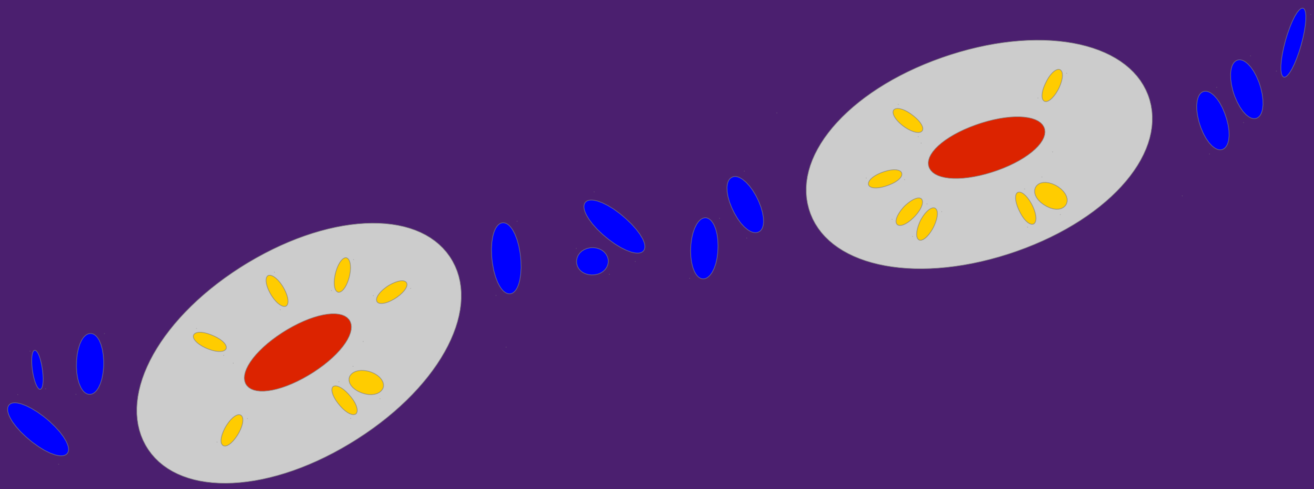
Intrinsic alignments: hydro-simulations & cosmology



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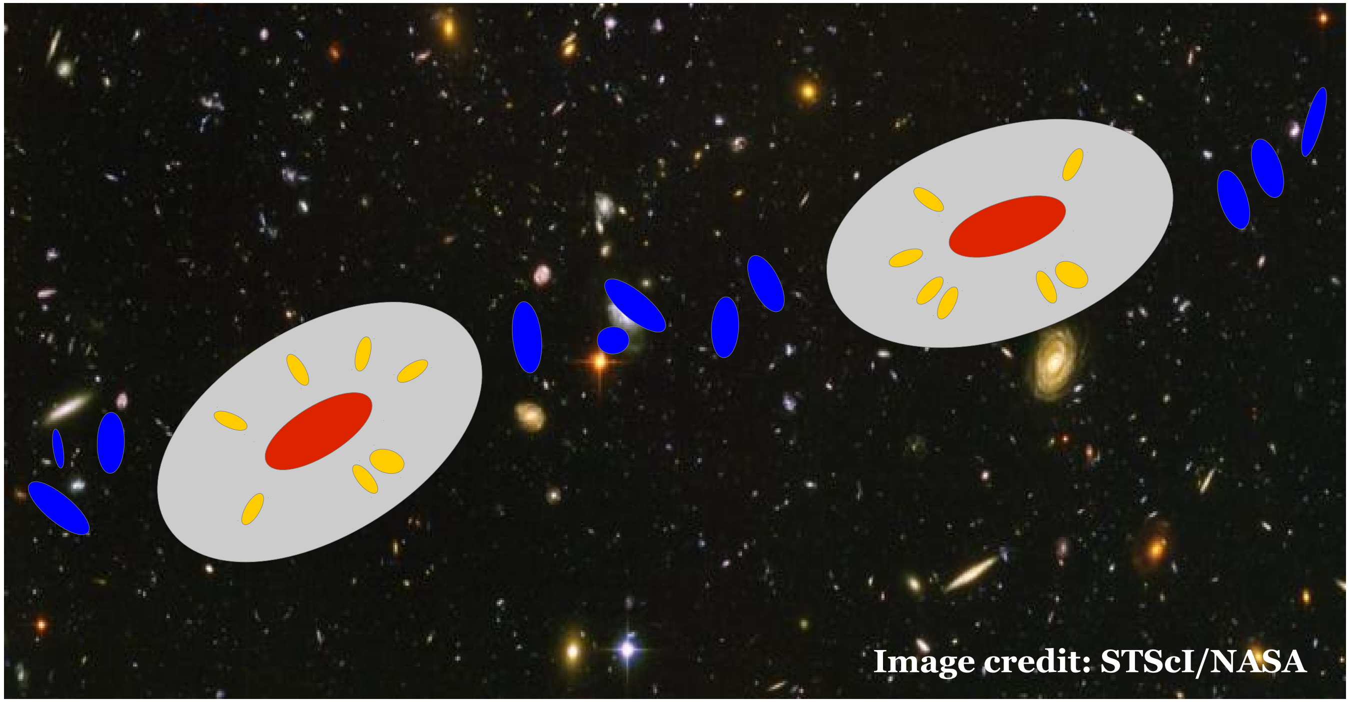
July 24, 2015

with F. Schmidt (MPA), C. Dvorkin (Harvard), S. Codis, C. Laigle, R. Gavazzi, C. Pichon, Y. Dubois, K. Benabed (IAP), L. Miller, J. Devriendt, A. Slyz (Oxford)

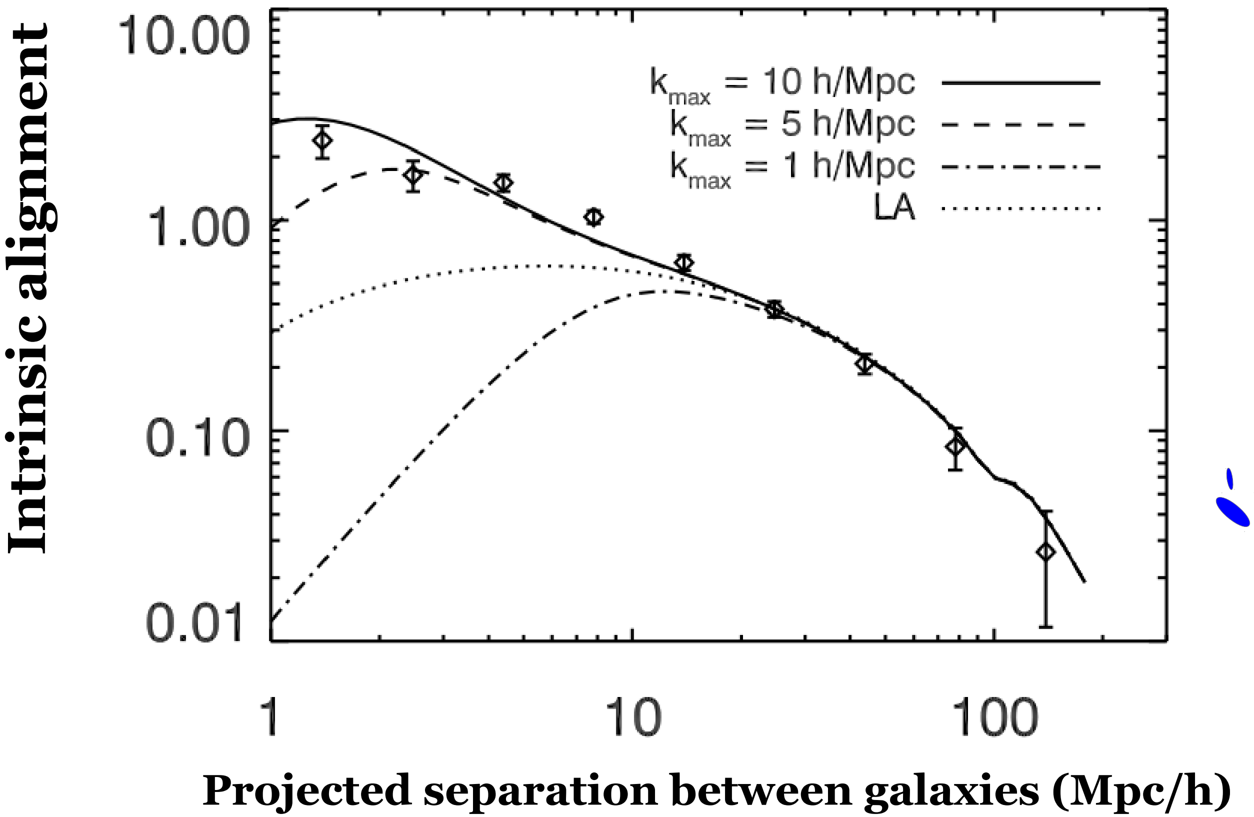
Intrinsic galaxy shape correlations



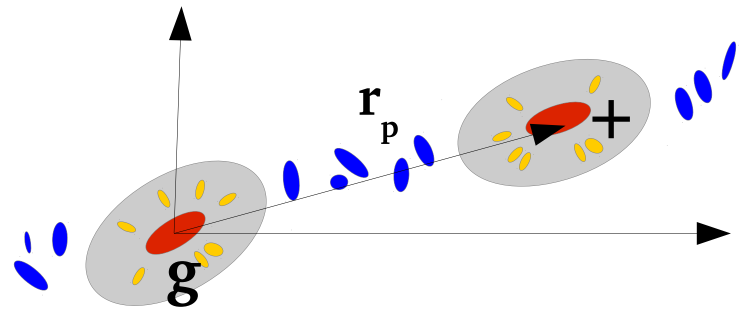
- A dark matter halo, a cluster of galaxies
- The central galaxy in the halo
- A satellite galaxy
- Galaxies along filaments connecting clusters

Current observations

Chisari & Dvorkin (2013)



Observed alignments
Okumura & Jing (2009)



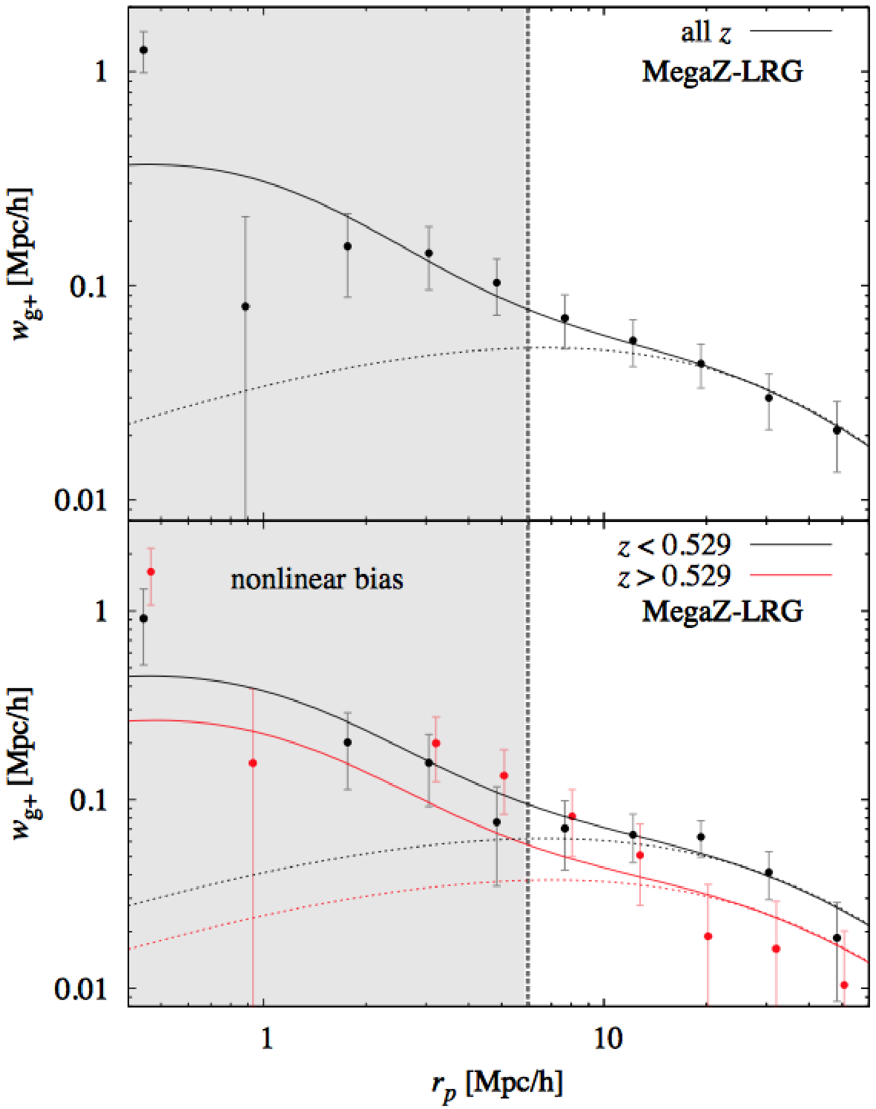
- Red galaxies preferentially point towards each other.

- Blue galaxies show no shape alignment.

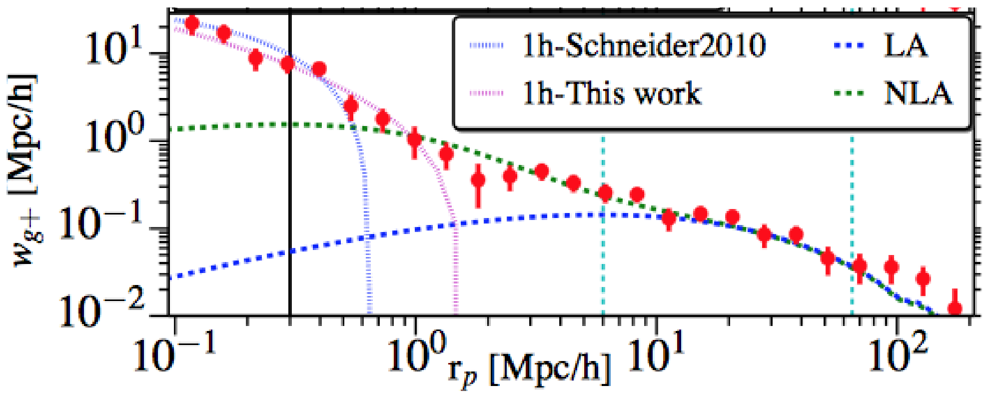
Okumura & Jing (2009)
Blazek et al. (2011)
Chisari & Dvorkin (2013)

Current observations

Joachimi et al. (2011)

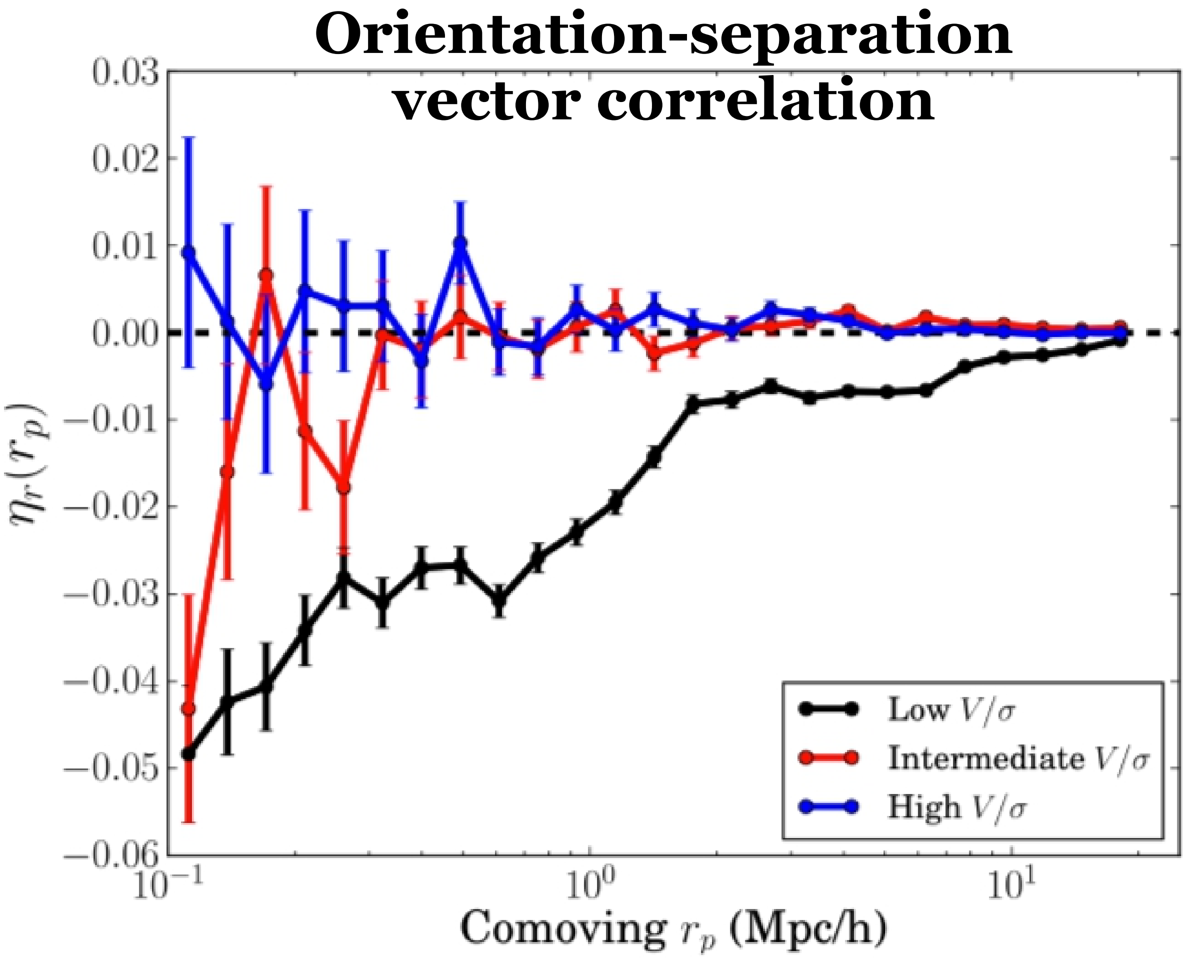


Singh et al. (2014)



Early-type galaxies show radial alignments across a large range of scales. On linear scales, the tidal alignment model provides a good description of the data.

Alignments in Horizon-AGN



Ellipticals point towards other ellipticals

Spirals oriented randomly around other spirals

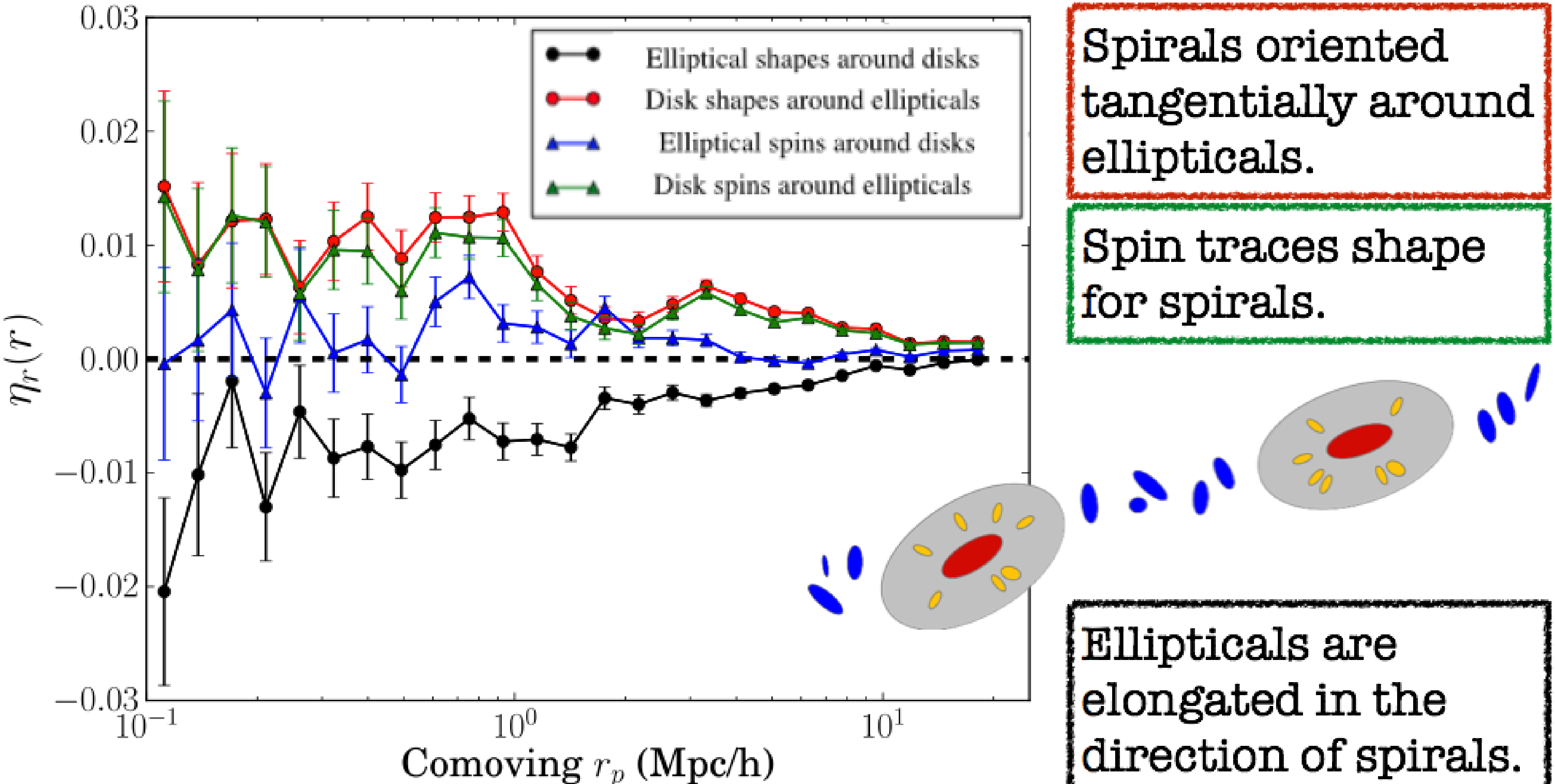
Correlations persist to large scales.

Chisari+, in prep

See also: Tenneti+ (2014), Velliscig+ (2015), Codis+ (2015)

Alignments in simulations

Evidence for two mechanisms for alignments



Spirals oriented tangentially around ellipticals.

Spin traces shape for spirals.

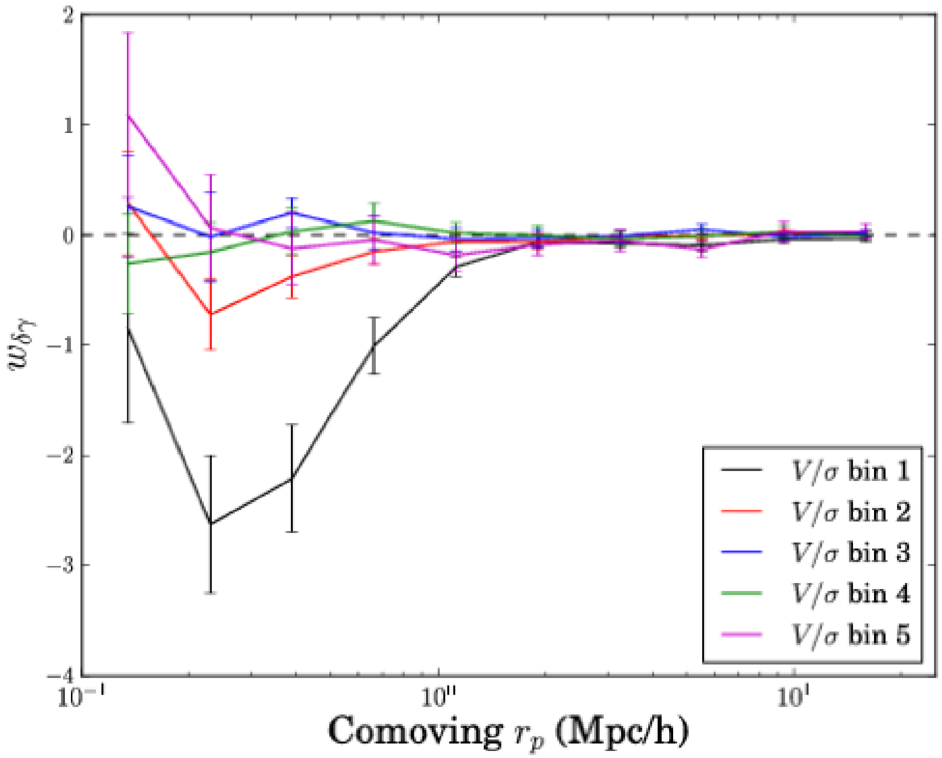
Ellipticals are elongated in the direction of spirals.

Chisari+, in prep

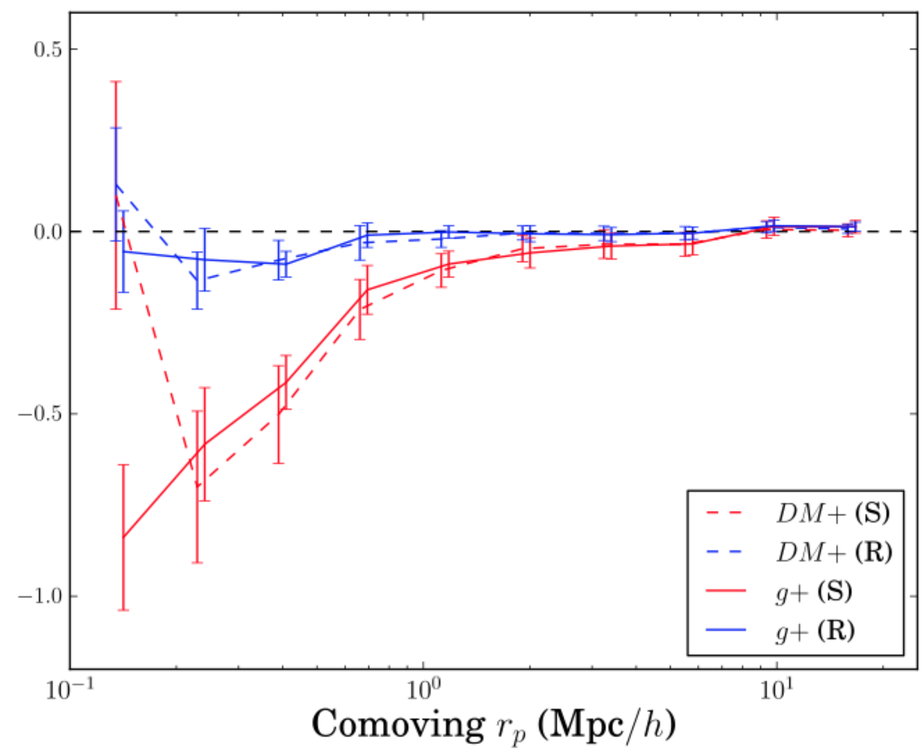
Alignments in simulations

Projected correlations for alignments

Red galaxies have random stellar motions and carry most of the alignment signal.



Monotonous trend with dynamics (or color), but not mass.

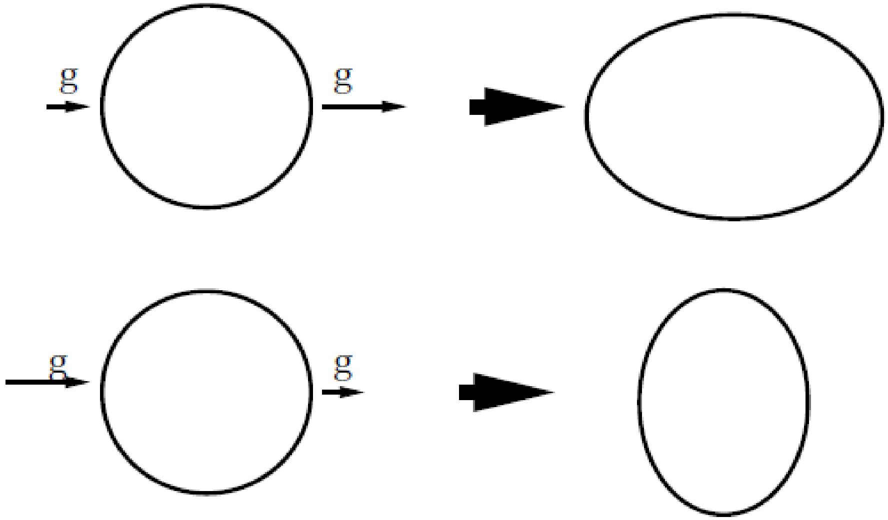


Shape measurement method matters

Chisari+, in prep

Tidal alignment model

The **tidal alignment model gives a good approximation** to the observed intrinsic alignments of Luminous Red Galaxies.



"intrinsic shear"

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

Catelan+ (2001)

- Shapes are imprinted at formation
- Model is valid on linear scales
- C_1 is a free parameter to be constrained from observations

See also: **halo model** (Schneider & Bridle, 2010)
perturbation theory approach (Blazek +, 2015)

Cosmology with intrinsic alignments

Theoretical model in place
(at least on the large scales!)

→ **CONSTRAIN COSMOLOGY**

Catelan et al. (2001)

1) Baryon acoustic oscillations.

Chisari & Dvorkin (2013), astro-ph: 1308.5972

2) Primordial gravitational waves from inflation.

Chisari, Dvorkin & Schmidt (2014), astro-ph: 1406.4871

3) Testing theories of inflation.

Schmidt, Chisari & Dvorkin (2015), astro-ph: 1506.02671

Cosmology with intrinsic alignments

Theoretical model in place
(at least on the large scales!)

→ **CONSTRAIN COSMOLOGY**

Catelan et al. (2001)

3) Testing theories of inflation.

Schmidt, Chisari & Dvorkin (2015), astro-ph: 1506.02671

Cosmology with intrinsic alignments

Anisotropic inflation

In these models, the amplitude of the squeezed-limit bispectrum of the curvature perturbation depends on the angle between vectors in Fourier space:

$$B_\phi(\mathbf{k}_L, \mathbf{k}_S, \mathbf{k}_S) = f(\hat{\mathbf{k}}_L \cdot \hat{\mathbf{k}}_S)\, P_\phi(k_L) P_\phi(k_S)$$ *squeezed-limit bispectrum*

$$f(\mu) = \sum_{L=0,2,4,\cdots} A_L \mathcal{P}_L(\mu)$$ *angular dependence*

Examples

- Solid inflation predicts $A_2 \gg A_0$ (Endlich+, 2012)
- Primordial large-scale magnetic fields (Shiraishi+, 2013)
- Additional degrees of freedom during inflation (Arkani-Hamed & Maldacena, 2015)

Planck constraints $A_2 = 13 \pm 93$ **(68% CL)**

Scale-dependent alignment bias from anisotropic inflation

Alignment model – Gaussian Universe

$$\langle \delta(\mathbf{k}) g_{ij}(\mathbf{k}') \rangle = b_1^I \left(\frac{k_i k_j}{k^2} - \frac{1}{3}\delta_{ij} \right) P_m(k) \, (2\pi)^3 \delta_D(\mathbf{k} + \mathbf{k}')$$

Schmidt, Chisari & Dvorkin (2015)

Scale-dependent alignment bias from anisotropic inflation

Alignment model – Gaussian Universe

$$\langle \delta(\mathbf{k}) g_{ij}(\mathbf{k}') \rangle = b_1^I \left(\frac{k_i k_j}{k^2} - \frac{1}{3}\delta_{ij} \right) P_m(k)\,(2\pi)^3 \delta_D(\mathbf{k}+\mathbf{k}')$$

Alignment model – anisotropic non-Gaussian Universe

$$\langle \delta(\mathbf{k}') g_{ij}(\mathbf{k}) \rangle = \left(\frac{k_i k_j}{k^2} - \frac{1}{3}\delta_{ij} \right) \left\{ b_1^I + 3 b_{\rm NG}^I A_2\,\mathcal{M}^{-1}(k) \right\} P_m(k)\,(2\pi)^3 \delta_D(\mathbf{k}+\mathbf{k}')$$

Schmidt, Chisari & Dvorkin (2015)

Scale-dependent alignment bias from anisotropic inflation

Alignment model – Gaussian Universe

$$\langle\delta(\mathbf{k})g_{ij}(\mathbf{k}')\rangle = b_1^I\left(\frac{k_ik_j}{k^2}-\frac{1}{3}\delta_{ij}\right)P_m(k)\,(2\pi)^3\delta_D(\mathbf{k}+\mathbf{k}')$$

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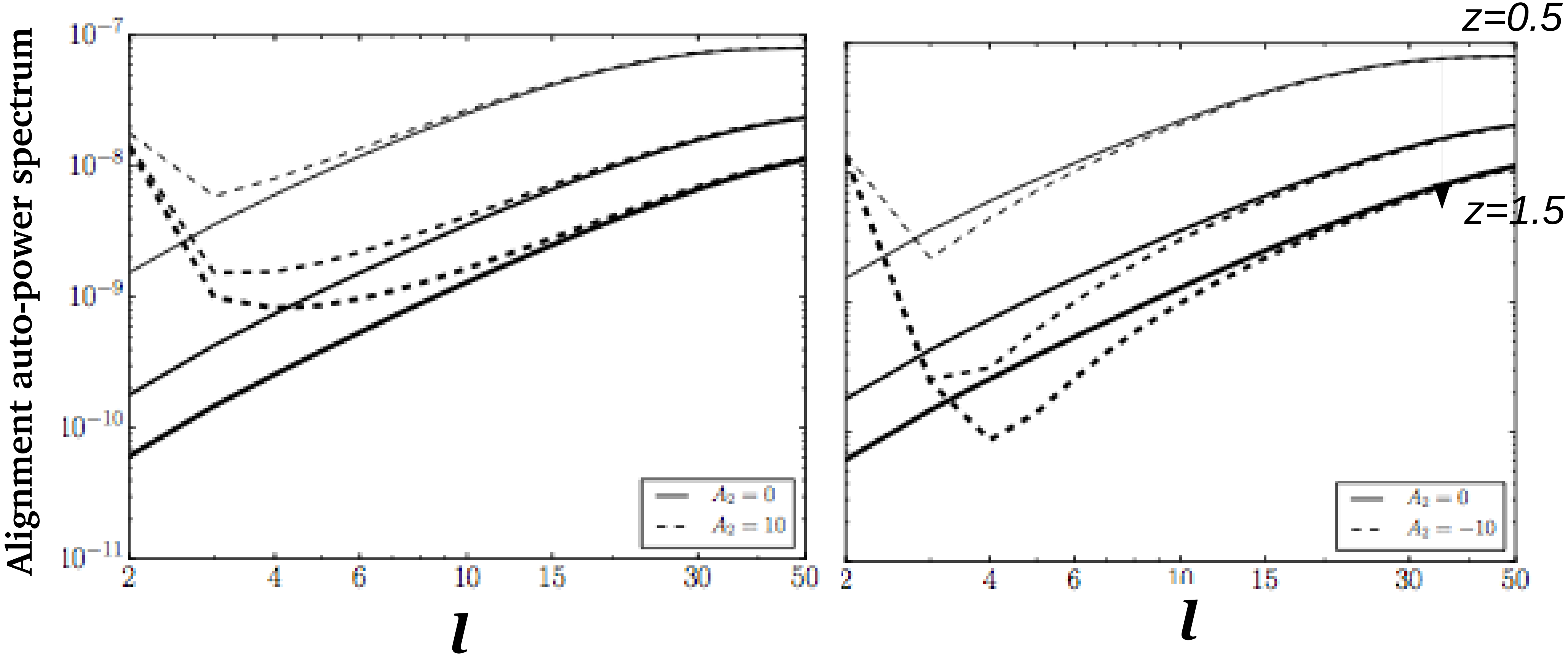
Analogy with non-Gaussian bias of tracers (Dalal+,2008)

$$\langle\delta(\mathbf{k}')\delta_n(\mathbf{k})\rangle = \left\{b_1^n+2\,b_{\rm NG}^n f_{NL}\,\mathcal{M}^{-1}(k)\right\}P_m(k)\,(2\pi)^3\delta_D(\mathbf{k}+\mathbf{k}')$$

Schmidt, Chisari & Dvorkin (2015)

Anisotropic inflation and intrinsic alignments

Physics of the early Universe imprints its signature in the alignments of galaxies through a scale-dependent bias on galaxy shapes



Schmidt, Chisari & Dvorkin (2015)

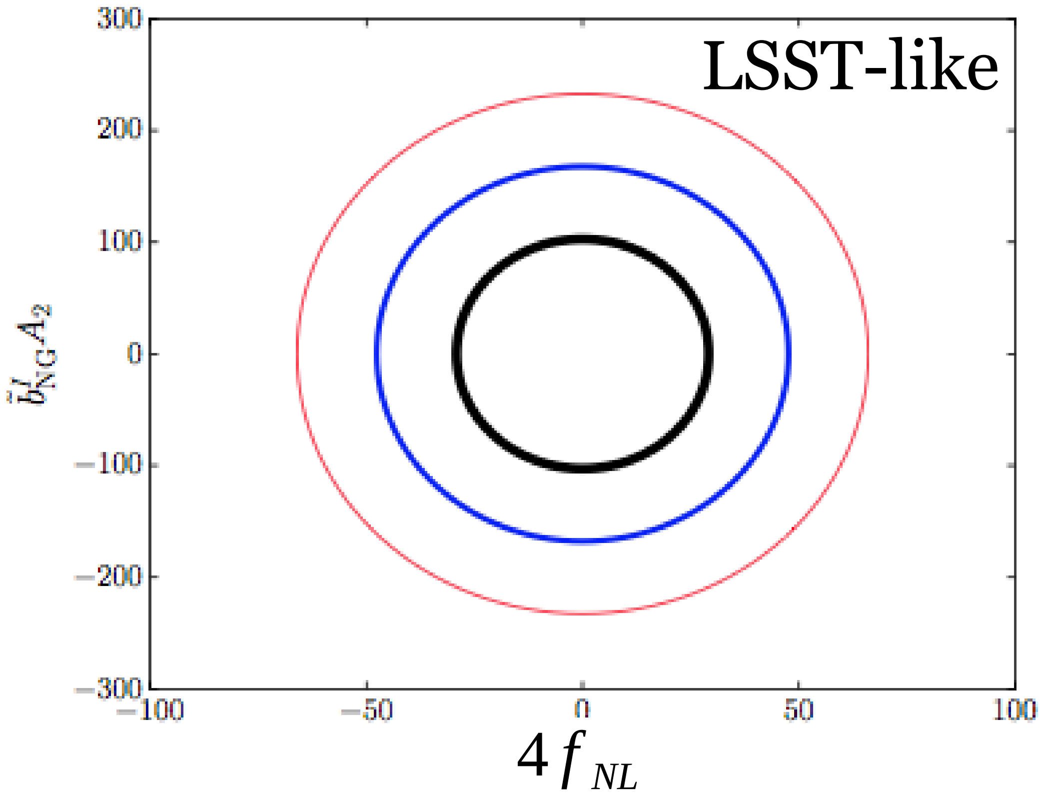
Forecast: Clustering + position-shape + auto-shape

(f_{NL}) (f_{NL}, A_2) (A_2)

Schmidt, Chisari & Dvorkin (2015)

Cosmology with intrinsic alignments

Forecast: Clustering + position-shape + auto-shape



- Potential constraints from an LSST-like survey are comparable to current CMB constraints.
- Degeneracy with f_{NL} is lifted by adding clustering.
- Dependence on sensitivity of shapes to tidal field ("shape bias")

Planck constraints $A_2 = 13 \pm 93$ **(68% CL)**

Schmidt, Chisari & Dvorkin (2015)

Conclusions

- **Intrinsic alignments have been observed** in the Universe. Observed alignments of **Luminous Red Galaxies** are consistent with galaxies being stretched by the **tidal field** of the large-scale structure.

- **Hydrodynamical simulations show evidence of two mechanisms for alignments**, which will give us insights into galaxy formation processes that lead to alignments and will allow us to quantify their contamination to lensing.

- **Anisotropic inflation induces a scale-dependent bias on galaxy shapes**, similar to the scale-dependent bias that arises from f_{NL} (Dalal+, 2008).

- In the future, alignments **may probe the physics of the early Universe** in novel ways, where clustering or lensing cannot reach.

Thank you.

Schmidt, Chisari & Dvorkin (2015), astro-ph: 1506.02671
Chisari+, in prep (Hz-AGN)

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