Space Cryogenics at the Rutherford Appleton Laboratory

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Cryogenic Cluster Day
STFC, Rutherford Appleton Laboratory
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• Rutherford Lab has a long history of cryogenics in space both for earth observation and astronomy

• Today – picking up on just three examples:
  – Herschel SPIRE
  – JWST MIRI
  – Planck
SPIRE Spectral and Photometric Imaging REceiver – Herschel

The SPIRE instrument contains an imaging photometer (camera) and an imaging spectrometer. The camera operates in three wavelength bands centred on 250, 350 and 500 μm, and so can make images of the sky simultaneously in three submillimetre “colours”. The spectrometer covers the range 200 – 670 μm, allowing the spectral features of atoms and molecules to be measured.

- 48hr Instrument Operation Cycles
  - 2 hr for Sorption Cooler Recycling
  - 46hr for scientific measurements with Bolometer Detector Arrays (five in total) at absolute temperature of 310 mK

- Herschel Cryostat provides a chain of four Temperature Stages 15K, 12K, 4K and 1.7K

- 6L $^3$He Sorption Cooler onboard SPIRE provides 300-mK stage for durations > 46hrs

Instrument PI on SPIRE is at Cardiff University
SPIRE Thermal Design Overview

Herschel Radiation Shield ~ 16K

Mech: BSM SMEC SCAL PCAL

Pump

6L Sorption Cooler

Evap

1.7K - 2K

300 mK

Photometer Spectro

PJFET

15K

L0

L1

L2

L3

3.7K - 5.5K

Herschel Optical Bench 8K-12K

SJJET

CFRP Supports

Kevlar Supports

Thermal Straps

Electrical Isolation

Low Conductance Cryo-Harness

Photometer Side

Spectrometer Side
Experience - SPIRE

ESARAD Geometric Model

Detectors cooled to ~300 mK (46 h hold time)
Optics cooled to ~4 K
Cryogenic testing undertaken at RAL

Thermal Testing

Cryogenic Qualification Model
Infrared sees dust from which stars are formed.
The James Webb Space Telescope (JWST):
- A large infrared optimised space telescope
- Due for launch in 2014 into an L2 orbit
- To study the very distant universe, looking for the first stars and galaxies that ever emerged

A European consortium and a US team lead by NASA JPL are designing the Mid Infrared Instrument (MIRI)
- Provides imaging, coronography – for detection of planets orbiting distant stars, and low/high resolution spectroscopy between 5 and 28 microns
James Webb Space Telescope – Mid InfraRed Instrument (MIRI)

- RAL Space Science Technology Department responsible for thermal design and thermal test of the instrument

**Test facility:**
- Aluminium interface bench and shroud fits inside space test chamber (STC)
  - Wrapped in multi-layer insulation to isolate from STC
- Cooling provided by two stage mechanical Gifford-Mahon cryo-coolers (Sumitomo):
  - Bench cooled to ~ 40 K by flexible aluminium straps to stage one of two coolers
  - MIRI cooled to ~ 6 K by aluminium straps connected to stage two of first cooler
  - Telescope simulator cooled by straps connected to stage two of a third cooler
- Special attention required at thermal interfaces to minimise temperature gradients
Main thermal requirements
- Detectors ~ 6 K
- Optics ~ 15 K
- 68 mW heat lift available at steady-state
- Instrument cooldown < 150 days (from deployment of JWST sunshield)

Observations in the infrared implies cryogenic technology required
- Minimise background thermal radiation that would swamp signal being detected
- Reduce signal to noise ratio in detectors
Planck – 4K JT Cryocooler

- Planck is a satellite that is measuring the Cosmic Microwave Background
- It is an ESA mission with significant contributions from all corners of the earth
- Two instruments – The HFI instrument which is led by France (Jean-Loup Puget) and the LFI which is led by Italy (Nazzareno Mandolesi)
- The instruments cover a very wide spectral range
- LFI 30-70GHz (three frequencies) HFI 100-857GHz (six frequencies)

+ cast of thousands from France, US, UK, Canada, Italy, Spain, Ireland, Germany, Netherlands, Denmark and Switzerland
How to Measure the Cosmic Microwave Background

• Space is cold therefore need cold detectors with high sensitivity
• Need to reduce background noise – cold mirrors, instrument etc..
• Need a stable environment – earth orbit no good – go to L2
• Need precision low noise electronics
• Need low vibration environment
• Launched May 2009
• ~8 weeks to cool-down
• In operation
Planck – 4K JT Cryocooler

- The RAL 4K Cooler is a part of the complex Planck cryogenic chain
- The cooler relies on two pre-cooling stages higher up the chain;
  - passive radiative pre-cooling to ~50K (spacecraft ‘3rd V-groove’) 
  - Hydrogen Sorbtion pre-cooler to ~18K (supplied by JPL)
- The cooler provides a stage at ~4.5K to continue the cryogenic chain
- He3/He4 dilution refrigerator incorporating a 1.6K JT stage and ultimately reaching 0.1K at the detectors (supplied by IAS/Air Liquide)

+ cast of thousands from SSTD, SEA, Astrium, Swindon etc…
Cryogenics on Planck

Service Module 300K

Hydrogen Sorption cooler
JPL

4K Cooler
RAL

Dilution SRTBT/AL

Low Frequency Instrument at 18K

V-groove passive radiators
50K
80K
140K

18K

4K

50K
• 4K Closed Cycle Joule-Thomson Cooling System
• Working fluid is $^4$He

4K Cooler total electrical input power (~110W)

$P_h = 10\text{bar}$
$P_l = 1.3\text{bar}$
$m = 4.5\text{mg/s}$
Cooler installed on the spacecraft

Picture courtesy A Arts
The switching of the beds in this period gives a 0.37 to 0.47K change in the pre-cooler temperature. The effect on the 4K stability is between 3 to 4mK. The overall sensitivity of the 4K cooler to the 18K interface is approximately 8-8.5 mK/K.

The cooler short term stability is correlated with the hydrogen sorbtion cooler stability.

Although the low pressure transducer is switching only a few bits, the first pressure excursion in the graph corresponds to 3mK in vapour pressure which agrees well with the temperature readings (2.9mK).

Data taken in March 2009 as an example. The switching of the beds in this period gives a 0.37 to 0.47K change in the pre-cooler temperature. The effect on the 4K stability is between 3 to 4mK. The overall sensitivity of the 4K cooler to the 18K interface is approximately 8-8.5 mK/K.
This shows the long term stability (over ~one year) of both the 4K cooler and its pre-cooling stage ~ 10mK
These figures show the harmonics from the cooler mechanisms.

The output is switching only a few bits in the A-D so the output is a bit granular.

The specification was for 0.04N on any harmonic.

1 N ~ force exacted by 100g ~ 2 x eggs.

One UK new penny ~ 35mN.
The image shows the filamentary structure of dust in the solar neighbourhood – within about 500 light-years of the Sun. The local filaments are connected to the Milky Way, which is the pink horizontal feature near the bottom of the image. Here, the emission is coming from much further away, across the disc of our Galaxy.

Angle about 50deg
Red 10K, White ~20K