

YITP-W-22-16 Workshop on

# New Frontiers in Cosmology with the Intrinsic Alignments of Galaxies

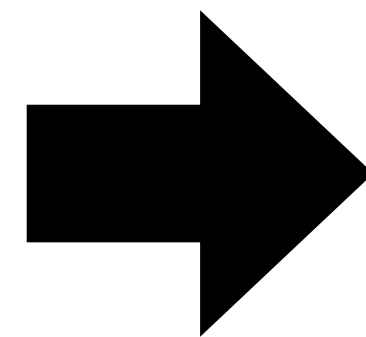
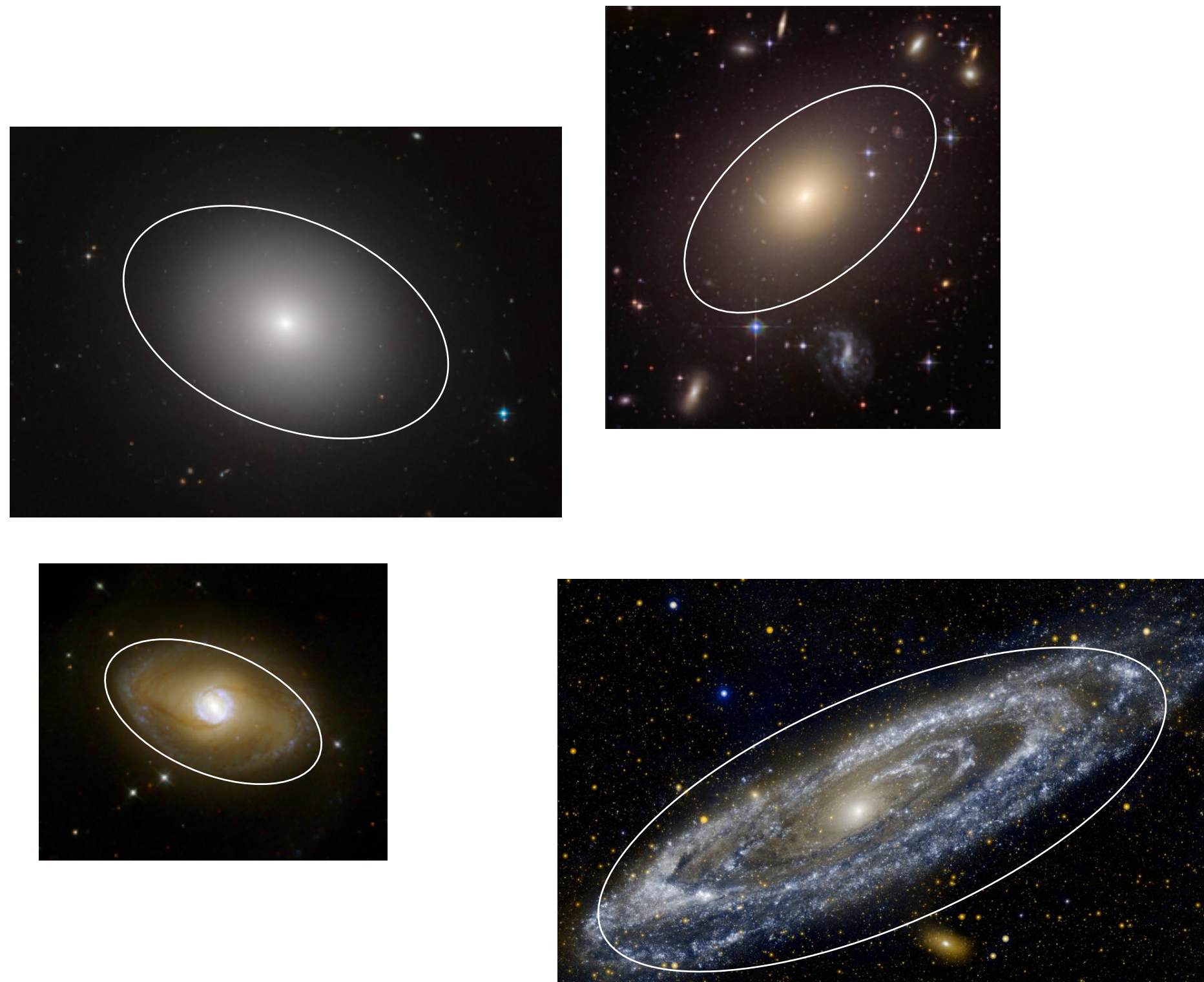
December 5—9, 2022

Panasonic auditorium at YITP

& Online

# Focus of this workshop

Implication of intrinsic alignments/shapes of galaxies to cosmological science



Test of fundamental hypothesis

Novel cosmological probe

Gravitational waves  $\Omega_{\text{GW}}$

Primordial non-Gaussianity  $f_{\text{NL}}$

Primordial chirality

Cosmological parameters

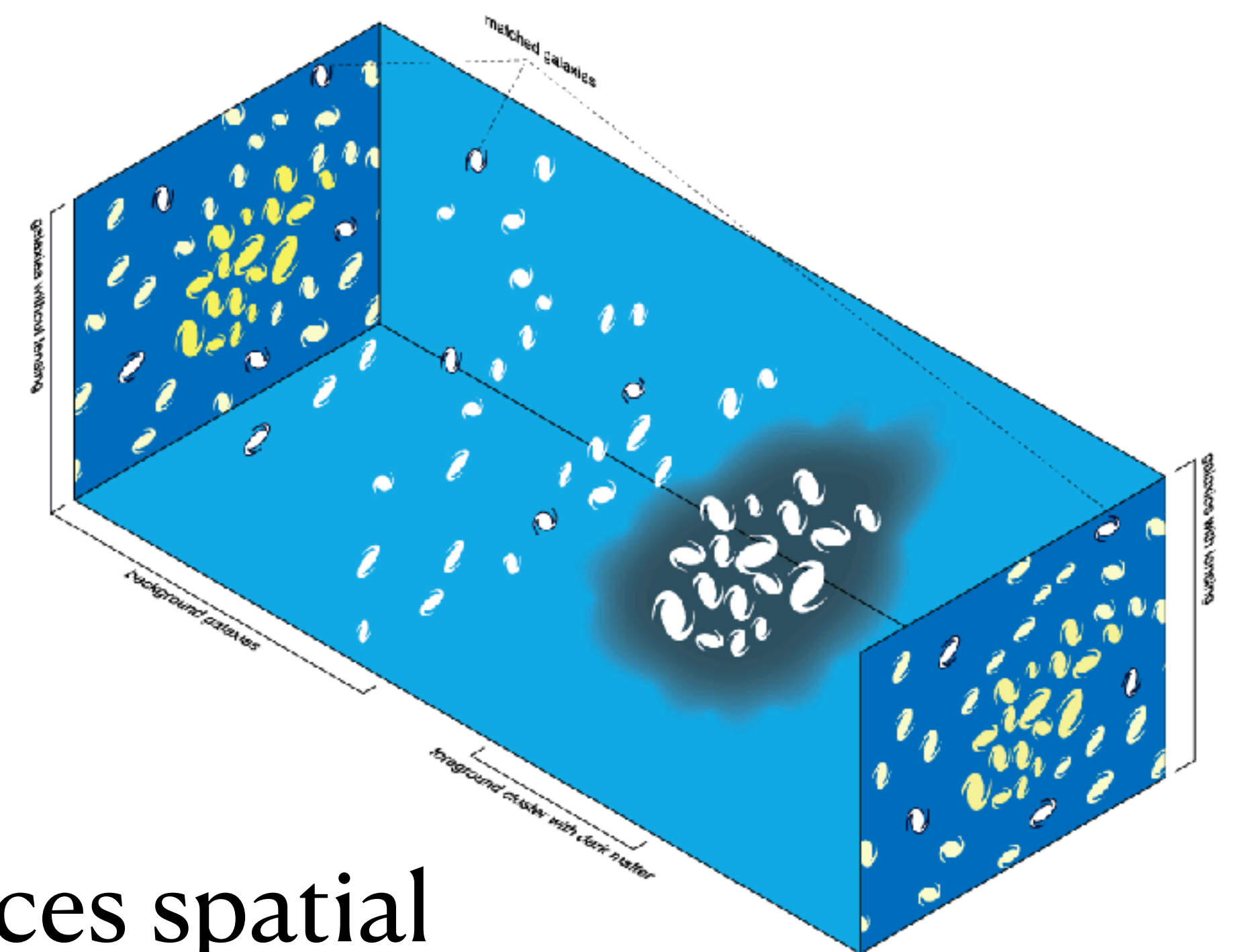
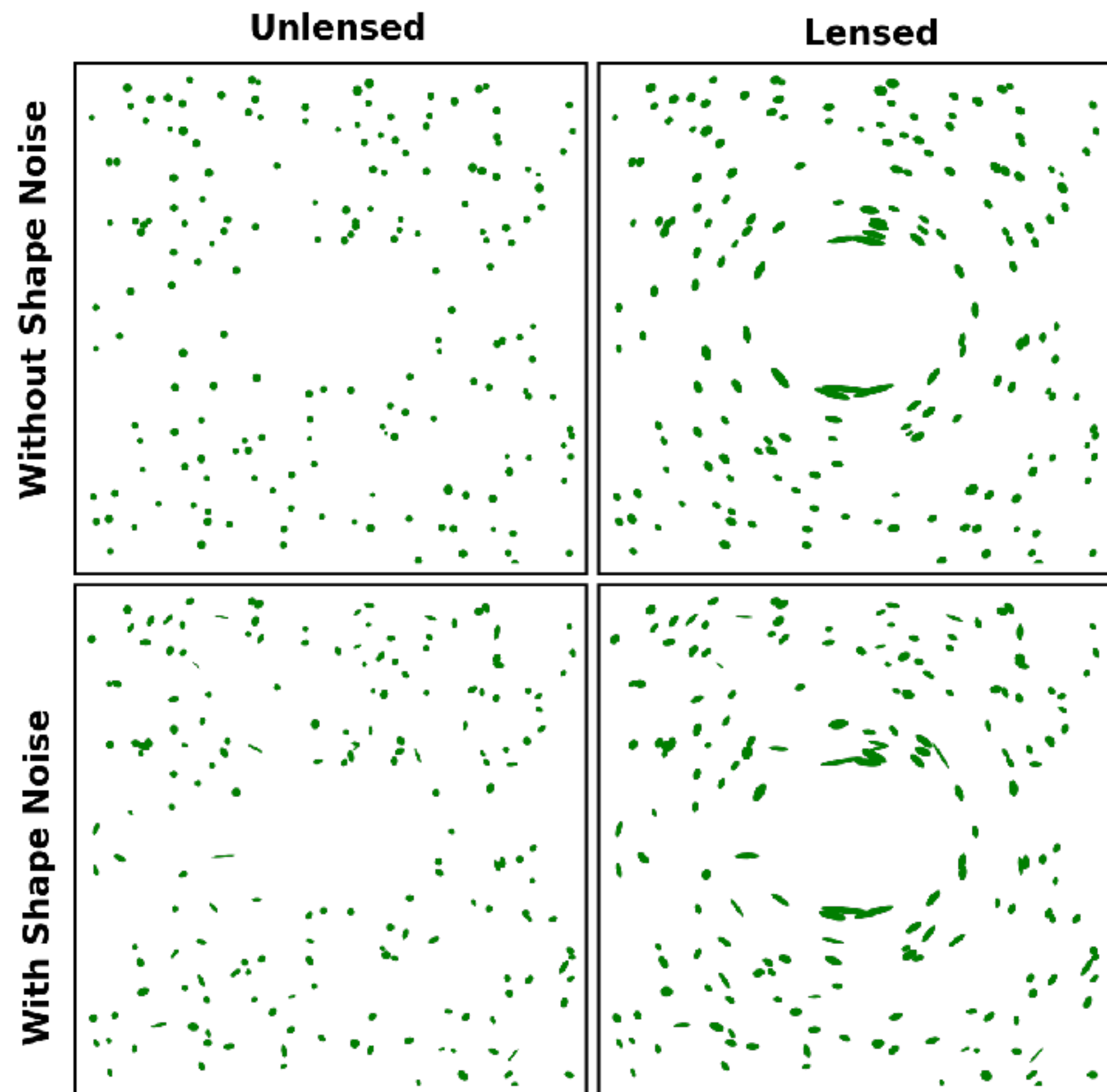
$$H_0 \quad S_8 = \sigma_8 (\Omega_m/0.3)^{1/2}$$

$$w_{\text{DE}}(a) = w_0 + w_1(1 - a)$$

Exchange ideas and discuss recent progress  
and perspective on future galaxy surveys

# Galaxy shape & cosmology

Shapes of distant galaxies as background light sources have now been extensively used to measure the **weak lensing effect**

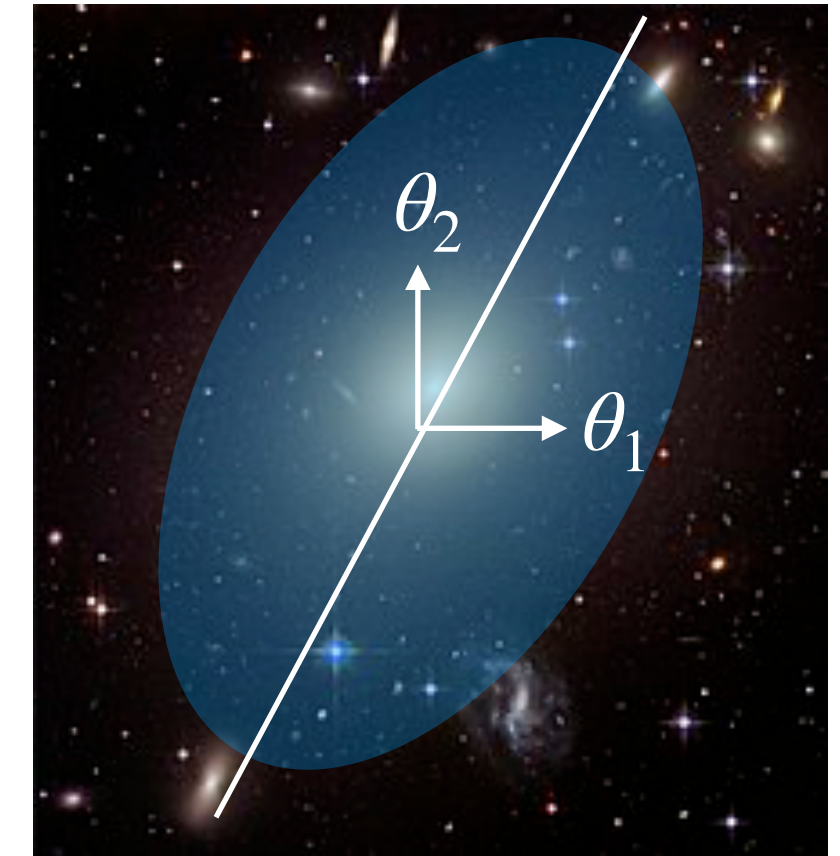


Lensing induces spatial correlations between widely separated galaxy shapes

# Galaxy shape & cosmology

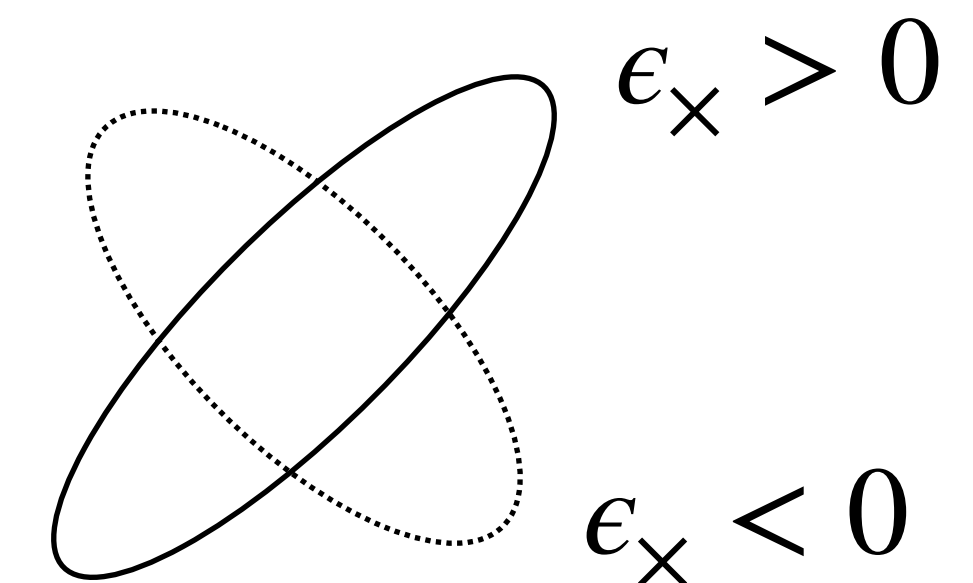
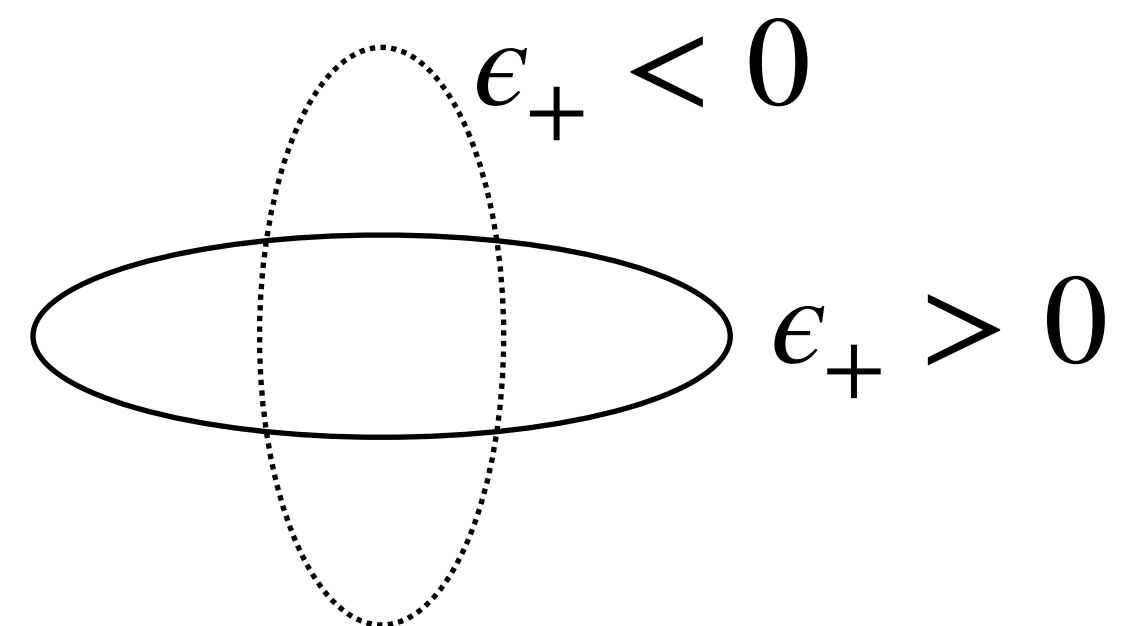
Quadrupole moment  
of galaxy image

$$q_{ij}^{\text{obs}} \equiv \frac{\int d^2\theta I_{\text{obs}}(\theta) \theta_i \theta_j}{\int d^2\theta I_{\text{obs}}(\theta)} \quad (i, j = 1, 2)$$



Ellipticity :

$$\epsilon_+ \equiv \frac{q_{11}^{\text{obs}} - q_{22}^{\text{obs}}}{q_{11}^{\text{obs}} + q_{22}^{\text{obs}}}, \quad \epsilon_x \equiv \frac{2q_{12}^{\text{obs}}}{q_{11}^{\text{obs}} + q_{22}^{\text{obs}}}$$



# Galaxy shape & cosmology

Non-zero ellipticity of distant galaxy consists of two contributions:

$$\epsilon_a \simeq \gamma_a^I + 2g_a \quad (a = + \text{ or } \times)$$

$$g_a \equiv \frac{\gamma_a}{1 - \kappa} \quad (\ll 1)$$

Reduced shear

Intrinsic alignment (IA)

Lensing

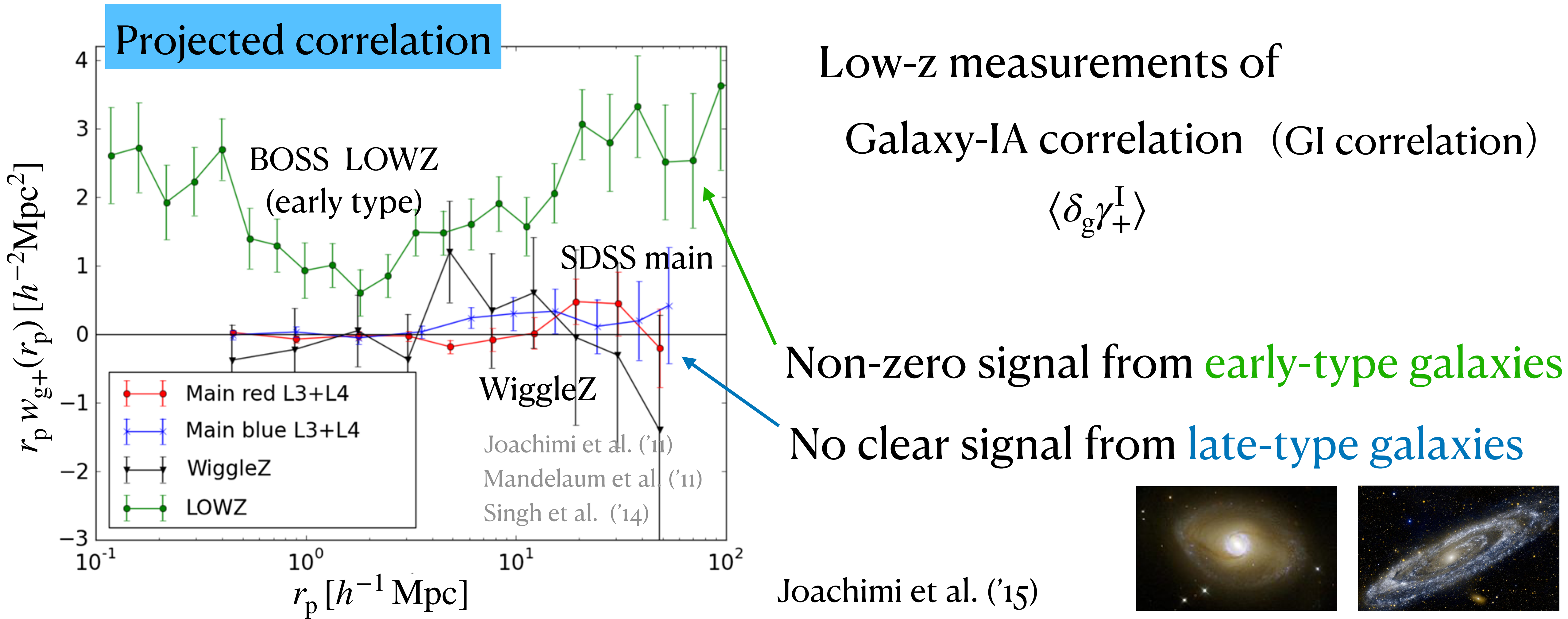
Lensing induces non-zero spatial correlation → A clue to detect lensing signal

*However,* IA can have non-zero spatial correlation

(contaminant of lensing measurement)

# Observations of IA: GI correlation

Behaviors of IA correlations crucially depend on galaxy type



# Alignment mechanisms

e.g, Kiessling et al. ('15)

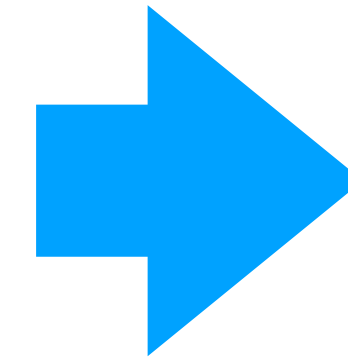
(c.f. EFT description by Vlah et al. '20, '21)

## Tidally induced alignment

aligned along the tidal field induced by large-scale structure

$$\gamma_a^I \propto \left( \nabla_x^2 - \nabla_y^2, 2 \nabla_x \nabla_y \right) \Phi$$

Gravitational potential



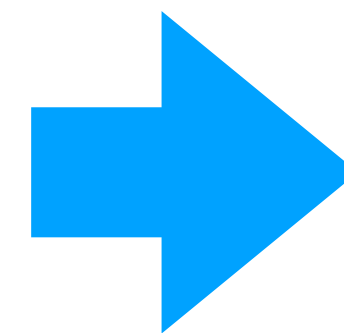
Strong correlation



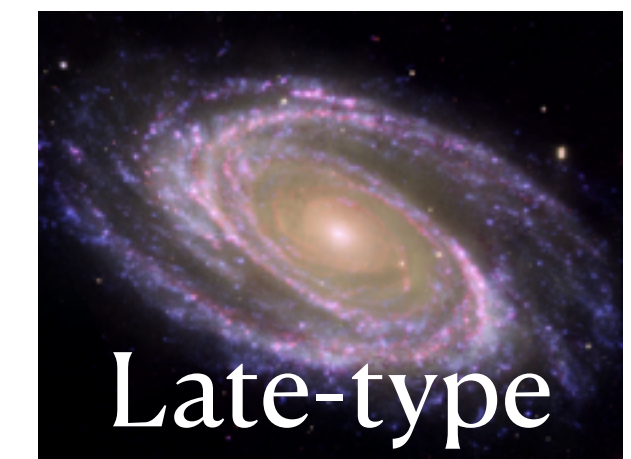
## Spin-induced alignment

aligned along the acquired angular momentum direction

$$\gamma_a^I \propto \left( T_{xk}^2 - T_{yk}^2, 2T_{xk}T_{yk} \right);$$
$$T_{ij} = \left( \nabla_i \nabla_j - \frac{1}{3} \delta_{ij}^K \nabla^2 \right) \Phi$$



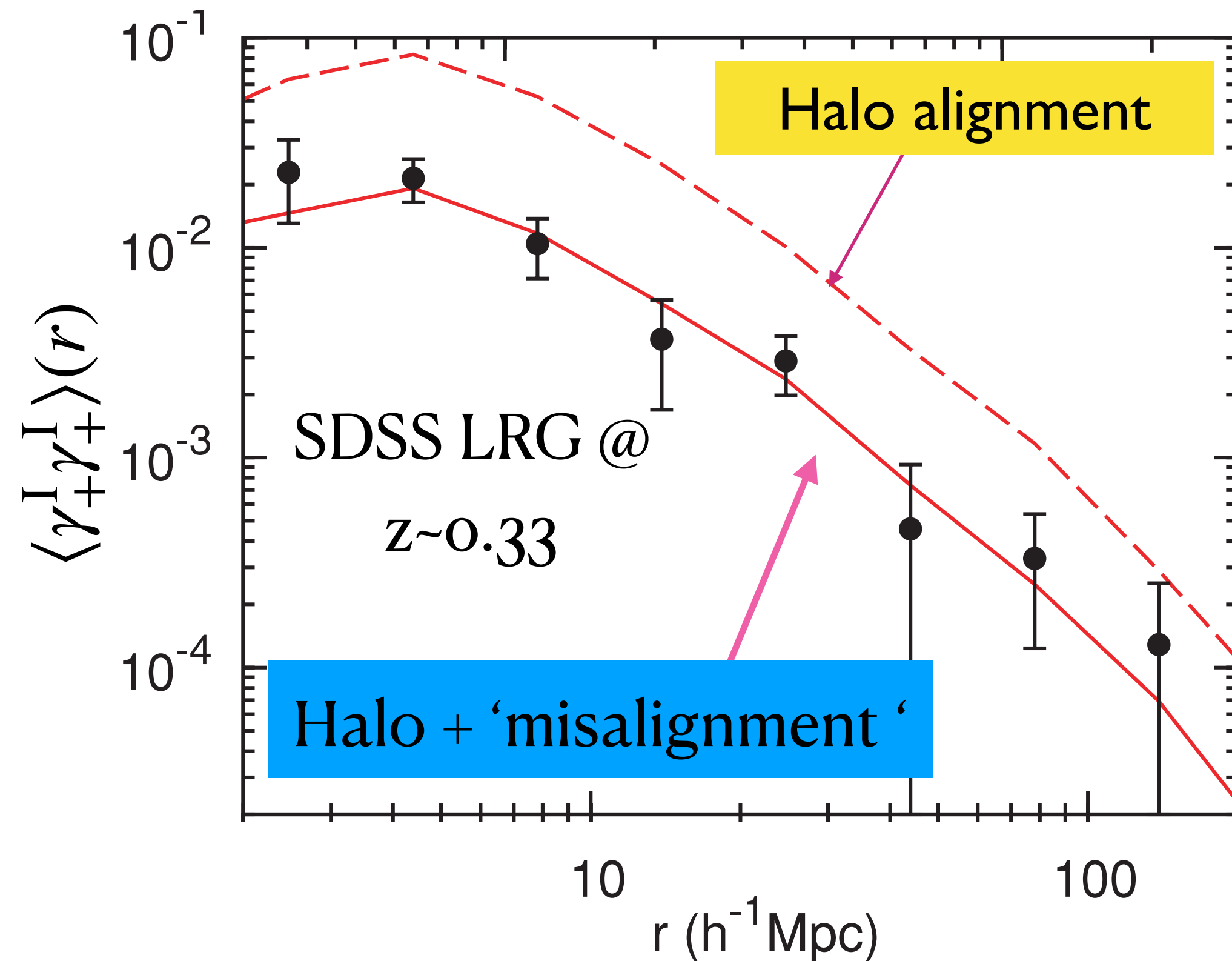
Weak correlation



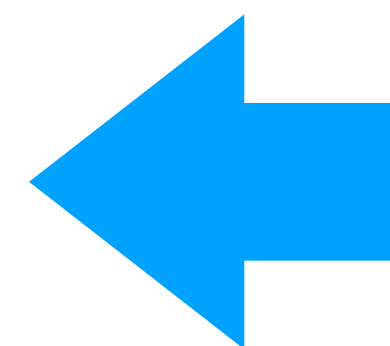
# 3D IA correlations on large scales

Using the information on angular position (2D) + redshift + shape

## 3D spatial correlation of luminous red galaxy (LRG) samples



Early-type



$\langle \gamma_+^I \gamma_+^I \rangle$  (II correlation)

Okumura, Jing & Li ('09)

Measured result resembles the halo ellipticity correlation in N-body simulations (solid & dashed)  $\rightarrow$  IA of LRG traces *tidal fields of LSS*



# Testing anisotropic IA correlations

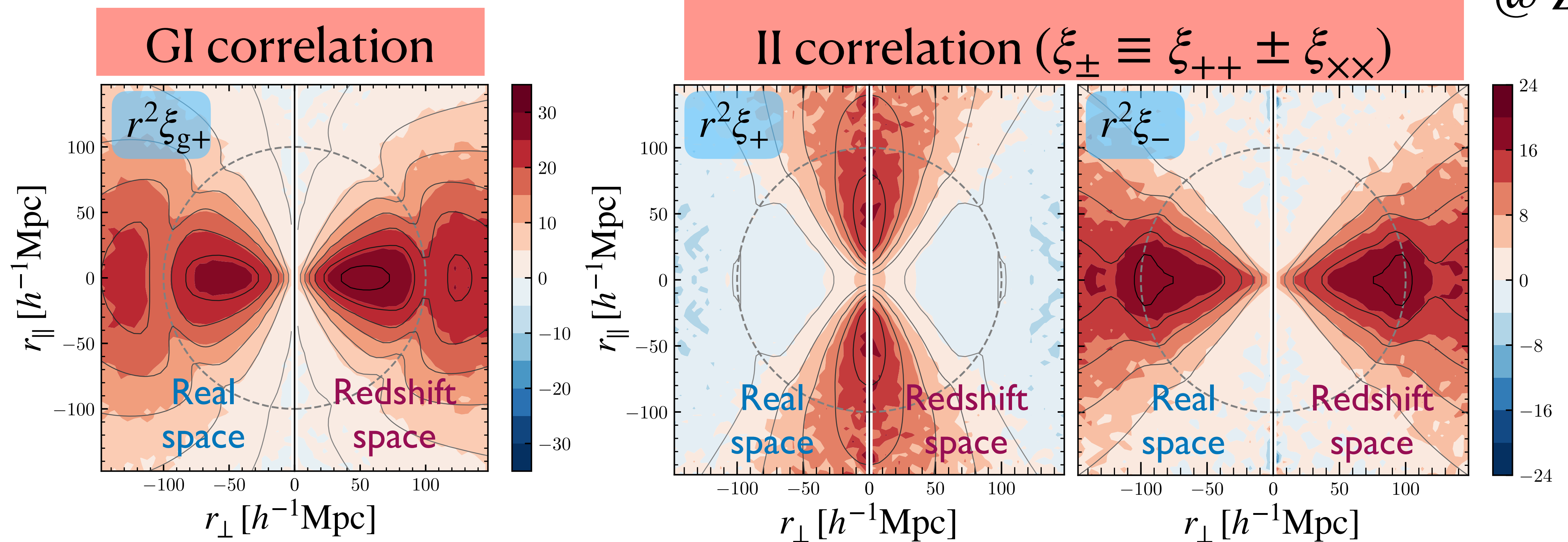
Okumura, AT & Nishimichi ('20)

Using (sub-)halos of  $M_h \geq 10^{13} h^{-1} M_\odot$ ,

(See also Kurita et al. '21)

GI & II correlations measured from cosmological  $N$ -body simulations

@  $z=0.3$

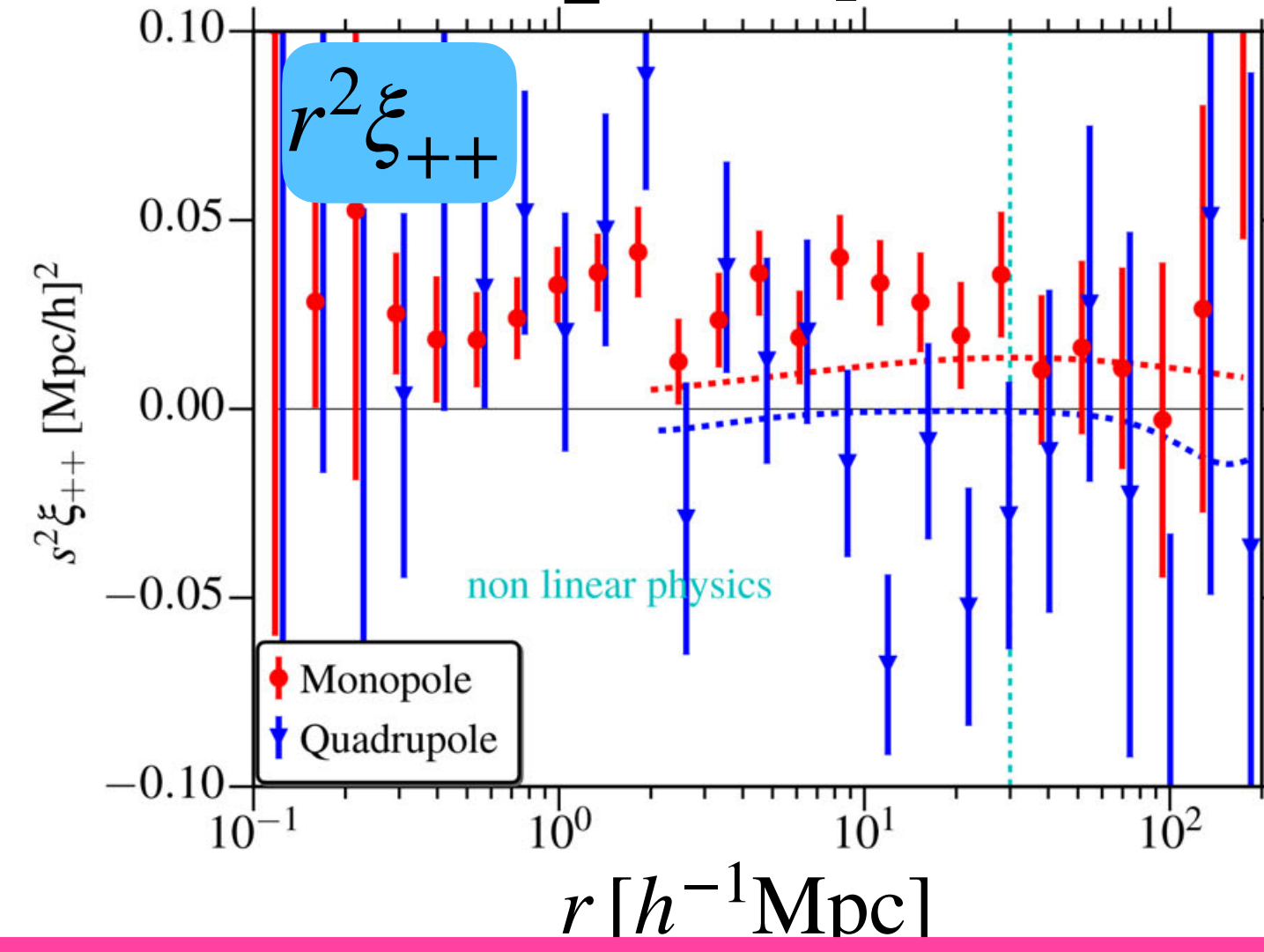
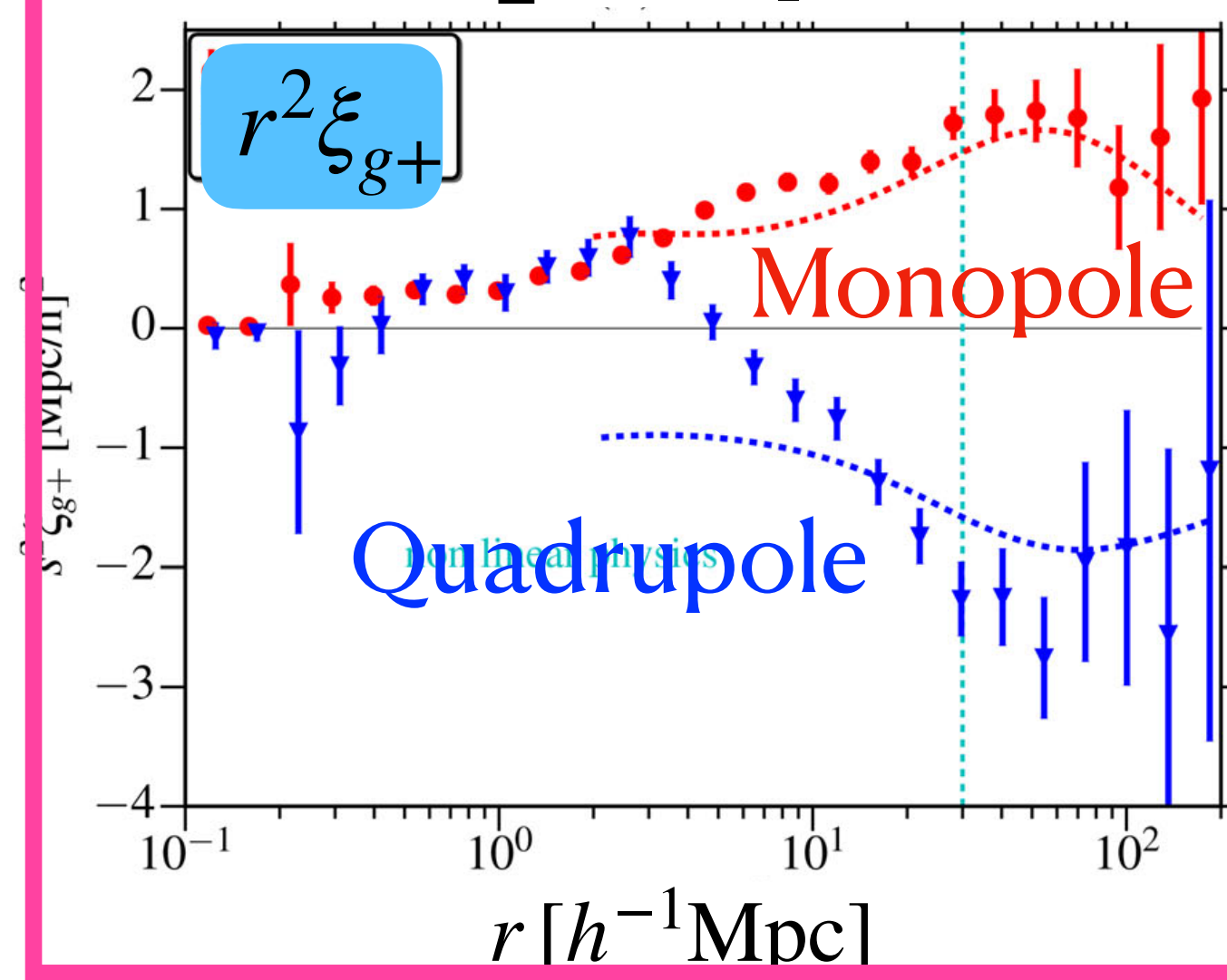
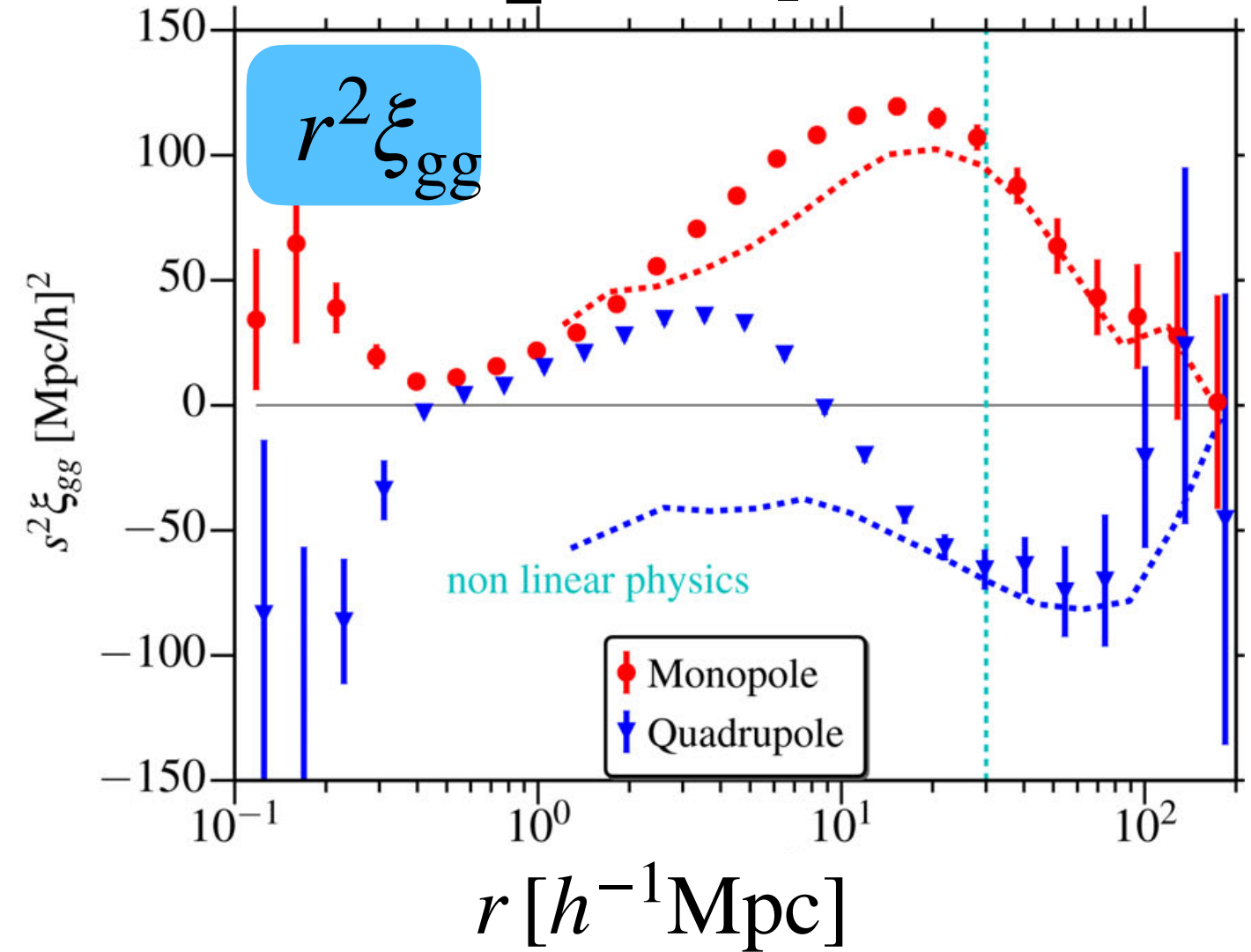
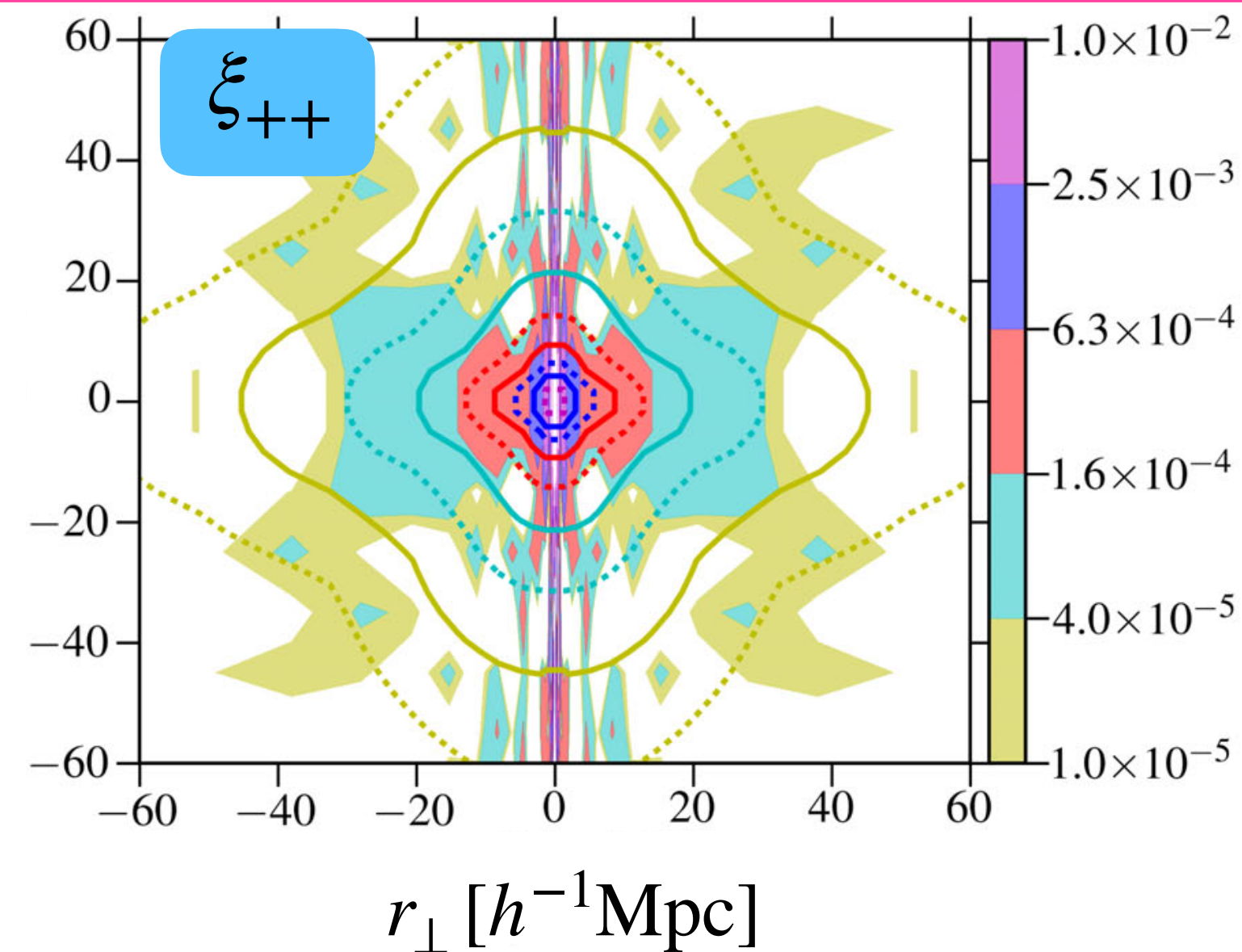
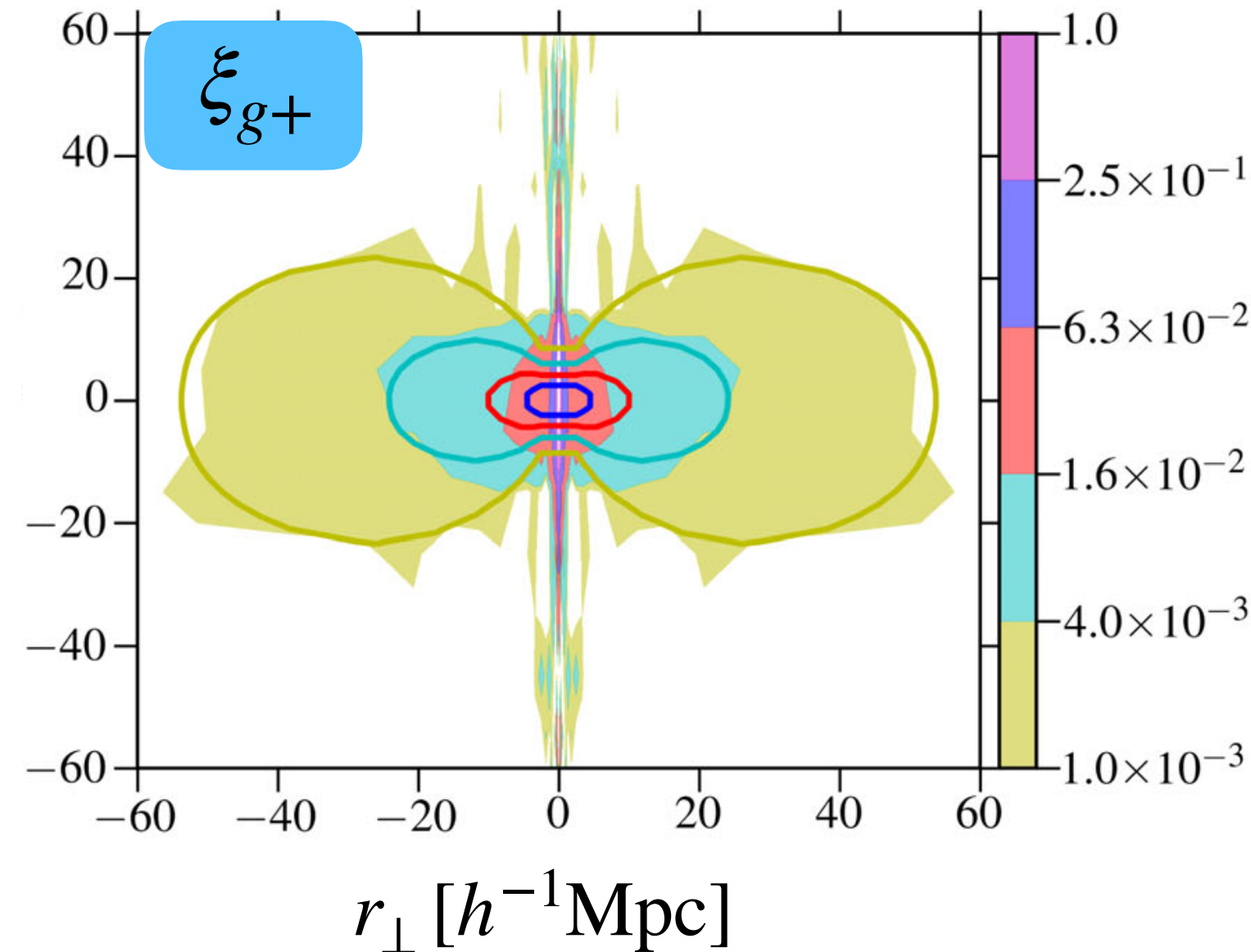
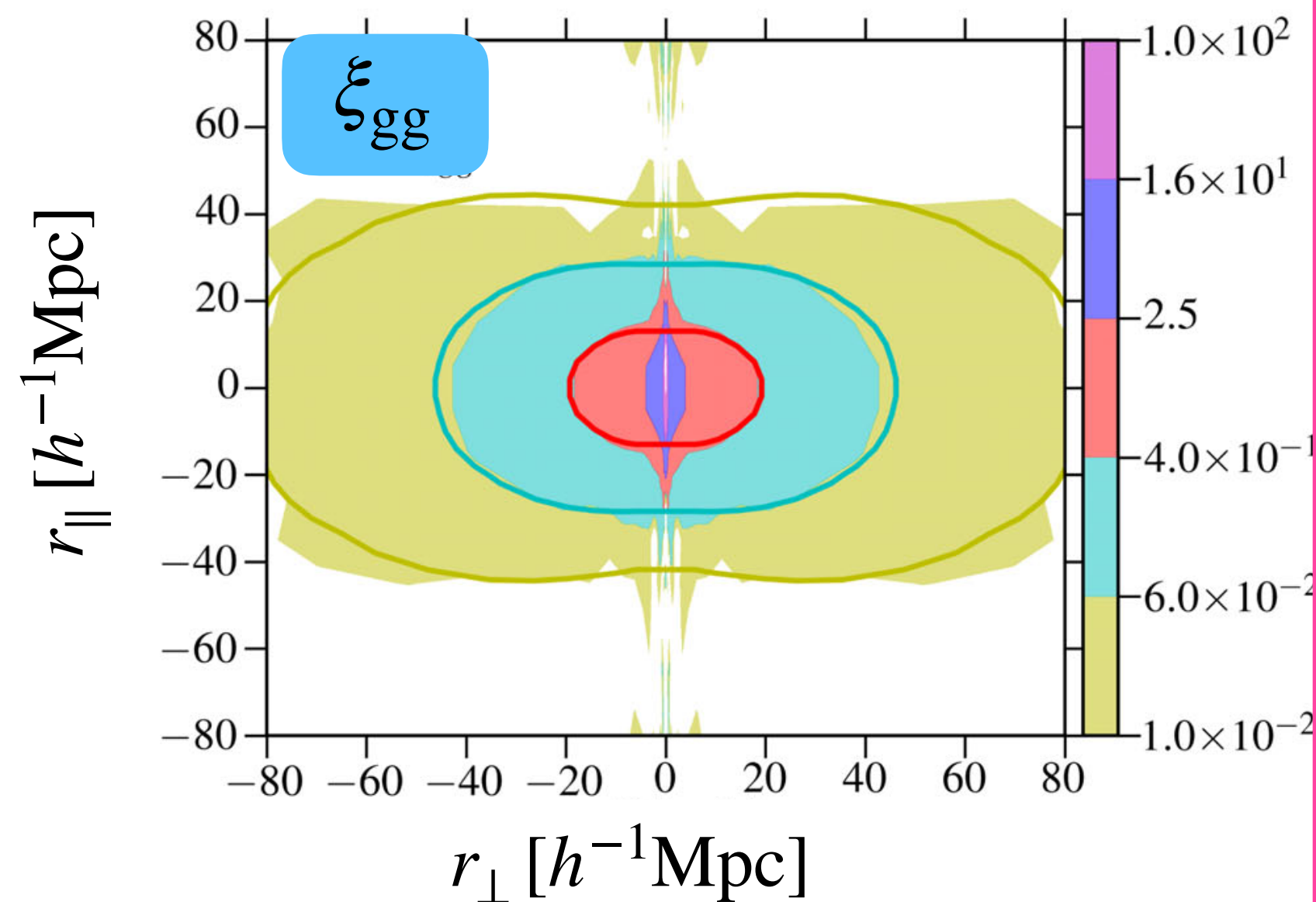


LA model predictions (solid contours) agree well with simulations !

# Measured anisotropic IA correlations!

SDSS BOSS LOWZ galaxies

Singh & Mandelbaum ('16)



# Geometric & dynamical constraints

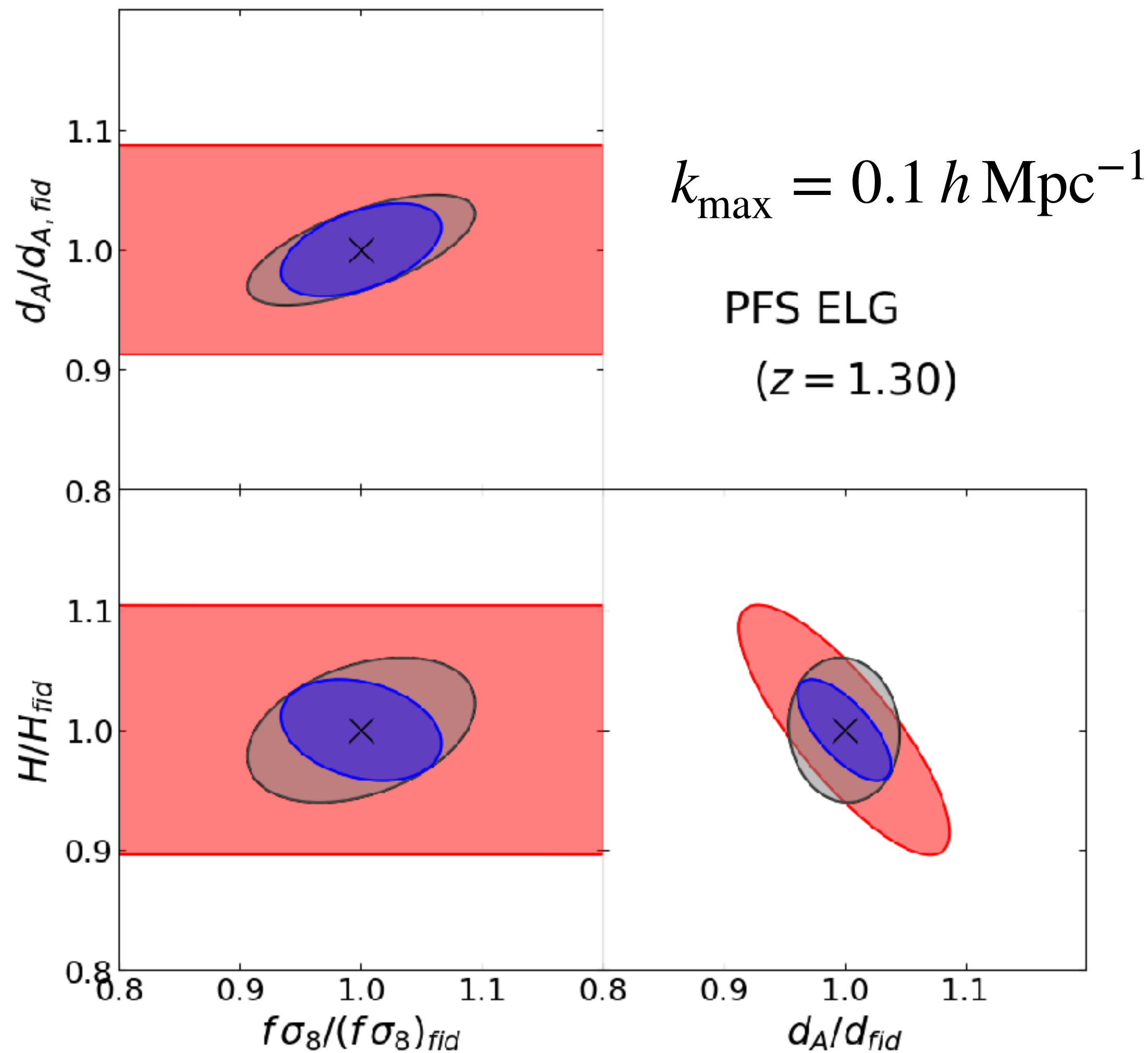
RSD & BAO can be measured  
from GI & II correlations

→  $\{d_A(z_i), H(z_i), f\sigma_8(z_i)\}$

Okumura & AT ('22)

AT & Okumura ('20)

(Chisari & Dvorkin '13  
for an early work)



*Fisher matrix forecast*

GG : galaxy clustering

II : IA statistics

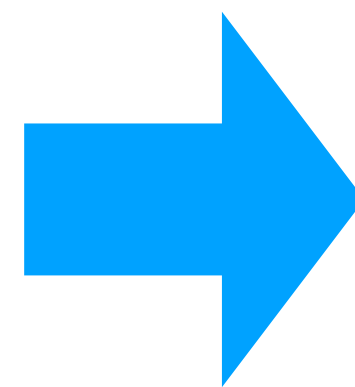
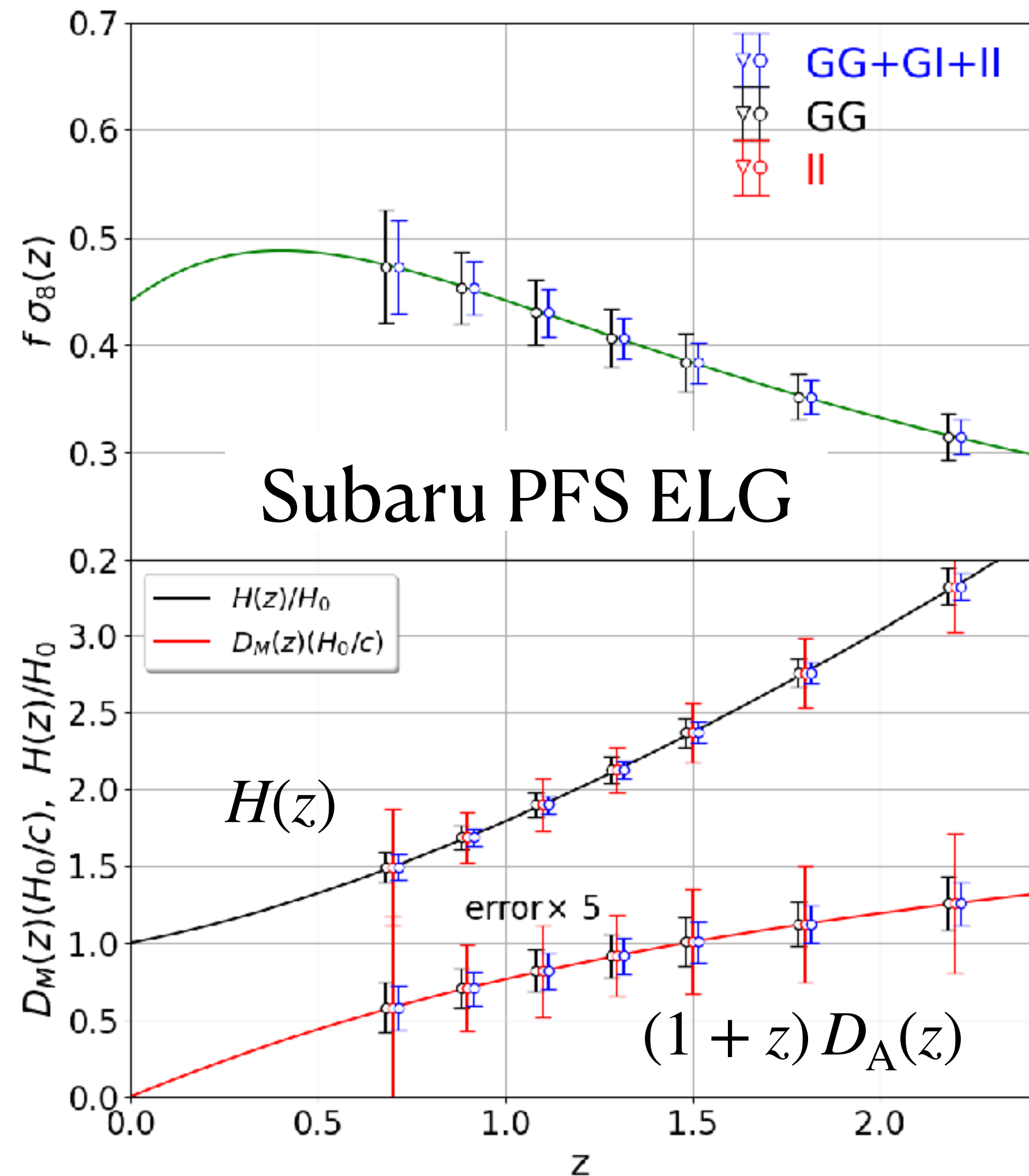
GG+GI+II : both combined

Combing conventional GG with **IA correlations** can improve constraints !

(Assuming a good IA measurement  
of ELGs based on Shi et al. '21)

# Fisher forecast from IA statistics

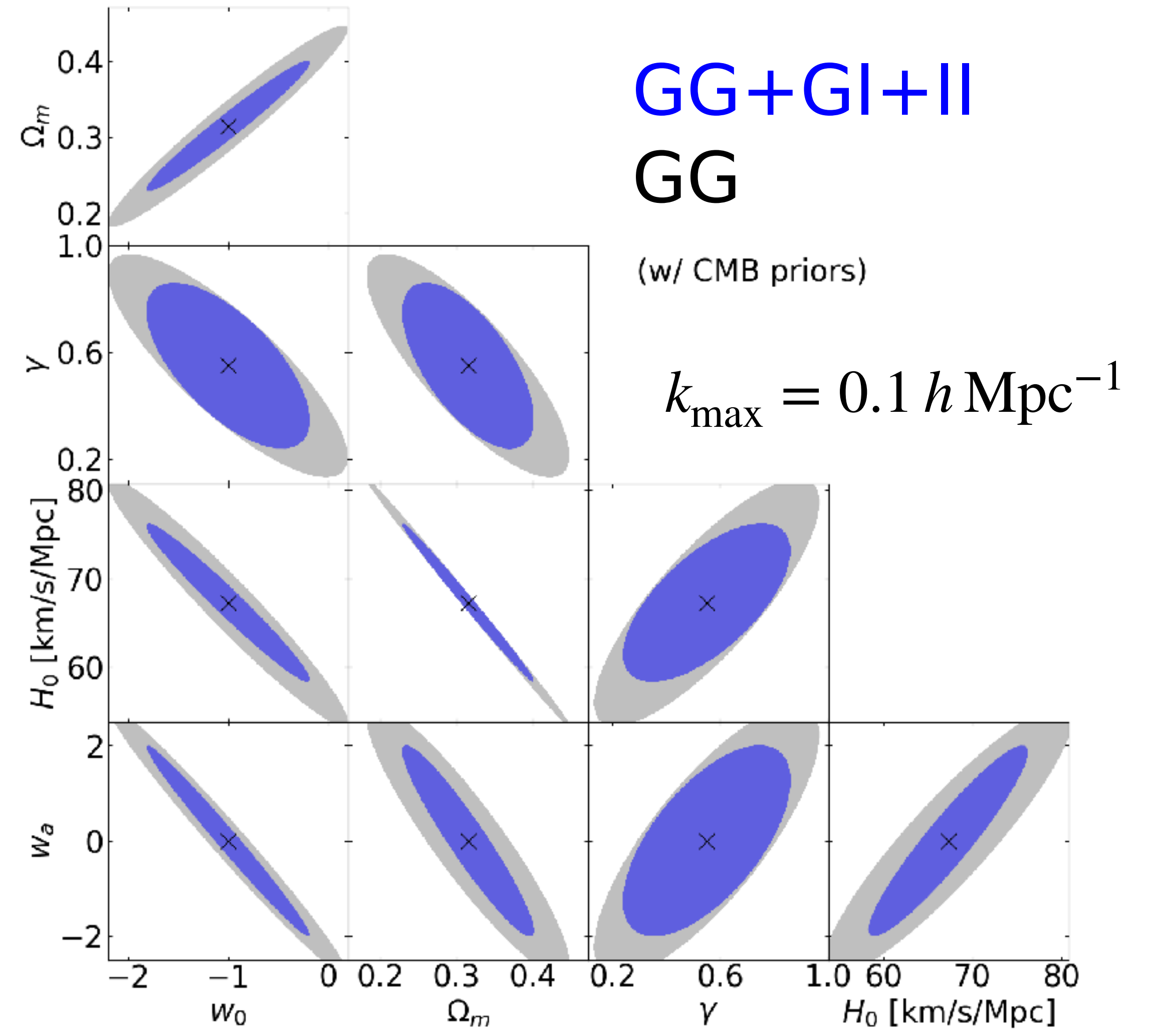
Geometric & dynamical constraints  
at  $0.6 < z < 2.3$  (from PFS ELG)



flat  $w_0 w_a \gamma$  CDM model

Okumura & AT ('22)

AT & Okumura ('20)



# Extending cosmological science with IA

**Beyond linear alignment model**

Schmitz, Hirata, Blazek & Krause ('18), Blazek, MacCrann, Troxel & Fang ('19), Vlah, Chisari & Schmidt ('20, '21)

**Testing modified gravity models with IA statistics**

Chuang, Okumura & Shirasaki ('22)

**Probing dark matter self-interaction with IA signals**

Harvey, Chisari, Robertson & McCarthy ('21)

**Synergy between imaging, spectroscopic & CMB observations**

Okumura & AT ('22)

**Imprint of relativistic effects on IA signal**

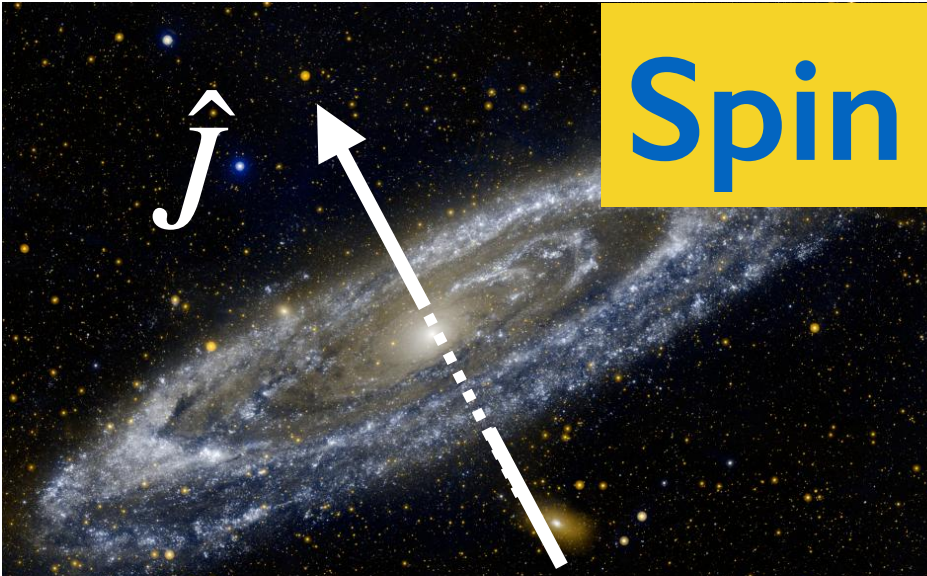
Saga et al. ('22) Inoue, Saga, Okumura & AT ('22, in prep.)

**IA statistics as a sensible primordial non-Gaussianity probe**

Schmidt, Chisari & Dvorkin ('15); Kogai, Matsubara, Nishizawa & Urakawa ('18); Kogai, Akitsu, Schmidt & Urakawa ('21); Akitsu, et al. ('21)

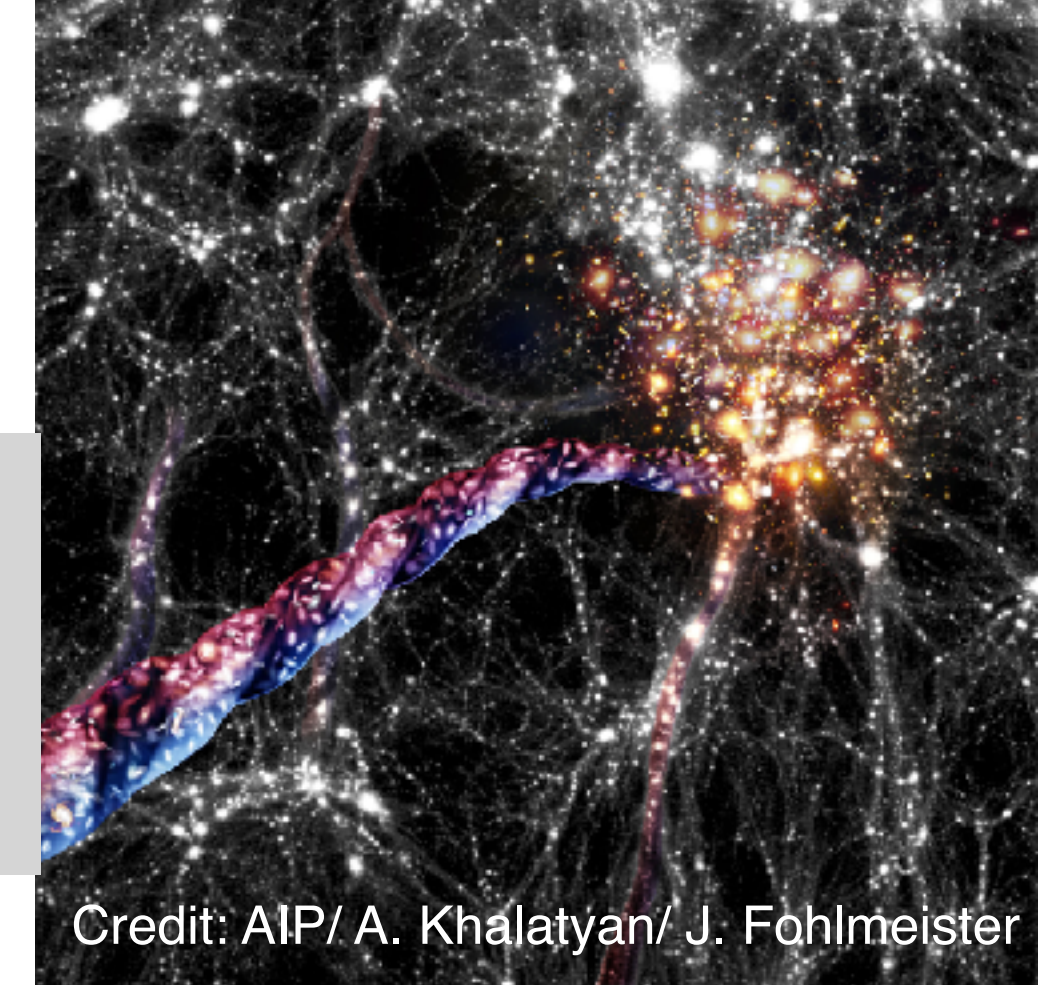
**and gravitational waves ?**

Schimit & Jeong ('12); Schimit Pajer & Zaldarriaga ('14); Akitsu, Li & Okumura ('22)



# More on IA statistics

Characterizing galaxy spins & angular momenta provides many interesting cosmological science



Credit: AIP/ A. Khalatyan/ J. Fohlmeister

**Spin-induced IA** Lee & Pen ('00, '01, '02, '08), Lee, Pen & Seljak ('00), Crittenden, Natarajan, Pen & Theuns ('01)

**Spin of cosmic filaments** Sheng, Li, Yu, Wang, Wang & Kang ('20)

**Probing primordial chirality with galaxy spins** Yu, Motloch, Pen, Yu, Wang, Mo Yang & Jing ('20)

**Spin mode reconstruction** Motloch, Pen & Yu ('21 a, b) Wu, Yu, Liao & Du ('21)

**Neutrino & galaxy spins/shape** Yu, Pen, & Wang ('19) Lee, Libeskind & Ryu ('20)

**Galaxy spins & initial conditions** Motloch, Yu, Pen & Xie ('21)

**Galaxy spins & dark energy** Lee & Libeskind ('20)

**Testing spin parity violation**

Iye, Yagi & Fukamoto ('21), Tadaki, Iye & Fukamoto ('20), Iye, Tadaki & Fukamoto ('19)

J. Lee

U-L. Pen

N. Libeskind

M. Iye

# Short history of this workshop

In 2021,

YITP international workshop on

In-person  
workshop

## New Frontiers in Cosmology with the Intrinsic alignments of galaxies

Budget 1,750,000 JPY ( $\approx 12,600$ USD  $\approx 12,000$ euro)



### Overview

Mapping the large-scale structure of the universe with galaxy surveys is a key science driver for cosmology. It enables us to probe the late-time cosmic expansion, growth of structure, and even the primordial fluctuations. So far, the spatial distribution of galaxies has long been used as the major observable, ignoring the shapes and orientations of individual galaxies. While the orientations of distant galaxy images have been established as a promising tool to measure the weak gravitational lensing, intrinsic alignments (IAs) of galaxies are thought to be a contaminant to be removed in the cosmological data analysis. However, there is growing evidence that IAs are a good tracer of the gravitational tidal field, making themselves a unique channel to access the dynamics of the large-scale matter inhomogeneities. Therefore, it is expected that the use of IAs is beneficial, and with

Nov. 30—Dec. 3, 2021

Workshop page (hidden page)

# Short history of this workshop

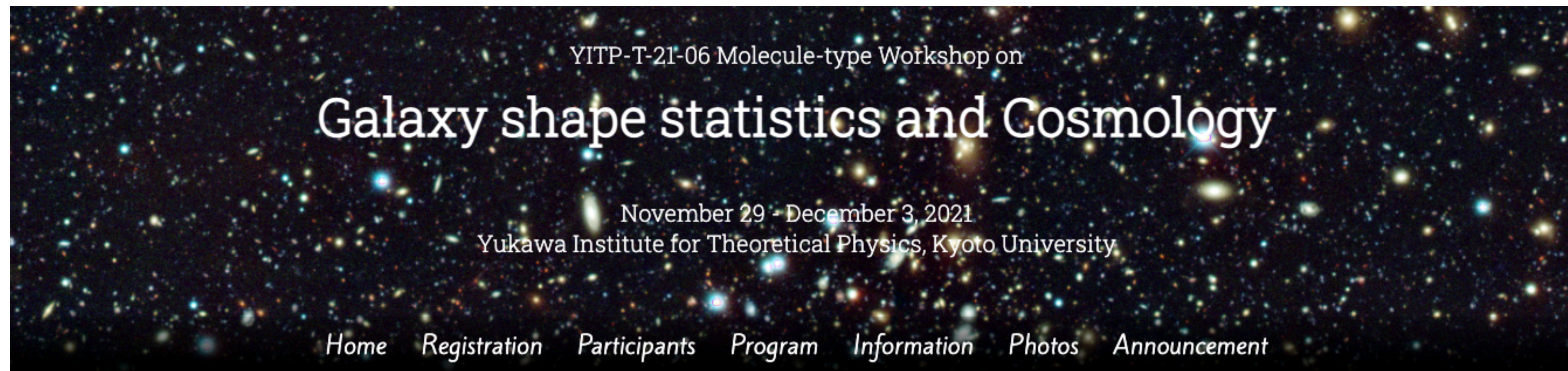
In 2021,

Molecule-type workshop on

Hybrid-type  
workshop

## Galaxy shape statistics and cosmology

allowing on-site participation only for people in Japan Budget 420,000 JPY



**37 participants**  
(onsite **12**)

### Overview

The aim of this workshop is to focus on the shape of galaxies as a potentially powerful cosmological probe, and to discuss future perspective on cosmology with large-scale structure surveys. The intrinsic galaxy shapes have been recently recognized as a good tracer of the gravitational tidal field, providing a unique channel to access the dynamics of the large-scale matter inhomogeneities. It is thus expected that the use of the intrinsic galaxy shape is beneficial, and with its

Nov. 30—Dec. 3, 2021

<https://www2.yukawa.kyoto-u.ac.jp/~iacosmology/MoleculeWorkshop/>



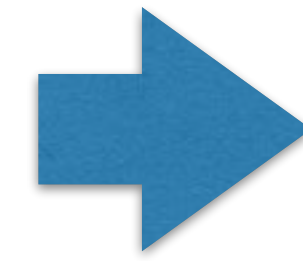
# Highlights

First evidence of high-z IA correlations

(T. Okumura)

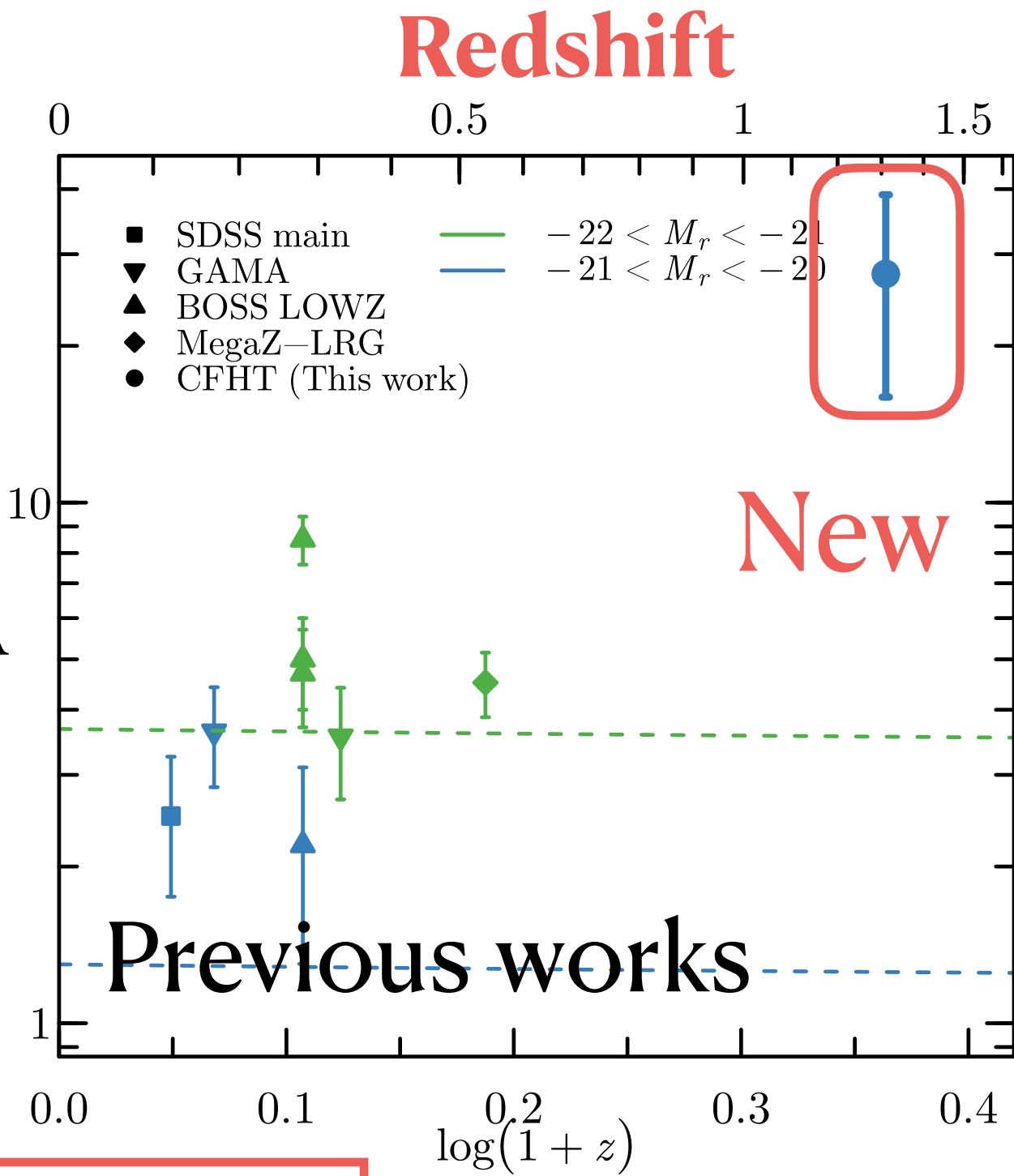
Amplitude of IA correlations

$$(A^{\text{LA}} \equiv C_1 \rho_{\text{cr}} / 0.0134)$$



$A^{\text{LA}}$

Promising for upcoming high-z surveys (DESI, PFS, Euclid,...)

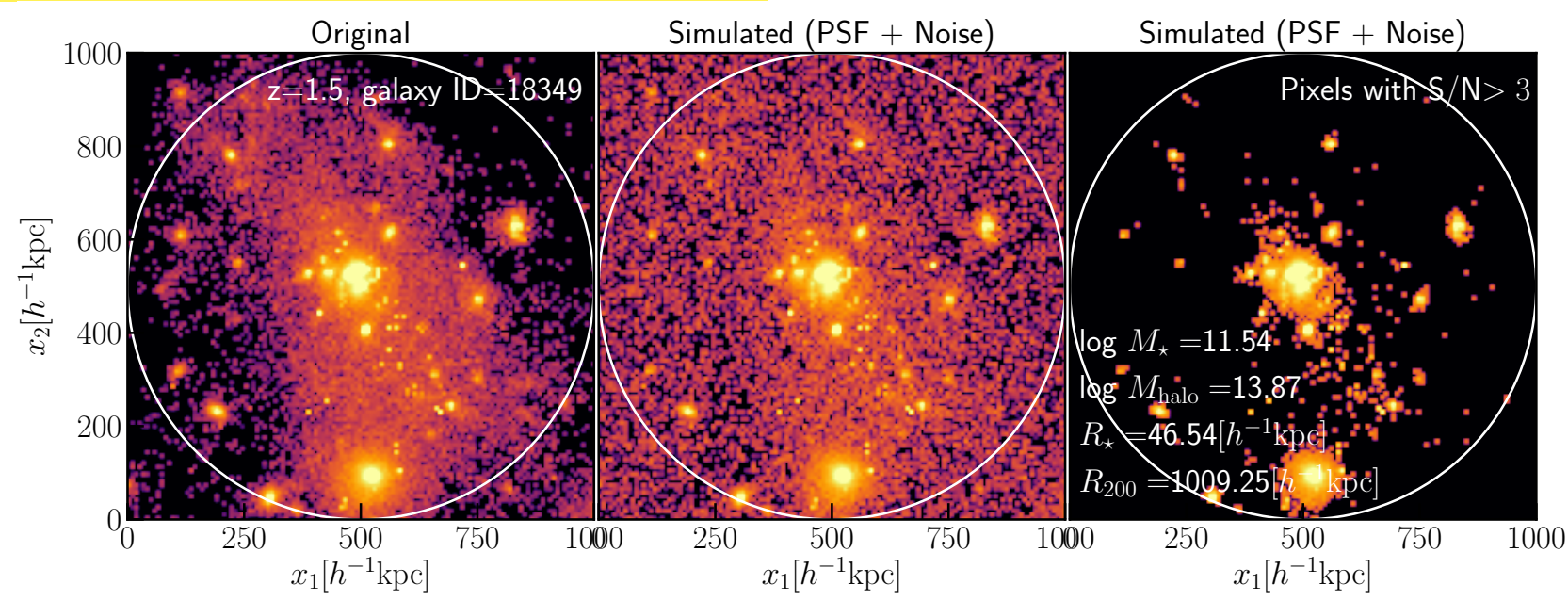


New estimator to enhance IA signals from non emission-line galaxies

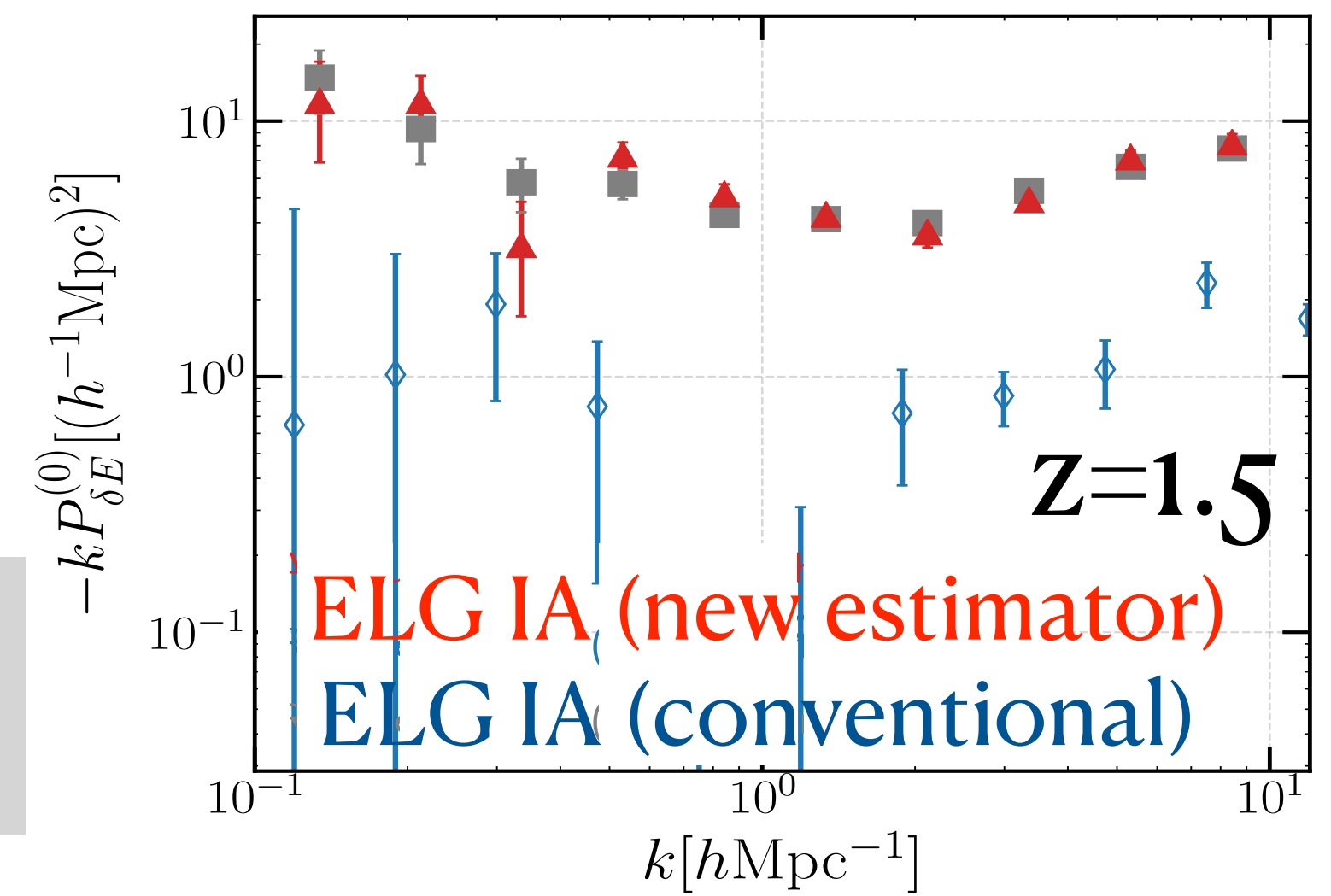
(J. Shi)

(New) aperture shape estimator

$$I_{ij}^{\text{ap}} = \frac{\sum_{n; (S/N)_{\text{pix}} > 3; r_n^{2\text{D}} \leq 500 h^{-1} \text{kpc}} f_n x_{ni} x_{nj}}{\sum_{n; (S/N)_{\text{pix}} > 3; r_n^{2\text{D}} \leq 500 h^{-1} \text{kpc}} f_n}$$

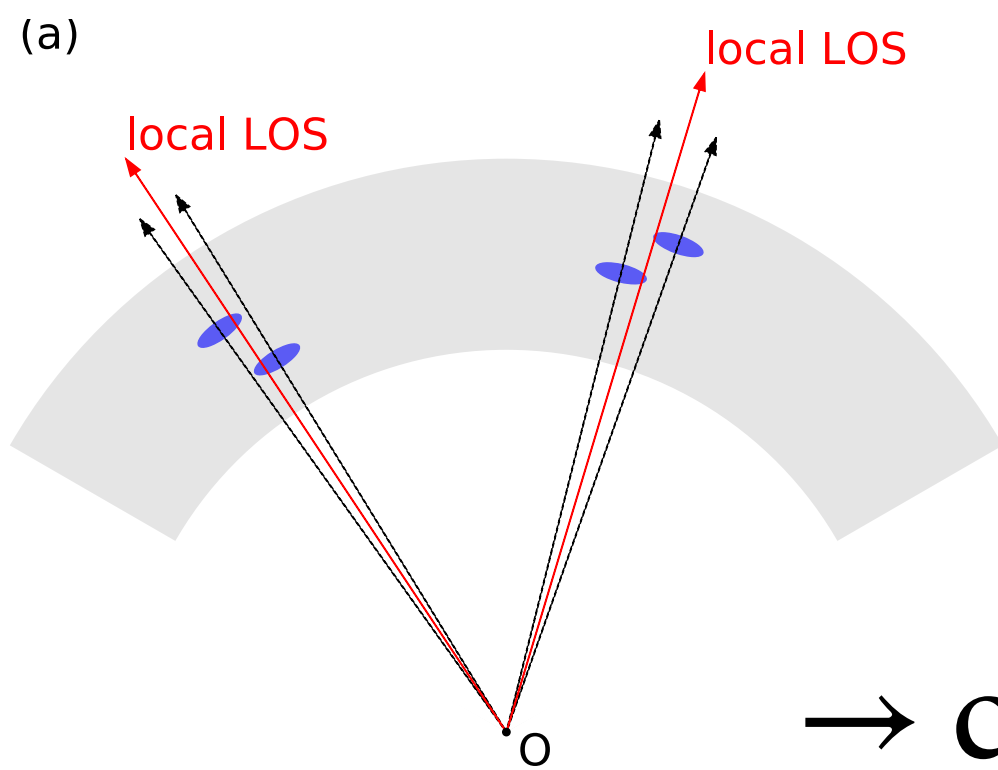


matter-IA cross spectrum  
(monopole) @ z=1.5



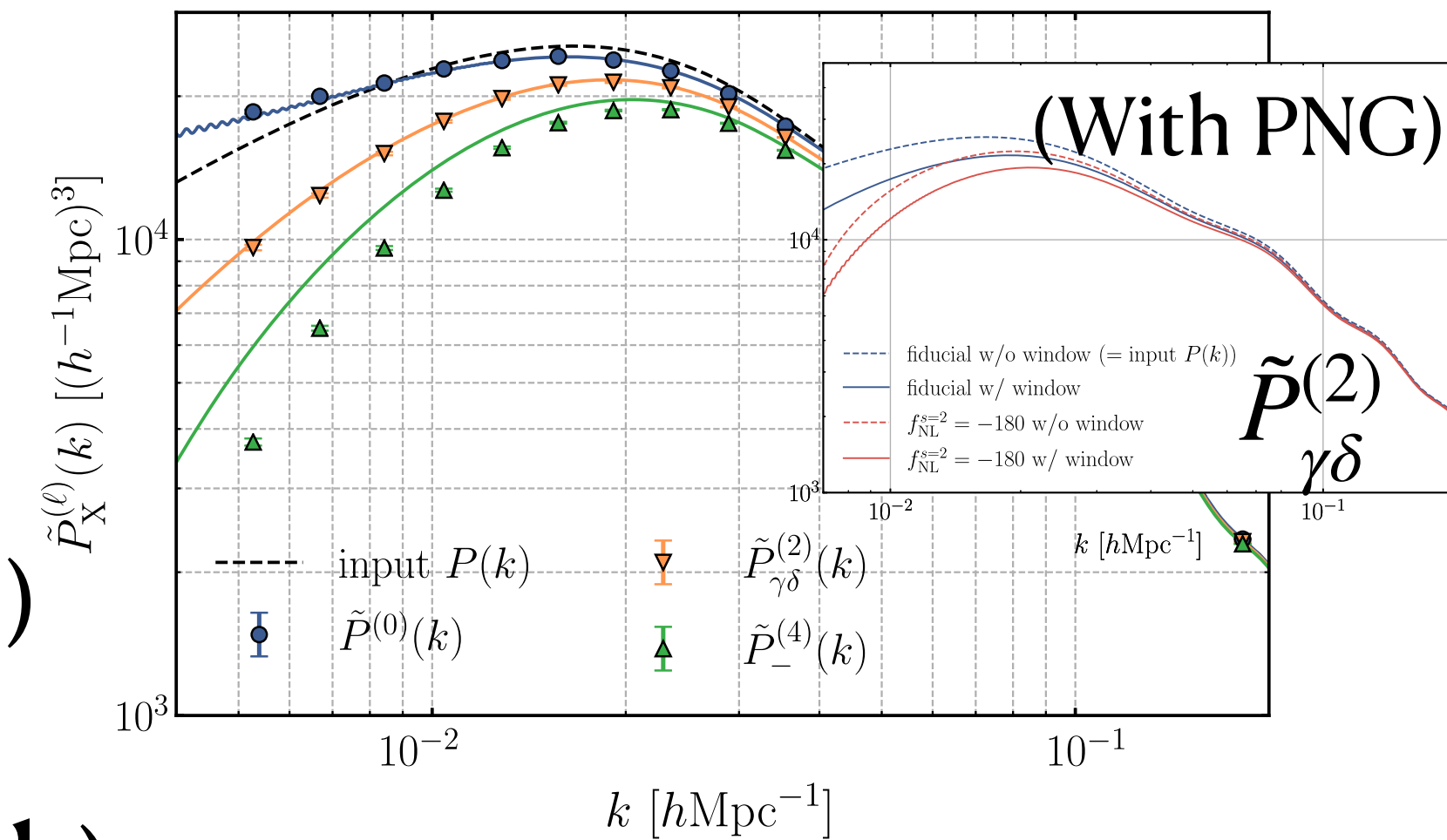
# Highlights

FFT-based estimator for IA power spectra in wide-angle surveys (T. Kurita)



With window function convolved,  
essential to probe large-scale modes

→ constraining primordial non-Gaussianity (PNG)



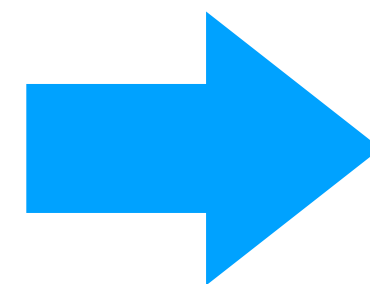
Effective-Field-Theory (EFT) description of IA (Z. Vlah)

EFT treatment developed in describing galaxy bias is generalized,  
including both linear alignment & tidal torque models

Galaxy  
shape field

$$g_{ij}(\boldsymbol{x}) = \sum_O b_O^{(g)} \text{TF}[O_{ij}](\boldsymbol{x})$$

Bias operators for IA

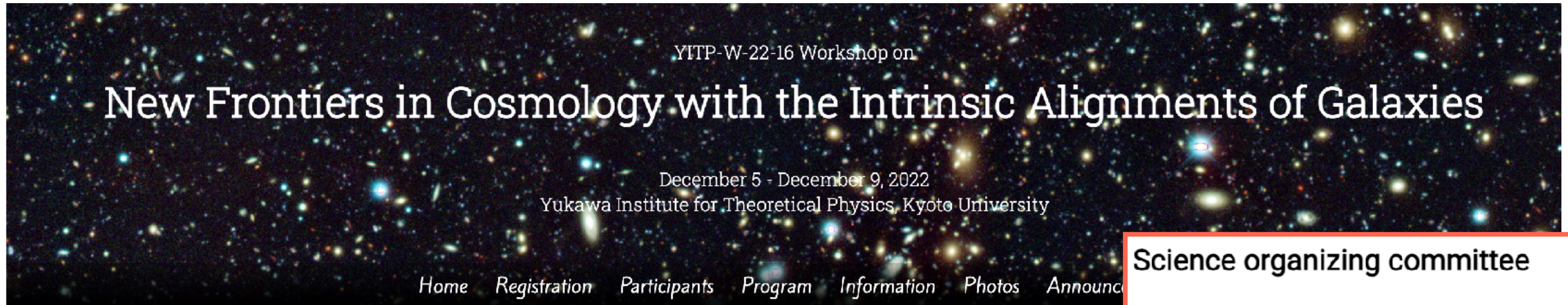


Explicit calculations of 1-loop  
power spectra/tree-level bispectra

# And in 2022,

Since October 11, cross-border travel has been resumed

Now able to invite people from abroad and to organize Int'l workshop



[Home](#) [Registration](#) [Participants](#) [Program](#) [Information](#) [Photos](#) [Announcements](#)

## Overview

Mapping the large-scale structure of the universe with galaxy surveys is a key science driver for cosmology. It enables us to probe the late-time cosmic expansion, growth of structure, and even the primordial fluctuations. So far, the spatial distribution of galaxies has long been used as the major observable, ignoring the shapes and orientations of individual galaxies. While the orientations of distant galaxy images have been established as a promising tool to measure the weak gravitational lensing, intrinsic alignments (IAs) of galaxies are thought to be a contaminant to be removed in the cosmological data analysis. However, there is growing evidence that IAs are a good tracer of the gravitational tidal field, making themselves a unique channel to access the dynamics of the large-scale matter inhomogeneities. Therefore, it is expected that the use of IAs is beneficial, and with a proper theoretical modeling, a measurement of IAs can deliver the cosmological information, complementary to the conventional galaxy clustering data.

## Science organizing committee

- Jonathan Blazek (Northeastern University)
- Jounghun Lee (Seoul National University)
- Atsushi Naruko (YITP)
- Takahiro Nishimichi (YITP)
- Teppei Okumura (ASIAA)
- Ue-Li Pen (ASIAA/CITA)
- Jingjing Shi (Kavli IPMU)
- Masahiro Takada (Kavli IPMU)
- Atsushi Taruya (YITP)

Onsite: 30 persons

Remote: 39 persons (?)

# And in 2022.

Since October 11, cross-border travel has

## Invited speakers

- Kazuyuki Akitsu (Institute for Advanced Study)
- Sandrine Codis (Université Paris-Saclay)
- Benjamin Joachimi (University College London)
- Noam Libeskind (Leibniz Institute for Astrophysics Potsdam)
- Rachel Mandelbaum (Carnegie Mellon University)
- Hironao Miyatake (Nagoya University)
- Andrés Plazas Malagón (SLAC/KIPAC/Rubin Observatory)
- Simon Samuroff (Northeastern University)
- Sukhdeep Singh (Carnegie Mellon University)
- Zvonimir Vlah (Ruder Boskovic Institute)
- Haoran Yu (Xiamen University)

2nd-order shape bias & nonlinearity of IA

Understanding IA from cosmic-web modeling

Forward modeling of full complexity of IA

Galaxy and cosmic filament spin

Simulating IA with deep learning

Subaru HSC WL measurements

Rubin Observatory

Constraining IA from DES/eBOSS

IA measurements from SDSS and simulations

EFT of galaxy shapes

Baryonic effects on Lagrangian clustering & spin

(CITA)

(IPMU)

# And in 2022,

Do not miss also interesting contribution talks !

JST UTC +9	5th Dec. (Mon.)	6th Dec. (Tue.)	7th Dec. (Wed.)	8th Dec. (Thu.)	9th Dec. (Fri.)
9:30-	Registration				
Chair	A. Taruya	A. Naruko	U. -L. Pen	T. Nishimichi	M. Takada
10:00 - 10:30		<a href="#">S. Samuroff</a> * [PDF]	<a href="#">R. Mandelbaum</a> * [PDF]	<a href="#">K. Osato</a> [PDF]	<a href="#">H. Yu</a> * [PDF]
10:30 - 11:00	<a href="#">A. Taruya</a> [PDF]			<a href="#">D. Osafune</a> * [PDF]	
11:00 - 11:30	Break				
11:30 - 12:00	<a href="#">S. Singh</a> * [PDF]	<a href="#">T. Okumura</a> [PDF]	<a href="#">J. Lee</a> [PDF]	<a href="#">J. Shi</a> [PDF]	<a href="#">T. Nishimichi</a> [PDF]
12:00 - 12:30	<a href="#">J. Blazek</a> * [PDF]	<a href="#">T. Kurita</a> [PDF]	<a href="#">A. Plazas Malagón</a> [PDF]	<a href="#">S. Ishikawa</a> [PDF]	<a href="#">K. -G. Lee</a> [PDF]
12:30 - 13:00	Lunch			Lunch	<a href="#">M. Takada</a> [PDF]
13:00 - 14:30					
Chair	J. Lee	J. Shi		T. Okumura	
14:30 - 15:30	<a href="#">N. Libeskind</a> [PDF]	<a href="#">H. Miyatake</a> [PDF]		<a href="#">K. Akitsu</a> [PDF]	
15:30 - 16:00	<a href="#">K. Nakashima</a> [PDF]	<a href="#">M. Iye</a> [PDF]		<a href="#">T. Matsubara</a> [PDF]	
16:00 - 16:30	<p>Hope all of participants to have stimulative discussions, and to initiate new projects and to develop collaboration</p>				
16:30 - 17:00					
17:00 - 18:00					

LOC/SOC members also  
give a contribution talk

# Tips

## Talks

**60 min** for all invited talks

will be recorded (if OK)

**30 min** for all contributed talks

(Comments/Discussions included)

Use *slack* for further discussions/chats if time is up (Remote participants)

Continue the discussions at *coffee/lunch break* (Onsite participants)

But, keeping the covid-19 prevention protection in mind !

# Tips

**Slack** [https://join.slack.com/t/yitpworkshopo-k3y8741/shared\\_invite/zt-1j93oued3-vHaBU7QuoQgeeia2eopELw](https://join.slack.com/t/yitpworkshopo-k3y8741/shared_invite/zt-1j93oued3-vHaBU7QuoQgeeia2eopELw)

For all speakers, **please put your talk slides to your talk channel**

(We will upload them to the workshop page)

IA Workshop 2022@YITP

Threads

Direct messages

Mentions & reactions

Drafts & sent

Slack Connect

More

Channels

- # 0\_announcements
- # 0\_free\_chat
- # 0\_lunch\_dinner
- # 1\_5th\_december\_2022
- # 1-1\_atsushi\_taruya
- # 1-2\_sukhdeep\_singh
- # 1-3\_jonathan\_blazek

# 0\_announcements

Friday, November 25

Pinned by Shogo Ishikawa

**Shogo Ishikawa** 10:20 AM

[Webpage]

[https://www2.yukawa.kyoto-u.ac.jp/~ia\\_wc](https://www2.yukawa.kyoto-u.ac.jp/~ia_wc)

[Program]

[https://www2.yukawa.kyoto-u.ac.jp/~ia\\_wc](https://www2.yukawa.kyoto-u.ac.jp/~ia_wc)

**naruko** 3:28 PM

joined #0\_announcements along with 7 others.

Pinned by you

**Atsushi Taruya** 1:26 PM

[Zoom link]

<https://kyoto-u-edu.zoom.us/j/87830223434?pwd=QIE2VTdhd1AzRTJnZk>

Meeting ID: 878 3022 3434

Passcode: 473542

Some local information, dinner/lunch  
will be announced & shared  
(Please check for onsite participants)

# Tips

## Group photos

Onsite & remote **Dec. 7 (Wed)** before lunch

Remote **Dec. 6 (Tue)** after afternoon session (UTC ~9:00)

**Dec. 8 (Thu)** before morning session (UTC ~01:00)



# Tips

For onsite participants,

## Visitor office

Rooms, **Y107** and **Y108**, are available during the workshop

## Card key

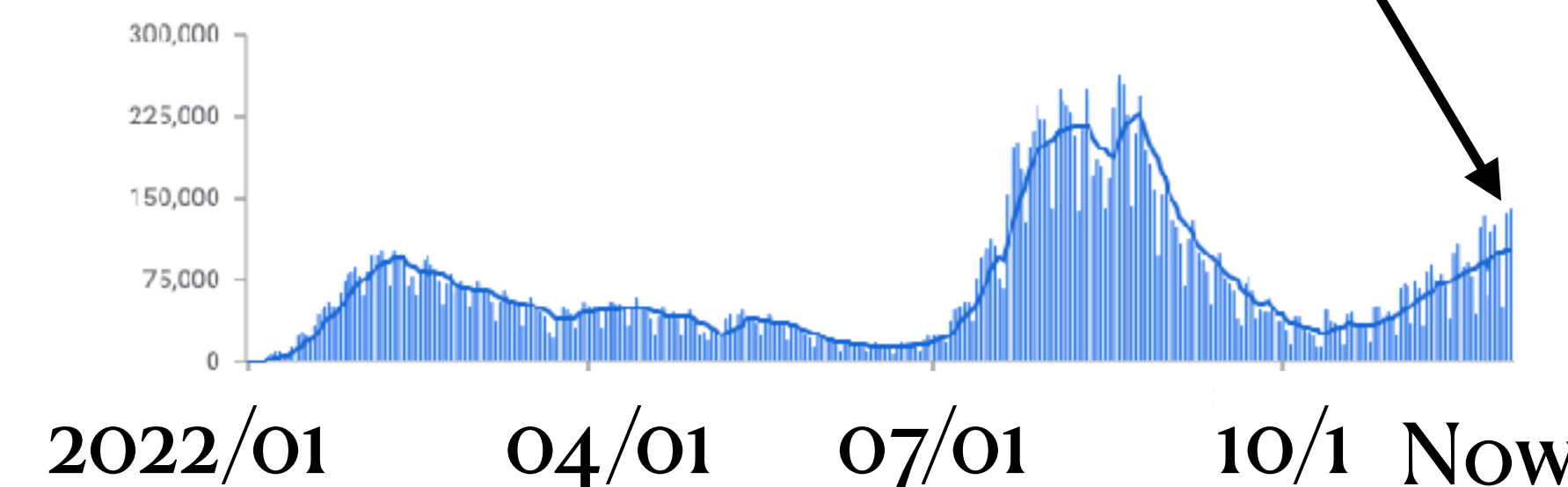
Please return the card key of the entrance to a return box (or to us) when you leave

## Covid-19 prevention measures

Please remind all of onsite participants to

- Keep social distancing
- Wear always a mask
- Sanitize your hands with alcohol frequently

# of people infected is still increasing





*Have an exciting and  
stimulative discussion!*