220/280 GHz Multichroic Feedhorn-Coupled TES Polarimeters for CMB Measurements

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Orals LM 003,183, 9:45-10:00am, July 24th, 2019

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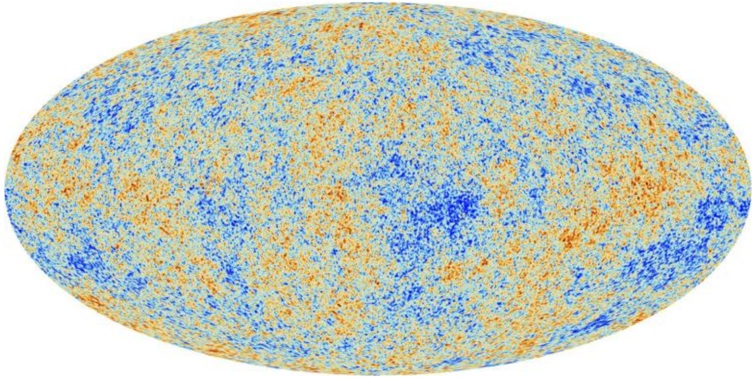
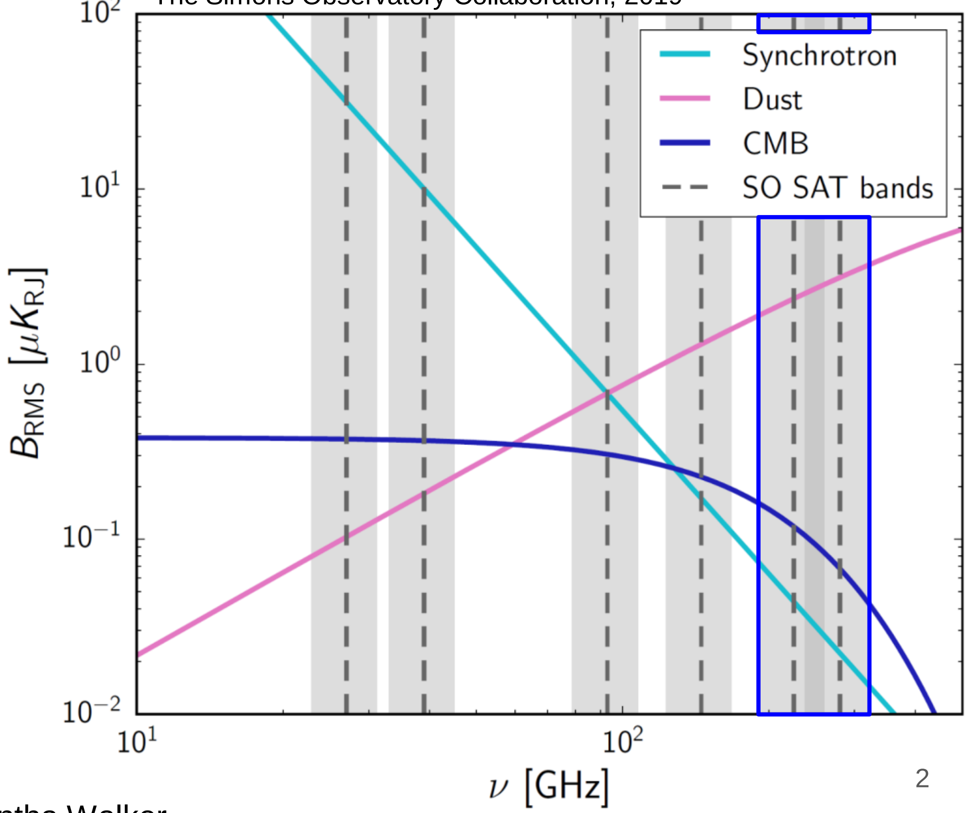
Distinguishing foregrounds from the cosmic microwave background (CMB)

CMB absolute temperature: 2.7K
Scale: ± 500μK

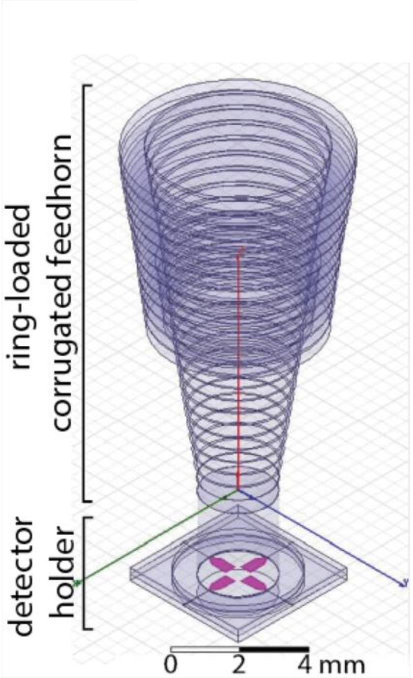


ESA and the Planck Collaboration

The Simons Observatory Collaboration, 2019

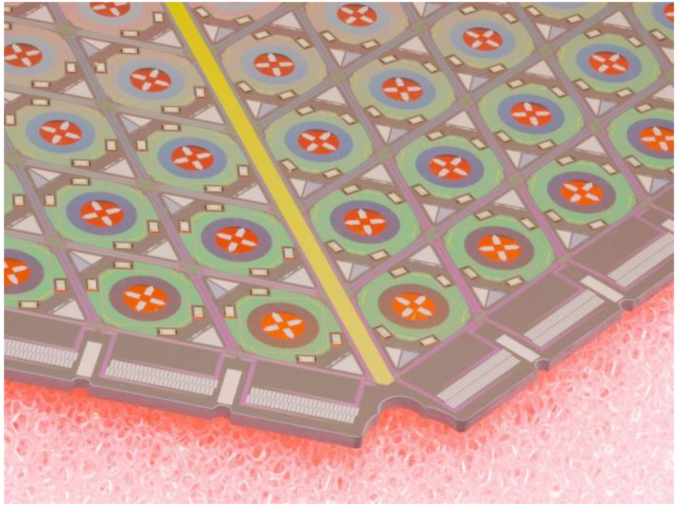


NIST multichroic feedhorn coupled approach

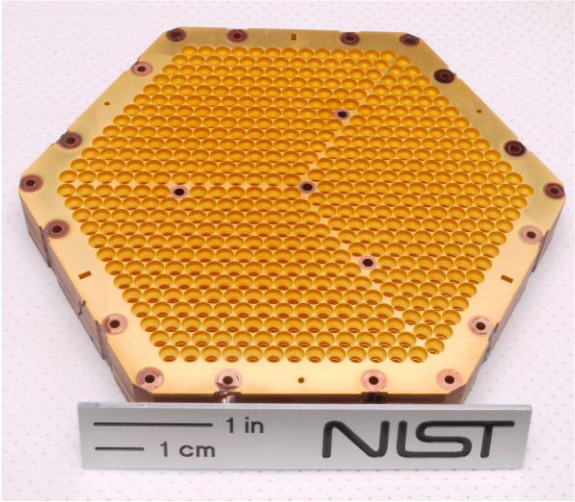


Datta, R. et al., 2016
(ACTPol Collaboration)

Advanced ACTPol high frequency band



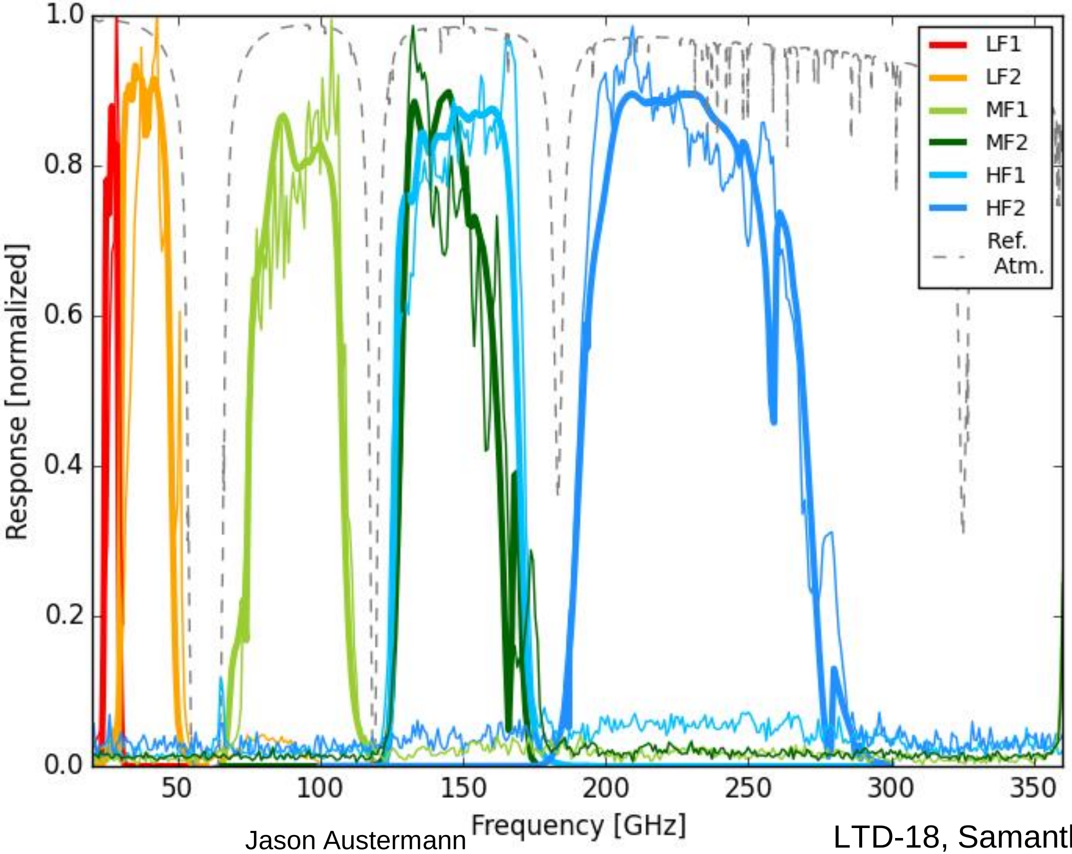
Pixel Array



Feedhorns

A state of the art array at 90/150 GHz has ~2000 TES bolometers.

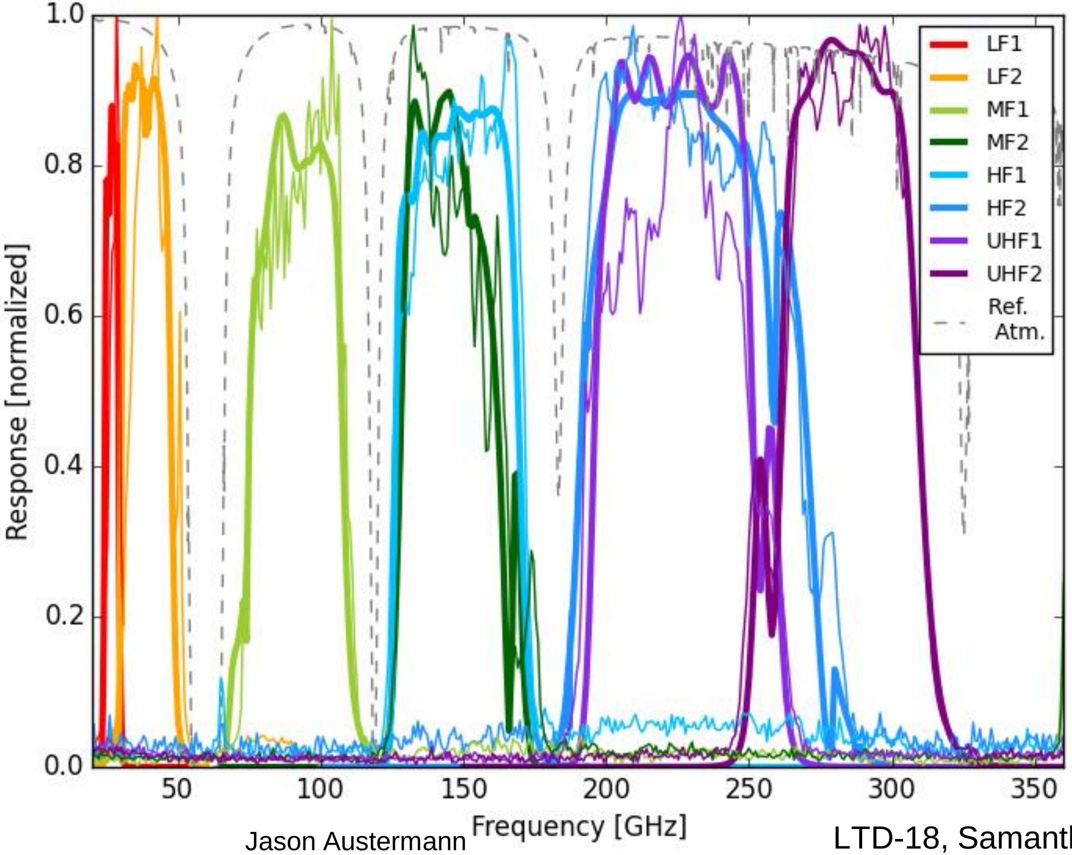
NIST TES polarimeter program



Jason Austermann

LTD-18, Samantha Walker

NIST TES polarimeter program



Jason Austermann

LTD-18, Samantha Walker

Overview of other SO talks and posters at LTD:

Simons Observatory (SO)

Large ground-based CMB experiment in the Atacama Desert with four telescopes.
Planned to begin observations in the early 2020s.

Instrument details

- 1 large-aperture 6-m telescope (LAT) to map small angular scales.
- 3 small-aperture 0.5-m refracting telescopes (SATs).
- 6 observation frequencies: 27, 39, 93, 145, **225**, **280 GHz**.
- Total of 60,000 bolometric sensors.

See Galitzki, N., et al. 2018 for more instrument details and The Simons Observatory Collaboration 2019 for more science details.

155. TES characterization, Poster, 17:45pm, July 23rd, Jason Stevens

205. SATs overview, Poster, 17:45pm, July 23rd, Aamir Ali

220. Readout assembly architecture, Orals LM 002, 9:00am, July 24th, Heather McCarrick

286. Kilopixel-scale readout, Orals LM 002, 9:15am, July 24th, Bradley Dober

340. Readout overview, Poster, 17:45pm, July 25th, Maximiliano Silva-Feaver

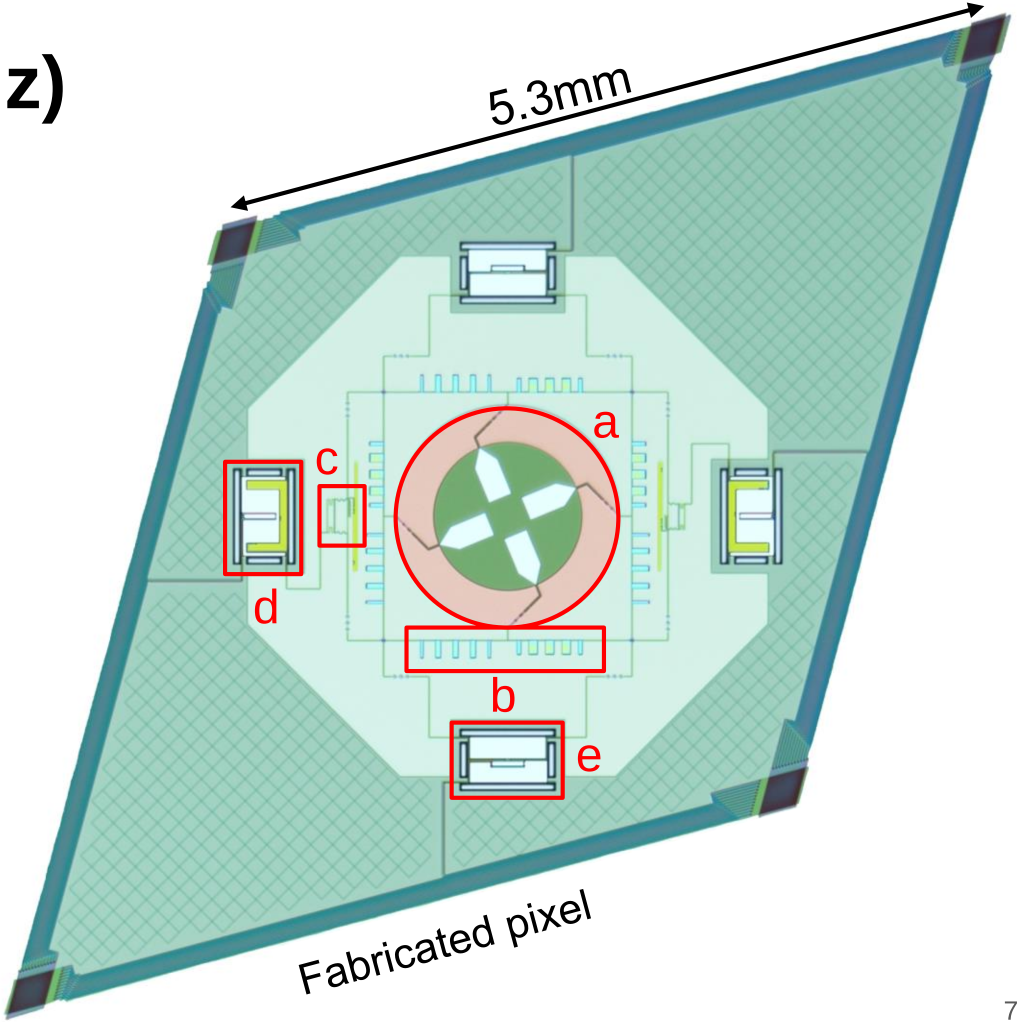
101. Assembly and integration, Poster, 17:45pm, July 25th, Yaqiong Li

322. Hemispherical lens arrays, Poster, 17:45pm, July 25th, Shawn Beckman

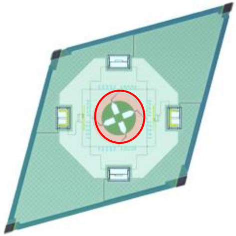
298. Sensitivity forecasting, Poster, 17:45pm, July 25th, Carlos Sierra

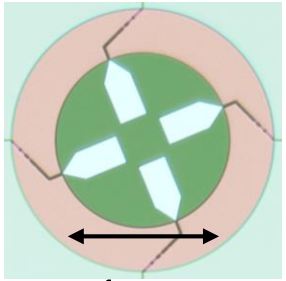
UHF pixel (190-315GHz)

a 960μm diameter waveguide orthomode transducer (OMT).
b 220/280GHz diplexer (4 total).
c 220 or 280 GHz band optimized hybrid tee.
d and **e** 4 optical TESs, one for each polarization and passband. Also, two non-optically coupled, or dark, TESs (not shown).



a Planar orthomode transducer (OMT)

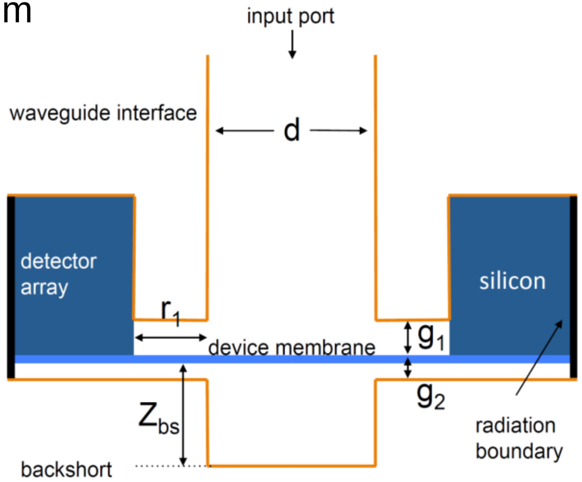




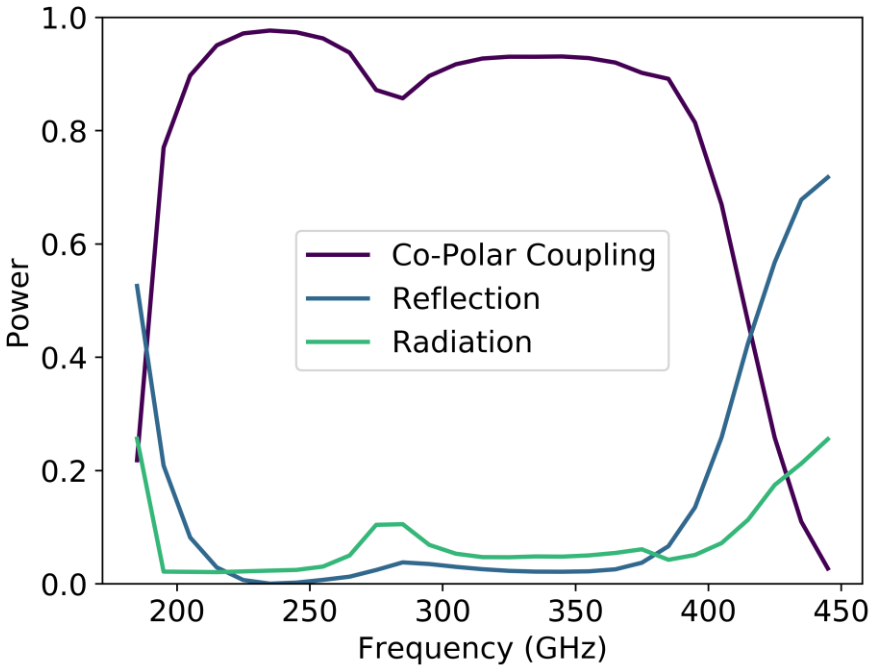
As fabricated, face down view

1mm

OMT side view

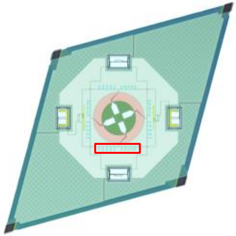


Coupling summary from 3D HFSS simulation

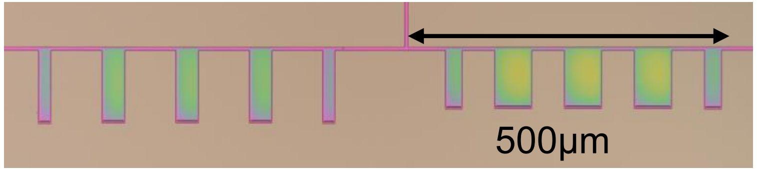


Hubmayr, J., et al. 2016

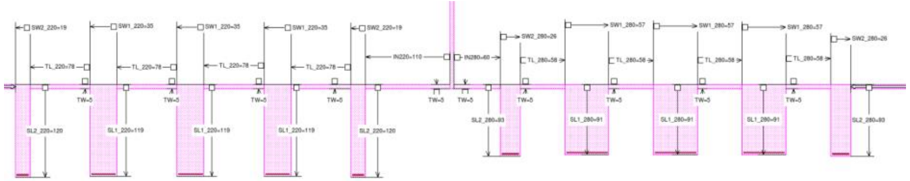
b Diplexer

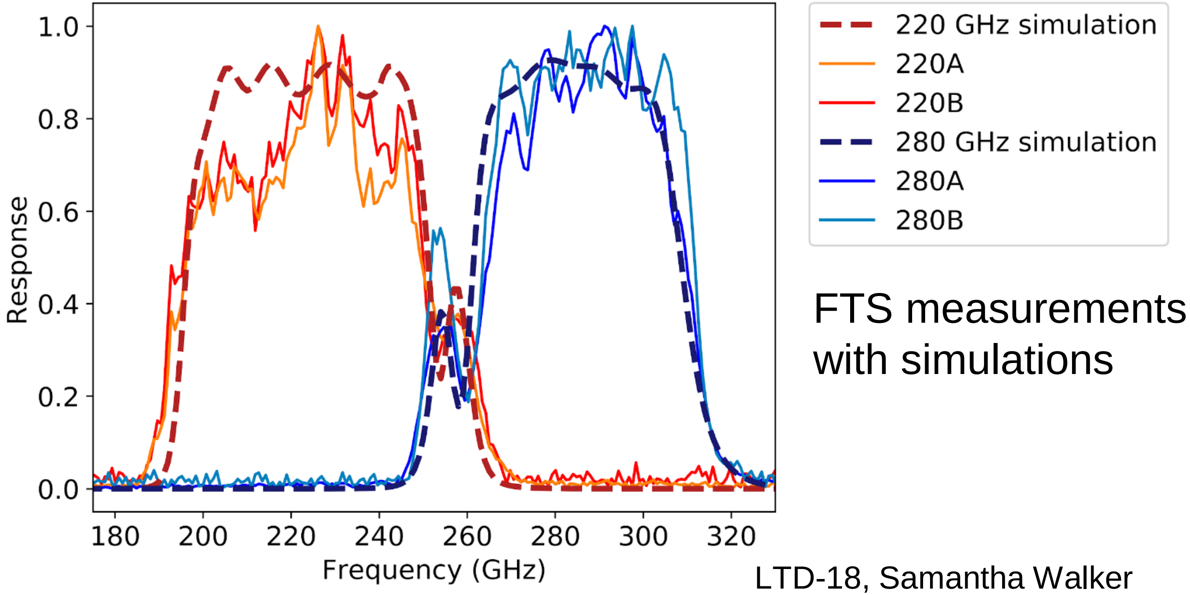


As fabricated



Sonnet 2.5D simulation

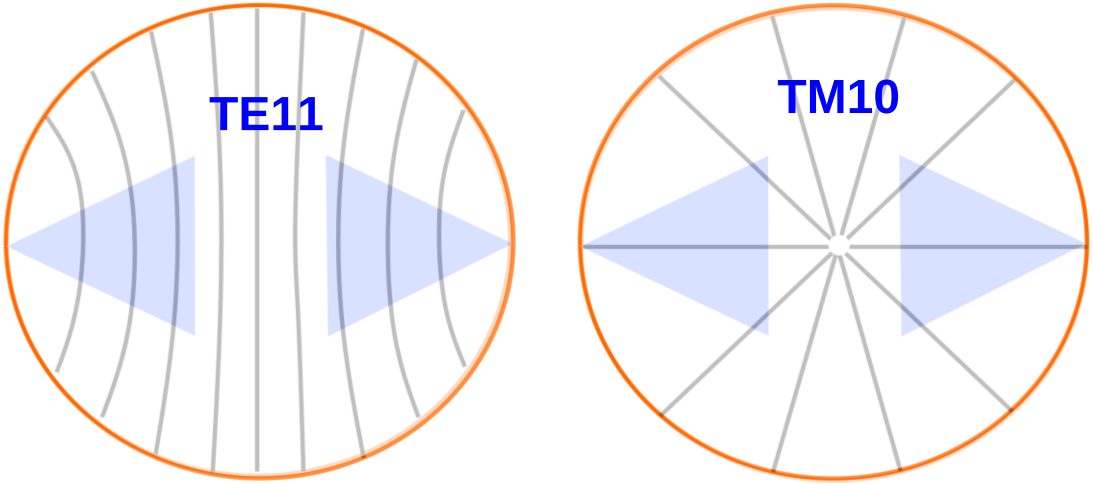




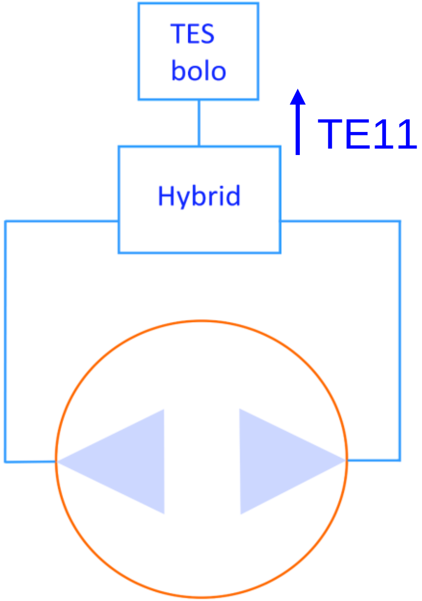
FTS measurements with simulations

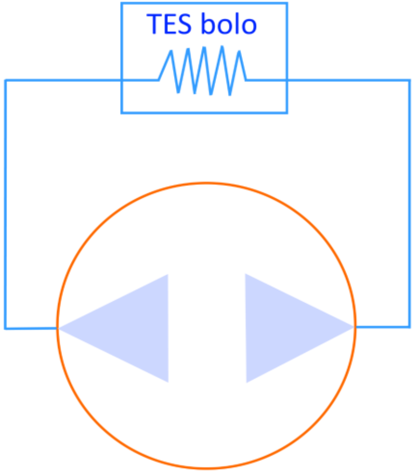
Challenge: Filtering multiple waveguide modes

- Issue: The circular waveguide supports multiple modes, but we only wish to measure the single lowest order mode, TE11.
- Coupling to multiple modes impacts:
  - Polarization response
  - Angular resolution



Two termination schemes, A and B





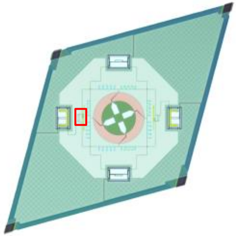
A: Hybrid tee + distributed resistor

Approach taken by NIST and NASA/Goddard (J. McMahon et al. 2011).

B: Lumped, differential resistor

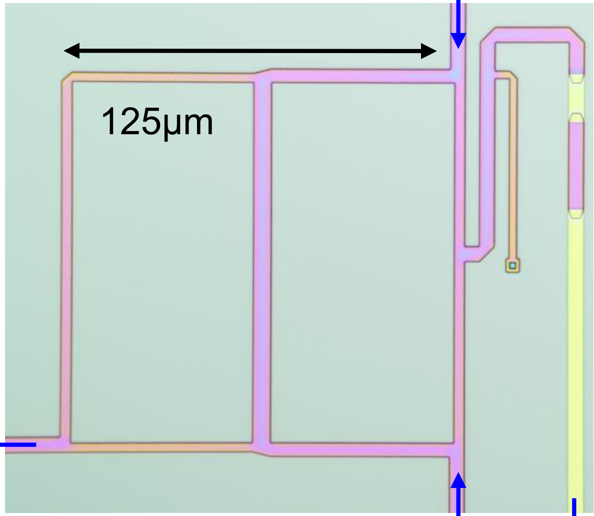
Approach taken by UC Berkeley (M. Meyers et al. 2006).

c A termination: Hybrid



As fabricated

From OMT probe 1

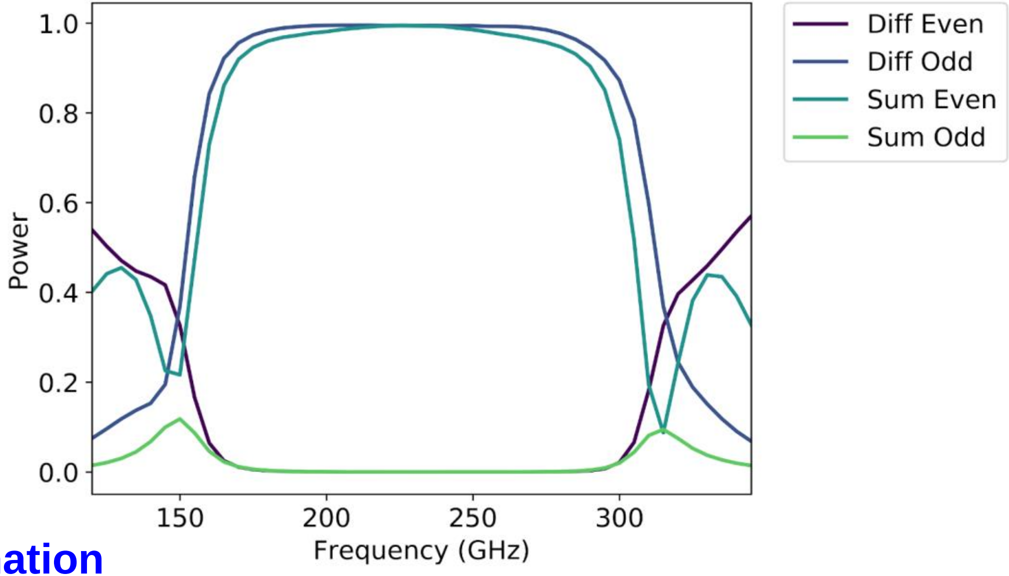


Differential output (TE11), to TES

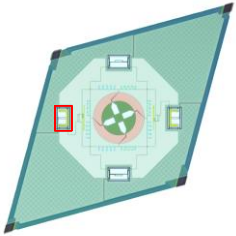
From OMT probe 2

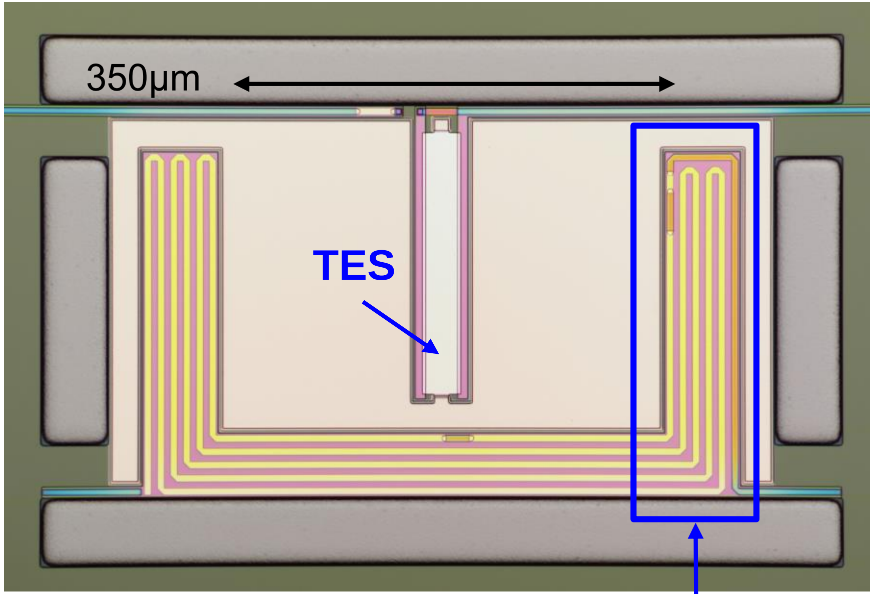
Summation output (TM10), dissipated on substrate

From 2.5D Sonnet simulation

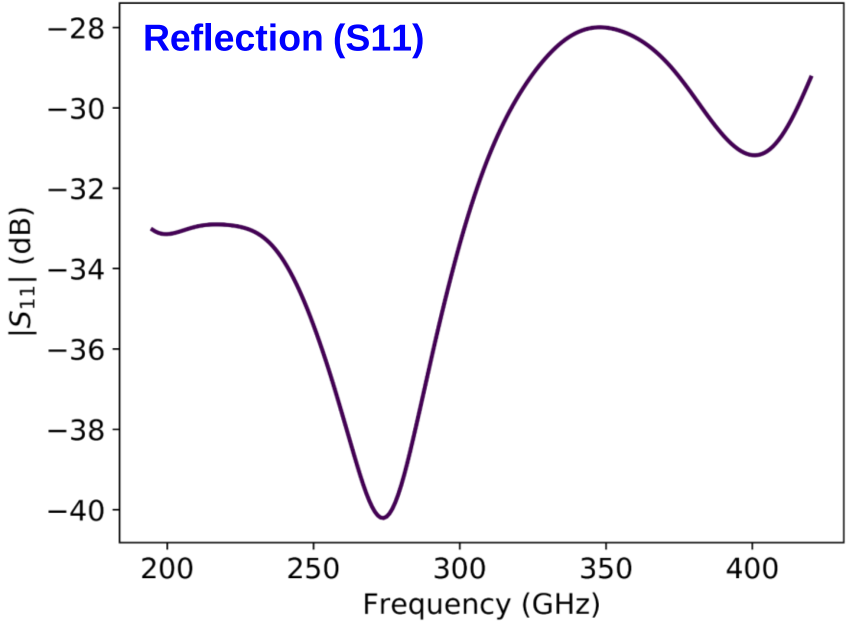


d A termination: Nb to Au transition and TES





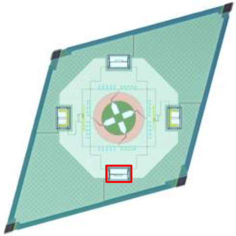
As fabricated

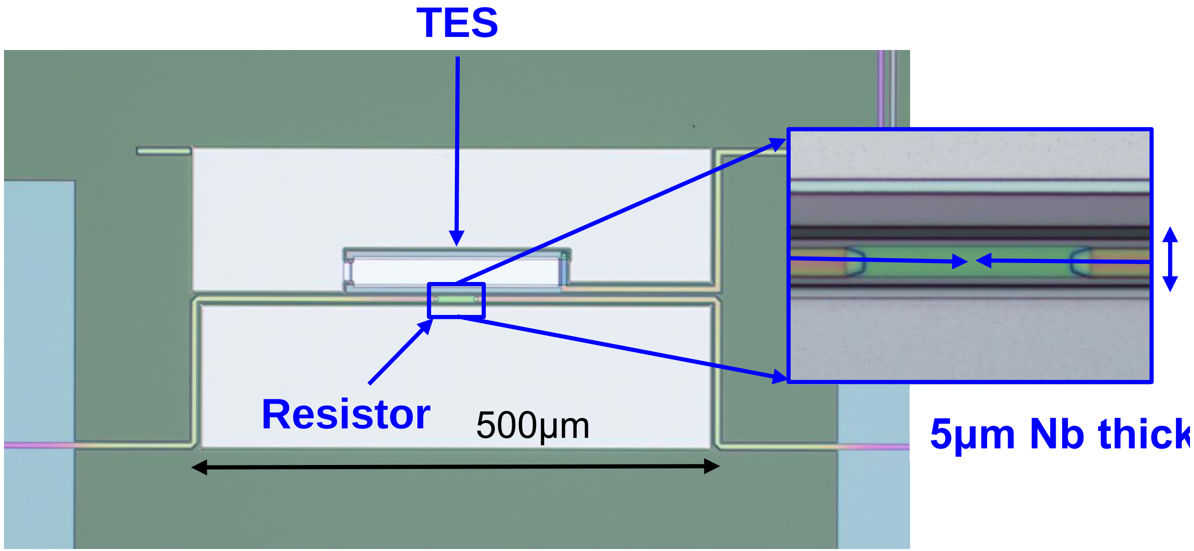


From Sonnet 2.5D simulation

Distributed resistor (Nb to Au transition)

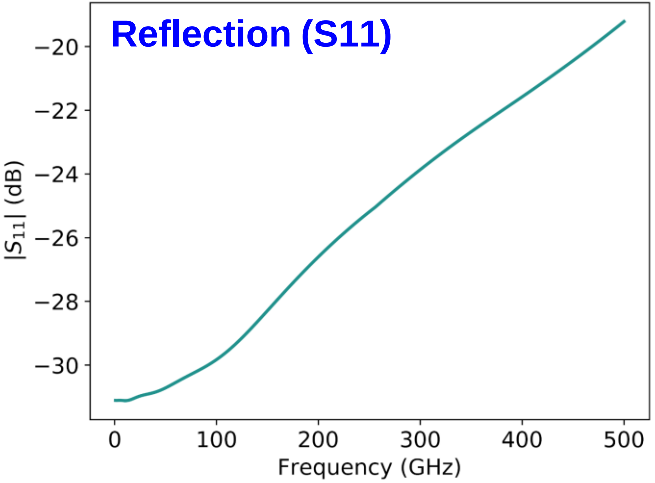
e B termination: Termination resistor and TES





As fabricated

Total impedance: 21.6Ω
Material: PdAu

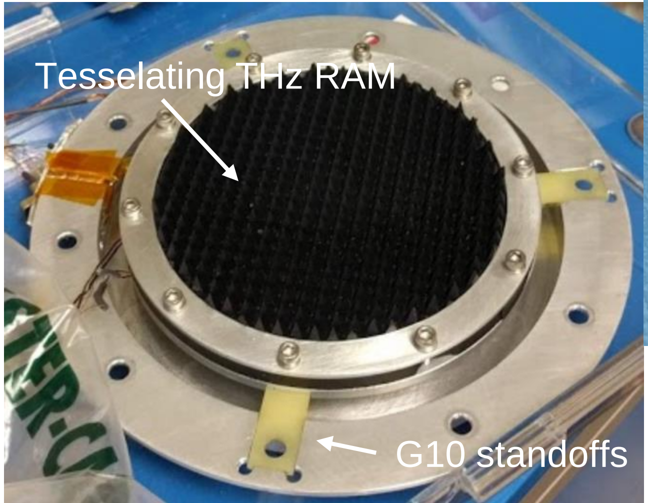


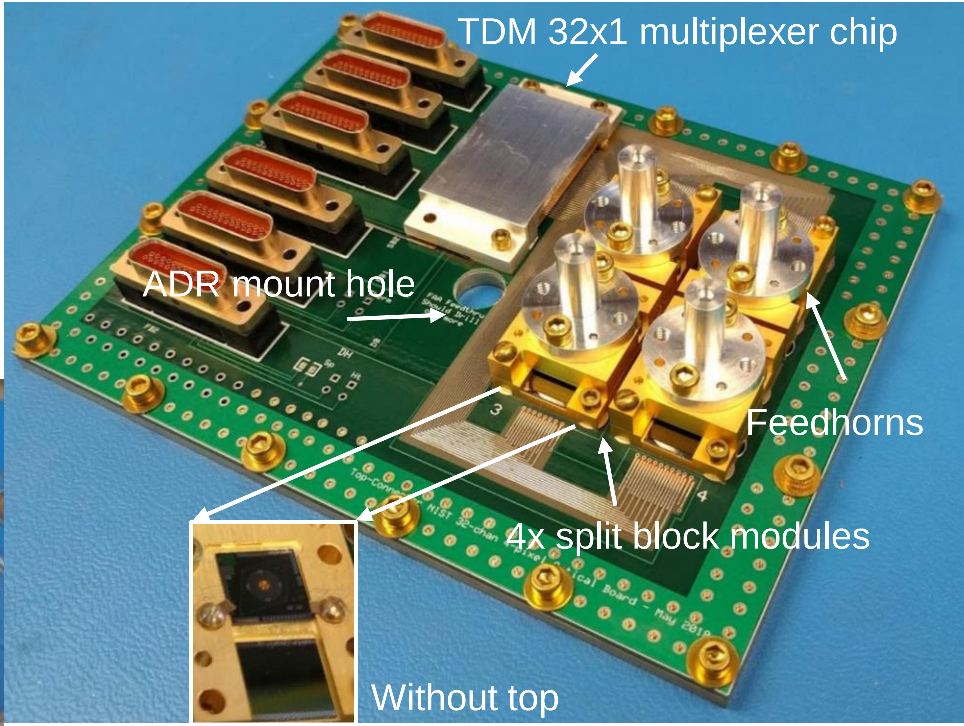
From Sonnet 2.5D simulation

Optical efficiency experimental setup

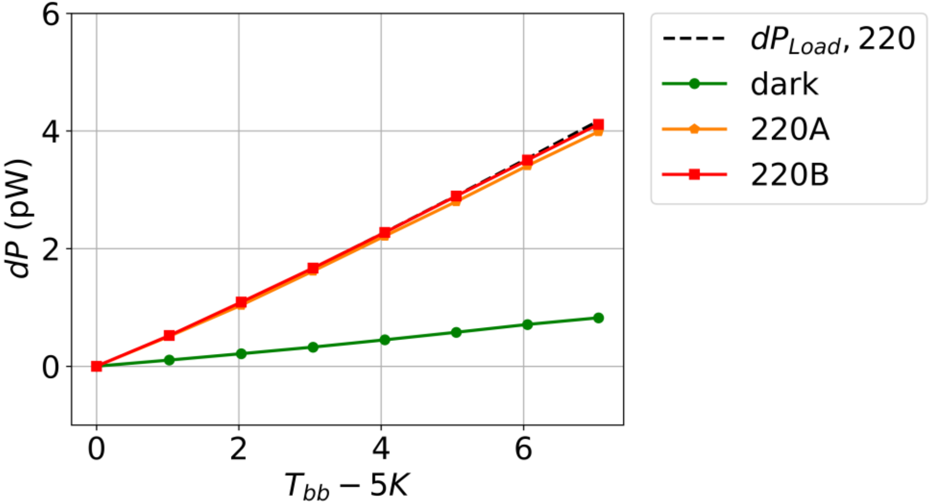
Optical efficiency determined by measuring power change in detectors as a function of temperature change of a cryogenic blackbody (lower left).

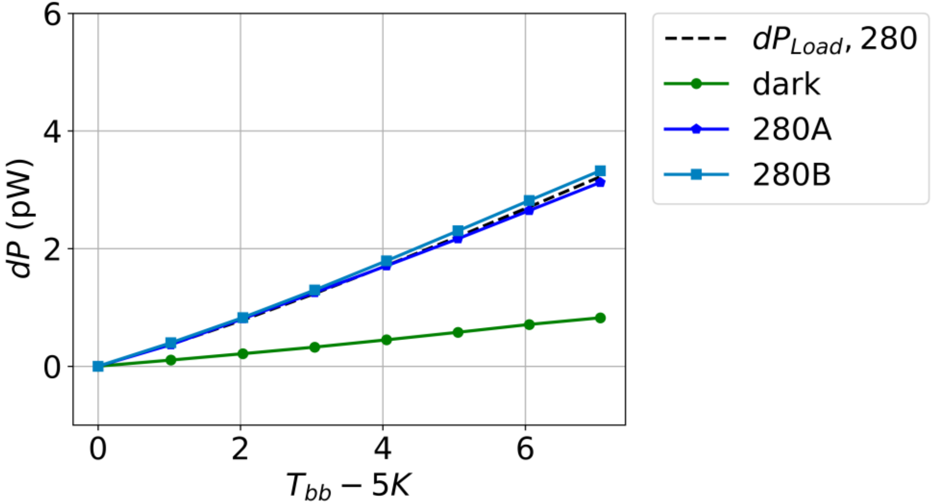
The 4-pixel test board is also shown (right).





dP vs. dT, 220 (left) and 280 (right)





dPload calculated for a single-mode includes simulated passbands and corrections for free space filter loss.

UHF optical efficiency

Type	Raw	With dark subtraction
220A	96.9% ± 1.4%	78.0% ± 2.2%
220B	99.7% ± 3.9%	80.5% ± 5.6%
280A	98.9% ± 3.8%	73.3% ± 3.7%
280B	105.4% ± 3.4%	79.8% ± 3.8%

Optical efficiency is defined as:

$$\eta = \frac{dP}{dP_{Load}}$$

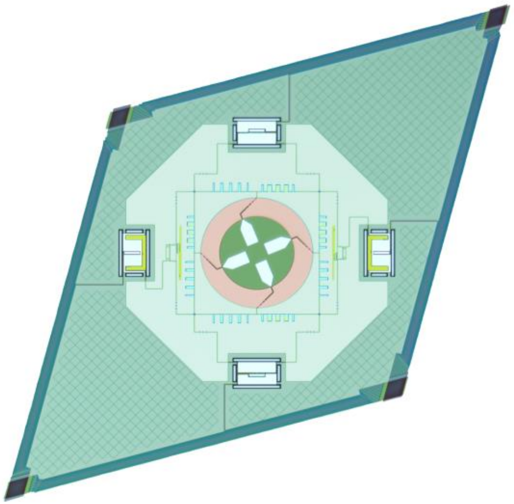
- **Our prediction of optical efficiency for our experimental setup, accounting for loss due to the diplexer and OMT, is 90.7% for 220 and 91.5% for 280.**
- In the table above, loss due to free space filters external to our feedhorns has been corrected for.
- Uncertainty is a quadrature error of N=21 (7 dT points and measured on 3 different days).

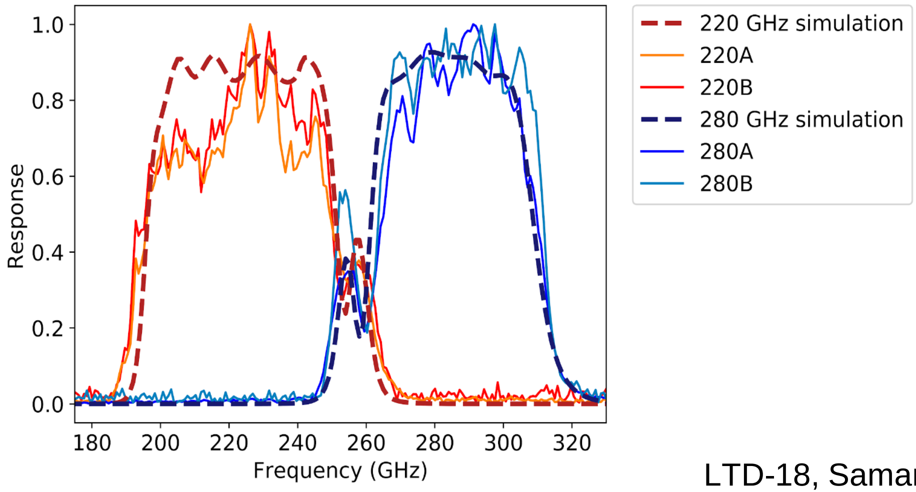
UHF optical efficiency summary

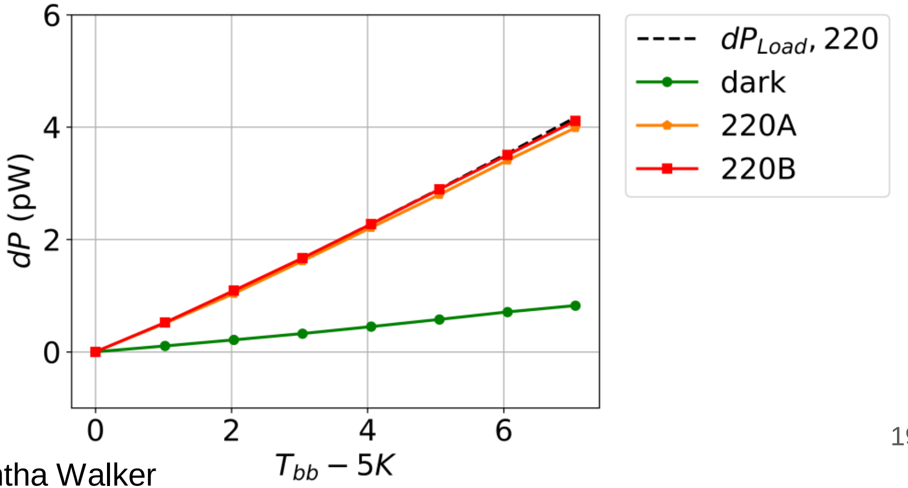
- Using either a hybrid tee and distributed resistor (A) or lumped termination resistor (B) for filtering multiple waveguide modes yields equivalent optical efficiency and passbands.
- The measured values for optical efficiency in the 220 and 280 GHz bands are about 11.5% and 15% lower than the expected values, respectively. This discrepancy might be explained by one or a combination of the following:
    1. Less coupling to the OMT than we expect because the waveguide gap is larger than 25μm above/below the probes.
    2. We are over subtracting power when we perform the dark subtraction. In dark subtraction, we assume the power coupled to a dark bolometer is the same as the direct pickup in the optical detectors.
    3. We actually do have 11.5% and 15% more loss in our horn/detector system.

Conclusions

1. We have demonstrated a working prototype of a multichroic feedhorn-coupled 220/280 GHz detector pixel.
2. Measured passbands match well to simulations and optical coupling is good.
3. After a second prototype, the UHF pixel will be implemented for arrays to be fielded in ground-based instruments for the Simons Observatory.







Acknowledgements

This work would not have been possible without my collaborators at NIST Boulder/CU Boulder and the University of Michigan.

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This work was supported in part by the NASA APRA program, grant #NNX17AL23G.

Extra Slides

Pload calculations

We peak normalize our passband simulations and calculate the theoretical loading for our detectors as:

$$P_{load} = \int_{\nu_1}^{\nu_2} d\nu \frac{h\nu}{e^x - 1} F_0(\nu) F_1(\nu) F_2(\nu)$$

$x = h\nu/kT$ and $F\_i(\nu)$, where i = 0,1,2 correspond to the peak normalized simulated passband, the 14icm filter response, and the 11icm filter response.

Pload was simplified using the assumption that the spectral radiance is described by a Planck blackbody and our detectors are single-moded.