Weak lensing magnification from cross-correlation studies

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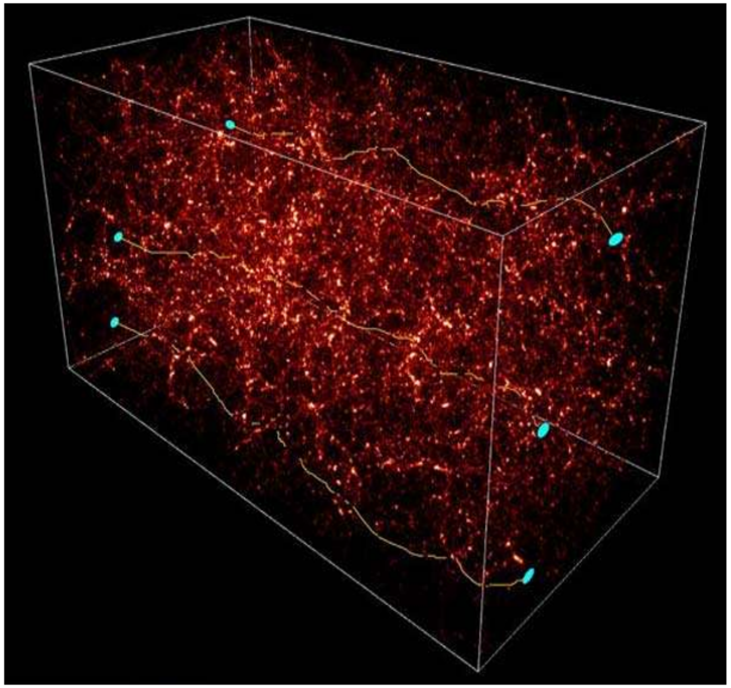
Powerful cosmological probe

- Weak gravitational lensing
- Large-scale structures in the universe perturb the propagation of light rays from background sources
- Small shape distortions and luminosity changes

- Equally sensitive to both dark and luminous matter
- Probes the large-scale mass distribution
- Sensitive to the geometry and the whole expansion history of the Universe

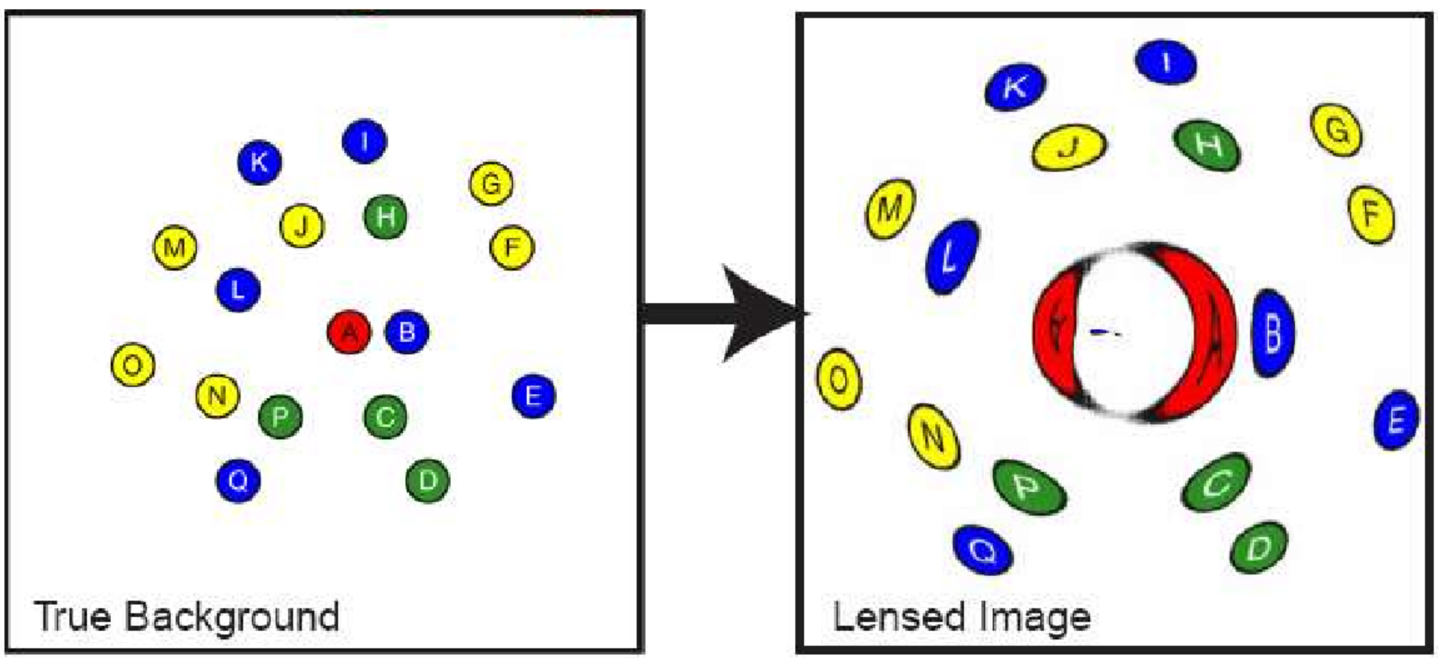


Powerful cosmological probe

- Weak gravitational lensing
- Two main signatures: shear and magnification

$$\mathcal{A}(\boldsymbol{\theta}) = \frac{\partial \boldsymbol{\beta}}{\partial \boldsymbol{\theta}} = \left(\delta_{ij} - \frac{\partial^2 \psi(\boldsymbol{\theta})}{\partial \theta_i \partial \theta_j}\right) = \begin{pmatrix} 1-\kappa & 0 \\ 0 & 1-\kappa \end{pmatrix} + \begin{pmatrix} -\gamma_1 & -\gamma_2 \\ -\gamma_2 & \gamma_1 \end{pmatrix}$$

Shape distortion by foreground lens



Powerful cosmological probe

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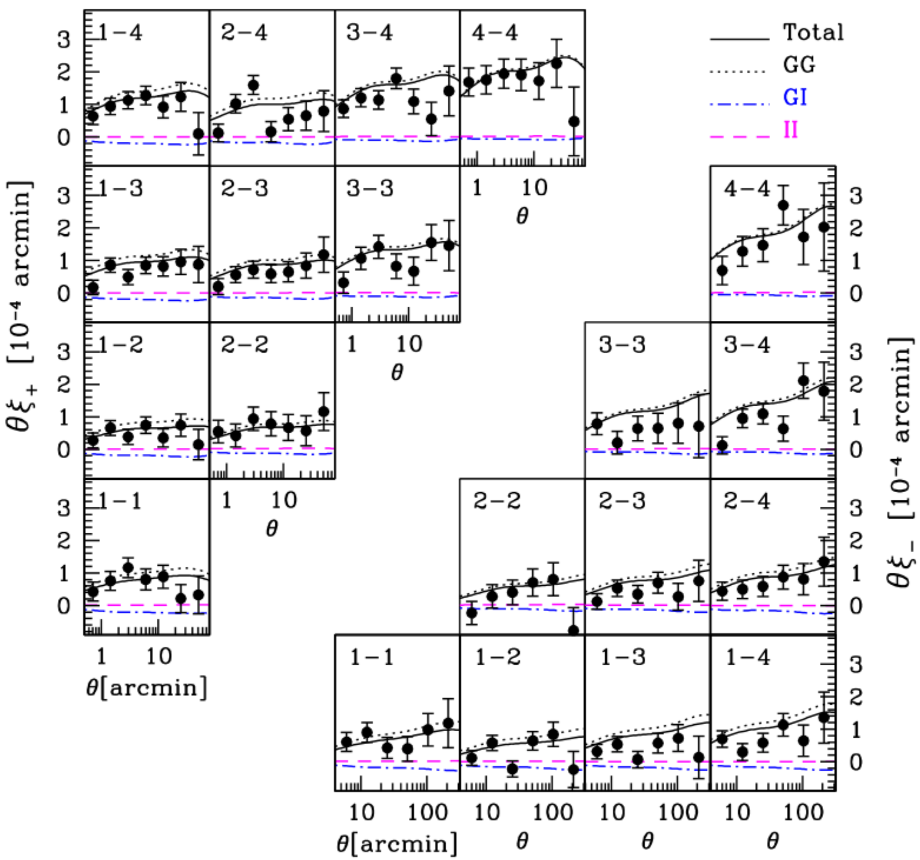
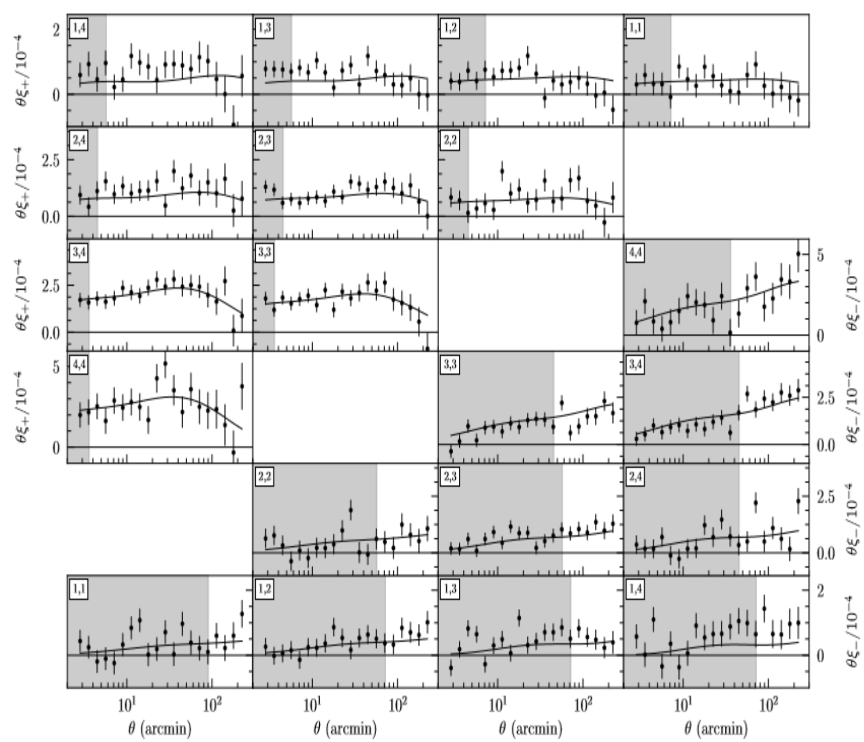


Hildebrandt et al. 2017



Troxel et al. 2018

Powerful cosmological probe

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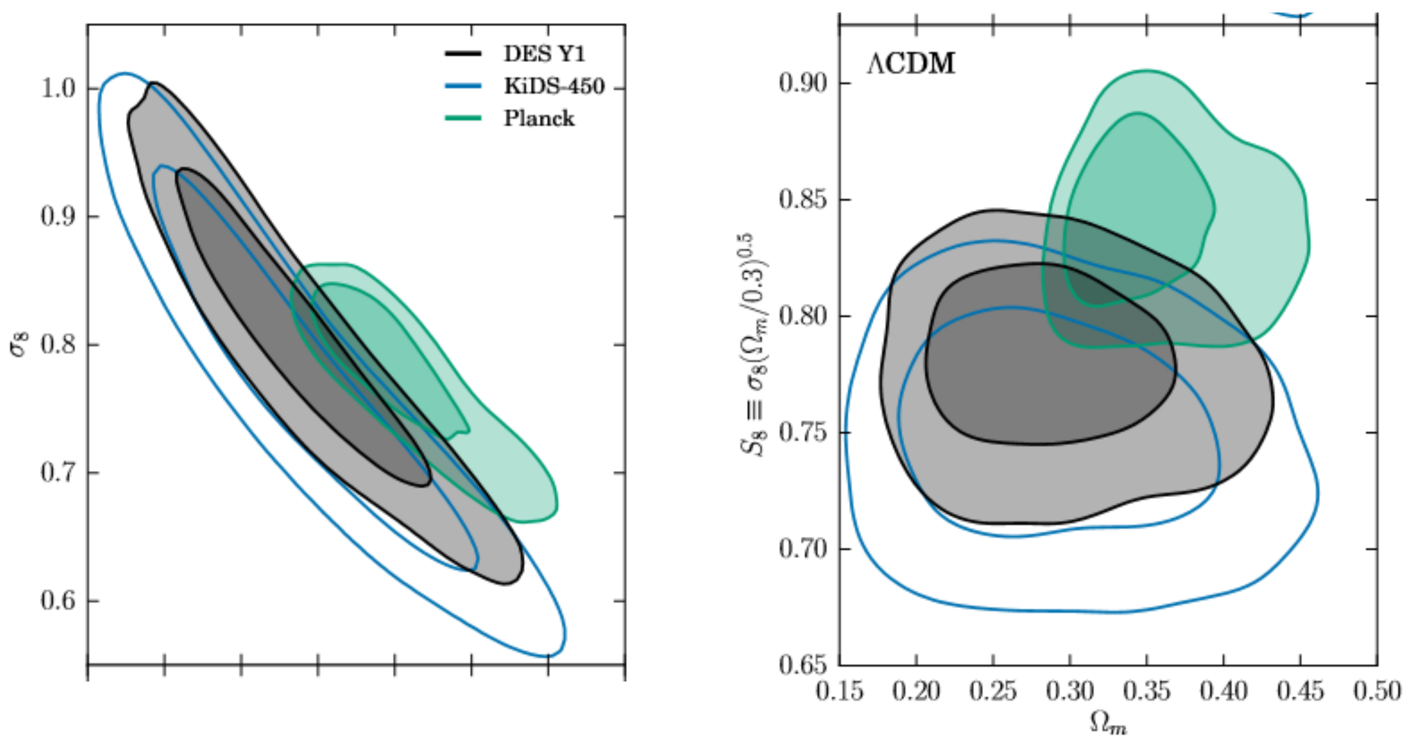


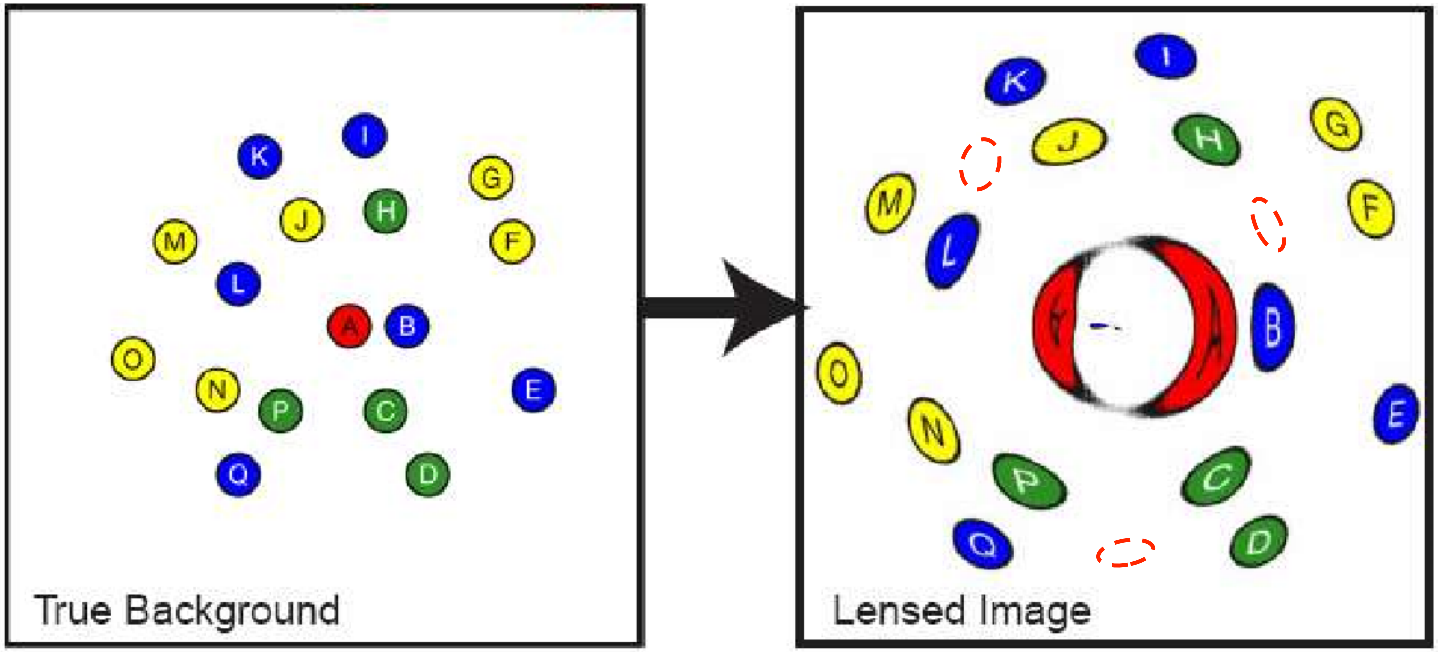
Troxel et al. 2018

Powerful cosmological probe

- Weak gravitational lensing
- Two main signatures: shear and magnification

$$\mu = \frac{1}{\det \mathcal{A}} = \frac{1}{(1-\kappa)^2 - |\gamma|^2}$$

Magnification by gravitational lenses increases the observed flux of background galaxies. At the same time, it stretches the solid angle behind the lenses, reducing the surface density of sources

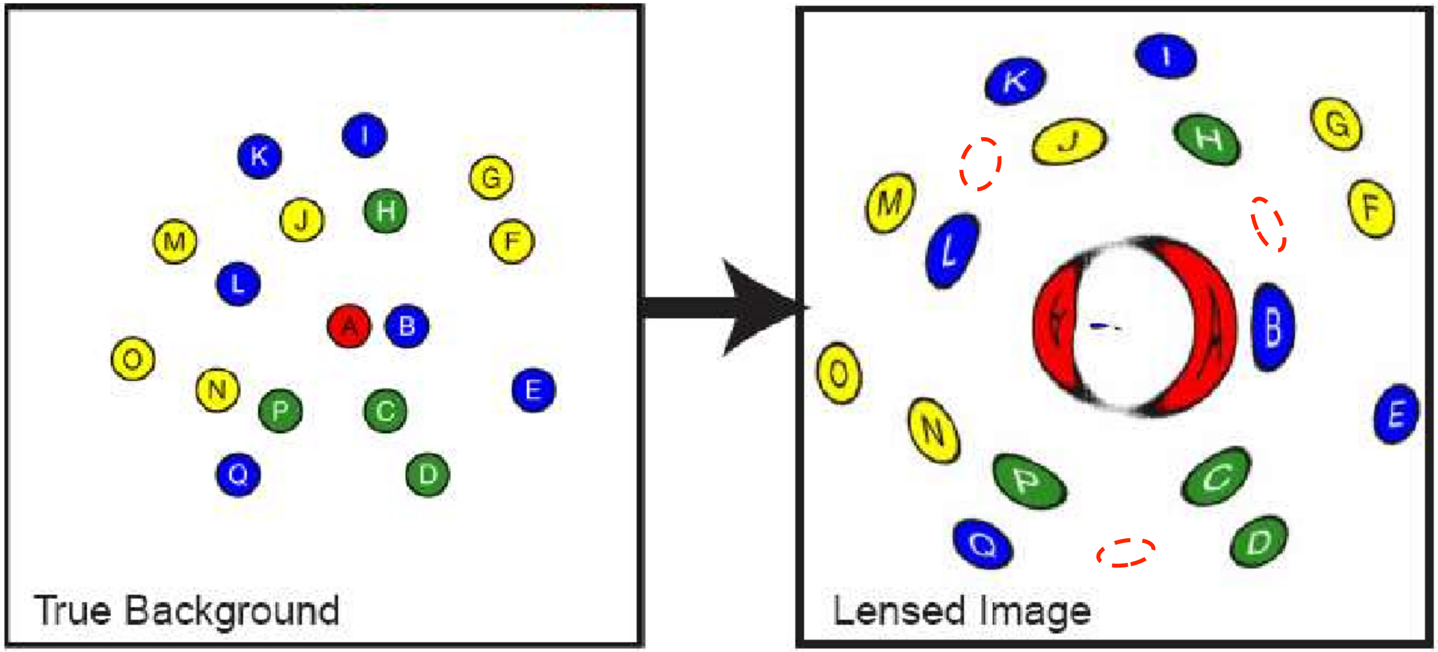


Powerful cosmological probe

- Weak gravitational lensing
- Two main signatures: shear and magnification

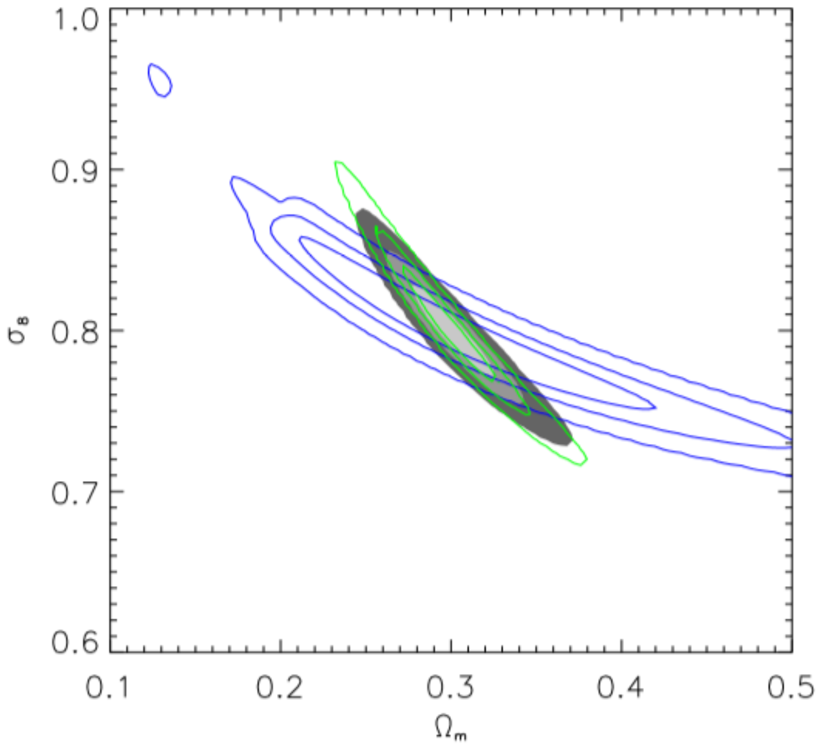
$$\mu = \frac{1}{\det \mathcal{A}} = \frac{1}{(1-\kappa)^2 - |\gamma|^2}$$

Magnification is dependent on the mass of the dark matter content along the line of sight to the source, therefore its effect is not homogeneous and is spatially correlated with the location of lens.



Powerful cosmological probe

- Weak gravitational lensing
- Two main signatures: shear and magnification
- Complementary effects: depend on the same cosmological parameters, but in a slightly different manner
- E.g. break some degeneracy on parameter constraints



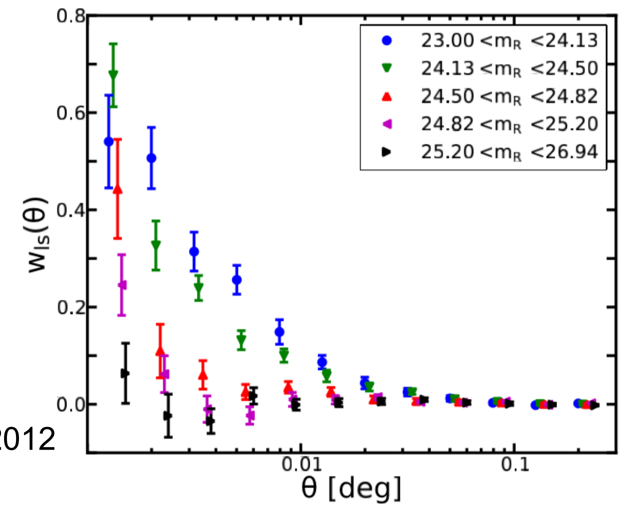
van Waerbeke 2010

Powerful cosmological probe

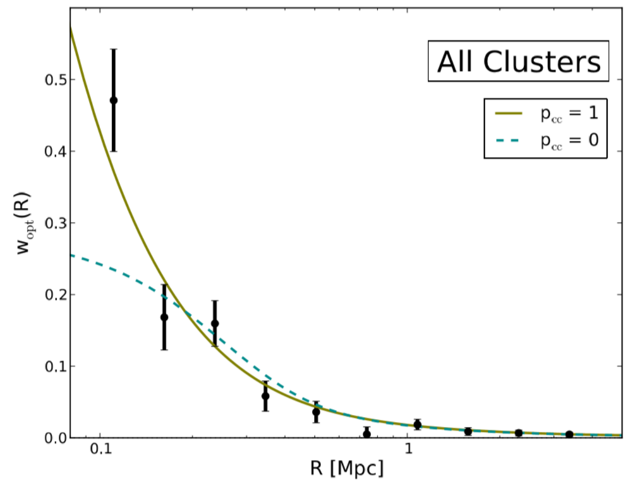
- Weak gravitational lensing
- Two main signatures: shear and magnification
- The major power of the combination is that they are sensitive to different sources of systematic errors
- The systematic effects could be minimized by suitable combination of magnification and shear.
- Previous magnification signal is mainly measured using the number-count technique
- 1. the use of very massive objects as lens, or high redshift objects as sources (Ford et al. 2014; Chiu et al. 2016, Morrison et al. 2012)
- 2. a more numerous population of source galaxies are used, e.g., All observed galaxies, selected only with photometric redshifts, are used both as lenses and sources (Garcia-Fernandez et al. 2018)

Powerful cosmological probe

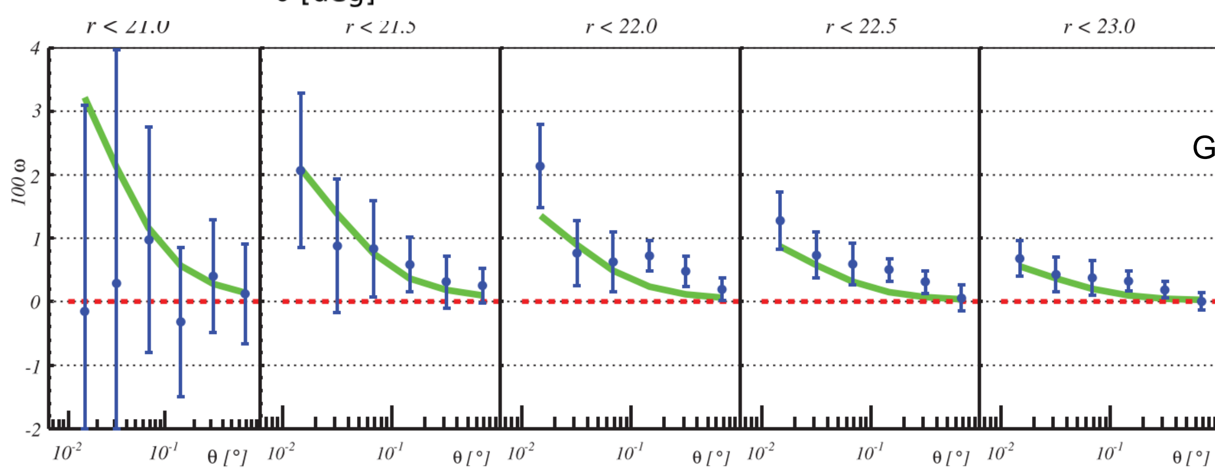
- Weak gravitational lensing
- Previous magnification signal is mainly measured using the number-count technique



Morrison et al. 2012



Ford et al. 2014



Garcia-Fernandez et al. 2018

A new and promising method

- Here we propose a new and promising method to measure the magnification signal – Cross-correlation between low-z convergence and high-z galaxy number density distribution.

$$\omega_{ij}(\theta) = \left\langle \kappa\left(\hat{n}, z_{bini}\right) \delta_O\left(\hat{n}', z_{binj}, f_j\right) \right\rangle_\theta$$

$$\delta_O\left(\hat{n}', z_{binj}, f_j\right) = \delta_g\left(\hat{n}', z_{binj}\right) + \delta_\mu\left(\hat{n}', z_{binj}, f_j\right)$$

$$\delta_g\left(\hat{n}', z_{binj}\right) = b_j \delta_M\left(\hat{n}', z_{binj}\right) \qquad \delta_\mu\left(\hat{n}', z_{binj}, f_j\right) = \frac{N_\mu\left(\hat{n}', z_{binj}, f_j\right)}{N_0\left(\hat{n}', z_{binj}, f_0\right)} - 1 = \frac{N_\mu\left(\hat{n}', z_{binj}, f_j\right)}{\mu N_\mu\left(\hat{n}', z_{binj}, \mu f_j\right)} - 1$$

$$N_\mu\left(\hat{n}', z_{binj}, f_j\right) = A\left(\frac{f_j}{f_*}\right)^{\alpha(f_j)} \qquad \mu \approx 1 + 2\kappa$$

In the weak-lensing limit

$$\omega_{ij}(\theta) = \left\langle b_j \kappa\left(\hat{n}, z_{bini}\right) \delta_M\left(\hat{n}', z_{binj}\right) \right\rangle_\theta + \boxed{\left\langle 2\left[\alpha(m_j) - 1\right] \kappa\left(\hat{n}, z_{bini}\right) \kappa\left(\hat{n}', z_{binj}\right) \right\rangle_\theta}$$

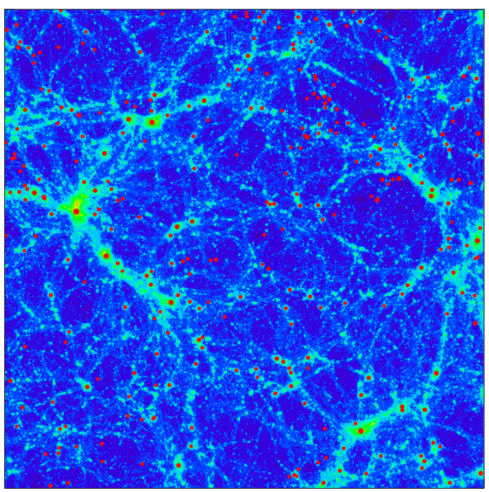
- No galaxy bias will be involved if the redshift distributions of the lens and sources have a negligible overlap.

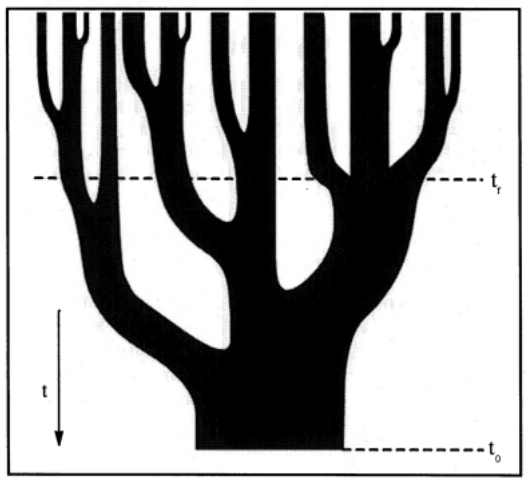
Semi-analytical galaxy catalog

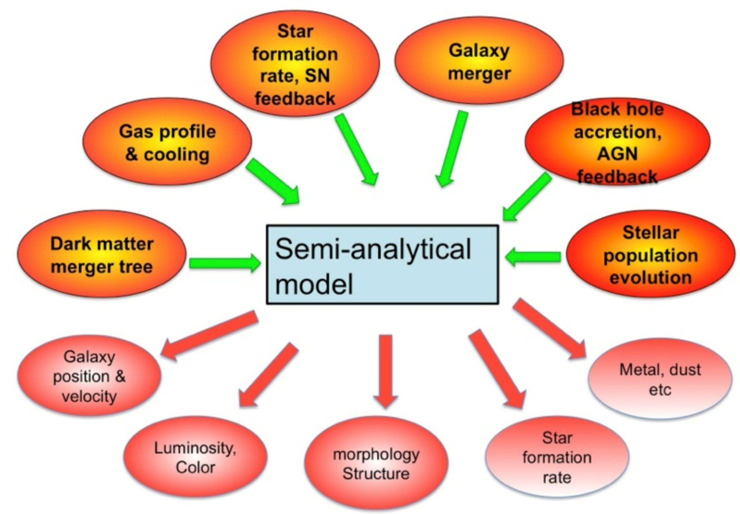
- From Chengliang Wei, Yu Luo et al.
- N-body simulations + merger tree + semi-analytical models

ELUCID Cosmology

Simulation	$\Omega_{\rm m}$	Ω_Λ	h	σ_8	$L_{\rm box}/h^{-1}{\rm Mpc}$	$m_{\rm p}/(10^{10}h^{-1}{\rm M}_\odot)$	$l_{\rm soft}/h^{-1}{\rm kpc}$
L500	0.282	0.718	0.697	0.82	500	0.034	3.5

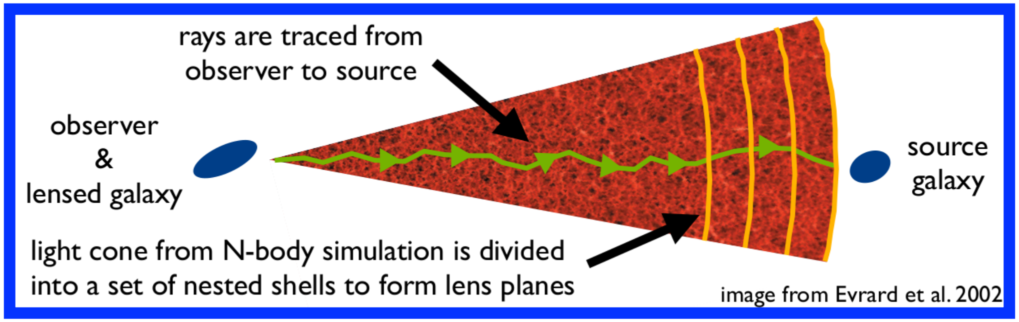


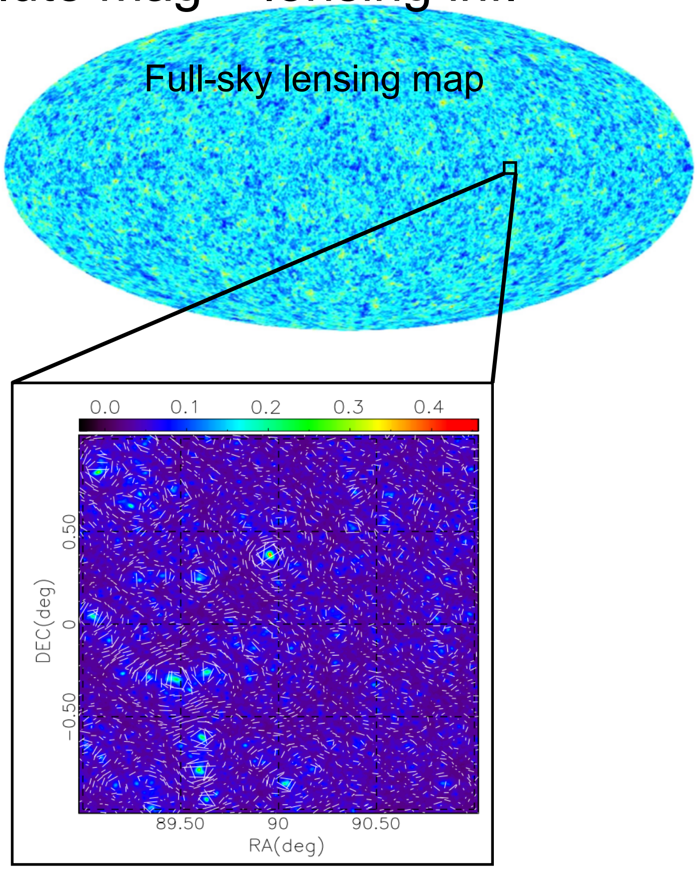


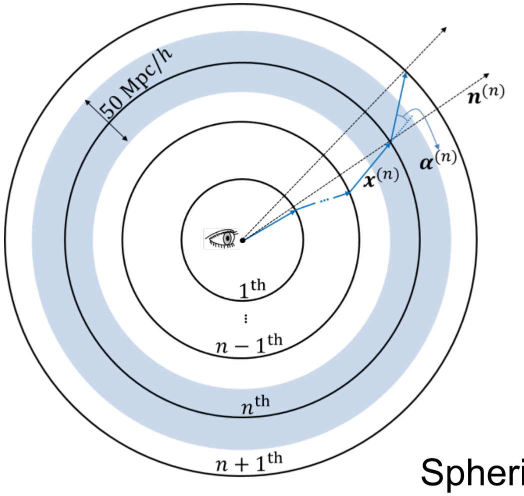


Semi-analytical galaxy catalog

- From Chengliang Wei, Yu Luo et al.
- N-body simulations + merger tree + semi-analytical models
- + lensing maps
- = 3D positions (bf. and af. lensing) + Absolute mag + lensing inf.



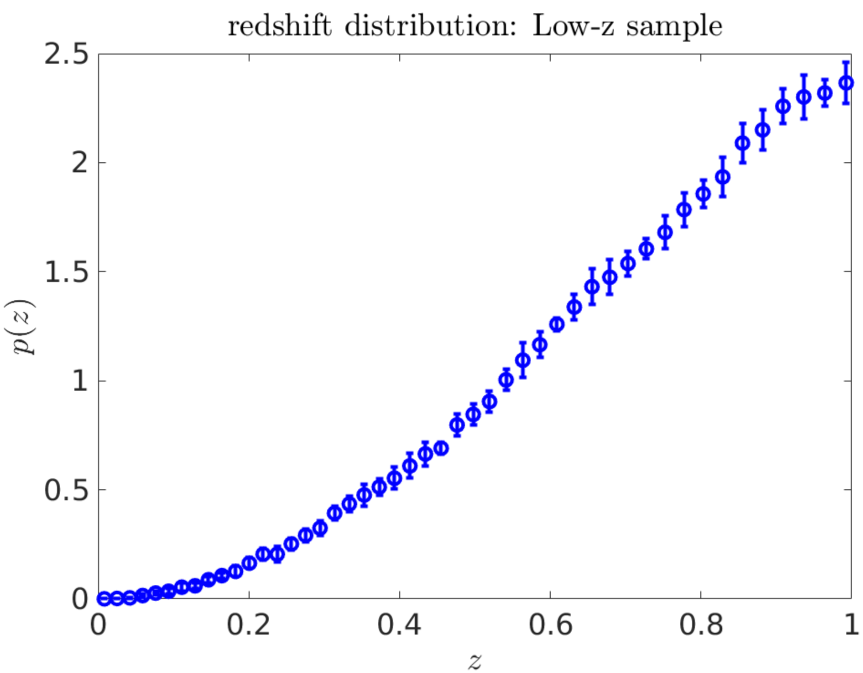


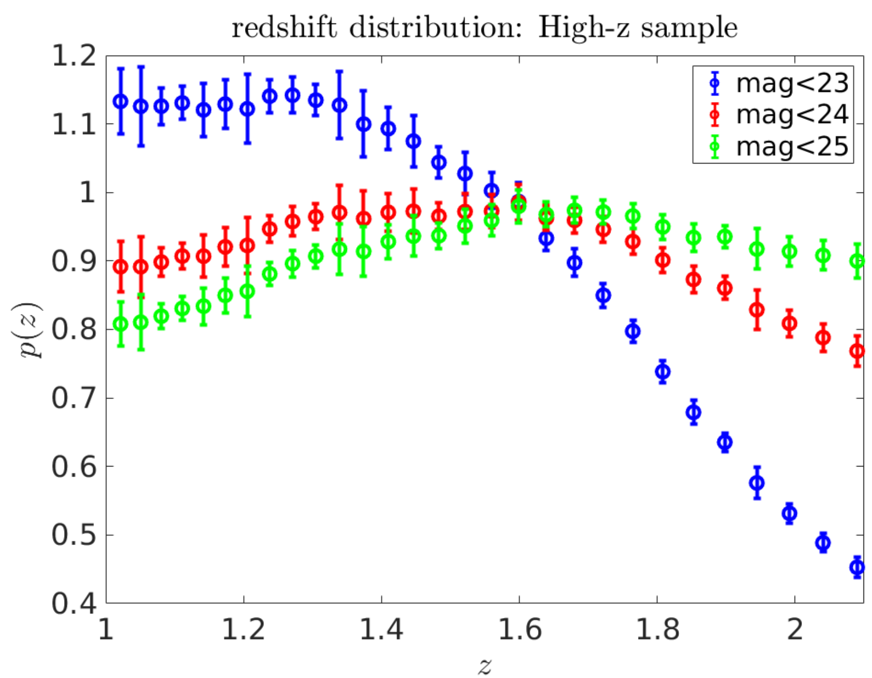


Spherical Ray-tracing

Preliminary results

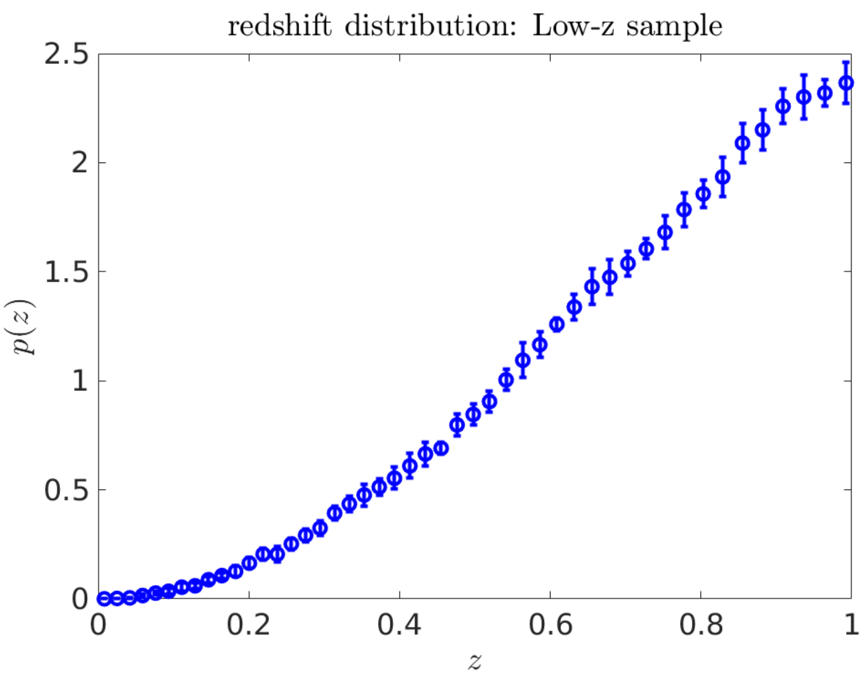
- Set z=1.0 to divide the low-z and high-z samples
- 10 fields with 10 deg* 10 deg
- For low-z samples (z<1):
  - 1. semi-analytical galaxy catalogs without any cut, with convergence inf.
  - 2. ray-tracing convergence maps weighted by the low-z redshift distribution
  - 3. maps in 2 with a Gaussian shape noise (ng=10/arcmin^2, sigma_e=0.4)

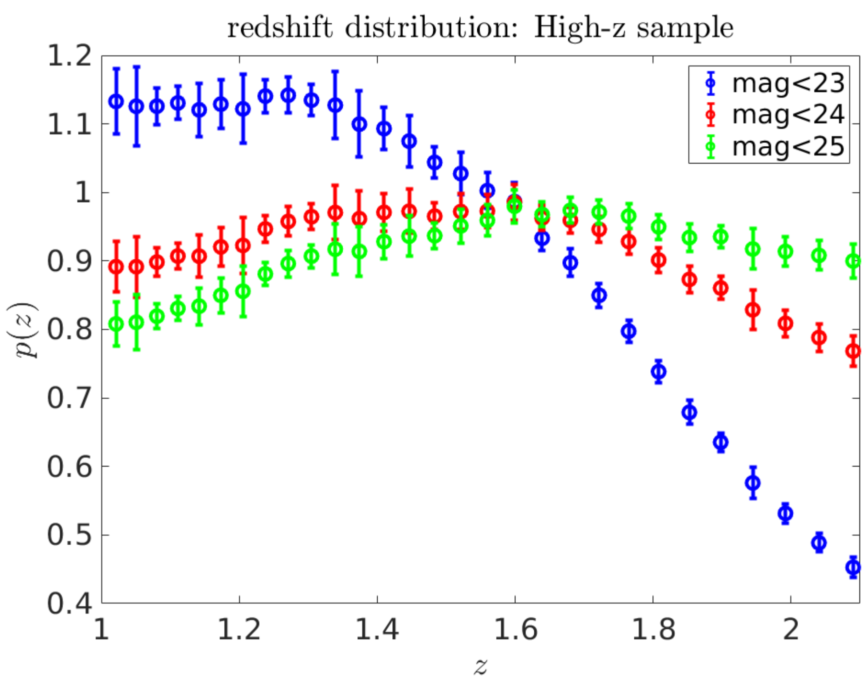




Preliminary results

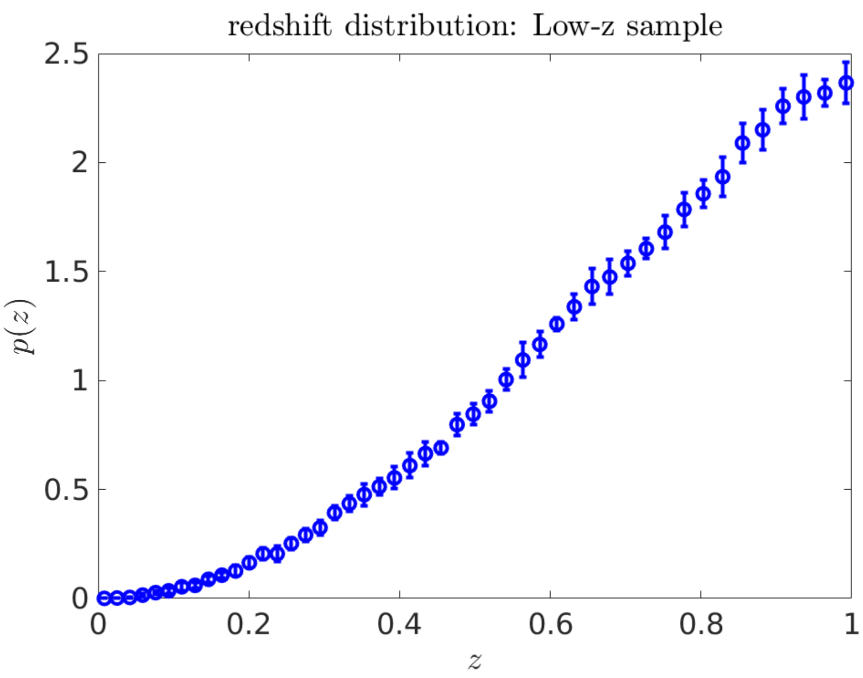
- Set z=1.0 to divide the low-z and high-z samples
- 10 fields with 10 deg* 10 deg
- For high-z samples (z>1.0):
  - 1. semi-analytical galaxy catalogs with apparant magnitude brighter than 24
  - 2. semi-analytical galaxy catalogs with apparant magnitude brighter than 23
  - 3. semi-analytical galaxy catalogs with apparant magnitude brighter than 25

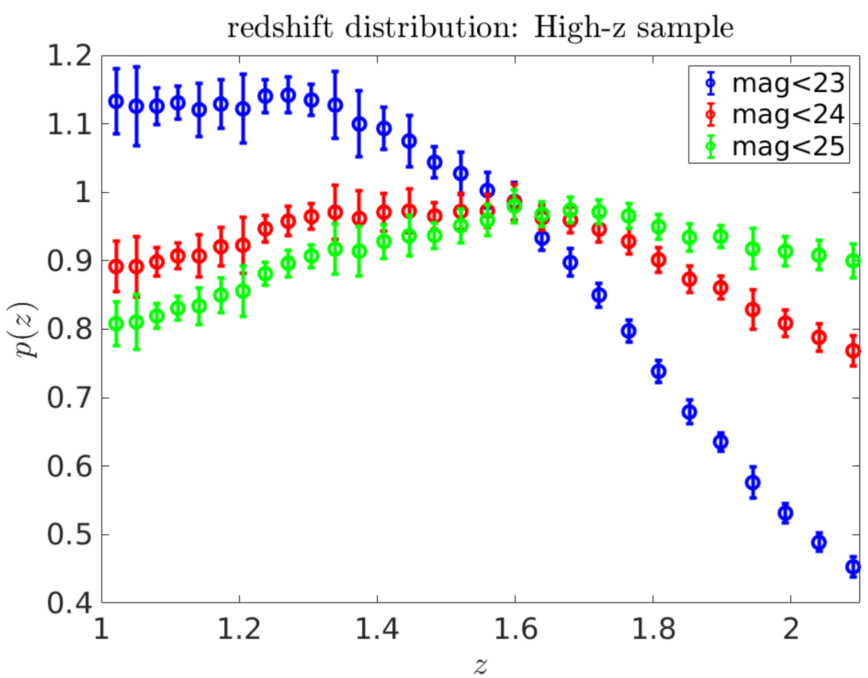




Preliminary results

- Set z=1.0 to divide the low-z and high-z sample
- 10 fields with 10 deg* 10 deg
- Number density of low-z sample: ~42/arcmin^2
- Number density of high-z sample: ~14.6 (mag<23), ~28.3 (mag<24), ~46.8 (mag<25) /arcmin^2





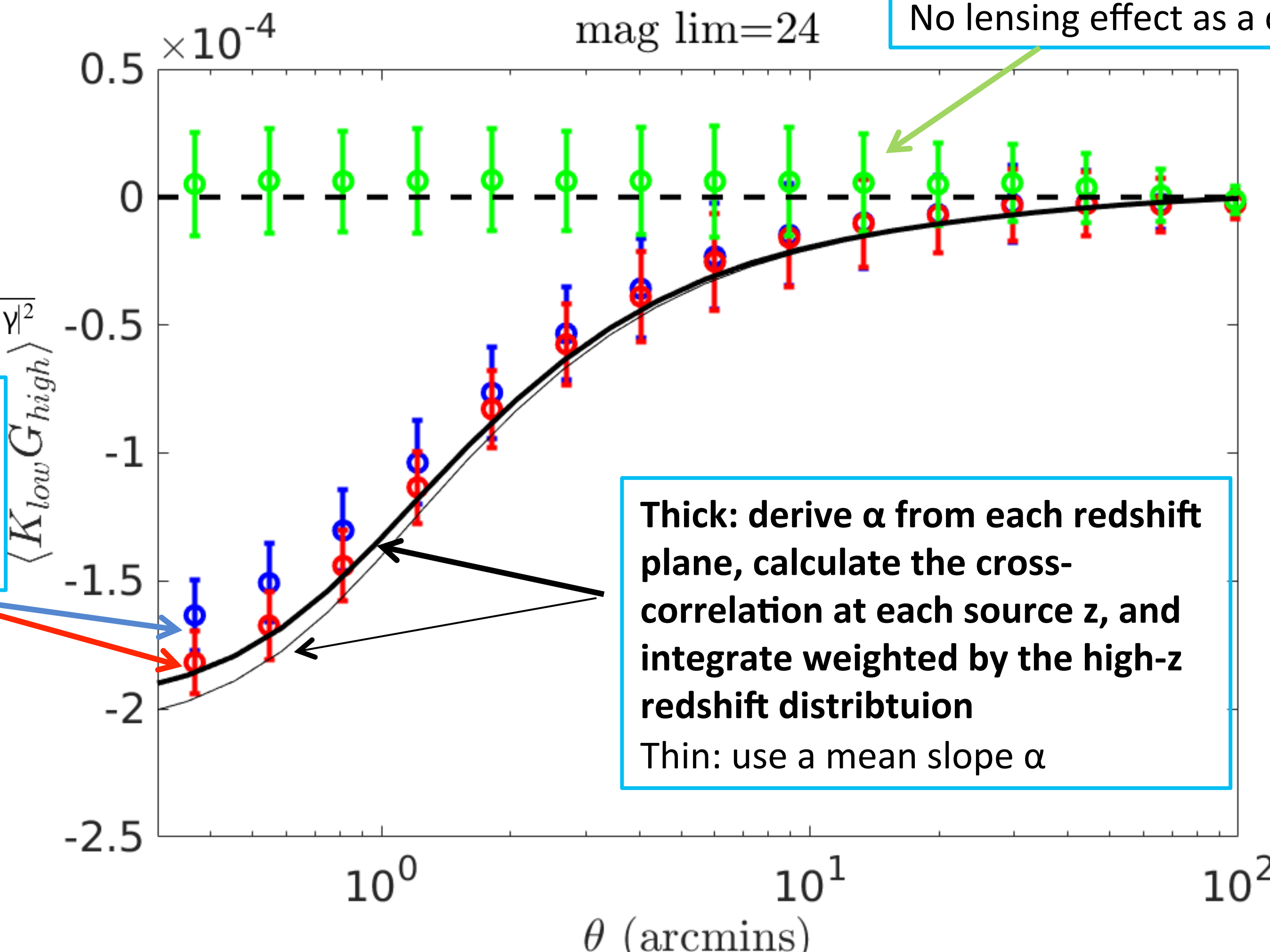
Preliminary results

$$\langle K_{\mathrm{lowz}} G_{highz} \rangle = \langle KG \rangle - \langle KR \rangle$$

- 1. low-z semi-analytical sample * high-z sample (mag<24)

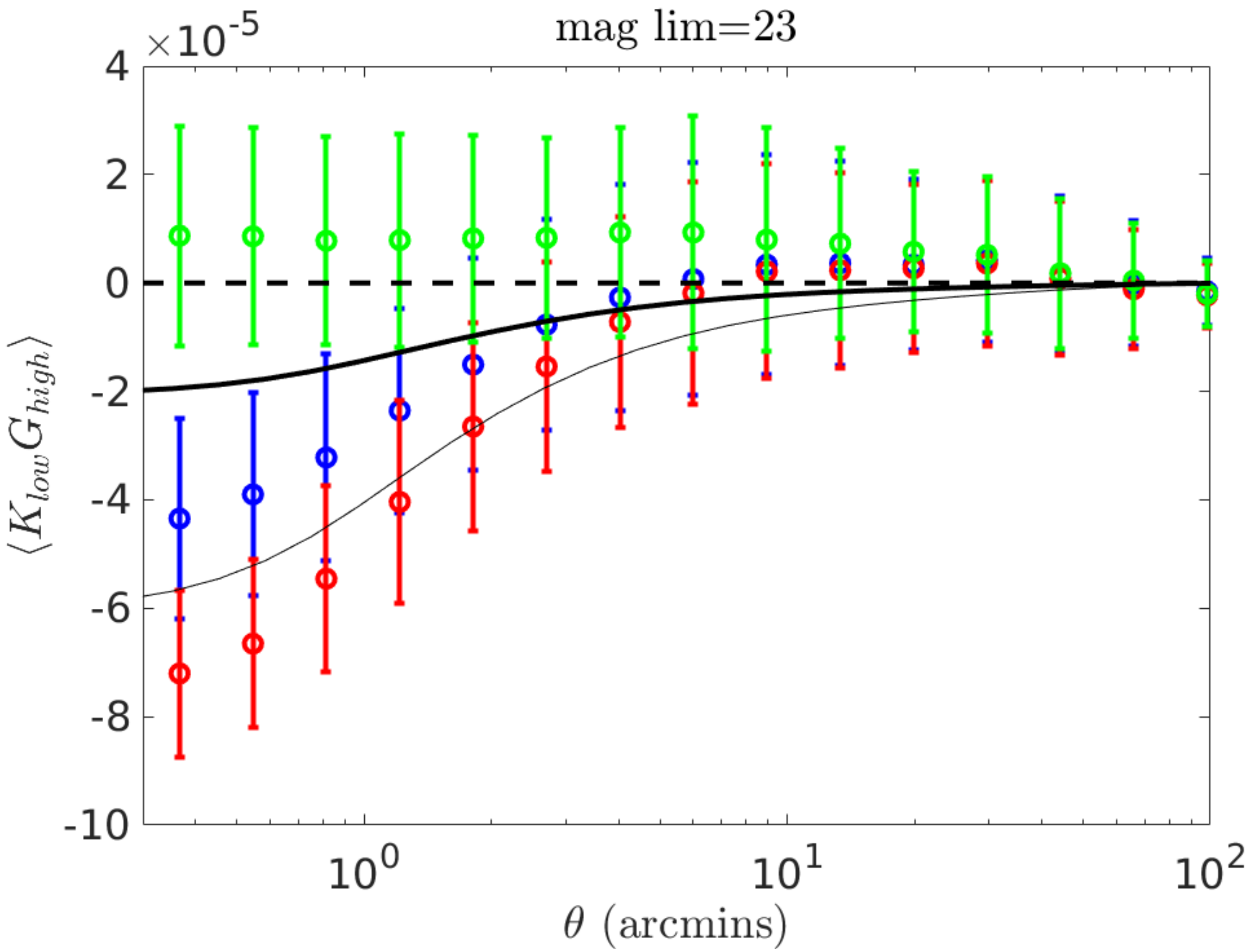
$$\mu = \frac{1}{\det \mathcal{A}} = \frac{1}{(1-\kappa)^2 - |\gamma|^2}$$

Blue: from strict magnification
Red: use 1+2κ as an approximation



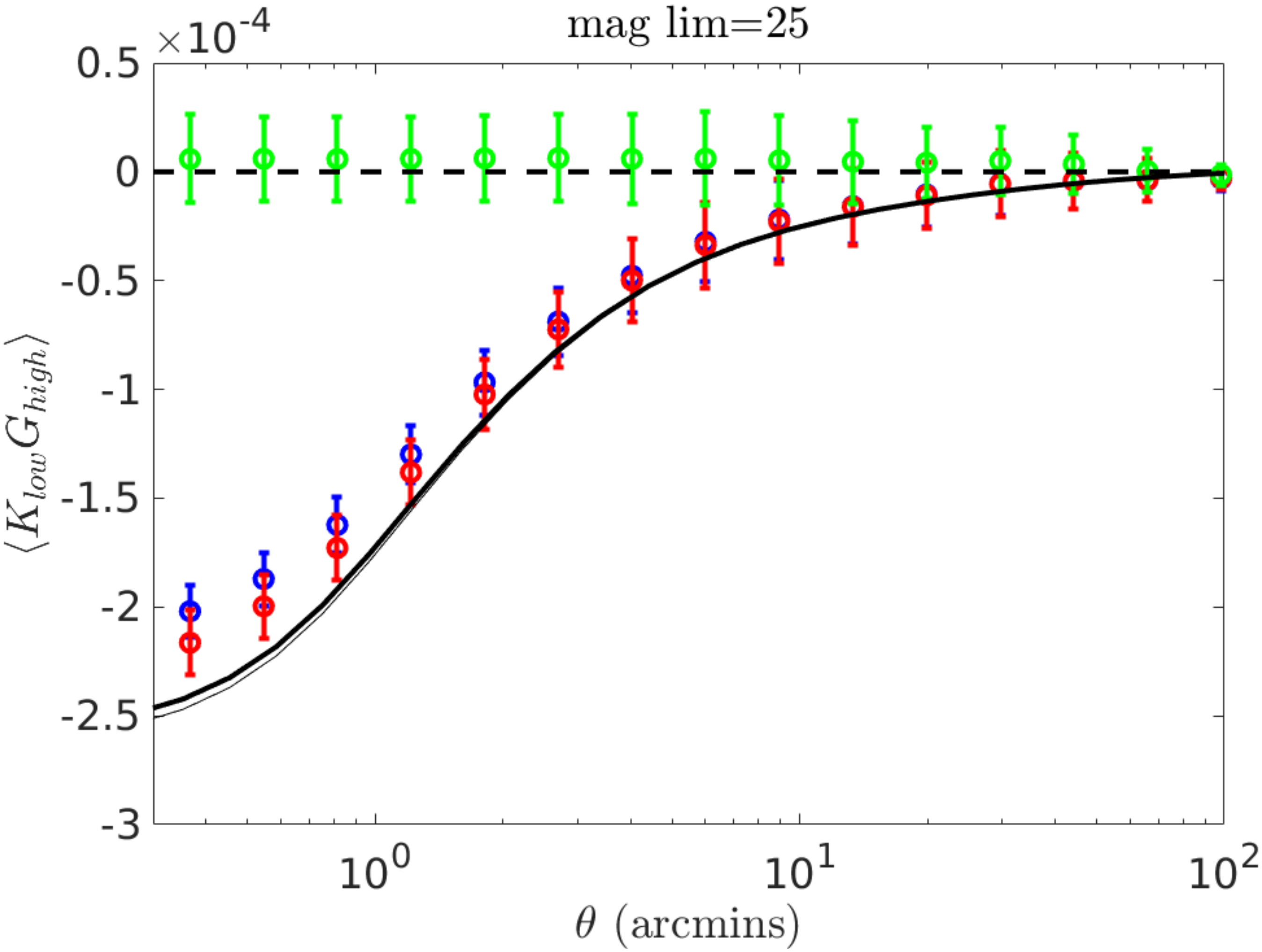
Preliminary results

- 2. low-z semi-analytical sample * high-z sample (mag<23)



Preliminary results

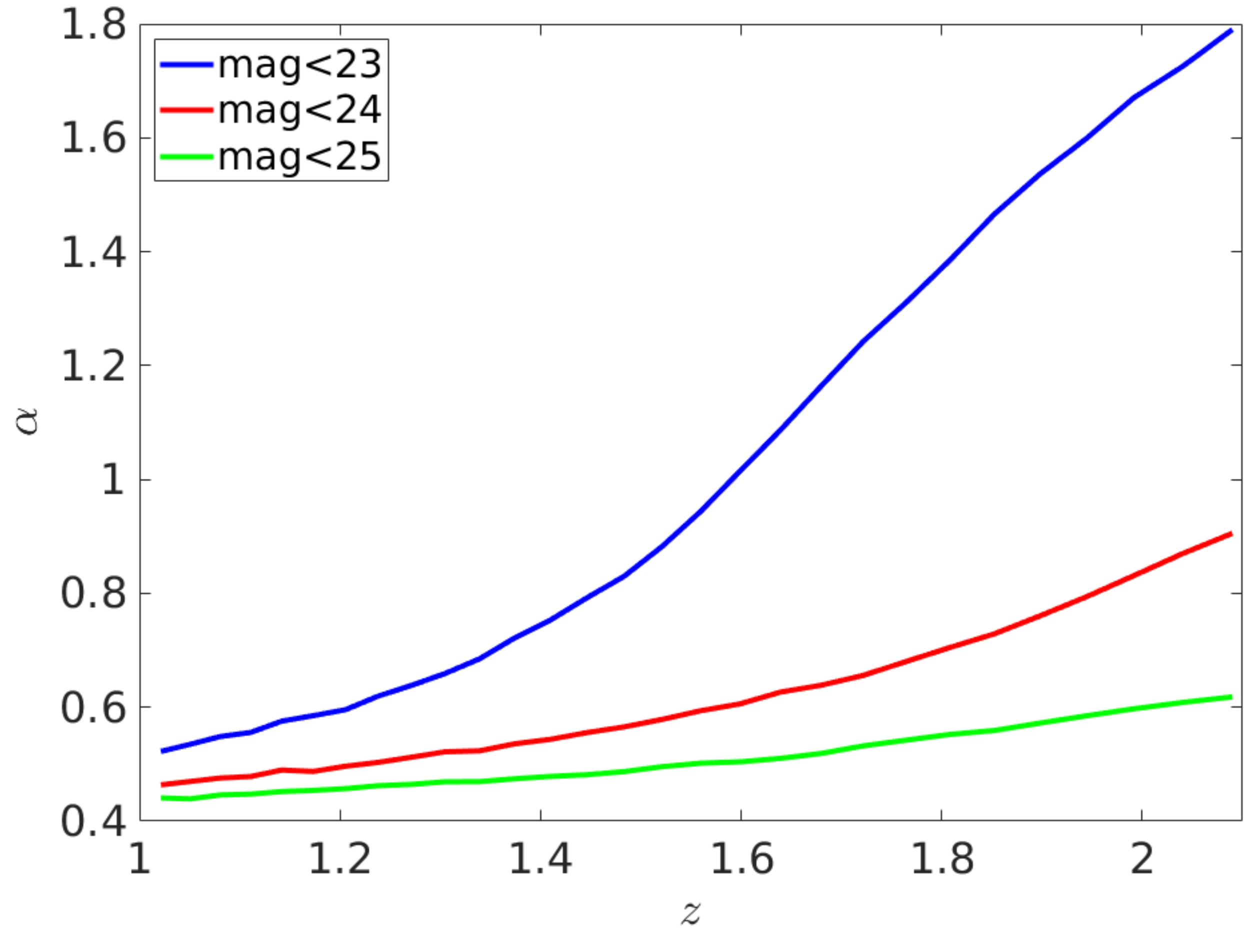
- 3. low-z semi-analytical sample * high-z sample (mag<25)



Preliminary results

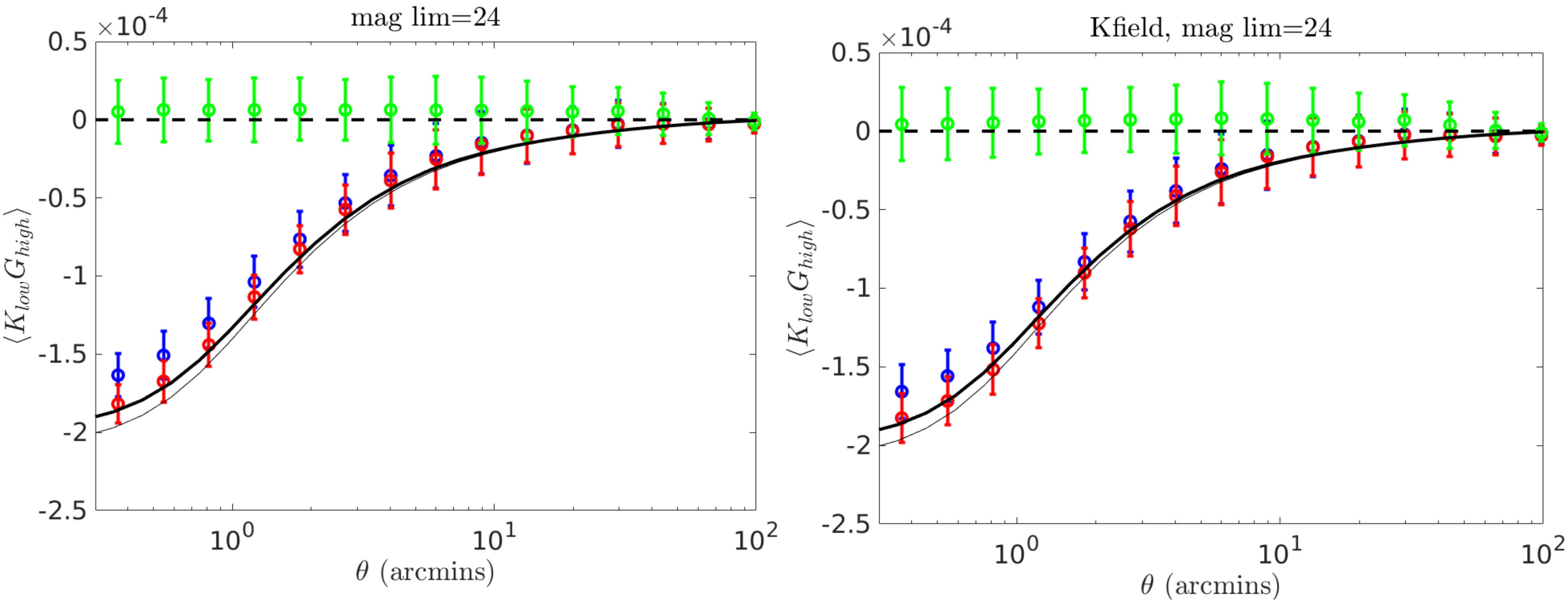
- α vs redshift for different high-z samples

$$\alpha(m) = 2.5 \frac{\mathrm{d}}{\mathrm{d}m}[\log N_\mu(m)]$$



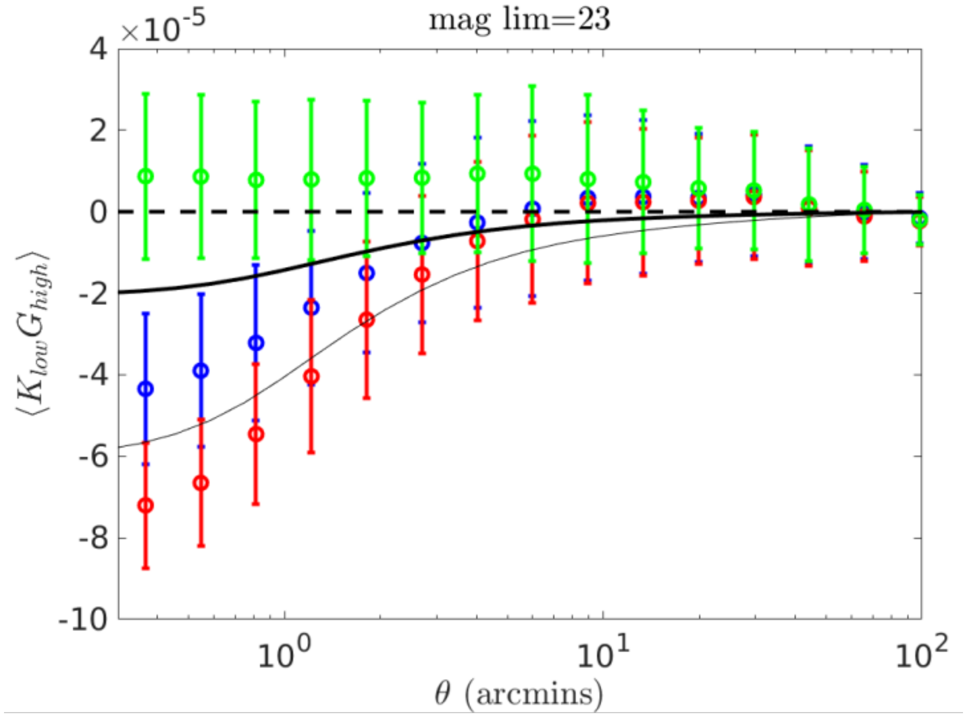
Preliminary results

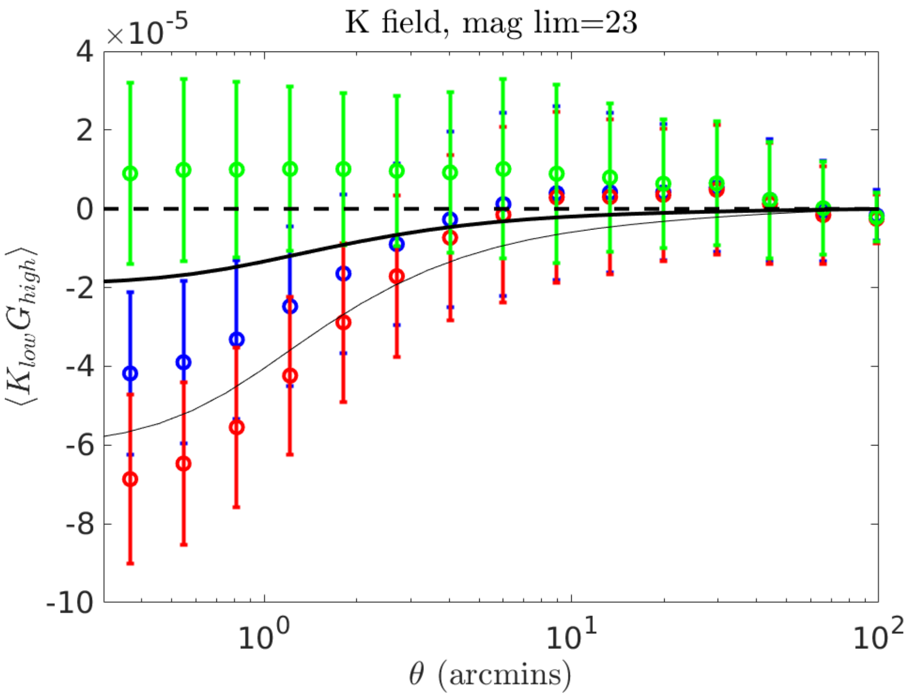
- 4. low-z convergence field * high-z sample (mag<24, right panel)



Preliminary results

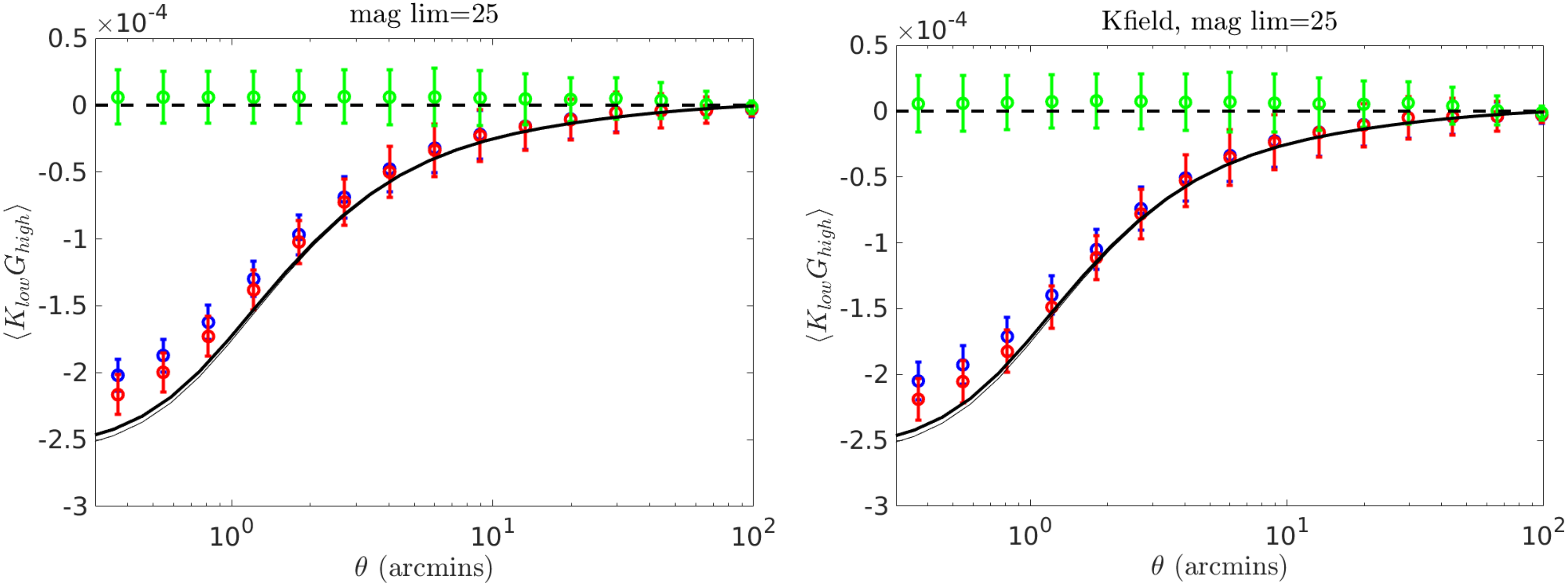
- 5. low-z convergence field * high-z sample (mag<23, right panel)





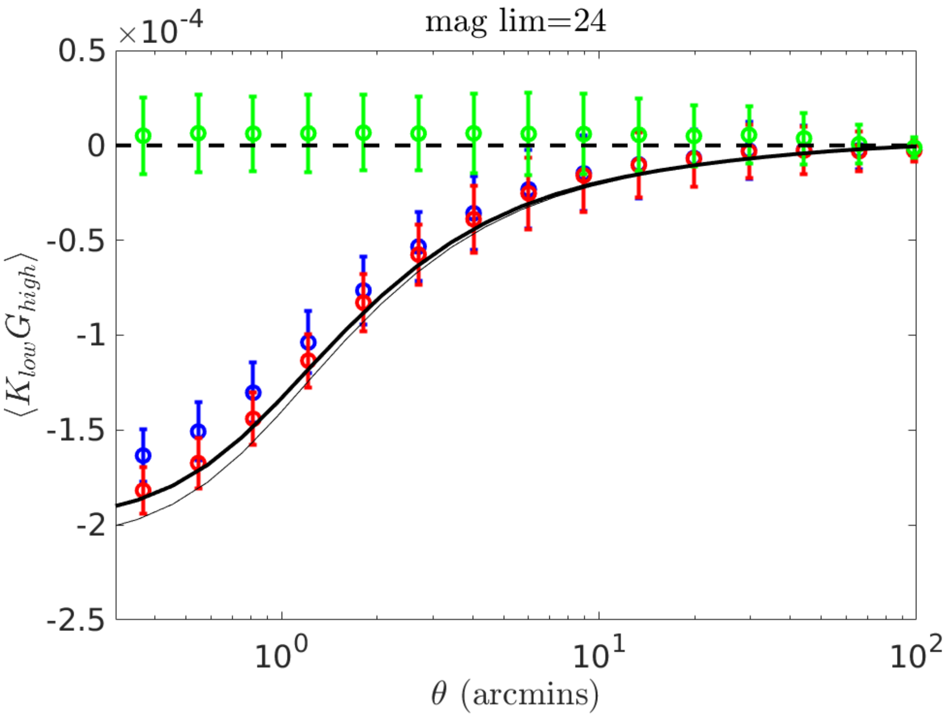
Preliminary results

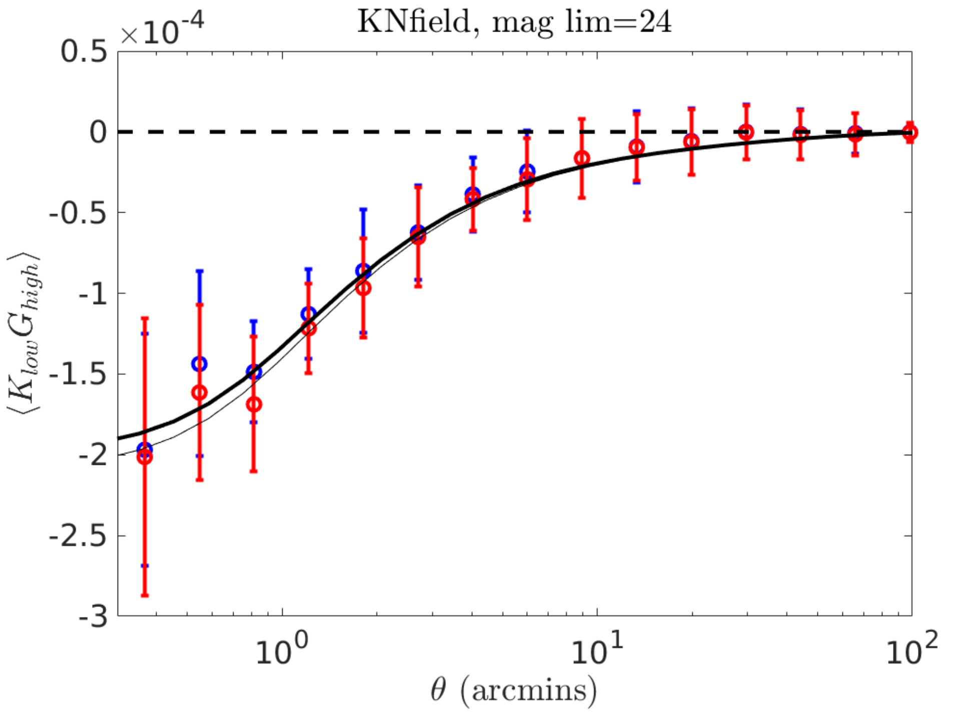
- 6. low-z convergence field * high-z sample (mag<25, right panel)



Preliminary results

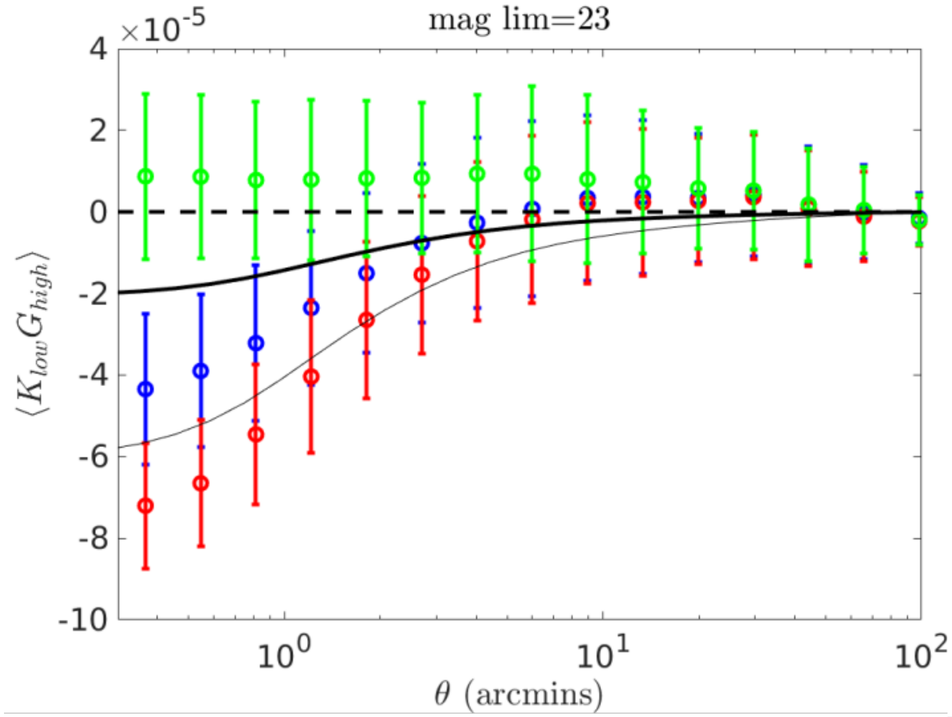
- 7. low-z noisy convergence field * high-z sample (mag<24, right panel)

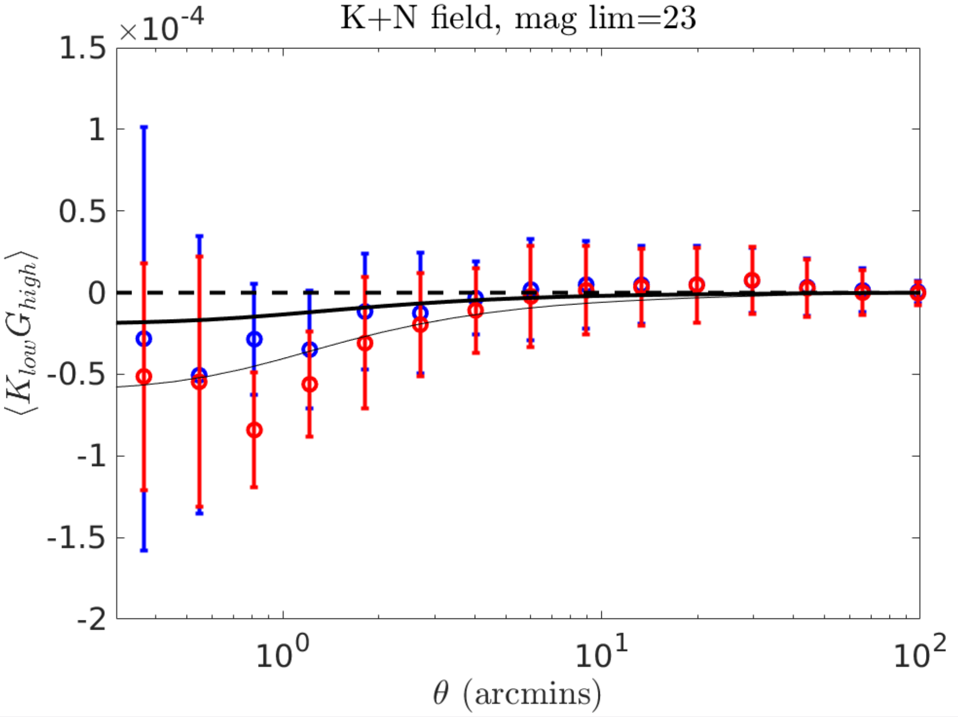




Preliminary results

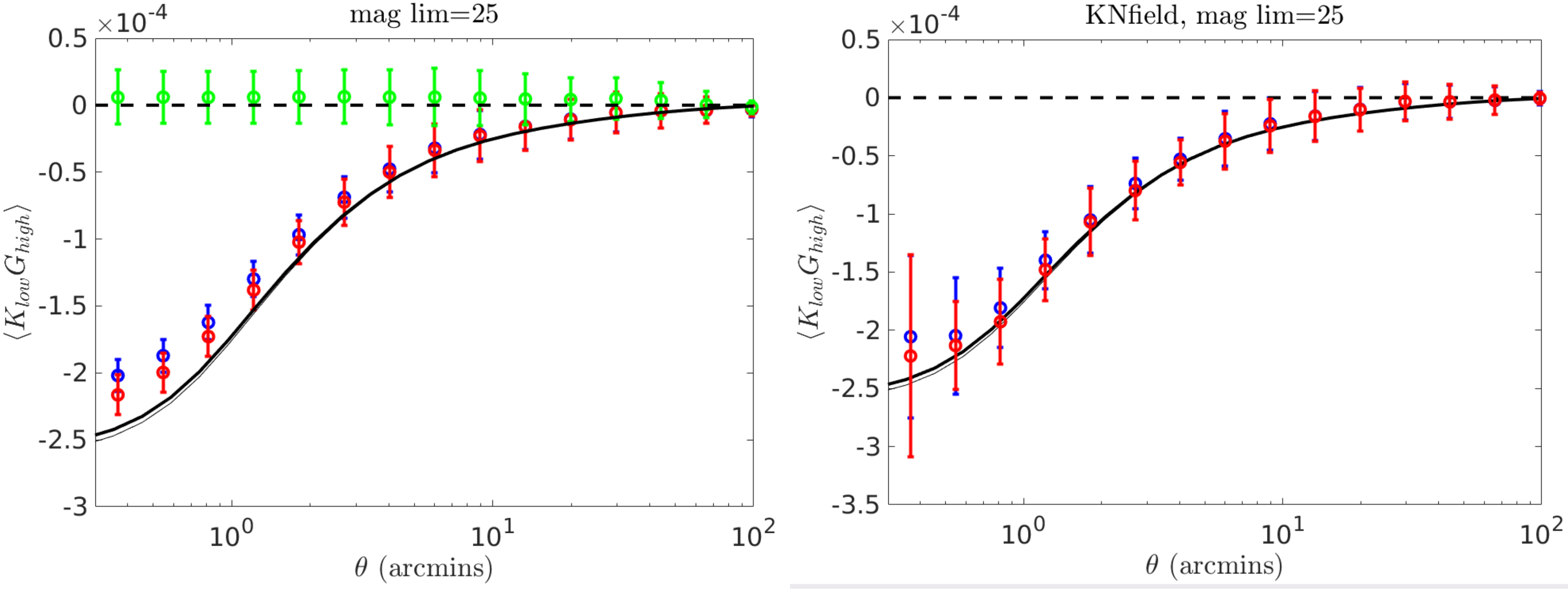
- 8. low-z noisy convergence field * high-z sample (mag<23, right panel)





Preliminary results

- 8. low-z noisy convergence field * high-z sample (mag<25, right panel)



Some preliminary conclusions

- Cross-correlation between low-z convergence and high-z galaxy number density distribution could be a new and promising method to measure the lensing magnification signal.

- Many effects could influence the results:
  - 1. magnification approximation $(1+2\kappa)$
  - 2. How to use α in the theoretical calculations
  - 3. Other hidden effects which need to be carefully investigated.

Future works

- Careful investigation on the possible effects that contribute the deviation between simulation results and theoretical predictions.
- Generate more realistic catalogs from simulation and perform detailed tests.
- Explore estimators directly from shear to measure the magnification signal.
- Apply to real observations, e.g., HSC data.

Thank you!