Detectors for the South Pole Telescope

Clarence Chang

TIPP, 2011

Outline

Cosmic Intro

Introduction to Bolometers
(eg: SPT-SZE)

Detectors for SPTpol

Transition Edge Sensors
(TES) & Multiplexing

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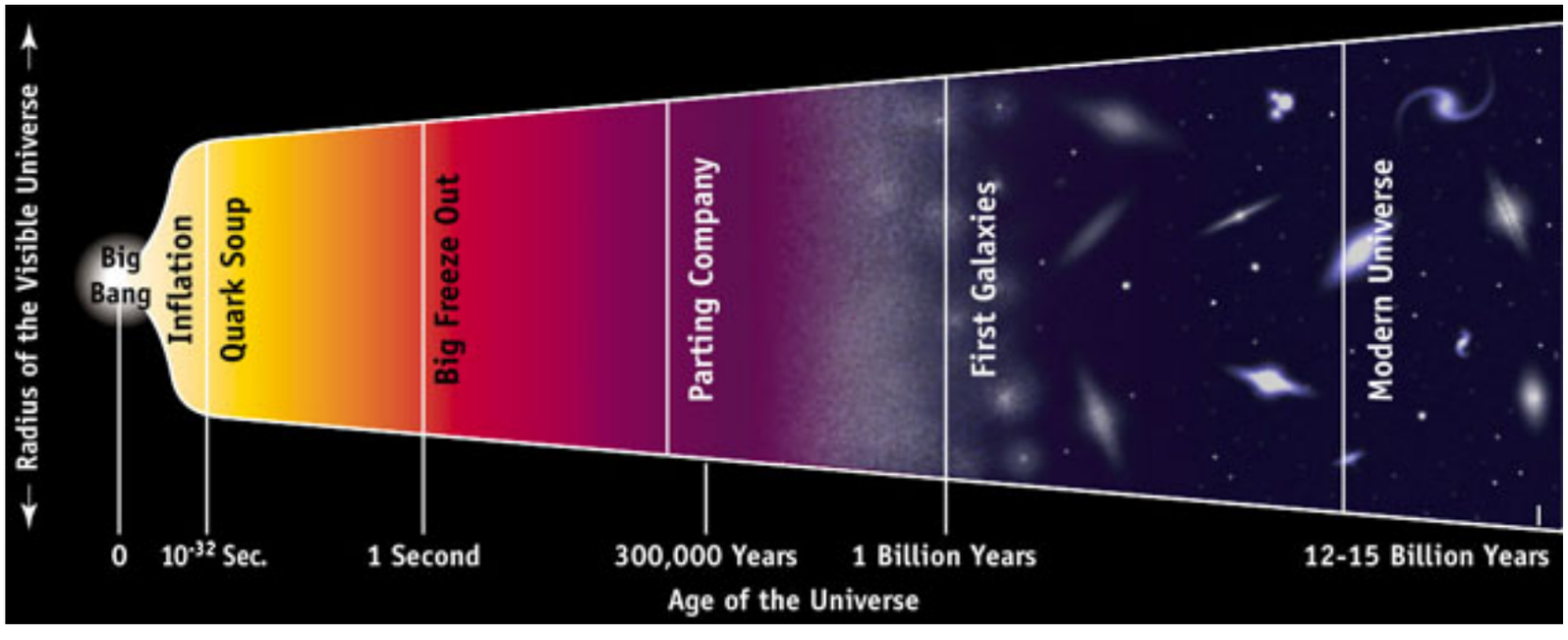
The goal: fundamental physics



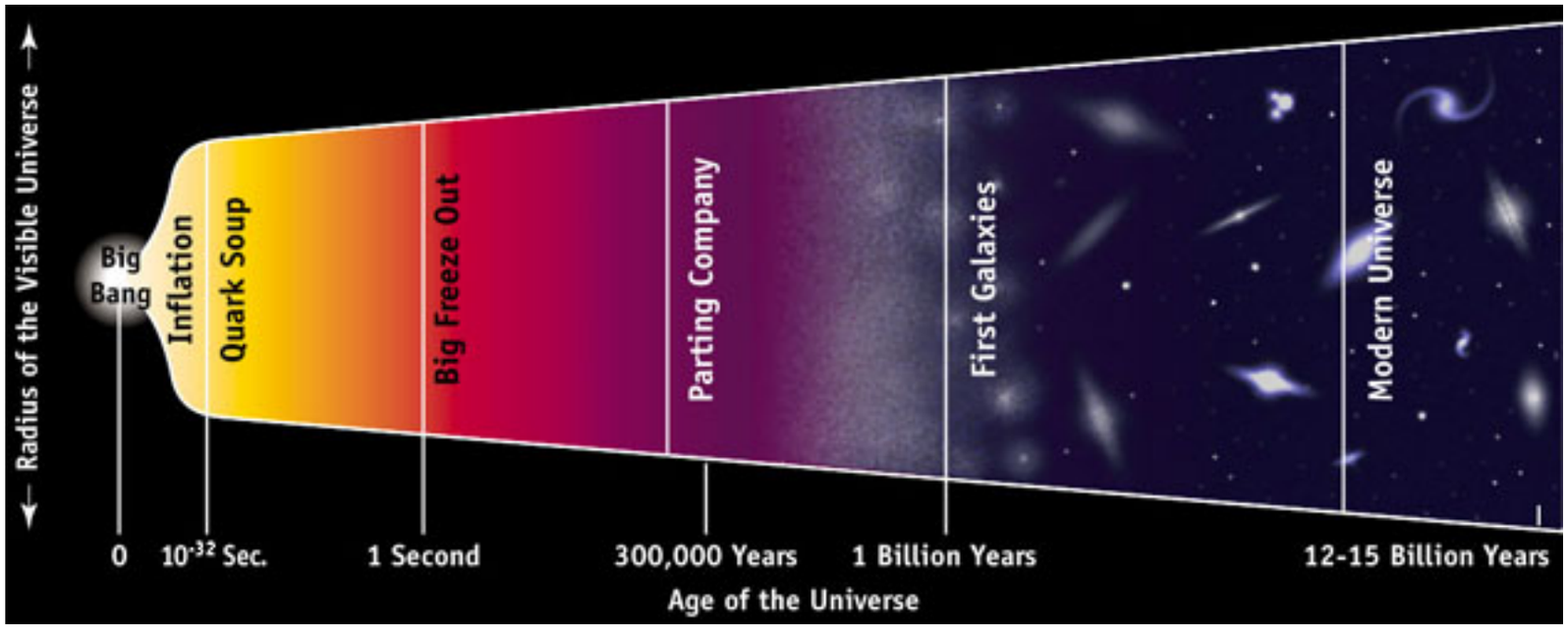
Early Universe

- Primordial Matter energy content
- BBN
- Inflation

Late Universe

- Dark Energy
- Neutrinos

The goal: fundamental physics



Early Universe

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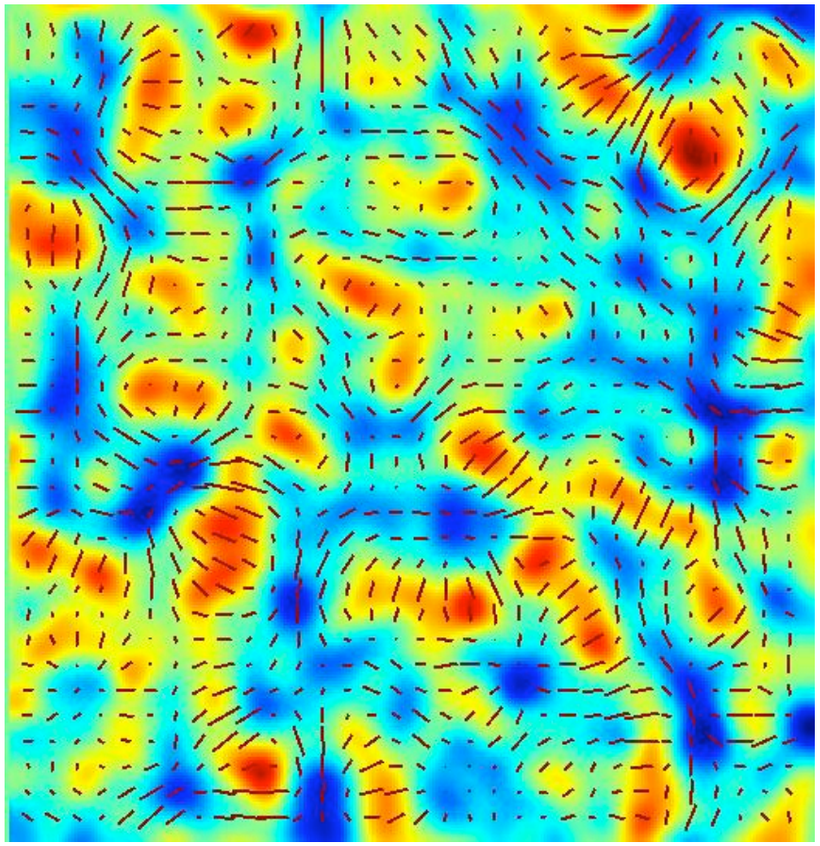
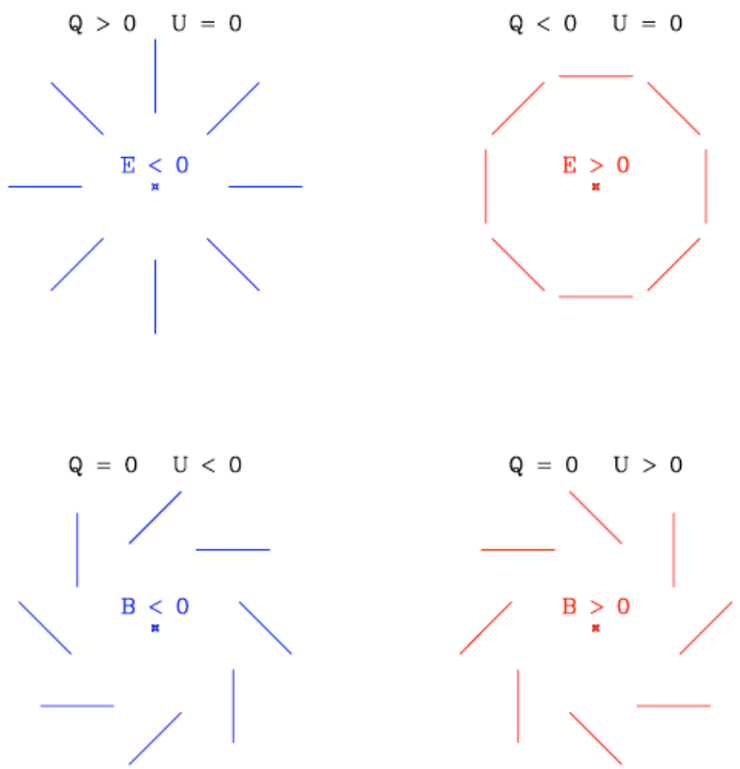
"B-modes"

CMB Polarization: E/B decomposition





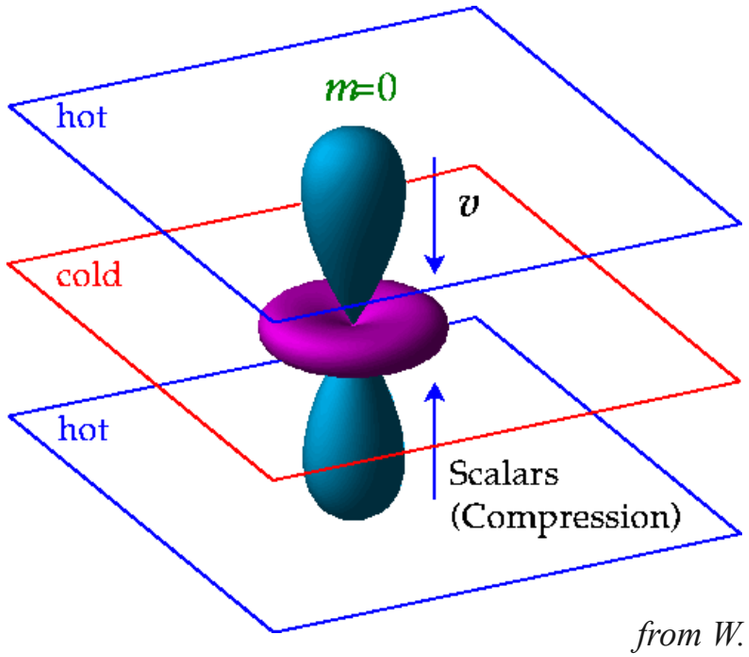
even parity

odd parity

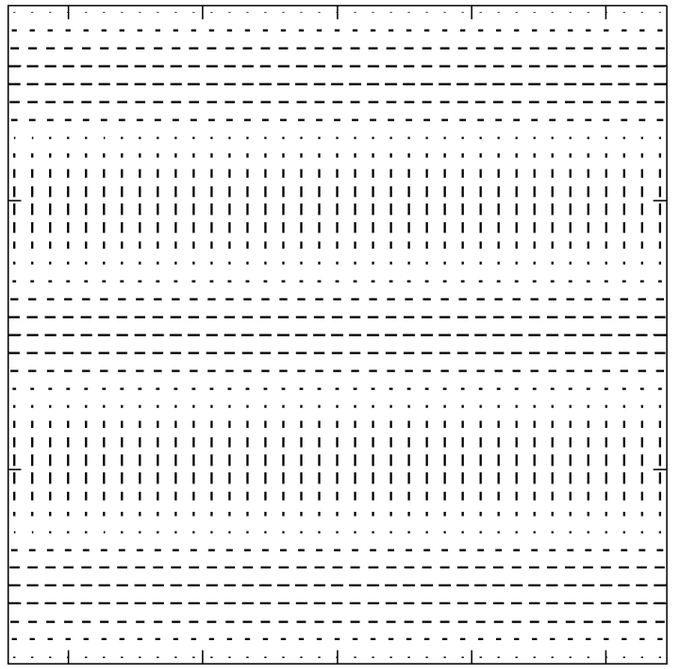
- CMB polarization field uniquely decomposed into two patterns “E” and “B”
- “New physics” in B-modes

Seljak and Zaldarriaga, astro-ph/9805010

CMB polarization: scalar perturbations

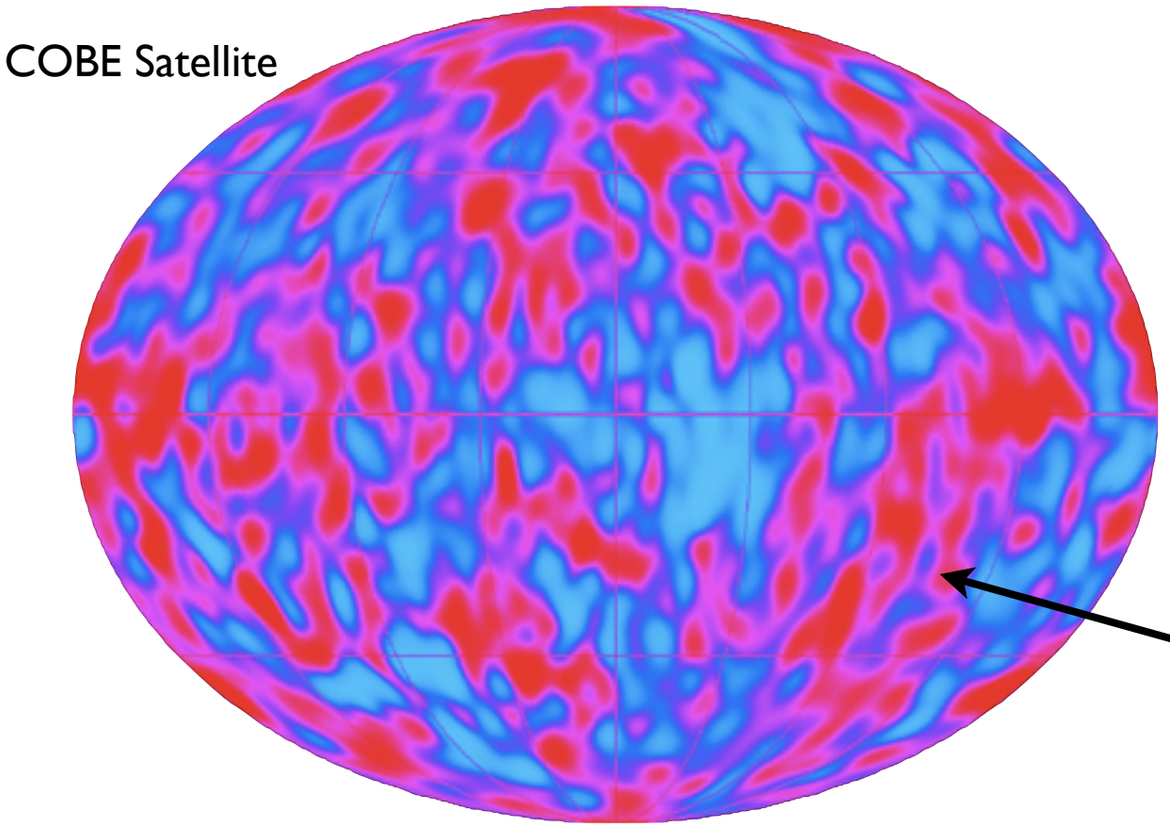


from W. Hu's web page



- Polarization generated by local quadrupole anisotropies
- For scalar waves (eg: pressure, temperature) quadrupole hot & cold lobes aligned along wave vector
- Polarization pattern is even under parity (k→-k) E-mode only

Sources of B-modes: Inflationary Gravitational Waves



- Universe undergoes rapid initial expansion
- Quantum fluctuations stretched into cosmological perturbations
- Scalar (density) perturbations
- Tensor (gravity) perturbations?

$$r = \frac{\text{Tensor (gravitational) perturbation amplitude}}{\text{Scalar (density) perturbation amplitude}}$$

$$V_{\text{inflation}}^{1/4} = 1.06 \times 10^{16}\ \text{GeV}\ \left(\frac{r}{.01}\right)^{1/4}$$

Sources of B-modes: Gravitational lensing

- Lensing distorts CMB. Pure E gets mixed to some B
- Probes growth of Large Scale Structure at moderate redshifts

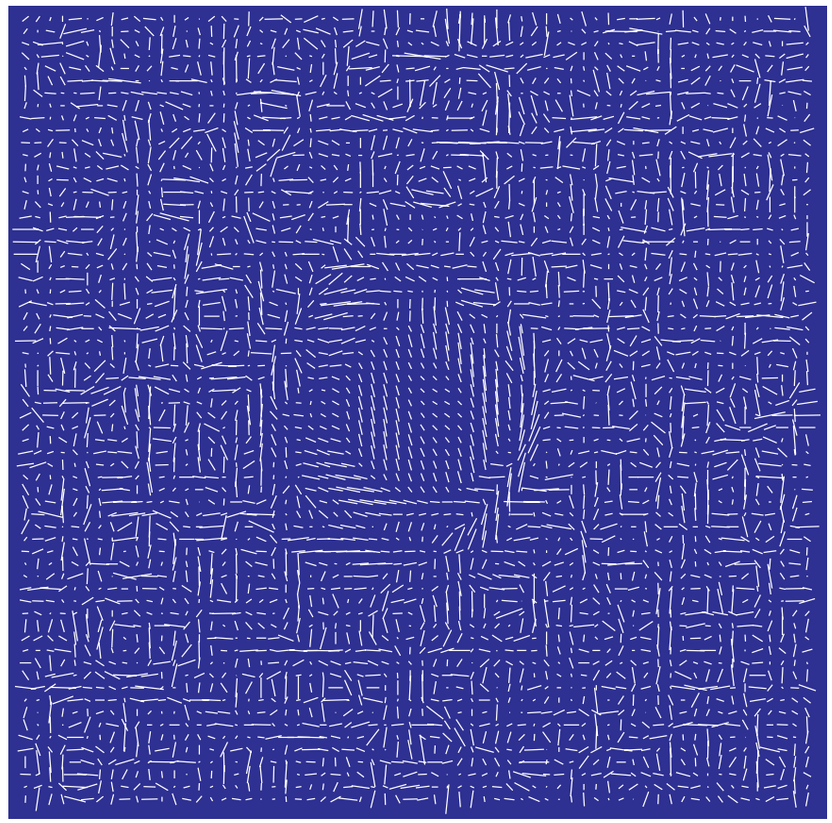
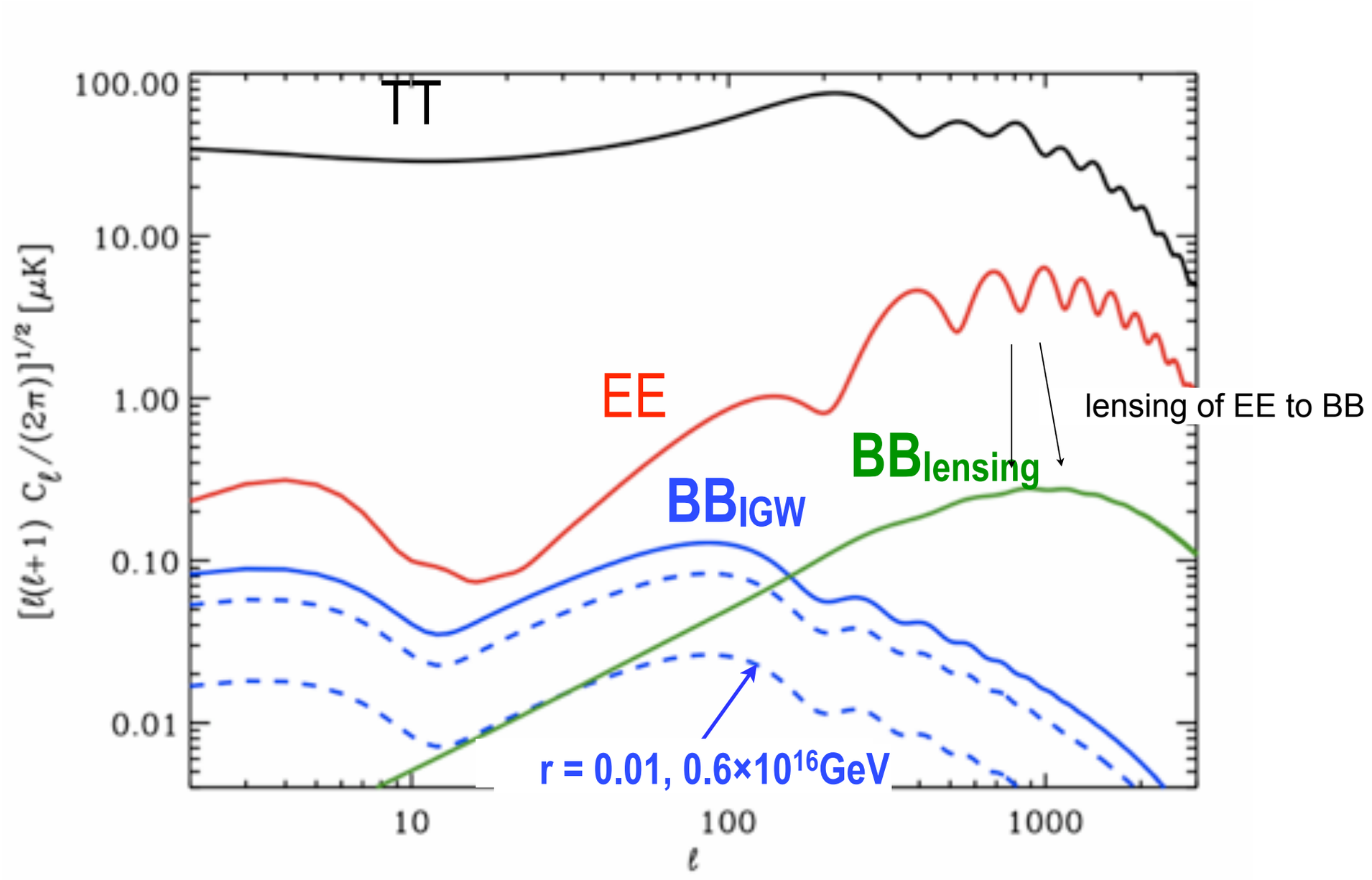
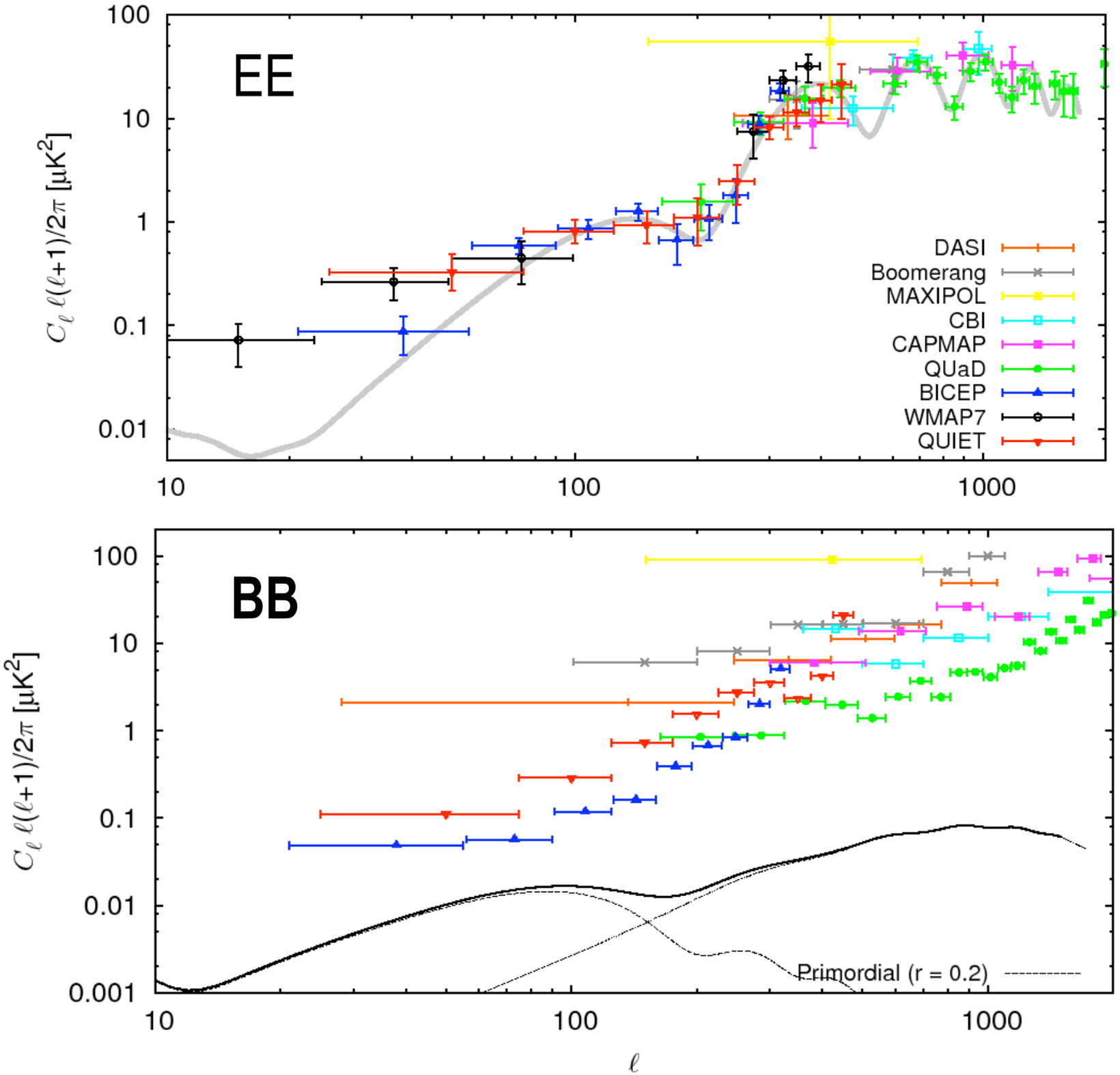


Figure from Hu

CMB angular power spectra



Where we are now...



Leitch et al (2005),
Montroy et al (2006),
Piacentini et al (2006),
Sievers et al (2007),
Wu et al (2007),
Bischoff et al (2008),
Brown et al (2009),
Chiang et al (2010),
QUIET (2010)

Where we are now...

- Current measurements sensitivity limited
- Current detectors are background limited
- 10-100 increase in science reach requires 10-100x more photons ⇒ larger focal planes
- Technology must “scale up” while maintaining background limited performance
- Spectrum of sites, platforms, and technologies

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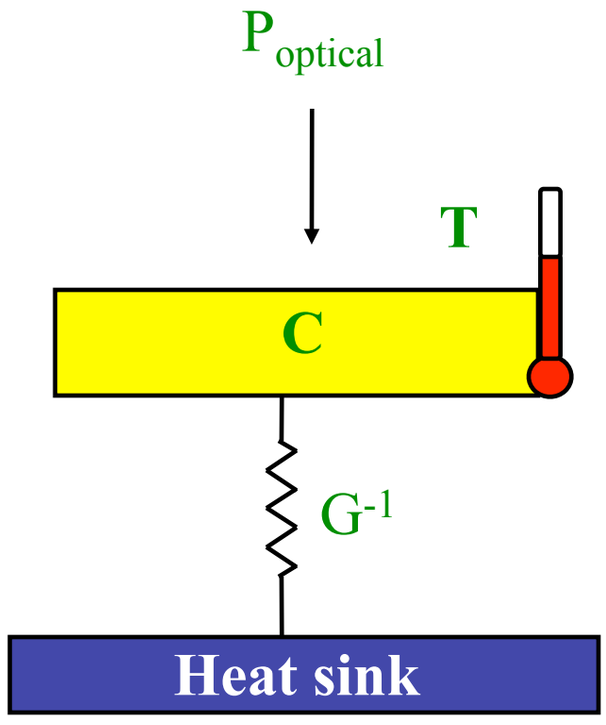
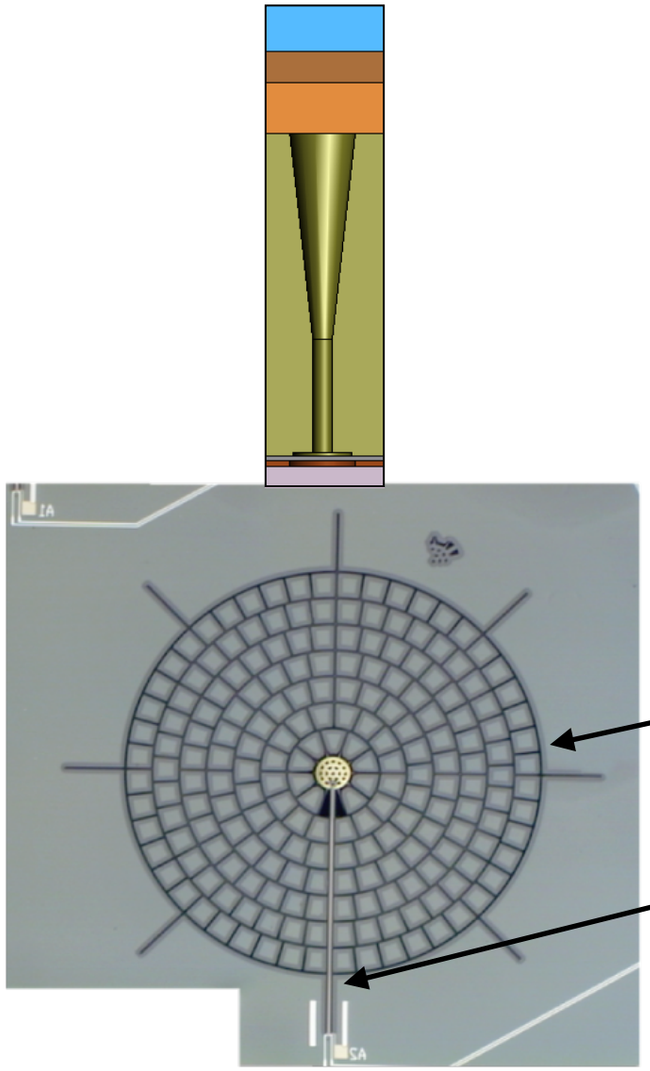
Intro to bolometers

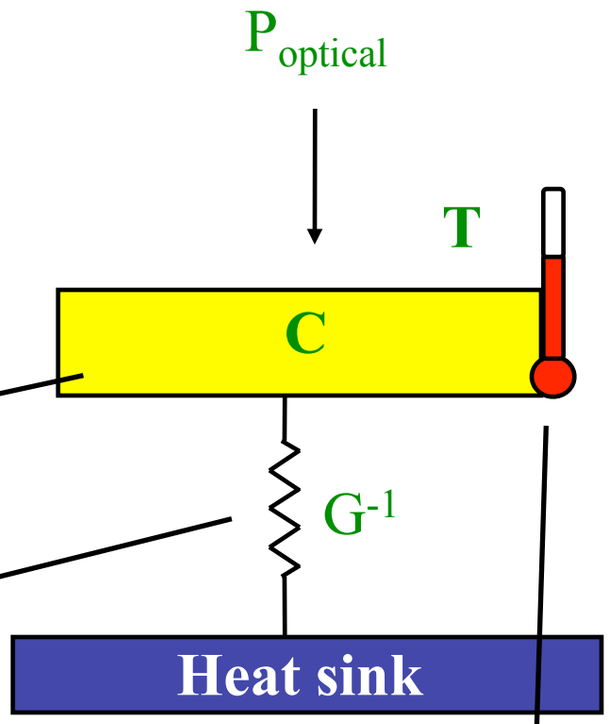
- Measure changes in power
- Weakly heat sunk thermal mass
- Change in absorbed power changes temperature
- Measure temperature

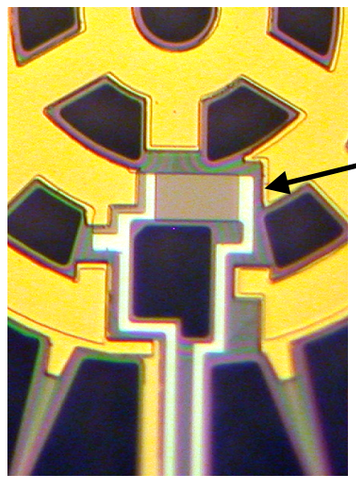


Intro to bolometers

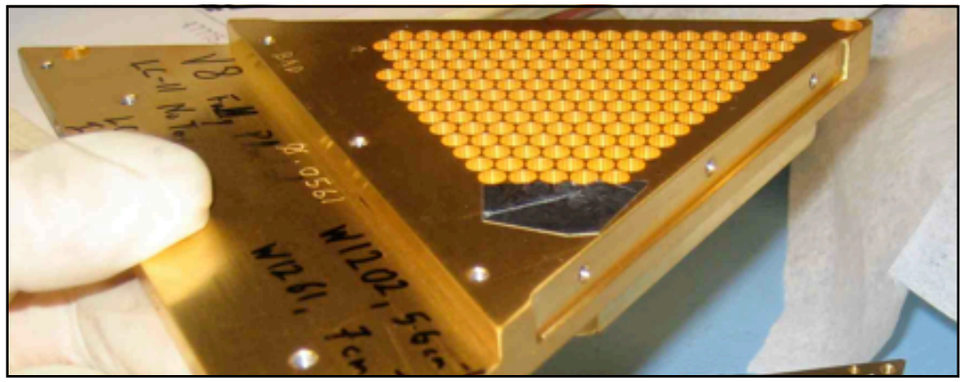
- Noise from fluctuations in absorbed optical power and weak link
- Background limited

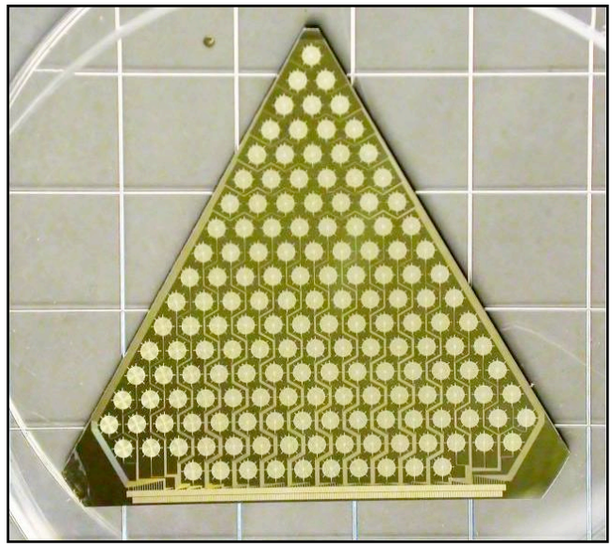


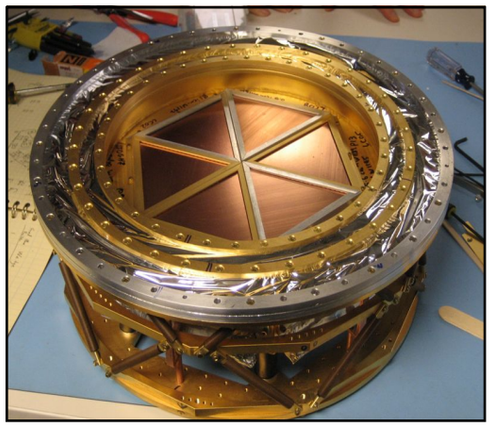




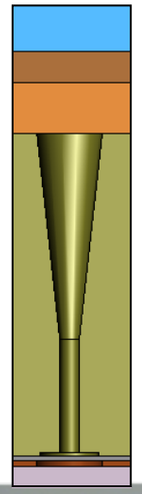
Intro to bolometers

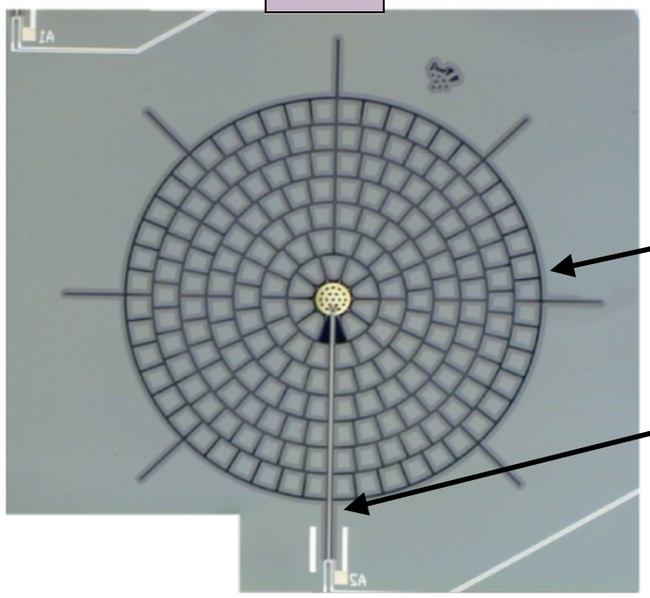


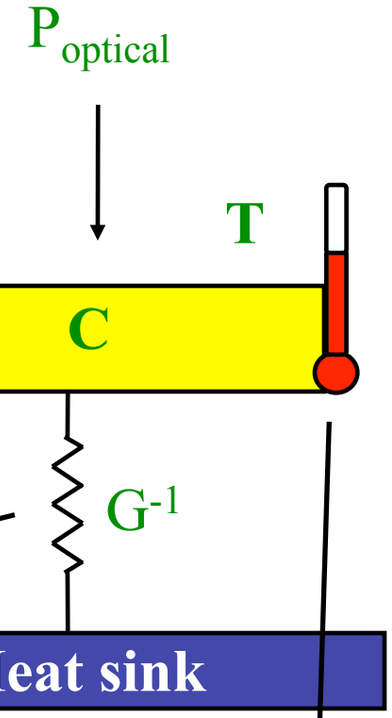


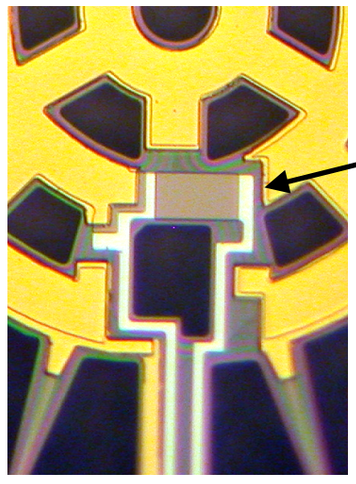


14”









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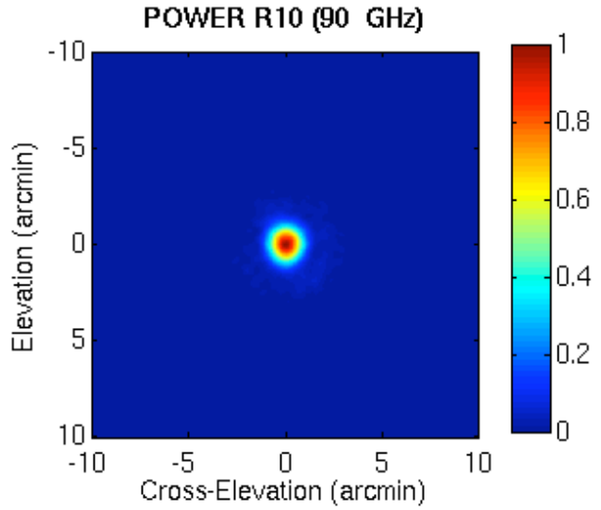
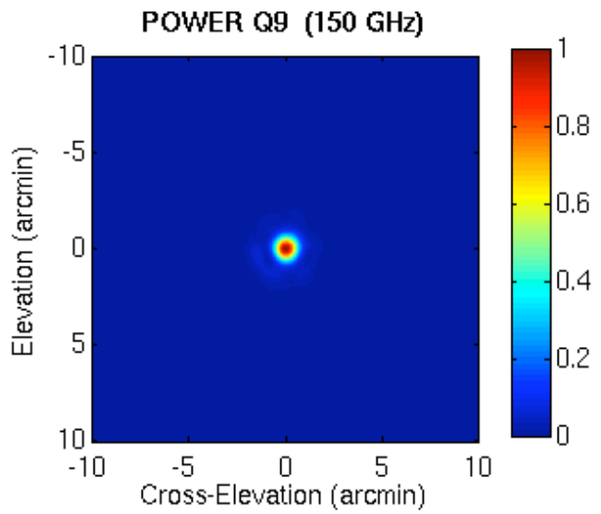
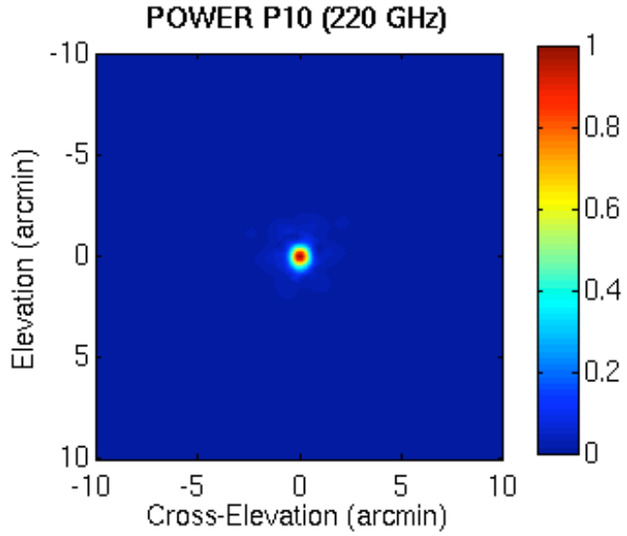
The SPT: Optical resolution and throughput

- 10-m dish at 150 GHz gives ~1 arcmin beam (PSF)
- ~260 panels aligned to 25 μm rms over 10-m surface gives 95% efficiency at 220 GHz

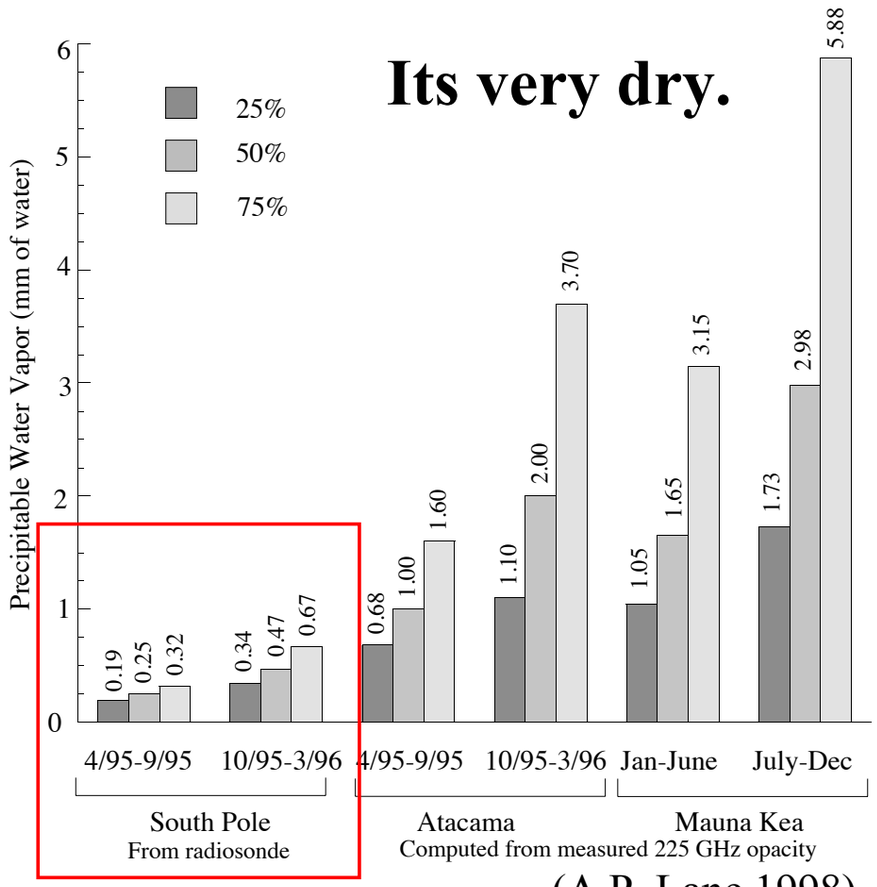




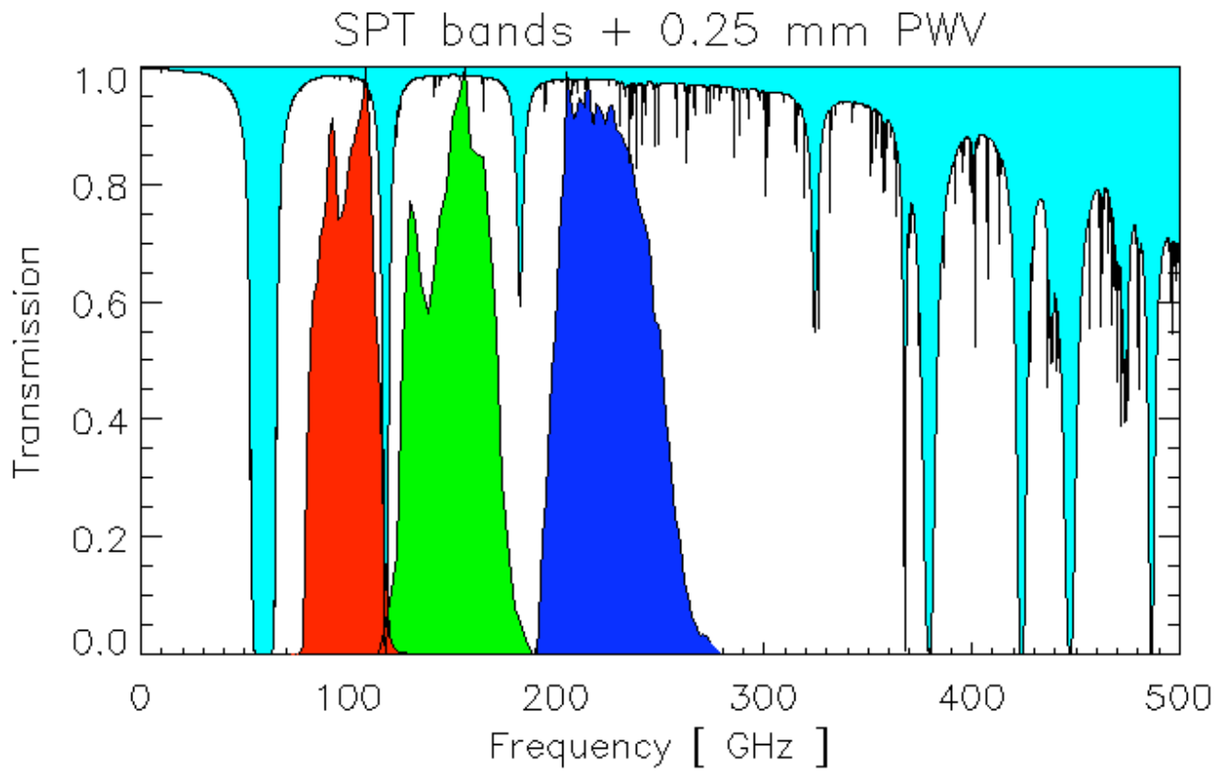


The South Pole Site

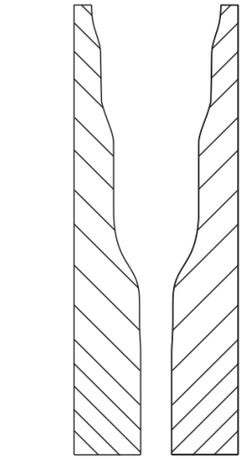
- Dry air for optimal atmospheric transmission
- Stable environment

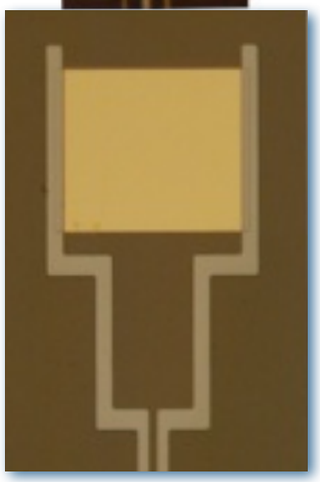


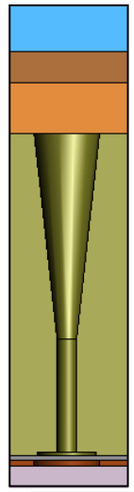
(A.P. Lane 1998)

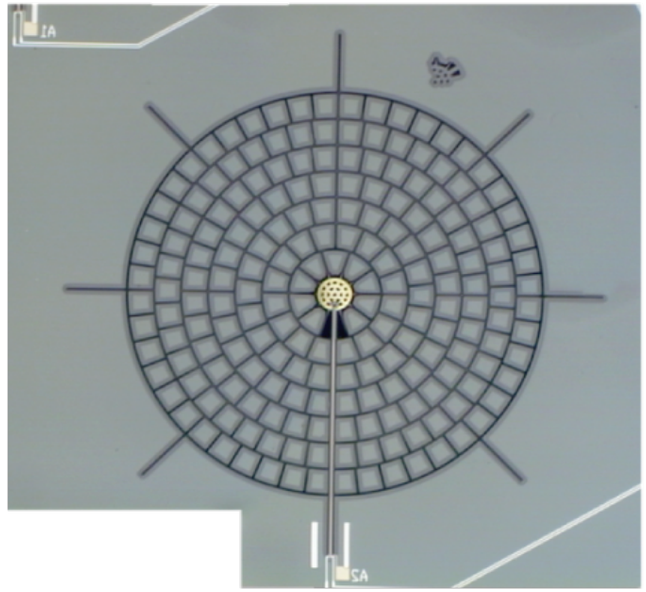


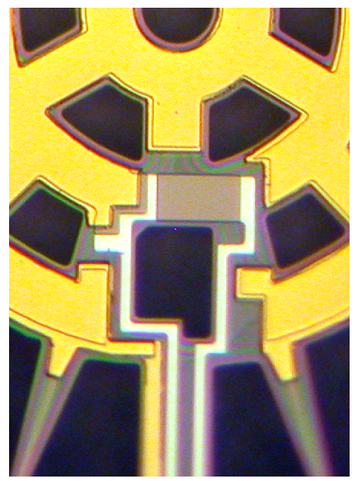
SPTpol detectors at 90 GHz











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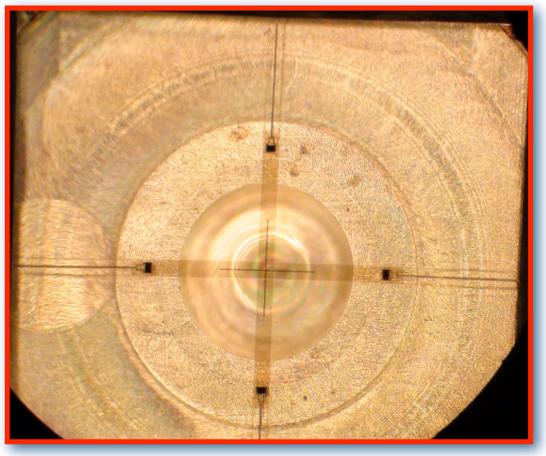

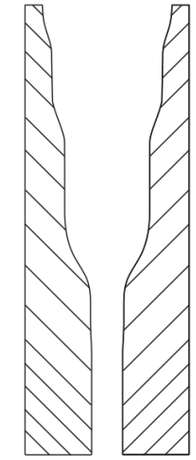

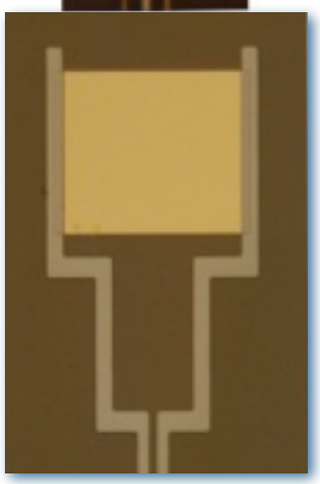

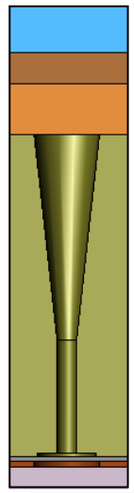

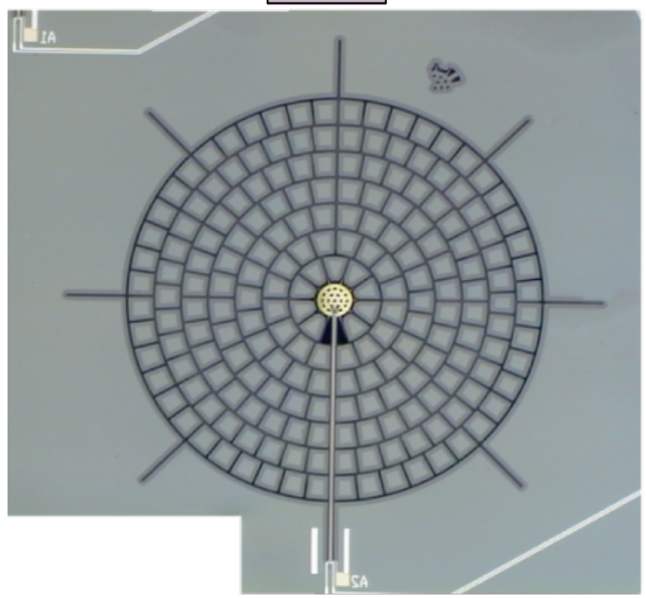

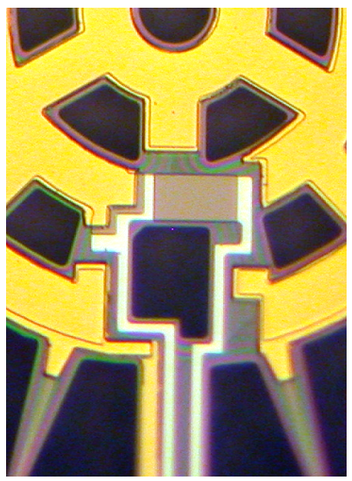

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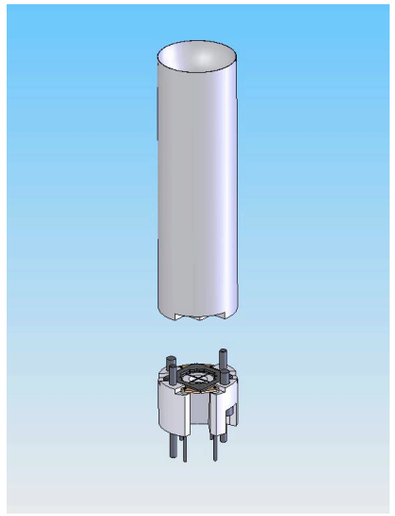

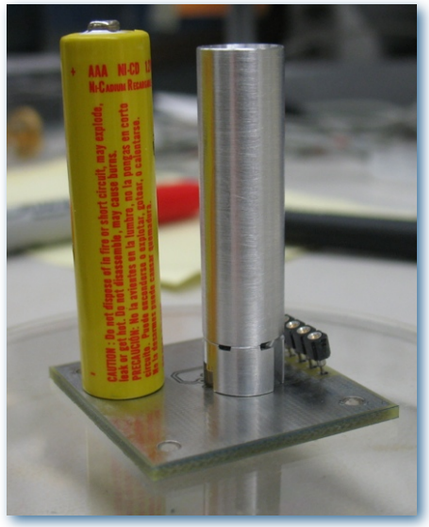

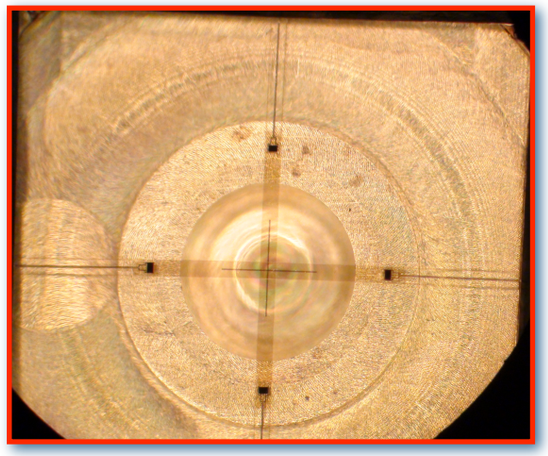

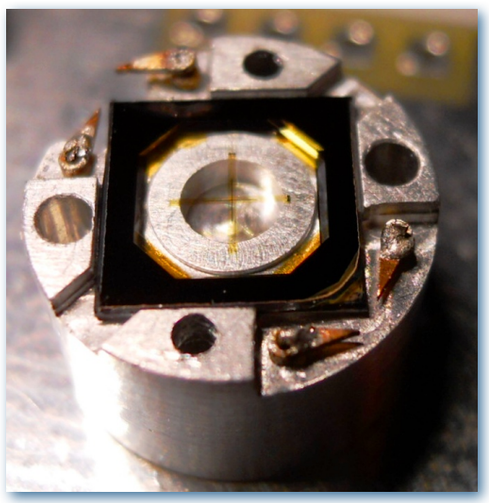

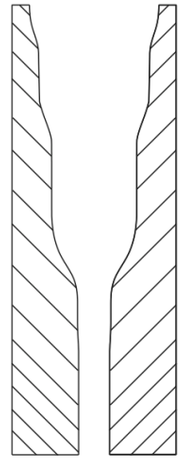

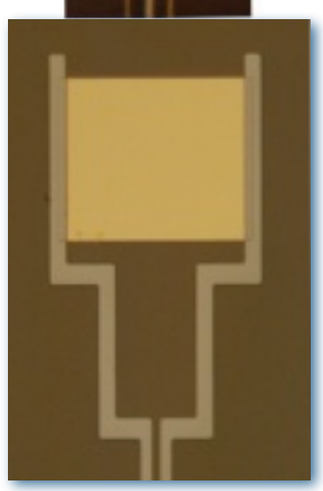

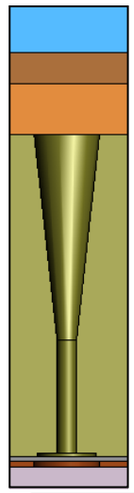

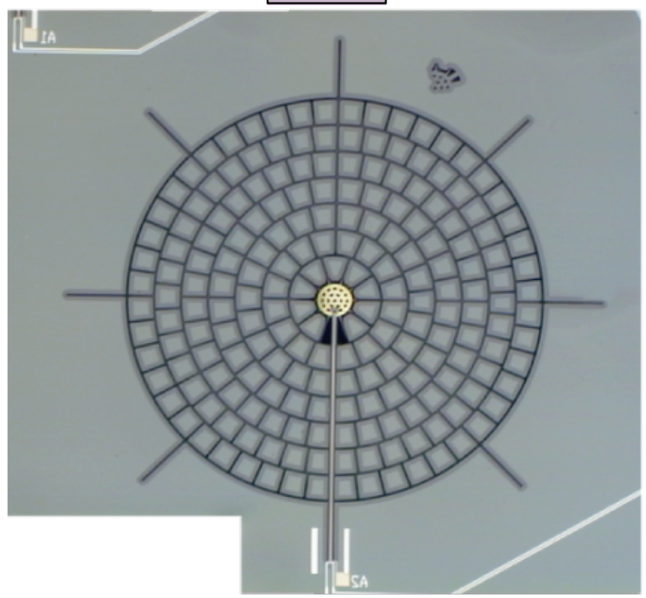

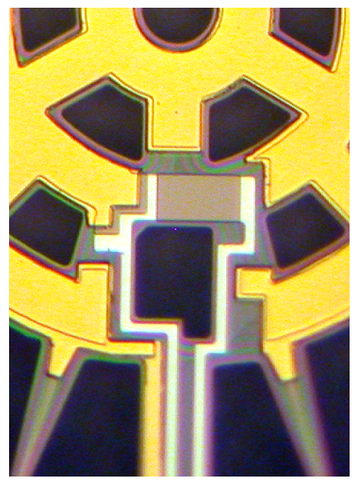

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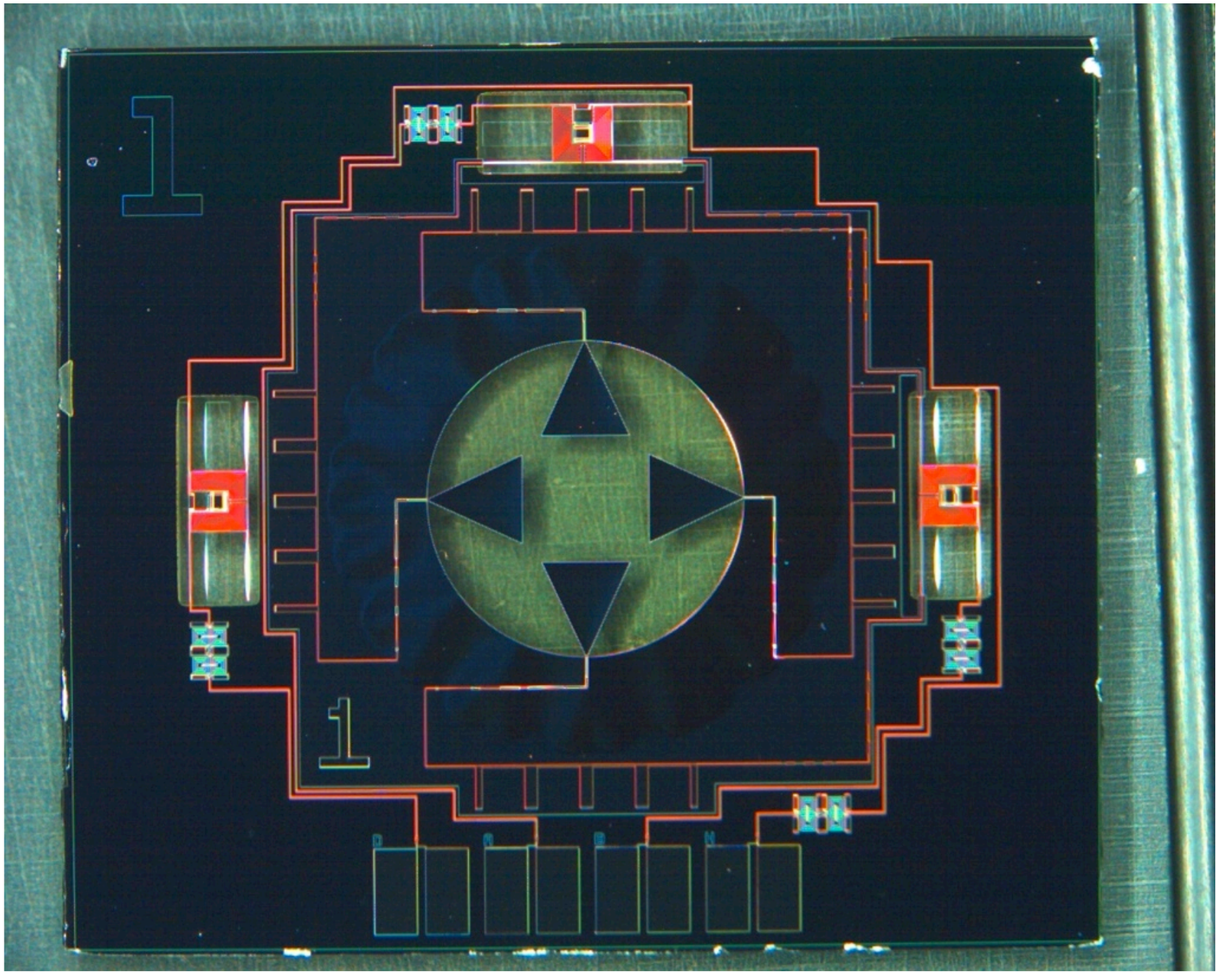
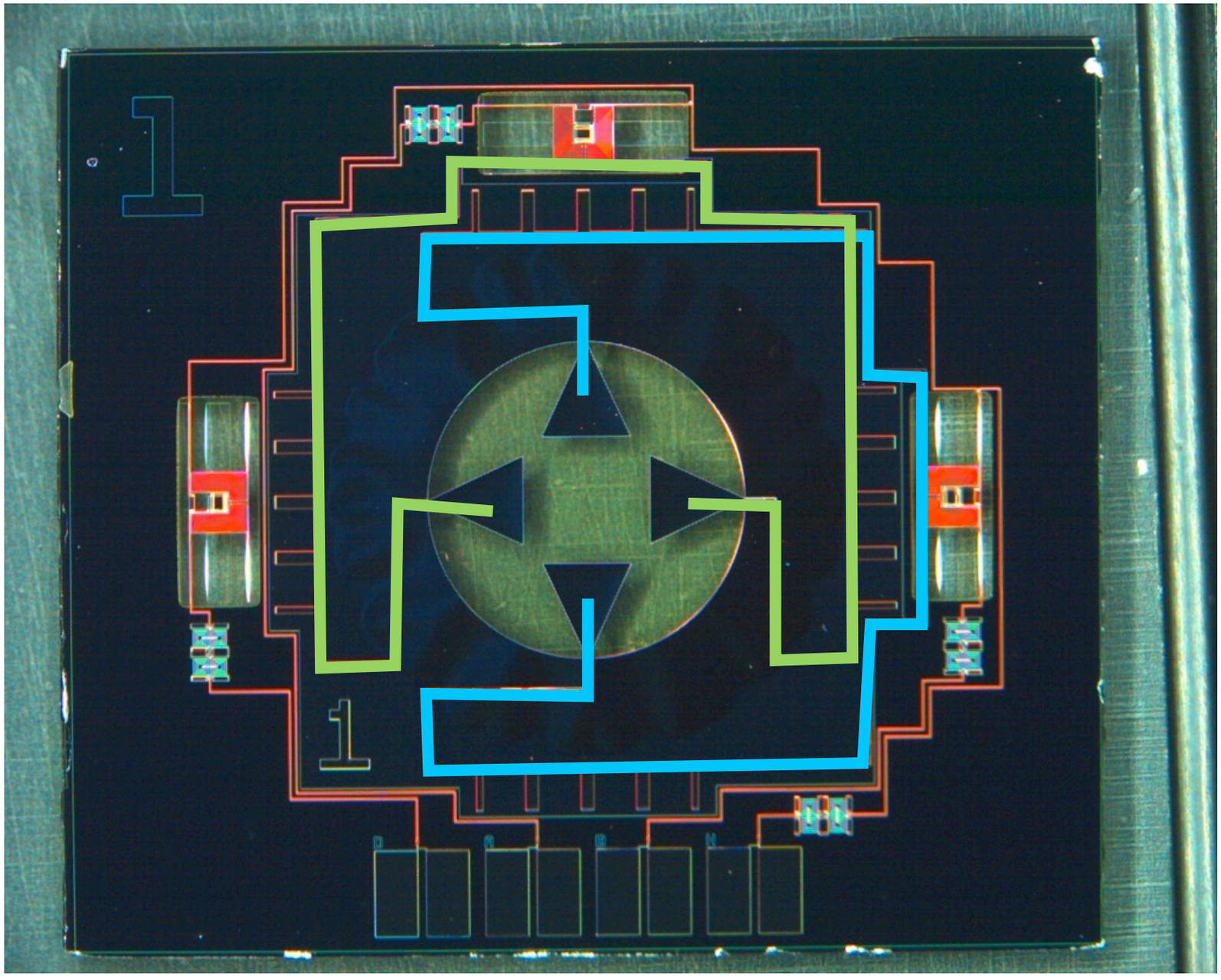
SPTpol detectors at 150 GHz

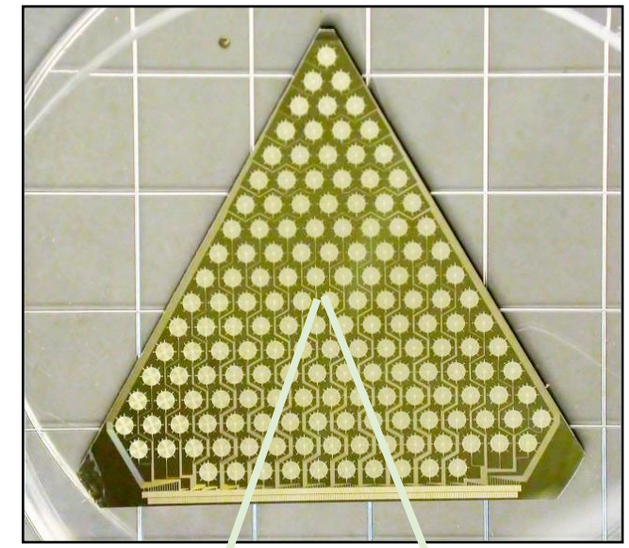


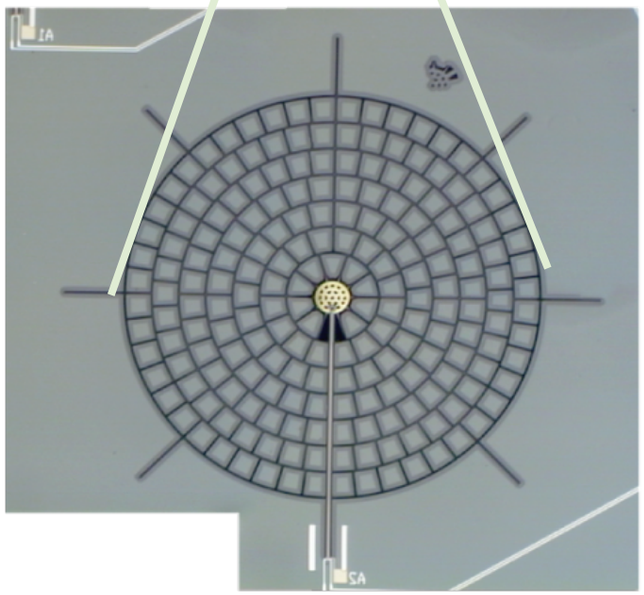
SPTpol detectors at 150 GHz

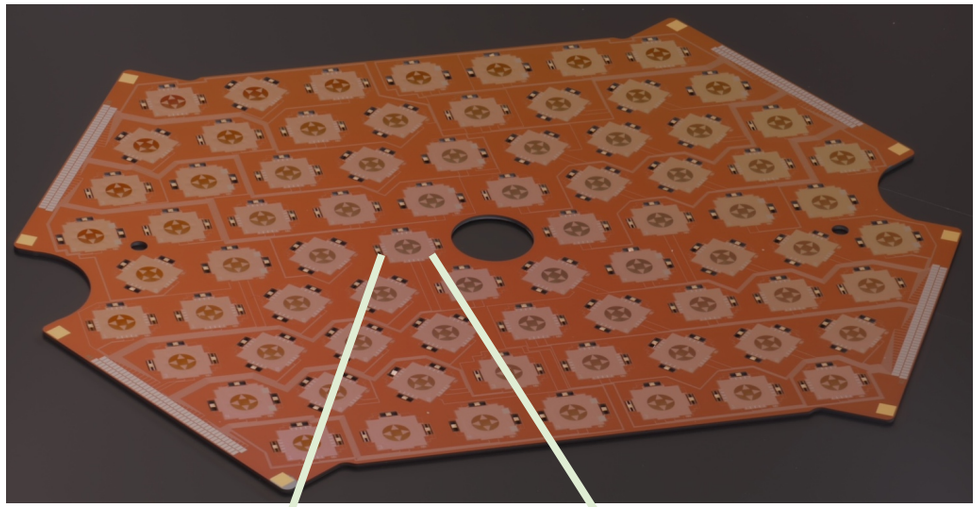


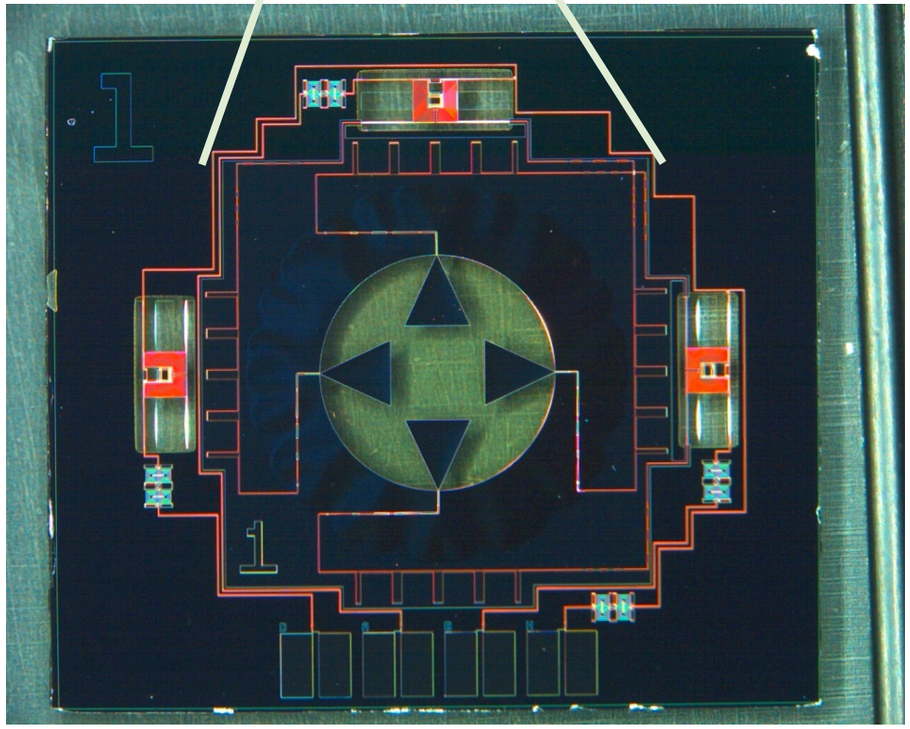
Superconducting Orthomode Transducer (OMT) separates two linear polarizations onto superconducting microstrip

SPTpol 150 GHz





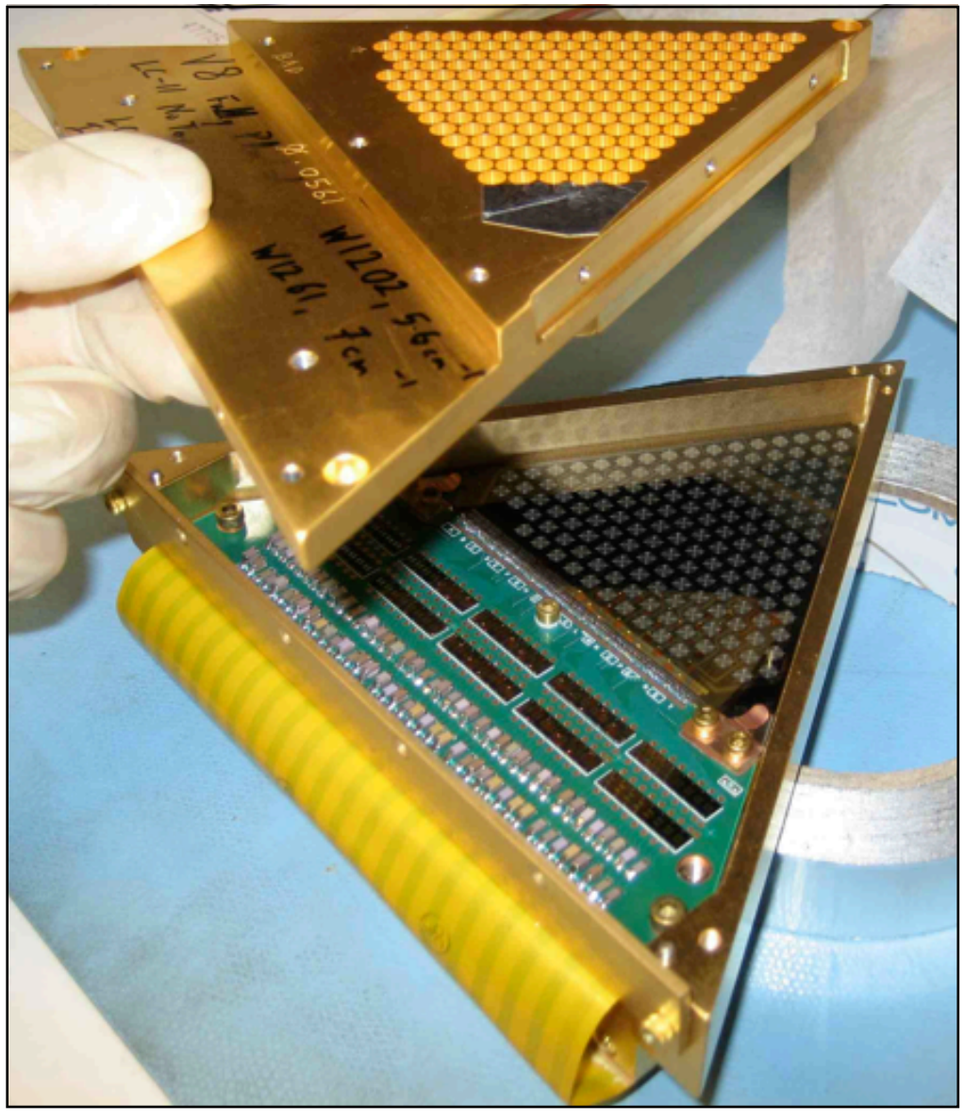


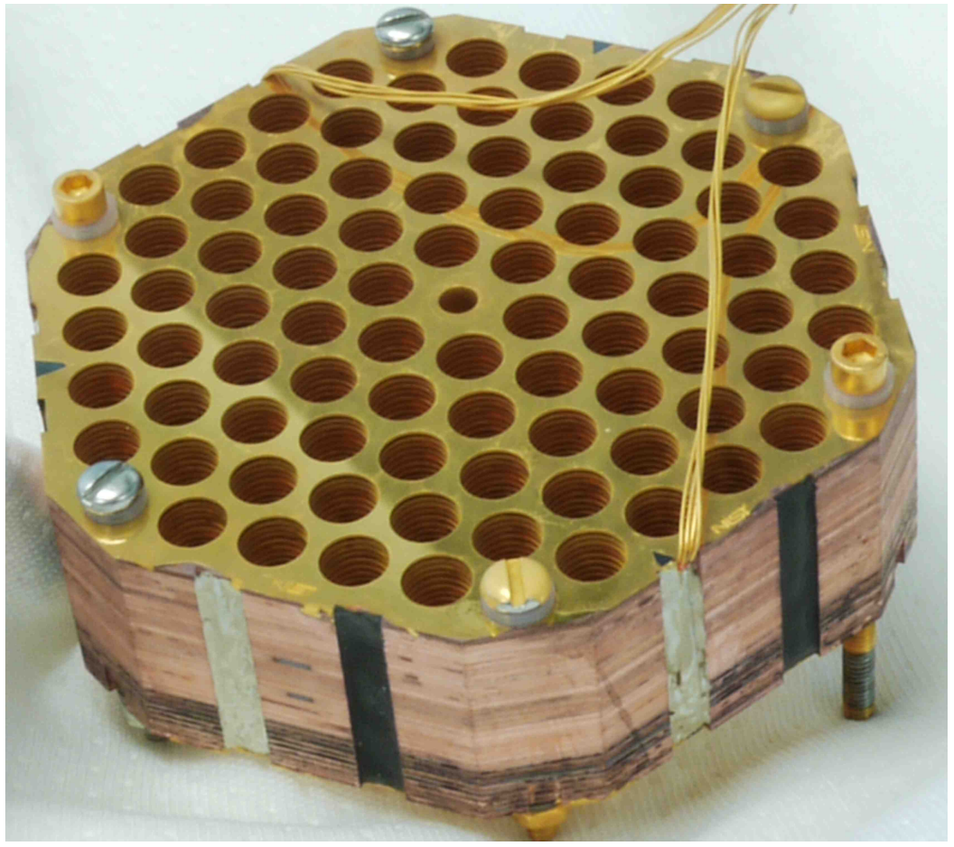


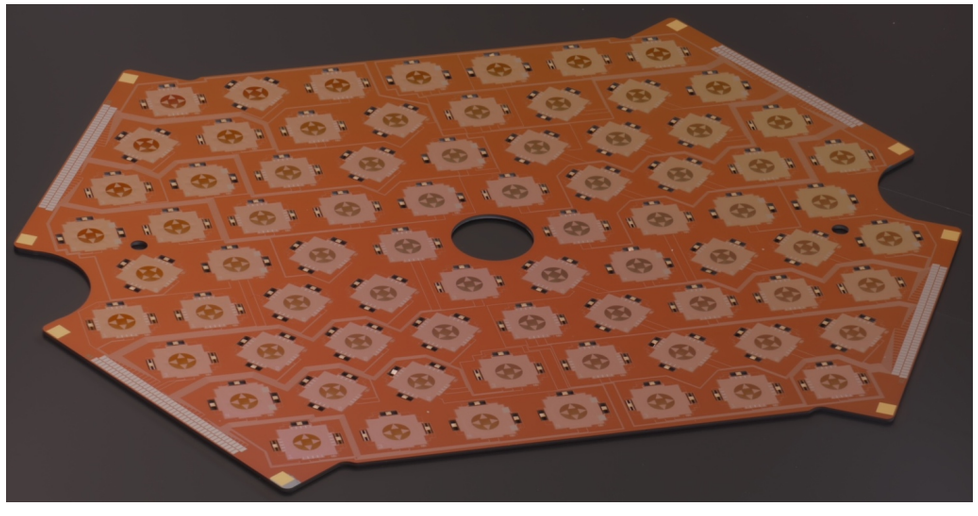
Integrated into arrays for optimal focal plane packing

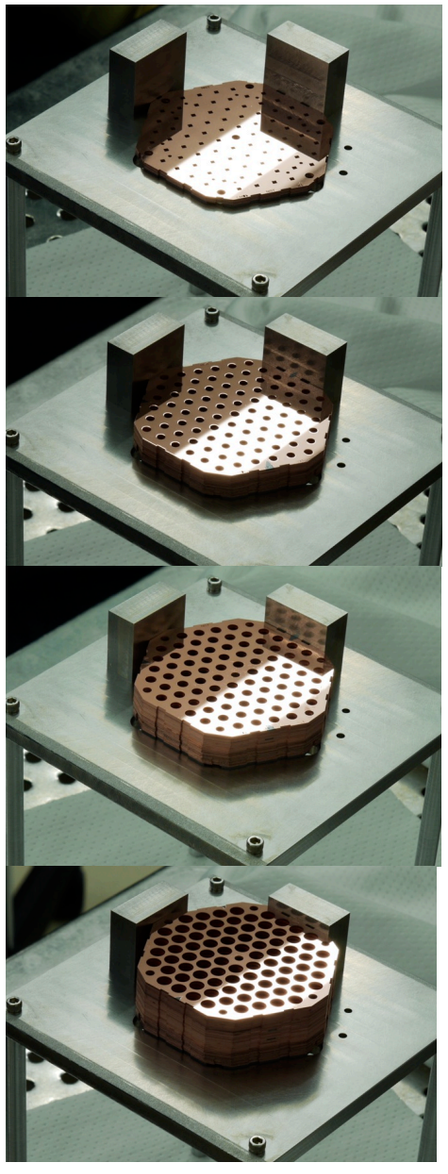
NIST

SPTpol 150 GHz

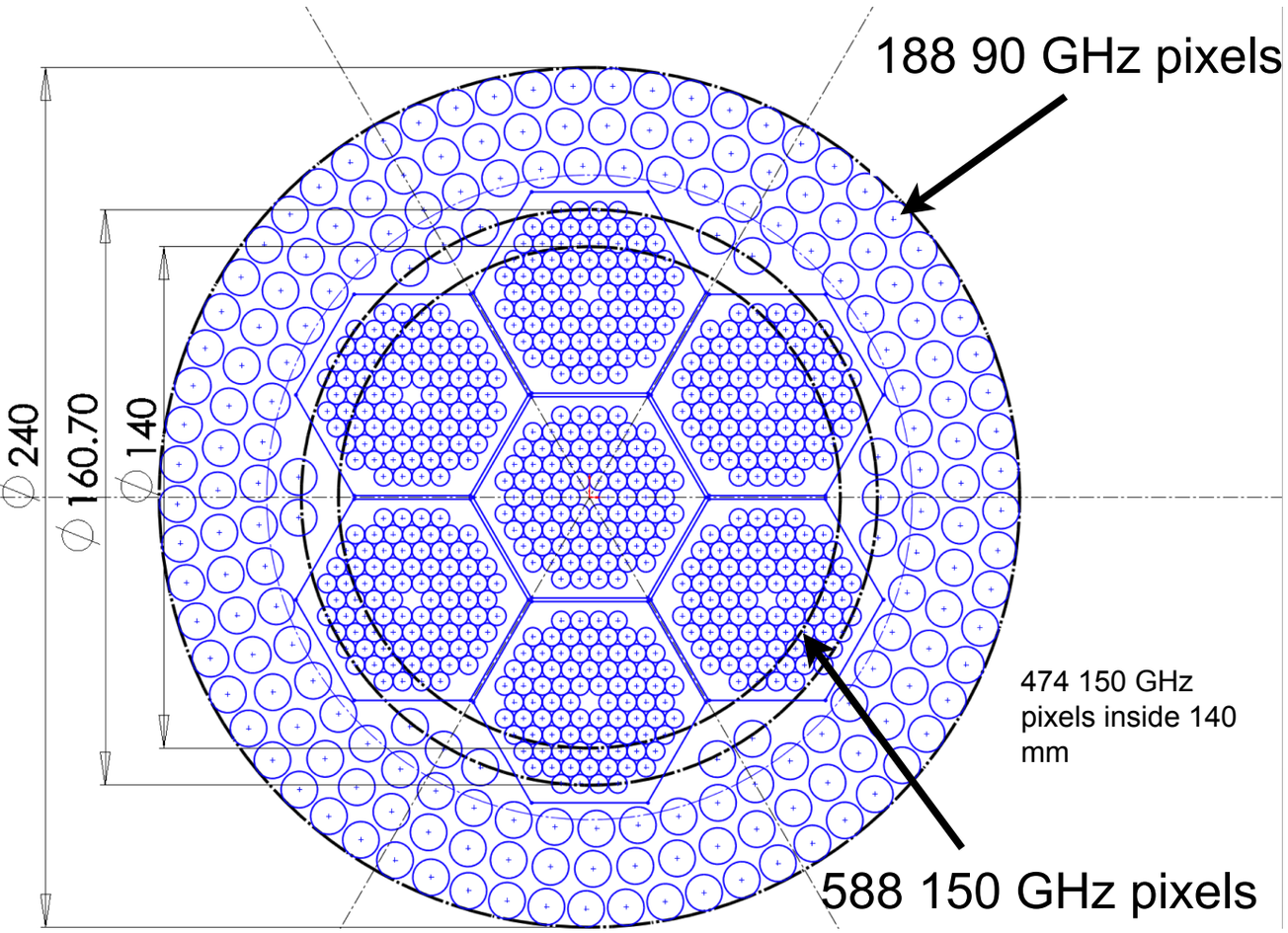


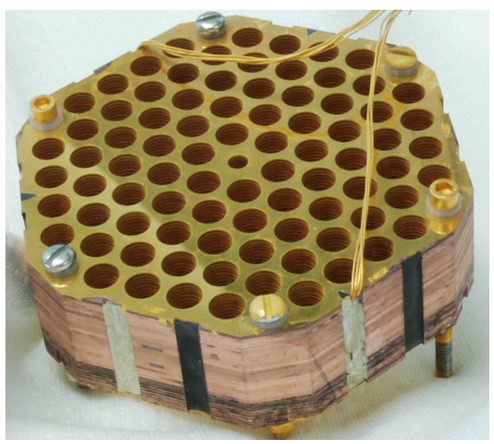


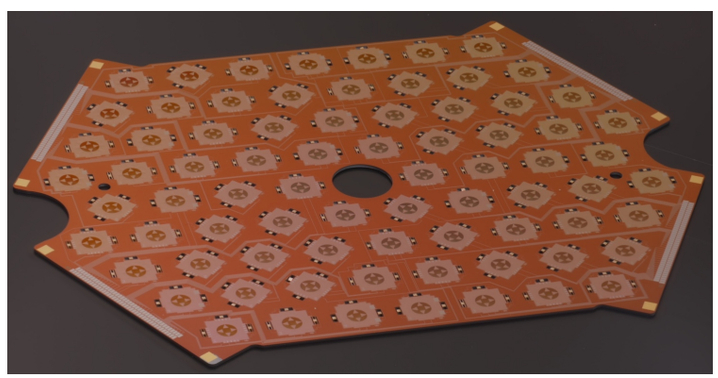




SPTpol focal plane







- Individual 90 GHz pixels on perimeter
- Arrays of 150 GHz detectors in the center
- Detectors have <1% xpol over 30-40 GHz bandwidth
- Thermal carrier noise at the background limit

Outline

Cosmic Intro

Introduction to Bolometers
(eg: SPT-SZE)

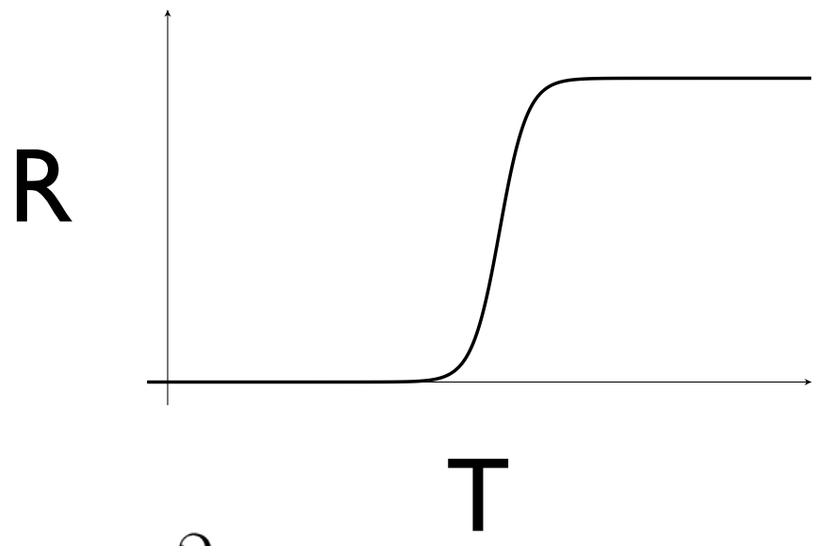
Detectors for SPTpol

Transition Edge Sensors
(TES) & Multiplexing

Transition Edge Sensors

- Measures bolometer temperature through R(T)

$$\alpha = \frac{d\ln R}{d\ln T}$$



- Voltage biased

$$C\dot{T} = P_{optical} - P_{cooling} + \frac{V^2}{R(T)}$$

(Electro-thermal) Feedback is negative

- “Open loop gain” proportional to α
- Linearizes response
- Increases bandwidth

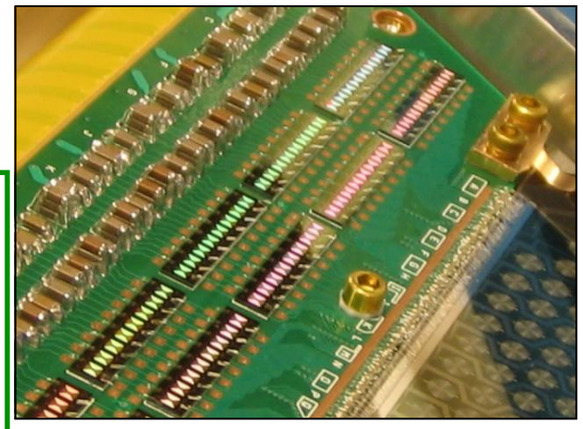
Multiplexing

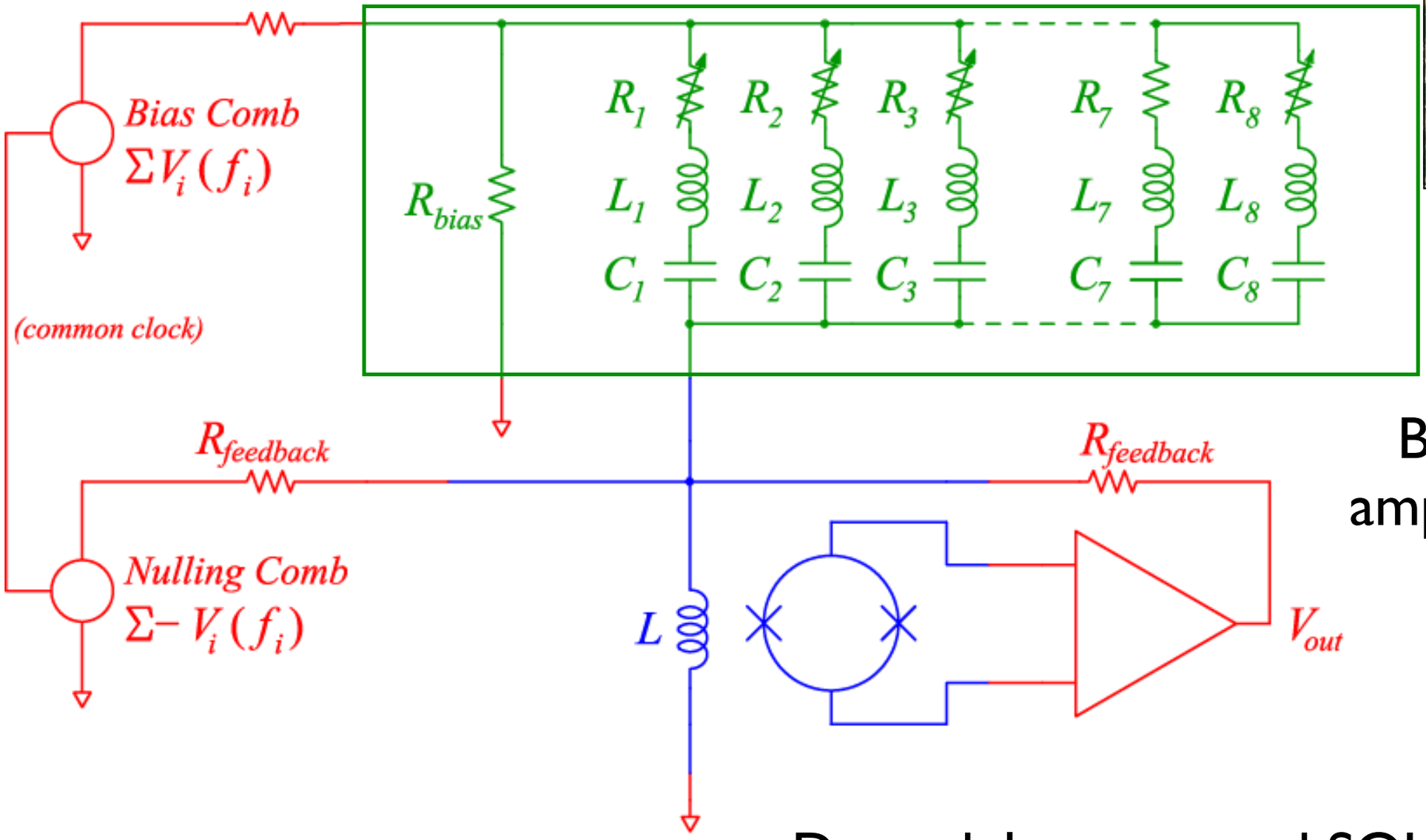
- Low impedance TES (~1 Ω); Voltaged biased; measure current with SQUID

- Multiplex to distribute small signal bandwidth (<100 Hz) over large SQUID low noise bandwidth (~MHz)
  - reduces cryogenic wiring/heat load

Frequency Domain Multiplexing

Individual resonant LC filters for each bolometer





Bolometer signal amplitude modulates one tone

Demodulate summed SQUID output to recover individual bolometer signals

fMUX considerations

- Stray inductance
  - 100 nH at 200 kHz ~100 mΩ
- Tuning for electro-thermal stability
  - fMultiplexing wants narrow detector bandwidth
  - ETF increases detector bandwidth
  - Resonators ~5 kHz
  - ETF bandwidth ≤1 kHz