



# Design and performance of the BICEP Array receivers

Alessandro Schillaci

California Institute of Technology on the behalf of the Bicep/Keck Collaboration

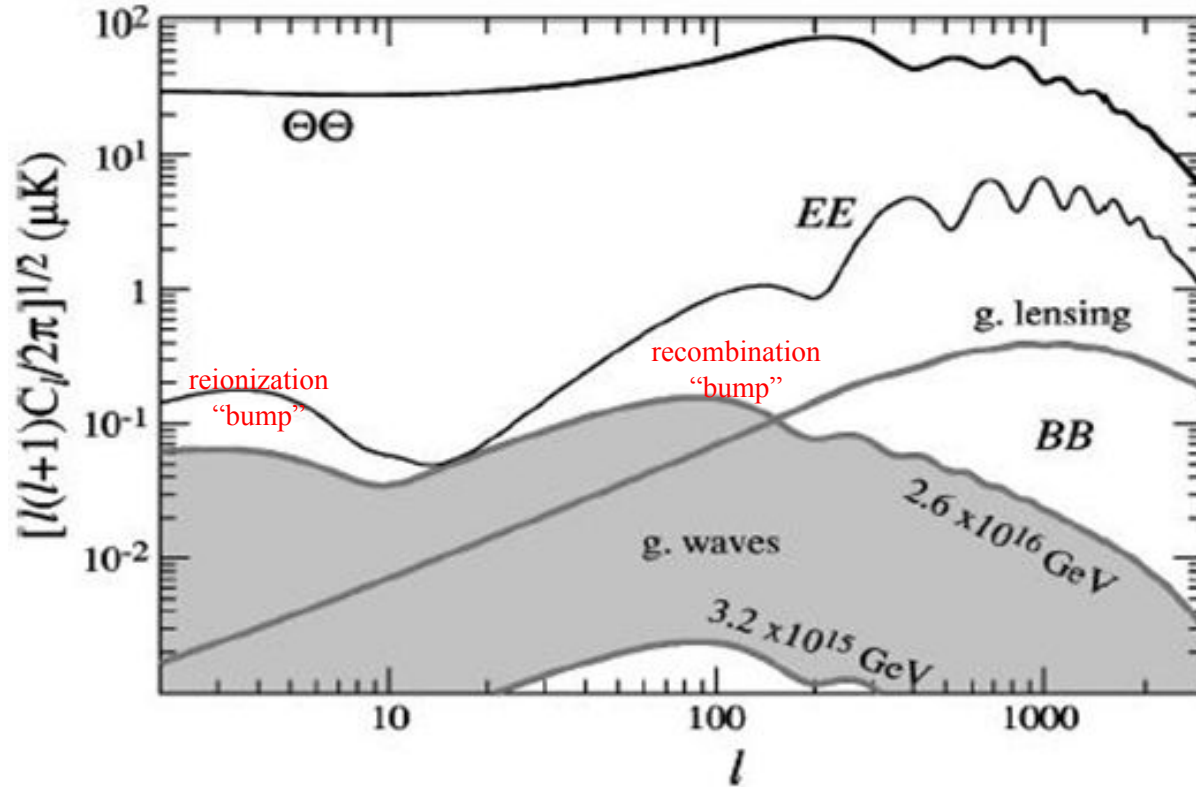
LTD18 - Milan - 07/23/2019



UNIVERSITY OF  
TORONTO



# Polarized power spectra



E-Mode count as 10% of CMB anisotropies signal and have been detected.

B-Mode power depends from the energy scale of the primordial Gravitational Waves and they have not been detected yet.

$r$  is defined as the ratio of tensor to scalar amplitude and it requires very clean and sensitive measurements.

Credit: W. Hu

# South Pole Station

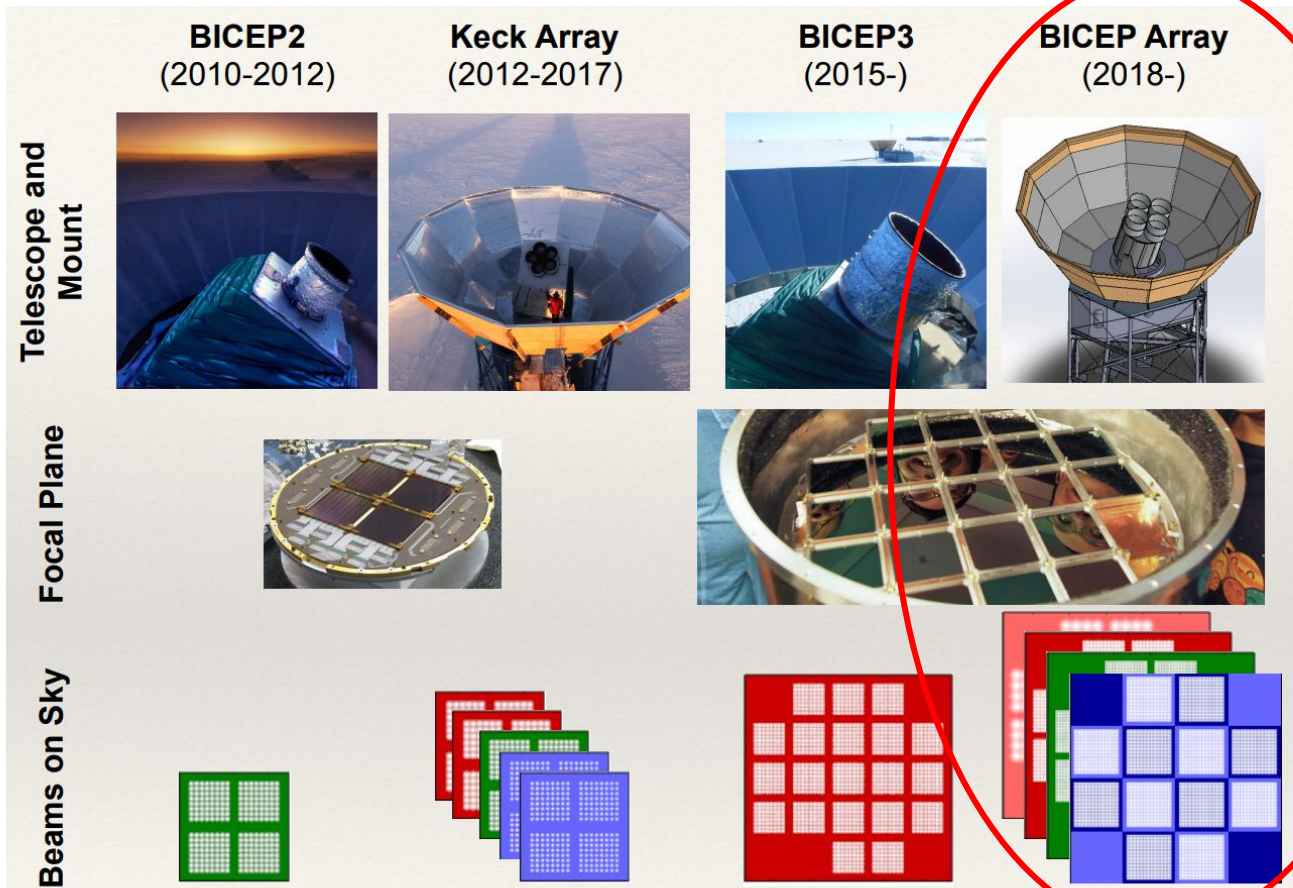
Main Station and Facilities

Keck Array (2011-2018)  
BICEP Array (2019-)

- Located at the NSF Amundsen-Scott South Pole Station
- Dry, stable atmosphere, high altitude
- 24 hours coverage of the Southern Sky with no elevation drift
- ~1.5 % of the sky, focus on ~600 deg<sup>2</sup> patch

BICEP (2006-2009)  
BICEP 2 (2010-2012)  
BICEP 3 (2015-)

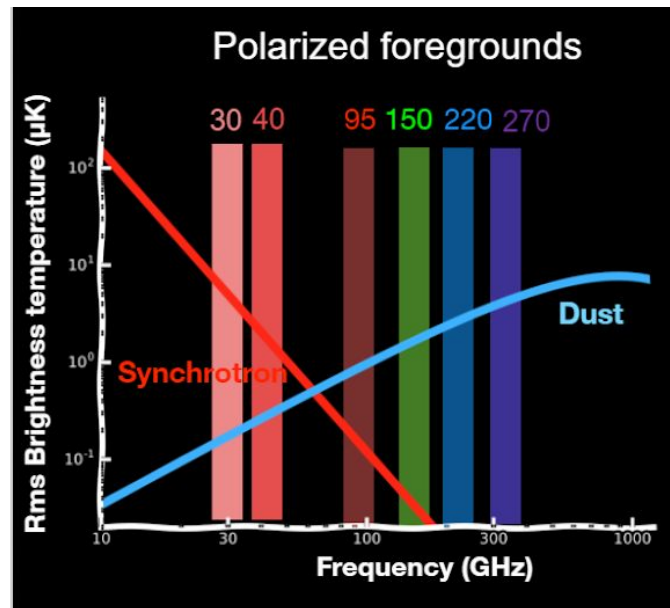
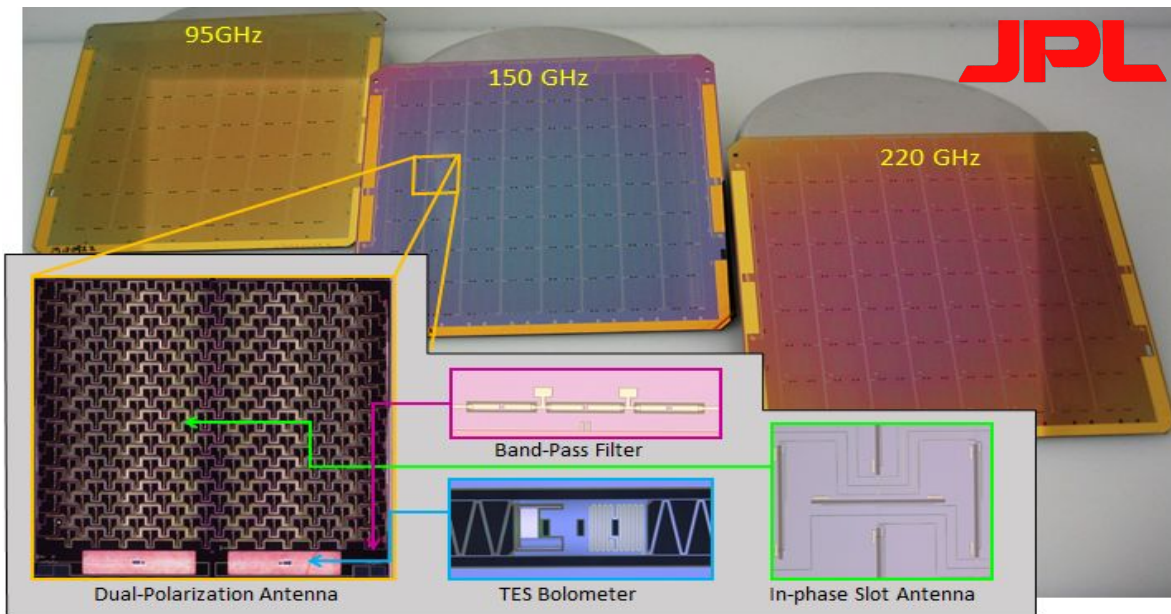
# BICEP Array





# Antenna-Coupled TES Bolometers for CMB Polarimetry

Wafers on the sky to date: **40 (95 GHz)**; **32 (150 GHz)**; **16 (220 GHz)**; **8 (270 GHz)**



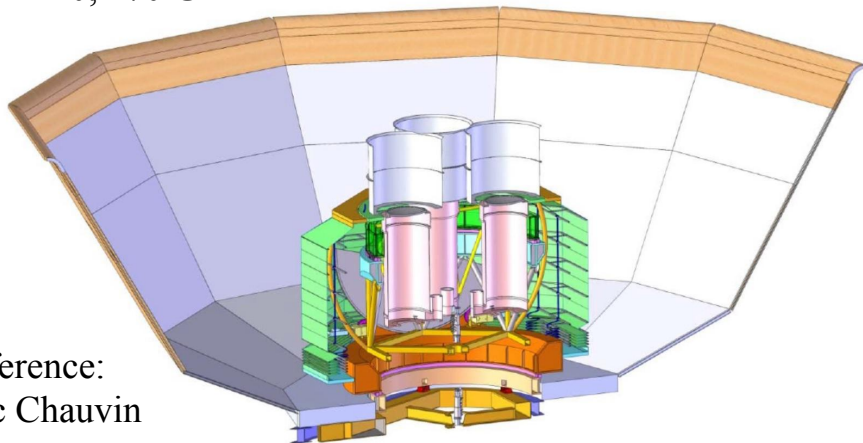
# BICEP Array facts

Cryostat based on Keck Array, Sub-K & Focal Plane based on BICEP3

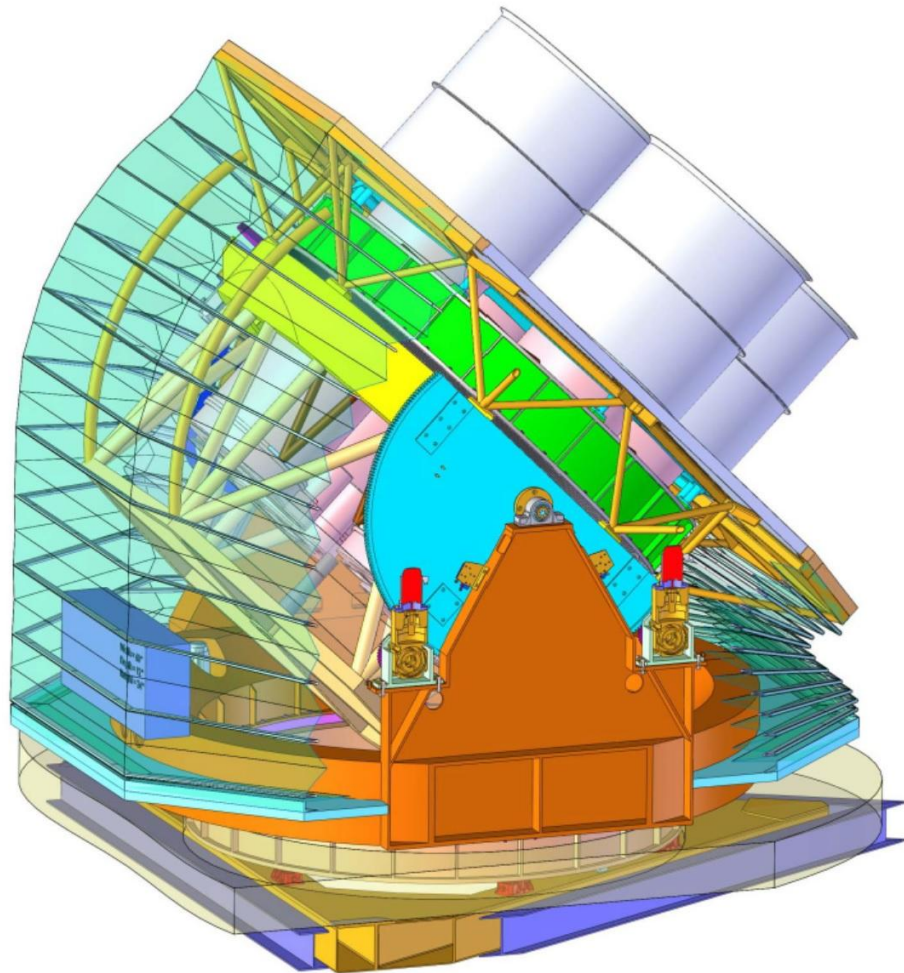
Replace Keck Array in 2018, new mount.

4 Receivers:

- 30, 40 GHz
- 95 GHz
- 150 GHz
- 220, 270 GHz



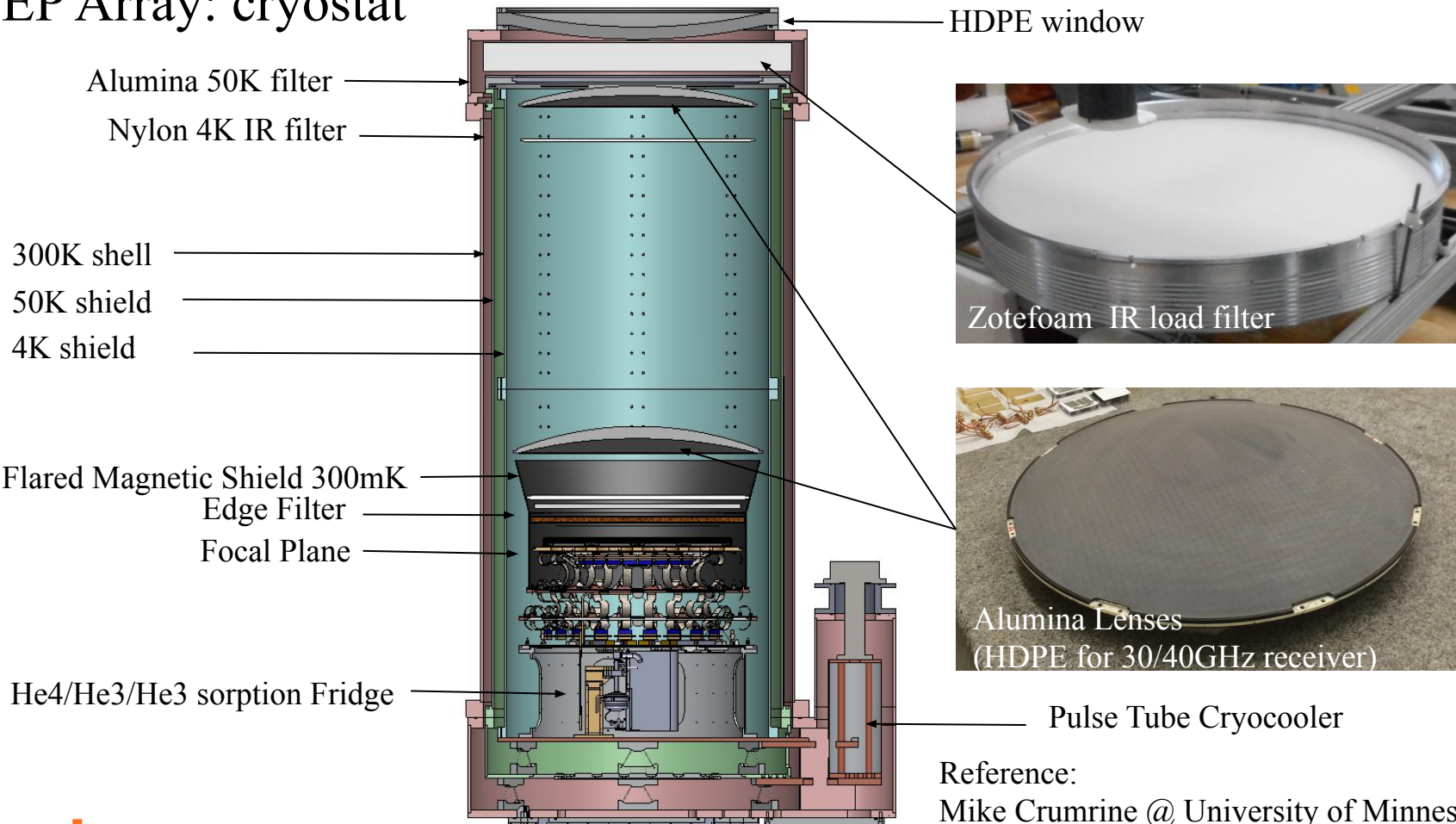
Reference:  
Eric Chauvin



# BICEP Array expected sensitivities

Frequency	30/40 GHz	95 GHz	150 GHz	220/270 GHz
Tiles	12	12	12	12
# Detectors	192/300	3456	7776	13824/16224
# Det/ Tile	32/50	288	648	1152/1352
Beam FWHM (arcmin)	76/57	24	15	10/8.5
NET per det (uK-rts)	268/334	267	315	900/1800
Instr. NET (uK-rts)	21/21	4.93	3.87	8.3/15
3-yr map depth (uK-arcmin)	7.5/7.5	1.9	1.4	3.0/5.5

# BICEP Array: cryostat



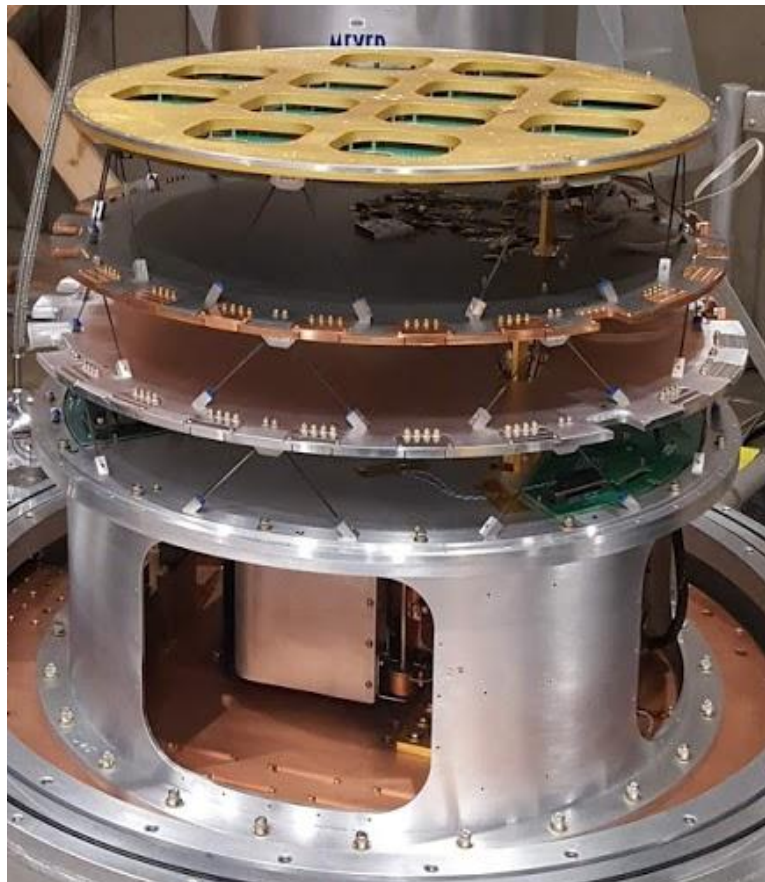
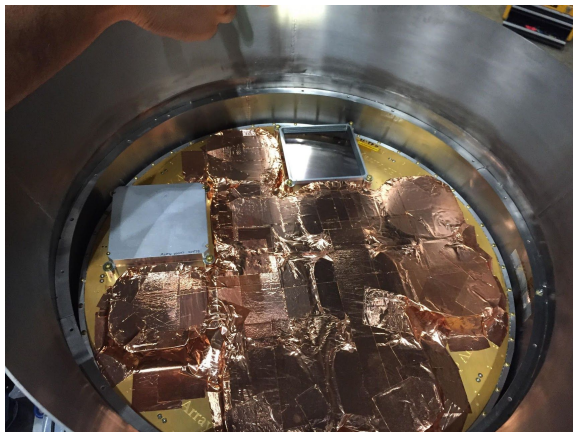
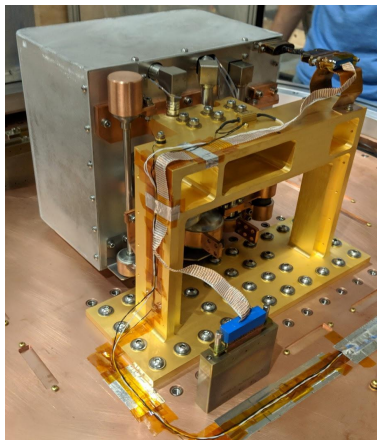
Reference:

Mike Crumrine @ University of Minnesota

LTD18 - Alessandro Schillaci - Milan 2019

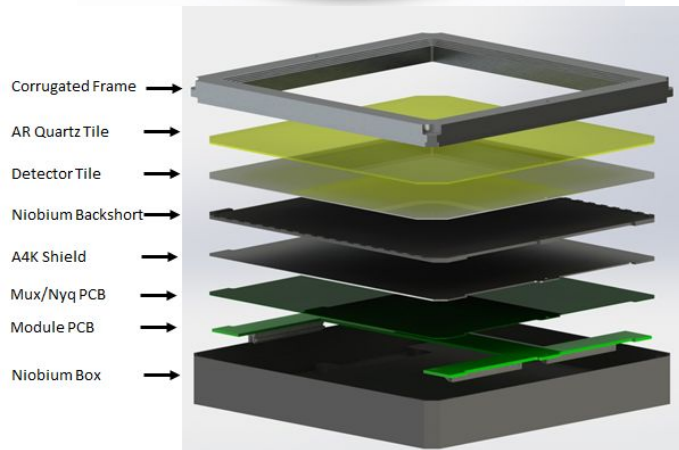
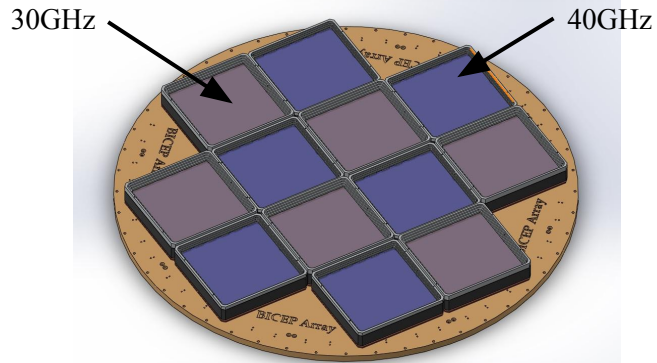


# BICEP Array: BA1 receiver integration and test

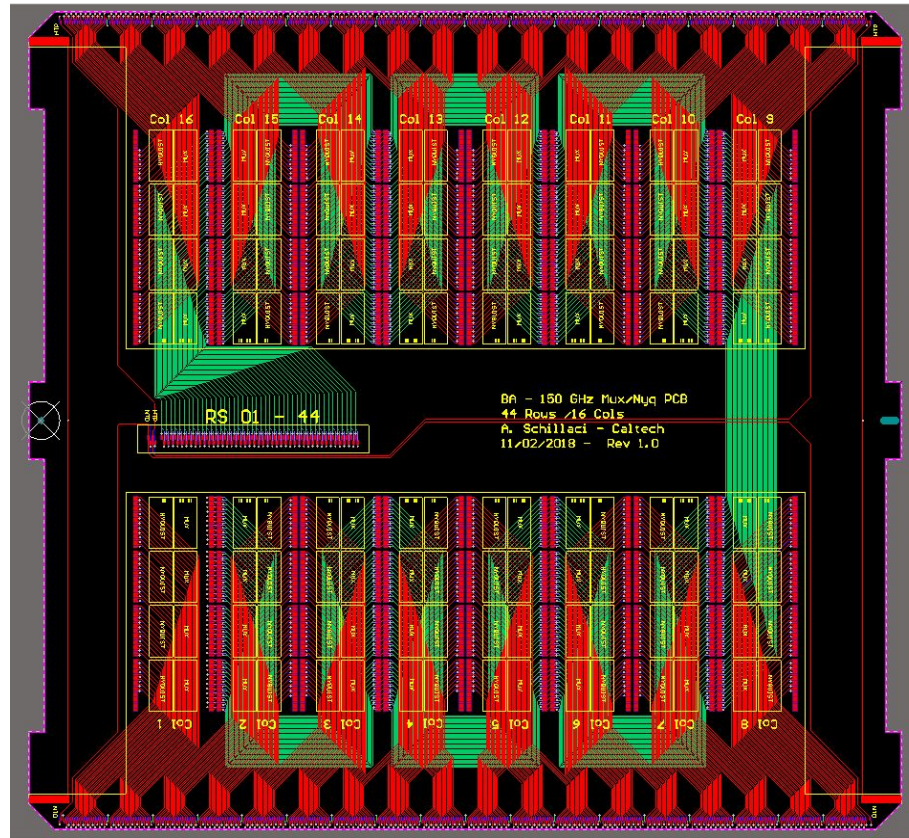


# BICEP Array: Focal Plane and Modules

30/40GHz Checker Board FPU

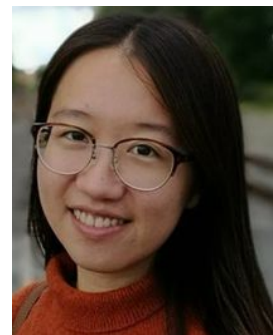
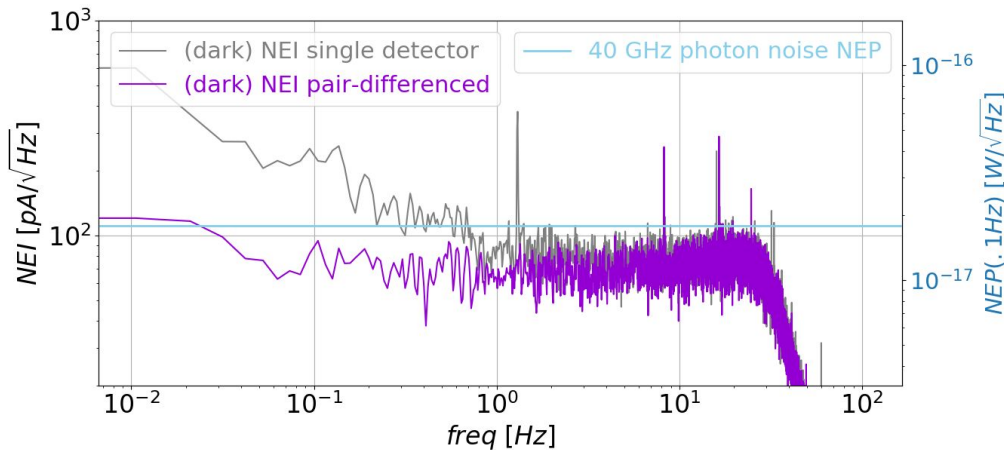
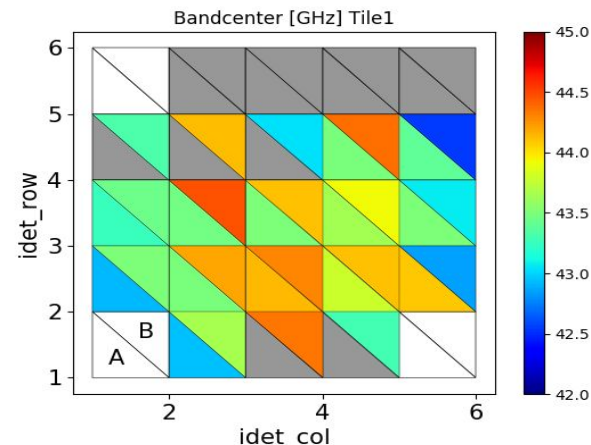
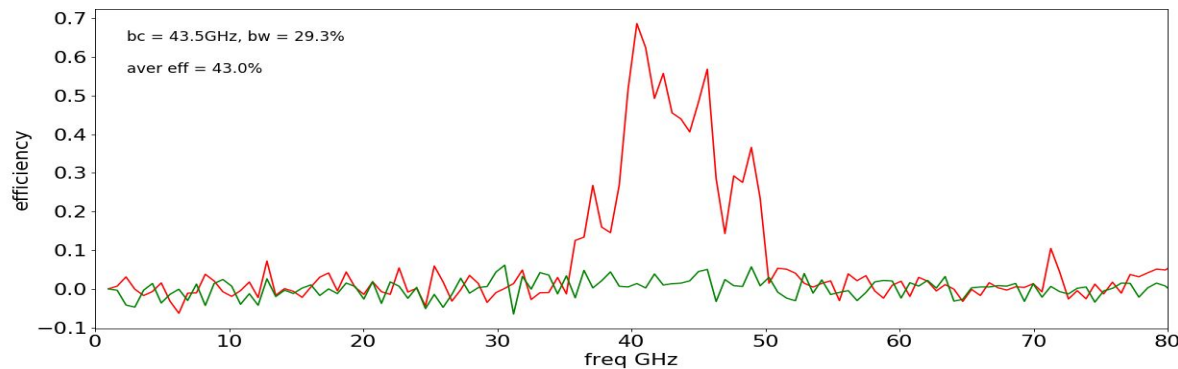


150GHz Mux/Nyq PCB (44 rows/ 16 cols)



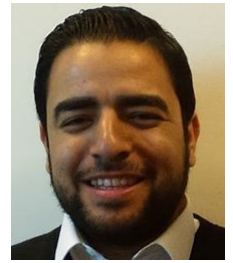


# BICEP Array: BA1 40GHz Module Spectral Response and Noise



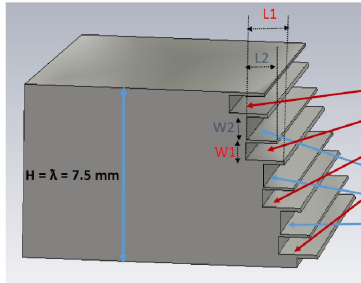
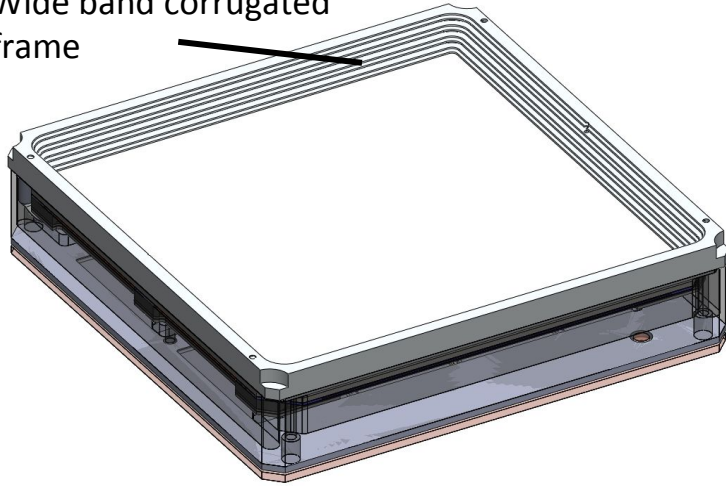
**See C. Zhang poster**

# BICEP Array: BA1 40GHz Antenna Beams



See A. Soliman poster

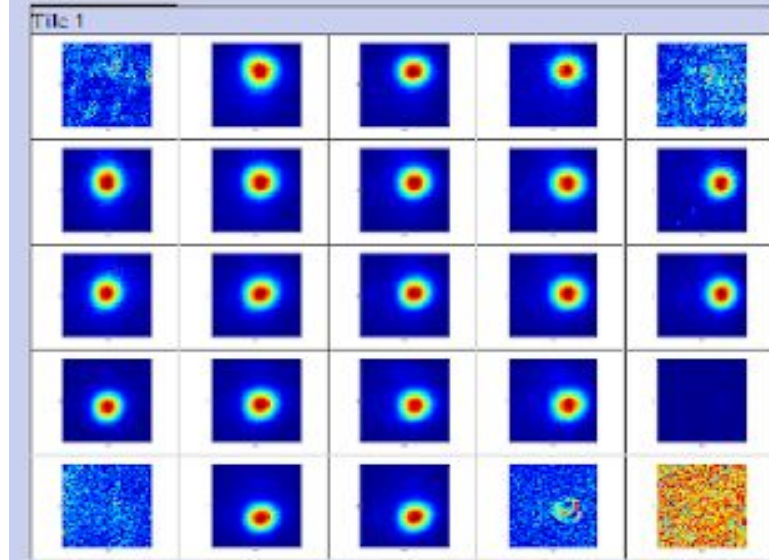
Wide band corrugated  
frame



$\lambda = 10 \text{ mm @ } 30 \text{ GHz}$   
 $L1 = \lambda/4 = 2.5 \text{ mm}$   
 $W1 = 0.6 \text{ mm}$   
(4 corrugations)

$\lambda = 7.5 \text{ mm @ } 40 \text{ GHz}$   
 $L2 = \lambda/4 = 1.875 \text{ mm}$   
 $W2 = \lambda/8 = 0.9375 \text{ mm}$   
(3 corrugations)

A-Polarization

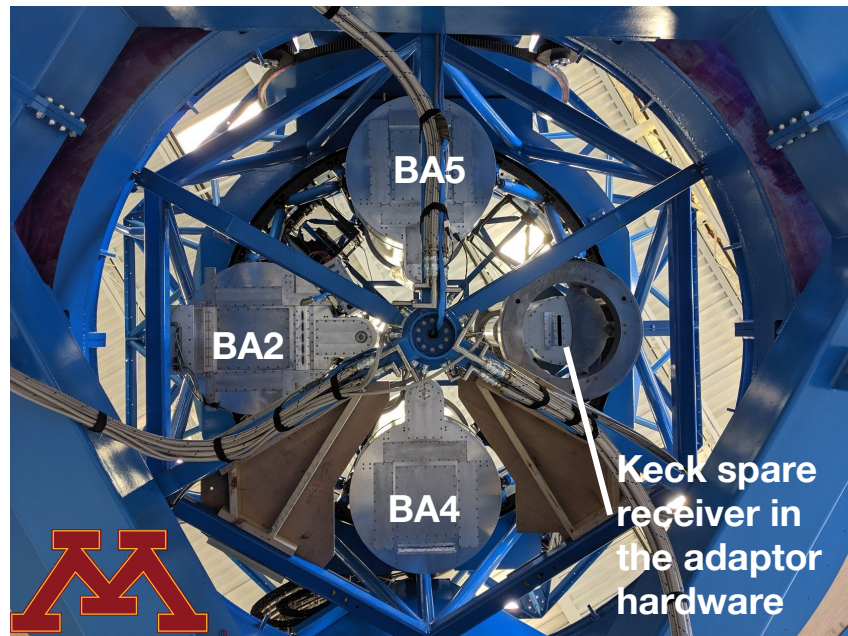




# BICEP Array: Mount integration and test

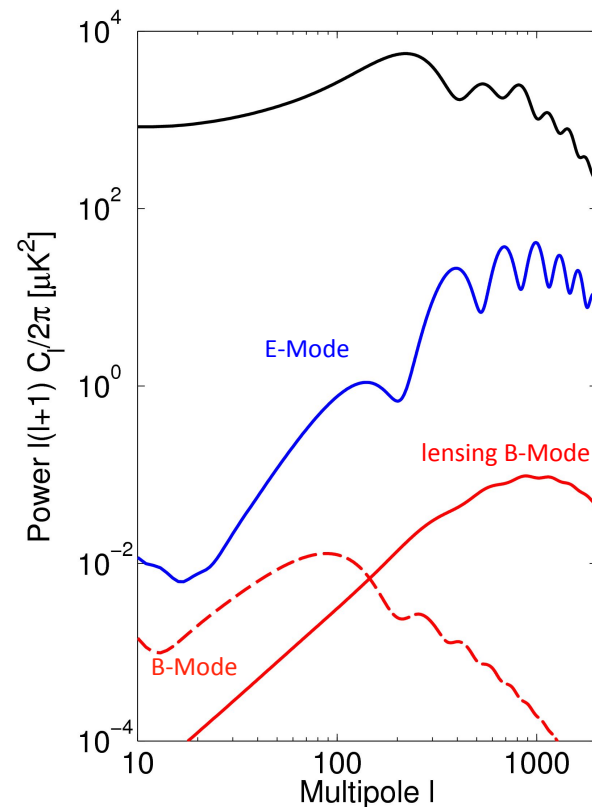
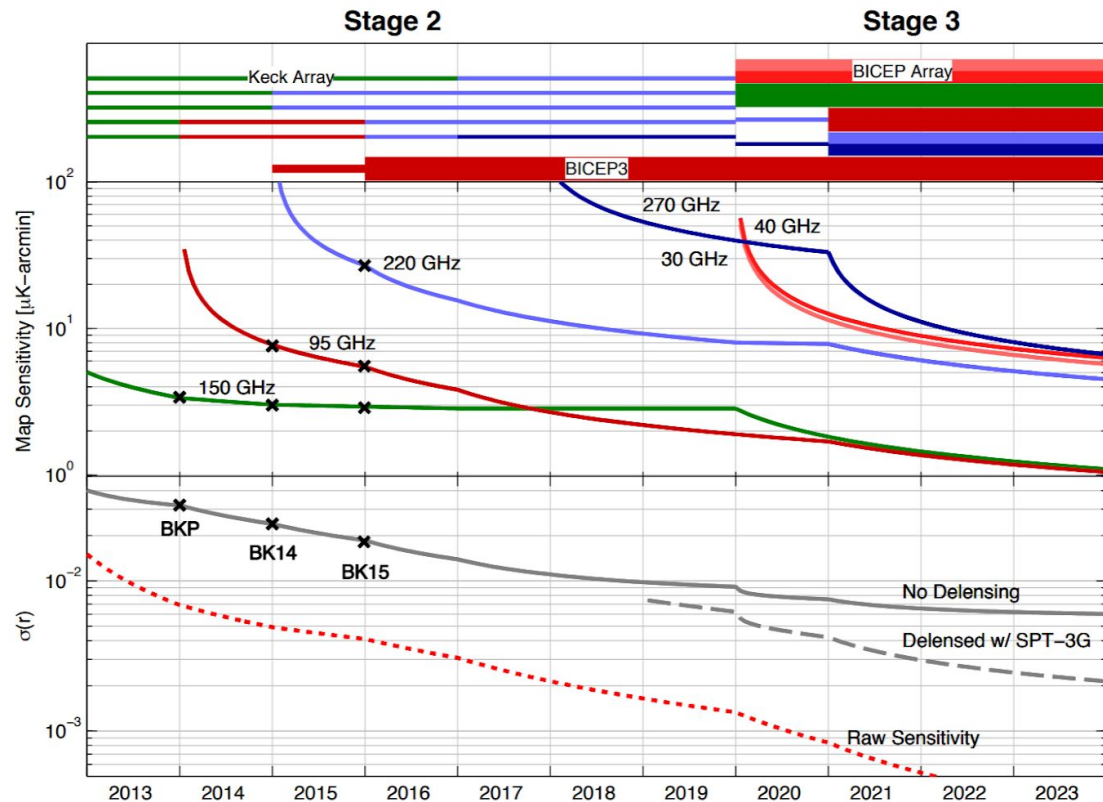


- The new mount is fully operative at UMN.
- BA-2 cold on mount with a 40GHz module.



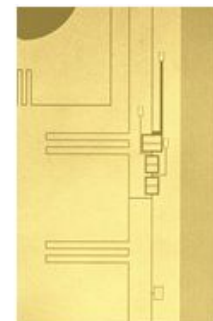
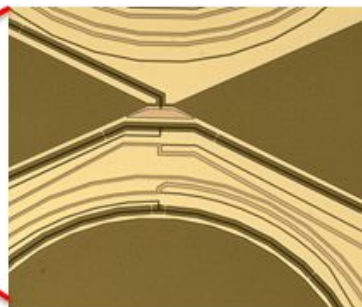
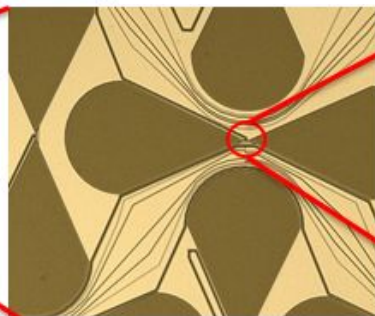
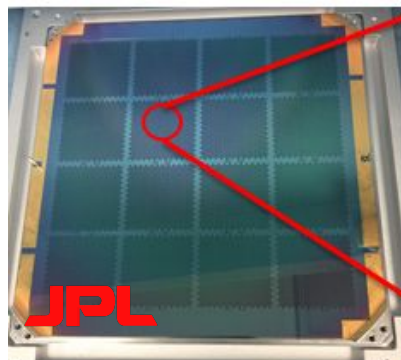
# BICEP Array: projected sensitivities

BK and SPT-3G communities working together for delensing

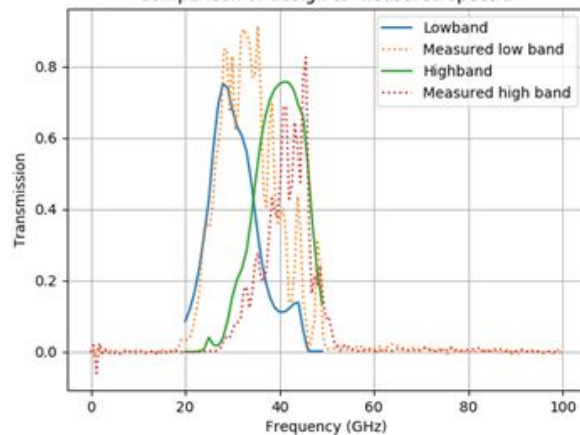


# 30/40GHz Diplexer

Work by Corwin Shiu, assisted by Bryan Steinbach, Roger O'Brient, and Krikor Megerian

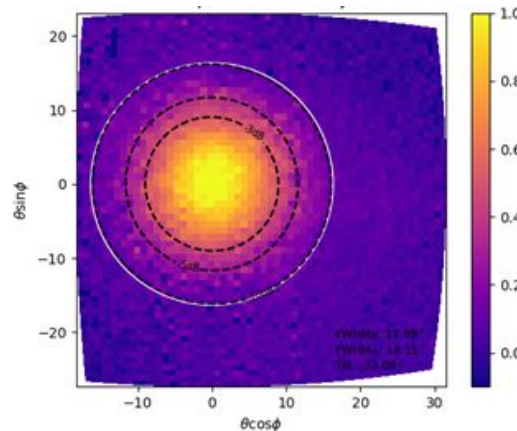


Comparison of design to measured spectra

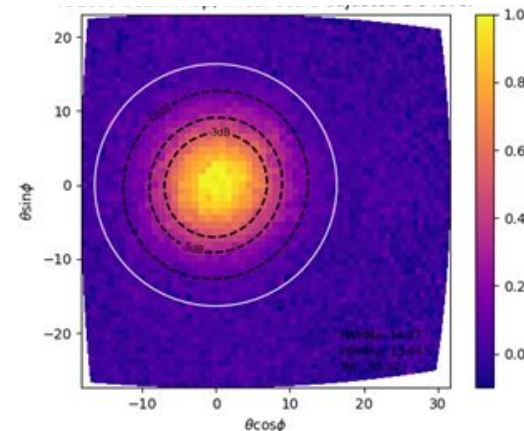


Antenna bandwidth ~100%

Black dashed lines are model, white is f/1.5 stop



30GHz Band OE=35%



40GHz Band=28%

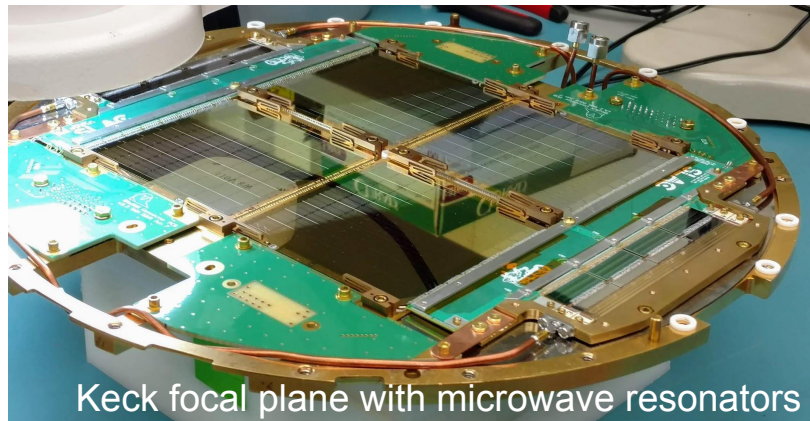
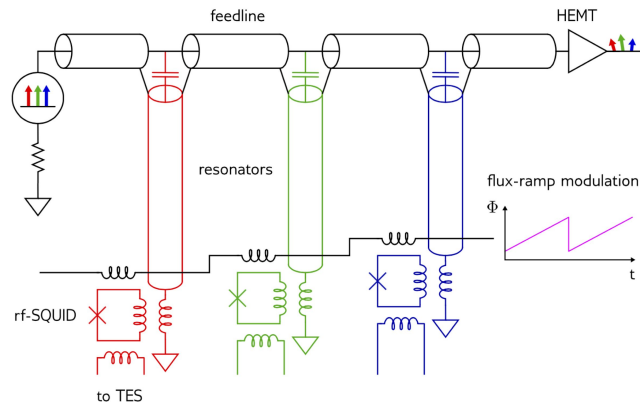


# Microwave multiplexing (umux)

## Frequency-domain multiplexing for DC-biased TESs

- Shunted resonances on single transmission line
  - TES current alters resonance frequency through rf SQUID
  - Signal is frequency modulation (FM)
- ~2000x over 4-8 GHz
- On-sky CMB demonstration with Keck 2019 @ 150GHz

**See Ari Cukierman Talk on Wed 8:45**

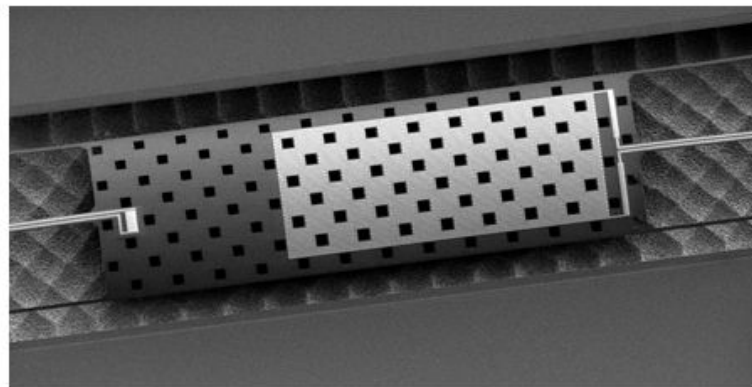
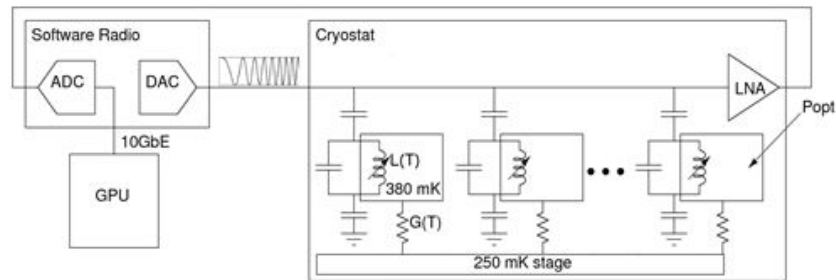


Keck focal plane with microwave resonators



# Thermal Kinetic Inductance Detectors (TKIDs)

- Bolometers with kinetic inductance thermometers
- KID-like readout, more design parameters
- Background limited for South Pole at 90GHz and higher
- $1/f \sim 1\text{Hz}$
- $20\text{aW/rtHz}$  at 10Hz
- $\sim 1\text{ms}$  time constants



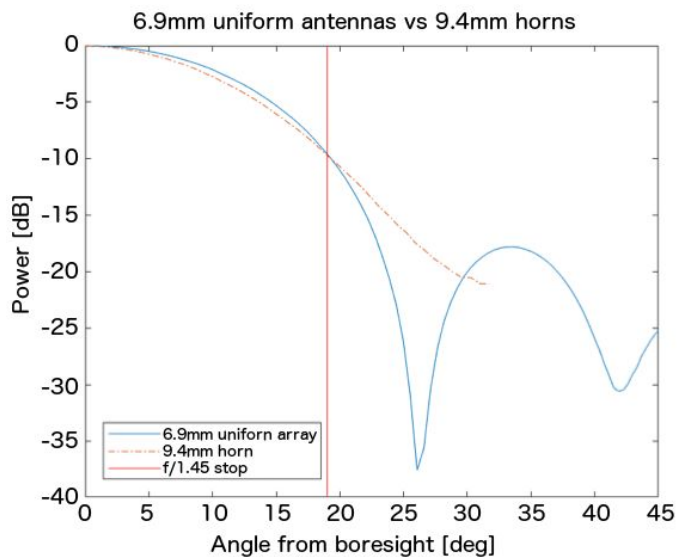
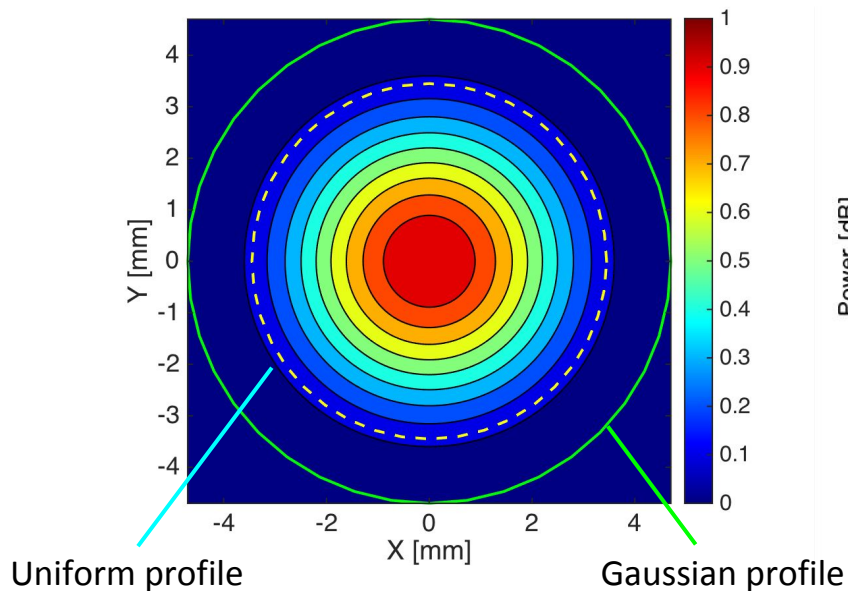
See Albert Wandui's Talk on Fri 2:45pm

See Lorenzo Minutolo's Poster



# Detector packing *Analysis by Lorenzo Moncelsi, Roger O'Brient, Corwin Shiu*

- Will have circular footprint, hex-pack more pixels in focal planes.
- With the same target beam, uniform illumination allows pixels to be ~90% smaller than gaussian illuminated, so could nearly double the pixels count (bolometers and bias lines reduce this advantage some)
- Left: Dashed line shows uniform size over gaussian illumination at the feed
- Right: Similar gain and edge taper in resultant beams



# Conclusions

- BICEP/Keck is producing the deepest maps in polarization at low- $l$  CMB and with BK15 we have the lowest constrain on  $r$  ever published.
- 3 years (2016-2018) of 95GHz data from Bicep3 and 2 years of 270GHz from Keck to be added to analysis (BK18 data analysis - See Howard Hui Poster).
- BICEP Array 30/40GHz first receiver is performing well and it is getting ready for deployment in the incoming 2019/2020 austral summer.
- Expect to detect synchrotron in BK patch with only 1 year of observations!
- Next 150GHz receiver is almost fully designed and partially built for 2020/2021 deployment season

# BICEP/Keck Synchrotron constraint

