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

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Astro-H Soft-X-ray Spectrometer

- 6x6 array of x-ray microcalorimeters cooled to 50 mK
• ADR is used to cool the detectors to 50 mK
  – 0.25 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 10 min)
Astro-H Cryogenic System

Dewar Main Shell, 300K

Outer Vapor Cooled Shield, 155K

Inner Vapor Cooled Shield, 28K

JT Shield, 4.5K

Detector Assembly, 1.3K

Calorimeter Thermal Sink, 0.05K

LHe Cryostat

ADR Stage 3

1.3K

4He JT

HS 4

HS 3

ADR Stage 2

ADR Stage 1

0.5K

0.05K

HS 2

HS 1
• 2-stage ADR operates by cascading heat from the detectors to the liquid helium.

- Detector Assembly, 1.3K
- Calorimeter Thermal Sink, 0.05K
- JT Shield, 4.5K
- Inner Vapor Cooled Shield, 28K
- Outer Vapor Cooled Shield, 155K
- Main Shell, 300K
Astro-H Cryogenic System

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

Heat Switch 1
Heat Switch 2
Stage 1
Stage 2
Thrust Tube
Stage 3
Heat Switch 3
Heat Switch 4
• 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

![Graph showing temperature and current over time for Stage 1 and Stage 2 of ADR Cycling.](image)
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
• Current during demagnetization fits well to standard curve

![Graph showing current (A) over time (hrs)]
Temperature Stability

• Required stability: 2.5 μK rms
• Actual: 0.37 μK rms
Autonomous Operation (GSFC Testing)

- 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 (cryocoolers at nominal power)
  – Heat load on S1 was 1.14 μW
  – Hold time at 50 mK is 32 hours
  – Recycle time (and recovery) <1 hour
  – Demonstrated observing efficiency of >97%

• Temperature stability <1 μK rms

• Issues
  – Heat load on S1 salt pill is higher than expected based on measurements at GSFC
    • With 1.25 K tank, expected <0.9 μW
  – Appears to be directly related to JT operation
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
3\textsuperscript{rd} 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
Full Cycle with He tank at 1.625 K

- 40 minute recycle
- 11.0 hour hold
- >94% observing efficiency
- S2 charges during hold time
- Some excess capability is evident
  - Can support 1.60 K operation
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
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

• Control should be autonomous (i.e. no intervention via ground control)
Cooldown from 4.5 K
Starting Current at 50 mK

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

![Graph showing current vs time](image1.png)

![Graph showing current vs time](image2.png)
• 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%