MKID 850µm camera for JCMT

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Summary

This is an overview of the new 850µm wide field camera to be built for the James Clerk Maxwell Telescope.

The project is conceived as a collaboration of EAO regions and JCMT partners. State-of-the-art detector arrays will be fabricated by NIST, Boulder. The instrument design, construction, assembly and testing will be done by the collaboration.

The new 850µm instrument will have all of the capabilities of SCUBA-2 at 850µm and yet will map an order of magnitude quicker. Large-scale structure in maps will be a better defined by virtue of a single uniform array and larger field of view. Mapping 850µm polarisation will be improved by a factor of at least 20.

Outline

- The case for a new instrument
- Lessons from SCUBA-2
- Concept of the instrument
- Highlight the critical aspects in the design
- What’s Next

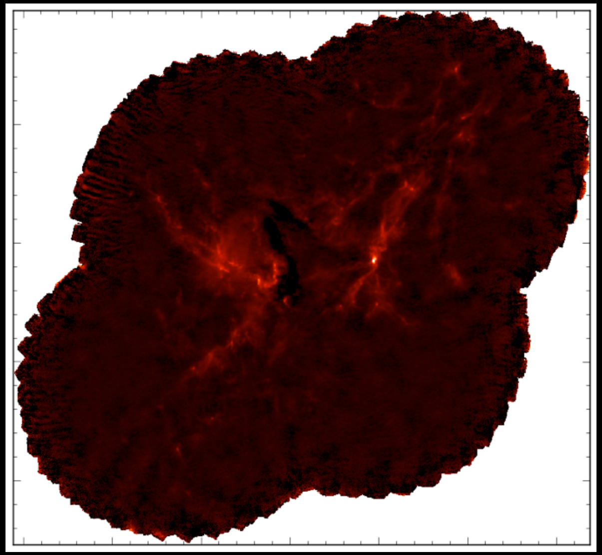
Will the new instrument make mapping extended emission easier ?

Will we be able to make intensity and polarisation maps simultaneously ?

Why do we need a better continuum instrument than SCUBA-2 ?

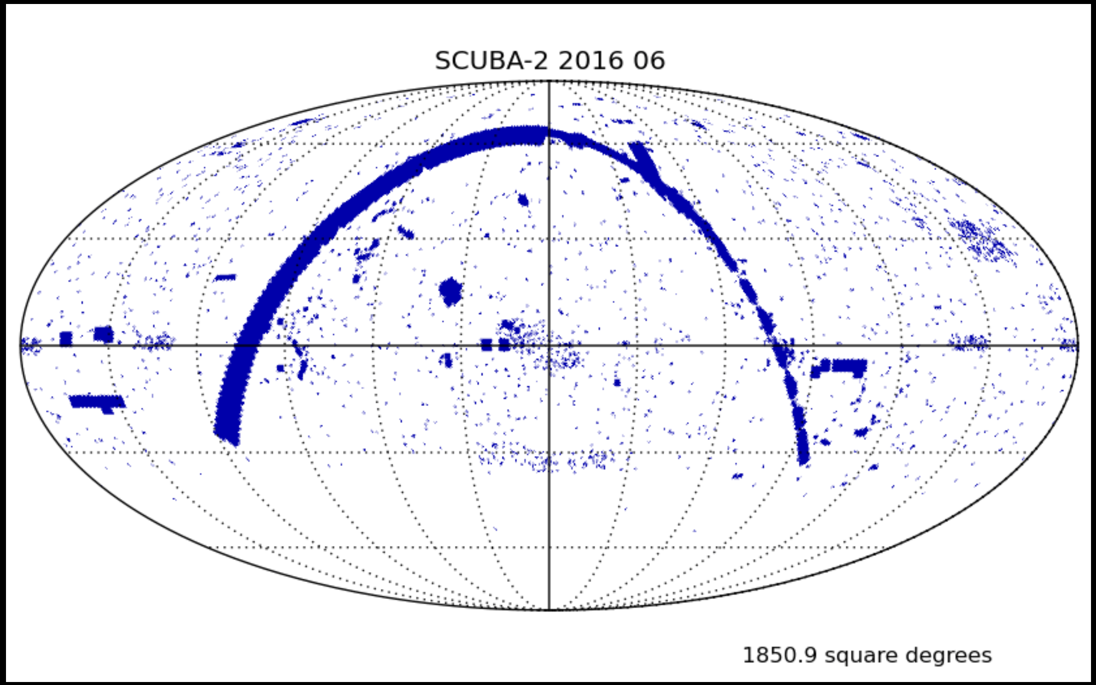
- JCMT is in a unique and critical position in the current submillimeter community.
    - With a 15m dish and potential 12 arcmin field of view – JCMT is ideal for conducting largescale and deep surveys, using a large format multi-pixel instrument.
    - With the success of ALMA, there is a pressing need for source-finding and mid to large-scale complements to ALMA’s high-resolution science. JCMT provides these capabilities, and at the shorter and more critical wavelengths.
- SCUBA-2, and in combination with POL-2, is in extremely high demand - ***limited only by what can be realistically be observed in a reasonable time***.
- New, larger single-dish observatories at 850um and shorter, are a minimum of a decade away.

SCUBA-2 has been remarkable success



Credit: JCMT/ Herschel Gould Belt Survey

The First 5 Years of science

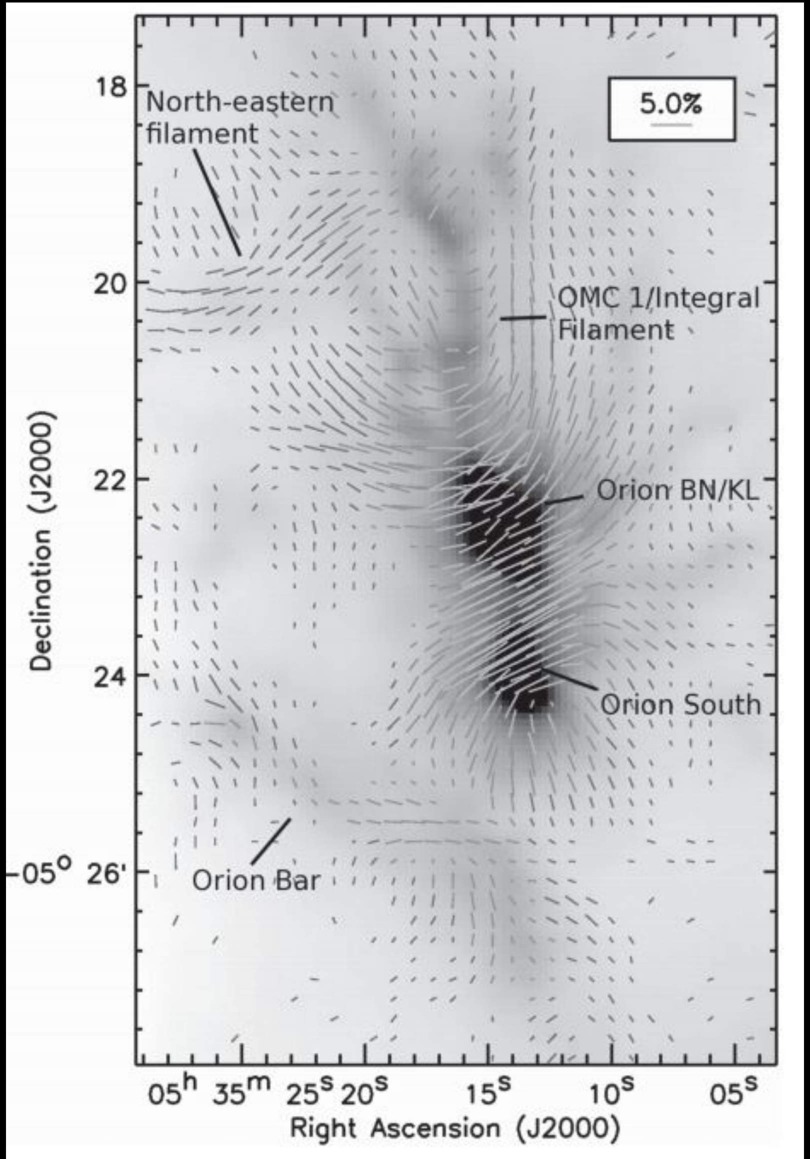


- *Reliable – few faults*
- *Consistent performance*
- *Easy to operate*

19 Large SCUBA-2 /POL-2 surveys, 9 currently in progress
Scores of PI projects (50% of the time allocated)

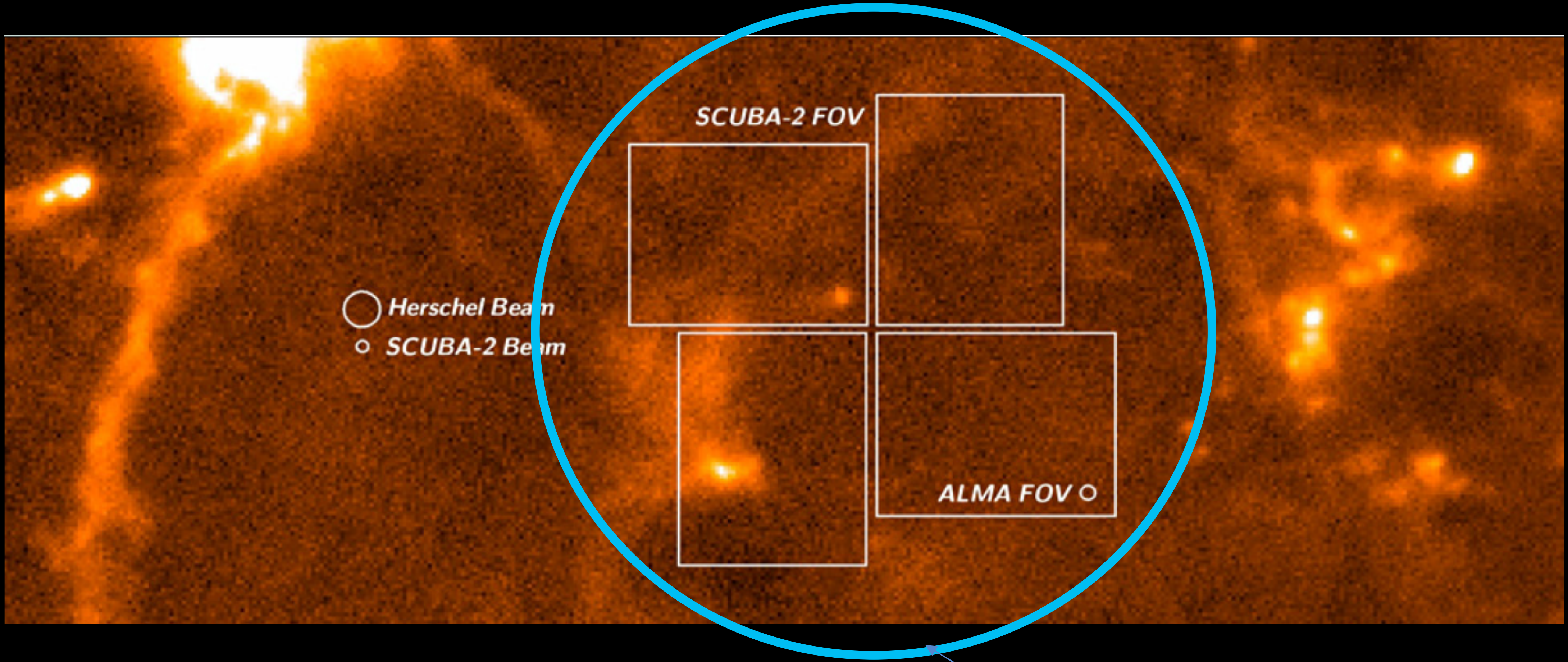
POL-2 has added a unique extra capability

POL-2 and SCUBA-2 currently provides the only capability for fast, accurate detection of submillimeter polarisation on crucial intermediate size scales - between the low resolution polarization maps of Planck and BLASTPOL and the arcsec scales measured by ALMA and SMA



BISTRO Polarisation map of OMC 1,

JCMT Beam Size (850µm) and Field of View compared to ALMA and Herschel



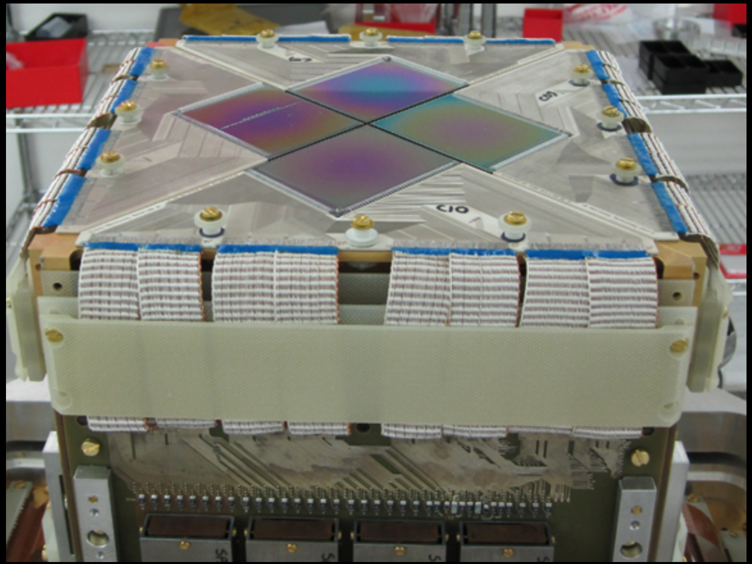
Field of View of new 850um MKID Instrument

Lessons of SCUBA-2

- Led by the science goals and requirements.
- Innovation needs time and effort.

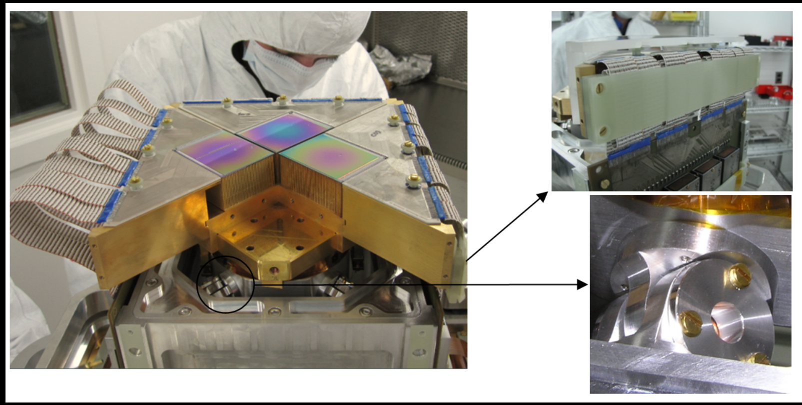
(Over budget and 5+ years late !)

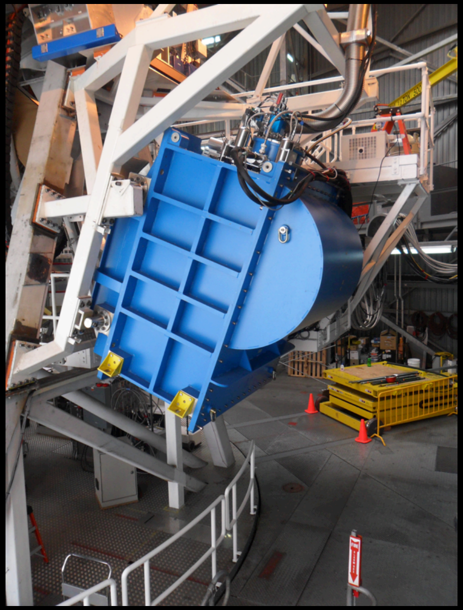
  - ***Almost everything was new and had not been done before***
  - Detector wafer design
  - Design of MUX wafer
  - Bump bonding, wire bonding (on the scale)
  - Interconnect between wafer and SQUID series arrays
  - Dry dilution fridge



Lessons of SCUBA-2

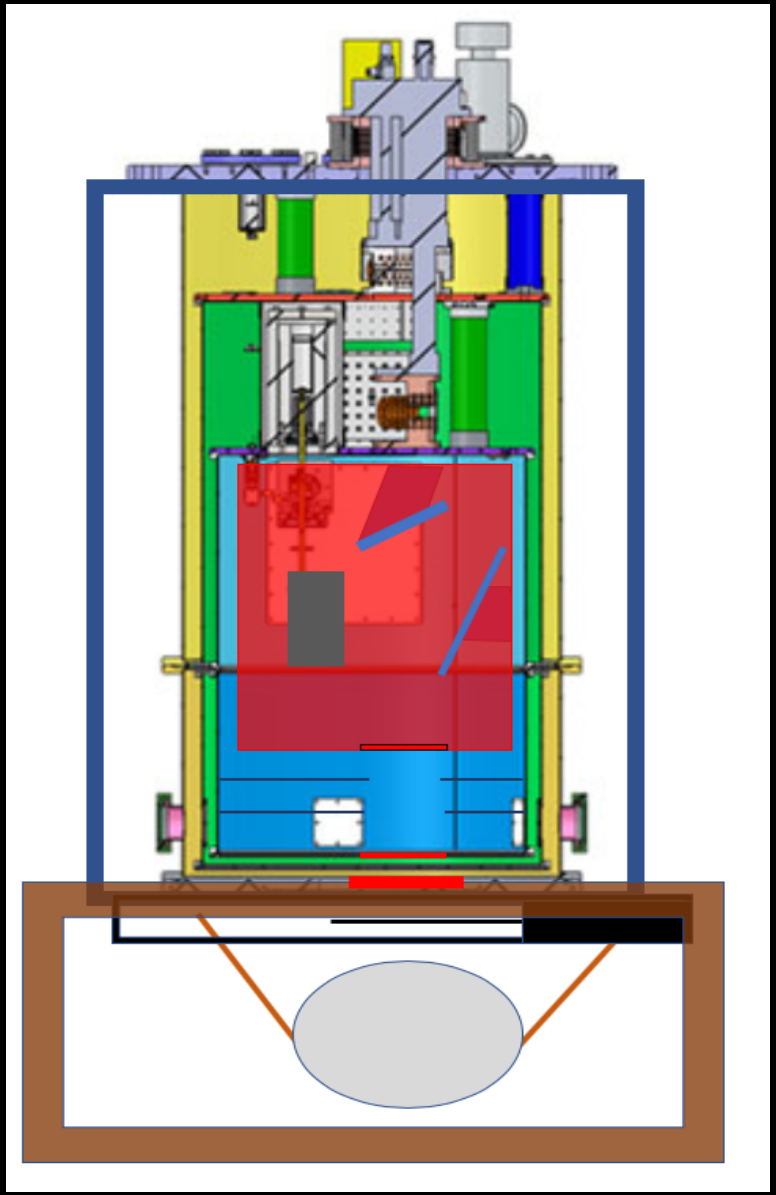
- Many positive lessons from the design, testing, instrument build etc, that we can apply.
  - Complex detector design – variation across the wafers and between the wafers – has limited the effective yield and the sensitivity.
  - Excess optical power when open on the sky – has reduced the effective NEFD.
  - Compromise in the mechanical design of the cryostat impacted fridge temperature stability.
  - Planned observing modes, such as STARE and DREAM have not been possible.
  - Effective sky removal is critical.
  - Mapping faint large scale structure, that extends beyond the sub-array FOV is difficult.





Lessons of SCUBA-2

- Many of the “shortcomings” of SCUBA-2 can be corrected with the new instrument.
  - The MKID detector design leads to uniformity across the wafers and the possibility to post process array wafer to maximise the yield. Detector performance less dependent on fab.
  - Reducing excess optical power and mitigation of stray light – will be critical for success.
  - MKIDs are less susceptible to temperature fluctuation.



Two Questions ?

- Will the new instrument make mapping extended emission easier
  - Larger FOV - effectively doubled
  - More sensitive detectors
  - Uniformity across array
  - Less common mode (magnetic, thermal) – just sky

- Polarimetry with the new instrument
  - We heard from Jason - the possibility of polarimetry without rotating wave plate - the same observation data can therefore be processed for intensity and polarisation – with no loss
  - **We need to investigate – Model observing modes, before we fabricate array**

Third question – why no 450 ?

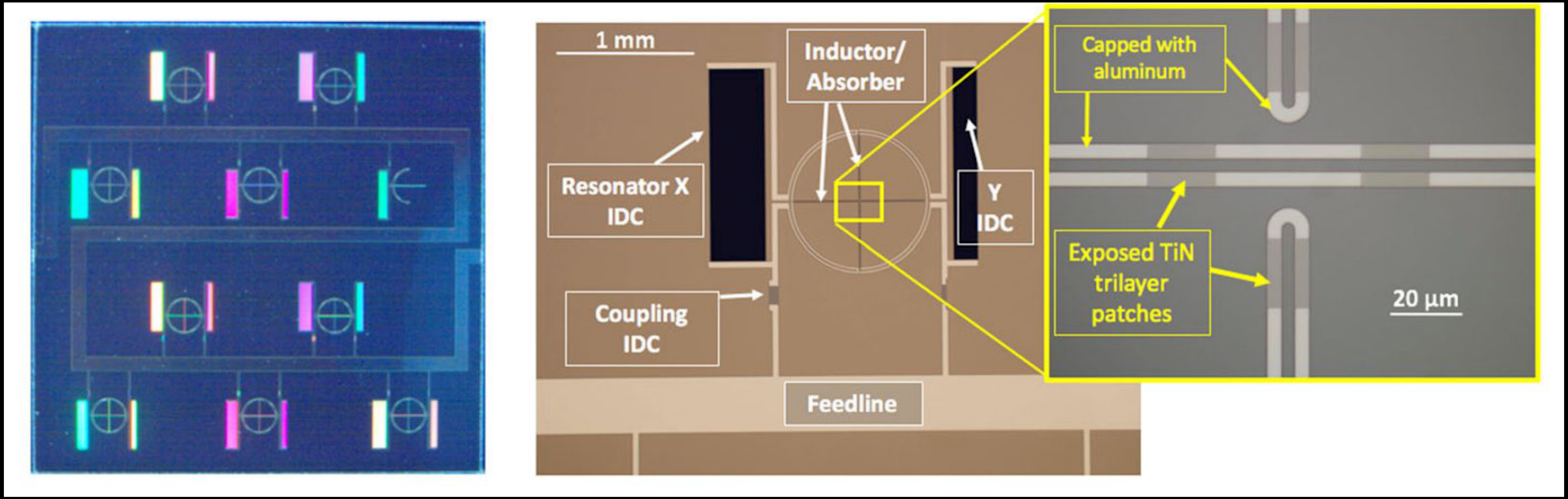
New Instrument – Initially single wavelength - 850μm

- JCMT is ideally situated to observe at 850μm. The prevailing weather on Mauna Kea provides consistently good observing conditions at 850μm, much more so than at 450μm.
- Building a single wavelength instrument means that we can focus on getting the key design aspects right and will lead to a much quicker delivery of the instrument.

Design Requirements for new instrument

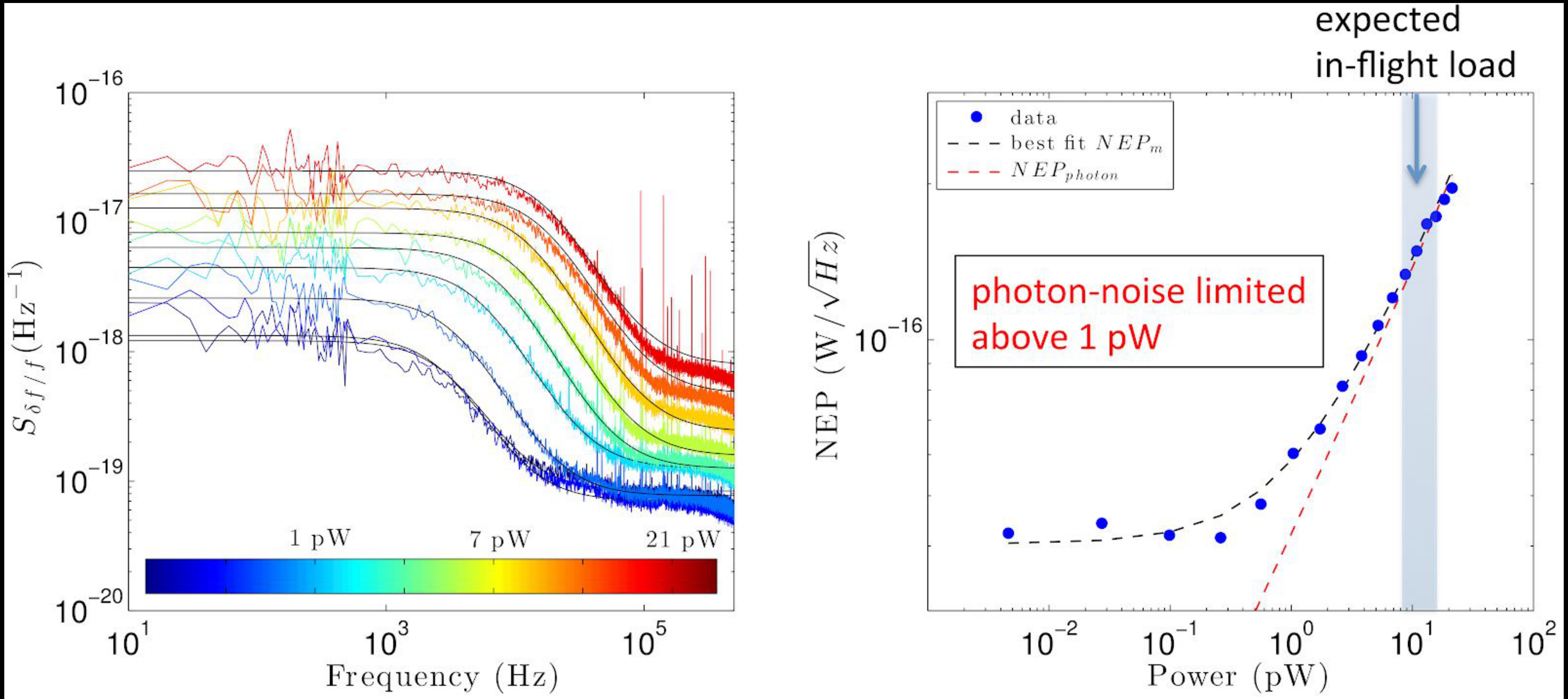
- Take full advantage of the 850μm atmospheric window and the JCMT field-of-view
- Be restricted in first-generation as a single-wavelength instrument
- Achieve *at least* a factor of 10 faster mapping speed than SCUBA-2 at 850μm (our modeling of expected performance is higher than this)
- Have intrinsic polarisation measurement capabilities
- Detect and map polarised emission at least 20 times faster than POL-2
- Be operational on the JCMT by 2022

MKID Detectors – from NIST



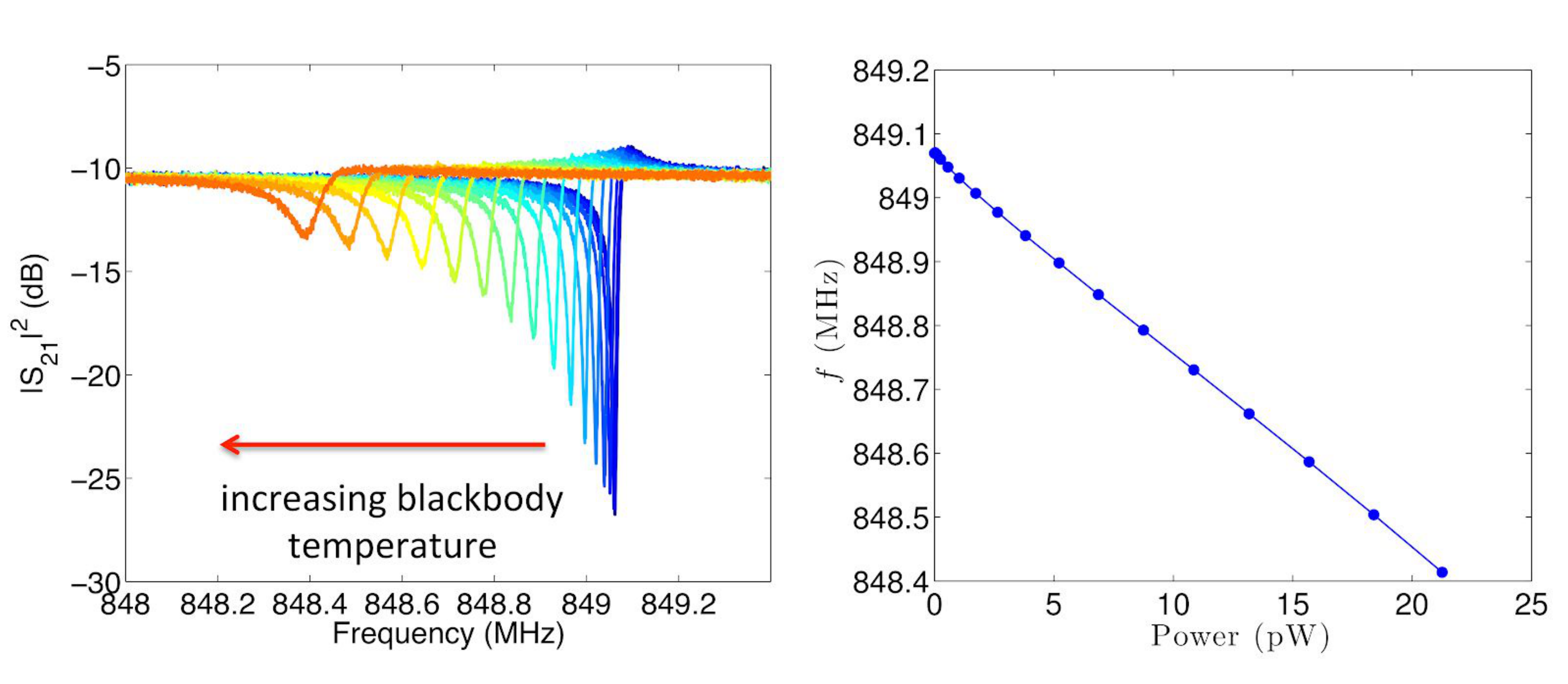
Prototype NIST 10 pixel 1.1 mm array. (Center) The layout of a single dual polarisation pixel and (Right) an expanded view of the inductor/absorbers. The new JCMT MKID pixel will have a similar design optimised for 850 µm

Optical power loading noise measurements



Test results of NIST pixel design, The (BLAST-TNG) NIST MKID is photon noise limited for optical loads greater than 1pW.

Large linear dynamic range



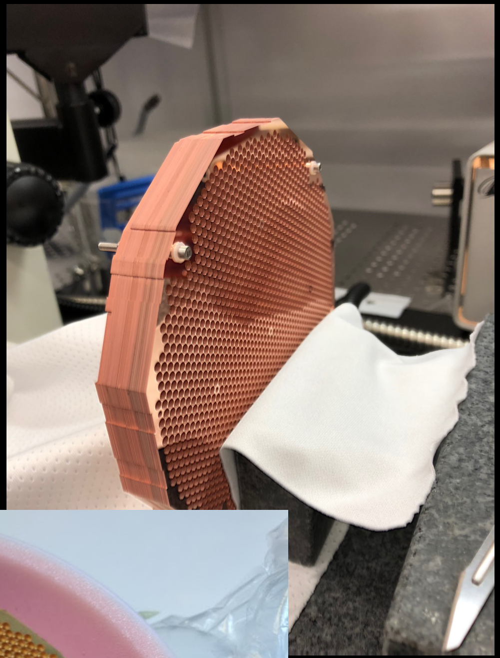
Test results of NIST pixel design, showing a large linear dynamic range under optical power loads.

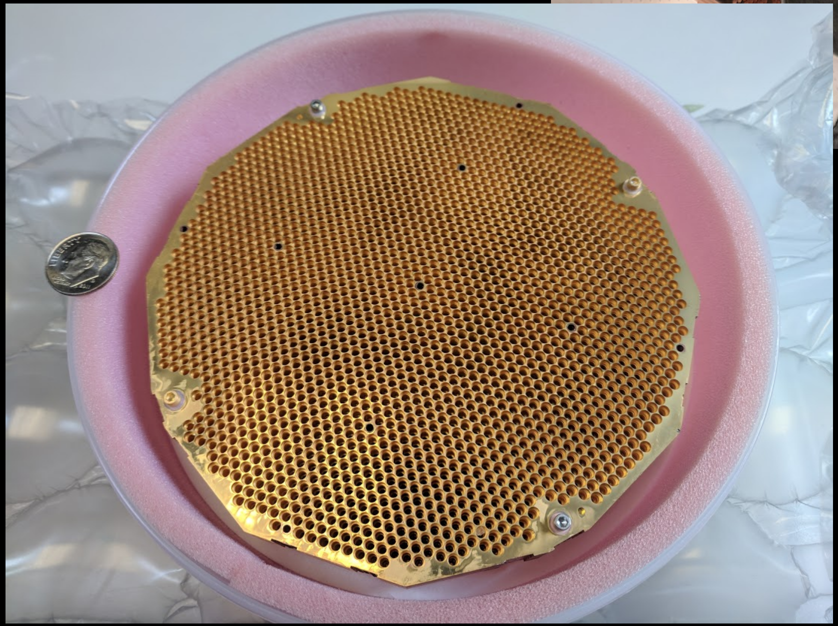
Feedhorn coupled MKID Array

Each pixel is comprised of two lumped element MKID that are sensitive to orthogonal linear polarization. The MKID form a resonant circuit consisting of an inductive strip and an interdigitated capacitor.

In the NIST MKID design arrays, the inductor is identical for each pixel, while each capacitor is trimmed to a unique value. The inductor is made from TiN/Ti multilayers, allowing the Tc to be tuned by varying the thickness and number of layers. The inductor also serves as the absorber that couples to radiation from the waveguide.

The choice of Tc, inductor geometry and impedance matching determine the optimal coupling, polarisation efficiency and saturation power. An aluminium layer over portions of the inductor provides further tuning of the optical coupling. The goal is to optimise these parameters for 850µm observing at JCMT.

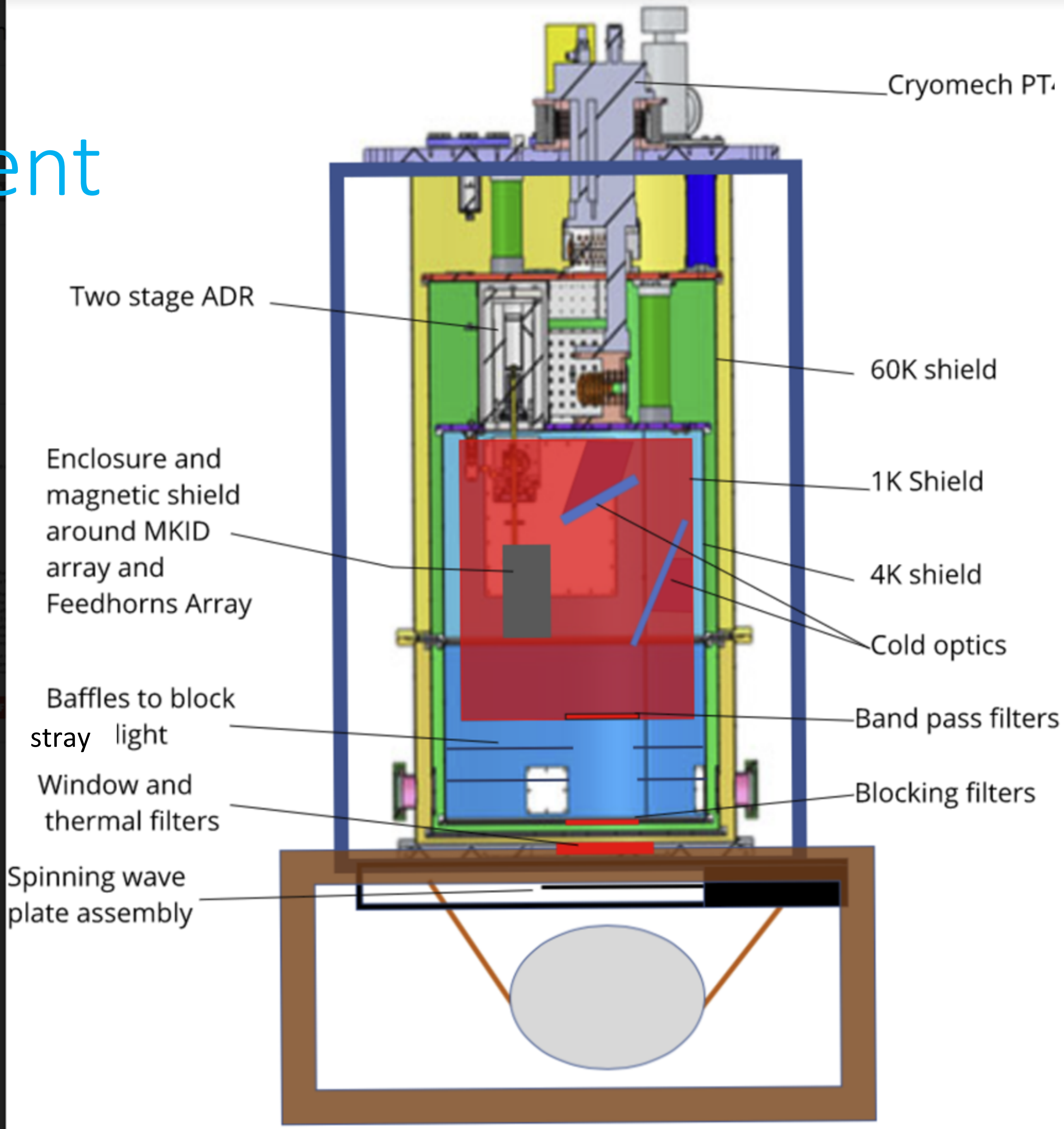




TolTEC Instrument 1.1mm Feedhorns, (Umass)

Concept of Instrument

- Circular 12 arcmin FOV
- 3600 1fλ spaced, hexagonal closed packed pixels, each with 2 detectors
- Focal plane temperature < 200mk
- 1K enclosure surrounding array and final mirrors
- Effective baffles at 4K
- ~~Rotating half-wave plate for polarimetry~~



Critical Aspects of the Instrument Design

• Optical design/Stray light	-	AAO/? -
• Detector sensitivity and yield	-	(NIST /Cardiff/PMO)
• Detector readout	-	PMO/Canada
• Engineering design	-	AAO/PMO/ASIAA ?
• Cryostat manufacture	-	ASIAA ?
• Instrument integration	-	PMO/Cardiff
• Data reduction	-	
• Methods for Sky removal	-	
• Observing modes	-	

What’s Next

- This workshop will help to expand and improve the science case this new instrument.
- We hope that you, the regions submm astronomers take ownership and promote the science case and assist with improving the conceptual design, to best achieve the science goals.
- The detailed plan for the building, testing and commissioning the instrument will follow this workshop. Further meetings/discussions this week to identify contact people in each region and agree a division of labour.