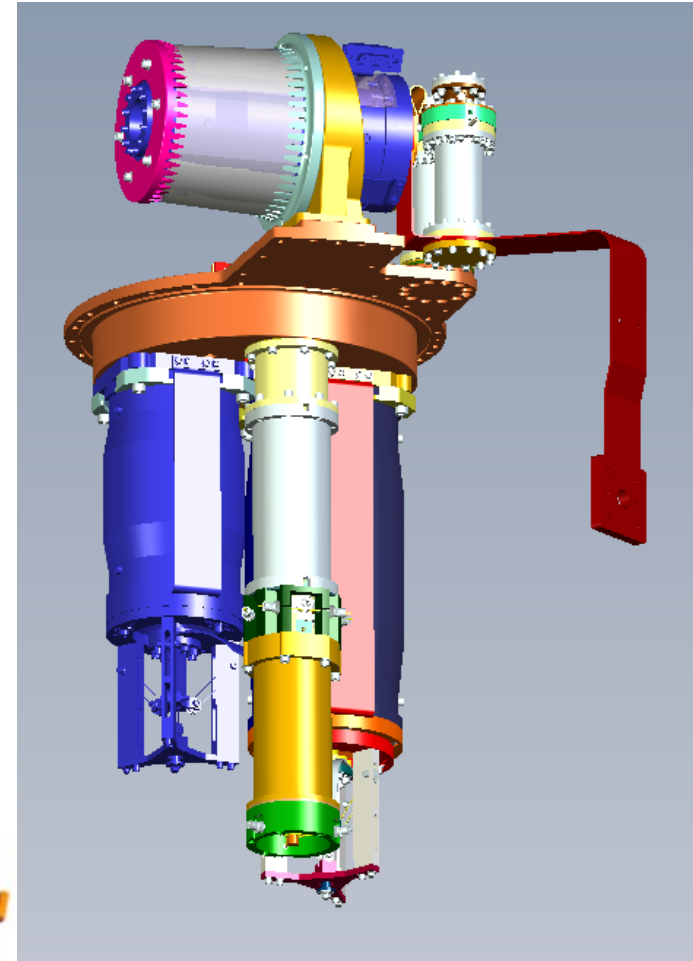
Astro-H Soft X-ray Spectrometer

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



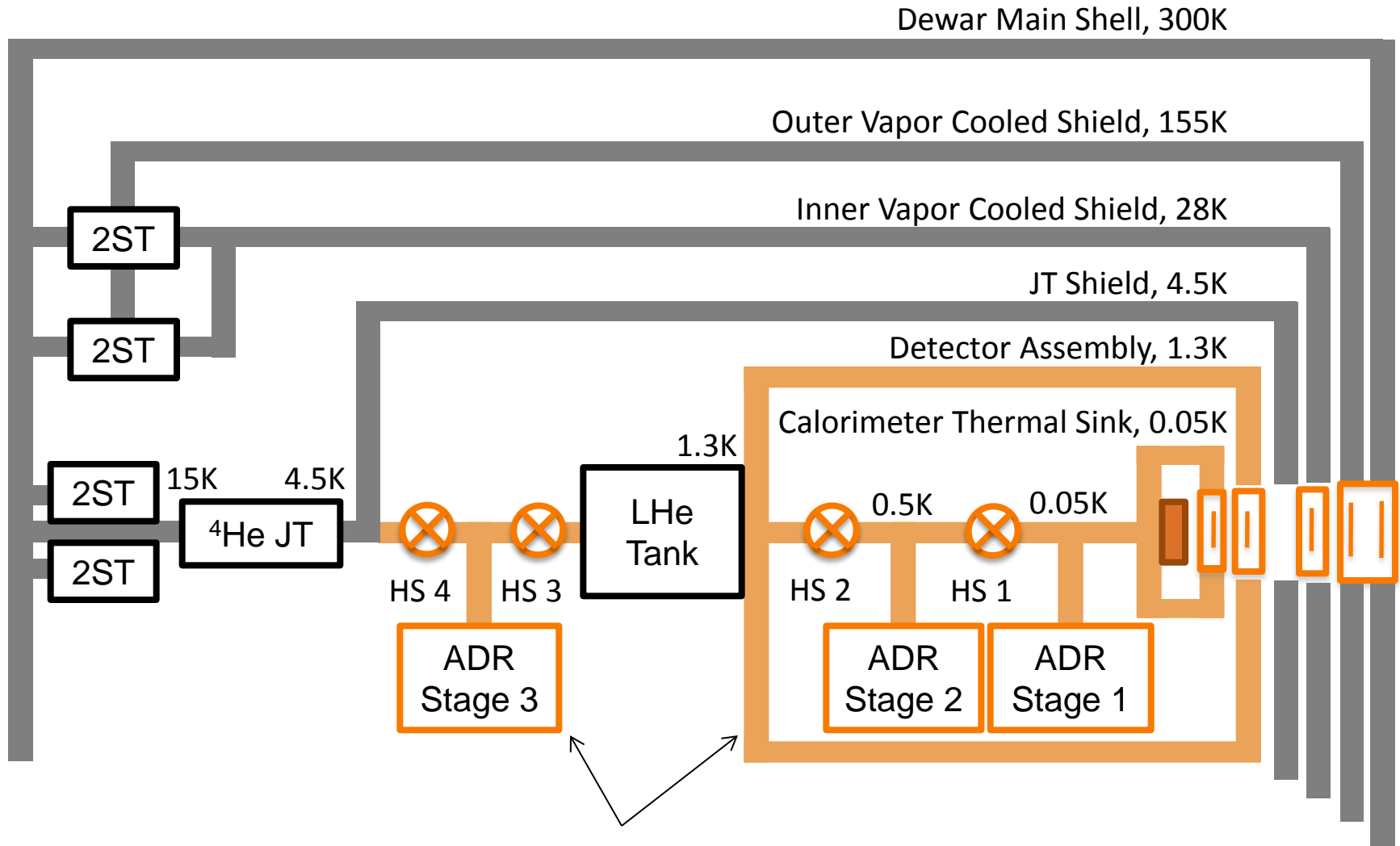
ADR Driving Requirements

- 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



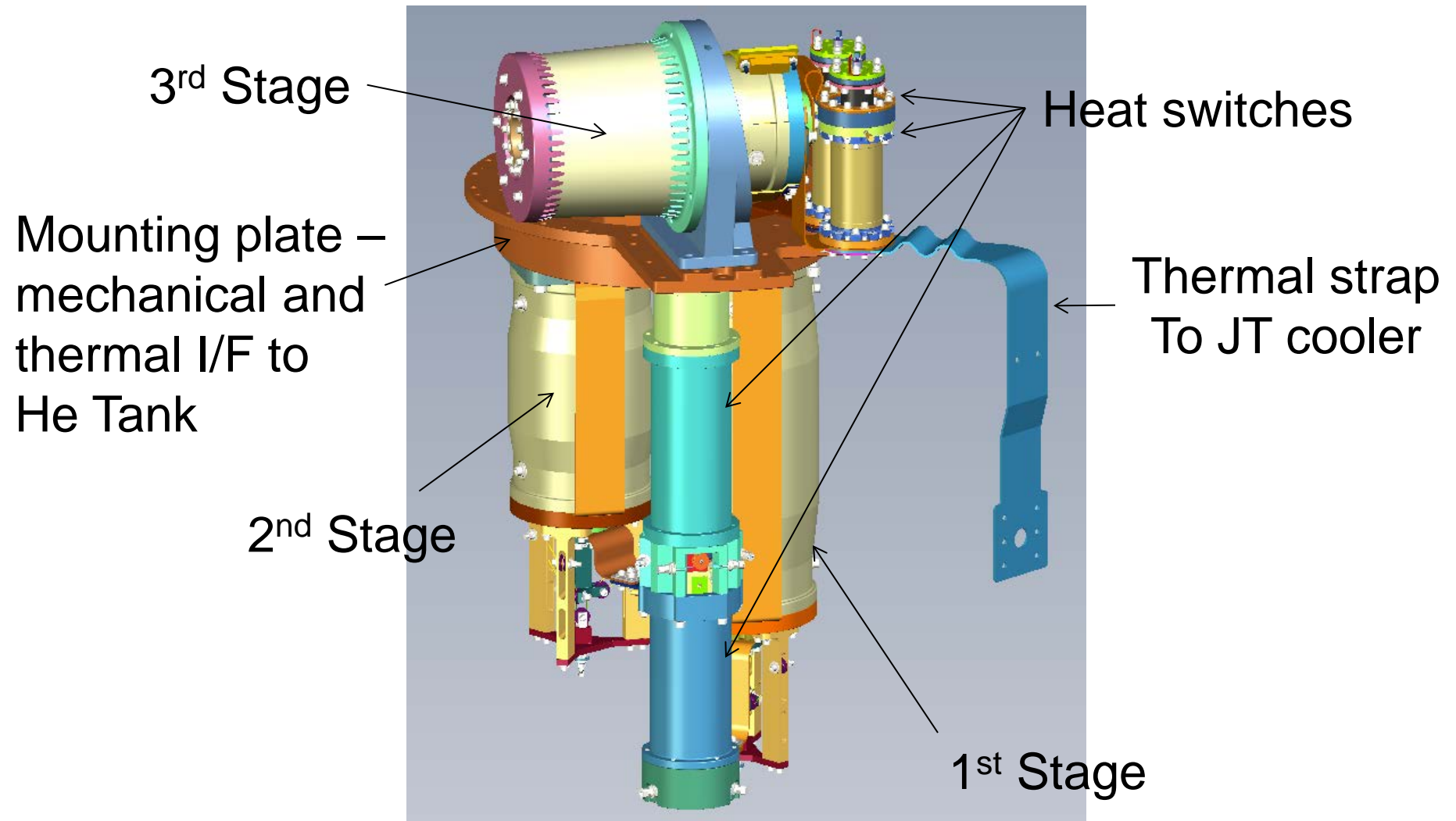
Requires 3- stage ADR

Astro-H Cryogenic System



NASA/GSFC hardware

ADR Layout



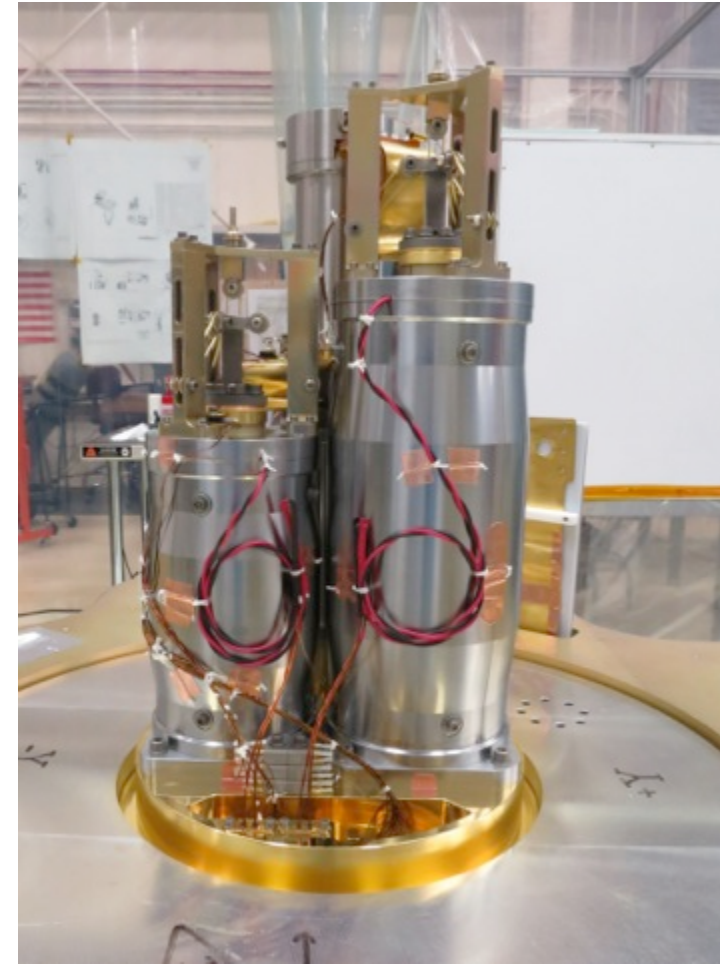
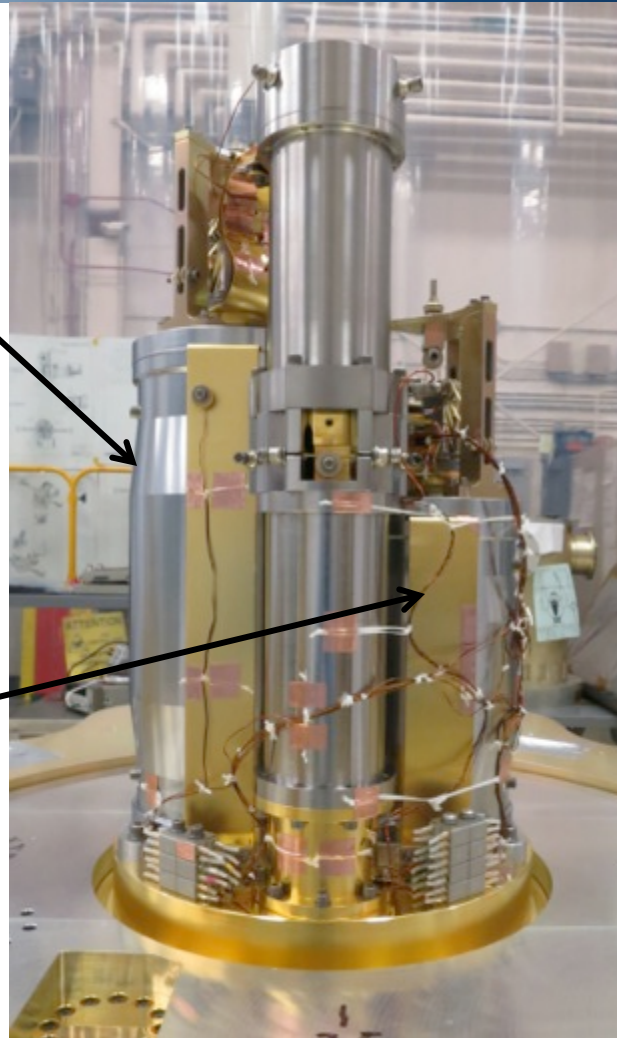
2-Stage ADR

Stage 1:

- 270 g CPA
- 2 T, 2 amp magnet

Stage 2:

- 150 g GLF
- 3 T, 2 amp magnet

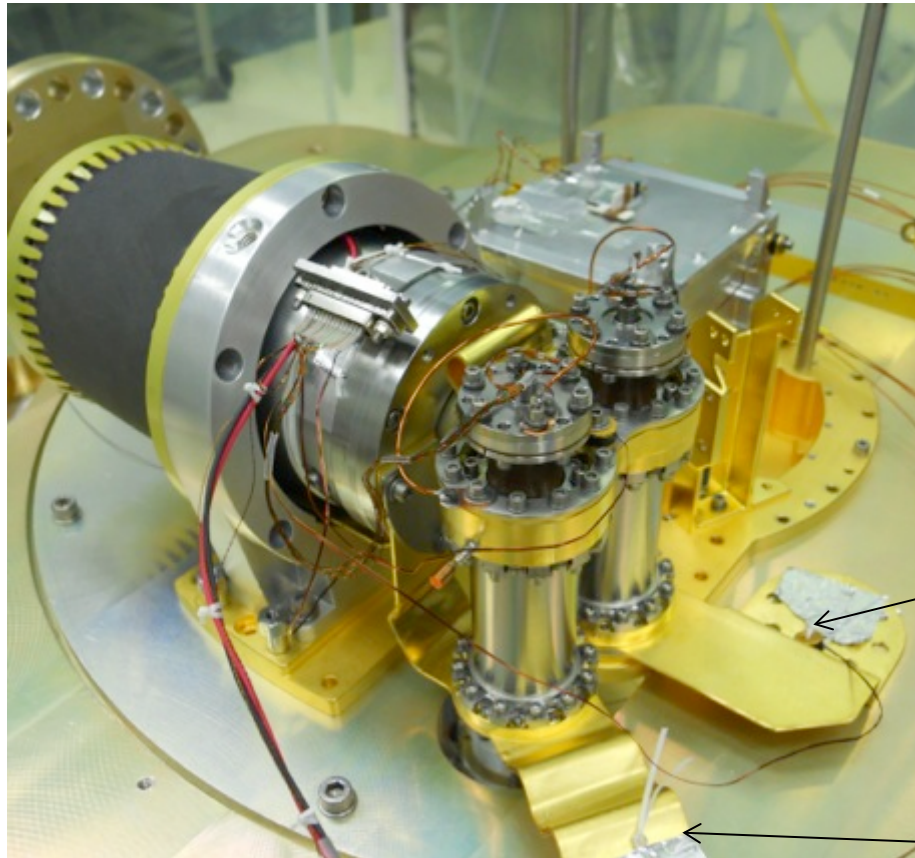


Heat switches are active gas-gap

3rd Stage ADR

Stage 3:

- 150 g GLF
- 3 T, 2 amp magnet

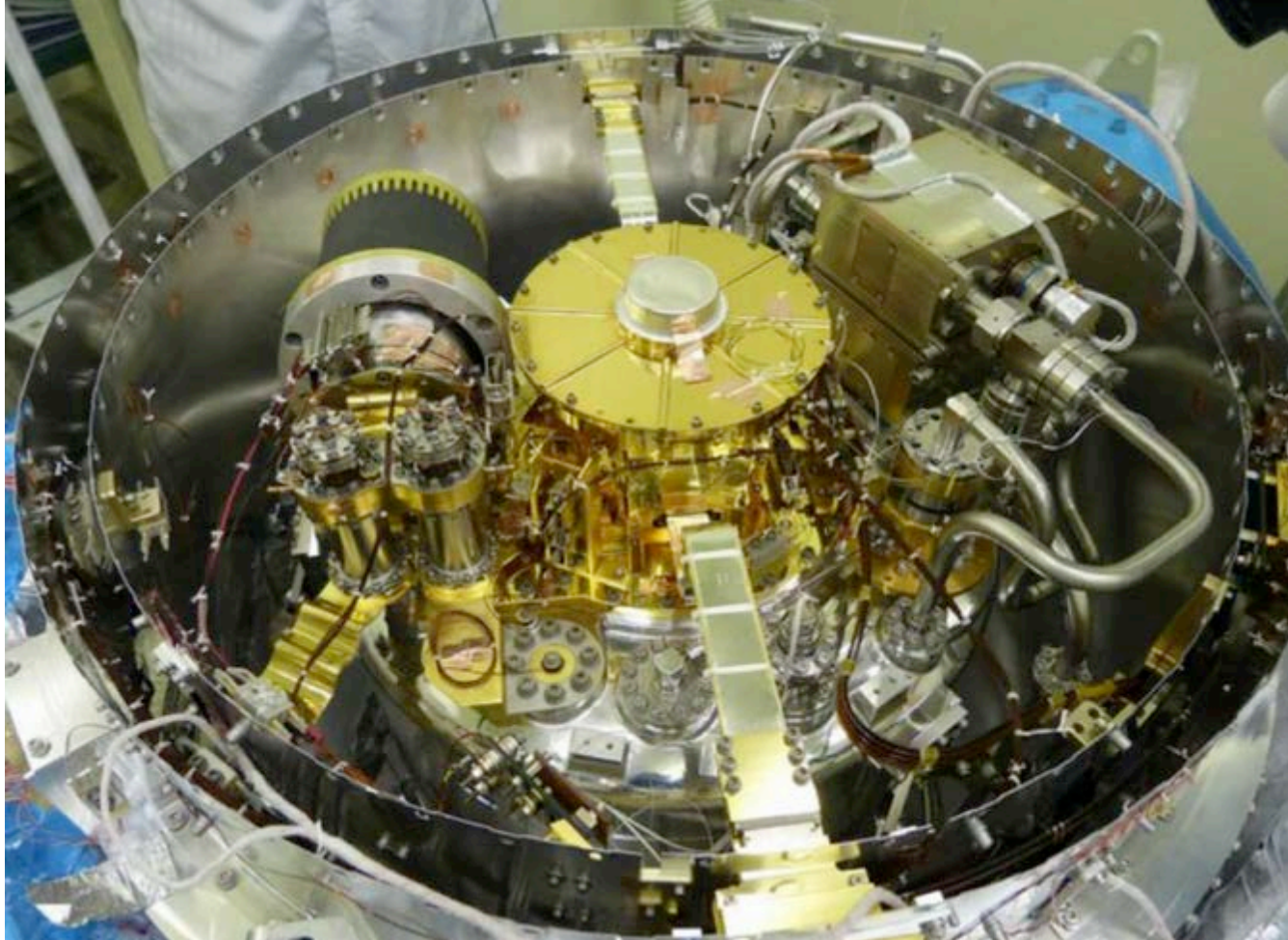


Thermal strap
to He tank

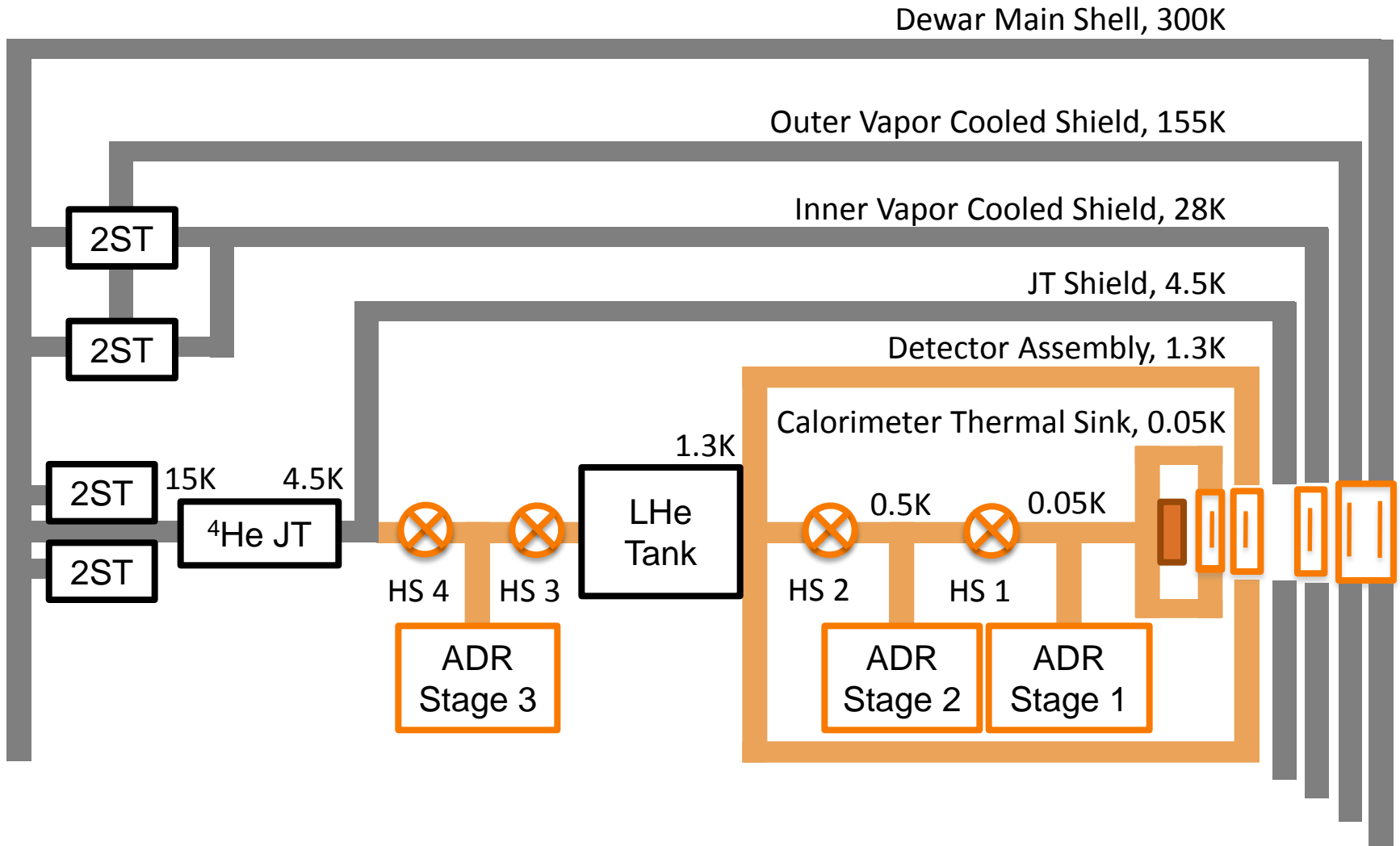
Thermal strap
to JT

Heat switches are active gas-gap

Flight ADR, Detector and Dewar (April '14)

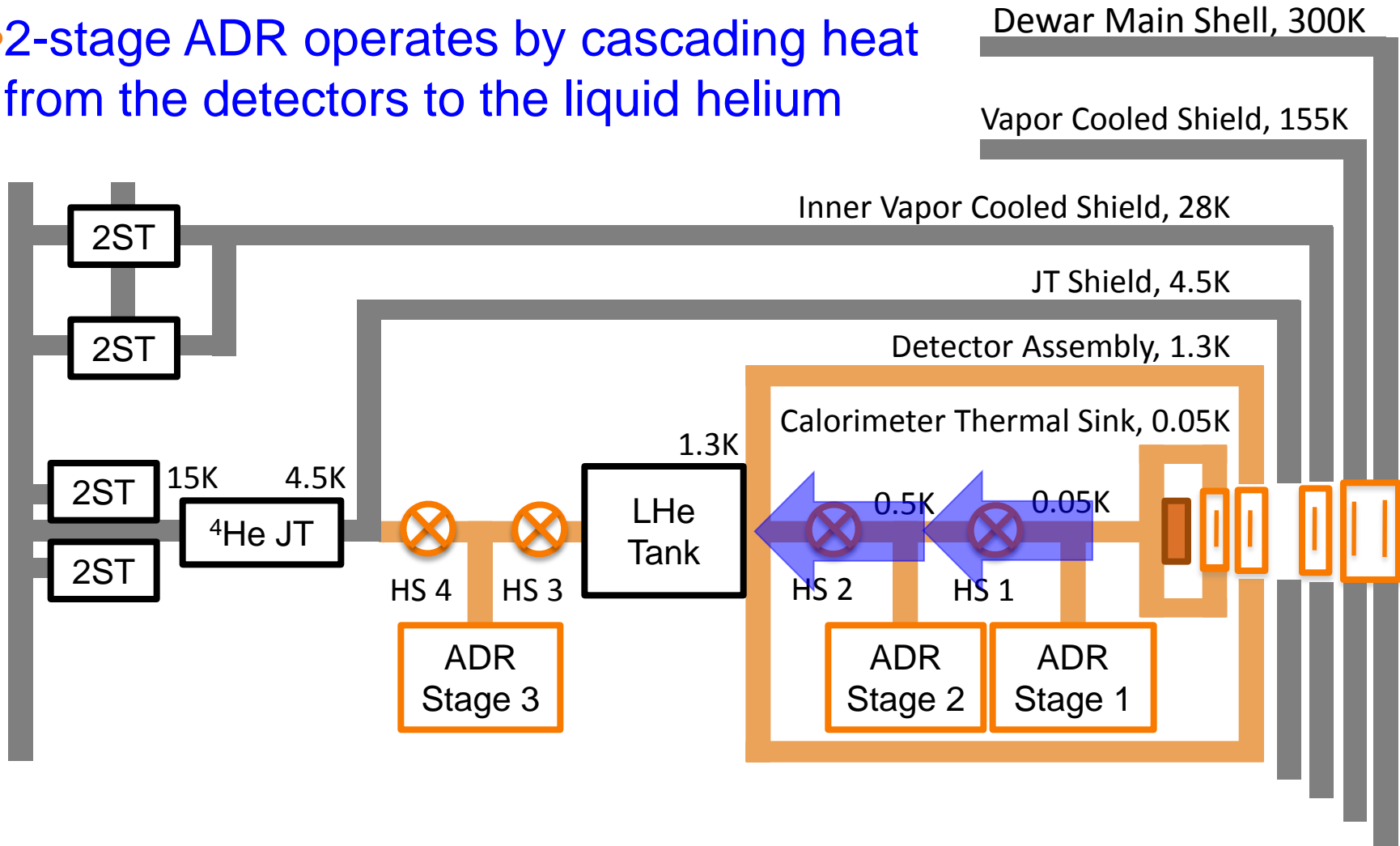


Astro-H Cryogenic System



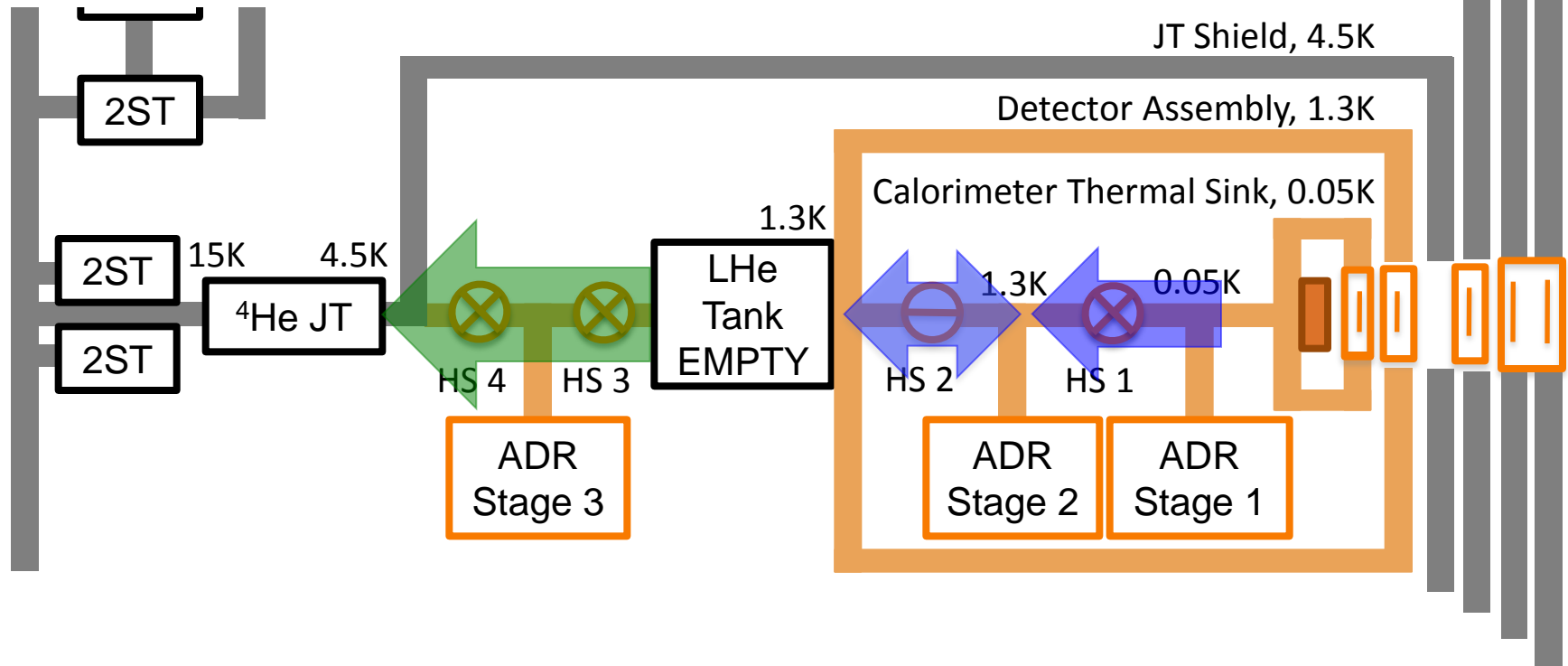
ADR Operation with Helium

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



Operation in Cryogen-Free Mode

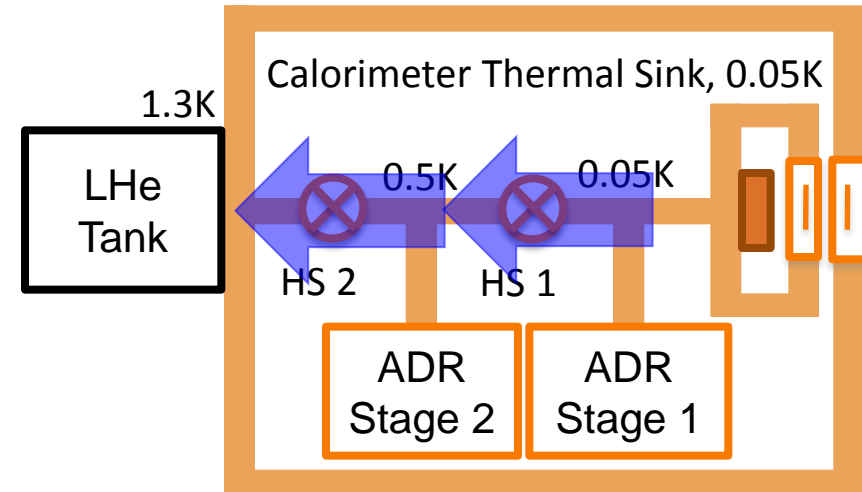
- 3rd stage transfers heat to JT cooler
- 2nd stage maintains helium tank temperature
- 1st stage cools detectors to 50 mK



Operation with Liquid Helium

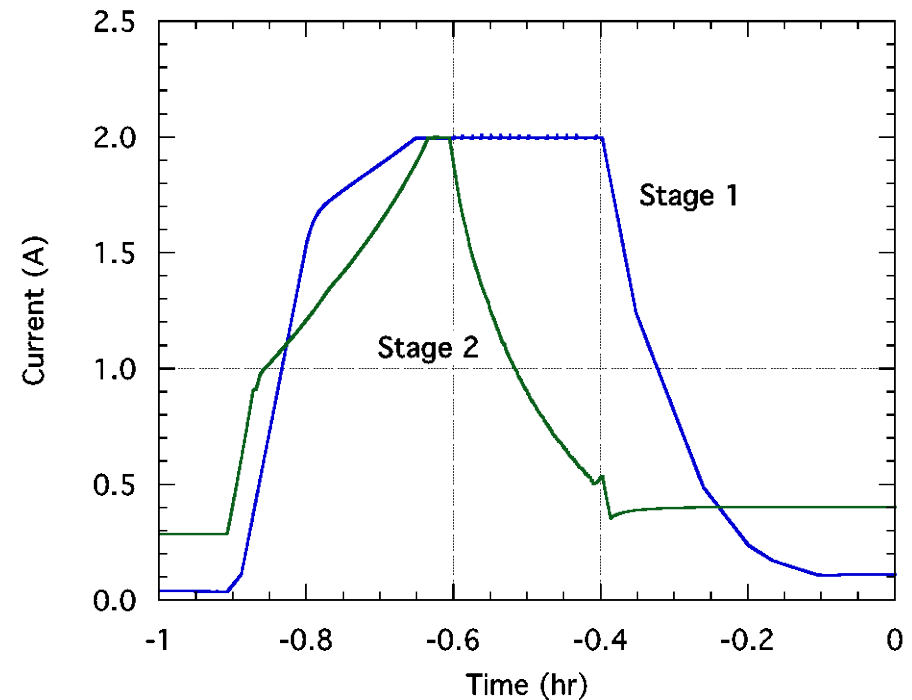
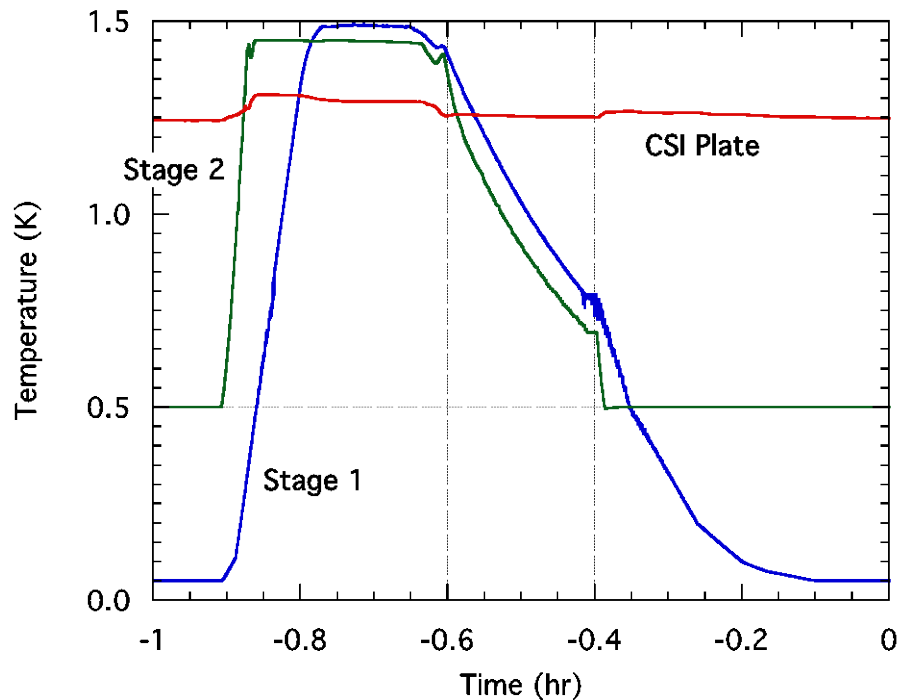
• Recycling sequence

- 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



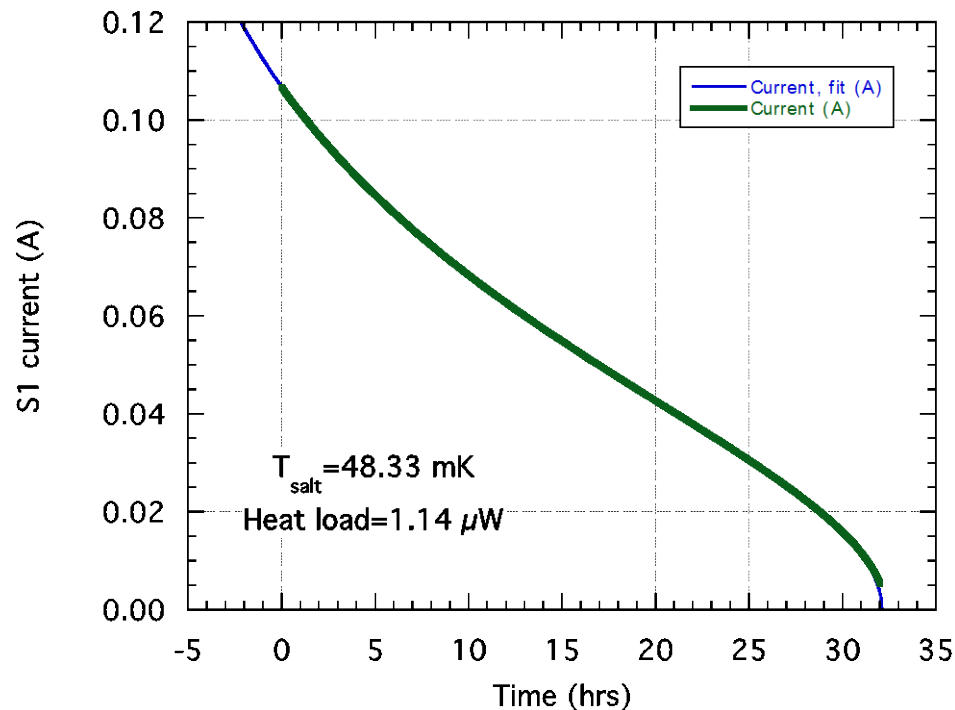
2-Stage ADR Cycling

- 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



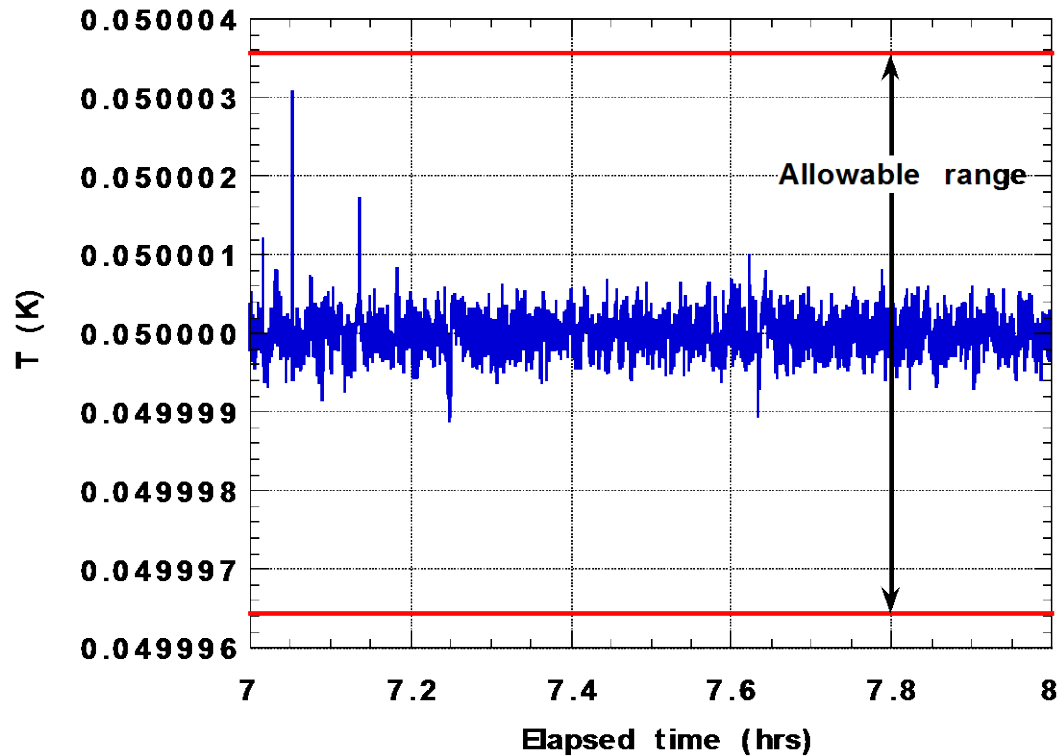
Stage 1 Hold

- Hold time of 32 hours
 - He bath at 1.25 K
 - On orbit expect <1.15 K, giving a hold time of 38 hours
- Heat load is 1.14 μW
 - Gives 84% heat absorption efficiency
 - Best fit to standard demag curve gives salt temperature of 48 mK



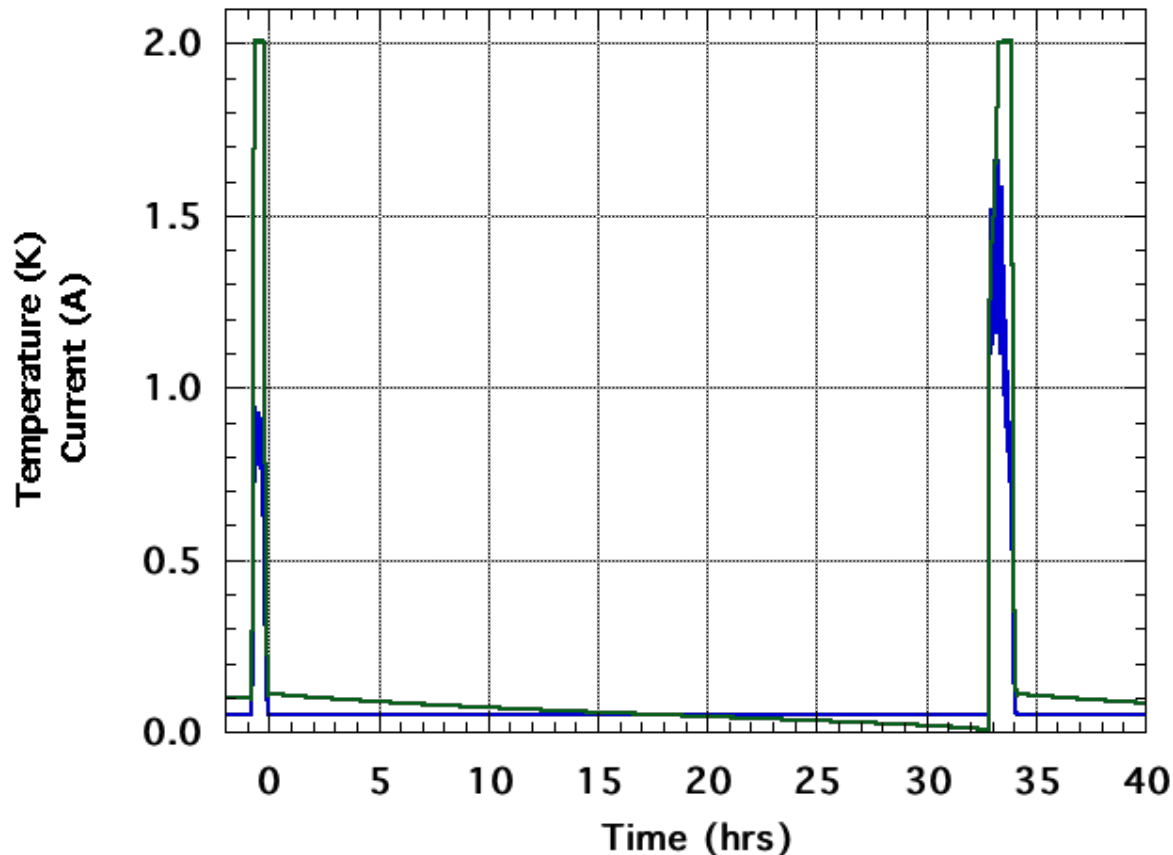
Temperature Stability

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



Autonomous Operation

- Recycling is triggered by Stage 1 current < 5 mA
- Control system operates autonomously based on preset parameters and real-time conditions (He tank temperature)

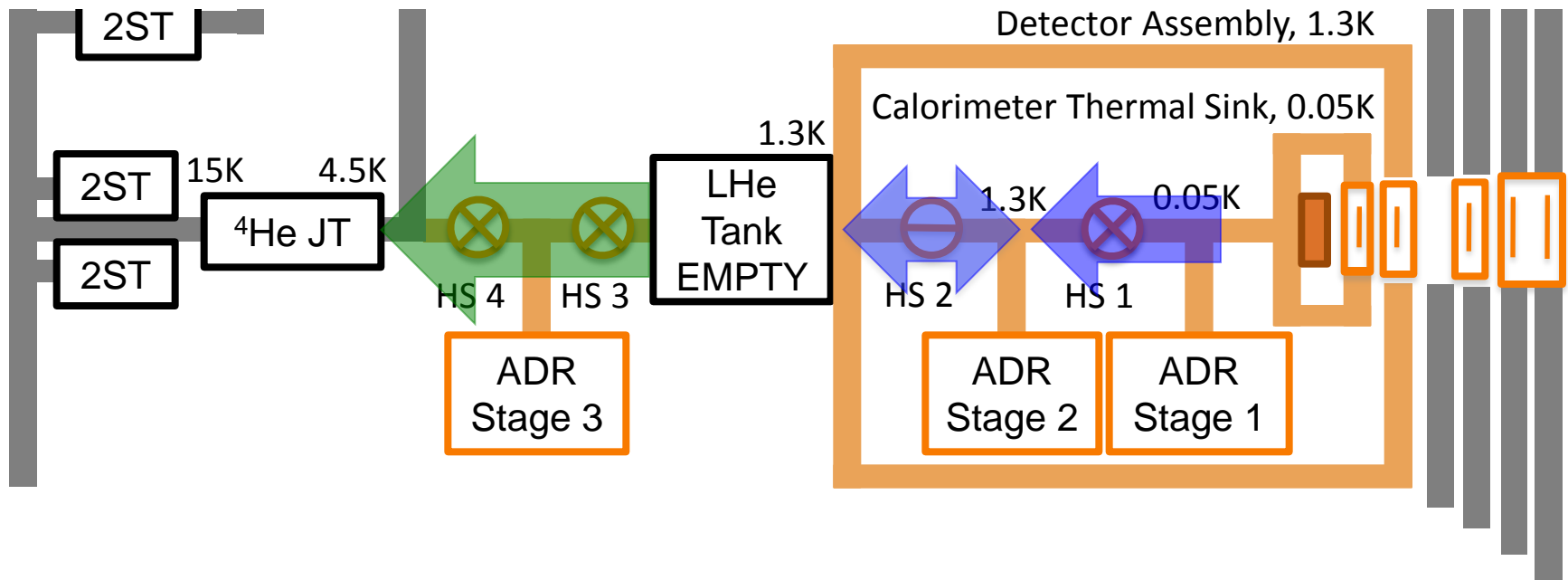


2-Stage ADR Operation Summary

- With He tank at ~ 1.25 K
 - Heat load on S1 was $1.14 \mu\text{W}$
 - Hold time at 50 mK is 32 hours
 - Recycle time (and recovery) < 1 hour
 - **Demonstrated observing efficiency of $> 97\%$**
- Temperature stability $< 1 \mu\text{K}$ rms
- Integrated heat flow to helium tank
 - Hysteresis from S1 and S2 magnets 4.61 J
 - HS1/HS2 getter power 2.19 J
 - Heat from S2 salt pill 8.11 J
 - Total 14.19 J
- Time average load to He tank is 0.120 mW
 - Requirement is < 0.2 mW

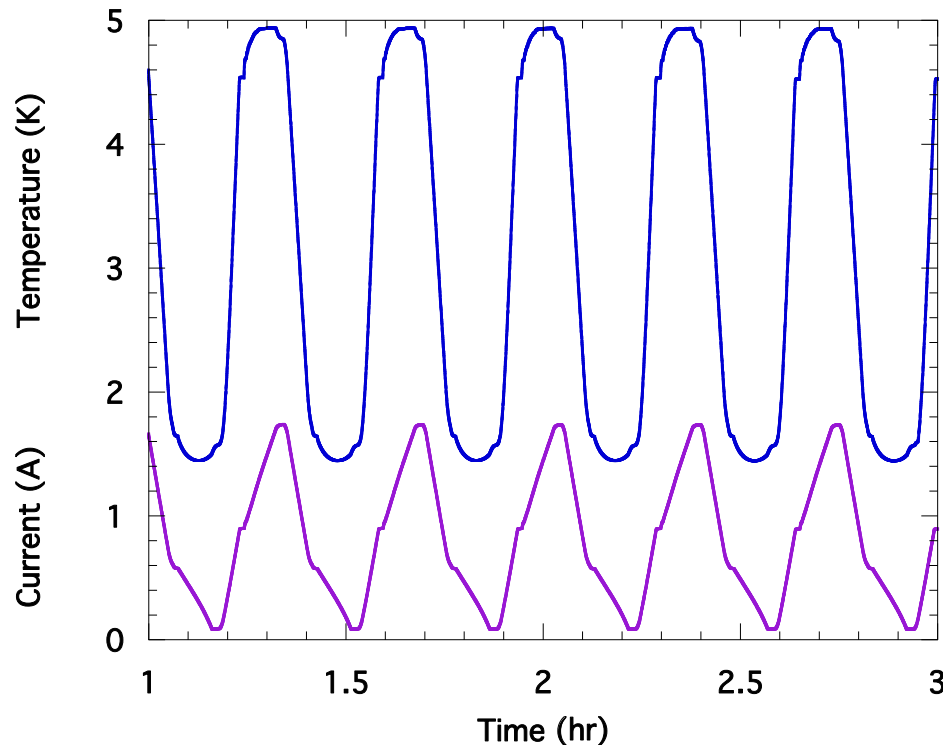
Cryogen-Free Operation

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

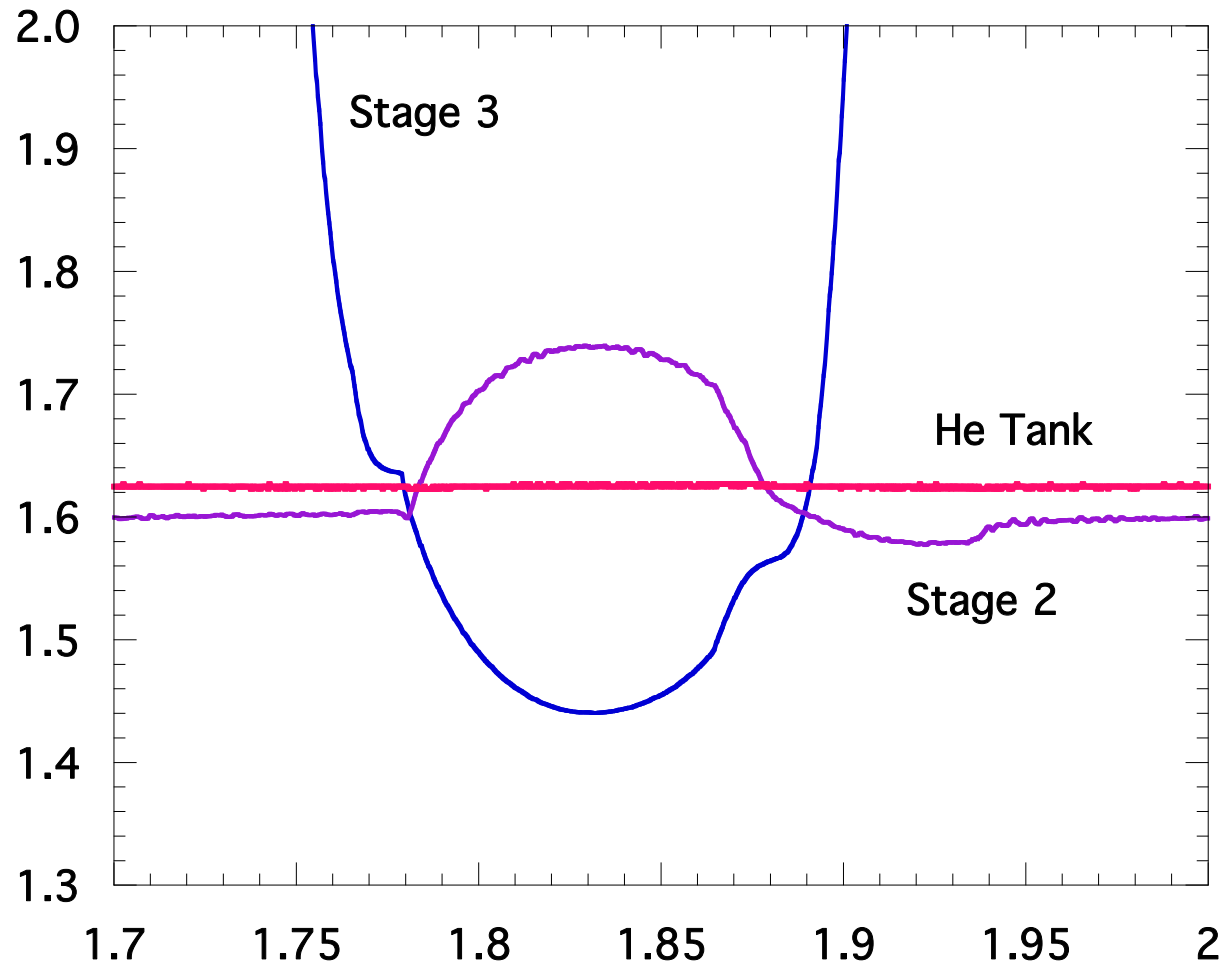


3rd Stage Cycling

- 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

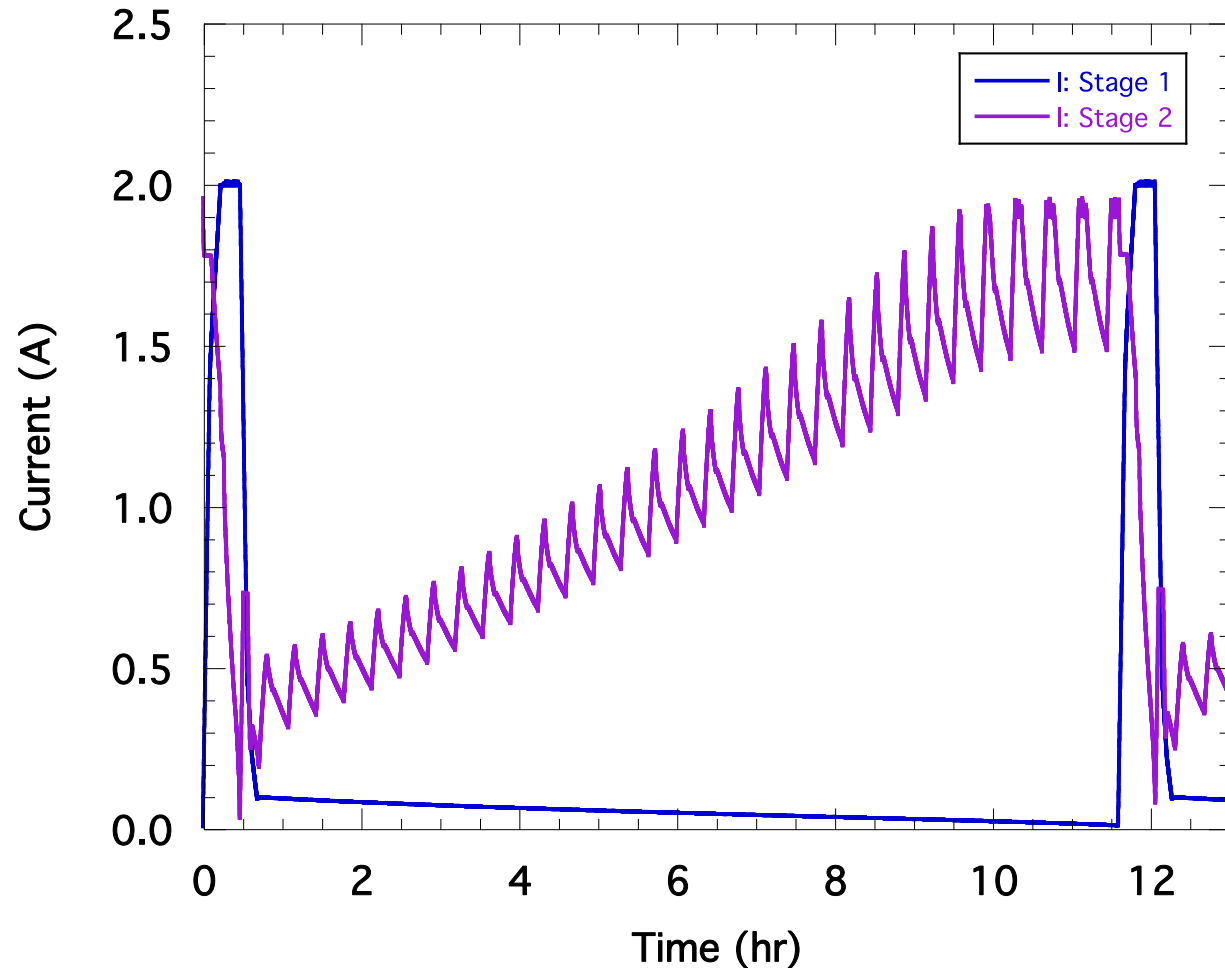


3rd Stage Cycling



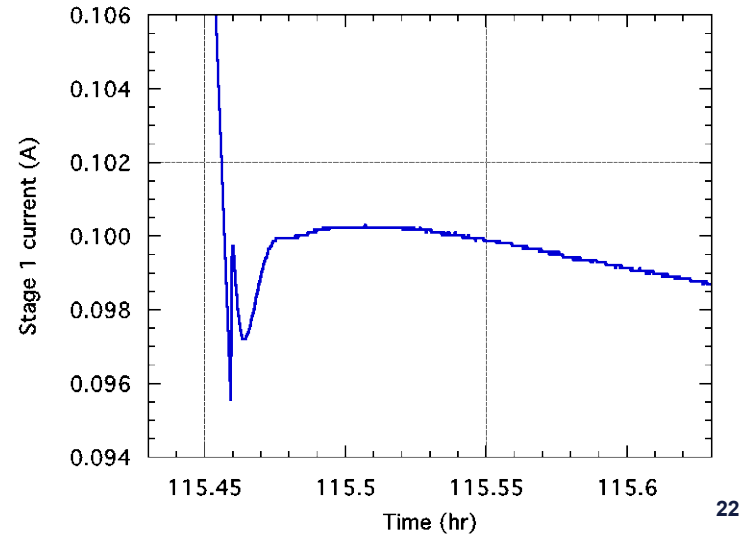
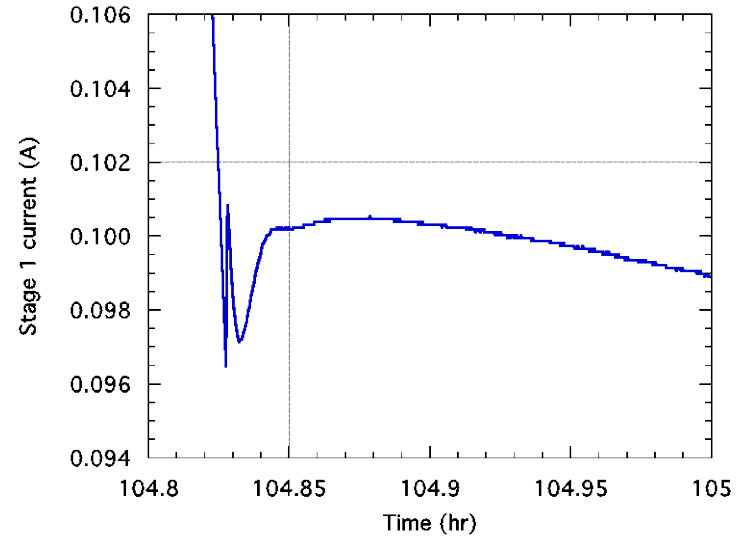
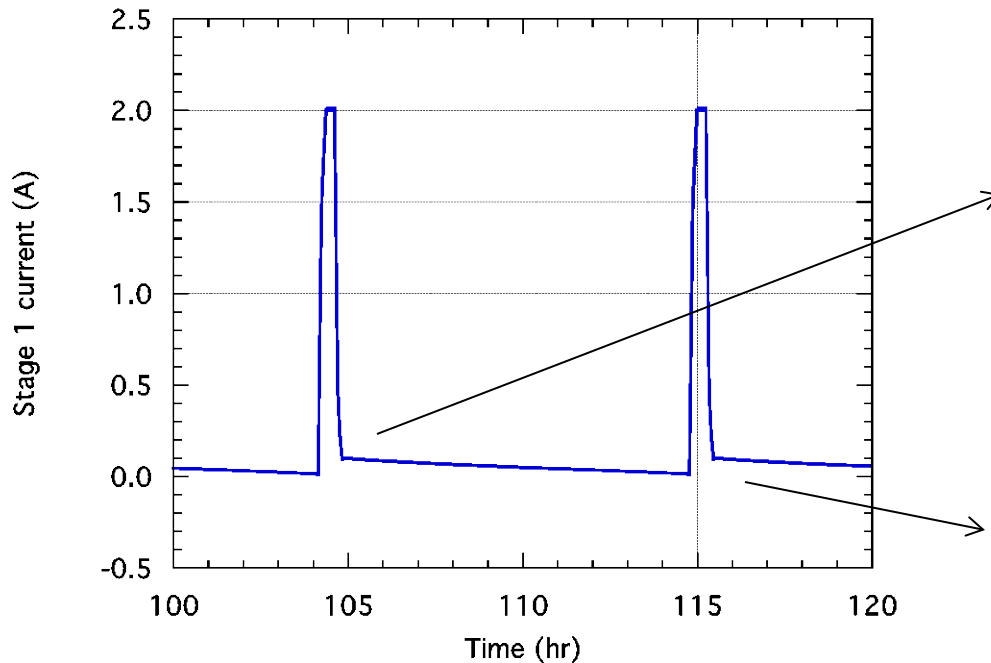
Full Cycle with He tank at 1.625 K

- 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



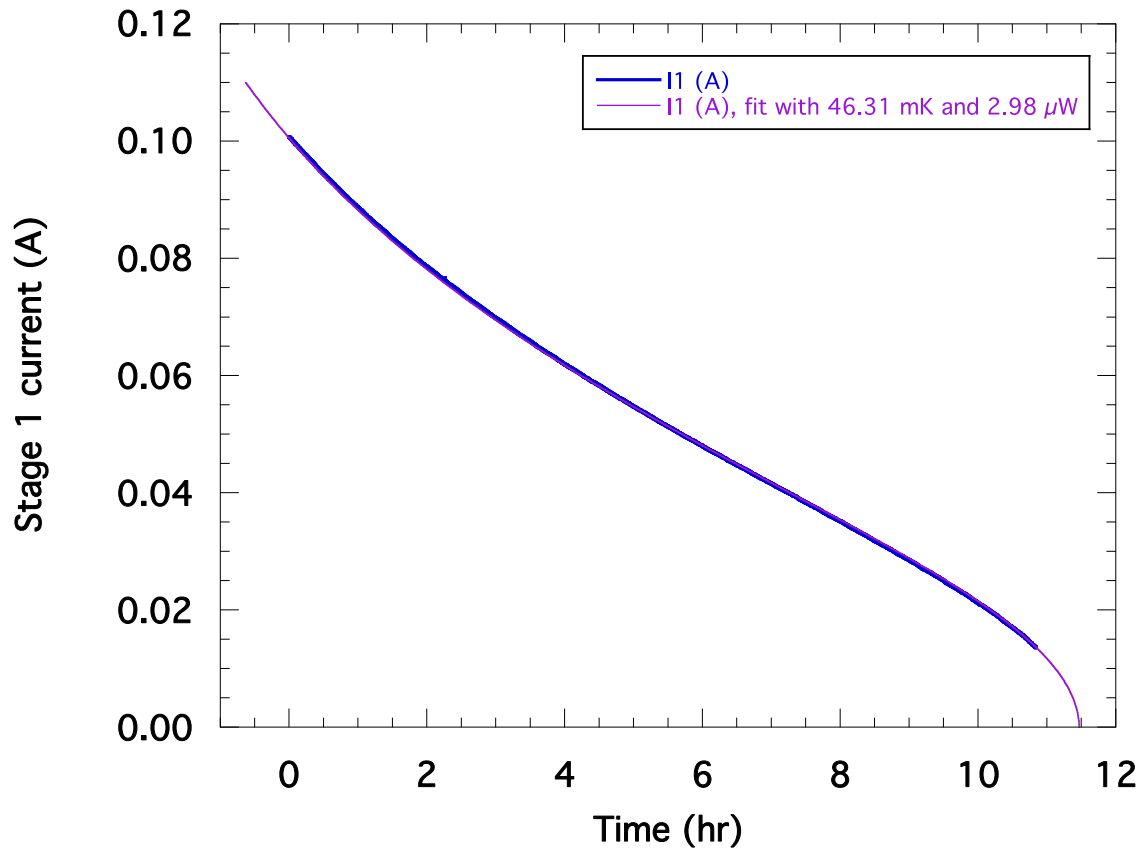
Starting Current at 50 mK

- Starting current from 0.80 K and 2 A is consistently 100 mA
 - +1, -2 mA



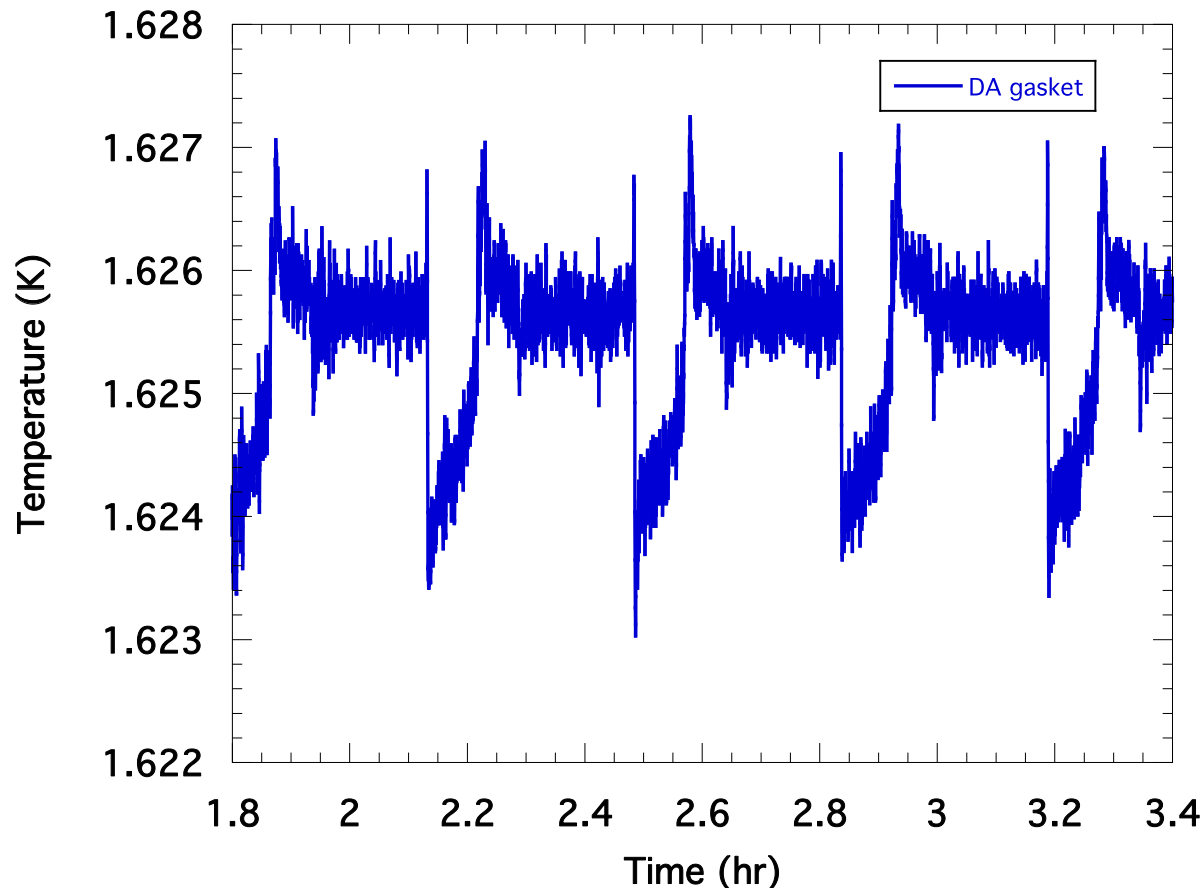
S1 Demag Curve Fit

- He tank at 1.625 K
 - S1 heat load = 2.98 μW
 - Salt temperature = 46.31 mK



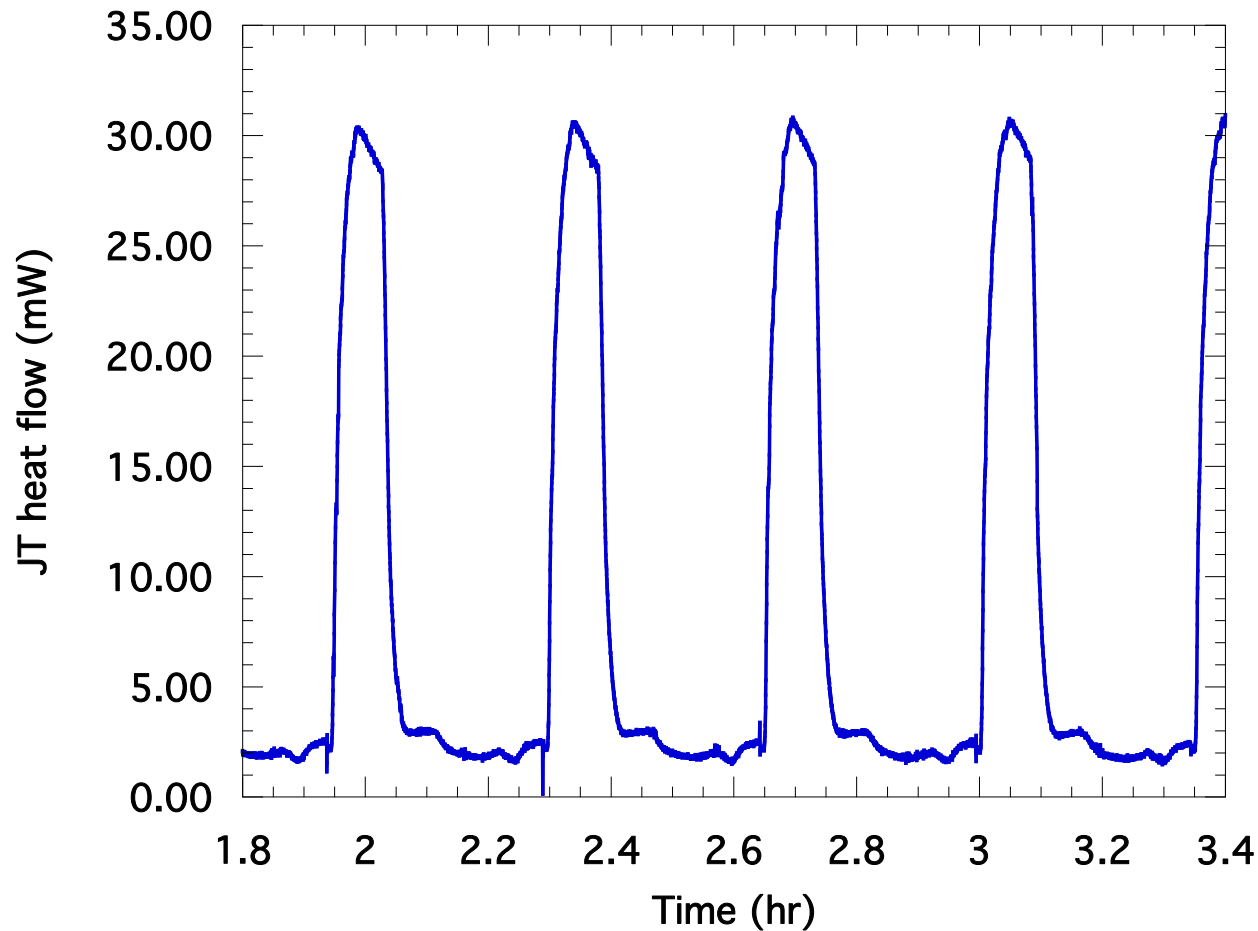
DA Housing Stability

- 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

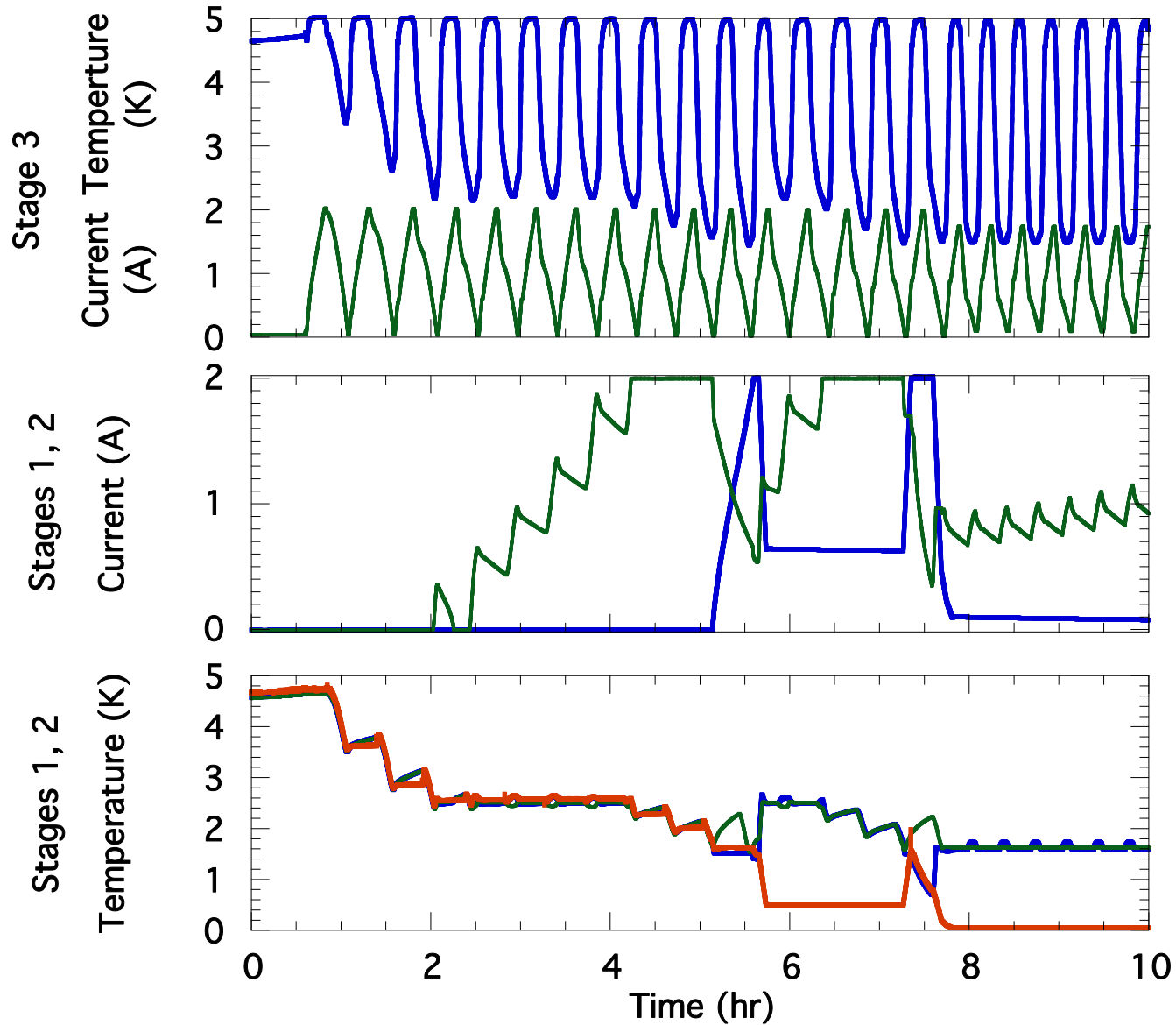
- Cycling was adjusted to give max heat flow of 30 mW
 - Maximum flow tolerable at nominal input power



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 should be autonomous (i.e. no intervention via ground control)

Cooldown from 4.5 K



Summary

- ADR has demonstrated autonomous control in nominal operating modes
 - 2-stage with helium, and 3-stage cryogen-free
 - Warm start, automatic recycling
- 2-stage with helium
 - Hold times ~32 hours
 - Recycle times <1 hour
 - Observing efficiency >97%
- 3-stage cryogen-free
 - Hold times typically ~11 hours
 - Heat load dominated by HS1 and kevlar from He tank
 - Recycle times <45 minutes
 - Observing efficiency >93%