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

Tom Brien

Cardiff University

On behalf of the MUSCAT collaboration

MUSCAT

Mexico UK Sub-mm Camera for AsTronomy

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Consejo Nacional de Ciencia y Tecnología

Science & Technology Facilities Council

RESEARCH COUNCILS UK

Newton Fund

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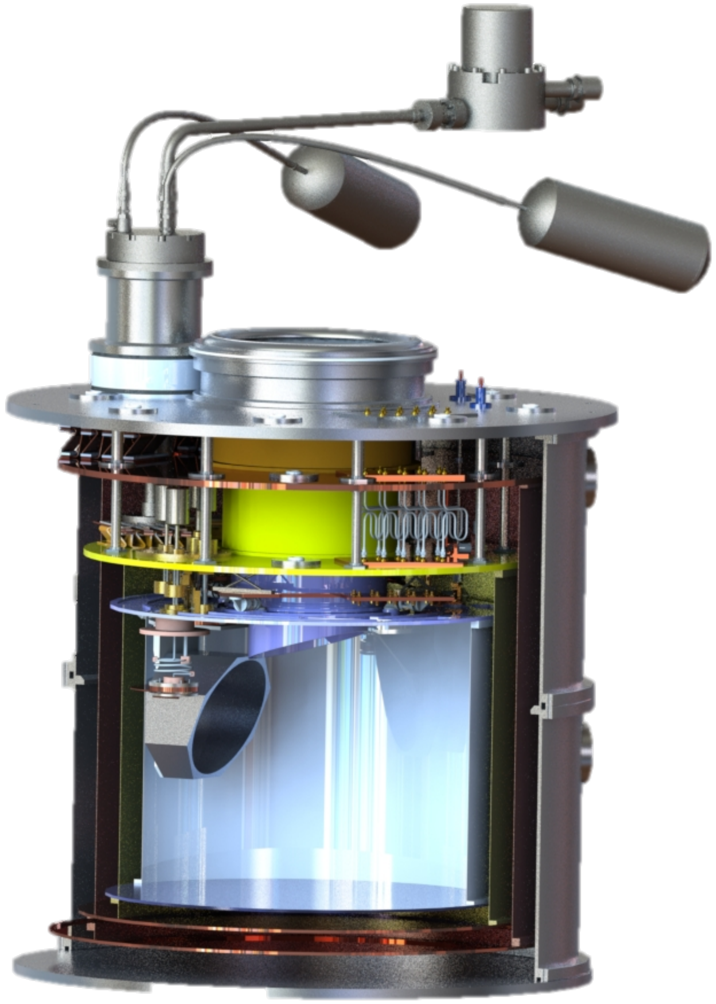
The MUSCAT Instrument

- 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 MUSCAT Team

UK

Simon Doyle (PI)
Pete Hargrave (Optics)
Carole Tucker (Filters)
Peter Ade (Filters)
Sam Rowe (Readout)
Tom Brien (Cryogenics, Integration)
Andreas Papageorgiou (Pipeline)
Ian Walker (Project Management)
Amber Hornsby
Steve Eales (Science – Galaxies, *H*-Atlas PI)
Matt Smith (Science – Galaxies)
Nicolas Peretto (Science – Star Formation)

Mexico

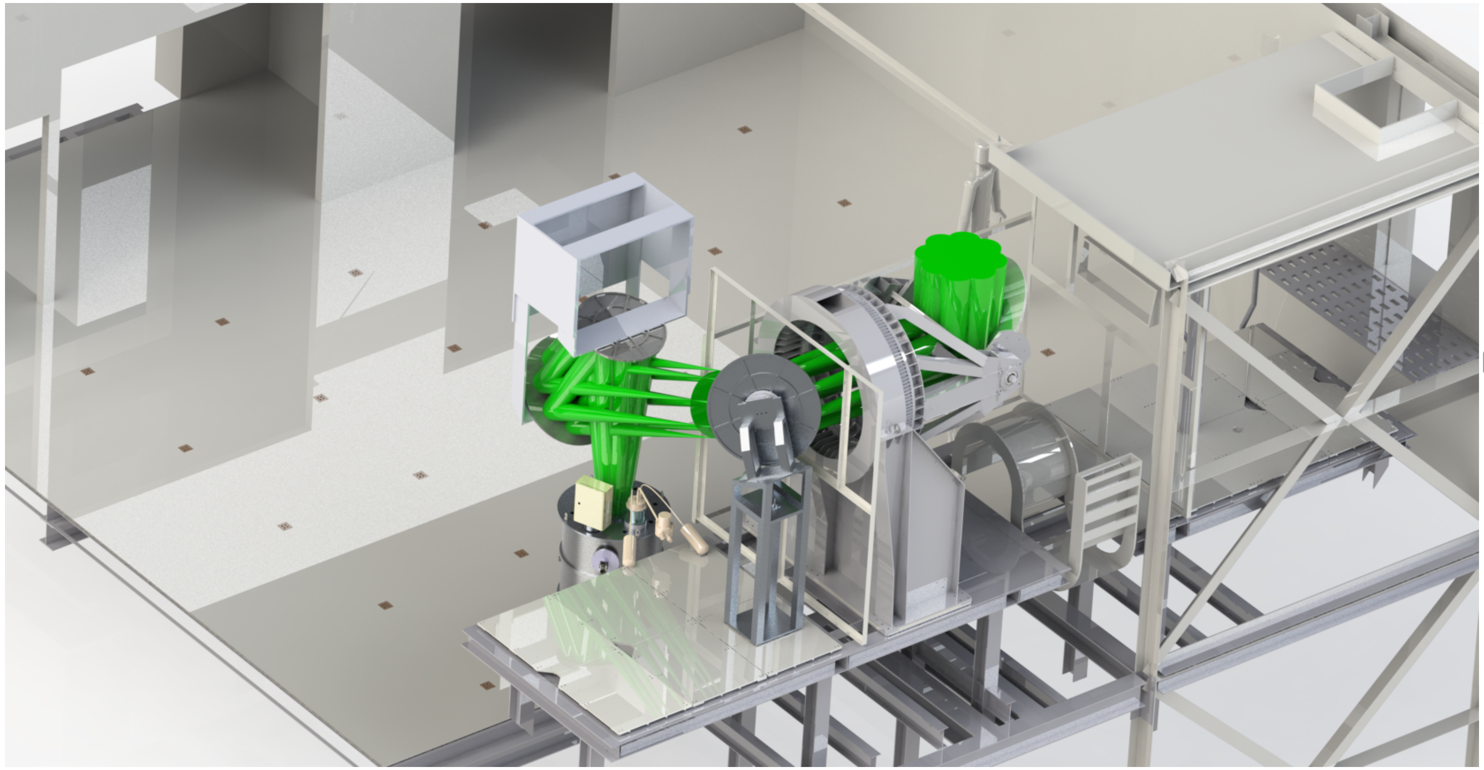
David Hughes (PI)
Edgar Castillo-Domínguez (System Design)
Marcial Tapia
Abel Perez
Salvador Ventura
Víctor Gómez
José Miguel Garciá
Daniel Ferrusca
Miguel Velázquez

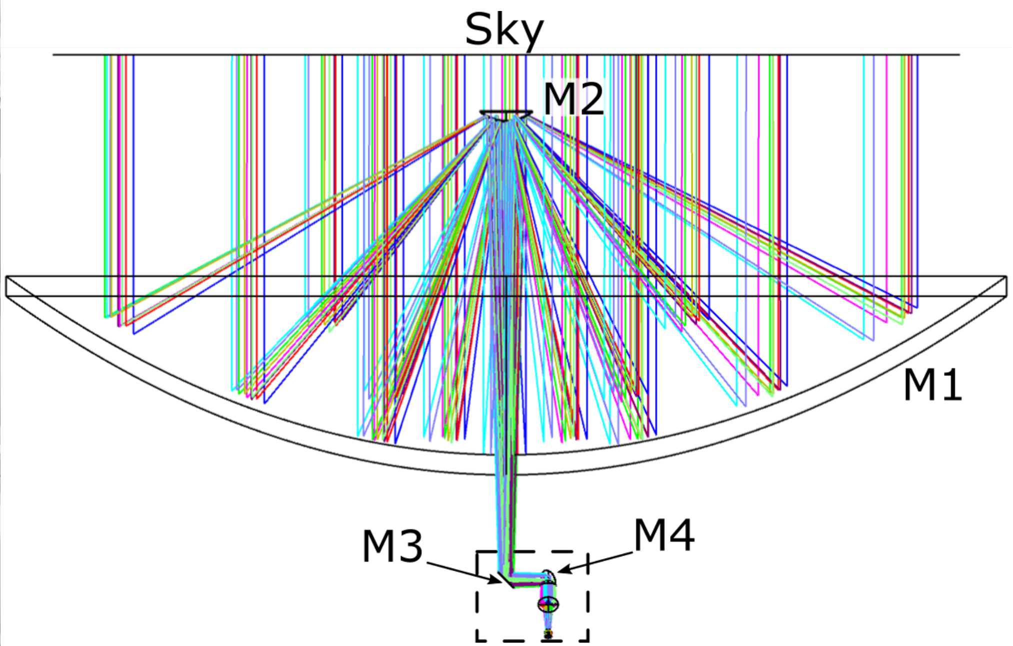
Other

Enzo Pascale (Data Analysis)
Philip Mauskopf (Horn blocks)
Pete Barry (Detectors)

Optics Design

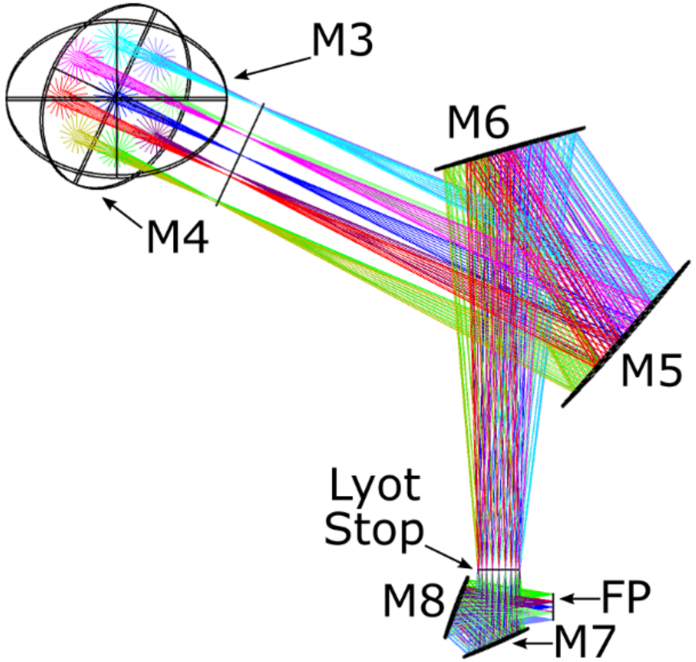
- MUSCAT picks off LMT beam after M3, just before prime focus
- Two crossed-Dragone mirror pairs used. One warm, one cold
- f/2.8 optics filling > 95 % of the LMT FOV

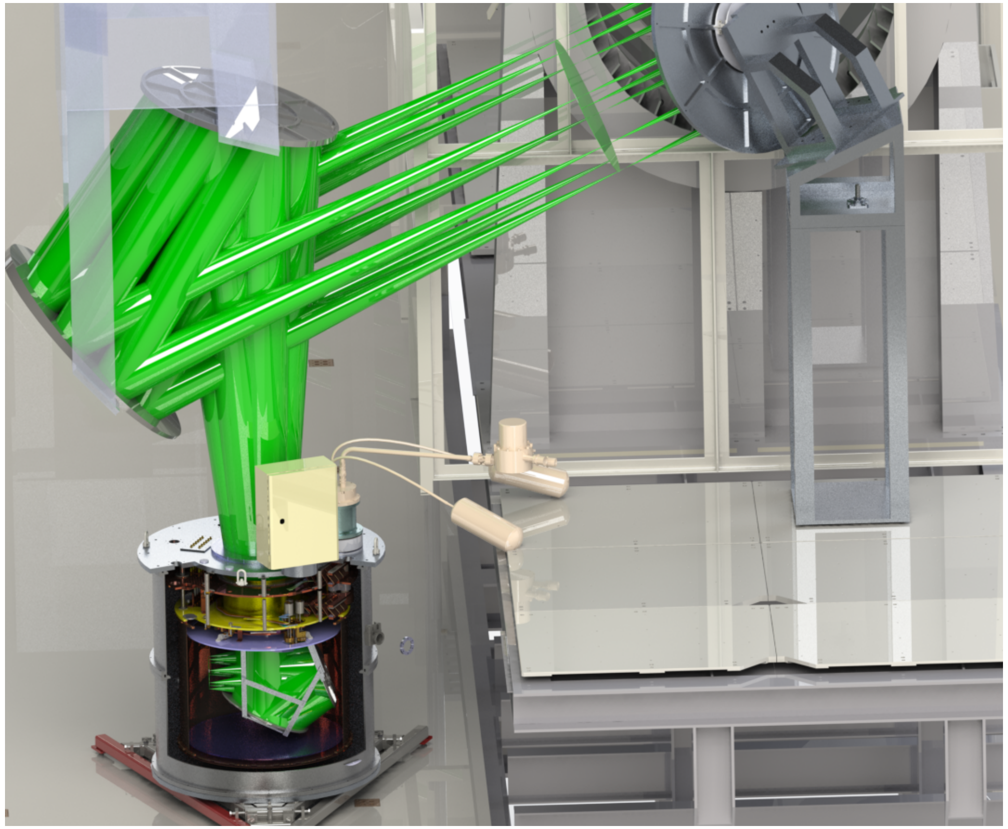




Optics Design

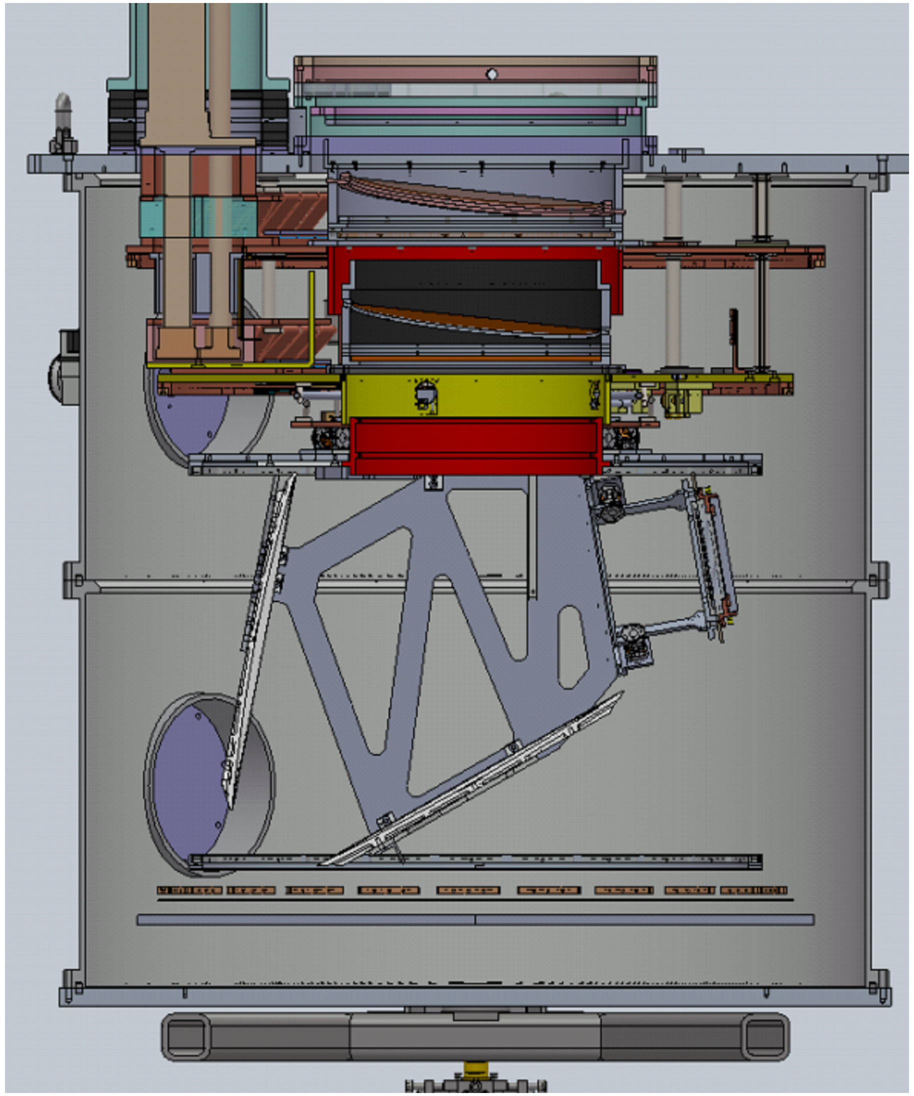
- Lyot stop inside cryostat before M7
- High-quality, highly telecentric beams produced across 140 mm focal plane
- Optics design is diffraction limited down to λ=850 μm
- Cold baffles protect against stray light



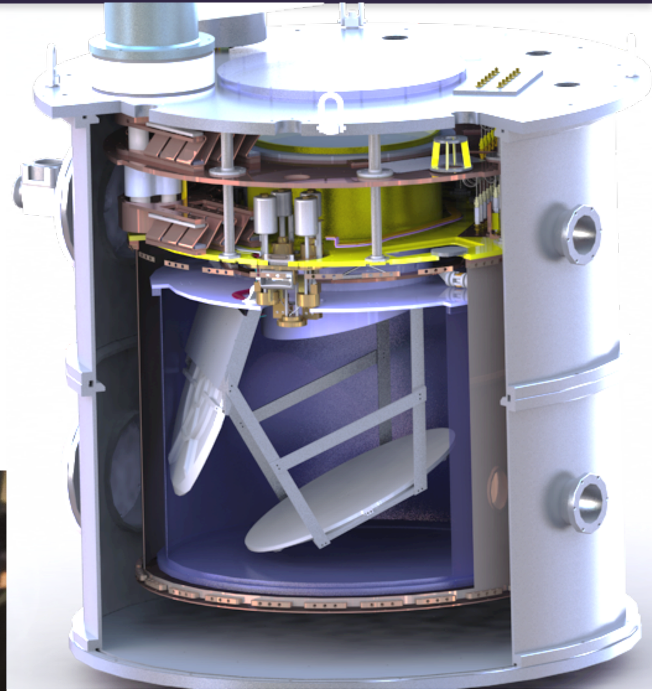


Cryostat Design

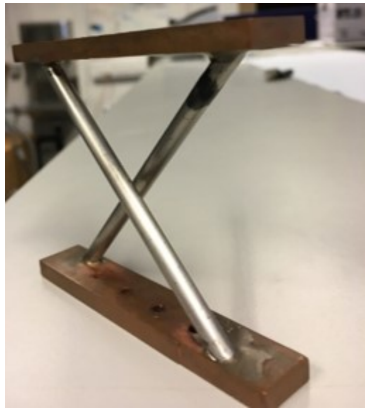
- Nested baffles from 300-K window down to 350-mK stage.
- Fully baffled design

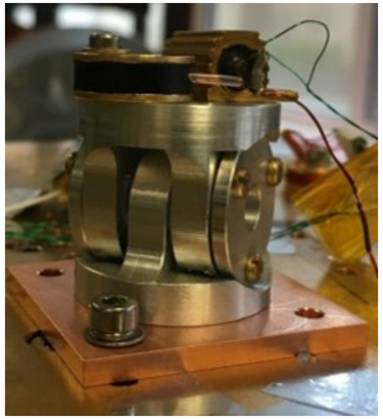


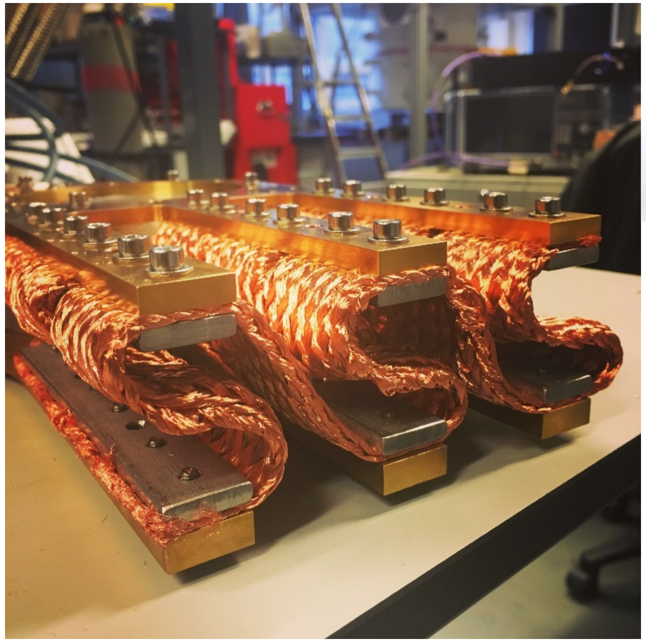
Cryostat Design



- 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 ø1 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



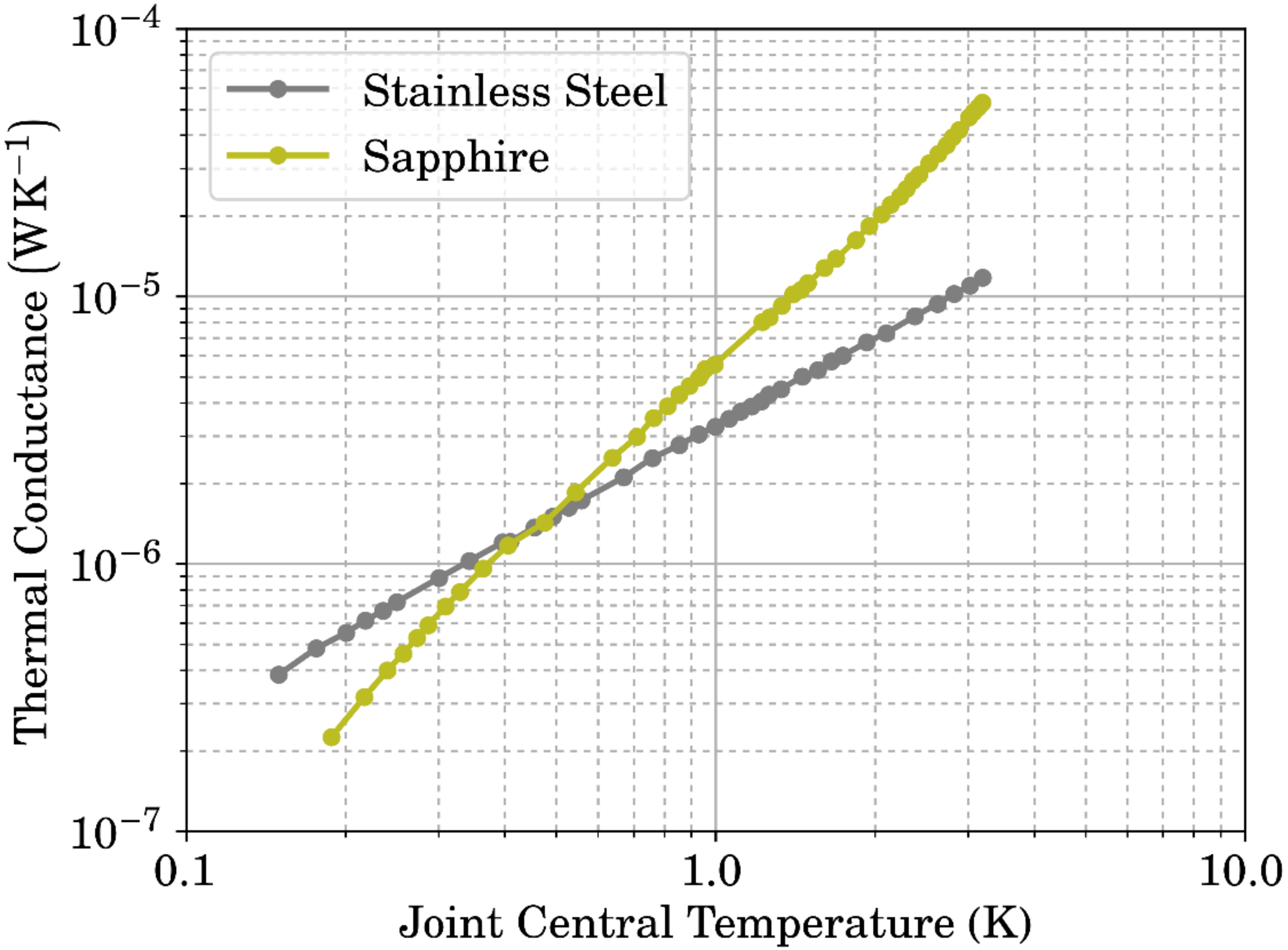




Joint Testing

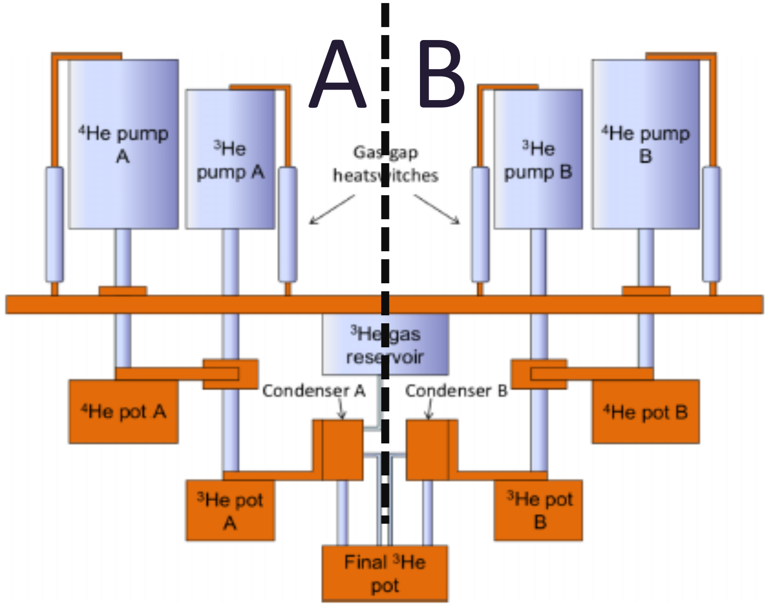
- Individual sapphire joints have a degree of freedom, hinge like
  - Not great for a support, however teaming up and rotating removes this
- Lab ‘testing’ shows test rig distorts only 30 μm under 30 kg load
  - Distortion is elastic up to 30 kg (> MUSCAT 450-mK stage)
- See: Bintley et al. (Cryogenics, 47, 2007)

Joint Thermal Testing

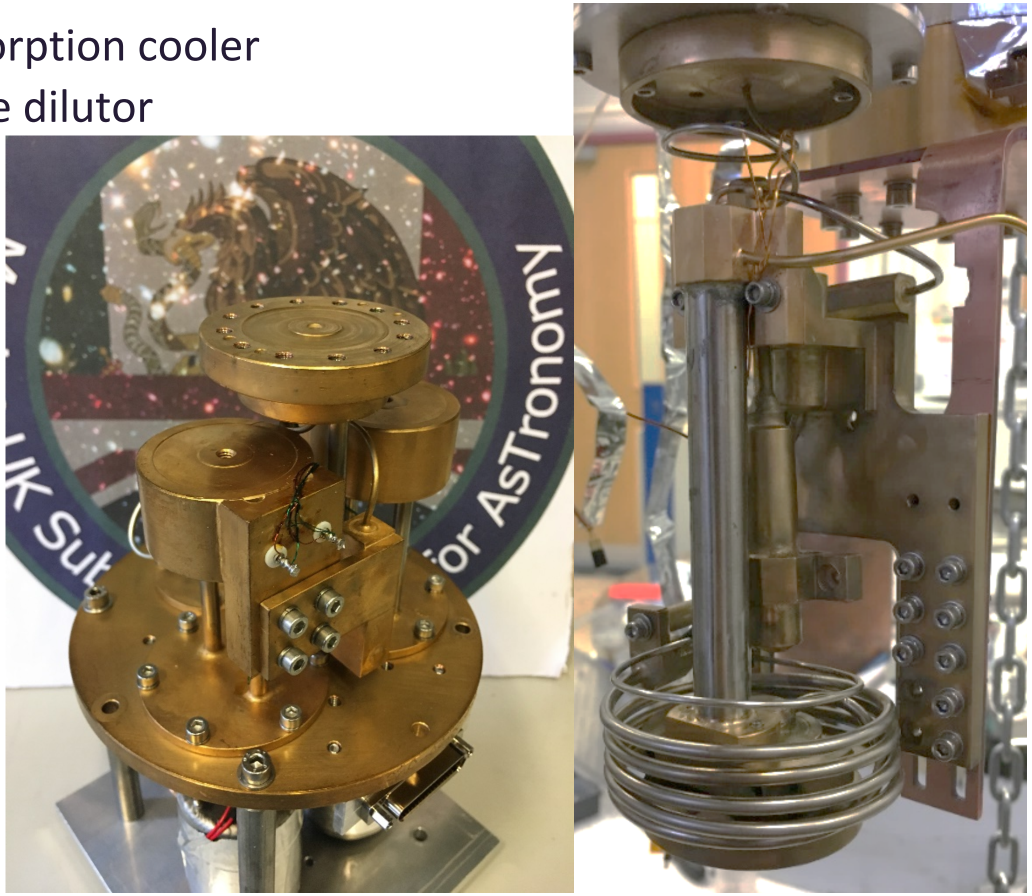


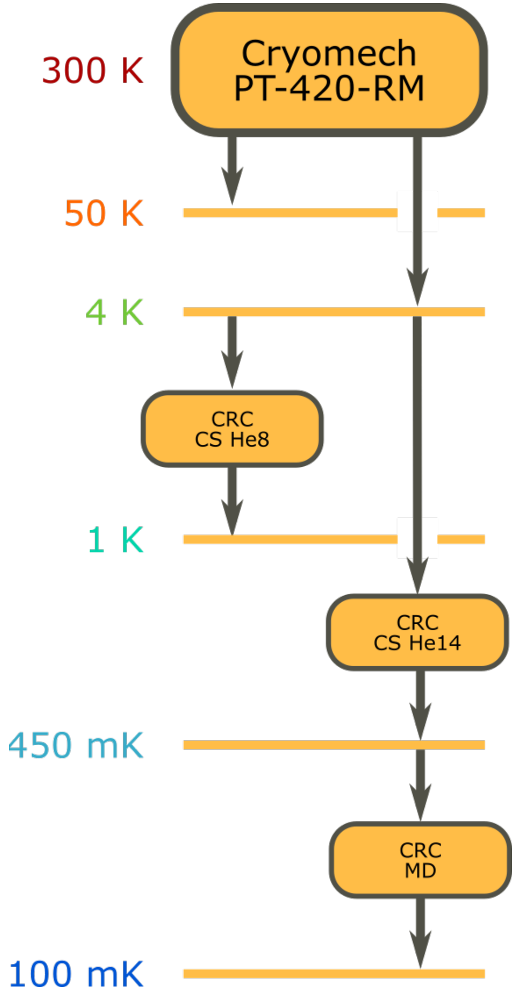
Cryogenics

- 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

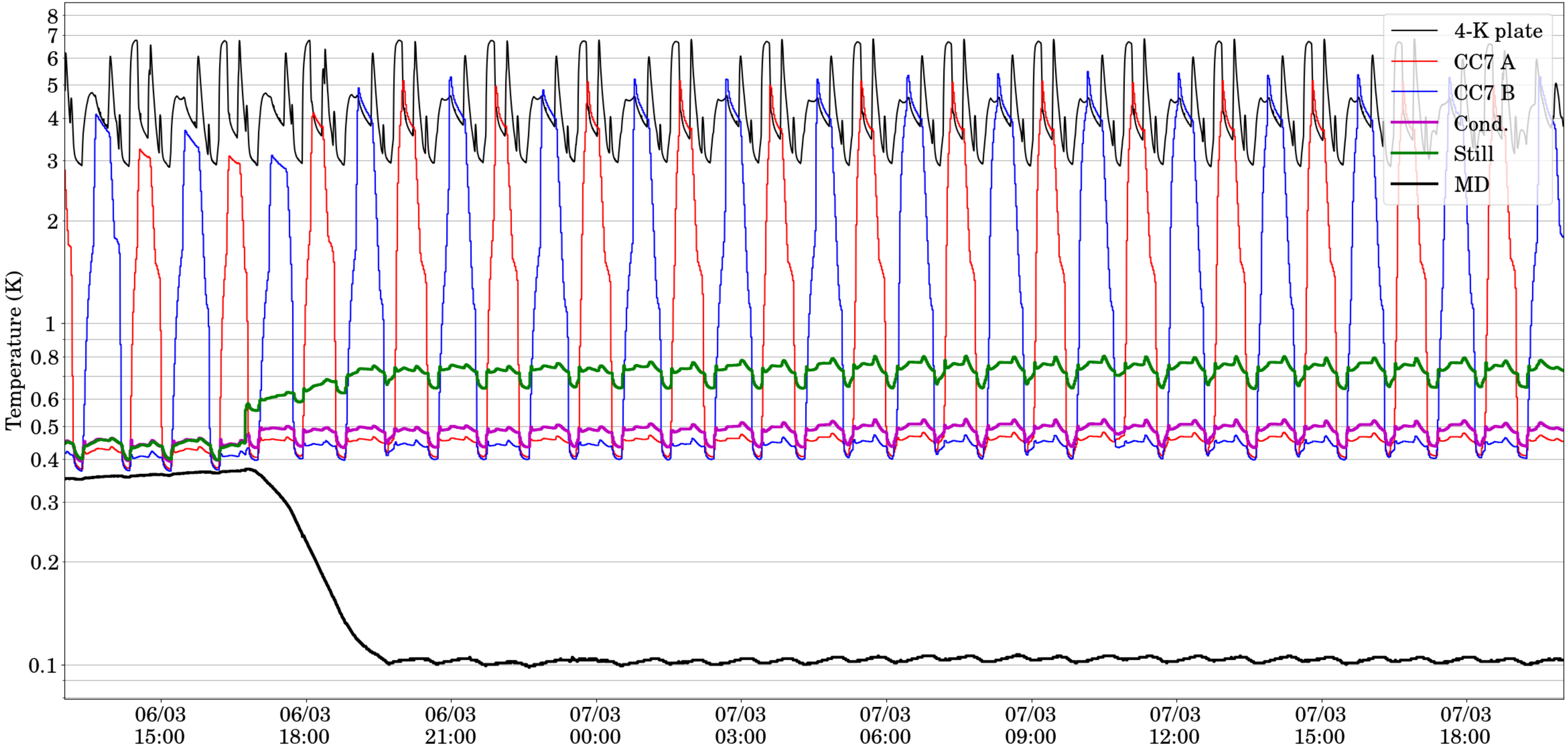


Klemncic et al., Rev. Sci. Inst., 2016



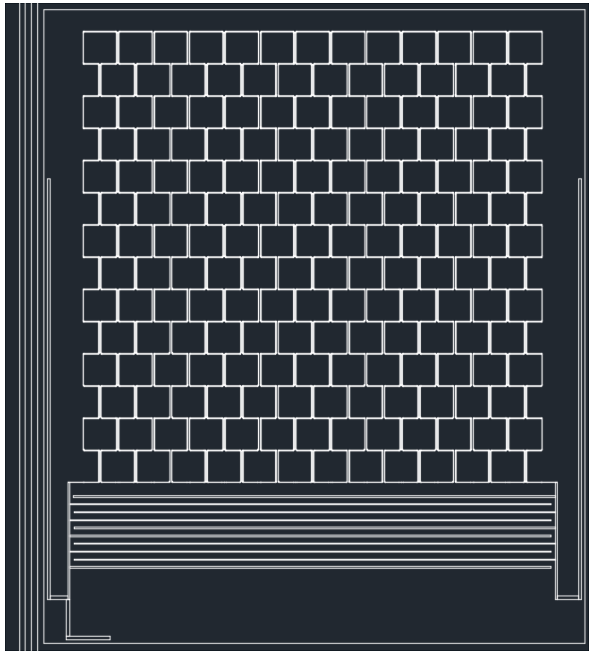


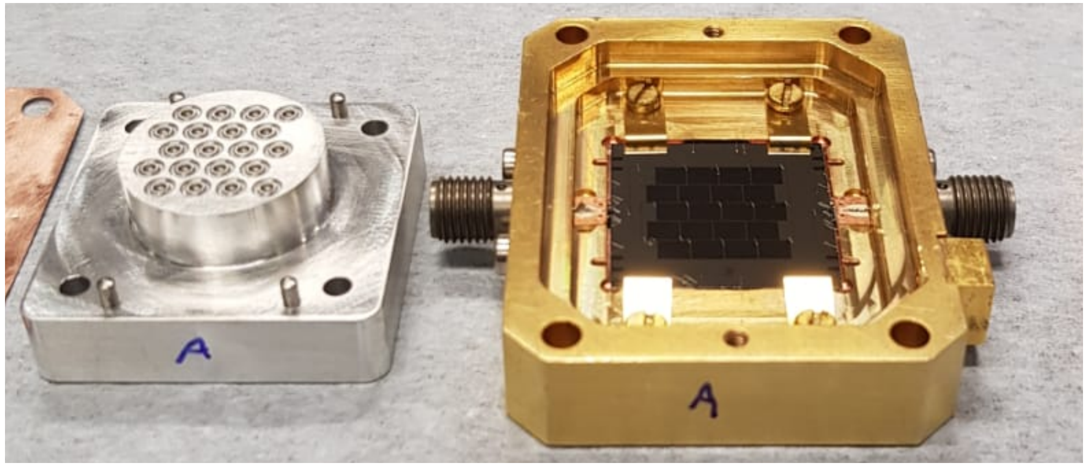
100-mK Cooldown

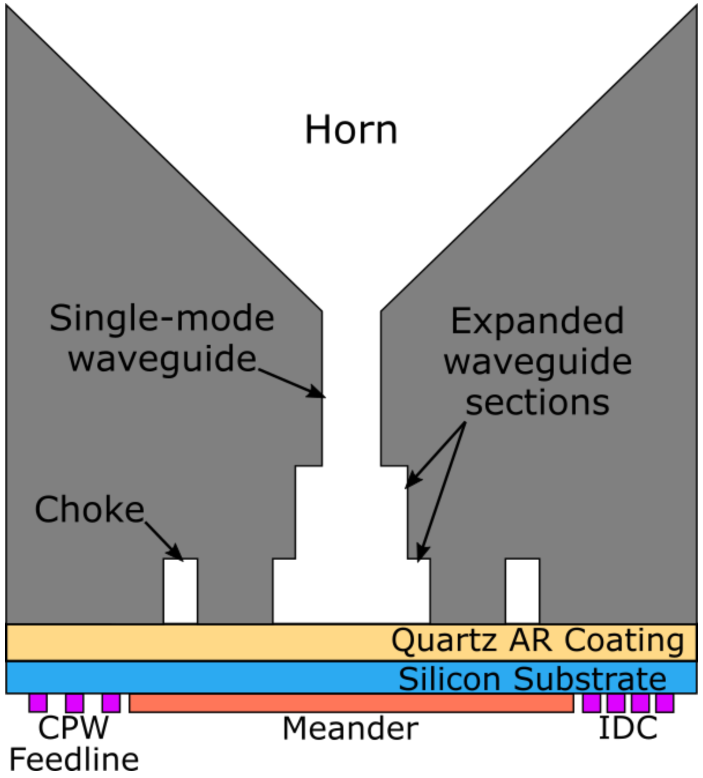


Detectors

- 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

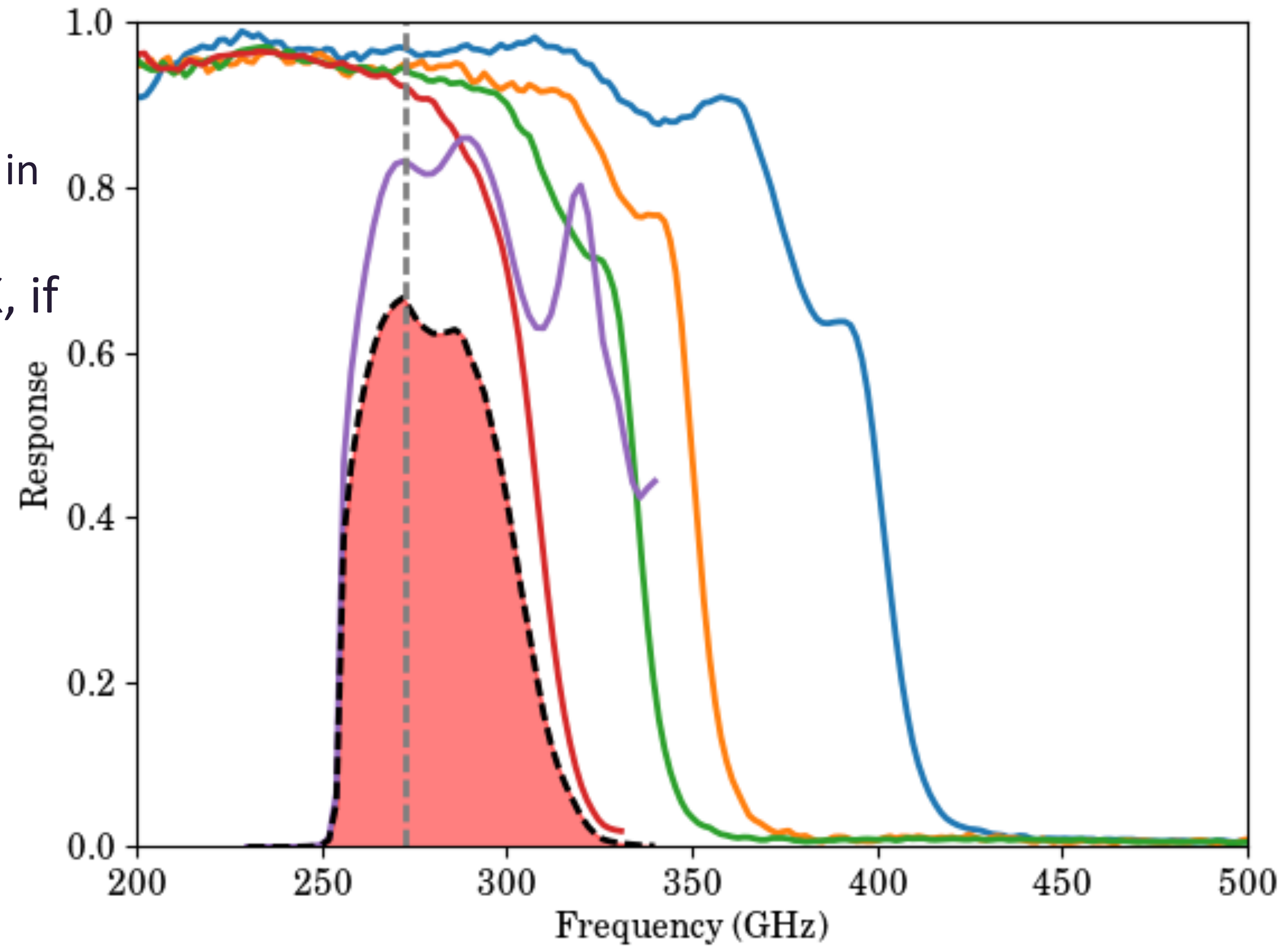






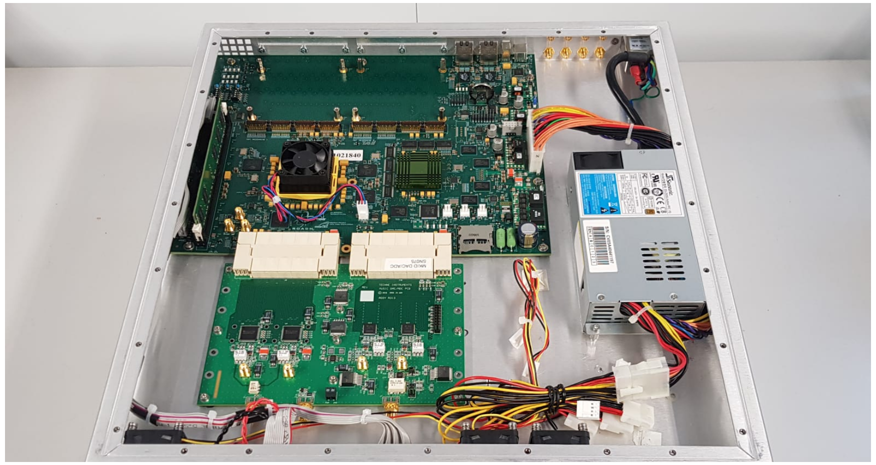
MUSCAT Band

- Upper (frequency) edges defined by metal-mesh filters
- Lower edge by waveguide cut-on
  - Simulated but to be tested in lab (measured in MUSCAT).
- Can add metal-mesh bandpass at 150 mK, 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



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
  - Also plan to explore increased MUX ratios
- Flat lenses (??)

Current Status

- Complete:
  - System Design
  - Cryogenic platform and baseline calibration
  - Cold optics
  - Filter fabrication
- Current work
  - Deployment candidate array testing (move to MUSCAT this week)
  - Warm mirror fabrication (some shared with SuperSPEC ETA 4 weeks)
  - Cryostat mounting plate for LMT and warm mirror mounts
  - Site preparation: 440-V supply extension, water cooling, mirror mounts
- Shipping in coming months. To be ready for good weather (Nov.)