

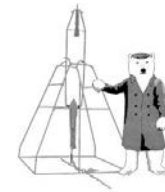
Development of a Space-Flight ADR Providing Continuous Cooling at 50 mK With Heat Rejection at 10 K

**Jim Tuttle, Amir Jahromi, Ed Canavan, Hudson DeLee,
Michael DiPirro, Mark Kimball, Peter Shirron**

NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA



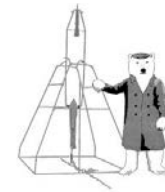
Introduction



- 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



Performance Requirements

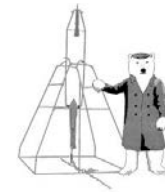


- Anticipated future missions with sub-Kelvin detector arrays:
 - Origins Space Telescope (OST) (two instruments)
 - Lynx
 - Probe of Inflation in Cosmic Origins (PICO)
 - Galaxy Evolution Probe (GEP)
- Proposed CADR can exceed most expected performance requirements

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	$\sim 10@4$ 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



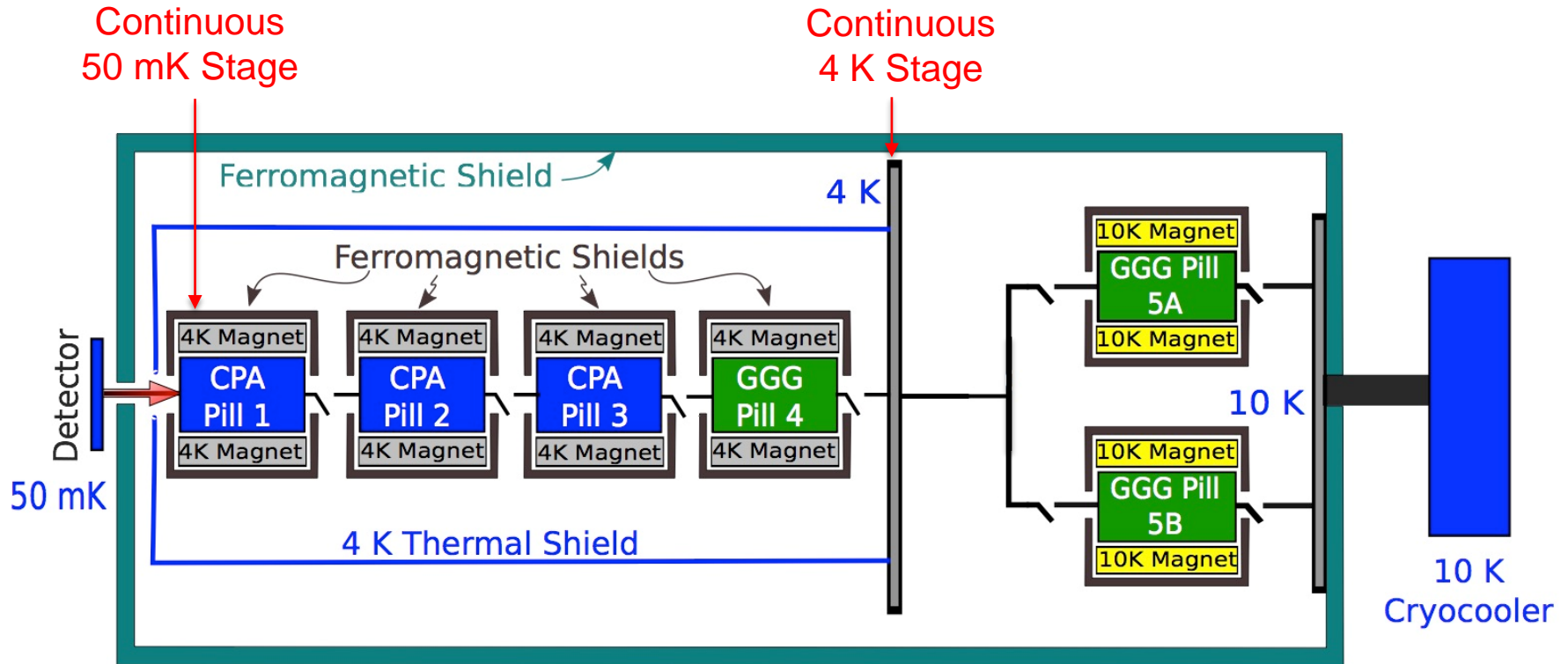
- ADRs have no moving parts; contribute zero vibrations
- Mechanical cryocooler vibrations are an issue on many flight missions
- Creare demonstrated sub-10 K operation of their Turbo-Brayton cooler
 - Very high-frequency vibrations - heavily damped by spacecraft structure
- A 10 K superconducting flight-compatible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



New CADR Schematic

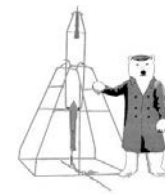


- 4 K to 50 mK subsystem will be flight-worthy version of a lab CADR
- Heat switch between stages 1,2 is superconducting; all others are gas-gap
- Salt pills: gadolinium-gallium-garnet (GGG) and chrome potassium alum (CPA)
- Design includes 10 K overall magnetic shield

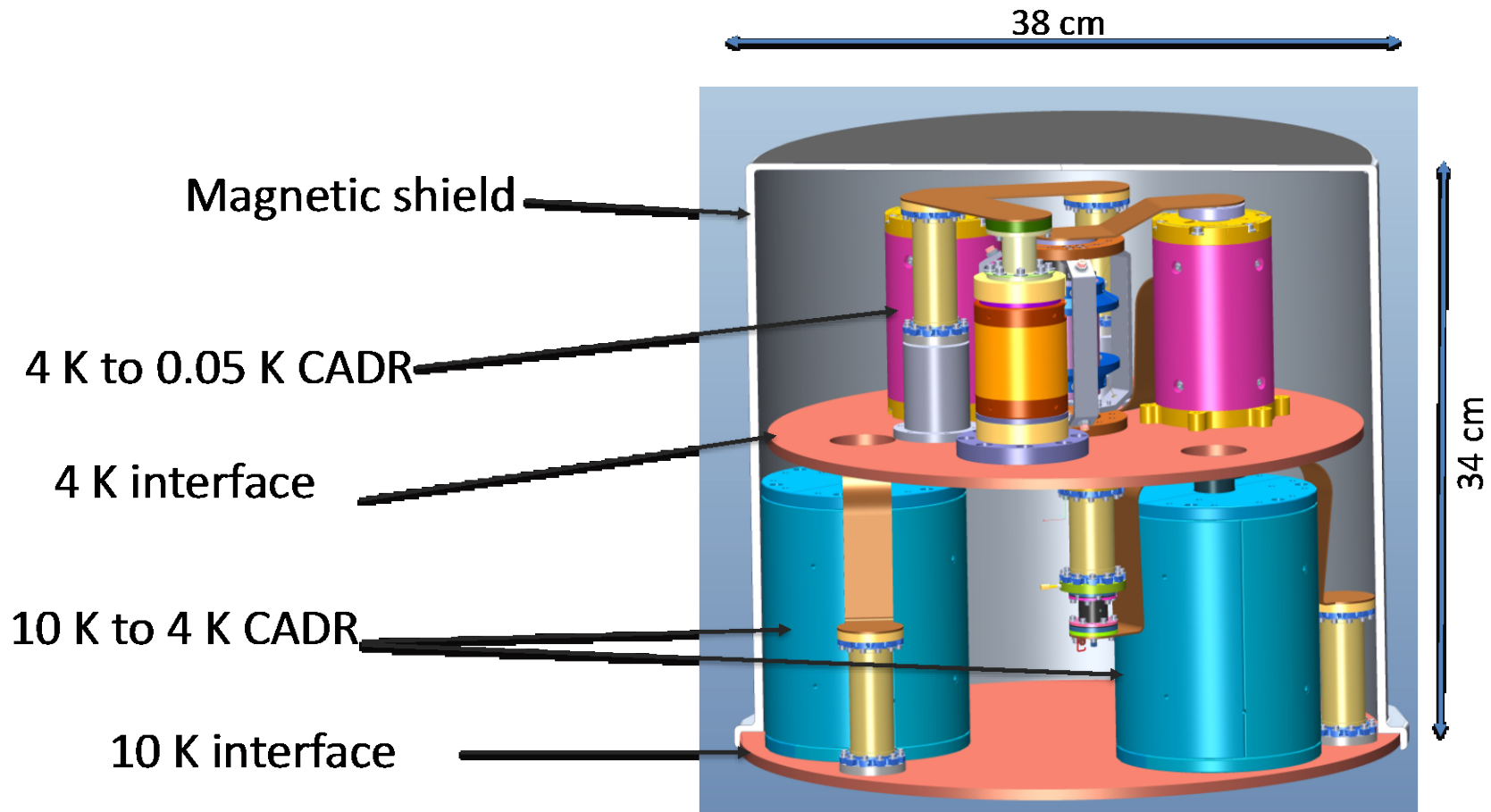




CADR Component Packaging



- 4 K thermal shield not shown
- Shields' strap feedthrough details are TBD

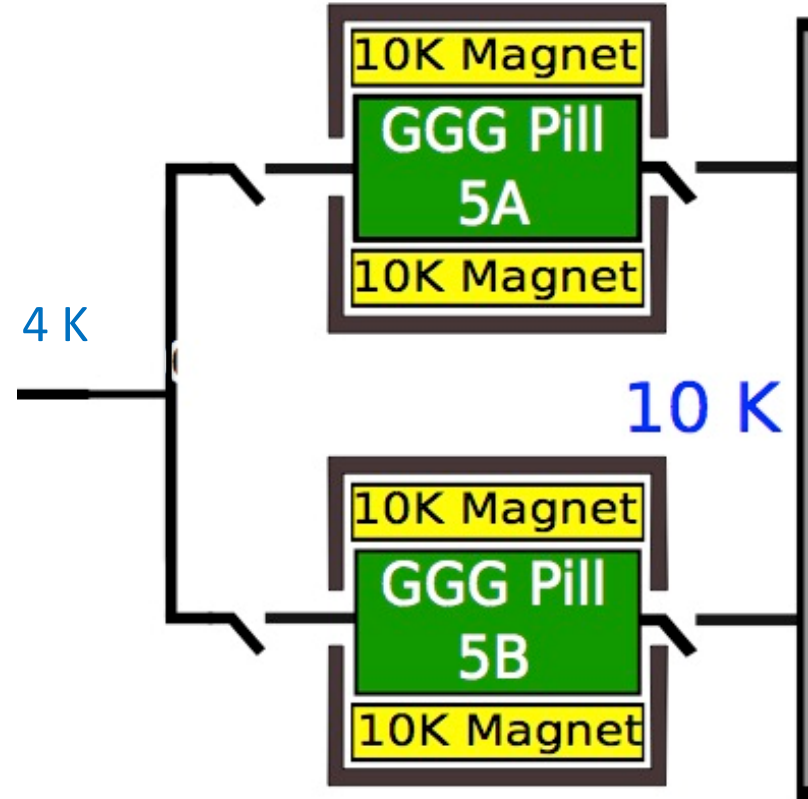




10 - 4 K CADR Subsystem

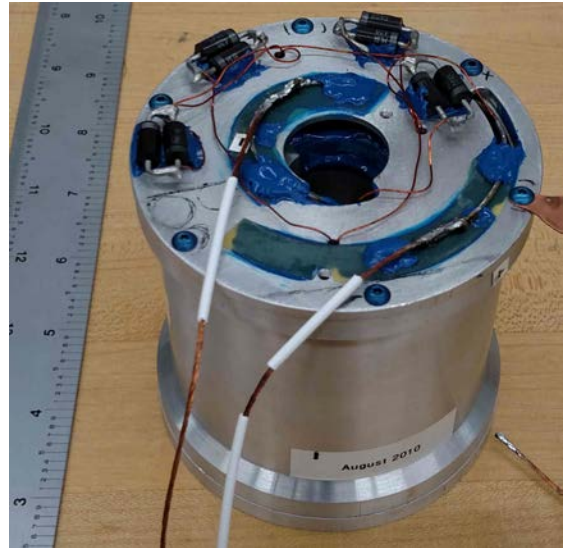
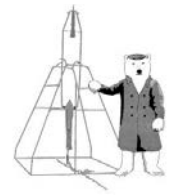


- Two parallel GGG salt pills alternating cooling/recycling
- Kevlar yarn and Vespel tubes used to suspend salt pills
- Includes two 10 K, 4 Tesla shielded Nb₃Sn magnets from Superconducting Systems
- Includes four gas-gap heat switches (2 passive, 2 active)
- Original target was 20 mW of continuous 4 K cooling





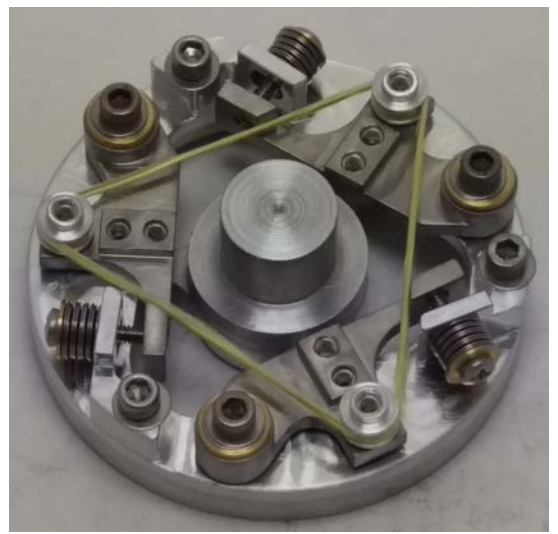
10 - 4 K CADR Components



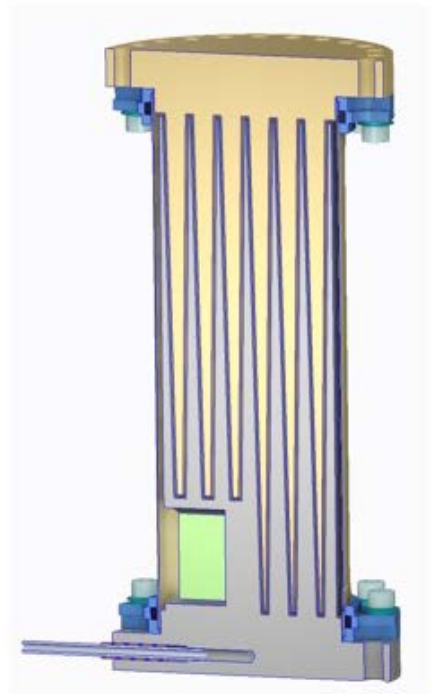
10 K Nb₃Sn Magnet



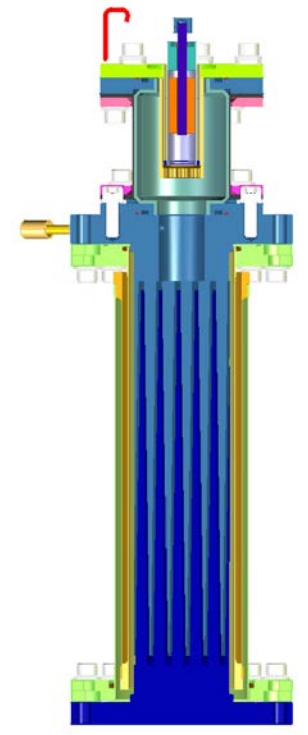
GGG Salt Pill Assembly



Kevlar Suspension Assembly



Passive Switch



Active Switch



Single-Stage 10 - 4 K ADR



Passive
Gas-Gap
Heat Switch

10 K Test Plate

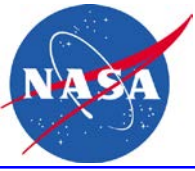
Silicon-Iron
Shield

Nb₃Sn
10 K
magnet

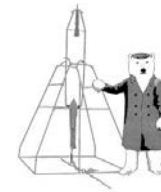


Copper
Strap

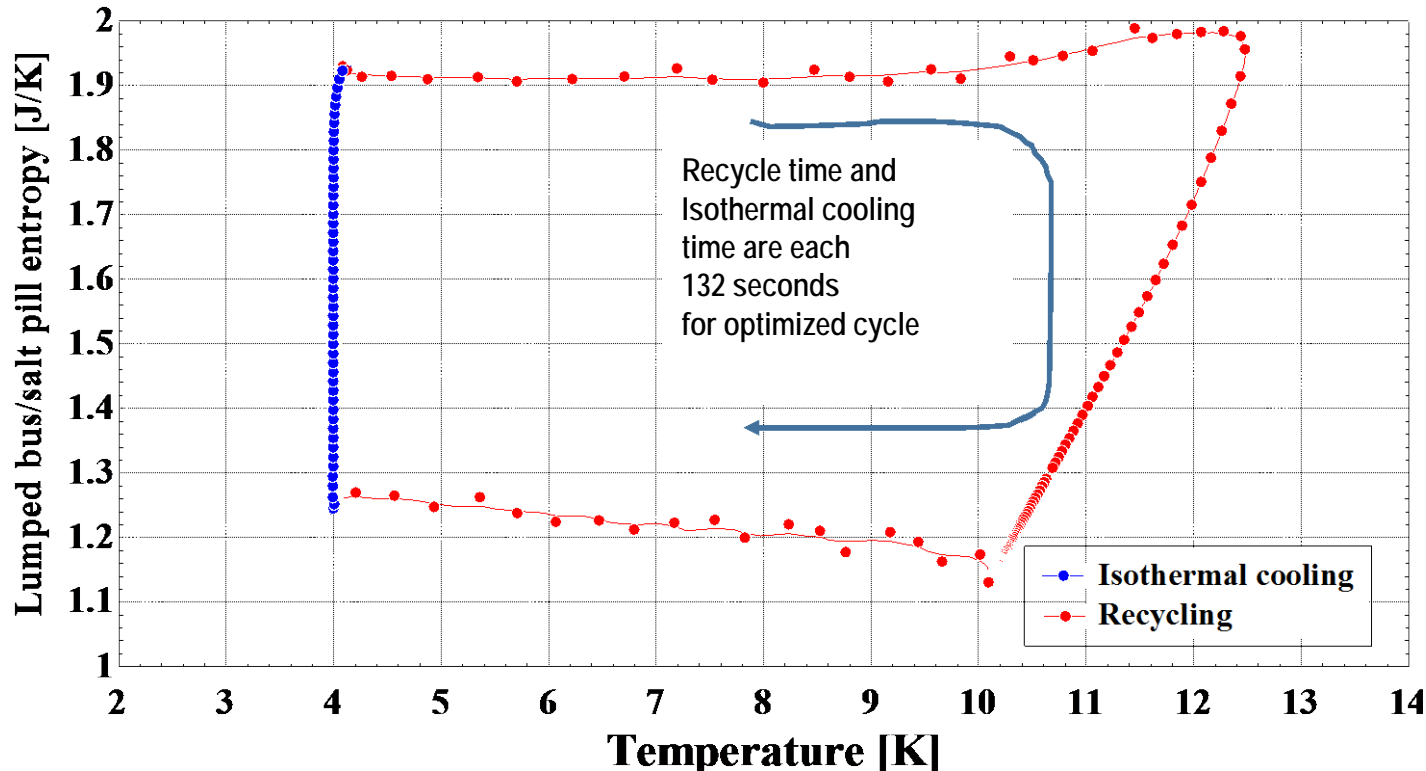
Salt Pill
End Flange



10 - 4 K ADR Test Results

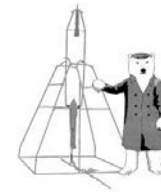


- For 13 mW load, cycle time equals 4 K hold time (prediction was 20 mW)
 - Under-performance partly due to historical misinterpretation of GGG magnetization data
 - Amir Jahromi's paper at CEC will discuss in more detail

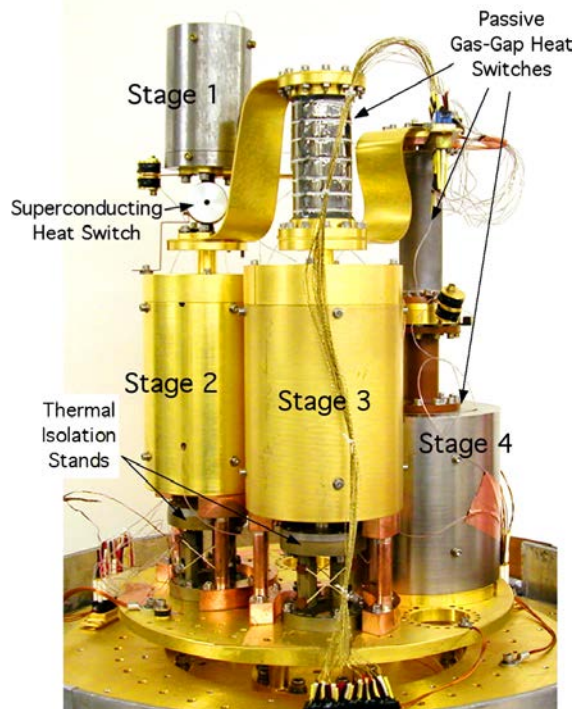




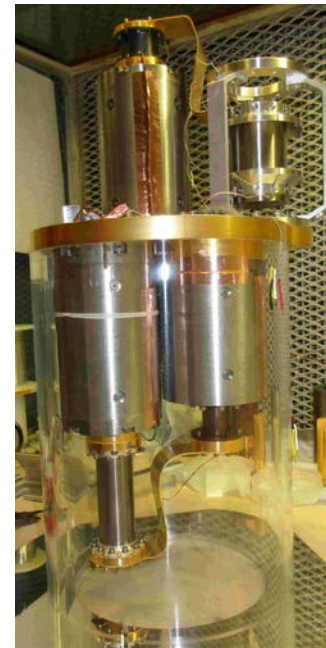
4 K – 0.05 K CADR Subsystem



- Four-stage lab CADR produced 6 μW of cooling at 50 mK in 2004
- New iterations have been built for lab use (2017) and a balloon flight (2018)
- Primary task: analyze/re-design salt pill suspensions to survive launch loads
- Secondary goal: identify/implement minor design/process improvements



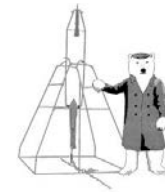
2004 CADR



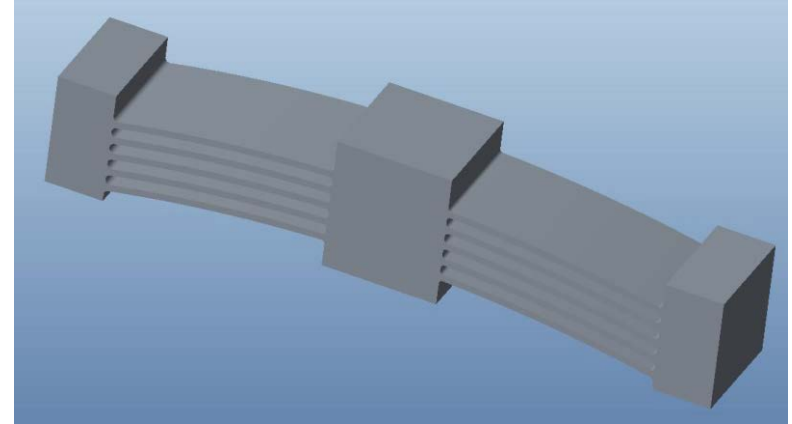
2017 CADR



Suspension System Re-design



- Lab Kevlar Suspension must be made to survive TBD launch loads
- Preliminary analysis of lab suspension:
 - Resonance frequencies are sufficiently high
 - May require larger Kevlar cross section in some locations
- We are studying strength of Kevlar/epoxy configurations
- Replacing Belleville washer stacks with flexures and stiff springs



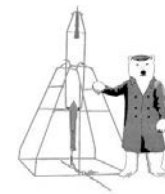
Preliminary flexure design



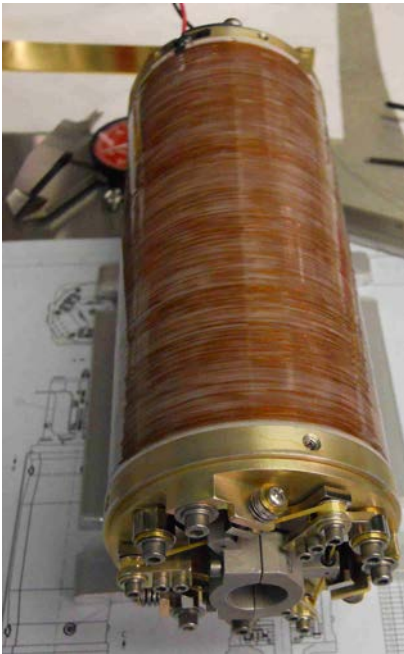
Testing of Kevlar/epoxy joints



4 K Magnets



- Our group has had great success fabricating NbTi magnets in-house
- New CNC winding system will improve the winding process
- We are beginning fabrication of four magnets for the 4 K to 0.05 K CADR



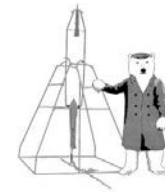
NbTi magnet wound
on our old machine



Our new CNC coil winding system



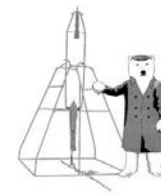
Magnetic Shielding



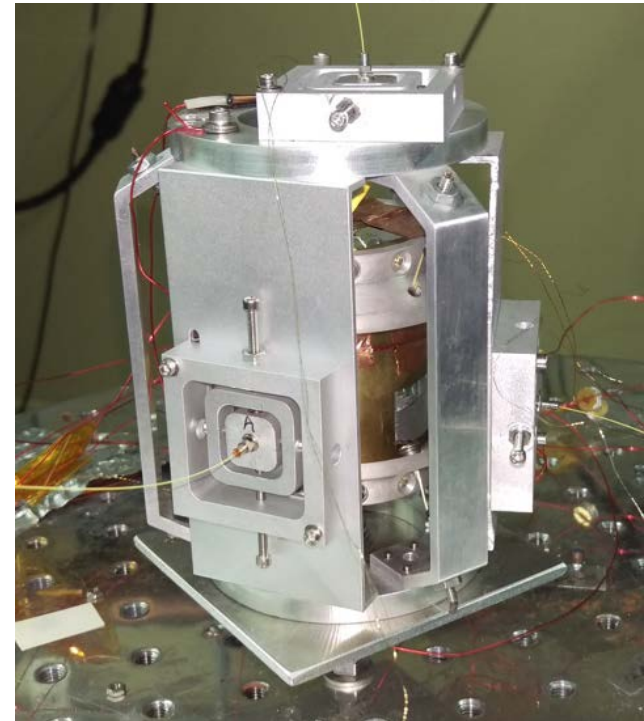
- Each magnet in the system has a ferromagnetic shield
- Overall 10 K ferromagnetic shield will bring nearby stray field $< 5 \mu\text{T}$
- Analysis shows that overall shield thickness is driven by structural concerns
- Baffled feed-thrus for 50 mK and 4 K straps have yet to be designed
- We will performance test prototype shield
 - Small coil on inside to produce field fluctuations
 - Flux-gate magnetometer on outside (20 nT resolution)



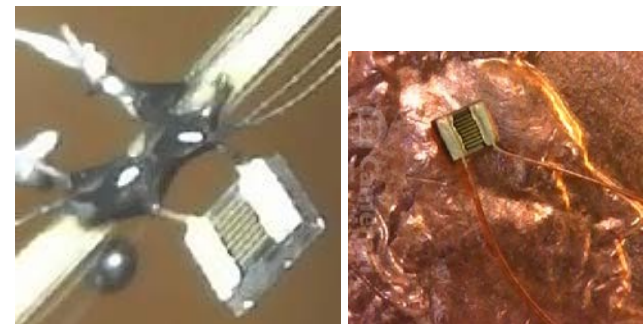
Vibration-Heating in Kevlar



- Lab CADR stages showed occasional 10+ μW heat loads correlated with excessive cryocooler vibrations
- Our theory: heating is due to stretching/rubbing in Kevlar suspension legs
- We developed a test rig to produce measureable vibrations in a 6 K simulated suspended CADR stage
- Simultaneously measure heat load into suspended mass and temperature at midpoint of one Kevlar leg
- Results consistent with uniform heating along Kevlar legs
- Tuttle presentation at CEC will describe this work in detail



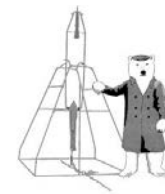
Test rig on cryostat cold plate



LakeShore Cernox chip sensor



Conclusion



- We are assembling a designed-for-flight 2-stage 10K to 4 K CADR
 - 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