Weak gravitational lensing, dark energy, and systematic effects

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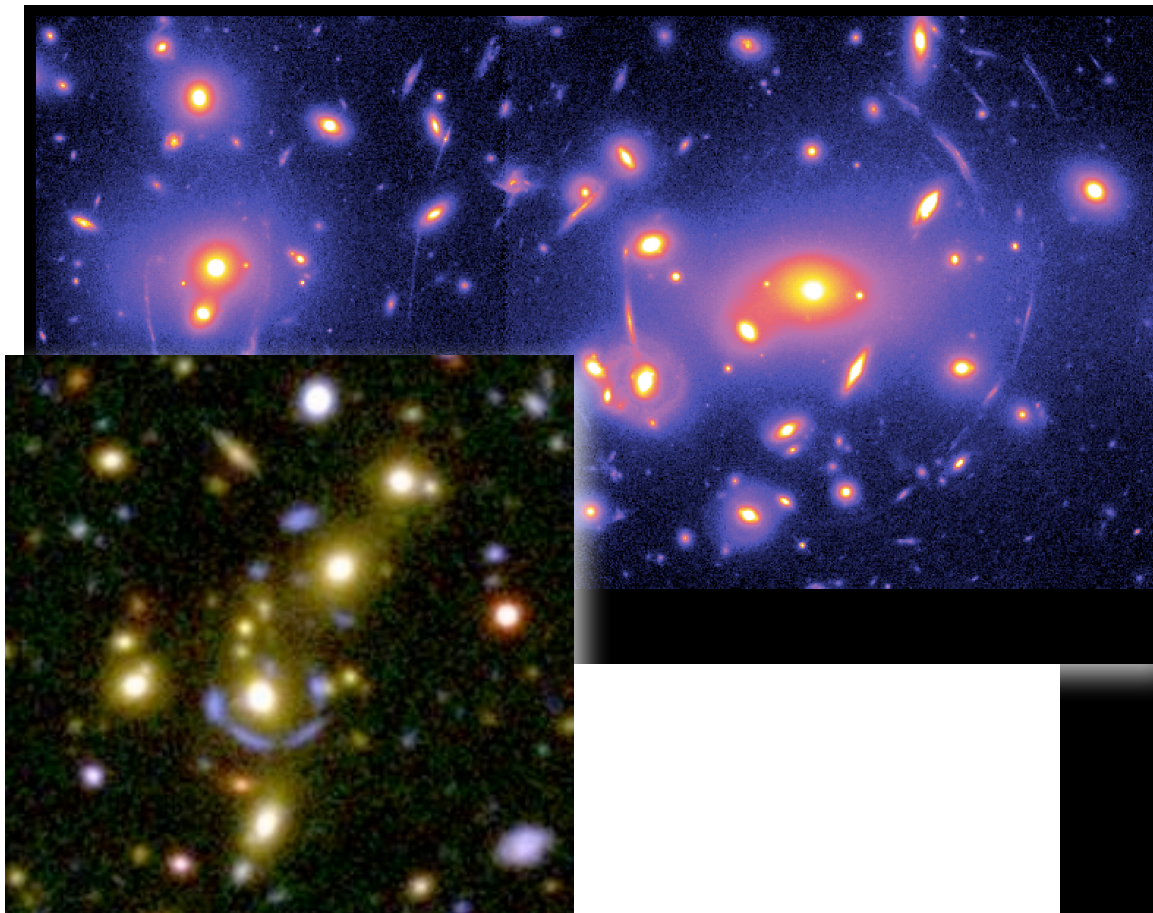
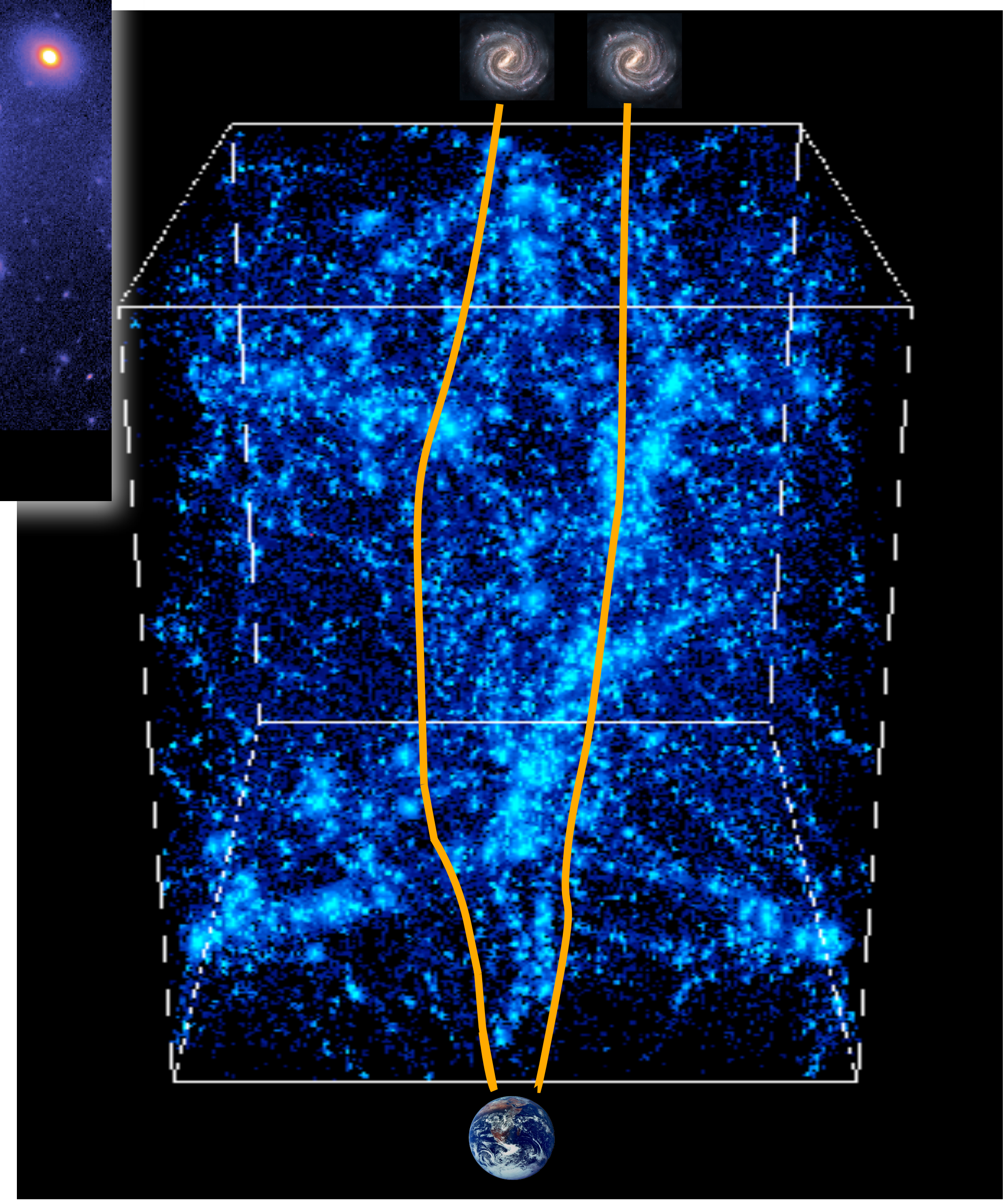
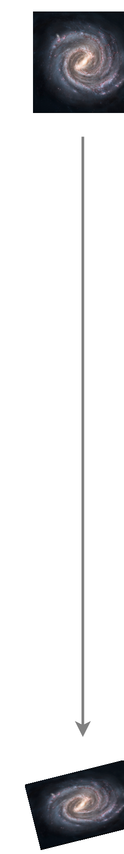
Colloque Nationale “Dark Energy”, LAL, 13/10/2017

Weak cosmological lensing





$z_s \sim 1$

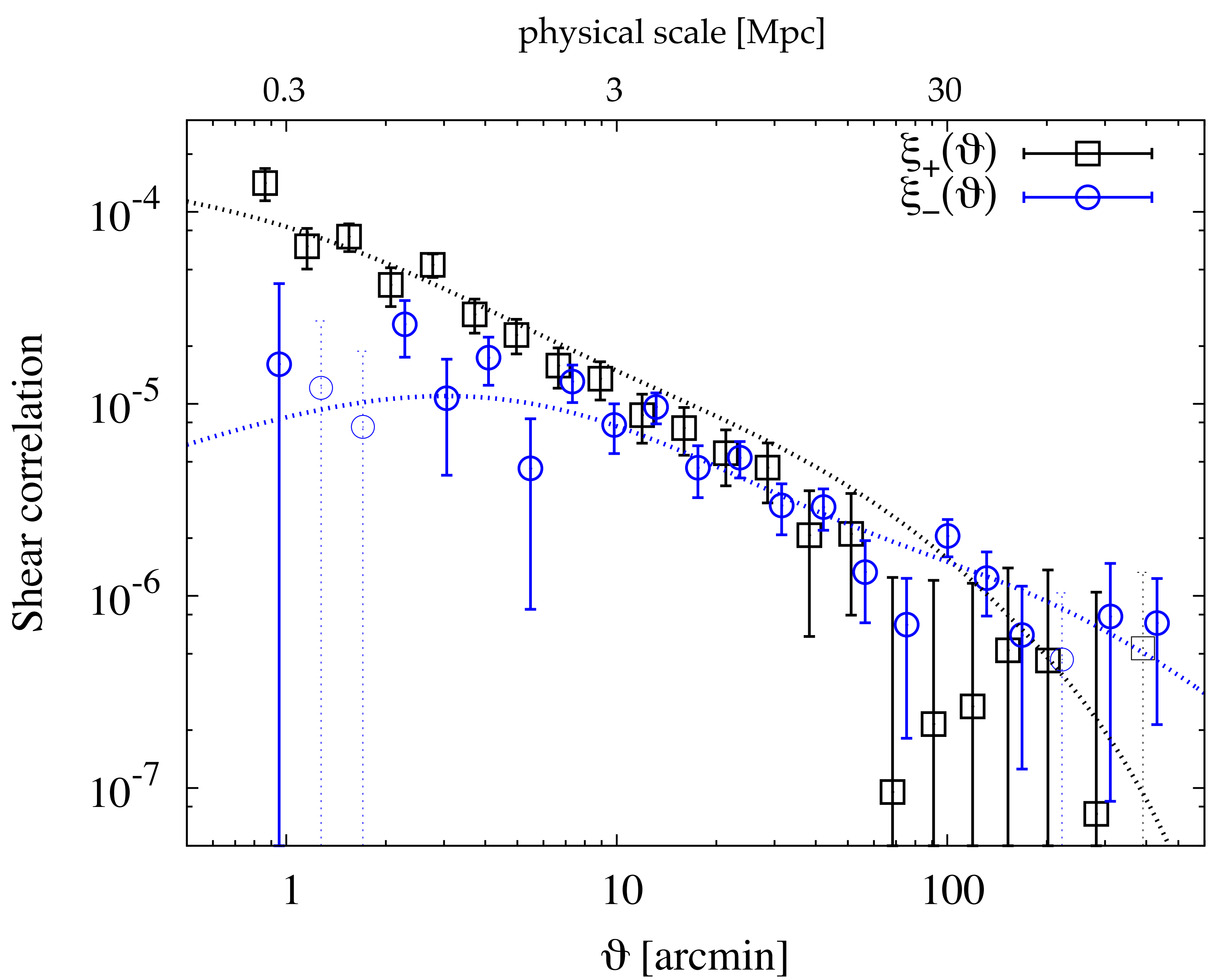


Lensing by LSS:
~ 3% distortion
$\kappa, \gamma \approx 0.03$

"Weak lensing"

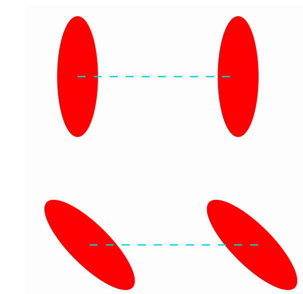
- Sensitive to total (baryonic + dark) matter
  No need to assume relation (bias) between galaxies & DM
- Low (z~0.1 … 1) redshifts
  Epoch of acceleration
- Probes geometry & structure
  Modified gravity

2-point shear correlation function



$\langle \gamma_t \gamma_t \rangle$

$\langle \gamma_\times \gamma_\times \rangle$



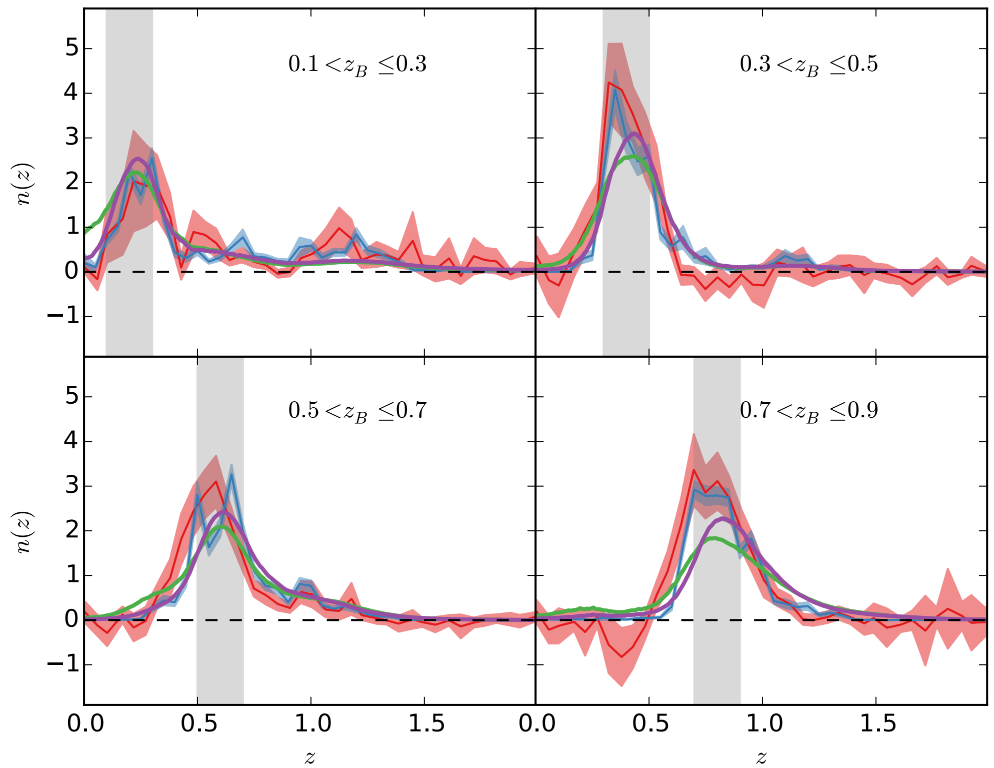
$$\xi_+(\vartheta) = \langle \gamma_t \gamma_t \rangle (\vartheta) + \langle \gamma_\times \gamma_\times \rangle (\vartheta)$$
$$\xi_-(\vartheta) = \langle \gamma_t \gamma_t \rangle (\vartheta) - \langle \gamma_\times \gamma_\times \rangle (\vartheta)$$

Prediction
(WMAP7 cosmology):
Flat Universe
$\Omega_m = 0.27$
$\sigma_8 = 0.8$
$w = -1$
Smith et al. (2003)
non-linear power spectrum

CFHTLenS: MK et al. (2013)

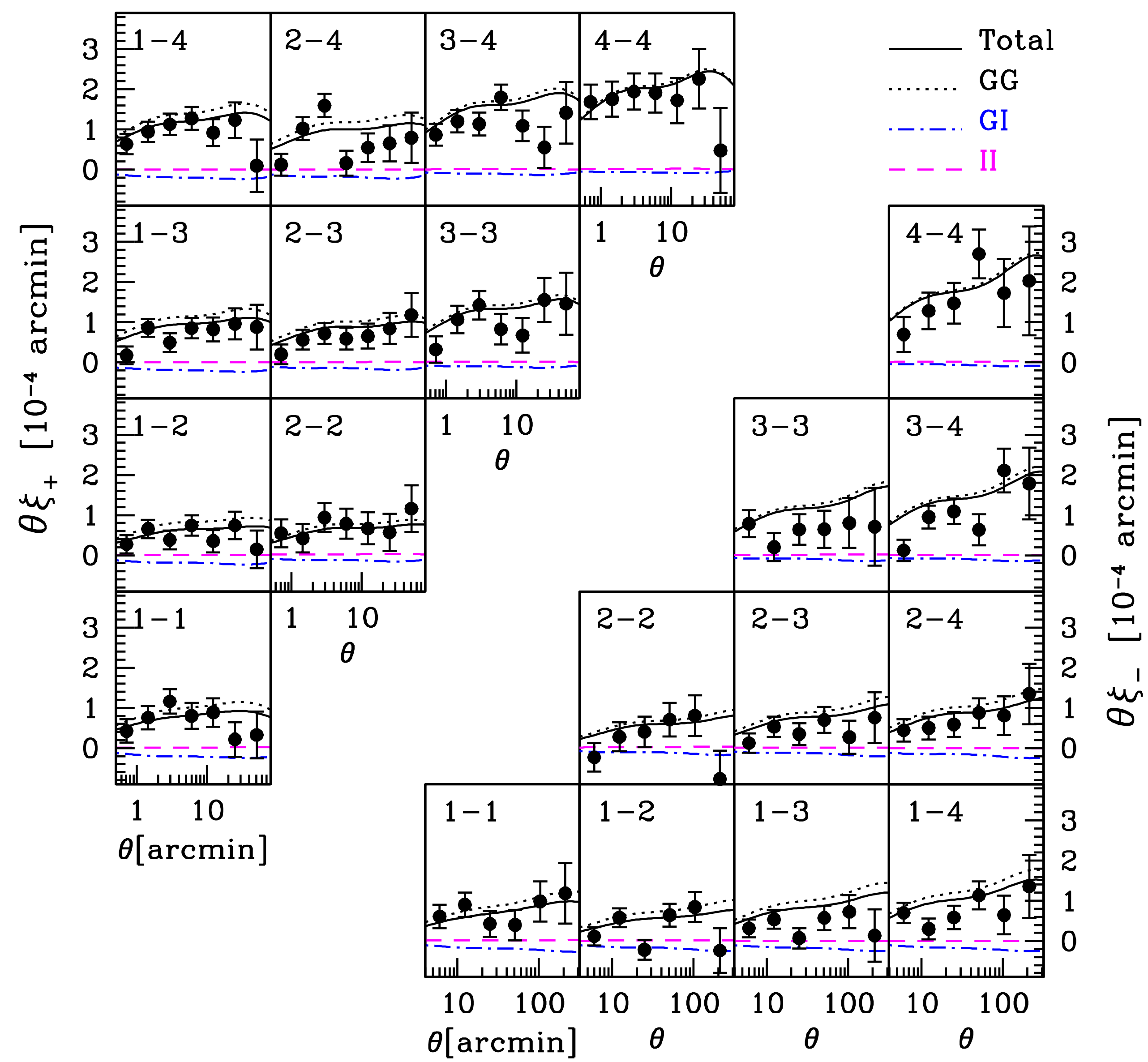
Results from KiDS

Four tomographic redshift bins



DR1/2, 450 deg²

2-point correlation function,
all combinations between z-bins

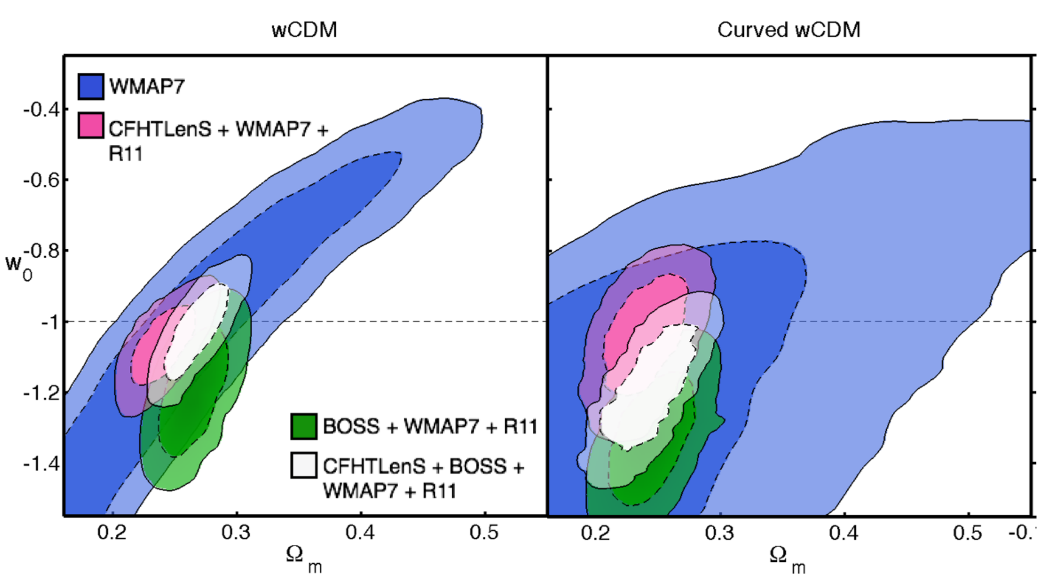


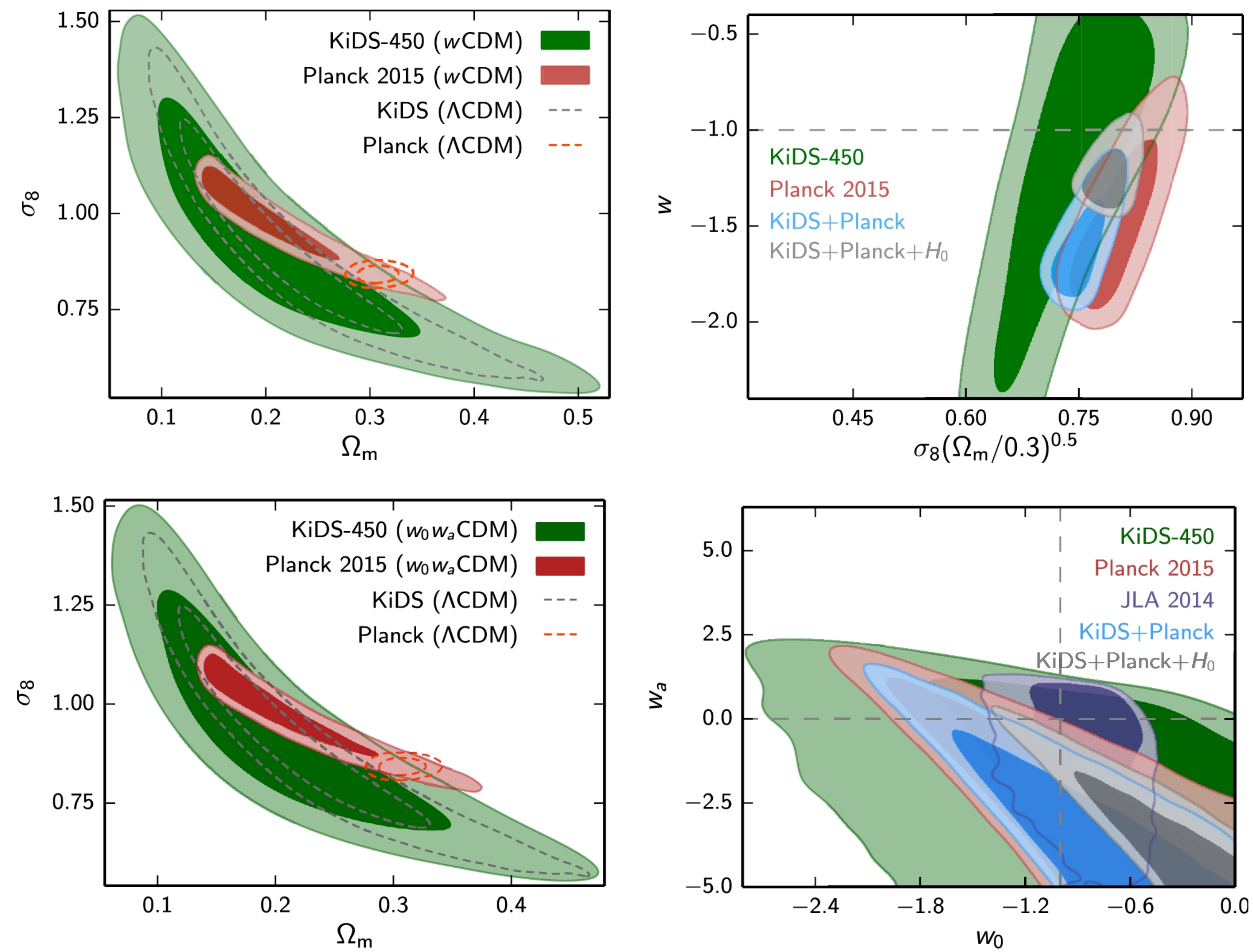
Hildebrandt et al. (2016)

Weak-lensing measurements of dark energy

KiDS-450 (Joudaki et al. 2016)

CFHTLenS (Heymans et al. 2013)





(Some) weak-lensing systematics:

shape measurement bias
photometric redshifts
intrinsic galaxy alignment
baryonic physics

WL dependence on dark energy, redshifts, and shear bias

Dependence on *w* weaker than for other parameters.

$$P_\kappa(\ell \sim 1000) \propto \Omega_{\rm de}^{-3.5} \sigma_8^{2.9} \bar z^{1.6} |w|^{0.31} \quad \text{(Huterer et al. 2006)}$$

For desired precision on *w*, need 5 times more precise mean redshift(s)!

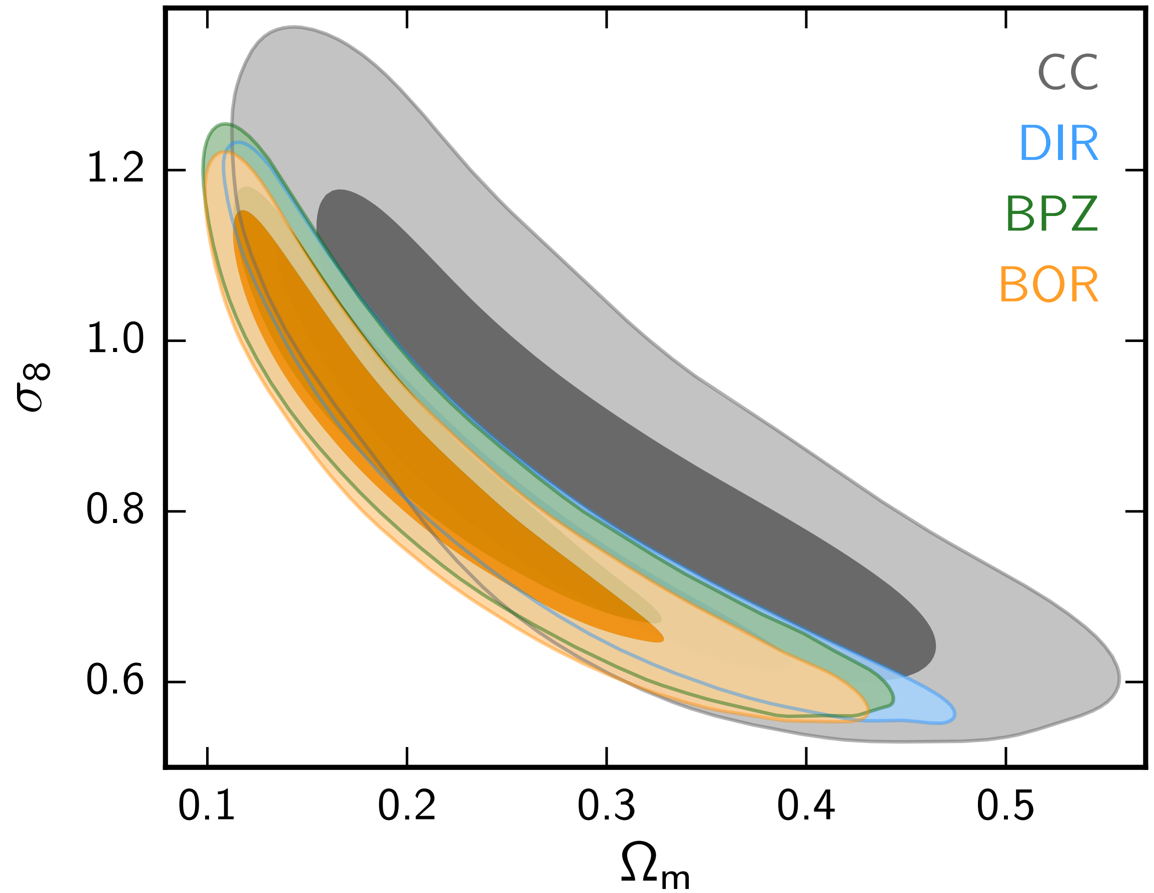
Shear bias:

$$\gamma_i^{\rm obs} = (1 + m_i) \gamma_i^{\rm true} + c_i; \quad i = 1, 2$$

$$P_\kappa \propto (1 + m)^2; \quad \sigma_8 \propto (1 + m)$$

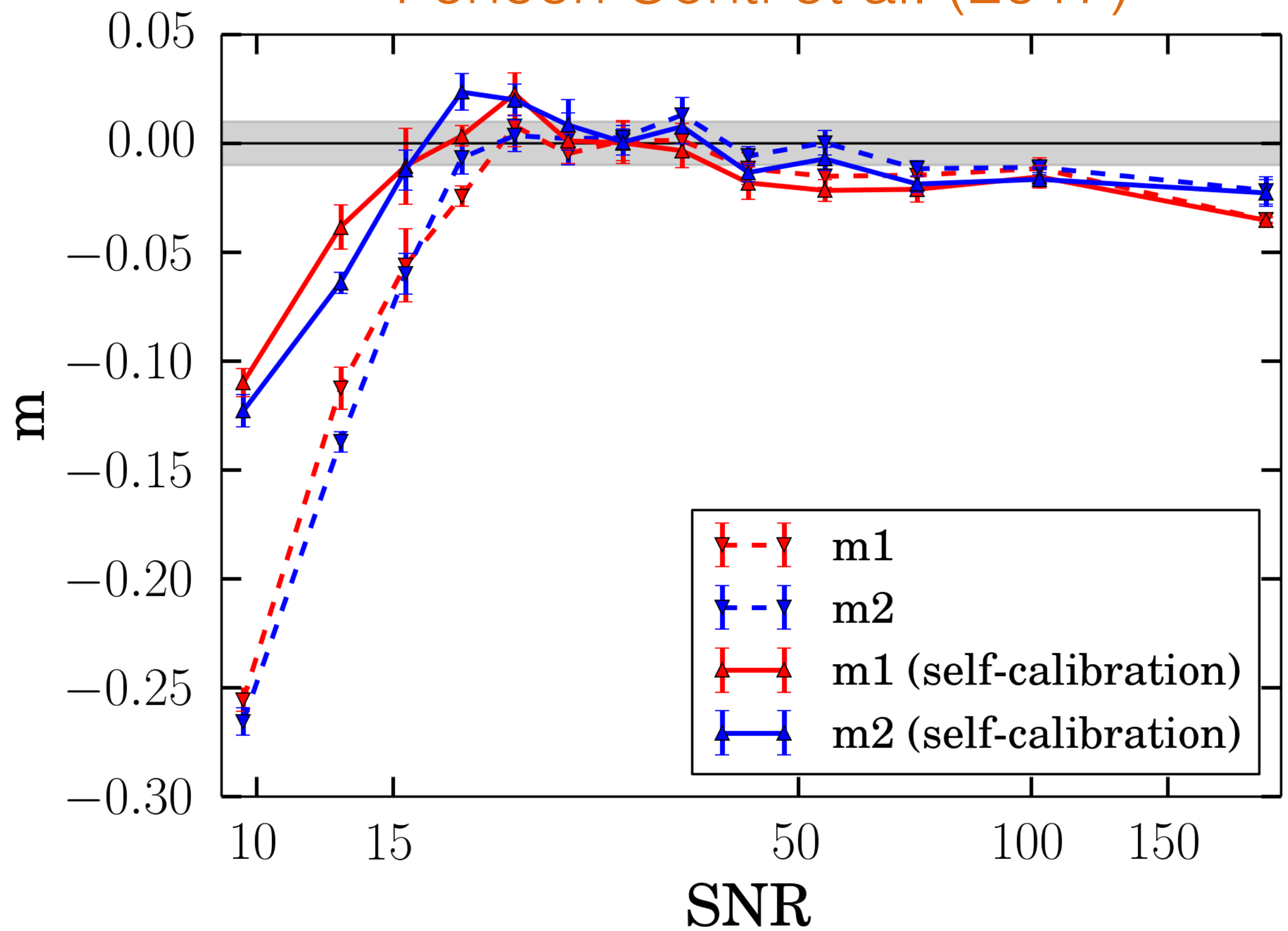
Results from KiDS

Hildebrandt et al. (2016)



Different *n(z)* estimates.

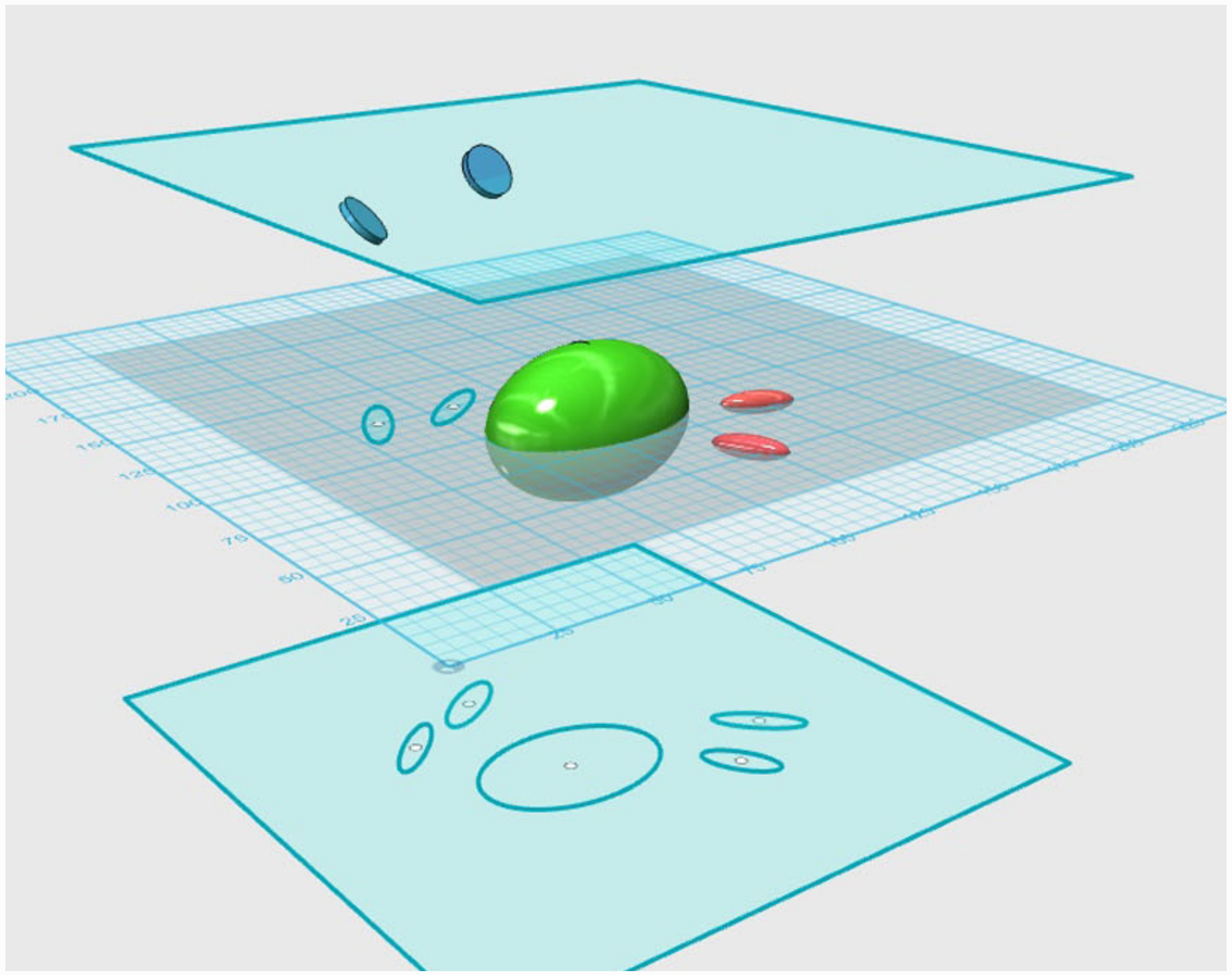
Fenech Conti et al. (2017)



Shear calibration

Necessary to remove tension with Planck: Δz~0.14, Δm~0.16.

Intrinsic galaxy alignment (IA)

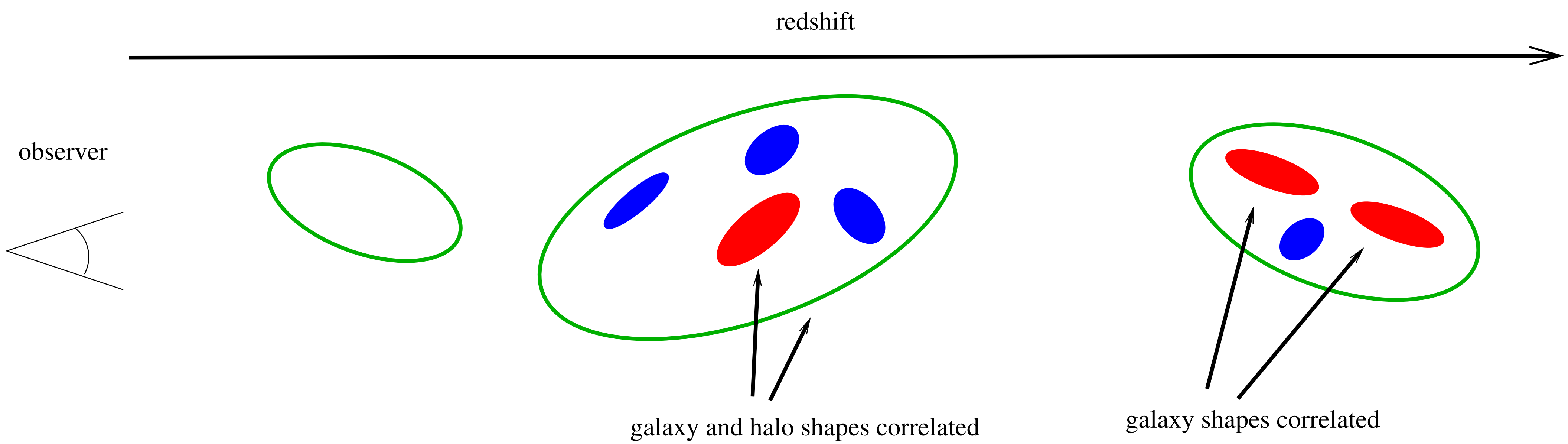


(Joachimi et al. 2015)

Galaxy shapes are correlated with surrounding tidal density field, due to coupling of spins for spiral galaxies, tidal stretching for elliptical galaxies. Shape of galaxies is sum of shear (G) and intrinsic (I) shape (remember $\varepsilon \approx \varepsilon^{\mathrm{s}} + \gamma$).
So, with intrinsic alignment, the correlation of galaxy shapes is not only shear-shear (GG), but also intrinsic-intrinsic (II) and shear-intrinsic (GI; (Hirata & Seljak 2004)).

Contamination to cosmic shear at $\sim$ 1 - 10%.
Need to model galaxy formation.

IA: mitigation



- II (intrinsic - intrinsic): concerns galaxies at same *z;* remove from analysis;

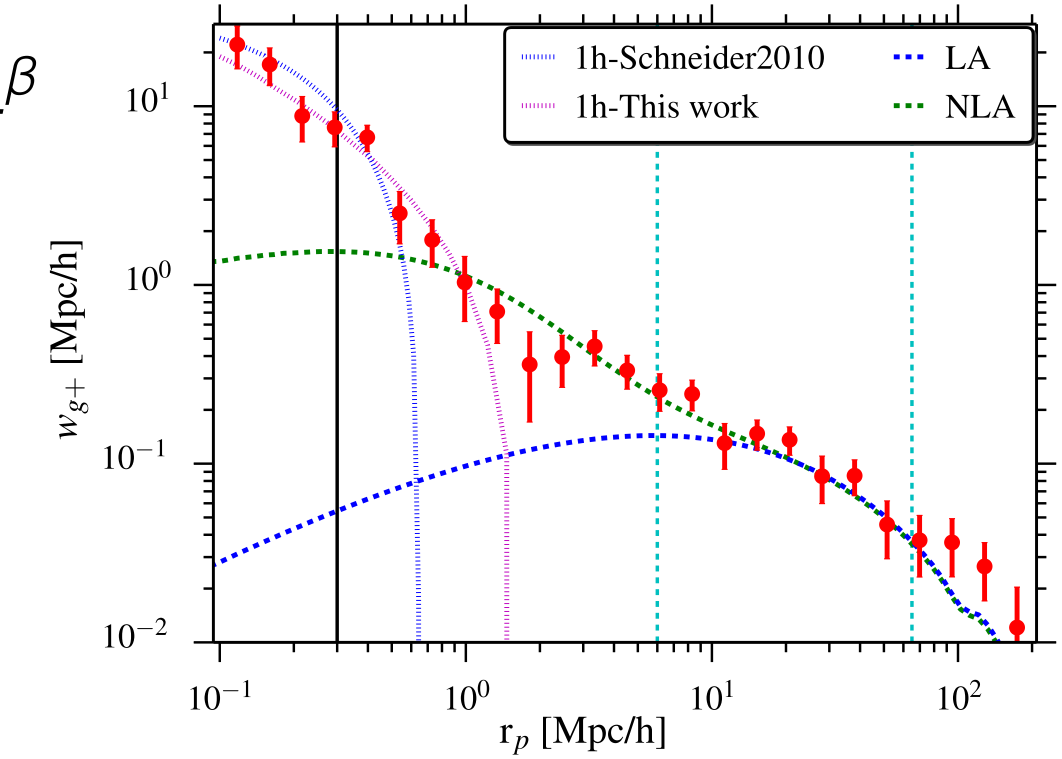
- GI (shear - intrinsic): galaxies at different *z;*
  - Remove LRGs (Schrabback et al. 2010)
  - Nulling (independent of IA model, only depends on distances) (Joachimi, Schneider 2008, 2009, 2010)
  - Joint modelling+fitting of IA & cosmo parameters (Bridle, King, Kirk and others)

IA: modelling

- Quadratic model
  - spin alignments from tidal torquing for spiral galaxies.

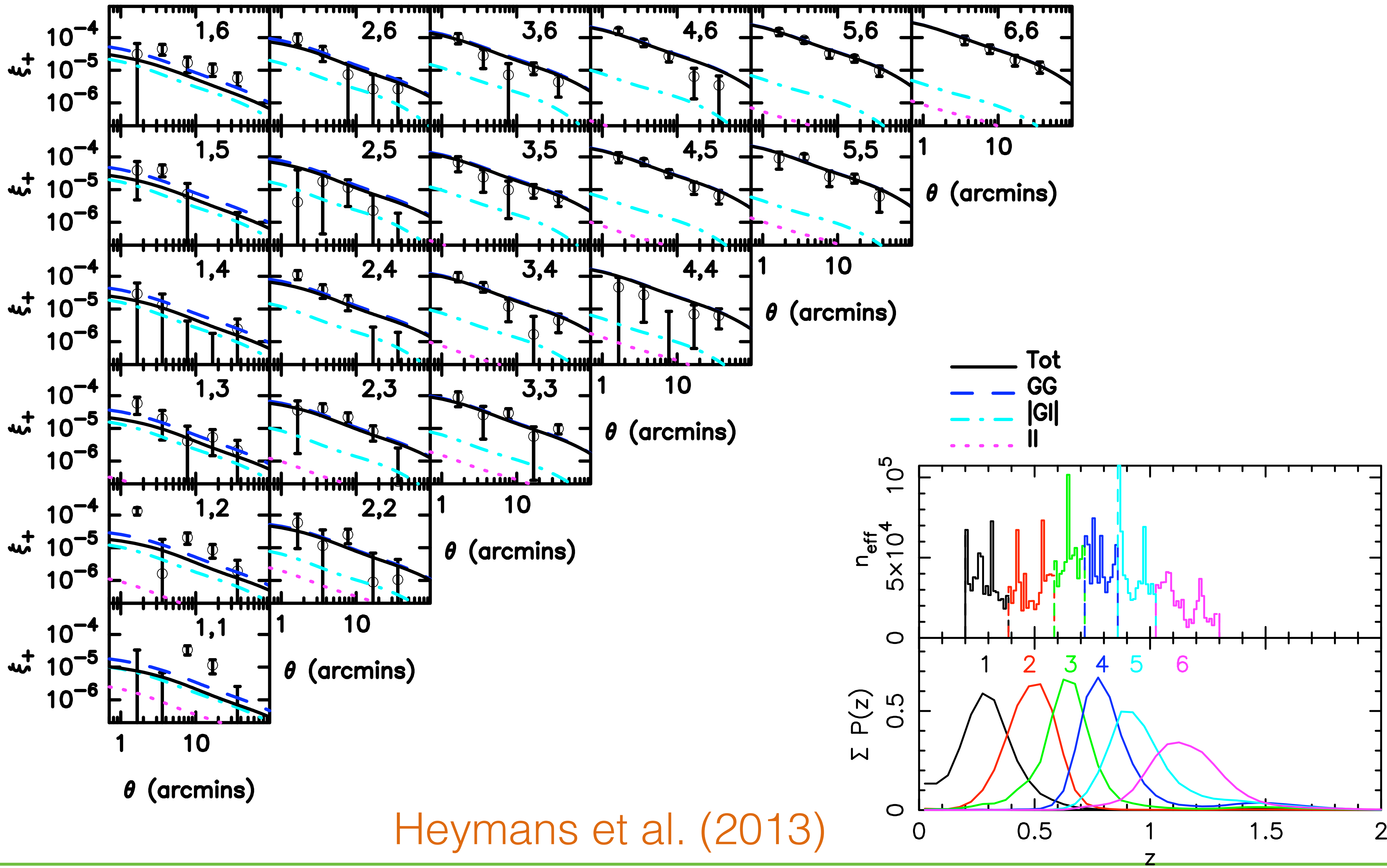
- Linear model
  - Halo shapes stretched by tidal field, linear in $P_\delta(k)$,
  - $P_{II} = A^2\, P_\delta$, $P_{GI} = -A\, P_\delta$.
  - $A(z$, galaxy type, luminosity)?
    - Parametric model, e.g. $A = (1+z)^\alpha\, L^\beta$
    - Non-parametric model, e.g. A on a grid in (z, L)
  - "non-linear" model: P_δ = non-linear power spectrum

- Halo model



Singh et al. (2014)

IA: measurement



Heymans et al. (2013)

IA: measurement

Linear intrinsic alignment model
[Hirata & Seljak 2004, Bridle & King 2007].

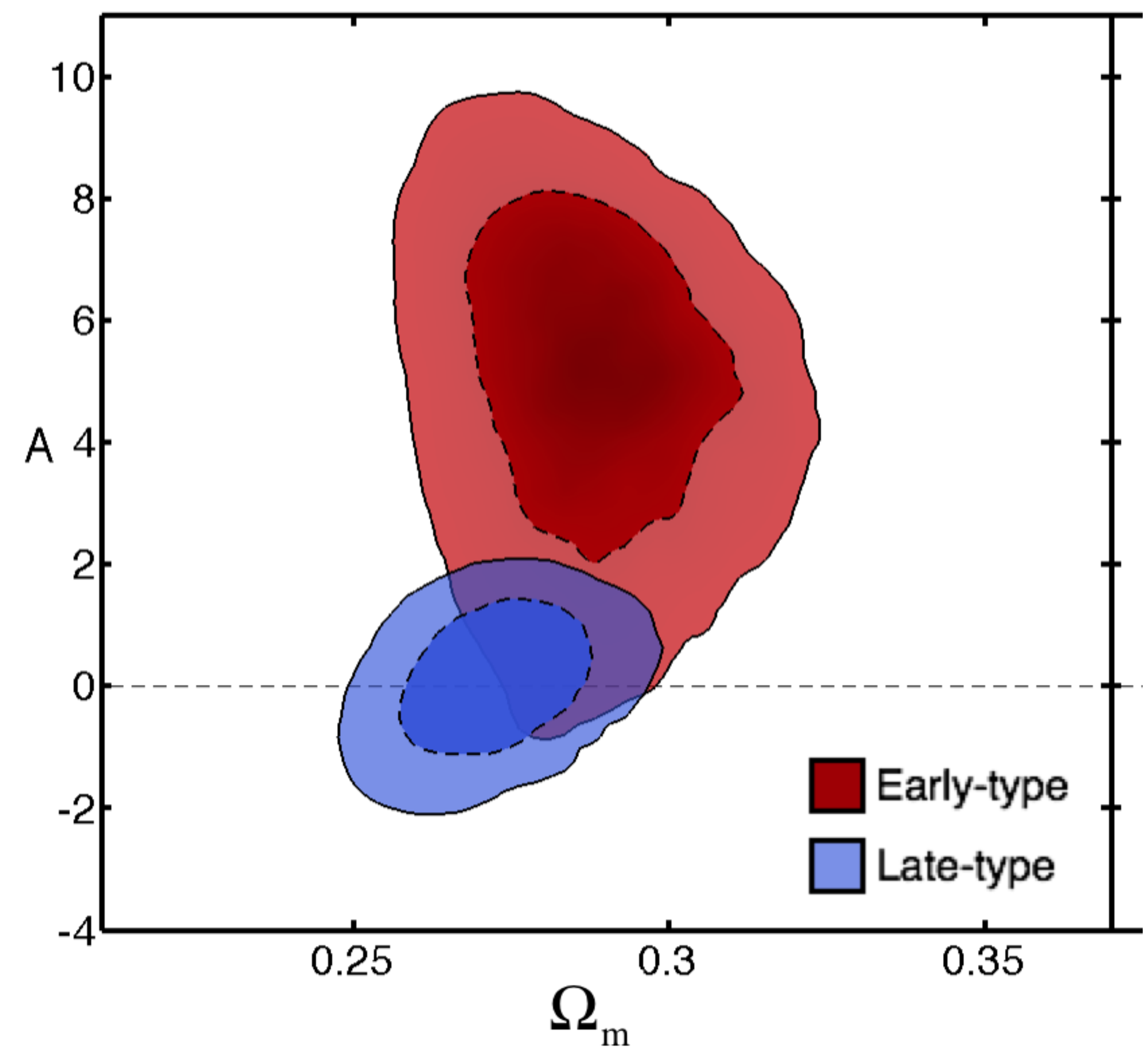
One free amplitude parameter *A*,
fixed *z*-and *L*-dependence.

A = 1: reference IA model.
A = 0: no IA

$$A_{\rm late} = 0.18^{+0.83}_{-0.82}$$

$$A_{\rm early} = 5.15^{+1.74}_{-2.32}$$

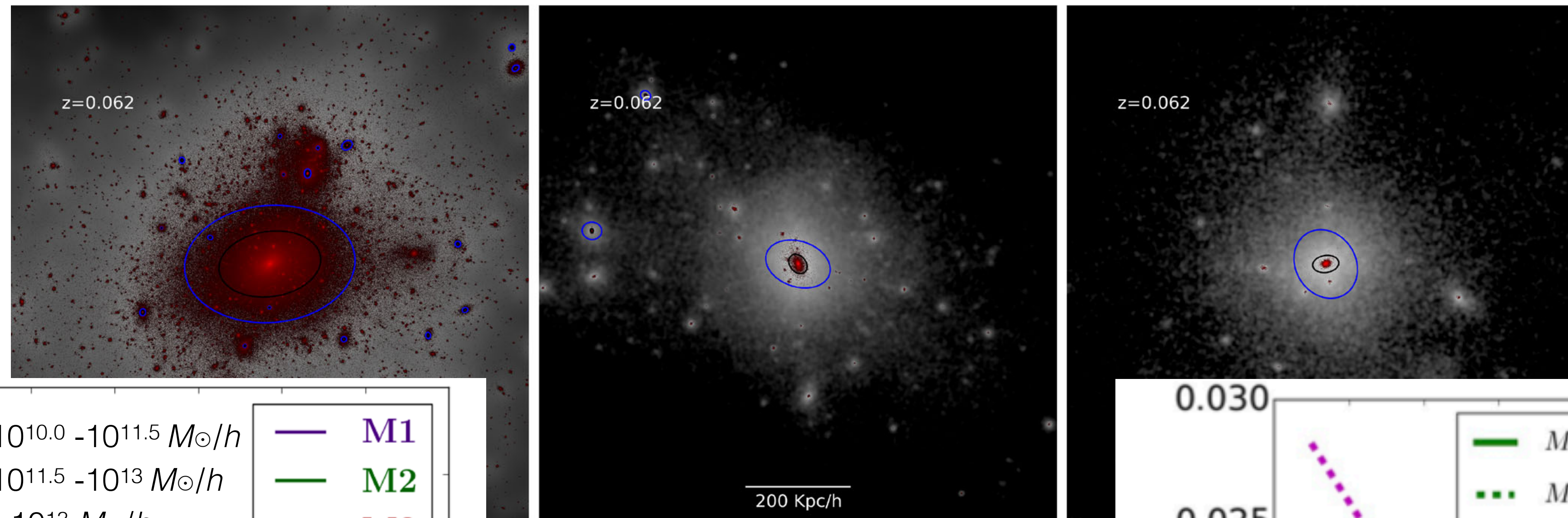
	$\sigma_8(\Omega_{\rm m}/0.27)^\alpha$
$A = 0$	$0.783^{+0.024}_{-0.032}$
A marginalized	$\mathbf{0.774^{+0.032}_{-0.041}}$



Heymans et al. (2013)

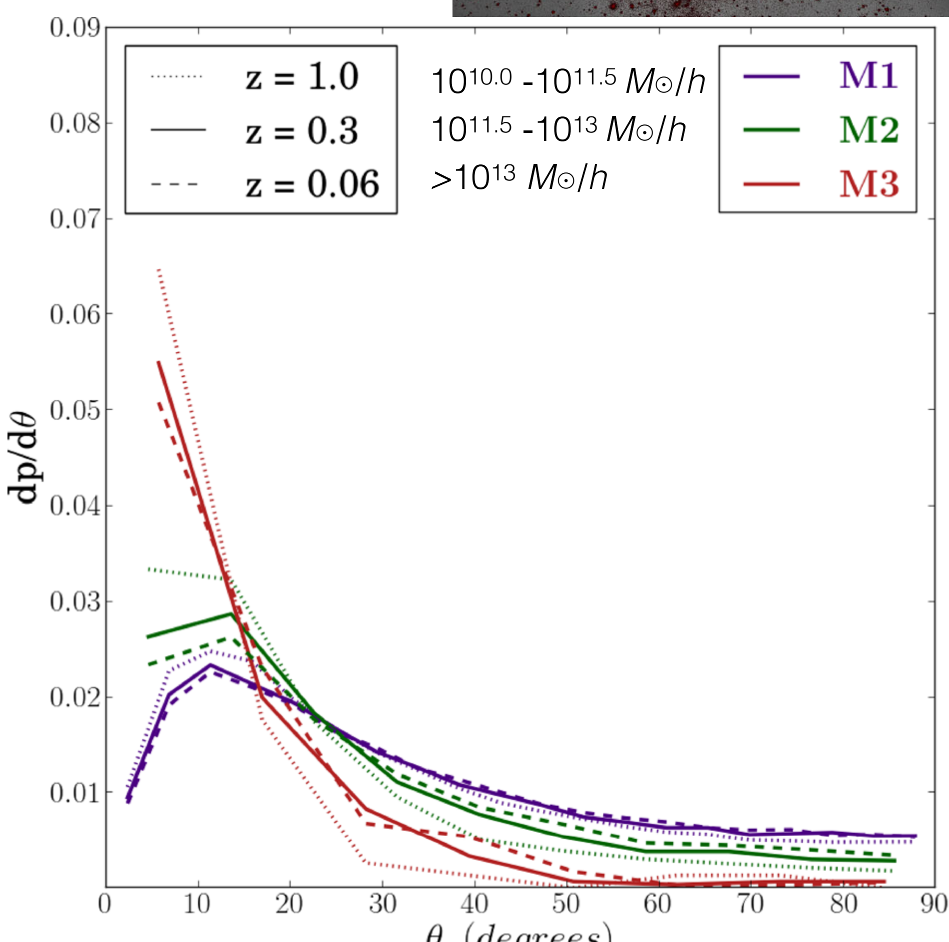
IA: difference between simulations

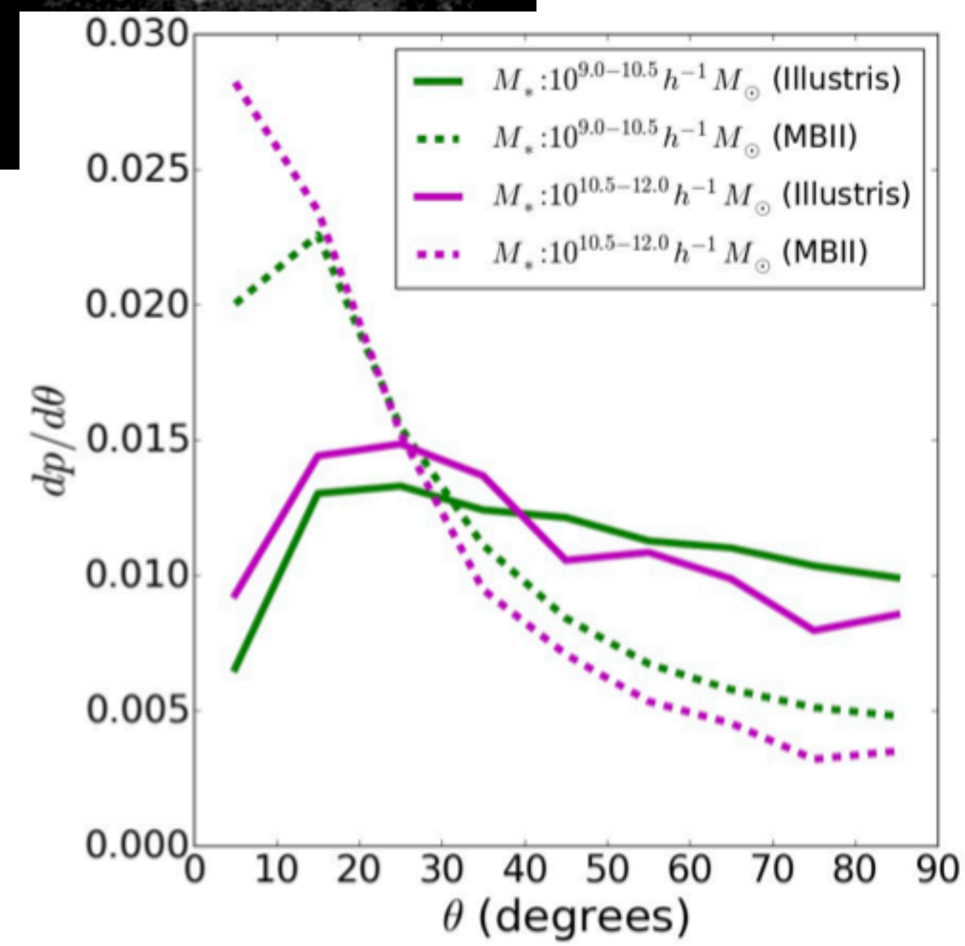
MassiveBlack-II simulations



dark matter

stellar matter



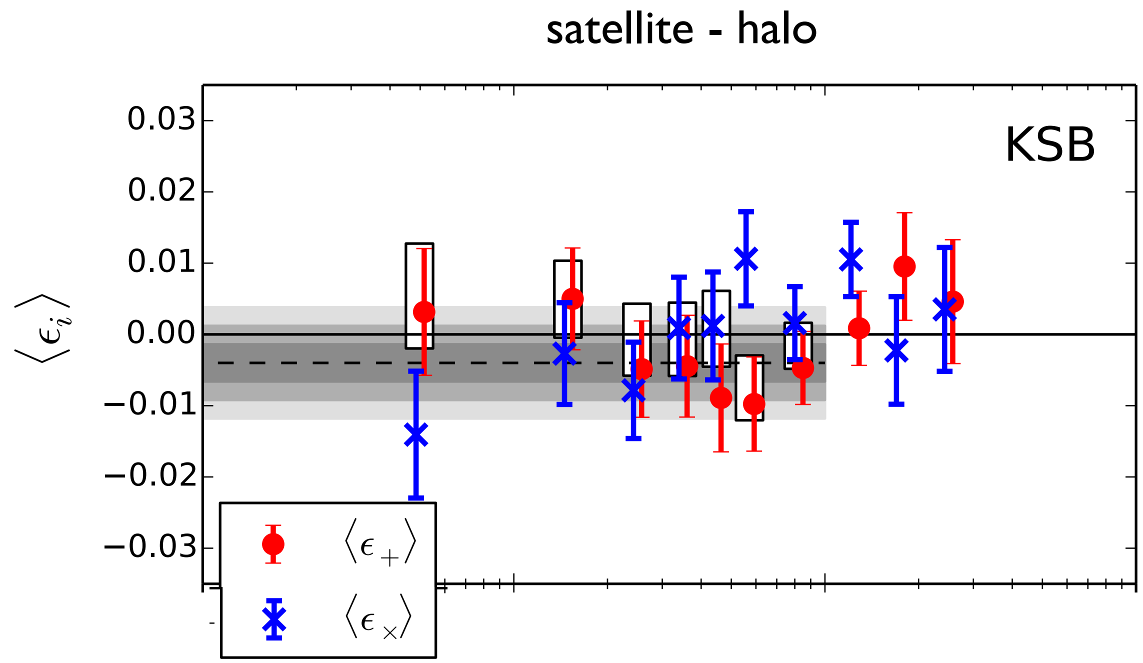


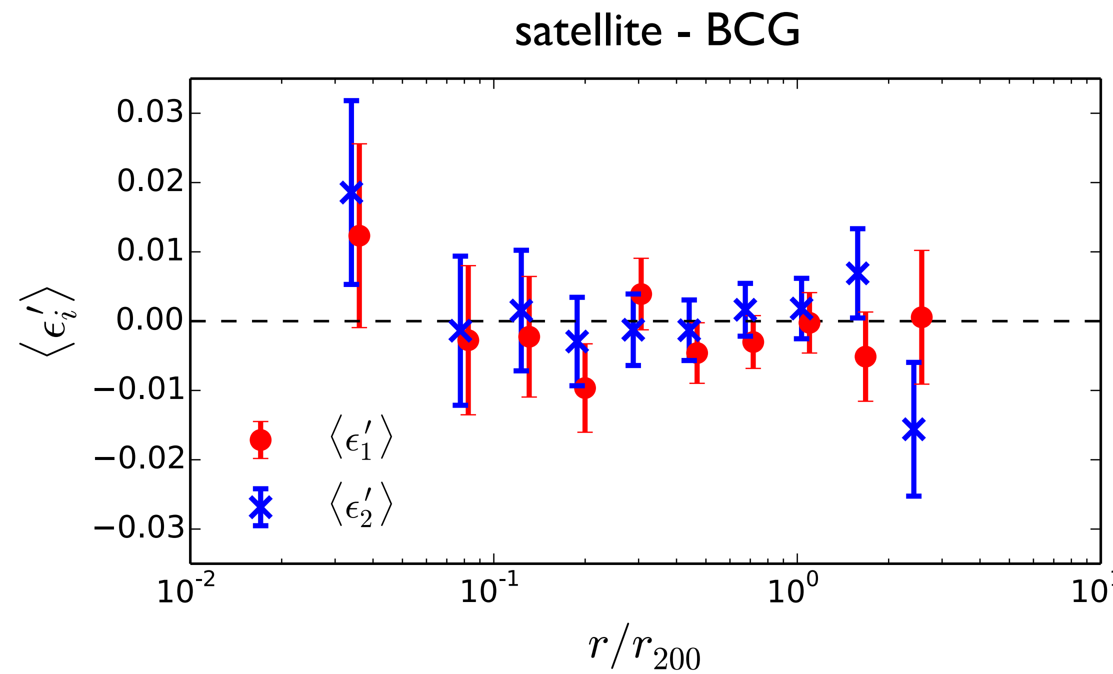
Tighter alignment of stellar and dark matter for more massive halos (Tenneti et al. 2014)

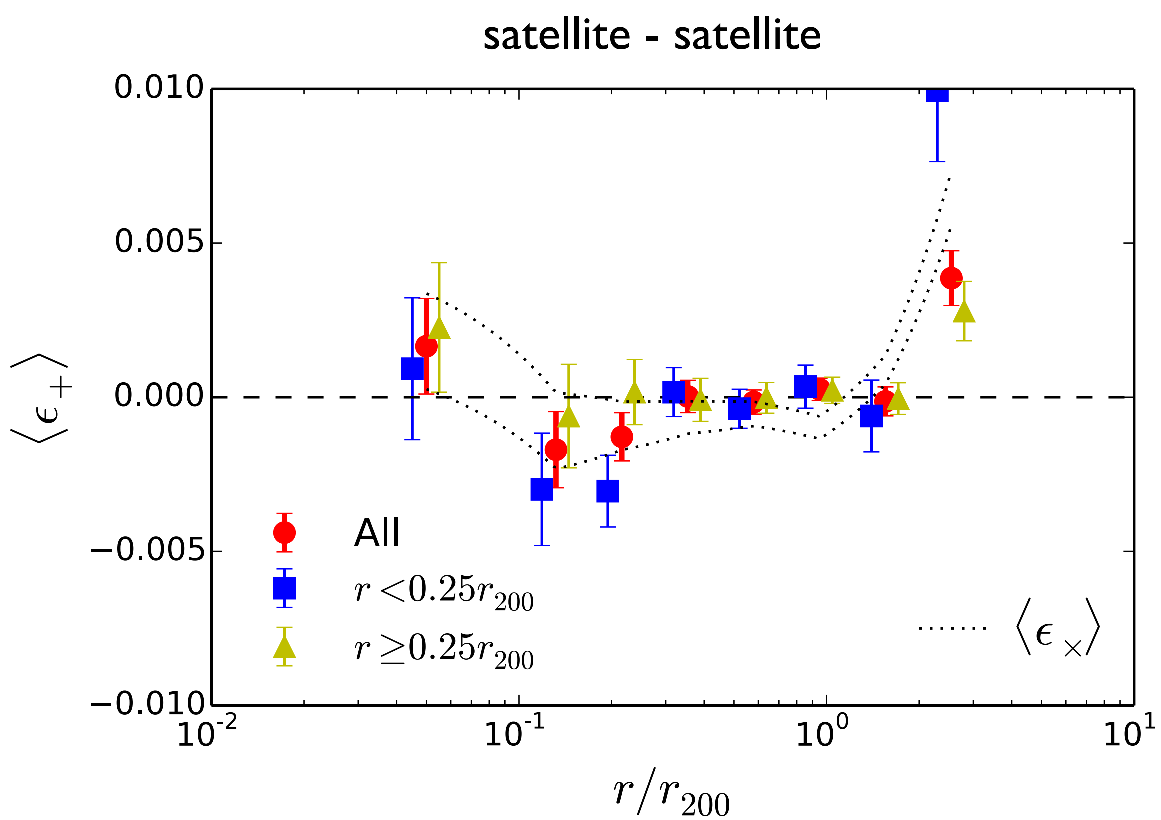
But differences between simulations (Tenneti et al. 2015)

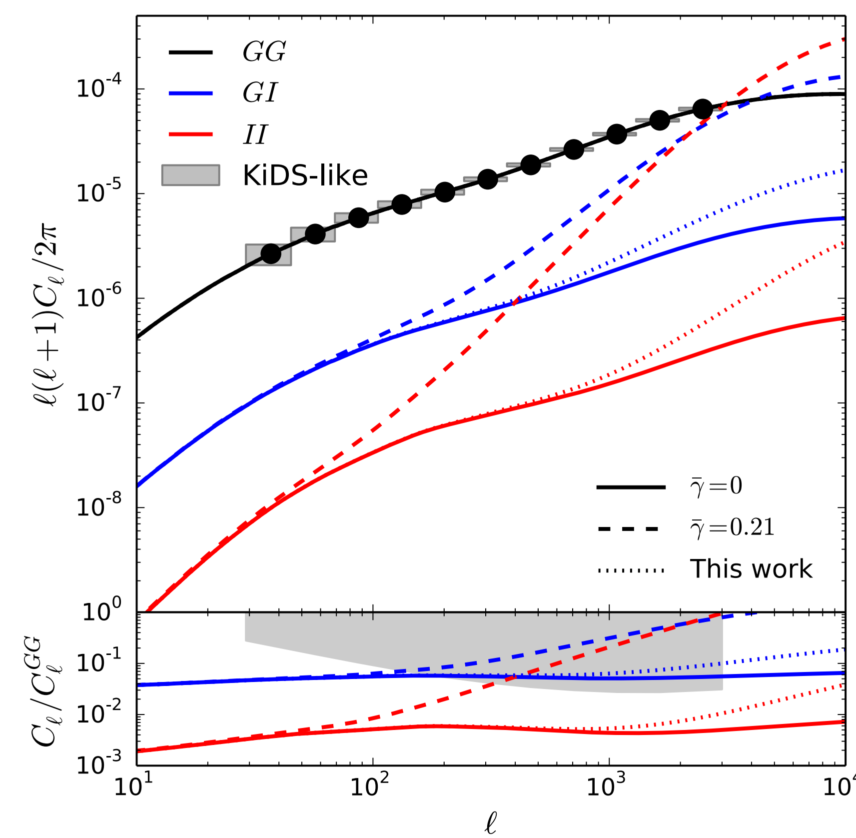
IA: not large problem for current surveys…

Sifon et al. (2015)

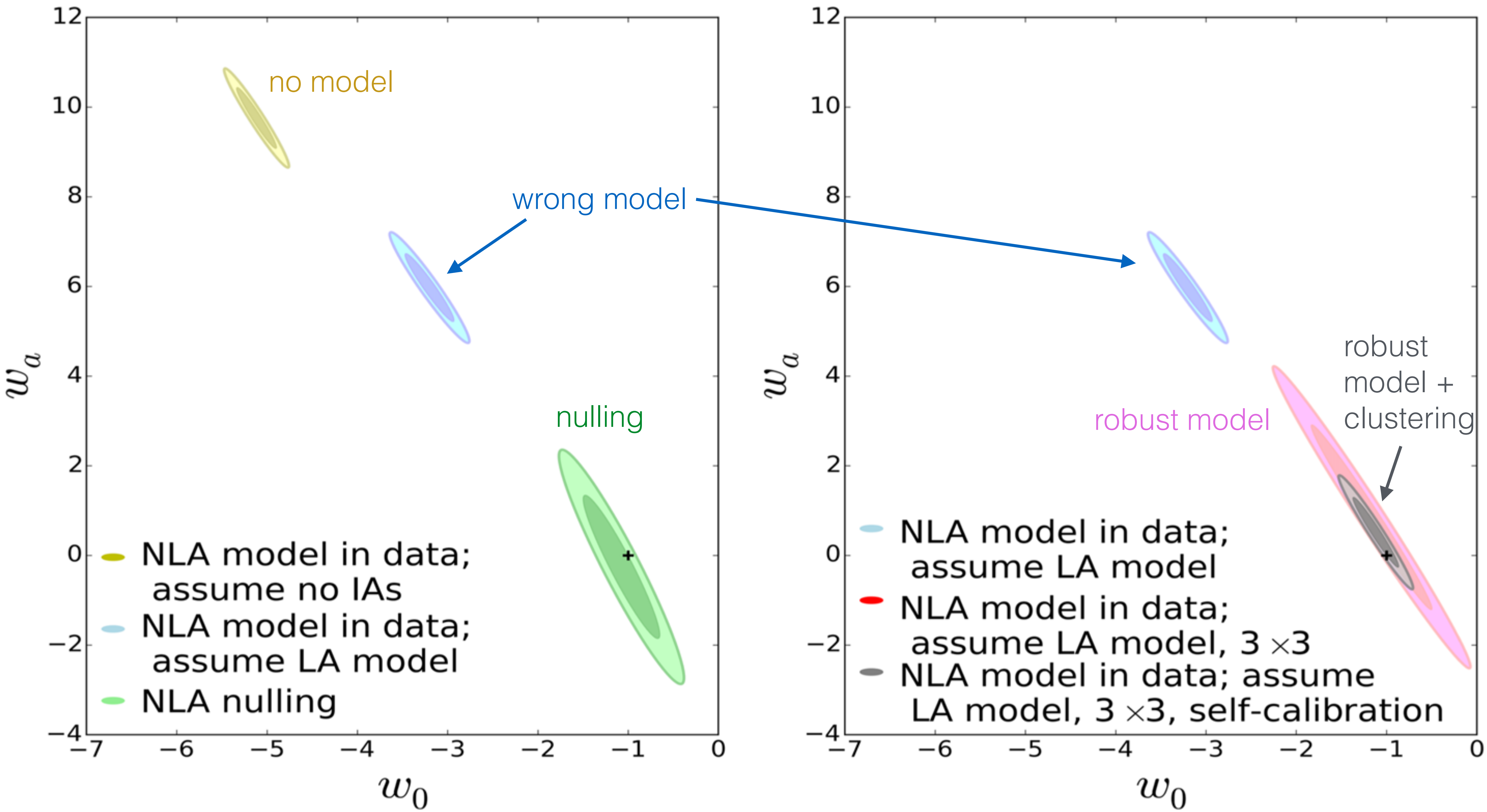








... but major contaminant for Euclid

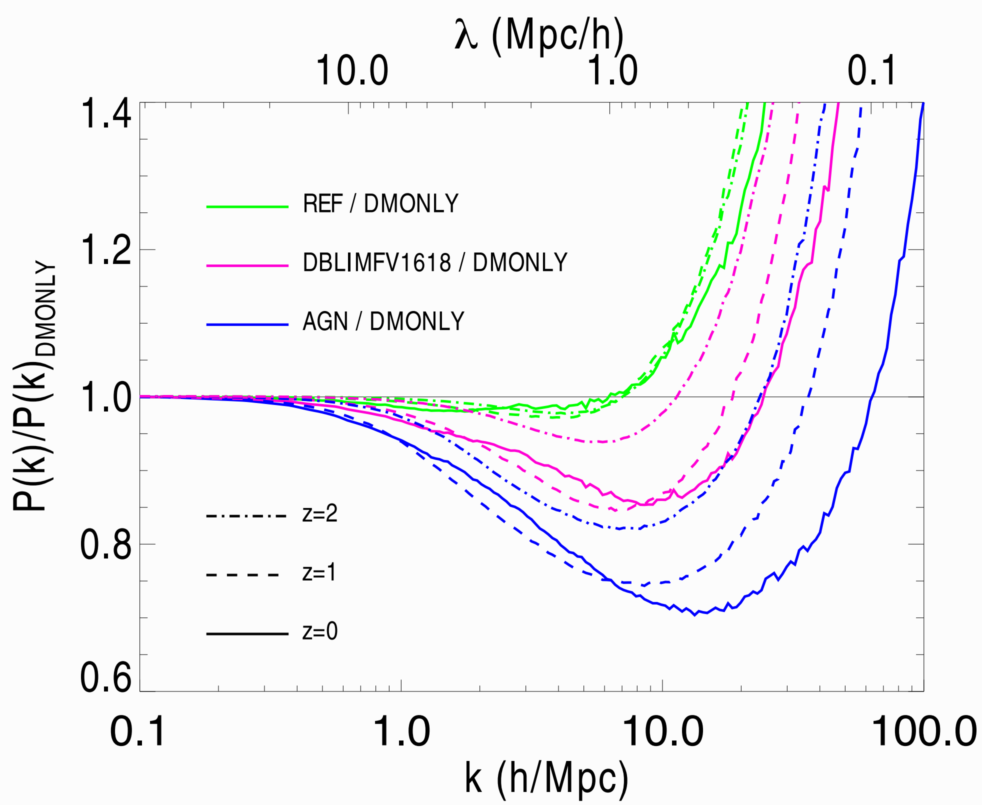


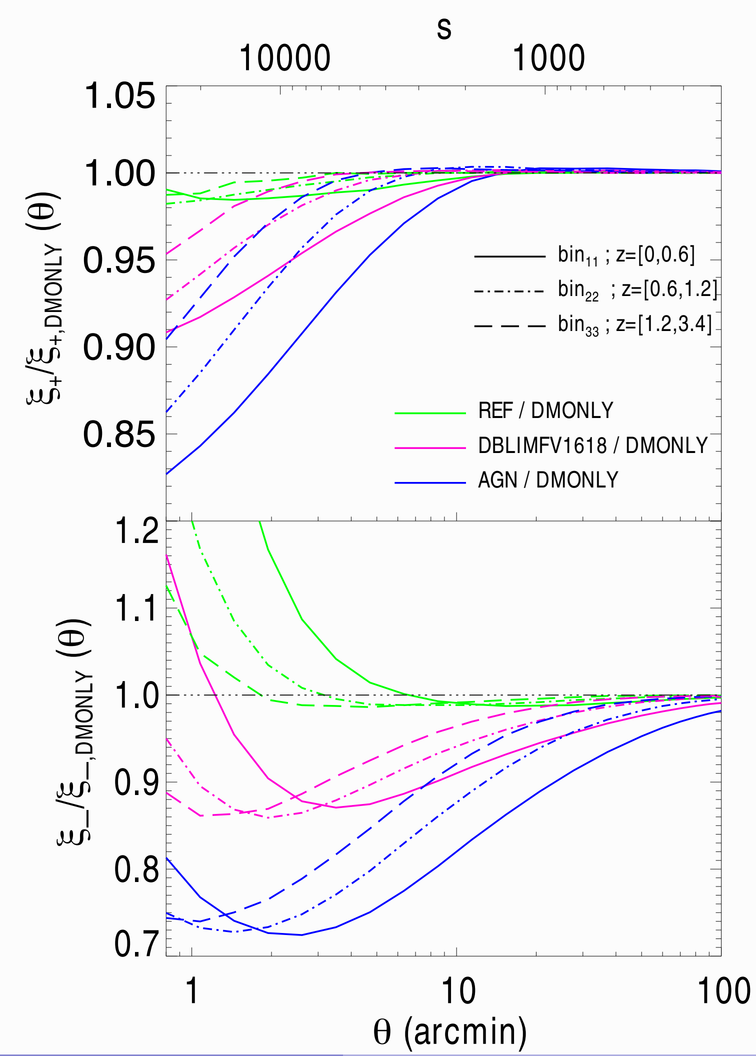
Kirk et al. (2015)

Baryonic physics

On small (halo) scales, dark-matter only models do not correctly reproduce clustering:

- $R \sim 1$ - 0.1 Mpc: gas pressure $\to$ suppression of structure formation, gas distribution more diffuse wrt dm
- $R < 0.1$ Mpc ($k > 10$/Mpc): Cooling, AGN+SN feedback $\to$ baryons condense & form stars & galaxies, increase of density & clustering

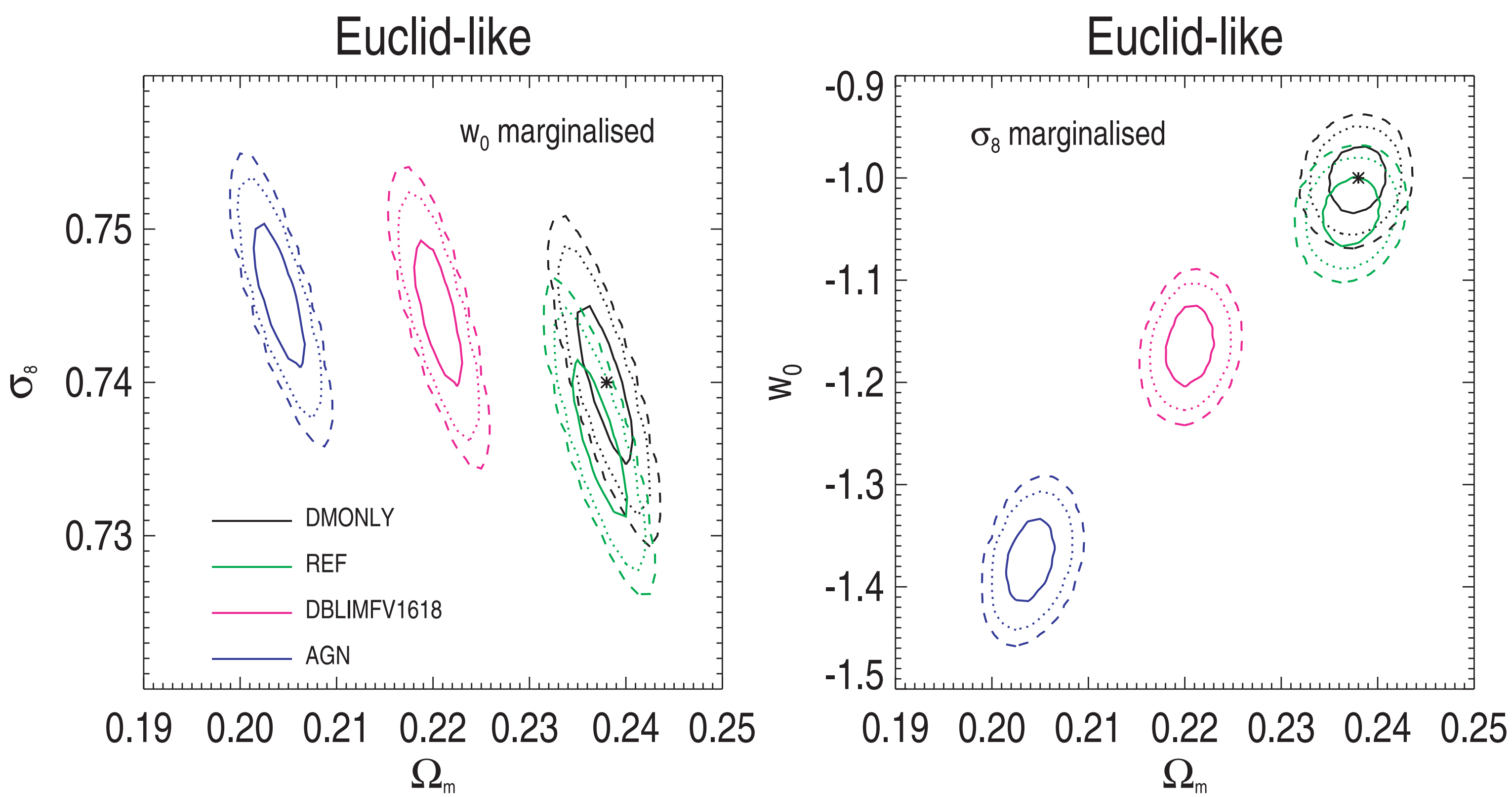




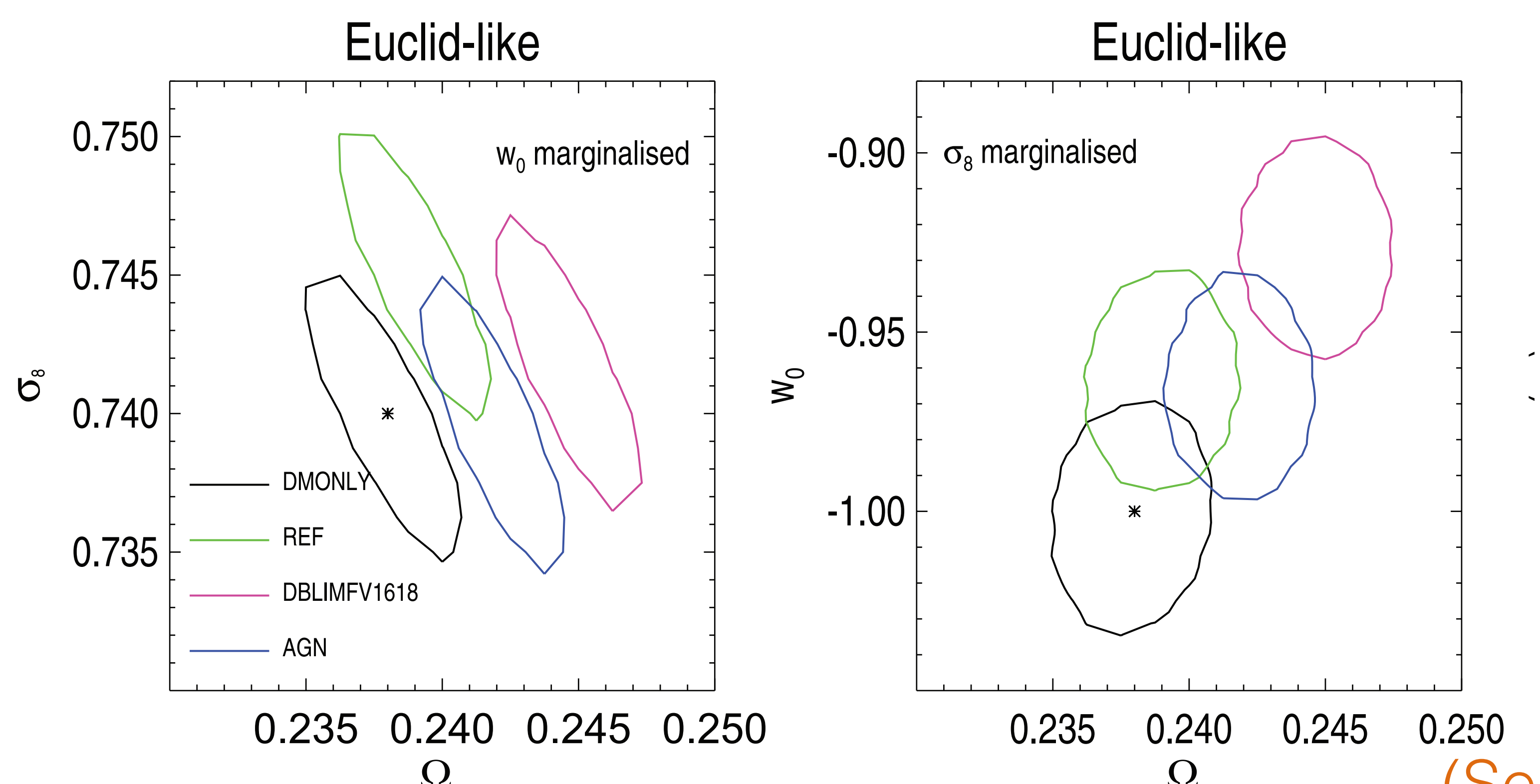
(Semboloni et al. 2011)

Baryonic physics

Baryons ignored



Baryons modeled



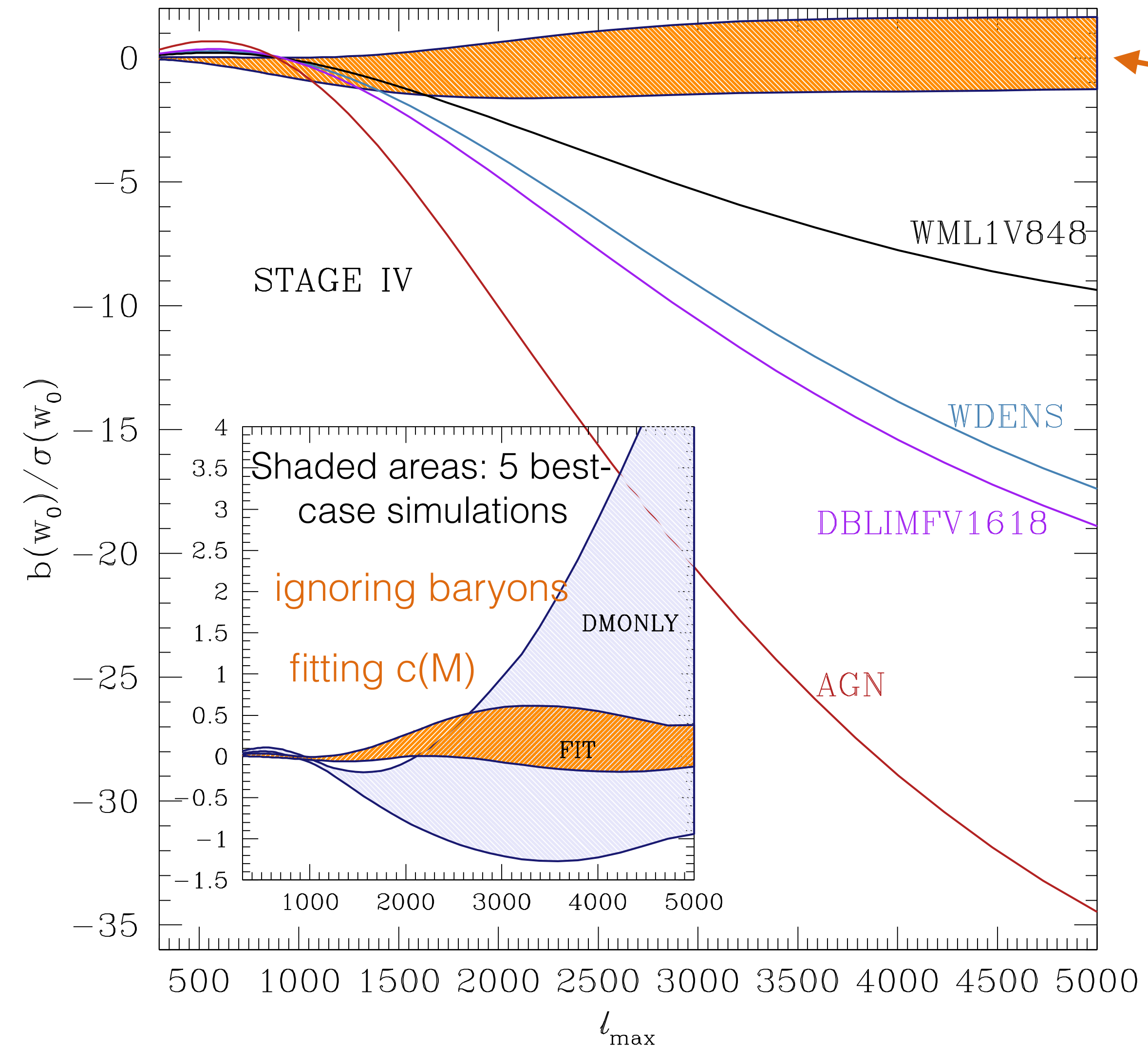
Scales: l = 10 … 6000

(Semboloni et al. 2011)

Baryonic physics

bias on DE if baryons are ignored in modelling

DE bias/RMS



Model: fitting c(M) relation

Lines: 4 worst-case simulations.
Model: ignoring baryons

35σ bias!

(Zentner et al. 2012)

Euclid requirement

Shear bias residuals $\Delta m < 2 \times 10^{-3}$.

Factor ~5 to improve.

Power spectrum to few percent to k ~ 5/Mpc.

Has to include IA, baryons.

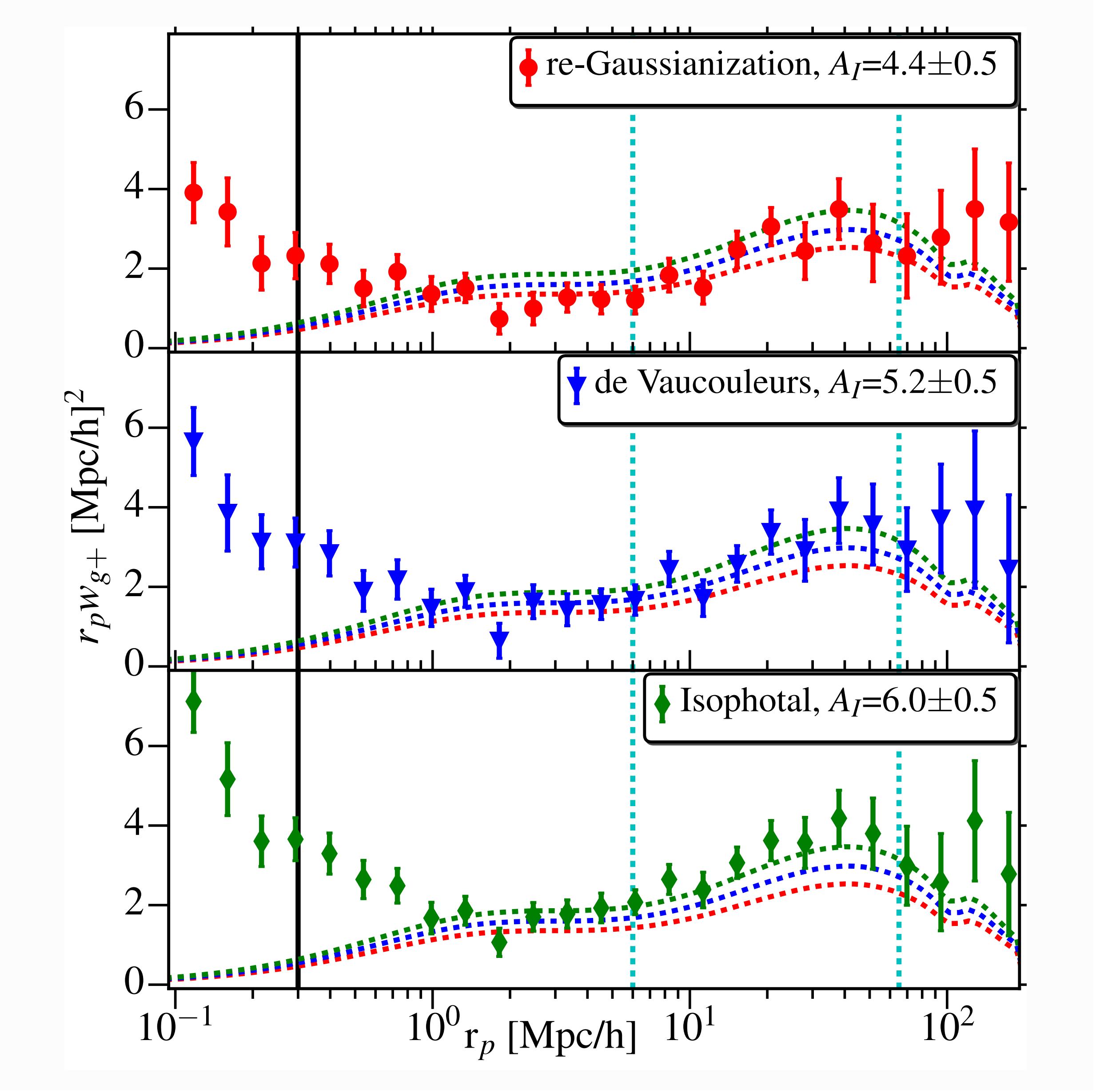
Photometric redshift, mean per bin $\Delta z \sim 0.002(1+z)$.

Ground-based surveys (DES, LSST, CFIS, …)

Extra slides

IA: correlation with shape measurement

IA contamination depends on shape measurement method!
IA affects more galaxy outskirts —- shape weighting kernel



(Singh & Mandelbaum 2016)

IA simulations

Tenetti et al. (2014)

- MassiveBlack hydro-simulations, $L_{\mathrm{box}} = 100\ h^{-1}$ Mpc, $m_{\mathrm{DM}} = 1.1 \times 10^{7}\ h^{-1}\ \mathrm{M}_{\odot}$, $m_{\mathrm{gas}} = 2.2 \times 10^{6}\ h^{-1}\ \mathrm{M}_{\odot}$

- Considering subhalos with 10^{10}–$6.0 \times 10^{14}\ h^{-1}\ \mathrm{M}_{\odot}$

- Dark matter distributions rounder than stellar mass

- Misalignment between 30° to 10° (low to high halo mass)

IA simulations

Codis et al. (2014)

- Horizon-AGN hydro-simulations, $L_{\mathrm{box}} = 100\ h^{-1}$ Mpc, $m_{\mathrm{DM}} = 8 \times 10^{7}\ h^{-1}\ \mathrm{M}_{\odot}$, $m_{*} = 2 \times 10^{6}\ \mathrm{M}_{\odot}$
- $z = 1.2$
- Blue galaxies more strongly aligned to tidal field than red galaxies, up to $10\ h^{-1}$ Mpc

IA measurements

Sifon et al. (2015)

- 13,966 spectroscopic galaxies with measured shapes in 91 massive clusters with $0.05 < z < 0.55$
- X-ray selected clusters (MENeaCS, CCCP), imaging with CFHTL12k and MegaCam, archival spectra (e.g. SDSS, Hectospec Cluster Survey)
- No IA signal detected, < 4% at l=3000, not detectable with KiDS