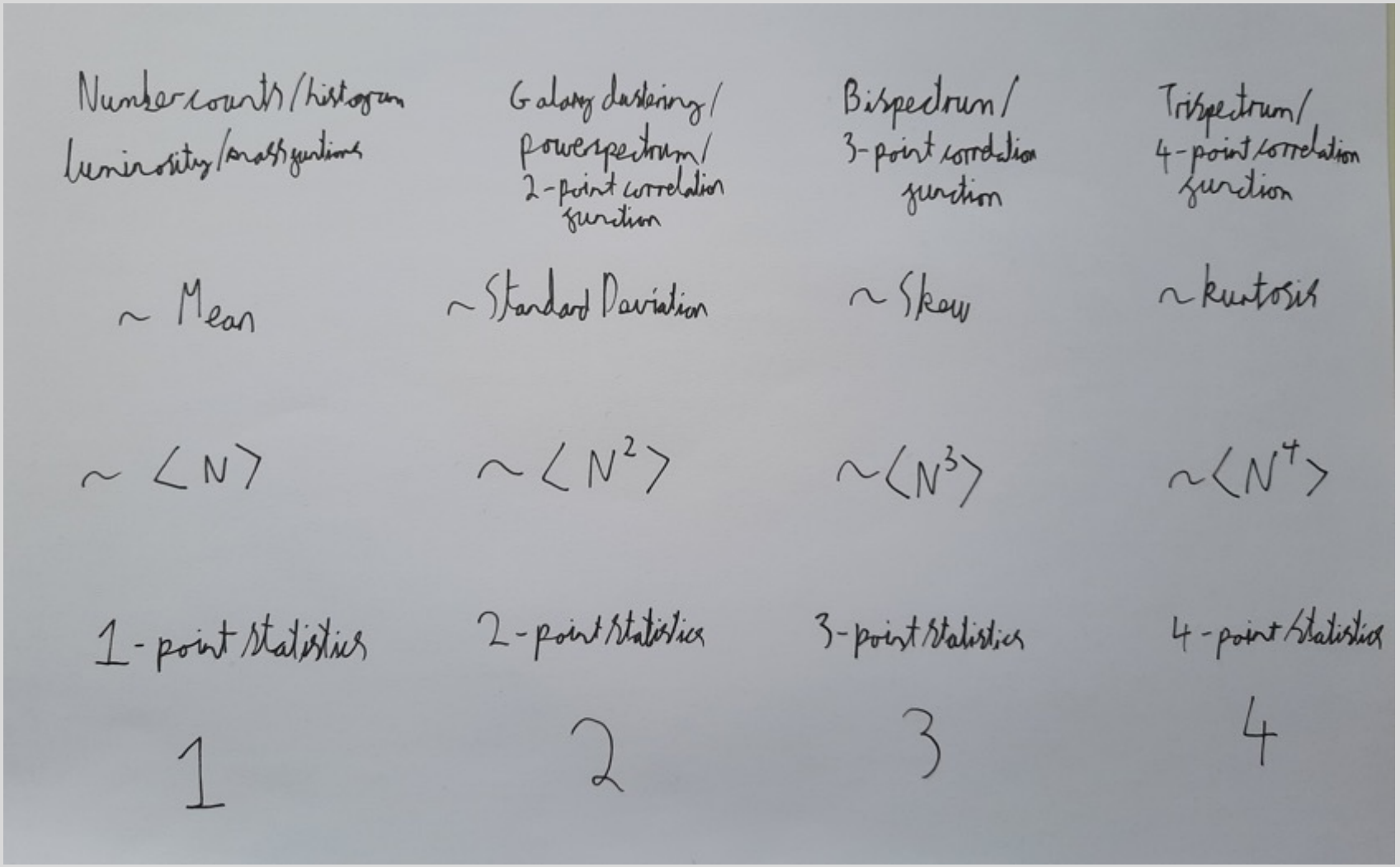
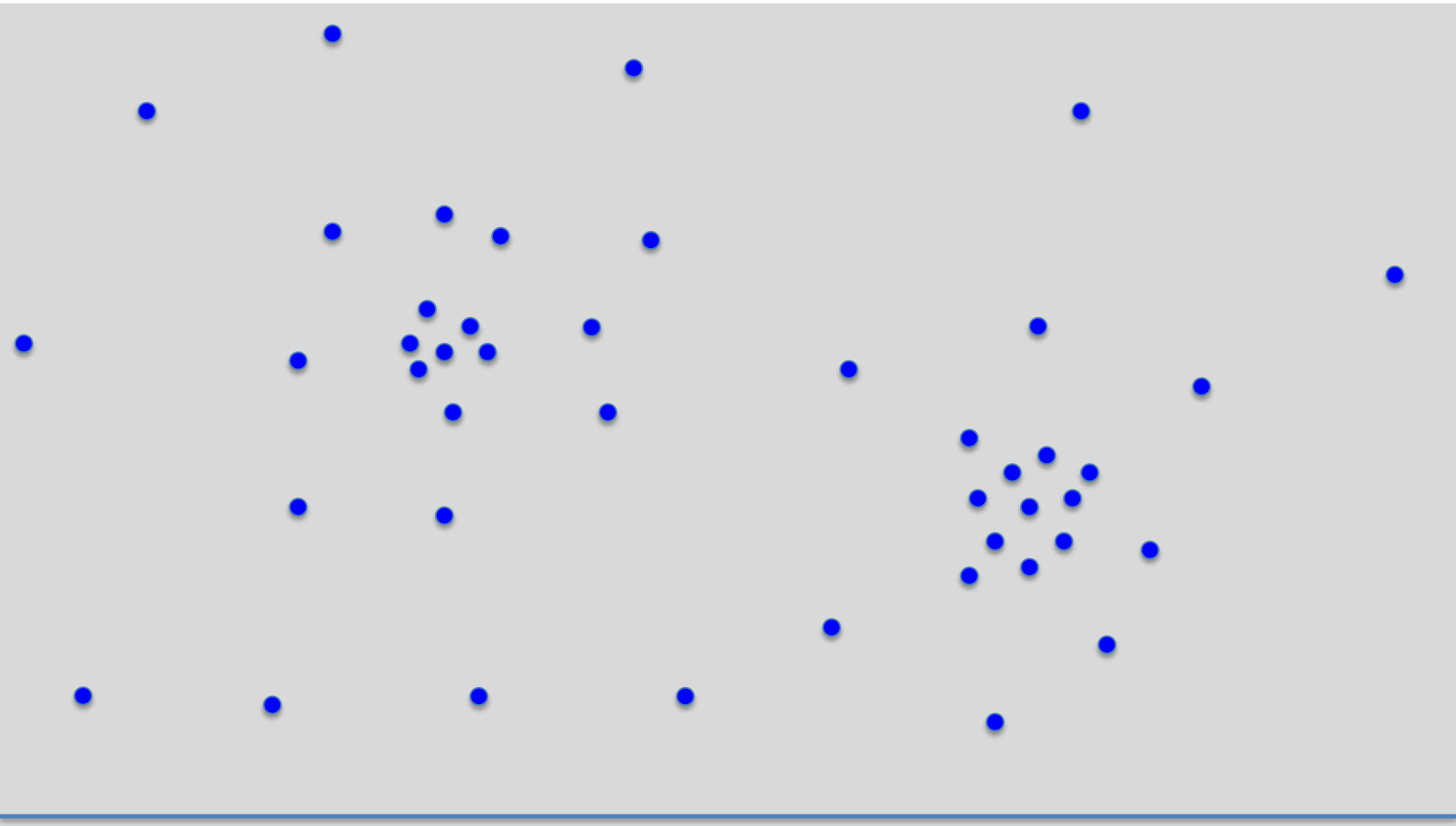
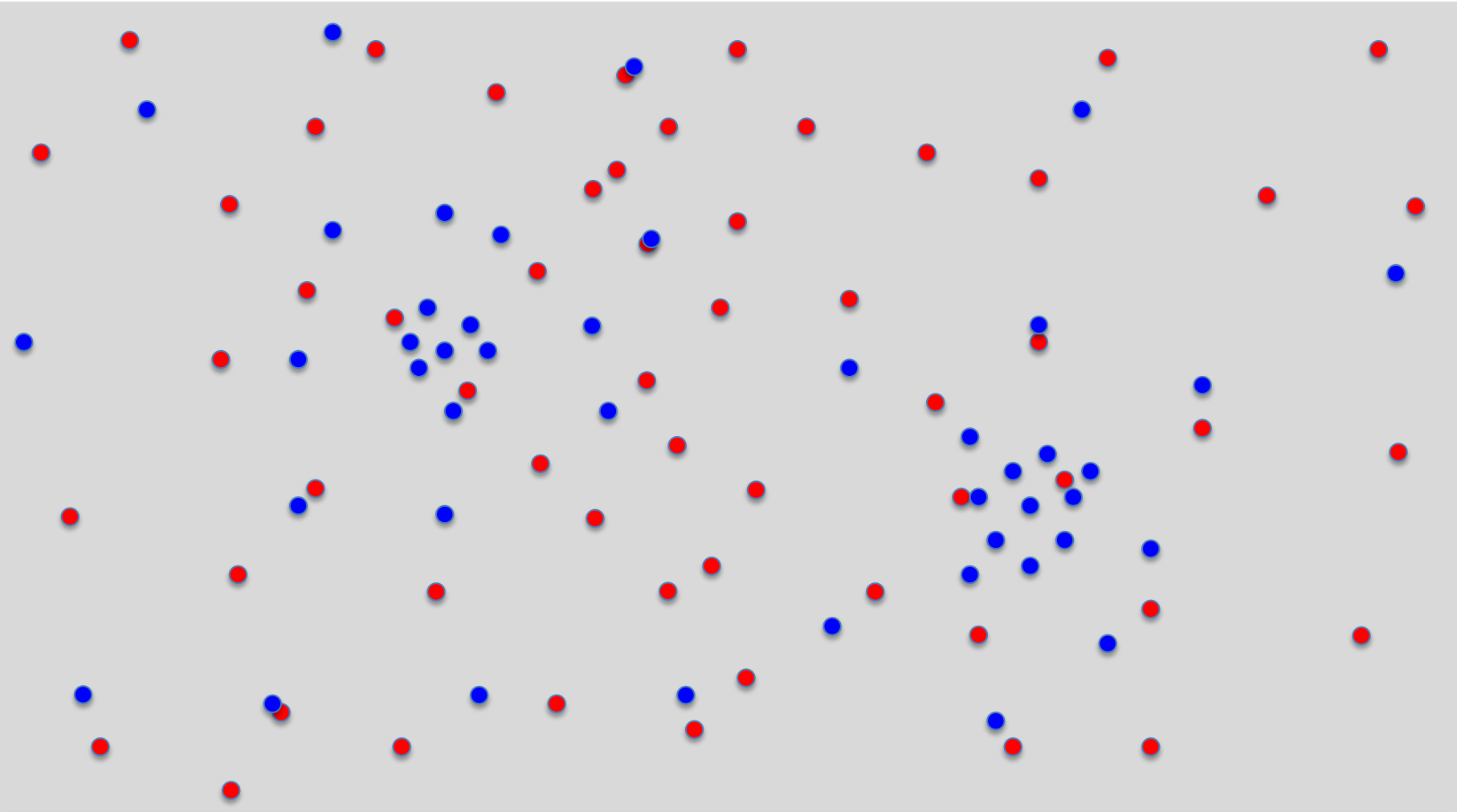
Galaxy Clustering

PH 7th June 2021

N-Point Statistics



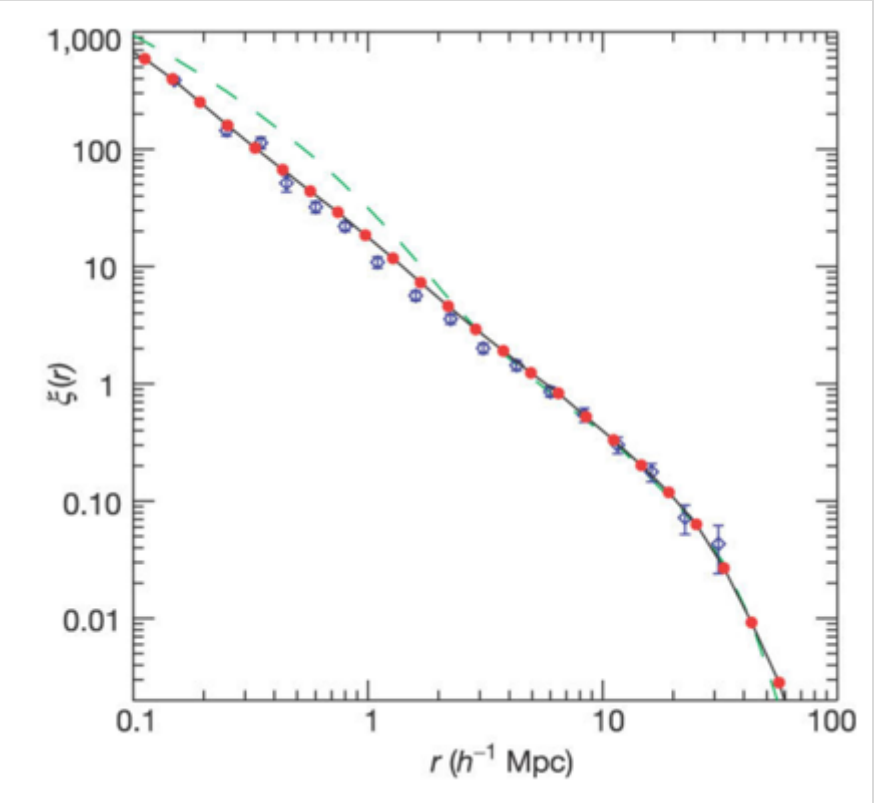


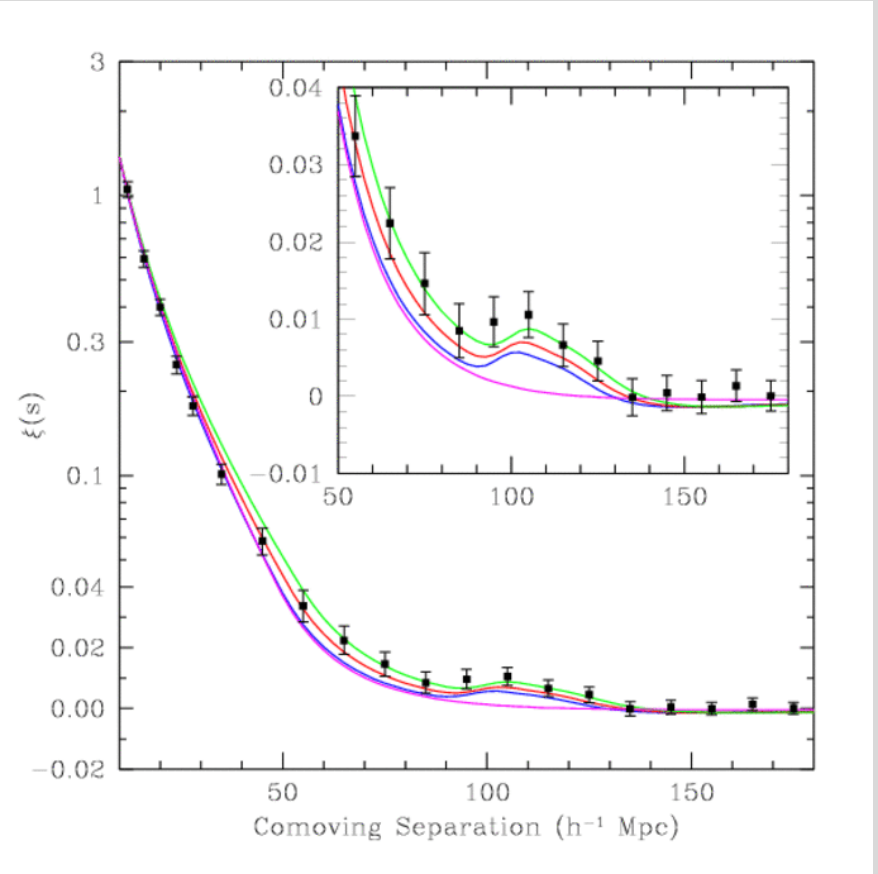


$$\omega(\theta) = \frac{DD}{RR} - 1$$

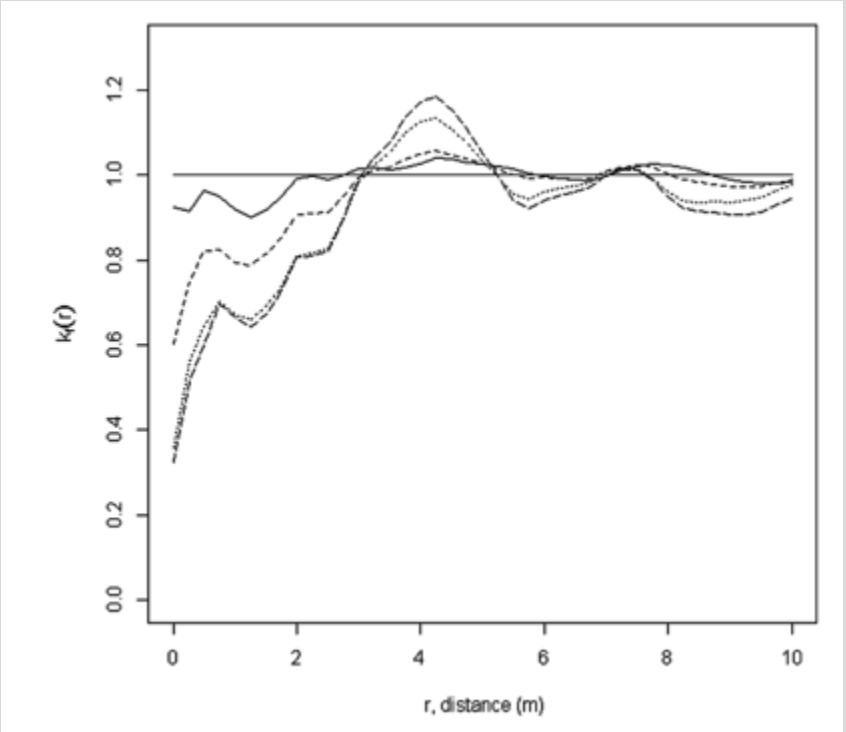
$$\omega(\theta) = \frac{DD - 2DR + RR}{RR},$$

Example Measurements

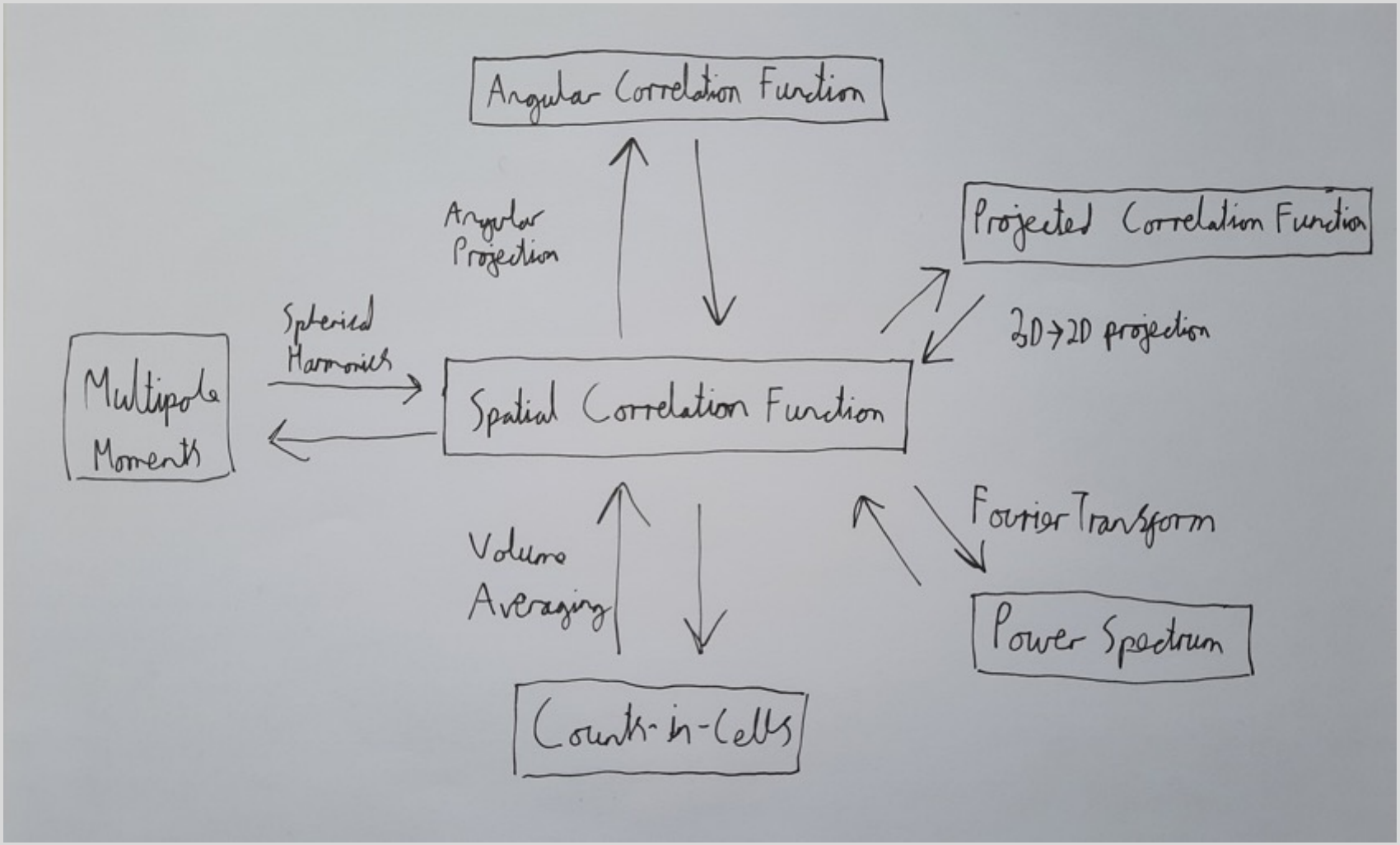




Example Measurements



Different Representations



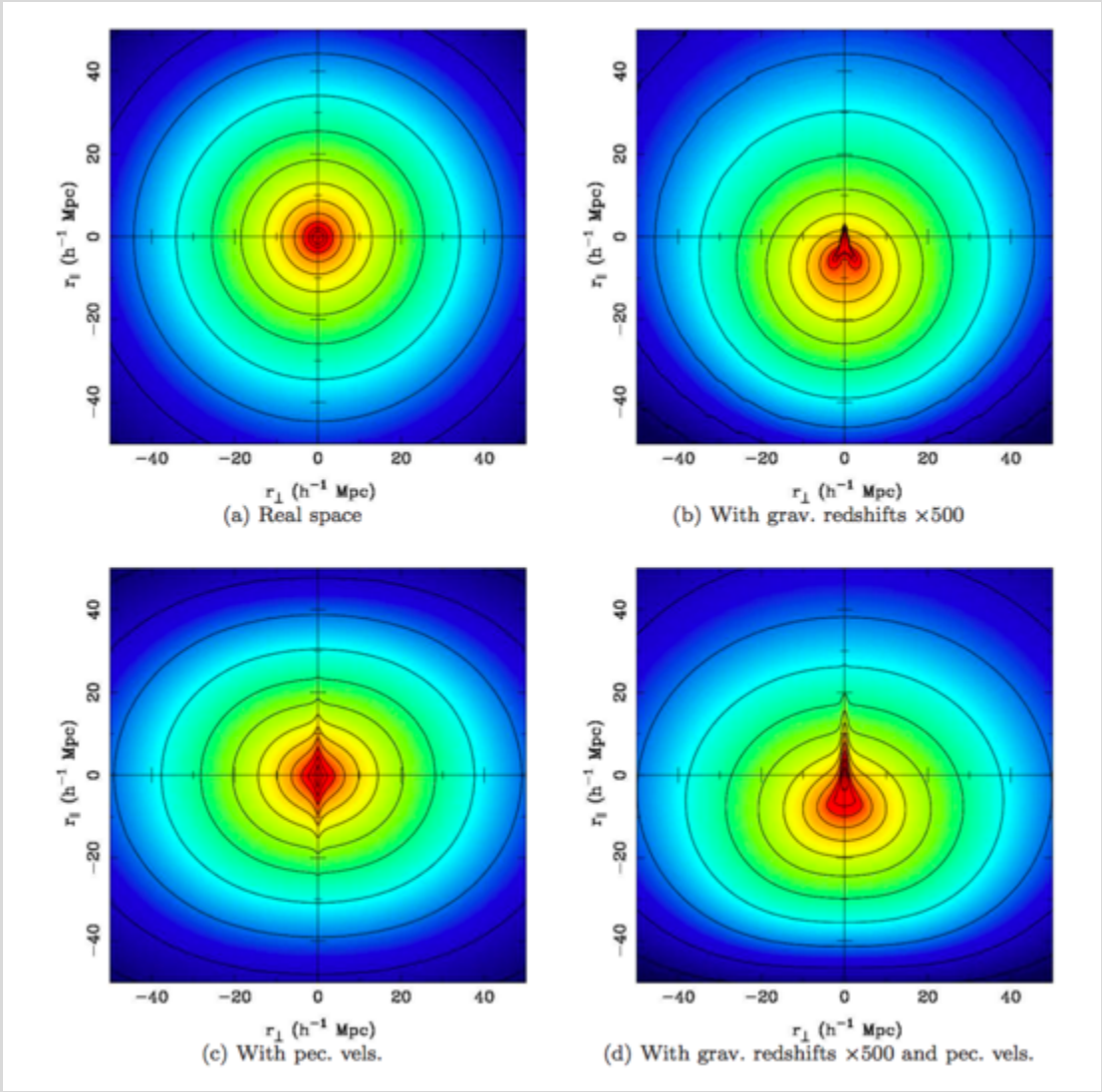
Classes

- **Auto**-Correlation Function: Clustering of a single sample
- **Cross**-Correlation Function: Clustering between two samples

- Galaxy Clustering: Gives galaxy auto-correlation
- Galaxy-Galaxy Lensing: Gives galaxy-DM cross-correlation
- Weak Lensing: Gives total matter auto-correlation

Also used for HI reionisation signal, CMB and more…

3D Effects



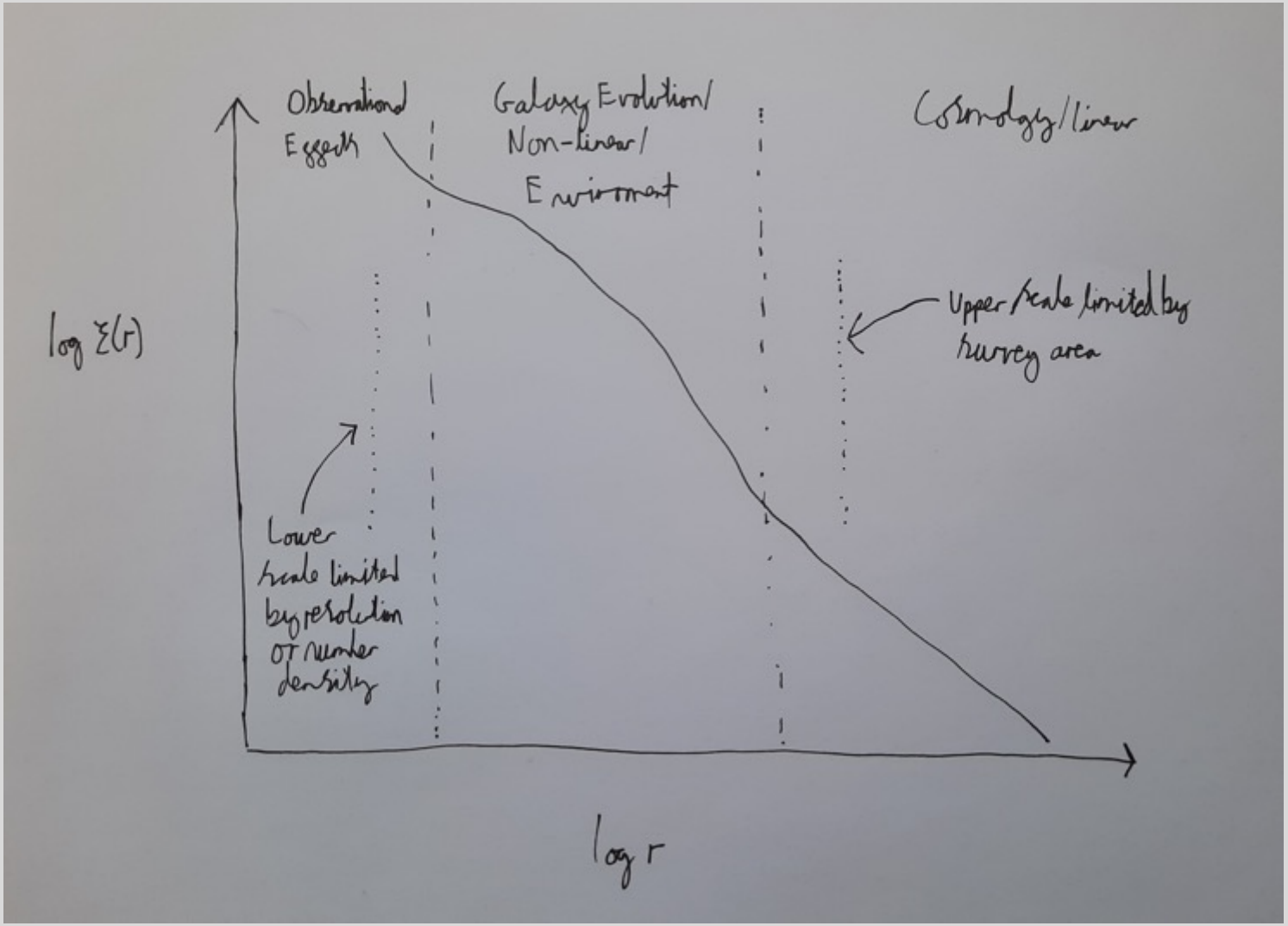
(a) Real space

(b) With grav. redshifts ×500

(c) With pec. vels.

(d) With grav. redshifts ×500 and pec. vels.

Scales


Observational Effects
Galaxy Evolution/ Non-linear/ Environment
Cosmology/linear
log Σ(r)
Upper scale limited by survey area
Lower scale limited by resolution or number density
log r

Observational Effects

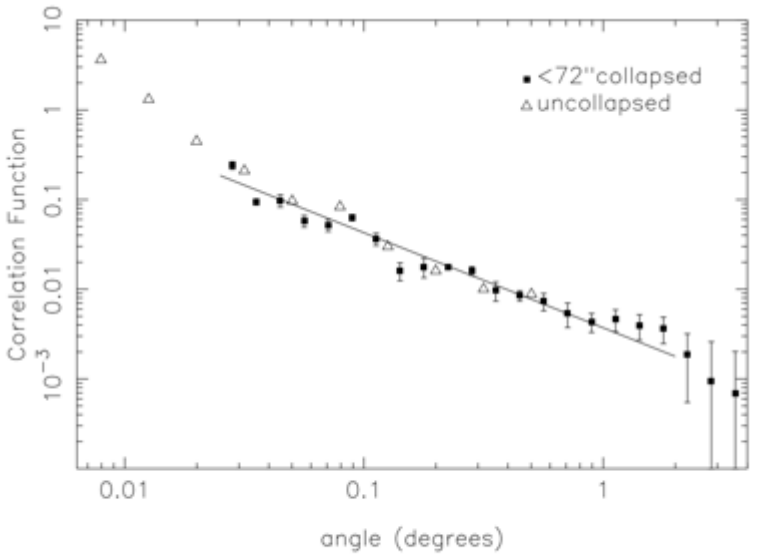
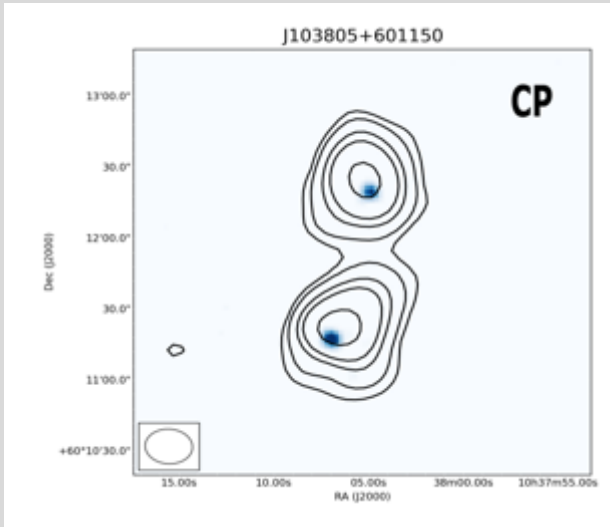
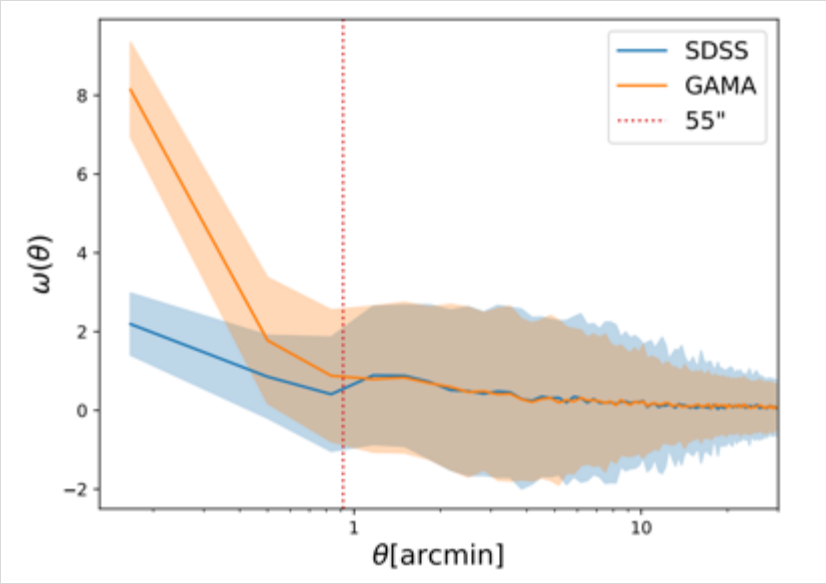
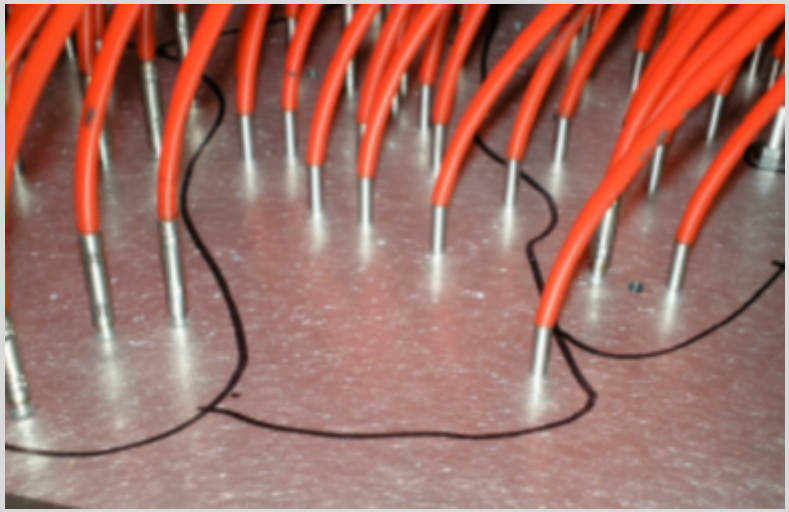


FIG. 1.—The filled squares show the autocorrelation function $[w(\theta) = 2DD/DR - 1]$ calculated for the whole sample (109,873 sources, where sources separated by less than 0".02 have been collapsed to a single source). The open triangles show the correlation function obtained when sources are not collapsed. Error bars are obtained using the bootstrapping technique described in § 3.

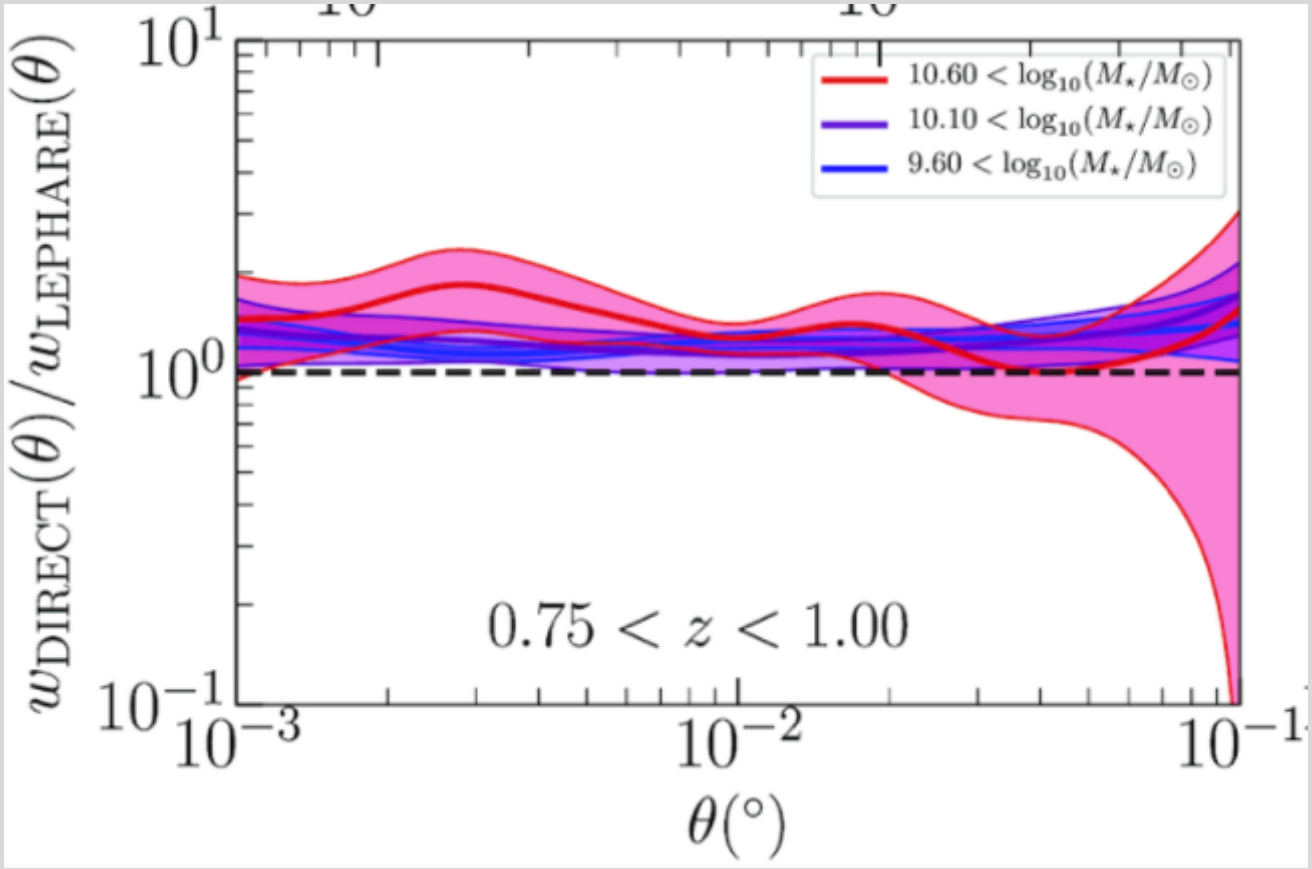


Observational Effects

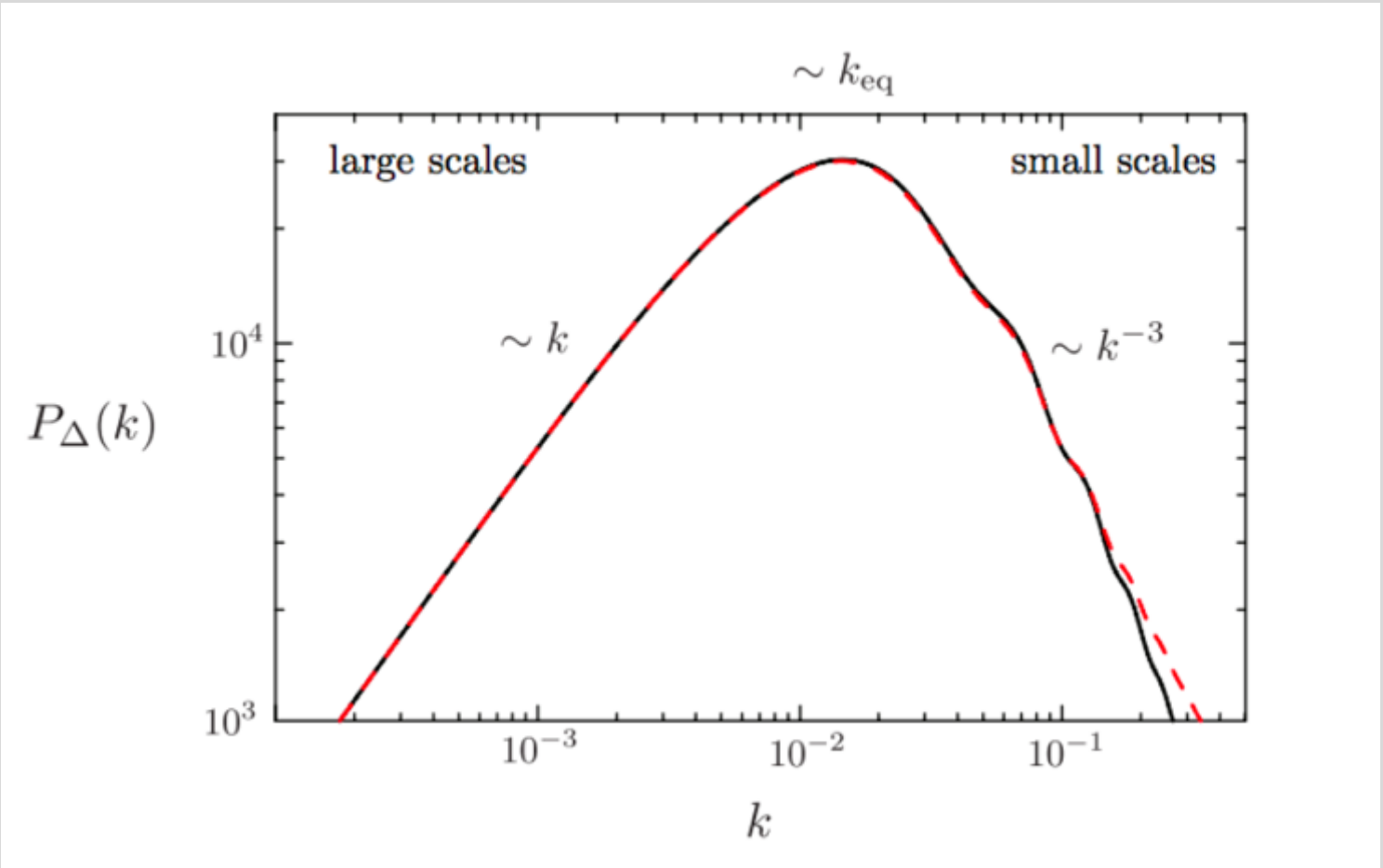




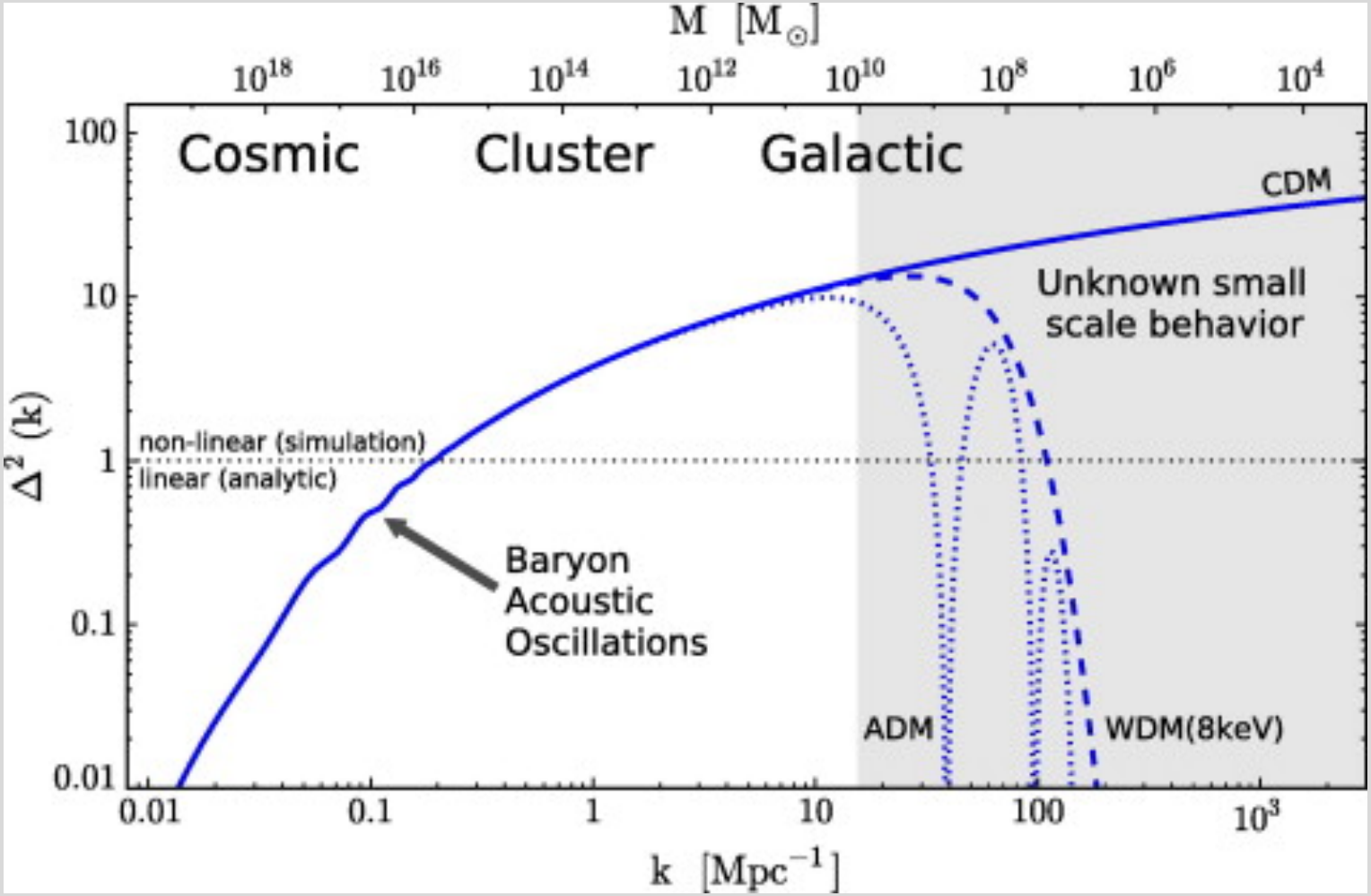
Observational Effects



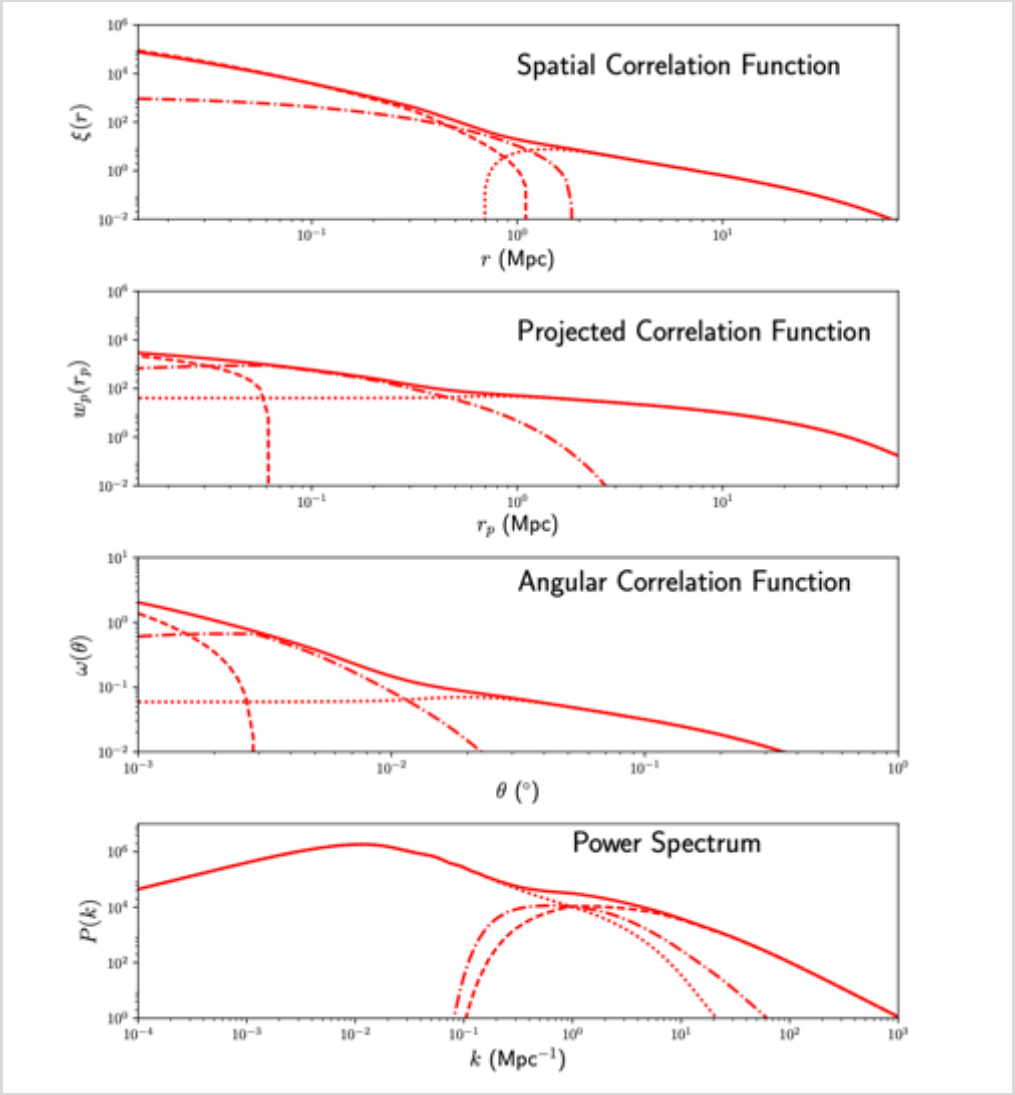
Cosmology


$\sim k_{\mathrm{eq}}$
large scales
small scales
$\sim k$
$\sim k^{-3}$
10^4
10^3
$P_\Delta(k)$
10^{-3}
10^{-2}
10^{-1}
k

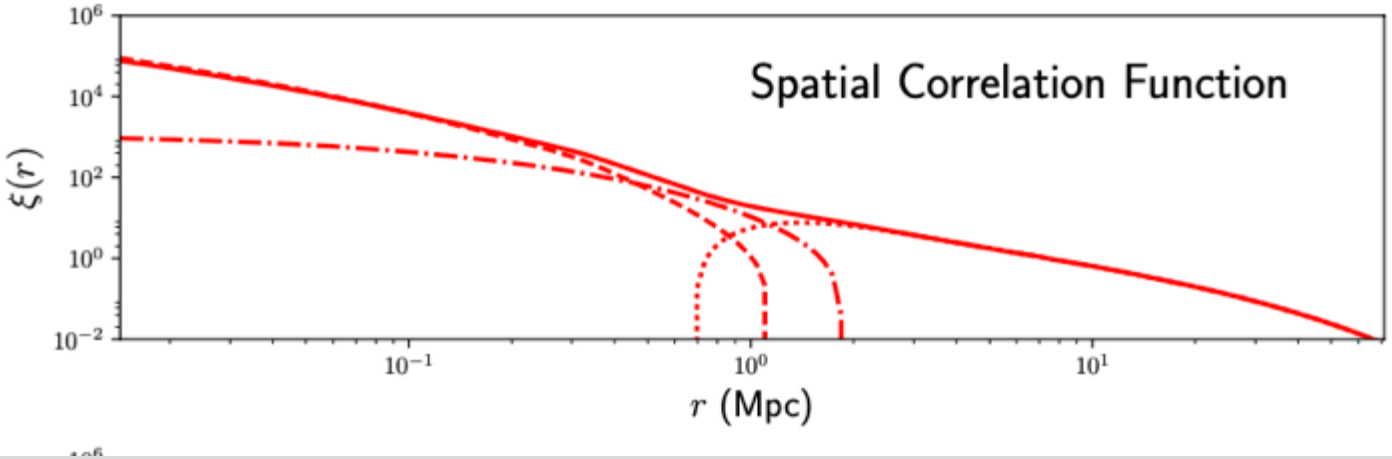
Cosmology


M [M⊙]
10^18
10^16
10^14
10^12
10^10
10^8
10^6
10^4
Cosmic
Cluster
Galactic
CDM
Unknown small scale behavior
non-linear (simulation)
linear (analytic)
Baryon Acoustic Oscillations
ADM
WDM(8keV)
Δ² (k)
100
10
1
0.1
0.01
0.01
0.1
1
10
100
10^3
k [Mpc^-1]

Galaxy Environment



Galaxy Environment

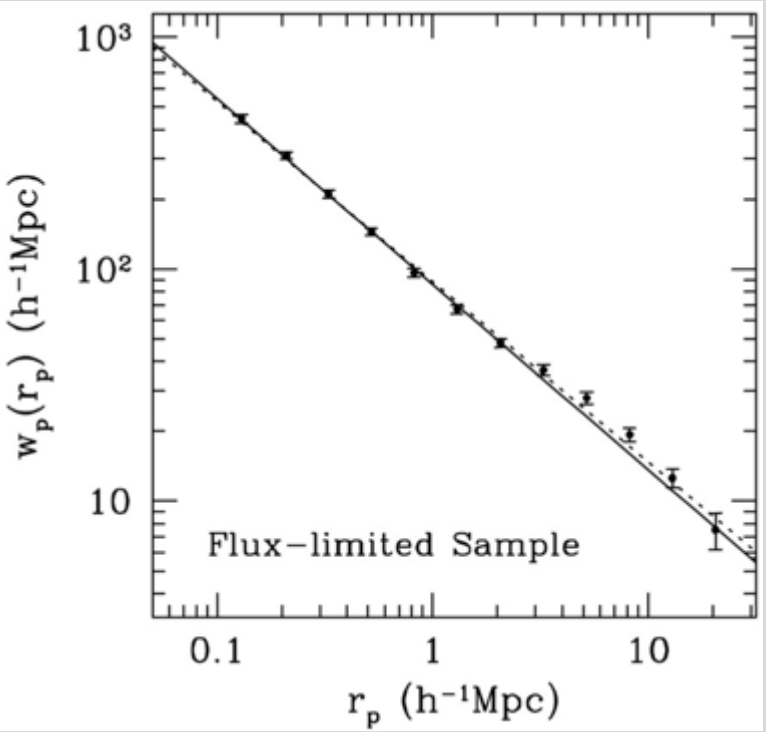


Galaxy Environment

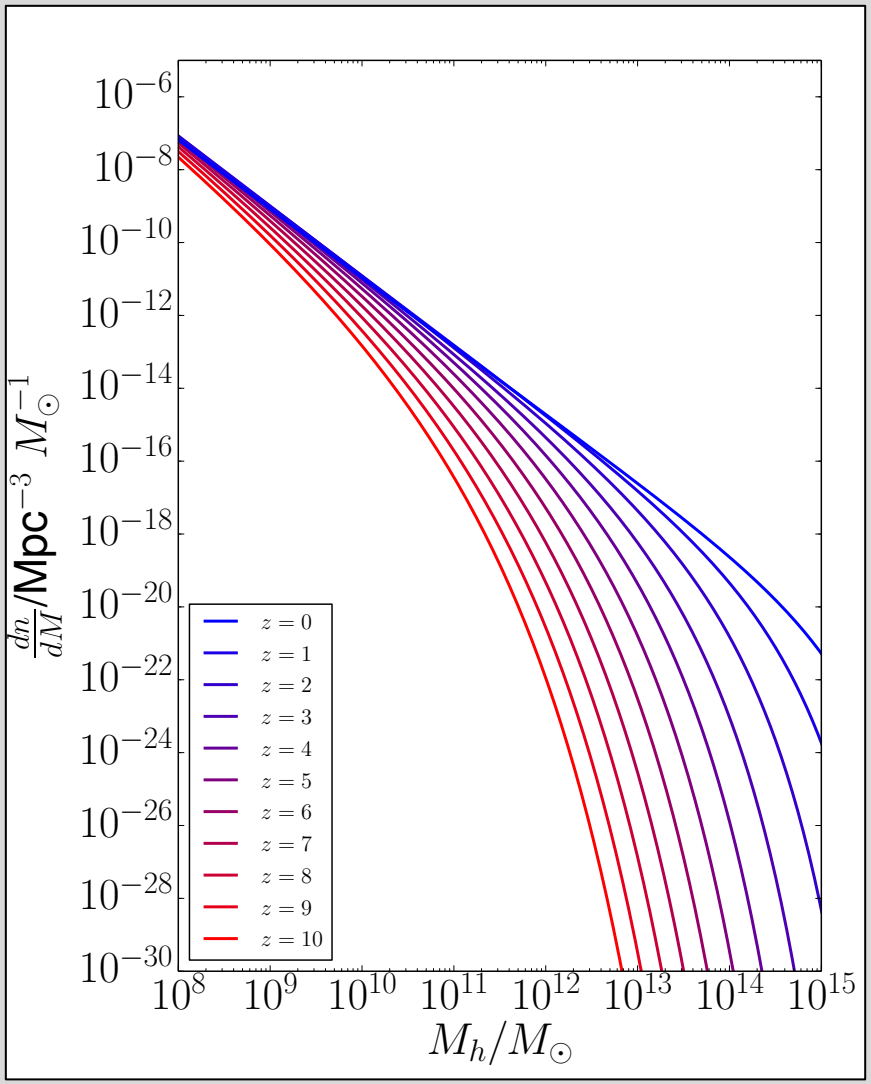
Power Law Modelling:

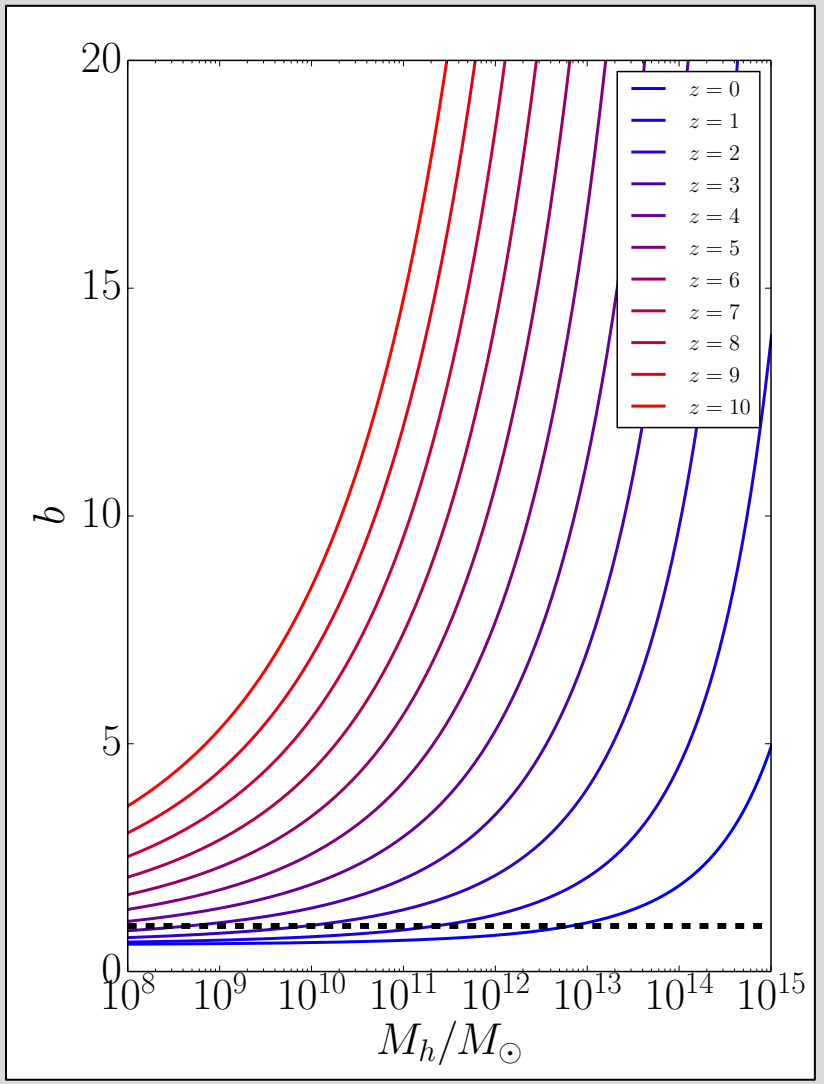
- Fit a power law to angular correlation function (index ~-0.8)
- De-project to get spatial correlation function amplitude
- Compare to theoretical DM clustering amplitude
- Get a bias, and average halo mass

$$\left(\frac{\delta n}{n}\right) = b\left(\frac{\delta \rho}{\rho}\right)$$



Halo Properties Over Cosmic Time





(Plots created using *Halomod*, Steven Murray+)

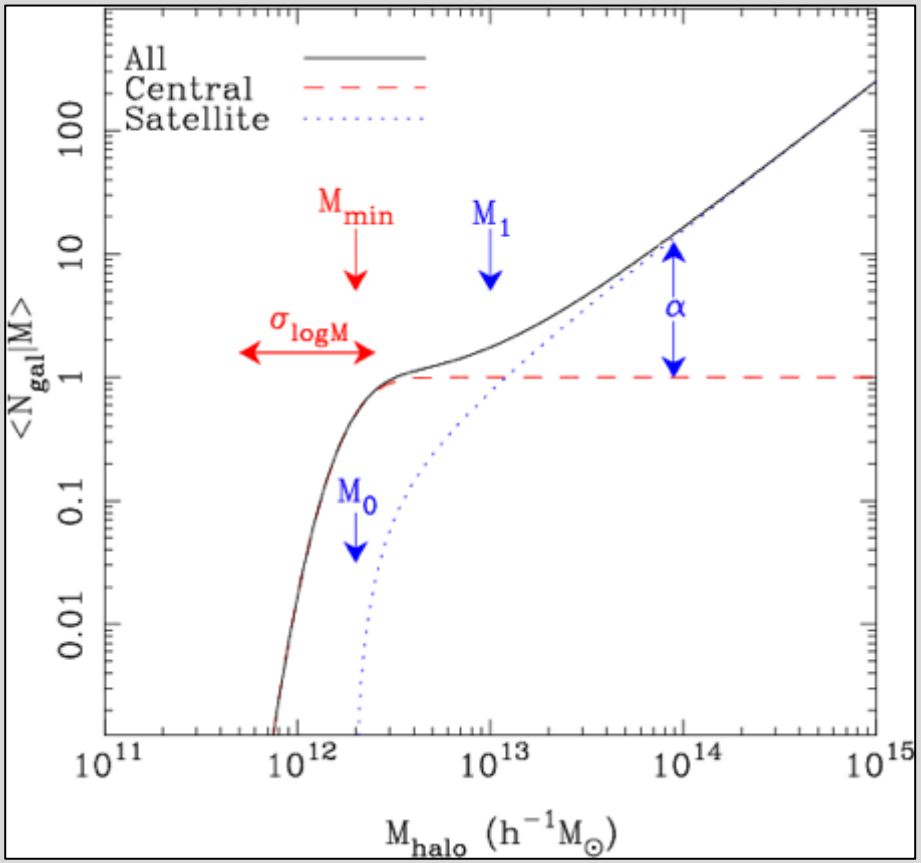
Halo Occupation Modelling

-> Measure correlation function (and other variables)
-> Generate model correlation functions from galaxy-halo relation model
-> Fit parameters

HOD Ingredients:

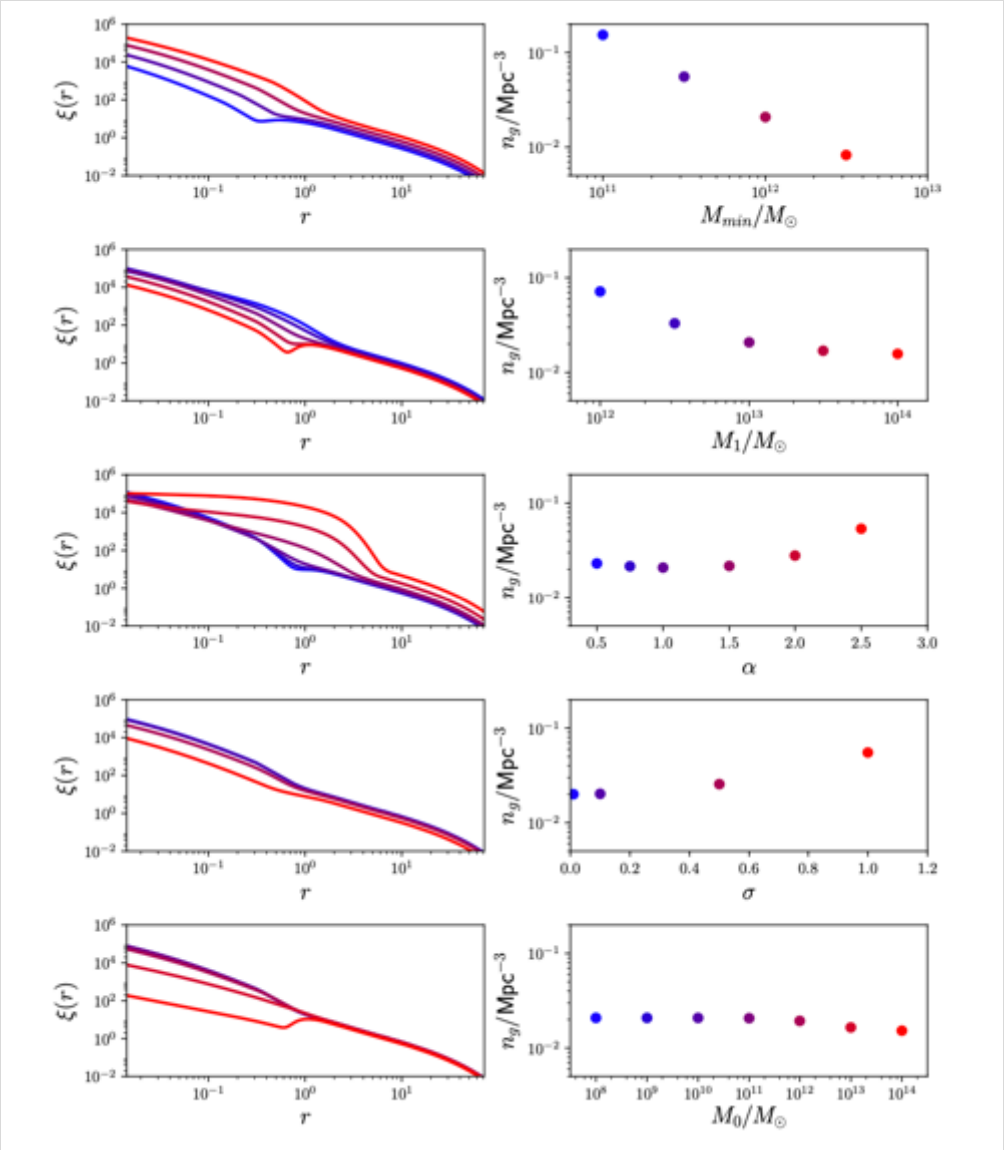
- (Cosmology)
- Halo mass function
- Halo bias prescription
- Dark matter power spectrum
- Halo profiles
- Occupation number
- Poisson assumption
- Central/satellite distinction
- 1-halo and 2-halo terms

$$\chi^2 = \frac{[n_{\rm gal}^{\rm obs} - n_{\rm gal}^{\rm model}]^2}{\sigma_n^2} + \sum_i \frac{[\omega^{\rm obs}(\theta_i) - \omega^{\rm model}(\theta_i)]^2}{\sigma_{w_i}^2},$$

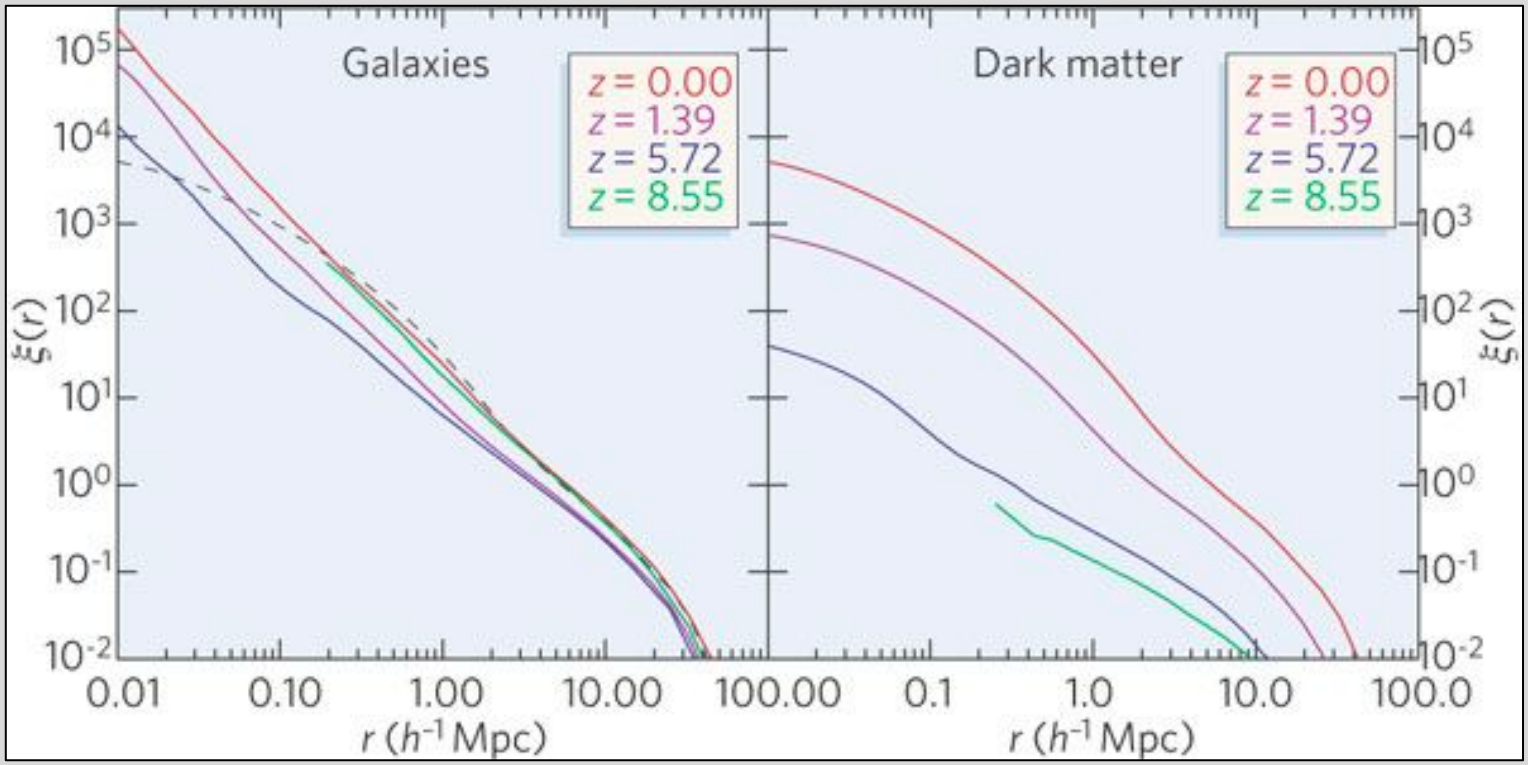


Wake et al., 2011

Galaxy Environment



Both the DM and the Galaxies are Evolving



Springel et al., 2006 (Millennium simulation)

Galaxy Environment

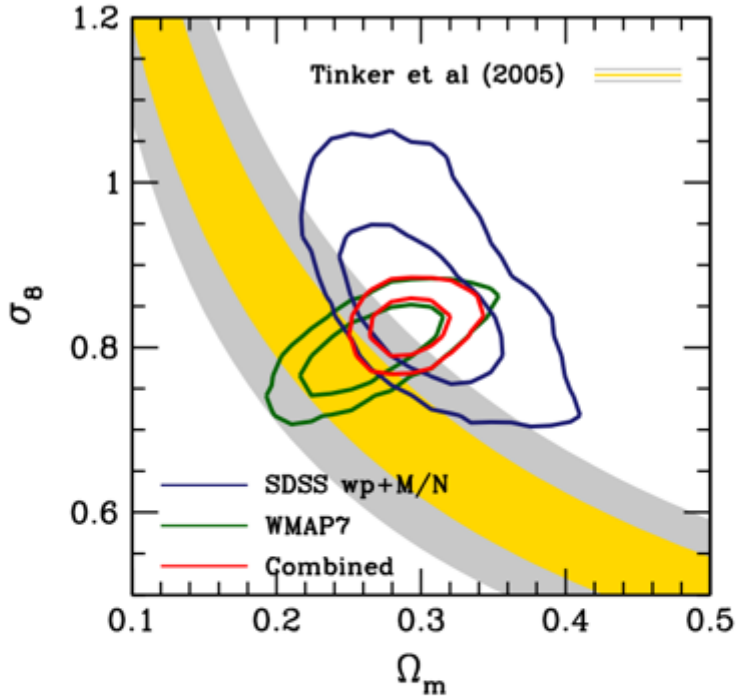
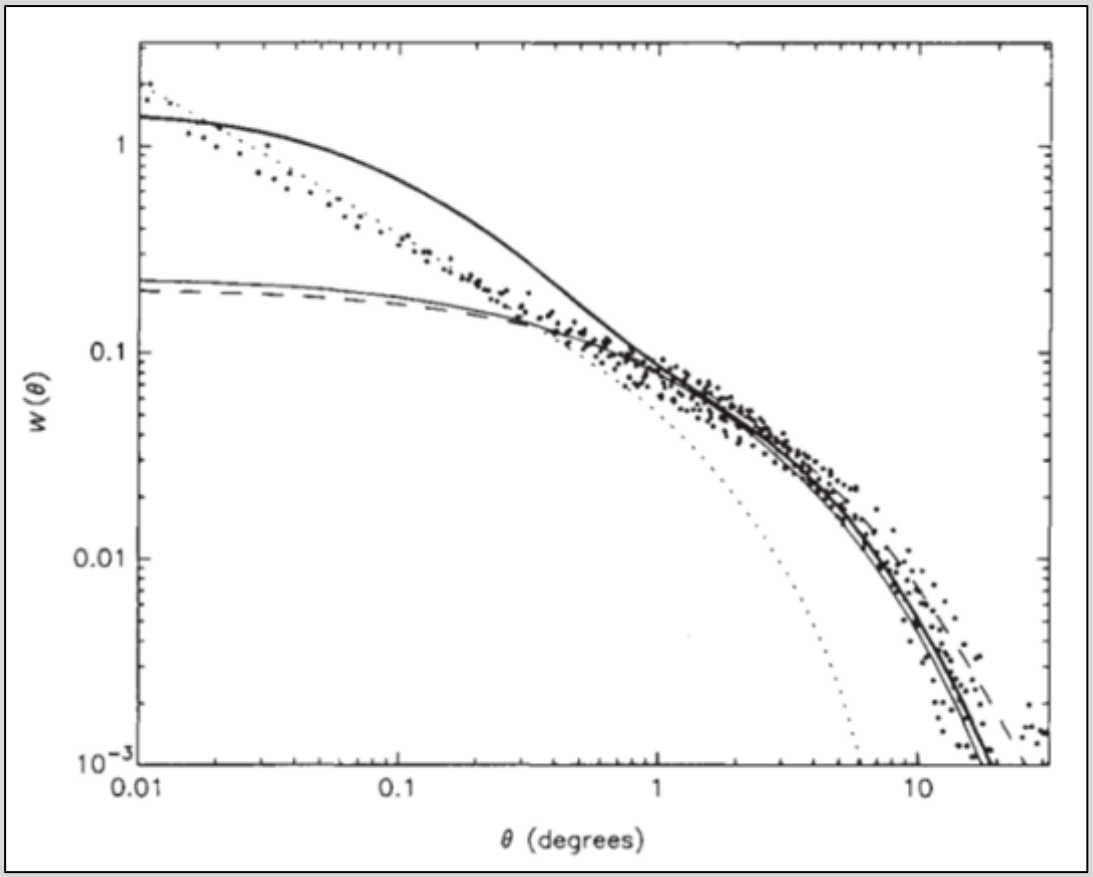


Figure 8. Constraints in the Ω_m–σ_8 plane, marginalizing over all other parameters and applying the priors listed in Table 3. The blue contours show 68% and 95% constraints from the M/N results. The yellow and gray shaded region indicates the 1σ and 2σ constraints, respectively, from Tinker et al. (2005). The green contour shows the constraints from WMAP7 (CMB alone, assuming a flat ΛCDM model; Komatsu et al. 2011). The red contours show the combined constraints from M/N and WMAP7.

(A color version of this figure is available in the online journal.)

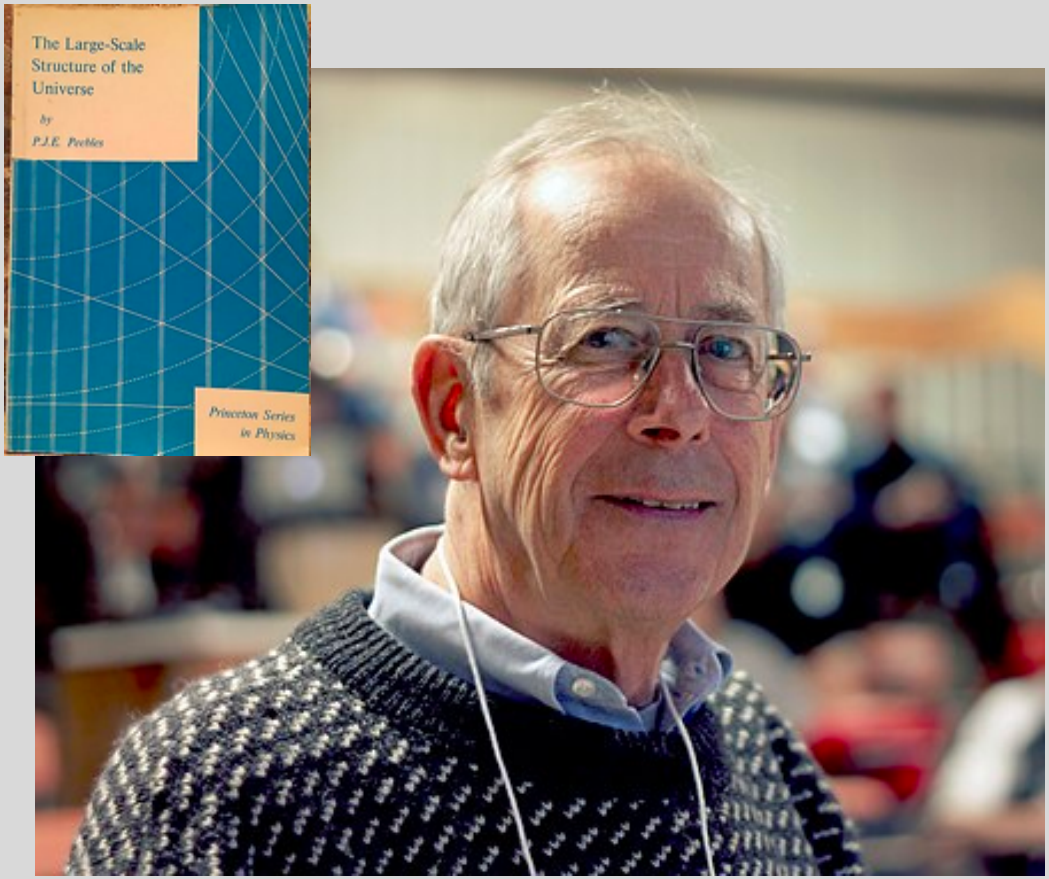
Historical Notes

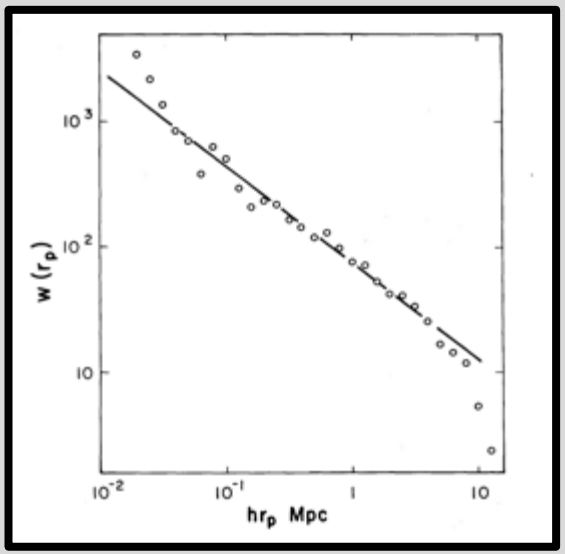
Galaxy clustering in the early 1990's – an early hint of dark energy? (SNe evidence comes out in 1998/1999, Efstathiou+1990 find suggestion of $\Omega_\Lambda \approx 0.8$…)



Historical Notes

2019 Nobel Prize in Physics goes to Jim Peebles for work on the large scale structure of the Universe! (and exoplanets)





Davis and Peebles 1982
(2400 galaxies!)

Future?

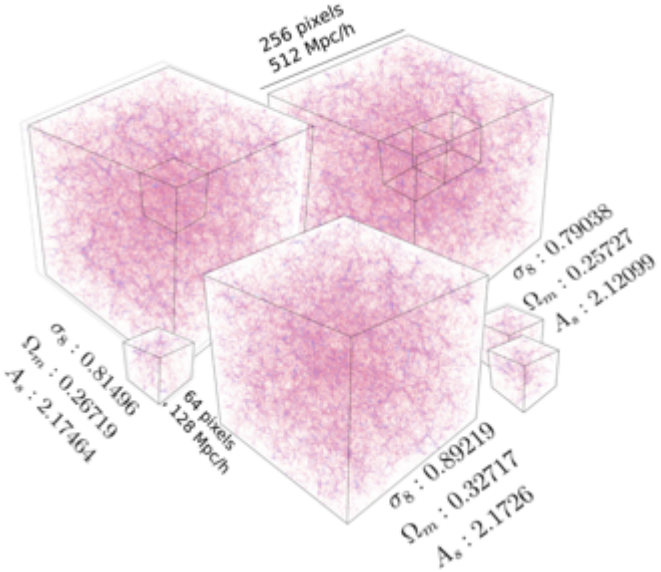


Figure 1. Dark matter distribution in three cubes produced using different sets of parameters. Each cube is divided into small sub-cubes for training and prediction. Note that although cubes in this figure are produced using very different cosmological parameters in our constrained sampled set, the effect is not visually discernible.

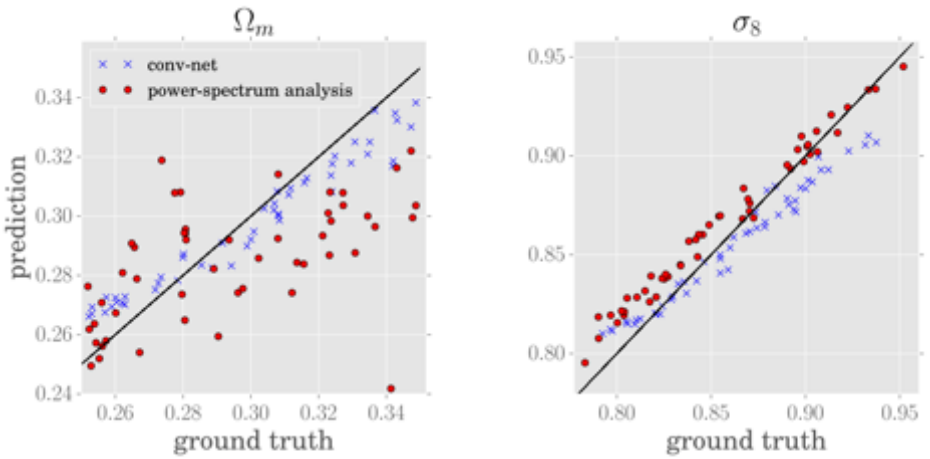


Figure 2. Prediction and ground truth of Ω_m and σ_8 using 3D conv-net and analysis of the power-spectrum on 50 test cube instances.