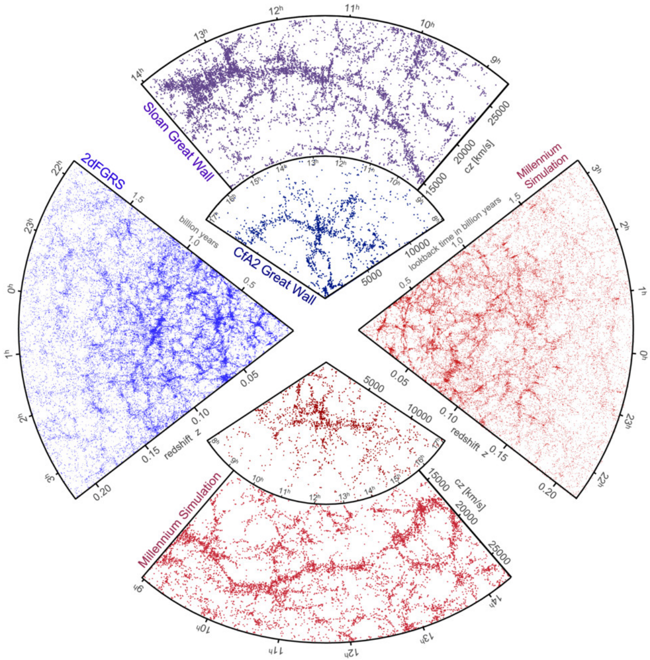
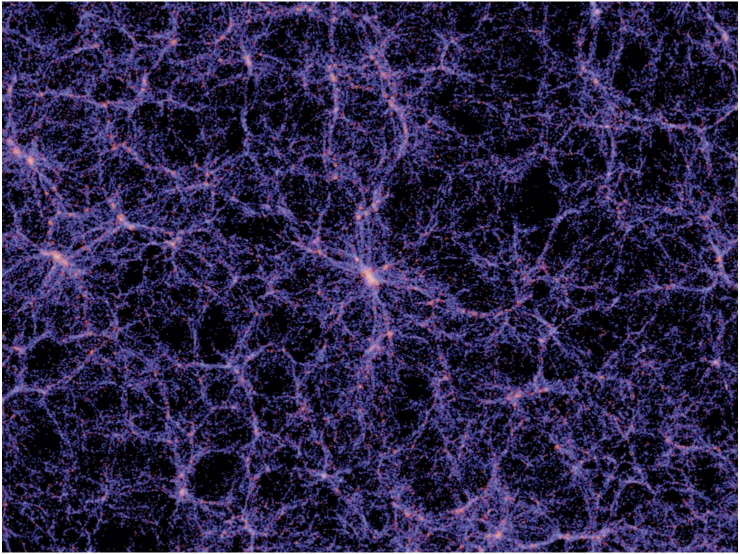
AST 354: Structure Formation in the Universe

Cameron McBride

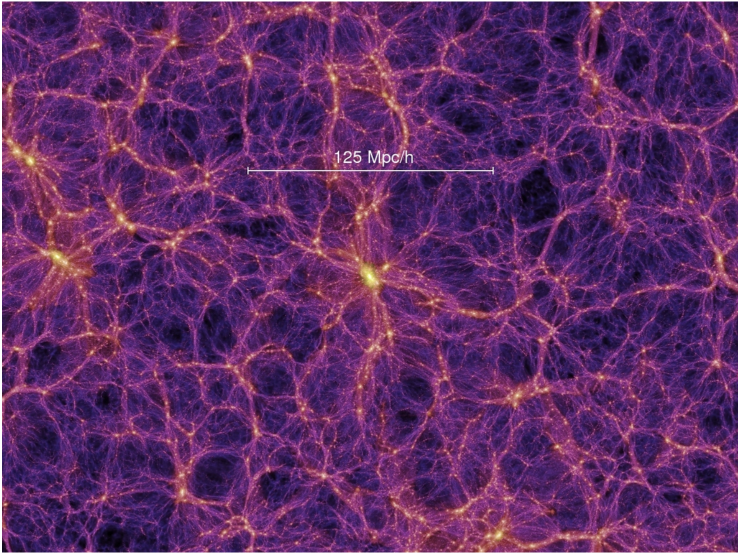
Department of Physics & Astronomy
Vanderbilt University

Describing Large Scale Structure

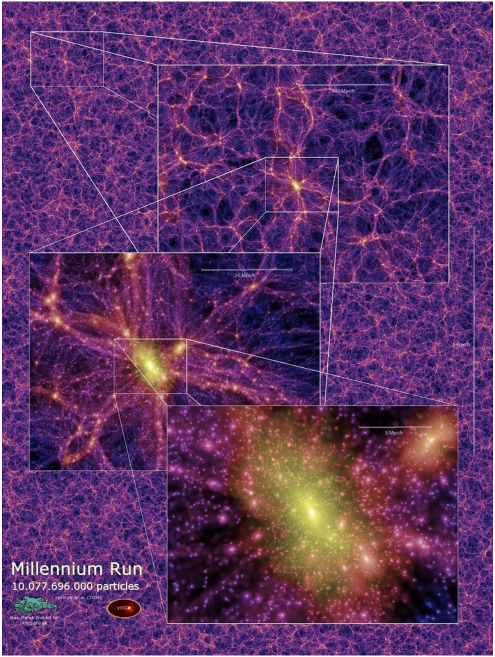

Sloan Great Wall
CfA2 Great Wall
2dFGRS
Millennium Simulation
Millennium Simulation
billion years
lookback time in billion years
redshift z
redshift z
cz [km/s]
cz [km/s]



Millennium Simulation: Springel et al. (2005)



Millennium Simulation: Springel et al. (2005)


100 Mpc/h
25 Mpc/h
5 Mpc/h
Millennium Run
10.077.696.000 particles
Springel et al. (2004)
Max-Planck Institut für Astrophysik
VIRGO

Correlation Function Introduction

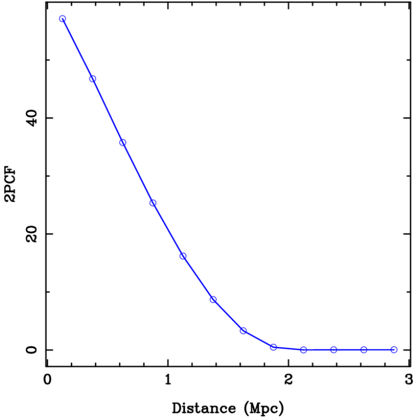
- Series of correlation functions is needed to completely describe arbitrary distribution.
  - $\hookrightarrow$ two-point correlation function (2PCF), three-point (3PCF), four-point, etc.
- 2PCF alone can fully describe a Gaussian universe.
- Correlation function formalism is Poisson model.
- Formalism developed in late 1970s and early 1980s.
- "easy" to calculate for distribution of points

The Purpose

A physically meaningful parameterization of large scale structure.

2PCF: A simple example
Cosmic Cotton Balls

- Isothermal spheres:
  - higher density center
  - truncated at 1 Mpc radius
- Distributed uniformly in volume
- *Note*: rapid reduction in correlation
- *Note*: $\xi(r)$ less than zero at 2 radii



Defining the 2pt correlation function

- Correlation of points with respect to Poisson:

$$\delta P = n^2 \delta V_1 \delta V_2 \left[1 + \xi(r_{12})\right]$$

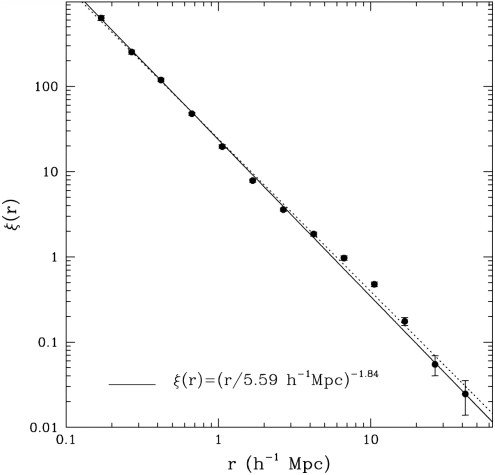
- $\xi(r)$: connected spatial two point correlation function
- Local density fluctuation about the mean:

$$\begin{aligned} \delta(\vec{x}) &= \frac{\rho(\vec{x}) - \langle\rho\rangle}{\langle\rho\rangle} \\ \xi(r_{12}) &= \langle\delta(\vec{x}_1)\delta(\vec{x}_2)\rangle \end{aligned}$$

- simple model:

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

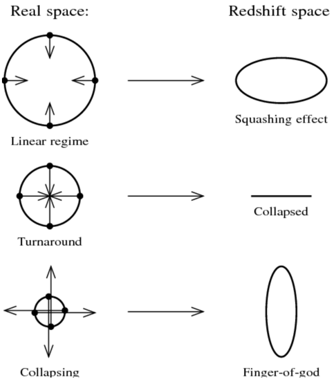
2PCF: Power Law Model Fit



Fit r_o and γ to SDSS galaxies: Zehavi et al. 2005

Redshift Space Distortions

$$cz \simeq H_o d + v_{\mathrm{los}}$$



Complicated effects based on the velocities and dynamics of region.

MOVIE: SDSS GALAXIES

Projected 2PCF: sidestepping distortions

- Decompose the separation vector between points into components:

$$r = \sqrt{r_p^2 + \pi^2}$$

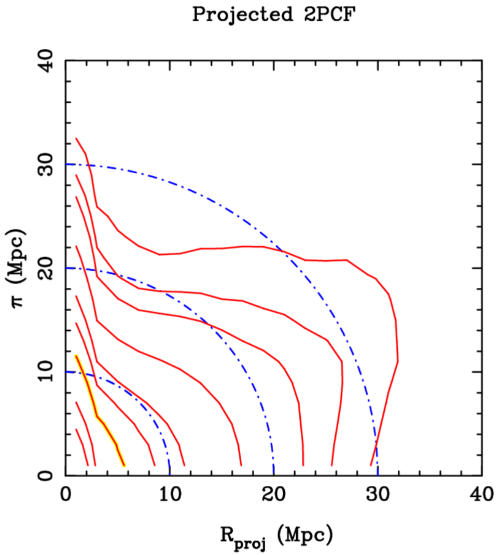
r_p	perpendicular to line of sight
π	path along line of sight

- π now contains the redshift distortion
- $\xi(r) \longrightarrow \xi(r_p, \pi)$

Projected 2PCF

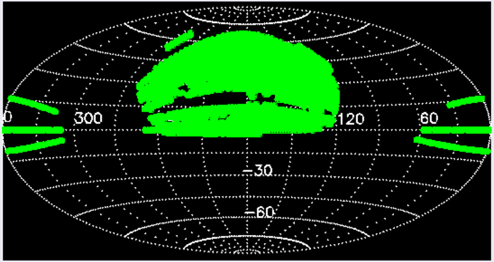
$$w_p(r_p) = 2\int_0^{\pi_{max}} \xi(r_p, \pi) d\pi$$

Projected 2PCF: r_p - π diagram



Sloan Digital Sky Survey

DR6 Spectroscopic

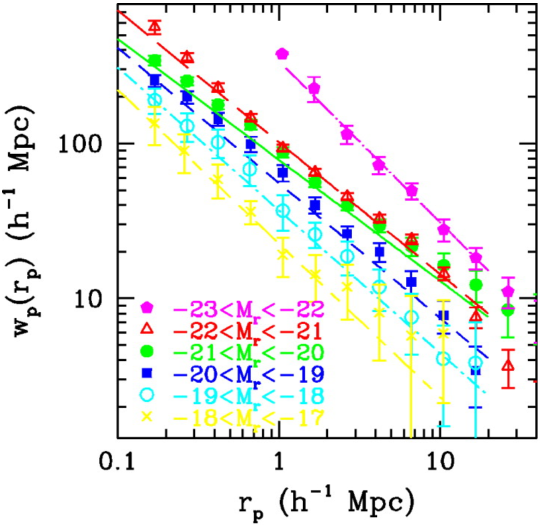


- 1,271,680 spectra
- 6800 sq. degrees
- 790,220 galaxies

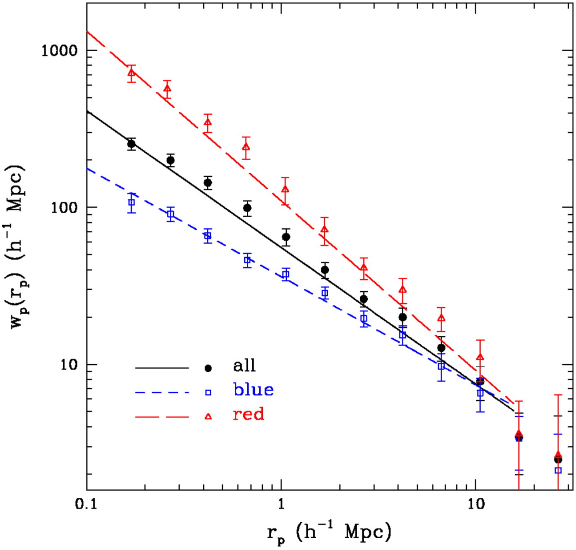
Galaxy Redshift Surveys:

- finite depth
- complicated footprint
- different samples:
  1. Flux-limited
  2. Volume-limited

$$m - M = 5\log(D_{\max}) + 25$$



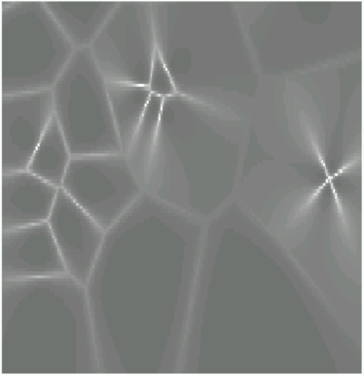
Zehavi et al. 2005, Fig 8, Panel 1

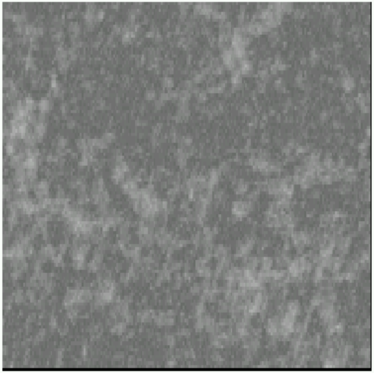


Zehavi et al. 2005, Fig 13

Higher order functions are important!
Three Point Correlation Function

- phase information randomized for image on right
- same 2PCF but very different distributions





Definition of 3PCF
Three Point Correlation Function

The probability for 3 points joined by three separations r_a, r_b and r_c

$$\delta P = n^3 \delta V_1 \delta V_2 \delta V_3 \left[1 + \xi_a + \xi_b + \xi_c + \zeta_{abc}\right]$$

Connected Three Point: $\zeta(r_a, r_b, r_c) = \zeta_{abc}$

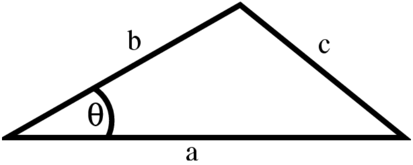
Q: Normalized 3PCF

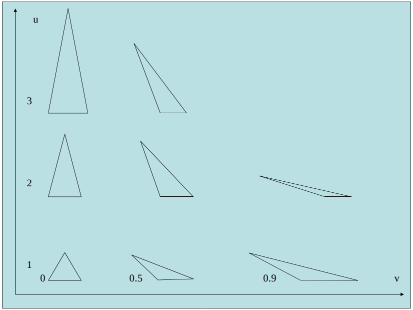
$$Q(r_a, r_b, r_c) = \frac{\zeta_{abc}}{\xi_a \xi_b + \xi_b \xi_c + \xi_c \xi_a}$$

$$Q(r_a, r_b, \theta) \qquad \text{where} \qquad \cos\theta = \frac{r_a^2 + r_b^2 - r_c^2}{2 r_a r_b}$$

- Q initially believed to be roughly constant
- measurements find Q not quite constant for any scales
- Useful normalization: varies much less than ζ or ξ
- Insensitive to many cosmological parameters (leading order)

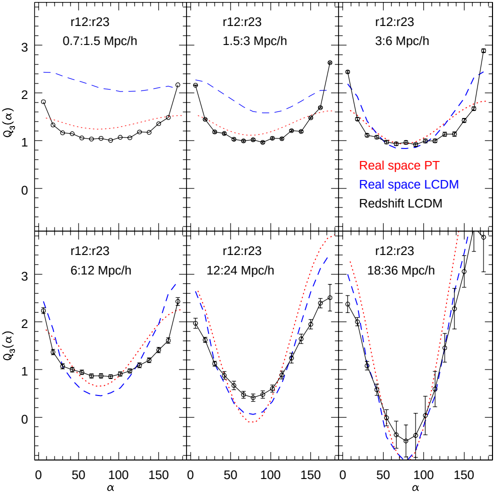
Triangle Configurations
Three Point Correlation Function



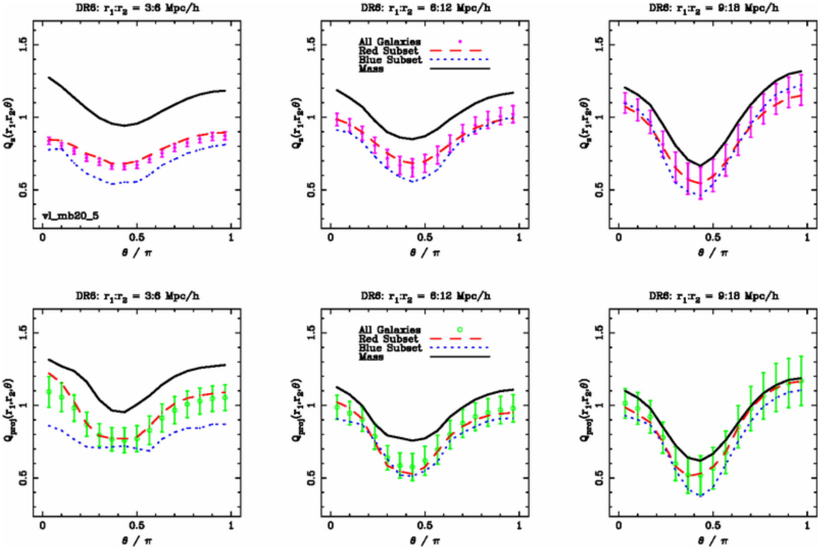


- Both *scale* and *configuration* dependence
- Characterize dependence on configurations as:
  - ↪ "weak dependence" when very little change (hierarchical)
  - ↪ "strong dependence" significant difference.

Gaztañaga and Scoccimarro 2005

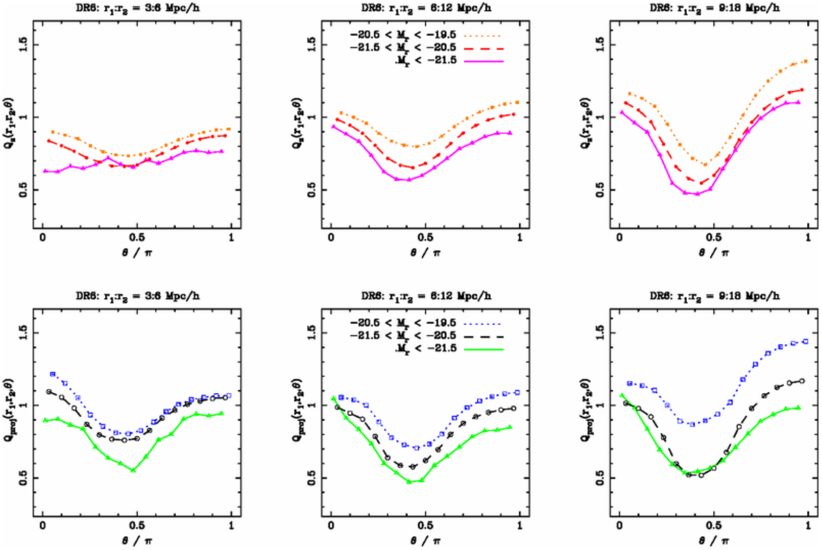


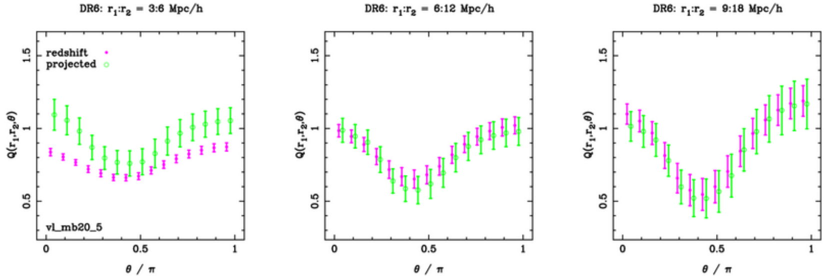
3pt Measurements on the Main Galaxy Sample
$-21.5 < M_r < -20.5$



Luminosity dependence?

3pt Measurements on the Main Galaxy Sample





DR6: r1:r2 = 3:6 Mpc/h
redshift
projected
vl_mb20_5
Q(r1,r2,θ)
θ / π
DR6: r1:r2 = 6:12 Mpc/h
Q(r1,r2,θ)
θ / π
DR6: r1:r2 = 9:18 Mpc/h
Q(r1,r2,θ)
θ / π