Intrinsic Alignments with Numerical Simulations

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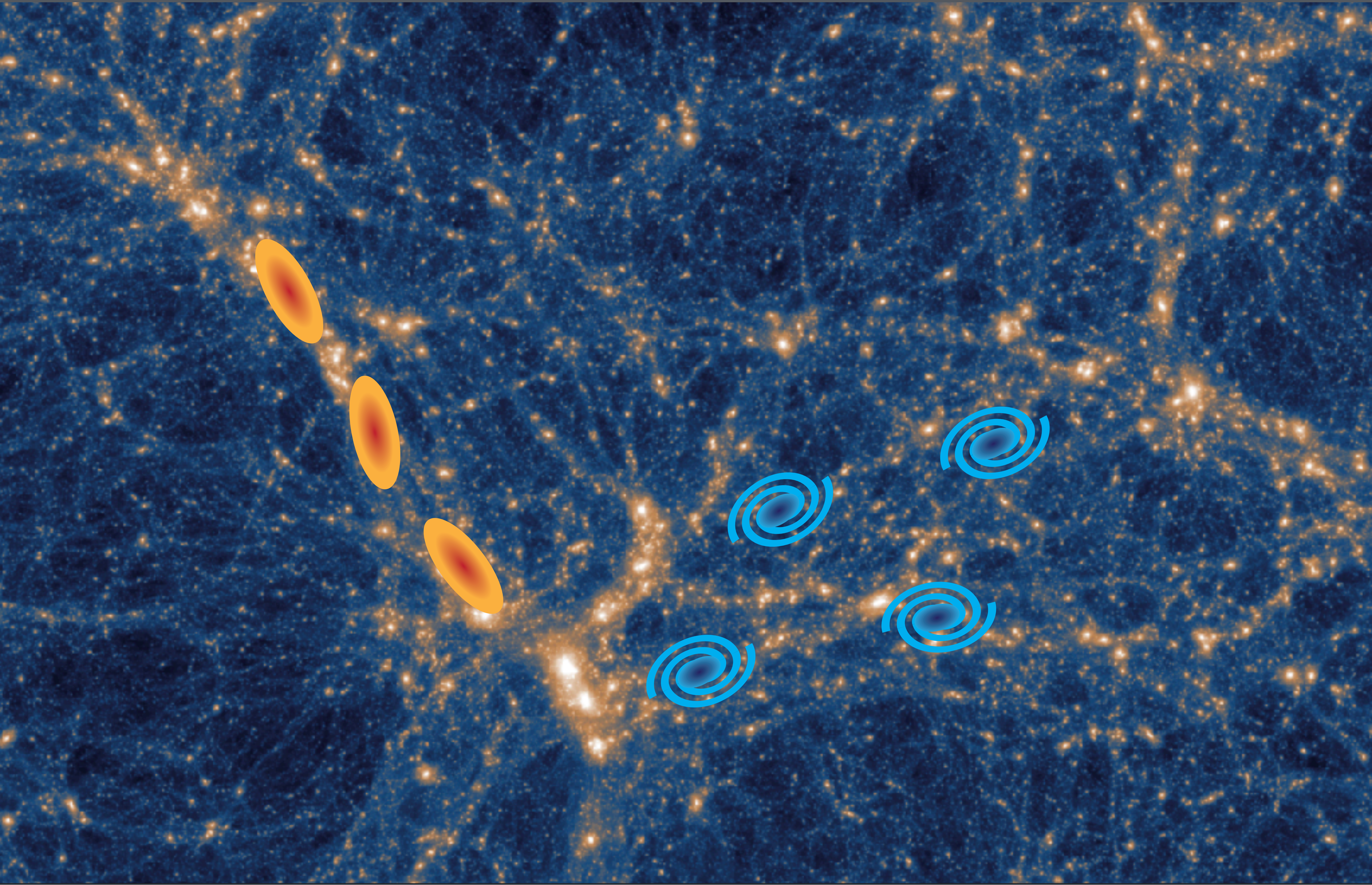
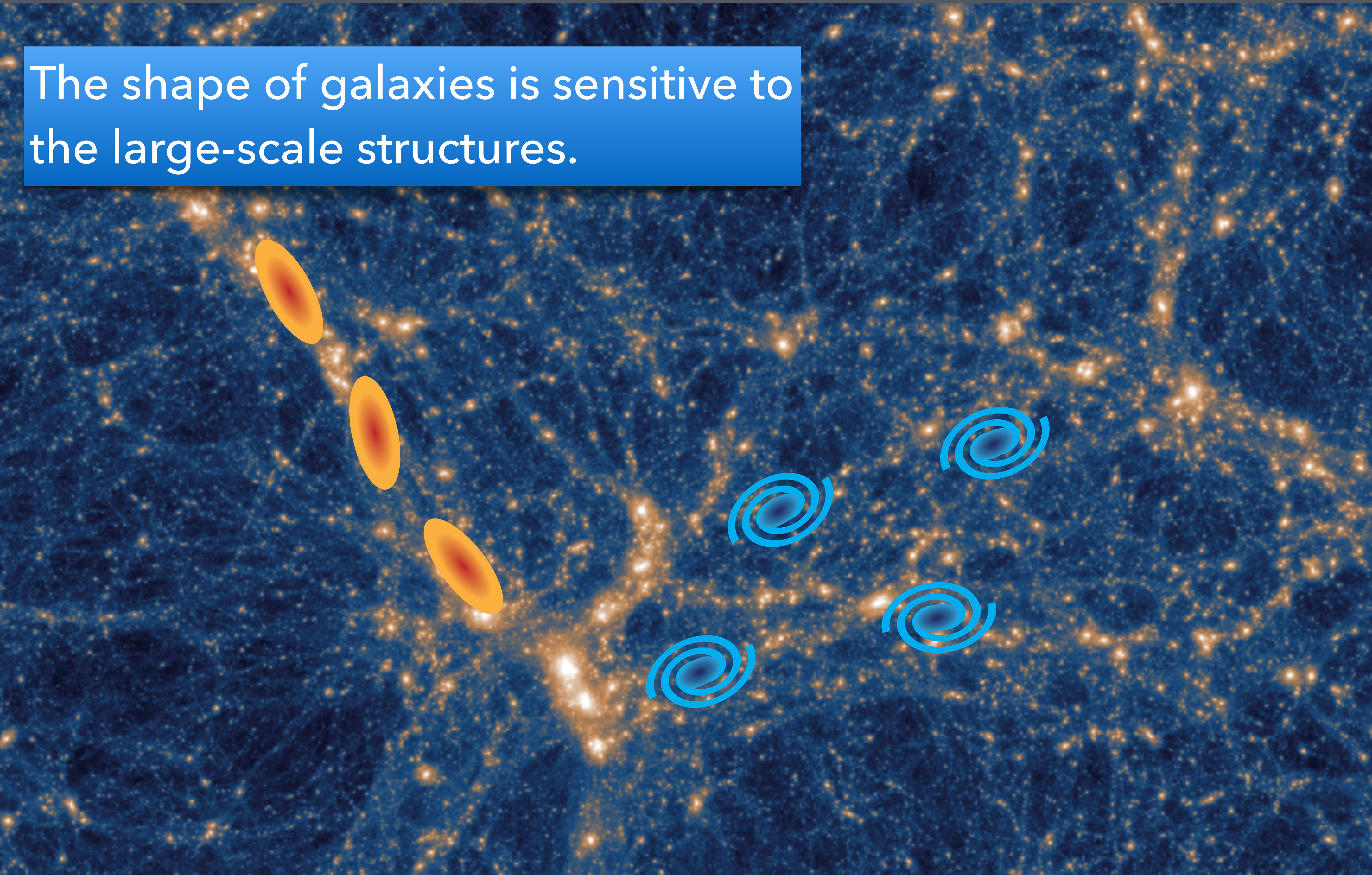
Intrinsic Alignments

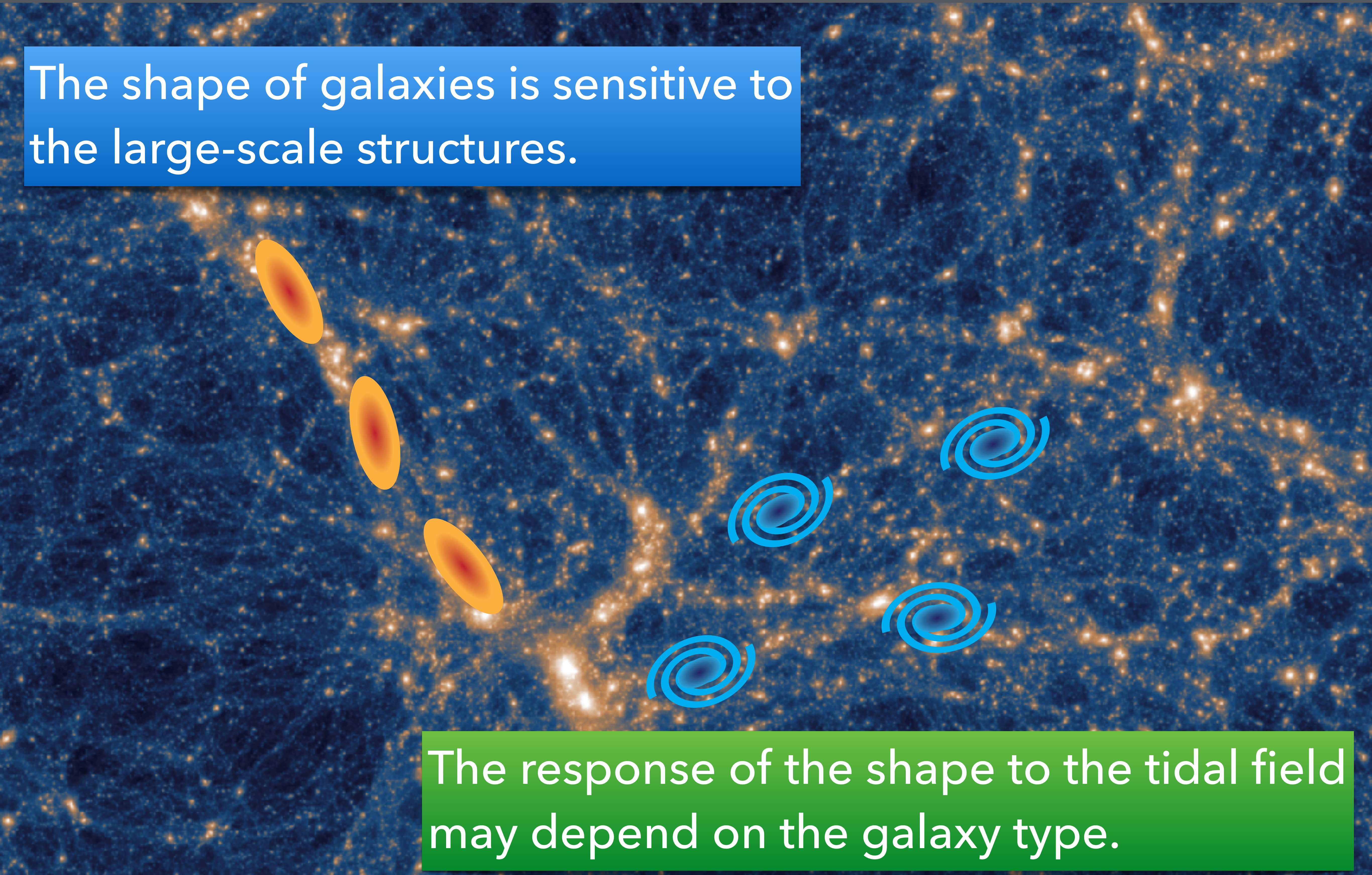


Intrinsic Alignments

The shape of galaxies is sensitive to the large-scale structures.



Intrinsic Alignments



The shape of galaxies is sensitive to the large-scale structures.

The response of the shape to the tidal field may depend on the galaxy type.

Theoretical Modelling of IA

- Intrinsic alignments were thought to be a dominant systematics in weak lensing cosmology. (Catelan+, 2001; Hirata & Seljak, 2004)

constant (depends on galaxy sample)

➡ ***Linear Alignment:*** $$\gamma^I = -\frac{C_1}{4\pi G}(\partial_x^2 - \partial_y^2, 2\partial_x\partial_y)\mathcal{S}[\Psi_P]$$

Gravitational potential

➡ ***Quadratic Alignment:*** $$\gamma^I = C_2(T_{x\mu}^2 - T_{y\mu}^2, 2T_{x\mu}T_{y\mu})$$

$$T_{\mu\nu} = \frac{1}{4\pi G}\left(\partial_x\partial_y - \frac{1}{3}\delta_{\mu\nu}\partial^2\right)\mathcal{S}[\Psi_P]$$

- The models beyond these have been proposed (incomplete list);

Nonlinear Linear Alignment (NLA; Bridle & King, 2007):

Replacing density field with non-linear one

Tidal Alignment and Tidal Torquing (TATT; Blazek+, 2015, 2019):

Higher order expansion as in galaxy biasing

Effective Field Theory (EFT; Vlah+, 2020, 2021):

The small-scale physics is integrated out and described by a set of free parameters.

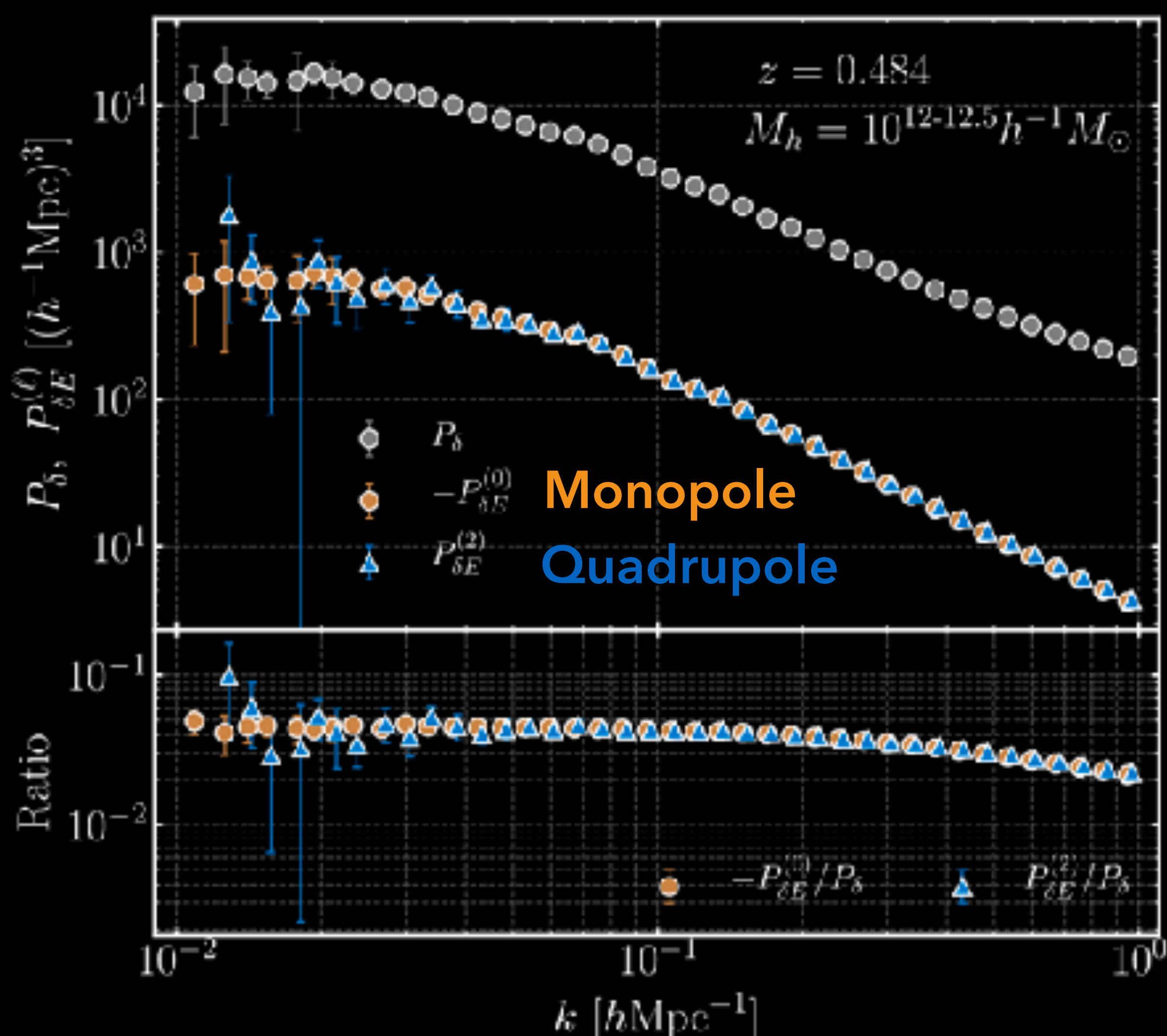
N-body Simulation for IA of halos

✦ ***Halo intrinsic alignments in simulations:***

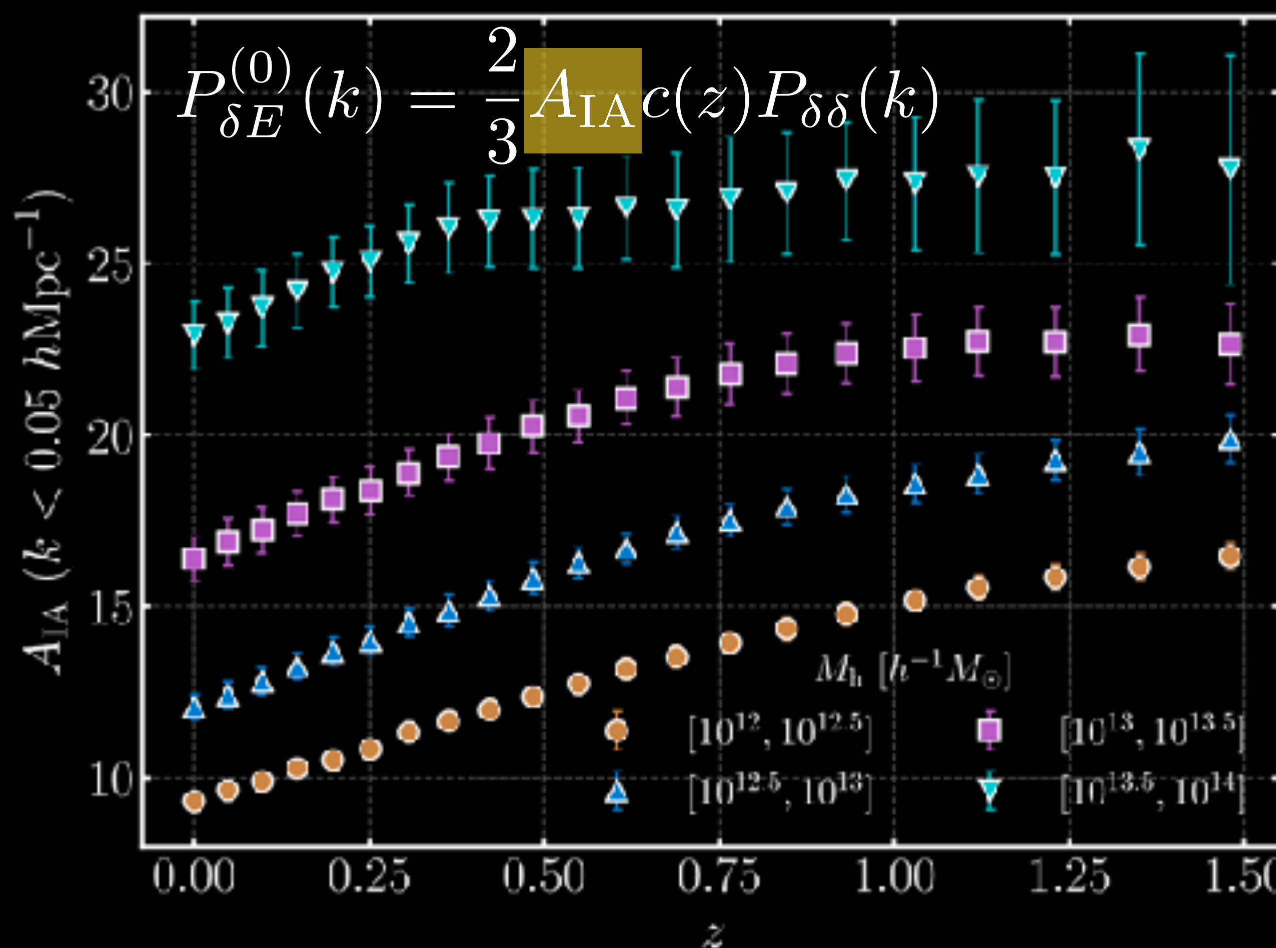
Inertia tensor — **Ellipticity** — **Shear**

$$I_{ij} = \sum_p m_p \frac{\Delta x_p^i \Delta x_p^j}{r_p^2} \rightarrow \epsilon_+ = \frac{I_{11} - I_{22}}{I_{11} + I_{22}},\ \epsilon_+ = \frac{2I_{12}}{I_{11} + I_{22}} \rightarrow \gamma_{(+,\times)} = \frac{1}{2\mathcal{R}} \epsilon_{(+,\times)}$$

E-mode and density cross-power spectra



Redshift evolution of IA amplitude



Kurita, Takada, Nishimichi, Takahashi, KO, Kobayashi (2021)

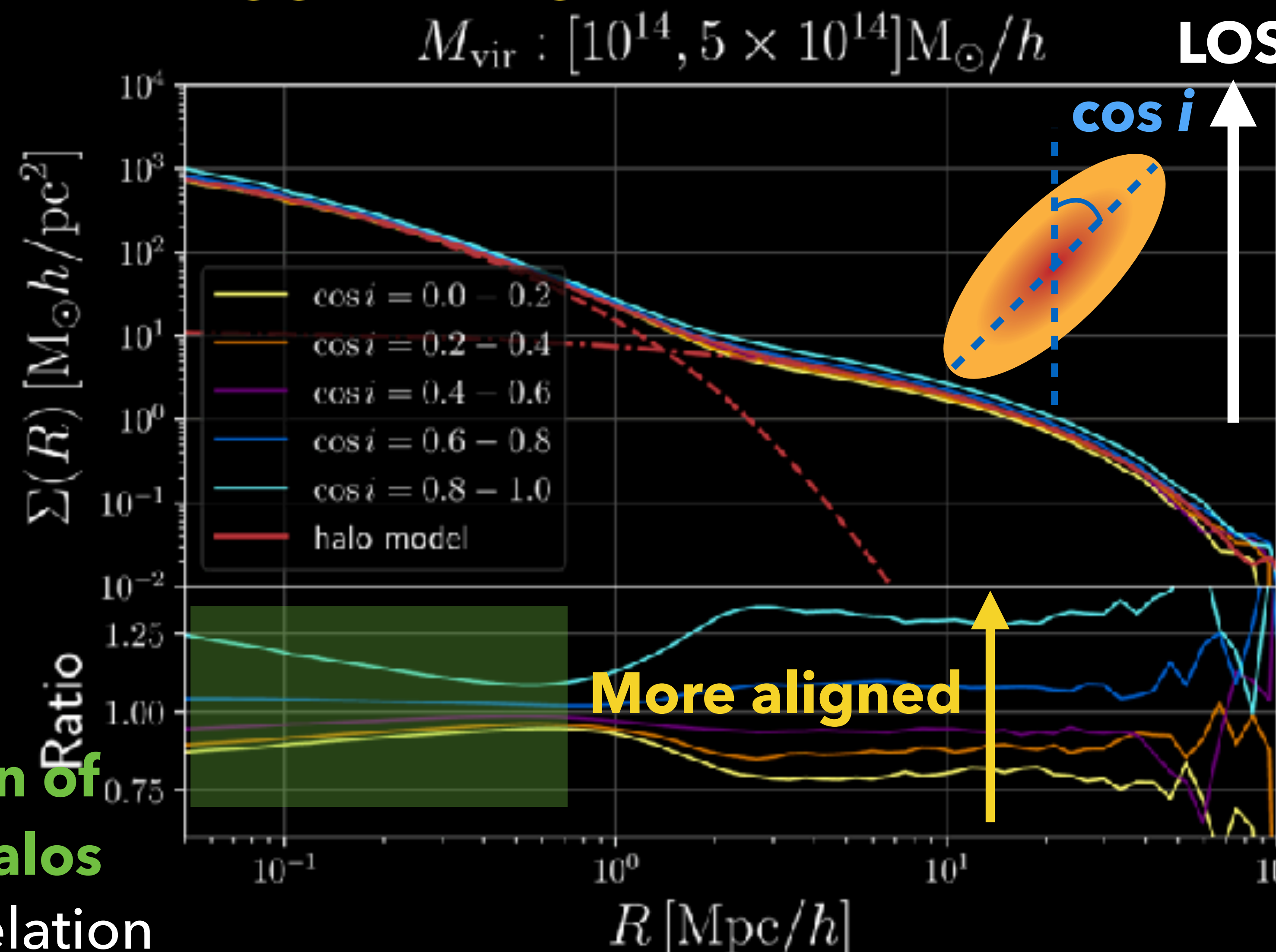
Effect of IA on Galaxy-Galaxy Lensing

✦ Galaxy-galaxy lensing: cross-correlation between WL and clustering

➡ ***Question: Does halo shape affects gg lensing?***

✦ The halo samples are divided according to angle w.r.t LOS

➡ The aligned halos are more likely to be found with cluster finding algorithm. That may lead to **inhomogeneous halo sample**.



★ We measure (projected) cross-correlation between each halo sample and matter.

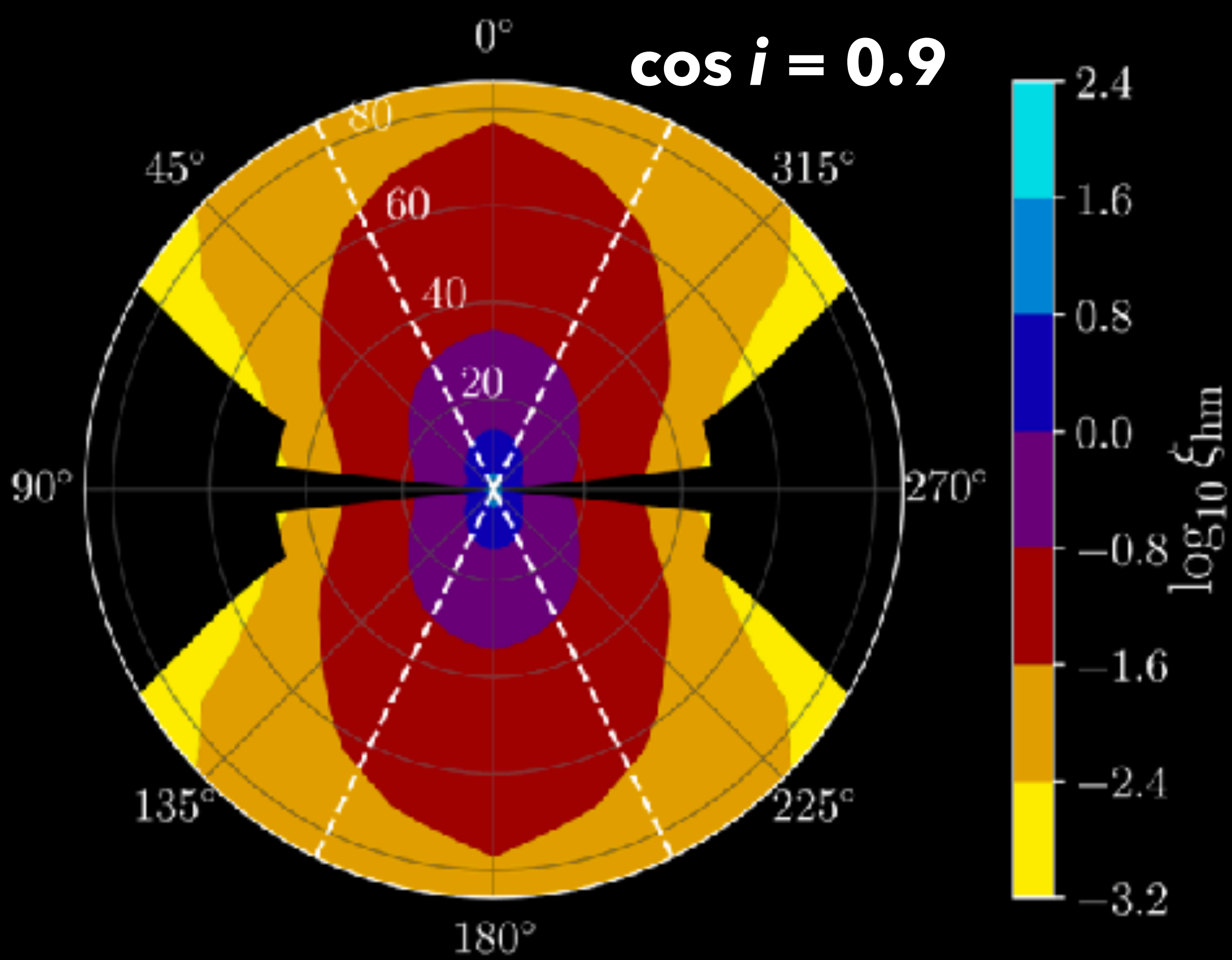
- **Answer: The halos aligned with LOS induce enhancement of the signal even at large scales (> 10 Mpc/*h*).**

KO, Nishimichi, Oguri, Takada, Okumura (2018)

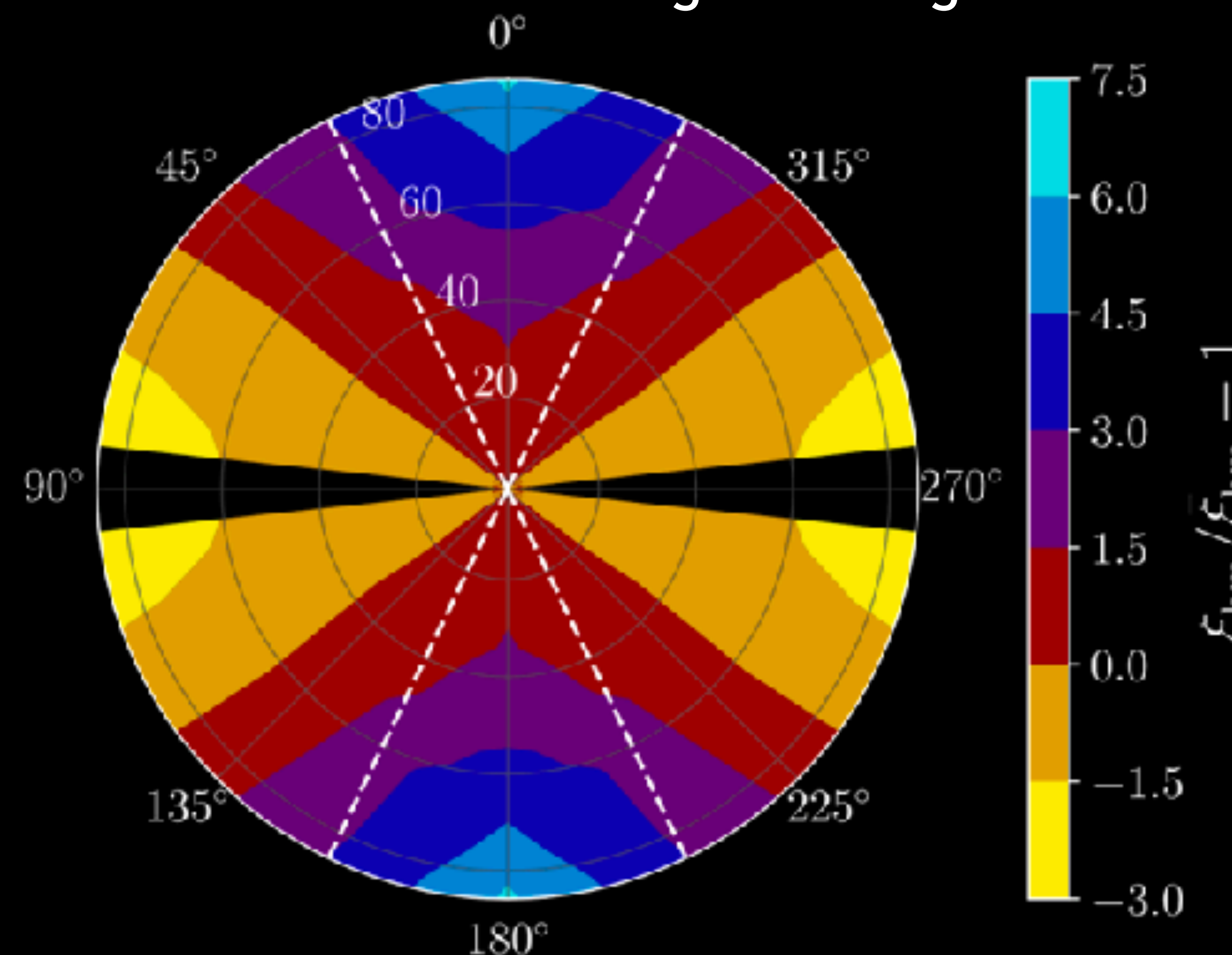
Effect of IA on Galaxy-Galaxy Lensing

- ✦ <u>2D anisotropic halo-matter cross-correlation</u>:
  Matter distribution around ***<u>highly aligned halos</u>*** (cos *i* = 0.9 - 1.0).

The 2D halo-matter cross-correlation



The difference from the angular averaged one

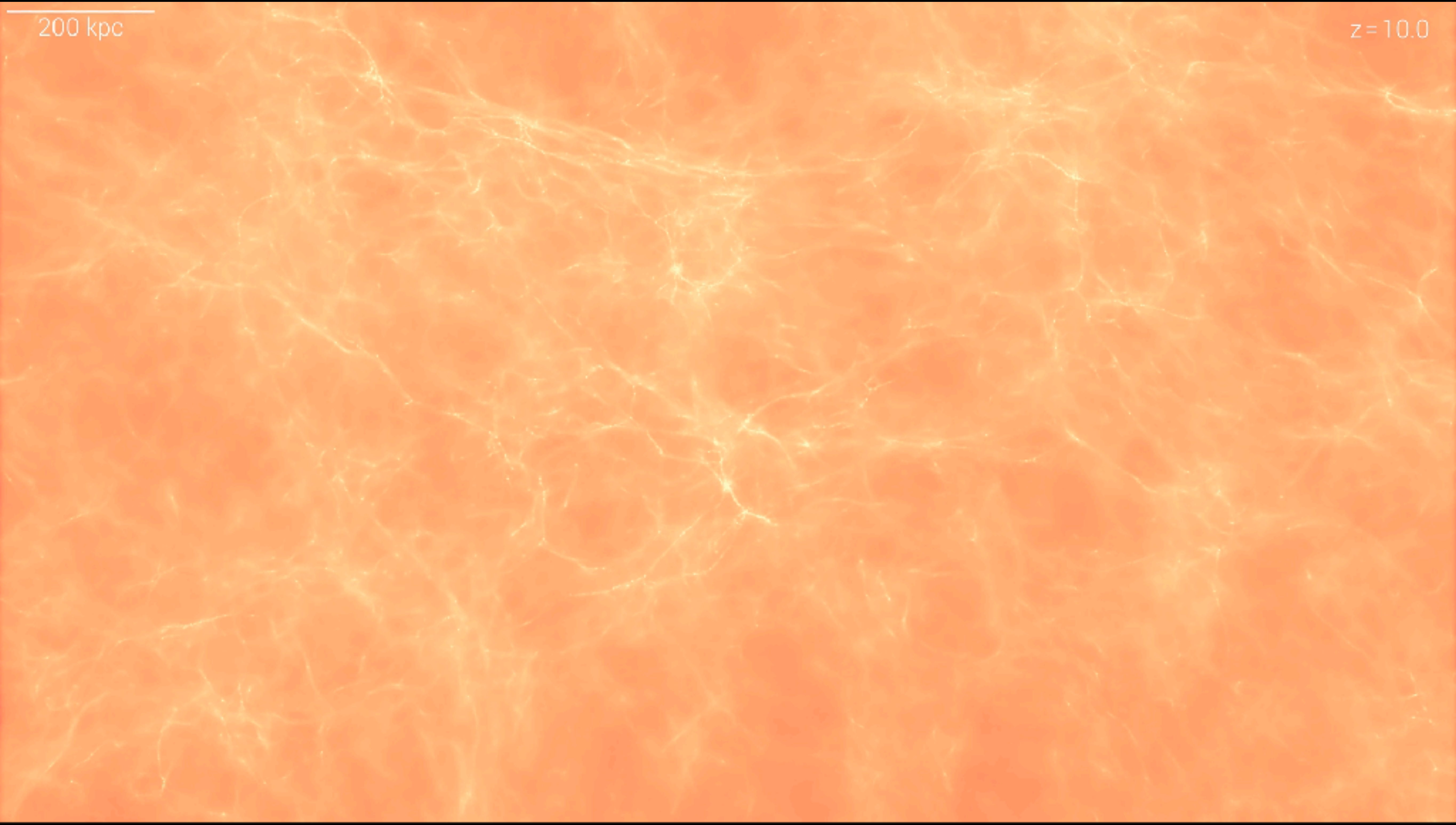


The halo shape and density field are strongly correlated well over halo radius or even 50 Mpc/h!

KO, Nishimichi, Oguri, Takada, Okumura (2018)

Galaxy Formation Hydrodynamical Simulations

✦Numerical simulations are the powerful tool to address the **multi-scale physics**



Credit: IllustrisTNG team

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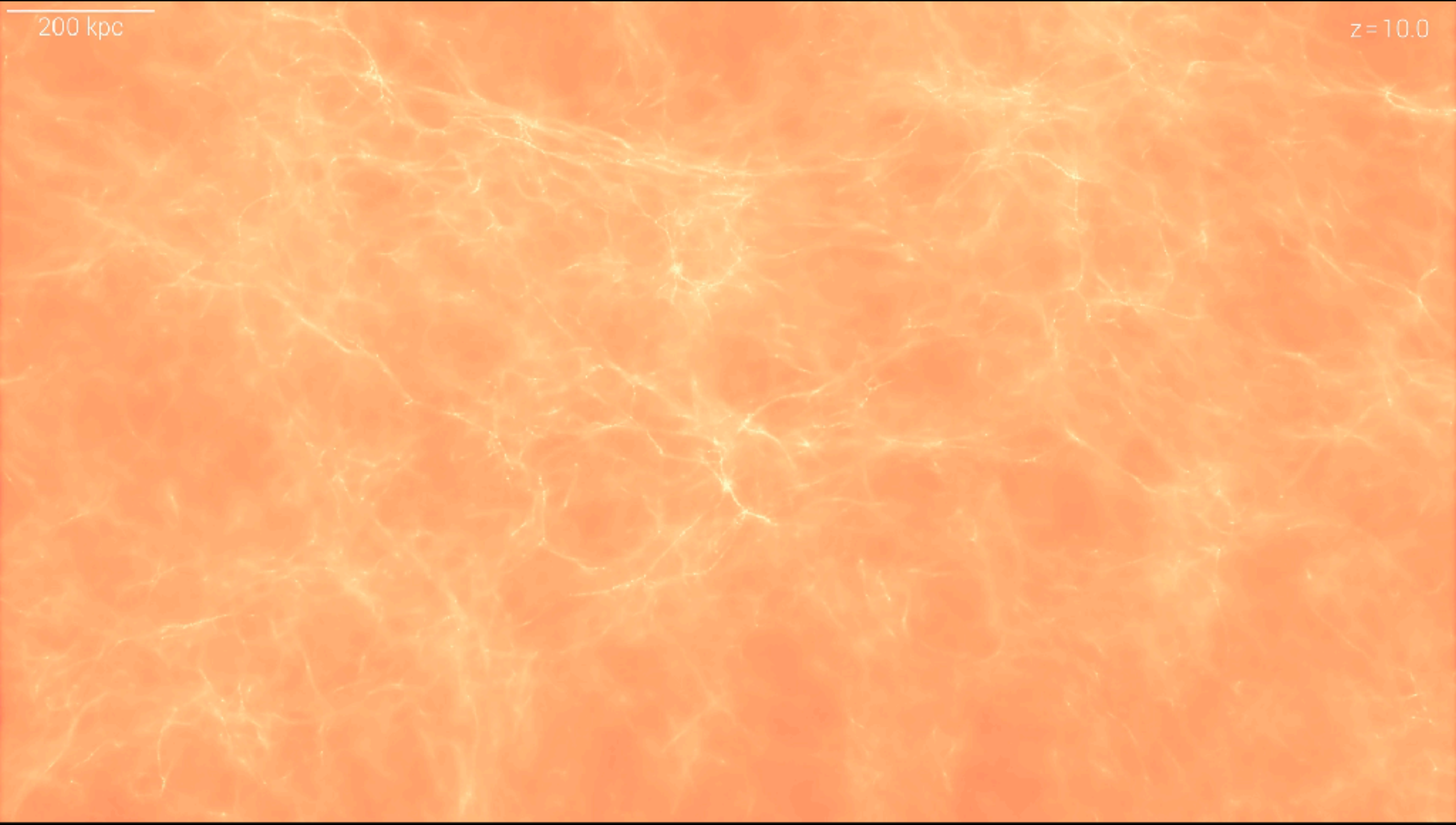


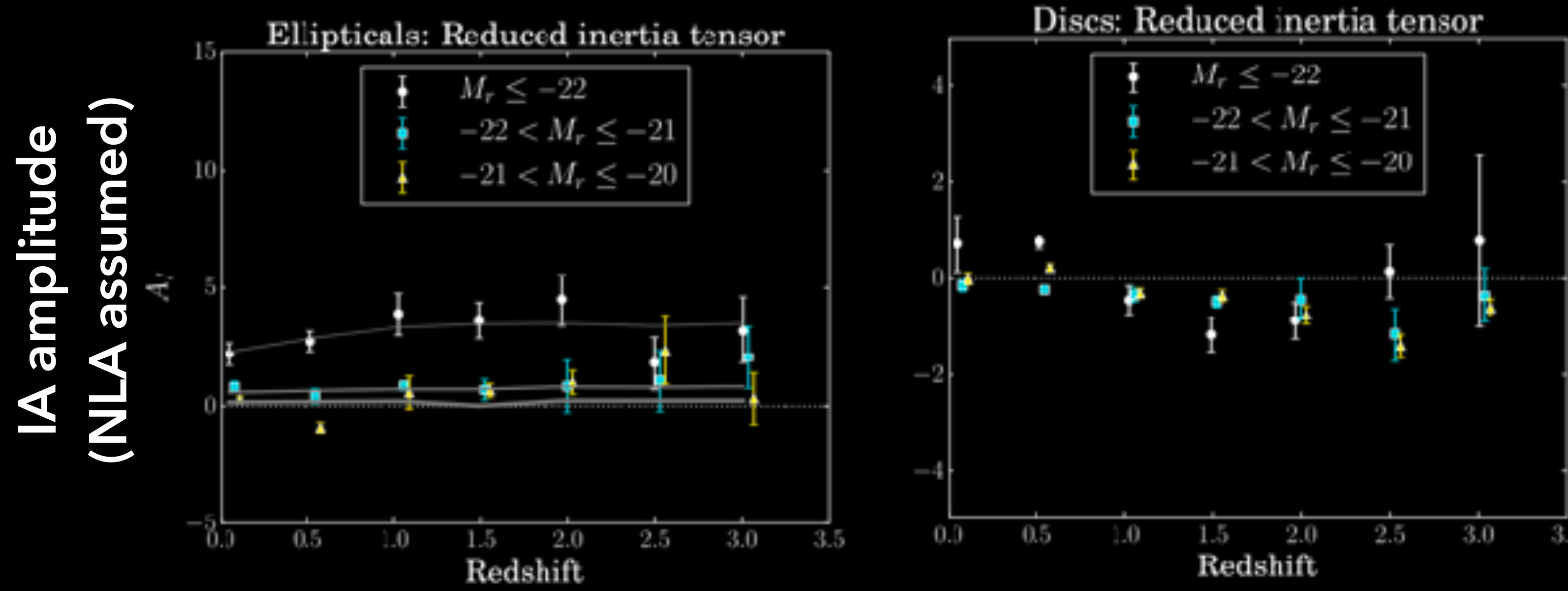
Credit: IllustrisTNG team

Hydrodynamical Simulations for IA

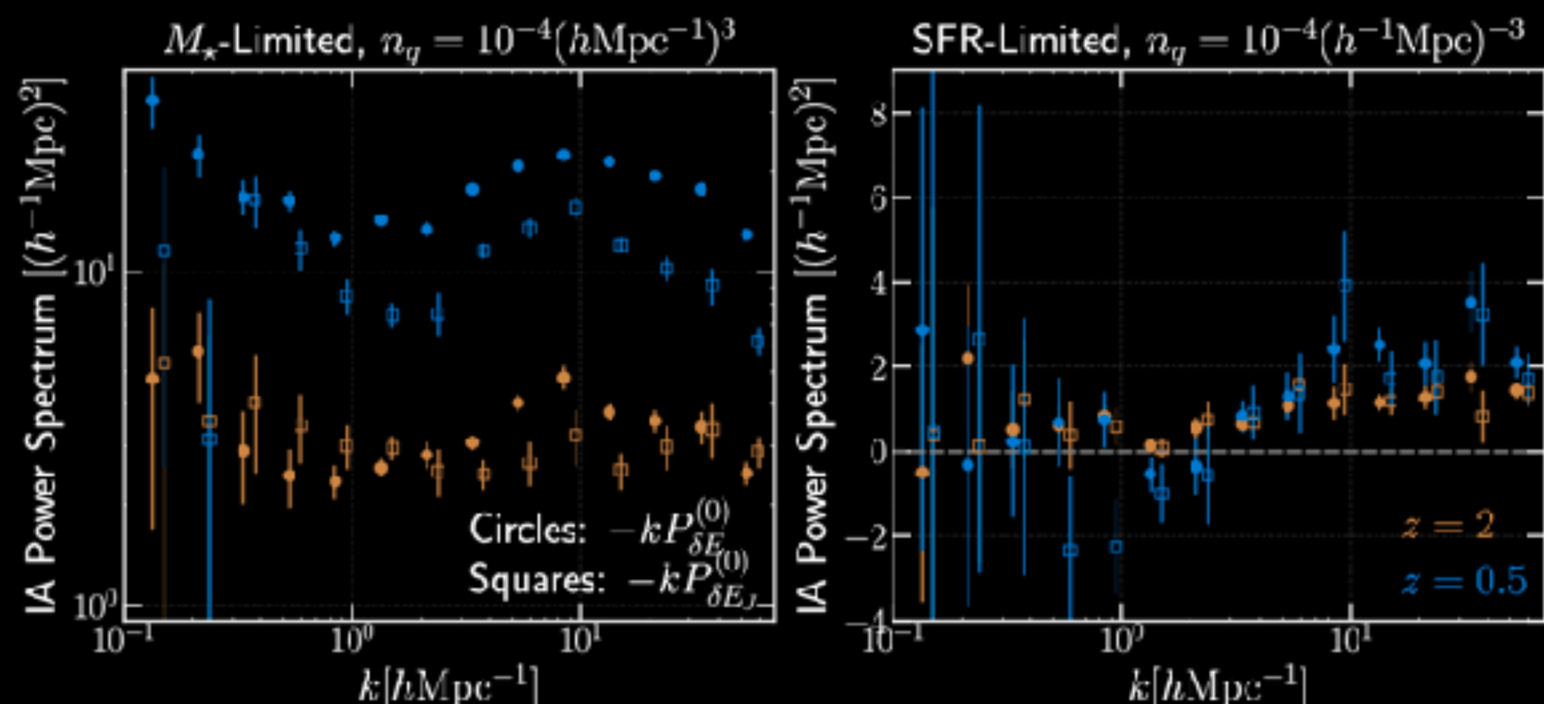
- ***Hydro simulations***: The dependence of IA amplitude on ***galaxy type*** can be investigated.

➡ Horizon-AGN (Chisari+, 2016)
IA measurements for two galaxy samples (discs/ellipticals) divided based on kinematics.

LRG-like **ELG-like**

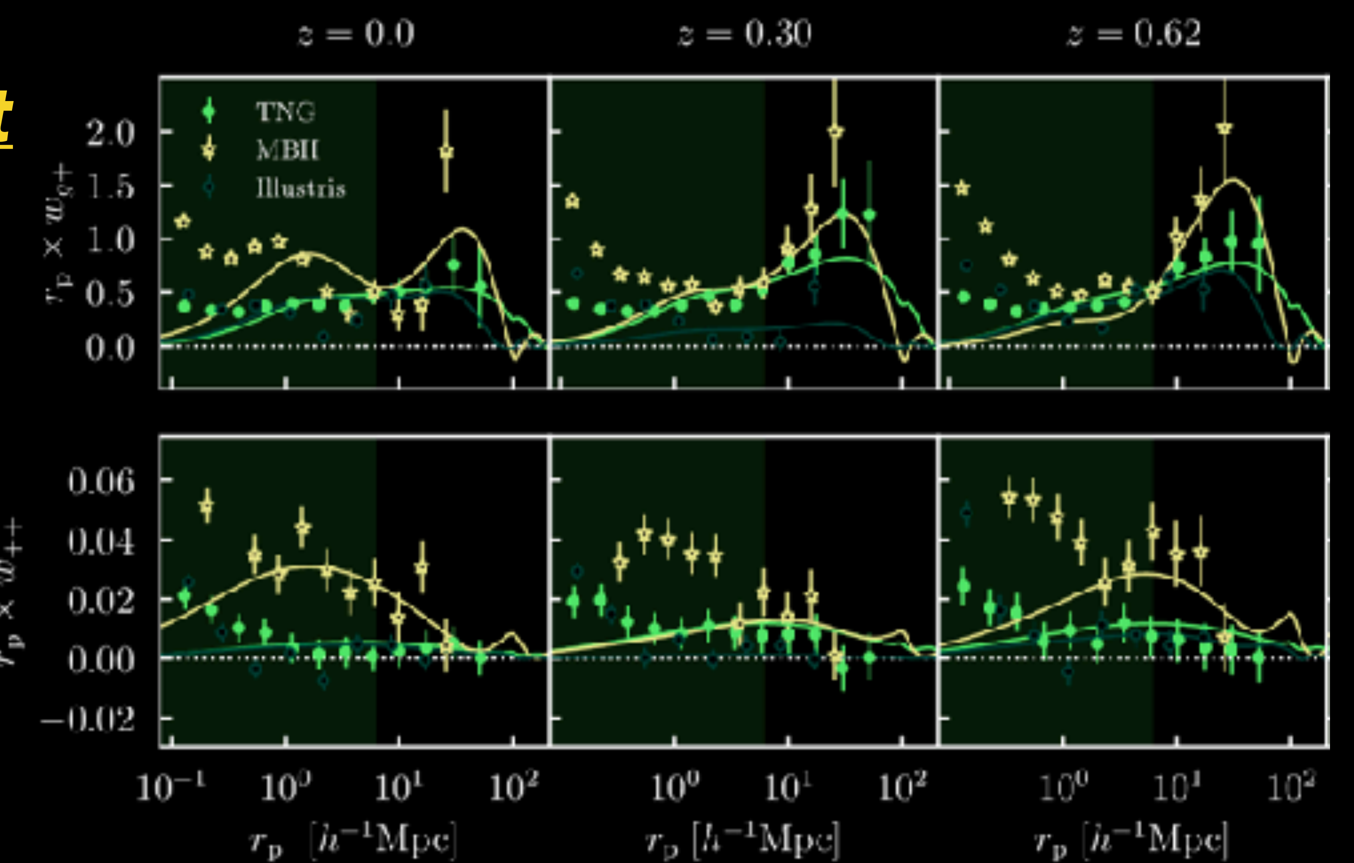


➡ IllustrisTNG (Shi+, 2021)
For M*-limited samples, significant correlation is detected and for SFR-limited sample, the signal is consistent with null signal. However, we can detect the signal with an optimised estimator *(Jingjing Shi's talk)*.

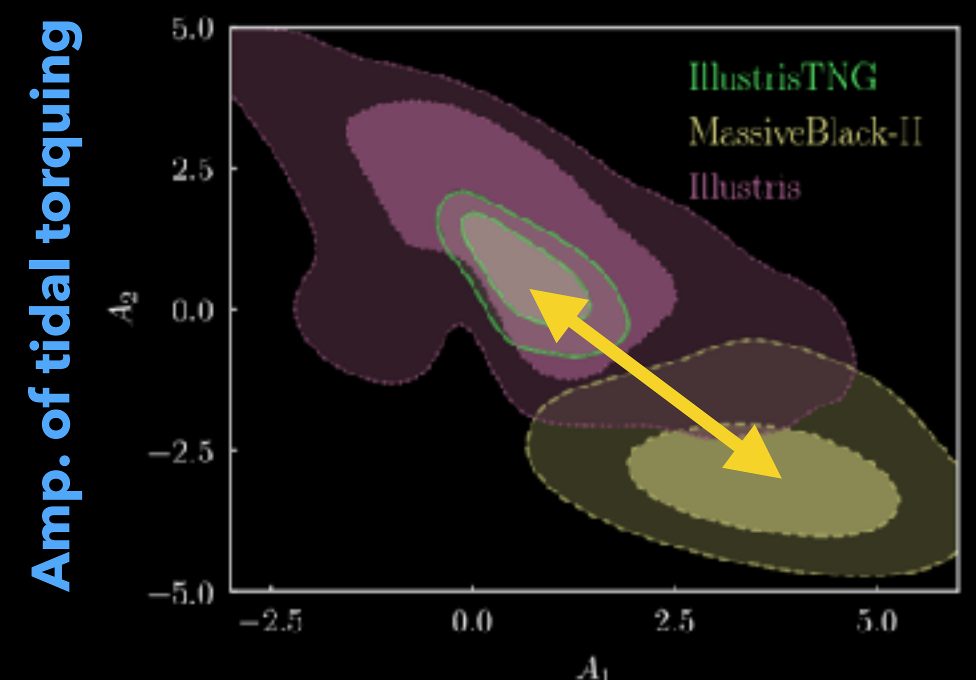


Hydrodynamical Simulations for IA

✦ ***Inconsistency between different galaxy formation recipes:***
The IA power spectra for
stellar mass selected galaxy samples
($M_* > 1.6 \times 10^9$ Msun/h)
with Illustris, IllustrisTNG, and MB-II.



➡ This inconsistency propagates to
the estimated IA amplitudes;
IA of Illustris(TNG) galaxies can be explained
with NLA and tidal torquing is zero consistent.
On the other hand, there is non-zero
tidal torquing contribution for MB-II galaxies.



Samuroff, Mandelbaum, and Blazek (2021)

Observations of Emission Line Galaxies

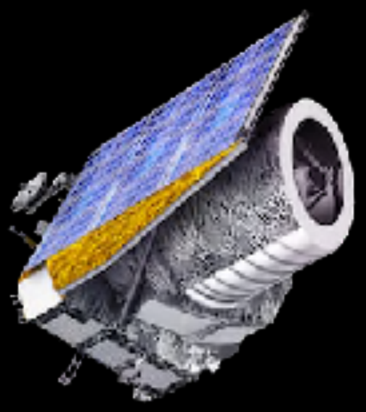
✦ Upcoming surveys will target ***emission line galaxies (ELGs)***.
ELGs are characterised by strong emission line (Hα, [O II], etc.) from nebular emission irradiated by **short-lived massive stars**.

➡ ELGs are **blue spiral galaxies** and the response of the shape to large-scale structures can be different from **red elliptical galaxies**.

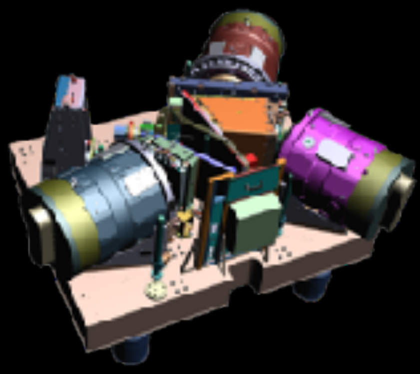
- ***Tidal alignment*** vs ***Tidal torquing***

✦Future spectroscopic surveys

	Redshift	Survey coverage (deg²)
PFS	0.6-2.4	1,200
DESI	0.6-1.6	14,000
Euclid	0.89-1.82	15,000



✦ ***Euclid*** (in 2023 Q1)
coverage: 15,000 deg²
Hα ELGs ($0.89 < z < 1.82$)



✦ ***PFS*** (in 2023)
coverage: 1,200 deg²
[O II] ELGs ($0.6 < z < 2.4$)

Construction of Mock ELG Catalogue

IllustrisTNG (Nelson+, 2019):

Run by moving-mesh code AREPO (Springel, 2010)

L = 205 Mpc/h, N = 2 x 2500^3

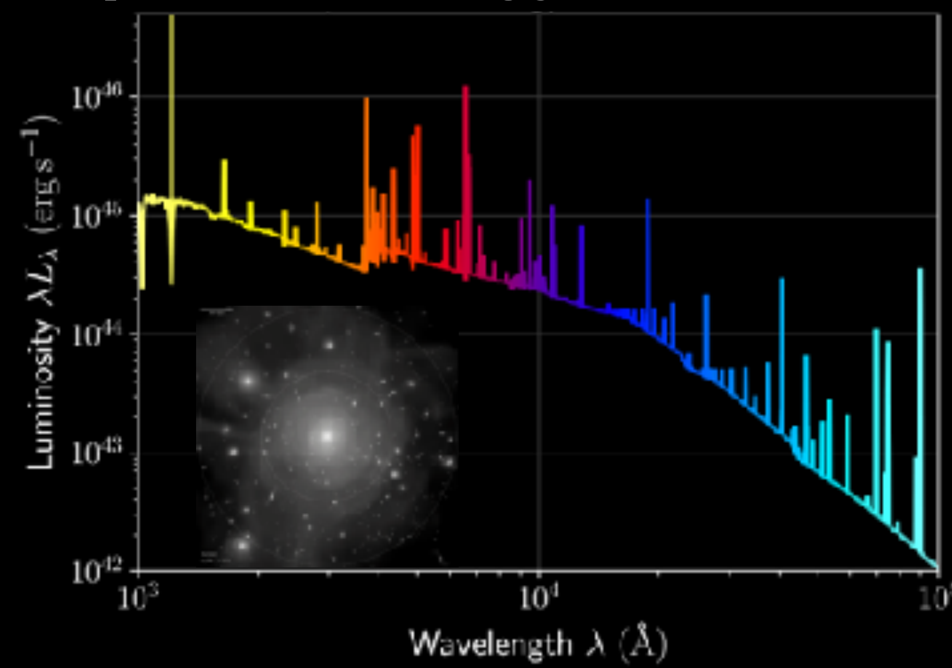
Various baryonic processes implemented:

Radiative cooling, star formation, stellar wind, stellar feedback, BH formation/evolution, AGN feedback, MHD, …

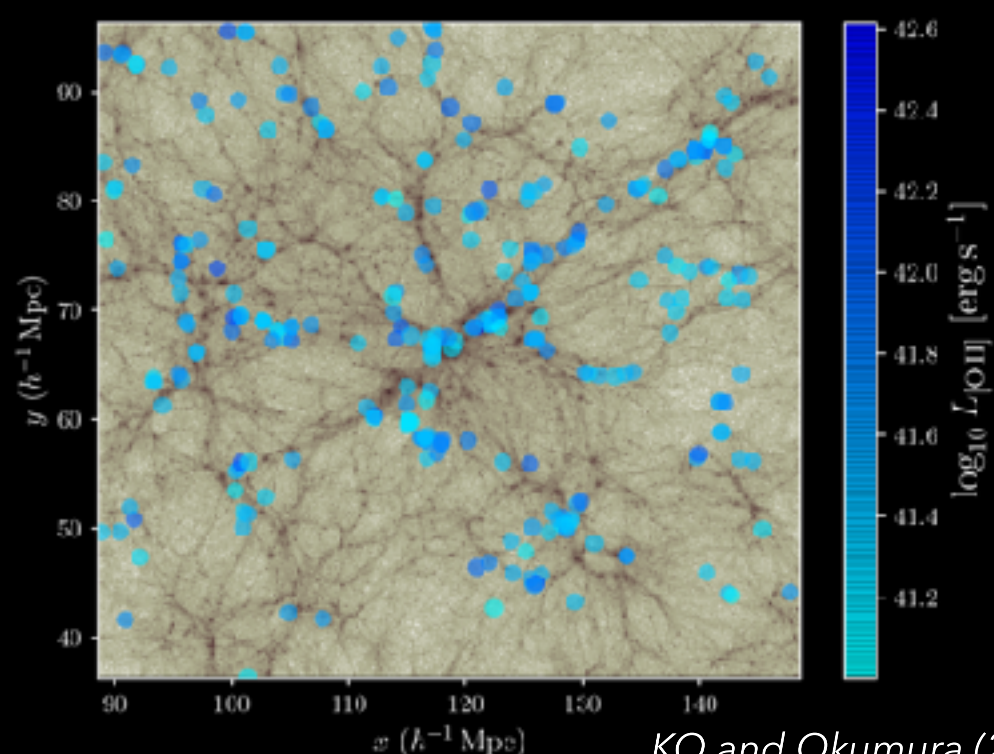
Stellar population synthesis:

For each star particle, we compute SED based on its metallicity and age with PÉGASE.3 (Fioc+, 2019) code coupled with photo-ionization code CLOUDY (Ferland+, 2017).

Spectral energy distribution

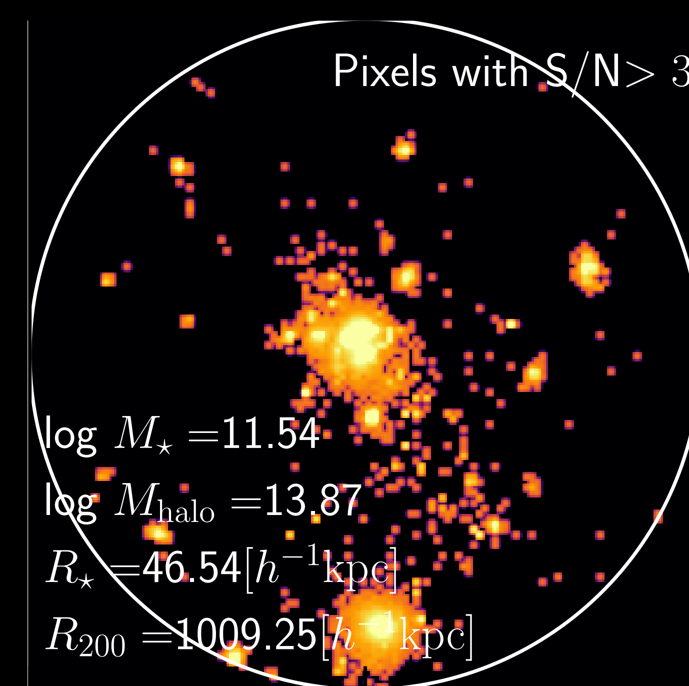


[O II] ELG distribution



KO and Okumura (2021)

HSC i-band luminosity



Shi, KO, Kurita and Takada (2021)

Luminosity Function of Hα and [O II] ELGs

- ✦ As validation of our mock ELG catalogues, luminosity functions of Hα and [O II] ELGs are compared with observations.
- ➡ When dust attenuation is taken into account, the results are consistent ***without tuning parameters***.

Hα ELGs

[O II] ELGs

without dust

with dust

Observations

Observations

Dust formation and evolution is consistently solved in PÉGASE3.

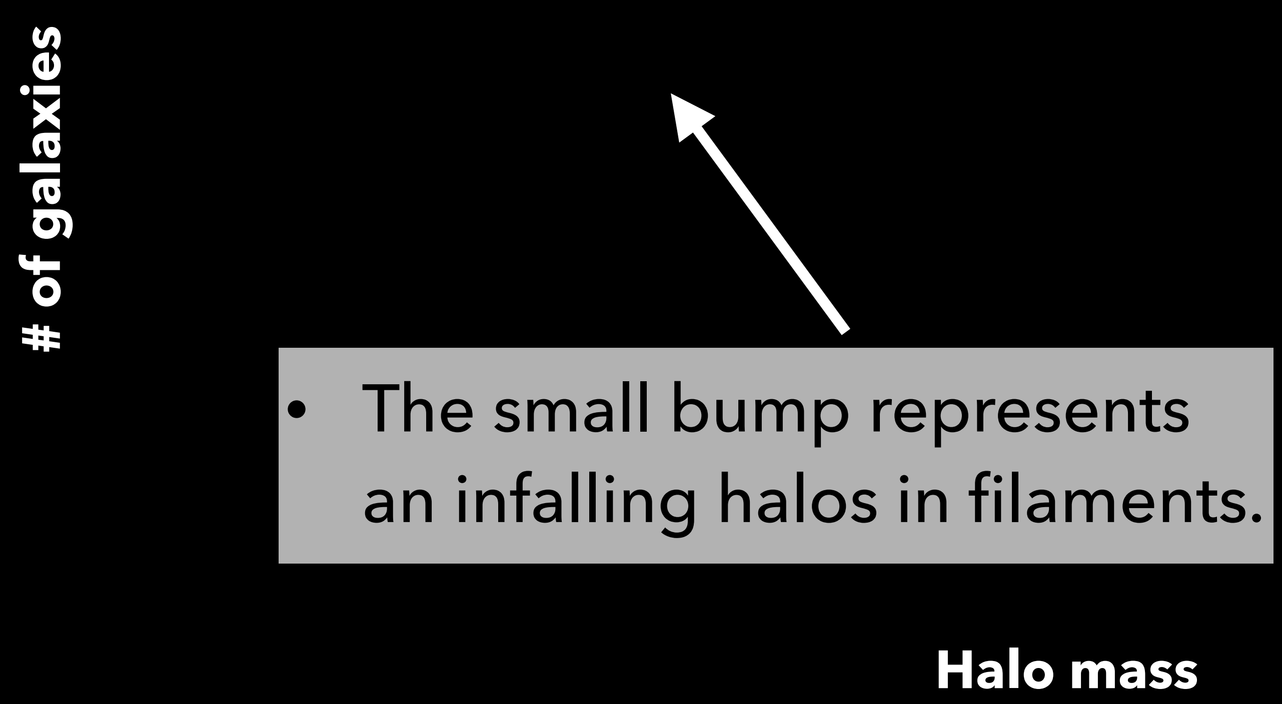
KO and Okumura (2021)

HOD and Anisotropic Correlation Function

- ***<u>Halo Occupation Distribution (HOD)</u>***:
  The mean number of galaxies as a function of halo mass. There is a distinct population, which are low-mass star forming halos and likely to be found in filaments.

- ***<u>Anisotropic correlation function</u>***:
  The FoG effect is weaker and due to infalling nature of ELGs, the growth rate may be underestimated (KO & Okumura, *in prep.*).

<u>Ha ELGs</u>



KO and Okumura (2021)

IA with mock ELG catalogues

- ***Detectability with future surveys***:
  Quantifying possible systematics for PFS, DESI, and *Euclid*.

- ***Luminosity and redshift dependence***:
  How large is the dependence on luminosity and redshift of IA amplitudes of ELGs? (c.f. Chisari+, 2016)

- ***Theoretical modelling***:
  NLA or TATT with non-zero tidal torquing?
  We can extract more information of
  3D (shape) power spectrum (though it requires IM).

- ***Forecast for cosmology***:
  What kind of physics (non-Gaussianity, BAO, RSD) can be probed with future IA observations? (c.f. Taruya & Okumura, 2020)

Summary

- ✦ Hydrodynamical simulations are a versatile tool for IA since growth of large-scale structures and formation and evolution of (source) galaxies are traced in a consistent manner.
- ✦ The tidal alignment model works for red elliptical galaxies and significant detections have already been reported. So far, there is **no significant detection of IA for ELGs**, which are main targets in upcoming spectroscopic observations. Furthermore, there is **inconsistency of IA amplitudes** among hydrodynamical simulations.
- ✦ We can employ realistic mock ELG catalogues to investigate detectability with future surveys and explore the capability to constrain cosmological models.