# Intrinsic Alignments with BOSS

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Work done with

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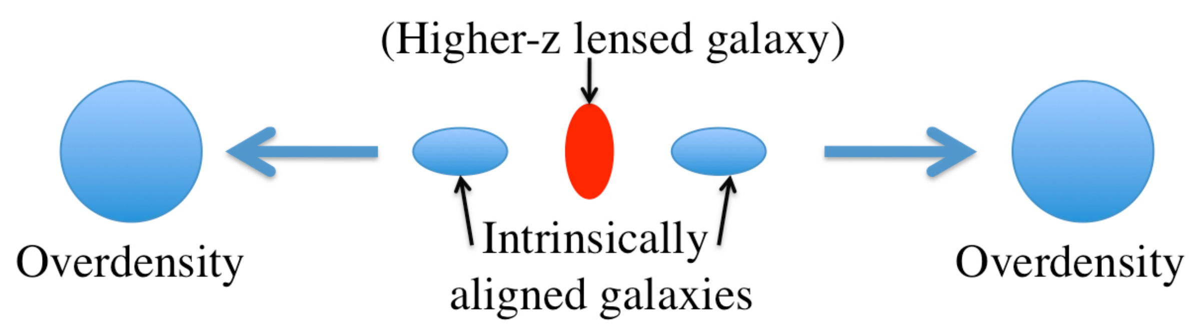
# Outline

- IA Overview
- Modeling
- Estimators
- Measurements
- IA effects on RSD measurements

# Intrinsic alignments overview




Galaxy Shapes are aligned with the matter distribution

**Biases the weak lensing measurements using galaxy shear**

**Can bias galaxy clustering measurements**

**(Hirata 2009, S. Singh+ 2020)**

# Modeling

- NLA model: IA is proportional to the Tidal field during the time of galaxy formation.

$$\gamma^I \propto \text{Tidal Field}$$

Hirata & Seljak+ 2004

- TATT model: We only observe IA at galaxy positions, a correction for the galaxy density weighting.

$$\gamma^I_{measured} \propto \text{Tidal Field} \times (1 + \delta_g)$$

Blazek+ 2015

- Halo model: Similar to NLA. A prescription for alignments between galaxy shapes and tidal fields. Can account for effects such as luminosity dependence, satellite alignments, etc.

Schneider+ 2010,
Fortuna+ 2020

# NLA Model

Writing Tidal alignment as function of matter field

$$\gamma_+ \propto \frac{k_x^2 - k_y^2}{k^2} \delta_m$$

Power spectra for galaxy X IA

$$P_{g+}(\vec{k}, z) = A_I b \frac{C_1 \rho_{\mathrm{crit}} \Omega_m}{D(z)} \frac{k_x^2 - k_y^2}{k^2} P_\delta \ (\vec{k}, z)$$

# NLA Model

## Multipole expansion

$$P_{g+}(\vec{k}, z) = A_I b \frac{C_1 \rho_{\text{crit}} \Omega_m}{D(z)} \frac{k_x^2 - k_y^2}{k^2} P_\delta (\vec{k}, z)$$

Spin-2 Field
Expand using spin harmonics

# NLA Model

## Multipole expansion

$$P_{g+}(\vec{k}, z) = A_I b \frac{C_1 \rho_{\rm crit} \Omega_m}{D(z)} \frac{k_x^2 - k_y^2}{k^2} P_\delta (\vec{k}, z)$$

Spin-2 Field
Expand using spin harmonics

## Only Quadrupole in real space

$$P_{g+} \propto (1 - \mu^2) P_\delta \propto \frac{1}{3} L_{2,2} P_\delta$$

Associated
Legendre polynomial

# NLA Model

## Multipole expansion

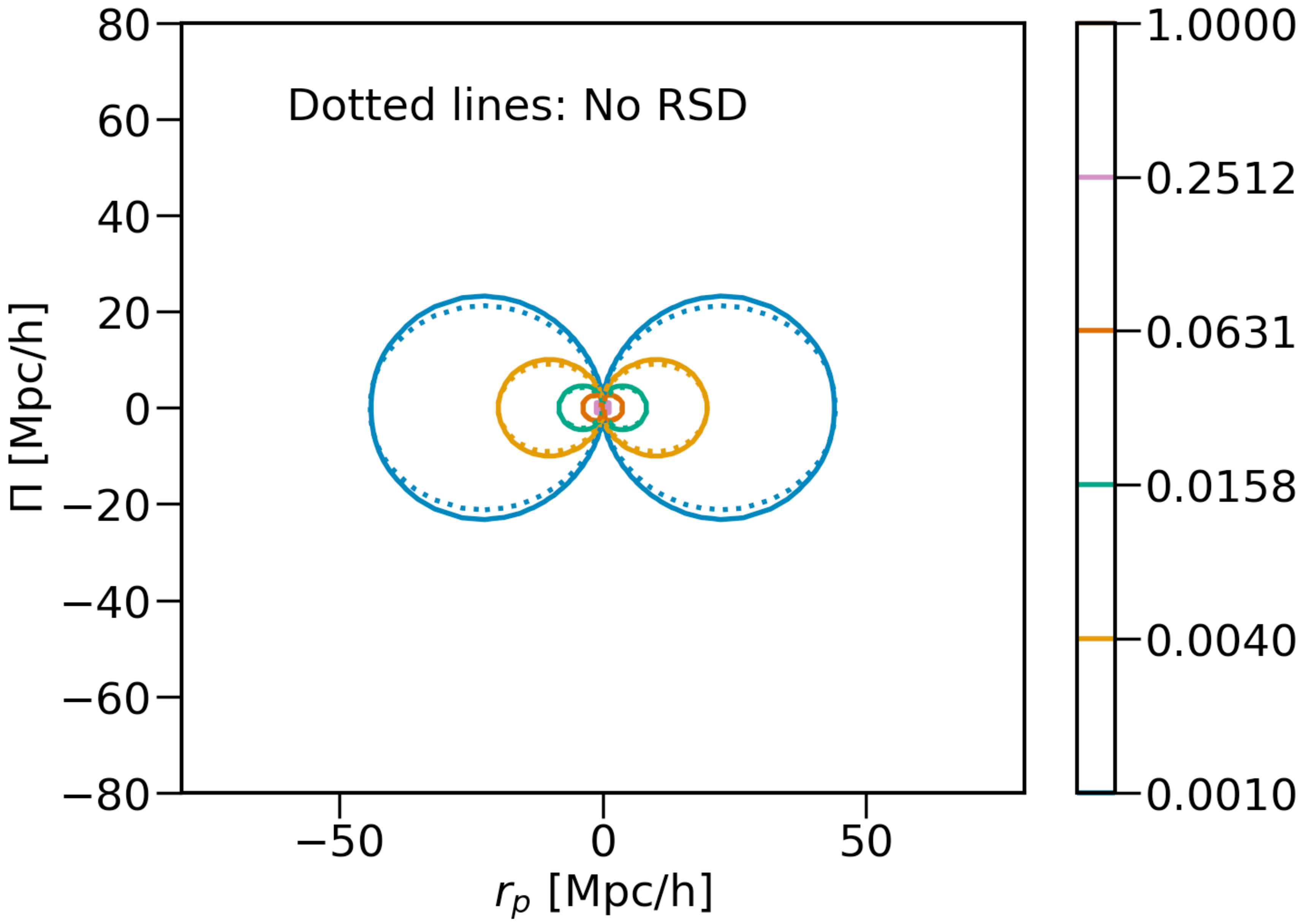
$$P_{g+}(\vec{k}, z) = A_I b \frac{C_1 \rho_{\rm crit} \Omega_m}{D(z)} \frac{k_x^2 - k_y^2}{k^2} P_\delta^{\rm lin}(\vec{k}, z)$$

Spin-2 Field
Expand using spin harmonics

## Quadrupole + Hexadecapole in redshift space

$$P_{g+} \propto (1-\mu^2)(1+\beta_g \mu^2) P_\delta \propto \left( \frac{1}{3}(1+\beta_g/7) L_{2,2} + \frac{2}{105} \beta_g L_{4,2} \right) P_\delta$$

# NLA Model



Dotted lines: No RSD
80
60
40
20
0
−20
−40
−60
−80
Π [Mpc/h]
−50
0
50
$r_p$ [Mpc/h]
1.0000
0.2512
0.0631
0.0158
0.0040
0.0010

# Estimators

## Landy-Szalay estimator

$$\xi_{g+} = \frac{S_+D - S_+R_D}{R_SR_D}$$

## Projected correlation function

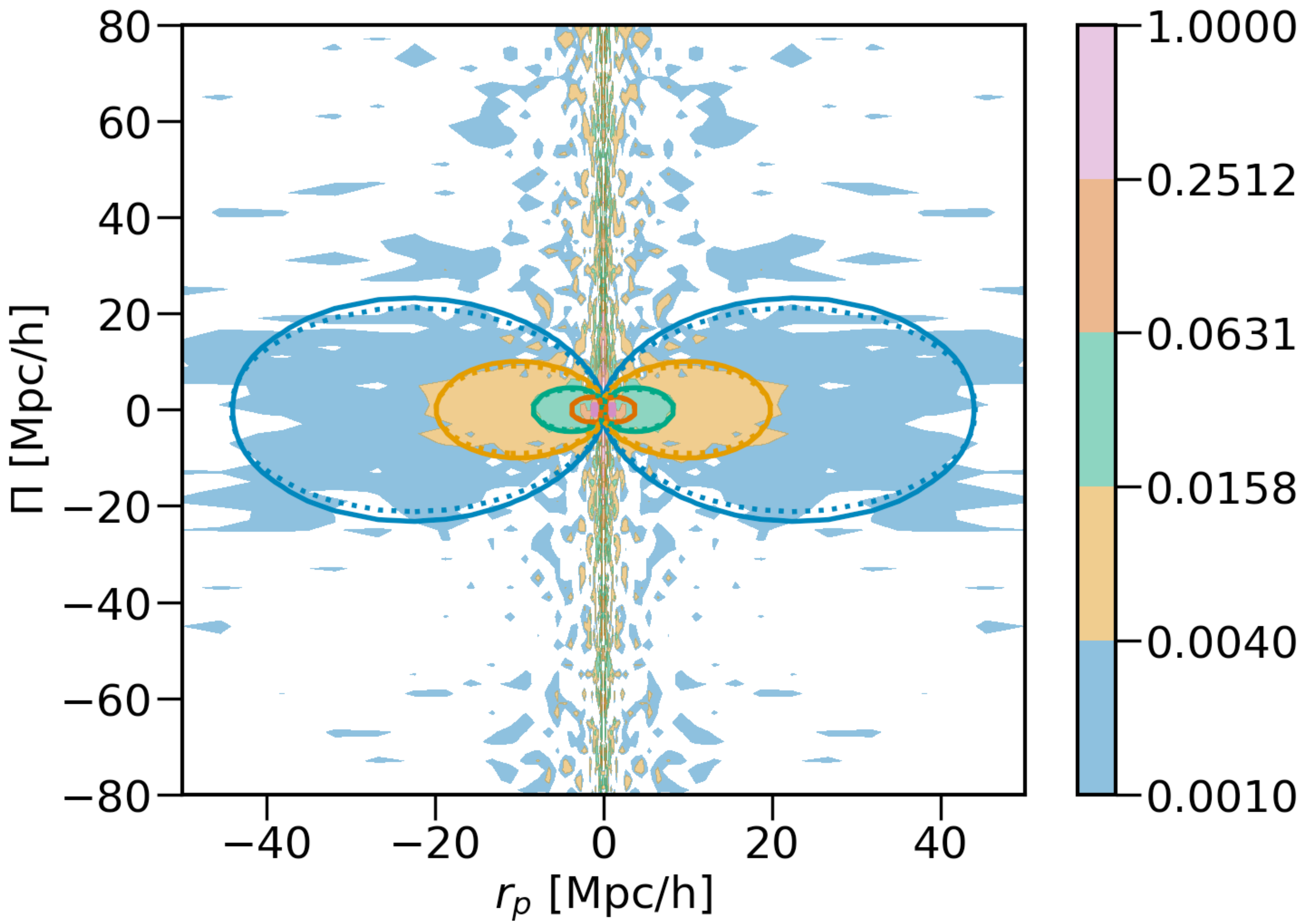
$$w_{ab} = \int_{-\Pi_{\rm max}}^{\Pi_{\rm max}} \xi_{ab}(r_p, \Pi) {\rm d}\Pi.$$

## Multipoles

$$\xi_{\ell,s}(r) = \frac{2\ell+1}{2}\frac{(\ell-s)!}{(\ell+s)!}\int d\mu L_{\ell,s}(\mu)\xi(\mu,r)$$

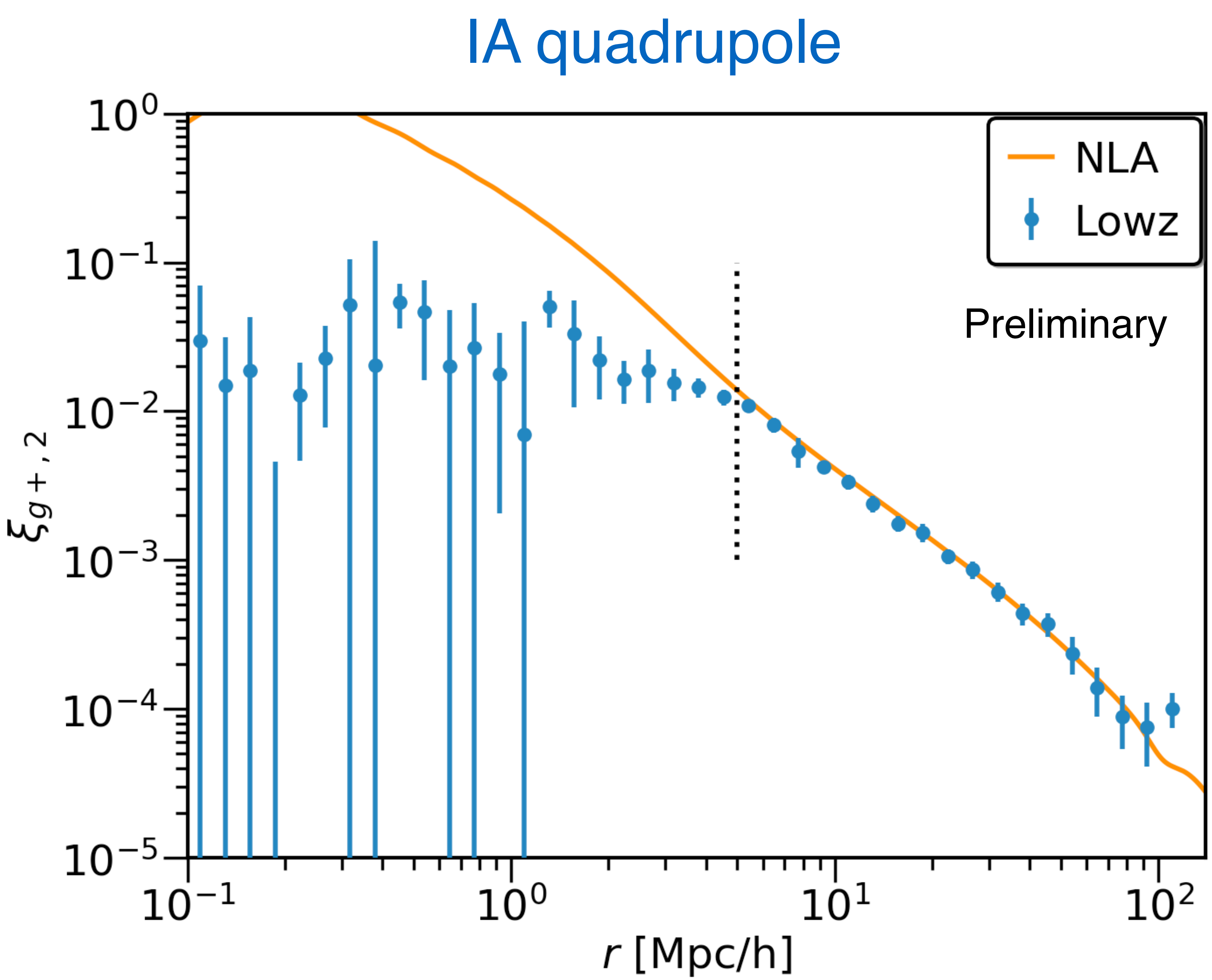
# Measurements

## 2D Correlation function




See also: 1510.06752

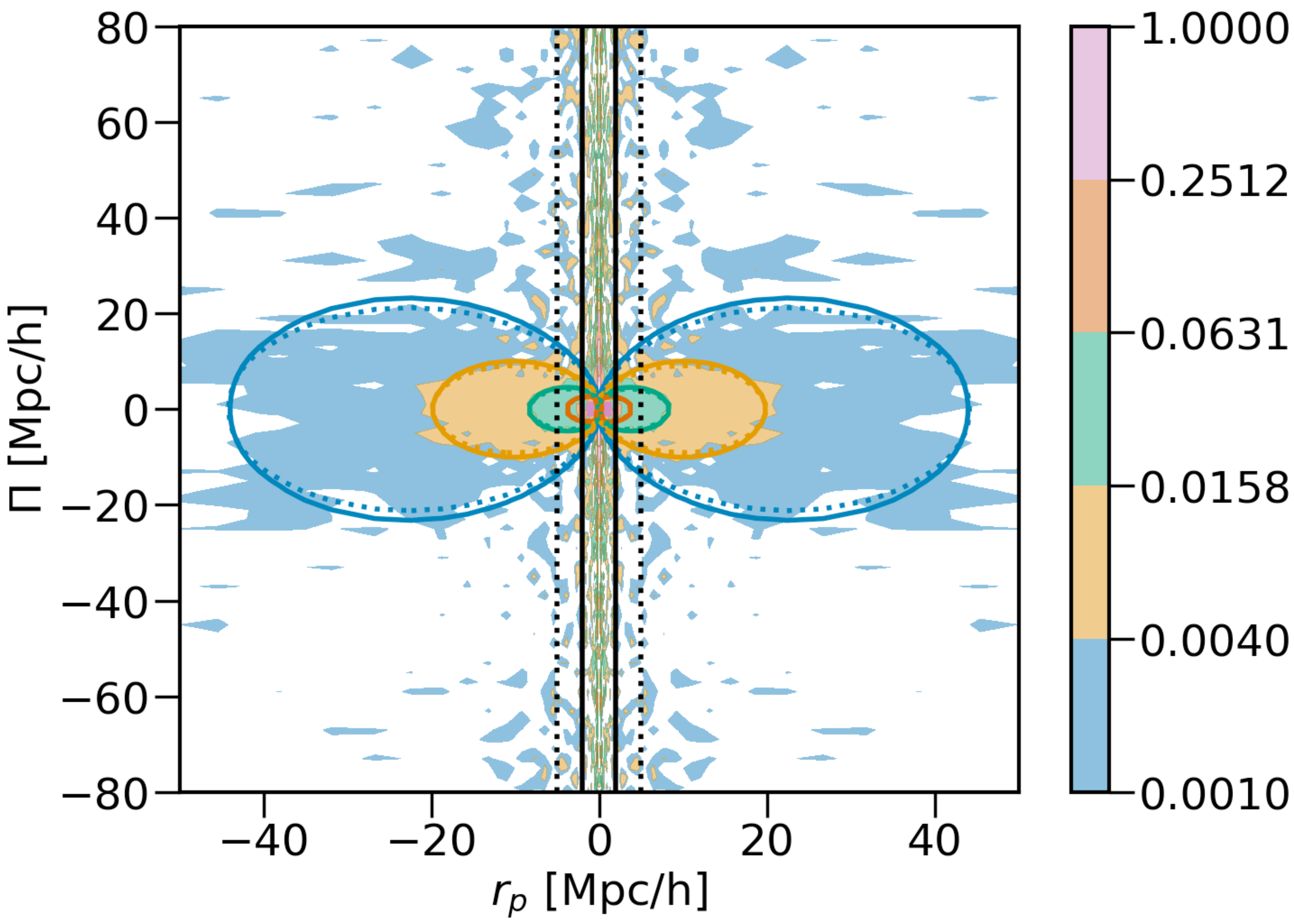
# Measurements




Work done with Ali Shakir,
Rachel Mandelbaum

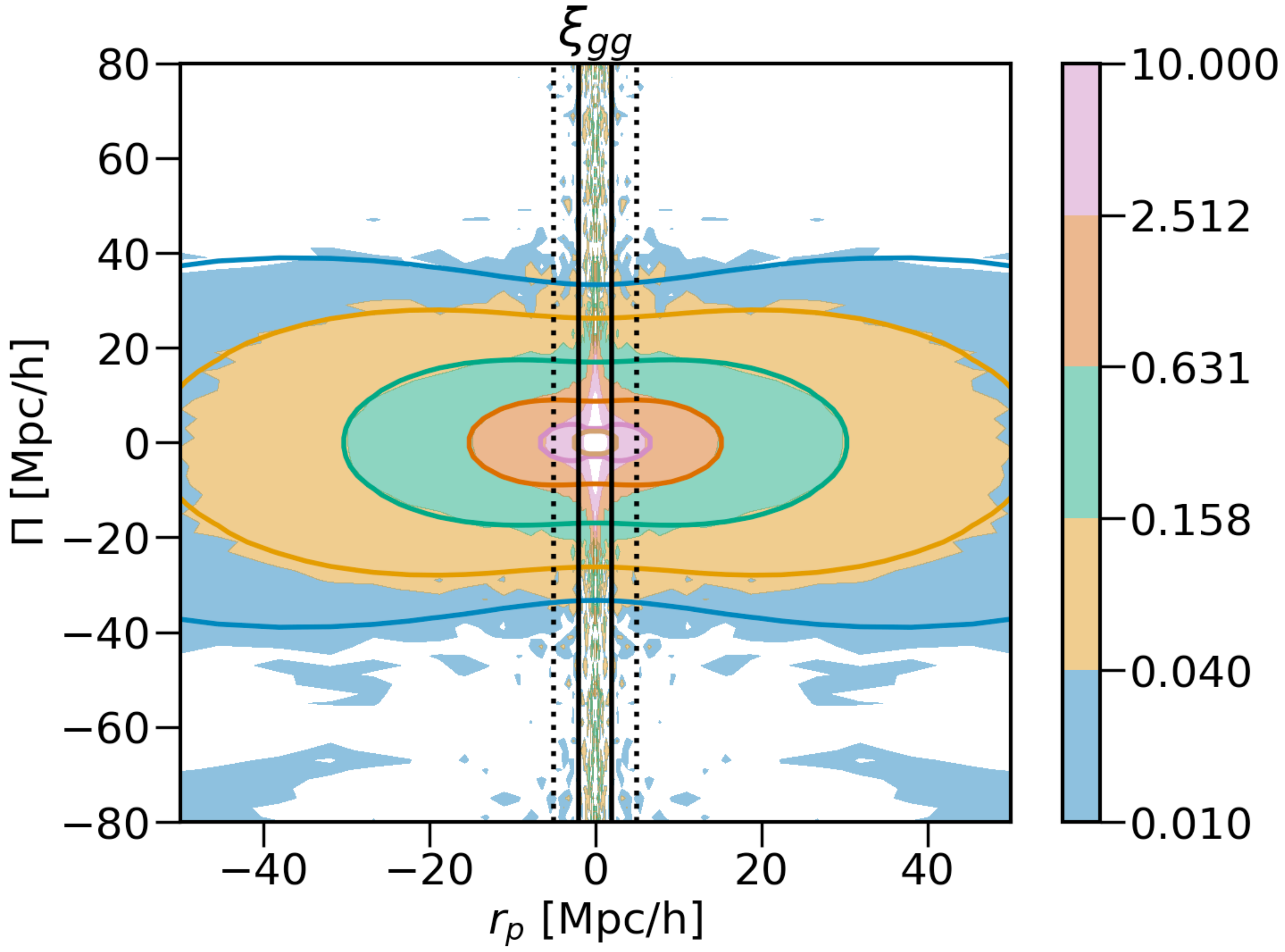
# Measurements

## Removing Finger of God effects



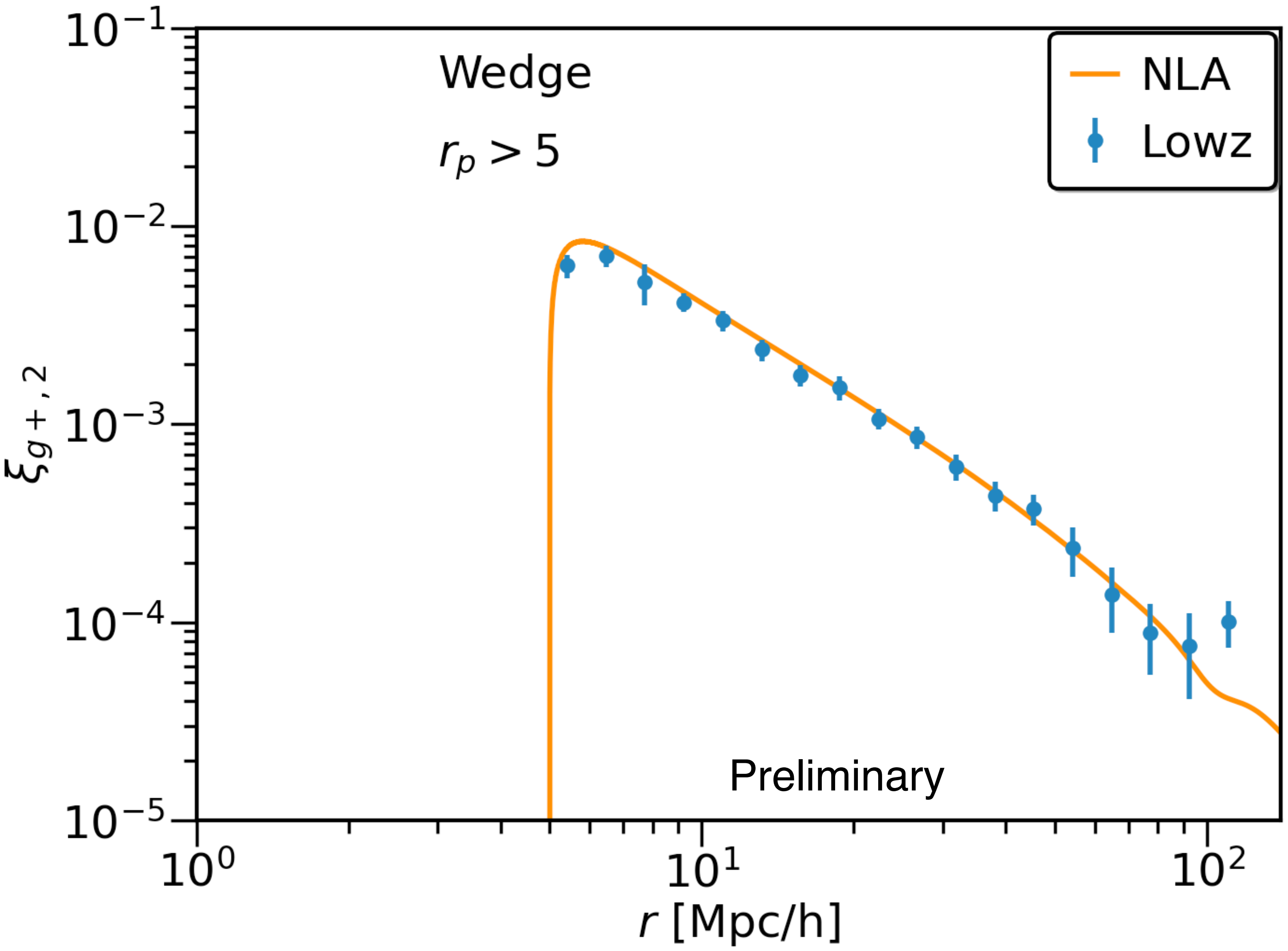
# Measurements

## Removing Finger of God effects



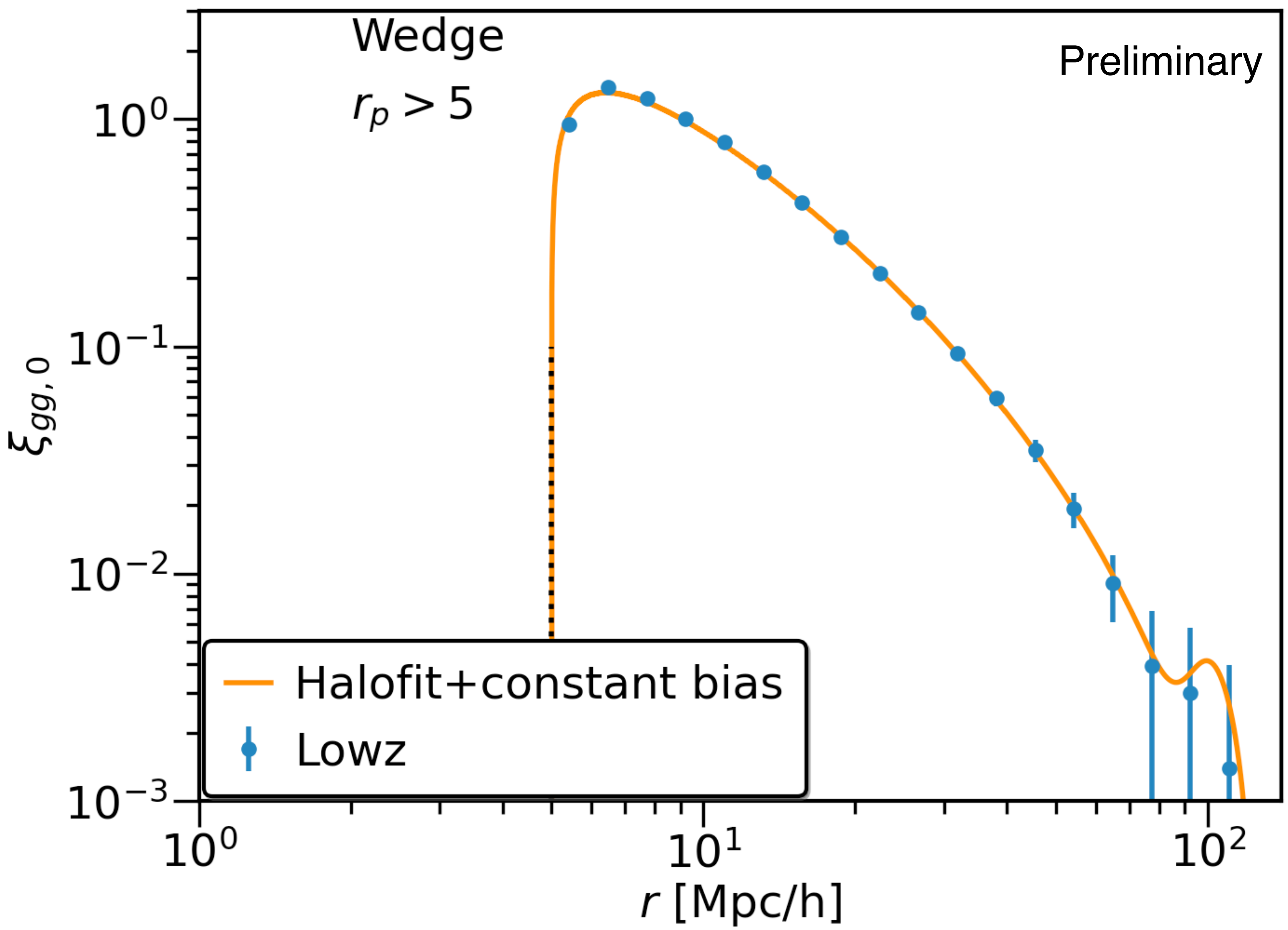
# Measurements

## Removing Finger of God effects



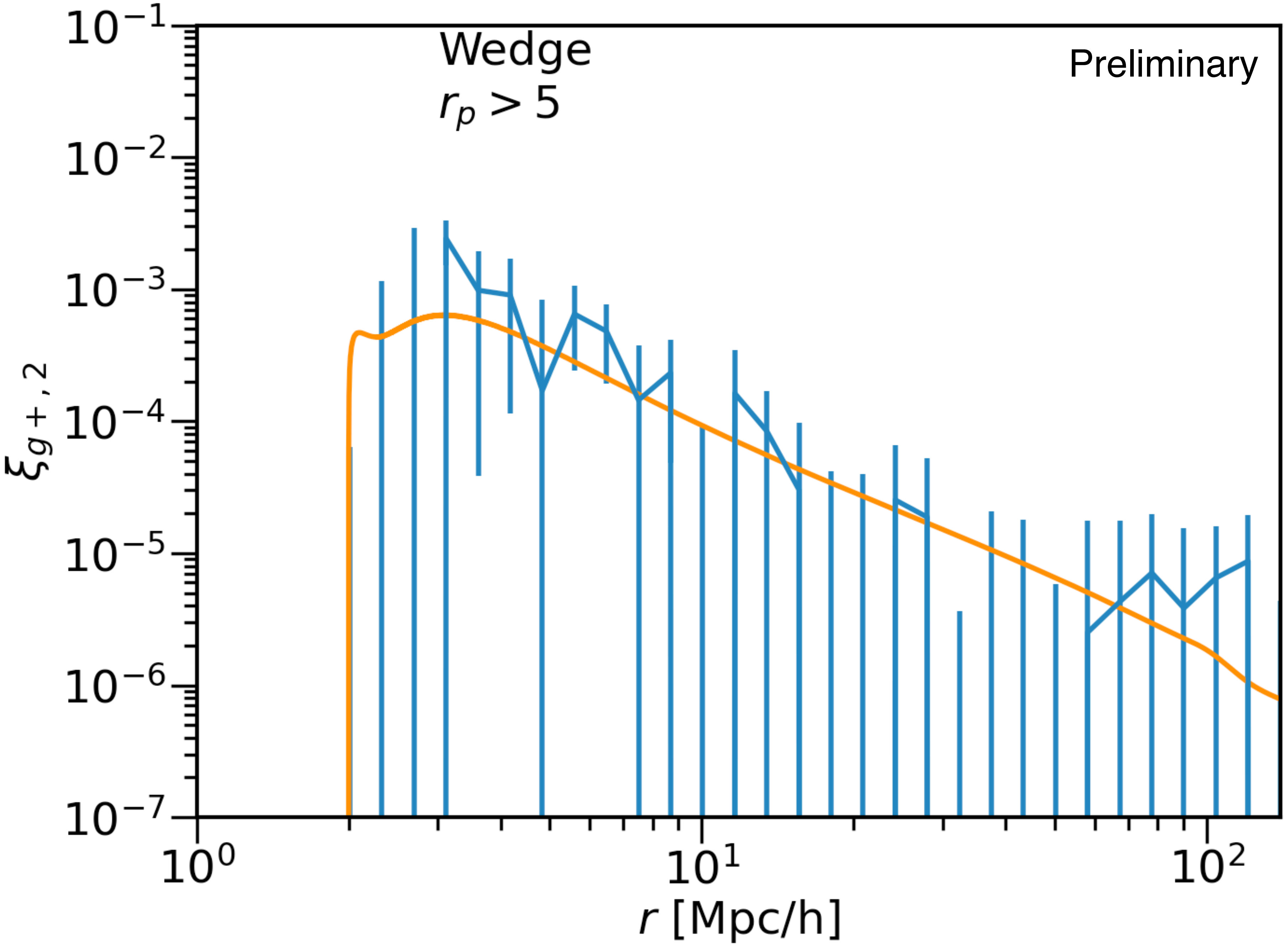
# Measurements

## Galaxy clustering monopole



# Measurements

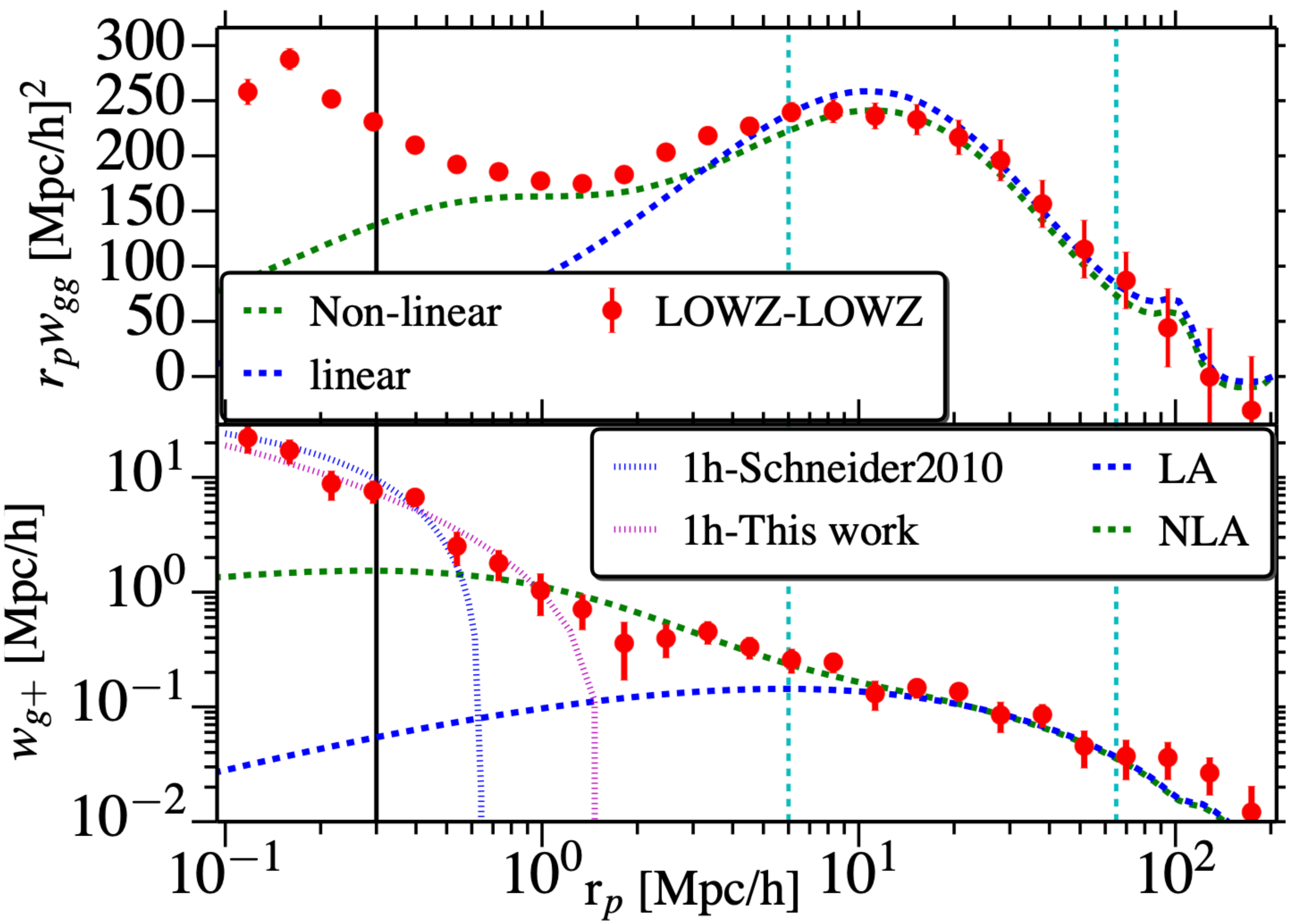
## IA hexadecapole



# Measurements

arxiv: 1411.1755

Projected Correlation functions

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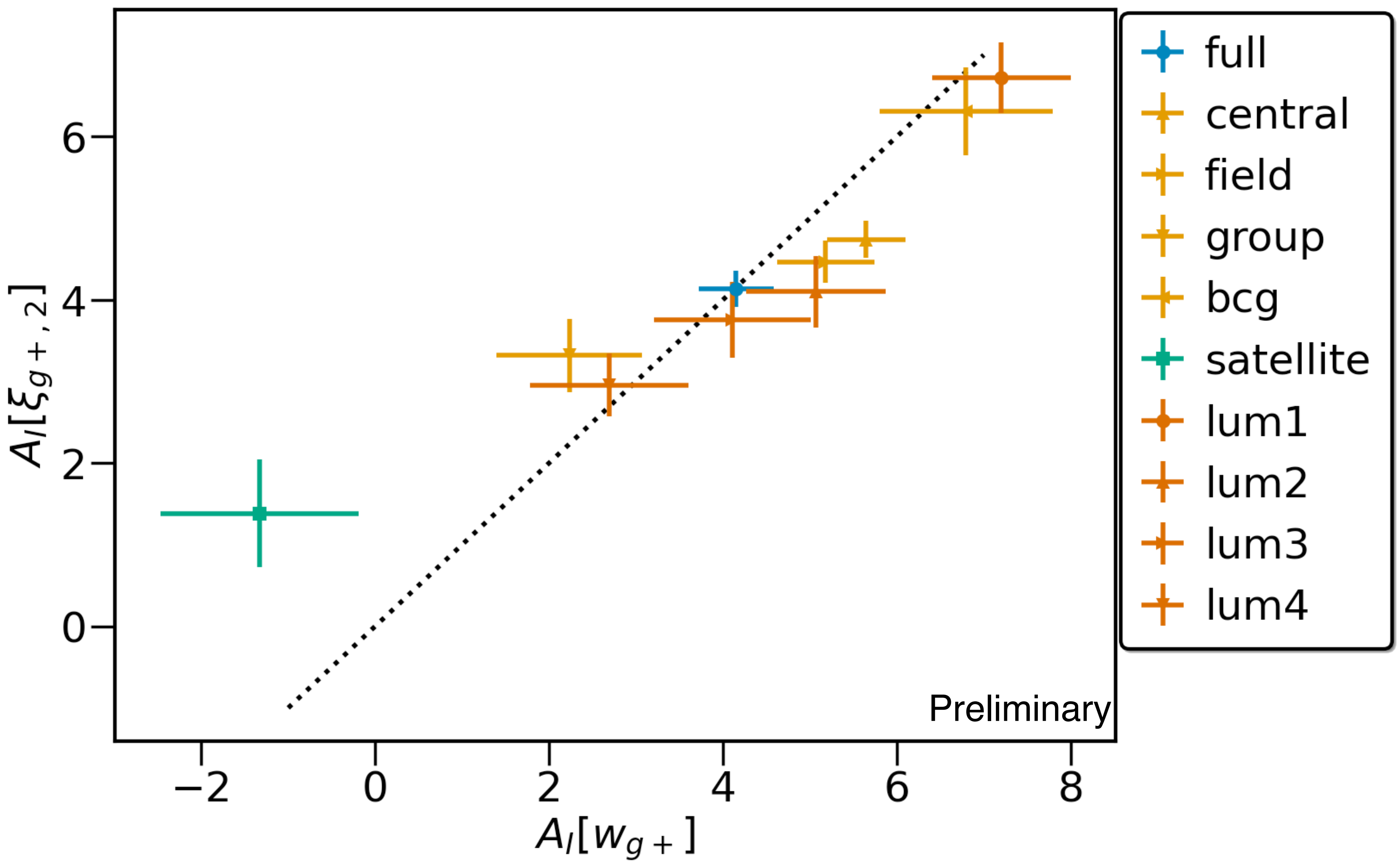
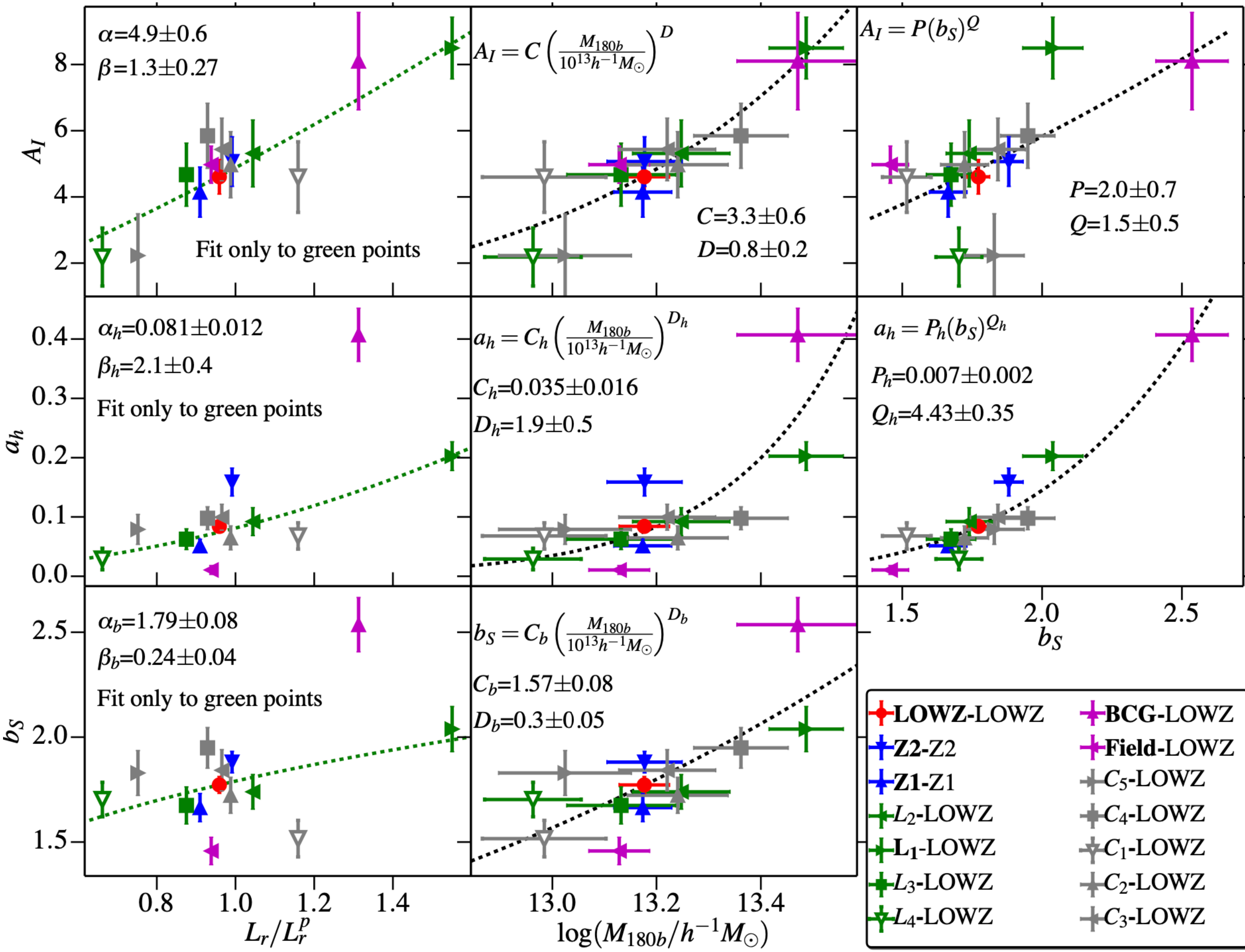
# Measurements

## Quadrupole vs Projected correlation function



# IA dependence on galaxy properties

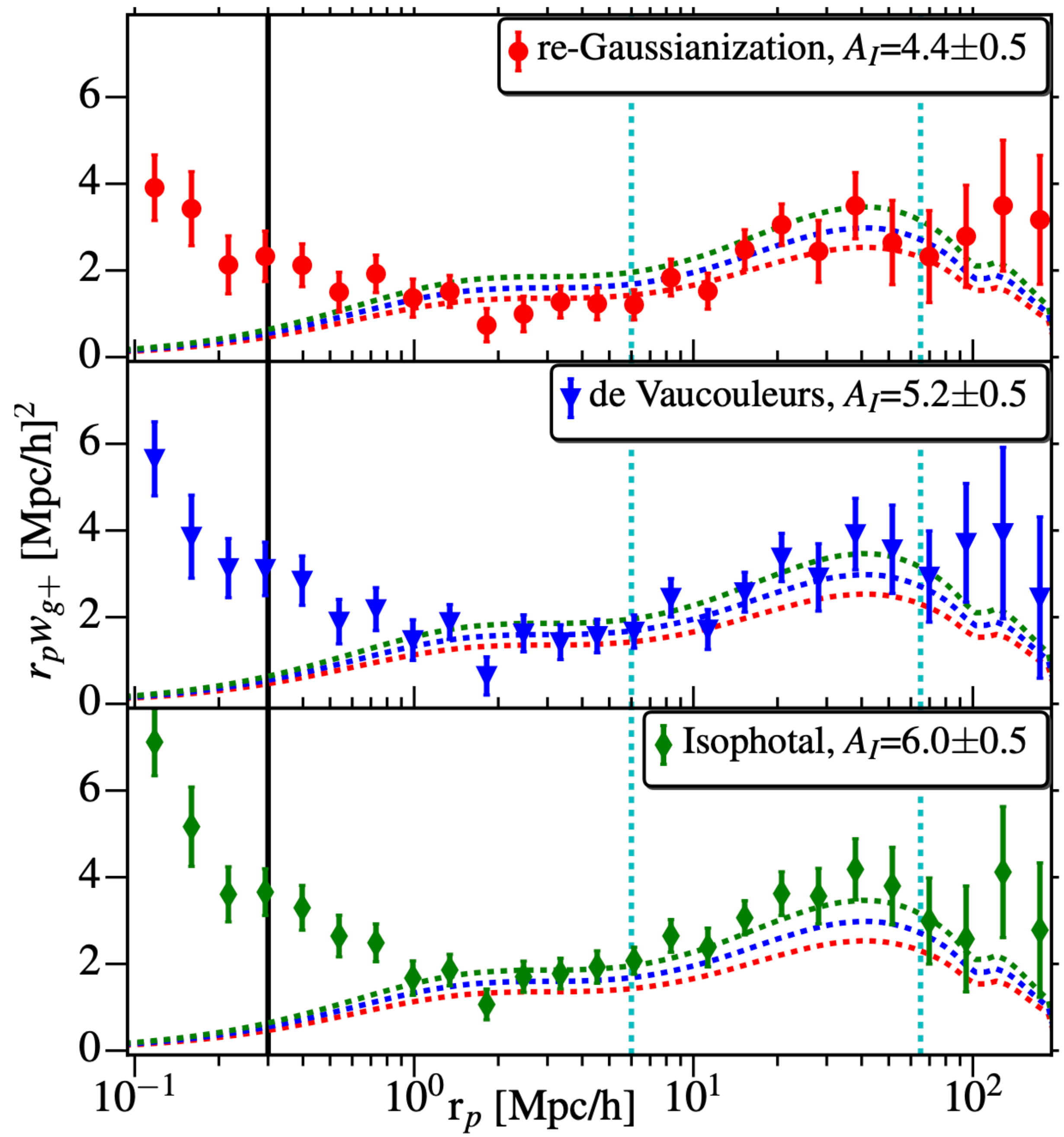
arxiv: 1411.1755



# Measurements

## Galaxy shape Twisting

- Outer parts of galaxies show stronger alignments than inner parts
- Can be used to test IA models and self calibration. See Leonard &Mandelbaum 2018




arxiv: 1510.06752

# NLA vs TATT models

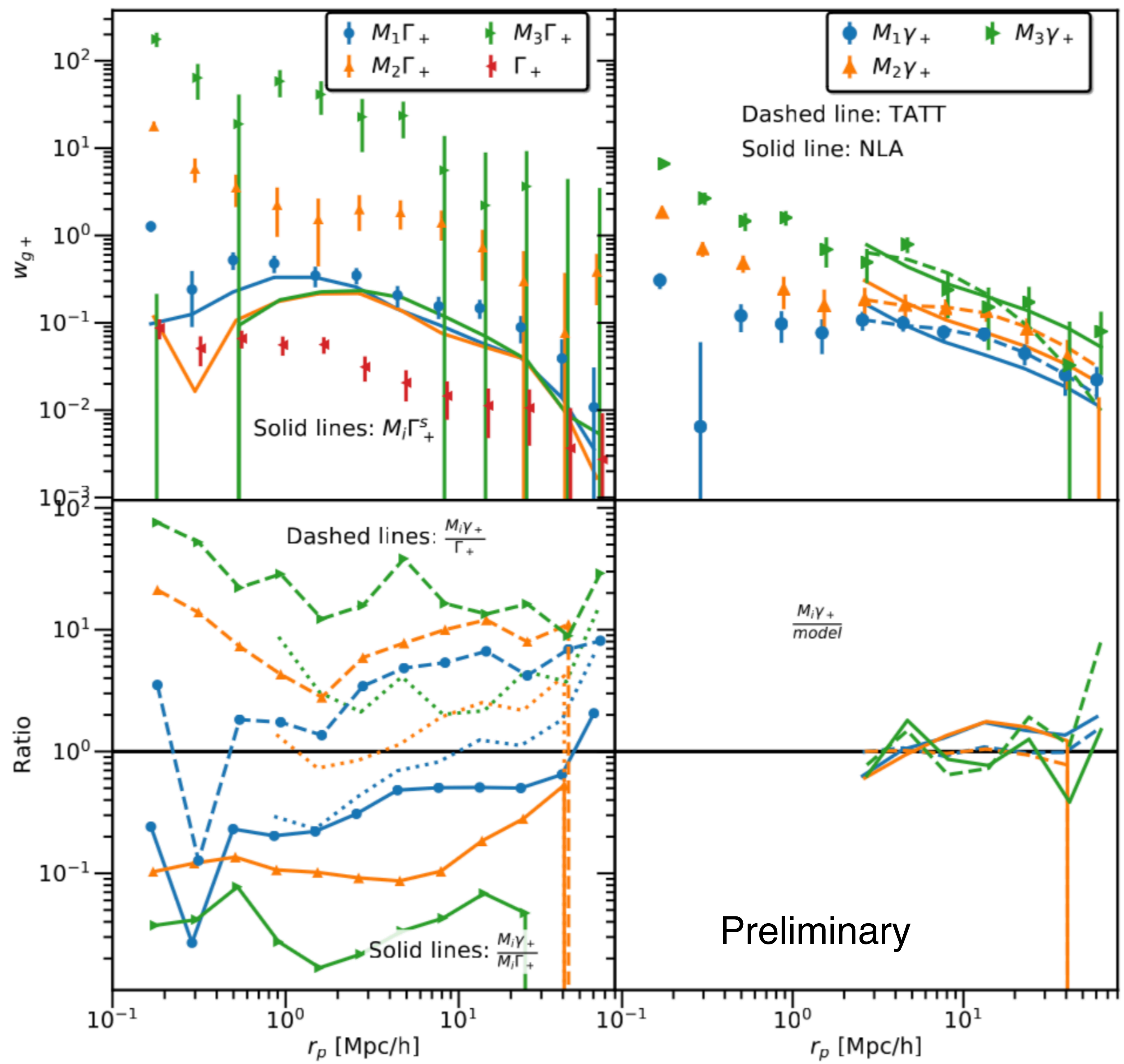
- We can compute Tidal fields directly and compare with IA measurements.
- For TATT model, weigh the Tidal field with galaxy density field.
- Need to choose smoothing scales, etc.

In prep with Ananth Tenneti, Jonathan Blazek, +

# Measurements

## NLA vs TATT models

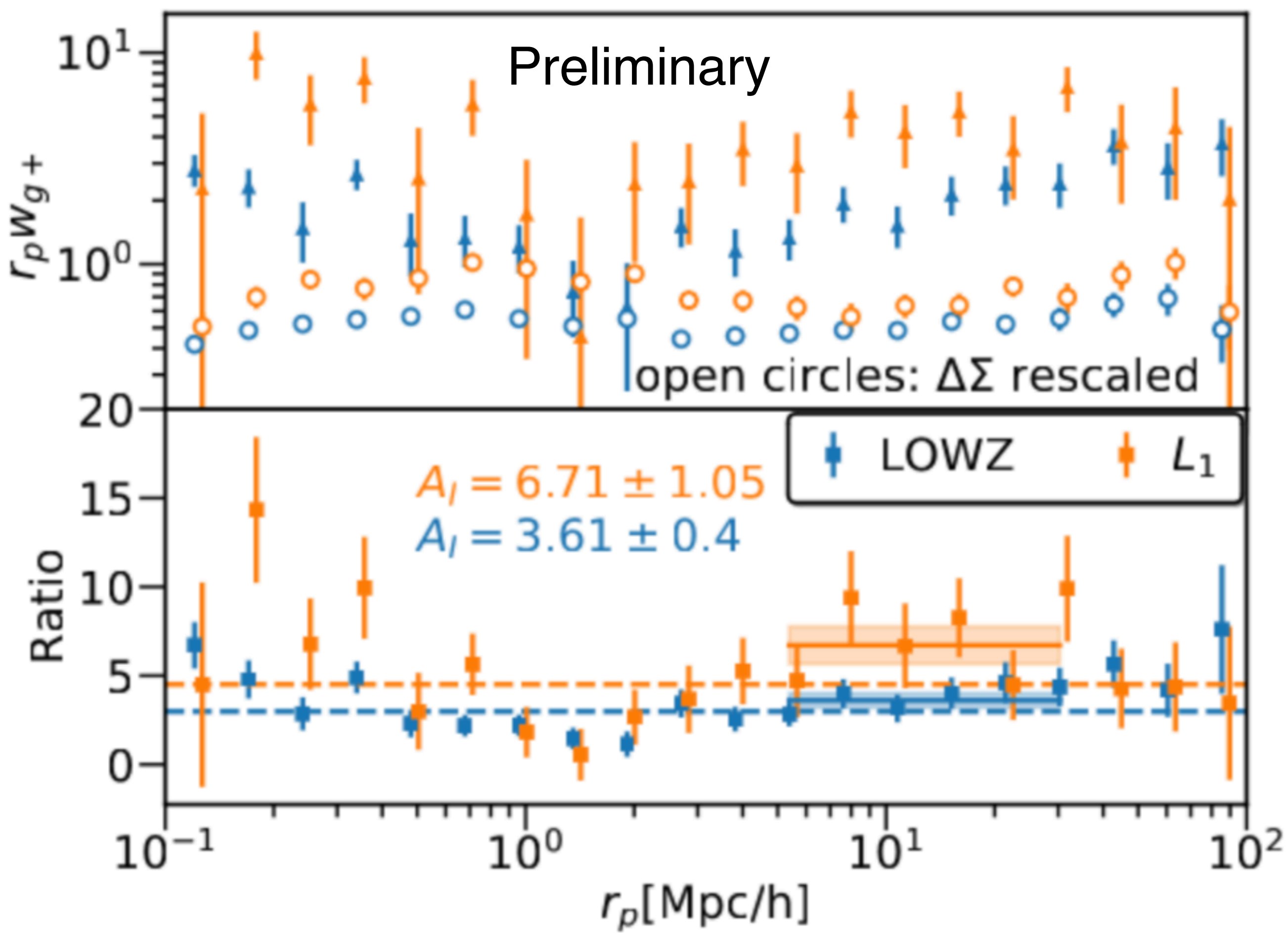
- Both NLA and TATT show scale dependent deviations.
- Need to model scale dependent IA amplitude. Similar to scale dependent galaxy bias



# Measurements

Using lensing to trace tidal fields

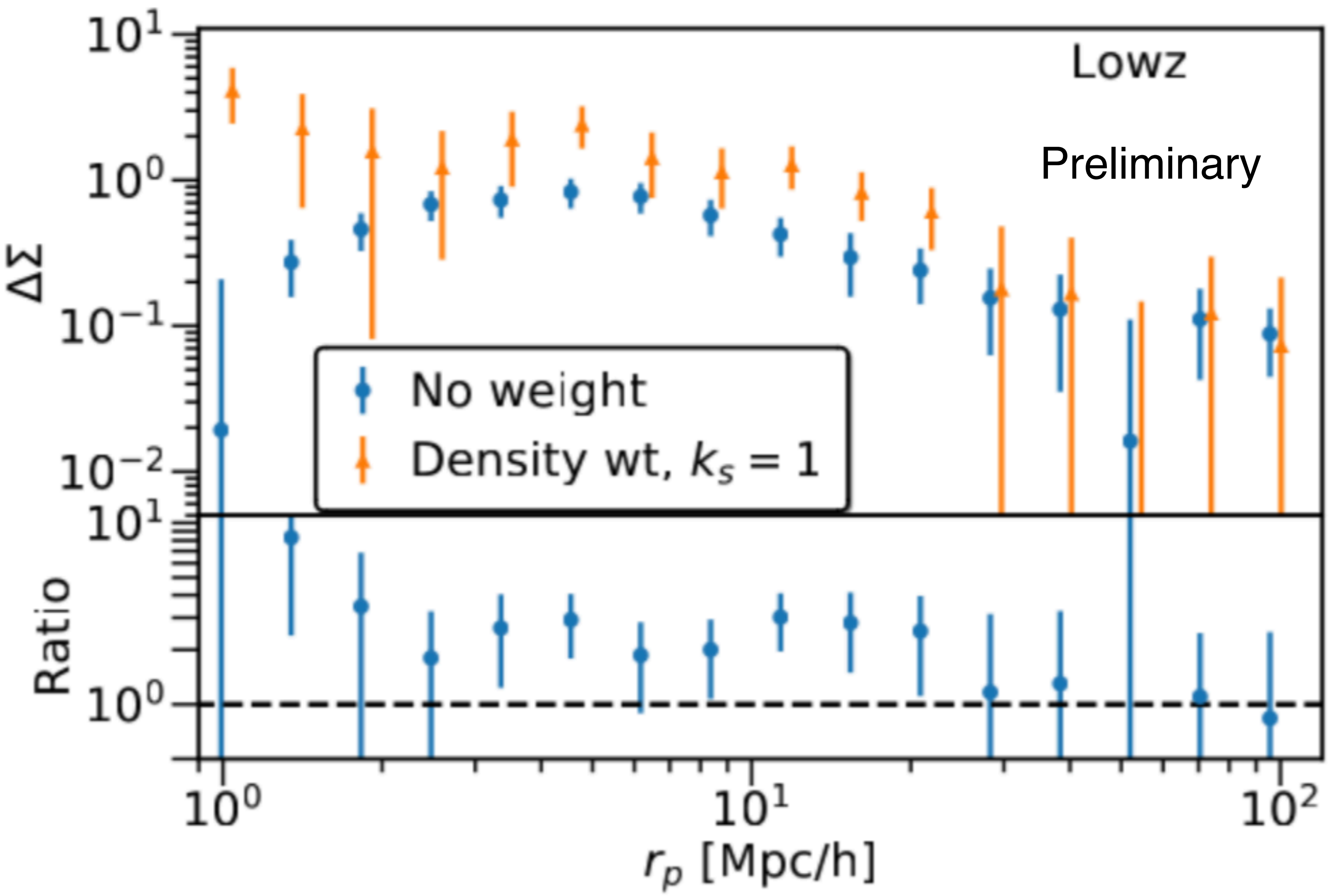
Galaxy-galaxy lensing can be used to compute NLA!



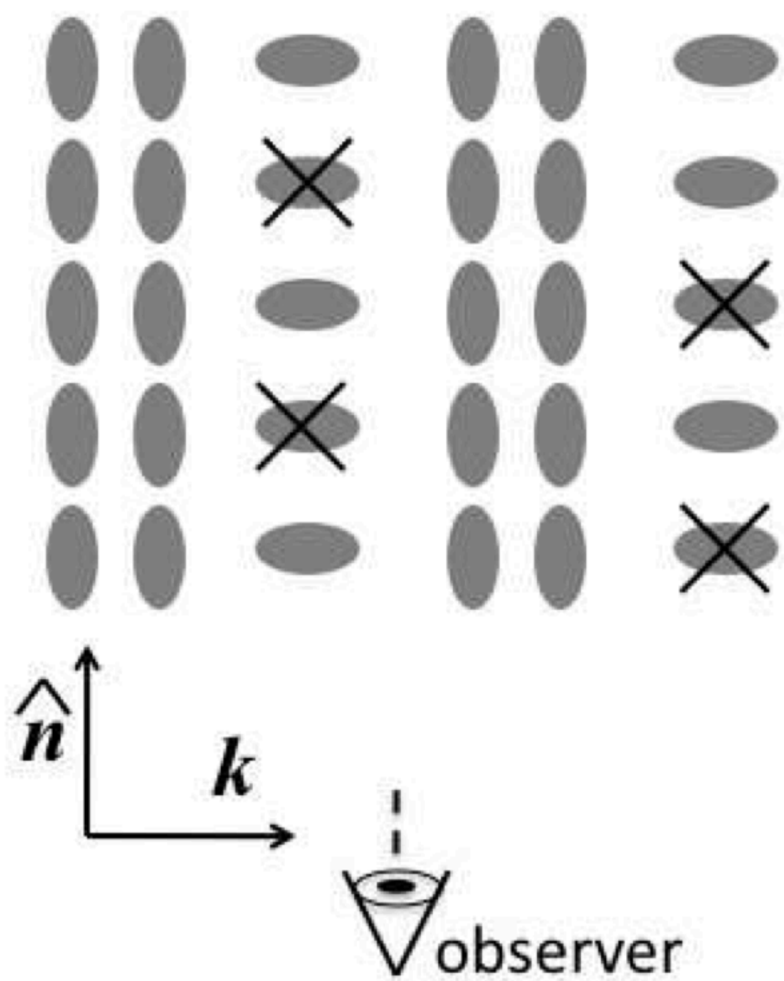
# Measurements

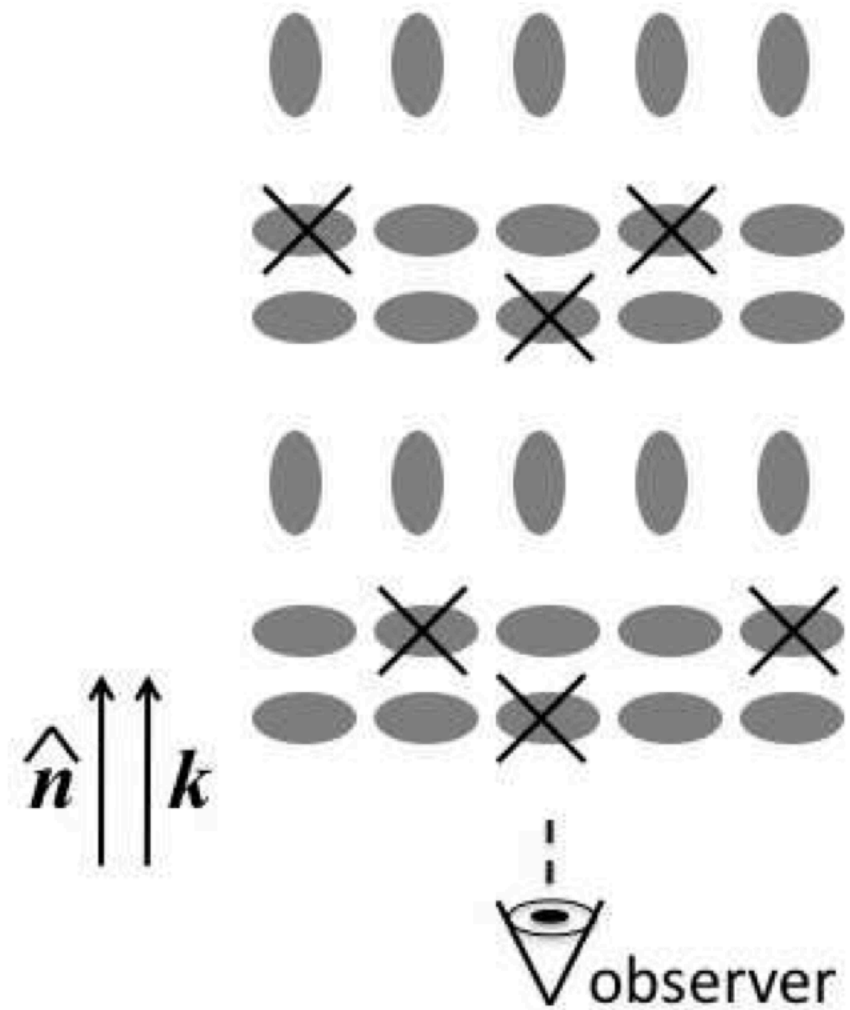
Using lensing to trace tidal fields

Density weighted lensing to compute TATT



# IA Effects on RSD measurements




Credit: Hirata 2009

# IA Effects on RSD measurements

IA leads to correlations between observed sizes and tidal fields

$$\lambda = A_\lambda \frac{\zeta}{3} \left[1 - 3\mu^2\right] \delta_m$$

Size dependent selection leads to coupling between galaxy density and tidal fields

$$\widehat{\delta}_g(\mathbf{x}, \lambda) = \delta_g(\mathbf{x}) + \epsilon(\lambda(\mathbf{x}))$$

$$\epsilon(\mathbf{x}) \approx \gamma A_\lambda \zeta \left[\frac{1}{3} - \mu^2\right] \delta_m(\mathbf{x})$$

**SS+: 2001.07700**

# IA Effects on RSD measurements

IA leads to correlations between observed sizes and tidal fields

$$\lambda = A_\lambda \frac{\zeta}{3} \left[1 - 3\mu^2\right] \delta_m$$

Results in biased measurement of growth function

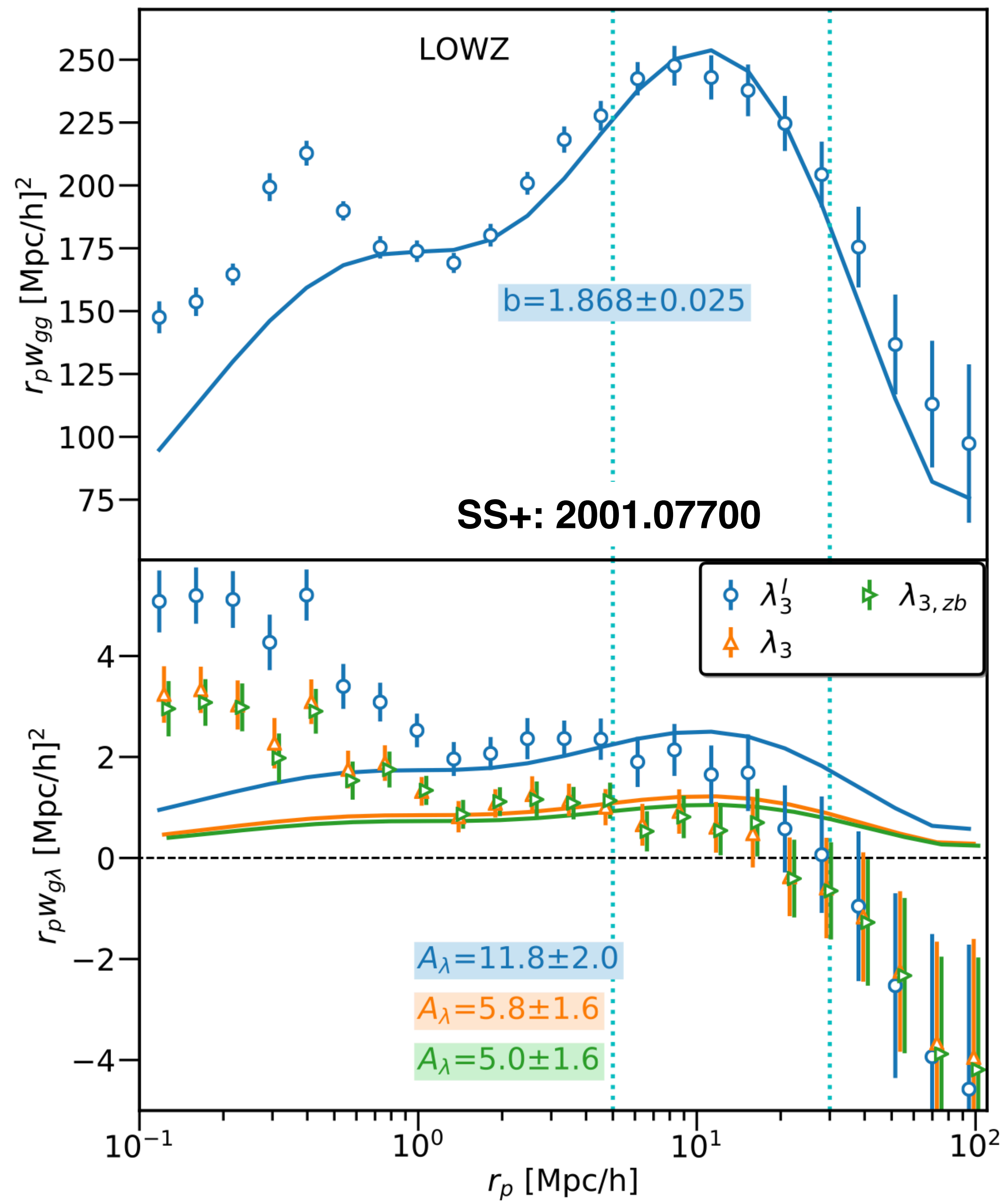
$$\Delta f = \widehat{f} - f_0 = -\gamma A_\lambda \zeta$$

$$\widehat{b}_g = b_{g,0} + \frac{1}{3}\gamma A_\lambda \zeta = b_{g,0} - \frac{1}{3}\Delta f$$

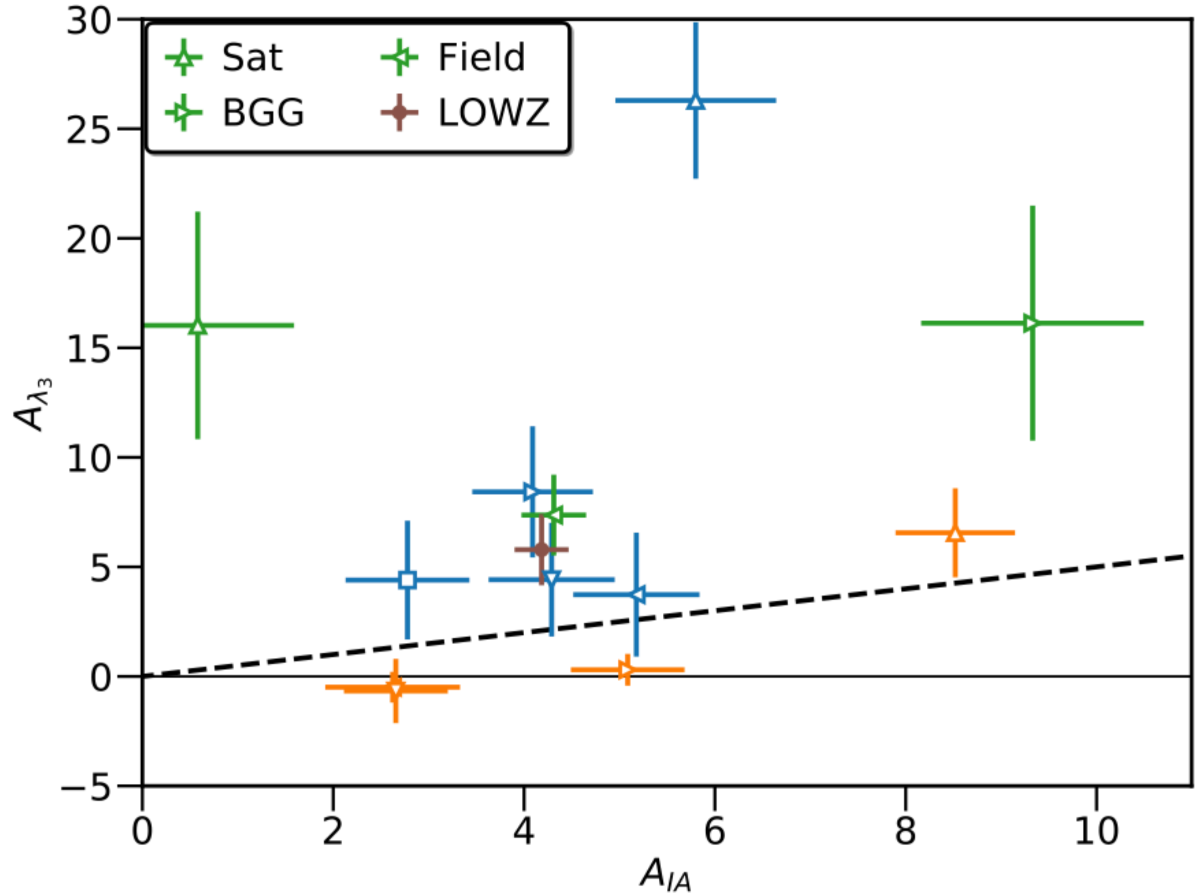
**SS+: 2001.07700**

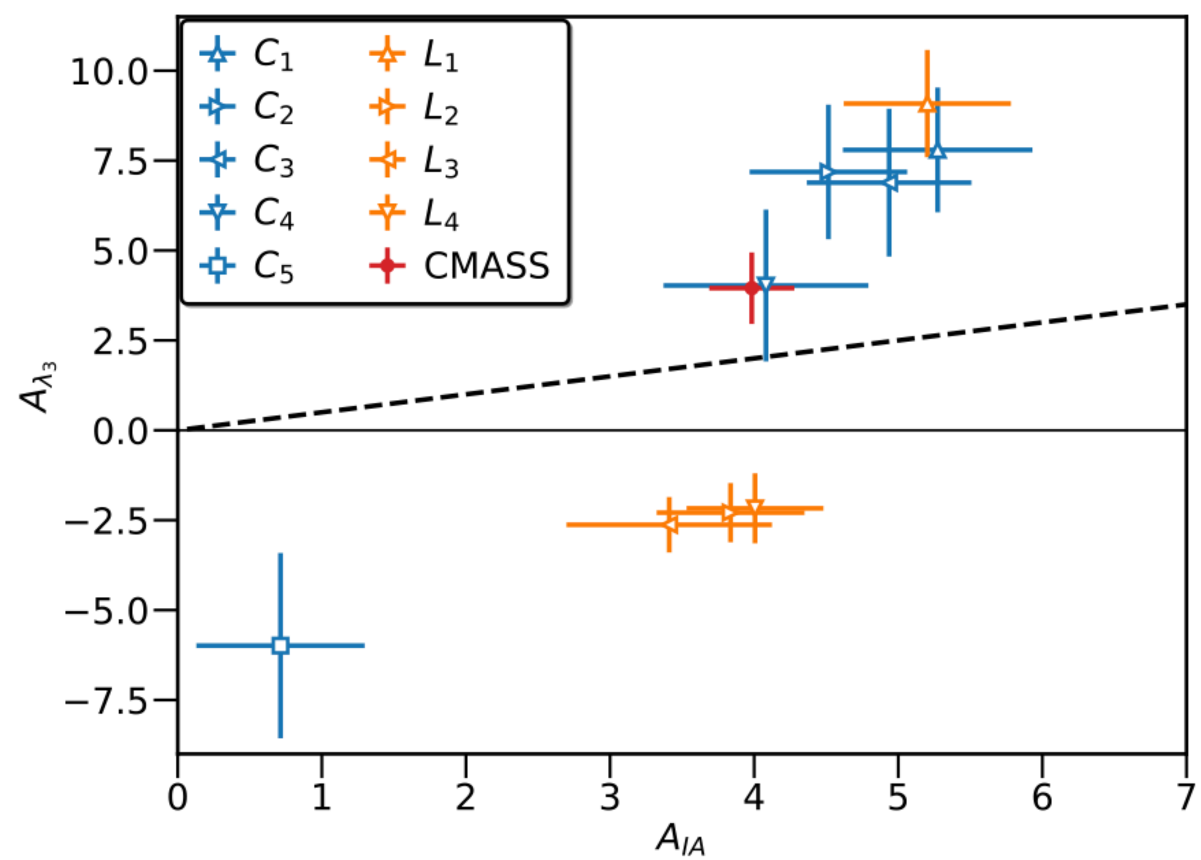
# Size correlation measurements

- Use Fundamental plane to predict galaxy sizes.
- Measure the correlations of size residuals with the density field.
- Significant correlations detected.
- Like IA, size correlations also depend on galaxy properties.
- FP has quite a few systematics as well (see paper for details).



# FP correlation vs IA



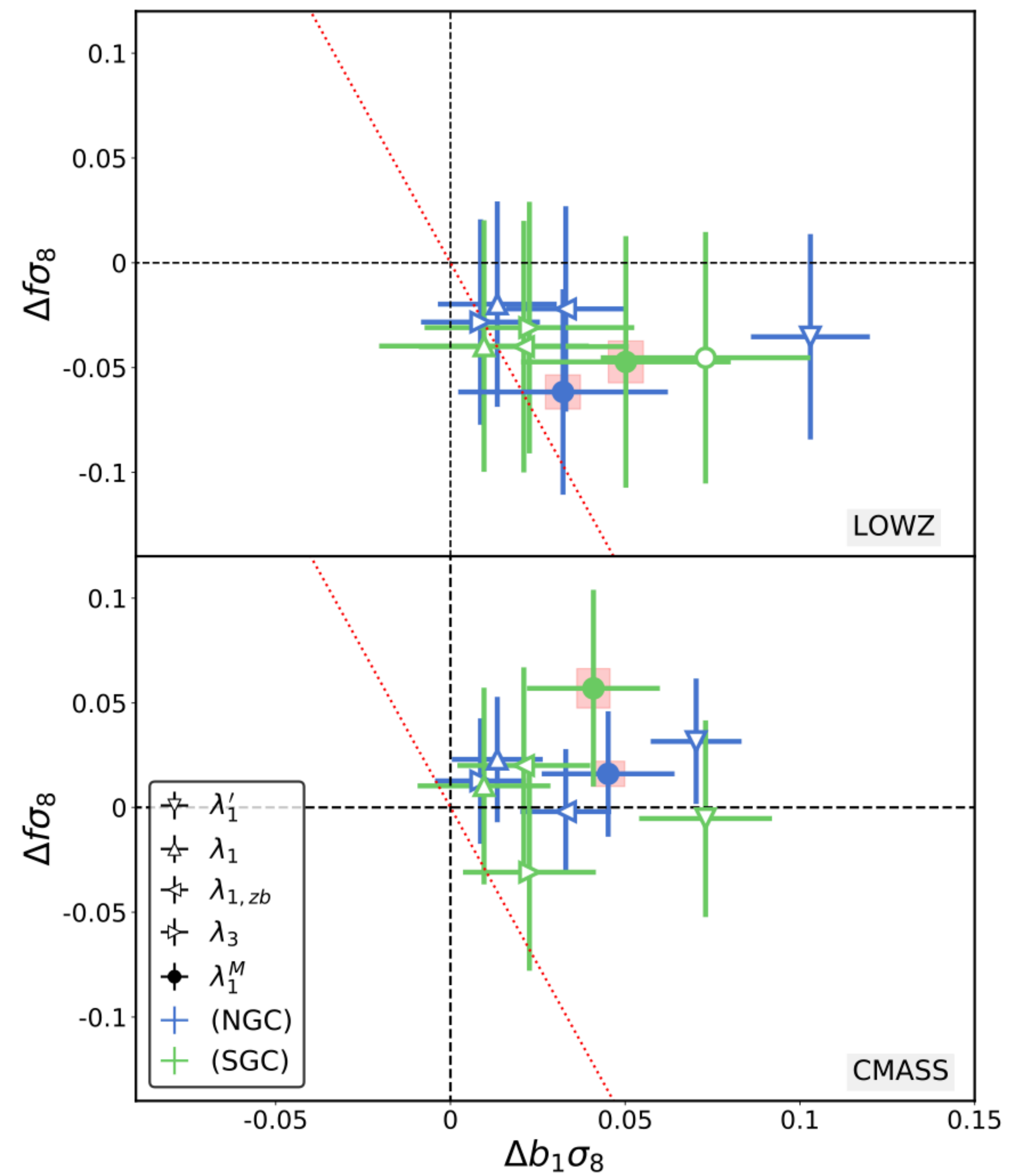




- If size correlations are driven by IA, there should be correlations between the two amplitudes.
- Data does not appear to be consistent with model, although FP is systematics dominated

# Tests on RSD measurements

- IA driven model predicts relation between biases in growth rate and galaxy bias estimates.
- No significant variations detected and data again not consistent with the model

No evidence for IA effects on RSD estimates in BOSS



# Summary

- SDSS-BOSS has provided high precision measurements of IA.
- We have learnt a lot about IA physics, especially its dependence on galaxy properties and environment.
- Moving forward, Quadrupole will be a better estimator for IA in spectroscopic samples.
- We can using tidal fields from lensing to test the tidal alignment models.
- Galaxy sizes also show similar correlations as IA.
- Using FP as galaxy size estimator, no evidence for IA contamination to RSD measurements using BOSS