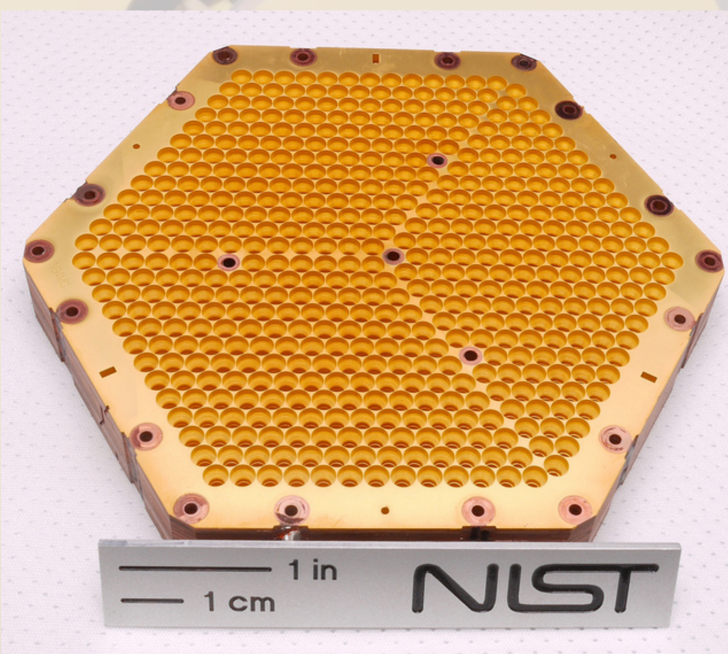
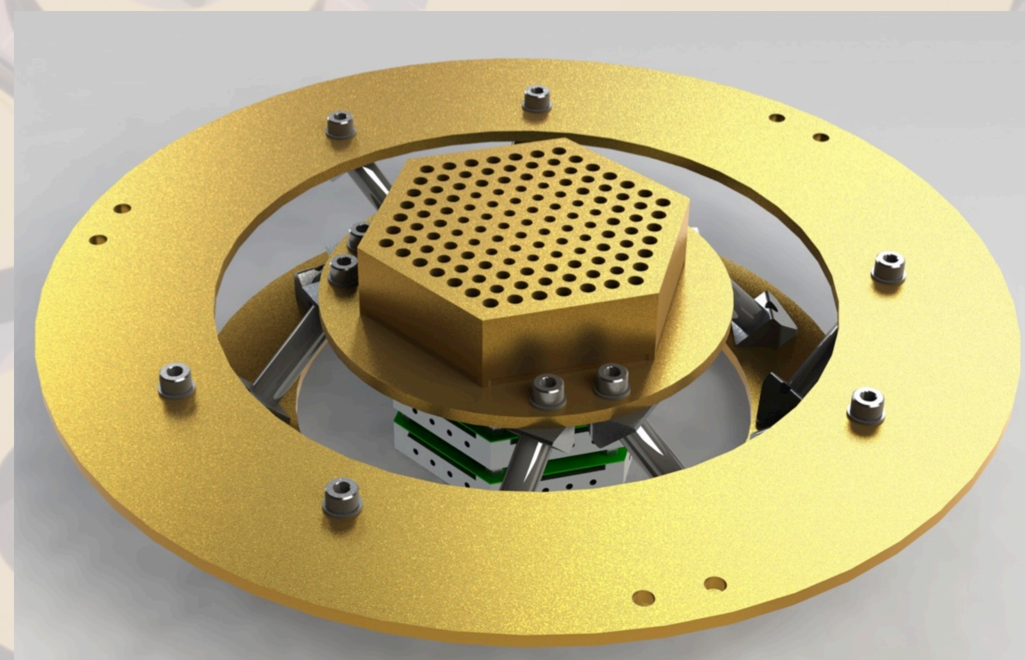
Feedhorn-Coupled TES Polarimeter Arrays

Hannes Hubmayr
NIST
B-modes from Space
Dec 16, 2015





Developed by a large fraction of US CMB community

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CMB power spectrum summary

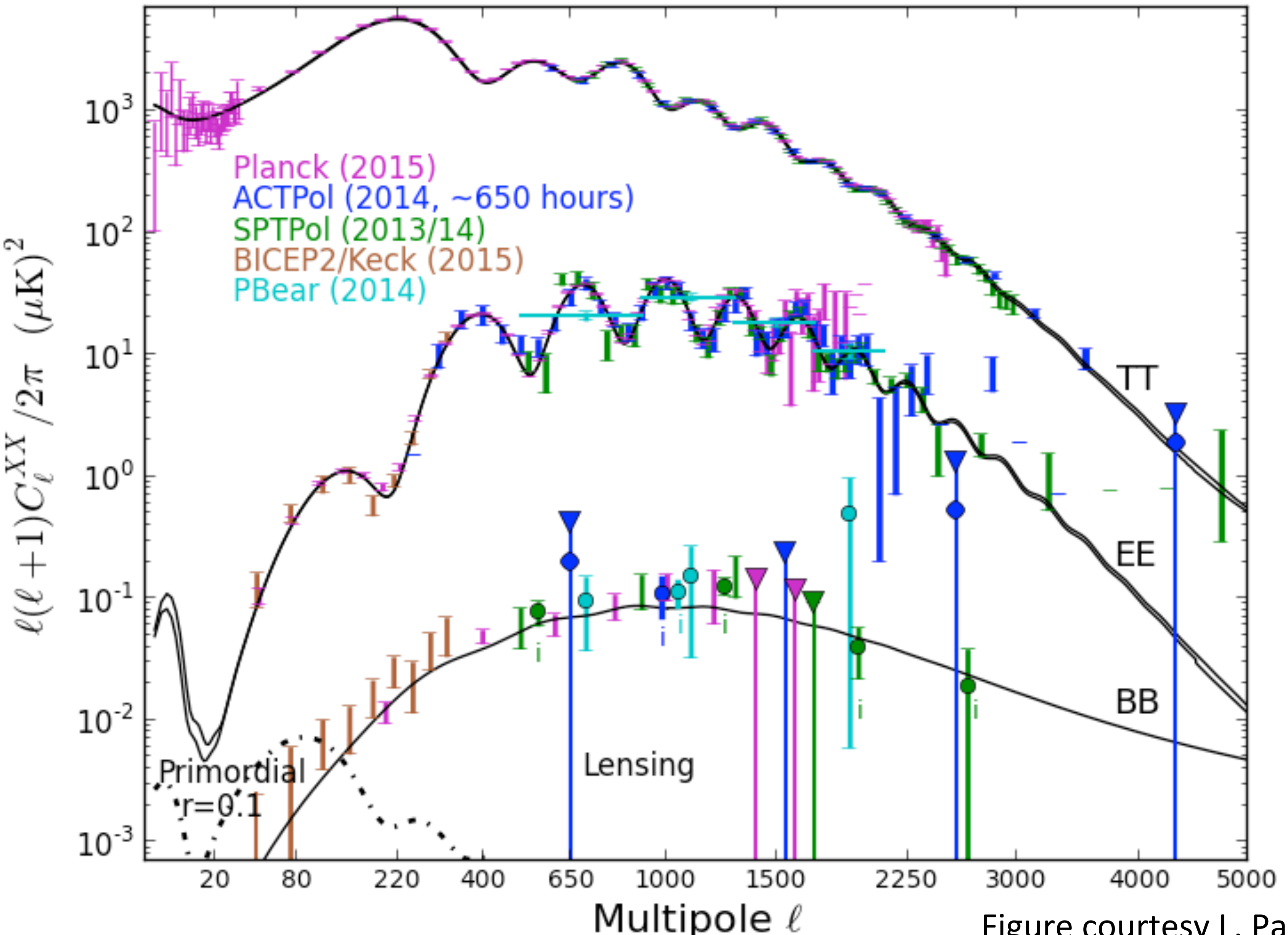
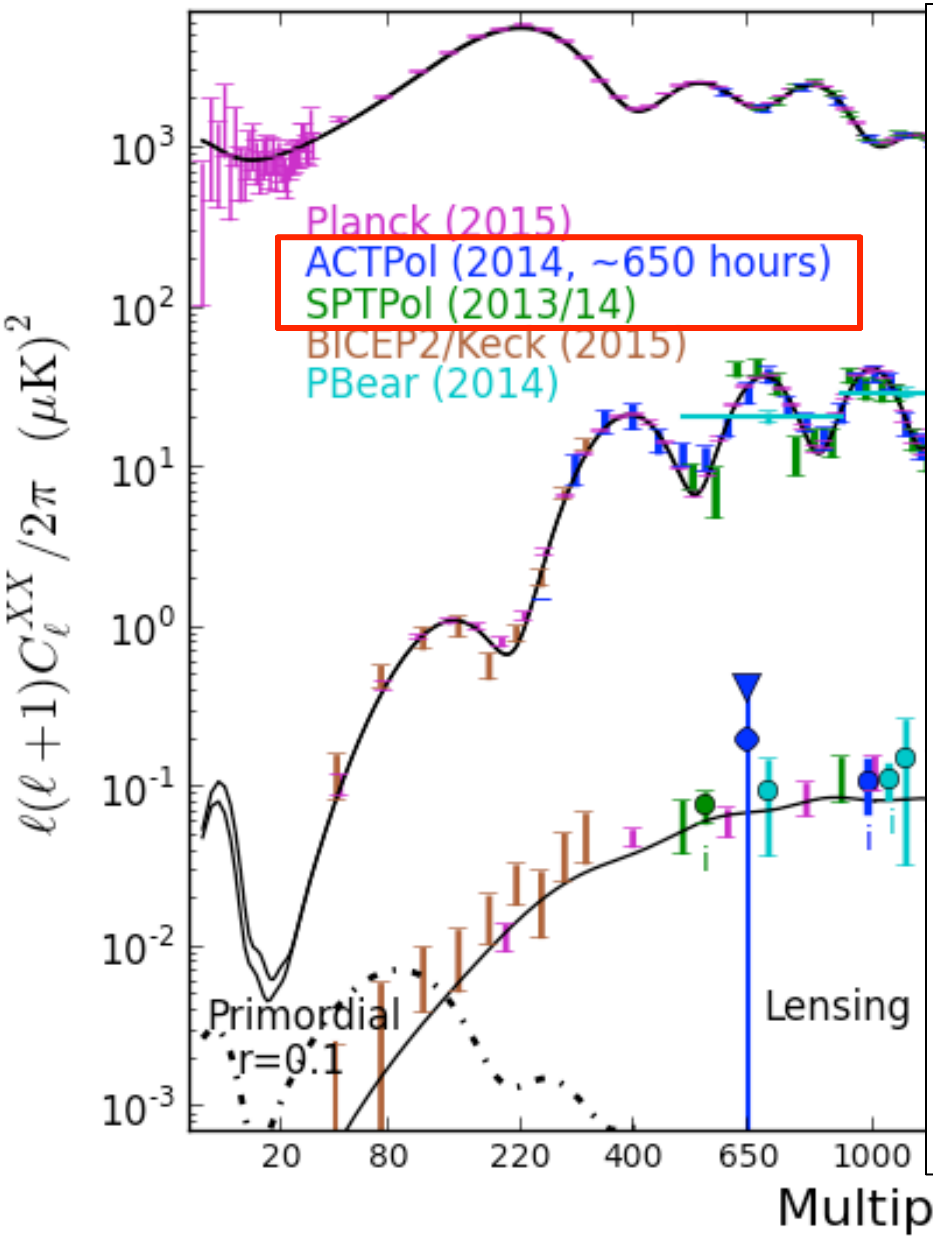
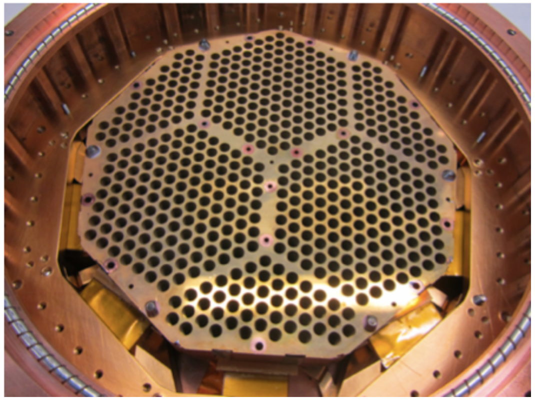


Figure courtesy L. Page

CMB power spectrum summary



Atacama Cosmology Telescope Polarimeter (1of 3 arrays)



South Pole Telescope Polarimeter

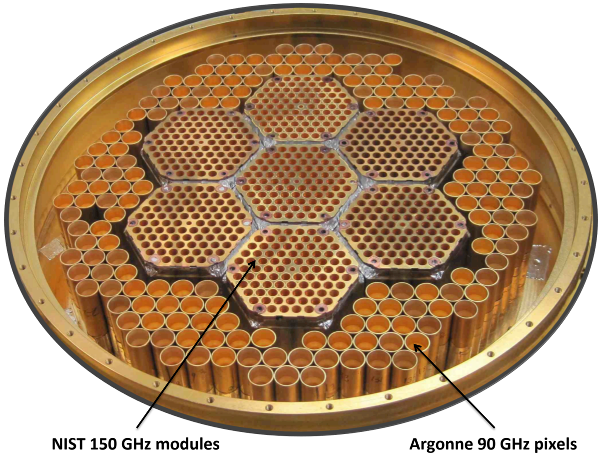
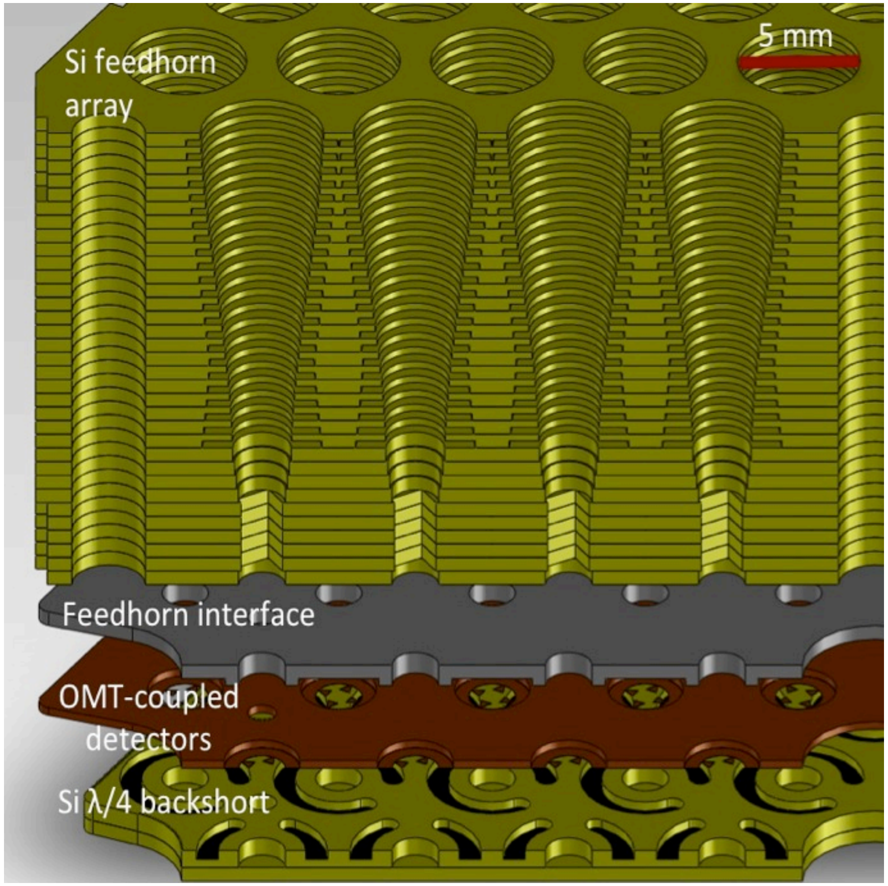


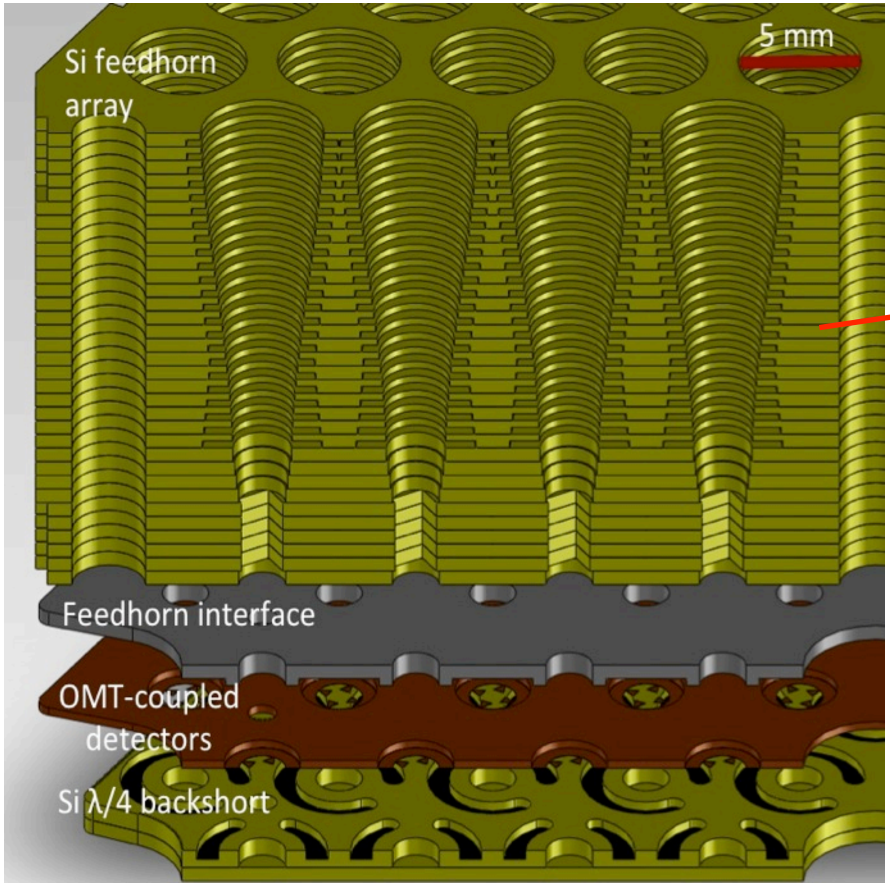
Figure courtesy L. Page

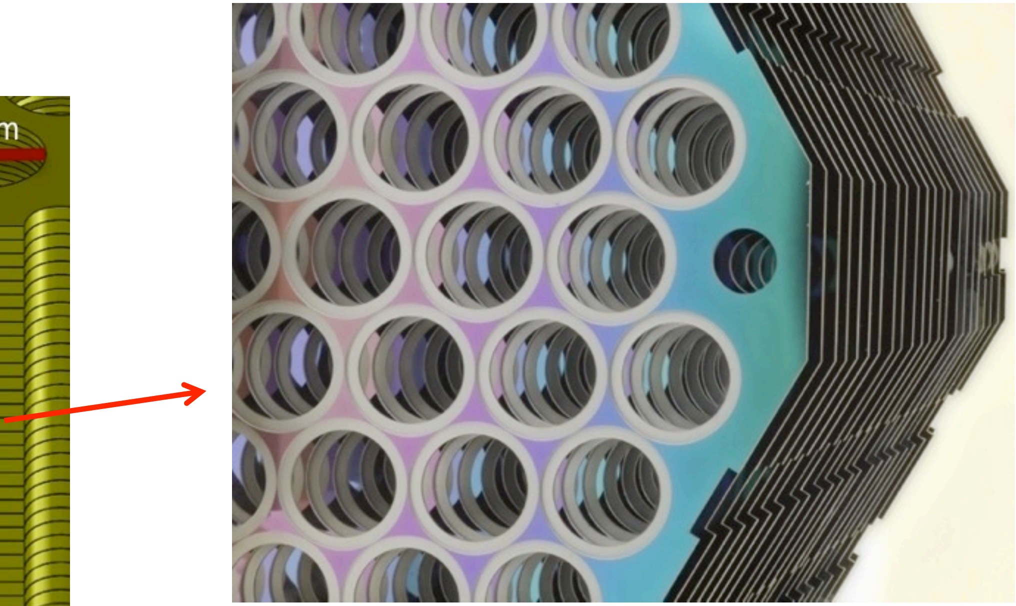
Silicon feedhorn-coupled arrays



Yoon et al. *AIP* 2009
Hubmayr et al. *JLTP* 2012

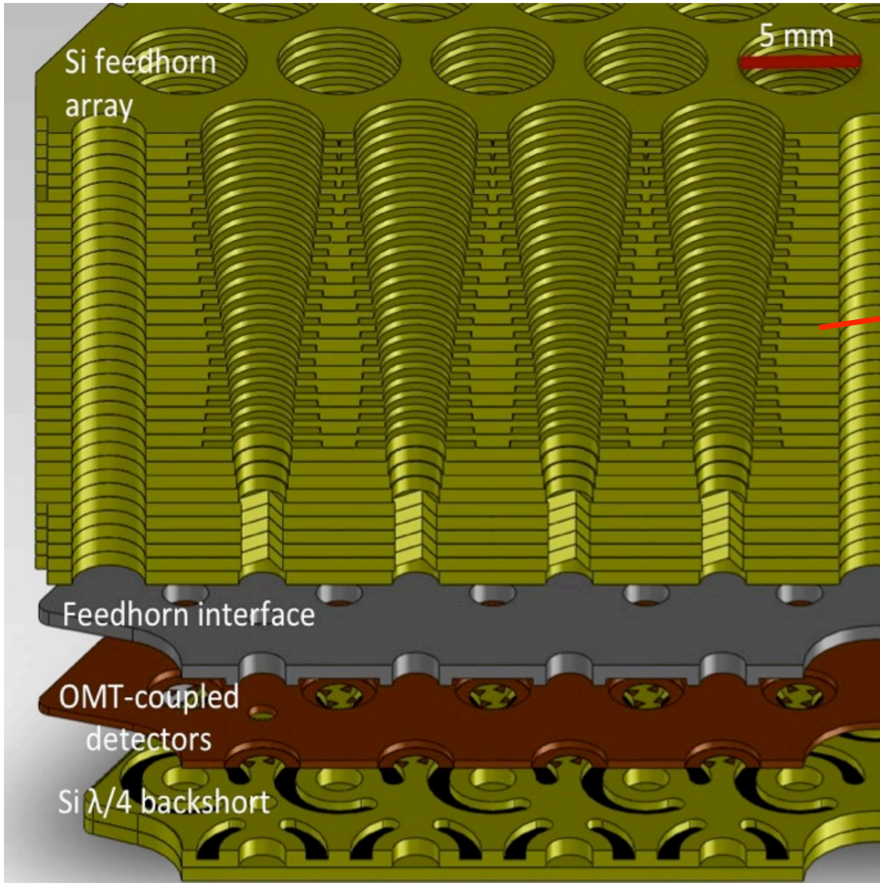
Silicon feedhorn-coupled arrays

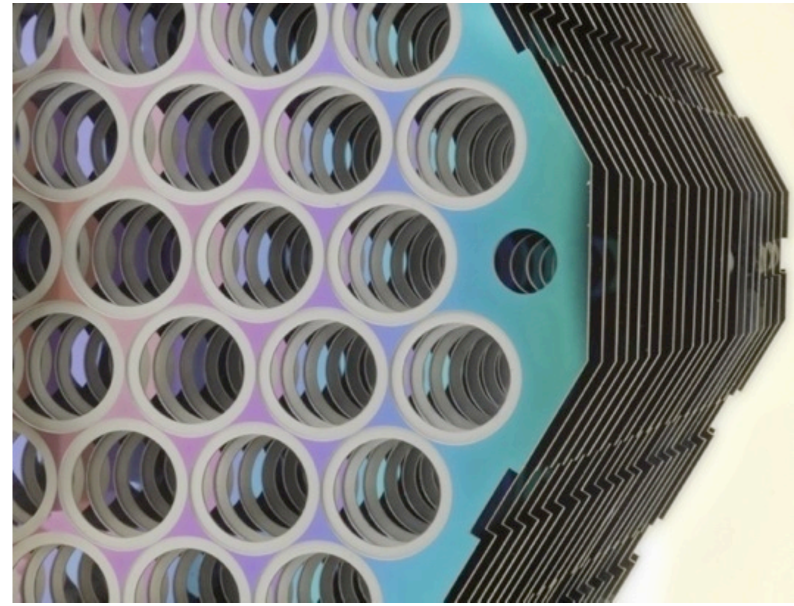




Yoon et al. *AIP* 2009
Hubmayr et al. *JLTP* 2012

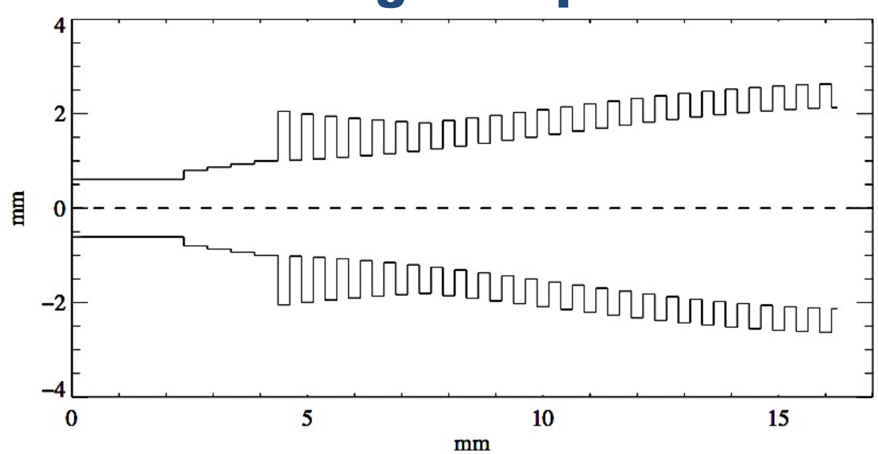
Silicon feedhorn-coupled arrays



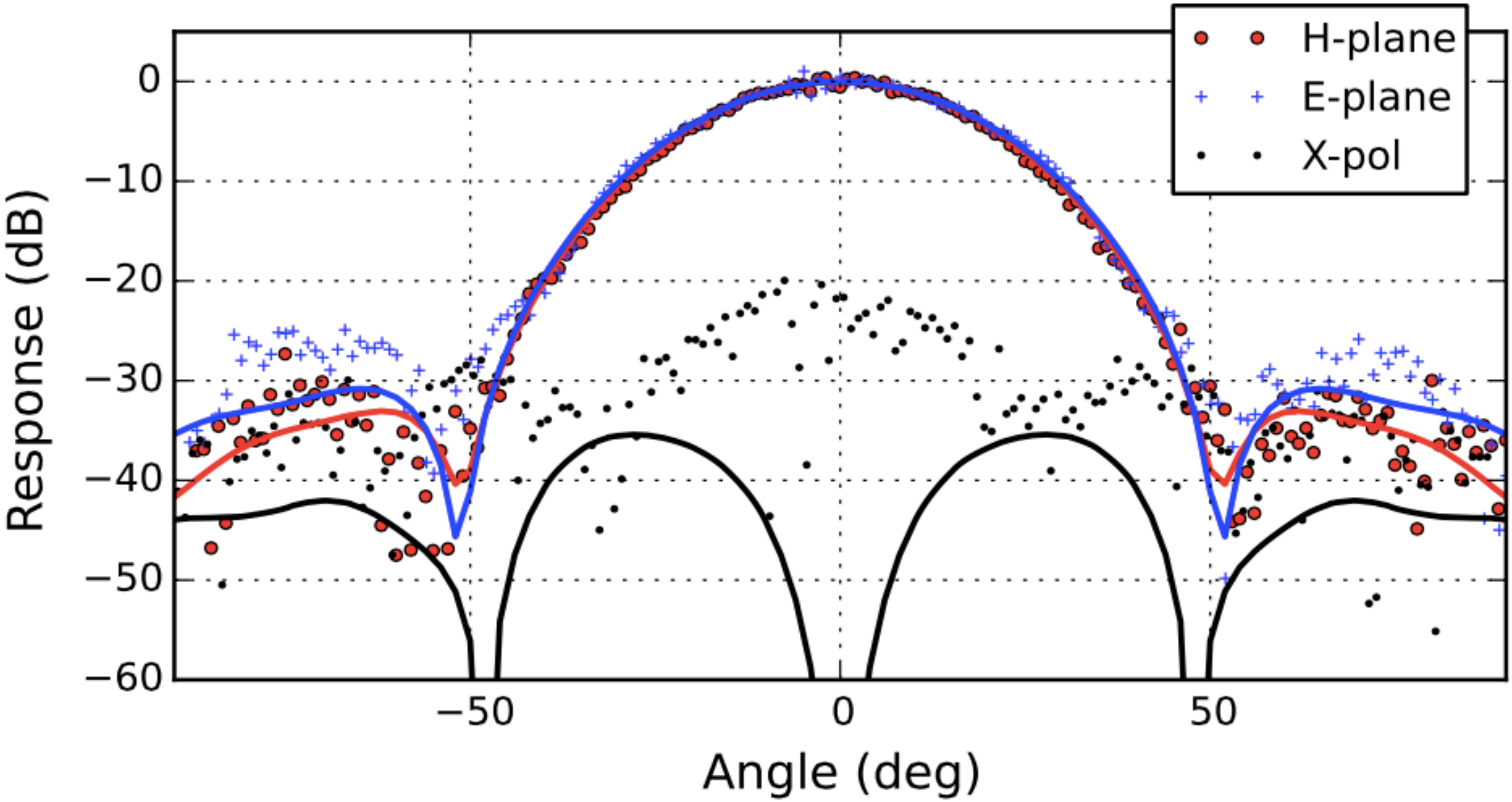


Yoon et al. *AIP* 2009
Hubmayr et al. *JLTP* 2012

corrugation profile

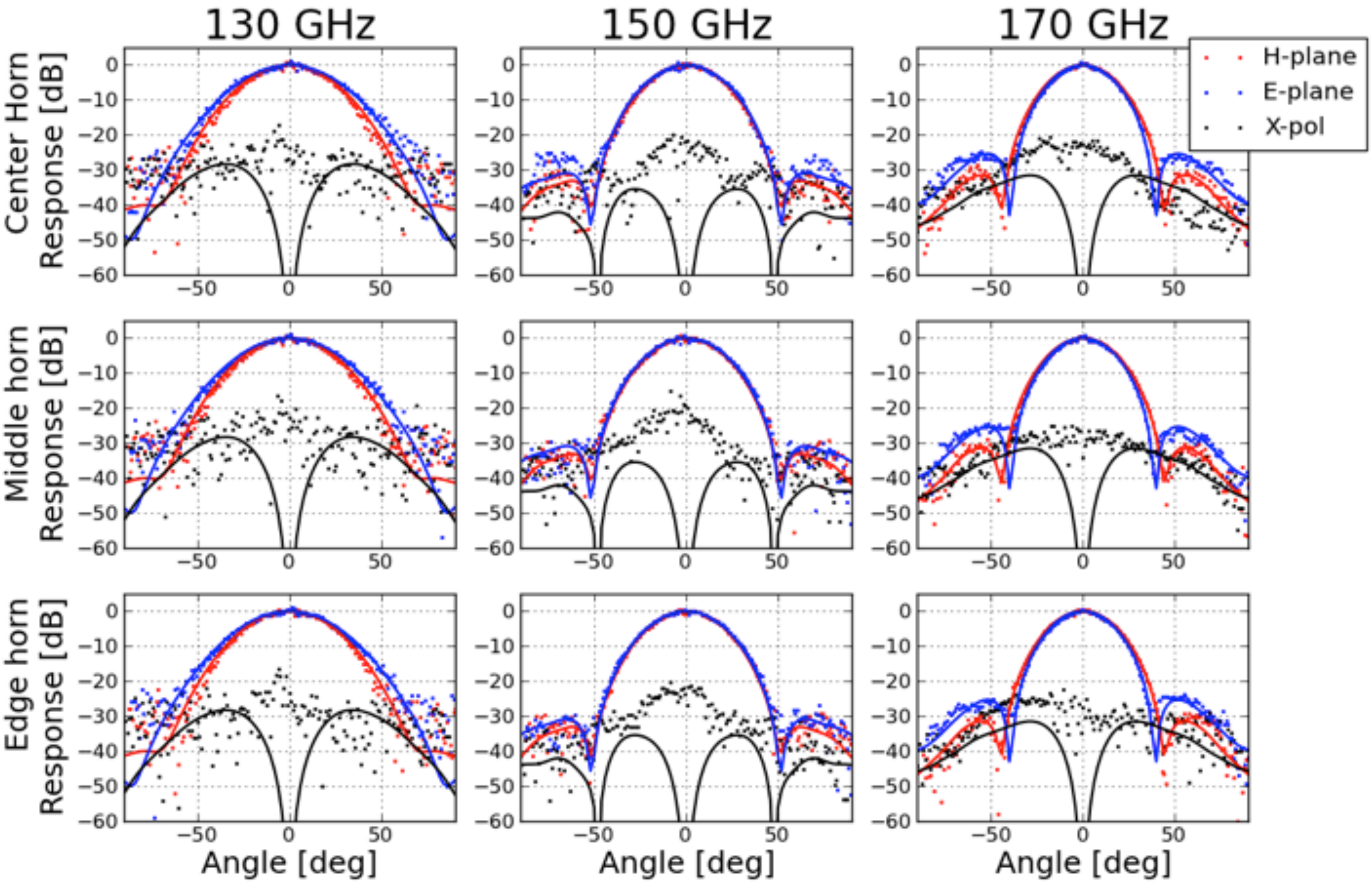


Silicon feedhorn-coupled arrays

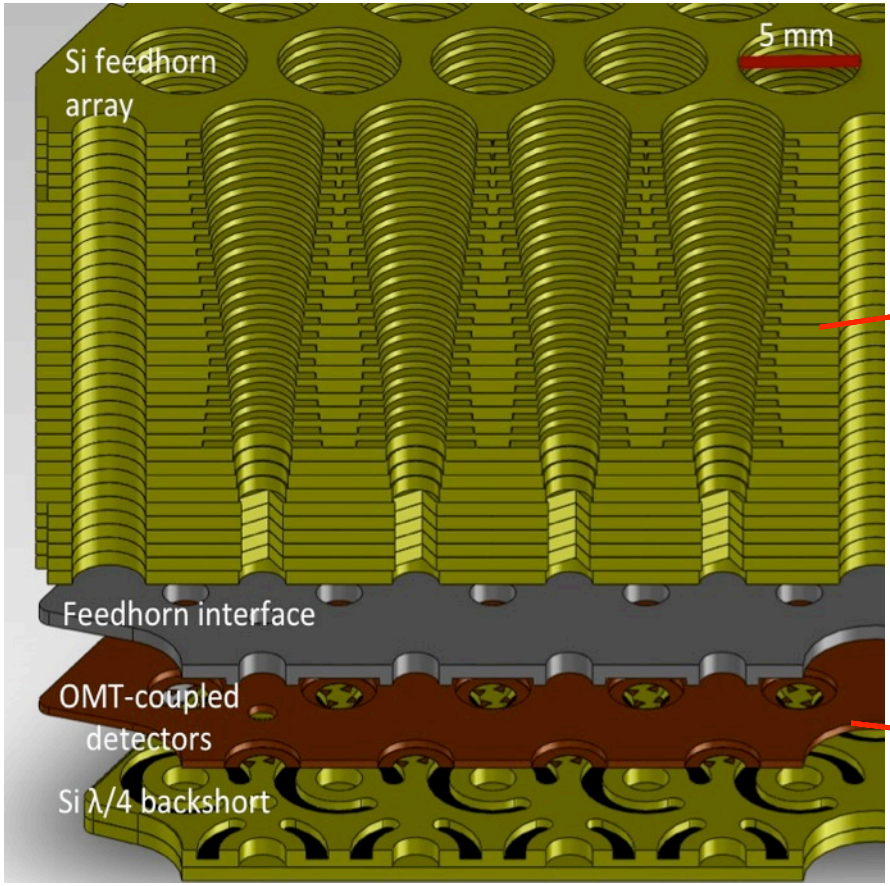


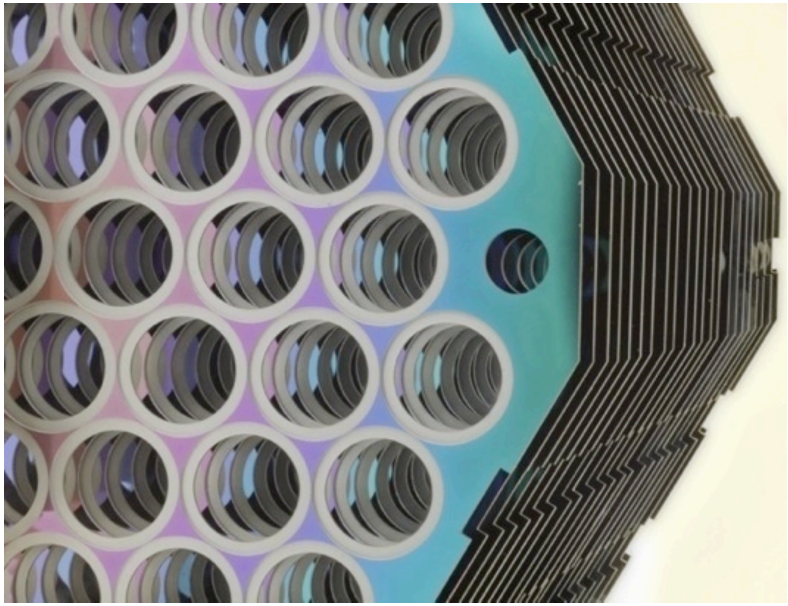
Hubmayr et al. *JLTP* 2012

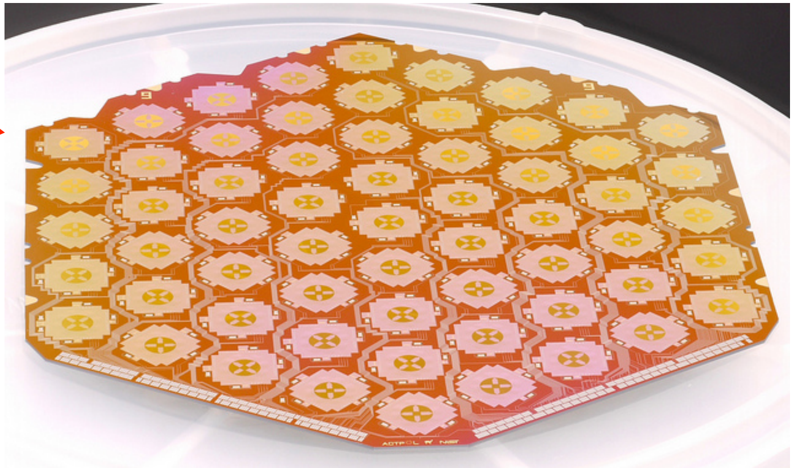
Silicon feedhorn-coupled arrays



Silicon feedhorn-coupled arrays







Yoon et al. *AIP* 2009
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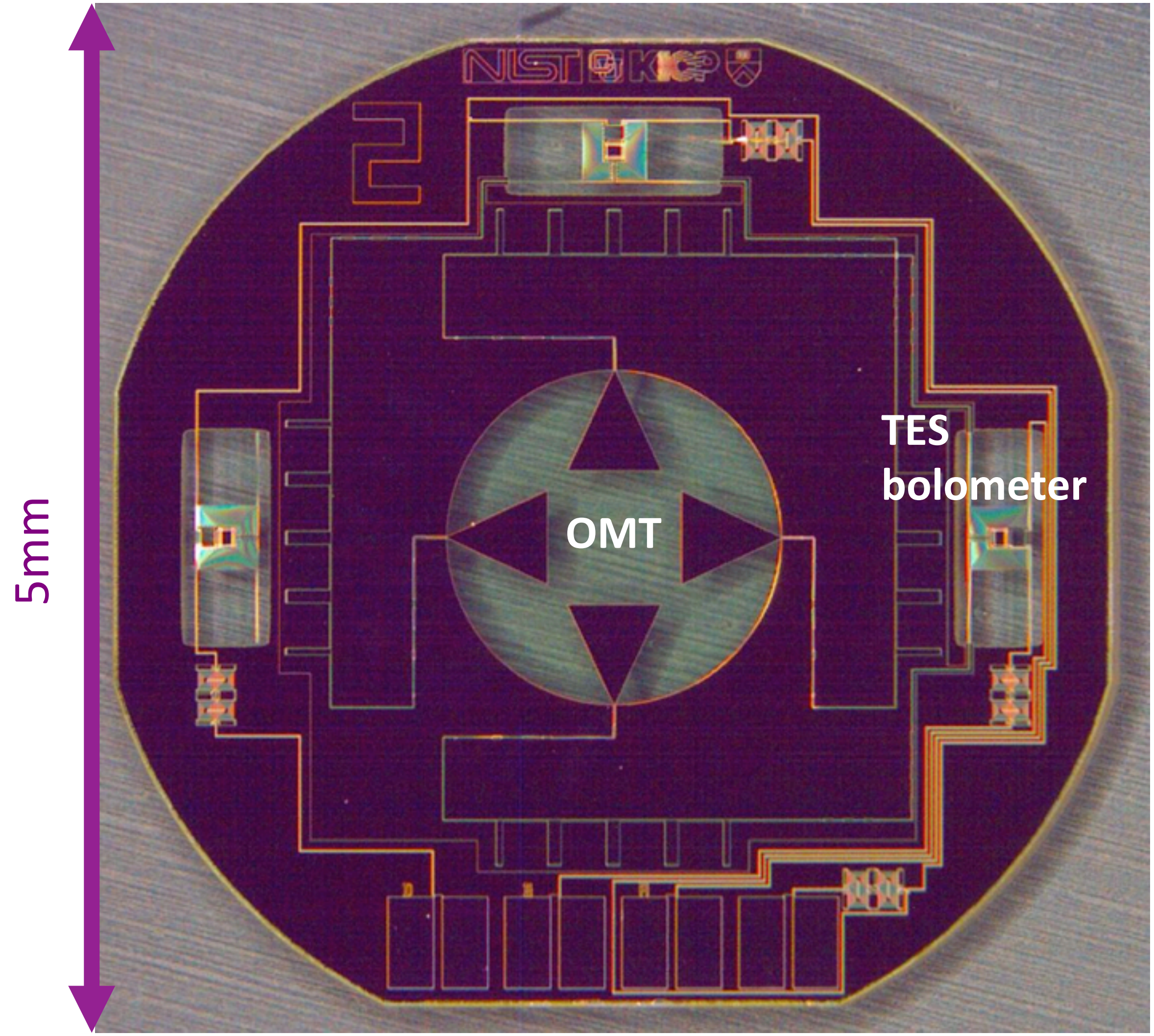
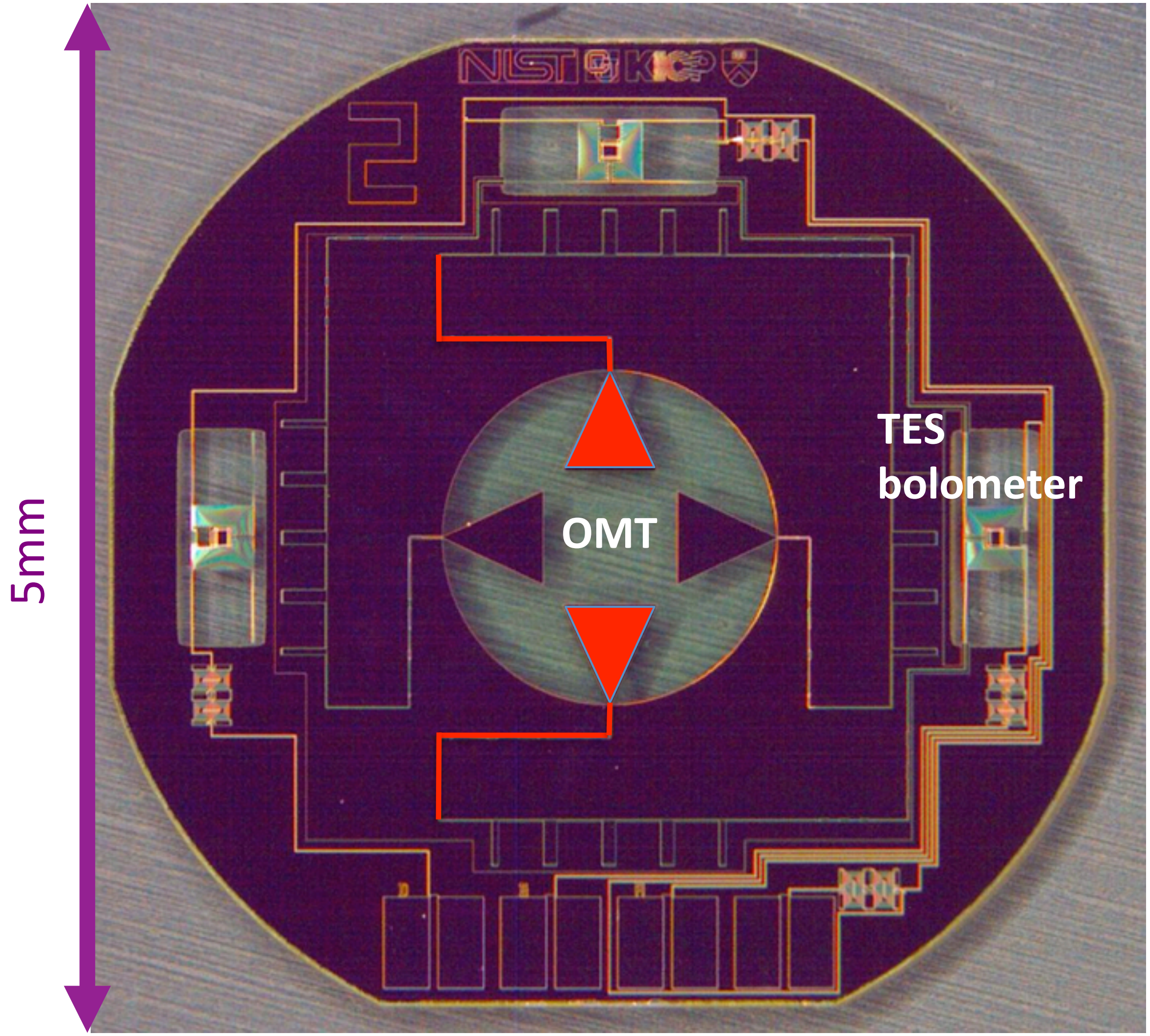
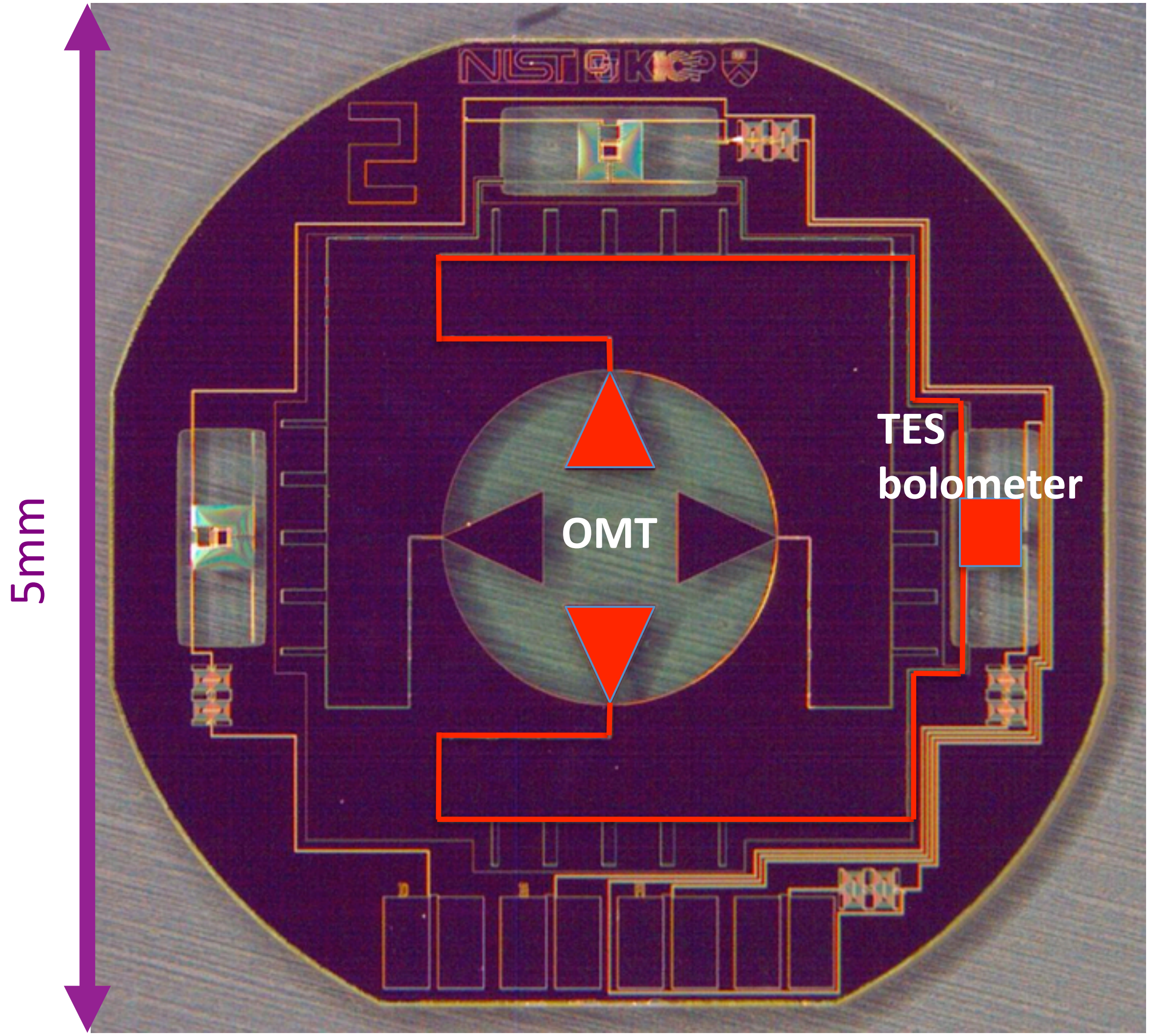
Detection concept



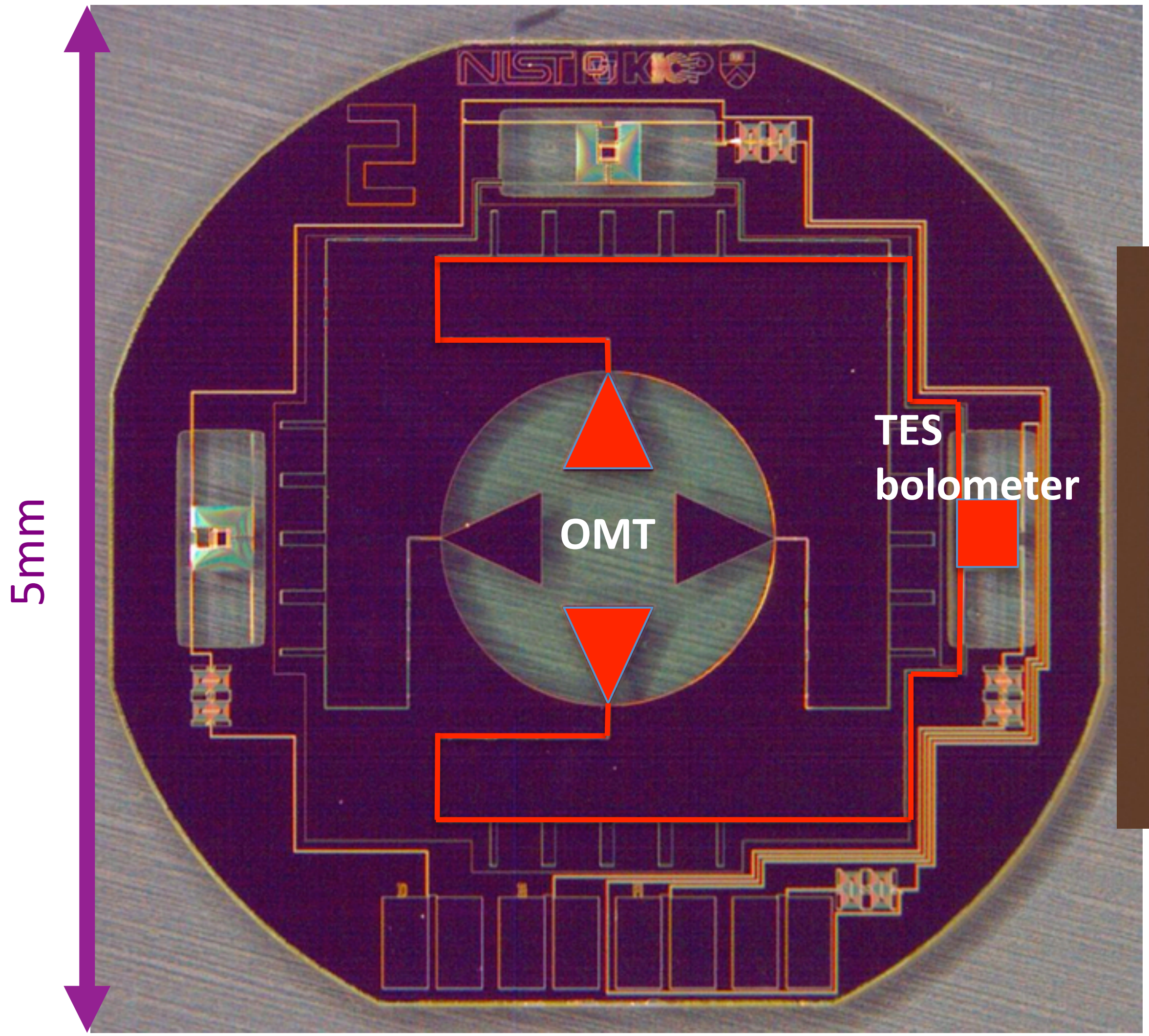
Detection concept

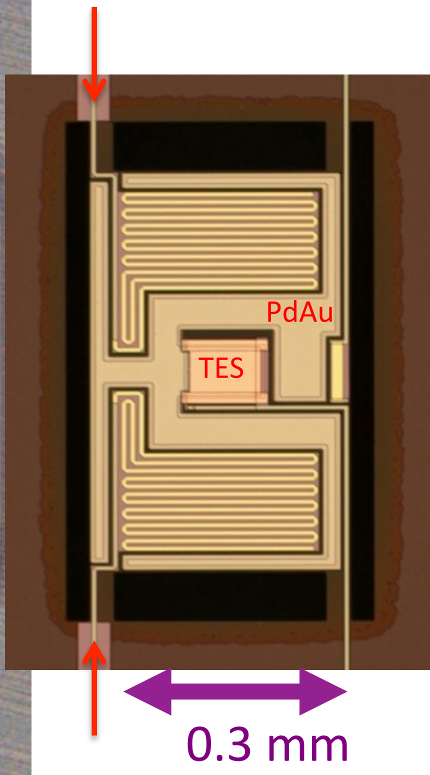


Detection concept

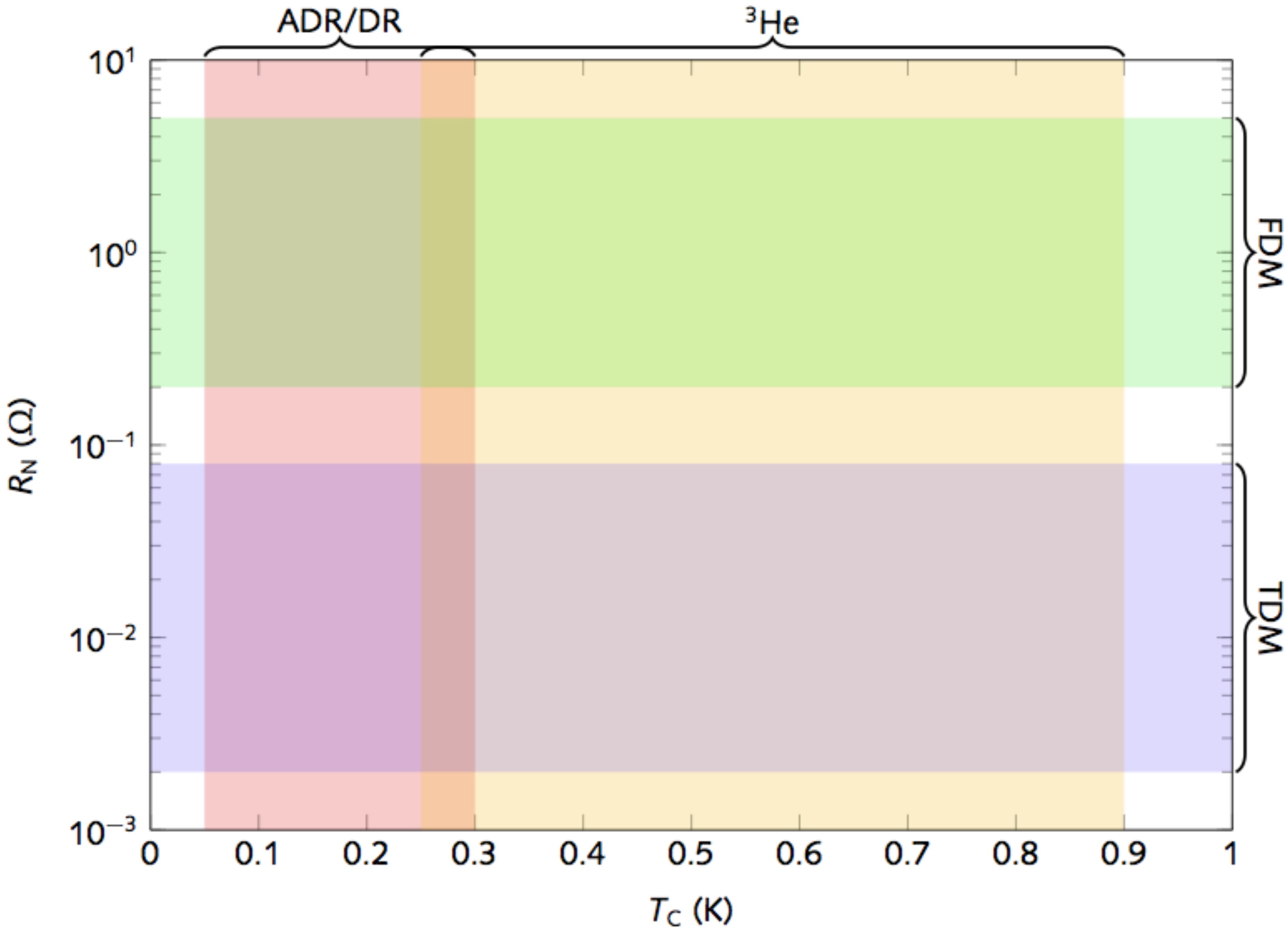


Detection concept

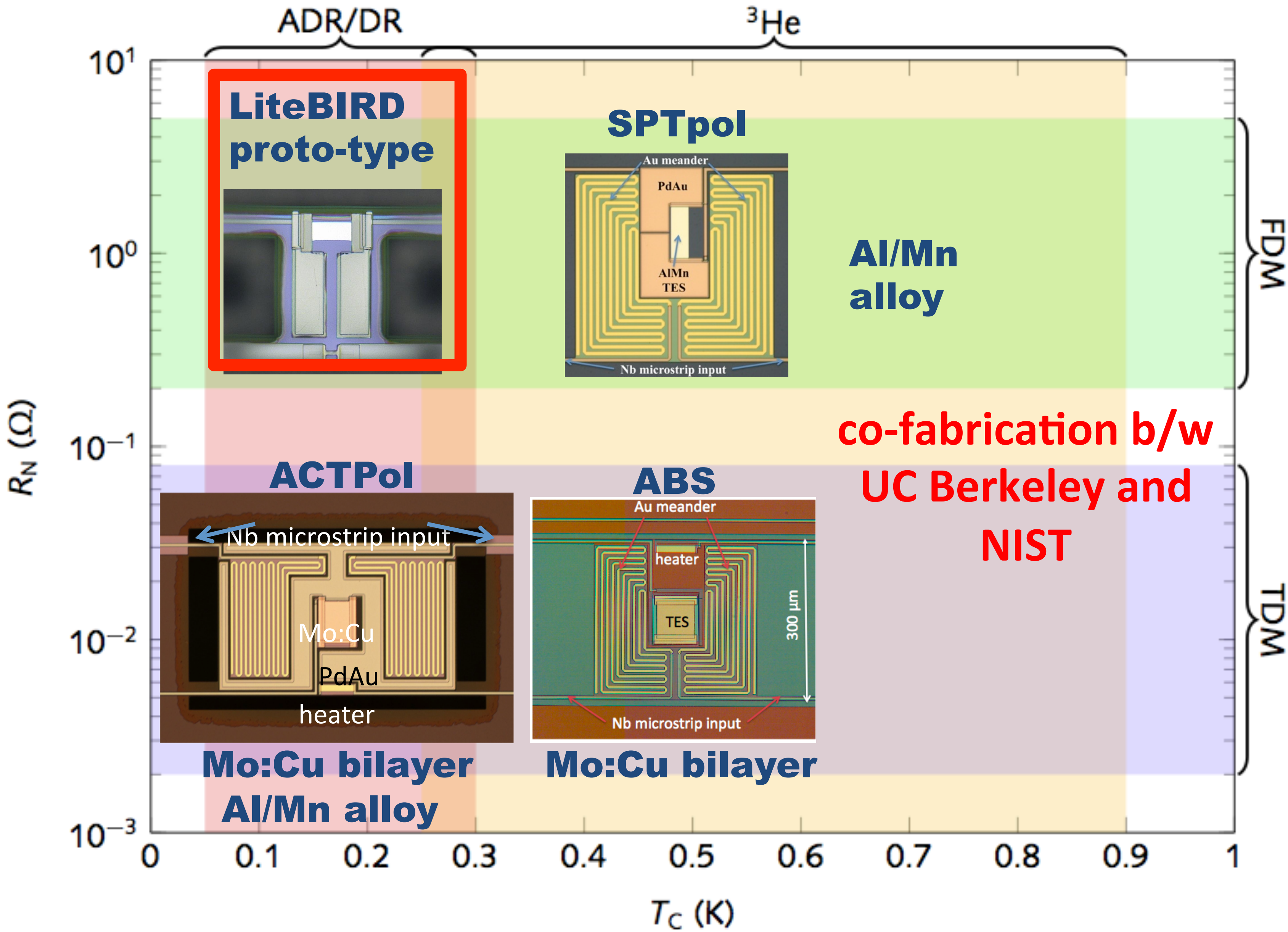




TES parameters driven by T_b and readout



TES parameters driven by T_b and readout



Advantages

- Flexible
  - couples to variety of telescope optics
  - accommodates variety of T_{bath}, multiplexing technologies, & loading conditions
  - band definition
    - waveguide + freespace filter
    - on-chip filtering
- Frequency scalable
  - antenna and waveguide size scales with wavelength, rest of circuit remains the same
  - no fabrication tolerance issues moving above 150 GHz
- Low Systematics
  - near Gaussian shaped beams
  - frequency independent polarization angles
  - natural RF shielding
  - no AR coating required

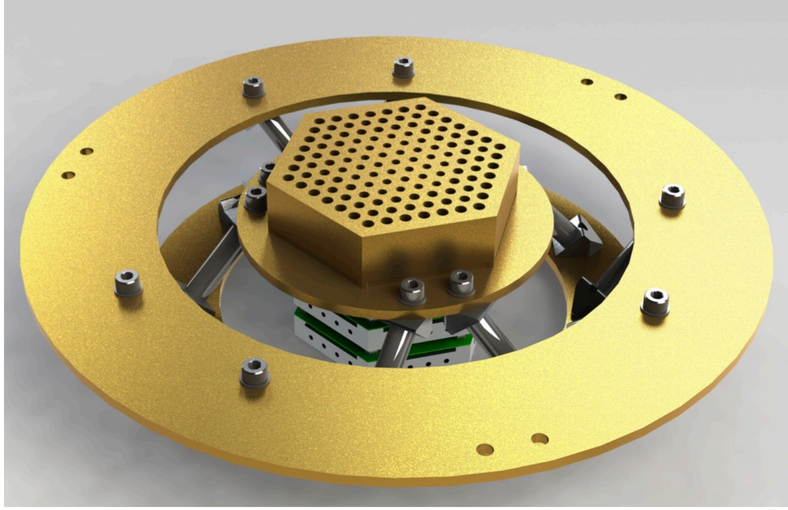
Preparing for LiteBIRD

Independent development items beneficial for LB

- Fabrication development: 150mm wafers and simplified process flow
- Scaling to higher frequency bands
- Deployment on balloon

Directed efforts

- TES bolometers optimized for space
- radiation tolerance testing

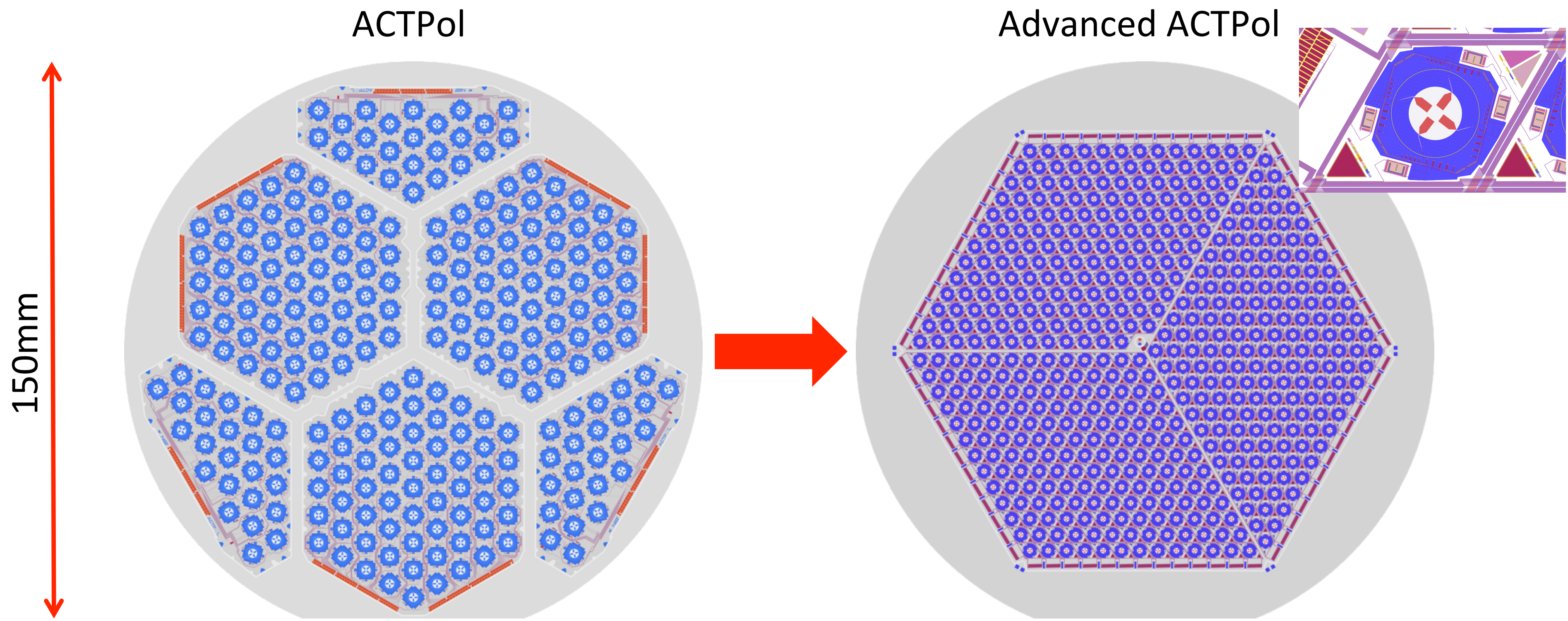


	Band Centers (GHz)	Detector Count	Noise Performance ($\mu K\sqrt{s}$)
HF	280	74	8.1
	337	108	8.1
	402	72	15.3

NIST Boulder Cleanroom

Used to provide readout for 30,000 mm/sub-mm - wave TES channels

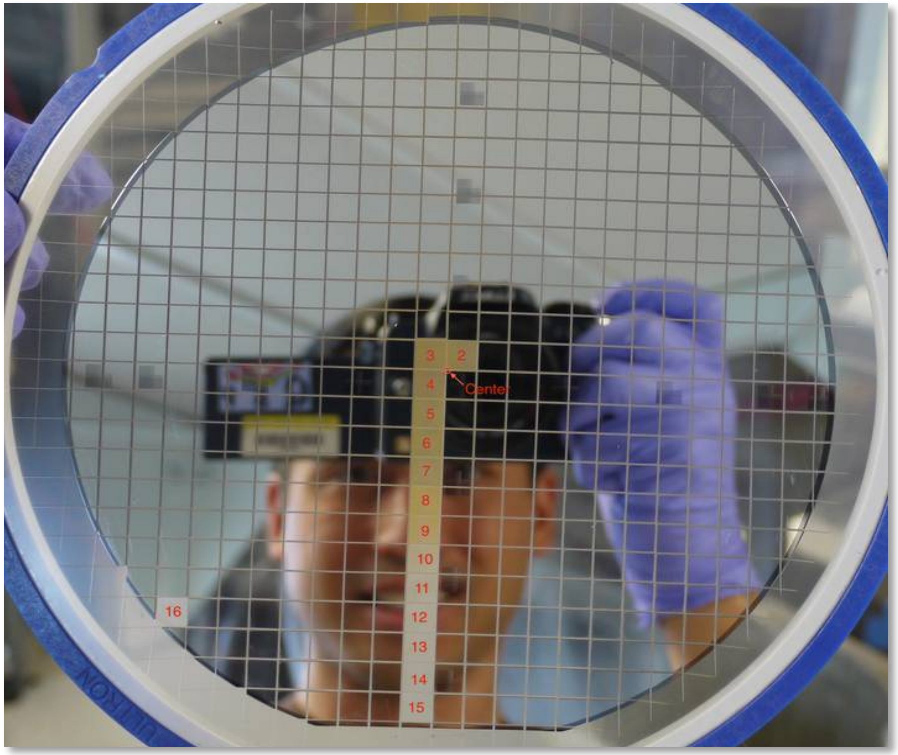
Fabrication -> make it simpler

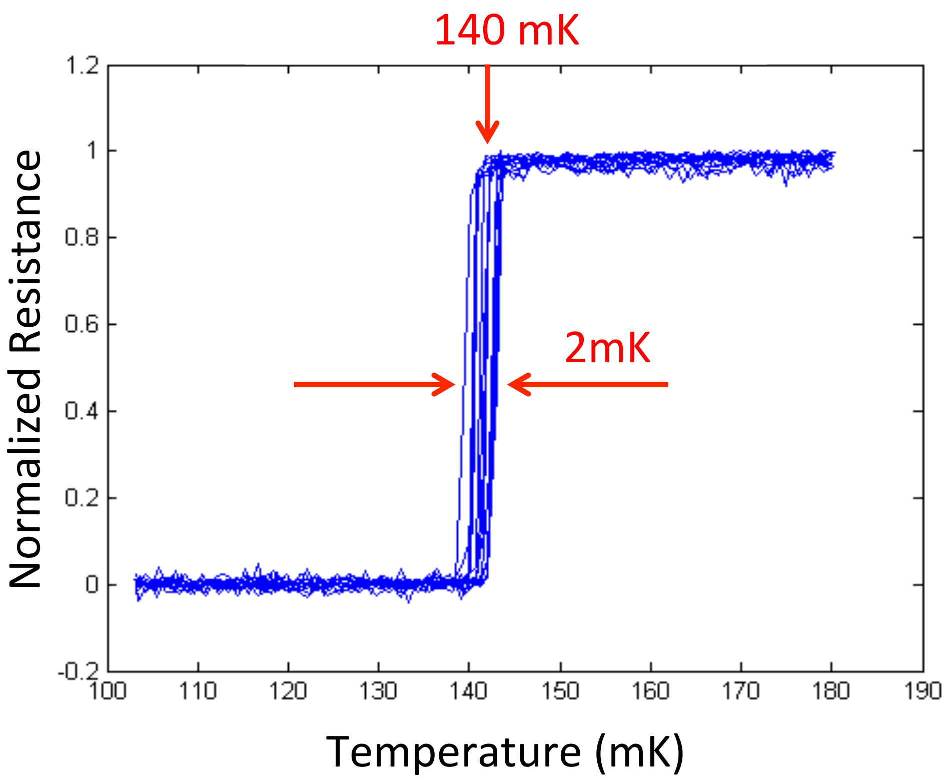


- 150mm wafer diameter -> make fewer wafers
- All stepper defined lithography -> higher yield, faster to produce
- AlMn sensors -> uniformity + fewer fabrication process steps
- Removed two fabrication layers
- 70% increase in mapping speed in one ACTPol 90/150 array to one AdvACT 90/150 by increased packing density alone

S.M. Duff et al. *JLTP* 2015

Spatially uniform AlMn films

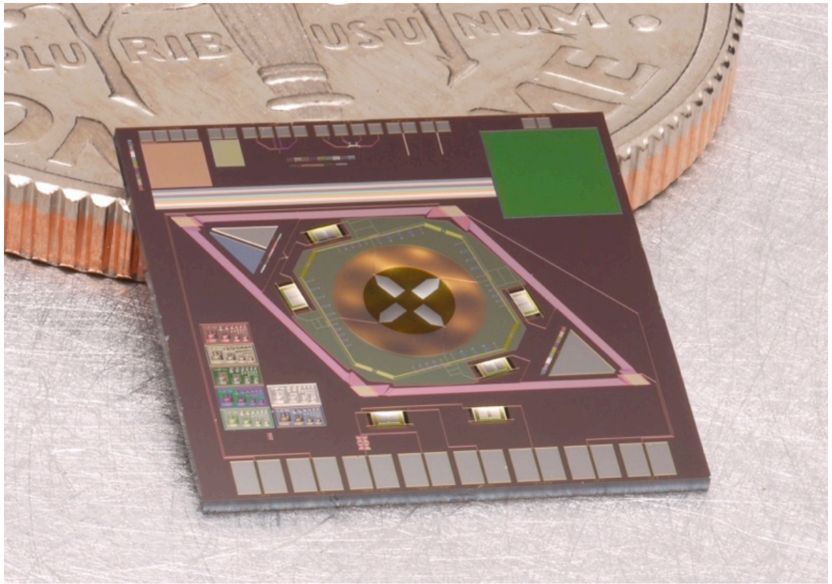


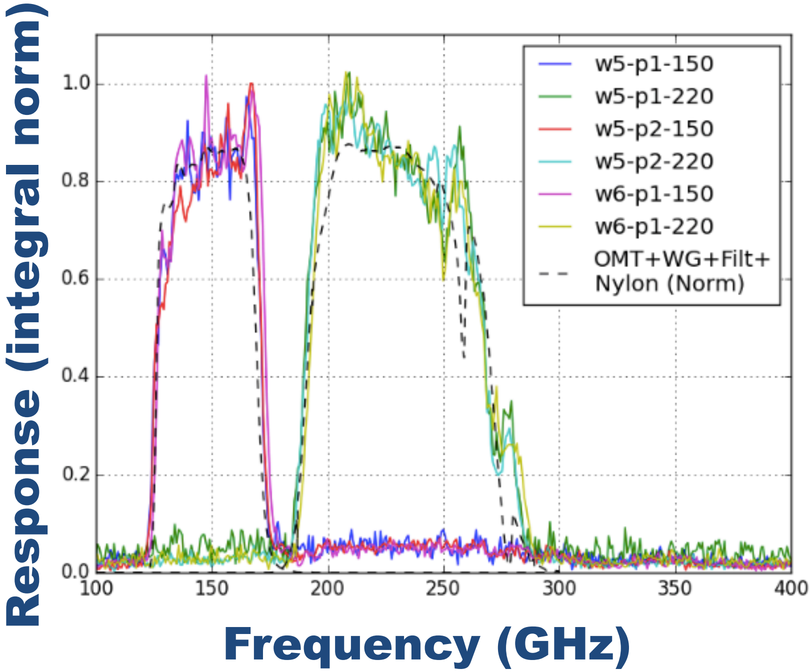


D. Li et al. *JLTP* 2015

2 mK peak-to-peak spread across a 150 mm diameter wafer

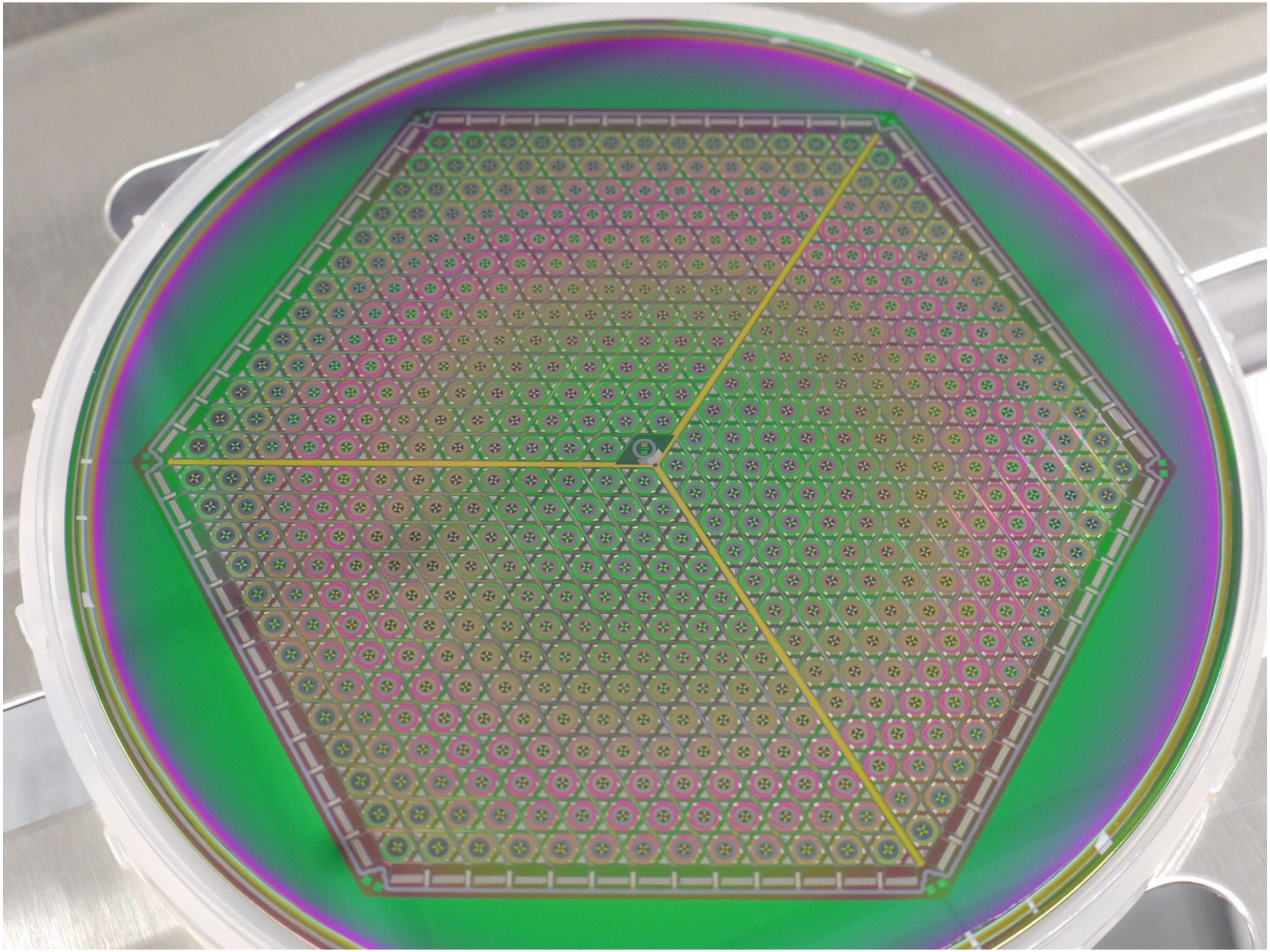
Advanced ACTPol 150/230 GHz prototype



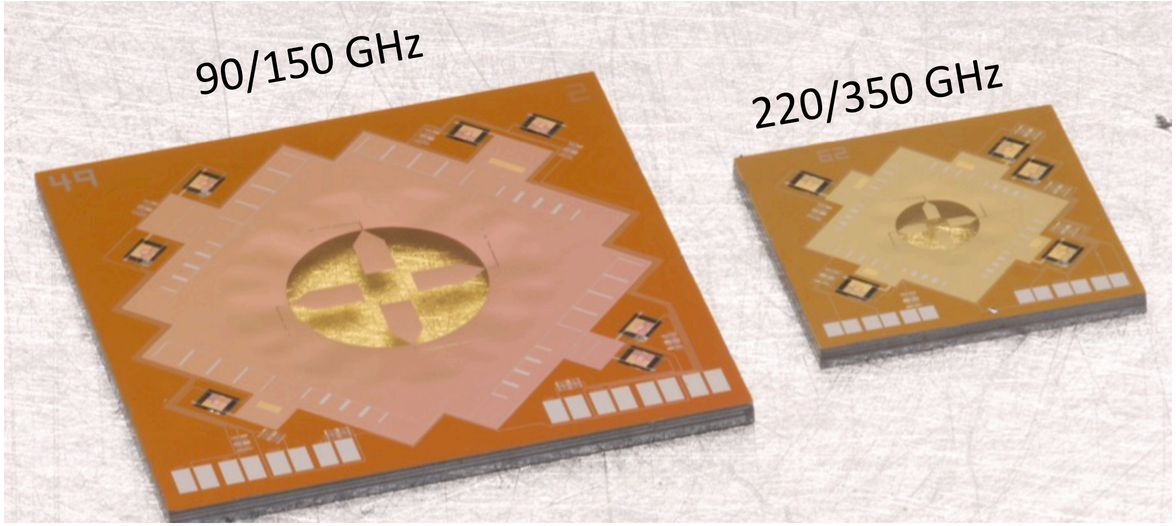


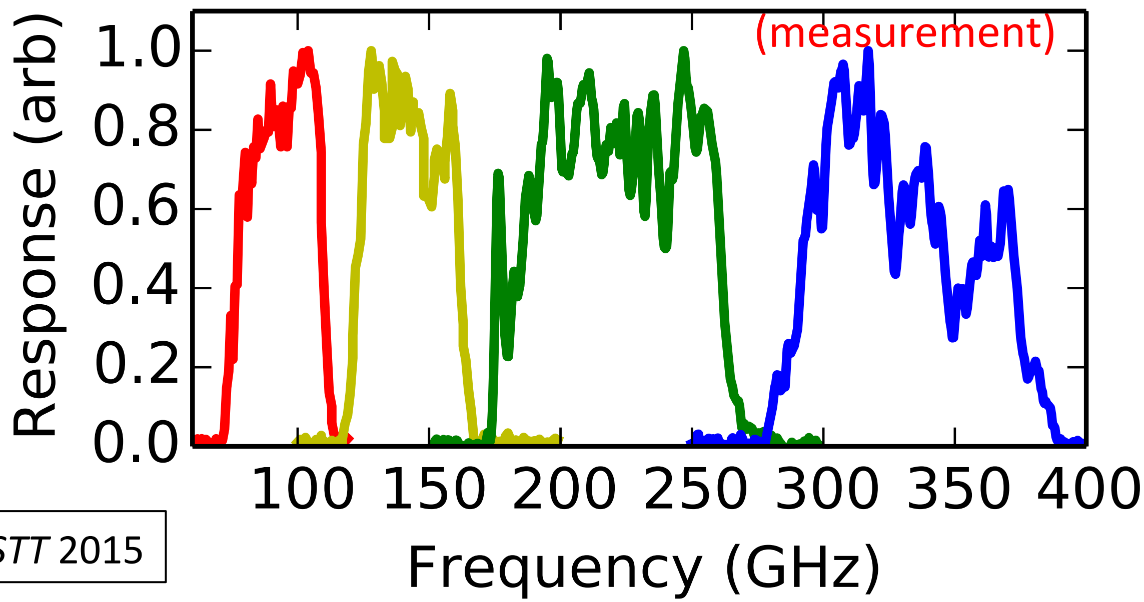
S.M. Duff et al. *JLTP* 2015

1st 150mm array near completion



Scaling to higher frequencies: Multichroics from 70 – 380 GHz



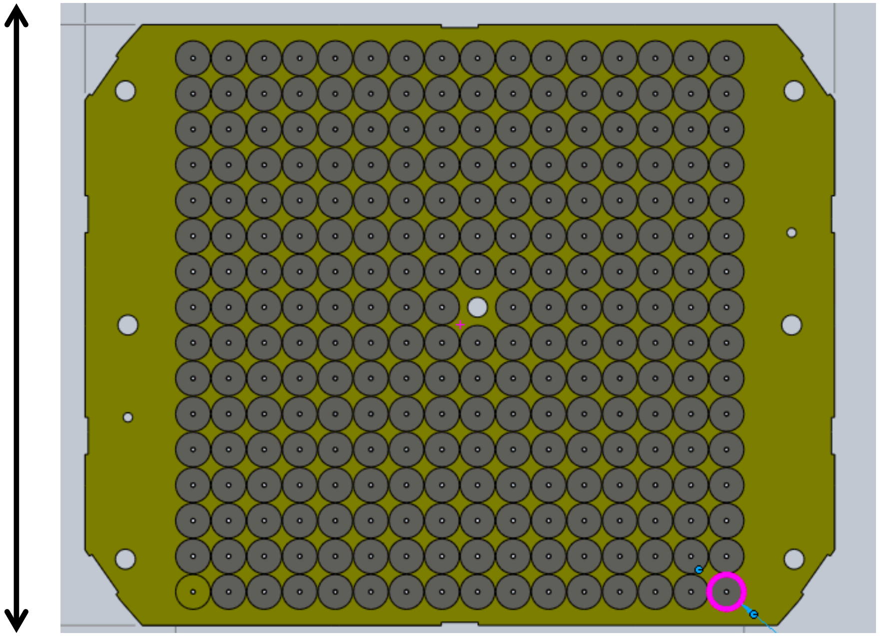


Hubmayr et al. *ISSTT* 2015

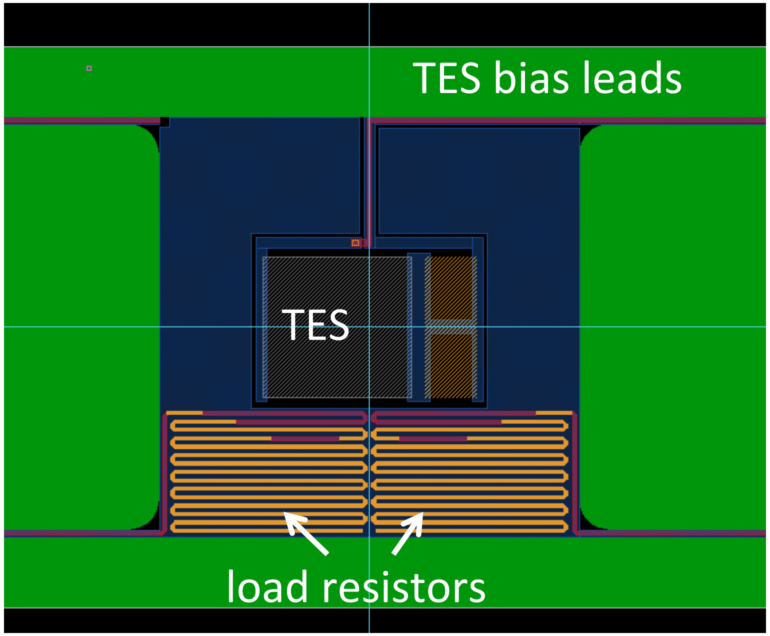
Scaling to higher frequencies: SPIDER 285 GHz arrays

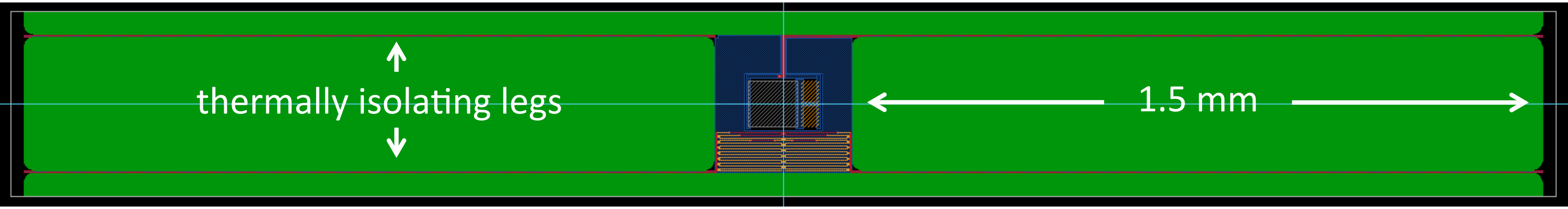
near identical frequency band as 1 of 3 LiteBIRD HFA channels

16 x 16 array (512 TES)

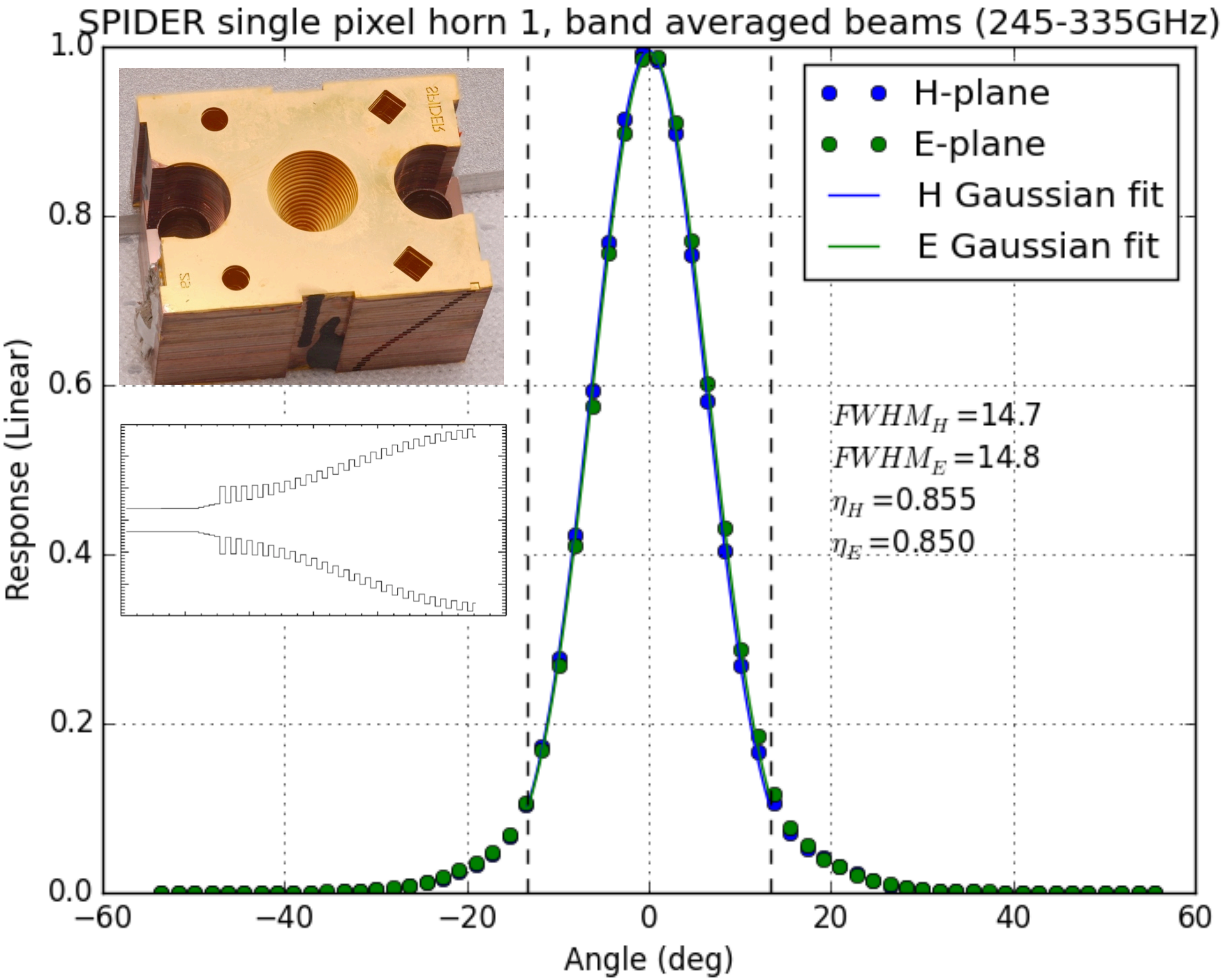


100 mm



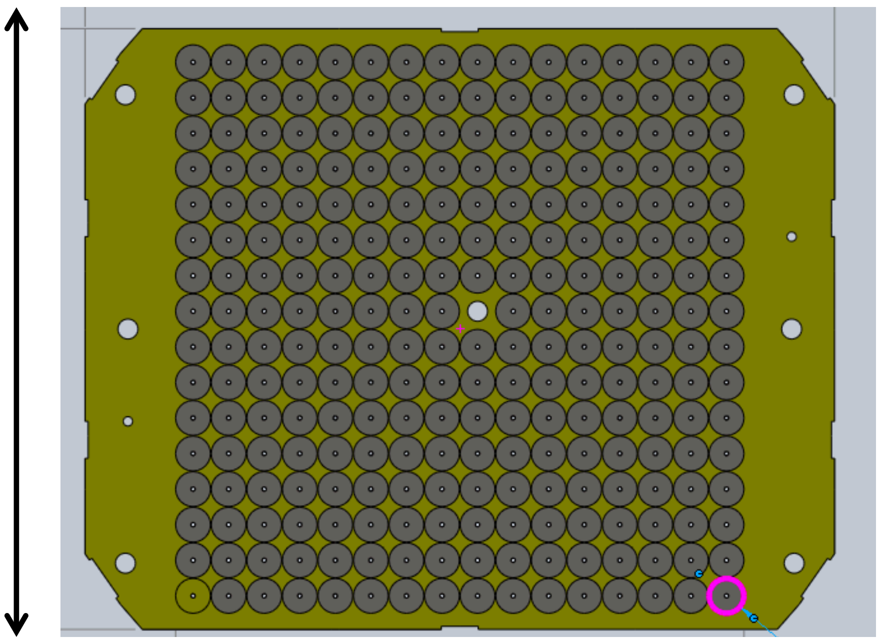


Due to 100mK base temperature, bolometer for LiteBIRD has much shorter legs


SPIDER single pixel horn 1, band averaged beams (245-335GHz)
H-plane
E-plane
H Gaussian fit
E Gaussian fit
$FWHM_H$ =14.7
$FWHM_E$ =14.8
η_H =0.855
η_E =0.850
Response (Linear)
Angle (deg)
1.0
0.8
0.6
0.4
0.2
0.0
−60
−40
−20
0
20
40
60
SPIDER

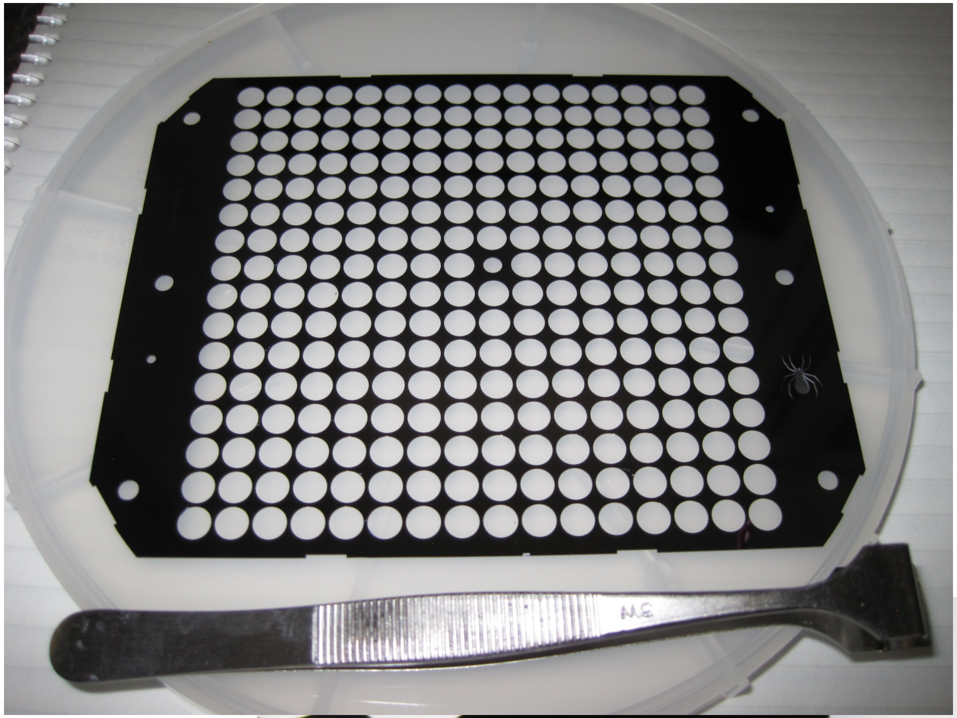
Scaling to higher frequencies: SPIDER 285 GHz arrays

16 x 16 array (512 TES)



100 mm

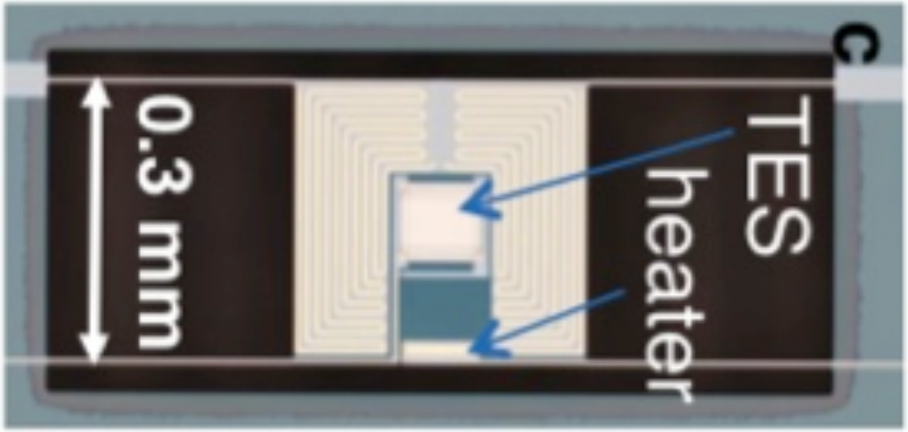
Platelets now being fabricated

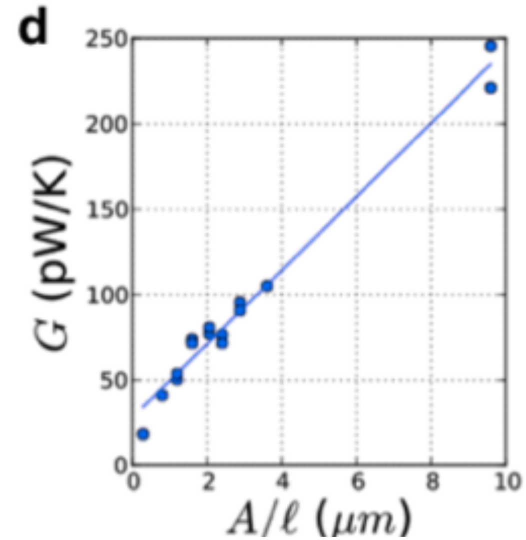


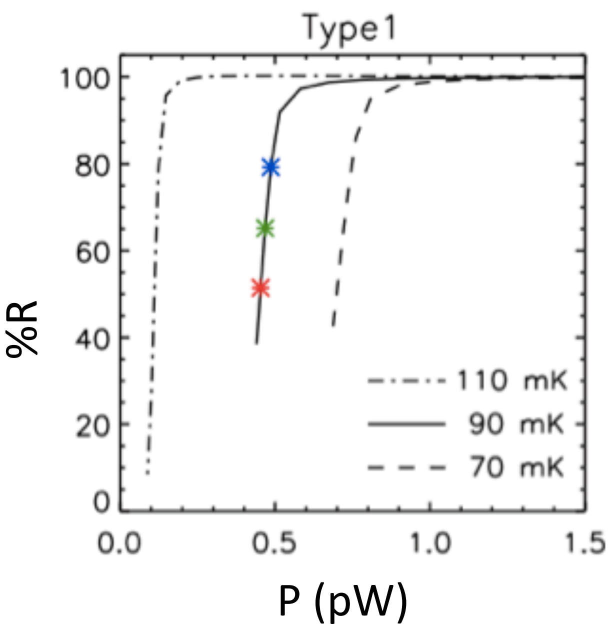
Balloon-borne demonstration
is path to achieve high TRL

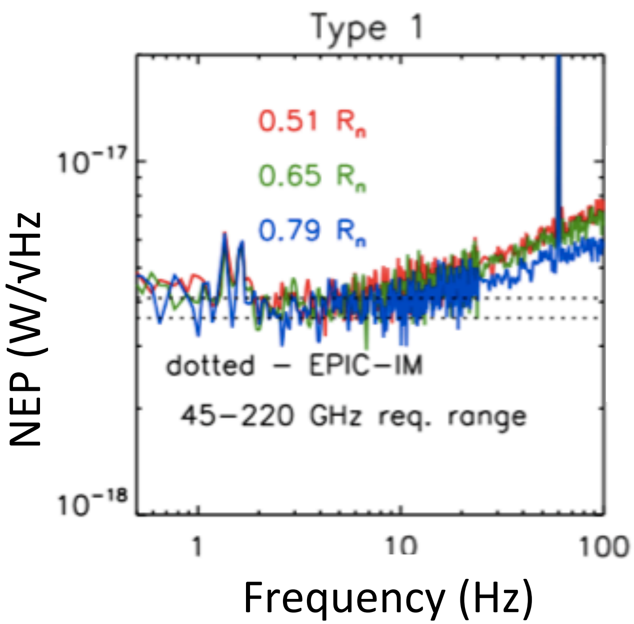
Space-optimized TES bolometers

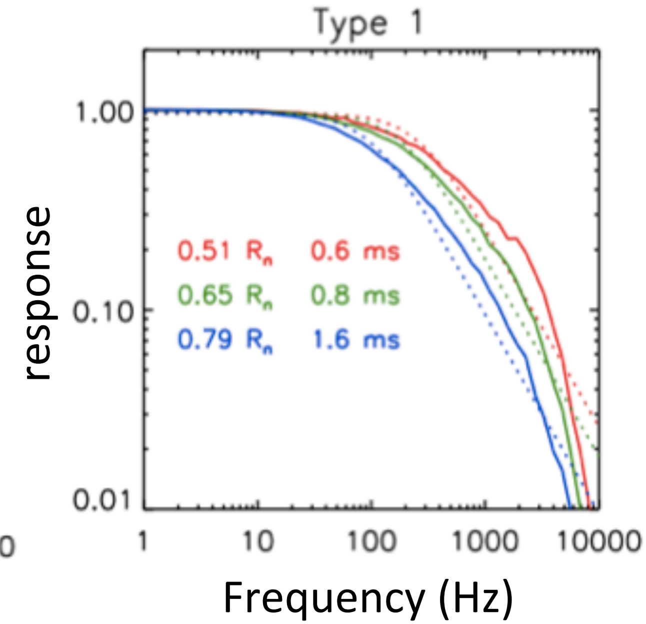
Niemack et al. *JLTP* 2012





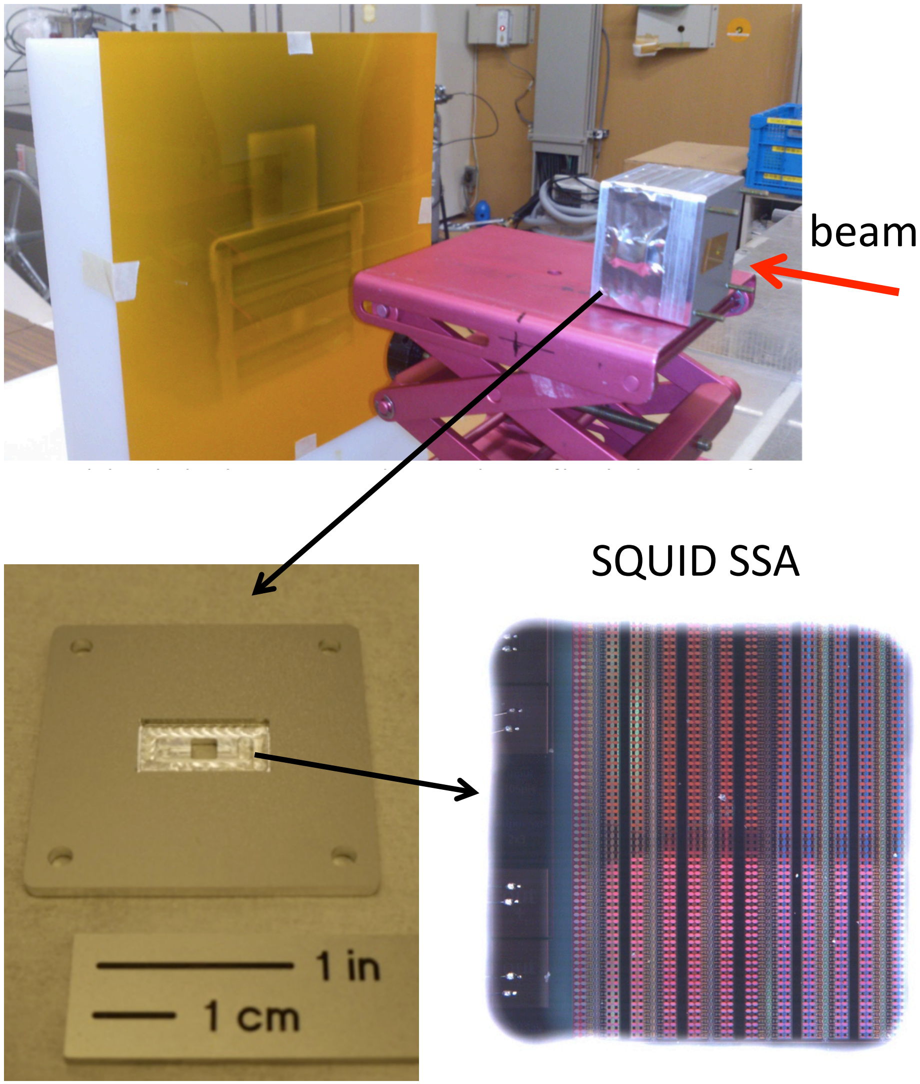




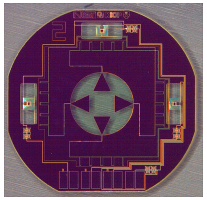


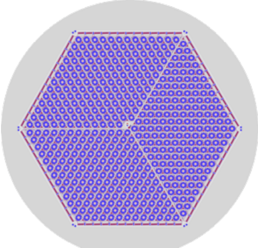
Radiation testing

- work in collaboration with Hirokazu Ishino and Tomotake Matsumura
- HIMAC 160MeV proton beam
- 10 krad dose
- Samples included AlMn films, full detector single pixels, AlMn TES bolometers, SQUID Series Arrays



Conclusions





- Silicon platelet feedhorn-coupled architecture is a mature technology (ie SPTpol, ACTPol)
- 10 monolithic arrays produced and fielded to date, 6 arrays will be fielded in the near term
- Demonstrated 10 uK arcmin array level sensitivity in 90/150 GHz array (~1000 sensors, recall Jeff McMahon's presentation)
- Shown reproducible, near-Gaussian shaped beams
- Frequency scaling via geometric scaling of antenna components demonstrated
- Balloon-borne demonstration upcoming on SPIDER