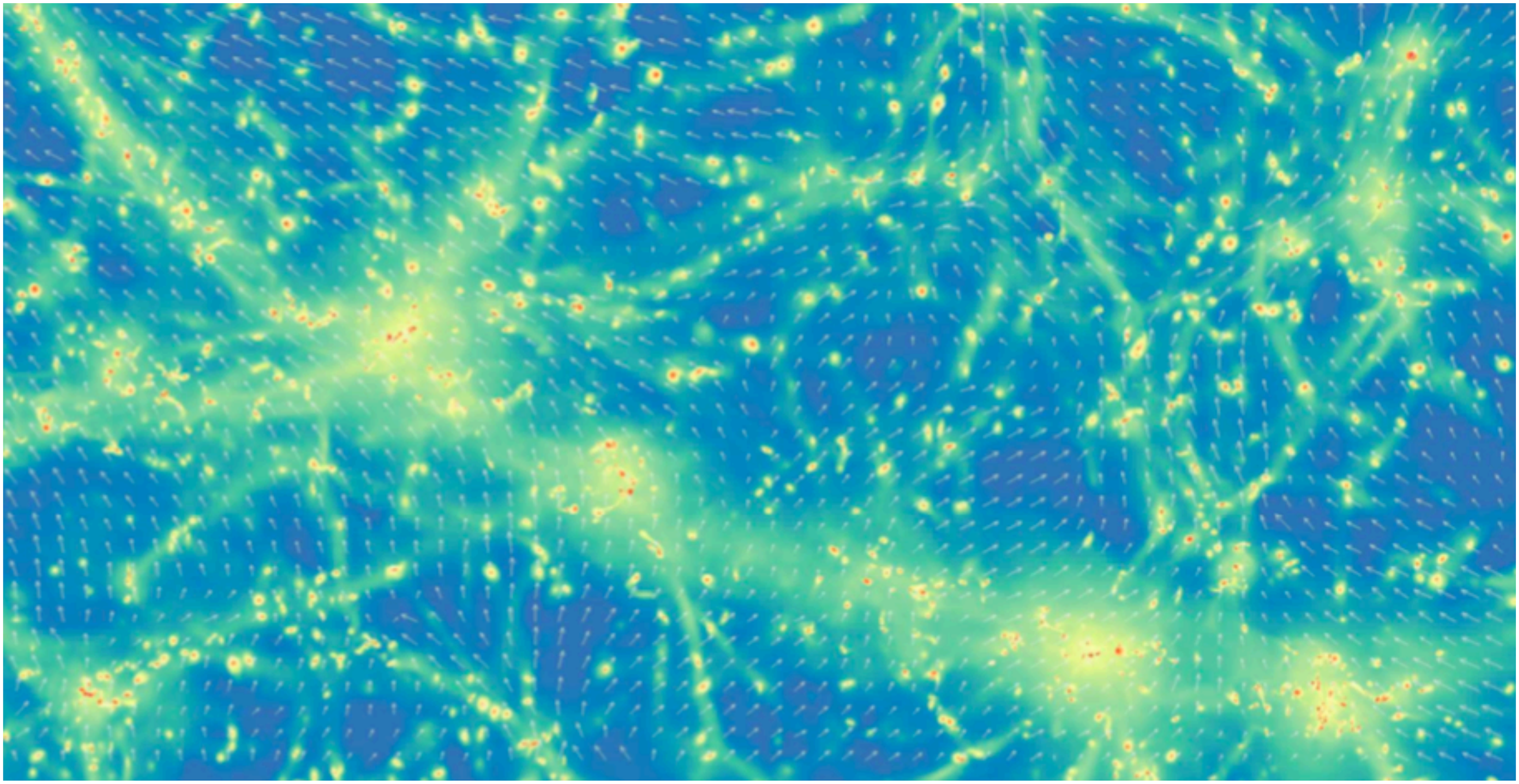
IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO

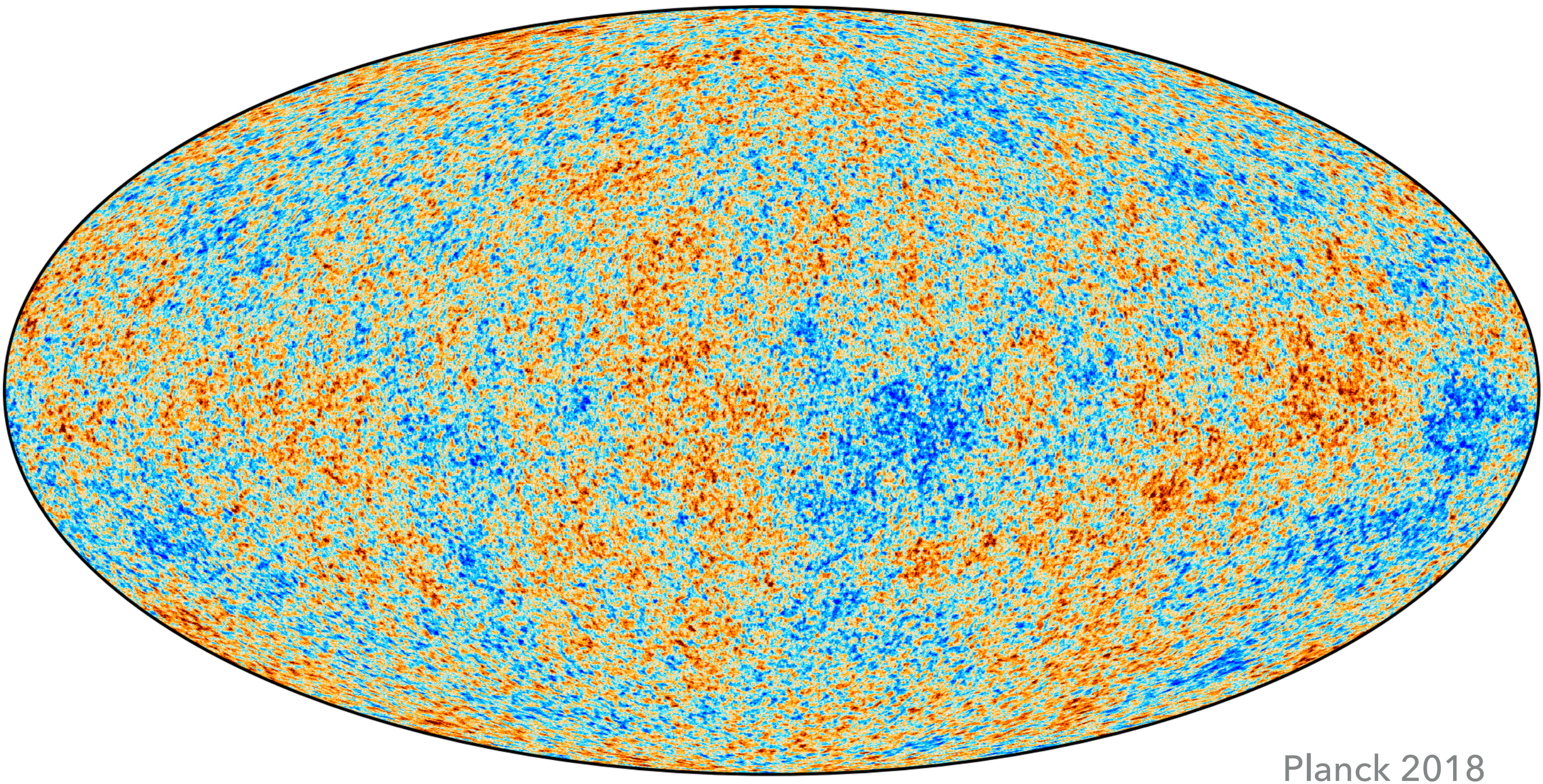
wpi



Jingjing Shi (史晶晶)

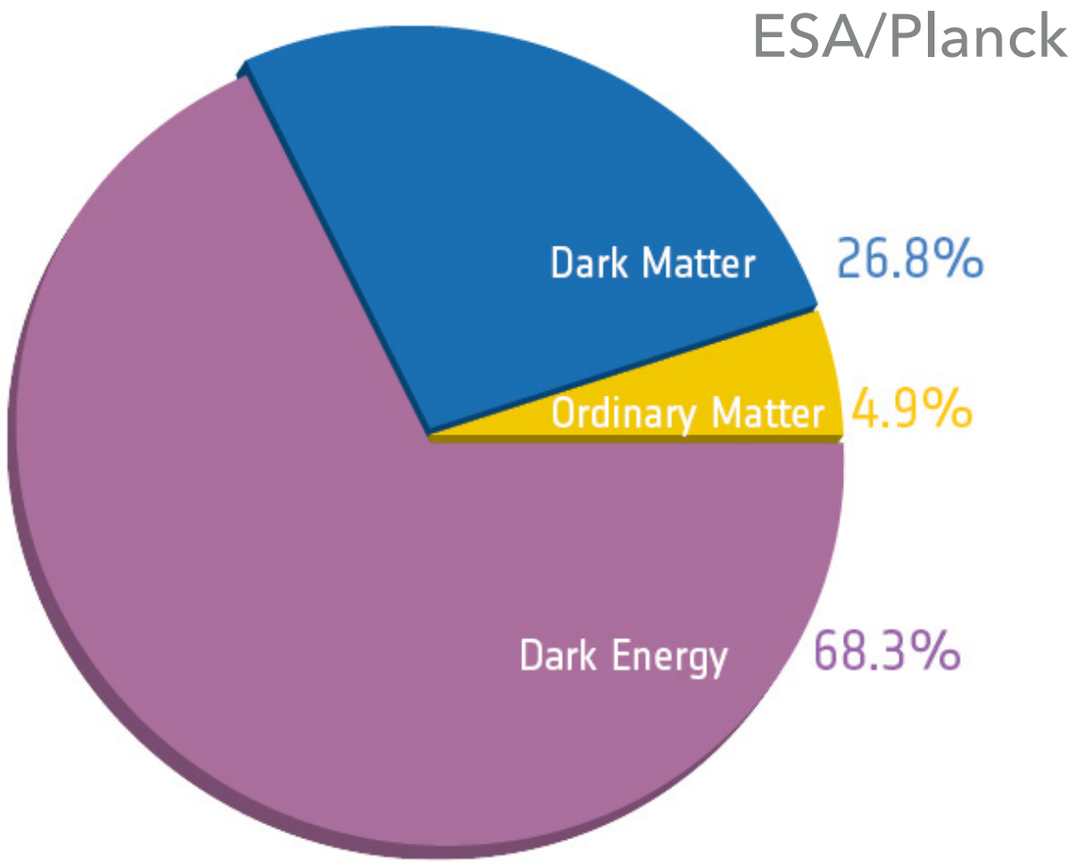
GALAXY INTRINSIC ALIGNMENT

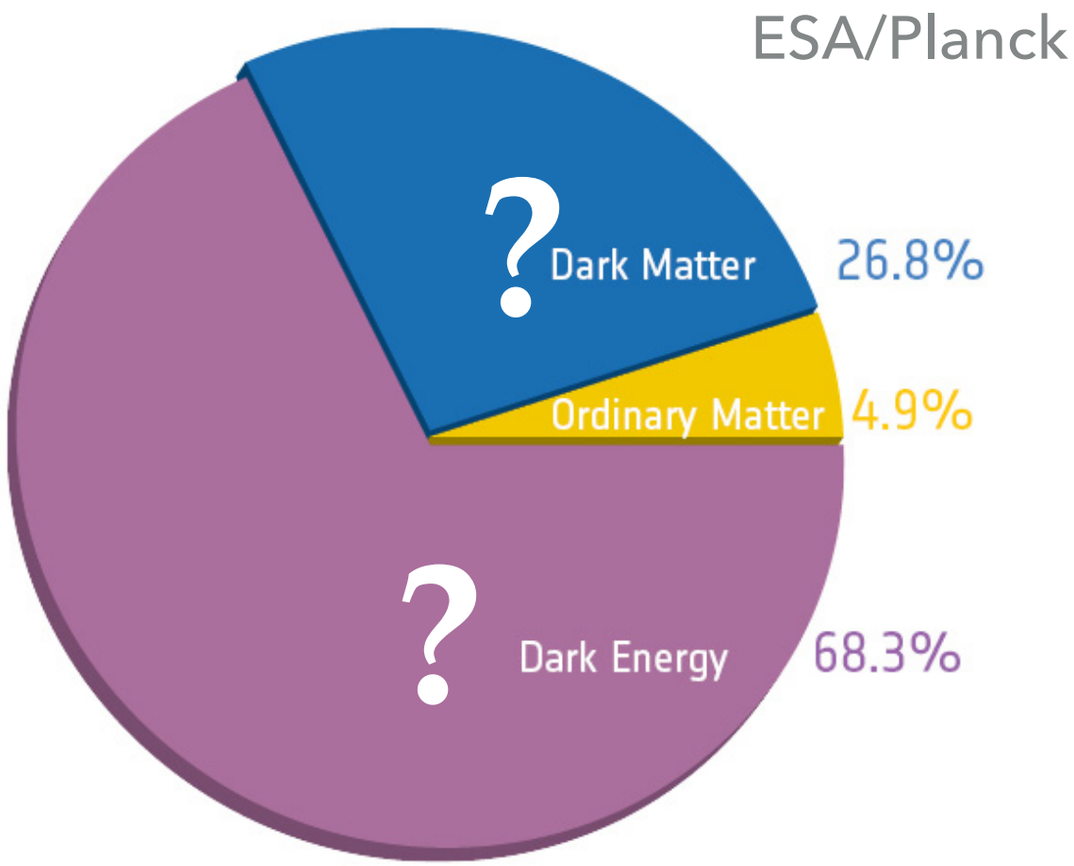
Precision Cosmology – origin, composition, and evolution of the Universe



Planck 2018

Cosmic Microwave Background, ~400,000 years after big bang


ESA/Planck
Dark Matter
26.8%
Ordinary Matter
4.9%
Dark Energy
68.3%

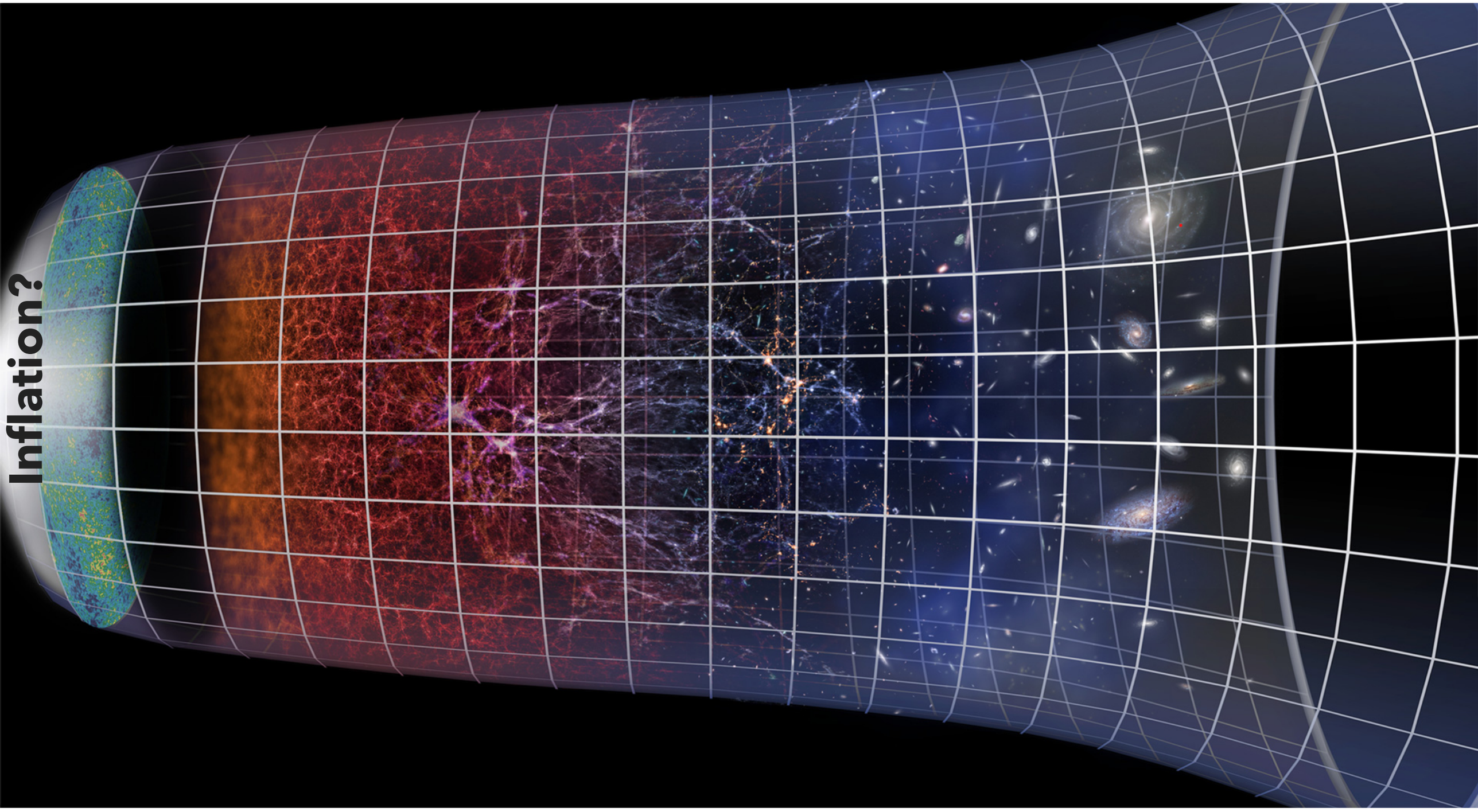


Dark Matter

- WIMP
- Axions (ultra light scalar field)
- Primordial Black Hole (PBH)

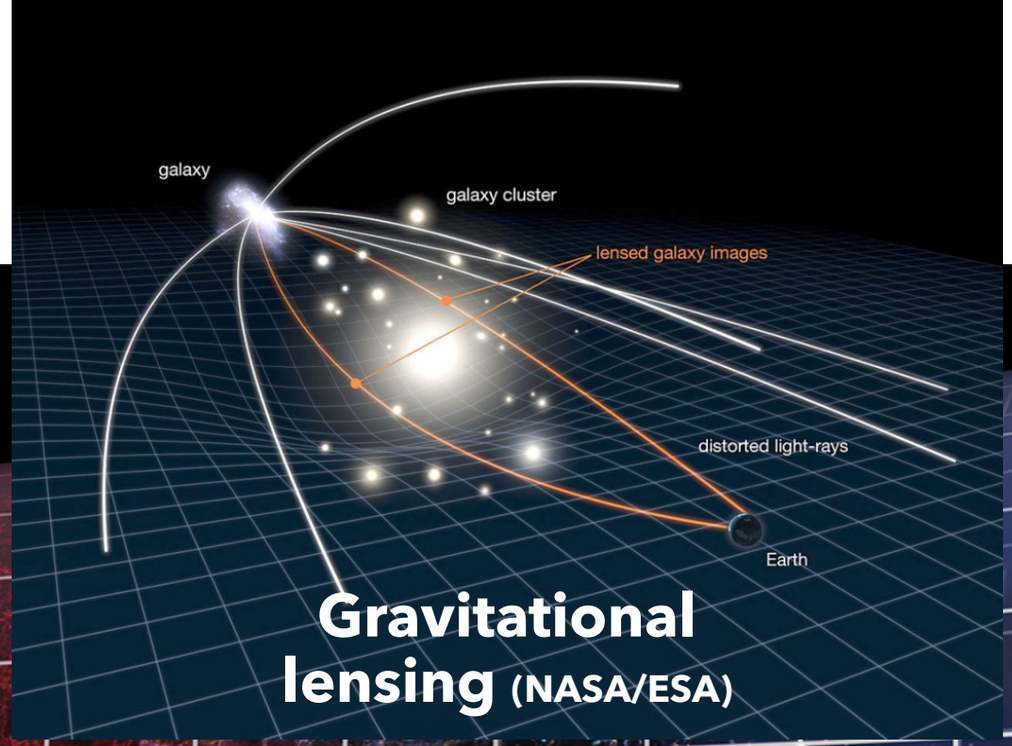
Dark Energy

- Cosmological constant Λ
- Dynamical field
- Modified gravity



ESO/ELT

Inflation?

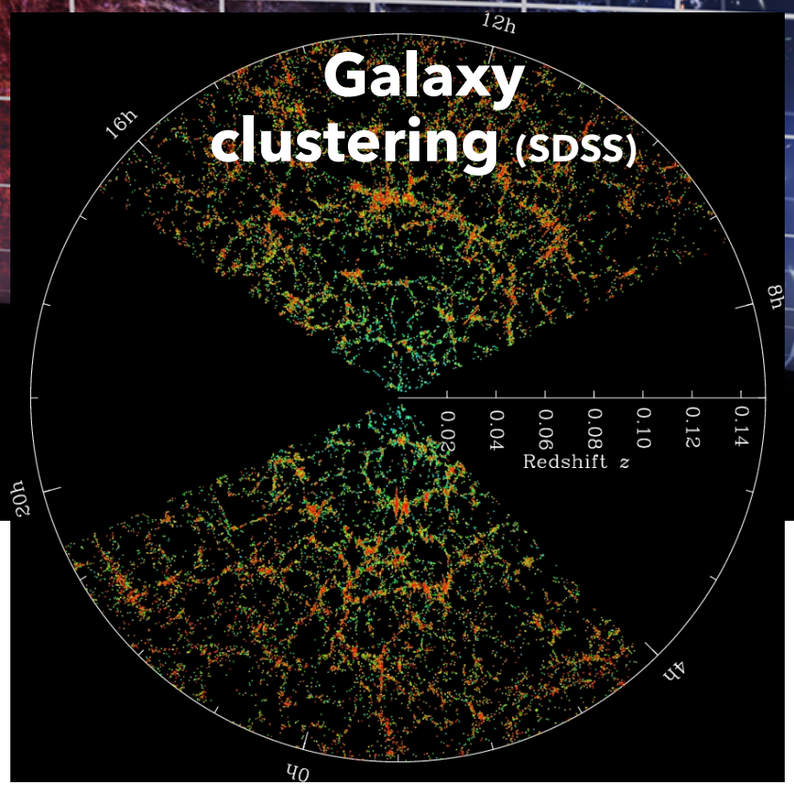


Gravitational lensing (NASA/ESA)

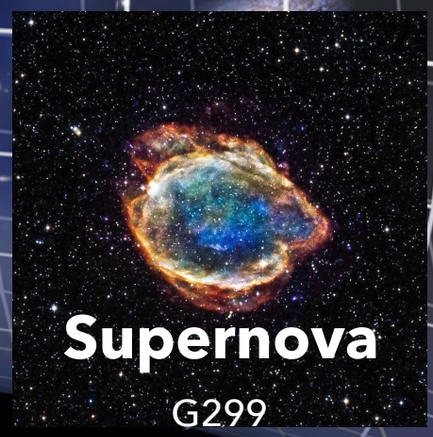
Galaxy Cluster

(MACS0416.1-2403)

$$\Omega_m = \Omega_{\rm DM} + \Omega_b, \Omega_\Lambda, w, h, S_8, \Sigma m_\nu$$



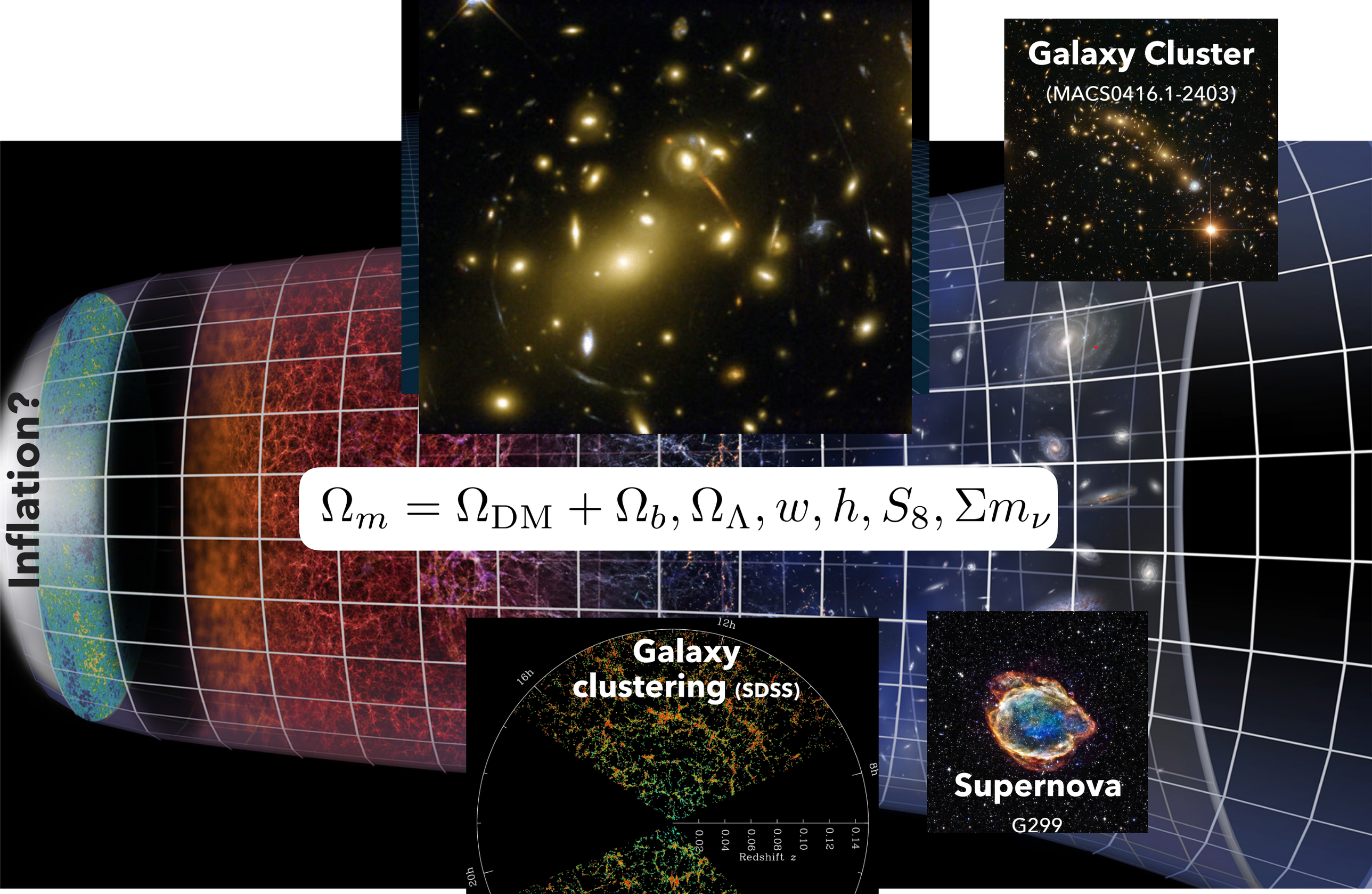
Galaxy clustering (SDSS)



Supernova

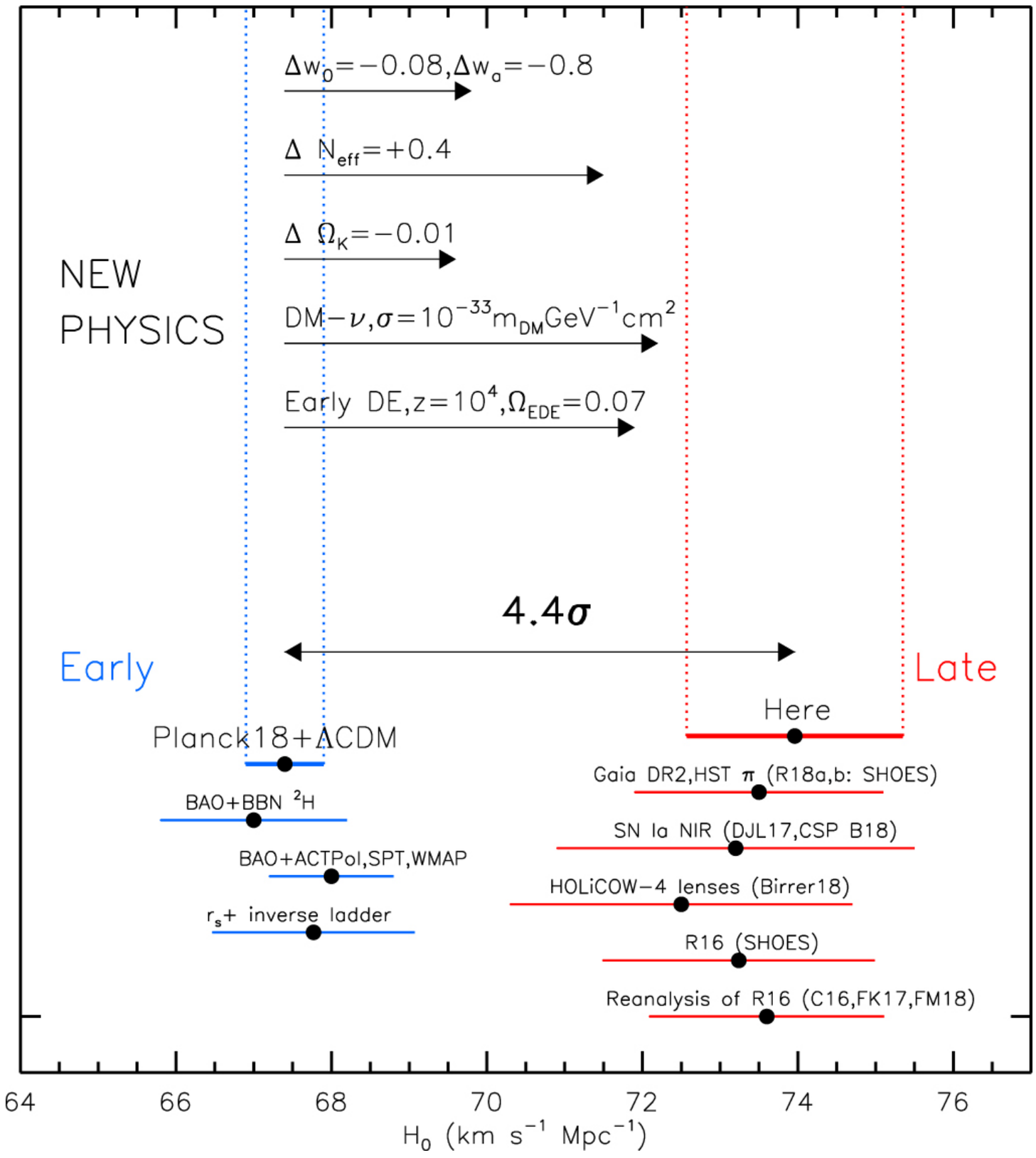
G299

ESO/ELT


Galaxy Cluster
(MACS0416.1-2403)
$\Omega_m = \Omega_{\rm DM} + \Omega_b, \Omega_\Lambda, w, h, S_8, \Sigma m_\nu$
Galaxy clustering (SDSS)
12h
8h
4h
0h
20h
16h
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Redshift z
Supernova
G299
Inflation?

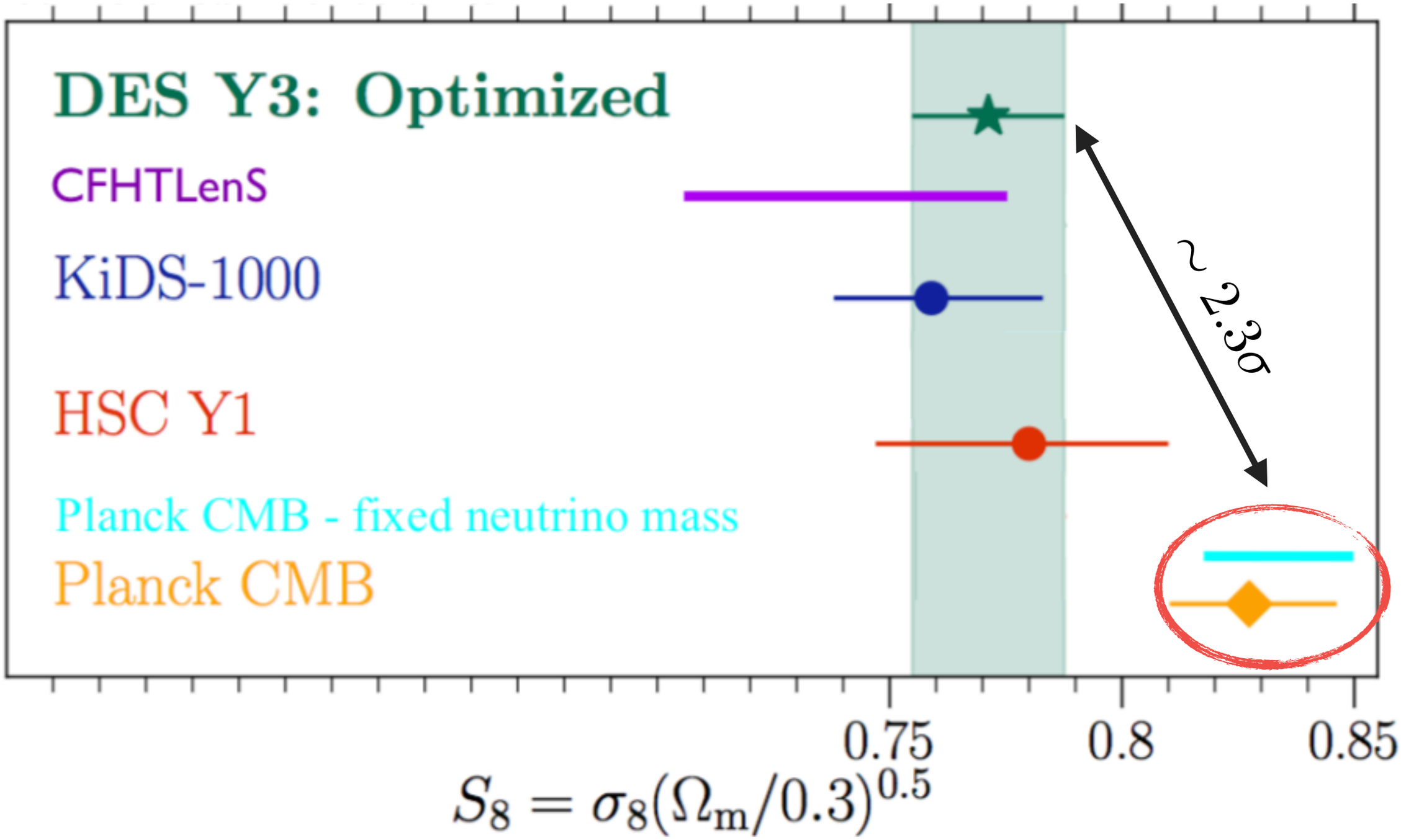
ESO/ELT

TENSIONS – HUBBLE PARAMETER



Riess et al. 2019

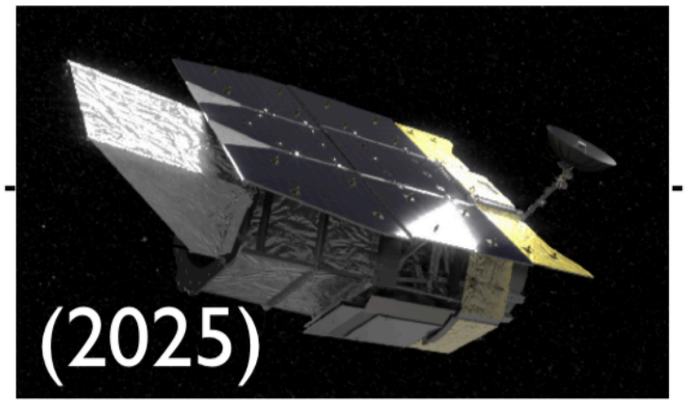
TENSIONS – LARGE SCALE STRUCTURE



Amon et al. 2021

ONGOING/UPCOMING SURVEYS

Imaging surveys

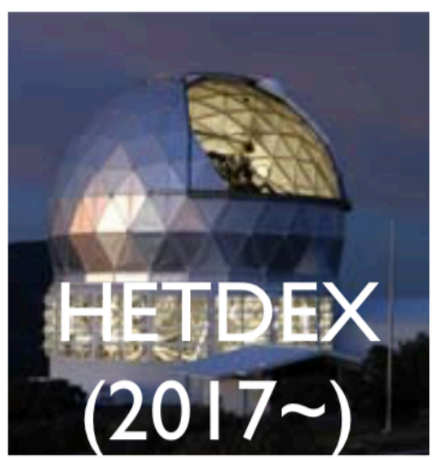


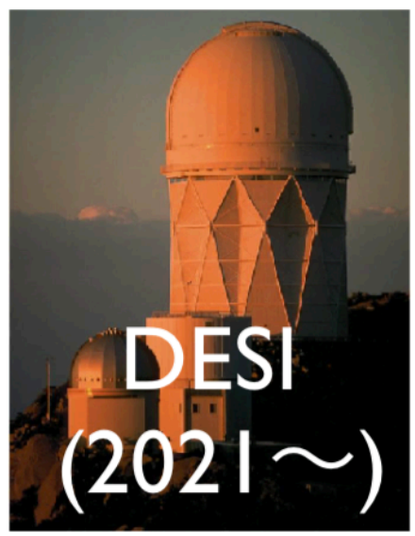
Nancy Grace Roman Space Telescope (WFIRST)

HSC (2014~)

PFS (2023~)

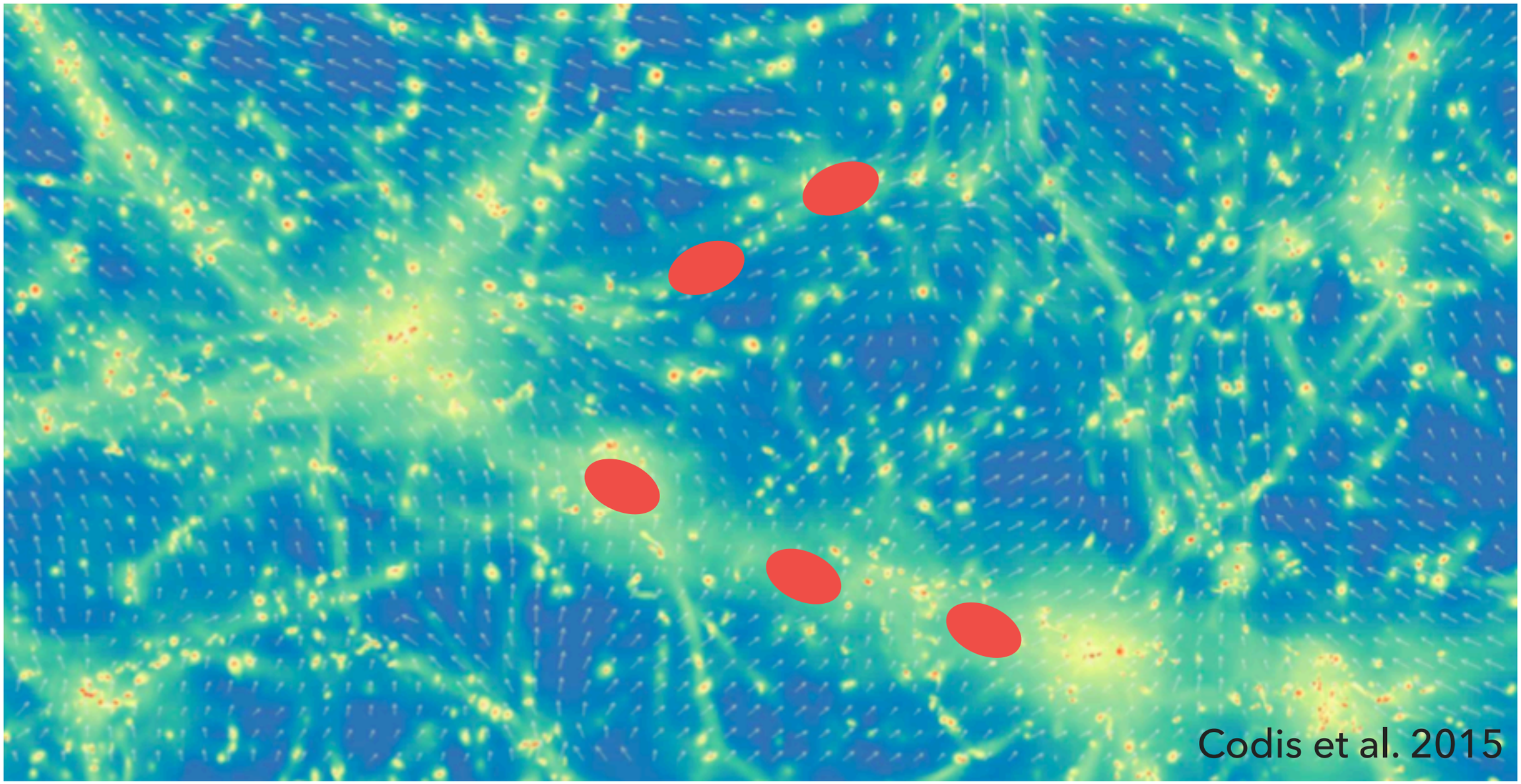
Spectroscopic surveys





Atsushi Taruya's slide

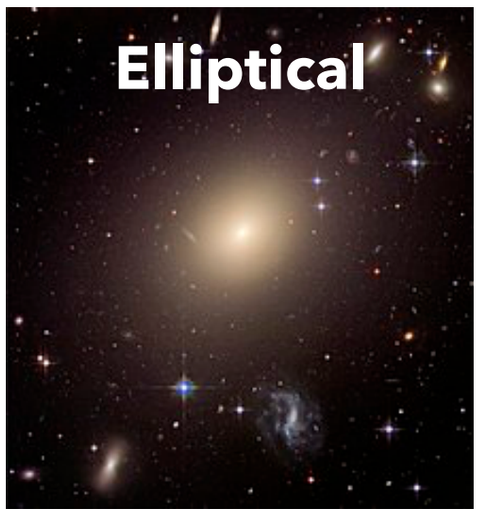
GALAXY INTRINSIC ALIGNMENT

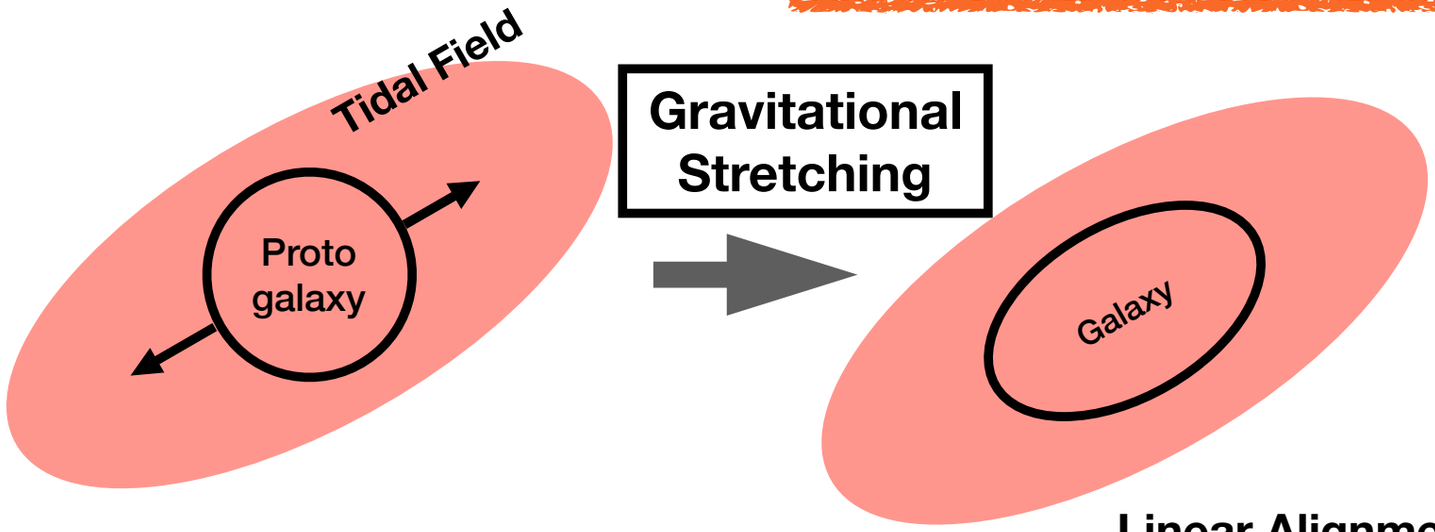


- **Challenge** – contaminates weak lensing cosmology
- **Opportunity** – probe of cosmology

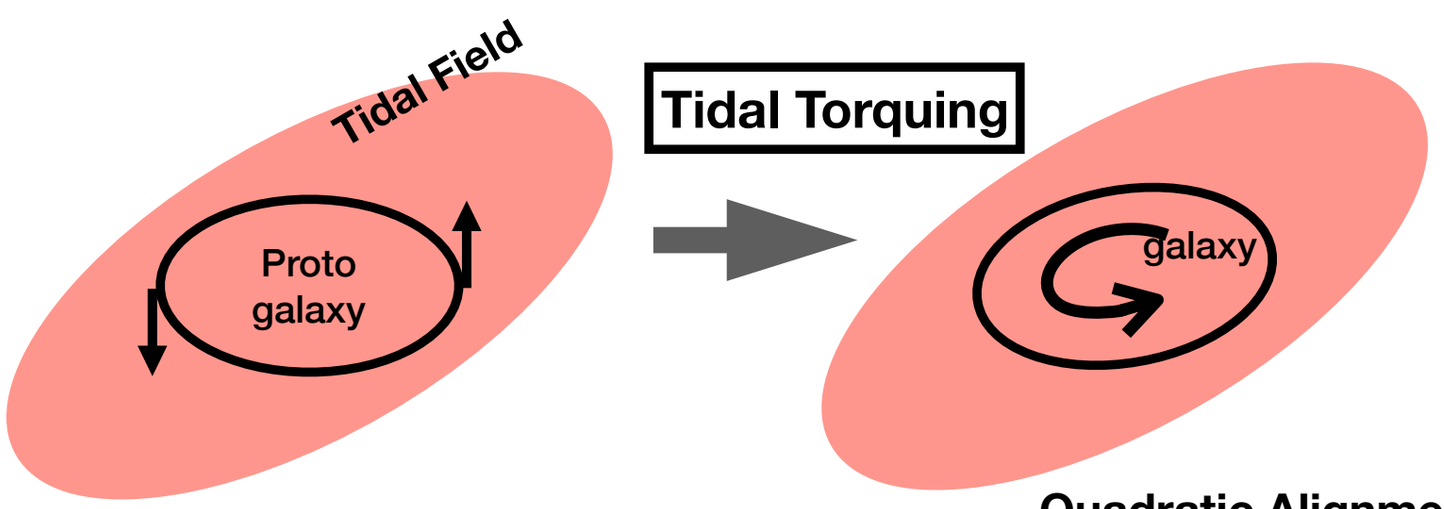
GALAXY INTRINSIC ALIGNMENT – THEORIES

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





Linear Alignment

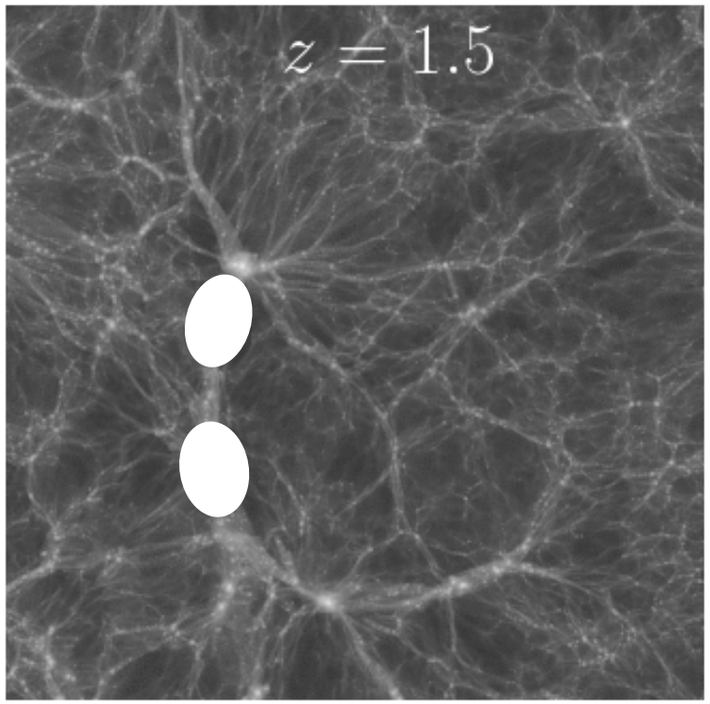


Quadratic Alignment

$$\gamma^I_{(+,\times)} = C_2(T^2_{1i} - T^2_{2i}, 2T_{1i}T_{2i})$$

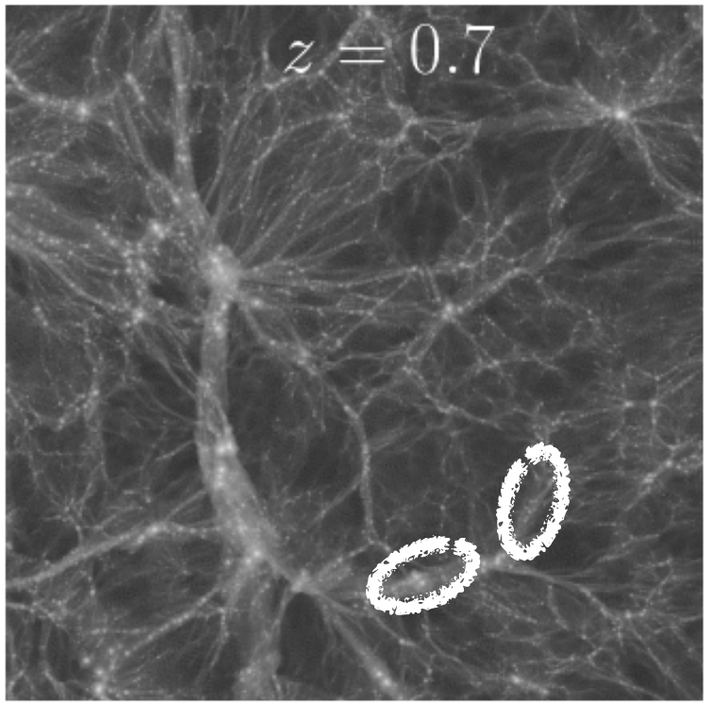
Catelan+2001, Hirata & Seljak 2004, Bridle & King 2007

Source

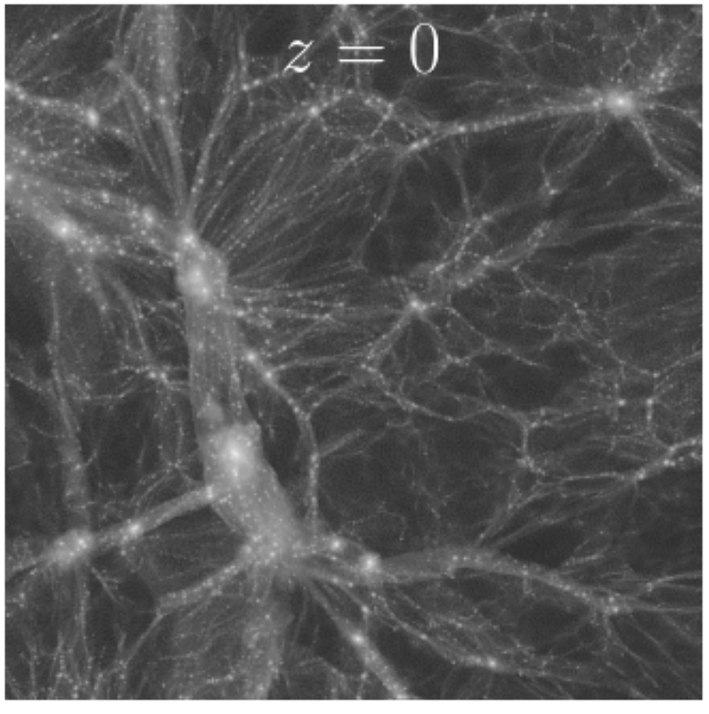


Structure Growth and Accelerating Expansion

Lens: matter along line of sight

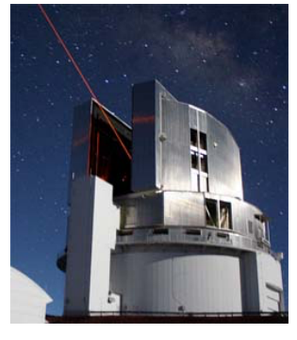


Observed Images



Galaxy intrinsic alignment – Primary contamination of cosmic shear cosmology

(Hirata & Seljak 2004, Troxel+2015)



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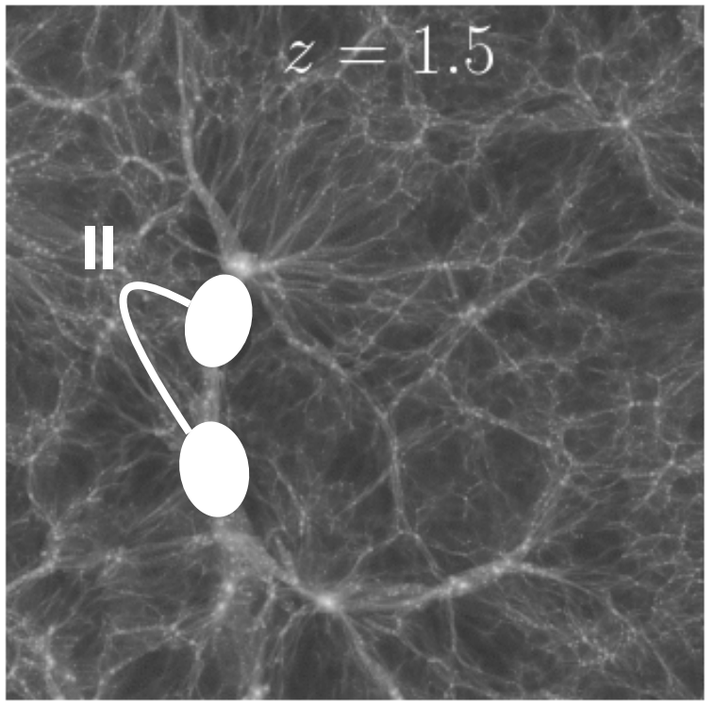
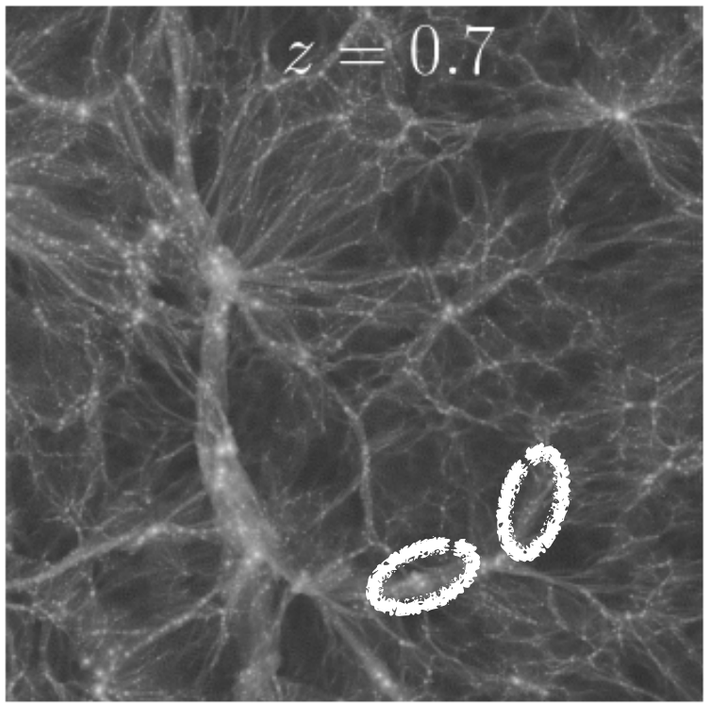
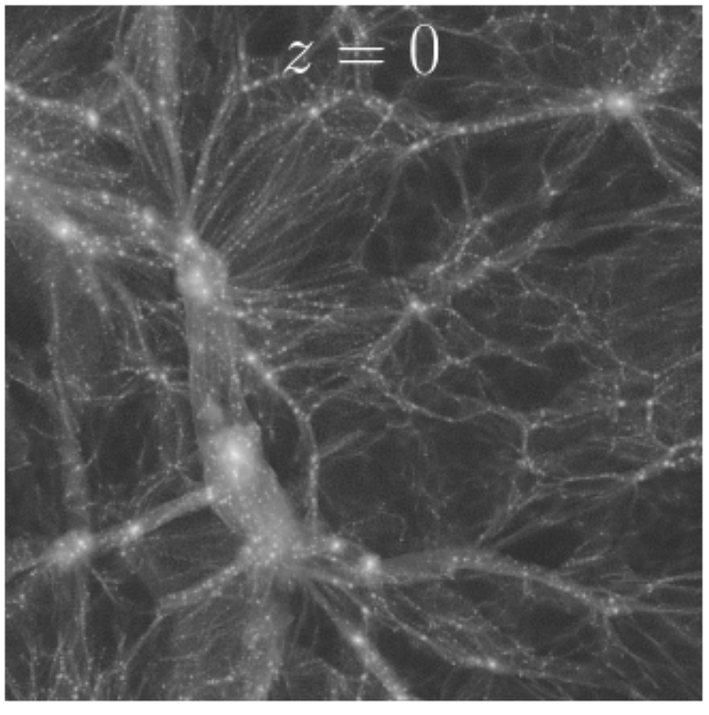


Structure Growth and Accelerating Expansion

Lens: matter along line of sight



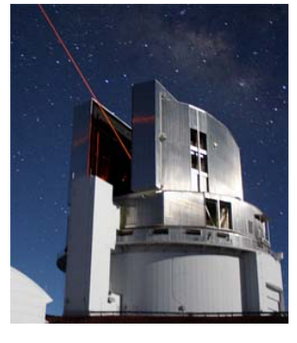
Observed Images



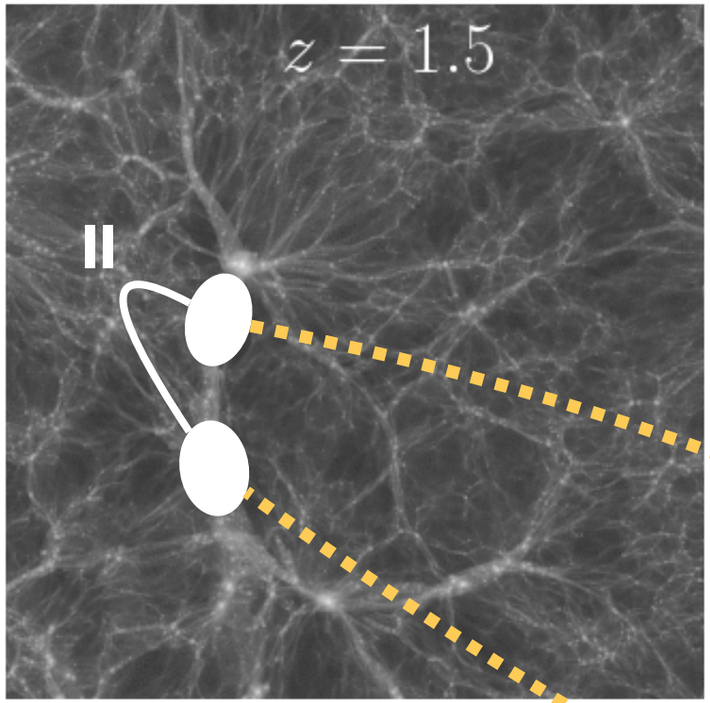
II: intrinsic alignment

Galaxy intrinsic alignment – Primary contamination of cosmic shear cosmology

(Hirata & Seljak 2004, Troxel+2015)

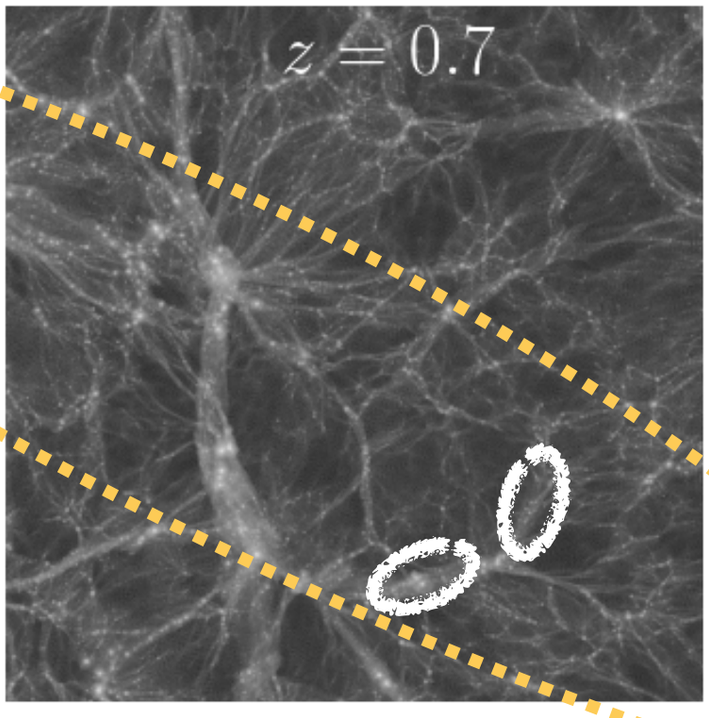


Source

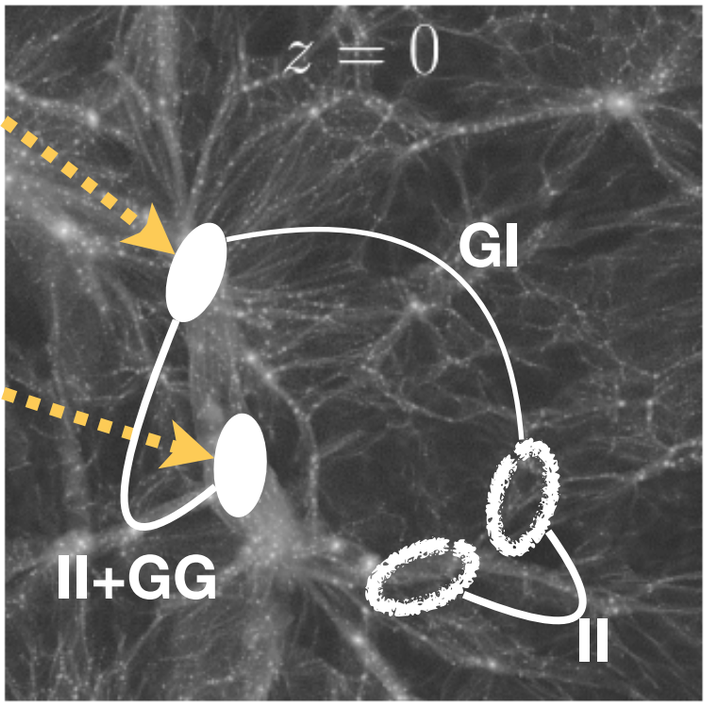


Structure Growth and Accelerating Expansion

Lens: matter along line of sight



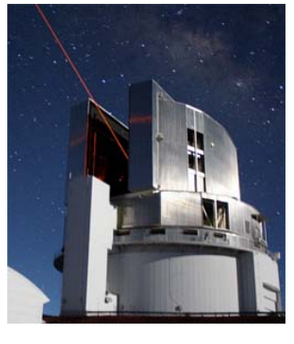
Observed Images



II: intrinsic alignment
GI: intrinsic alignment
GG: cosmic shear

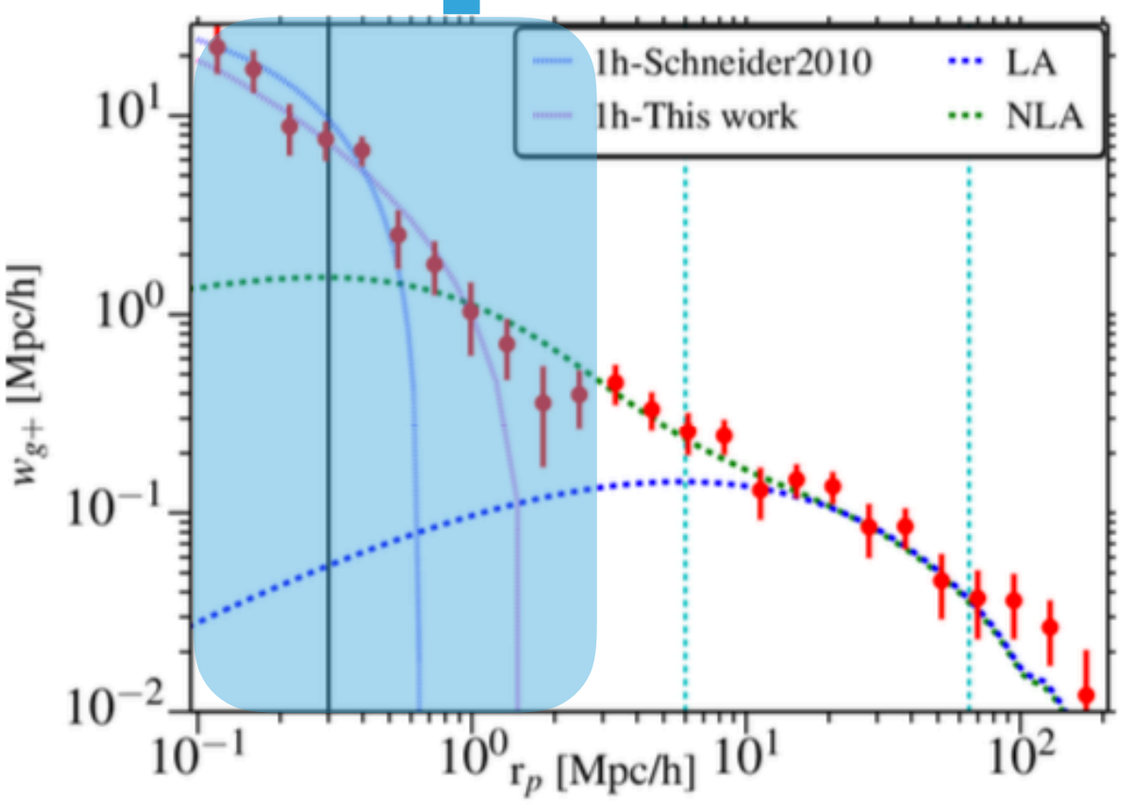
Galaxy intrinsic alignment – Primary contamination of cosmic shear cosmology

(Hirata & Seljak 2004, Troxel+2015)



INTRINSIC ALIGNMENT – OBSERVATIONS

Non-linear and baryonic physics dominates !

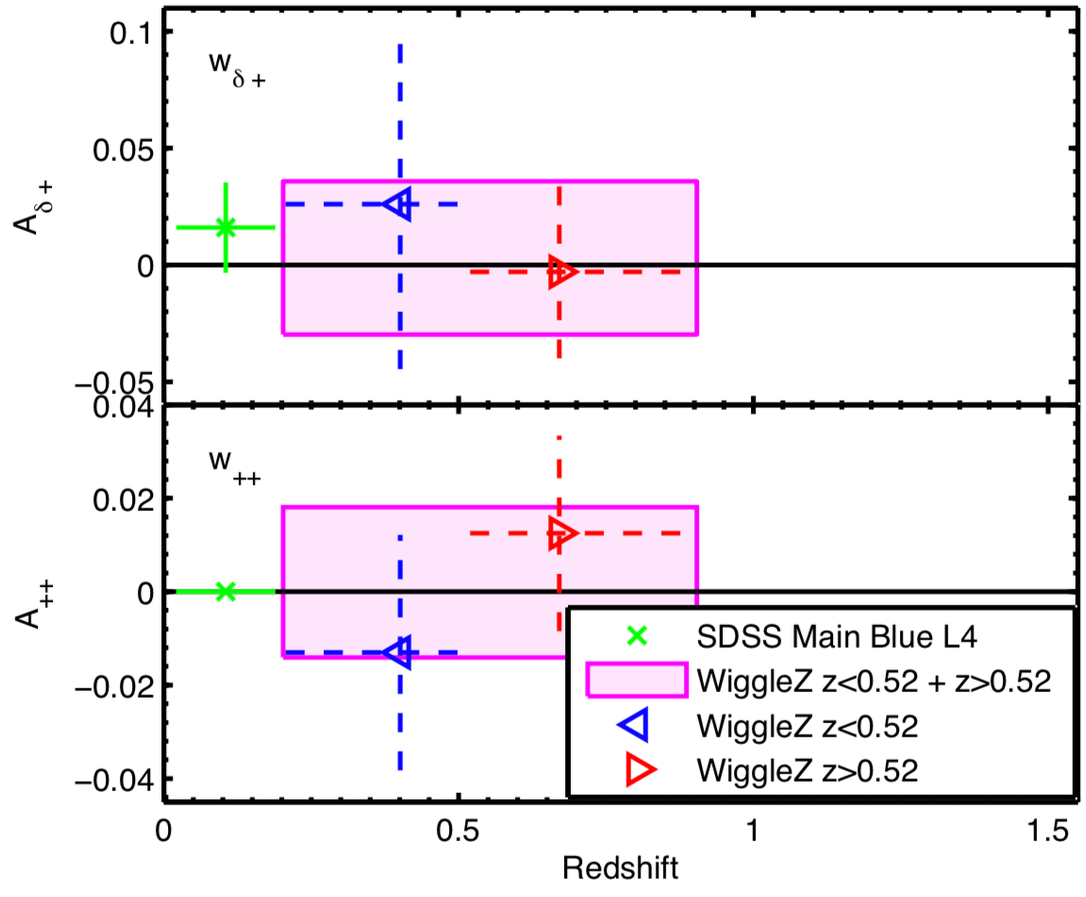


Luminous red galaxies – clear IA signal shown by the correlation function between galaxy positions and intrinsic ellipticities

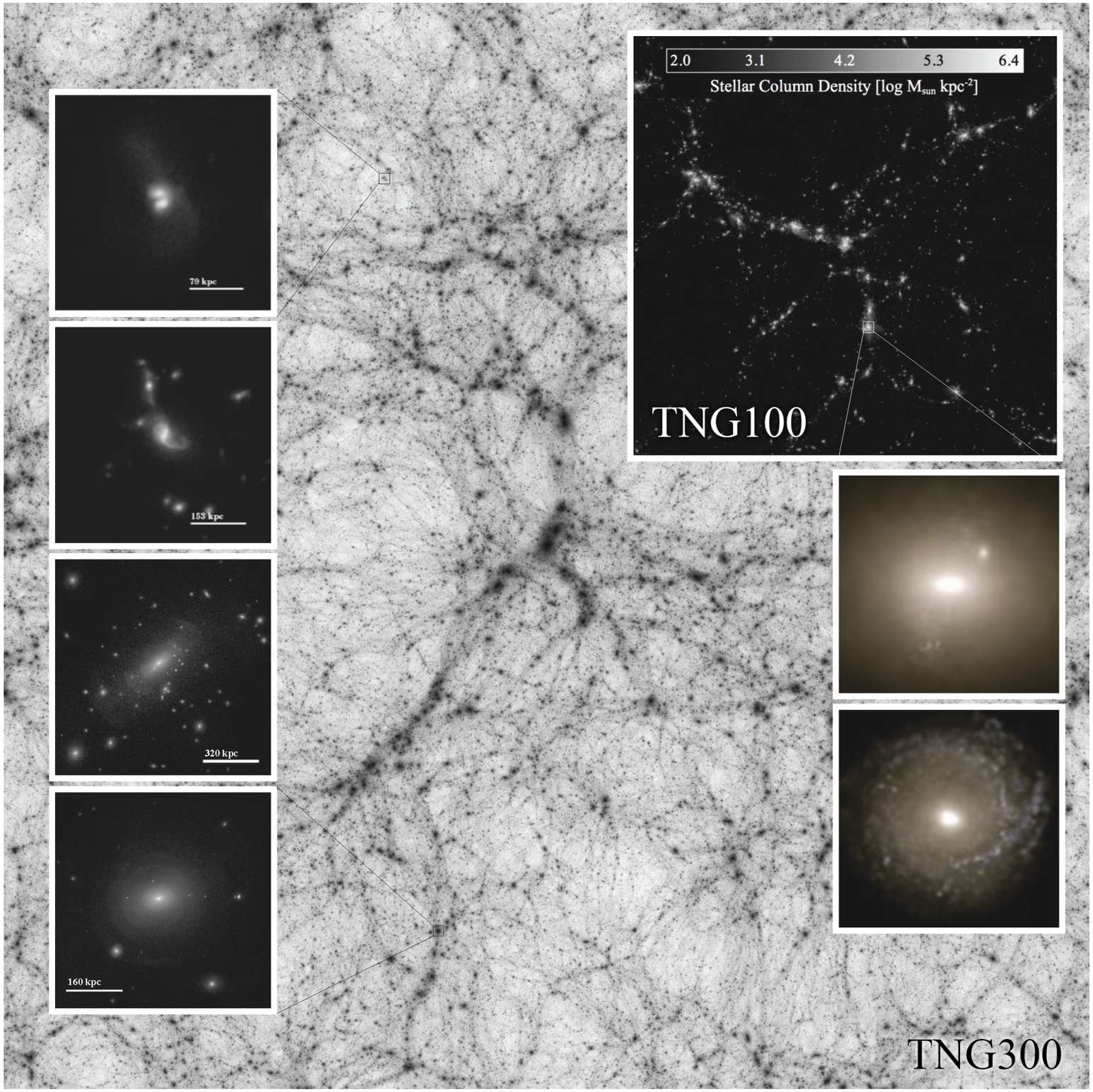
Singh et al. 2015

Mandelbaum+2011, Yao+2020

Blue star-forming galaxies – no clear IA signal detected so far

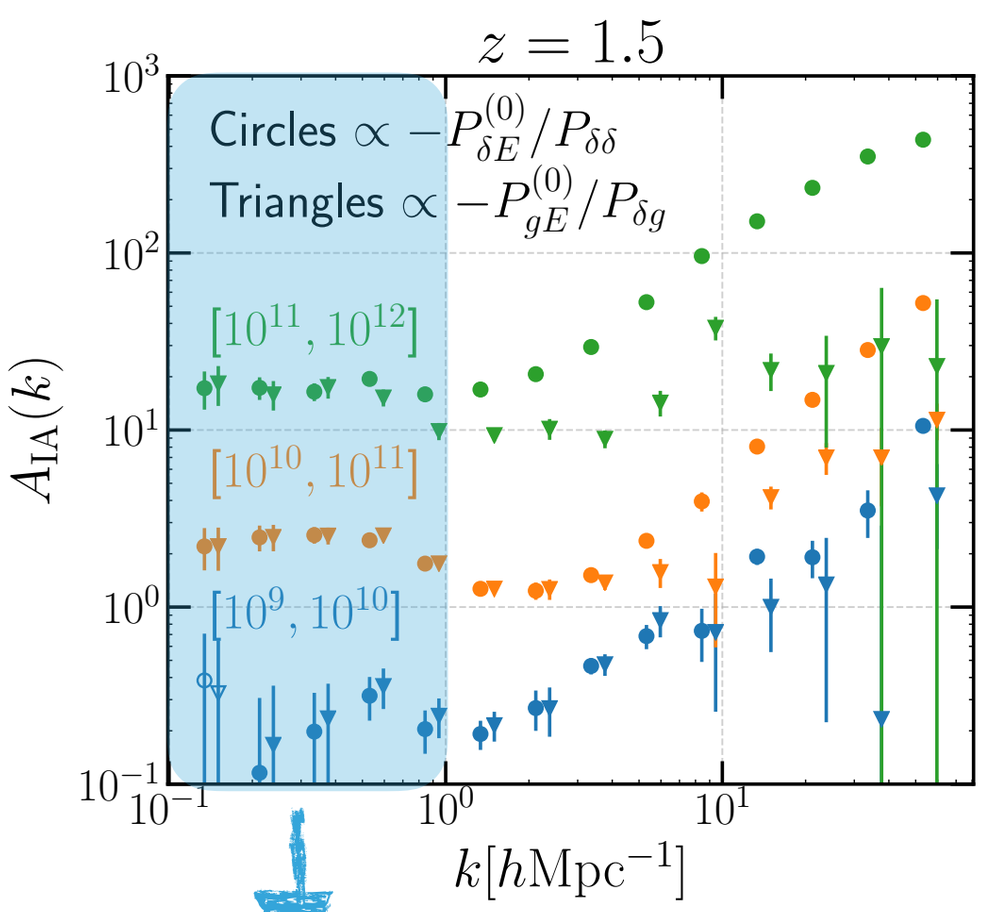


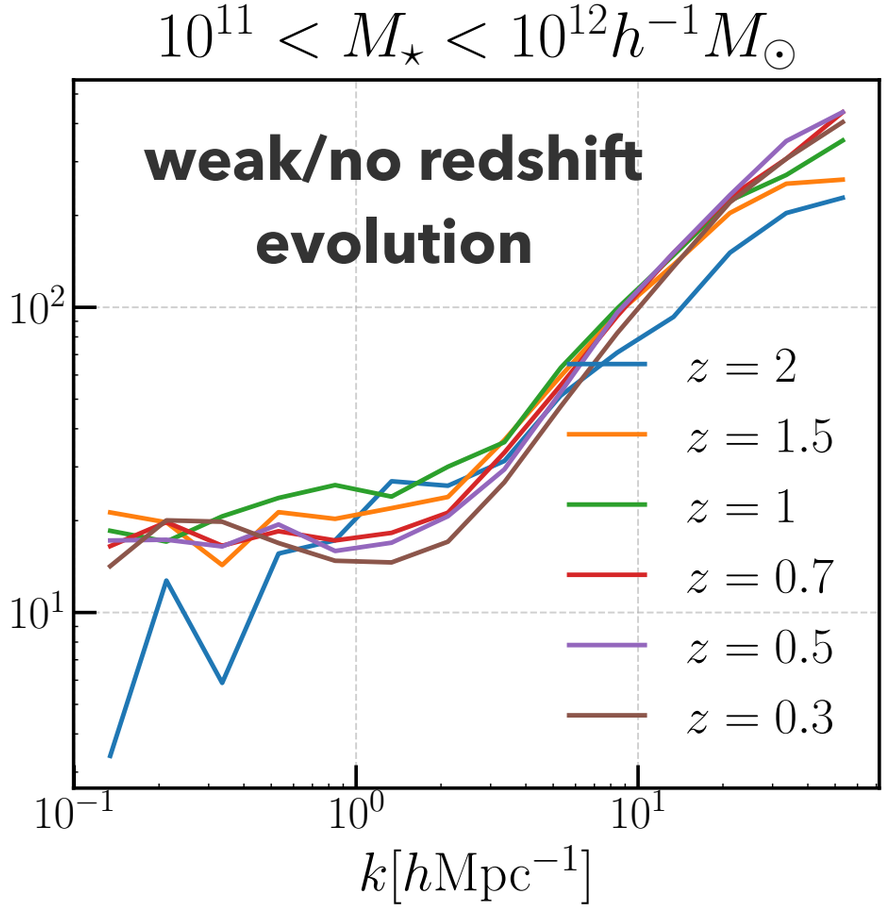
INTRINSIC ALIGNMENT – SIMULATIONS



Ideal for studying hard-to-model baryonic/non-linear effects

INTRINSIC ALIGNMENT – M* AND REDSHIFT DEPENDENCE



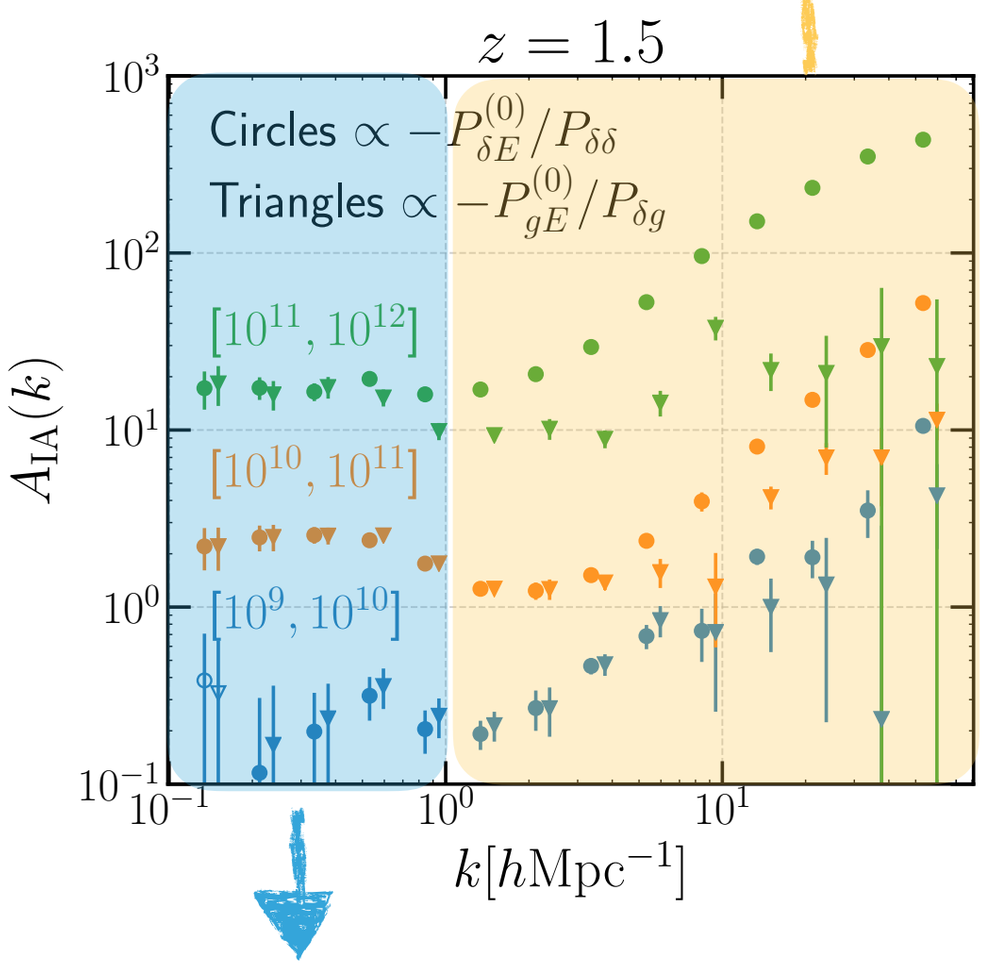


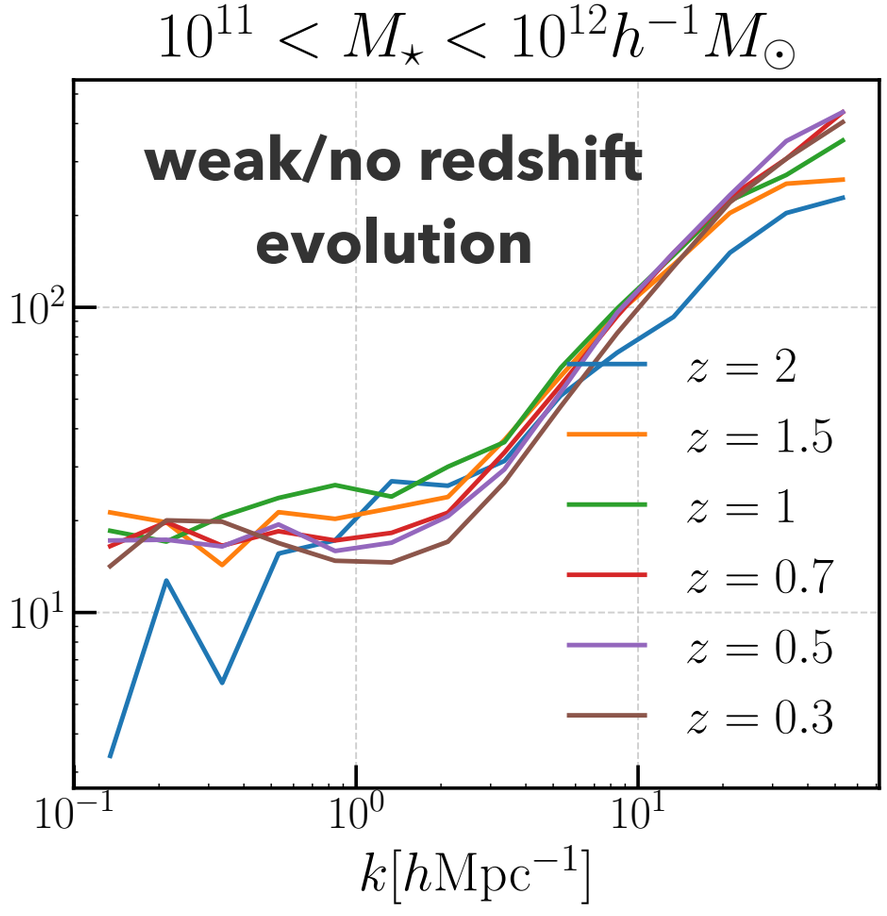
Consistent with NLA prediction

$$P_{\delta E}(k,\mu) = -A_{\rm IA} C_1 \rho_{\rm cr0} \frac{\Omega_{\rm m}}{D(z)} (1-\mu^2) P_{\delta\delta}(k,z)$$

INTRINSIC ALIGNMENT – M_* AND REDSHIFT DEPENDENCE

Non-linear effects in dense region weakens the IA of galaxies

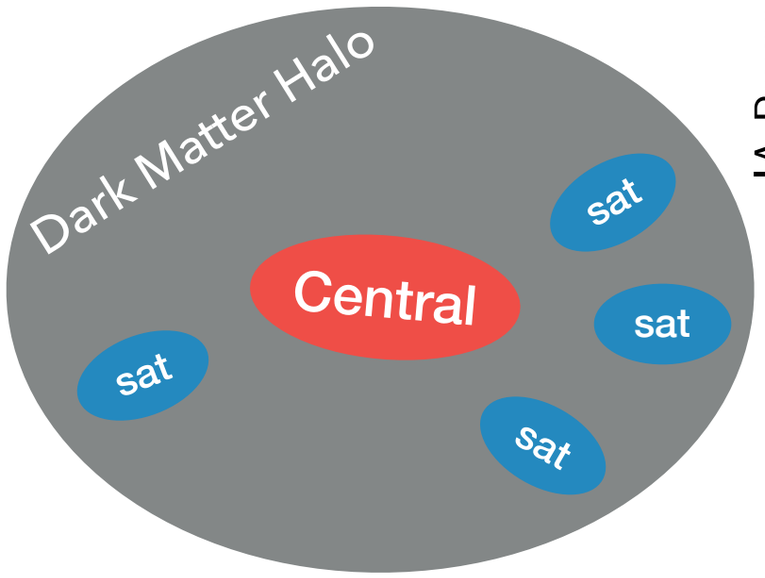


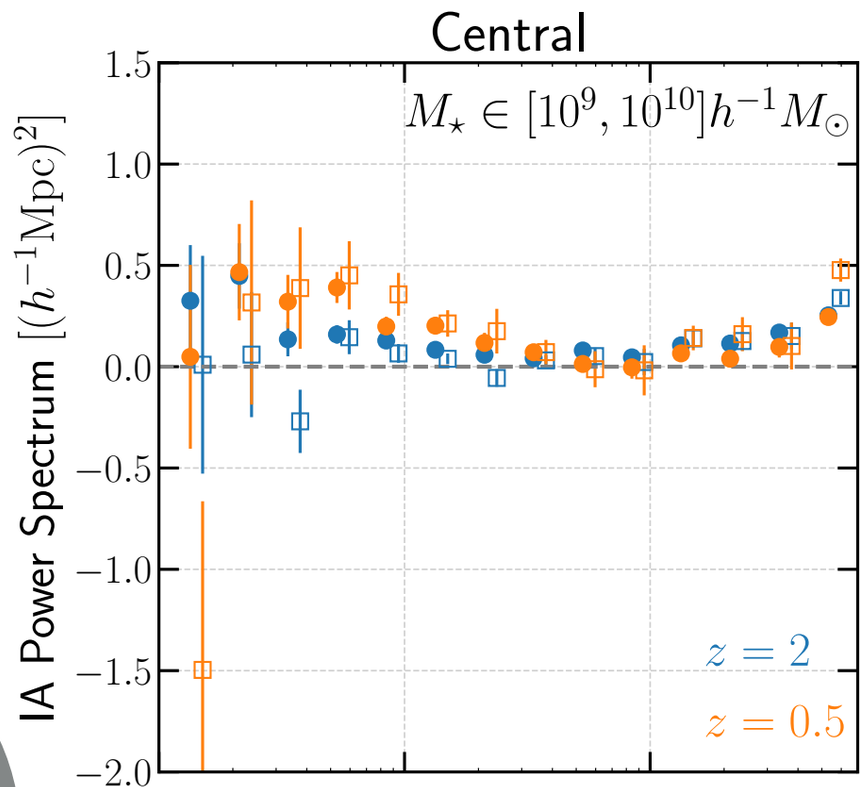


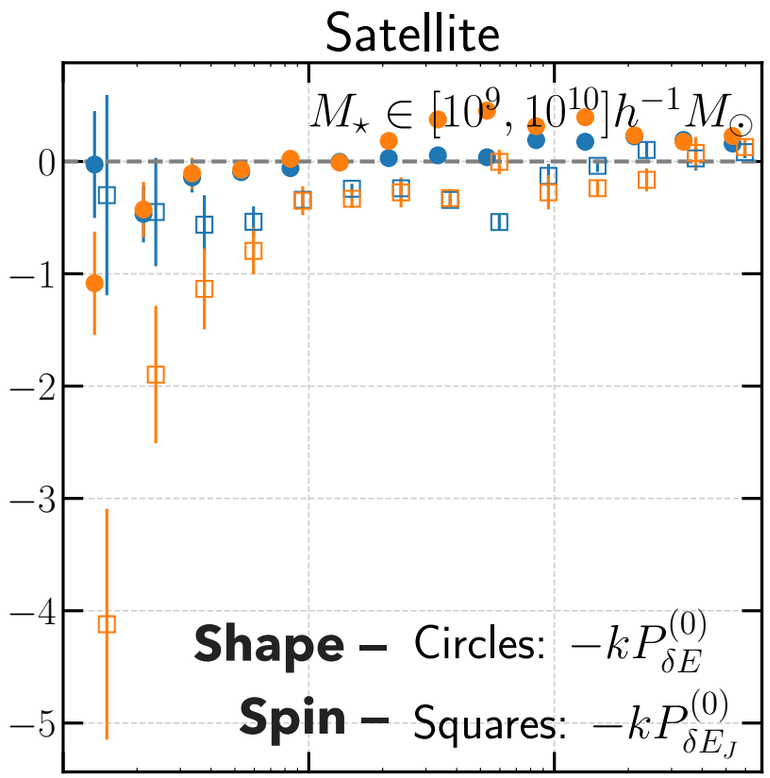
Consistent with NLA prediction

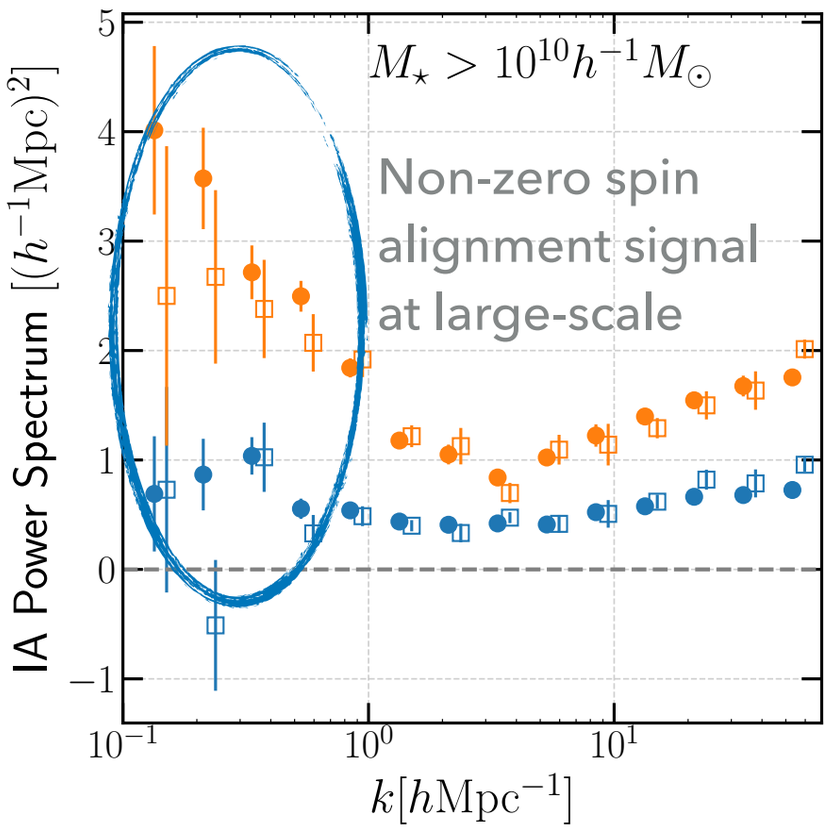
$$P_{\delta E}(k,\mu) = -A_{\rm IA} C_1 \rho_{\rm cr0} \frac{\Omega_{\rm m}}{D(z)} (1-\mu^2) P_{\delta\delta}(k,z)$$

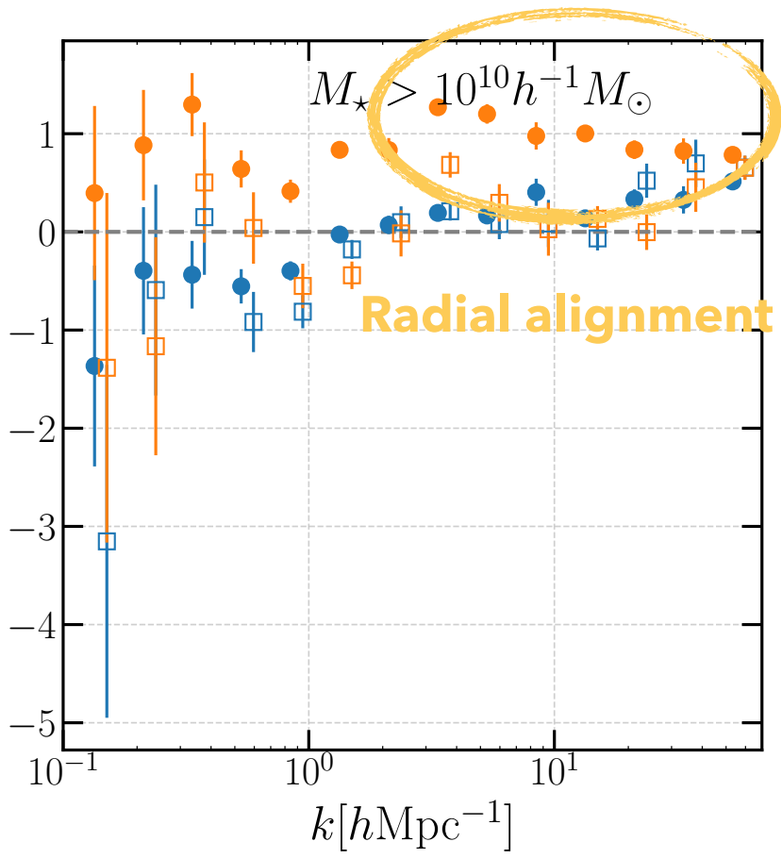
INTRINSIC ALIGNMENT – ENVIRONMENT DEPENDENCE



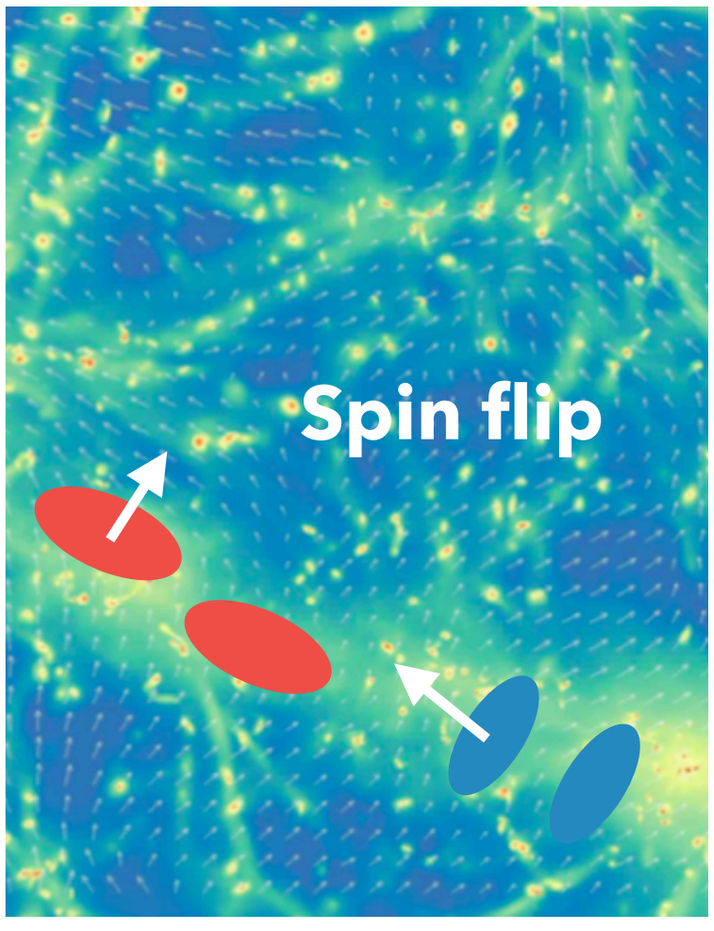








INTRINSIC ALIGNMENT – MORPHOLOGICAL DEPENDENCE



Spheroid

Disk

$M_\star \in [10^9, 10^{10}]h^{-1}M_\odot$

$z = 2$

$z = 0.5$

Spin Flip

Shape – Circles: $-kP^{(0)}_{\delta E}$

Spin – Squares: $-kP^{(0)}_{\delta E_J}$

IA Power Spectrum $[(h^{-1}\mathrm{Mpc})^2]$

$M_\star > 10^{10}h^{-1}M_\odot$

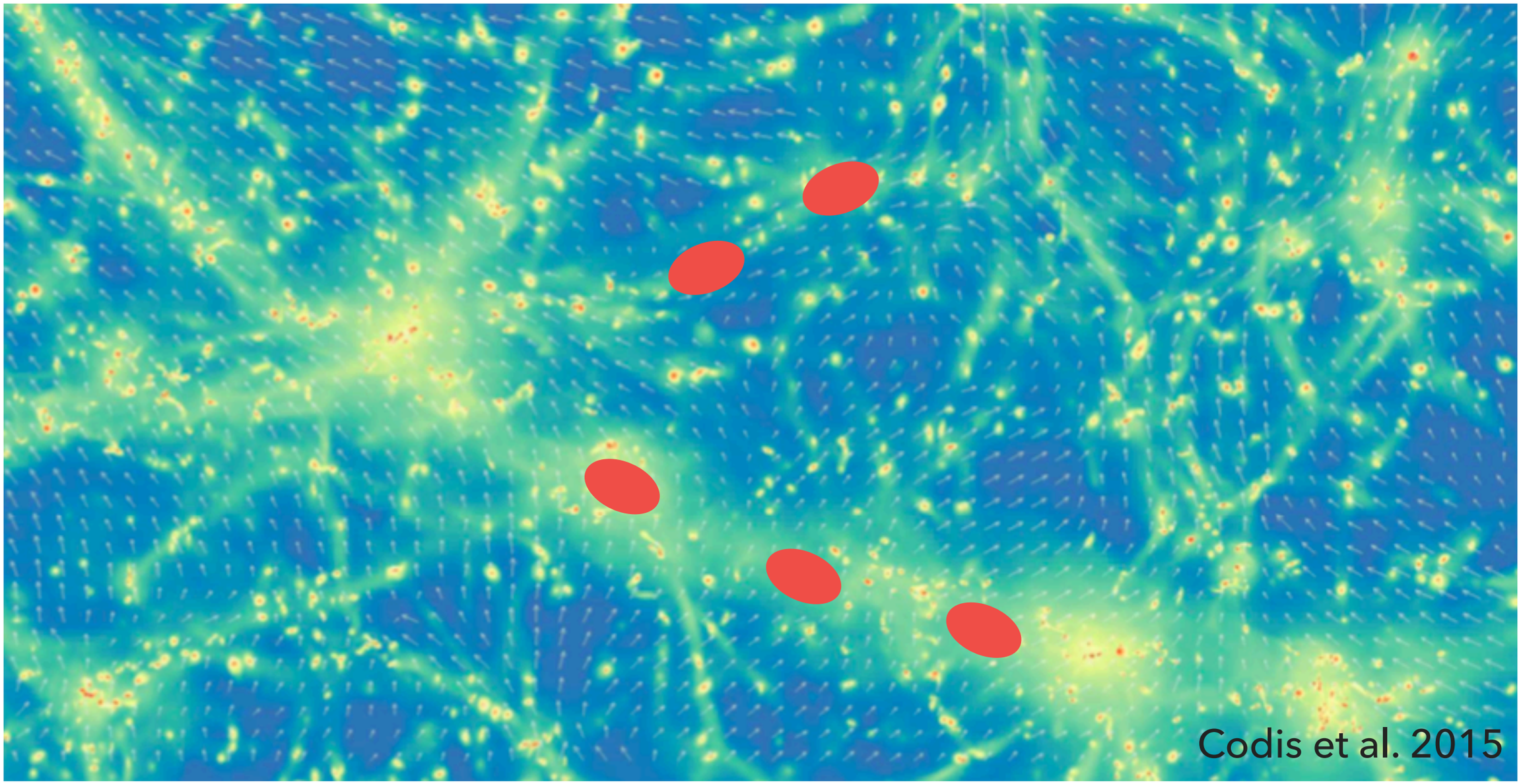
Strongest alignment

$M_\star > 10^{10}h^{-1}M_\odot$

$k[h\mathrm{Mpc}^{-1}]$

$k[h\mathrm{Mpc}^{-1}]$

GALAXY INTRINSIC ALIGNMENT

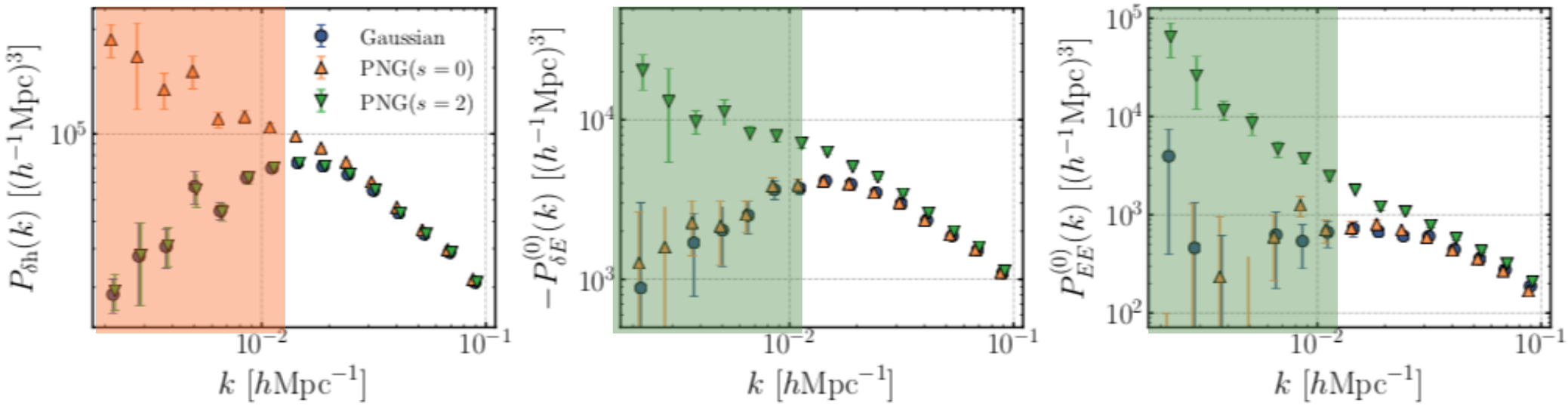


- **Challenge** – contaminates weak lensing cosmology
- **Opportunities** – probe of cosmology

INTRINSIC ALIGNMENT – PROBE OF COSMOLOGY

- Complementary probe of Baryonic Acoustic Oscillation, Redshift Space Distortion (Chisari+2013, Taruya & Okumura2020)
- Special probe of anisotropic Primordial non-Gaussianity

IA –> sensitive probe of anisotropic PNG (s=2)



Akitsu+2020

Clustering –> isotropic PNG (s=0)

Dalal+2008

EMISSION LINE GALAXY (ELG) SURVEYS

Prime Focus Spectrograph

SuMIRe

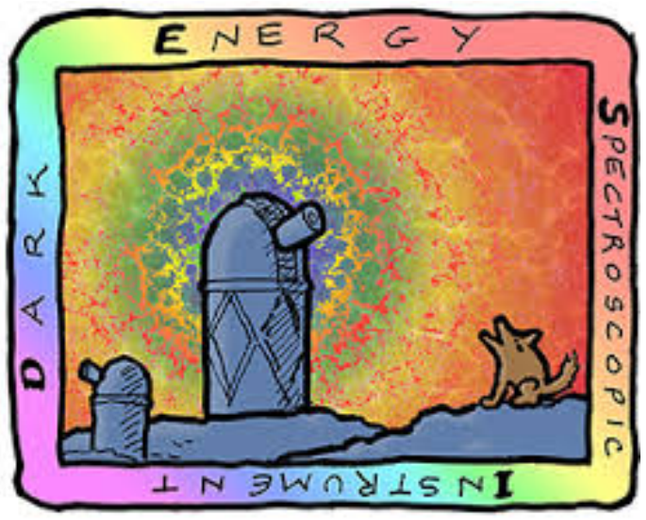
	Testing ΛCDM	Assembly history of galaxies	Importance of IGM
CO	• Nature & role of neutrinos • Expansion rate via BAO up to z=2.4 • PFS+HSC tests of GR • Curvature of space: Ω_K • Primordial power spectrum	• PFS+HSC synergy • Absorption probes with PFS/SDSS QSOs around PFS/HSC host galaxies	• Search for emission from stacked spectra
GA	• Nature of DM (dSphs) • Structure of MW dark halo	• Stellar kinematics and chemical abundances – MW & M31 assembly history	• dSph as relic probe of reionization feedback • Past massive star IMF from element abundances
GE	• Small-scale tests of structure growth	• Halo-galaxy connection: $M_*/M_{\rm halo}$ • Outflows & inflows of gas • Environment-dependent evolution	• Physics of cosmic reionization via LAEs & 21cm studies • Tomography of gas & DM

PFS survey cosmology: use single tracer ([OII] emission line galaxies, i.e. ELGs) to map evolution of the large-scale structure of the Universe in a wide range of redshifts, $0.6 < z < 2.4$, over 1400 deg^2 sky area covered also by the HSC image survey

DESI targets:

Galaxy type	Redshift range	Bands used	Targets per deg^2	Exposures per deg^2	Good z's per deg^2	Baseline sample
LRG	0.4–1.0	r,z,$W1$	350	580	285	4.0 M
ELG	0.6–1.6	g,r,z	2400	1870	1220	17.1 M
QSO (tracers)	< 2.1	g,r,z,$W1$,$W2$	170	170	120	1.7 M
QSO (Ly-α)	> 2.1	g,r,z,$W1$,$W2$	90	250	50	0.7 M
Total in dark time			**3010**	**2870**	**1675**	**23.6 M**
BGS	0.05–0.4	r	700	700	700	9.8 M
Total in bright time			**700**	**700**	**700**	**9.8 M**

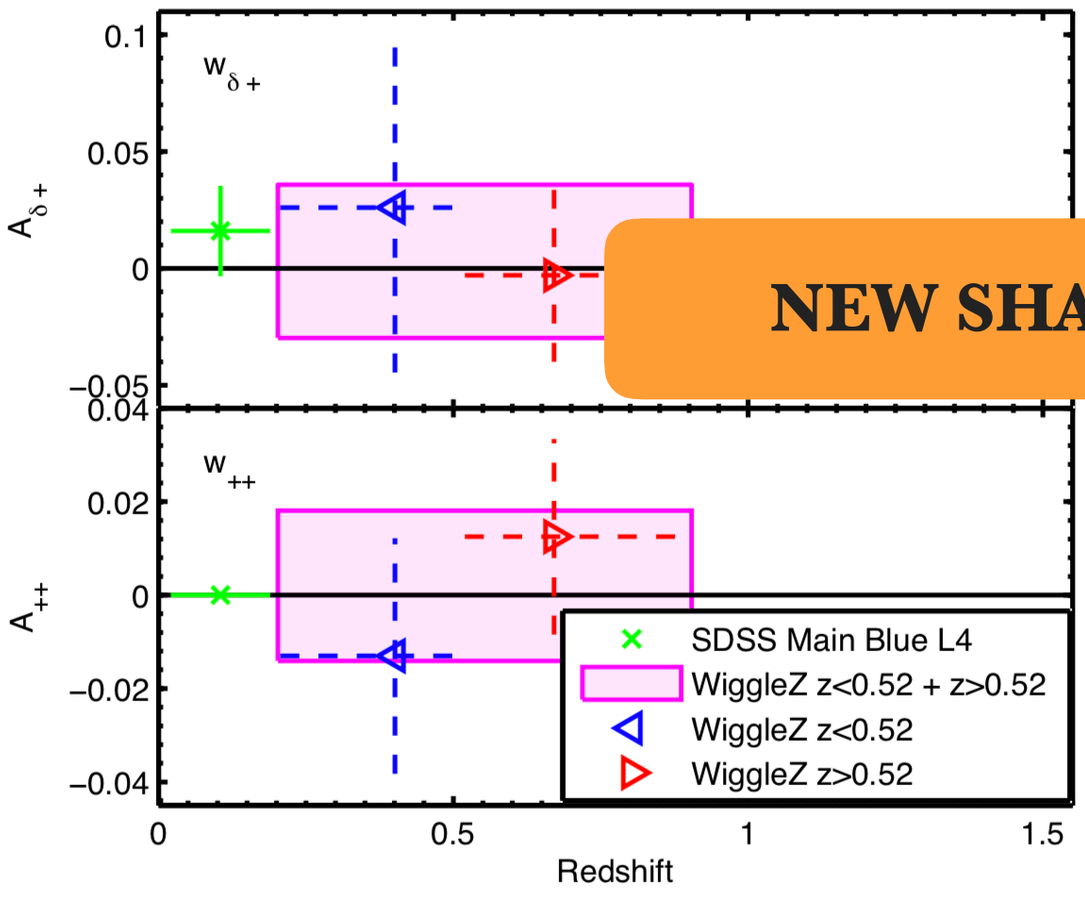
DESI Collaboration, 2016



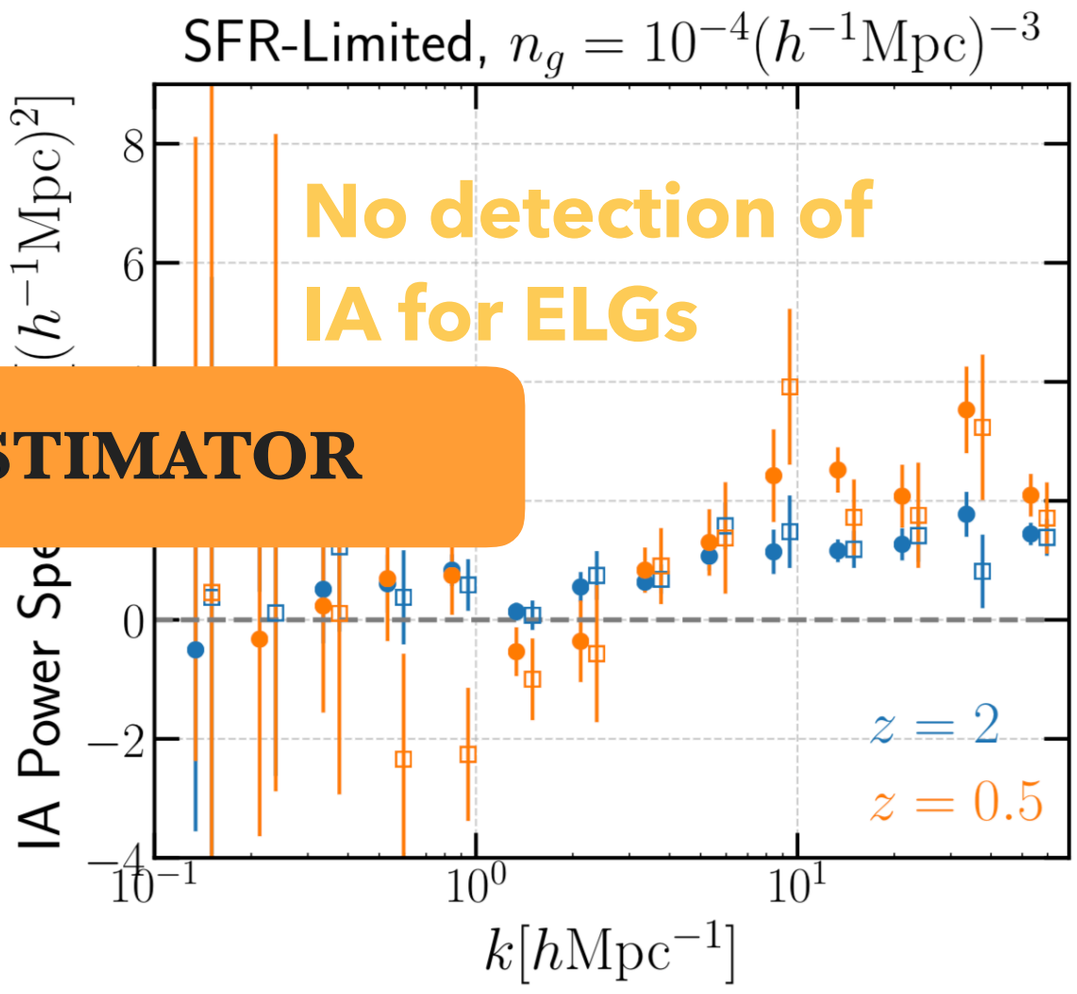
INTRINSIC ALIGNMENT OF ELGS

Mandelbaum+2011, Yao+2020

Blue star-forming galaxies – no clear IA signal detected so far



NEW SHAPE ESTIMATOR



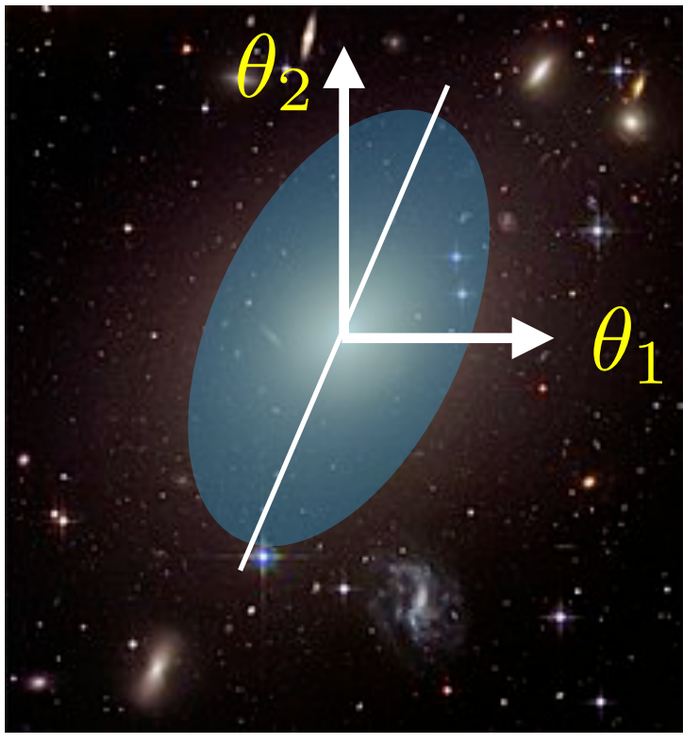
Shi+2021a

OBSERVATION

SIMULATION

SHAPE ESTIMATOR

OBSERVATION

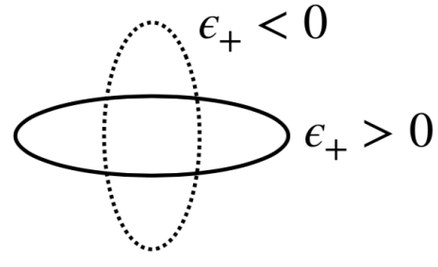


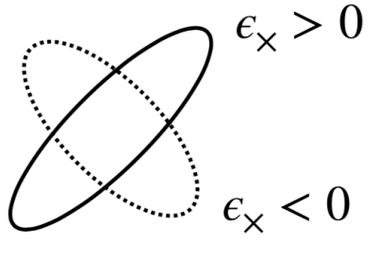
$$I_{ij} = \frac{\int d^2\theta w(\theta) f(\theta) \theta_i \theta_j}{\int d^2\theta w(\theta) f(\theta)}$$

$$\epsilon_+ \equiv \frac{I_{11} - I_{22}}{I_{11} + I_{22}}, \epsilon_\times \equiv \frac{2I_{12}}{I_{11} + I_{22}}$$

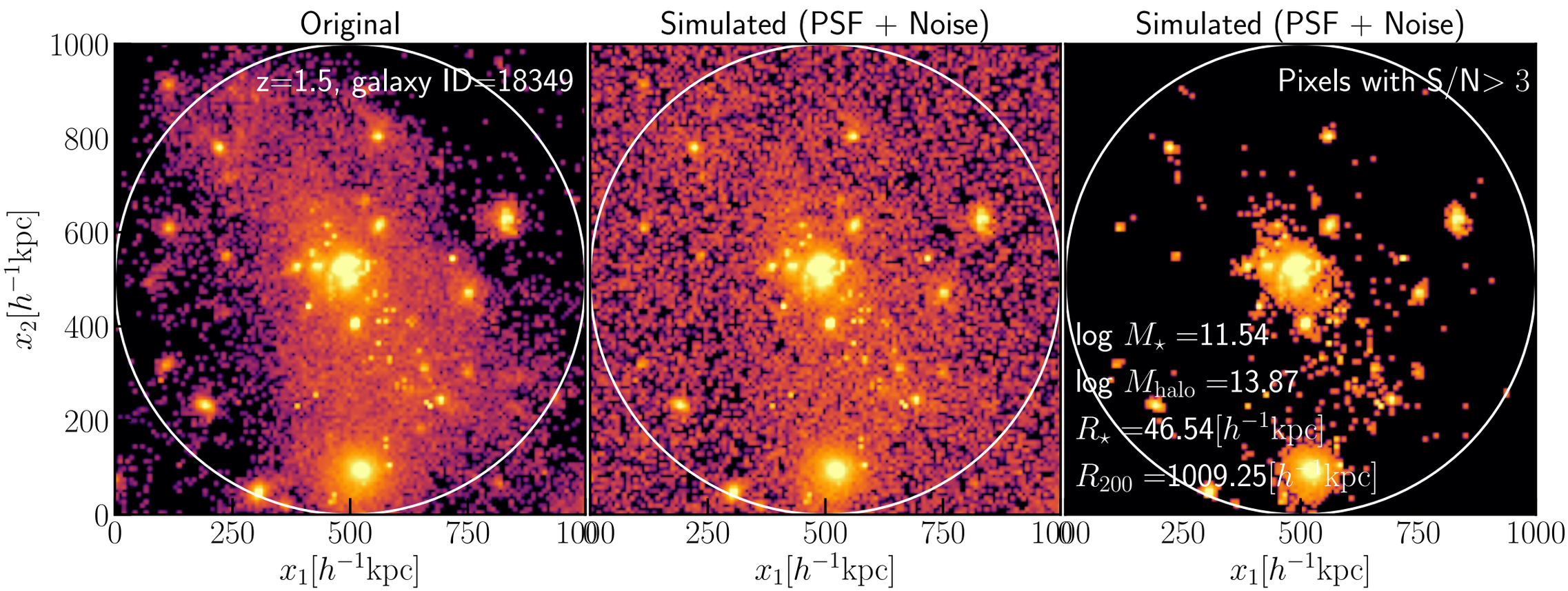
SIMULATION

$$I_{ij}^{\text{reduced}} = \frac{\sum_n m_n \frac{x_{ni} x_{nj}}{r_n^2}}{\sum_n m_n}$$





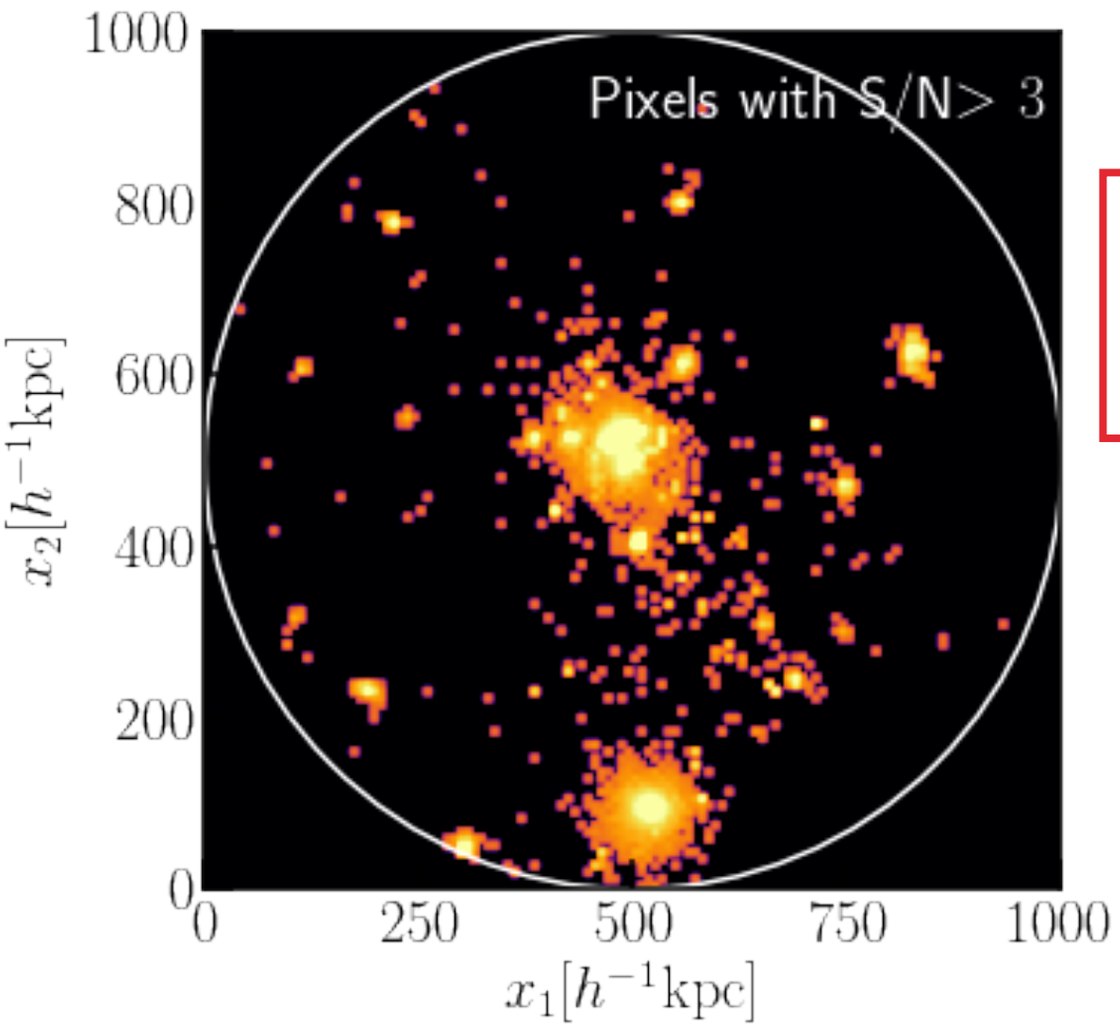
Ray-tracing simulation using Pégase.3 code



0.6 arcsec seeing
1200sec exposure
8.2m Subaru aperture

Shi+2021b

APERTURE SHAPE ESTIMATOR



Shi+2021b

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

f_n —— flux of pixels

x_{ni}, x_{nj} —— distance of pixels to the ELG

1Mpc/h aperture *versus* **within ELG**

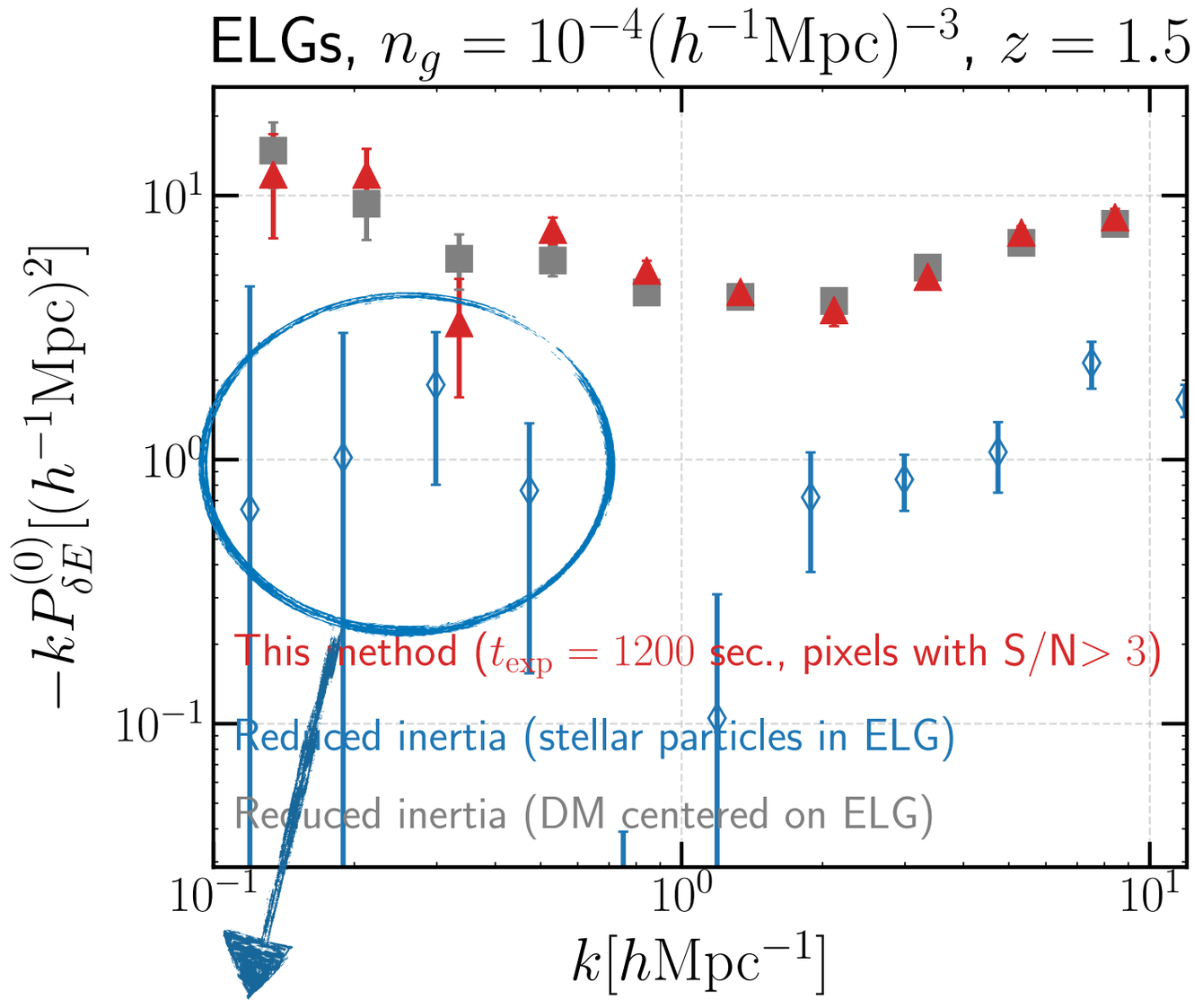
no weighting *versus* **1/r² weighting**

Reduced inertia tensor

$$I_{ij}^{\mathrm{reduced}} = \frac{\sum_n m_n \frac{x_{ni}x_{nj}}{r_n^2}}{\sum_n m_n}$$

m_n —— mass of the stellar particles within the galaxy

INTRINSIC ALIGNMENT OF ELGS



Shi+2021b

High S/N IA signal obtained with

Aperture shape estimator

No IA signal with reduced shape estimator

$$\langle \gamma_E(\boldsymbol{k})\delta_m(\boldsymbol{k'})\rangle \equiv (2\pi)^3\delta_D(\boldsymbol{k}+\boldsymbol{k'})P_{\delta E}(\boldsymbol{k})$$

→ IA power spectrum

(Kurita+2020, Shi+2021a)

SUMMARY AND WORKING DIRECTION

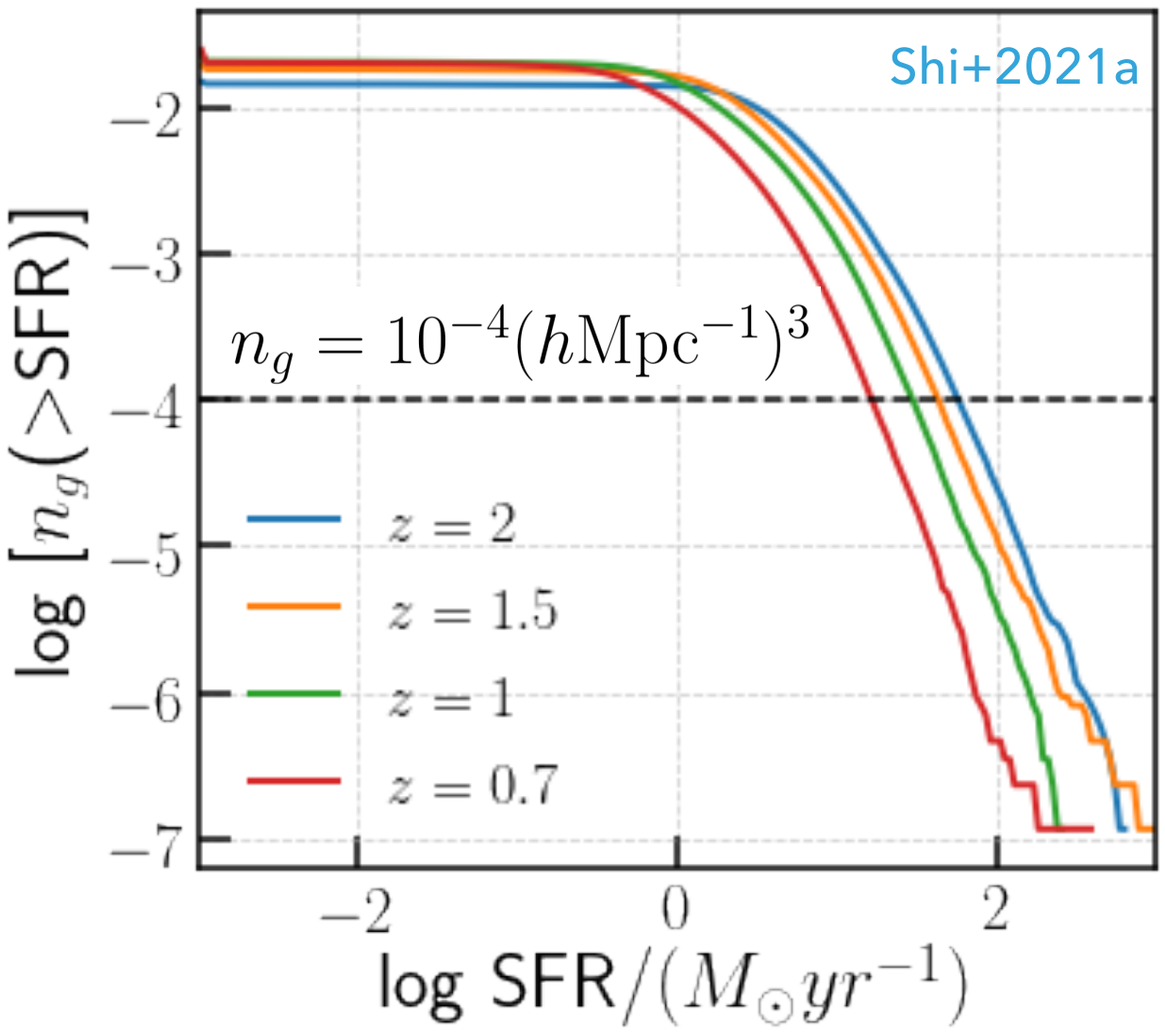
Galaxy intrinsic alignment contaminate weak lensing cosmology

- Test the theoretical model prediction in the simulation
- Mass, redshift, scale, morphological, environmental dependence of both shape and spin are studied in the simulation
- Work in progress – direct measure intrinsic alignment in HSC survey

Galaxy intrinsic alignment as cosmological probe

- A new shape estimator is developed to extract the IA signal of galaxies targeted by ongoing/future surveys
- Work in progress – apply this estimator to observed image

SELECTION OF ELGS IN TNG300



SFR ranked selected galaxies

roughly corresponds to

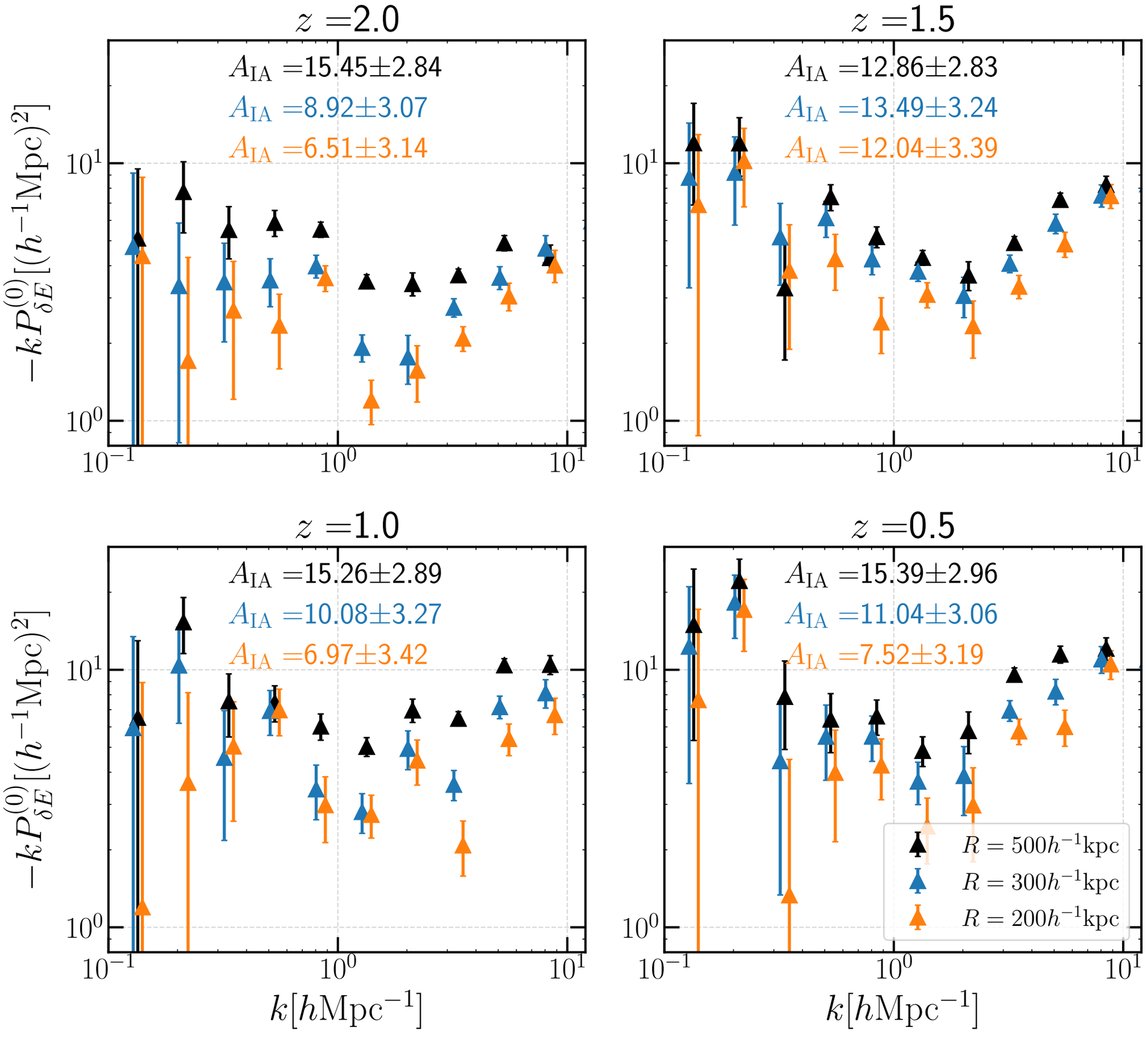
[OII] emission line strength selected galaxies

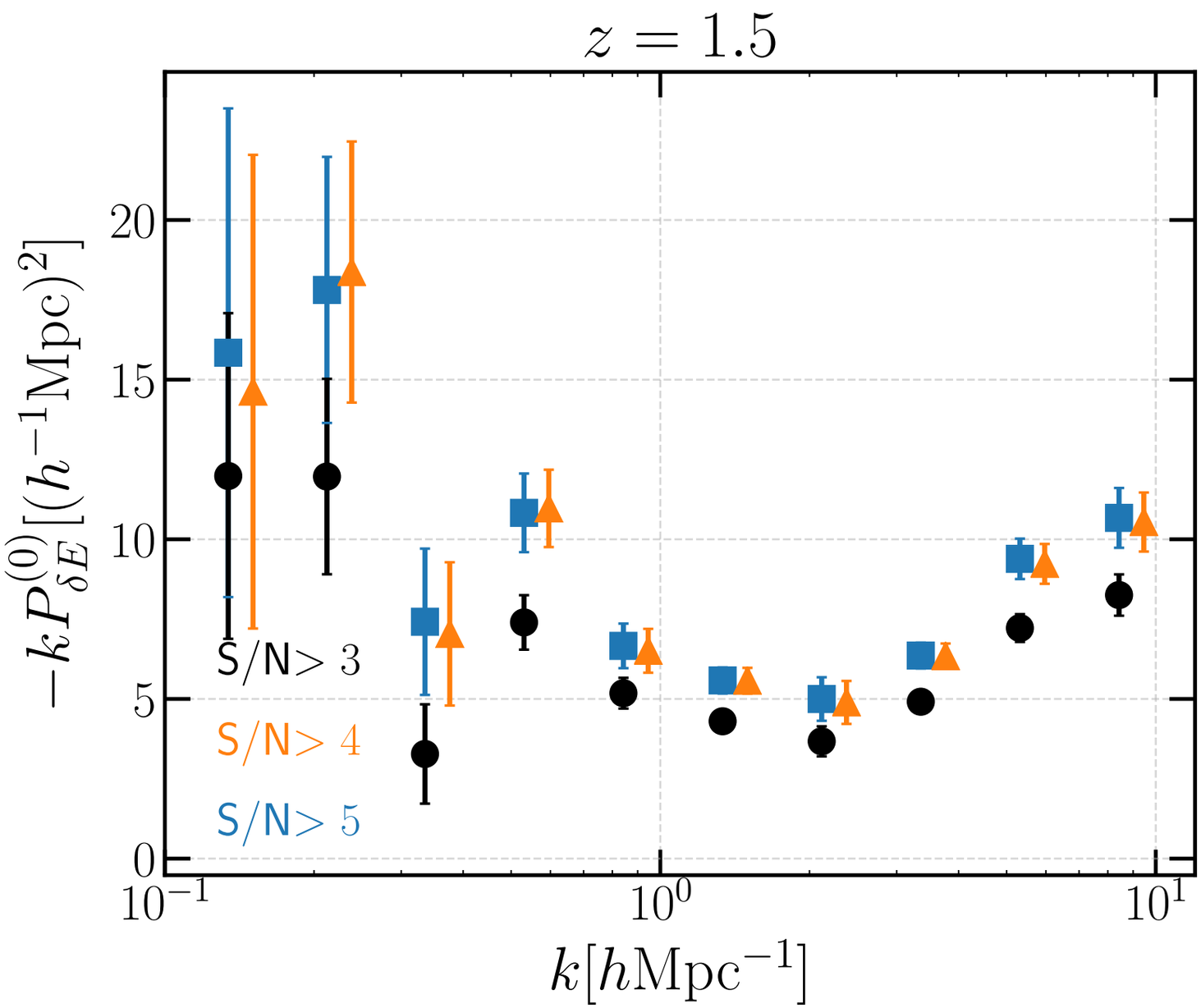
Gonzalez-Perez+2020; Osato & Okumura 2021, in prep

Table 1
Properties of ELGs in Illustris-TNG300, Studied in this Work

z	$\langle \log M_\star \rangle$	$\langle \log M_{\mathrm{halo}} \rangle$	$\langle \mathrm{SFR} \rangle$	f_{cen}	A_{IA}	σ_ϵ
0.5	10.39	13.20	25.75	0.667	15.39 ± 2.96	0.43
1.0	10.41	13.04	47.78	0.682	15.26 ± 2.89	0.41
1.5	10.42	12.88	71.64	0.741	12.86 ± 2.83	0.39
2.0	10.41	12.67	94.01	0.798	15.45 ± 2.84	0.40

Shi+2021b


z =2.0
$A_{\rm IA}$ =15.45±2.84
$A_{\rm IA}$ =8.92±3.07
$A_{\rm IA}$ =6.51±3.14
z =1.5
$A_{\rm IA}$ =12.86±2.83
$A_{\rm IA}$ =13.49±3.24
$A_{\rm IA}$ =12.04±3.39
z =1.0
$A_{\rm IA}$ =15.26±2.89
$A_{\rm IA}$ =10.08±3.27
$A_{\rm IA}$ =6.97±3.42
z =0.5
$A_{\rm IA}$ =15.39±2.96
$A_{\rm IA}$ =11.04±3.06
$A_{\rm IA}$ =7.52±3.19
$R = 500h^{-1}$kpc
$R = 300h^{-1}$kpc
$R = 200h^{-1}$kpc
$-kP^{(0)}_{\delta E}[(h^{-1}{\rm Mpc})^2]$
$k[h{\rm Mpc}^{-1}]$
10^{-1}
10^{0}
10^{1}


$z = 1.5$
$-kP^{(0)}_{\delta E}[(h^{-1}\mathrm{Mpc})^2]$
20
15
10
5
0
S/N> 3
S/N> 4
S/N> 5
10^{-1}
10^{0}
10^{1}
$k[h\mathrm{Mpc}^{-1}]$