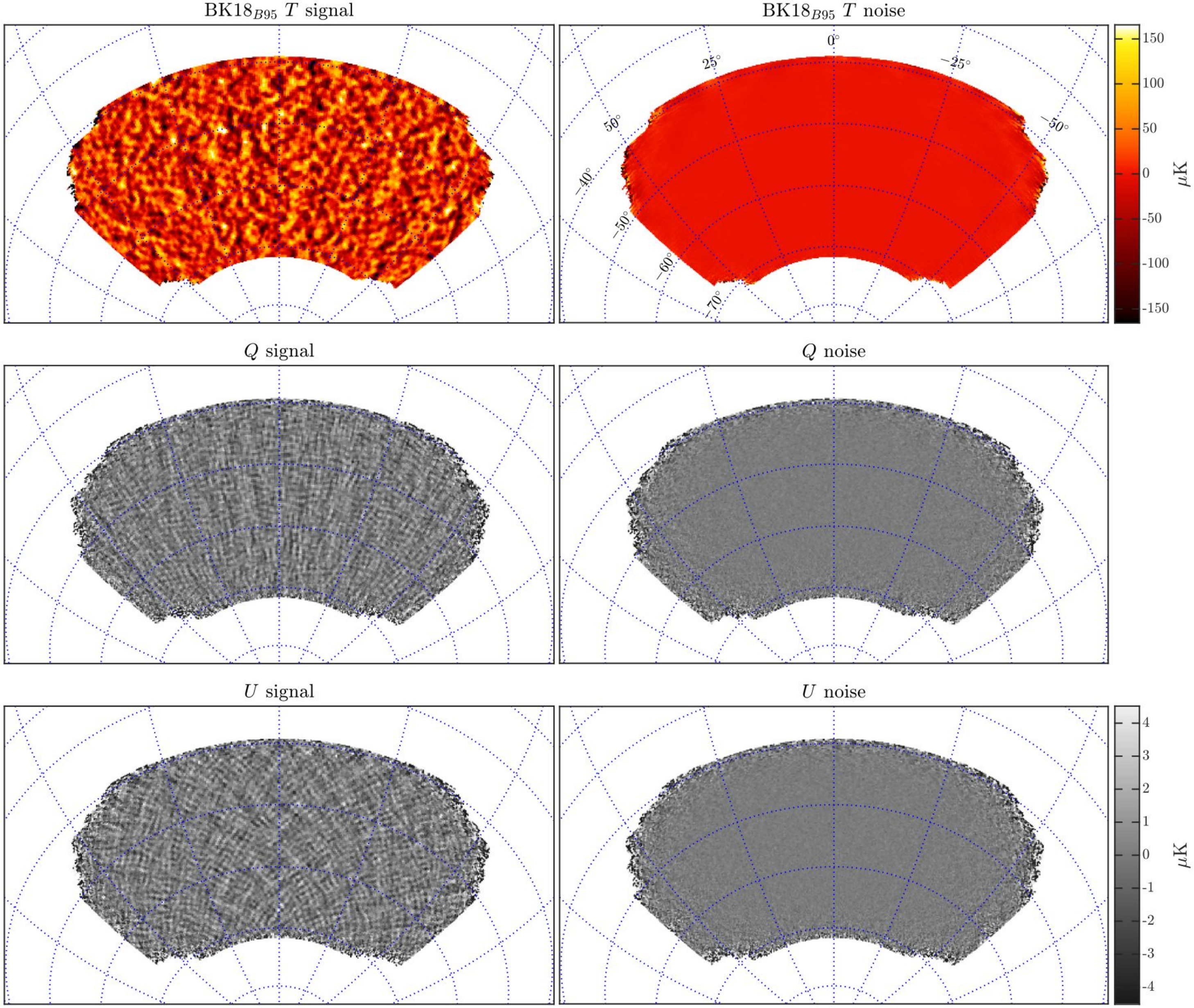
Measure Non Standard Tensors with BK-like SAT experiment?

CMB-S4 Collab Meeting Aug 2021

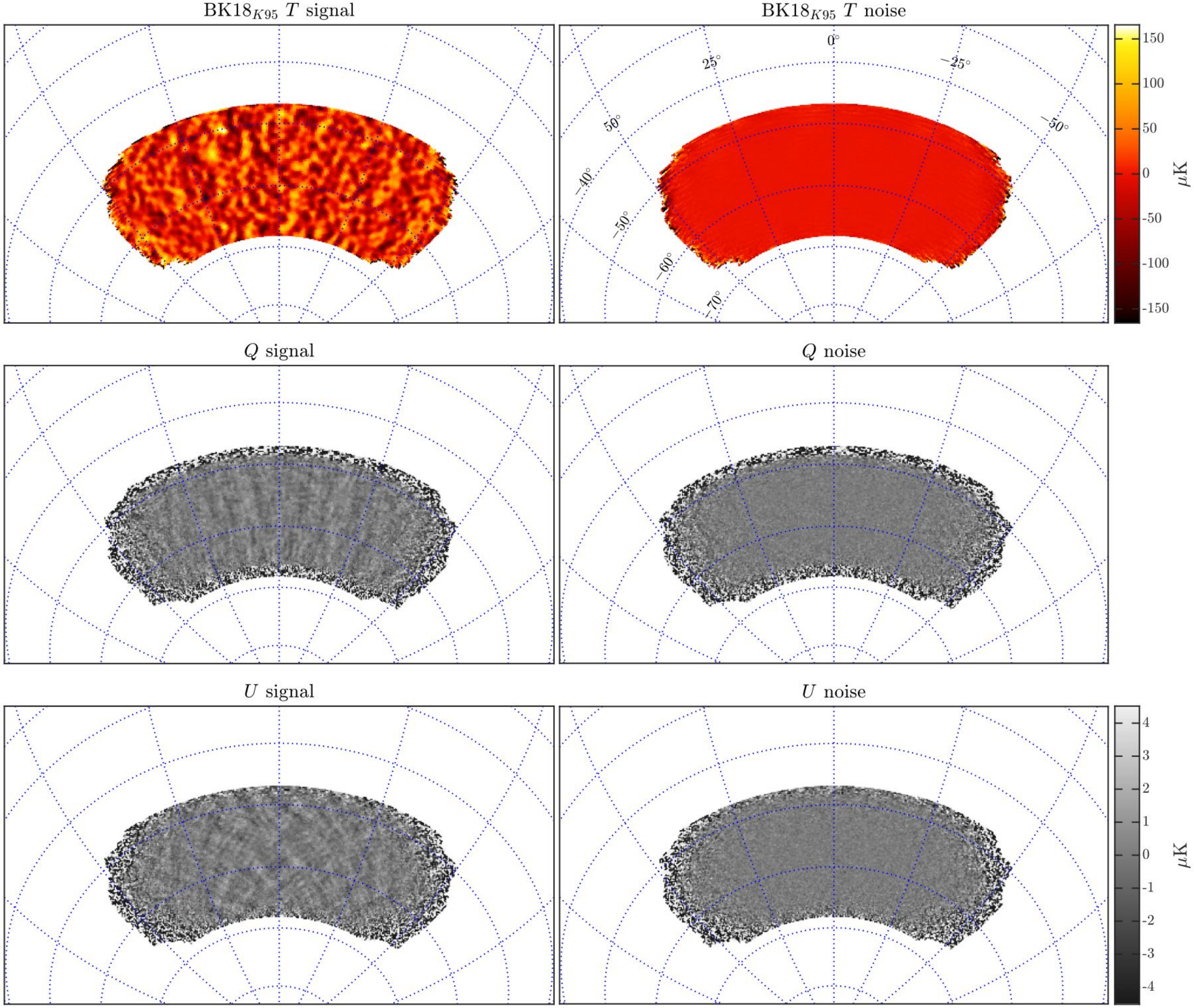
(Clem Pryke, John Kovac, Kirit Karkare, James Cornelison

BK18 95GHz Map (BICEP3)



The BICEP/Keck Collaboration

BK18 95GHz Map (*Keck*)



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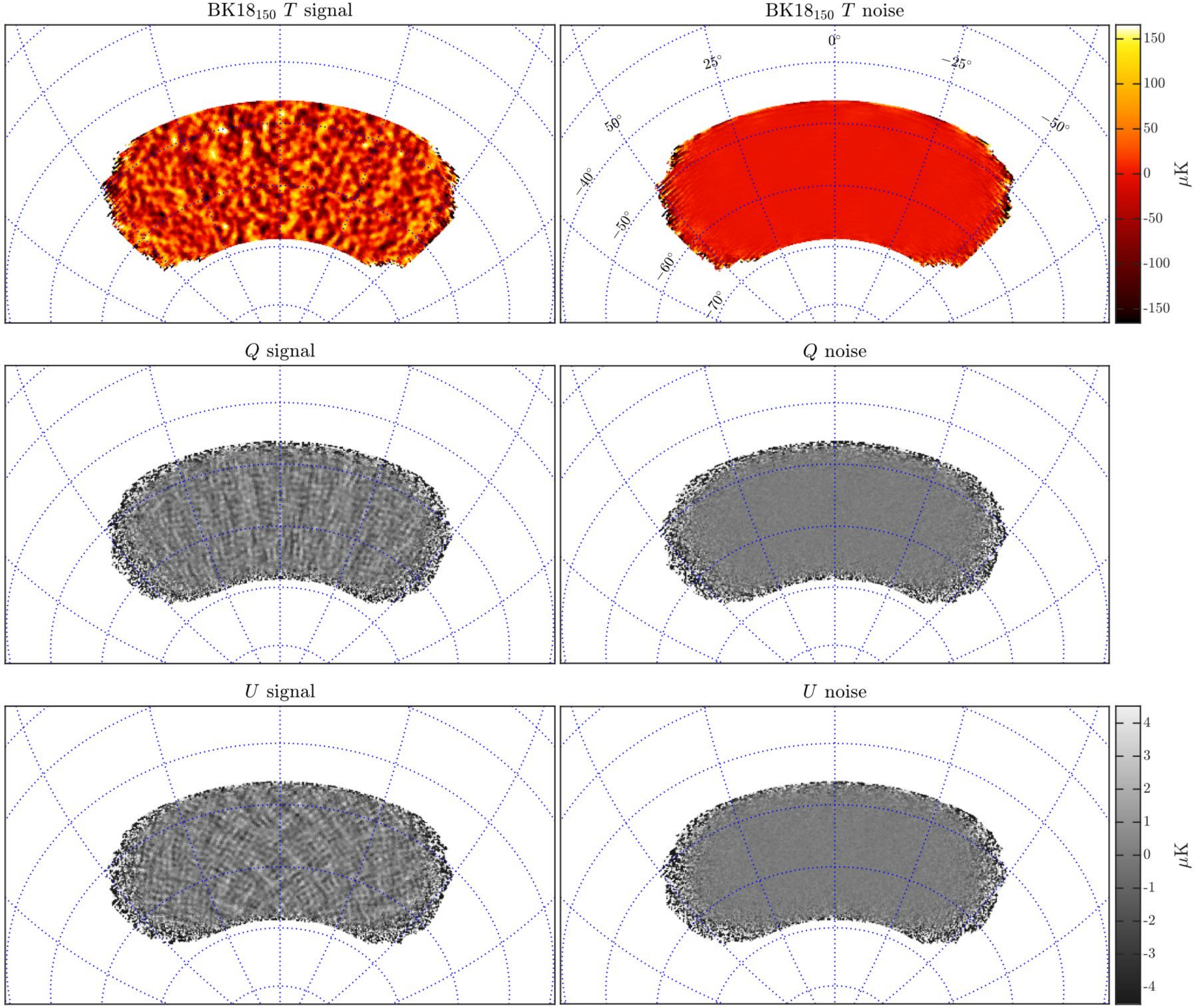
BK18 150GHz Map



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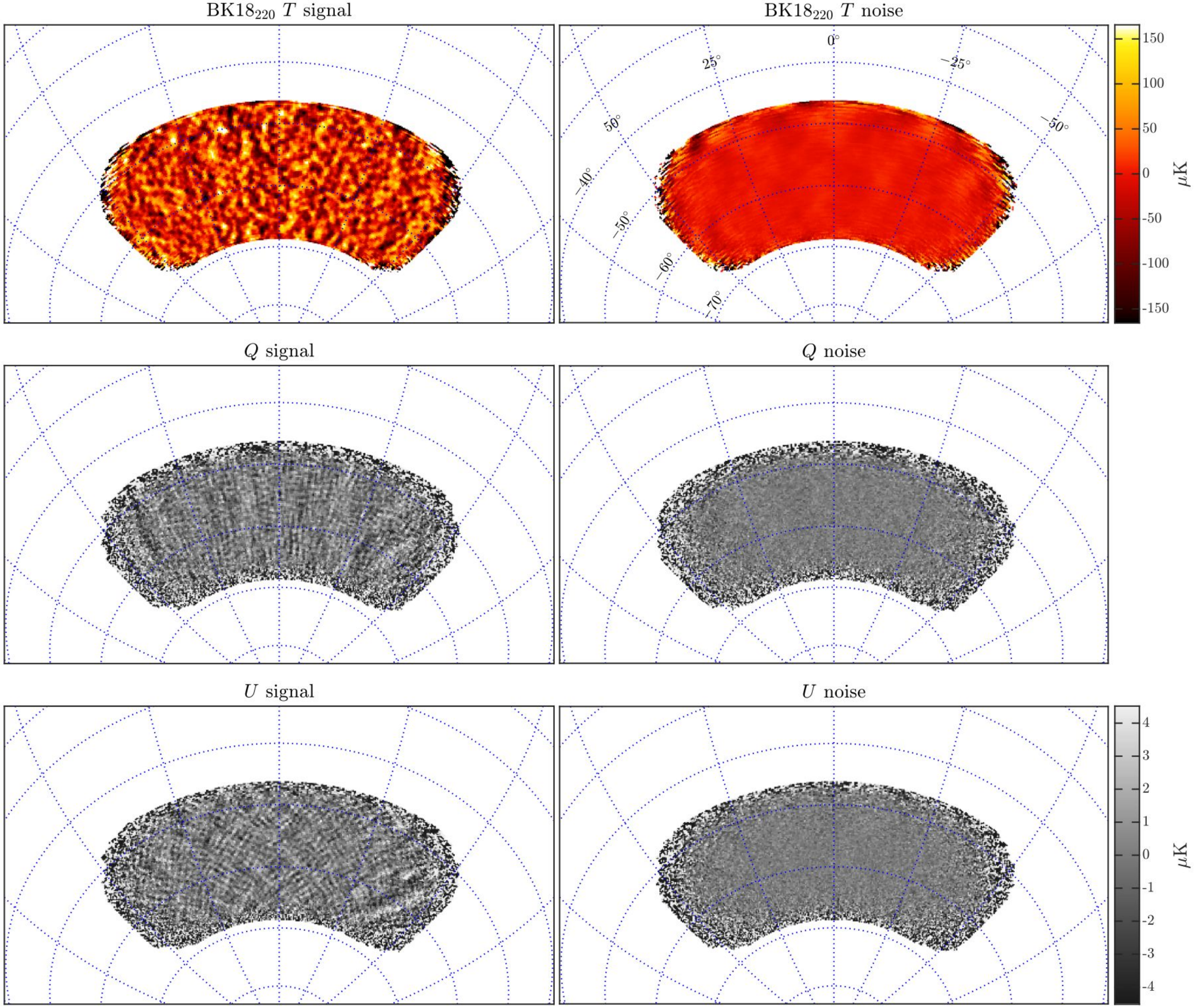
BK18 220GHz Map



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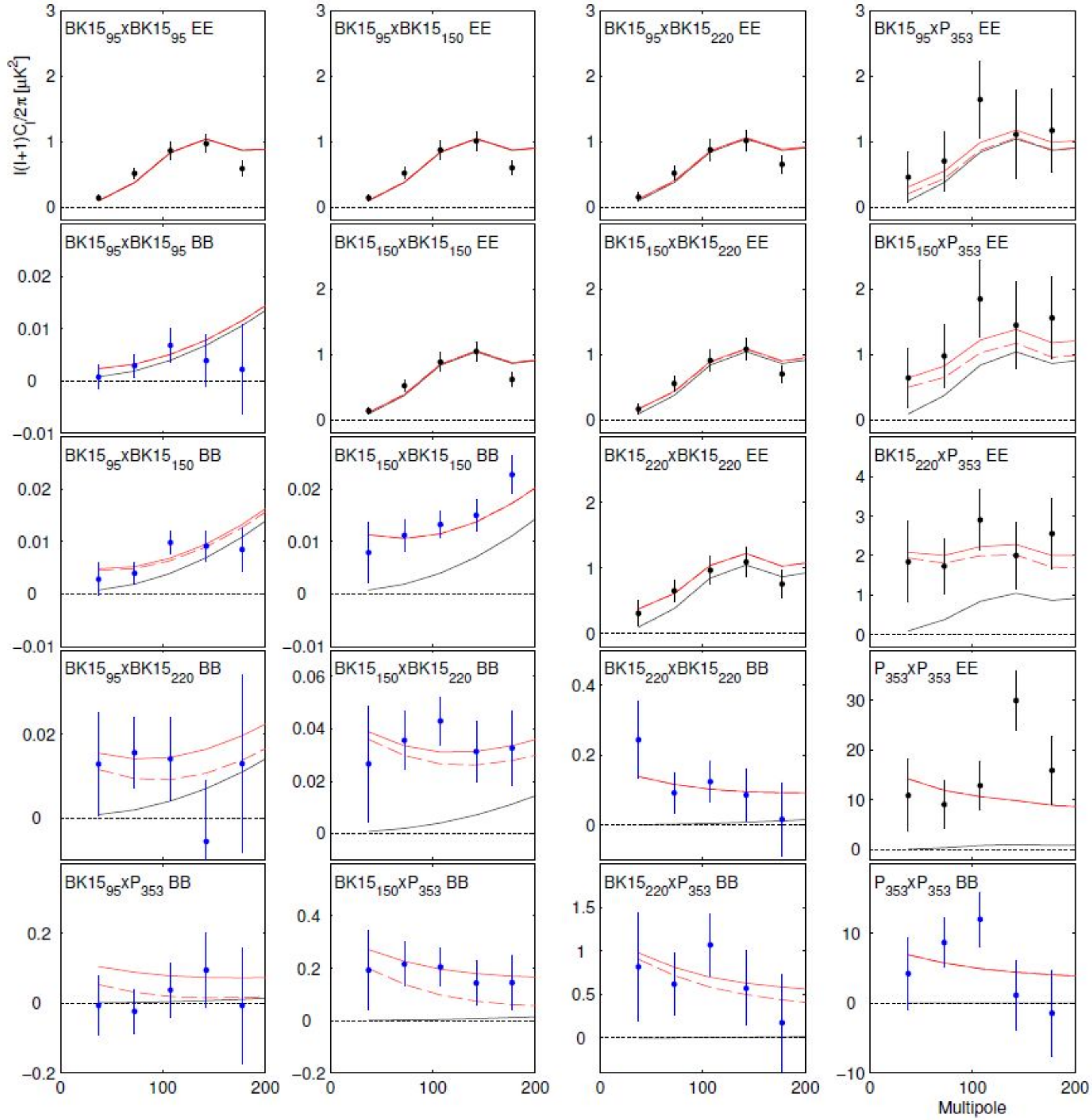
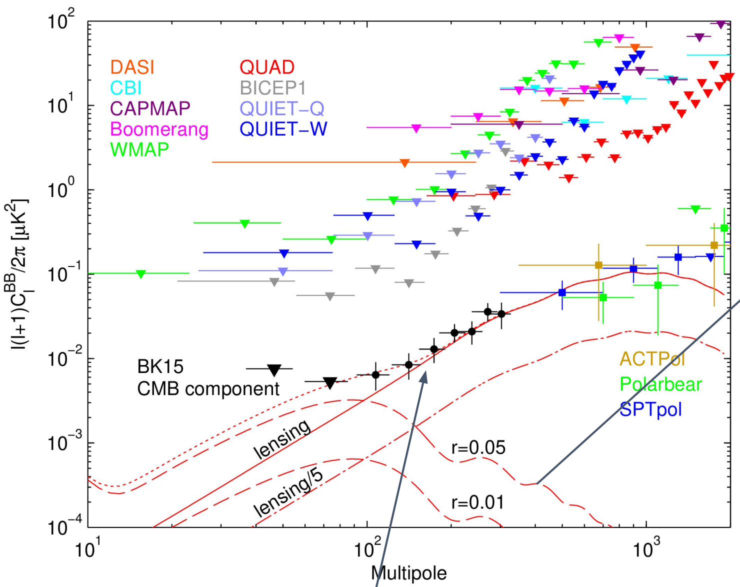
BK15 Spectra



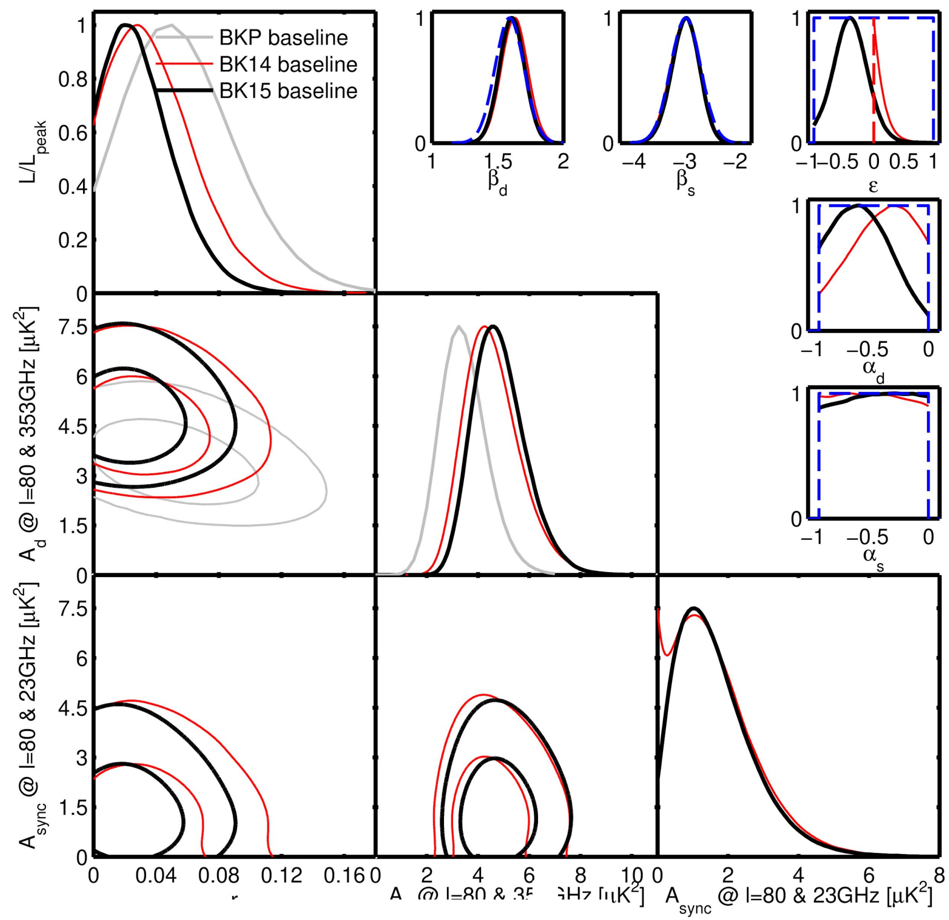
Spectra using all data up to and including 2015

Spectral analysis process makes no assumption about shape of EE/BB/TB spectra except EB "self calibration" of overall polarization angle

The BICEF



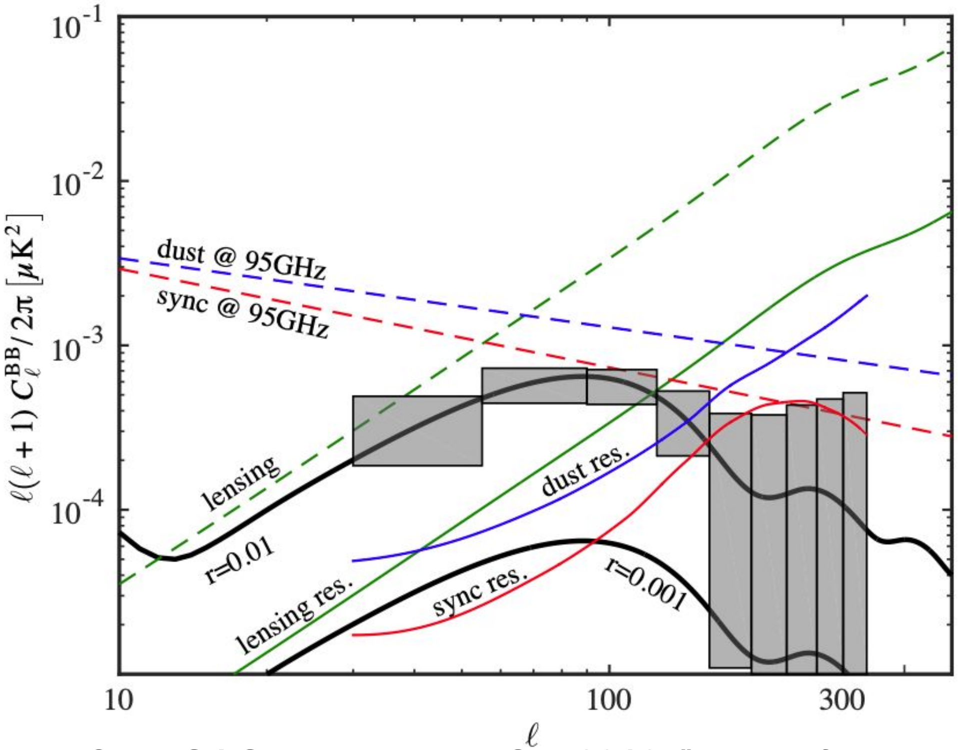
Going from spectra to *r* constraint we assume we know the *template shape* of the tensor spectrum (and this is also assumed in S4 forecasts so far)

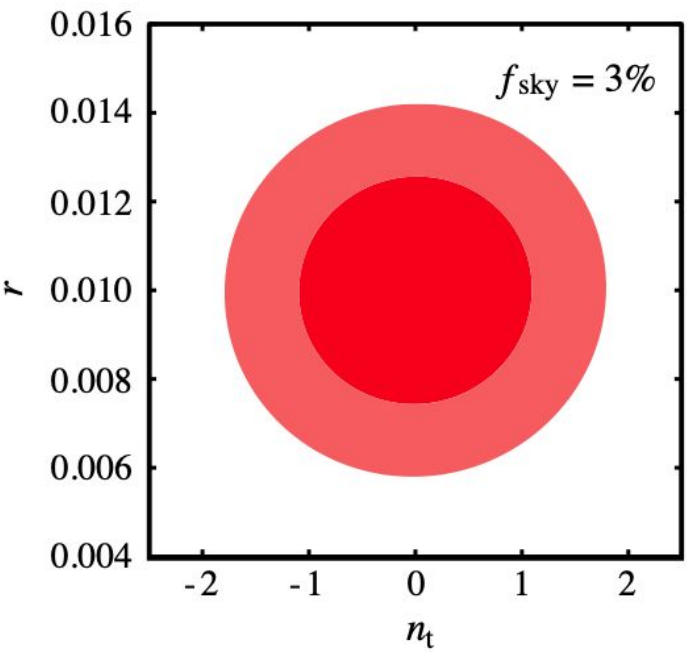


Alternate analysis makes per ell bin estimate of CMB spectrum (at the expense of more foreground model parameters so less powerful)

n_t measurements in S4

Given deep delensing, how well can we do on tensor BB spectrum slope and/or features in its shape?





CMB-S4 Science Book, Oct 2016: "A test of the canonical single-field consistency relation $n_t = -r/8$ is unfortunately out of reach. However, a significant bump in the spectrum, as would be produced if a non-vacuum source of gravitational waves dominates the signal [78] (see Section 2.6.3 for details) would be detectable."

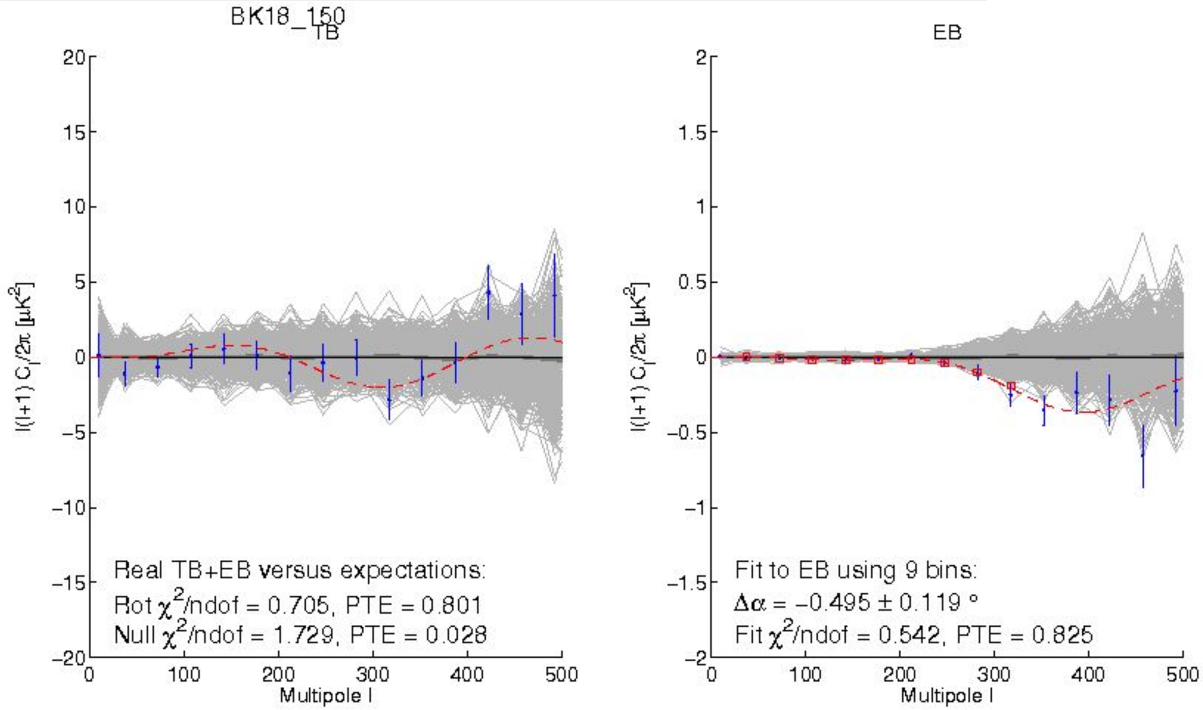
→ **Updates to forecasts and science case?**

Global Polarization Angle “Self Calibration”

$$C_\ell^{\prime TB} = C_\ell^{TE} \sin(2\alpha)$$

$$C_\ell^{\prime EB} = \frac{1}{2}\left(C_\ell^{EE} - C_\ell^{BB}\right) \sin(4\alpha)$$

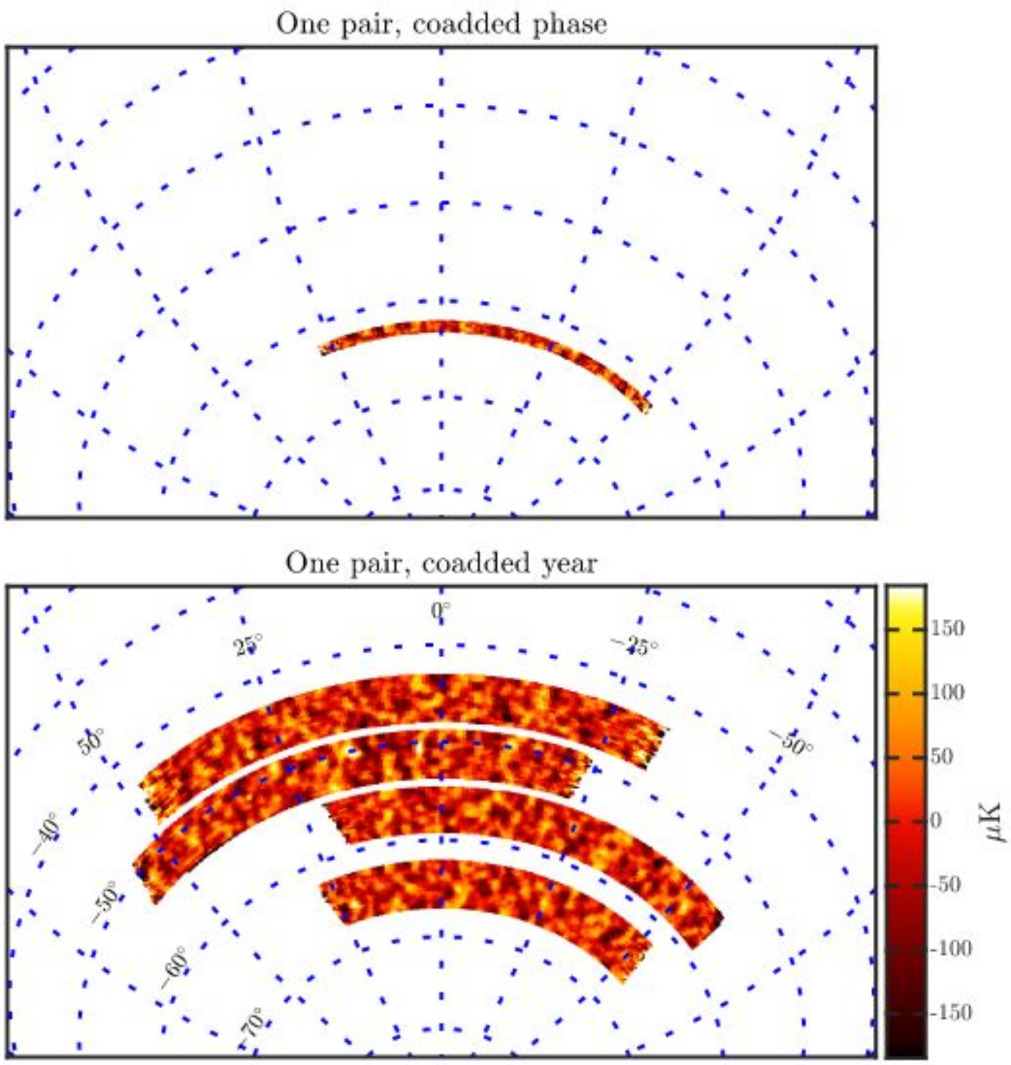
If observed maps are subject to overall pol. angle miscalibration α then LCDM TE and EE spectra leak into observed TB and EB spectra



Fit the observed spectra to the template with α as free parameter (using bandpower covariance matrix) - this is best fit to 150GHz EB lowest 9 ell bins compared to TB and EB over all ell bins - the expected spectral form appears to be present

Do one fit per frequency band and apply counter-rotation to the *Q/U* maps. This “self calibration” would allow to see unexpected TB/EB if sufficiently distinct in spectral form. (Also note effect on BB is second order.)

Sky coverage of individual detector pairs



Each detector pair covers only a small fraction of the overall sky coverage area, in some cases with zero overlap between the area covered at the different line-of-sight instrument rotation angles.

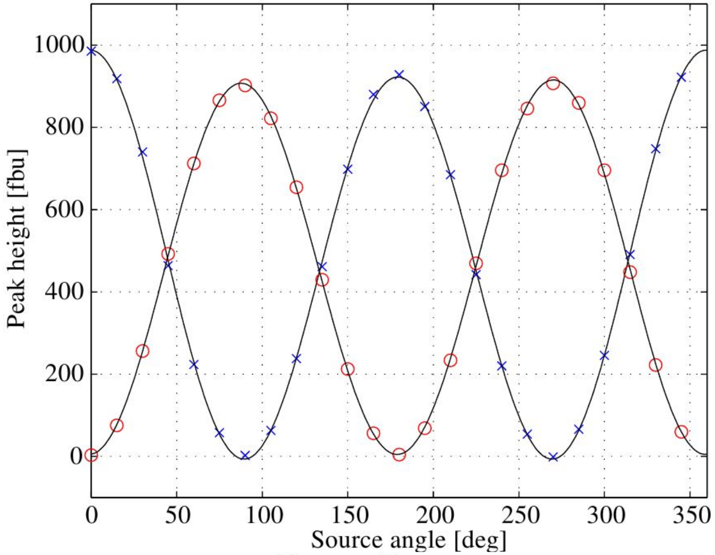
Single pol angle de-rotation is only a good model if focal plane has single overall rotation angle error versus assumed.

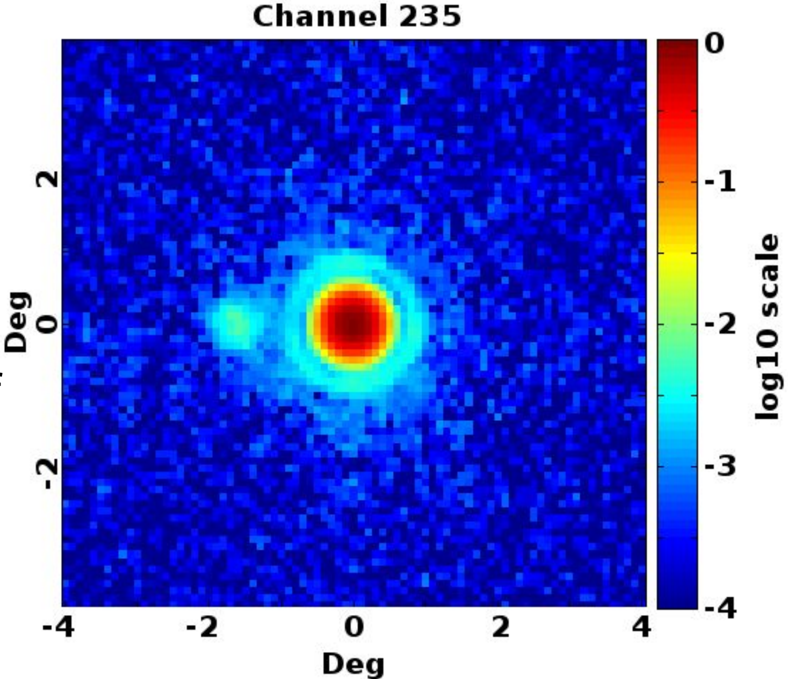
Direct Measurement of Polarization Angles

For instance...

Far field beam mapping

Detector Polarization Calibration

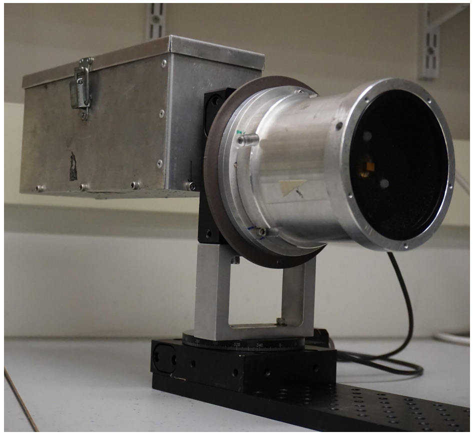




Hi-Fi beam maps of individual detectors

Detailed description in Instrument and beams papers arxiv/1403.4302 and 1502.00596

Direct Measurement of Polarization Angles



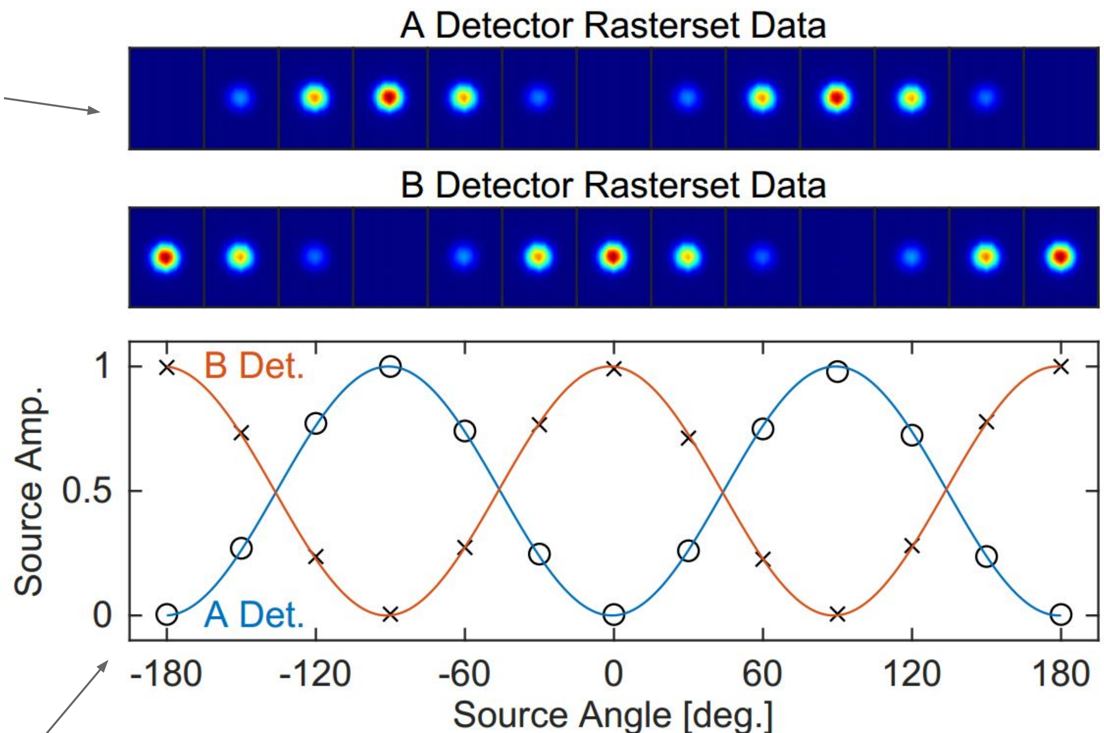
Broadband noise source with rotatable polarizing grid in front and tilt meter to reference polarization angle to gravity vector

Source on mast

Flat mirror reflects source signal into telescope

Direct Measurement of Polarization Angles

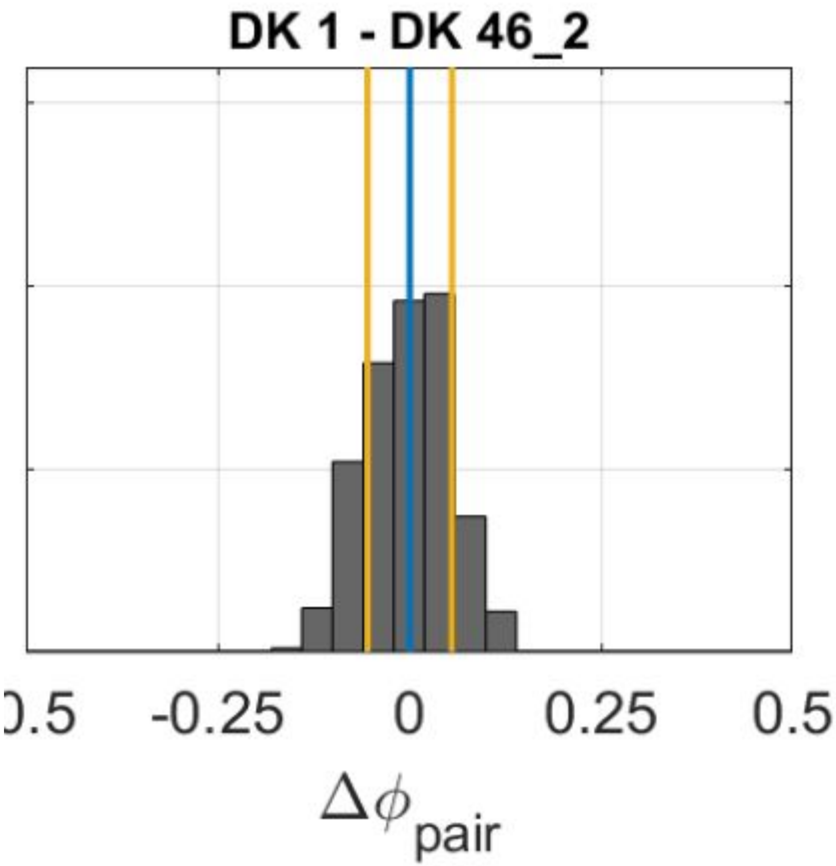
Raster telescope over source to map out response of each detector, rotate source angle, repeat



Integrate total response at each angle and plot. Fit to get detector pol angle and efficiency

Then rotate telescope about line-of-sight axis and repeat - check repeatability

BICEP3 Pol Angle Repeatability



From SPIE paper arxiv/2012.05934 (James Cornelison)

Repeatability of detector pair polarization angle measured at two boresight angles
(765 pairs in histogram)

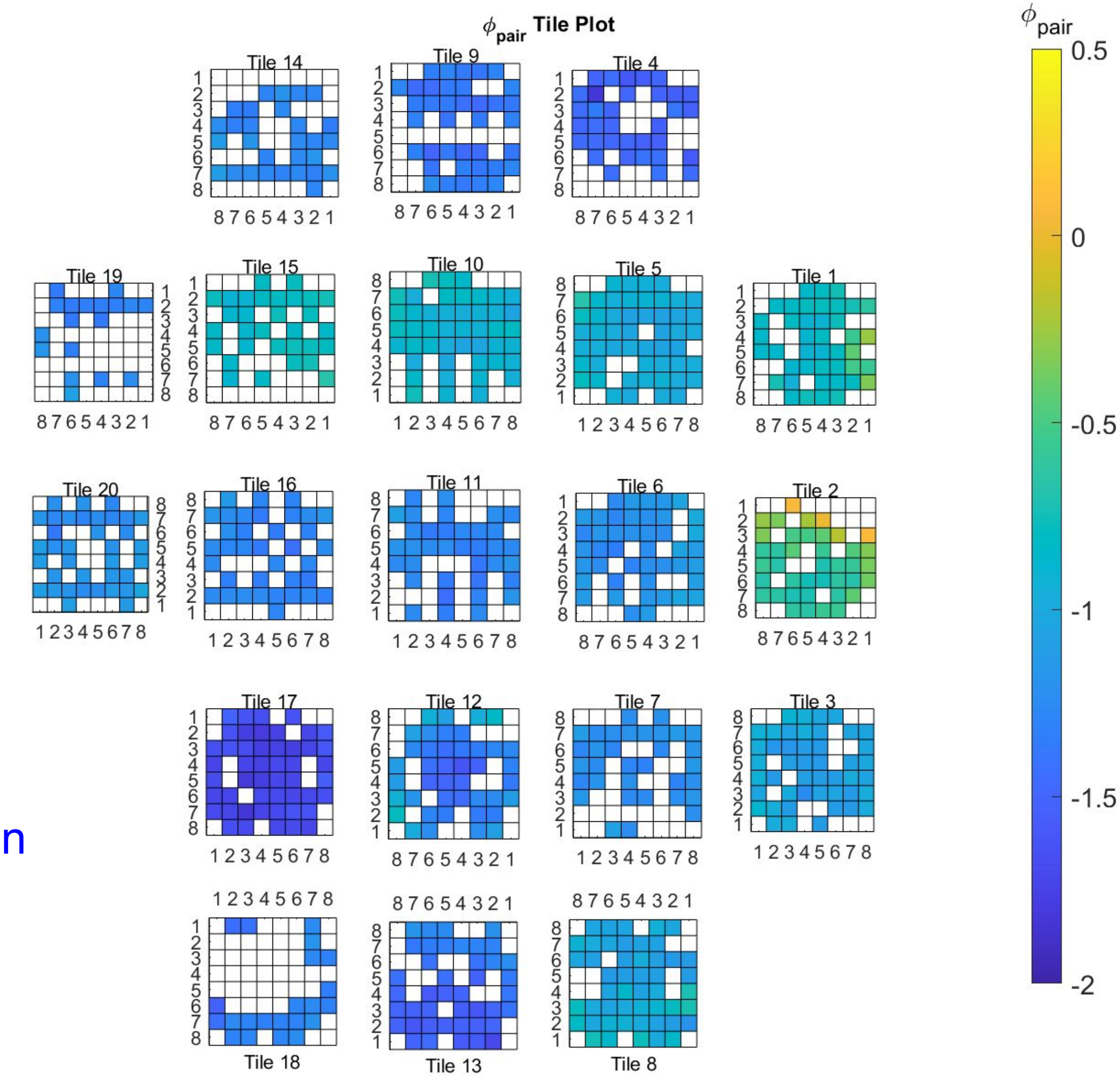
1 sigma = 0.075 deg

BICEP3 Pol Angles Across Focal Plane

From SPIE paper
arxiv/2012.05934

Detector pair pol angle across focal plane

We can measure both tile-to-tile variations O(0.3deg) and pair-to-pair variations within each tile O(0.1deg)



Overall angle versus nominal is approx -1deg in this case - but a lot more work required on geometric modelling (EB fit gave -0.4deg)

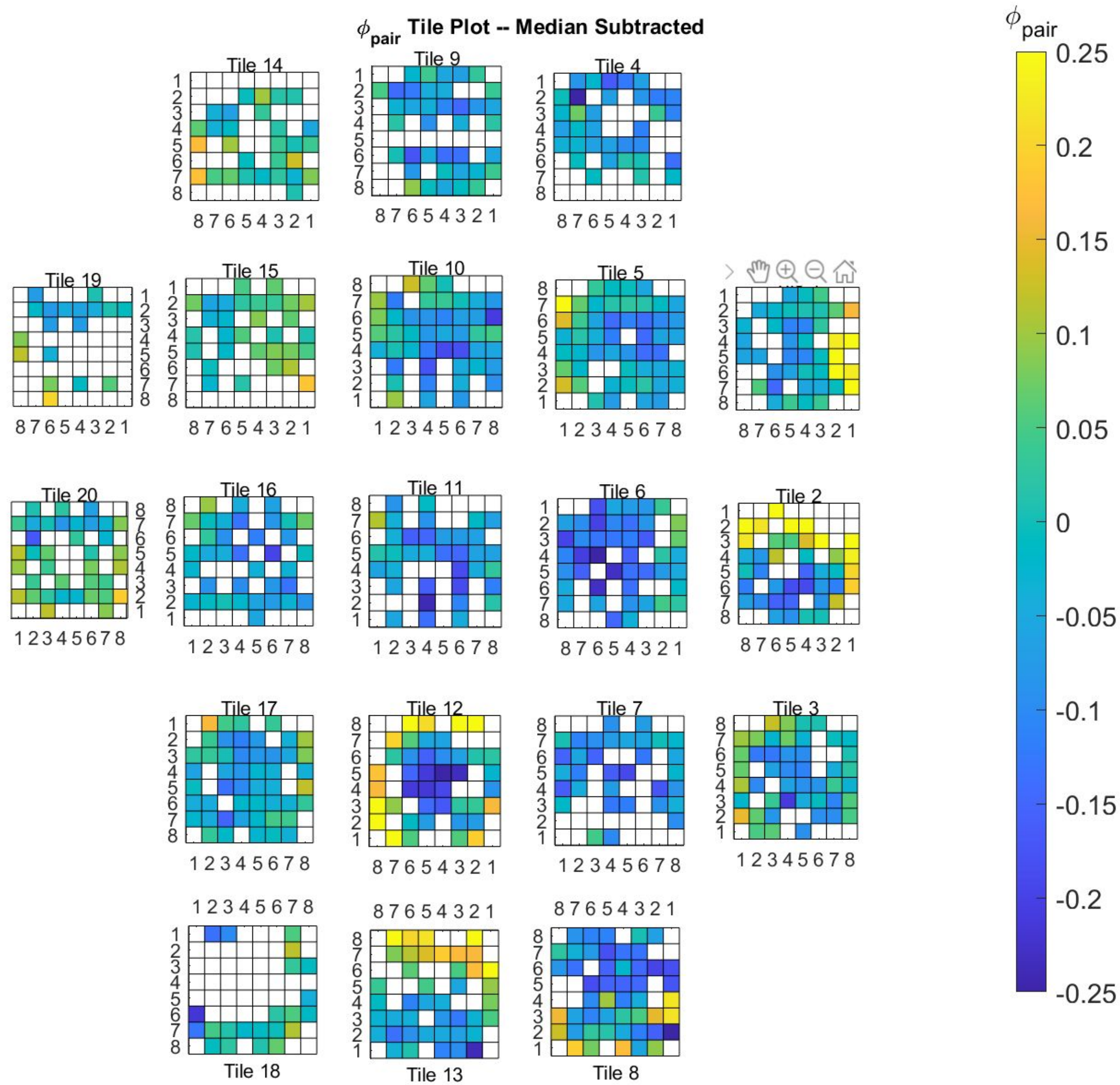
BICEP3 Pol Angles within tiles

From SPIE paper
arxiv/2012.05934

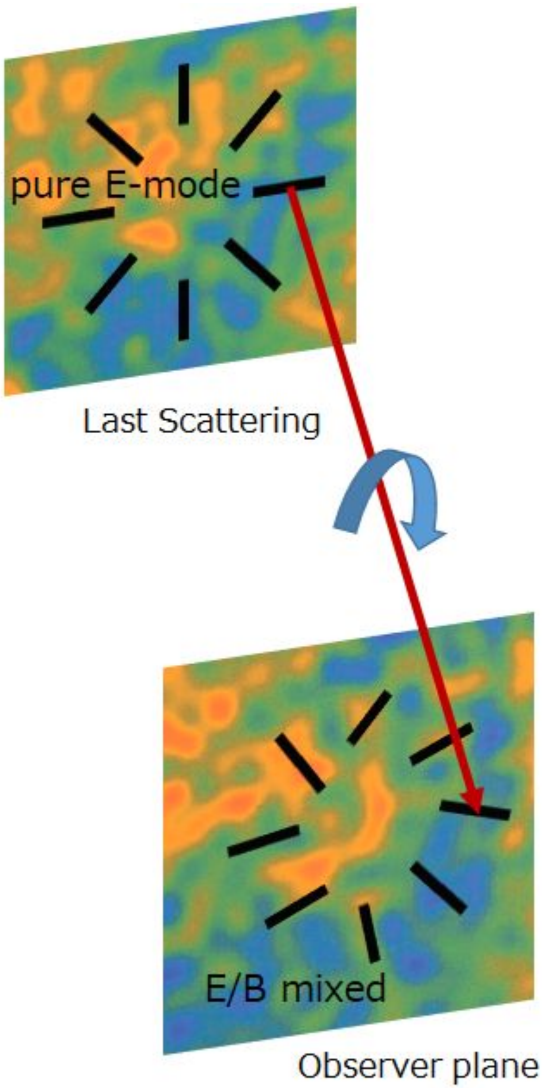
Detector pair pol angle across focal plane

Tile median subtracted

Within each tile the pair-to-pair variations are consistently smaller O(0.1deg), but subject to their own systematics



Spatially varying polarization rotation



- **Axion-like particles**

String theory generally predicts presence of axion-like particles coupled with electromagnetic fields (e.g. Pospelov+'09, Caldwell+'11)

$$\text{Lagrangian} \supset \frac{\phi}{2f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}$$

Coupling constant

This coupling leads to spatial variation of polarization angle rotation

rotation angle → $\alpha(n) = \frac{\Delta\phi(n)}{f_a}$ ← Changes in phi during photon propagation

- **Primordial magnetic fields**

Lead to the polarization rotation by the Faraday rotation (e.g. Kosowsky&Loeb'96, Harari+'97)

Total rotation angle

$$\alpha(n) = \frac{3c^2}{16\pi e^2}\nu^{-2}\int \dot{\tau}\, \vec{B}\cdot d\vec{l}$$

Magnetic field

Measurement of the anisotropic polarization rotation is a unique probe of the early universe and provides important implications for high energy physics!

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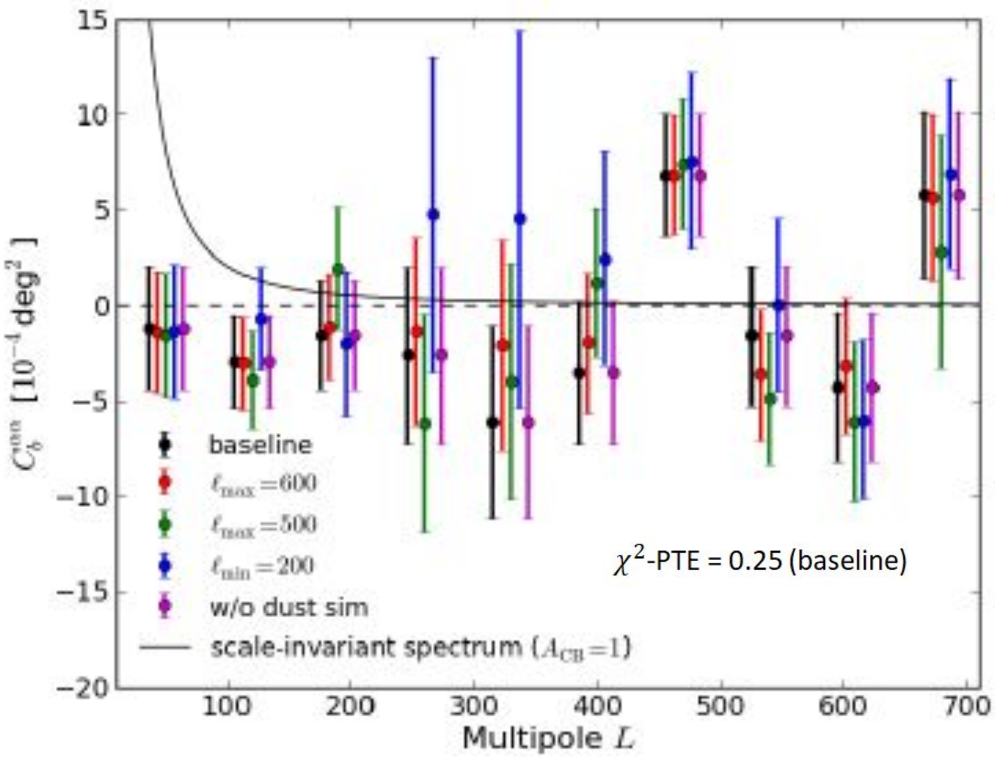
Measurement of the polarization rotation spectrum

- **Analysis Method**

Anisotropic pol. rotation leads to mode-coupling between E and B modes as similar to lensing. Thus we can apply the same analysis method as in the lensing case but using different weight function to optimally reconstruct rotation angle

- **Measured spectrum**



From arxiv 1705.02523

- The spectrum is consistent with null (even if we change the analysis choices)
- The reconstructed spectra measured from our 14 jackknife maps are also consistent with null
- Instrumental relative pol. rotation < 1% of the 1 sigma statistical error

Conclusions

- Standard *r* constraint analysis assumes we know the template shape of tensor spectrum
  - and so do S4 forecasts so far
- Alternate analysis can extract the BB spectrum without this assumption
  - at the cost of adding more foreground parameters
- BK analysis so far includes “self calibration of instrumental polarization angle
  - this limits, but does not destroy, the ability to see arbitrary EB signal if one were to exist.
- Not clear a single overall angle is really appropriate although it seems to work so far.
- Presumably will be possible to do better with more calibration efforts