

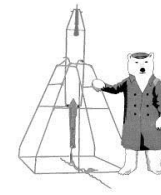
Development of a Space-Flight ADR Providing Continuous Cooling at 50 mK With Heat Rejection at 10 K

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Amir Jahromi, Mark Kimball, Peter Shirron, Dan Sullivan,
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Introduction

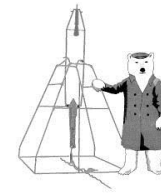


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- Future (post-PIXIE) flight missions will need:
 - sub-Kelvin cooling with higher heat loads than past missions
 - significant cooling at 2 – 6 K optics/instrument temperature
- NASA/GSFC is developing a flight-ready 10 to 0.05 K continuous ADR (CADR) to meet these needs



Performance Requirements



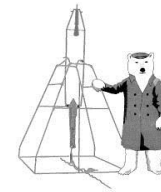
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- Anticipated future missions with sub-Kelvin detector arrays:
 - Origins Space Telescope
 - Lynx
 - Inflation Probe
 - Possibly HabEx and LUVOIR
- Proposed CADR can exceed expected performance requirements

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)	2	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	$> 20@4\text{ K}$
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

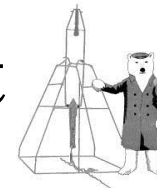


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- ADRs have no moving parts; contribute zero vibrations
- Mechanical cryocooler vibrations end up being an issue on flight missions
- Recently Creare demonstrated 10 K operation of their Turbo-Brayton cooler
 - Very high-frequency vibrations - heavily damped by spacecraft structure
- A 10 K superconducting flight-compatible magnet was developed with NASA fundint 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

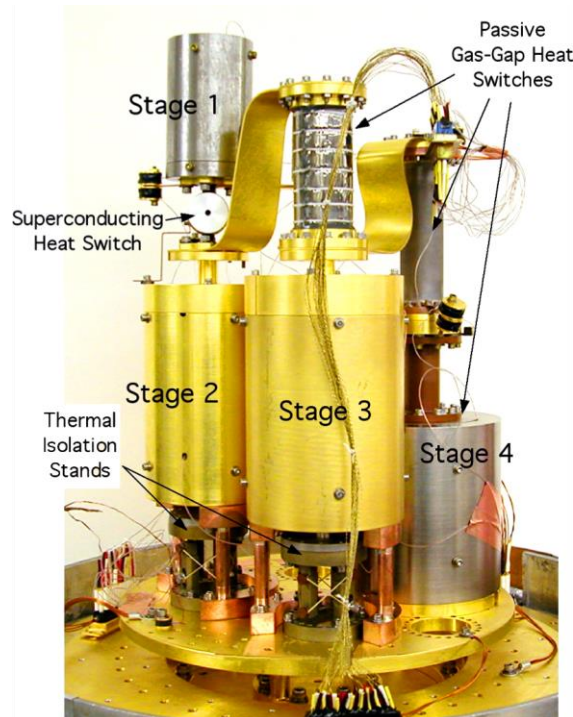


4 - 0.05 K CADR State-of-the-Art

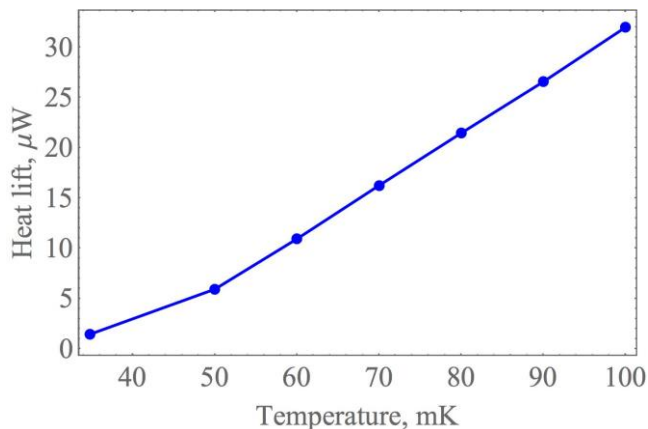


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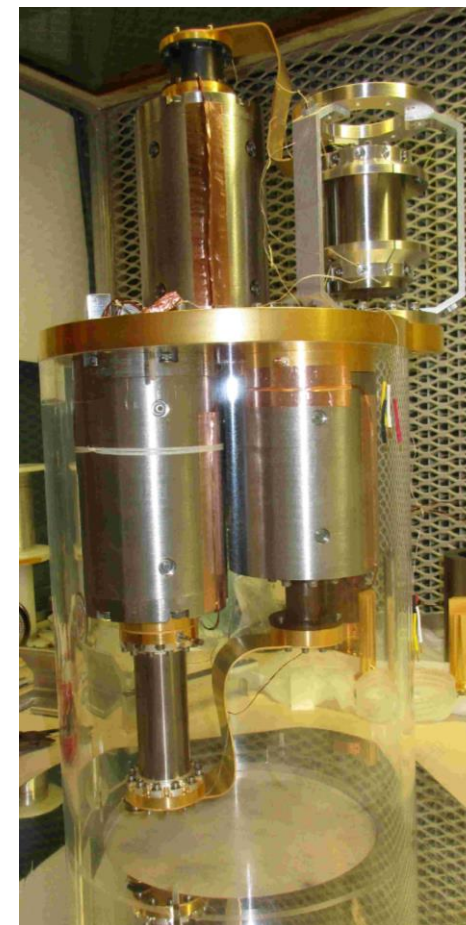
2004 Version



2004
performance
test results

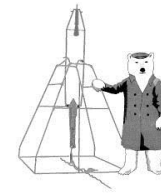


2017 Version
(~35 cm tall)



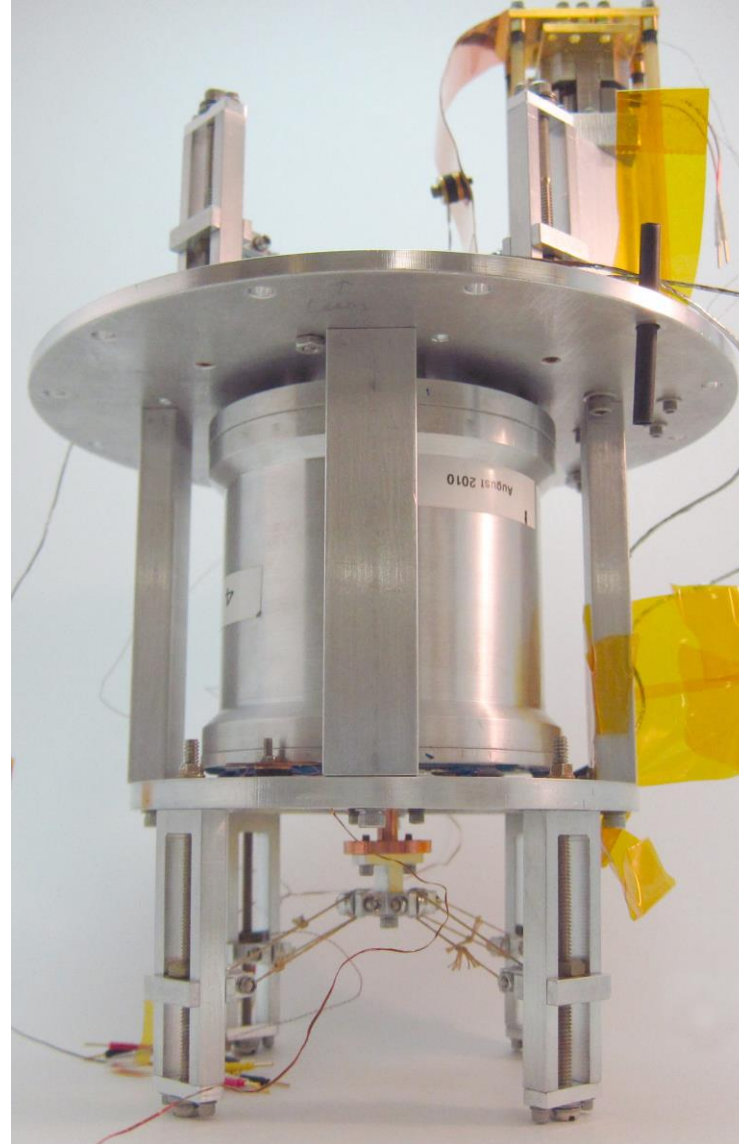


10 - 4 K CADR State-of-the Art



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- Proof-of-concept single-stage 10 – 4 K ADR was tested at NASA-GSFC
- Included prototype Nb_3Sn 10 K magnet
- Cooling was demonstrated



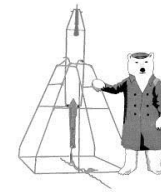
Piezo-electric
heat switch

Nb_3Sn
10 K
magnet

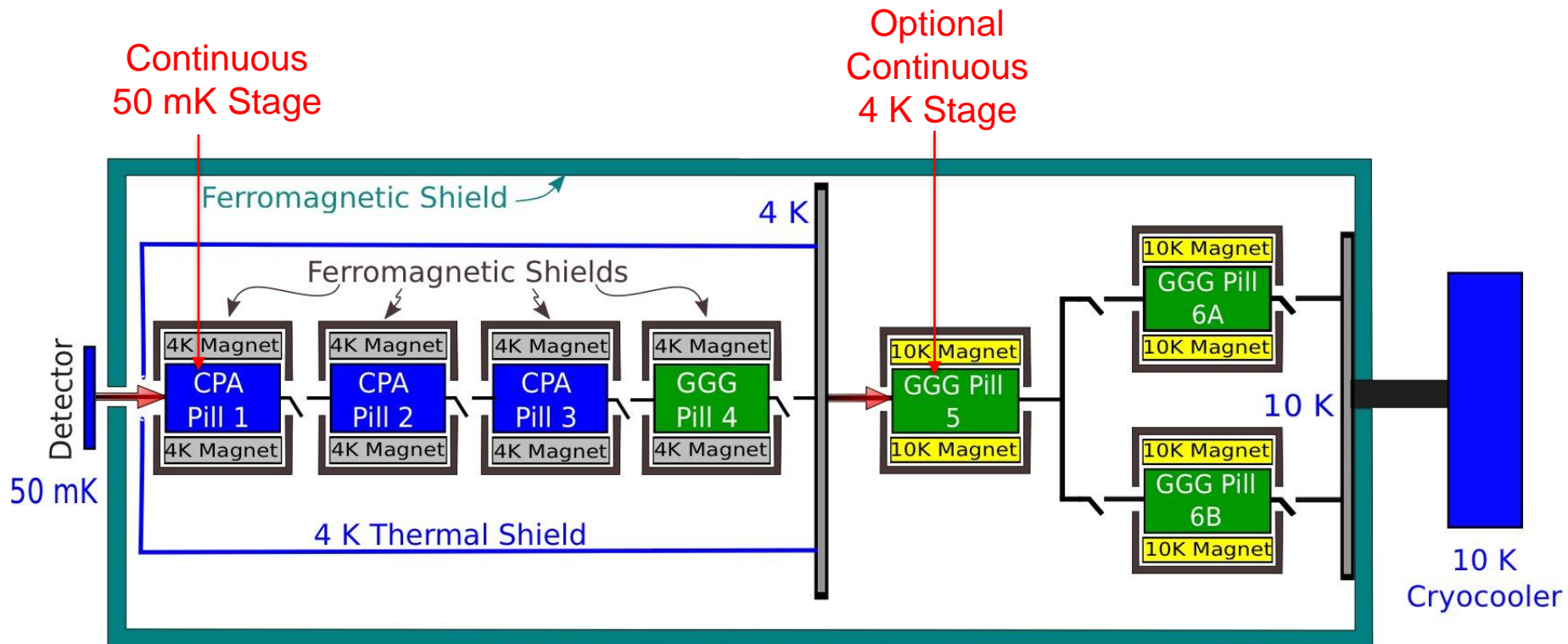
Laboratory
Kevlar
salt pill
suspension



New CADR Schematic

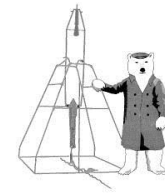


- Stages 1-2 switch is superconducting; all others passive gas-gap
- Includes 10 K vanadium permendur overall shield
- Stage 5 provides extra cooling at 4 K; could be removed to save mass
- 4 K to 50 mK subsystem will be flight-worthy version of lab CADR



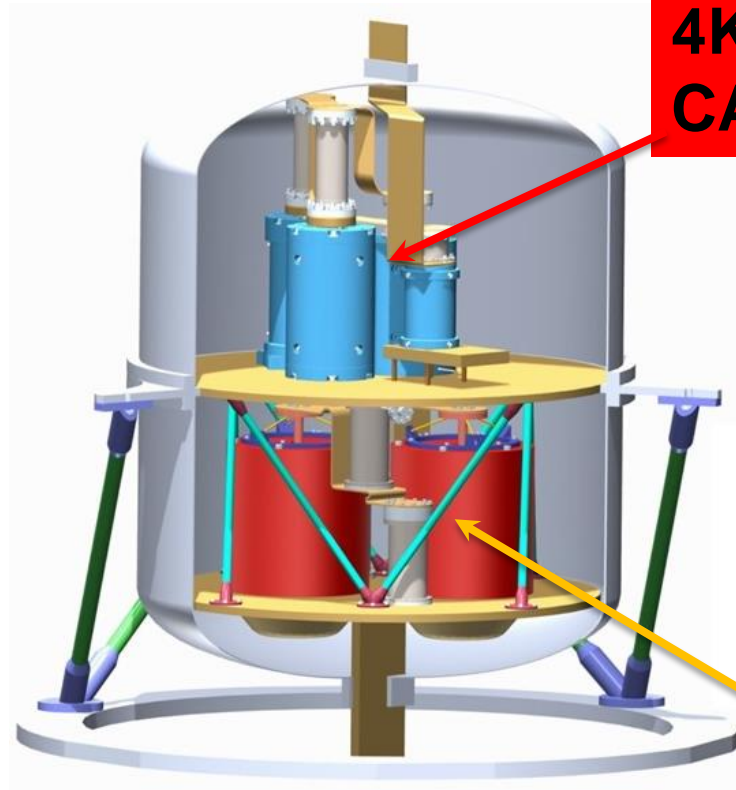


CADR Component Packaging



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Original proposed version with
4 K superconducting
overall magnetic shield

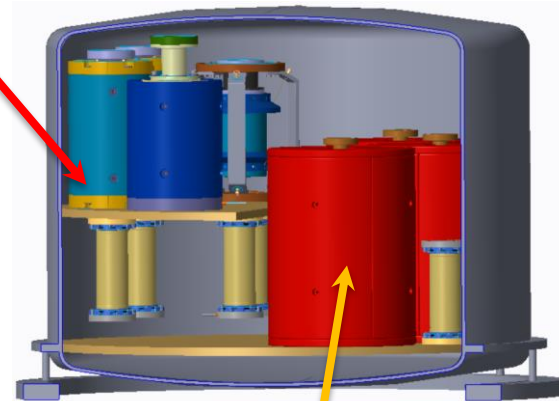


**4-stage
4K - 0.05K
CADR**

**2-stage
10K - 4K
CADR**

Re-packaged version with
10 K magnetic shield
(4 K thermal shield and some
straps not shown)

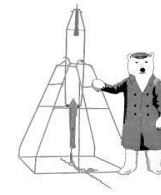
← O.D. ~ 35 cm →



**3-stage
10K - 4K
CADR**

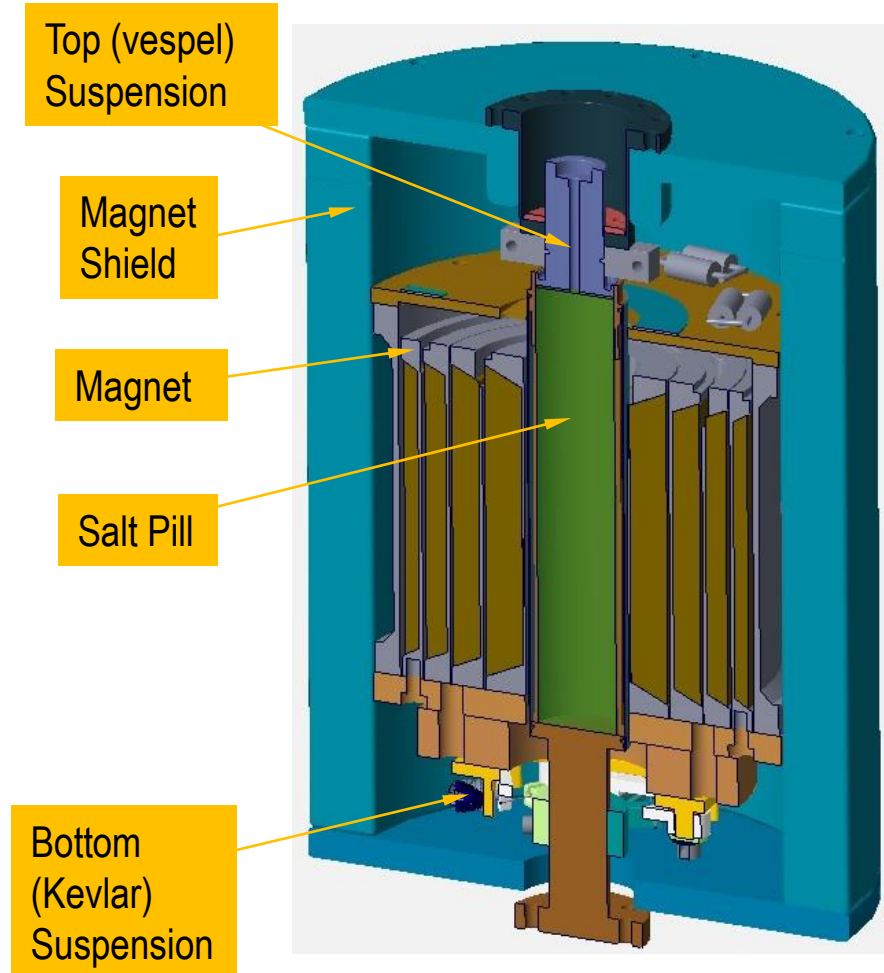


Updated 10 - 4 K Stage Design



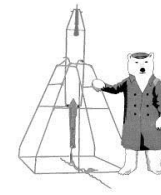
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- Silicon iron magnetic shield
 - minimizes stray field
 - enhances central field
- Magnet hangs from shield
 - 4 concentric coils
 - 4 Tesla max. central field
- GGG pill suspended from shield
 - optimized length: extends beyond magnet coils
 - Kevlar suspension design copied from ASTRO-H



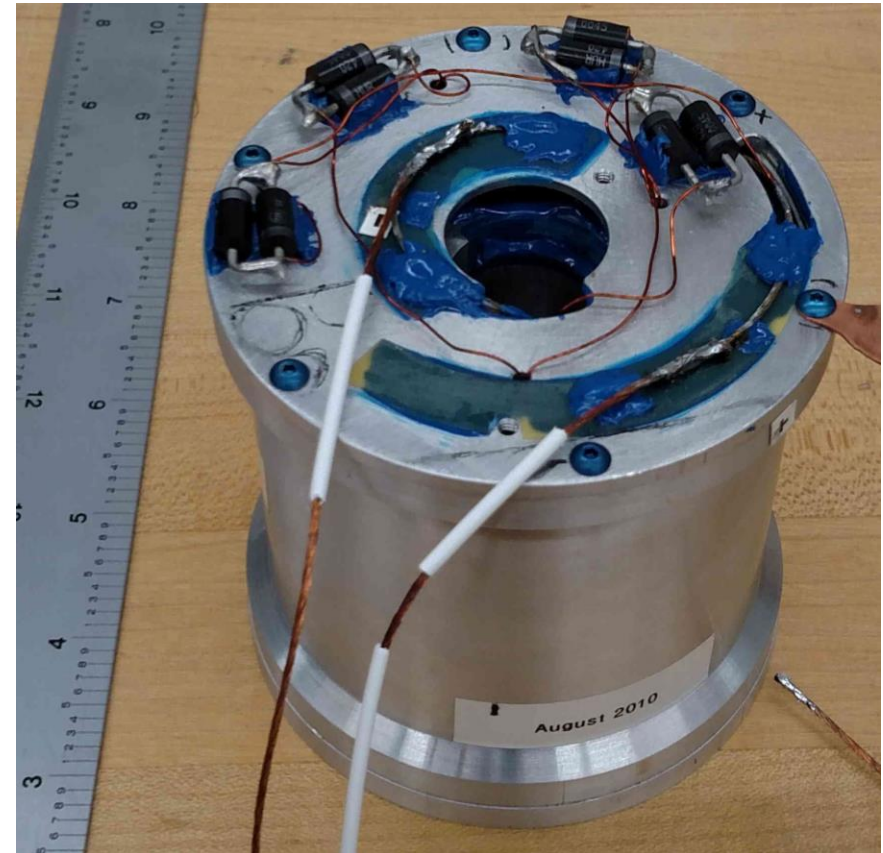


10 K Nb₃Sn Magnet



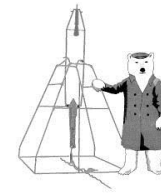
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- Developed from 2002 – 2010 by Superconducting Systems, Inc. with NASA funding
- Central field = 4 Tesla with 6.5 Amp operating current
- Mass = 1.85 kg
- We measured AC heating for one cycle from zero – 4 T– zero field:
 - 0.9 Joules/cycle
 - nearly independent of ramp rate: hysteresis heat dominates
 - for 2 parallel stages with 10 minute overall cycle time: magnet heating = 3 mW at 10 K
 - will re-test soon with shield

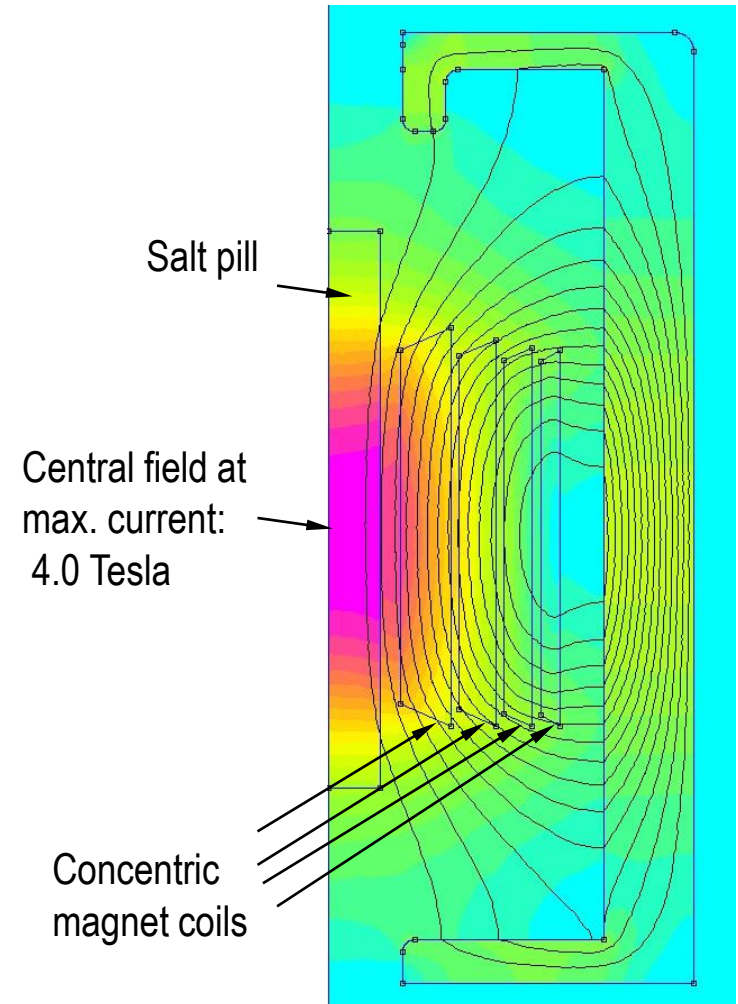




10 K Magnet Modeling

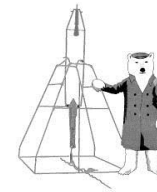


- Structural model showed no resonance modes below 600 Hz
- Magnetic/thermal model results
 - shield's shape and wall thickness chosen to keep its internal field below 2.1 T saturation limit
 - shield enhances central field (or reduces operating current)
 - field as low as 1.5 T produces useful cooling in GGG
 - optimum salt length extends beyond magnet coil ends



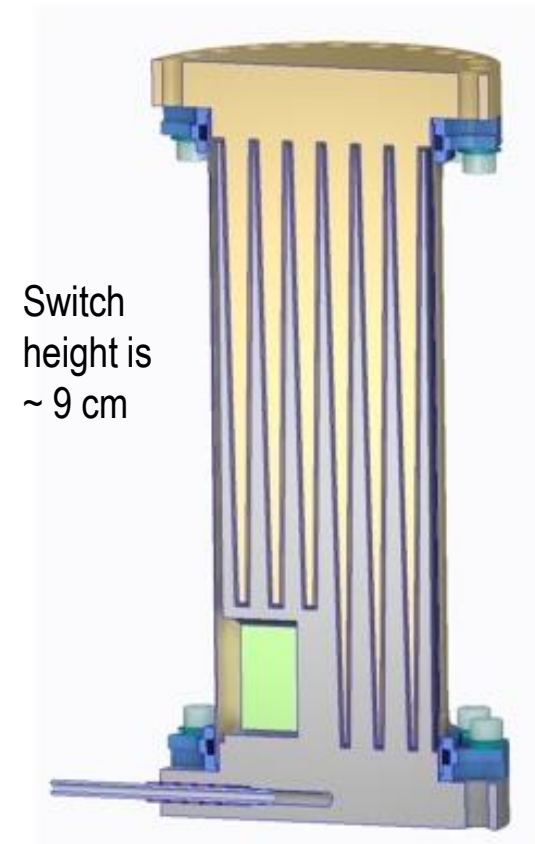


10 K – 4 K Gas Gap Heat Switch



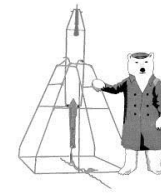
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- Two copper stages separated by a stainless steel hermetic shell
- ^3He gas is sealed inside shell volume
- High gas thermal conduction between interleaved fins when switch is closed
- Contains a charcoal getter on cold side
- Gas pressure optimized so switch opens at just below 10 K
- Test results will be shown in Kimball talk later in this session





Plan Forward



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- 2017: Demonstrate a one-stage 10 to 4 K ADR
- 2018: Assemble/test a flight-worthy 3-stage (or 2-stage) 10 to 4 K CADR
- 2019:
 - 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