

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

Amir Jahromi

Jim Tuttle

Ed Canavan

Hudson DeLee

Michael DiPirro

Mark Kimball

Peter Shirron



*NASA Goddard Space Flight Center,
Greenbelt, MD 20771 USA*



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 $\sim 0.5 \text{ K} - 4 \text{ K}$ 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 much lighter 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 Evolution 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	$\sim 10@4\text{ K}$
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

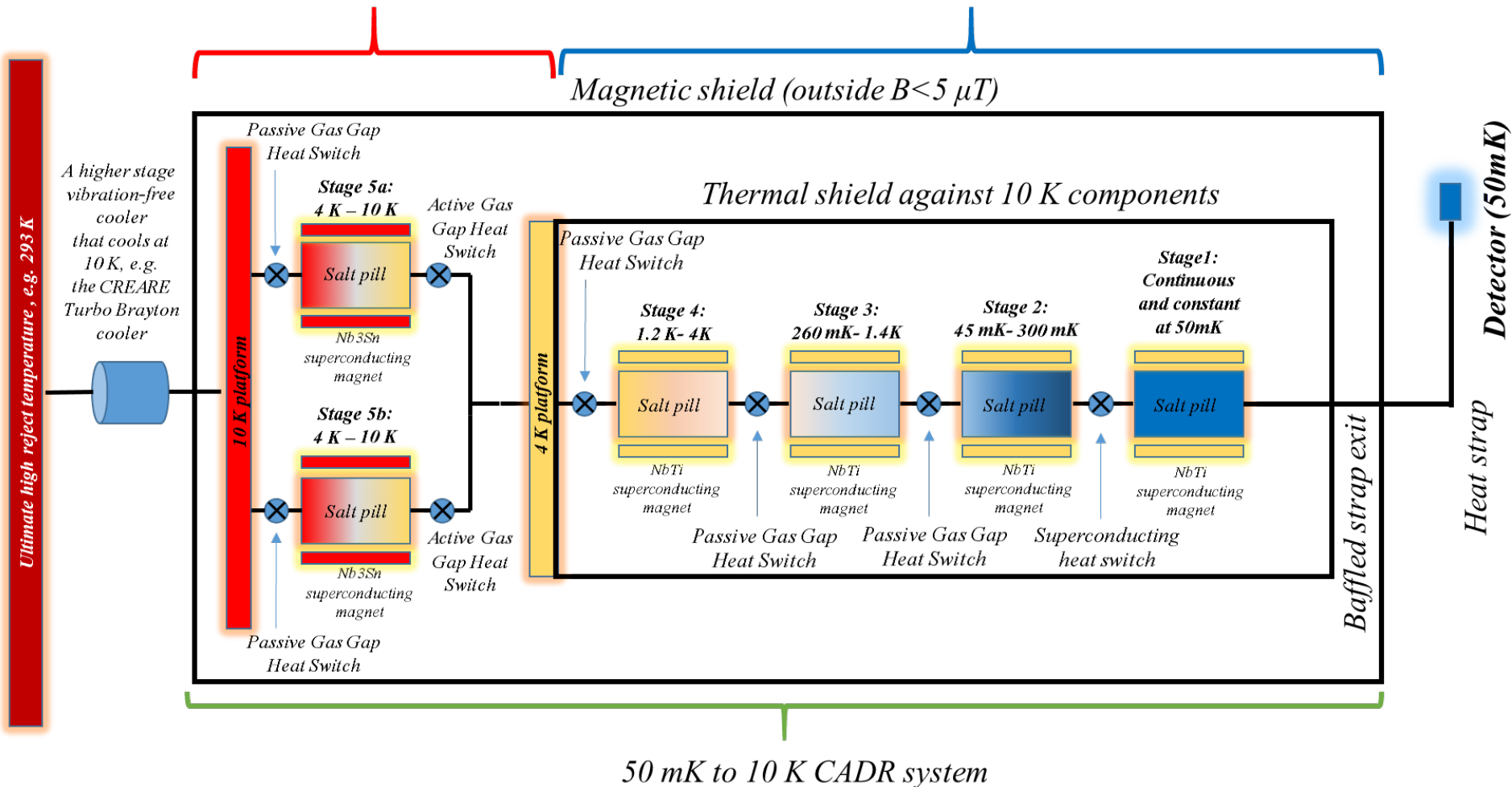
- ADRs have no moving parts; contribute zero vibrations
- Mechanical cryocooler vibrations are an issue on many flight missions
- Creare demonstrated sub-10 K operation of their Turbo-Brayton cooler
 - Very high-frequency vibrations - heavily damped by spacecraft structure
- A 10 K superconducting flight-compatible 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

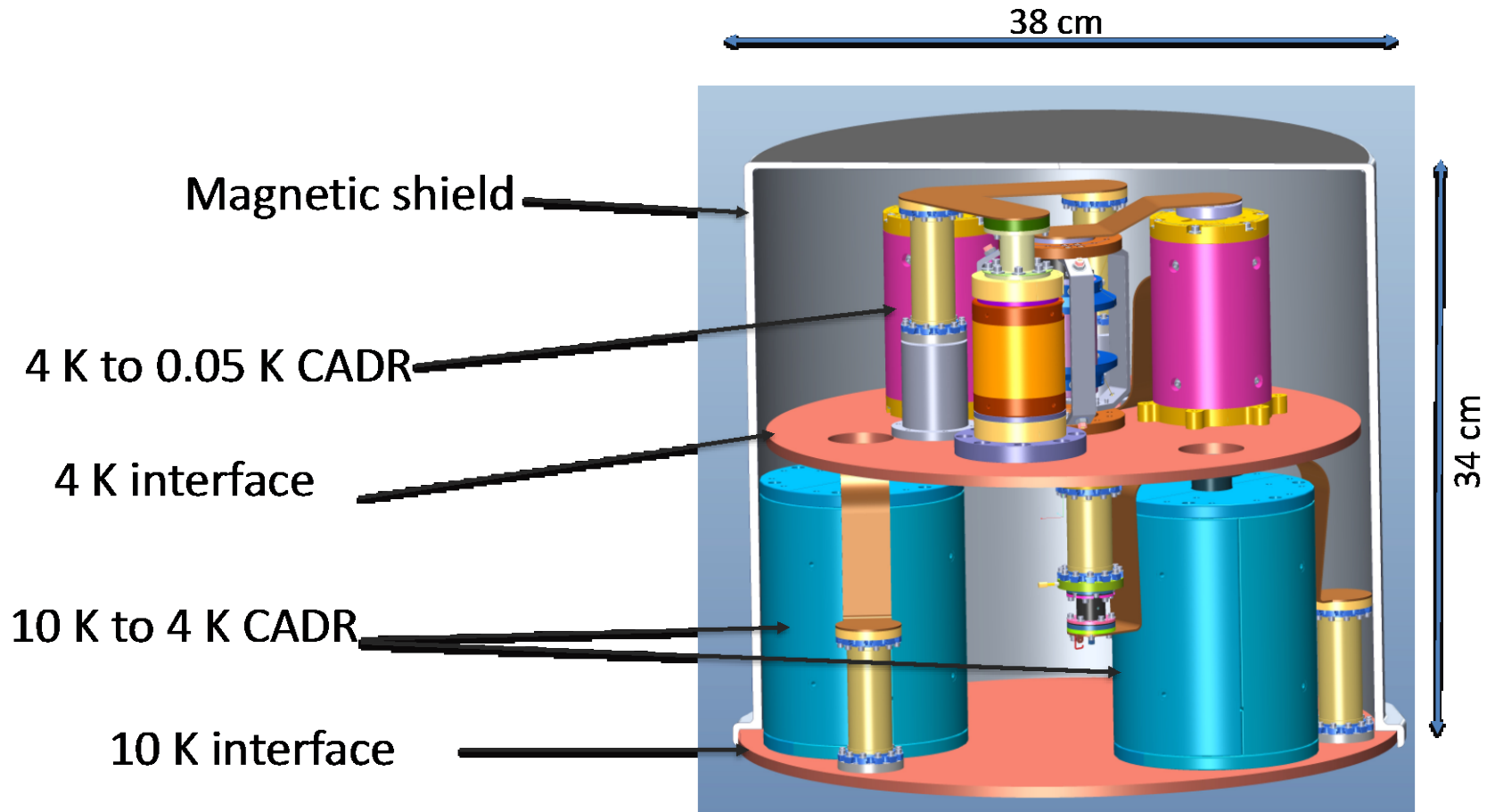
High Temperature CADR (4K – 10 K)

Low Temperature CADR (50mK – 4 K)



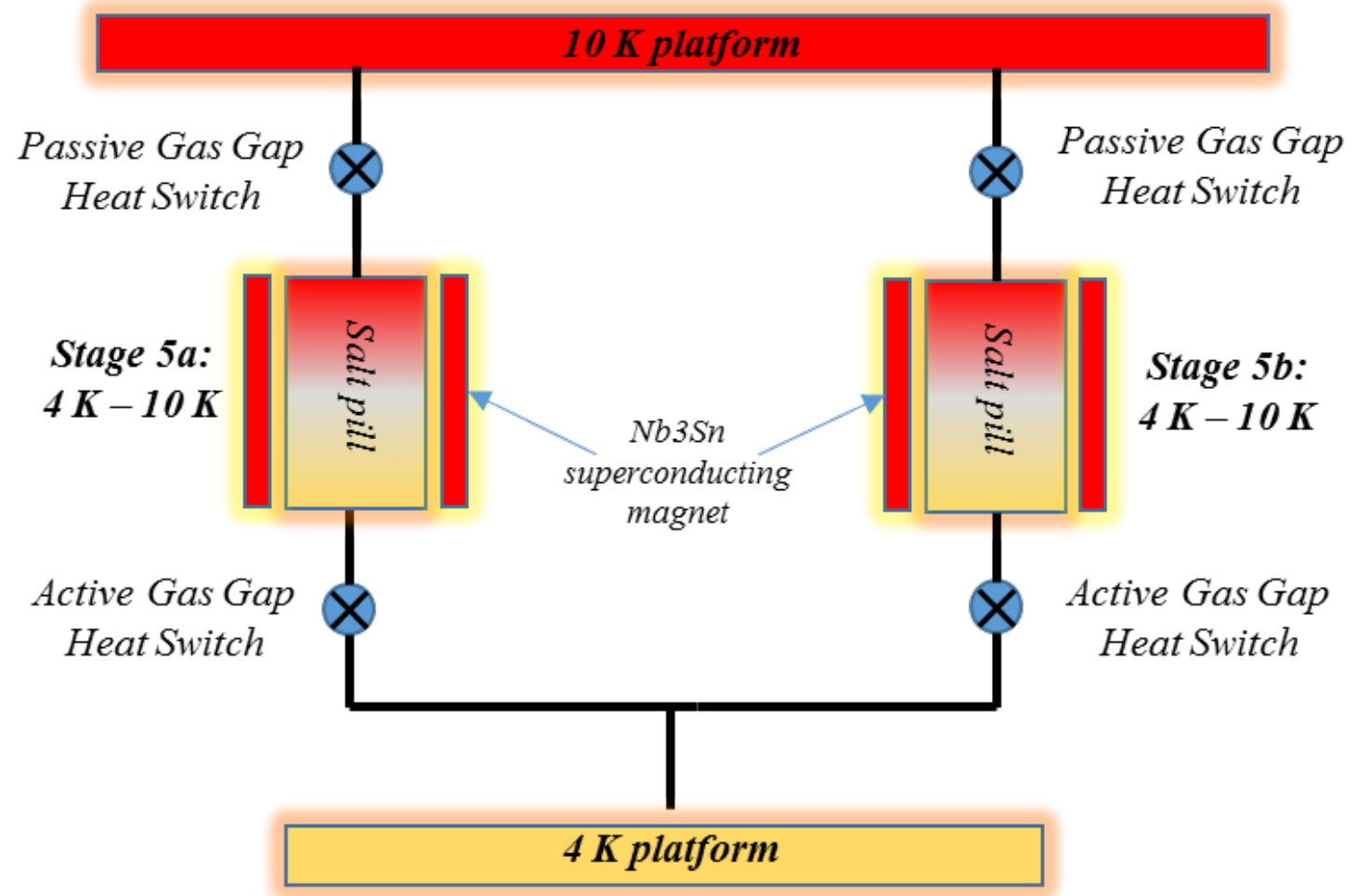


CADR Component Packaging





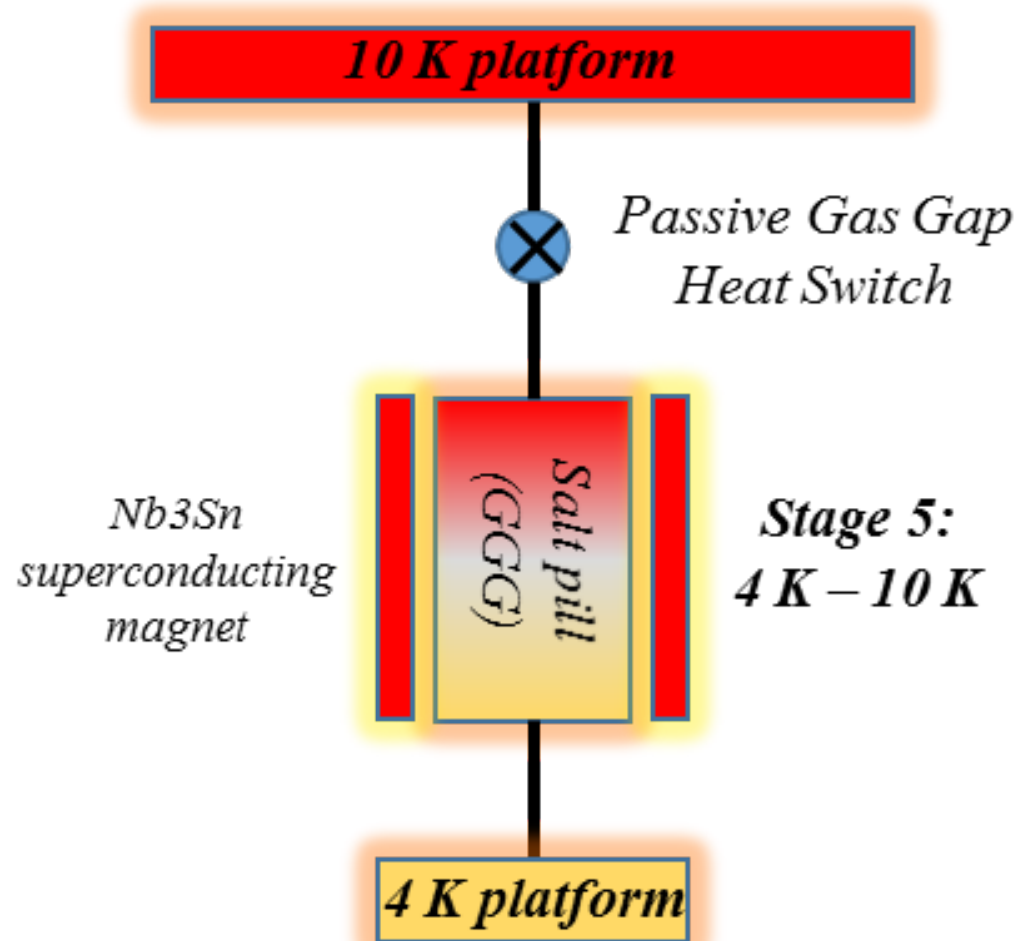
10 to 4 K CADR Subsystem





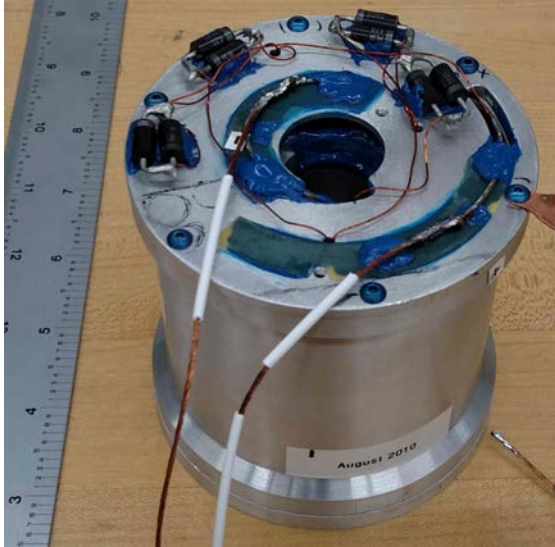
10 to 4 K single-stage ADR

- 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





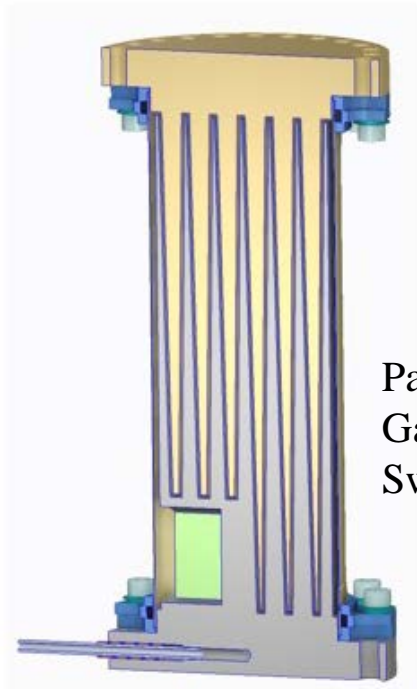
10 to 4 K CADR Components



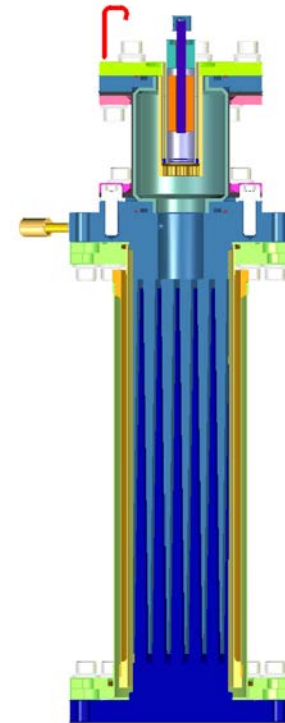
10 K Nb₃Sn Magnet



GGG Salt Pill Assembly



Passive Gas
Gap Heat
Switch



Active Gas
Gap Heat
Switch



Kevlar Suspension Assembly



Single-Stage 10 - 4 K ADR

Passive
Gas-Gap
Heat Switch

10 K Test Plate

Silicon-Iron
Shield

Nb₃Sn
10 K
magnet



Copper
Strap

Salt Pill
End Flange

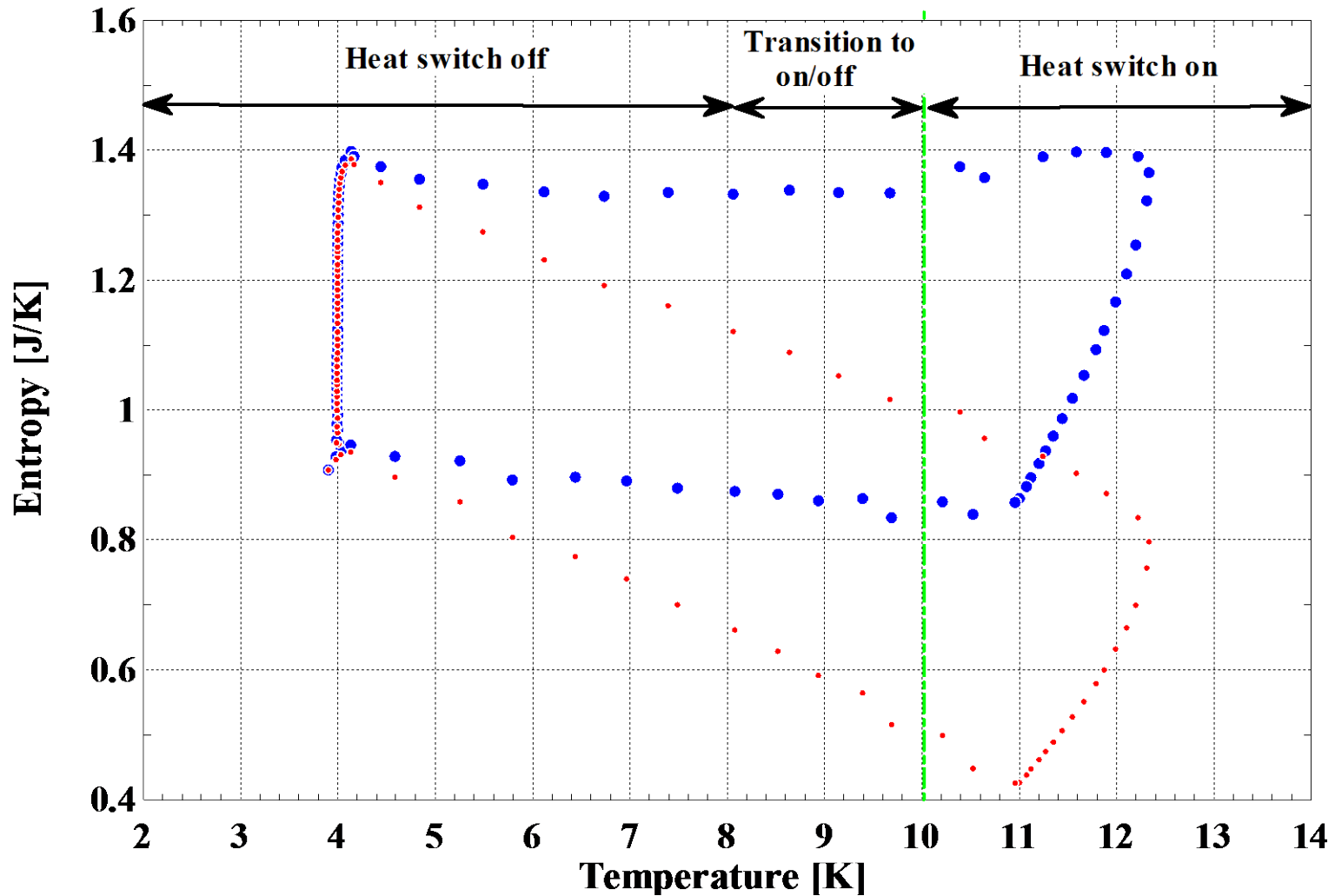


10 to 4 K ADR Test Results

- 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

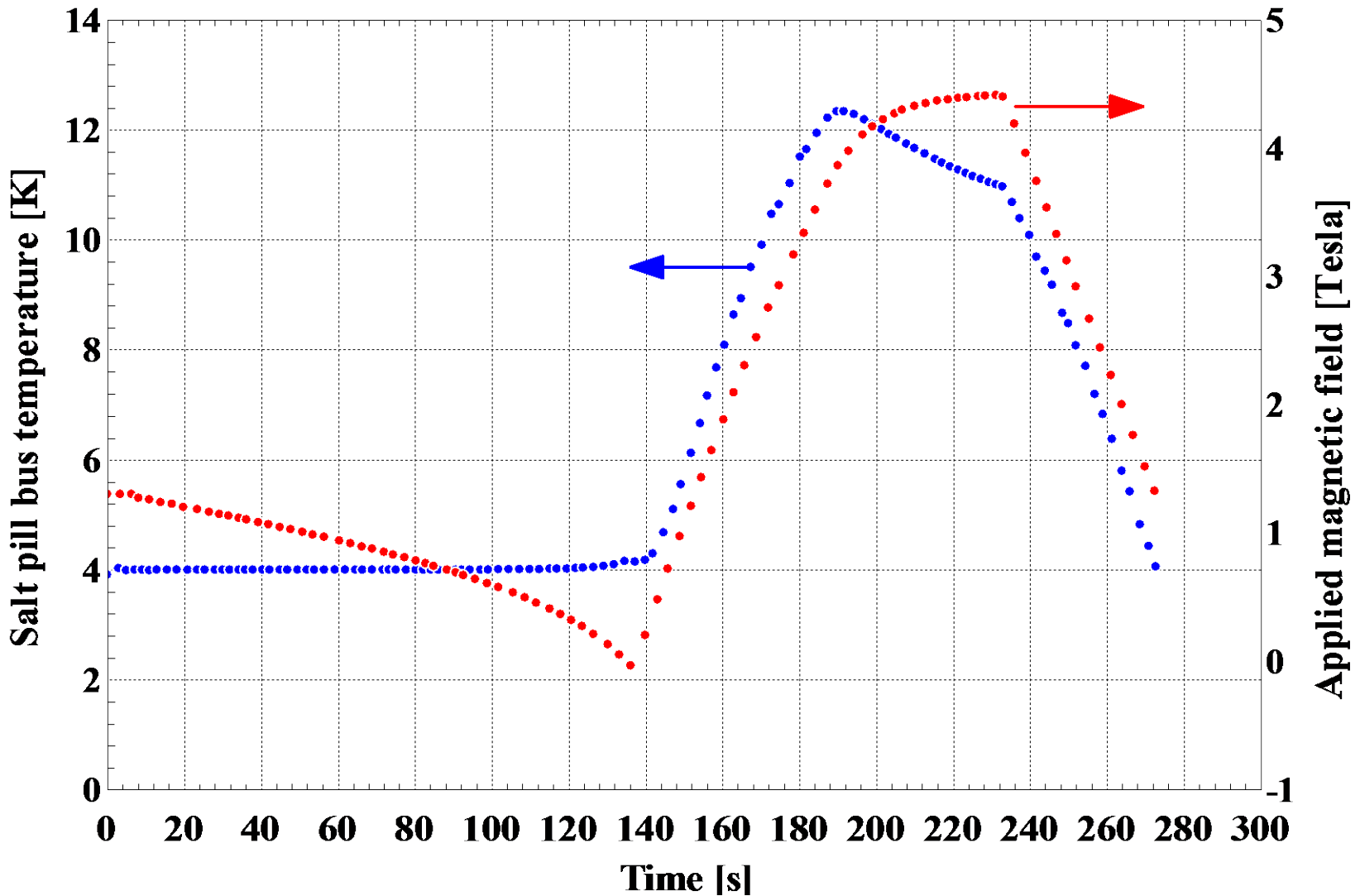


10 to 4 K single stage ADR test results





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