Galaxies: Structure, formation and evolution
Lecture 7

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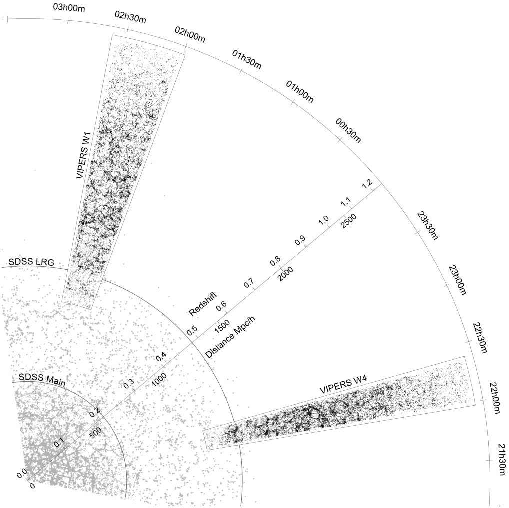
Ergodic principle crucial for galaxy evolution

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?

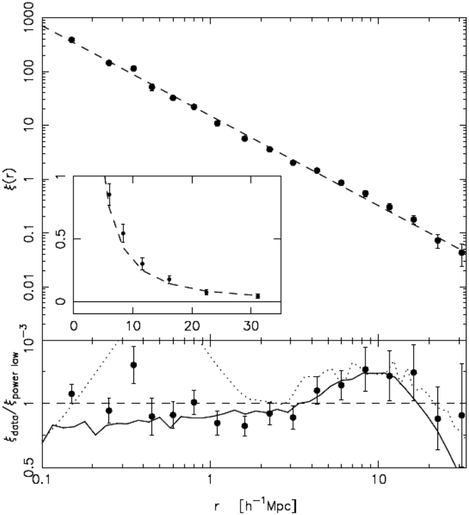
Question

Why have we essentially ignored radio and X-ray observations of galaxies in this course?

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, $\langle RR \rangle$:

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

How to estimate $\xi(r)$

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

A better estimator not affected by edge effects is:

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

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

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

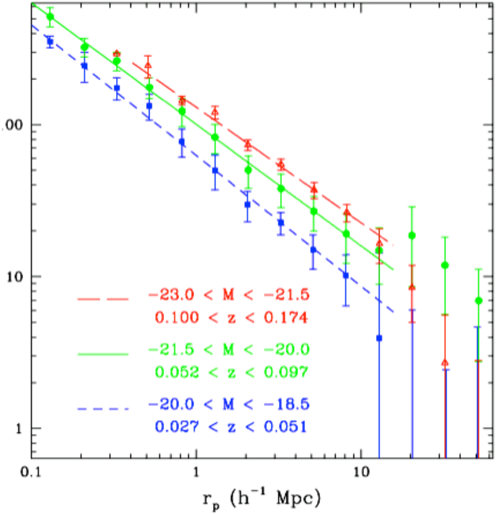
is via the overdensity in a particular cell relative to the average density

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

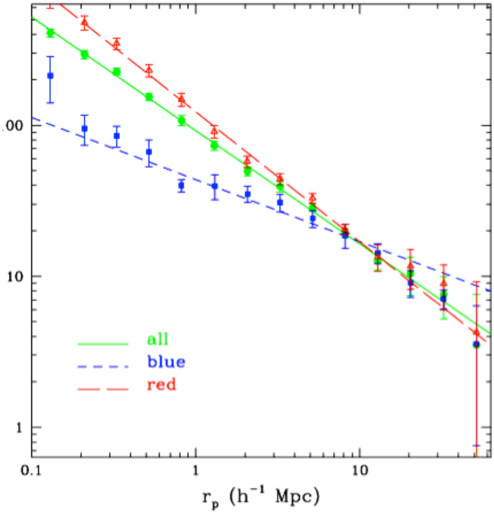
The $\xi(\mathbf{r})$ is the expectation value

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

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?

Three point (auto) correlation function

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

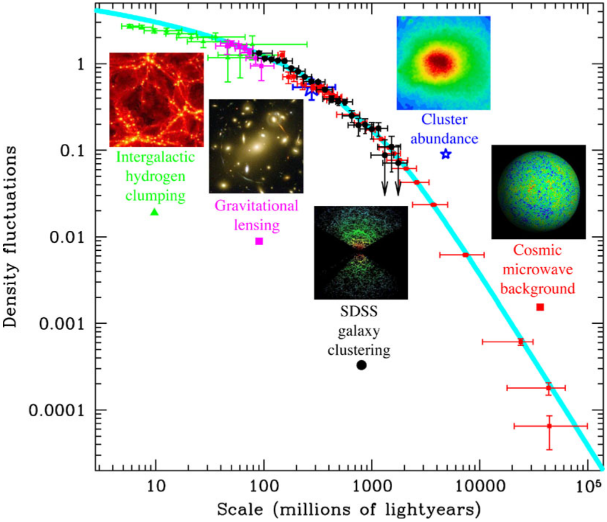
Angular correlation function

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

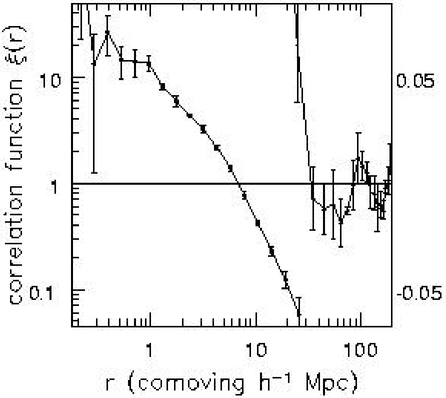
Methods of probing the LSS

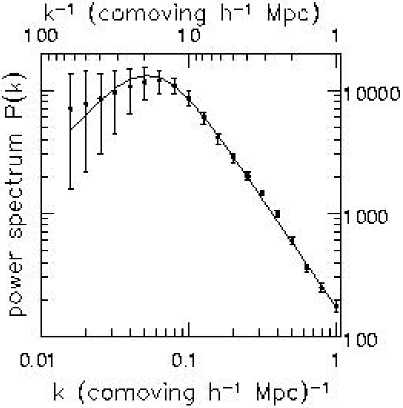


Correlation function and power spectrum

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.

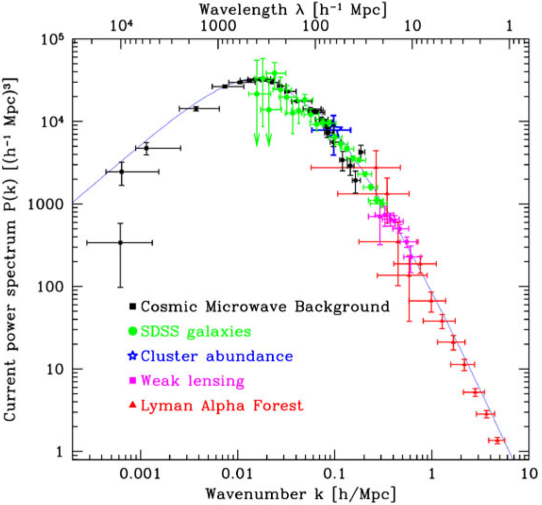
LCRS correlation function and power spectrum





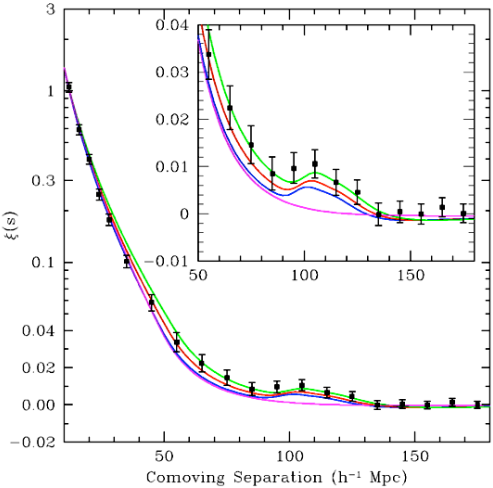
Correlation function is easier to measure, but we need power spectrum to compare with theory.

Power spectrum and CDM model



Tegmark et al. (2004)

Baryon Acoustic Oscillations



Eisenstein et al. (2005)

Power Spectrum does not capture the phase information