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

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On behalf of the MUSCAT collaboration

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Consejo Nacional de Ciencia y Tecnología

Science & Technology Facilities Council

RESEARCH COUNCILS UK

Newton Fund

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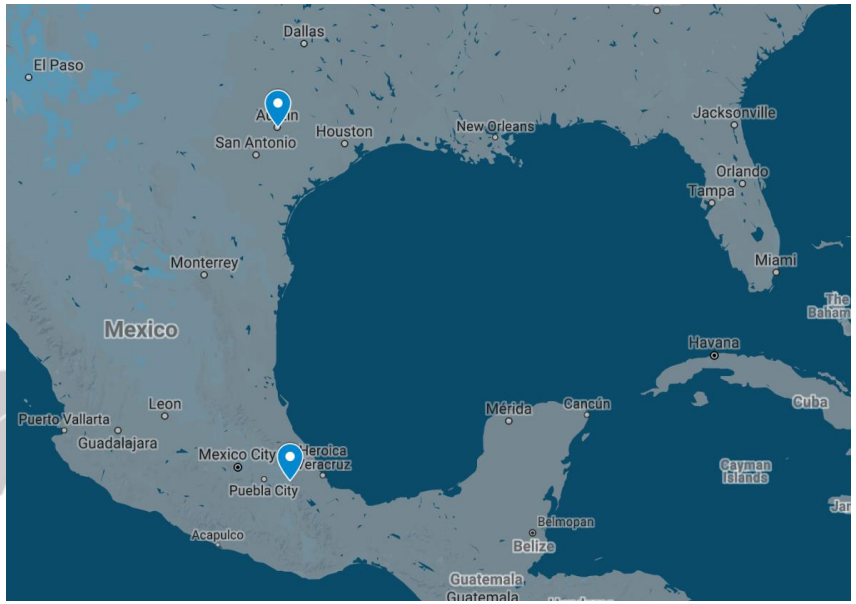
The MUSCAT Instrument

- Funded 50 % UK & 50 % Mexico under Newton Fund. £1M ($1.3M)
- Funding council goal: to develop closer UK-Mexico links and transfer knowledge
- Instrument Specification (first generation):
  - Single band @ 1.1 mm
  - 1,500 LEKID detectors at photon noise limit
  - ≈Full LMT field of view (approx. 3.8 arc minute)
  - 5.8 arc second resolution
  - Diffraction limited down to 850 µm
- Scientific goals:
  - Follow up *H*-Atlas sources and assign counterparts
  - Map star-forming regions beyond Gould belt (d > 400 pc)
- MUSCAT is designed to be easily upgradeable and can act as an on-sky demonstrator

The LMT

- Located at an altitude of 4,640 m atop Sierra Negra, Mexico
- Recently upgraded to 50-m primary (Hughes talk Sunday) – world's largest single-dish mm-wave telescope
- Nominally 1.1 – 4 mm, capable at 850 µm



The MUSCAT Team

UK

Simon Doyle (PI)
Pete Hargrave (Optics)
Carole Tucker (Filters)
Peter Ade (Filters)
Tom Brien (Cryogenics)
Sam Rowe (Readout)
Pete Barry (Detectors)
Andreas Papageorgiou (Pipeline)
Ian Walker (Project Management)
Paul Moseley (EM Design)
Thomas Gasgard
Josie Parrianen
Amber Hornsby
Steve Eales (Science – Galaxies, *H*-Atlas PI)
Nicolas Peretto (Science – Star Formation)

Mexico

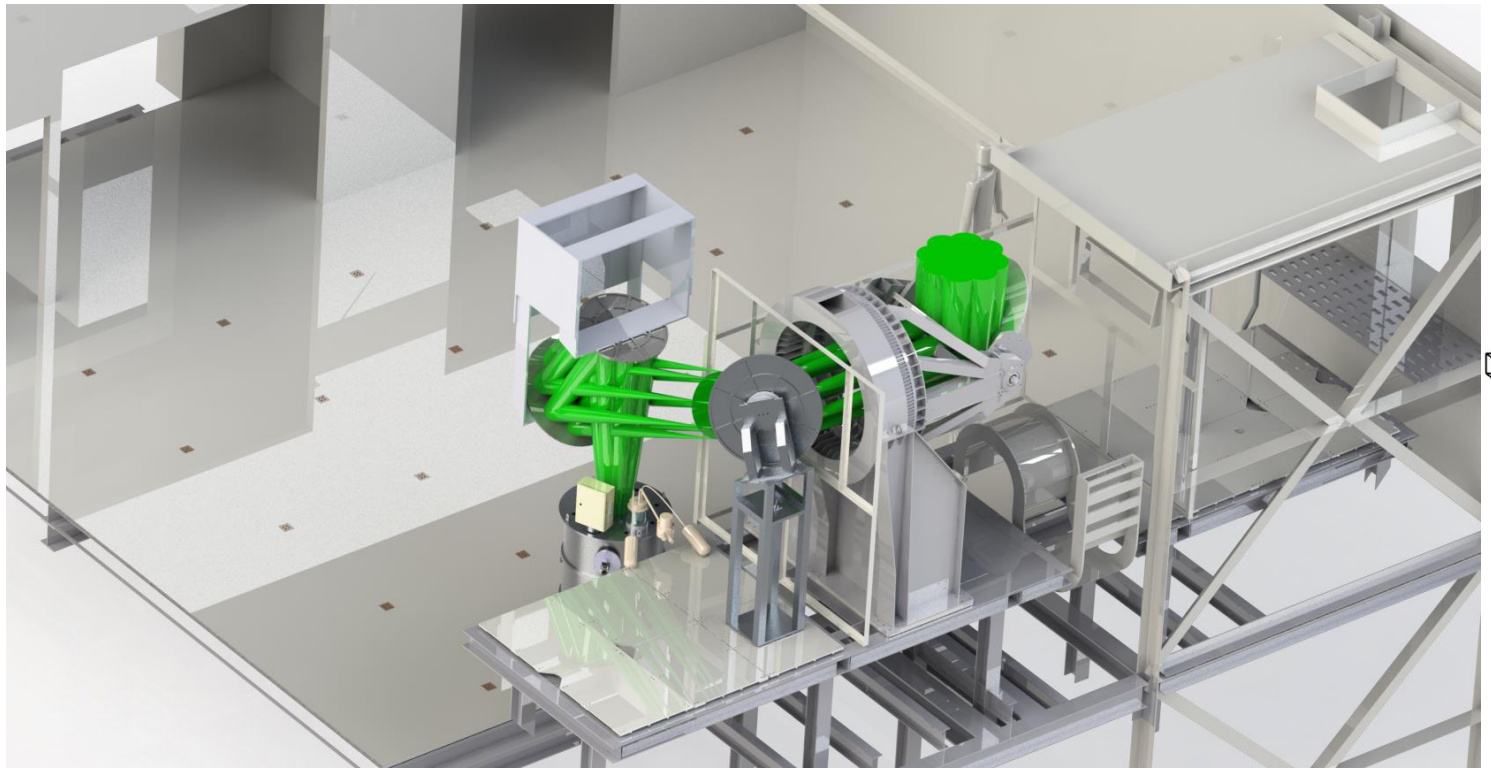
David Hughes (PI)
Edgar Castillo-Domínguez (System Design)
Abel Perez
Salvador Ventura
Víctor Gómez
Daniel Ferrusca
Miguel Velázquez

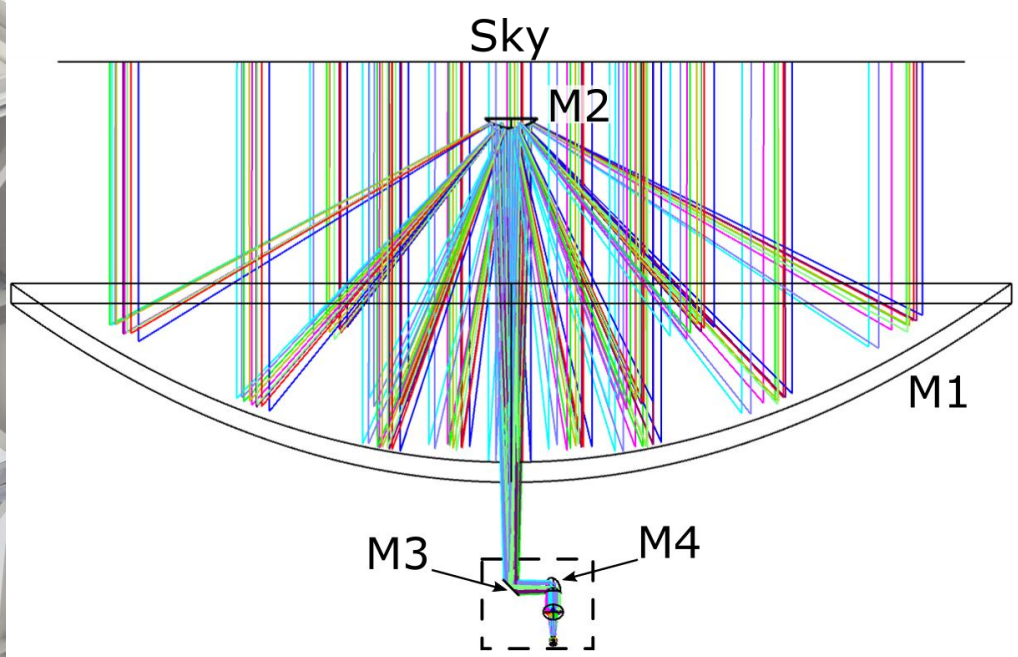
Other

Enzo Pascale (Data Analysis)
Philip Mauskopf

Optics Design

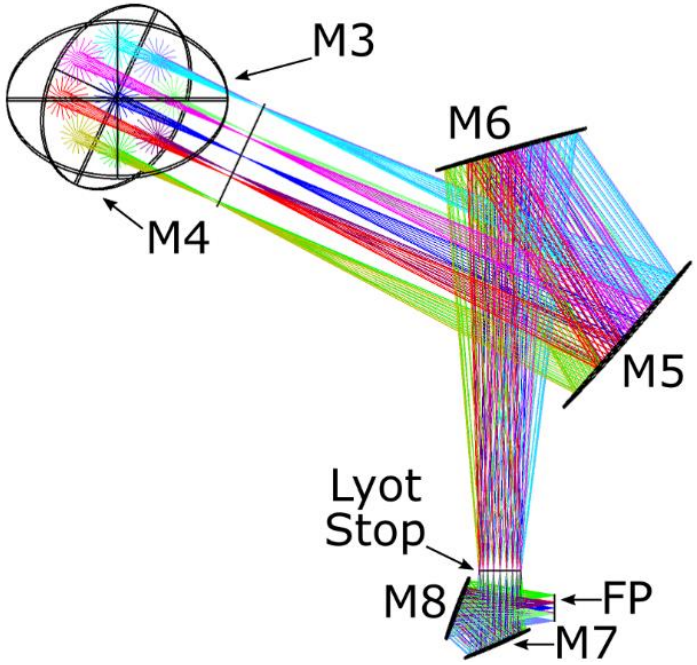
- MUSCAT picks off LMT beam after M3, just before prime focus
- Two crossed-Dragone mirror pairs used. One warm, one cold
- f/2.8 optics filling 95 % of the LMT FOV

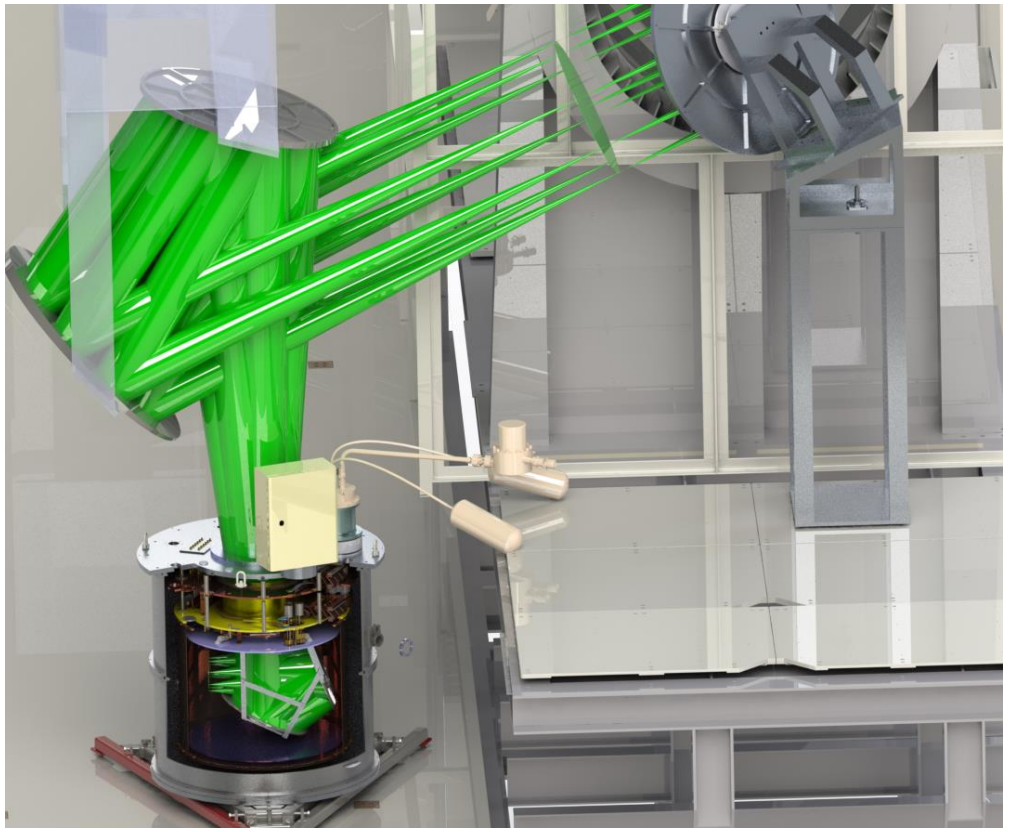




Optics Design

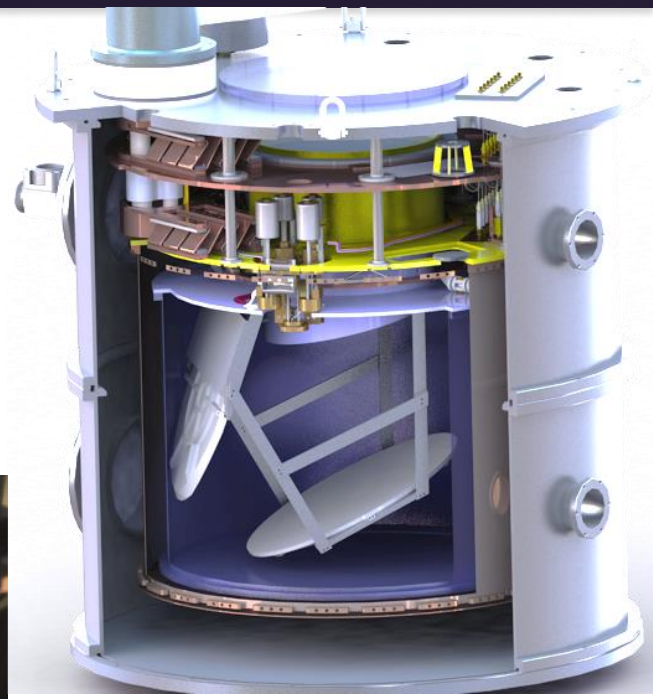
- Lyot stop inside cryostat before M7
- High-quality, highly telecentric beams produced across 140 mm focal plane
- Optics design is diffraction limited down to $\lambda = 850\ \mu\mathrm{m}$
- Cold baffles protect against stray light

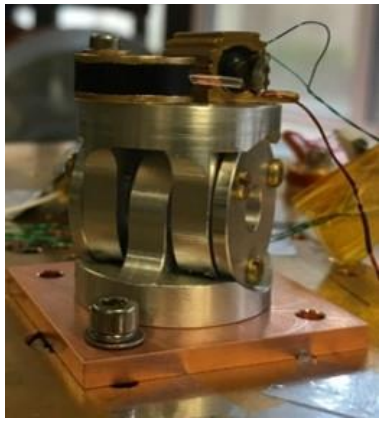


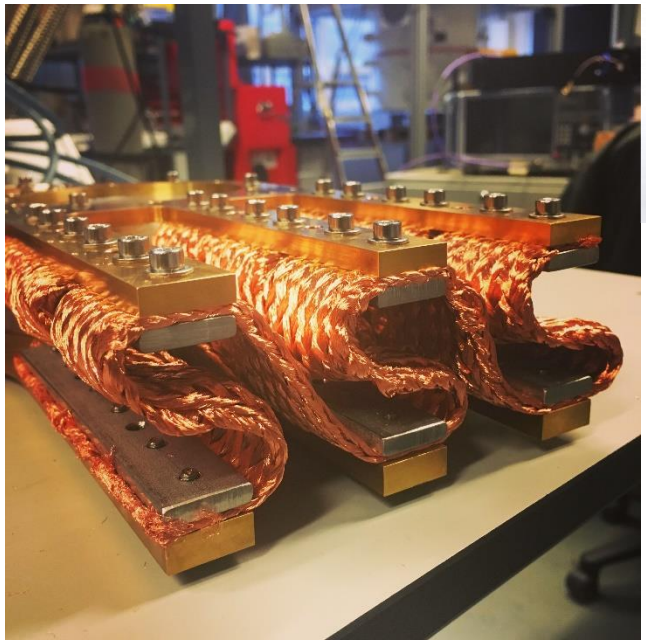


Cryostat Design

- Cryostat design based on *standard* lab test cryostat
  - Russian-doll construction with vacuum, 50-K, 4-K and 450-mK shields
- “Easy” to open and change out components
- Vacuum can is ø 1 m; 450-mK, superconducting shield is ø 0.6 m.
- Total mass is close to 300 kg excluding support structure
- PTC vibration dampening via rubber gaskets and OFHP copper braid
- Thermal isolation with stainless cross beams and SCUBA-2 sapphire joints

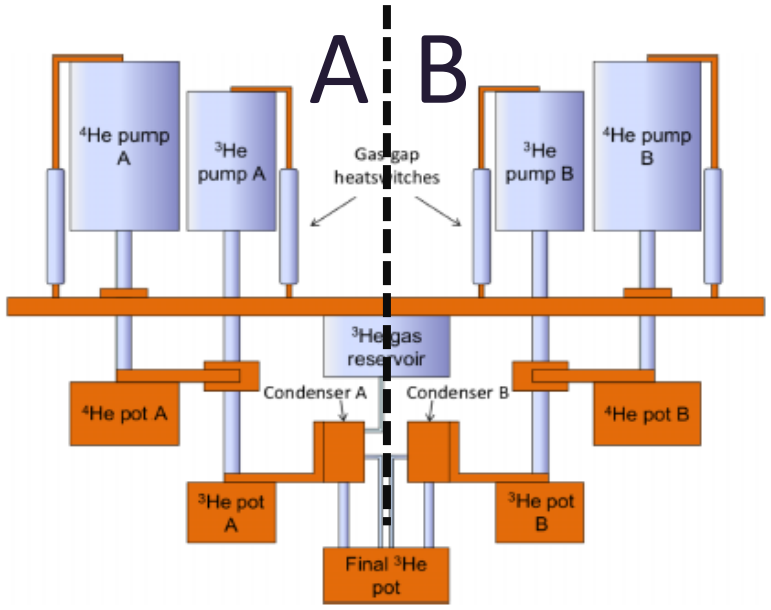




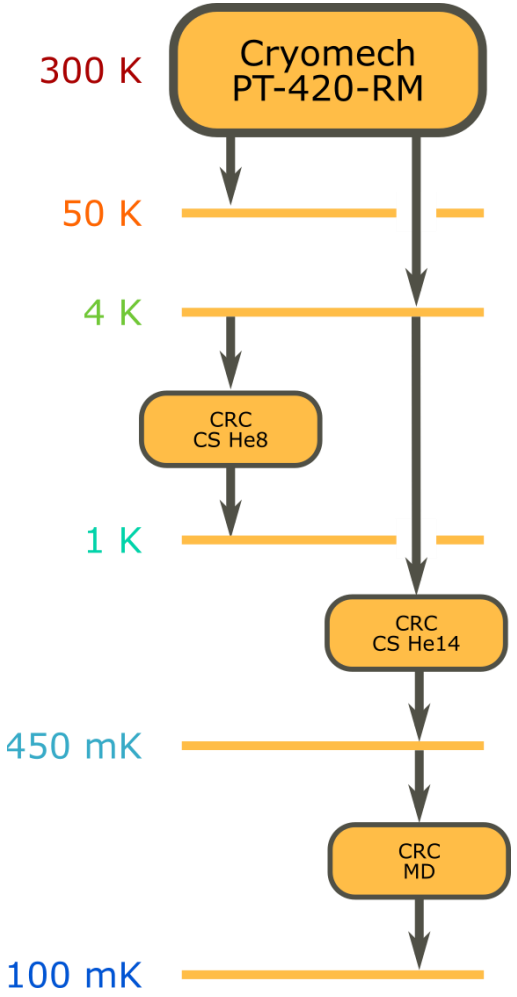


Cryogenics

- Continuous cooling to < 100 mK provided by four helium-based cooling systems:
  - 300 K → 4 K: Cryomech PT-420-RM
  - 4 K → 1 K: CRC continuous sorption cooler
  - 4 K → 450 mK: CRC continuous sorption cooler
  - 450 mK → 100 mK: CRC miniature dilutor

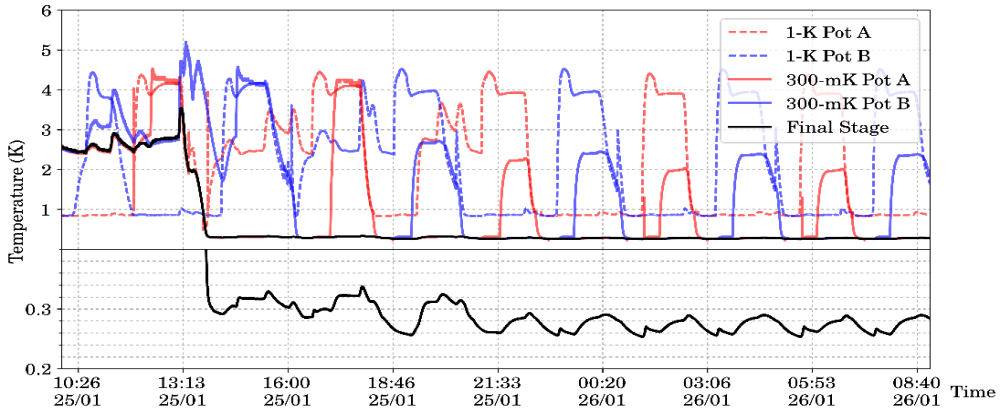


Klemncic et al., Rev. Sci. Inst., 2016



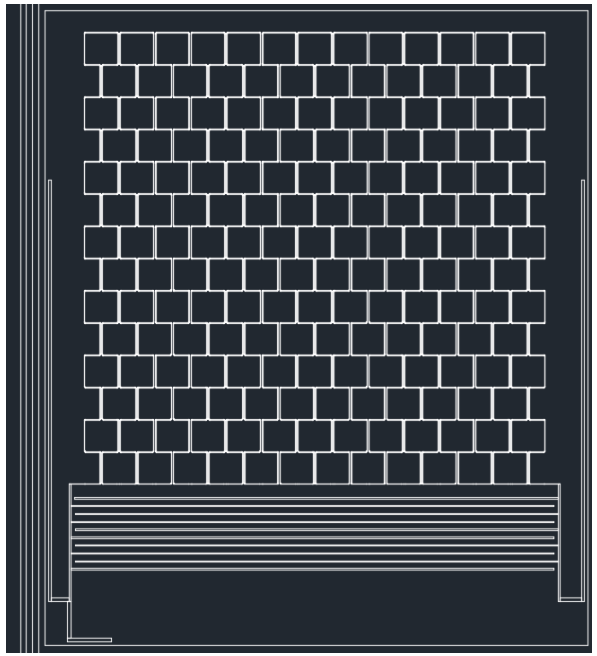
Thermal Viability Study

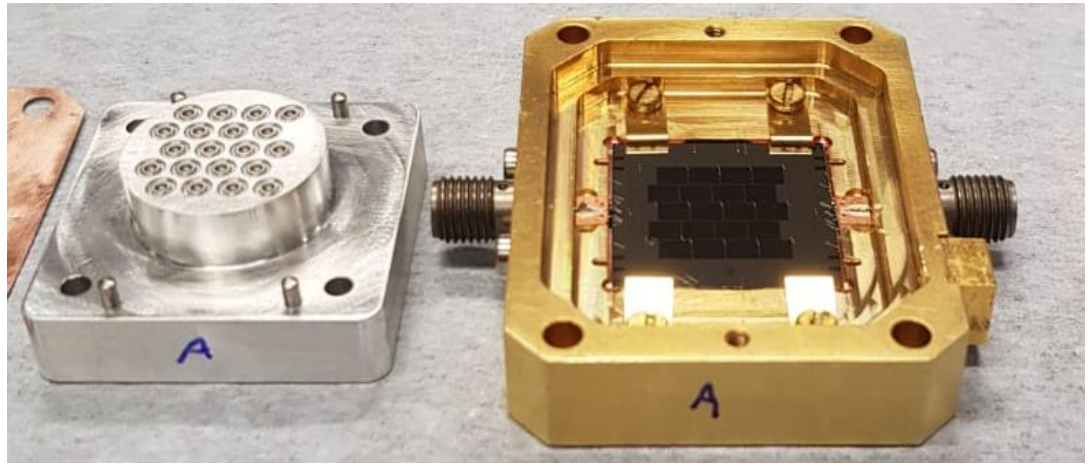
Consideration	50 K	4 K	1 K	450 mK	100 mK
Mechanical load through supports	8.92 W	64 mW	116 µW	12.4 µW	1.04 µW
Radiative load from previous shield	25.68 W	7 mW	-	30 µW	0.005 µW
Optical load from cryostat window and filters	3.10 W	32 mW	-	22.3 µW	0.019 µW
Loading from RF lines	0.50 W	10 mW	22 µW	16.1 µW	0.14 µW
Loading through the DC looms	0.17 W	8 mW	28 µW	14.6 µW	0.23 µW
Amplifier power dissipation	-	150 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—1.8 W**	**166 µW**	**395.4 µW**	**3.08 µW**
EXPECTED TEMPERATURE	**44 K**	**2.8—4.2 K**	**1.10—1.15 K**	**440—460 mK**	**95 mK**

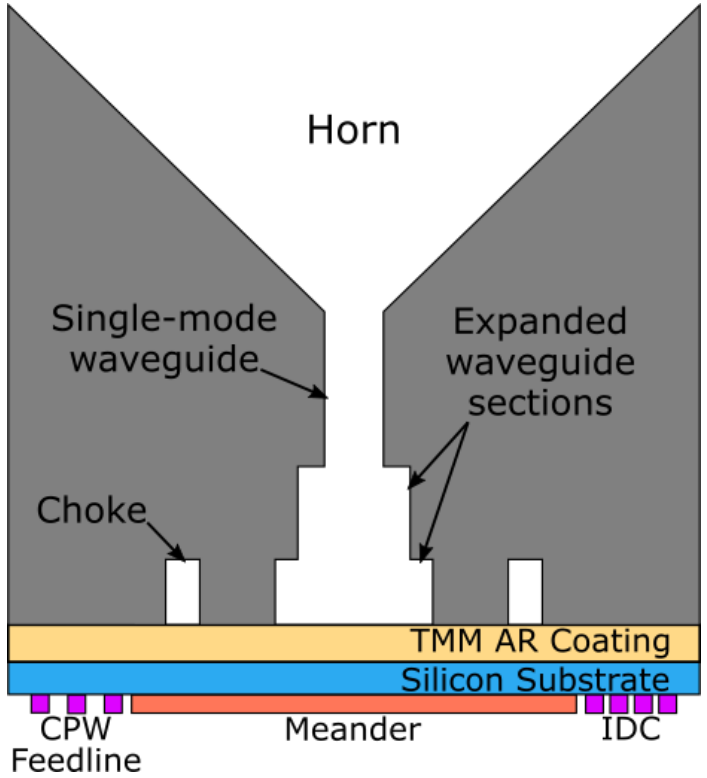


Detectors

- First-generation MUSCAT: 1,500 1.1-mm LEKIDs
- Hex-packed across the focal plane with $1F\lambda$ spacing
- Horn-coupled with anti-reflection layer
- Absorbing inductor meander 1 Ω/□

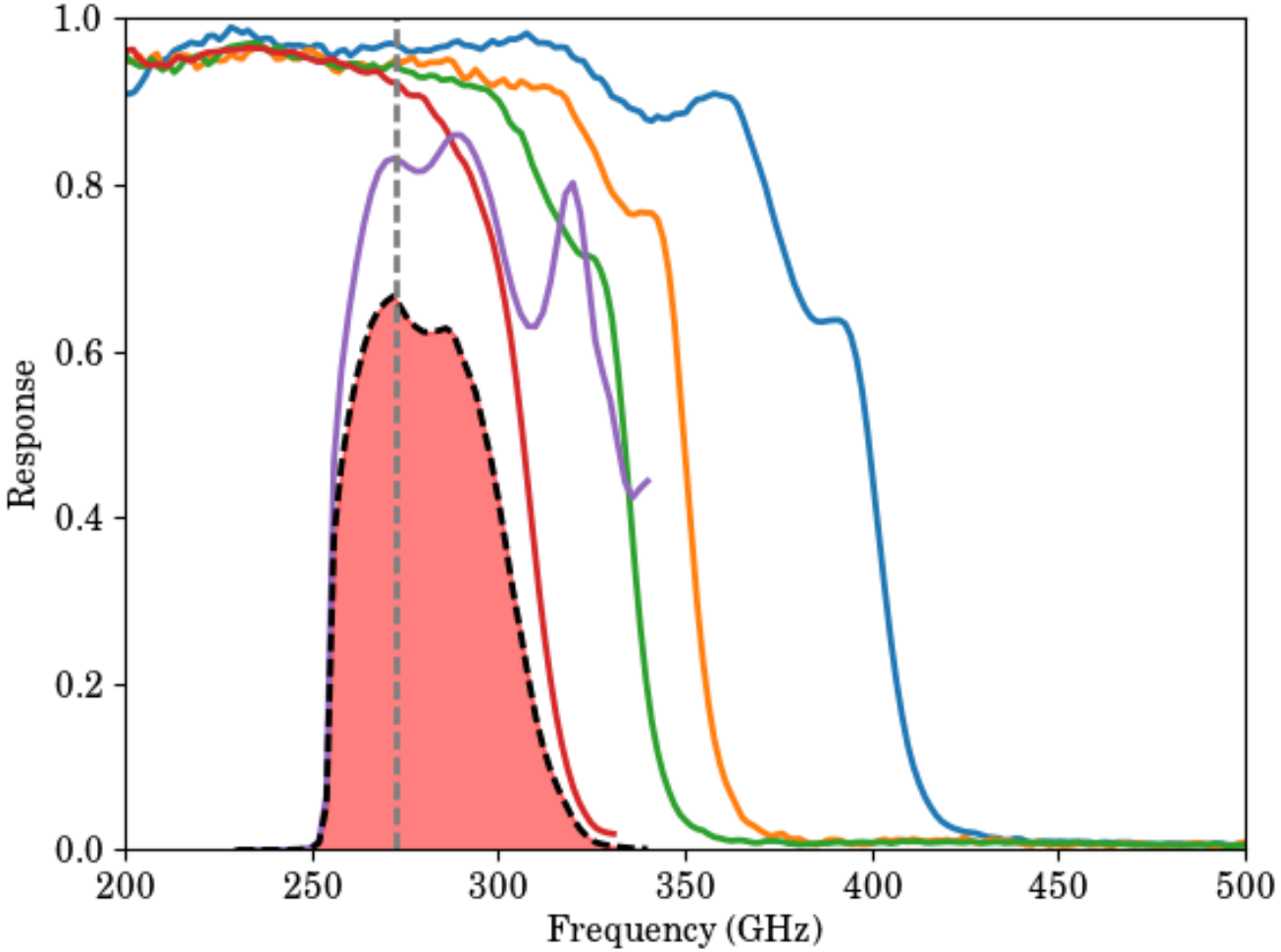






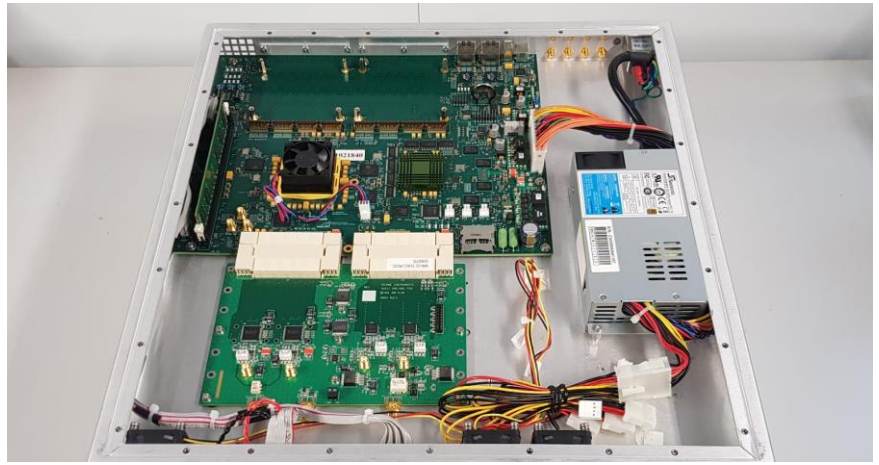
MUSCAT Band

- Upper (frequency) edges defined by metal-mesh filters
- Lower edge by waveguide cut-on
  - Simulated but to be tested in lab
- Can add metal-mesh bandpass, if needed



Readout

- Focal plane made of six sub panels each with its own readout channel
  - Easily attainable 250:1 MUX ratio
- ASU HEMT LNAs at 4 K
  - 30 dB gain in a 0.5-3.0 GHz band
- ROACH-2 boards with MUSIC DAC/ADC cards
  - Readout band 0.6-1.1 GHz
- IF electronics are commercially-sourced and low risk
  - Prototype board currently undergoing lab characterisation



Current Status

- Complete:
  - Outer vacuum vessel
  - 50-K Stage
  - 4-K Stage (this week)
- Current work
  - 1-K fridge characterisation
  - Detailing of 450-mK stage
  - Detector design and characterisation program
  - IF electronics prototyping (final testing)
  - Mirror procurement underway
  - Miniature dilutor R&D program (near completion)
  - Cryostat mounting plate for LMT
  - Site preparation: 440-V supply extension, water cooling, mirror mounts
- Shipping by end of 2018

MUSCAT & The Future

- TolTEC will supersede first-generation MUSCAT at 1.1 mm upon arrival
- MUSCAT is designed to be easily upgradable
- Simple switch out of focal plane. 2nd generation arrays currently considered include:
  - 850 µm array. LMT is capable of 850 µm operation. MUSCAT can enable new science at LMT
  - On-chip spectrometer; 100-mK platform can allow high sensitivity detectors to handle low in-band power
  - Multichroic pixels from on-chip filters (Hornsby talk Friday)
- Also plan to explore increased MUX ratios
- Flat lenses (??)

Summary

- MUSCAT now fully designed and in fabrication
- Currently constructed to 1-kelvin with thermal characterisation taking place currently
- Detector and material study and knowledge transfer nearly complete. Multiple prototype array currently under test
- Mirror fabrication about to start in Mexico
- Target on-sky early 2019