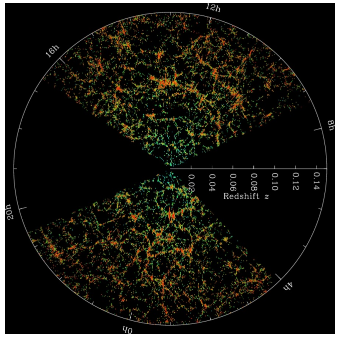
Constraints on growth rate with intrinsic ellipticity correlations of SDSS BOSS galaxies

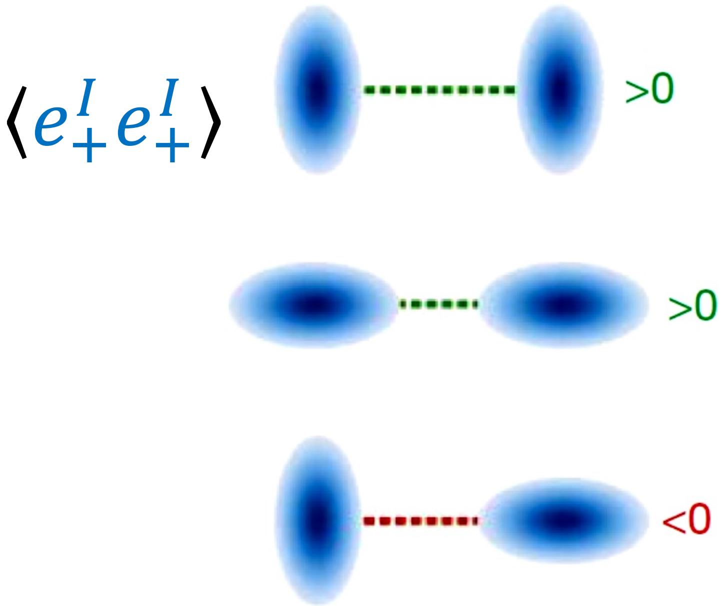
Teppei Okumura
(ASIAA, Taiwan)

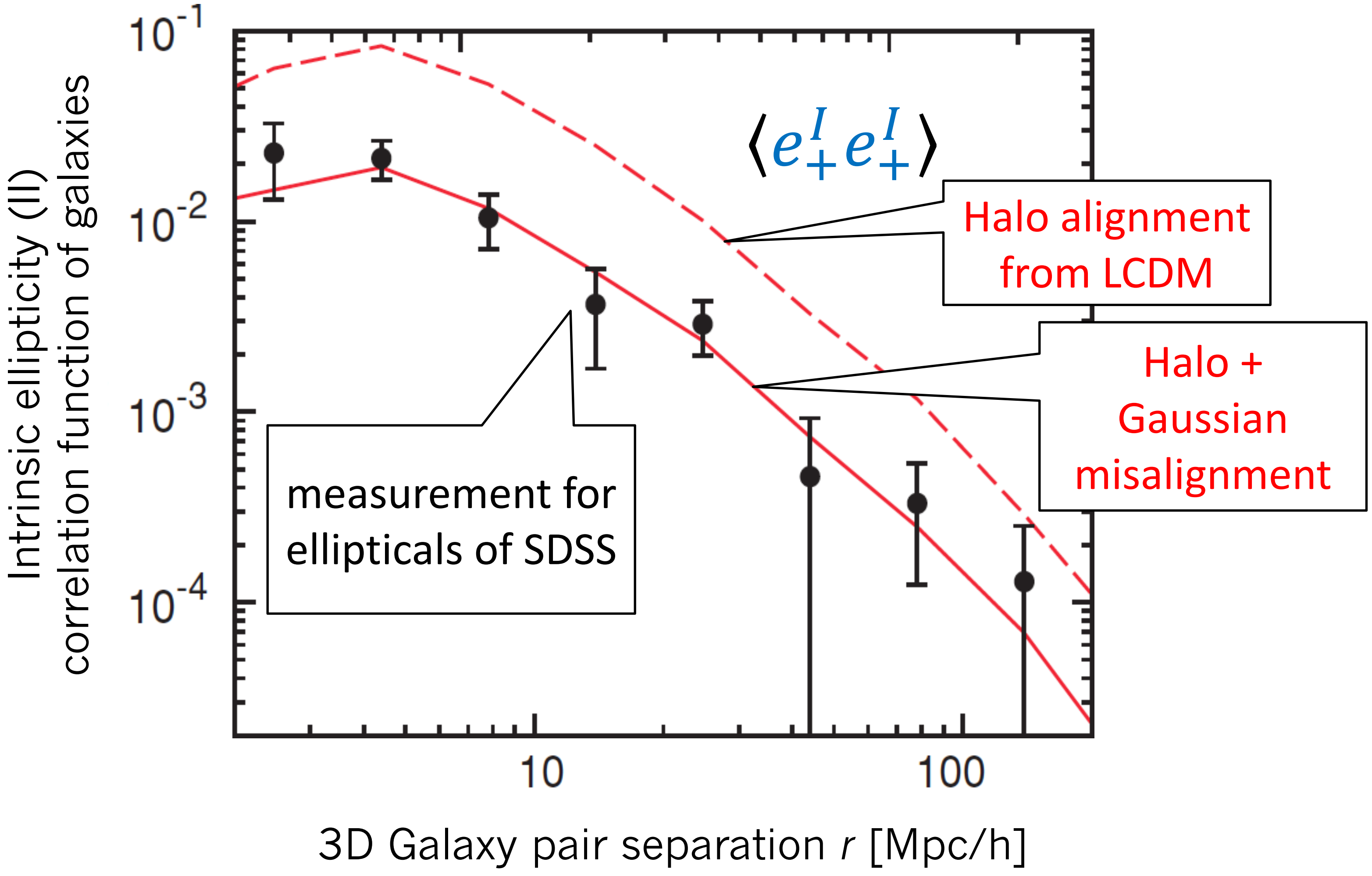
IA cosmology workshop, YITP, Kyoto U.
Dec. 5 - 9, 2022

Ongoing work with Atsushi Taruya (YITP) and Hironao Miyatake (Nagoya)

Intrinsic ellipticity auto correlation (II) of elliptical galaxies and the host halos

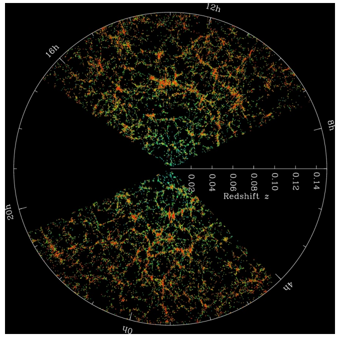




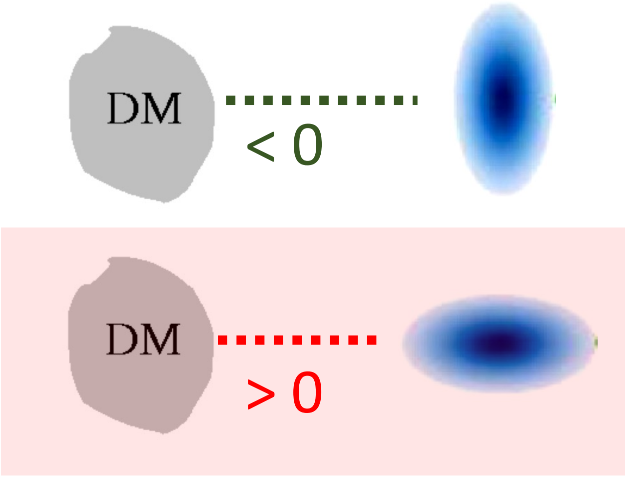


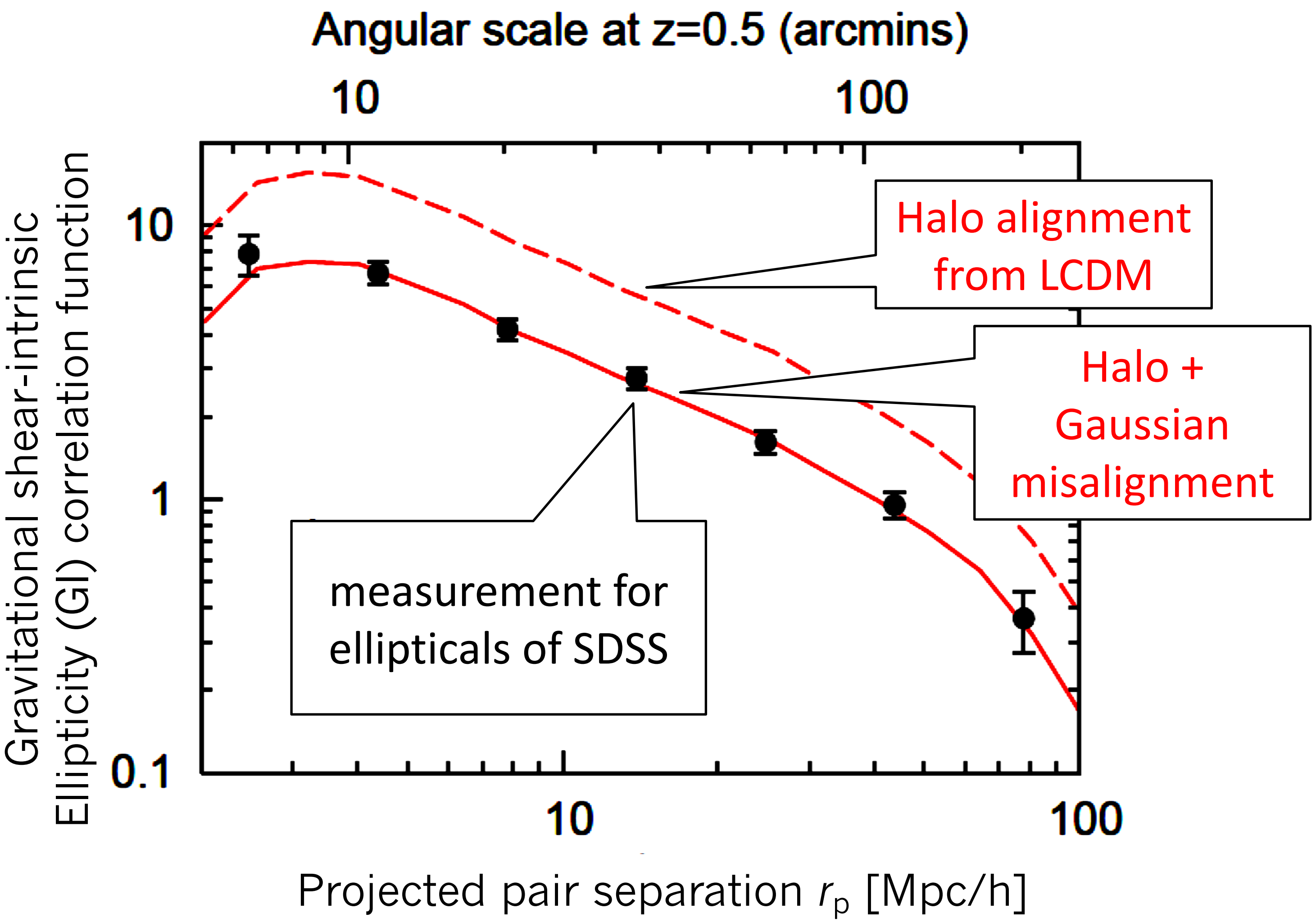
Okumura, Jing & Li (2009a)

Galaxy density—intrinsic ellipticity (GI) correlation



$\langle \delta e_+^I \rangle$





Okumura & Jing (2009b)

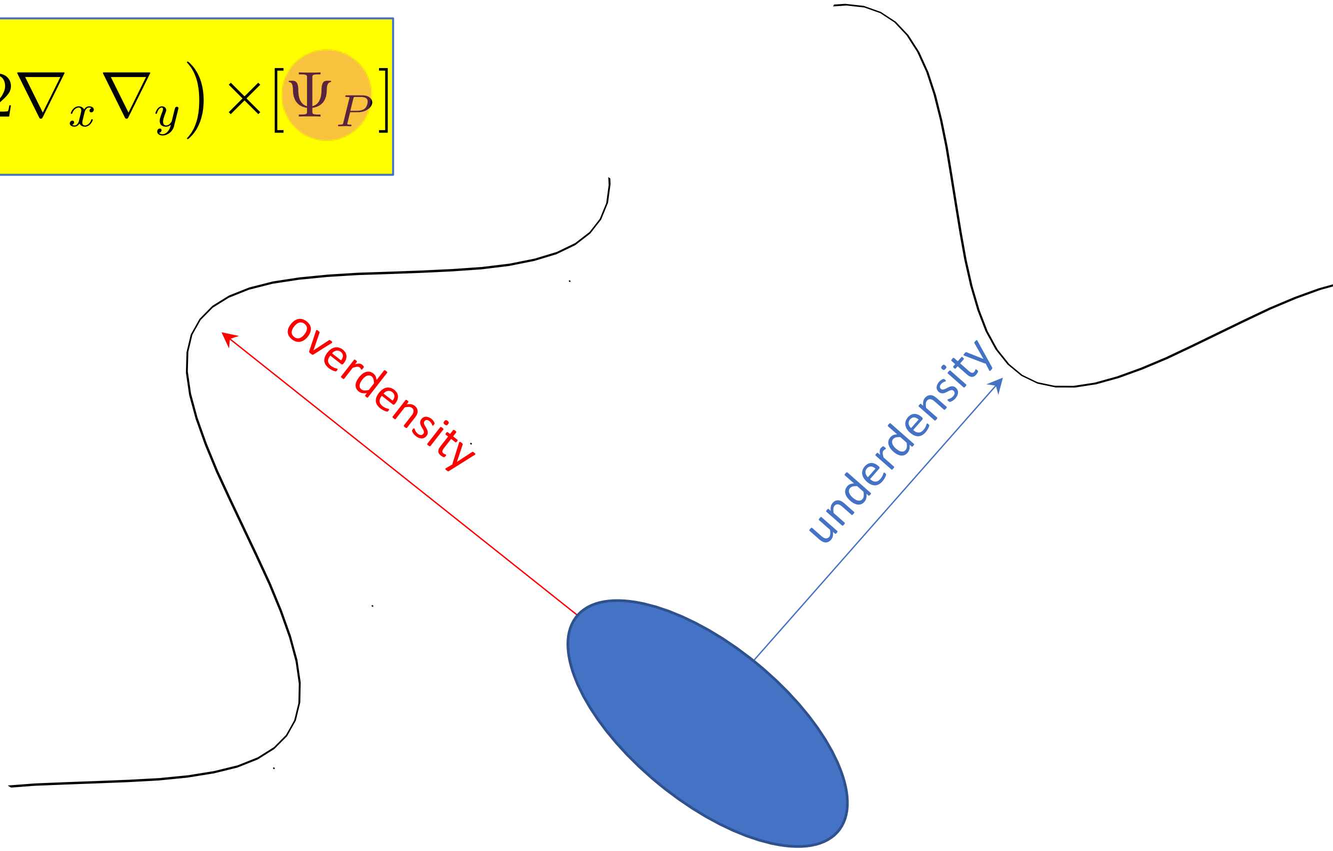
Linear alignment (LA) model of galaxy/halo shapes

Catelan, Kamionkowski & Blandford (2001)
Hirata & Seljak (2004)

- Relates linear tidal field with galaxy/halo shape

$$\gamma_{(+,\times)}(\mathbf{x}) = -\frac{C_1}{4\pi G}\left(\nabla_x^2 - \nabla_y^2, 2\nabla_x\nabla_y\right)\times[\Psi_P]$$

- Ψ_P: (Linear) Newton potential
- C_1 (= - $4\pi G\, b_K$) has to be determined by observation/simulation (this parameter absorbs misalignment and other uncertainties)



Intrinsic alignment contains cosmological information via dynamical and geometric distortions

- Linear theory in redshift space
  - GG correlation : $P_{\rm gg}(k,\mu) = \left(b + f\mu^2\right)^2 P_{\rm mm}(k),$
  - GI correlation : $P_{\rm gE}(k,\mu) = b_K(1-\mu^2)(b+f\mu^2)P_{\rm mm}(k),$
  - II correlation : $P_{\rm EE}(k,\mu) = b_K^2(1-\mu^2)^2 P_{\rm mm}(k),$

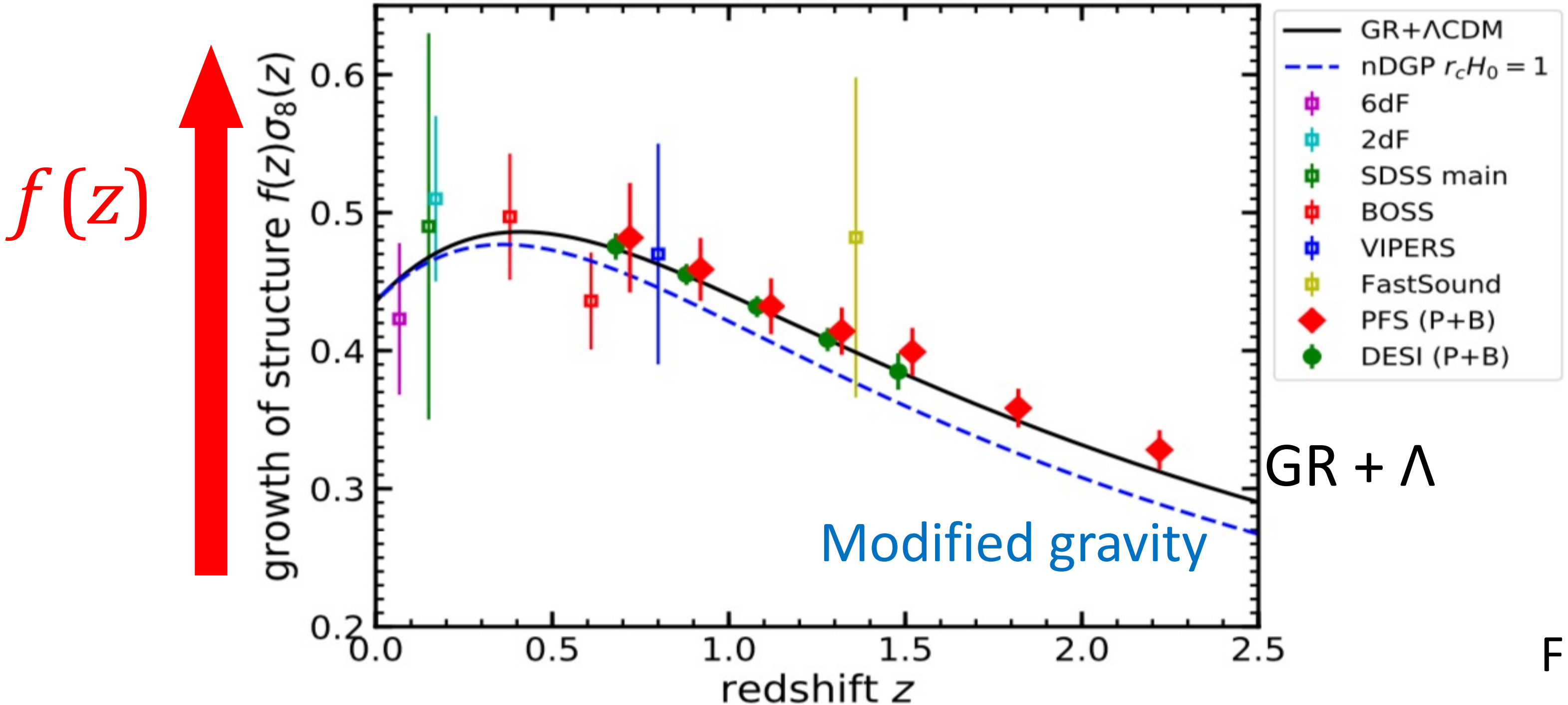


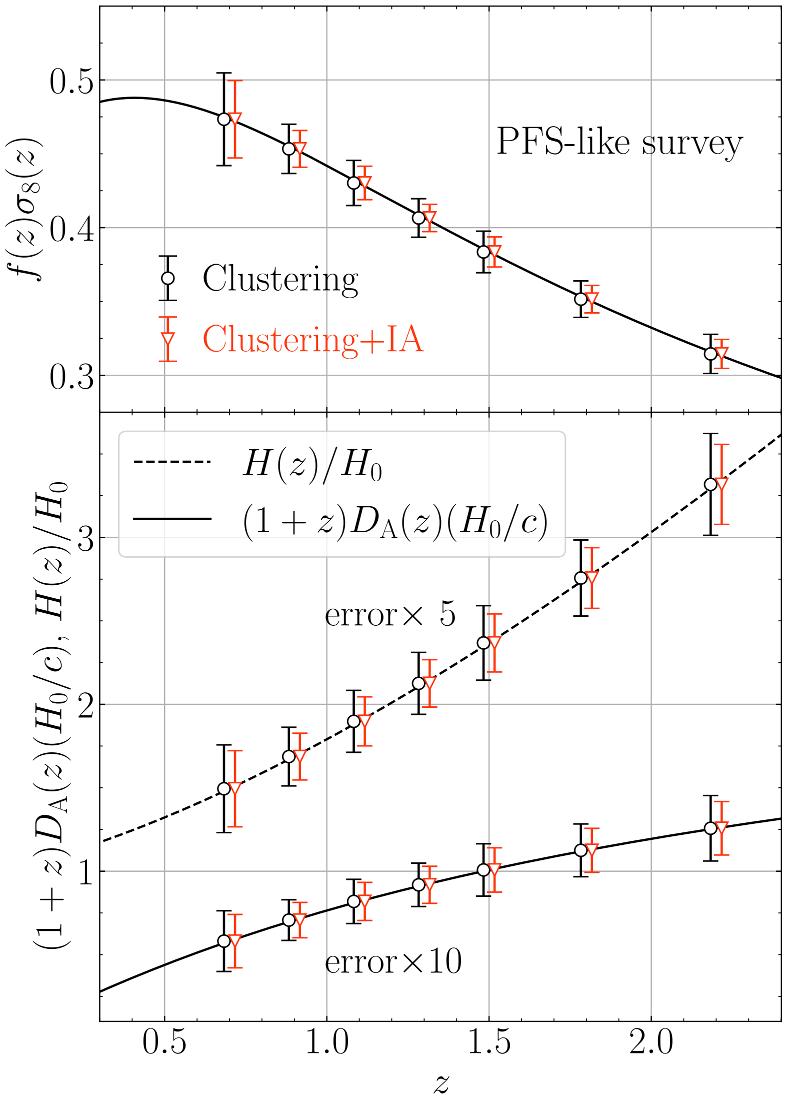
Figure made by Ryu Makiya

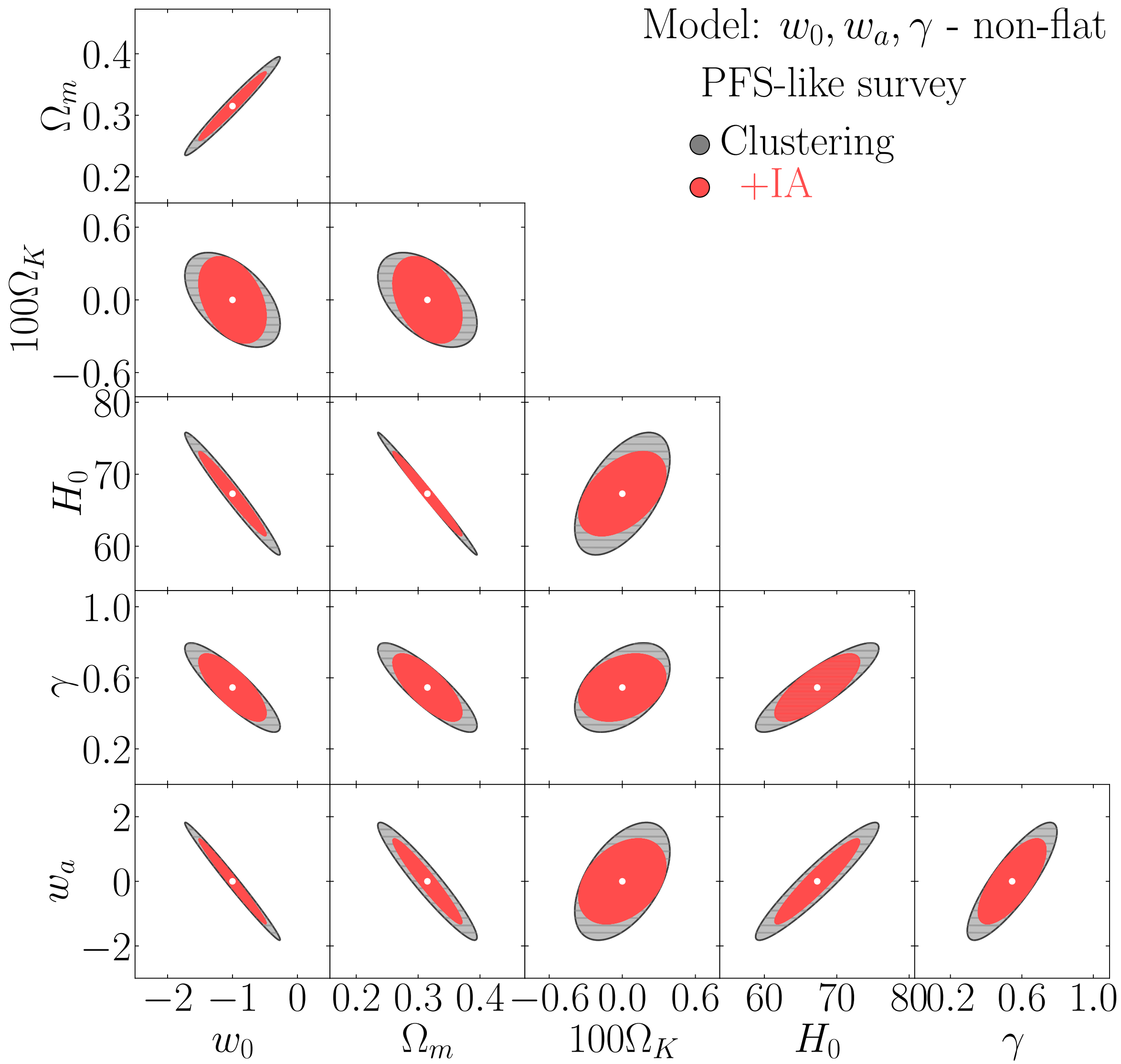
IA measurements enhance cosmological returns from galaxy redshift surveys

Okumura & Taruya (2022)
(see also Taruya & Okumura (2020)

Forecasts assume

- Clustering (PFS)
- Clustering +IA (PFS + HSC)





Formulating the IA statistics in redshift space

Okumura & Taruya (2020)

- Analytic formuale of redshift-space alignment statistics in linear theory
  - GG correlation : $P_{\rm gg}(k,\mu) = \left(b + f\mu^2\right)^2 P_{\rm mm}(k),$ ---> Kaiser multipoles (Hamilton 1992)
  - GI correlation : $P_{\rm gE}(k,\mu) = b_K(1-\mu^2)(b+f\mu^2)P_{\rm mm}(k),$

    ---> $\xi^S_{g+}(\mathbf{r}) = \xi^R_{g+}(\mathbf{r}) + \frac{1}{7}\widetilde{C}_1 f \cos(2\phi)\left(1-\mu^2\right)\left[\Xi^{(0)}_{\delta\Theta,2}(r) - \left(7\mu^2-1\right)\Xi^{(0)}_{\delta\Theta,4}(r)\right]$
  - II correlation : $P_{\rm EE}(k,\mu) = b_K^2(1-\mu^2)^2 P_{\rm mm}(k),$

    ---> $\xi_\pm(\mathbf{r}) = \xi_{++}(\mathbf{r}) \pm \xi_{\times\times}(\mathbf{r})$

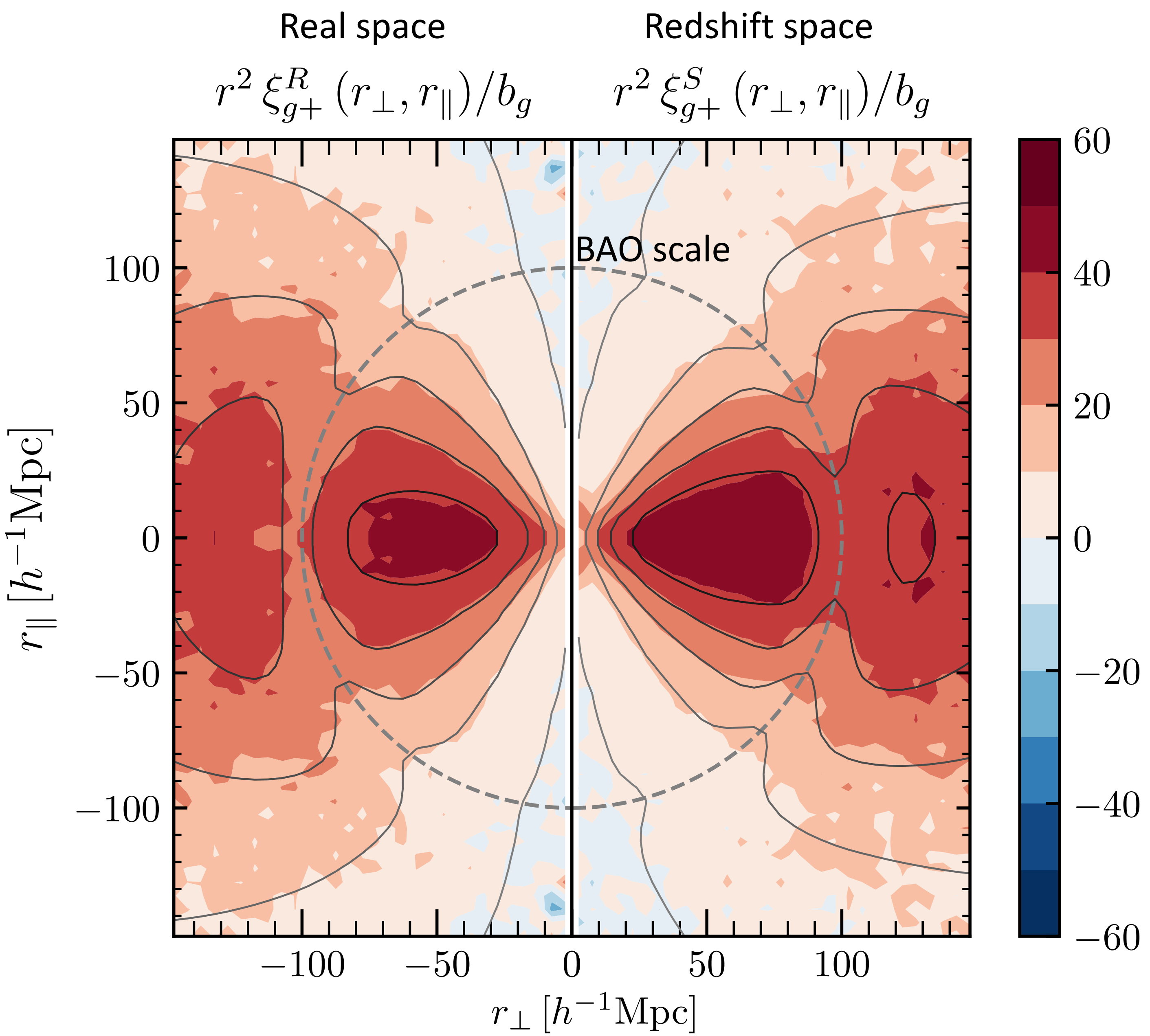
$$\xi_+(\mathbf{r}) = \frac{8}{105}\widetilde{C}_1^2\left[7\,\mathcal{P}_0(\mu)\,\Xi^{(0)}_{\delta\delta,0}(r) + 10\,\mathcal{P}_2(\mu)\,\Xi^{(0)}_{\delta\delta,2}(r) + 3\,\mathcal{P}_4(\mu)\,\Xi^{(0)}_{\delta\delta,4}(r)\right]$$

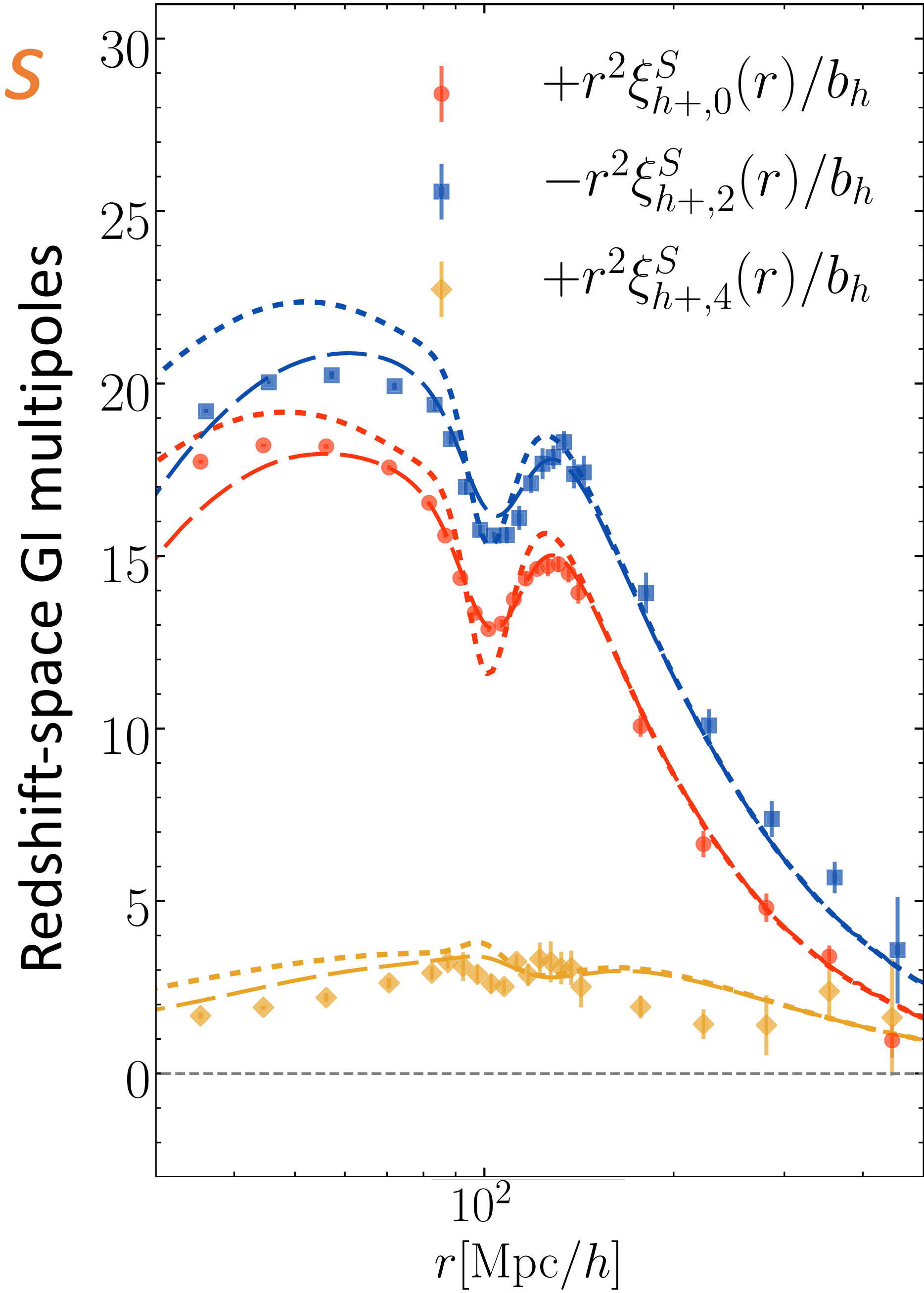
$$\xi_-(\mathbf{r}) = \widetilde{C}_1^2\cos(4\phi)\left(1-\mu^2\right)^2\,\Xi^{(0)}_{\delta\delta,4}(r)$$

$$= \frac{8}{105}\widetilde{C}_1^2\cos(4\phi)\left[7\,\mathcal{P}_0(\mu) + 10\,\mathcal{P}_2(\mu) + 3\,\mathcal{P}_4(\mu)\right]\,\Xi^{(0)}_{\delta\delta,4}(r)$$

$$\Xi^{(0)}_{XY,\ell}(r) = \int_0^\infty \frac{k^2dk}{2\pi^2}P_{XY}(k)j_\ell(kr)$$

Comparison of 2-D GI to simulations





Okumura, Taruya and Nishimichi (2020)

Short summary and the purpose of this study

- According to the Fisher forecast study, intrinsic alignment contains cosmological information via dynamical and geometric effects.
- And we can predict the full two-point statistics of intrinsic alignment in redshift space to some extent.

- So, we are ready to analyze the real data to see actual cosmological constraints.
- As a first step, we consider only the dynamical constraint (RSD), but not geometric constraint (Alcock-Paczynski and BAO).

SDSS-III BOSS DR12 galaxy data

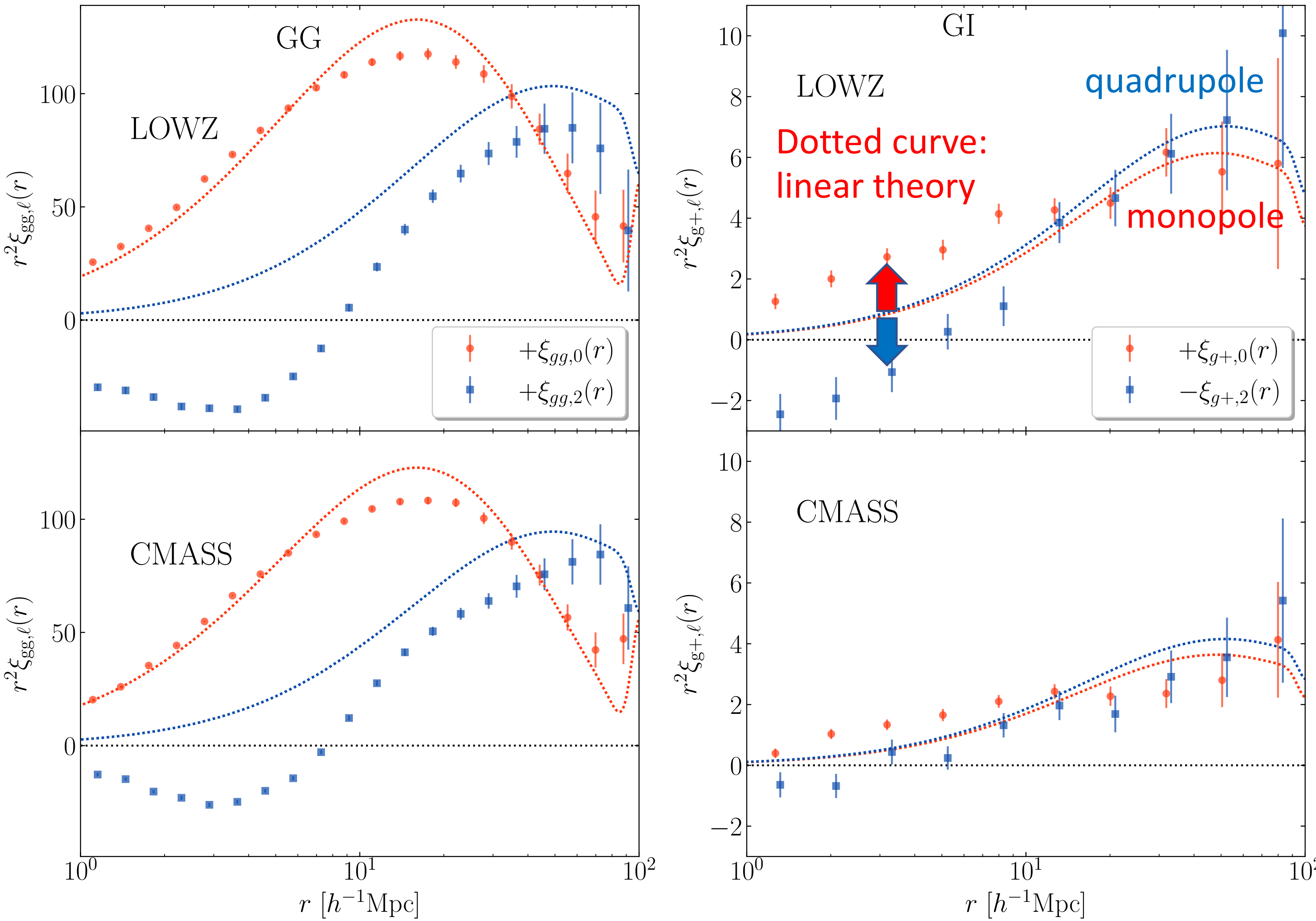
- LOWZ ($0.16 < z < 0.43$) and CMASS ($0.43 < z < 0.70$) samples
  - 353804 LOWZ galaxies
  - 761567 CMASS galaxies

- Adaptive moments are adopted for the shape estimation
  - see Bernstein & Jarvis (2002)
  - As pointed by Hirata & Seljak (2003), the PSF systematics are not properly corrected.
  - It affects the amplitude of the IA measurements (namely, b_K or A_{IA} parameters) that are nuisance parameters for cosmological analysis
  - Also, it affects the large-scale shape of the II correlation at > 10Mpc/h (See Singh & Mandelbaum 2016) that we are not interested in because they are noisy.

$$\begin{pmatrix} e_+ \\ e_- \end{pmatrix} = \frac{1-q^2}{1+q^2} \begin{pmatrix} \cos 2\theta \\ \sin 2\theta \end{pmatrix}$$

- Axis ratio q is set to $q = 0$, which further affects the value of b_K or A_{IA}.

Measurements of clustering and IA multipoles



(Exended) Landy-szalay estimators (Mandelbaum+ 2006)

$$\xi^s_{gg}(\boldsymbol{r}) = \frac{(D-R)^2}{RR} = \frac{DD-2DR+RR}{RR}$$

$$\xi_{g+}(\boldsymbol{r}) = \frac{(D-R)S_+}{RR} = \frac{DS_+ - RS_+}{RR},$$

$$\xi_{\pm}(\boldsymbol{r}) = \frac{S_+S_+ \pm S_\times S_\times}{RR},$$

The monopole and quadruple deviate from linear alignment model and their amplitude flips due to the Finger-of-god effect.

Compare with the associated Legendre basis results in Sukhdeep's talk and Kurita-san's talk

Nonlinear model of IA

- Nonlinear alignment + Finger-of-God model

$$\xi^s_X(\boldsymbol{r}) = \int \frac{d^3\boldsymbol{k}}{(2\pi)^3} P^s_X(\boldsymbol{k}) e^{i\boldsymbol{k}\cdot\boldsymbol{r}}$$

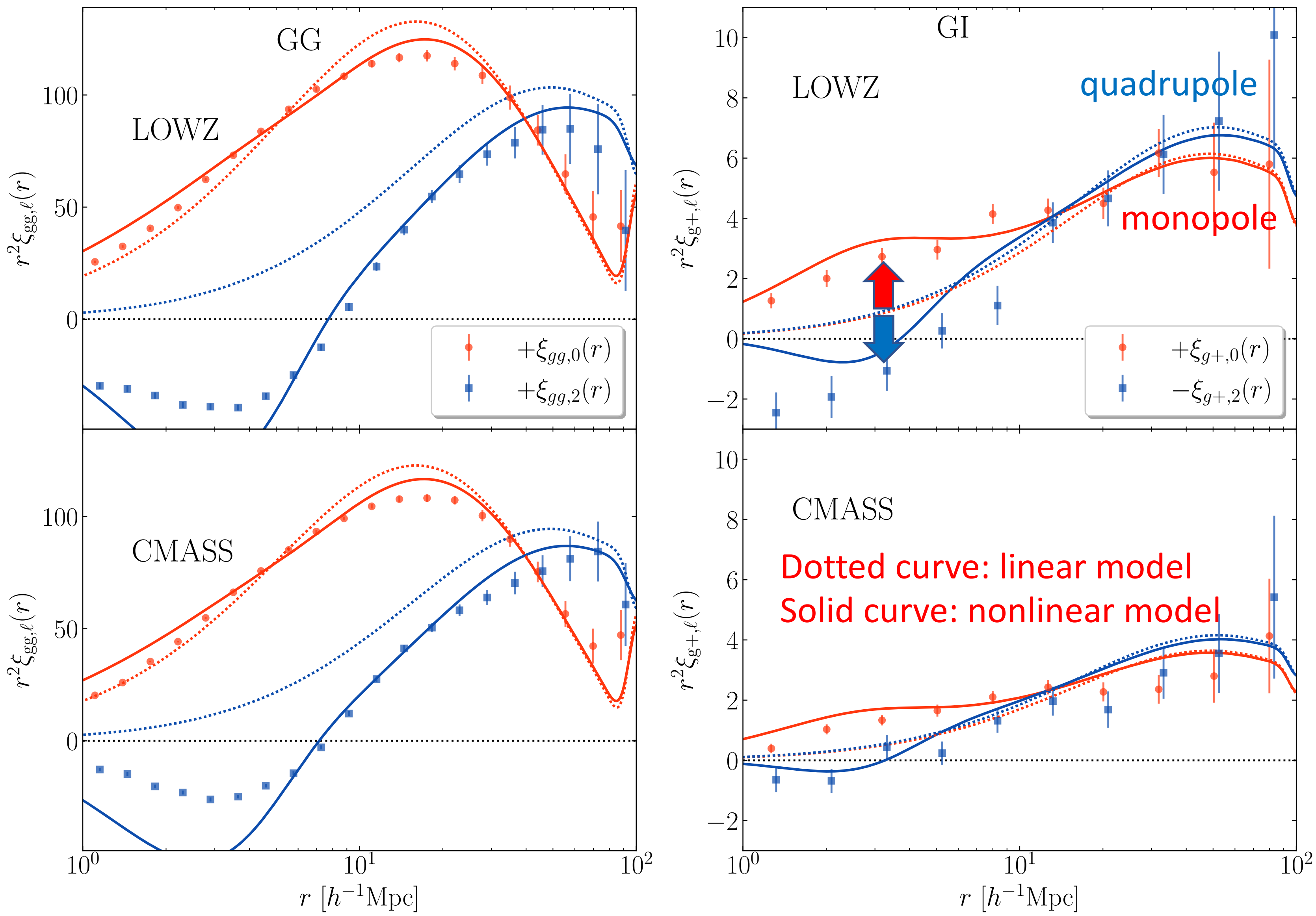
$$P^S_{gg}(\boldsymbol{k}) = \left[b_g^2 P_{\delta\delta}(k) + 2b_g f\mu^2 P_{\delta\Theta}(k) + f^2\mu^4 P_{\Theta\Theta}(k)\right] D^2_{\rm FoG}(k\mu;\sigma_v)$$ (Scoccimarro 2004)

$$P^S_{g+}(\boldsymbol{k}) = -b_K \left\{b_g P_{\delta\delta}(k) + f\mu^2 P_{\delta\theta}(k)\right\} D_{\rm FoG}(k\mu;\sigma_v)$$

Finger-of-God damping factor: $D_{\rm FoG}(k\mu;\sigma_v) = \exp\left\{-(k\mu\sigma_v)^2/2\right\}$

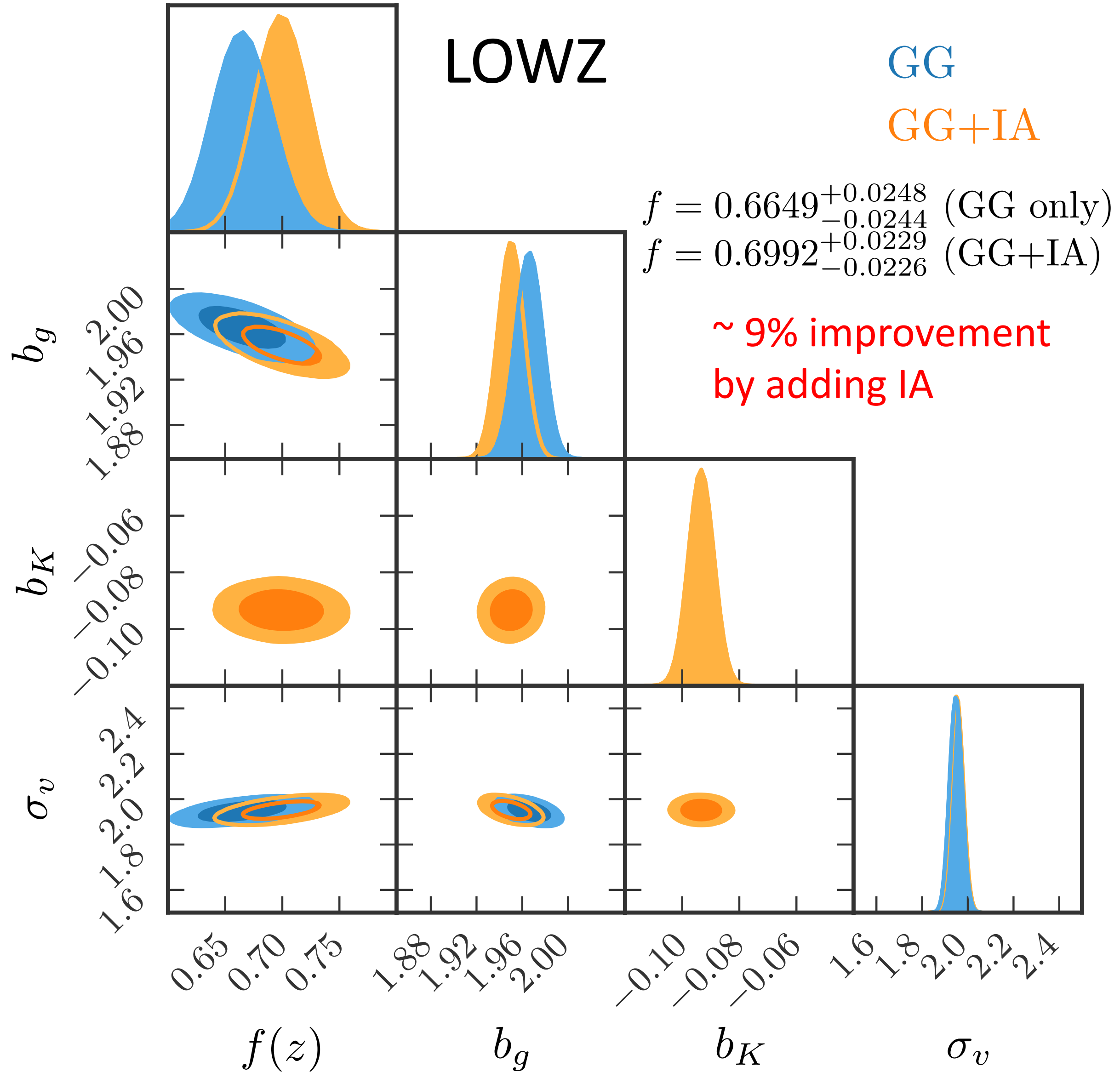
- Unlike the Associate Legendre basis (P_{lm}), the multipole expansion of the non-linear correlation function with the Gaussian damping factor (P_l) has infinite terms.
- We thus terminate the expansion at 12th order of the Associated Legendre polynomials ($P_{12,\pm 2}$).

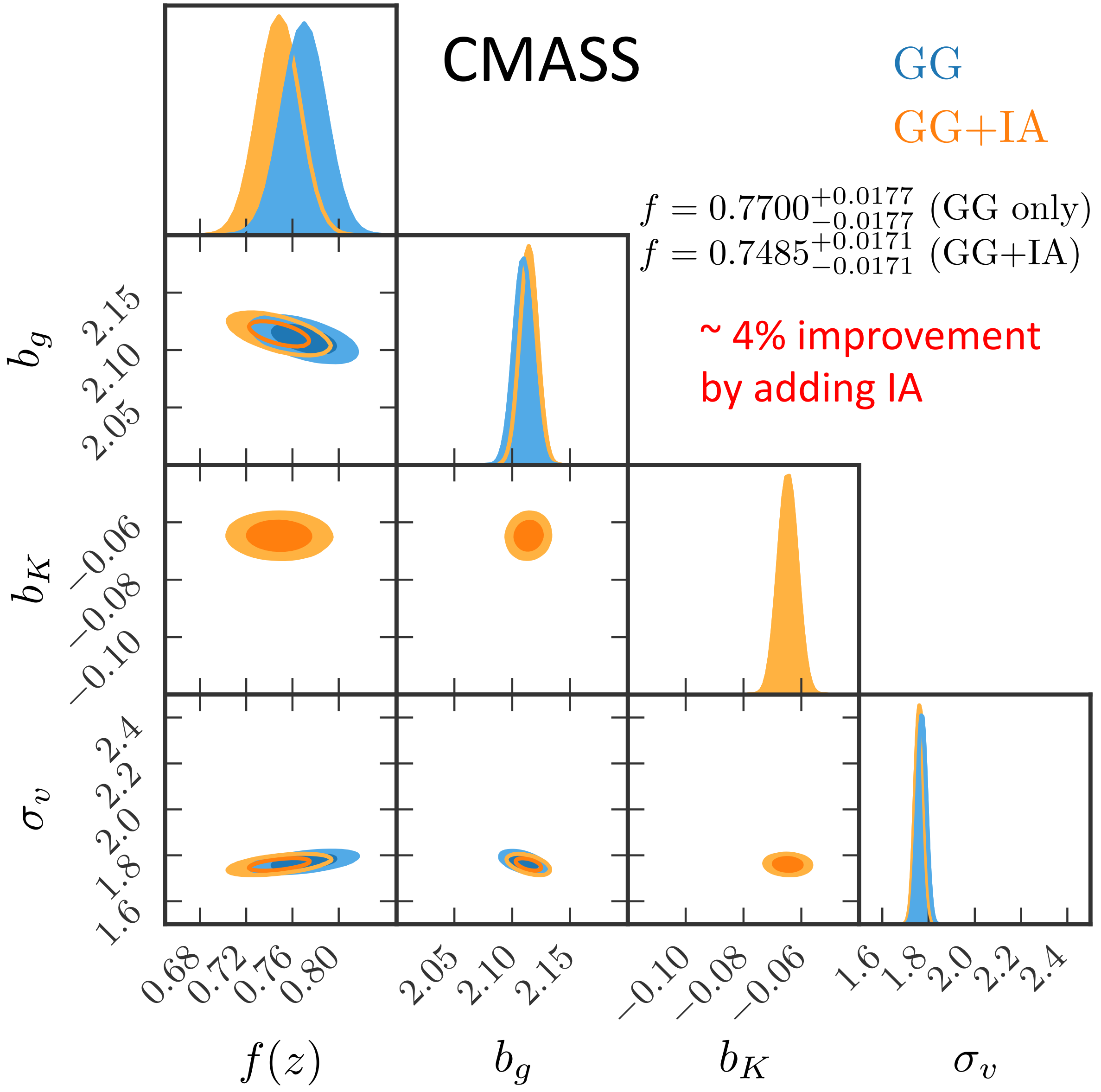
Measurements of clustering and IA statistics



- The nonlinear model extends the agreement with the measurements to smaller scales.
- For the likelihood analysis, we use the GG and GI measurements at 5 < r < 100 h^{-1}Mpc, and II measurements at 5 < r < 30 h^{-1}Mpc.

Dynamical constraints





Conclusions and discussion

- Using the SDSS BOSS LOWZ and CMASS galaxy samples, we showed that the growth rate constraint can be improved by adding the measurements of galaxy intrinsic alignment to the conventional clustering measurement.
- The improvement largely depends on the amplitude of IA (b_K).
- A new method of estimating the halo IA from ELG will be useful (Jingjing+ 2021).
- Or consider the alignment of galaxy clusters (Jingjing's and Ishikawa-san's talks)
- We have not considered the Alcock-Paczynski (AP) and geometric distortion effect yet. Taking into account the AP effect would enhance the cosmological return from intrinsic alignment measurements.