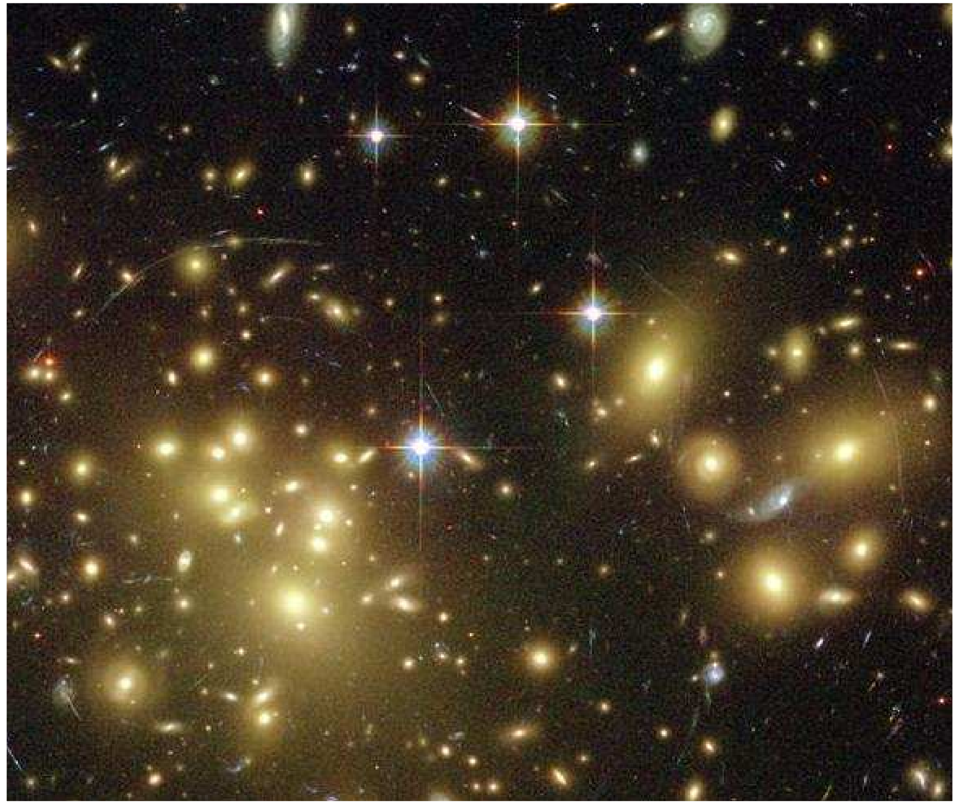
The Galaxy–Dark Matter Connection



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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:

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

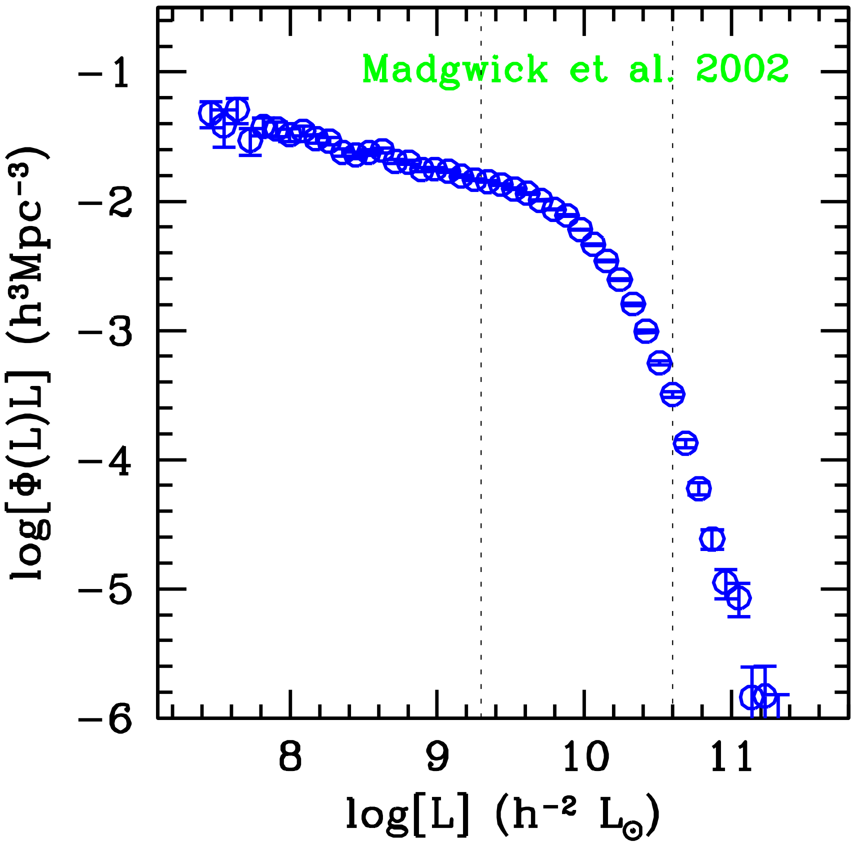
- Galaxy clustering properties as function of luminosity:

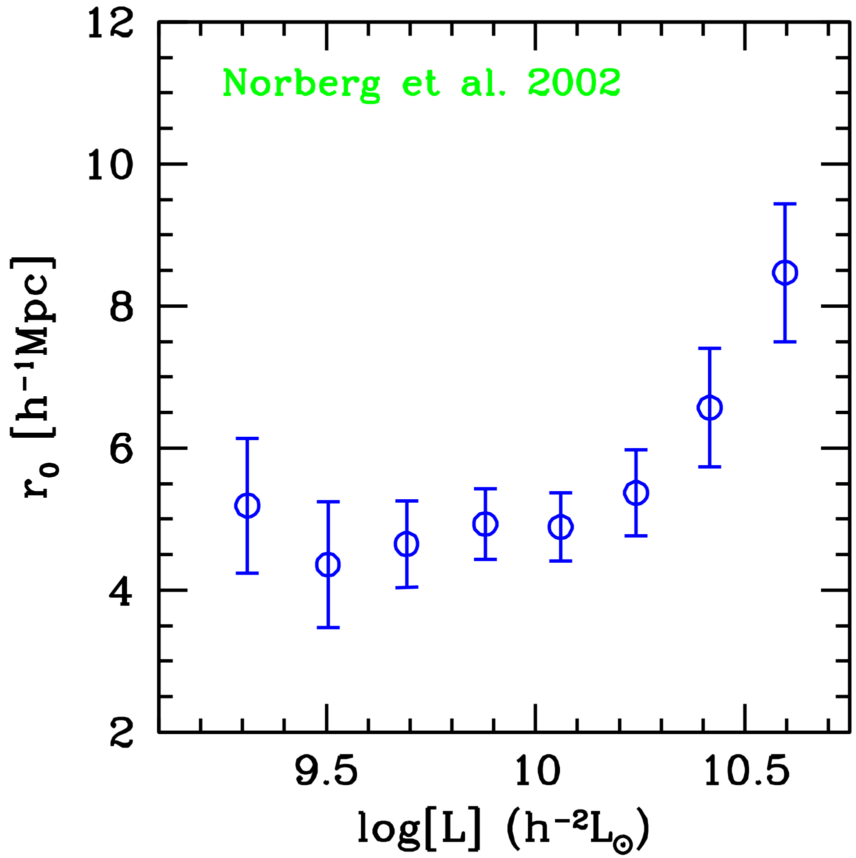
$$\xi_{\rm gg}(r|L) = b^2(L)\, \xi_{\rm dm}(r)$$

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

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** $\xi(r_0) = 1$

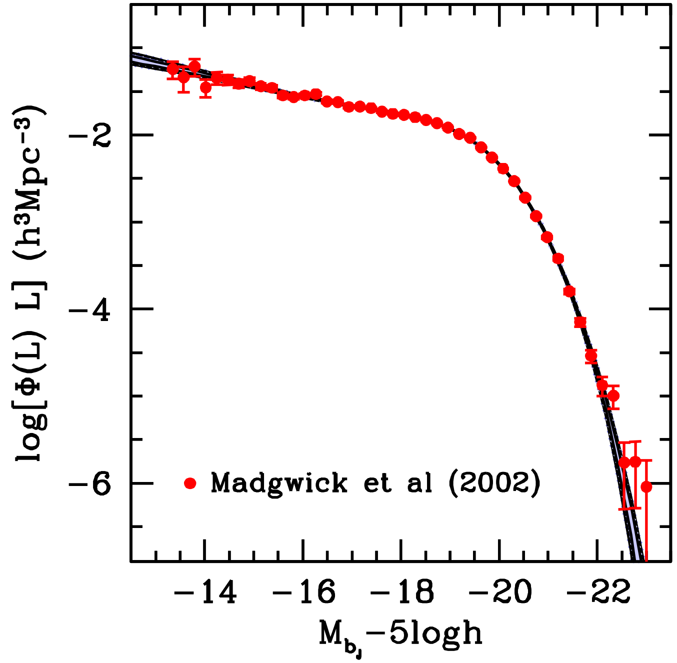
The CLF Model

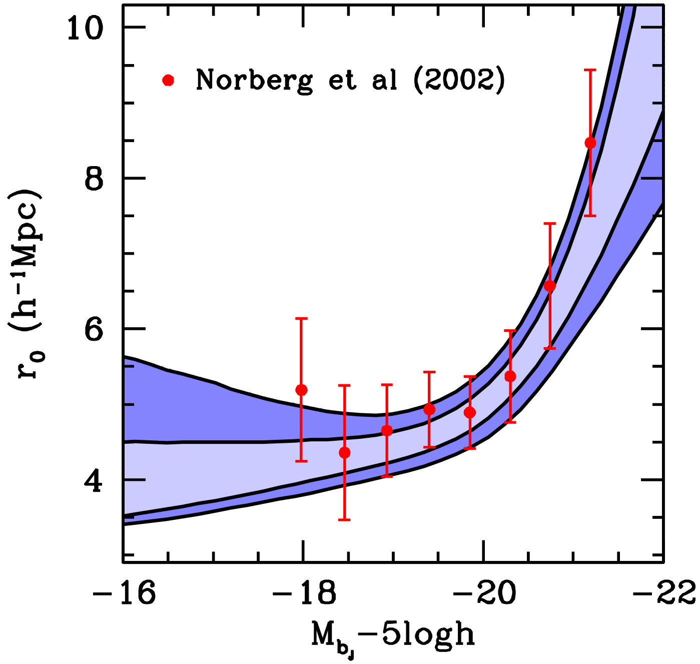
We assume that the CLF has the Schechter form:

$$\Phi(L|M)\mathrm{d}L = \frac{\tilde{\Phi}^*}{\tilde{L}^*}\left(\frac{L}{\tilde{L}^*}\right)^{\tilde{\alpha}} \exp(-L/\tilde{L}^*)\,\mathrm{d}L$$

Here $\tilde{\Phi}^*$, $\tilde{L}^*$ and $\tilde{\alpha}$ all depend on M.

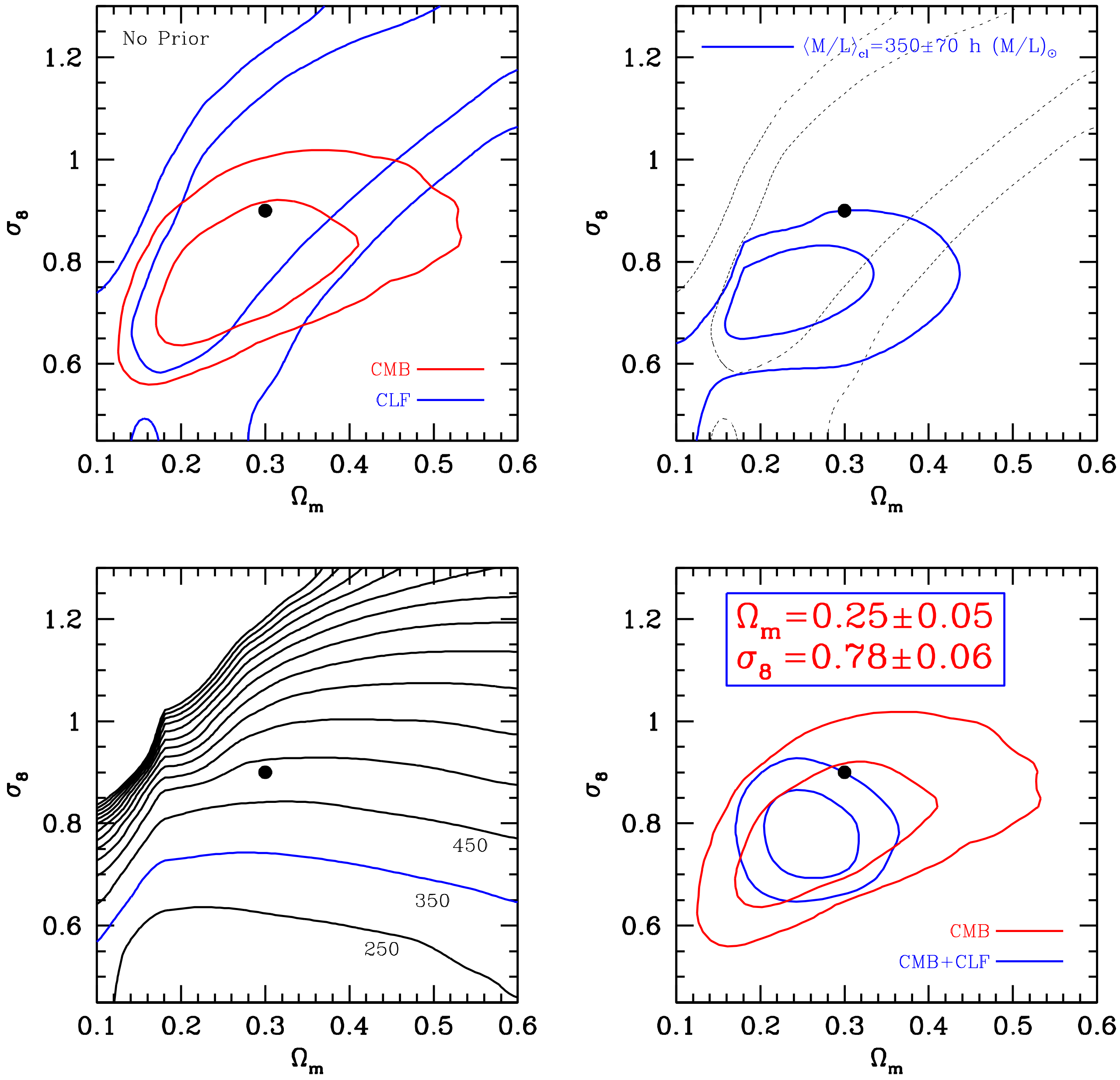
We use Monte-Carlo Markov Chain to sample posterior distribution of free parameters, and to put confidence levels on derived quantities





▷ **Model accurately fits both $\Phi(L)$ and $r_0(L)$.**

Cosmological Constraints



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

See also Tinker et al. 2005; Vale & Ostriker 2005

HODs from Galaxy Groups

Halo Occupation Statistics can also be obtained directly from galaxy groups

Potential Problems: interlopers, (in)completeness, mass estimates

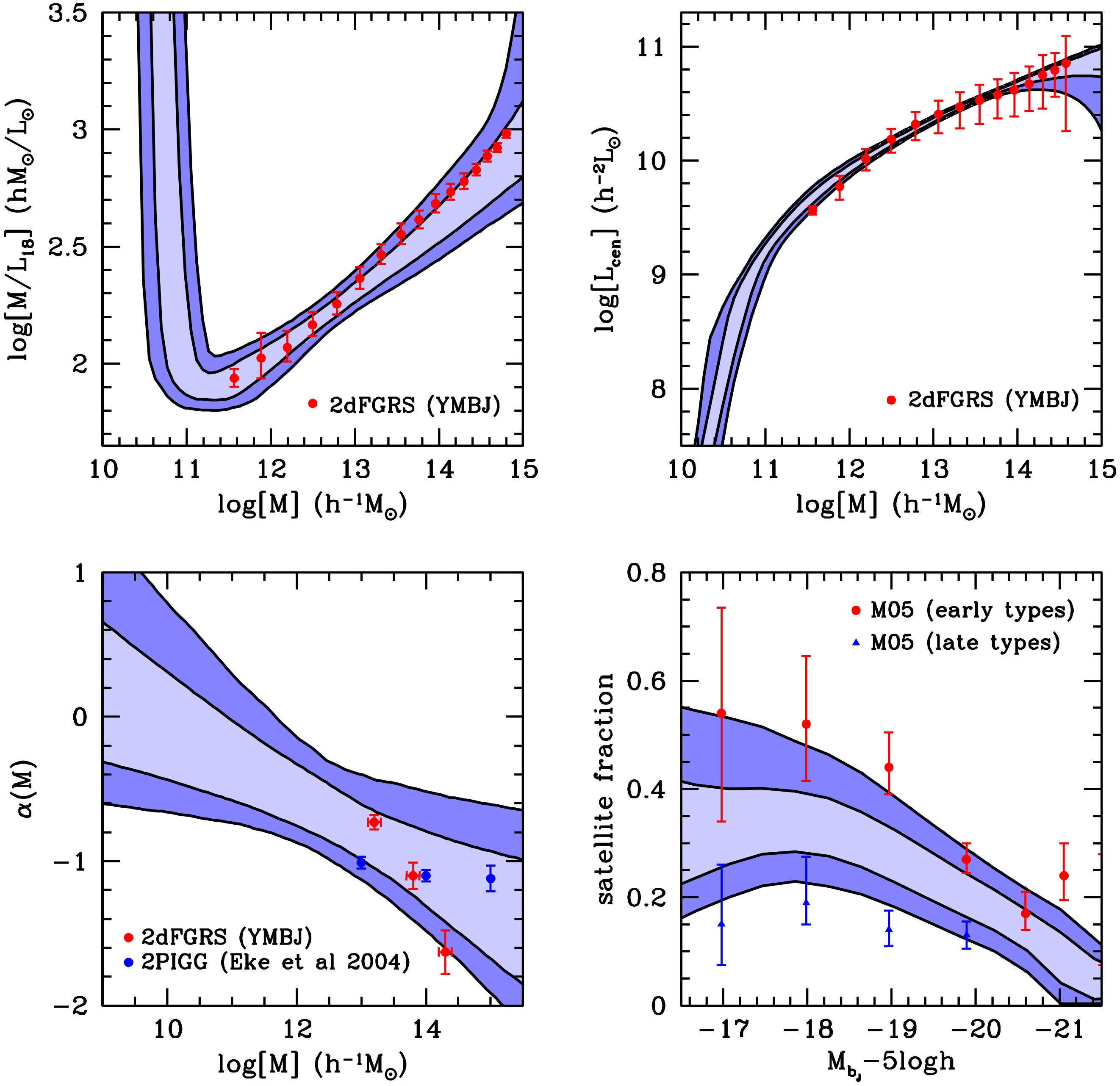
We developed new, iterative group finder, using an adaptive filter modeled after halo virial properties

Yang, Mo, vdB, Jing 2005, MNRAS, 356, 1293

- Calibrated & Optmized with Mock Galaxy Redshift Surveys
- Low interloper fraction ($\lesssim 20\%$).
- High completeness of members ($\gtrsim 90\%$).
- Masses estimated from group luminosities.
  More accurate than using velocity dispersion of members.
- Can also detect “groups” with single member
  ▷ Large dynamic range ($11.5 \lesssim \log[M] \lesssim 15$).

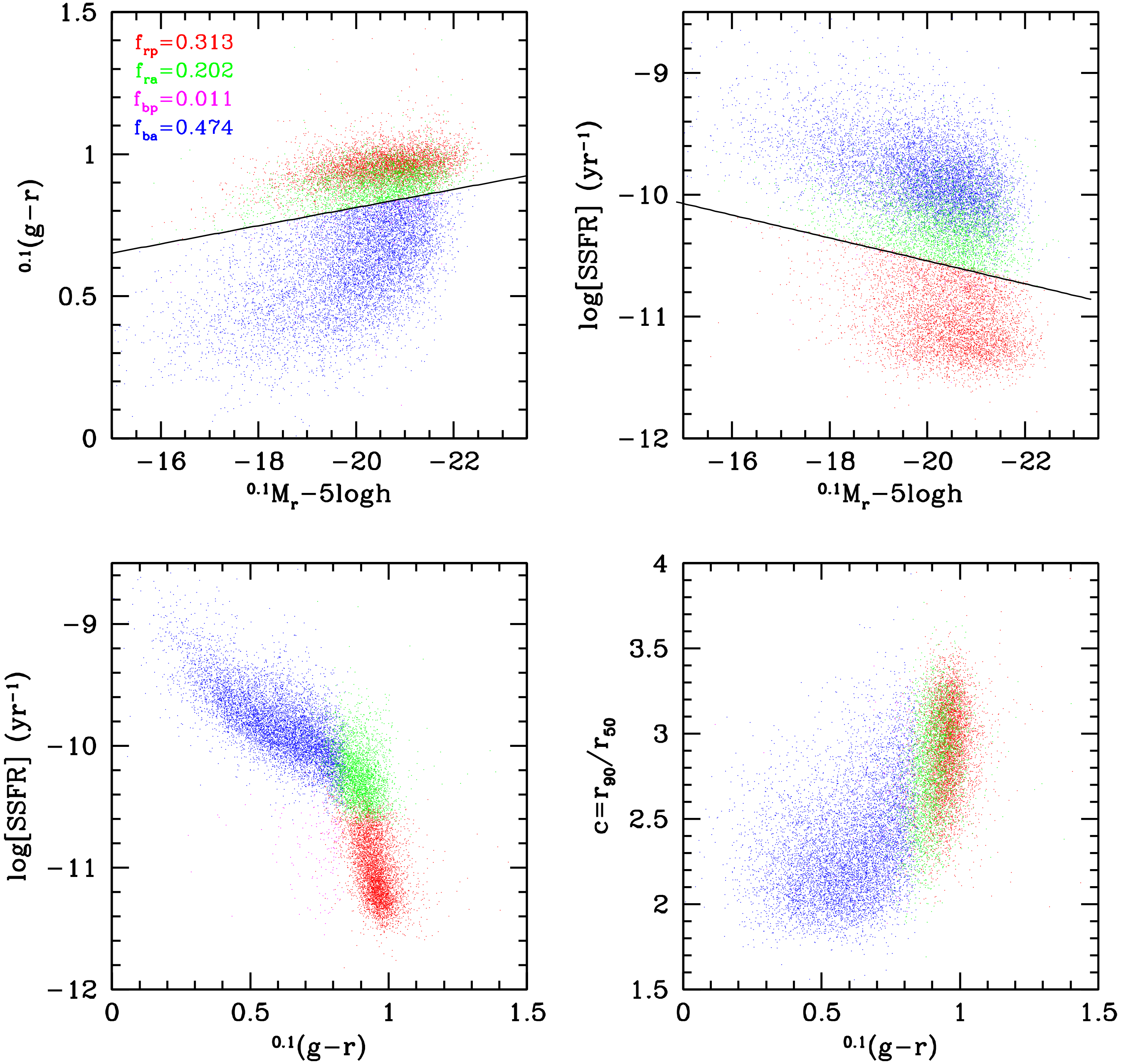
Group finder has been applied to both the 2dFGRS (completed survey) and to the SDSS (NYU-VAGC; Blanton et al. 2005)

The Relation between Light & Mass



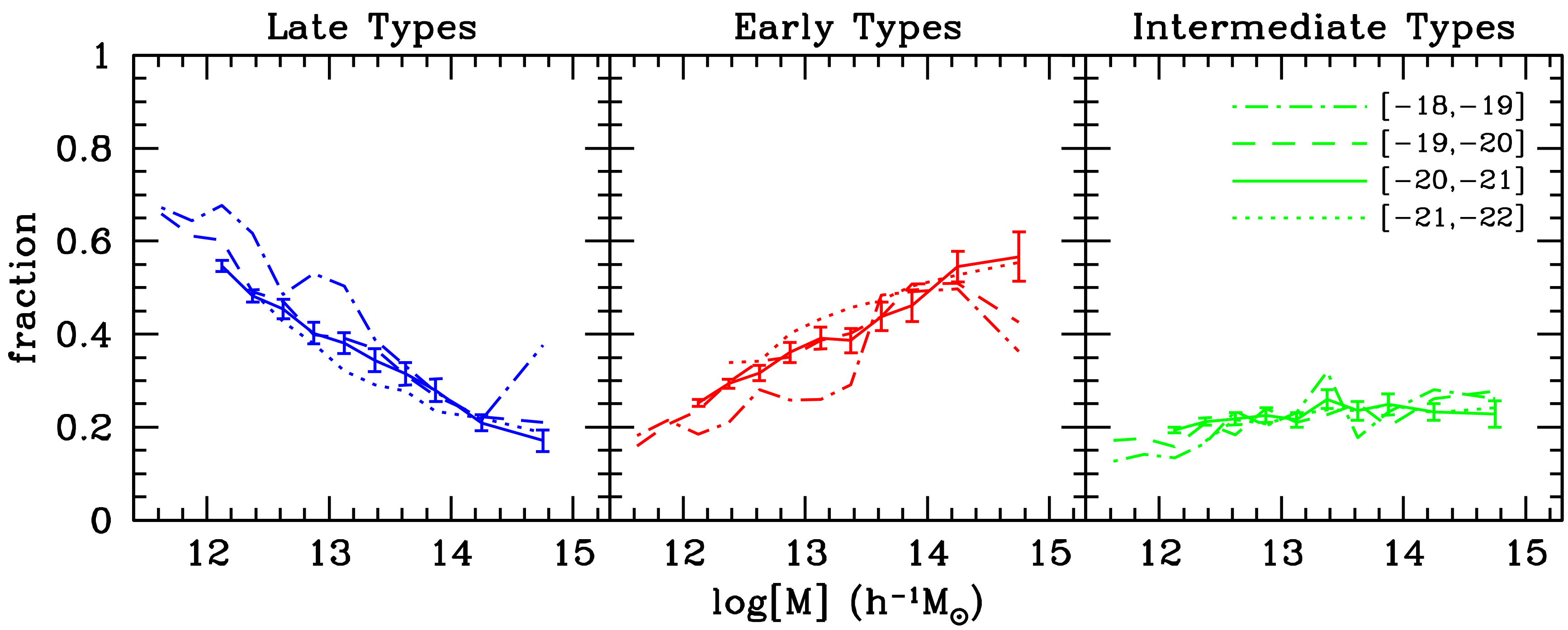
vdB et al. 2006, in prep.

Galaxy Ecology



Data from NYU-VAGC (Blanton et al. 2005): SSFRs from Kauffmann et al. (2003) and Brinchmann et al. (2004)

Halo Mass Dependence



The fractions of early and late type galaxies depend strongly on halo mass.

At fixed halo mass, there is virtually no luminosity dependence.

The mass dependence is smooth: there is no characteristic mass scale; i.e., no indication that something special happens at the group or cluster scales.

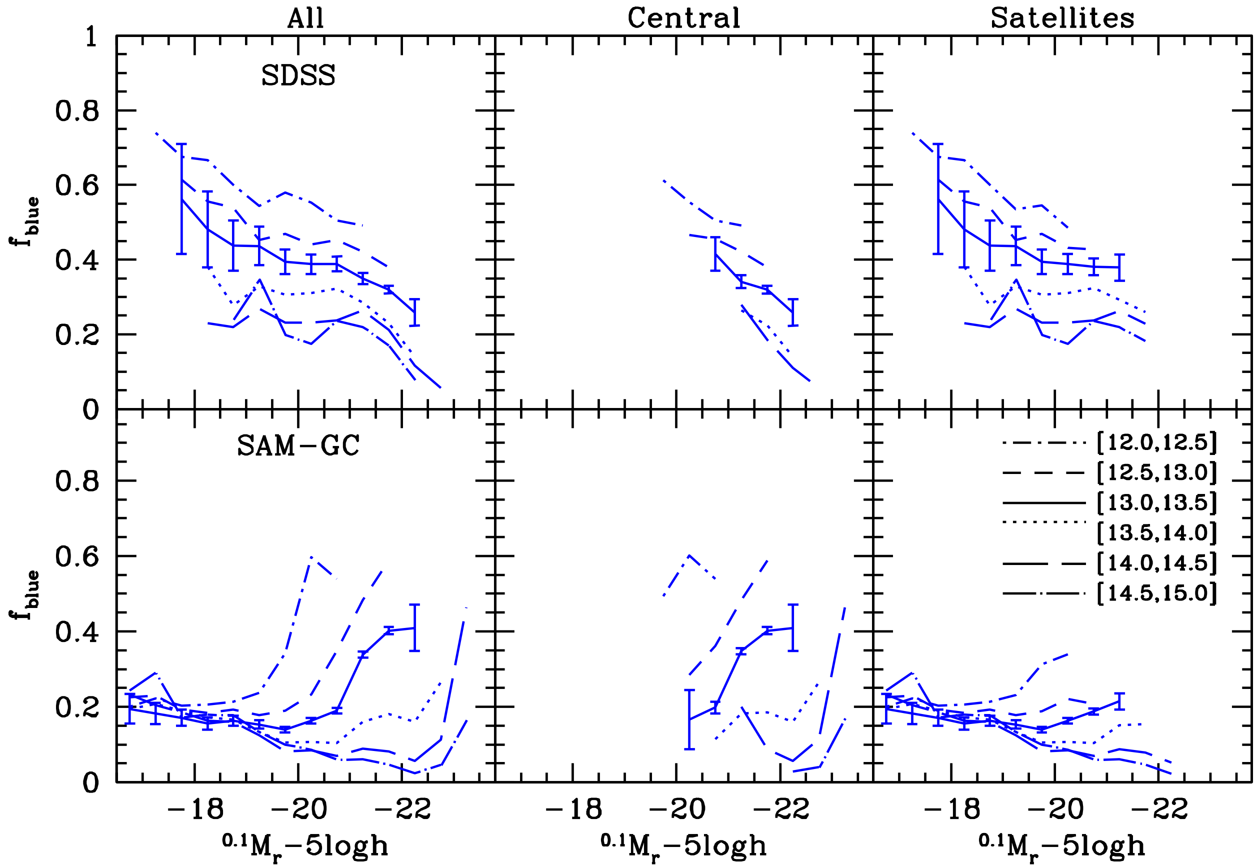
The intermediate type fraction is independent of luminosity and mass.

(Weinmann, vdB, Yang & Mo, 2006)

Comparison with Semi-Analytical Model

We compare blue fractions between SDSS and SAM of Croton et al. (2006)

To allow for fair comparison, we run our Group Finder over SAM.



Satellites: red fraction too large: ▷ strangulation too efficient as modelled

Centrals: $f_{\rm blue}(L|M)$ wrong: ▷ AGN feedback/dust modelling wrong

$f_{\rm blue}(L,M)$ useful to constrain SF truncation mechanism

Conclusions

- CLF is powerful statistical tool, well constrained by $\Phi(L)$ and $r_0(L)$. (Yang, Mo & vdB 2003)
- CLF specifies universal relation between mass and light as well as galaxy bias as function of luminosity, type, etc. (vdB, Yang & Mo 2003)
- CLF yields tight constraints on cosmological parameters when combined with independent constraints on $\langle M/L \rangle_M$. These have now been confirmed by WMAP. (vdB, Mo & Yang 2003)
- Relation between mass and light inferred from CLF fully concordant with many other, independent data sets (vdB et al., in prep)
- Colour and SFR of galaxies depend more strongly on halo mass than on luminosity. There is no indication for a specific transition at either group or cluster scale. (Weinmann, vdB, Yang & Mo 2006)
- SAMs predict too many red satellites, suggesting strangulation is less efficient than in models. (Weinmann et al., in prep)
- SAMs predict that blue fraction increases with L at fixed M, contrary to data. AGN feedback not yet modelled correctly. (Weinmann et al., in prep)