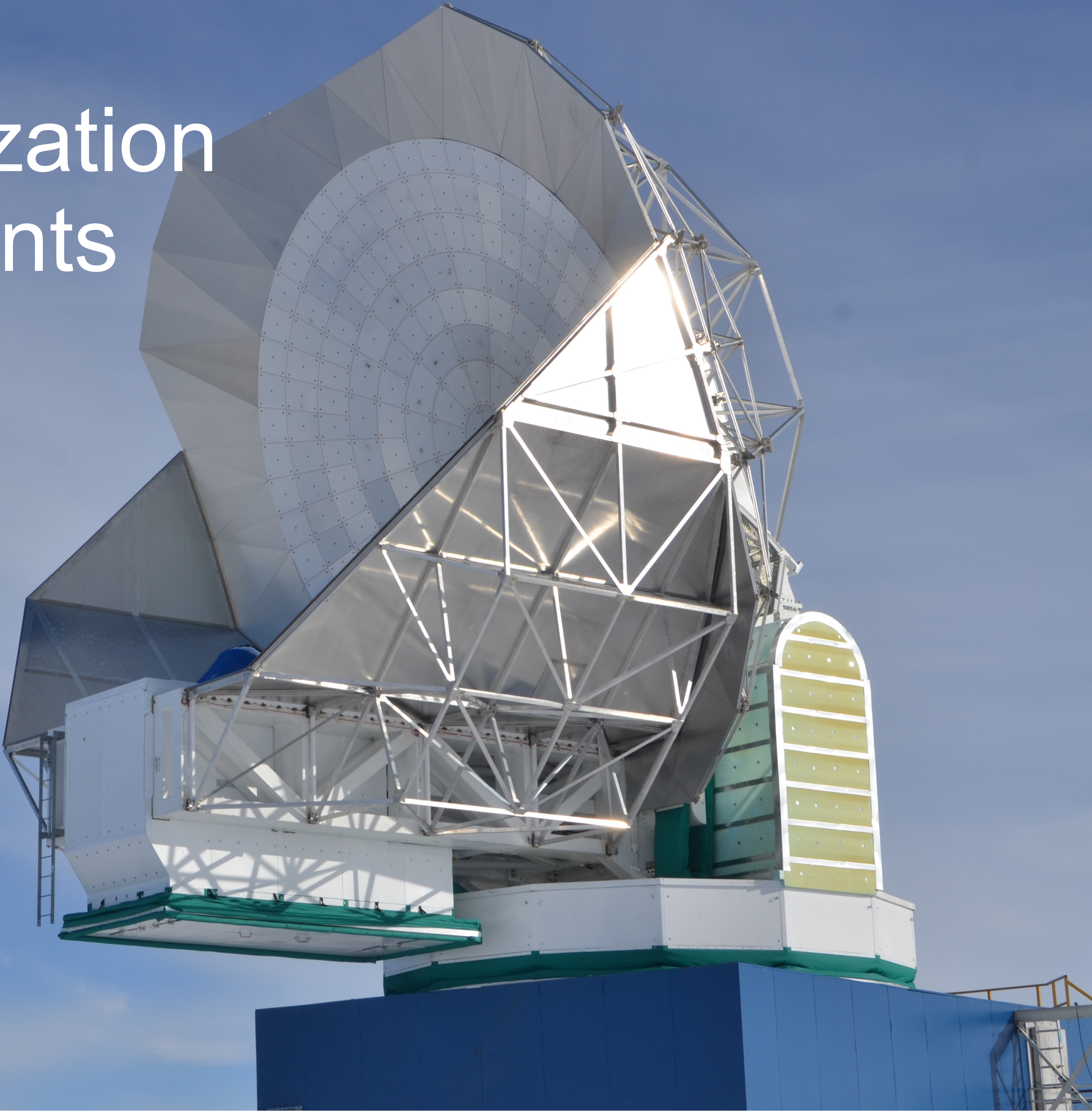
# CMB Polarization Measurements with SPTpol

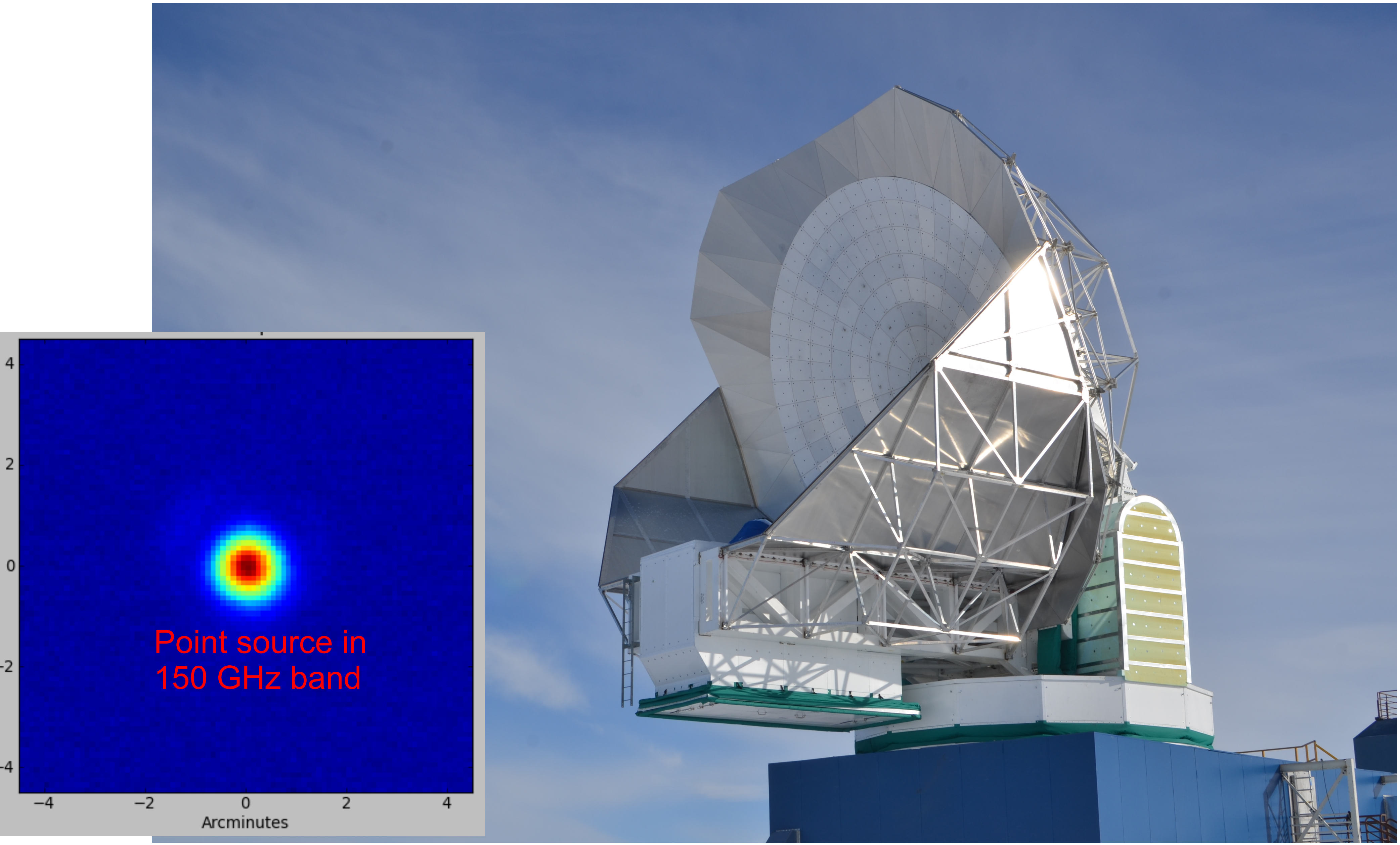


Nicholas Harrington
UC Berkeley

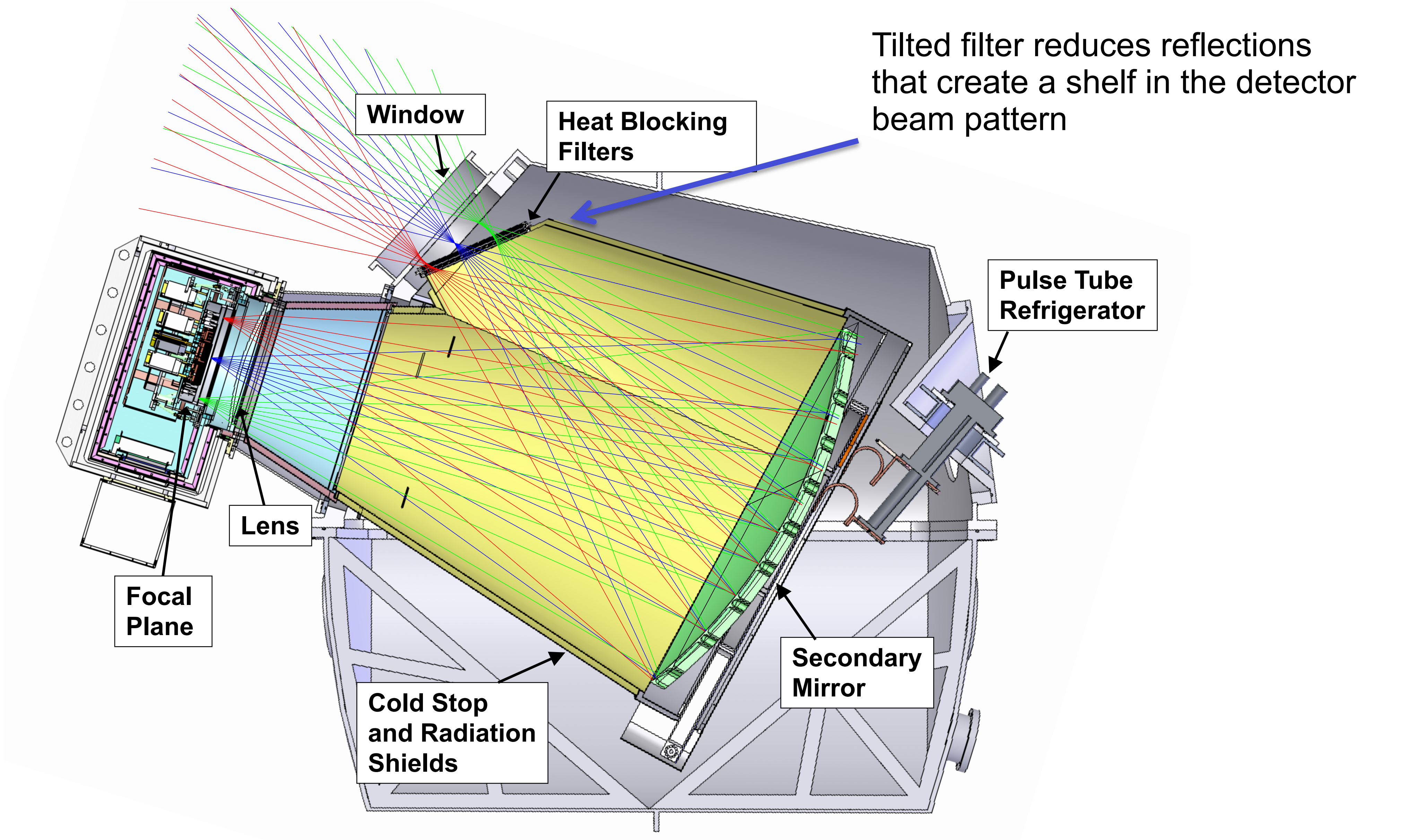
# Why Measure CMB Polarization?

- Additional test of current models of cosmology
- Constrain sum of neutrino masses
- Probe inflationary physics

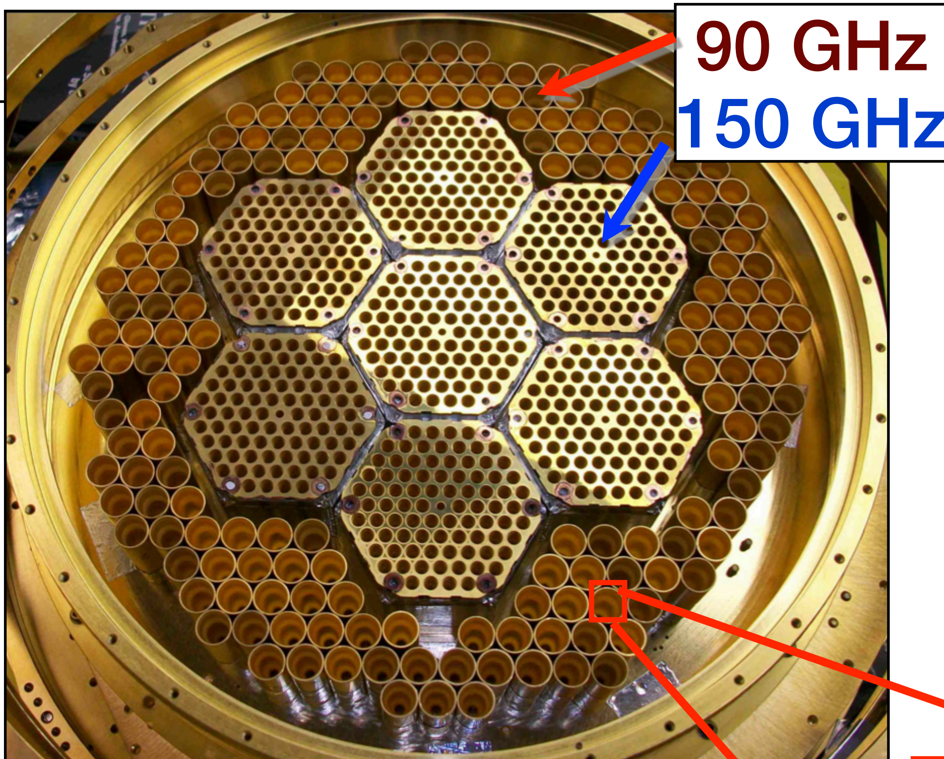
# A 10m dish yields1-arcmin resolution



# Optics Cutaway



# SPTpol Focal Plane

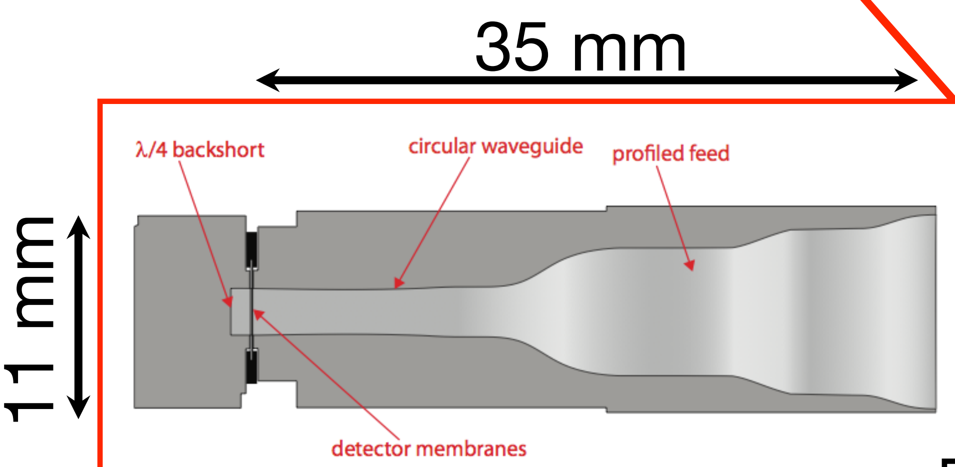


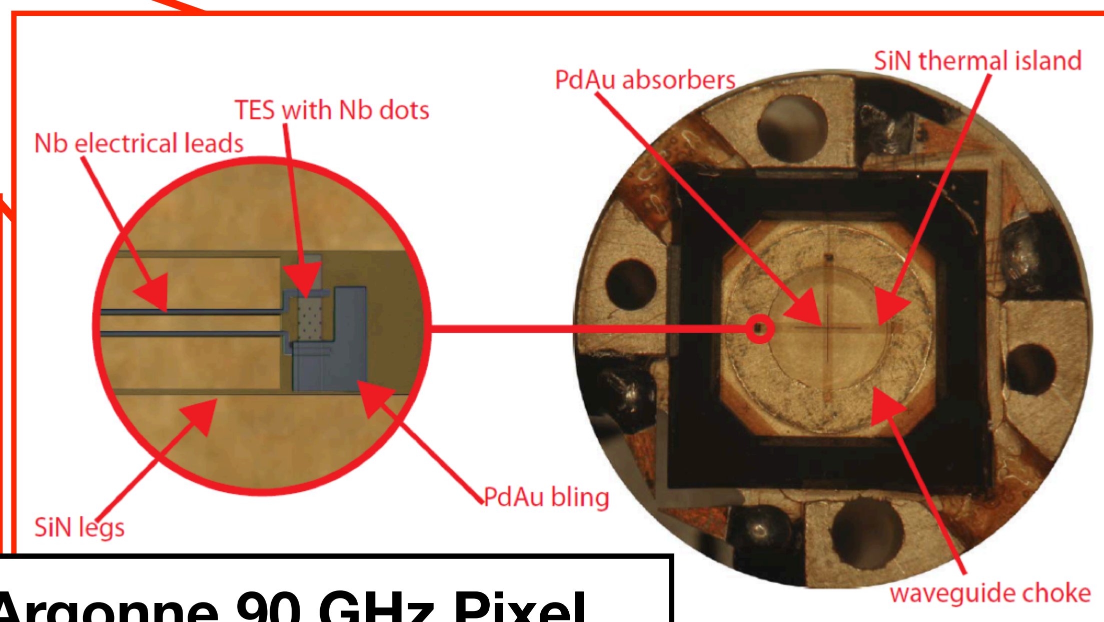

**90 and 150 GHz Focal Plane:**

- 90 GHz detectors made at Argonne National Labs
- 150 GHz detectors made at NIST (Boulder)

## Argonne 90 GHz array

- 180x single pixels
- Individual contoured horns
- Crossed absorbers
- 0.50 K Mo/Au TES



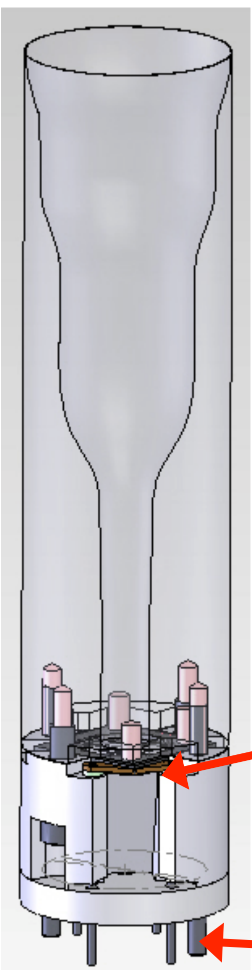




**Argonne 90 GHz Pixel**

# 95 GHz Detectors

Fabricated by Vlad Yefremenko at ANL

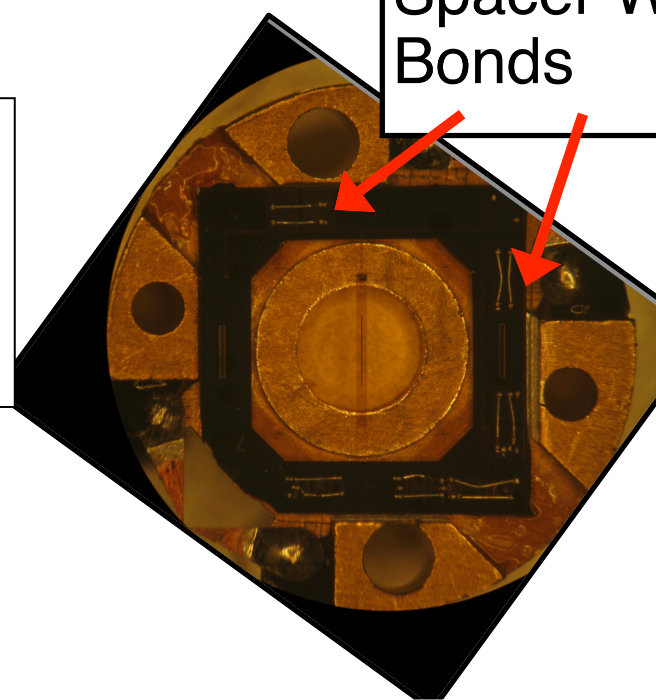
- 190 individual pixels (380 bolometers) at 95 GHz
- Orthogonal crossed absorbers in each pixel separated by ~50 $\mu$m by spacer wire bonds



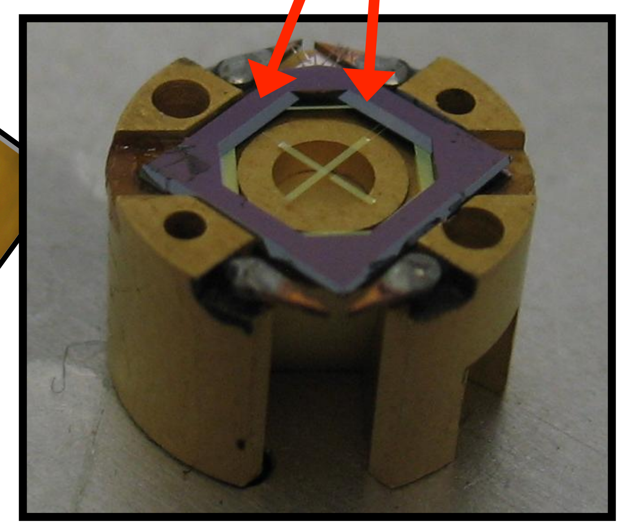
Contoured feed horn; maintains polarization angle

Detector in wave-guide section with $\lambda/4$ backshort

Readout from back via pins

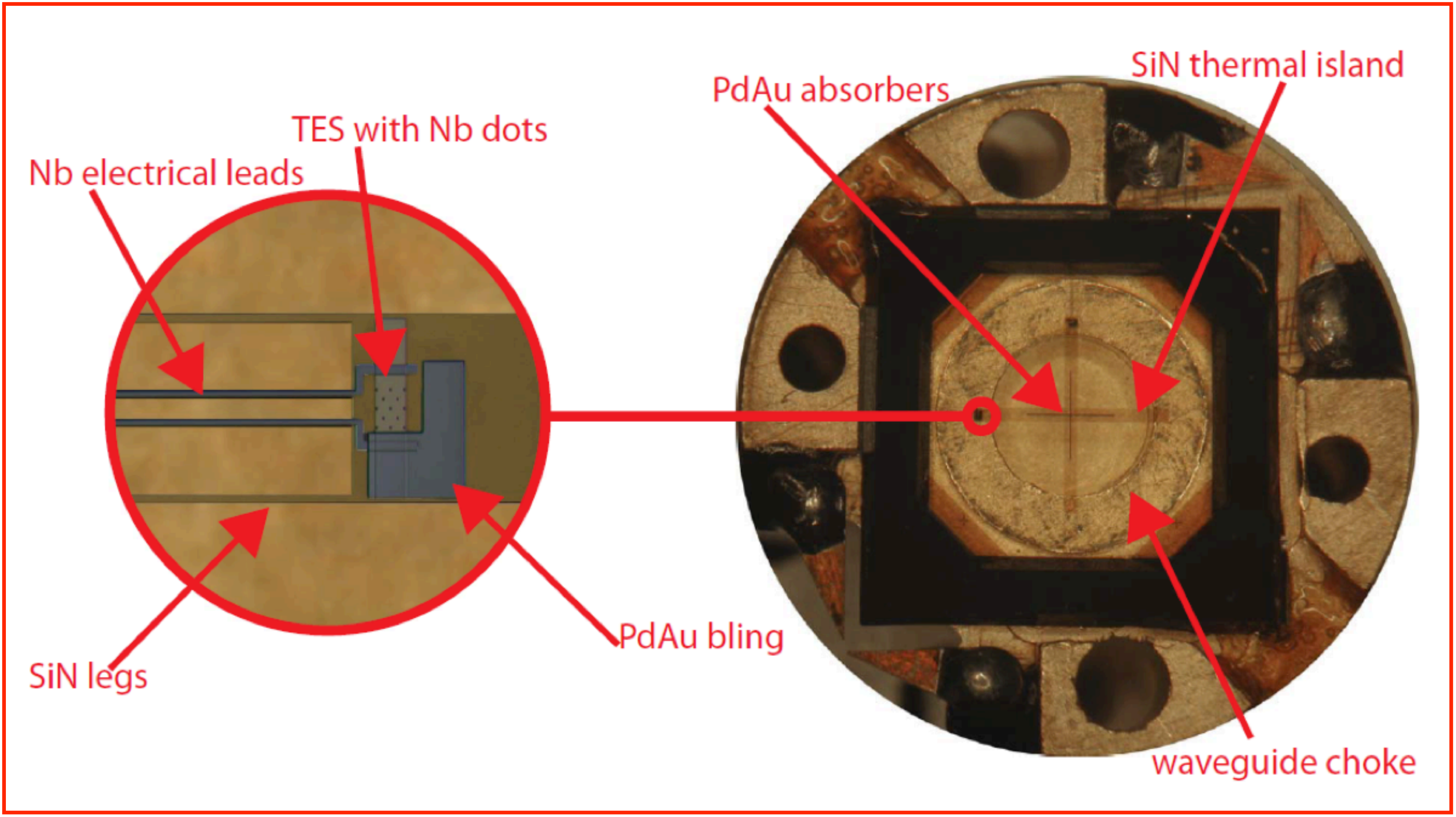


Spacer Wire Bonds



Crossed absorbers

# 95 GHz Detectors

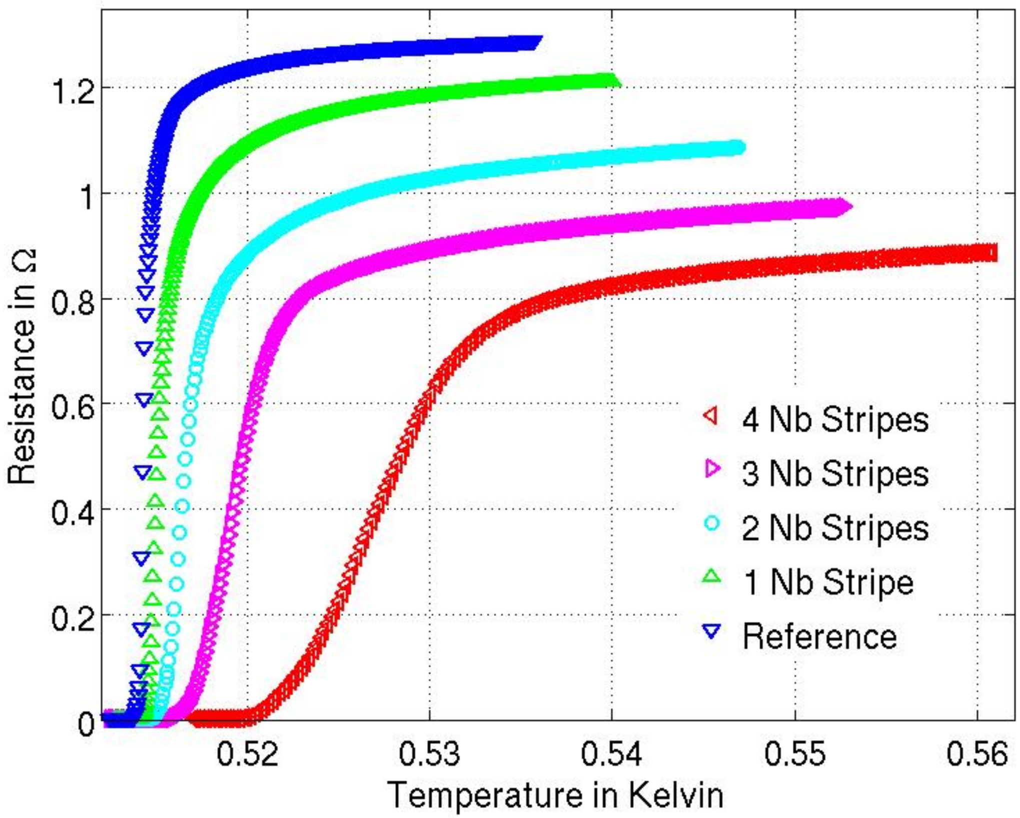


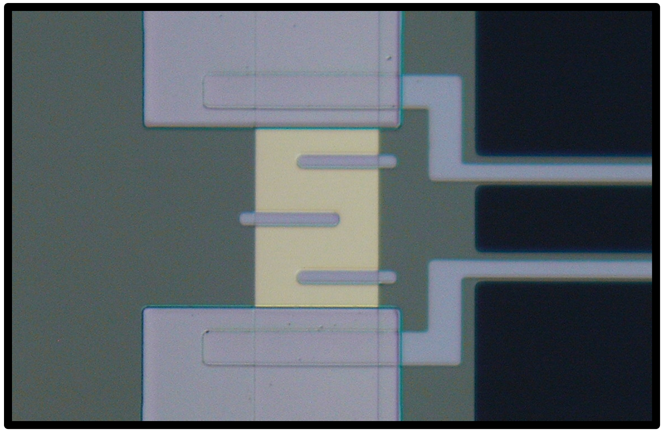
# 95 GHz Detectors

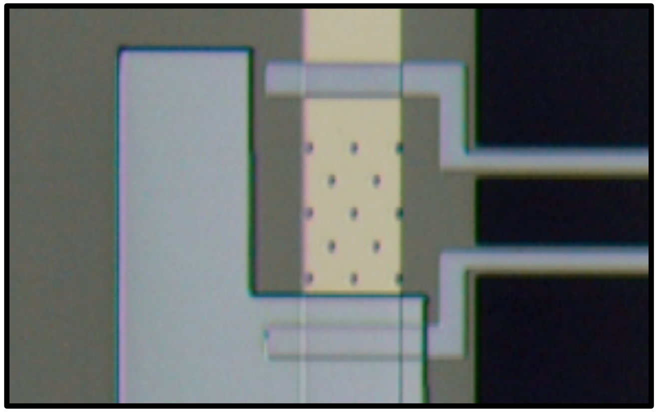
$R(T)$ curve:
Steeper = Faster, more linear
Broader = More stable

Engineer TES speed and responsivity
- Palladium-Gold (PdAu) added head capacity to slow detectors (ala SPT-SZ)

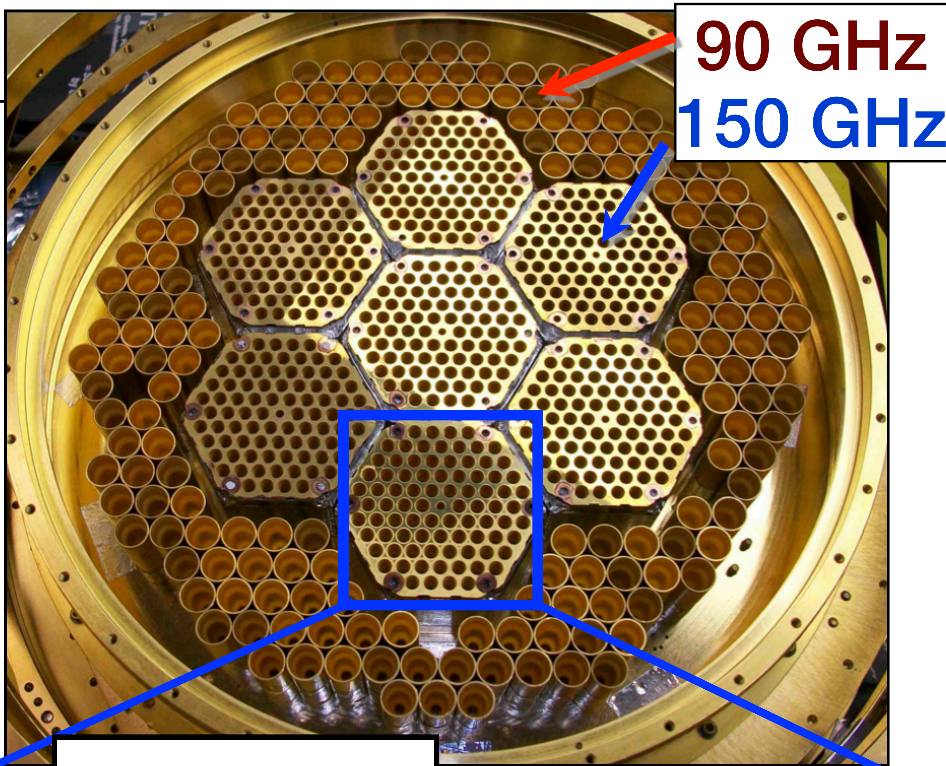
- Tested superconducting stripe and dot architecture on TES to “soften” $R(T)$ curve and add responsivity high in the transition





# SPTpol Focal Plane

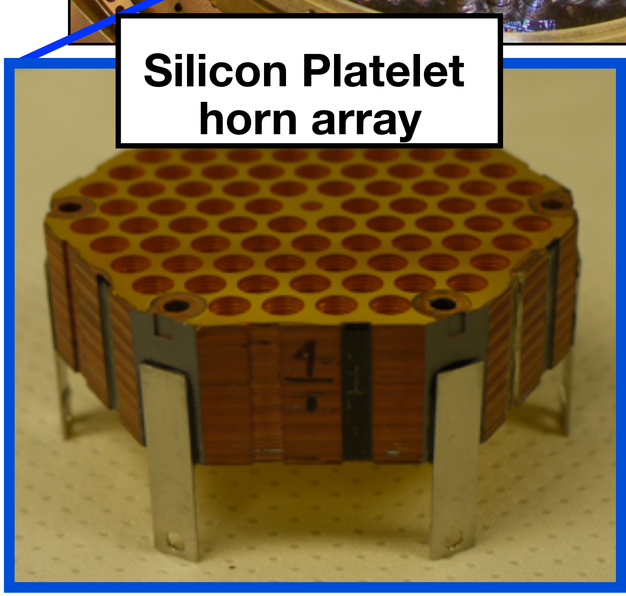


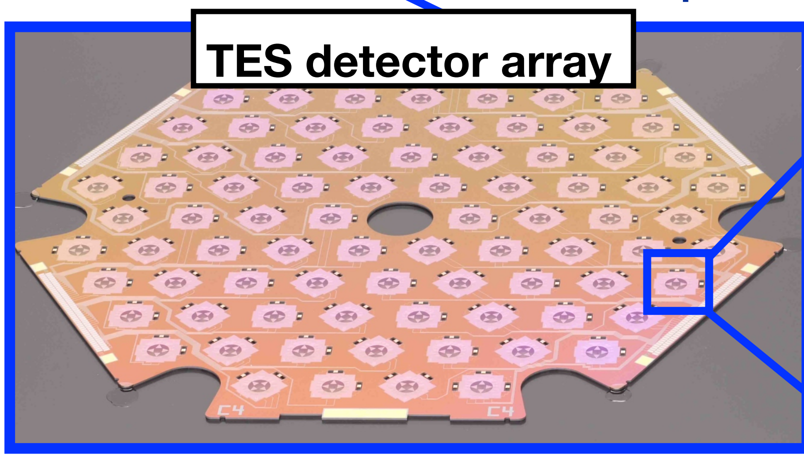

**90 and 150 GHz Focal Plane:**

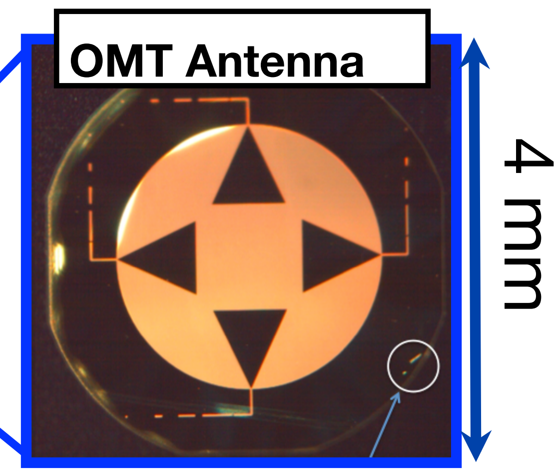
- 90 GHz detectors made at Argonne National Labs
- 150 GHz detectors made at NIST (Boulder)

## NIST 150 GHz array

- 588x pixels total in 7x arrays
- Monolithic silicon platelet corrugated horn array
- Crossed OMT antenna
- Micro-strip to 0.50 K Al/Mn TES



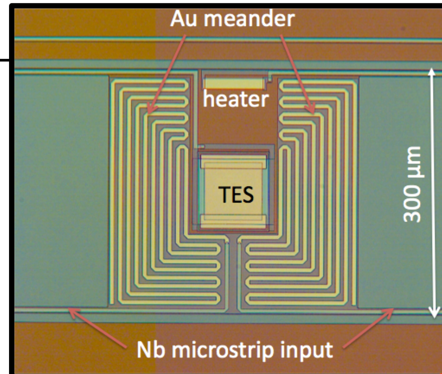



NIST

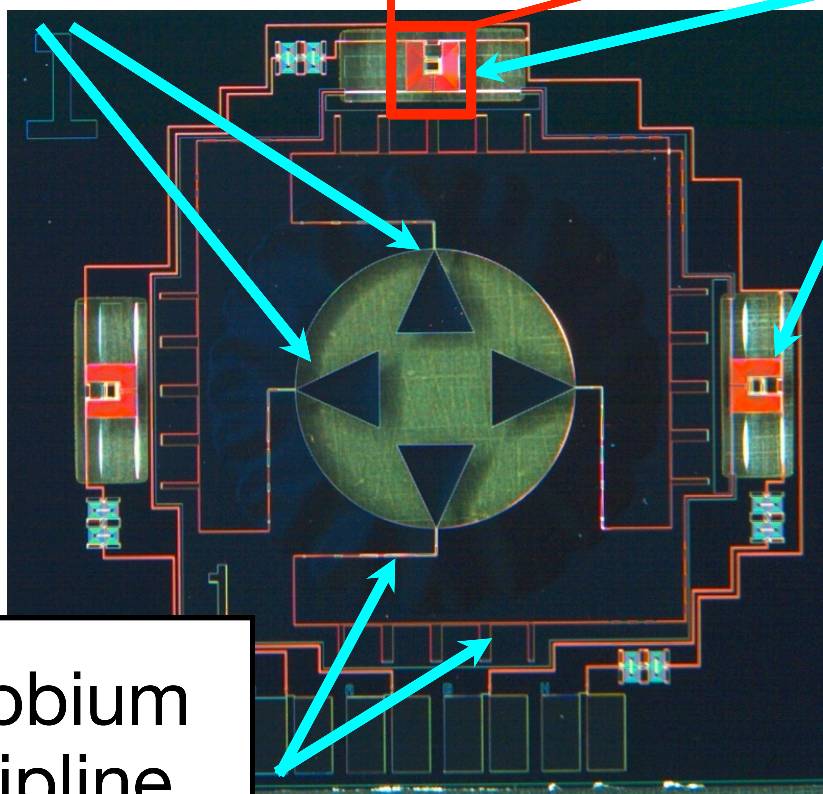
# 150 GHz Detectors

Fabricated by Dale Li, Sherry Cho at NIST

Polarization Splitter (OMT)
- Niobium on SiN



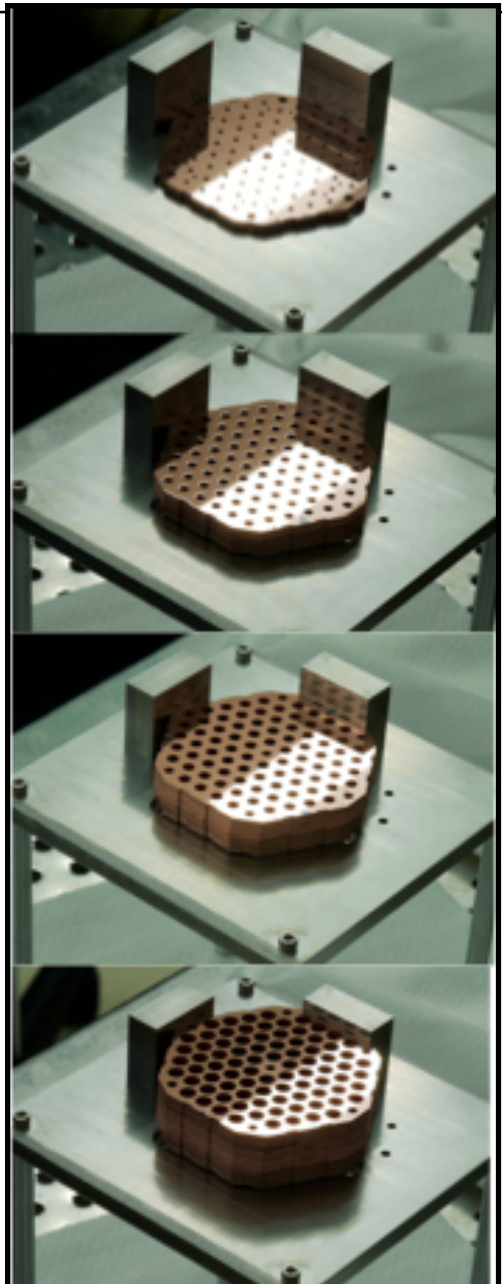

Al/Mn TES (Tc ~ 0.5 K)

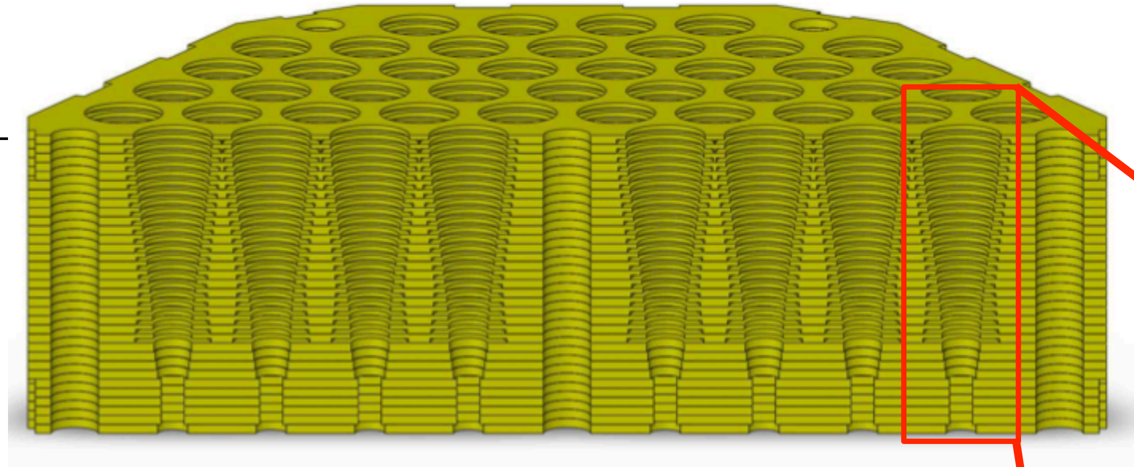


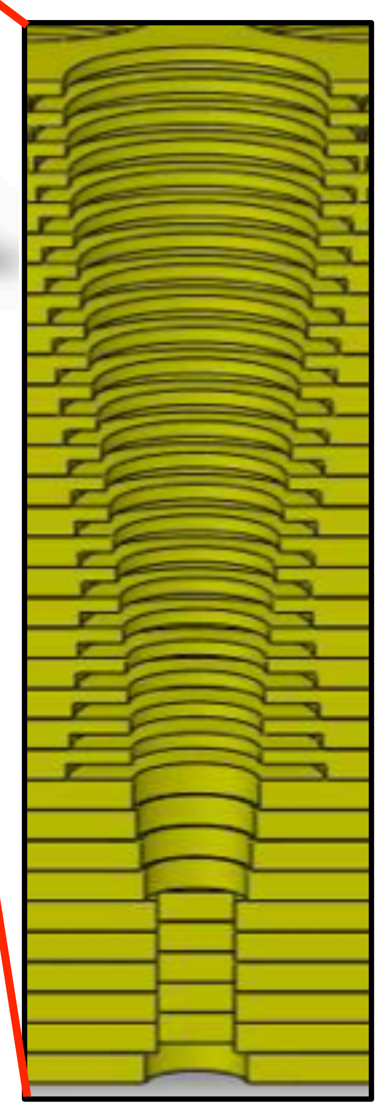
Niobium stripline

NIST 150 GHz detectors uses antenna-coupled TES design

- Niobium OMT antenna splits light into two polarizations, fed through strip-lines to TES island, where heat is dissipated through lossy Gold (Au) meander



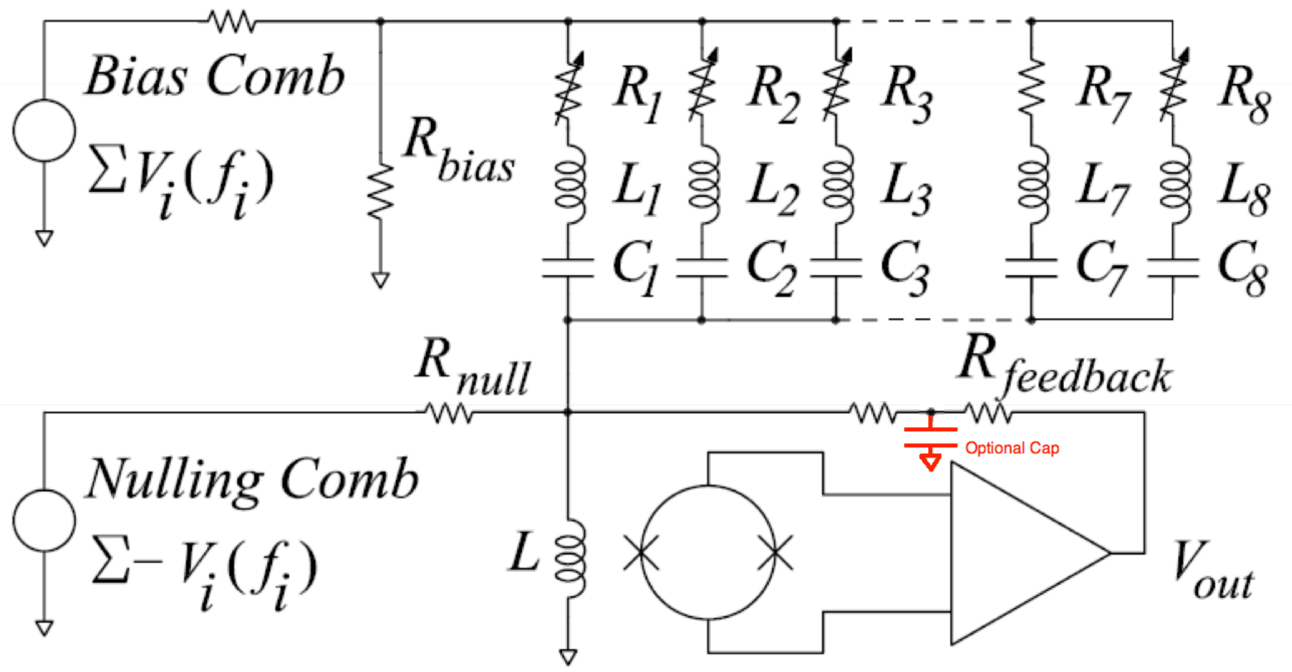




# Corrugated feed horns

- Excellent beam and RF pickup systematics control
- 84 pixel gold-plated, silicon horn array with optimal 1.5 f l spacing
- Stack of 33 silicon wafers (500 mm), deep-etched in shape of horn profile, stacked, and gold-plated
- Thermal contraction naturally matched to Silicon detector array

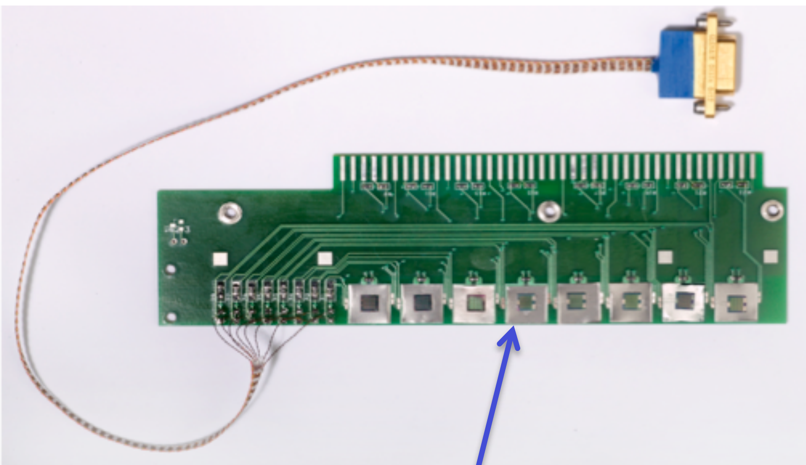
# Digital Frequency Multiplexing System




- Digital Active Nulling (DAN aka BBFB) run at bolometer bias frequencies
- Low frequency flux locked loop (<1kHz) is used to mitigate the changing flux caused by the telescope scanning through the Earth's magnetic field

# Cold Electronics

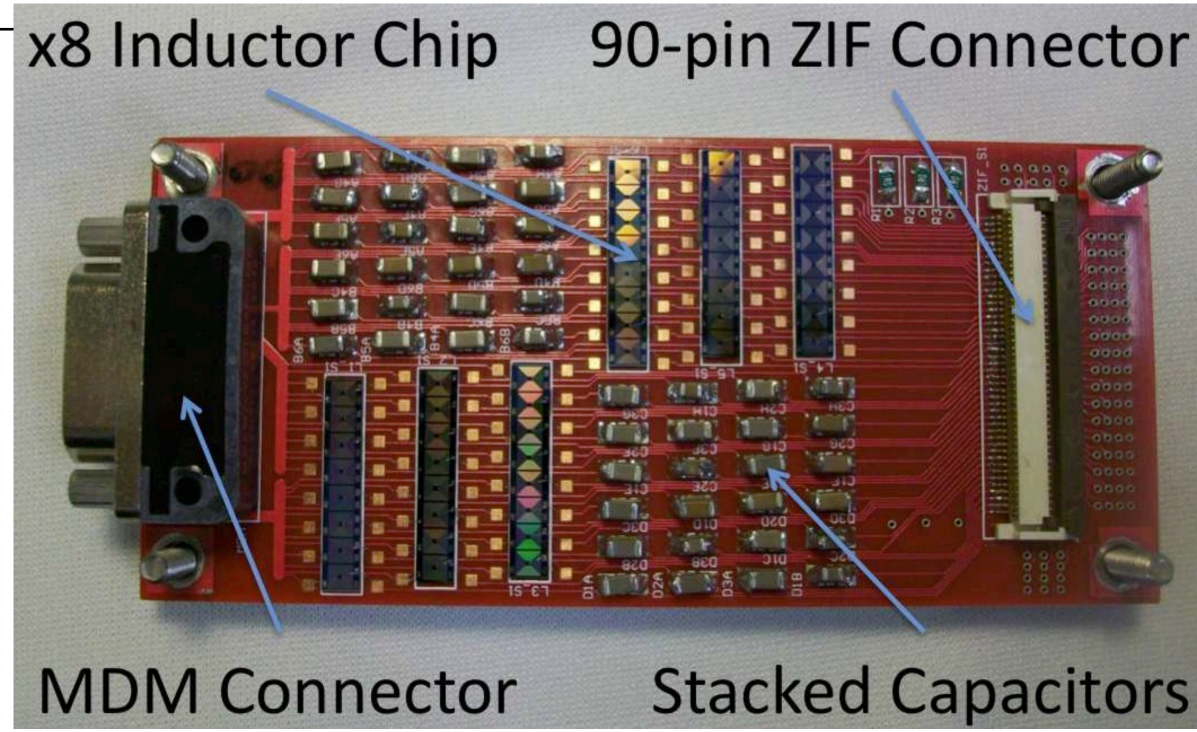
SQUID Board at 4K

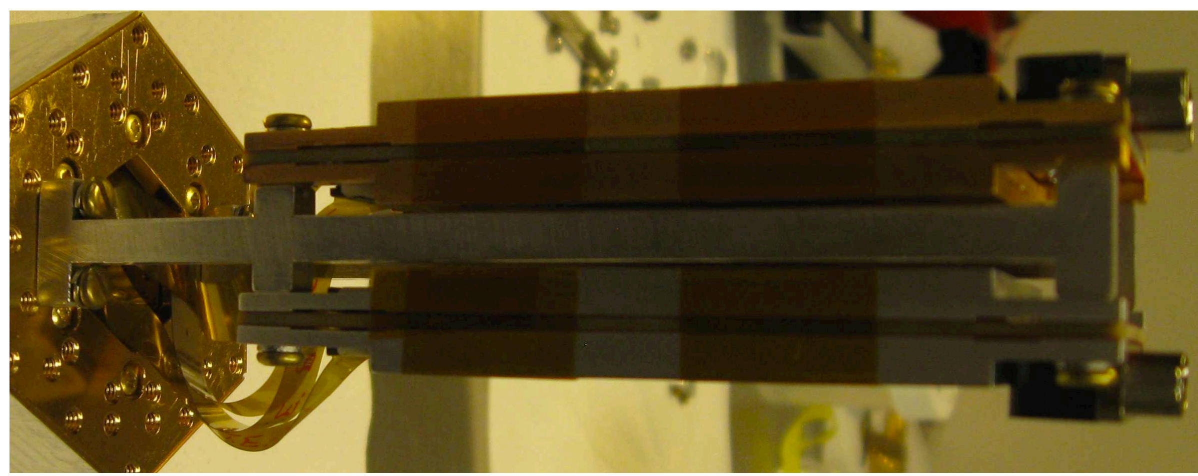


Serial SQUID Arrays
Fabricated at NIST

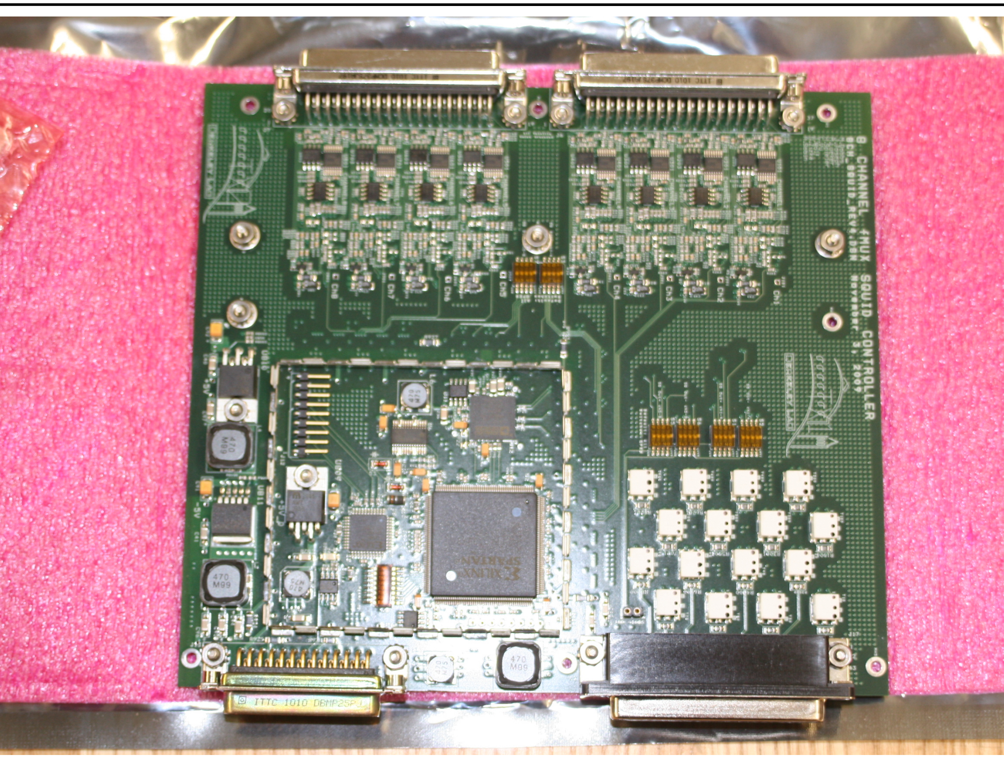
Not Shown: shields to reduce the low frequency background magnetic field.

LC Board at 270mK

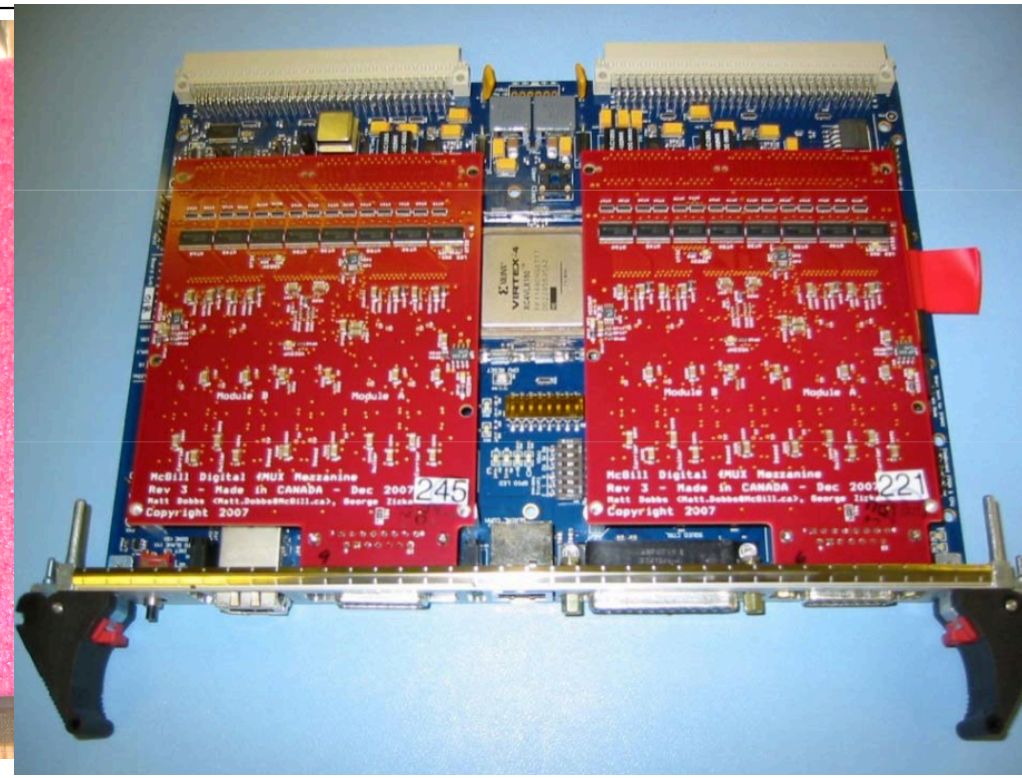


# Warm Electronics



- Attached to cryostat
- 1$^{st}$ and 2$^{nd}$ stage amplifiers
- DACs for setting SQUID operating points

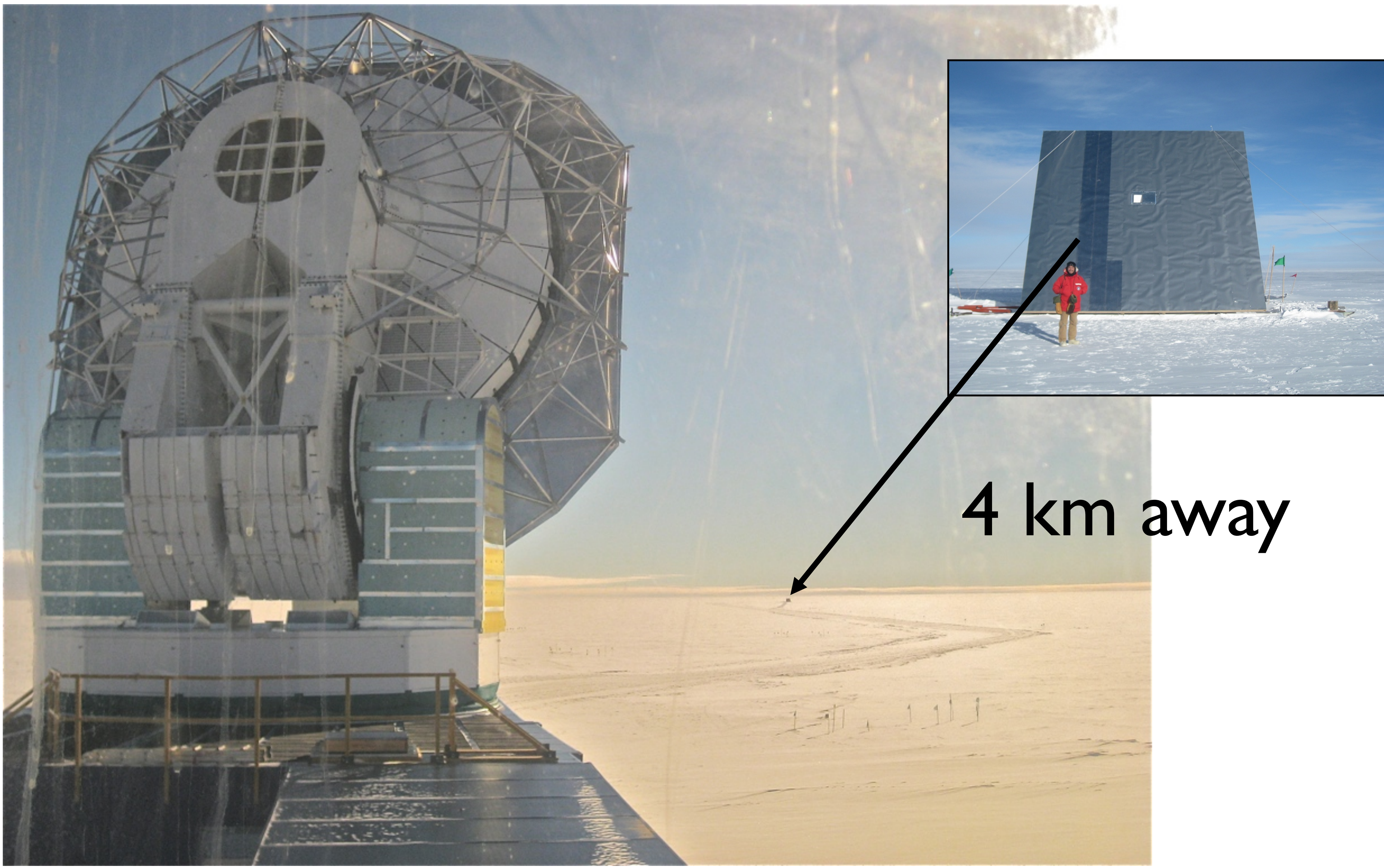


DfMux Board Designed by WinterLand Cosmology Lab at McGill

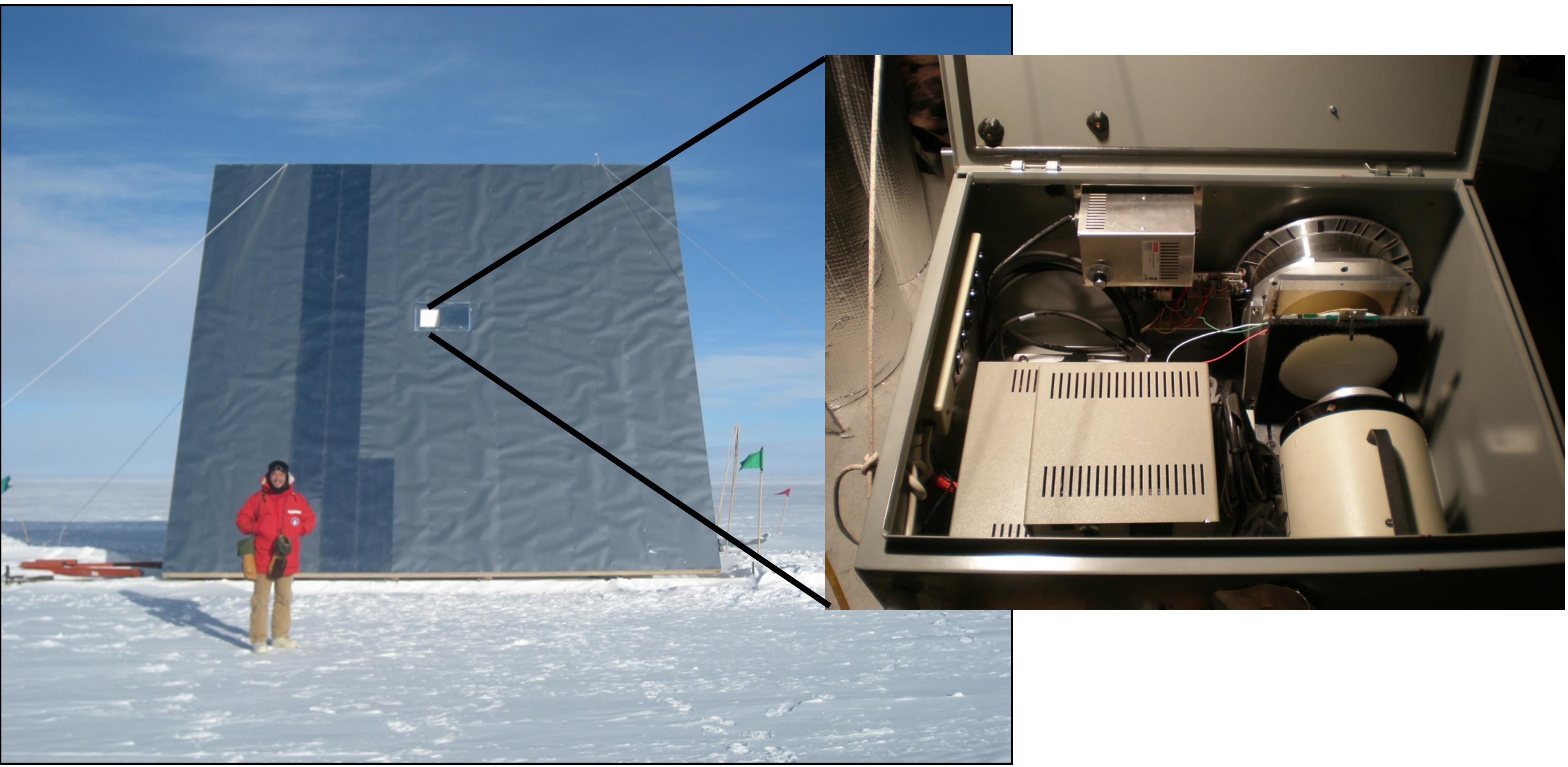
- Handles signal generation
- Demodulation of bolo time streams
- Communicates with control computer

Software

# Detector polarization angle calibrated with polarization source



# The source is an oven behind a rotating polarizing grid



# First year's observations have yielded good data

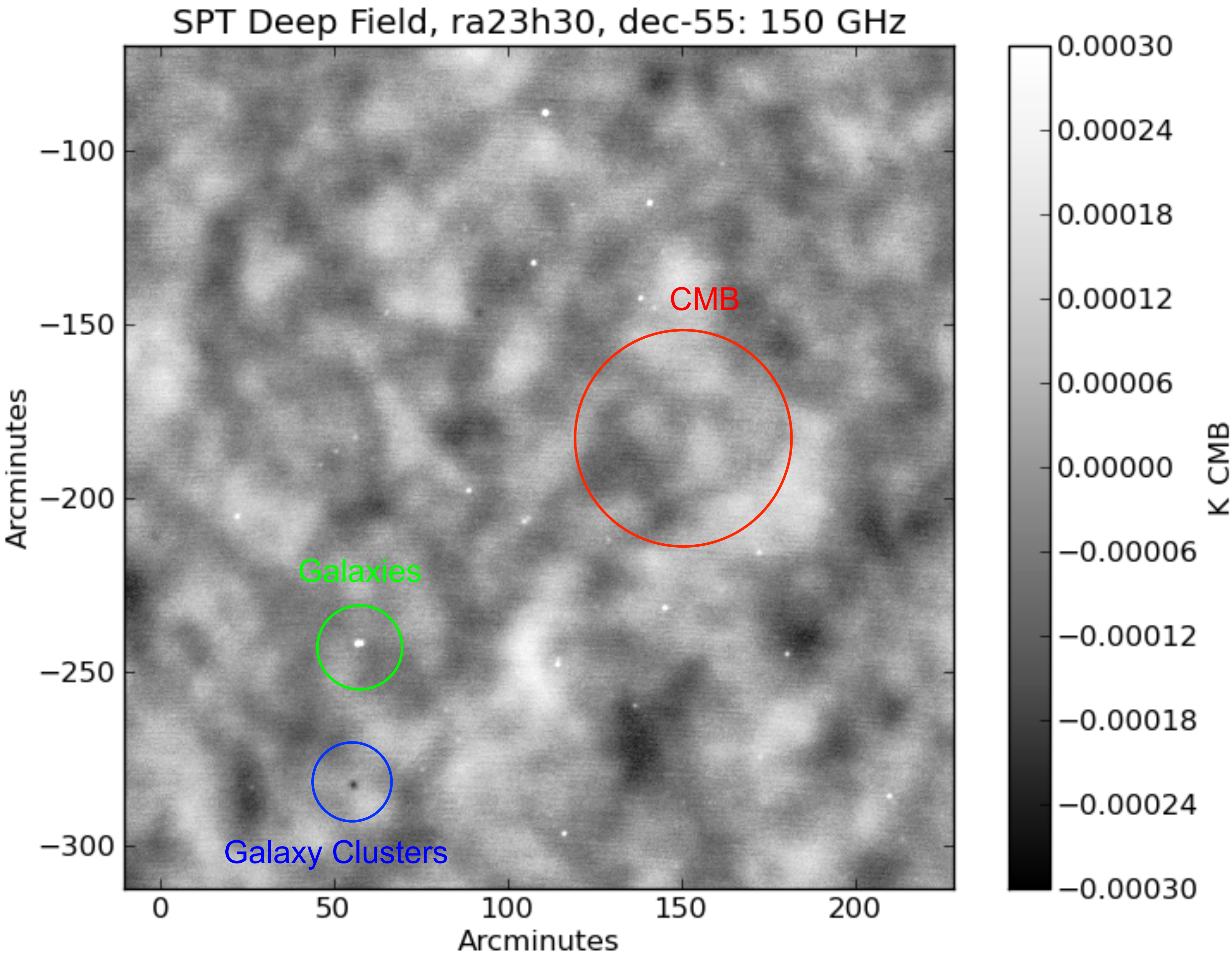
Observed ~100 $deg^2$ field in low-foreground region of southern sky

- $-50 < \text{declination} < -60$
- 23h < RA < 24h

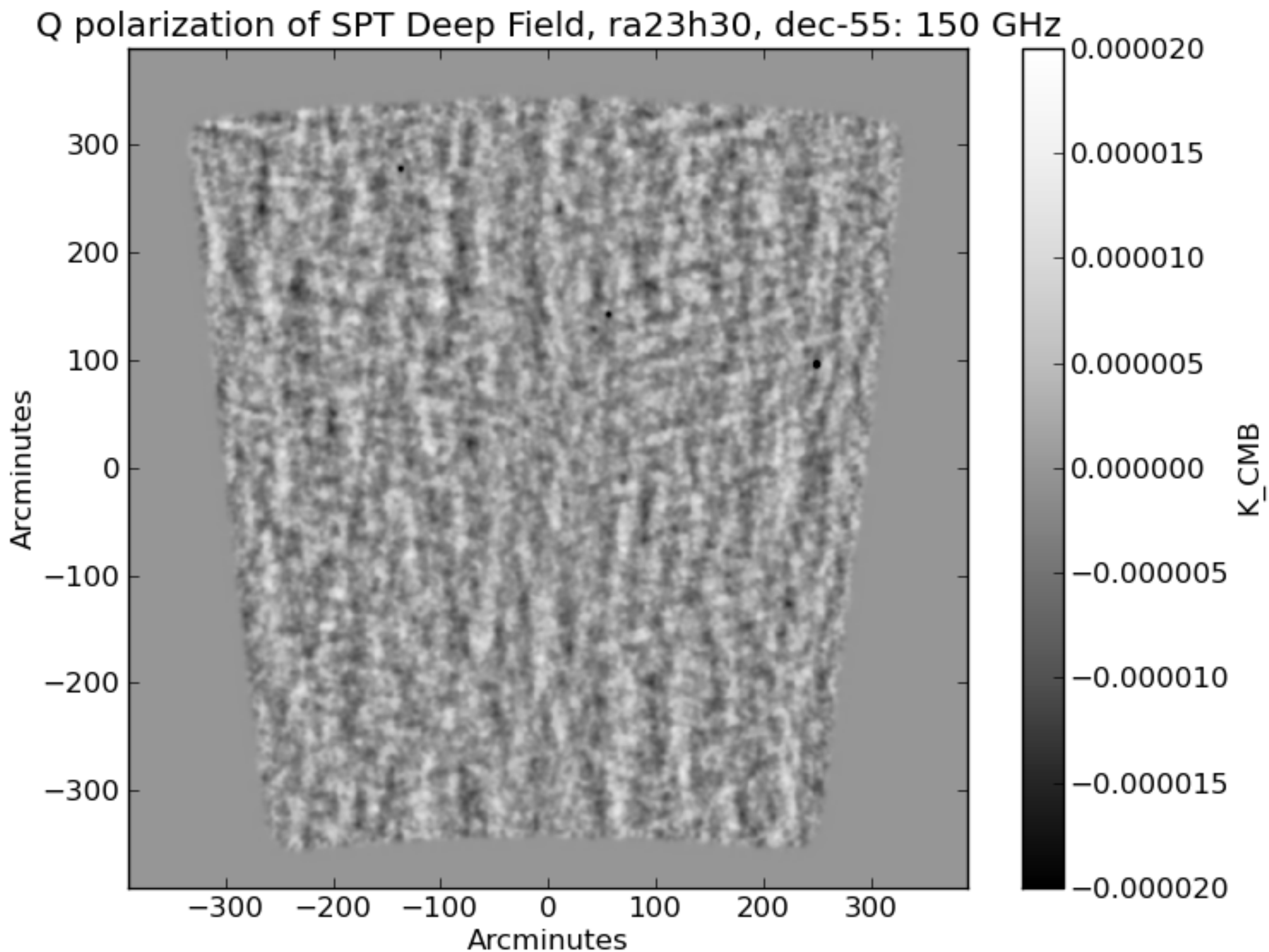
Full-season map noise

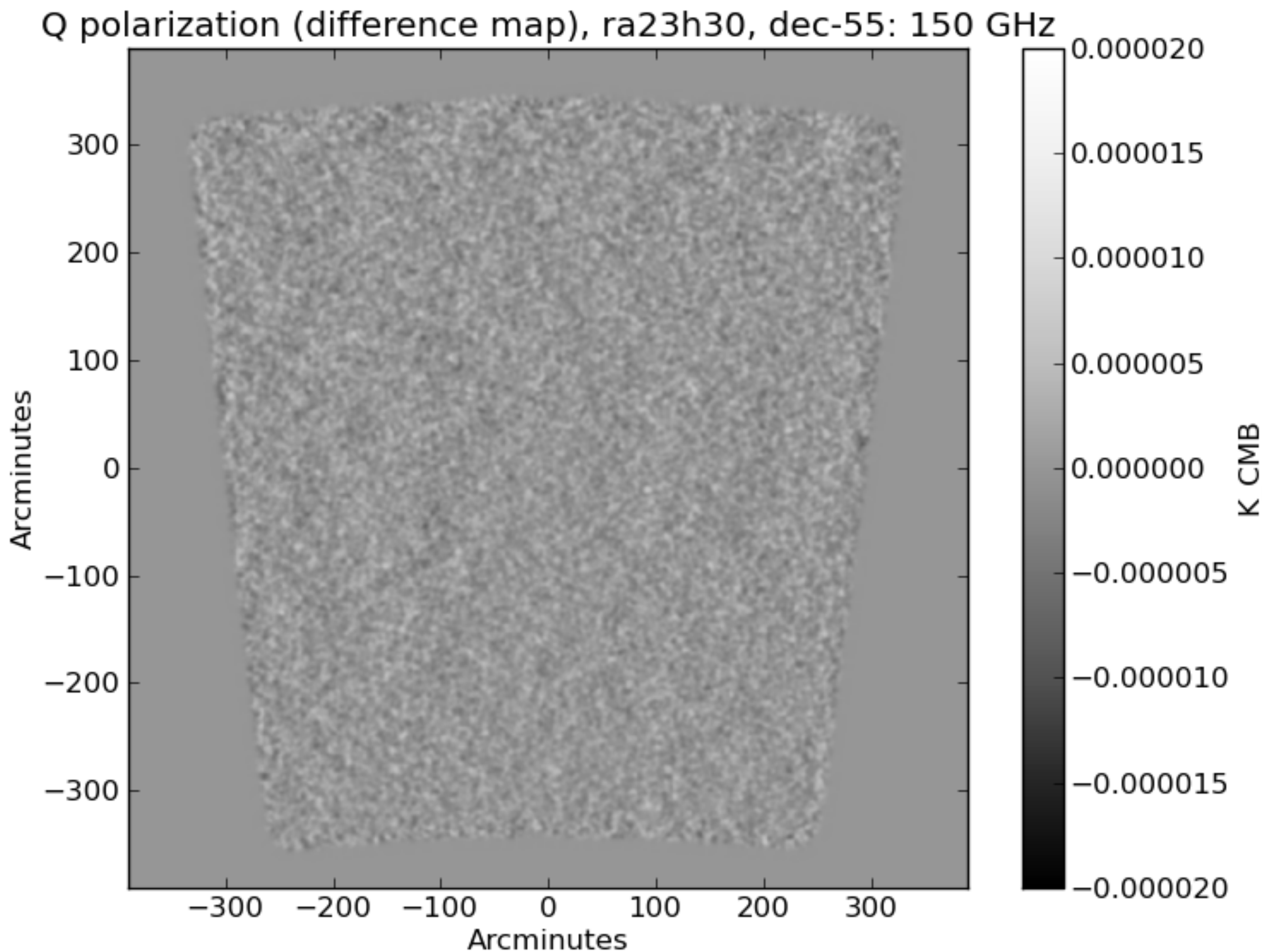
- ~8 μK-arcmin in temperature @ 150 GHz
- ~10 μK-arcmin in polarization @ 150 GHz

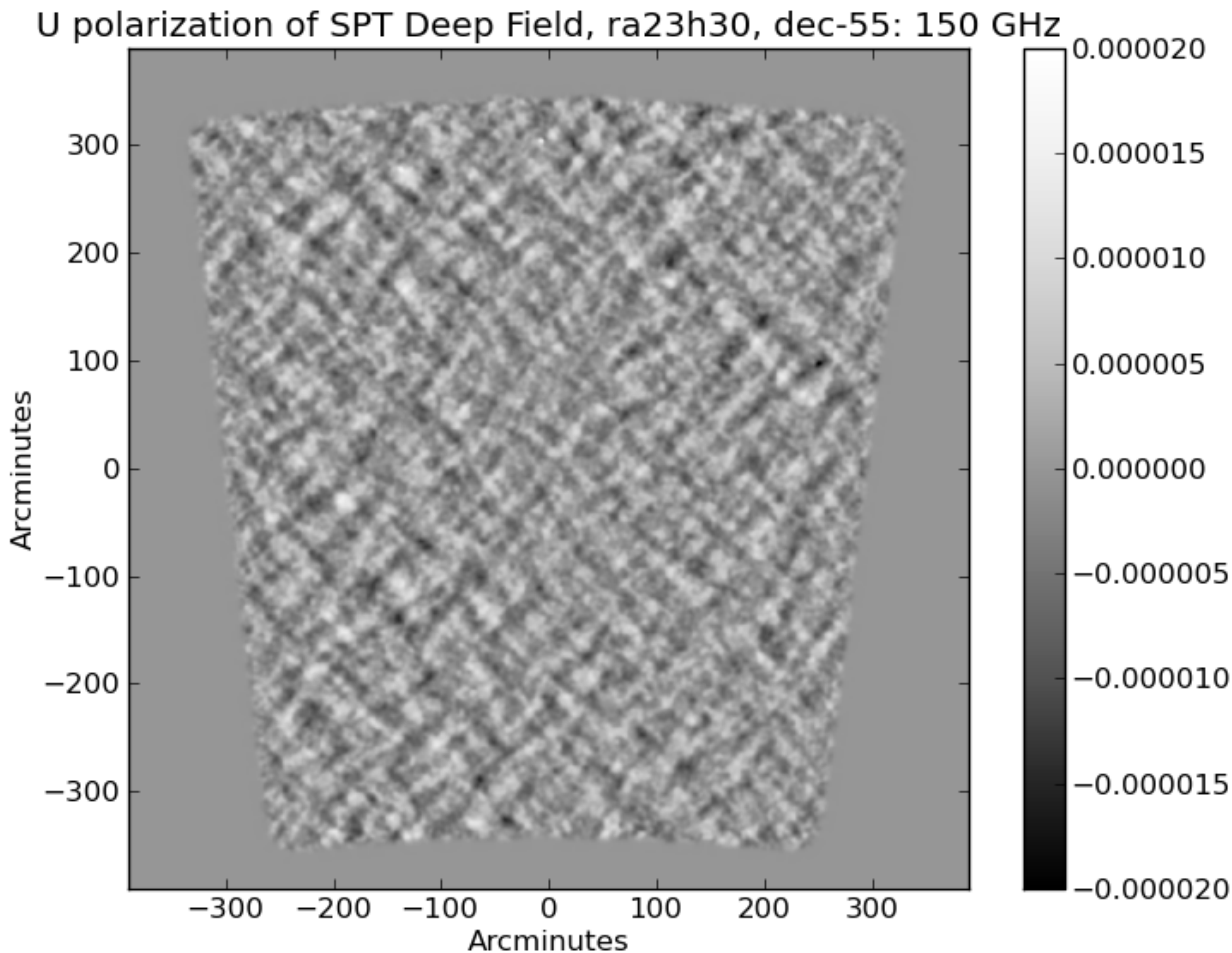
We have switched to observing the full 500 sq deg survey field and will until 2016



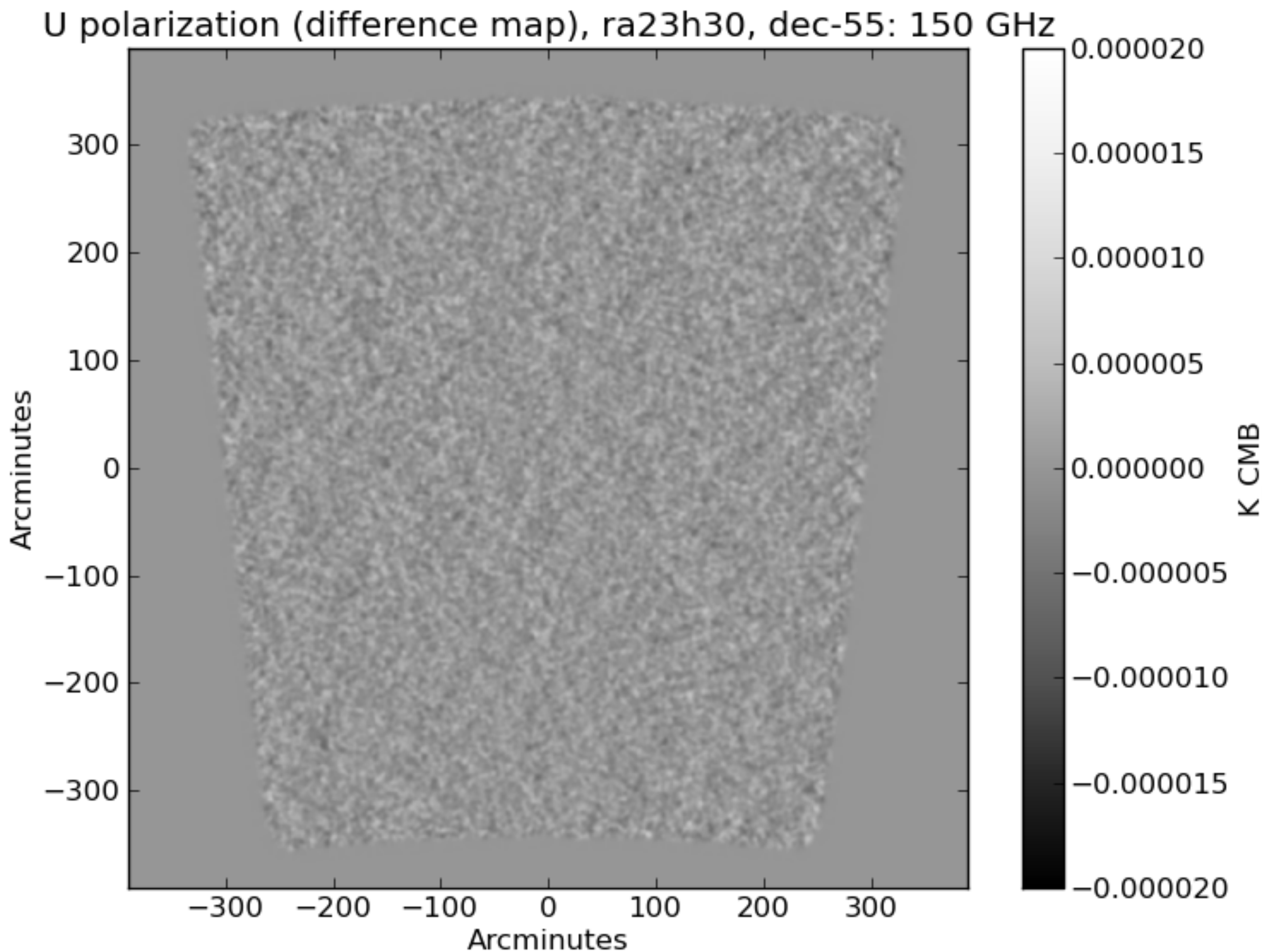
SPT Deep Field, ra23h30, dec-55: 150 GHz
CMB
Galaxies
Galaxy Clusters
Arcminutes
Arcminutes
K_CMB
0.00030
0.00024
0.00018
0.00012
0.00006
0.00000
−0.00006
−0.00012
−0.00018
−0.00024
−0.00030
−100
−150
−200
−250
−300
0
50
100
150
200


Q polarization of SPT Deep Field, ra23h30, dec-55: 150 GHz
Arcminutes
Arcminutes
K_CMB
300
200
100
0
−100
−200
−300
0.000020
0.000015
0.000010
0.000005
0.000000
−0.000005
−0.000010
−0.000015
−0.000020


Q polarization (difference map), ra23h30, dec-55: 150 GHz
Arcminutes
Arcminutes
300
200
100
0
−100
−200
−300
−300
−200
−100
0
100
200
300
0.000020
0.000015
0.000010
0.000005
0.000000
−0.000005
−0.000010
−0.000015
−0.000020
K_CMB



U polarization of SPT Deep Field, ra23h30, dec-55: 150 GHz
Arcminutes
−300
−200
−100
0
100
200
300
Arcminutes
300
200
100
0
−100
−200
−300
K_CMB
0.000020
0.000015
0.000010
0.000005
0.000000
−0.000005
−0.000010
−0.000015
−0.000020


U polarization (difference map), ra23h30, dec-55: 150 GHz
Arcminutes
Arcminutes
300
200
100
0
−100
−200
−300
−300
−200
−100
0
100
200
300
0.000020
0.000015
0.000010
0.000005
0.000000
−0.000005
−0.000010
−0.000015
−0.000020
K_CMB

# SPTpol Science Projections

For the full 4 year survey we will constrain:

- The sum of neutrino masses:

$$\sigma(\Sigma m_\nu) \approx 0.1\text{eV}$$

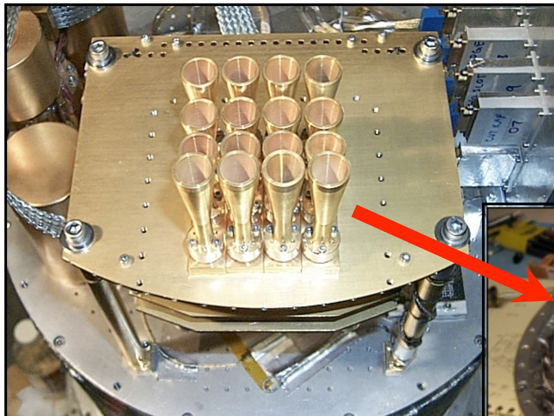
- The tensor-to-scalar ratio:

$$\sigma(r) = 0.03$$

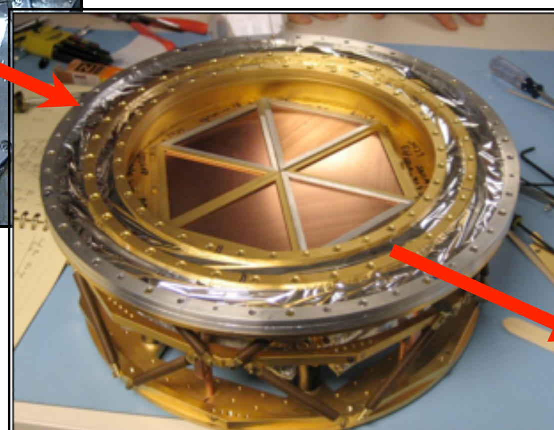
- SPTpol will detect lensing at 45σ
- Will provide high signal-to-noise mass maps to calibrate other surveys

# SPT-3G: The Next Generation Camera for the SPT

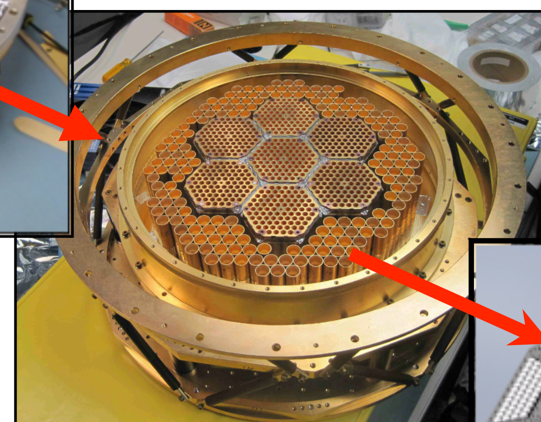
2001: ACBAR
16 detectors



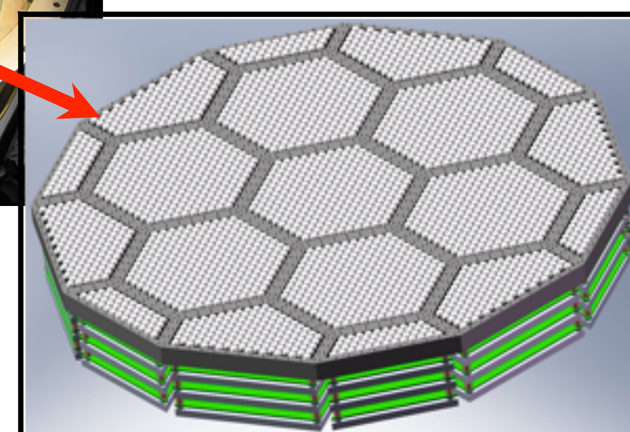
2007: SPT
2500 deg²
960 detectors



2012: SPTpol
500 deg²
~1600 detectors



2016: SPT-3G
2500 deg²
~15,200 detectors

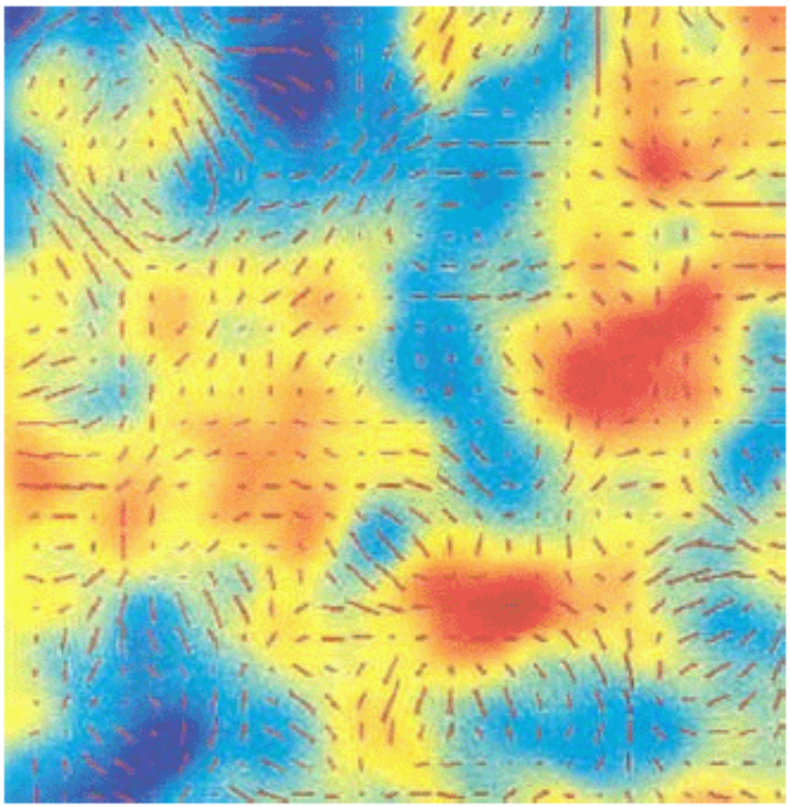


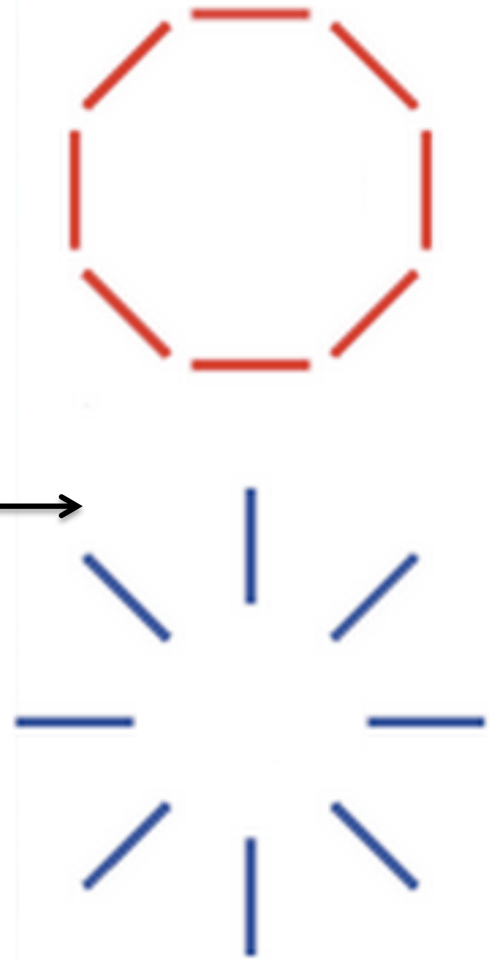
When combined with Planck SPT3g will constrain:

$$\sigma(\Sigma m_\nu) \approx 0.06eV$$

$$\sigma(r) \approx 0.01$$

# The CMB Polarization Can be Decomposed in to E-modes and B-modes



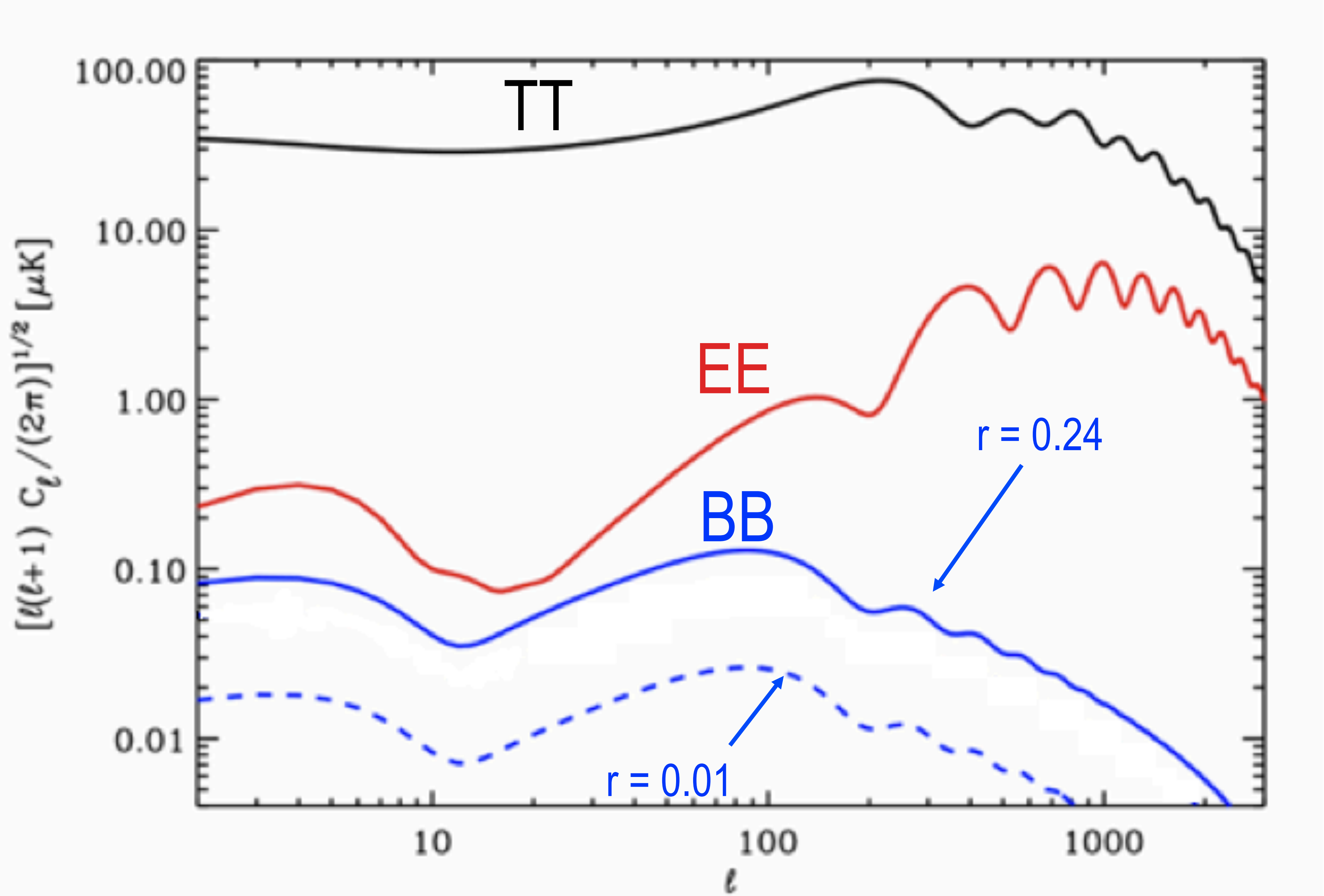


E Modes

B Modes

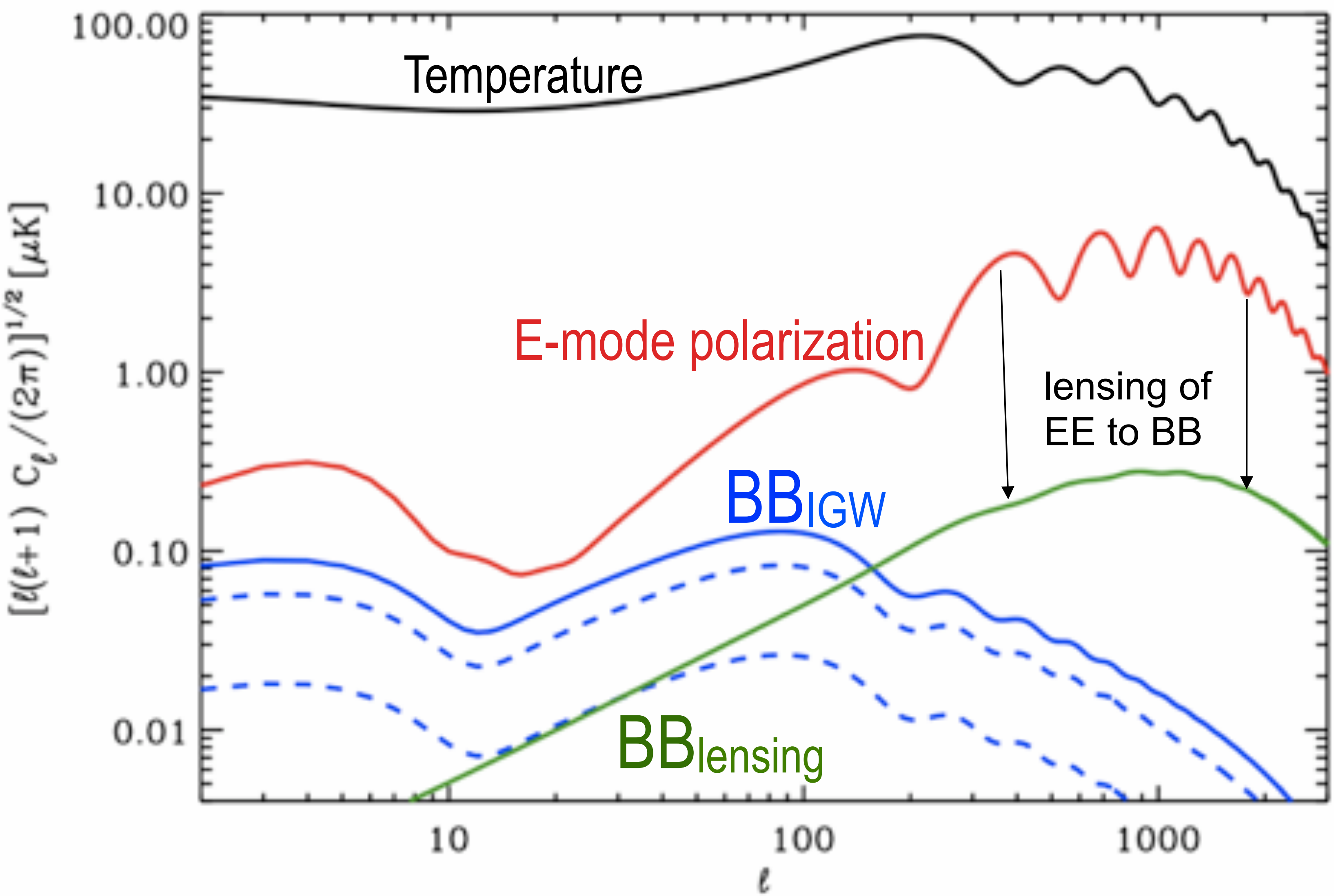
Image by Seljak and Zaldarriaga

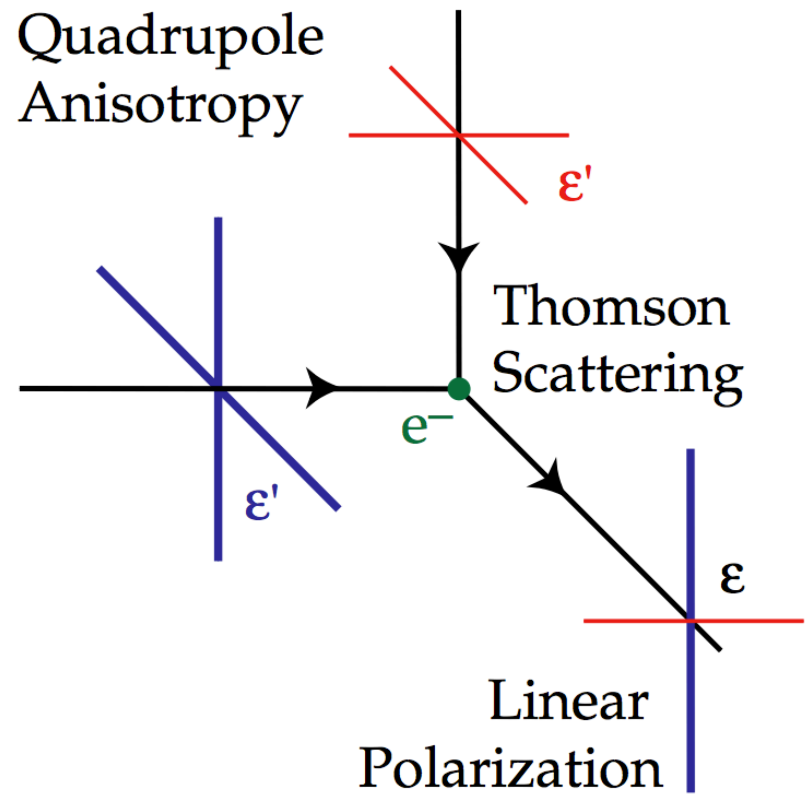
# Gravity Waves Create B Modes




r == Tensor-to-scalar ratio

# Gravitational lensing mixes types of polarization






From Hu and White 1997