Where does the intrinsic alignment of galaxies stem from? An answer through reconstructive simulations

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Presentation

ENS DE LYON

- M2 student in theoretical physics.
- next year : intern at CRAL/ Monash U in black hole theory (Bardeen-Patterson effect).

Previous works :

- numerical simulation in plasma physics (X).
- Diffusion of dust particles in protoplanetary disks (Nagoya U).

Currently working with Jingjing SHI and Jia LIU at IPMU.

4 reasons why Lyon > Paris

Large Scale Strucutres (LSS) of the Universe

Cosmic web elements ($\geq$ 100 Mpc) :

- clusters
- voids
- walls/sheets
- filaments

create a tidal field :

$$T_{ij}(x) = \frac{\partial^2 \Phi}{\partial x_i \partial x_j}. \qquad (1)$$

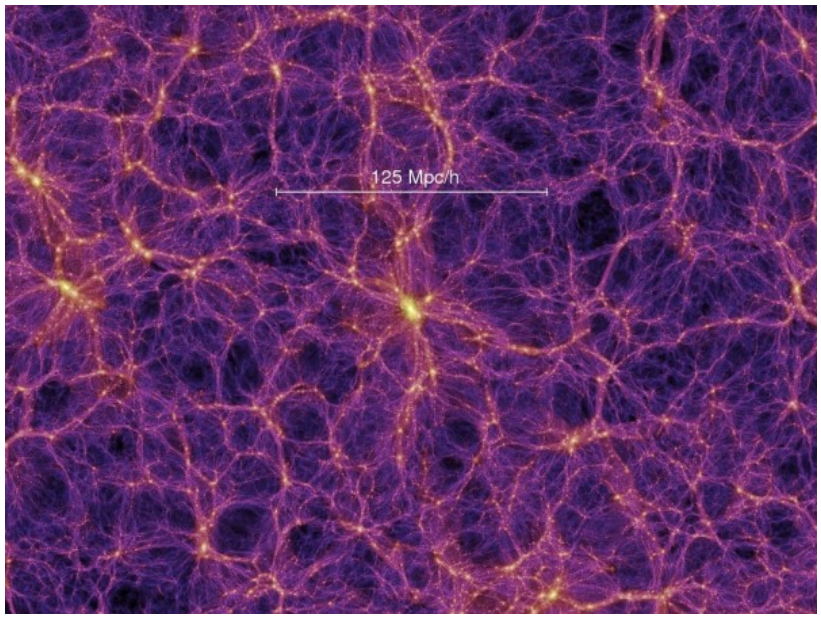

Figure 1 – Illustration of LSS via Volker Springel (Virgo Consortium).

Galaxies and their shape

Figure 2 - Photos by Trevor Jones.

$\longrightarrow$ important observable in cosmology !

$\longrightarrow$ Their shape is 3D but observed in 2D, and expressed in terms of *ellipticities*

The Intrinsic Alignment (IA) of galaxies

The orientation of galaxies is not random. It tends to align :

- with the orientation of surrounding galaxies : **intrinsic ellipticity alignment**
- with the tidal field : **tidal alignment**

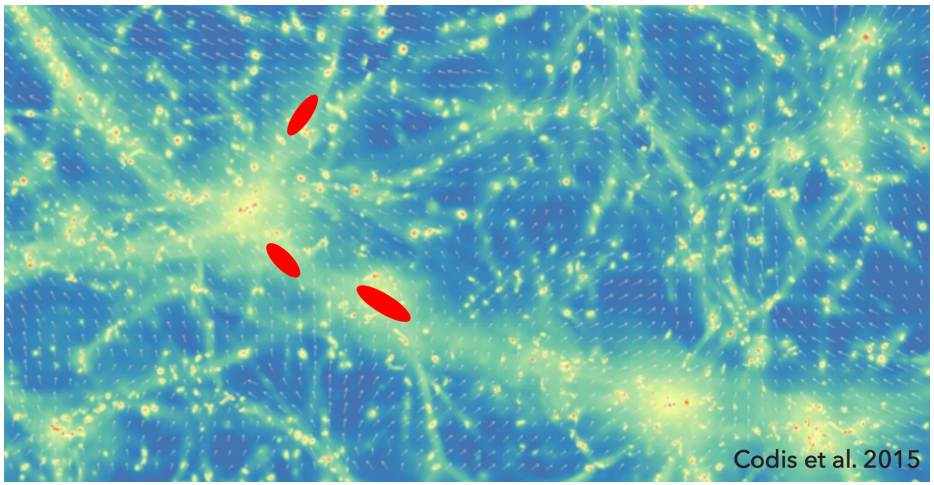

Figure 2 – Illustration of IA. Adapted from Codis et. al. (2015).

$\longrightarrow$ primordial IA formation model suppose that galaxy intrinsic shape is determined upon formation, is it true ?

Gravitational lensing (GL)

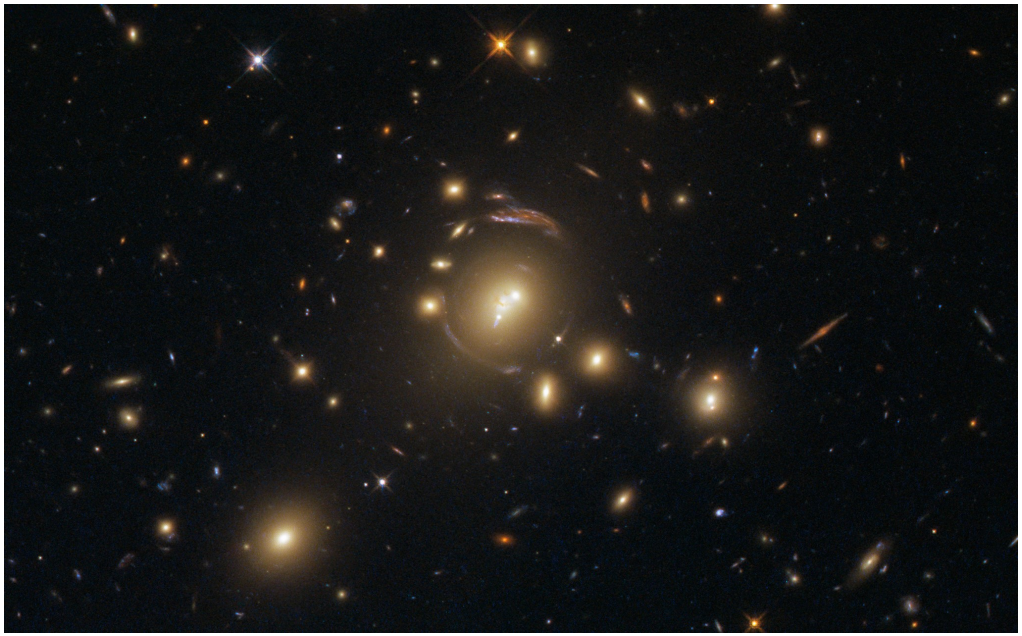

Figure 3 – Image of LRG 3-757 taken by the Hubble Telescope. The galaxy was originally spotted in SDSS data in 2007.

$\longrightarrow$ crucial cosmological probe (cosmological constants measurement, dark matter mapping).
$\longrightarrow$ measured through the shape of galaxies.
(shear power spectra)
$\longrightarrow$ problem : IA contributes + to the observed galaxy shapes than GL !

The Sloan Digital Sky Survey (SDSS)

$\longrightarrow$ 930,000 galaxies.

$\longrightarrow$ Spectroscopic and image survey of galaxies. Provides redshift and shape measurement.

Figure 4 – Photo of the SDSS telescope : a 2.5 m diameter telescope in the Apache Point Observatory. Credits to The Astrophysical Research Consortium.

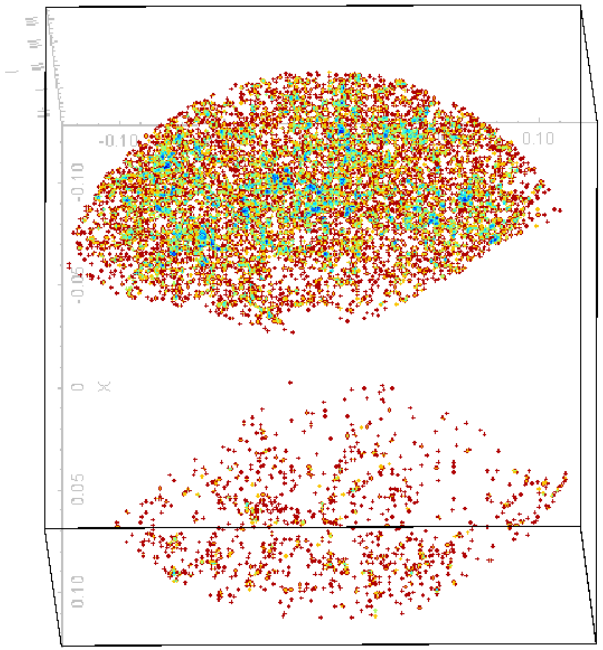

Figure 5 – Sample of SDSS galaxies plotted in 3d space (ra/dec/z), colour-coded according to density.

Let's be quantitative !

Cosmologists are interested in the weak lensing signal (called cosmic shear) :

$$\gamma = \gamma_I + \gamma_G . \tag{2}$$

Considering two galaxies (differentiated by a prime), what we actually measure is the correlation function :

$$\underbrace{\langle \gamma\gamma' \rangle}_{\text{observed}} = \underbrace{\langle \gamma_G\gamma'_G \rangle}_{\text{GG}} + \underbrace{\langle \gamma_I\gamma'_I \rangle}_{\text{II}} + \underbrace{\langle \gamma\gamma'_I \rangle + \langle \gamma_I\gamma' \rangle}_{\text{GI}} . \tag{3}$$

Isolating GG (or II) is **difficult.** GI is stronger than II (Hirata Seljak 2004). They are evaluated through an estimator :

$$\xi(r_p, \pi) = \frac{DD - 2DR + RR}{RR} \tag{4}$$

Building the catalogues

Density catalogue		**Shape catalogue**	
data	**random**	**data**	**random**
Magnitude cut Redshift selection			
		cross-match catalogues	
Fgot cut			
	assign redshift (rejection sampling)		assign redshift (rejection sampling)
compute comoving distance			
		angular selection	

Example of the density catalogue

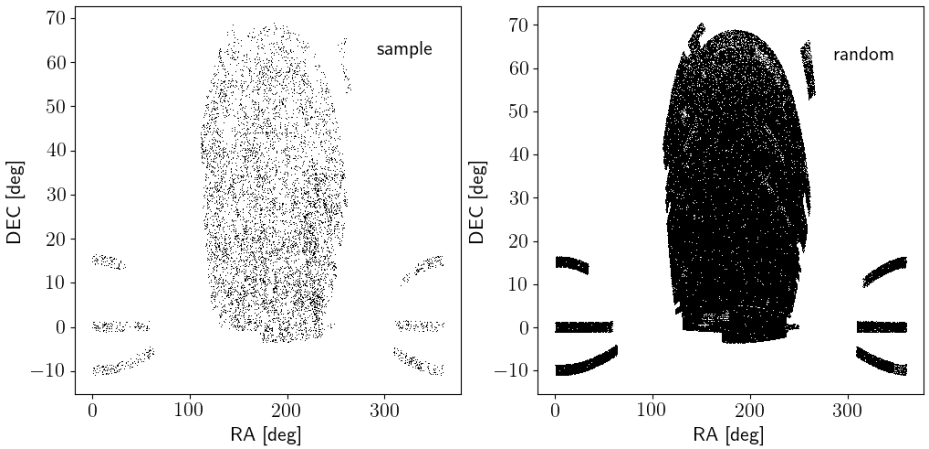

Figure 6 – Sky coverage.

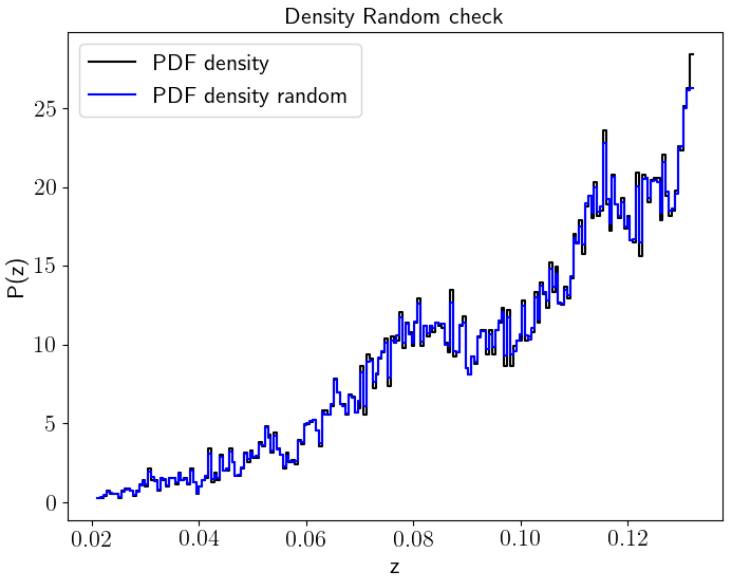

Figure 7 – Redshift assignation.

Autocorrelation

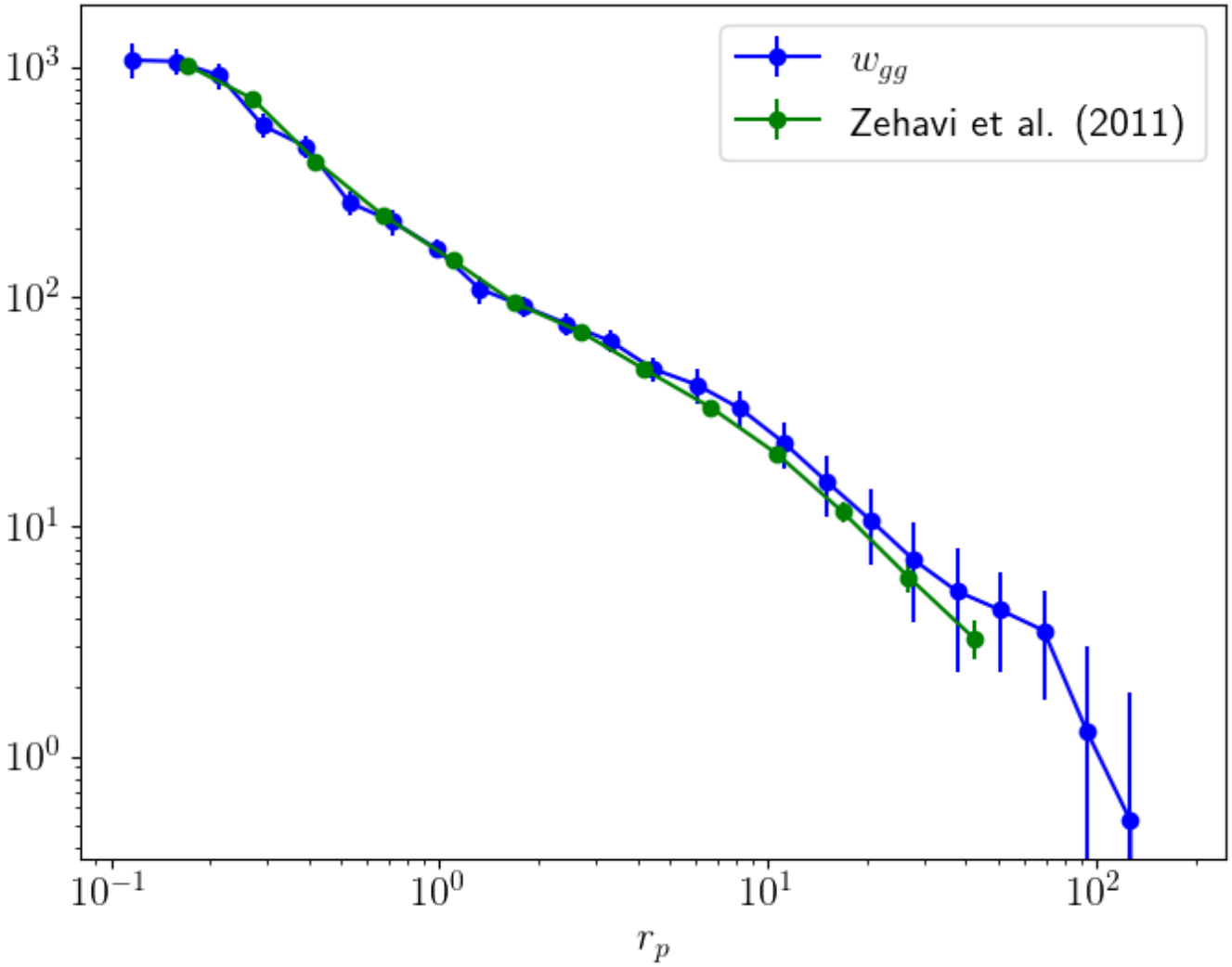

Figure 8 – Autocorrelation signal for Mr < -21.5.

IA

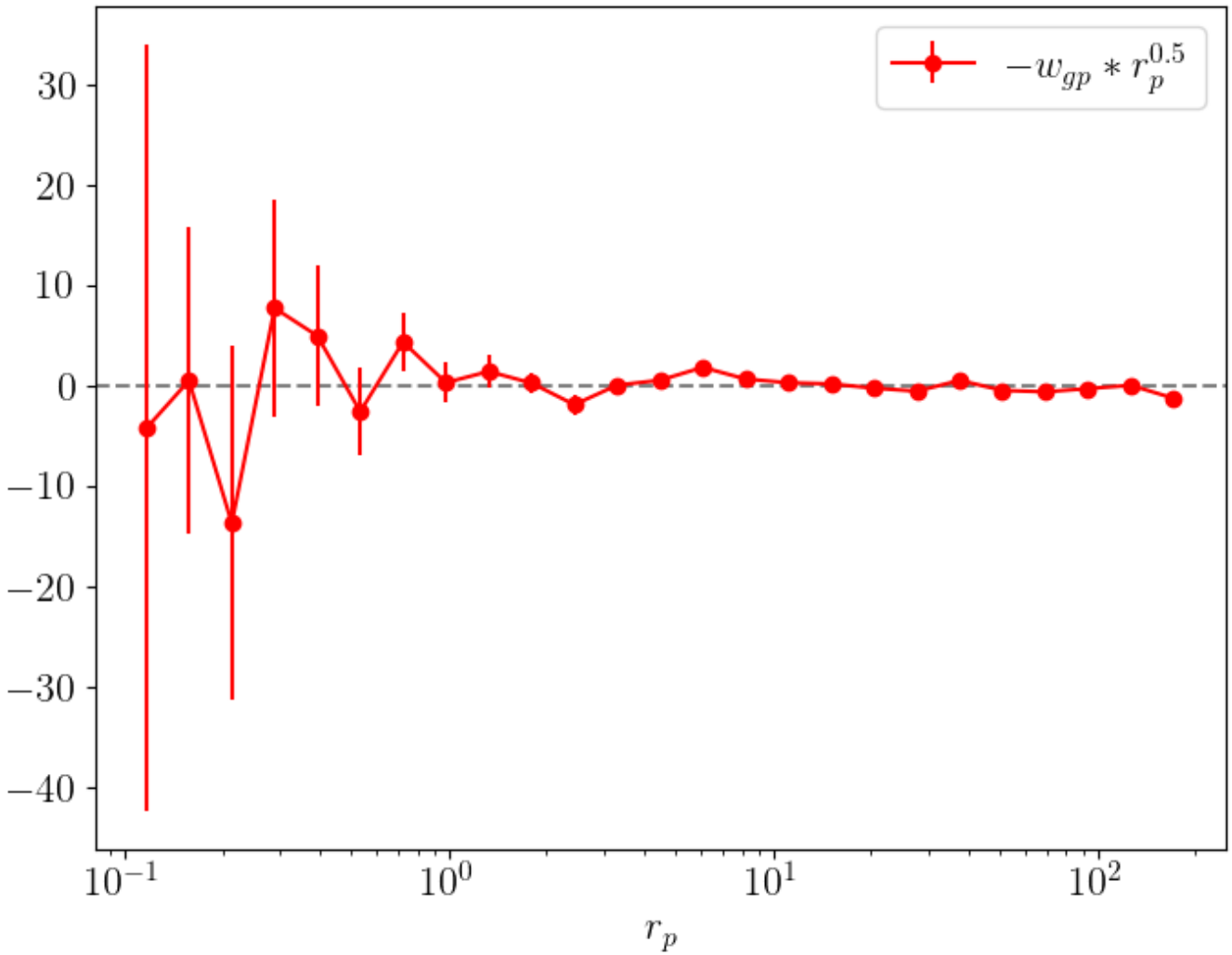

Figure 9 – IA signal for Mr < -21.5.

Elucid

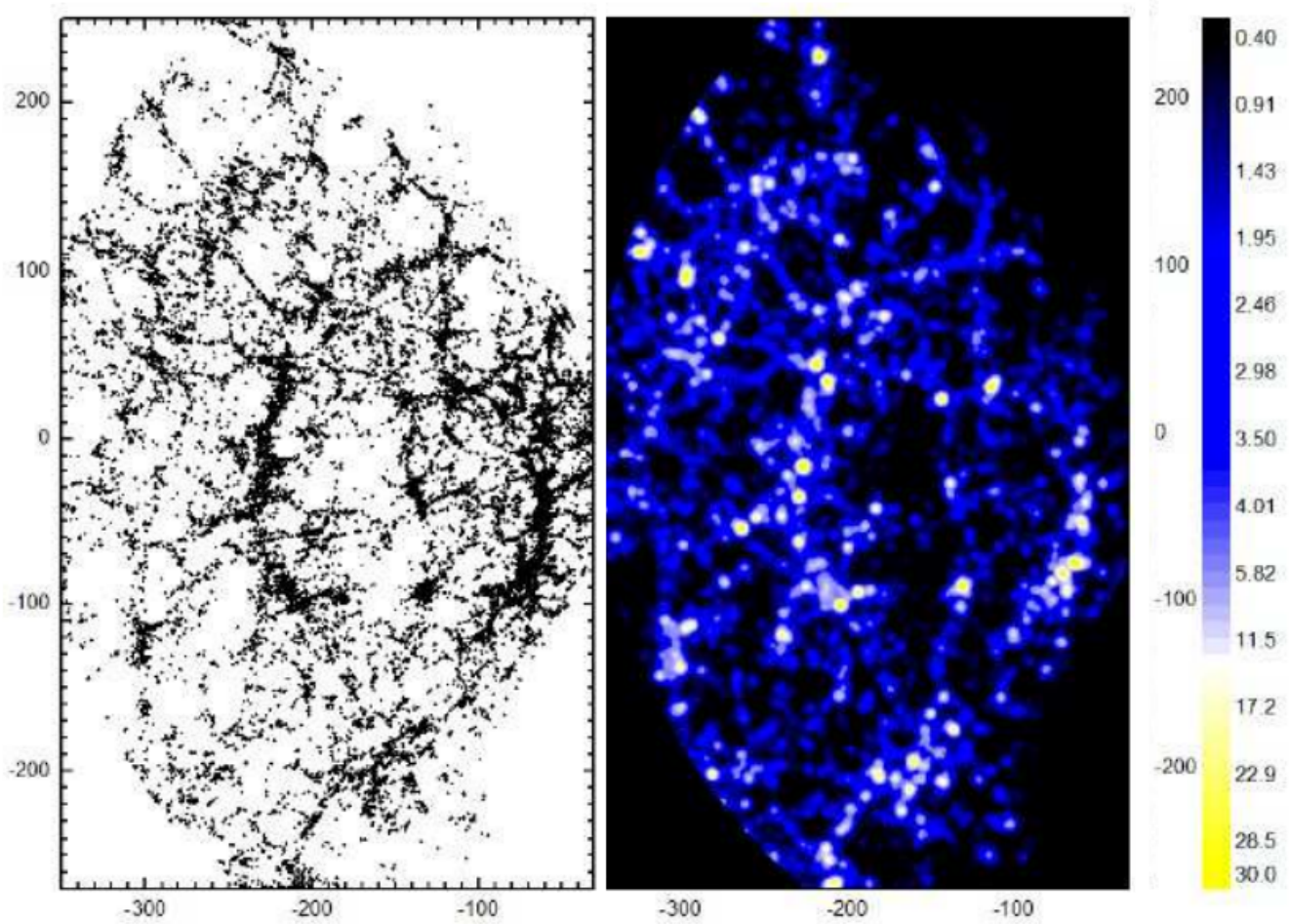

Figure 10 – Slice of the Sloan Great Wall. Left : galaxy distribution from the Sloan data. Right : reconstructed mass distribution by ELUCID. Via Huiyuan Wang et. al. (2018)

Conclusion and prospects

- IA : a major contaminant of cosmic shear, but also a physically rich phenomenon.
- catalogue building is not trivial ! And navigating the data sets is time-consuming (and confusing).
- Next step : Cross-correlate with Elucid data (matter density field of different redshift) and compare with IA signal in SDSS. The set-up is ready, should go smoothly.

Thanks !

Bibliography

[1] Shun Arai et. al., 'Cosmological gravity probes : connecting recent theoretical developments to forthcoming observations', *Progress of Theoretical and Experimental Physics*, **ptad052** (2023).

[2] Idit Zehavi et. al., 'Galaxy Clustering in the Completed SDSS Redshift Survey : The Dependence on Color and Luminosity', *The Astrophysical Journal*, **Vol. 736, Number 1**, pages 59-88 (2011).

[3] Huiyuan Wang et. al., 'ELUCID - Exploring the Local Universe with reConstructed Initial Density field III : Constrained Simulation in the SDSS Volume', *The Astrophysical Journal*, **Vol. 831, Number 2**, page 164 (2016).