DDays : 01/07/2015

COSMIC HOMOGENEITY : A 28 GPC^3 STUDY WITH THE BOSS QSO SAMPLE

Pierre Laurent, advisor : Jean-Marc Le Goff

- Homogeneity and cosmological principle
- The BOSS survey
- Defining observables and their estimators
- Is the Universe homogeneous ?

The context

The need for a cosmological principle

The cosmological principle

- Cosmological models rely on 2 assumptions :

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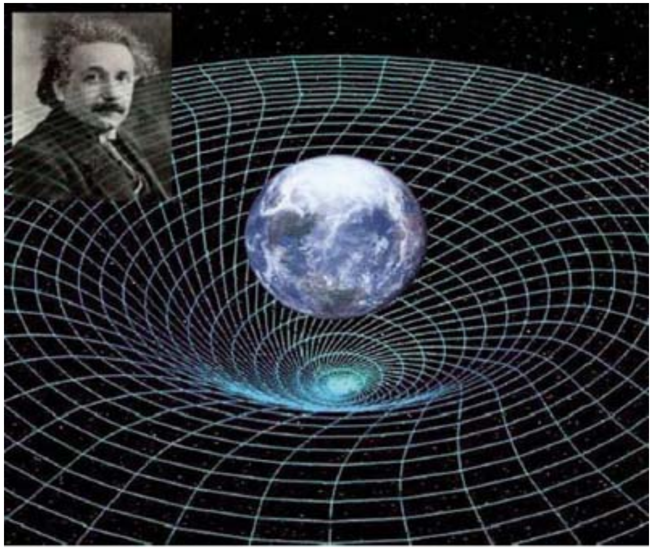
General Relativity

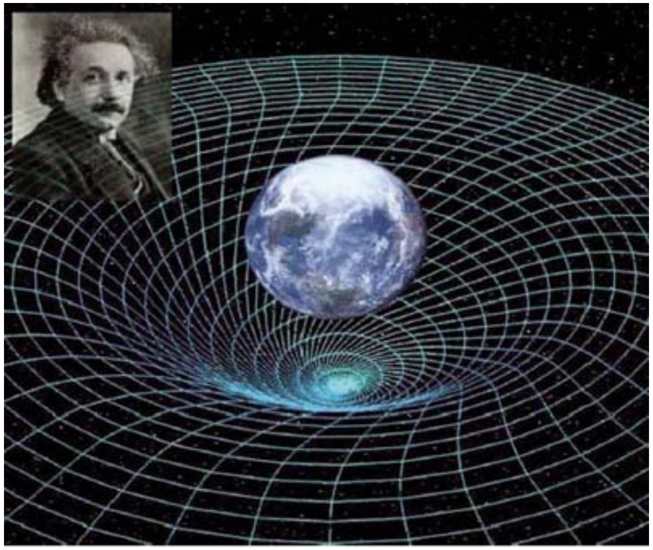


The cosmological principle

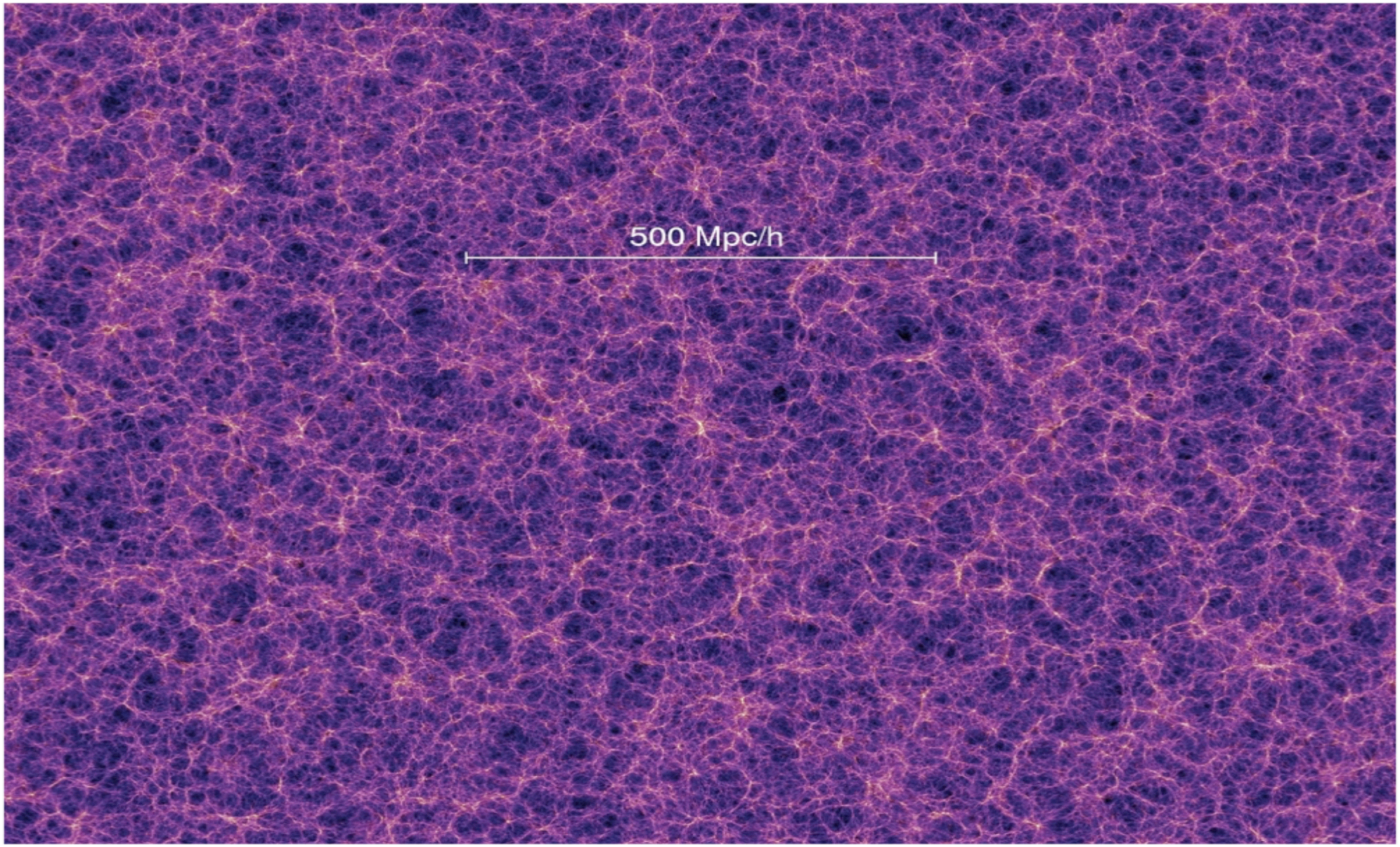
- Cosmological models rely on 2 assumptions :

General Relativity

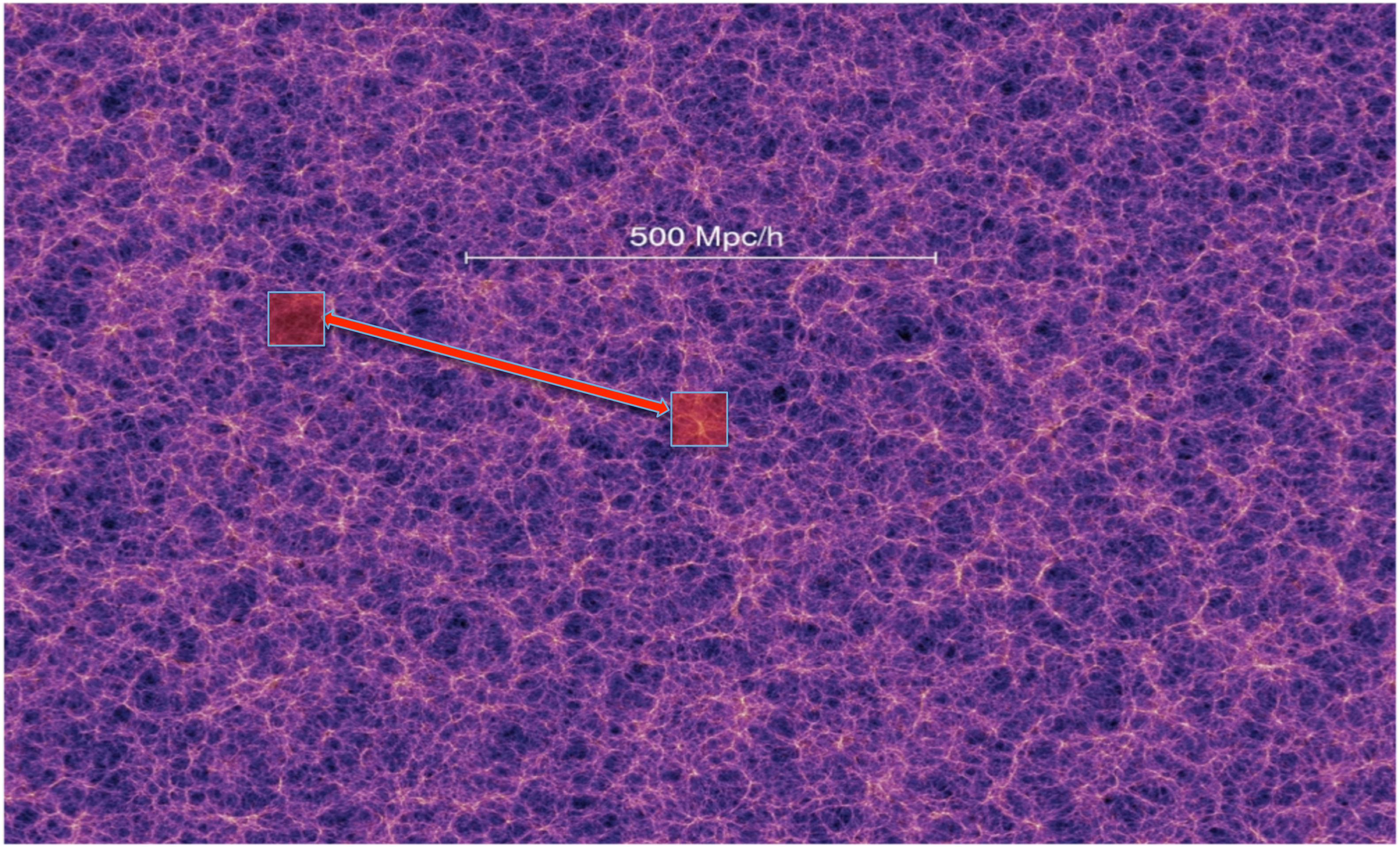
Cosmological Principle



Universe is isotropic and homogeneous



The universe is statistically homogeneous and isotropic



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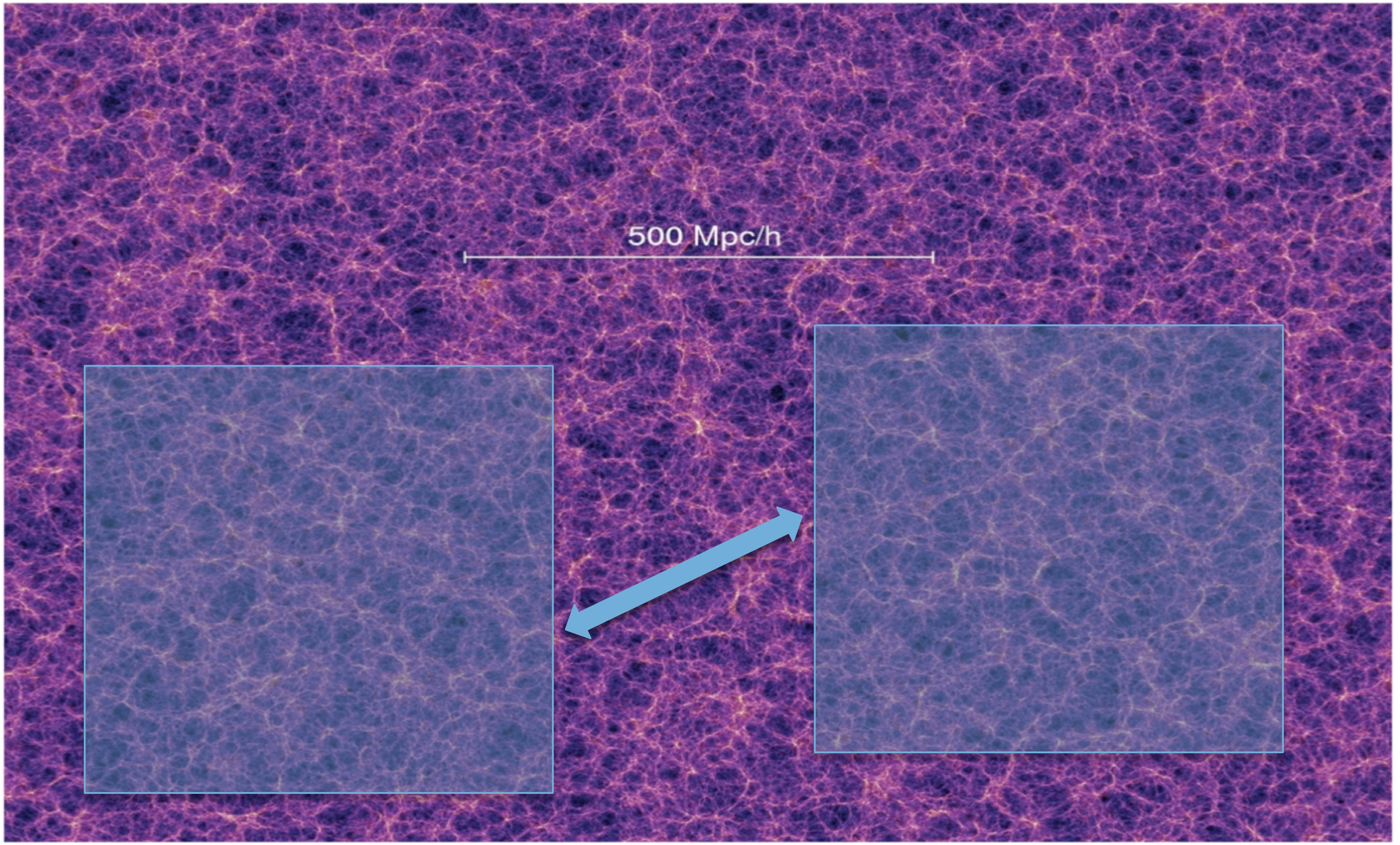
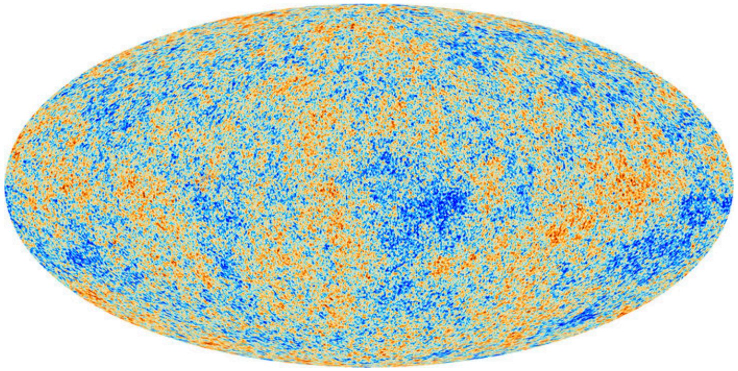


The universe is statistically homogeneous and isotropic

How can we test it ?

- Isotropy well tested :



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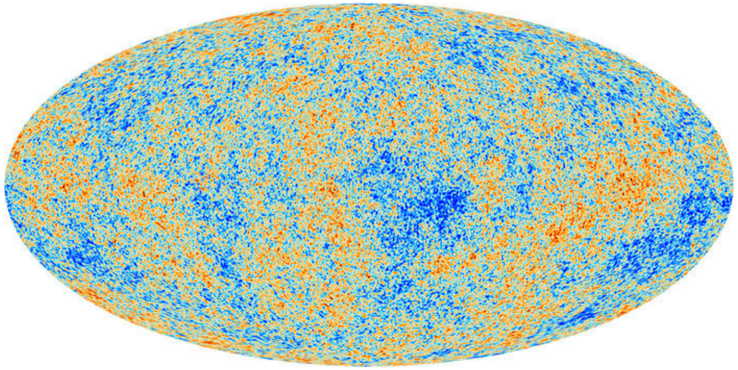

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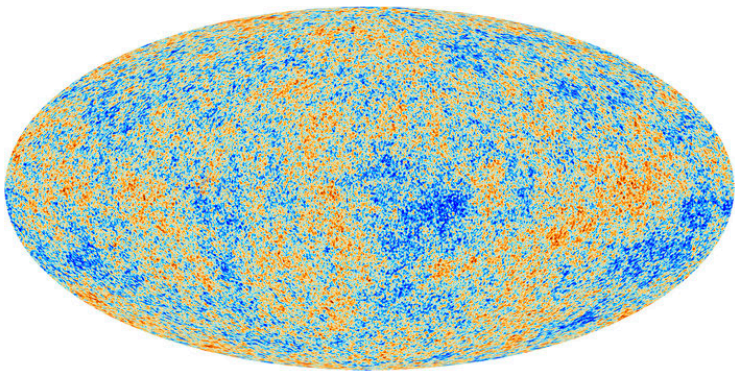

- Copernican principle : we do not occupy a peculiar place in the universe.
- Isotropy + Copernican principle → Homogeneity …
- … but not true fractal universe, and CP is a principle → need a direct test for homogeneity !
- Need 3D-survey with huge volume to have access to scales of interest (> 100 Mpc/h) !

The survey

SDSS and the BOSS QSO sample

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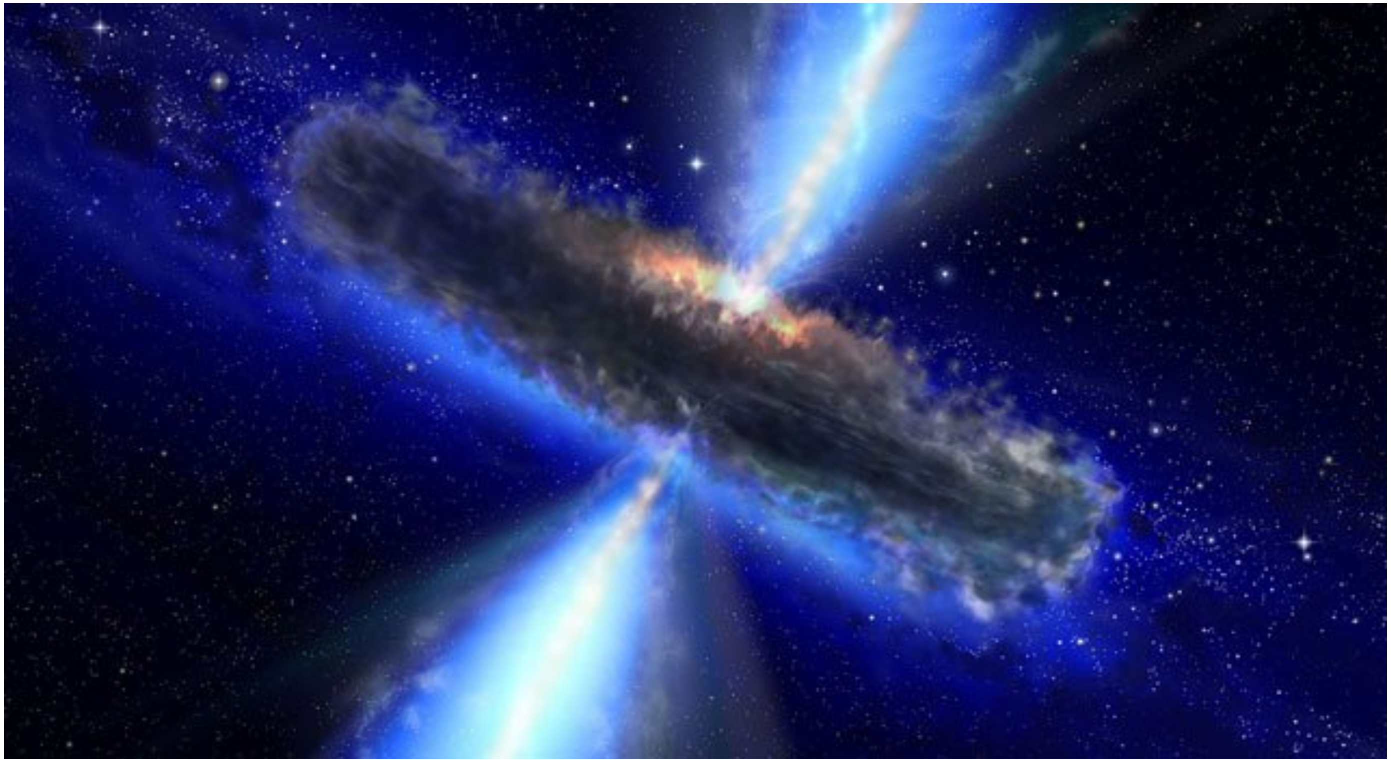
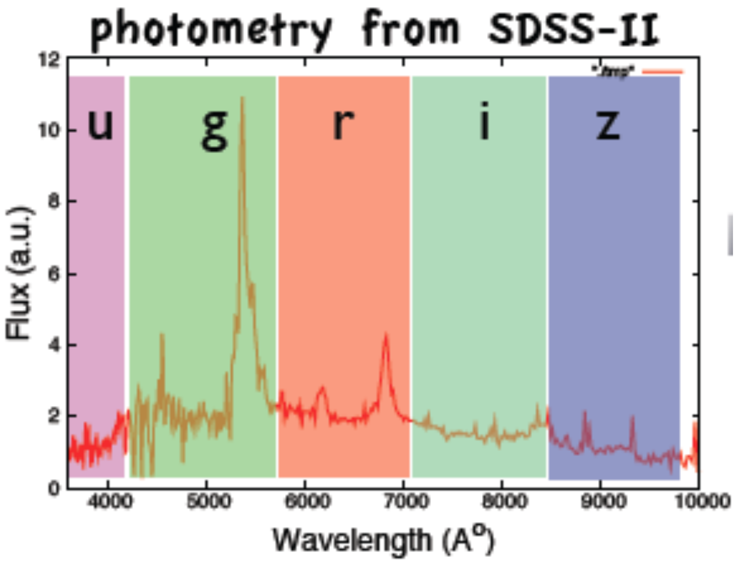
- Spectroscopic survey at the 2.5-meter Sloan telescope (APO, New Mexico)
- Roughly 150,000 QSOs ($z > 2.2$)



The procedure



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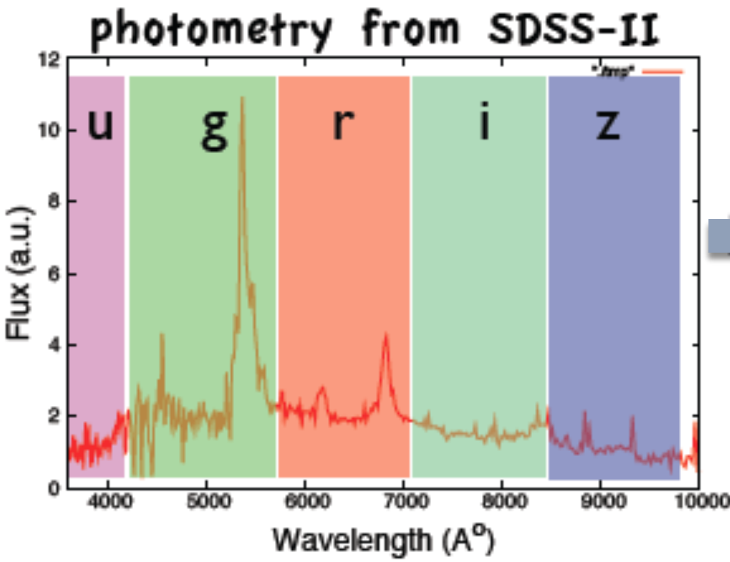

QSO selection

SDSS J112253.51+005329.8
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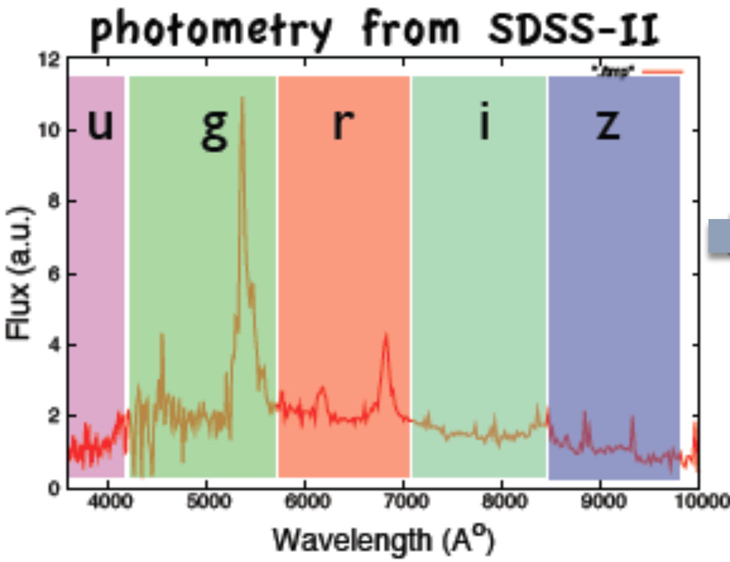

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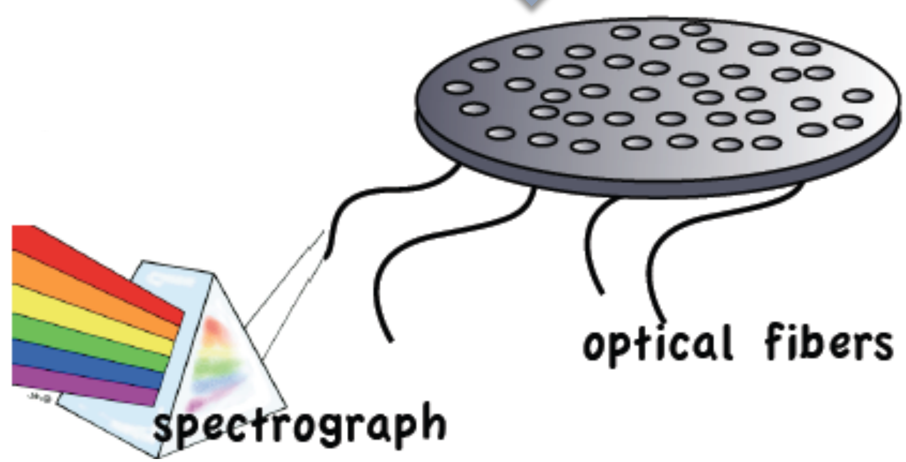
1000 fibers
per plate



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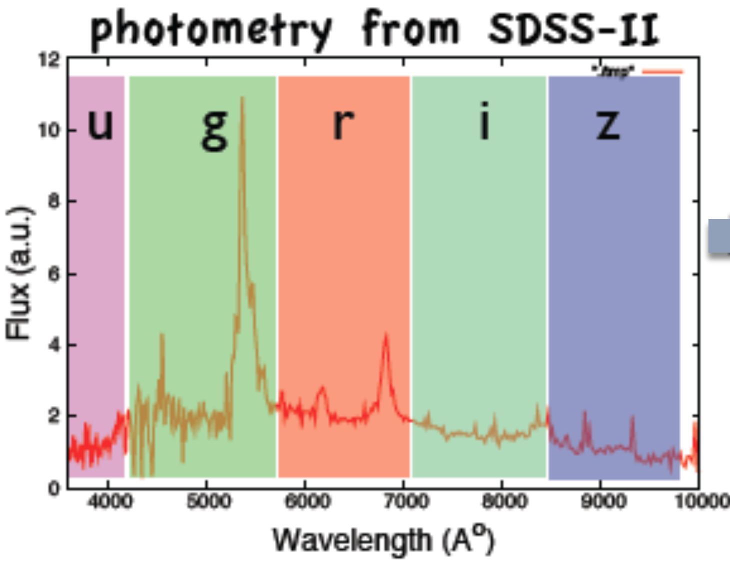

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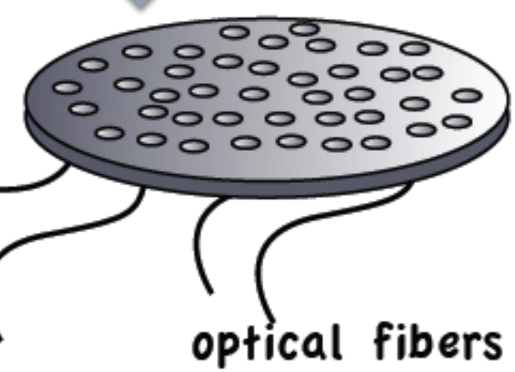

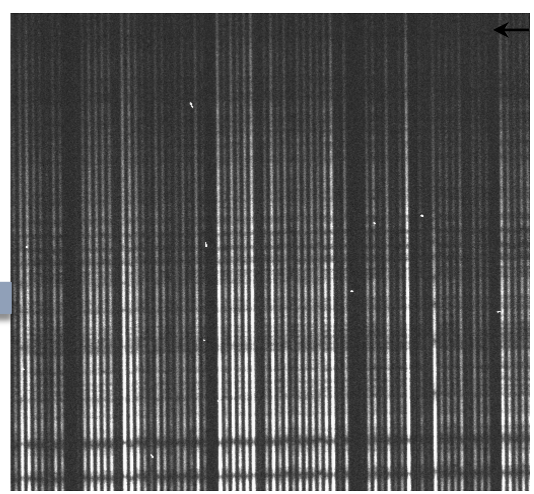

Redshifts

The analysis

Observables and estimators

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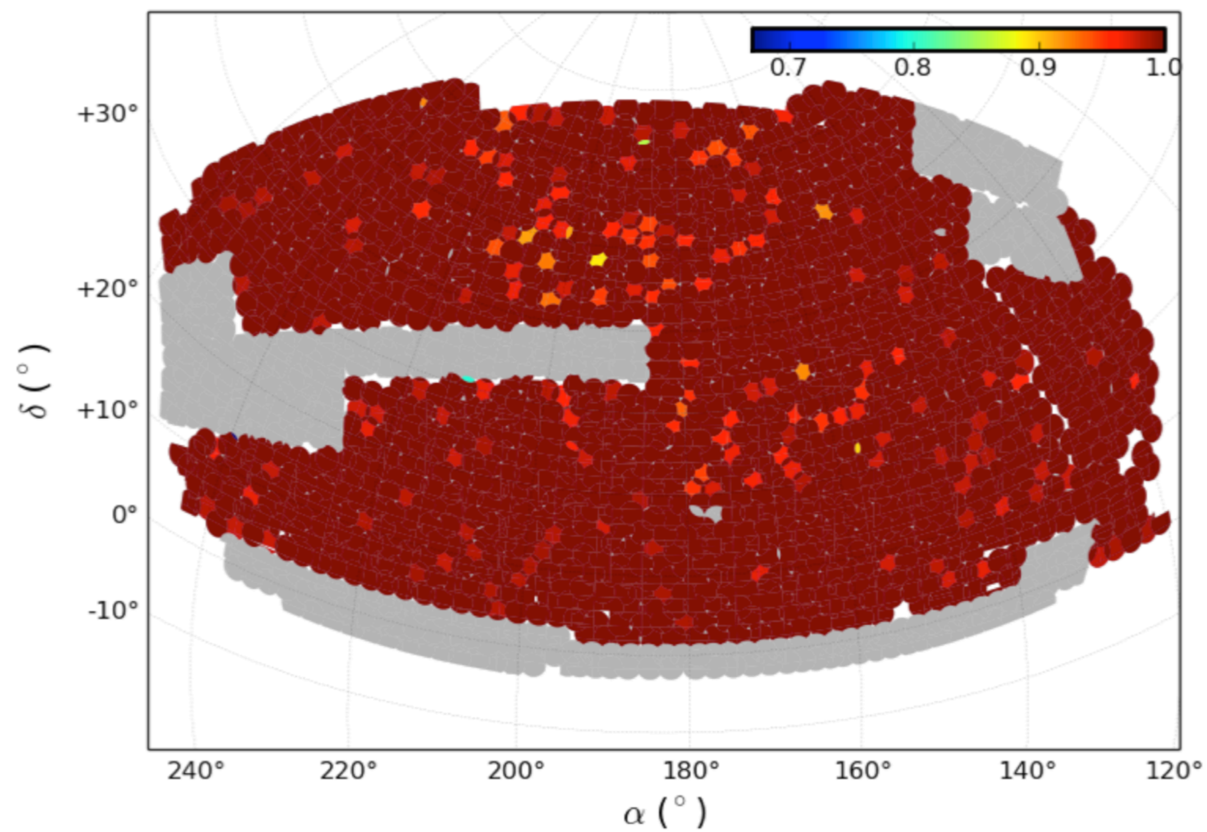
- When homogeneity is reached :

$$\boxed{N(< r) \propto r^3 \qquad D_2(r) = 3}$$



BOSS North Galactic Cap (NGC) footprint

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- When homogeneity is reached :

$$\boxed{\mathcal{N}(<r) = 1 \qquad\qquad D_2(r) = 3}$$

1) Establishing homogeneity

$$\mathcal{N}(< r) = \frac{\int_0^r DD(s)ds}{A.\int_0^r RR(s)ds}$$

- Uncertainty on $\langle\rho\rangle$ → uncertainty on A
- When homogeneity is reached :

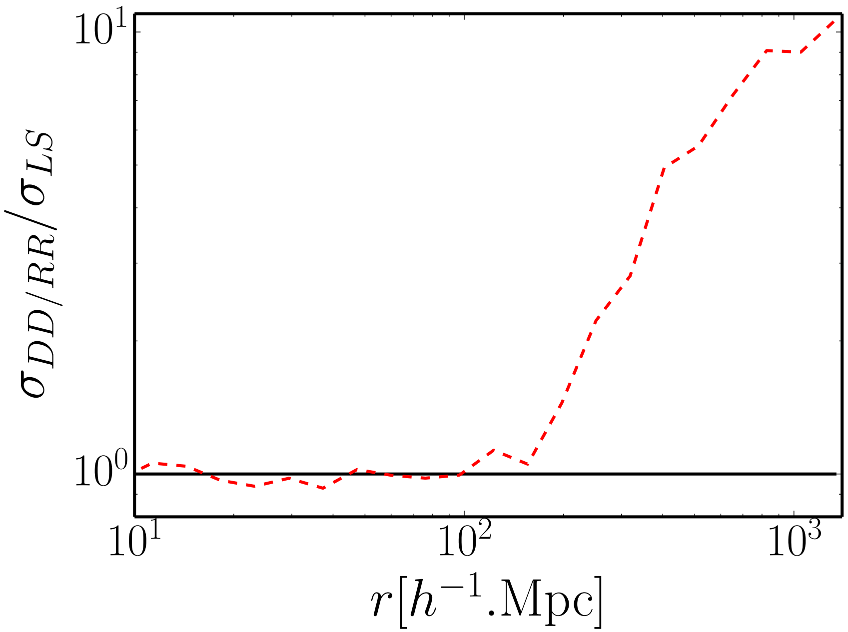
$$\mathcal{N}(< r) = cste$$

$$\boxed{D_2(r) = 3}$$

2) More quantitative test

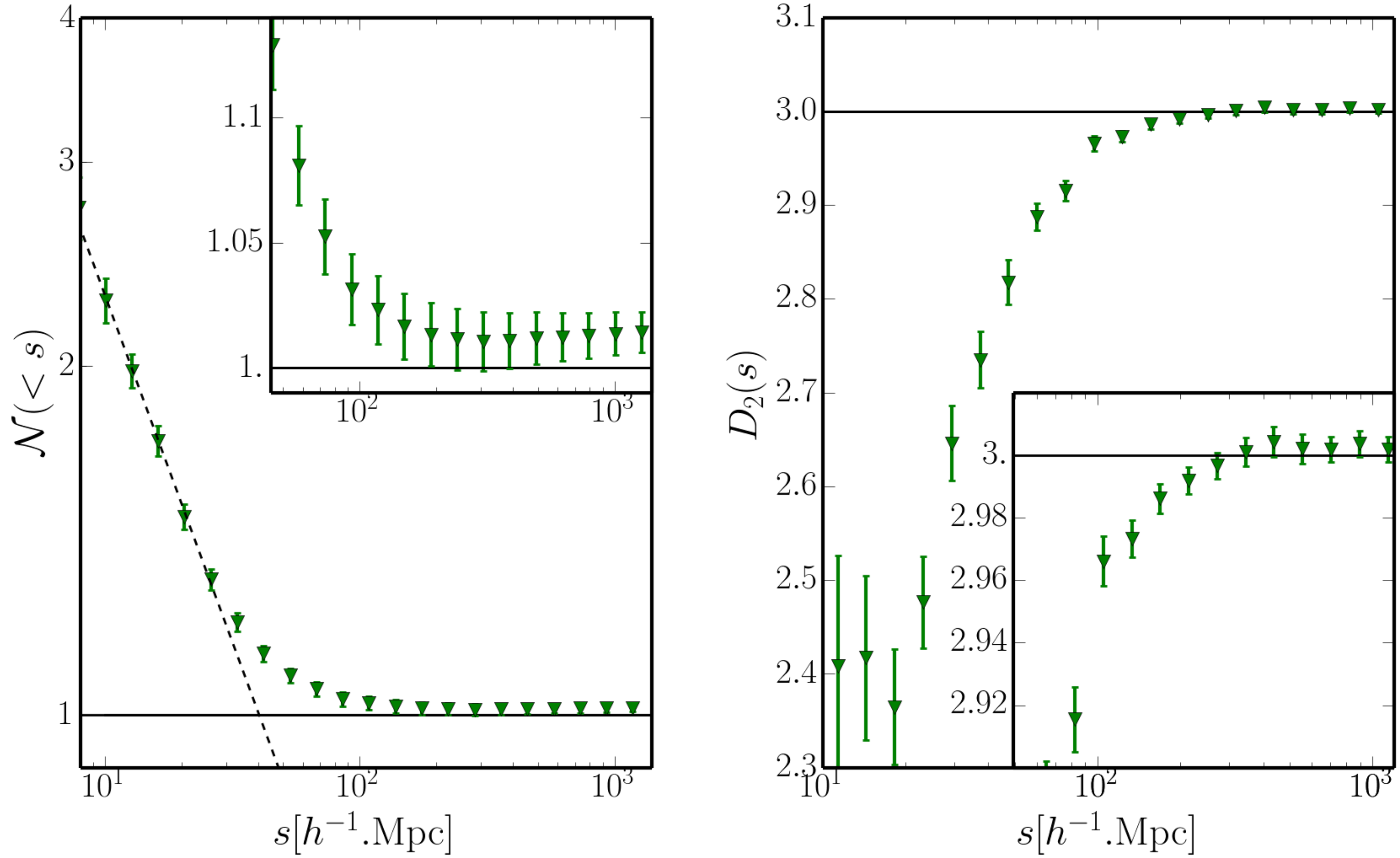
- Optimal estimator ('Landy-Szalay'-like), but needs a well-defined mean density.

- Less variance than the previous estimator



The results

- Is the Universe homogeneous ?
- Consistency test with ΛCDM



Results with simple estimator

1) $\mathcal{N}(<r)$ compatible with power law at small scales and remains constant at from 200 Mpc.h^{-1} until 1500 Mpc.h^{-1}

2) $D_2(r)$ compatible with 3 at large scales

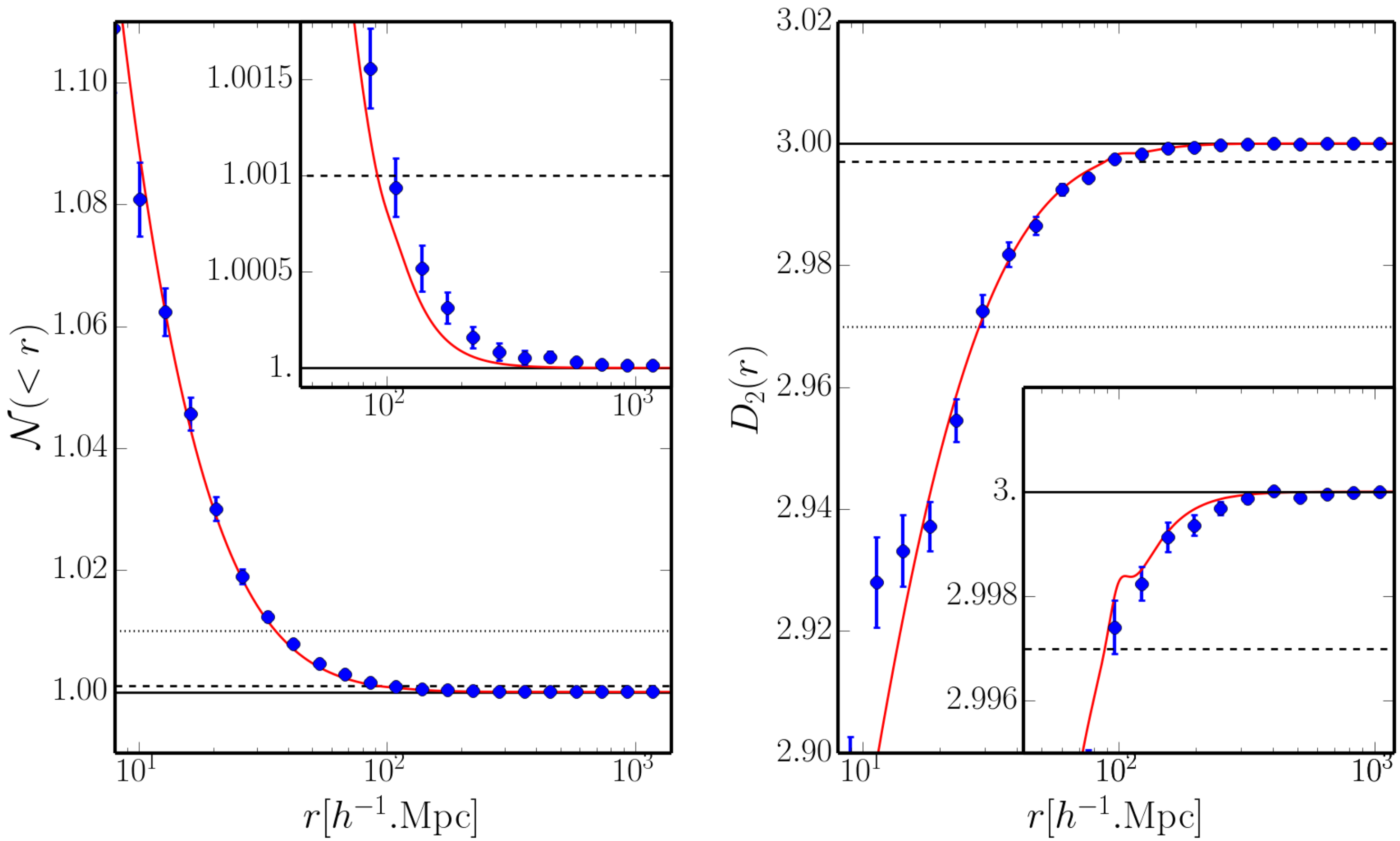
Homogeneity is established up to 1500 Mpc.h^{-1} with this estimator

Homogeneity of matter distribution and comparison to ΛCDM

- Check agreement with ΛCDM, with parameter from PLANCK 2015

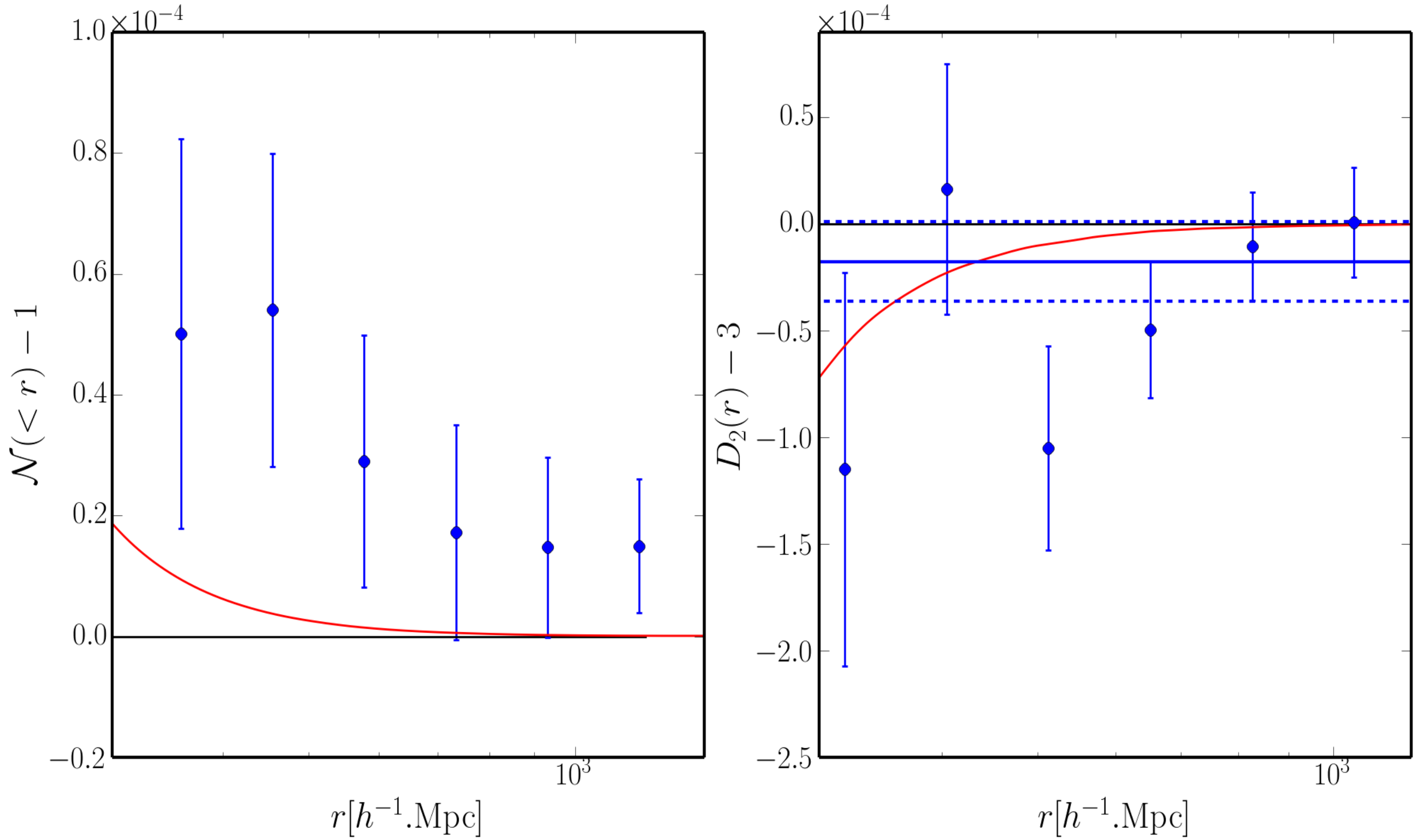
- $\mathcal{N}_{QSO}(< r) - 1 = b^2(\mathcal{N}_{DM}(< r) - 1)$

- Quantify homogeneity for dark matter distribution



Comparison with ΛCDM

1) Good Agreement between data and ΛCDM
2) b^2 compatible with former studies : $b = 3.89 \pm 0.12$



Quantitative limit on homogeneity

3) Fractal universes rejected :

$$D_2(r) - 3 = (-1.8 \pm 1.9) \times 10^{-5} (1\sigma)$$

Conclusion

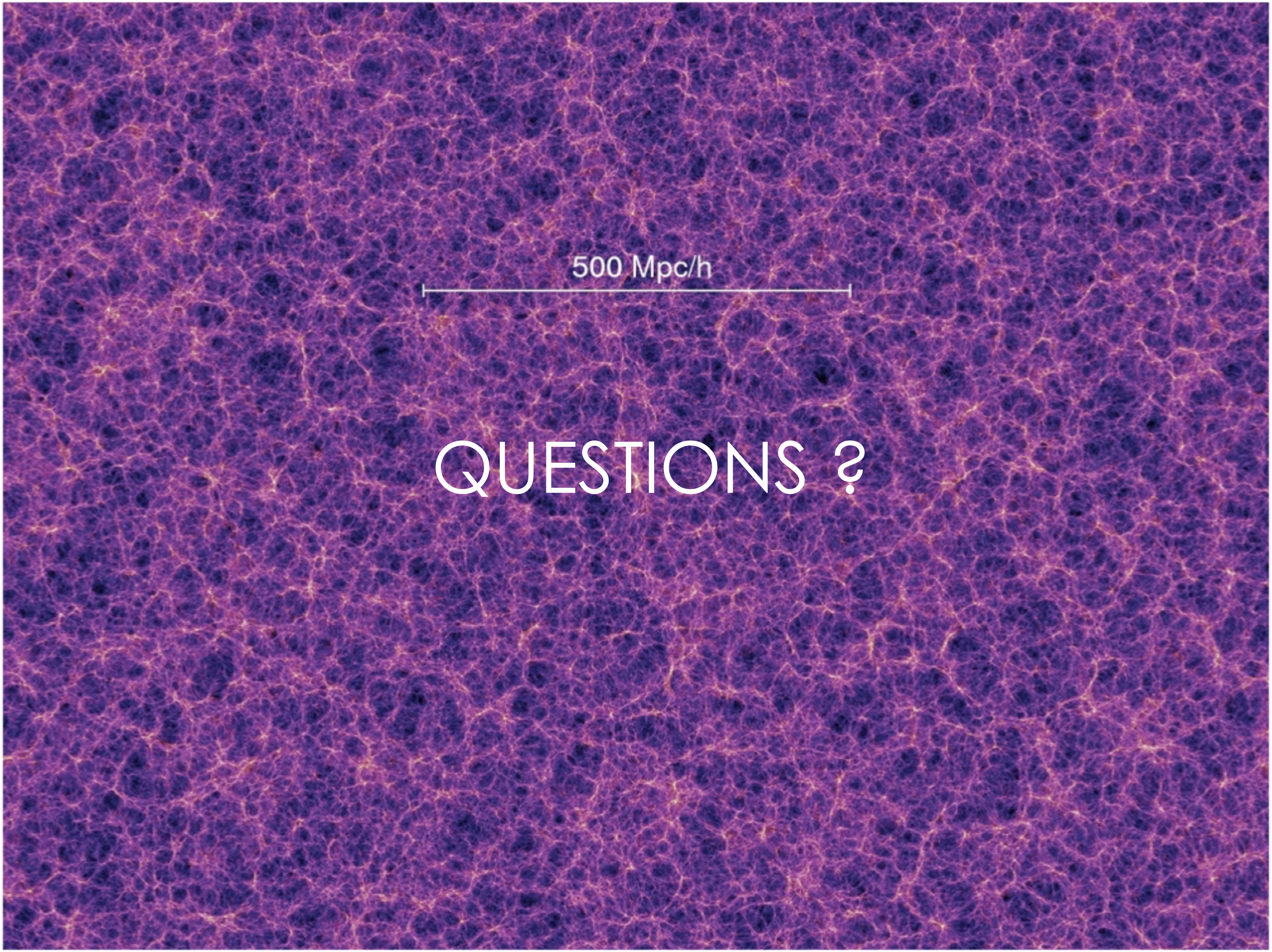
- Universe is homogeneous : $\rho = cste$

But are we really testing homogeneity ?

- ~~Universe is homogeneous :~~ $\cancel{\rho = cste}$

- Redshift of random distribution taken from data → cannot exclude $\rho = \rho(r)$
- Safer conclusions :
  - Universe statistically isotropic in each redshift layer
  - Universe is non-fractal :

$$D_2(r) - 3 = (-1.8 \pm 1.9) \times 10^{-5} (1\sigma)$$



QUESTIONS ?

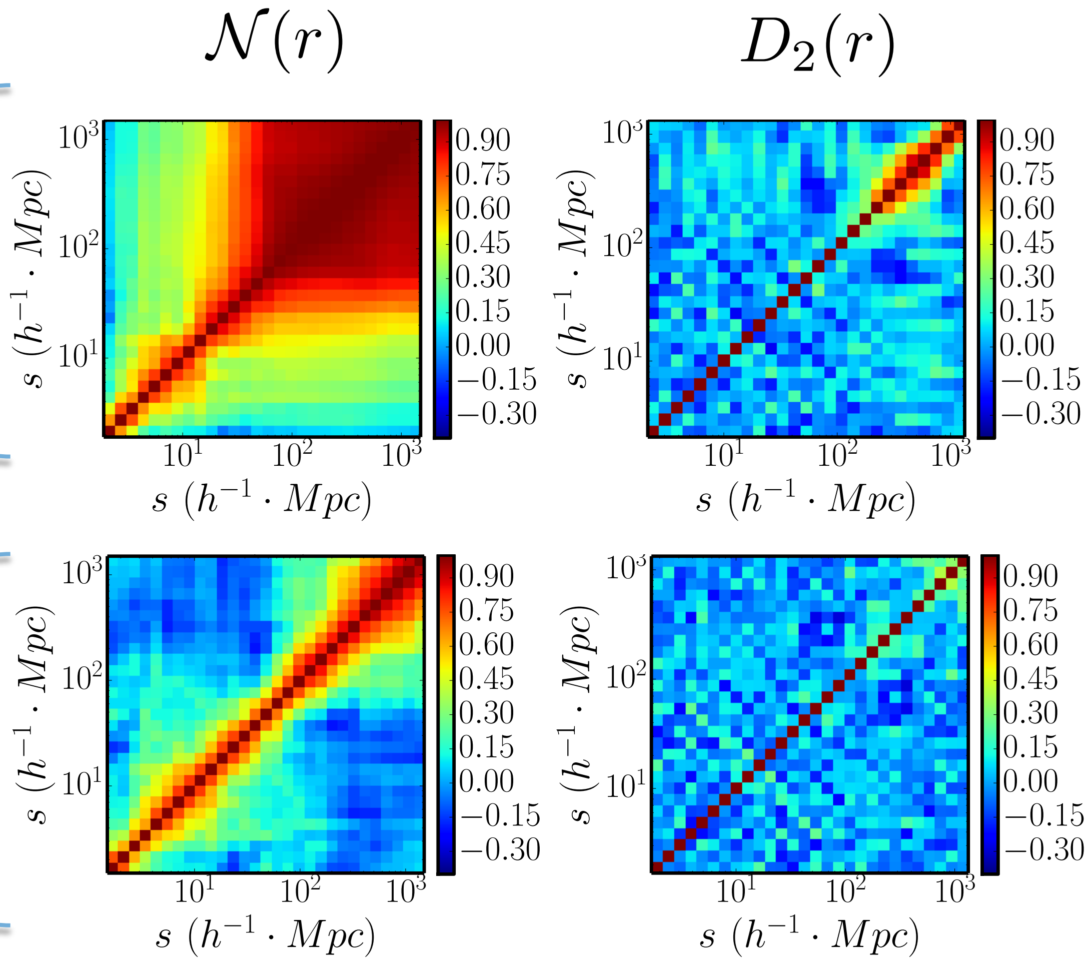
Back-up

Statistical uncertainties

- Correlation matrices are obtained from bootstrap resampling :

1[st] estimator (independent on homogeneity)

2[nd] estimator (less variance and correlation)



Systematic effects

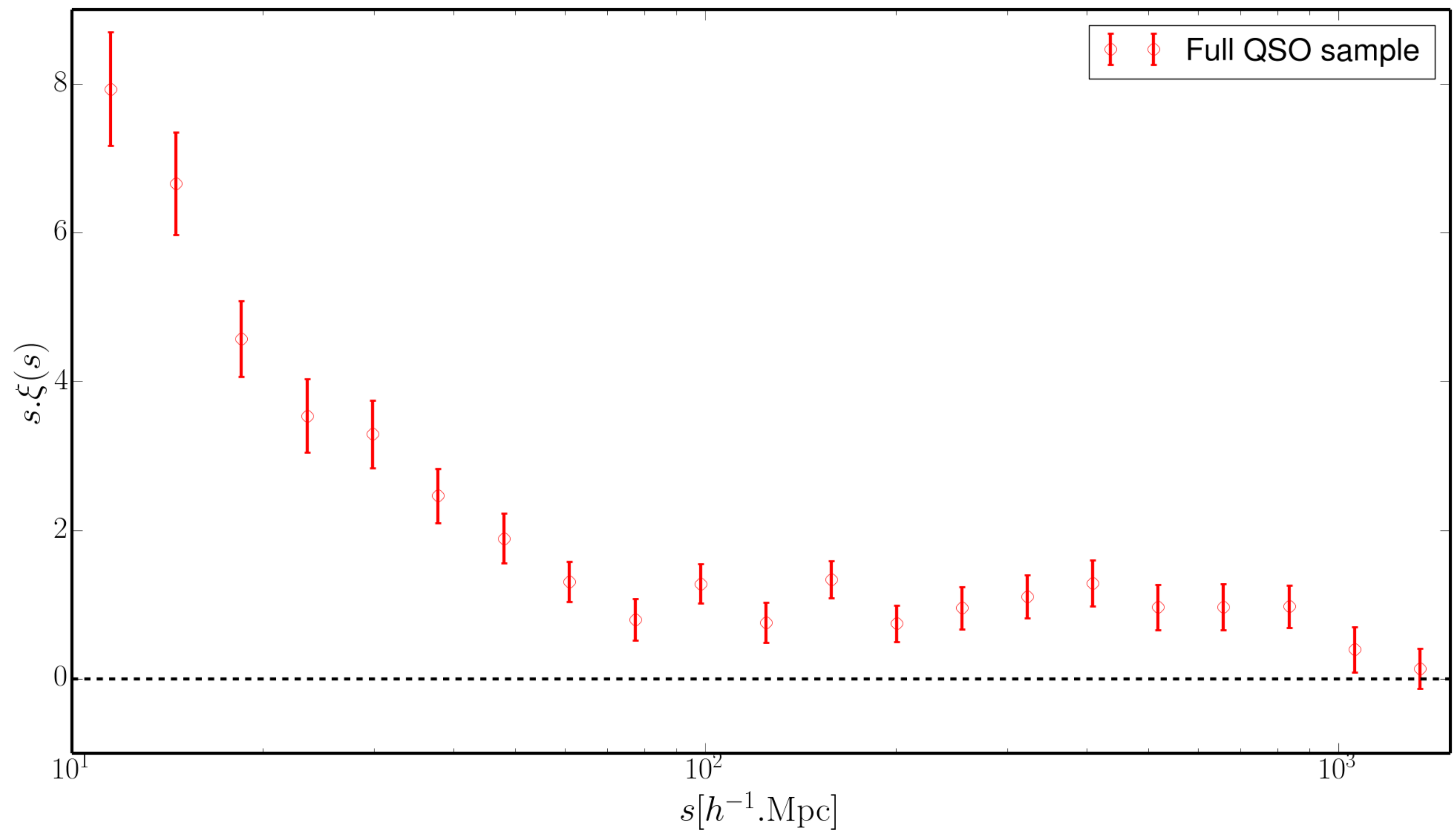
- Different sources of systematic effects:

  - 1) Errors on the QSO position
    - Error on angular position and redshift negligible

  - 2) Inhomogeneity from target selection (TS)
    - Dependence of TS with angular position → cuts and correction applied to mitigate systematic effects

Correction for TS inhomogeneity

- How to mitigate variation in TS angular completeness
  - 1) Restrain the analysis to homogeneous target selection : removal of the 1^{st} year.



s. ξ (s) after first year removal

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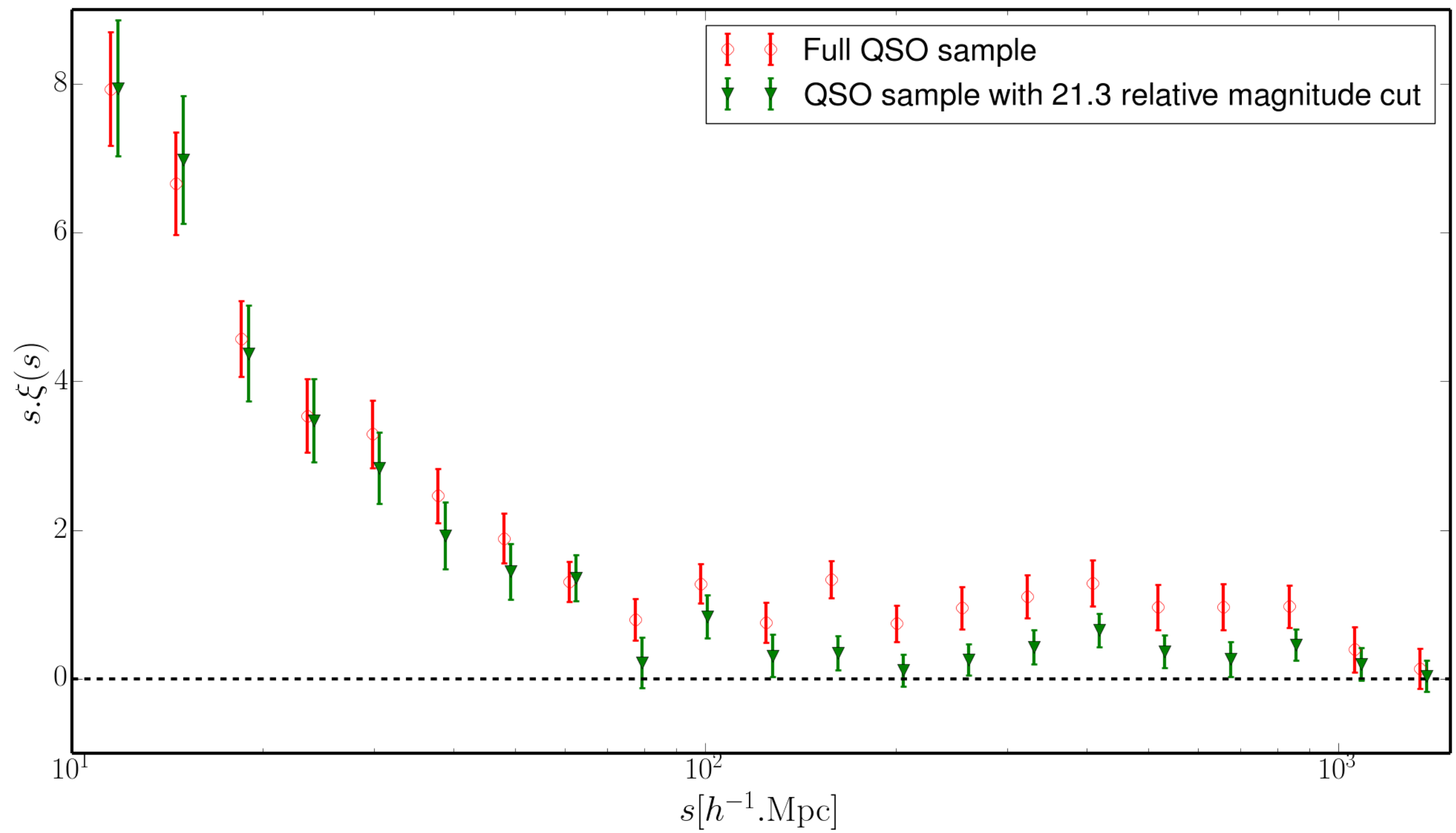

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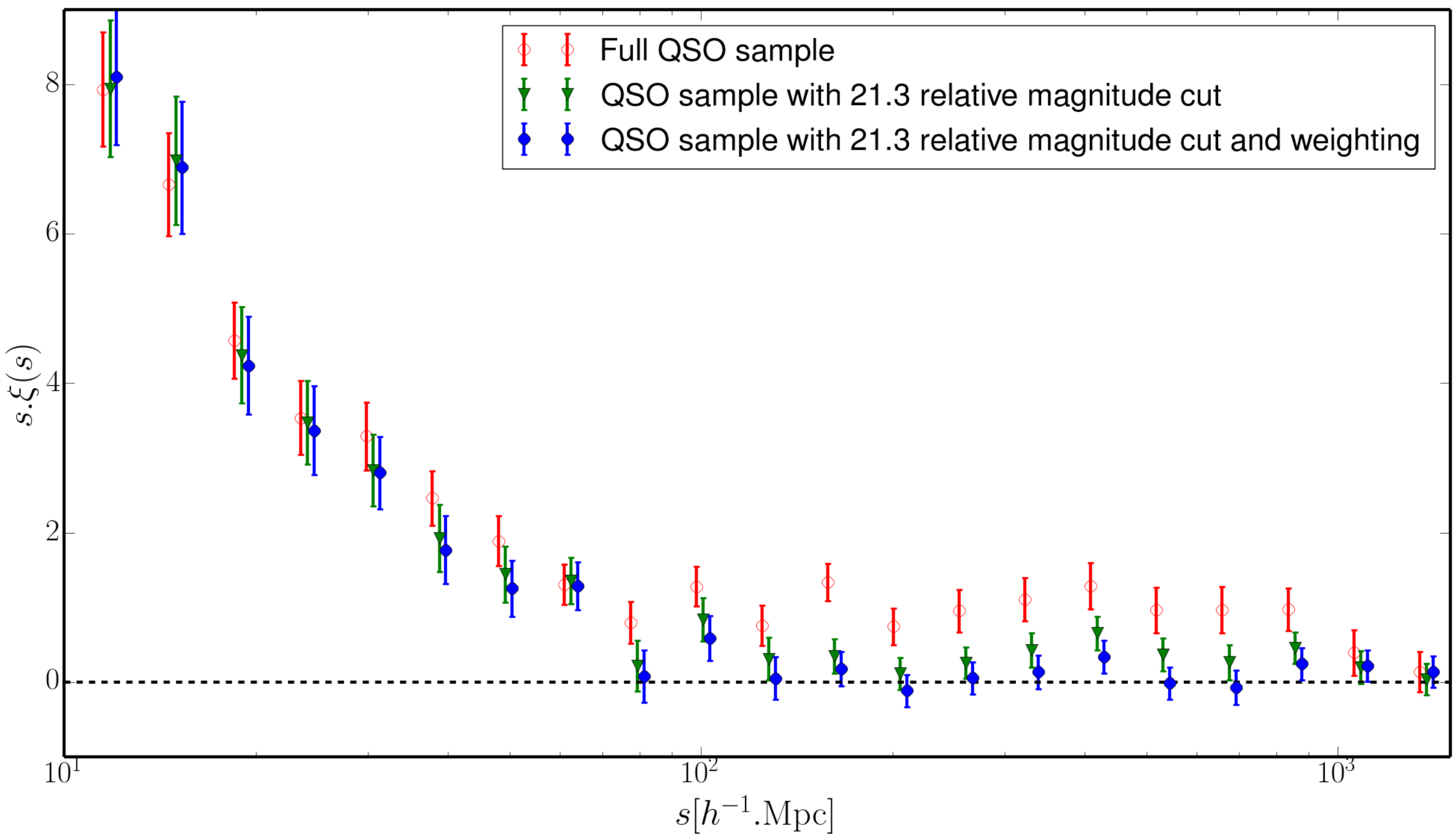
  - 3) Depth of photometric survey used for TS is angular dependent → we apply a weight to each QSOs to correct for this effect.



s. ξ (s) after apparent magnitude cut and weighting