BERKELEY LAB

Emmanuel Schaan Chamberlain fellow

Foreground-immune CMB lensing with shear-only reconstruction

arXiv:1804.06403

with Simone Ferraro

Simons Observatory science goals

Qualitative leap from S3

Large overlap with LSST

Survey start: 2021

Title	Parameter	Goal	Current[a]	SO Method
Primordial fluctuations	r	**0.002**	0.03	BB
	$P(k=0.2\ /\mathrm{Mpc})$	**0.4%**	6%	T/E/k
	f_{NL}	**1**	5	kSZ+LSST
		1		kk+LSST
Relativistic Species	N_{eff}	**0.05**	0.2	T/E
Neutrino mass	Σm_ν (eV)	**0.03**	0.1	kk+DESI
		0.03		tSZ-N+LSST
		0.04		tSZ-Y+DESI
Dark Energy	$\sigma_8(z=1\text{-}2)$	**1%**	7%	kk+LSST
		1%		tSZ+LSST/k
	H_0 (LCDM)	**0.3**	0.7	T/E
Galaxy Evolution	feedback efficiency in massive halos	**2%**	50-100%	tSZ+kSZ
	non-thermal pressure in massive halos	**5%**	50-100%	tSZ+kSZ
Reionization	duration Δz	**0.3**	1.4	T/E (kSZ)

SO Science paper

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SO Science paper

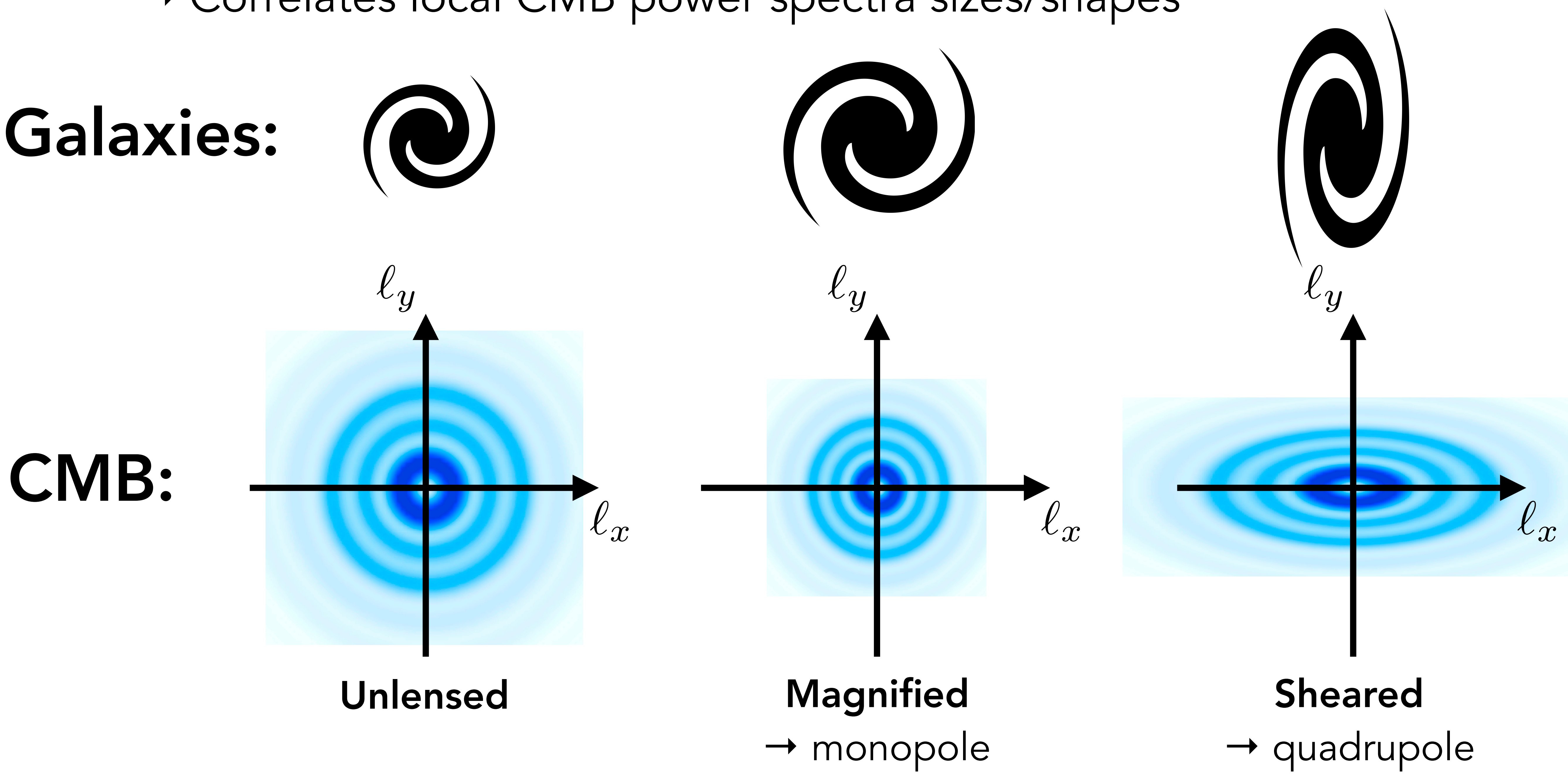
→ **CMB lensing is crucial**

Large lens regime: CMB ⇔ galaxies

$$\partial_i d^j = \mathcal{I} + \begin{bmatrix} \kappa + \gamma_1 & \gamma_2 - \omega \\ \gamma_2 + \omega & \kappa - \gamma_1 \end{bmatrix}$$, uniform over degree scales

→ Correlates galaxy sizes/shapes

→ Correlates local CMB power spectra sizes/shapes



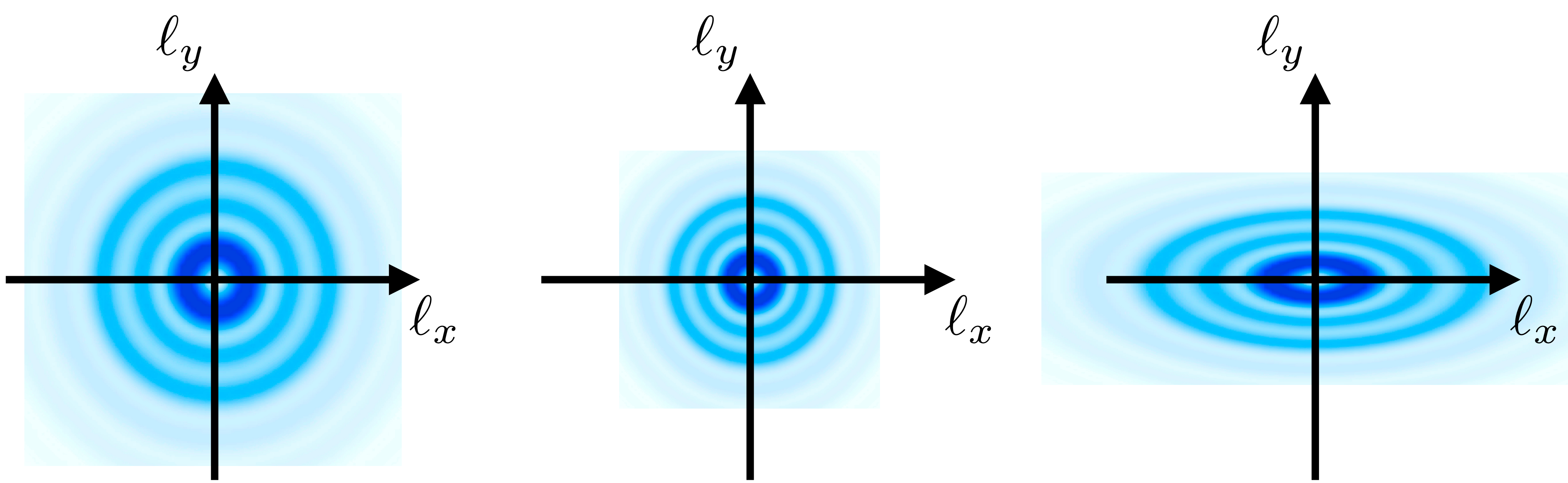
Zaldarriaga Seljak 98, Lu Pen 08, Bucher+10, Prince+17

Quadratic estimator ≃ Shear & Magnification

"Does the observed power spectrum C_ℓ vary on scale L?"

$$\langle T_{\boldsymbol{\ell}} T_{\boldsymbol{L}-\boldsymbol{\ell}} \rangle = \phi_{\boldsymbol{L}} \left(\frac{2\boldsymbol{L}}{L^2} \right) \left[\boldsymbol{\ell} C^0_\ell + (\boldsymbol{L} - \boldsymbol{\ell}) C^0_{|\boldsymbol{L}-\boldsymbol{\ell}|} \right]$$

$$\simeq \phi_{\boldsymbol{L}} \; C^0_\ell \left[\underbrace{\frac{d \ln \ell^2 C^0_\ell}{d \ln \ell}}_{\text{magnification}} + \underbrace{\cos 2\theta_{\boldsymbol{L},\boldsymbol{\ell}} \frac{d \ln C^0_\ell}{d \ln \ell}}_{\text{shear E-mode}} + \ldots \right] \quad \text{for } L \ll \ell$$



Unlensed

Magnified
→ monopole

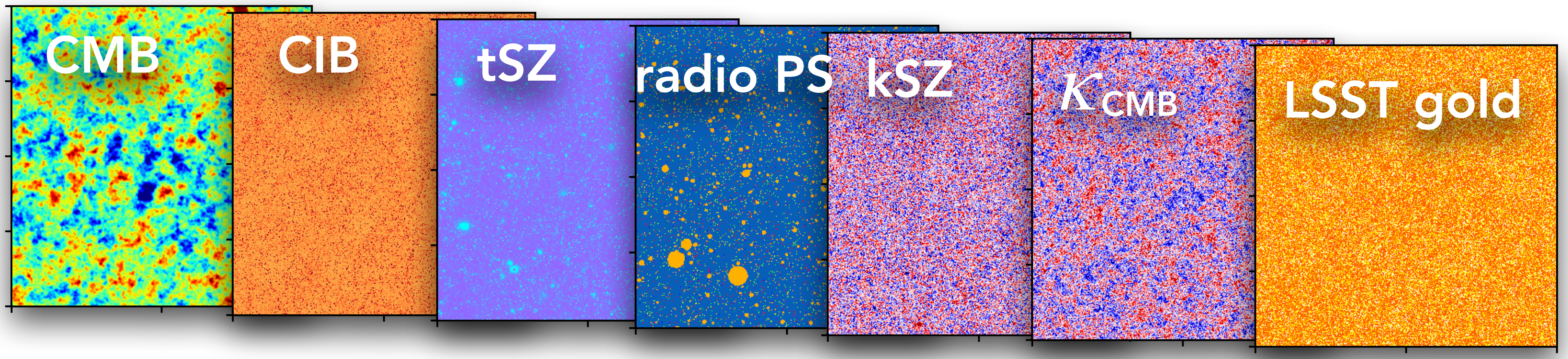
Sheared
→ quadrupole

Emmanuel Schaan

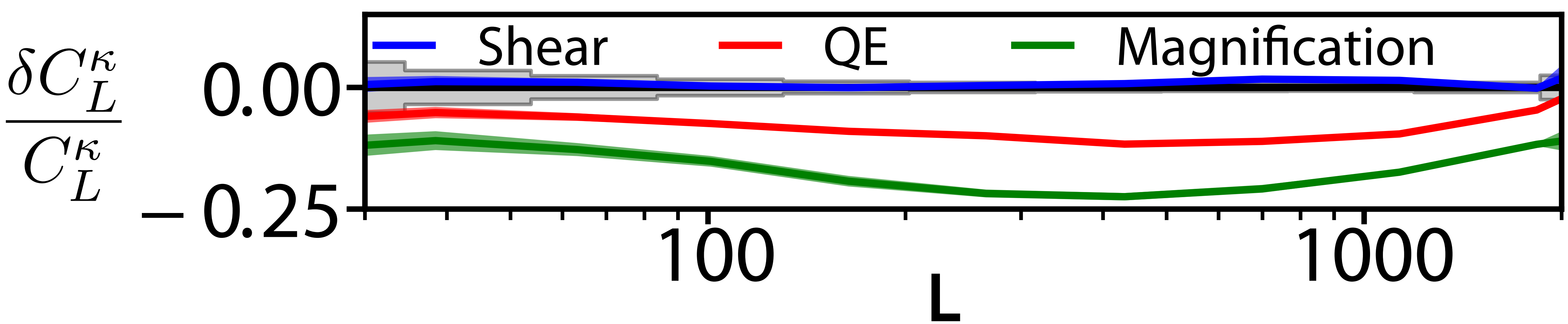
Zaldarriaga Seljak 98, Lu Pen 08, Bucher+10, Prince+17

Dramatic foreground reduction

Realistic simulations: Sehgal+09

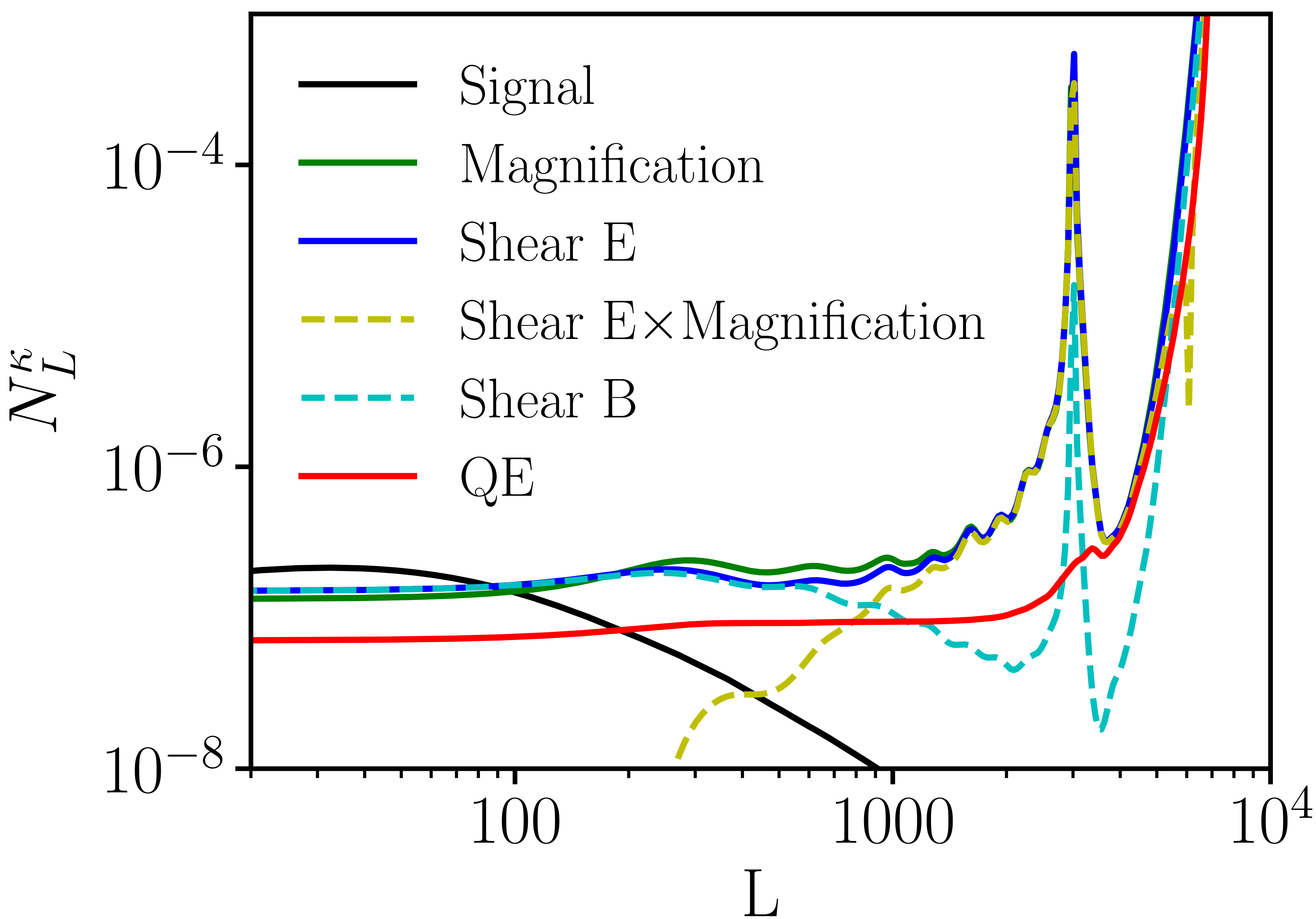


Foreground bias to lensing: Schaan Ferraro 18



Emmanuel Schaan

Quadratic estimator ≃ Shear & Magnification

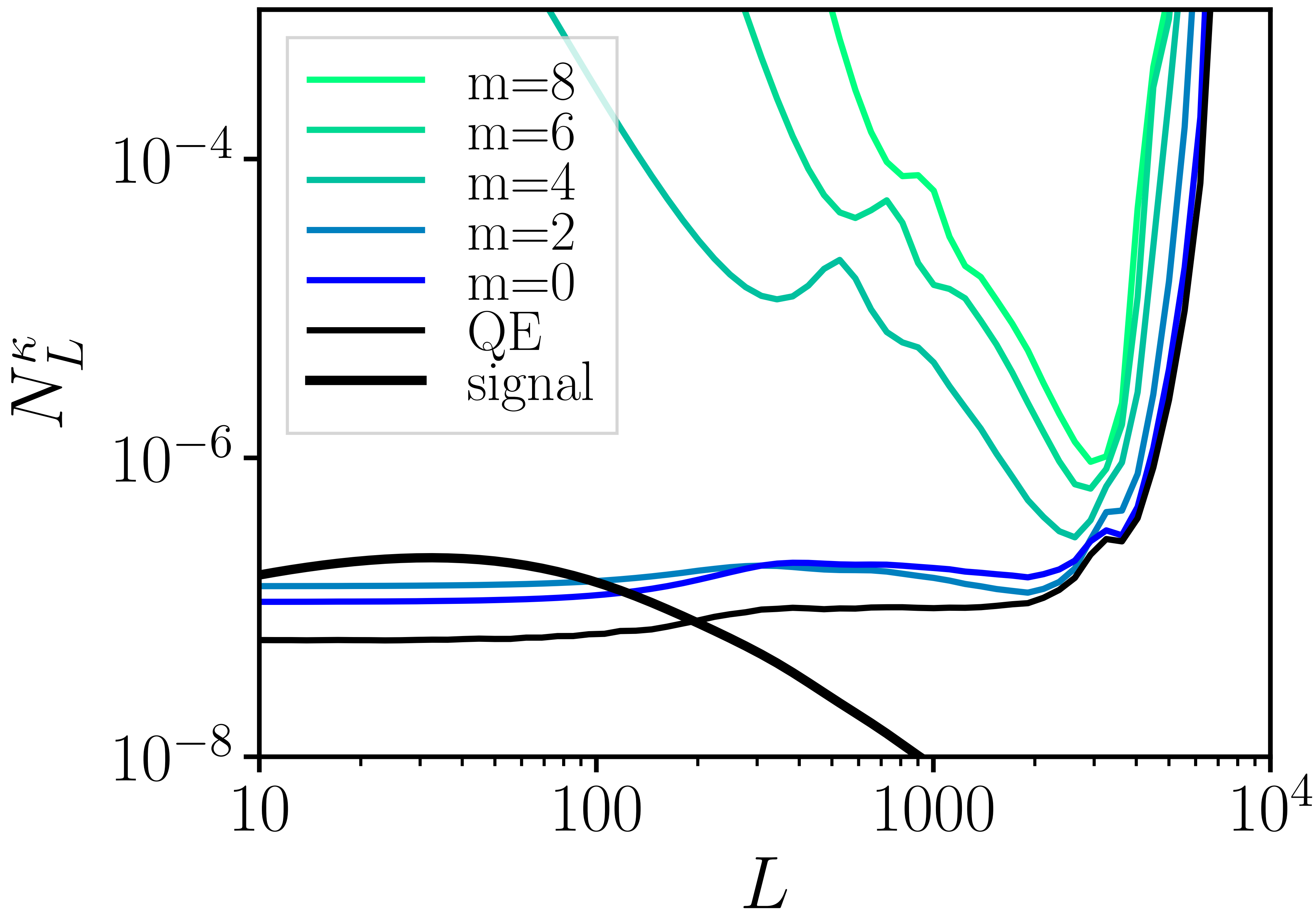


Shear E & magnification: similar SNR

Shear E & magnification uncorrelated on large scales

Shear B null test (~curl null test)

Generalization: Multipole estimators



Magnification → Monopole

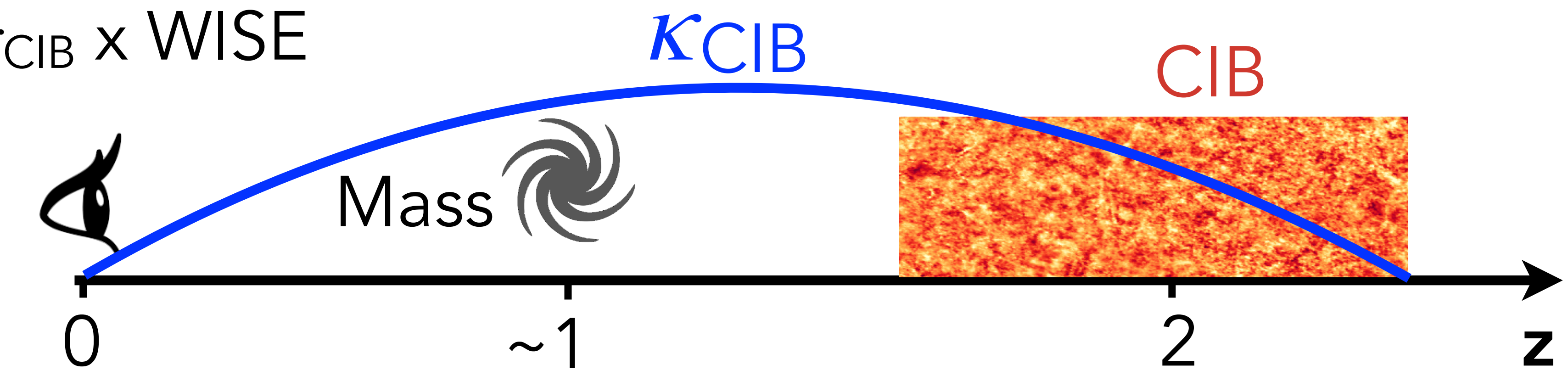
Shear E → Quadrupole

Lossless decomposition of the standard quadratic estimator

Foregrounds are themselves lensed

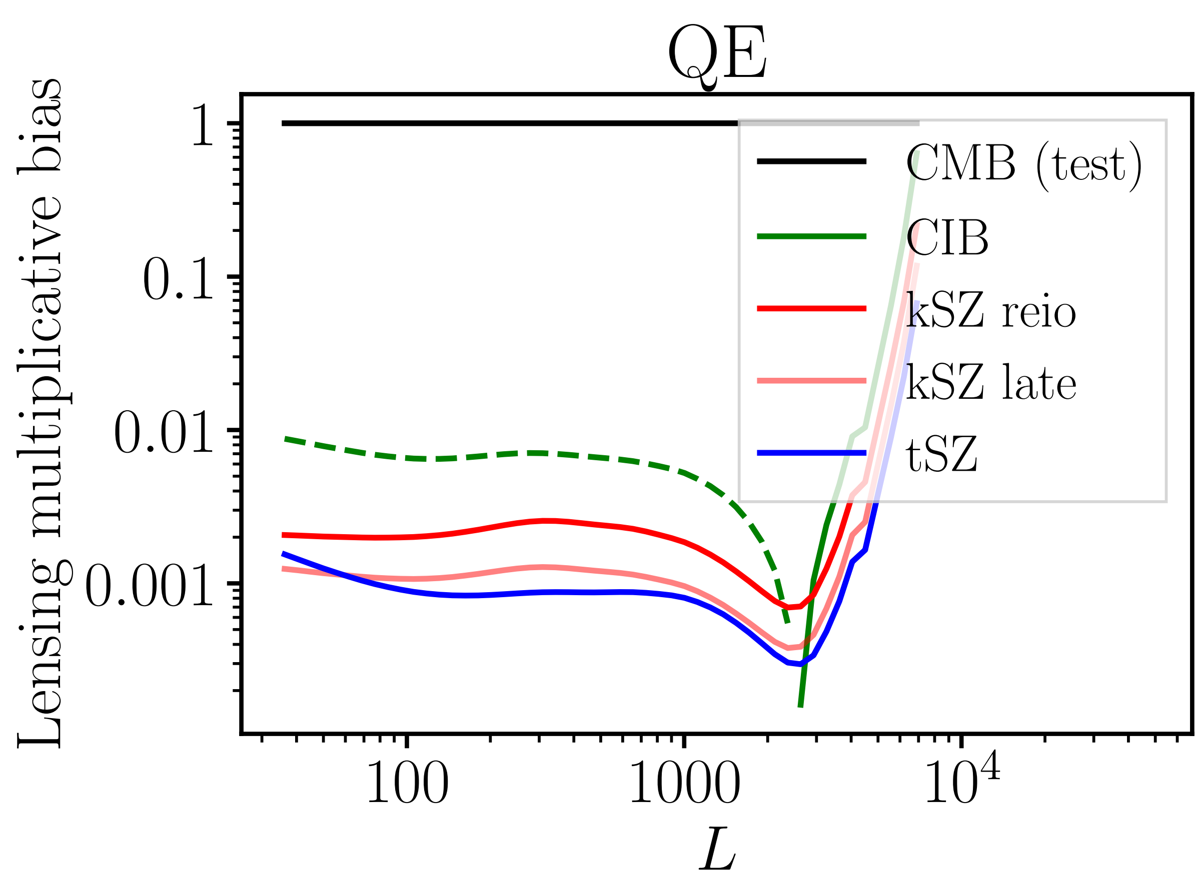
Measure lensing *of* the CIB, not *by* the CIB:

SNR~100 for $\kappa_{\rm CIB}$ x $\kappa_{\rm CMB}$ or $\kappa_{\rm CIB}$ x WISE



Schaan Ferraro Spergel 18

Cause a multiplicative bias in $\kappa_{\rm CMB}$:



Nishant Mishra & Schaan, in prep

Conclusions

Foregrounds > noise for upcoming CMB lensing from temperature.

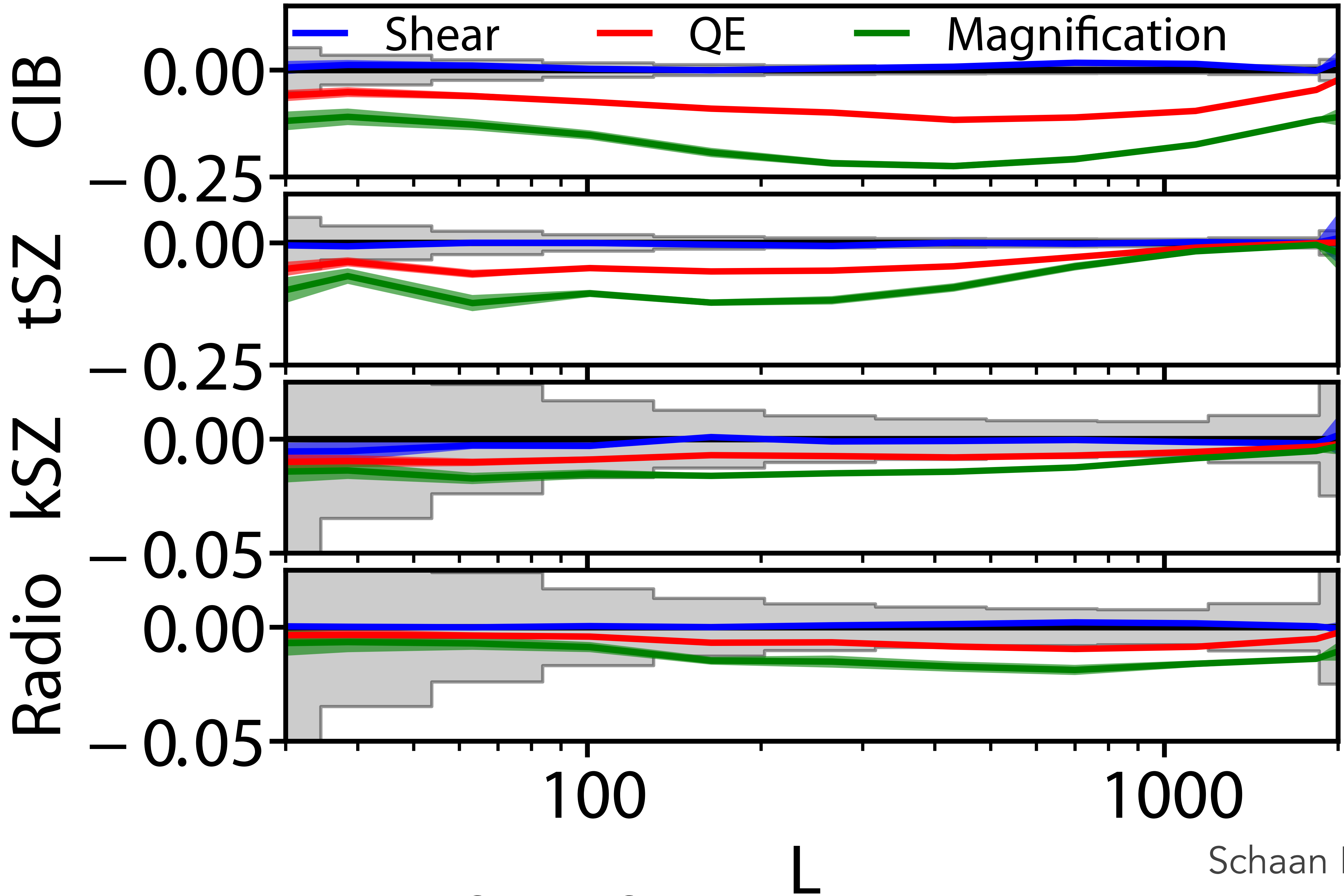
Shear E reduces *all* extragalactic foregrounds, *both* in auto and cross-correlation

Magnification & Shear B provide null tests

Generalization: multipoles

arXiv:1804.06403

Bias on $C_L^{\kappa_{CMB} \times LSST}$

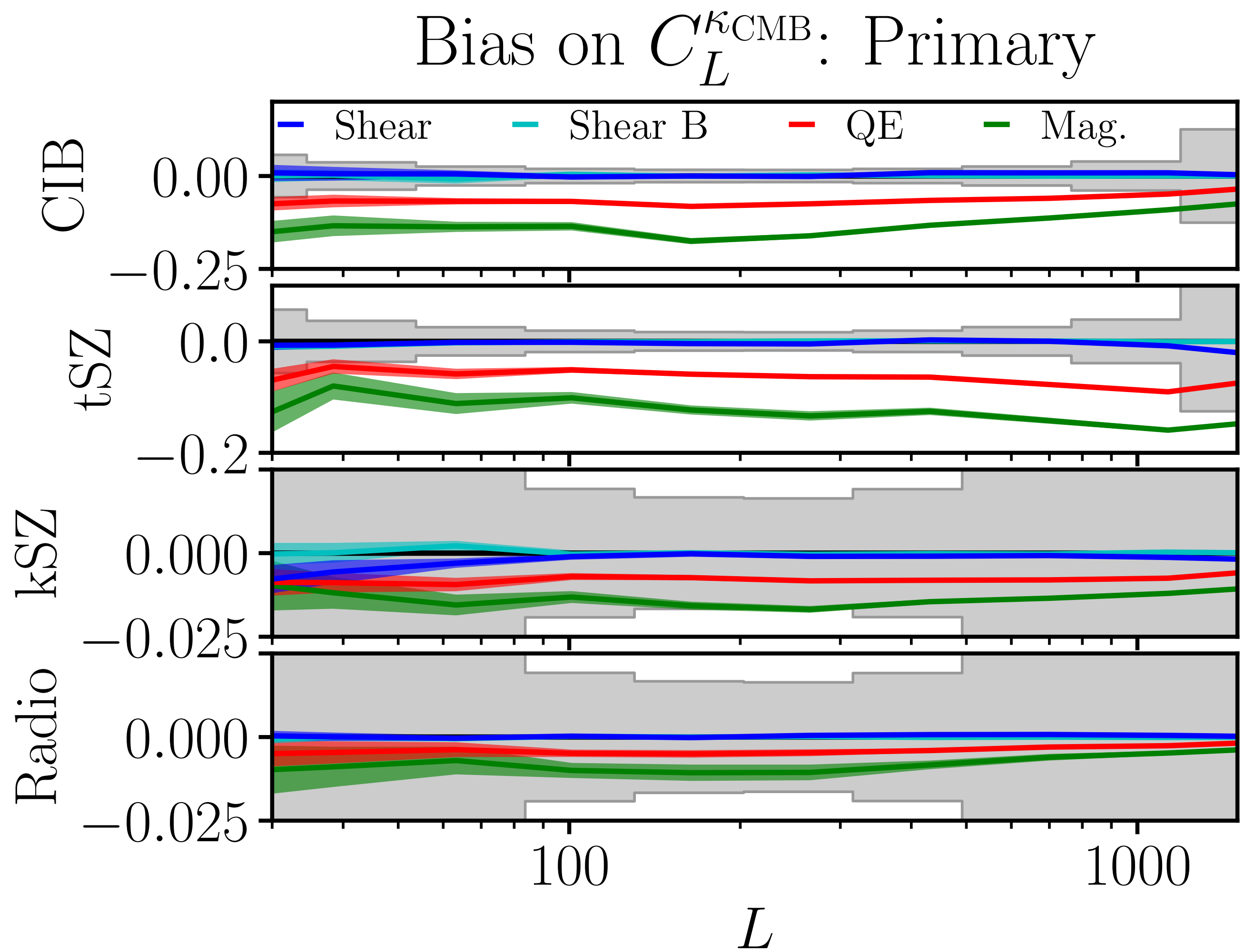


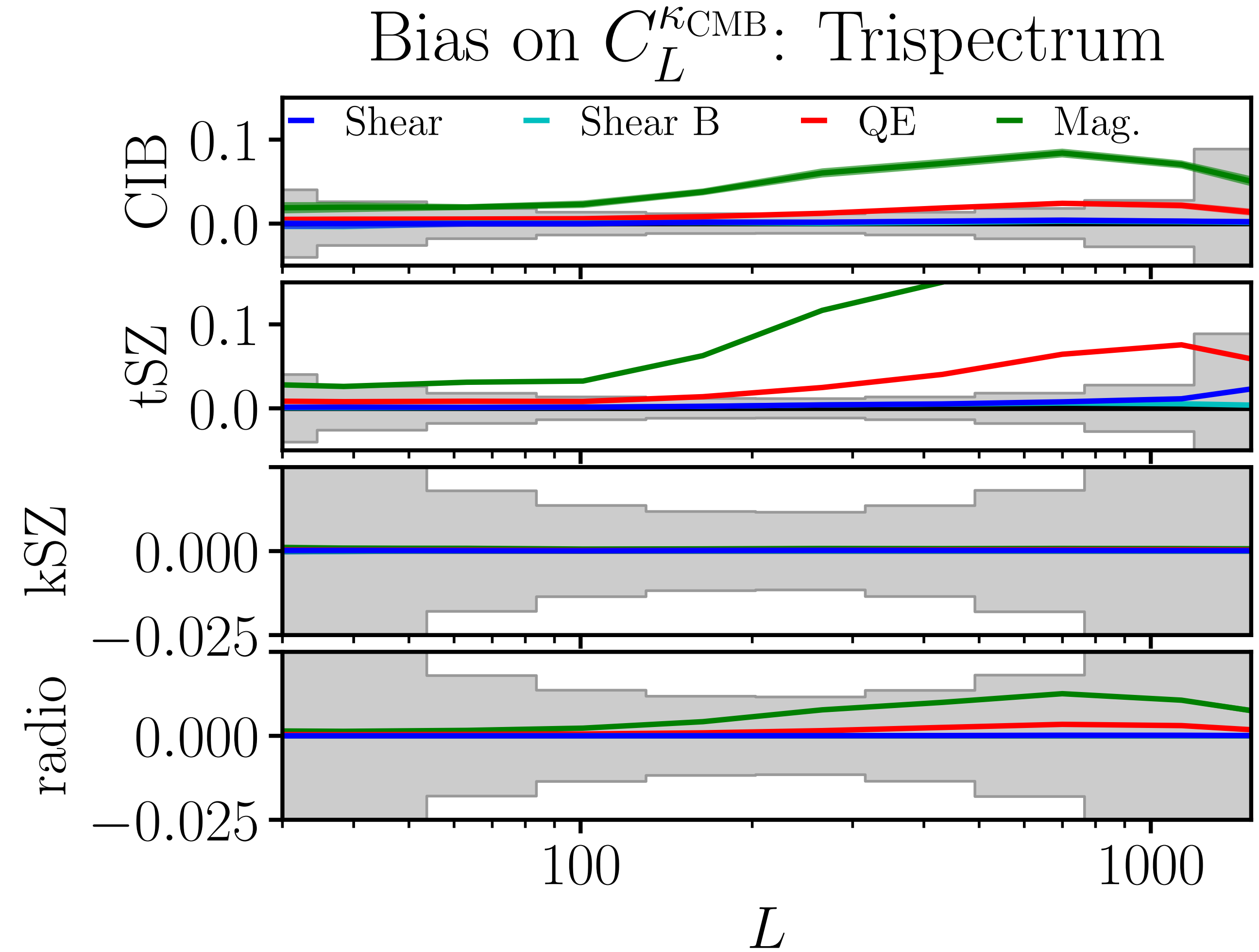
Schaan Ferraro 18

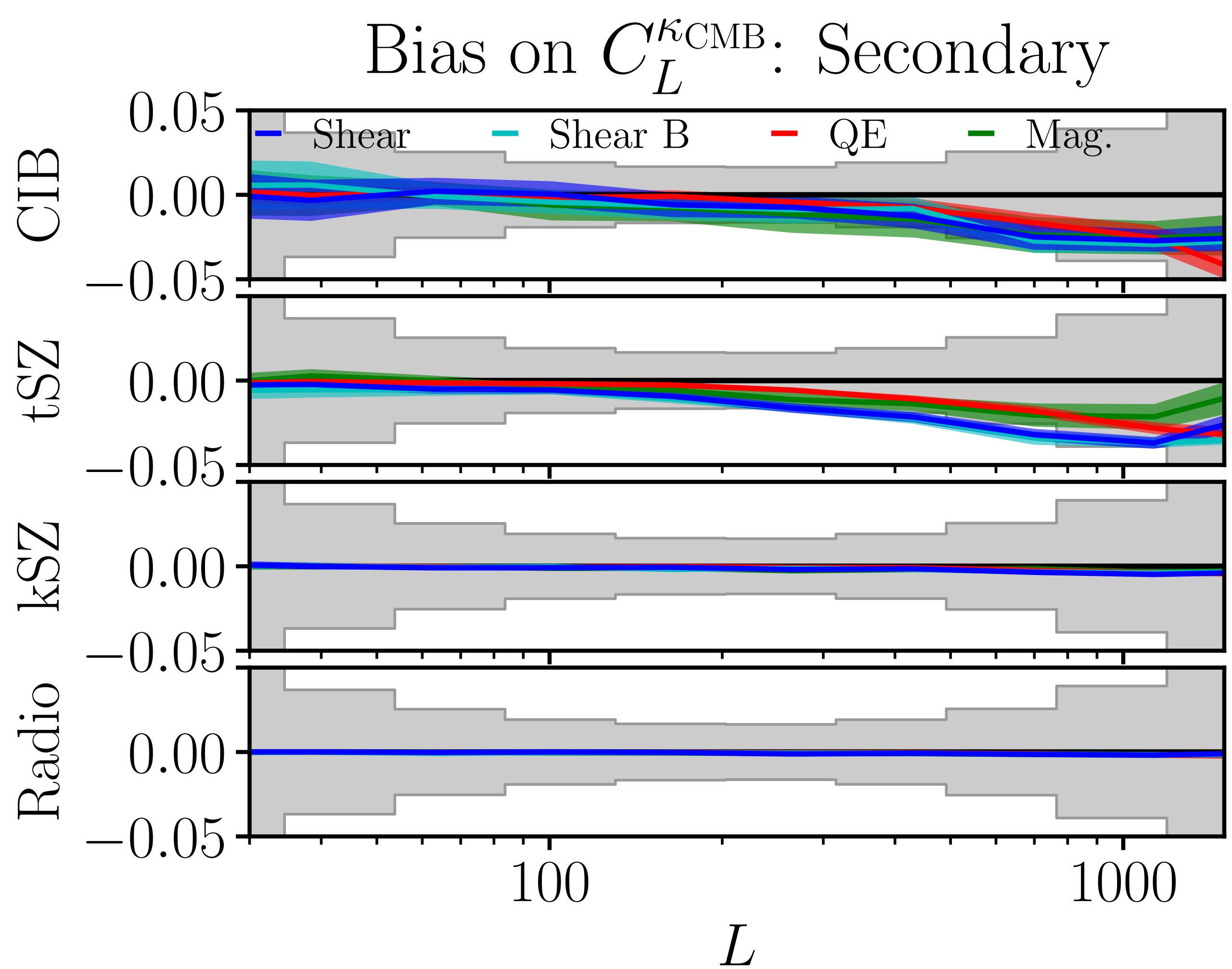
→ **Very significant foreground biases in QE**

→ **Dramatic improvement with shear!**

→ **Magnification: sensitive null test**



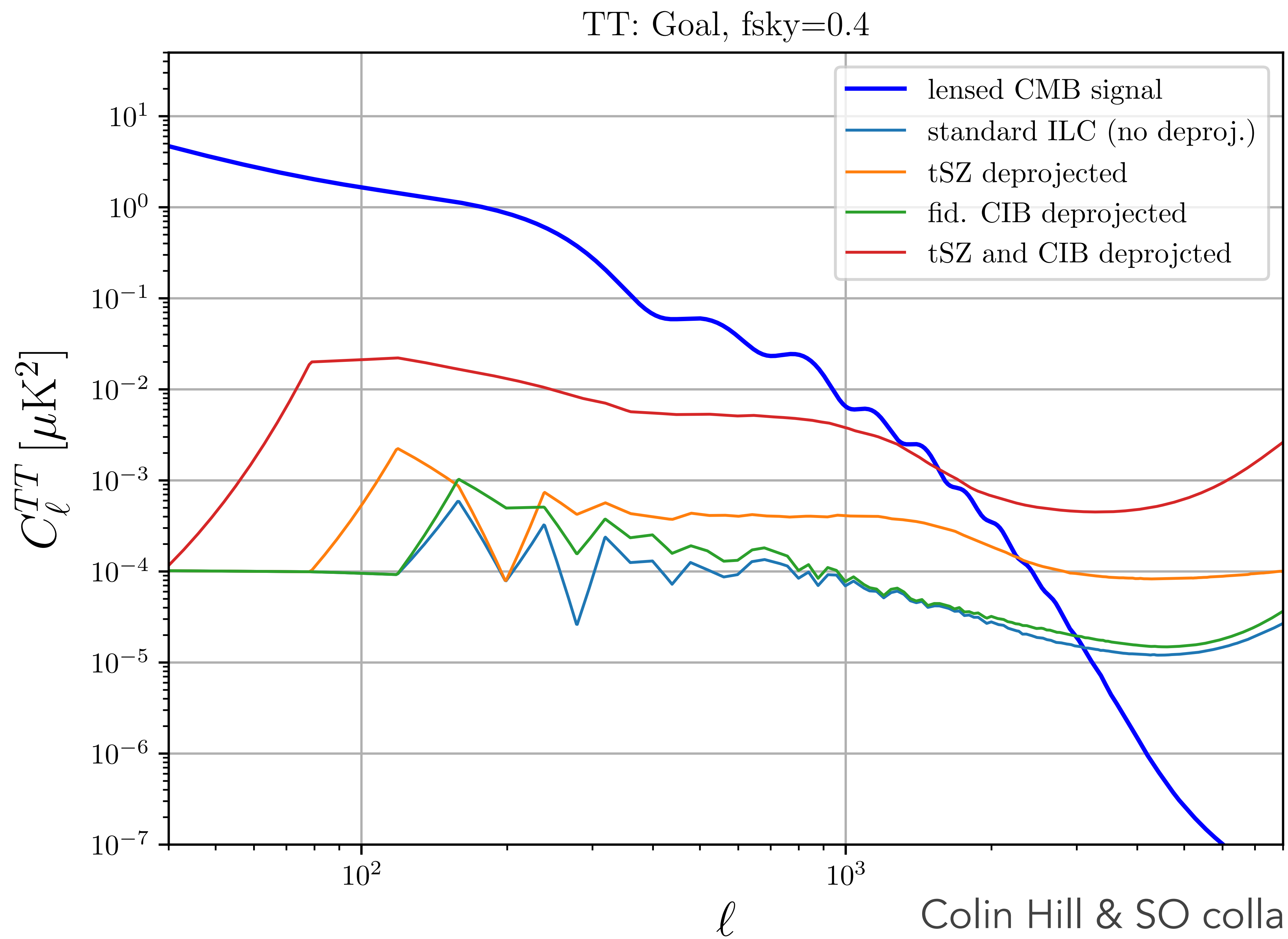




→ **Dramatic reduction of primary and trispectrum biases**

→ **Secondary contraction subtracted with shear B**

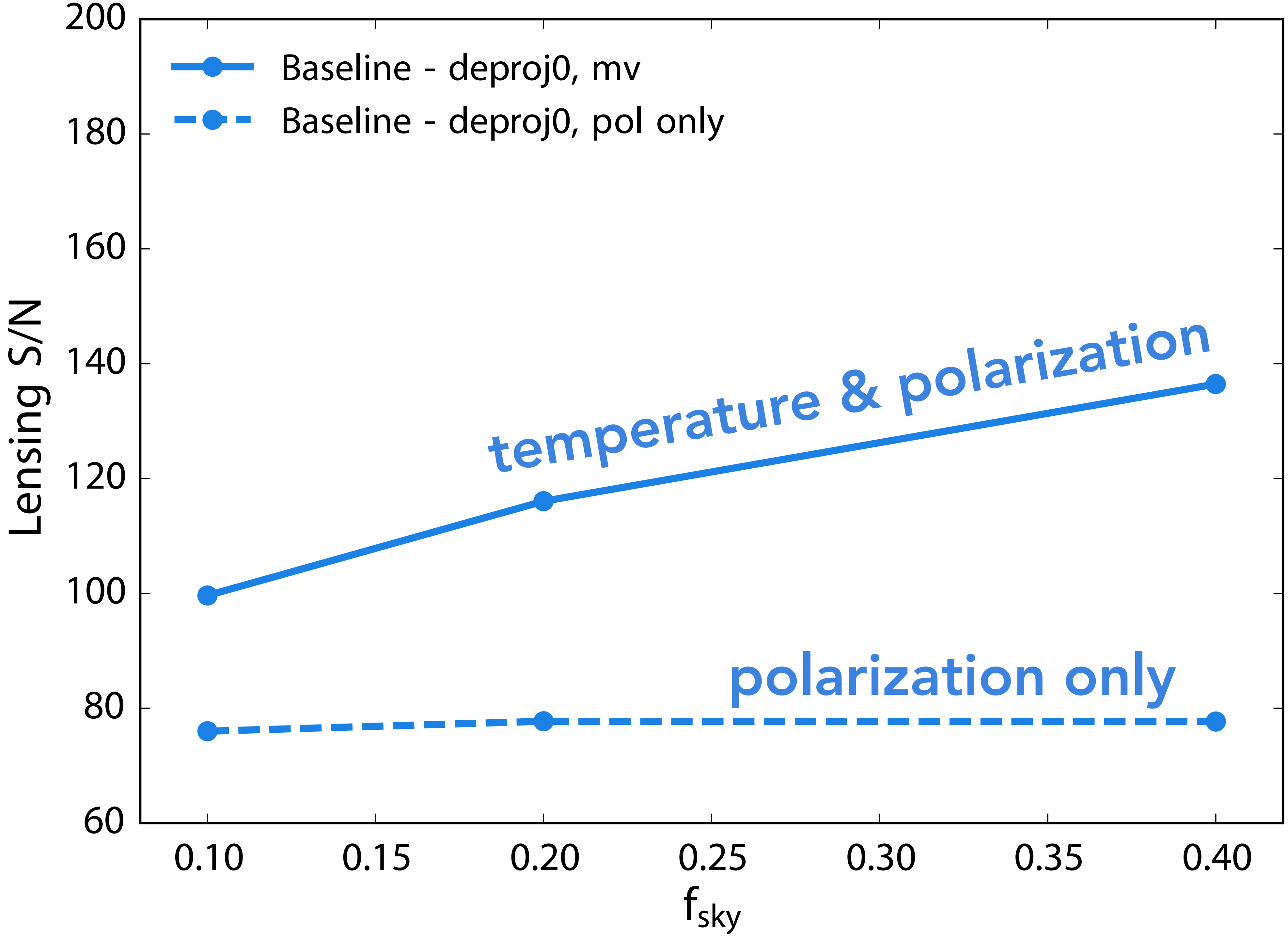
Multi-frequency component separation: noise cost



Colin Hill & SO collaboration

Nulling CIB & tSZ ⇒ Noise power spectrum x ~50

SO lensing relies on temperature



SO Science paper

Shear & magnification estimators

$$\kappa_{\boldsymbol{L}}^{\text{shear/magnification}} = \left(\frac{L^2}{2}\right) \frac{\int \frac{d^2\boldsymbol{\ell}}{(2\pi)^2}\; T_{\boldsymbol{\ell}} T_{\boldsymbol{L}-\boldsymbol{\ell}}\; g_{\boldsymbol{\ell}}}{\boldsymbol{L} \cdot \int \frac{d^2\boldsymbol{\ell}}{(2\pi)^2}\; (\boldsymbol{L}-\boldsymbol{\ell})\, C^0_{\boldsymbol{L}-\boldsymbol{\ell}}\; g_{\boldsymbol{\ell}}}, \tag{2}$$

where

$$\begin{cases} g_{\boldsymbol{\ell}}^{\text{magnification}} = \dfrac{C^0_\ell}{2(C^{\text{total}}_\ell)^2} \dfrac{\partial \ln \ell^2 C^0_\ell}{\partial \ln \ell}, \\[2ex] g_{\boldsymbol{\ell}}^{\text{shear}} = \cos(2\theta_{\boldsymbol{L},\boldsymbol{\ell}}) \dfrac{C^0_\ell}{2(C^{\text{total}}_\ell)^2} \dfrac{\partial \ln C^0_\ell}{\partial \ln \ell}. \end{cases} \tag{3}$$