Full-sky Weak Lensing Simulation with Semi-analytic Galaxy Formation

— Exploring Galaxy Intrinsic Alignment and Cosmic Shear

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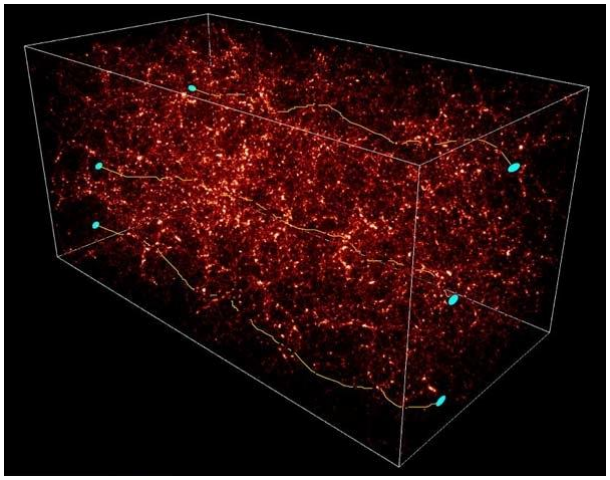
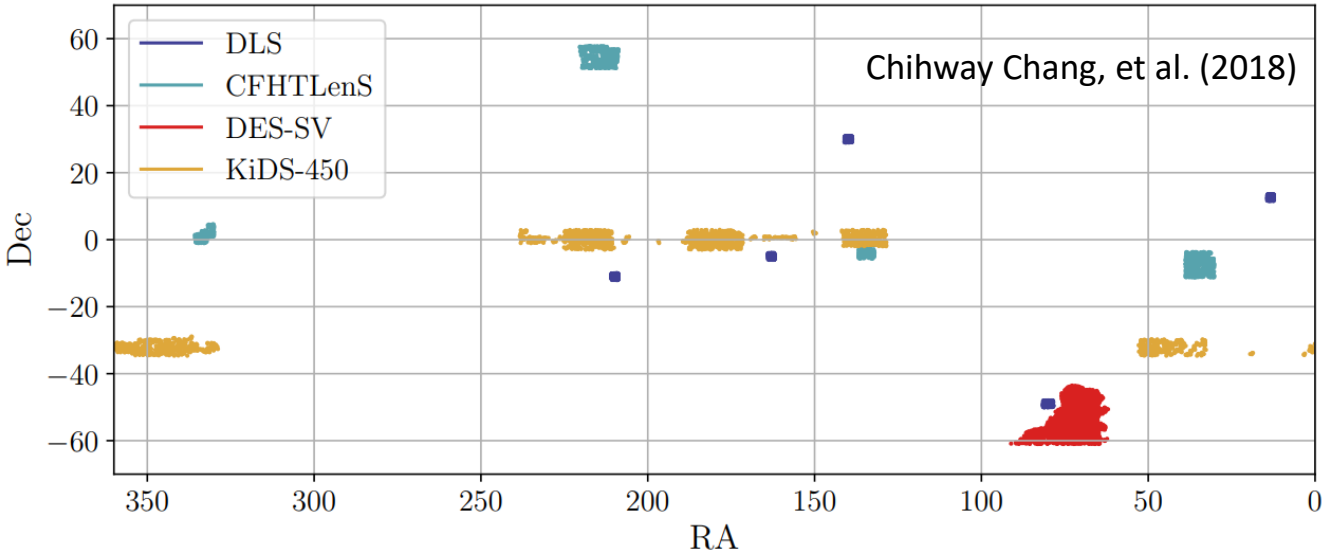
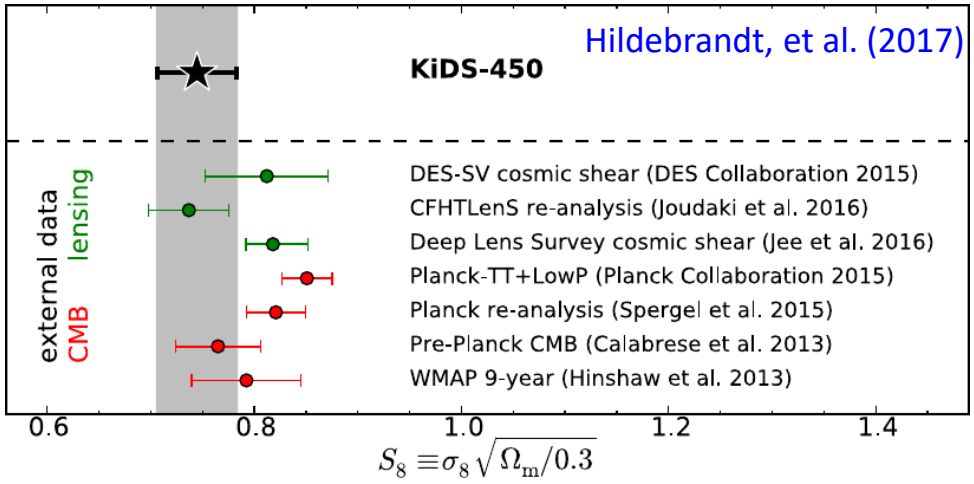
Weak Lensing and Cosmology

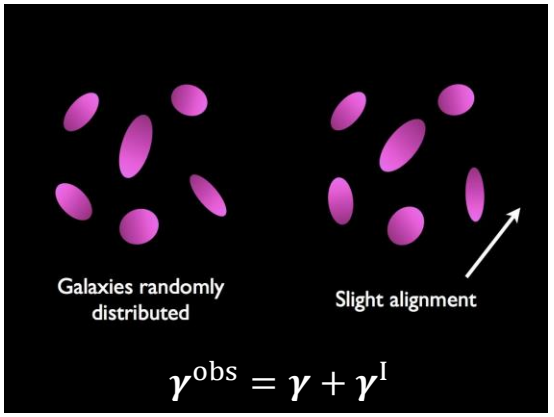


- Weak-lensing is powerful in directly mapping the mass distribution
- If galaxy intrinsic shape is randomly distributed, $\langle \boldsymbol{\gamma}_i^{\mathbf{obs}}\, \boldsymbol{\gamma}_j^{\mathbf{obs}} \rangle = \langle \boldsymbol{\gamma}_i\, \boldsymbol{\gamma}_j \rangle$, so it is easy to get the matter power $\langle \boldsymbol{\gamma}\, \boldsymbol{\gamma} \rangle$ and then $S_8 = \sigma_8 \sqrt{\Omega_{\mathrm{m}}/0.3}$



Tension in S_8 between recent weak lensing surveys





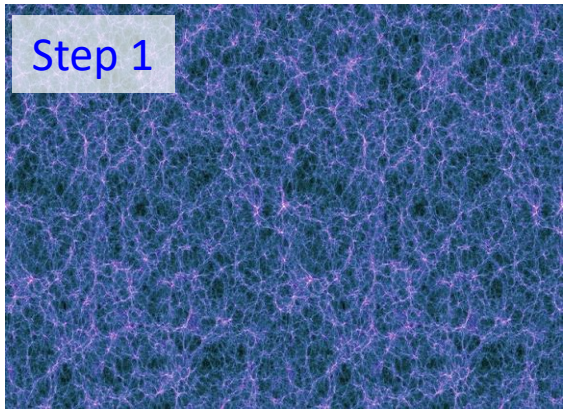
$$\langle \gamma_i^{\rm obs}\, \gamma_j^{\rm obs} \rangle = \langle \gamma_i\, \gamma_j \rangle + \langle \gamma_i^{\rm I}\, \gamma_j \rangle + \langle \gamma_i^{\rm I}\, \gamma_j^{\rm I} \rangle$$

What cause the discrepancy between different WL surveys?
We need better understanding of the effects of:

- Systematic effects: IA, PSF, shear measurement, etc.
- Sky coverage, magnitude limit, source redshift distribution, mask effect, etc.

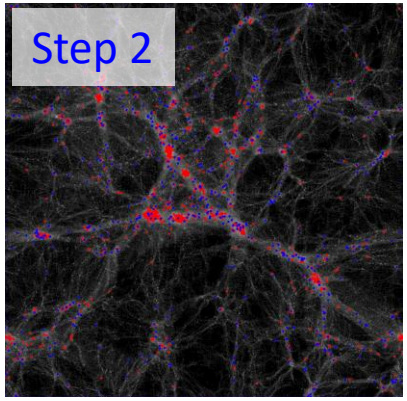
Realistic Simulation of WL

To understand different effects, we need the simulation: producing mock galaxy catalogues with lensed images: including galaxy intrinsic shape and lensing effect



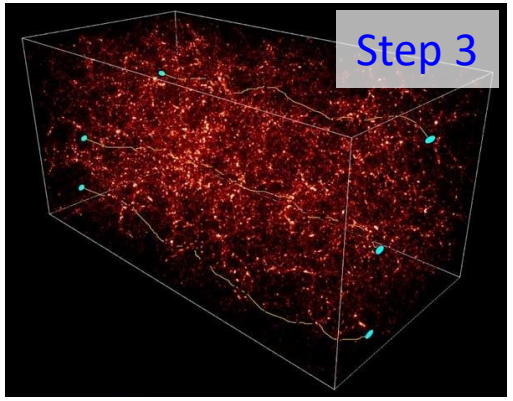
DM simulation

+

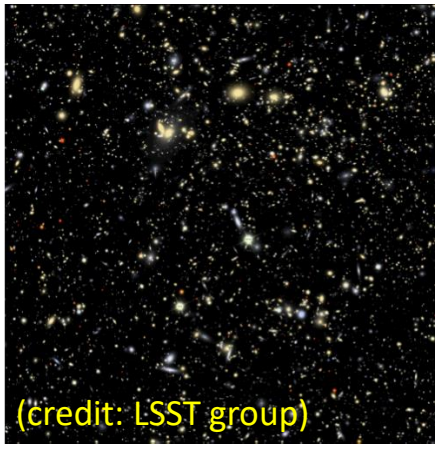


Semi-analytical model

+



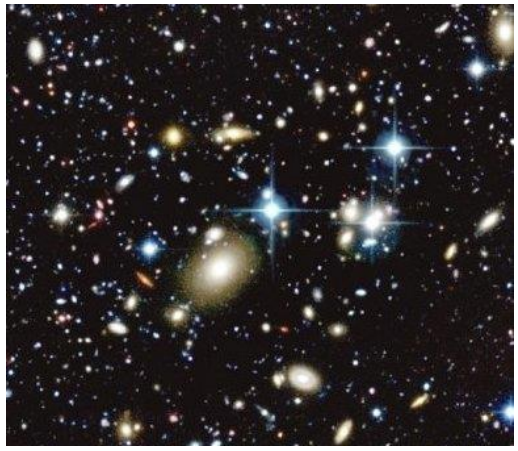
Ray-tracing Simulation



Simulated galaxy image

cosmic shear

comparison



Real observation

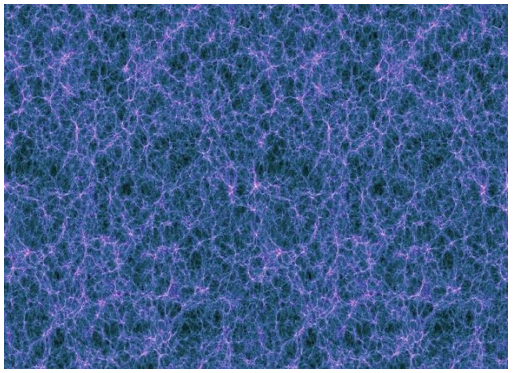
How to produce mock galaxy image catalogue

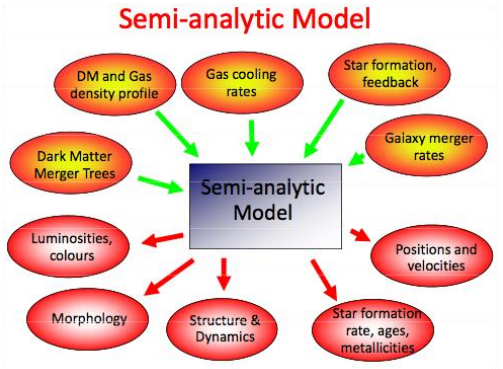
Step 1, N-body simulation: ELUCID (local universe reconstructed)

- L_{box}=500Mpc/h, $N_p=3072^3$, $m_p=3.4*10^8 M_\odot$, 2 times of the resolution of Millennium Simulation,

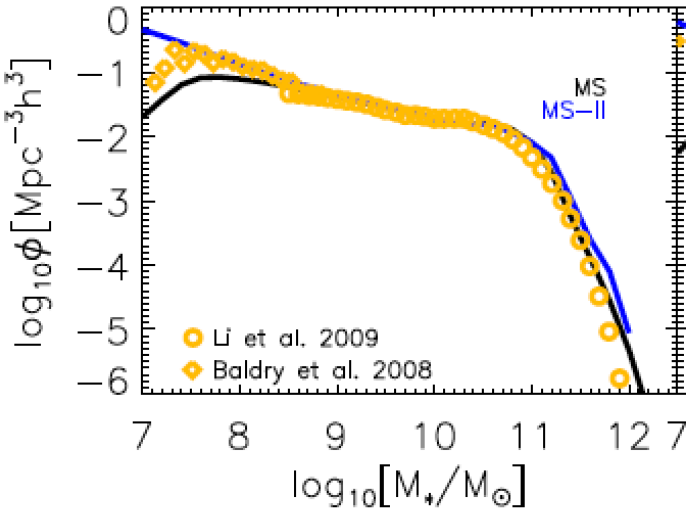
  WMAP9 cosmology: Ω_m=0.28, $\boldsymbol{\sigma}_8$=0.82
  → $S_8=\boldsymbol{\sigma}_8(\Omega_m/0.3)^{0.5} \simeq 0.79$

- L_{box}=1000Mpc/h, $N_p=3072^3$, for check of power spectrum on large scales





Step 2, Semi-analytical model for galaxy formation: Luo Y, KX., Kauffmann G., Fu J, 2016 (based on the **L-Galaxy** Munich model)

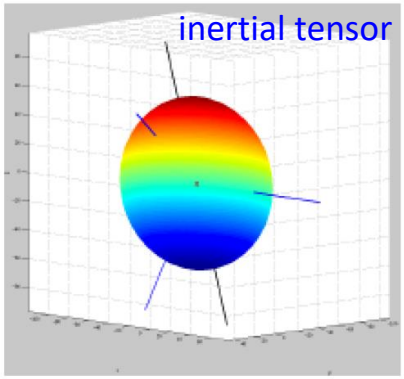


How to define galaxy intrinsic shape?

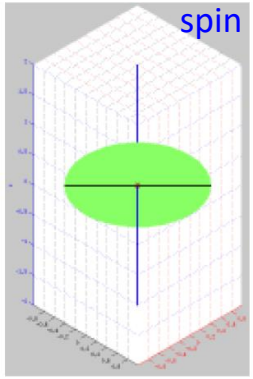
(we follow Joachimi et al. 2013)

Central galaxies

- Elliptical (Early-type)
- Spiral (Late-type)



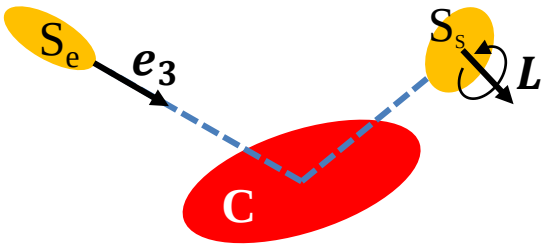
$$I_{ij} = \sum_{n=1}^{N} m_p x_{i,n} x_{j,n}$$



$$\boldsymbol{L} = \sum_{n=1}^{N} m_p \boldsymbol{x}_n \times \boldsymbol{v}_n$$

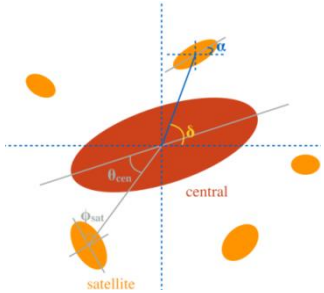
Satellite galaxies

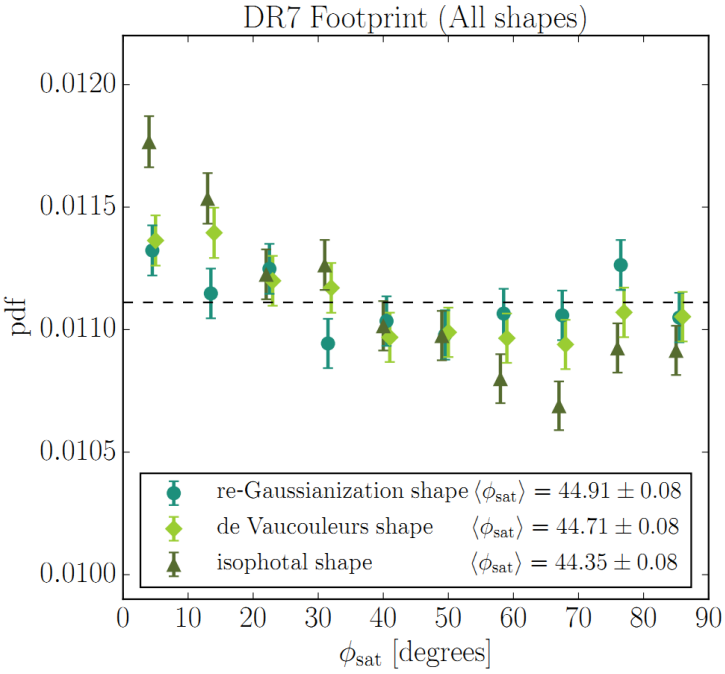
Joachimi et al. 2013 model **(J13)**



Random model

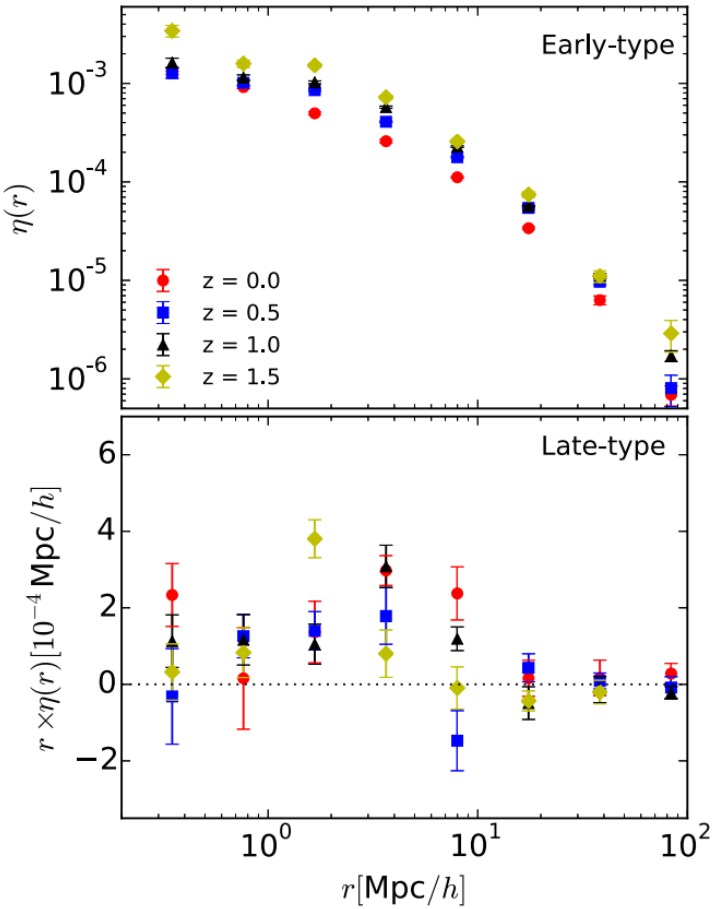
(Hung-Jin Huang, R. Mandelbaum et al. 2018)





Galaxy intrinsic alignment: dependence on morphology

$$\eta(r) = \langle \epsilon_t(\boldsymbol{x})\epsilon_t(\boldsymbol{x}+\boldsymbol{r}) + \epsilon_\times(\boldsymbol{x})\epsilon_\times(\boldsymbol{x}+\boldsymbol{r})\rangle_{\boldsymbol{x}}$$ （Wei+, 2018, ApJ, 853, 25）

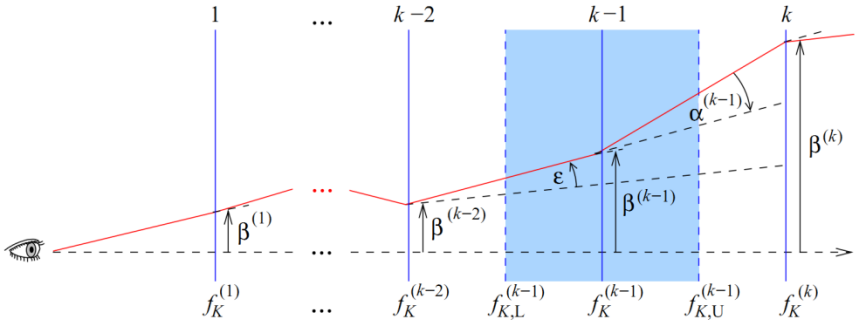


These correlations are consistent with that in Joachimi et al. (2013)

Step 3: Spherical Ray-tracing (RT) Simulation

Multiple-lens-plane RT

Jain+(2000), White & Vale (2004),
Hilbert+(2009), etc.

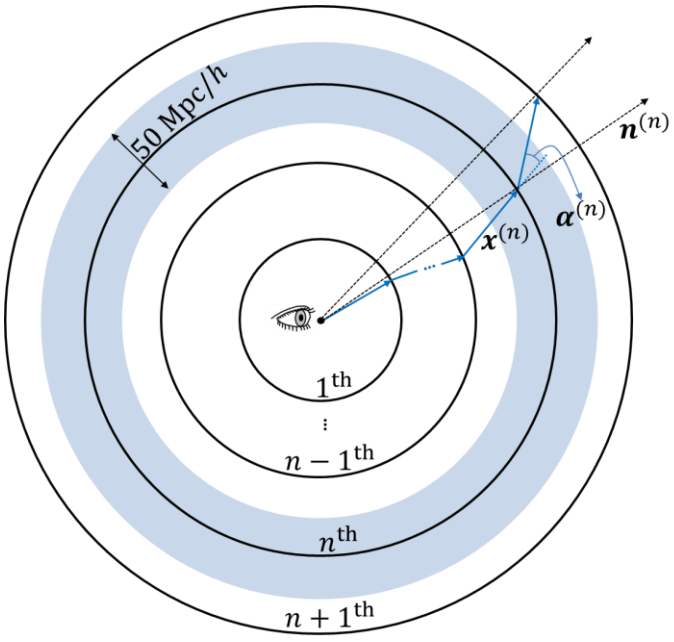


S. Hilbert et al.(2009)

$$\boldsymbol{\theta}^{(k)} = \frac{1}{D_0^k}\left[D_0^{k-1}\left(1+\frac{D_{k-1}^k}{D_{k-2}^{k-1}}\right)\boldsymbol{\theta}^{(k-1)} - D_{k-1}^k\boldsymbol{\alpha}^{(k-1)} - \frac{D_{k-1}^k}{D_{k-2}^{k-1}}D_0^{k-2}\boldsymbol{\theta}^{(k-2)}\right]$$

Spherical RT

Das & Bode(2008), Fosalba+(2008),
Teyssier+(2009), Becker (2013)



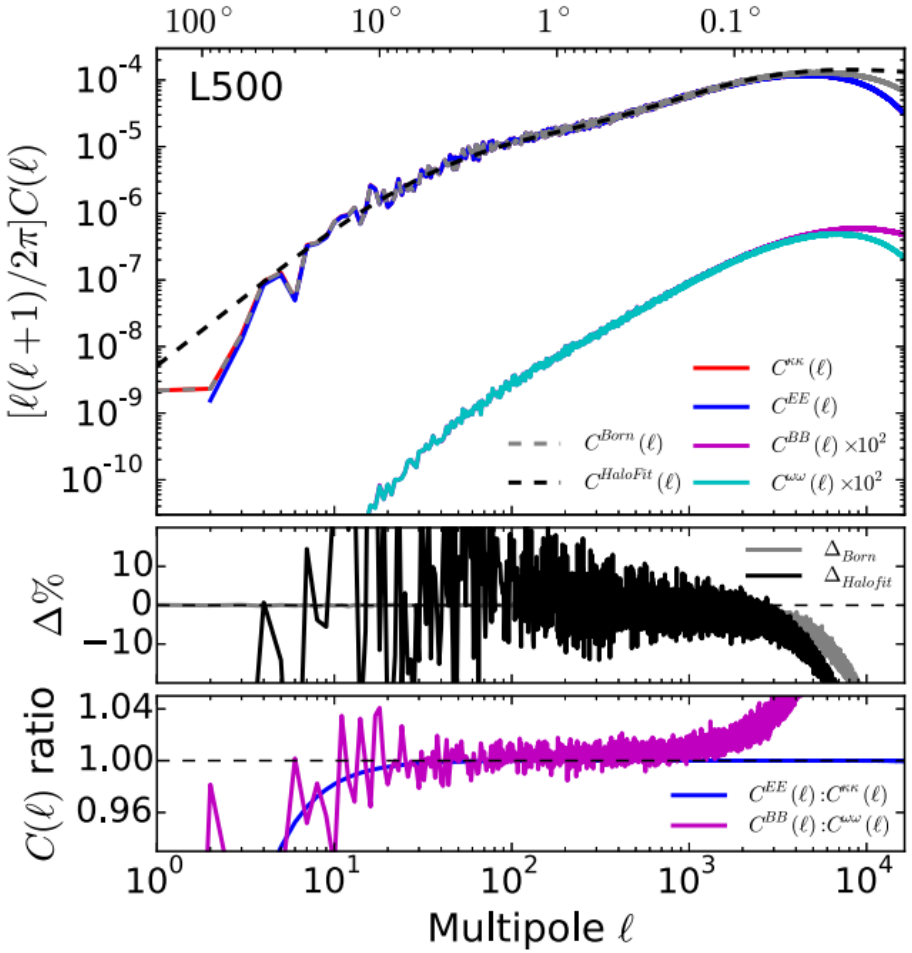
$$\boldsymbol{x}^{(n+1)} = \mathcal{R}\left(\boldsymbol{n}^{(n)} \times \boldsymbol{\alpha}^{(n)}, \|\boldsymbol{\alpha}^{(n)}\|\right)\boldsymbol{x}^{(n)}$$

The Flat-sky Approx.

- good enough for current lensing surveys (Kilbinger+, 2017)

- suppress power by > 1% on scales of l < 40, which would account for at least 11% of the total budget for systematic effects for a power spectrum analysis of a Euclid or LSST-like experiment (Kitching+, 2016)

How accurate is our ray-tracing?

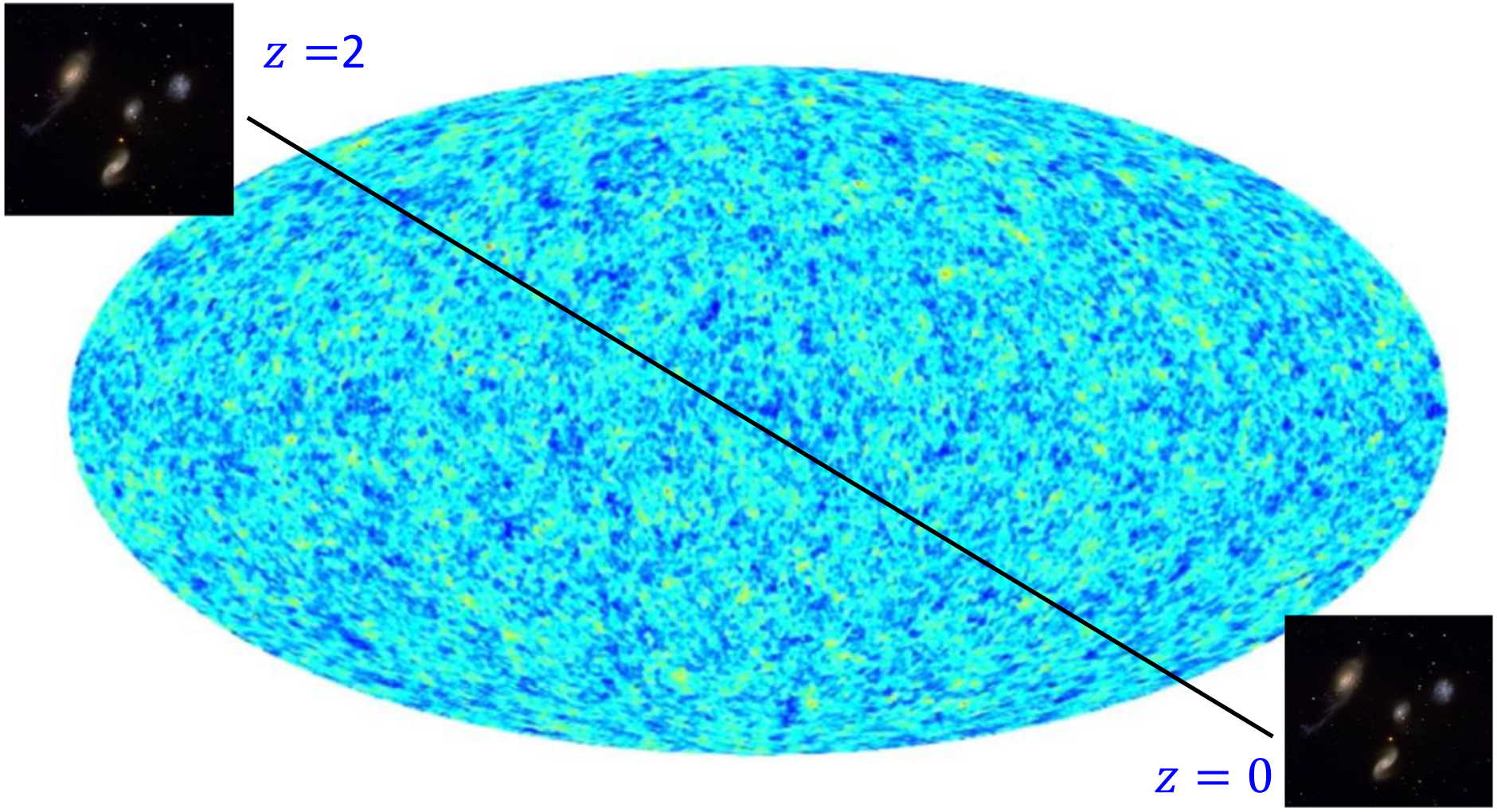


The power spectrum of E/B model, also show comparison with theoretical prediction.

Our RT is accurate

- The simulated power spectrum from RT agree with both Born approximation and Halofit theoretical prediction, up to very small scales
- The B-mode is strongly suppressed (numerical effect is very small)

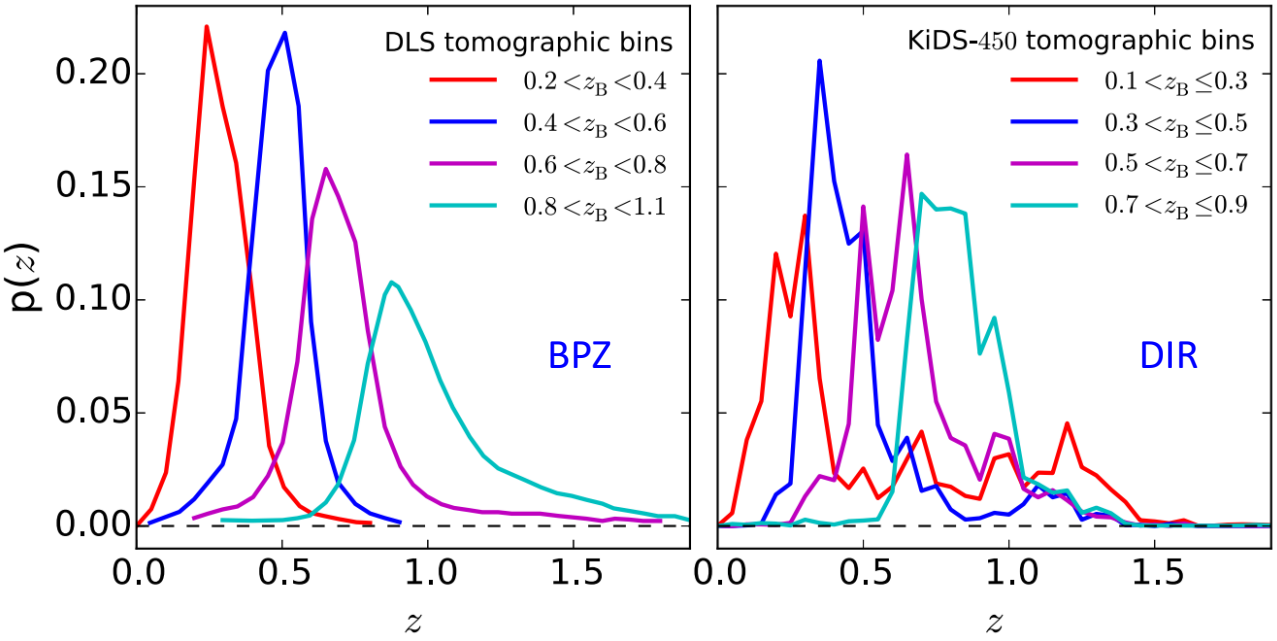
Full-Sky Convergence/Shear Field Map



Wei C, Li G, Kang X, +, 2018 ApJ, 853, 25

To compare with the data, we select simulated galaxies which have the same

- Redshift distribution of source galaxies
- Sky coverage (KiDS: 450 deg^2, DLS: 20 deg^2)
- Source galaxies number density

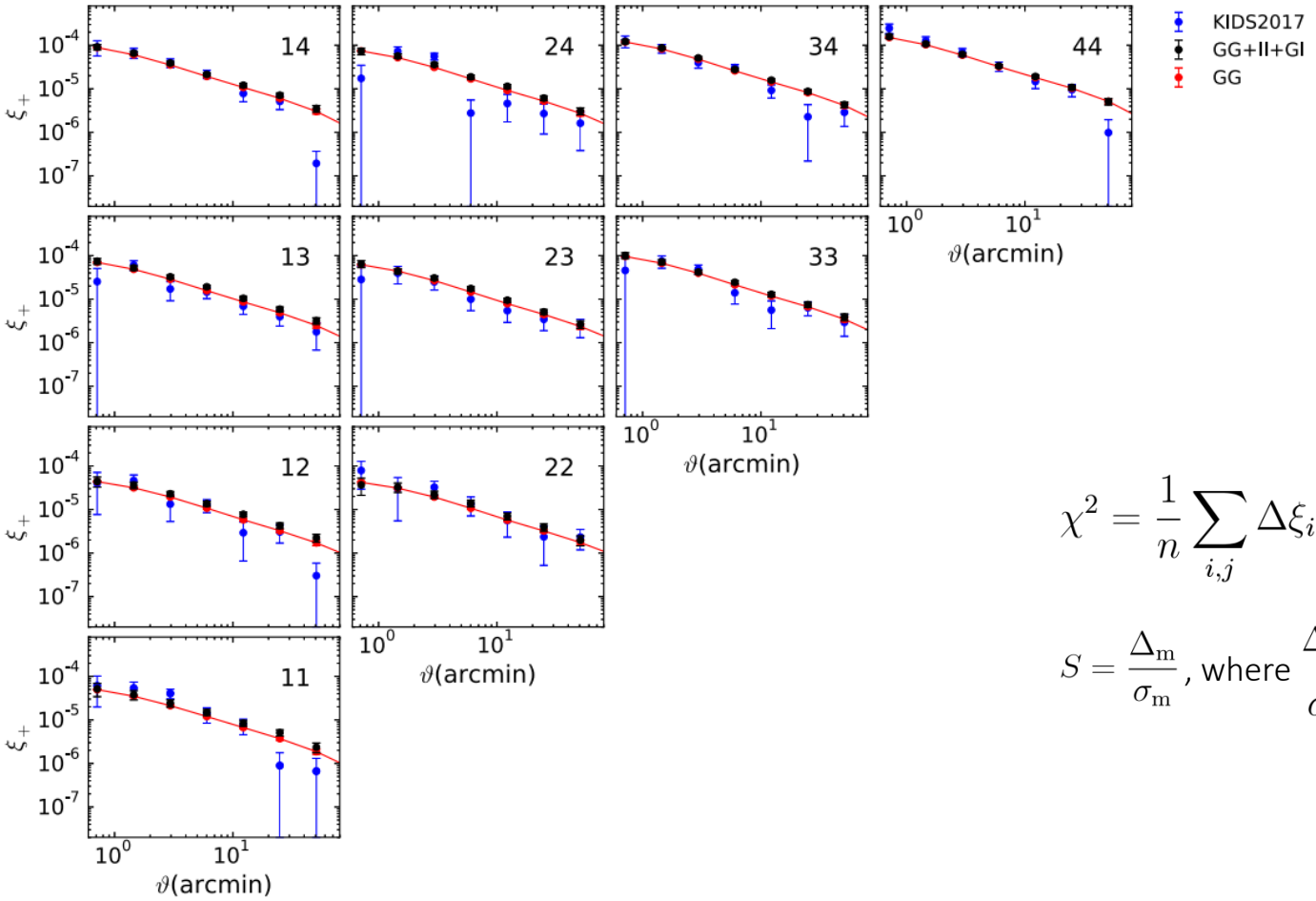


The source redshift distributions in KiDS and DLS

- The photo-z of source galaxies are derived from the DIR (KiDS) and BPZ (DLS) methods
- The two distributions are very different

Model predictions VS Observations

Tomographic shear correlations: comparison with KiDS-450 results by Hildebrandt et al. (2017)



$$\chi^2 = \frac{1}{n}\sum_{i,j}\Delta\xi_i C_{ij}^{-1}\Delta\xi_j$$

$$S = \frac{\Delta_{\rm m}}{\sigma_{\rm m}}, \text{ where } \Delta_{\rm m} = \frac{1}{n}\sum\frac{\Delta\xi_i}{\sigma_i}, \quad \sigma_{\rm m} = 1/\sqrt{n}$$

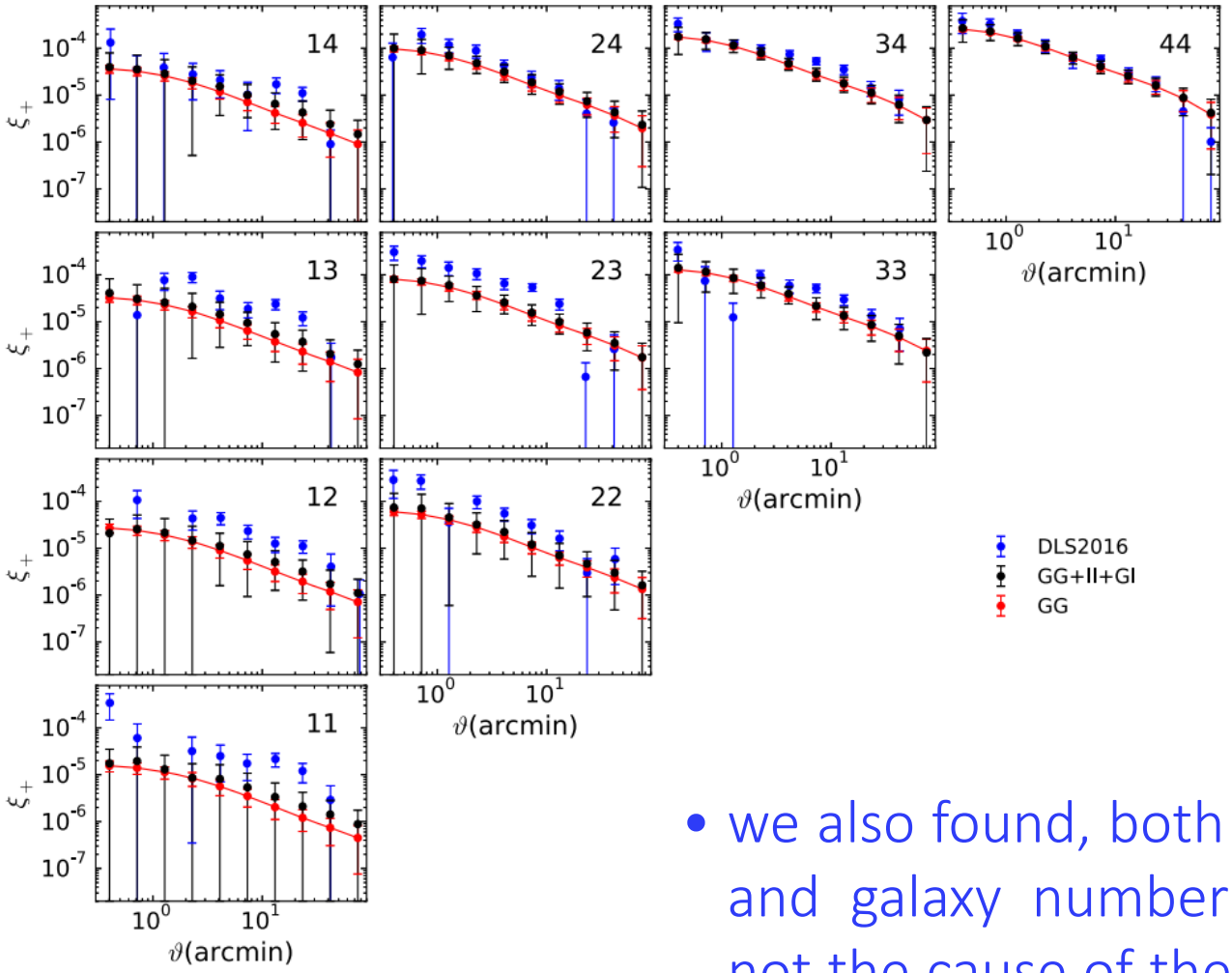
Our model agrees well with KiDS, with reduced χ^2=1.36 and S=1.80σ

Model predictions VS Observations

Tomographic shear correlations: comparison with DLS (Jee et al. 2016)

$\chi^2_+ = 1.56$

$S = 2.57$

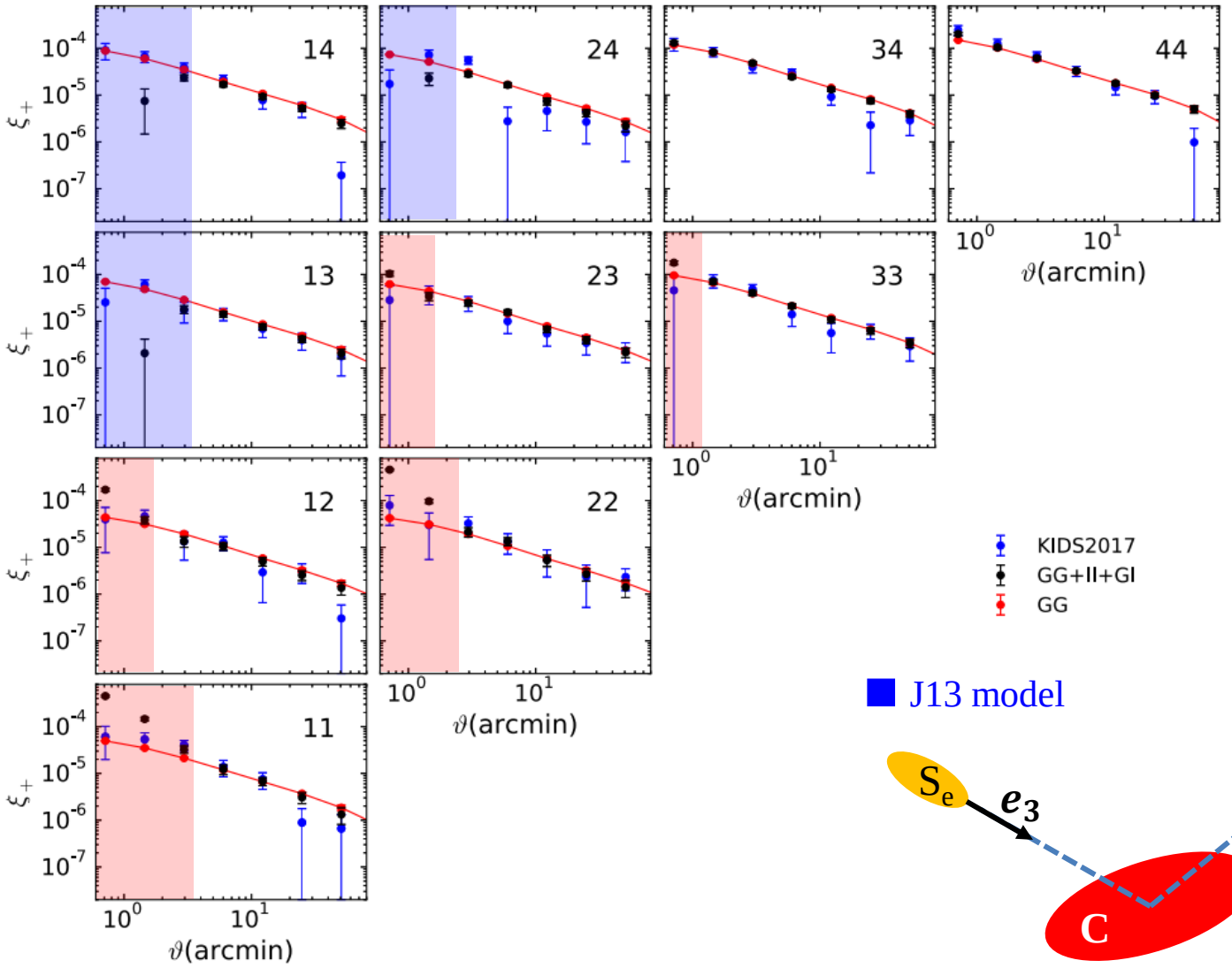


- we also found, both sky coverage and galaxy number density, are not the cause of the higher shear correlations of DLS

Model predictions VS Observations

constraints on satellite alignment model

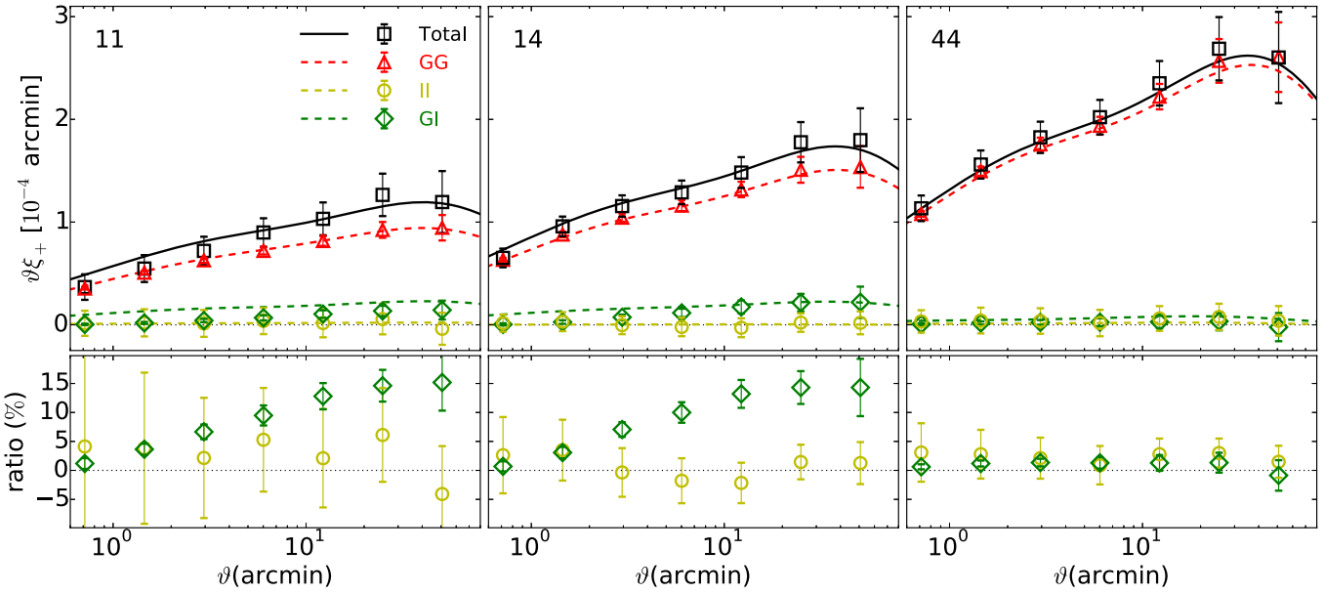
$\chi^2 = 3.73$



J13 model

J13 model produces too strong power on small scales

Contribution of II and GI terms



Non-linear model of galaxy IA:

$$P_{\rm II}(k,z) = f^2(z) P_\delta(k,z)$$
$$P_{\rm GI}(k,z) = f(z) P_\delta(k,z)$$
$$f(z) = -A_{\rm IA} C_1 \rho_{\rm c} \frac{\Omega_{\rm m}}{D(z)} \left(\frac{1+z}{1+z_0}\right)^\eta \left(\frac{L}{L_0}\right)^\beta$$

$$A_{\rm IA} = -0.972 \pm 0.217$$

- We found II term is very weak, GI is 10% of the matter power spectrum
- The GI term is positive, not negative from the linear model (Hirata & Seljak 2004)

$A_{\rm IA} > 0$

1.10 ± 0.64 for KiDS-450 (Hildebrandt et al. 2017)

$1.0^{+0.4}_{-0.7}$ for DES Y1 Fiducial (Troxel et al. 2017)

$6.27^{+1.10}_{-1.01}$ for SDSS LRG (Joachimi et al. 2013)

$5.92^{+0.77}_{-0.75}$ for MegaZ-LRG + SDSS LRG

$A_{\rm IA} < 0$

$-1.10^{+96}_{-0.7}$ for KiDS-450 BPZ (Hildebrandt et al. 2017)

-0.9 for DES Y1 tidal torque model (Troxel et al. 2017)

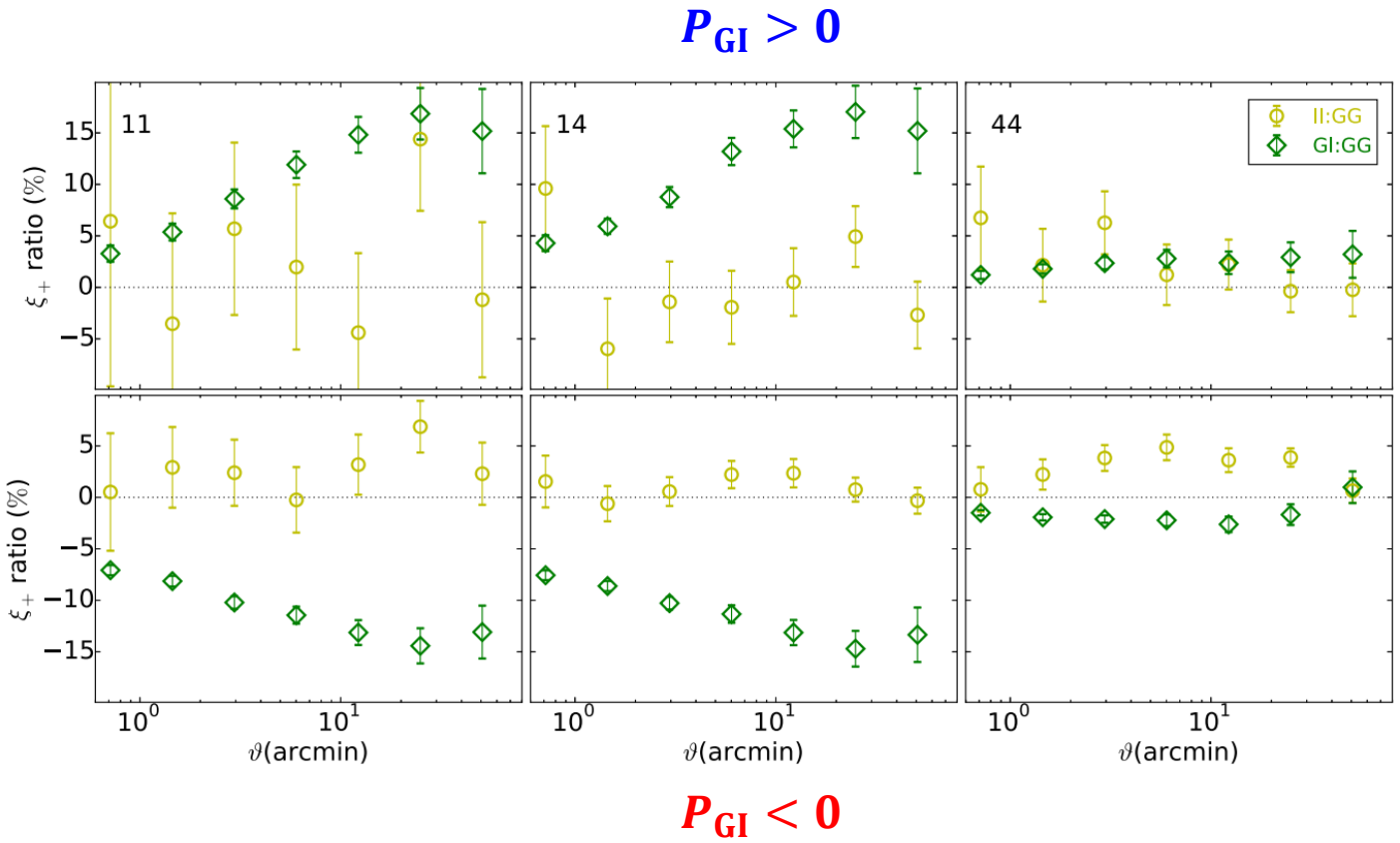
-3.6 ± 1.6 for CFHTLenS revisit (Joudaki et al. 2017)

$-1.18^{+0.96}_{-1.17}$ for CFHTLenS Full(Heymans et al. 2013)

The GI terms: dependence on galaxy morphology

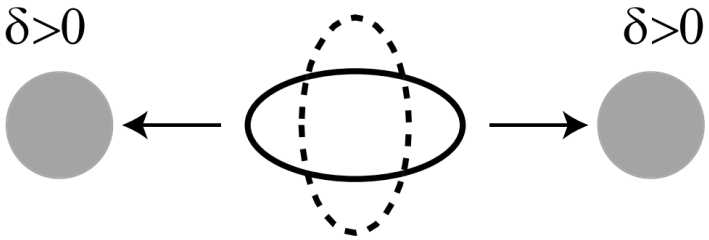
Pure Spirals

Pure Ellipticals



We argue the existed WL theory (intrinsic IA model) should consider the GI contribution from early-type and late-type galaxies separately (actually, most observed galaxies are spirals)

Classic Galaxy II and GI model



Hirata & Seljak (2004)

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **454,** 2736–2753 (2015) doi:10.1093/mnras/stv2154

Intrinsic alignments of galaxies in the Horizon-AGN cosmological hydrodynamical simulation

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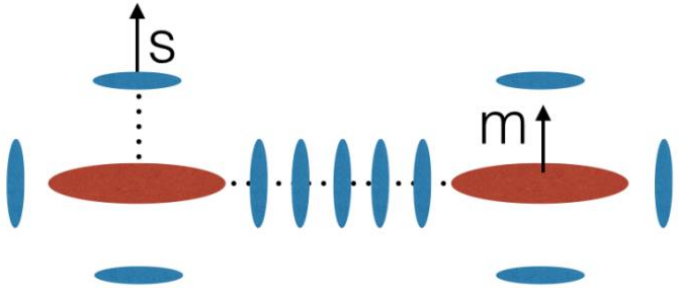
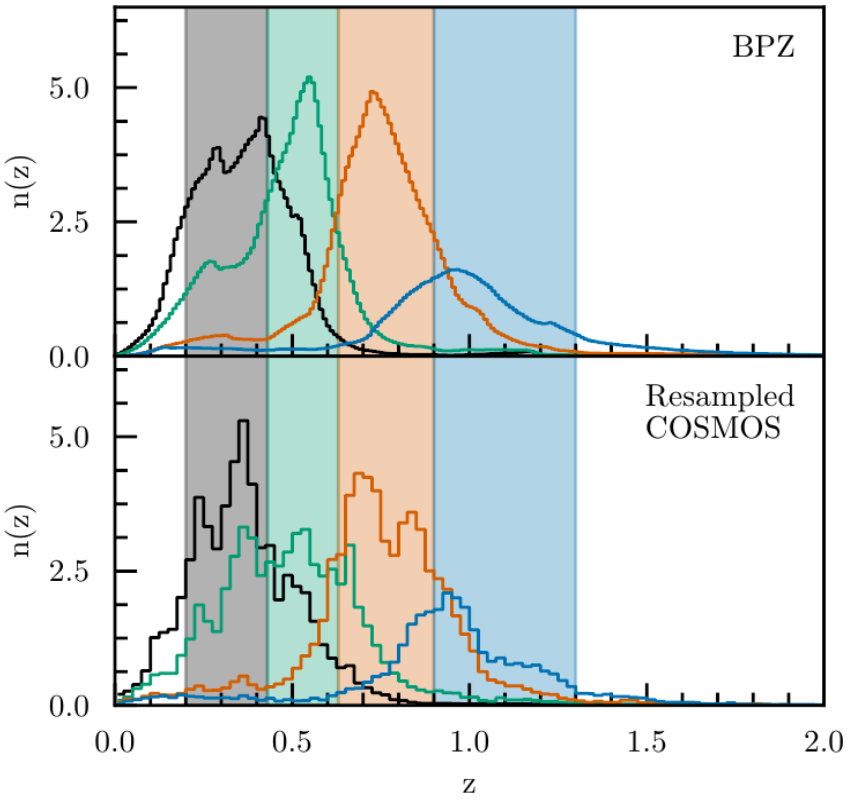
[2]*Institut d'Astrophysique de Paris, CNRS & UPMC, UMR 7095, 98 bis Boulevard Arago, F-75014 Paris, France*
[3]*Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK*



N. Chisari et al. (2015)

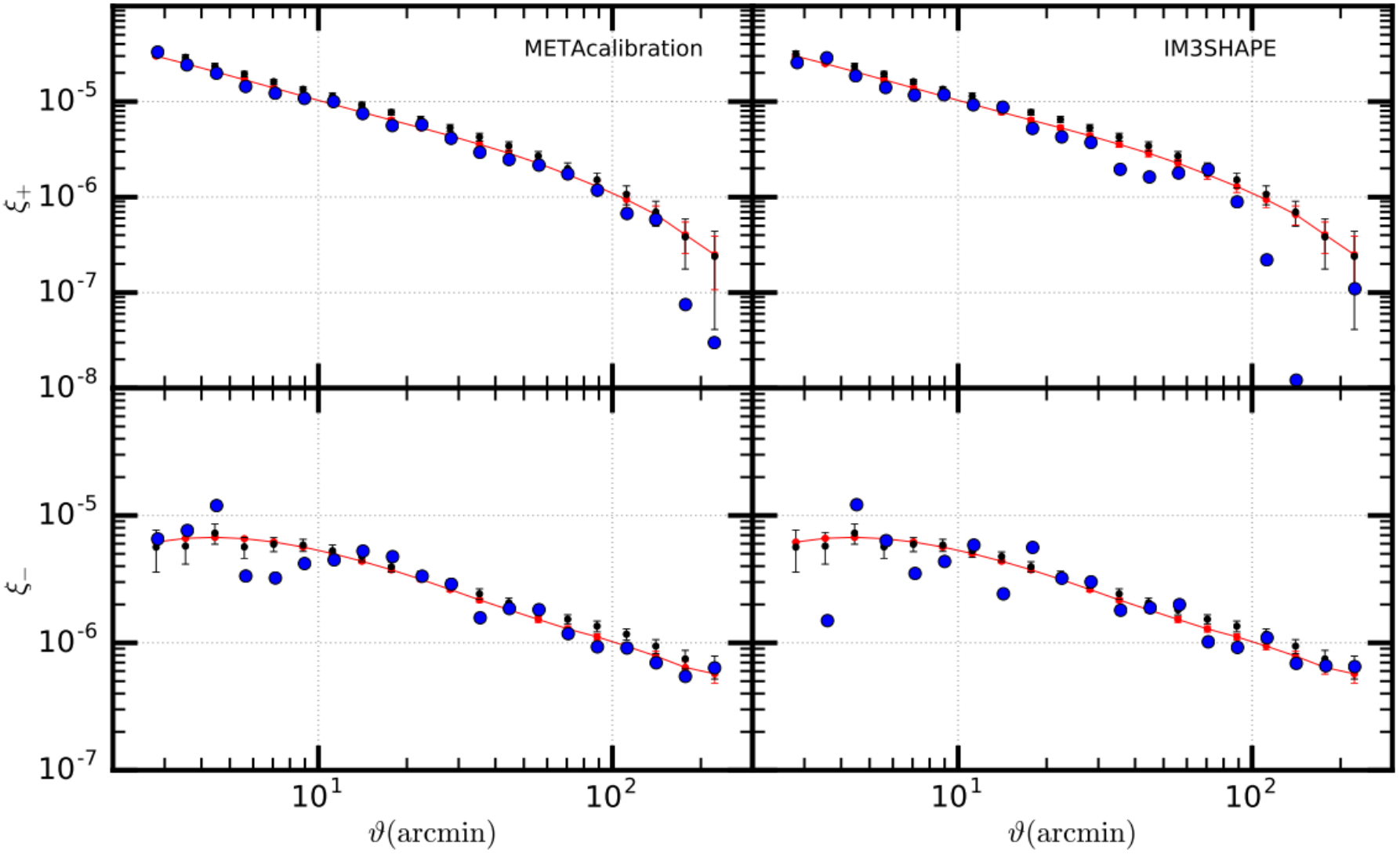
in the simulation. Disc galaxies show a tendency to be oriented tangentially around spheroidals in three-dimensions. While this signal seems suppressed in projection, this does not guarantee that disc alignments can be safely ignored in future weak lensing surveys. The shape alignments of luminous galaxies in Horizon-AGN are in agreement with observations and other simulation works, but we find less alignment for lower luminosity populations. We also characterize the systematics of galaxy shapes in the

Redshift Distribution in DES Y1 (2018)

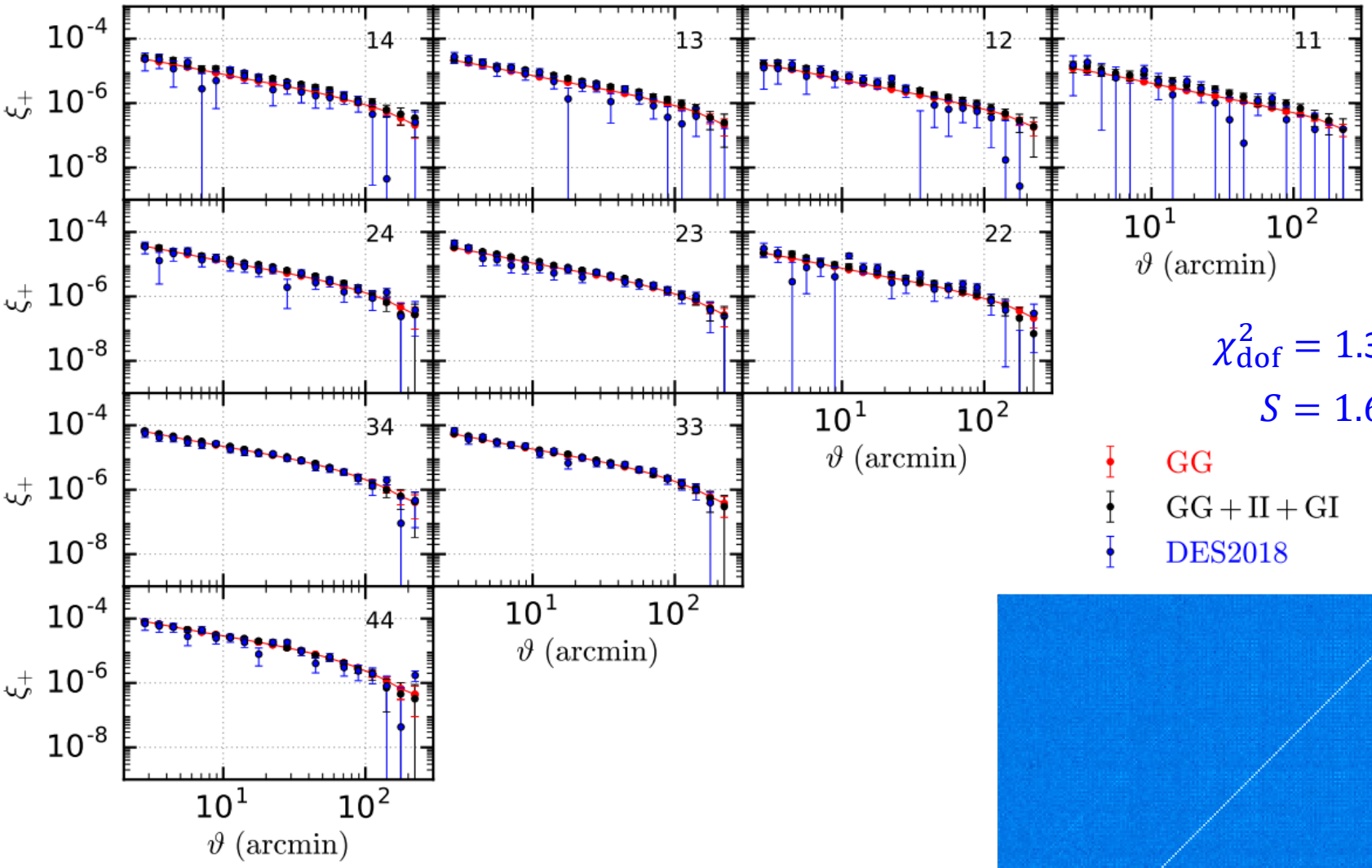


Bin	Extent	$n_{\rm eff}$		$\sigma_{\rm sh}$	$\sigma_{\rm sh} + \sigma_{\rm m}$
		C13	H12	C13	H12
Full	0.20 – 1.30	5.14	5.50	0.27	0.27
1	0.20 – 0.43	1.47	1.52	0.25	0.26
2	0.43 – 0.63	1.46	1.55	0.28	0.29
3	0.63 – 0.90	1.50	1.63	0.26	0.27
4	0.90 – 1.30	0.73	0.83	0.27	0.29

Results in non-tomographic test



Results in tomographic test



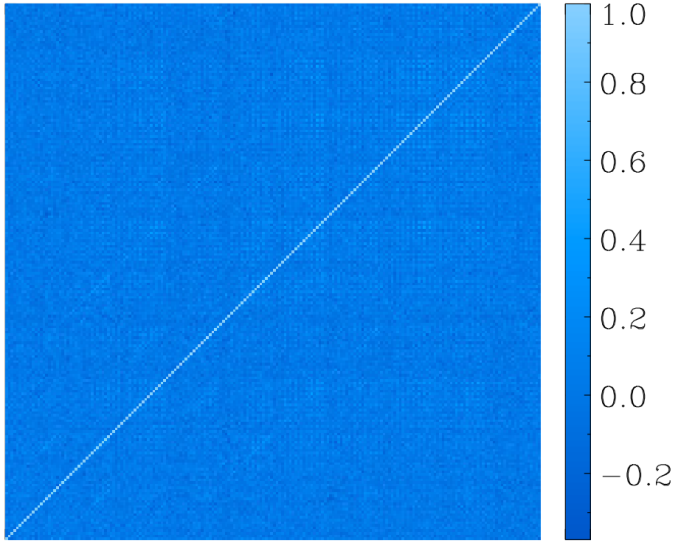
$\chi^2_{\rm dof} = 1.348\ (1.347)$

$S = 1.65\ \ (1.15)$

GG

GG + II + GI

DES2018



$S_8 \equiv \sigma_8\sqrt{\Omega_m/0.3}$

$0.789^{+0.024}_{-0.026}$ for DES Y1

0.79 for mock data

Summary

- We have constructed a mock galaxy catalog (lensed images) , using ray tracing simulation with realistic galaxy formation

- Our cosmic shear correlations stay between in KiDS and DLS, and DLS results are not affected by sky coverage and galaxy number density (yet we do not know why DLS results are higher than KiDS results)

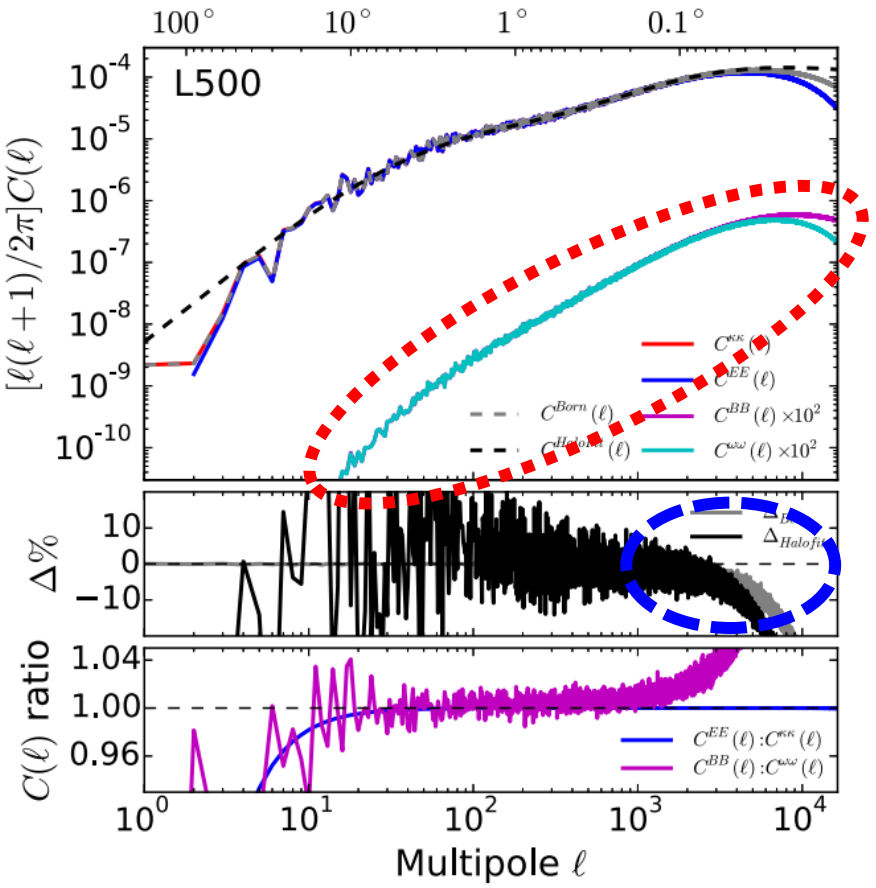
- We favor a random distribution for satellite orientation around central galaxy

- We found a significant Positive GI signal, from spiral galaxies, contrary to usual expectation from linear model for elliptical galaxy

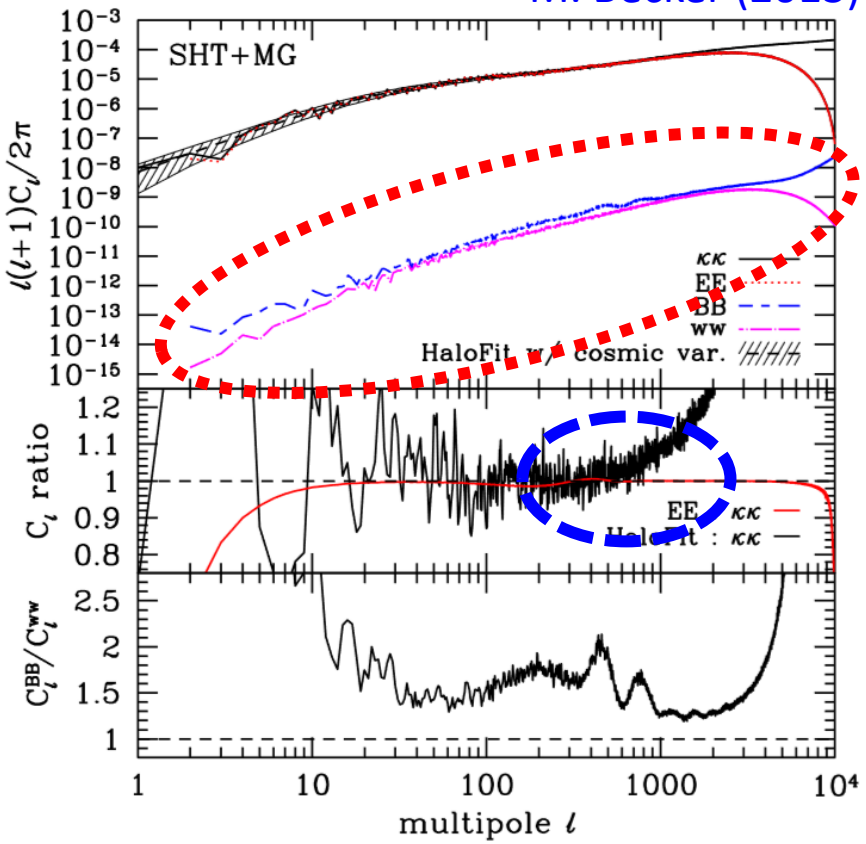
Thanks for your attention!

Spherical Ray-tracing Simulation

Simulation	Ω_m	Ω_Λ	h	L_{box}	m_p	l_{soft}
PS-I	0.260	0.740	0.710	1000	0.249	7.0
L500	0.282	0.718	0.697	500	0.034	3.5



M. Becker (2013)



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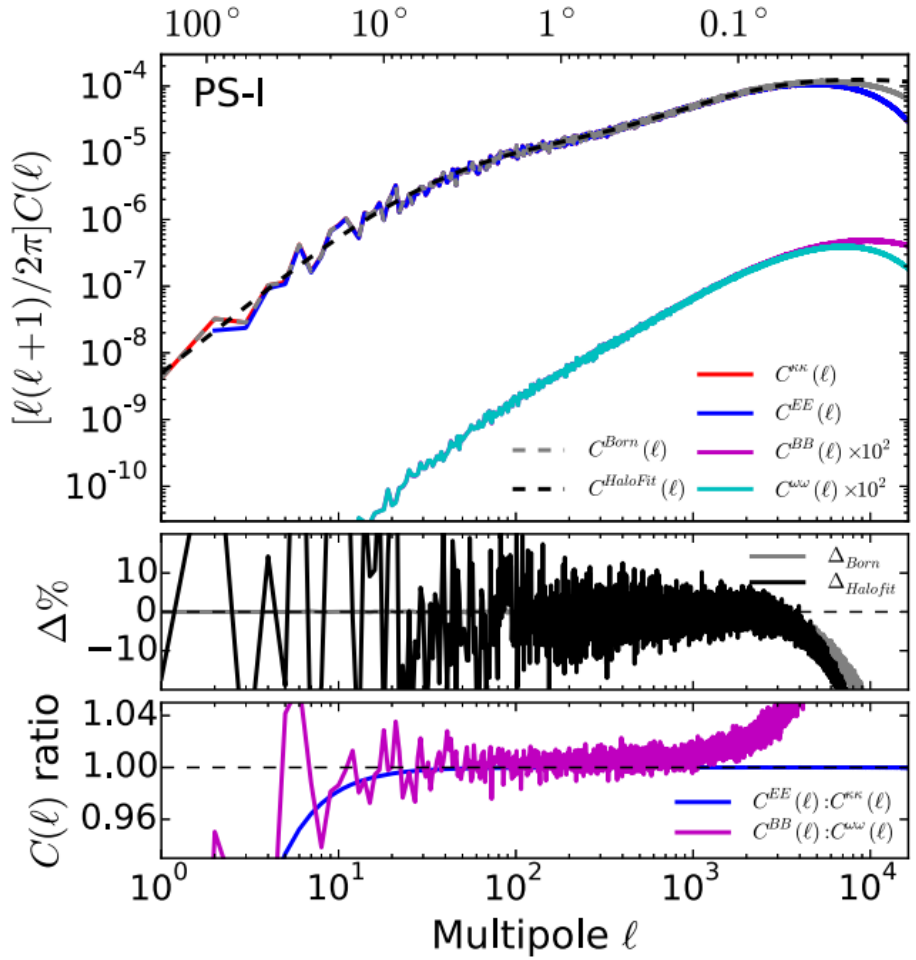
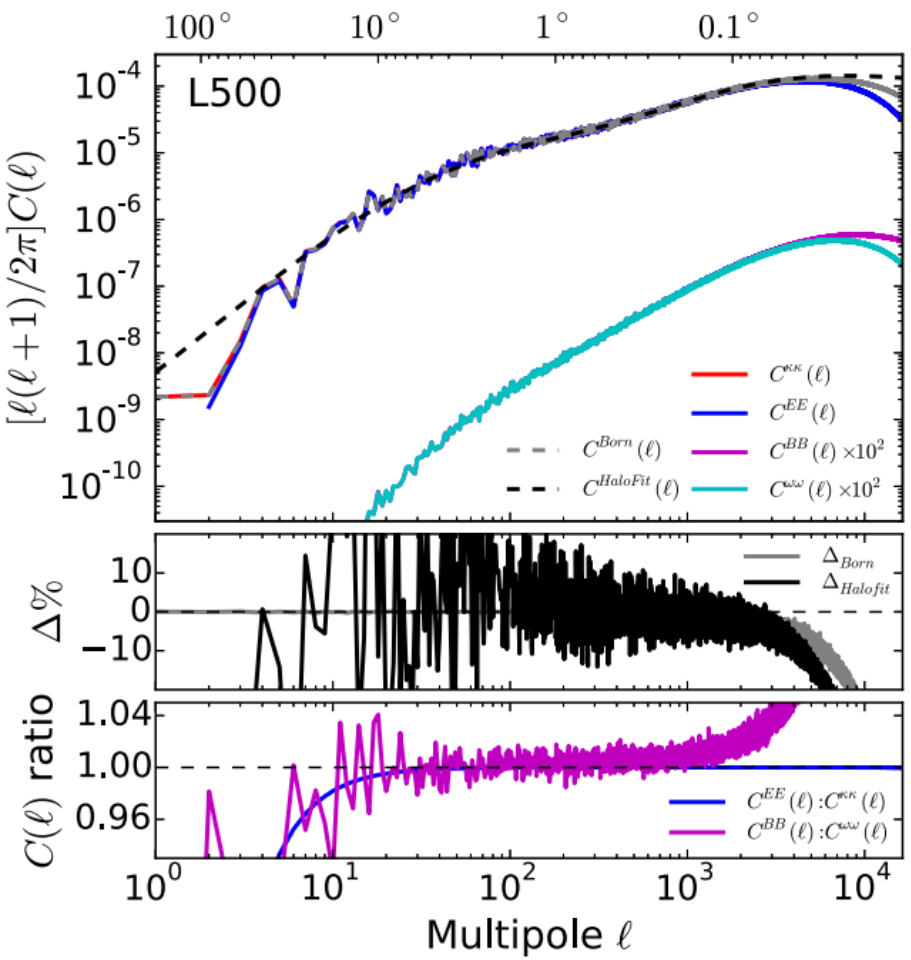
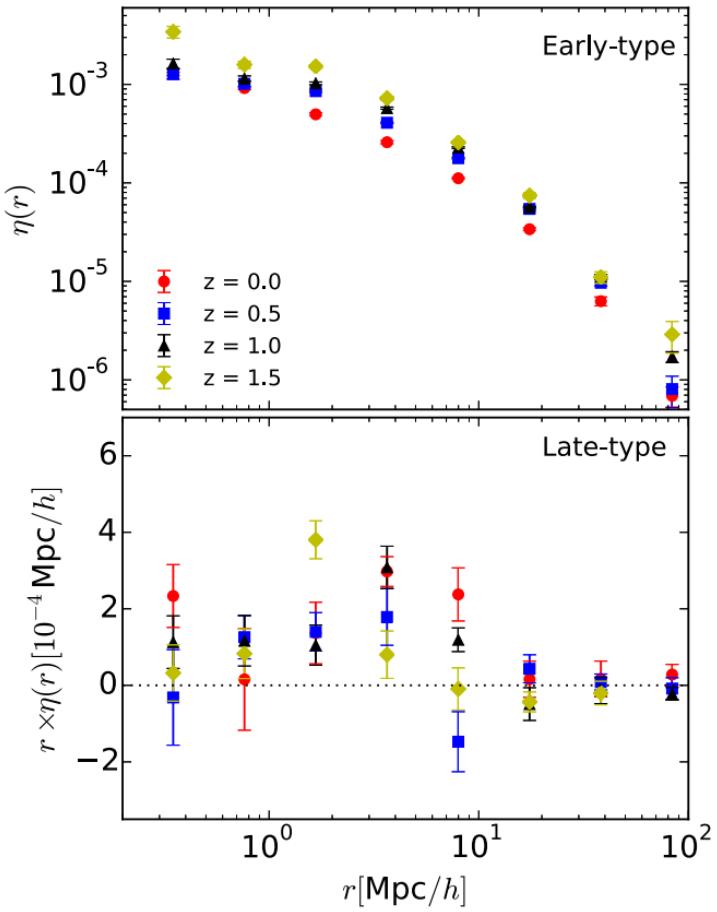
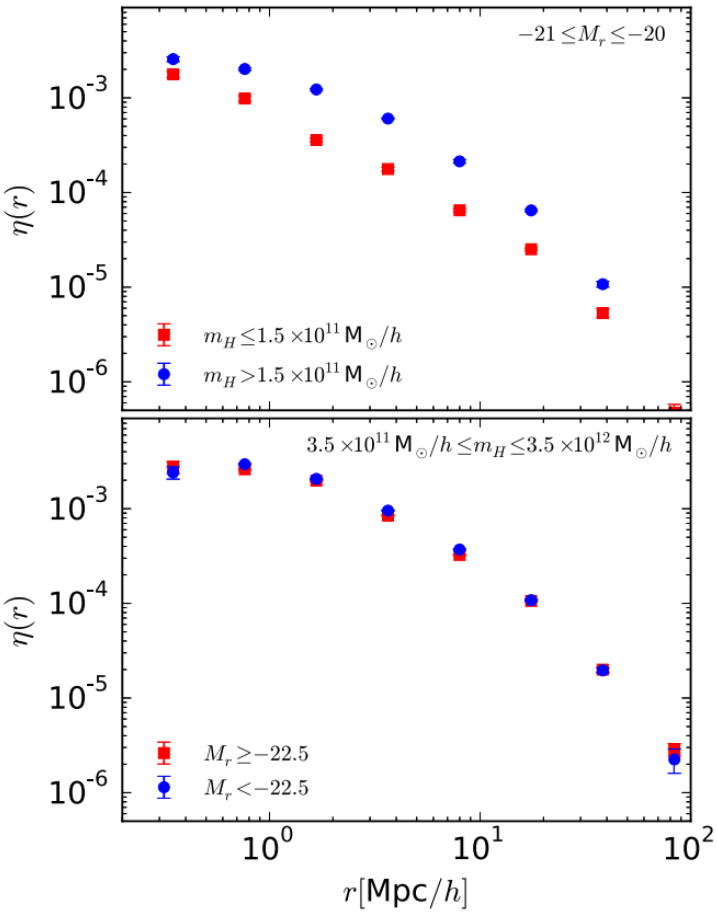




Galaxy intrinsic alignment: dependence on morphology

$$\eta(r) = \langle \epsilon_t(\boldsymbol{x})\epsilon_t(\boldsymbol{x}+\boldsymbol{r}) + \epsilon_\times(\boldsymbol{x})\epsilon_\times(\boldsymbol{x}+\boldsymbol{r})\rangle_{\boldsymbol{x}}$$ （Wei+, 2018, ApJ, 853, 25）





These correlations are consistent with that in Joachimi et al. (2013)

Tomographic Analyses:

KiDS-like mock (ξ_-)