上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

SJTUPA
上海交通大学物理与天文学院

Seeking Lensing Effects from Counting Galaxies

Yu Yu 余瑜

Shanghai Jiao Tong University

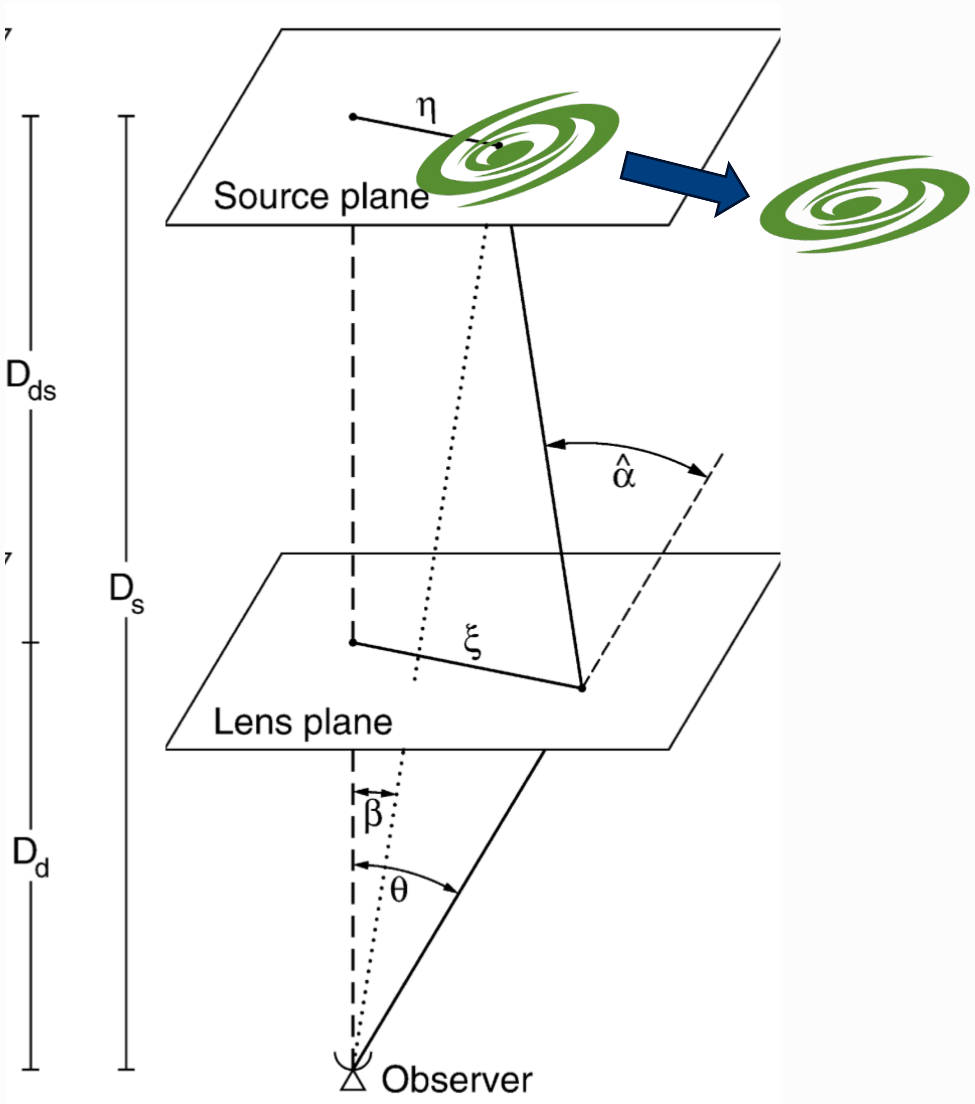
Texas in Shanghai

2023-12-15

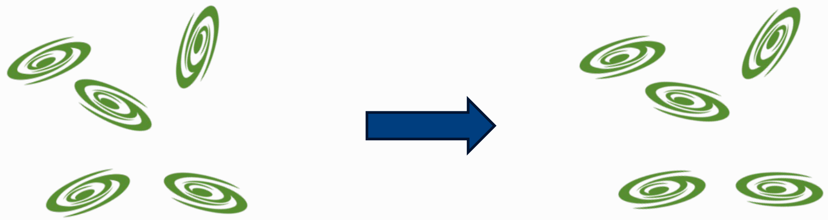
Content

- Cosmic shear & magnification
- Modified internal linear combination method
- Optimal Weighting method
- Application of MILC on observation
- Summary

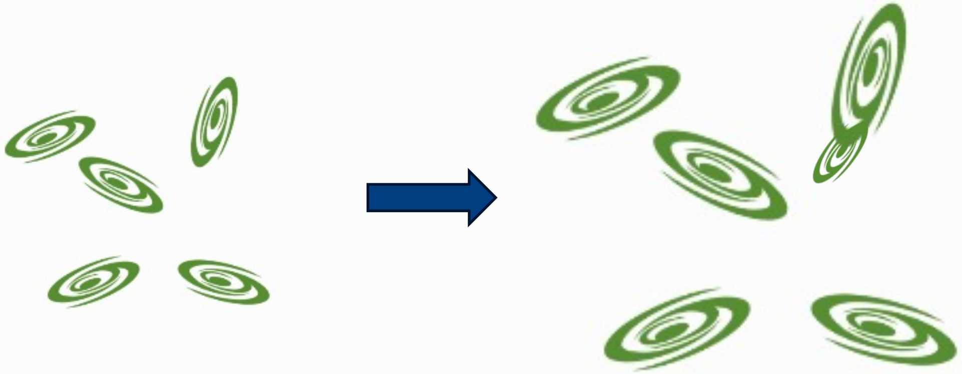
cosmic shear & cosmic magnification



coherent change in galaxy shape: cosmic shear



(de)magnify the galaxy image/sky area: cosmic magnification



change in galaxy number density

Bartelmann & Schneider 2001, Munshi et al. 2008

Cosmic Shear v.s. Cosmic Magnification

$$e^L = e_{\mathrm{IA}} + \underline{\gamma} + e^S$$

- intrinsic alignment
- cosmic shear
- shape noise

$$\delta^L = \delta_g + \underline{g\kappa} + \delta^S$$

- intrinsic clustering
- cosmic magnification
- shot noise

$$g = 2(a-1)\,, \quad a = -\frac{d \ln n(F)}{d \ln F} - 1$$

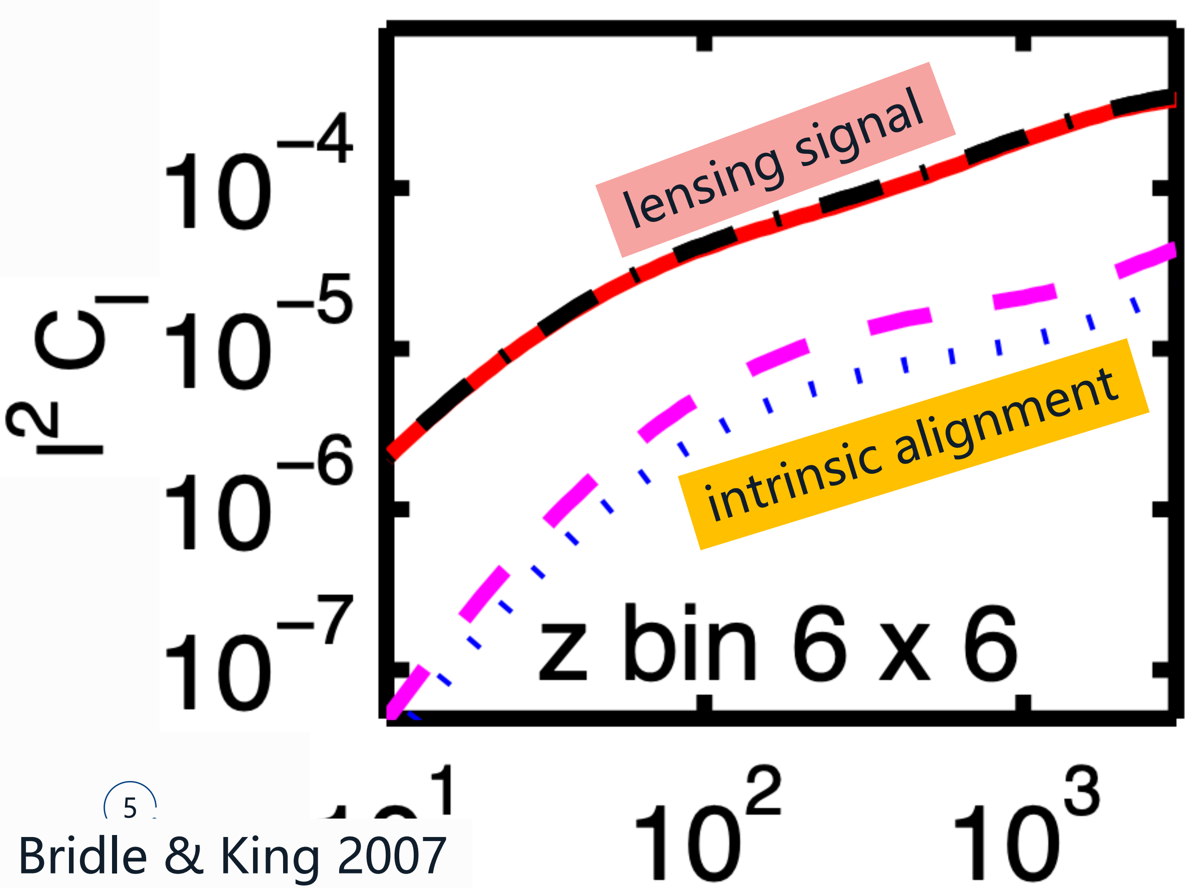
observable

observable

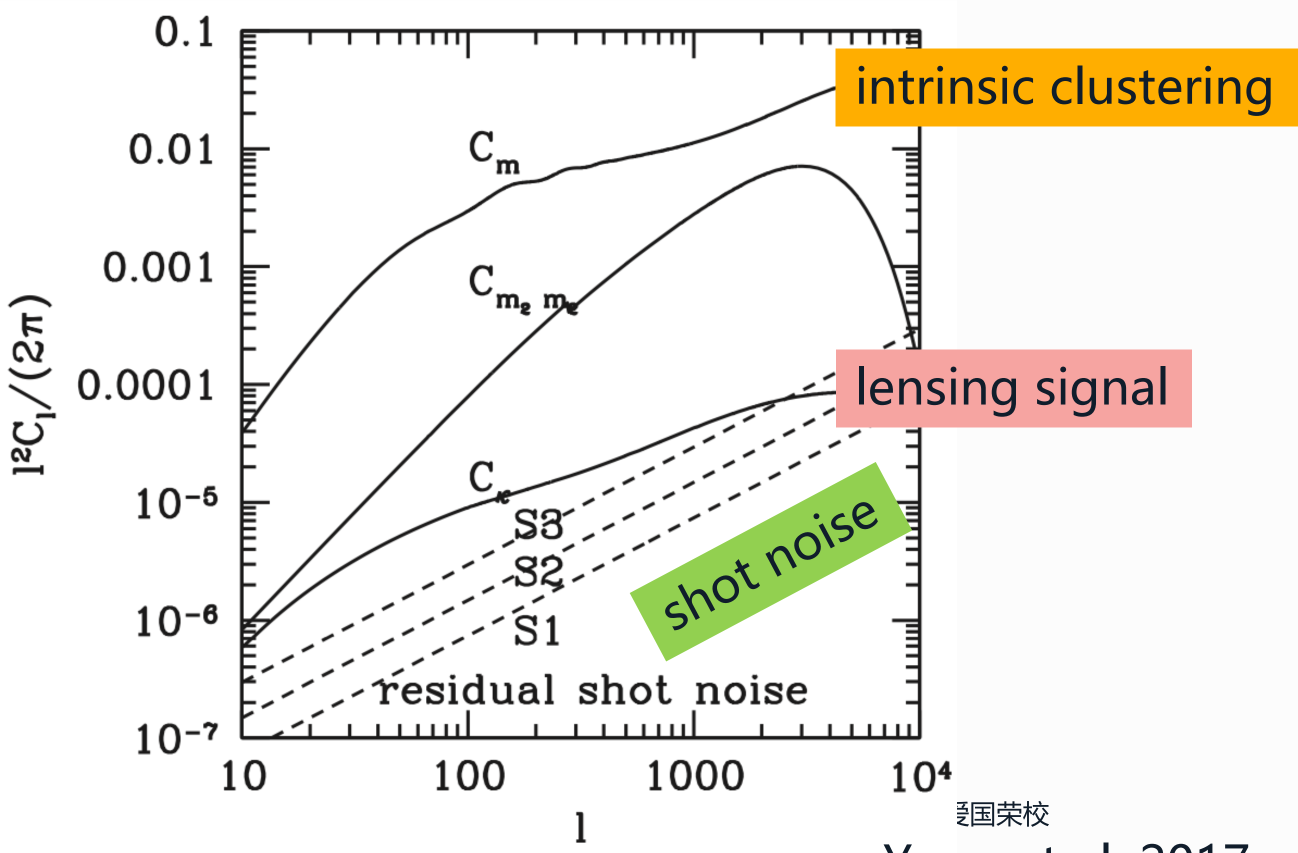
Cosmic Shear v.s. Cosmic Magnification

Much more challenge !

$$e^L = e_{\mathrm{IA}} + \underline{\gamma} + e^S \qquad \delta^L = \delta_g + \underline{g\kappa} + \delta^S$$



Bridle & King 2007



Yang et al. 2017

Magnification History

- Cross correlate two Gal/QSO samples far from each other:

SDSS QSO X SDSS LRG, Scranton et al. 2005

CFHTLS X LBG $2.5<z<5$, Hildebrandt et al. 2009, 2013

SDSS X HerMES submillimetre galaxies, $z\sim2$, Wang et al. 2011; González-Nuevo et al. 2014; Bonavera et al. 2021; González-Nuevo et al. 2021

DES SV X DES SV Garcia-Fernandez et al. 2018

$$<\delta_f \delta_b> \rightarrow <\delta_f \kappa_b>$$, suffer from galaxy bias

Indirect measurement

No magnification map

- HSC cosmic shear ->convergence X HSC galaxy Liu et al. 2021

$$<\kappa_f \delta_b> \rightarrow <\kappa_f \kappa_b>$$, free from galaxy bias

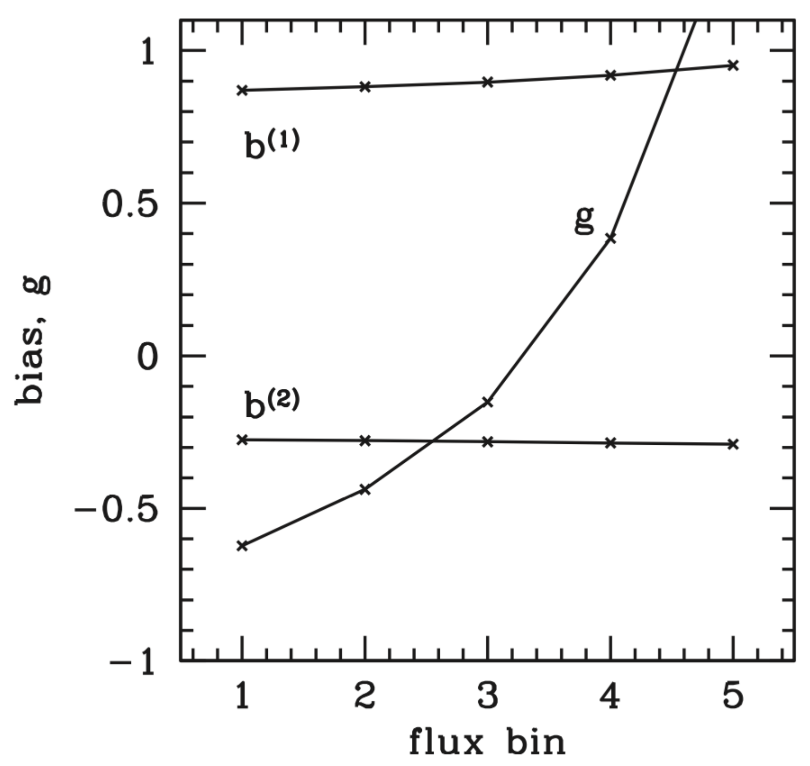
Magnification History

- Separate the lensing signal using the known dependence on the prefactor g

$$\delta^L = b\delta_m + g\kappa + \delta^S$$

$$g = 2(a-1)\,, \quad a = -\frac{d\ln n(F)}{d\ln F} - 1$$

observable



Proposed in Zhang & Pen 2005

Analytically validated in Yang & Zhang (2011); Yang et al. (2015)

Analytic Blind Separation Yang et al. 2017; Zhang et al. 2018)

…

We want a magnification map!

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Content

arXiv: 2106.09970
Shutong HOU +

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Cosmic Magnification v.s. CMB observation

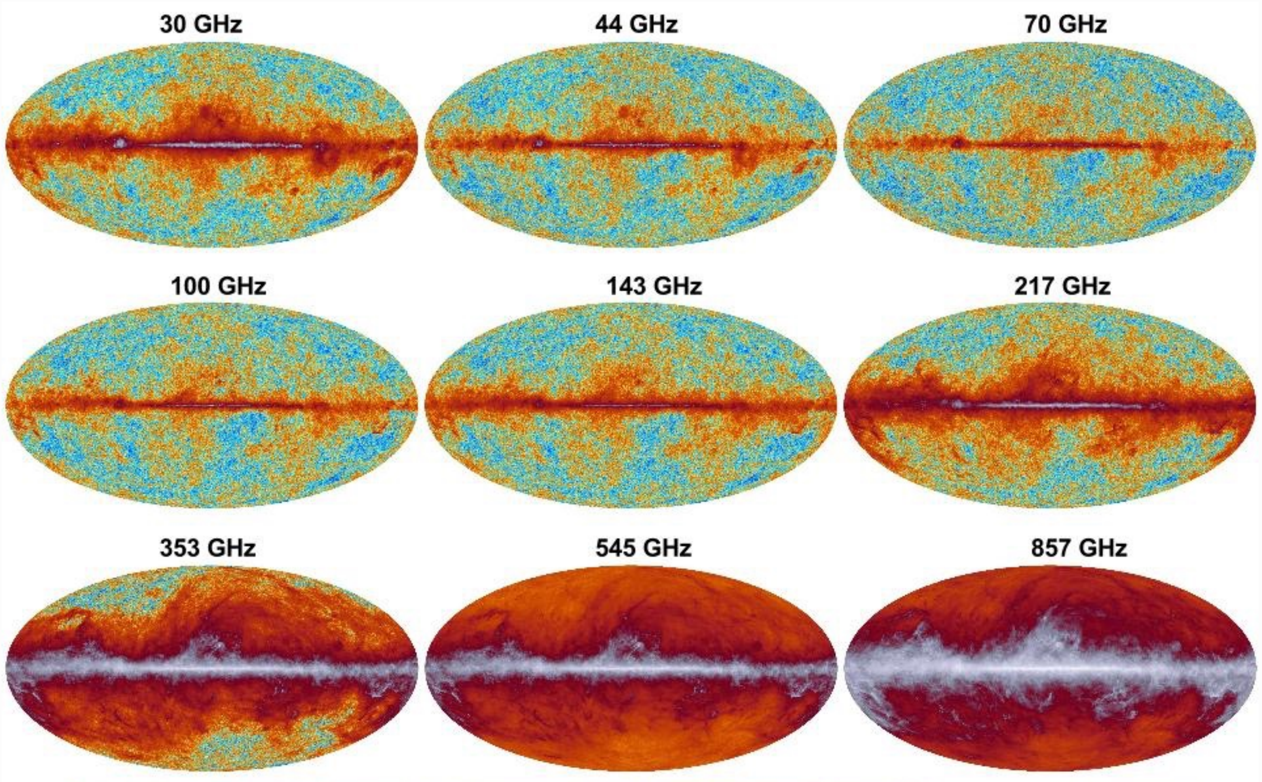
$$\delta^L = \delta_g + \underline{g\kappa} + \delta^S$$

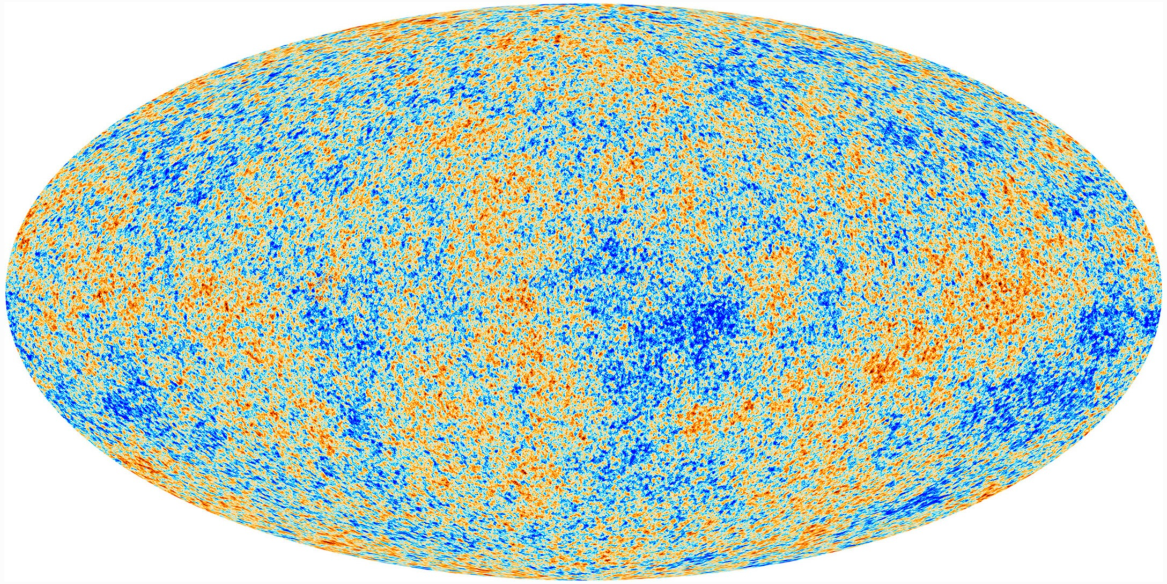
- intrinsic clustering
- cosmic magnification
  known dependence on g
- shot noise

$$T^{\rm obs} = T_{\rm fore} + \underline{T_{\rm CMB}} + T_{\rm noise}$$

- foreground contamination
- CMB
  known dependence on frequency
- instrument noise

foreground removal in CMB





- template fitting
- internal linear combination (ILC)
- …

Cosmic Magnification: Modified ILC

$$\delta^L = \delta_g + g\kappa + \delta^S$$

$$\delta^L_1 = \delta_{g,1} + g_1\underline{\kappa} + \delta^S_1$$

$$\delta^L_2 = \delta_{g,2} + g_2\underline{\kappa} + \delta^S_2$$

$$\vdots \qquad \vdots$$

$$\delta^L_n = \delta_{g,n} + g_n\underline{\kappa} + \delta^S_n$$

Divide into subsamples according to some galaxy property

Modified internal linear combination

If g_i is known, we can construct an estimator

$$\hat{\kappa} = \sum_i w_i \delta^L_i = \sum_i w_i \delta_{g,i} + \underline{\kappa} \sum_i w_i g_i + \sum_i w_i \delta^S_i$$

$$\left[\begin{array}{ll} \sum_i w_i = 0 & \Rightarrow \text{suppress the intrinsic clustering} \\ \sum_i w_i g_i = 1 & \Rightarrow \text{unbiased estimator} \\ \left\langle \left(\sum_i w_i \delta^L_i \right)^2 \right\rangle \text{ minimized} & \Rightarrow \text{minimize the noise} \end{array}\right.$$

Cosmic Magnification: Modified ILC

If g_i is known, we can construct an estimator

$$\hat{\kappa} = \sum_i w_i \delta_i^L = \sum_i w_i \delta_{g,i} + \underline{\kappa} \sum_i w_i g_i + \sum_i w_i \delta_i^S$$

$$\begin{cases} \sum_i w_i = 0 \\ \sum_i w_i g_i = 1 \\ \left\langle \left(\sum_i w_i \delta_i^L \right)^2 \right\rangle \end{cases}$$

minimized

- $\sum_i w_i = 0$ → suppress the intrinsic clustering
- $\sum_i w_i g_i = 1$ → unbiased estimator
- $\left\langle \left(\sum_i w_i \delta_i^L \right)^2 \right\rangle$ minimized → minimize the noise

- $\sum_i w_i \delta_{g,i} \neq 0$ → additive bias
- $\sum_i w_i g_i \neq 1$ → multiplicative bias
- → statistical uncertainty

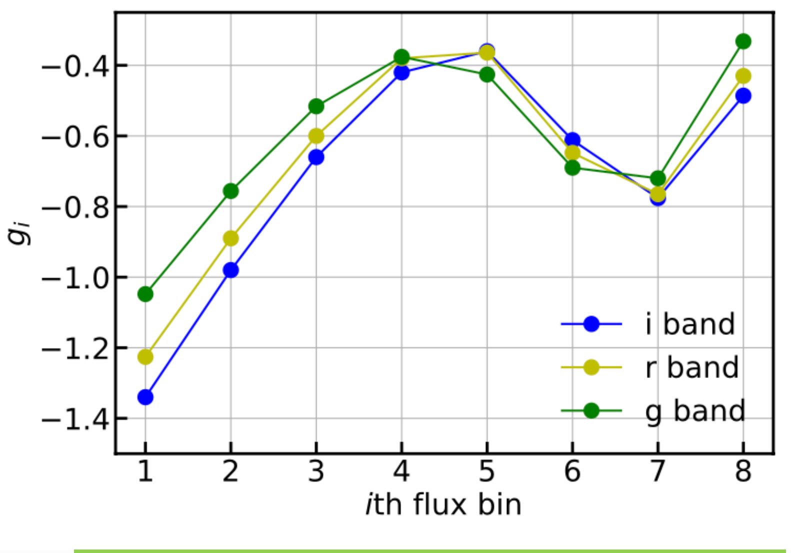
Numerical Validation

We use FASTPM to generate 200 halo catalogue at z=1, each spanning 10*10 deg^2.

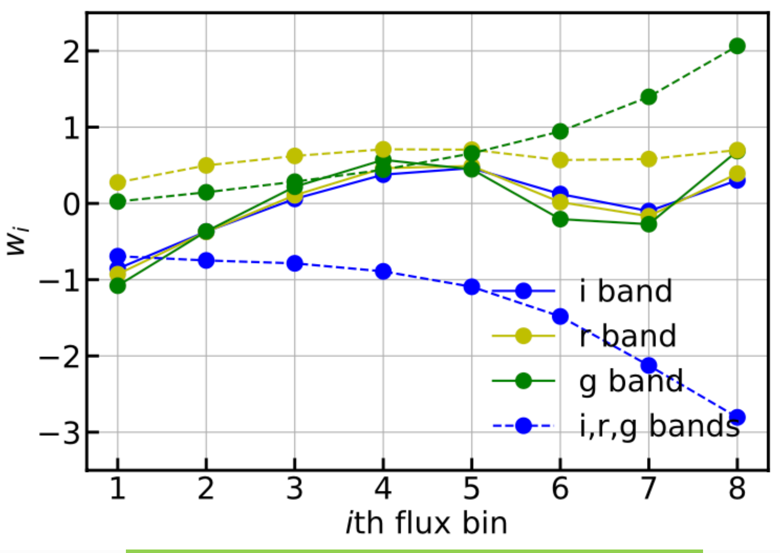
For each halo we randomly pick galaxies with same halo mass from CosmoDC2 catalogue.

We generate Gaussian lensing fields according to nonlinear lensing power spectrum at z=1.

Lensed galaxy catalogue with *r, i, g* band photometry, n ~ 12 arcmin^{-2} for 0.8 < z^P < 1.2.



measure lensing prefactor g



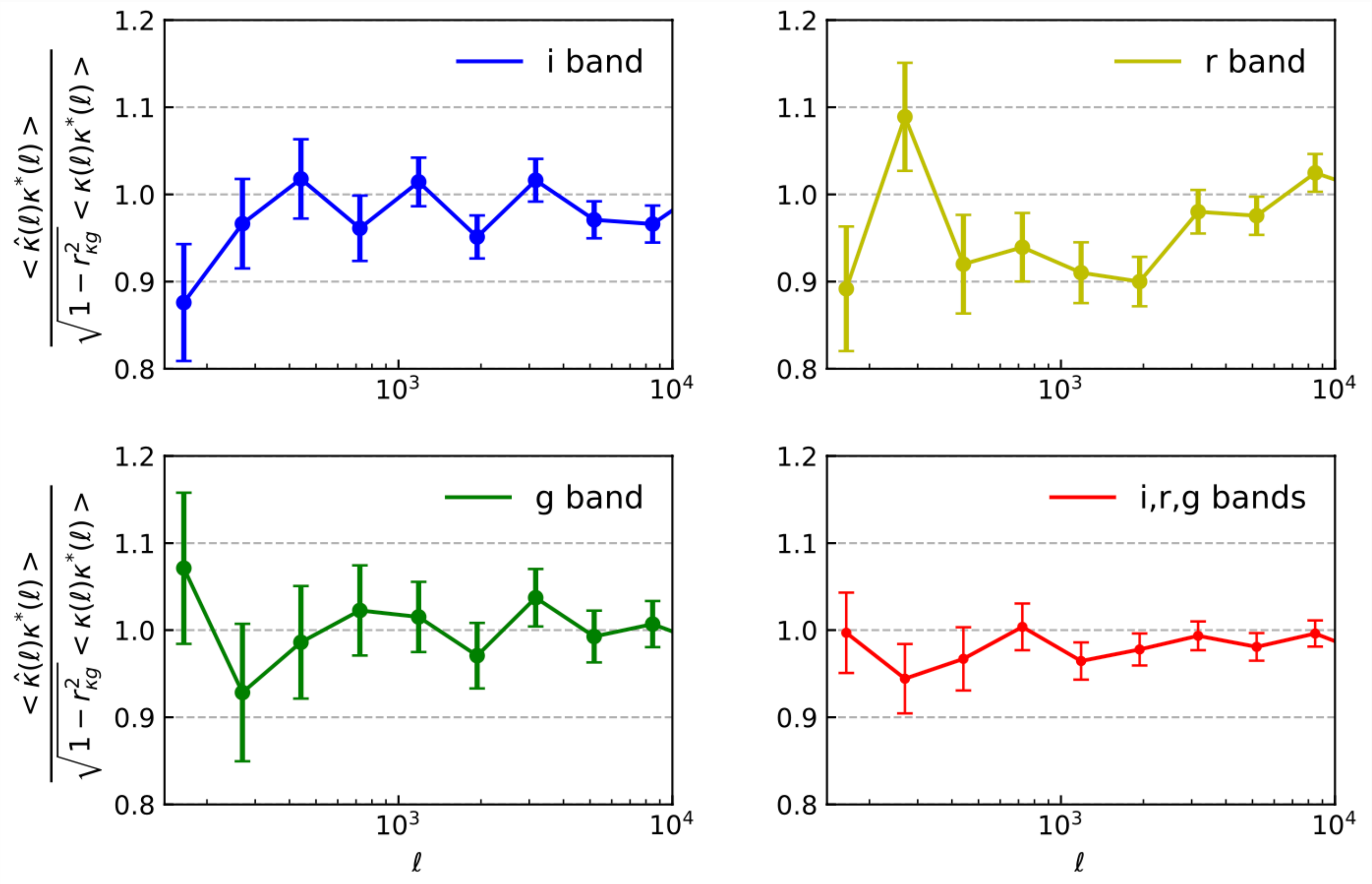
obtain the weighting w

$\hat{\kappa}$ map

$$\hat{\kappa} = \sum_i w_i \delta_i^L$$

Numerical Validation

How much true kappa is contained in the reconstructed kappa map



- Narrow photo-z bin Δz=0.2,

No obvious bias

5% level uncertainty in cross-correlation for LSST-like survey

How to improve ?

$$\delta^L = \delta_g + g\kappa + \delta^S$$

intrinsic clustering

shot noise

$$\sum_i w_i = 0$$

$$\sum_i w_i \delta_{g,i} \neq 0$$

systematic bias

$$\delta^L = b\delta_m + g\kappa + \delta^S$$

deterministic bias

stochasticity

$$\sum_i w_i b_i = 0$$

if bias is known ...

Content

arXiv: 2306.15177
Ruijie MA +

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Bias

$$\delta_{g,1} = b_1 \delta_m \quad \times \quad \delta_{g,2} = b_2 \delta_m$$

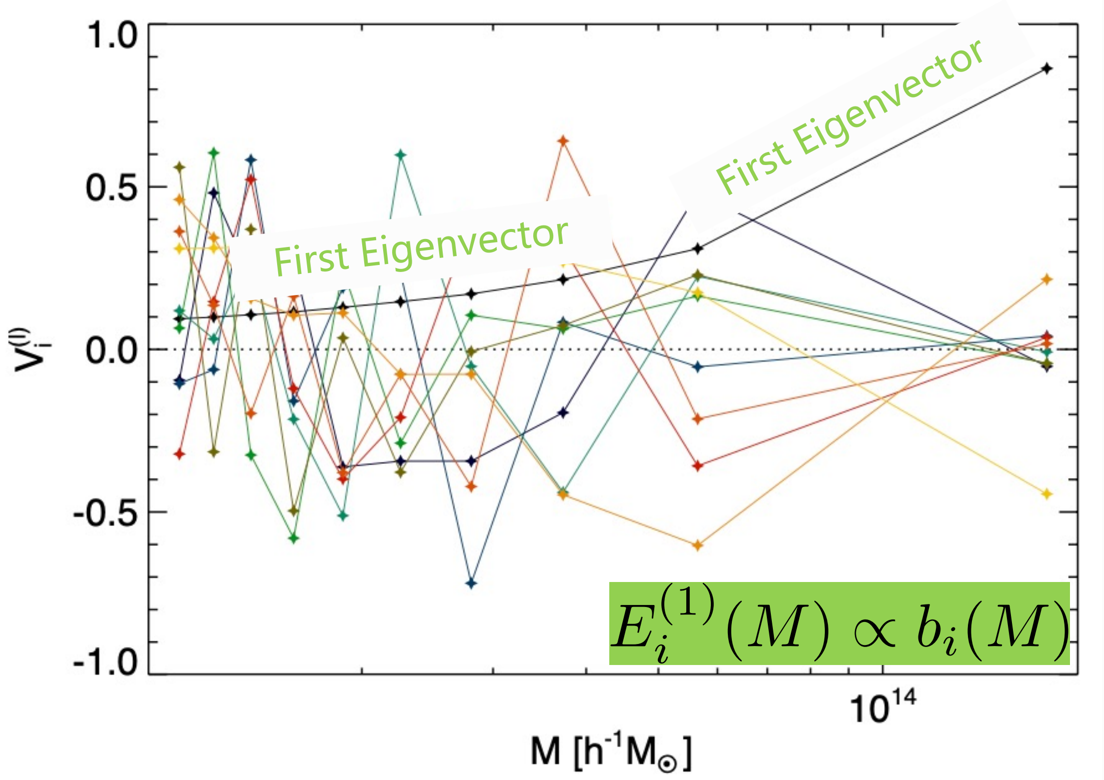
$$\mathbf{C} = \begin{pmatrix} P_{11}(k) & P_{12}(k) \\ P_{12}(k) & P_{22}(k) \end{pmatrix} = \begin{pmatrix} b_1^2 & b_1 b_2 \\ b_1 b_2 & b_2^2 \end{pmatrix} P_m(k)$$

$$E^{(1)} = \frac{1}{\sqrt{b_1^2 + b_2^2}}(b_1, b_2)$$

In ideal case, the relative bias can be measured.

$$\sum_i w_i b_i = 0$$

Bonoli & Pen 2009



Numerical Validation

- CosmicGrowth Suite (Jing 2019)

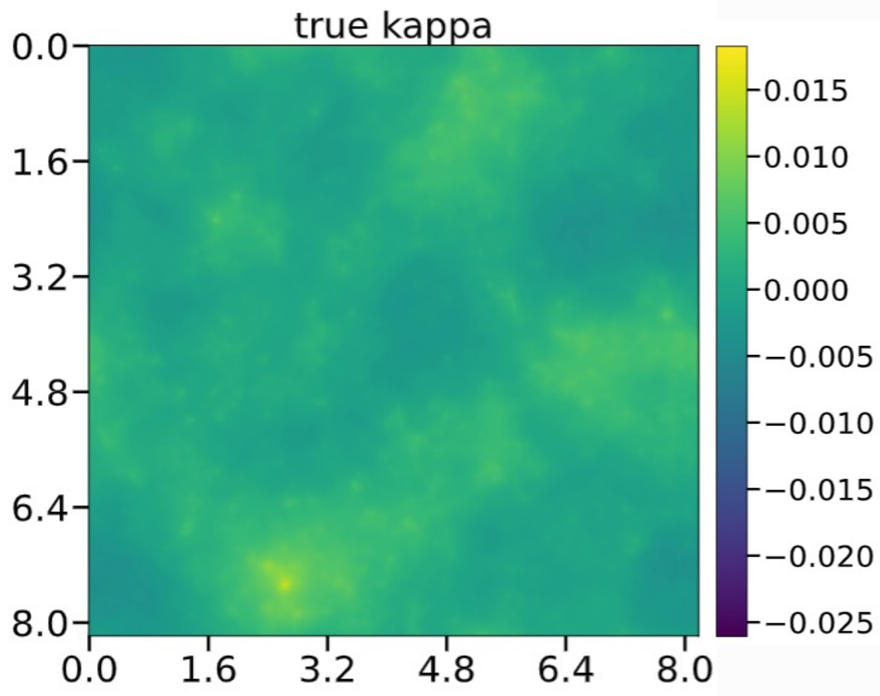
L = 1200 Mpc/h

$N_p = 3072^3$

FoF halo

lightcone 8.2*8.2 deg²

20 lightcones



- CosmoDC2 (Korytov et al. 2019)

440 deg²

ugrizY

Photometry band	u	g	r	i	z	Y
Magnitude cut	26.0	27.3	27.4	26.6	26.1	24.9
$\bar{n}$ of each band(arcmin^{-2})	1.27	9.14	13.97	9.84	7.28	2.04
Number of flux bins	2	5	7	6	4	2

$N_F = 26$

Road map

Galaxy subsamples

- Auto and cross powers to form correlation matrix $\mathbf{C} = \begin{pmatrix} P_{11}(k) & P_{12}(k) \\ P_{12}(k) & P_{22}(k) \end{pmatrix}$
- Eigen decomposition to obtain the first eigen vector $E_i^{(1)} \propto b_i$
- Use this condition $\sum_i w_i E_i^{(1)} = 0$ to find w_i
- $\hat{\kappa} = \sum_i w_i \delta_i^L$

Error budget

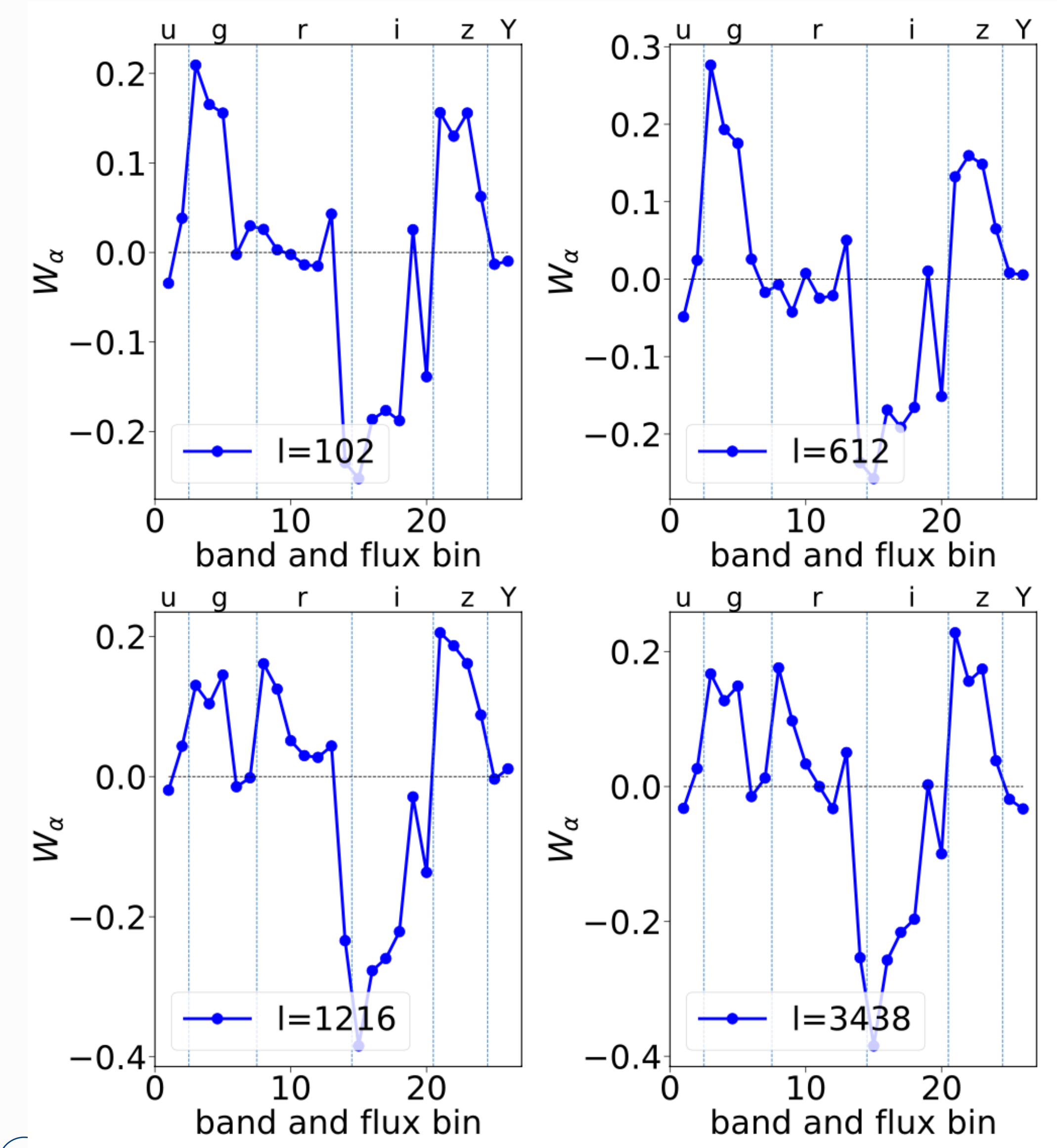
$$\hat{\kappa} = \kappa \sum_i w_i g_i + \delta_m \sum_i w_i b_i + \sum_i w_i \delta_i^S$$

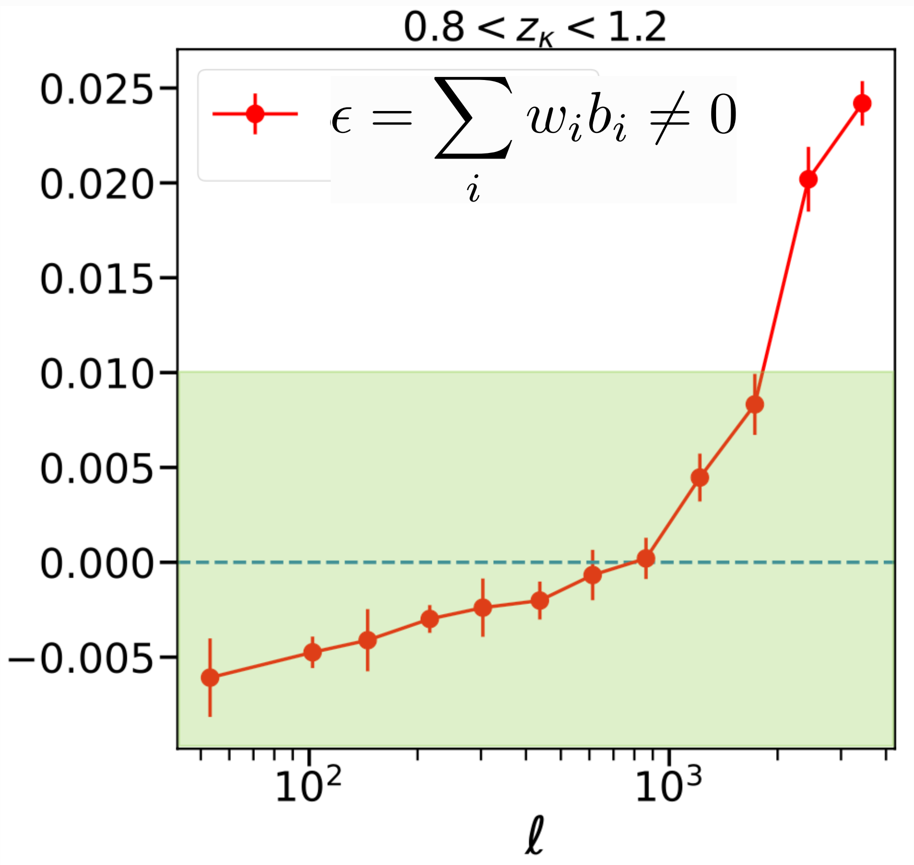
$$= \kappa \qquad + \epsilon \delta_m \qquad + \sum_i w_i \delta_i^S$$

Additive bias Weighted shot noise

$E_i^{(1)} \overset{?}{\propto} b_i \qquad \epsilon = \sum_i w_i b_i \overset{?}{\neq} 0$

Numerical Validation

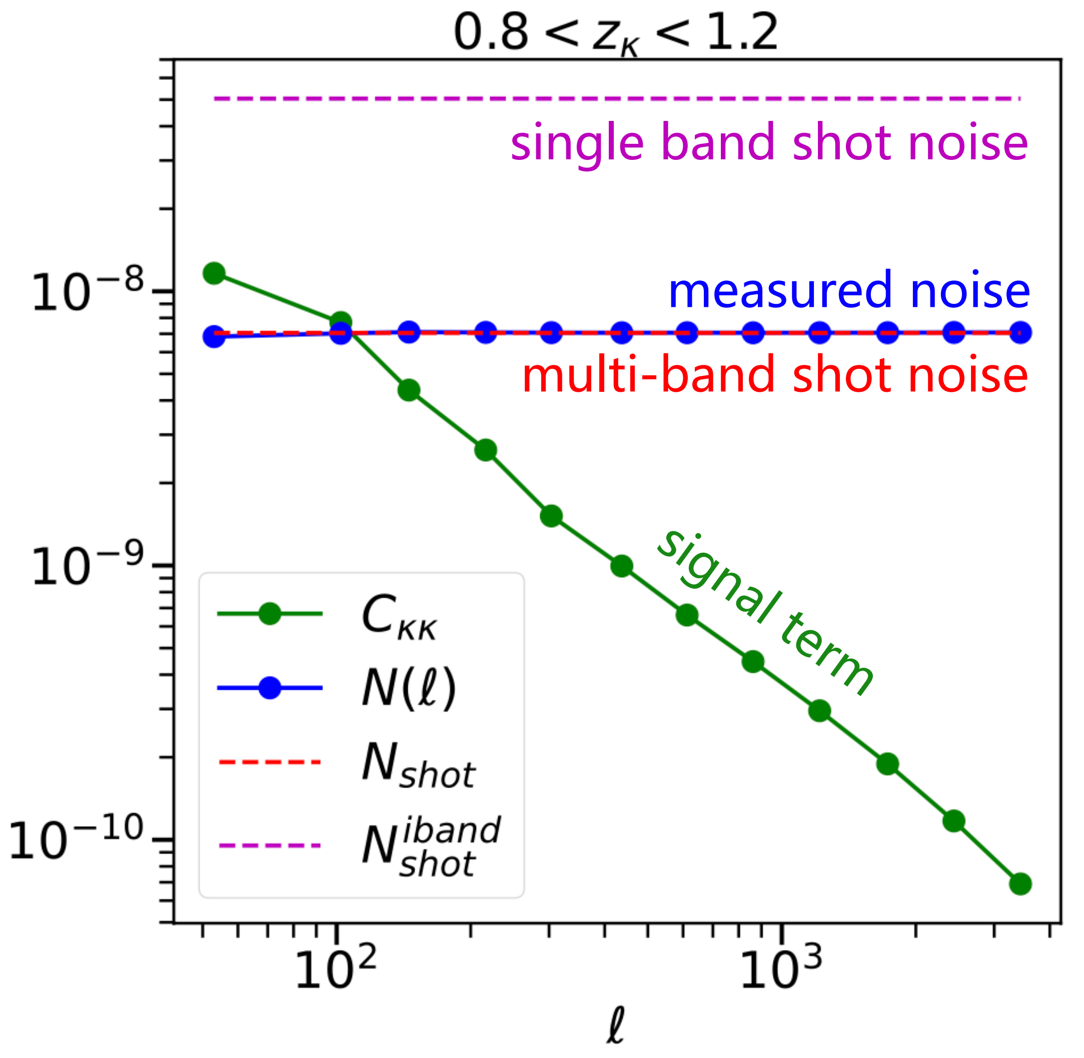




$$\hat{\kappa} = \kappa \boxed{+ \epsilon\delta_m} + \sum_i w_i \delta_i^S$$

Intrinsic clustering is greatly suppressed by an order of 100 for ell < 2000.

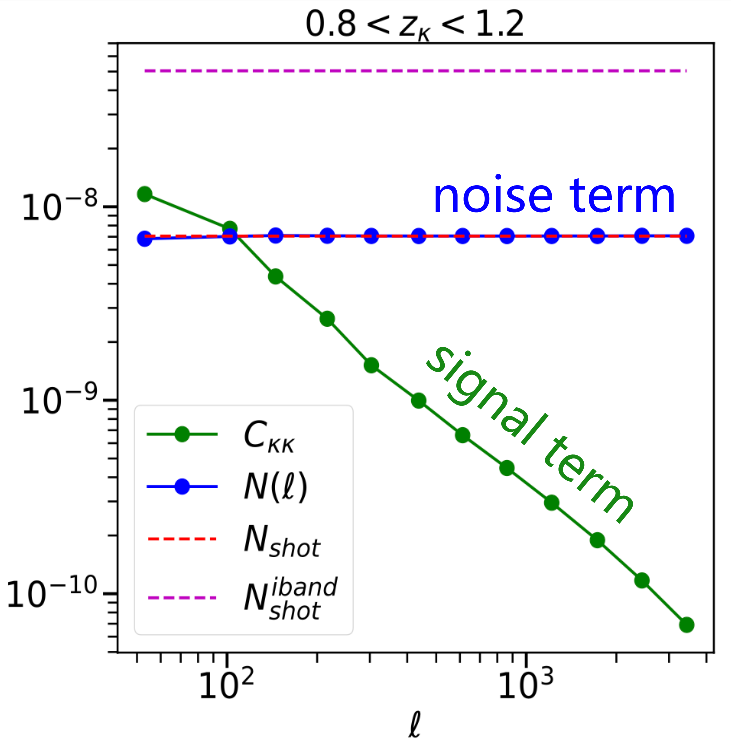
Error Budget

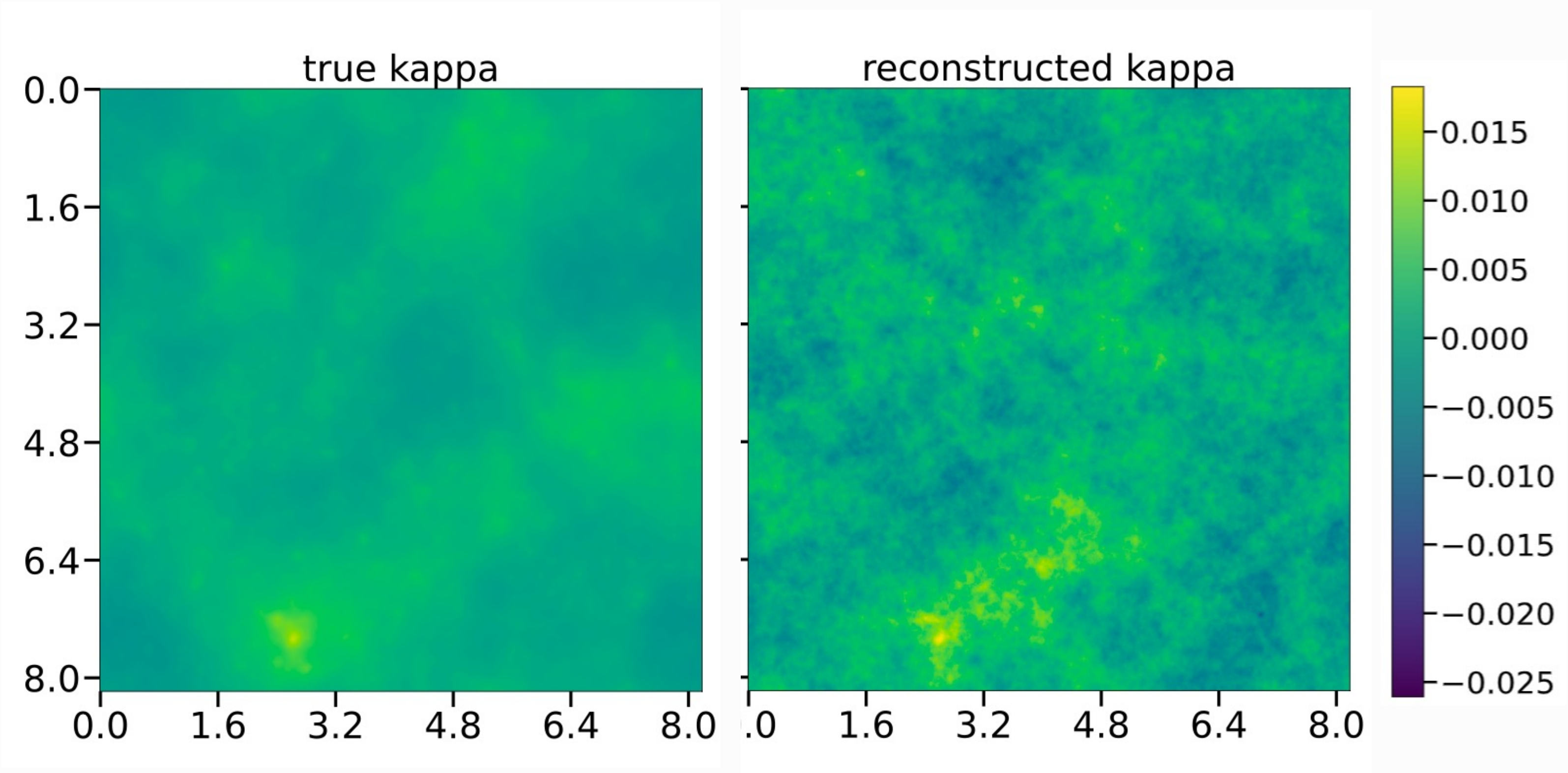


$$\underline{\hat{\kappa}} = \underline{\kappa} + \underline{\epsilon\delta_m + \sum_i w_i \delta_i^S}$$

$$C_{\hat{\kappa}\hat{\kappa}}(\ell) = \underline{C_{\kappa\kappa}(\ell)} + \underline{N(\ell)}$$

- signal dominated at ell < 200
- noise dominated at ell > 200
- noise is dominated by shot noise
- multiband is useful

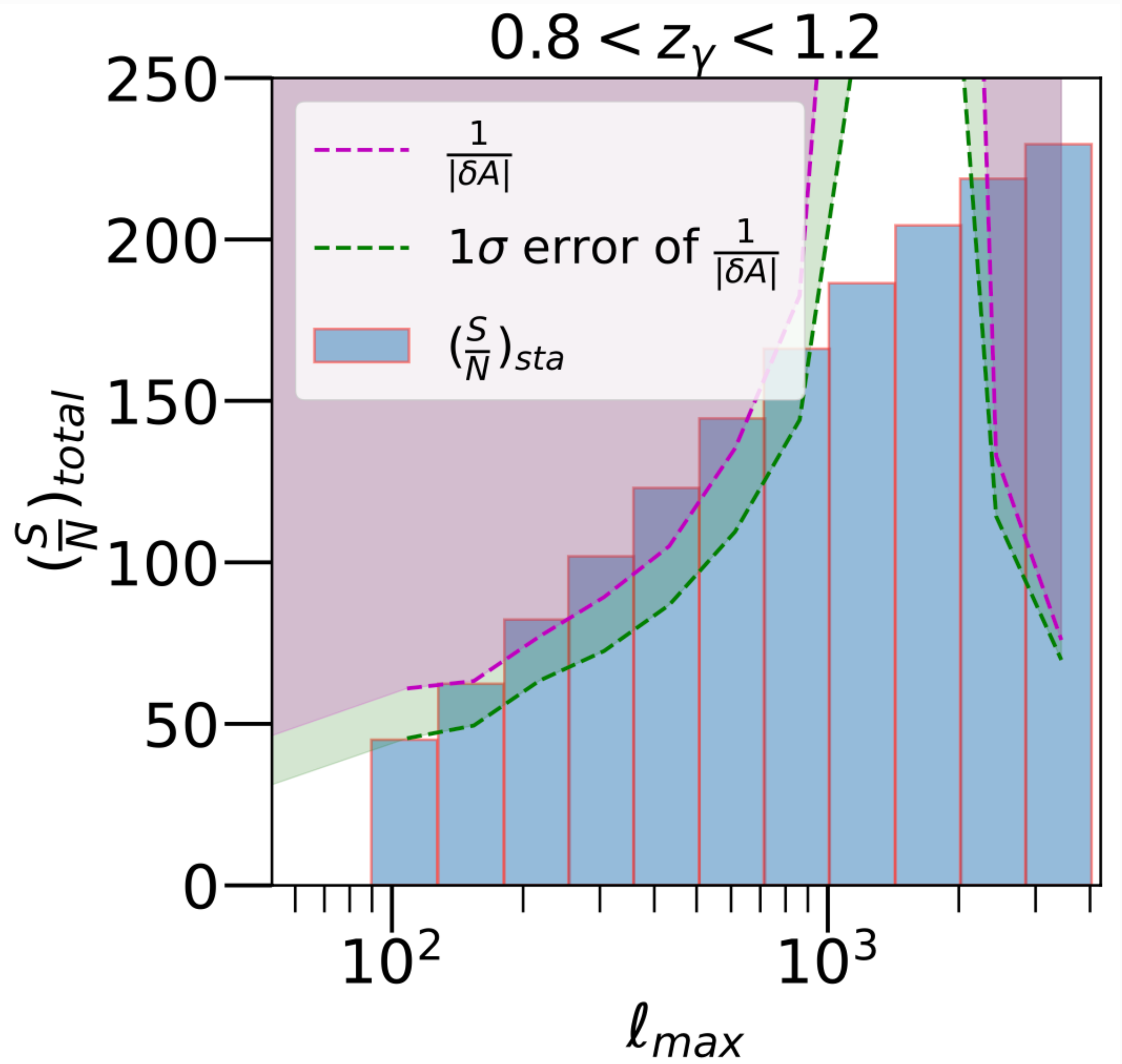




The reconstructed kappa map is noisy.

The cross correlation with external lensing field will be much cleaner.

Cross with External



for $z_\kappa \sim z_\gamma \sim 1$, LSST-like survey
using ell < 2000

cosmic magnification X cosmic shear
has

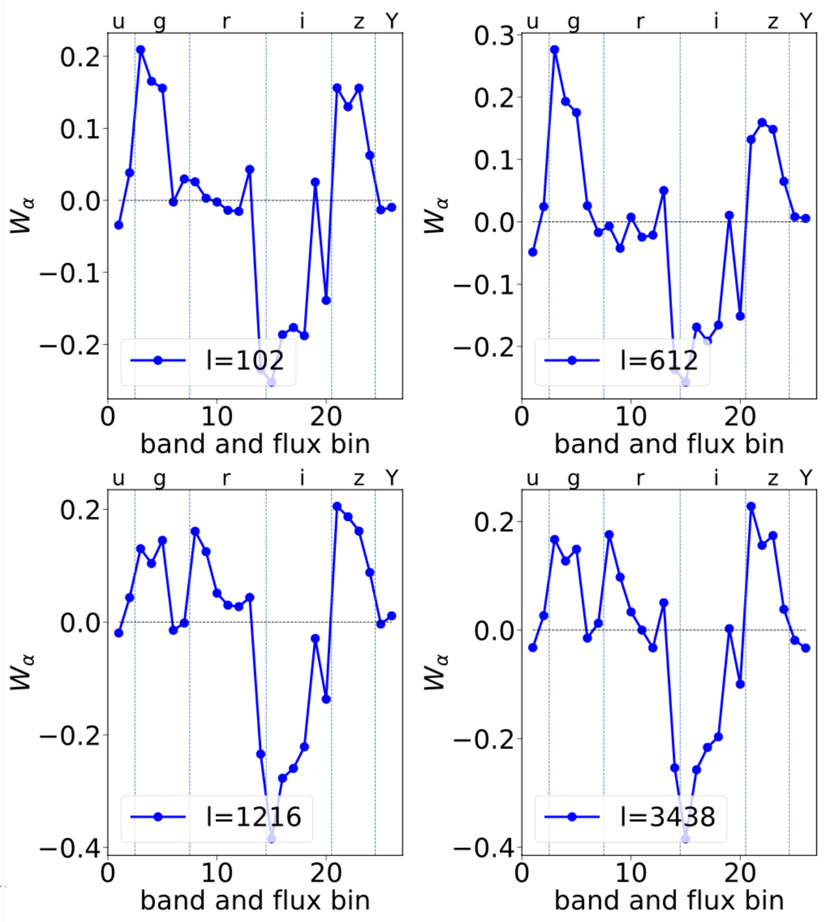
S/N ~ 200

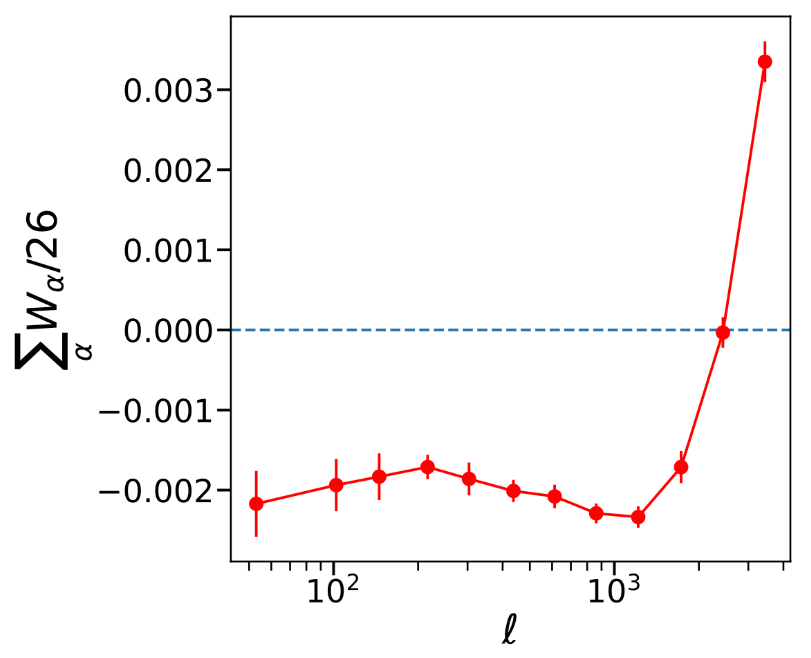
Optimal weighting v.s. Modified ILC

$$\sum_i w_i g_i = 1$$

$$\sum_i w_i b_i = 0$$

$$\sum_i w_i = 0$$





Condition required by MILC is approximately satisfied

Content

arXiv: 2310.15053
Jian QIN +

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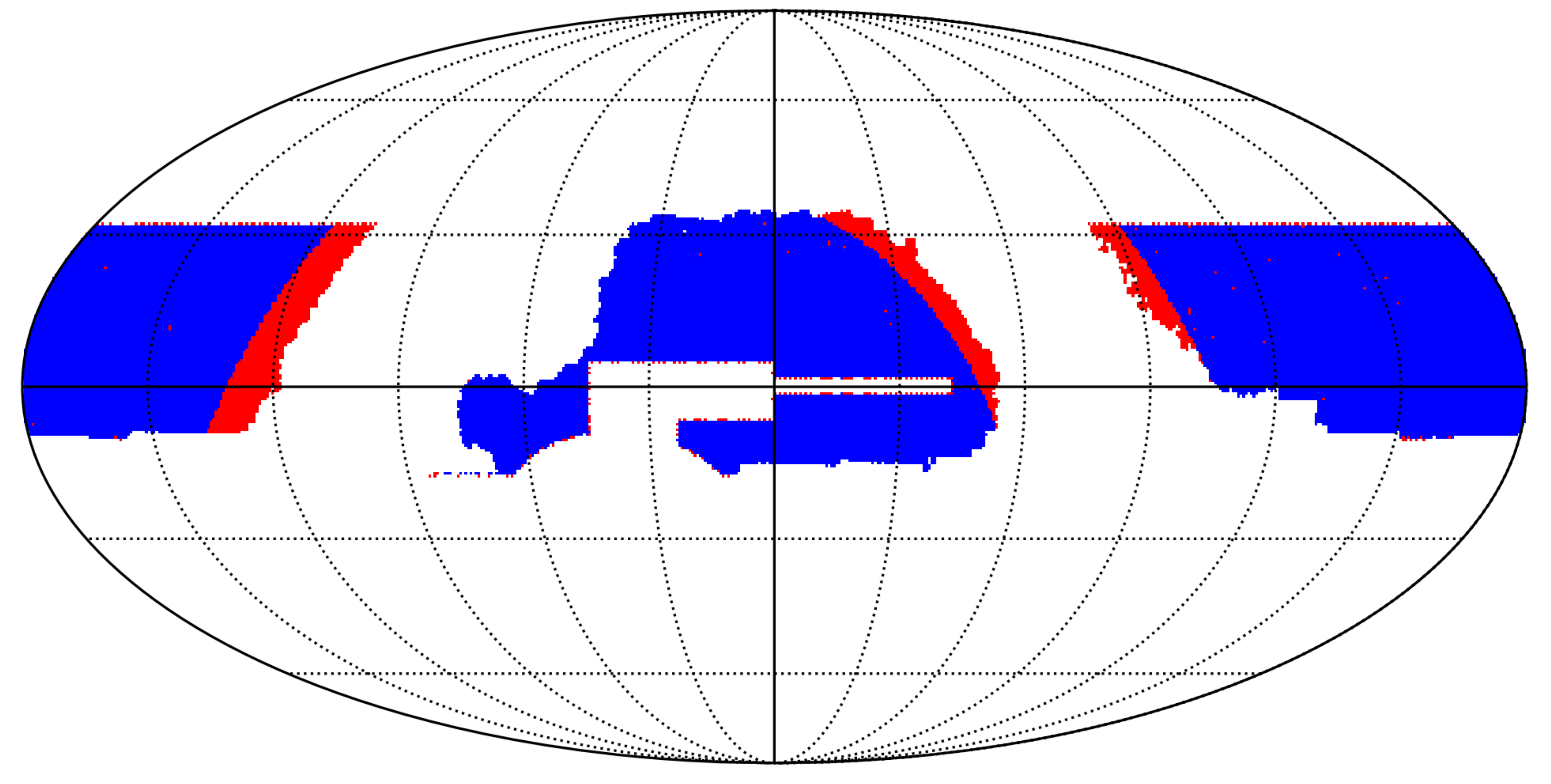
Application in observation

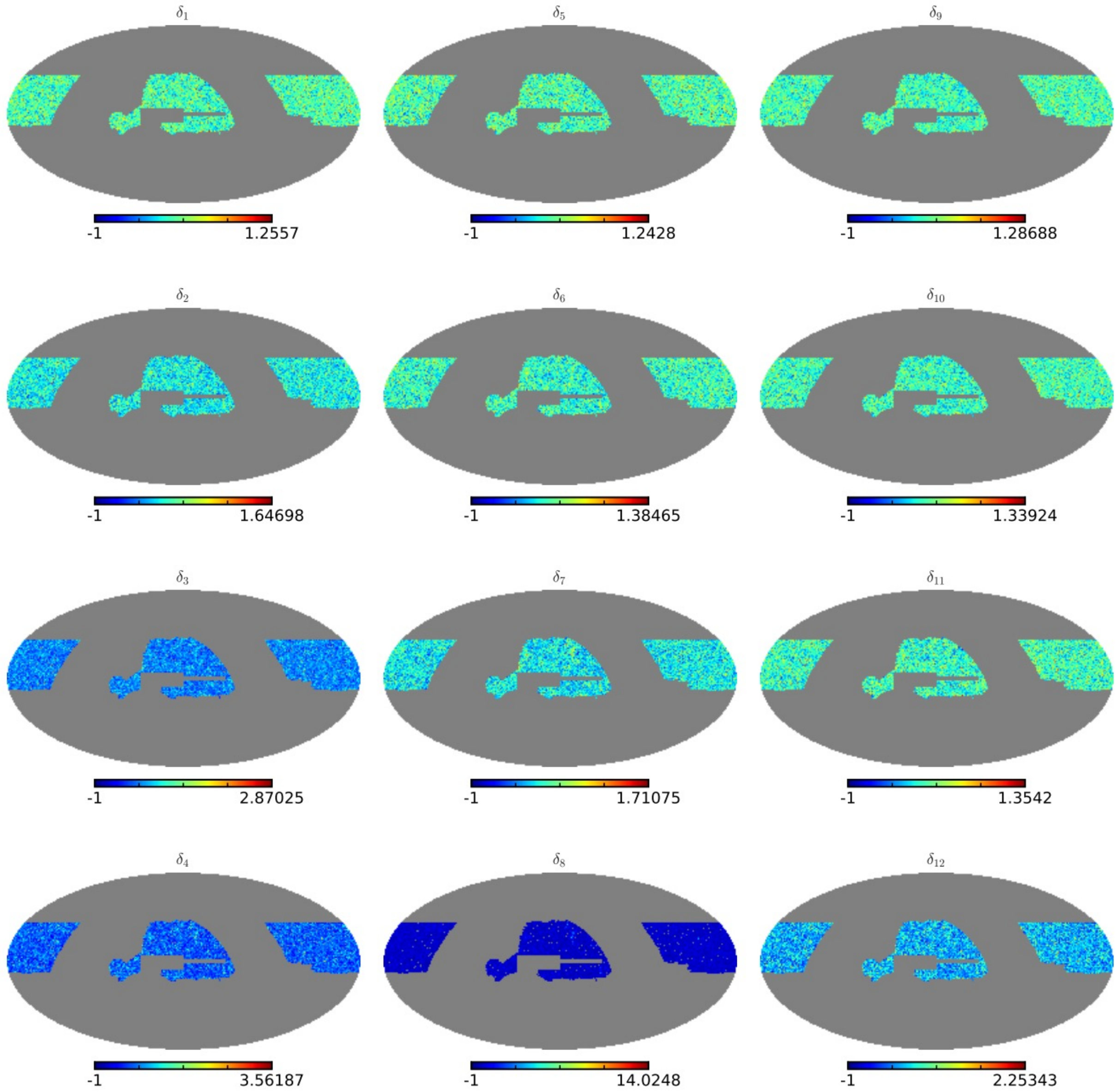


DECaLS DR9 galaxy distribution
for lensing magnification (MILC)
8365 deg^2

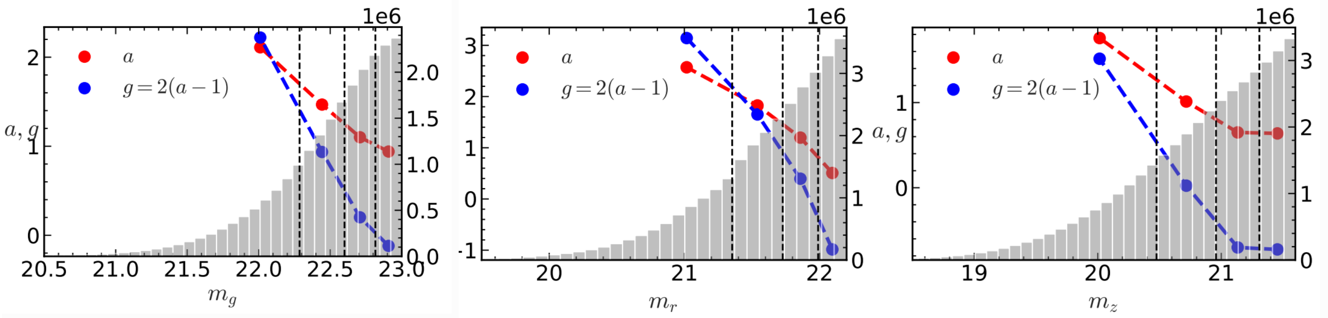
DECaLS DR8 shape catalogue
for cosmic shear
8960 deg^2

$$\xi^{\kappa\gamma}$$

Application in observation



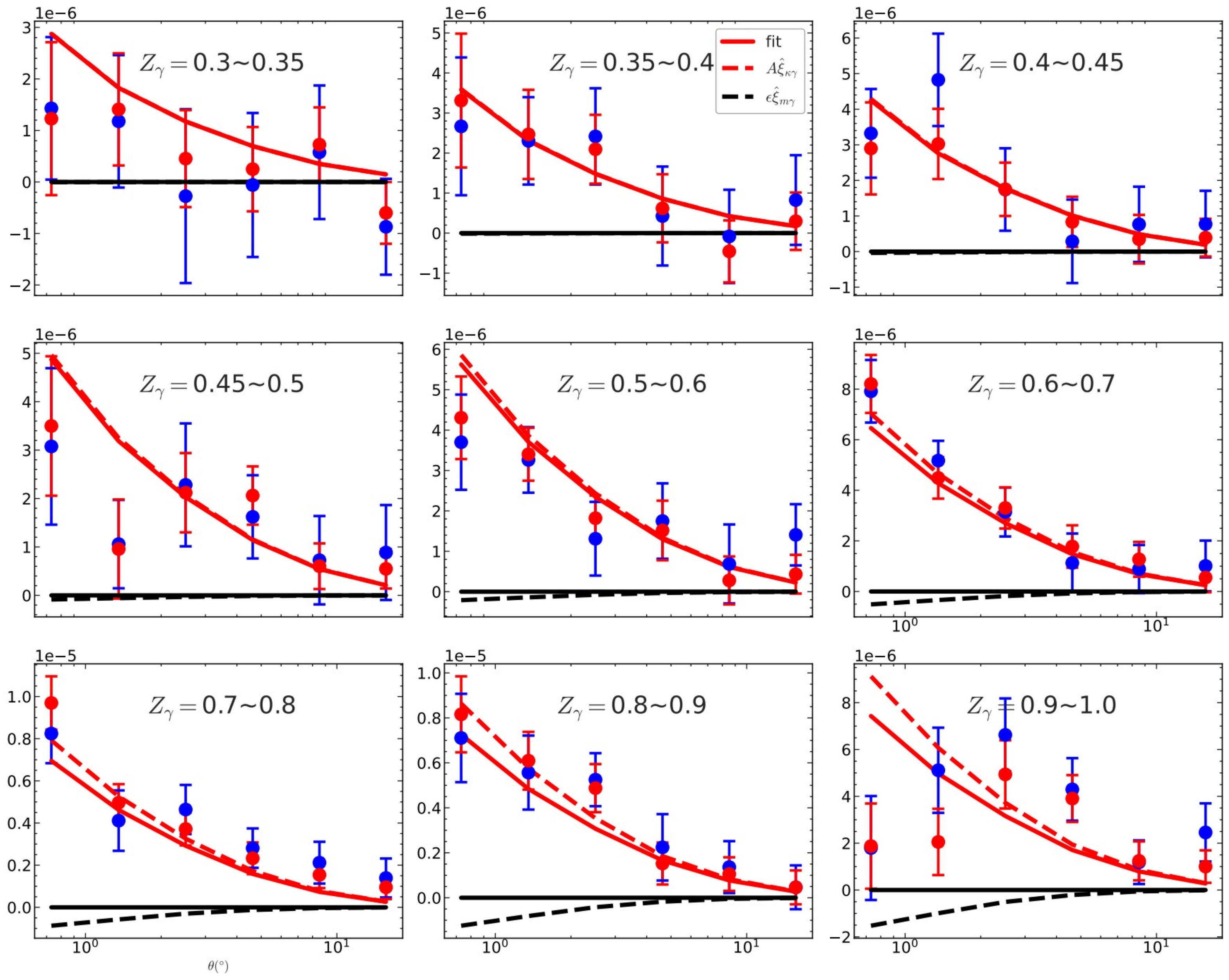
Sample	Magnitude Range	Galaxy Number	$\bar{n}(\mathrm{arcmin}^{-2})$	a	g	w	band
1	(22.8, 23.0)	5590717	0.19	0.51	-0.99	-0.09	g
2	(22.6, 22.8)	5590717	0.19	1.20	0.40	-0.00	g
3	(22.3, 22.6)	5590717	0.19	1.83	1.65	0.09	g
4	(, 22.3)	5590717	0.19	2.57	3.14	0.20	g
5	(22.0, 22.2)	7740929	0.26	0.94	-0.12	0.04	r
6	(21.7, 22.0)	7740929	0.26	1.10	0.20	0.07	r
7	(21.4, 21.7)	7740929	0.26	1.47	0.94	0.06	r
8	(, 21.4)	7740929	0.26	2.11	2.22	0.03	r
9	(21.3, 21.6)	9882012	0.33	0.64	-0.72	-0.08	z
10	(21.0, 21.3)	9882012	0.33	0.65	-0.70	-0.11	z
11	(20.5, 21.0)	9882012	0.33	1.01	0.02	-0.11	z
12	(, 20.5)	9882012	0.33	1.76	1.51	-0.09	z

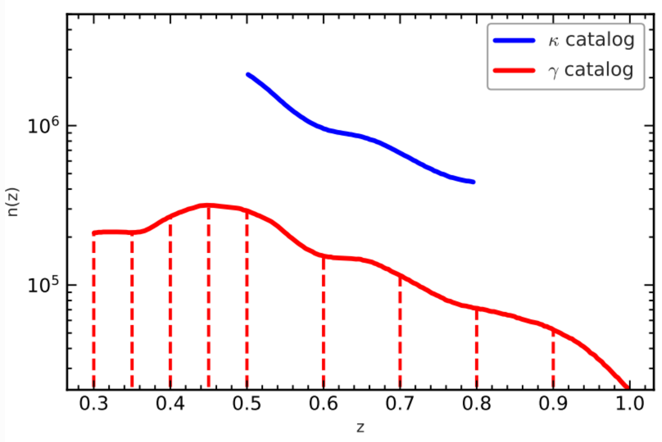


$$a = \frac{\log\left(\int_{f_1/(1+2\delta_F)}^{f_2/(1+2\delta_F)} n(F)dF\right) - \log\left(\int_{f_1(1+2\delta_F)}^{f_2(1+2\delta_F)} n(F)dF\right)}{2\log(1+2\delta_F)}$$

$$g = 2(a-1)$$

Application in observation





Imaging systematics not corrected

Imaging systematics corrected by RF

$$\xi_{\rm th}^{\rm bestfit} = A^{\rm bestfit}\xi^{\kappa\gamma} + \epsilon^{\rm bestfit}\xi^{m\gamma}$$

d.o.f = 52

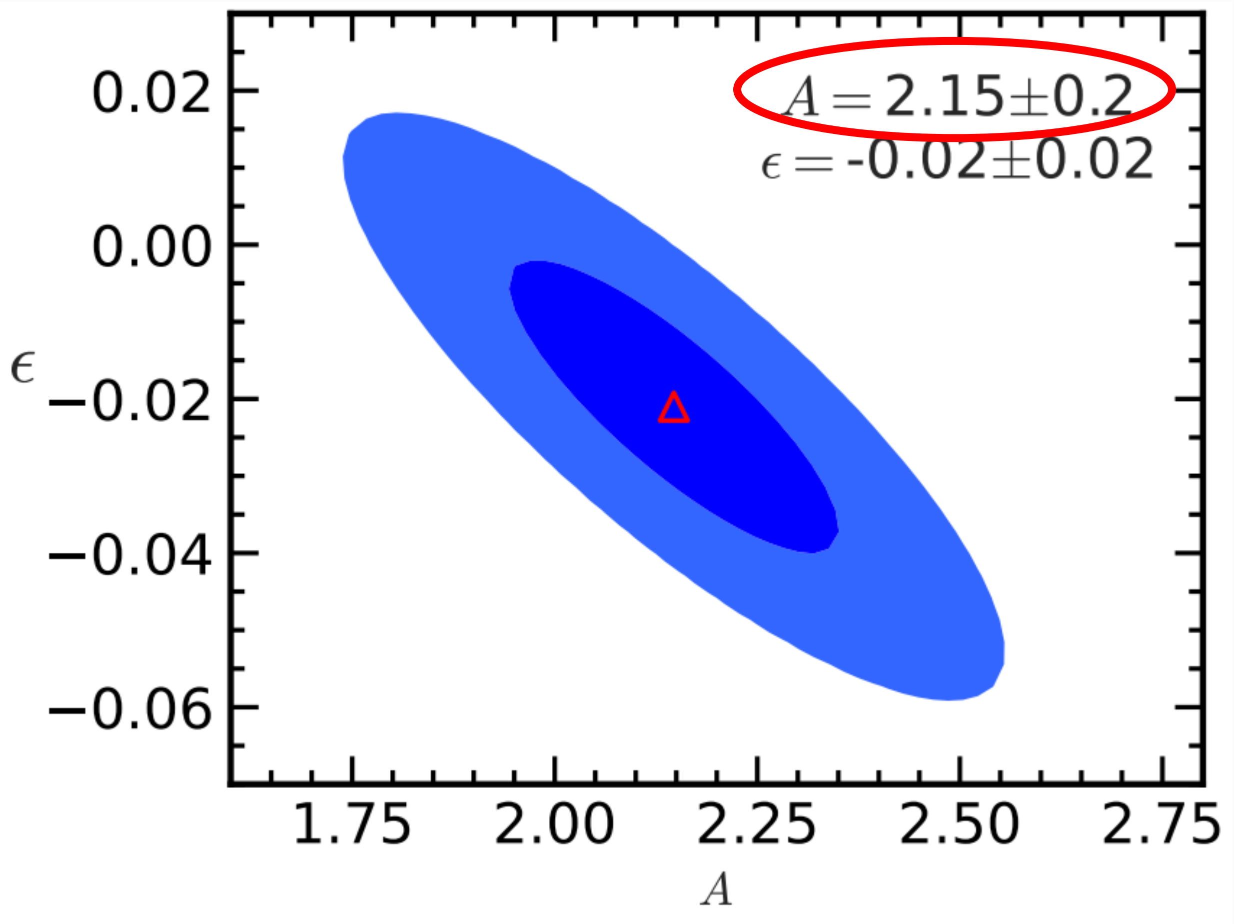
χ^2_{null} = 367.6

χ^2_{min} = 59

19.1σ from null

10.7σ from fitting

Application in observation



$$\xi_{\rm th}^{\rm bestfit} = A^{\rm bestfit}\xi^{\kappa\gamma} + \epsilon^{\rm bestfit}\xi^{m\gamma}$$

$$\hat{\kappa} = \kappa\sum_i w_i g_i + \delta_m \sum_i w_i b_i + \sum_i w_i \delta_i^S$$

Multiplicative bias Additive bias

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Summary

- We are developping the various approaches to extract the cosmic magnification signal.
  - MILC, weighting using estimated bias, …
- The intrinsic clustering is greatly suppressed (~100x) by these methods.
- The reconstructed kappa map is generally noisy.
- The numerical validation shows very promising results. The predicted S/N for $z_\gamma \sim z_\kappa \sim 1$ cross correlation can reach ~ 200 for ell < 2000 and LSST-like survey.
- The MILC method has been applied on multi-band observational data. We obtain a ~10σ detection using DECaLS galaxies and shapes over 8365 deg^2.
  - First direct lensing map over such a large sky area.
  - Multiplicative bias is identified, largely due to the g measurement.

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THANK YOU

Thank You！

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