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

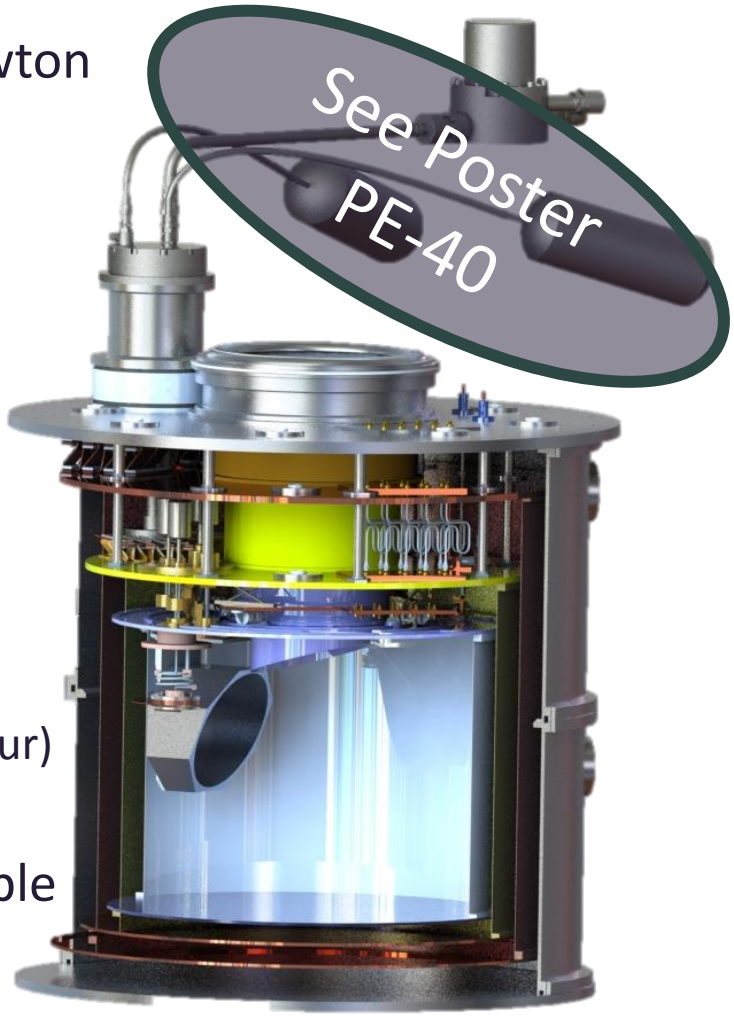
Tom Brien
Cardiff University

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 $Deg^2/mJy^2/hour$)
  - High angular resolution (5 arc seconds)
- MUSCAT is designed to be easily upgradeable and can act as an on-sky demonstrator

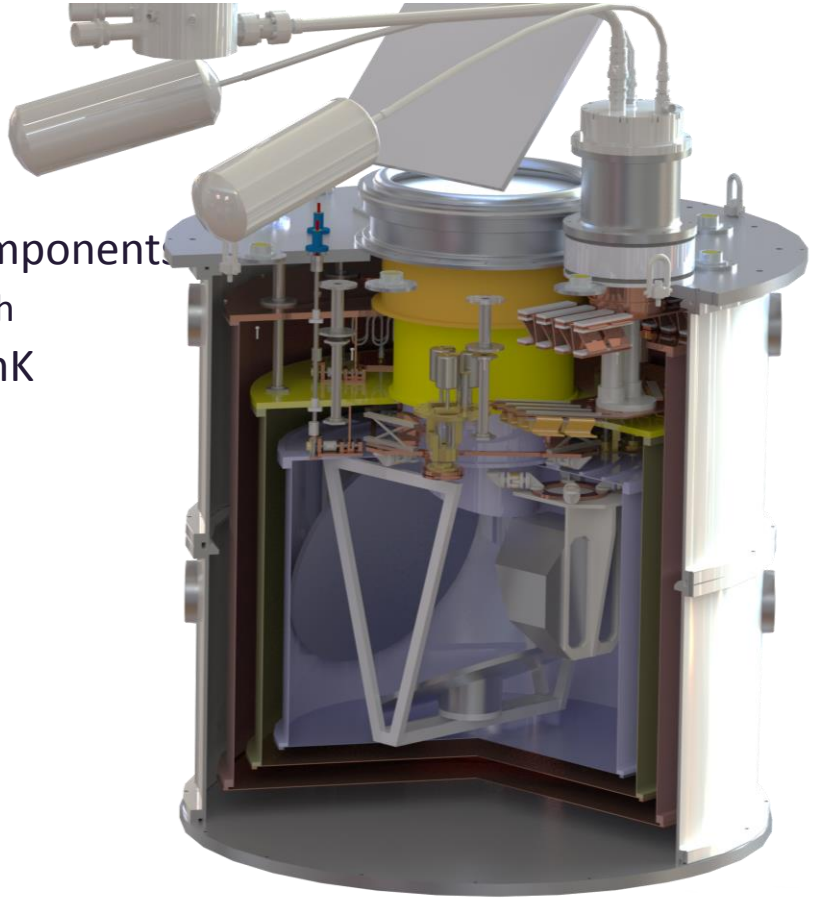


Cryogenic Requirements

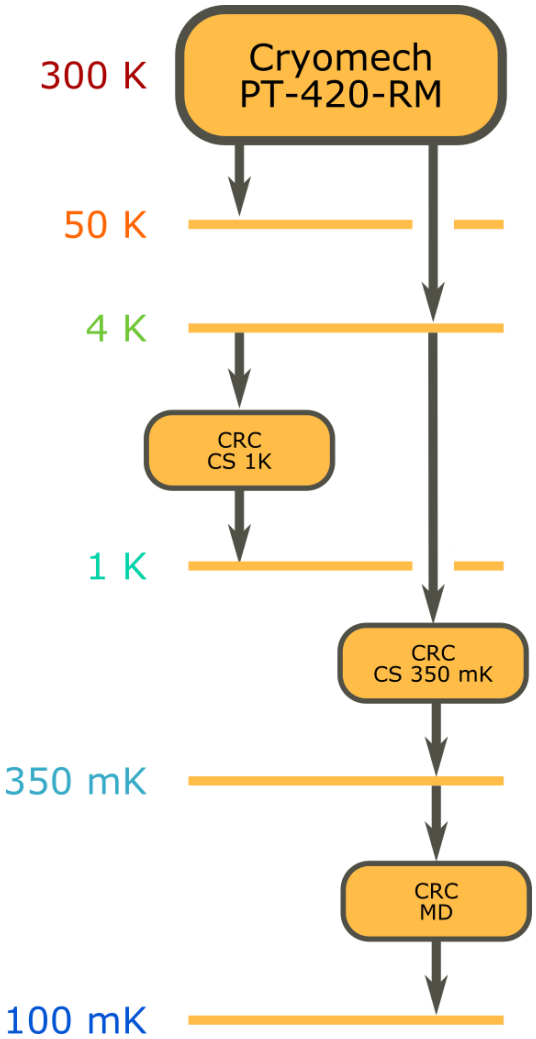
Main requirement:
Provide adequate cooling of the MUSCAT focal plane for photon-noise limited operation of a 1000+ pixel detector array

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

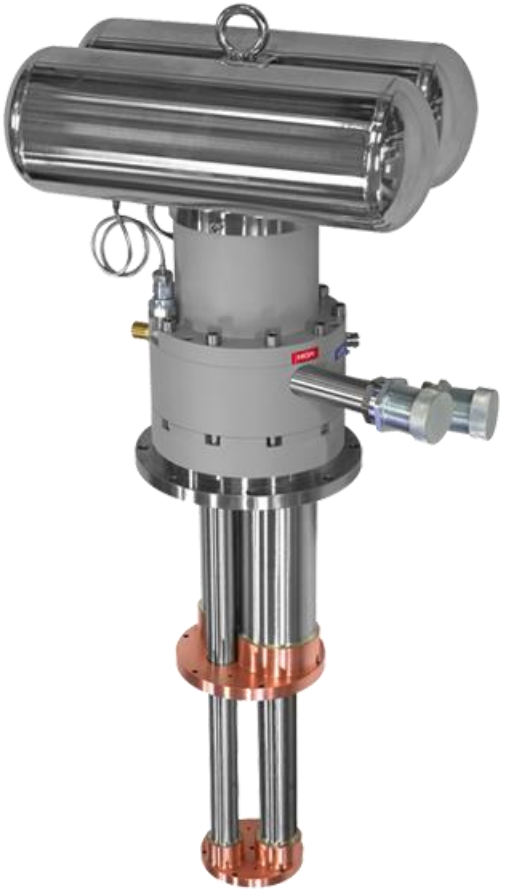


Cooling Chain



Cooling from 300 K

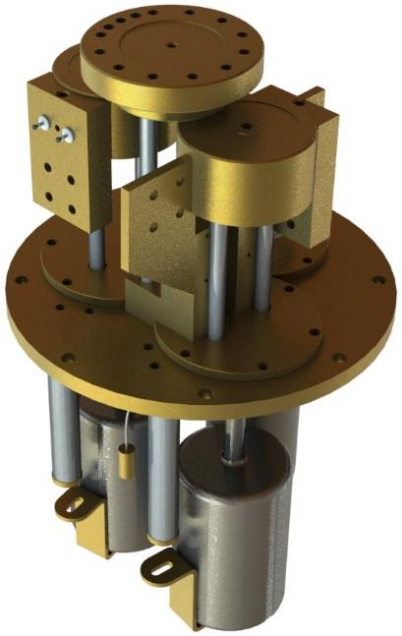
- Using the recently released Cryomech PT-420-RM pulse tube cooler
- First stage: 50 W of cooling at 45 K
- Second stage: 2.0 W of cooling at 4 K
- Remote motor acts as first protection from microphonics
- Further isolation through rubber gaskets
- Minimum temperature with no load: 2.8 K

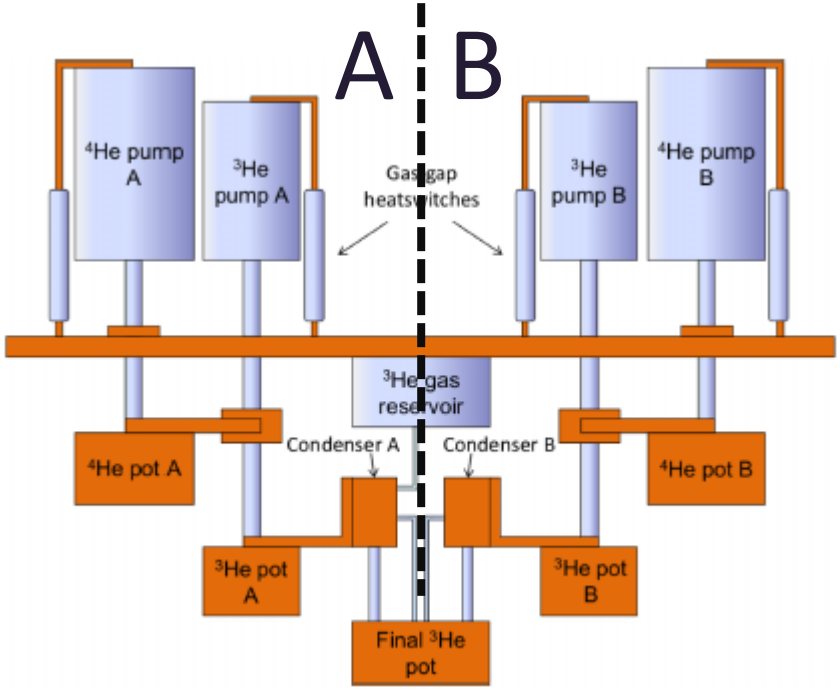


(Non remote motor version shown)

Cooling to 1 K & 350 mK

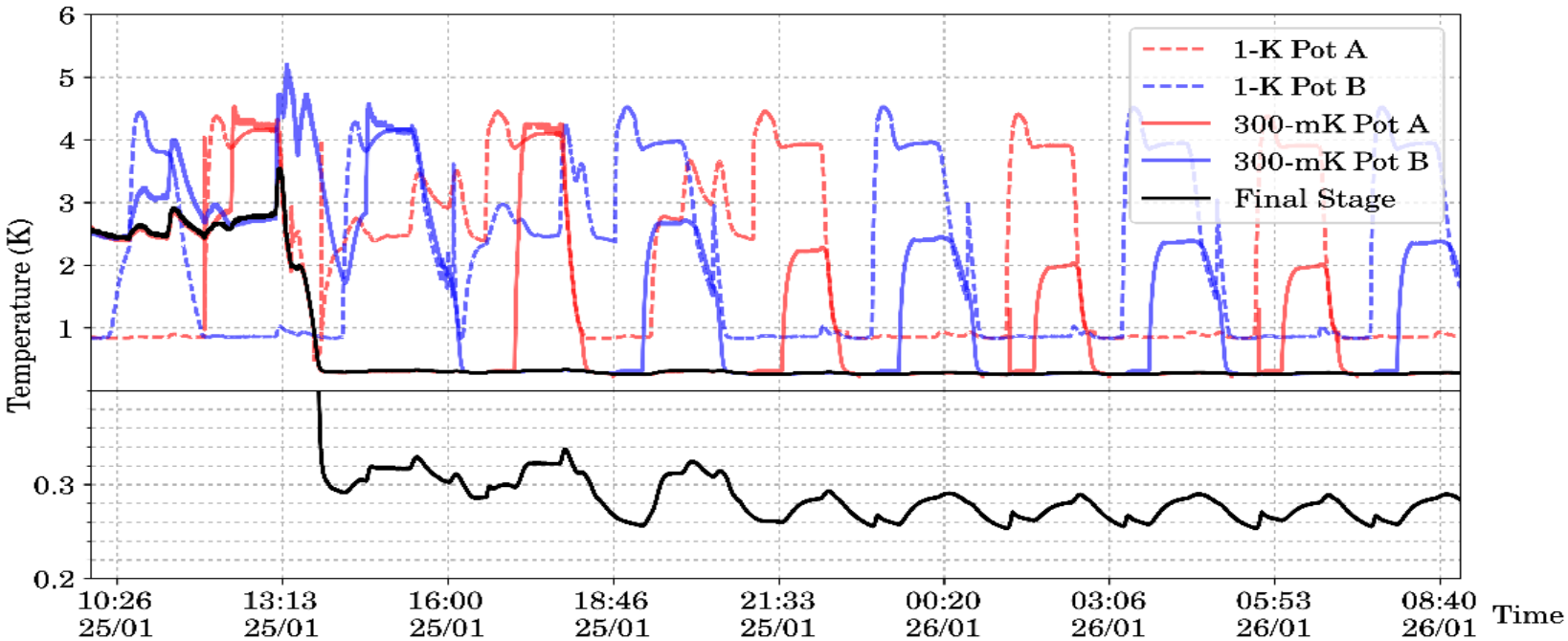
- Two sets of Chase Research Cryogenics (CRC) Continuous Sorption (CS) Coolers
- Each unit contains 2 sets of pumps
- The pumps in each cooler are cycled out of phase
  - When subsystem A is pumping B is condensing





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

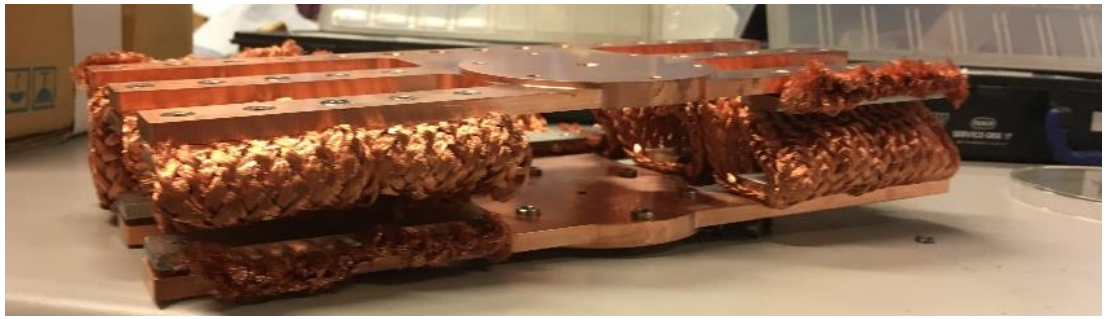
Cooling to 100 mK

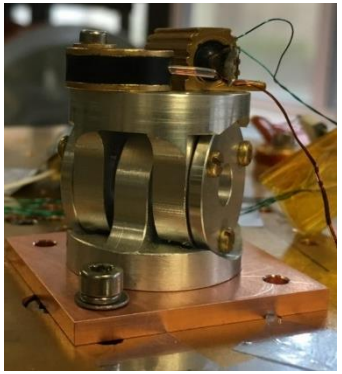
- Performed with CRC miniature dilutor
- Similar to conventional dilutor but all house in cryostat (no external gas handling system)
- Much lower He3 required (typically 2–3 litres)
- Cardiff have been running similar unit since 2014
- Minimum achieved temperature is 77 mK
- Achieve 88 mK under 5 µW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

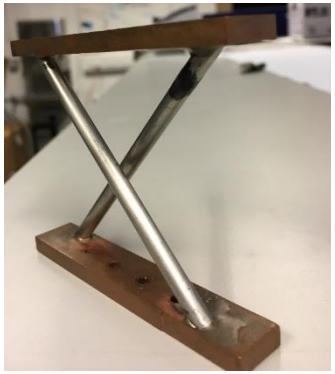
	He3 Required
1-K CS final stage	1.5 L
350-mK CS pre coolers	4 L (2 L in each head)
350-mK CS final stage	1.5 L
Miniature Dilutor	2 L
TOTAL	9 L

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

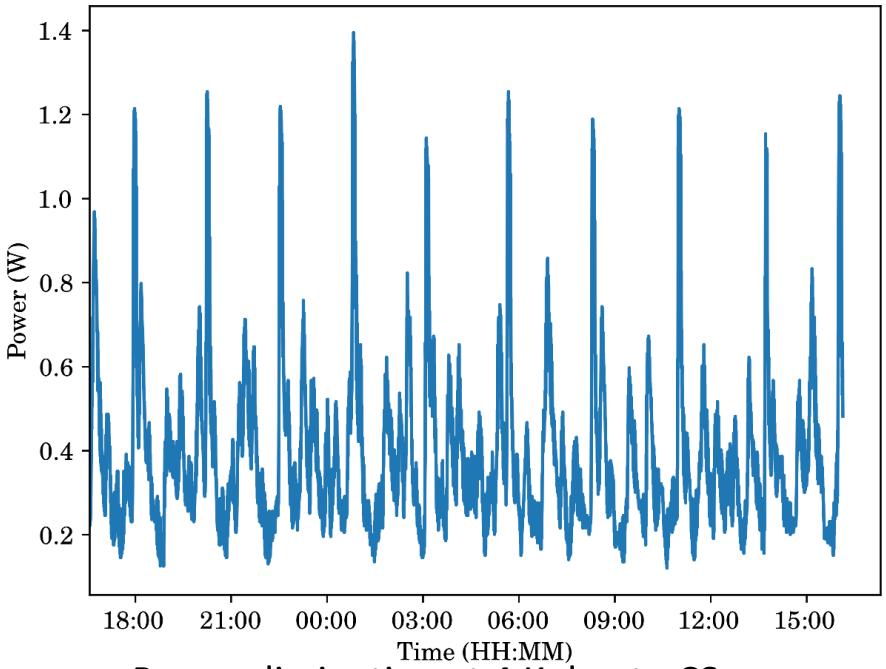






4-Kelvin Stage Model

- 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

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

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.

Temperature stage	Expected thermal load	Anticipated temperature
50 Kelvin	38.37 W	44 K
4 Kelvin	0.5–1.6 W	2.8–4.1 K
1 Kelvin	166 µW	1.10–1.15 K
350 mK	395.4 µW	440–460 mK
100 mK	3.1 µW	< 88 mK