Introduction to Astronomy and Astrophysics I

Lecture 12

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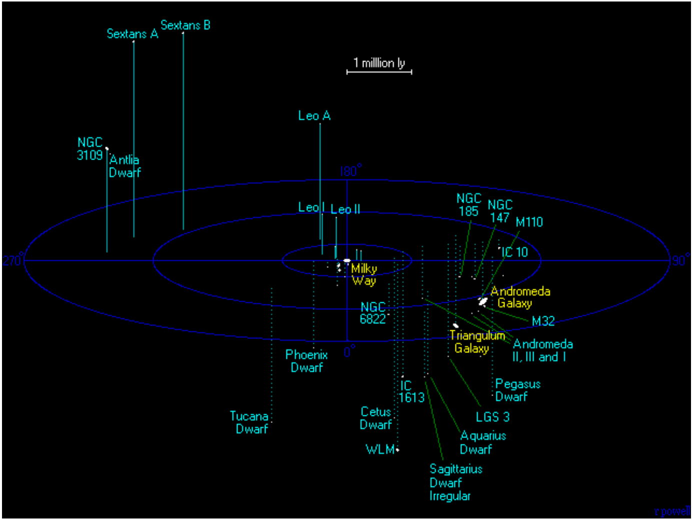
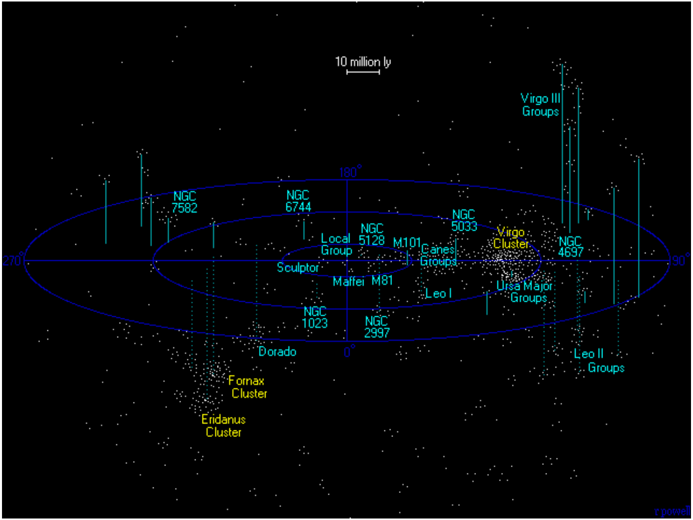
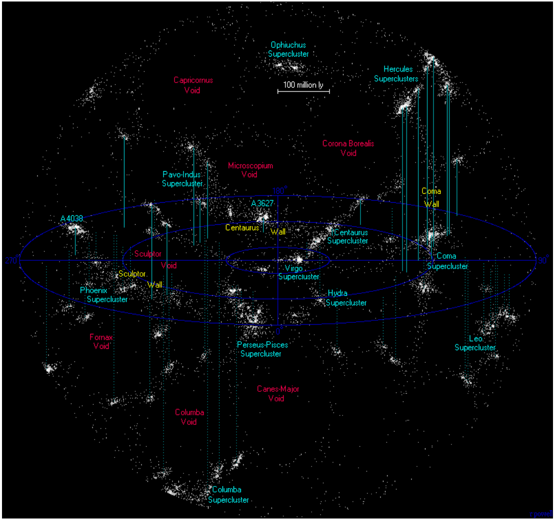
The Local group

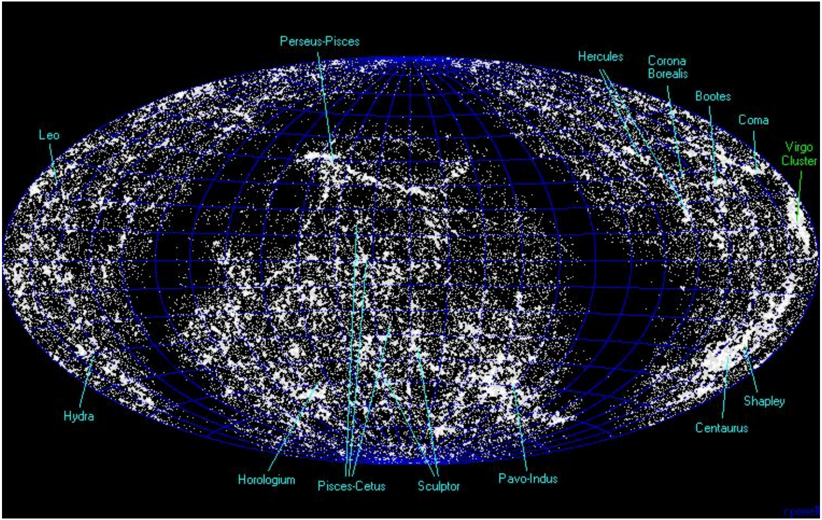


The local supercluster



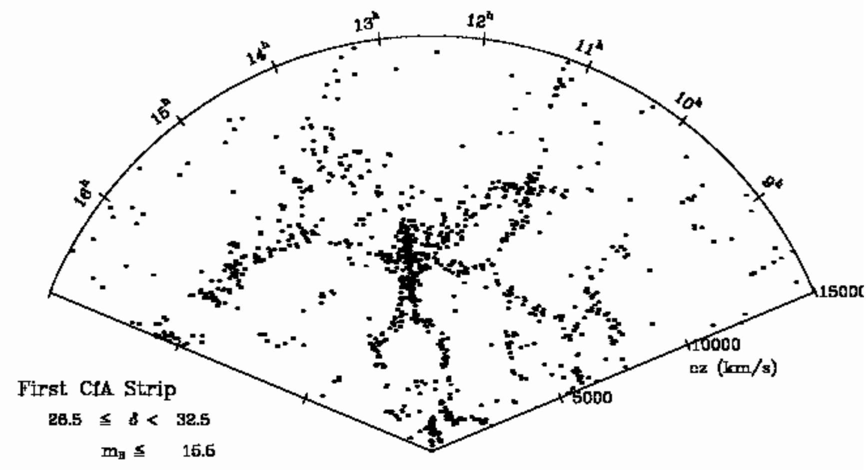
Nearby superclusters



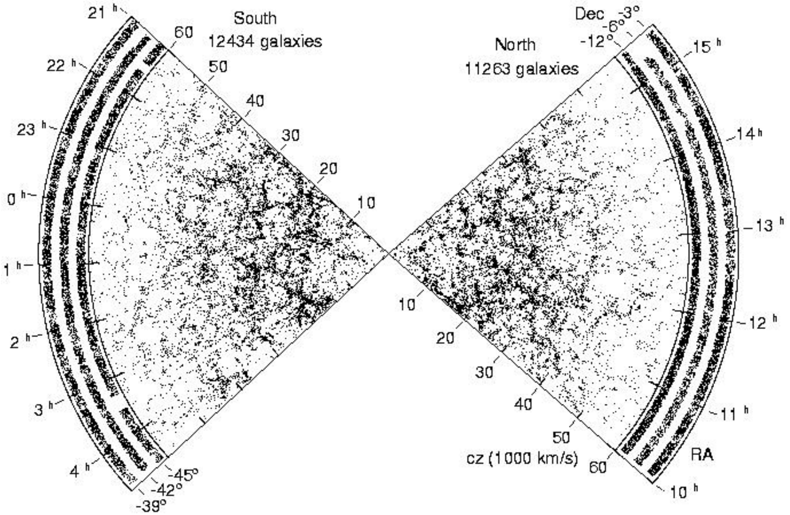


Where would the 6000 brightest stars lie?

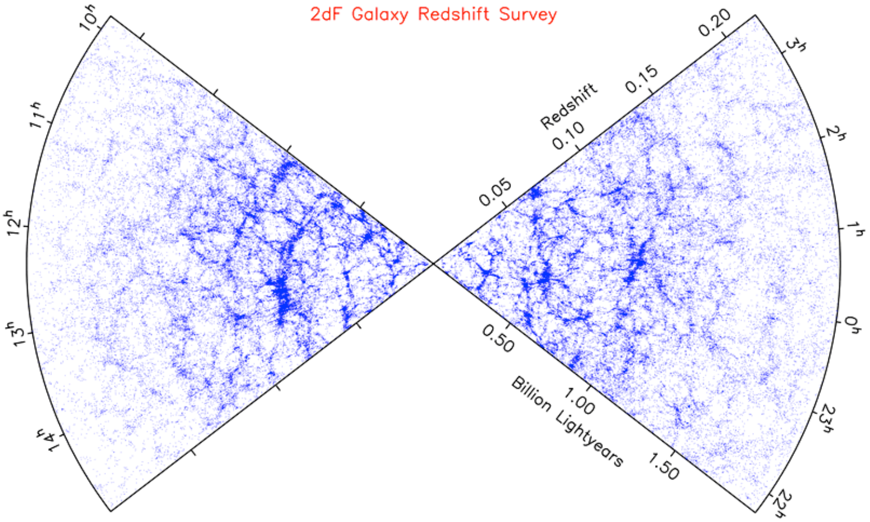
CFA stickman - Coma cluster, peculiar velocity biases



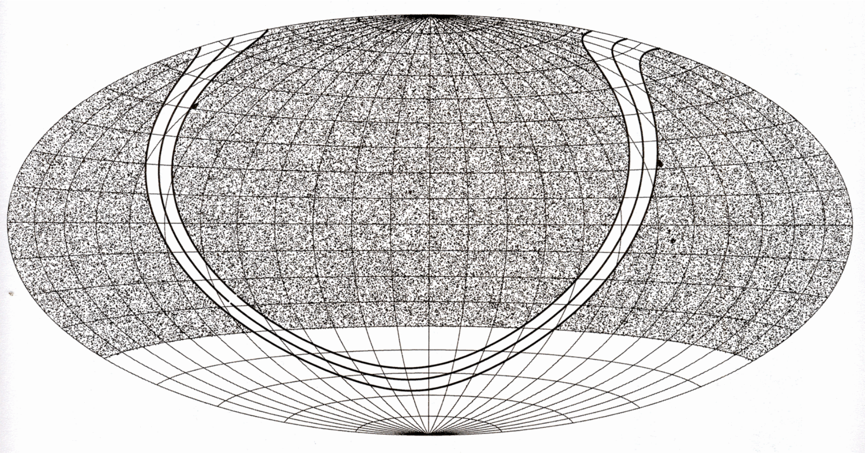
Las Campanas Redshift survey



2dFGRS

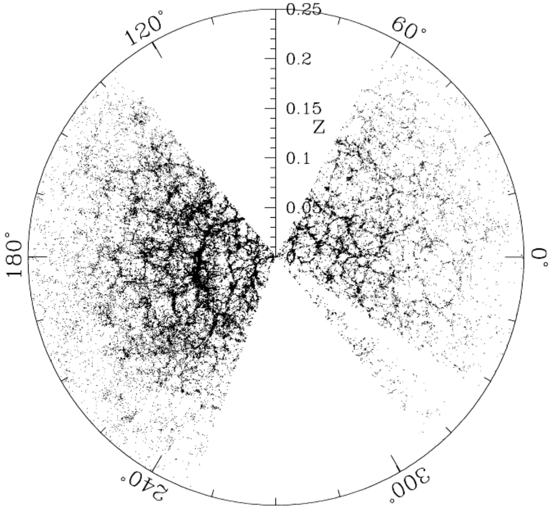

2dF Galaxy Redshift Survey
Redshift
0.05
0.10
0.15
0.20
Billion Lightyears
0.50
1.00
1.50
10h
11h
12h
13h
14h
3h
2h
1h
0h
23h
22h

NVSS source count distribution

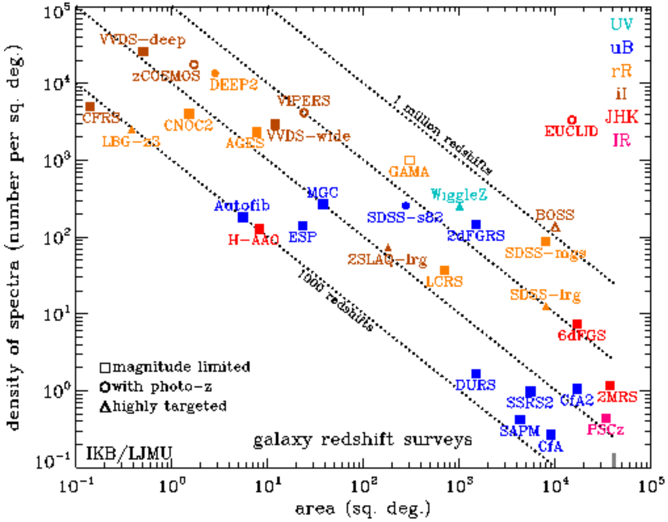


Why is this distribution much less clustered than the optical surveys?

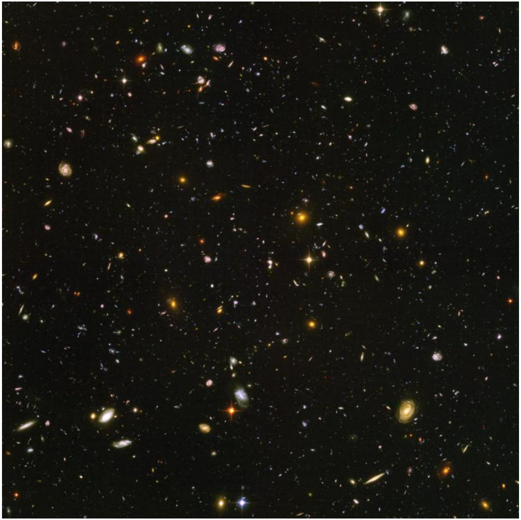
Sloan digital Sky Survey (SDSS)



LSS optical surveys compared



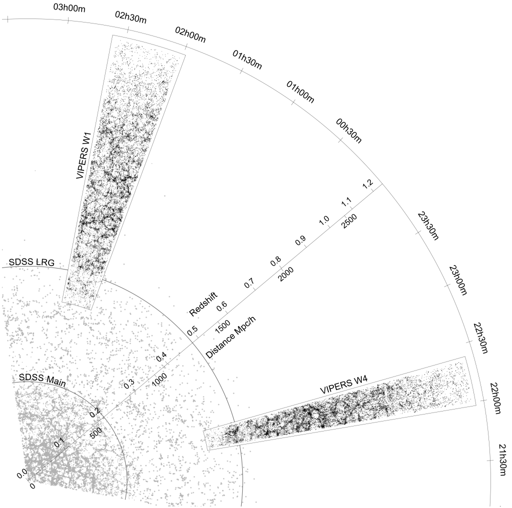
Pencil beam surveys e.g. Hubble Ultra Deep Field



These surveys map out evolution of field galaxies and LSS out to $z \sim 1 - 2$ and beyond.

Ergodic principle crucial for galaxy evolution

VIPERS survey



Large Area Surveys at other wavelengths

- Xray: ROSAT all sky survey (RASS)
- GALEX: all sky imaging survey (AIS)
- near-IR: 2MASS all sky survey
- Mid-infrared: WISE survey in 4 mid-infrared bands
- Far Infrared: IRAS, COBE/WMAP/PLANCK
- Radio: NVSS, FIRST, TGSS

Pencil beam surveys at other wavelengths are also very numerous.
But all these are less useful than surveys involving optical spectroscopy. Why?

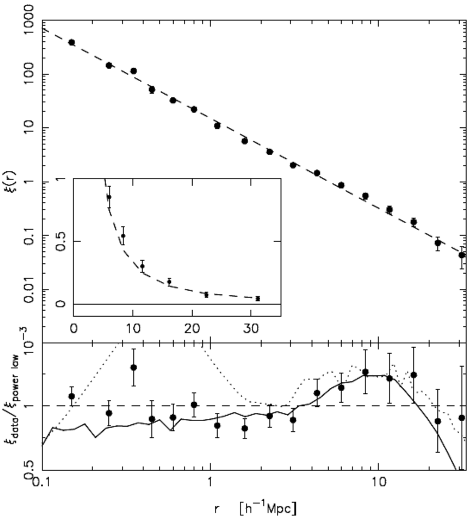
Two-point (auto) correlation function

$\xi(r)$, defined as an "excess probability" of finding another galaxy at a distance r from some galaxy, relative to a uniform random distribution

For small values of r this is well fit by a power law $\xi(r) = (r/r_0)^{-\gamma}$. The best fit r_0 is 5 h^{-1} Mpc and $\gamma \sim 1.8$

γ and r_0 are functions of various galaxy properties; clustering in clusters is stronger. The slope also steepens at $r/r_0 \gtrsim 2$

2DF auto correlation function



Question

Can the two point auto correlation function have a negative value?

How to estimate $\xi(r)$

Simplest estimator: count the number of data-data pairs, $\langle DD \rangle$, and the equivalent number in a randomly generated (Poissonian) catalog, $\langle RR \rangle$:

$$\xi(\mathbf{r}) = \frac{\langle DD \rangle}{\langle RR \rangle} - 1 \tag{1}$$

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$$\xi(\mathbf{r}) = \frac{\langle DD\rangle}{\langle RR\rangle} - 1 \tag{1}$$

A better estimator not affected by edge effects is:

$$\xi(\mathbf{r}) = \frac{\langle DD\rangle - 2\langle RD\rangle + \langle RR\rangle}{\langle RR\rangle} \tag{2}$$

where $\langle RD\rangle$ is the number of data random pairs (Landy & Szalay 1993).

Another way to estimate $\xi(\mathbf{r})$

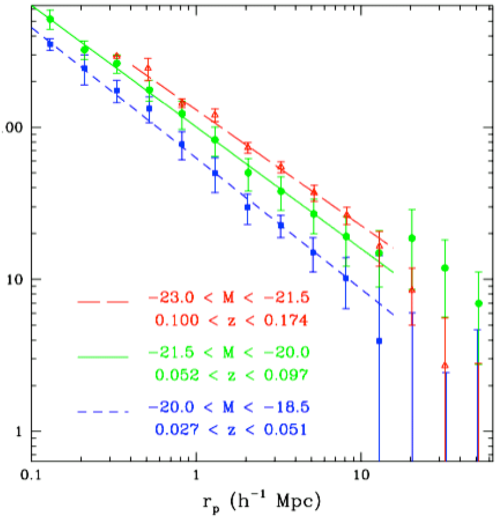
is via the overdensity in a particular cell relative to the average density

$$\delta_i(\mathbf{r}) = \frac{N_i - \langle N_i \rangle}{\langle N_i \rangle} \tag{3}$$

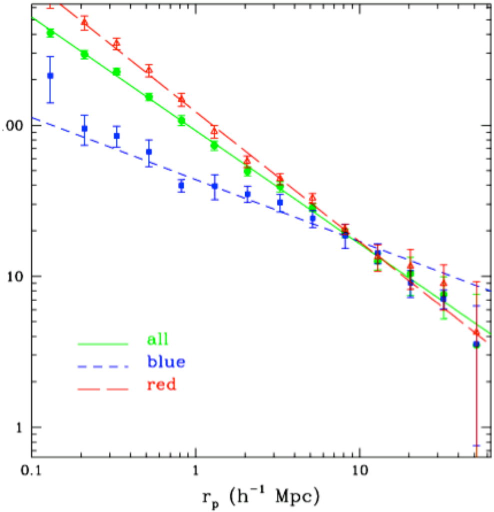
The $\xi(\mathbf{r})$ is the expectation value

$$\xi(\mathbf{x}_1, \mathbf{x}_2) = \langle \delta(\mathbf{x}_1) \delta(\mathbf{x}_2) \rangle \tag{4}$$

Are bright galaxies more clustered than faint ones?



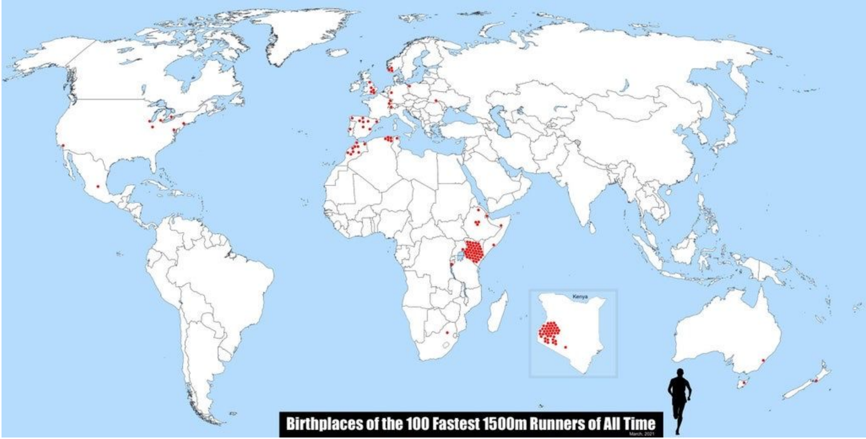
Are red galaxies more clustered than blue ones?



Two-point cross correlation function

Corellate two populations - e.g. are galaxies clustered around quasars?

Rare objects are clustered. Why?



100 Highest Mountains in the world

Three point (auto) correlation function

$\zeta = \langle \delta_1 \delta_2 \delta_3 \rangle$

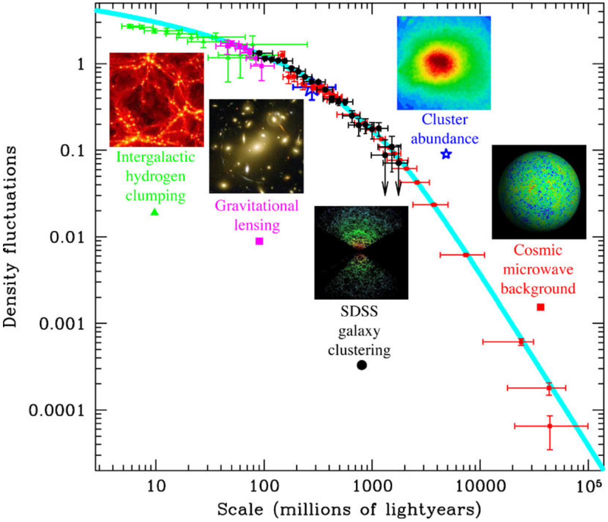
Angular correlation function

If only 2D information is available you can use the angular auto-correlation function - $w(\theta) = (\theta/\theta_0)^{-\beta}$ If all galaxies are at about the same distance, $\beta = \gamma - 1$.

Various correlation functions

- Two point auto correlation function
- Two point cross correlation function
- Two point angular correlation function
- Three point correlation function

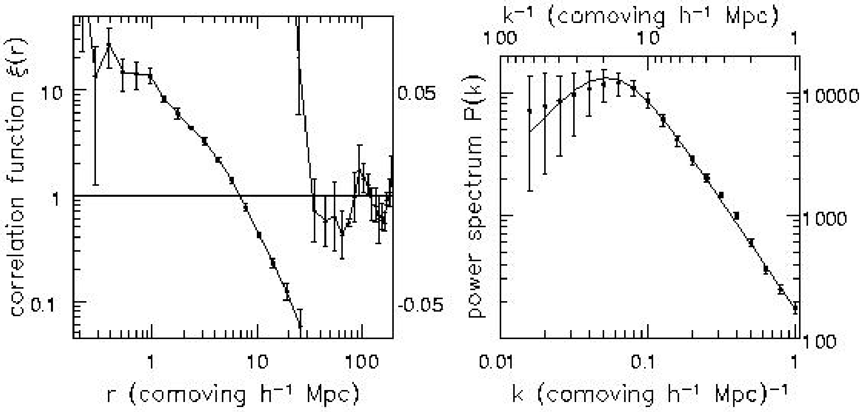
Methods of probing the LSS



Correlation function and power spectrum

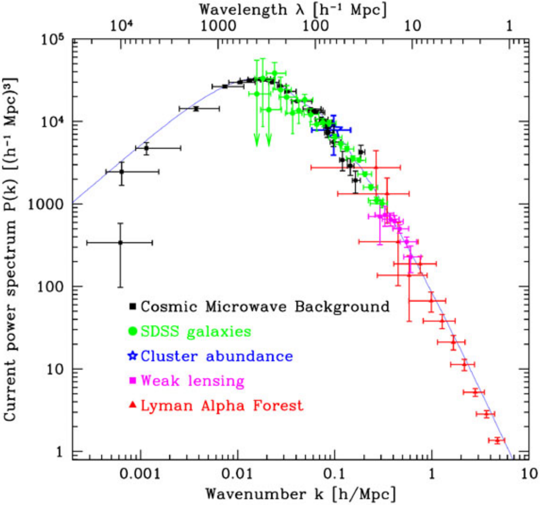
The overdensity field is: $\delta(\mathbf{x}) = \frac{n(\mathbf{x})}{\langle n \rangle} - 1$
Then the following Fourier pairs can be defined:
$\delta(\mathbf{x}) = \frac{1}{(2\pi)^3} \int d^3\mathbf{k} e^{i\mathbf{kx}} \delta(\mathbf{k})$
$\delta(\mathbf{k}) = \int d^3\mathbf{x} e^{-i\mathbf{kx}} \delta(\mathbf{x})$ where $k = 2\pi/\lambda$ is the wave number.
Power spectrum is defined as: $P(\mathbf{k}) = |\delta(\mathbf{k})|^2$
If 2 point correlation function is the expectation of the overdensity field then the power spectrum is its Fourier pair. The two are equivalent.

LCRS correlation function and power spectrum



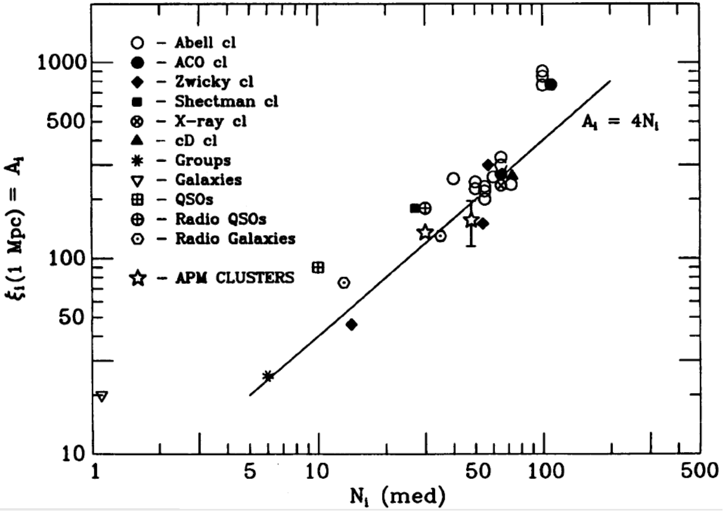
Correlation function is easier to measure, but we need power spectrum to compare with theory.

Power spectrum and CDM model



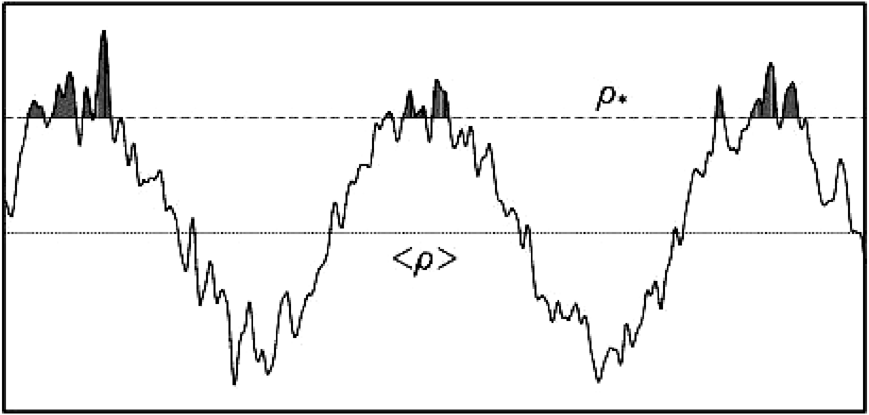
Tegmark et al. (2004)

Cluster correlation function



Clusters are more strongly correlated than individual galaxies and rich ones are more clustered than poor ones. Why?

Biasing



See Kaiser (1984) and Bardeen et al. (1996)

Biasing in galaxies

Bardeen et al. (1996) show that for a Gaussian distribution of initial mass density fluctuations, the peaks which first collapse to form galaxies will be more clustered than the underlying mass distribution.

Large Scale Structure of galaxies

- A range of structures: galaxies (10 kpc), groups (0.3 - 1 Mpc), clusters (few Mpc), superclusters (10 - 100 Mpc)
- Redshift surveys are used to map LSS $> 2 \times 10^6$ galaxies now
- LSS quantified through 2-point correlation function, well fit by a power-law: $\gamma \sim 1.8$, $r_0 \sim$ few Mpc. Equivalent description: power spectrum $P(k)$
- CDM model fits the data over a very broad range of scales
- Objects of different types have different clustering strengths and more massive structures cluster more strongly

Question

There is one major component of the baryonic large scale structure that we have ignored so far