Final Summary of On-Orbit ADR Operation on Hitomi's Soft X-ray Spectrometer Instrument

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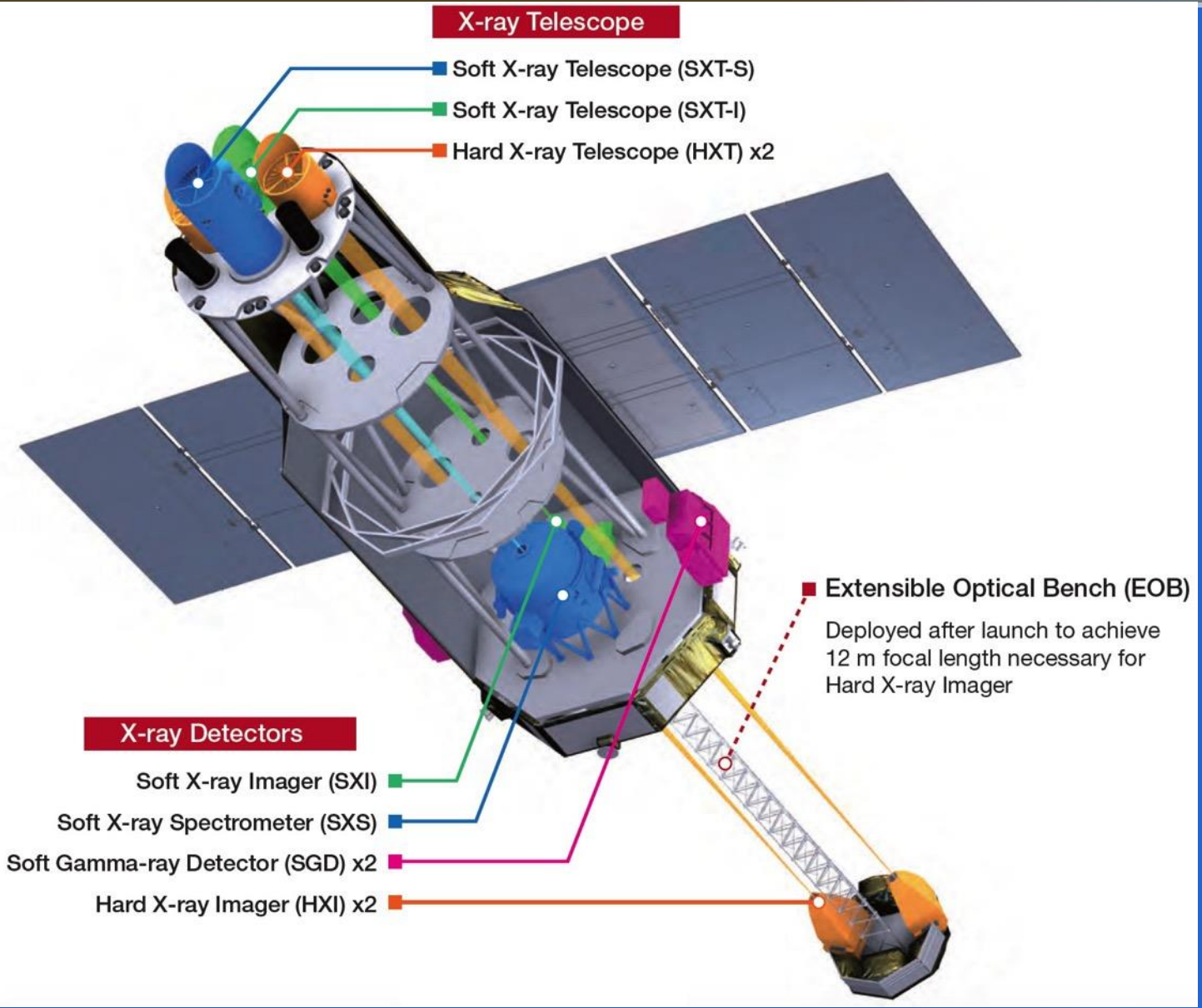
March 8, 2016

Launch: February 17, 2016

Hitomi (formerly Astro-H)



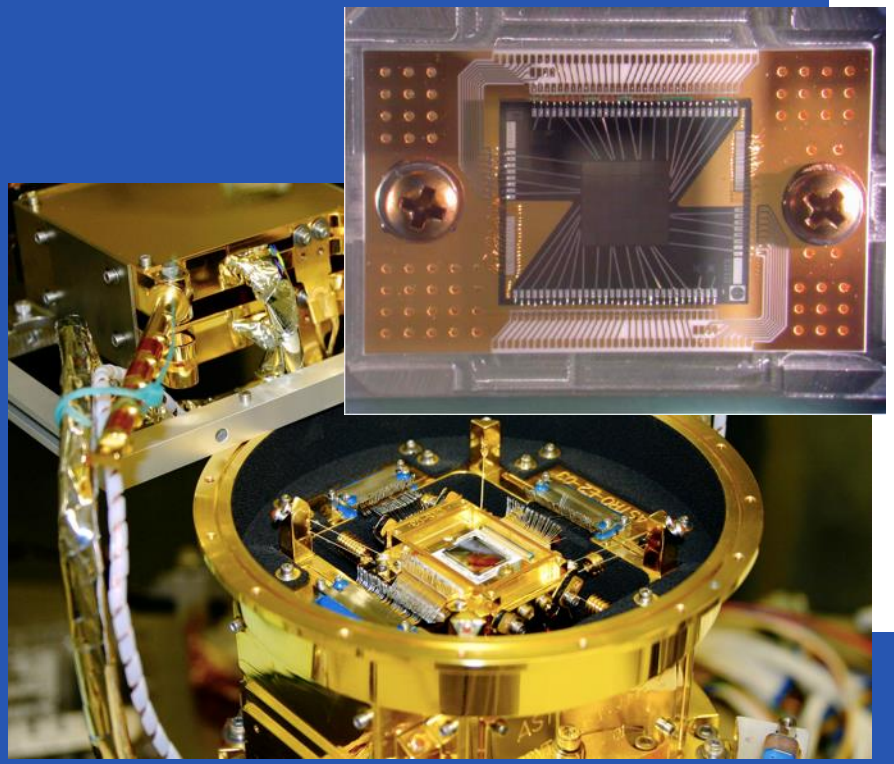
Study structure and evolution of the Universe

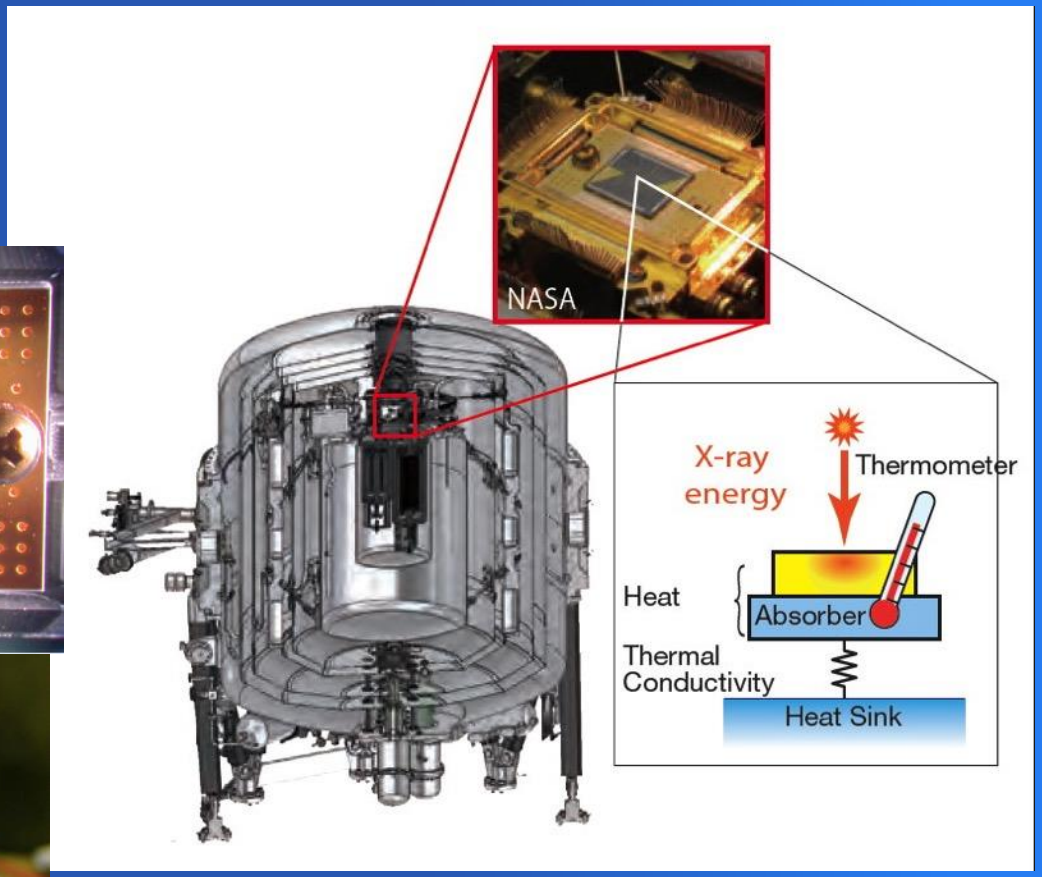
Study matter in extreme environments

- Black holes
- Galaxies
- Heavy elements
- Cosmic rays

Soft X-ray Spectrometer

- Hybrid cooling system: superfluid helium dewar with 4.5 K JT shield cooler
  - Redundant ADR heat sinks
- ADR for detector cooling
  - 50 mK operation

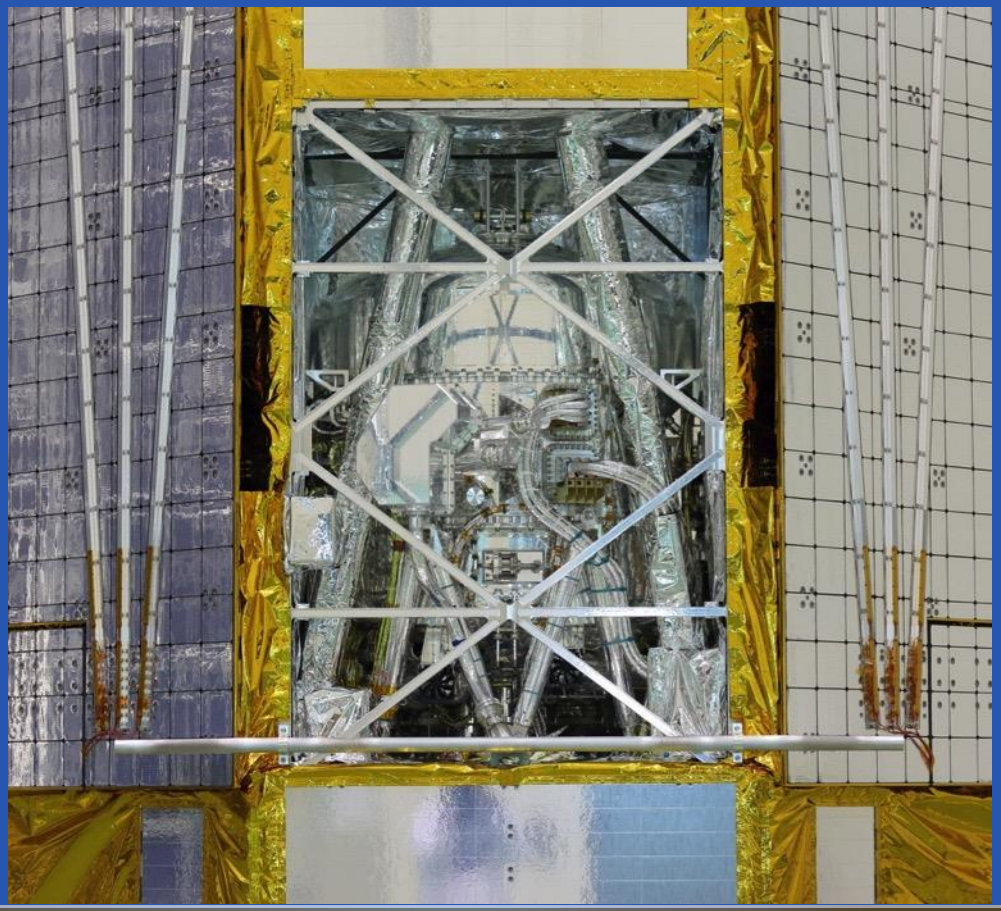


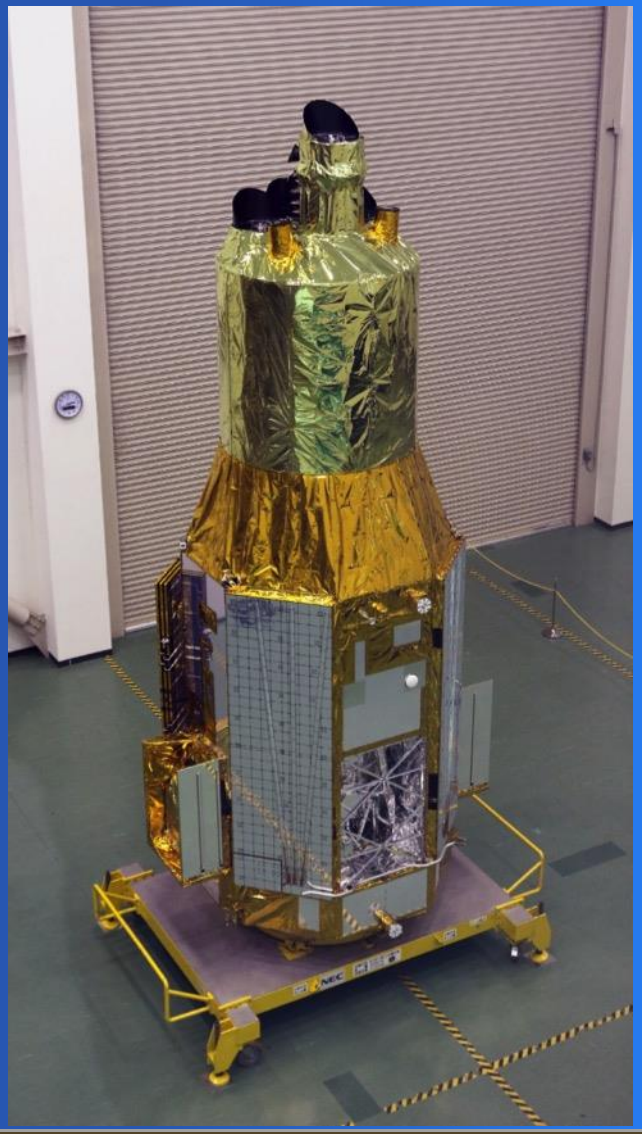


Low temperature ⇔ low heat capacity
ΔE ~ 4-5 eV for 0.2-13 keV x-rays

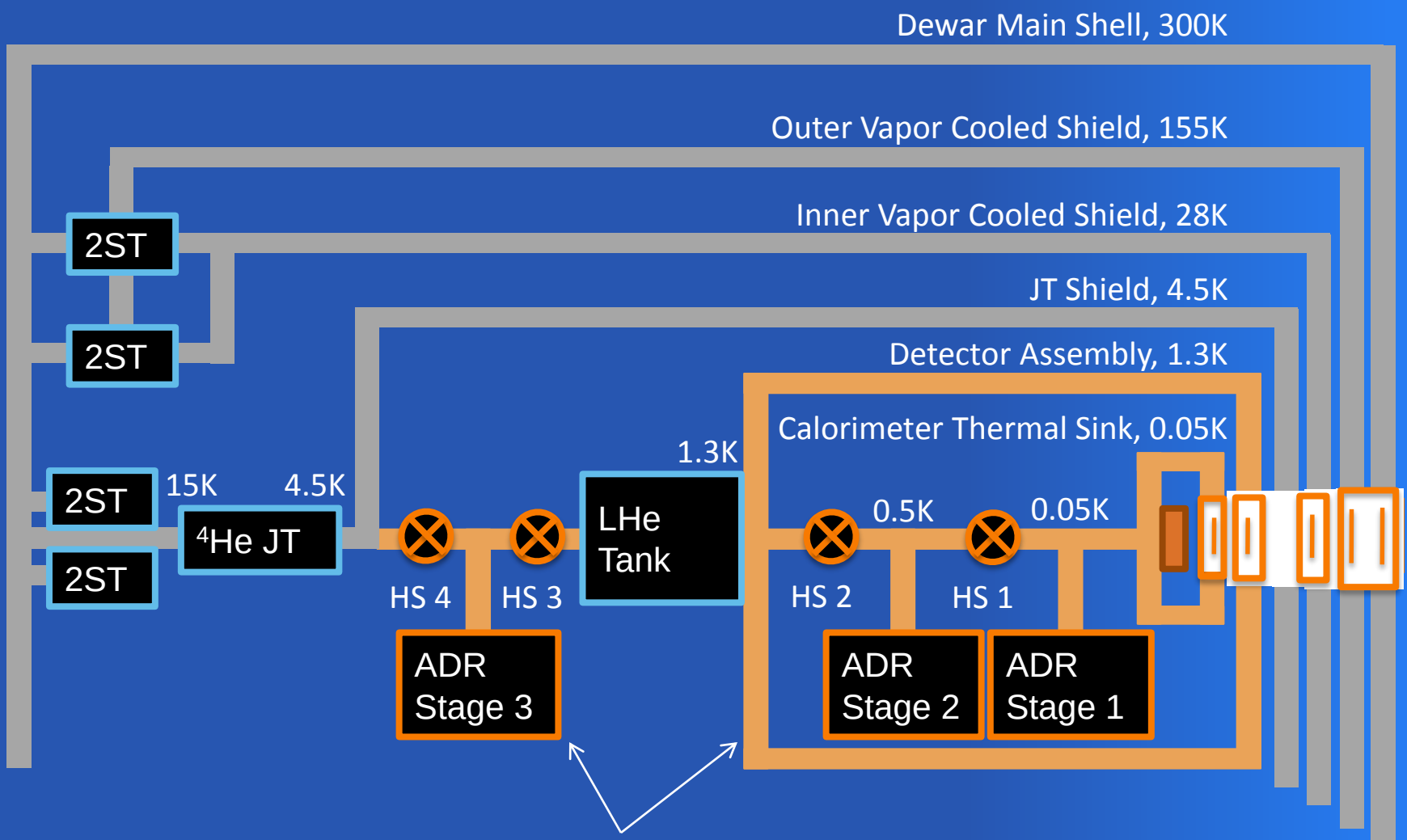
Soft X-ray Spectrometer

November 2015, Tsukuba Space Center, Japan (photos courtesy of JAXA)



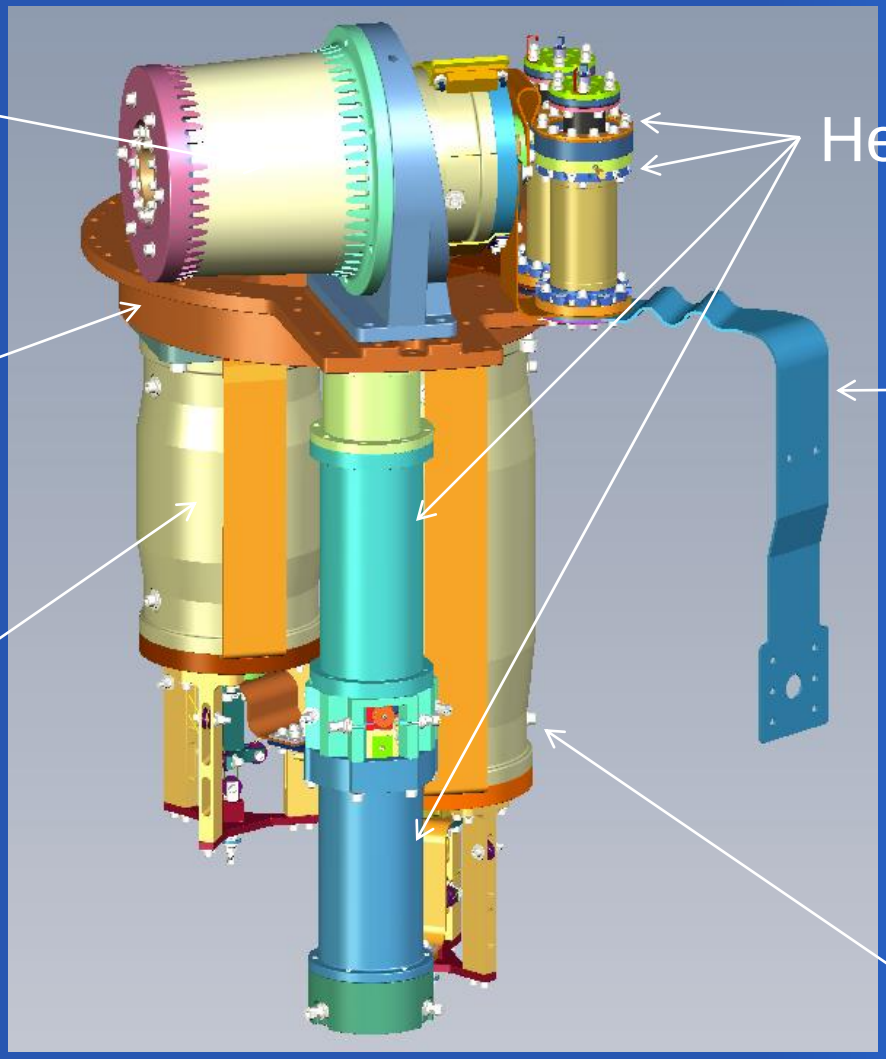


SXS Cryogenic System



NASA/GSFC hardware

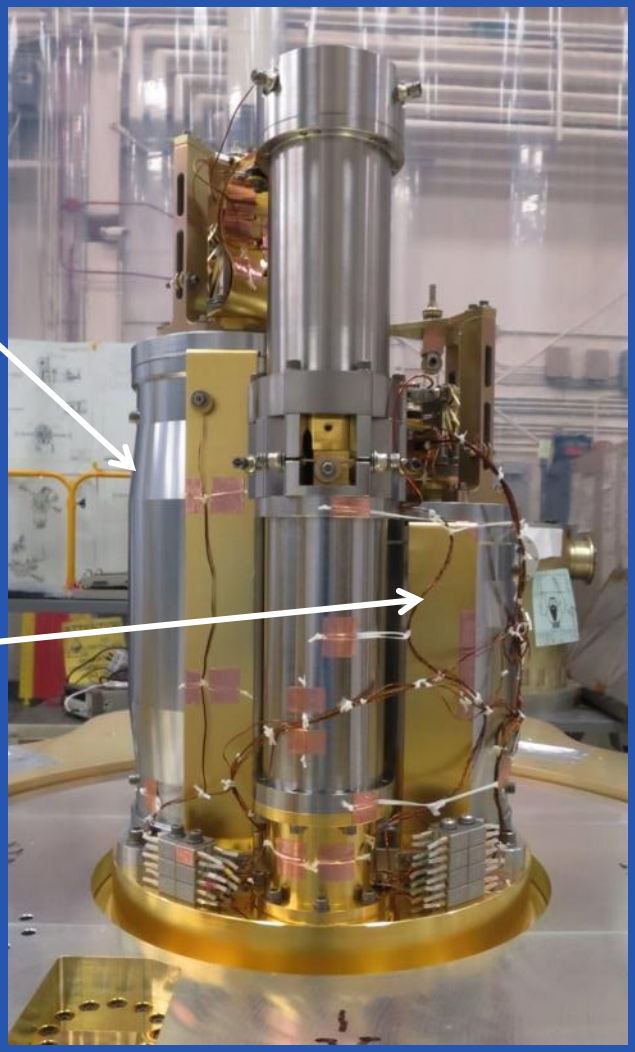
SXS ADR Layout

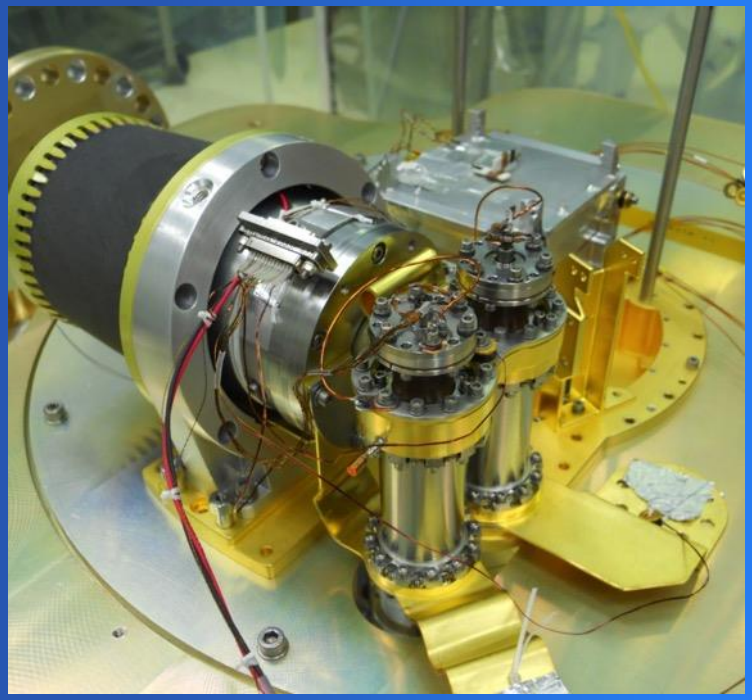


ADR Assemblies

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

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

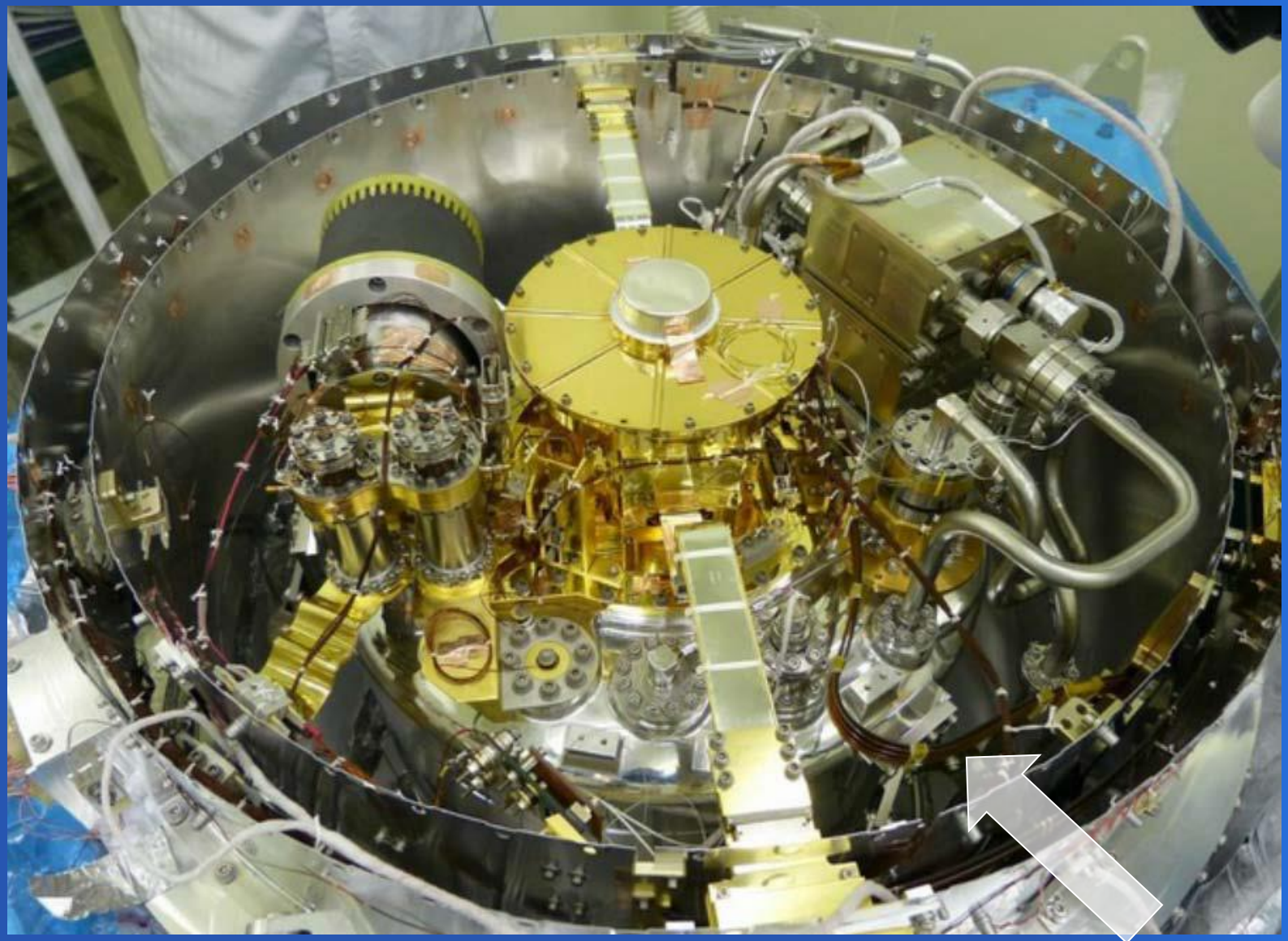




Stage 3:
- 150 g GLF
- 3 T, 2 amp magnet

Heat switches are active gas-gap

Flight ADR, Detector and Dewar (April ‘14)



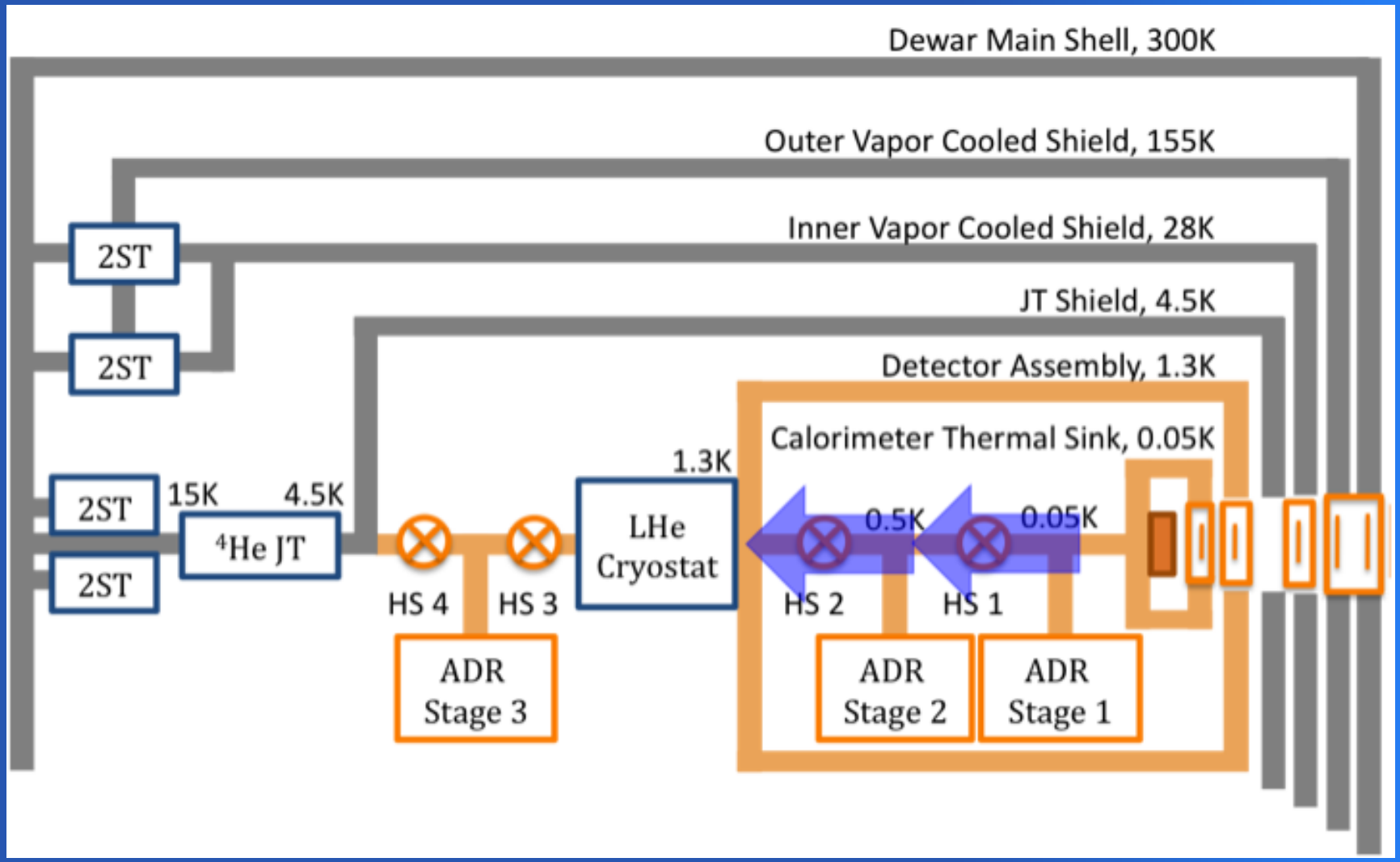
HTS leads:

YBCO tape

Supported by carbon fiber composite carrier

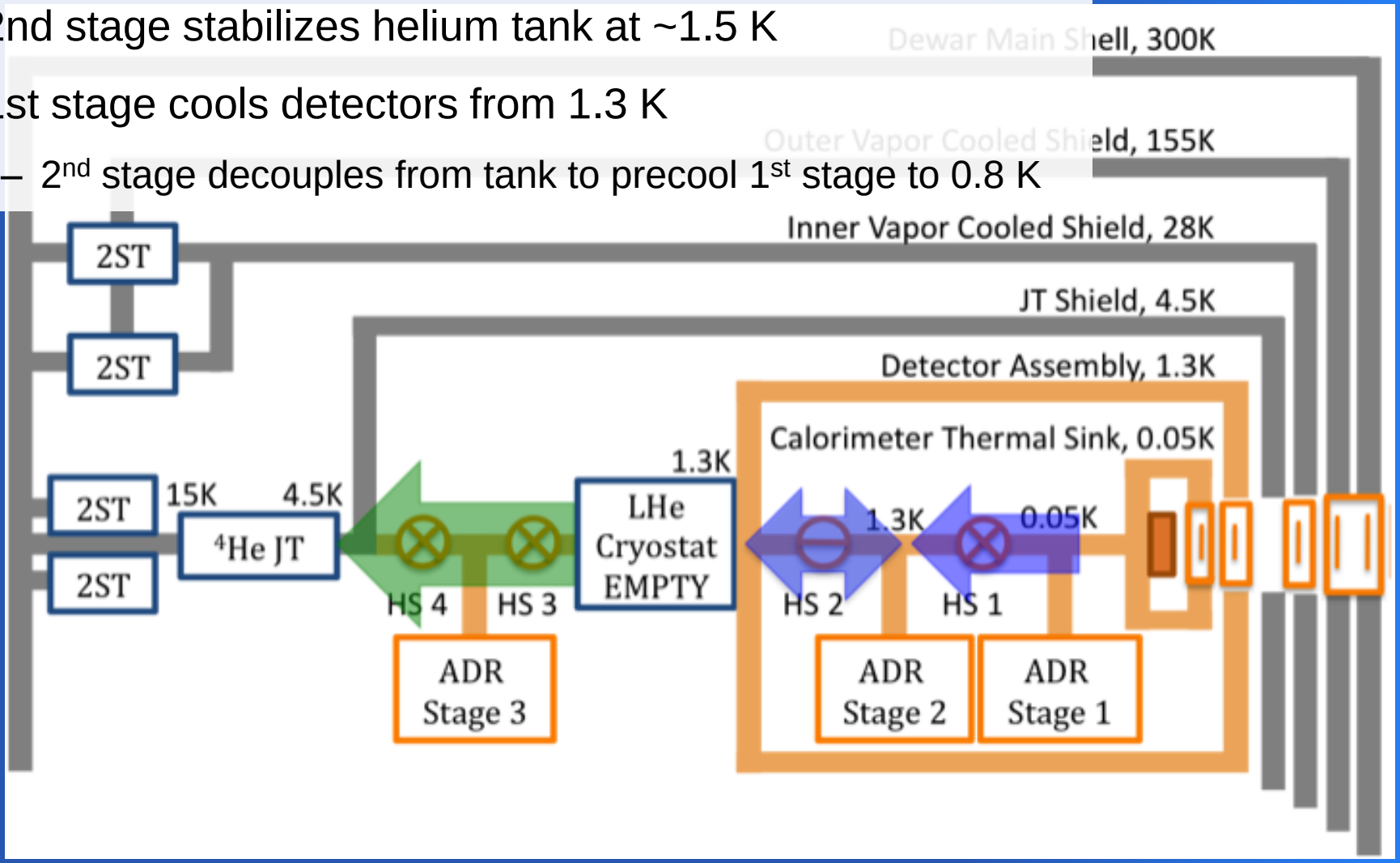
ADR Operation with Liquid Helium

2-stage ADR uses liquid helium as a heat sink



ADR Operation in Cryogen-Free Mode

- 3rd stage transfers heat from tank to JT cooler
- 2nd stage stabilizes helium tank at ~1.5 K
- 1st stage cools detectors from 1.3 K
  - 2nd stage decouples from tank to precool 1st stage to 0.8 K

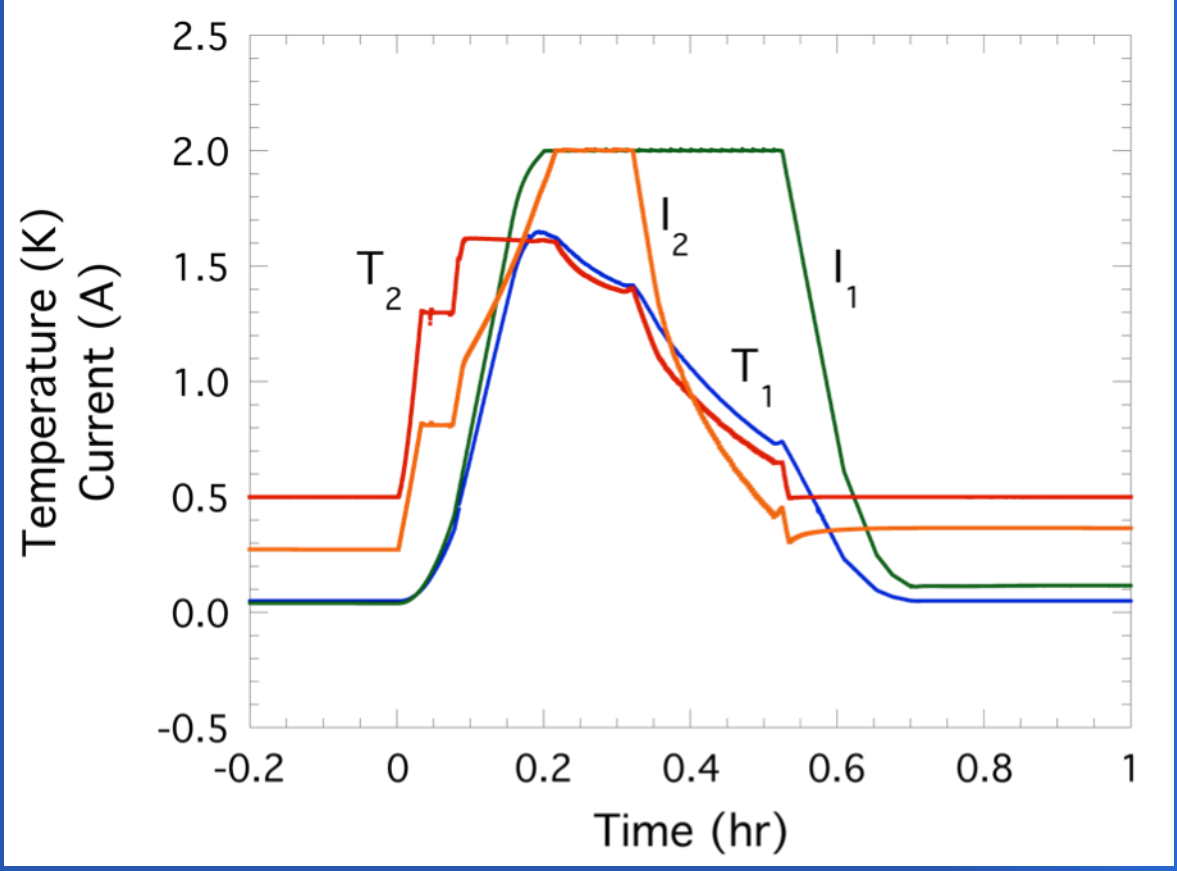


Astro-H Design and Operating Strategy

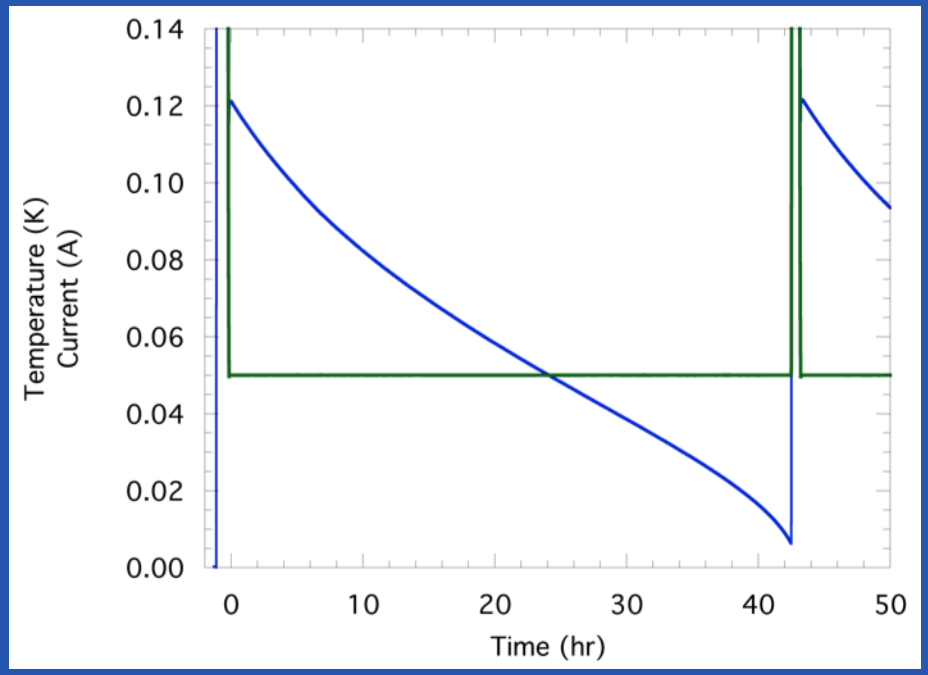
- SXS is launched with minimum of 33 L of liquid helium (<1.3 K)
  - Cryocoolers act as guards to intercept parasitic heat loads
  - Nominal lifetime >3 years
- 2-stage ADR single-shot cools the detectors, rejecting heat to the liquid helium
- When helium is depleted, ADR operation changes to 3-stage operation
  - Upper stages continuously cool the helium tank, rejecting heat to 4.5 K JT cooler
  - CPA stage single-shot cools the detectors, rejecting heat to He tank

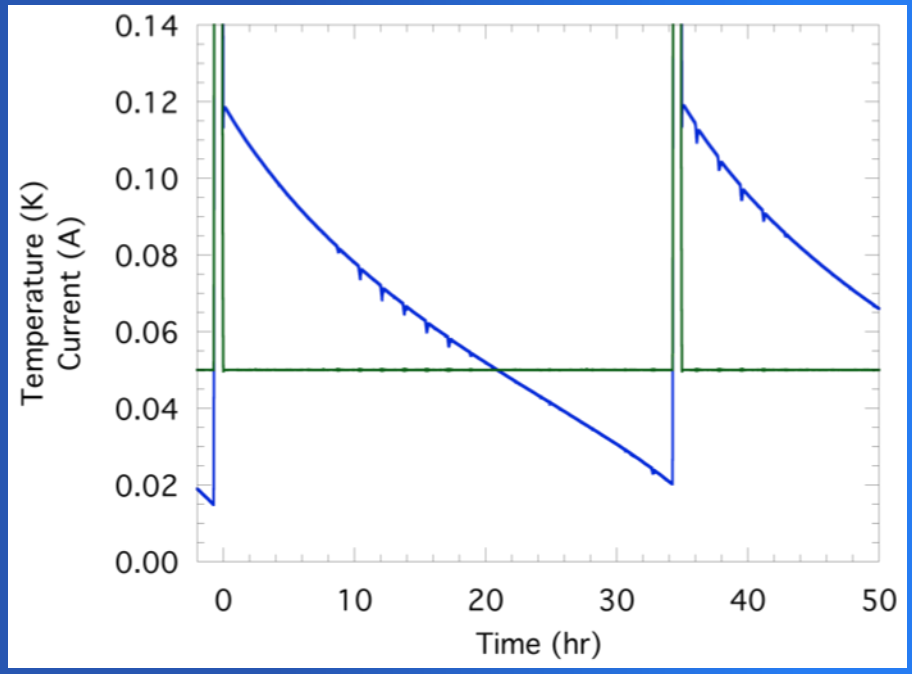
ADR Recycling

- Recycling sequence was structured to minimize recycle time and to minimize I^2R heating of the IVCS
  - JFET amplifiers are thermally coupled to IVCS



Stage 1 Performance – Ground vs On Orbit

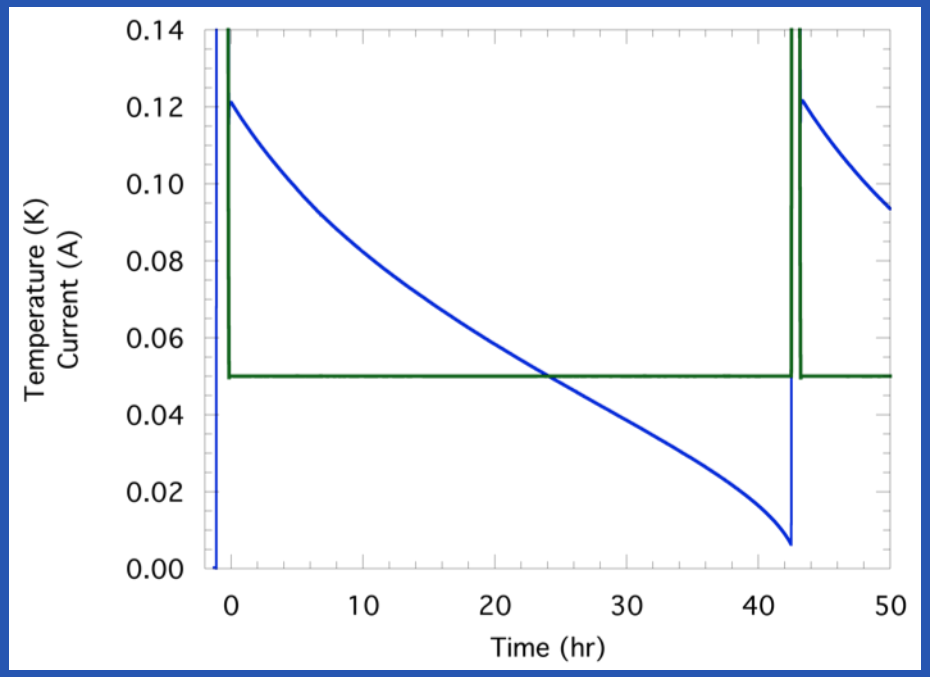


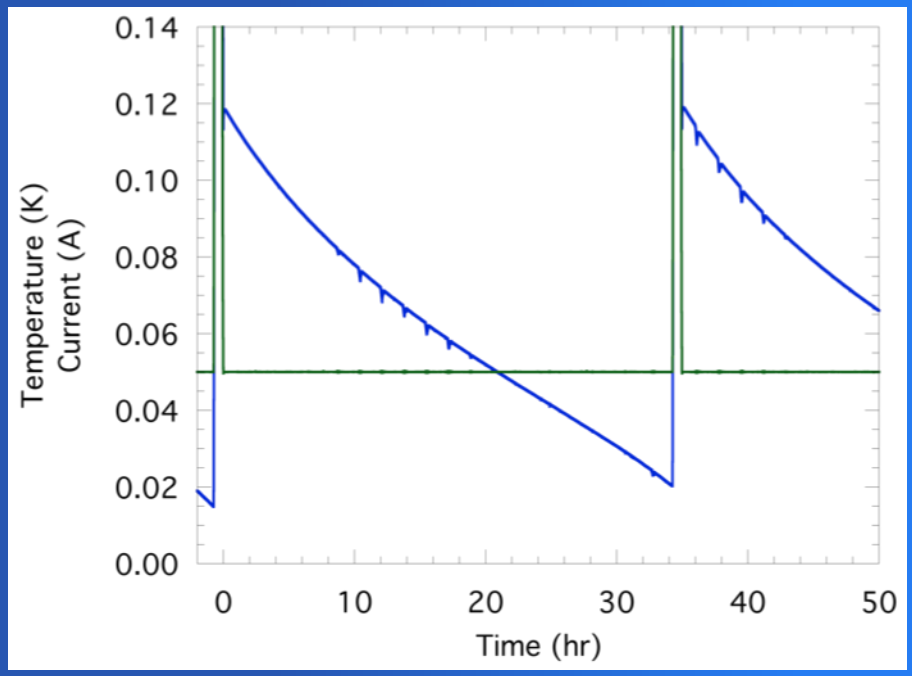


Recycle time	~45 minutes	~45 minutes
Heat load	0.80 µW	0.86 µW
Hold time*	~42 hours	~39 hours

* Dependent on tank temperature; values shown are for ~1.20 K

Stage 1 – Ground vs On Orbit





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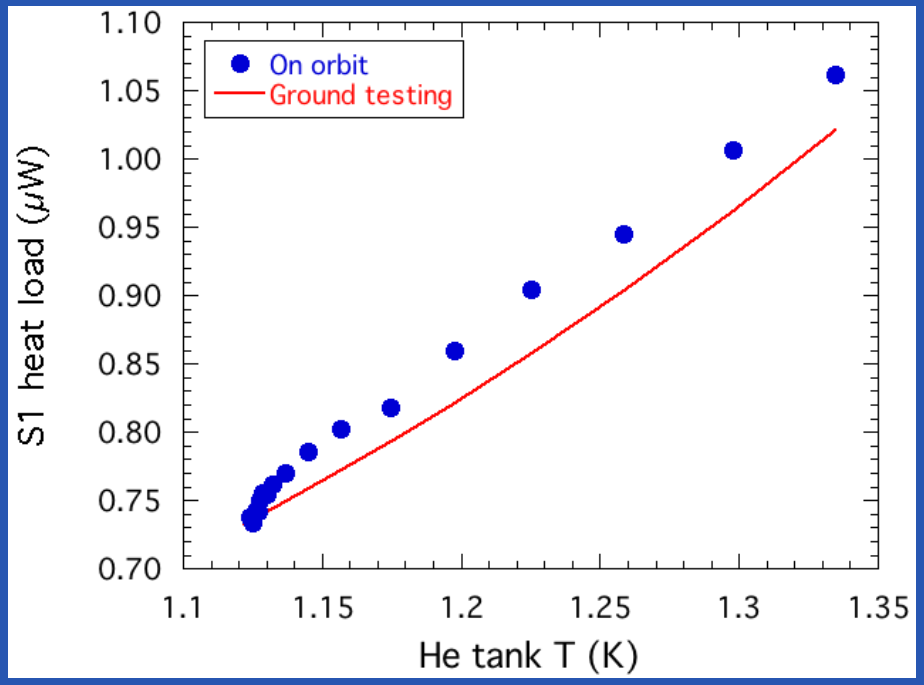
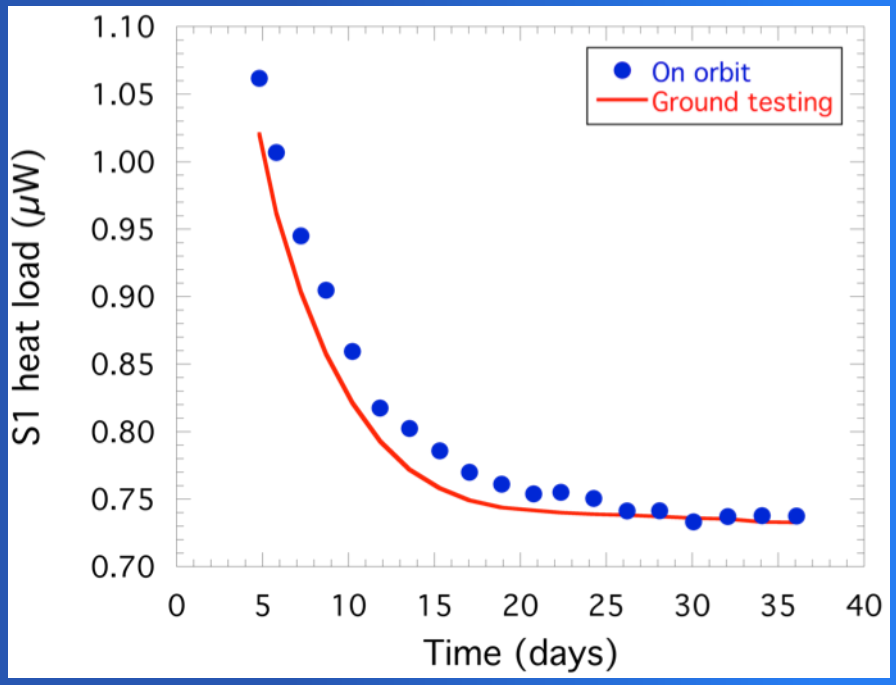
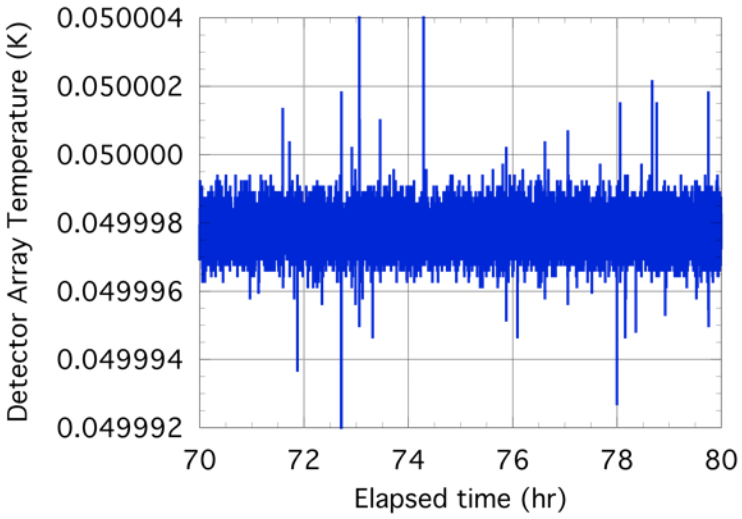
Stage 1 Heat Load

- Heat load to Stage 1 decreased as He tank cooled
- Discrepancy between on-orbit and ground tests appears to depend on time rather than He tank temperature

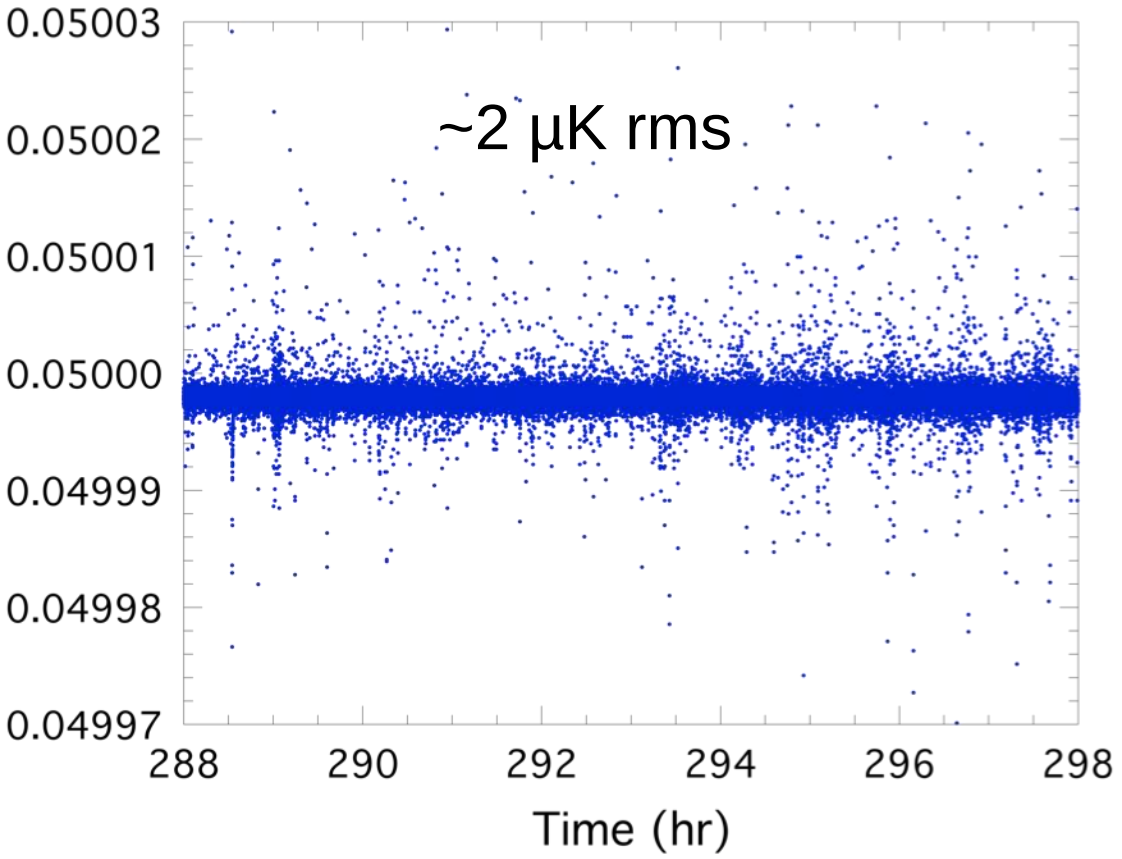




Temperature Stability



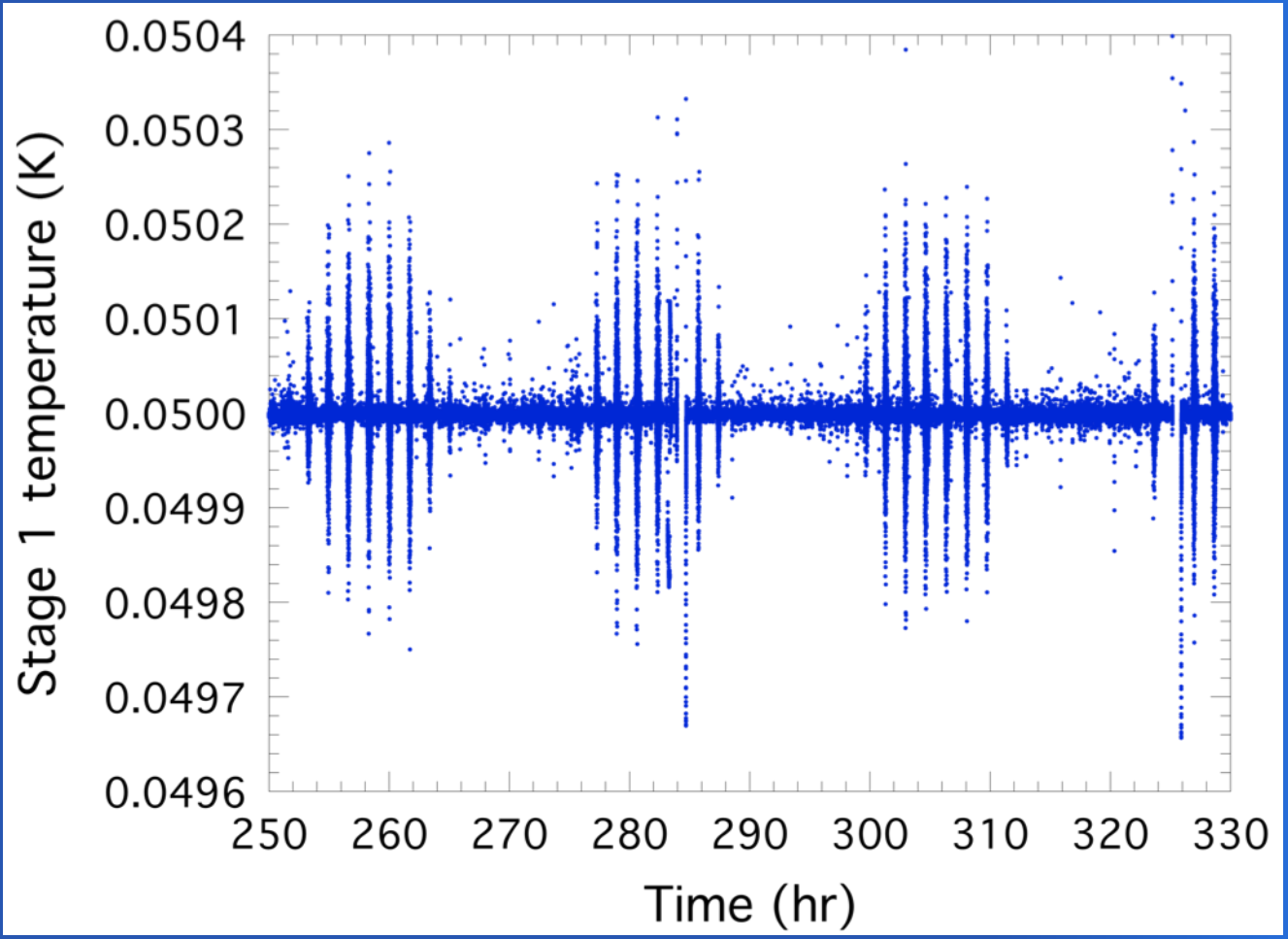
Ground tests: ~0.4 μK rms



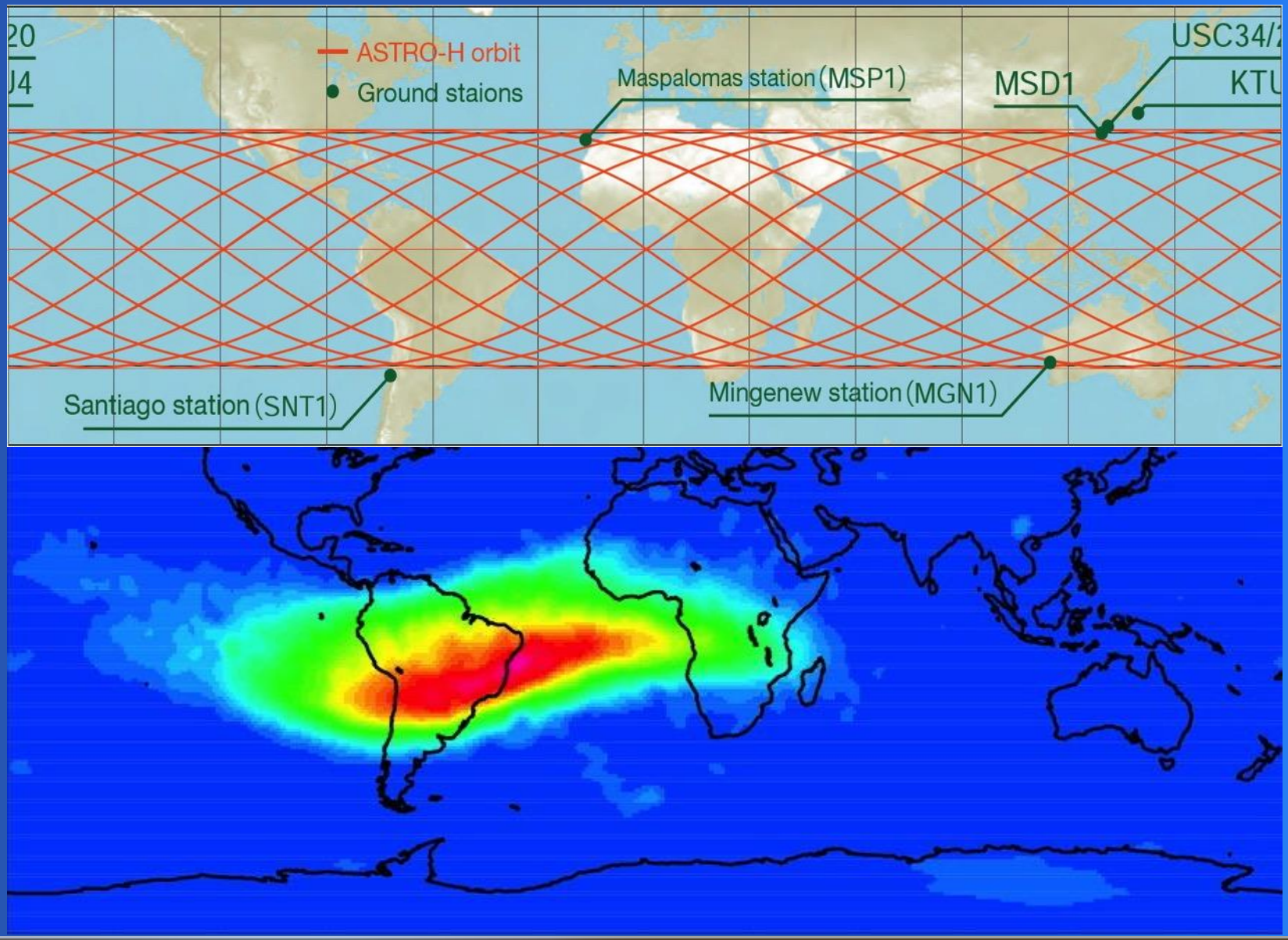
On orbit: ~2 μK rms

Effect of High Energy Particles

- Effect concentrated in SAA
- Response appears to be primarily within thermometers

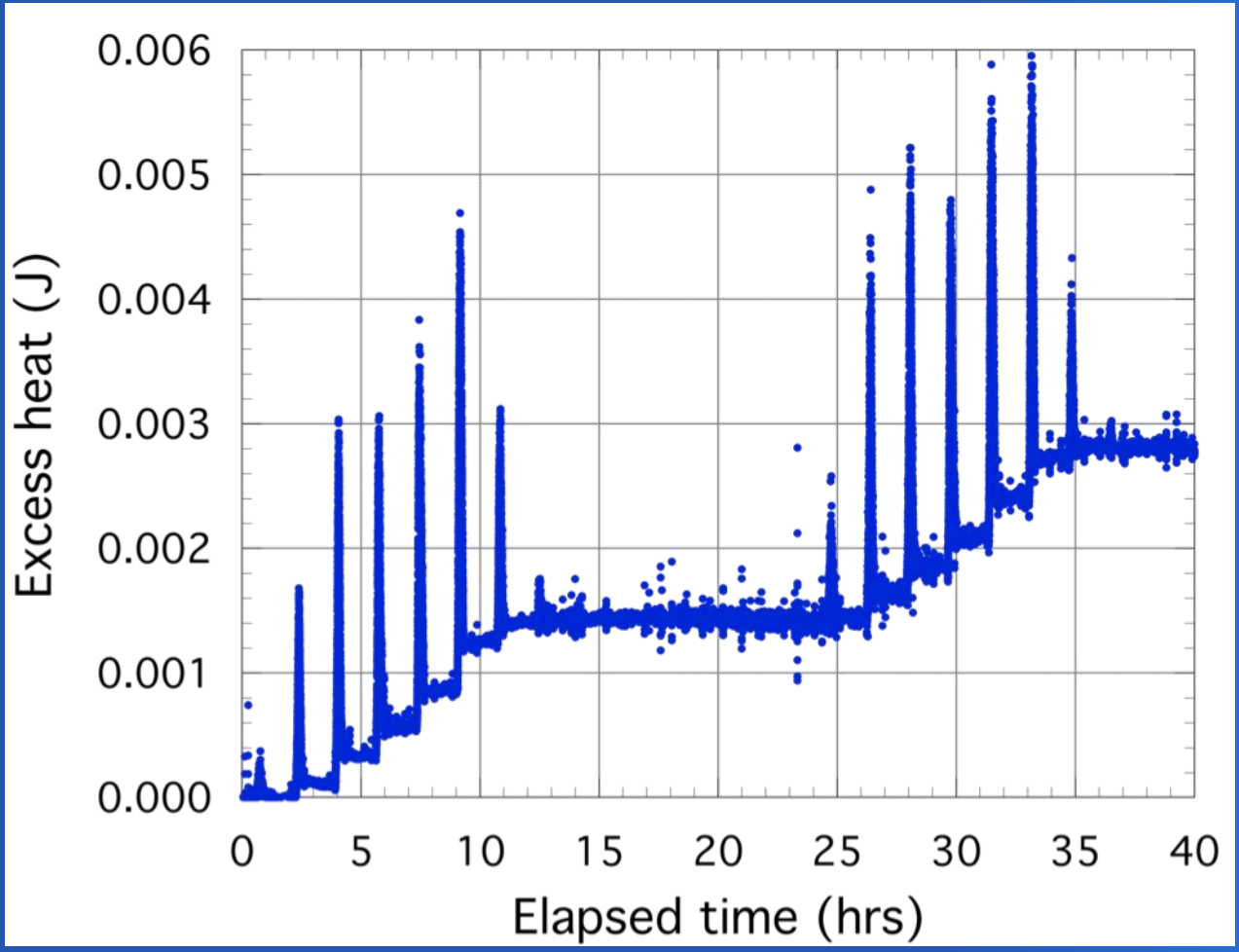


South Atlantic Anomaly and Hitomi Orbit



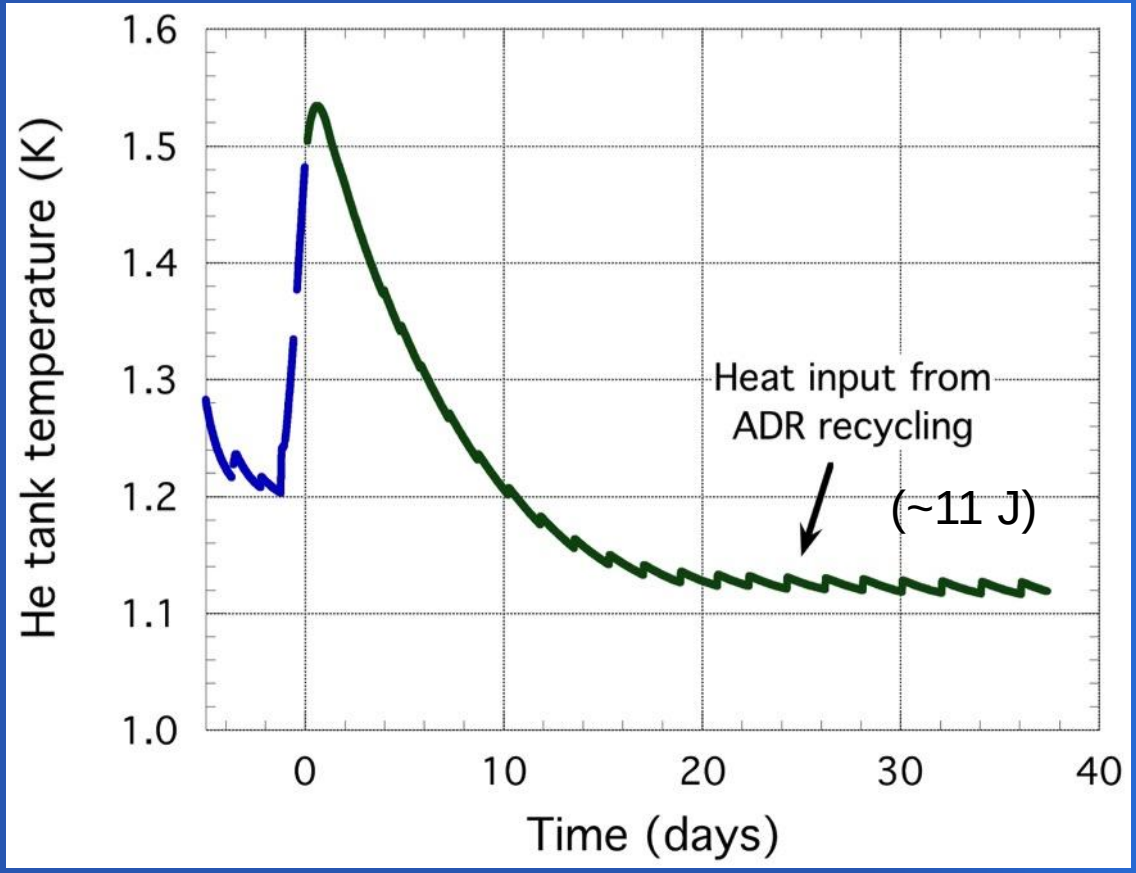
SAA Heating

- Heating during orbits passing through the SAA
  - 1.4 mJ per 24 hour period, or 0.018 µW



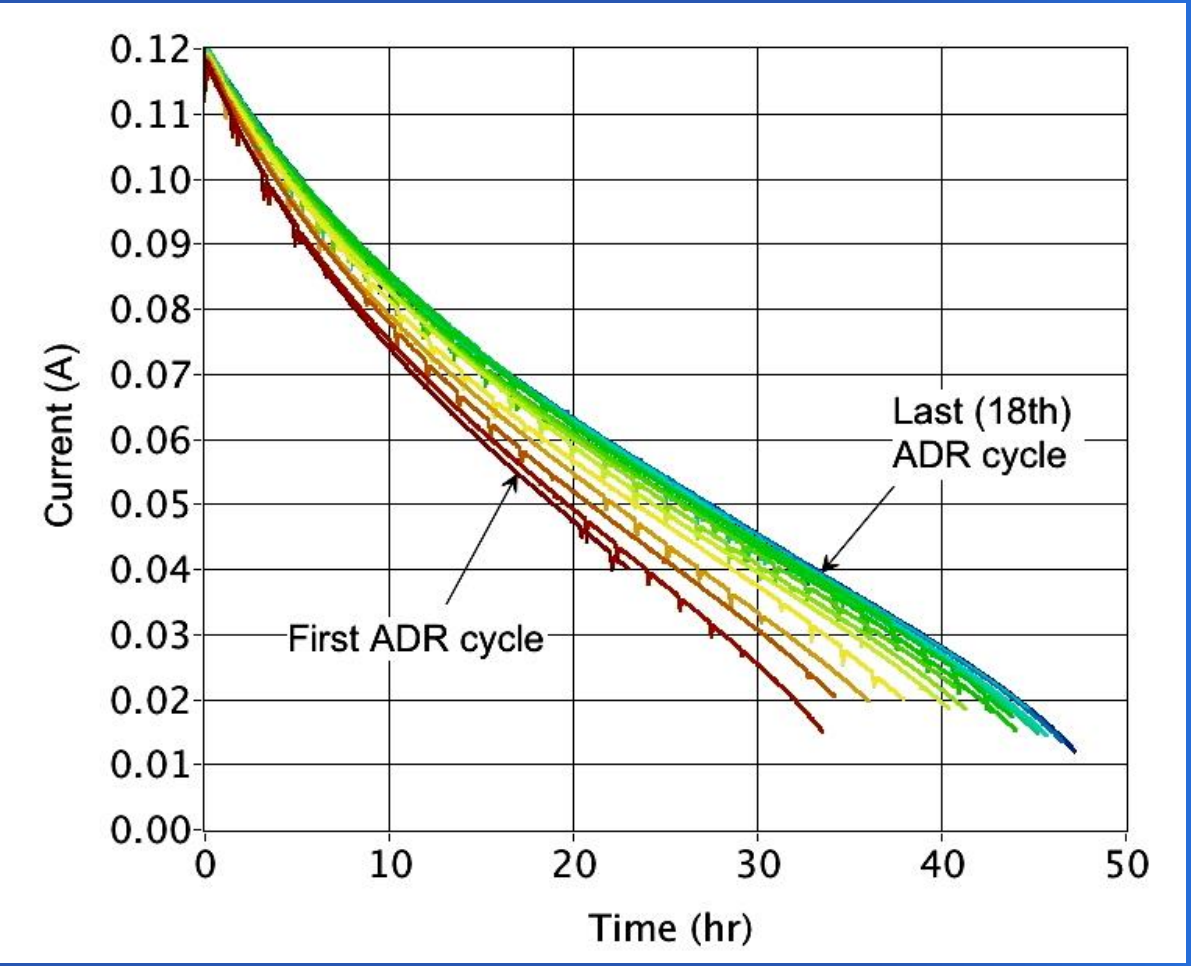
He Tank Temperature

- Cooling rate is consistent with ground tests of porous plug phase separator
- Steady-state temperature was ~1.12 K



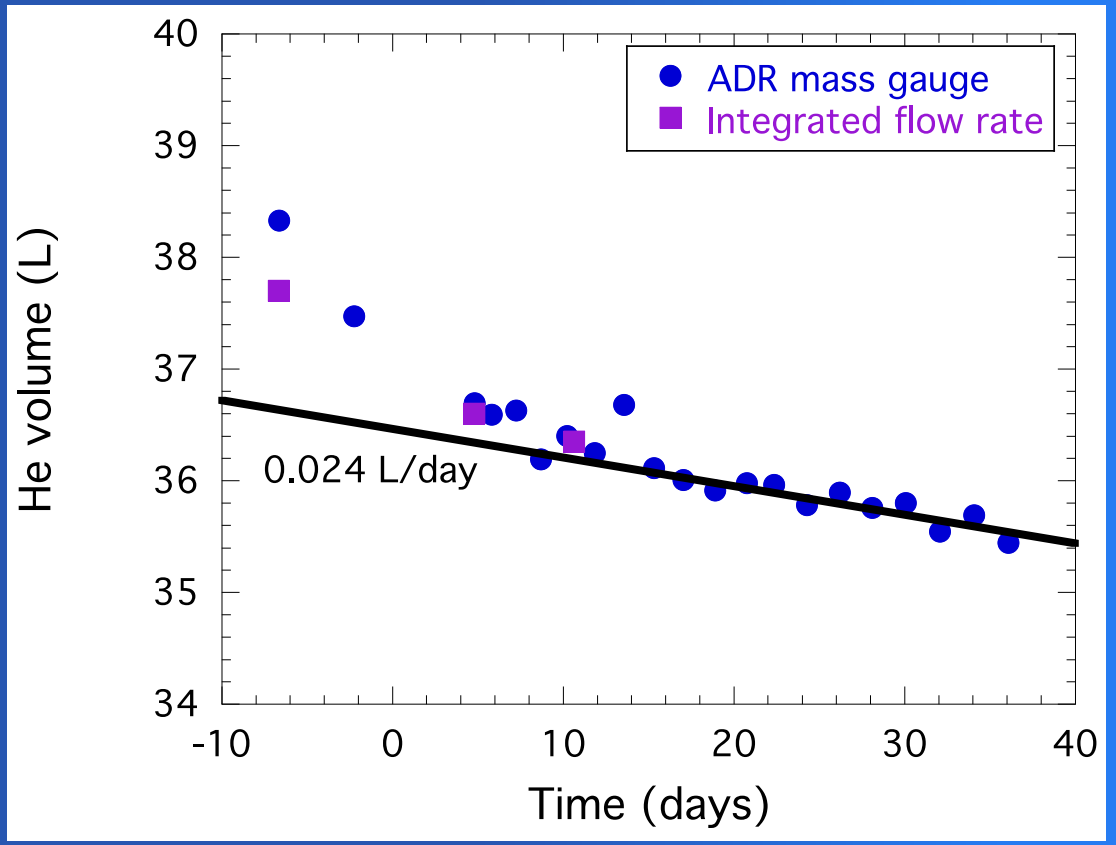
ADR Performance

- ADR hold time has been steadily increasing as He tank cools
- At 1.12 K, hold time was ~48 hours



Helium Volume and Lifetime

- Direct volume meas. after low temperature topoff: 37.7 L
- ADR heat output can be used to gauge liquid mass on orbit
- Tank heat load
  - 0.060 mW from ADR
  - Parasitic
    - 0.65 mW expected
    - 0.77 mW from
- Lifetime of >3 years



Summary

- Since beginning operation on 2/22, the SXS ADR has provided stable 50 mK detector cooling with >98% duty cycle
  - Electronics capable of automated recycling, but only manual recycling used
- Only observable difference between ground and on-orbit performance is heating and temperature fluctuations due to cosmic rays
  - Concentrated in SAA
  - Outside of SAA, no significant impact on detector performance
    - Anti-coincidence detector acts as a veto for pulses due to high energy particles
  - Increases time average heat load by 40 nW
    - Stage 1 salt pill: 270 grams of CPA, 650 gram total mass