NASA Cryocooler Development Program Overview

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Topics

- Background
  - History of NASA cryocooler missions
  - Space cryocooler flight operating experience
- Planck sorption cooler
- DoD large capacity 35K/85K two-stage cryocoolers
- NASA ACTDP cryocooler development program
  - Objectives and Requirements
  - Contractors and Concepts
- Example application of ACTDP cryocoolers to 4-6 K cooling of a large space observatory
  - JWST/MIRI cryocooler integration concept
  - Cooling capacity versus temperature
  - Predicted in-space cooldown time for MIRI
- Summary
Cryocoolers are an enabling technology for many NASA space-science missions. NASA first flew long-life cryocoolers on UARS in 1991 (British ISAMS instrument); this started the history of the very successful "Oxford cooler" designs. NASA has now put nine more long-life coolers into flight service including four in 2002, and three more are scheduled for launch on the Aura spacecraft this month.
# Space Cryocooler Flight Operating Experience

<table>
<thead>
<tr>
<th>Cooler / Mission</th>
<th>Running Hours</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Creare Turbo Brayton</td>
<td>19,000</td>
<td>As of 5/04, Ongoing, No degrad.</td>
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<tr>
<td>NICMOS</td>
<td></td>
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<tr>
<td>Japanese Stirling</td>
<td>37,000</td>
<td>As of 5/04, Ongoing, No degrad.</td>
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<tr>
<td>ASTER (2 units)</td>
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<tr>
<td>NGST (TRW) Pulse Tubes</td>
<td>57,000</td>
<td>As of 5/04, Ongoing, No degrad.</td>
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<td>CX (Mini PT (2 units))</td>
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<td>MTI (6020 10cc PT)</td>
<td>37,000</td>
<td>As of 5/04, Ongoing, No degrad.</td>
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<td>Hyperion (Mini PT)</td>
<td>30,000</td>
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<td>SABER (Mini PT)</td>
<td>24,000</td>
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<td>AIRS (10cc PT (2 units))</td>
<td>18,000</td>
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<tr>
<td>Oxford/BAe/MMS/Astrium Stirling</td>
<td>16,223</td>
<td>Near continuous 10/91 thru 7/92</td>
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<tr>
<td>HTSSE-2 (80K BAe)</td>
<td>24,000</td>
<td>As of 5/04, Ongoing, No degrad.</td>
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<td>INTEGRAL (50-80K Astrium (4))</td>
<td>13,000</td>
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<td>MOPITT (50-80K BAe (2 units))</td>
<td>37,000</td>
<td>As of 5/04, one displacer failed at 11,000 hours; other still running</td>
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<td>RAL 80K Integral Stirling</td>
<td>42,000</td>
<td>Near continuous 7/91 thru 6/96</td>
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<td>ATSR 1</td>
<td>~74,000</td>
<td>As of 5/04; launched 5/95; No degrad.</td>
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<td>ATSR 2</td>
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<tr>
<td>Sunpower Integral Stirling</td>
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<td>As of 5/04, Ongoing, No degrad.</td>
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Planck mission of the European Space Agency
  – Very high resolution mapping of temperature anisotropy in the CMB (2007 launch)

Two JPL hydrogen sorption cryocoolers
  – Cool the LFI detectors to 18 - 20 K
  – Precool RAL 4 K helium J-T for HFI system
  – Deliver flight units in Nov. 2004 and April 2005
• DoD Missile Defense Agency missions desire large cooling capacities:
  • 2 W at 35 K ...plus
  • 20 W at 85 K

• Large "Oxford style" pulse tube cryocoolers have been developed at NGST and Lockheed Martin for this need with input power capacities up to 600 watts

• These large-capacity coolers provide near-flight-qualified hardware for future NASA missions to build upon

NGST (TRW) HCC 35K/85K 2-stage pulse tube cryocooler (14 kg, 600 W)
ACTDP Objective
(Advanced Cryocooler Technology Development Program)

- Cryocooler development for next generation space-based observatories
  - 4-6 K / 18 K two-stage cooling
  - Remote coldheads (on deployable structures)
  - Minimal generated noise (EMI and Vibration)

- Three key missions have served as focus
  - Terrestrial Planet Finder
  - Constellation-X
  - James Web Space Telescope

- Designed to provide proven Development Model (DM) coolers in the 2006 timeframe
Top-Level Requirements

Consensus Top-level cooler requirements for TPF, JWST, and Con-X have been identified and reflected in a detailed ACTDP cryocooler specification. Key requirements include:

- 30 mW at 6 K plus 150 mW at 18 K
- <200 watts input power
- < 40 kg cooler system mass
- Accommodate 5 to 25 meter cold-end deployment length
- Low Generated Vibration and EMI, 10 year life

TPF

SAFIR

Con-X
ACTDP Cryocooler
Contractors and Concepts

Ball Aerospace

Northrop Grumman (NGST)

Lockheed Martin
ACTDP Hybrid J-T Cryocooler Thermal Flow Diagram

20 W

288 K

140 W

Electronics & Cables

295 K

40 W

Stirling or PT Precooler

Frame

30-40K Stage

Upper Stage

50 mW

30 mW

15-16K Stage

Bypass valve

6 K Load (30 mW)

18 K Load (150 mW)
Example Cryocooler Application to James Webb Space Telescope

- MIRI Instrument
- Cryocooler Compressors
- Sun Facing Surface
- Compressor Heat Rejection System Radiator
- Cryocooler Electronics
- Optical Telescope Element
- V-Groove Sunshade
- Piping Assembly
- Deployed
- 35K ISIM
- 6K OBA
- 6K Coldhead
- 18K Coldhead
- Spacecraft Bus (~300 K)
- MIRI 6K OBA

Diagram showing Cryocooler Compressor Assembly and associated components.
Example MIRI Instrument Cryocooler Integration Concept

18K heat interceptor for conduction loads

JWST ISIM (~40K)

18 K lines

Ball Aerospace Stirling Cooler

NGST PT Cooler

J-T coldhead

MIRI Instrument (~6K)

Cryocooler

RR-12
MIRI Cryocooler Piping Assembly
Thermal Boundary Conditions

Disconnect fitting (35K)

Total length ~10m

Deployment section (118 K)

Disconnect fitting (145 K)
ACTDP Hybrid J-T Cryocooler Cooling Capacity vs Temperature

Capacity of 6K stage for temperature > 18K

Load on 18K stage

Baseline Operating Point

Capacity of 6K stage for temperature < 18K

Closure of bypass valve at ~15 K transfers cooling over to J-T expander

Coldhead Cooling Capacity, mW

6K Coldhead Interface Temperature, K
MIRI Cooldown vs Time
Using an ACTDP Cryocooler

Thermal mass = 90 kg of Aluminum
## Procurement Schedule

### Milestone Schedule

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<th>CY03</th>
<th>CY04</th>
<th>CY05</th>
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<td>AWD</td>
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<td>Perf. and Char. Tests</td>
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**Legend:**
- **AWD**: Award
- **PDR**: Preliminary Design Review
- **DTR**: Development Test Review
- **TRR**: Technology Readiness Review
- **PSR**: Pre-ship Review

**Abbreviations:**
- **DTR** = Development Test Review
- **TRR** = Technology Readiness Review
- **PSR** = Pre-ship Review
Three teams were selected in January 2003 for Demo-Phase contracts and have completed detail designs at this point:

- Ball Aerospace, Boulder Colorado
- NGST (TRW), Redondo Beach, California
- Lockheed Martin, Palo Alto, California

Current effort is on design refinement and development testing at testbed level to achieve efficiency and life goals.

Development Test Review scheduled for this summer and Technology Readiness Review is scheduled for summer 2005.

Assembly and test of complete Development Model coolers at systems level is scheduled for completion by summer 2006.
Space cryocoolers have reached a high level of maturity
- Life times in excess of 10 years in ground tests
- Over 20 coolers operating in space with multi-year lifetimes
- Two more cooler missions are scheduled for launch this summer

Present NASA development emphasis is on 4-6K / 18K coolers to enable the use of low-temperature detectors and optics with future multi-year observatory missions; the coolers are being developed as part of the Advanced Cryocooler Technology Development Program (ACTDP)

Development Models of these new ACTDP coolers are currently in the detailed design and test phase as part of the TPF project; system-level demonstrations of these DM cryocoolers are scheduled for summer 2006