Measuring B-mode bispectrum with BICEP/Keck Array

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Measuring B-mode bispectrum

- B-mode power spectrum on large scale is sensitive to the inflationary GW and has been explored by multiple CMB experiments (e.g. BICEP/Keck Array), but B-mode bispectrum (and other higher order B-mode correlations) has not been well measured yet.

- B-mode bispectrum: sensitive to tensor non-Gaussianity; we can gain more information on the inflationary mechanism (e.g. a short review by Shiraishi 2019).

    An inflationary model including SU(2) gauge fields could produce a large BBB, and there is a parameter region where BBB has larger S/N than BB (Agrawal et al. 2018).

    primordial magnetic fields, U(1) gauge field coupled with a pseudo-scalar field, etc

Detection of the bispectrum rules out the standard inflationary model analogues to the fNL search for the density perturbations

Search for tensor non-Gaussianity

- In other CMB experiments, e.g. Planck, B-mode is noisy and it is hard to constrain tensor non-Gaussainity from B-mode bispectrum.

- Although the best way to constrain tensor non-Gaussianity is to use B-mode bispectrum, the tensor non-Gaussianity can also produce T and E bispectrum and is constrained by Planck T/E

  Planck constraints

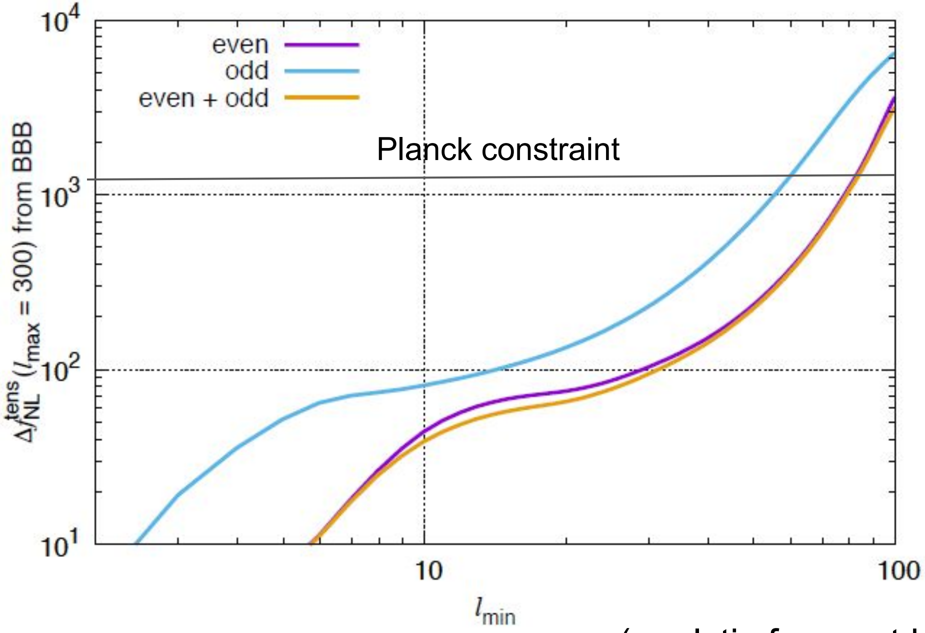
  $$\sigma(f_{NL}^{\rm tens}) = 1100$$ (Planck Collaboration 2018)

  $$f_{\rm NL}^{\rm tens} \equiv \lim_{k_i \to k} \frac{B_{\rm h}^{+++}(\boldsymbol{k}_1, \boldsymbol{k}_2, \boldsymbol{k}_3)}{F_{\zeta}^{\rm equil}(k_1, k_2, k_3)}$$

- BICEP B-mode is much better than Planck

  BICEP can provide better constraint on the tensor non-Gaussianity than that obtained from Planck

Search for tensor non-Gaussianity



(analytic forecast by M. Shiraishi)

However, there are several issues which reduce the sensitivity to fNL from ground based experiments

SNR of fNL from BICEP: Large-scale filtering

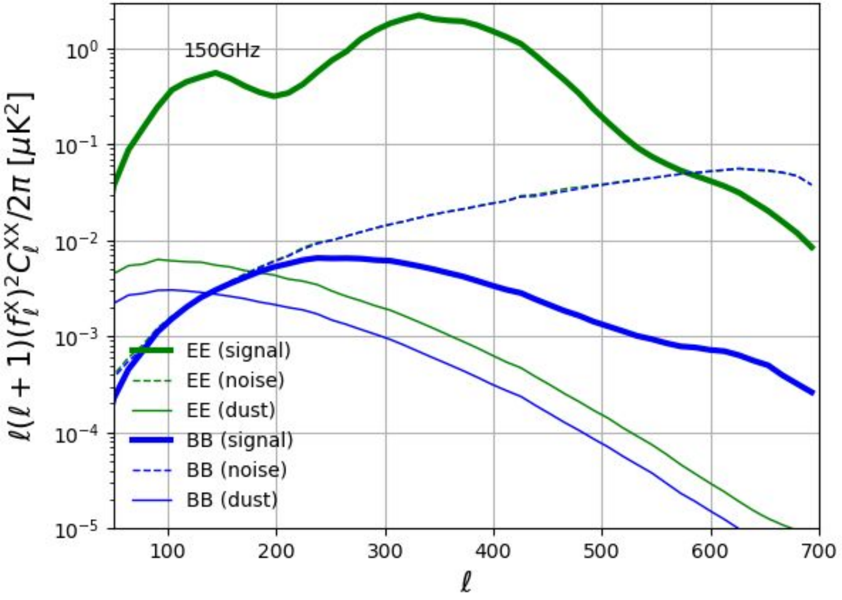
- Minimum multiple (largest scale) we can access to

  BICEP observes 1% of the CMB sky, and large scale mode is also partially removed by filtering process (L<~30)

- Scatter from the Galactic dust on large scales

  Large scale (L<150) of BK15 150GHz (the lowest noise channel, data taken up to 2015) is dominated by dust foreground without foreground cleaning

B-mode power spectrum of BK15 150GHz (sim)



SNR of fNL from BICEP: Large-scale filtering

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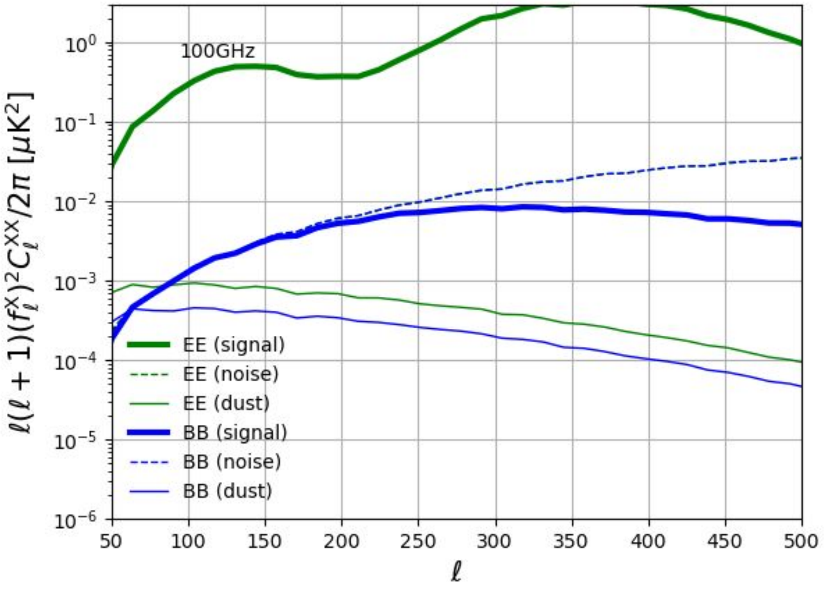
- Scatter from the Galactic dust on large scales

  Large scale (L<150) of BK15 150GHz (the lowest noise channel, data taken up to 2015) is dominated by dust foreground without foreground cleaning

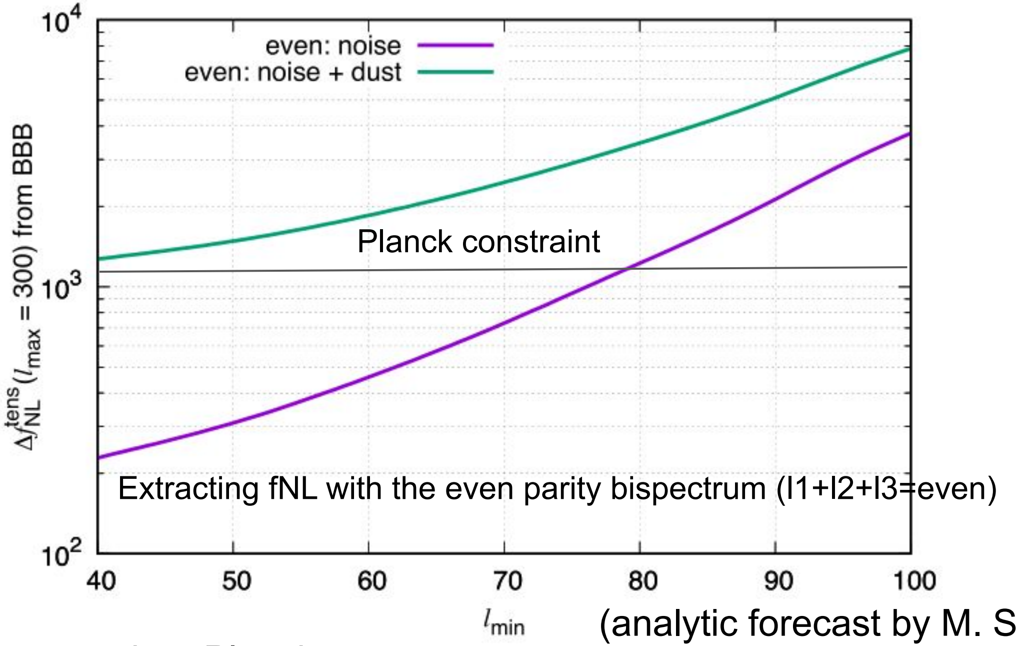
  However, this is improved for BK18 100GHz (the lowest noise channel, data taken up to 2018) where dust foreground is no longer a significant source even without foreground cleaning

B-mode power spectrum of BK18 100GHz (sim)



SNR of fNL from BICEP: Large-scale filtering

- An analytic forecast when including noise and dust for BK15



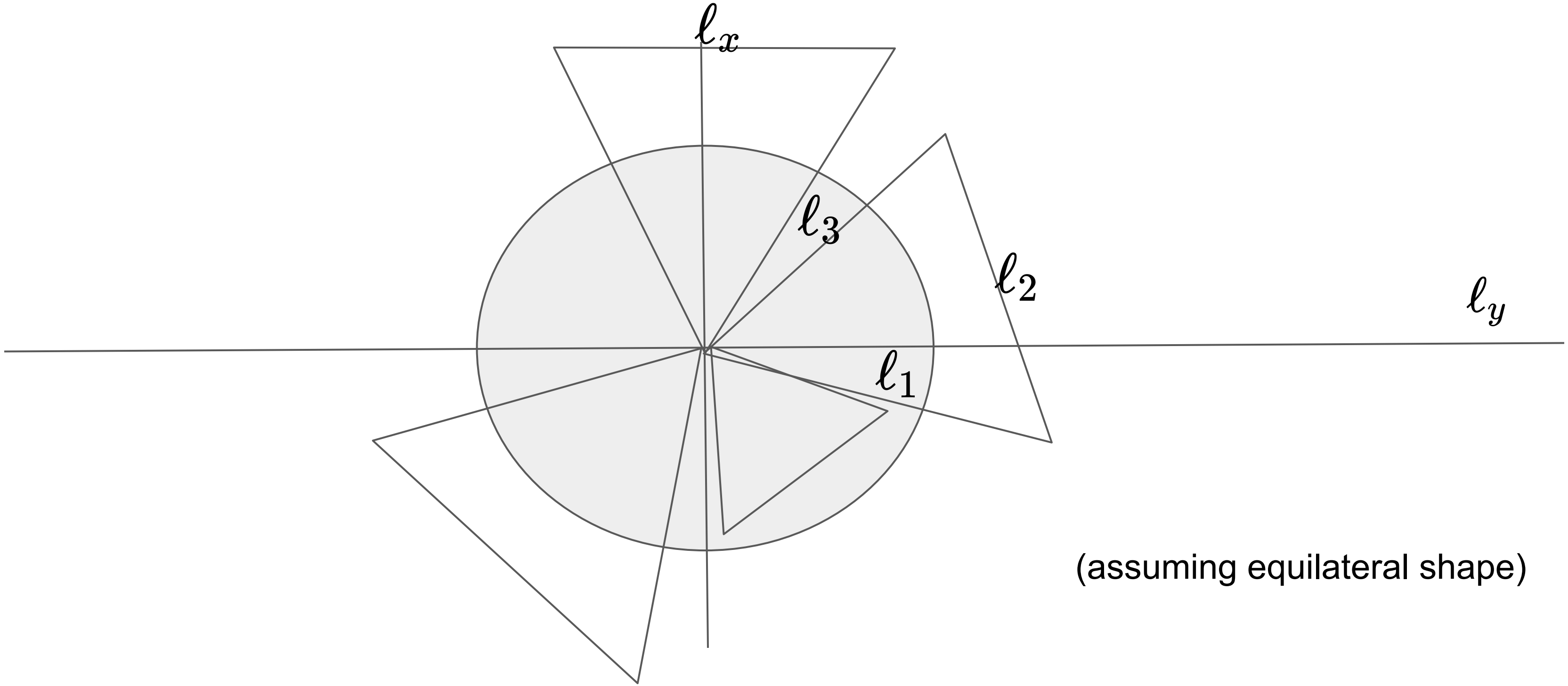
(analytic forecast by M. Shiraishi)

BK15: constraint is worse than Planck

BK18: constraint would be much better than Planck

SNR of fNL from BICEP: Additional mode loss

- Restriction of triangle configuration by timestream filtering

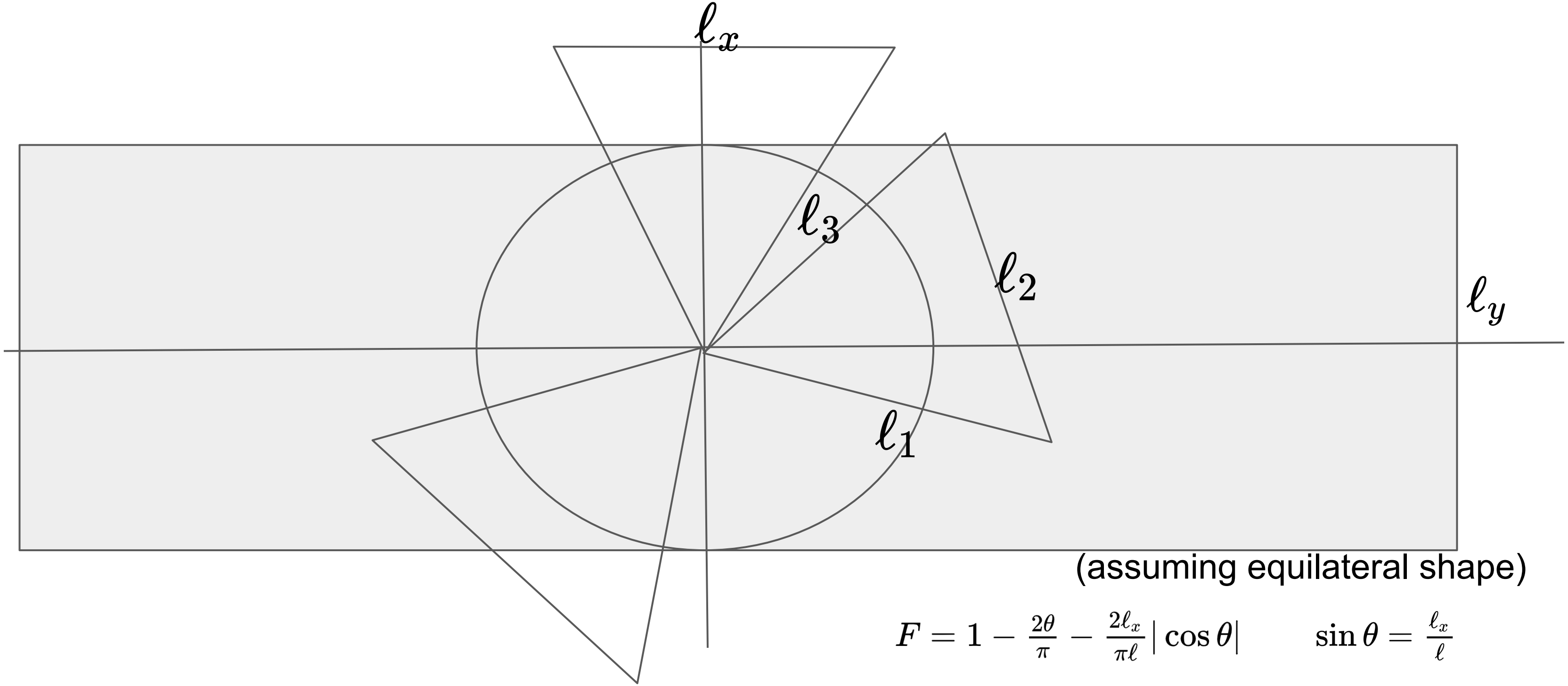


(assuming equilateral shape)

SNR of fNL from BICEP: Additional mode loss

- Restriction of triangle configuration by timestream filtering

Timestream filtering process further removes Fourier modes of |lx|<~30



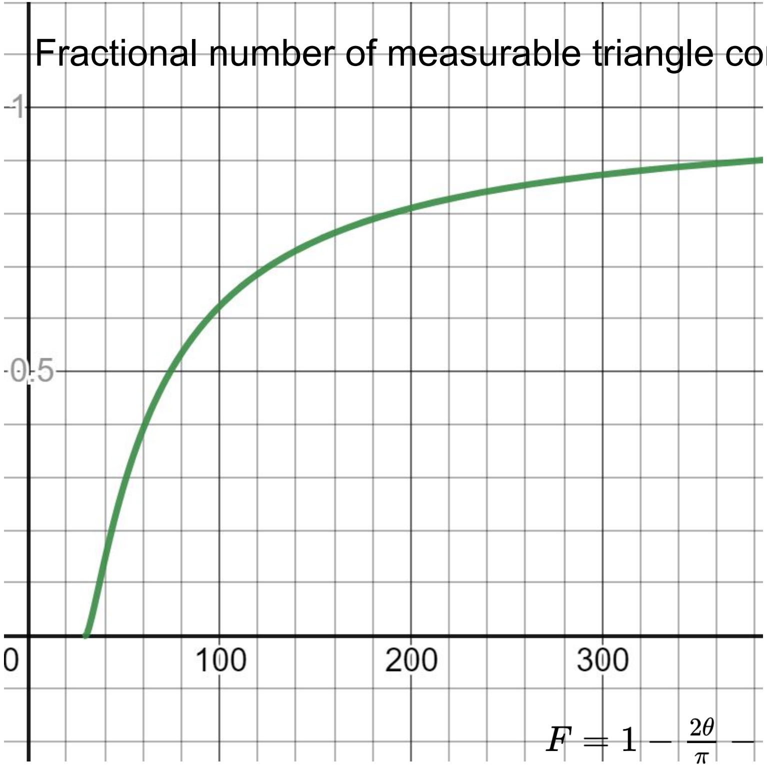
(assuming equilateral shape)

$$F = 1 - \frac{2\theta}{\pi} - \frac{2\ell_x}{\pi\ell}|\cos\theta| \qquad \sin\theta = \frac{\ell_x}{\ell}$$

SNR of fNL from BICEP: Additional mode loss

- Restriction of triangle configuration by timestream filtering

Fractional number of measurable triangle configurations at each multipole



$$\ell_x = 30$$

$$F = 1 - \frac{2\theta}{\pi} - \frac{2\ell_x}{\pi\ell}|\cos\theta| \qquad \sin\theta = \frac{\ell_x}{\ell}$$

SNR of fNL from BICEP with realistic sim

- SNR estimate with a realistic simulation

  - 3D binned estimator is applied to BK18 B-modes
  (flat-sky counterpart of Bucher et al. 2016, Coulton & Spergel 2019)

$$b_{ijk} = \frac{1}{N_{ijk}} \int d^2 n B^{\rm f}_i(n) B^{\rm f}_j(n) B^{\rm f}_k(n) \qquad B^{\rm f}_i(n) = \int d^2 \ell e^{i\ell n} f_{i.\ell} B_\ell$$

$$f^{\rm tens}_{NL} = \sum_{I=ijk} b_I^{f_{\rm NL}=1} {\rm Cov}_I^{-1} b_I$$

$$\Rightarrow \quad \sigma(f^{\rm tens}_{NL}) \sim 600$$

  - realization-dependent (linear) term does not help to increase SNR

Other potential concerns

- Lensing non-Gaussian covariance:
  - Small at $L<100$ and is negligible for equilateral fNL (Namikawa & Nagata 2015)
  - Could be an issue when constraining squeezed fNL. Delensing would help (Coulton et al. 2020).

- Bias from foreground non-Gaussianity
  - Currently investigating but we rely on non-Gaussian simulations
  - Multifrequency measurement of B-mode bispectrum will help analogous to BB?

Summary & Prospects for S4

- Summary of BICEP B-mode bispectrum analysis
  - BICEP would provide the best and first B-mode bispectrum measurement
  - Several restrictions which reduce SNR
  - Impact of galactic foreground is under investigation, although we observe the lowest foreground region
- Implications for CMB-S4 B-mode bispectrum analysis
  - Much better constraint than BICEP, fNL~O(1), with a larger sky coverage, improving lmin + B-mode scatter by foreground removal + delensing
  - Need to characterize foreground non-Gaussianity