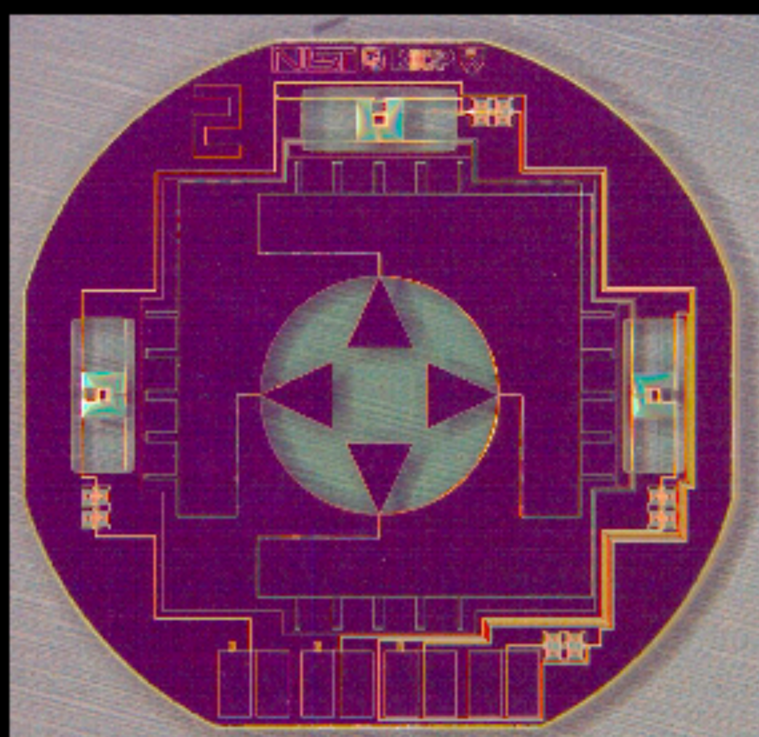
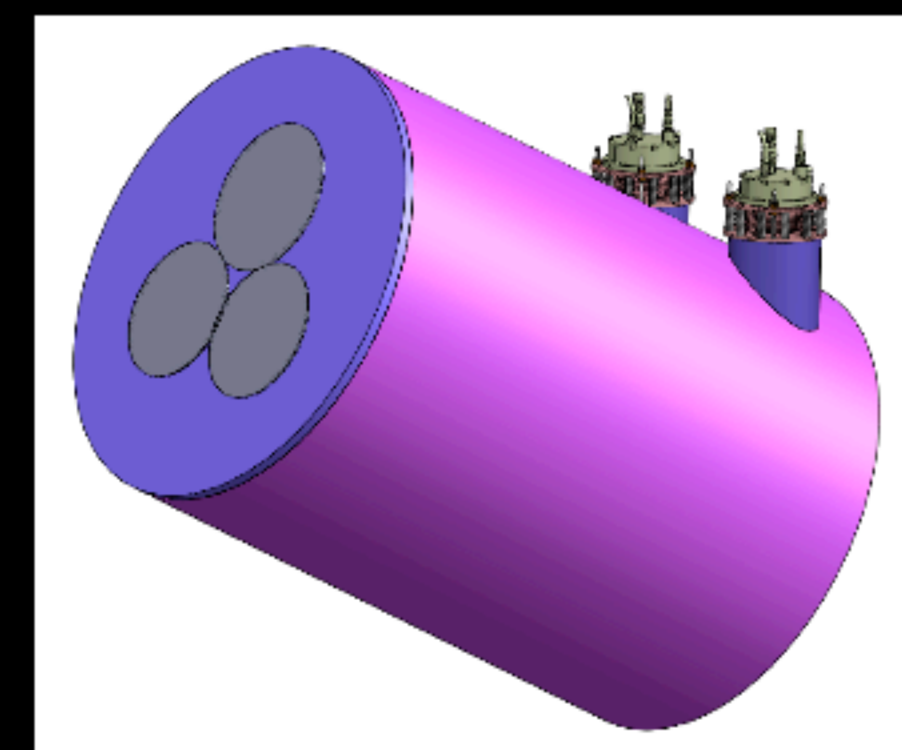
ACTpol: A polarization sensitive receiver for the Atacama Cosmology Telescope





Michael Niemack, NIST

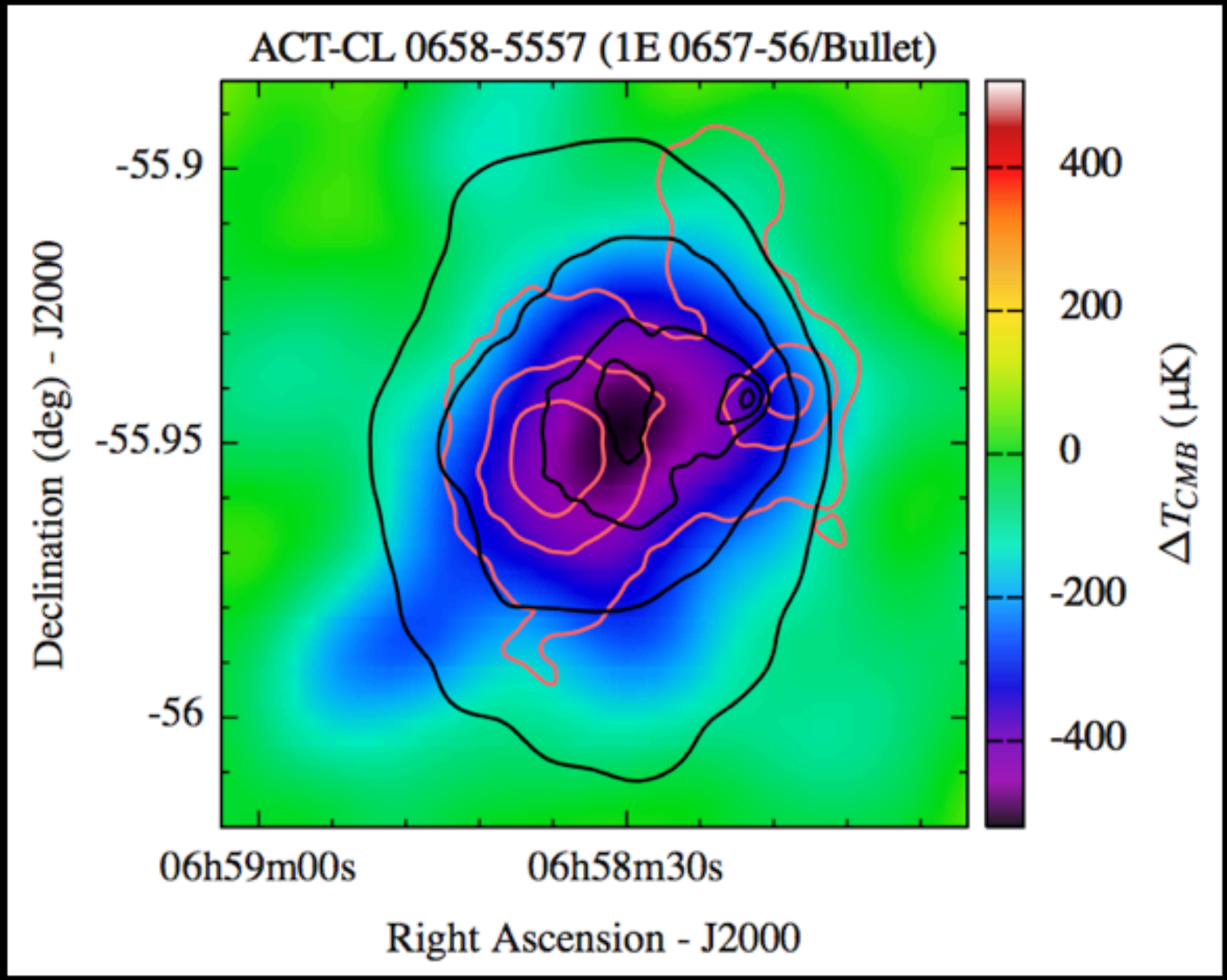
ACTpol Collaboration

Path to CMB Polarization, Chicago

July 2, 2009

Atacama Cosmology Telescope (ACT)

- Began 3-band observations in 2008 from the Atacama Plateau, Chile
  - MBAC - 145, 220, & 280 GHz
  - Three 1024 TES bolometer arrays with 1/2 $F\lambda$ to 1 $F\lambda$ spacing
- Primary Observations Underway
  - Temperature power spectrum, $l \sim 10{,}000$
  - SZ cluster catalog

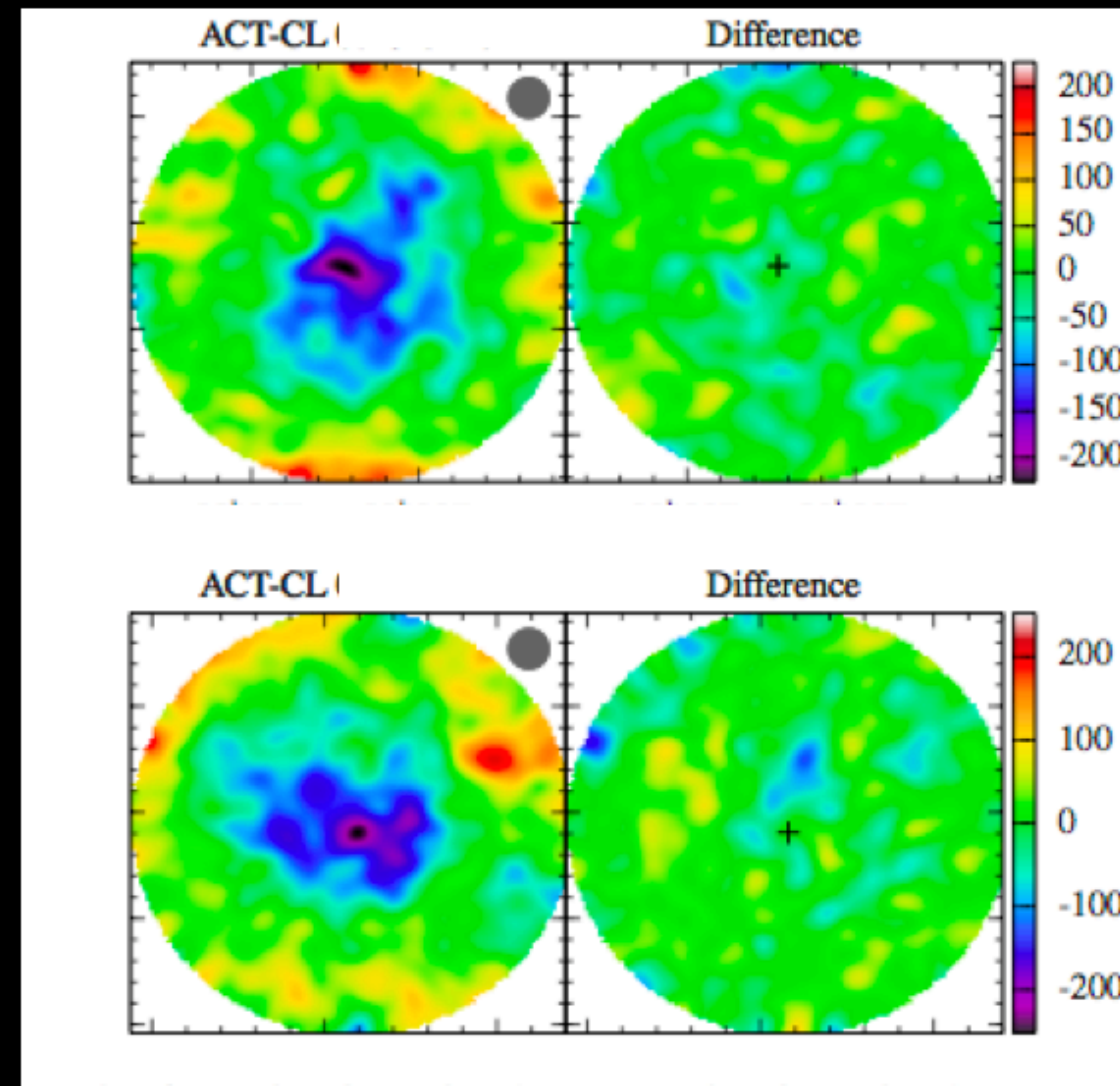


ACT Collaboration:

Atacama Cosmology Telescope (ACT)

- Began 3-band observations in 2008 from the Atacama Plateau, Chile
  - MBAC - 145, 220, & 280 GHz
  - Three 1024 TES bolometer arrays with 1/2 $F\lambda$ to 1 $F\lambda$ spacing
- Primary Observations Underway
  - Temperature power spectrum, $l \sim 10{,}000$
  - SZ cluster catalog

Blind Cluster Candidates



(Hincks et al. 2009, submitted, arXiv soon!)

ACT Collaboration:

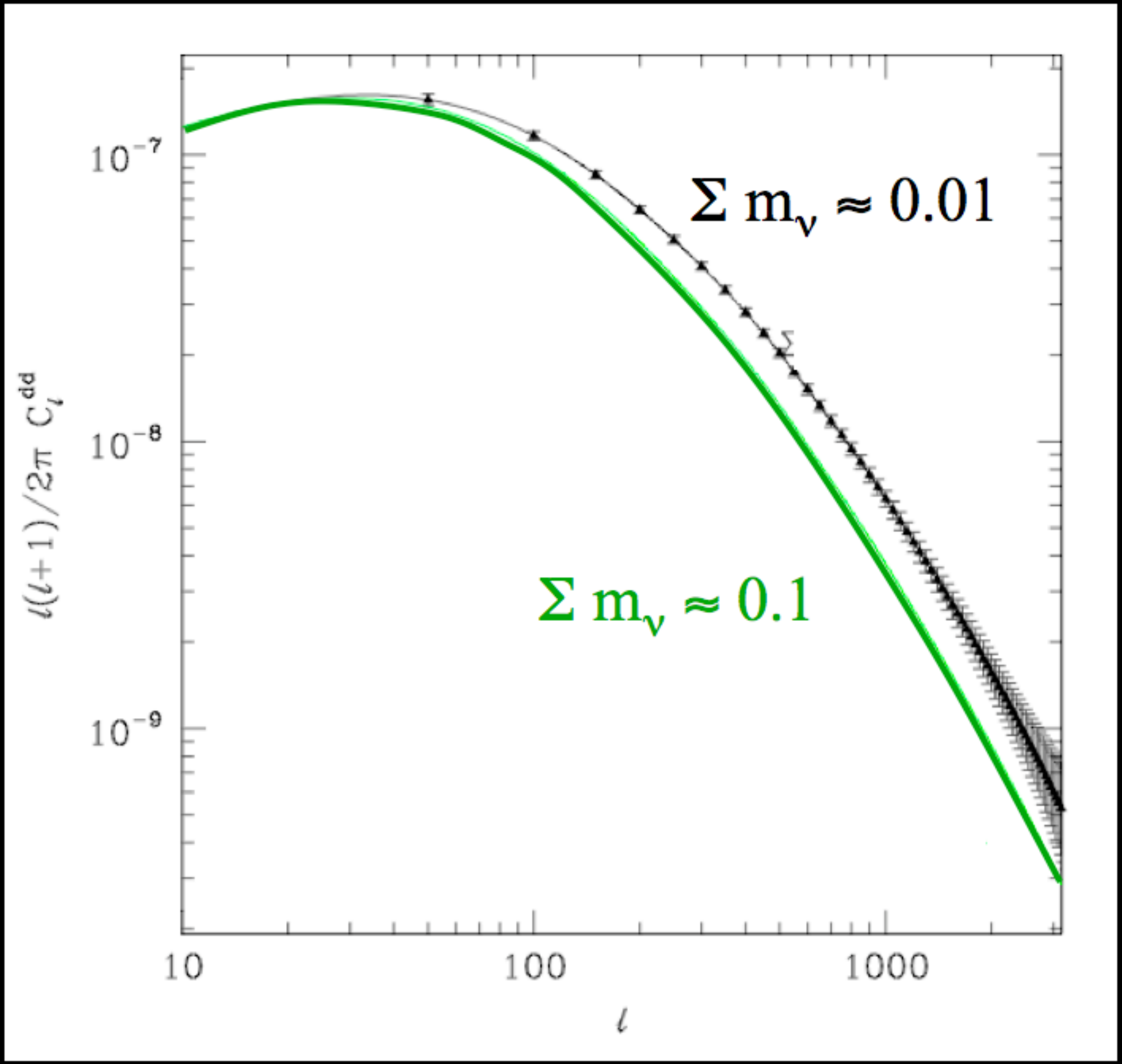
ACTpol Experiment Summary

Frequencies	90, 150, 220	GHz
Angular resolutions	2.5, 1.5, 1.0	arcmin at each freq
Field centers and sizes	Wide - 4000 deg^2 Deep - 5x 30 deg^2	Ra/Dec/Sq-Deg
Telescope type	Gregorian/Lenses	Refractor, Gregorian, Compact-range etc
Polarization Modulations	Sky rot. and scan, waveplate?	Waveplate, boresight rot., sky rot., scan etc. – list all that apply
Detector type	Bolometer	Bolometer, HEMT etc.
Location	Atacama, Chile	
Instrument NET	Spec. 300/det => 8 Goal 210/det => 5	$\mu K\ s^{1/2}$
Observation start date	2^{nd} quarter 2012	
Planned observing time	3000 hours in 2 years	Elapsed/effective days
Projected limit on *r*	n/a	

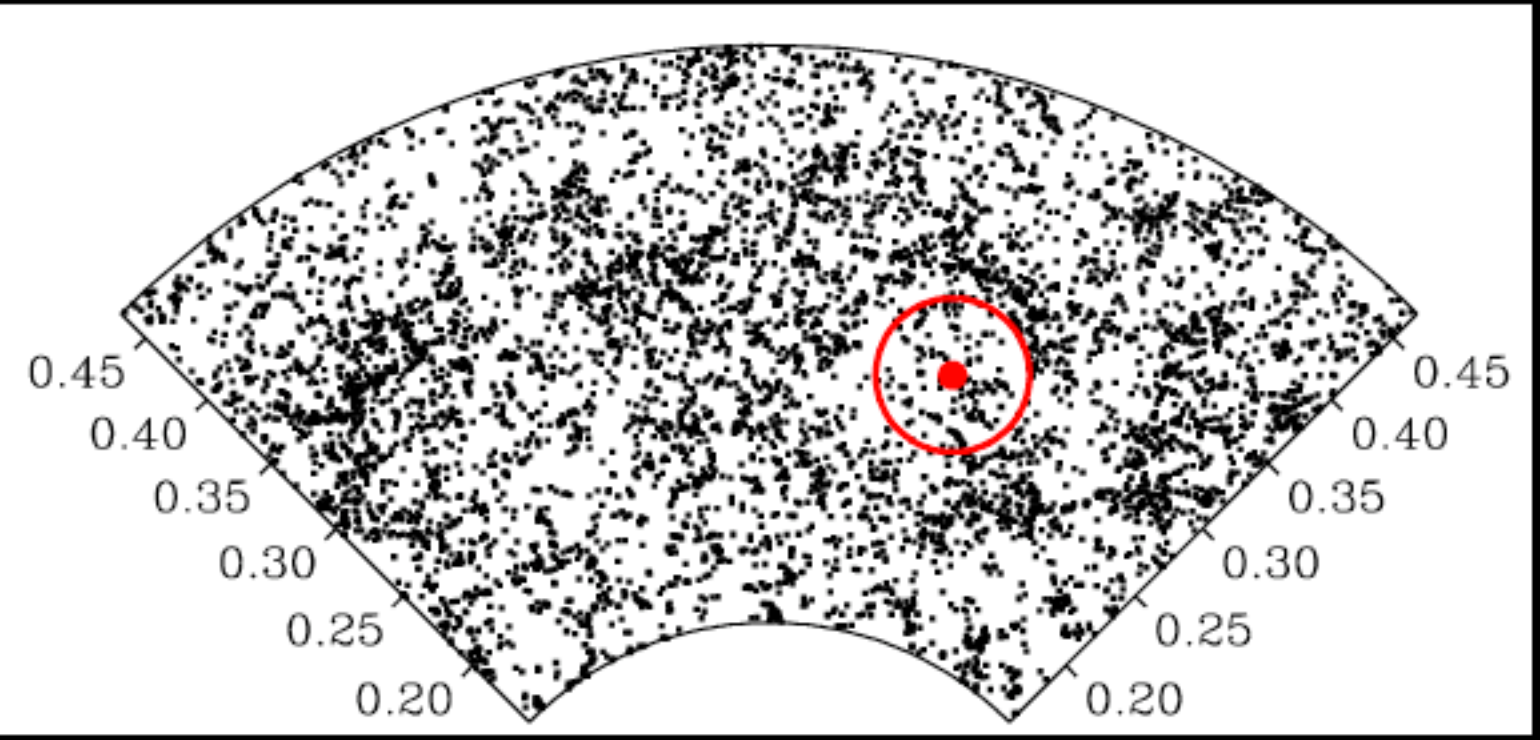
ACTpol Science

- High l power spectra
  - TT constrains n_s
  - EE constrains running of n_s
- Lensing deflection field
  - Matter fluctuations at z ~ 2
  - Constrain sum of neutrino masses and dark energy
- Non-Gaussianity
- <u>Improved SZ sensitivity</u>
- Cross-correlations

Deflection field power spectrum



ACTpol Science Cross-correlations

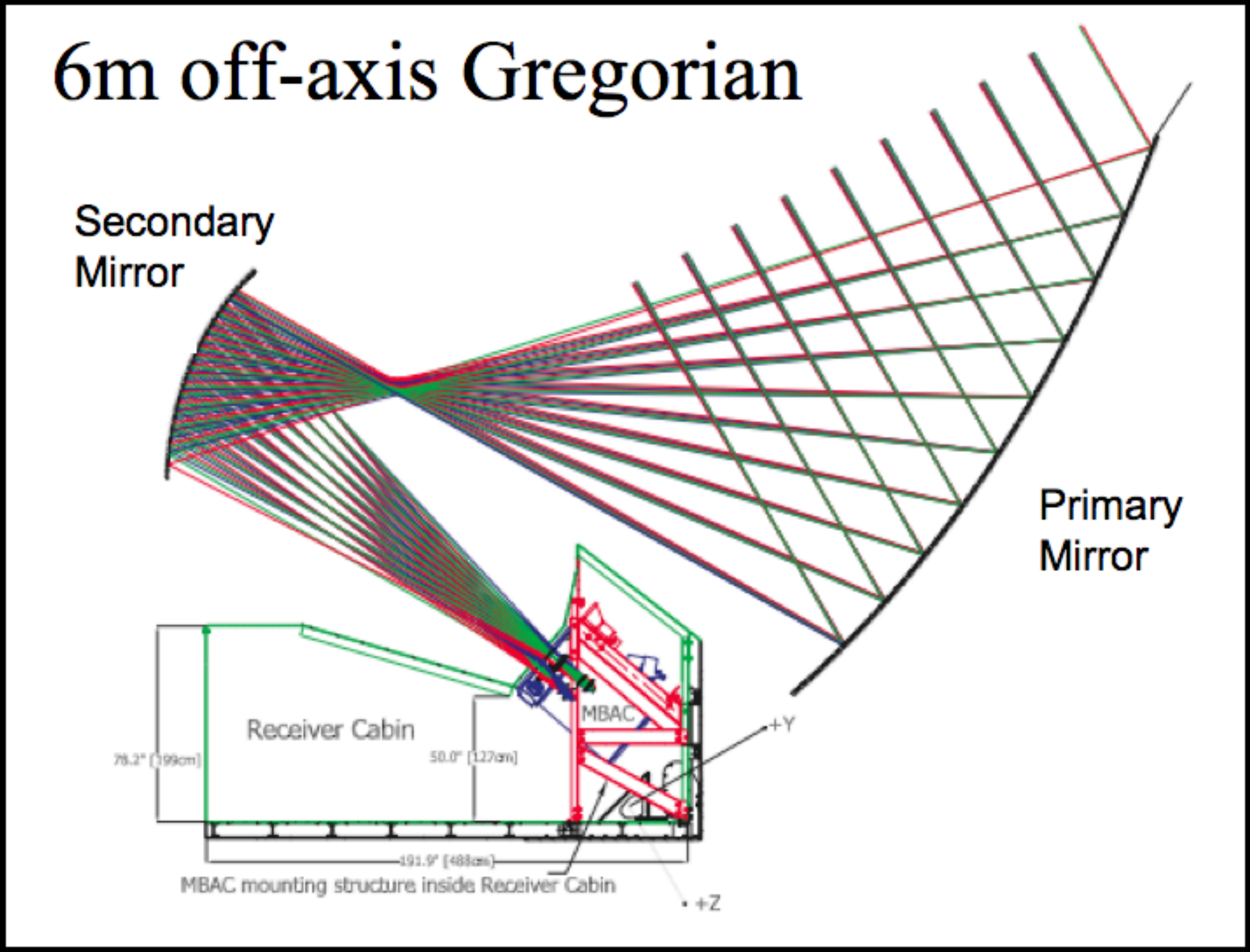


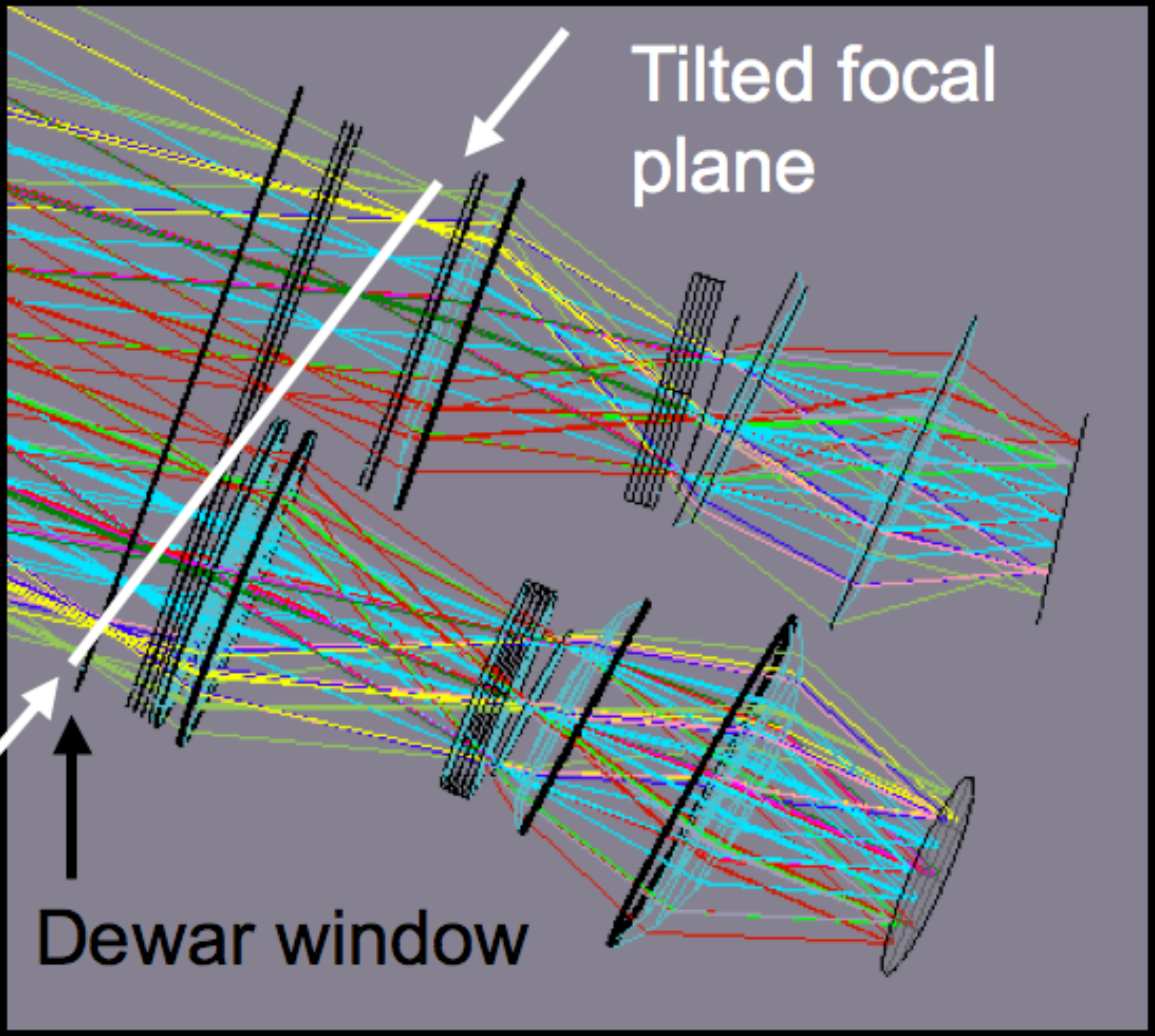
- SDSS-III's Baryon Oscillation Spectroscopic Survey (BOSS)
  - 10,000 square degrees
  - Spectroscopic z of 1.5 million galaxies to $z = 0.7$
  - Lyman-α forests of 160,000 quasars at redshifts $2.2 < z < 3$
  - Fall 2009 - Spring 2014

- Cross-correlation examples
  - Lensing & LRGs, Lyman-α Forests, Quasars with S/N of 20-40
    => Galaxy and matter power spectra vs. z
  - kSZ & Galaxies with S/N ~ 20
    => Find missing baryons

ACTpol Optics

- Off-axis "aplanatic" Gregorian
  - Ellipsoidal primary
    - => Wider field of view
    - => Tilted focal plane
  - Need to remove tilt for a feedhorn array

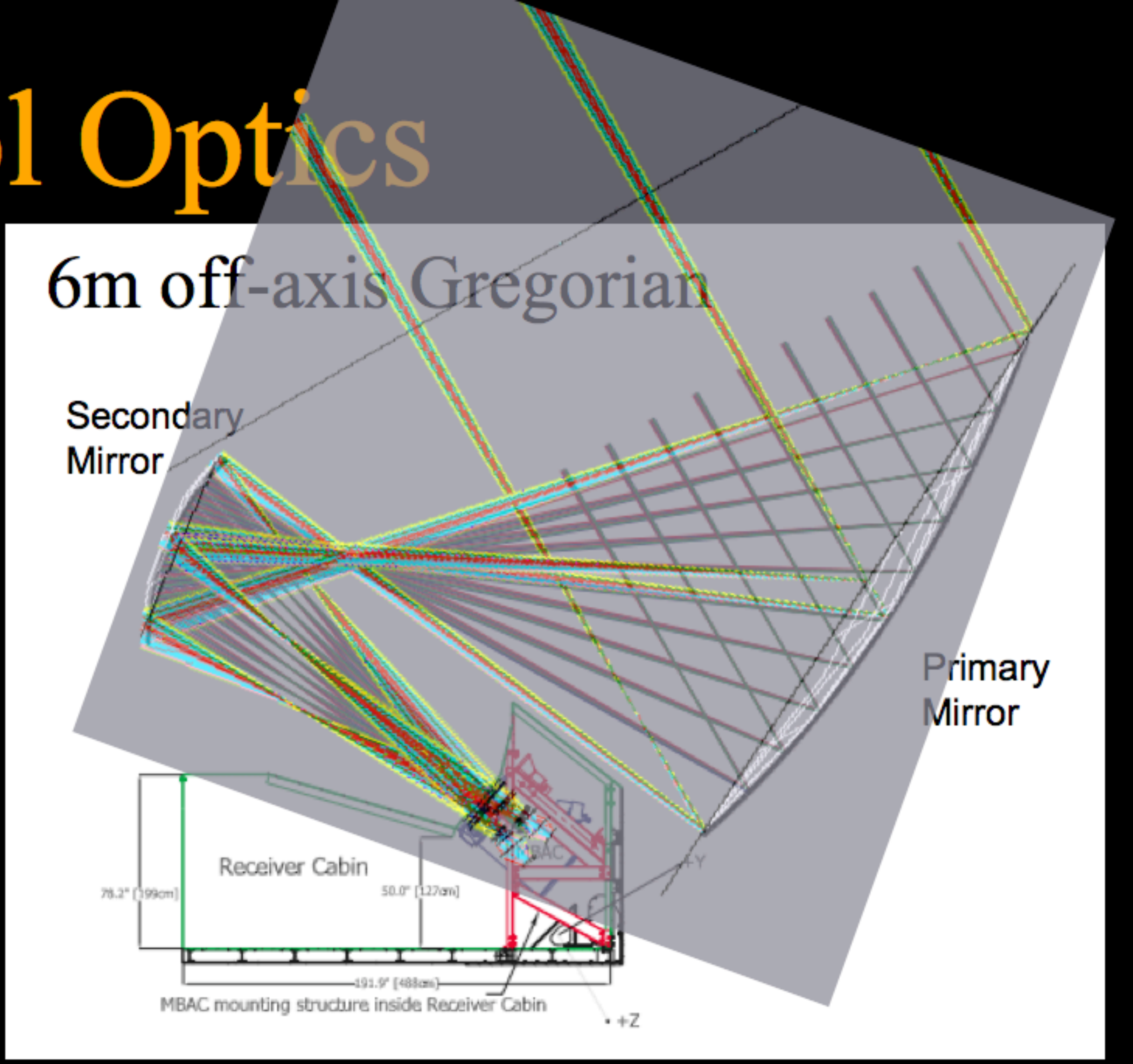


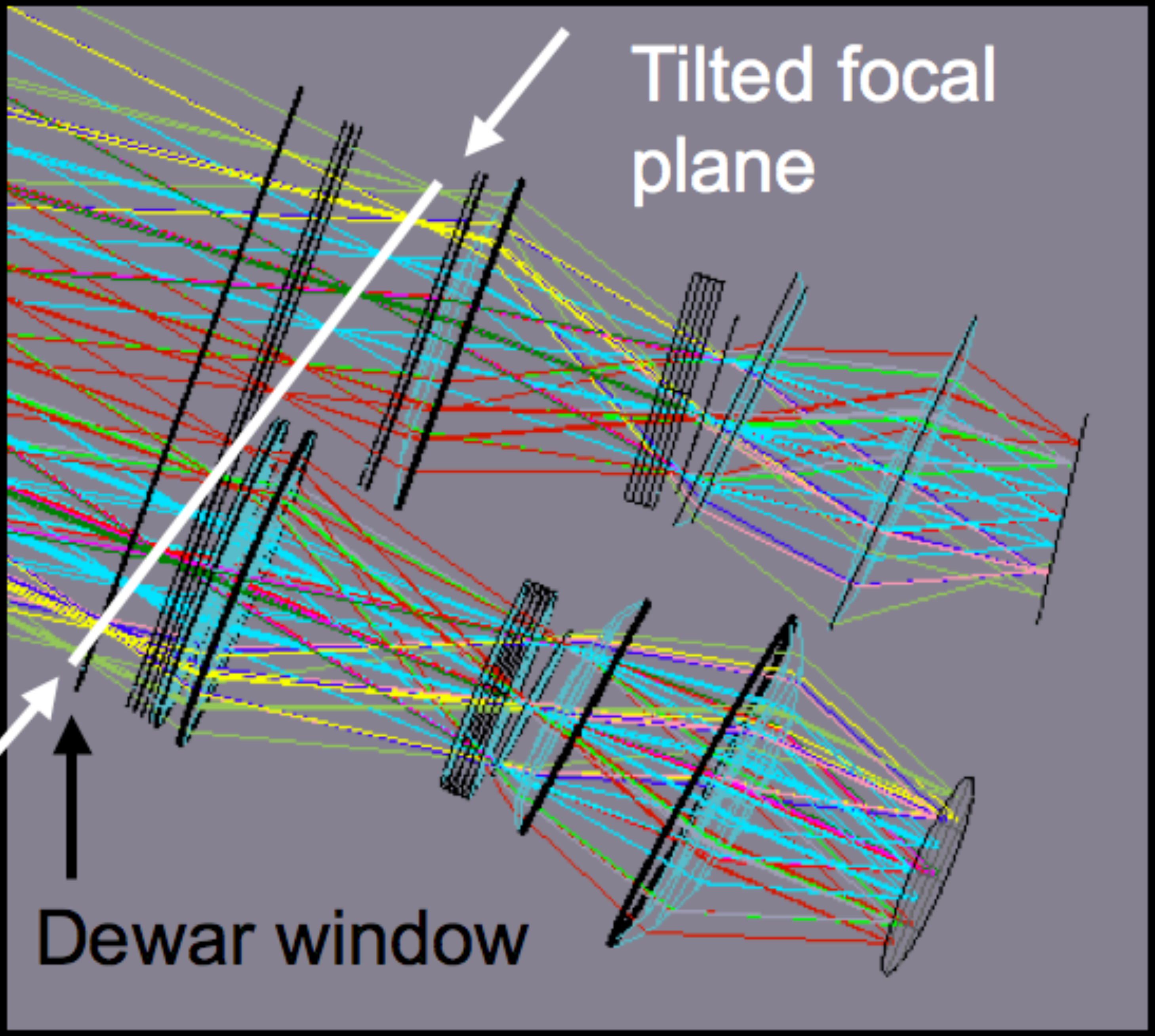


- Target horn spacing ~1.7 $F\lambda$
  - => ~ 1° FOV for ~600 det. at 150 GHz

ACTpol Optics

- Off-axis "aplanatic" Gregorian
  - Ellipsoidal primary
    => Wider field of view
    => Tilted focal plane
  - Need to remove tilt for a feedhorn array



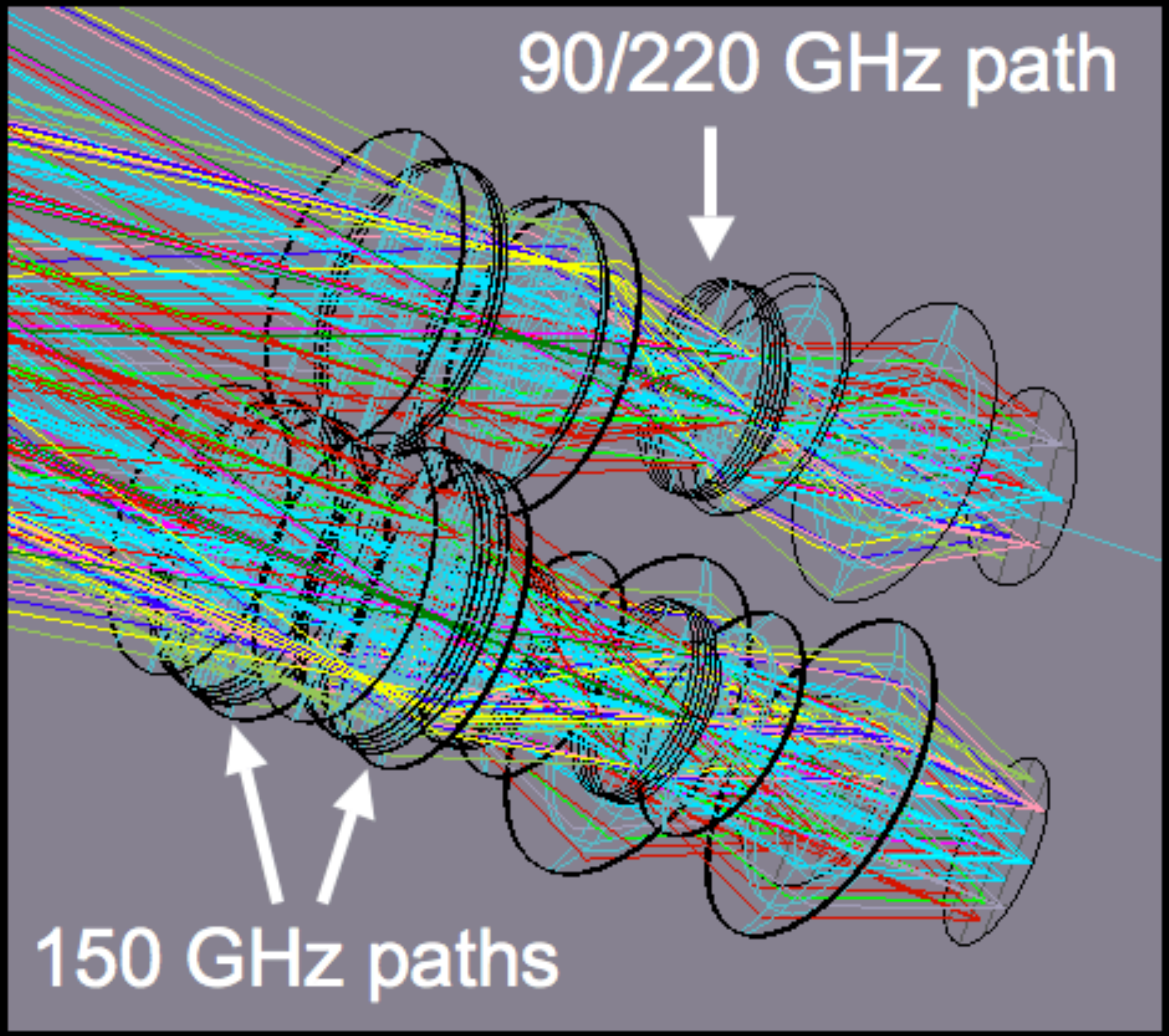


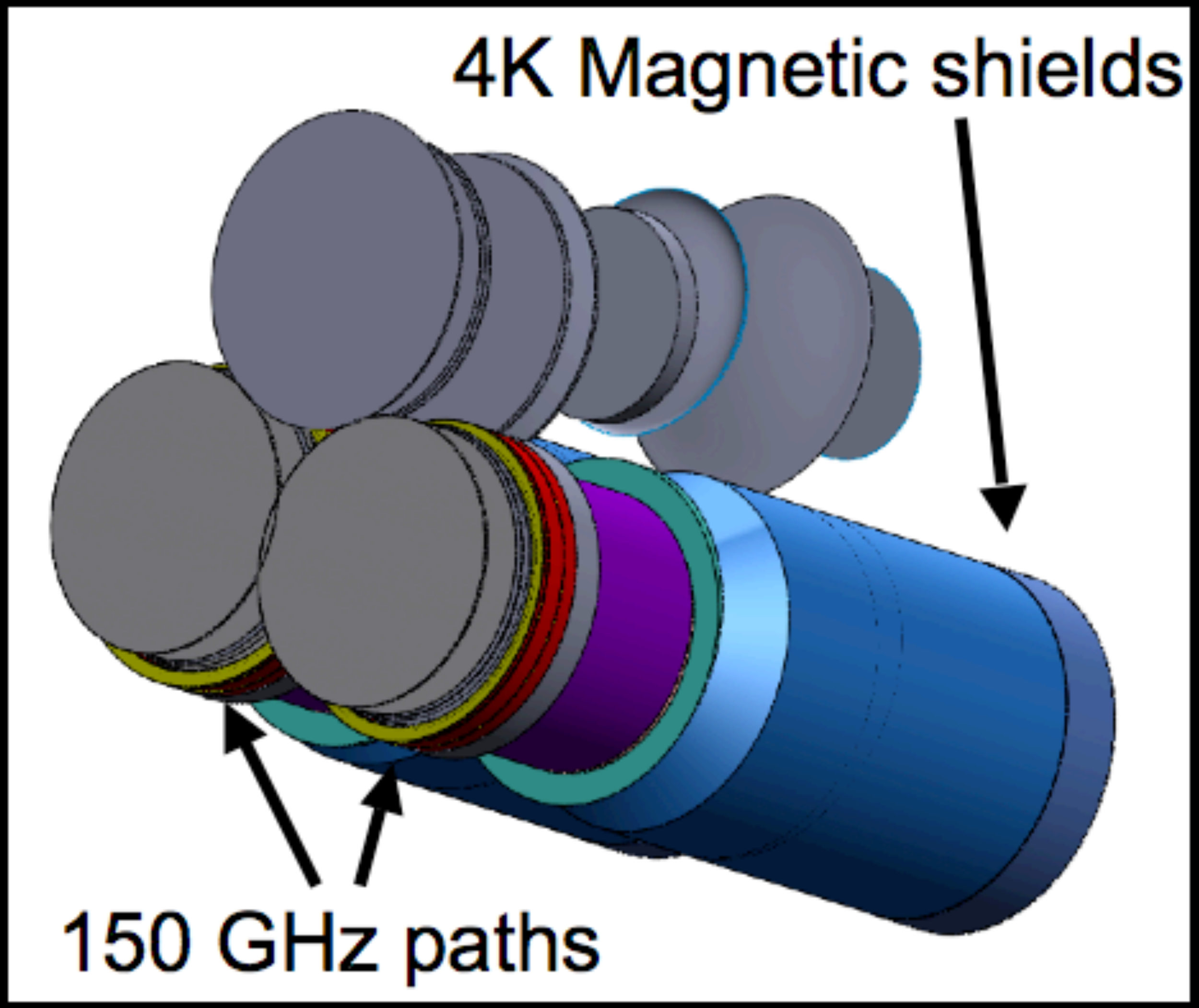
- Target horn spacing ~1.7 $F\,\lambda$
  => ~ 1° FOV for ~600 det. at 150 GHz
- Silicon lenses
  - Proven in MBAC
  - Multiple optical paths

ACTpol Optics

- Three independent optical paths
  - ~5x FOV of MBAC
  - Two 150 GHz optical paths
  - Third path switches between 90 & 220 GHz

- Silicon lenses (n ~ 3.4)
  - Up to 395 mm diameter
  - High thermal conductivity
  - High efficiency
  - Anti-reflection coating
    - Cirlex used in MBAC
    - Laser machining
  - Developing testing facilities at NIST





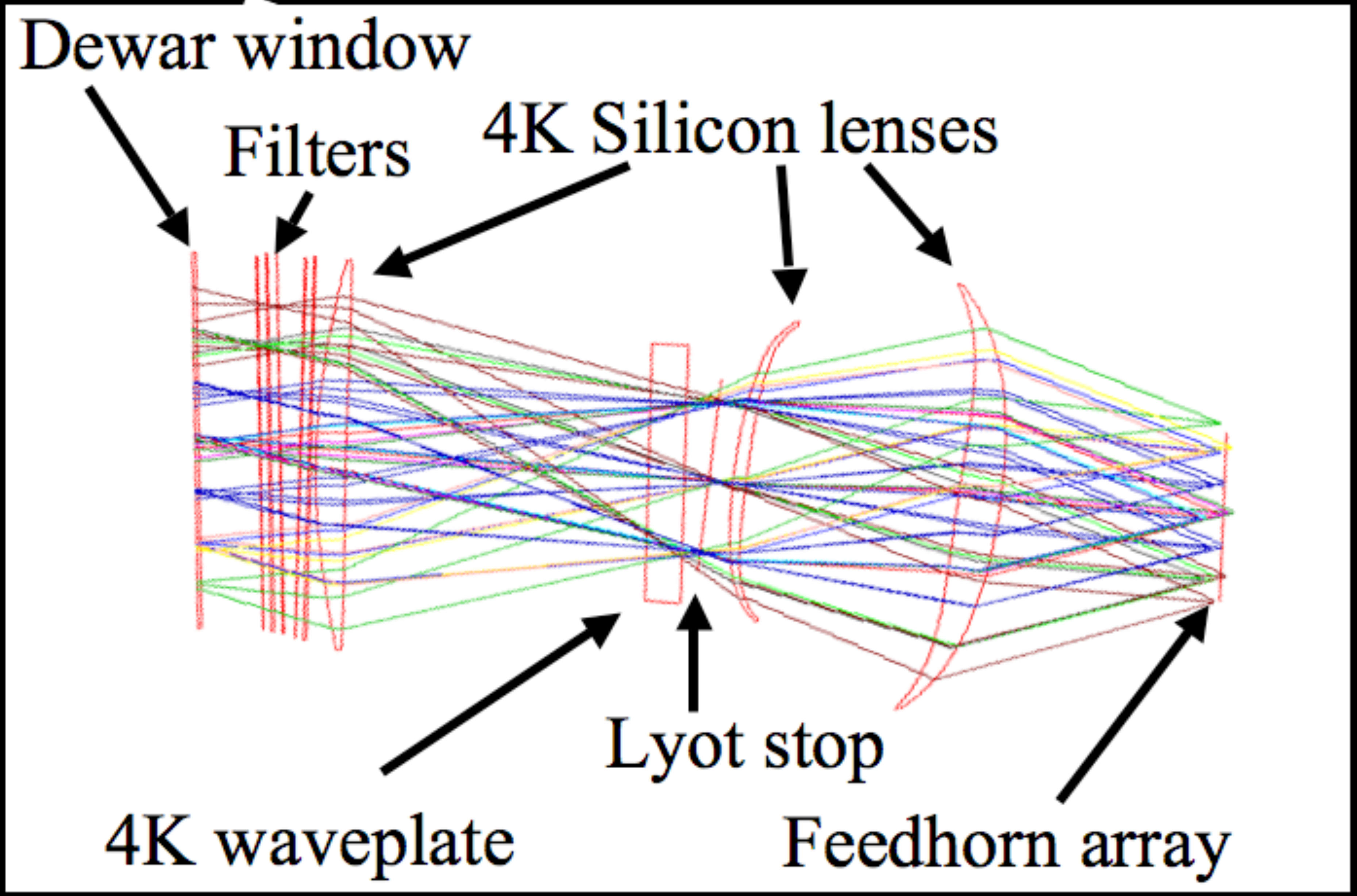
ACTpol Optics

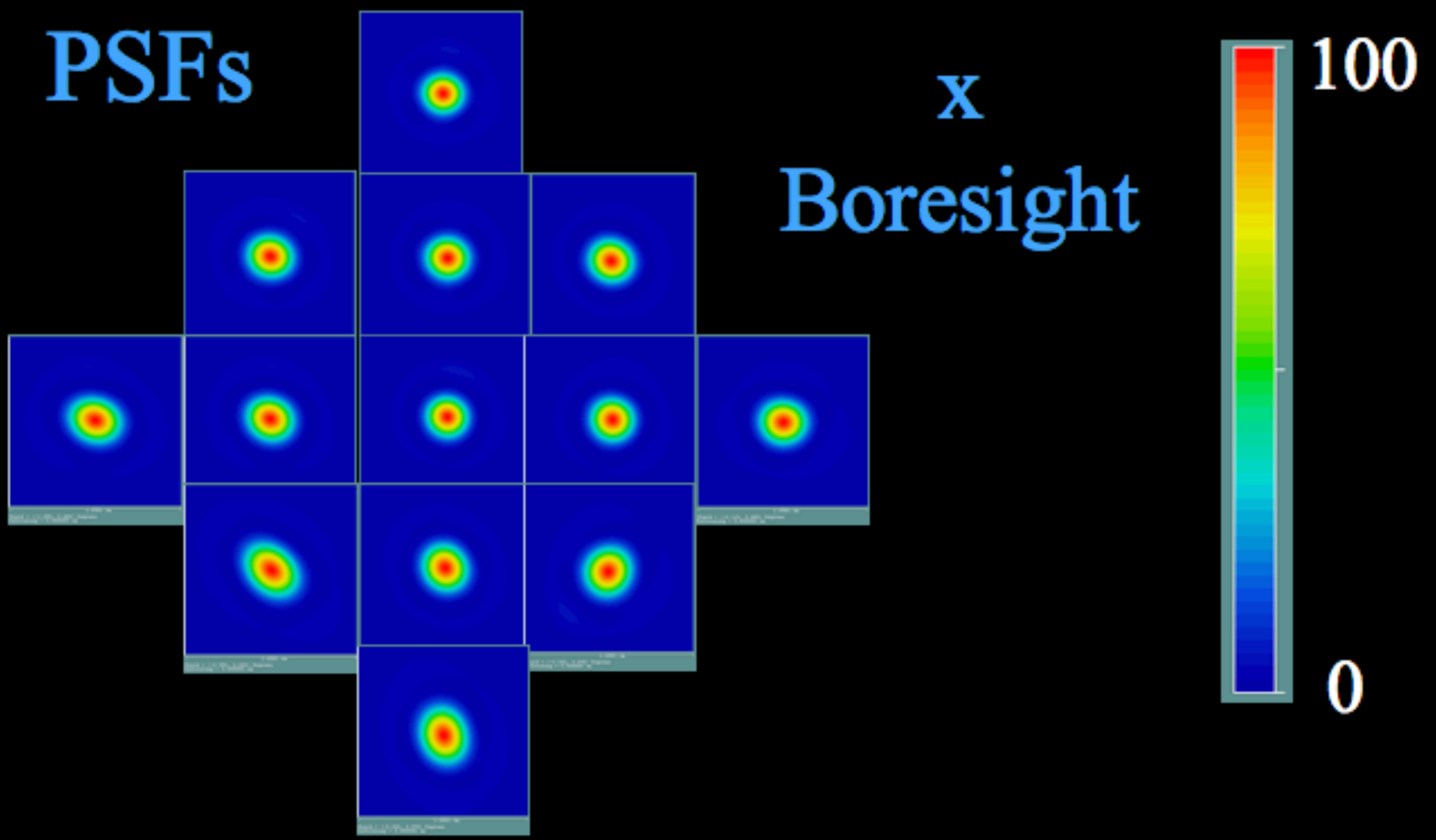
- Design requirements
  - ~ 1° FOV per array
  - Telecentric
  - 4K Lyot stop
    (~ 5.8 m primary illumination)

- Focal plane tilt removed with tilted and offset aspheric lenses
  - To do: Reduce lens curvature

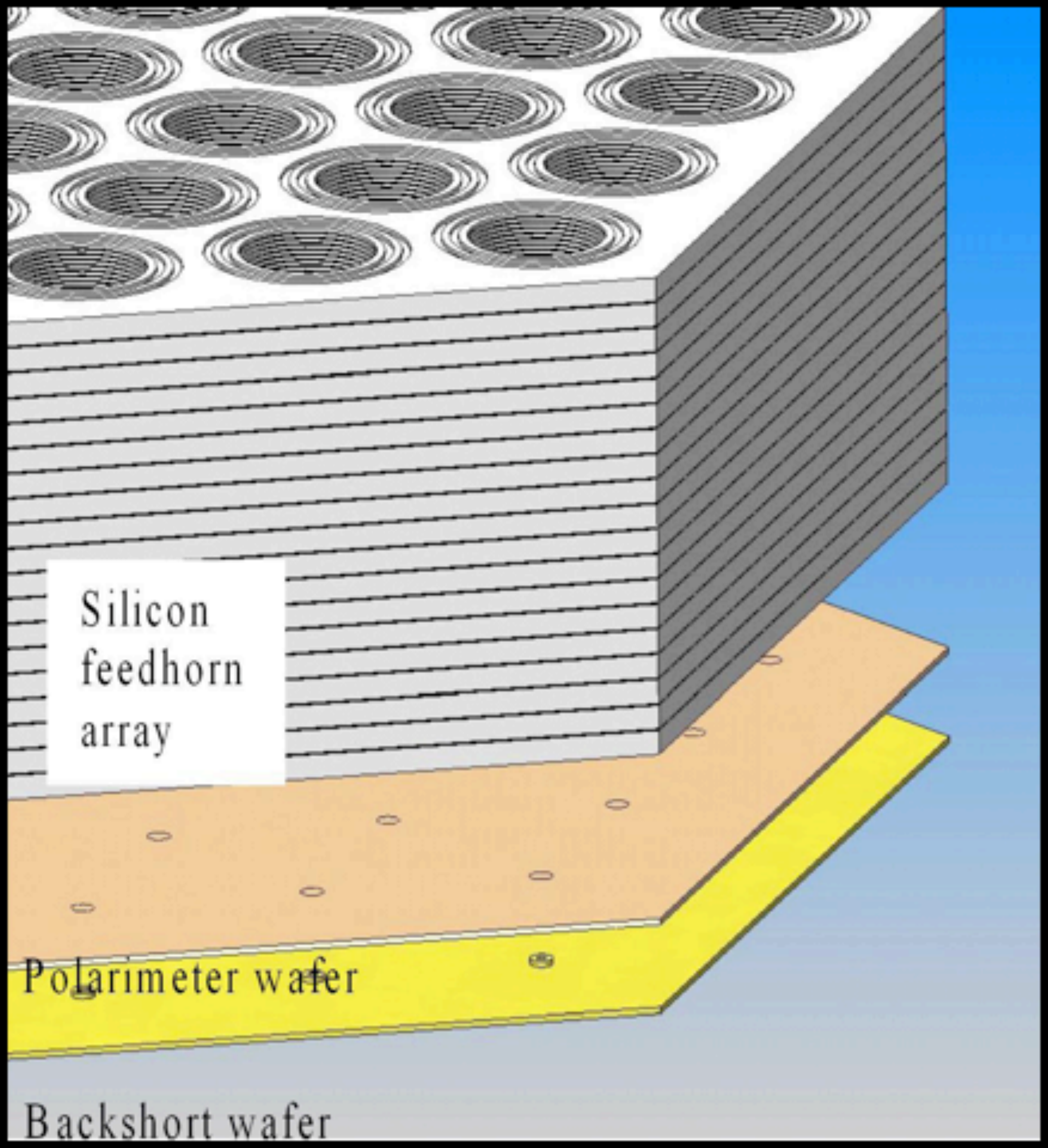
- Optional 4K waveplate

- 150 GHz Analysis
  - Strehl ratios > 0.95
  - Symmetric PSFs



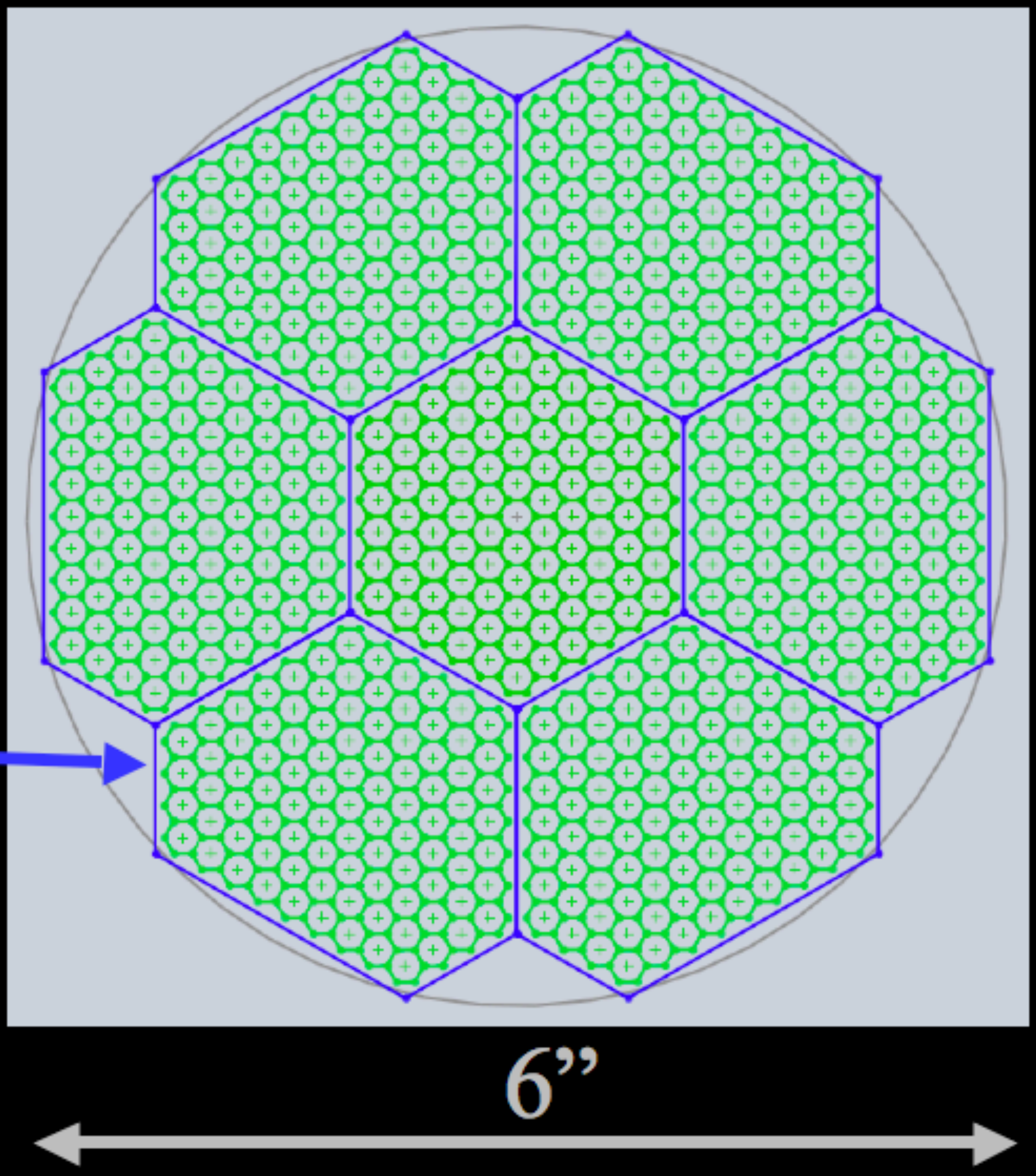


NIST Arrays



- Micromachined silicon feedhorn arrays
  - Gold-plated stack of 6” silicon wafers
  - Easily corrugated
  - Thermally matched to detector arrays

- Baseline 150 GHz array layout
  - 5 mm horn spacing
  - Seven 3” detector wafers
  - 640 polarimeters (1280 TESs)
  - MCE 32x41 TDM readout

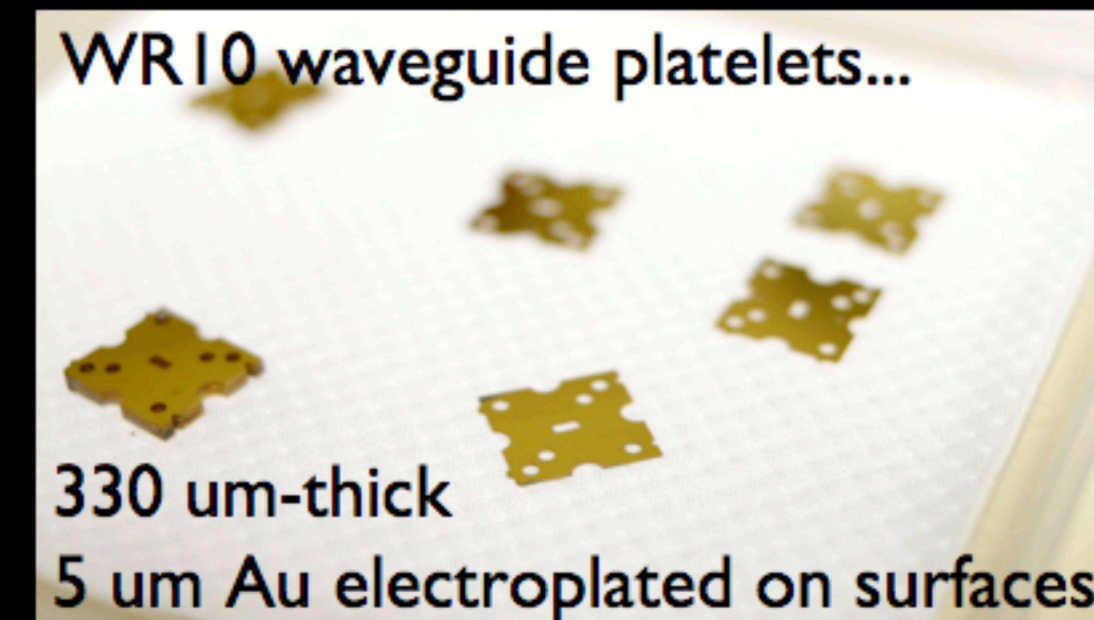


ACTpol, Michael Niemack, NIST

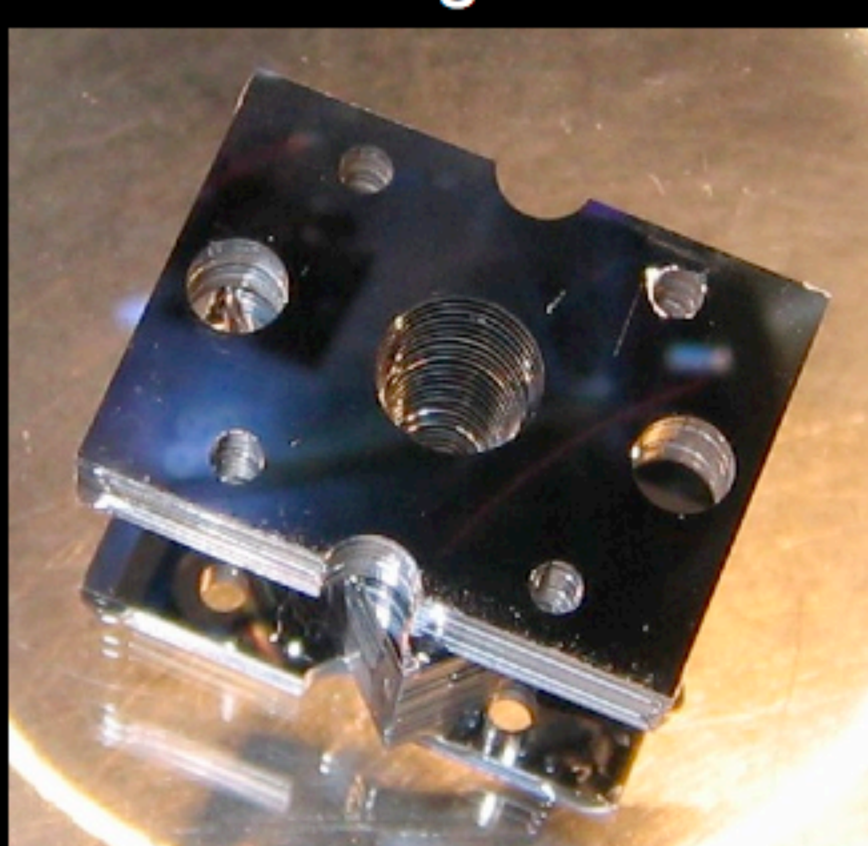
NIST Feedhorn Development

- Prototype Waveguide Testing at 300 K
  - Before electroplating, measured ~15% loss
  - 5um electroplating => ~ 0.12 dB/cm loss
  - Similar for straight and corrugated
- Plan: prototype 4” horn array in 2009

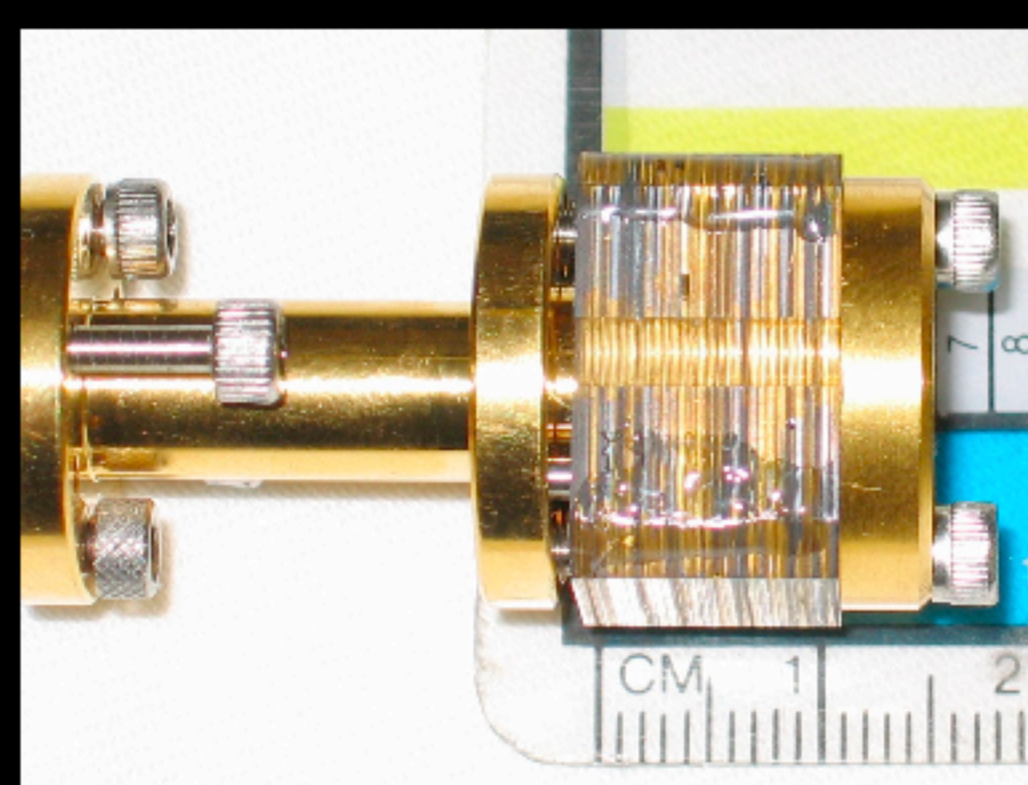
  6” arrays in 2010

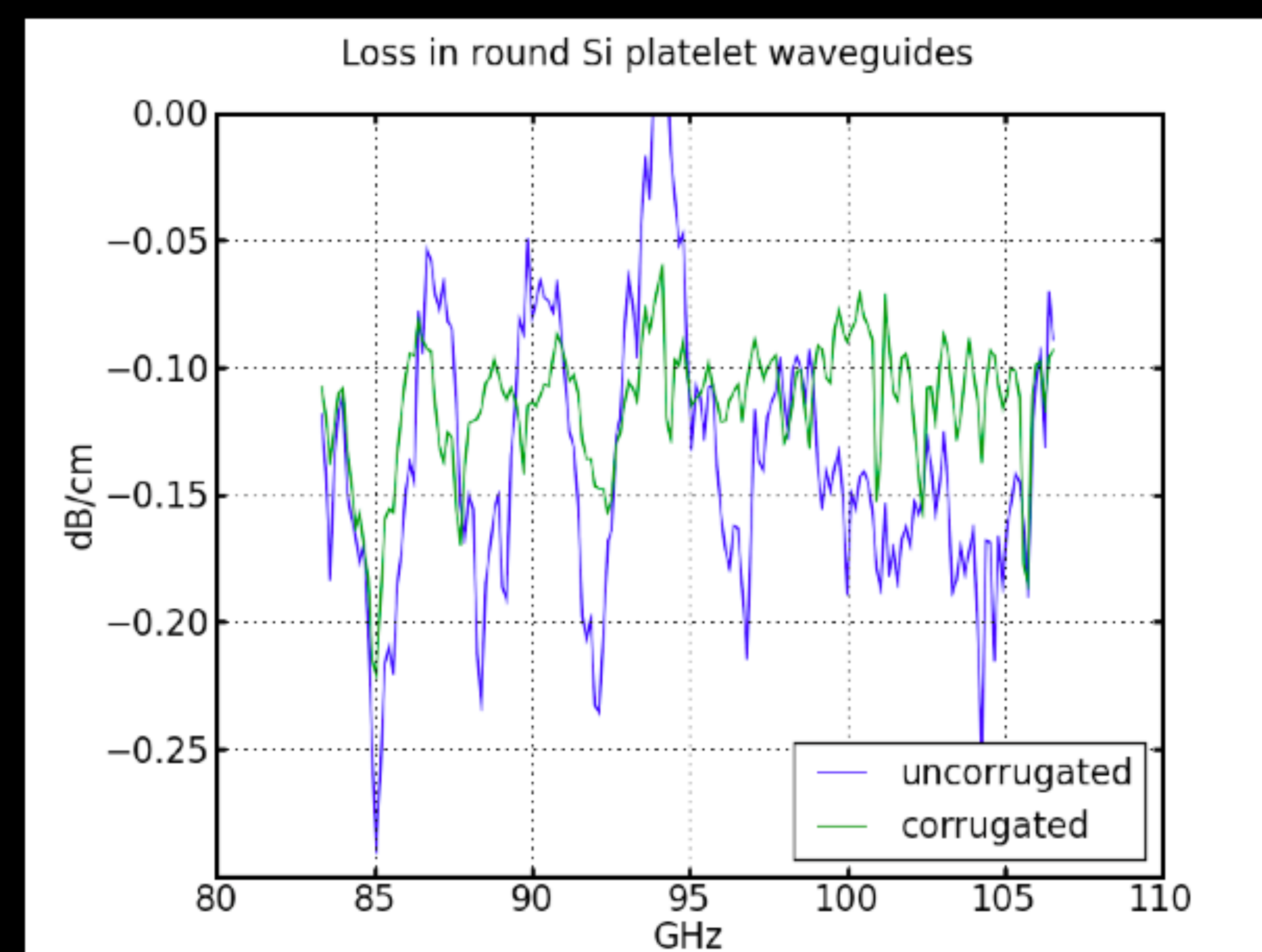


Mechanical prototype of a corrugated horn



30-plate stack during VNA testing



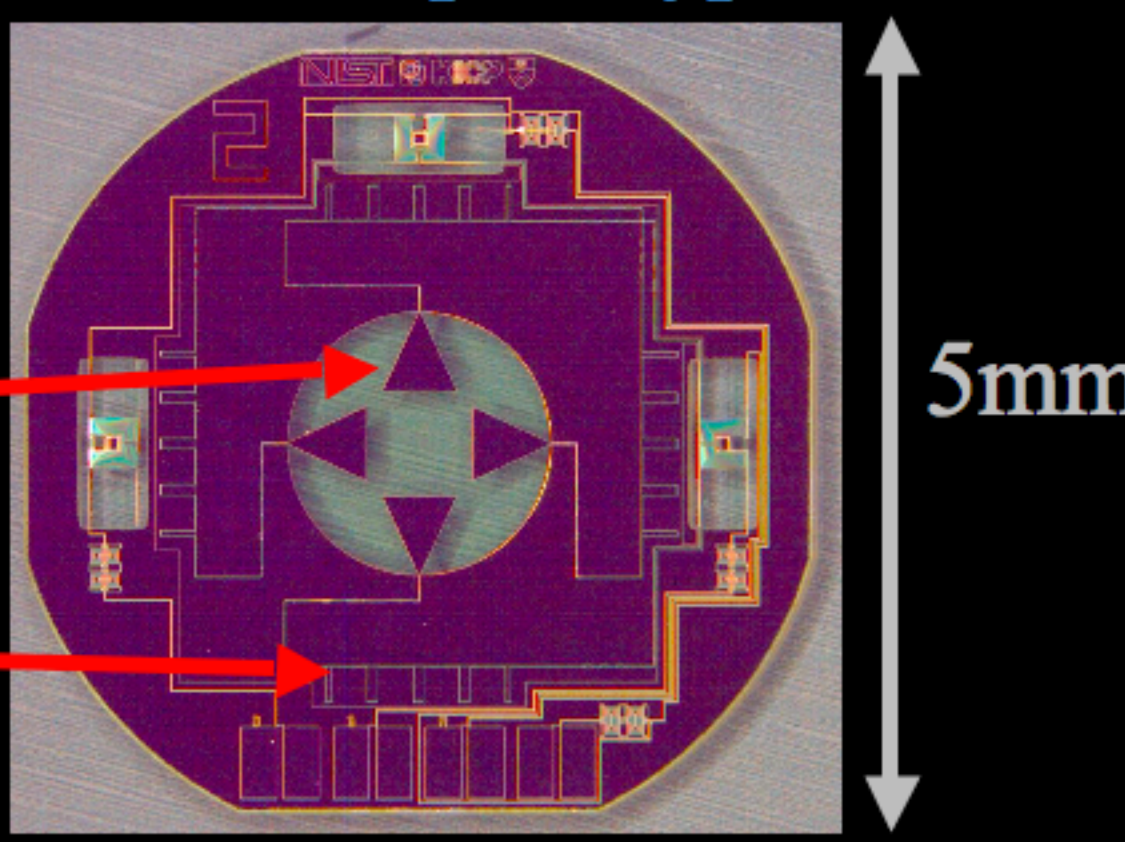


NIST Polarimeter Development

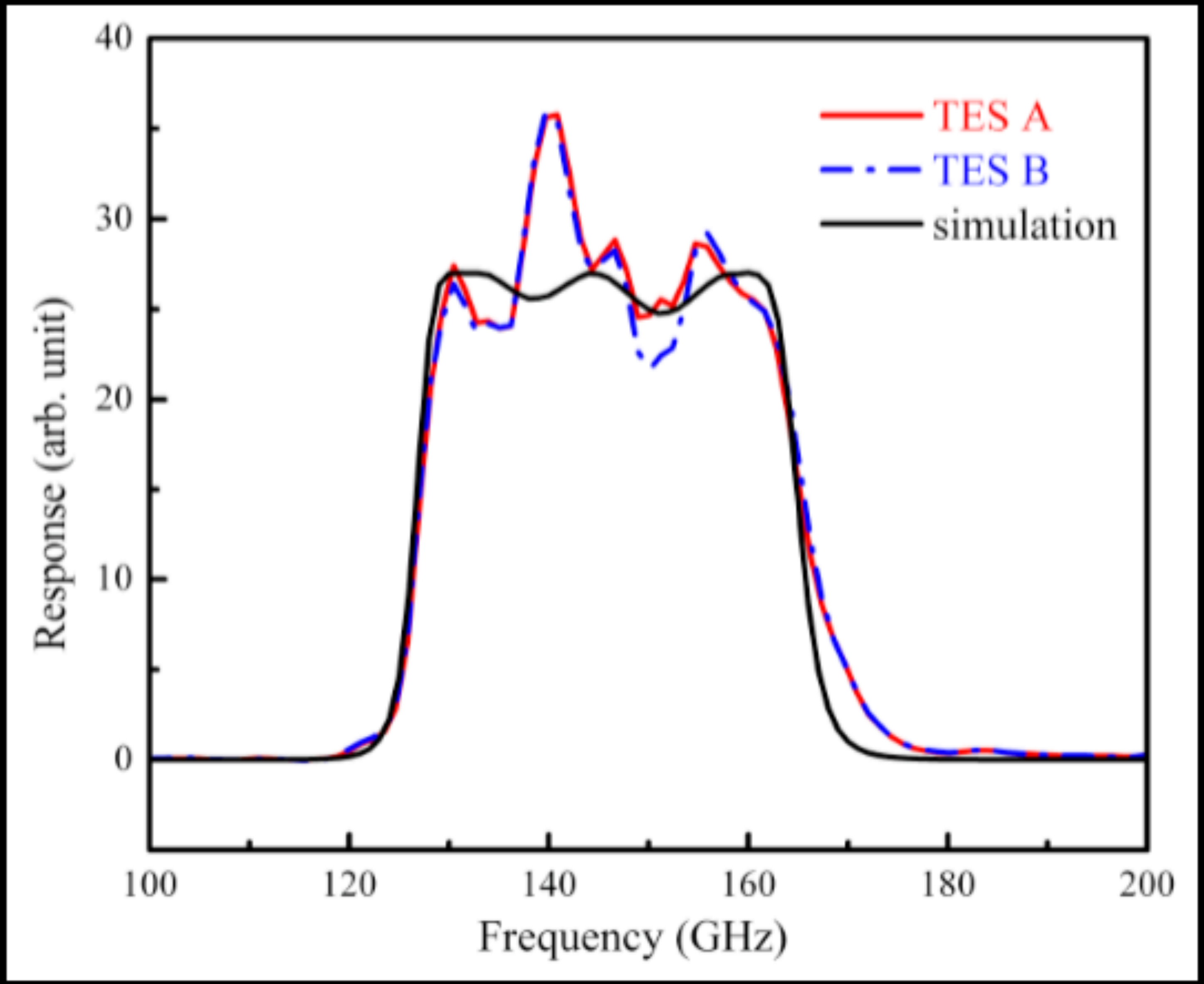
Collaborators: U. Chicago, U. Colorado, Princeton U.

- Feedhorn Coupled TES Polarimeters
  - Inspired by 40 GHz work at GSFC
  - Feedhorn coupled radiation
    - ⇒ OMT
    - ⇒ stub filters
    - ⇒ lossy microstrip
    - ⇒ TES bolometers

150 GHz prototype



- Prototype testing
  - Bandpass is on target
  - Wafer uniformity is sufficient
  - Noise is consistent with thermal background



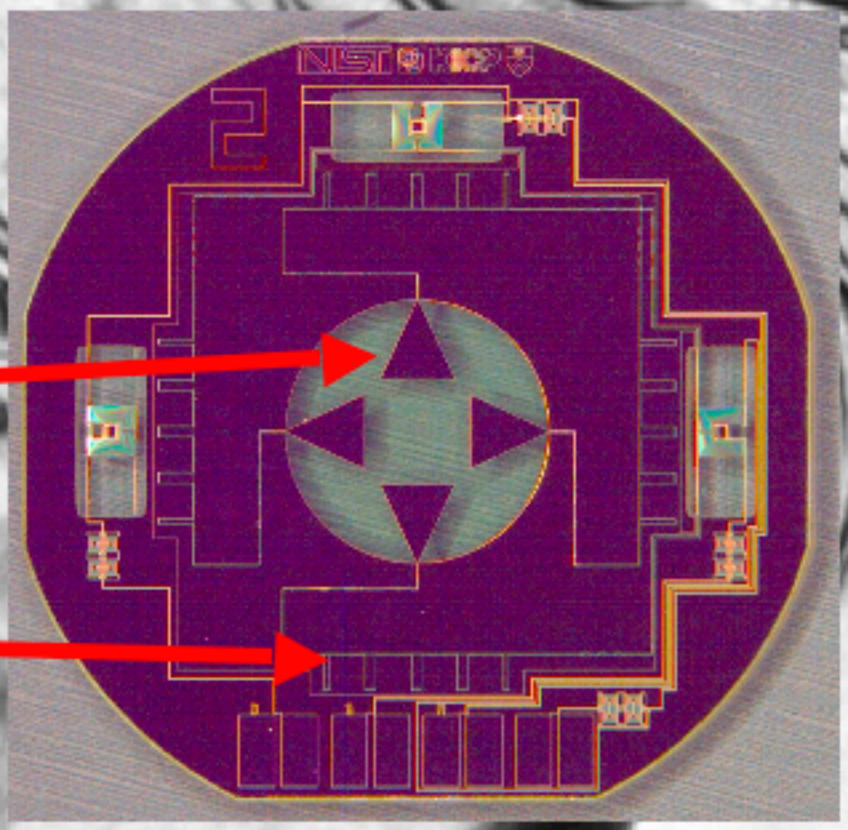
ACTpol, Michael Niemack, NIST

NIST Polarimeter Development

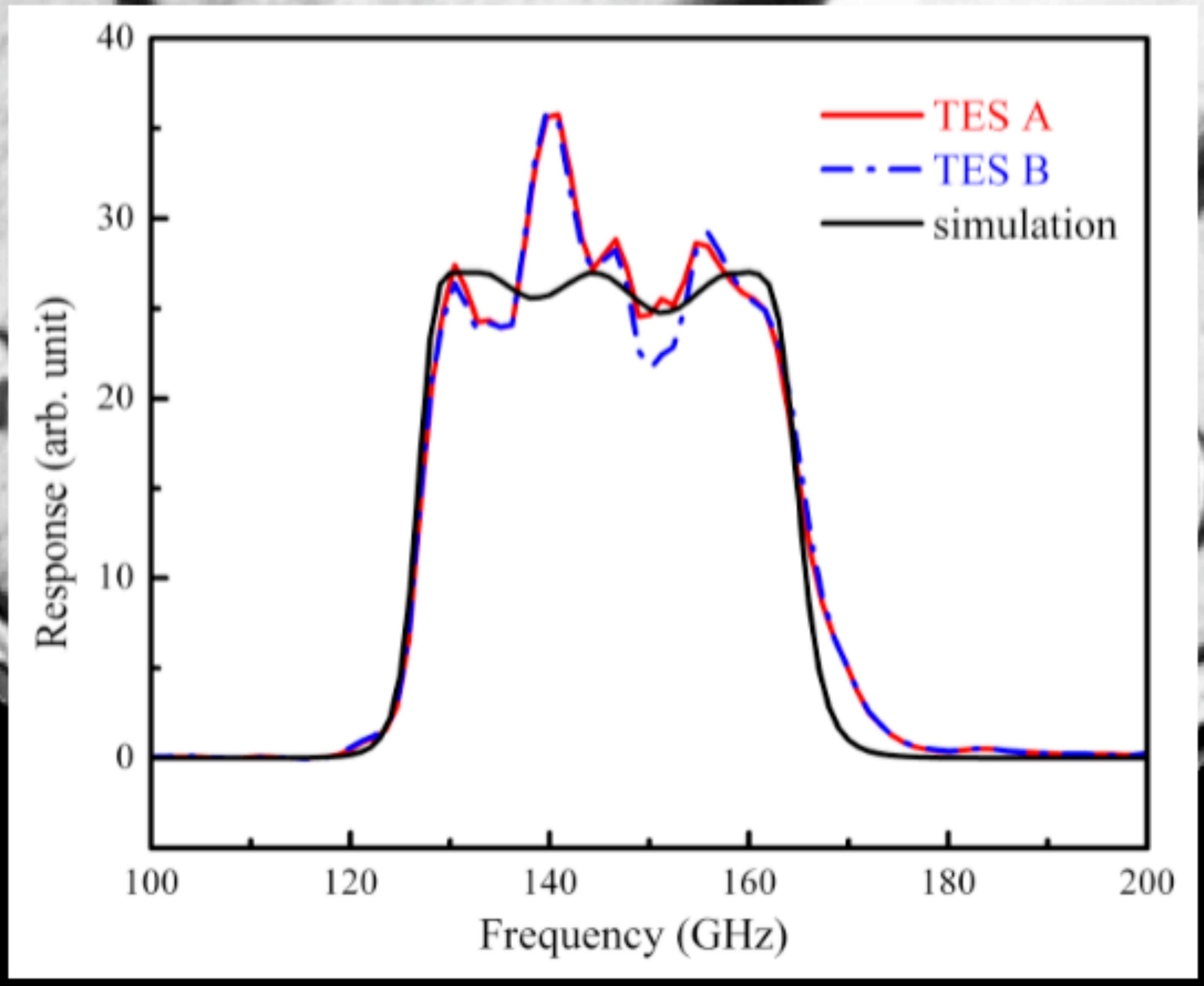
Collaborators: U. Chicago, U. Colorado, Princeton U.

- Feedhorn Coupled TES Polarimeters
  - Inspired by 40 GHz work at GSFC
  - Feedhorn coupled radiation
    - ⇒ OMT
    - ⇒ stub filters
    - ⇒ lossy microstrip
    - ⇒ TES bolometers

150 GHz prototype



- Prototype testing
  - Bandpass is on target
  - Wafer uniformity is sufficient
  - Noise is consistent with thermal background



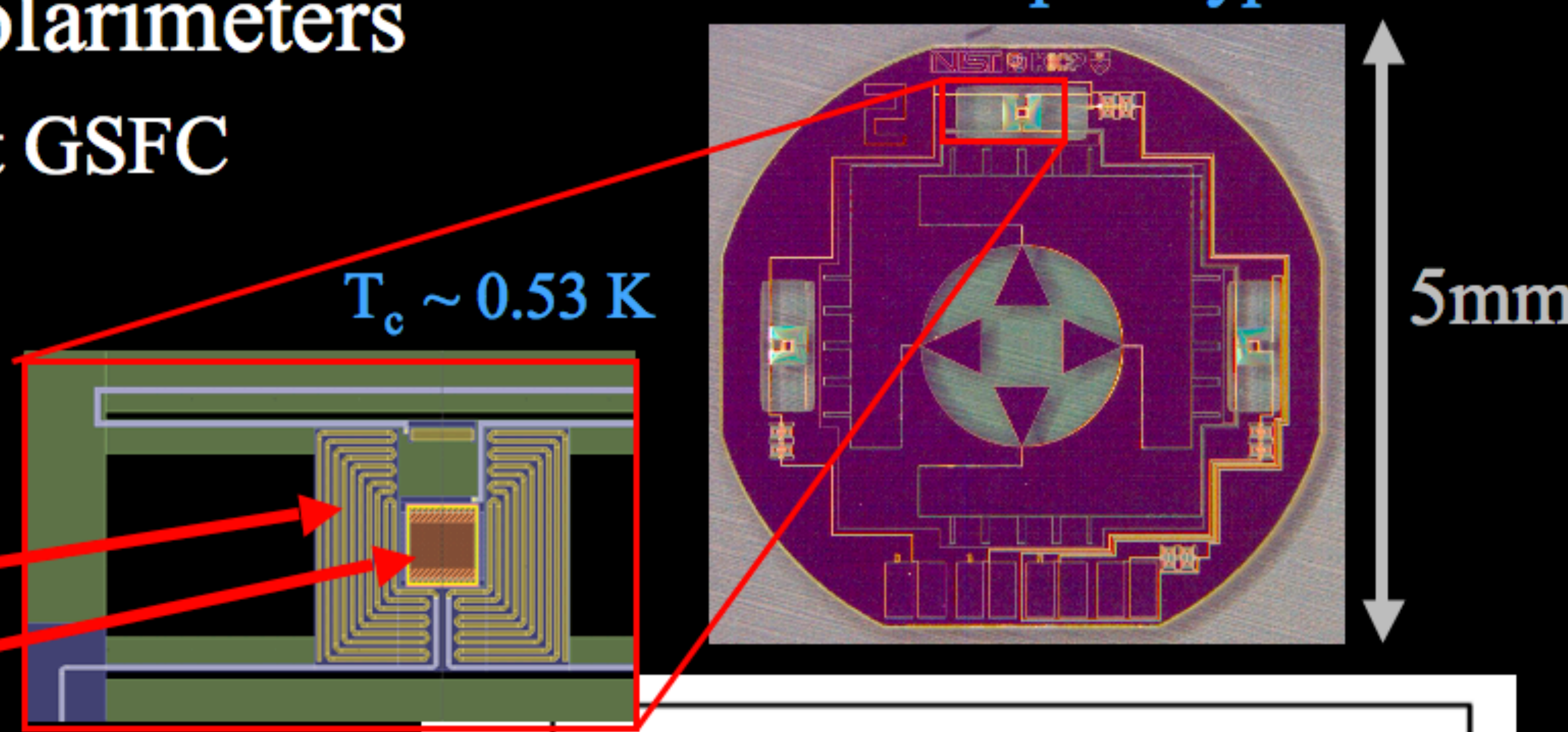
ACTpol, Michael Niemack, NIST

NIST Polarimeter Development

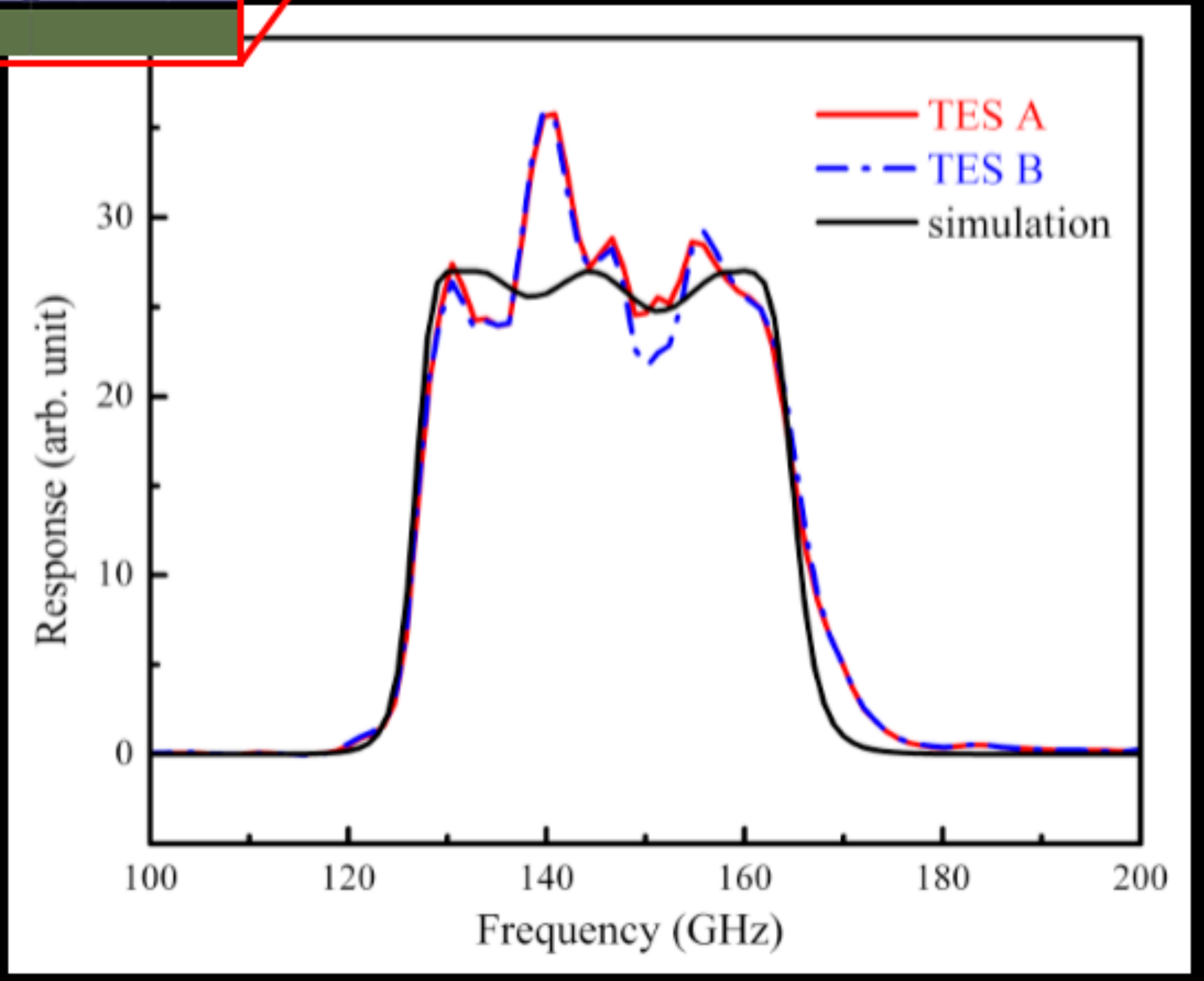
Collaborators: U. Chicago, U. Colorado, Princeton U.

- Feedhorn Coupled TES Polarimeters
  - Inspired by 40 GHz work at GSFC
  - Feedhorn coupled radiation
    - ⇒ OMT
    - ⇒ stub filters
    - ⇒ lossy microstrip
    - ⇒ TES bolometers

150 GHz prototype



- Prototype testing
  - Bandpass is on target
  - Wafer uniformity is sufficient
  - Noise is consistent with thermal background



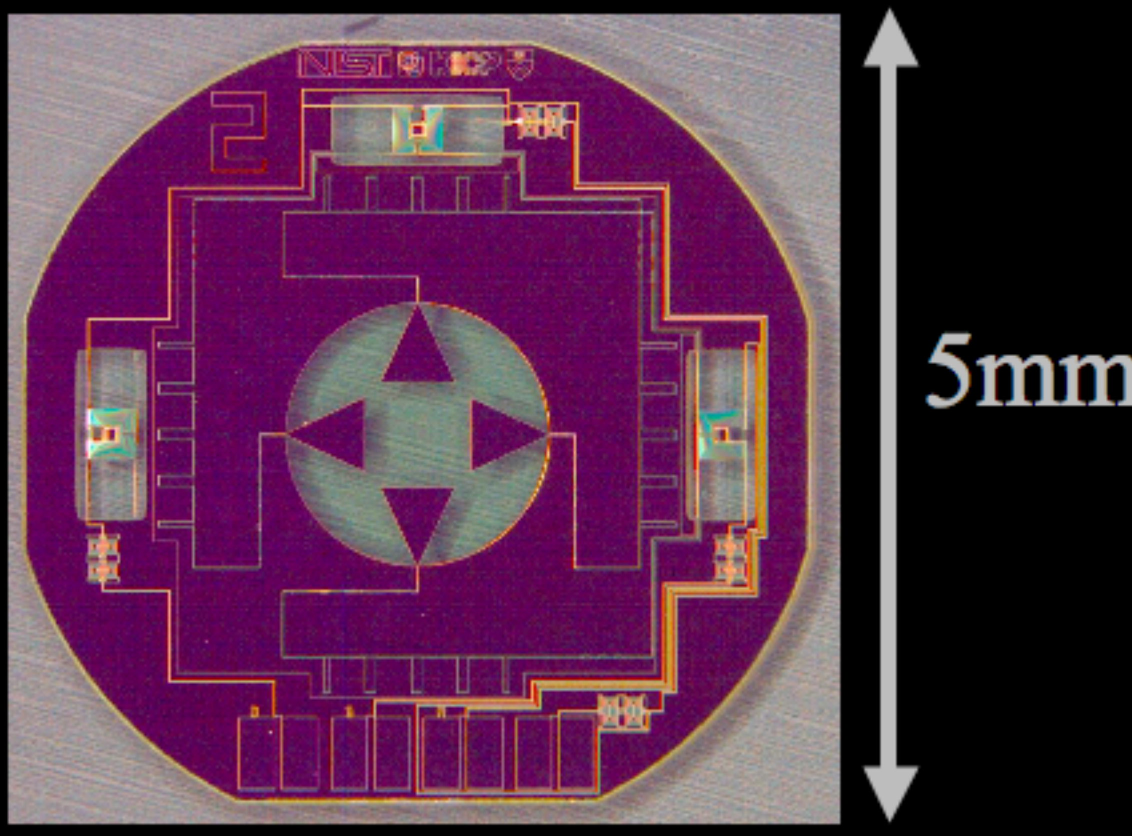
ACTpol, Michael Niemack, NIST

NIST Polarimeter Development

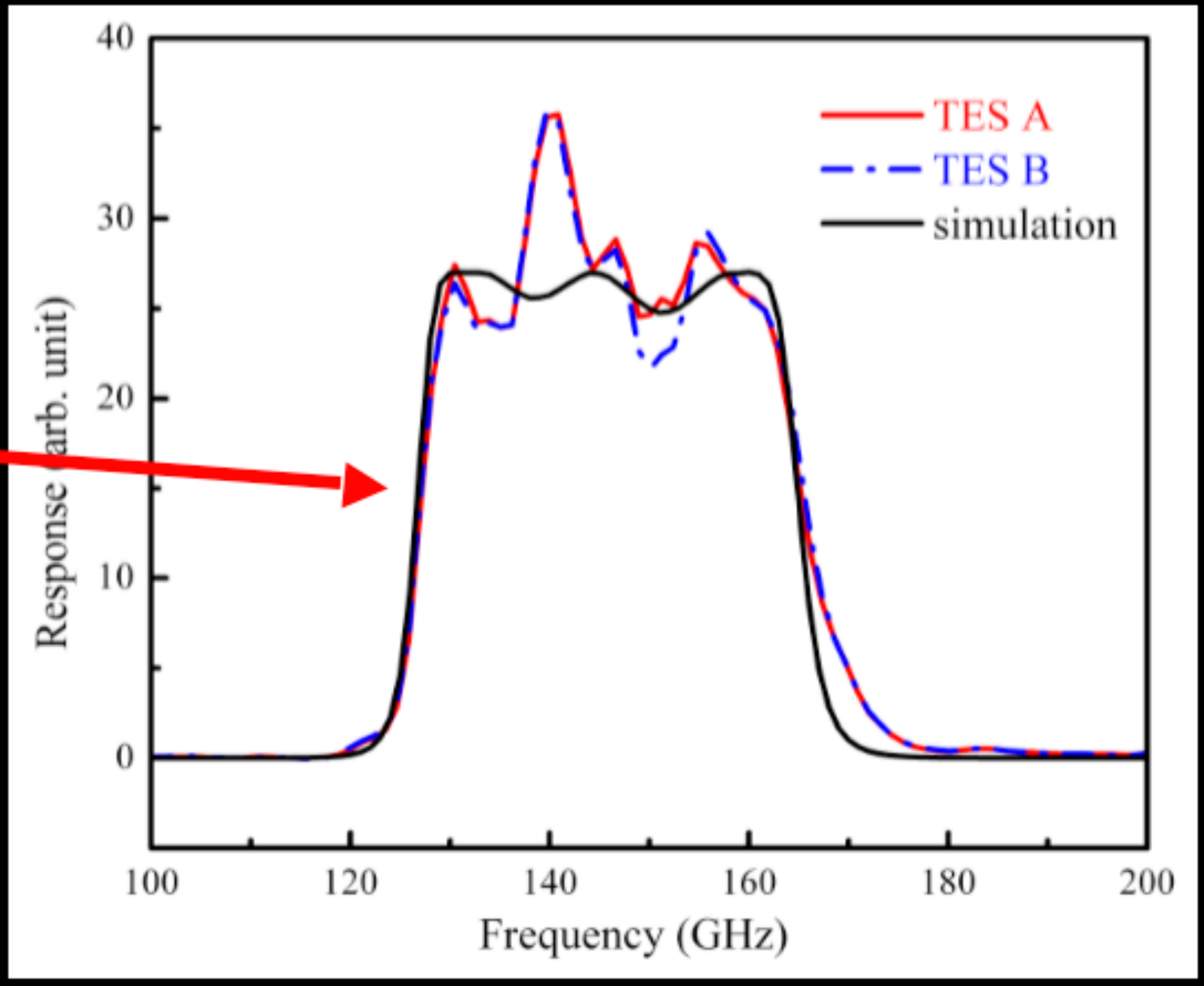
Collaborators: U. Chicago, U. Colorado, Princeton U.

- Feedhorn Coupled TES Polarimeters
  - Inspired by 40 GHz work at GSFC
  - Feedhorn coupled radiation
    - ⇒ OMT
    - ⇒ stub filters
    - ⇒ lossy microstrip
    - ⇒ TES bolometers

150 GHz prototype



- Prototype testing
  - Bandpass is on target
  - Wafer uniformity is sufficient
  - Noise is consistent with thermal background



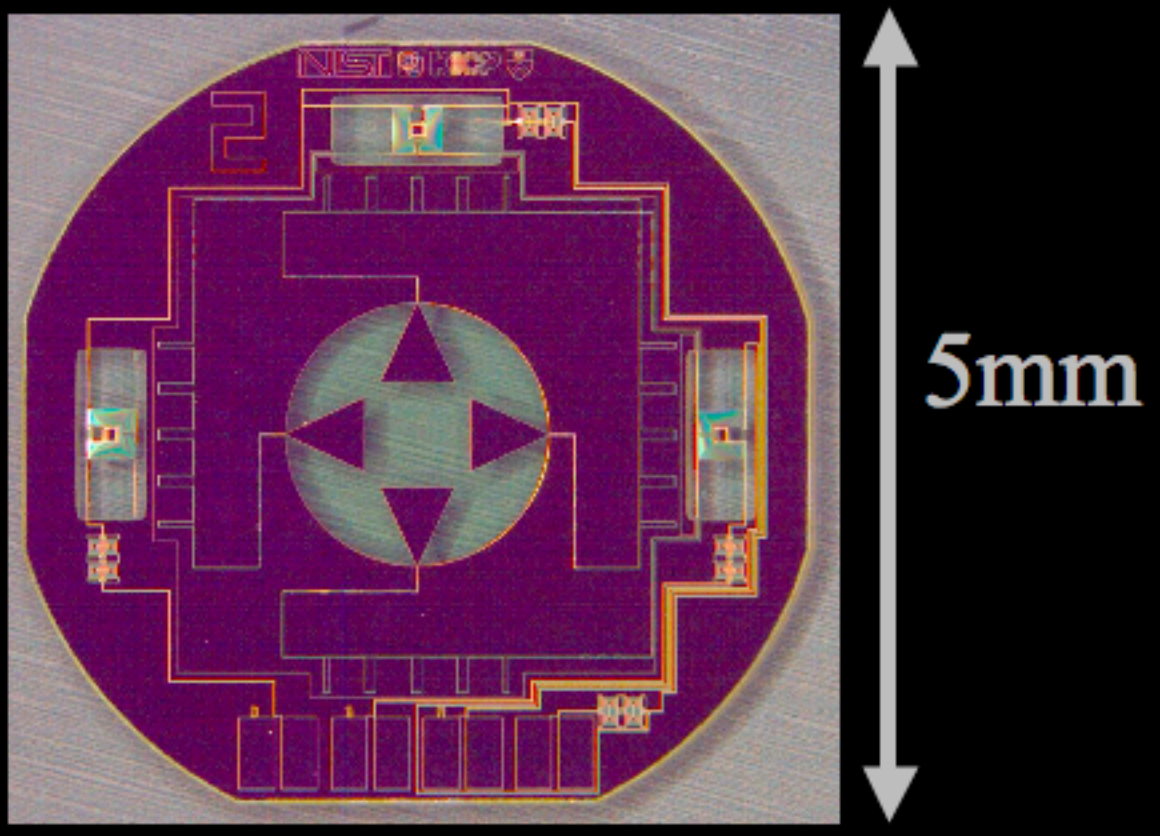
ACTpol, Michael Niemack, NIST

NIST Polarimeter Development

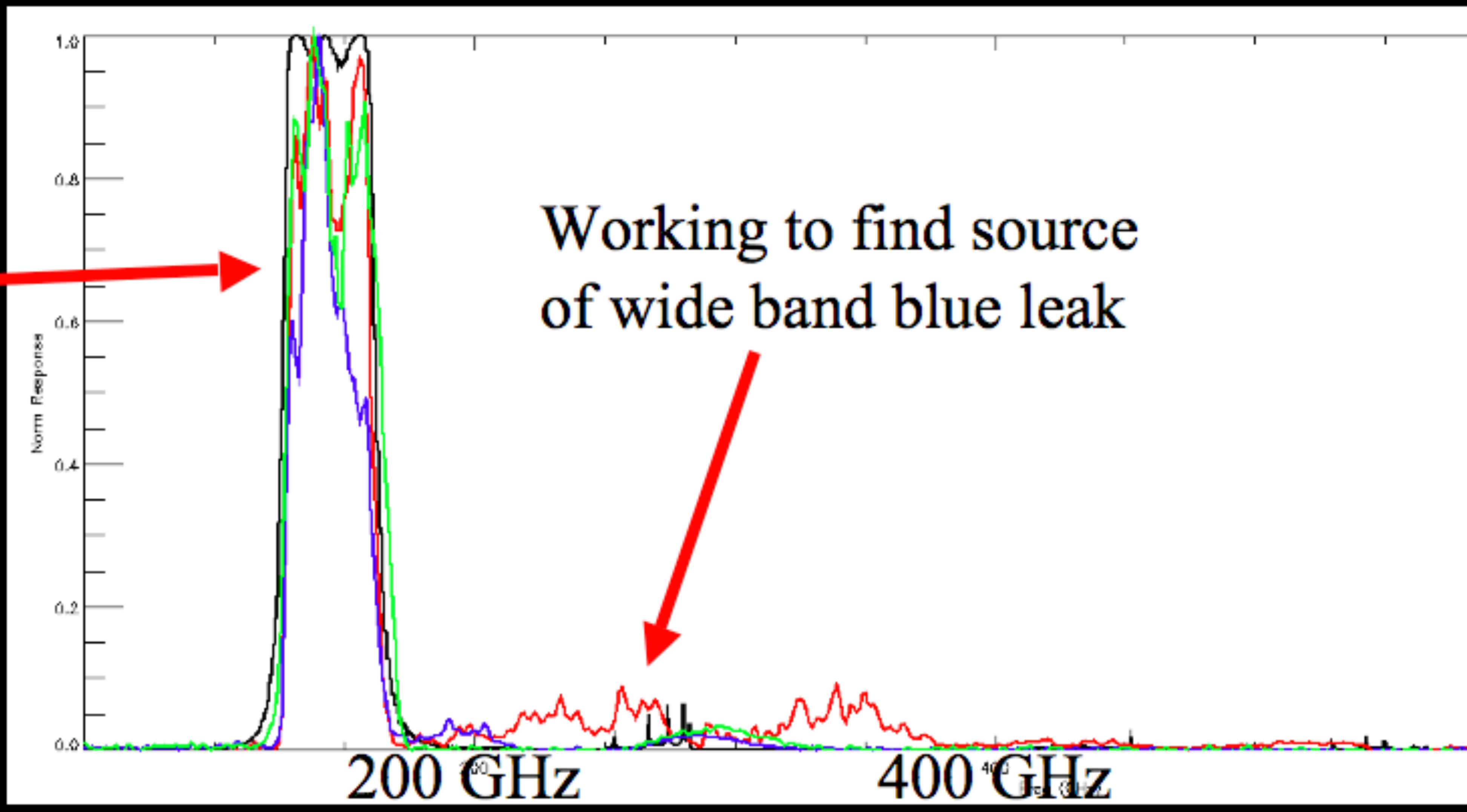
Collaborators: U. Chicago, U. Colorado, Princeton U.

- Feedhorn Coupled TES Polarimeters
  - Inspired by 40 GHz work at GSFC
  - Feedhorn coupled radiation
    - ⇒ OMT
    - ⇒ stub filters
    - ⇒ lossy microstrip
    - ⇒ TES bolometers

150 GHz prototype



- Prototype testing
  - Bandpass is on target
  - Wafer uniformity is sufficient
  - Noise is consistent with thermal background



ACTpol, Michael Niemack, NIST

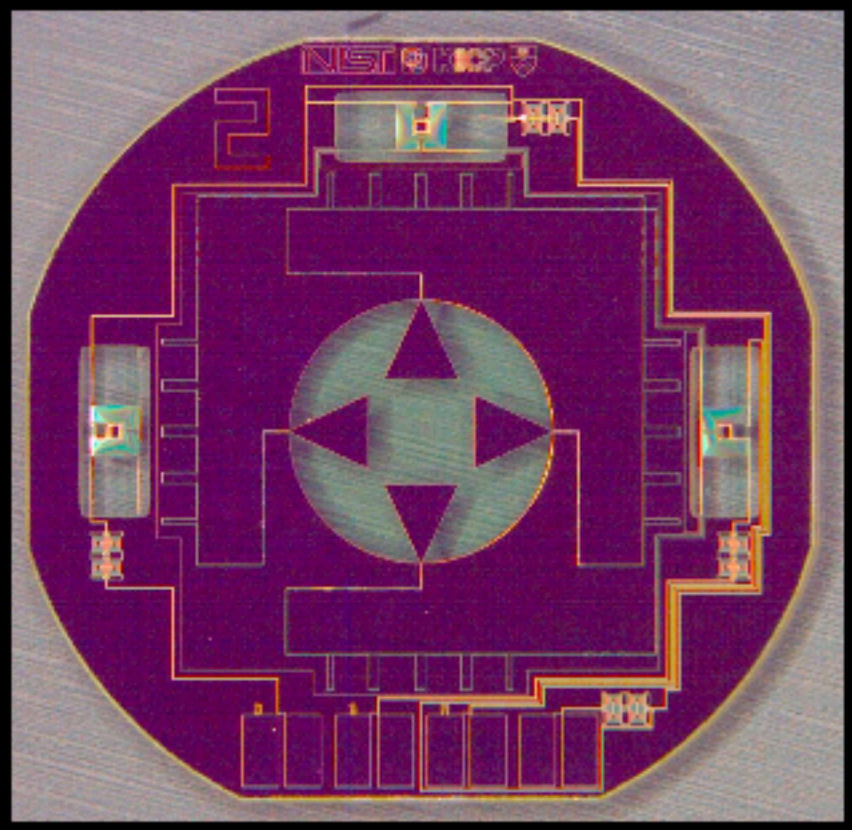
NIST Polarimeter Development

Collaborators: U. Chicago, U. Colorado, Princeton U.

- Feedhorn Coupled TES Polarimeters
  - Inspired by 40 GHz work at GSFC
  - Feedhorn coupled radiation
    - ⇒ OMT
    - ⇒ stub filters
    - ⇒ lossy microstrip
    - ⇒ TES bolometers

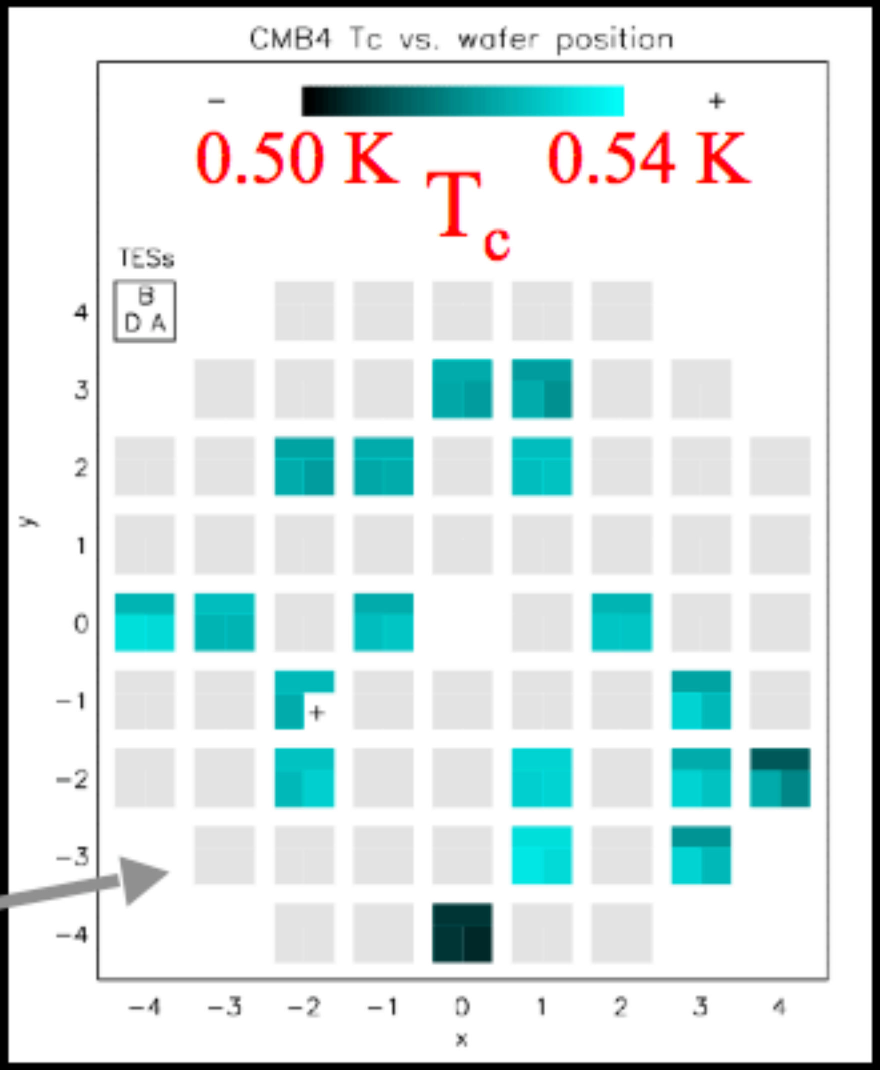
- Prototype testing
  - Bandpass is on target
  - Wafer uniformity is sufficient
  - Noise is consistent with thermal background

150 GHz prototype



5mm

T_c vs. Wafer position



Grey squares not tested

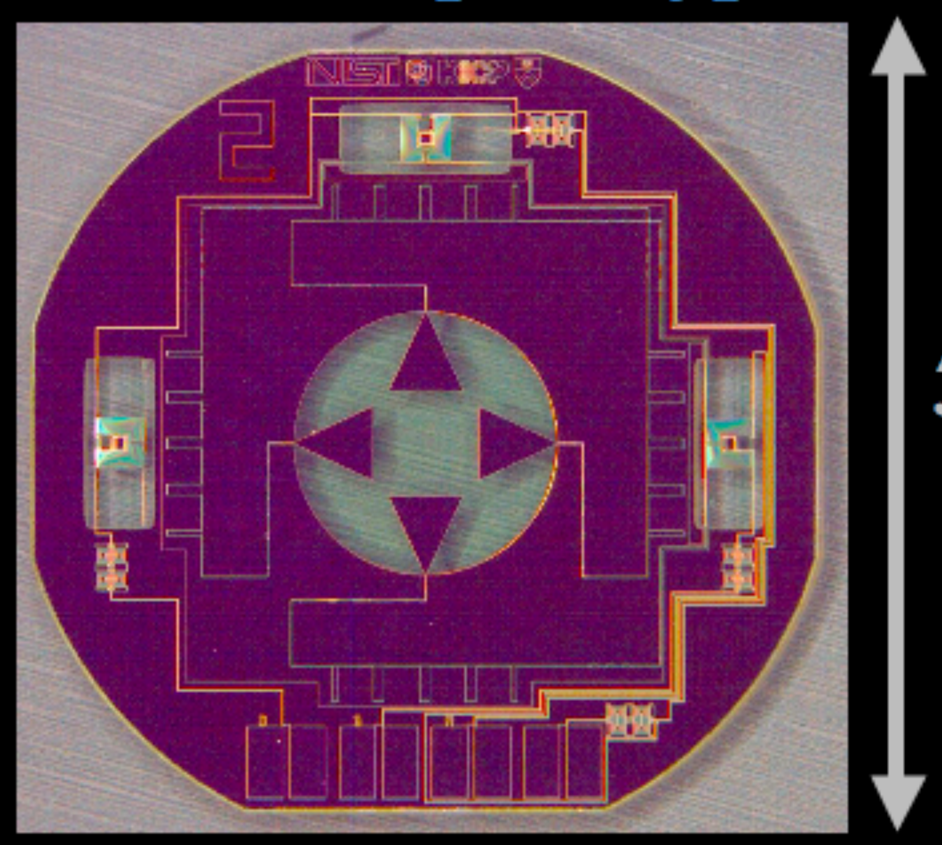
ACTpol, Michael Niemack, NIST

NIST Polarimeter Development

Collaborators: U. Chicago, U. Colorado, Princeton U.

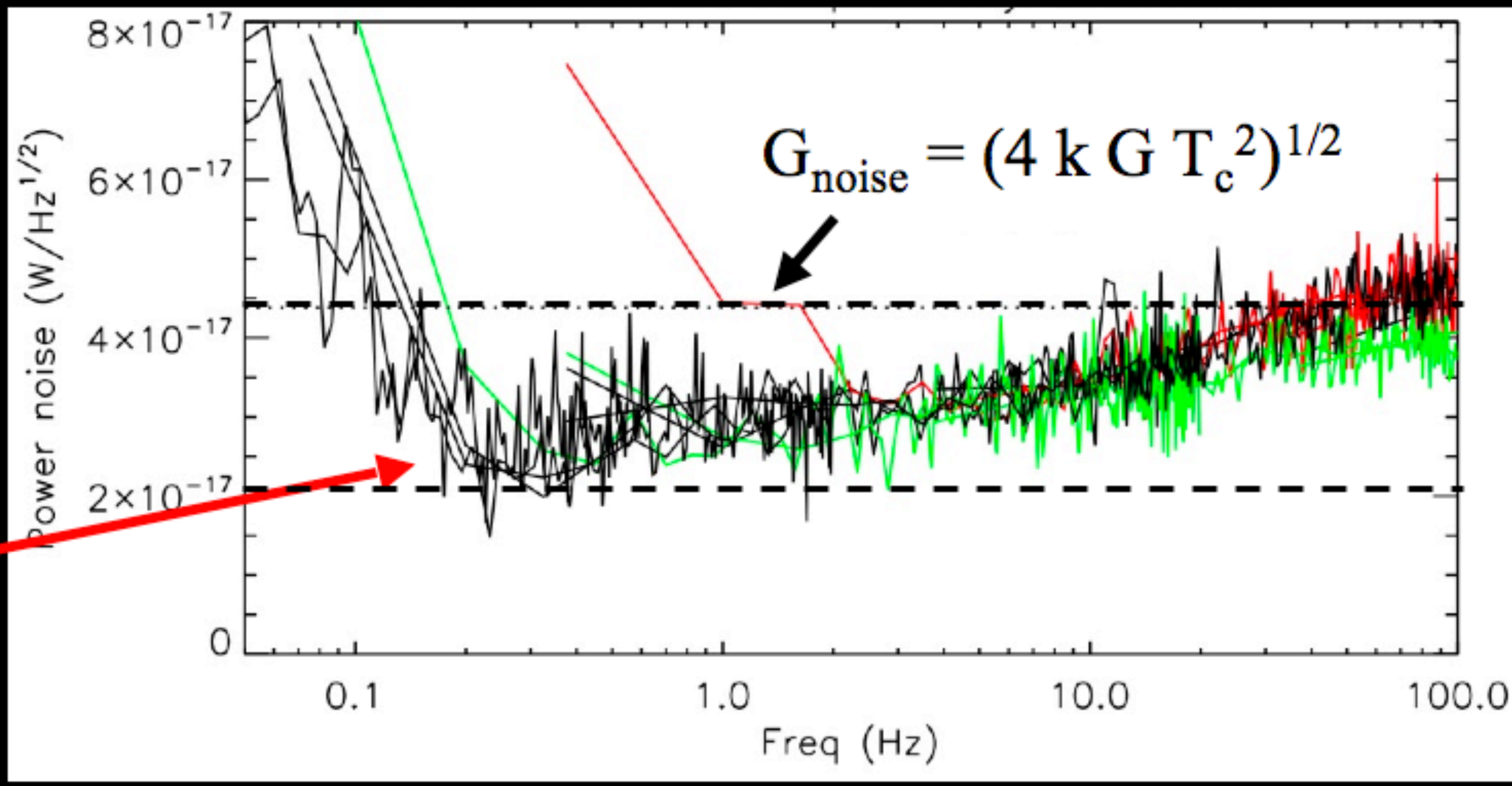
- Feedhorn Coupled TES Polarimeters
  - Inspired by 40 GHz work at GSFC
  - Feedhorn coupled radiation
    - ⇒ OMT
    - ⇒ stub filters
    - ⇒ lossy microstrip
    - ⇒ TES bolometers

150 GHz prototype



5mm

- Prototype testing
  - Bandpass is on target
  - Wafer uniformity is sufficient
  - Noise is consistent with thermal background

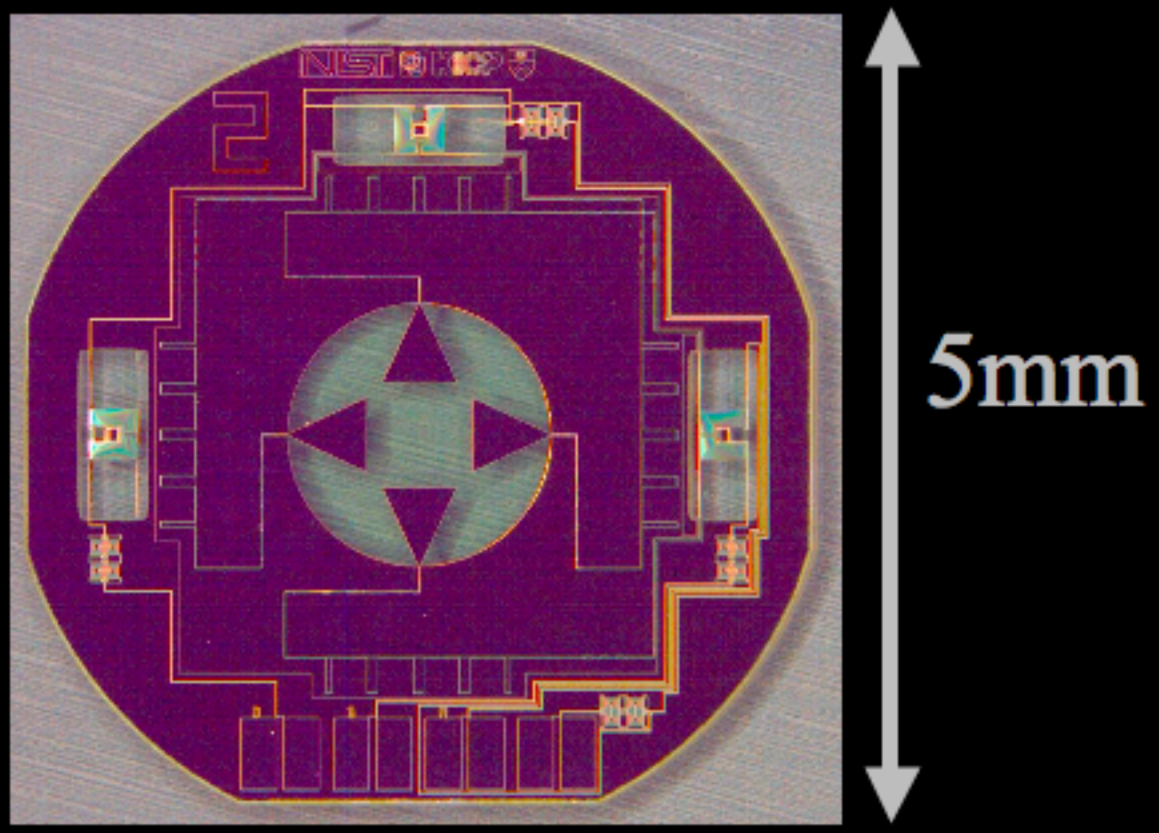


ACTpol, Michael Niemack, NIST

NIST Polarimeter Development

Collaborators: U. Chicago, U. Colorado, Princeton U.

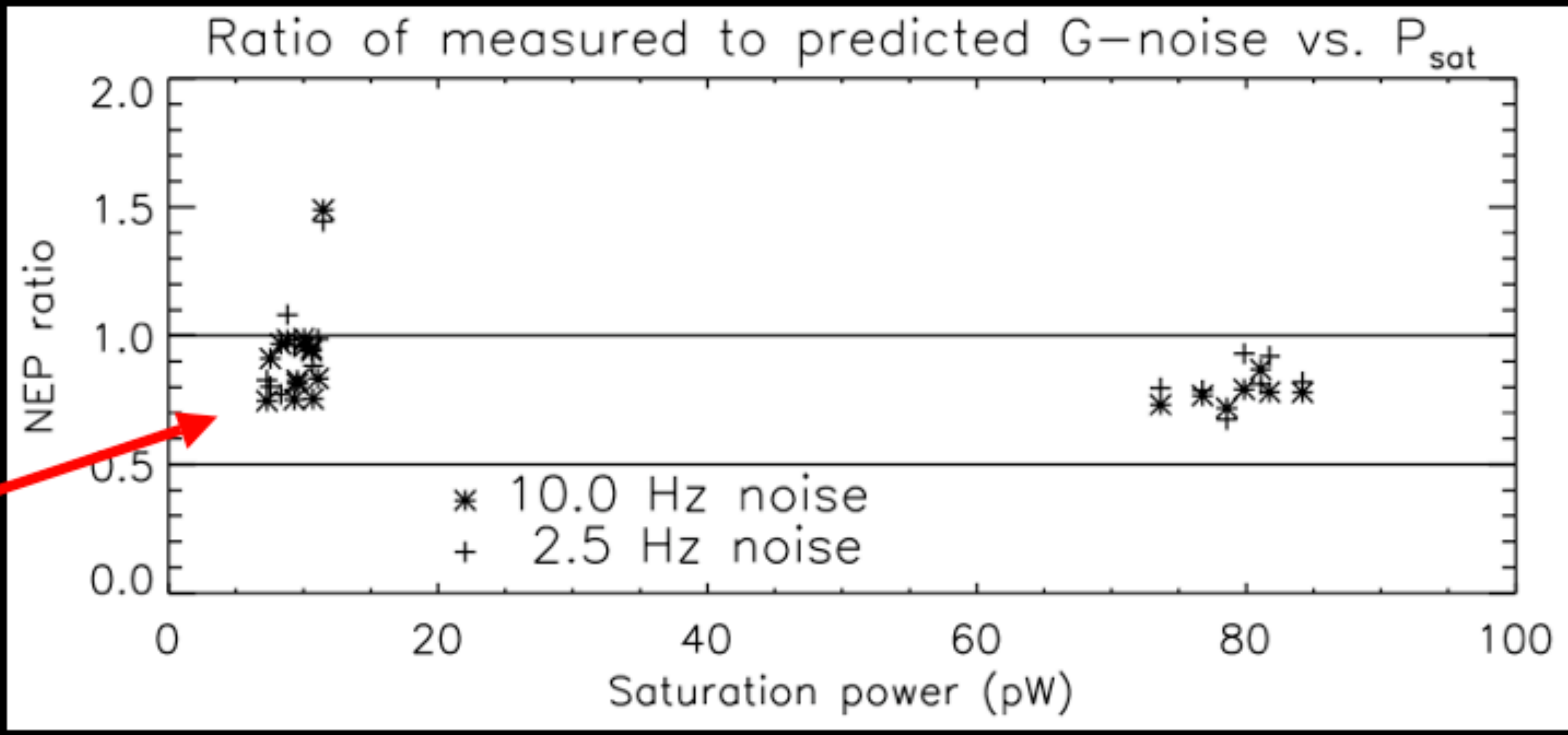
150 GHz prototype



- Feedhorn Coupled TES Polarimeters
  - Inspired by 40 GHz work at GSFC
  - Feedhorn coupled radiation
    - ⇒ OMT
    - ⇒ stub filters
    - ⇒ lossy microstrip
    - ⇒ TES bolometers

- Prototype testing
  - Bandpass is on target
  - Wafer uniformity is sufficient
  - Noise is consistent with thermal background

Over a wide range of G's

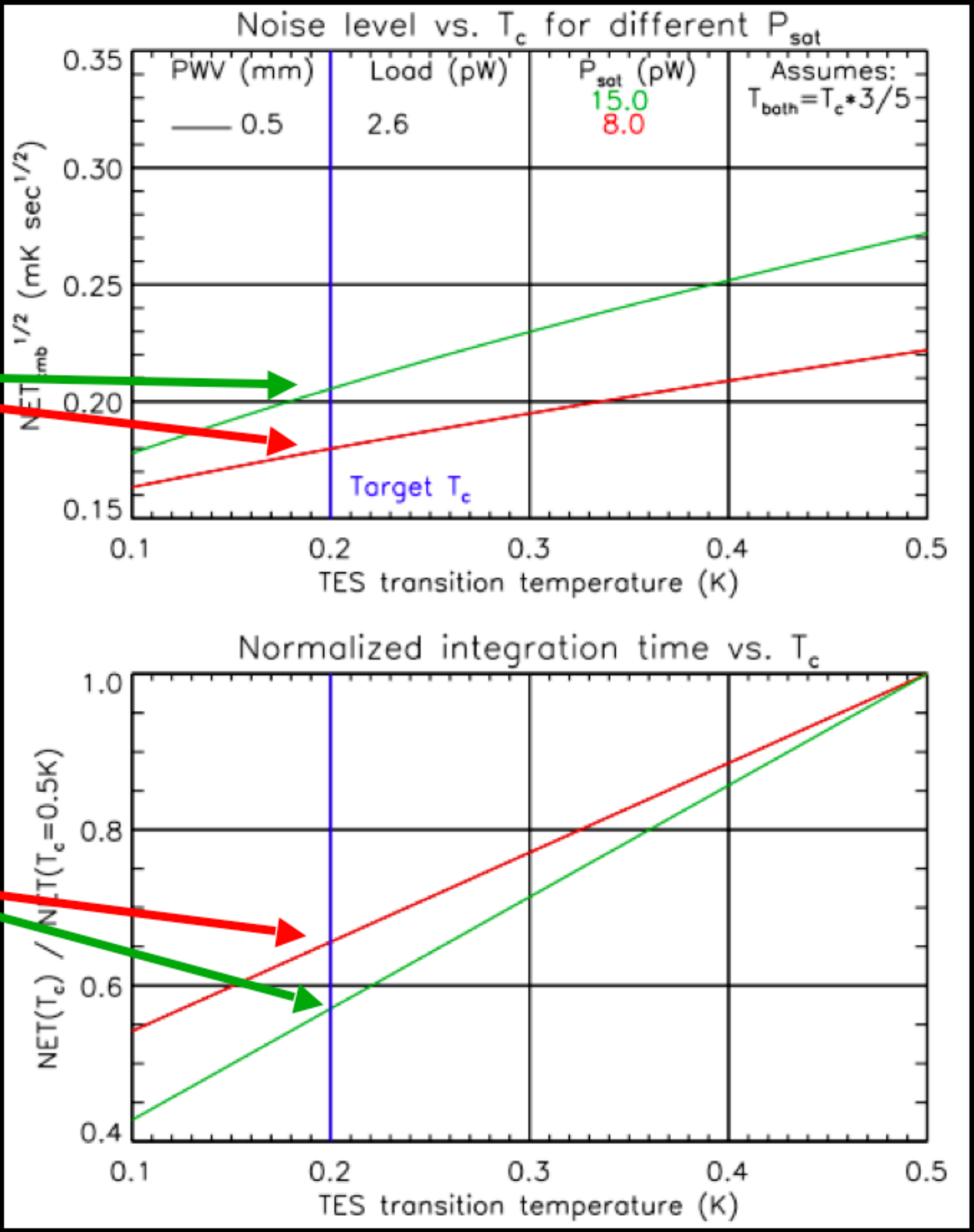


ACTpol, Michael Niemack, NIST

Noise vs. Detector Temperature

- Noise calculation
  - Bose, shot, and G noise
  - Detector efficiency ~ 0.6
  - Median ACT PWV ~ 0.5 mm for two saturation powers
- What happens when you drop T_{bath} and T_c?
  - Noise drops steadily
  - $T_c \sim 0.2$ K drops integration time to ~ 60% of $T_c \sim 0.5$ K

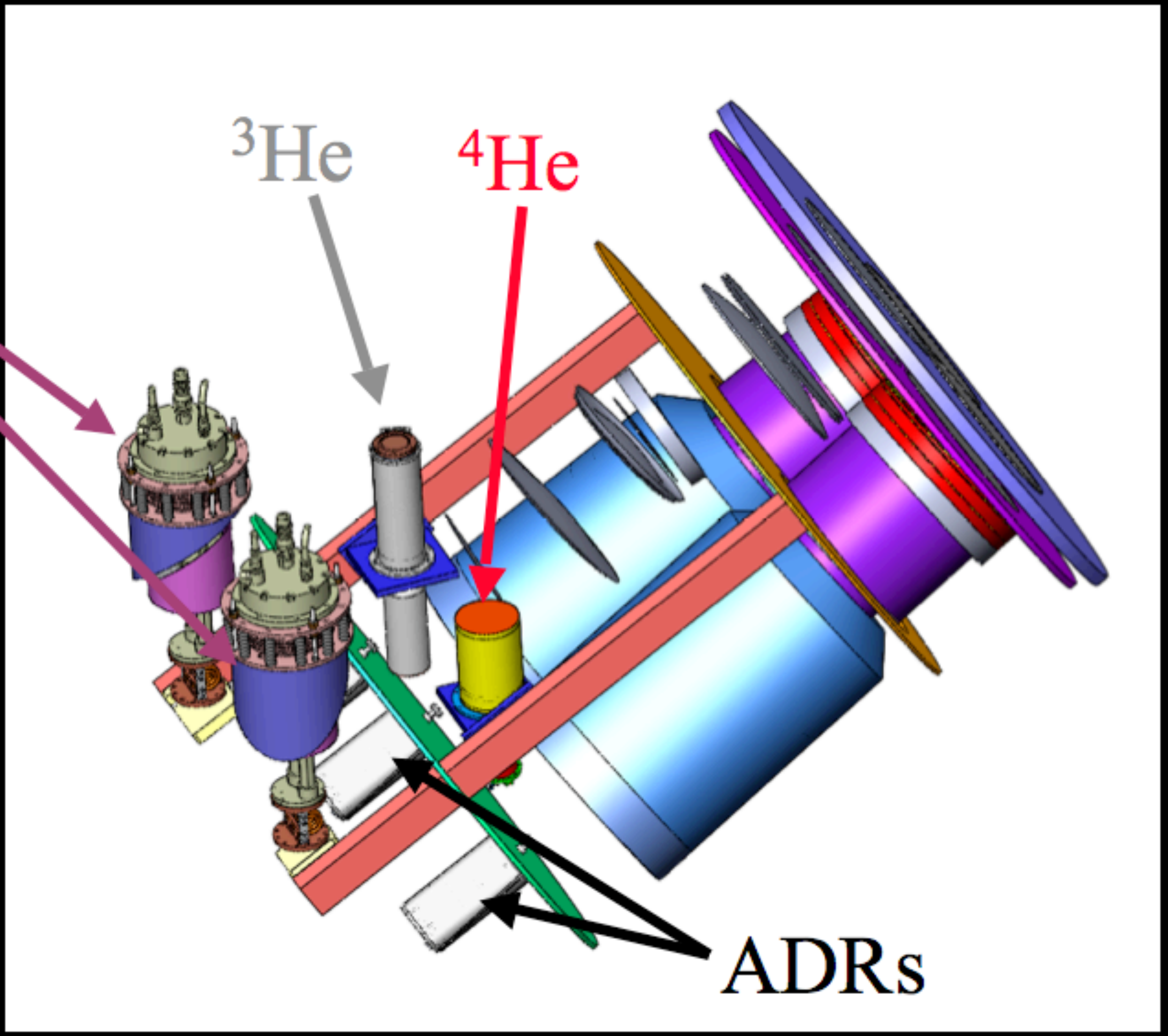
ACTpol will use ADRs for $T_{bath} \sim 0.10$ K and $T_c \sim 0.2$ K



ACTpol, Michael Niemack, NIST

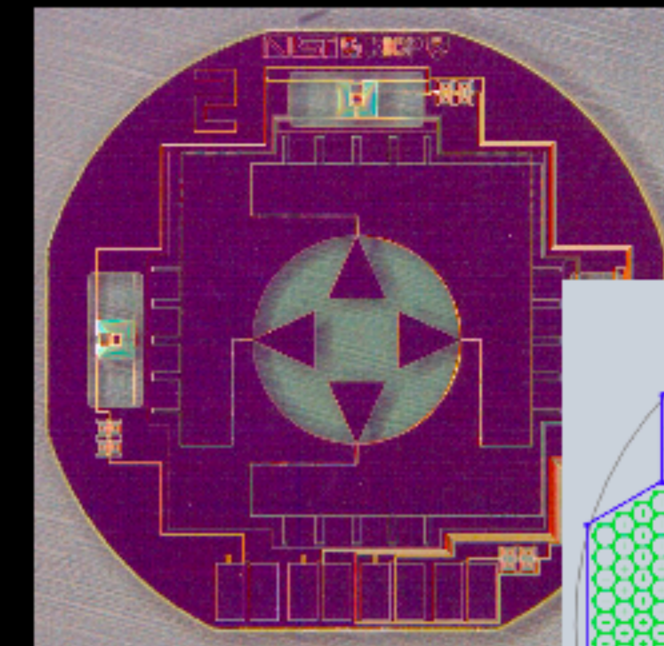
Cryogenics for T_{bath} = 0.1 K

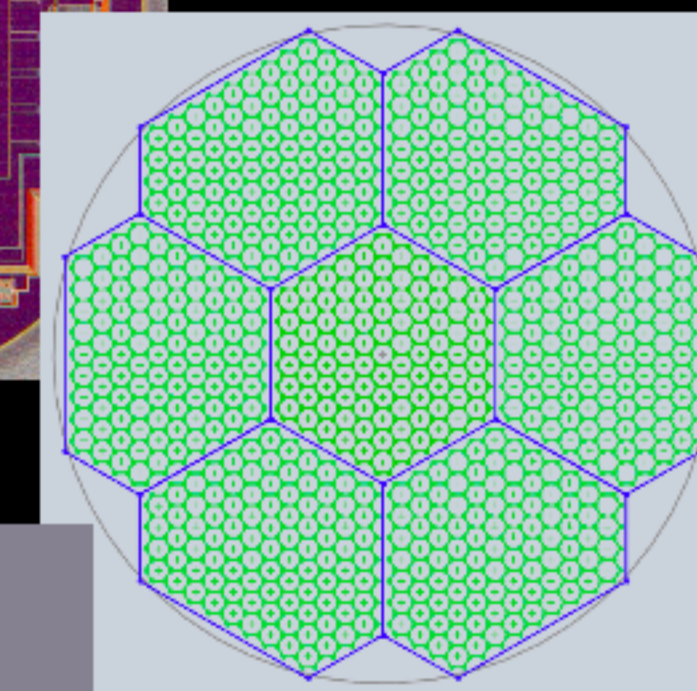
- Commercial cryogenics
  - 2 Cryomech 410 Pulse tubes
  - ^4He for heat sinking
  - ^3He backed Adiabatic Demagnetization Refrigerator (ADR)
    - Single FAA stage ADRs
    - Sapphire thermal isolation
    - Low magnetic field
    - ~ 150 mJ per FAA at T_{bath} ~ 0.1 K



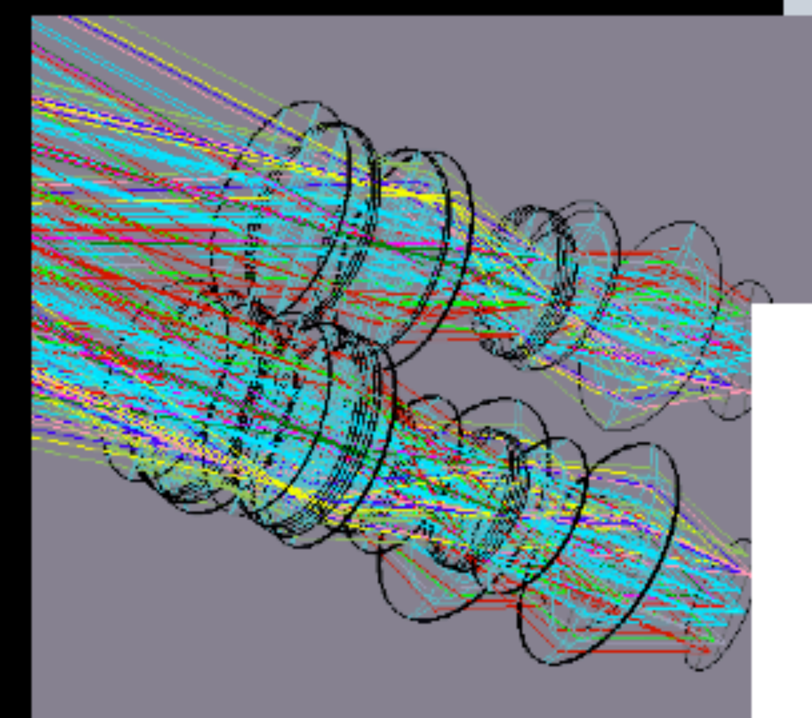
- Baseline plan => ~ 50 hours hold time at 0.1 K

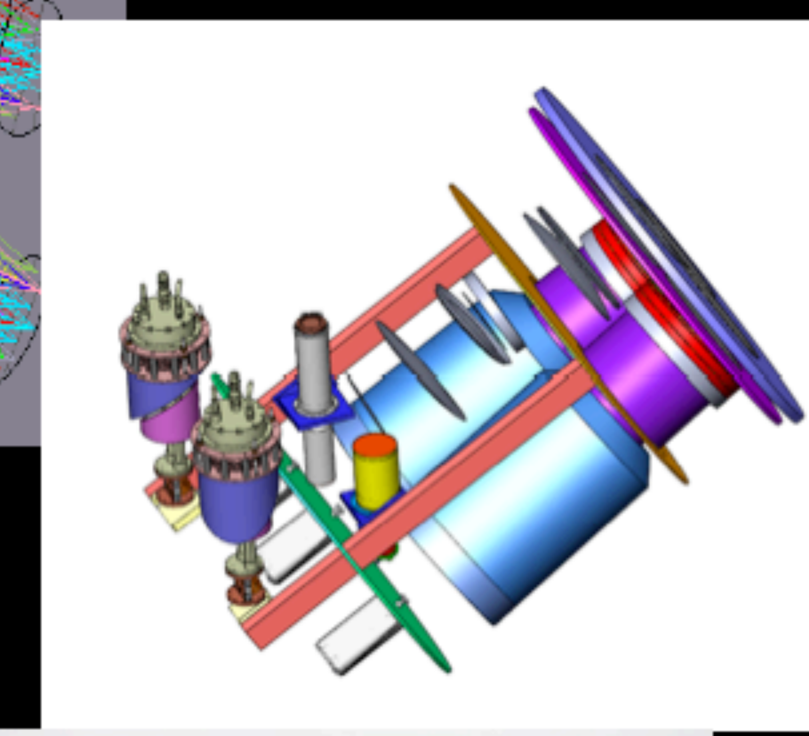
Overview





- ACTpol
  - 150 GHz with 1.5' resolution
    - 1280 polarimeters (x2 TESs)
    - ~ 210 uK rt(sec) for median obs.
  - Swappable 90 GHz and 220 GHz
    - ~ 300 and 640 polarimeters
    - Swap bet. seasons

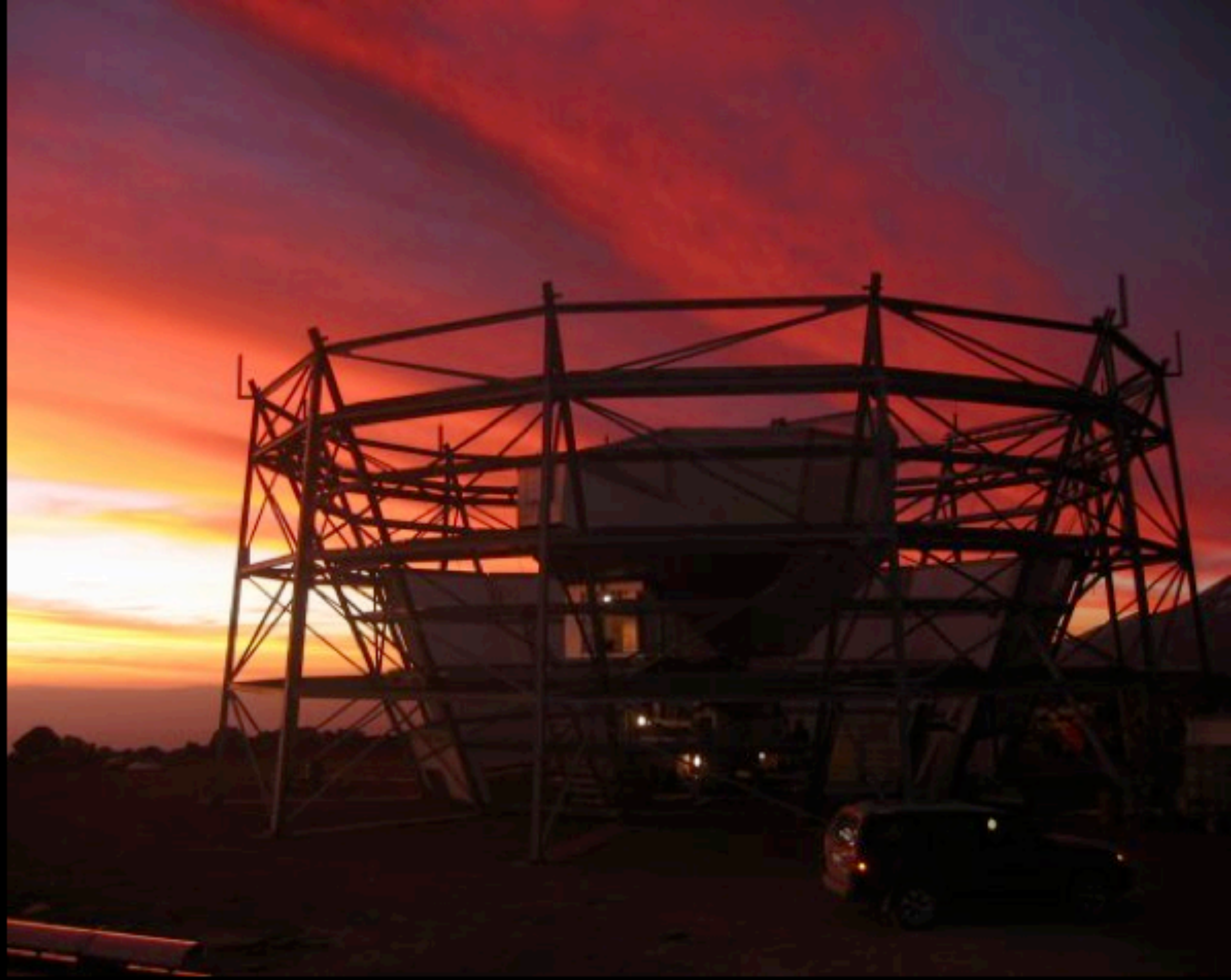




- Temperature sensitivity from 2 years of 150 GHz observations
  - 4000 deg^2 to ~ 17 uK / $arcmin^2$
  - 5x 30 deg^2 to ~ 2.6 uK / $arcmin^2$

Schedule

- First light target with 1 array 2012
- First light with 3 arrays 2013



Acknowledgements

ACTpol work was done with members of the ACT collaboration

The NIST polarimeter development and testing is a collaboration between NIST, Princeton U., U. Colorado, and U. Chicago