Evolution of real-space correlation function from next generation cluster surveys

Srivatsan Sridhar

with Sophie Maurogordato, Christophe Benoist and Alberto Cappi
Observatoire de la Côte d'Azur

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Outline

Use two-point correlation function to study the evolution of clustering with

- Mass
- Redshift

→ Sensitive to Cosmology

Make use of cosmological simulations to study them.

How do simulations compare with theoretical predictions?

How to measure the above evolution, when we are provided with only photometric redshifts?

The two--point correlation function

In the case of clustering (due to density perturbations), there will be an excess with respect to the Poisson distribution. This is given by:

$$dP_{12} = n^2 \{1 + \xi(r)\} \, dV_1 \, dV_2$$

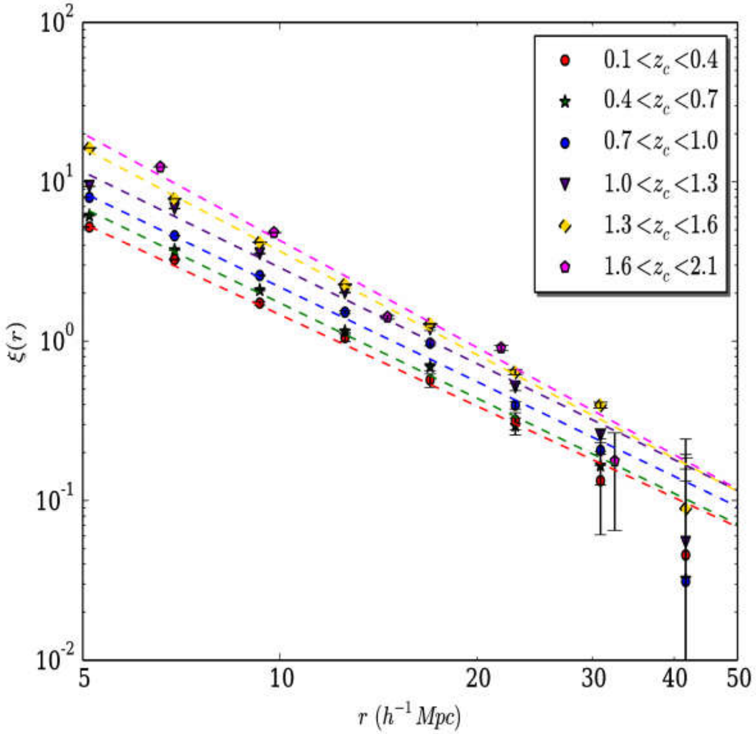
So the correlation function measures the excess probability. If there is clustering at a distance r, then $\xi(r) > 0$.

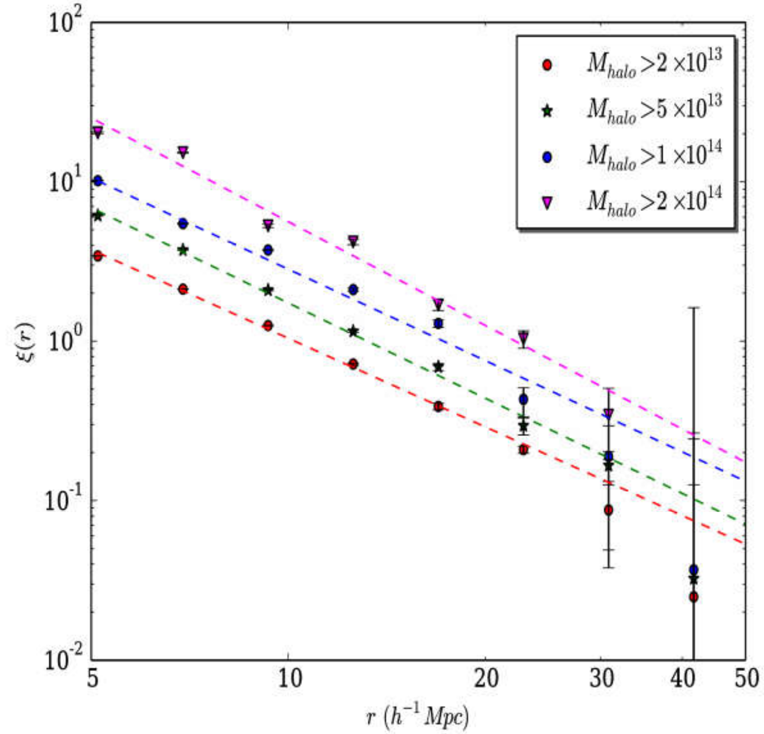
Two-point correlation function on galaxy clusters

- Redshift evolution of cluster correlation has received little attention. Future surveys (Euclid, LSST) will probe up to redshift of 2.0 and further
- Baryon Acoustic Osciallation (BAO) can be detected using $\xi(r)$, tight constraints on $\Omega_m, H_0, \Omega_\Lambda$ can be placed (Veropalumbo et al. 2015)
- Constraints on cosmological parameters (Ω_m, σ_8) by comparison with model expectations (Governato et al. 1999; Bahcall et al. 2003; Basilakos & Plionis, 2003; Tinker et al. 2011; Sartoris et al. 2013)

Simulation used

- We make use of light-cone simulations of Merson et al. 2013 constructed using the Lagos 12 GALFORM model (Lagos et al. 2012).
- Light-cone constructed using a semi-analytic model onto the N-body dark matter halo merger trees of the Millennium simulation under the ΛCDM framework.
- Area covered is 500 deg^2 and the cosmology being (Ω_m, Ω_Λ, Ω_b, h = 0.25, 0.75, 0.045, 0.73)
- Light-cone extends up to z~3.0 with halo masses in the range $12.0<\log_{10}(M_{200})<15.0$ (h^{-1} M_{sun})



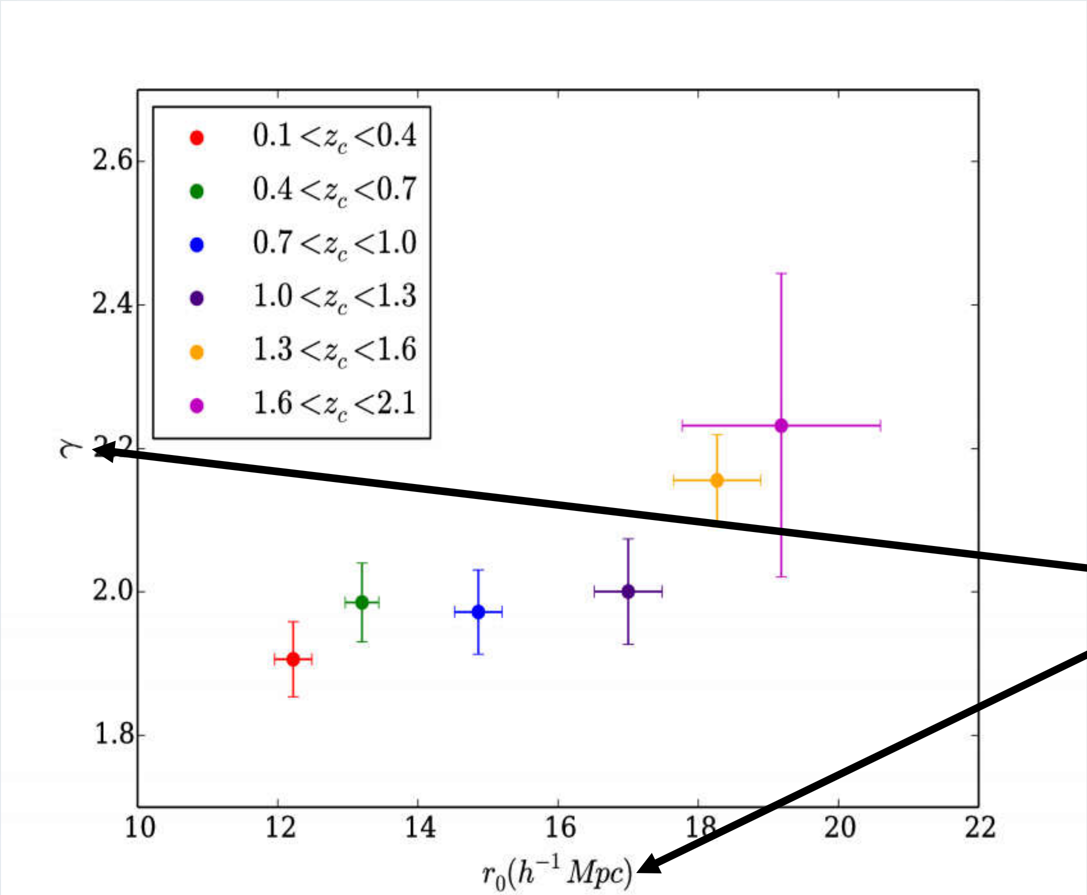


Srivatsan Sridhar et al. 2016a (in prep)

Evolution of the two-point correlation function with redshift for a common mass cut $M > 5 \times 10^{13}\ M_{sun}$

Evolution of the two-point correlation function with mass for a common redshift cut $0.4 < z_c < 0.7$

Evolution of the best-fit parameters with redshift



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Fit done using the equation:

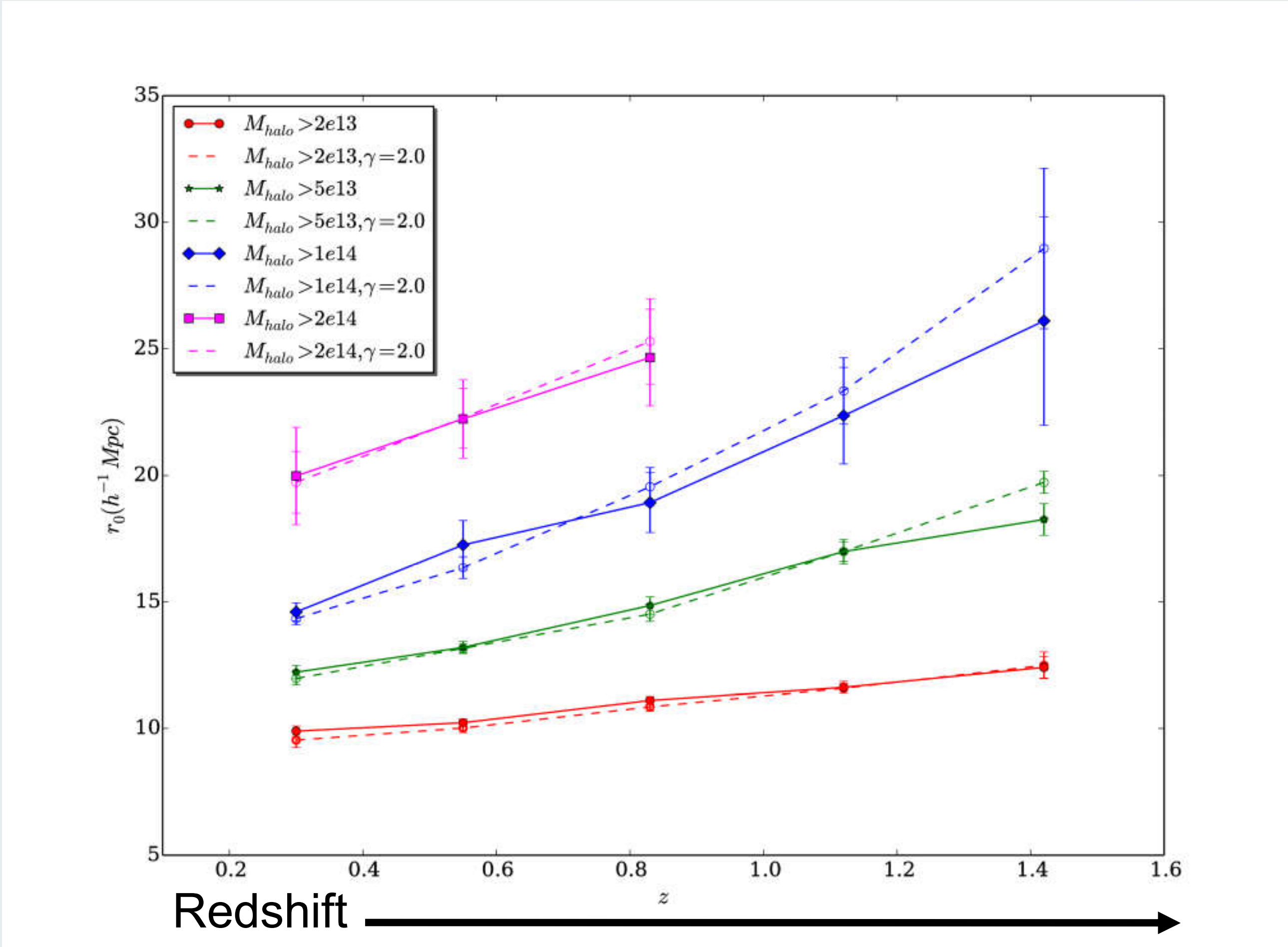
$$\xi(r) = \left(\frac{r}{r_0}\right)^{\gamma}$$

where:

γ → slope

r_0 → correlation length

Evolution of r_0 with redshift for increasing mass cut's



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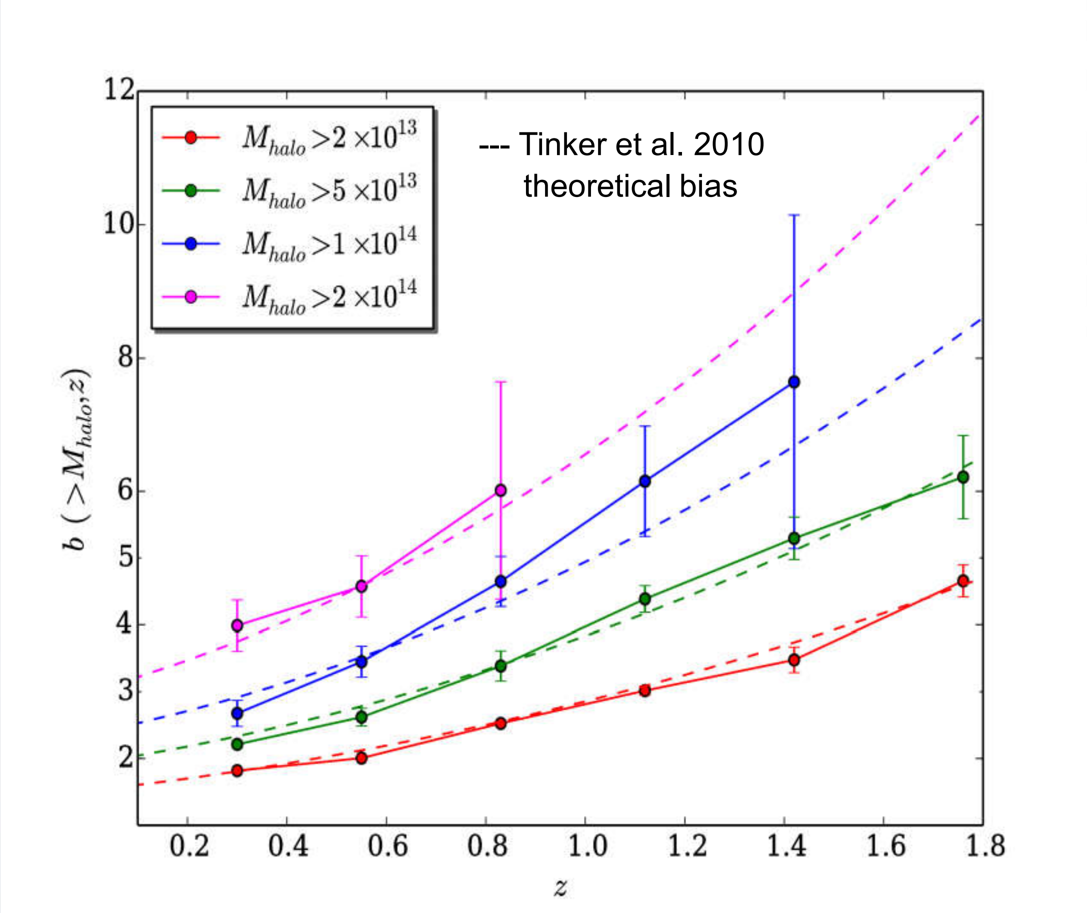
Evolution of bias with redshift



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$$\xi_{light}(r) = b^2(M, z)\,\xi_{Mass}(r)$$

where *b(M,z)* -> bias factor

Light is a biased tracer of mass

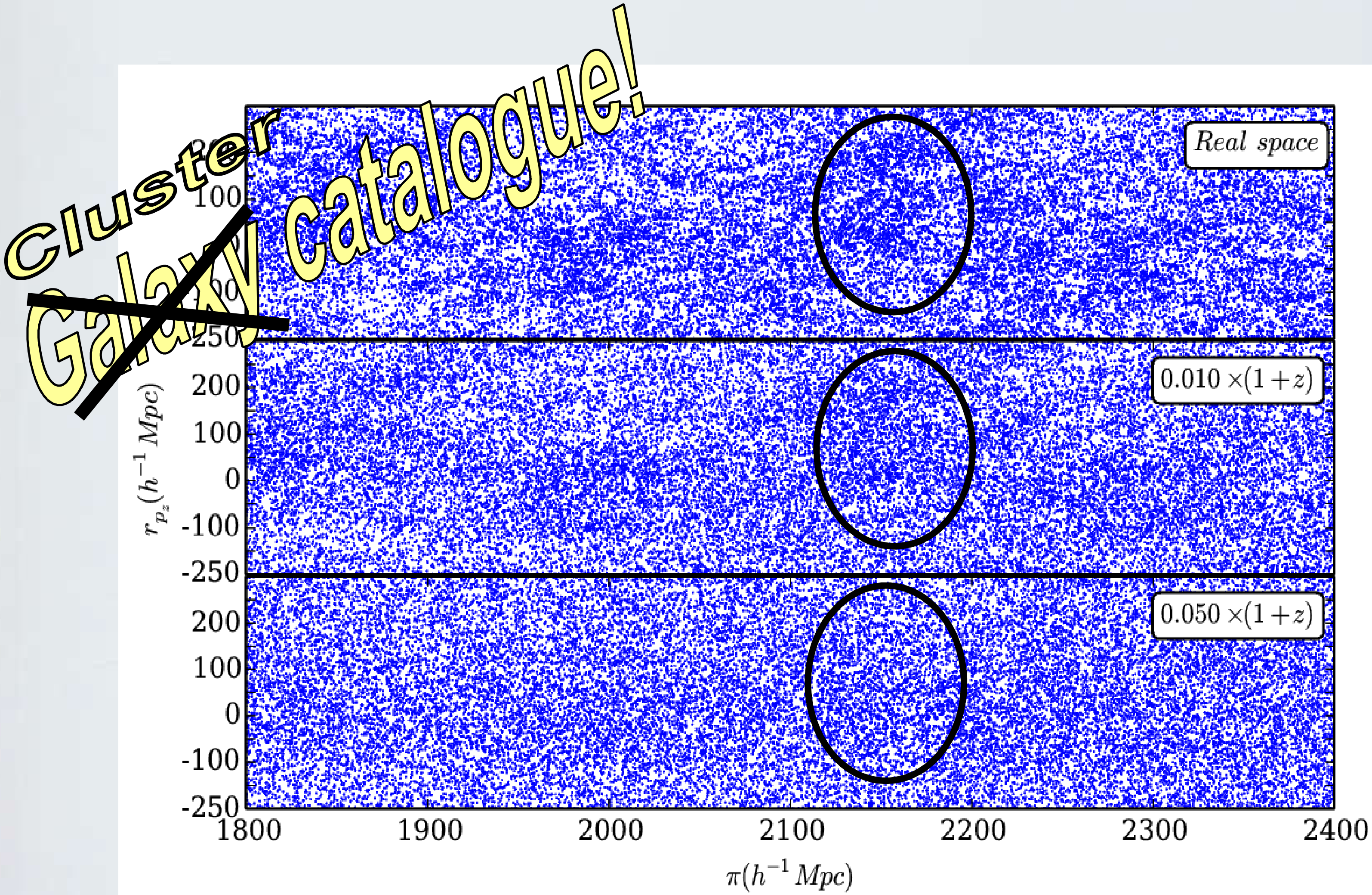
Simulation agrees with theoretical predictions

All the results we have seen so far have been calculated using cosmological redshifts (i.e. true redshifts). Distances calculated to these clusters are without any errors in them.

Simulations are cool !!

Going from simulations to observed data

- Observations do not have 100% purity and completeness
- Projection effects
- Mass estimates are not always available (need to rely on mass tracers and mass proxies)
- Have to deal with photometric redshifts, which have large errors associated



Structures clearly seen in real-space BUT

smoothed and hardly recognisable in photo-z space.

So how does one recover the real--space clustering signal from a photometric survey when the errors increase with redshift as:

$$\sigma_z = \sigma_{z=0} \times (1+z_c)$$

where $\sigma_{z=0}$ can be 0.005, 0.010, 0.030 and so on

To recover the real--space clustering we make use of the method used by Davis & Peebles 1983 and Saunders et al. 1992.

Also adopted by Arnalte-Mur et al. 2008 for galaxies

Split into two planes

$$\Xi(\sigma) \equiv 2\int_0^\infty \xi(\sigma, \pi) d\pi \,.$$

Line of sight plane (π)

Across the line of sight plane (σ)

Invert it to get the real-space correlation function

$$\Xi(\sigma) = 2\int_\sigma^\infty \xi_r(r) \frac{r dr}{(r^2 - \sigma^2)^{1/2}} \,. \quad (4)$$

This relation can be inverted, obtaining ξ_r in terms of Ξ as the Abel integral:

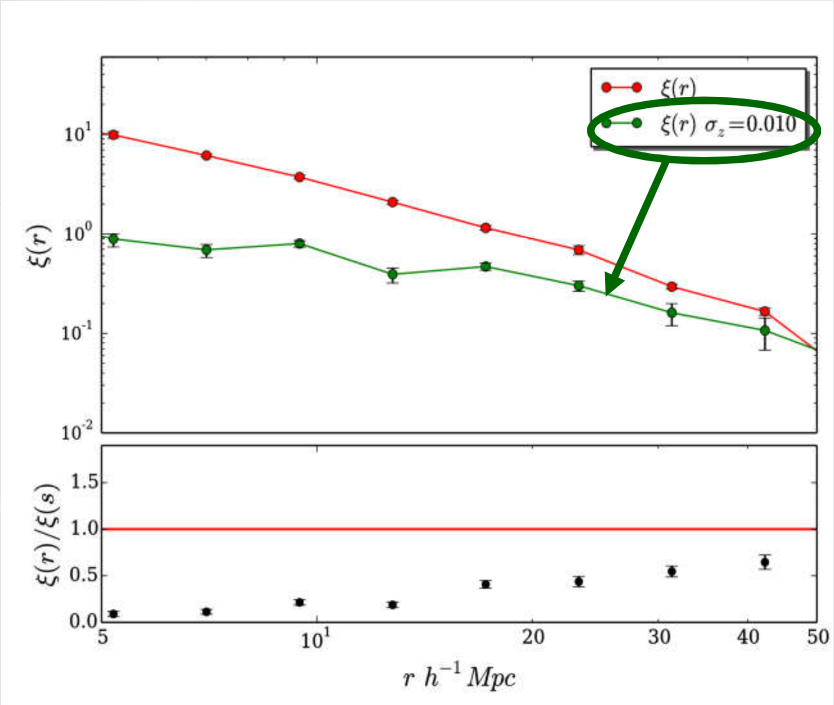
$$\xi_r(r) = -\frac{1}{\pi}\int_r^\infty \frac{d\Xi(\sigma)}{d\sigma} \frac{d\sigma}{(\sigma^2 - r^2)^{1/2}} \,. \quad (5)$$

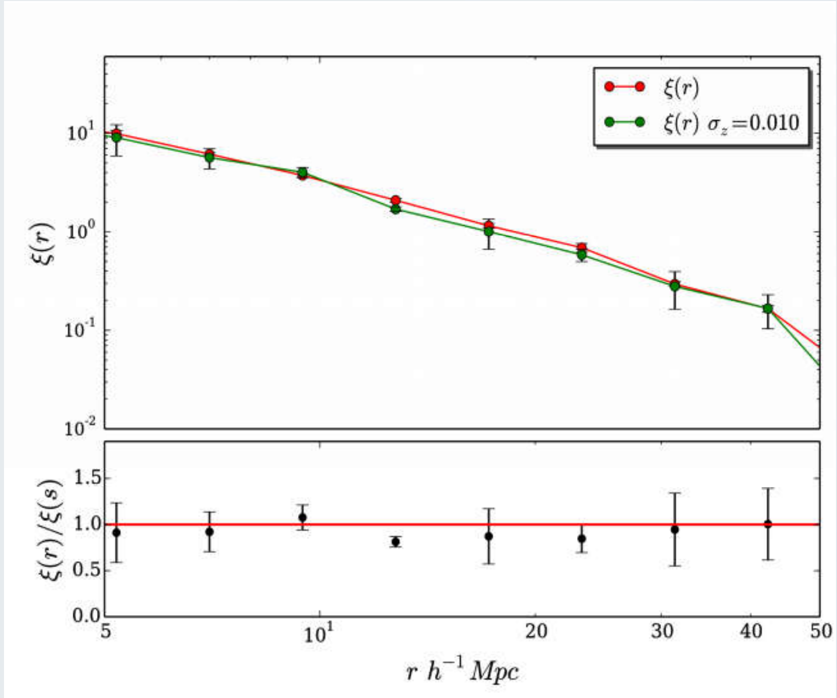
Sum up all the values in each bin

$$\xi(\sigma_i) = -\frac{1}{\pi}\sum_{j \geqslant i} \frac{\Xi_{j+1} - \Xi_j}{\sigma_{j+1} - \sigma_j} \ln\left(\frac{\sigma_{j+1} + \sqrt{\sigma_{j+1}^2 - \sigma_i^2}}{\sigma_j + \sqrt{\sigma_j^2 - \sigma_i^2}}\right) \,.$$

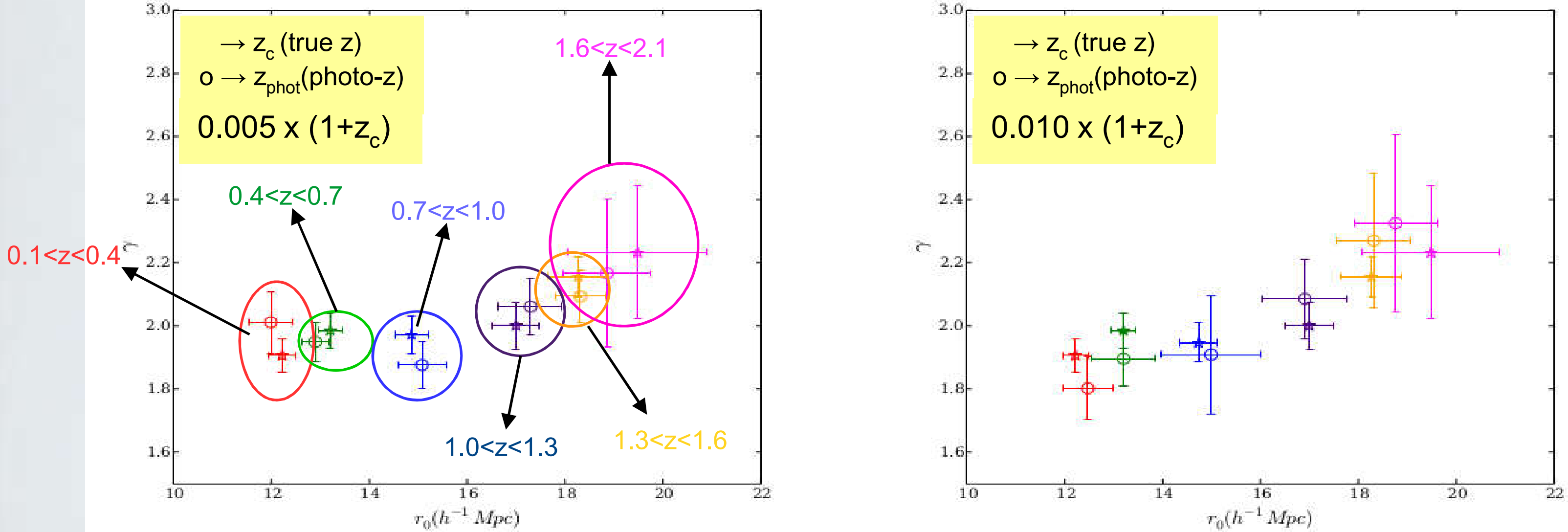
Direct application of Landy & Szalay method

Deprojection method

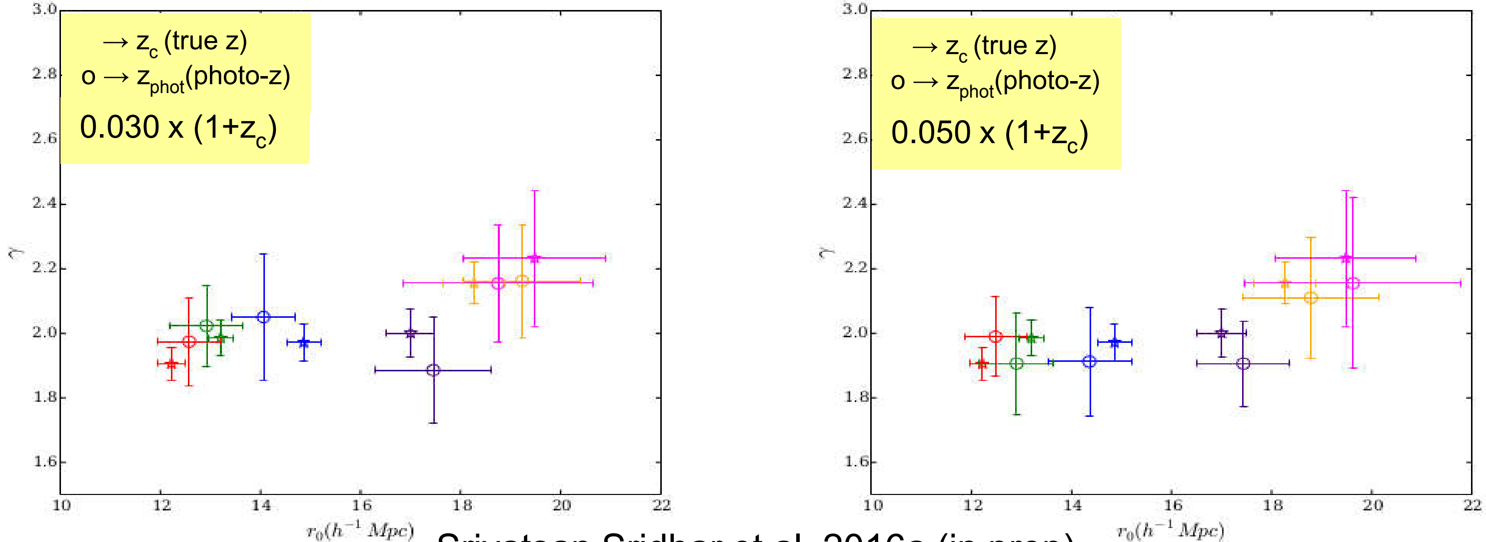




Applying the
de-projection method



Redshift evolution of the best-fit parameters for each photo-z uncertainty



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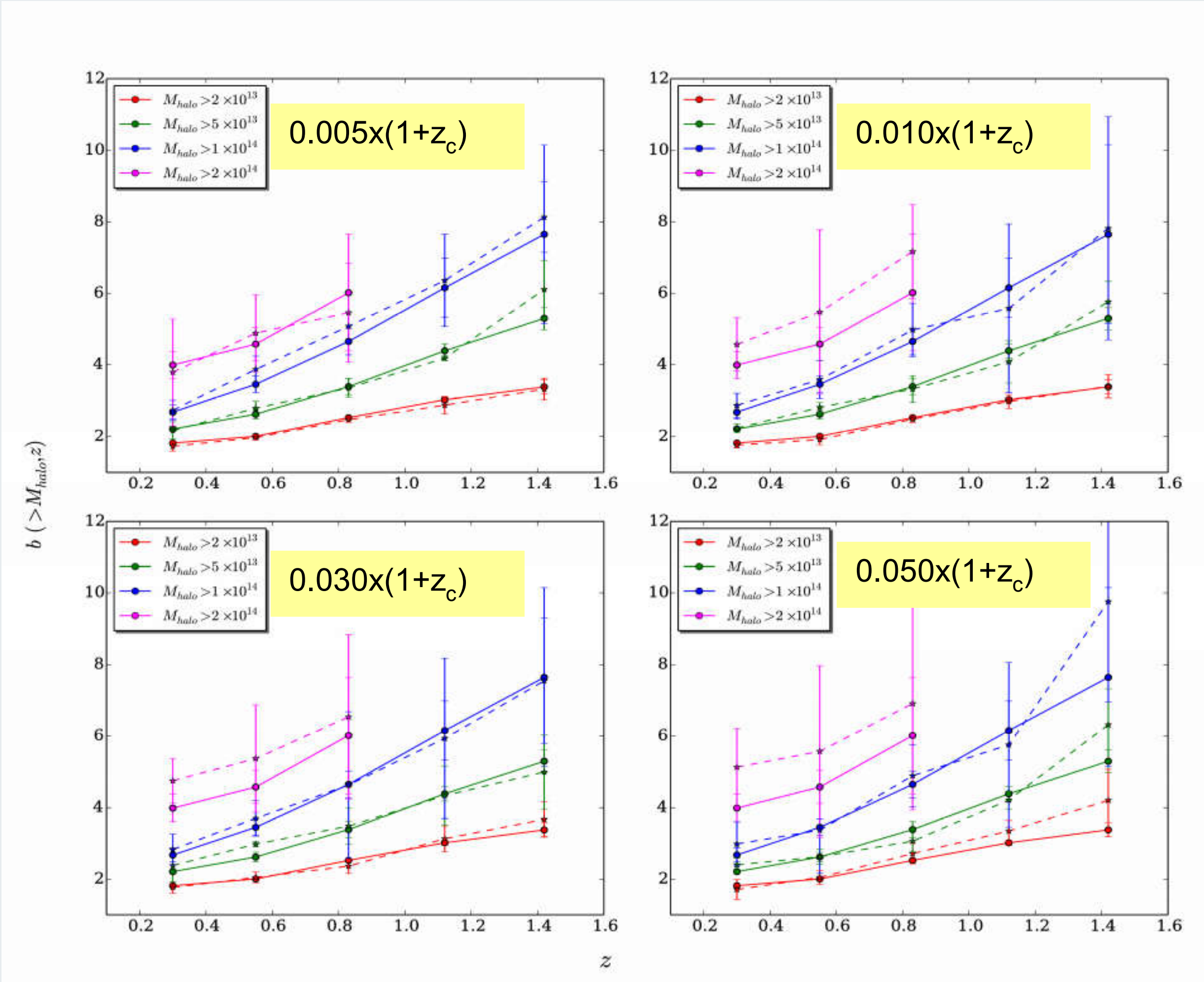
Redshift vs bias (solid lines → true sample, dotted lines → photo-z samples)



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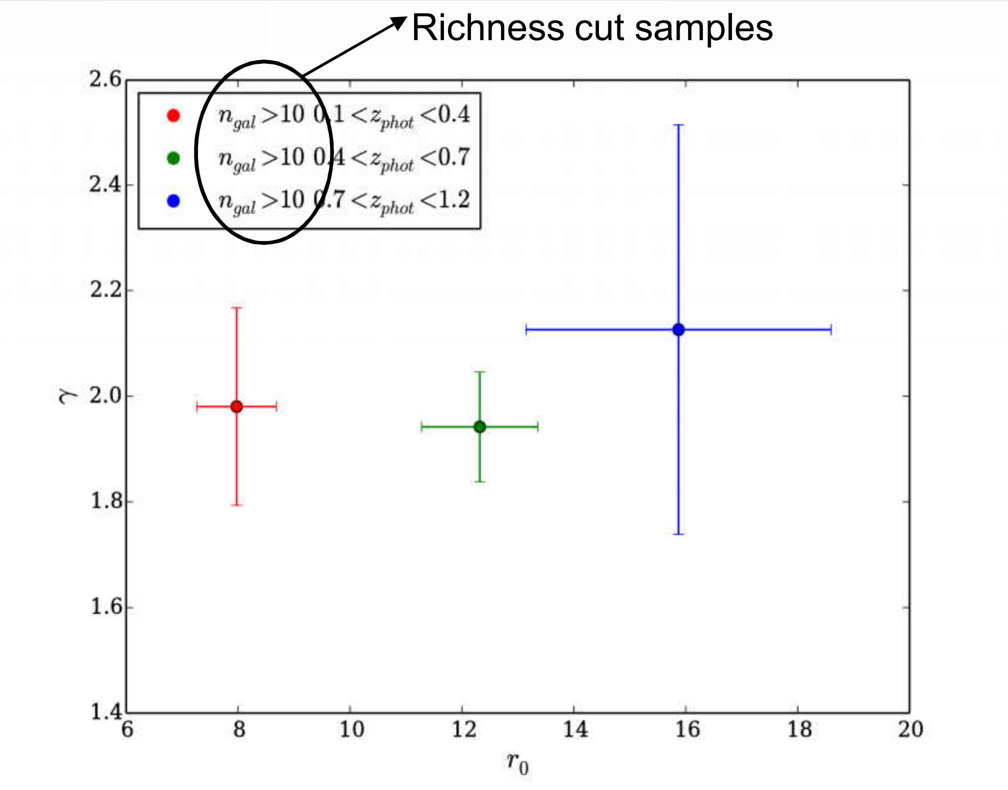
Results from CFHTLS-W1 survey

Area of survey ~ 63 deg^2



z-range	r_0	slope
0.1<z<0.4	7.97±0.7	1.98±0.18
0.4<z<0.7	12.31±1.03	1.94±0.10
0.7<z<1.2	15.87±2.12	2.12±0.38

Behaviour of best-fit parameters similar to what we obtained using simulations

A richness-mass comparison can be made

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What do future cluster surveys have to offer?

- Dark Energy Survey (ongoing):

  Area of 4000 deg^2, redshift coverage of z~1.3

  Photo-z accuracy (σ_z~0.02 up to z~1.3) (Dark Energy Collaboration)

- The Euclid Survey (launch in 2020):

  Area of 15,000 deg^2, redshift coverage of z~2.0

  Photo-z pessimistic case (σ_z~0.05 up to z~2.0) for galaxies
  (roughly σ_z~0.015 up to z~2.0 for a cluster with 10 galaxies)
  Photo-z optimistic case (σ_z~0.03 up to z~2.0) for galaxies
  (roughly σ_z~0.009 up to z~2.0 for a cluster with 10 galaxies)
  (Laureijs et al. 2011)

Summary

- Redshift and mass evolution of cluster correlation calculated up to z~2.0 (can be compared with future observations of high redshift clusters)
- Cluster bias calculated up to z~2.0, agrees with theoretical predictions of Tinker et al. 2010
- Recovery of the two-point correlation function (within 1σ) is possible for clusters even with a redshift uncertainty of 0.050x $(1+z_c)$ up to redshifts of z~2.0

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Вопросы?

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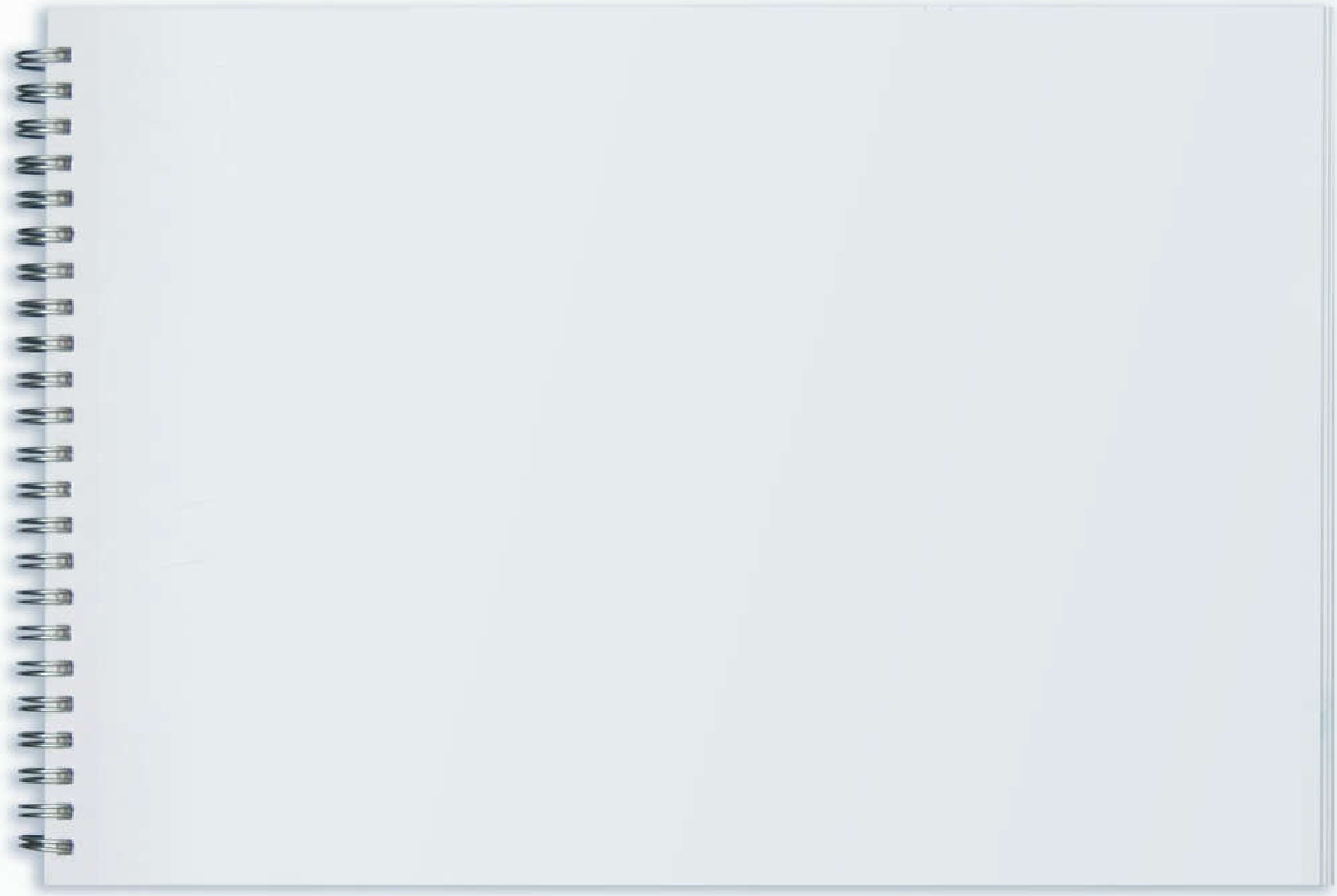

The estimator used to calculate ξ(r)

We make use of the Landy & Szalay estimator which has been proven to be the best among several other estimators (Kerscher et al. 2000)

$$\hat{\xi}(r) = 1 + \left(\frac{N_R}{N_D}\right)^2 \frac{DD(r)}{RR(r)} - 2\frac{N_R}{N_D}\frac{DR(r)}{RR(r)}$$

N_D → Number of data points (from data catalogue)

N_R → Number of random points (from random catalogue constructed)

DD → data-data points counted within a spherical shell of radius($r,r+dr$)

DR → data-random points in the same shell

RR → random-random points in the same shell