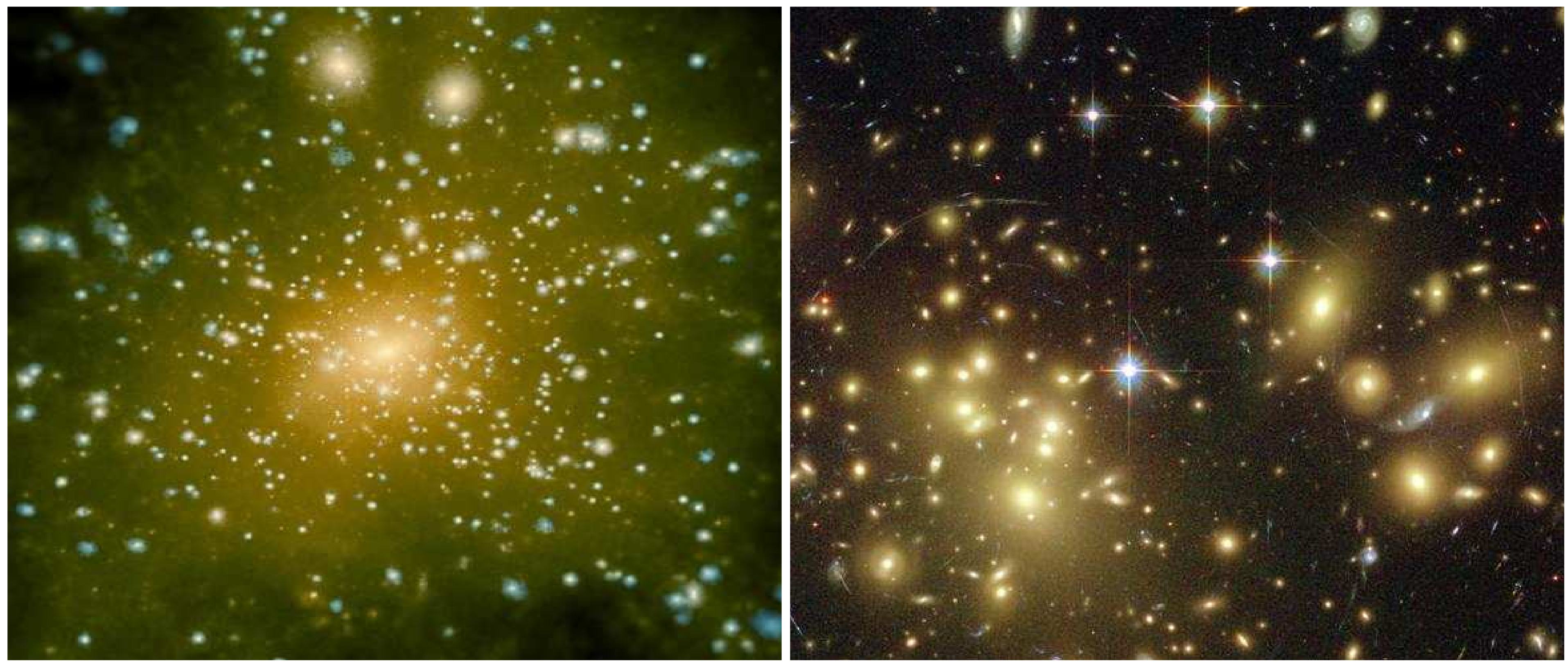
The Galaxy–Dark Matter Connection



Frank C. van den Bosch (MPIA)

in collaboration with

Xiaohu Yang (SHAO)
Houjun Mo (UMass)
Simone Weinmann (Zurich)

Introduction

PARADIGM: **Galaxies live in extended Cold Dark Matter Haloes.**

QUESTION: **What Galaxy lives in What Halo?**

- **How many galaxies, on average, per halo?**
- **How does $\langle N \rangle$ depend on M and L?**
- **What is $\langle L \rangle(M)$?**
- **How are galaxies distributed (spatially & kinematically) within halo?**

The answers to these questions hold important information regarding

- **Galaxy Formation (cooling/starformation/feedback)**
- **Large Scale Structure (galaxy bias)**
- **Cosmology (Halo mass function/CDM distribution)**

The galaxy-dark matter connection can be studied

Physically: Ab initio galaxy formation models (SAMs)

Statistically: The Conditional Luminosity Function (CLF)

The Conditional Luminosity Function

The CLF $\Phi(L|M)$ is the direct link between halo mass function $n(M)$ and the galaxy luminosity function $\Phi(L)$:

$$\Phi(L) = \int_0^\infty \Phi(L|M)\, n(M)\, \mathrm{d}M$$

The CLF contains a lot of important information, such as:

- halo occupation numbers as function of luminosity:

$$N_M(L > L_1) = \int_{L_1}^\infty \Phi(L|M)\, \mathrm{d}L$$

- The average relation between light and mass:

$$\langle L \rangle(M) = \int_0^\infty \Phi(L|M)\, L\, \mathrm{d}L$$

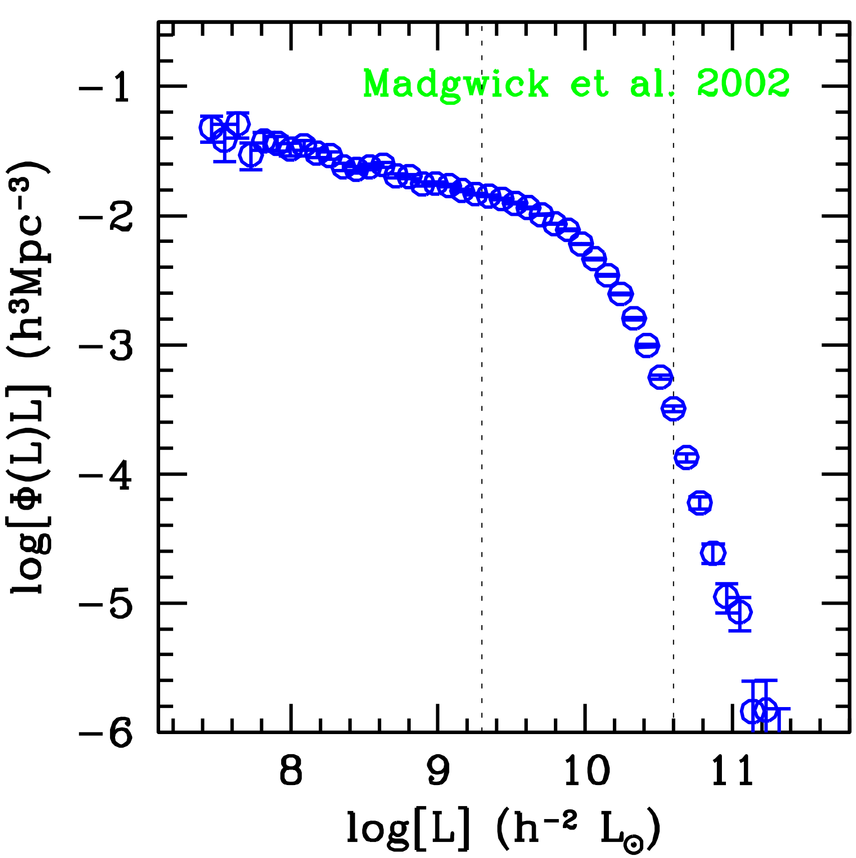
- Galaxy clustering properties as function of luminosity:

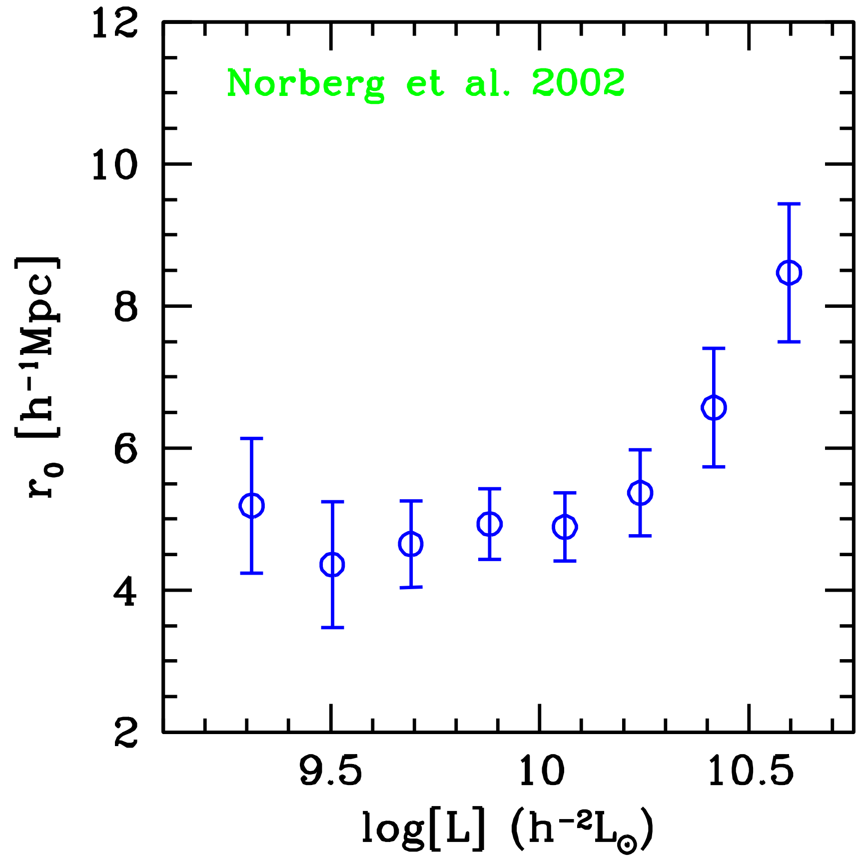
$$\xi_{\mathrm{gg}}(r|L) = b^2(L)\, \xi_{\mathrm{dm}}(r)$$

$$b(L) = \frac{1}{\Phi(L)} \int_0^\infty \Phi(L|M)\, b(M)\, n(M)\, \mathrm{d}M$$

CLF is ideal statistical ‘tool’ to investigate Galaxy-Dark Matter Connection

Luminosity & Correlation Functions



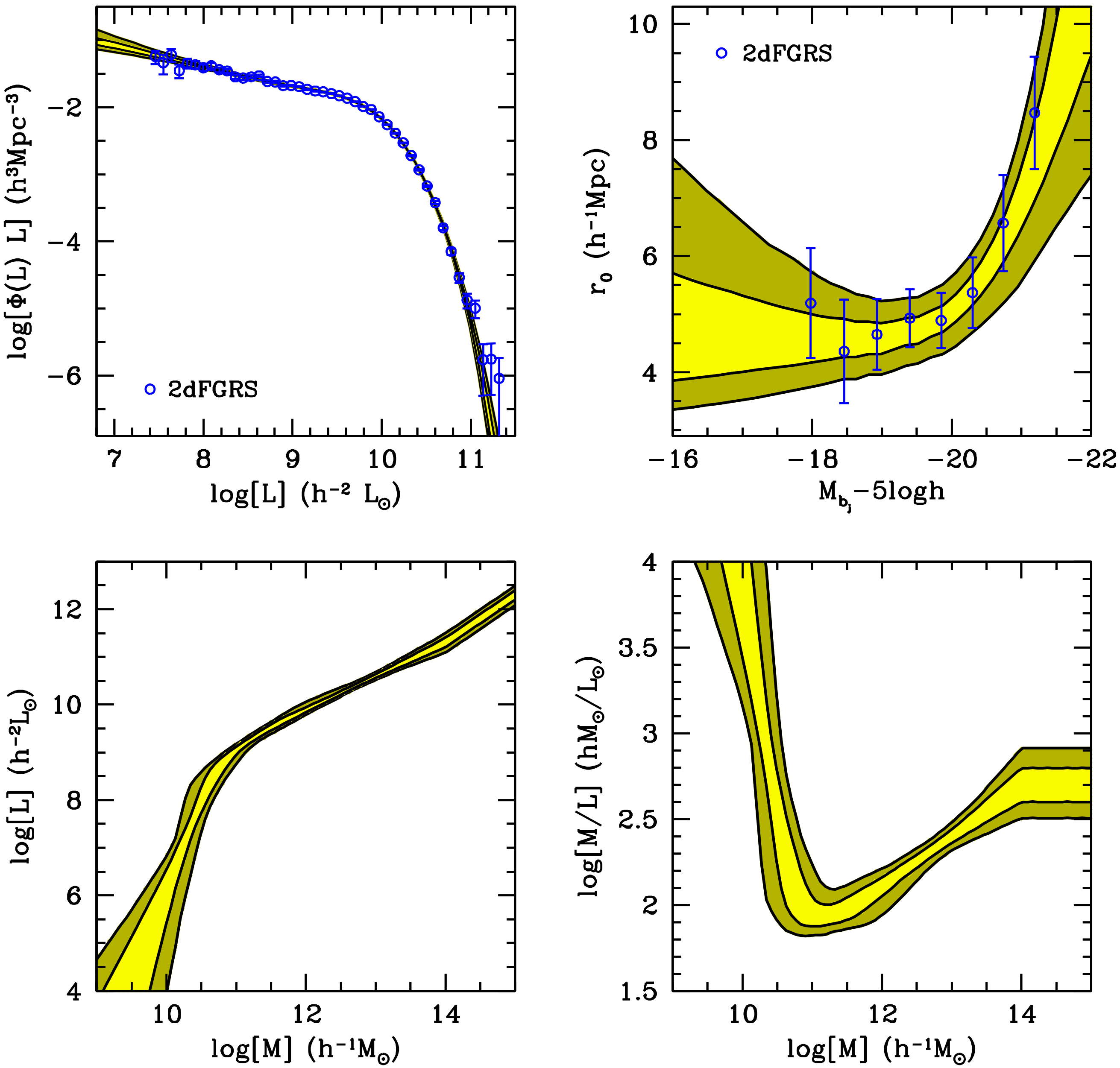


- **2dFGRS:** More luminous galaxies are more strongly clustered.
- **ΛCDM:** More massive haloes are more strongly clustered.

More luminous galaxies reside in more massive haloes

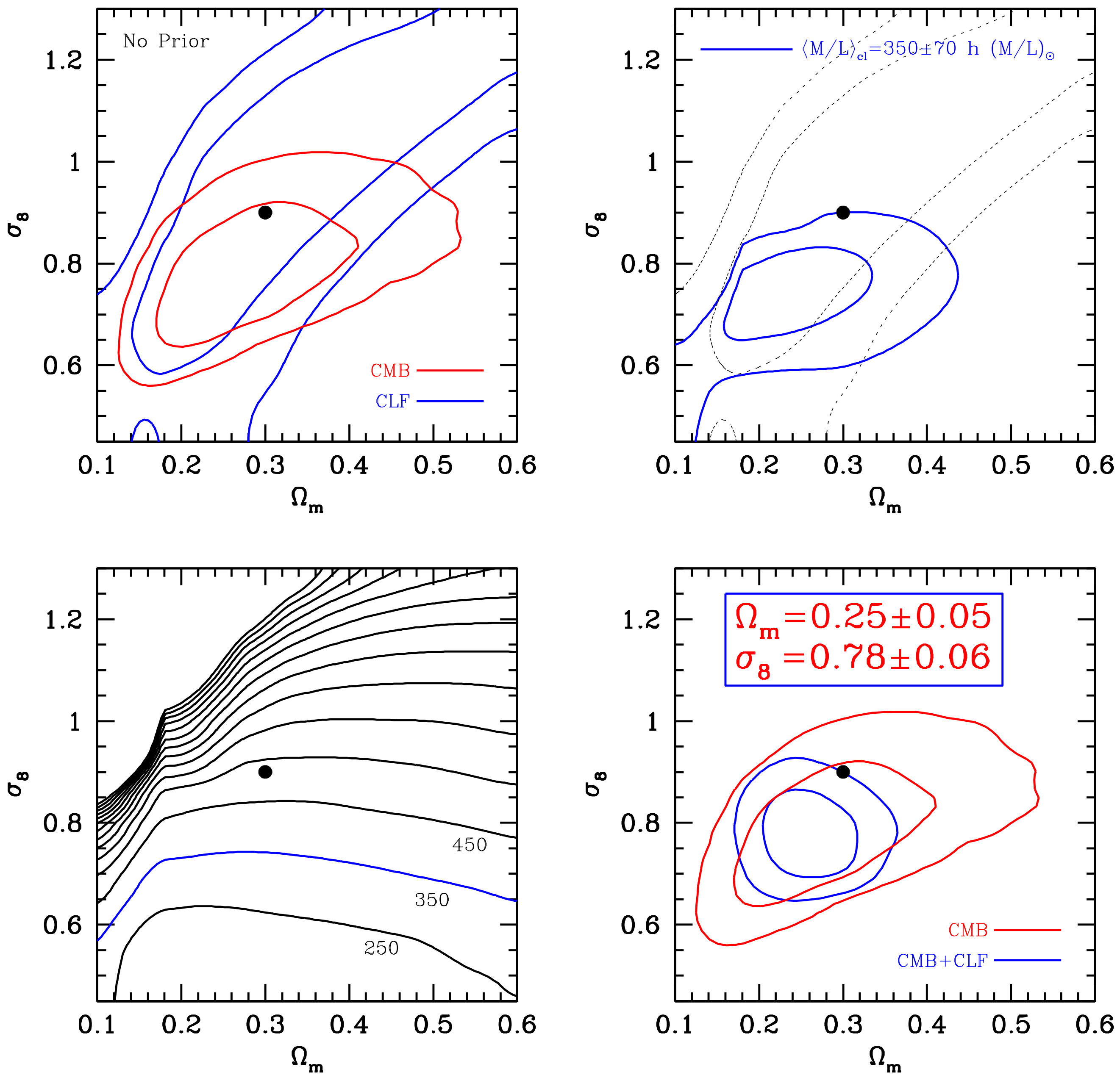
REMINDER: Correlation length r_0 defined by $\xi(r_0) = 1$

The Relation between Light & Mass



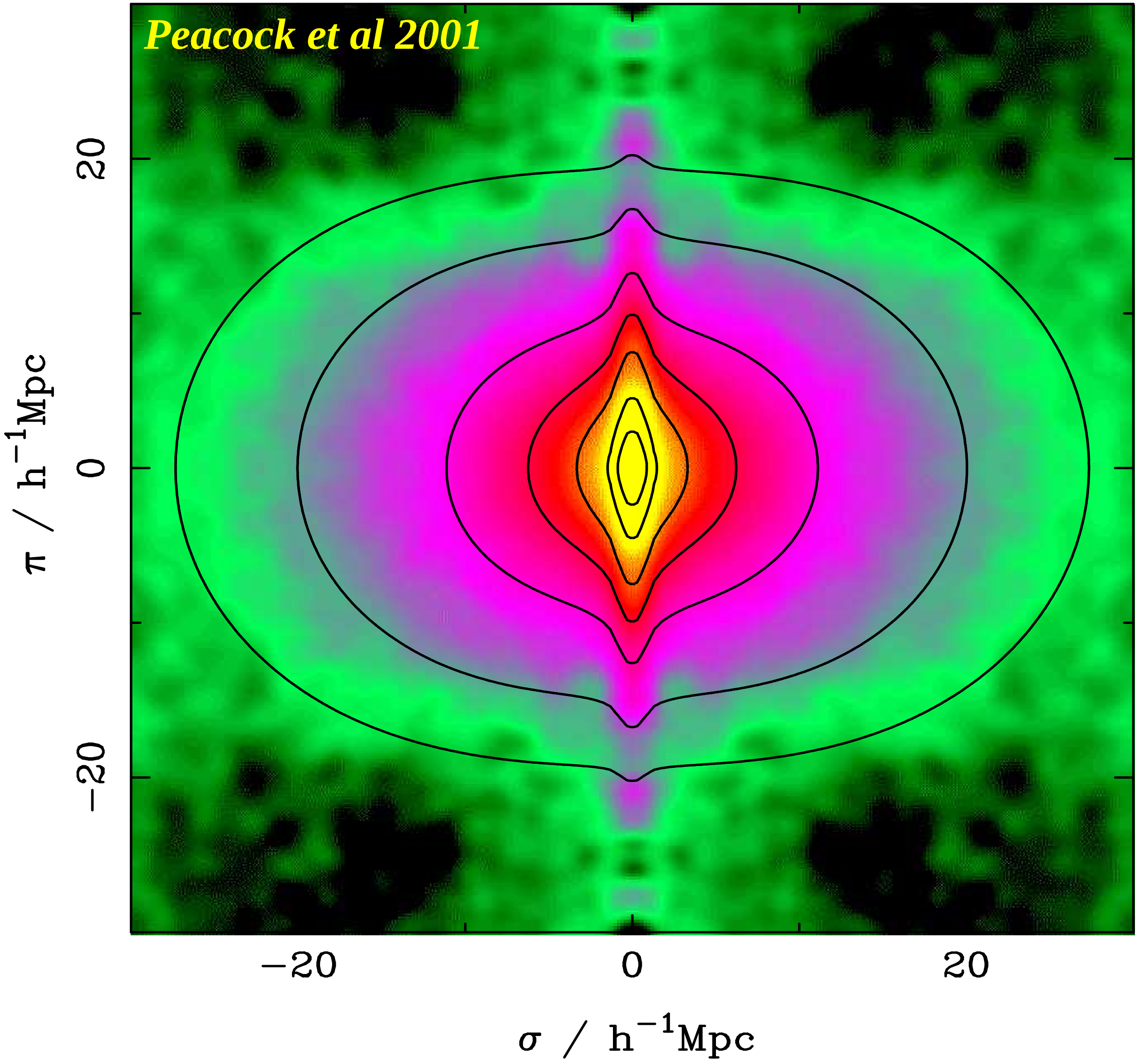
vdB, Yang, Mo & Norberg, 2005, MNRAS, 356, 1233

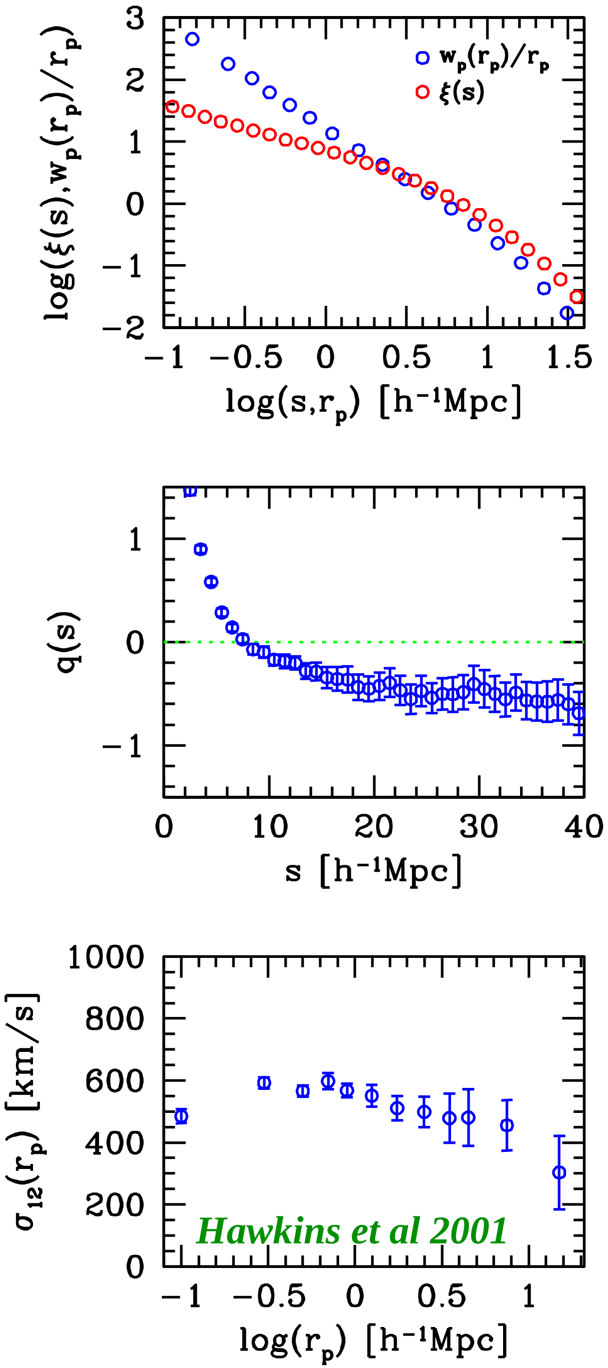
Constraints on Ω_m and σ_8



vdB, Mo & Yang 2003, MNRAS, 345, 923

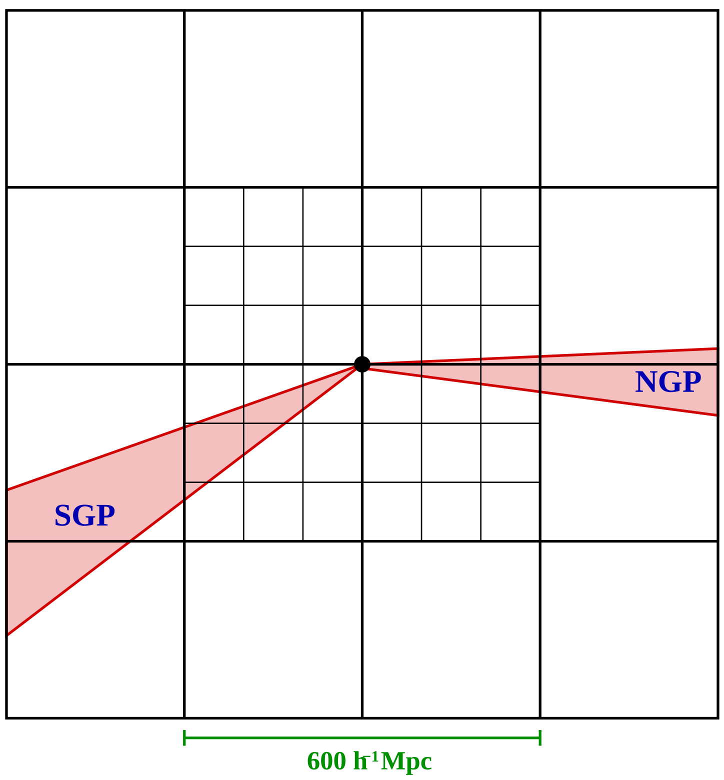
Large Scale Structure: The 2dFGRS



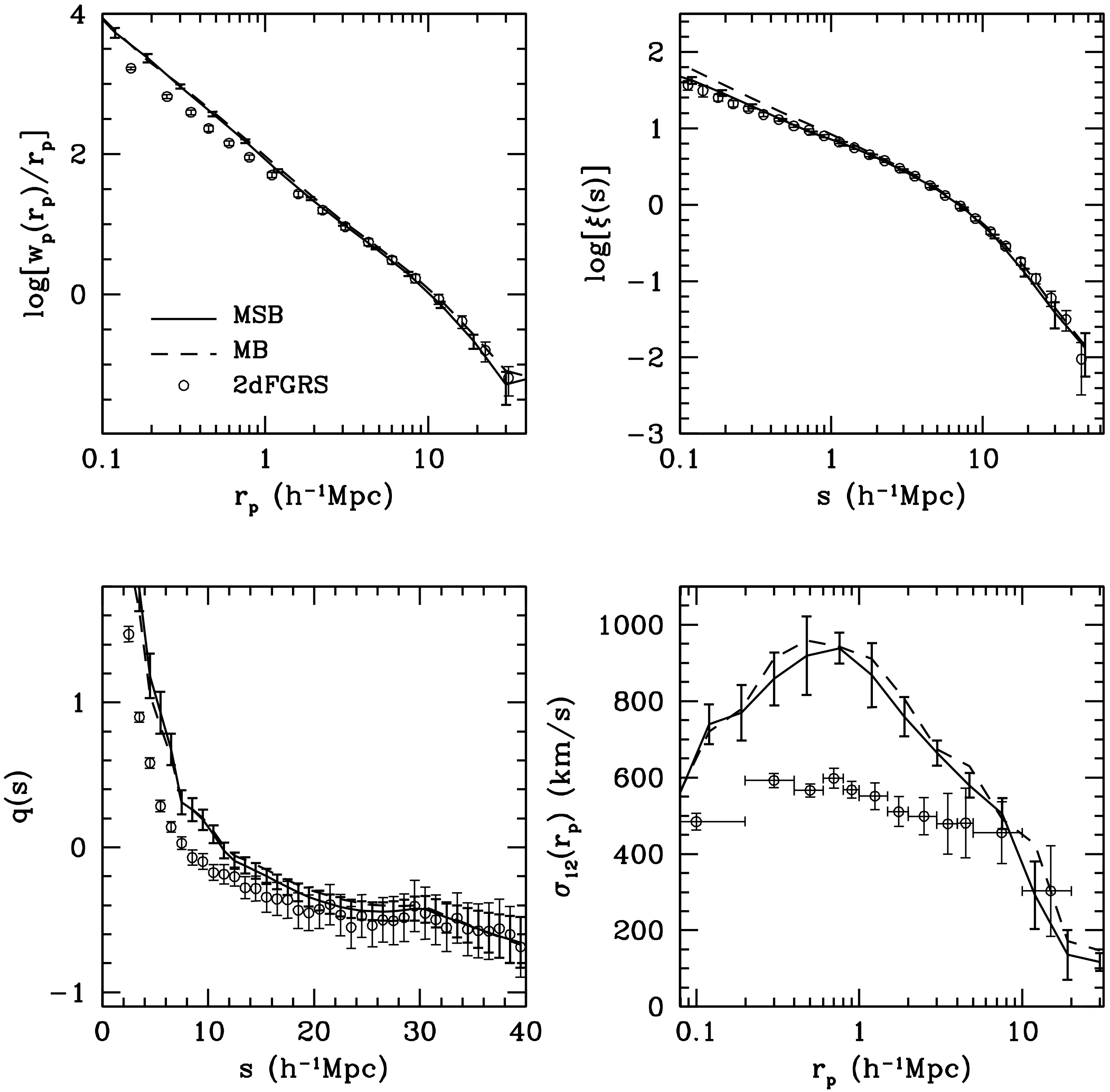


Constructing Mock Surveys

- **Run numerical simulations: ΛCDM concordance cosmology; $L_{\rm box} = 100h^{-1}$ Mpc and $L_{\rm box} = 300h^{-1}$ Mpc with 512^3 CDM particles each.**
- **Identify dark matter haloes (FOF algorithm, $b = 0.2$).**
- **Populate haloes with galaxies using CLF.**
- **Stack boxes to create virtual universe and mimick observations (magnitude limit, completeness, geometry)**

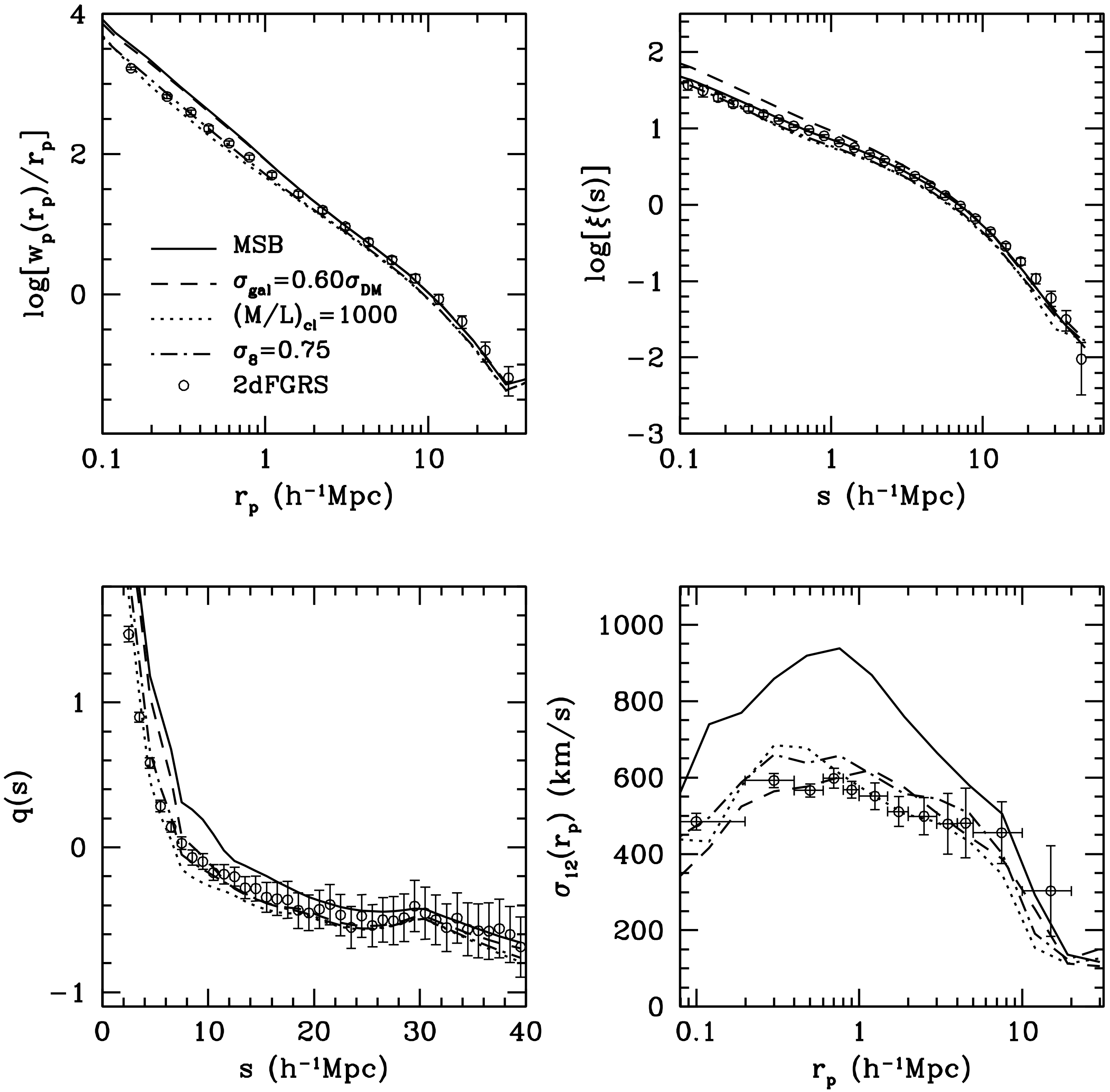


Mock versus 2dFGRS: round 1



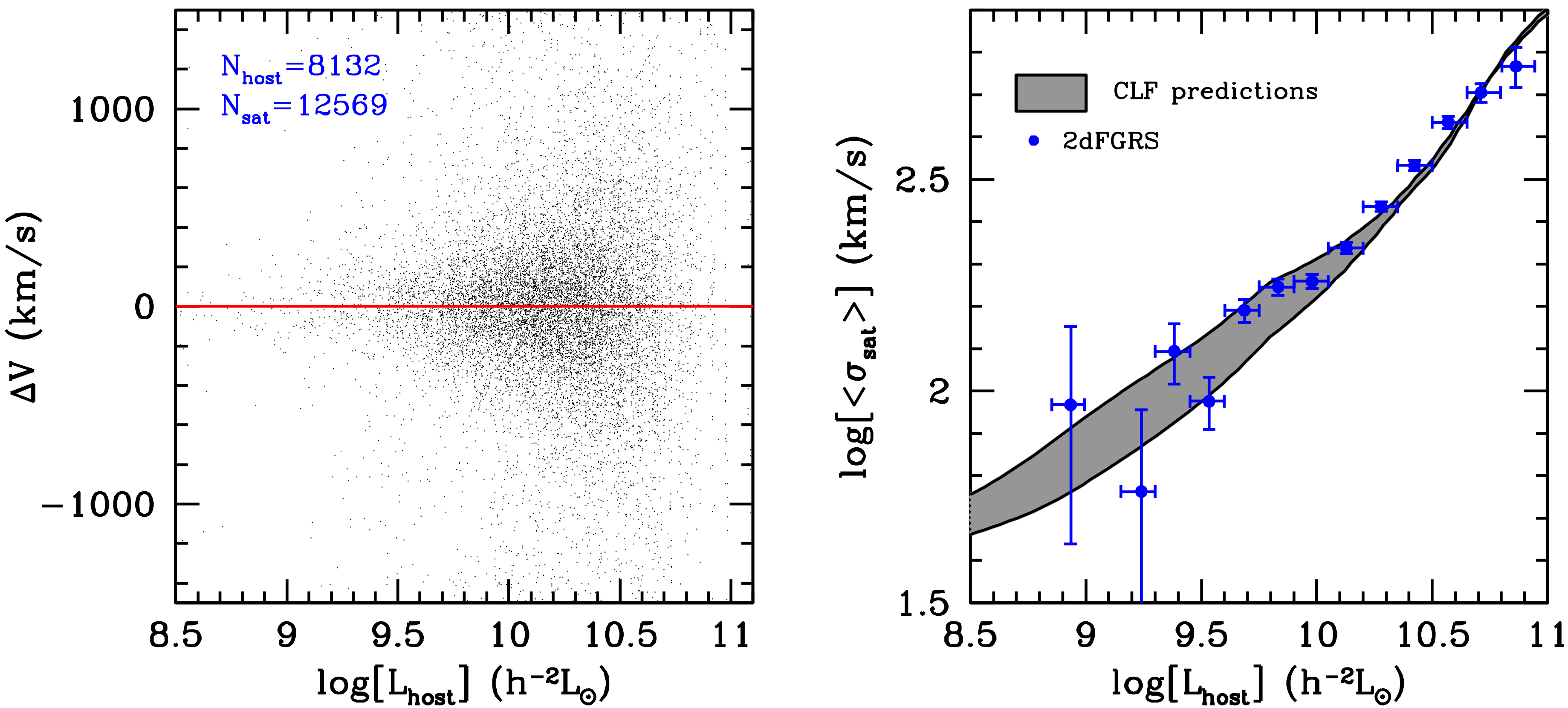
Yang, Mo, Jing, vdB & Chu, 2004, MNRAS, 350, 1153

Mock versus 2dFGRS: round 2



Yang, Mo, Jing, vdB & Chu, 2004, MNRAS, 350, 1153

Satellite Kinematics in the 2dFGRS

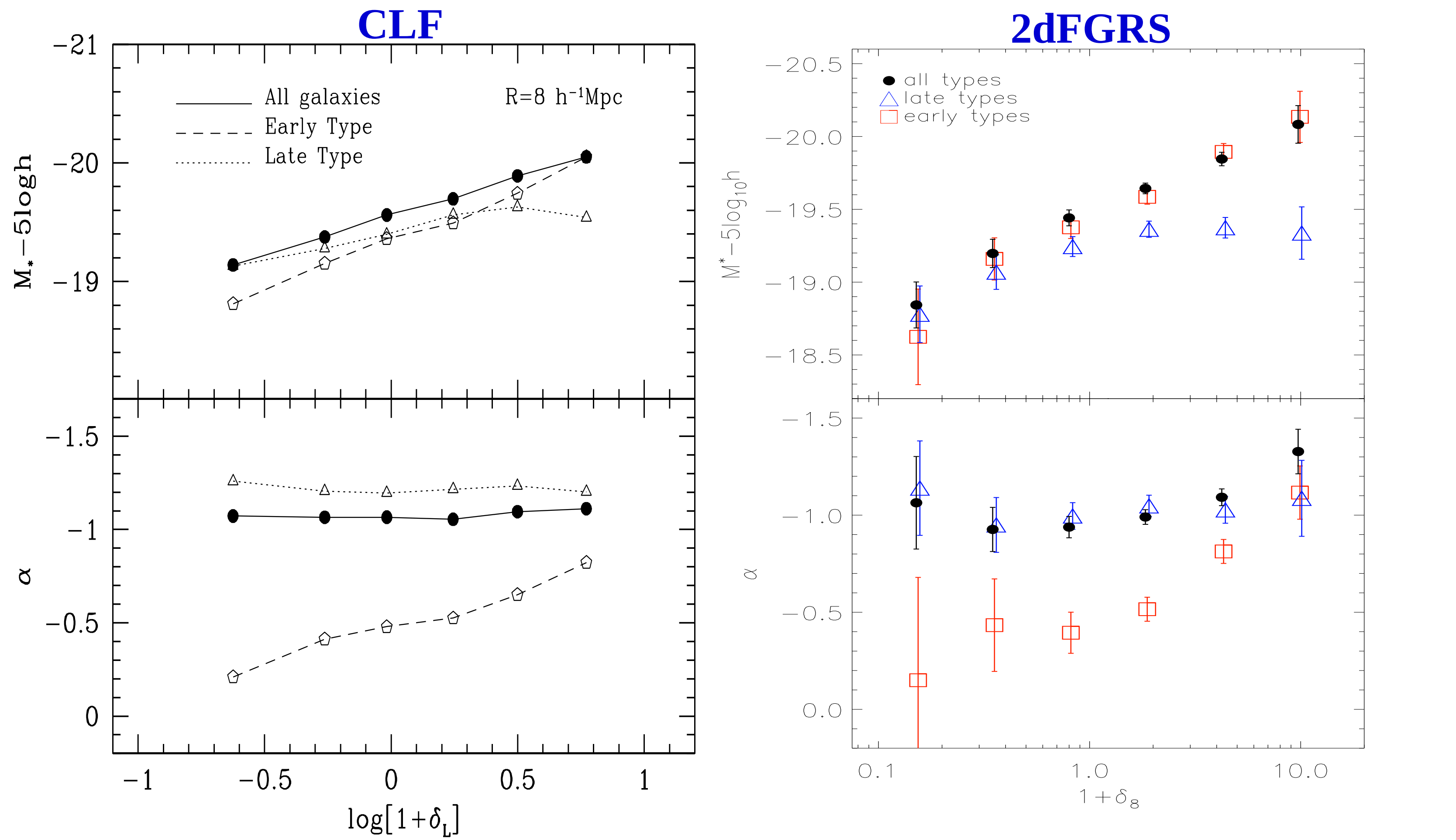


- Mocks are used to optimize host-satellite selection criteria
- Using an iterative, adaptive selection criterion minimizes interlopers
- Application to 2dFGRS yields 12569 satellites & 8132 hosts
- Independent dynamical evidence to support CLF results

vdB, Norberg, Mo & Yang, 2004, MNRAS, 352, 1302

vdB, Yang, Mo & Norberg, 2005, MNRAS, 356, 1233

Large-Scale Environment Dependence



(Mo, Yang, vdB & Jing, 2004, MNRAS, 349, 205)

Populate haloes in N-body simulations with galaxies using $\Phi(L|M)$

Compute $\Phi(L)$ as function of environment and type as in Croton et al. (2005)

Because $n(M)$ depends on environment, we reproduce observed trend

There is no environment dependence, only halo-mass dependence

Conclusions

- $\Phi(L|M)$ is a powerful statistical tool. It is strongly constrained by $\Phi(L)$ and $r_0(L)$ (Yang, Mo & vdB 2003)
- $\Phi(L|M)$ yields mass-to-light ratios $\langle M/L\rangle(M)$ and galaxy bias as function of luminosity, type, etc (vdB, Yang & Mo 2003)
- Relation between mass and light inferred from $\Phi(L|M)$ in excellent agreement with satellite kinematics (vdB, Norberg, Mo & Yang 2004)
- $\Phi(L|M)$ ideal to construct mock galaxy redshift surveys and to study large scale structure (Yang, Mo, Jing, vdB & Chu 2004)
- There is no environment dependence, only halo-mass dependence (Mo, Yang, vdB & Jing 2004)

The ΛCDM concordance cosmology predicts too many massive clusters, unless $\langle M/L\rangle_{\rm cl} \simeq 1000h\,({\rm M/L})_{\odot}$ or $\sigma_8 \simeq 0.75$.
