Ground based search for CMB B modes from primordial gravitational waves

Oct. 31st, 2012
@KIAS

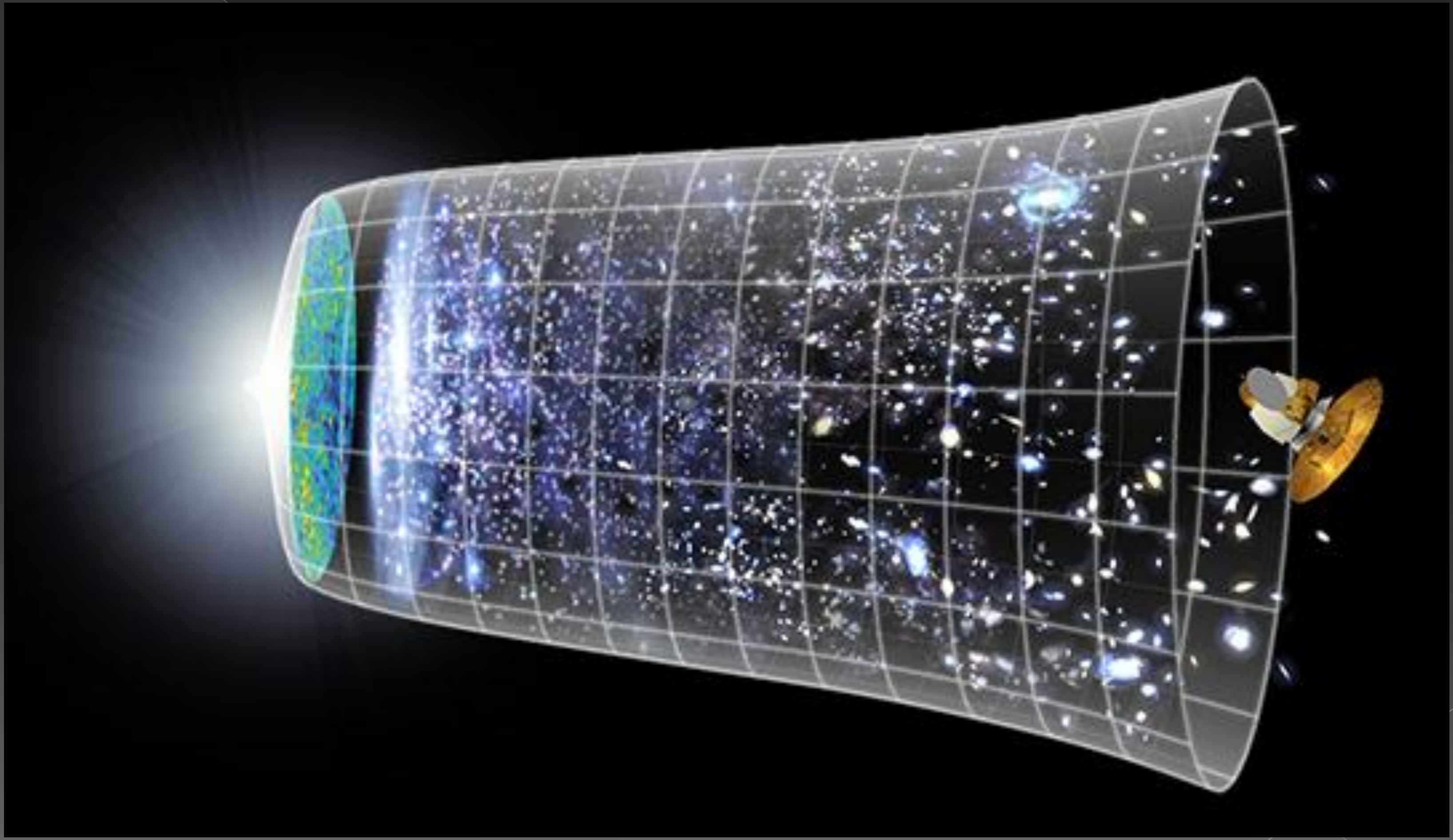
Akito KUSAKA
Princeton University

Contents

- Introduction
  - Physics of CMB polarization
- Experimental approaches
  - General techniques
  - Examples: QUIET, ABS
- Summary

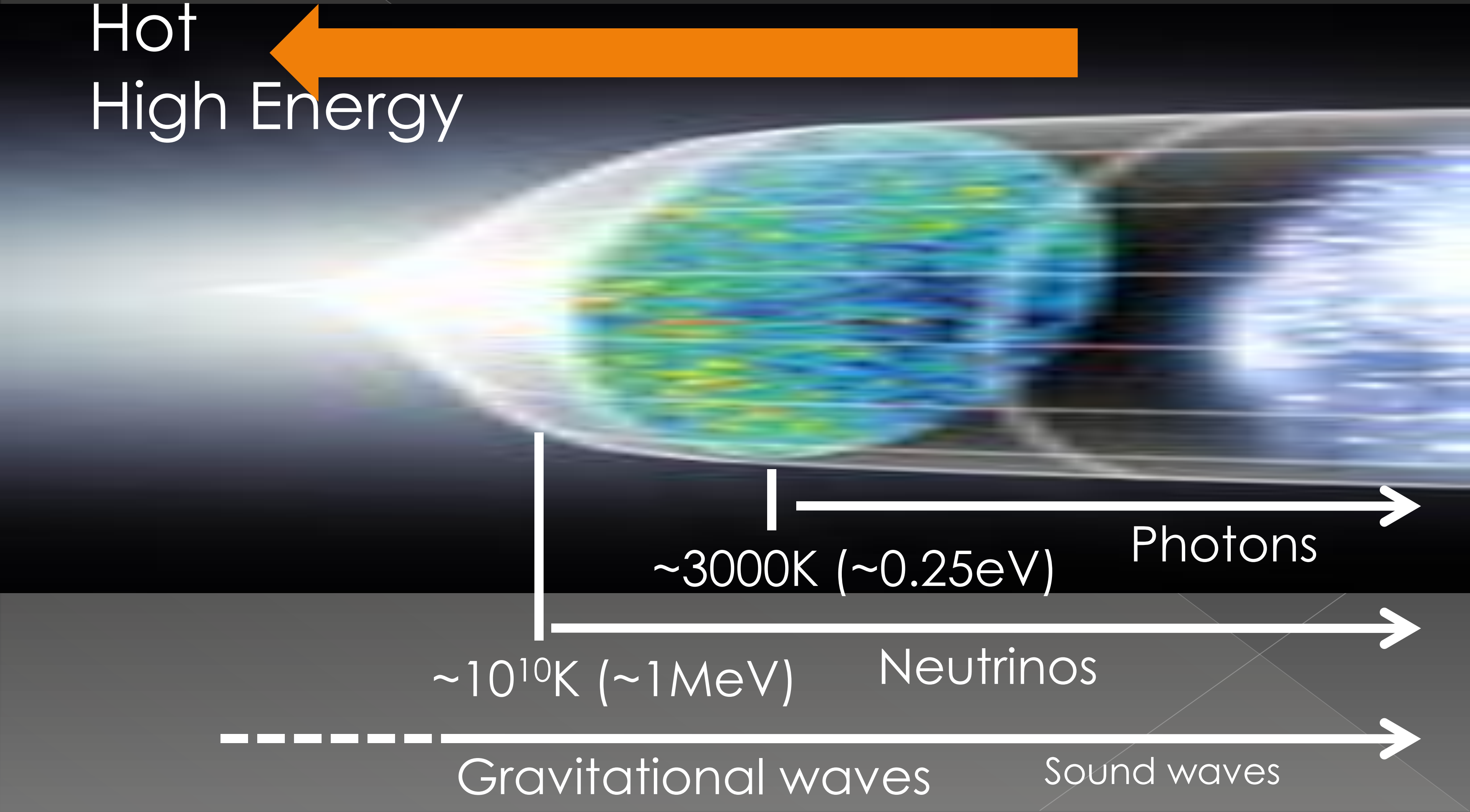
Introduction

A probe into the Early Universe

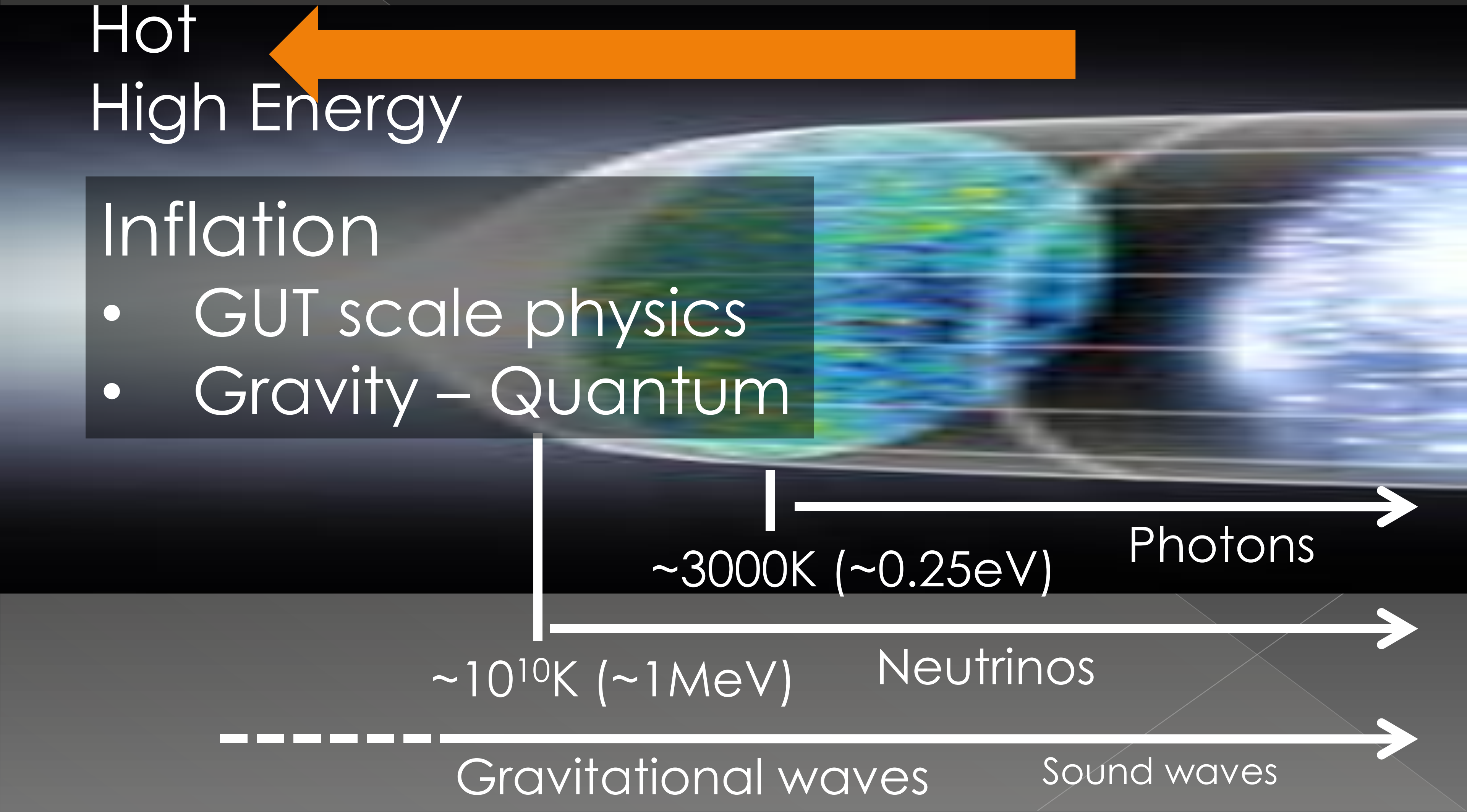


Picture from WMAP group

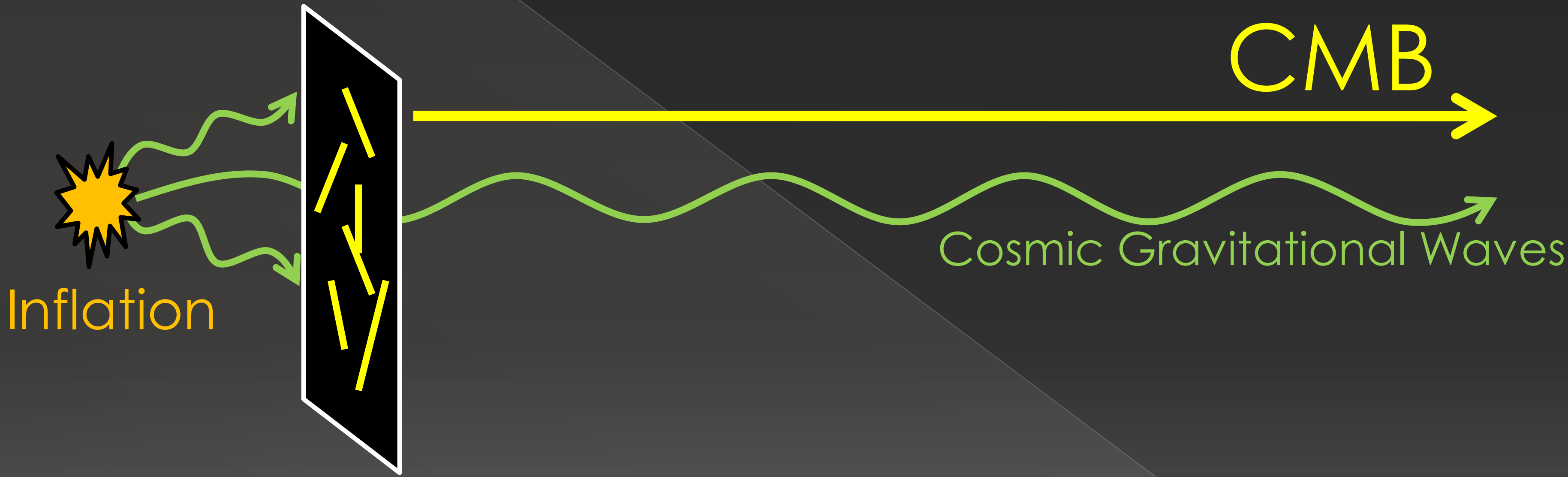
Probe into Early Universe



Probe into Early Universe



Is it detectable? How?



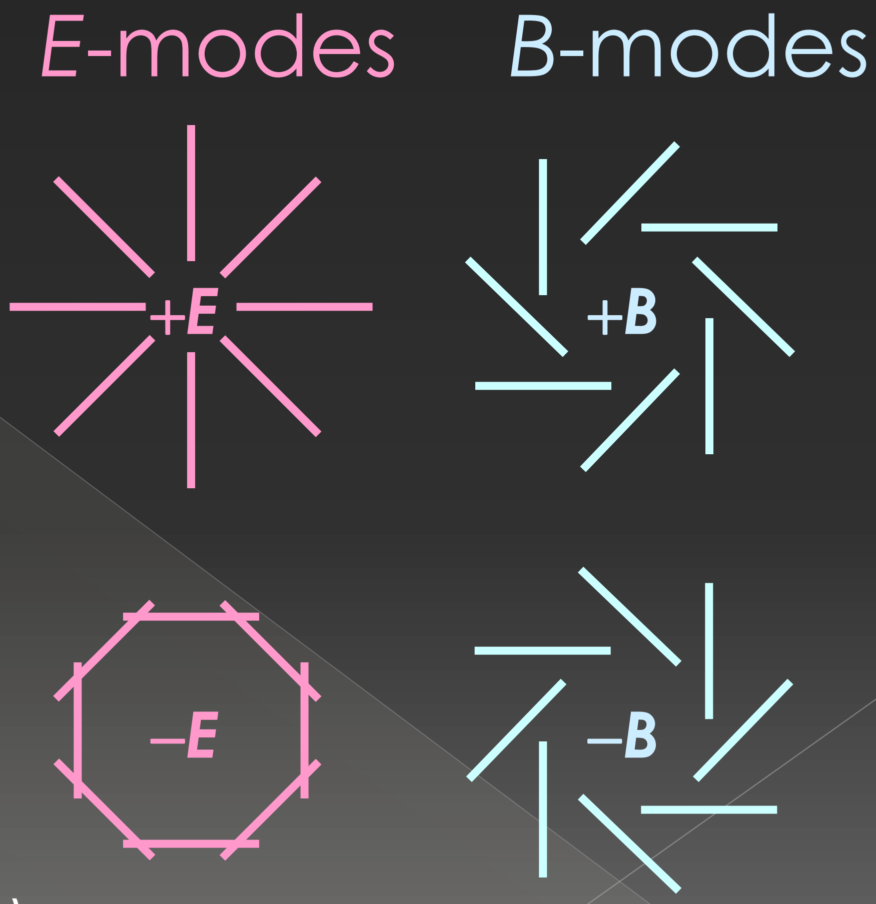
Last Scattering Surface

Screen for GW to put its fingerprint

E-modes and *B*-modes

- Patterns in the polarization map
- Decomposition into two "modes"

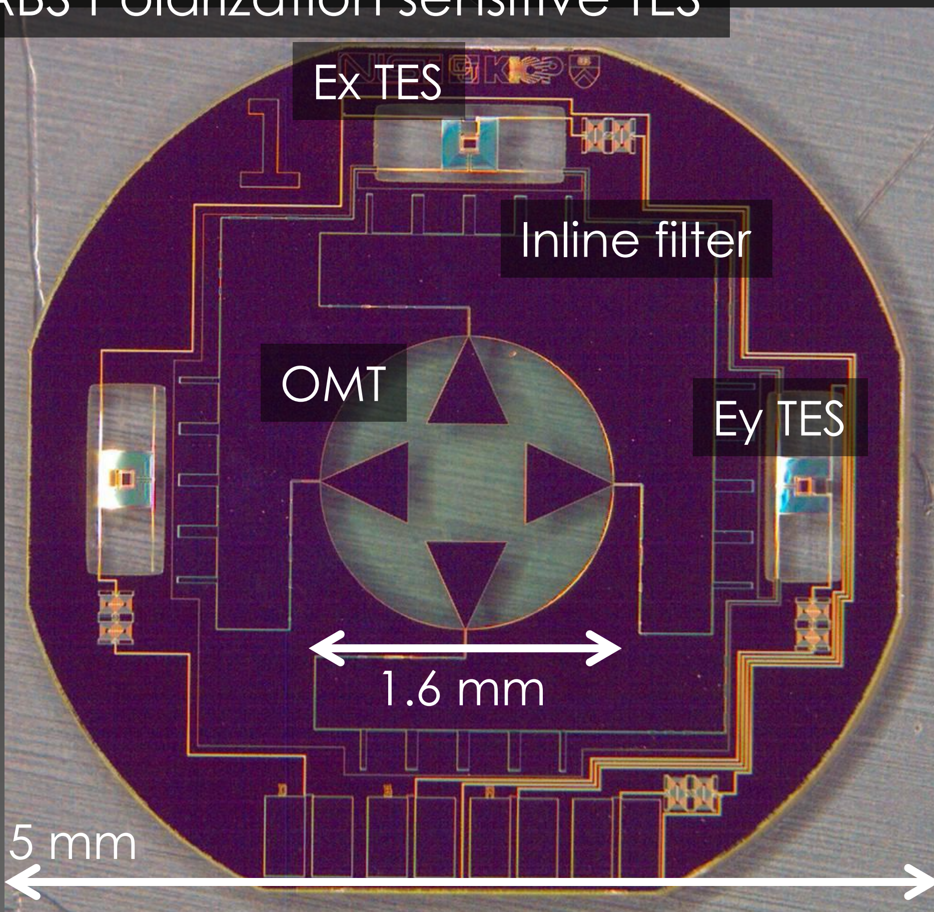
- *E*-modes
  - "Rotation" free
- *B*-modes
  - "Divergence" free
  - Sourced by GW (~2° scale)



Experimental Approach

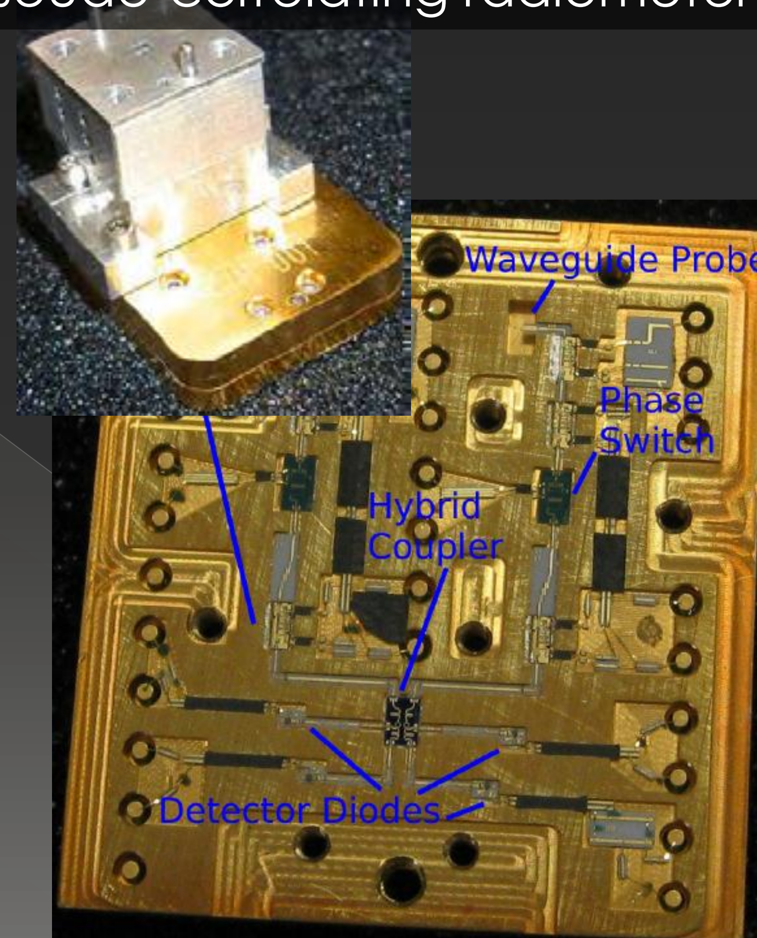
Ways to attain polarization sensitivity?

ABS Polarization sensitive TES



Fabricated at NIST

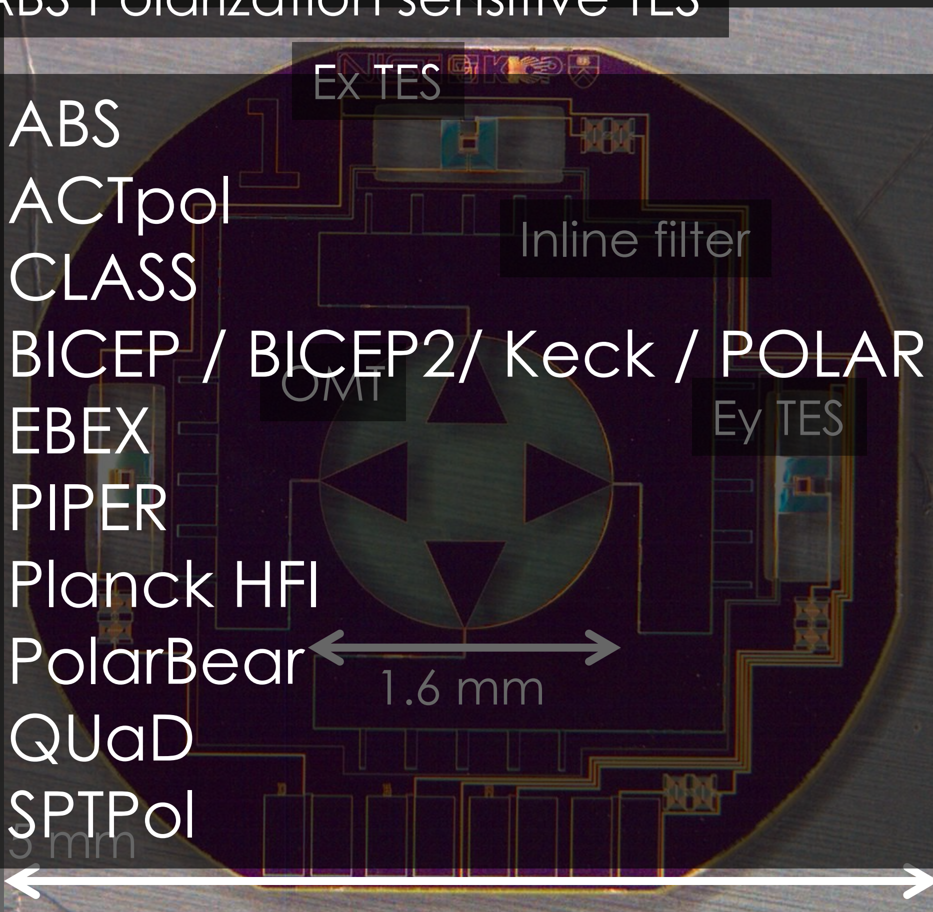
QUIET
Pseudo-correlating radiometer



~3cm, made at JPL

Ways to attain polarization sensitivity?

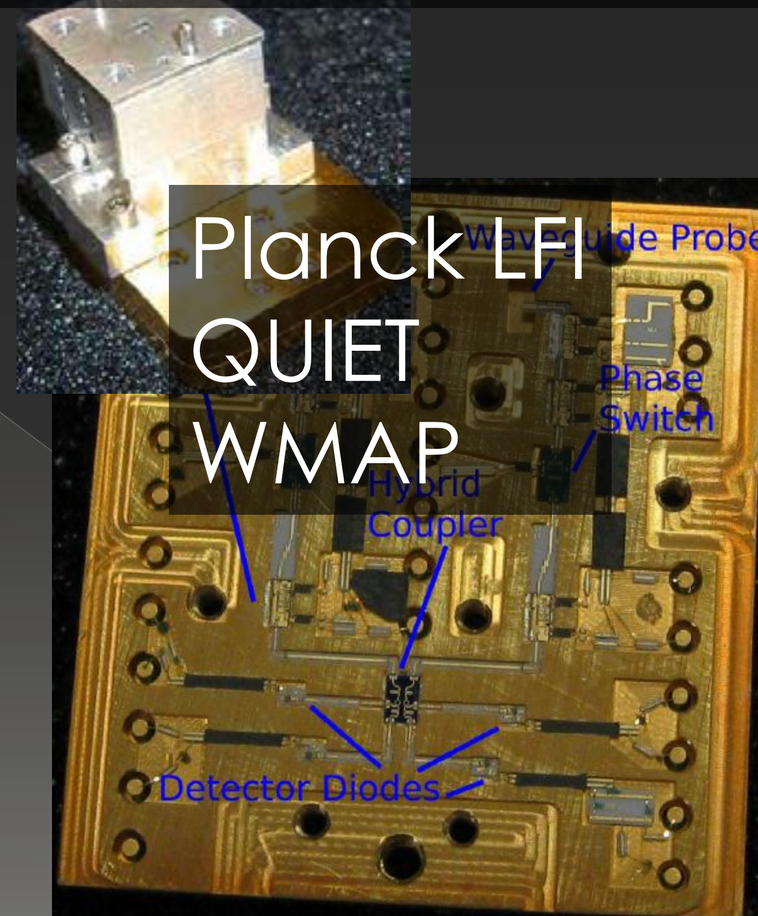
ABS Polarization sensitive TES



- ABS
- ACTpol
- CLASS
- BICEP / BICEP2/ Keck / POLAR
- EBEX
- PIPER
- Planck HFI
- PolarBear
- QUaD
- SPTPol

Fabricated at NIST

QUIET
Pseudo-correlating radiometer



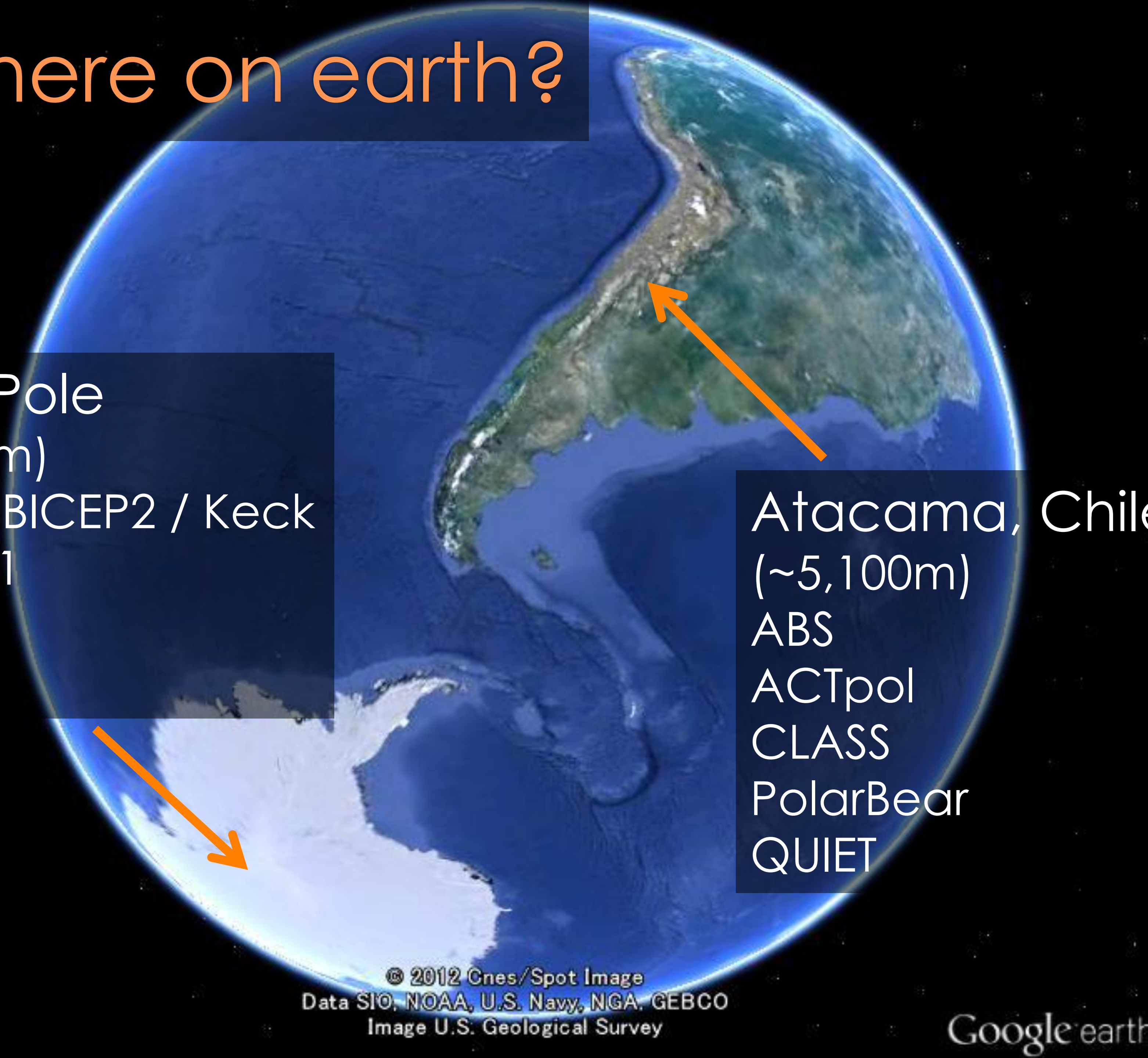
- Planck LFI
- QUIET
- WMAP

~3cm, made at JPL

Where on earth?

South Pole
(~2,800m)
BICEP / BICEP2 / Keck
POLAR-1
QUaD
SPTPol

Atacama, Chile
(~5,100m)
ABS
ACTpol
CLASS
PolarBear
QUIET



What is important?

Sensitivity (statistics)

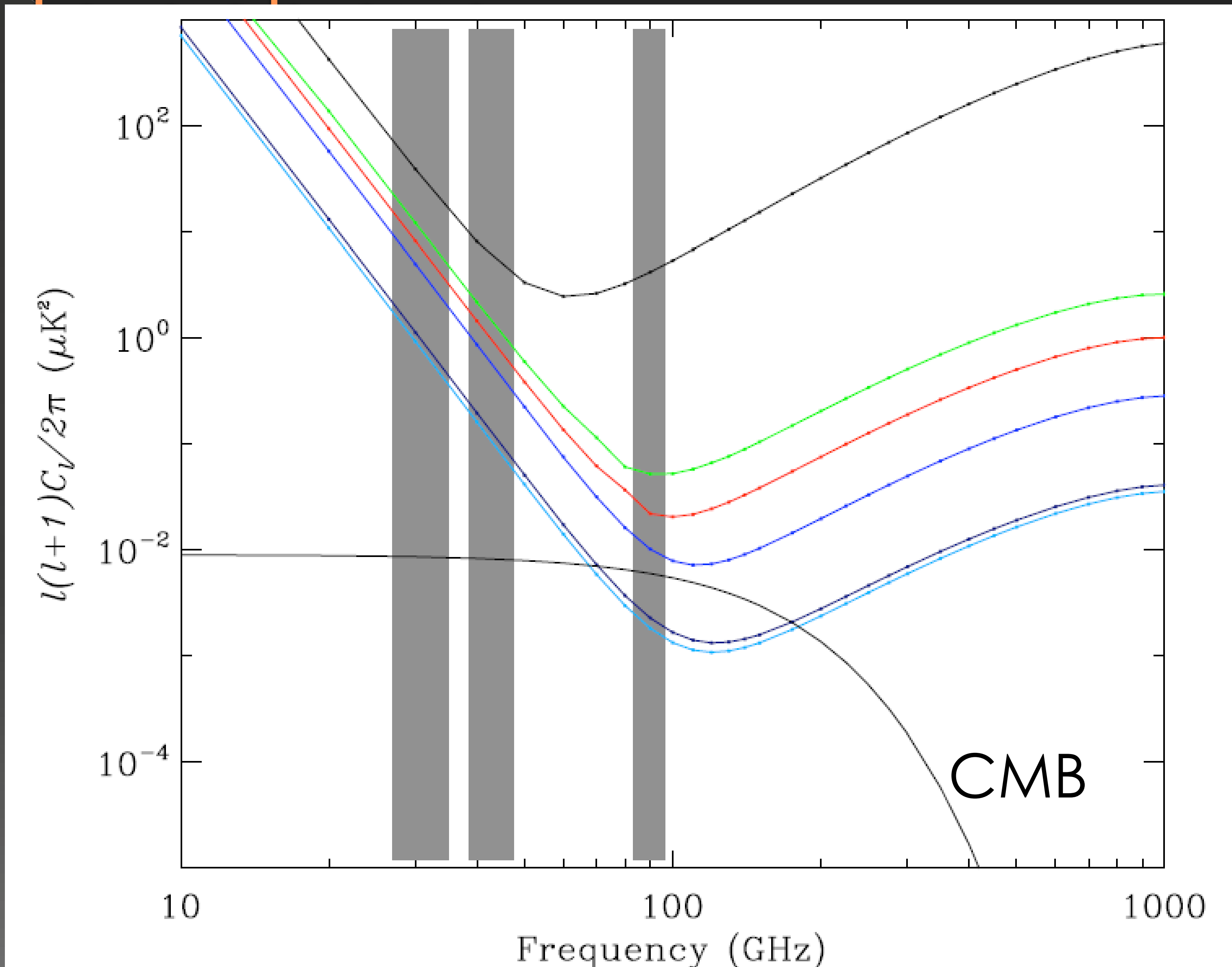
Rigorous analysis

Instrumental systematics

Physics systematics

To understand…

- Instrumental systematics
  - Hard to predict what would eventually be the limiting factor
    - Still, do the best to estimate.
  - Wide variety of instruments: different instruments have different systematics
- Physics systematics: Galactic foregrounds
  - Wide variety of frequency.
  - Different types of detectors are good at different frequencies



10^2
10^0
10^{-2}
10^{-4}
$l(l+1)C_l/2\pi$ (μK^2)
10
100
1000
Frequency (GHz)
CMB

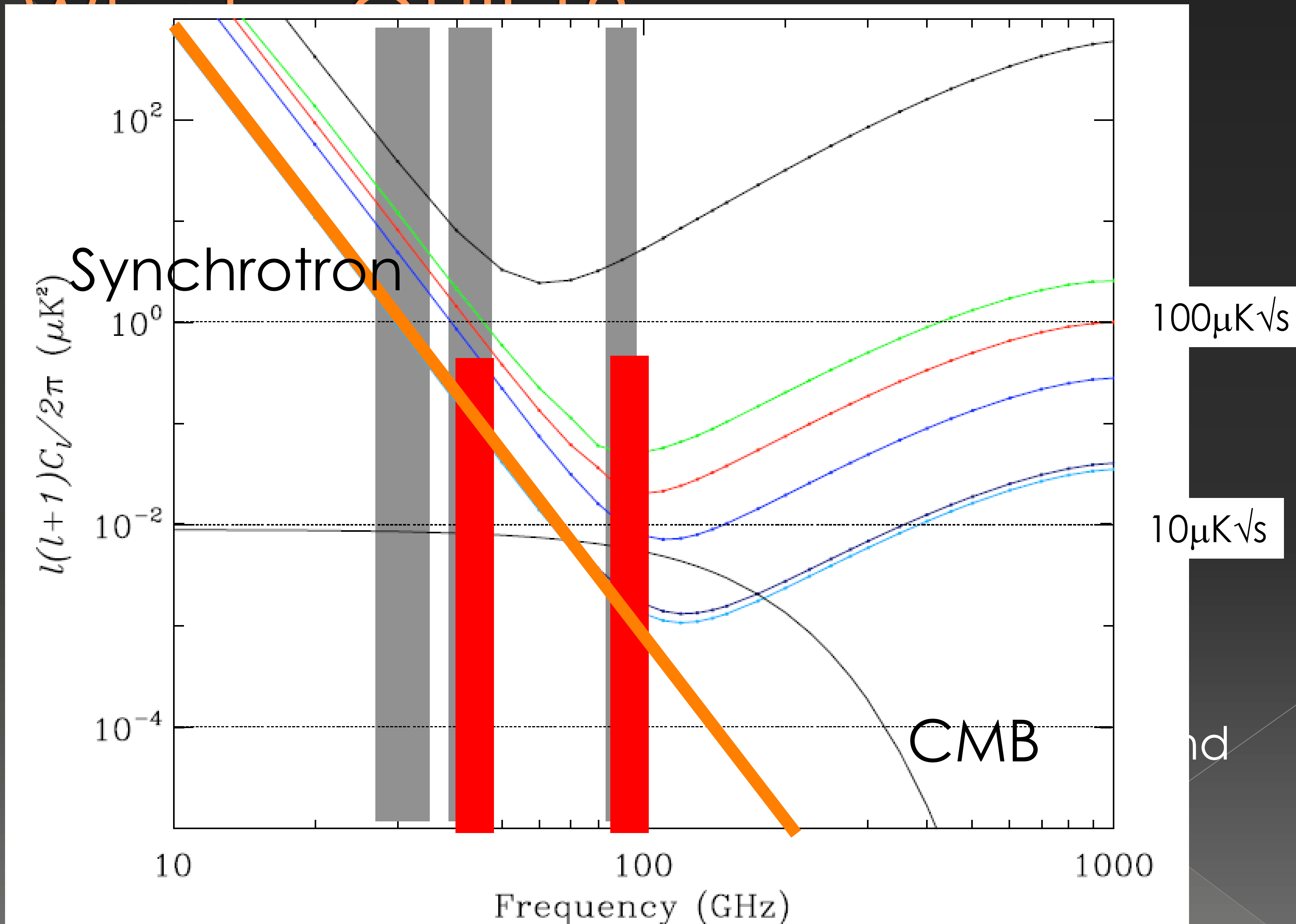
QUIET
(Q/U Imaging ExperimenT)

Caltech, Chicago (KICP), Columbia, Fermilab, JPL, KEK, Manchester, Miami, Michigan, MPI-Bonn, Oslo, Oxford, Princeton, Stanford (KIPAC)

Observation: 2008 – 2010

What is QUIET?

- Ground based
- CMB polarization (with some T sensitivity)
- Angular scale: l~100(~2°), B-mode from GW
- Coherent receiver
  - Q-band (43GHz): 19 elements, 69μK·√s
  - W-band (95GHz): 90 elements, ~80μK·√s
- One of the most sensitive polarimeter arrays published to date
- Unique HEMT amplifier technology
  - Frequency: 43GHz+95GHz (uniqueness in foreground treatment)
  - Systematics different from (perhaps better than) bolometer experiments.

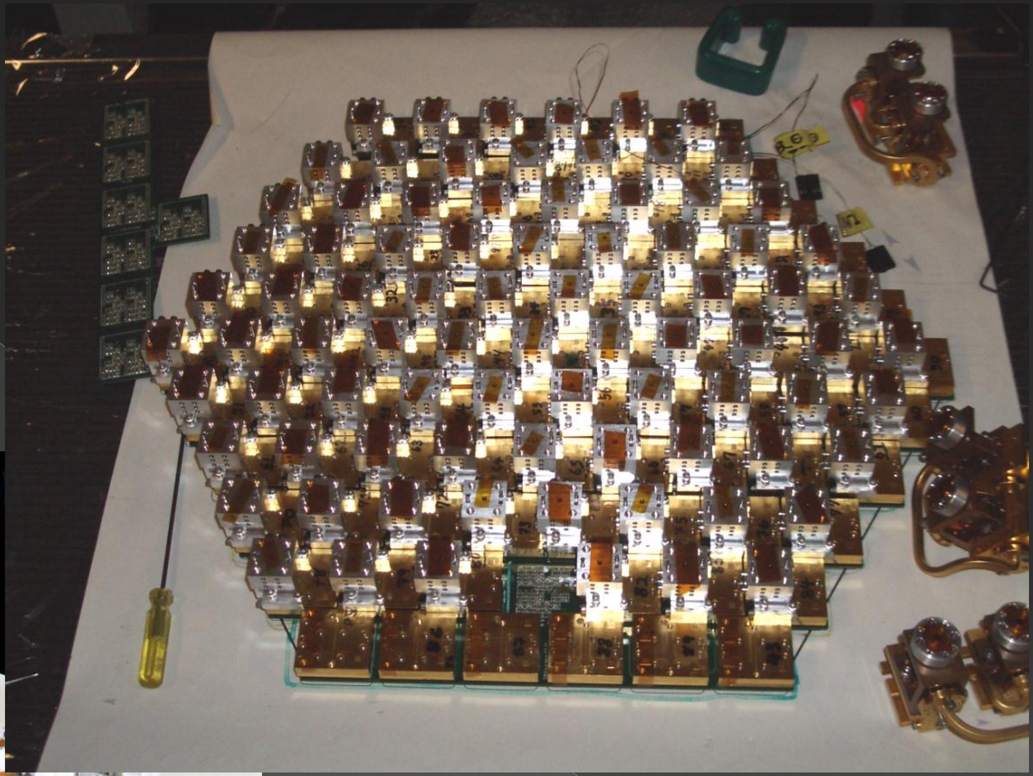

Synchrotron
CMB
100μK√s
10μK√s
10^2
10^0
10^{-2}
10^{-4}
$l(l+1)C_l/2\pi$ (μK^2)
10
100
1000
Frequency (GHz)

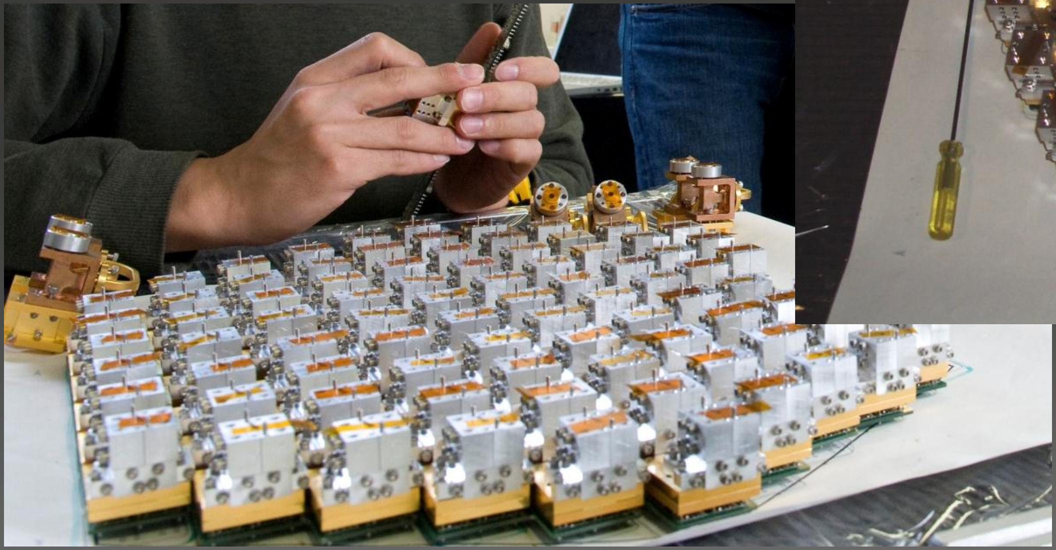
nd

Coordinated observation among CMB experiments

W-band Array

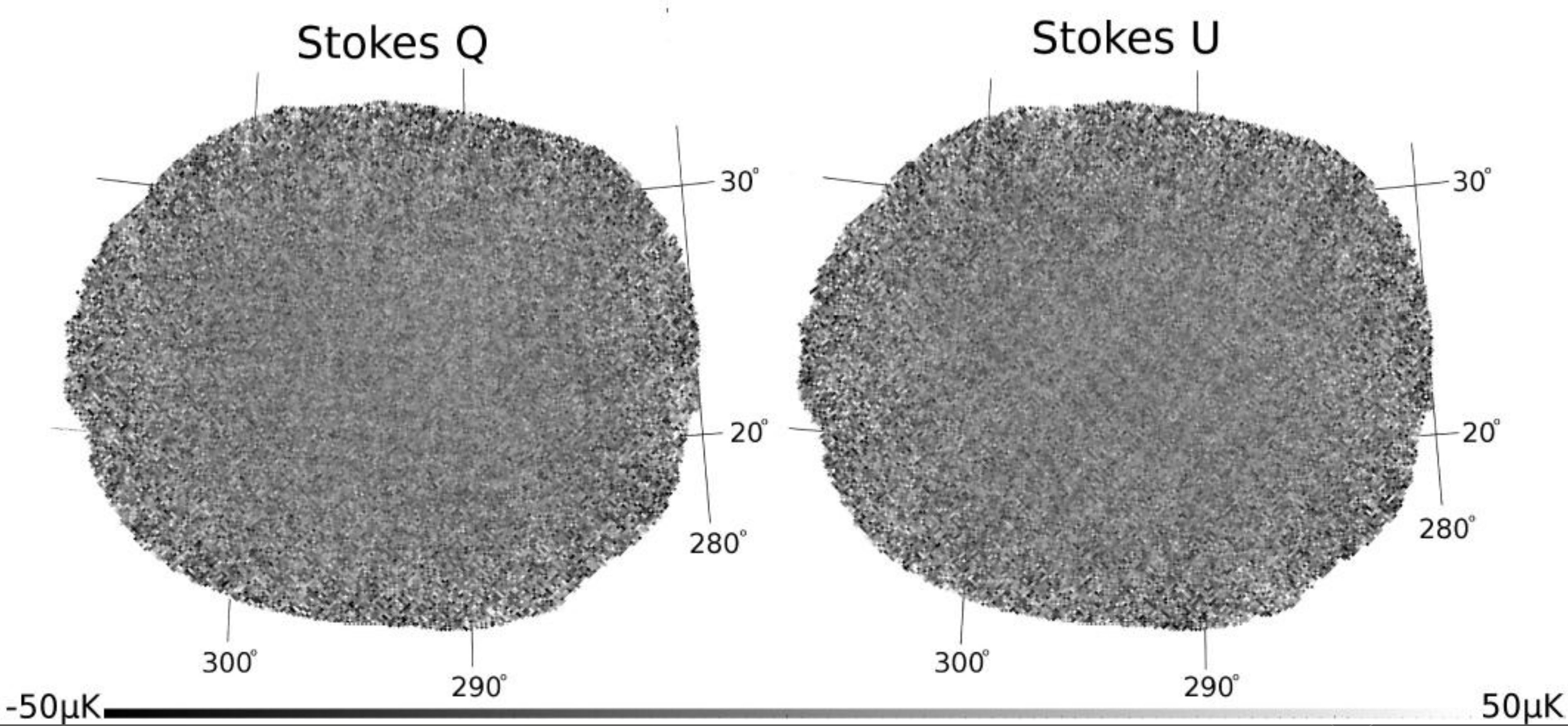
Array sensitivity
~80 $\mu K \cdot \sqrt{s}$





The world largest HEMT array polarimeter

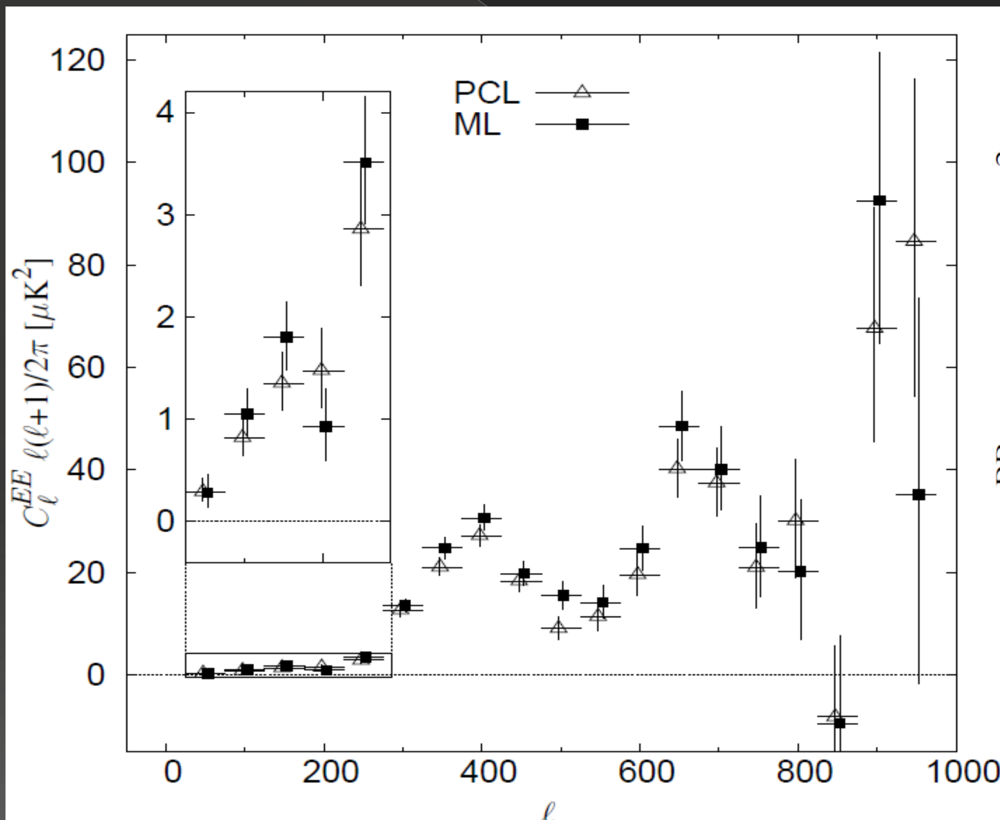
Polarization maps

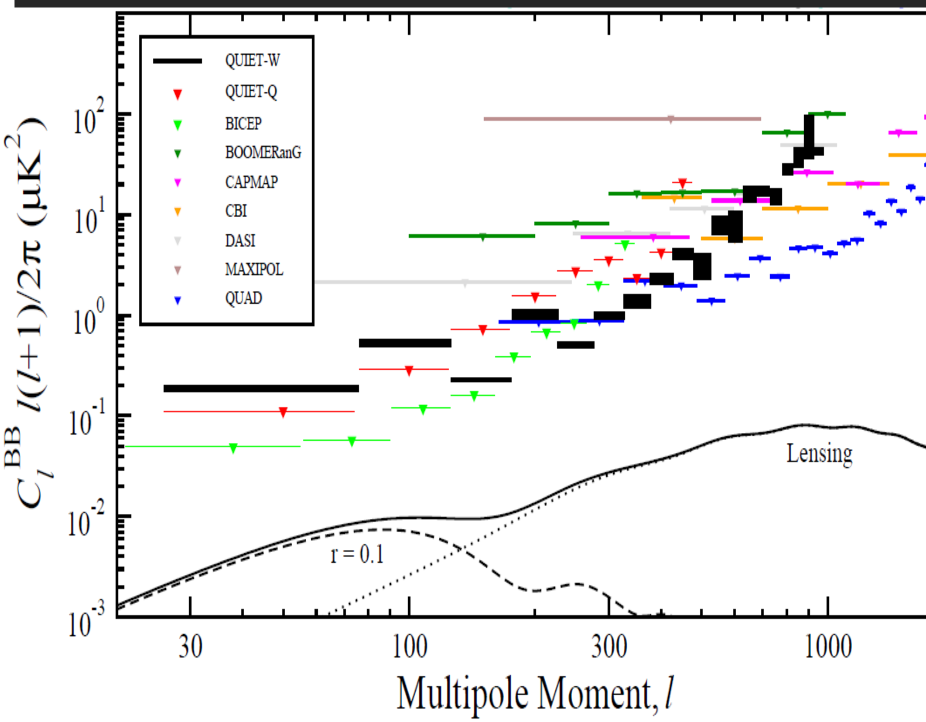


E-mode pattern visible in the maps

arXiv:1207.5034 (ApJ, in press)
arXiv:1207.5562 (ApJ, submitted)
ApJ 741 (2011), 111.

Results





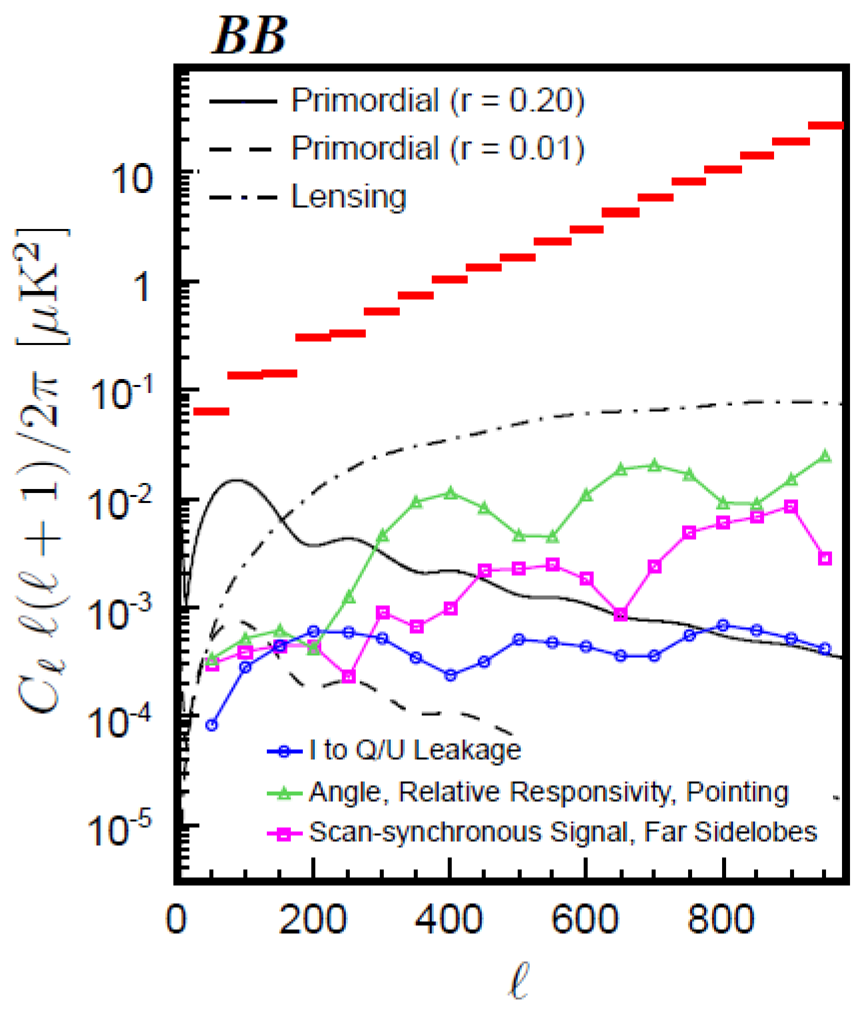
Clear acoustic peaks even without "guiding" eyes by ΛCDM curve

Competitive limits on BB power

Limit on T/S=r < 2.8, 2.7 (95% C.L.)
(BICEP: r<0.7, QUIET-Q: r<2.2
WMAP TT+all: r<0.2)

Systematic errors

- Instrumental systematuics: key toward r~0.01
- QUIET successfully showed r<0.01 is possible.



ABS
(Atacama B-mode Search)

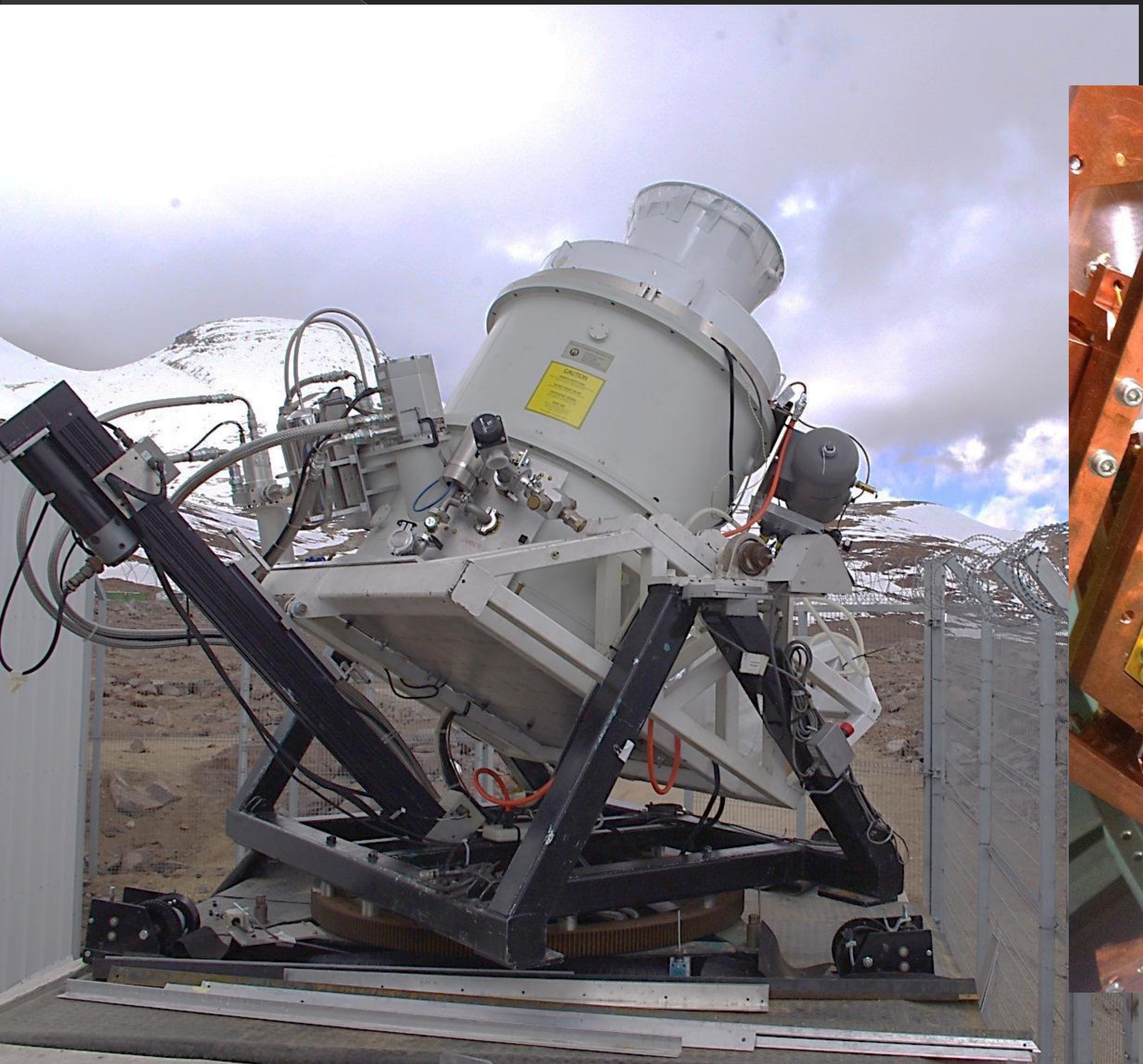
Johns Hopkins, NIST, Princeton, Univ. of British Columbia

Observation: 2012 – 2014(?)

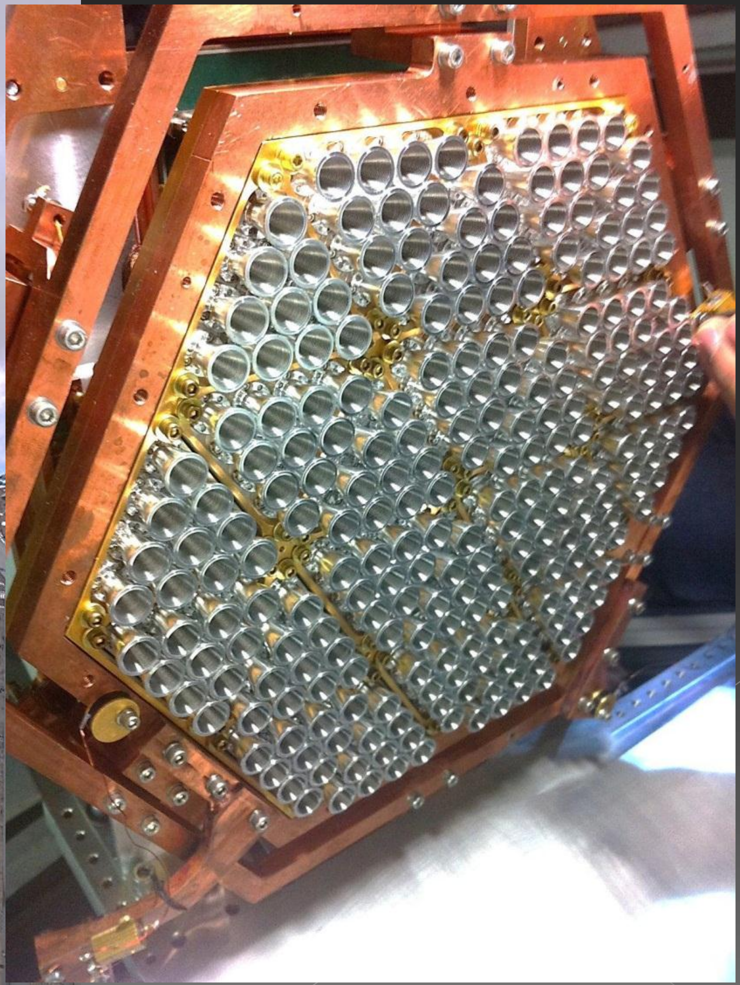
What is ABS?

- Ground based
- CMB polarization (with T sensitivity)
- Angular scale: l~100(~2°), B-mode from GW
- TES bolometer at 150GHz
  - 240 pixel / 480 bolometers
- Unique Systematic error mitigation
  - Cold optics
  - Continuously rotating half-wave plate

ABS instrument

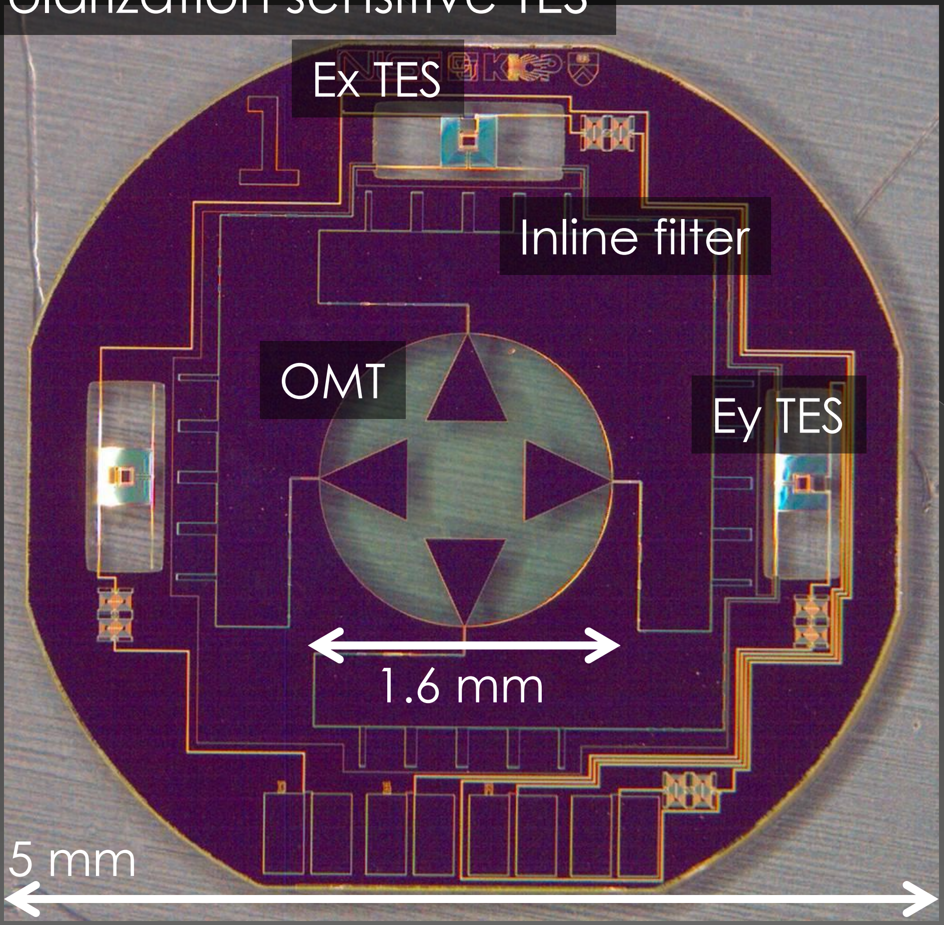


Focal plane ~300mK



Key technologies

Polarization sensitive TES



Fabricated at NIST

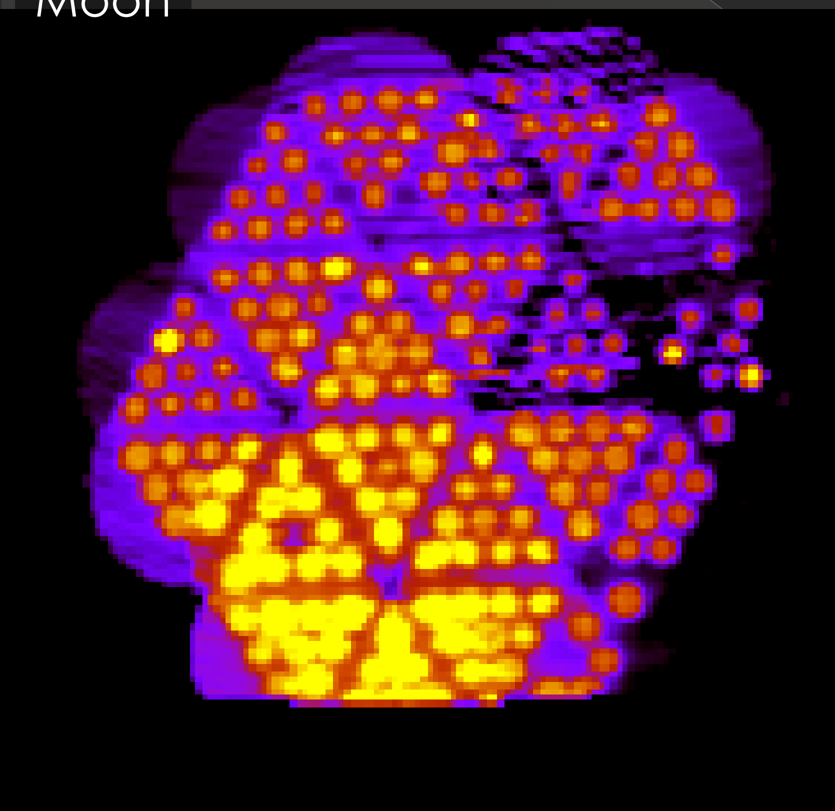
Continuously rotating
Half wave plate

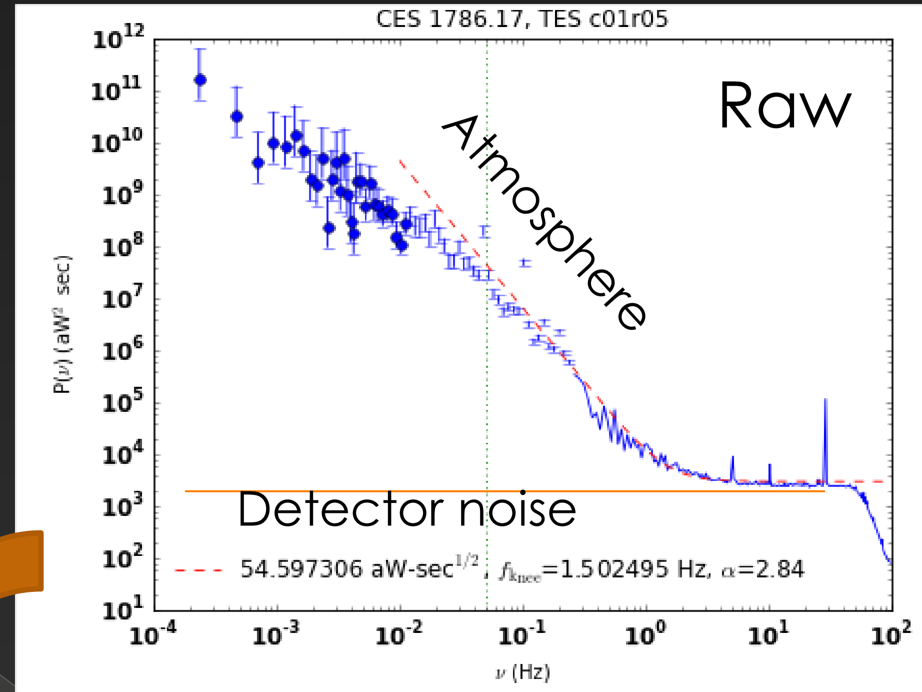
A-cut sapphire (D=330m)
f~2.5Hz rotation
→ *f*~10Hz modulation
Air-baring → Stable rotation

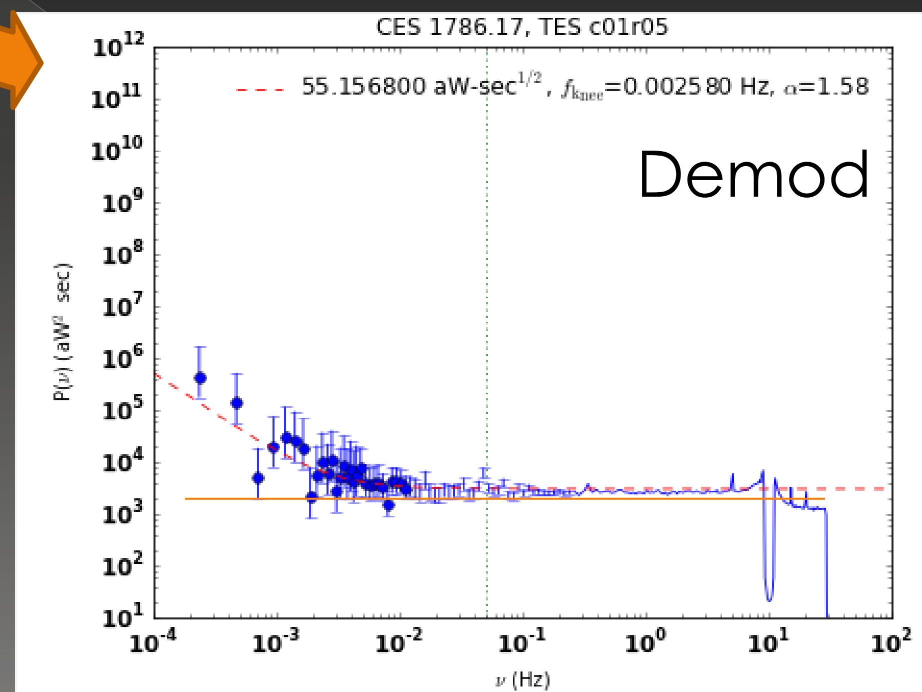
Detection and modulation is in X-Y polarizations, not L-R.

Initial data

Moon







Summary

- CMB B-mode polarization
  - Very attractive and exciting physics
  - Subtle signal
- Approach to the subtle signal
  - All four are important: sensitivity, instr. systematics, galactic foreground, analysis
- QUIET, ABS
  - cover different frequency, and
  - very different instrumental characteristics → different systematics