

# Superconducting Detectors and Multiplexed SQUID Readout for CMB Polarimetry

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TIPP - June 9, 2011, Chicago

# OVERVIEW

Detectors now reach the fundamental noise limit,  
which leads to photon noise limited instruments

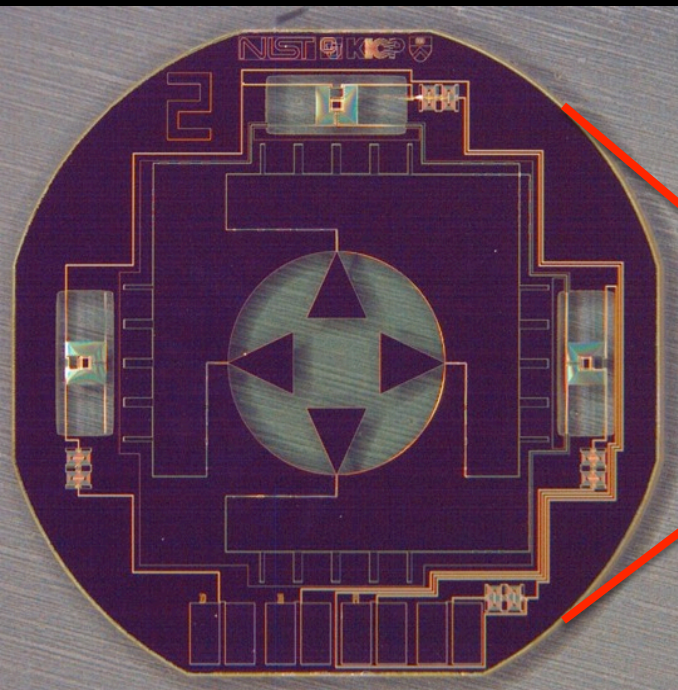
=> Path to better sensitivity is more detectors

- CMB polarimeters and instruments underway
  - Other NIST TES detector work and SQUID multiplexing techniques for larger arrays
  - Future CMB Polarimeters and deLITE
-

# NIST Polarimeter Arrays

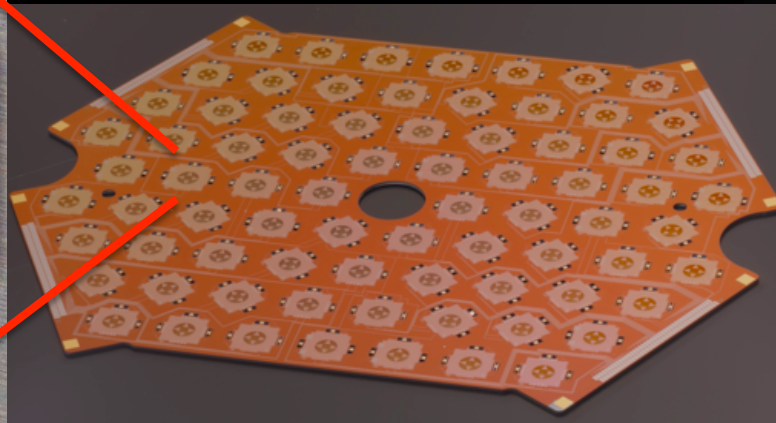
- **Truce Collaboration:** NIST, UC Berkeley, CU Boulder, U Chicago, U Michigan, U Penn., Princeton U, NASA GSFC, Stanford U
  - Superconducting transition-edge-sensor (TES) polarimeters
  - Monolithic corrugated silicon feedhorn arrays

Single Truce polarimeter

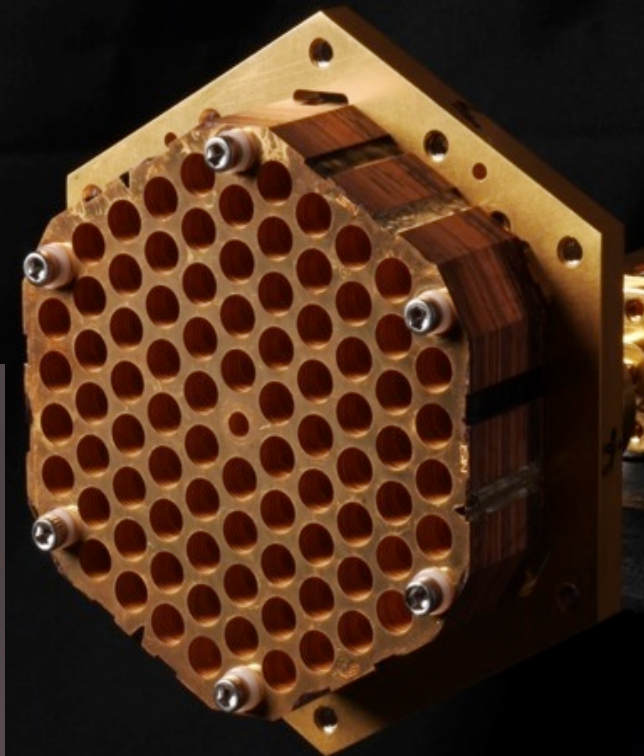


5 mm

Polarimeter array



Gold-plated silicon feed array



5 cm

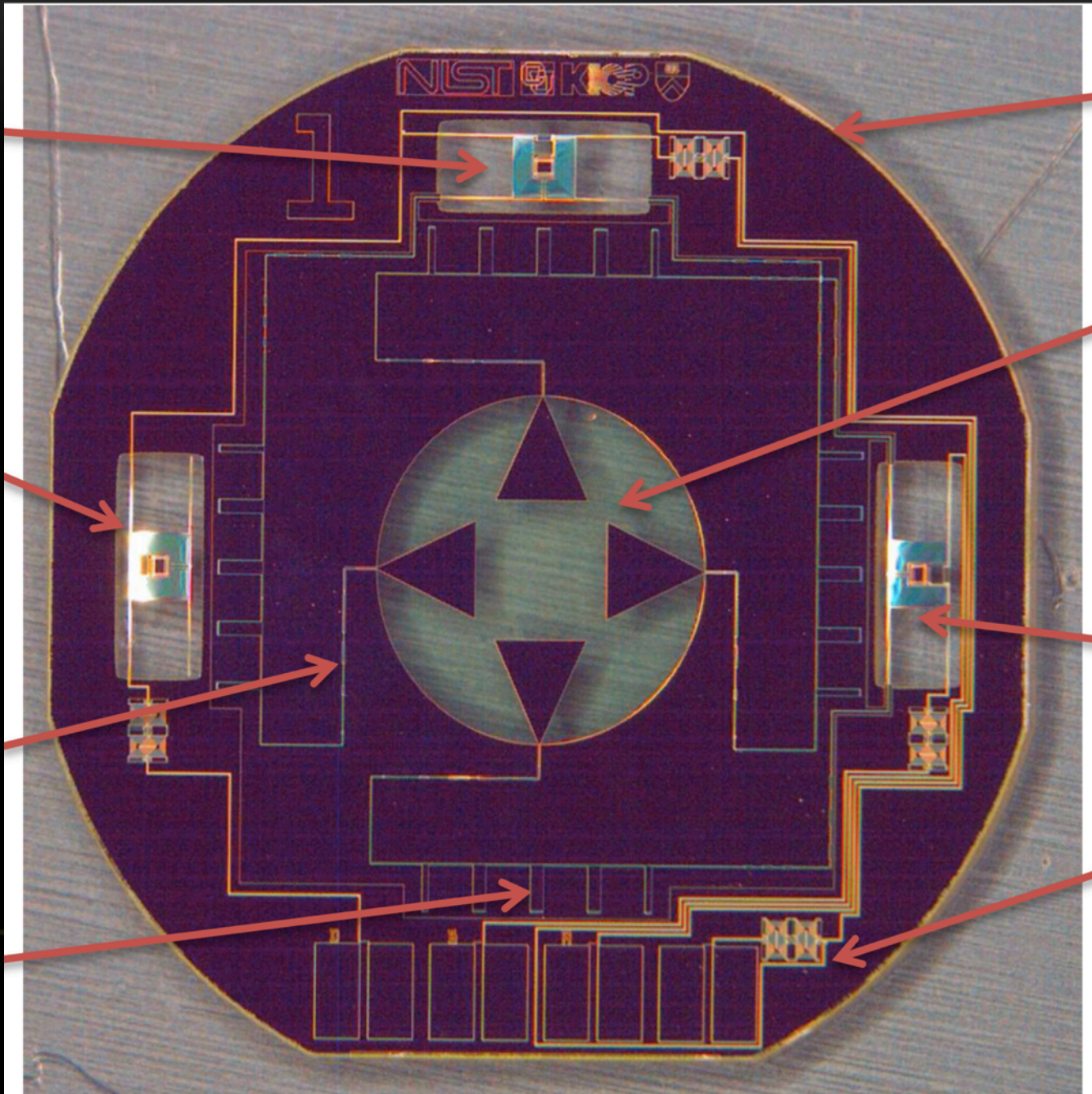
# Superconducting Transition-Edge-Sensor (TES) Polarimeter

Horizontal pol.  
TES bolometer

Dark prototype  
TES bolometer

Superconducting  
circuit

Bandpass filter



5 mm diameter

Ortho-mode  
Transducer

Vertical pol.  
TES bolometer

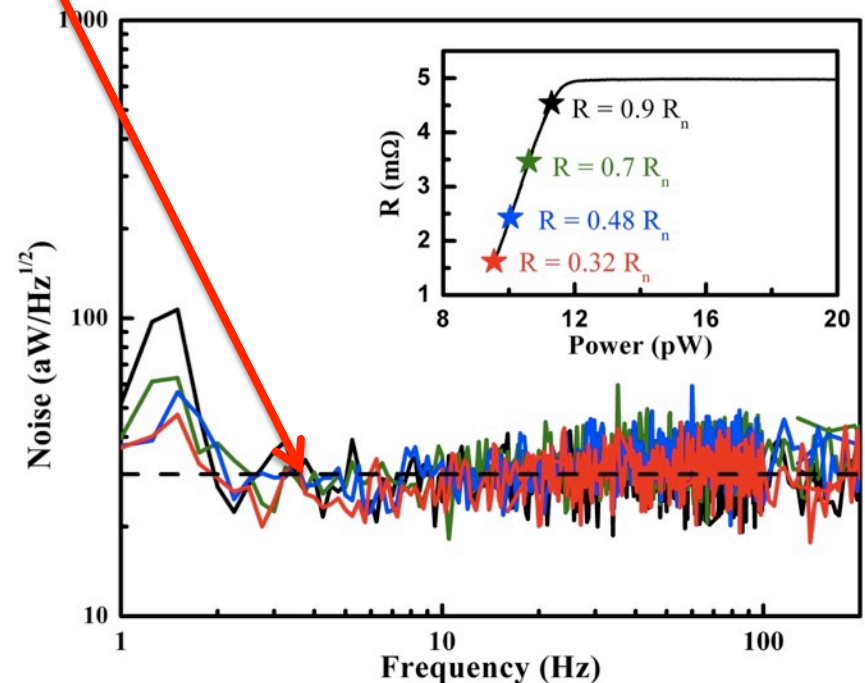
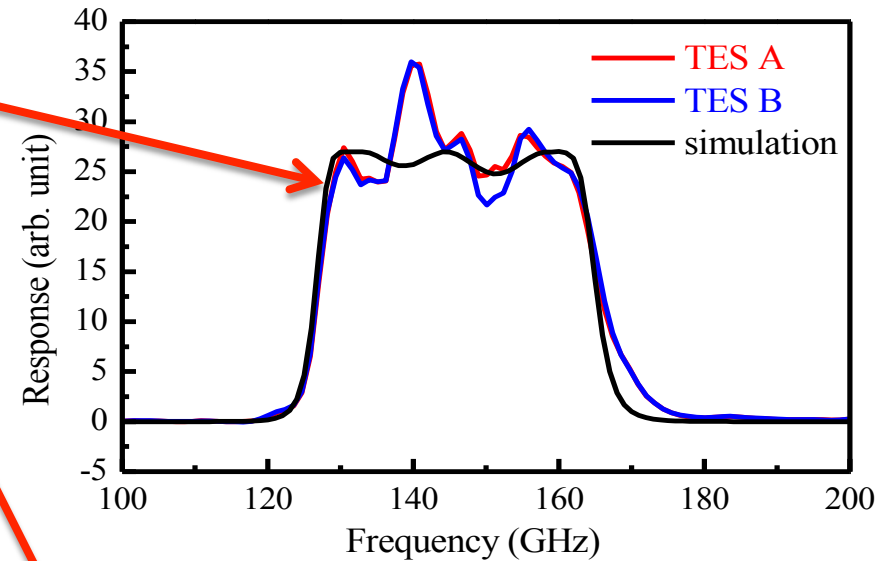
DC line filter

M. Niemack, NIST

# Prototype Polarimeter Characterization

- Bandpass on target
- Noise matches fundamental limit
  - No sign of excess in band
- Efficiency  $\sim 60\%$ 
  - Cold load measurements
  - Improvements to detector  $\text{SiO}_2$  recipe are now being tested

( Details in LTD-2009 and SPIE-2010 proceedings )

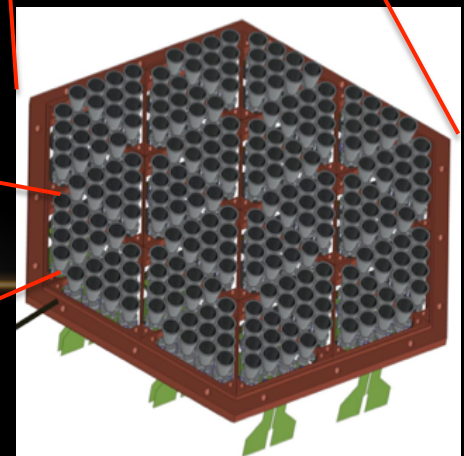
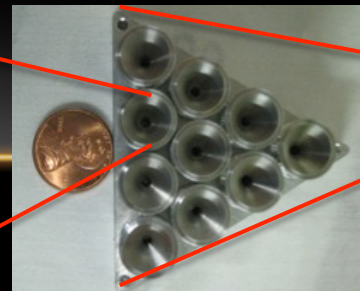
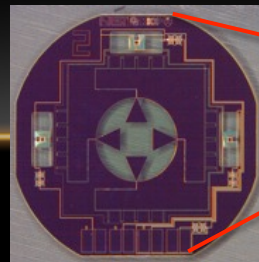
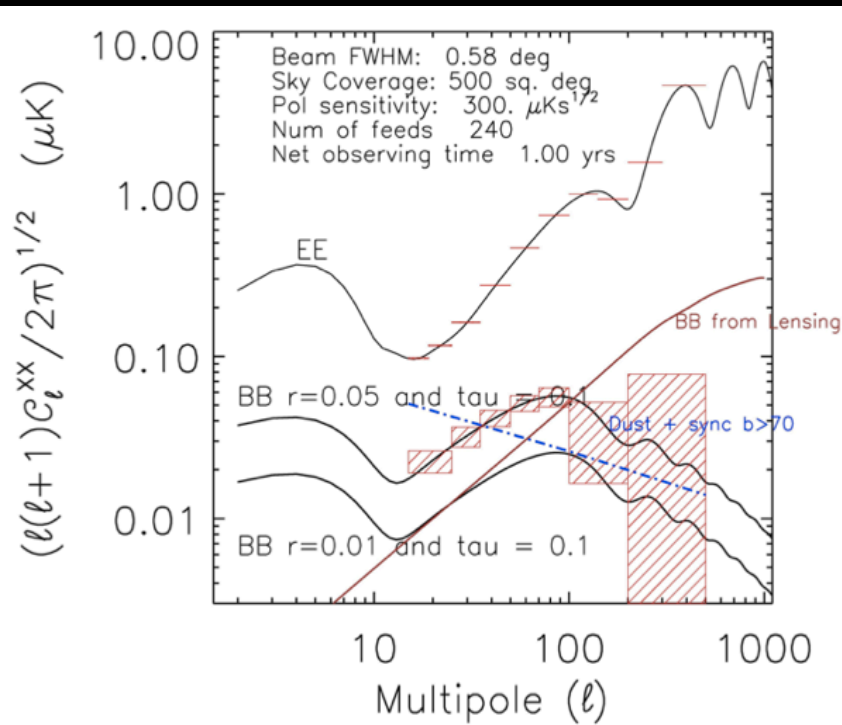
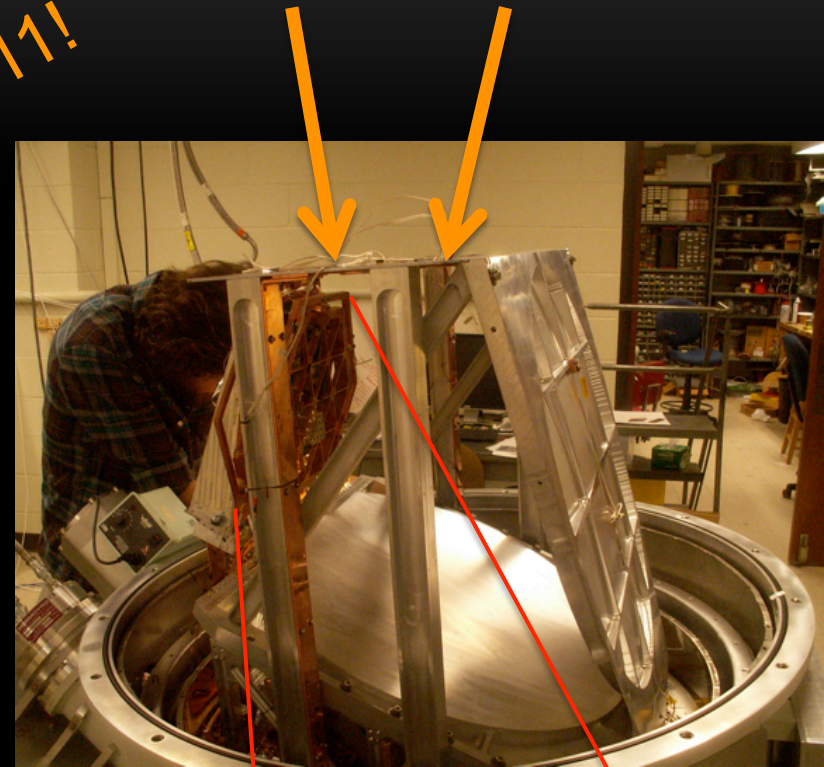


# Atacama B-mode Search (ABS)

Princeton U., NIST, U. British Columbia

- 0.3 m cryogenic telescope in Chile
- Large angular scale B-modes
- Detectors
  - 240 Individual 150 GHz polarimeters (480 TES)
  - First deployment of NIST polarimeters

Deploy in 2011!



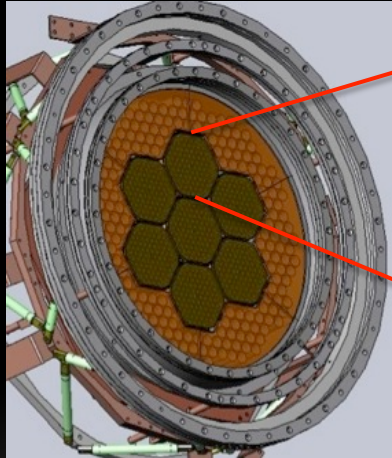
(Essinger-Hileman et al., SPIE 2010)

# South Pole Telescope Polarimeter (SPTpol)

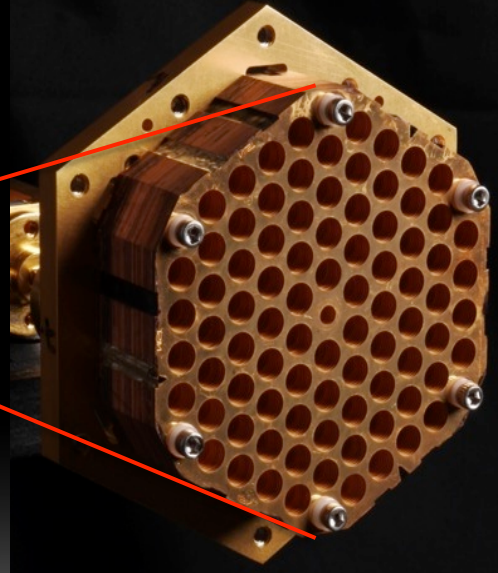
- 10 m telescope at South Pole
- Described by C. Chang in previous talk
- Detectors
  - NIST – 150 GHz – 1176 TES
  - Argonne – 90 GHz – 376 TES



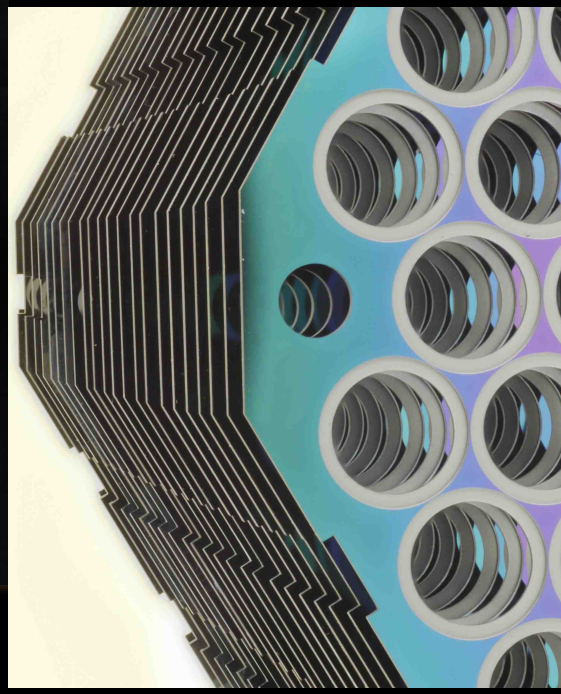
Deploy early 2012!



Silicon platelet feed array



Silicon Platelets



M. Niemack, NIST

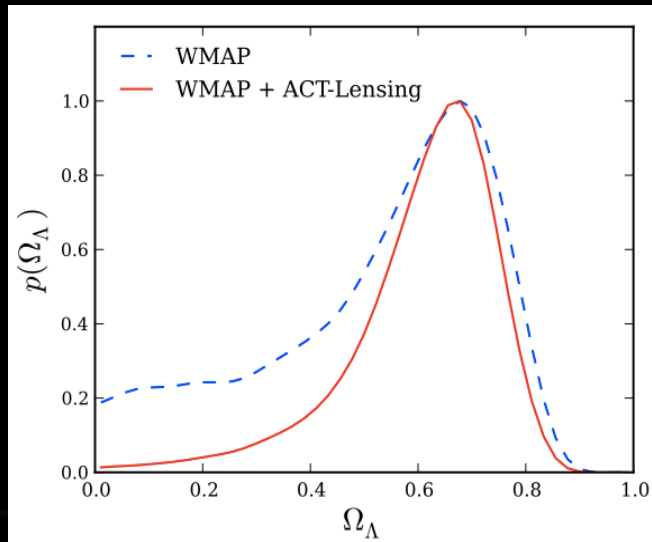
# Atacama Cosmology Telescope Polarimeter (ACTPol)

- 6 m telescope in Chile
- Focus on neutrino mass ( $\sigma \sim 0.05$  eV), gravitational lensing, cross-correlations (overlap with XMM-LSS survey)

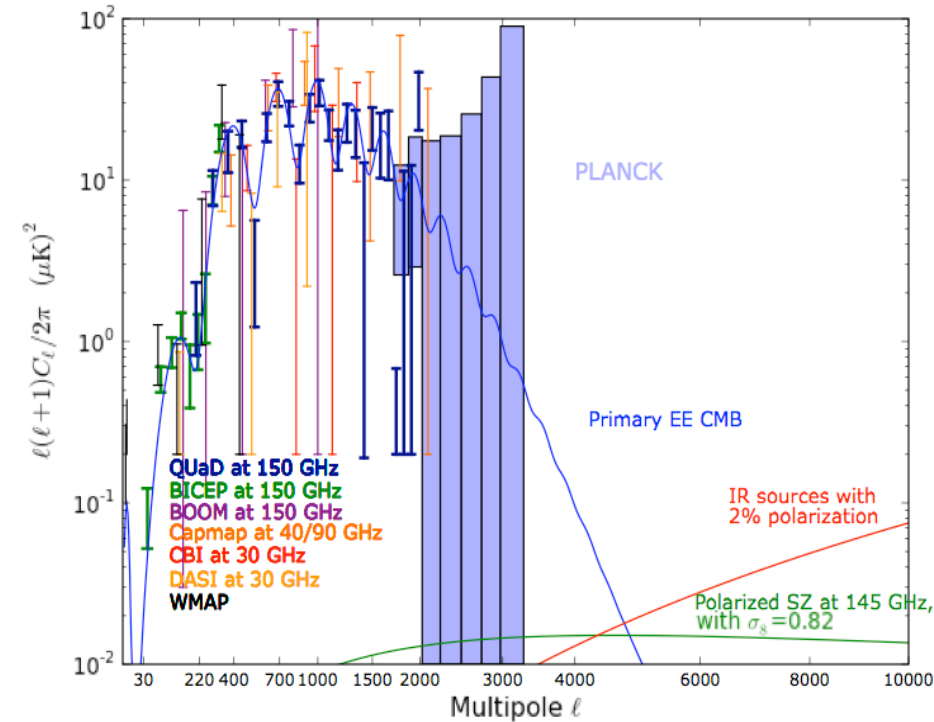


## Aside: Evidence for Dark Energy from CMB Alone – WMAP + ACT lensing

(Sherwin et al., PRL in press)



## Recent E-mode measurements



(Niemack et al., SPIE 2010)





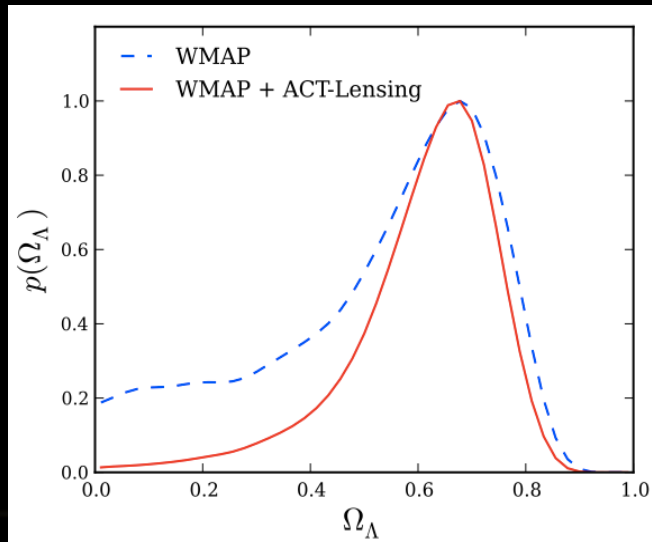
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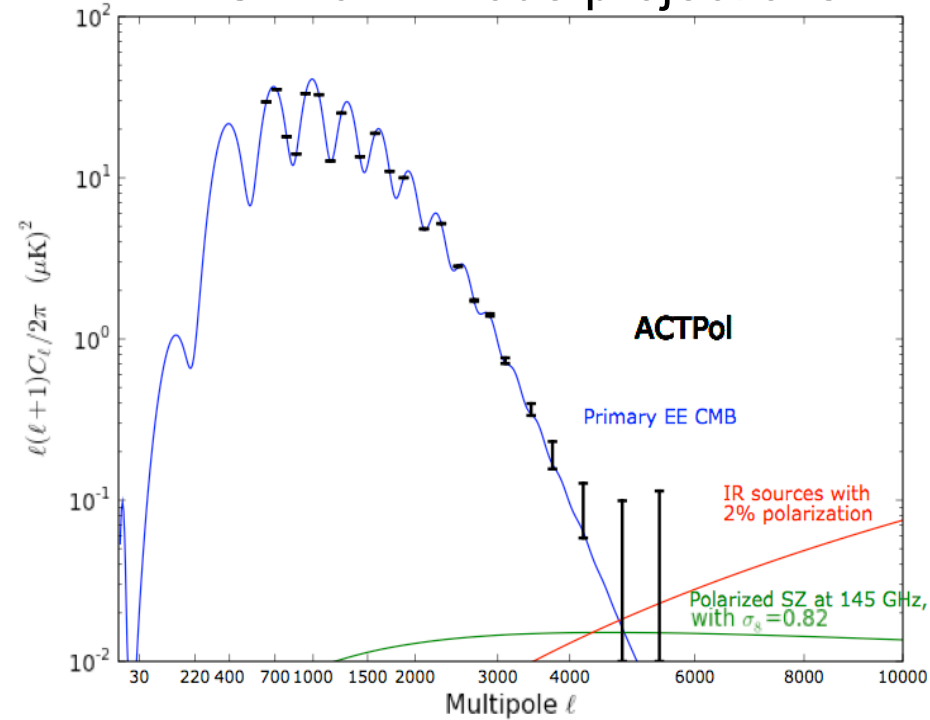


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(Sherwin et al., PRL in press)



## ACTPol E-mode projections



(Niemack et al., SPIE 2010)



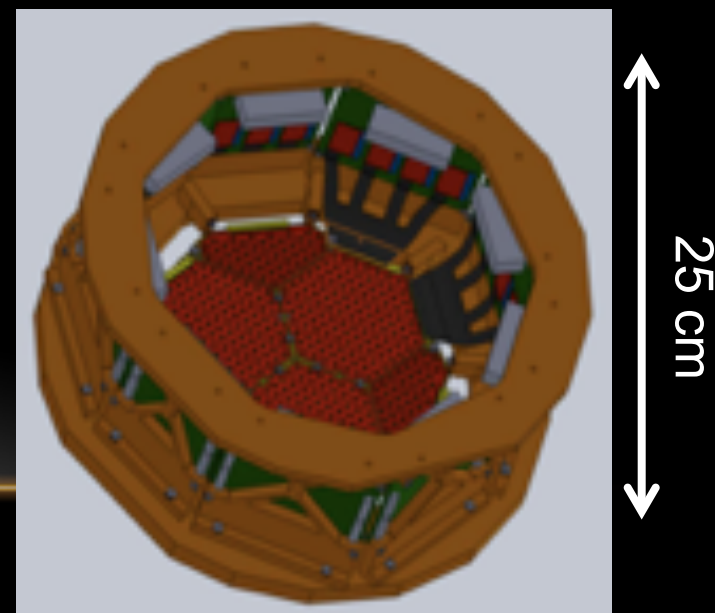
# Atacama Cosmology Telescope Polarimeter (ACTPol)

- Three Detector Arrays operated at 0.1 K
  - 2x 150 GHz arrays – 2024 TES
  - Planned **multi-chroic** 90/150 GHz ~ 1000 TES
- Superconducting Quantum Interference Device (SQUID) Readout
  - Low-temp ammeter
  - Large cryogenic arrays require multiplexing
- Time-Division SQUID Multiplexing
  - Used for a variety of TES applications



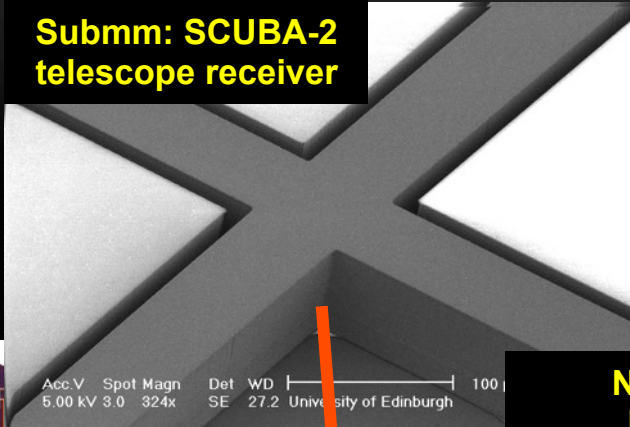
*Deploy in 2012  
and 2013!*

150 GHz ACTPol array



# Transition-Edge Sensors (TES): used across 8 orders of magnitude of wavelength

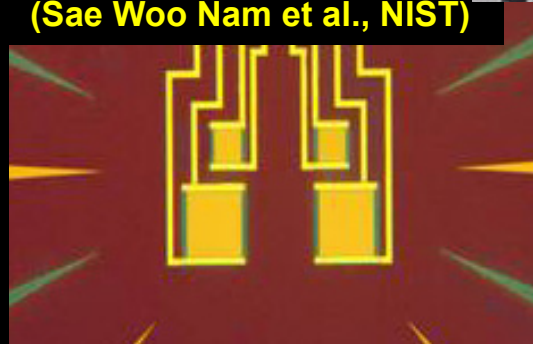
**Submm: SCUBA-2  
telescope receiver**



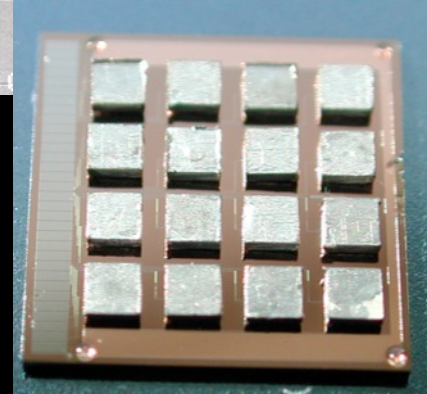
**Soft x-ray: Astrophysics,  
Synchrotron, Materials**



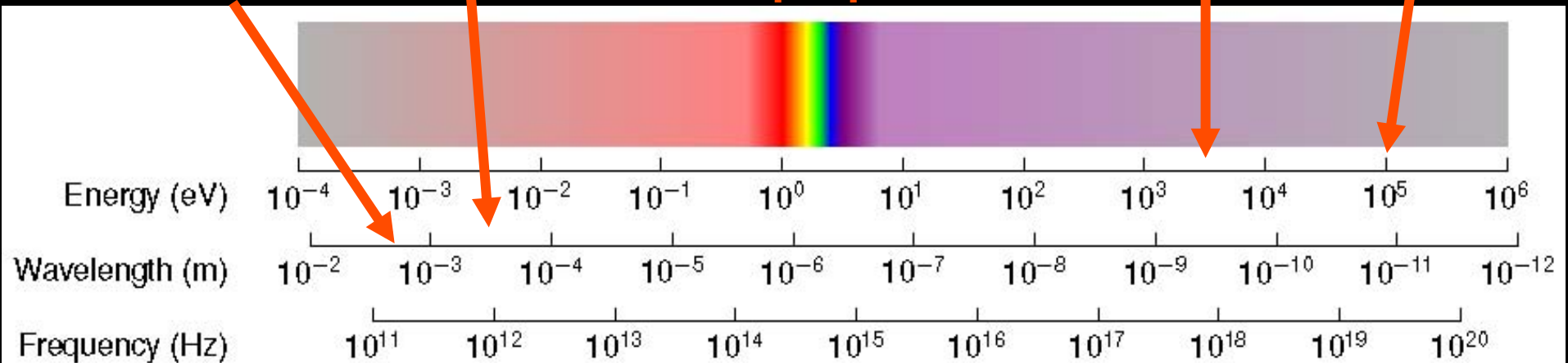
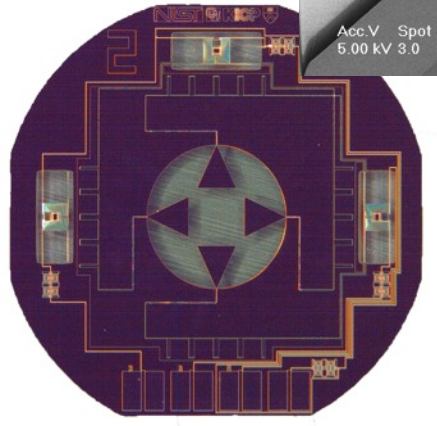
**Near IR & Optical:  
Photon Counting  
(Sae Woo Nam et al., NIST)**



**Gamma-ray: Nuclear  
Non-Proliferation**



**Millimeter: Cosmic  
Microwave Background**



# Time-Division SQUID Multiplexing of TES arrays

## 2x2 Array

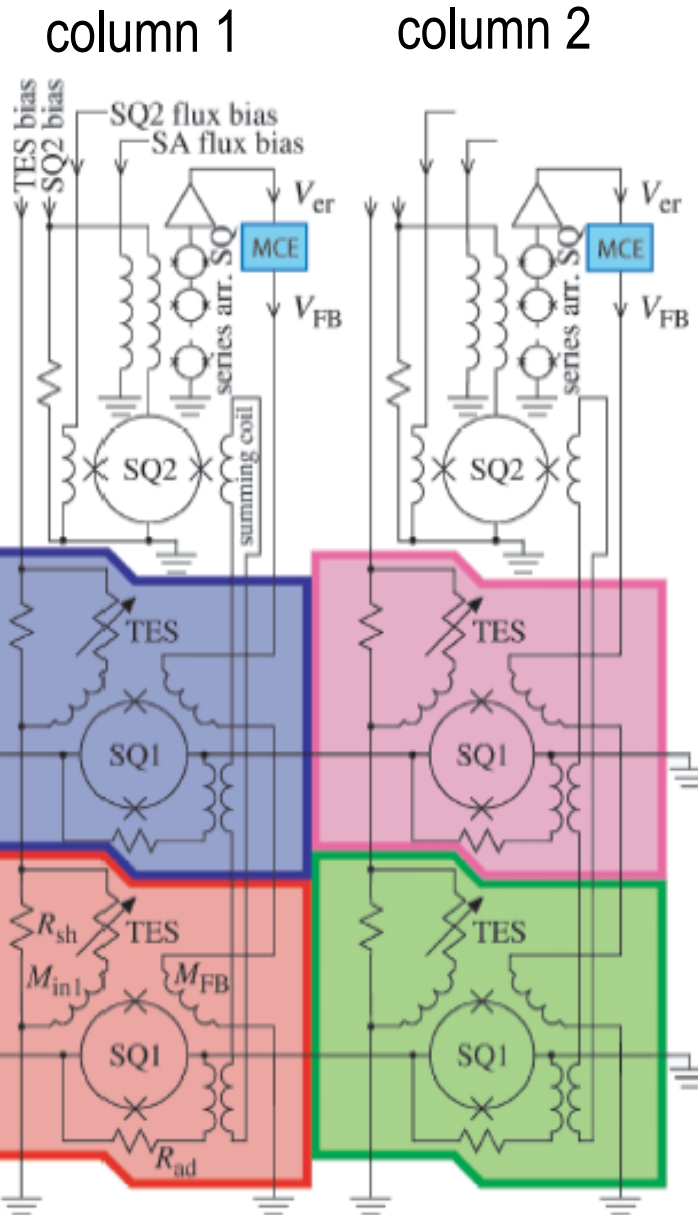
Each block  
= 1 TES

Row currents

row 1

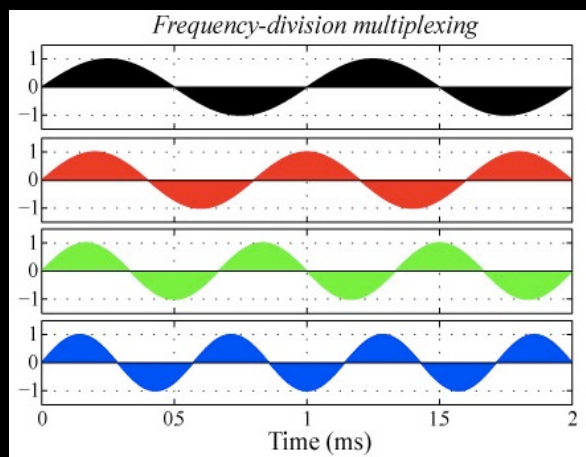
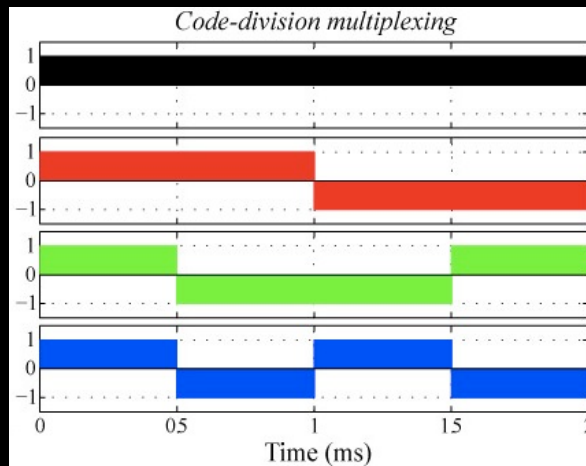
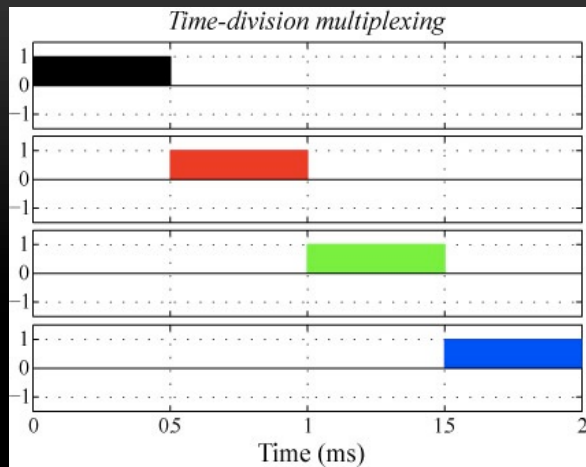


row 2



- 3 SQUID Stages
- Array readout in columns, sequential row addressing
- Reduce electrical connections by  $\sim 10x$
- Individual arrays operating with 32 columns x 40 rows

# SQUID multiplexing for larger TES arrays



## Different signal modulation techniques

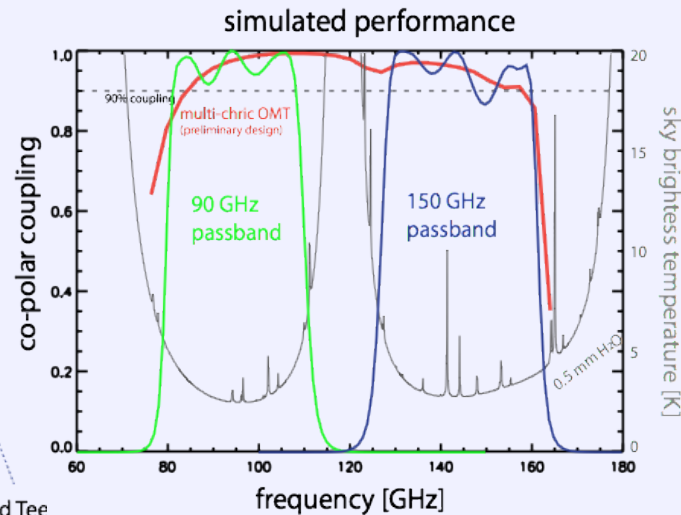
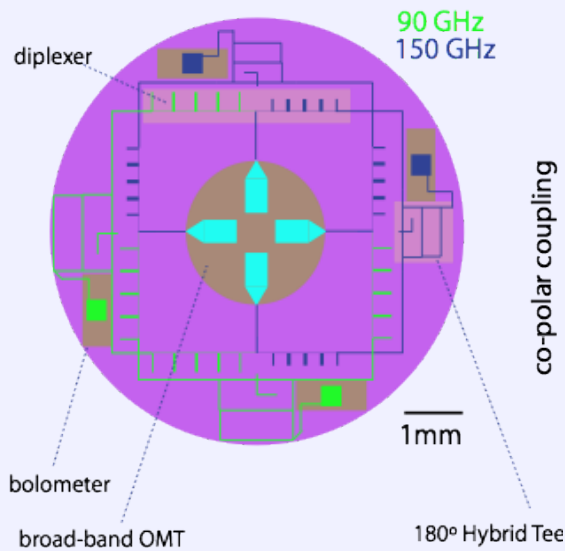
- Time-division multiplexing (Chervenak et al., APL 1999 )  
status: SCUBA-2 arrays operating with  $10^4$  TES
- Code-division multiplexing (Niemack et al., APL 2010 )  
status: 8-row demo with X-ray TES
- GHz frequency-division multiplexing  
(similar technique to MKIDs – next talk) (Mates et al., APL 2008 )  
status: working 32-row multiplexer  
Used to read out polarimeter TES  
=> no TES noise degradation

# Multi-chroic Feedhorn-coupled Polarimeters

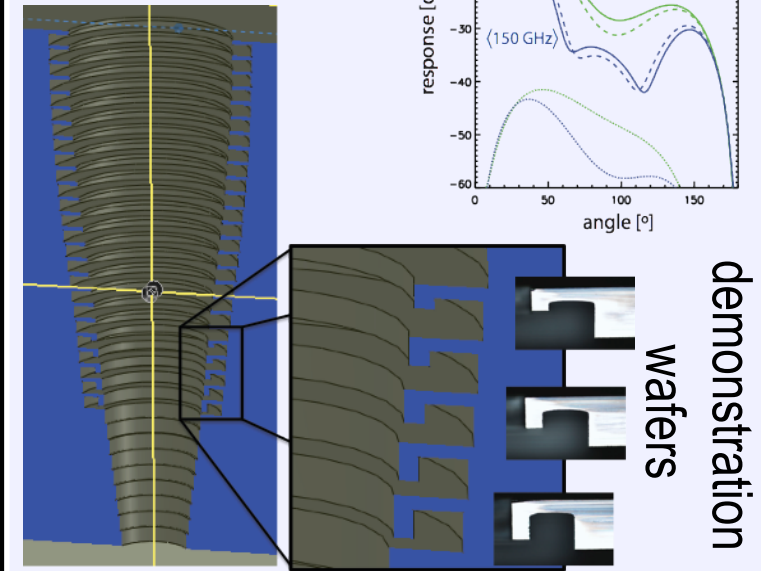
to maximize focal plane efficiency

led by J. McMahon, U. Michigan

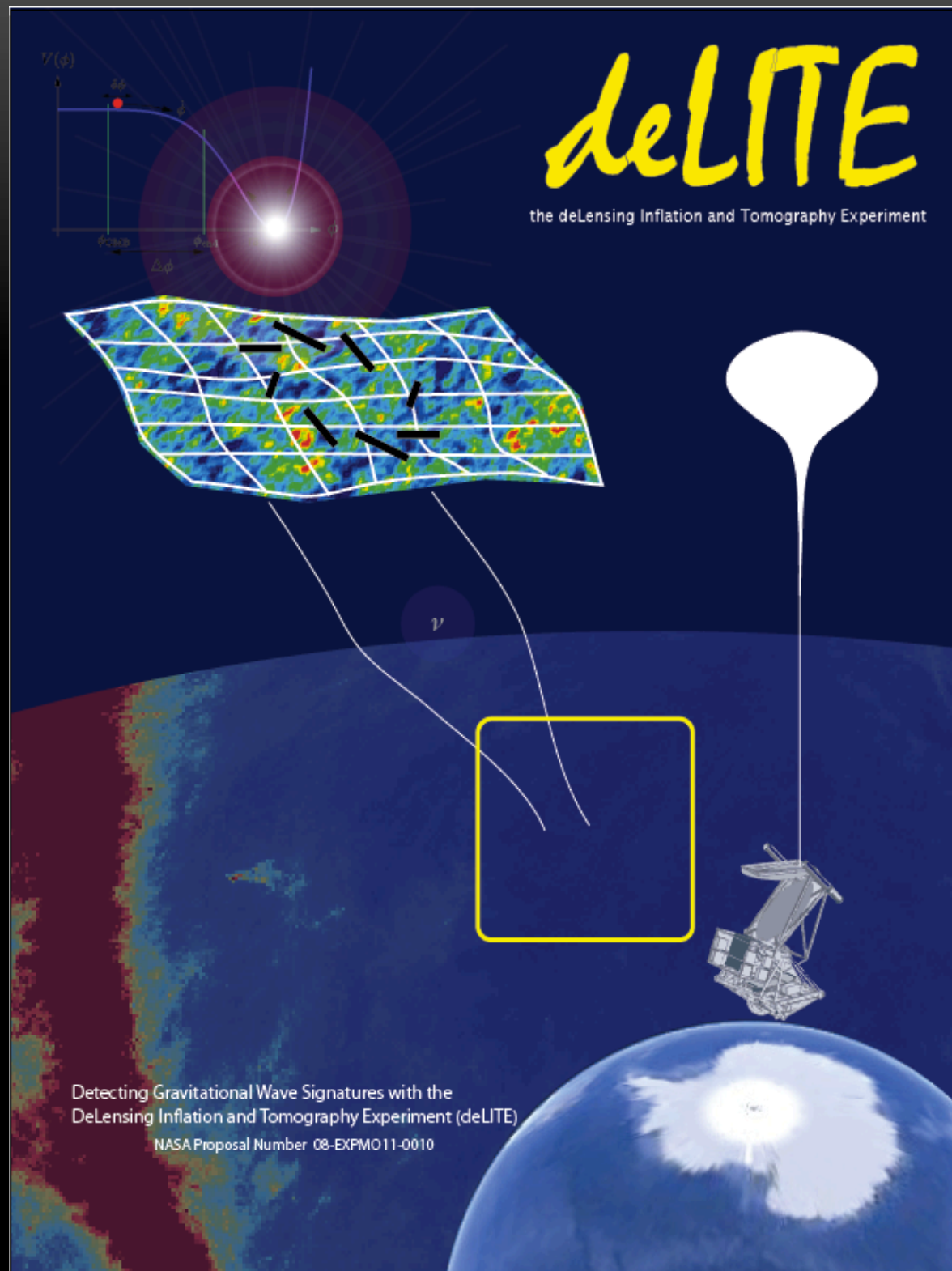
multi-chroic polarimeter design



broad-band silicon platelet horn



- One octave of single-moded bandwidth (ring loaded feedhorn + hybrid tee)
- Prototypes this summer
- Multi-chroic 90/150 GHz array of 250 horns (1000 det.) planned for ACTPol
  - Near optimal at 90 GHz + 3/4 mapping speed of optimal 150 GHz array



# deLensing Inflation by Tomography Experiment

PI: Suzanne Staggs,  
Princeton University

Collaborators:

Cardiff University

Johns Hopkins University

NIST

Oxford University

Princeton University

University of British Columbia

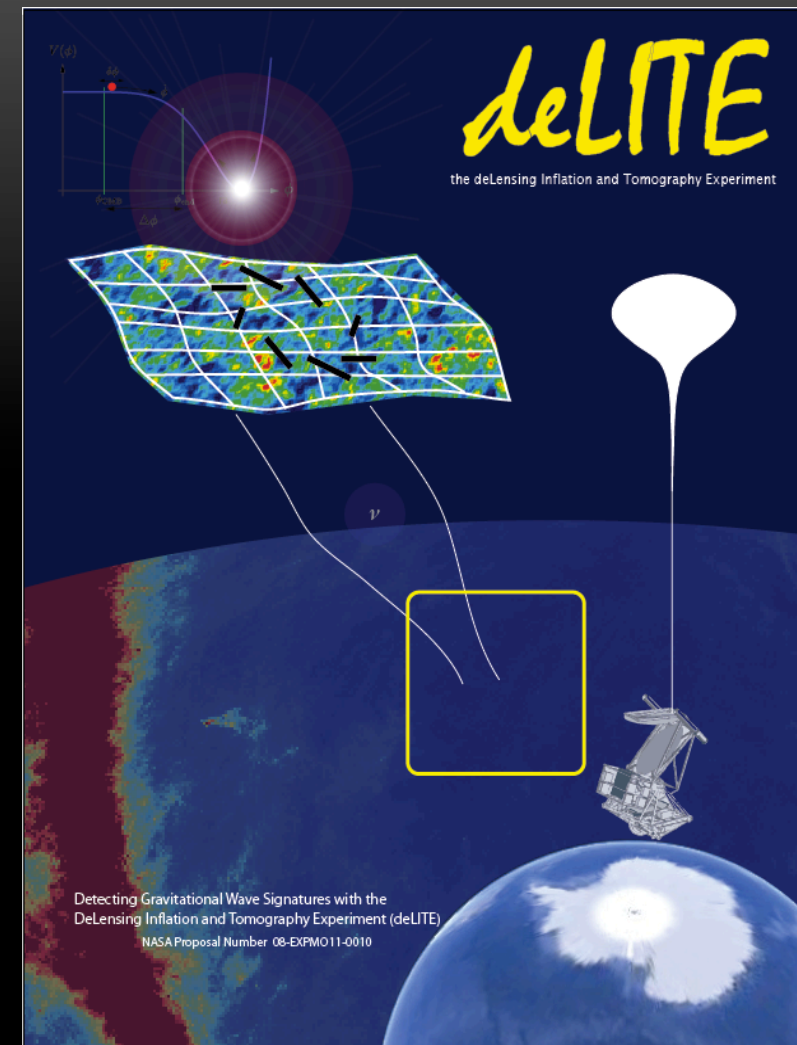
University of Colorado

University of Michigan

University of Pennsylvania

# deLensing Inflation by Tomography Experiment

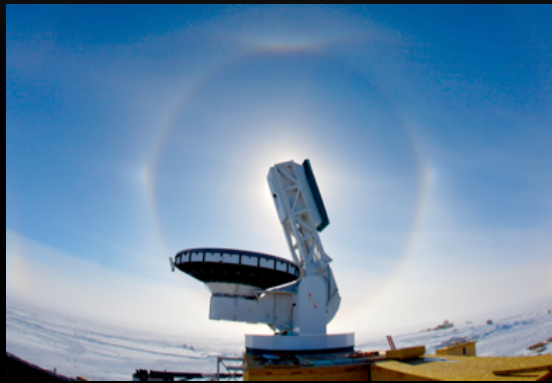
- Balloon-borne 2 m telescope
- Multi-chroic arrays
  - 100/140 and 200/280 GHz
  - 2050 feedhorns ( 8200 TES )
- Map cleanest 1000 deg<sup>2</sup> of sky
- High signal to noise measurement of lensing B-modes enables sensitive probe of  $r$
- **Projected 5-sigma limit below  $r = 0.01$**





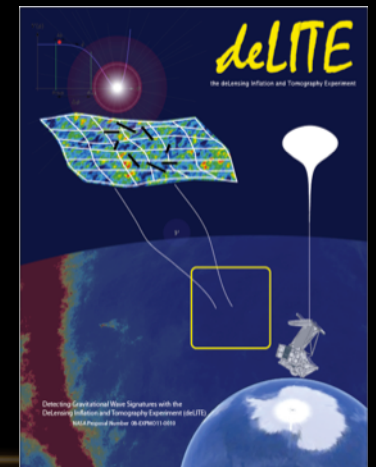
# Summary

- NIST polarimeter arrays will be deployed on ABS, SPTPoI, & ACTPoI



- Next generation multiplexing techniques will enable larger TES arrays
- deLITE – High sensitivity lensing and inflation probe

Thank you



This work is primarily supported by NIST, NSF, NASA, and collaborating institutions.