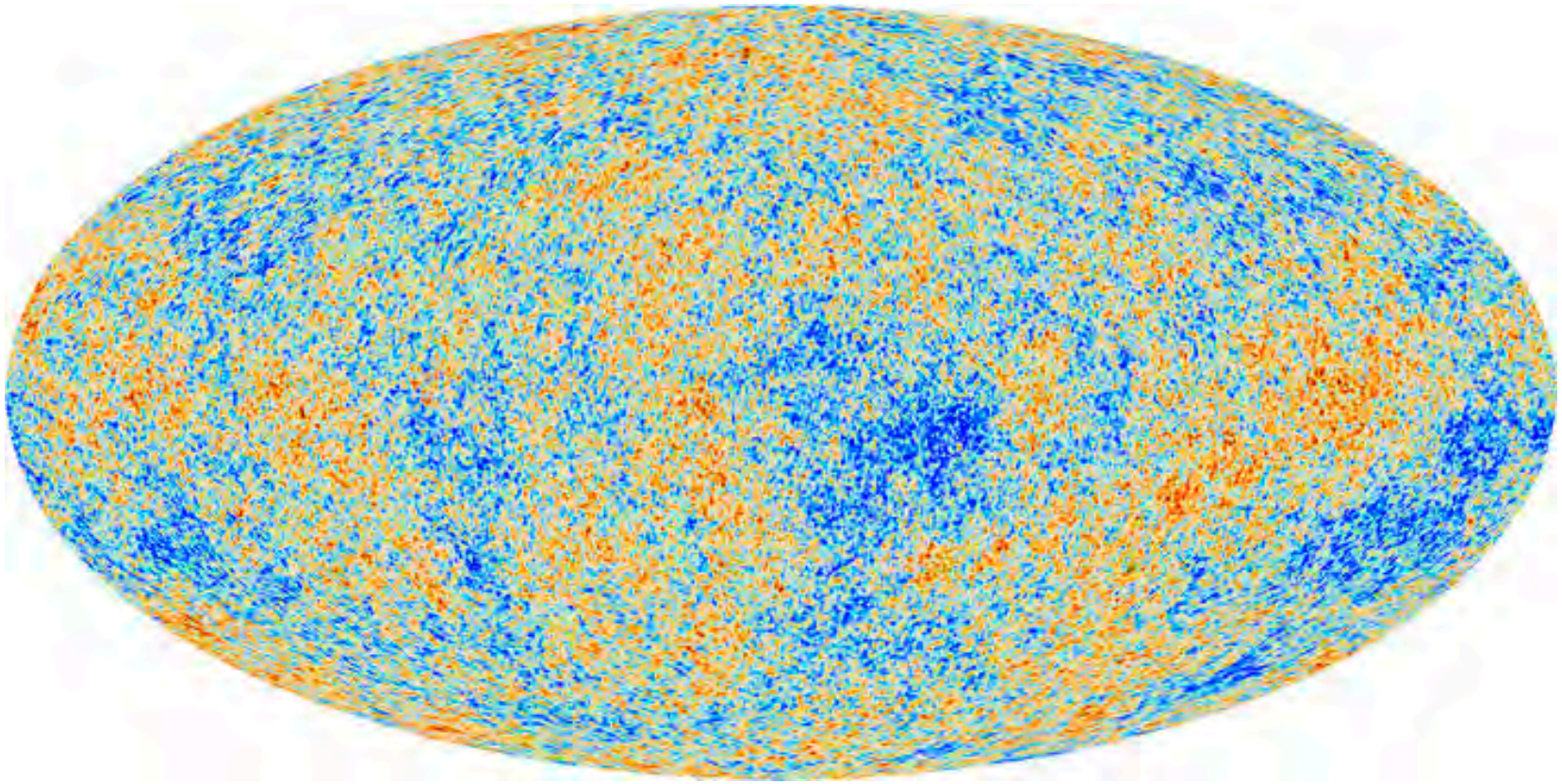
COSMOLOGY WITH WEAK LENSING
CHALLENGES & OPPORTUNITIES

Elisa Chisari

Royal Astronomical Society Research Fellow

University of Oxford

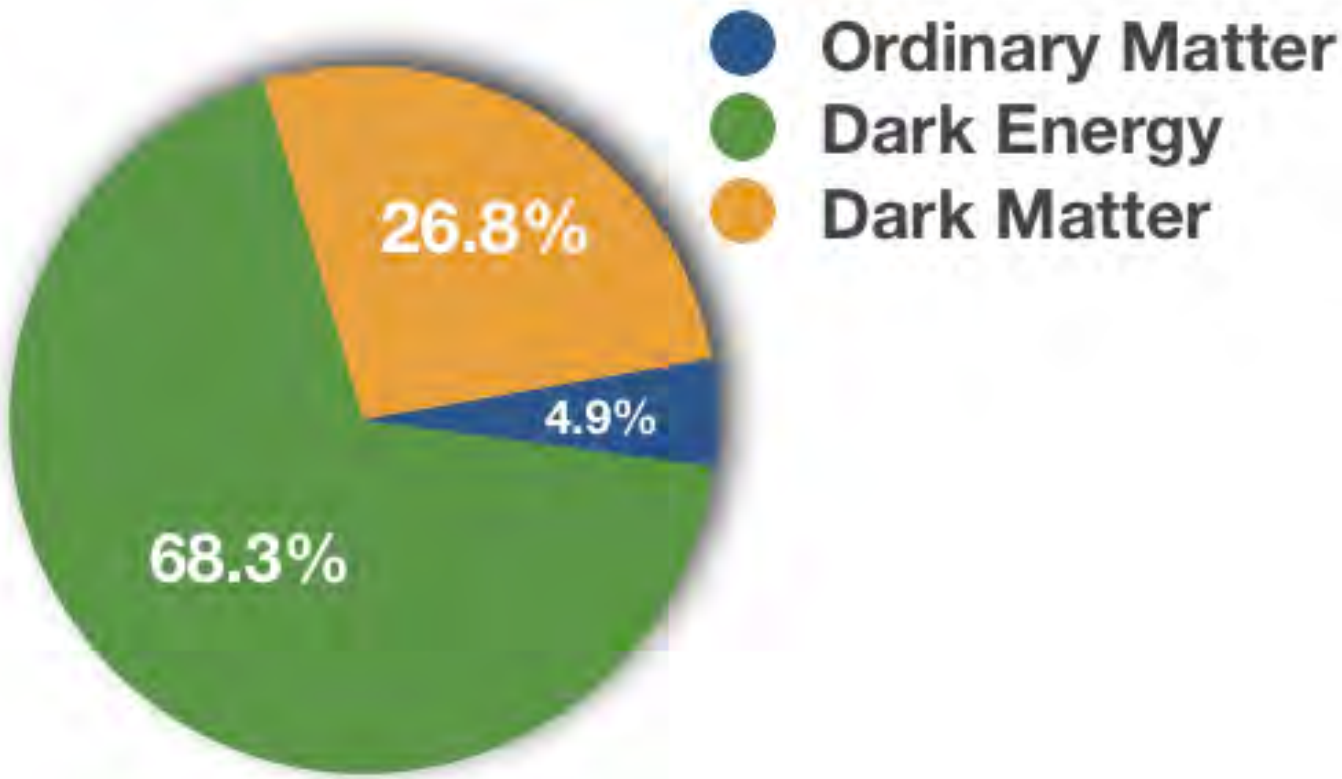
PRECISION COSMOLOGY



The cosmic microwave background (CMB)
400,000 years after the Big Bang

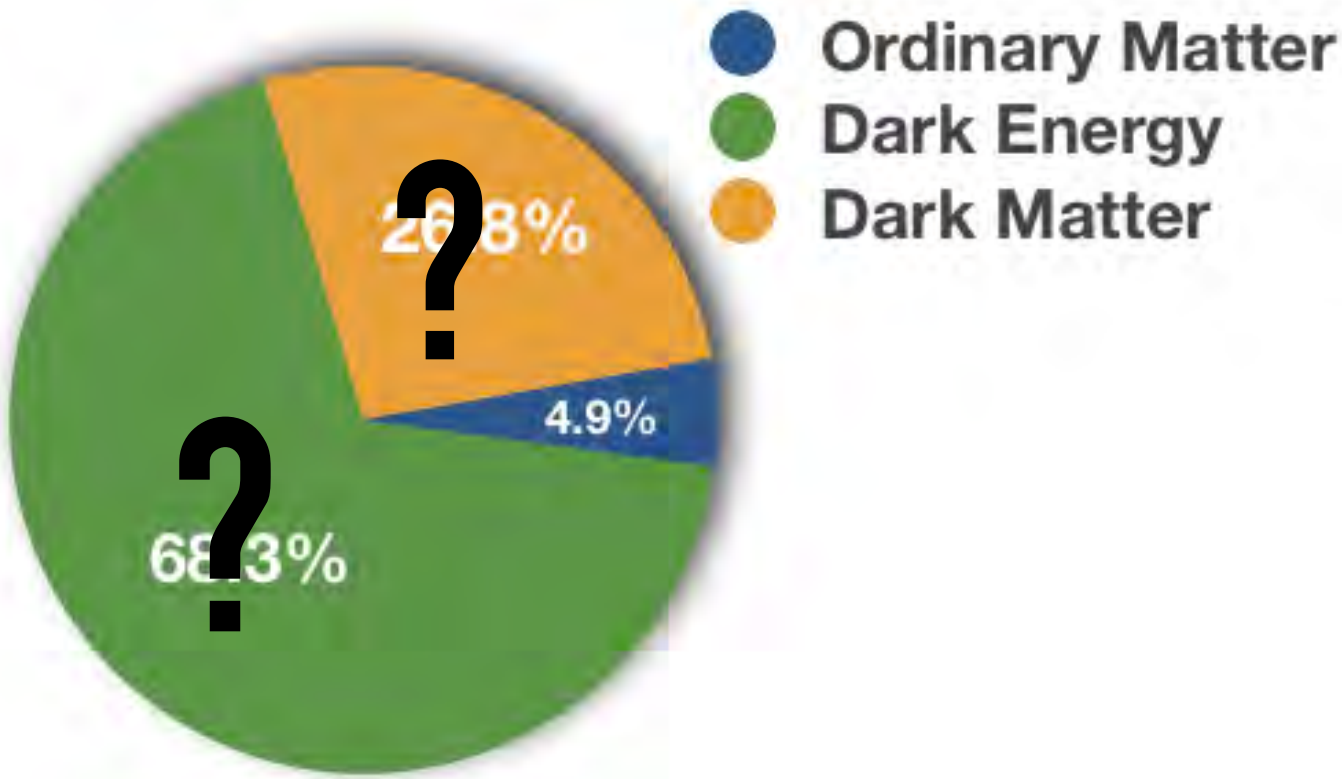
Image: ESA & the Planck Collaboration

PRECISION COSMOLOGY



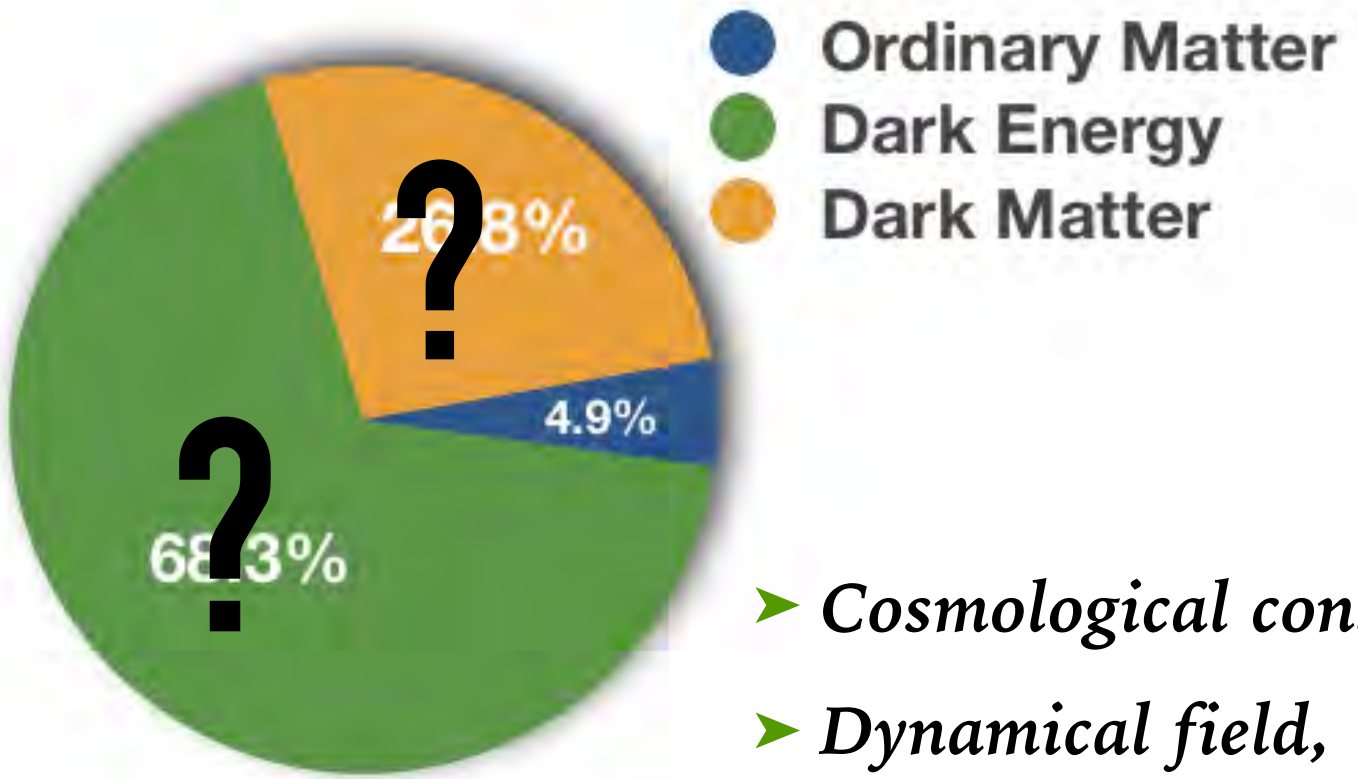
Planck Collaboration

PRECISION COSMOLOGY



Planck Collaboration

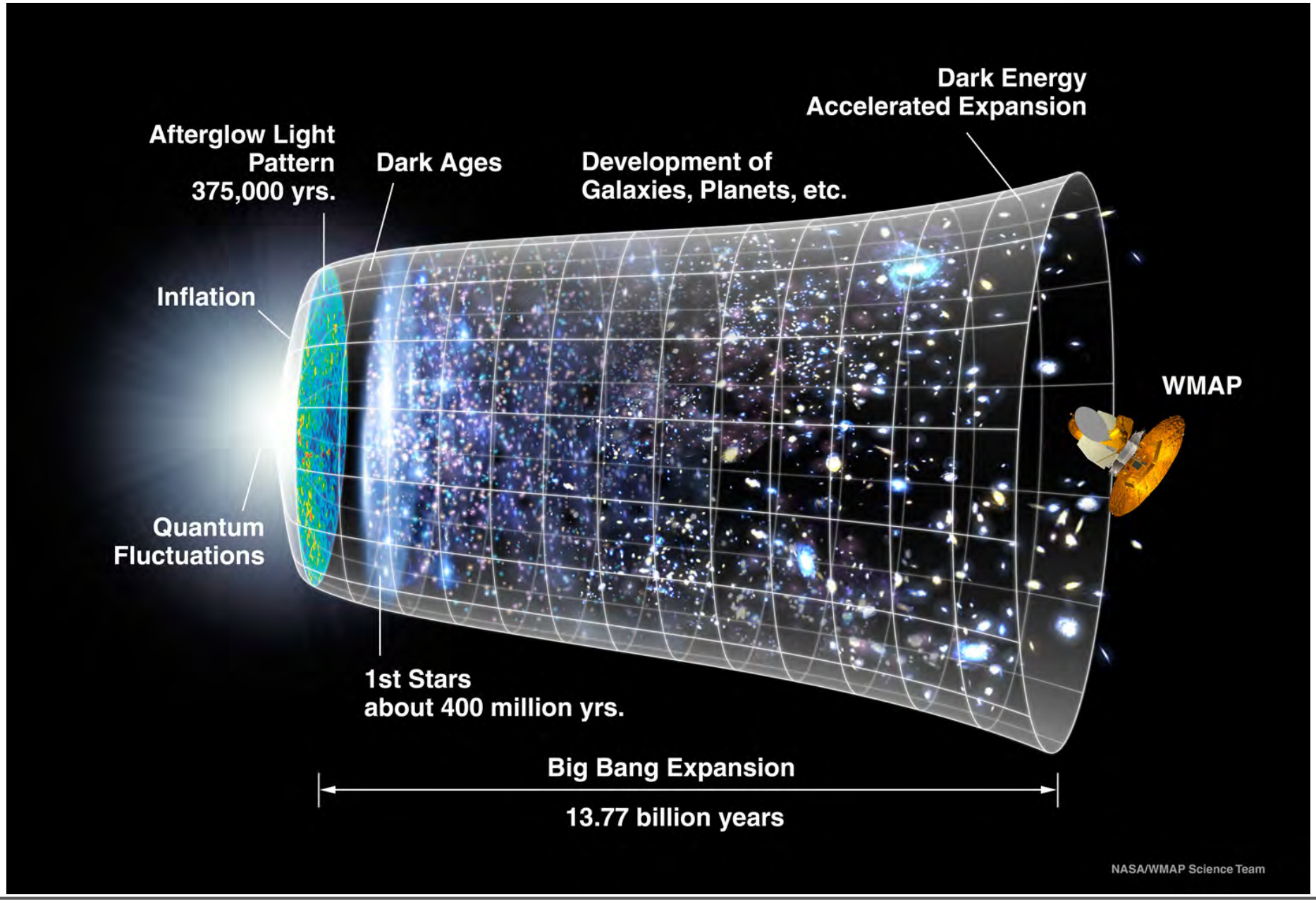
PRECISION COSMOLOGY



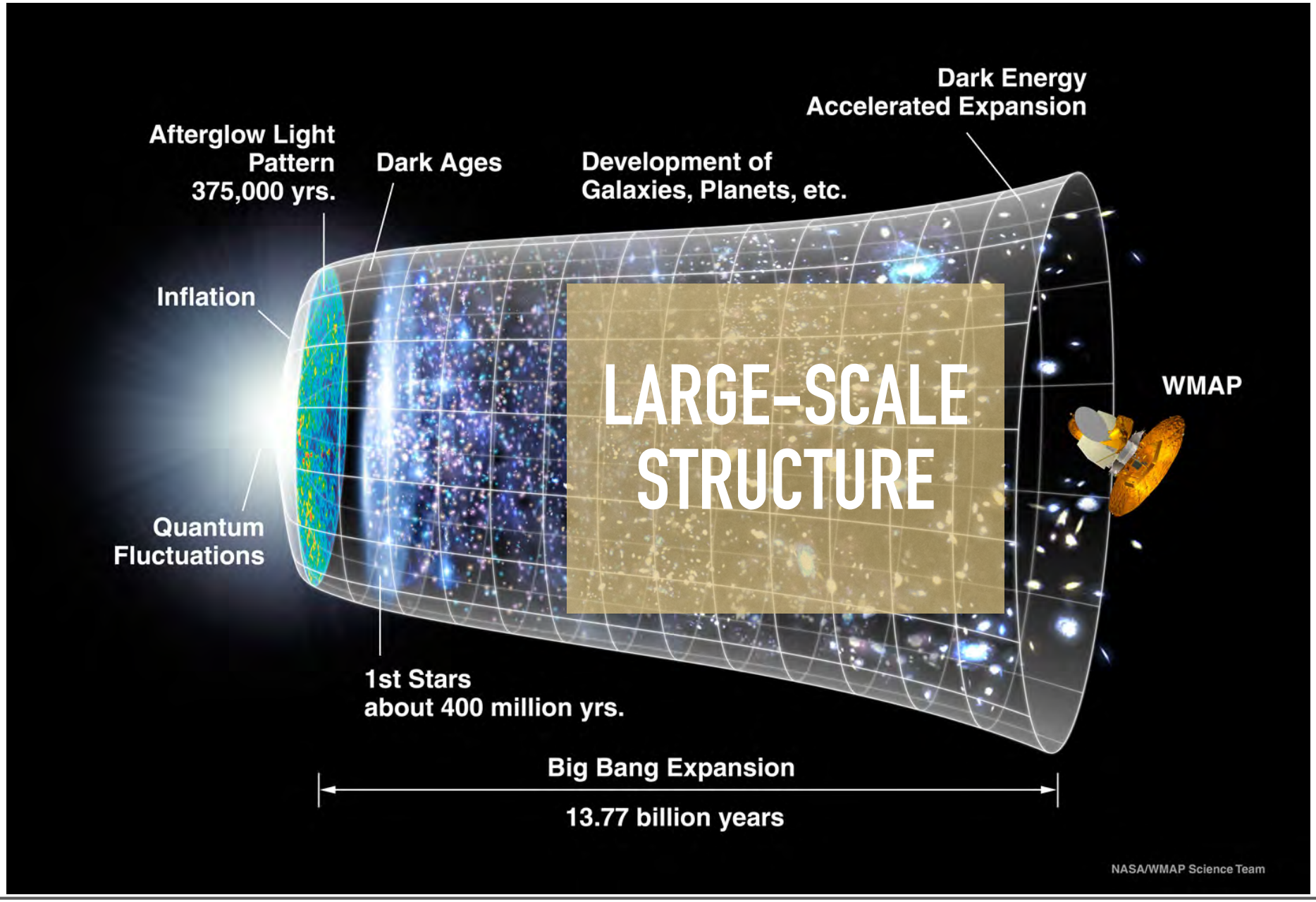
- *Cosmological constant,* Λ
- *Dynamical field,* $p = w c^2 \rho$
- *Modification of gravity.*

Planck Collaboration

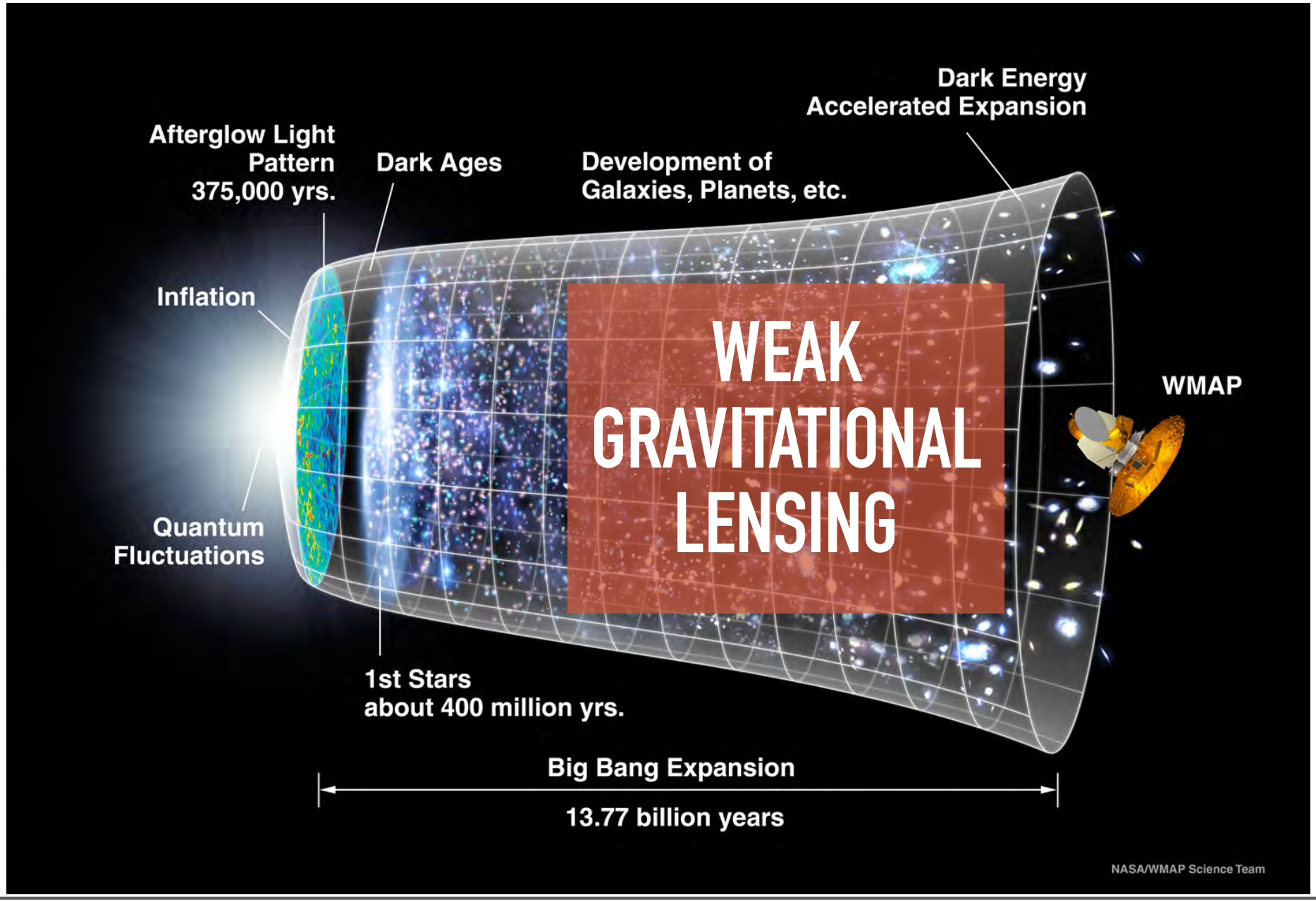
PRECISION COSMOLOGY



PRECISION COSMOLOGY



PRECISION COSMOLOGY



OUTLINE

Precision cosmology with galaxy surveys

Gravitational lensing

OUTLINE

Precision cosmology with galaxy surveys

Gravitational lensing

Theoretical challenges

I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies

OUTLINE

Precision cosmology with galaxy surveys

Gravitational lensing

Theoretical challenges

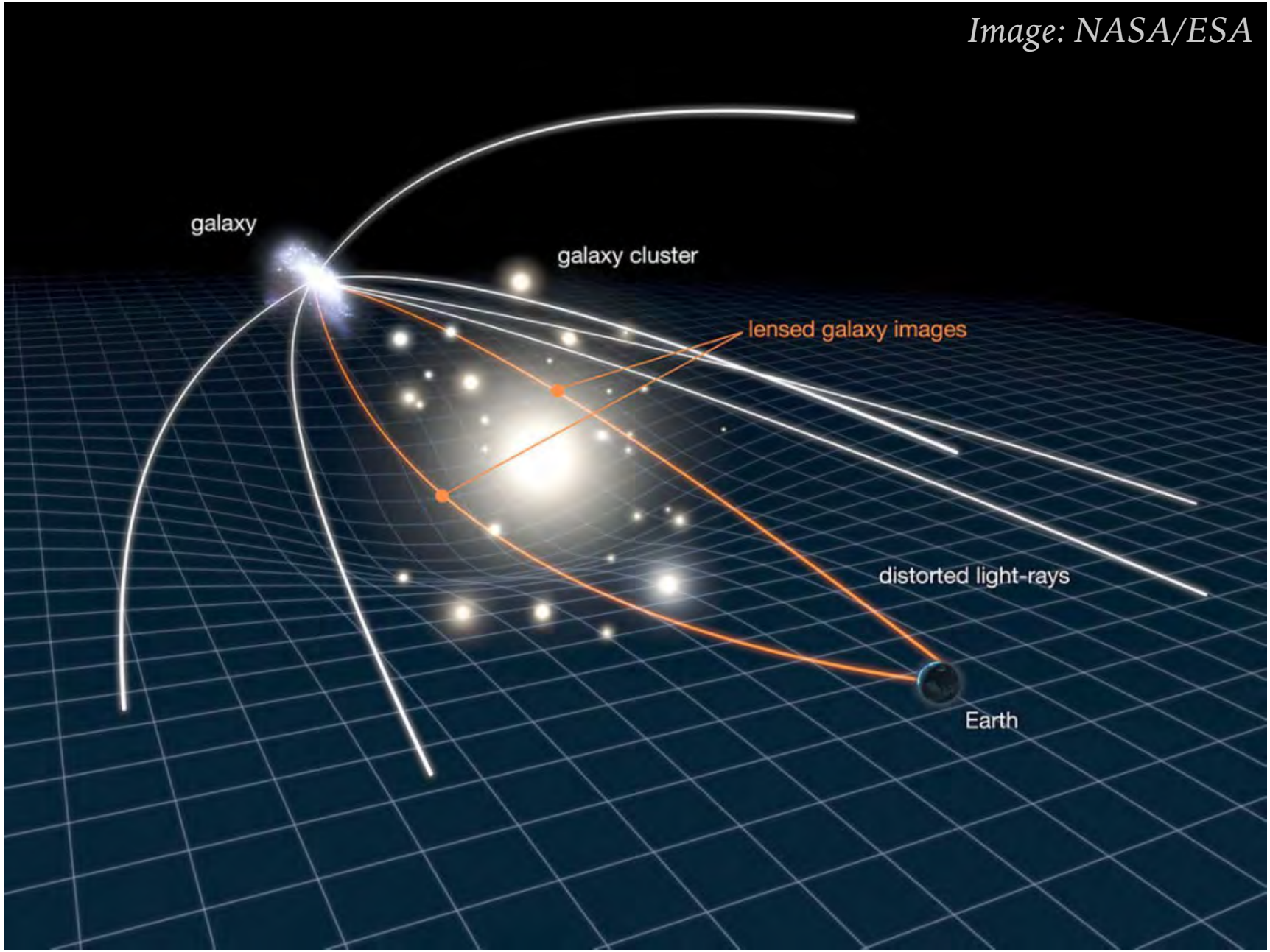
I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies

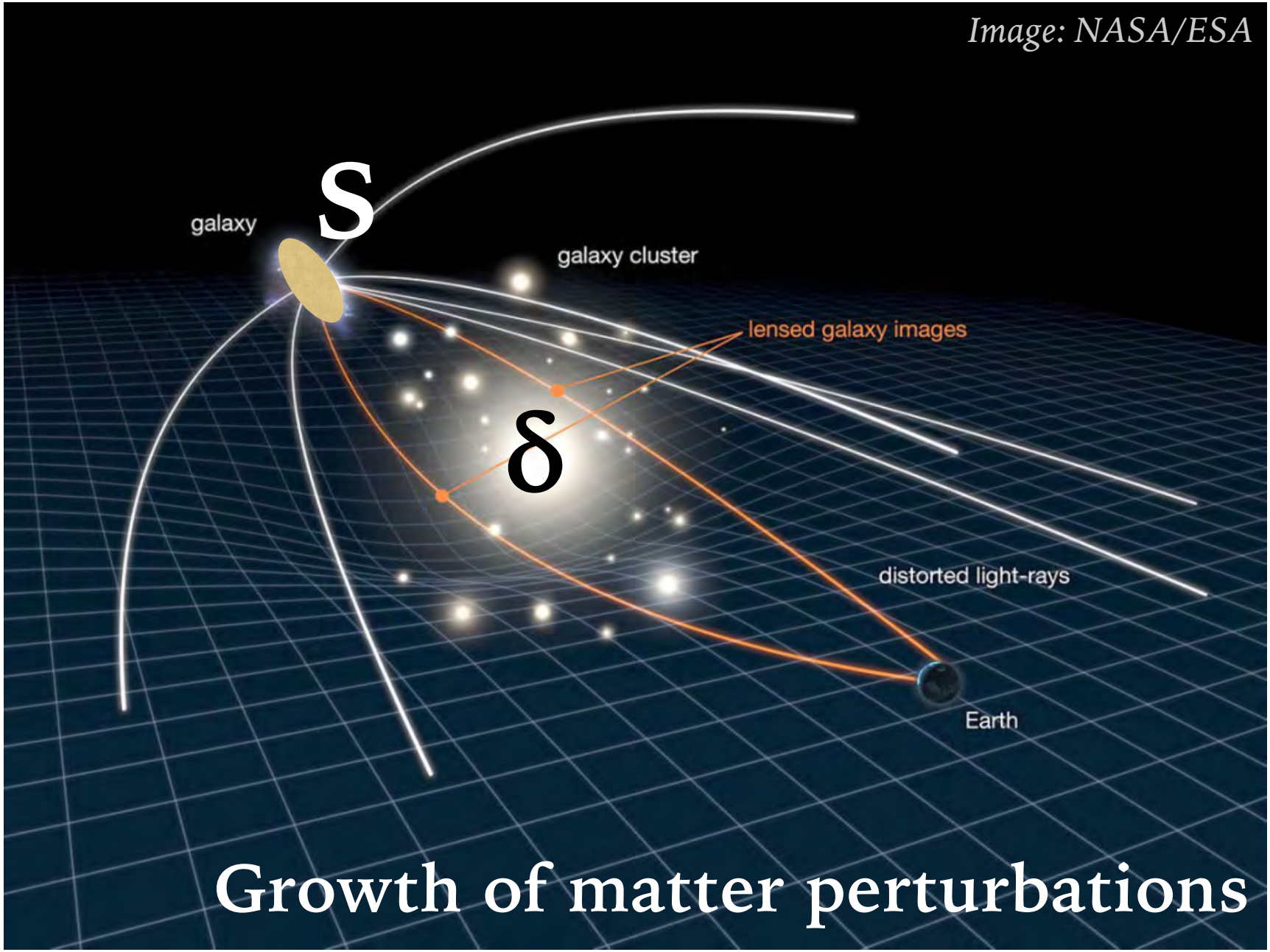
New opportunities

Cosmology with intrinsic alignments

GRAVITATIONAL LENSING



GRAVITATIONAL LENSING



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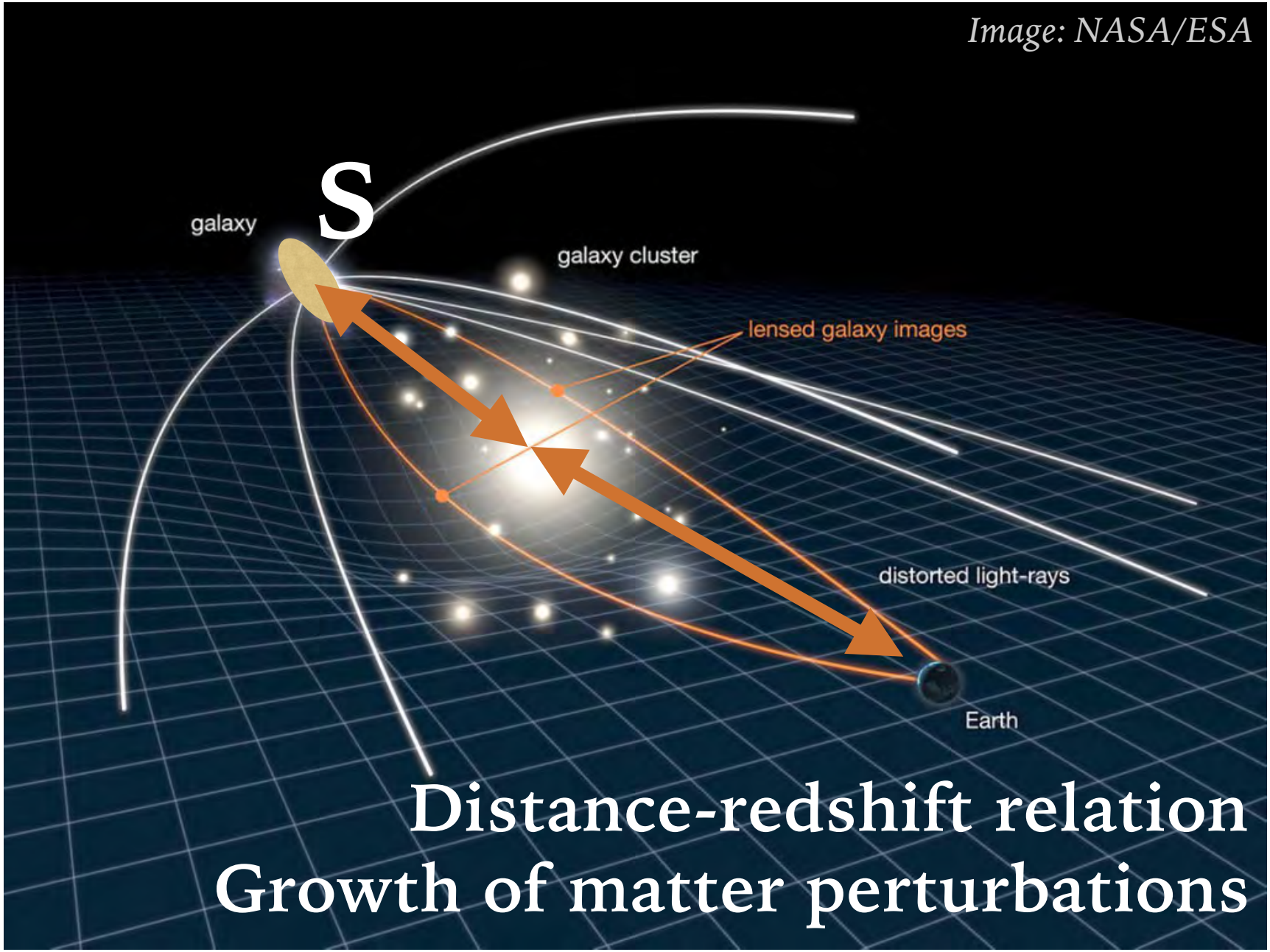

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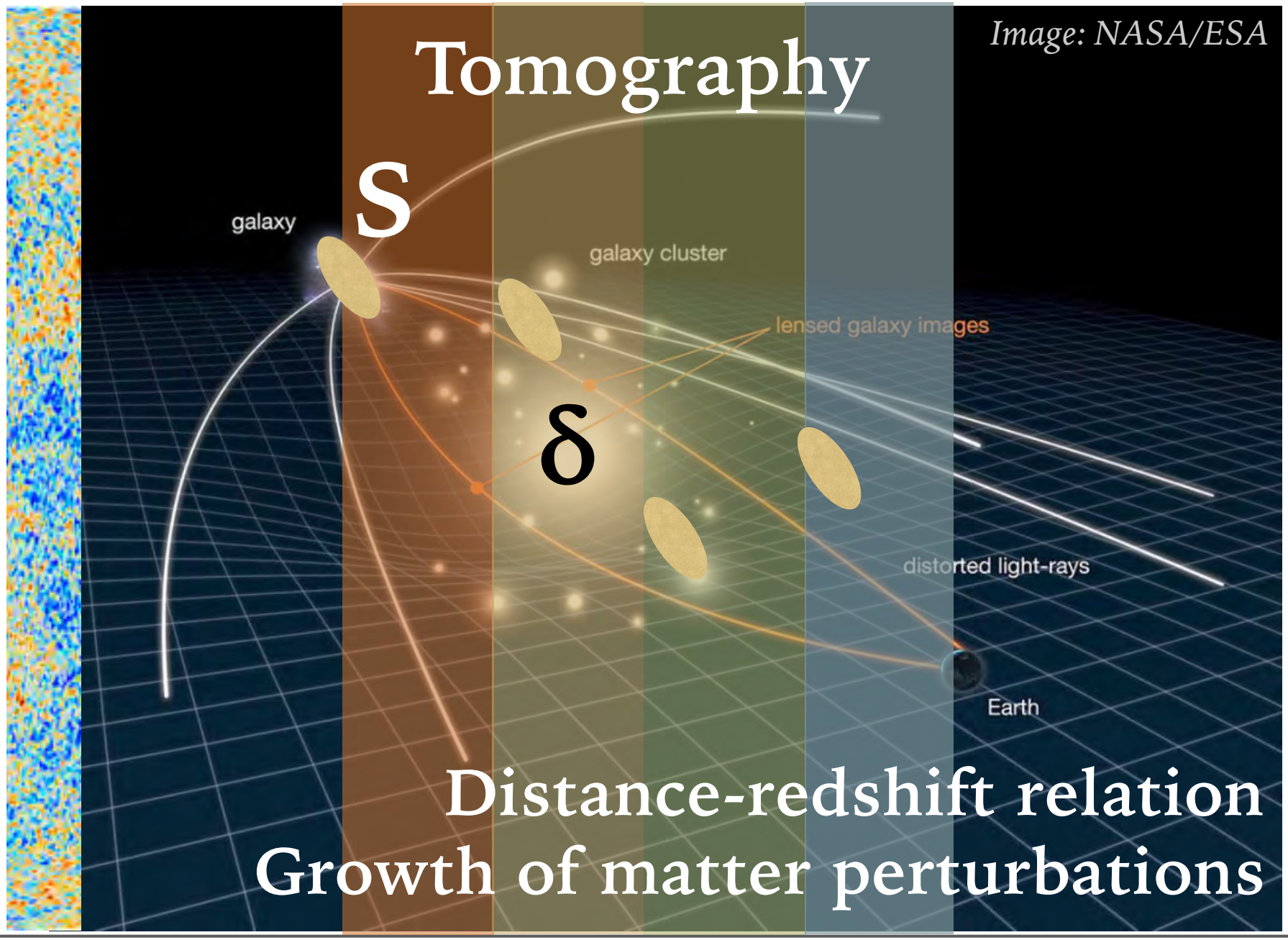
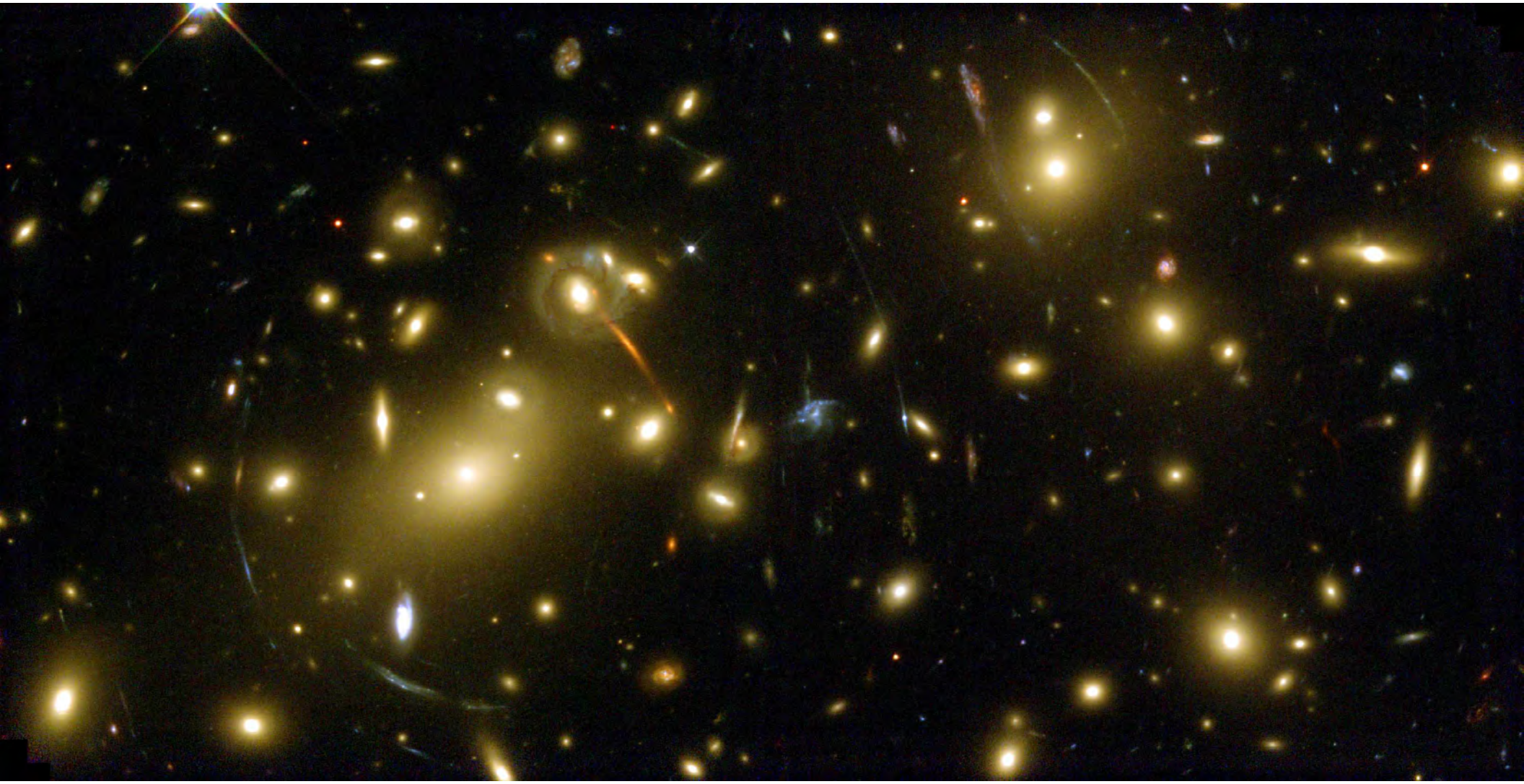


GRAVITATIONAL LENSING

Image: Abell 2218, NASA/ESA



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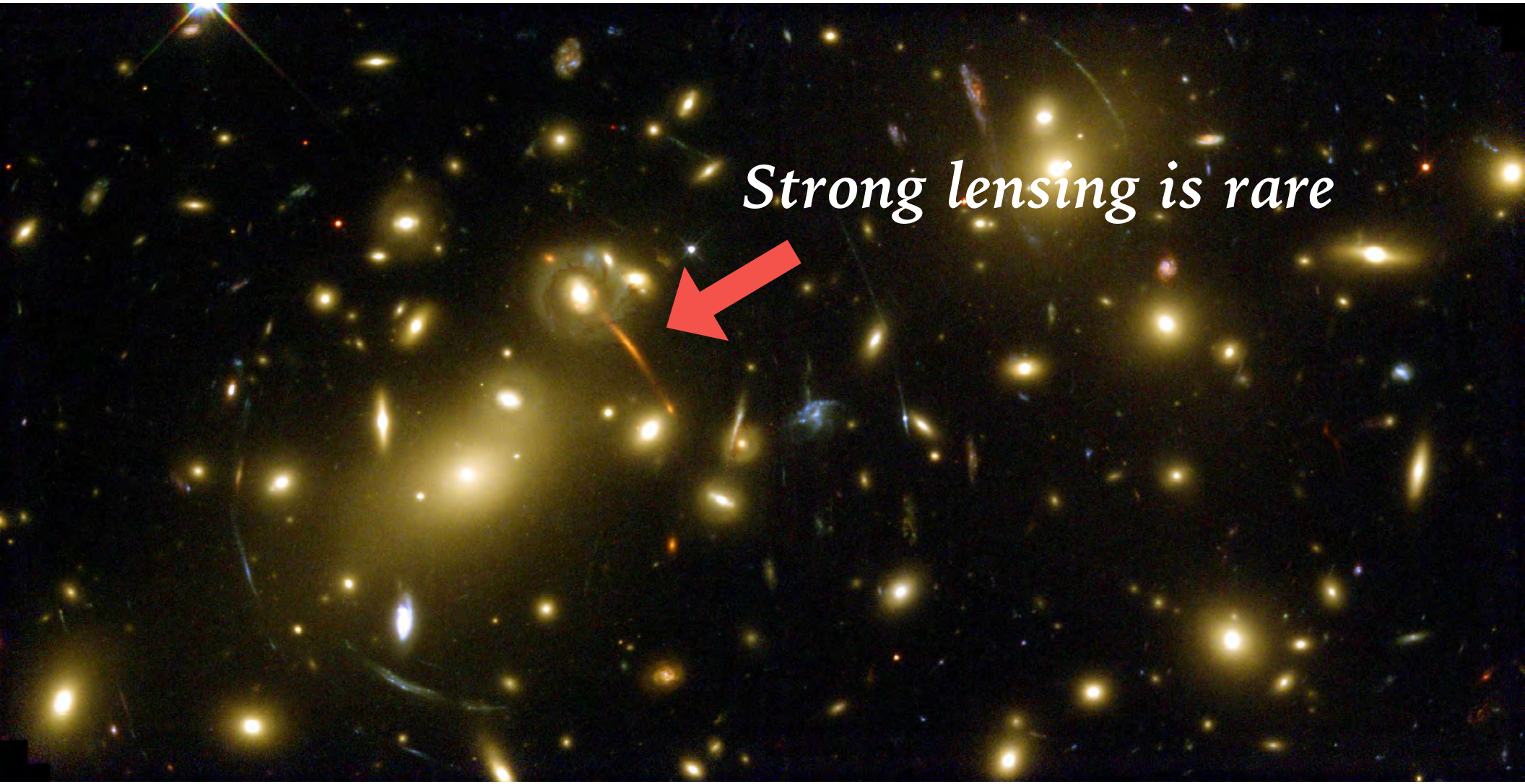

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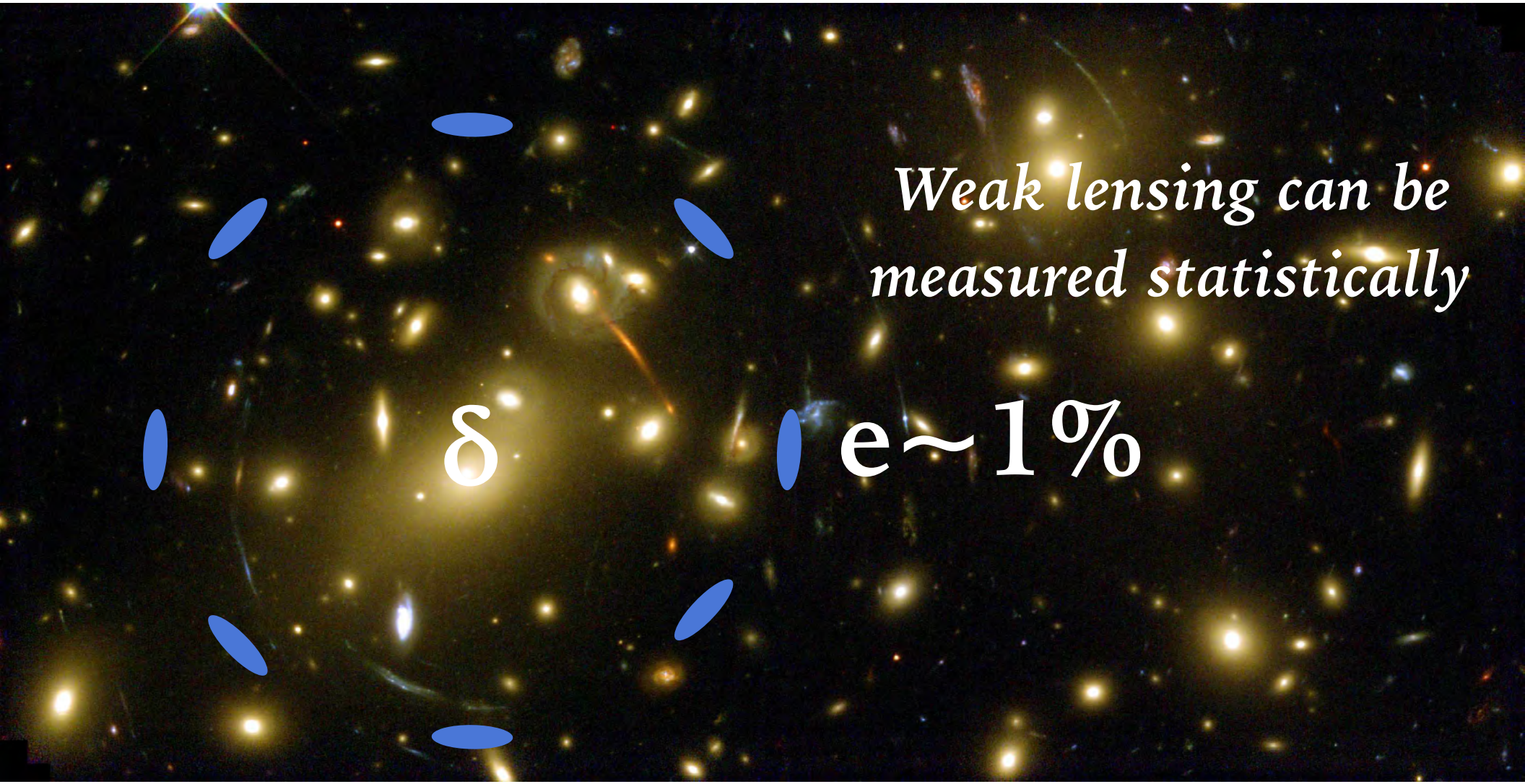


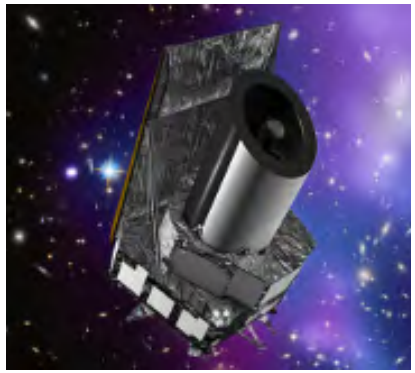
Weak lensing can be measured statistically

COSMOLOGY WITH LENSING SURVEYS

SDSS

Kilo-Degree Survey

Euclid (2021)



LSST (2021)

CFHTLenS

DES

DARK ENERGY SURVEY

HSC

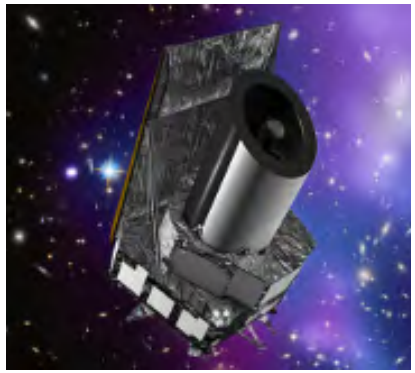
WFIRST (2025)

COSMOLOGY WITH LENSING SURVEYS

SDSS

Kilo-Degree Survey

Euclid (2021)



LSST (2021)

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DES

DARK ENERGY SURVEY

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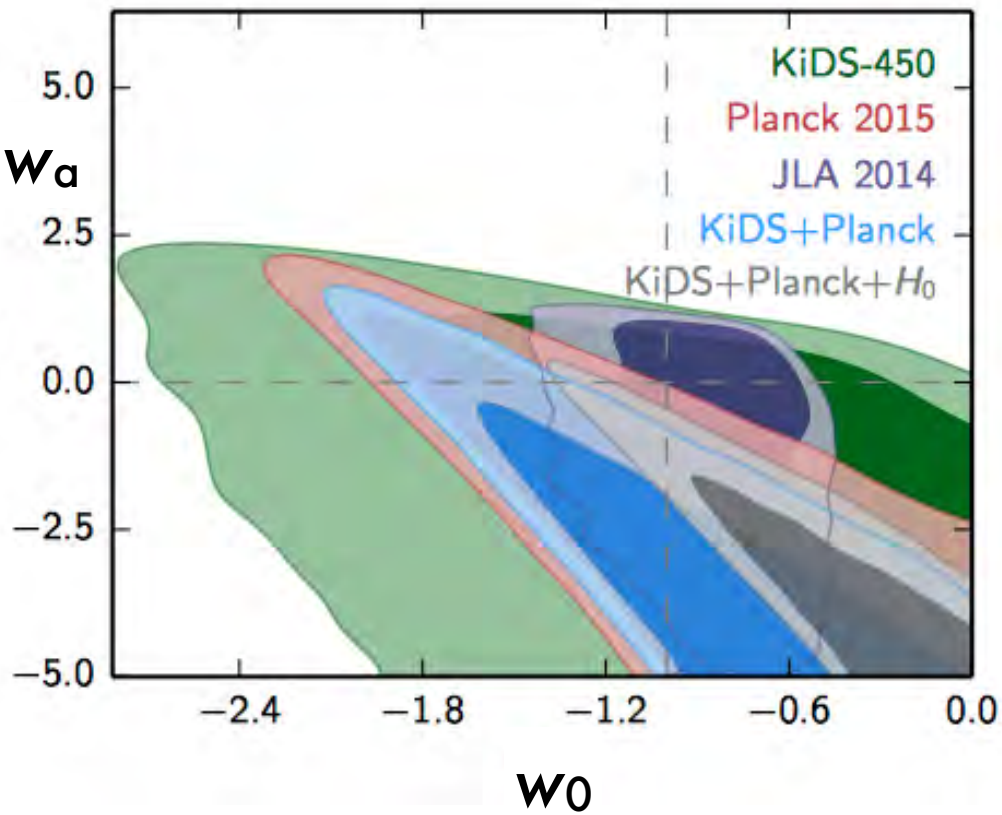
COSMOLOGY WITH LENSING SURVEYS

$$w = w_0 + w_a(1-a)$$

KiDS-450



Joudaki+, KiDS collaboration, 2016

see also: DES Y1, 2017

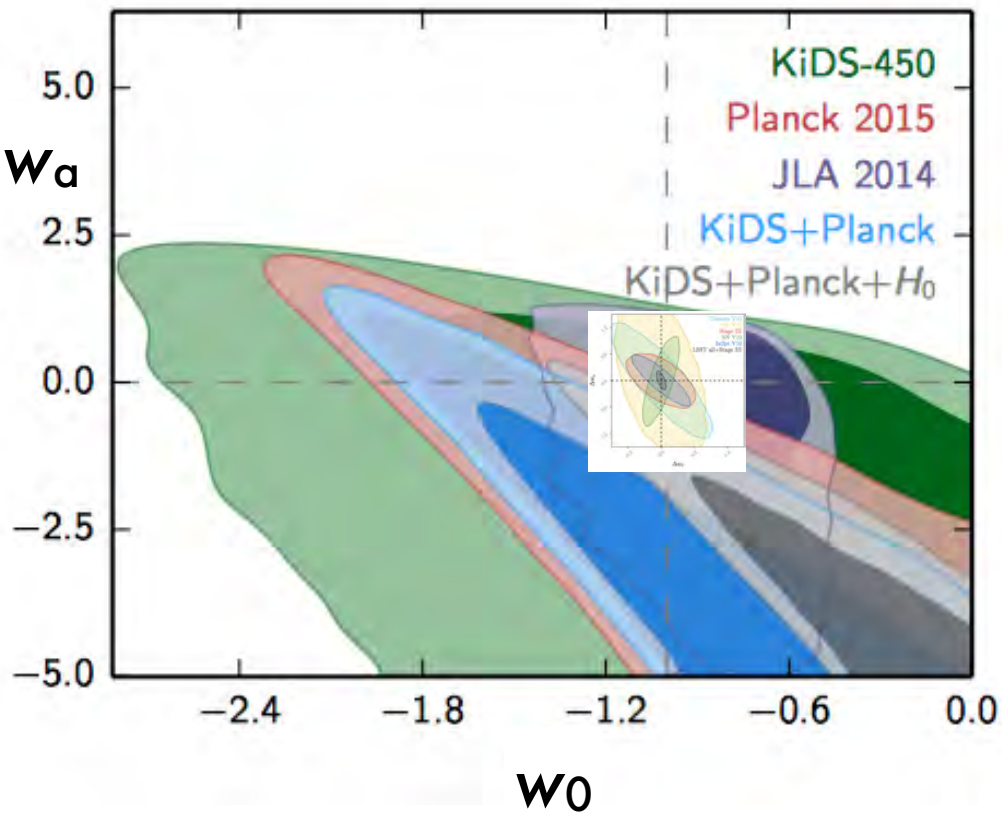
Hikage+, 2018

COSMOLOGY WITH LENSING SURVEYS

$$w = w_0 + w_a(1-a)$$

KiDS-450

LSST DESC SRD v1



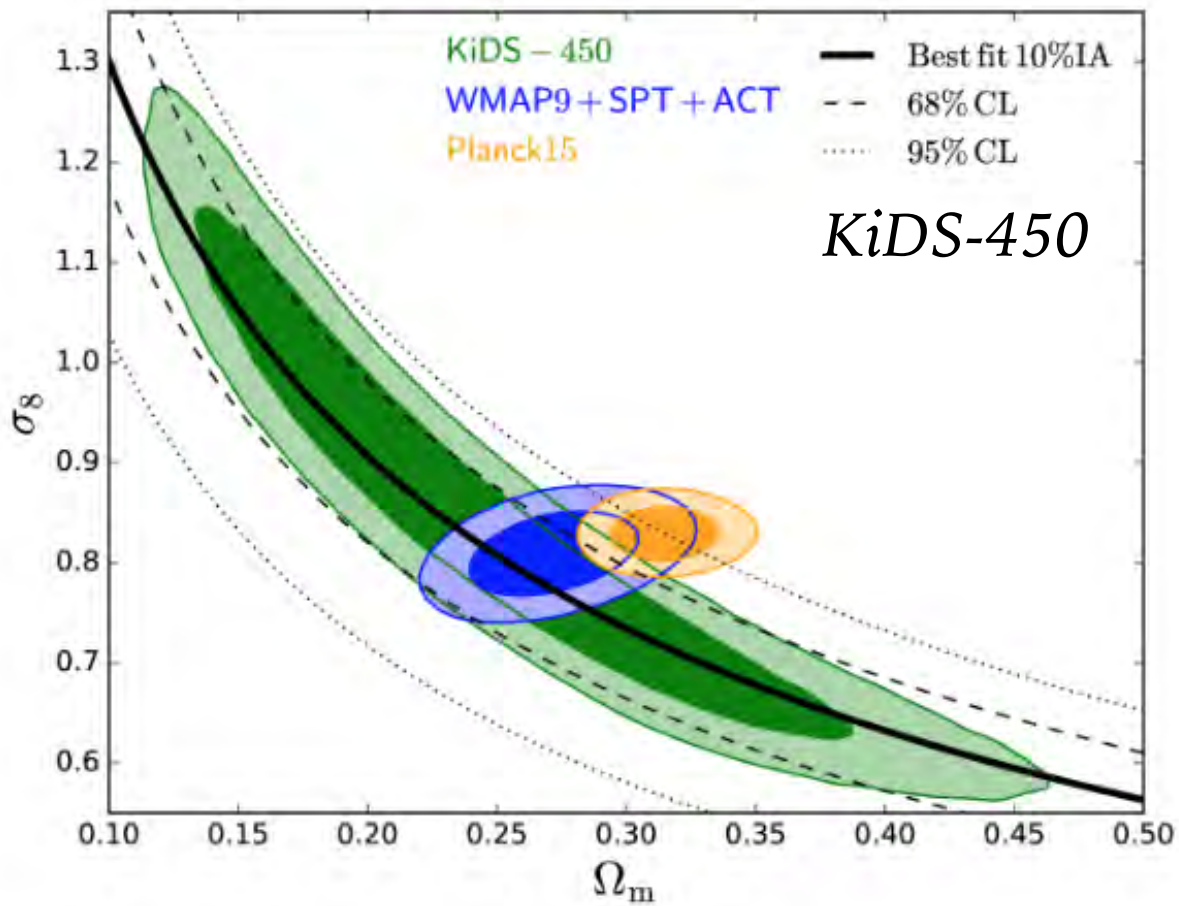
Joudaki+, KiDS collaboration, 2016

see also: DES Y1, 2017

Hikage+, 2018

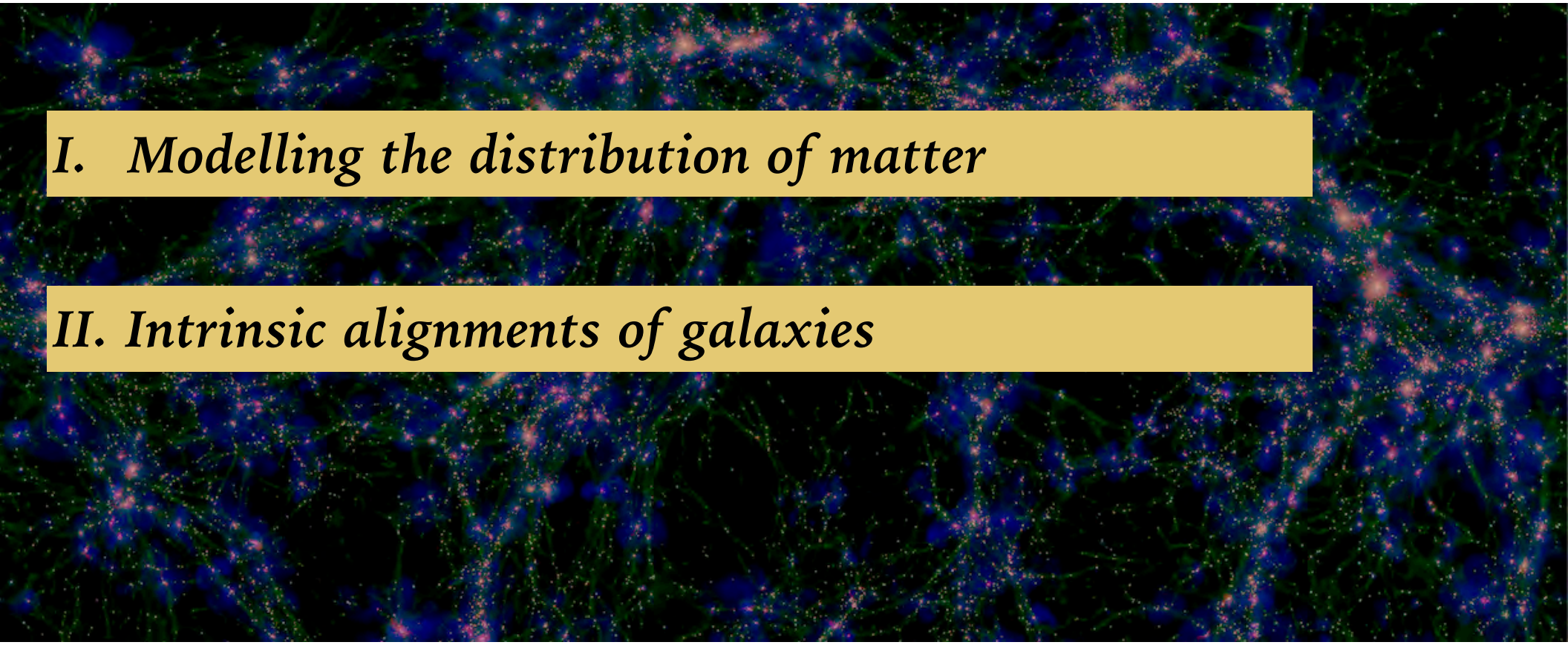
COSMOLOGY WITH LENSING SURVEYS

Combining probes: cross-correlation with CMB lensing



Harnois-Déraps, Troester, Chisari+ (KiDS collaboration, 2017)

CHALLENGES IN WEAK LENSING



I. Modelling the distribution of matter

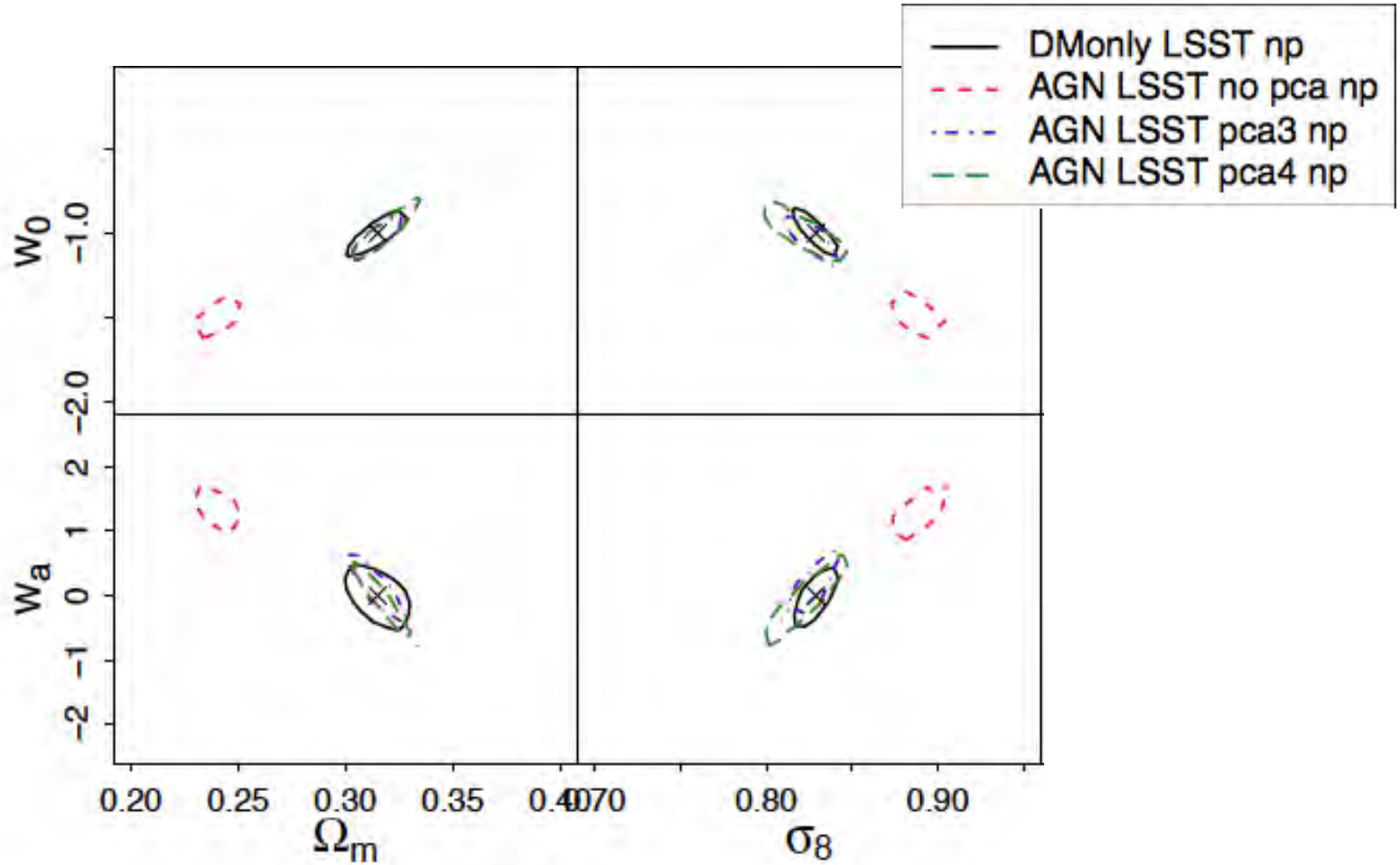
II. Intrinsic alignments of galaxies

CHALLENGES IN WEAK LENSING

I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies

I. MODELLING THE DISTRIBUTION OF MATTER



Cosmic shear in an LSST-like survey, Eifler+ (2015)
See also Semboloni+ (2011), Huang+ (2018)

COSMOLOGICAL SIMULATIONS

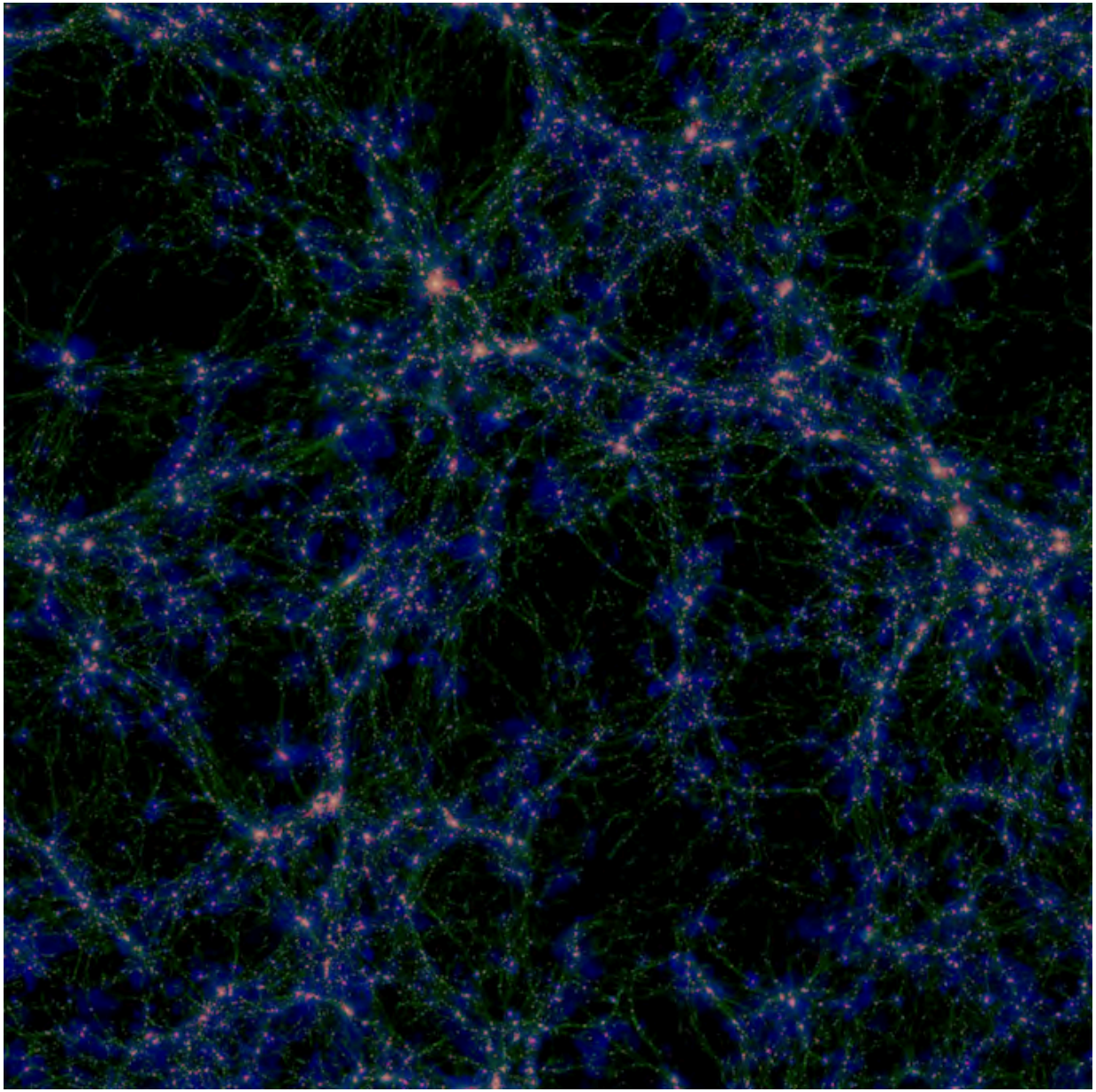
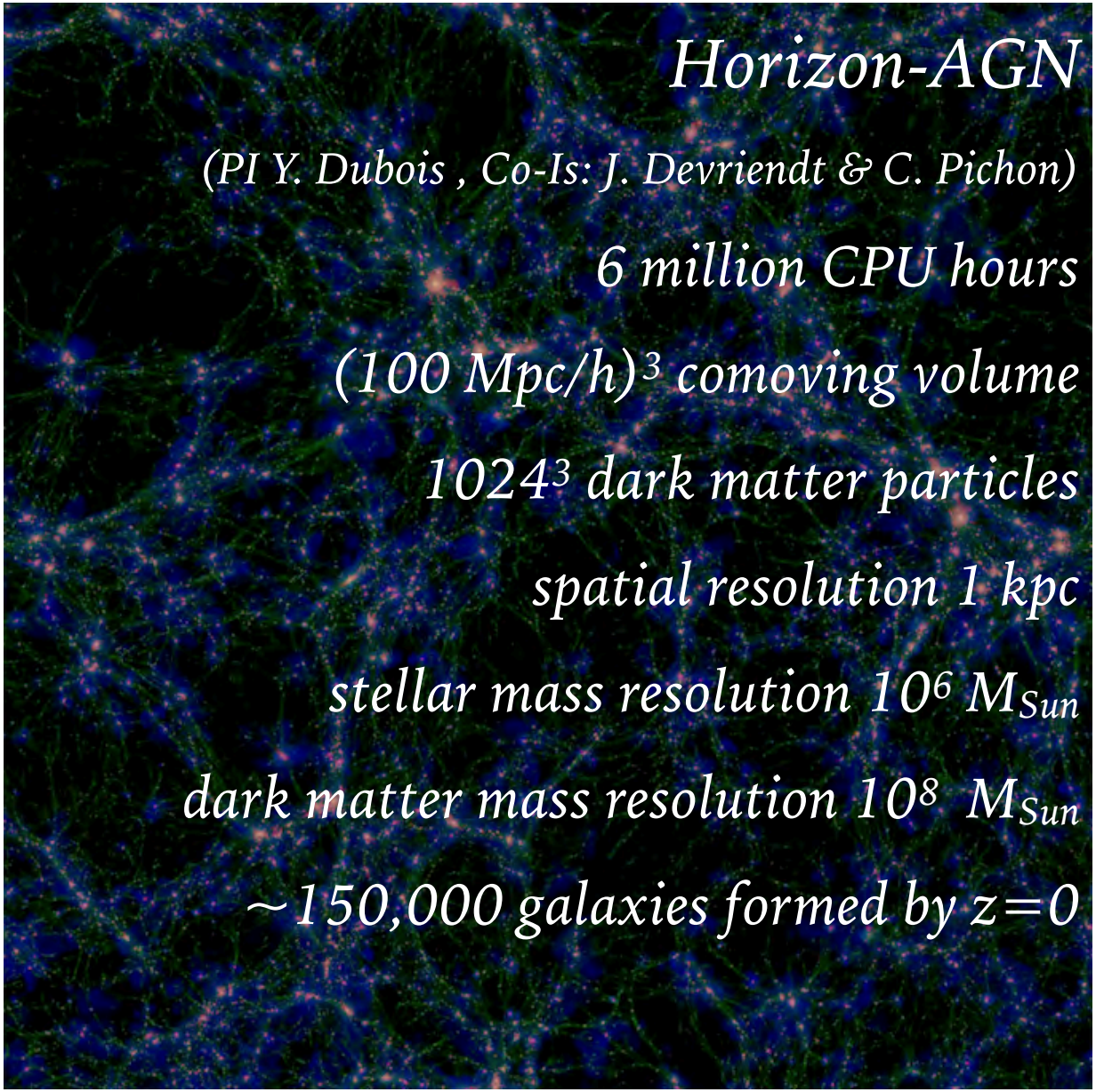


Image: J. Devriendt, Horizon-AGN

COSMOLOGICAL SIMULATIONS



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COSMOLOGICAL SIMULATIONS

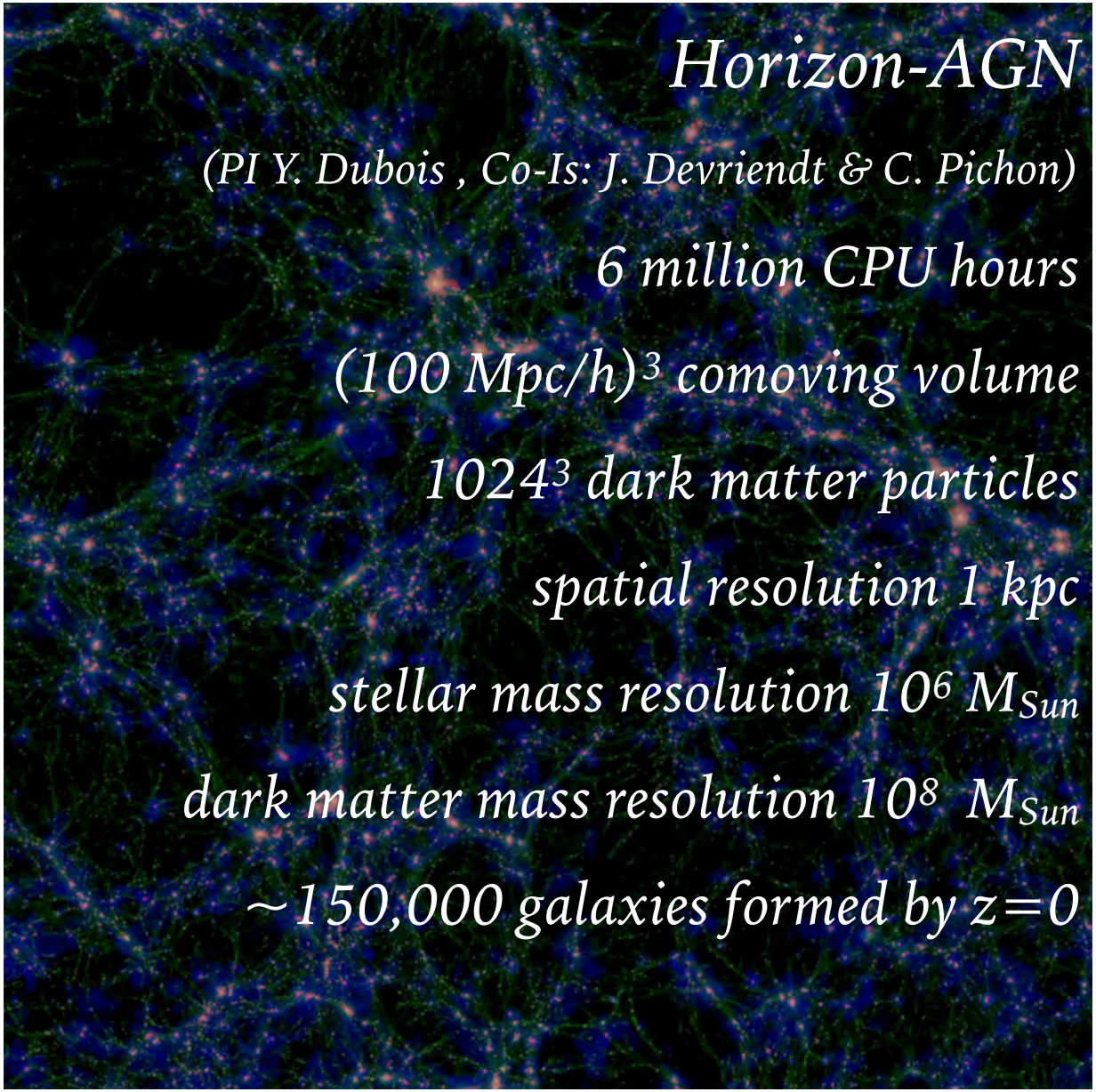


Image: J. Devriendt, Horizon-AGN

Horizon-noAGN
no energy injection by Active Galactic Nuclei

Horizon-DM
pure dark matter

I. MODELLING THE DISTRIBUTION OF MATTER

$$\delta(\mathbf{x}, z) = \rho(\mathbf{x}, z)/\bar{\rho}(z) - 1$$

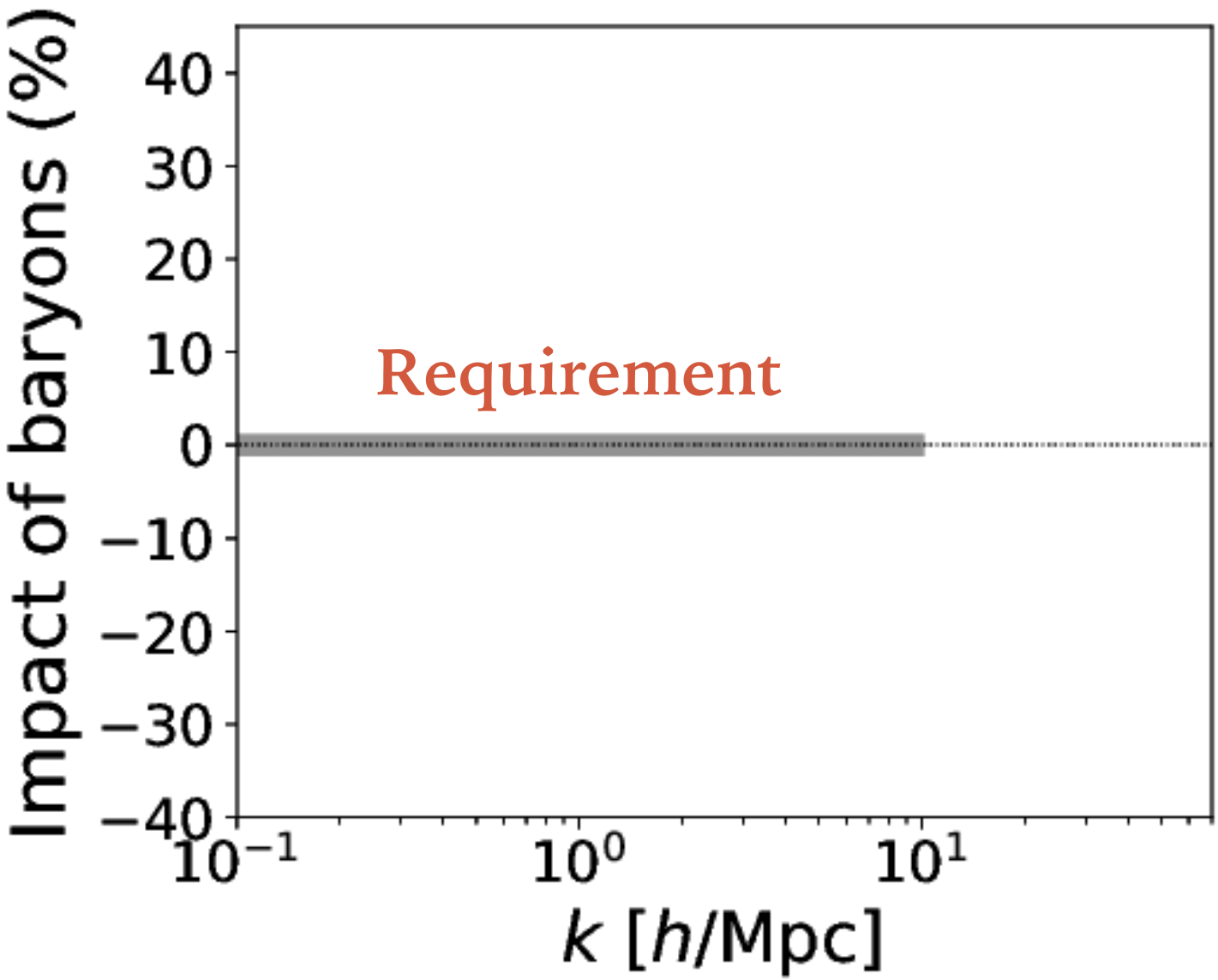
Density field

$$P(k) = \langle |\delta_{\mathbf{k}}|^2 \rangle$$

Total matter power spectrum

I. MODELLING THE DISTRIBUTION OF MATTER

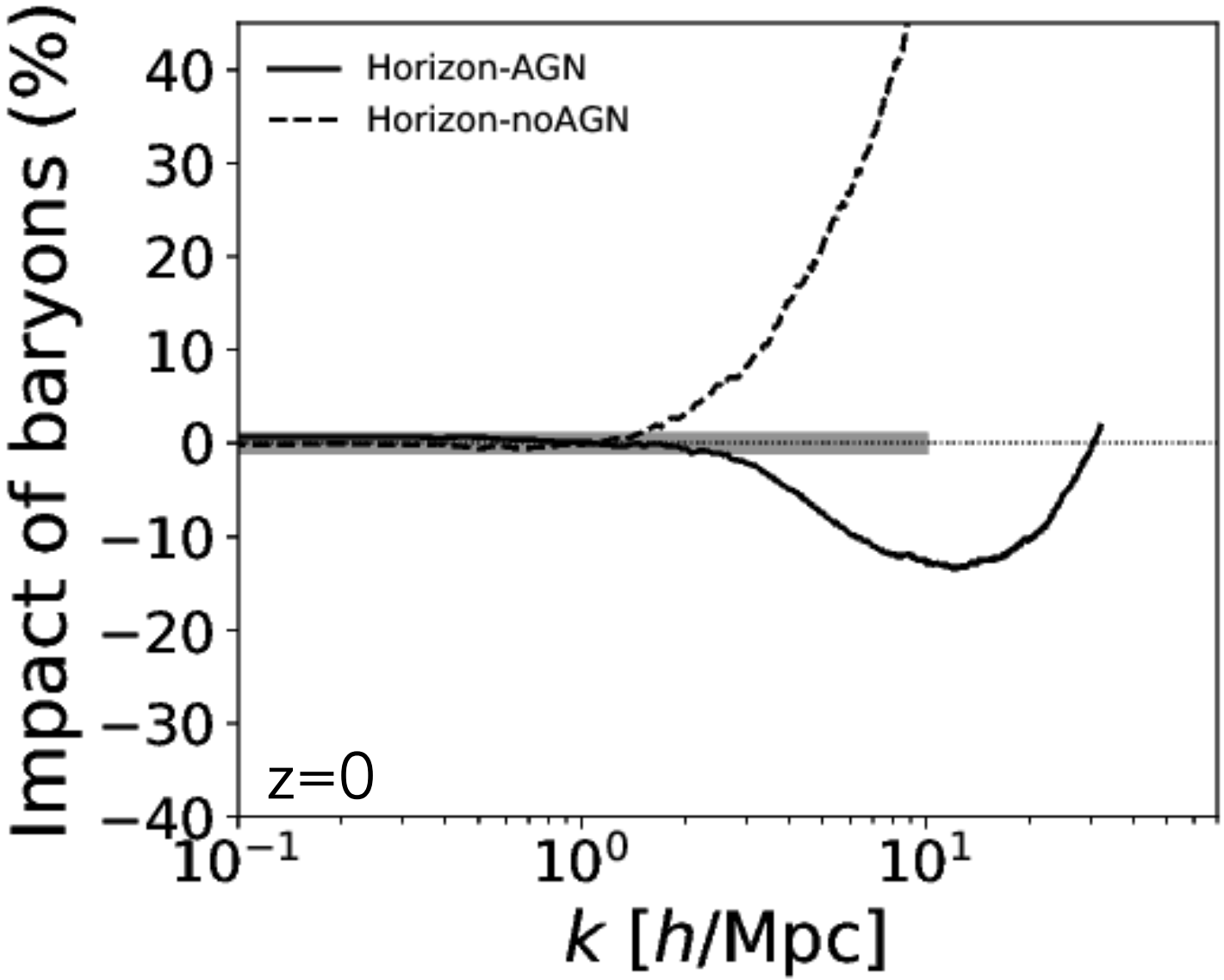
$$P(k) = \langle |\delta_{\mathbf{k}}|^2 \rangle$$



Small scales →

I. MODELLING THE DISTRIBUTION OF MATTER

$$P(k) = \langle |\delta_{\mathbf{k}}|^2 \rangle$$



Small scales →

Chisari+ (2018)

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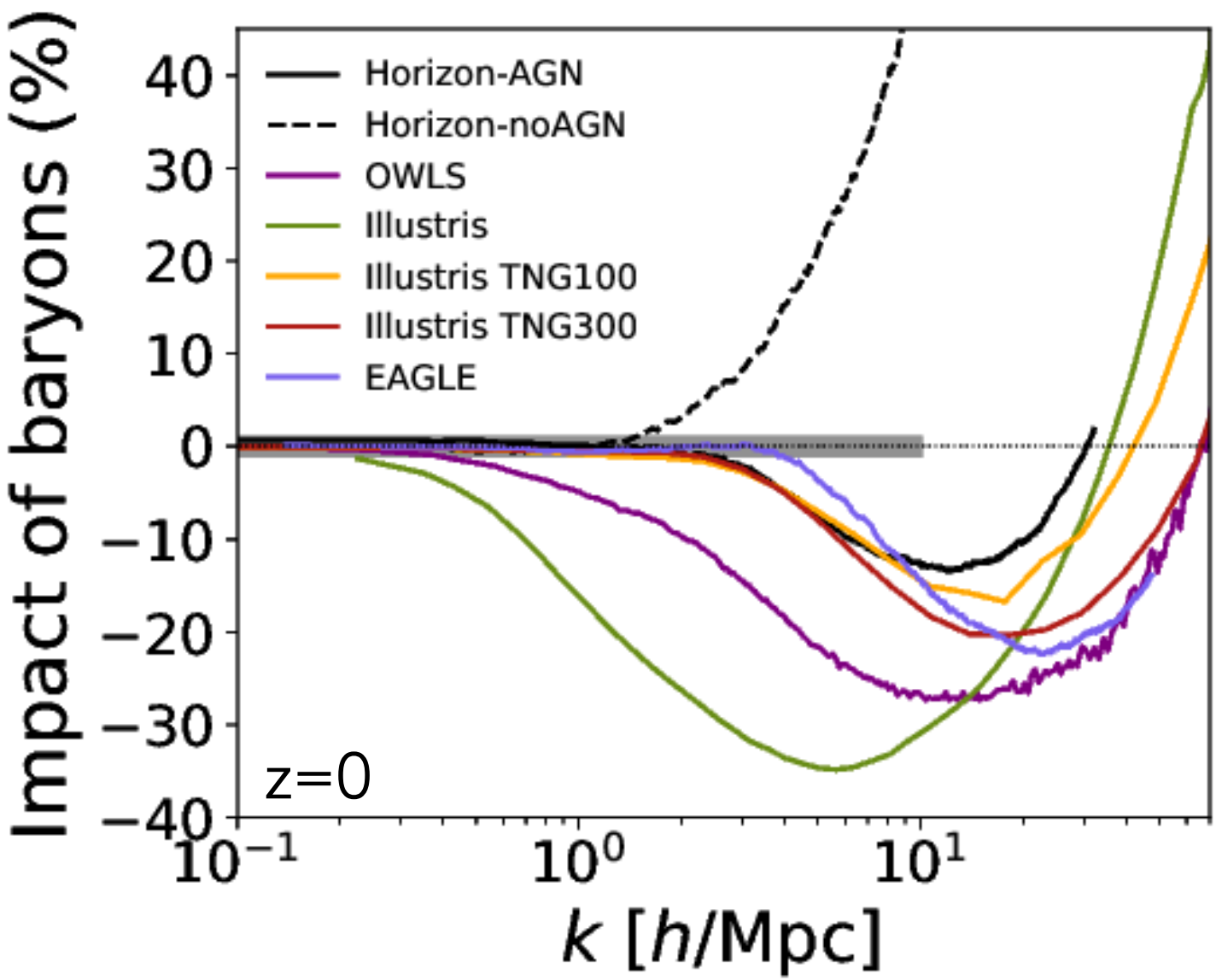
$$P(k) = \langle |\delta_{\mathbf{k}}|^2 \rangle$$

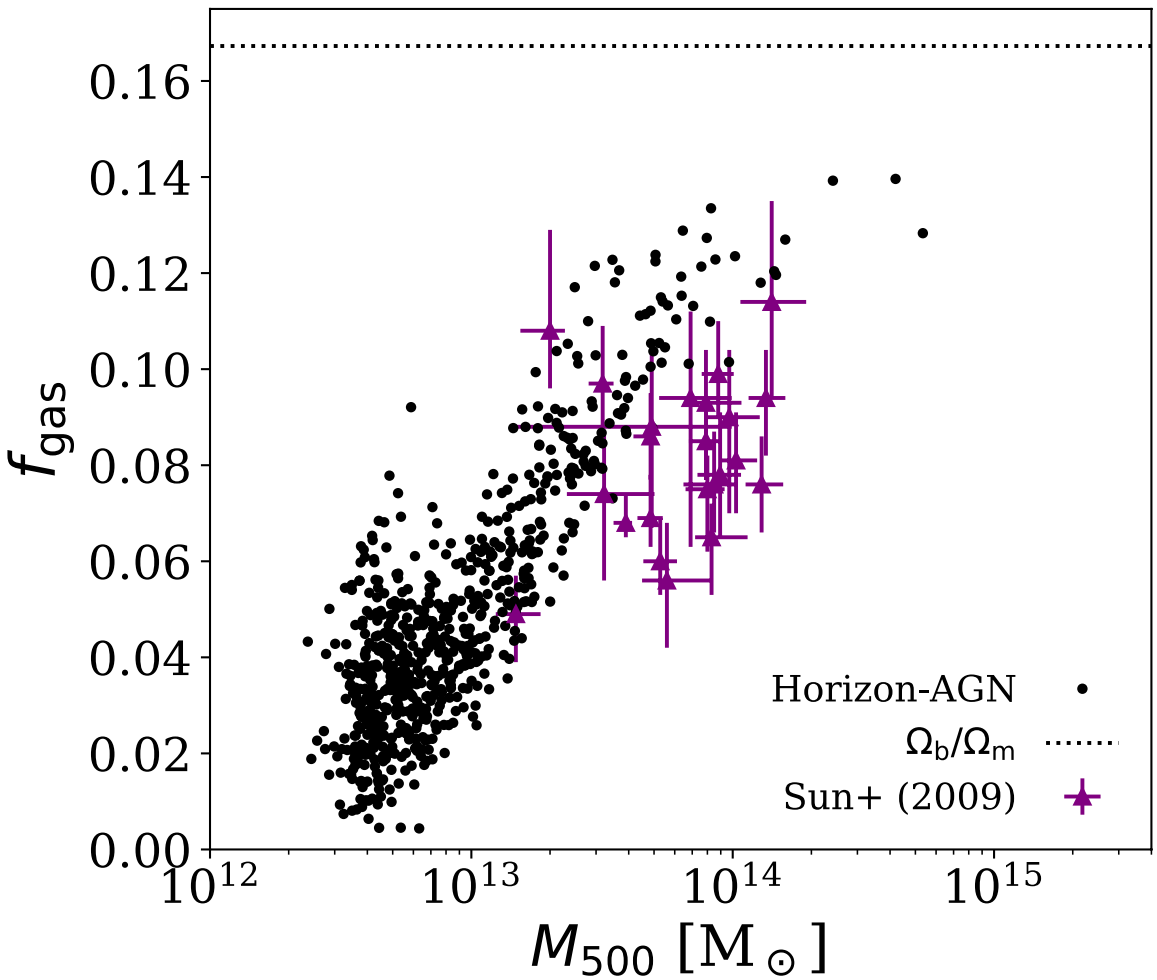


Small scales

Chisari+ (2018)
van Daalen+ (2011)
Vogelsberger+ (2014)
Hellwing+ (2016)
Springel+ (2017)

I. MODELLING THE DISTRIBUTION OF MATTER

X-ray/SZ synergies could help us constrain the impact of baryons

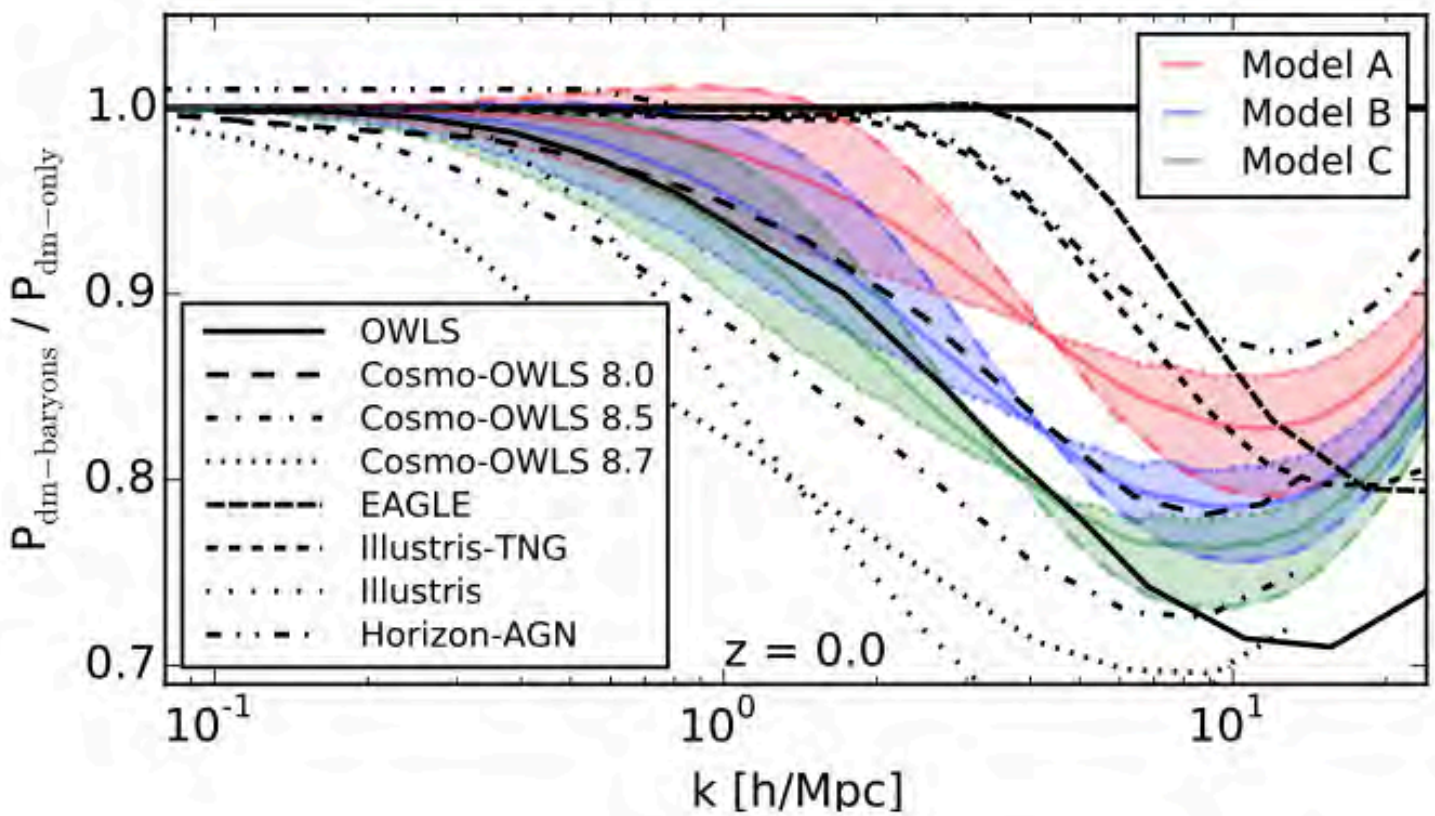


Chisari+ (2018)
Schneider+ (2018)
see also Semoboloni+ (2011/3)

I. MODELLING THE DISTRIBUTION OF MATTER

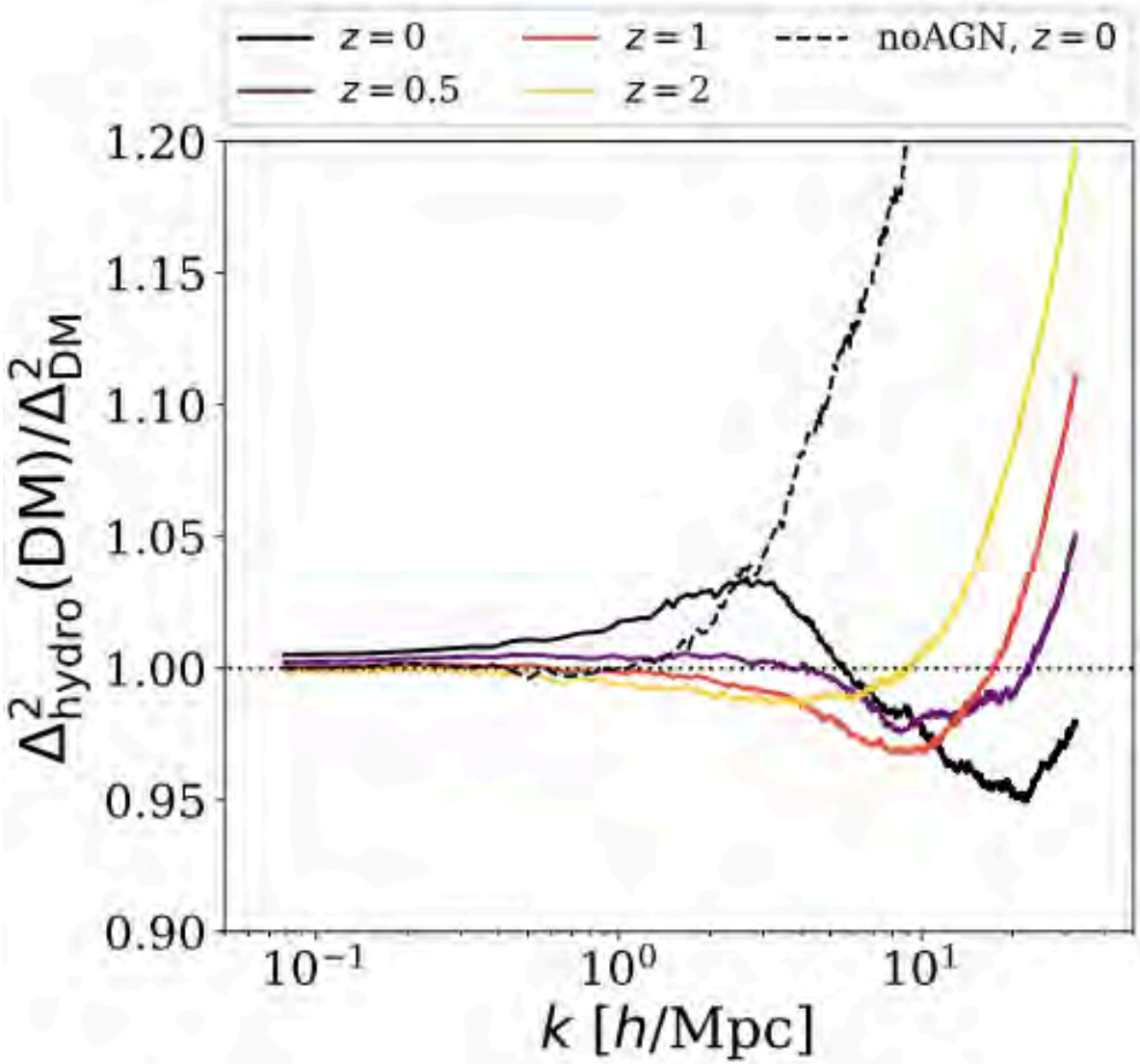
A model for halos with baryons: stars+gas+DM

- Use constraints from observations
- Do not rely on simulations as priors
- But verify against simulations, ~ few per cent agreement



Schneider+ (2018)

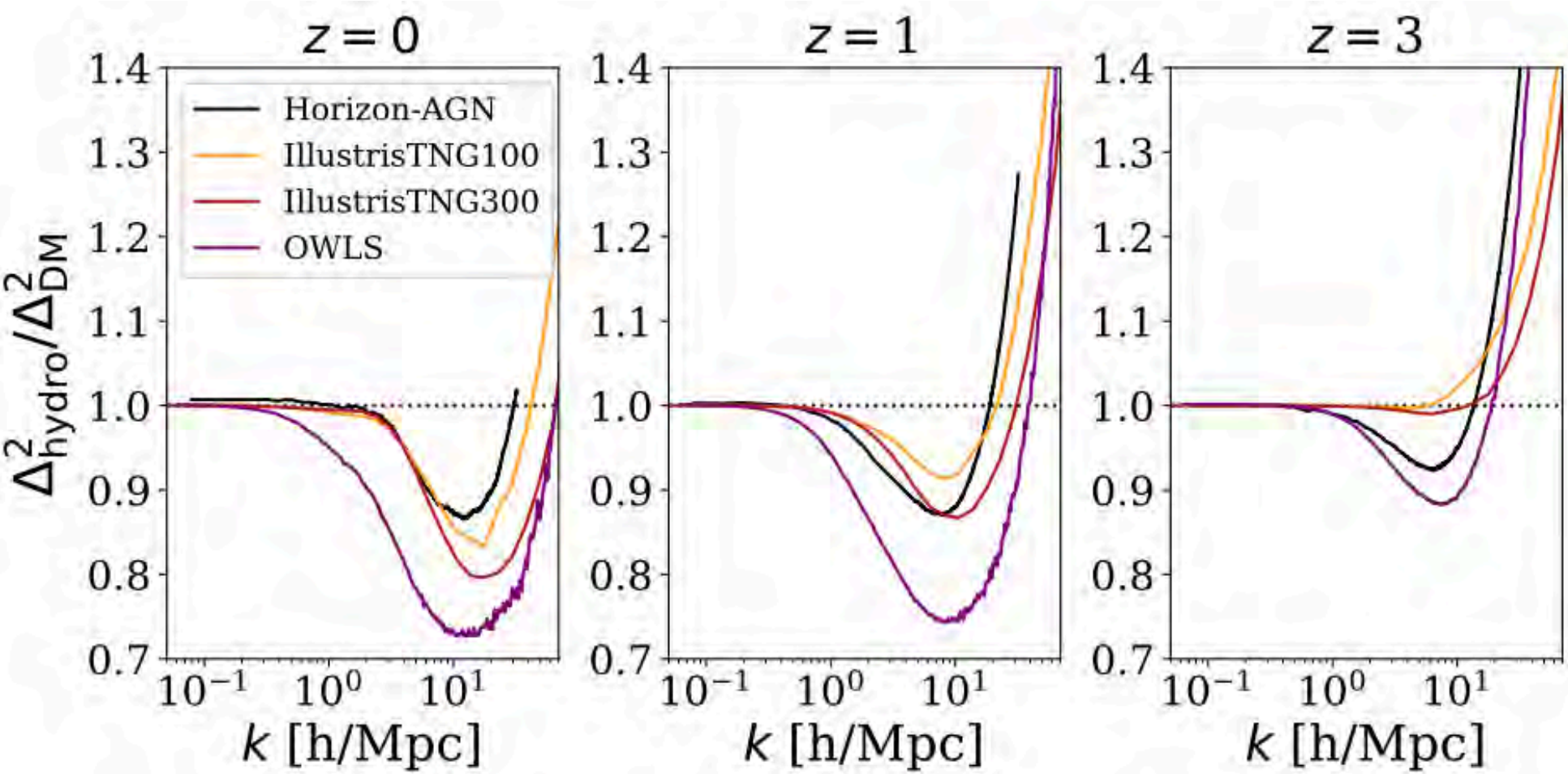
I. MODELLING THE DISTRIBUTION OF MATTER



THE IMPACT ON THE DARK MATTER DISTRIBUTION

Chisari+ (2018)

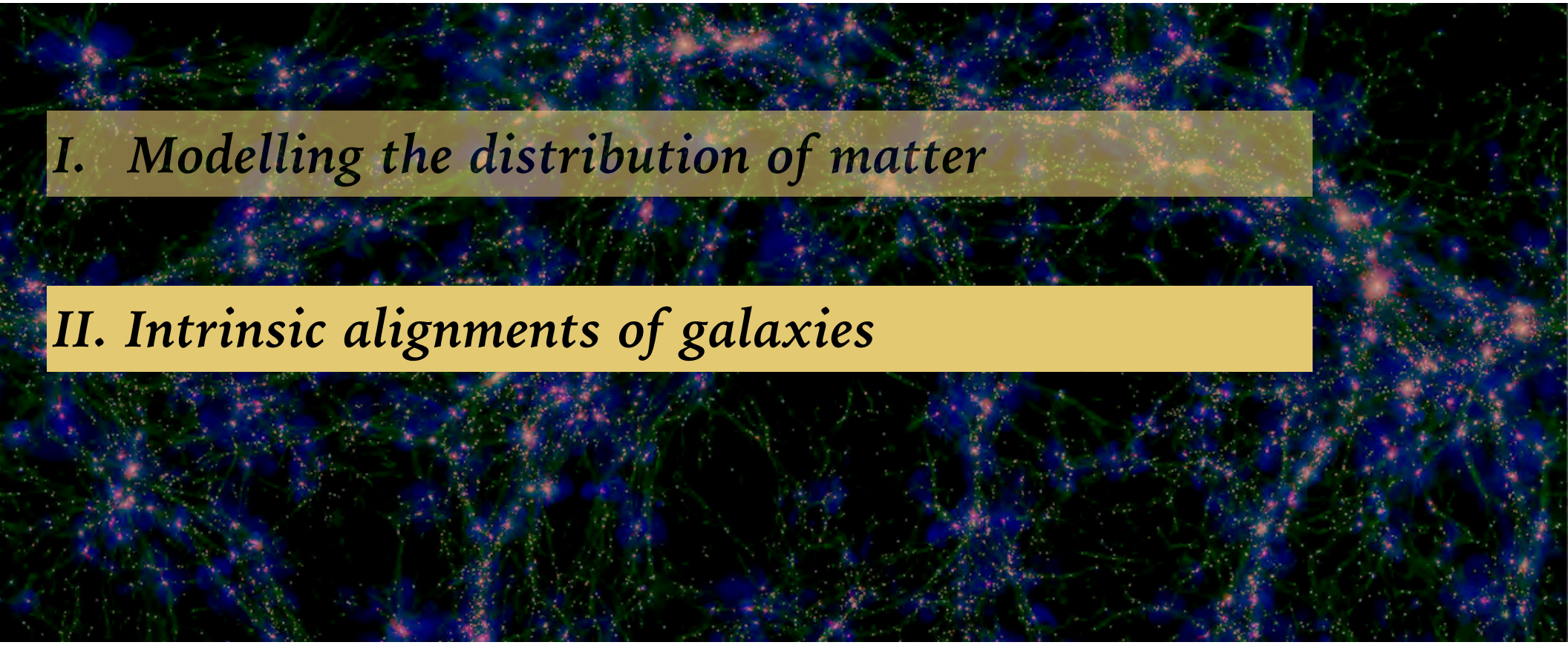
I. MODELLING THE DISTRIBUTION OF MATTER



REDSHIFT EVOLUTION IN DIFFERENT HYDRO SIMS

Chisari+ (2018)

CHALLENGES IN WEAK LENSING

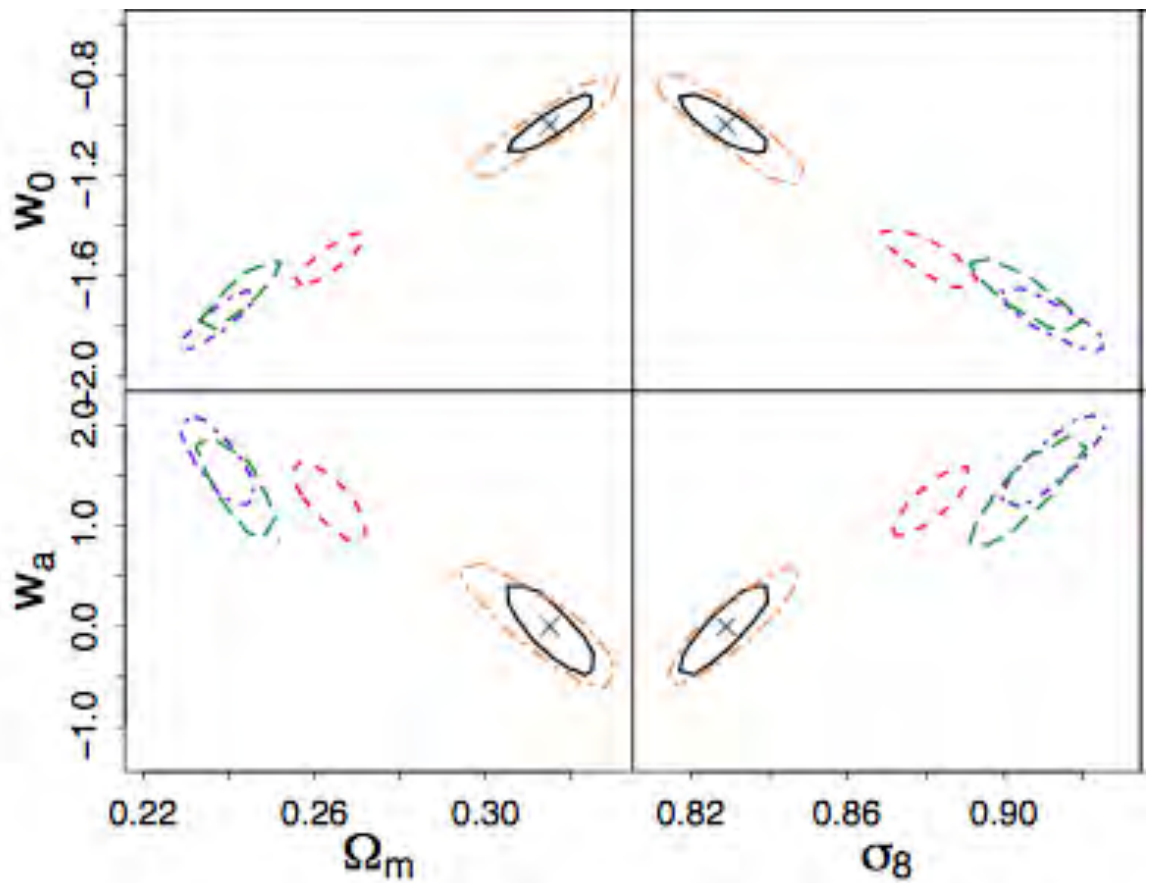


I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies

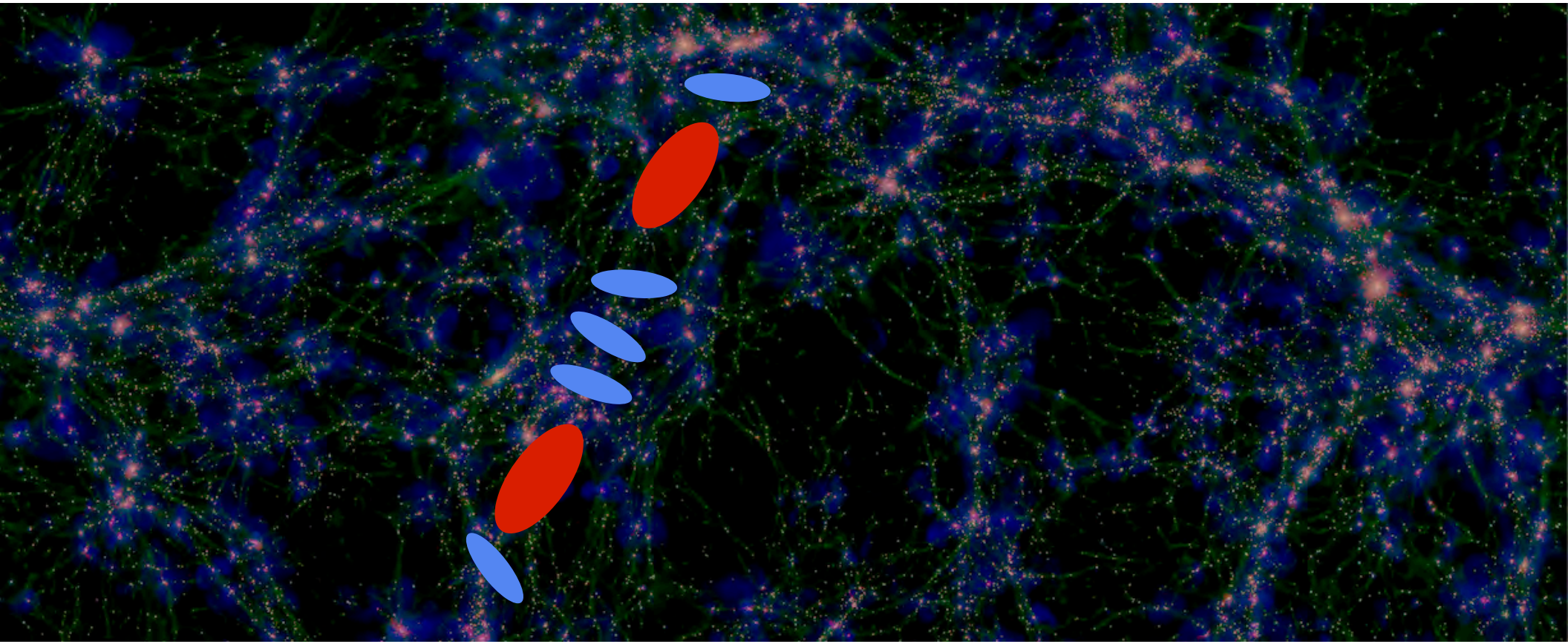
II. INTRINSIC ALIGNMENTS

Bias in cosmology due to galaxy alignments



Krause+ (2015)

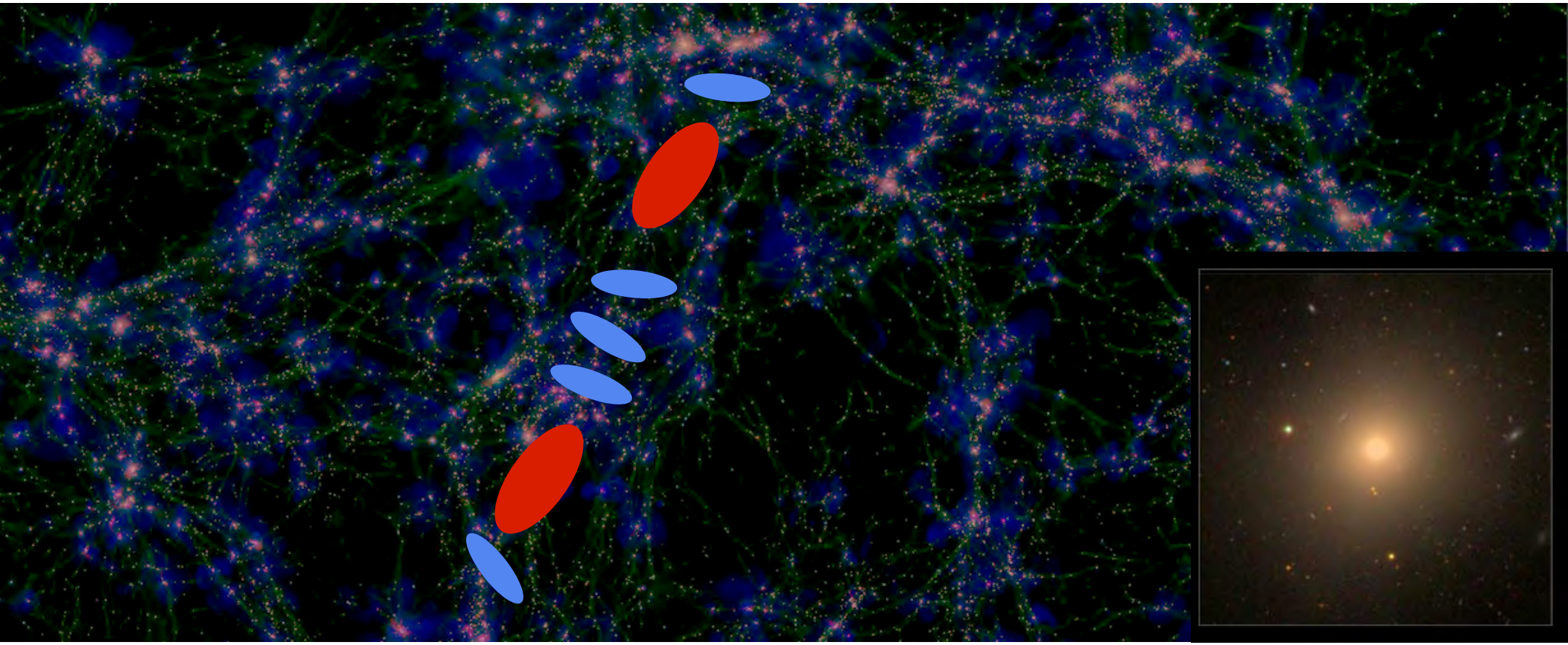
II. INTRINSIC ALIGNMENTS



$$\textit{Galaxy shapes} = \textit{Lensing} + \textit{Intrinsic alignment} + \textit{Noise}$$

$$\boldsymbol{SS = GG + GI + IG + II + Noise}$$

II. INTRINSIC ALIGNMENTS

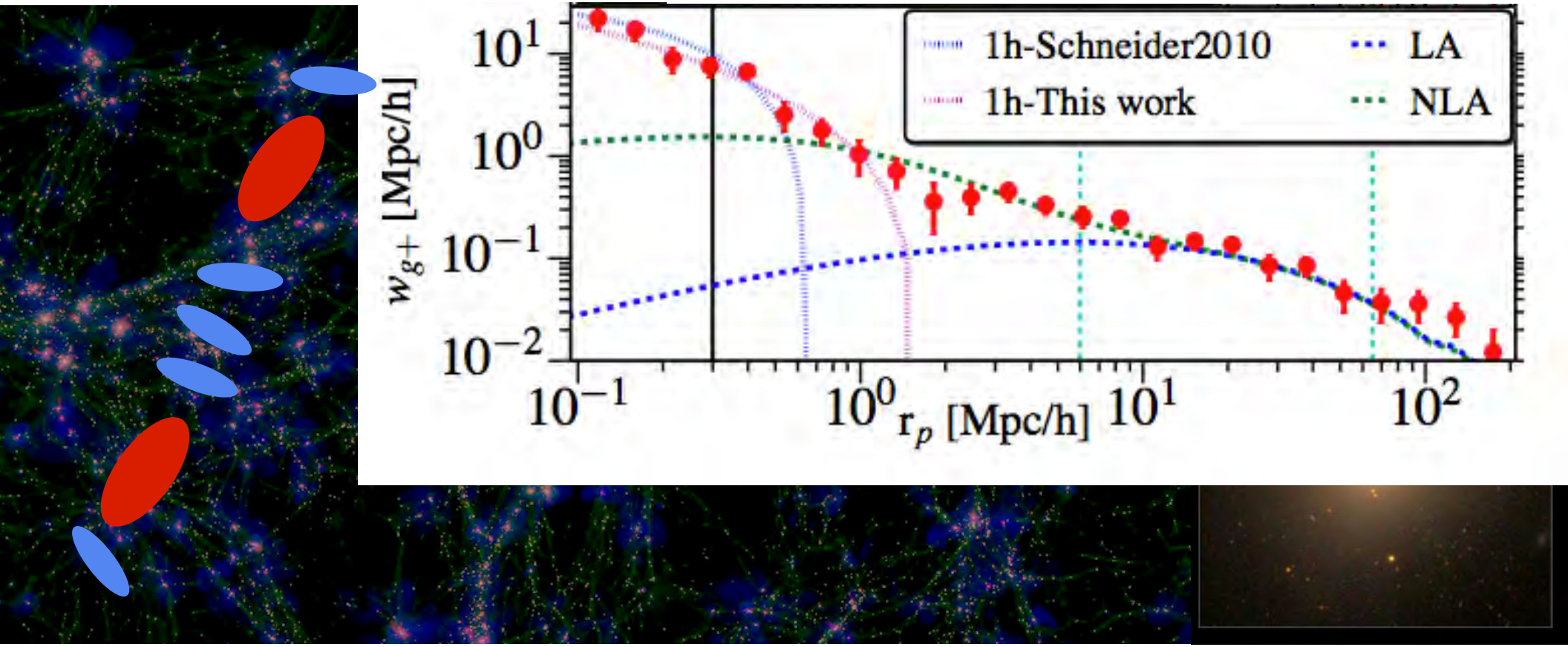


Galaxy shapes ~ *Tidal field of the large-scale structure*

Catelan+ (2001)

II. INTRINSIC ALIGNMENTS

SDSS LOWZ sample - Singh+ (2014)



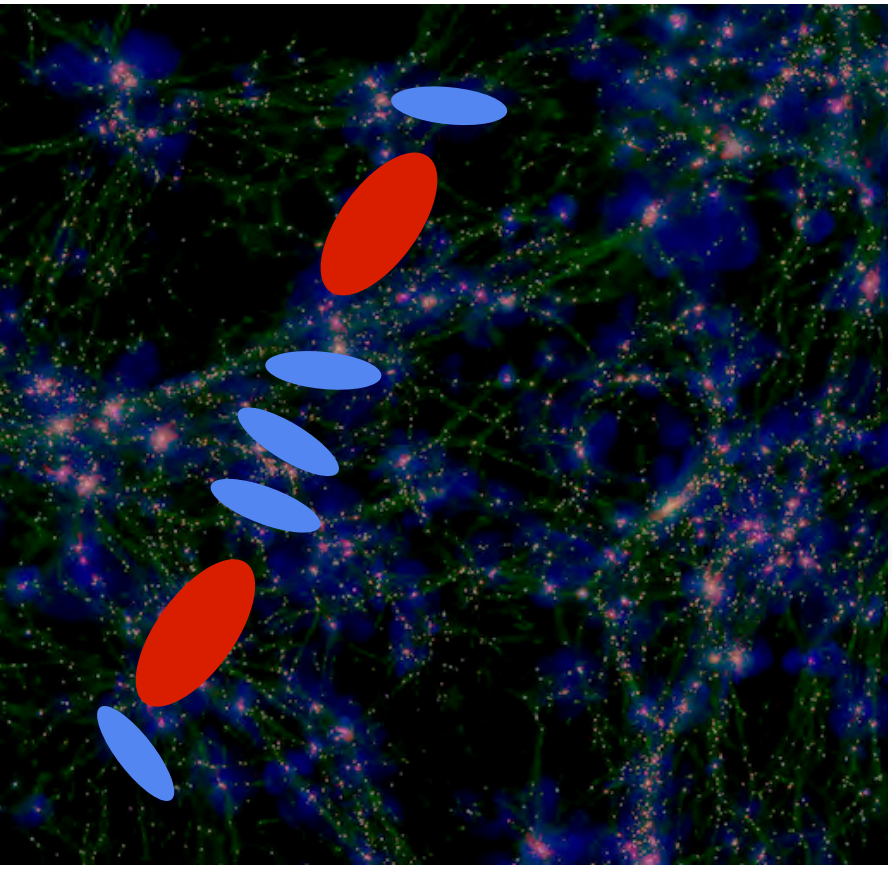
Galaxy shapes ~ Tidal field of the large-scale structure

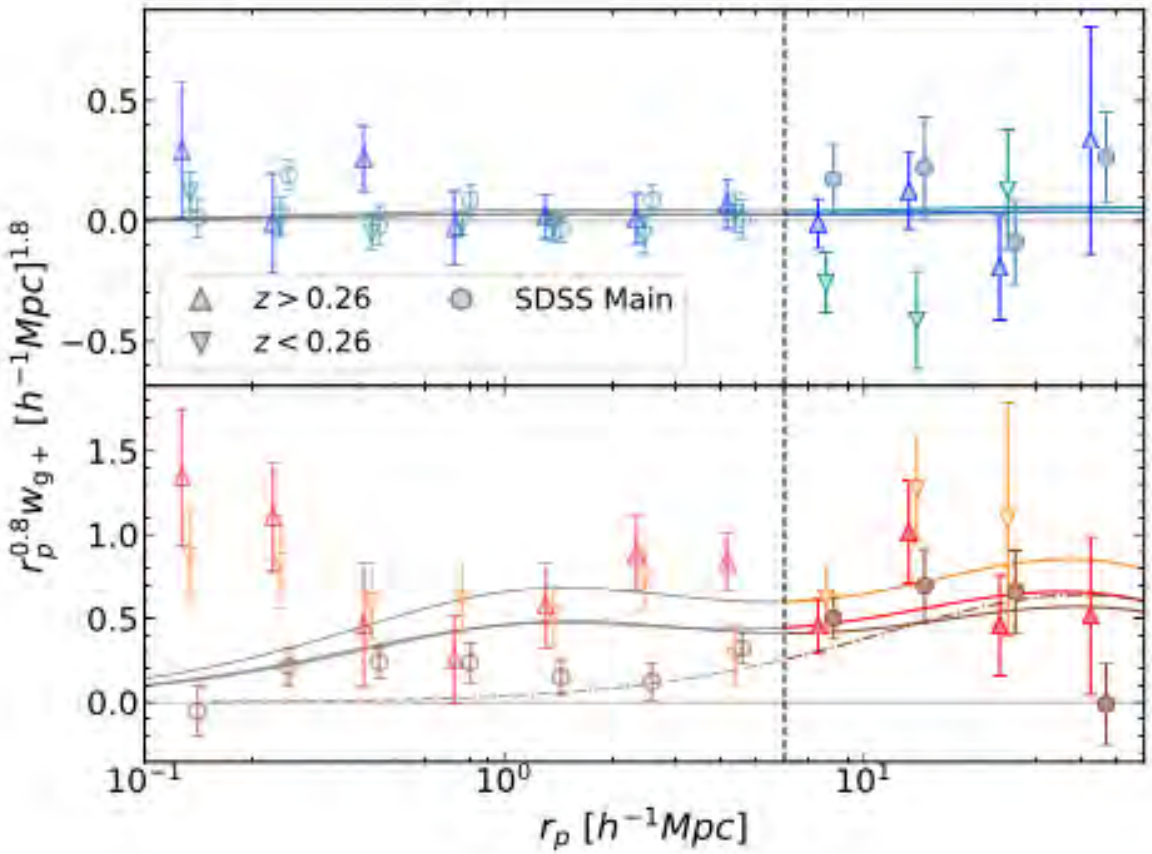
Catelan+ (2001)

II. INTRINSIC ALIGNMENTS

KiDS

KiDS+GAMA - Johnston+, incl. EC (2018)





Galaxy shapes ~ Tidal field of the large-scale structure

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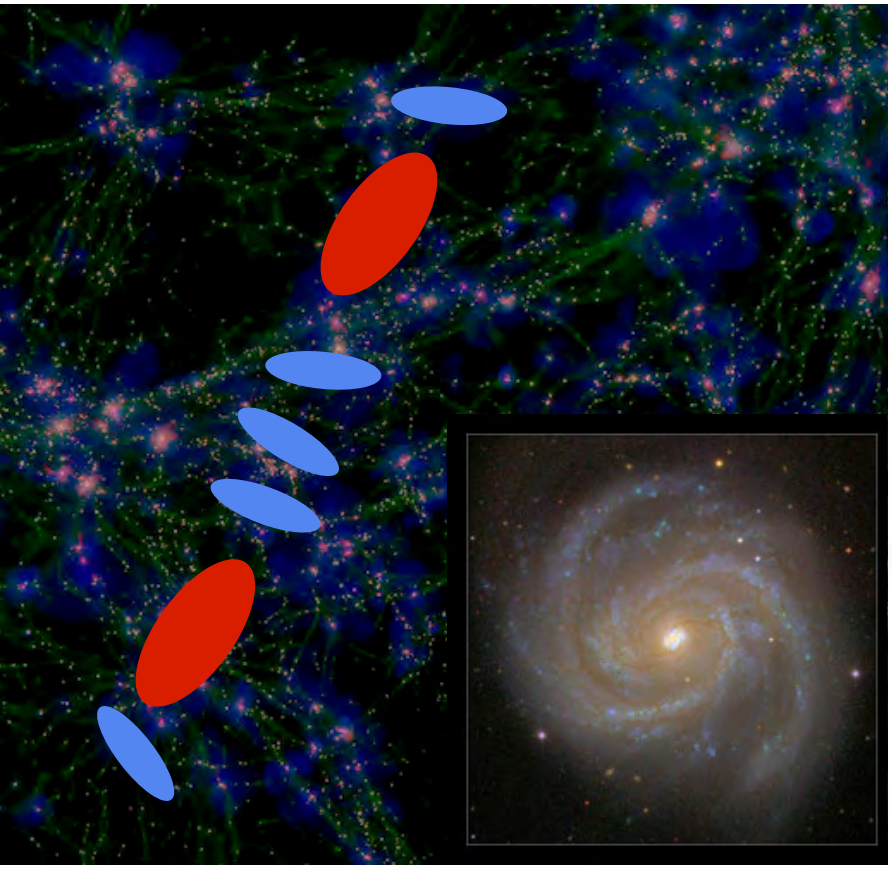
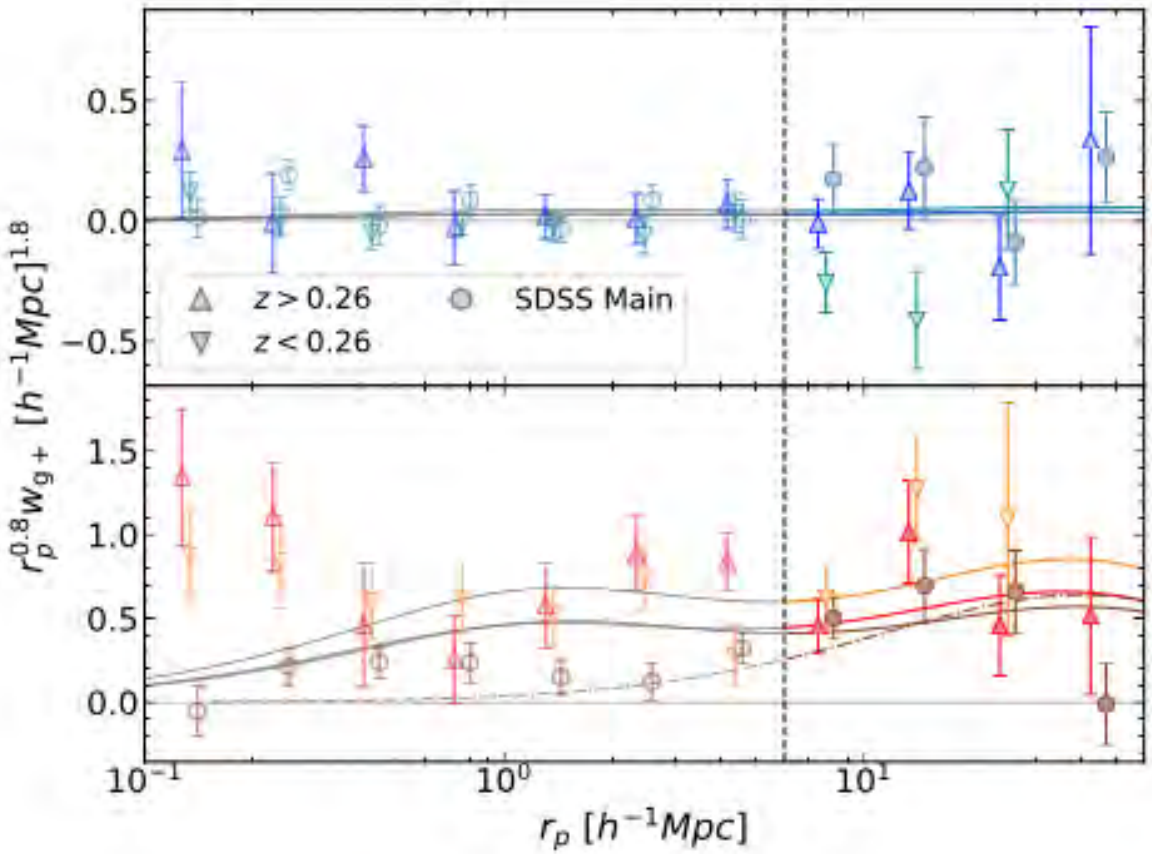
II. INTRINSIC ALIGNMENTS

KiDS+GAMA - Johnston+, incl. EC (2018)





$$\text{Galaxy shapes} \sim \left(\begin{array}{c}\text{Tidal field of the large-}\\ \text{scale structure}\end{array}\right)^2$$

Catelan+ (2001)

COSMOLOGICAL SIMULATIONS

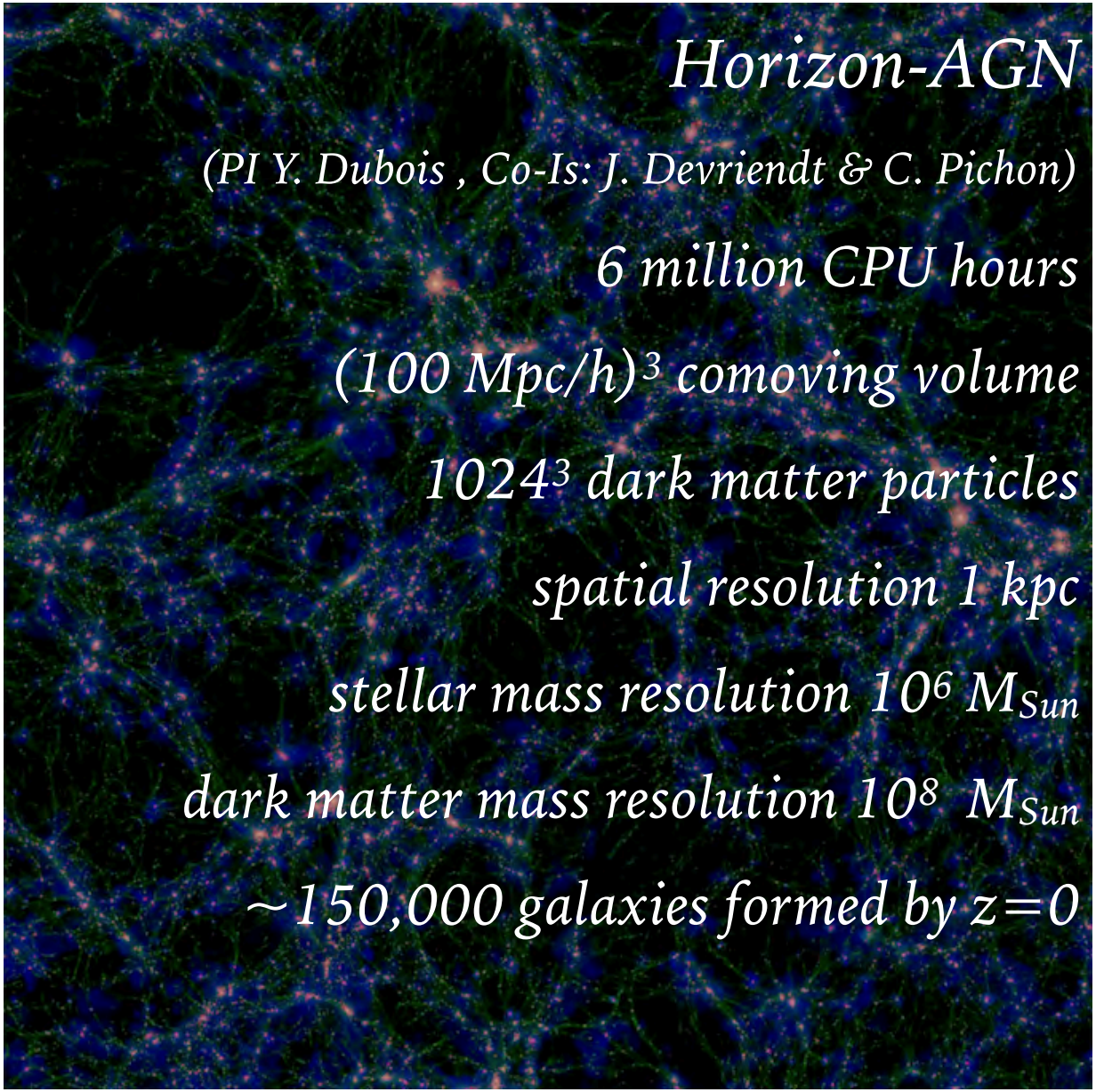
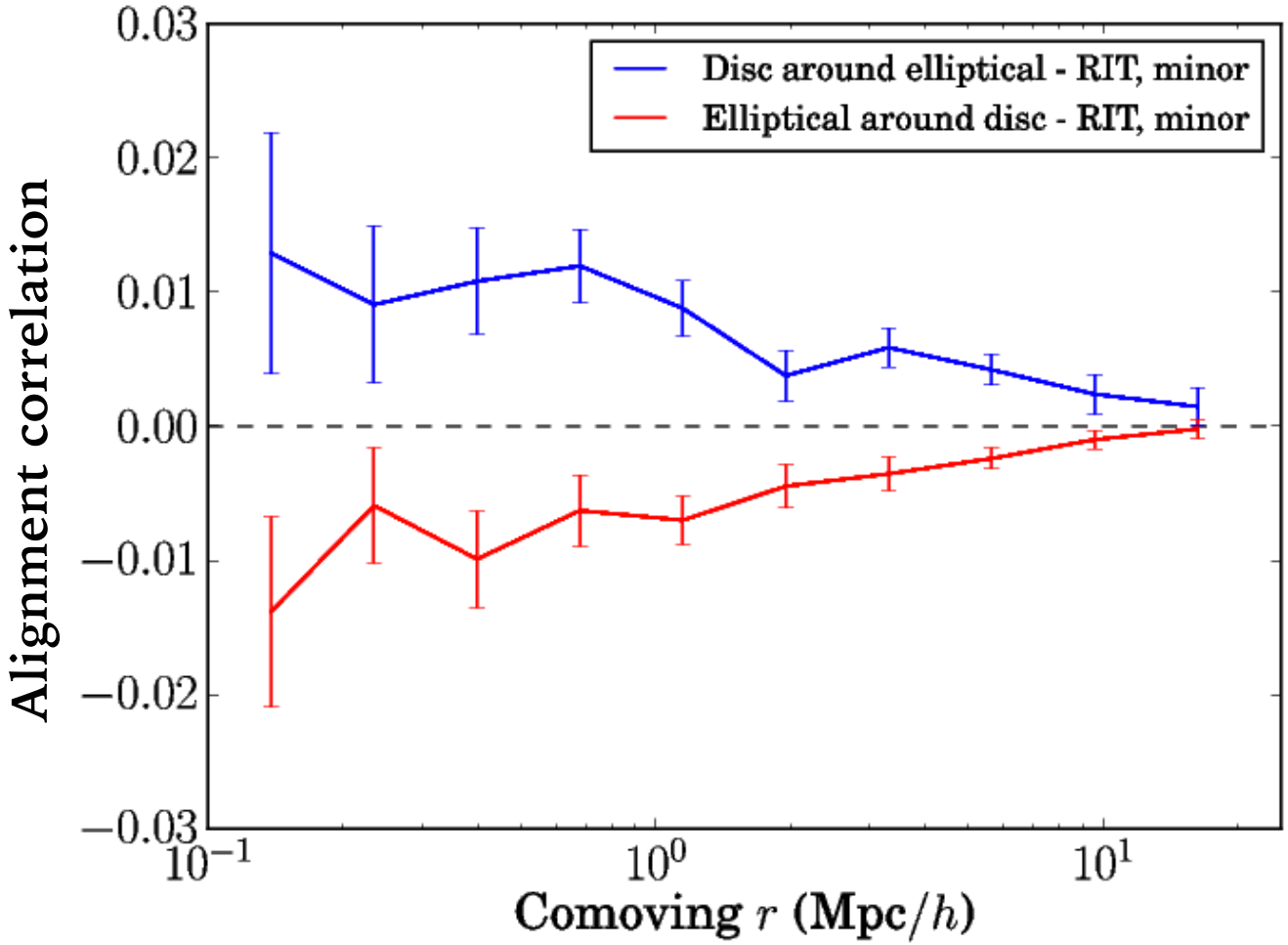
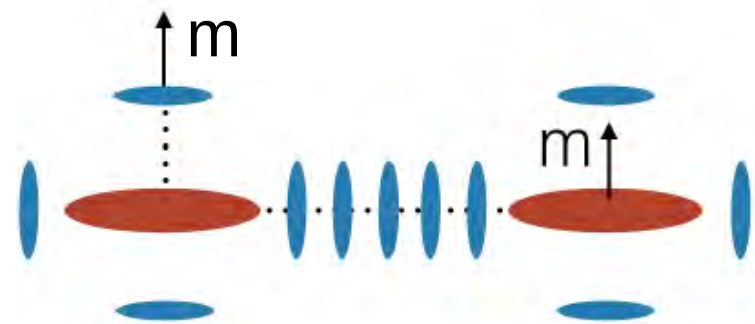


Image: J. Devriendt, Horizon-AGN

II. INTRINSIC ALIGNMENTS

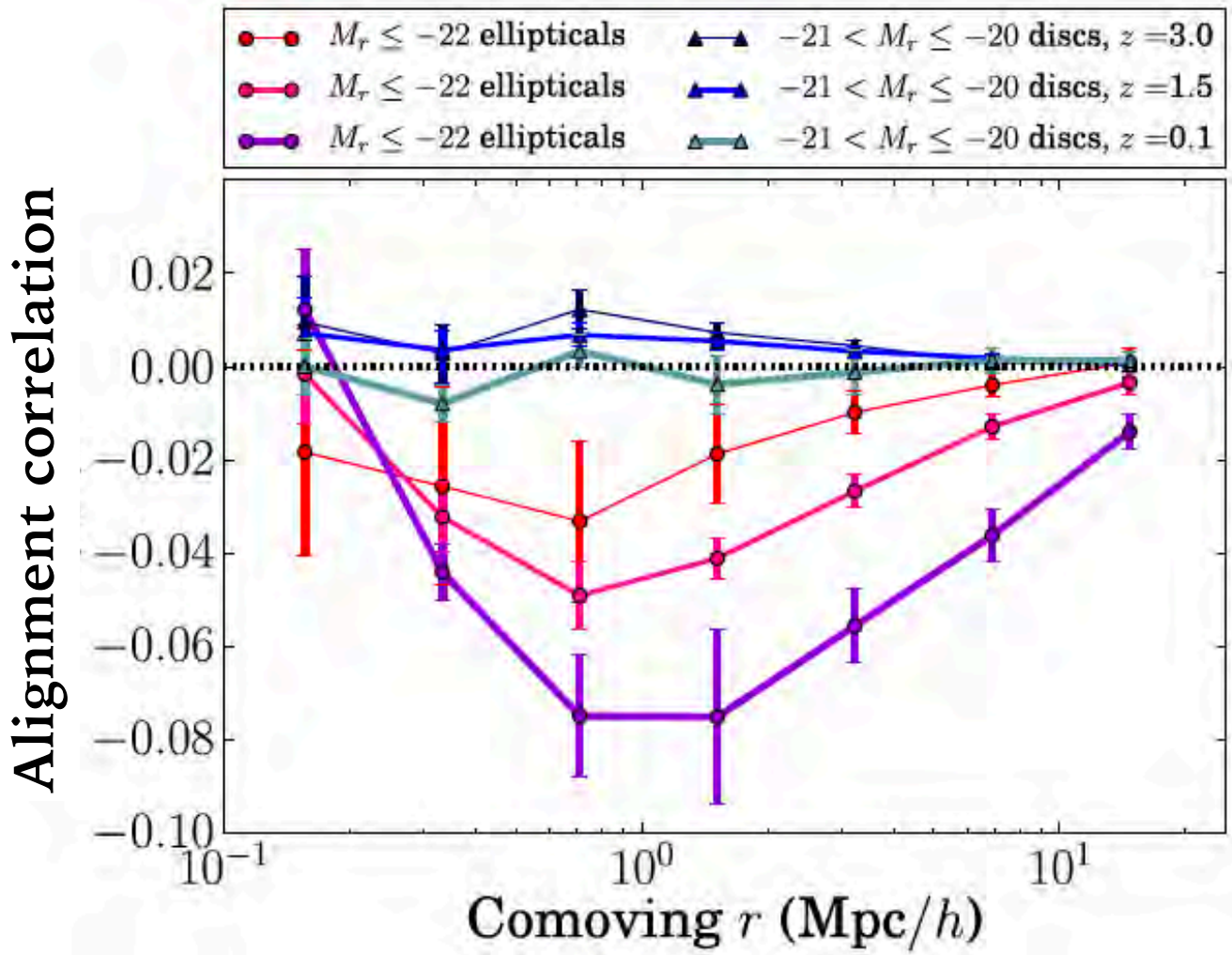




DISC GALAXIES ALIGN MIMICKING WEAK LENSING

Chisari+ (2015)

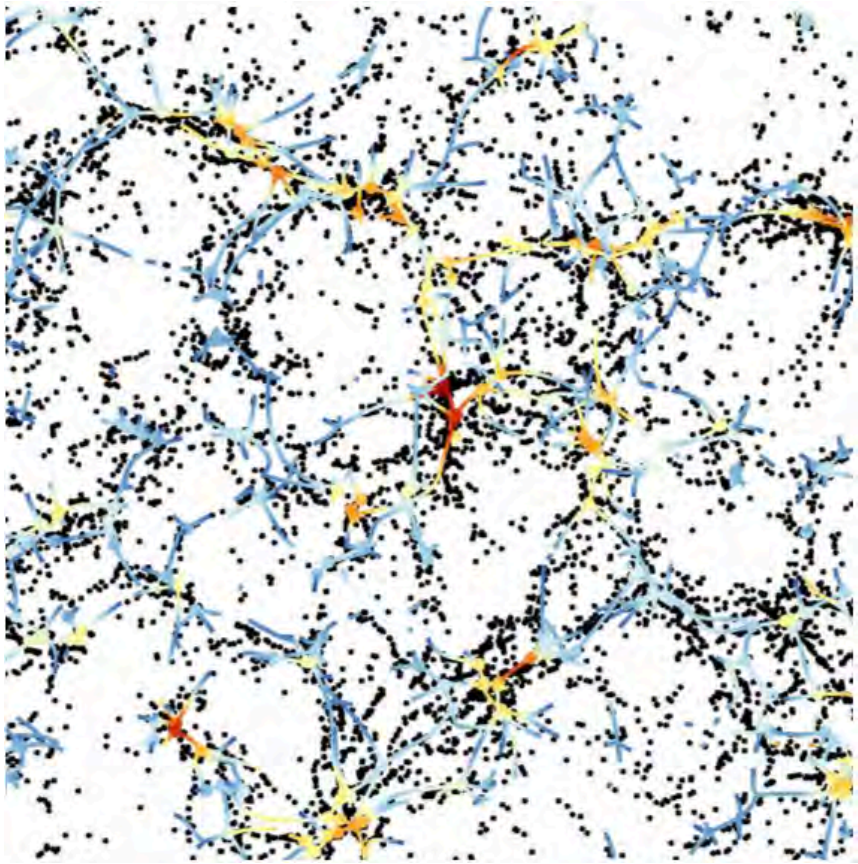
II. INTRINSIC ALIGNMENTS

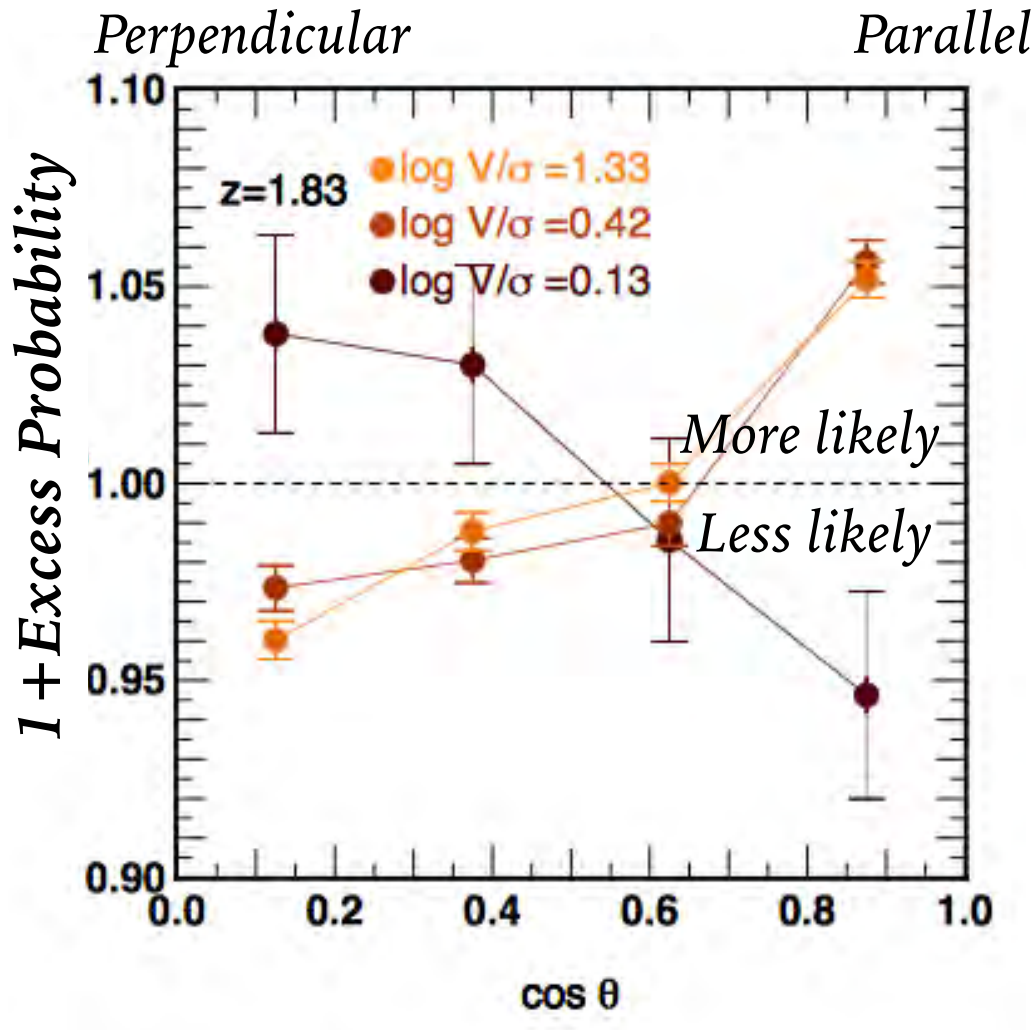


REDSHIFT, COLOR AND LUMINOSITY DEPENDENCE

Chisari+ (2016)

II. INTRINSIC ALIGNMENTS

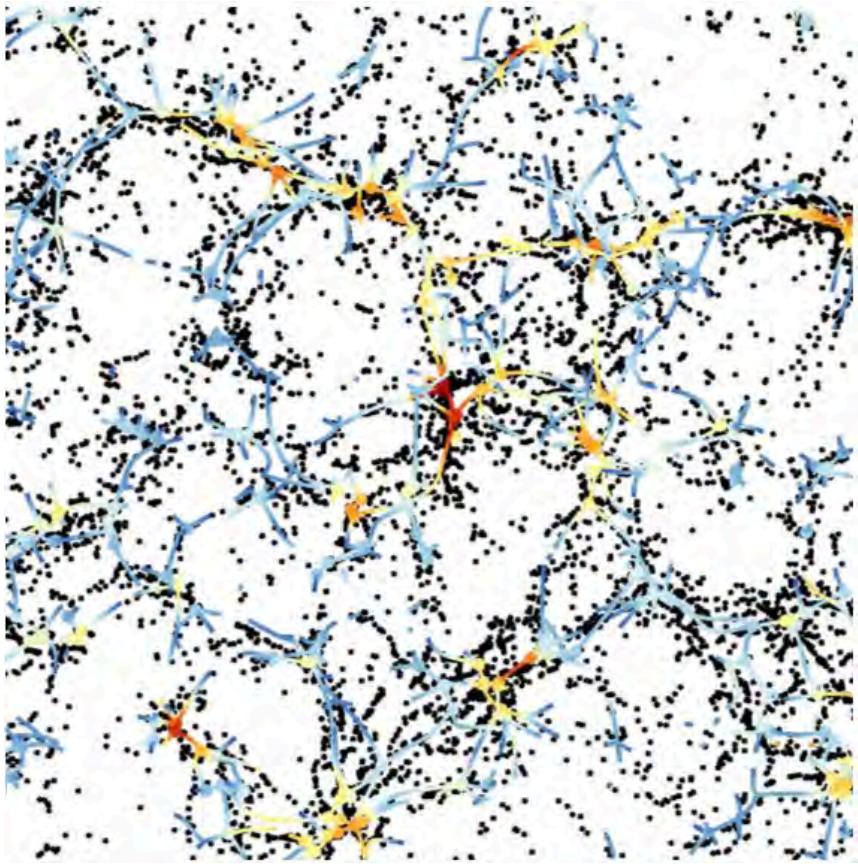


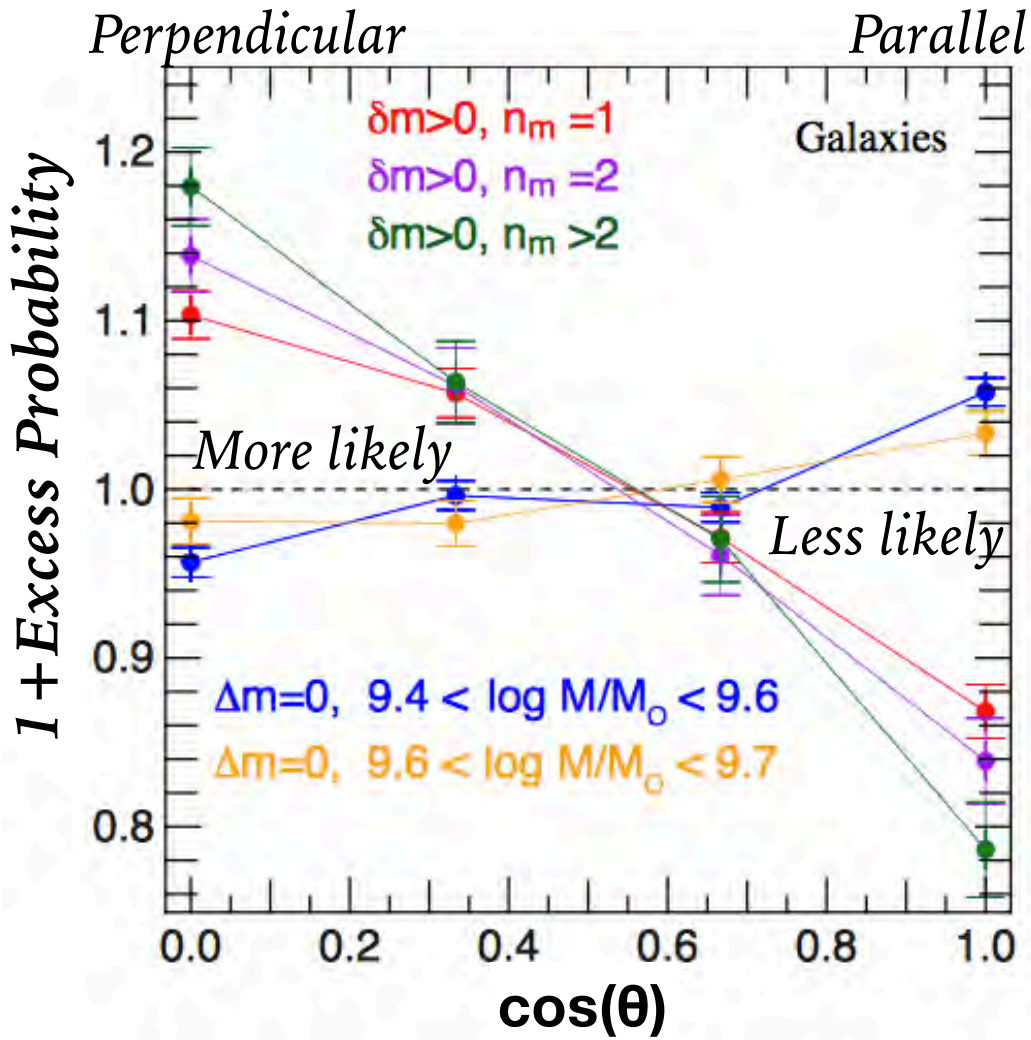


SPIN SWINGS IN THE COSMIC WEB

Dubois+ (2014)
Codis+ (2018)

II. INTRINSIC ALIGNMENTS



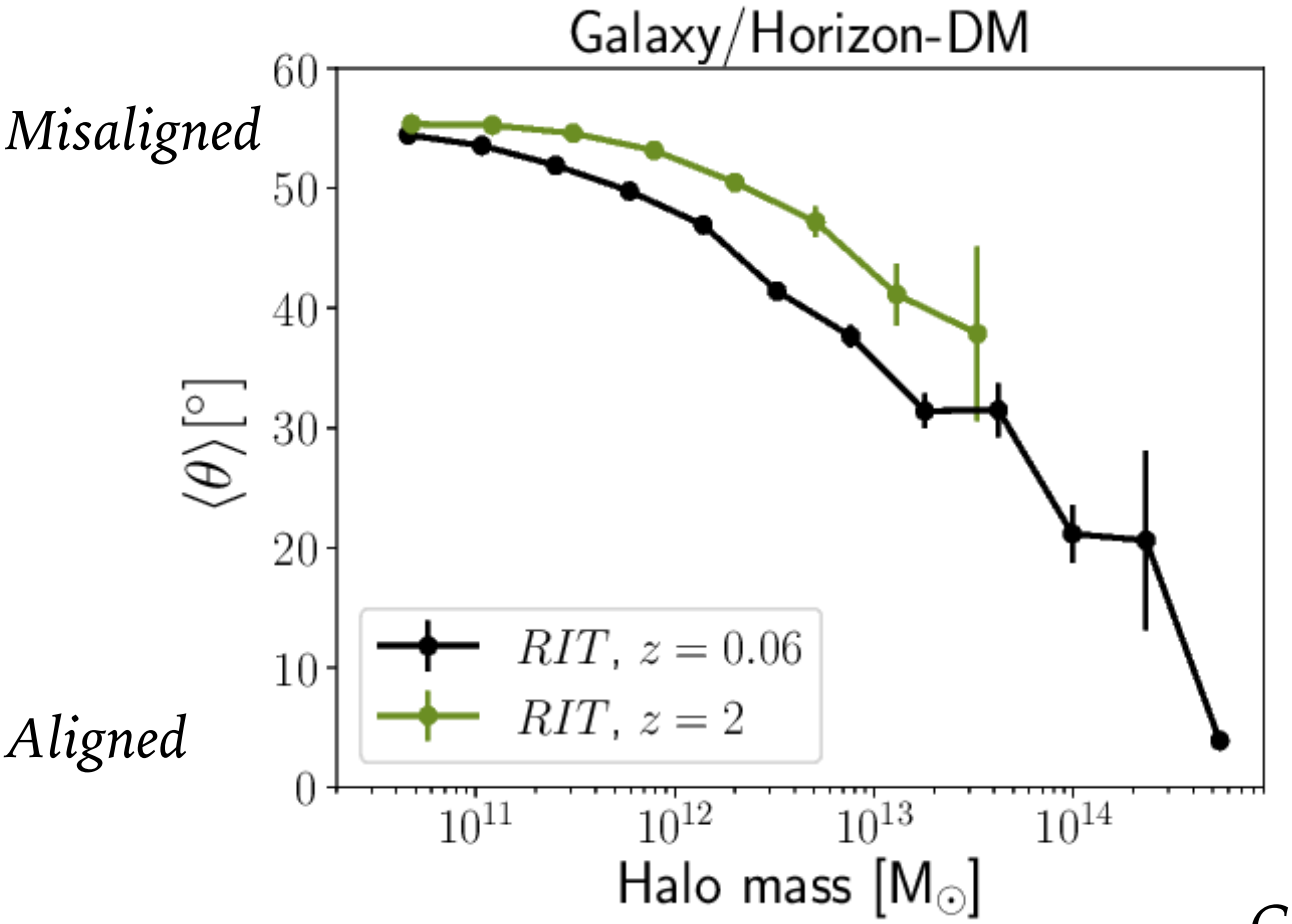


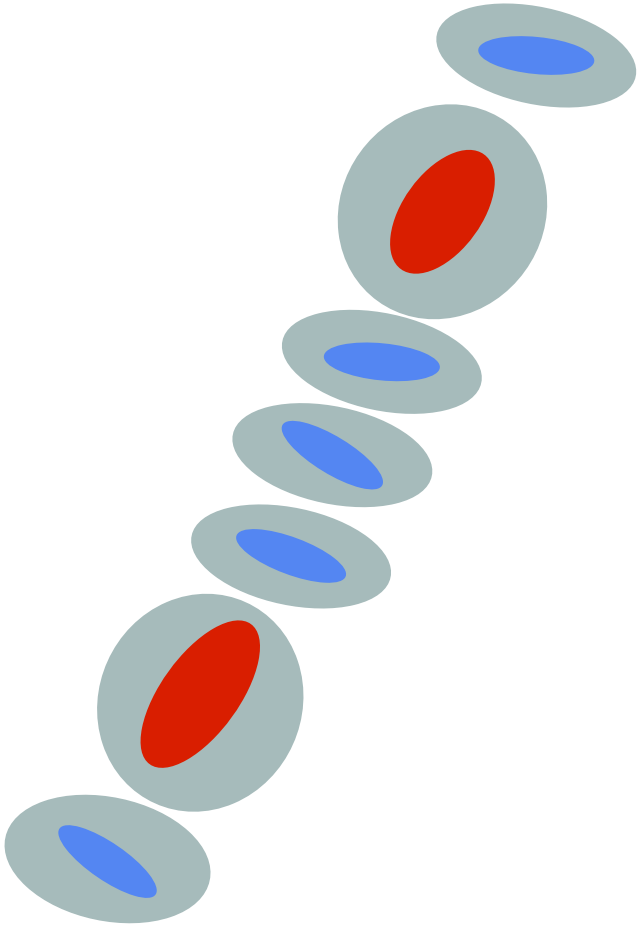
MERGERS AS DRIVERS OF SPIN SWINGS

Dubois+ (2014)
Welker+ (2014)

II. INTRINSIC ALIGNMENTS

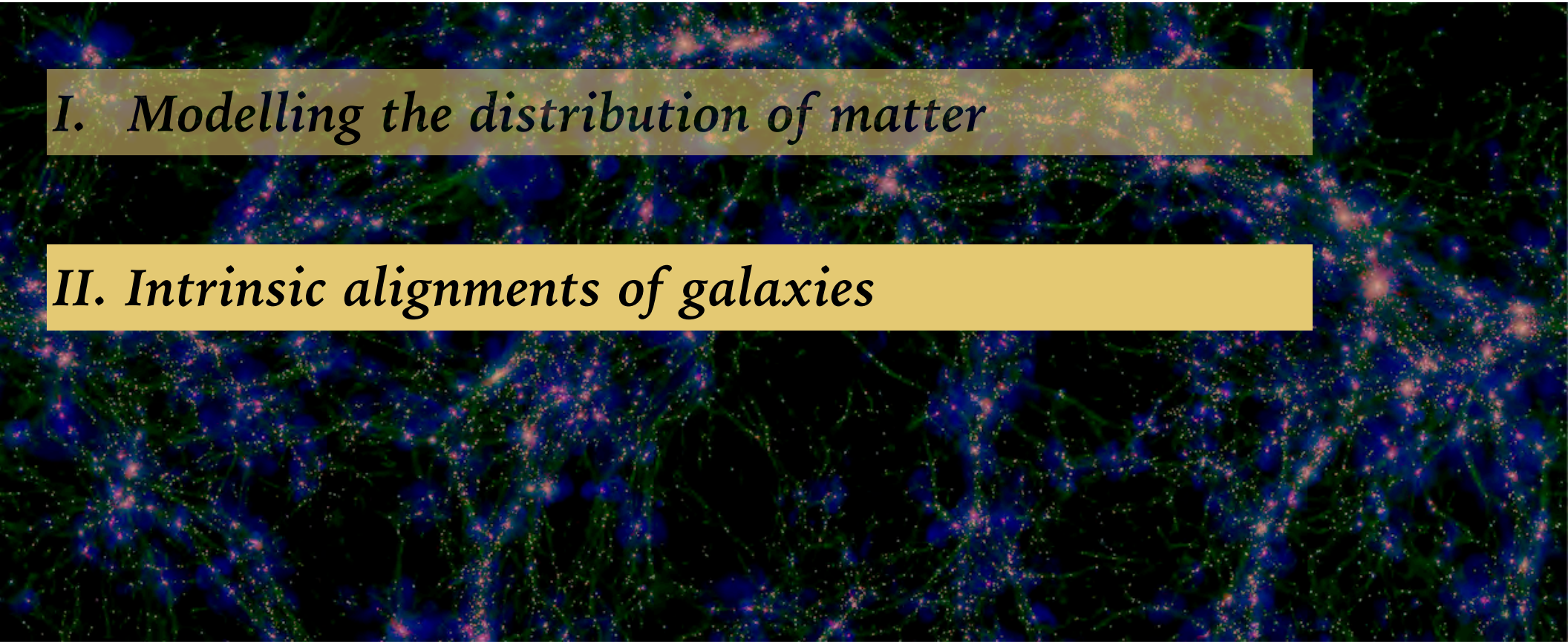
GALAXY-HALO ALIGNMENTS ARE MASS-, TYPE- AND REDSHIFT-DEPENDENT





Chisari, Koukoufilippas+ (2017)

~~CHALLENGES~~ IN WEAK LENSING OPPORTUNITIES



I. Modelling the distribution of matter

II. Intrinsic alignments of galaxies

COSMOLOGY WITH INTRINSIC ALIGNMENTS

Galaxy shapes ~ *Tidal field of the large-scale structure*

TESTING THEORIES OF INFLATION

$$\langle \delta(\mathbf{x}) g_{ij}(\mathbf{y}) \rangle = \underbrace{b_1^I \langle \delta(\mathbf{x}) K_{ij}(\mathbf{y}) \rangle}_{\textit{Gaussian}} + \underbrace{\frac{1}{2} b_2^I \langle \delta(\mathbf{x}) \delta(\mathbf{y}) K_{ij}(\mathbf{y}) \rangle}_{\textit{Primordial non-Gaussianity}}$$

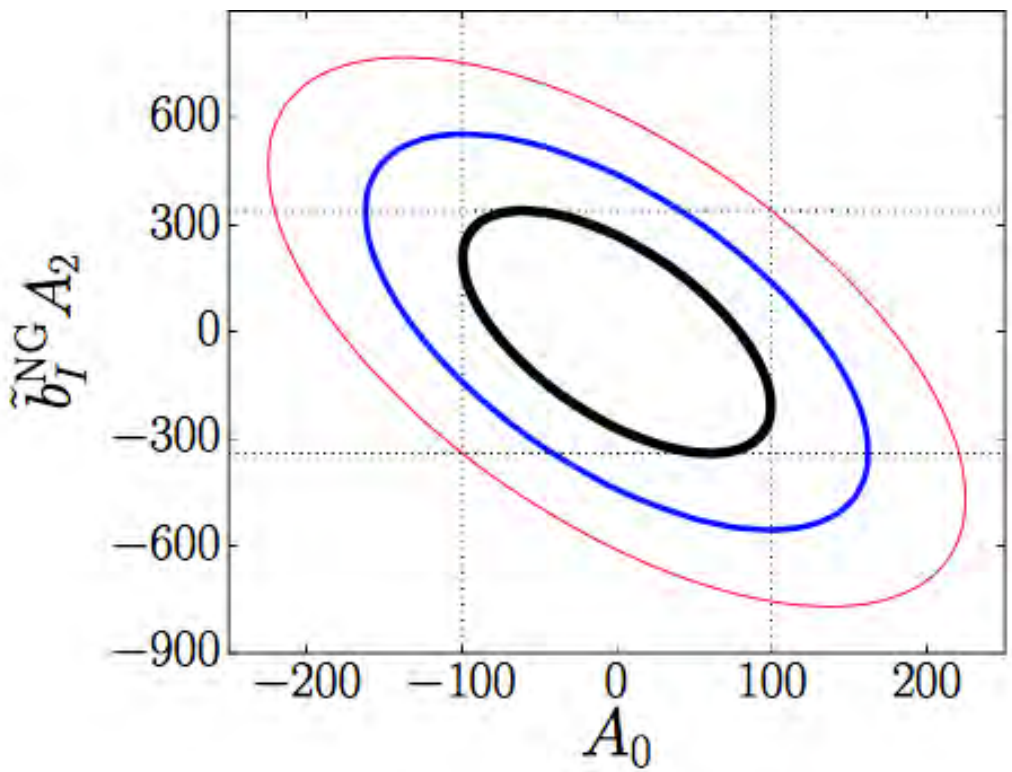
Spin-2 particles during inflation
Magnetic fields
Solid inflation

Chisari+ (2016)
Schmidt, Chisari & Dvorkin (2015)

COSMOLOGY WITH INTRINSIC ALIGNMENTS

$\tilde{b}^I_{\rm NG} A_2$	*Scale-dependent bias of intrinsic shapes*
A_0	*Scale-dependent clustering bias*

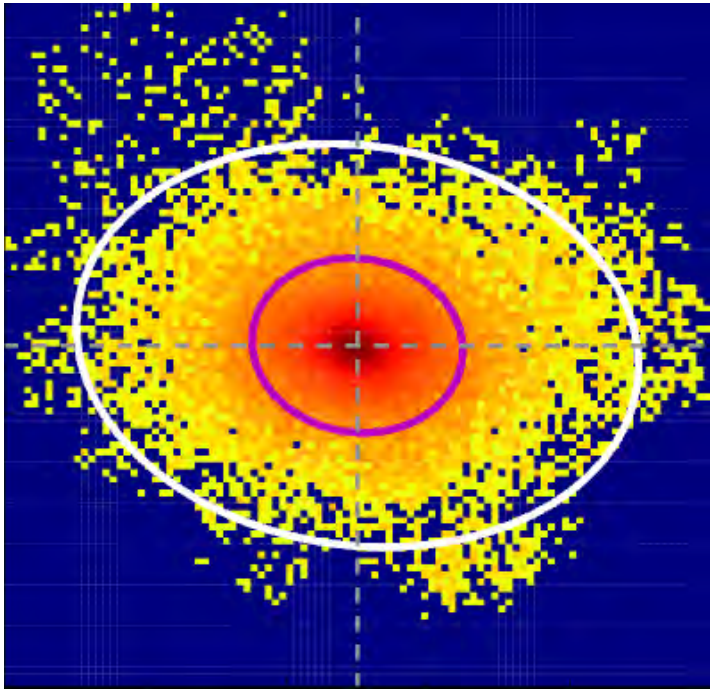
Euclid expected – single-tracer



Schmidt, Chisari & Dvorkin (2015)

COSMOLOGY WITH INTRINSIC ALIGNMENTS

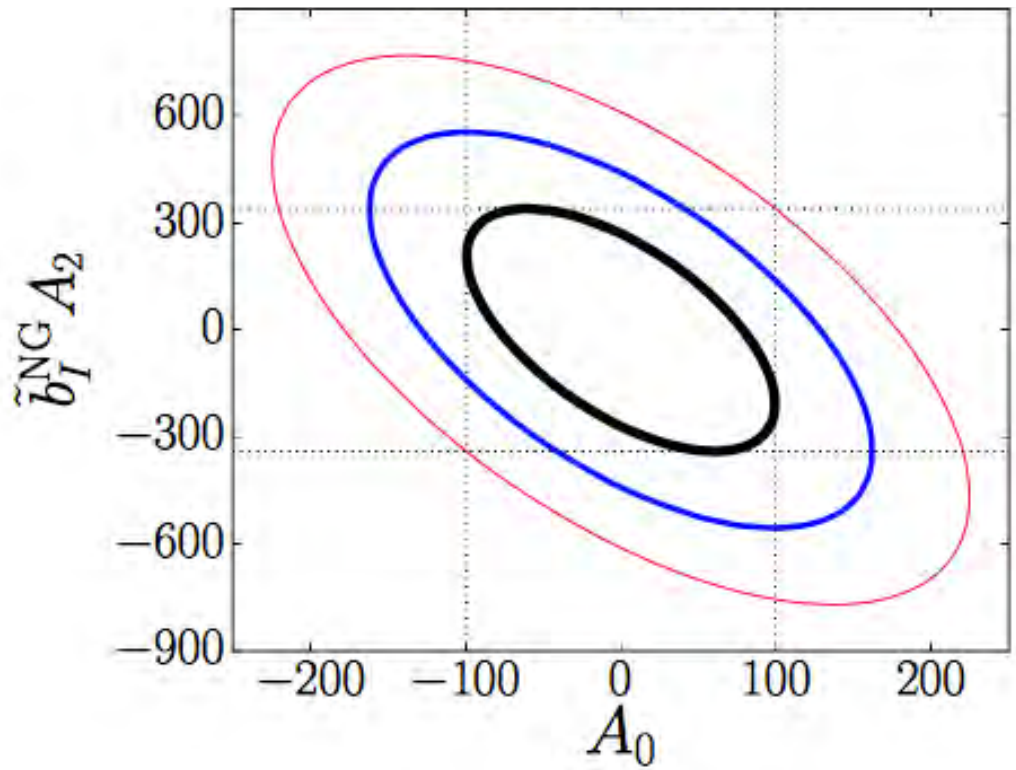
Multi-tracer approach



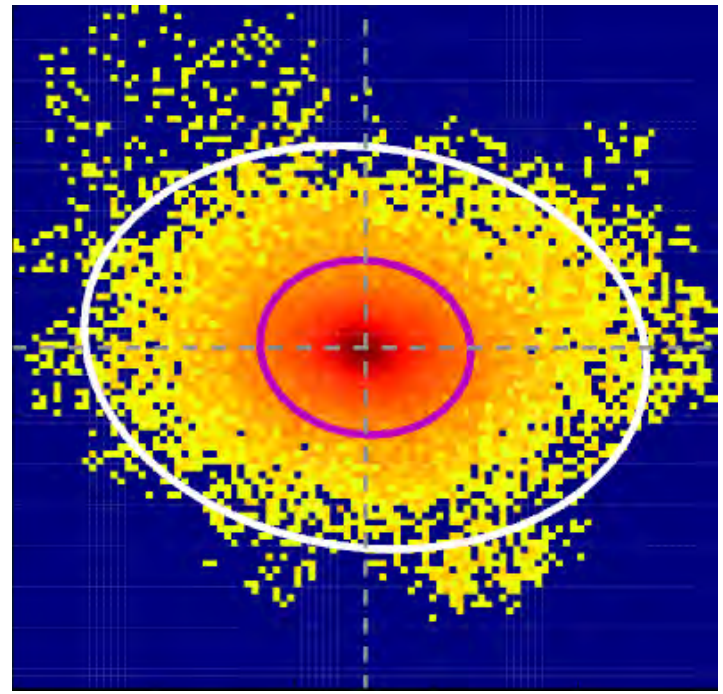
Schmidt, Chisari & Dvorkin (2015)
Chisari+(2016)

COSMOLOGY WITH INTRINSIC ALIGNMENTS

Euclid expected – single-tracer



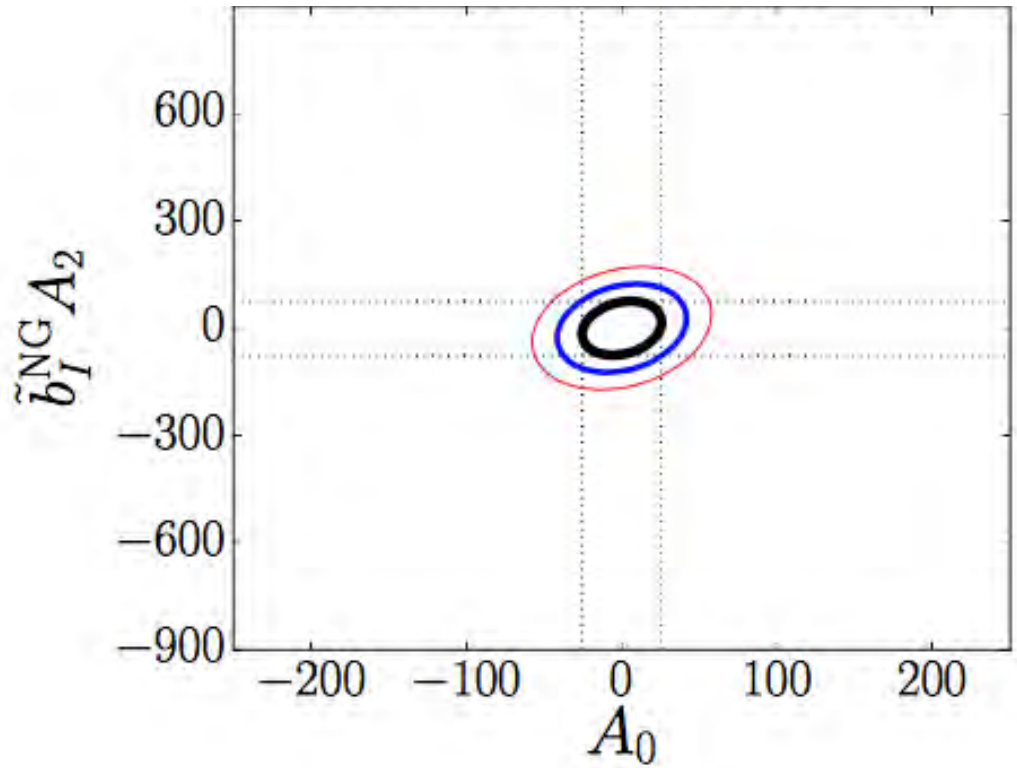
Multi-tracer approach



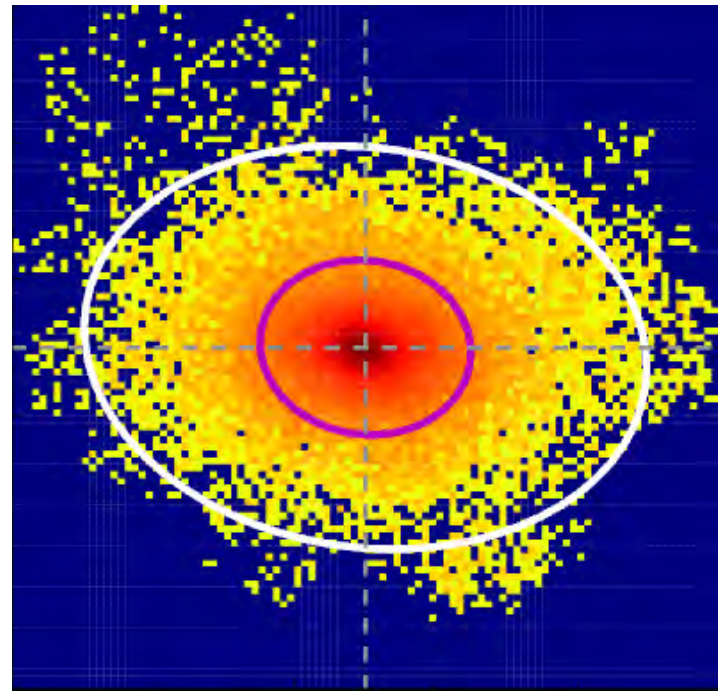
Schmidt, Chisari & Dvorkin (2015)
Chisari+(2016)

COSMOLOGY WITH INTRINSIC ALIGNMENTS

Euclid expected – multi-tracer



Multi-tracer approach



Schmidt, Chisari & Dvorkin (2015)
Chisari+(2016)

SUMMARY

Exciting prospects for *weak lensing and combined probes* come at a PRICE.

The need to understand & model astrophysical systematics:

- *the large-scale distribution of matter &*
- *intrinsic alignments.*

An opportunity to learn about inflation & galaxy formation.