Enigmass meeting | October 20th 2023

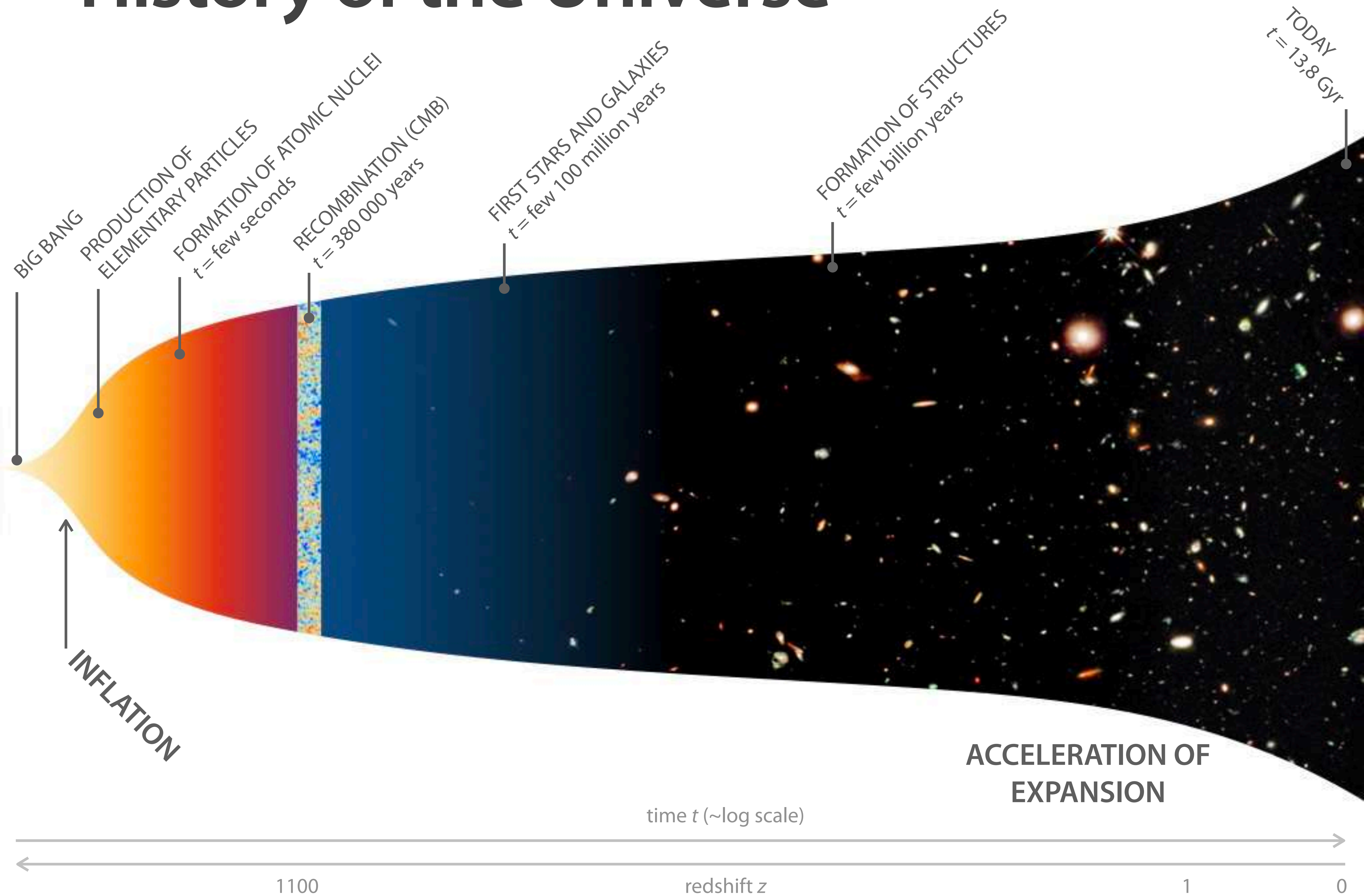
Cosmology from weak gravitational lensing with upcoming galaxy surveys

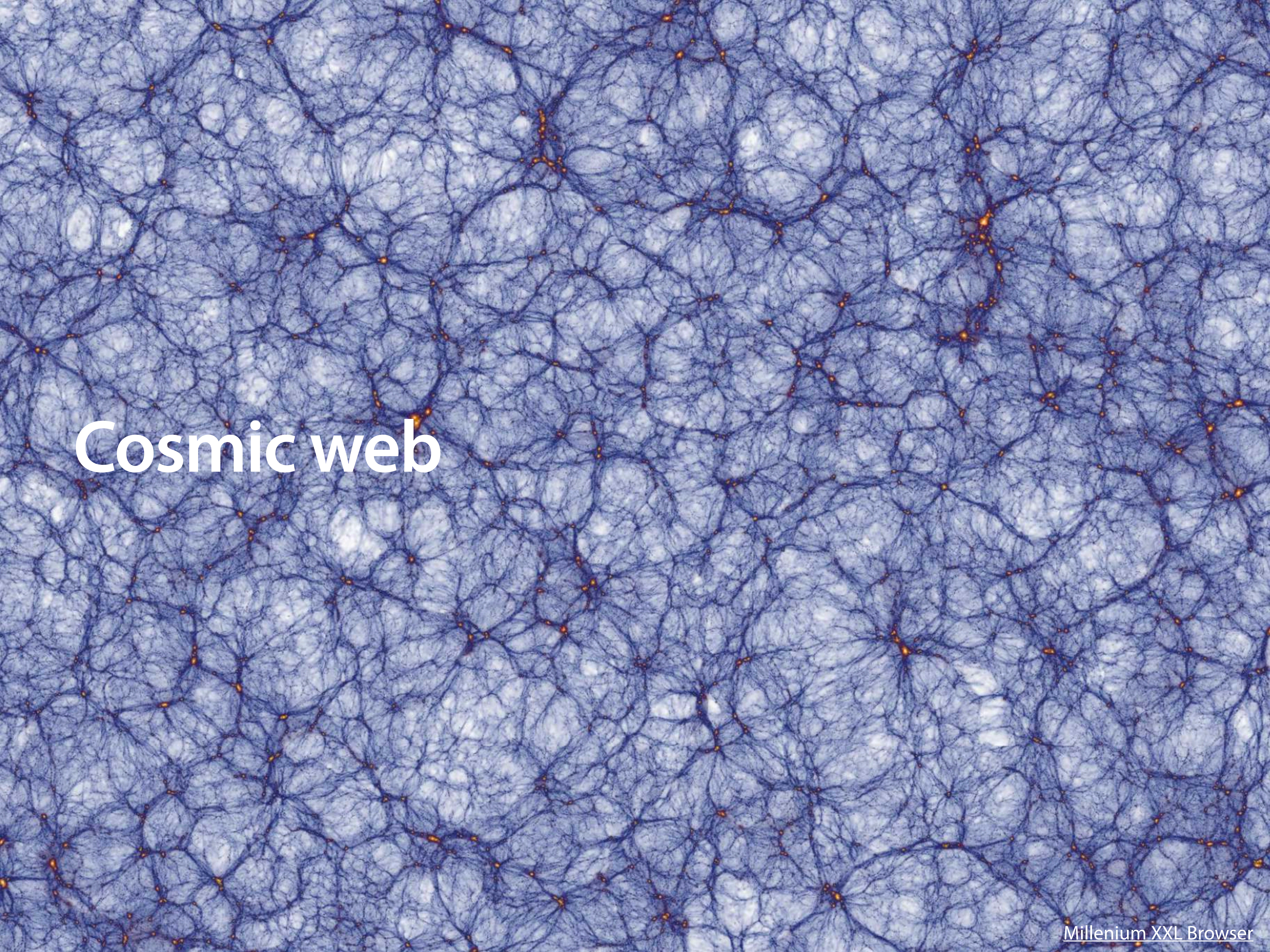
Cyrille Doux

LPSC GRENOBLE / IN2P3 / CNRS

- Cosmic shear 101
- Dark Energy Survey
- Future surveys: LSST and Euclid

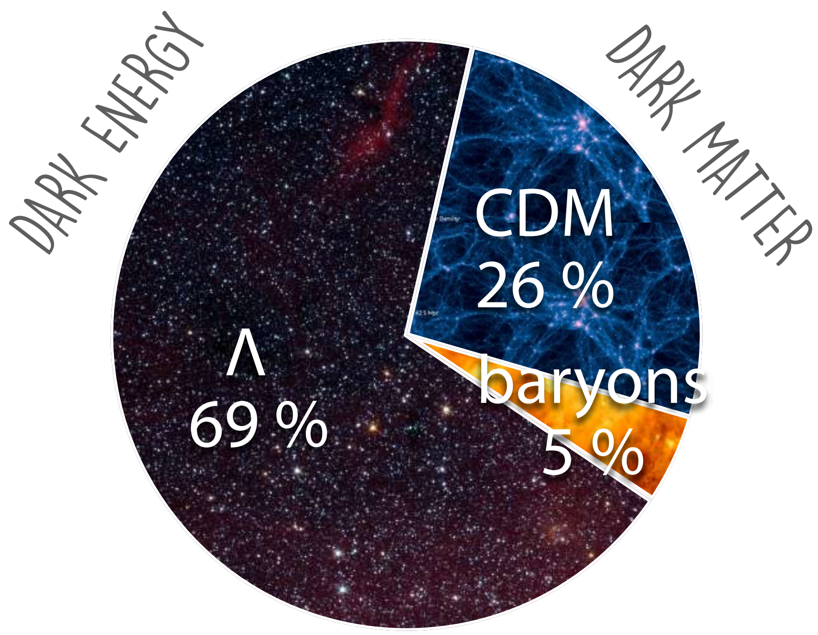
History of the Universe




Cosmic web
Millenium XXL Browser

Standard model ΛCDM

Content of the Universe



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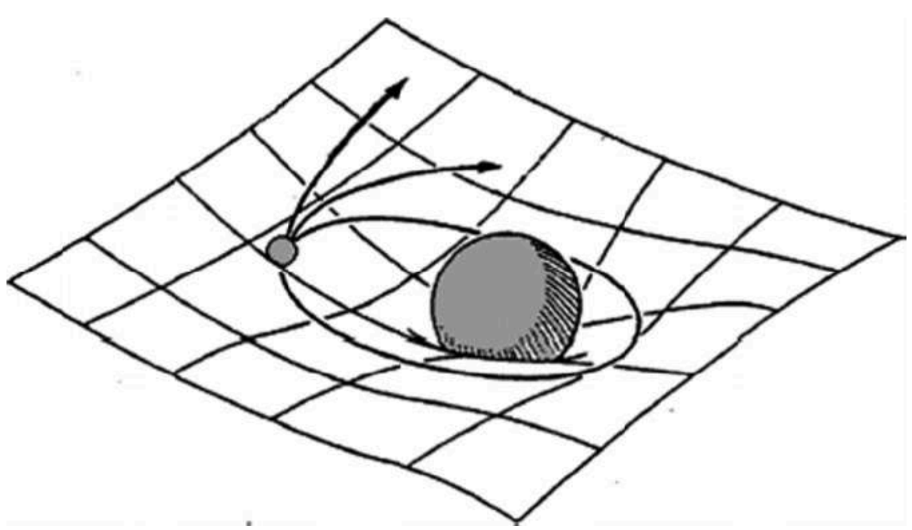
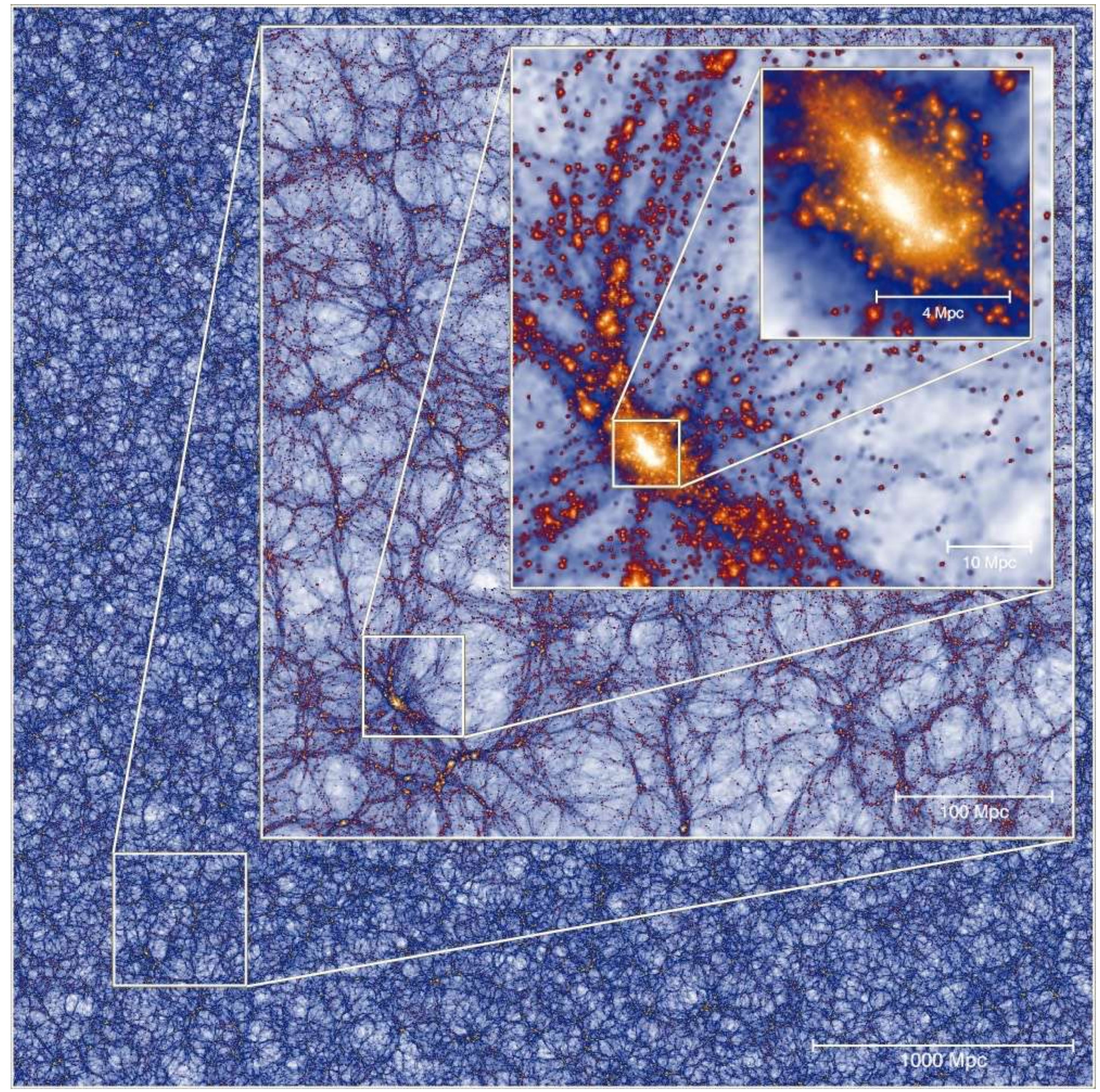
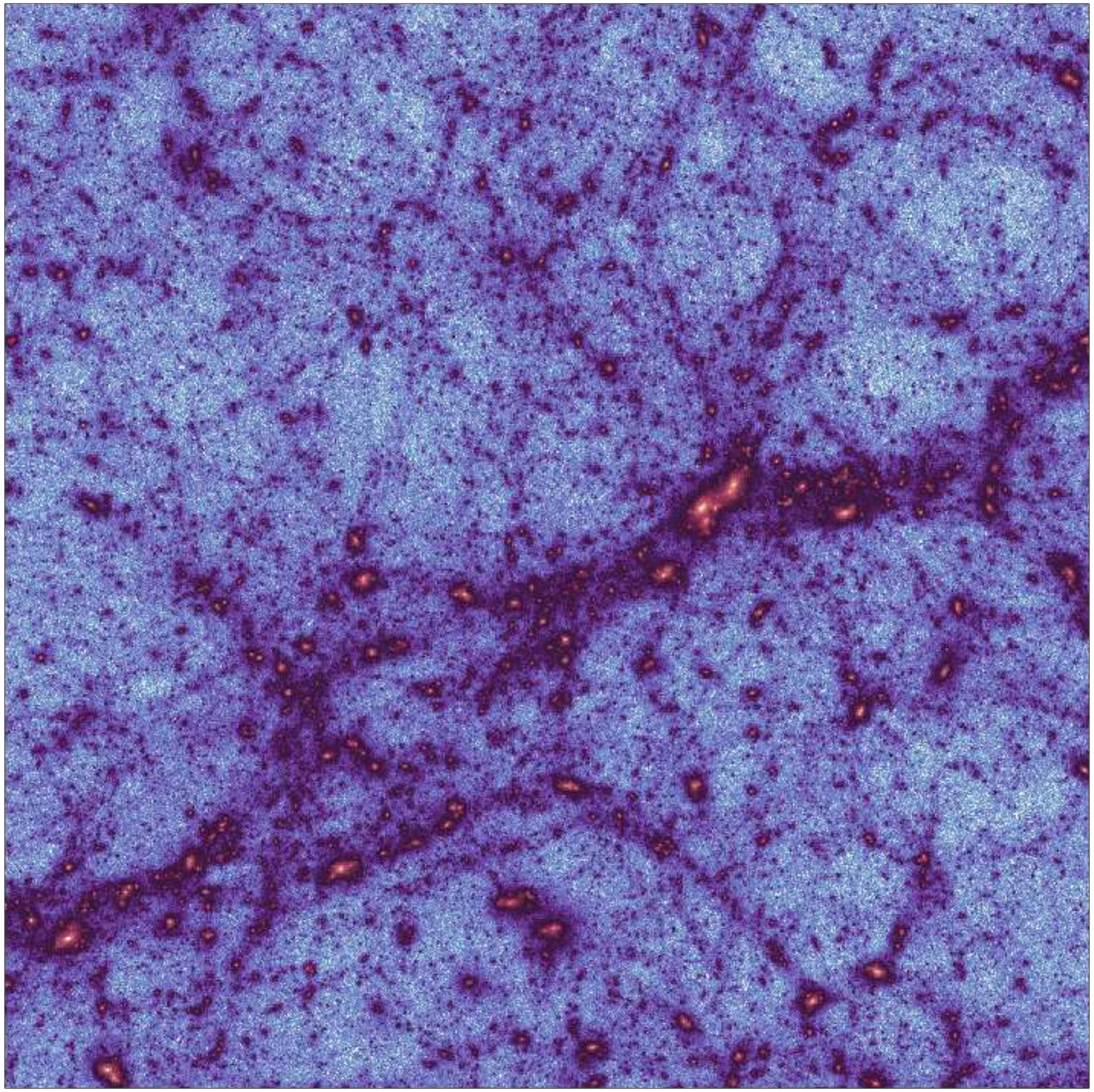
General relativity





Large-scale structure

Matter power spectrum



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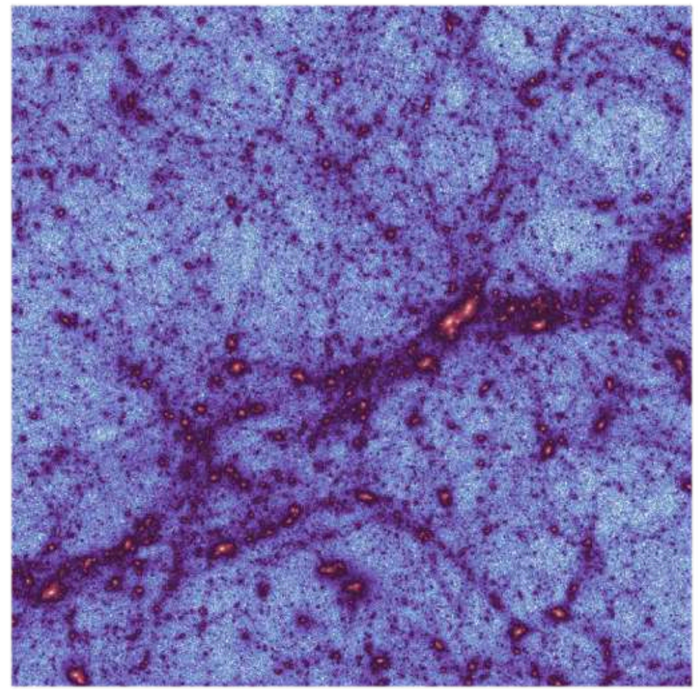
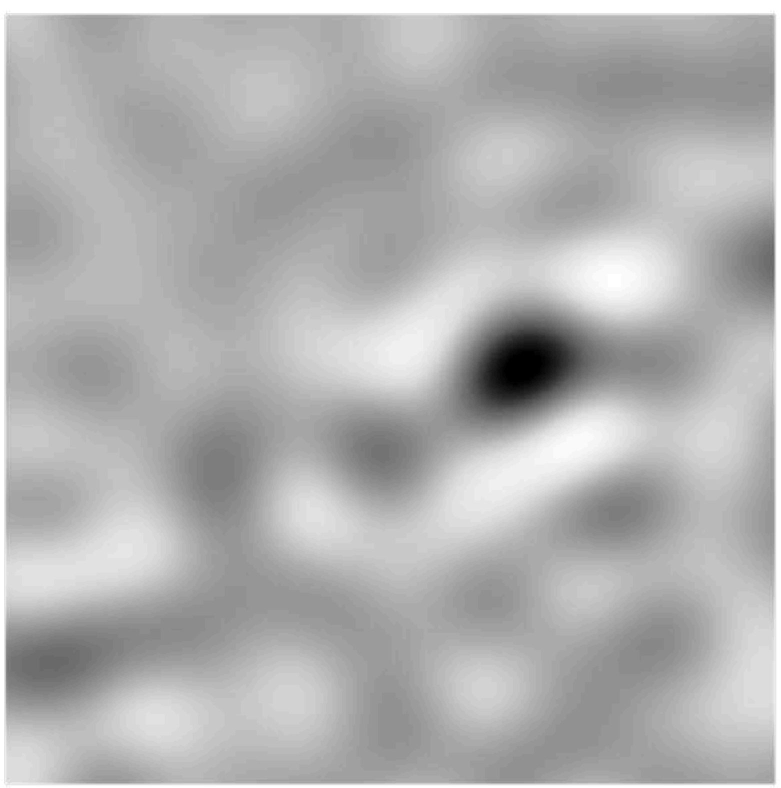
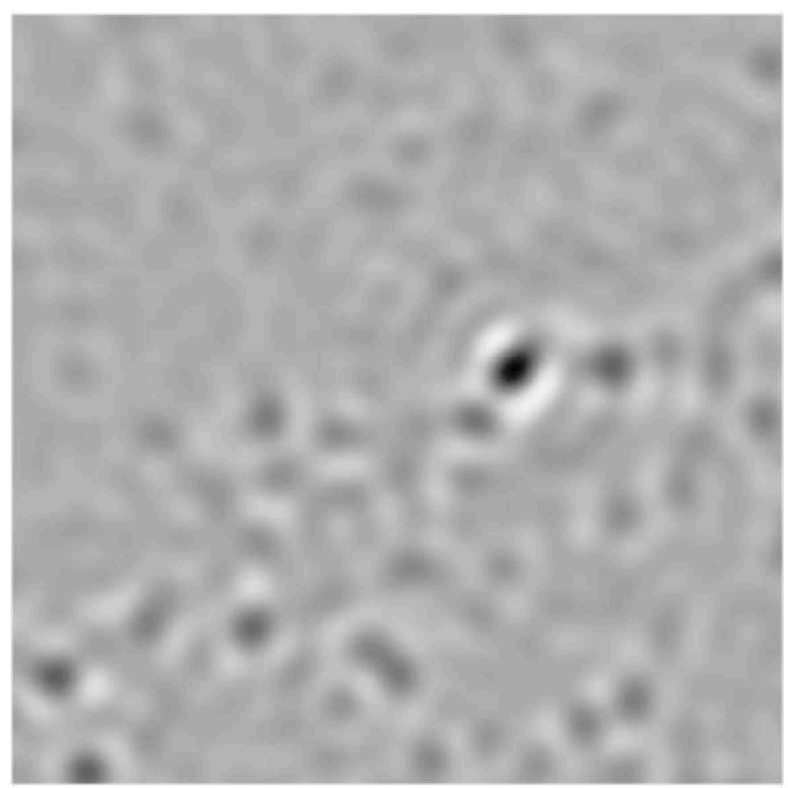
Matter power spectrum



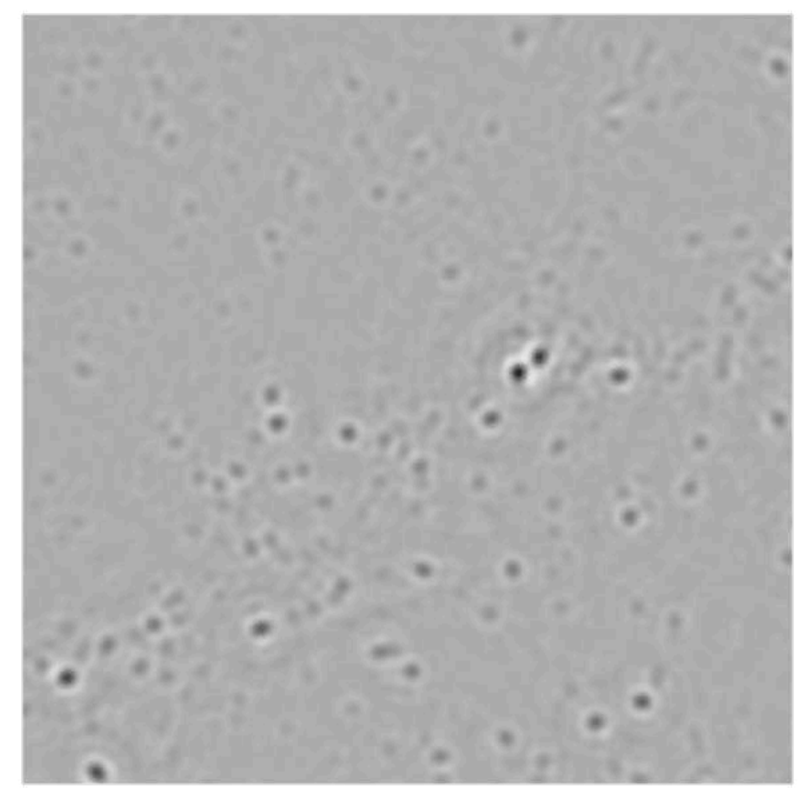
LARGE SCALES



MEDIUM SCALES

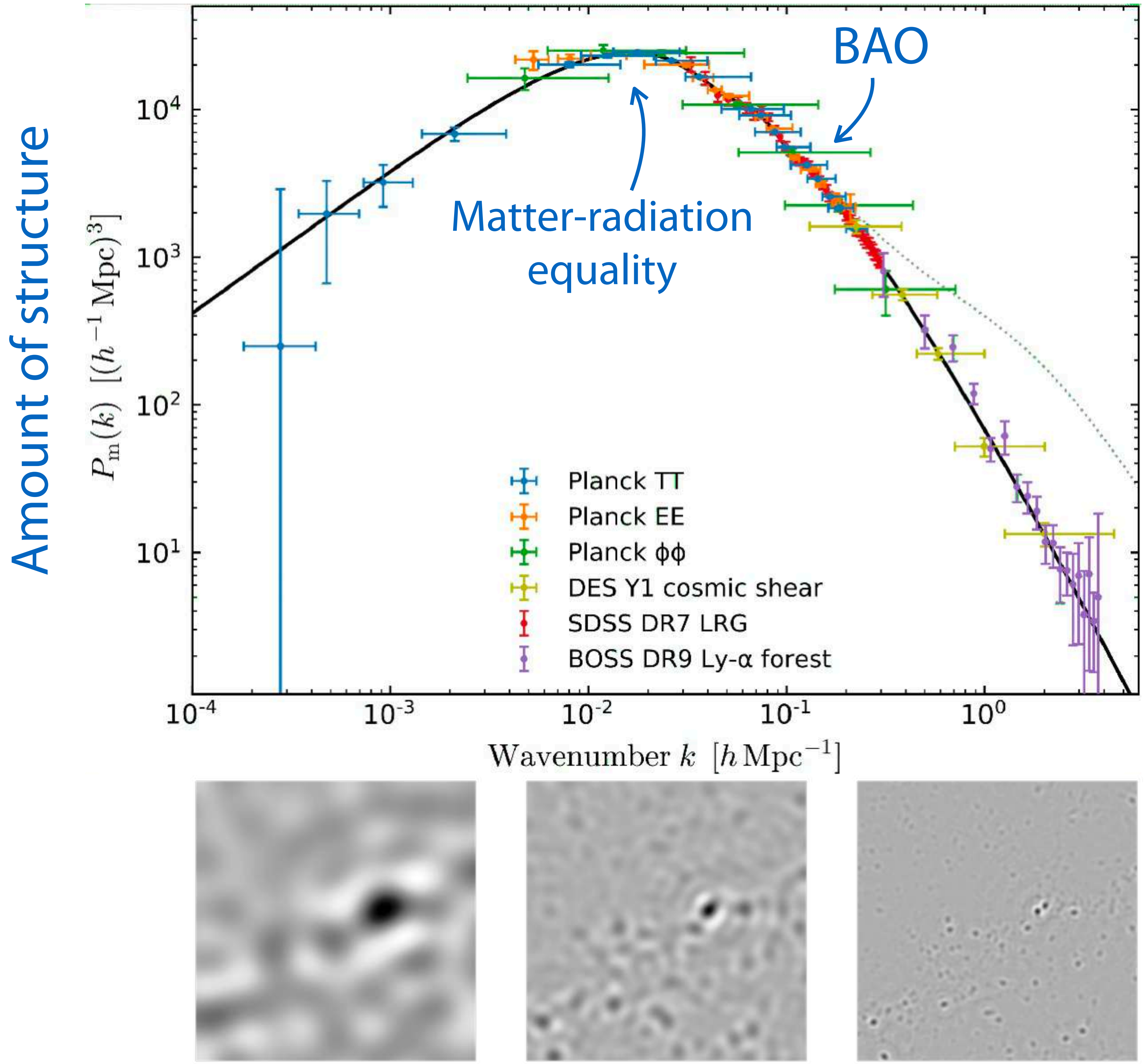


SMALL SCALES



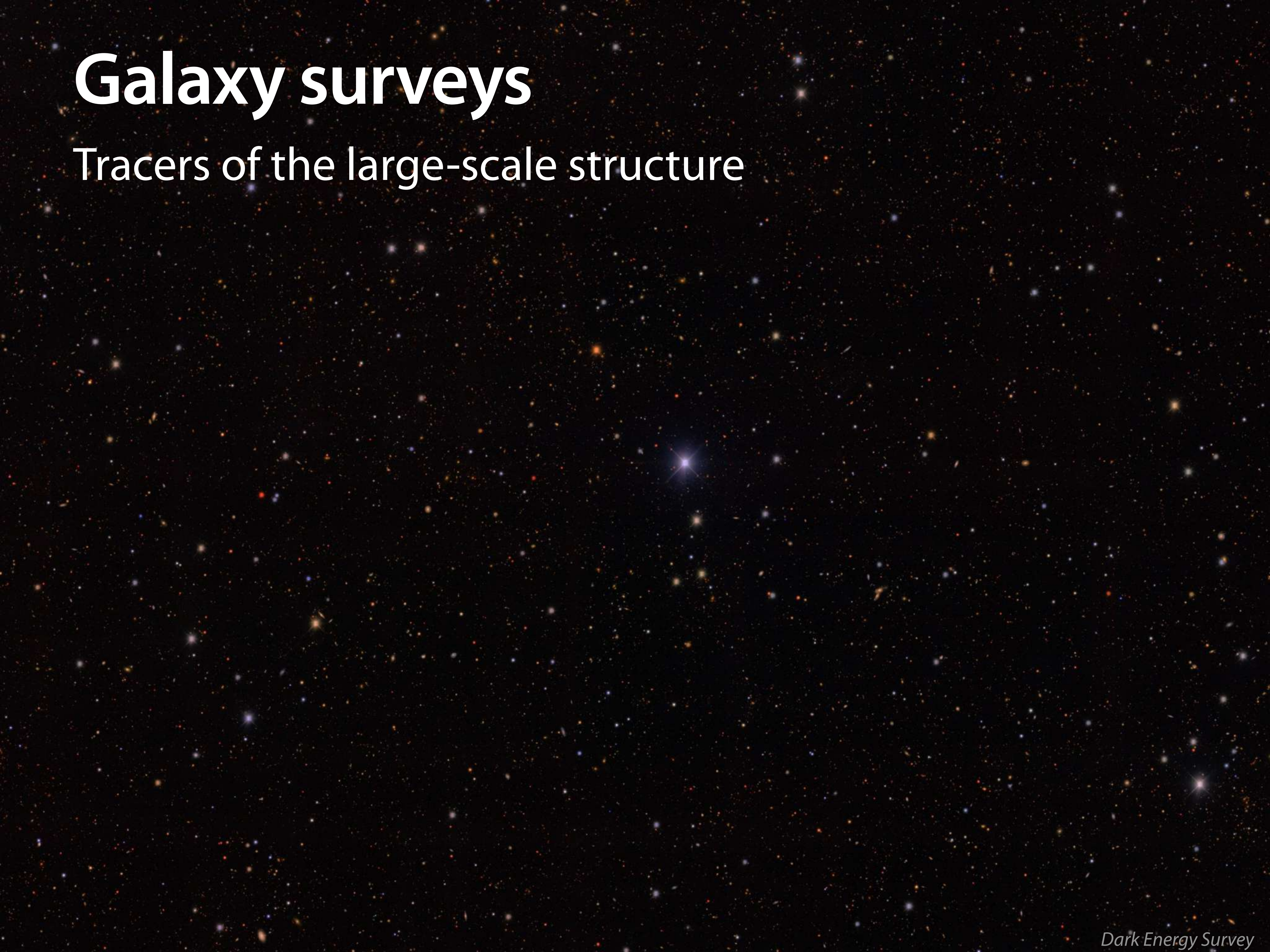
Large-scale structure

Matter power spectrum



Galaxy surveys

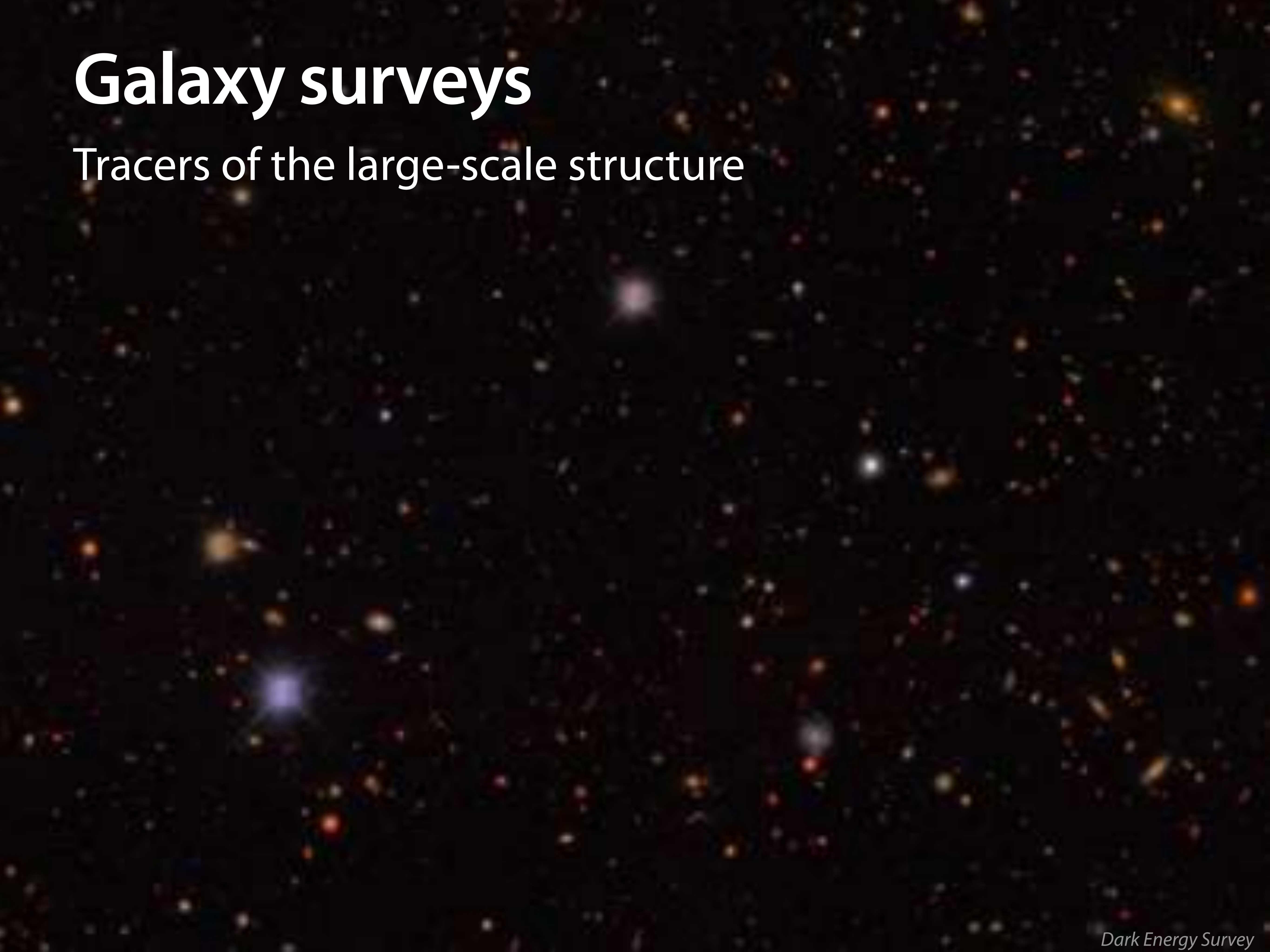
Tracers of the large-scale structure



Dark Energy Survey

Galaxy surveys

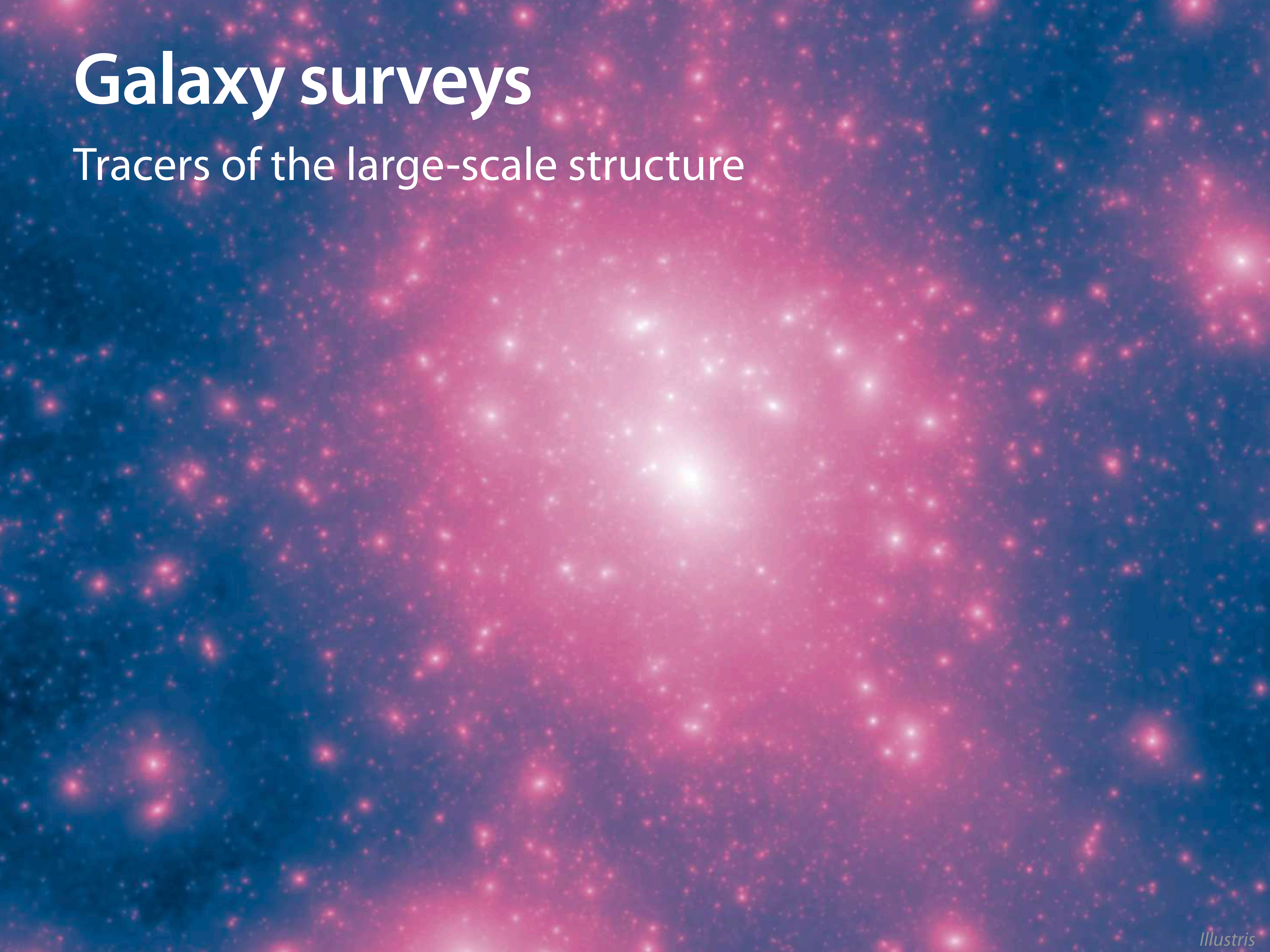
Tracers of the large-scale structure



Dark Energy Survey

Galaxy surveys

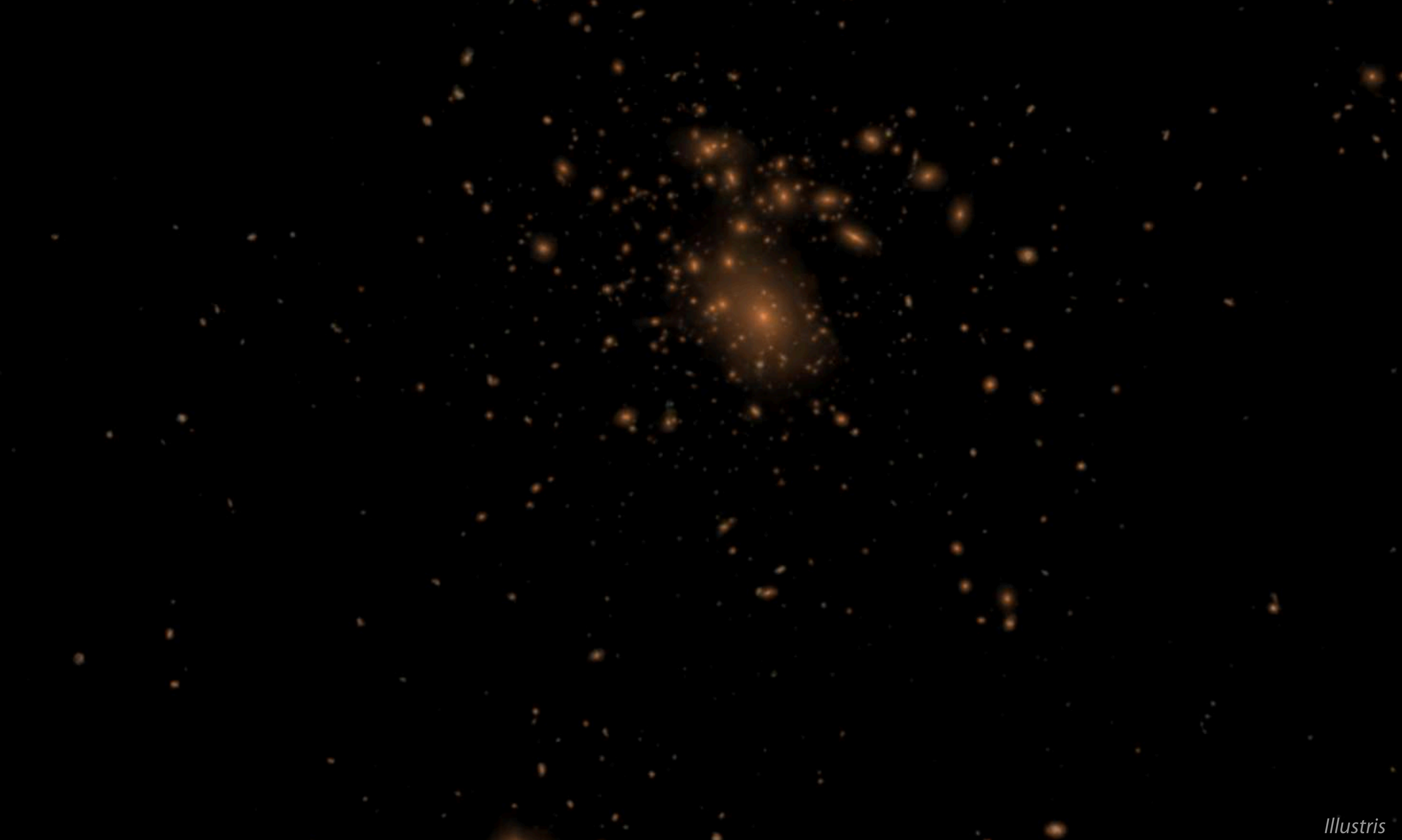
Tracers of the large-scale structure



Illustris

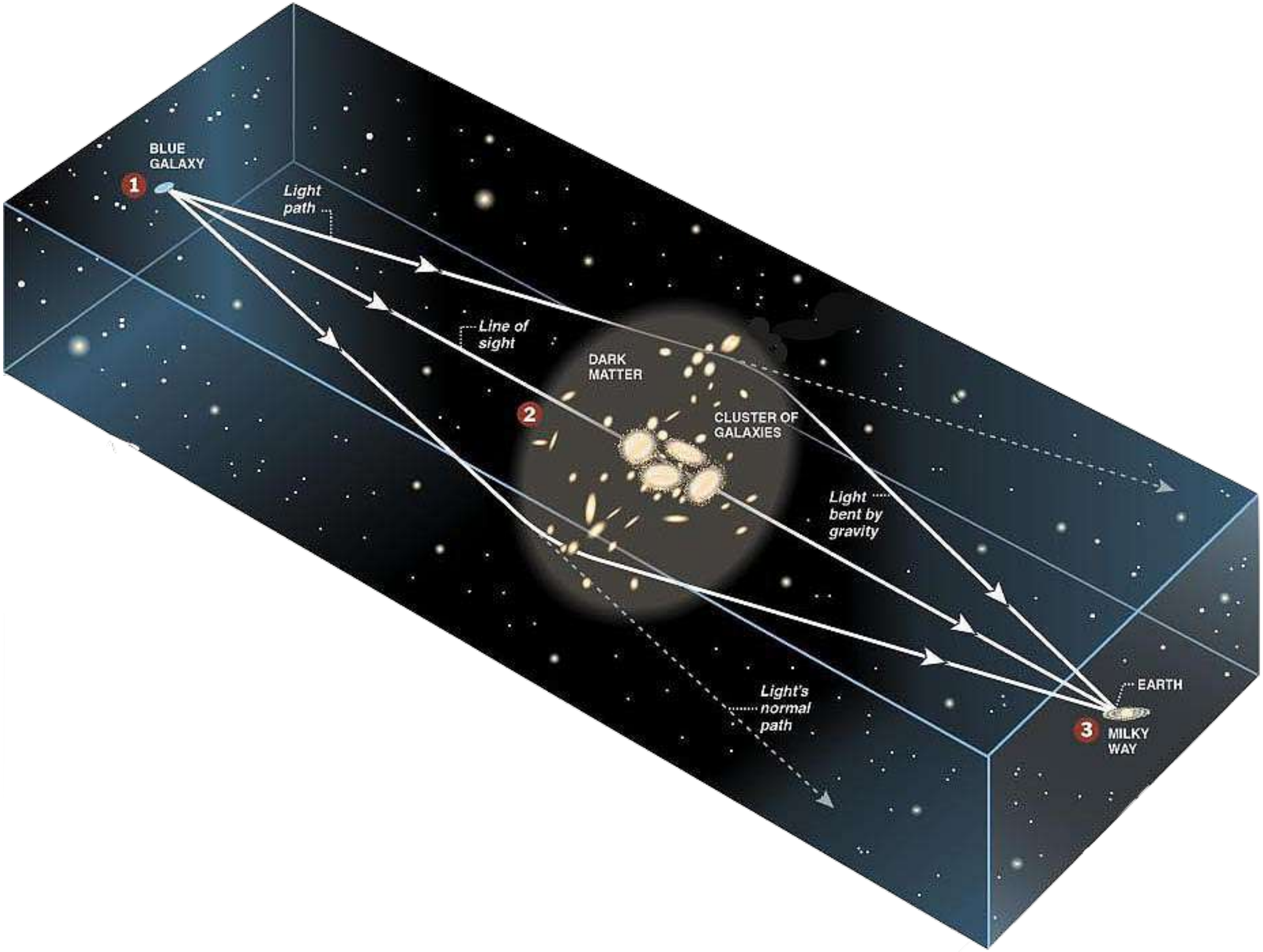
Galaxy surveys

Tracers of the large-scale structure



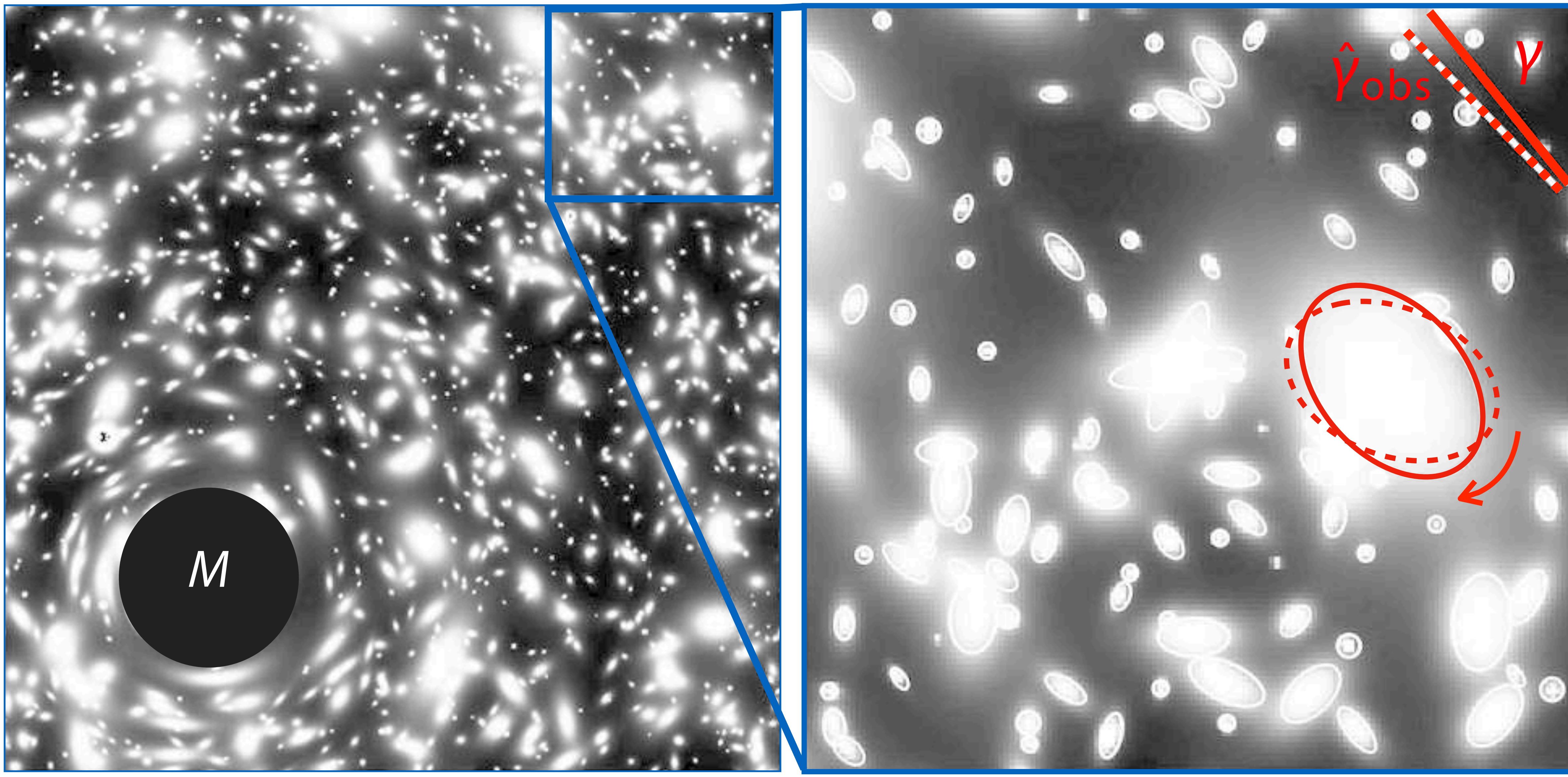
Illustris

Weak gravitational lensing



Weak gravitational lensing

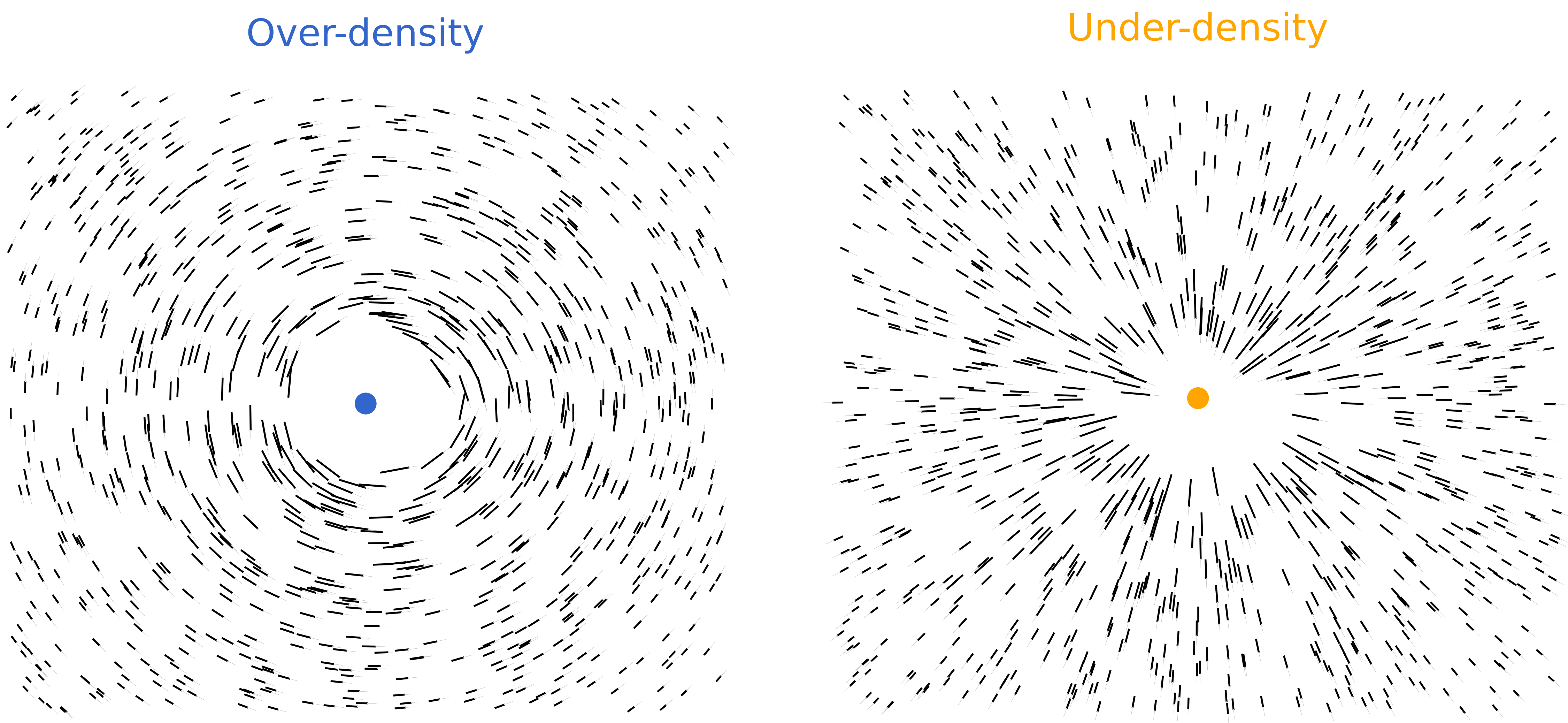
Cosmic shear



In practice, $|\gamma| \sim 0.01$ (in the field) to 0.1 (in clusters)

Weak gravitational lensing

Cosmic shear

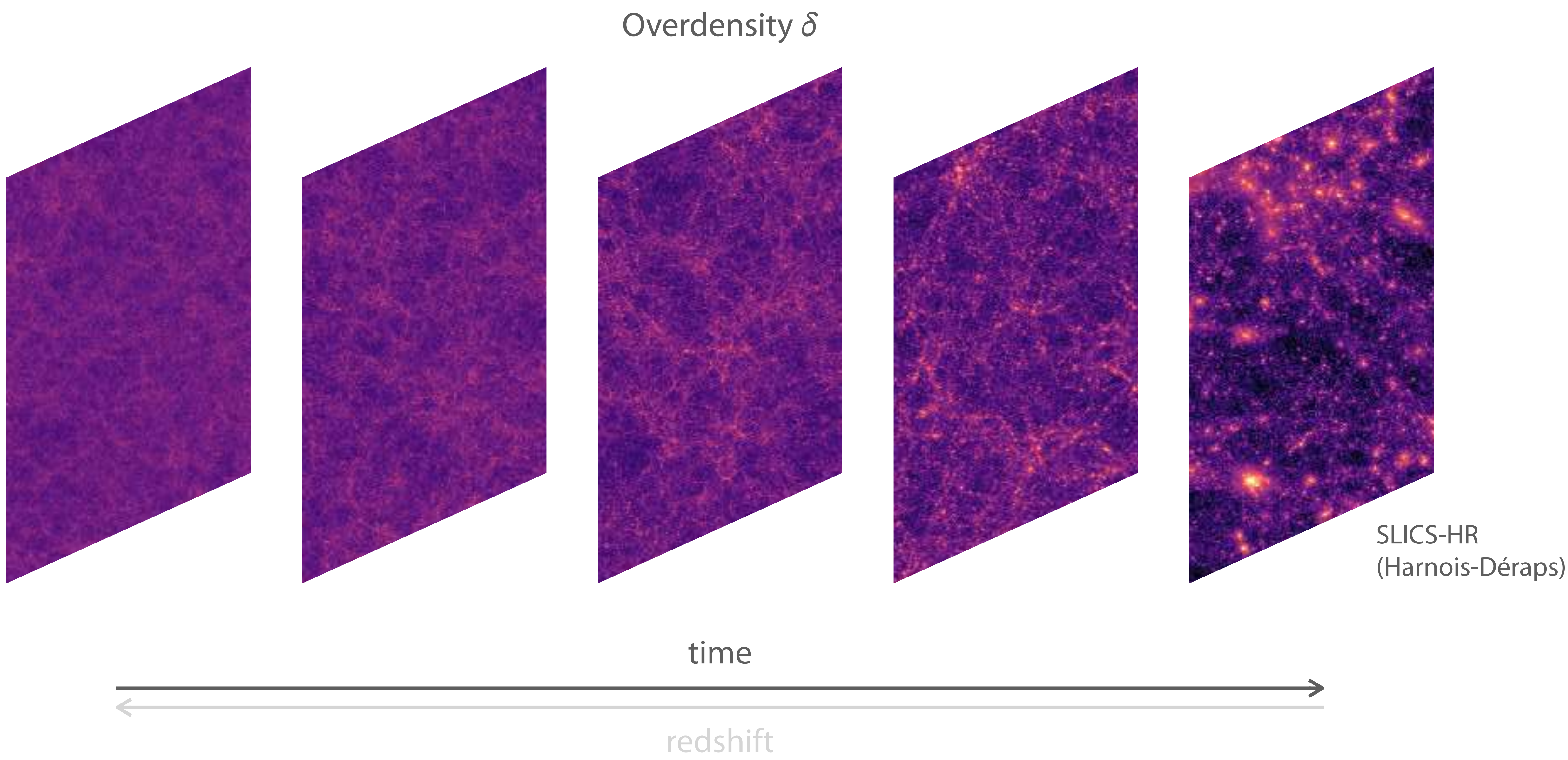


* Lengths do not scale

https://github.com/LSSTDESC/CLMM

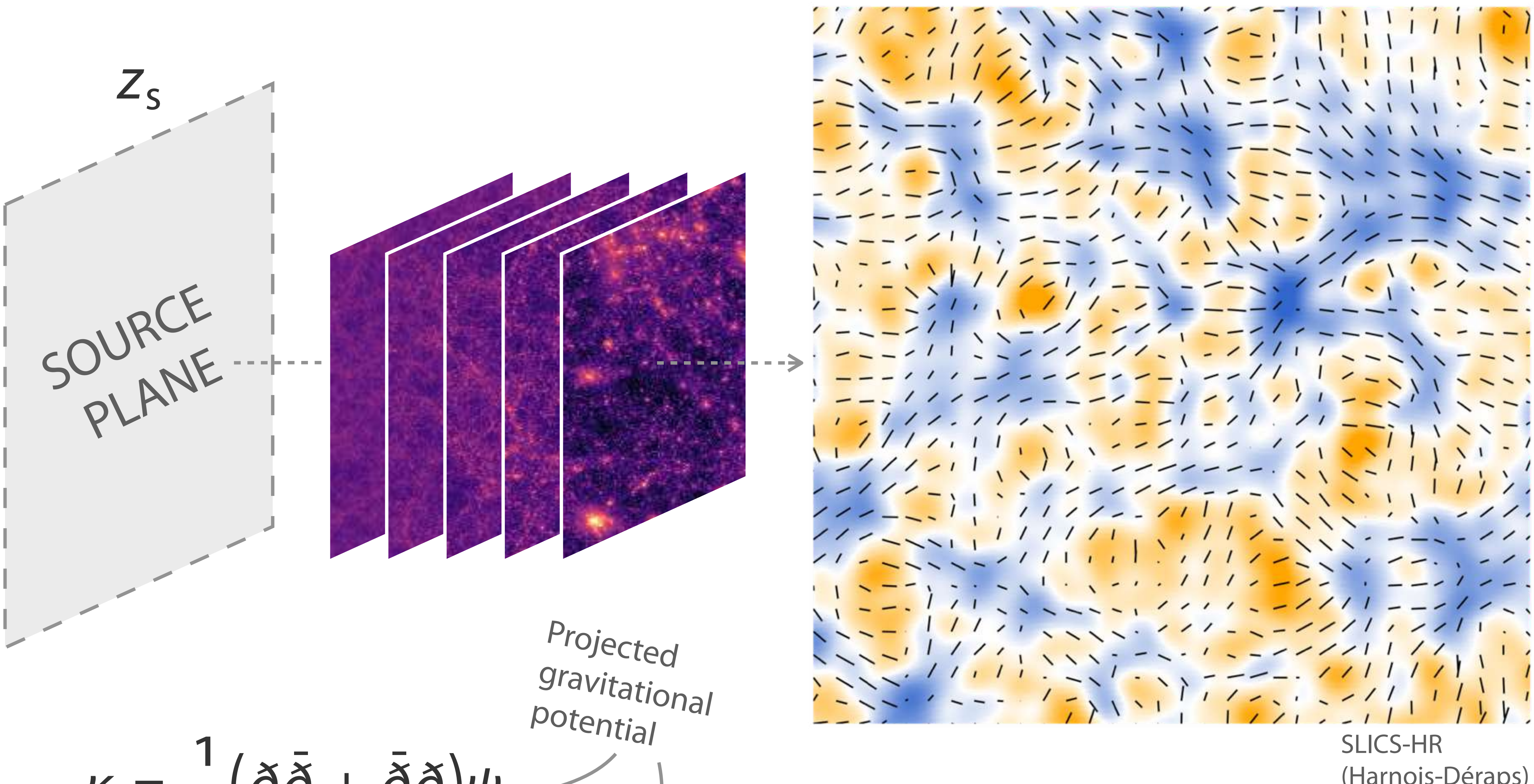
Weak gravitational lensing

A large-scale structure probe



Weak gravitational lensing

A large-scale structure probe



$$\kappa = \frac{1}{4}\left(\eth\bar{\eth} + \bar{\eth}\eth\right)\psi$$

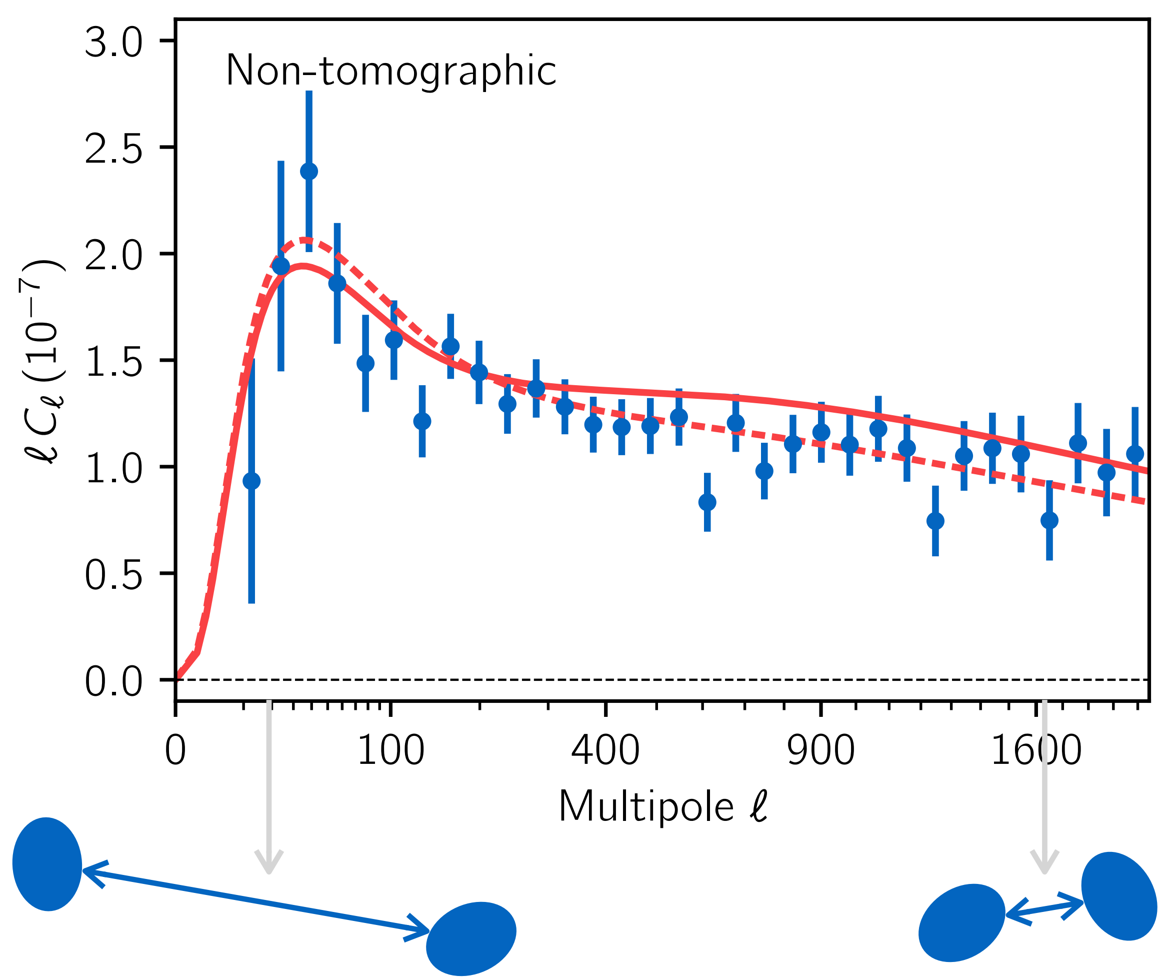
$$\gamma = \gamma_1 + i\gamma_2 = \frac{1}{2}\eth\eth\psi$$

$$\kappa(\theta) = \int \mathrm{d}z\, W^{\kappa}(z, z_s)\delta(\theta, z)$$

Cosmic shear power spectrum

$$C_\ell^{\gamma_a\gamma_b} = \int_0^{z_\star} dz \, \frac{H(z)}{c\,\chi(z)} \, W^a(z) W^b(z) \, P_\mathrm{m}\left(k = \frac{\ell + 1/2}{\chi(z)}, z\right)$$

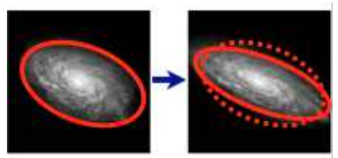
GEOMETRY GROWTH



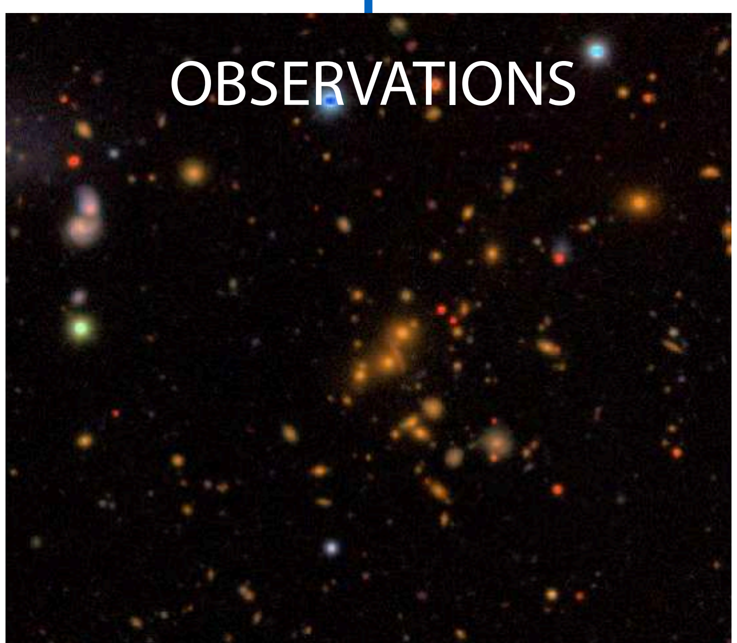
$$\ell \sim \frac{\pi}{\theta}$$

The cosmic shear power spectrum is a *projection* of the matter power spectrum !

Cosmic shear recipe

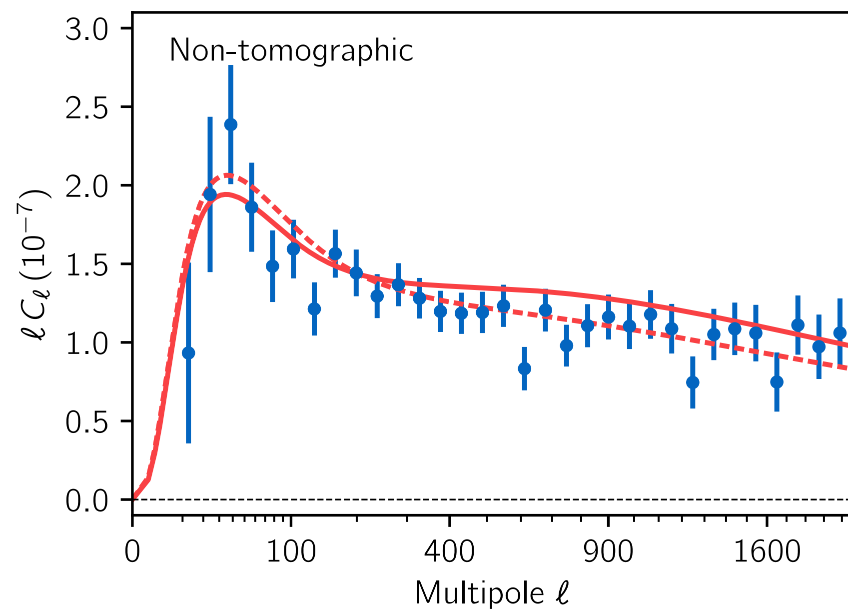


ELLIPTICITIES
POSITIONS

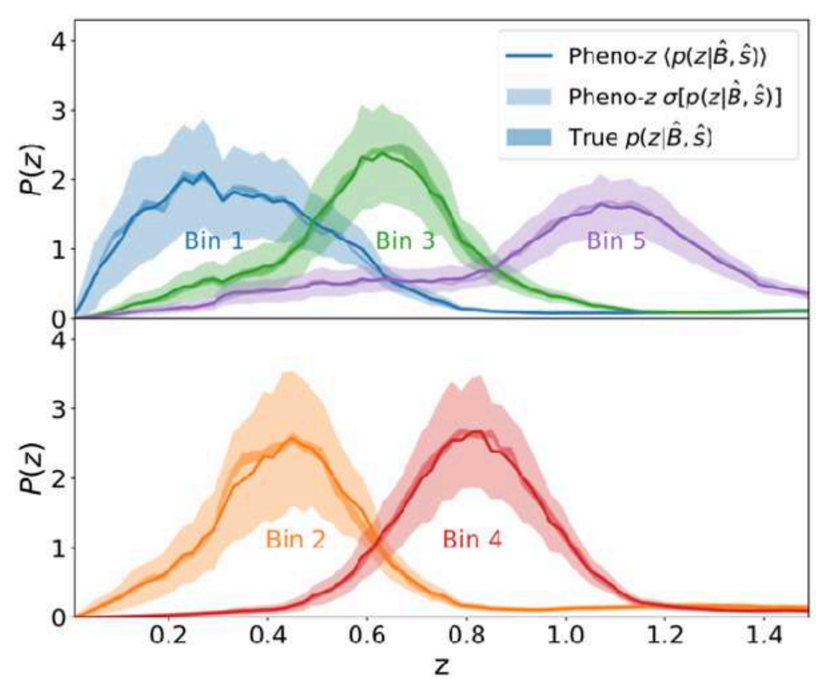


FLUXES
griz

- STATISTICS



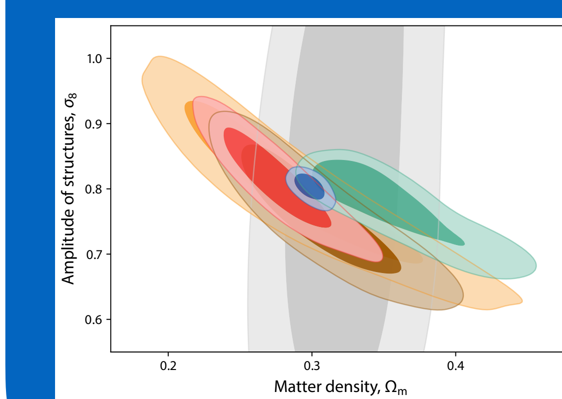
- REDSHIFT DISTRIBUTIONS



- COSMOLOGICAL SIGNAL
  - Matter power spectrum $P_{\rm NL}$
  - Lensing window functions q^i

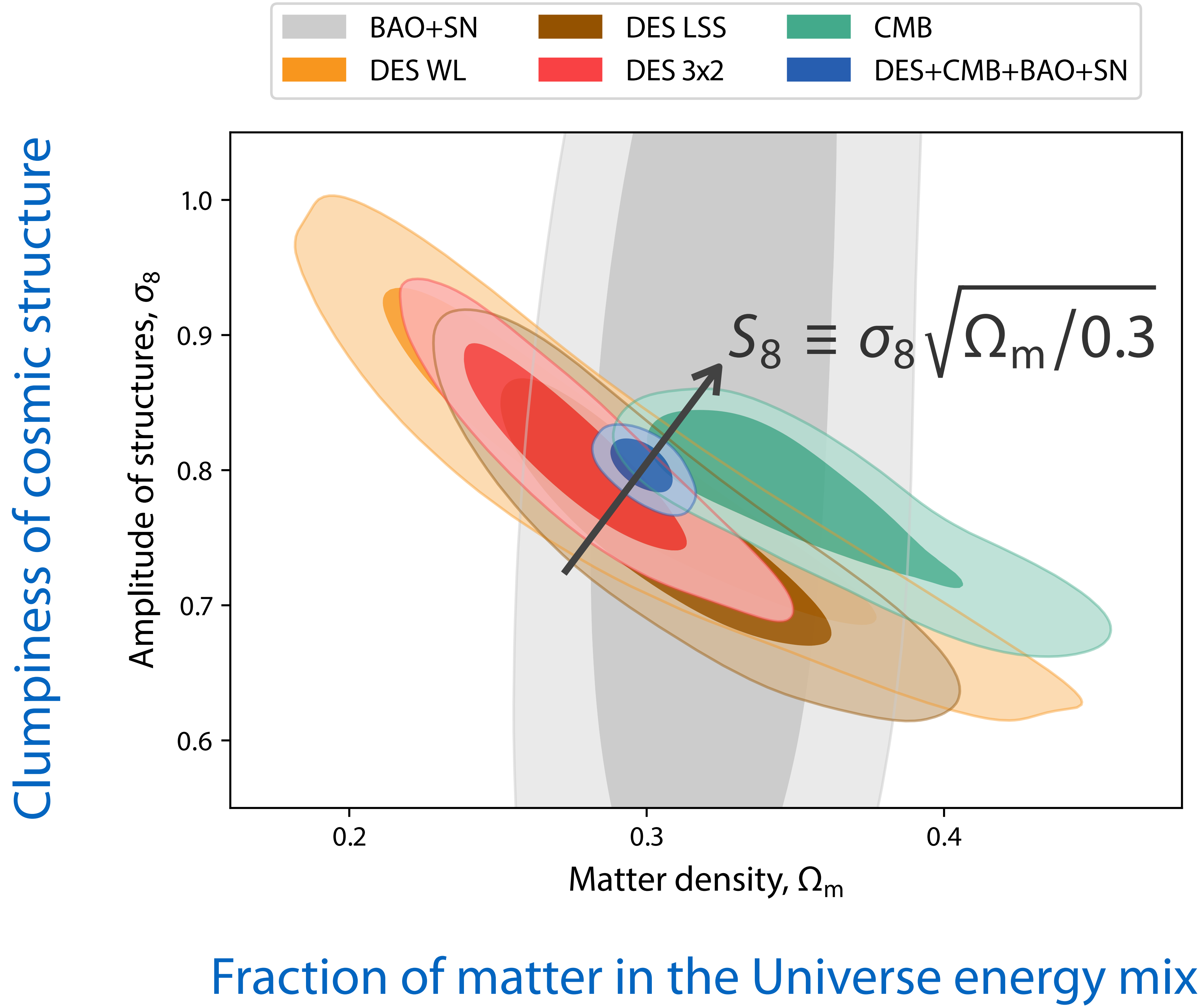
$$C_\ell^{ij} = \int_0^{\chi_{\rm H}} {\rm d}\chi \, \frac{q^i(\chi)q^j(\chi)}{\chi^2} P_{\rm NL}\left(k = \frac{\ell + 1/2}{\chi}, \chi\right)$$

COSMOLOGICAL PARAMETERS



- SYSTEMATIC UNCERTAINTIES
  - Shear calibration m_i
  - Redshift uncertainties Δz_i
  - Intrinsic alignements model

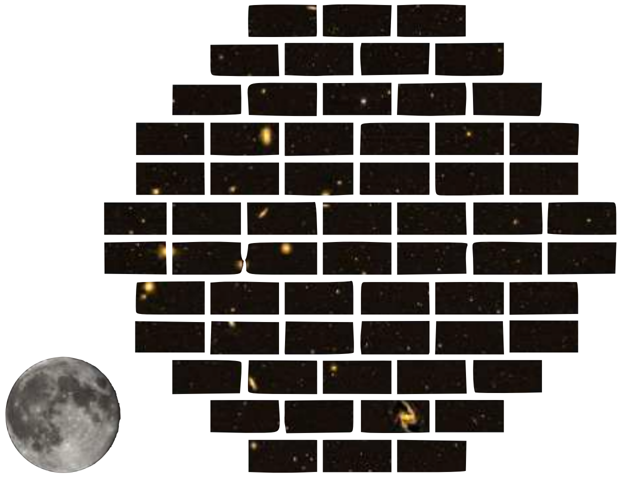
Constraints on cosmic growth

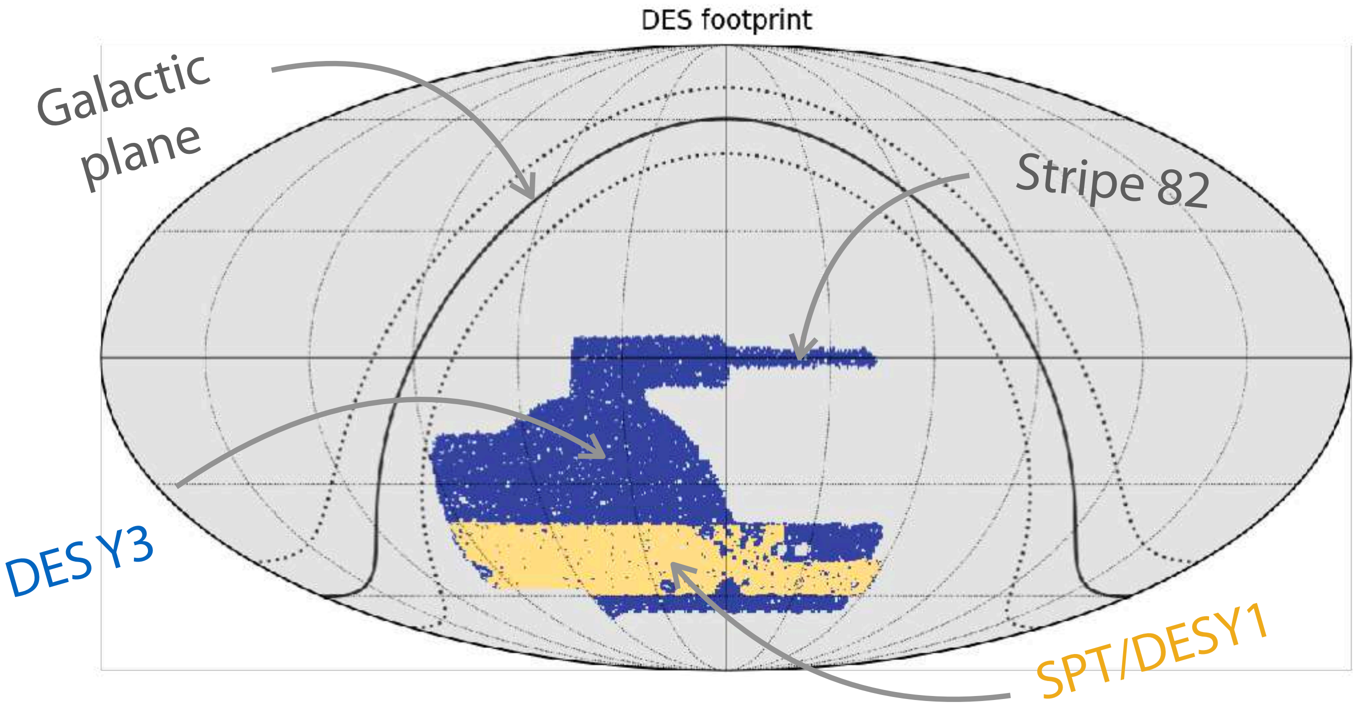


- Cosmic shear 101
- Dark Energy Survey
- Future surveys: LSST and Euclid

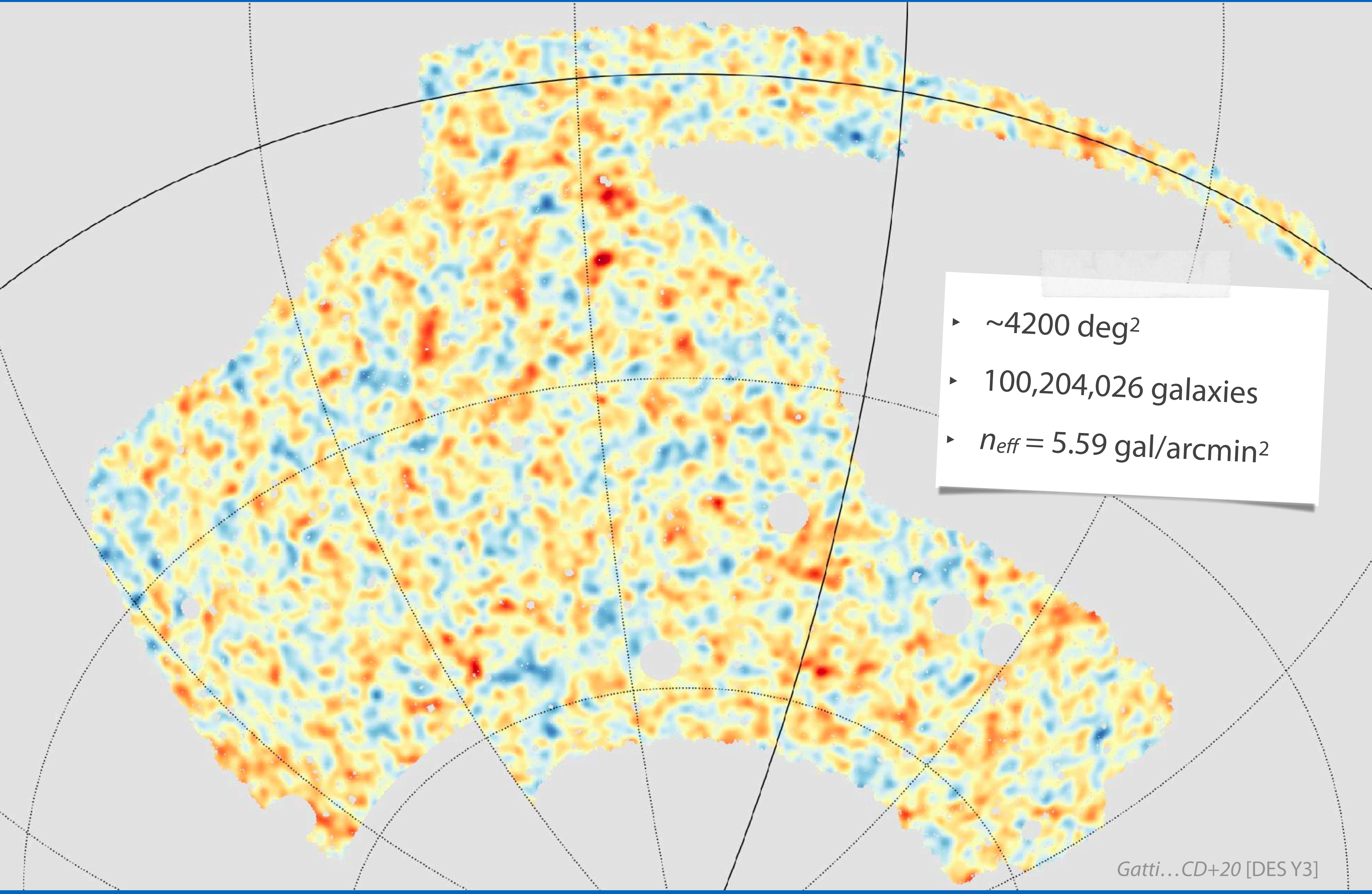
The Dark Energy Survey

- **Blanco 4-meter telescope** at Cerro Tololo (CTIO) in Chile
- **Dark Energy Camera** (DECam)
  - 3.0 deg² field-of-view, 70 CCD chips, 570 Mpix, *griz(Y)* filters
  - Seeing ~0.9′ in *r*-band, magnitude i_{AB}<23.0, *r*<23.5
- **Survey(s)**
  - 5000 deg² footprint + **deep fields**, observed 2013-2019
- **DES Year 3 in numbers**
  - ~100 people, ~100M galaxies, ~30 papers





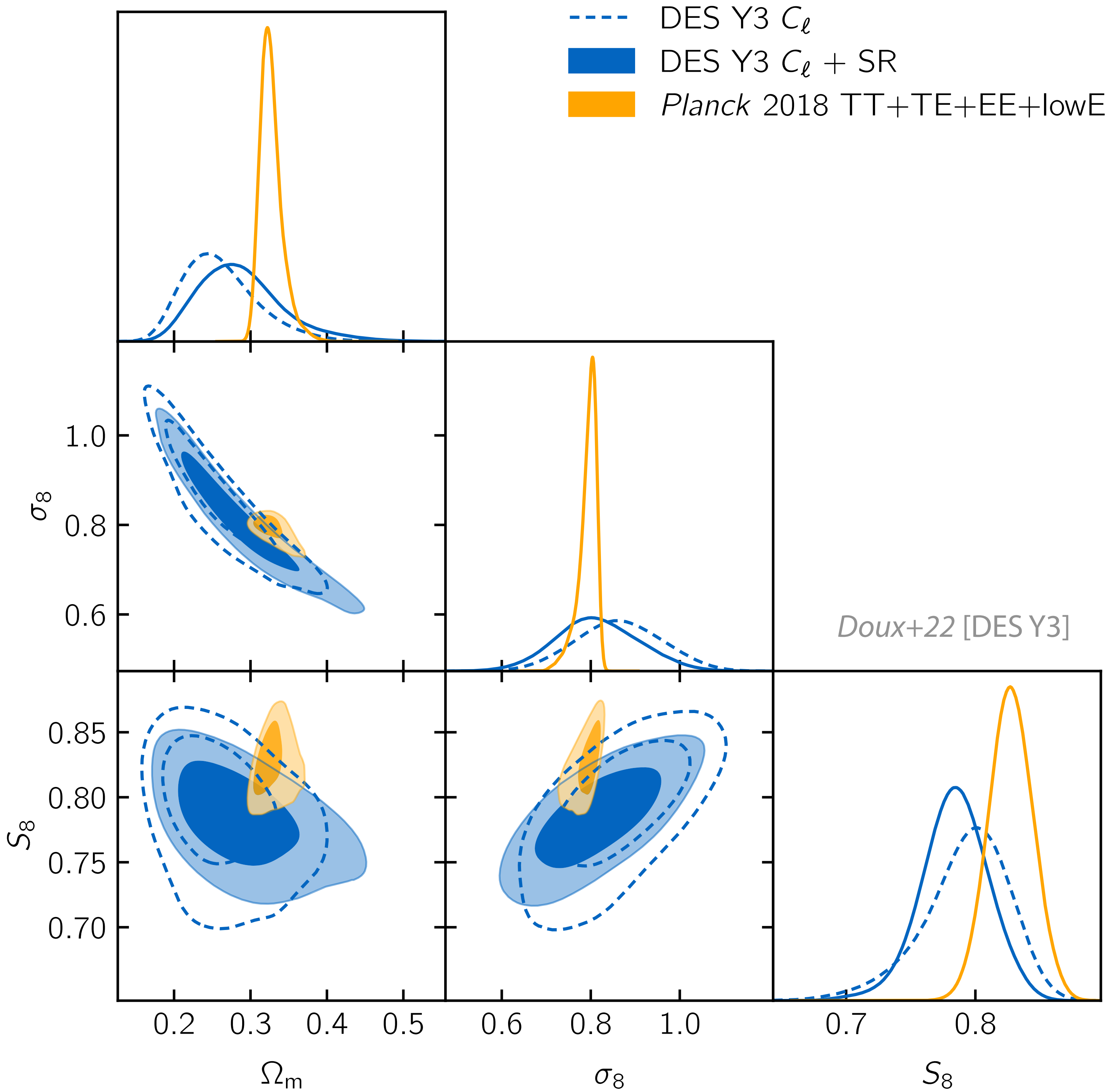
DES Y3 convergence map



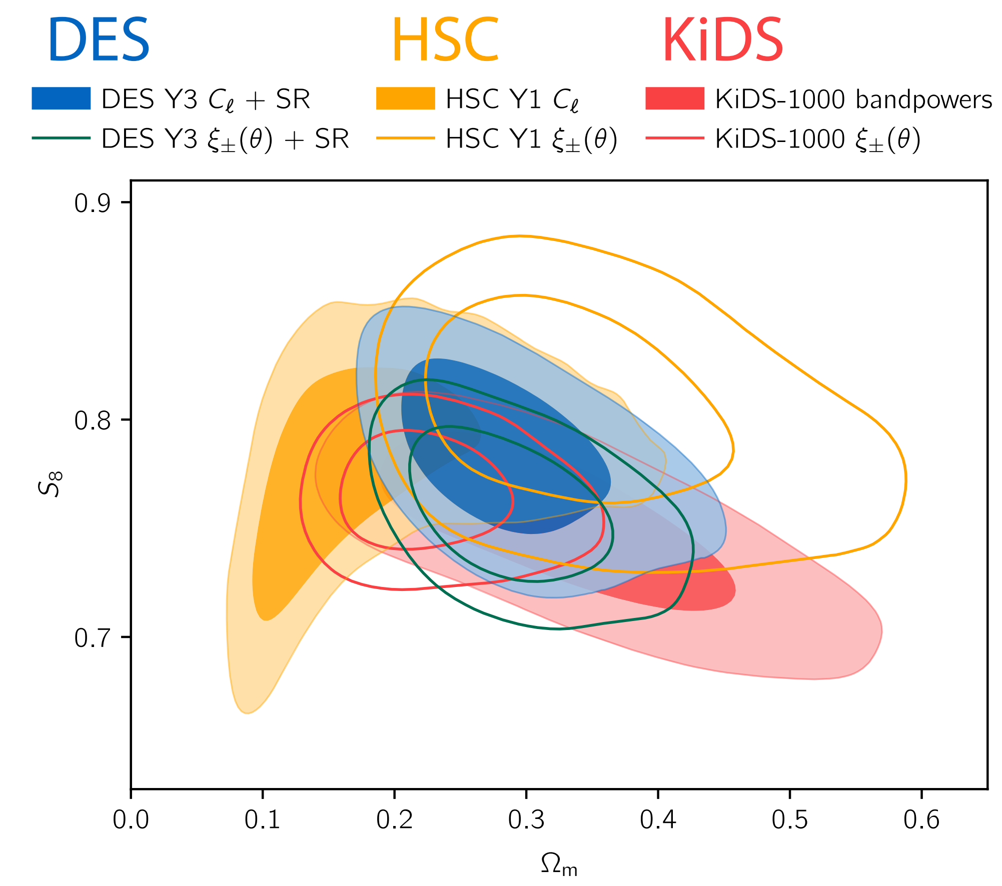
- ~4200 deg^2
- 100,204,026 galaxies
- n_{eff} = 5.59 gal/arcmin^2

Gatti…CD+20 [DES Y3]

Cosmological constraints: shear *vs* CMB

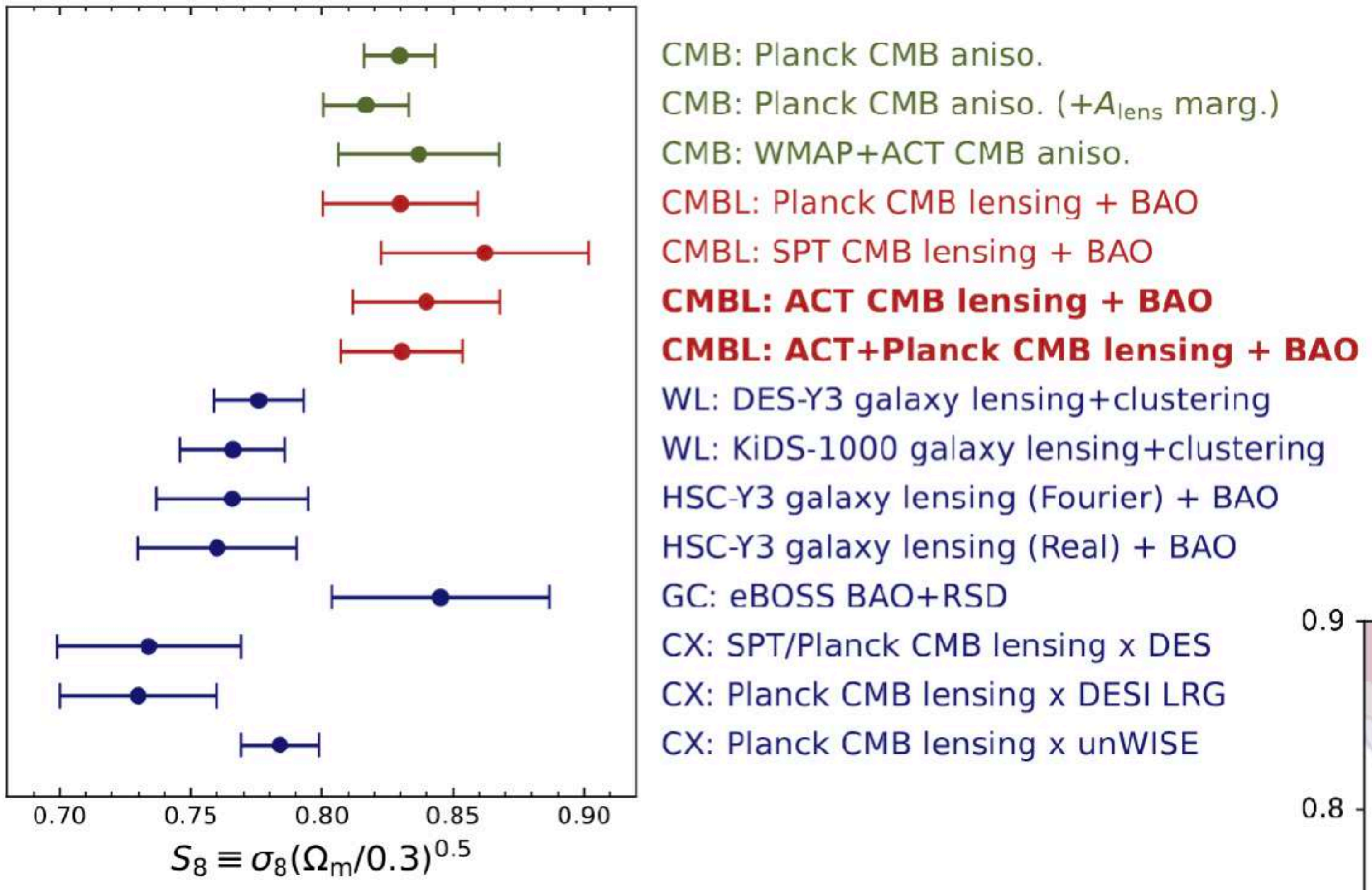


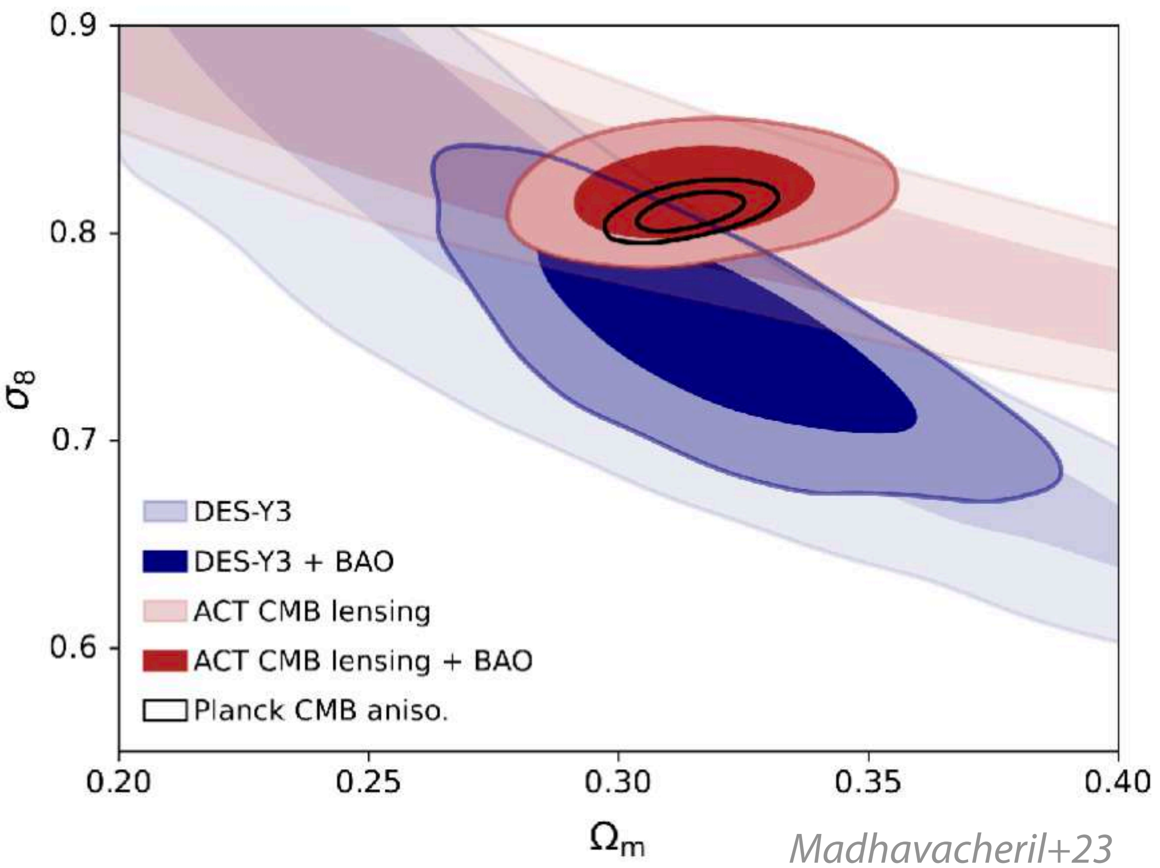
Doux+22 [DES Y3]



- Lensing surveys *consistently* find lower S_8 than Planck CMB

The σ_8 tension?





Madhavacheril+23

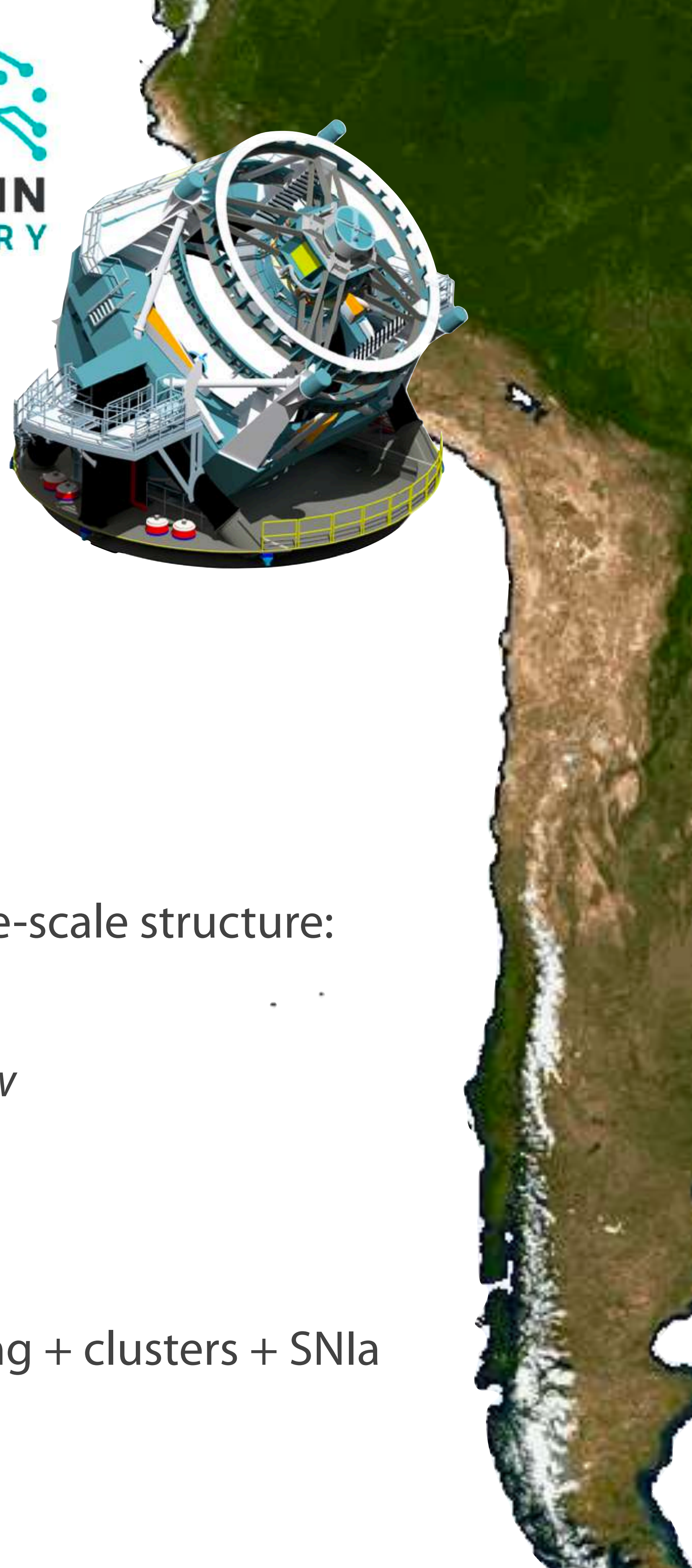
- Late-time Universe appears more *clumpy* than expected from the CMB
  1. Unknown systematics?
  2. Theory predictions off?
  3. New physics?

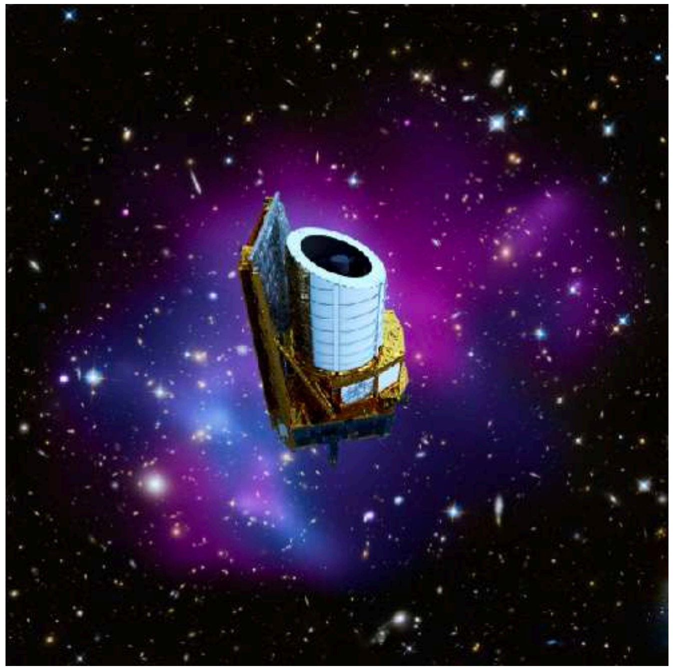
- Cosmic shear 101
- Dark Energy Survey
- Future surveys: LSST and Euclid

Galaxy surveys

What's next?

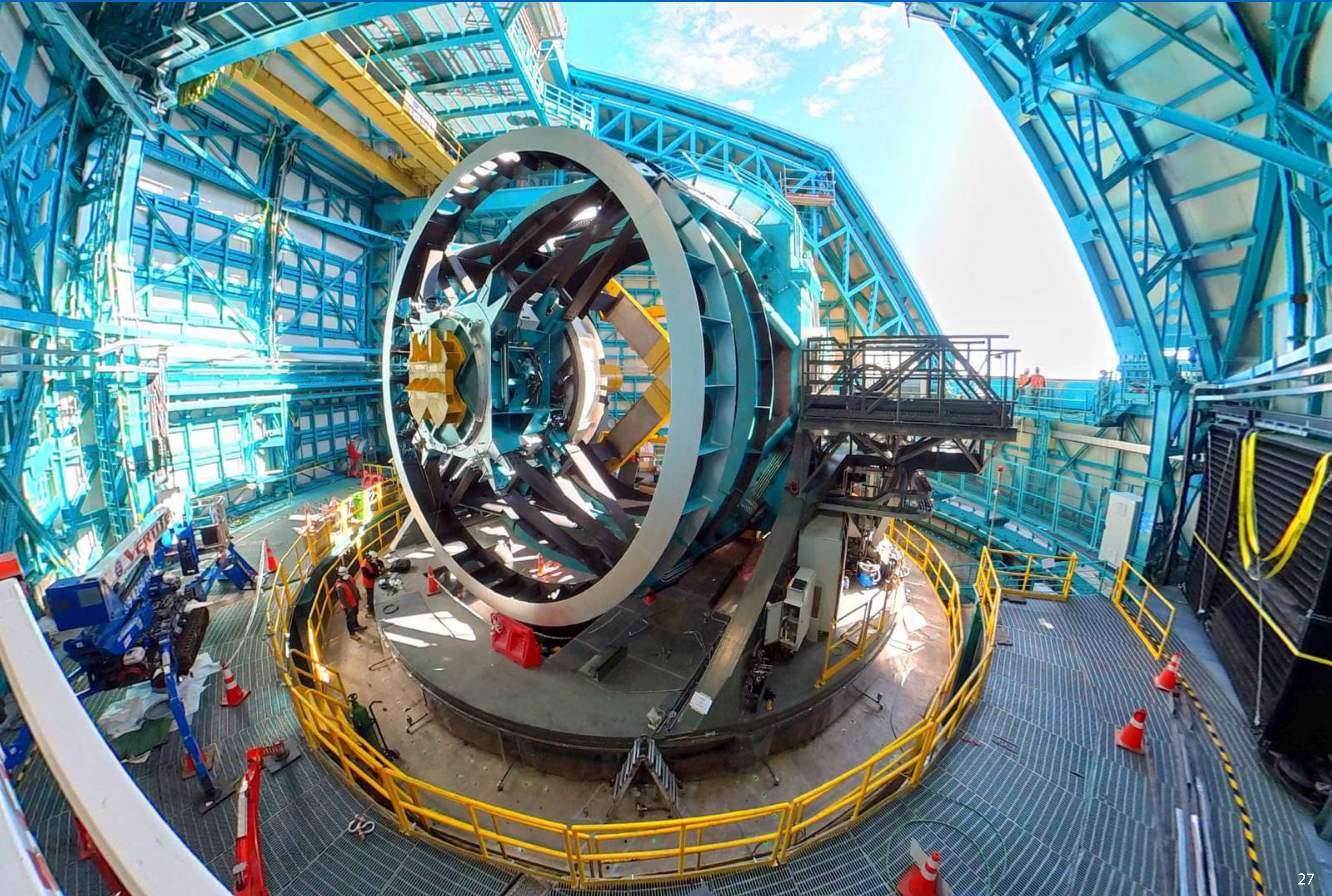
- **Experiments**
  - **Euclid** satellite (2023-) at L2 point (space!)
  - **LSST** at the Rubin Observatory (2025-) in Chile





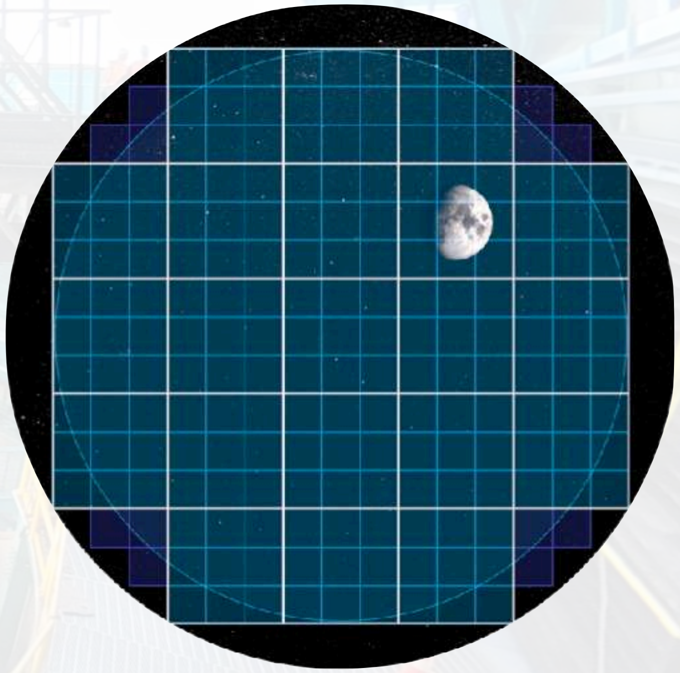
- **Science questions**
  - Measure the evolution of the large-scale structure: gravity *vs* comic acceleration
  - Equation-of-state of dark energy *w*
    - evolution over time or $w = -1$?
  - Combination of probes
    - galaxy clustering + weak lensing + clusters + SNIa (LSST only) + BAO (Euclid only)

LSST in a nutshell

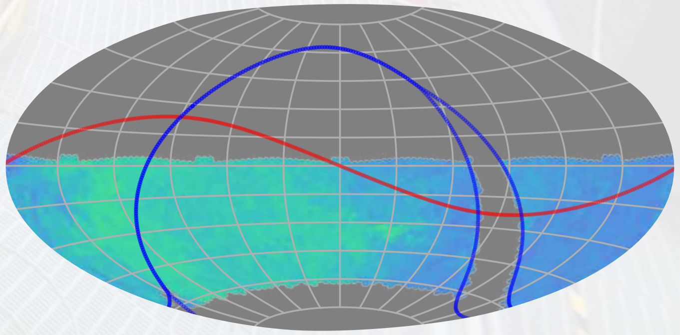


LSST in a nutshell

- **Rubin Observatory in Cerro Pachón, Chili**
  - 8m telescope, 3.5 Gpix camera, 6 optical filters
  - Large field-of-view ~ 50 moons

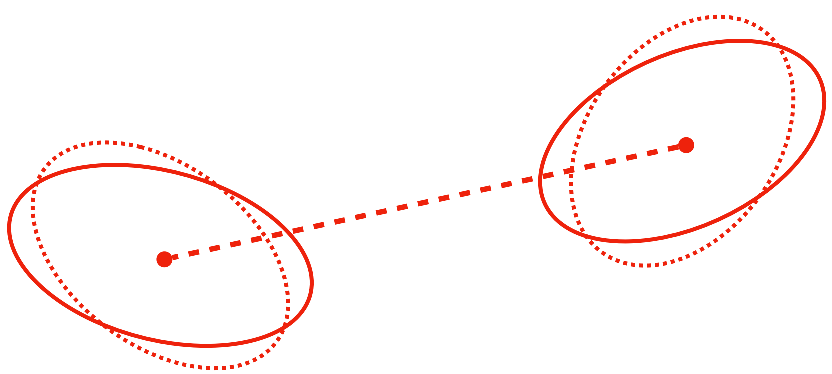


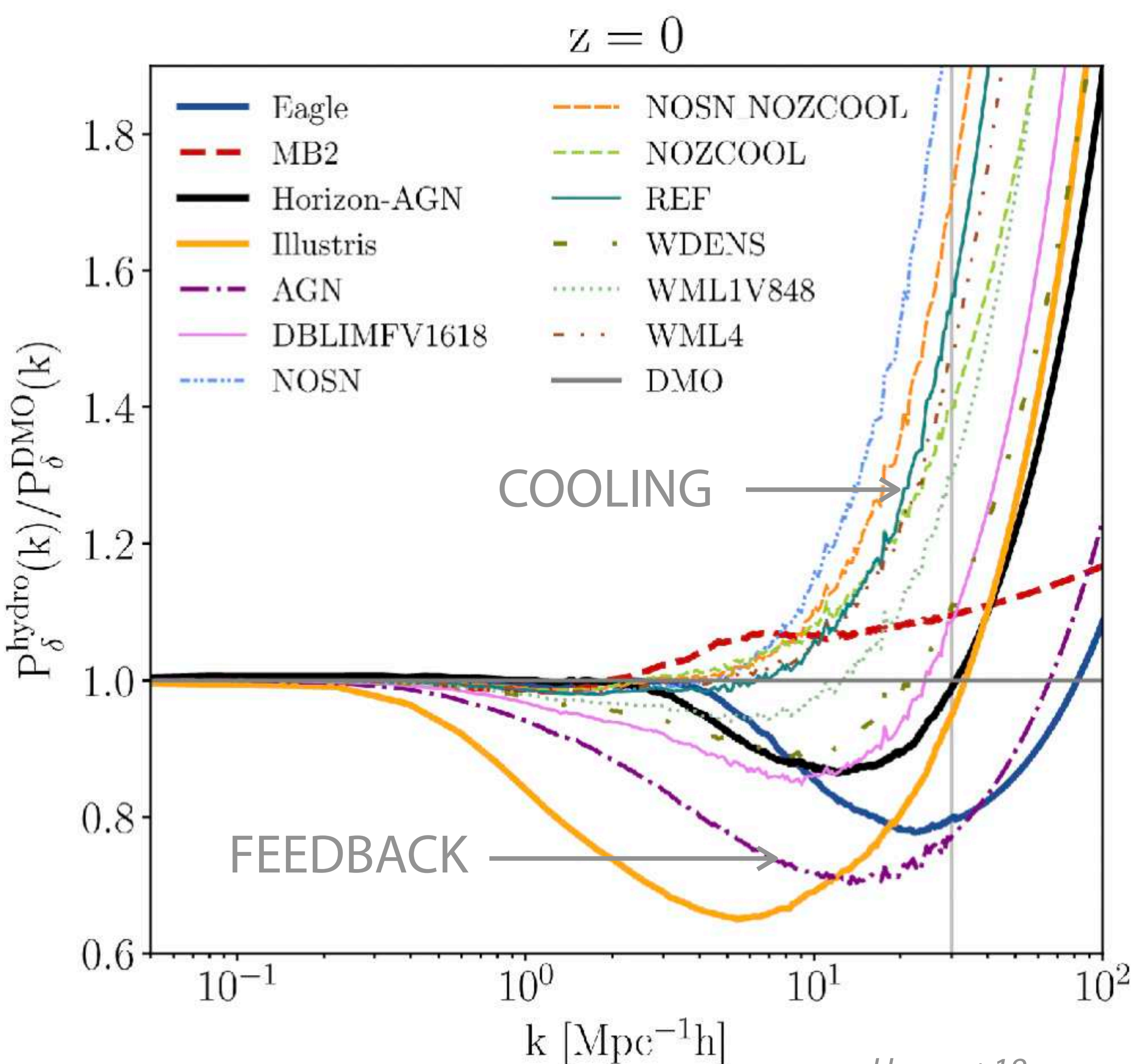
- **LSST = 10-year long "wide-fast-deep" survey**
  - Full southern sky every 2-3 nights ⇒ 60 Pb after 10 years
  - 37 billions objects, incl. 20 billions galaxies, 2 millions SN Ia
- **LSST/DES for weak lensing**
  - Limiting magnitude=27/23.5 (r-band)
  - Density=30/6 gal/arcmin^2
  - Area= 18000/5000 deg^2
  - Error bars ~ (area)$^{-1/2}$. (density)$^{-1}$ …



Challenges ahead: (g)astrophysics!

- **Baryonic feedback**
  - Non-gravitational processes that redistribute matter
  - Brooooaaaad variations across *hydrodynamical* simulations…
- **Intrinsic alignments**
  - Alignment with tidal field of nearby galaxies

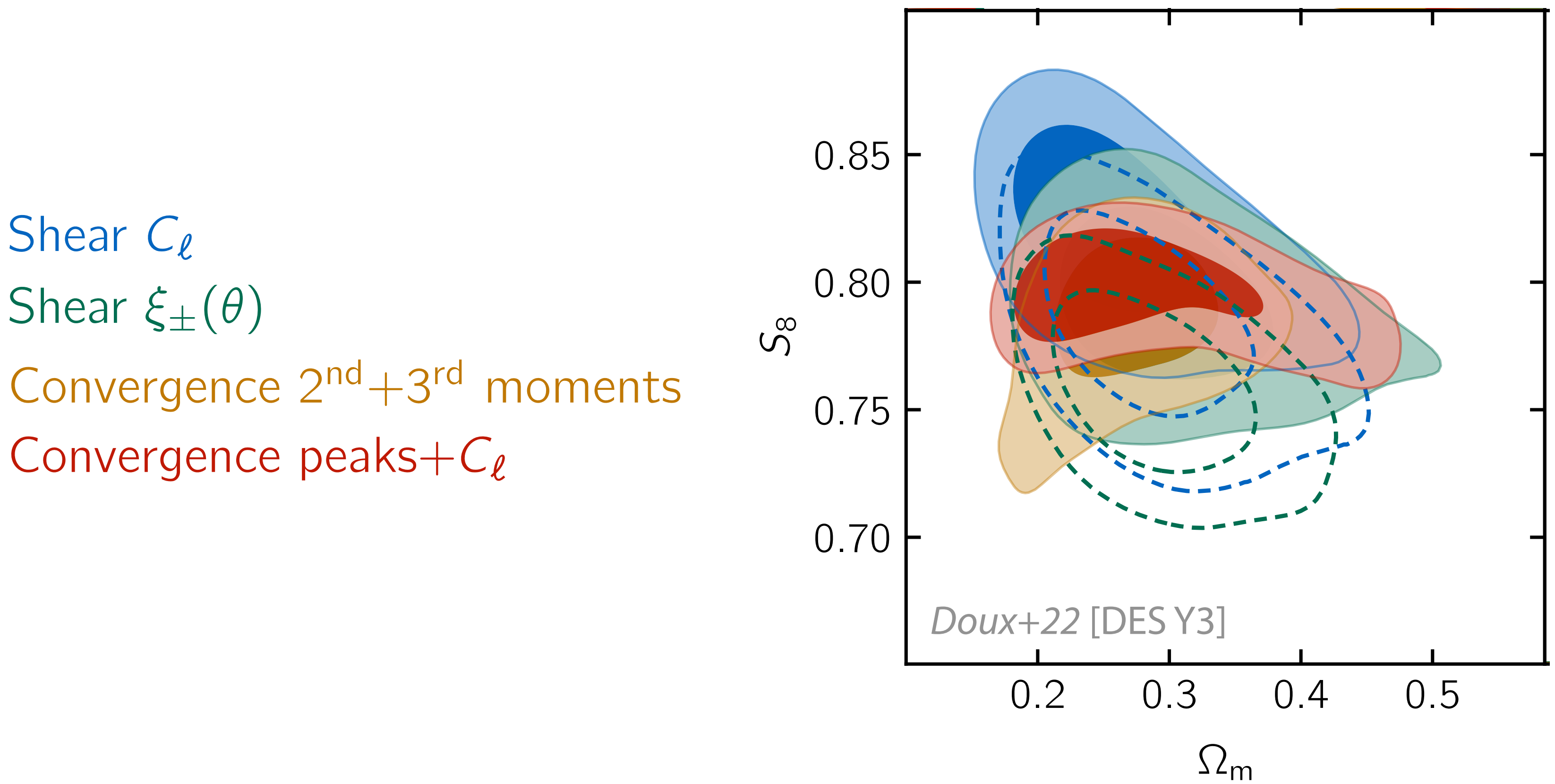


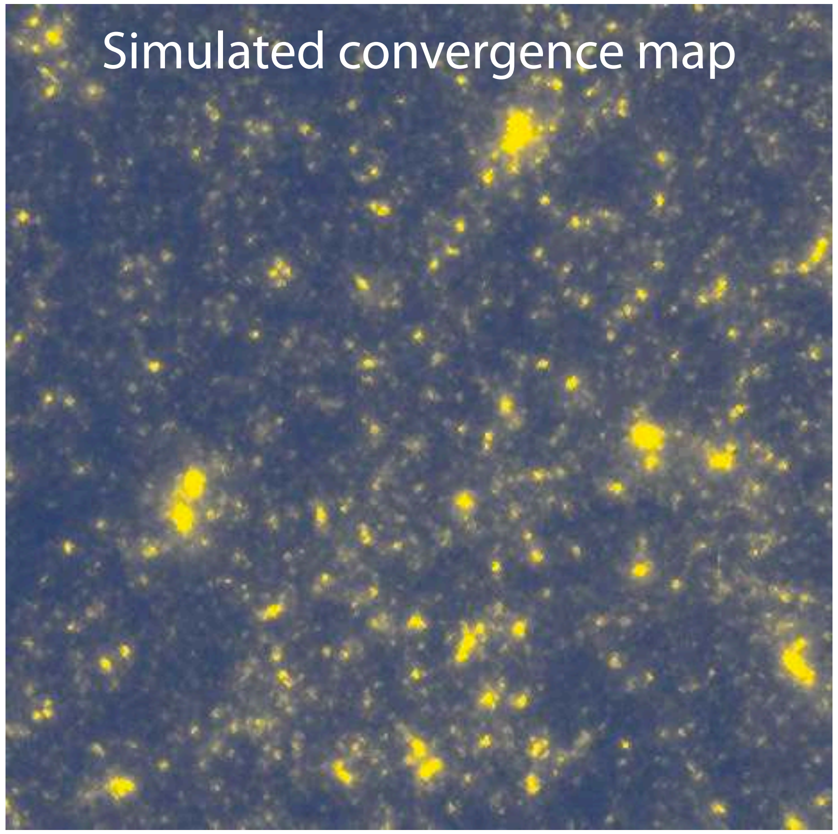


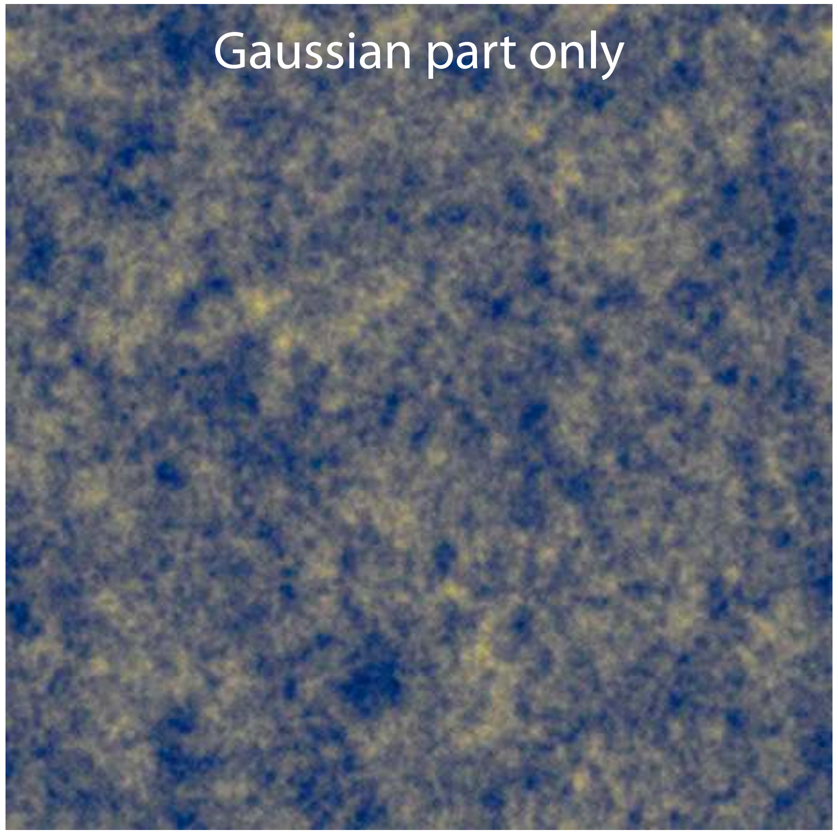
Huang+18

Challenges ahead: extracting information

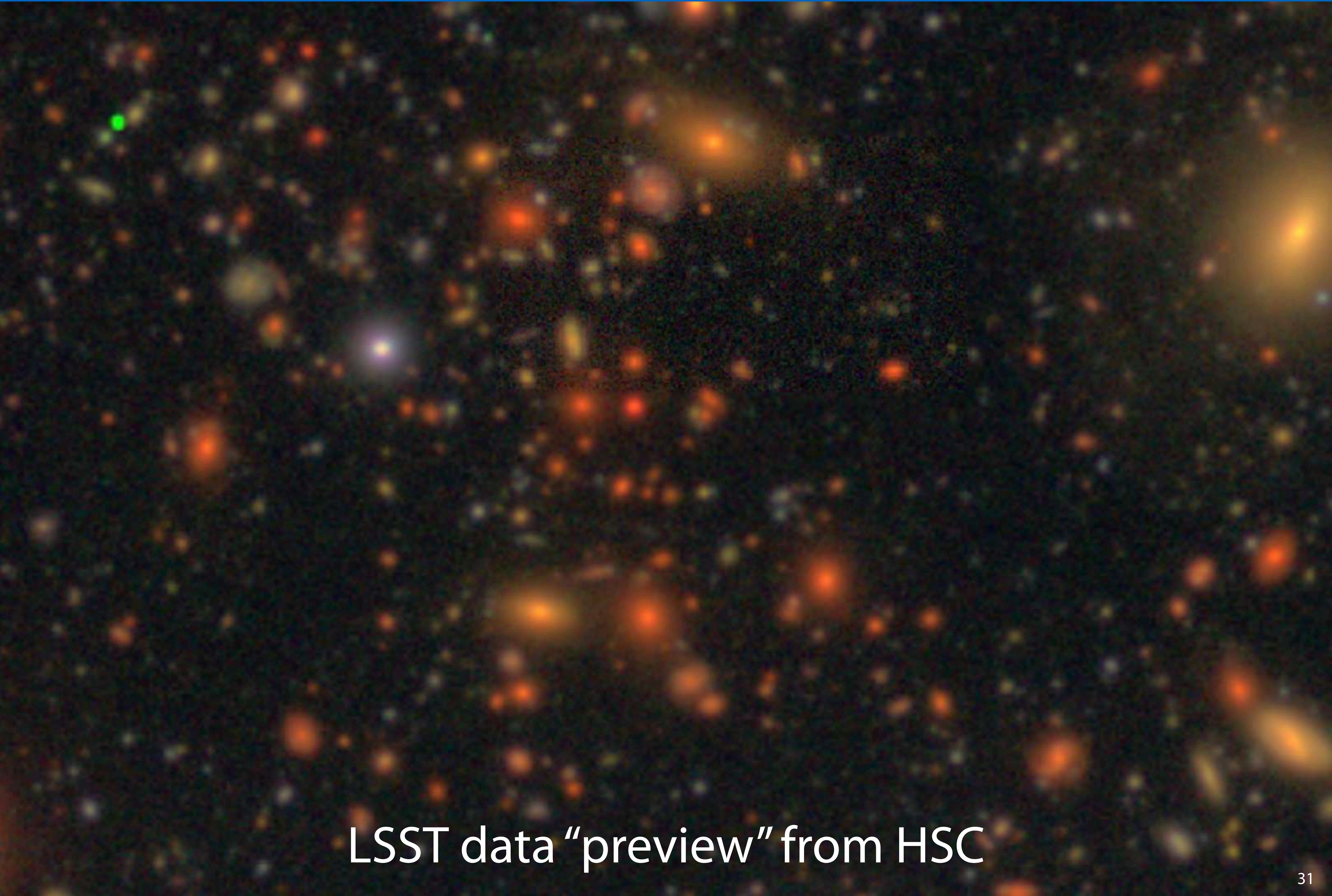
- **Non-Gaussian structure**
  - Gravity is non-linear
  - Haloes, filaments and stuff
- **Higher-order statistics**
  - 3pt function, peaks/troughs, topology, etc
  - Simulation-based analysis
  - More information and/or finding ΛCDM breakdown

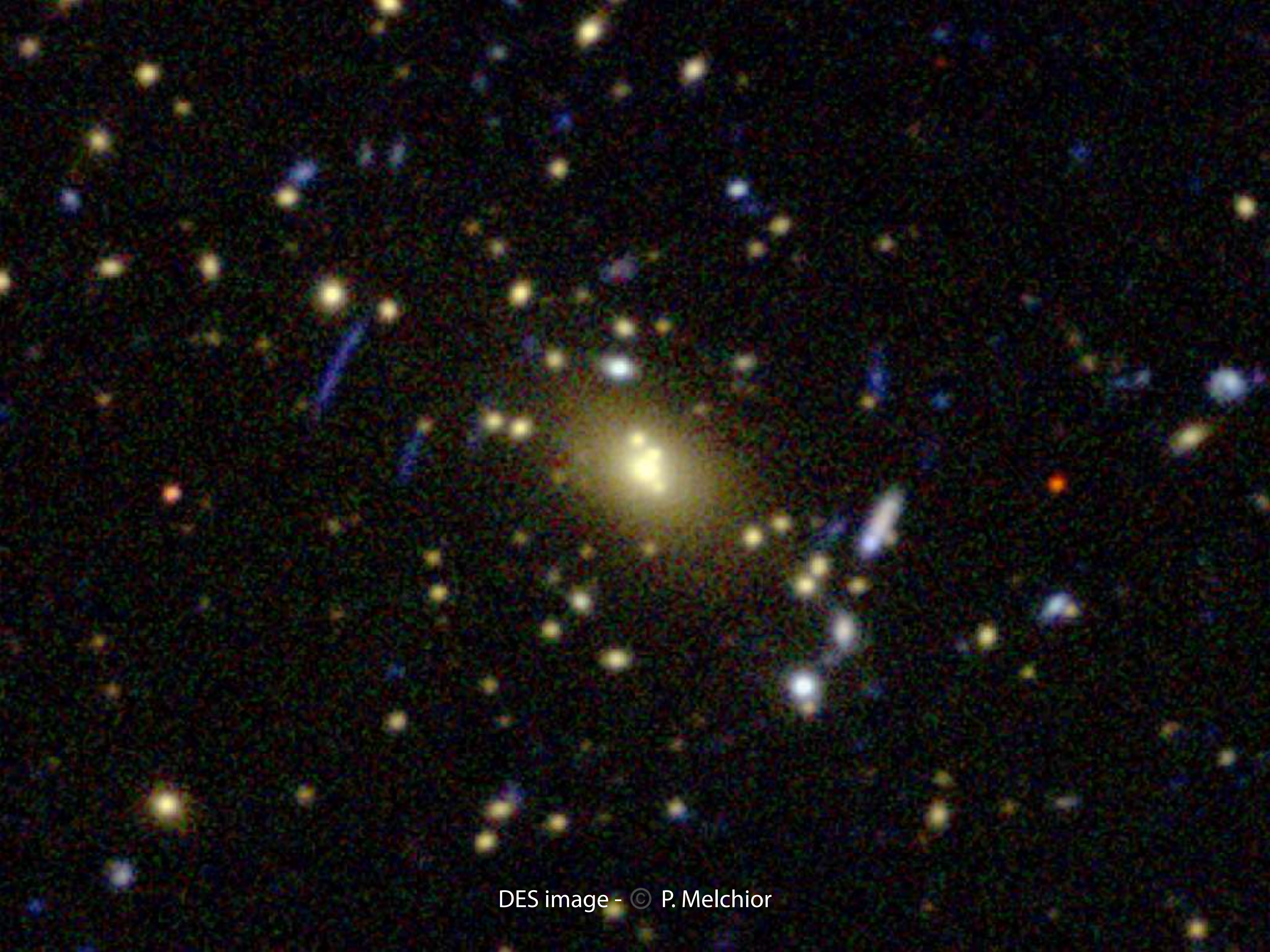






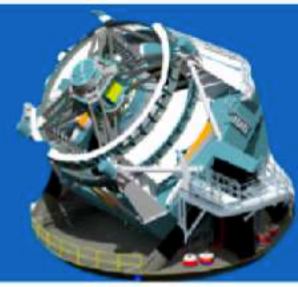
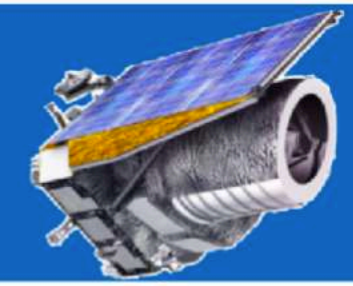
Challenges ahead: images



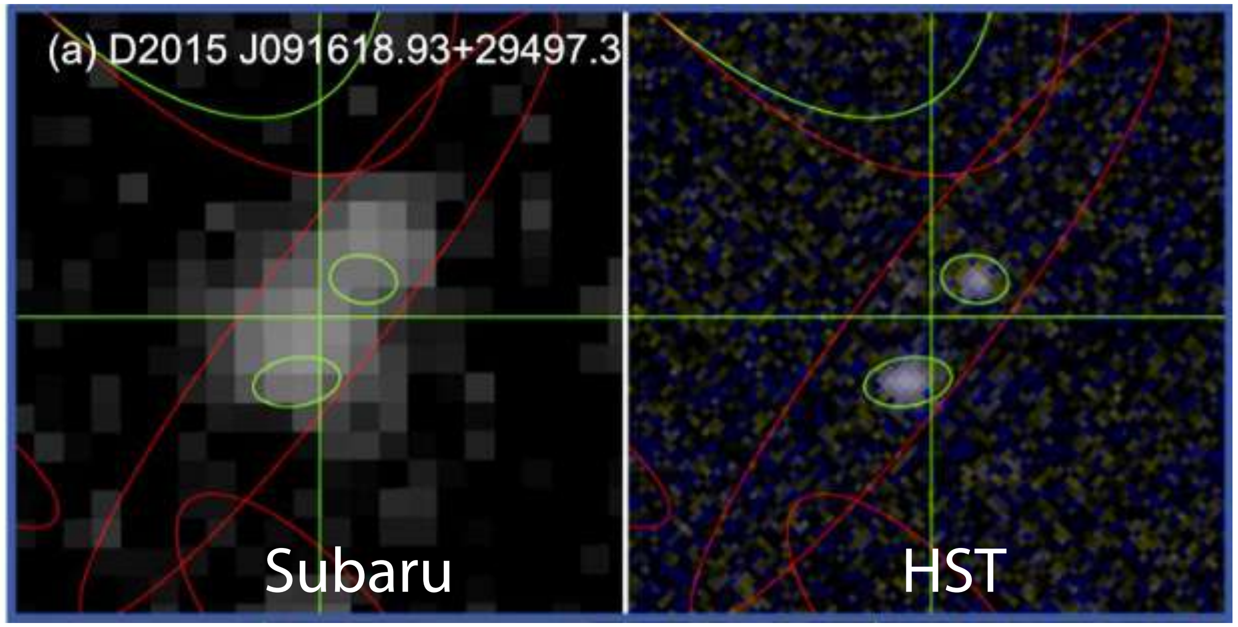

DES image - © P. Melchior

HST image - © P. Melchior

Challenges ahead: blending

Expérience		
Bandes photométriques	Optique (*ugrizy*)	VIS + 3 NIR + spectro
Résolution	Atmosphère	Diffraction

- **Opportunity for *synergies*?**
  - Combine LSST's depth + Euclid's resolution
  - Joint pixel-level analysis improves detection, deblending, shape/flux measurements, photo-z… TBC!



Dawson+15

Take-away messages

- Weak lensing is a very powerful probe of cosmic growth and thus dark energy
- LSST and Euclid will provide massive data sets
- Many challenges ahead: systematics, theory, analysis…
- … and opportunities for synergies!


THANKS!