Intrinsic alignments
Cosmology from the large scales & constraining the non-linear regime

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October 1 2013

Intrinsic alignments: the big picture

A dark matter halo, a cluster of galaxies

The central galaxy in the halo

A satellite galaxy

Galaxies along filaments connecting clusters

Outline

I. Alignments of luminous red galaxies: **the linear alignment model**

- **Status of** observations
- **When** are alignments imprinted?
- **Cosmology** from intrinsic alignments
  - **Baryon Acoustic Oscillations**
  - **Primordial** non-gaussianity (and redshift space distortions)

II. Alignments of cluster galaxies

- **Status of** observations
- **Separating alignments and lensing with *P(z)***
- Preliminary **results**

Conclusions & future work

Alignments of Luminous Red Galaxies

Cosmology from the large scales

Chisari & Dvorkin, submitted

arXiv:1308.5972

The tidal alignment model

Ellipticity of a halo due to the tidal field

"intrinsic shear"

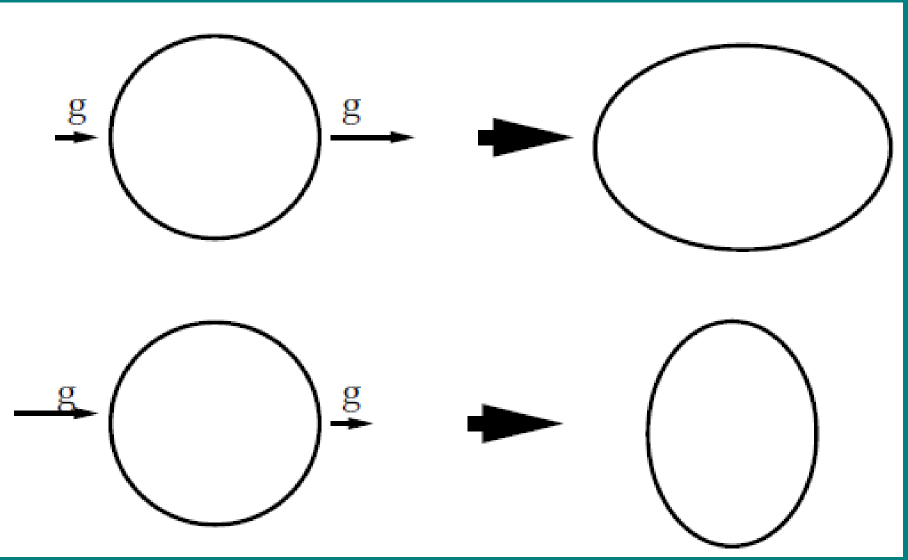
$$\gamma^I = -\frac{C_1}{4\pi G}(\nabla_x^2 - \nabla_y^2, 2\nabla_x\nabla_y)\mathcal{S}[\Psi_P]$$

The alignment occurs at formation

Primordial potential

$$\Psi_P(\mathbf{k}) = -4\pi G\frac{\bar{\rho}(z)}{\bar{D}(z)}a^2k^{-2}\delta_{lin}(\mathbf{k})$$

Response of a spherical overdensity to a tidal field



Assumptions

- LRG shape follows shape of halo
- Shapes are imprinted at formation
- Non-linear/Linear scales

Catelan+ (2001)

Hirata & Seljak (2004)

Contamination vs. cosmological information

Intrinsic alignments contaminate weak lensing observables

Observed shape of a galaxy

$$\gamma^{obs} = \gamma^{I} + \gamma^{G} \left(+ \gamma^{rnd} \right)$$

Intrinsic alignments in lensing and clustering cross-correlations

$$C_{\epsilon\epsilon}^{(ij)}(\ell) = C_{\rm GG}^{(ij)}(\ell) + C_{\rm IG}^{(ij)}(\ell) + C_{\rm IG}^{(ji)}(\ell) + C_{\rm II}^{(ij)}(\ell)$$ Ellipticities

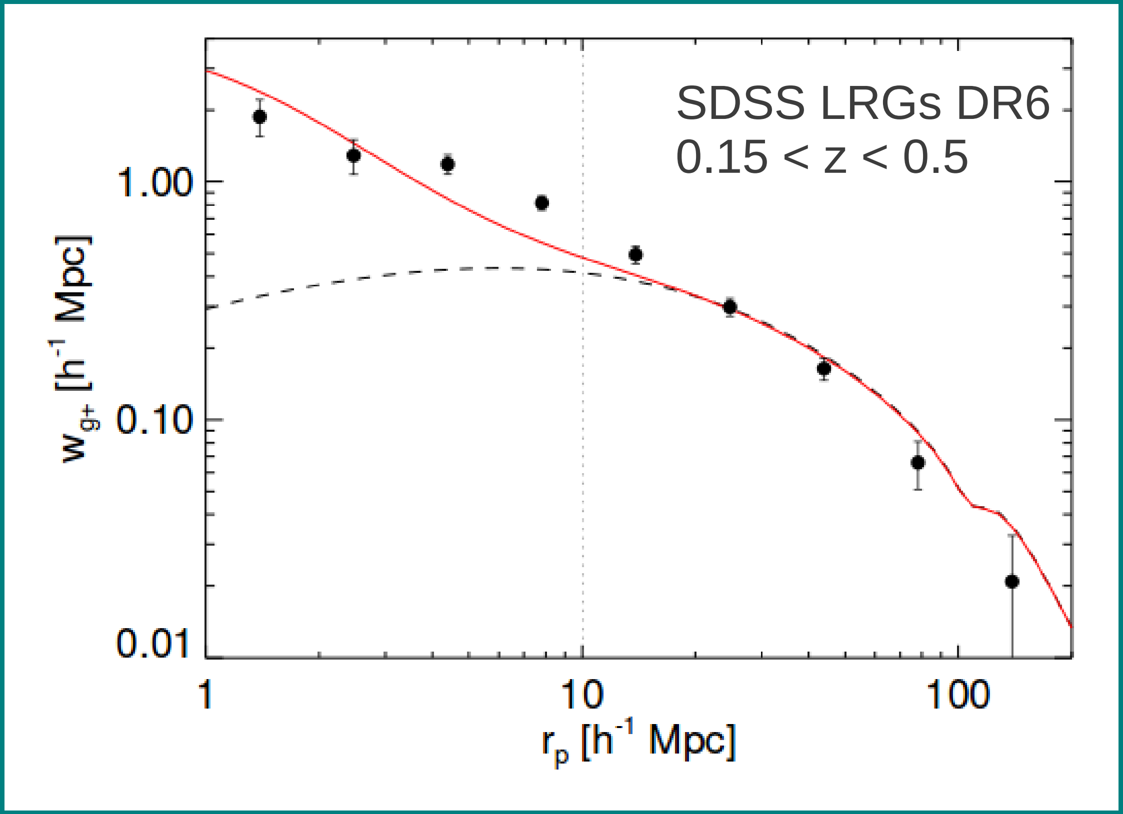
$$C_{nn}^{(ij)}(\ell) = C_{\rm gg}^{(ij)}(\ell) + C_{\rm gm}^{(ij)}(\ell) + C_{\rm gm}^{(ji)}(\ell) + C_{\rm mm}^{(ij)}(\ell)$$ Clustering

$$C_{n\epsilon}^{(ij)}(\ell) = C_{\rm gG}^{(ij)}(\ell) + C_{\rm gI}^{(ij)}(\ell) + C_{\rm mG}^{(ij)}(\ell) + C_{\rm mI}^{(ij)}(\ell)$$ Density-ellipticity correlation or “galaxy-galaxy” lensing

Joachimi & Bridle (2010)

Status of observations

The correlation function of **galaxy positions** and **intrinsic ellipticities** *(a galaxy-galaxy lensing analogue)*



Linear alignment model Hirata & Seljak (2004)

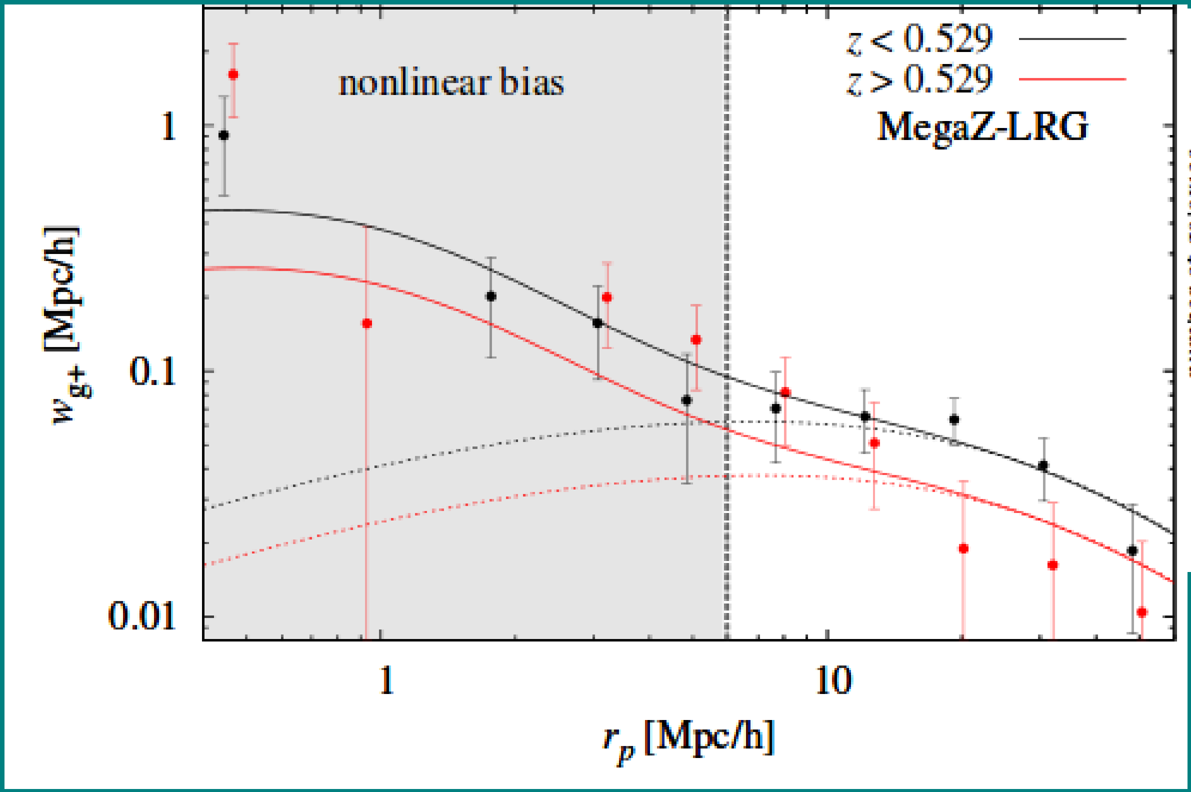
Non-linear alignment model Bridle & King (2007)

NLA: Assumes a linear Poisson equation for density perturbations but replaces the linear matter power spectrum by its non-linear version.

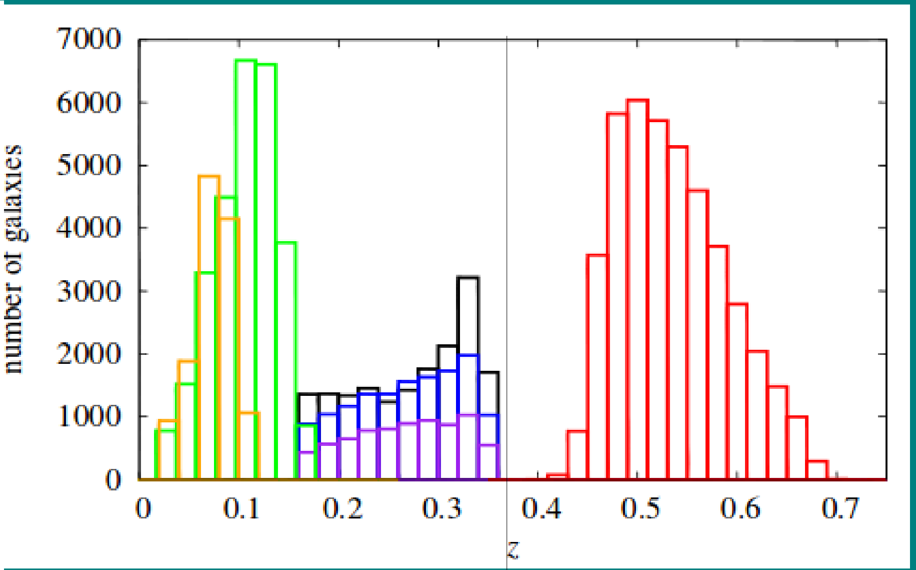
$$\gamma^I = -\frac{C_1}{4\pi G}(\nabla_x^2 - \nabla_y^2, 2\nabla_x\nabla_y)\mathcal{S}[\Psi_P]$$

Blazek+ (2011), Okumura & Jing (2009)

Status of observations



Joachimi+ (2011)



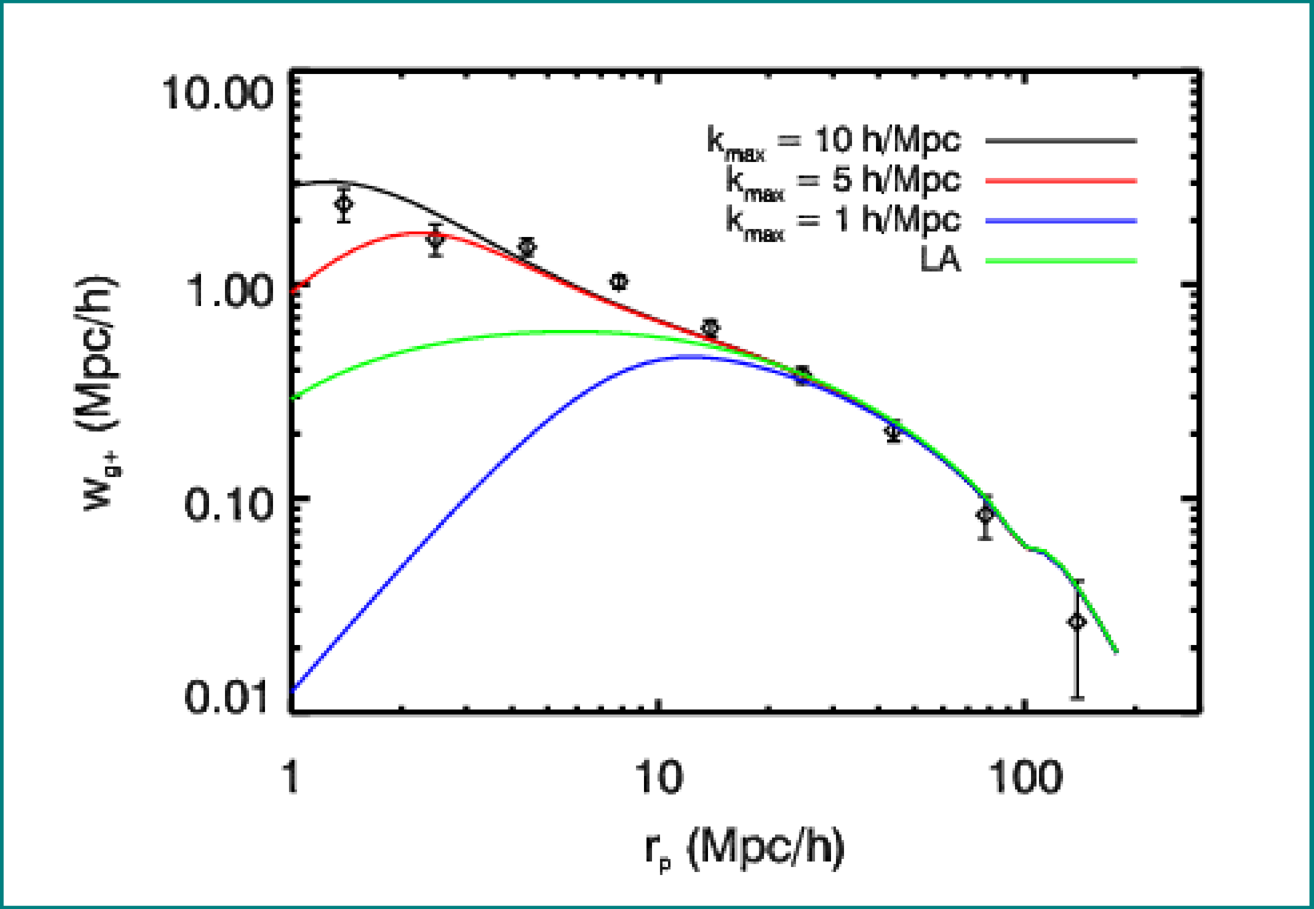
Blazek+ (2011), Okumura & Jing (2009)

Joachimi+ (2011) MegaZ-LRGs Photo-z calibrated from 2SLAQ

The strength of alignment and the smoothing scale

$$\gamma^I = -\frac{C_1}{4\pi G}(\nabla_x^2 - \nabla_y^2, 2\nabla_x\nabla_y)\mathcal{S}[\Psi_P]$$

$$\mathcal{S}(k) = \exp[-(3k/k_{\rm max})^2]$$



Measured g+ correlation function from Okumura & Jing (2009)

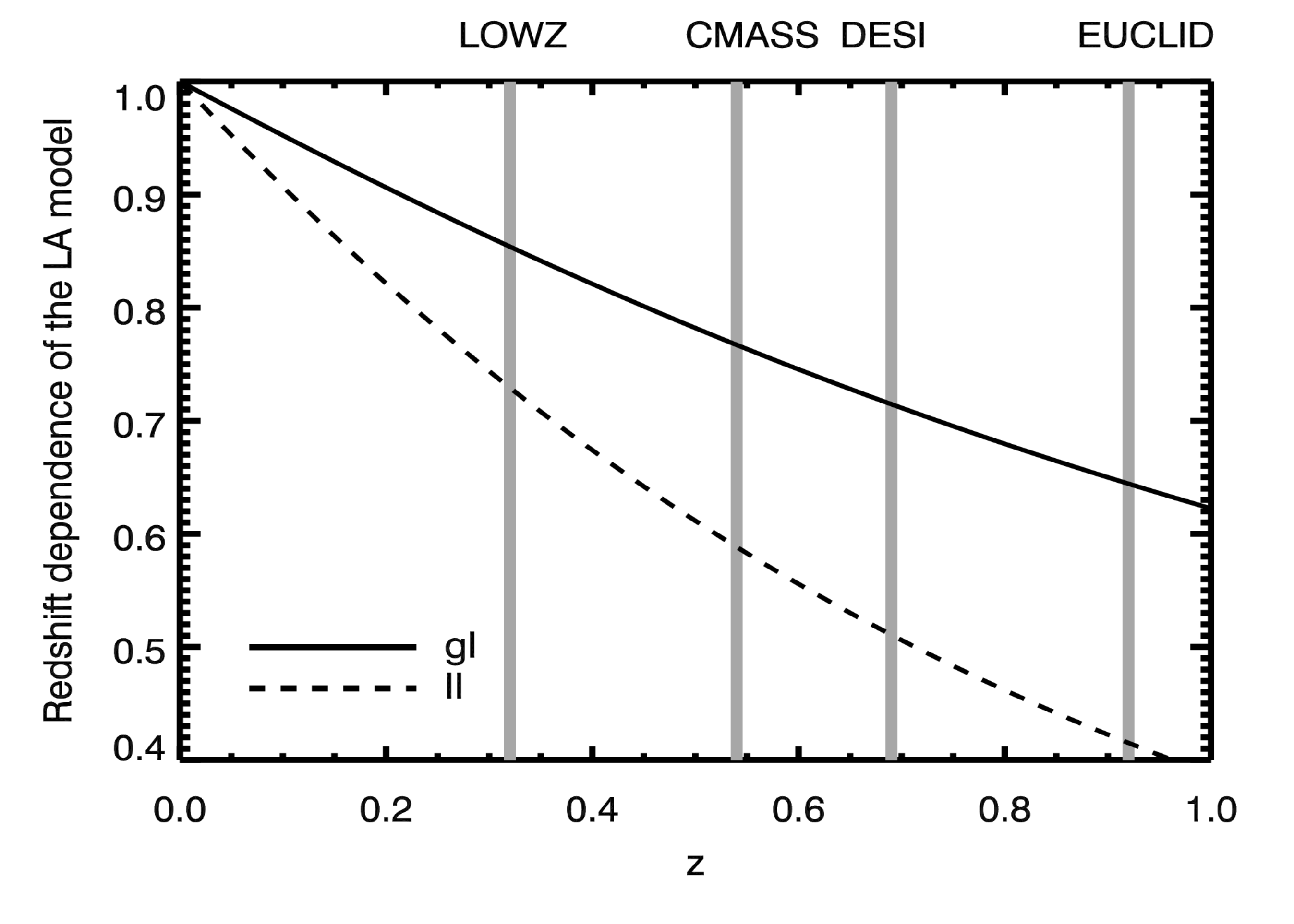
SDSS LRGs DR6
0.15 < z < 0.5

Chisari & Dvorkin, submitted

The epoch of alignment

When are alignments imprinted?

Instantaneous vs. Primordial alignment



Current surveys

Baryon Oscillations Spectroscopic Survey (BOSS)

LOWZ, 0.2<z<0.4

CMASS, 0.43<z<0.7

Upcoming surveys

DESI (2018)

0.1<z<1.1

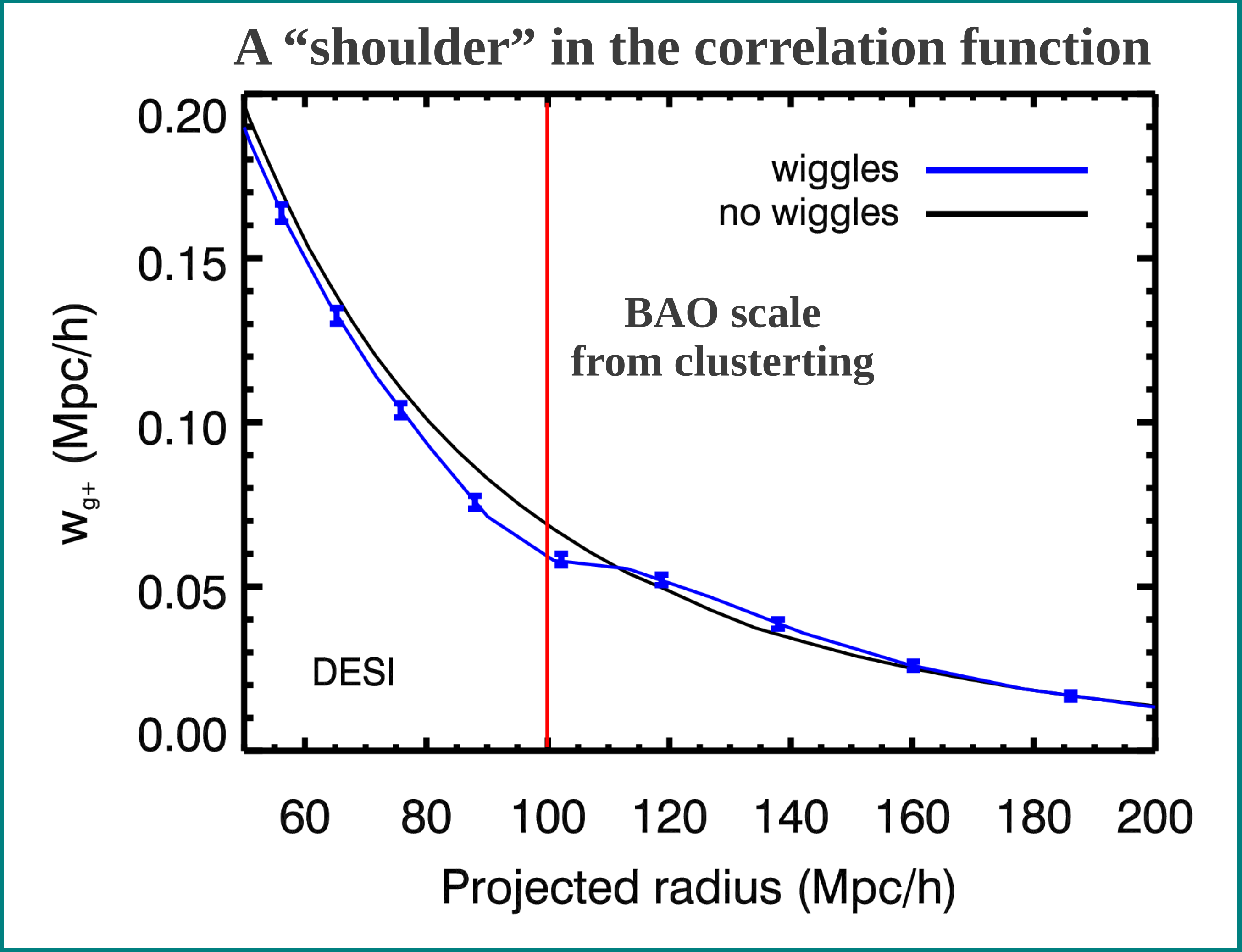
EUCLID (2020)

0.5<z<1.5

At the current level of uncertainty, these models *cannot be distinguished.*

Chisari & Dvorkin, submitted

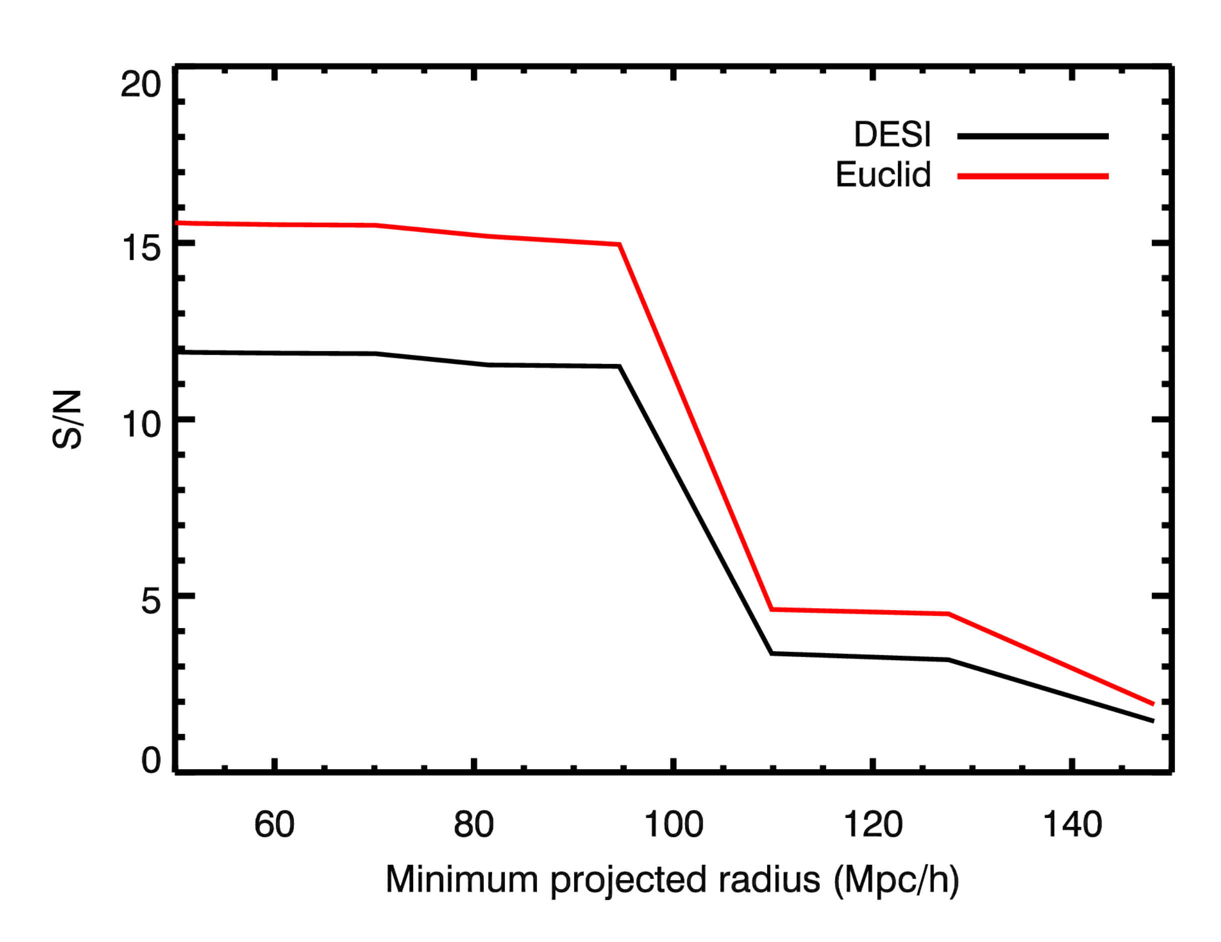
Baryon Acoustic Oscillations



Chisari & Dvorkin, submitted

Baryon Acoustic Oscillations

S/N for BAO detection
Integrated in $[r_p, 200\ \mathrm{Mpc}/h]$



DESI: S/N ~ 12
Euclid: S/N ~ 15

CMASS: S/N ~ 2.2
LOWZ: S/N ~ 1.8

No incidence of cosmic variance at these scales *except for LOWZ*.

Chisari & Dvorkin, submitted

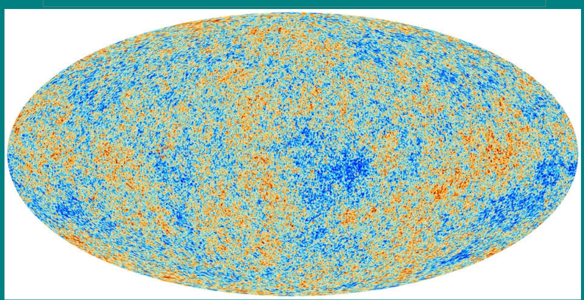
Primordial non-Gaussianity

Non-gaussian primordial potential

$$\Phi(\mathbf{x}) = \Phi_L(\mathbf{x}) + f_{\rm NL}(\Phi_L^2(\mathbf{x}) - \langle\Phi_L^2(\mathbf{x})\rangle)$$

A detection of f_{NL} would rule out simple models of single-field inflation

Constraints on f^{loc}_{NL}



Planck XXIV (2013)

f^{loc}_{NL} =2.7 ± 5.8 (68%CL)

Expected Euclid constraints $\Delta f^{loc}_{NL} \sim 2$ (2020)

Primordial non-gaussianity leads to scale dependent bias

Dalal+(2008)

$$P_{\rm observed}(k) = [b + \Delta b(k, f_{\rm NL})]^2 P_{\rm lin}(k)$$

$$\Delta b(k) = \frac{3(b_1 - 1) f_{\rm NL} \Omega_m H_0^2 \delta_c}{D(z) k^2 T(k)}$$

Primordial non-Gaussianity

Position-shape correlations

$$w_{g+}^{NG}(r_p) = \int dz \mathcal{W}(z) \frac{1}{\pi^2} \frac{C_1 \rho_{\rm crit} \Omega_M}{D(z)} \int_0^\infty dk_z \int_0^\infty dk_\perp \frac{k_\perp^3}{(k_\perp^2 + k_z^2) k_z} P_s(\mathbf{k}, z) \sin(k_z \Pi_{\rm max}) J_2(k_\perp r_p)$$
$$\times \left[b + \Delta b(k,z) + \frac{3 b^2 f_{NL} H_0^2 \Omega_M (1+z)}{2\pi^2} \int_0^\infty dk_{1z} \int_0^\infty dk_{1\perp} k_{1\perp} \frac{P_s(\mathbf{k}_1, z)}{k_1^2} \right]$$

Non-Gaussian bias
Dalal et al, (2008)

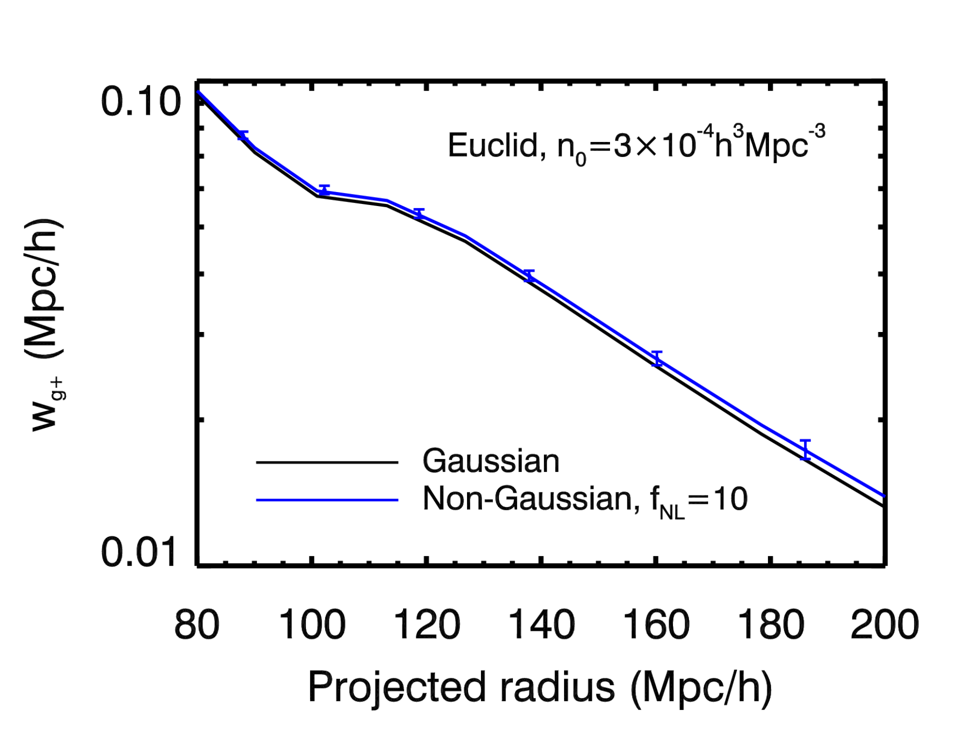
$$\Delta b(k,z) = 3 f_{NL} (b-p) \frac{\delta_c \Omega_M}{k^2 T(k) D(z)} \frac{H_0^2}{c^2}$$

Sampling the tidal shears at the position of galaxies.

$$\tilde{\gamma}^I(\mathbf{k}, z) = \int d^3\mathbf{k}_1 \gamma^I(\mathbf{k} - \mathbf{k}_1, z) \left[\delta^{(3)}(\mathbf{k}_1) + \frac{b}{(2\pi)^3} \delta_{\rm lin}(\mathbf{k}_1, z) \right]$$

Chisari & Dvorkin, submitted

Primordial non-Gaussianity



EUCLID forecast

LRGs in the range
0.5<z<1.5
20,000 deg^2

$f_{NL}=10$ from intrinsic alignments yields S/N~1.7 in EUCLID.

Survey	LOWZ		CMASS		DESI	EUCLID	
	DR10	DR12	DR10	DR12		$n_0 = 3\times10^{-4}h^3\mathrm{Mpc}^{-3}$	$n_0 = 4\times10^{-4}h^3\mathrm{Mpc}^{-3}$
With cosmic variance	<0.1	0.11	0.14	0.17	0.95	1.7	1.8
Without cosmic variance	0.26	0.33	0.20	0.24	1.3	2.1	2.5

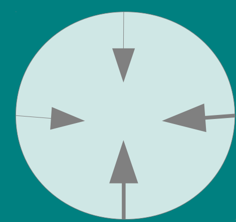
Chisari & Dvorkin, submitted

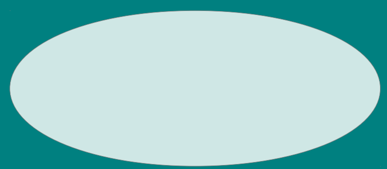
Redshift space distortions

Kaiser effect

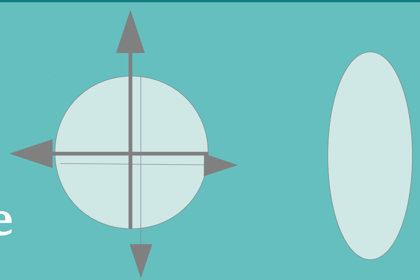
Real space **Redshift space**

Collapsing region
in the linear **regime**





Fingers-of-God:
Collapsing region
in the nonlinear **regime**

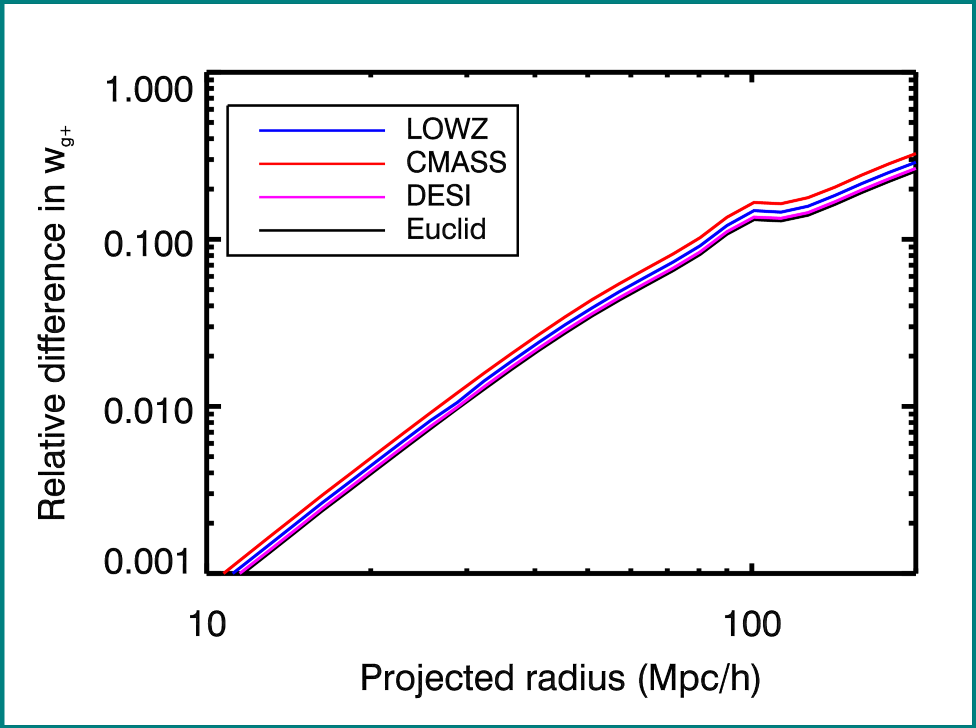


$$P_s(k,z) = P_r(k,z)\left[1+\beta\left(\frac{k_z}{k}\right)^2\right]^2$$

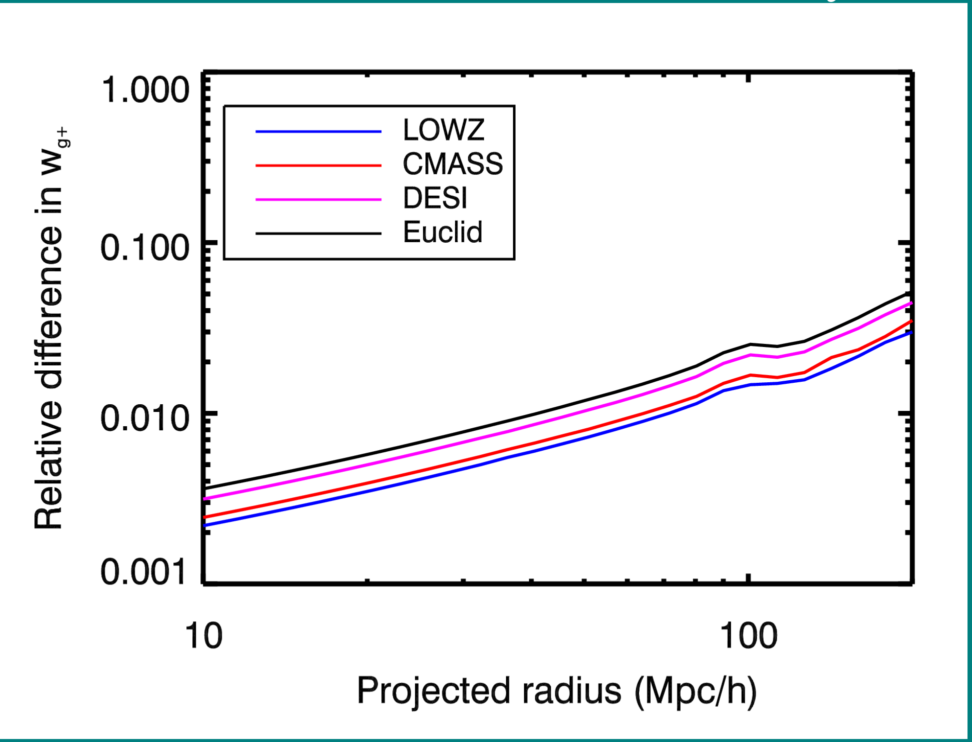
$$\beta = \Omega_m^{0.55}/b$$

Redshift space distortions

Linear Kaiser effect



Primordial non-Gaussianity



On large scales, RSDs **mimic** the non-Gaussianity signal.
They need to be taken into account.

Chisari & Dvorkin, submitted

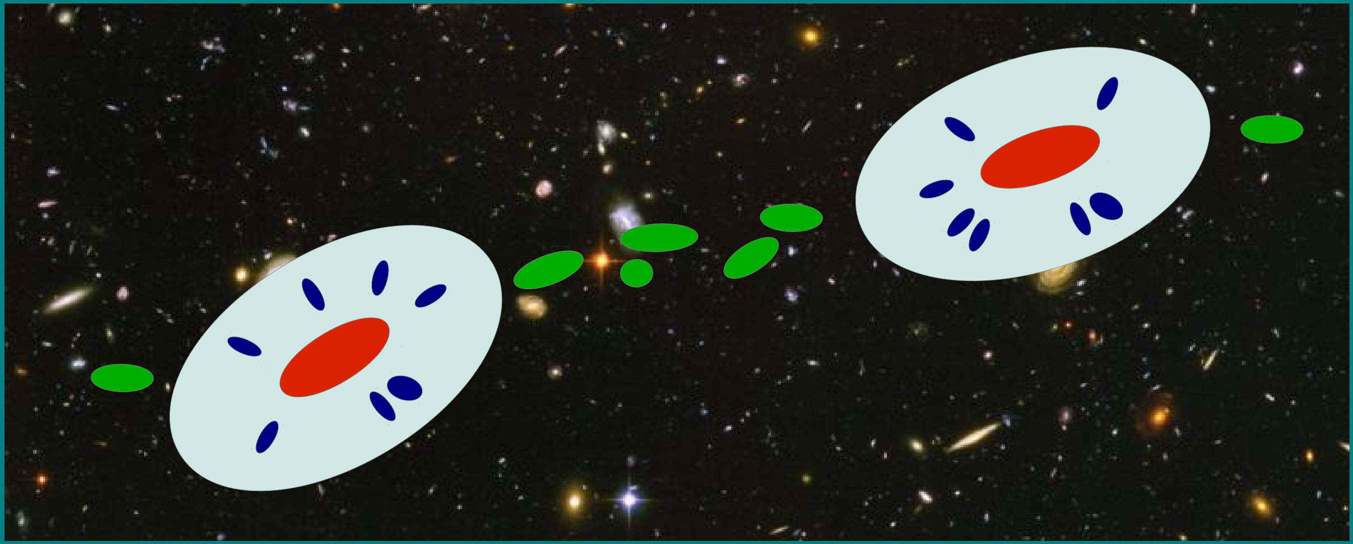
Lessons from the linear regime

- **Intrinsic alignments of LRG are** consistent with the LA/NLA model.
- **We can** test the IA model **through its redshift and scale dependence. We ultimately need simulations to understand the coupling of the baryons to the tidal field.**
- **Intrinsic alignments are not only a major contaminant of cosmic shear measurements. They can add** cosmological information.
- Constrains on the BAO scale **could be achieved from IA alone in future surveys.**

Alignments of cluster galaxies
Constraining the non-linear regime

Chisari, Mandelbaum, Strauss, Huff & Bahcall, in prep.

Status of observations



Cluster-galaxy alignments

Ciotti & Dutta (1994)
Schneider & Bridle (2010)

Pereira & Kuhn (2005)
Hao et al. (2011)
Siverd et al.(2009)
Schneider et al. (2012)

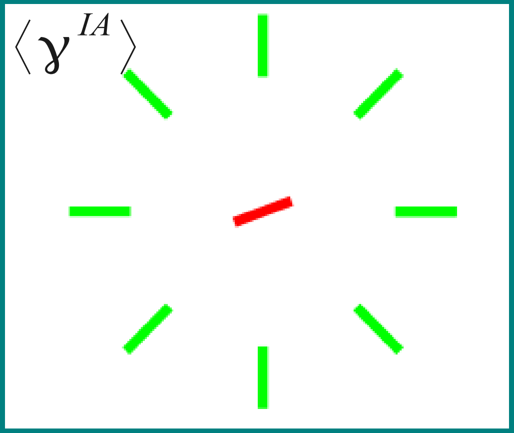
Alignment of satellite galaxies marginally detected but detection *depends on the method used to determine shapes.*

Do satellites align? Does the alignment bias cluster mass estimates?

Separating IA and cluster-gxy lensing

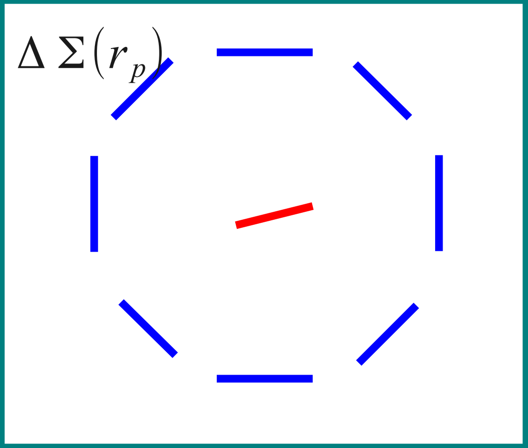
Weak lensing vs. intrinsic alignments

The average radial shear around a lens



Intrinsically aligned galaxies at the redshift of the central galaxy and physically associated with it

The surface mass density profile of the cluster

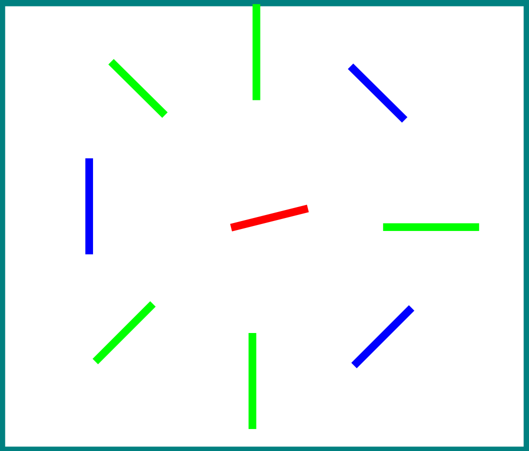


Lensed galaxies behind the central galaxy

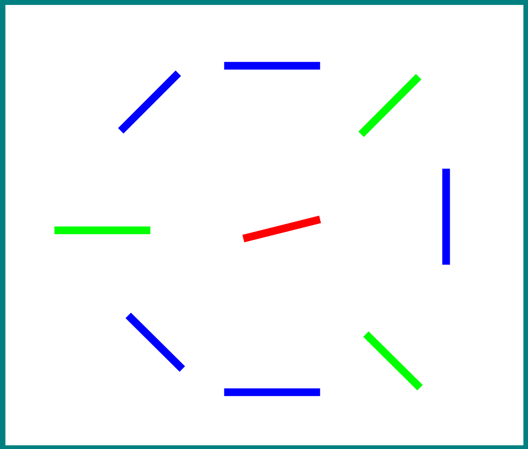
Separating IA and cluster-gxy lensing

The effect of photometric redshifts

The intrinsic uncertainty in the photometric redshift of the galaxy leads to **cross-contamination** between galaxies lensed, behind the lens, and galaxies intrinsically aligned with the lens and physically associated with it.



contamination



What we think is ASSOCIATED with the lens

What we think is BEHIND the lens

Previous work:

Separating intrinsic alignment and galaxy-galaxy lensing, Blazek et al. (2013)

Separating IA and cluster-gxy lensing

The ingredients

- A sample of **lenses**. In our case, galaxy clusters.

  Geach et al. (2011), 3000 clusters in 0.1<z<0.4 on Stripe 82

- Galaxies with measured **shapes** behind the lenses.

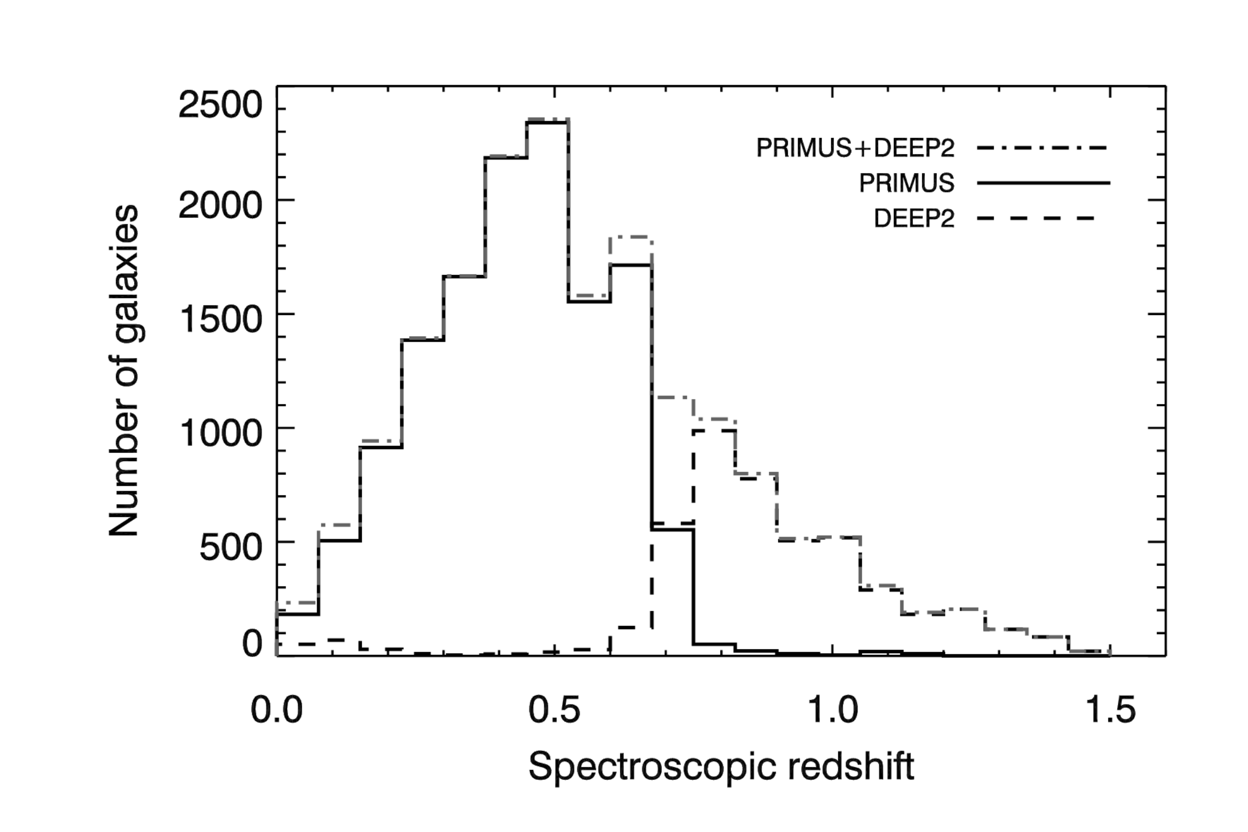
  Shapes from Huff et al. (2011), i and r, 2.2 galaxies arcmin^{-2}

- **Distances** to lenses and to galaxies: *P(z)* distributions.

- A **calibration sample** of galaxies with accurate distance estimates to define a prior for the *P(z)* calculation and to estimate the contamination from cluster-galaxy lensing.

Application to Stripe 82

Calibration of photometric redshifts



DEEP2+PRIMUS
Complete to R<23.3
Area ~1.25 deg^2
~18000 galaxies

We use the publicly available code, ZEBRA, to obtain photometric redshift posteriors.

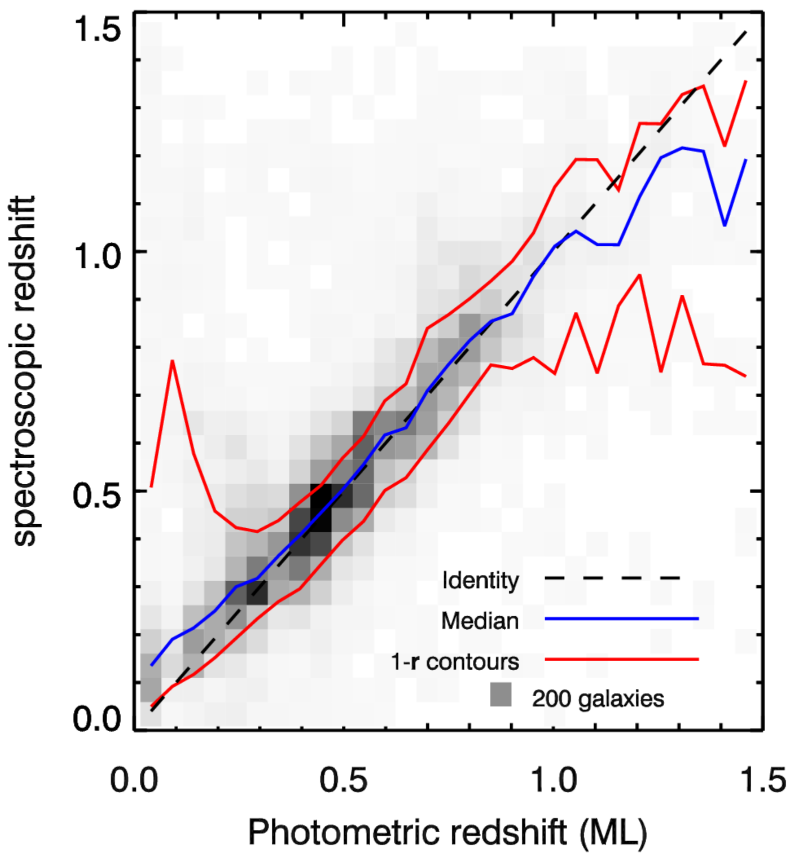
Feldmann et al. (2008)
Newman et al.(2012)
Coil et al. (2011)
Nakajima et al. (2012)

Application to Stripe 82

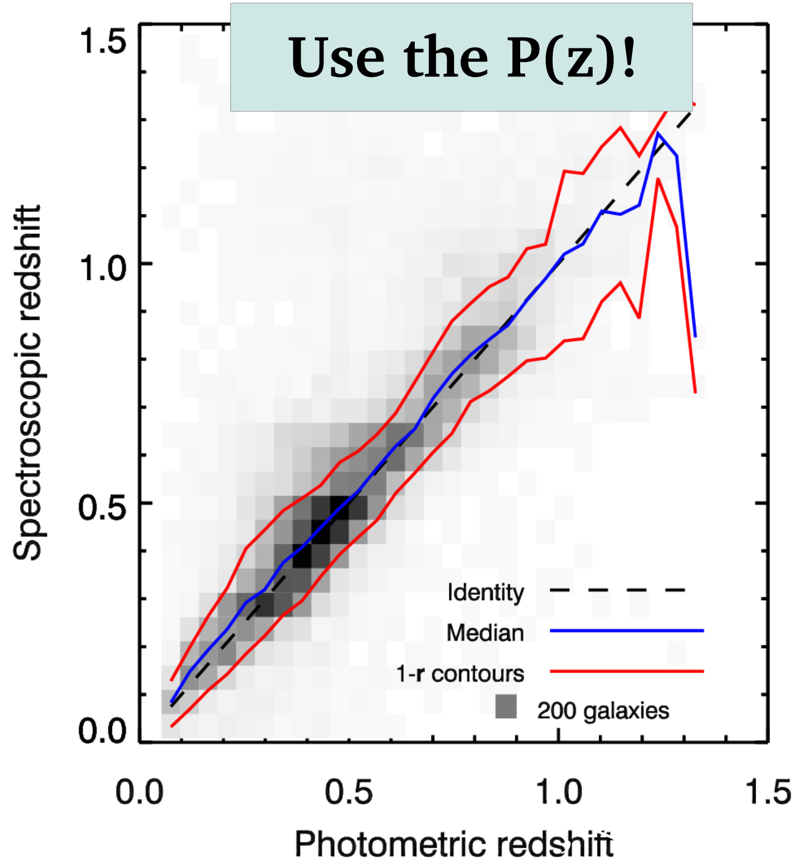
Calibration of photometric redshifts

Maximum of the *likelihood*

(similarly for maximum of the *posterior*)



Average over the posterior



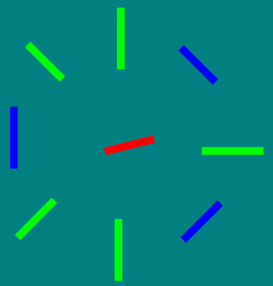
The formalism

Galaxies **associated** with the lens

$$\int_{z_{\rm min}}^{z_{\rm max}} P(z)dz \rightarrow \int_{z_L-\Delta z}^{z_L+\Delta z} P(z)dz$$

Galaxies **behind** the lens

$$\int_{z_{\rm min}}^{z_{\rm max}} P(z)dz \rightarrow \int_{z_L+\Delta z}^{z} P(z)dz$$



Sum over all galaxies in a radial bin around the stacked lenses

$$\frac{\sum_j^{\rm lens} w_j^{\rm IA} \int_{z_L-\Delta z}^{z_L+\Delta z} P_j(z)dz\gamma_j}{\sum_j^{\rm lens} w_j^{\rm IA} \int_{z_L-\Delta z}^{z_L+\Delta z} P_j(z)dz} = \gamma_a^{\rm IA} + \gamma_{b\to a}^{\rm G}$$

$$\frac{\sum_j^{\rm lens} w_j^{\rm IA} \int_{z_L+\Delta z}^{z_{\rm max}} P_j(z)dz\gamma_j}{\sum_j^{\rm lens} w_j^{\rm IA} \int_{z_L+\Delta z}^{z_{\rm max}} P_j(z)dz} = \cancel{\gamma_{a\to b}^{\rm IA}} + \gamma_b^{\rm G}$$

This allows us to **separate:** $\langle \gamma^{IA} \rangle$ from $\Delta\Sigma(r_p)$

The formalism

The **lensing signal** of galaxies behind the lens

Projected surface mass density

$$\Delta\Sigma^{\rm stack}(r_p) = \frac{\sum_j^{\rm lens} w_j^{\rm IA} \int_{z_L+\Delta z}^{z_{\max}} P_j(z) dz \gamma_j}{\sum_j^{\rm lens} w_j^{\rm IA} \int_{z_L+\Delta z}^{z_{\max}} P_j(z) dz \Sigma_{j,c}^{-1}}$$

Construct the **intrinsic alignment signal**:

$$\gamma_a^{\rm IA} = \frac{\sum_j^{\rm lens} w_j^{\rm IA} \int_{z_L-\Delta z}^{z_L+\Delta z} P_j(z) dz \gamma_j}{\sum_j^{\rm lens} w_j^{\rm IA} \int_{z_L-\Delta z}^{z_L+\Delta z} P_j(z) dz} - \Delta\Sigma^{\rm stack}(r_p) \frac{\sum_j^{\rm rand} w_j^{\rm IA} \int_{z_L-\Delta z}^{z_L+\Delta z} P_j(z) dz \Sigma_{j,c}^{-1}}{\sum_j^{\rm lens} w_j^{\rm IA} \int_{z_L-\Delta z}^{z_L+\Delta z} P_j(z) dz}$$

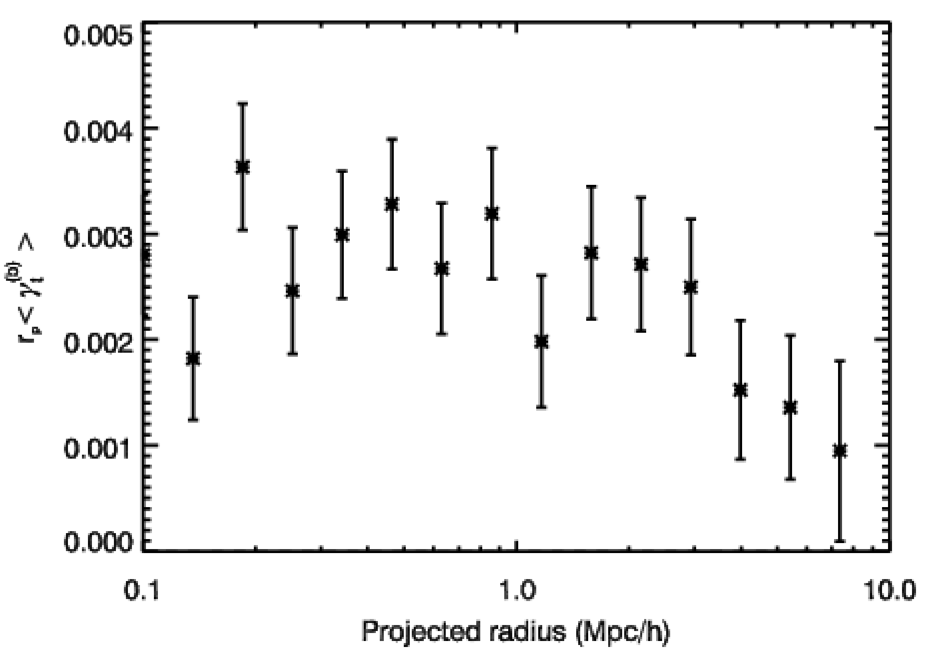
True lensing efficiency x Probability of being at the cluster redshift.
Calibration using the spectroscopic redshifts.

Application to Stripe 82

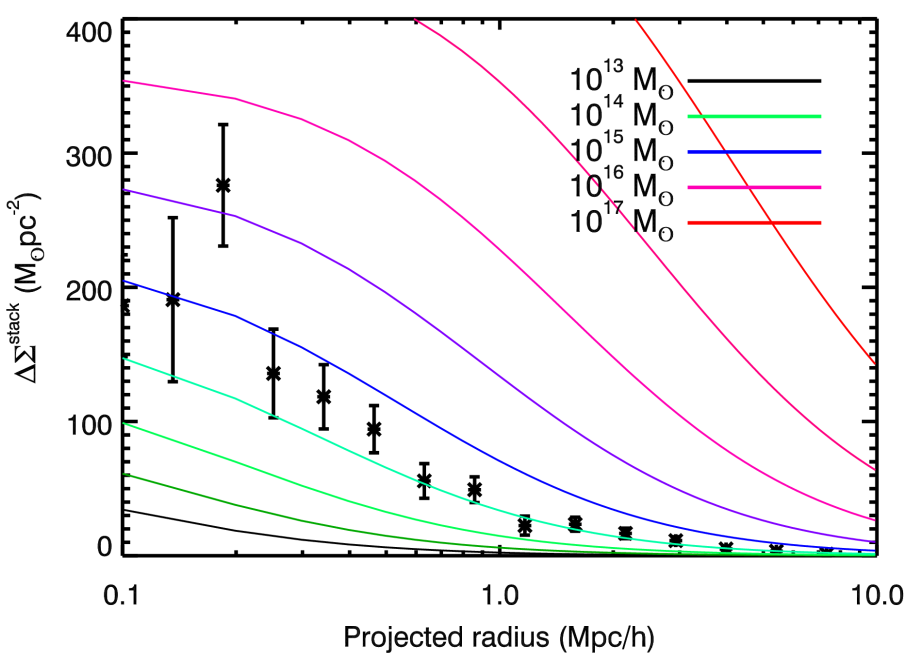
*The **lensing contamination***

Fraction of the total shear behind the lens that contaminates the total shear at the lens redshift for $\Delta z = 0.2$ is

$$\frac{\sum_j^{\rm lens} \tilde{w}_j^{\rm IA} \int_{z_L-\Delta z}^{z_L+\Delta z} \tilde{P}_j(z) dz \Sigma_{j,c}^{-1}}{\sum_j^{\rm lens} \tilde{w}_j^{\rm IA} \int_{z_L+\Delta z}^{z_{\rm max}} \tilde{P}_j(z) dz \Sigma_{j,c}^{-1}} \simeq 0.2$$

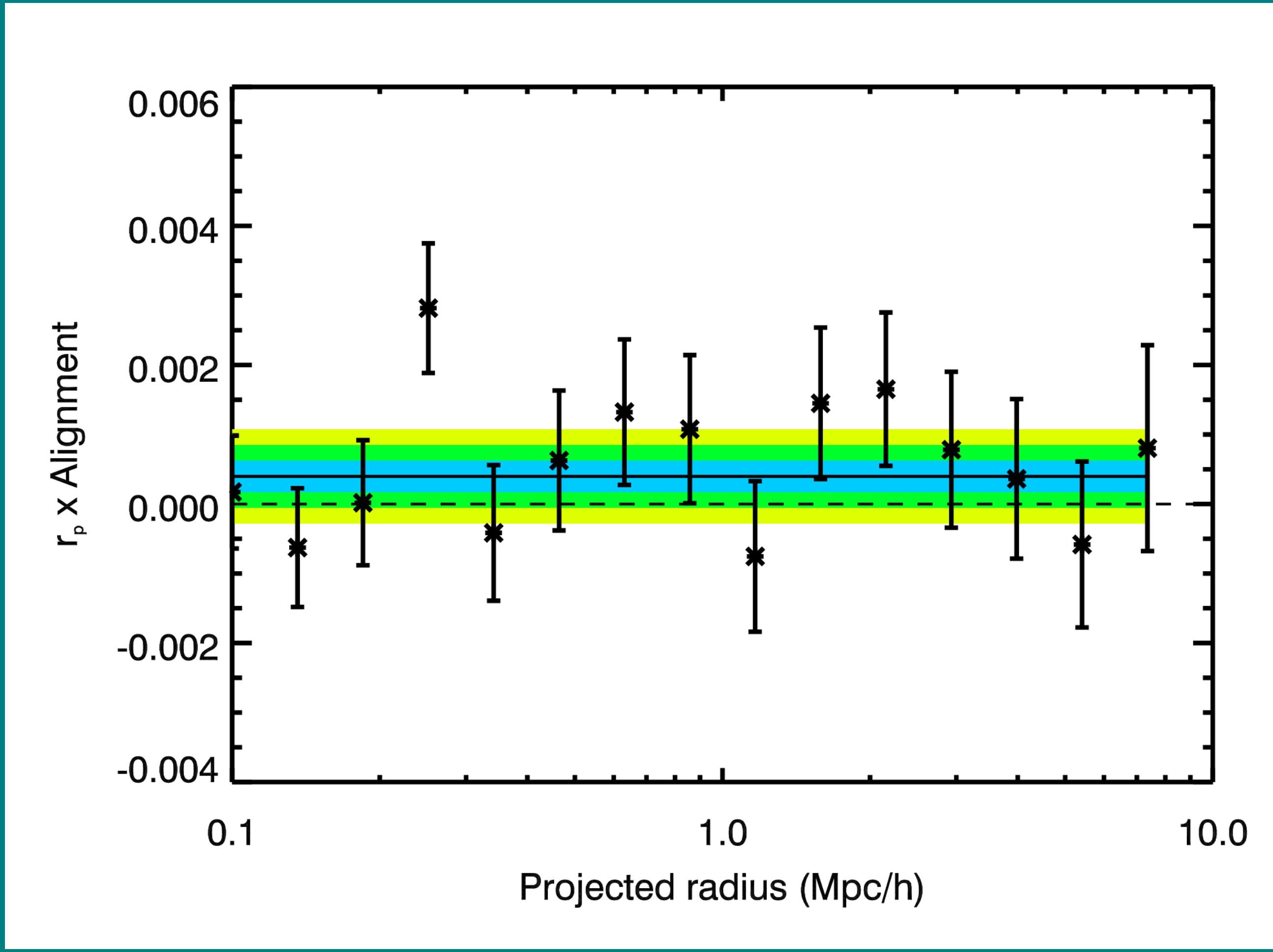


Calibration using the spectroscopic redshifts.



Application to Stripe 82

No detection of alignment of cluster galaxies.
i-band shapes



Similar results hold for:

- ***r*-band shapes**
- **restricting to high richness clusters**
- **centering on the geometrical center of the clusters**

Conclusions & future work

- Intrinsic alignments are a **contaminant** to galaxy-galaxy and cluster-galaxy lensing measurements, but they also provide information on the **cluster tidal field and its assembly.**

- We have applied a formalism to **measure intrinsic alignments of cluster galaxies** (extensible to galaxy-galaxy lensing) making use of ***P(z)* distributions** for separating the alignment and lensing signals.

- We looked for alignments around Stripe 82 clusters up to z~0.4. Preliminary results show that our alignment signal is **consistent with 0** around clusters on scales between 100 kpc/h and 10 Mpc/h.

- In future work, we will focus on *isolating cluster members* through color cuts.

Thank you.