Cosmology through Weak Gravitational Lensing

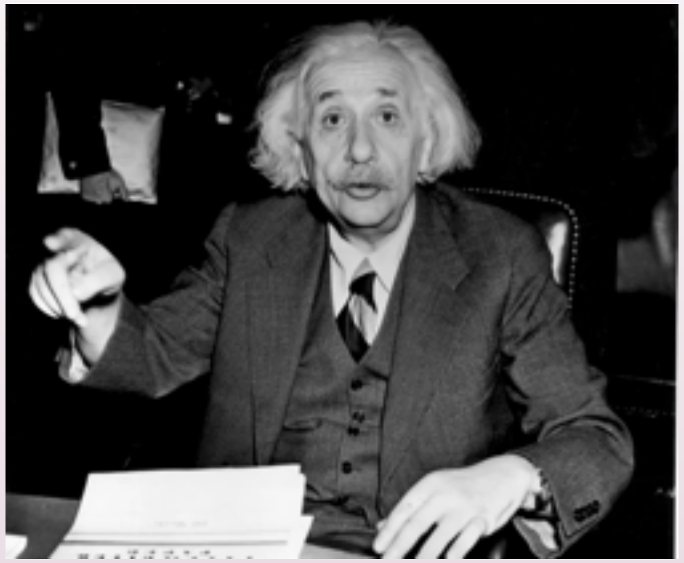
Mijin Yoon, Yonsei University, APCTP meeting on gravitation and cosmology, Dec. 2nd

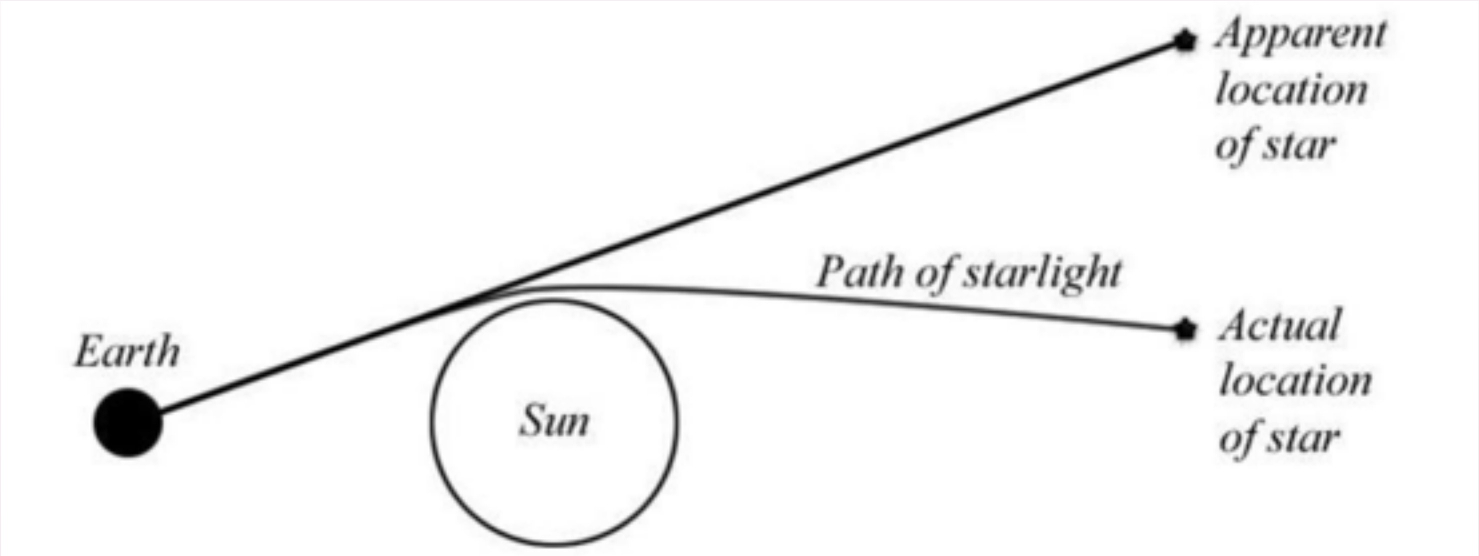
Collaborator: Myungkook James Jee (Yonsei)

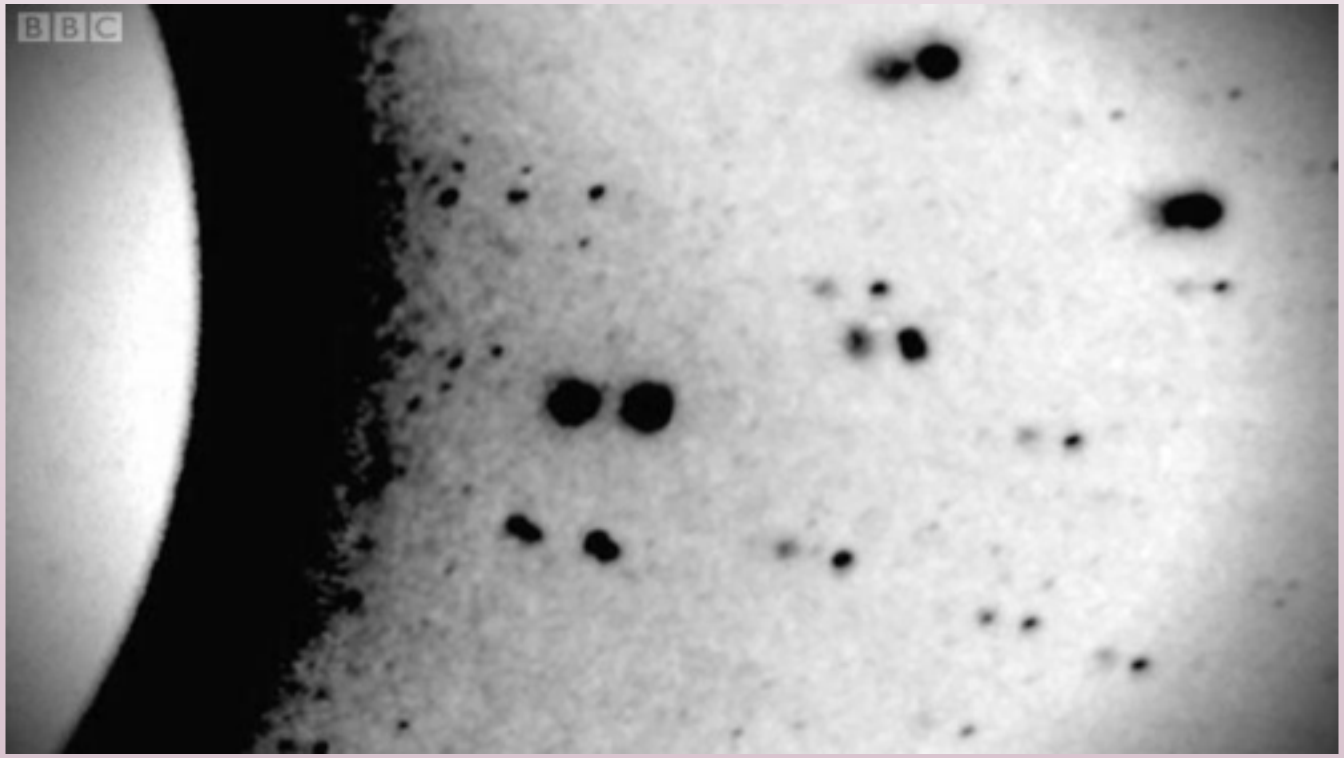
OUTLINE

- Introduction to weak lensing
- DLS Cosmology
- Summary

Verification of General Relativity







1919 Eclipse: First detection of gravitational lensing by Arthur Eddington

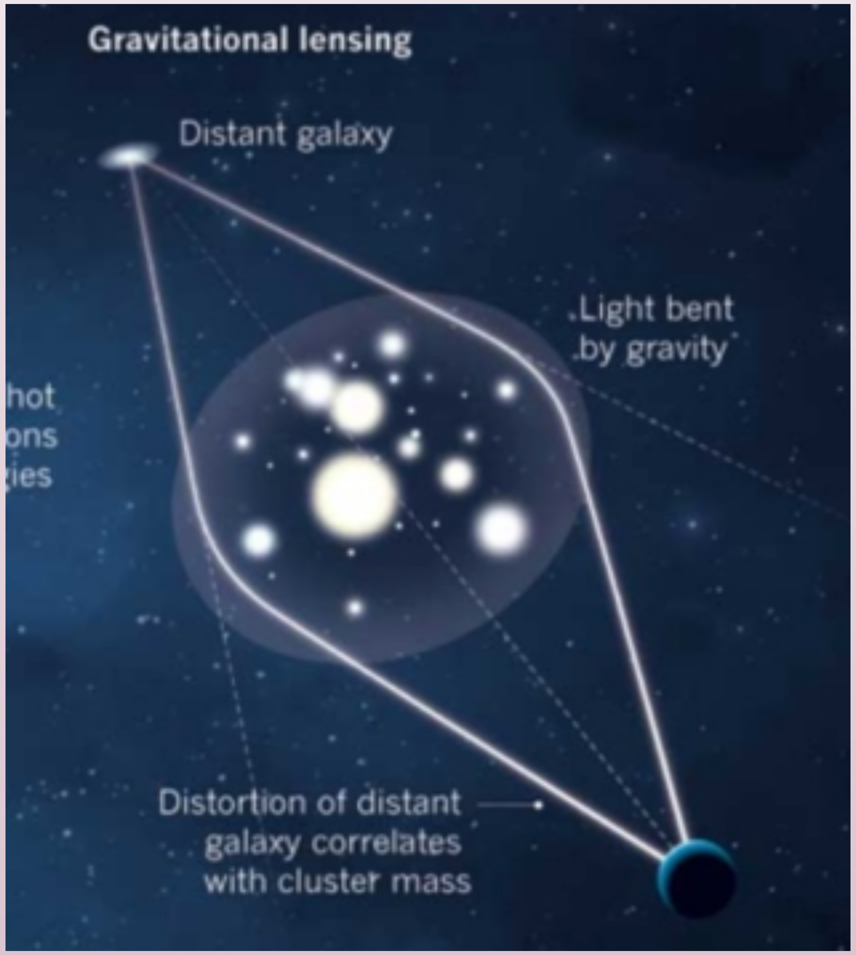
"There is no hope of observing this outside the solar system."

Prediction of Gravitational Lensing on a Cosmic Scale

Fritz Zwicky

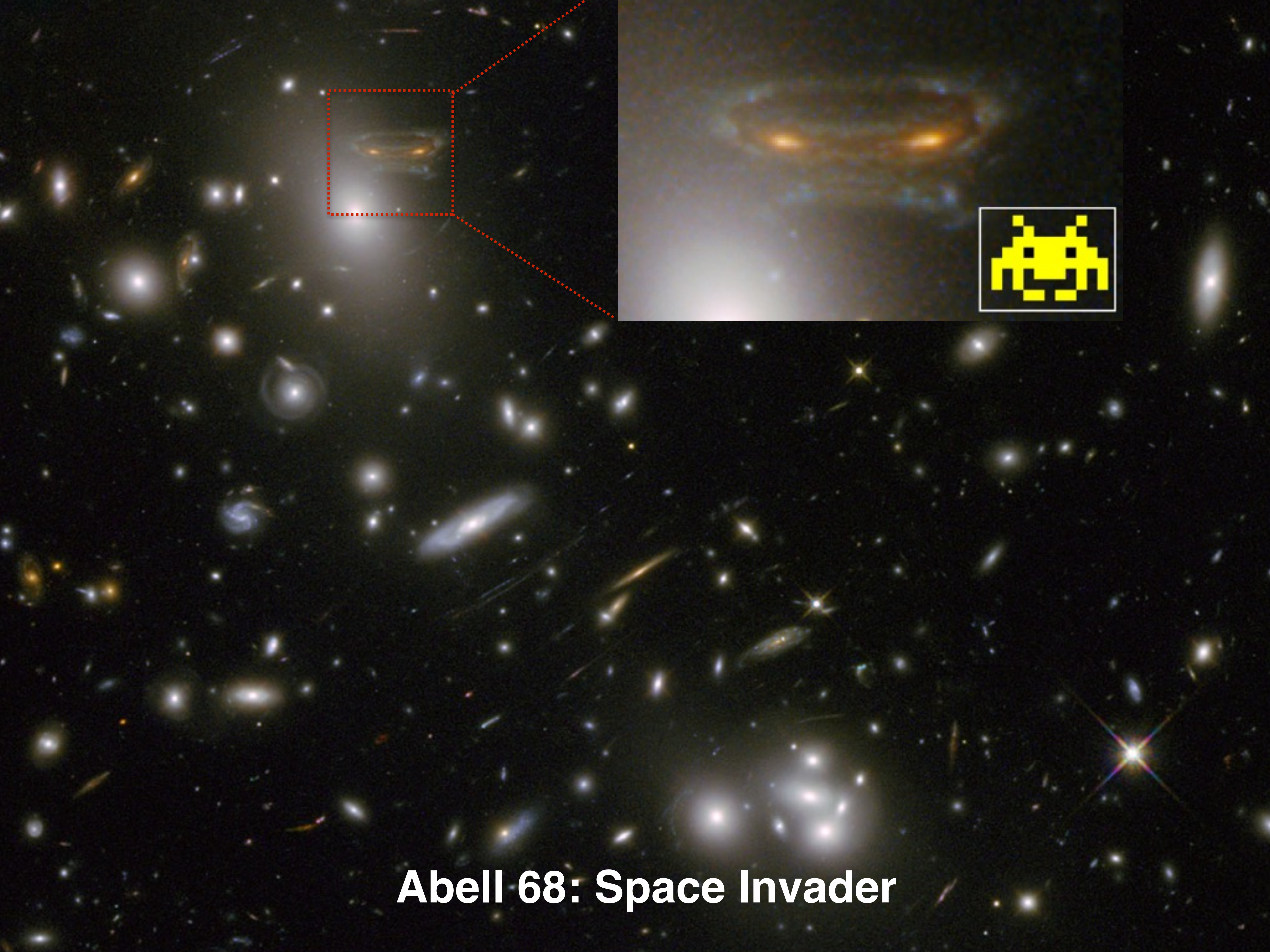
"Astronomers are spherical bastards. No matter how you look at them they are just bastards."

In 1937 Zwicky predicted, "Perhaps, galaxies or galaxy clusters would be far more useful lenses."

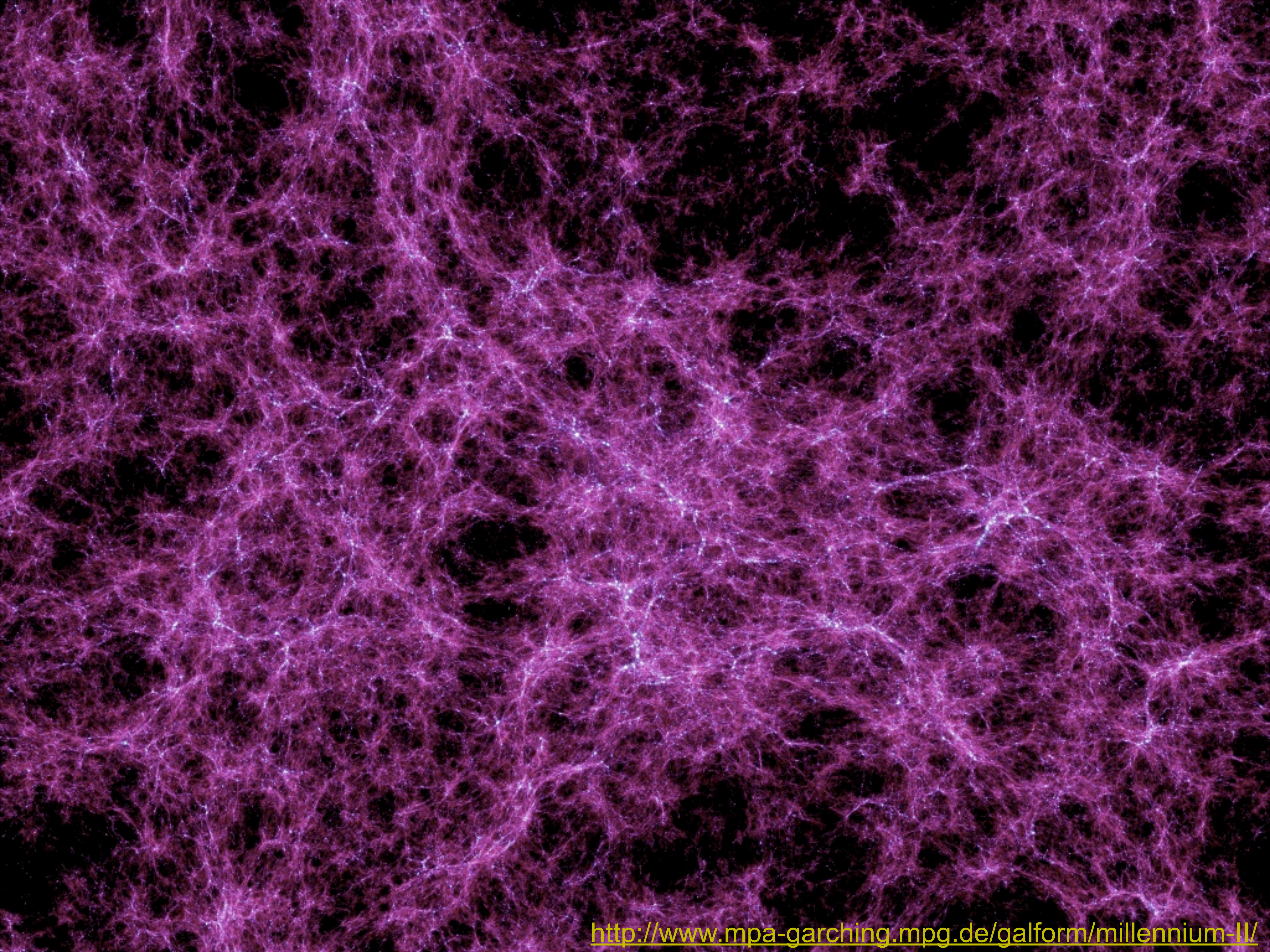


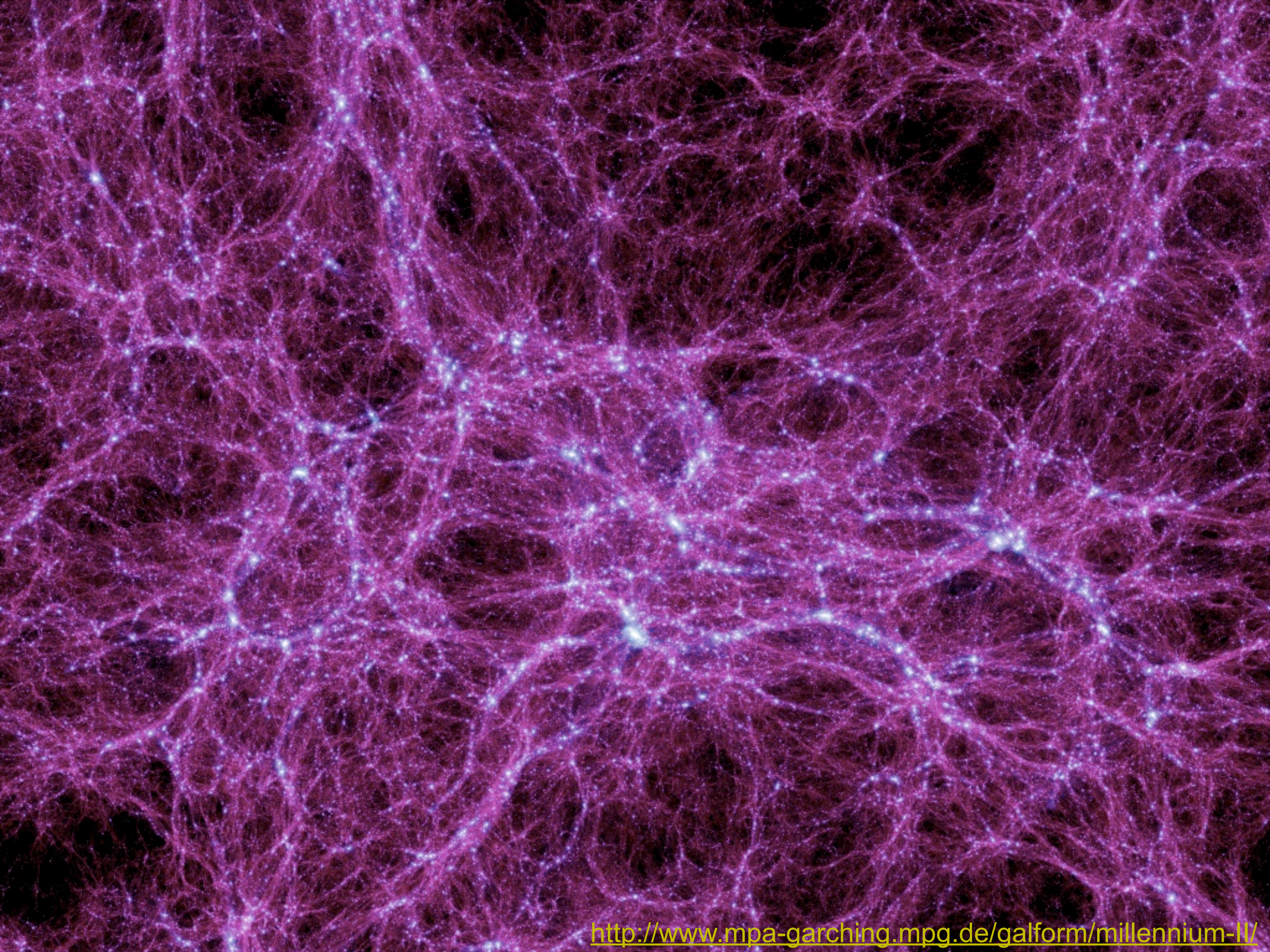
Horseshoe

SDSS J1038+4849: Smiley

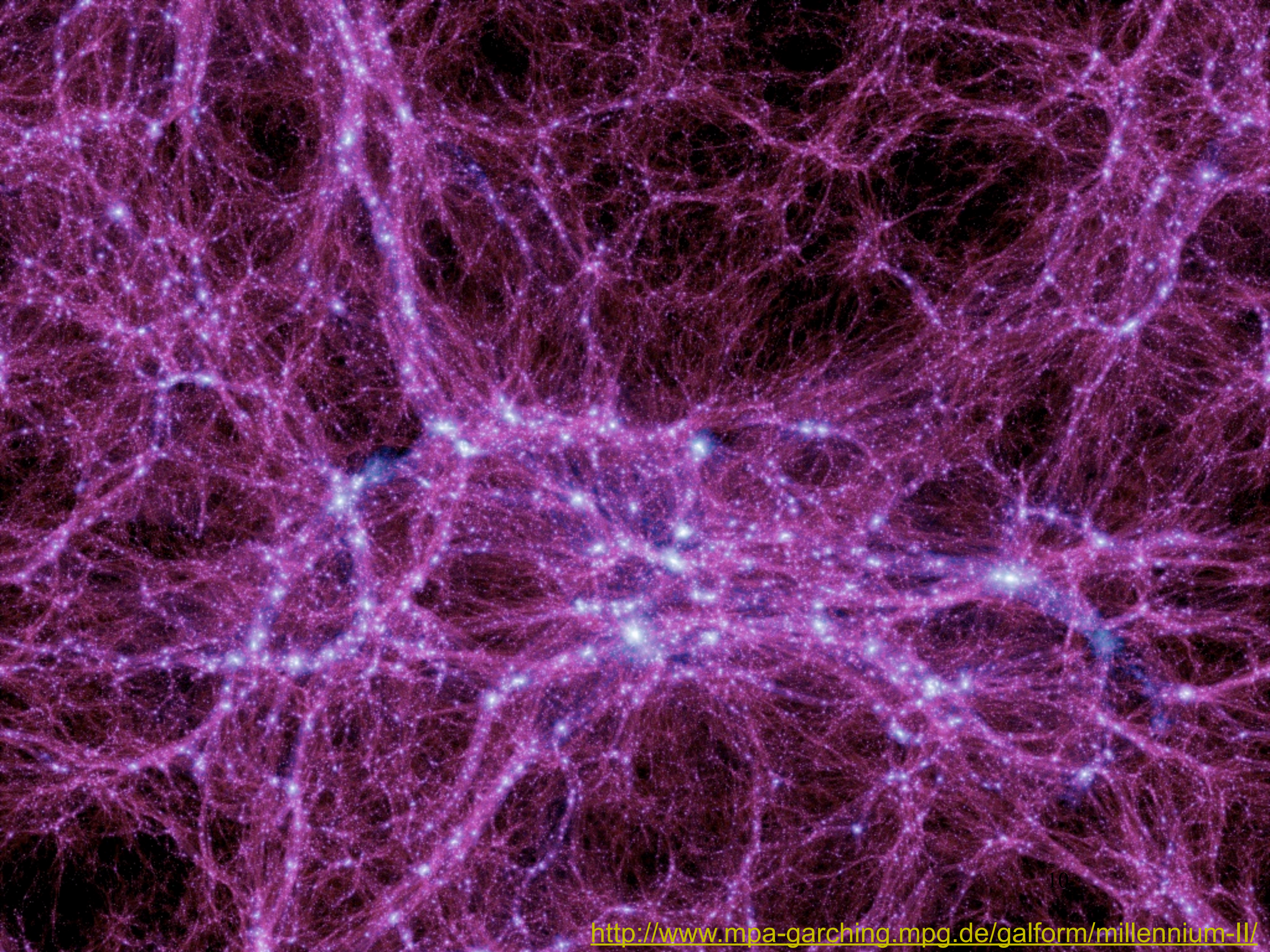


Abell 68: Space Invader

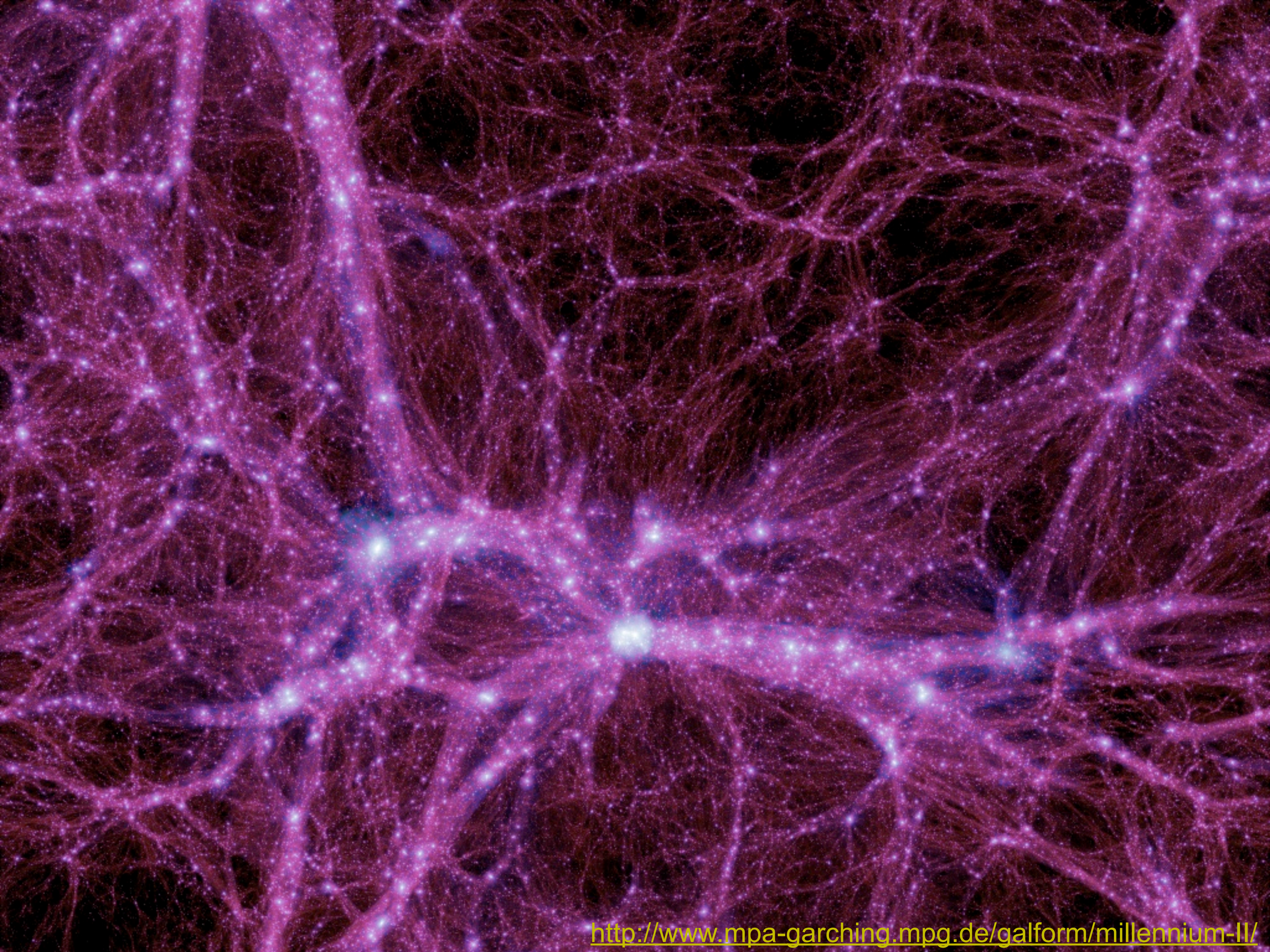

http://www.mpa-garching.mpg.de/galform/millennium-II/



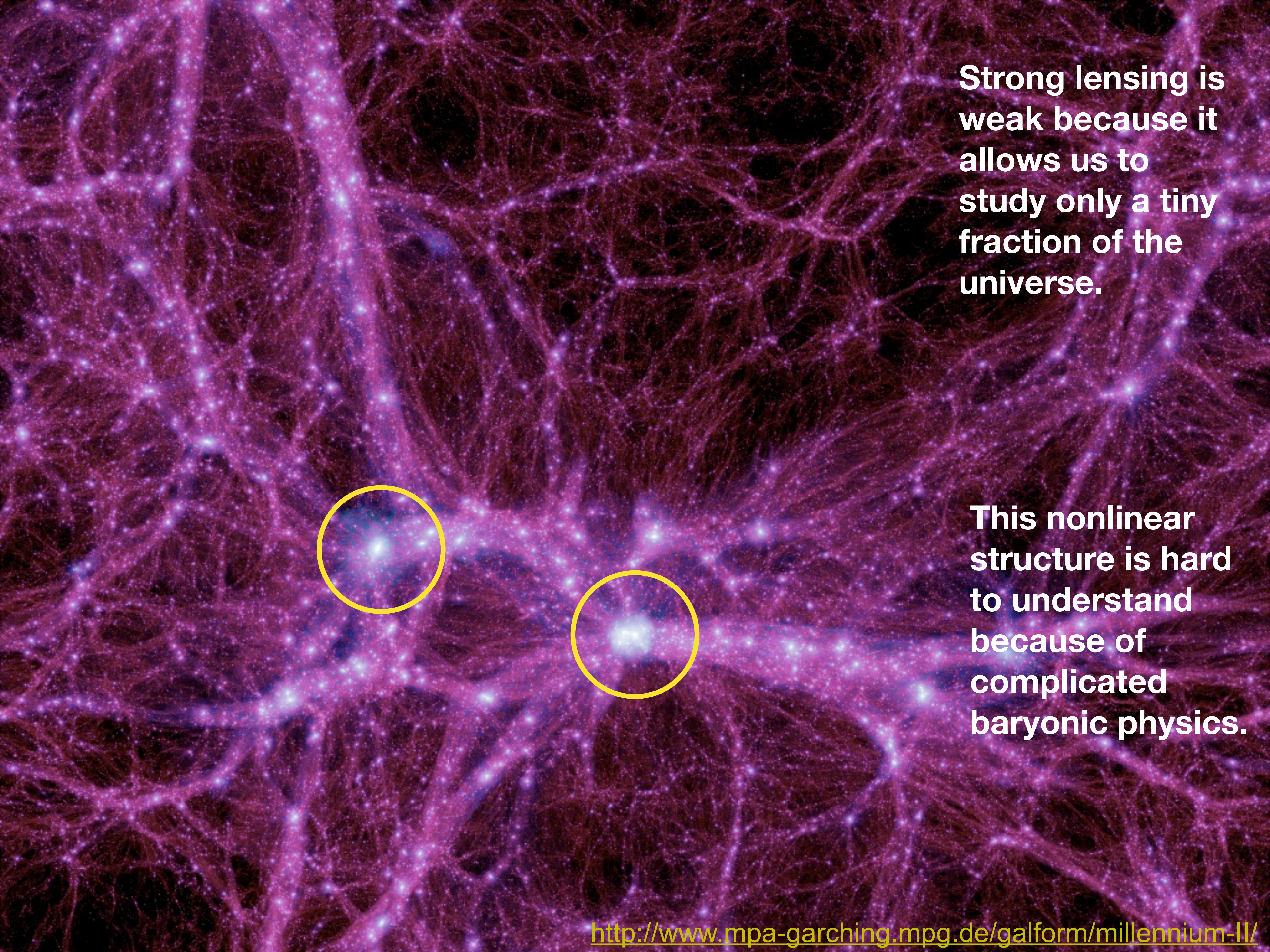
http://www.mpa-garching.mpg.de/galform/millennium-II/

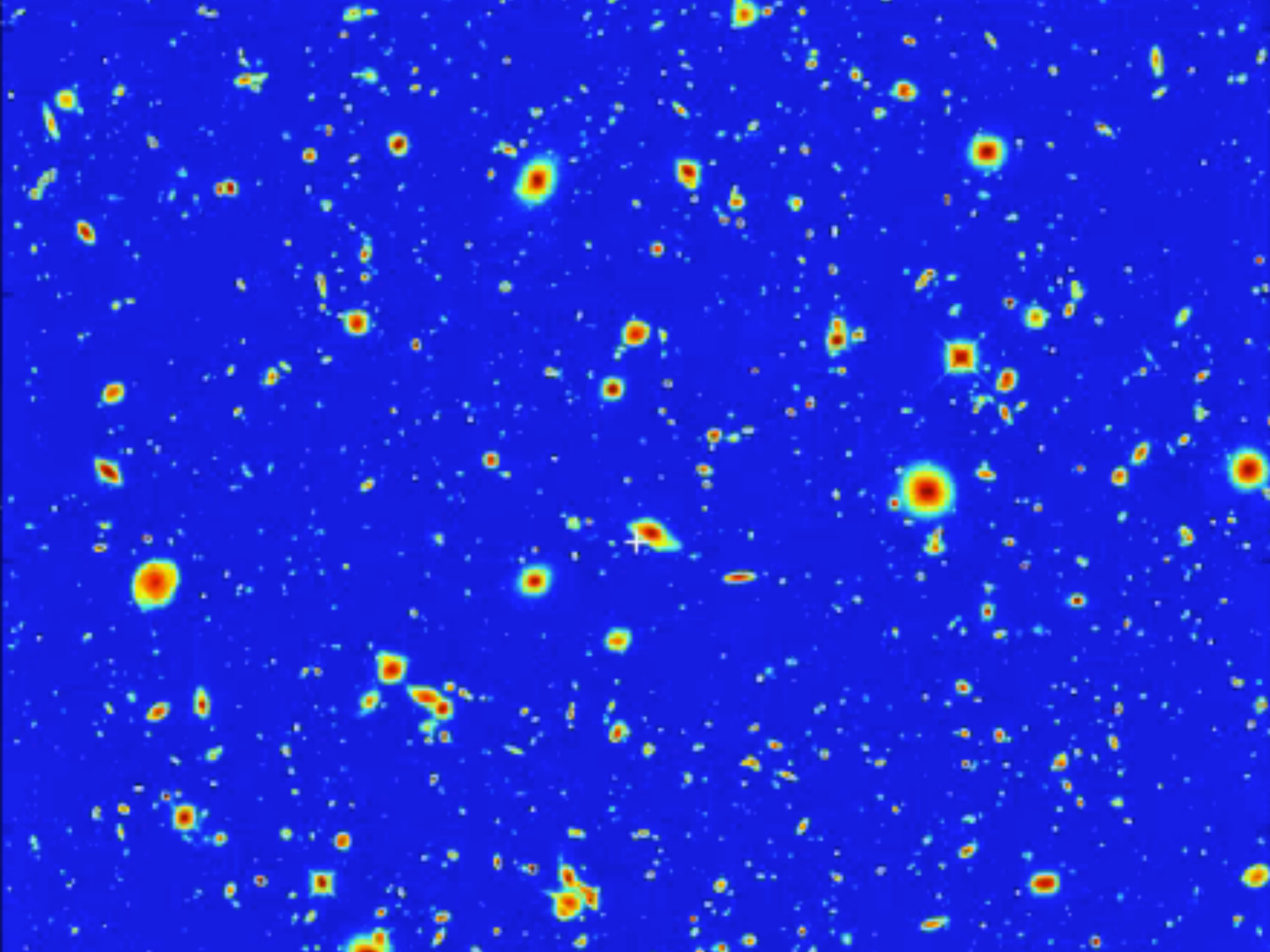


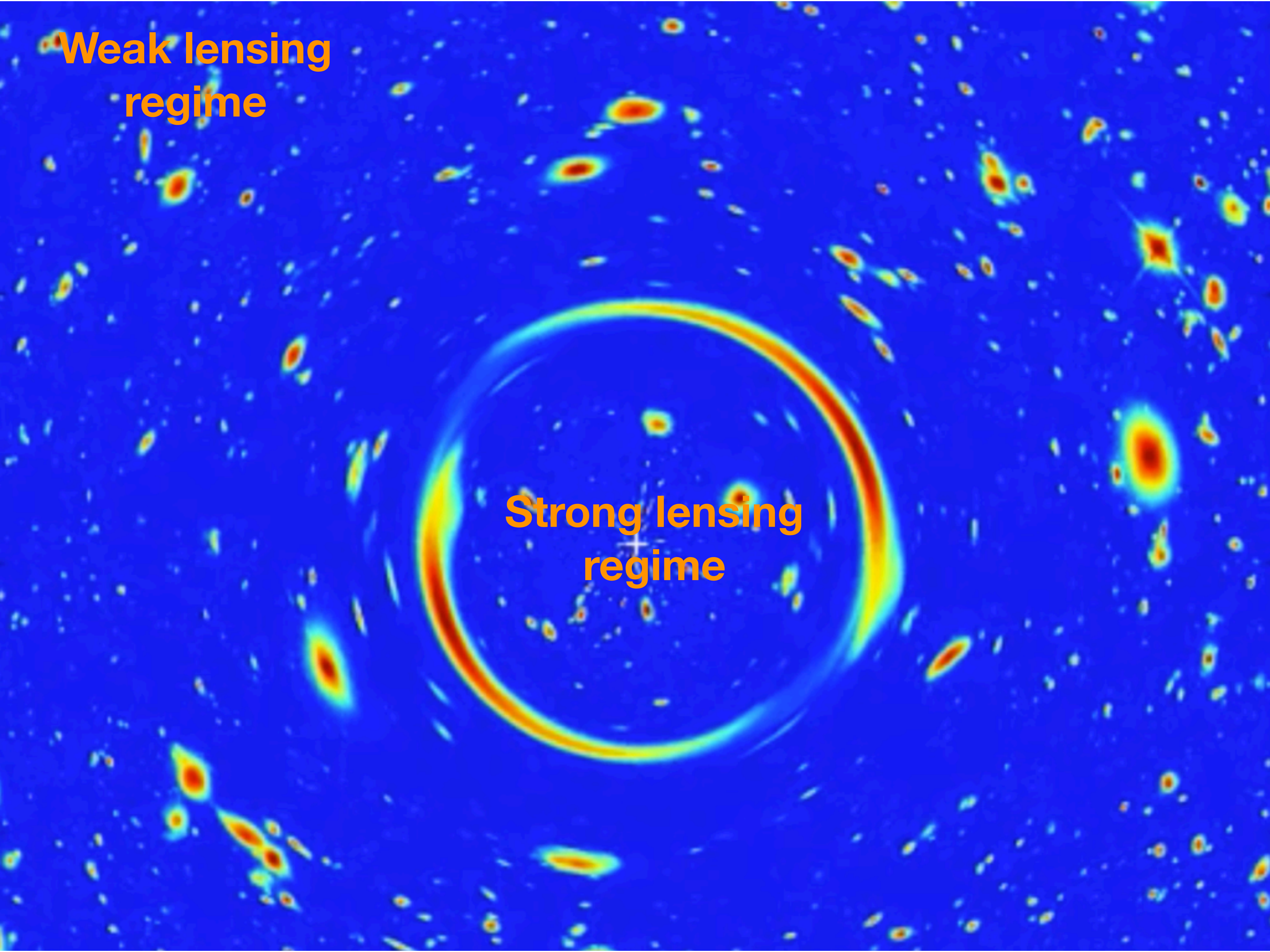
http://www.mpa-garching.mpg.de/galform/millennium-II/



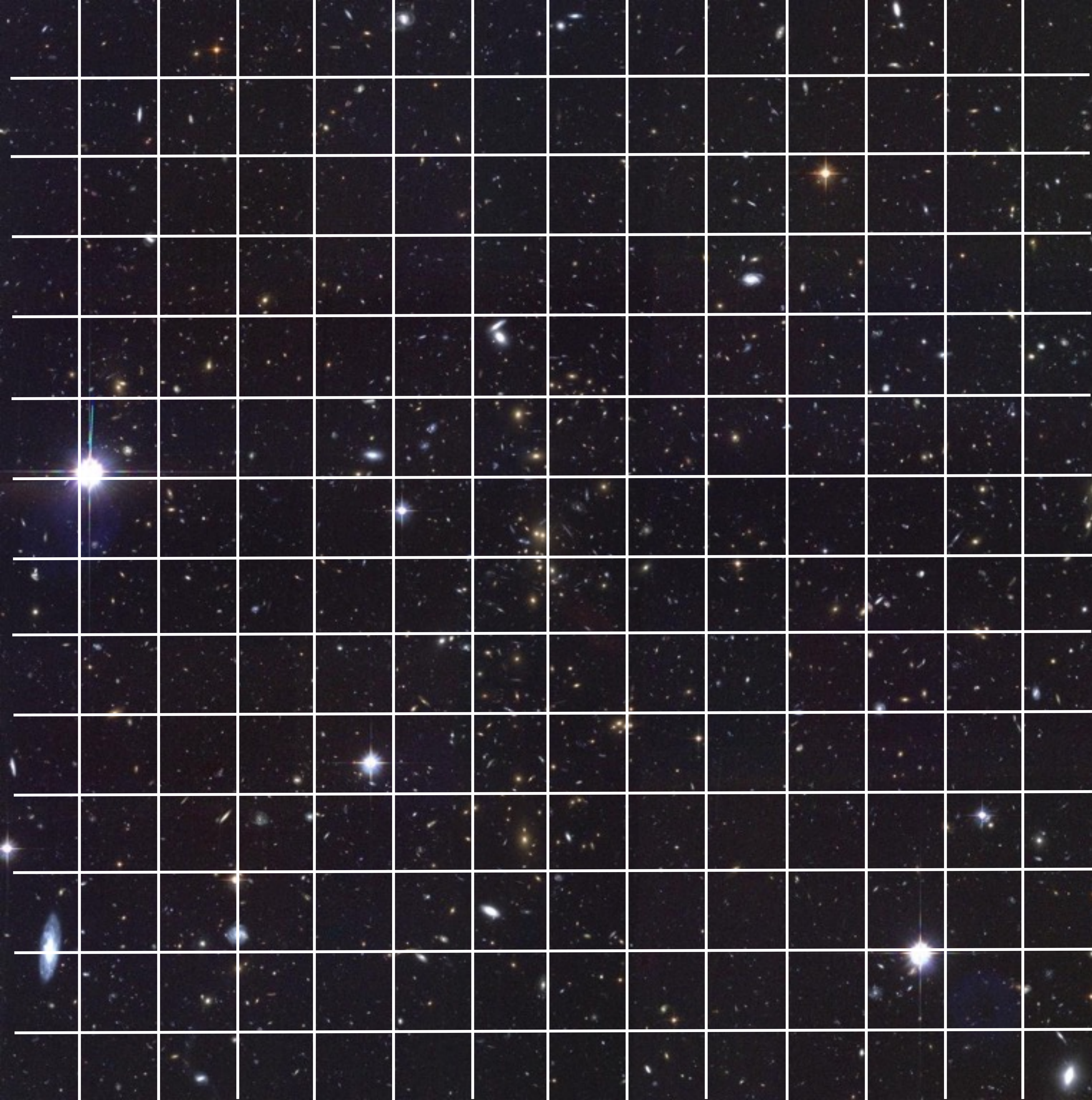
http://www.mpa-garching.mpg.de/galform/millennium-II/


Strong lensing is weak because it allows us to study only a tiny fraction of the universe.
This nonlinear structure is hard to understand because of complicated baryonic physics.
http://www.mpa-garching.mpg.de/galform/millennium-II/




Weak lensing regime
Strong lensing regime

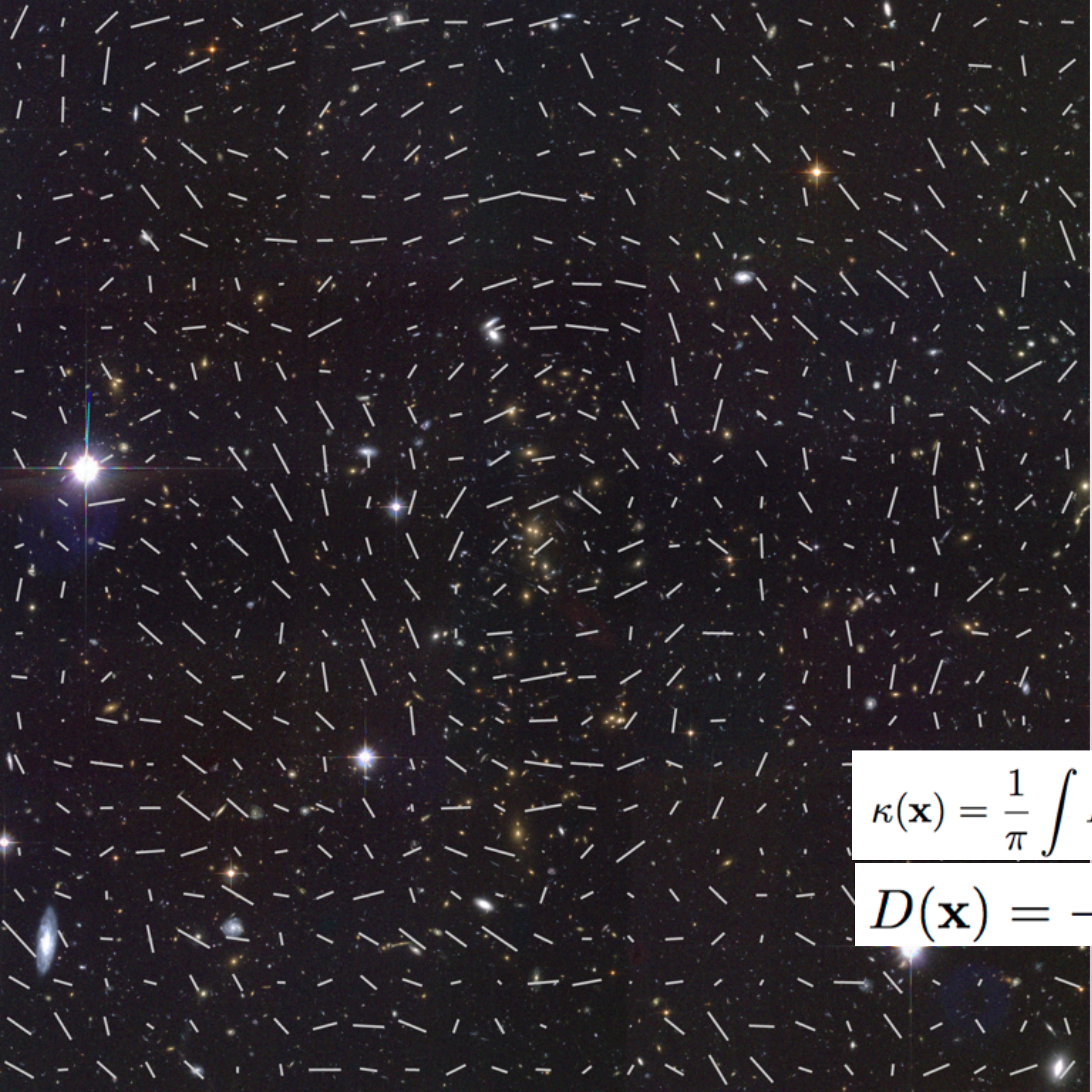
CL0152-1357
z=0.83



CL0152-1357
z=0.83

Divide the field into tiles

Measure shapes of background galaxies



CL0152-1357
z=0.83

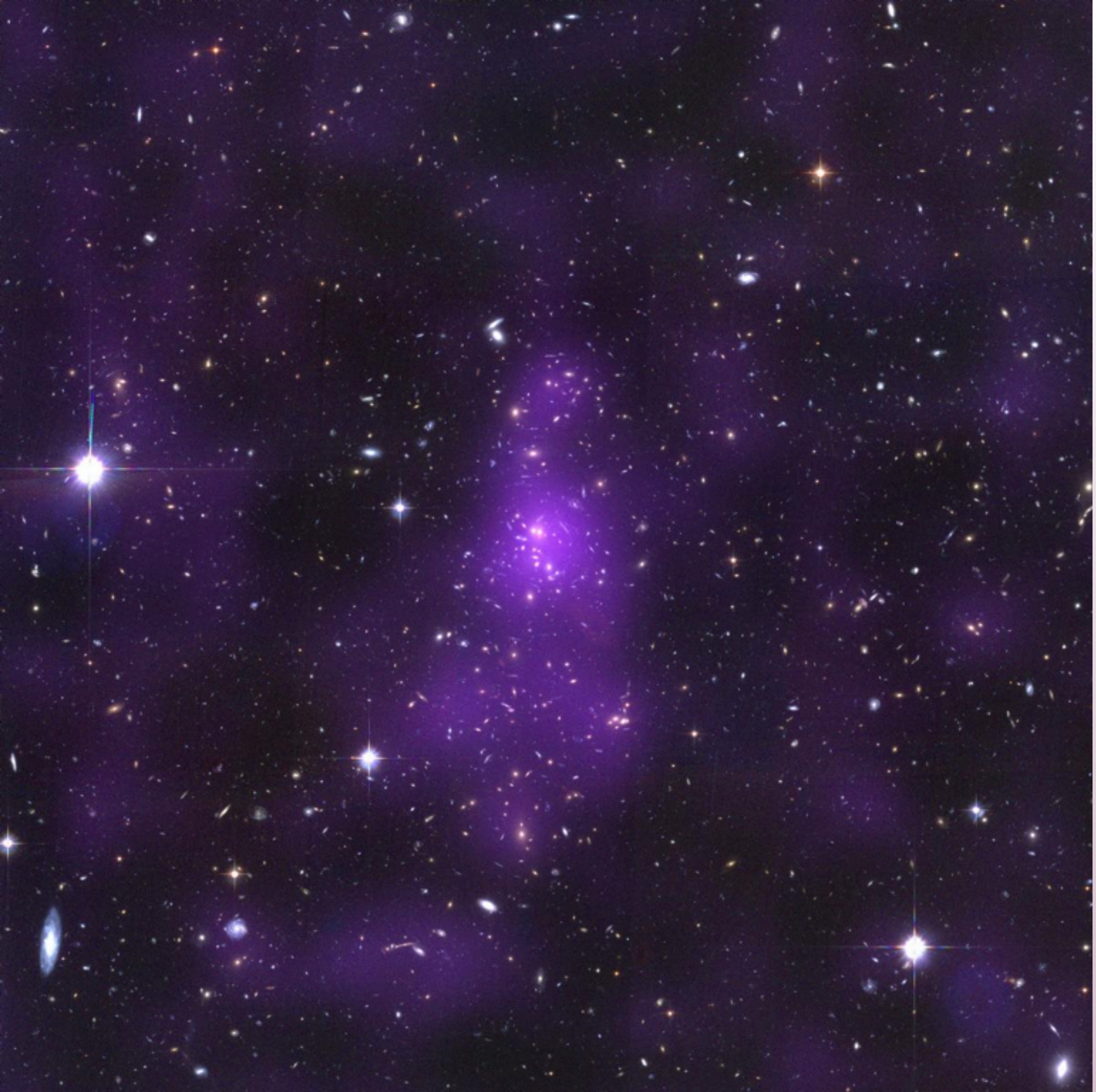
Divide the field into tiles

Measure shapes of background galaxies

Average ellipticity

$$\kappa(\mathbf{x}) = \frac{1}{\pi}\int D^*(\mathbf{x}-\mathbf{x}')\gamma(\mathbf{x}')d^2\mathbf{x}'$$

$$D(\mathbf{x}) = -1/(x_1 - ix_2)^2$$



CL0152-1357
z=0.83

Divide the field into tiles

Measure shapes of background galaxies

Average ellipticity

Mass map

Dark matter distribution revealed

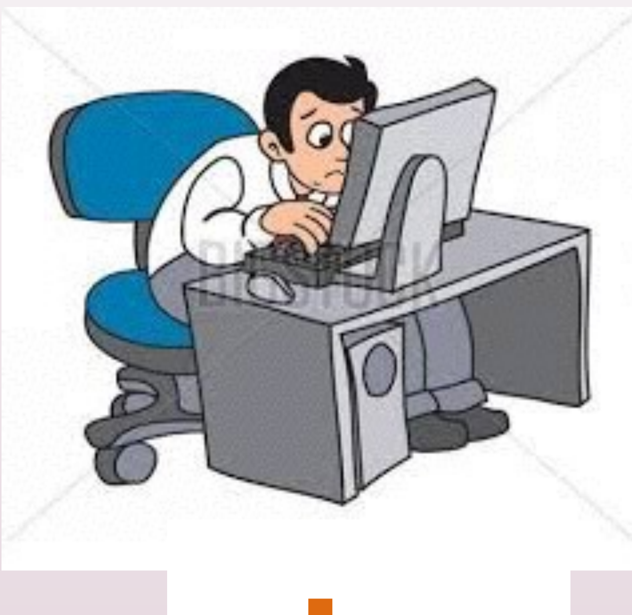
Consistent with galaxy distribution

A WARNING

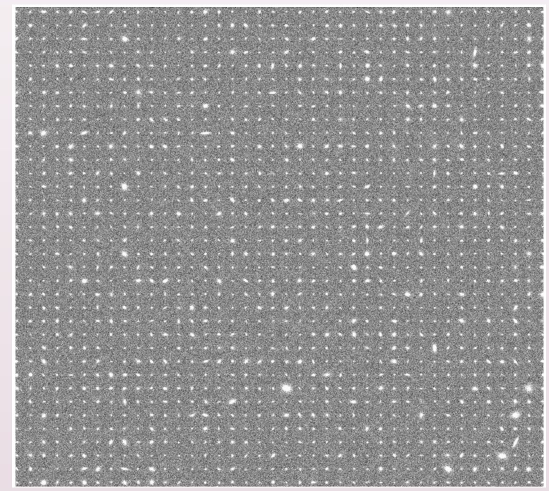
Interpretation of future WL surveys will be limited by systematics

Intrinsic shape | **Lensed** | **Atmospheric turbulence** | **Pixelated** | **Noise added**

BLIND SHEAR CHALLENGE



Analyze

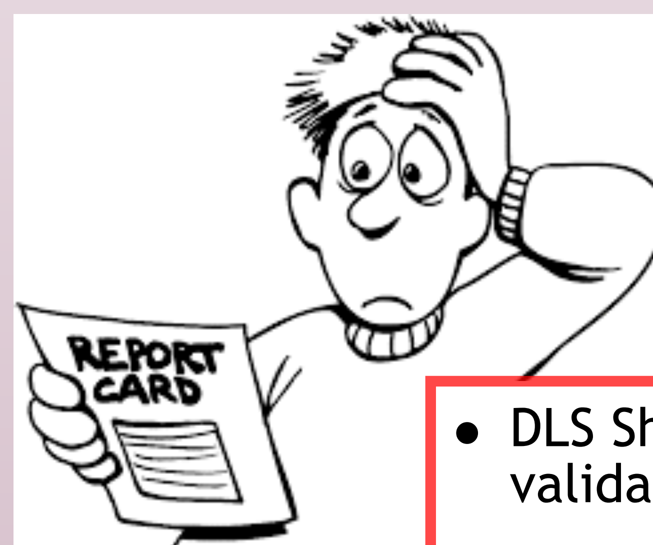


~1 million galaxy images

Download

upload

feedback



- DLS Shape measurement was validated:

  Winner of ‘Great3 Challenge’ [Mandelbaum et al. 2015].

Merits of Weak Lensing

- Measure something that does not give off light
- Powerful probe of dark matter distribution
- Sensitive only to mass (no dynamical assumption)
- Not limited by astrophysics
- Large scale structure (linear regime)

OUTLINE

- **Introduction to weak lensing**
- **DLS Cosmology**
- **Summary**

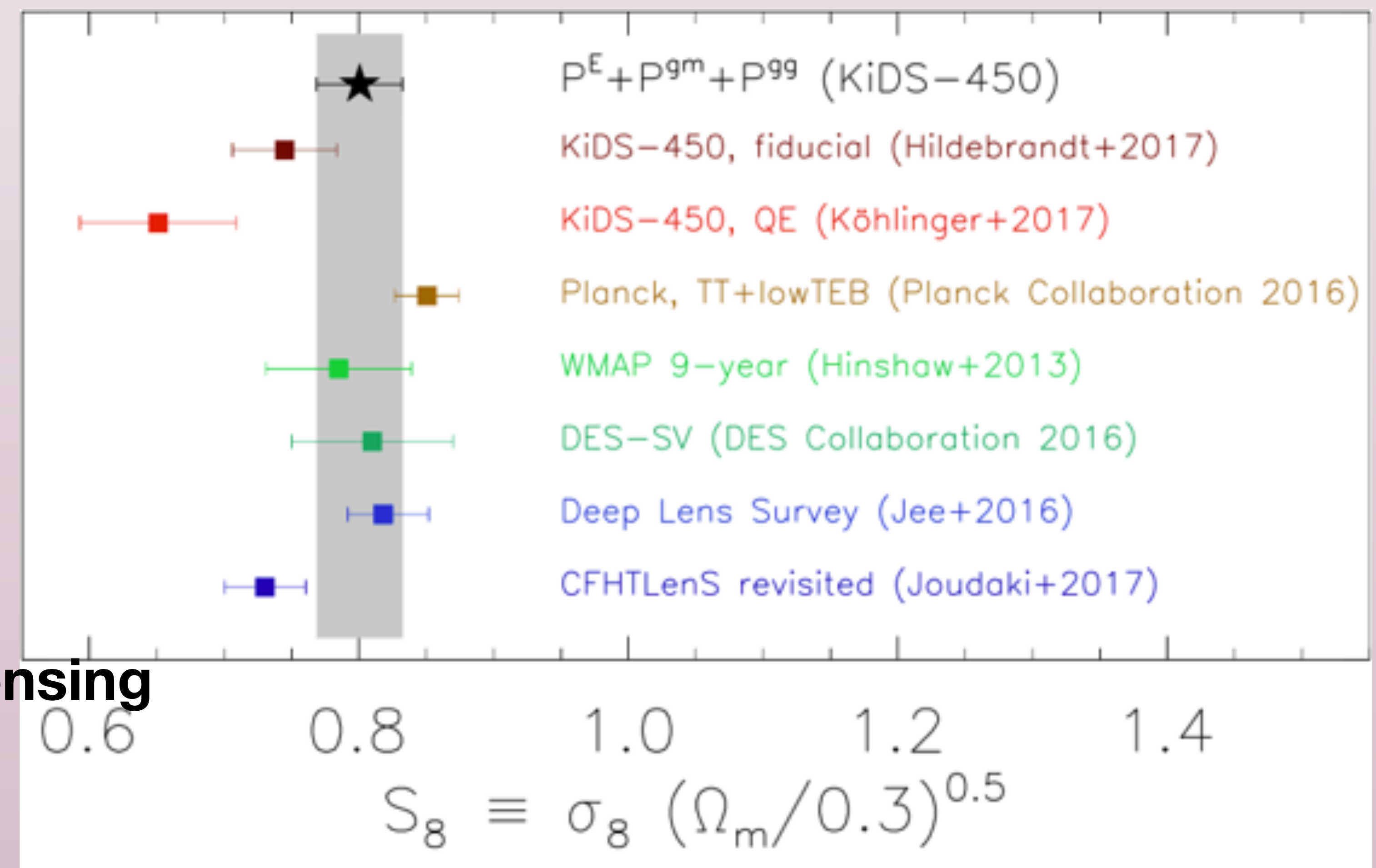
Tensions in Cosmology

1. Tension in
Hubble constant
CMB vs. Direct measurement

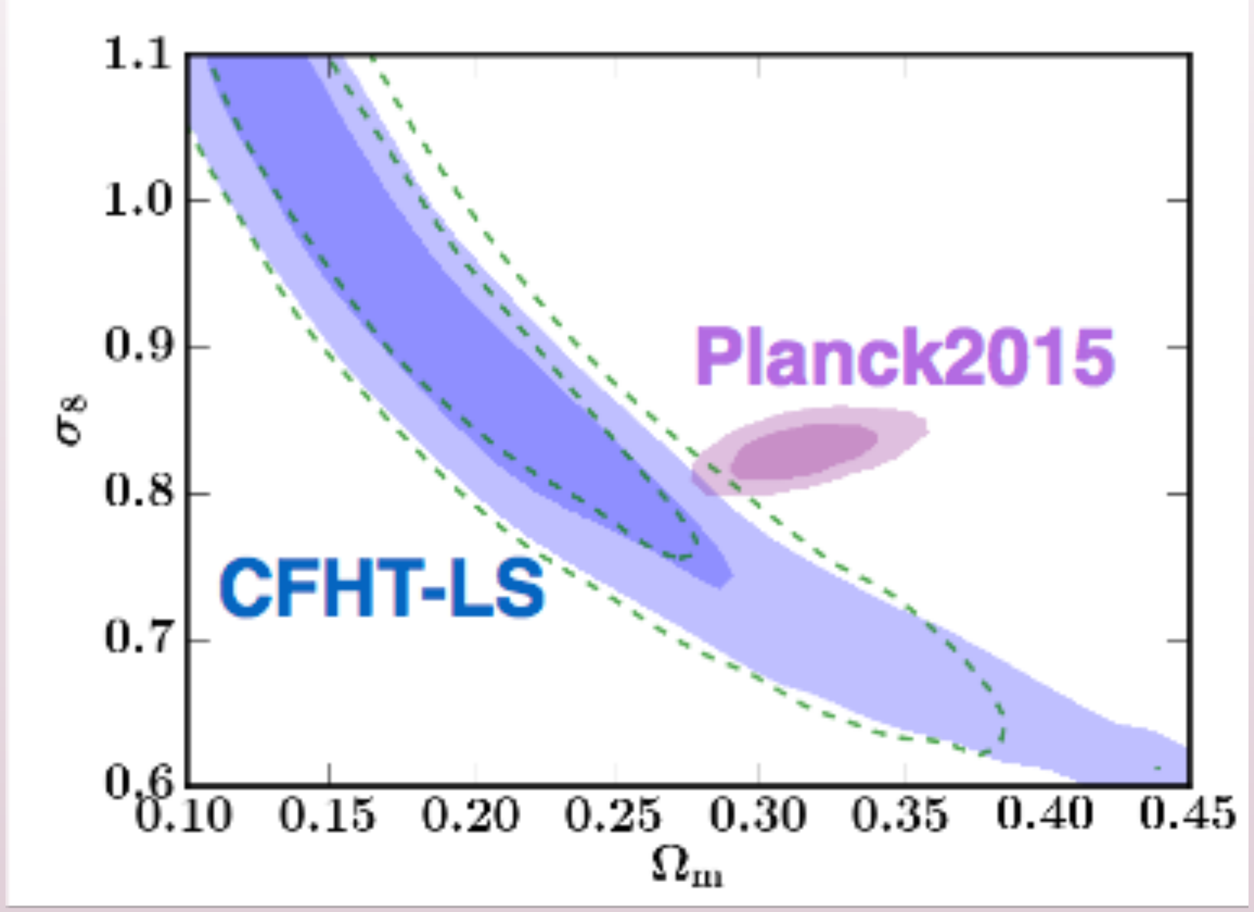
PlanckTT15+lowP_HFI H_0=66.9±0.9
Planck coll. 2016 arXiv:1605.02985
Riess+ 2016 H_0=73.02±1.79

3σ tension

2. Tension in S_8
CMB vs.
Galaxy clustering + Weak lensing



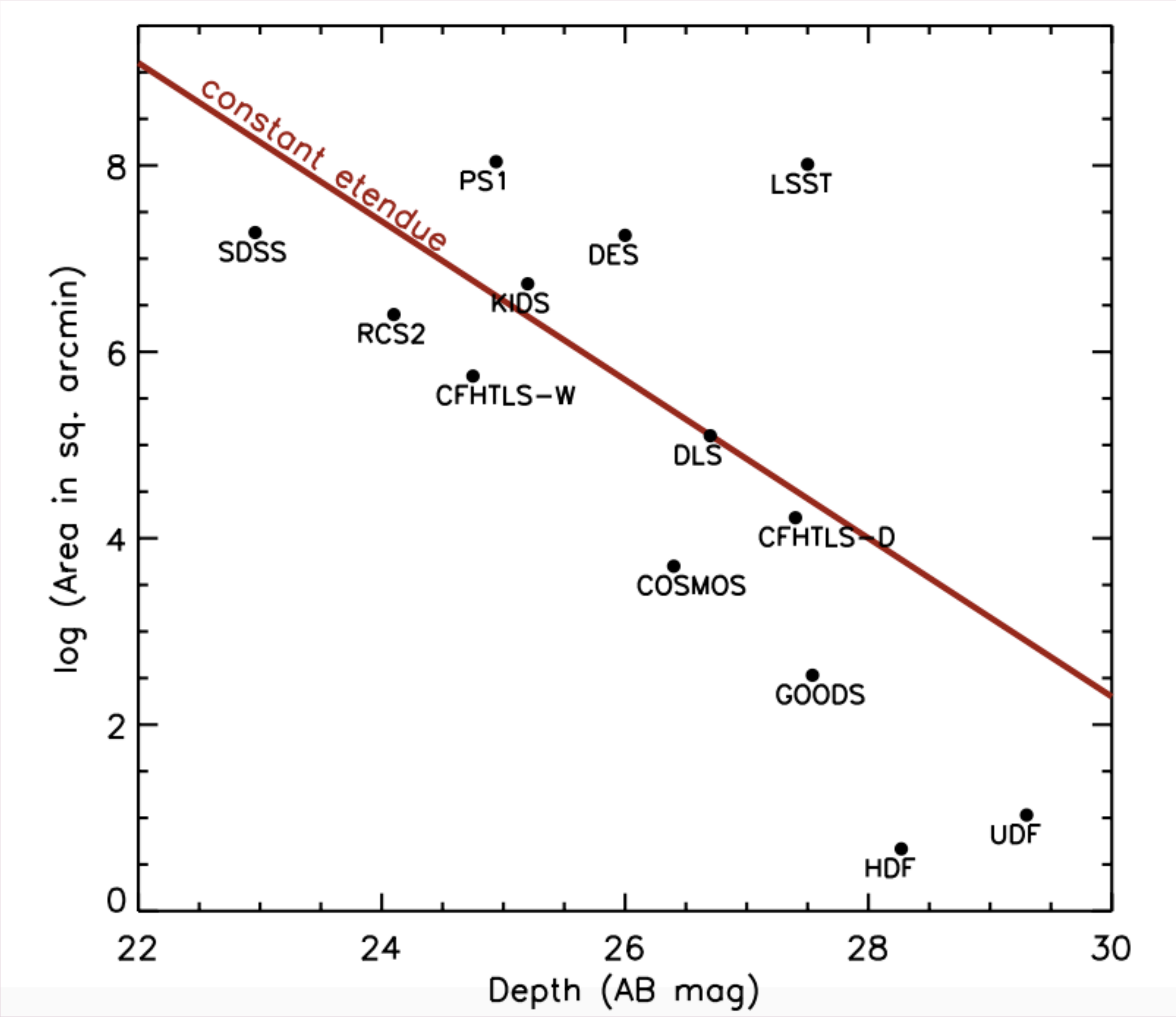
Cosmology Crisis?

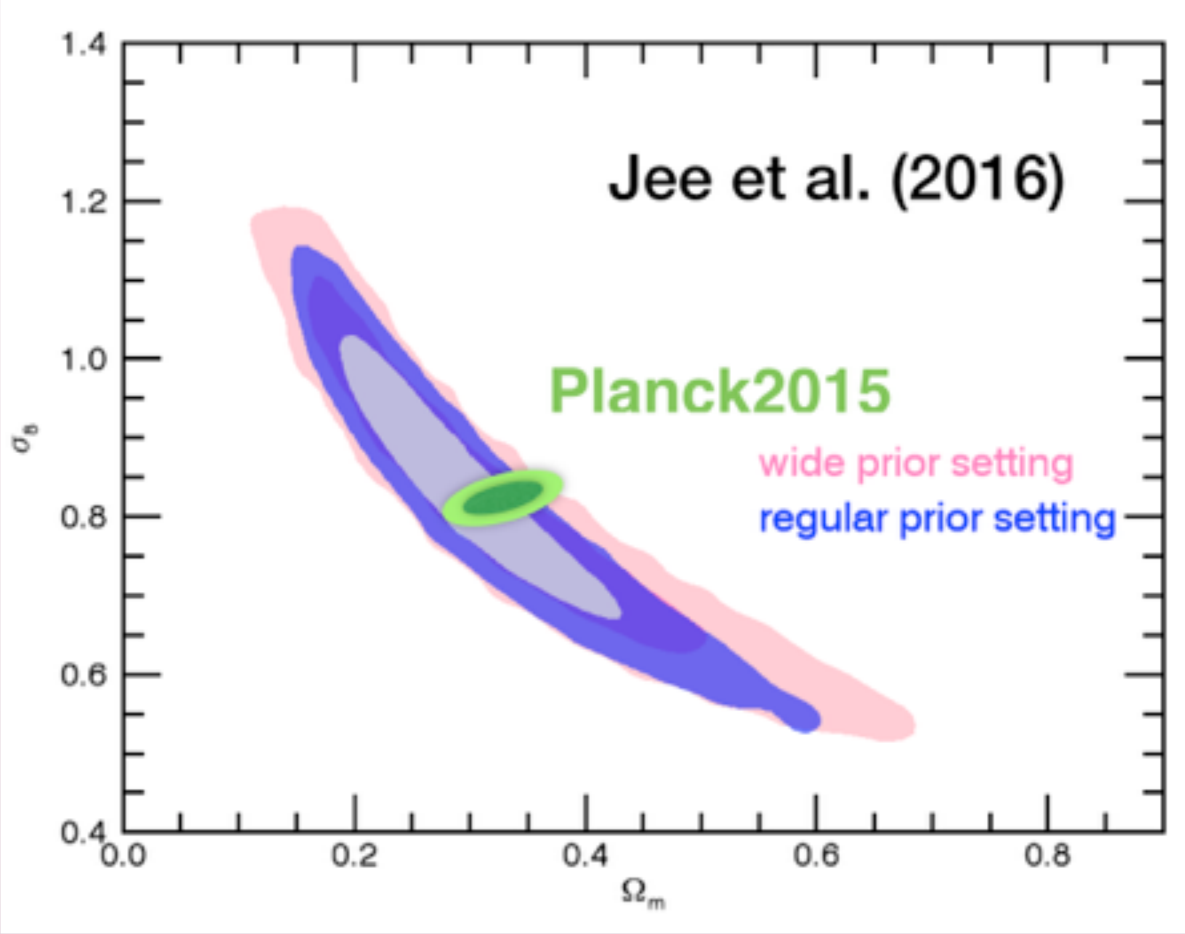


MacCrann et al. (2015)

Can change of neutrino mass or intrinsic alignment alleviate the tension?

Deep Lens Survey





- DLS is dedicated to deeper depth.
  (BVRz' magnitudes ~ down to 27th mag)
  - ✓ good for accurate shape measurement.
  - ✓ optimal for cosmological studies.

Cosmic Shear Result of DLS

Cosmic shear study in DLS investigated dark matter clustering.

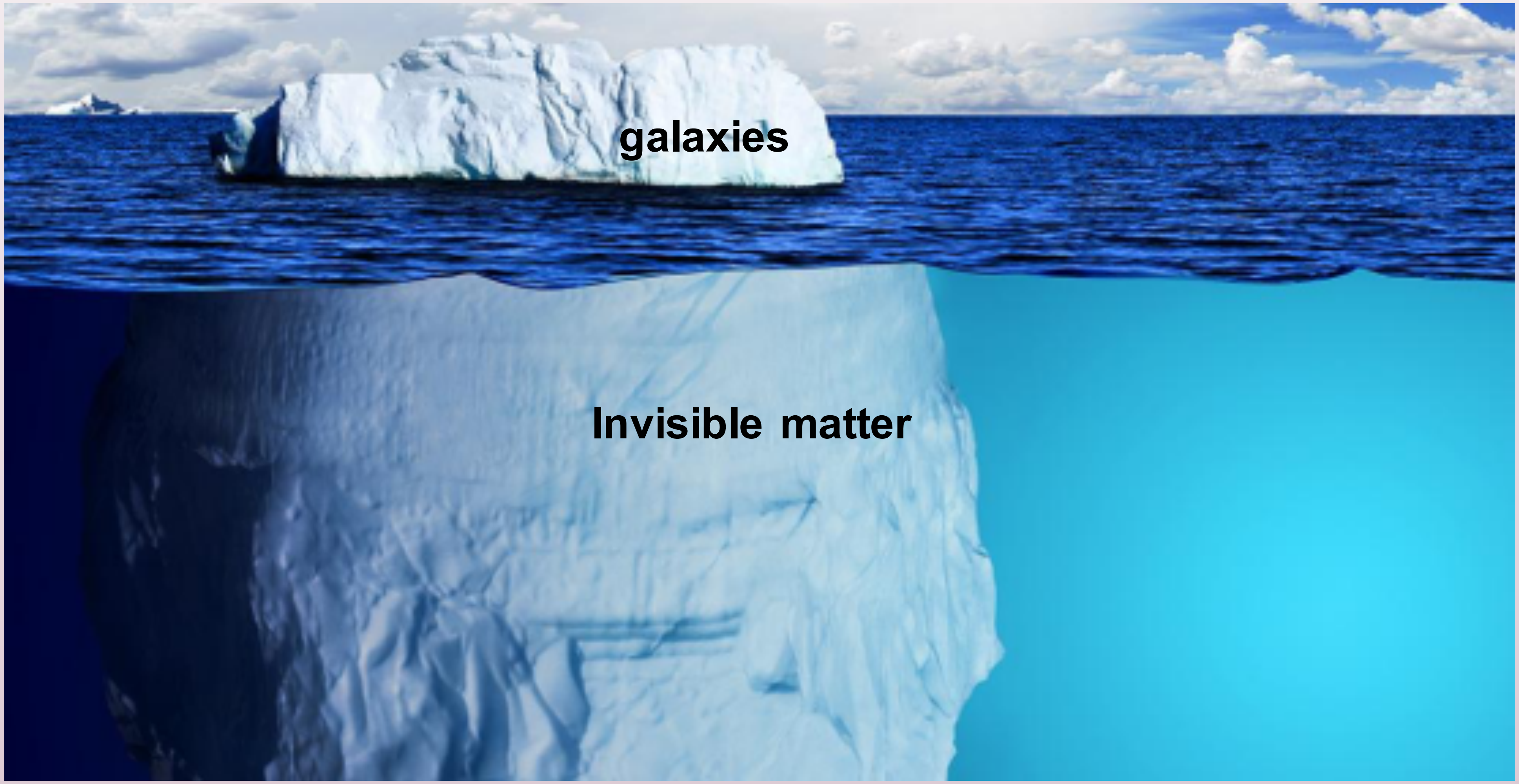
Deep Lens Survey

- DLS has BVRz' band images.
- DLS has widely separated 5 fields, 4 deg^2 each.

Mayall Telescope at Kitt Peak

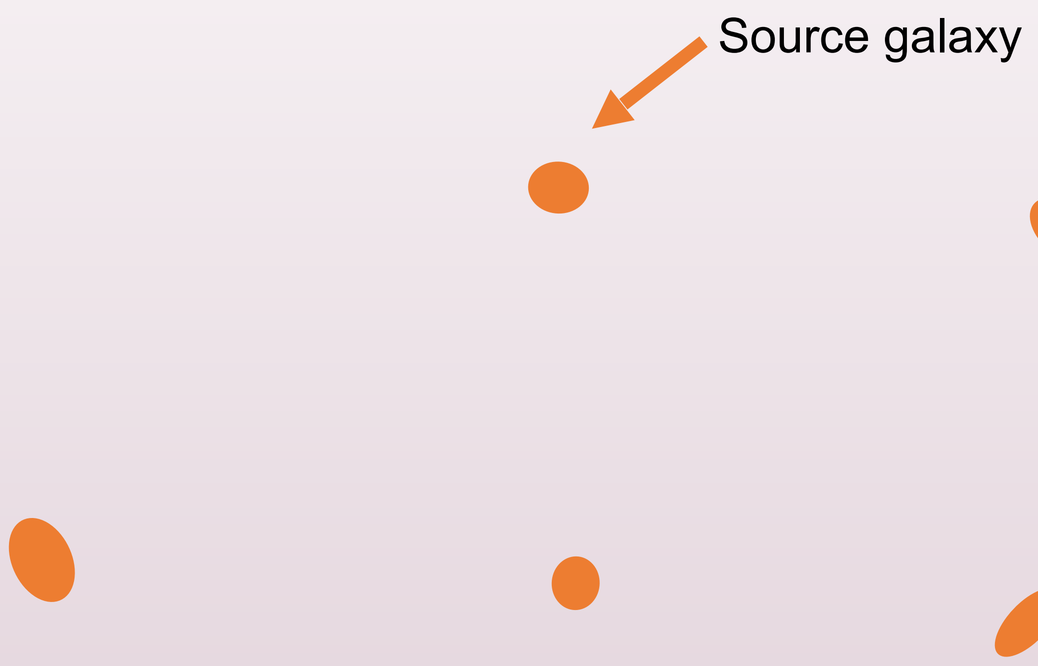
Blanco Telescope at CTIO

Galaxy-galaxy lensing

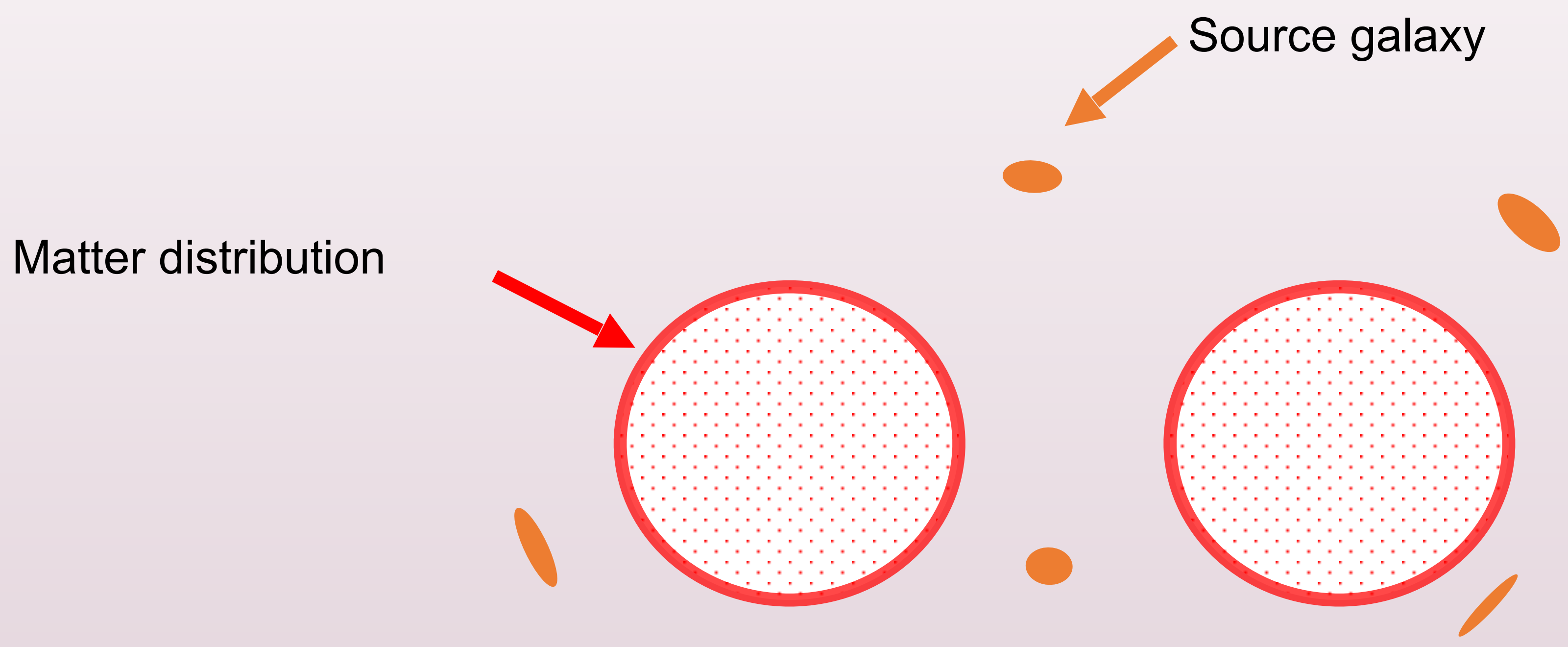


Galaxy-galaxy lensing reveals the distribution of matter around galaxies.
Galaxy Clustering + Galaxy-galaxy lensing-> Cosmological parameter constraints

Galaxy-galaxy lensing

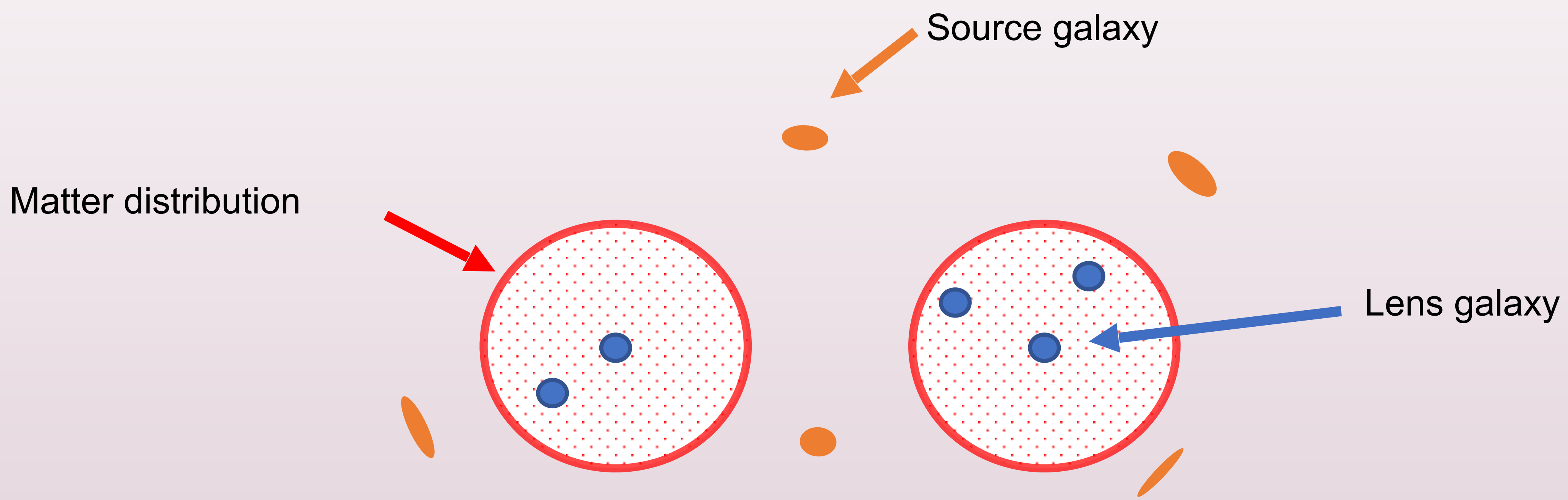


Galaxy-galaxy lensing



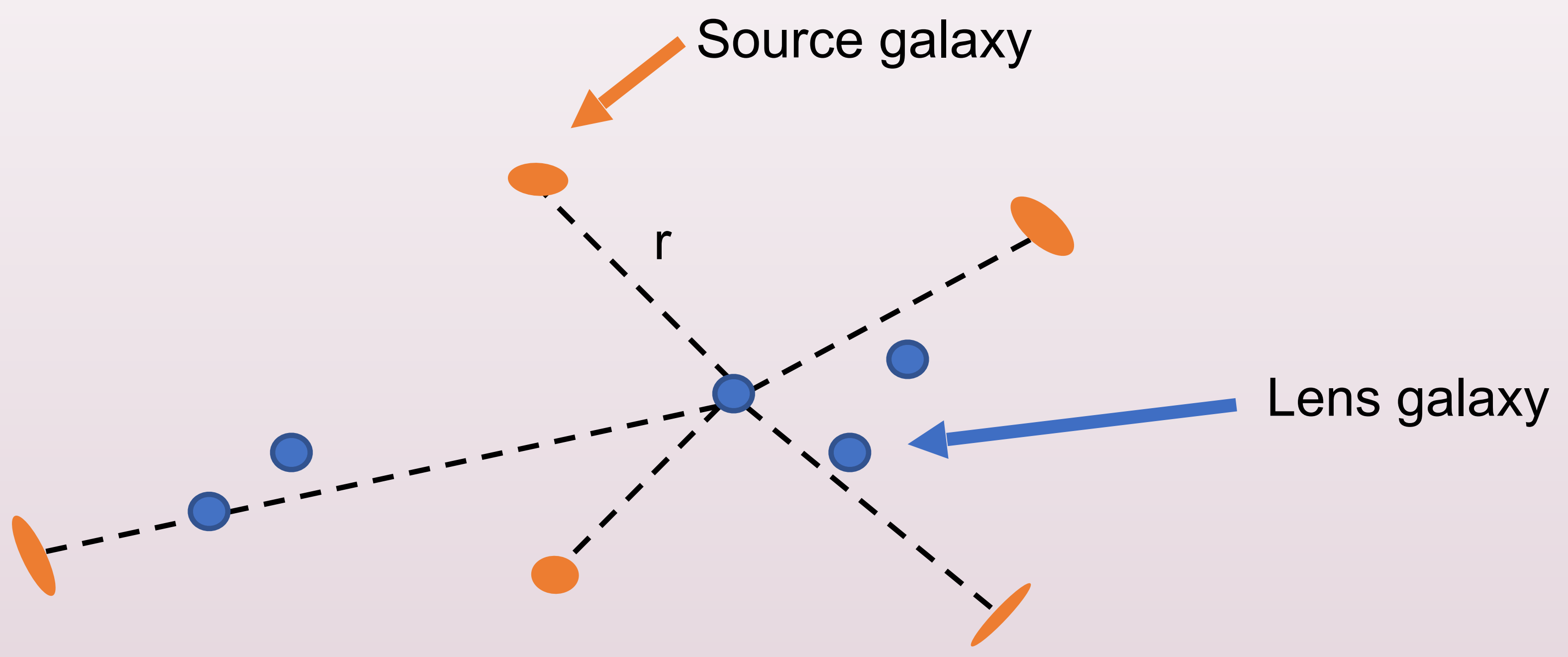
- The images of background galaxies get distorted by the mass of foreground matter distribution.

Galaxy-galaxy lensing



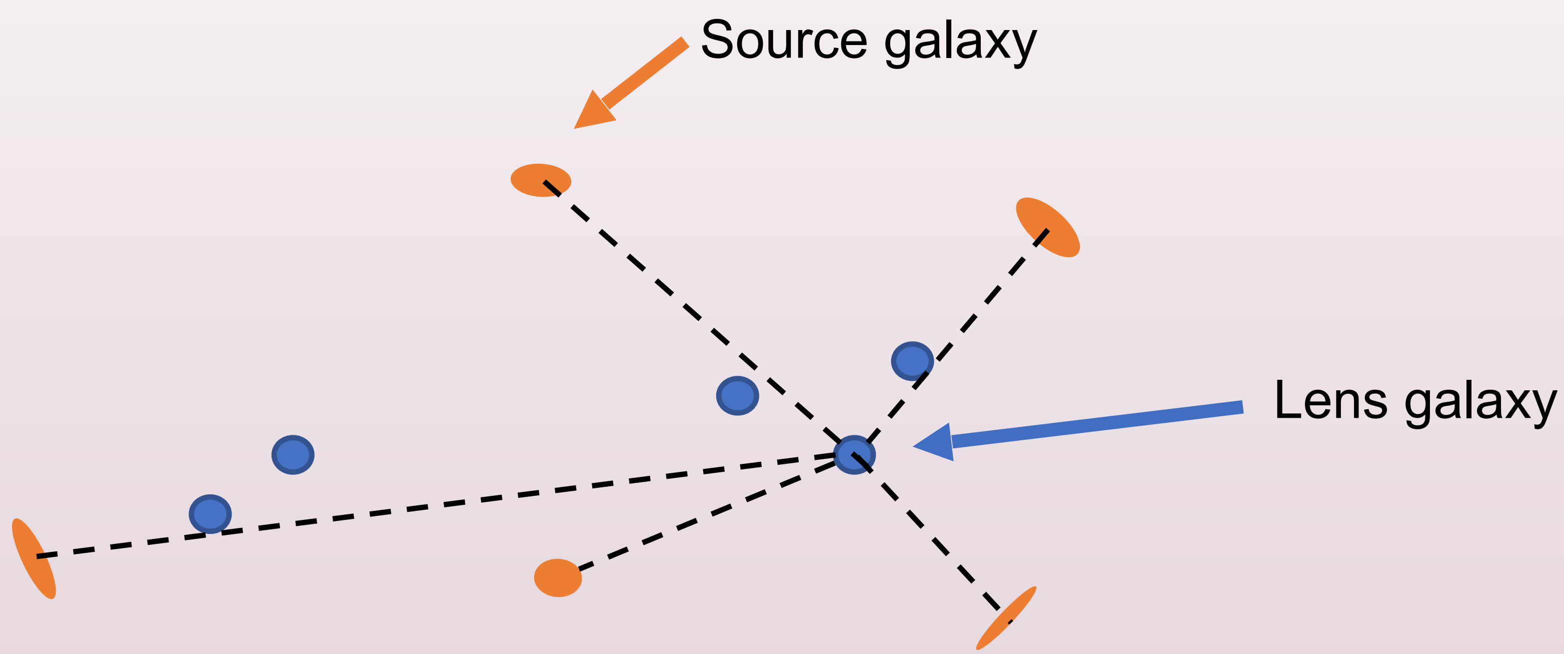
- The images of background galaxies get distorted by the mass of foreground matter distribution.

Galaxy-galaxy lensing



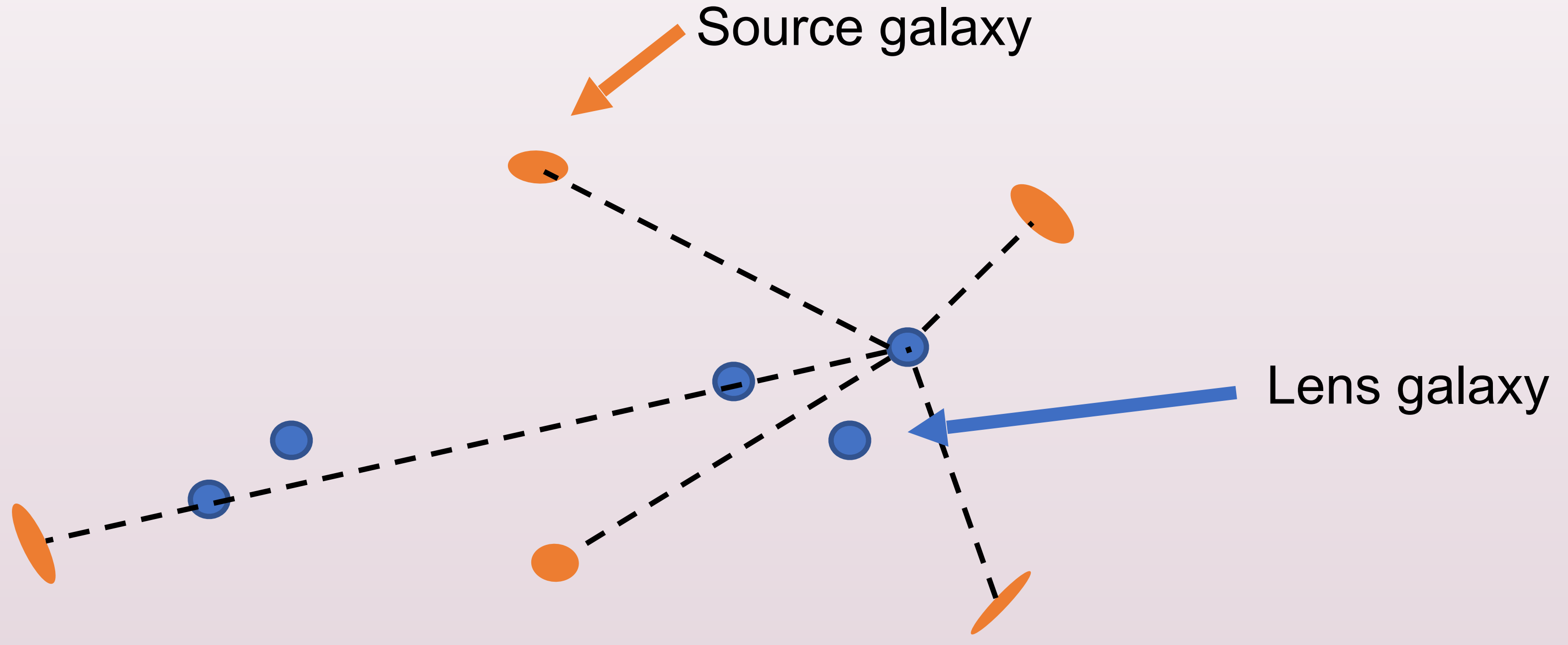
- The images of background galaxies get distorted by the mass of foreground matter distribution.
- The distortion is too weak for each individual lens galaxy.

Galaxy-galaxy lensing



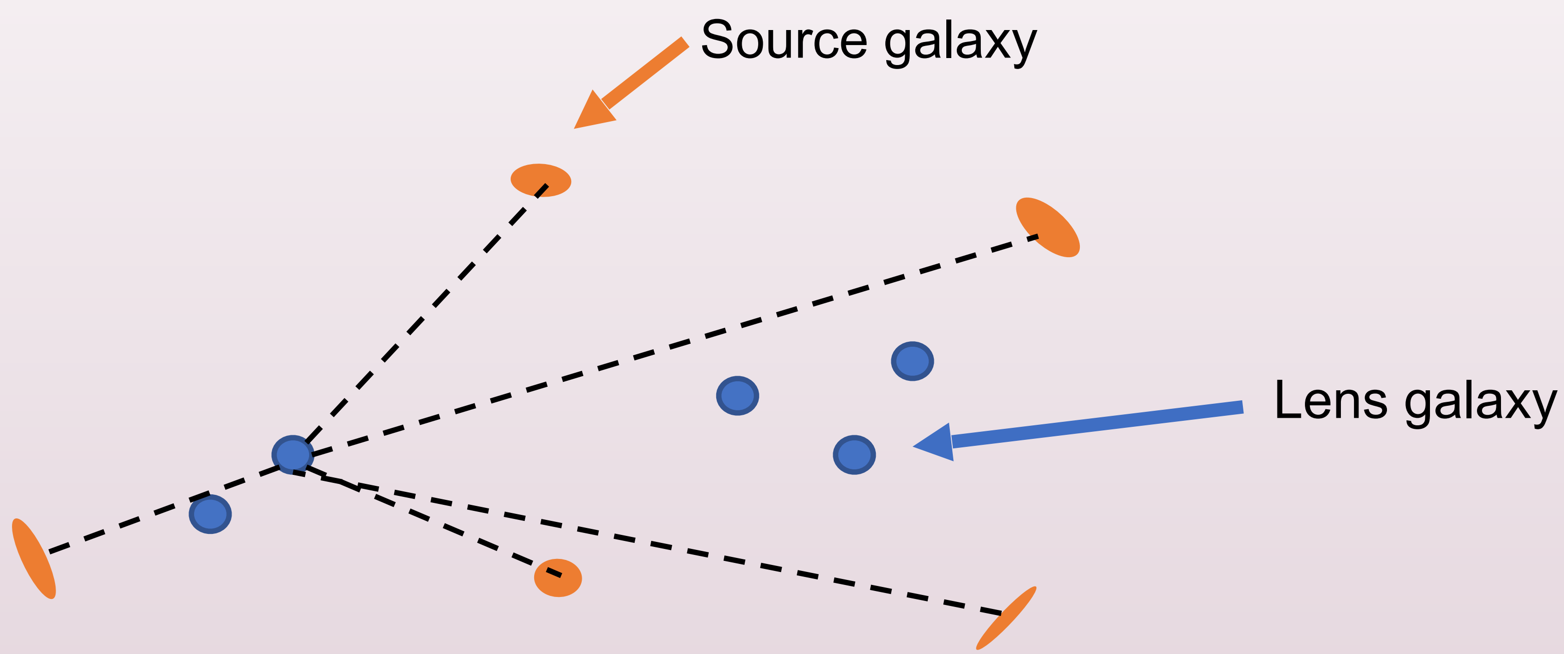
- The images of background galaxies get distorted by the mass of foreground matter distribution.
- The distortion is too weak for each individual lens galaxy.
- The signal needs to be stacked up for all the pairs of lens and source galaxies.

Galaxy-galaxy lensing



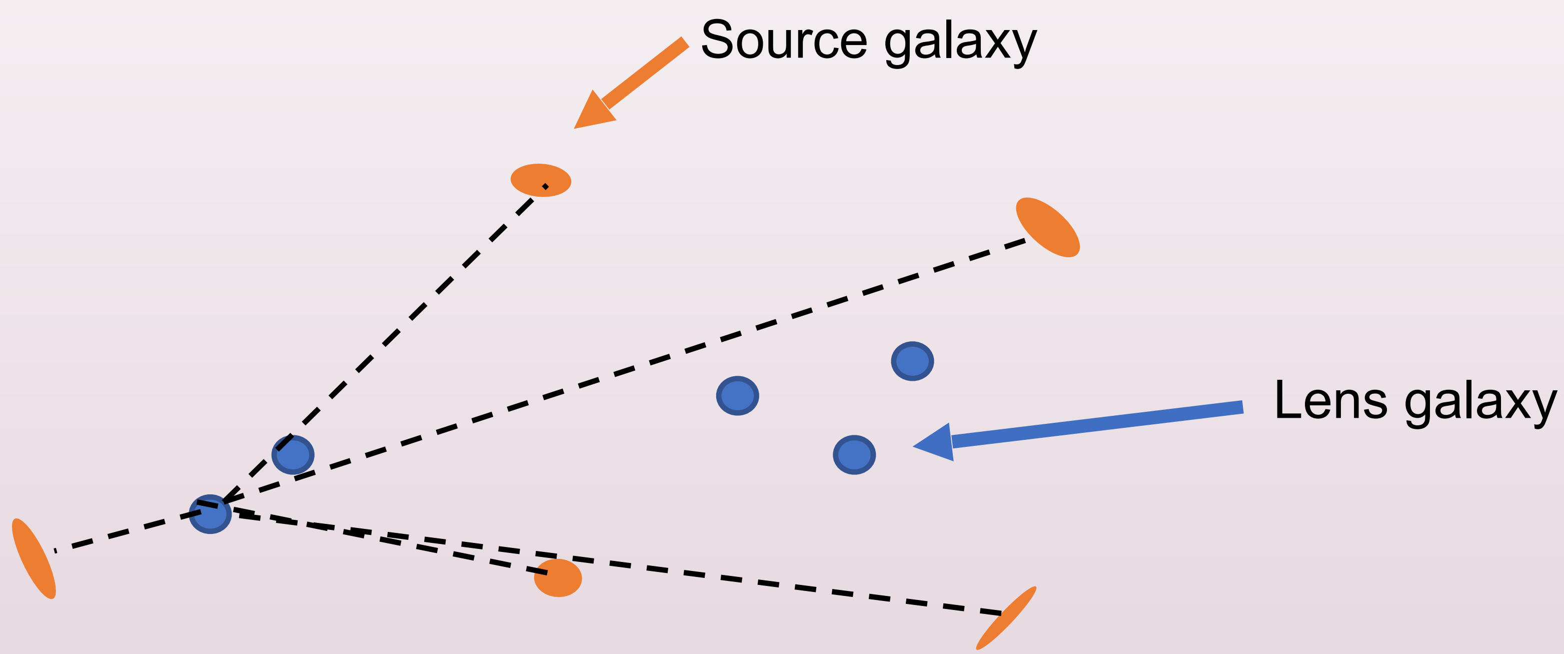
- The images of background galaxies get distorted by the mass of foreground matter distribution.
- The distortion is too weak for each individual lens galaxy.
- The signal needs to be stacked up for all the pairs of lens and source galaxies.

Galaxy-galaxy lensing



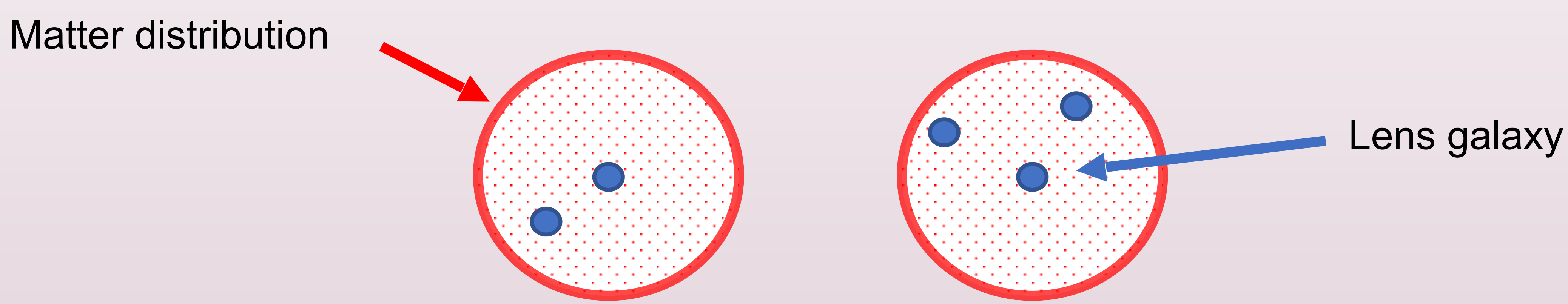
- The images of background galaxies get distorted by the mass of foreground matter distribution.
- The distortion is too weak for each individual lens galaxy.
- The signal needs to be stacked up for all the pairs of lens and source galaxies.

Galaxy-galaxy lensing



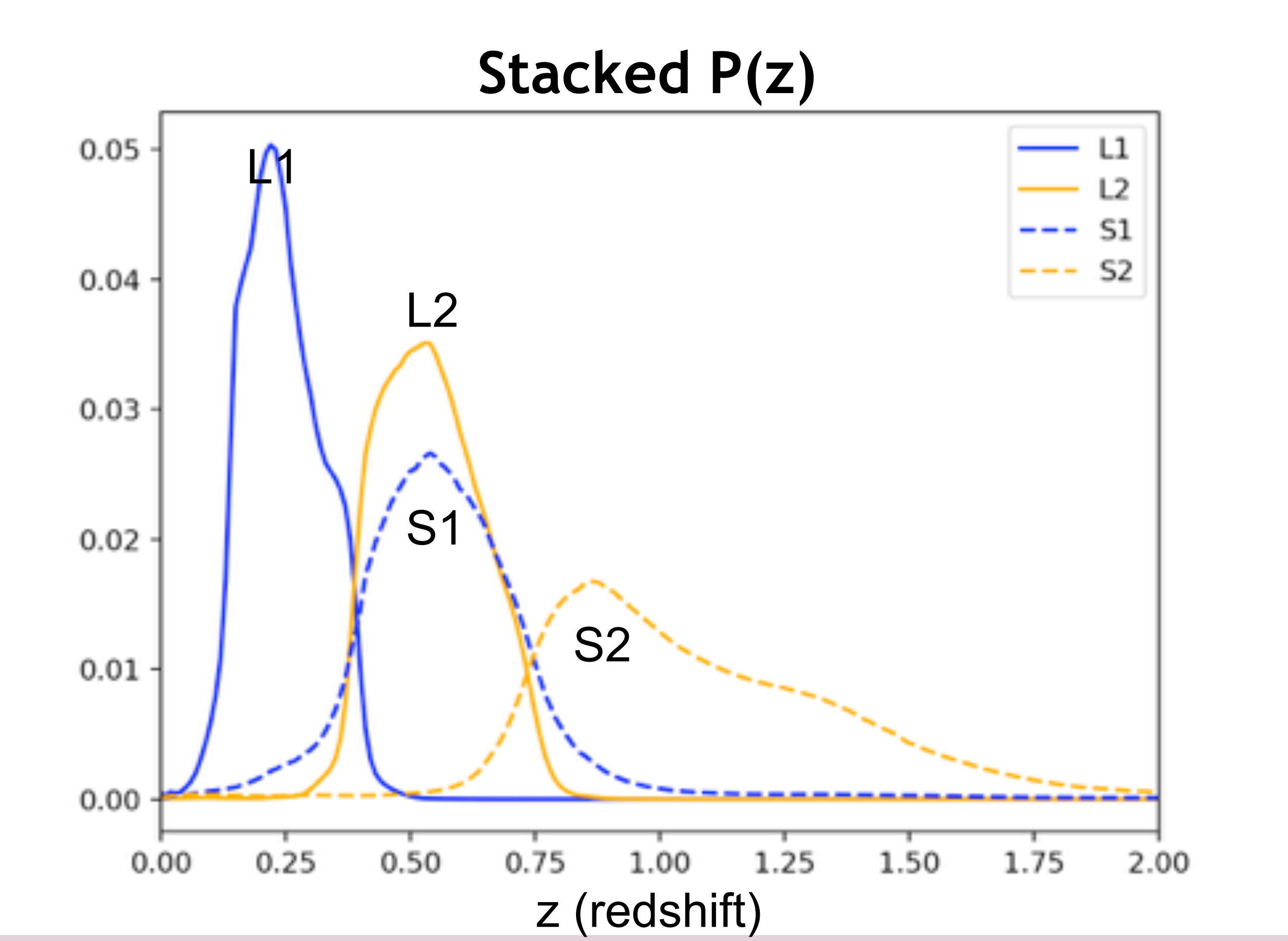
- The images of background galaxies get distorted by the mass of foreground matter distribution.
- The distortion is too weak for each individual lens galaxy.
- The signal needs to be stacked up for all the pairs of lens and source galaxies.

Galaxy-galaxy lensing



- Eventually, the measured shear informs how matter is distributed around lens galaxies.

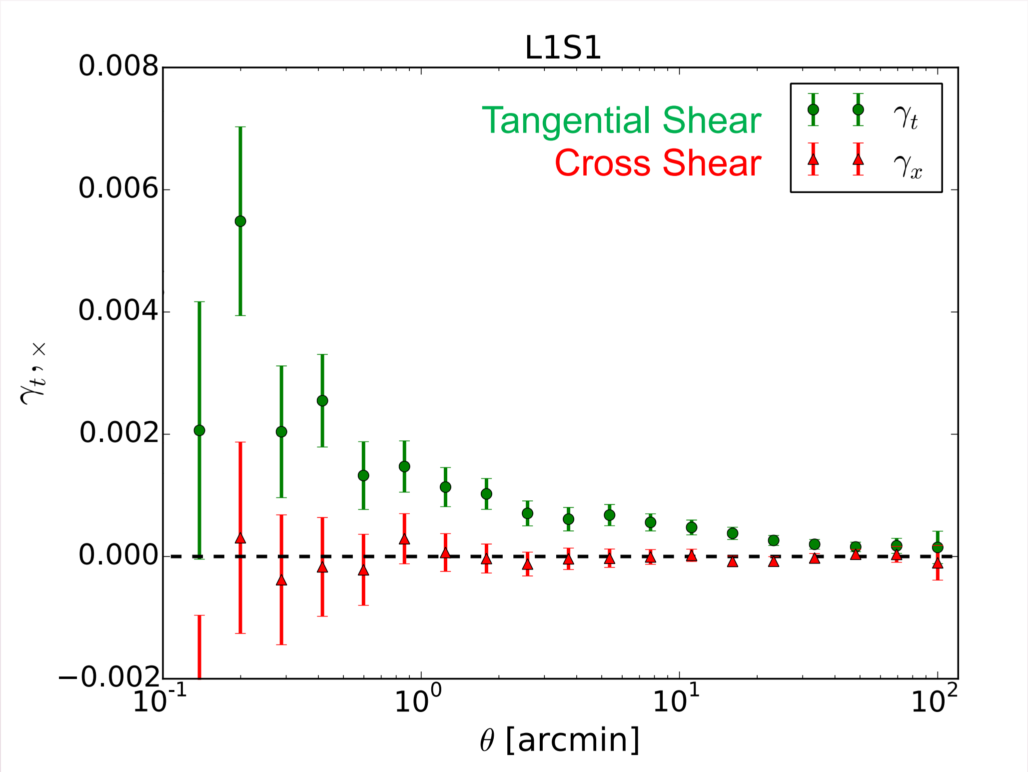
Lens & Source selection

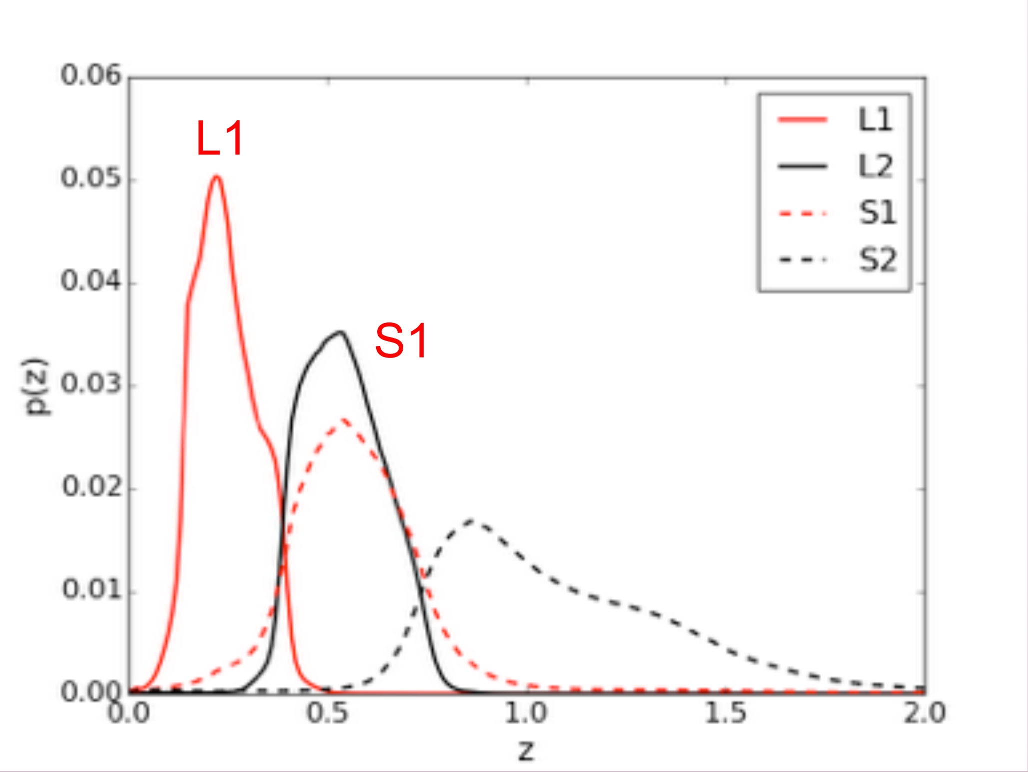


	Redshift cut		Magnitude cut		
	z_b -	**z_b +**	**m_R -**	**m_R +**	**# of galaxy**
L1	0.1	0.4	18	21	57,802
L2	0.4	0.75	18	22	98,267
S1	0.4	0.75	21	24.5	418,932
S2	0.75	1.5	21	24.5	450,353

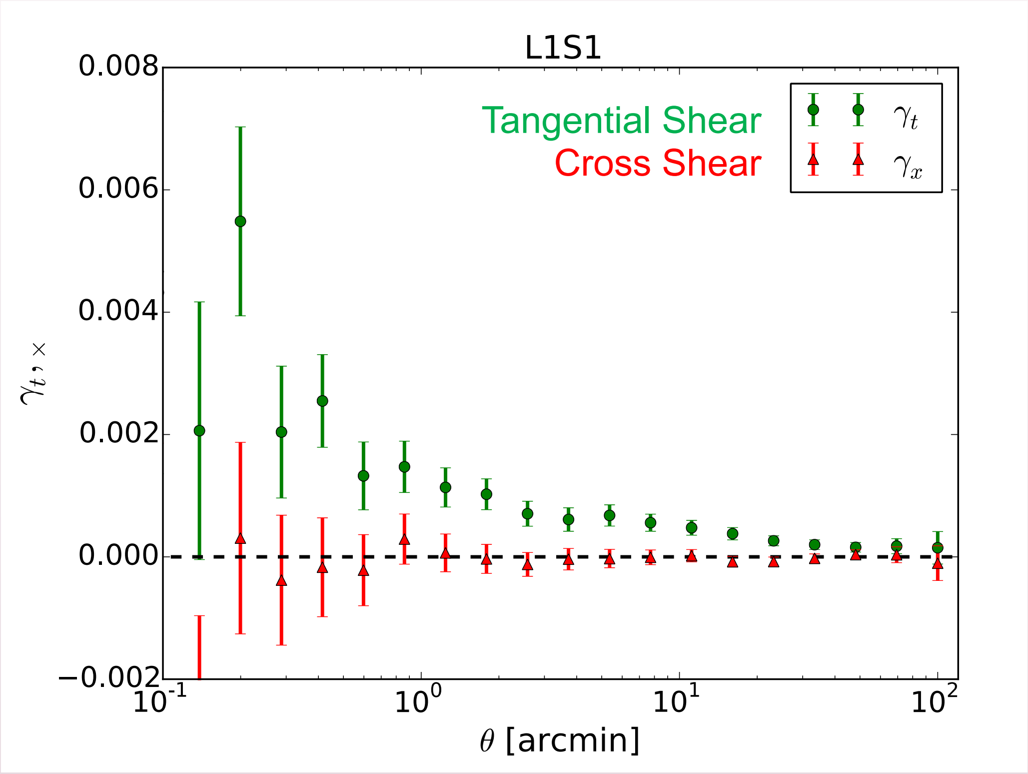
- For lens objects, bright galaxies were selected to increase the signal.
- Source criteria: Status = 1, de <0.3, b > 0.3
- Galaxy clustering: L1, L2
- Galaxy-galaxy lensing: L1 – S1, L1 – S2, L2 – S2

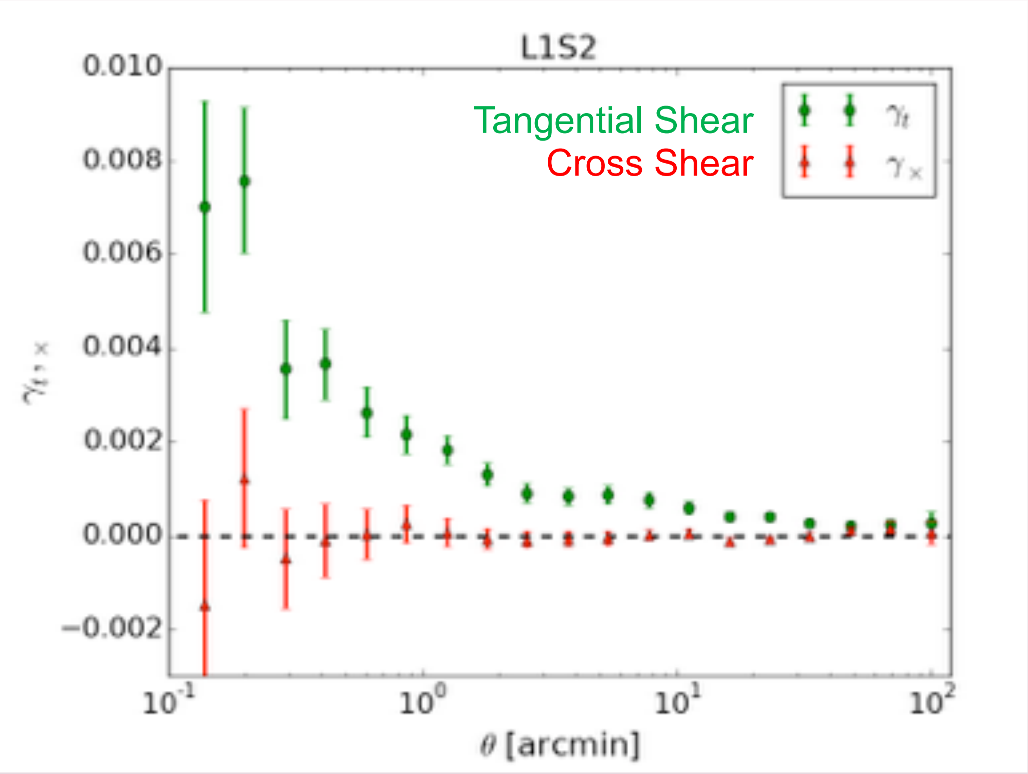
Shear measurement

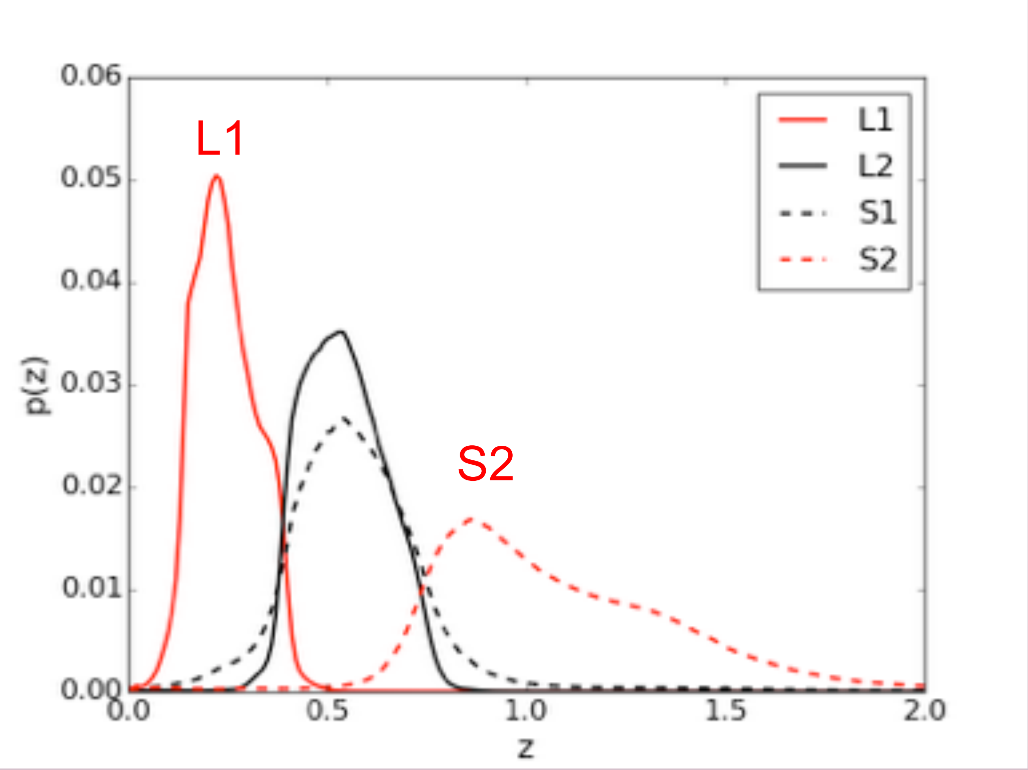




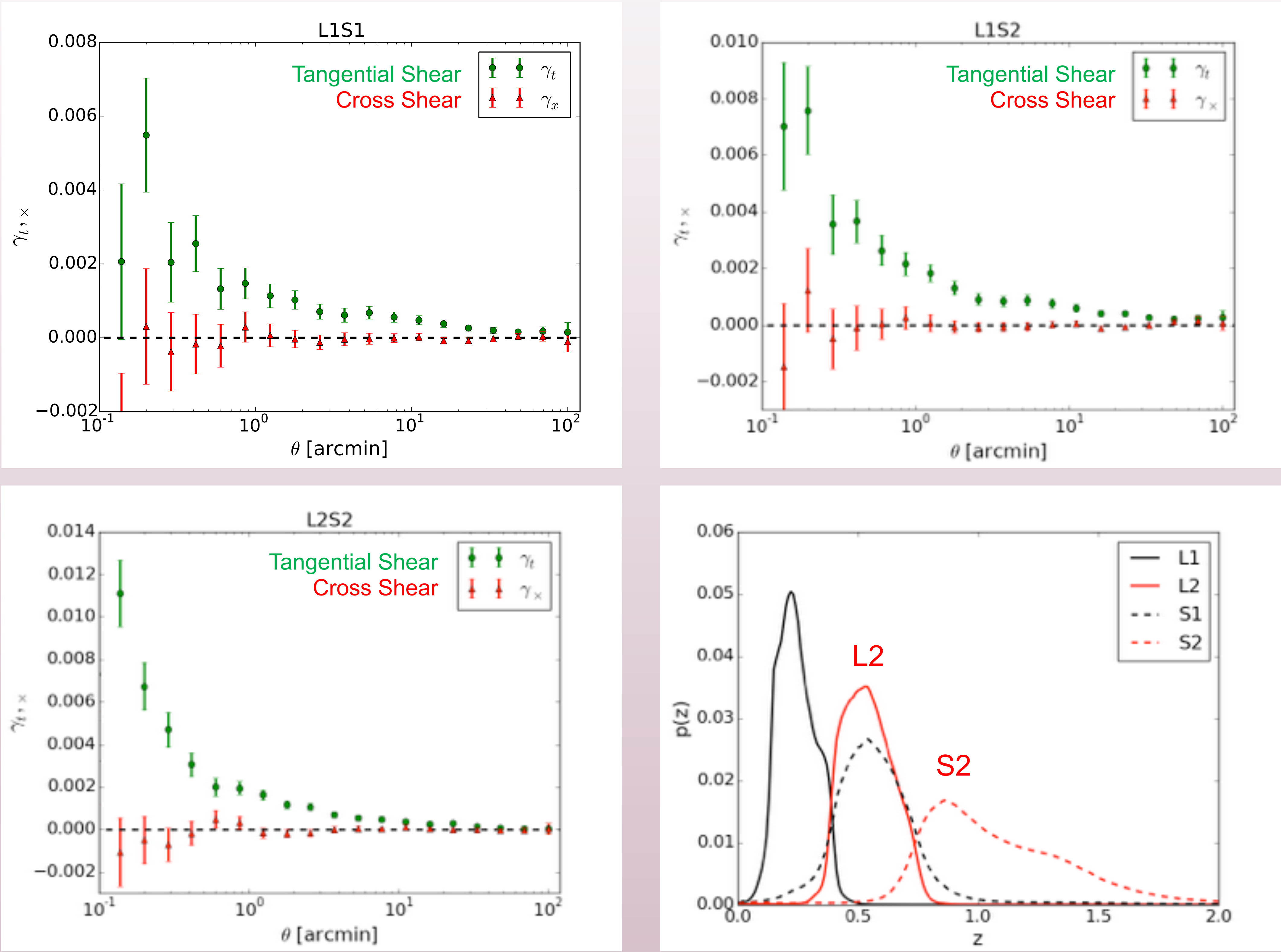
Shear measurement







Shear measurement



Correlation in real space
-> Power spectrum

Galaxy clustering

$$P^{gg}_{band,i} = \frac{2\pi}{\Delta_i} \int_{\theta_{min}}^{\theta_{max}} \frac{d\theta}{\theta} w(\theta) [f(\ell_{iu}\theta) - f(\ell_{il}\theta)]$$

$$f(x) = xJ_1(x)$$

Tangential shear

$$P^{gm}_{band,i} = \frac{2\pi}{\Delta_i} \int_{\theta_{min}}^{\theta_{max}} \frac{d\theta}{\theta} \gamma_t(\theta) [h(\ell_{iu}\theta) - h(\ell_{il}\theta)]$$

$$h(x) = -xJ_1(x) - 2J_0(x)$$

Covariance of power spectra is more diagonal.

Cleaner separation of scales.

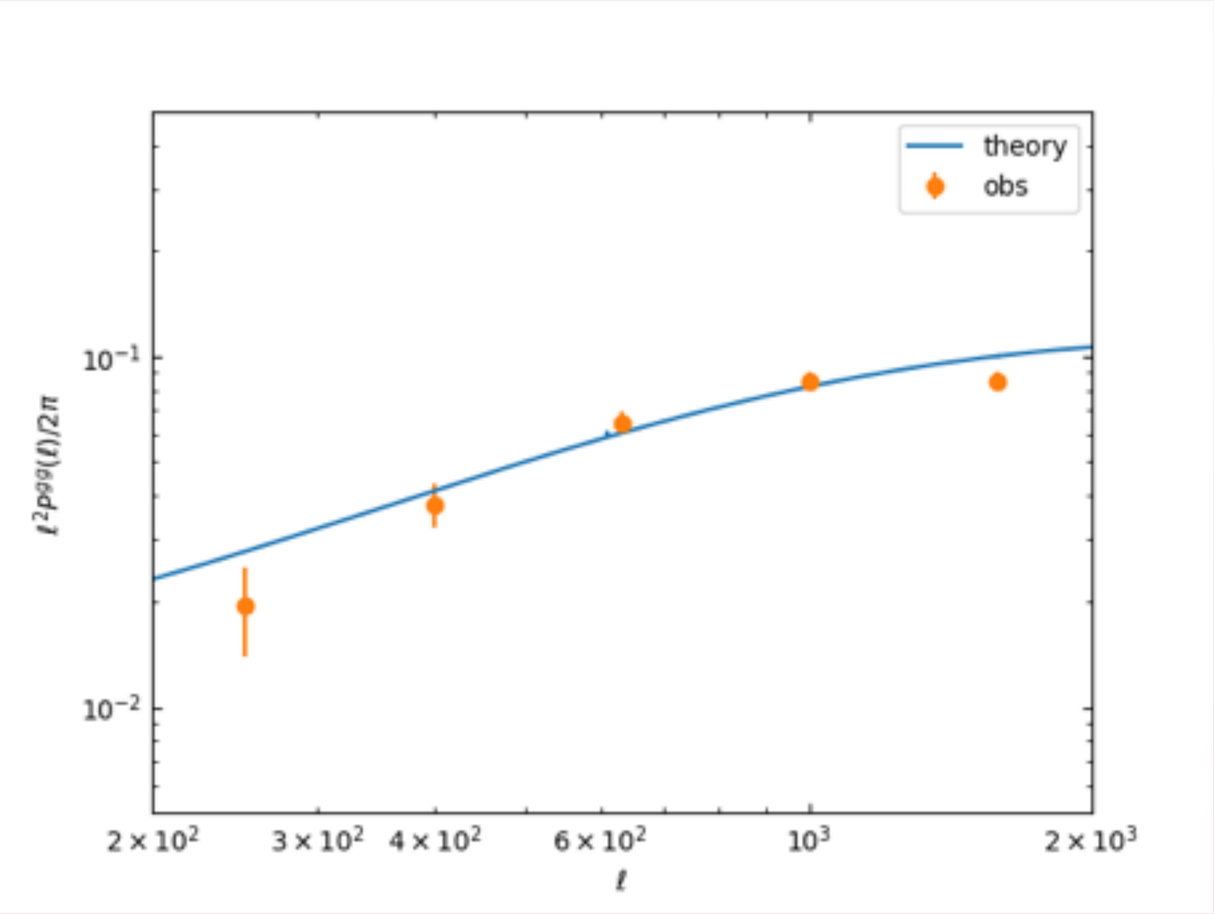
MCMC (Markov chain Monte Carlo) run setting

- Flat priors for 12 free parameters

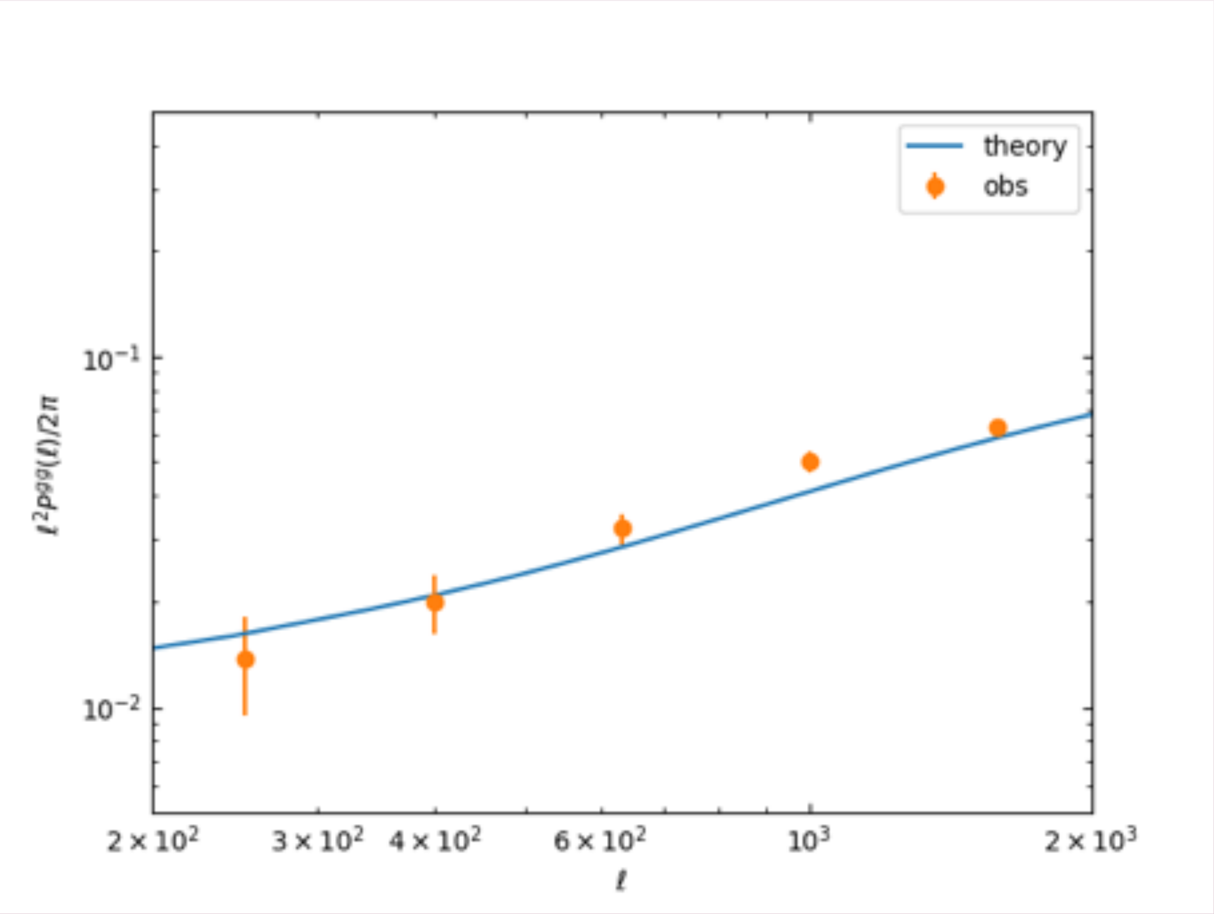
parameter	Lower bound	Upper bound
photo z error in L1	-0.02	+0.02
photo z error in L2	-0.02	+0.02
photo z error in S1	-0.02	+0.02
photo z error in S2	-0.02	+0.02
multiplicative shear calibration error	-0.02	+0.02
galaxy bias of L1 (b1)	0.1	2.5
galaxy bias of L2 (b2)	0.1	2.5
matter density (Ωm)	0.1	1.0
baryon density (Ωb)	0.03	0.06
Hubble constant (h)	0.55	0.85
power spectrum normalization ($\sigma 8$)	0.1	1.5
spectral index (ns)	0.6	1.2

Power spectrum (1)
Pgg: galaxy position – galaxy position

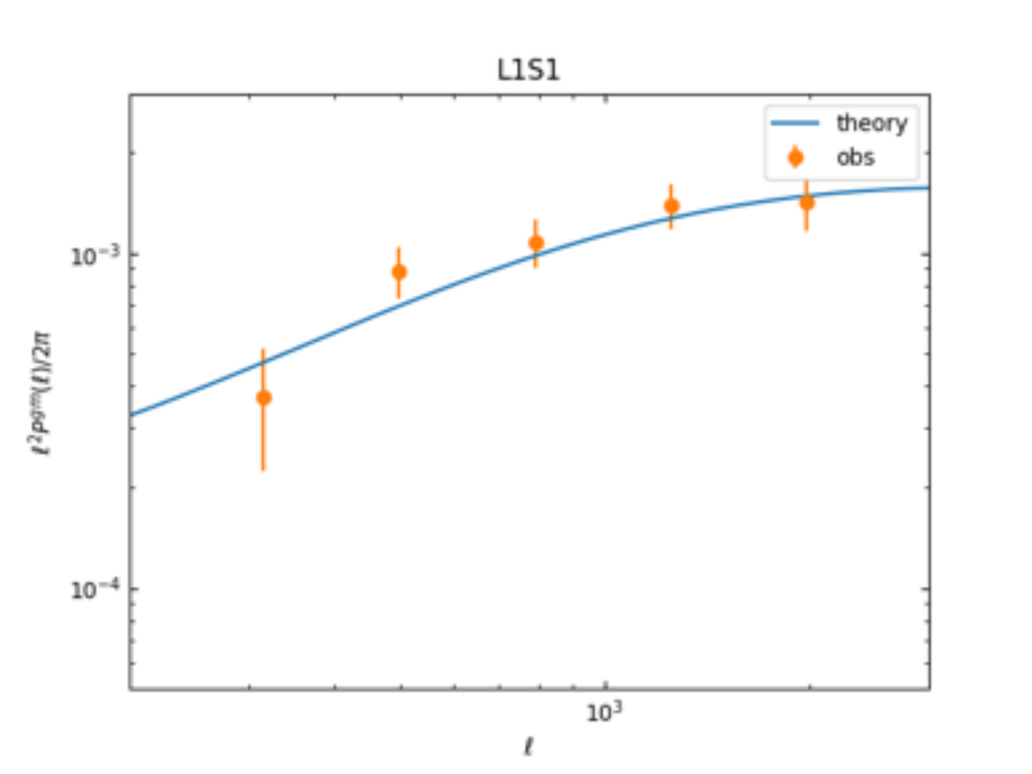
L1

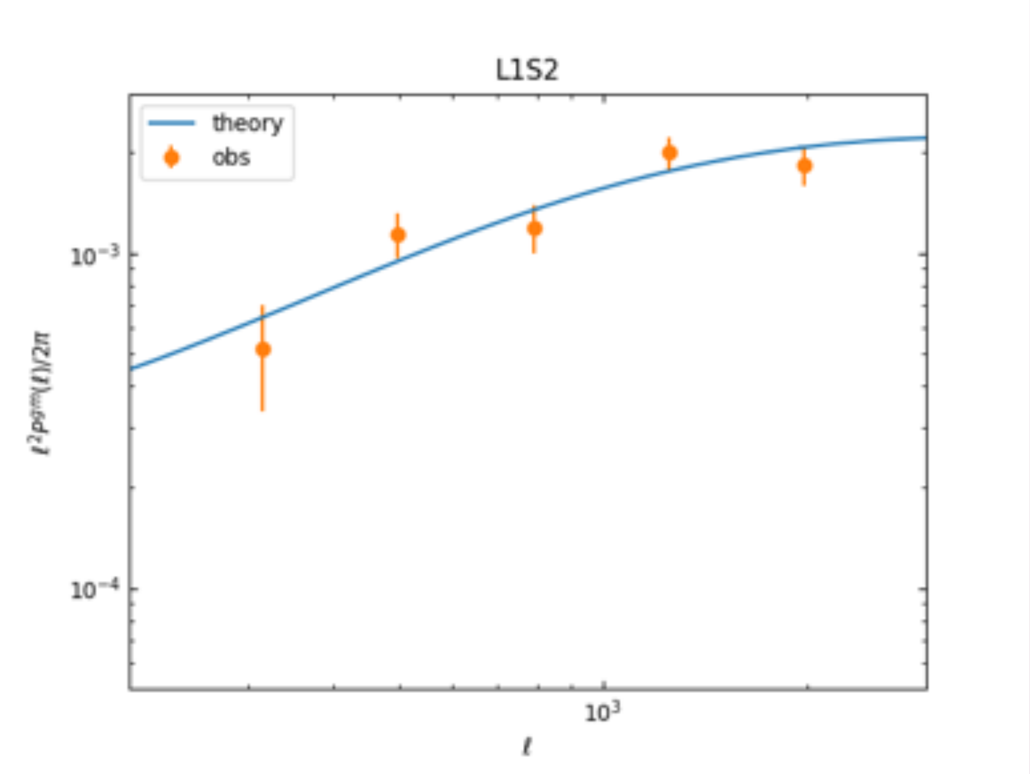


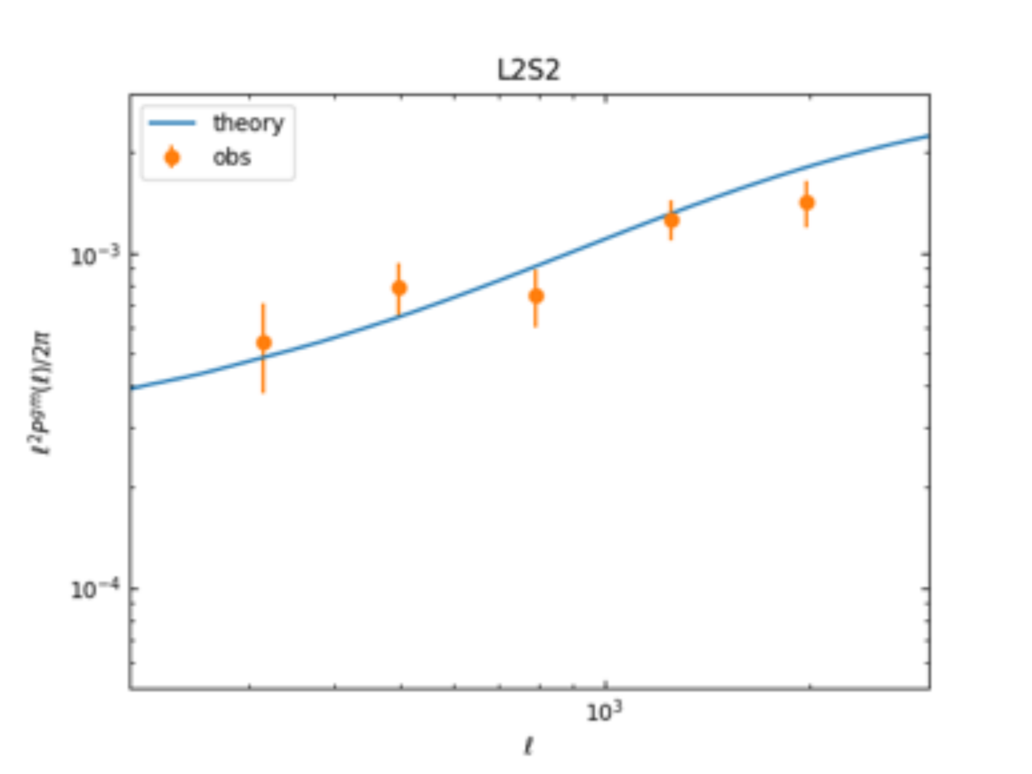
L2



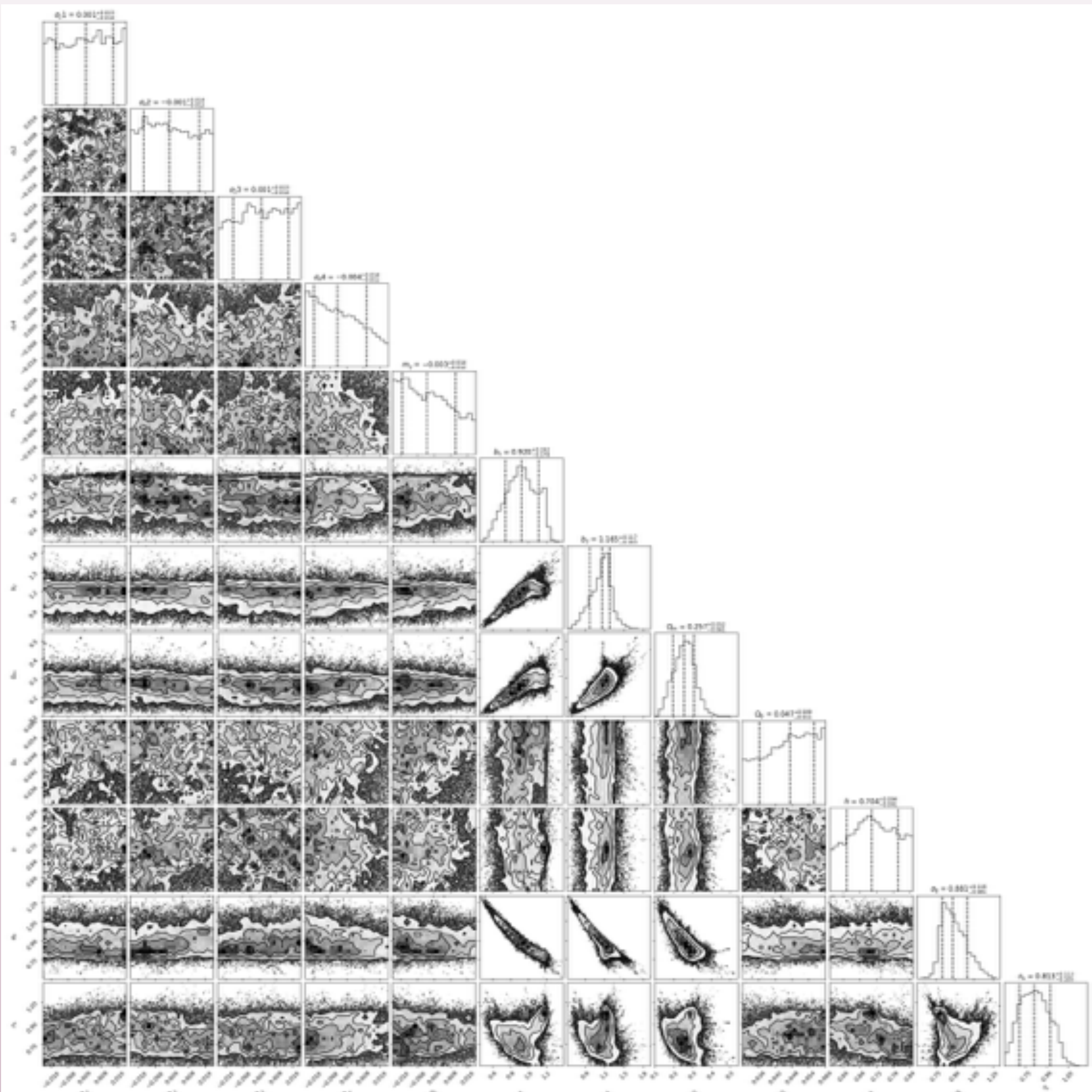
Power spectrum (2)
Pgm: galaxy position – mass distribution







MCMC results

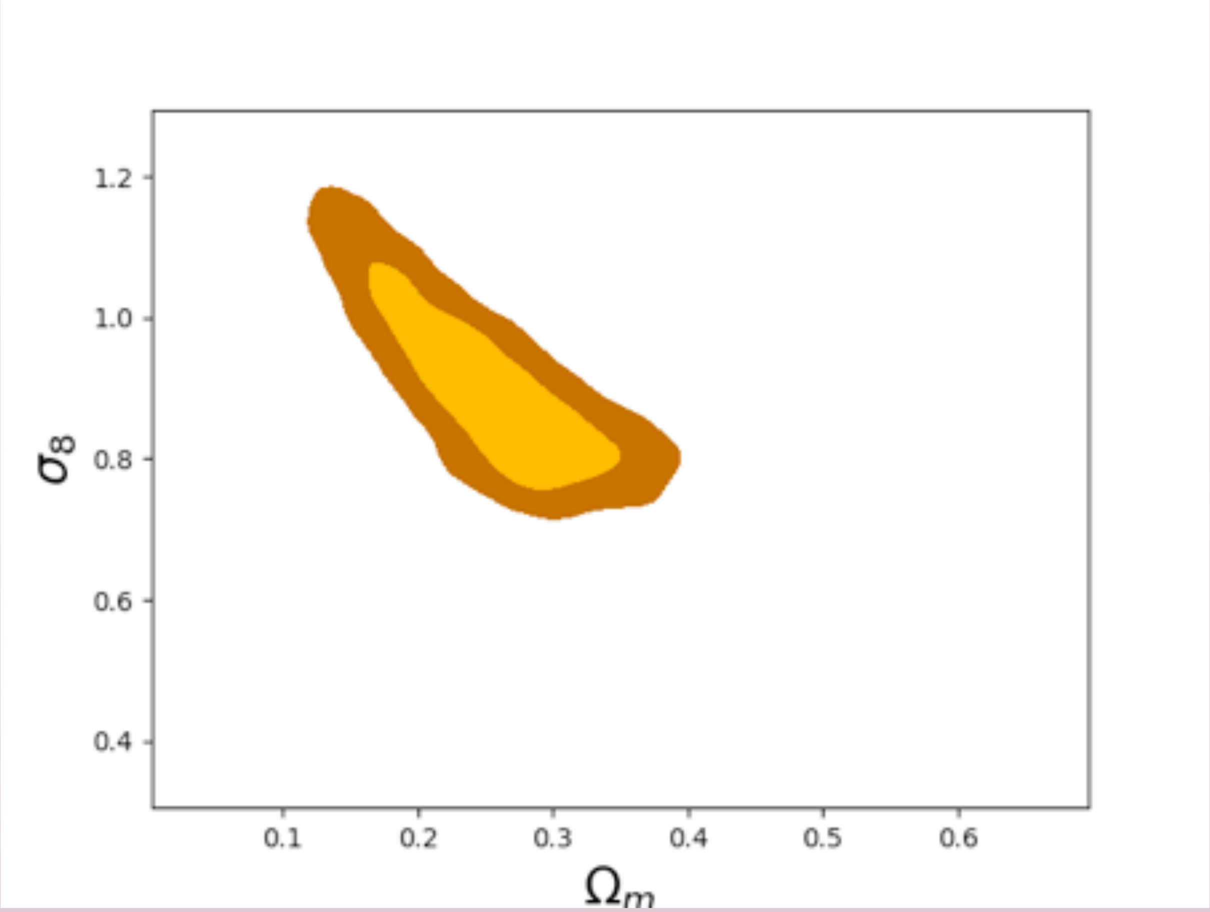


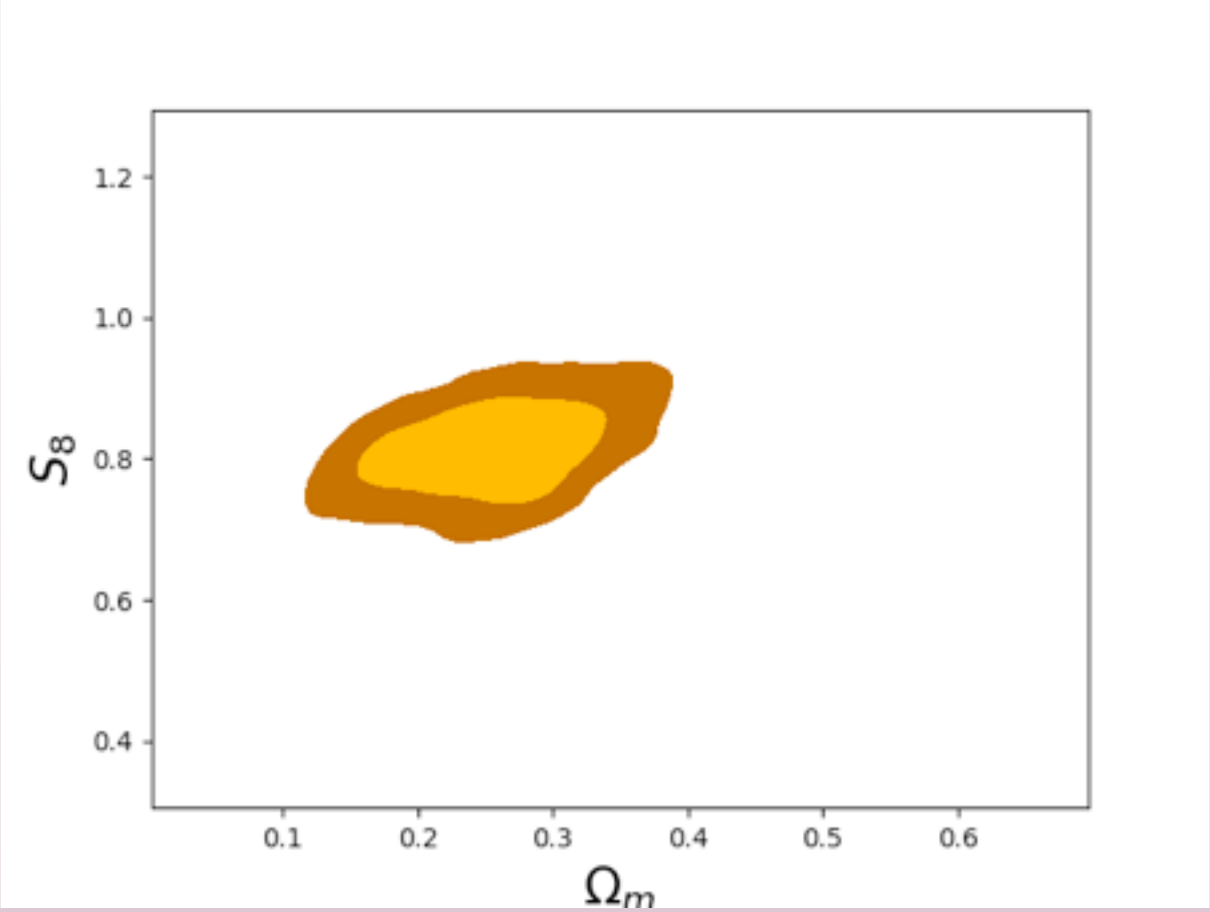
Constrained values

galaxy bias of L1 (b1)	$0.920^{+0.192}_{-0.178}$
galaxy bias of L2 (b2)	$1.165^{+0.117}_{-0.193}$
matter density (Ωm)	$0.257^{+0.052}_{-0.061}$
power spectrum normalization ($\sigma 8$)	$0.881^{+0.116}_{-0.081}$

MCMC results

- **GGL + Galaxy clustering**





$\Omega_m = 0.257^{+0.052}_{-0.061}$

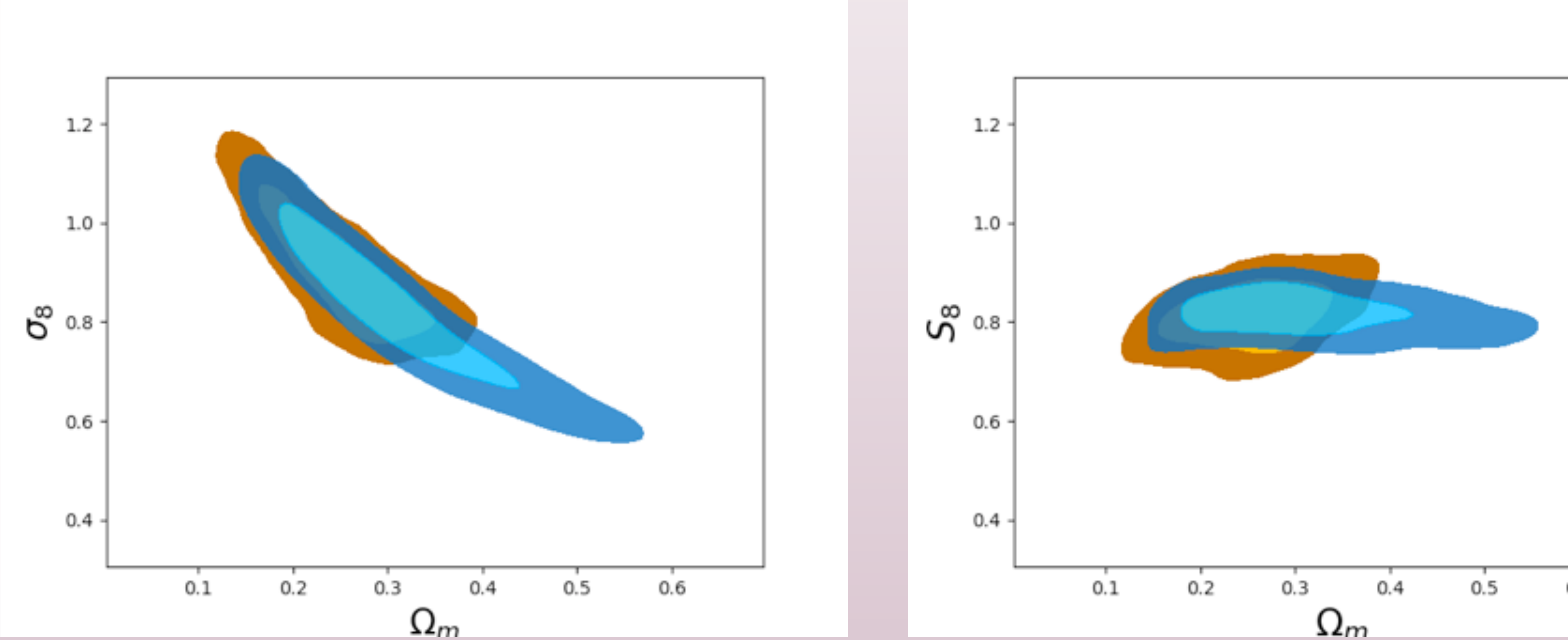
$\sigma_8 = 0.881^{+0.116}_{-0.081}$

$S_8 = \sigma_8(\Omega_m/0.3)^{0.5}$

$= 0.812^{+0.051}_{-0.047}$

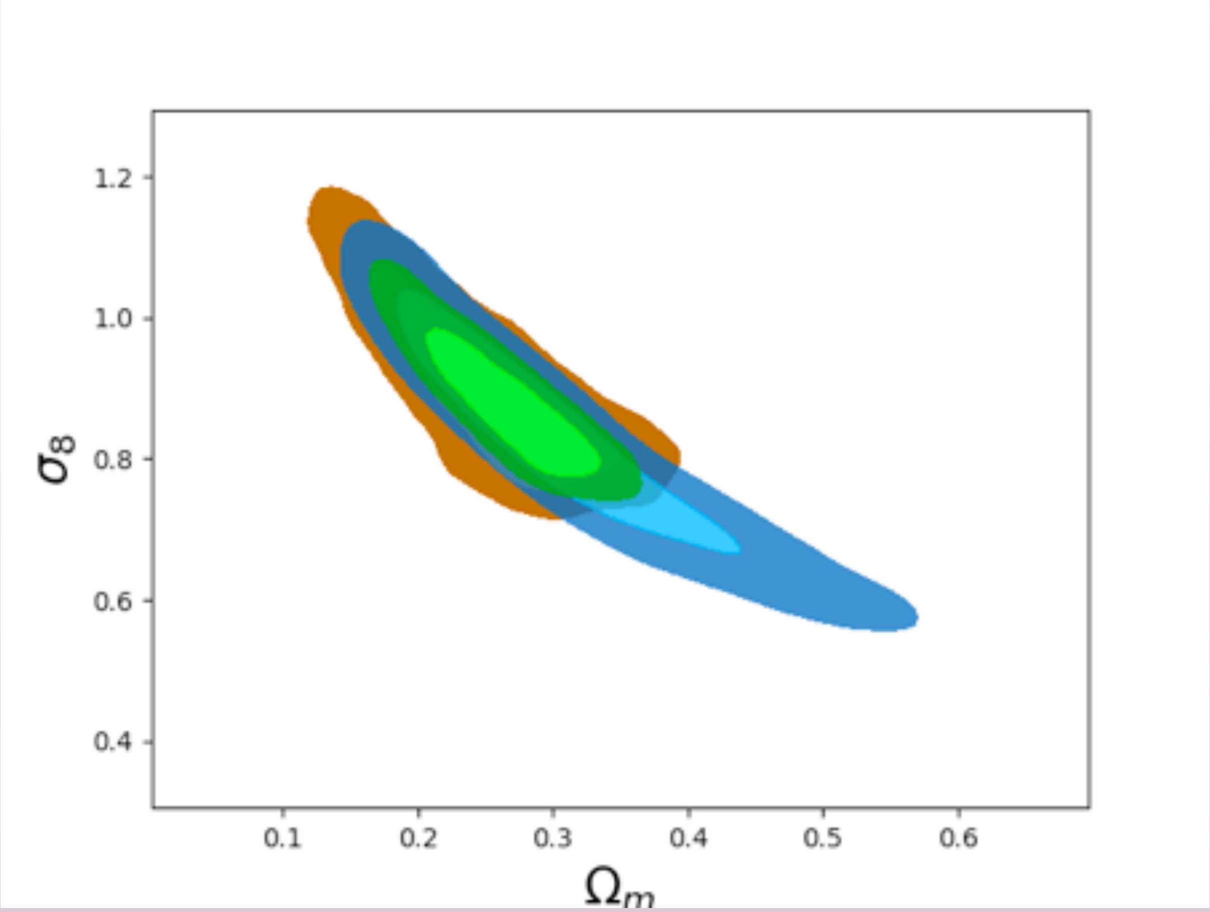
Comparison with cosmic shear and Planck

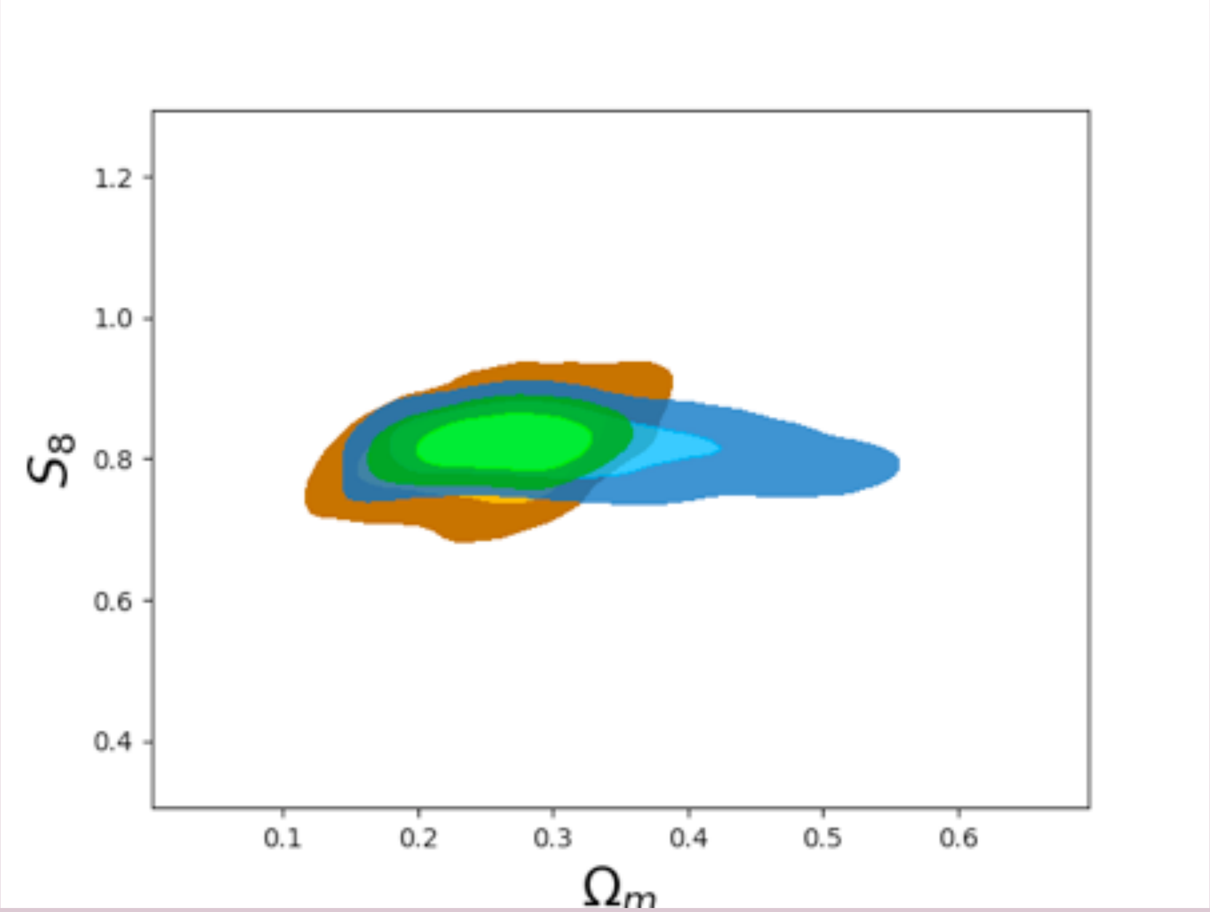
- GGL + Galaxy clustering
- Cosmic Shear



Comparison with cosmic shear and Planck

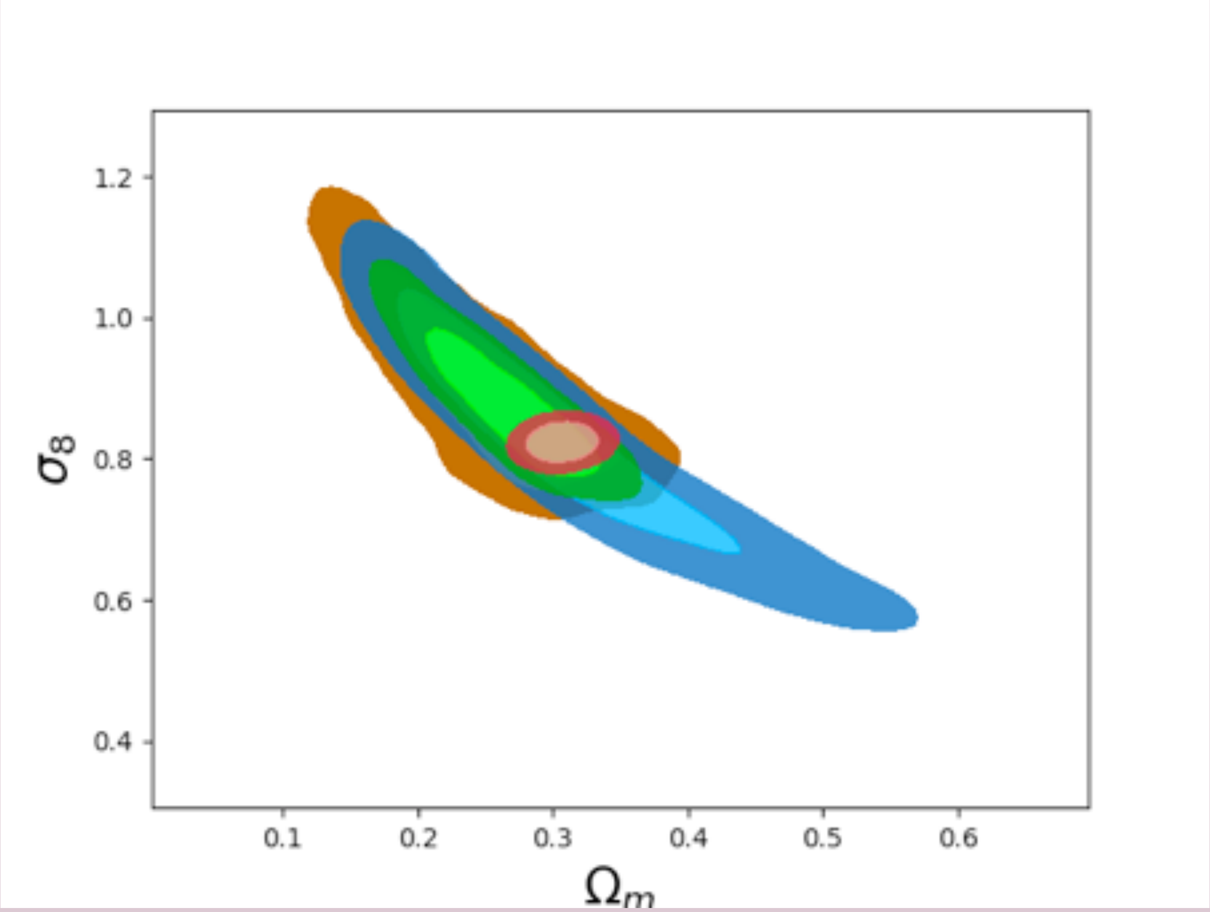
- GGL + Galaxy clustering
- Cosmic Shear
- GGL + Galaxy clustering + Cosmic Shear

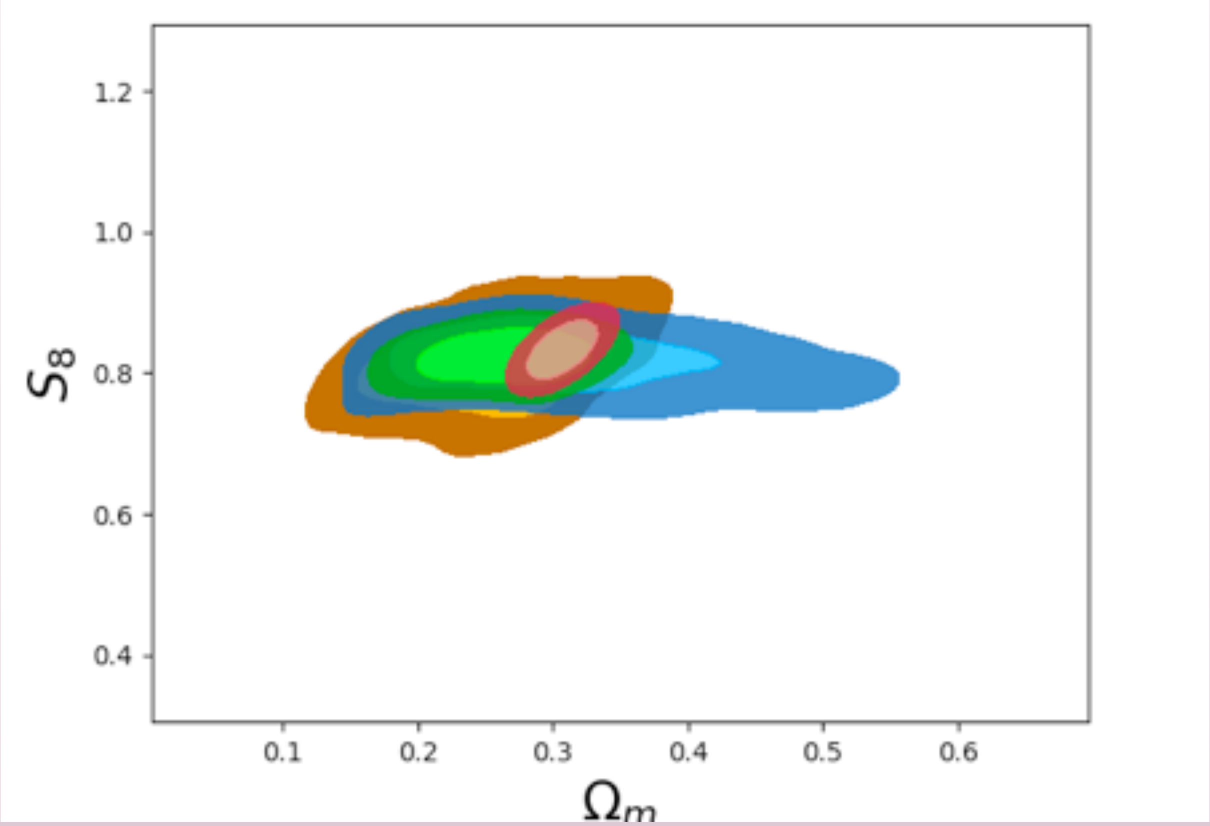




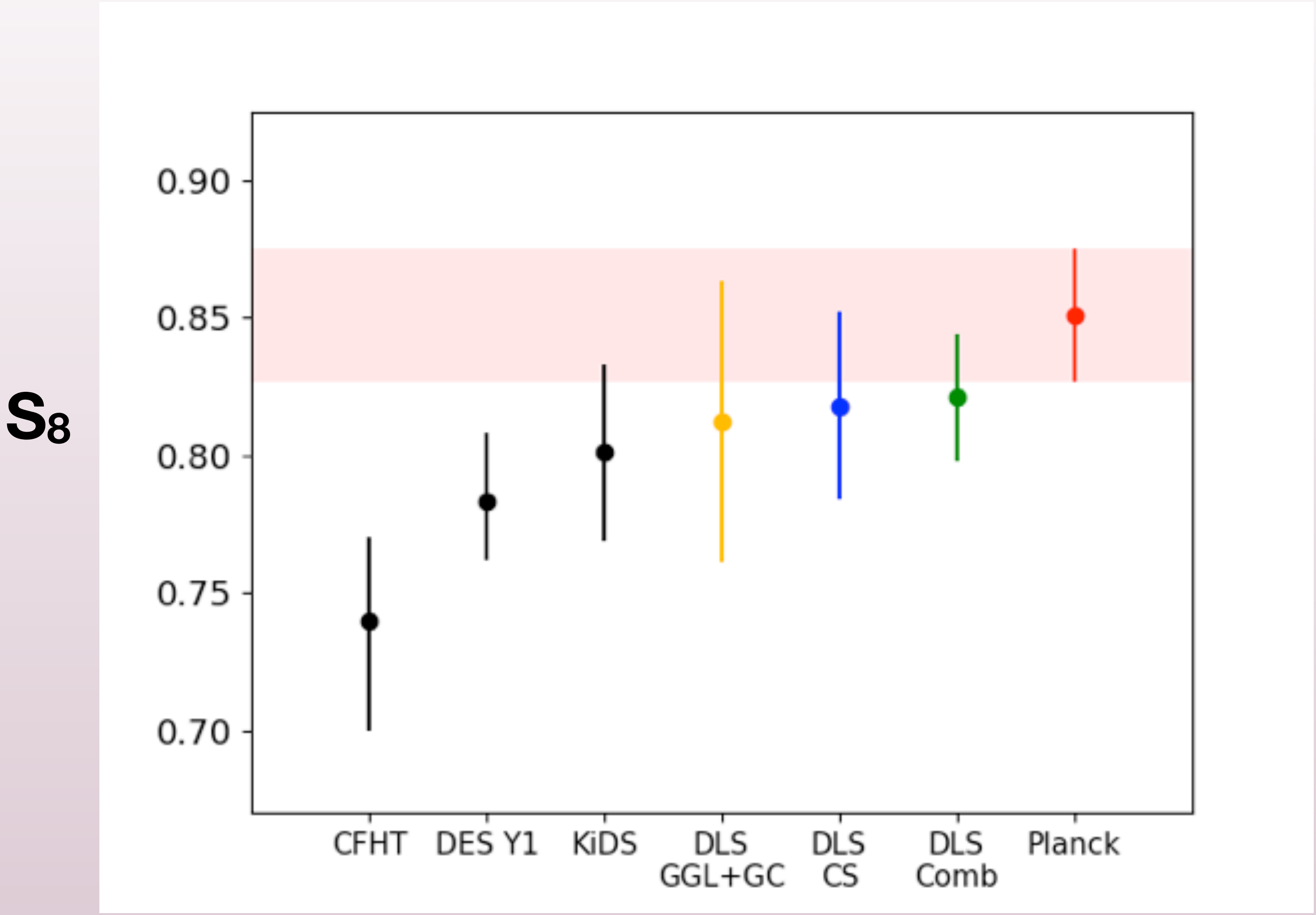
Comparison with cosmic shear and Planck

- GGL + Galaxy clustering
- Cosmic Shear
- GGL + Galaxy clustering + Cosmic Shear
- Planck with lensing





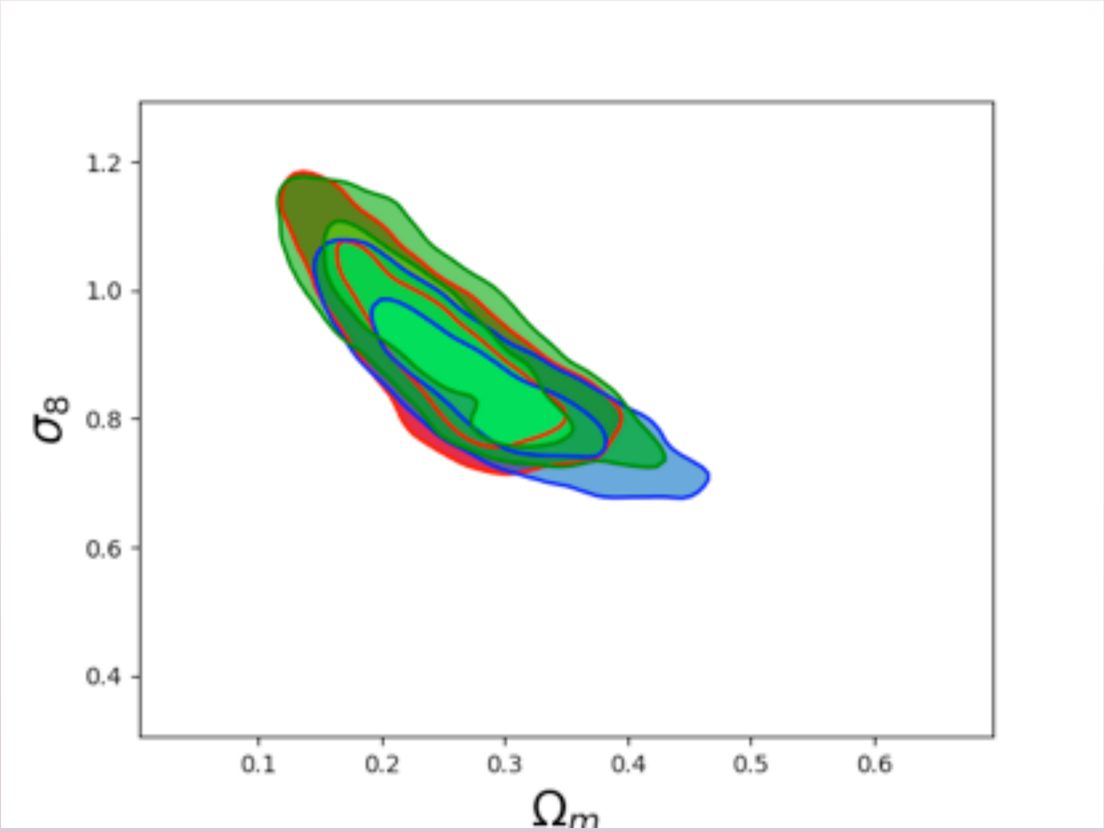
Comparison with other surveys

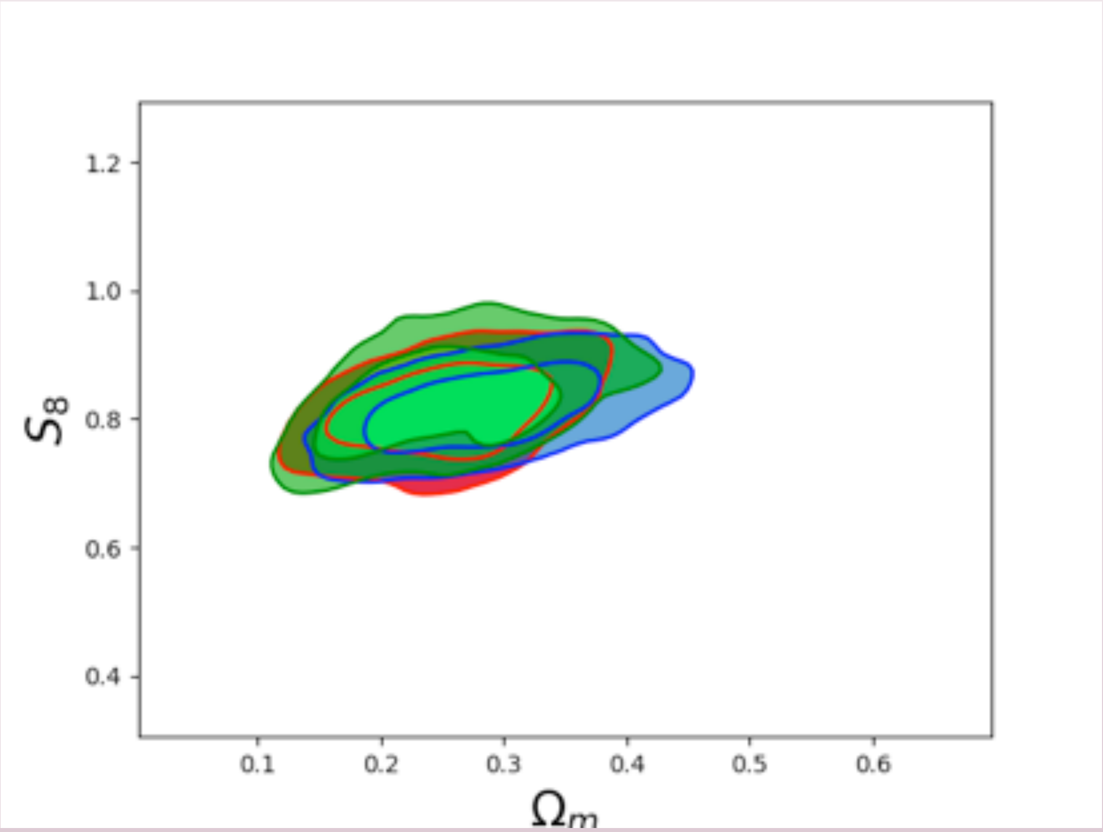


- DLS results are consistent with Planck.
- The constraining power of DLS are comparable with Planck.

Comparison with one parameter extension to flat ΛCDM

- **flat ΛCDM: $\Omega_k = 0$, w0 = -1**
- **Non-flat ΛCDM: $-0.15 < \Omega_k < 0.15$**
- **wCDM: -2 < w0 < 0**





- Constraint on S8 still preserves with model extensions.
- We will investigate further to constrain more cosmological parameters.

Summary

- Weak lensing enables us to determine distribution of dark matter without assuming the dynamical state.

- We successfully measured galaxy-galaxy lensing and galaxy clustering and constrained cosmological parameters.

- GGL + Galaxy clustering results are consistent with previous study Cosmic Shear in DLS.

- There is no tension between DLS and Planck.

Thank you.