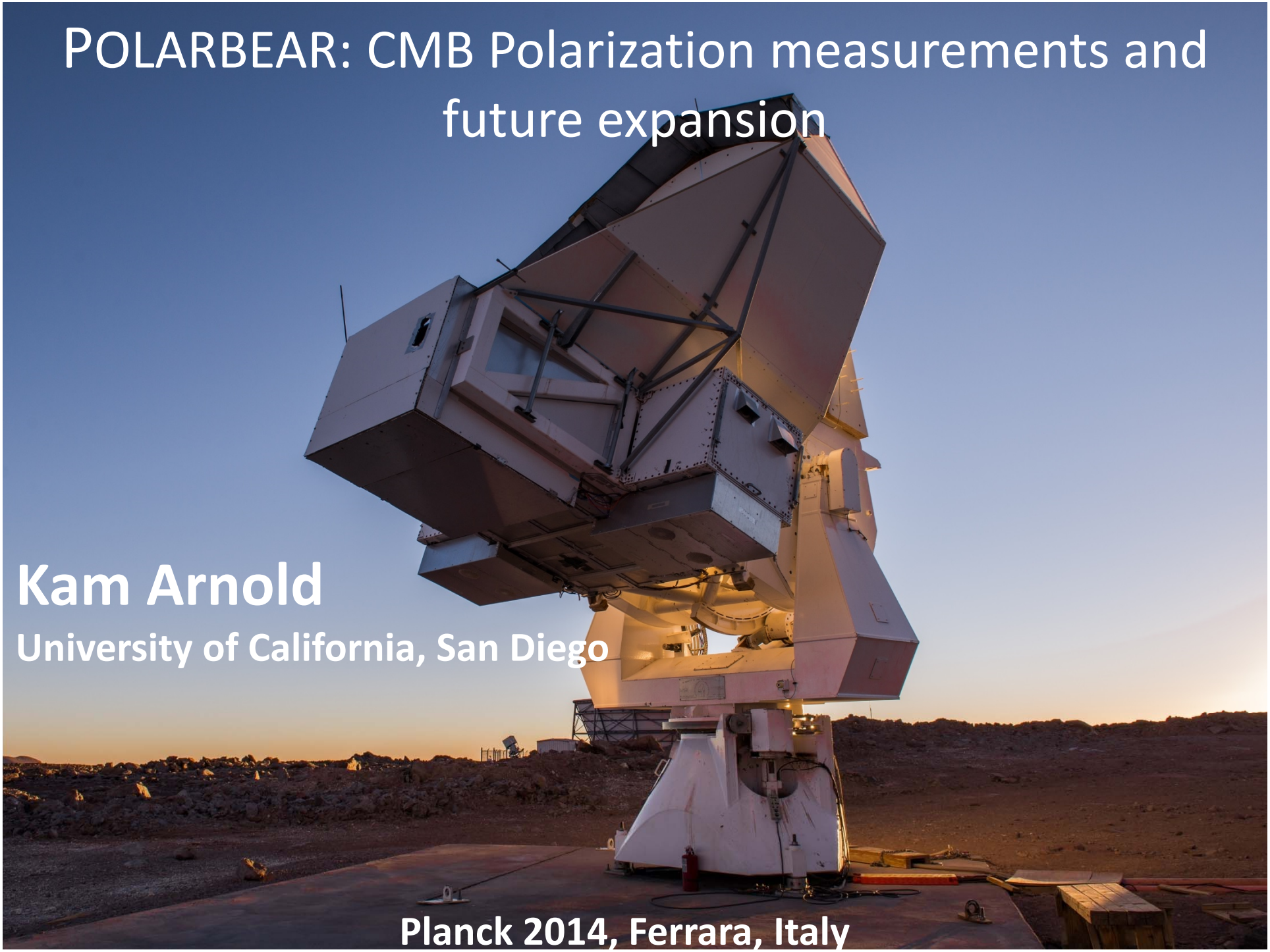
POLARBEAR: CMB Polarization measurements and future expansion



Kam Arnold

University of California, San Diego

Planck 2014, Ferrara, Italy

POLARBEAR Collaboration

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Josquin Errard
Neil Goeckner-Wald
Charles Hill
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Yasuto Hori
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David Boettger
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CONICYT Gobierno de Chile · NSF · NASA · MEXT · SIMONS FOUNDATION Advancing Research in Basic Science and Mathematics

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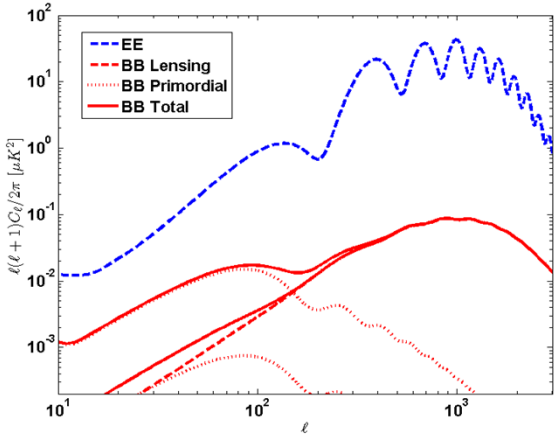
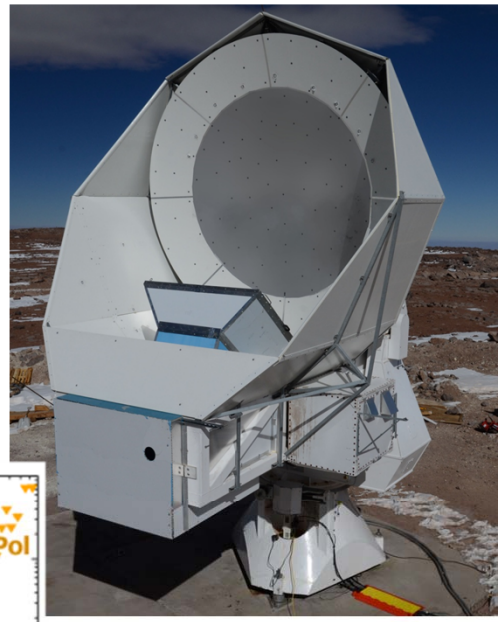
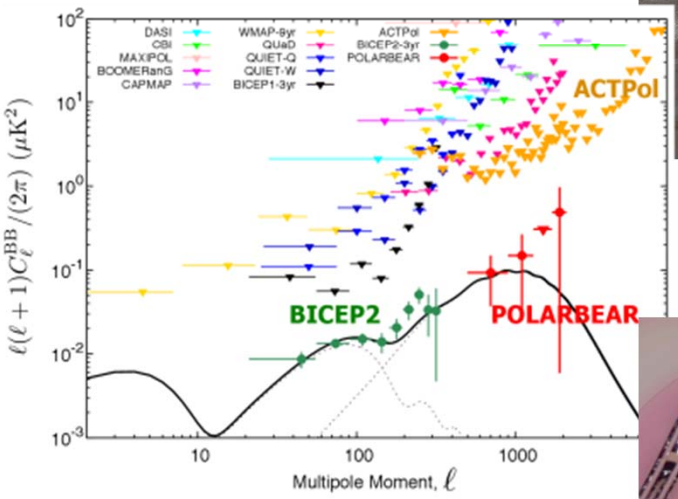
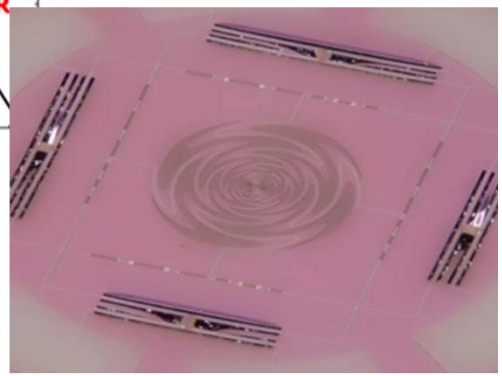
Outline



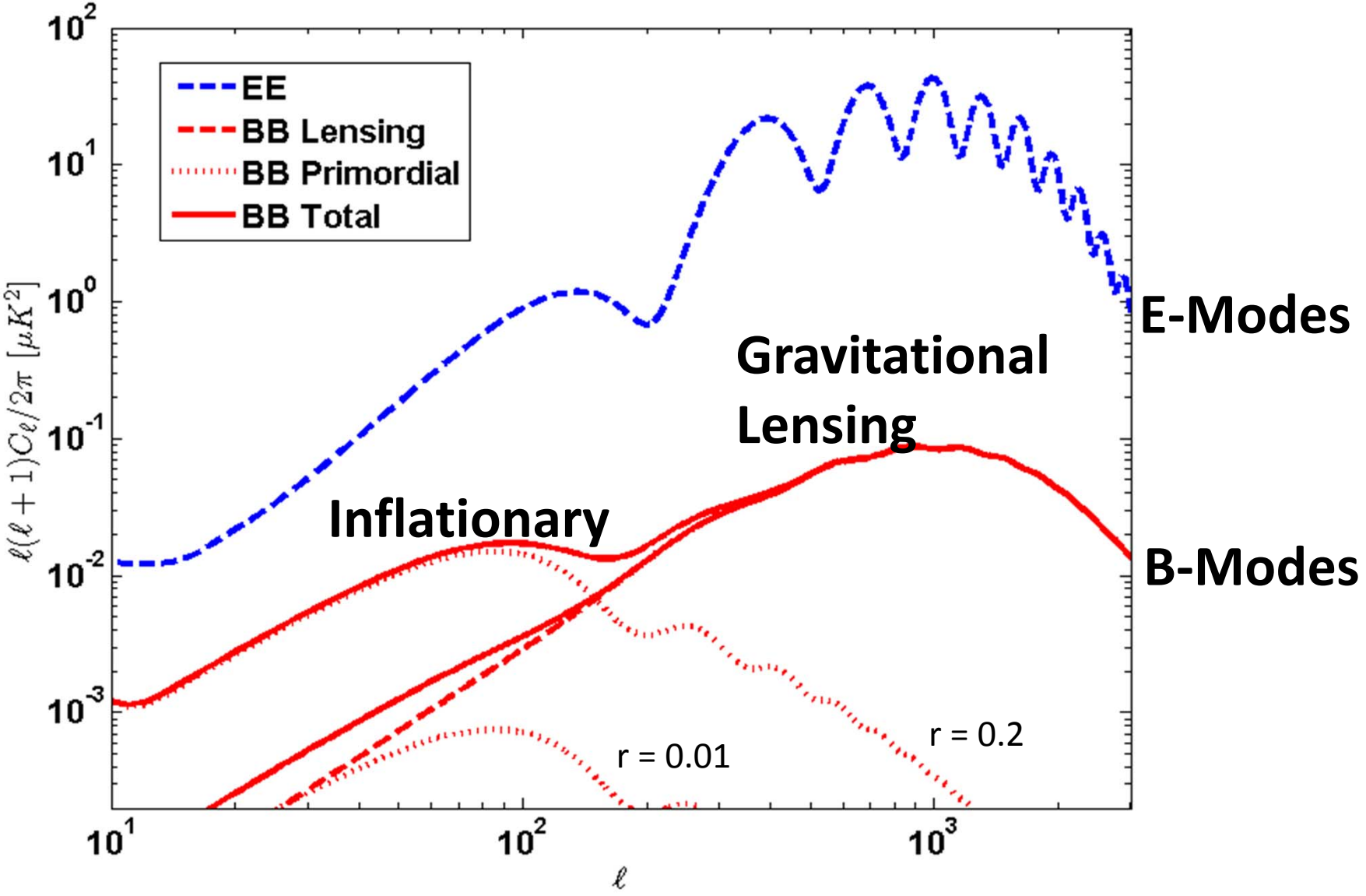






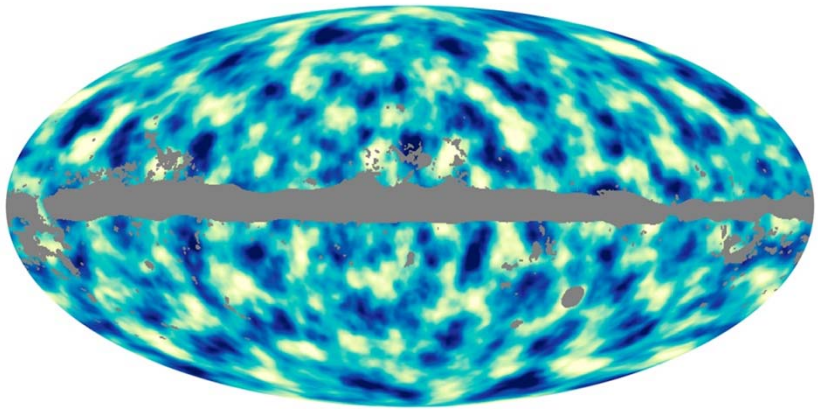
- Scientific goals
- The POLARBEAR instrument
- First season results
- The next generation

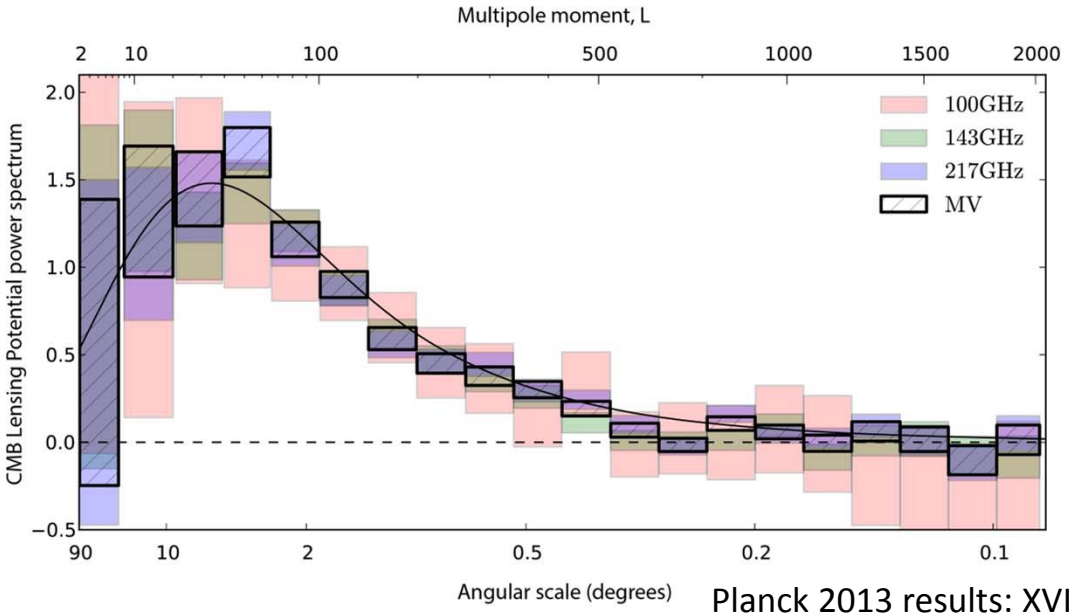
Predicted Polarization Power Spectrum



Lensing potential map from correlating across angular scales in T,E,B

- Reconstruct gravitational potential
- Lensing potential power spectrum:
  - Neutrino mass
  - Dark energy
- Deflection map:
  - De-lensing





Planck 2013 results: XVII

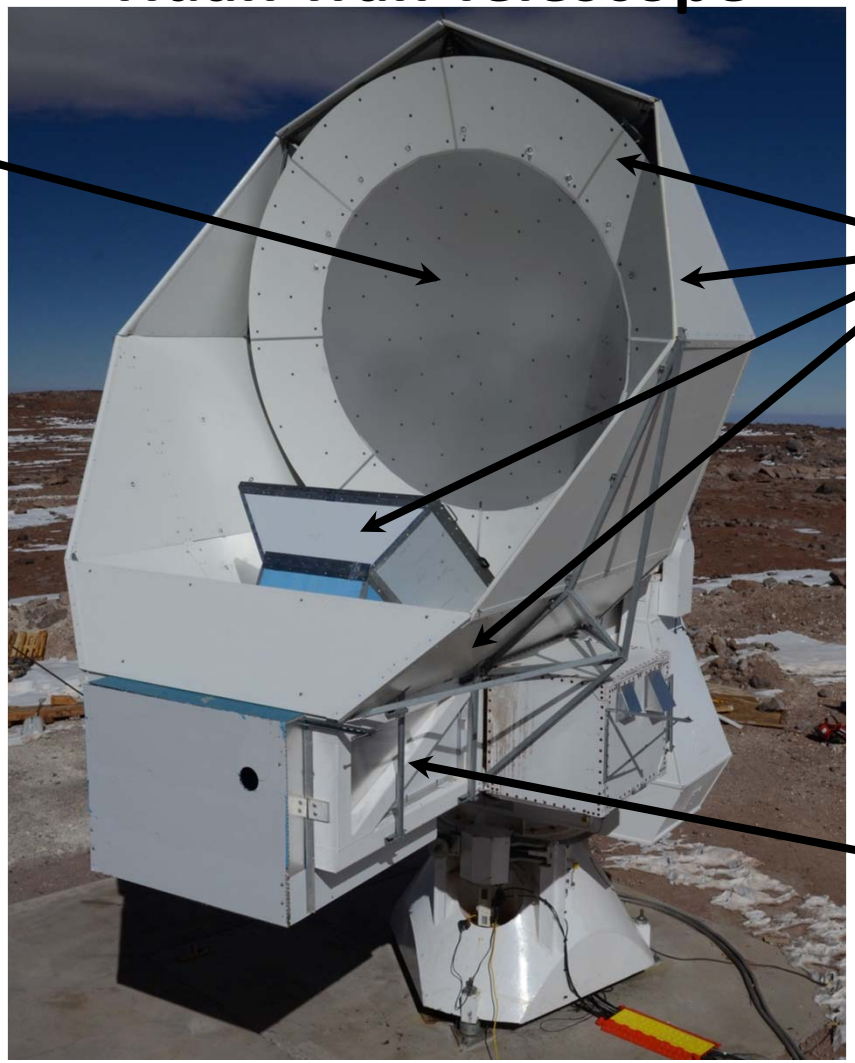
POLARBEAR Instrument Design: Telescope

Huan Tran Telescope

Angular resolution to characterize lensing

Off-axis Gregorian-Dragone

- Low cross polarization
- Large field of view
- Large throughput

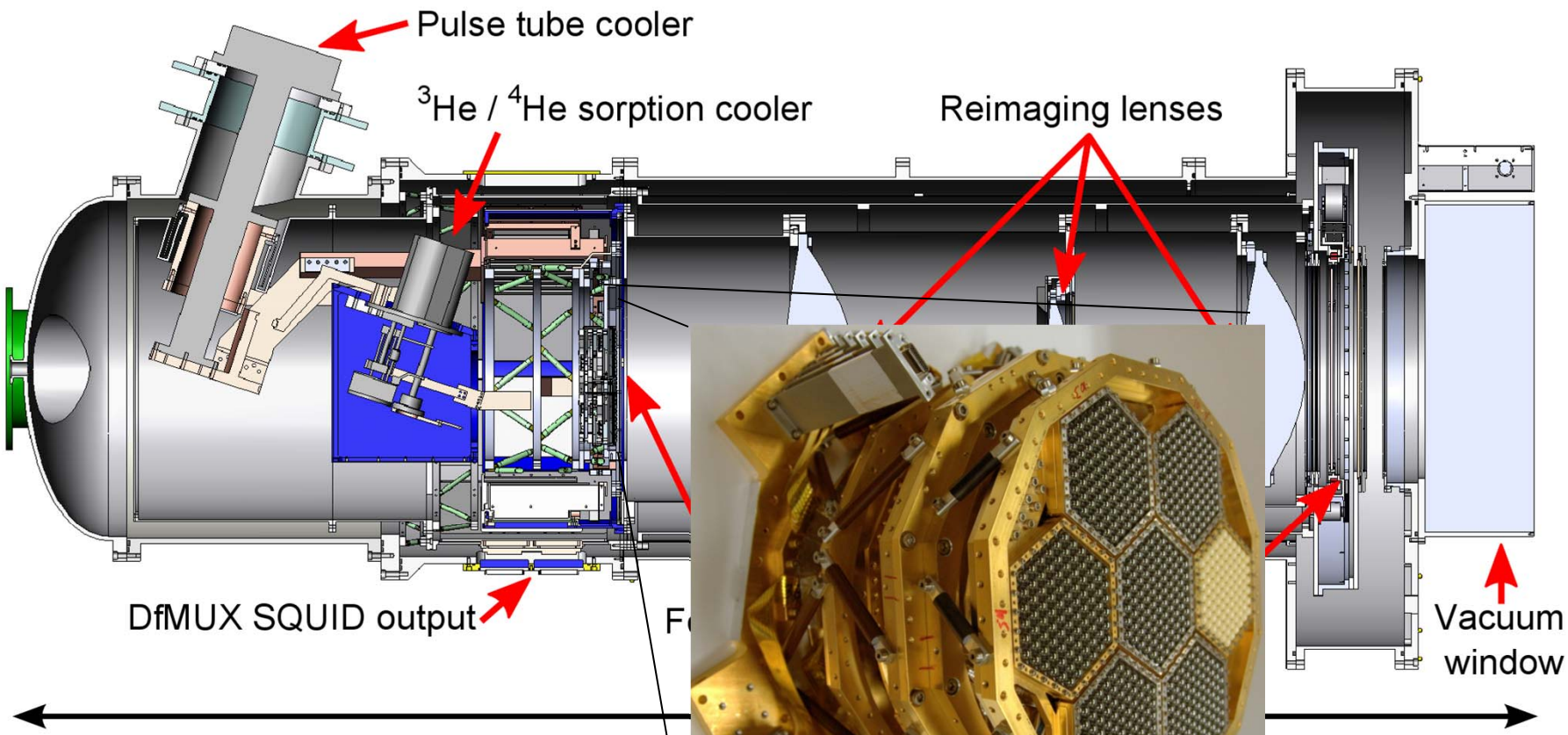


Elevation: 5200 m

Shielding to reduce sidelobe response

Cryogenic Receiver enclosure

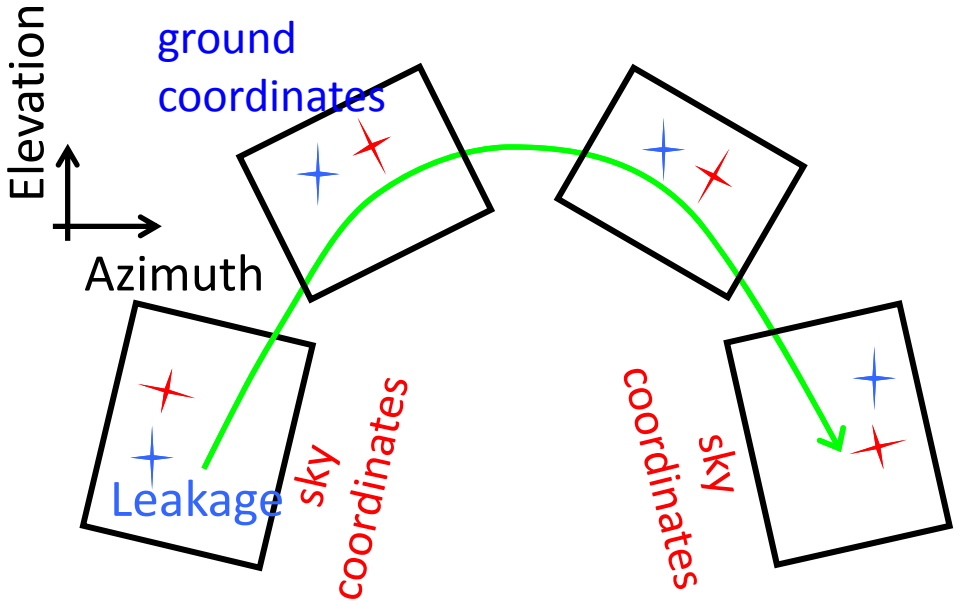
POLARBEAR Cryogenic Receiver



1274 superconducting TES bolometers (2 per pixel)

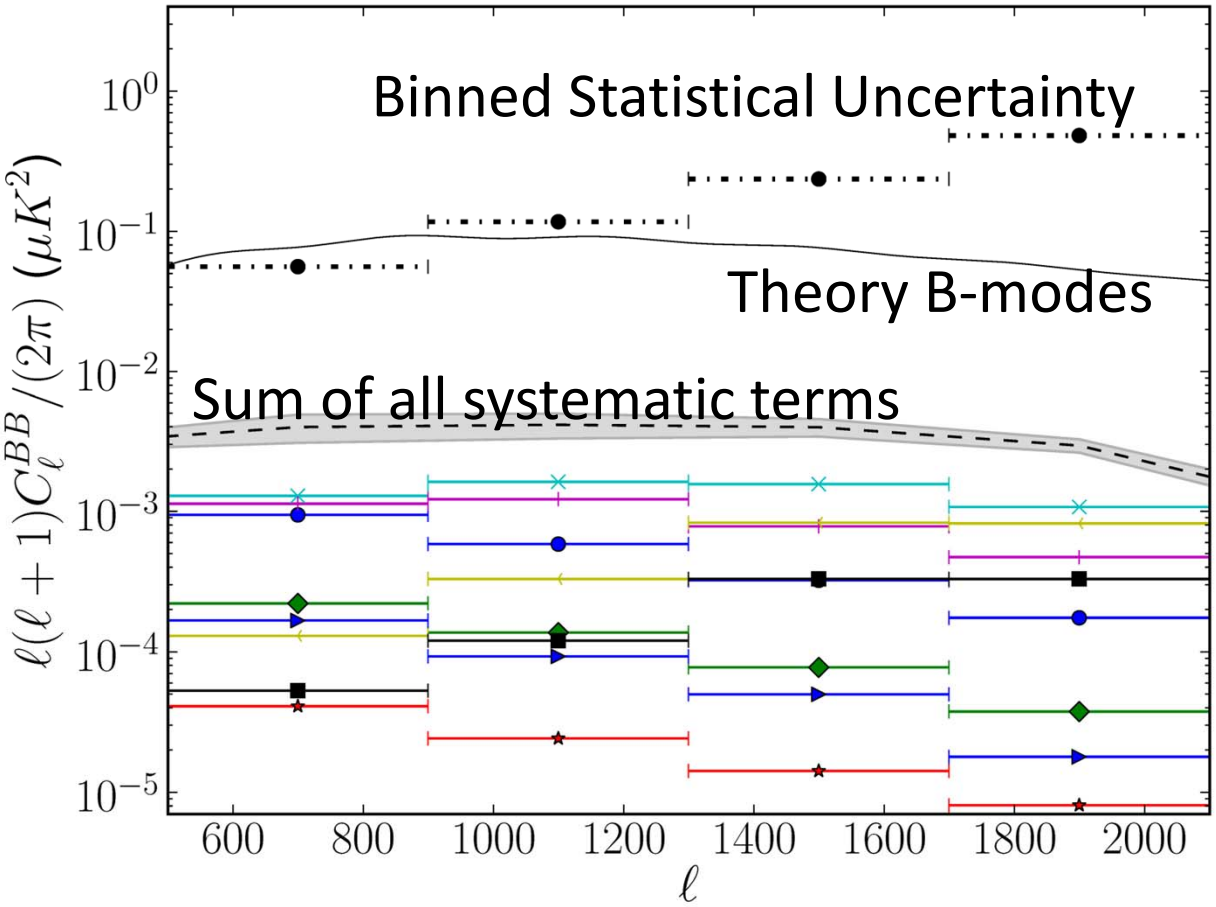
POLARBEAR: Control of systematic instrumental effects

- Instantaneous measurement of polarization with each pixel
- Modulation of CMB Polarization:
  - Half-wave plate
  - Apparent sky rotation
- Low sidelobe response
  - Co-moving baffling
  - Scan strategy allows ground removal



Instrumental Bias Estimation

End-to-end simulations using measured instrument characteristics and cross-checks

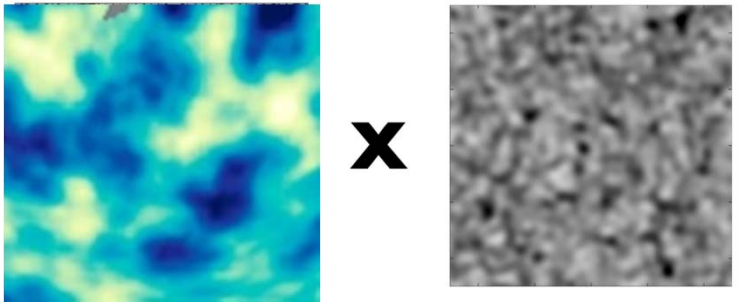


Boresight & diff pointing
Differential beamsize
Polarization angle
Differential ellipticity
HWP-dependent gain •
HWP-independent gain
Electrical crosstalk
Gain drift

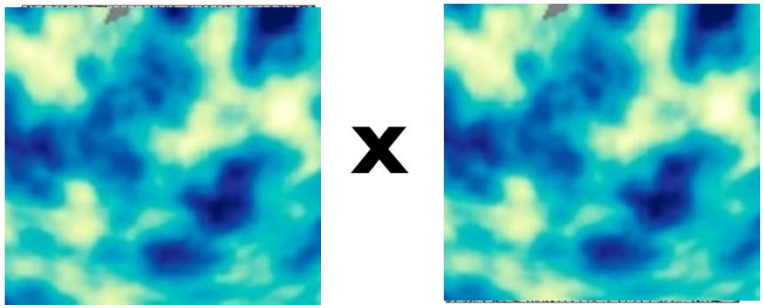
Confirmed all known systematics are much smaller than statistical uncertainty before “unblinding” the spectrum

First-Season POLARBEAR Results: Three B-mode Analyses

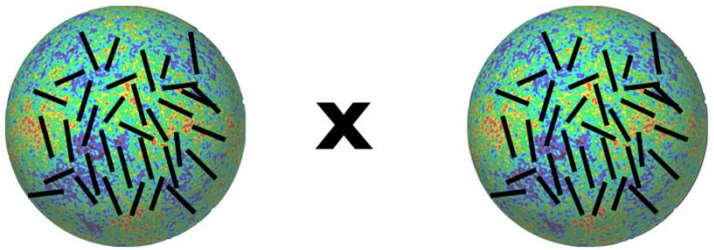
Galaxy cross-correlation:
PRL 112, 131302 (2014)



Deflection power spectrum:
PRL 113, 021301 (2014)

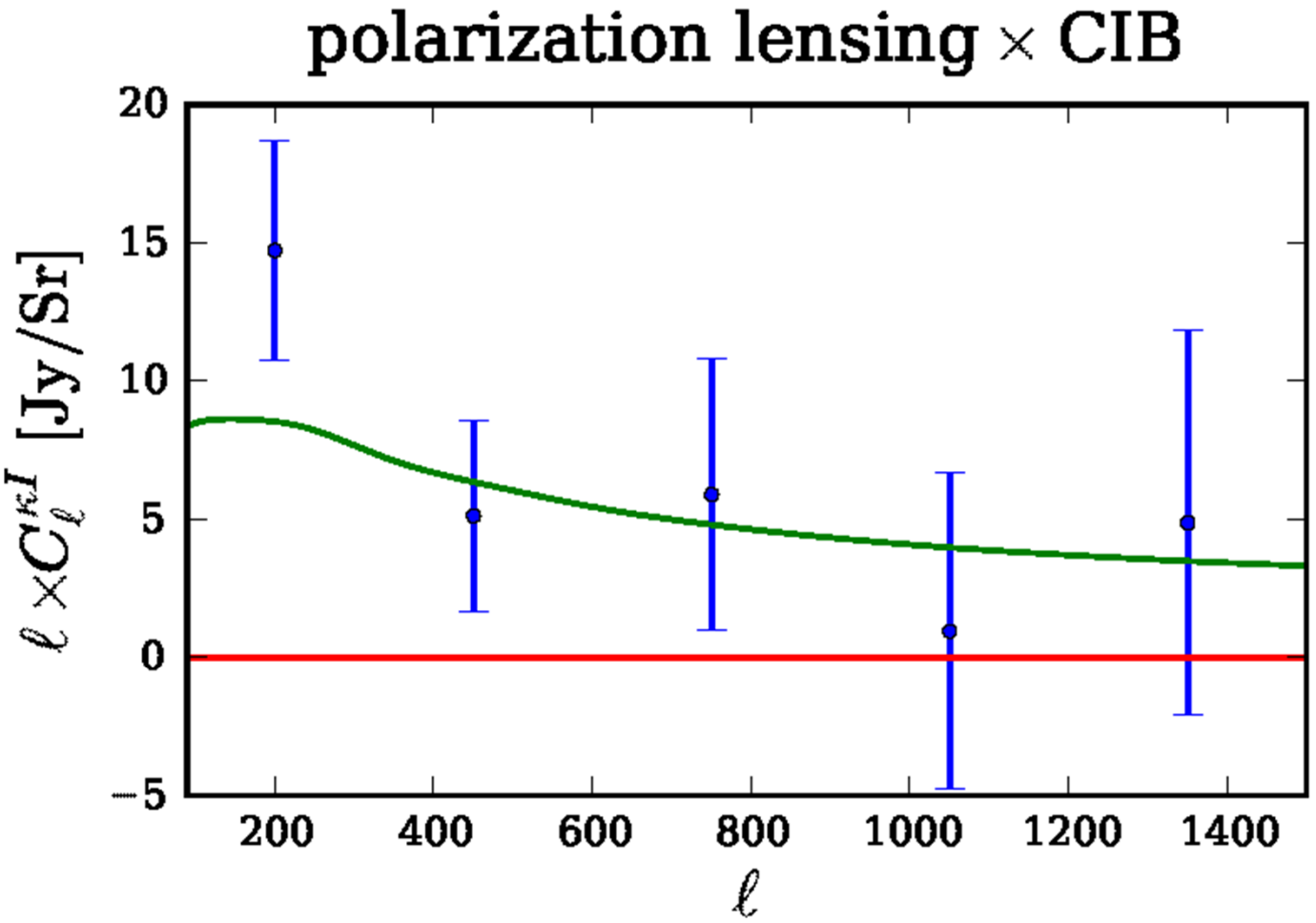


Angular power spectrum: C_ℓ^{BB}
ApJ 794, 171 (2014)



All Spectra available on NASA LAMBDA site
All analysis use 13 calendar months of observations

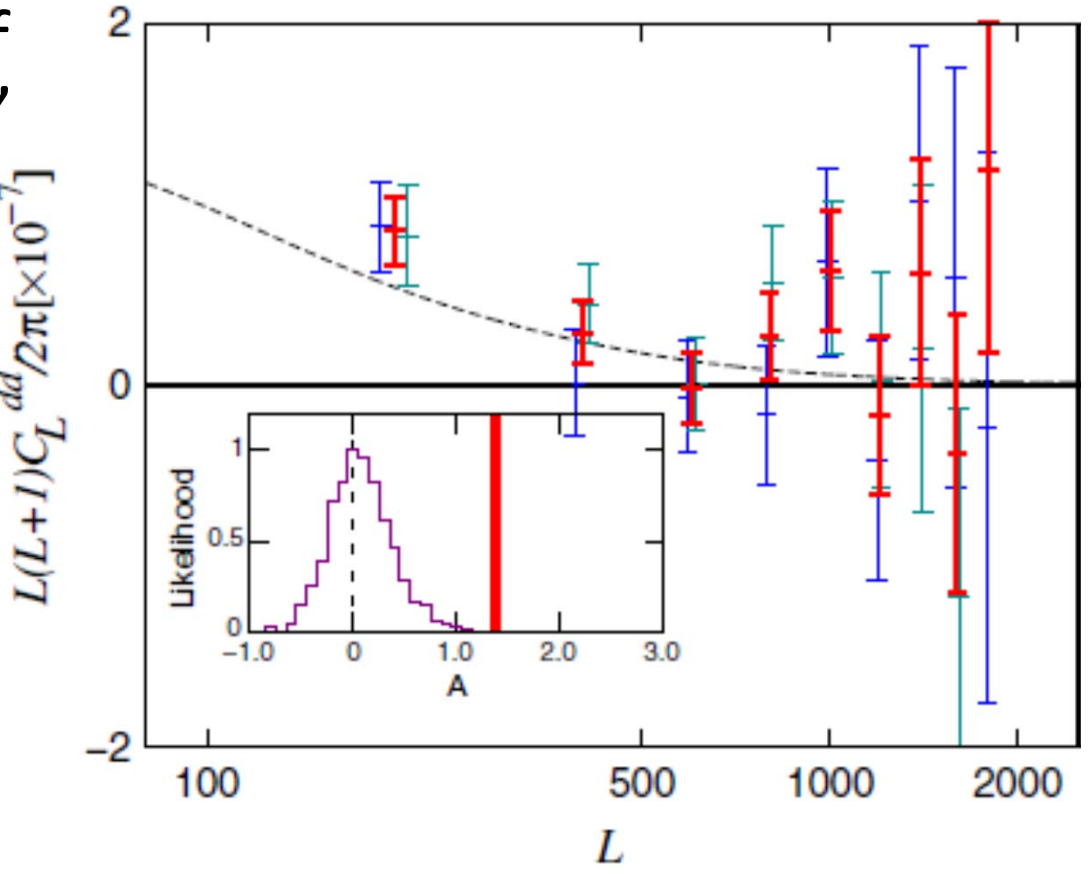
B-modes: Galaxy cross correlation



- 2.3 sigma rejection of “no lensing *B*-modes”
- Consistent with SPTpol measurement

B-modes: deflection power spectrum

- 4.2 sigma rejection of "no lensing *B*-modes"
- First reported CMB-polarization-only C_L^{dd} spectrum
- Polarization will be the most sensitive measure of C_L^{dd}
  - Groundwork for neutrino masses, dark energy



Green: $< EBEB >$

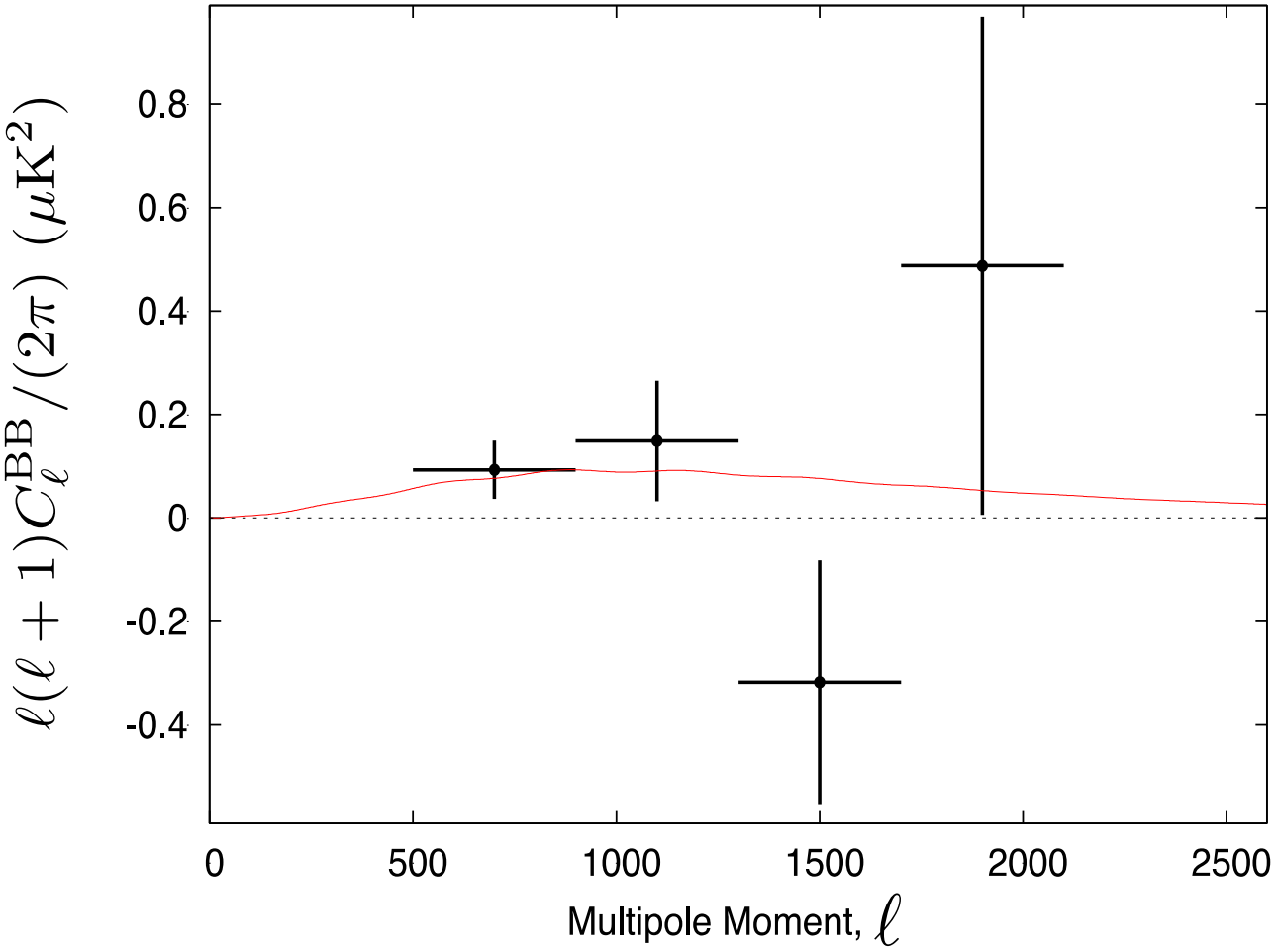
Blue: $< EEEB >$

Red: Combined

B-modes: Power Spectrum C_ℓ^{BB}

97.2% rejection of
"no lensing *B*-modes"

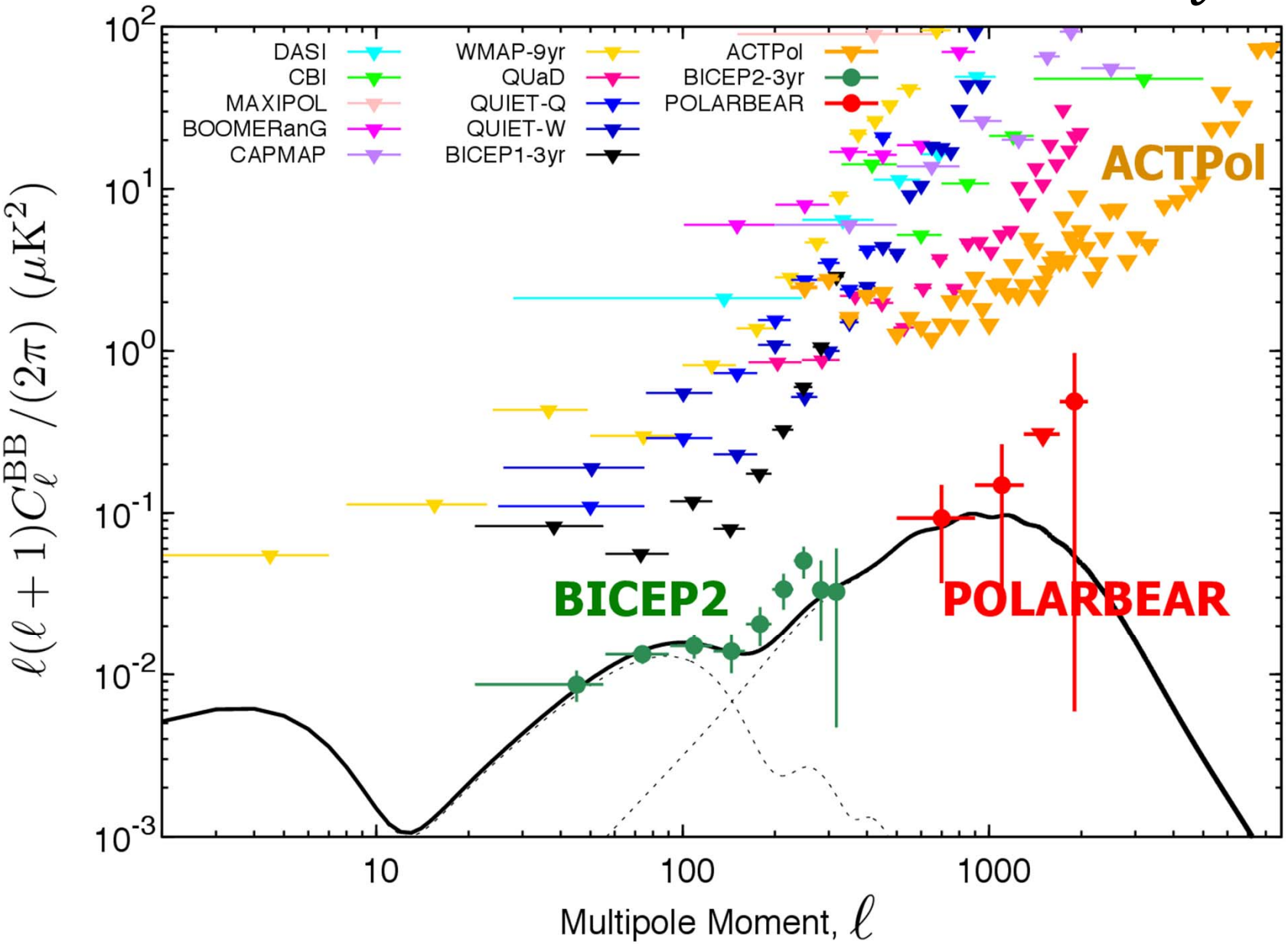
- including possible systematic instrumental biases
- Including estimate of foreground bias



Amplitude of lensing compared to ΛCDM:

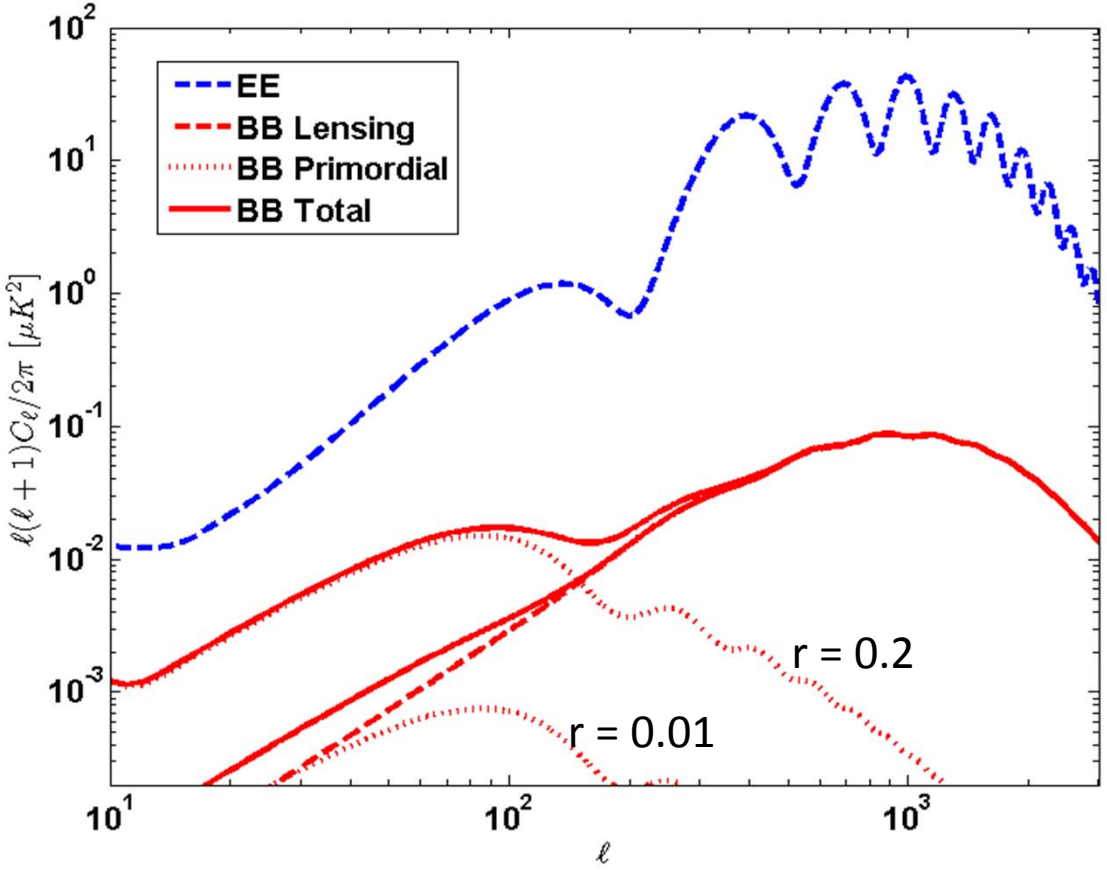
$1.12 \pm 0.61\ (stat)\ ^{+0.04}_{-0.12}\ (sys) \pm 0.07\ (mult)$

B-modes: Power Spectrum C_ℓ^{BB}



The Next Generation of CMB Instruments - Requirements

- Higher sensitivity
  - Reduce noise variance
- Large sky coverage
  - Reduce sample variance
- Spectral information
  - Characterize and remove polarized foregrounds
- Beamsize < 4’
  - Characterize large-scale structure



Multichroic Pixels Development

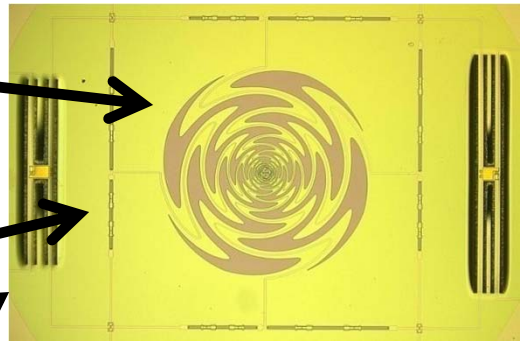
Broadband antenna.
Same fab process

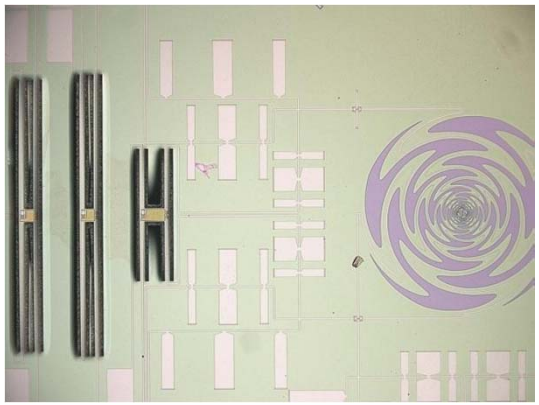
Filter bank to separate spectral bands

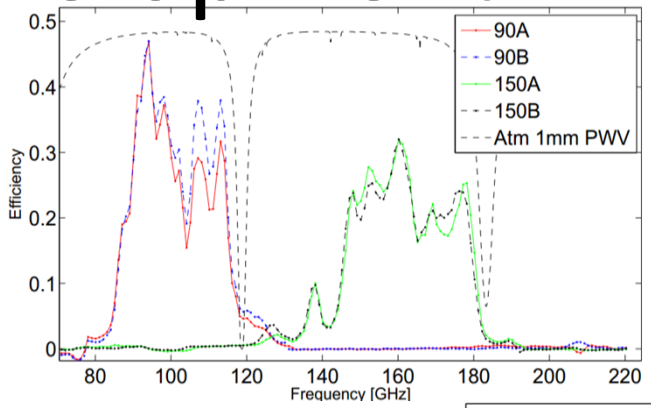
Diplexer

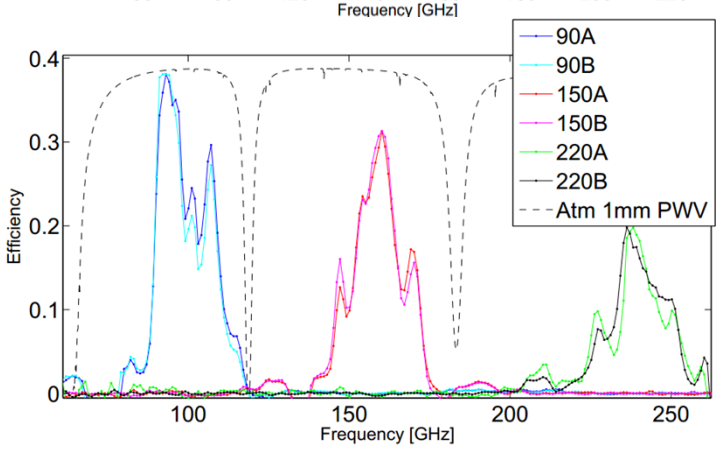
Triplexer

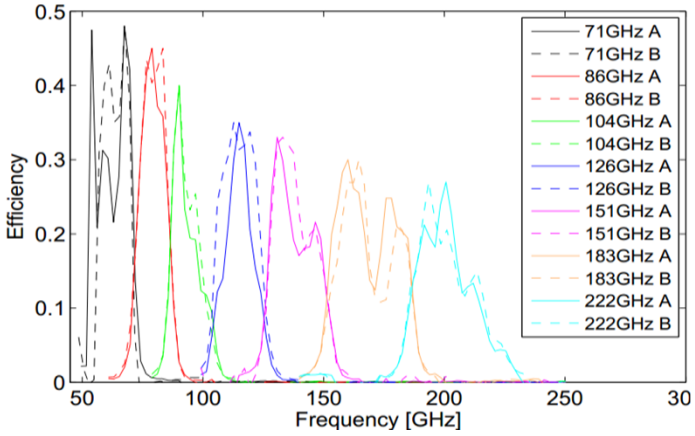
7 channel channelizer



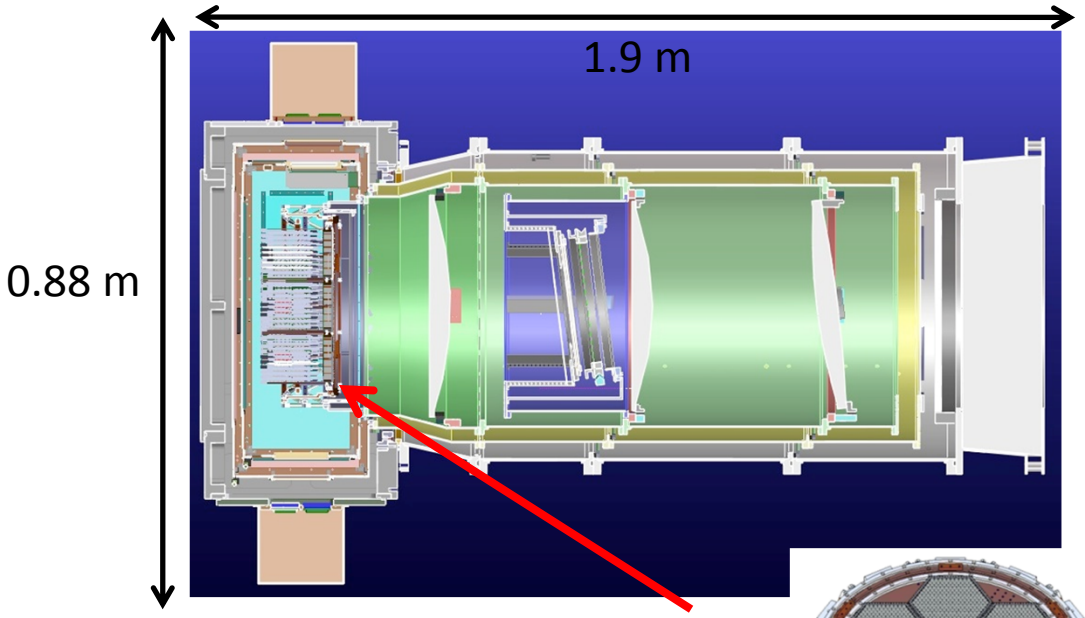


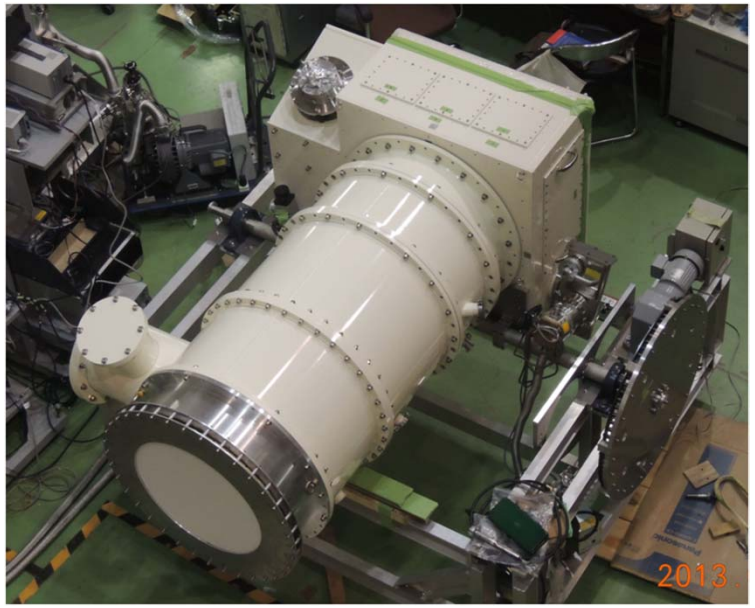


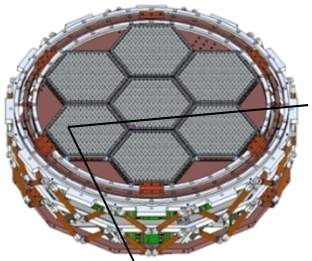


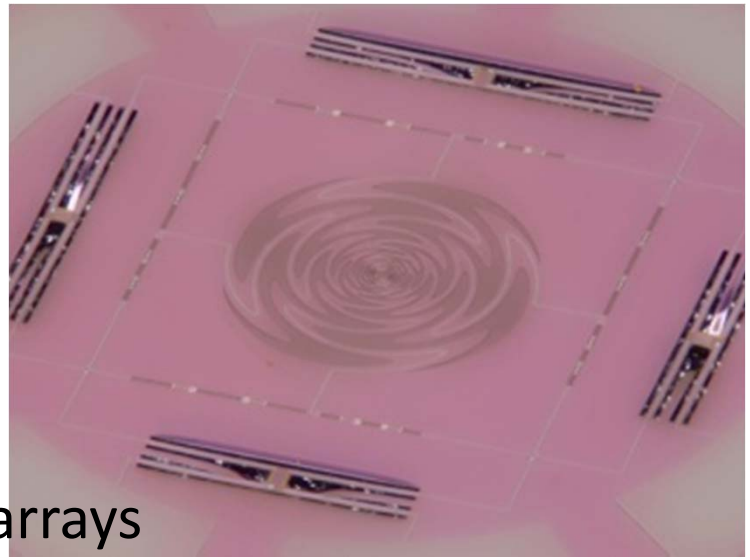


POLARBEAR-2 Receiver









365 mm diameter focal plane
7,588 bolometers
- 6x the POLARBEAR-1 bolometers

Lab tests underway of:
- Assembled cryogenic receiver
- Deployment-style 150 mm detector sub-arrays
- 40x frequency multiplexed readout

The Simons Array

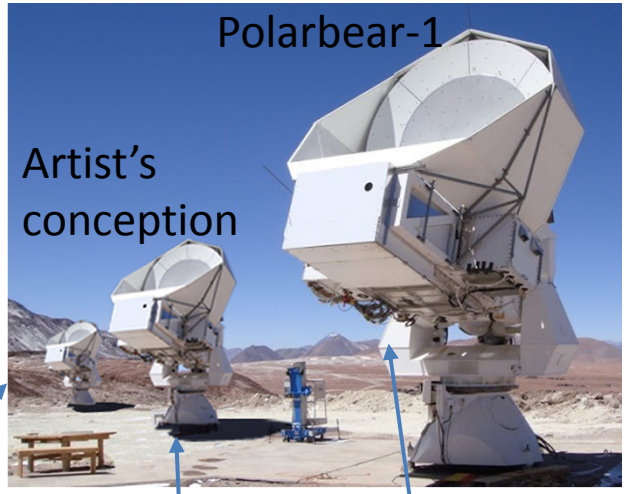
Leverage POLARBEAR experience to rapidly increase sensitivity

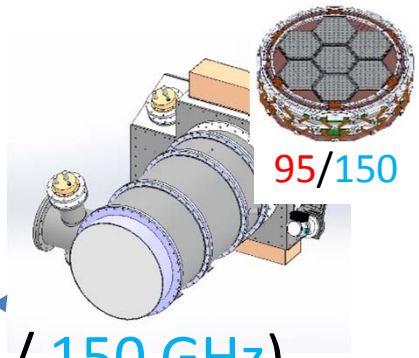
2014-2015: Construct two more telescopes

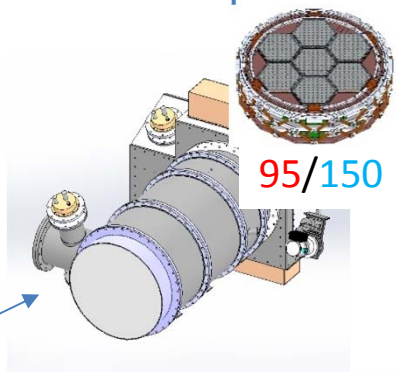
2015: POLARBEAR-2 (95 GHz / 150 GHz) first light on one new telescope

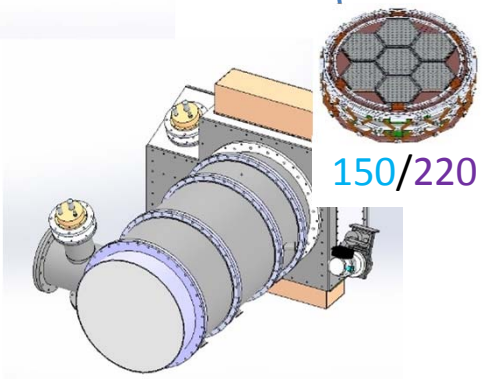
2016: A copy of POLARBEAR-2 deploys onto second new telescope

2016: A 150 GHz / 220 GHz receiver replaces POLARBEAR-1 on the original telescope





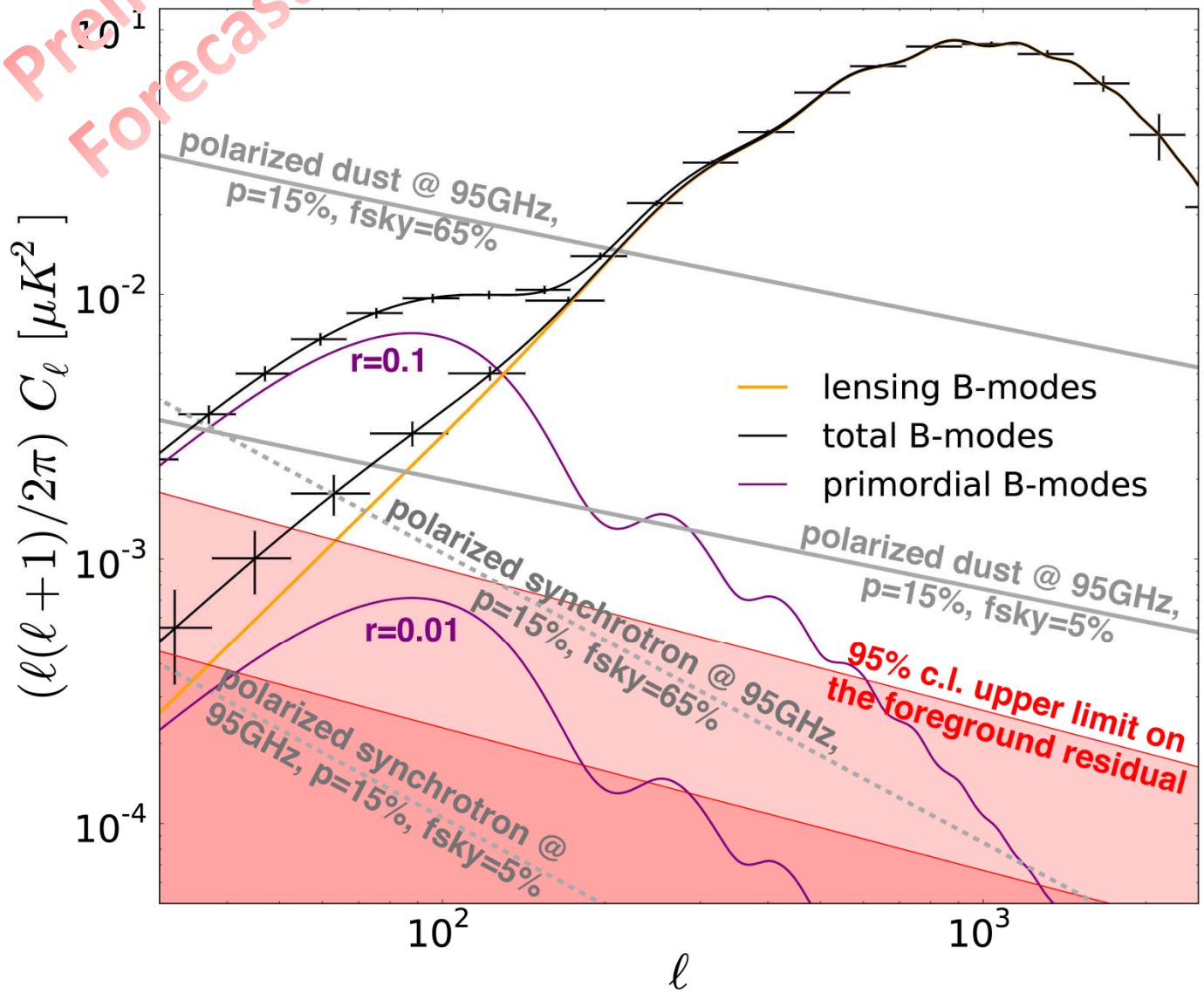




3 receivers (22,764 bolometers) observing at 95,150,220 GHz

All hardware funded by the Simons Foundation, MEXT, and NSF

Simons Array Sensitivity



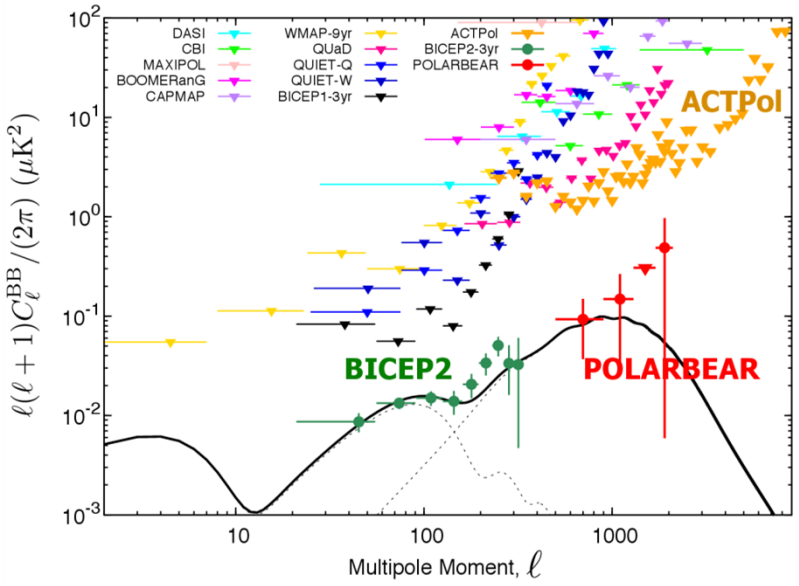
Foreground rejection with 95/150/220 GHz, Planck & C-BASS

- Here: 280 GHz channel

- $\sigma(r = 0.1) = 2 \cdot 10^{-3}$
- $\sigma(n_s) = 5 \cdot 10^{-3}$
- Neutrino Mass: $\sigma(\Sigma m_\nu) = 19$ meV (w / DESI BAO)

Residual computation method: Errard et al. 2011, Phys. Rev. D 84, 063005

In Summary…



- **POLARBEAR-1**: three analyses showing B-modes (CMB alone: 4.7σ):
  - CIB cross-correlation
  - Deflection power spectrum
  - C_ℓ^{BB}
- Future: multi-chroic arrays in the Simons Array
  - Increased sensitivity
  - Foreground mitigation