Development of a flight-worthy 10 to 4 K Continuous Adiabatic Demagnetization Refrigerator

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Introduction

Future space-flight missions will need:

- sub-Kelvin detector cooling (at 50 mK or below) with higher heat loads than past missions
- significant cooling at ~ 0.5 K – 4 K for optics/instrument

- NASA/GSFC is developing a flight-ready 10 K to 0.05 K Continuous ADR (CADR) to meet these needs

- The 4 to 10 K ADR is newly tested and characterized for use in the 10 K to 0.05 K CADR

- A CADR is <u>much lighter</u> compared to its single-shot counterpart

Performance Requirements

- Anticipated future missions with sub-Kelvin detector arrays:
  - Origins Space Telescope (OST) (two instruments)
  - Lynx
  - Probe of Inflation in Cosmic Origins (PICO)
  - Galaxy Evolutioin Probe (GEP)

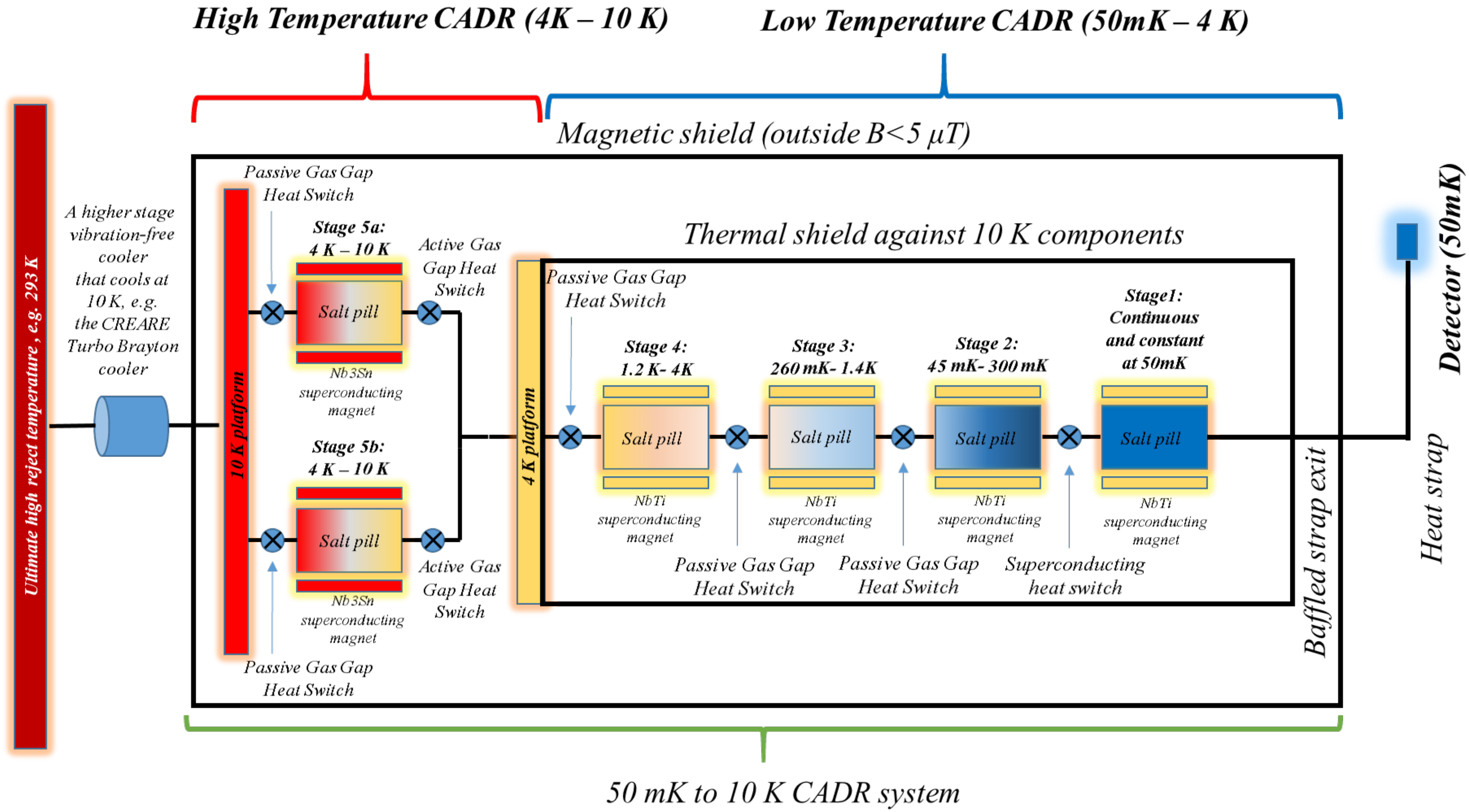
- Proposed CADR can exceed most expected performance requirements

Performance metrics	Requirements	Current SOA	Proposed CADR
Cold Stage Operating temp. (mK)	≤ 50	50	≤ 50
Cold Stage temp. stability (μK)	1	1	≤ 1
Cold Stage Cooling power (μW)	3	0.5	> 6
Warmer Stage Stability at Operating Temp. (mK@K)	1@4-6	1@4.5	1@4
Telescope Cooling (power@temp., mW@K)	100@4-6	20@4.5	~10@4 K
Mag. Field at detector assembly (μT)	5	7500	< 5
Allowable vibration levels (milli Newtons, mN)	0.001	5	~ 0
Lifetime (years)	> 5	> 5	> 5

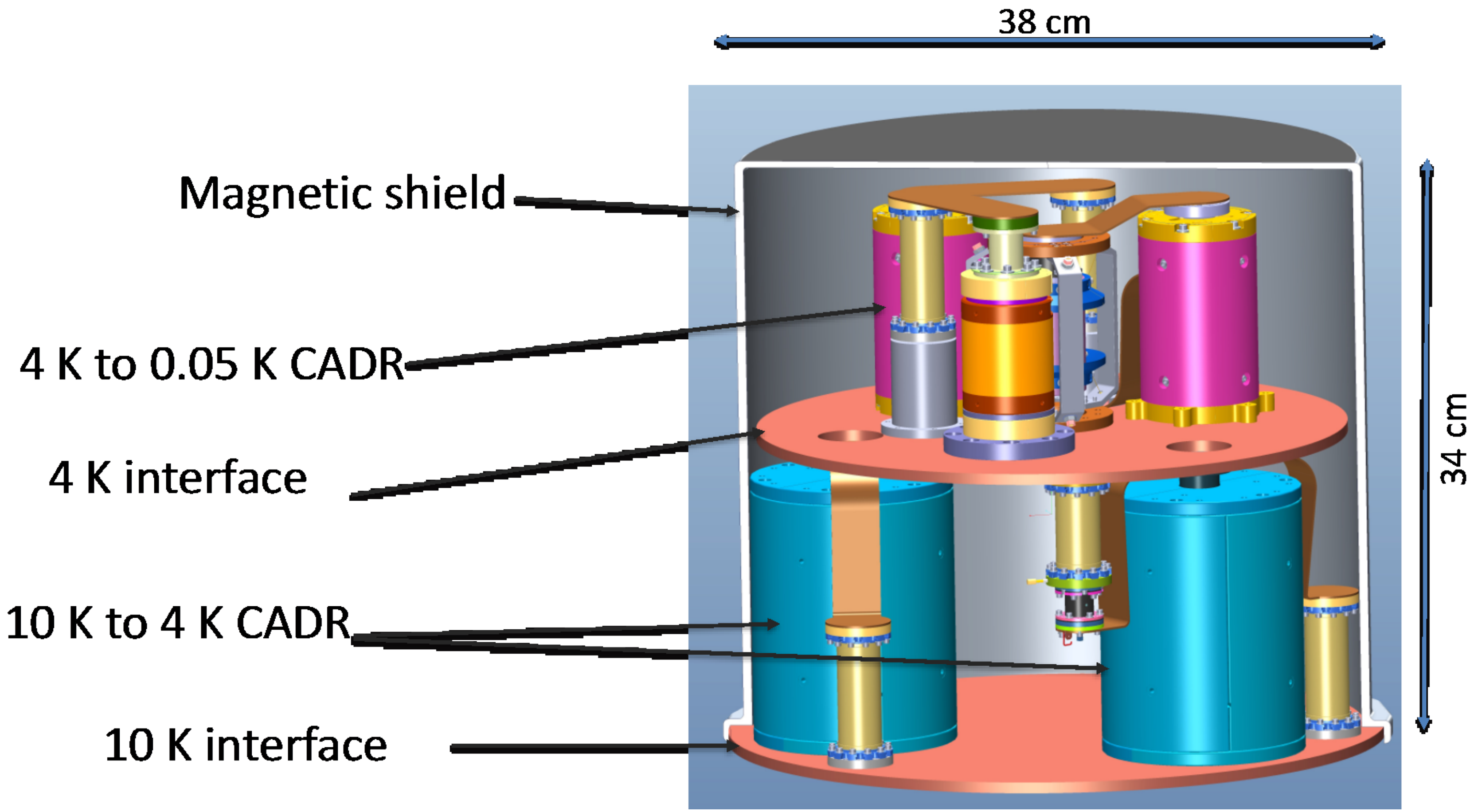
Vibration Reduction

- ADRs have no moving parts; contribute zero vibrations
- Mechanical cryocooler vibrations are an issue on many flight missions
- Creare demonstrated sub-10 K operation of their Turbo-Brayton cooler
  - Very high-frequency vibrations - heavily damped by spacecraft structure
- A 10 K superconducting flight-compatible magnet was developed with NASA funding between 2002 and 2010
  - It’s now possible for a flight CADR to reject heat at 10 K
- These two technologies enable 300 K to 50 mK “vibration-free” cooling

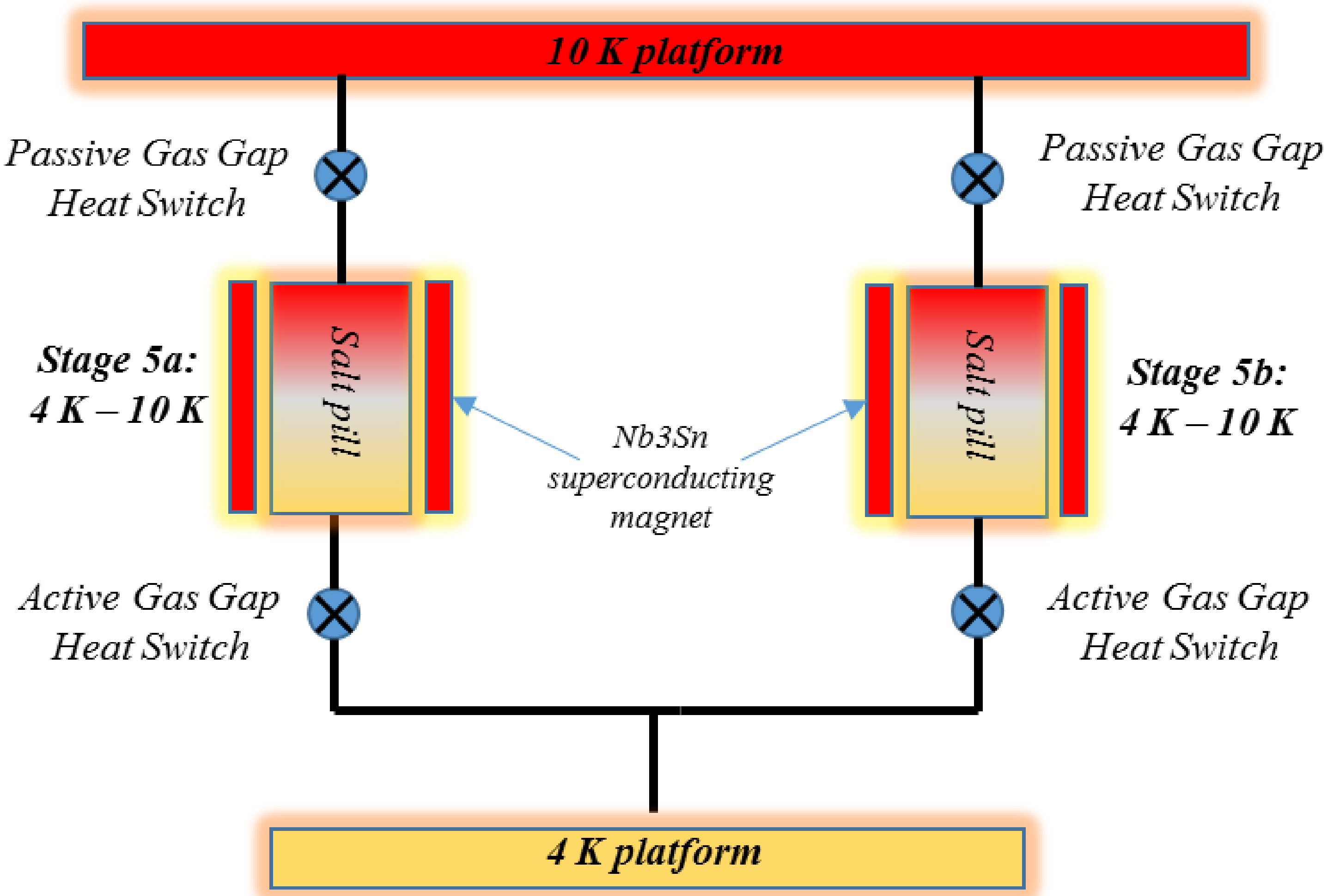
Overall CADR Schematic



CADR Component Packaging

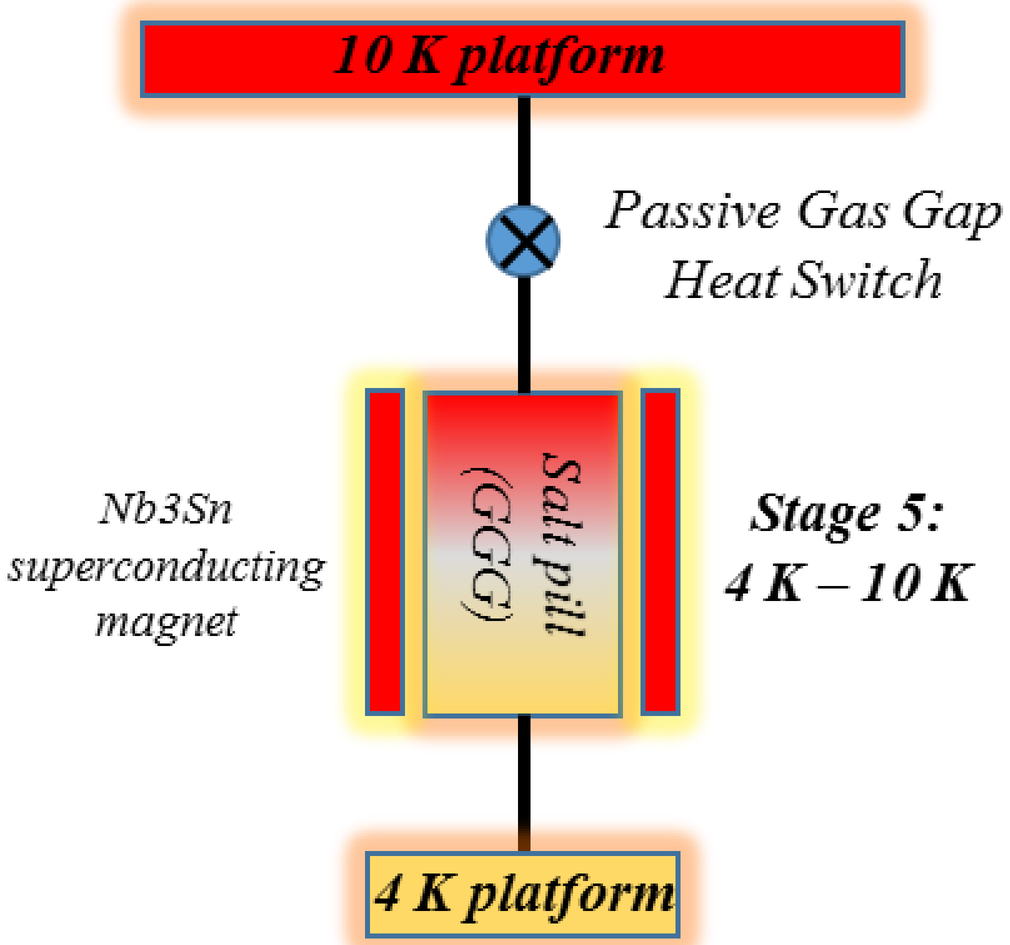


10 to 4 K CADR Subsystem

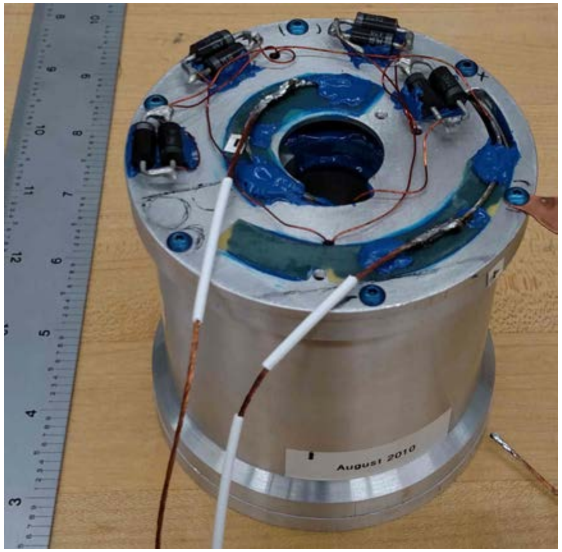


10 to 4 K single-stage ADR

- A 10 K platform is simulated by temperature controlling the cold plate
- The Passive Gas Gap Heat Switch (PGGHS) is tuned to turn "on" at 10 K
- The salt pill, a single crystal of Gadolinium Gallium Garnet (GGG), slightly protrudes out of the magnet bore (optimized size)
- 4K platform is simulated by a small plate and instrumented with heater to enable temperature controlling



10 to 4 K CADR Components

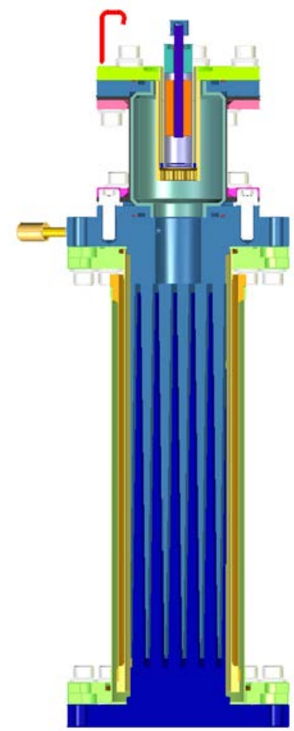


10 K Nb_3Sn Magnet

GGG Salt Pill Assembly

Kevlar Suspension Assembly

Passive Gas Gap Heat Switch



Active Gas Gap Heat Switch

Single-Stage 10 - 4 K ADR

Passive Gas-Gap Heat Switch

Copper Strap

10 K Test Plate

Salt Pill End Flange

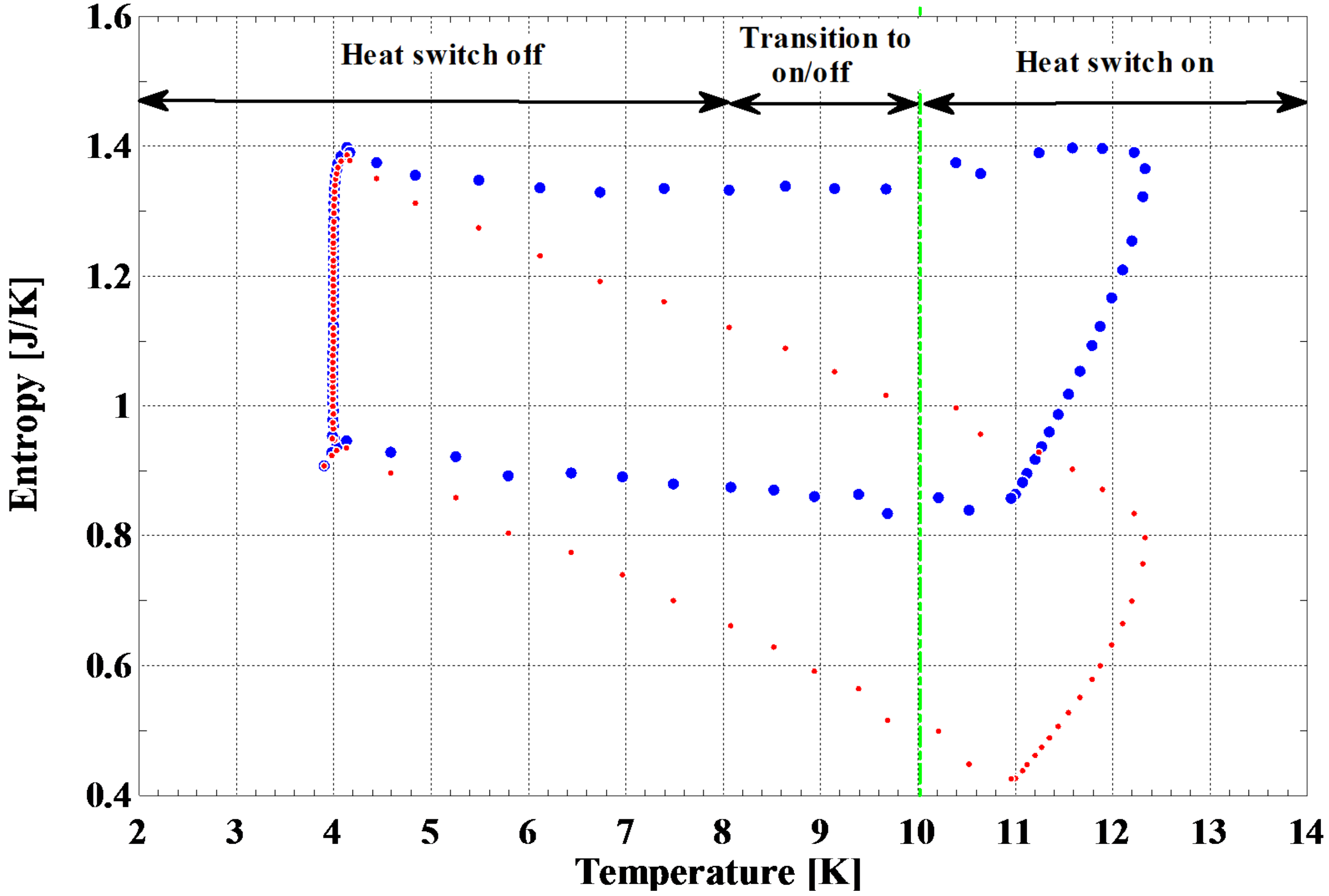
Silicon-Iron Shield

Nb_3Sn 10 K magnet

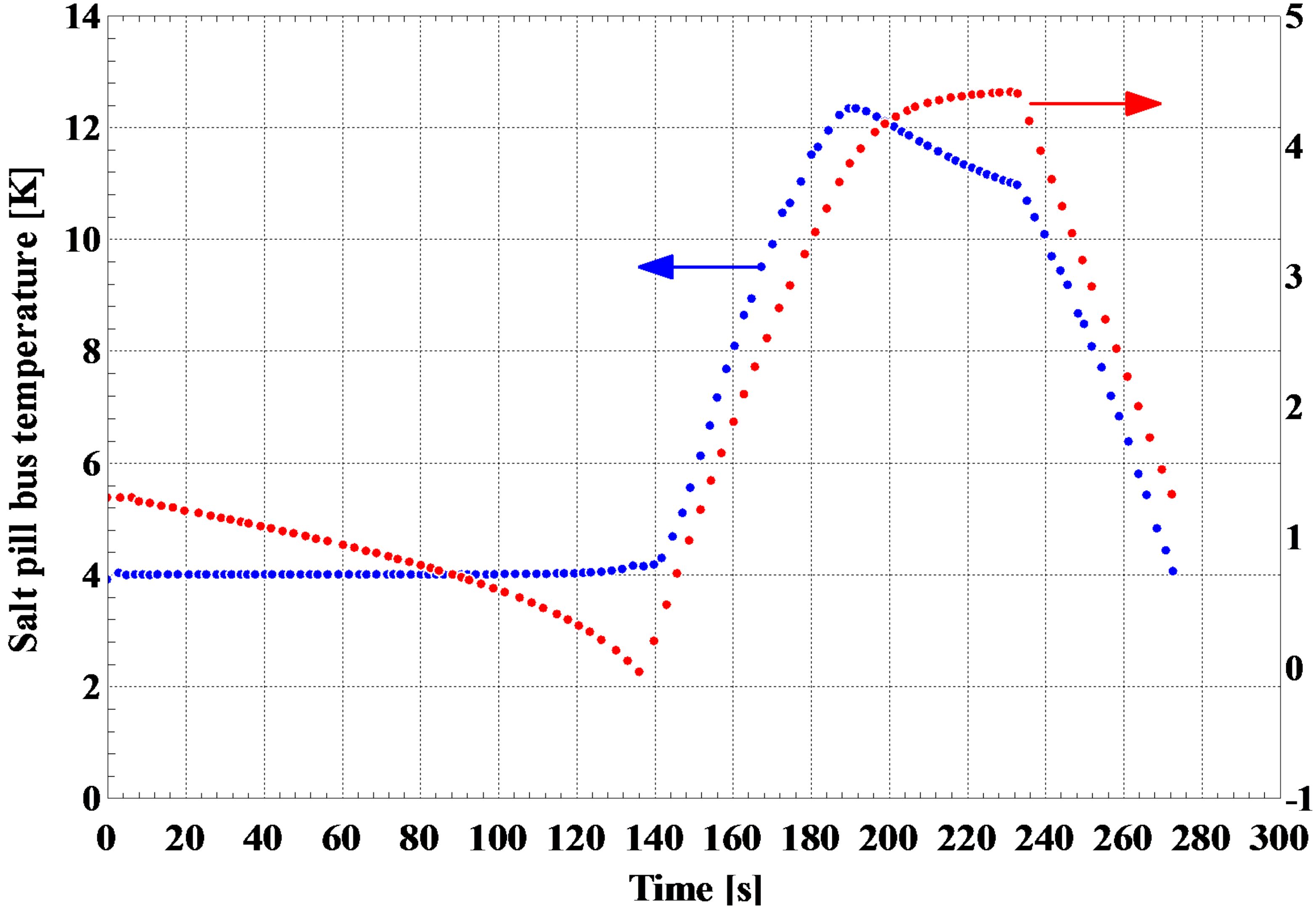
10 to 4 K ADR Test Results

- Optimized cycle for a 2-stage (parallel configuration) is one where the recycle time equals the hold time
- The optimized cycle was experimentally found to have a 130 second hold time/recycle time
- This corresponds to a cooling power of 13 mW at 4K- timing affects demag start temperature
- Earlier a model predicted 20 mW of cooling power however the under-performance is partly due to historical misinterpretation of GGG magnetization data, and partly due to the addenda mass

10 to 4 K single stage ADR test results



10 to 4 K single stage ADR test results



Conclusion

- A designed-for-flight 2-stage 10K to 4 K CADR is being assembled
  - Testing to begin soon

- Steps to follow:
  - Assemble a flight-worthy 4 to 0.05 K CADR
  - Integrate 10 to 4 K CADR with 4 to 0.05 K CADR
  - Performance test full 10 to 0.05 K CADR
  - Vibrate CADR to flight levels
  - Post-vibe performance test

- This work is very valuable for Goddard's ADR program
  - Developing a product to meet the known needs of future missions
  - Expanding the flight ADR expertise of the Cryogenics group