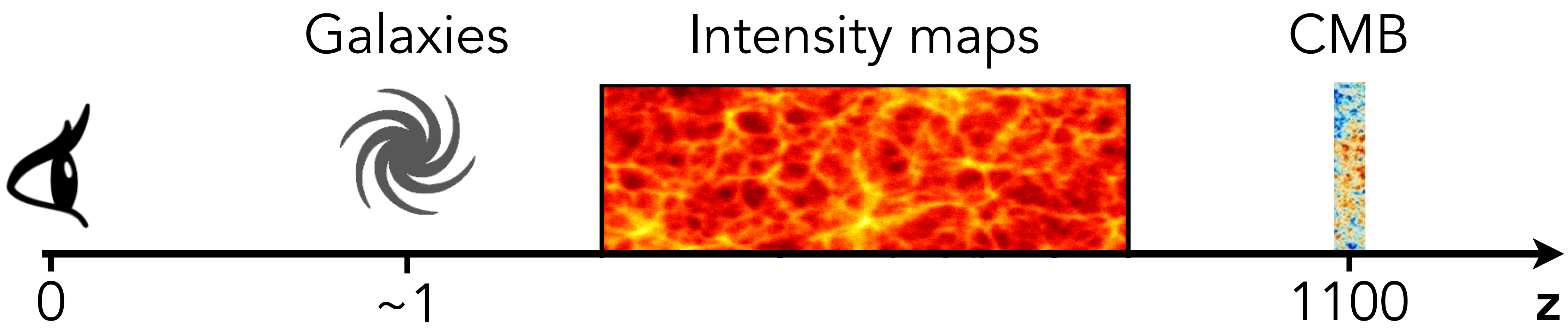
Lensing from intensity maps: lessons learned from the CIB

arxiv:1802.05706, 1804.06403

Emmanuel Schaan, Chamberlain fellow, LBL
Simone Ferraro, David Spergel

Lensing from intensity maps?



Motivation: Enable x-correlations despite missing $k_\parallel$ modes

Simpler modeling

New source plane at intermediate z

Challenges: Foregrounds: line/continuum

3d continuous field *Zahn Zaldarriaga 06, Croft+17, Metcalf+17*

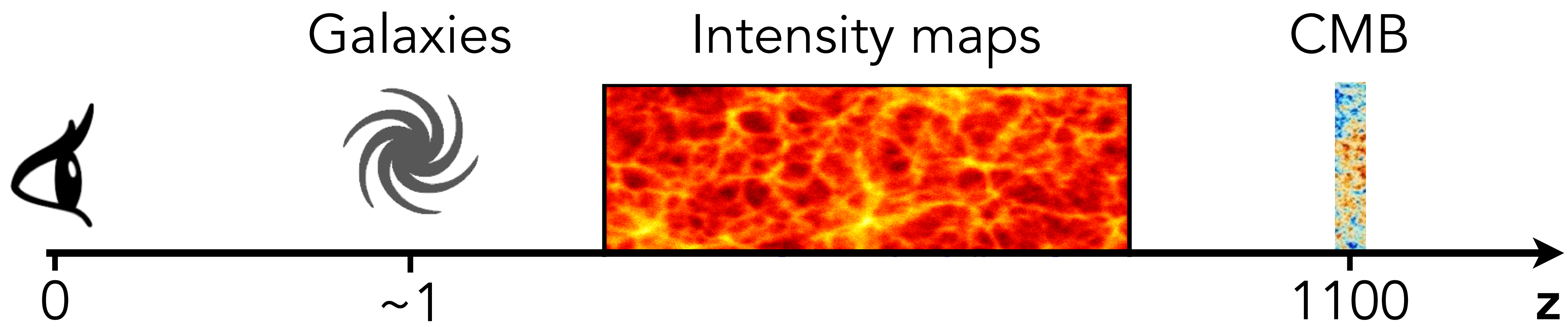
Estimator? *Pen 04, Cooray 04, Zhang+ 05,06,11, Metcalf White 07, Lu Pen 07*

Non-Gaussian source plane *Portsidou Metcalf 13, Foreman+18*

Extended redshift range

Curved sky *Chakraborty Pullen in prep*

Lensing from intensity maps?



Motivation:

Enable x-correlations despite missing $k_\parallel$ modes

Simpler modeling

New source plane at intermediate z

Challenges:

Foregrounds: line/continuum

3d continuous field *Zahn Zaldarriaga 06, Croft+17, Metcalf+17*

Estimator? *Pen 04, Cooray 04, Zhang+ 05,06,11, Metcalf White 07, Lu Pen 07*

Non-Gaussian source plane *Portsidou Metcalf 13, Foreman+18*

Extended redshift range

Curved sky *Chakraborty Pullen in prep*

→ ***Schaan Ferraro Spergel 18***

The CIB as a sandbox

Generic IM properties:

Traces matter at z~2

Complex relation matter-intensity

Weak and modeled non-Gaussianity

Difficult foreground: Milky Way dust

Pros:

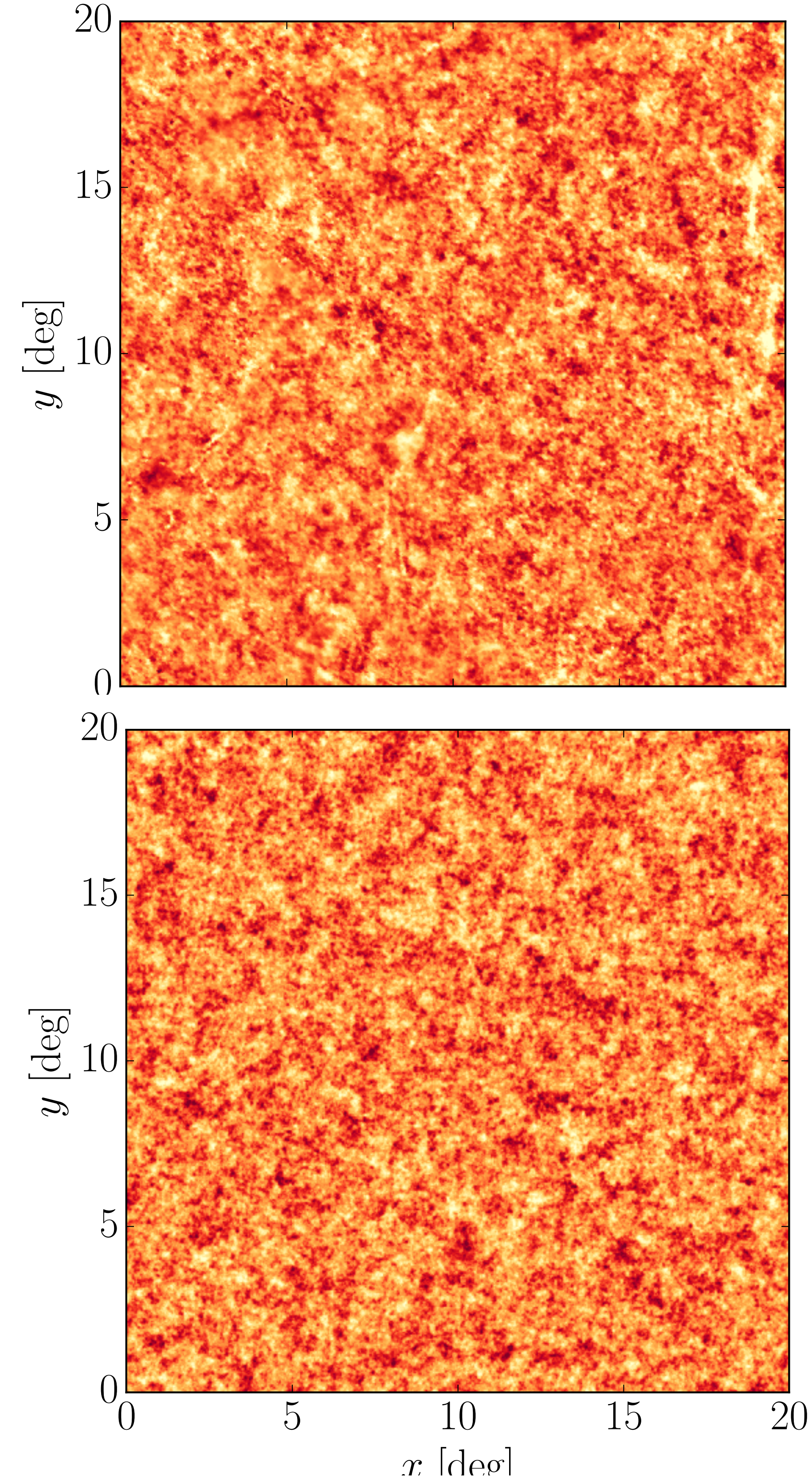
Data exists

Foreground-cleaned maps exist *Herschel, Planck, Lenz+18, …*

Cons:

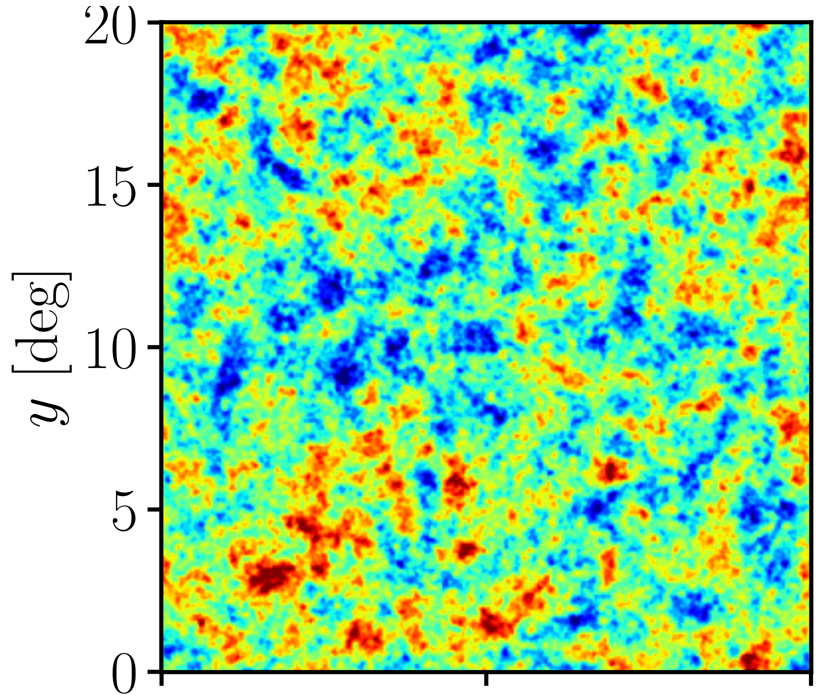
No redshift information

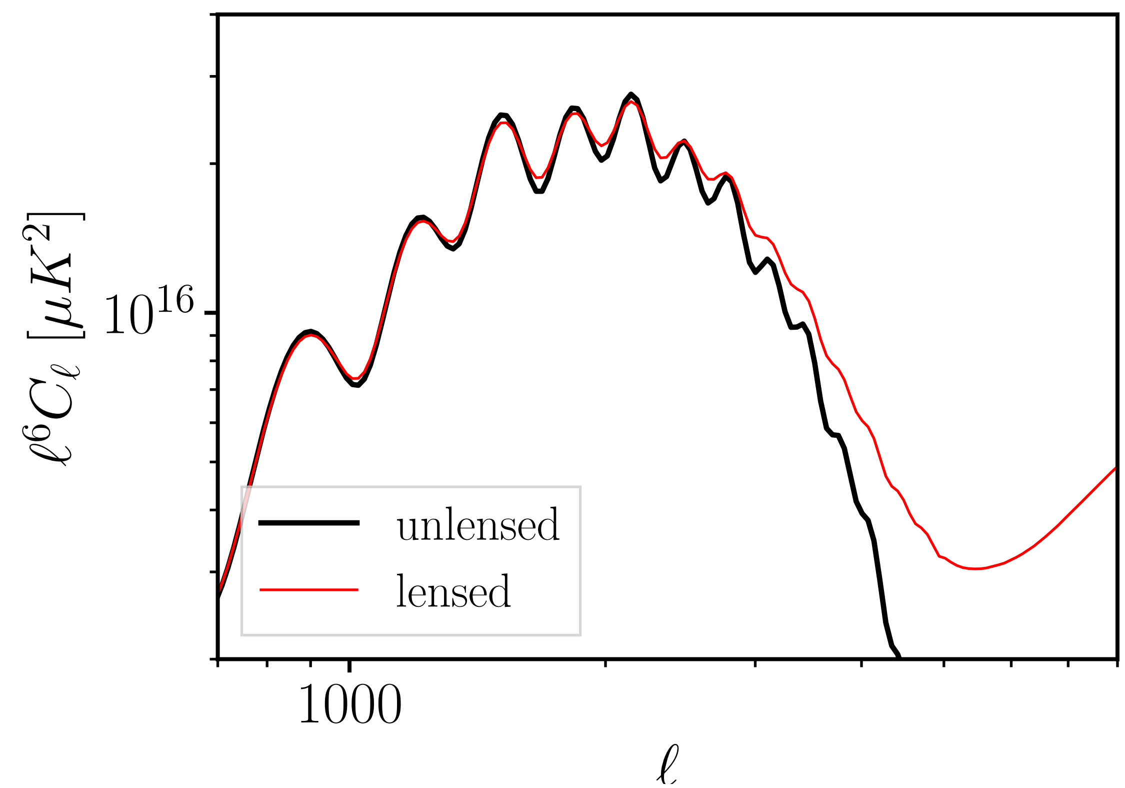
Extends to z=0



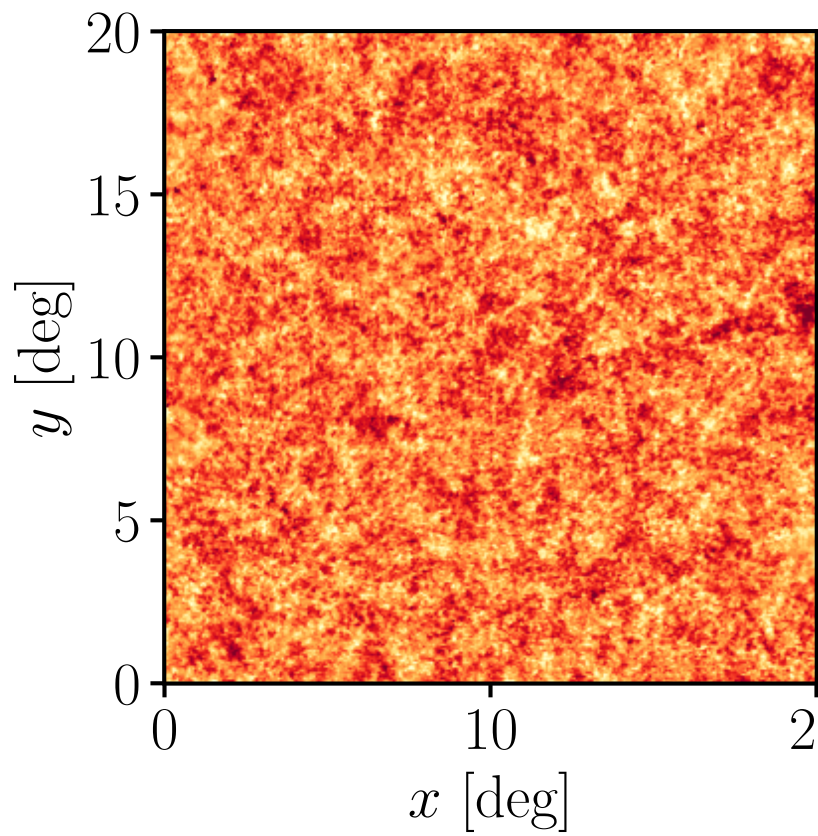
Featureless power → lensed = unlensed

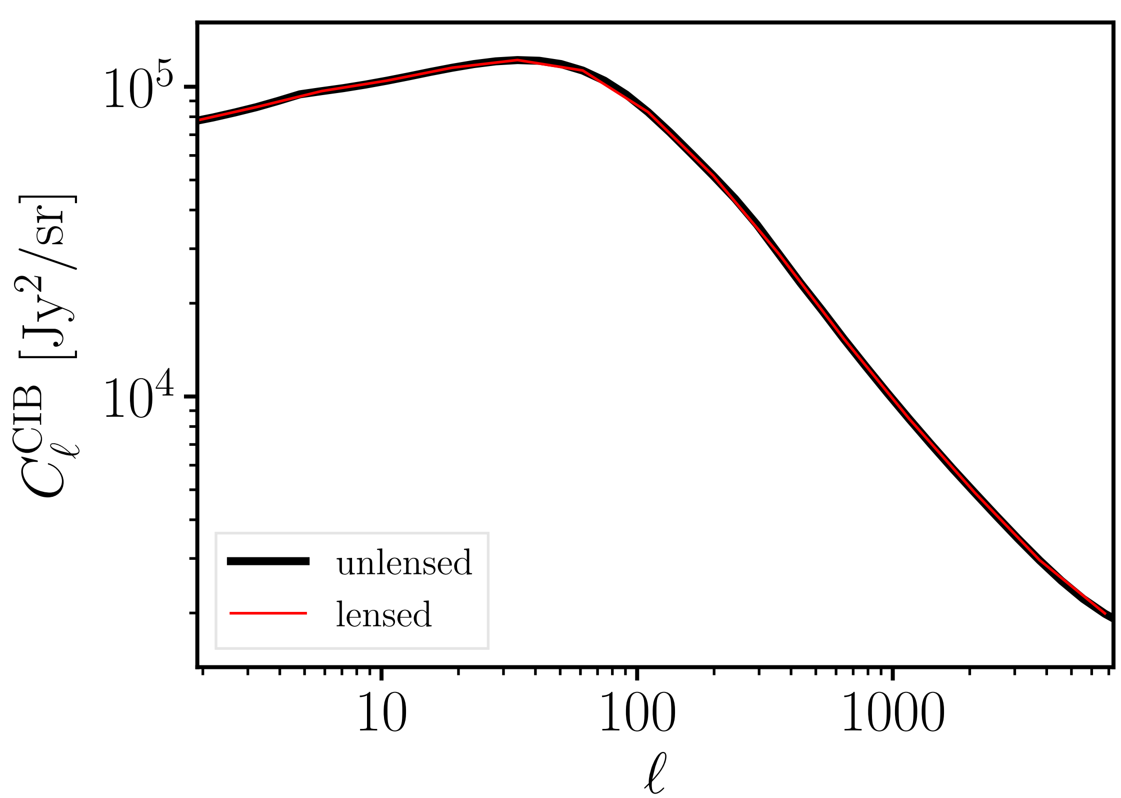
CMB





CIB





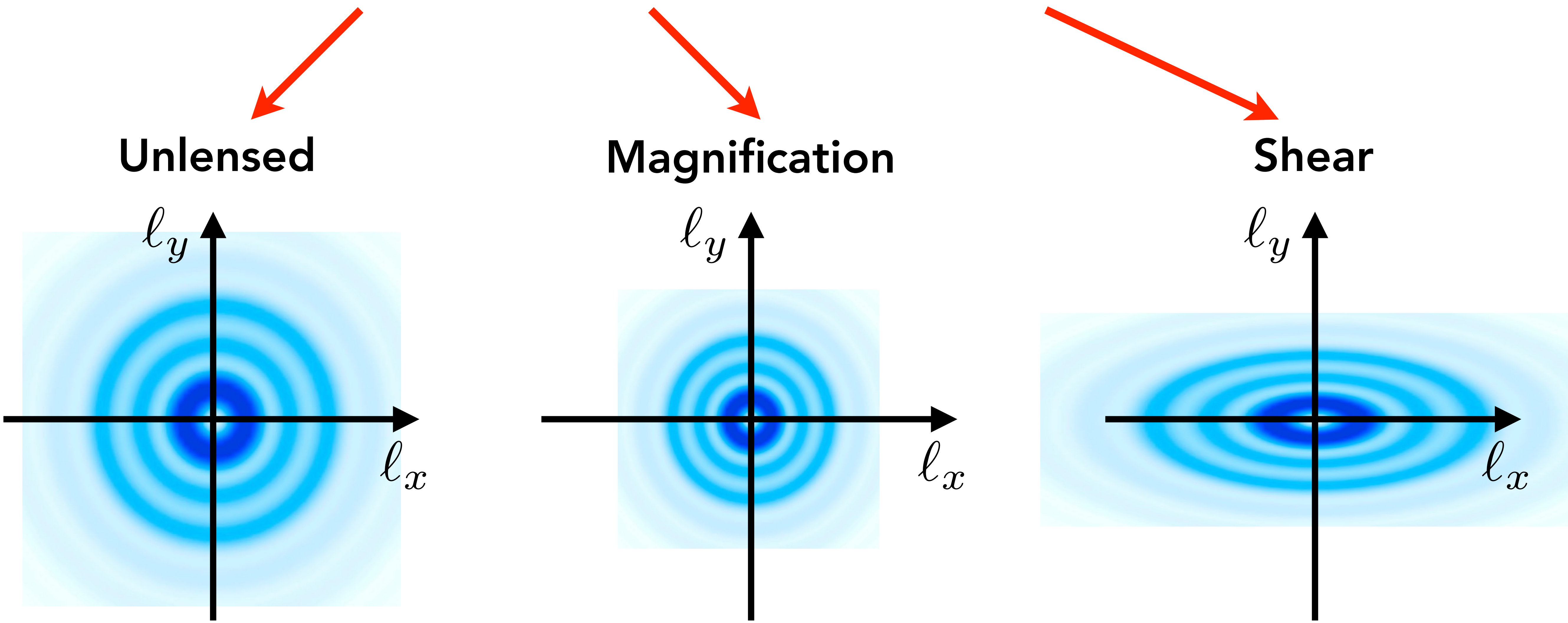
→ Lensing not detectable from mean power spectrum

Emmanuel Schaan

Cooray 04, Lewis Challinor 06, Schaan+18

Lensing is always observable locally

$$C_{\boldsymbol{\ell}} = \underbrace{C^0_\ell}\left[1 + \underbrace{\kappa \frac{\partial \ln \ell^2 C^0_\ell}{\partial \ln \ell}} + \underbrace{\kappa \cos(2\theta_{\boldsymbol{\ell}}) \frac{\partial \ln C^0_\ell}{\partial \ln \ell}} + \mathcal{O}(\kappa^2)\right]$$



→ Measure shear and magnification from local power

Zaldarriaga Seljak 98, Lewis Challinor 06, Lu Pen 08, Lu Pen Doré 09, Bucher+10, Prince+17, Schaan Ferraro18

Non-Gaussianity → Prefer cross over auto

$$\kappa \propto TT \implies \langle \kappa\kappa \rangle \propto \langle TTTT \rangle$$
$$\propto C^2 + \text{trispectrum}$$

Trispectrum is a bias in auto…
→ Difficult to model and subtract

… but simply noise in cross-correlation

$$N^{\kappa}_{\boldsymbol{L}} \sim \left(\frac{\sigma_{C^0}}{C^0}\right)^2 \sim \underbrace{\frac{2\pi}{N_{\text{modes}}}}_{\text{Gaussian noise}} + \underbrace{\frac{\mathcal{T}^0}{4(C^0)^2}}_{\text{non-Gaussian correction}}$$

→ **Lowers SNR** and **modifies optimal lensing weights**

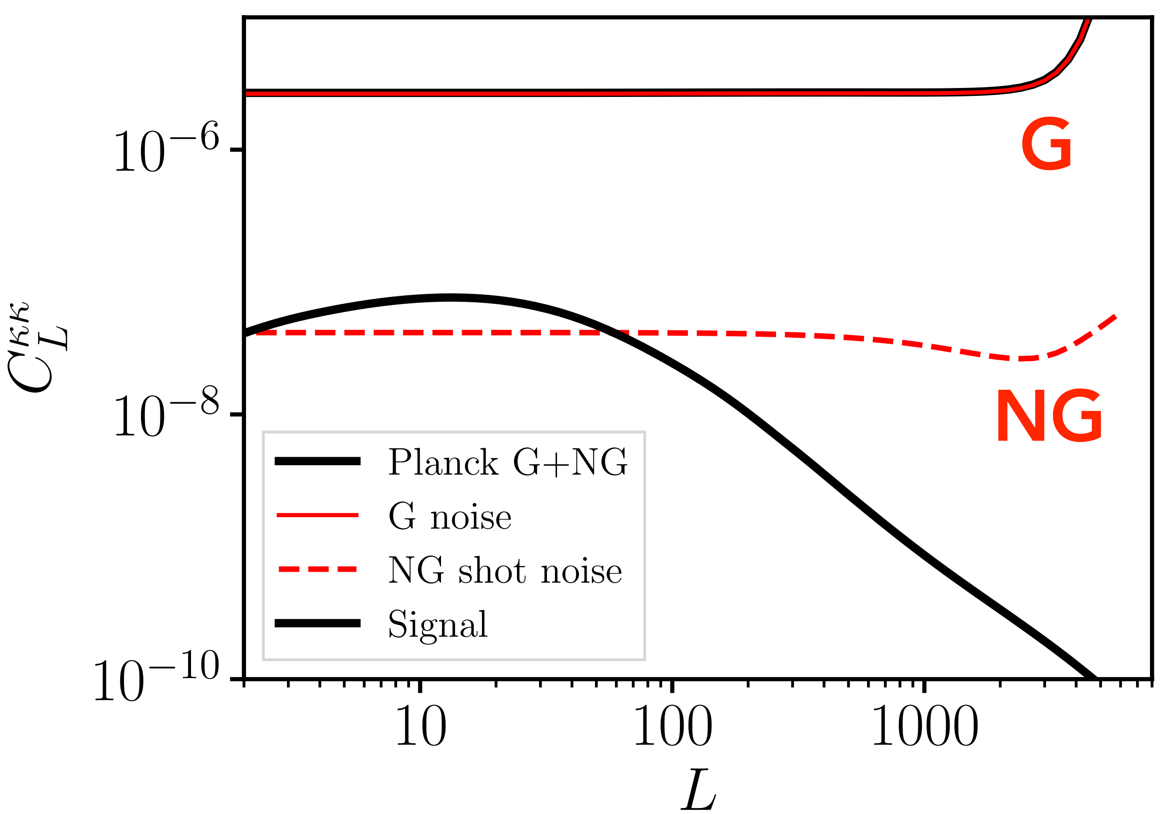
Schaan Ferraro Spergel 18

SNR: angular resolution is key

$$N_{\boldsymbol{L}}^{\kappa} \sim \left(\frac{\sigma_{C^0}}{C^0}\right)^2 \sim \underbrace{\frac{2\pi}{N_{\rm modes}}}_{\text{Gaussian noise}} + \underbrace{\frac{\mathcal{T}^0}{4(C^0)^2}}_{\text{non-Gaussian correction}}$$

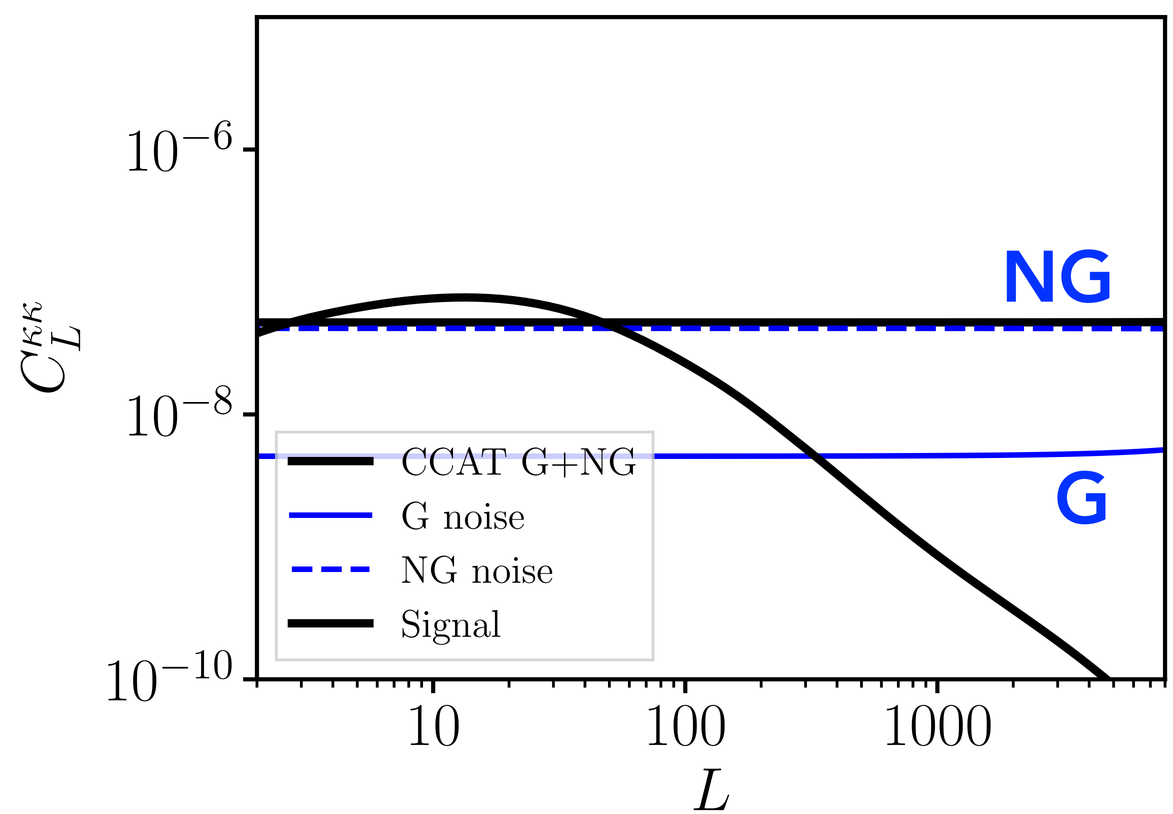
Planck (l=2000):	10^{-6}	+	10^{-8}
CCAT (l=30000):	10^{-8}	+	10^{-7}

Planck



Auto 1σ, Cross 18σ

CCAT



Auto 40σ, Cross 130σ

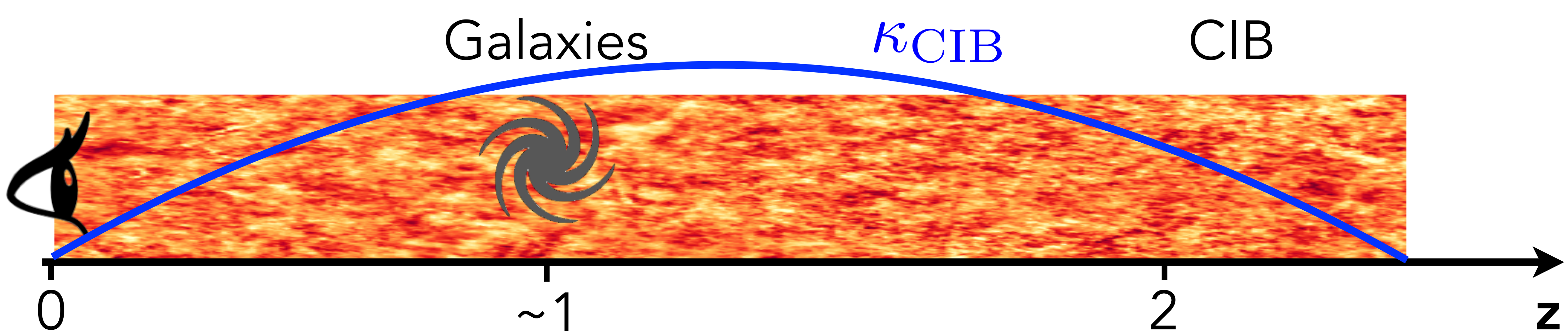
Emmanuel Schaan

Schaan Ferraro Spergel 18

Bispectrum biases cross-correlations

$$\kappa \propto TT \implies \langle g\, \kappa \rangle \propto \langle g\, TT \rangle$$
$$\propto \text{bispectrum}$$

→ **Bispectrum may bias both auto and cross-correlation**



Well-known in CMB lensing van Engelen+14, Osborne+14, Ferraro Hill 18, Schaan Ferraro 18

Shear-convergence split very powerful in Poisson regime Schaan Ferraro 18

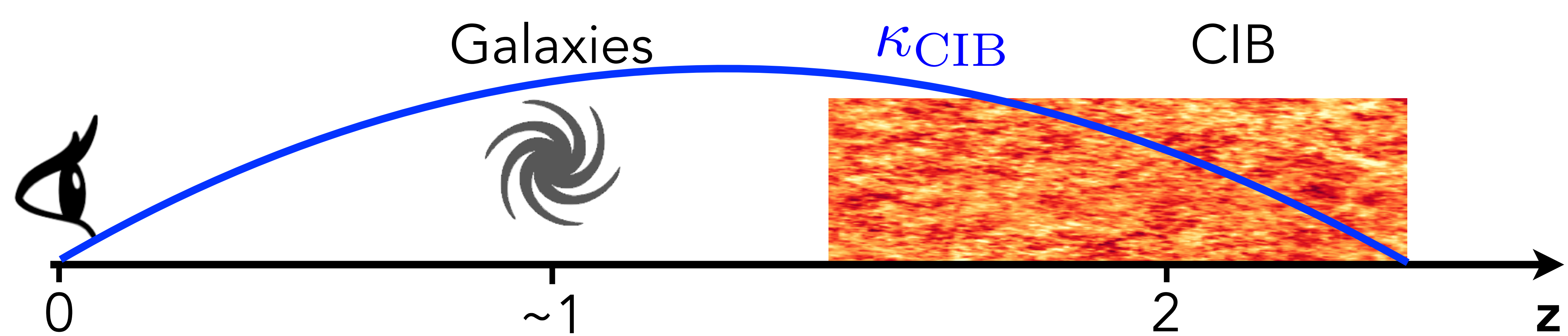
Subtract signal from emission template

Bias-hardening Namikawa+13, Foreman+18

Bispectrum biases cross-correlations

$$\kappa \propto TT \implies \langle g\, \kappa \rangle \propto \langle g\, TT \rangle$$
$$\propto \text{bispectrum}$$

→ Bispectrum may bias both auto and cross-correlation



Well-known in CMB lensing van Engelen+14, Osborne+14, Ferraro Hill 18, Schaan Ferraro 18

Shear-convergence split very powerful in Poisson regime Schaan Ferraro 18

Subtract signal from emission template

Bias-hardening Namikawa+13, Foreman+18

Conclusions

arxiv:1802.0576, arxiv:1804.06403

Lensing from IM enables cross-correlations and simplifies modeling

CIB lensing is detectable; resolution is key

Trispectrum biases auto, but only noise in cross

Bispectrum biases both auto and cross, like in CMB lensing
→ Many mitigation techniques exist

Generalizing the quadratic estimator

$$C_{\boldsymbol{\ell}} = C_\ell^0 \left[1 + \kappa \frac{\partial \ln \ell^2 C_\ell^0}{\partial \ln \ell} + \kappa \cos(2\theta_{\boldsymbol{\ell}}) \frac{\partial \ln C_\ell^0}{\partial \ln \ell} + \mathcal{O}(\kappa^2) \right]$$

Set of estimators: $\langle \dfrac{T_{\boldsymbol{\ell}} T_{\boldsymbol{L}-\boldsymbol{\ell}}}{f_{\boldsymbol{\ell},\boldsymbol{L}-\boldsymbol{\ell}}} \rangle_{\text{fixed } \kappa} = \kappa_{\boldsymbol{L}} \; + \; \mathcal{O}(\phi^2)$

→ Combine by inverse-variance weighting

Gaussian case:

$$\kappa_{\boldsymbol{L}} = \frac{\sum_{\boldsymbol{\ell}} \left(\frac{T_{\boldsymbol{\ell}} T_{\boldsymbol{L}-\boldsymbol{\ell}}}{f_{\boldsymbol{\ell},\boldsymbol{L}-\boldsymbol{\ell}}} \right) / \sigma_{\boldsymbol{\ell}}^2}{\sum_{\boldsymbol{\ell}} 1/\sigma_{\boldsymbol{\ell}}^2}$$

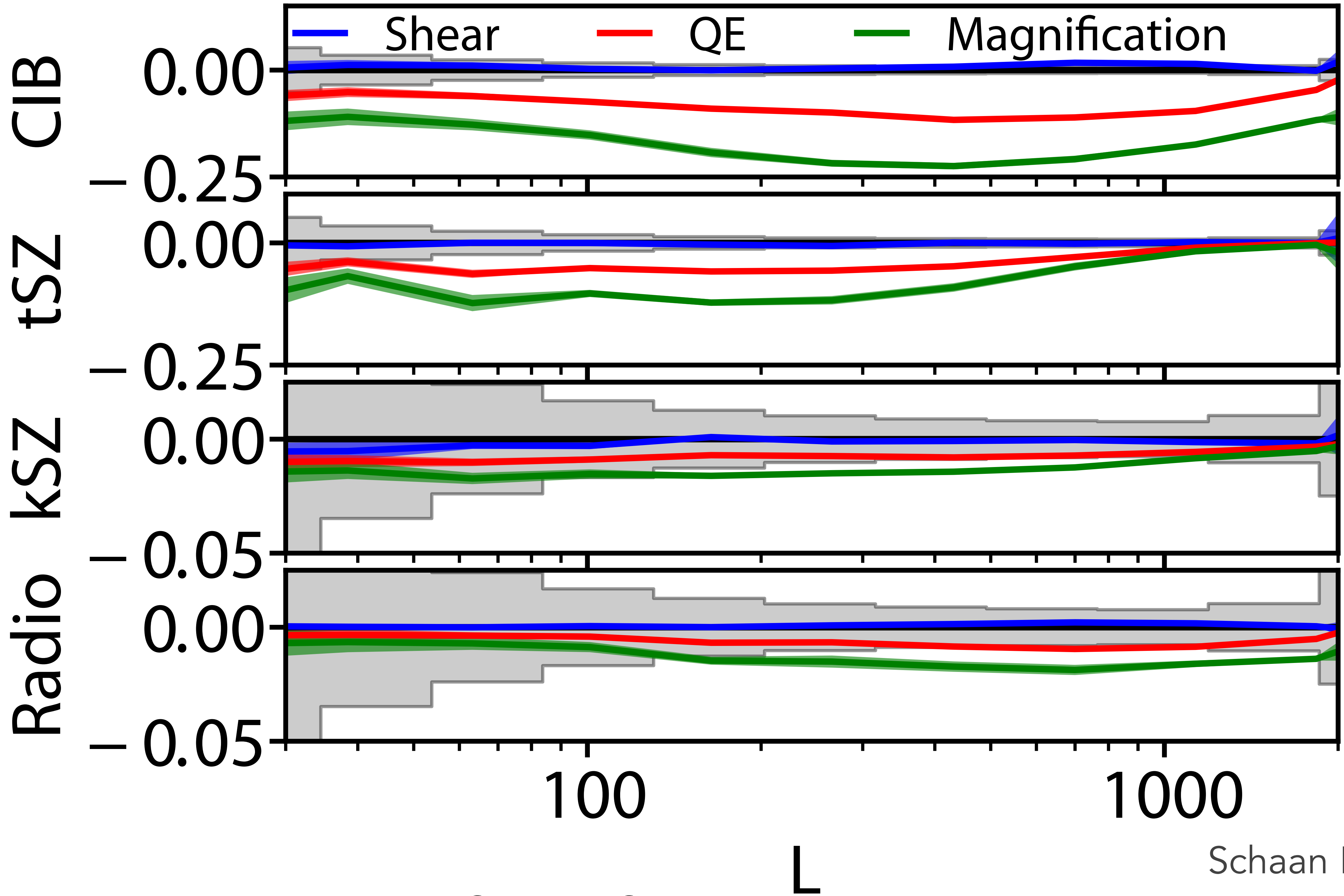
Non-Gaussian case:

$$\kappa_{\boldsymbol{L}} = \frac{\sum_{\boldsymbol{\ell}} \left(\frac{T_{\boldsymbol{\ell}} T_{\boldsymbol{L}-\boldsymbol{\ell}}}{f_{\boldsymbol{\ell},\boldsymbol{L}-\boldsymbol{\ell}}} \right) \sum_{\boldsymbol{\ell}'} \sigma_{\boldsymbol{\ell},\boldsymbol{\ell}'}^{-1}}{\sum_{\boldsymbol{\ell},\boldsymbol{\ell}'} \sigma_{\boldsymbol{\ell},\boldsymbol{\ell}'}^{-1}}$$

→ **CIB trispectrum modifies the optimal weights**

→ **Extra noise & noise bias in auto-correlation**

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



Schaan Ferraro 18

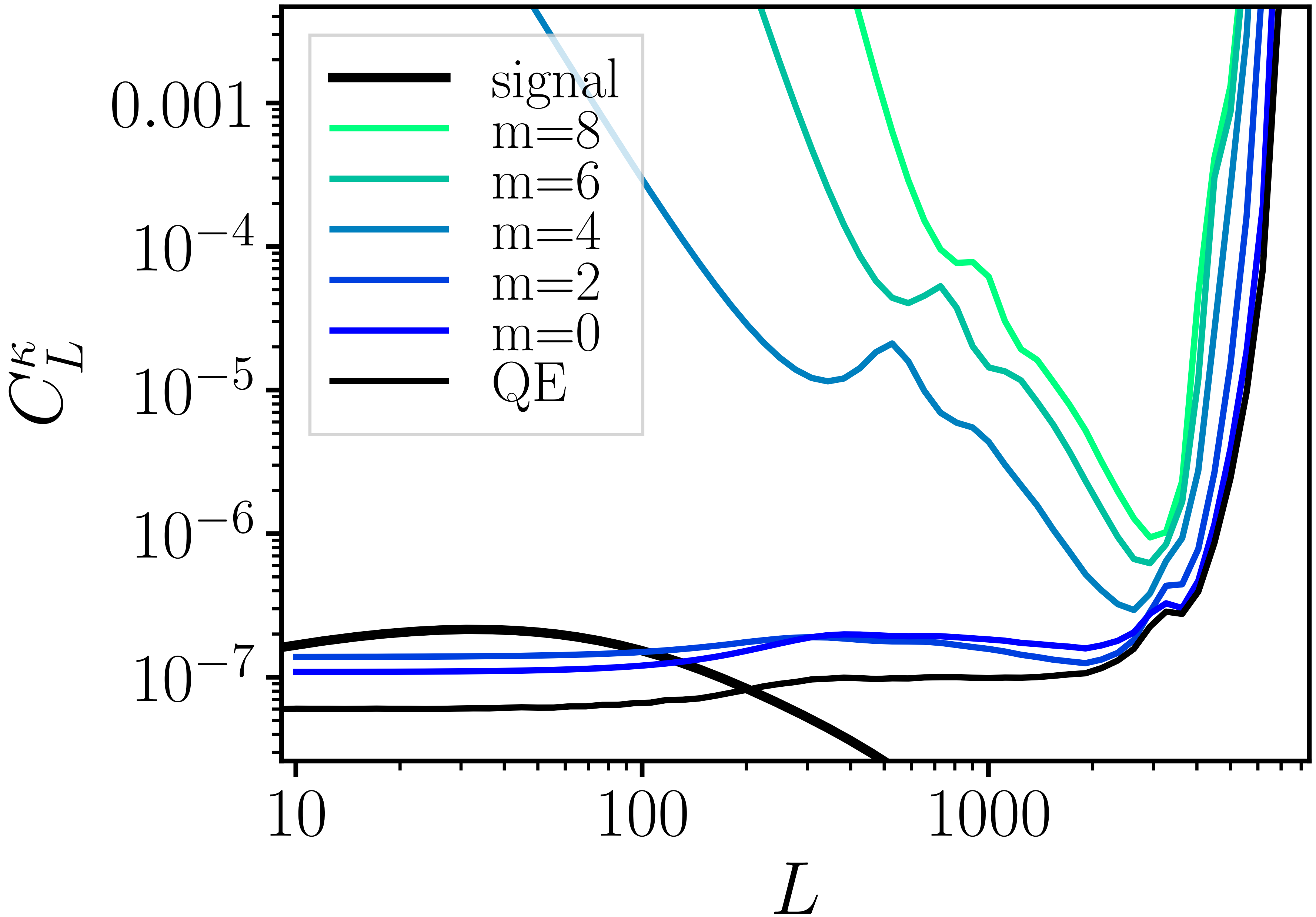
→ **Very significant foreground biases in QE**

→ **Dramatic improvement with shear!**

→ **Magnification: sensitive null test**

Solution? Shear/magnification for CMB

Schaan Ferraro 2018 (arxiv:1804.06403)



Dramatically reduce foreground contamination

Push to smaller scales

Double effective survey area

Emmanuel Schaan