THE HALO MODEL AS A VERSATILE TOOL TO PREDICT INTRINSIC ALIGNMENTS

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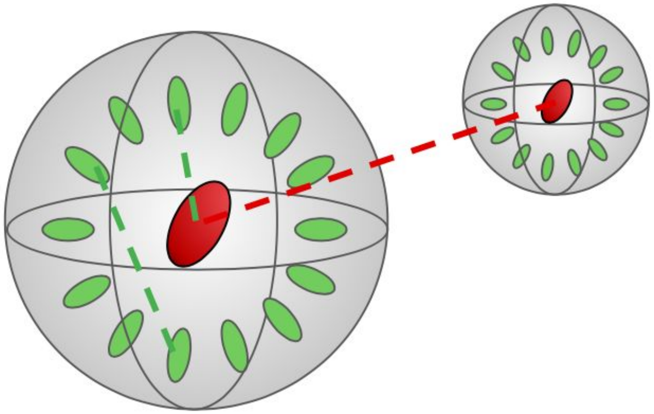
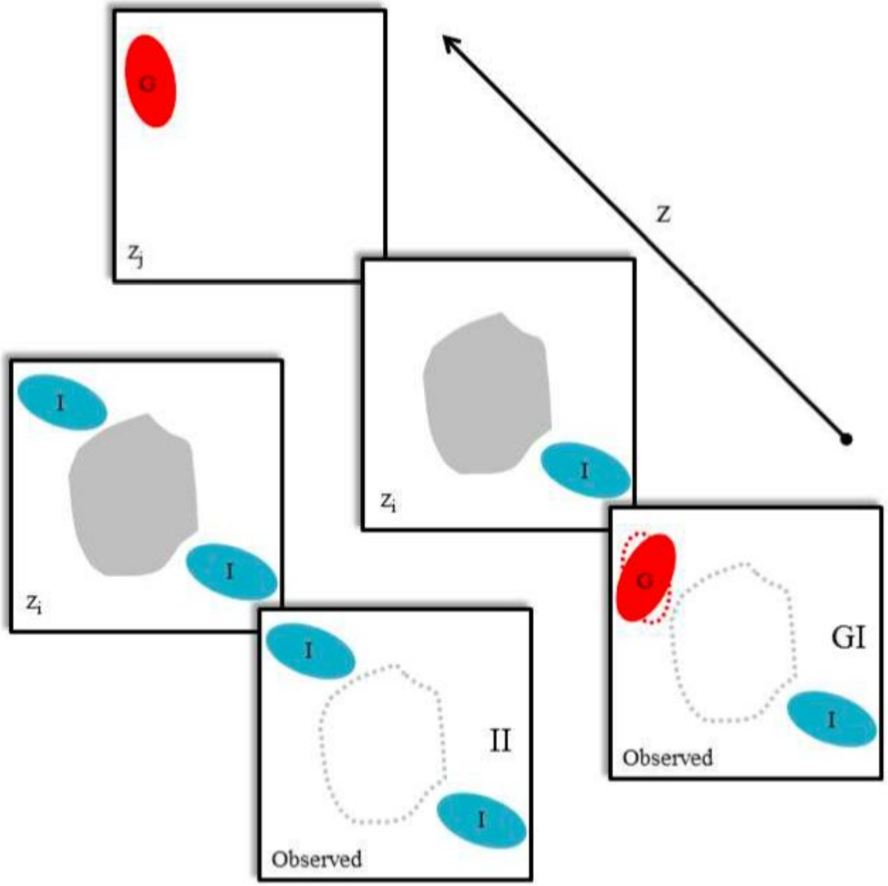
Leiden Observatory



arXiv:2003.02700

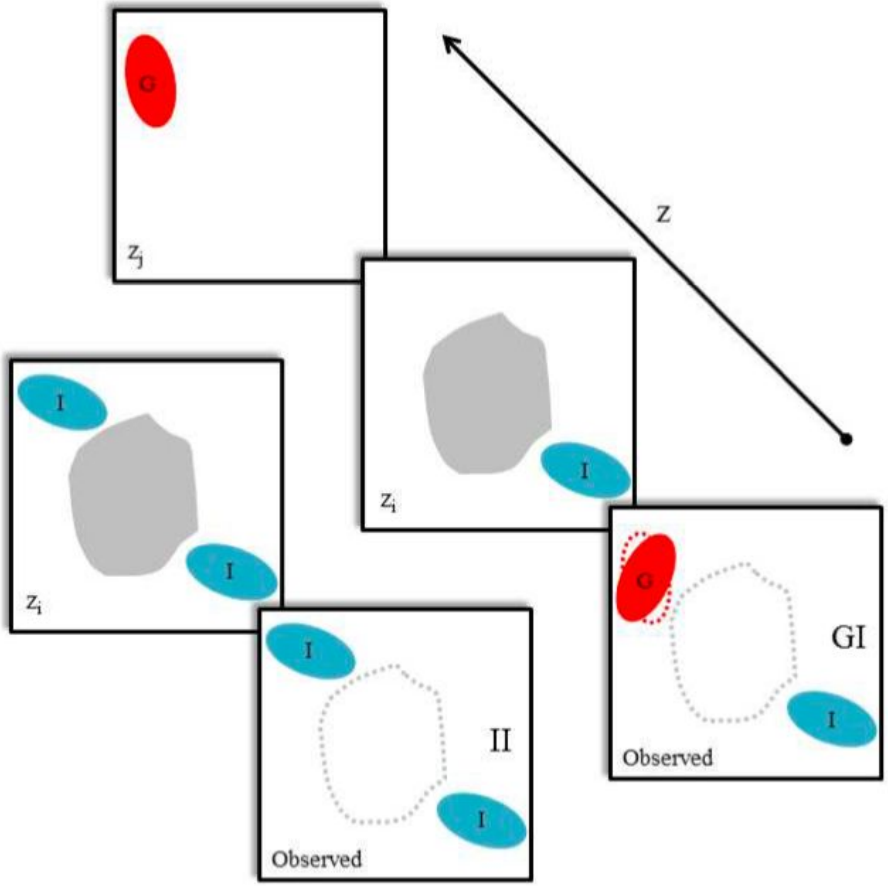
GCCL SEMINAR, March 20, 2020

INTRINSIC ALIGNMENT : AN INTRODUCTION



Troxel & Ishak 2015

INTRINSIC ALIGNMENT : NOMENCLATURE



INTRINSIC-INTRINSIC (II)

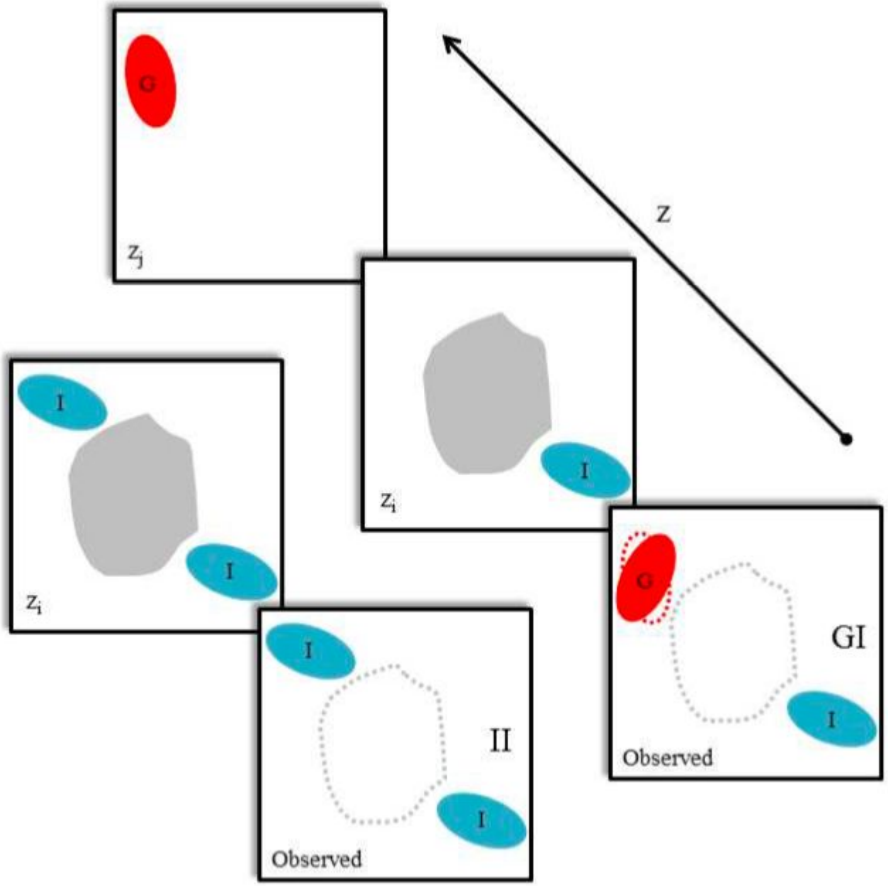
close pair of galaxies tend to coherently align due to the effect of the same tidal field

Troxel & Ishak 2015

INTRINSIC ALIGNMENT : NOMENCLATURE

INTRINSIC-INTRINSIC (II)

close pair of galaxies tend to coherently align due to the effect of the same tidal field

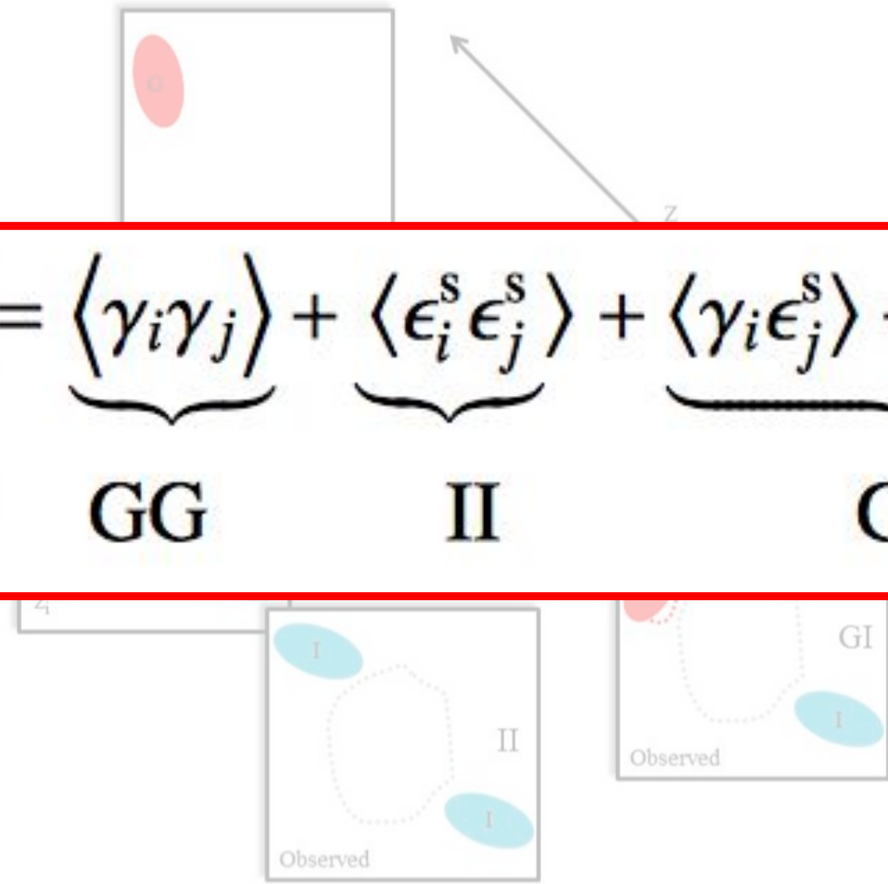


MATTER-INTRINSIC (GI)

the same matter overdensity simultaneously lenses one galaxy from the background and align one galaxy in the foreground

Troxel & Ishak 2015

INTRINSIC ALIGNMENT : NOMENCLATURE



MATTER-INTRINSIC (GI)

$$\underbrace{\langle\epsilon_i\epsilon_j\rangle}_{\text{observed}} = \underbrace{\langle\gamma_i\gamma_j\rangle}_{\text{GG}} + \underbrace{\langle\epsilon^s_i\epsilon^s_j\rangle}_{\text{II}} + \underbrace{\langle\gamma_i\epsilon^s_j\rangle + \langle\epsilon^s_i\gamma_j\rangle}_{\text{GI}}$$

galaxies tend to coherently align due to the effect of the same tidal field

align one galaxy in the foreground

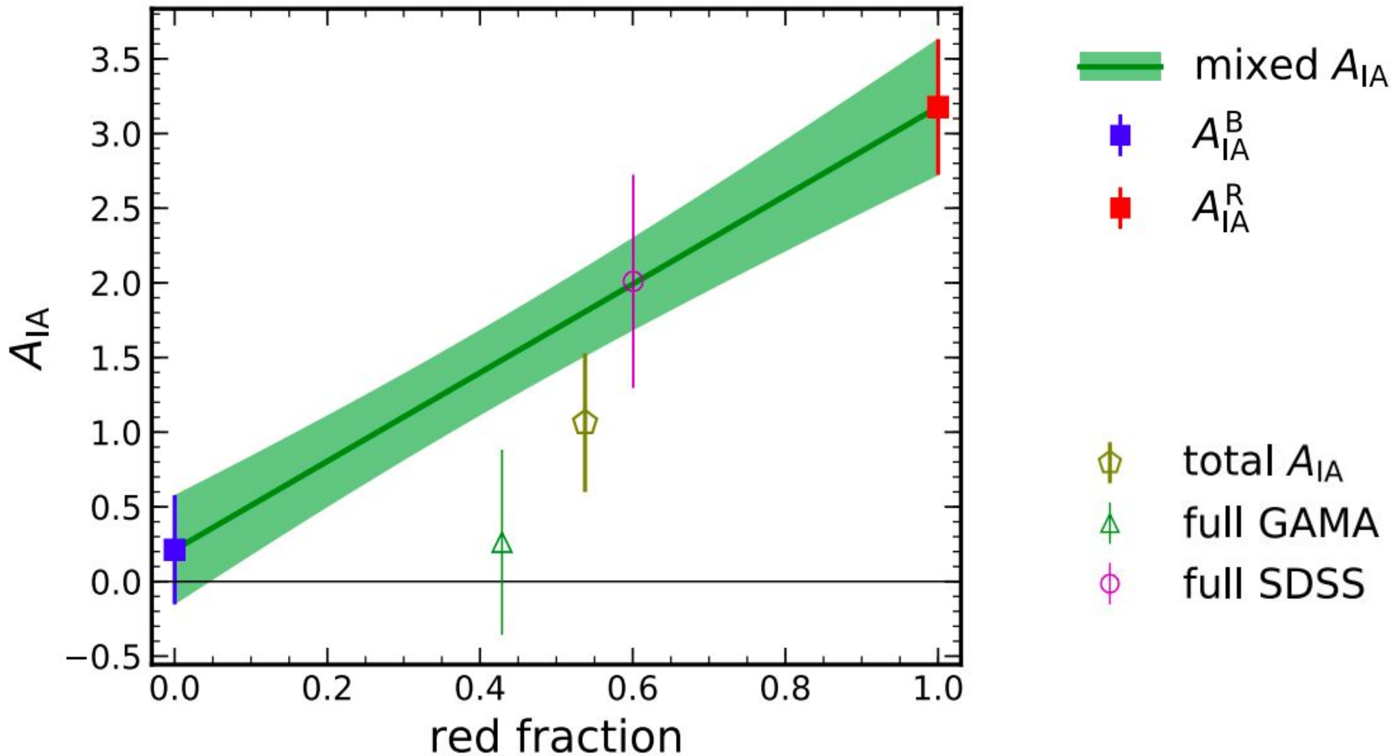
Troxel & Ishak 2015

INTRINSIC ALIGNMENT : MEASURING THE SIGNAL

GI ← gI

- We cannot directly measure the GI term
- We measure the projected correlation between galaxy shapes and galaxy positions, using galaxies as tracers of the underlying matter distribution
- A number of studies have found a significant signal for red (bright) galaxies
- No significant detection of blue galaxy alignment
- IA galaxy studies typically use galaxy samples which are not representative of cosmic shear surveys

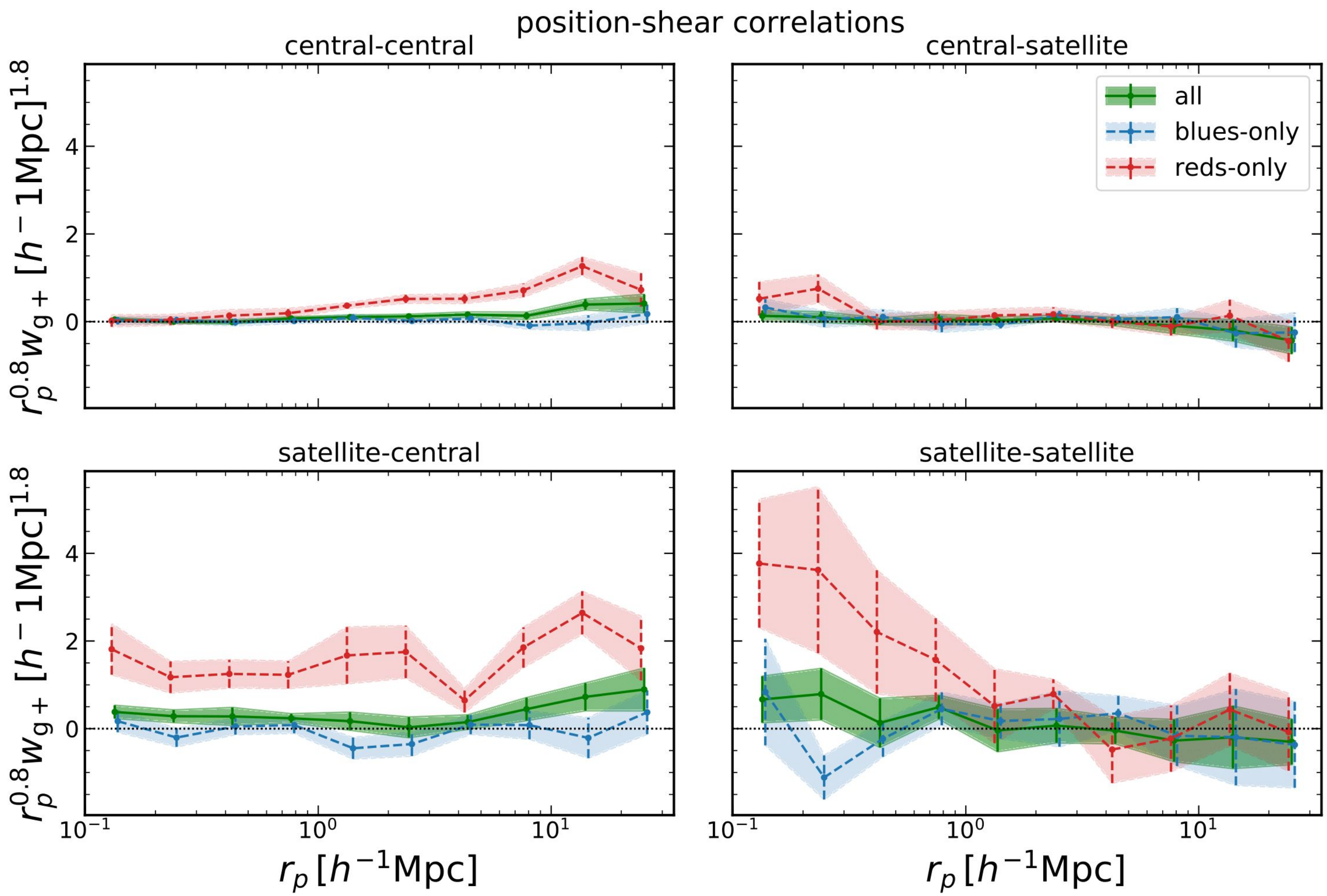
HOW SATELLITE GALAXIES COMPLICATE THE PICTURE



$$A_{\mathrm{IA}} = A_{\mathrm{IA}}^{\mathrm{R}} f_{\mathrm{red}} + A_{\mathrm{IA}}^{\mathrm{B}} (1 - f_{\mathrm{red}})$$

Johnston et al. 2019

HOW SATELLITE GALAXIES COMPLICATE THE PICTURE



Johnston et al. 2019

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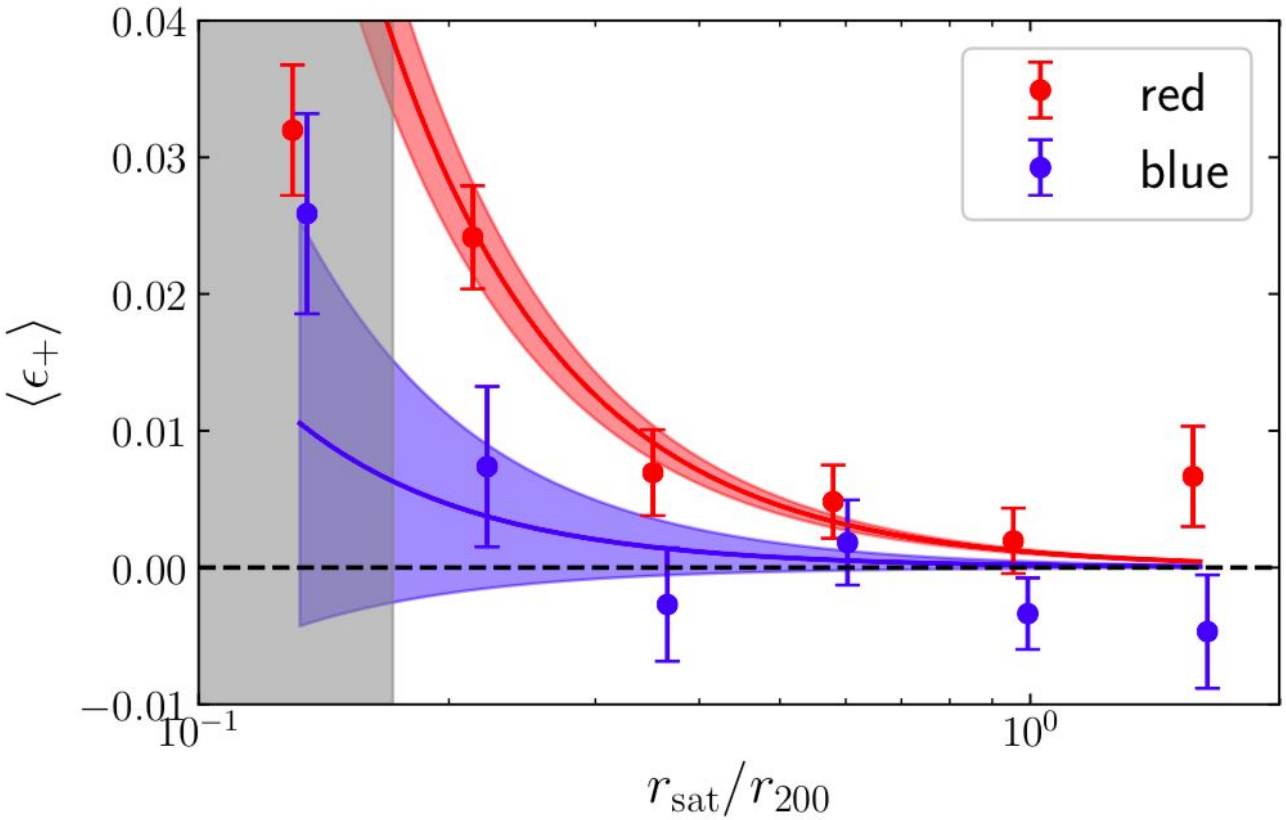
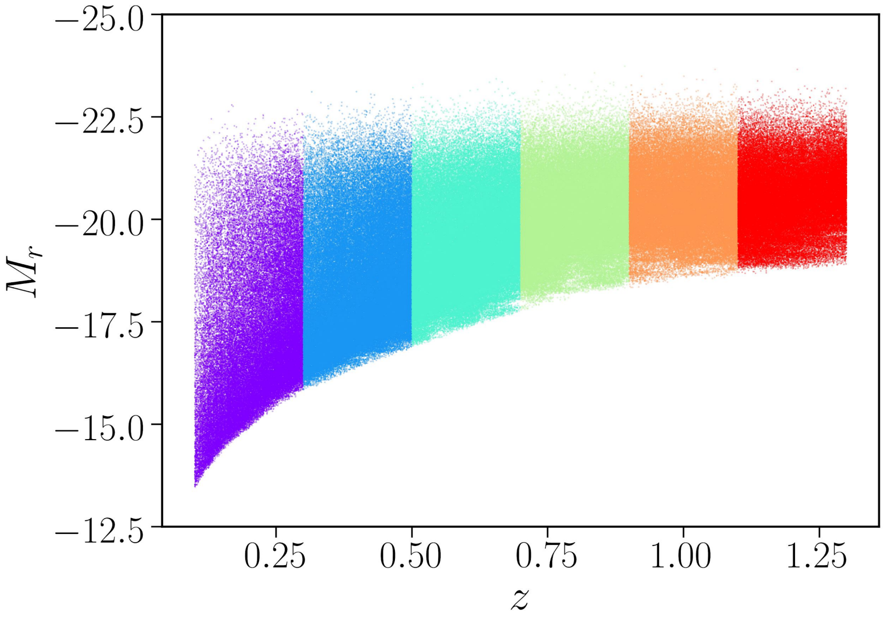
HOW SATELLITE GALAXIES COMPLICATE THE PICTURE



Georgiou et al. 2019b

COSMIC SHEAR AND IA SAMPLE DEPENDENCE



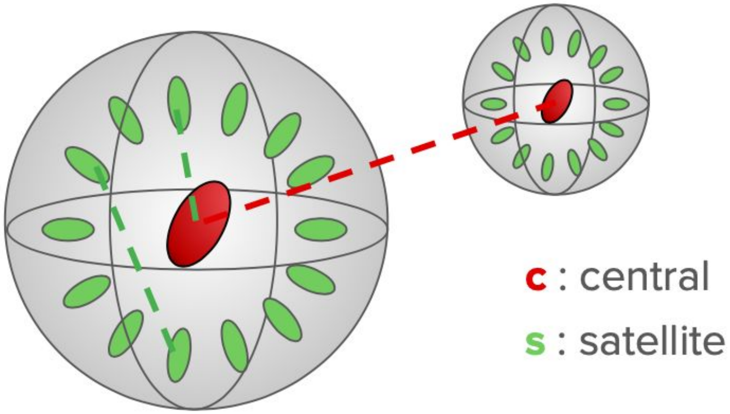
We make use of MICE simulations, selecting galaxies that resemble a Stage III (KiDS-like) survey:

- ~1000 deg2
- r<24
- 0.1<z<1.2
- 6 redshift bins

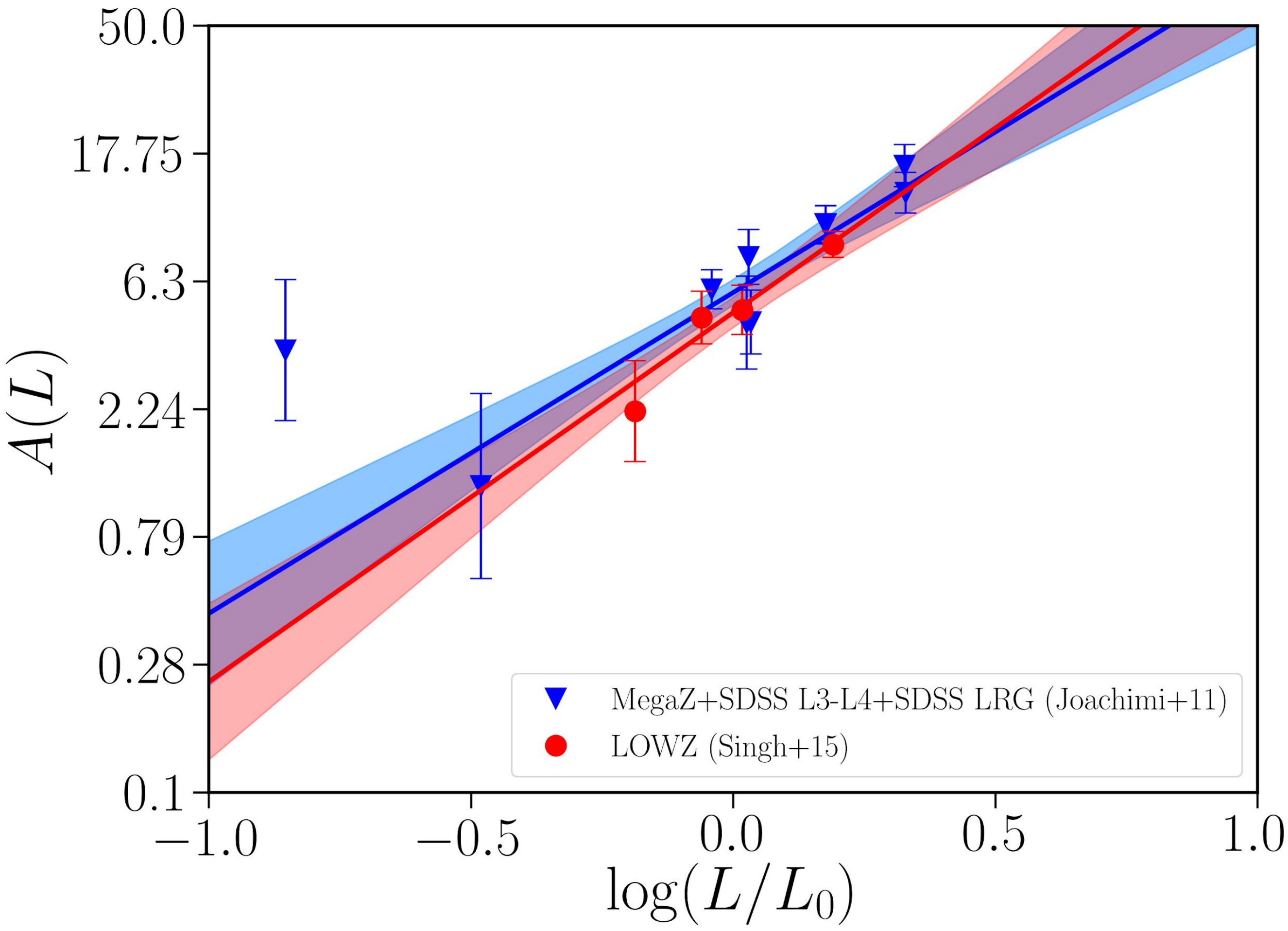
We simulate a cosmic shear survey to explore how the IA sample dependence propagates to the full lensing signal

LARGE SCALES

(2-halo term)



THE LUMINOSITY DEPENDENCE AT LARGE SCALES



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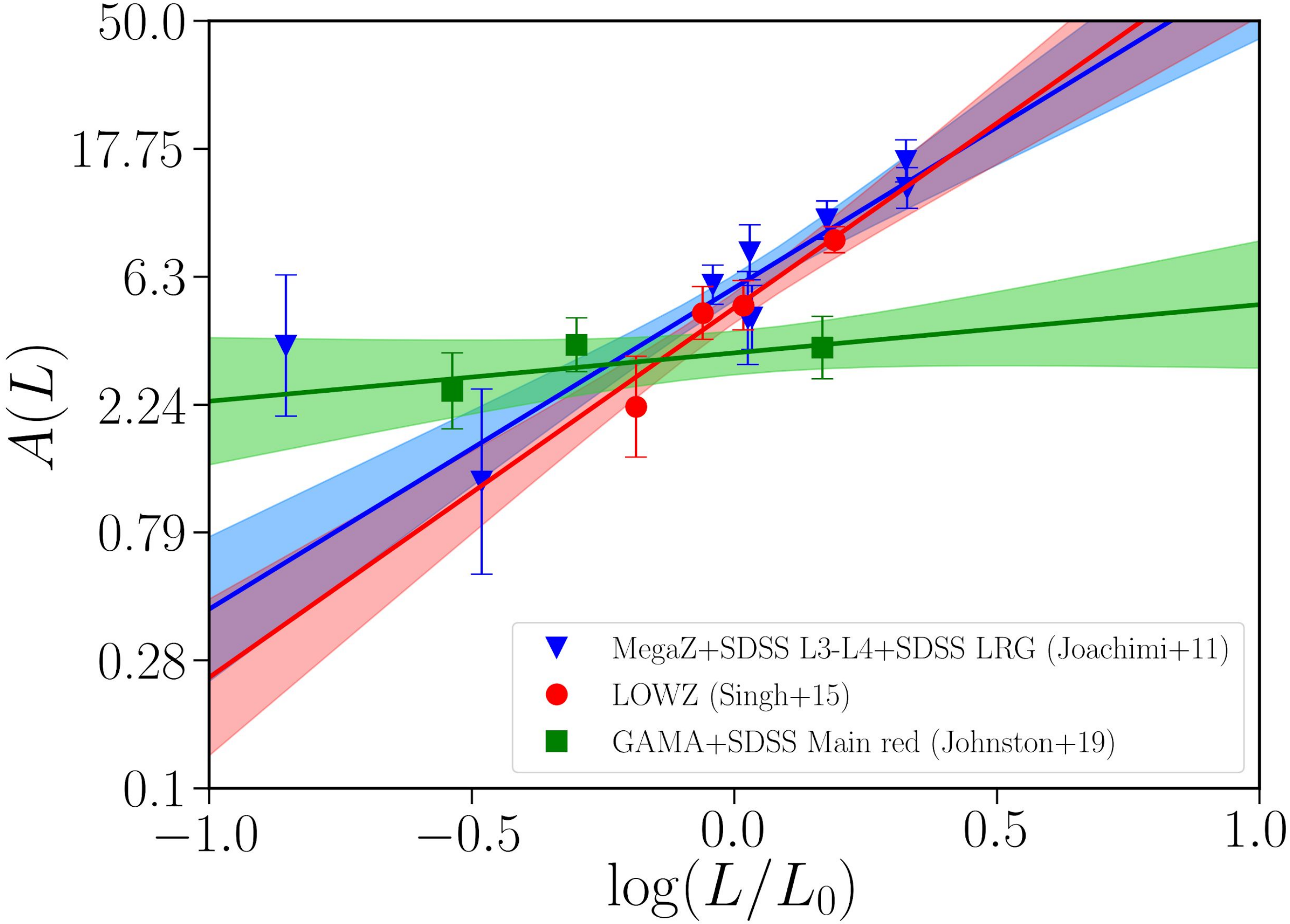
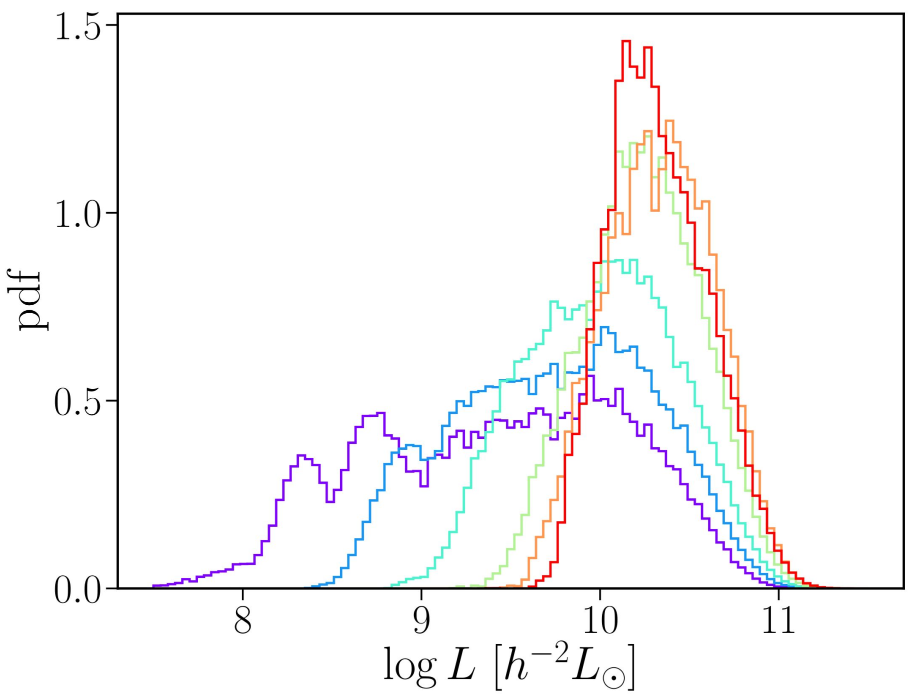
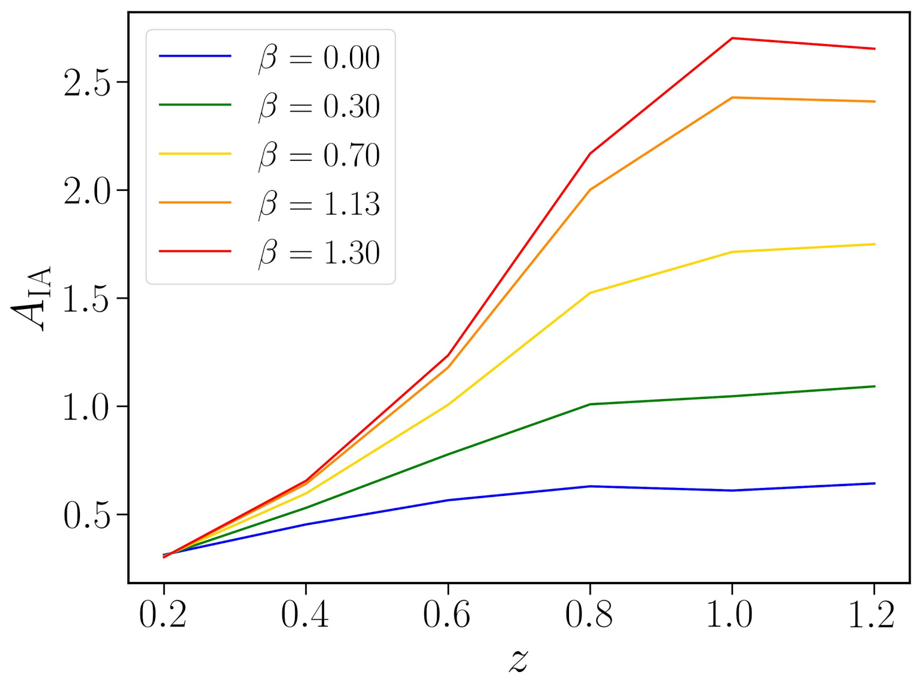


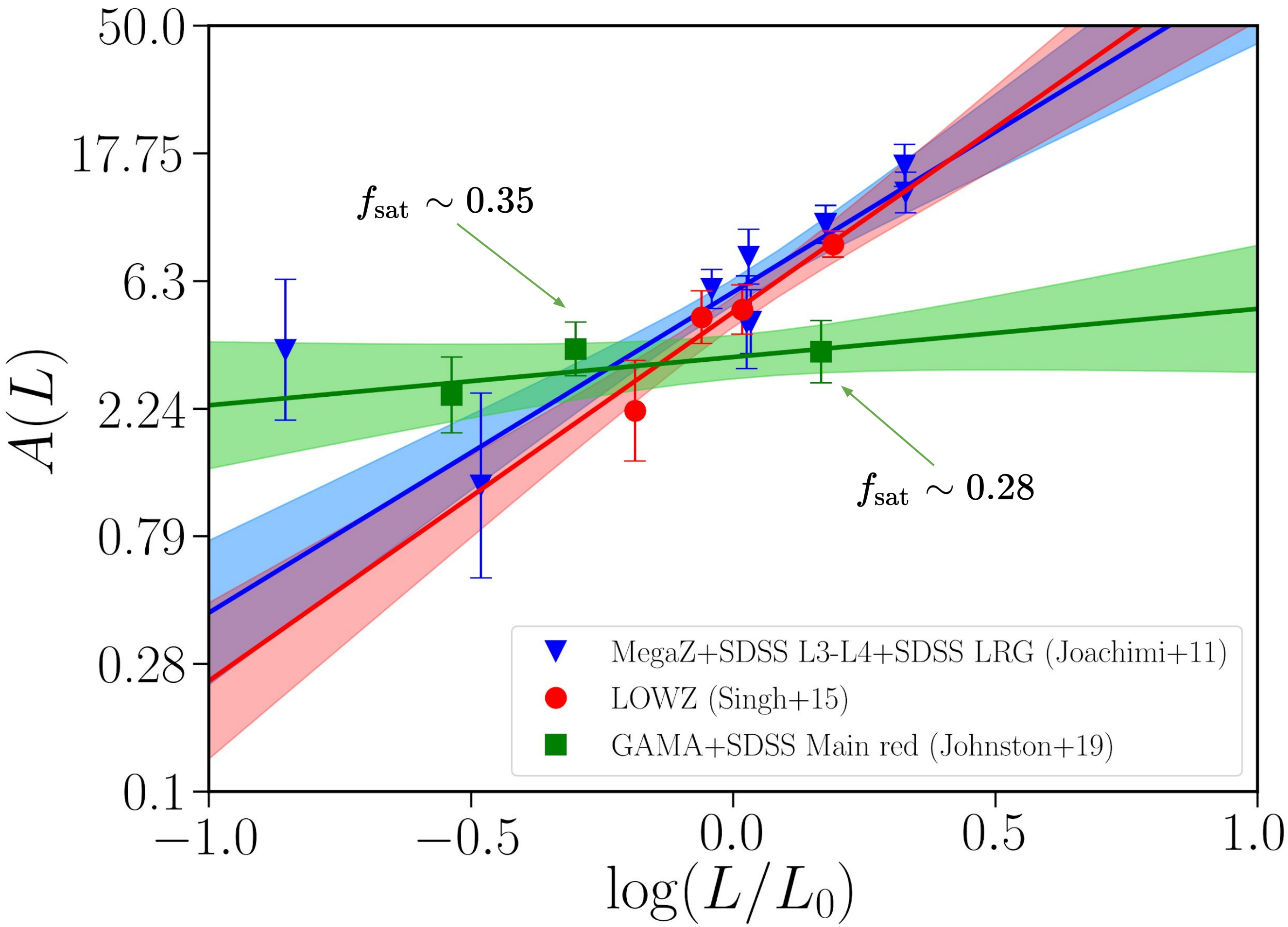
SAMPLE DEPENDENCE OF THE SIGNAL





Galaxy luminosities vary between the z-bins and can imprint a different alignment signal in different tomographic bins

THE LUMINOSITY DEPENDENCE AT LARGE SCALES



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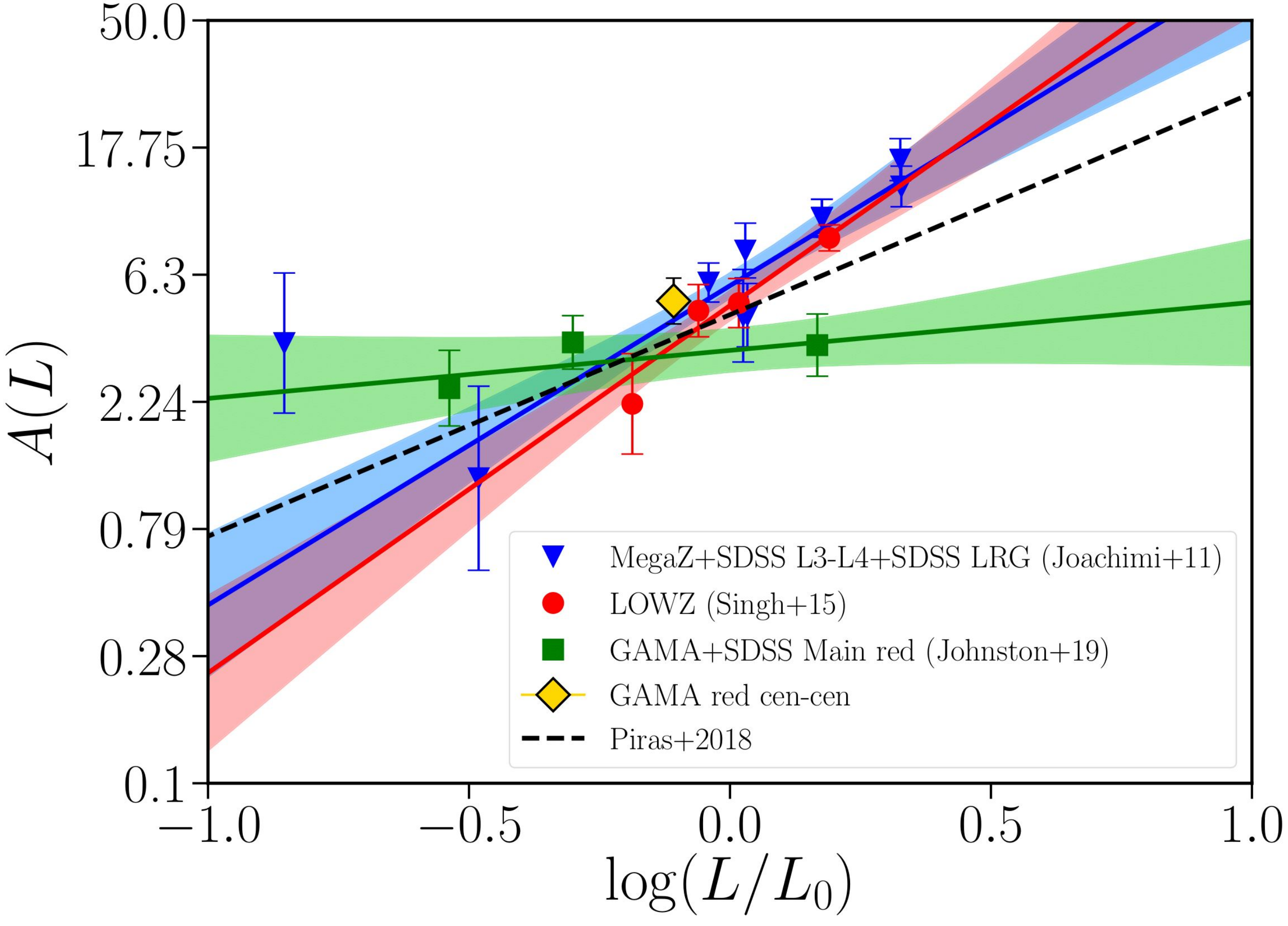
THE LUMINOSITY DEPENDENCE AT LARGE SCALES



2-HALO POWER SPECTRA

Matter - Intrinsic:

$$P_{\delta \mathrm{I}}^{2\mathrm{h}}(k,z) = f_{\mathrm{cen}}^{\mathrm{red}}(z)\left\langle \left(\frac{L_{\mathrm{cen}}^{\mathrm{red}}}{L_0}\right)^{\beta} \right\rangle P_{\delta \mathrm{I}}^{\mathrm{red}}(k,z) + f_{\mathrm{cen}}^{\mathrm{blue}}(z) P_{\delta \mathrm{I}}^{\mathrm{blue}}(k,z)$$

The usual NLA model with the different best-fit amplitudes for the given sample

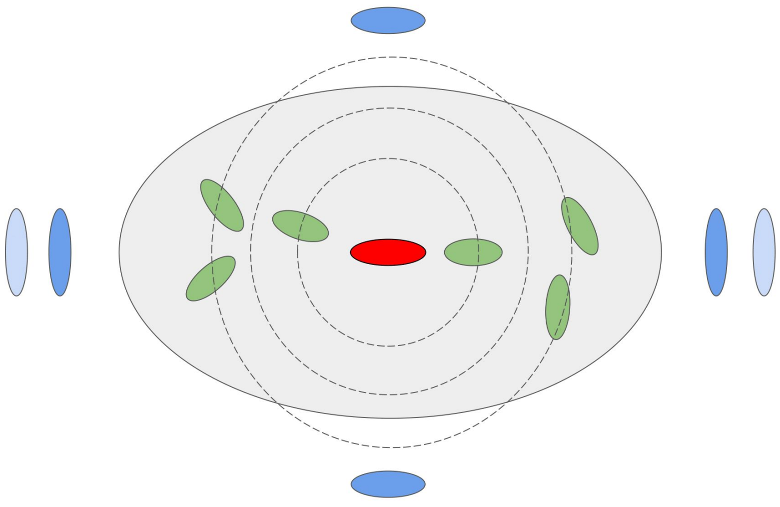
$$P_{\delta \mathrm{I}}^{\mathrm{LA}}(k,z) = A_{\mathrm{IA}} C_1 \rho_c \frac{\Omega_m}{D(z)} P_{\delta}^{\mathrm{lin}}$$

Intrinsic - Intrinsic:

$$P_{\mathrm{II}}^{2\mathrm{h}}(k,z) = \left(f_{\mathrm{cen}}^{\mathrm{red}}(z)\right)^2 \left\langle \left(\frac{L_{\mathrm{cen}}^{\mathrm{red}}}{L_0}\right)^{2\beta} \right\rangle P_{\mathrm{II}}^{\mathrm{red}}(k,z) + \left(f_{\mathrm{cen}}^{\mathrm{blue}}(z)\right)^2 P_{\mathrm{II}}^{\mathrm{blue}}(k,z)$$

SMALL SCALES

(1-halo term)



THE HALO MODEL FORMALISM FOR SATELLITE ALIGNMENT

We define the density-weighted shear per halo as (Schneider&Bridle 2010):

$$\tilde{\gamma}^{I}_{1-\mathrm{halo}}(\mathbf{r}, M) = \underbrace{\bar{\gamma}^{I}(r, M)\sin\theta \mathrm{e}^{2i\phi}}_{\text{intrinsic shear (stick model)}} \underbrace{N_g u(\mathbf{r}|M)}_{\text{density-weighting}}, \quad (1)$$

This is necessary because we can only measure the IA signal at galaxy locations

and construct a continuous intrinsic shear density field by summing up the contribution from each individual halo:

$$\begin{aligned}\tilde{\gamma}^{I}_{s}(\mathbf{r}) &= \frac{1}{\bar{n}_g}\sum_i \gamma^{I}(\mathbf{r}-\mathbf{r_i}, M_i) N_{g,i} u(\mathbf{r}-\mathbf{r_i}, M_i) \\ &= \sum_i \int \mathrm{d}M \int \mathrm{d}^3 r' \; \delta_D(M - M_i)\delta_D^{(3)}(\mathbf{r}-\mathbf{r_i})\frac{N_{g,i}}{\bar{n}_g} \\ &\quad \times \gamma^{I}(\mathbf{r}-\mathbf{r}', M) u(\mathbf{r}-\mathbf{r}', M),\end{aligned}$$

Analogous to the matter density field, where instead of (1) you have the density profile inside the halo

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THE HALO MODEL FORMALISM FOR SATELLITE ALIGNMENT

We can then correlate the shear with itself and the matter density field to find the relevant observables. In Fourier space we have:

$$P^{s}_{\delta\mathrm{I},\,1\mathrm{h}}(\mathbf{k},z) = \int \mathrm{d}M\; n(M)\,\frac{M}{\bar{\rho}_m}\,f_s(z)\,\frac{\langle N_s|M\rangle}{\bar{n}_s(z)}\,|\hat{\gamma}^I_s(\mathbf{k}|M)|\,u(k,M)$$

Fourier transform of the weighted density shear

$$P^{ss}_{\mathrm{II},\,1\mathrm{h}}(\mathbf{k},z) = \int \mathrm{d}M\; n(M)\,f_s^2(z)\,\frac{\langle N_s(N_s-1)|M\rangle}{\bar{n}_s^2(z)}\,|\hat{\gamma}^I_s(\mathbf{k}|M)|^2$$

Schneider&Bridle 2010 demonstrated that the central-satellite term is subdominant, such that the only relevant terms are the

- II: satellite-satellite
- δI: matter-satellite

so we only include those two terms in our analysis.

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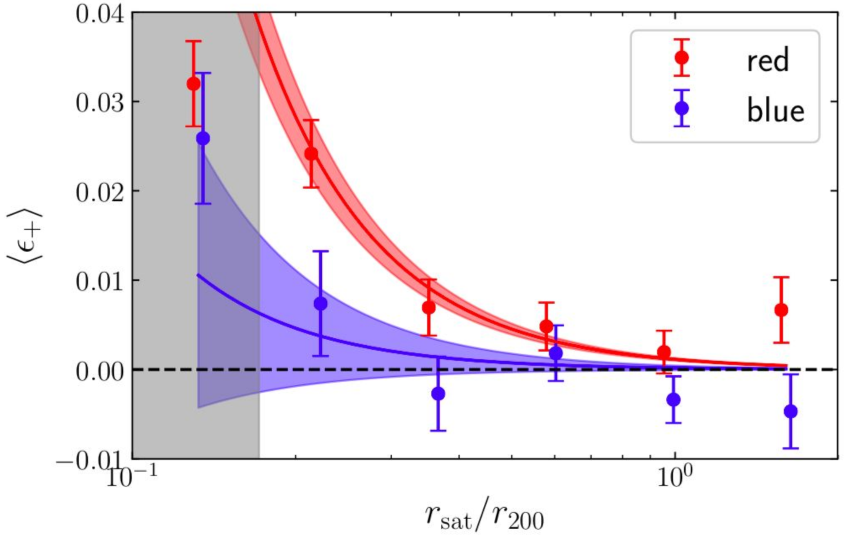
RADIAL DEPENDENT SATELLITE ALIGNMENT

$$\langle \epsilon_+ \rangle \mapsto \bar{\gamma}(r)$$

This is measured in projection

We want to express it in 3D



$$\bar{\gamma}(r) = \begin{cases} a_{1h}\left(\frac{0.06}{r_{\rm vir}}\right)^b, & \text{if } r < 0.06\ \text{Mpc}/h \\ a_{1h}\left(\frac{r}{r_{\rm vir}}\right)^b, & \text{if } r > 0.06\ \text{Mpc}/h \end{cases}$$

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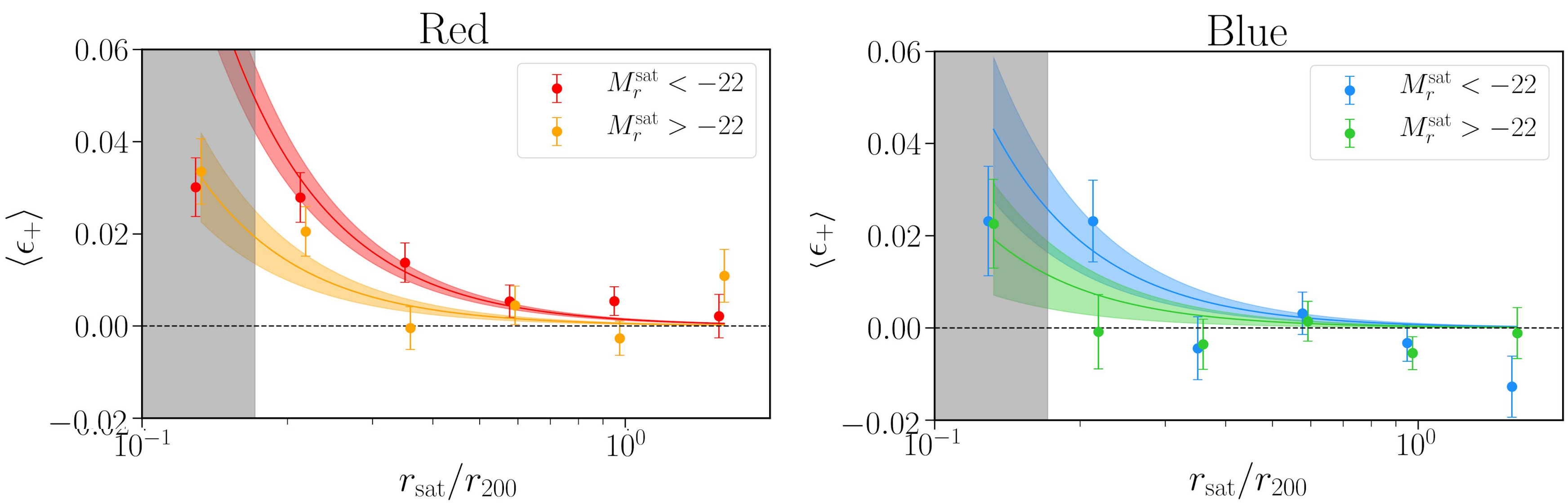
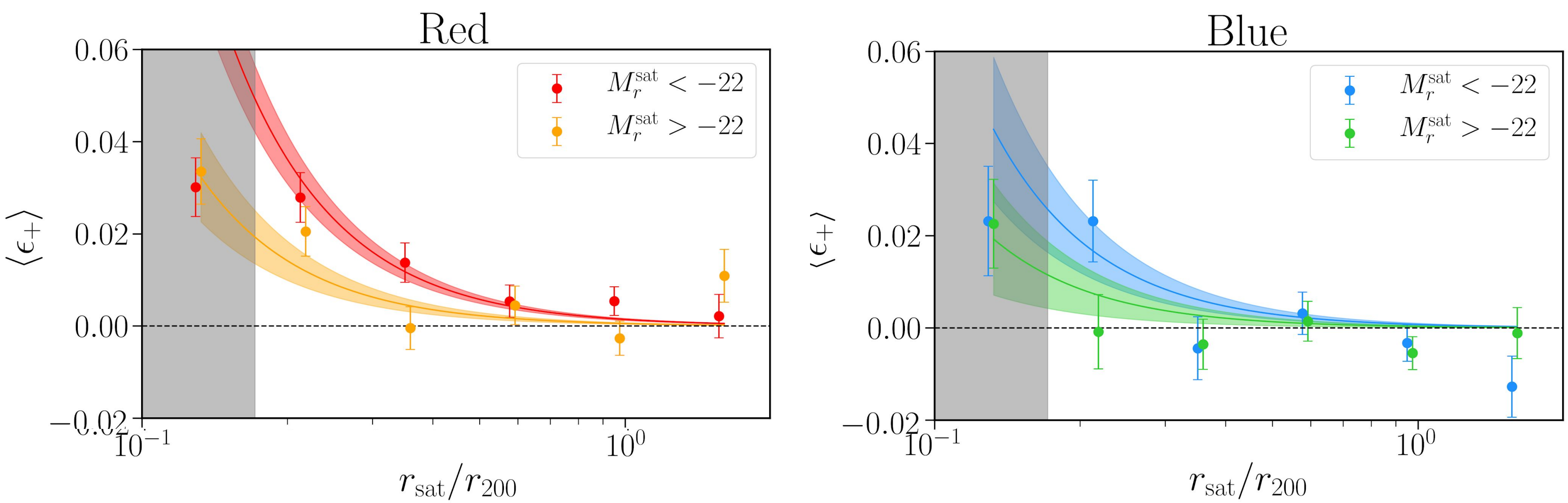
THE FUNCTIONAL FORM FOR THE 1-HALO SHEAR



THE FUNCTIONAL FORM FOR THE 1-HALO SHEAR



$$\bar{\gamma}_{\mathrm{red/blue}}(r, L) = a_{1h} \left(\frac{L_{\mathrm{red/blue}}}{L_0} \right)^{\zeta} \left(\frac{r_{\mathrm{sat}}}{r_{\mathrm{vir}}} \right)^{b}$$

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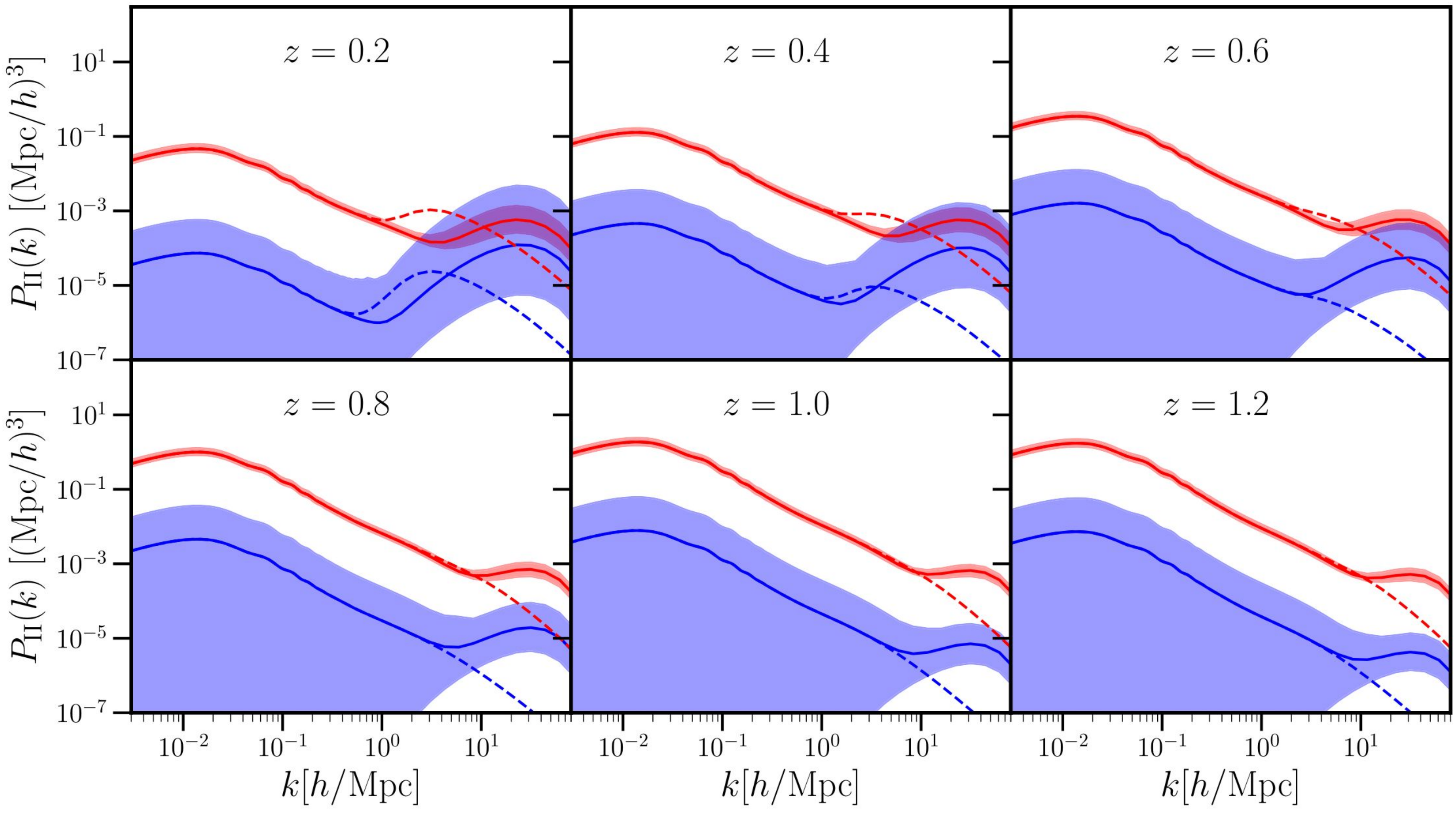
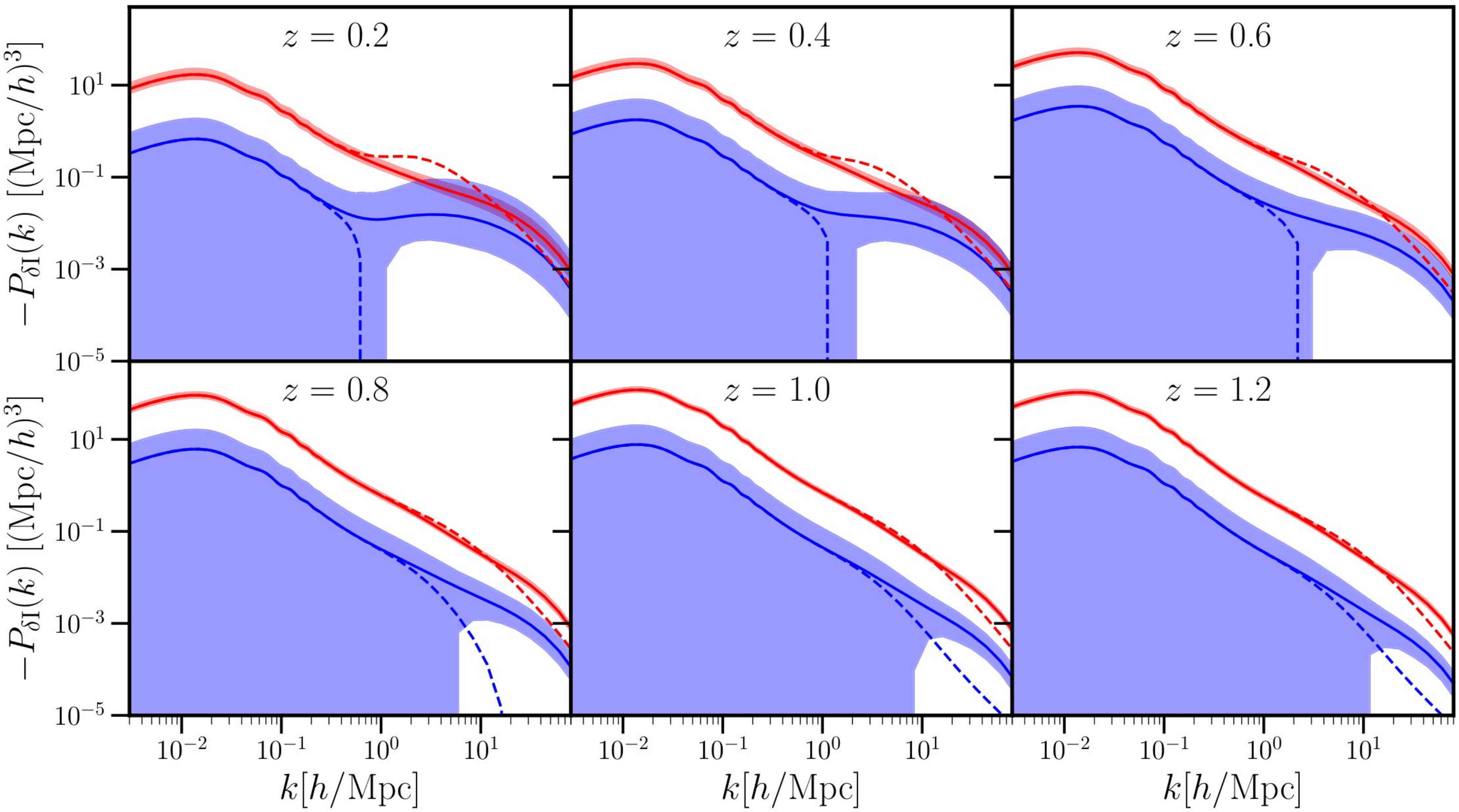
THE INTRINSIC-INTRINSIC POWER SPECTRUM



THE MATTER-INTRINSIC POWER SPECTRUM



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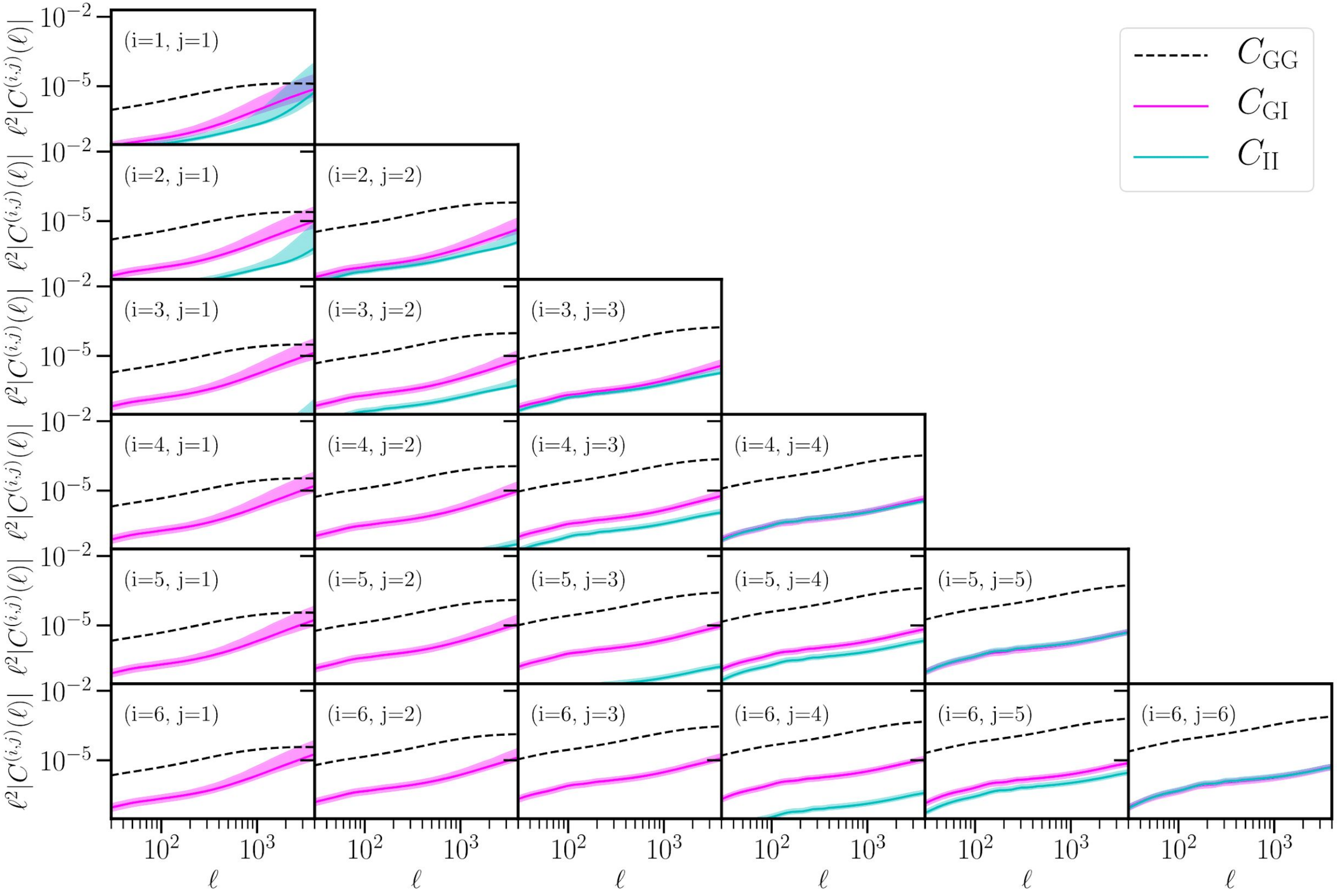
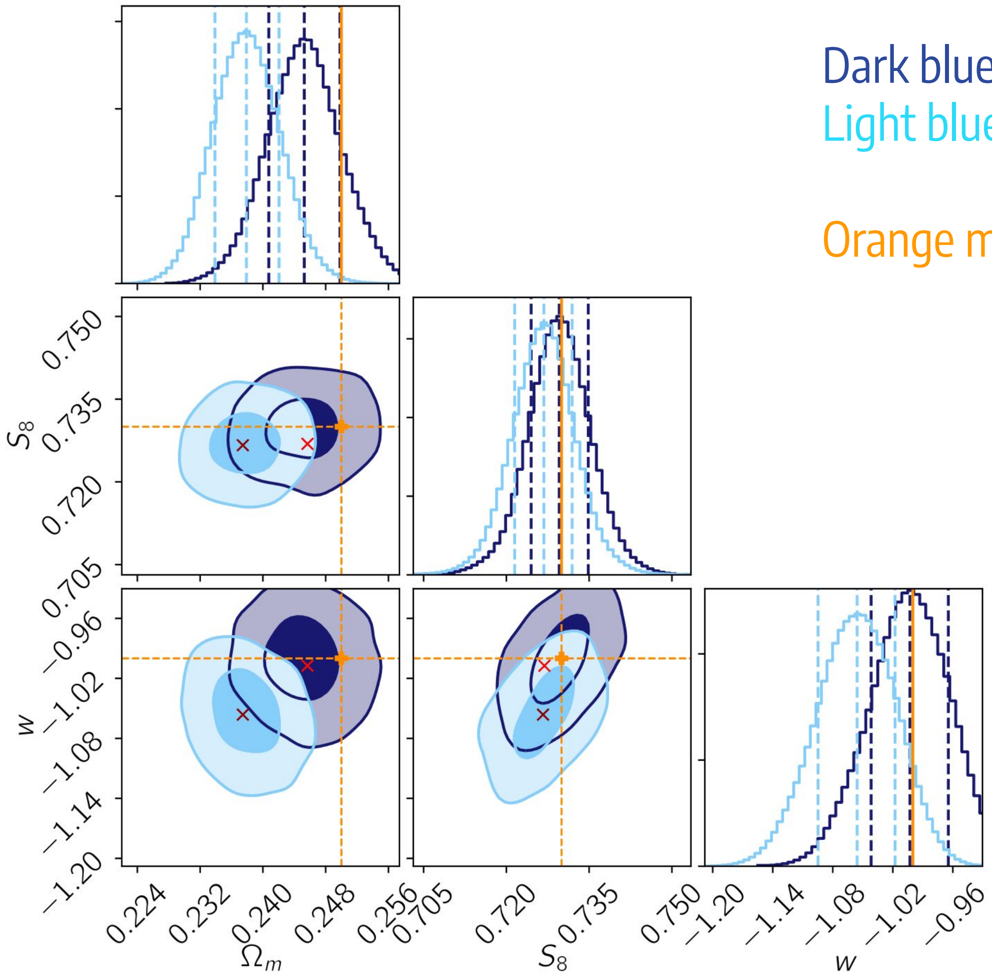
IMPLICATIONS FOR COSMIC SHEAR



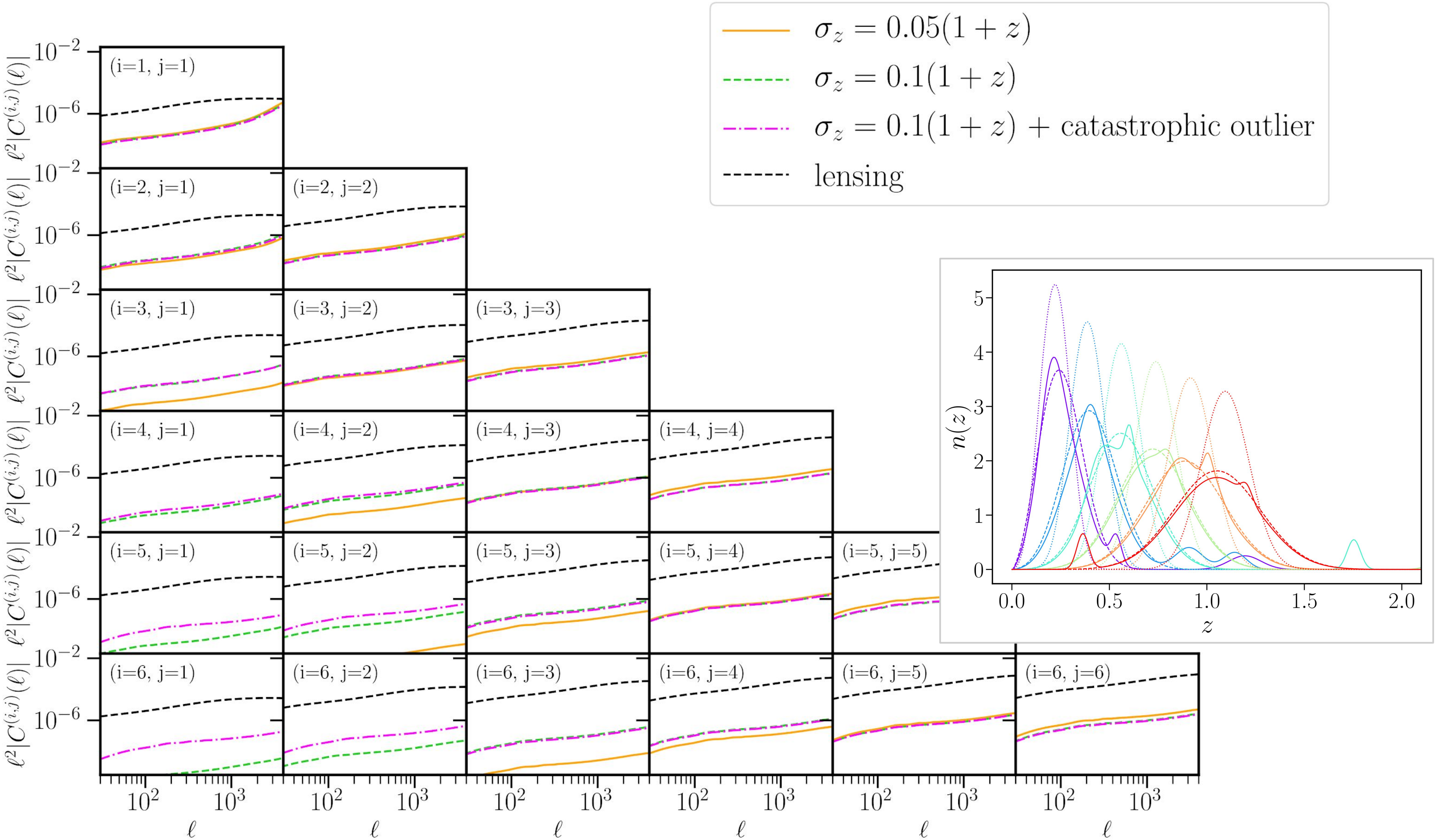
IMPLICATIONS FOR COSMIC SHEAR - STAGE IV



Dark blue: simple NLA
Light blue: no IA

Orange markers: true values

THE ROLE OF THE n(z)



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IA - WHAT'S NEXT?

- Our understanding of the intrinsic alignment is greatly increasing thanks to new observational studies

- We are now able to include the variety of IA signatures into a unified framework
    - provide priors
    - possibility to include other models at large and intermediate scales
    - joint fit for IA, lensing and clustering

- Future works should focus on understanding the faint-end of the IA, both for centrals and satellites
    - PAU survey
    - LRG alignment in KiDS-1000 -> stay tuned!

- Can we better constrain the blue galaxy alignment?

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THANKS