The large scale inhomogeneity of the galaxy distribution

Francesco Sylos Labini

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- Institute for Complex Systems, CNR, Rome Italy
- University of Brescia, Italy

Outline

- Data and standard results
- Standard theoretical predictions
- Clustering, correlations and structures
- Results
- Conclusions

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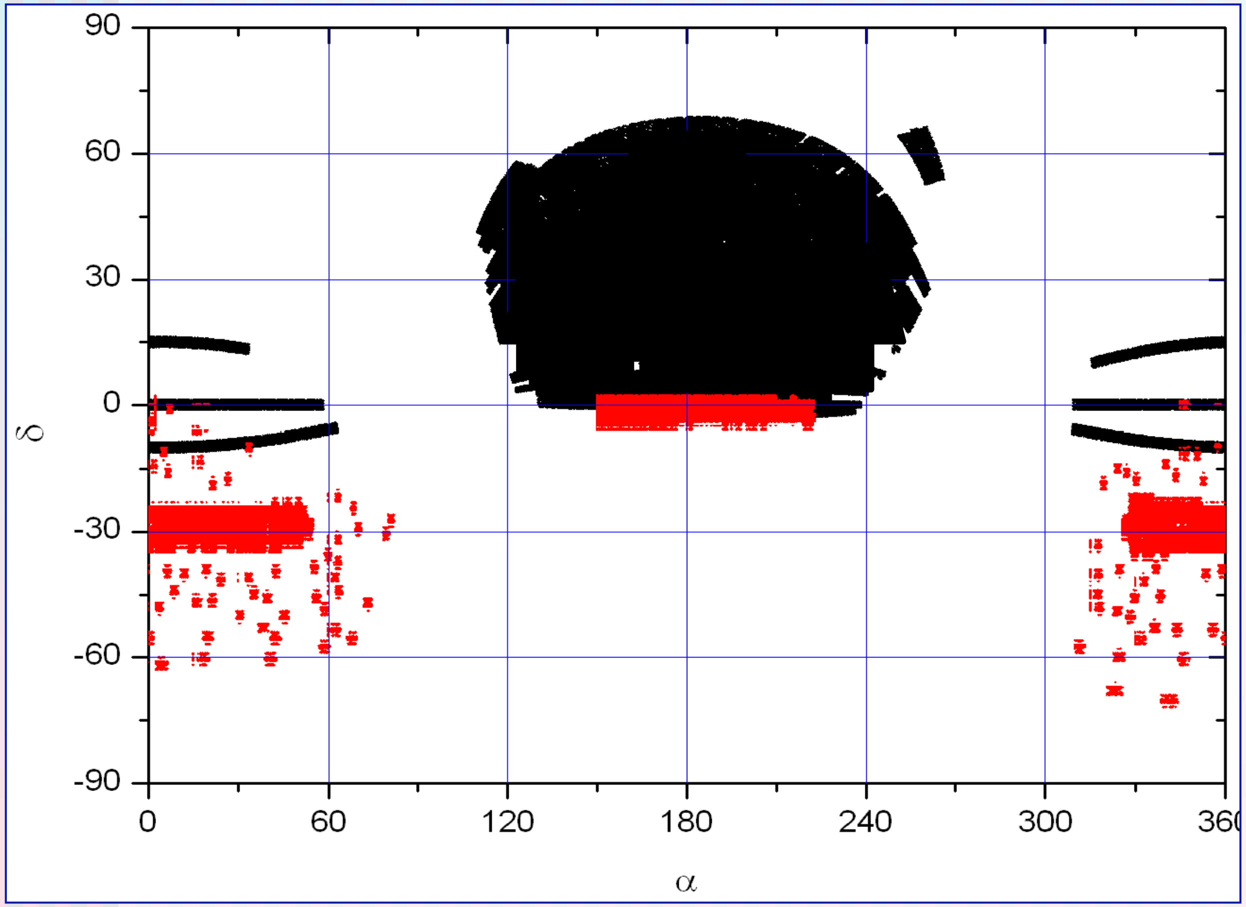
Galaxy Surveys

- York, D., et al., Astron.J.,**120**, (2000) 1579 (http://*www.sdss.org*)
- Colless et al., MNRAS **328** (2001) 1039 (*http://www.mso.anu.edu.au/2dFGRS/*)

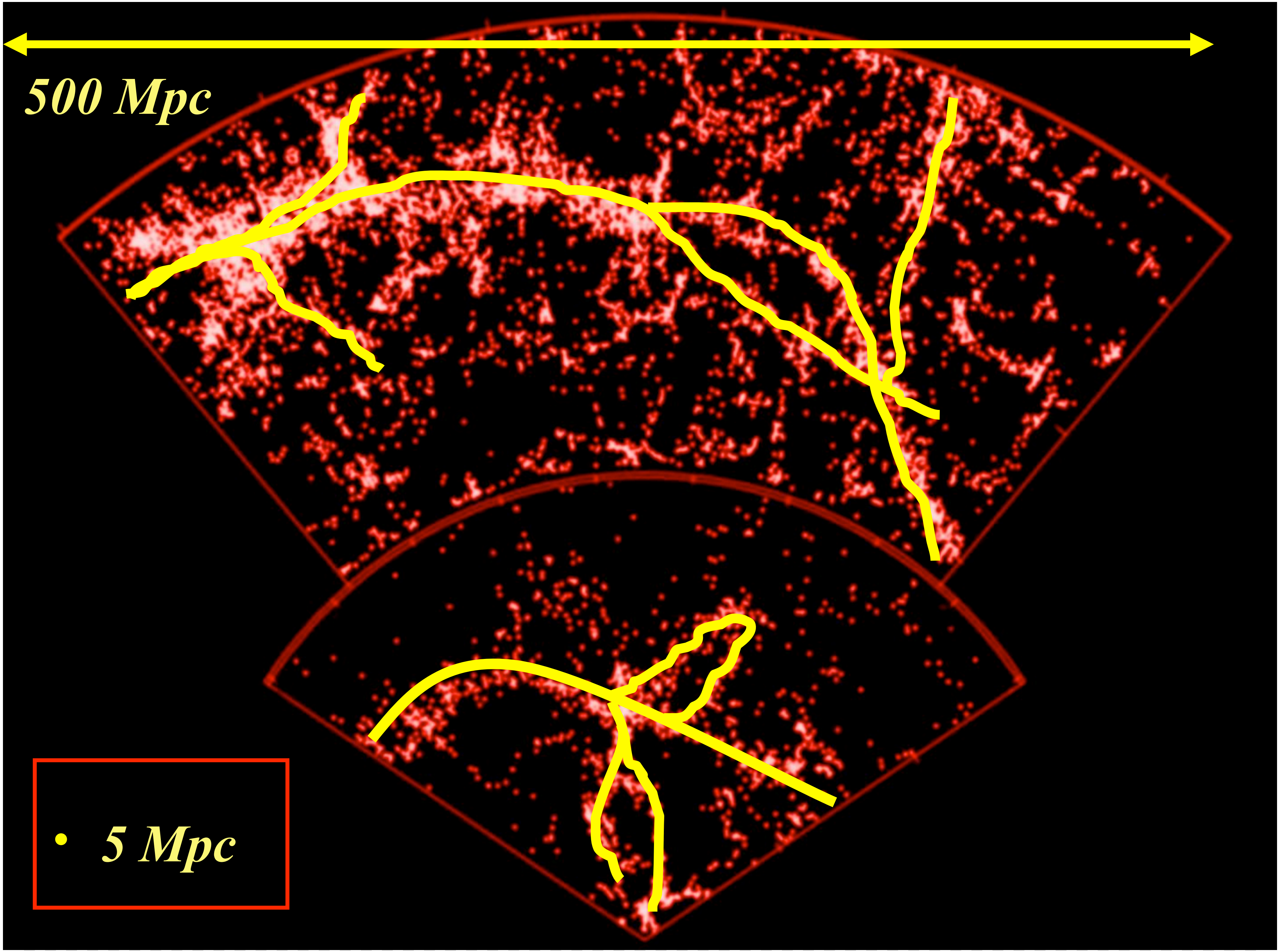


SDSS DR7(2008)

- u,g,r,i,z, $r < 17.7$
- MG sample ~ *900,000* galaxies ($z < 0.2$)
- LRG sample ~*100,000* galaxies ($z < 0.6$),
- A~ *8000* deg^2

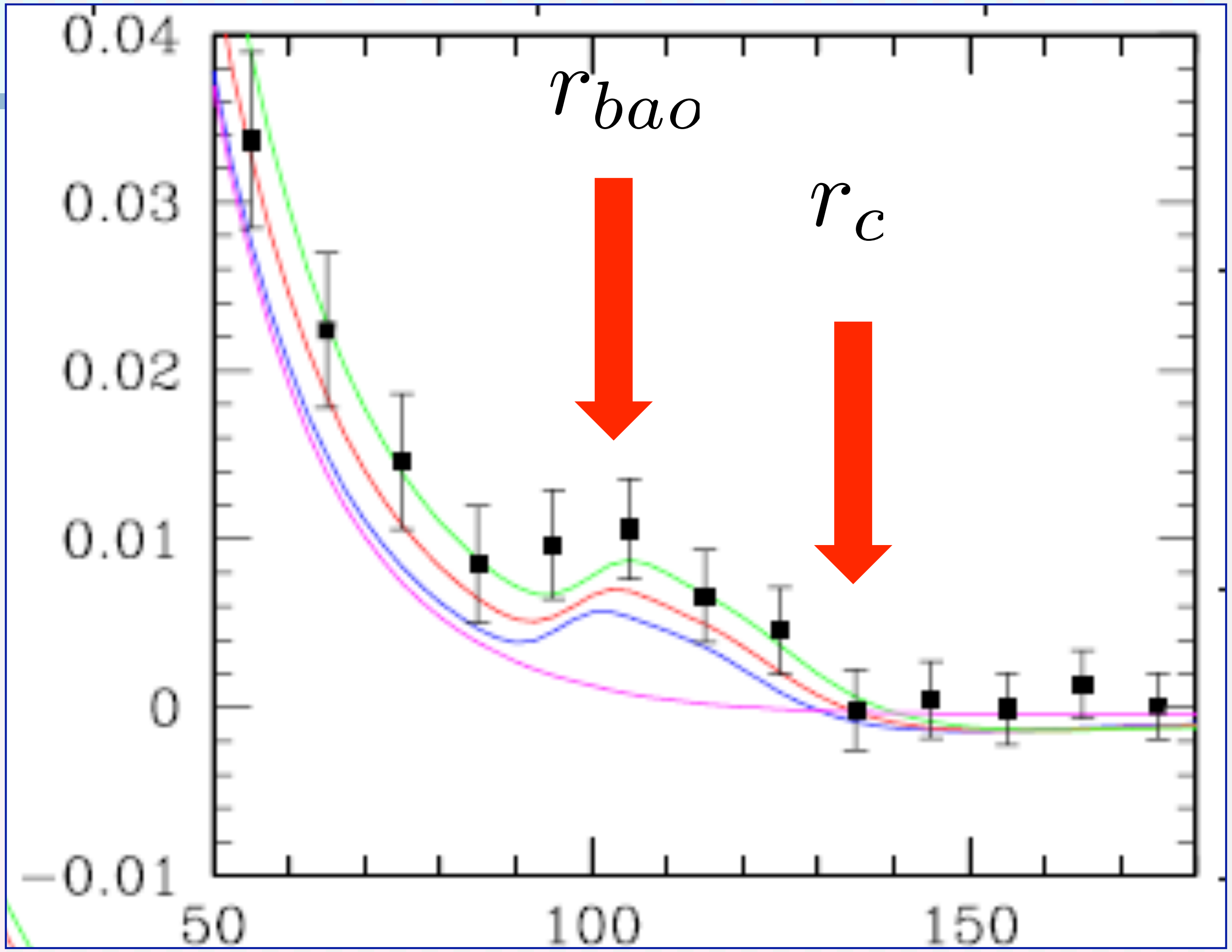
2dFGRS (2006)

- ~*245,000* galaxies
- $b_j < 19.45$
- $z < 0.3$
- A~*1500* deg^2


500 Mpc
5 Mpc

The BAO scale

- . Eisenstein, D.J., et al., 2005, Ap.J., 633, 560



$$\xi(r_0) = 1 \rightarrow r_0 \approx 15\text{Mpc/h}$$

The Local Hole in the Galaxy Distribution: New Optical Evidence

G.S. Busswell, T. Shanks, P.J. Outram, W.J. Frith, N. Metcalfe & R. Fong

- Busswell G.S, et al., 2004, MNRAS, **354**, 991

We find conclusive evidence that the Southern counts with B<17 mag are down by ≈30 per cent relative to both the Northern counts and to the models of Metcalfe et al in the same magnitude range.

Such a 25 per cent deficiency extending over $\approx 10^7\ h^{-3}$ Mpc^3 may imply that the galaxy correlation function's power-law behaviour extends to $\approx 150\ h^{-1}$Mpc with no break and show more excess large-scale power than detected in the 2dFGRS correlation function or expected in the ΛCDM cosmology.

The Local Hole in the Galaxy Distribution: New Optical Evidence

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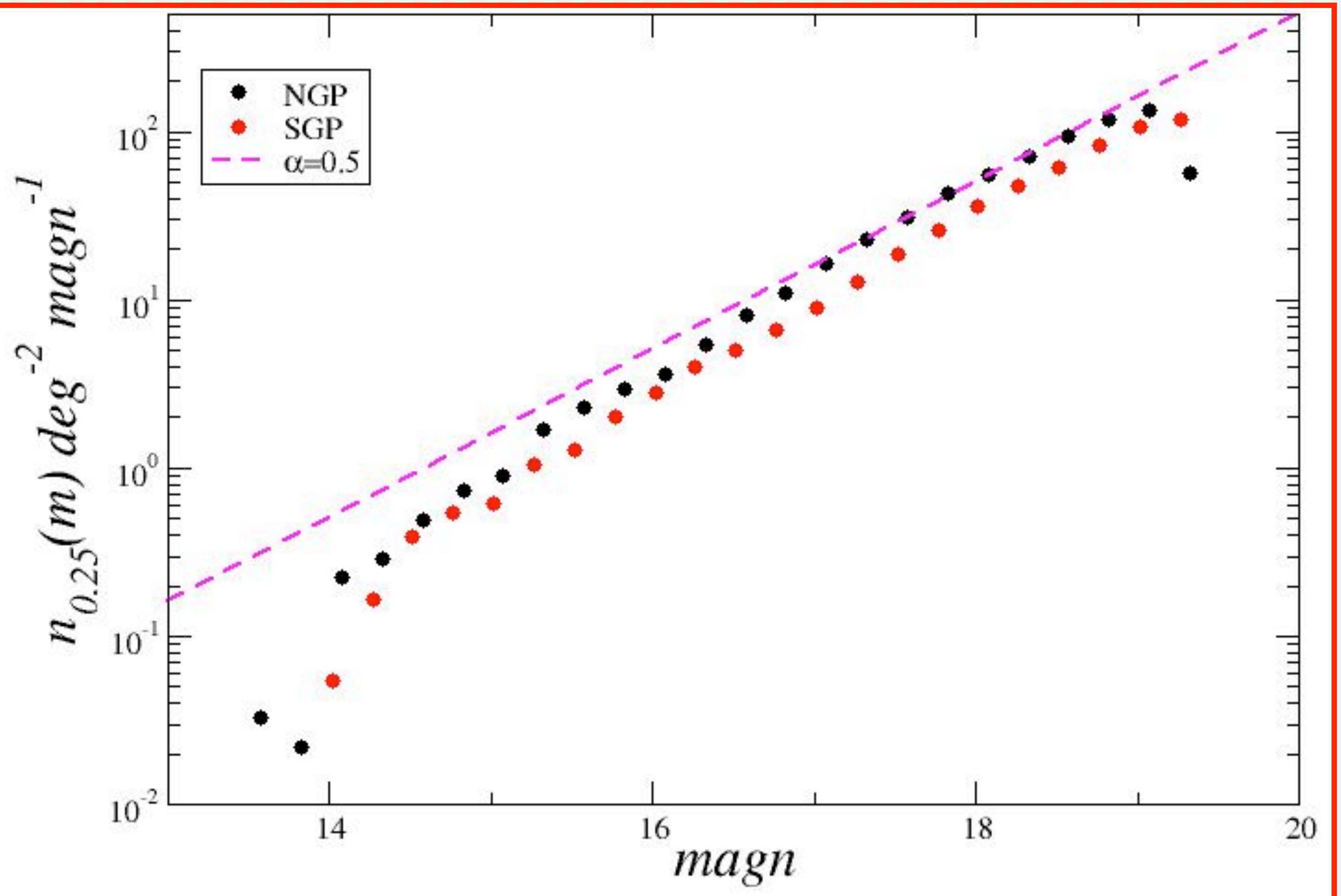
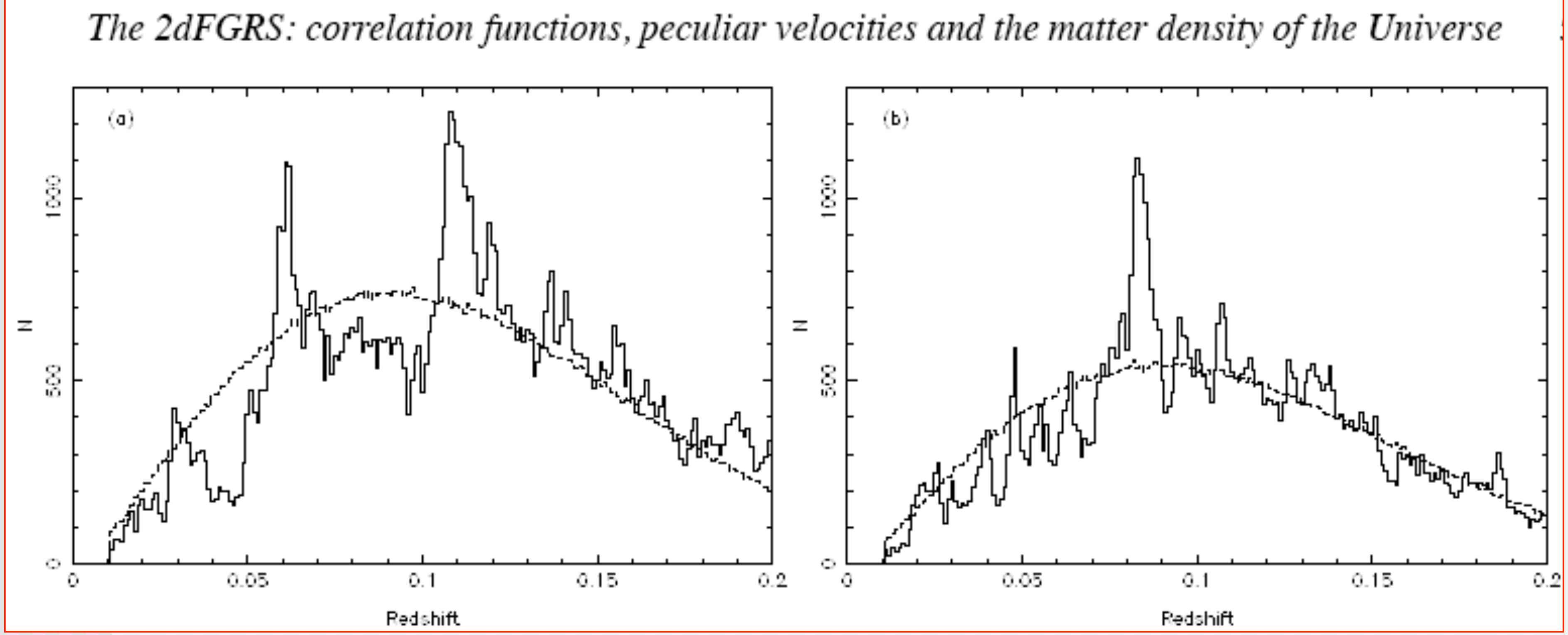


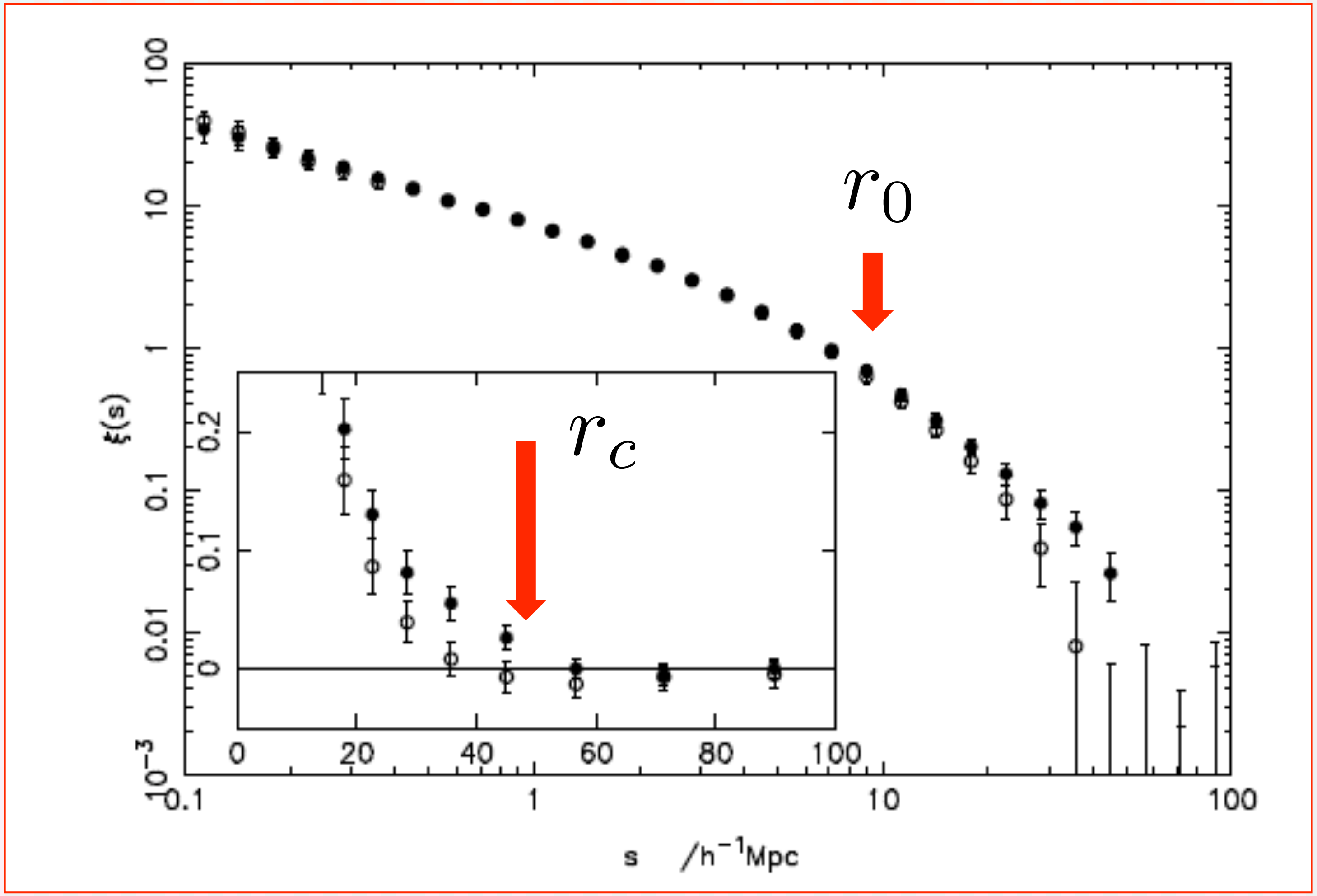
Large scale fluctuations from the 2dFGRS

- Hawkins et al. MNRAS, **346**, 78, 2003



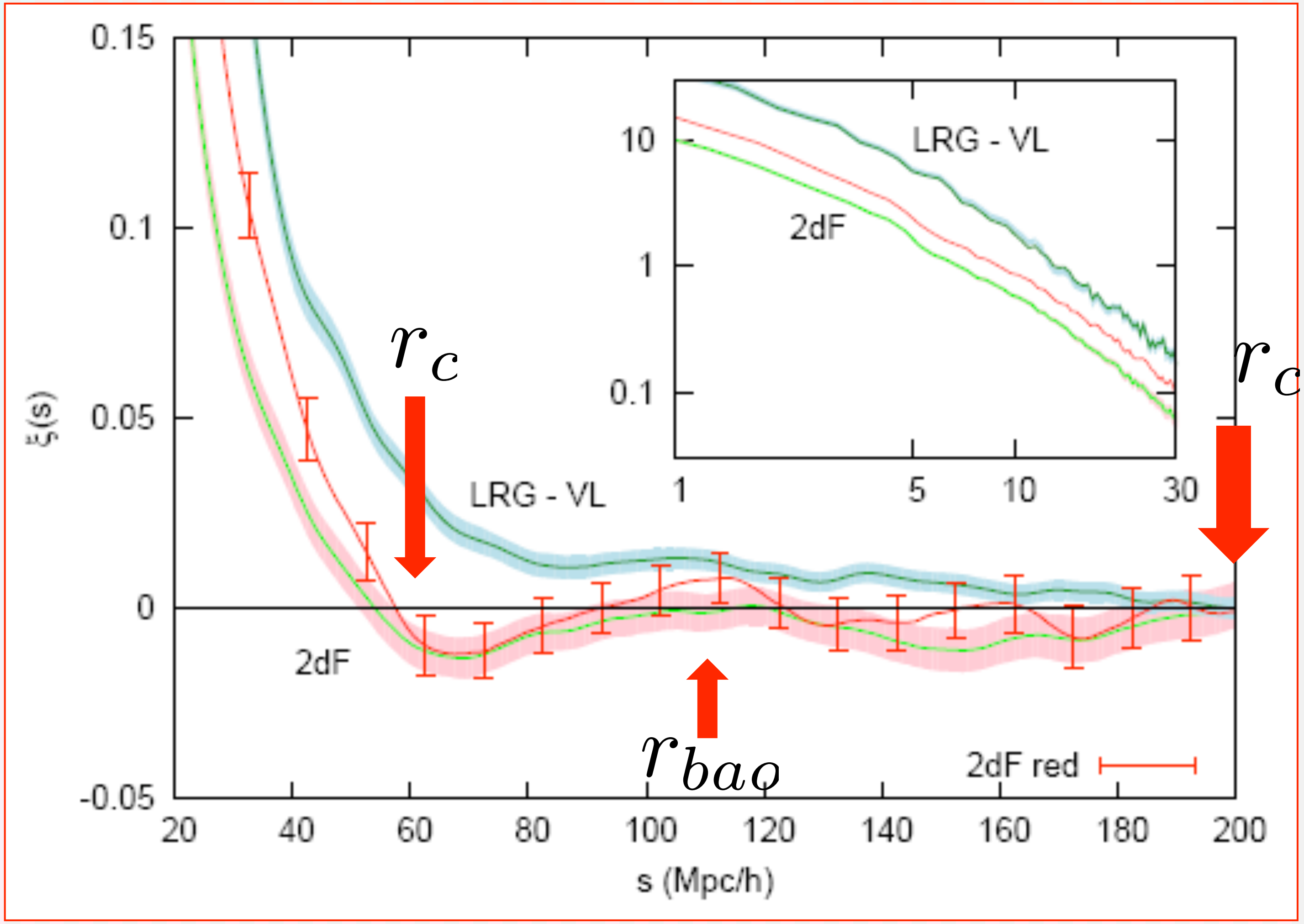
Two-point correlation function from the 2dFGRS

- Hawkins et al. MNRAS, **346**, 78, 2003



Two-point correlation function from the 2dFGRS

- Martinez et al. (2009) ApJ, **696,** L93-L97

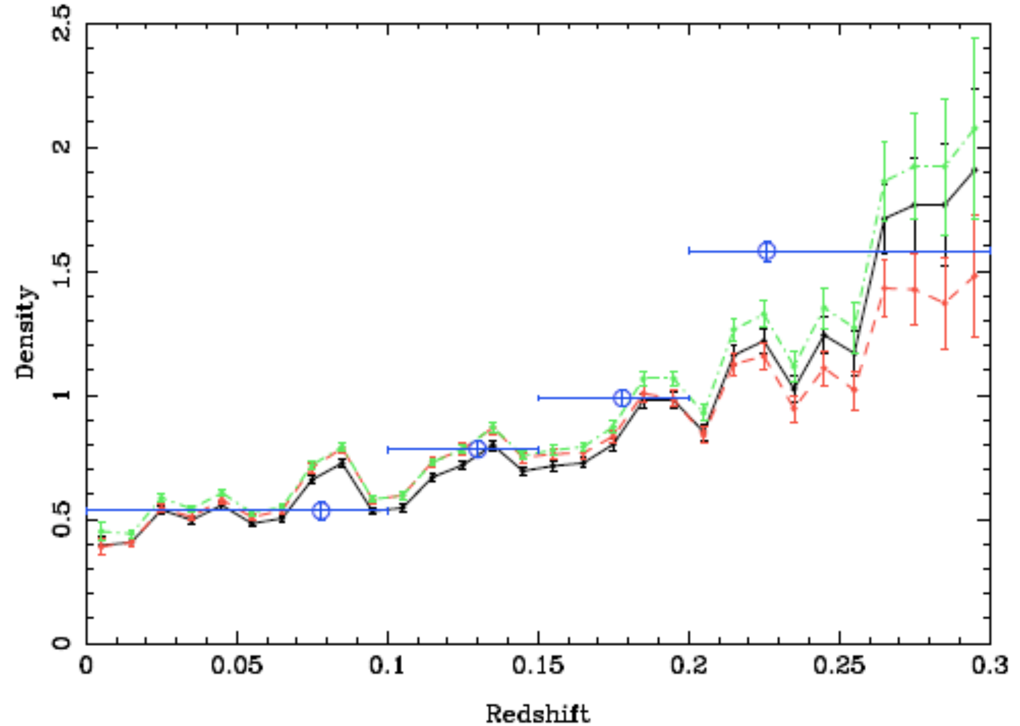


SDSS

•Loveday (2004) MNARS, **347,** 601

ABSTRACT

We measure the redshift-dependent luminosity function and the comoving radial density of galaxies in the Sloan Digital Sky Survey Data Release 1 (SDSS DR1). Both measurements indicate that the apparent number density of bright galaxies increases by a factor ≈ 3 as redshift increases from $z = 0$ to $z = 0.3$. This result is robust

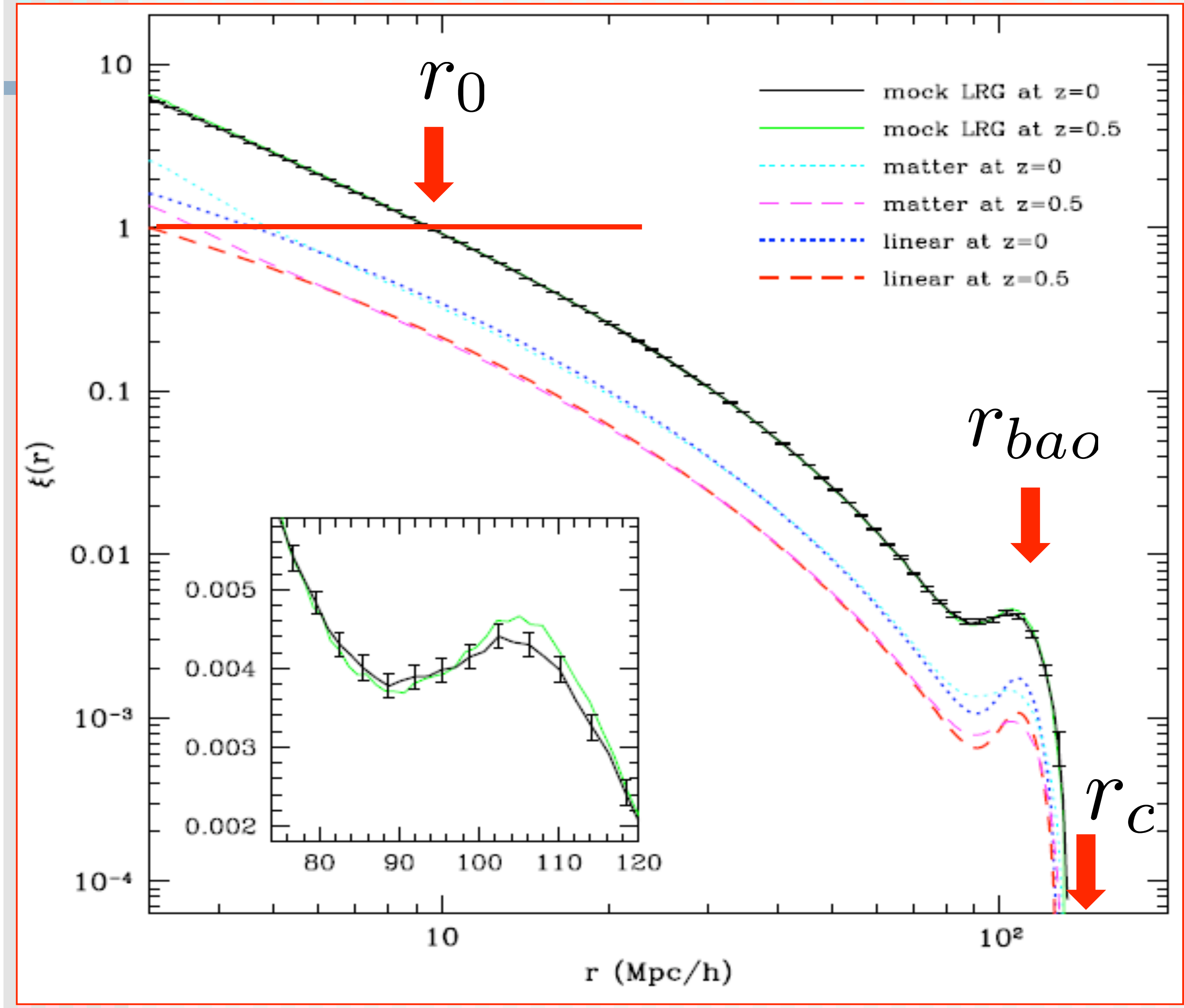


Outline

- Data and standard results
- **Standard theoretical predictions**
- Clustering, correlations and structures
- Results
- Conclusions

Standard cosmological models of structure formation

- Kim, J., Park, C., Gott, J.R., Dubinski, J. 2009 arXiv0812.1392

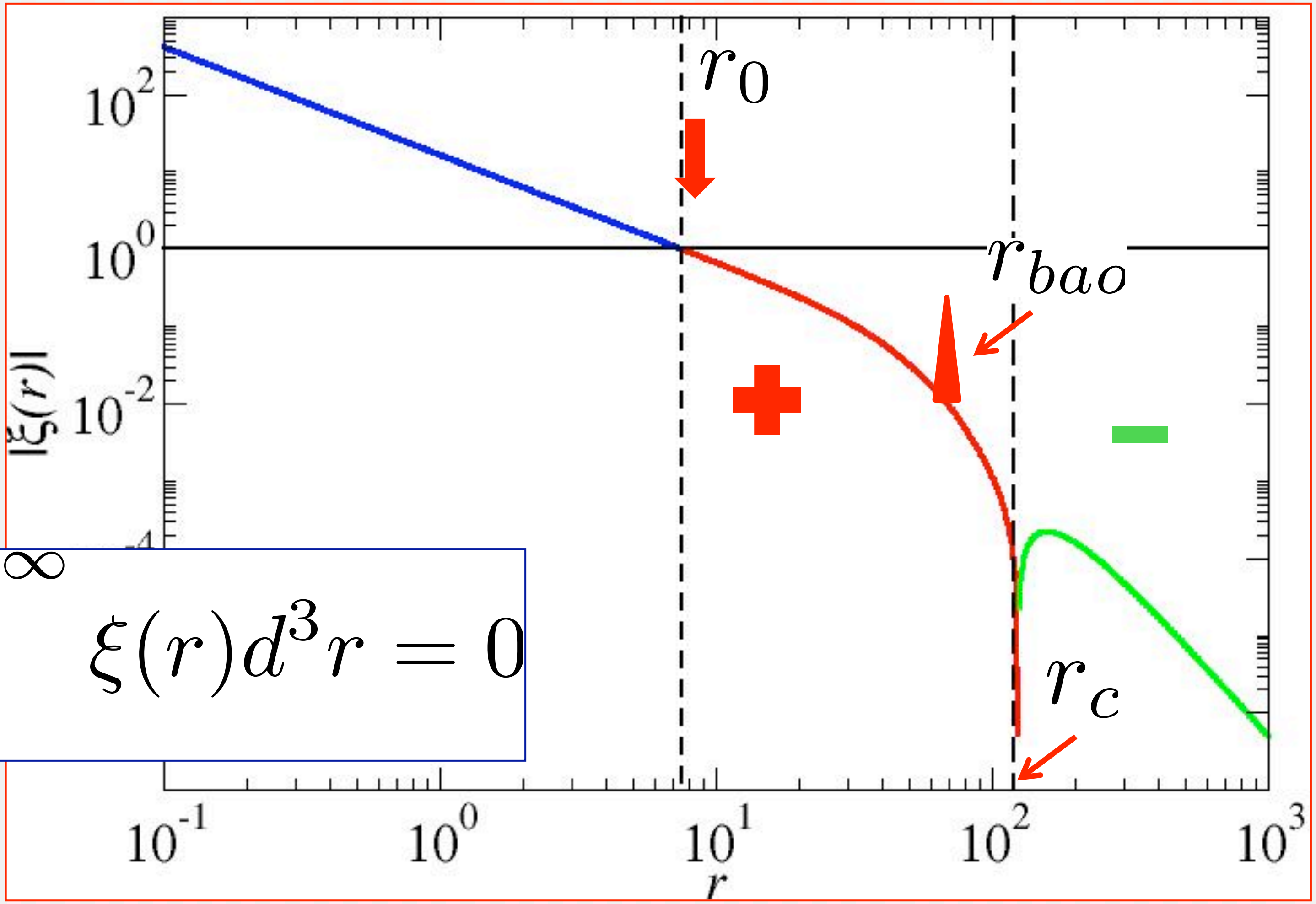


$$\xi(r,t) = A(t)\xi(r,0)$$

$$\xi^b(r,t) = b^2\xi(r,t)$$

Standard cosmological models of structure formation

- F. Sylos Labini and N. L. Vasilyev Astron.Astrophys. **477**, 381-395 (2008)



$$\int_0^\infty \xi(r) d^3r = 0$$

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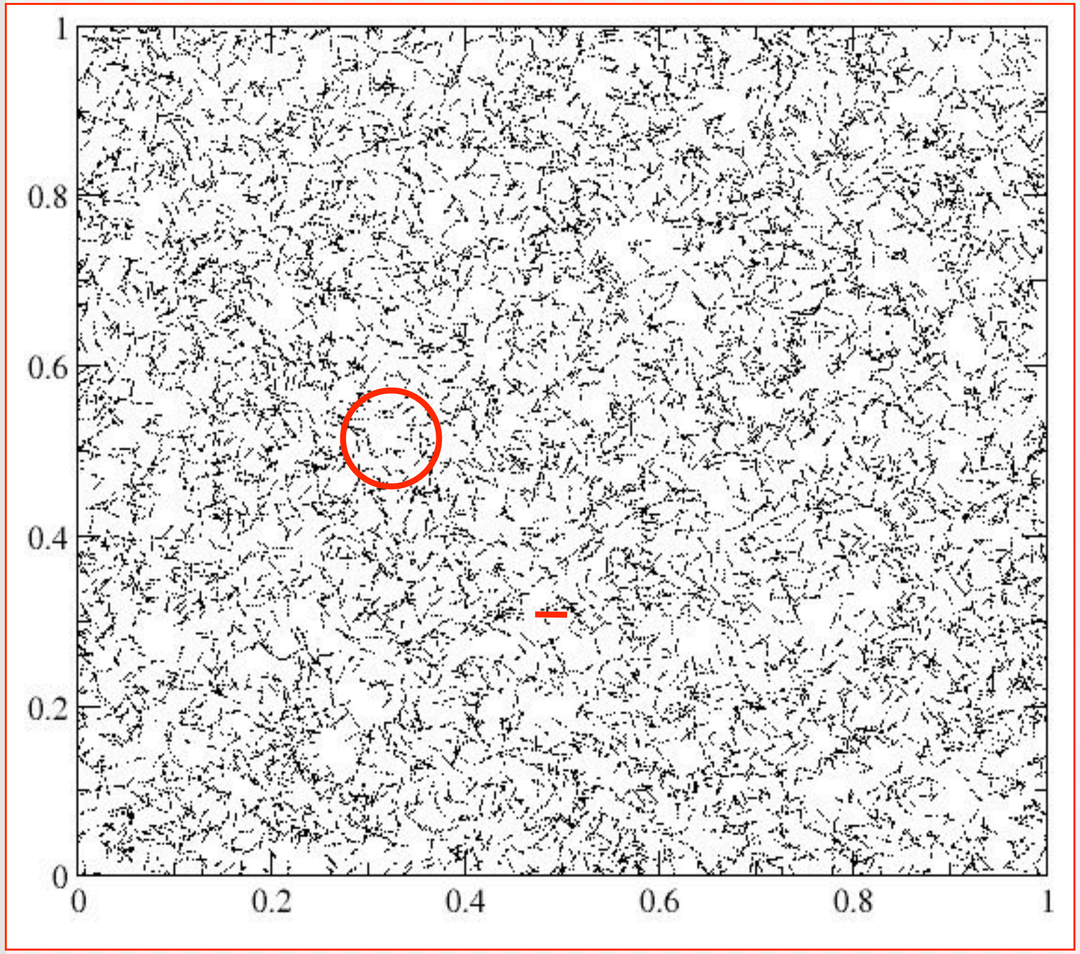
Clustering, Correlation and Structures

- Uniform and short-range correlated

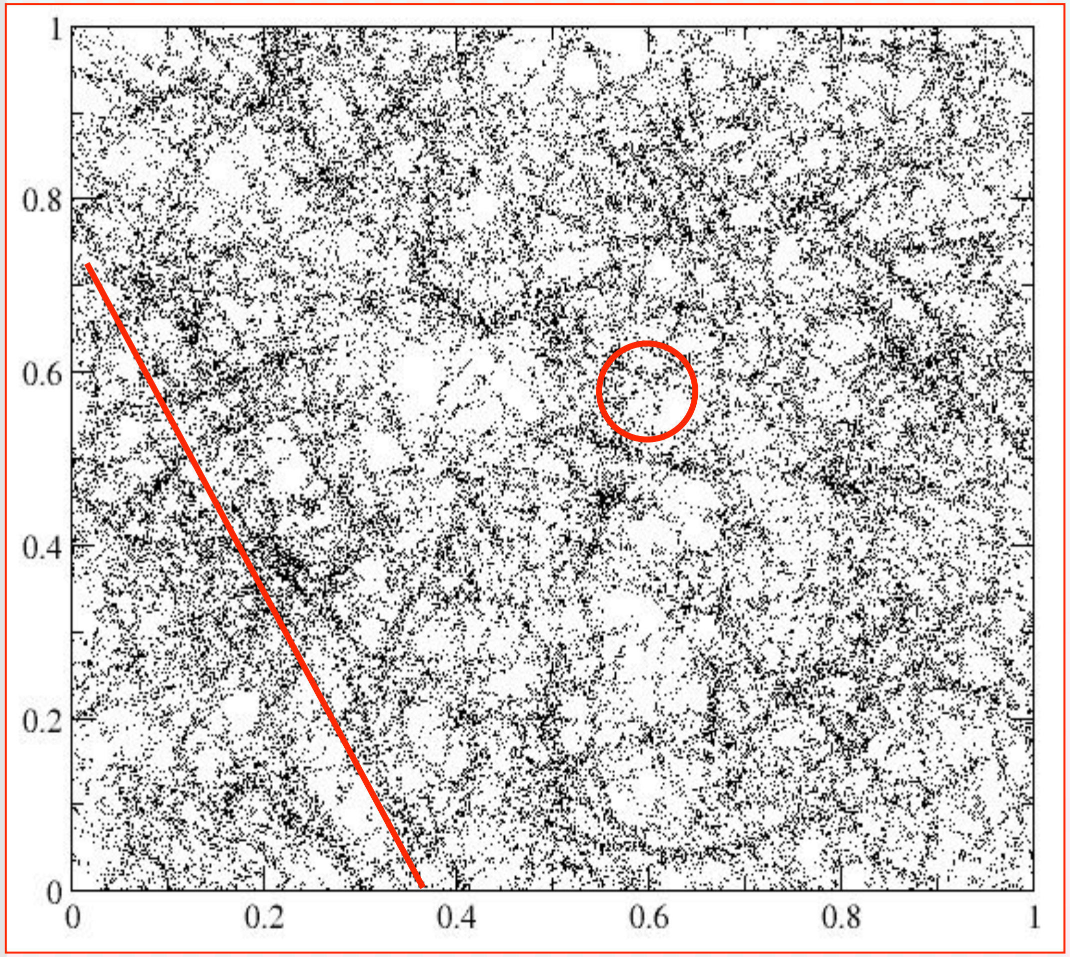


$$\overline{n} \approx const$$

$$\xi(r) \sim \exp(-r/r_c)$$

Clustering, Correlation and Structures

•Uniform and long-range correlated

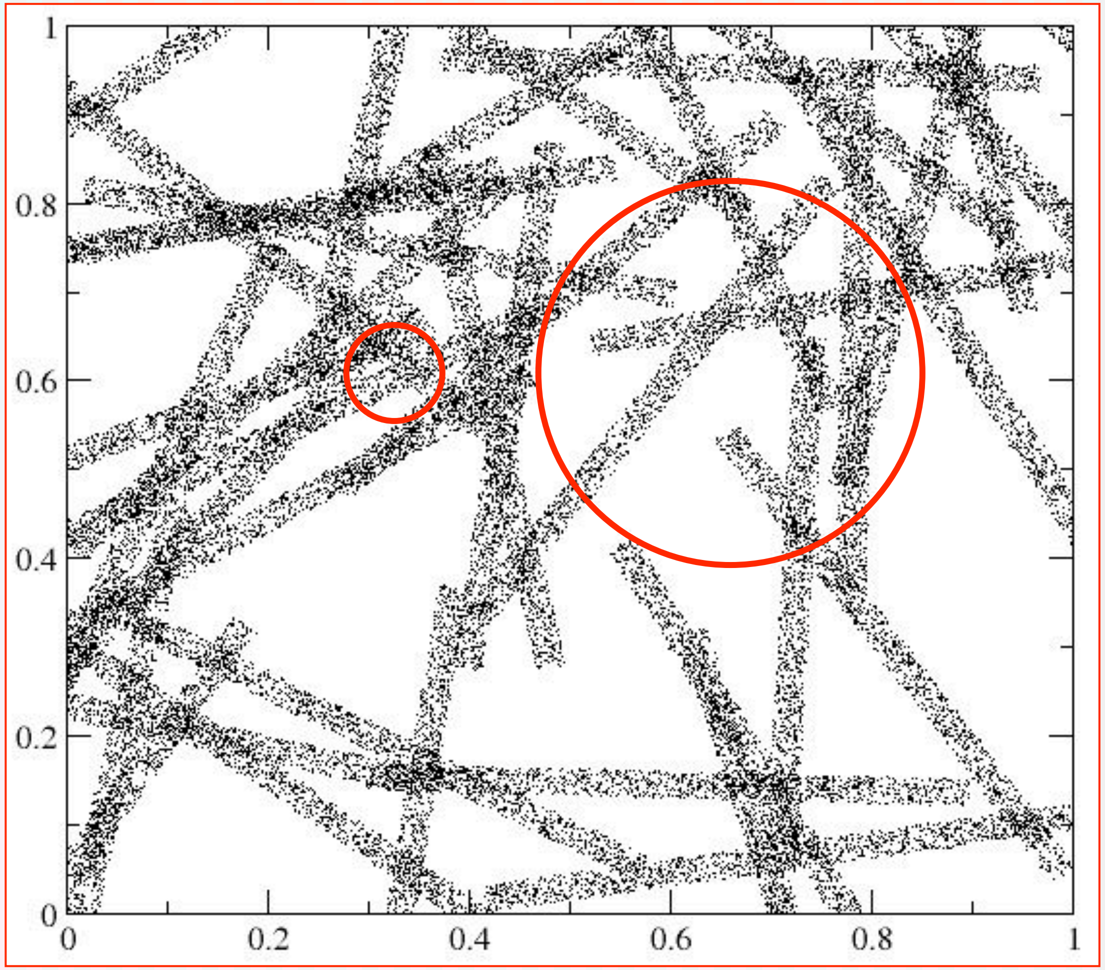


$$\overline{n} \approx const$$

$$\xi(r) > 0 \;\; \forall \;\; r \leq 1$$

Clustering, Correlation and Structures

- Non-uniform and self-averaging

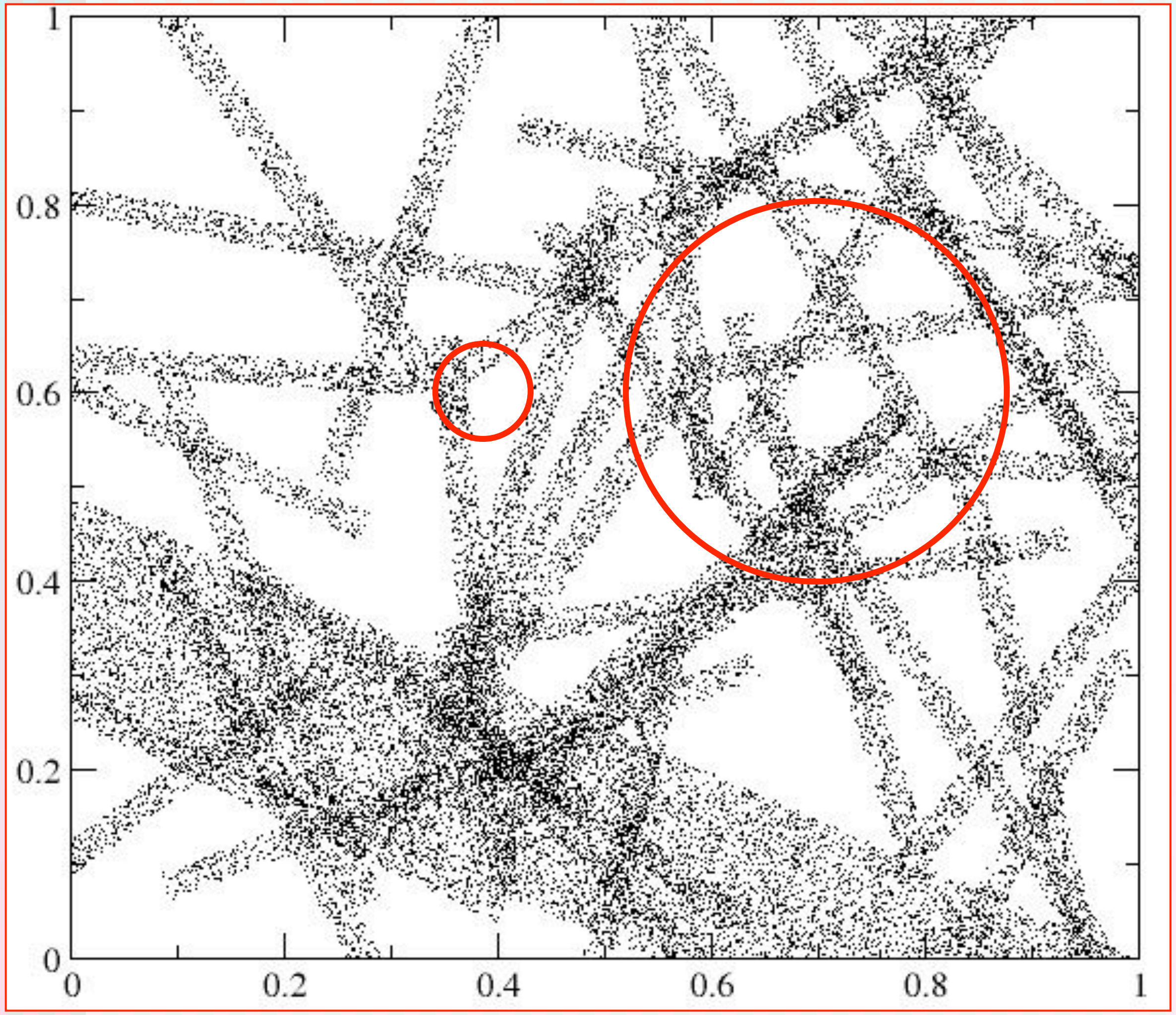


$$\overline{n} = \text{OK}$$

$$P(N, r) \approx \text{stable}$$

Clustering, Correlation and Structures

- Non-uniform and non self-averaging



$$\overline{n} = ?$$

$$P(N, r) = ?$$

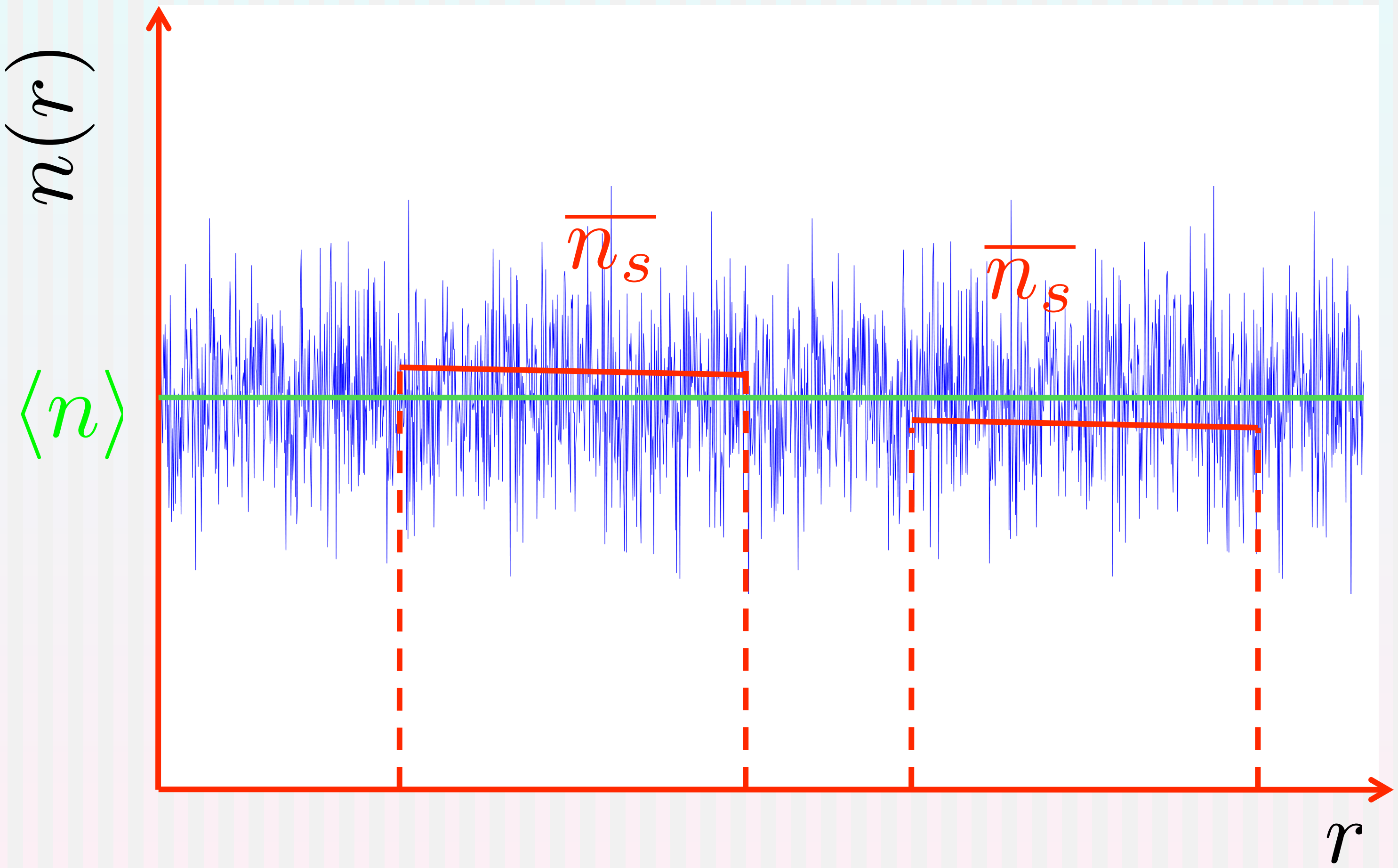
Clustering, Correlation and Structures

Q1: At which scale does the average density become well defined ?

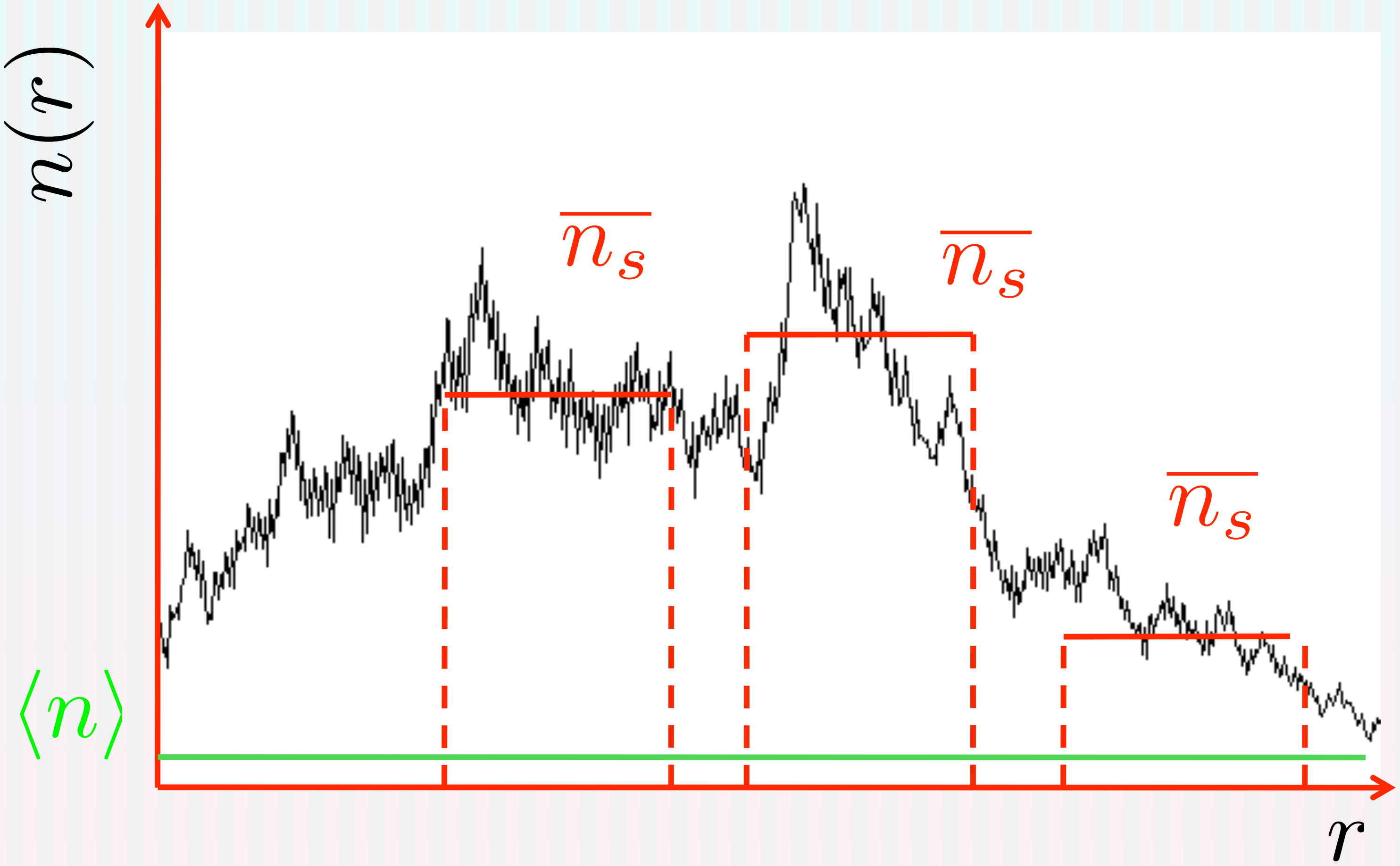
Q2: How can one study the case is which one does not know whether the average density is well defined ?

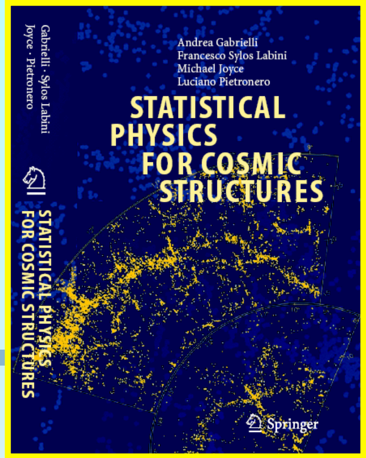
Conditional (local) vs. unconditional (global) properties

Clustering, Correlation and Structures



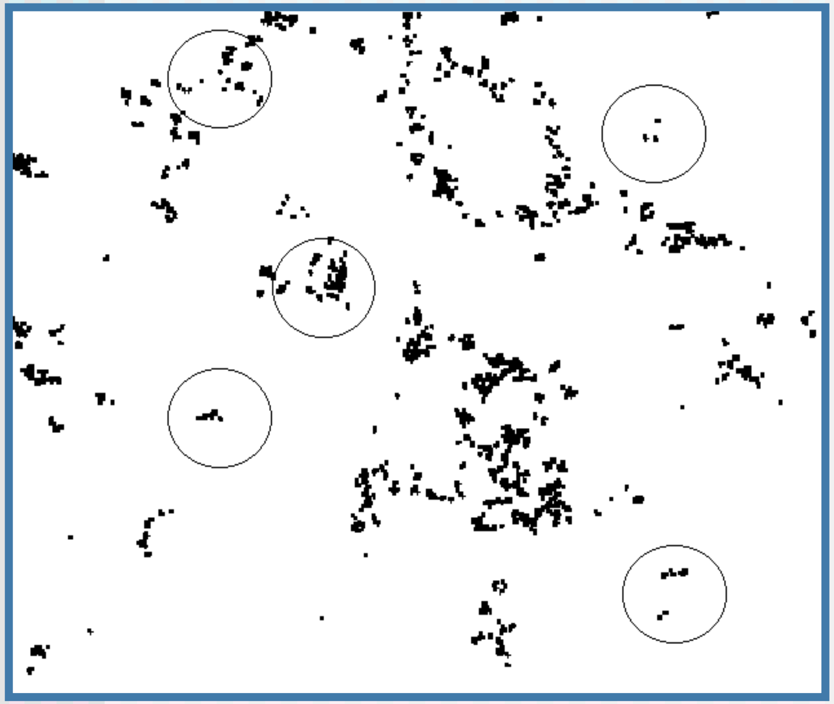
Clustering, Correlation and Structures



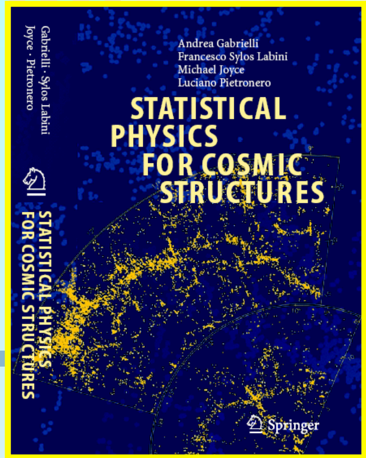


Clustering, Correlation and Structures

- A.Gabrielli, FSL, M. Joyce, L. Pietronero
Statistical physics for cosmic structures Springer Verlag 2005



$$\langle N(r) \rangle_P = \frac{1}{M} \sum_{i=1}^{M} N_i(r)$$



Clustering, Correlation and Structures

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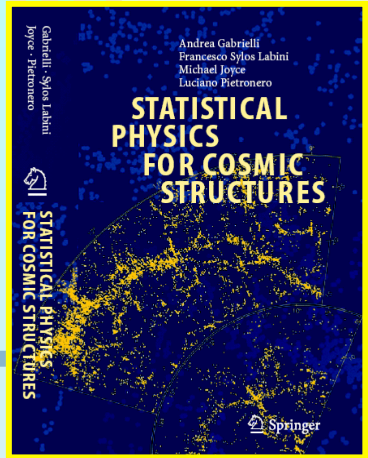
$$\xi(r) = \frac{\langle n(r)n(0)\rangle}{\langle n\rangle^2} - 1 = \frac{\langle n(r)\rangle_p}{n(r^*)} - 1$$

$$\langle n(r)\rangle_p = \frac{\langle n(r)n(0)\rangle}{\langle n\rangle}$$

$$n(r^*) = \frac{M}{V}$$



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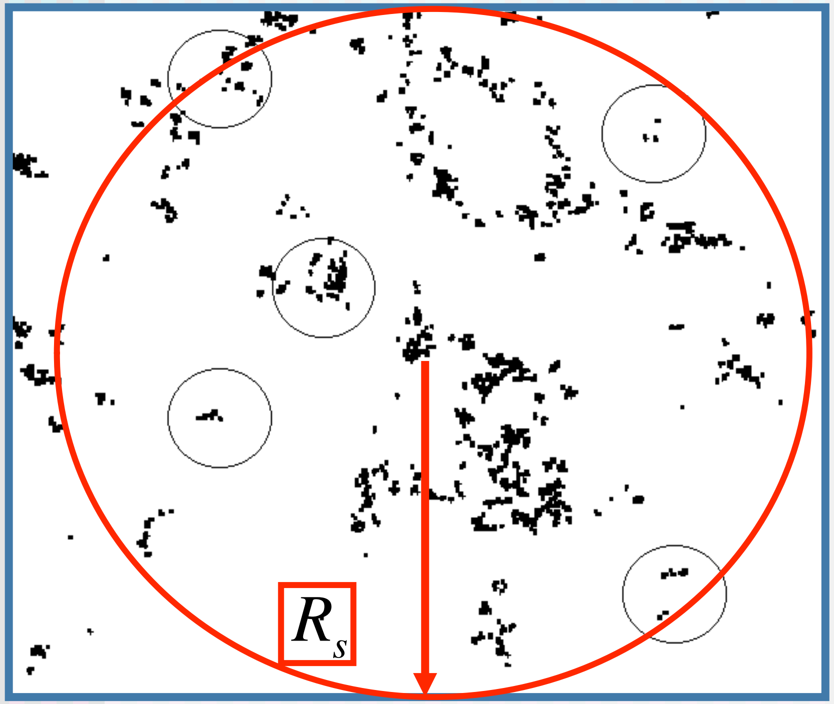
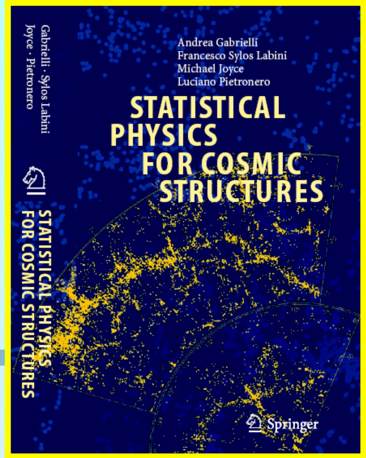


$$\xi(r) = \frac{\langle n(r) \rangle_p}{n(r^*)} - 1$$

$$\langle N(r) \rangle_P = \frac{1}{M(r)} \sum_{i=1}^{M(r)} N_i(r) = B r^D$$

$$\xi(r, R_s) = \frac{\langle n(r) \rangle_p}{n(R_s)} - 1 = \frac{D}{3} \left(\frac{r}{R_s} \right)^{D-3} - 1$$



Clustering, Correlation and Structures

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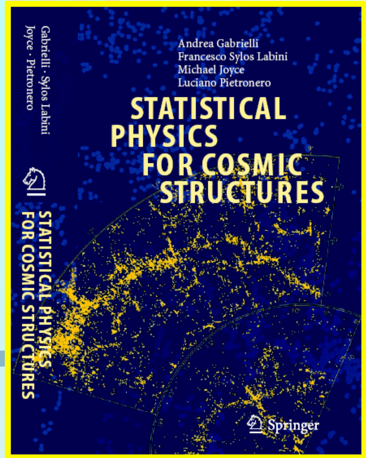
$$\langle N(r) \rangle_P = \begin{cases} r^D \rightarrow r < \lambda_0 \\ r^3 \rightarrow r > \lambda_0 \end{cases}$$

Homogeneity scale



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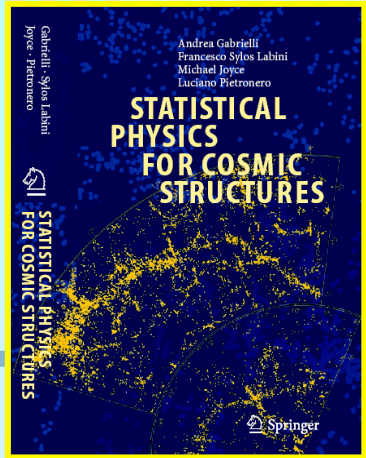
$$\langle N(r) \rangle_P = \begin{cases} r^D \rightarrow r < \lambda_0 \\ r^3 \rightarrow r > \lambda_0 \end{cases}$$

Homogeneity scale

$$\lambda_0 \Leftrightarrow \xi(r_0) = 1$$

$$\xi(r) \approx \exp\left(-\frac{r}{r_c}\right)$$

Correlation length....



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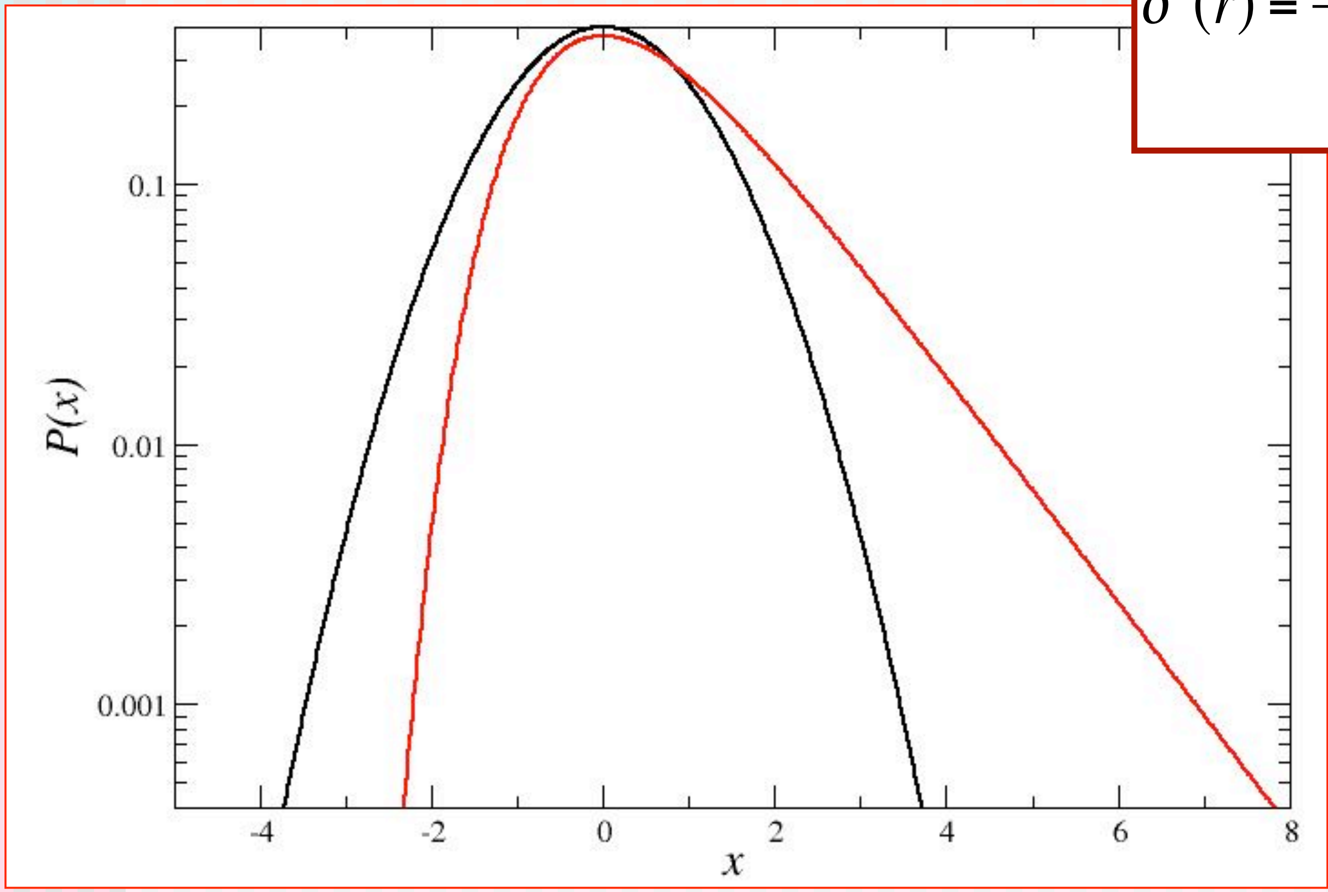
$$\delta^2(r) = \frac{\langle N(r)^2 \rangle - \langle N(r) \rangle^2}{\langle N(r) \rangle^2} \begin{cases} << 1 \\ \sim 1 \end{cases}$$



Homogeneous

(Gaussian)

Inhomogeneous

(long tails,
large variance)

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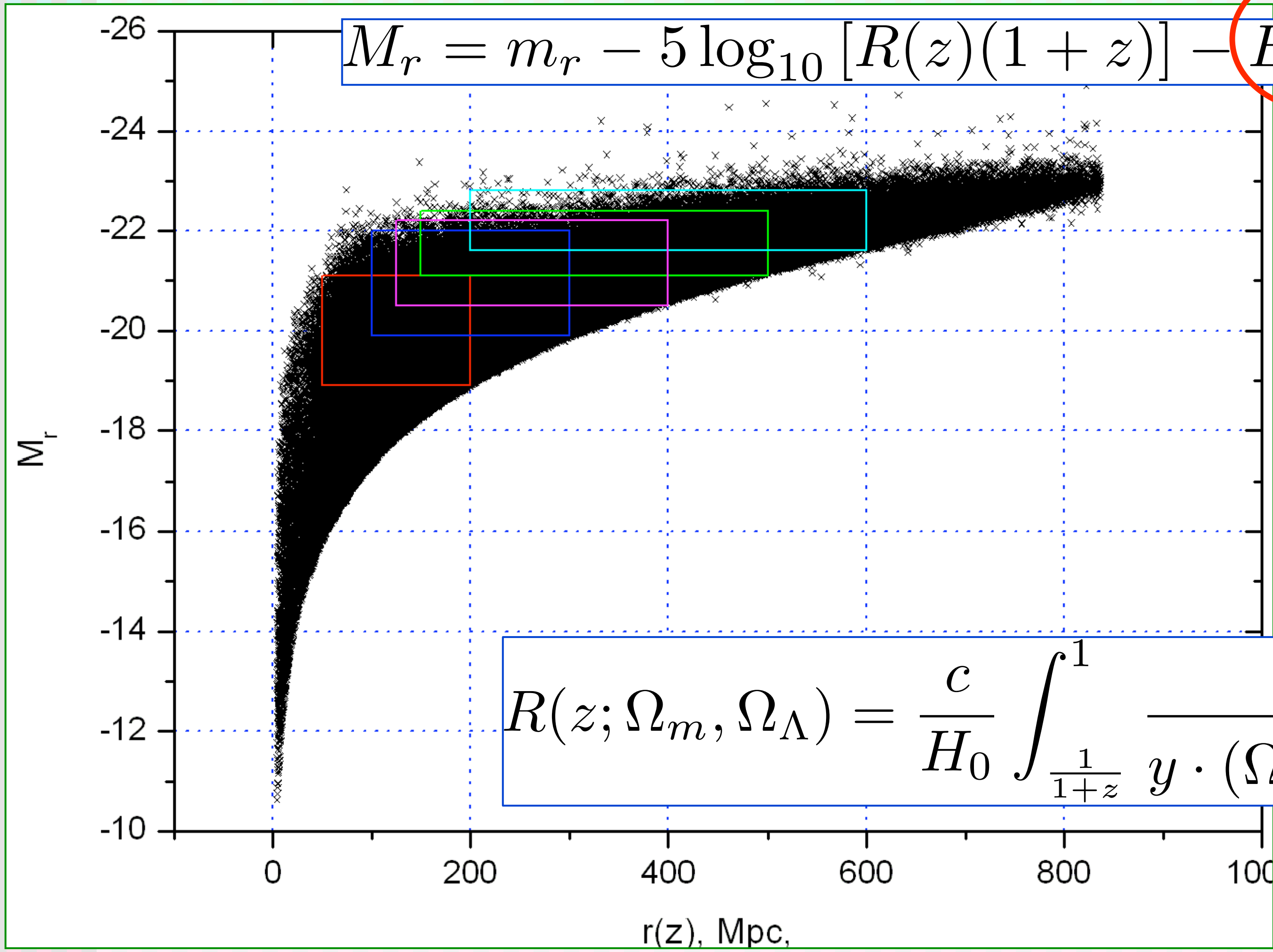
Volume limited samples



$$M_r = m_r - 5\log_{10}[R(z)(1+z)] - E_r(z) - K_r(z) - 25$$

$$R(z;\Omega_m,\Omega_\Lambda) = \frac{c}{H_0}\int_{\frac{1}{1+z}}^{1} \frac{dy}{y\cdot(\Omega_m/y + \Omega_\Lambda \cdot y^2)^{1/2}}$$

Results: the scale-length method

- FSL., Vasilyev N., Pietronero L. Baryshev Y.V. , Europhys.Lett, **86**, 49001 (2009)

$$N_i(r) = N(r;\vec{x_i}) \rightarrow N(r;[\alpha,\delta,R]_i) \rightarrow N(r;R_i)$$

$$\langle N(r) \rangle_P = \frac{1}{M(r)} \sum_{i=1}^{M(r)} N_i(r)$$

$$f(N;r) \rightarrow f(N;r;V)$$

Results: the scale-length method

- FSL., Vasilyev N., Baryshev Y.V. preprint (2009)
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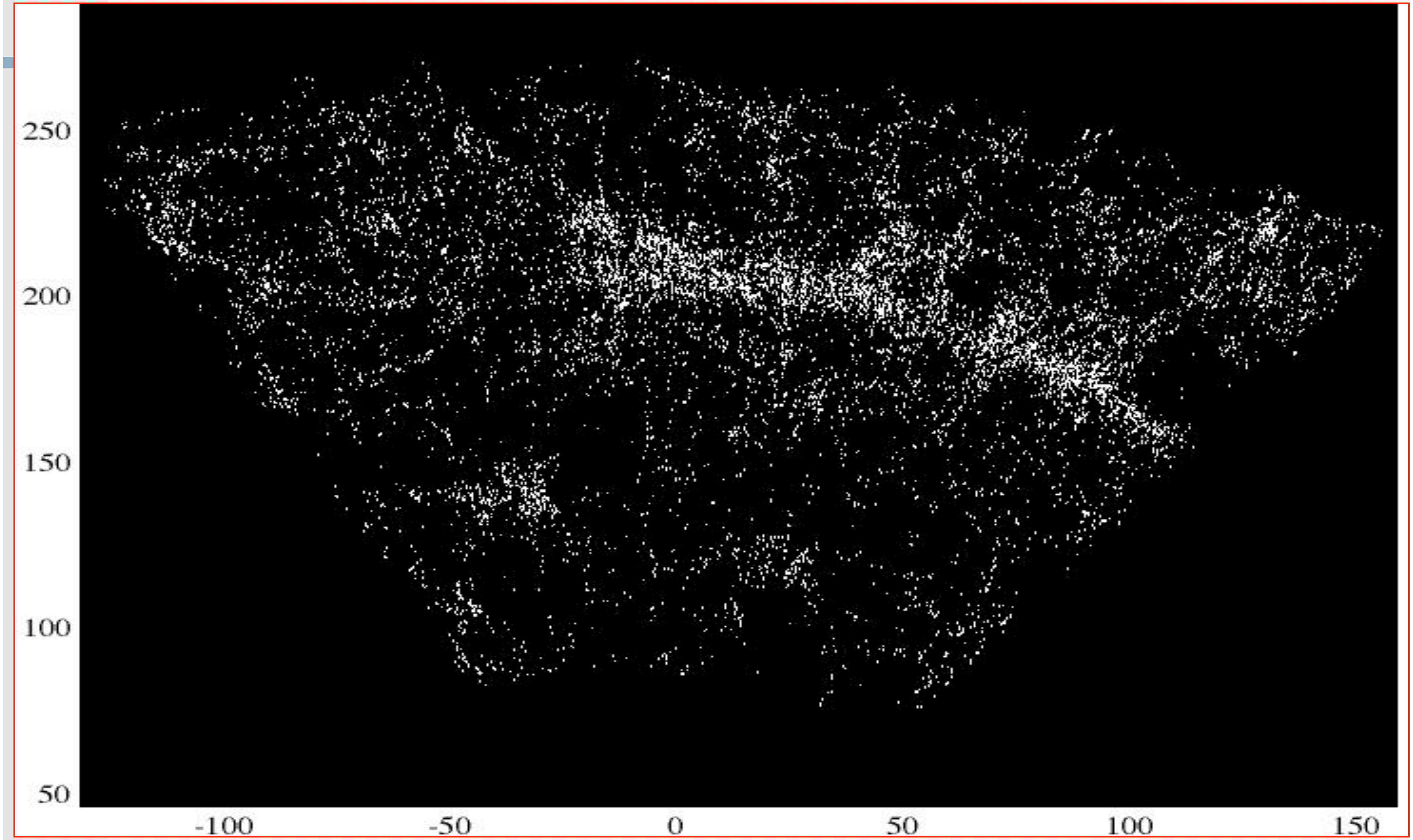

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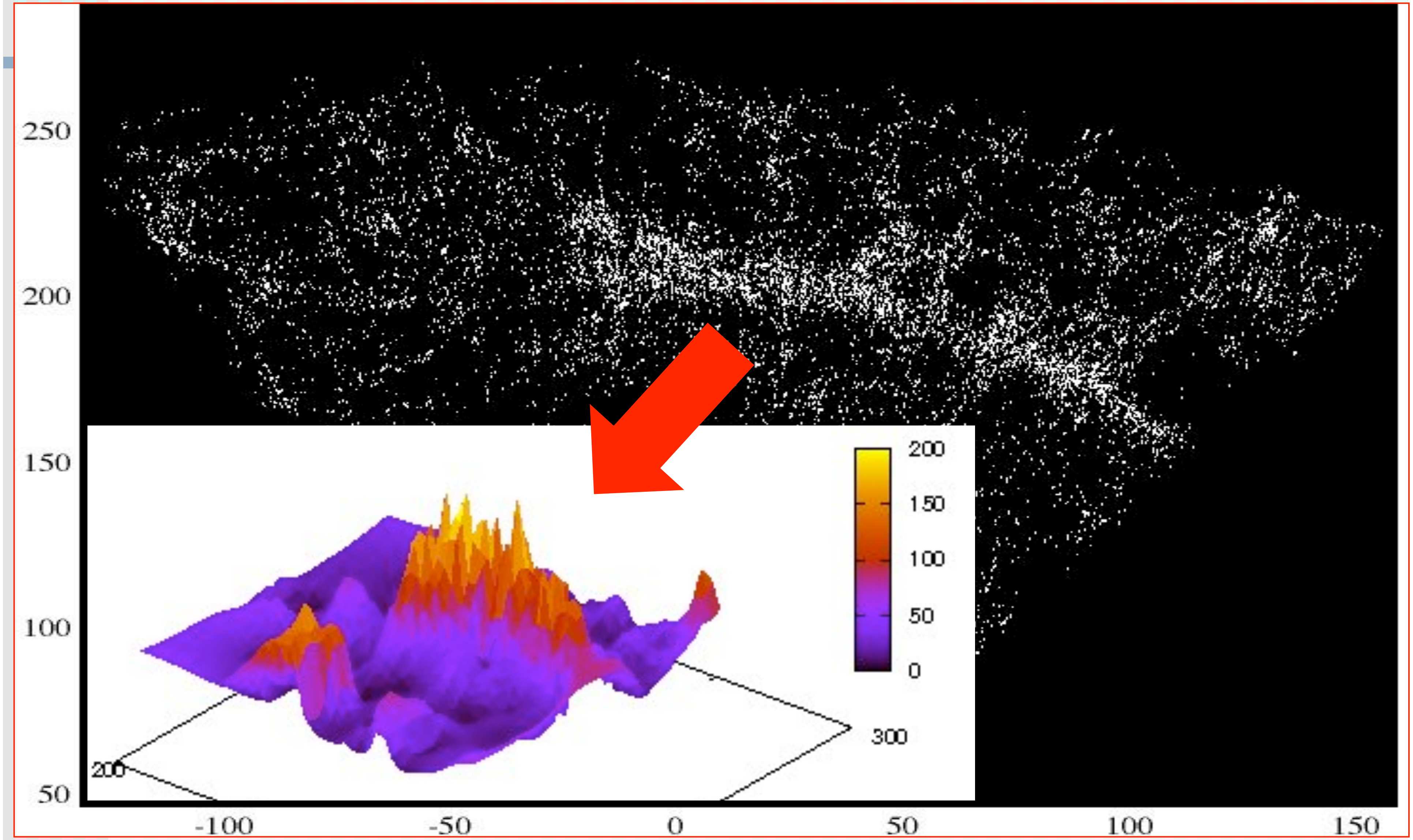

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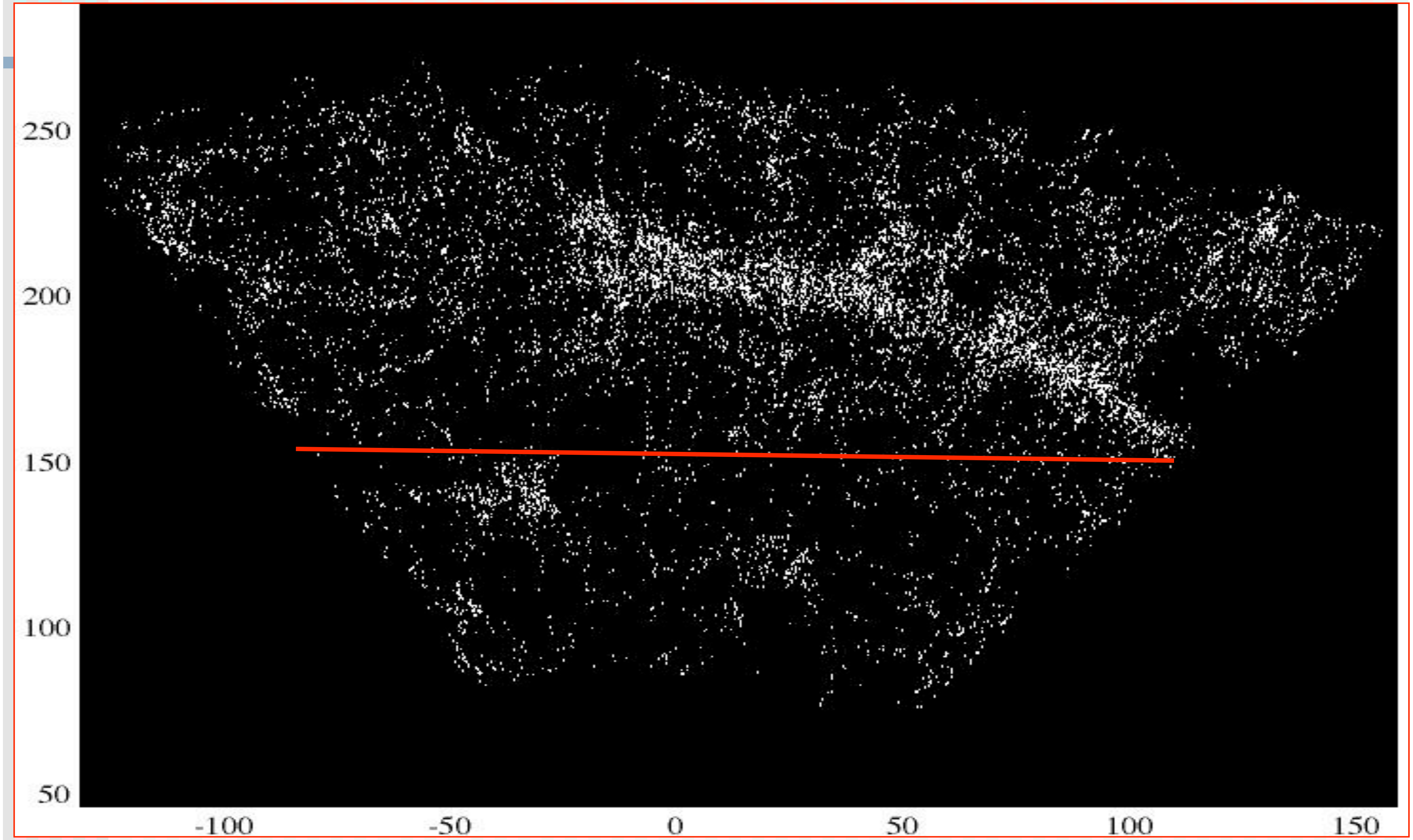

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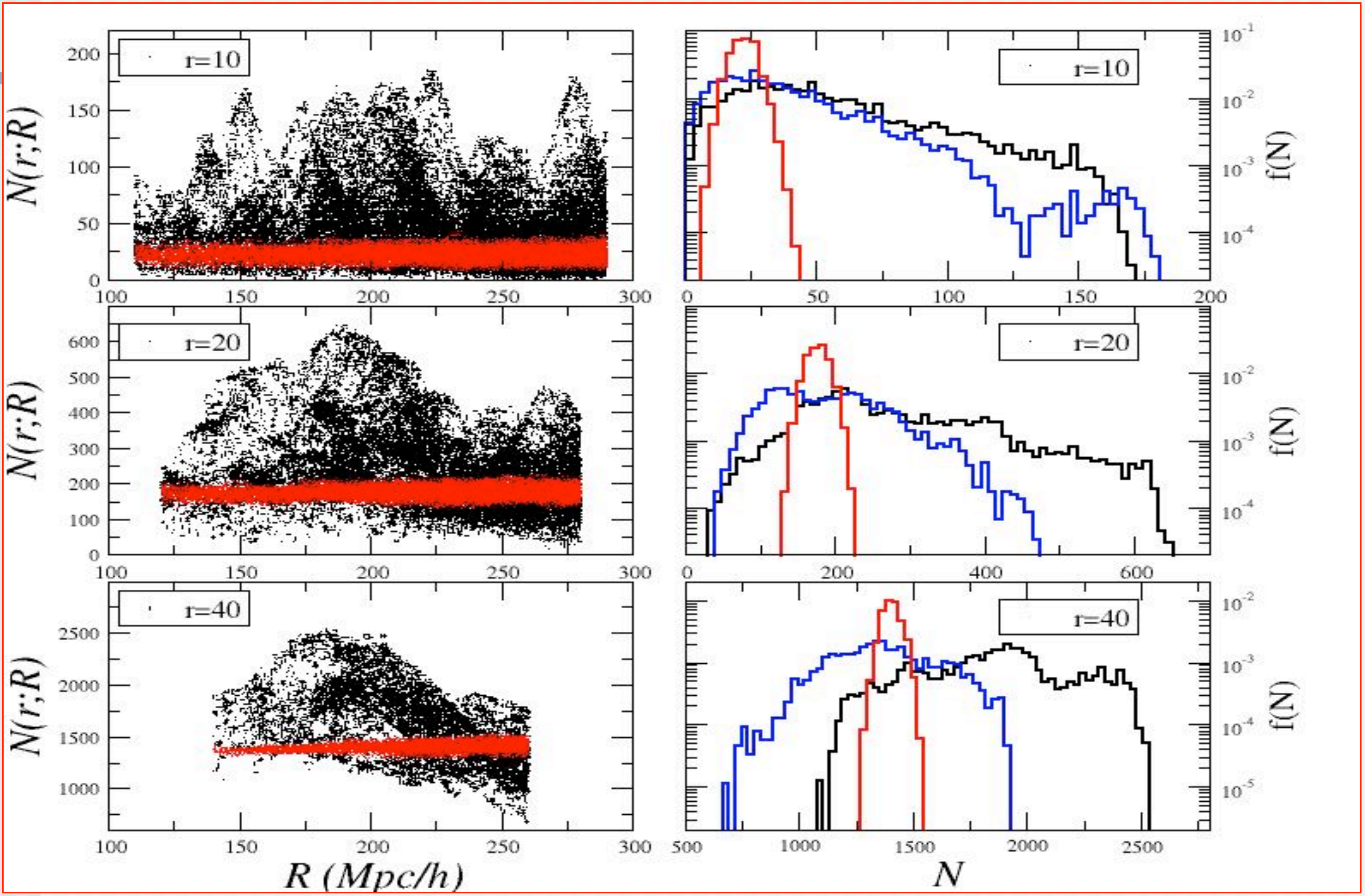

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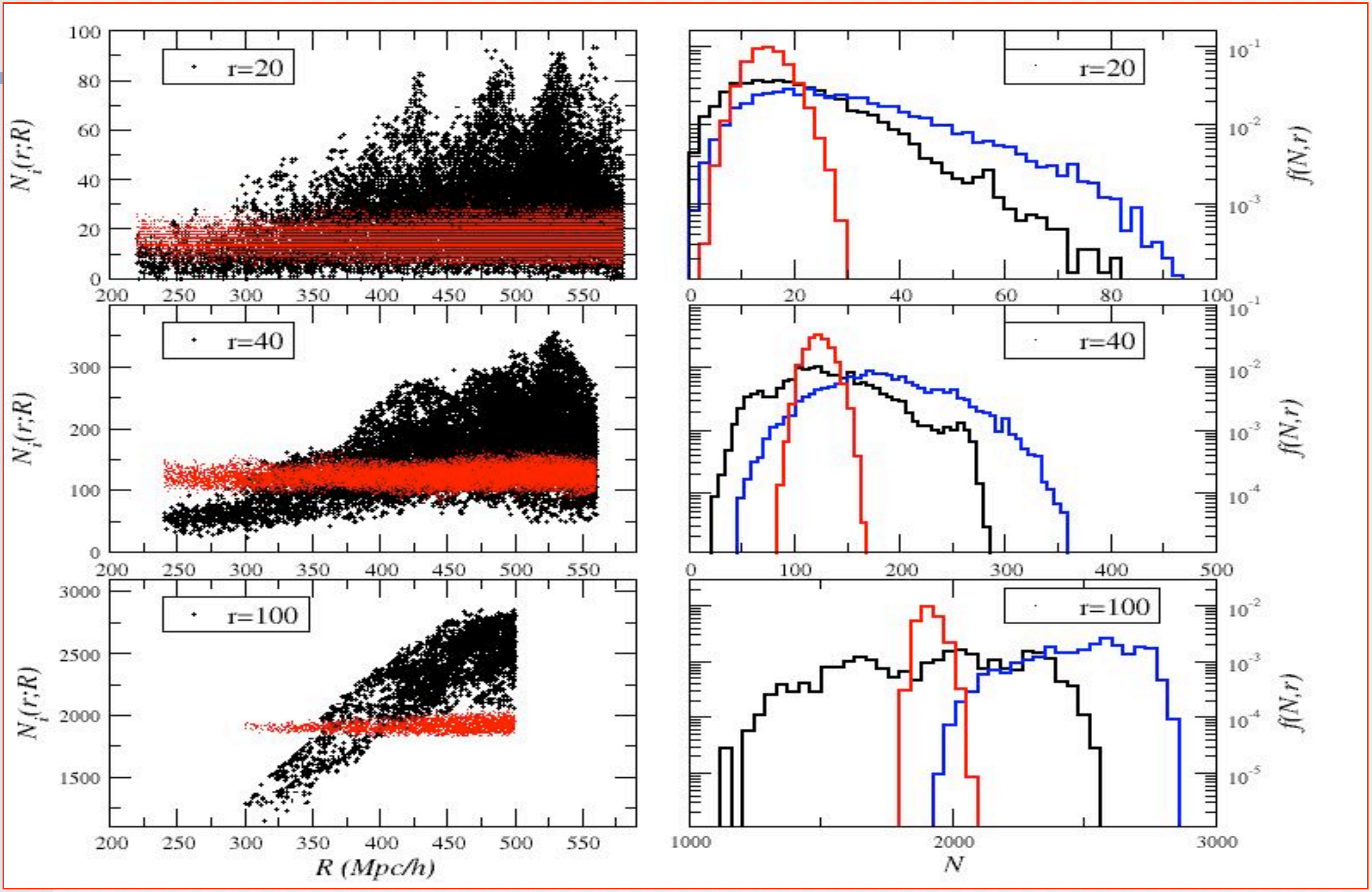
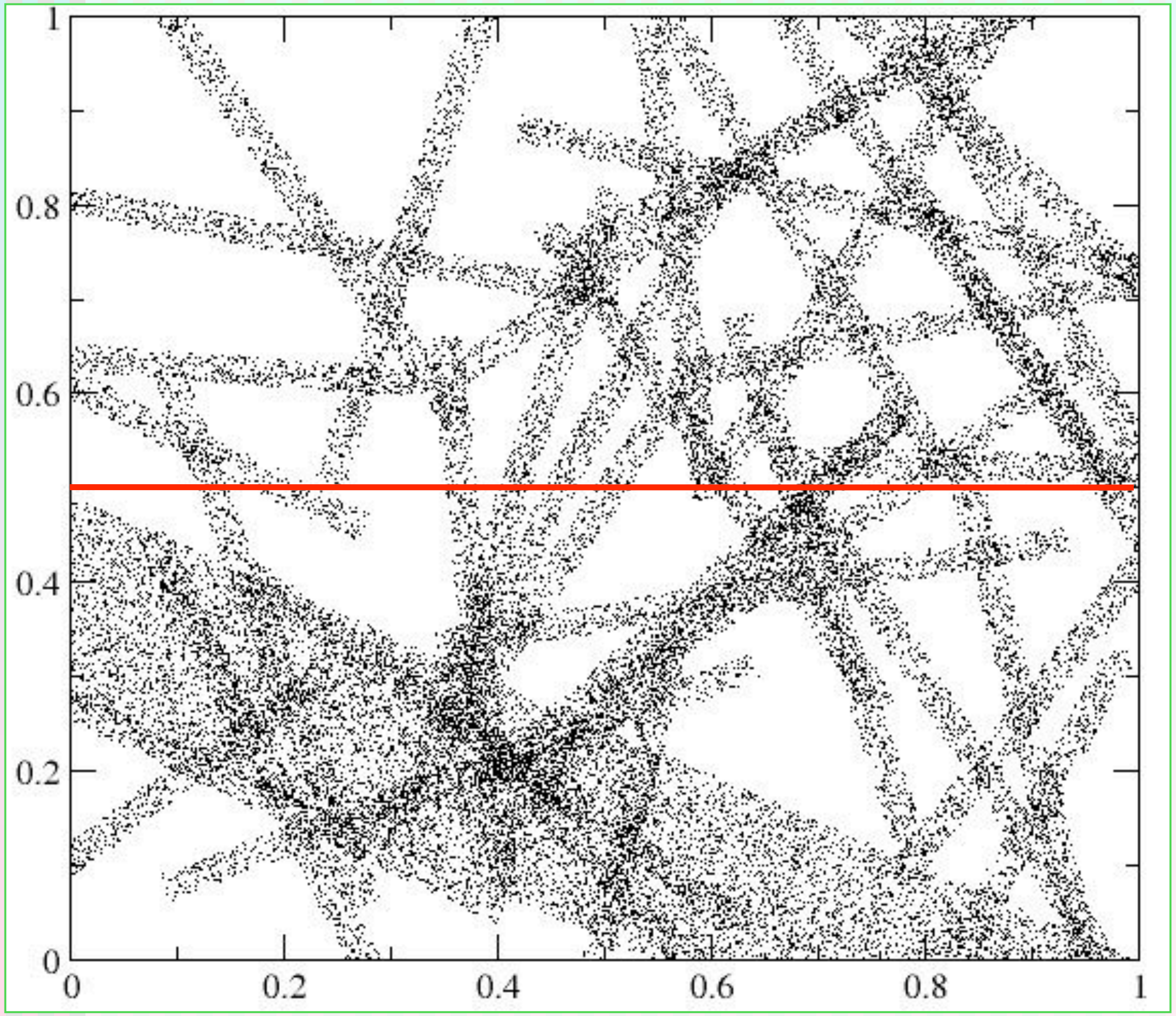


Clustering, Correlation and Structures

- Non-uniform and non self-averaging



$$\langle n \rangle = ?$$

$$P(N, r) = ?$$

Results: the scale-length method

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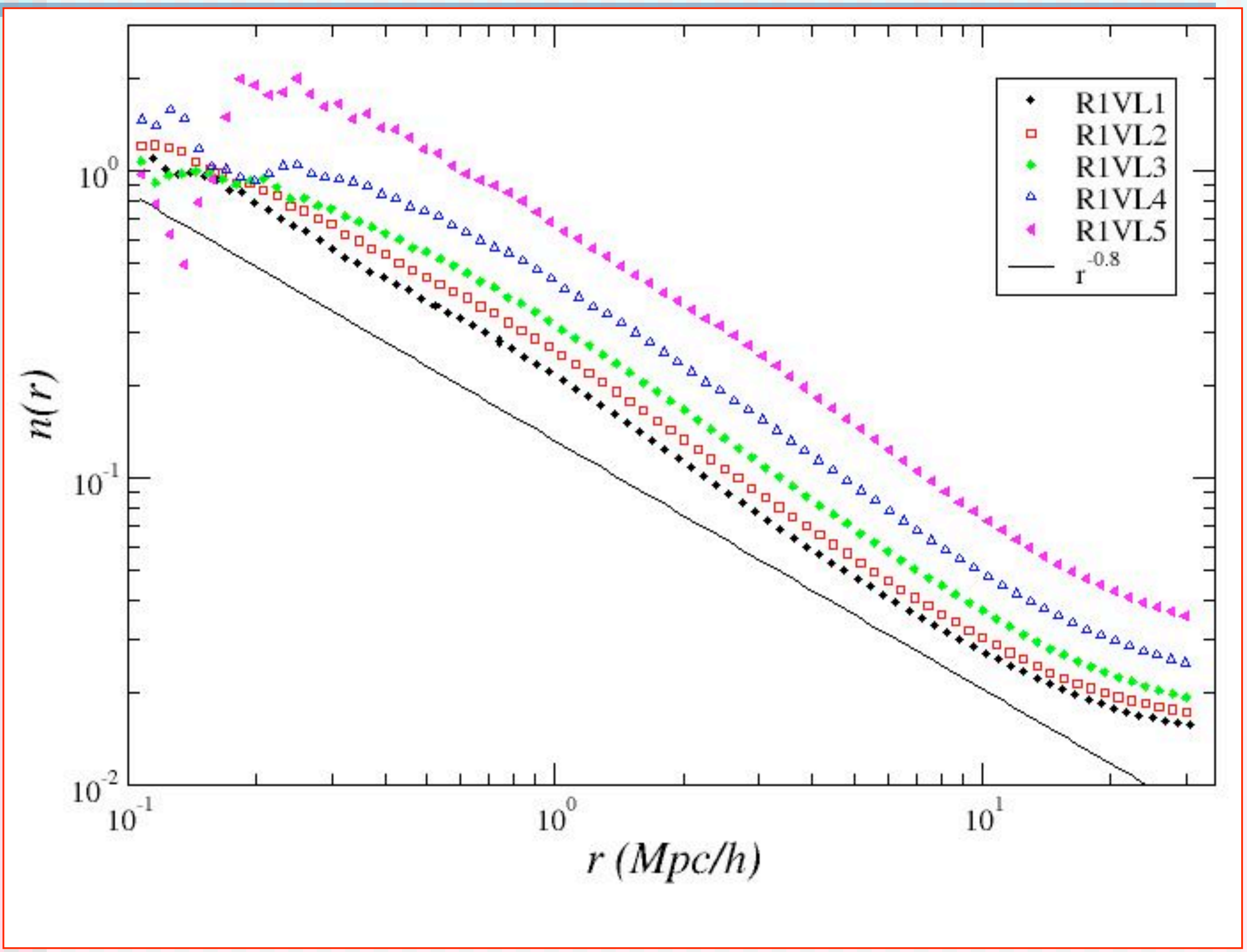

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$$\xi(r) = \frac{\langle n(r)n(0)\rangle}{\langle n\rangle^2} - 1 = \frac{\langle N(r,\Delta r)\rangle_p}{V(r,\Delta r)} \times \frac{1}{n(R > \lambda_0)} - 1$$

$$\overline{\xi(r)} = \frac{\overline{N(r,\Delta r)}}{V(r,\Delta r)} \cdot \frac{1}{n_S} - 1$$

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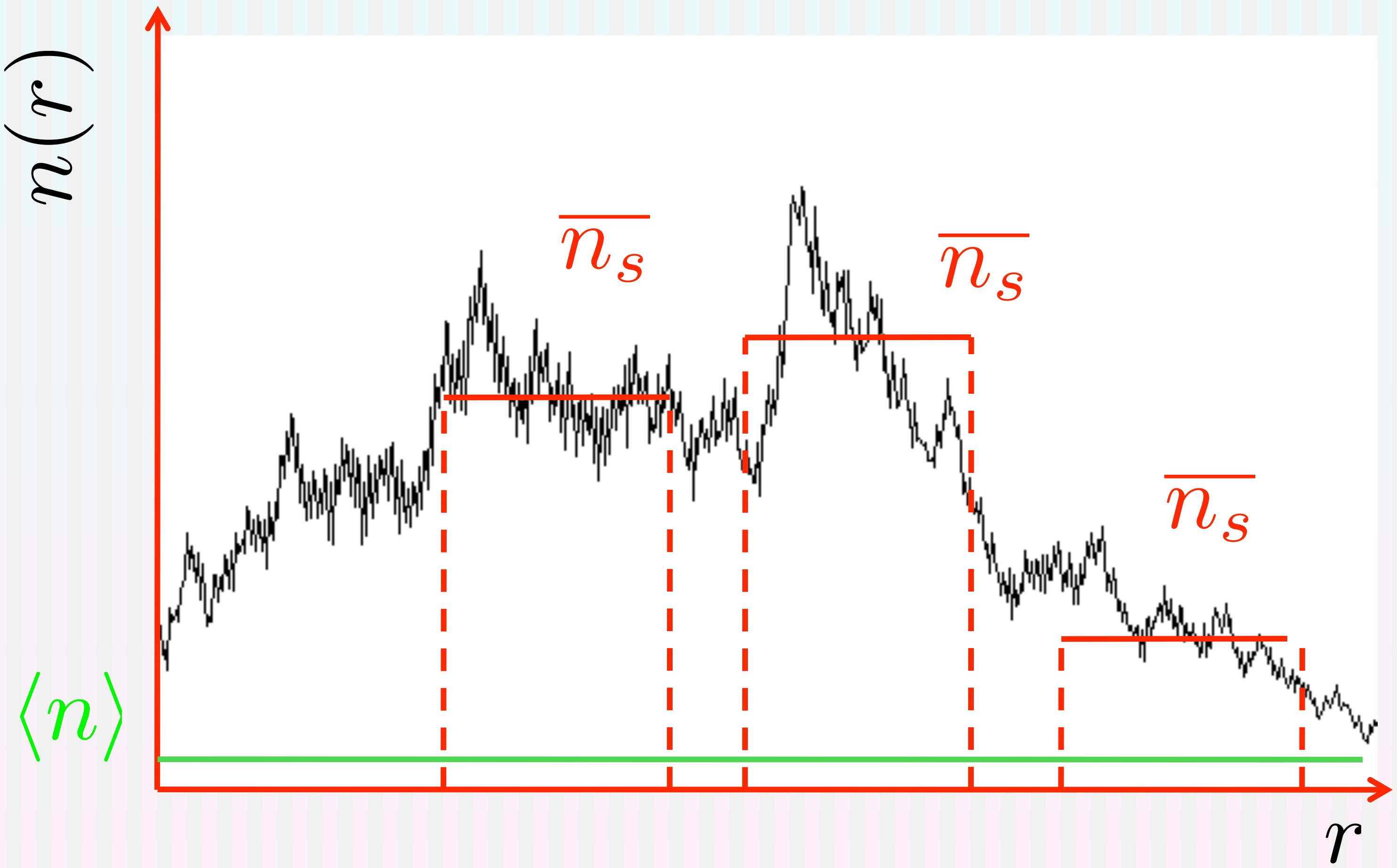

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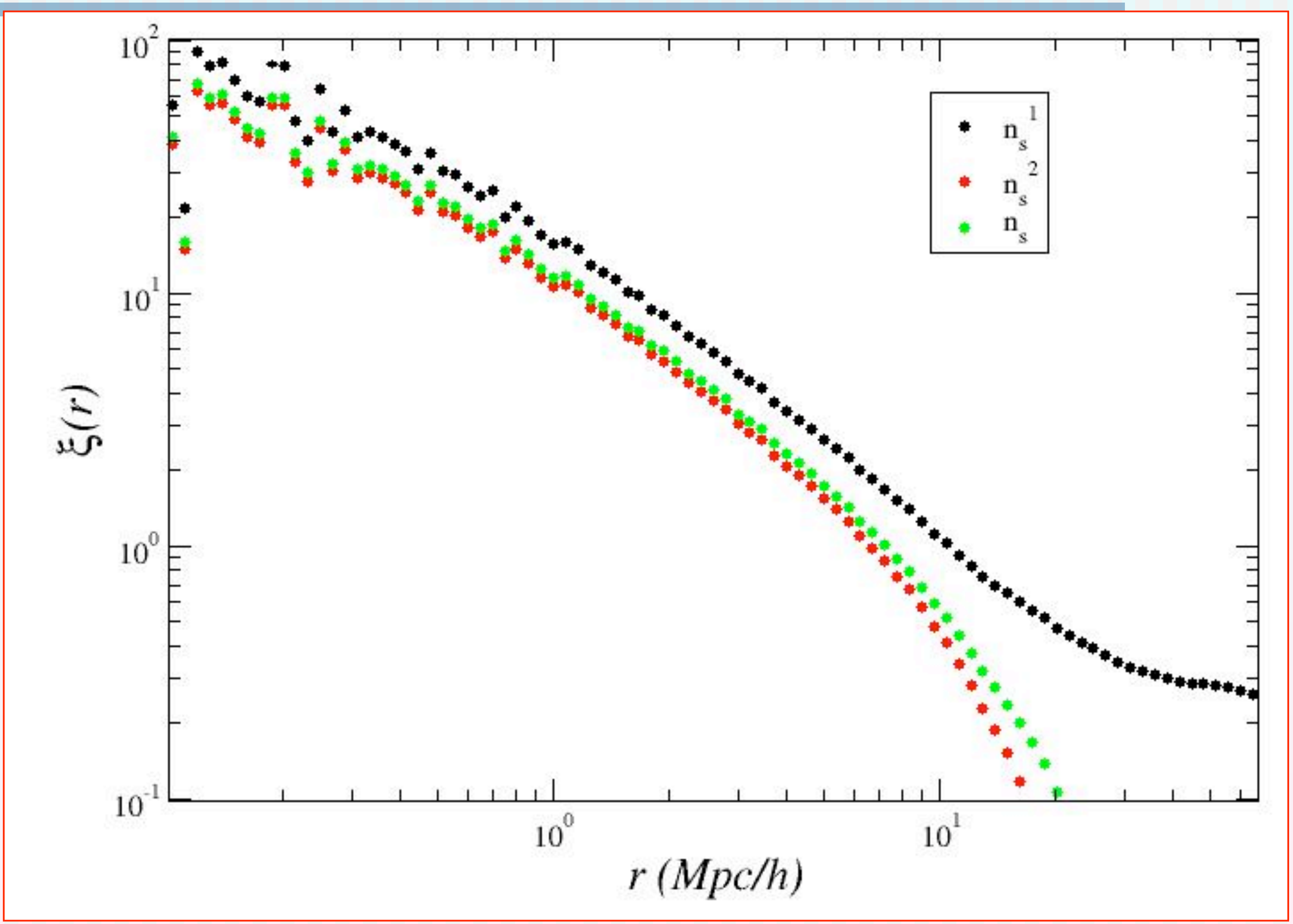

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$$\overline{N(r;R,\Delta R)} = \frac{1}{M_b} \sum_{R_j \in [R,\Delta R]}^{j=1,M_b} N(r;R_j)$$

Results: the scale-length method

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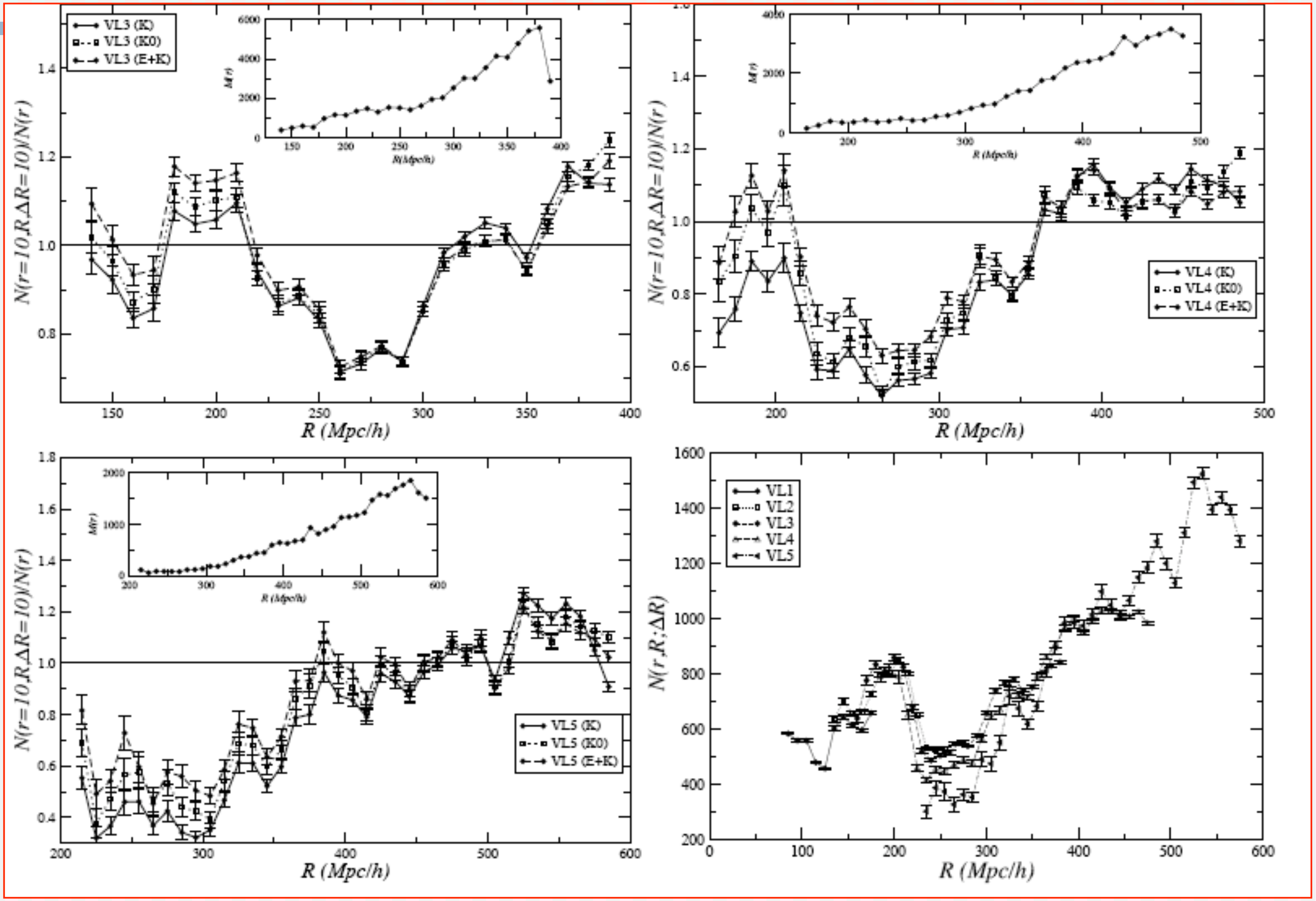
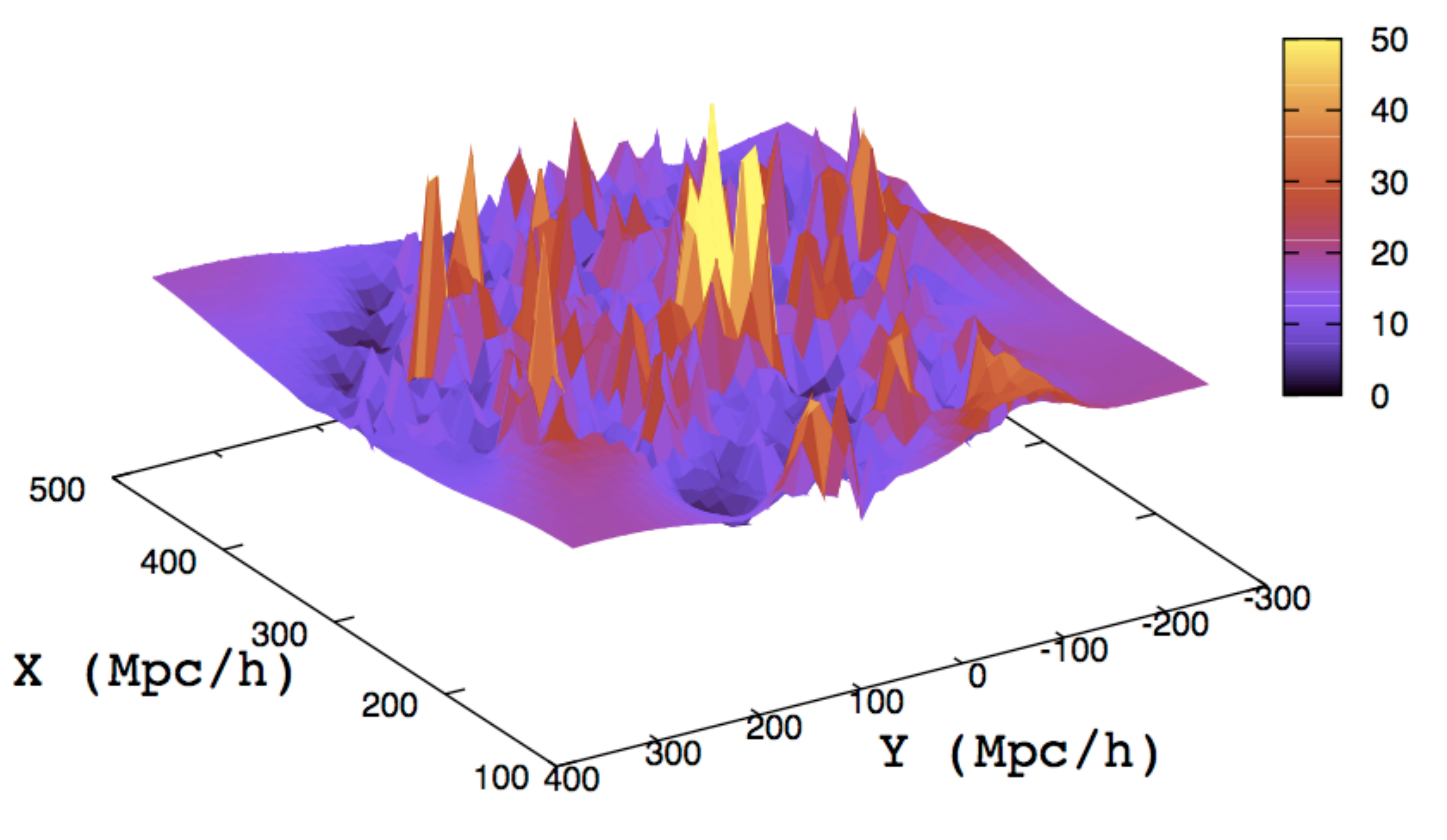


Results

- FSL., Vasilyev N., Baryshev Y.V. , Eurohys.Lett., **85**, 29002 (2009)
- FSL , Vasilyev N., Baryshev Y.V., Astron.Astrophys. **496**, 7 (2009)



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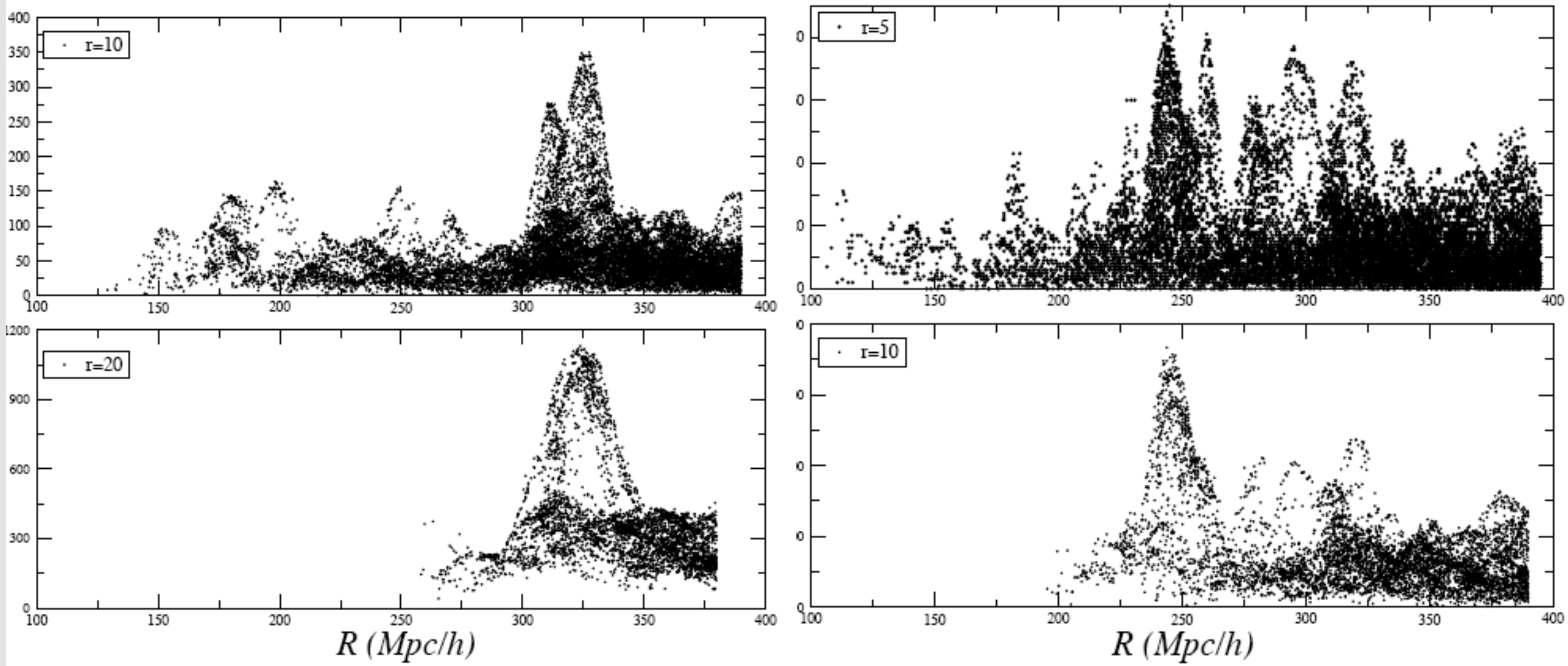

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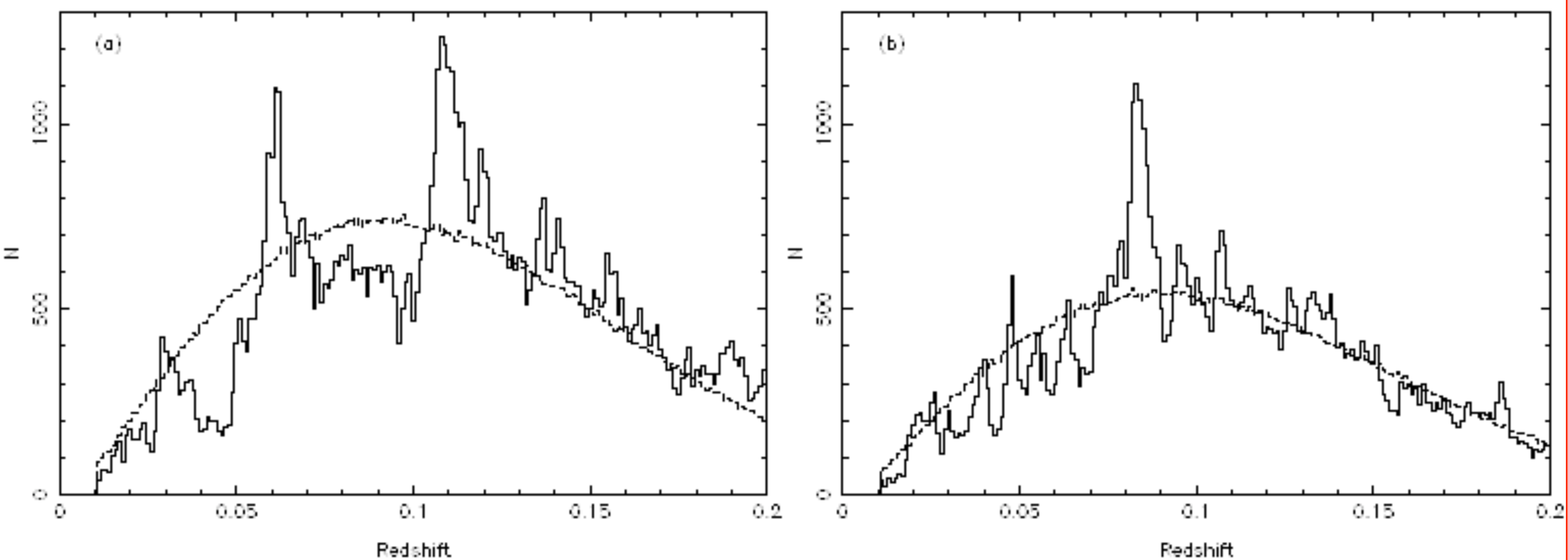
The 2dFGRS: correlation functions, peculiar velocities and the matter density of the Universe



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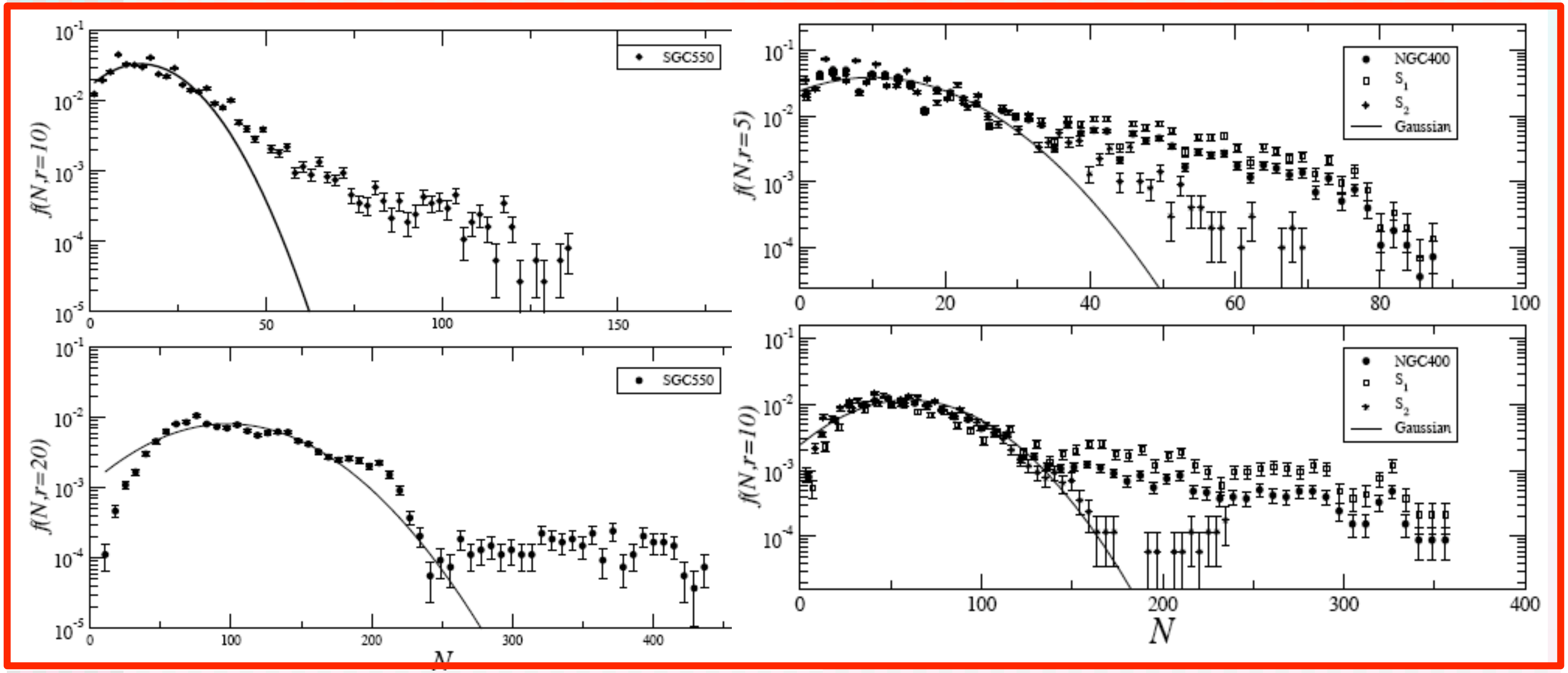

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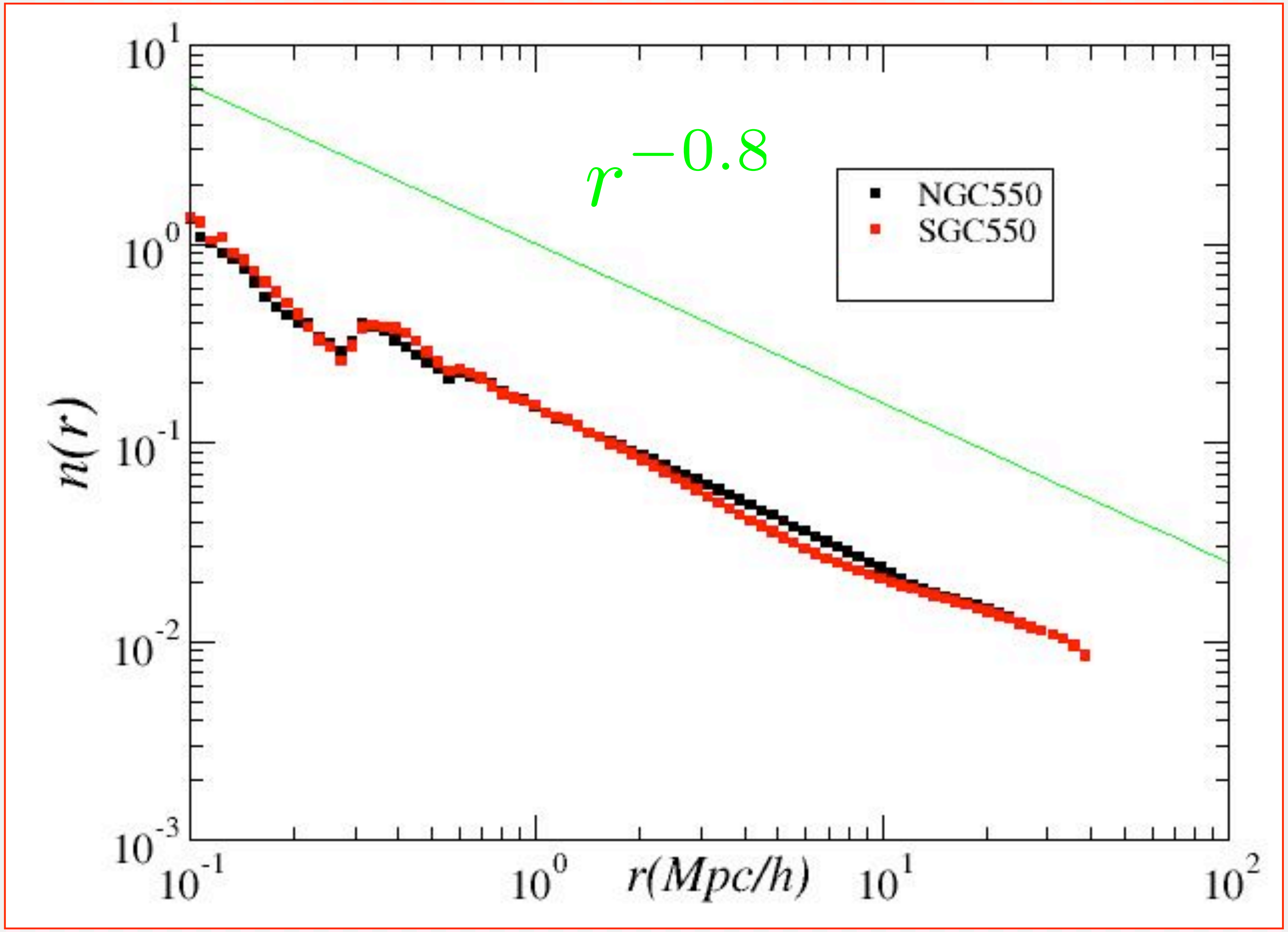

The BAO scale

- FSL, Vasilyev N., Baryshev Y.V. , Lopez-Corredoira M., **arXiv:0903.0950**

•**Measured by** Eiseinstein et al. (2005), Cabre et al. (2008), Martinez et al. (2009)

•**Where** SDSS-LRG

•**How** Landy and Szalay estimator

•**Errors** Jack-knife

The BAO scale

- FSL, Vasilyev N., Baryshev Y.V. , Lopez-Corredoira M., **arXiv:0903.0950**

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•**How** Landy and Szalay estimator

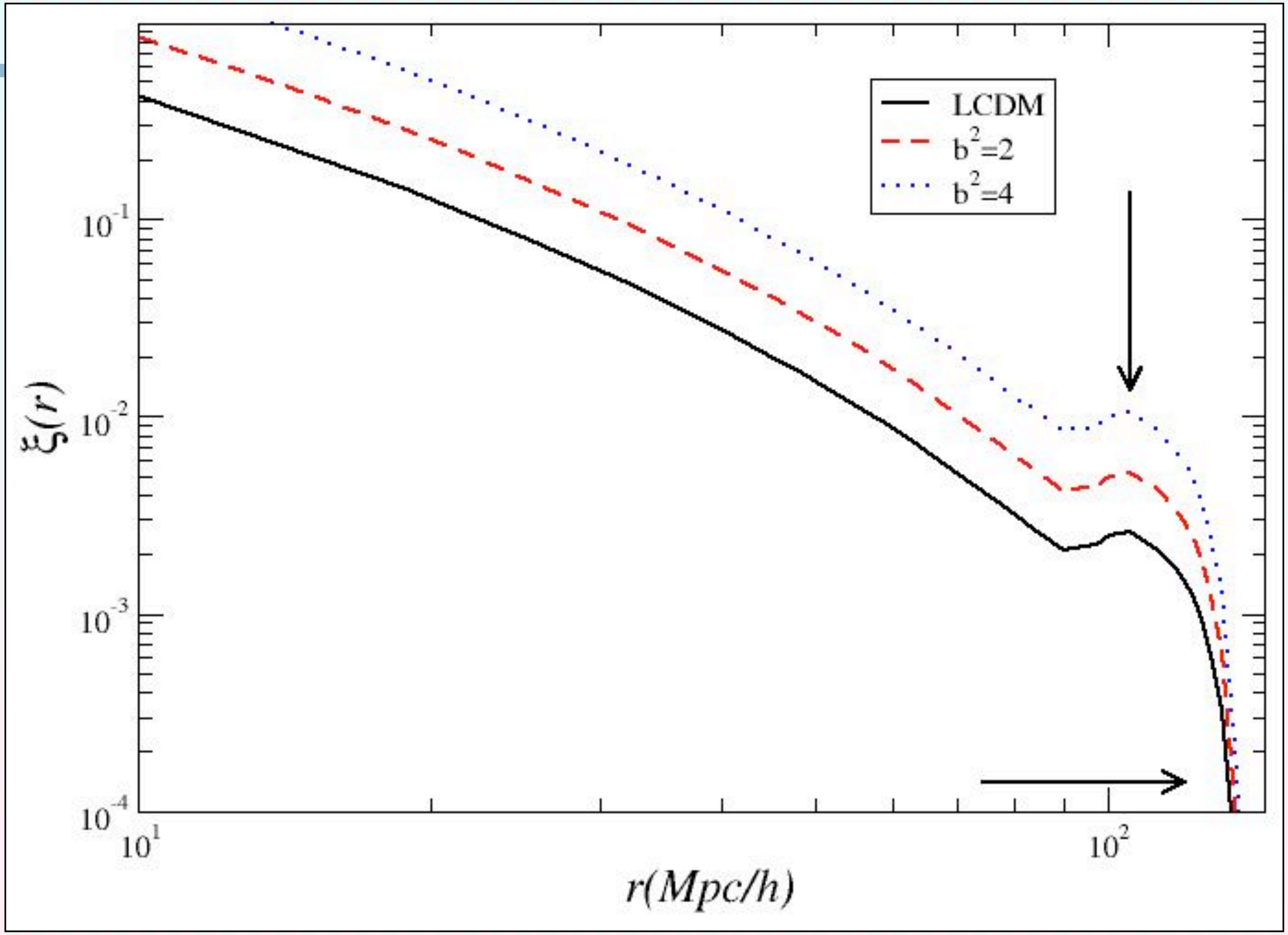
•**Errors** Jack-knife

•Q1: Does it make sense to detect $\xi(r) \approx 0.01 \rightarrow \delta n \approx 0.01$?

•Q2: What about the SDSS-MG sample ?

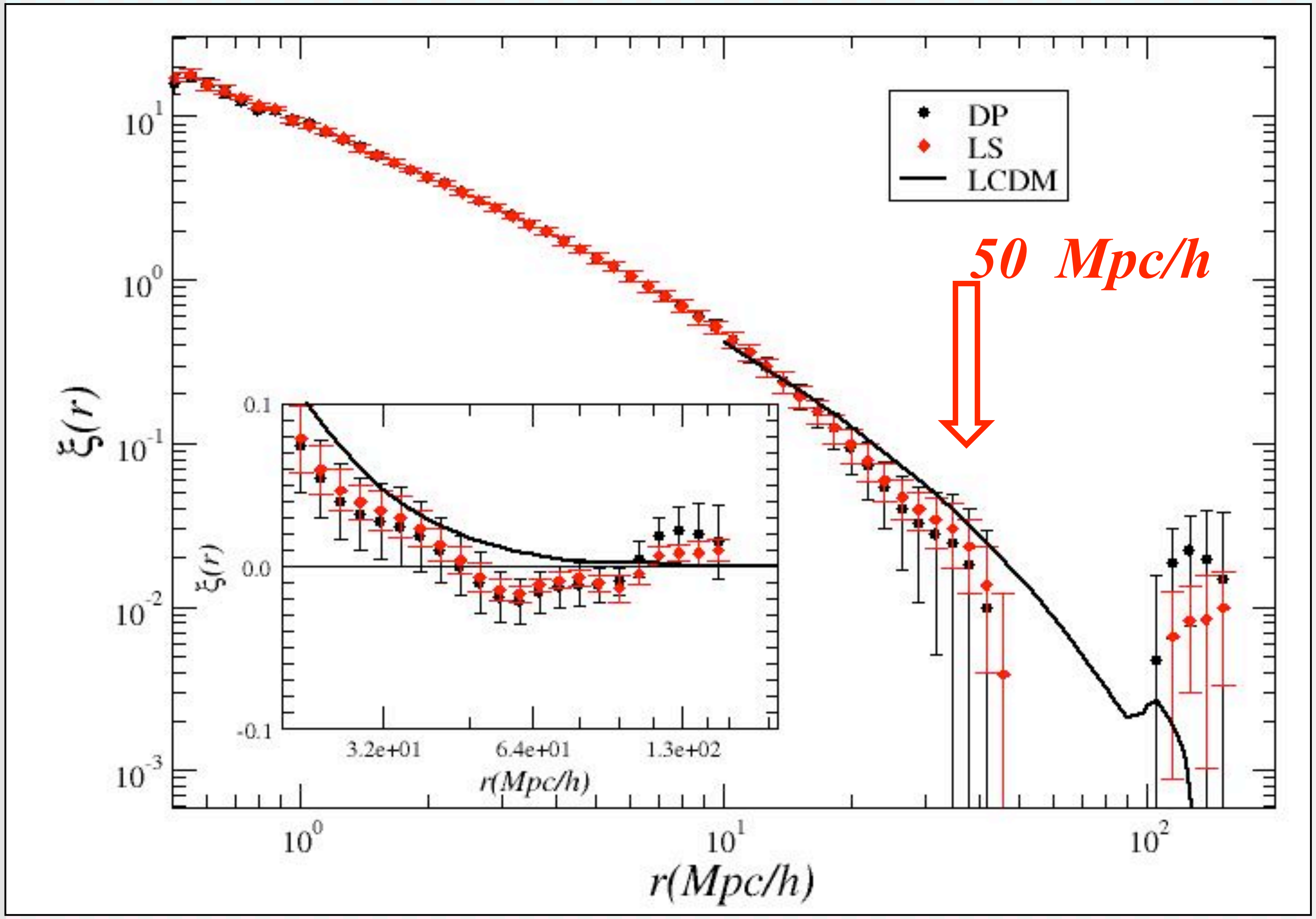
The BAO scale

- FSL, Vasilyev N., Baryshev Y.V. , Lopez-Corredoira M., **arXiv:0903.0950**



The BAO scale

- FSL, Vasilyev N., Baryshev Y.V. , Lopez-Corredoira M., **arXiv:0903.0950**



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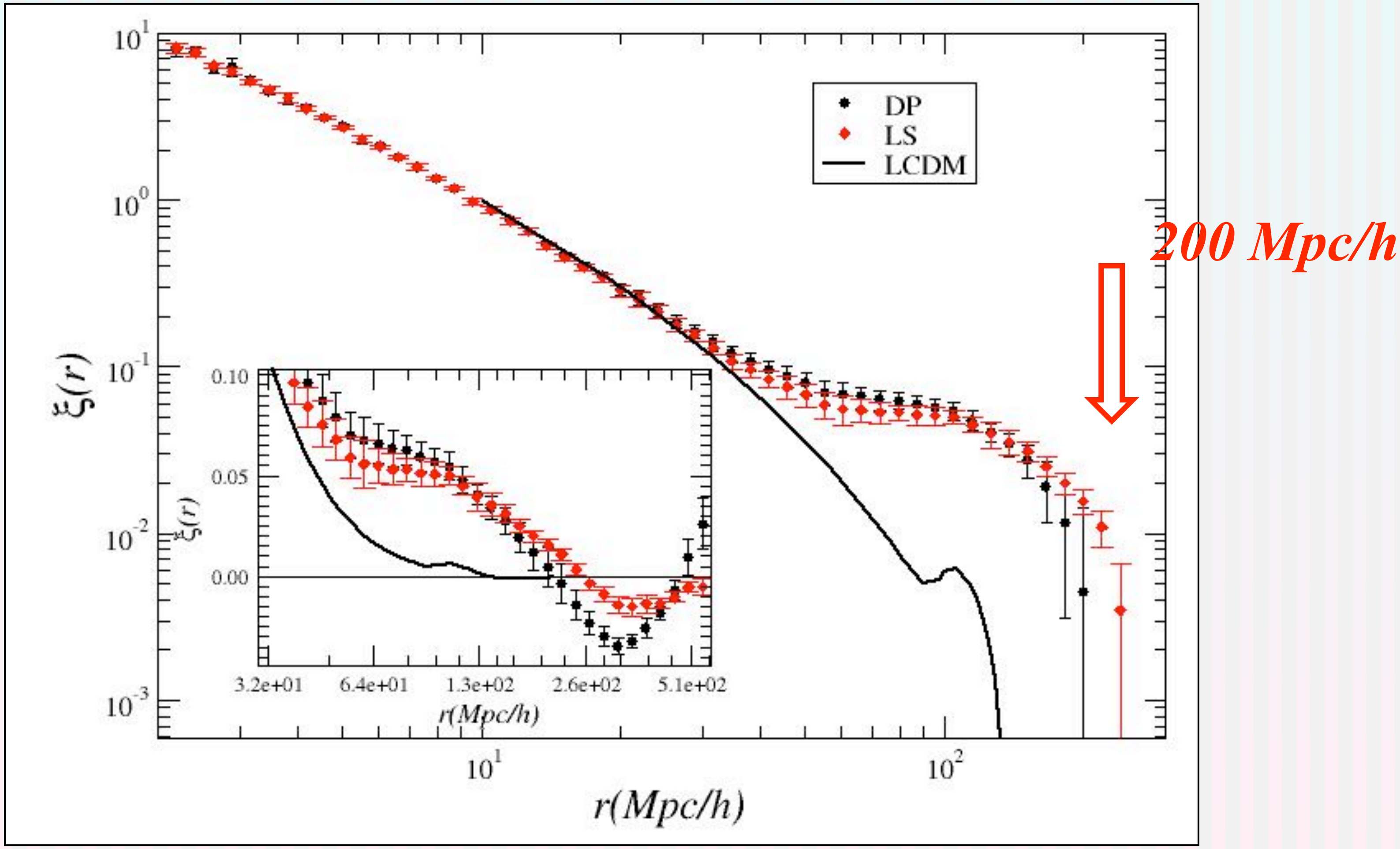

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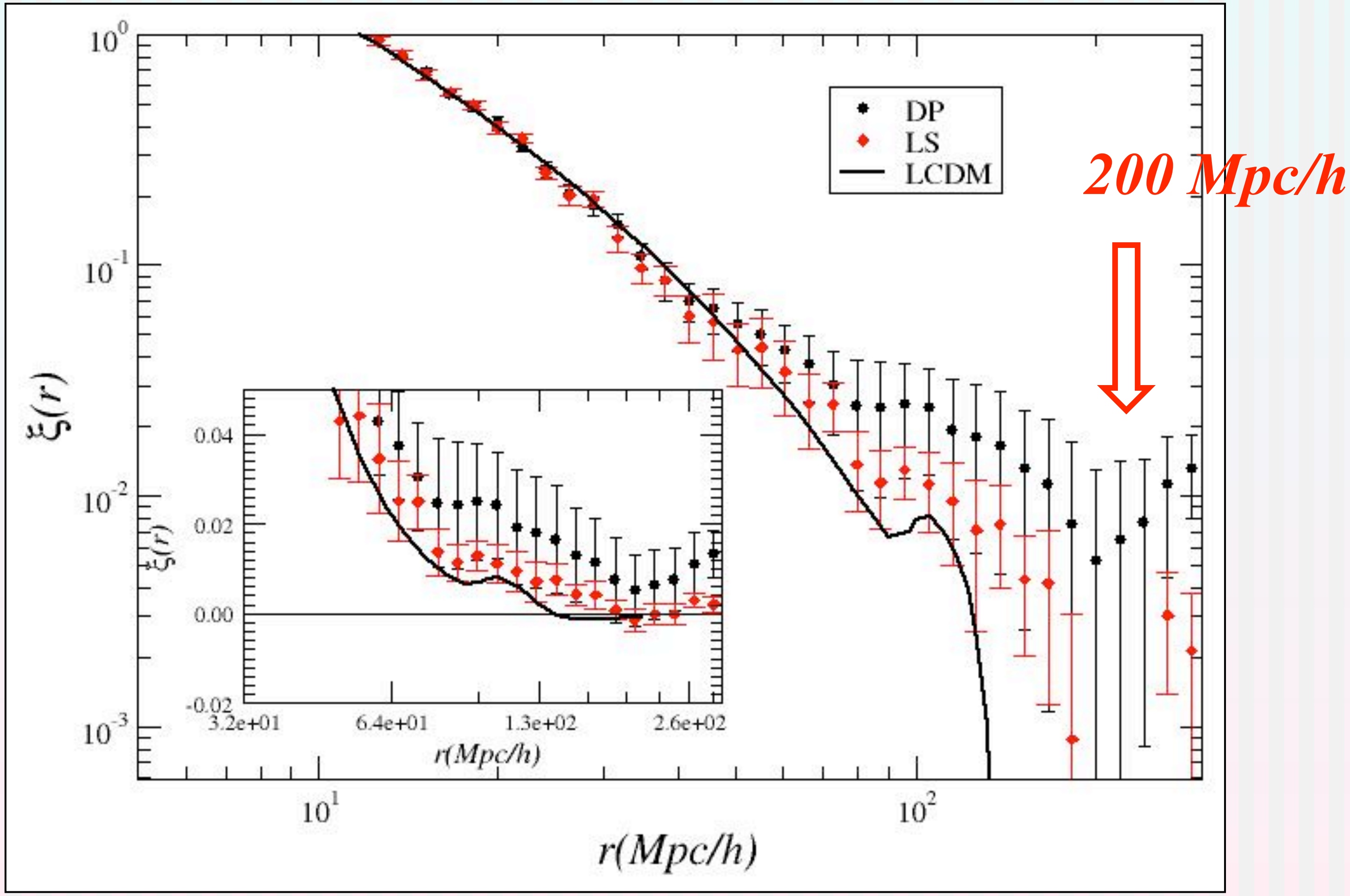


The BAO scale

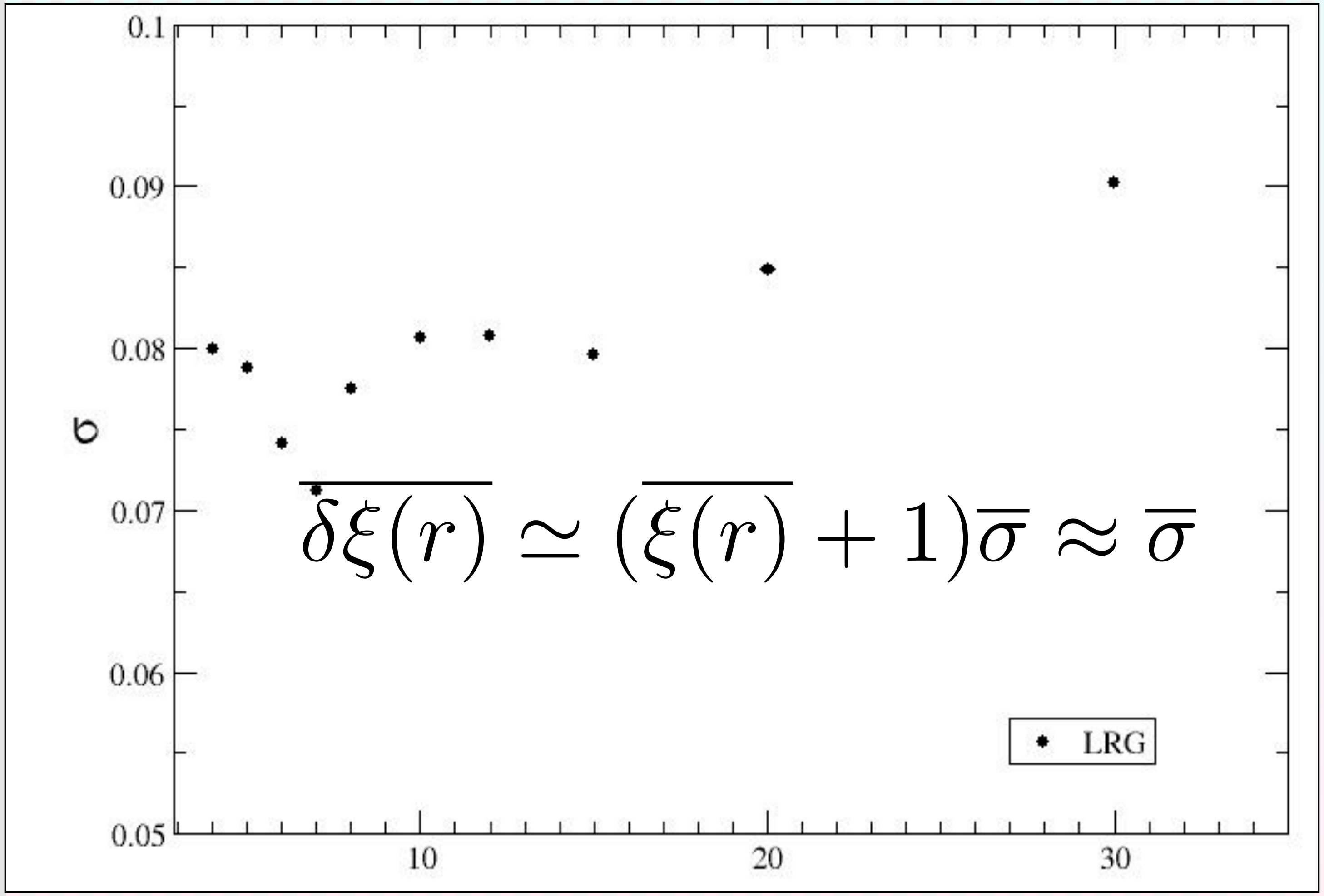
- FSL, Vasilyev N., Baryshev Y.V. , Lopez-Corredoira M., **arXiv:0903.0950**

$$\overline{n} \neq \langle n \rangle \quad \Leftrightarrow \quad \lim_{V \to \infty} \overline{\sigma^2(V)} = \lim_{V \to \infty} \frac{\overline{\Delta N(V)^2}}{\overline{N(V)}^2} = 0$$

$$\sigma^2(V) = \frac{1}{V^2} \int_V \int_V \xi(\vec{r}_1 - \vec{r}_2) d^3 r_1 d^3 r_2 + \frac{1}{\langle N(V) \rangle}$$

The BAO scale

- FSL, Vasilyev N., Baryshev Y.V. , Lopez-Corredoira M., **arXiv:0903.0950**



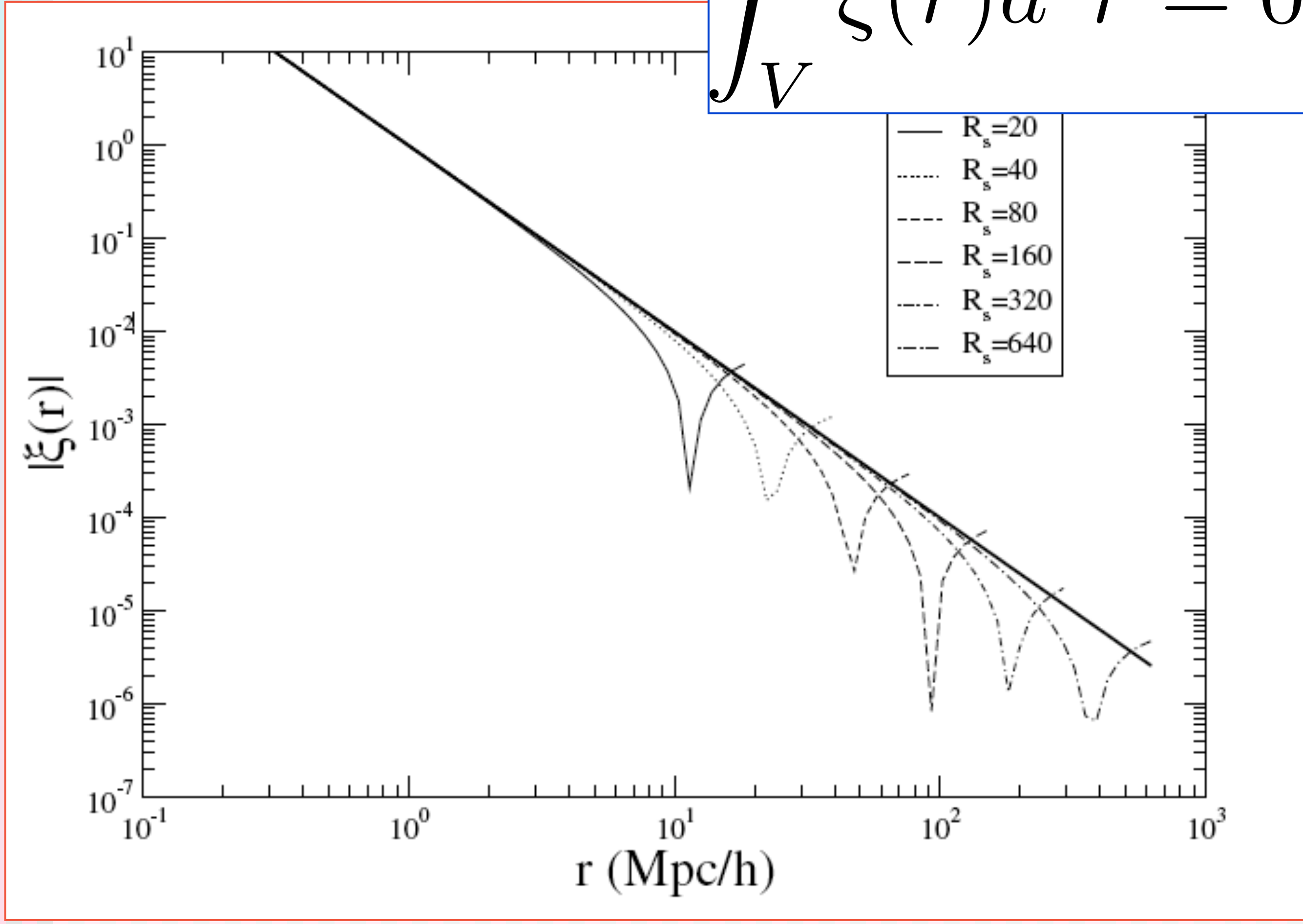
$$\overline{\delta\xi(r)} \simeq (\overline{\xi(r)} + 1)\overline{\sigma} \approx \overline{\sigma}$$

The BAO scale

• FSL, Vasilyev N., Baryshev Y.V. , Lopez-Corredoira M., **arXiv:0903.0950**

•F. Sylos Labini and N. L. Vasilyev Astron.Astrophys. **477**, 381-395 (2008)

$$\int_V \overline{\xi(r)} d^3 r = 0 \;\; \forall V \;\; \forall \xi(r)$$



The BAO scale

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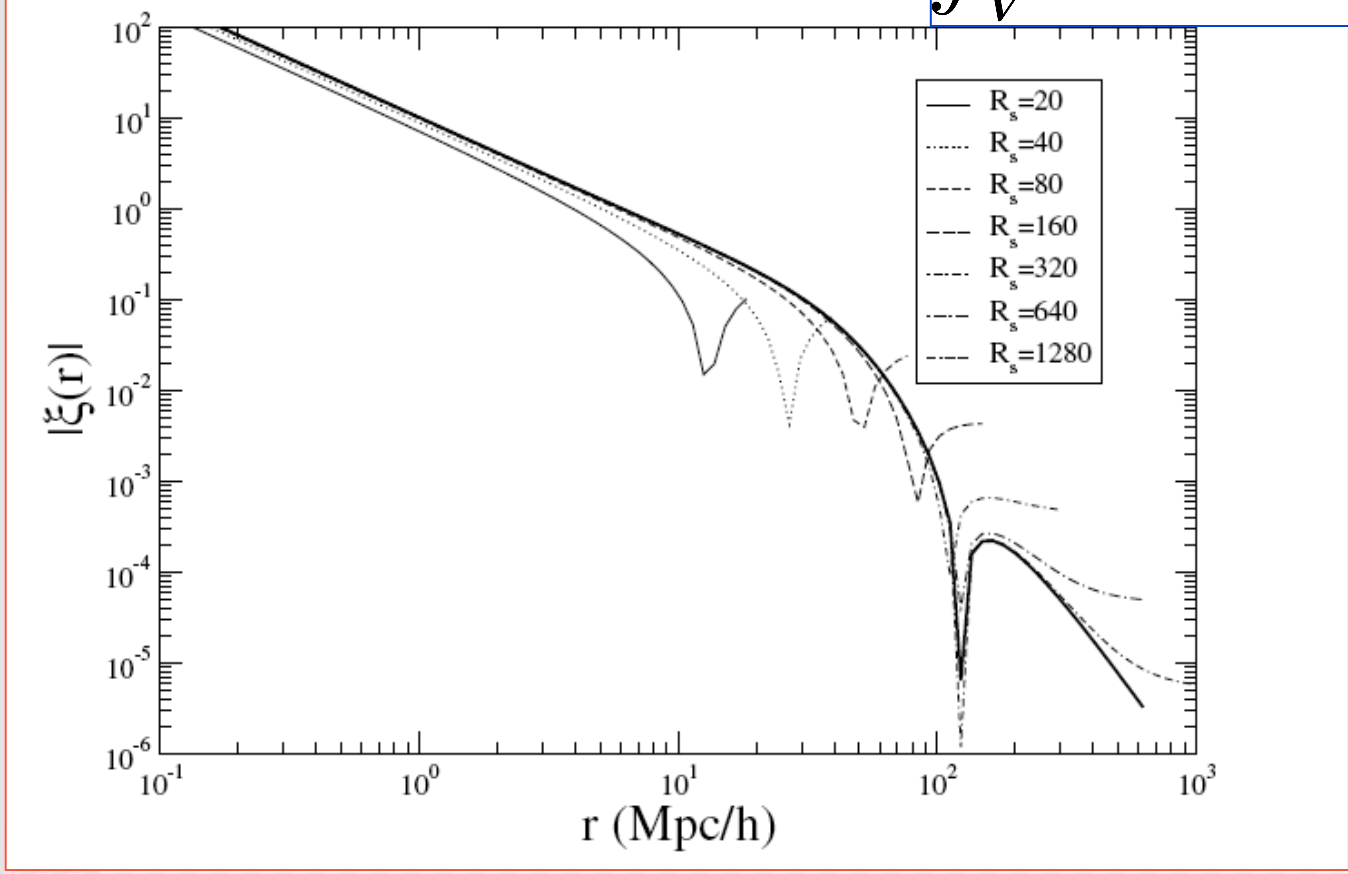
  - F. Sylos Labini and N. L. Vasilyev Astron.Astrophys. **477**, 381-395 (2008)

$$\int_V \overline{\xi(r)} d^3 r = 0 \;\; \forall V$$



Outline

- A brief introduction
- Data and standard results
- Standard theoretical predictions
- Clustering, correlations and structures
- Conclusions

Standard cosmological models of structure formation

- FSL and N. L. Vasilyev Astron.Astrophys. **477**, 381-395 (2008)

$$P(k,t) = A \times P(k,0) \times g(t)$$

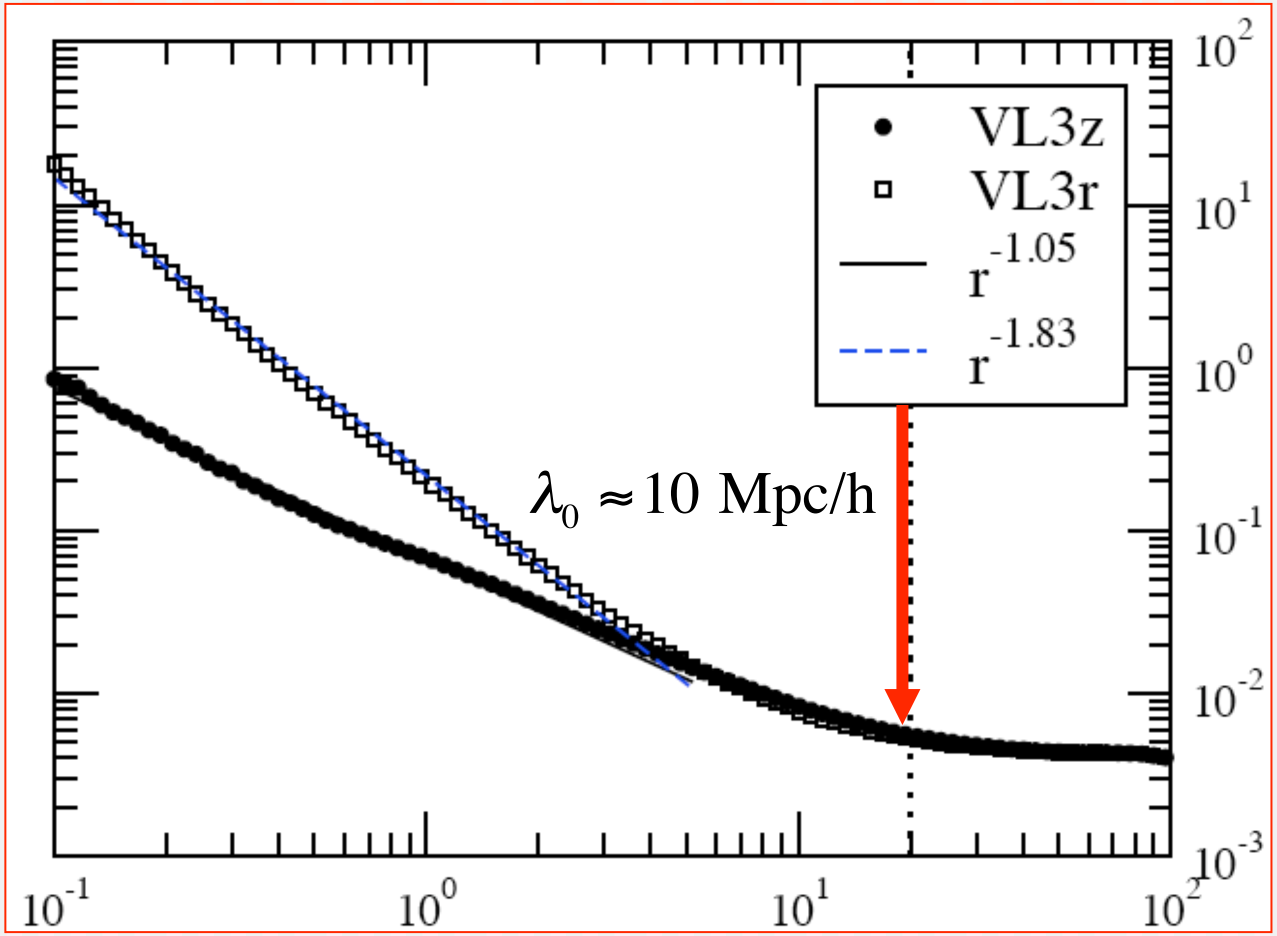
$$A \Leftrightarrow \xi(\lambda_0, t_0) = 1$$

$\lambda_0 \approx 10$ Mpc/h ⟶ Non-linearity length scale (clusterization)

$r_c \approx 100$ Mpc/h ⟶ Linearity length scale (correlation)

Standard cosmological models of structure formation

- FSL., Vasilyev N., Baryshev Y.V. preprint (2009)
- FSL., Vasilyev N., Pietronero L. Baryshev Y.V. , Europhys.Lett, **86**, 49001 (2009)



Standard cosmological models of structure formation

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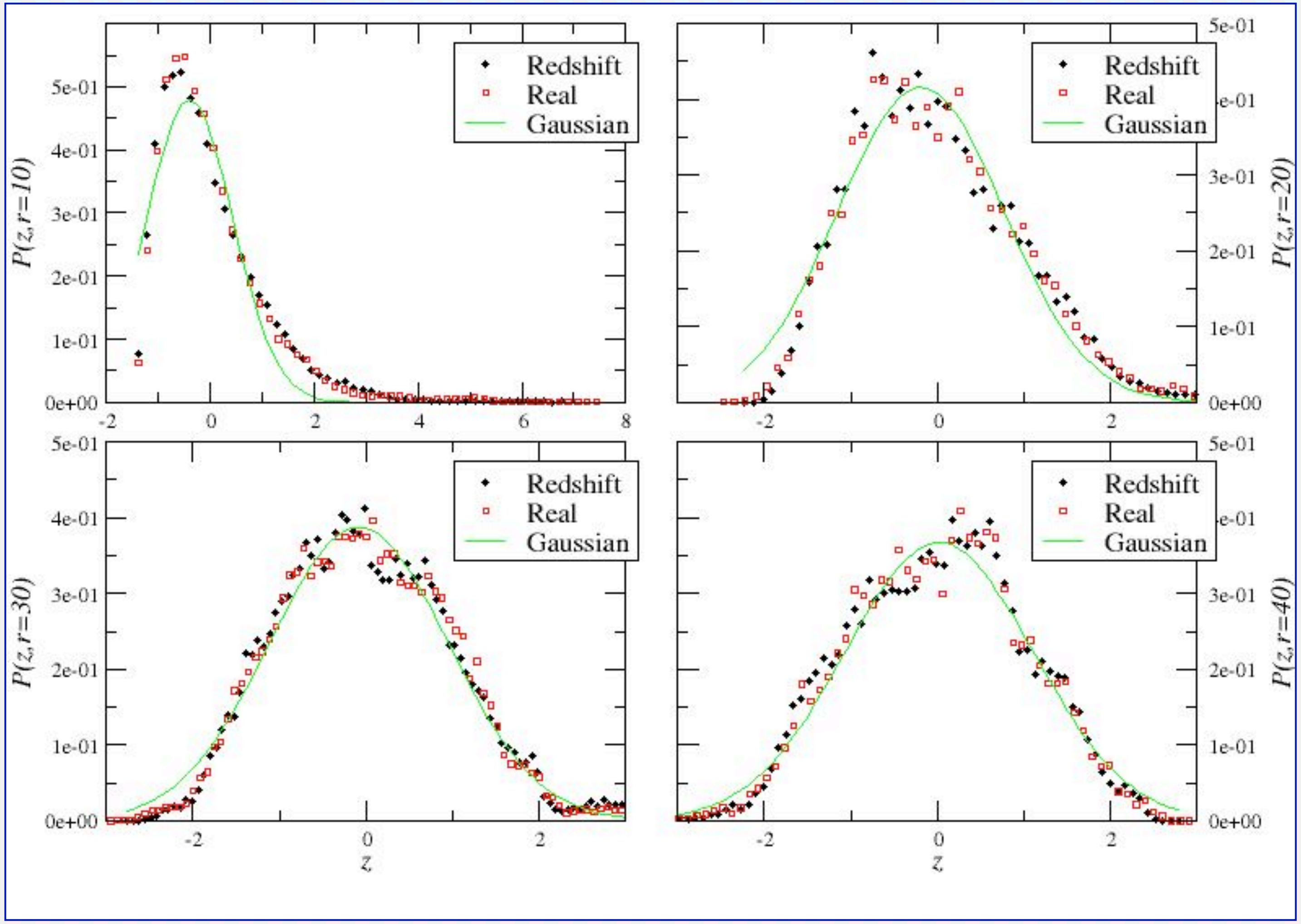
- FSL., Vasilyev N., Pietronero L. Baryshev Y.V. , Europhys.Lett, **86**, 49001 (2009)



Conclusions

Model predictions

$\lambda_0^{\ M} \approx 10$ Mpc/h ⟶ Non-linear length scale (homogeneity scale)

$r_c^{\ M} \approx 100$ Mpc/h ⟶ Linear length scale (super-homogeneity scale)

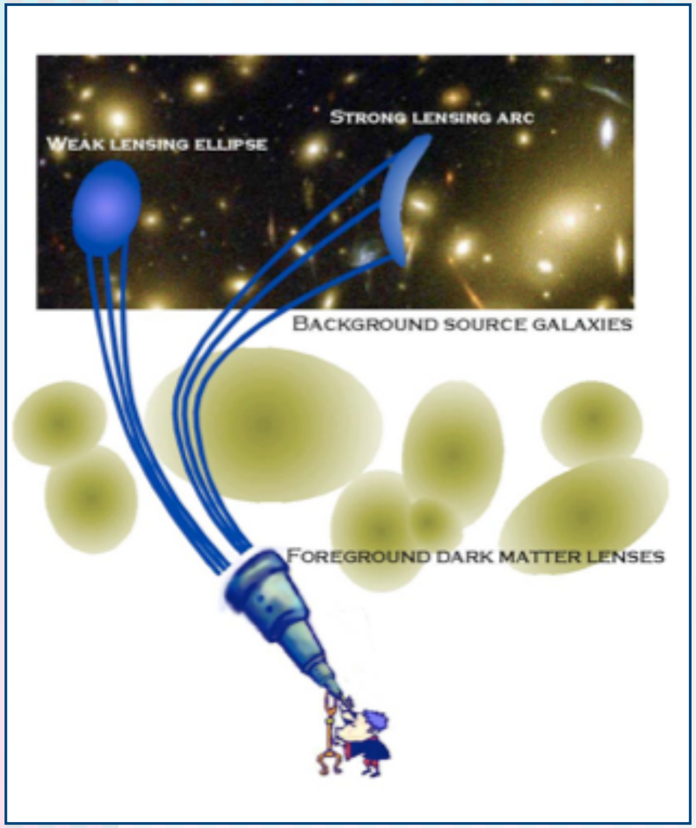
Observations

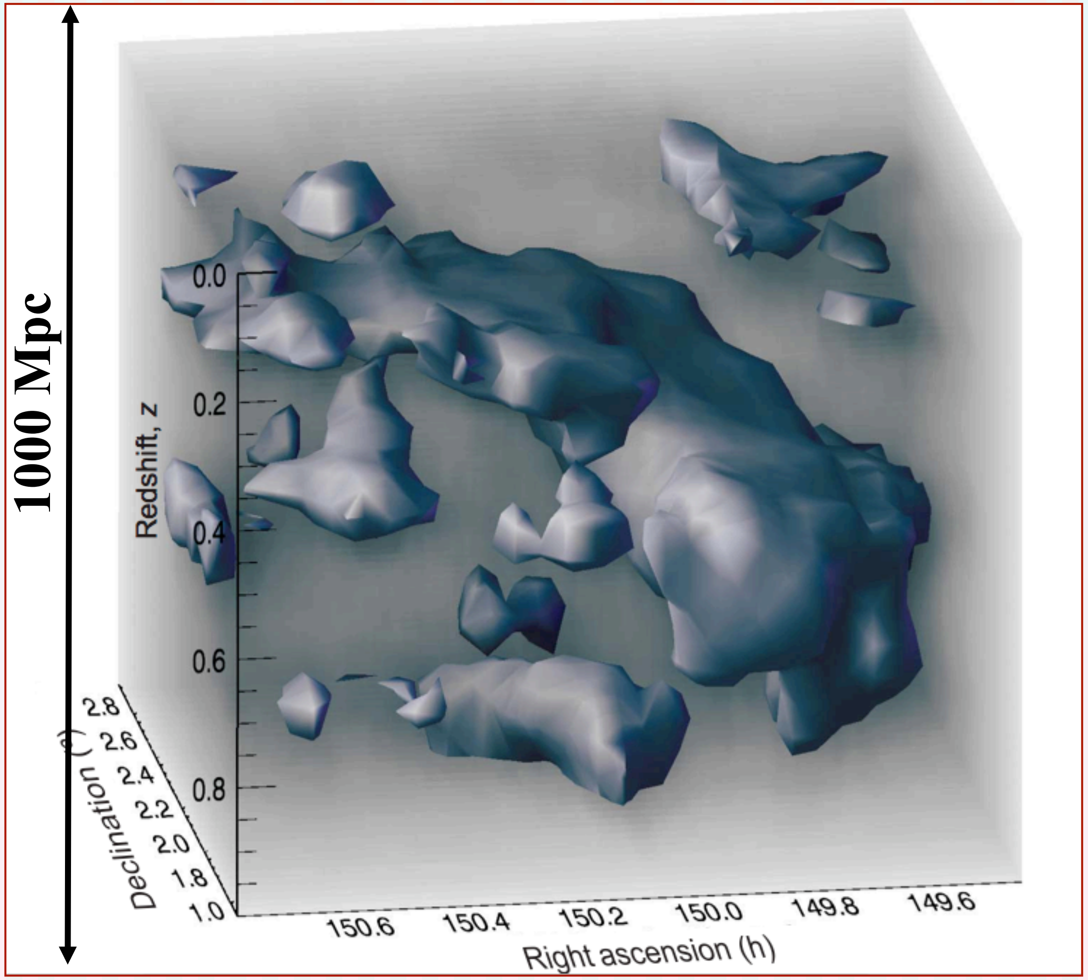
$$\lambda_0 \geq 100 \text{ Mpc/h} \approx r_c^{\ M}$$

$$r_c >> 100 \text{ Mpc/h} >> r_c^{\ M}$$

Conclusions

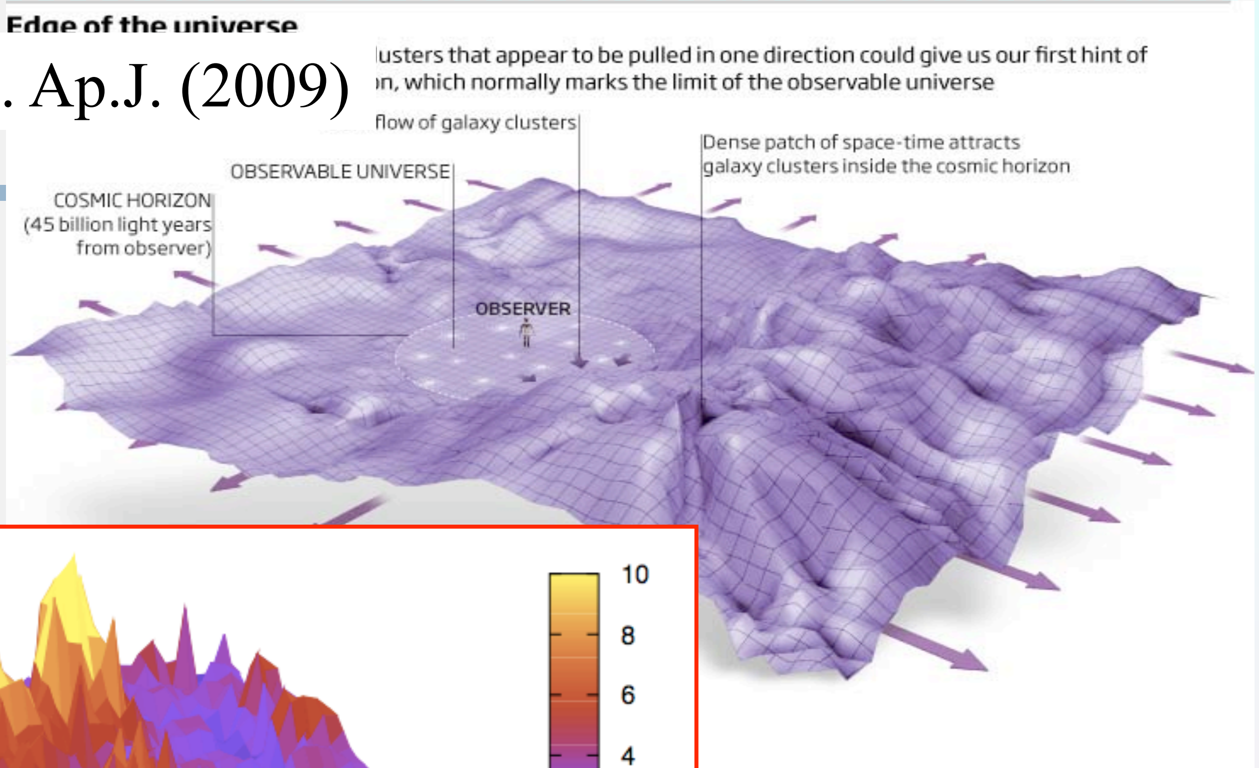
•R. Massey et al. Nature **445**, 286 (2007)

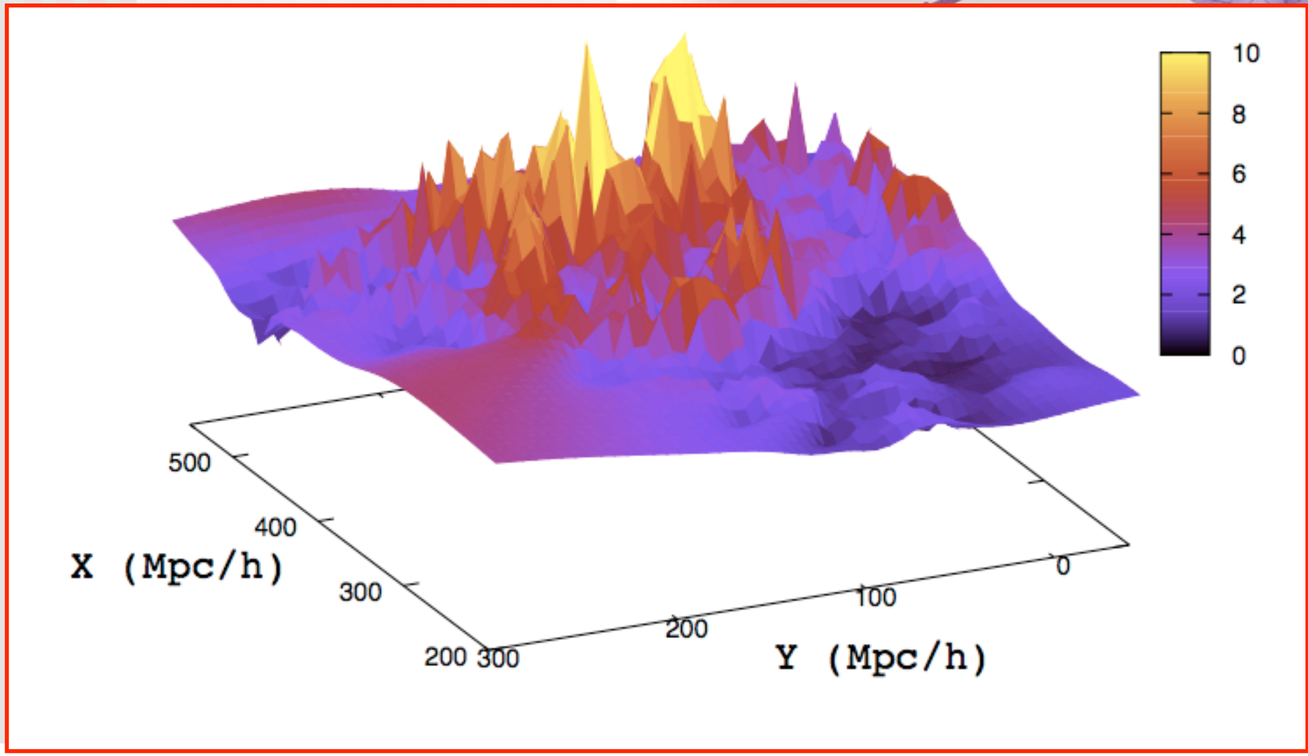




Conclusions

- S. Kashlinsky et al. Ap.J. (2009)





Conclusions

Fractal cosmology in an open universe

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L. Pietronero[1,3] and F. Sylos Labini[5,3]

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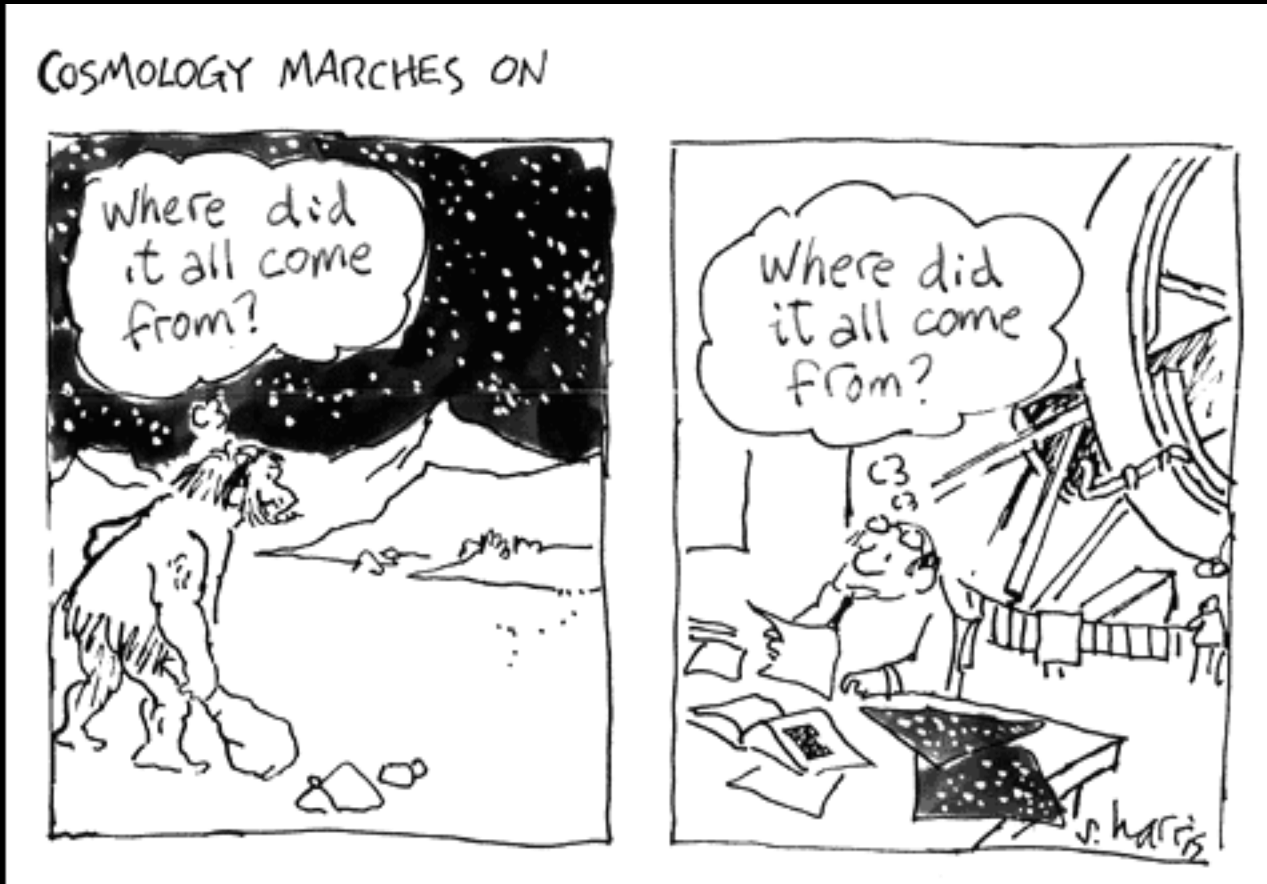
(received 4 October 1999; accepted in final form 22 February 2000)

PACS. 98.80.-k – Cosmology.
PACS. 98.65.Dx – Superclusters; large-scale structure of the Universe (including voids, pancakes, great wall, etc.).
PACS. 05.45.Df – Fractals.

Abstract. – The clustering of galaxies is well characterized by fractal properties, with the presence of an eventual cross-over to homogeneity still a matter of considerable debate. In this letter we discuss the cosmological implications of a fractal distribution of matter, with a possible cross-over to homogeneity at an undetermined scale R_{homo}. Contrary to what is generally assumed, we show that, even when $R_{\mathrm{homo}} \to \infty$, this possibility can be treated consistently within the framework of the expanding universe solutions of Friedmann. The fractal is a perturbation to an open cosmology in which the leading homogeneous component is the cosmic background radiation (CBR). This cosmology, inspired by the observed galaxy distributions, provides a simple explanation for the recent data which indicate the absence of deceleration in the expansion ($q_0 \approx 0$). Correspondingly the "age problem" is also resolved. Further we show that the model can be extended back from the curvature-dominated arbitrarily deep into the radiation-dominated era, and we discuss qualitatively the modifications to the physics of the anisotropy of the CBR, nucleosynthesis and structure formation.


COSMOLOGY MARCHES ON
Where did it all come from?
Where did it all come from?
S. Harris

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