Primordial non-Gaussianity from the CIB-CMB lensing cross correlation

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Cosmology with the CIB

- The Cosmic Infrared Background is the **brightest extragalactic anisotropy source** at frequencies **>~300 GHz**
- It is sourced by the **thermal emission from grains of dust in distant galaxies**
- Dust levels are highly correlated with **star formation rate** so the CIB emissivity peaks at redshifts $z \sim 2$ when the Universe's SFR was higher
- The CIB **traces the galaxies sourcing the emission**

Cosmology with the CIB

- The CIB intensity at frequency ν is

$$I_\nu(\hat{\boldsymbol{n}}) = \int_0^{\chi_{\rm re}} d\chi a(\chi) j_\nu(z, \hat{n}) \qquad \bar{j}_\nu(z) = \frac{\rho_{SFR}(z)(1+z)S_{\nu,\rm eff}(z)\chi^2}{K}$$

- The **CIB fluctuations** trace the **underlying galaxy fluctuations.** The power spectrum of j_ν is modelled with a linear CIB bias (**on large scales**)

$$P_{jj}^{\nu\nu'}(k,z) = b^{CIB}(z)^2 P^{\rm lin}(k,z)$$

Cosmology dependence

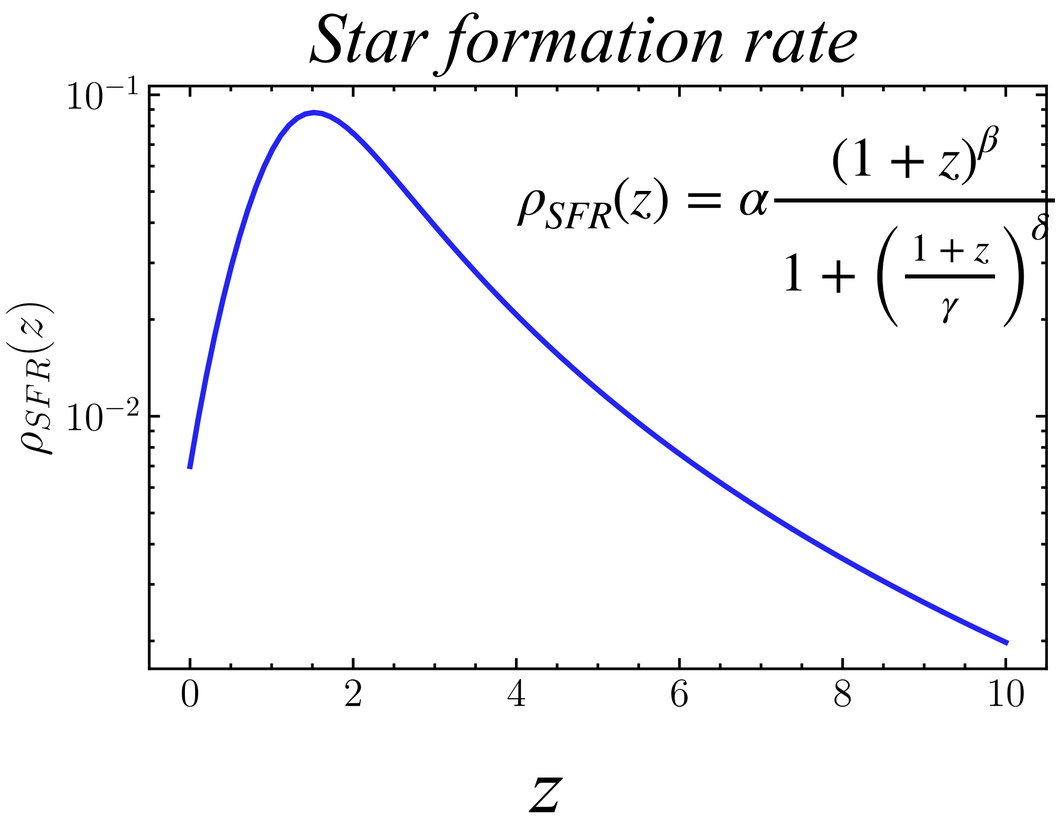
- The angular power spectrum is then

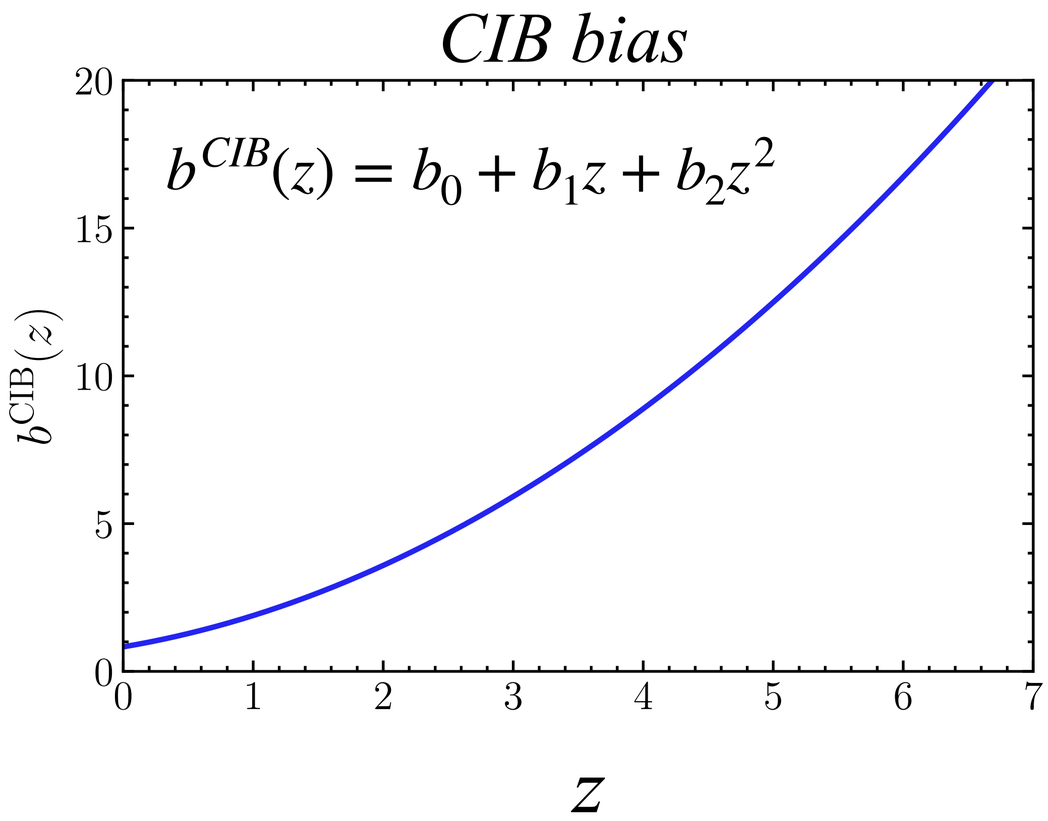
$$C_\ell^{\nu\nu'} = \int \frac{d\chi}{\chi^2} a^2(\chi) \bar{j}_\nu(\chi) \bar{j}_{\nu'}(\chi) P_{jj}^{\nu\nu'}\left(k = \frac{\ell}{\chi}, z\right)$$

The CIB redshift evolution

- This linear model was fit in **Maniyar et al 2018** to CIB observations

- CIB galaxies are **highly biased**





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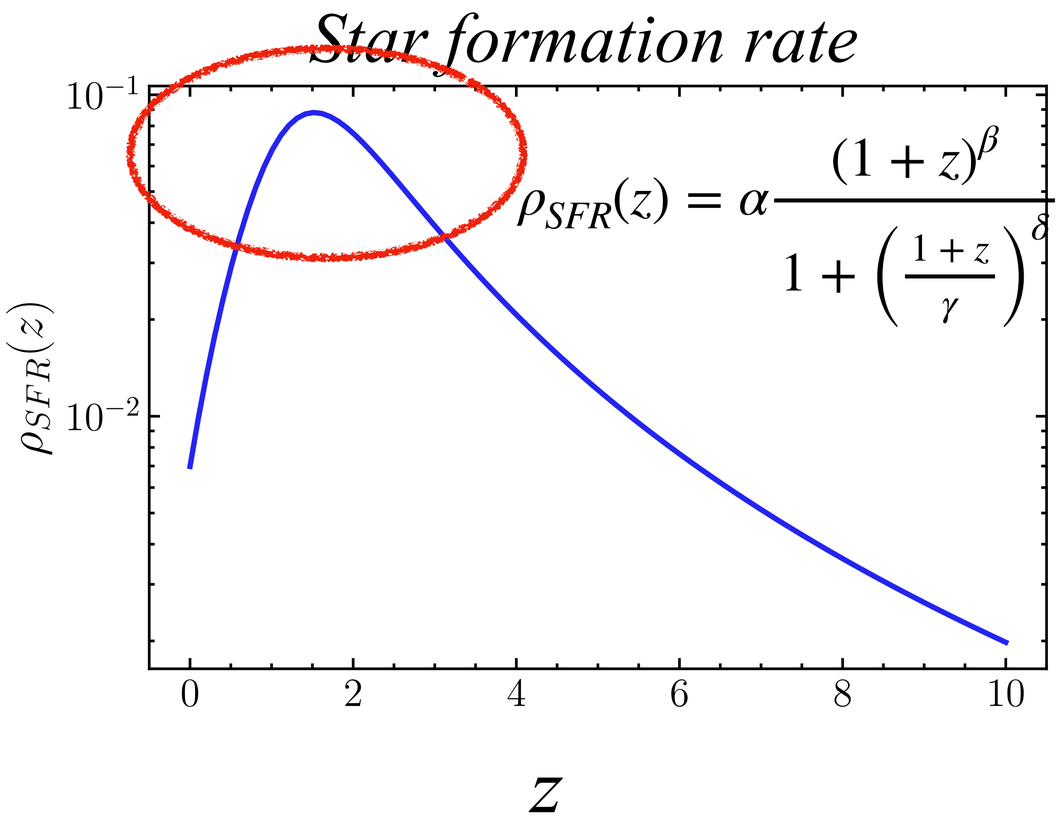
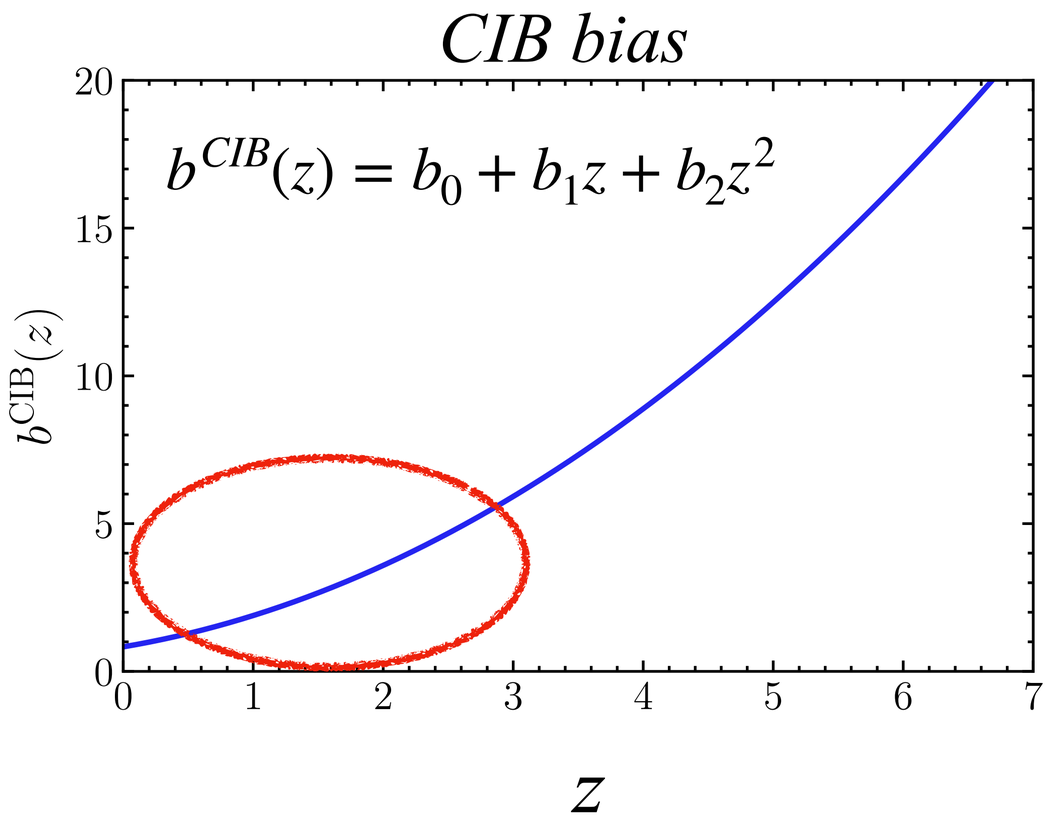
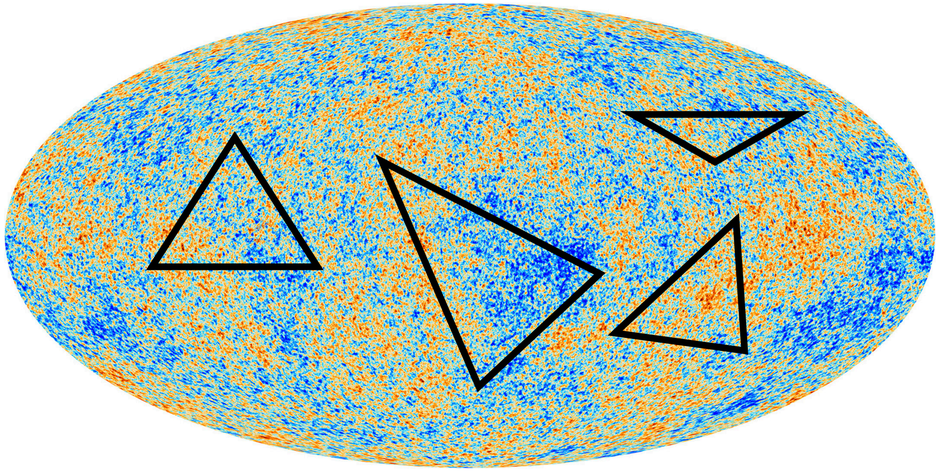




Primordial non-Gaussianity: probing inflation

- Inflation seeded the Universe with the initial perturbations
- Different inflation models predict **different distributions of perturbations**, in particular **different amounts and types of non-Gaussianity**
- All tests are consistent with **Gaussianity and single field, slow roll inflation**
- Focus on **local** non-Gaussianity ($f_{NL}^{\rm loc}$), multi-field inflation models a signal ($f_{NL}^{\rm loc} \sim 1$)
- From *Planck* bispectrum: $f_{NL}^{\rm loc} = -0.9 \pm 5.1$



CMB map from Planck

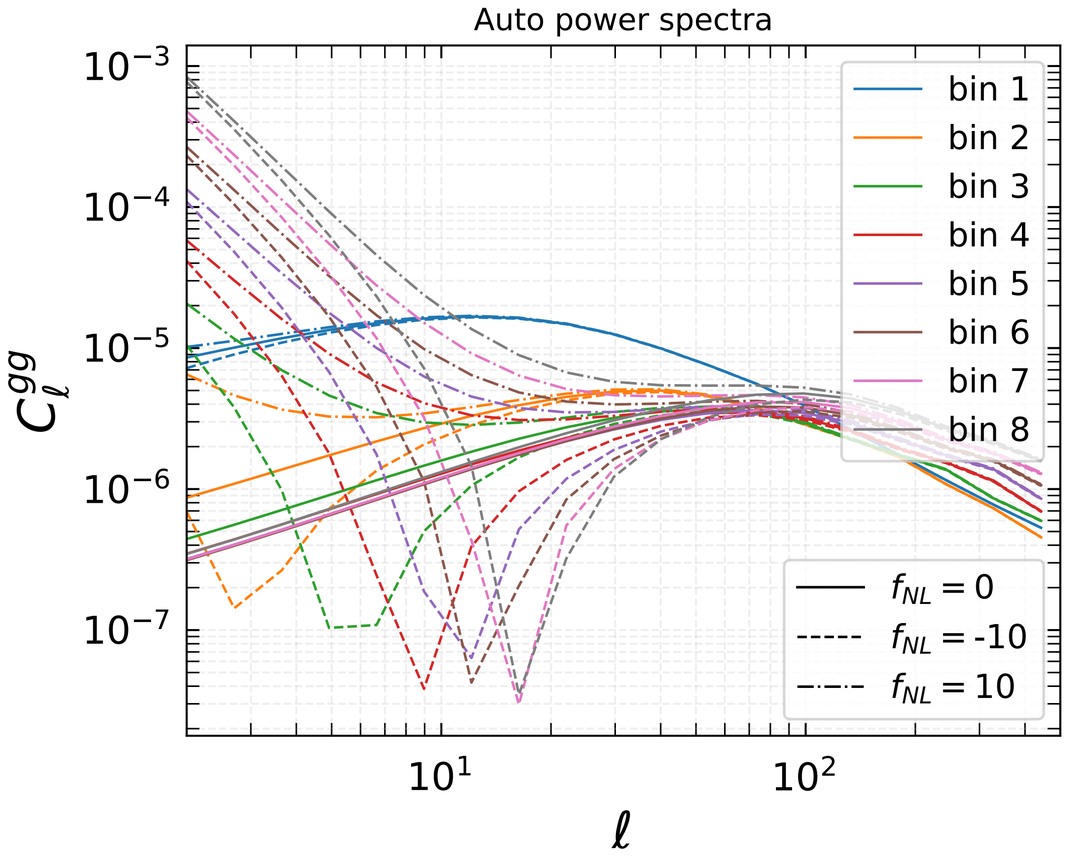
f_{NL} from scale-dependent bias

- Galaxies are biased with respect to DM:

$$\delta^g = b\delta$$

- Local primordial non-Gaussianity → scale dependence of b **on large scales** [Dalal et al 2007]

$$b^{NG} = b^G + f_{NL}^{\rm loc}\frac{1}{k^2}\frac{3\Omega_m H_0^2}{T(k)D(z)}\delta_c(b^G - 1)$$



Plot from Boris Bolliet's talk: class_sz

- This signal appears **in the power spectrum** on large scales

f_{NL} from galaxy power spectra

- Scale dependence of the **galaxy power spectrum** is a major target for next-gen **galaxy surveys**

- Currently Boss quasars give $f_{NL}^{\rm loc} = -12 \pm 21$ (*Mueller et al 2021*) (cf CMB bispectrum from *Planck*, $f_{NL}^{\rm loc} = -0.9 \pm 5.1$)

- SphereX forecast: $\sigma(f_{NL}^{\rm loc})$ = 0.87

- CIB objects have **high bias -> high sensitivity to** $f_{NL}\ (b^G + f_{NL}^{\rm loc}\frac{1}{k^2}\frac{3\Omega_m H_0^2}{T(k)D(z)}\delta_c(b^G - 1))$

- Need to **understand** and **measure** the **largest scales**: this is a huge challenge

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Lots of large-scale systematics!! How to separate the galaxy?

The large scale CIB maps

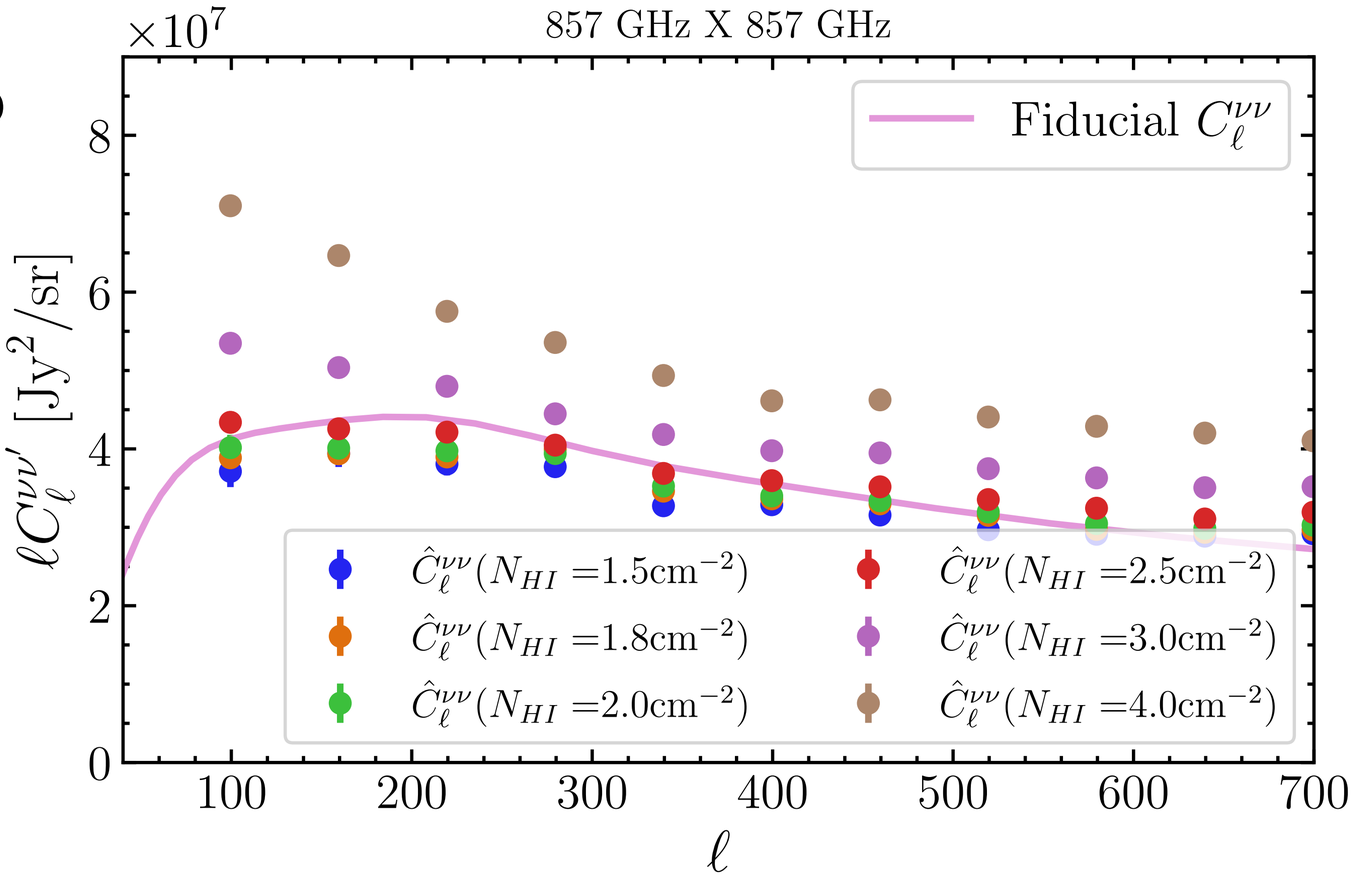
- *Lenz et al 2019* created dust templates with HI emission data to create **large scale galactic-dust-cleaned CIB maps**
- CIB maps on up to 30% of the sky at 353, 545, 857 GHz from *Planck* data
- Various levels of clean maps were presented, with the cleanest on $\sim 10\,\%$ of the sky and the dustiest on $\sim 30\,\%$ of the sky

The CIB and galactic dust

- Dust power **mimics the $f_{NL}^{\rm loc}$ scale dependence! See these measured power spectra** using **Lenz et al** CIB maps

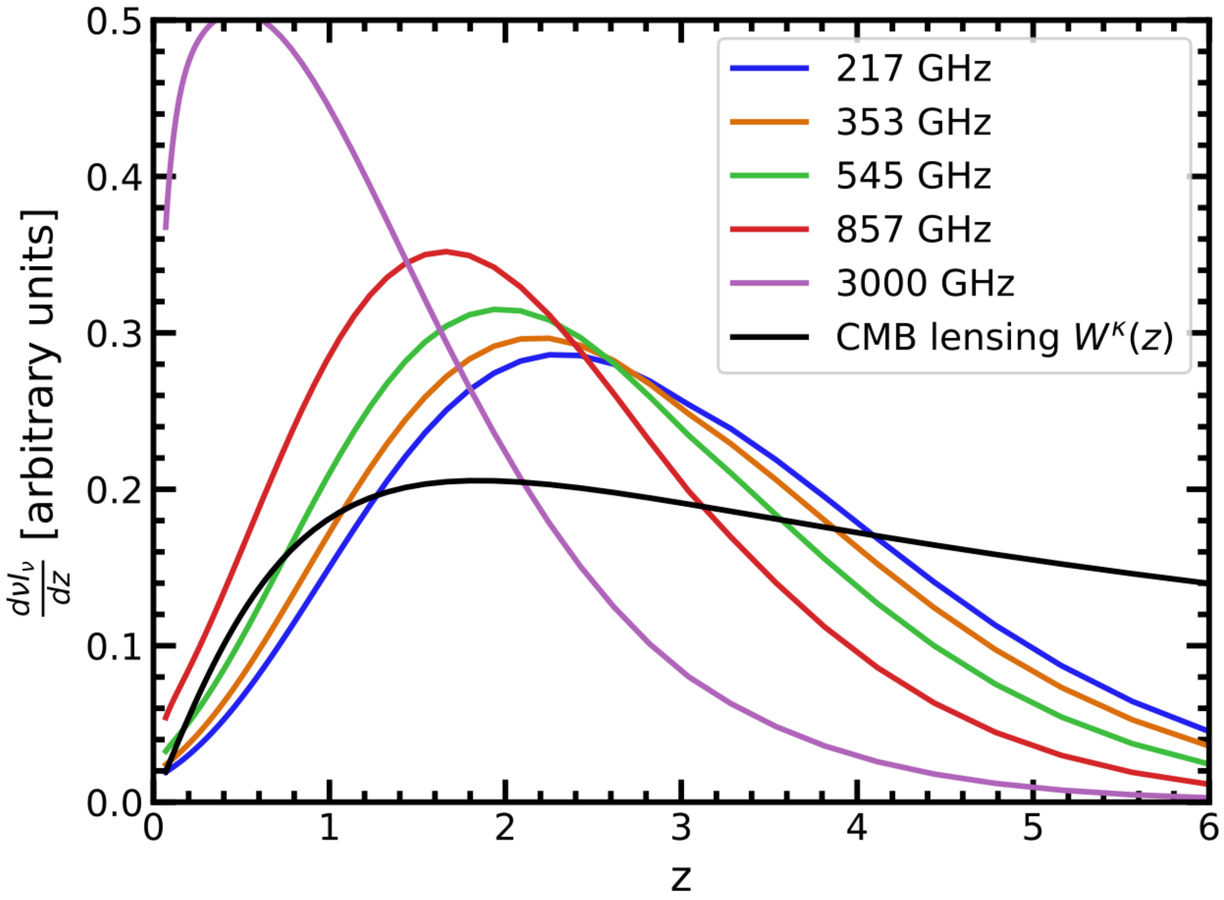
- Any $f_{NL}^{\rm loc}$ analysis of the CIB auto power spectrum would need to marginalize over this effect

- Or, we can look at a probe that is not sensitive to this bias - the **cross correlation with CMB lensing**



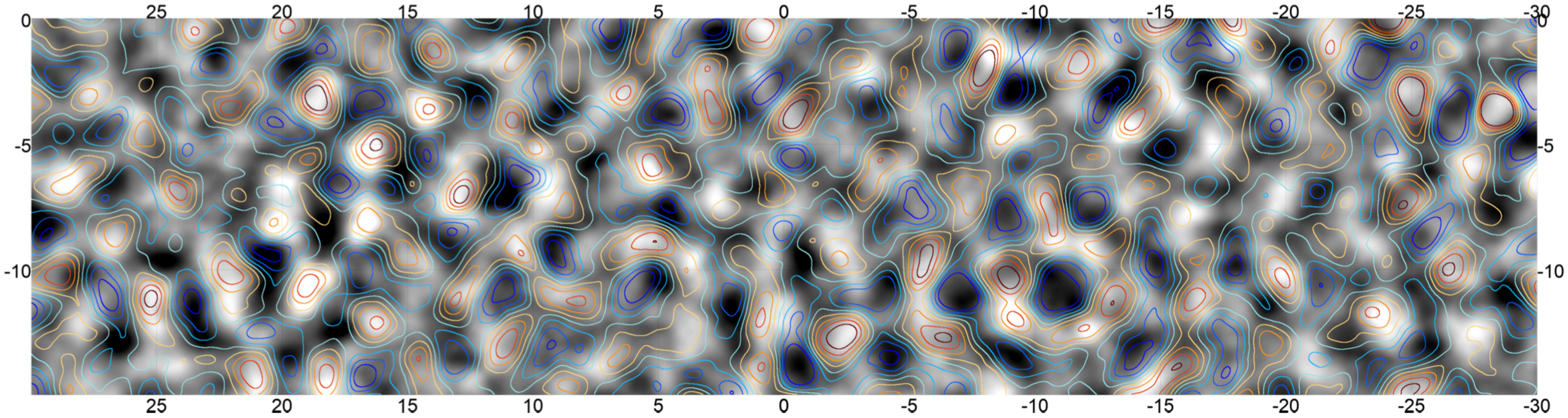
CIB-CMB lensing cross correlation

- The CIB and CMB lensing kernels peak at similar redshifts



CIB-CMB lensing cross correlation

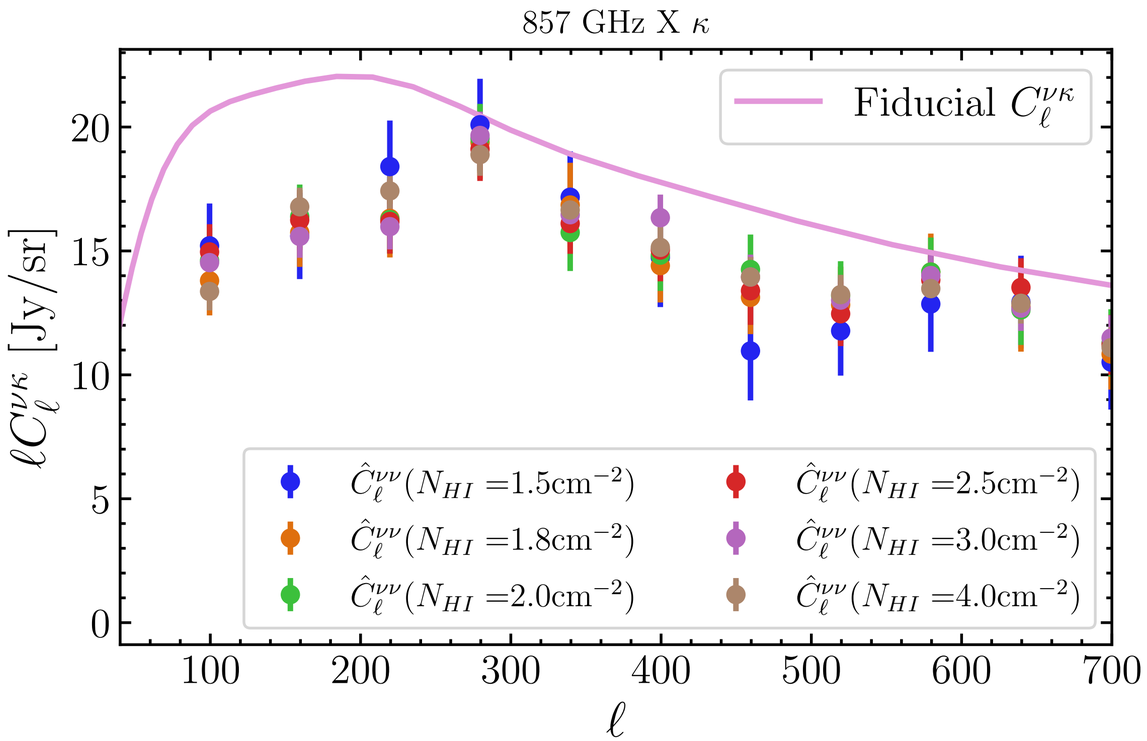
- The CIB is **highly correlated with CMB lensing -** see the amazing picture from **Madhavacheril et al 2023**: (**ACT DR6 lensing map** in grayscale, *Planck* CIB in red-blue contours)



- CMB lensing maps **do not contain galactic dust**

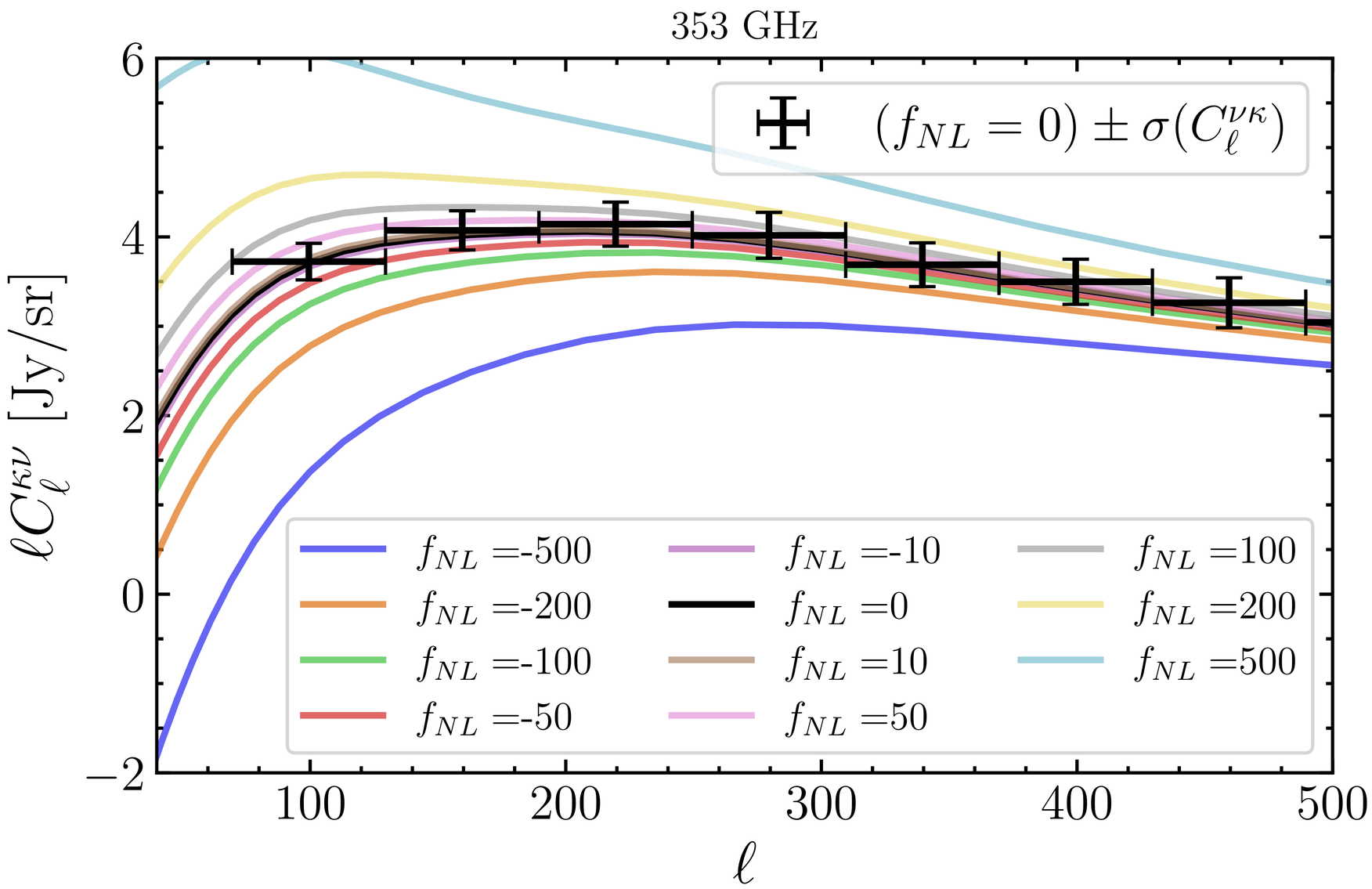
CIB-CMB lensing cross correlation

- No galactic dust in CMB lensing



- Measured cross-correlation of the *Lenz*+ CIB maps with *Planck* κ is **unbiased**

Effects of f_{NL}



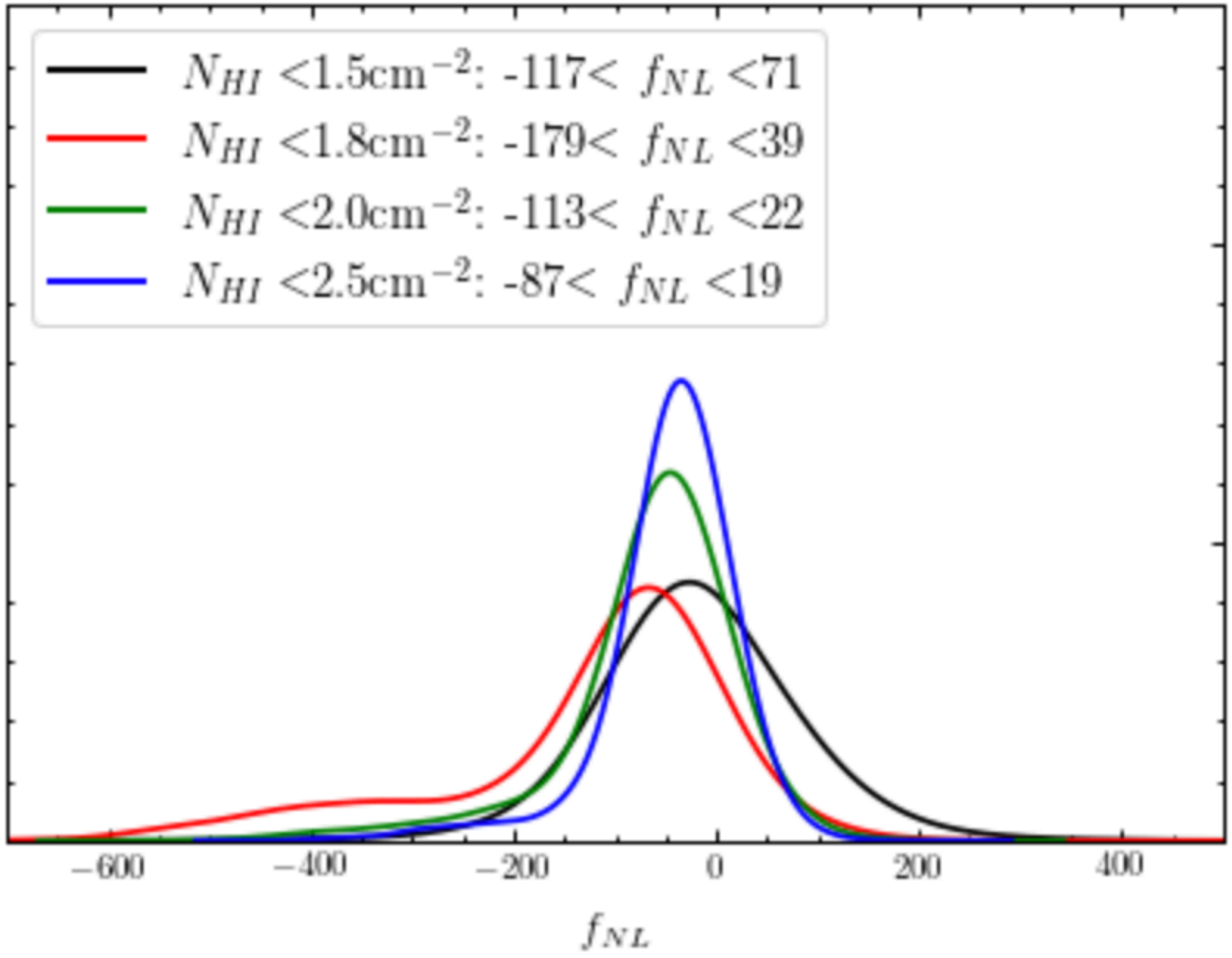
f_{NL} analysis

- We write a likelihood for $f_{NL}^{\rm loc}$ and marginalize over the **7 other CIB parameters; shot noise in the auto power spectra; and calibration factors for the frequency channels**

- We use **only the cross power** on scales $70 < \ell < 400$ and **also include the CIB power** for $400 < \ell < 600$

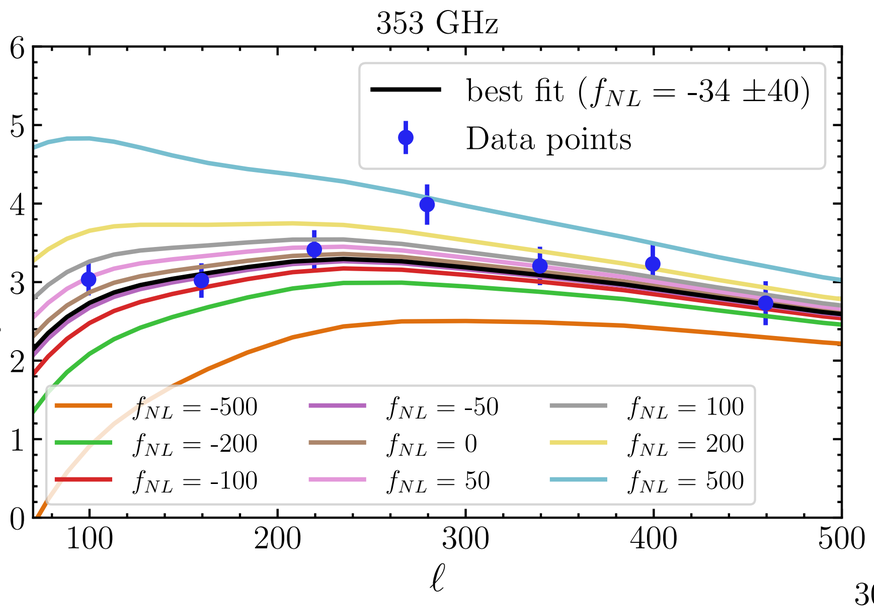
- *Lenz et al* provide various maps with various levels of dust-cleaning (and sky areas). We perform the analysis separately on the four cleanest, where **our fiducial model captures the variance in the auto power**

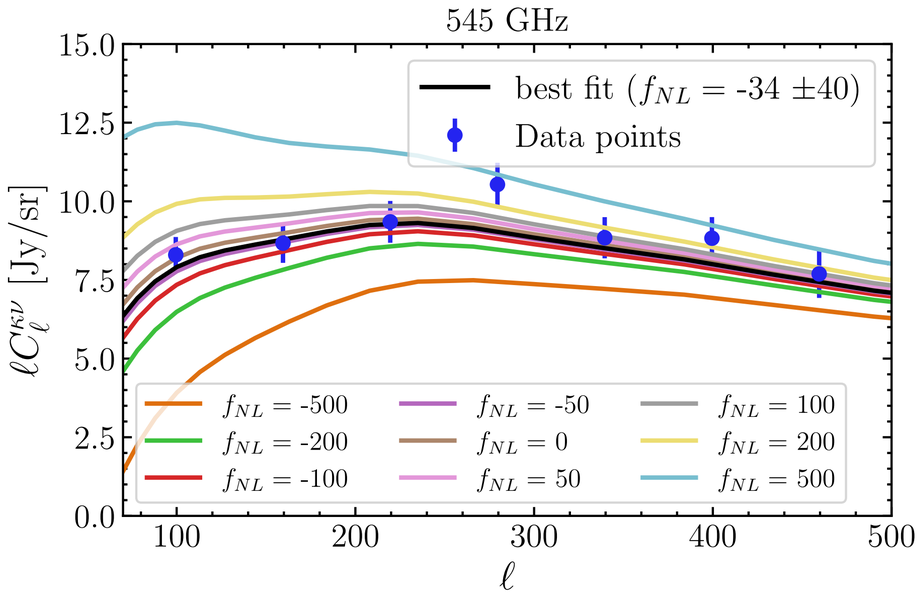
f_{NL} constraints

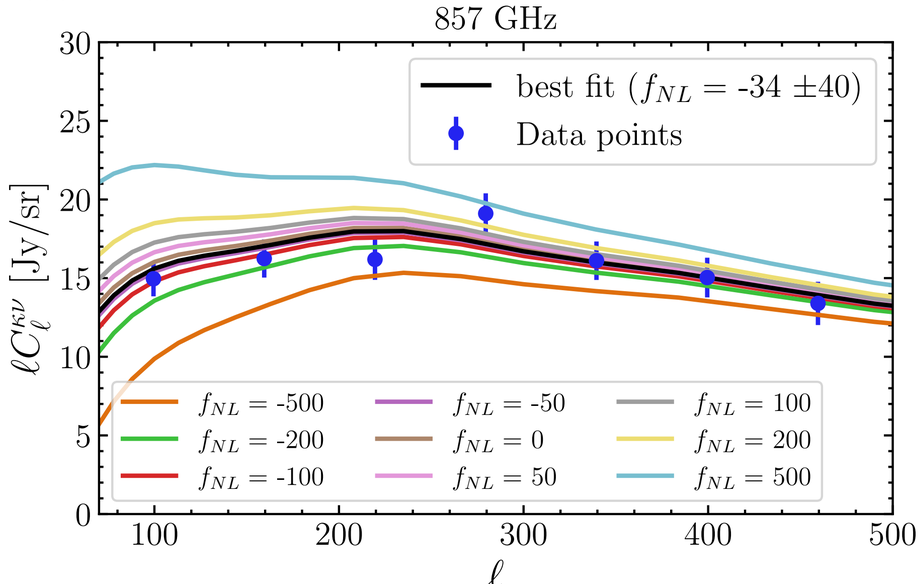


- We combine all frequencies and analyses the different dust thresholds separately
- No detection of $f_{NL}^{\rm loc}$, $\sigma(f_{NL}^{\rm loc}) \sim 50$ from the largest map

f_{NL} constraints

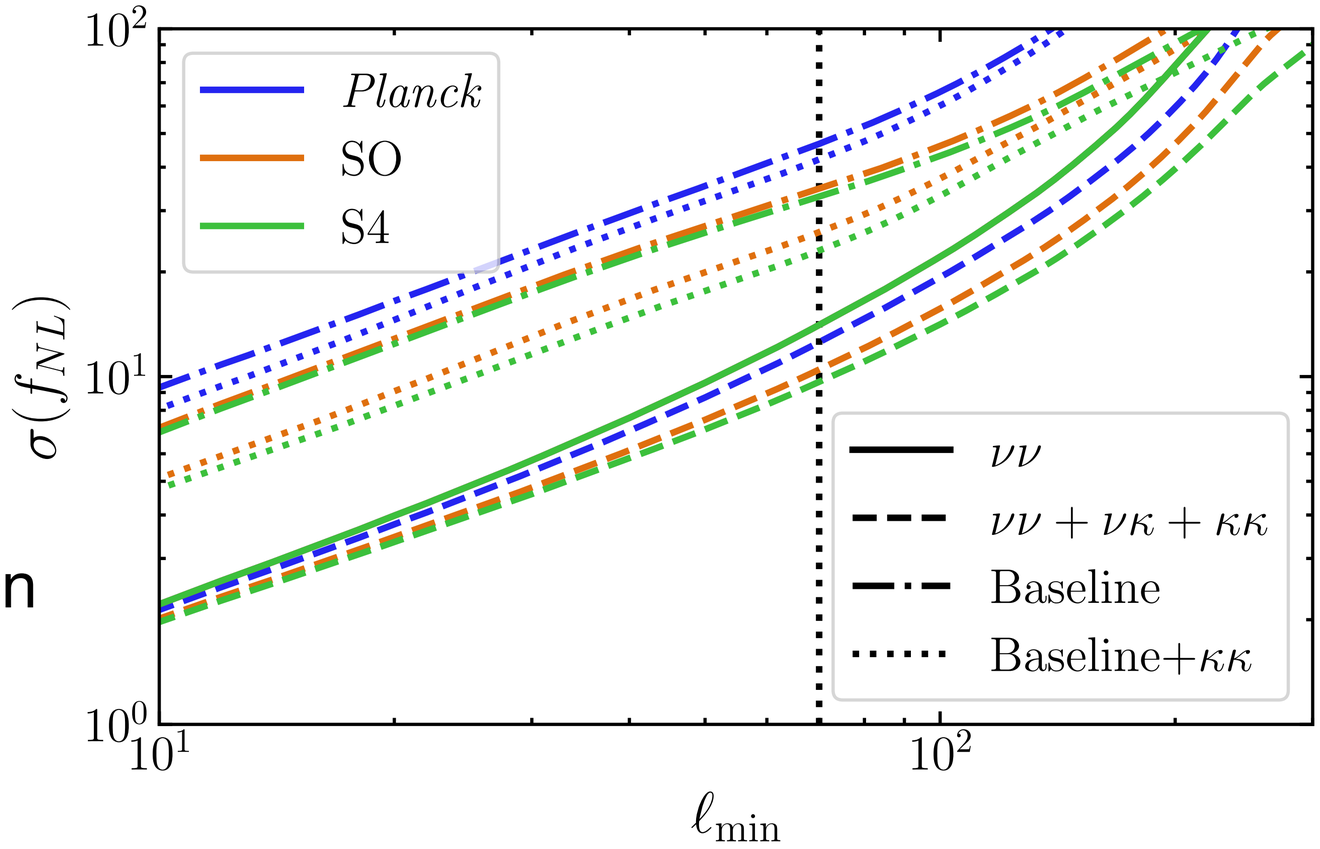






f_{NL} forecasts

- We are getting better lensing data!
- SO can get to $\sigma(f_{NL}^{\rm loc}) \sim 23$
- CMBS4 can get to $\sigma(f_{NL}^{\rm loc}) \sim 20$
- Worth noting how much information there is in the CIB!



Conclusions

- We can do cosmology with the CIB!
- $f_{NL}^{\rm loc}$ is a major goal for upcoming LSS surveys, with $\sigma(f_{NL}^{\rm loc}) = 1$ a target
- CMB lensing cross correlations can add a lot of robustness to auto-power spectra with galactic systematics
- With current CIB data we get $\sigma(f_{NL}^{\rm loc}) \sim 50$ but this could improve
- Better **dust-cleaning on large scales** -> much better constraints