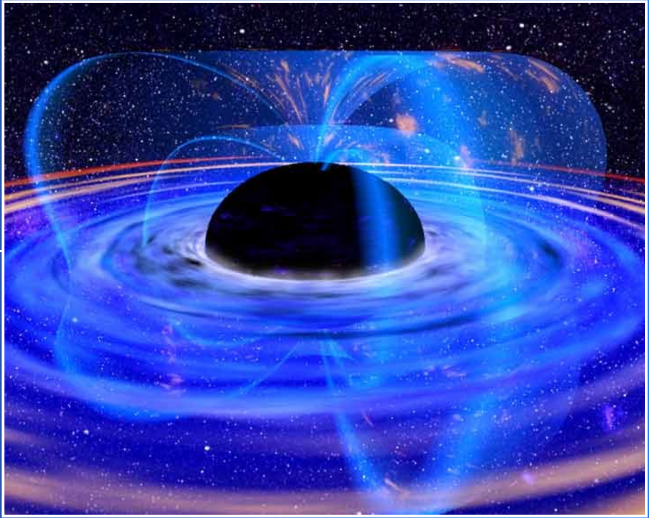
Workshop on X-Ray Mission Architectural Concepts

December 14-15, 2011

ADR Options for Future X-Ray Missions



Peter Shirron

NASA/GSFC

Detector Cooling Requirements

- Required temperatures and cooling power
  - Detector cooling: 50 mK (lower?), 2-5 μW
  - Amplifiers, heat intercept for detector wiring: 1-4 K, ~1 mW or more
- Heat sink temperature
  - Cryocoolers will be used to provide cooling to <5 K
    - Long life
    - Support warm launch concepts
    - Avoids complexity and risks of stored-cryogen systems

Flight Cryocoolers	Cryocooler Type	Cryocooler Capability
Sumitomo Heavy Industries	Joule-Thomson with Stirling pre-coolers	1.7 K, 10 mW or 4.5 K, 40 mW
Ball Aerospace, Northrup Grumman, Lockheed-Martin, Creare	JT with Stirling, JT with Pulse tube, Pulse tube, Turbo-Brayton	4-5 K, 30-40 mW

Cooler Options

Low Temperature cooler options (flight)	Demonstrated capability
– ^{3}He sorption cooler	>200 mK
– Dilution refrigeration (open cycle)	100 mK
– Adiabatic demagnetization refrigeration	<20 mK

- Can consider hybrid combinations
- But…
  - ADRs are considerably more efficient than other options, and can span the range from <20 mK to >5 K
  - ADRs are more efficient than cryocoolers over the same temperature range
    - From system perspective, it is advantageous to use ADRs over widest possible temperature range

ADR Basics

- Magnetocaloric effect
  - Increasing magnetic field causes the refrigerant to warm up or give off heat; decreasing field causes it to cool down or absorb heat

ADR Architectures for 5 K Operation

- Single-shot Operation

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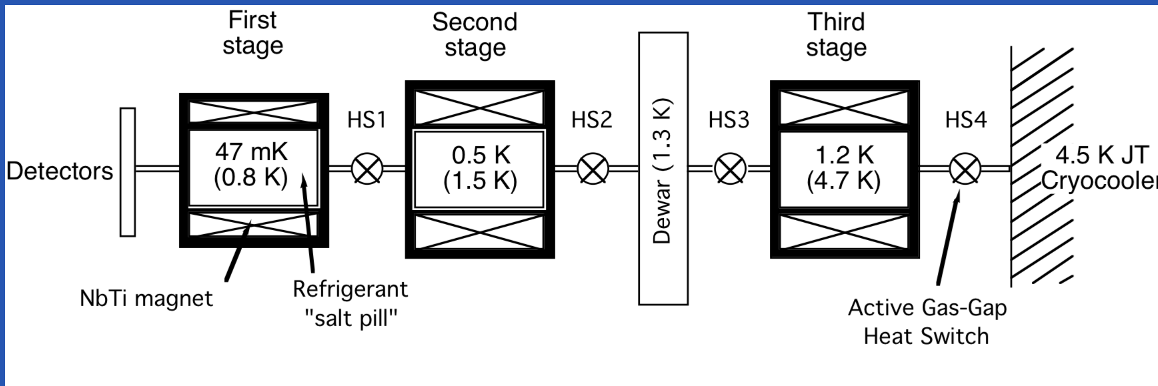
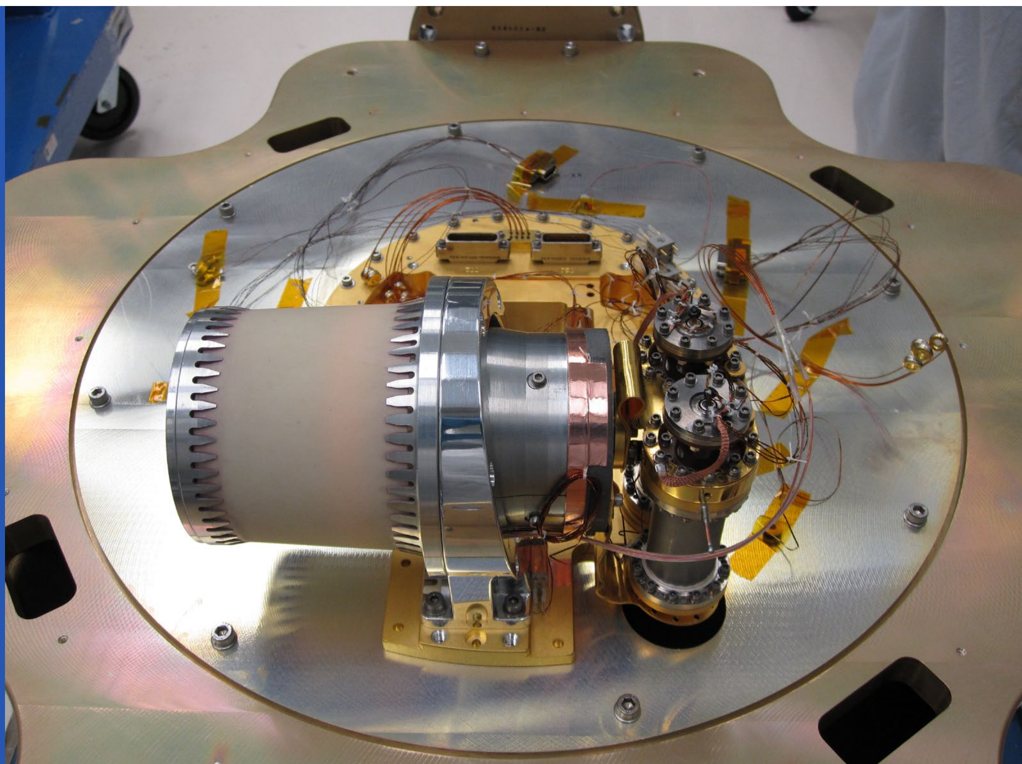
- Benefits
  – Very stable temperatures during hold time
  – Each stage is a heat intercept for leads, etc.
  – Low magnetic fields present during detector operation
- Drawbacks
  – Limited cooling power or large mass (or both)

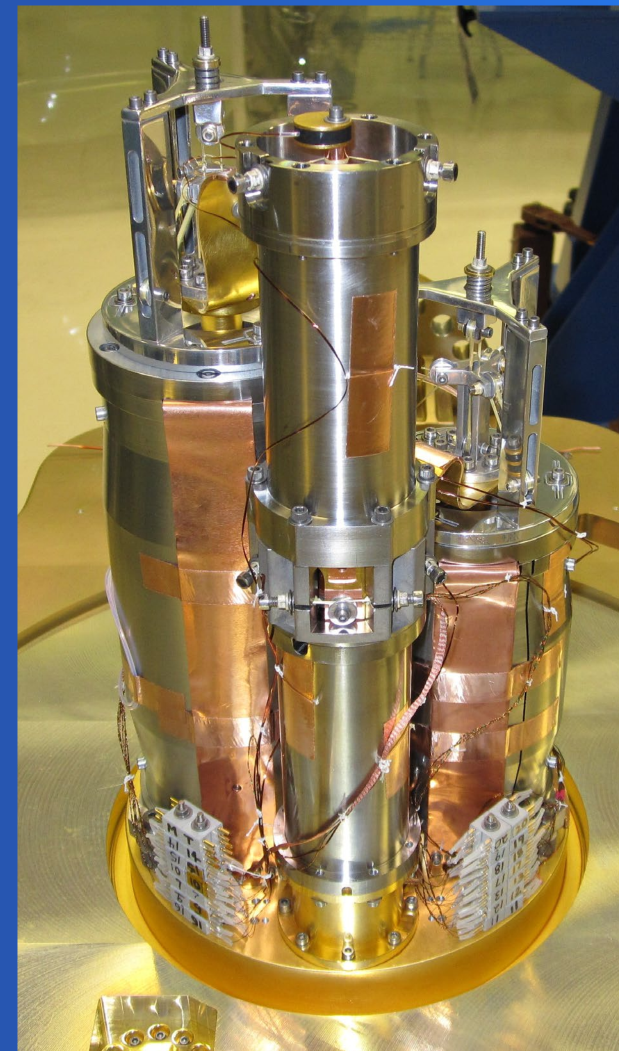
ADR Architectures for 5 K Operation

- Continuous Operation
- Benefits
  - Continuous cooling at two temperatures
  - High cooling power per mass
  - High efficiency
  - Low peak heat rejection rate
- Drawbacks
  - Fluctuating magnetic fields and temperatures during detector operation

3-Stage ADR for Astro-H

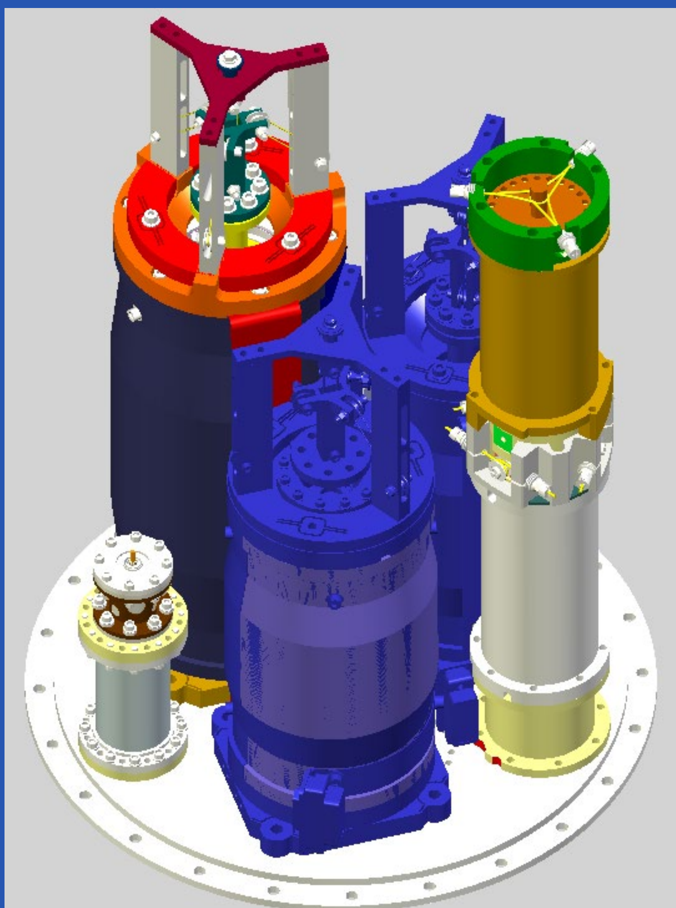






3-Stage ADR for Athena (reconfigured Astro-H ADR)

- Designed for 2 μW detector load at 50 mK
- Peak heat rejection rate of 20 mW at 4.5 K
- 15 kg total mass



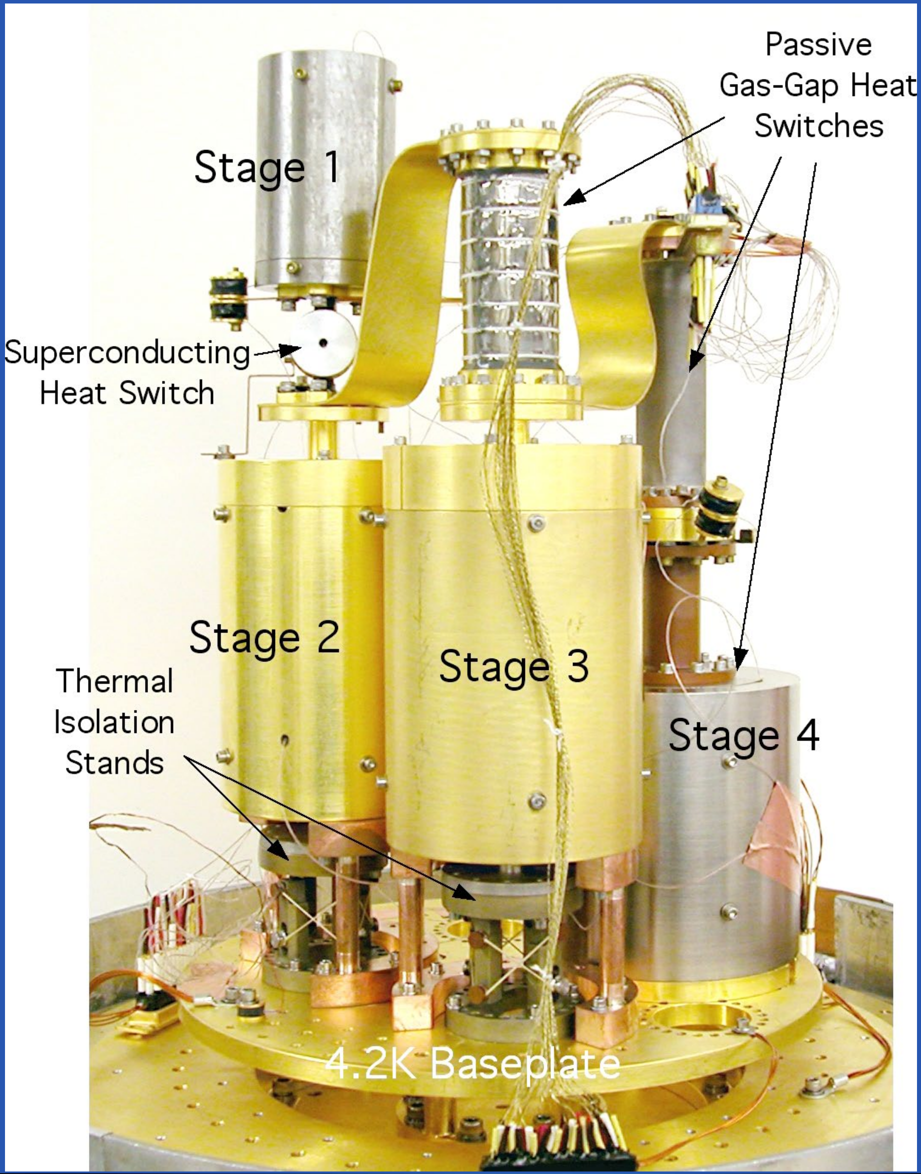
- Recycle time of <2 hours
- Hold time of >30 hours
- Duty cycle of >94%

4-Stage CADR Prototype

- Development funded by NASA targeting Constellation-X needs
  - 5 μW detector load at 50 mK, with 100% margin
  - Maximum heat rejection rate of 10 mW at 4.5 K

- Stage 1 works to stabilize detector temperature at 50 mK
- Upper stages work to cascade heat to the heat sink

Prototype 4-Stage CADR



- Up to 5 K heat sink
- Total mass of 7.7 kg
  - 1: 40 g CPA, 0.2 T
  - 2: 100 g CPA, 0.5 T
  - 3: 100 g CPA, 1.5 T
  - 4: 60 g GLF, 4 T
- Operation is fully automated

4-Stage Cycling

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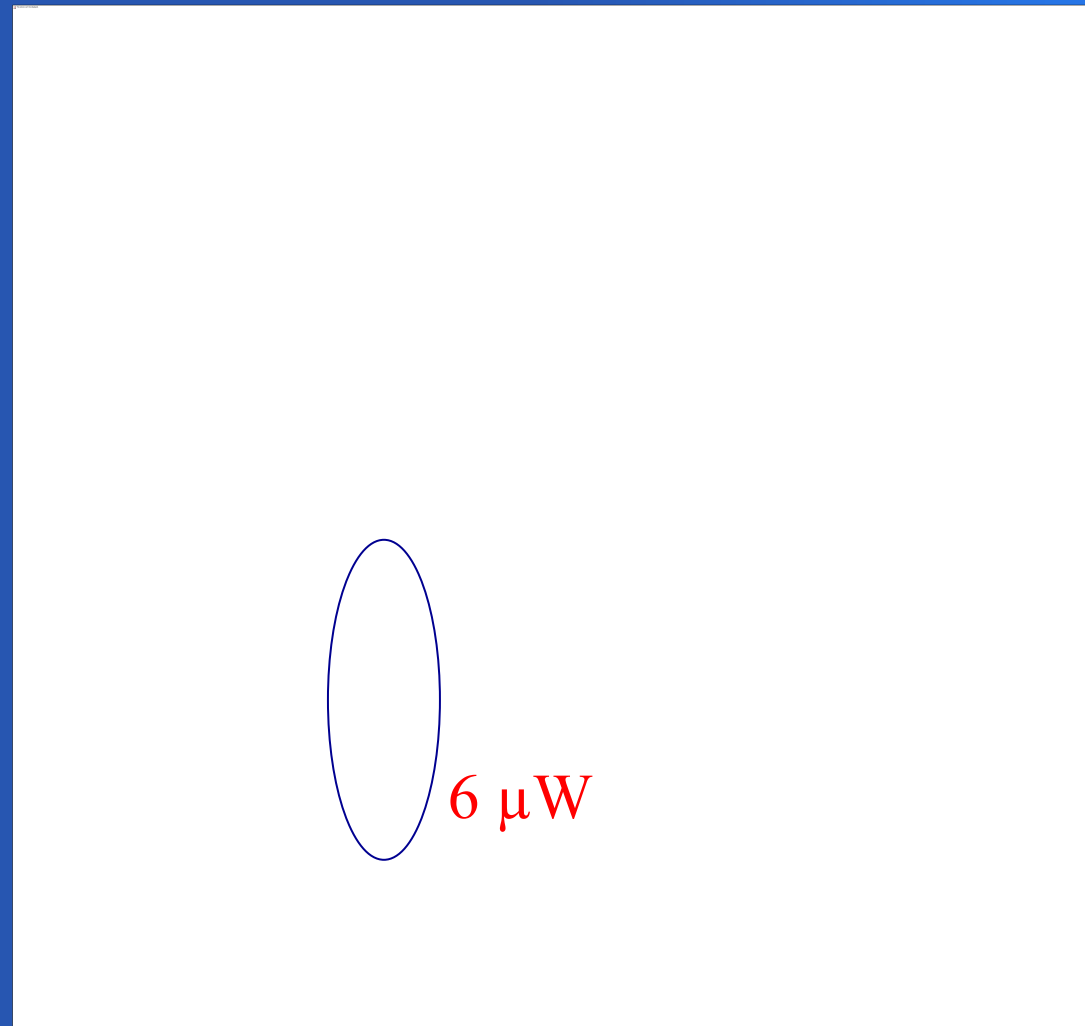
Demonstrated Cooling Power and Efficiency

- Peak heat rejection at 4.5 K is 8 mW
- Cooling power represents available cooling above internal parasitics

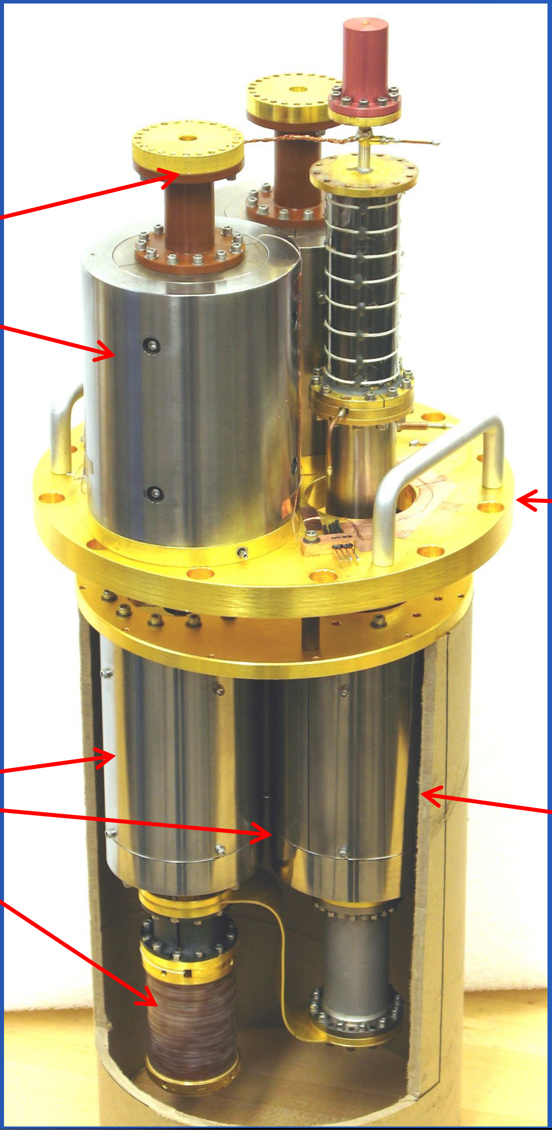


5-Stage Prototype

- Funded by GSFC IRAD
  - Development is on-going

2 stages cool continuously to ~1 K (~15 minute cycle)

3 stages cool continuously to 50 mK (~15 min cycle)



Cryocooled heat sink at 4-5 K

1 K shield (removed for assembly)

Summary

- ADR technology is well suited to requirements for future x-ray missions using low temperature detectors
- Different architectures have been implemented
  - Single-shot ADR
    - Requires minimum of 2 stages, but 3 stages provides greater cooling power and less mass
    - More conventional
    - Requires very little development from current state
  - Continuous ADR
    - Requires 5 stages to achieve 2 fixed temperatures
    - Highest cooling power
    - Most efficient
    - Lowest heat rejection rate – most compatible with cryocooler capabilities
    - Requires some development to reach TRL 6
      - » Temperature stability of coldest stage