MUSCAT: The Mexico-UK Sub-mm Camera for Astronomy

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The LMT

- The Large Millimeter Telescope (Spanish: Gran Telescopio Milimétrico)
- Located at an altitude of 4,640 m atop Sierra Negra, Mexico
- Currently being upgraded to 50-m primary diameter – world’s largest single-dish mm-wave telescope
The MUSCAT Instrument

• Funded 50 % UK & 50 % Mexico under Newton Fund
• Funding council goal: to develop closer UK-Mexico links and transfer knowledge
• Instrument Specification (first generation):
  • Single band 1.1 mm
  • 1,800 LEKID detectors at photon noise limit
  • Full LMT field of view (approx. 4 arc minute)
  • Diffraction limited down to 850 µm

• Scientific goals:
  • High mapping speed (target 3.0 Deg²/mJy²/hour)
  • High angular resolution (5 arc seconds)
• MUSCAT is designed to be easily upgradeable and can act as an on-sky demonstrator
Main requirement:
Provide adequate cooling of the MUSCAT focal plane for photon-noise limited operation of a 1000+ pixel detector array
Cryogenic Requirements

• Required performance:
  • Provide cooling of the MUSCAT structure
    • 160 kg below 50 K;
    • 42 kg below 1 K
  • Provide cooling for cryogenic readout components
    • Mainly 5 low-noise amplifier: 10–25 mW each
  • Cooling of the focal plane to below 300 mK

• Aspirations:
  • Continuous cooling of the focal plane
  • Cooling of focal plane to 100 mK
Cooling Chain

300 K

Cryomech PT-420-RM

50 K

CRC CS 1K

4 K

CRC CS 350 mK

1 K

CRC MD

350 mK

100 mK
Cooling from 300 K

- Using the recently released Cryomech PT-420-RM pulse tube cooler
- First stage: 50 W of cooling at 45 K
- Second stage: 2.0 W of cooling at 4 K
- Remote motor acts as first protection from microphonics
- Further isolation through rubber gaskets
- Minimum temperature with no load: 2.8 K

(Non remote motor version shown)
Cooling to 1 K & 350 mK

- Two sets of Chase Research Cryogenics (CRC) Continuous Sorption (CS) Coolers
- Each unit contains 2 sets of pumps
- The pumps in each cooler are cycled out of phase
  - When subsystem A is pumping B is condensing
Cooling to 1 K & 350 mK

- Initial cycles give increasing performance as ballast and load is cooled
- During ‘steady state’ there are slight variations due to recycling
- These can be minimised to <1 mK through PID control (Klemencic et al., RSI, 87, 045107, 2016)

Temperature of final stage under minimal of load
Cooling to 100 mK

- Performed with CRC miniature dilutor
- Similar to conventional dilutor but all housed in cryostat (no external gas handling system)
- Much lower He3 required (typically 2–3 litres)
- Cardiff have been running similar unit since 2014
- Minimum achieved temperature is 77 mK
- Achieve 88 mK under 5 µW of load

<table>
<thead>
<tr>
<th></th>
<th>He3 Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-K CS final stage</td>
<td>1.5 L</td>
</tr>
<tr>
<td>350-mK CS pre coolers</td>
<td>4 L (2 L in each head)</td>
</tr>
<tr>
<td>350-mK CS final stage</td>
<td>1.5 L</td>
</tr>
<tr>
<td>Miniature Dilutor</td>
<td>2 L</td>
</tr>
<tr>
<td>TOTAL</td>
<td>9 L</td>
</tr>
</tbody>
</table>
Thermal Modelling

• Model load on each of MUSCAT’s five temperature stages

• Consider loads from:
  • Mechanical supports
  • Radiative load between stages
  • Optical loading from windows and filters
  • DC and RF cabling
  • Readout electronics
  • Cooling Systems

• Due to recycling of continuous sorption coolers, load on 4-Kelvin stage is not static
4-Kelvin Stage Model

- Two types of thermal load on 4-Kelvin stage:
  - Static due to radiation, supports etc.
  - Non static due to constant operation of sorption fridges

- Non static load found from combining power into pulse tube from CS systems when run individually

Power dissipation at 4 K due to CS pumps
### Thermal Modelling: Results

<table>
<thead>
<tr>
<th>Consideration</th>
<th>50 K</th>
<th>4 K</th>
<th>1 K</th>
<th>350 mK</th>
<th>100 mK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical load through supports</td>
<td>8.92 W</td>
<td>64 mW</td>
<td>116 µW</td>
<td>12.4 µW</td>
<td>1.04 µW</td>
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<tr>
<td>Radiative load from previous shield</td>
<td>25.68 W</td>
<td>7 mW</td>
<td>-</td>
<td>30 µW</td>
<td>0.005 µW</td>
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<tr>
<td>Optical load from cryostat window and filters</td>
<td>3.10 W</td>
<td>32 mW</td>
<td>-</td>
<td>22.3 µW</td>
<td>0.019 µW</td>
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<tr>
<td>Loading from RF lines</td>
<td>0.50 W</td>
<td>10 mW</td>
<td>22 µW</td>
<td>16.1 µW</td>
<td>0.14 µW</td>
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<tr>
<td>Loading through the DC looms</td>
<td>0.17 W</td>
<td>8 mW</td>
<td>28 µW</td>
<td>14.6 µW</td>
<td>0.23 µW</td>
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<tr>
<td>Amplifier power dissipation</td>
<td>-</td>
<td>125 mW</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cooling Systems</td>
<td>-</td>
<td>0.2—1.2 W</td>
<td>-</td>
<td>300 µW</td>
<td>-</td>
</tr>
<tr>
<td>Sky Load (300 K in lab testing)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.65 µW</td>
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<td><strong>TOTAL</strong></td>
<td><strong>38.37 W</strong></td>
<td><strong>0.5—1.6 W</strong></td>
<td><strong>166 µW</strong></td>
<td><strong>395.4 µW</strong></td>
<td><strong>3.08 µW</strong></td>
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<tr>
<td><strong>EXPECTED TEMPERATURE</strong></td>
<td><strong>44 K</strong></td>
<td><strong>2.8—4.1 K</strong></td>
<td><strong>1.10—1.15 K</strong></td>
<td><strong>440—460 mK</strong></td>
<td>&lt; 88 mK</td>
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Summary

• MUSCAT will use a number of novel technologies to cool to below 100 mK

• Total Helium-3 requirement is approx. 9 litres (STP gas)
  • Factor of 3 less than conventional dilutor

• Worst-case thermal modelling shows all temperature stages will perform acceptably

• MUSCAT will operate continuously below 100 mK.

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<th>Expected thermal load</th>
<th>Anticipated temperature</th>
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