The Galaxy Content of Groups and Clusters

results from the SDSS

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in collaboration with

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Galaxy Ecology

Many studies have investigated relation between various **galaxy properties** (morphology / SFR / colour) and **environment**

(e.g., Dressler 1980; Balogh et al. 2004; Goto et al. 2003; Hogg et al. 2004)

Environment estimated using **galaxy overdensity** (projected) to $n^{\rm th}$ nearest neighbour, Σ_n or using fixed, metric aperture, Σ_R.

Previous studies have found that:

- Fraction of early types **increases** with density
- There is a **characteristic density** ($\sim$ group-scale) below which the environment dependence vanishes

Danger: Physical meaning of Σ_n and Σ_R depends on environment

Physically more meaningful to investigate **halo mass dependence** of galaxy properties. This requires **galaxy group catalogues**.

Important: Separate L-dependence from M-dependence

Constructing Galaxy Groups Catalogues

Galaxy-Dark Matter connection can be studied more directly by measuring the occupation statistics of galaxy groups.

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

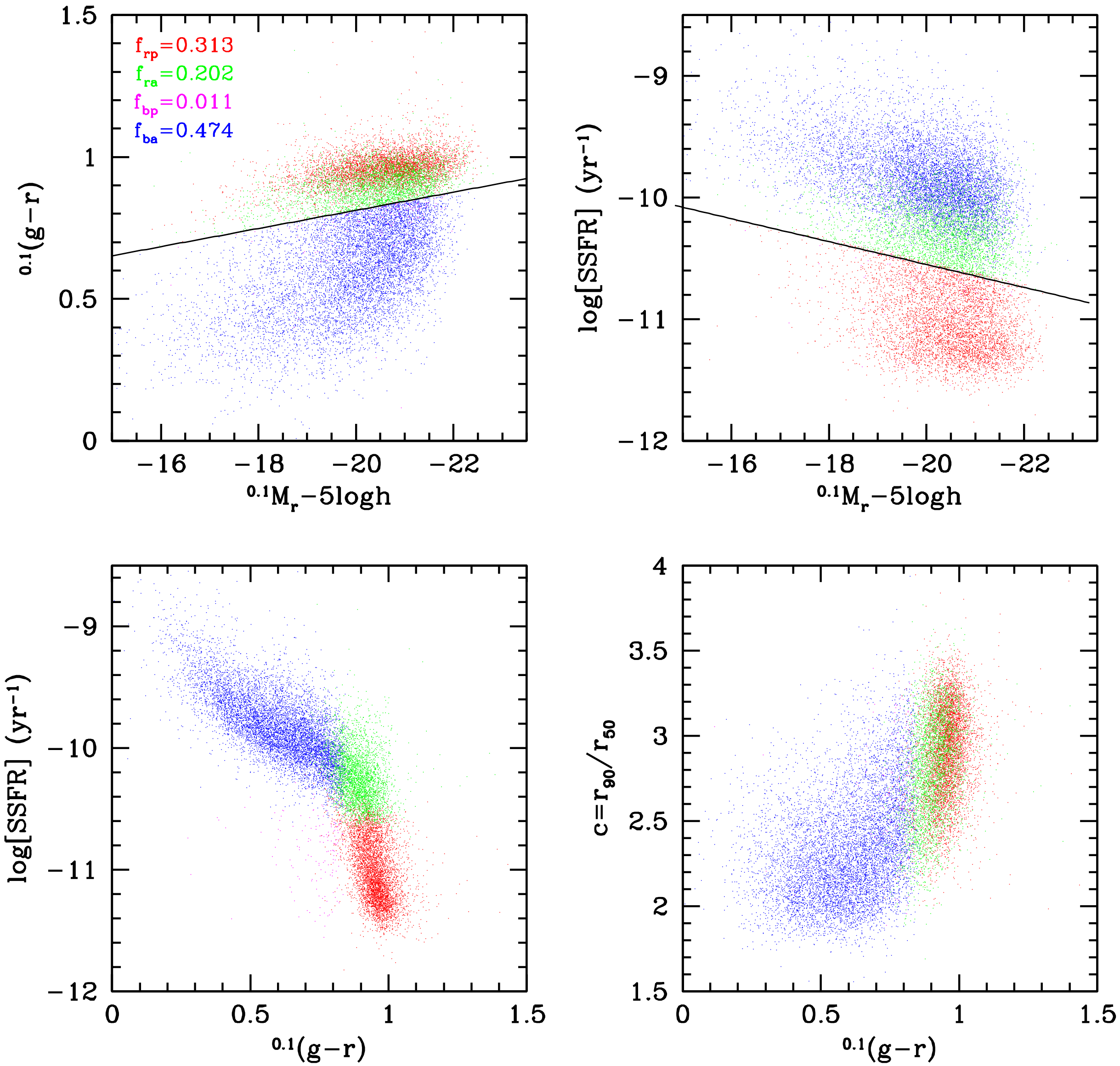
We have developed a new, iterative group finder which uses an adaptive filter modeled after halo virial properties

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

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

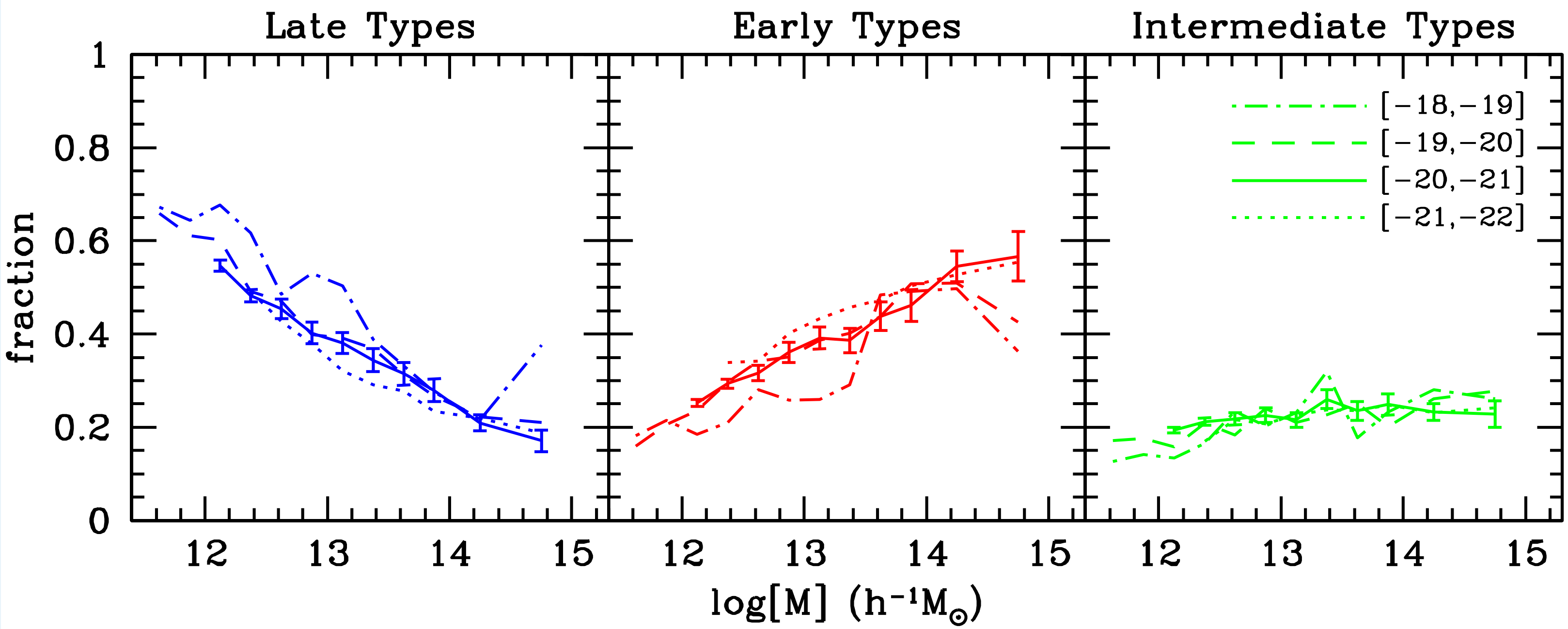
Group finder has been applied to both the 2dFGRS (completed survey) and to the SDSS (NYU-VAGC DR2 + DR4; Blanton et al. 2005)

Defining Galaxy Types



SDSS-DR2 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 types depend strongly on halo mass.

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

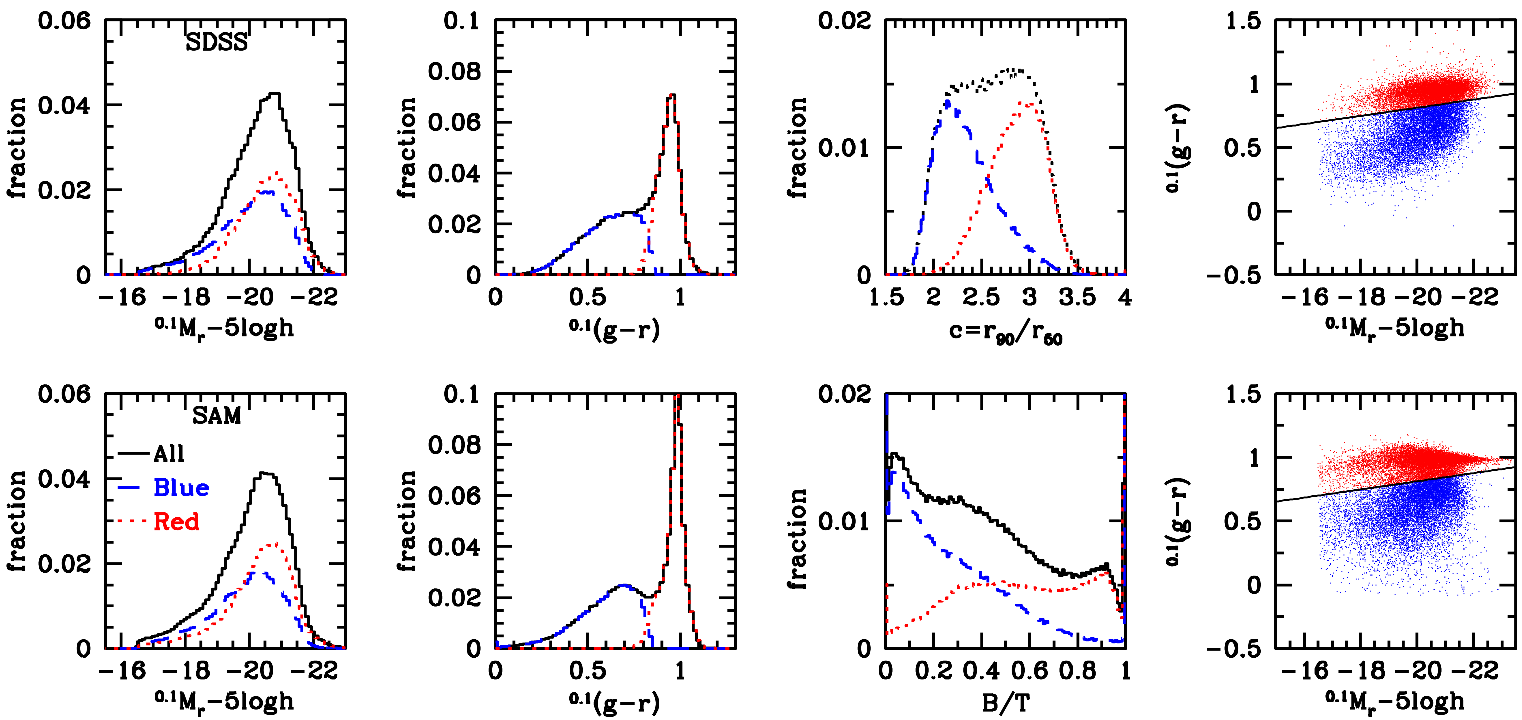
The mass dependence is smooth: there is no characteristic mass scale

The intermediate type fraction is independent of luminosity and mass.

(Weinmann, vdB, Yang & Mo, 2006)

Comparison with Semi-Analytical Model

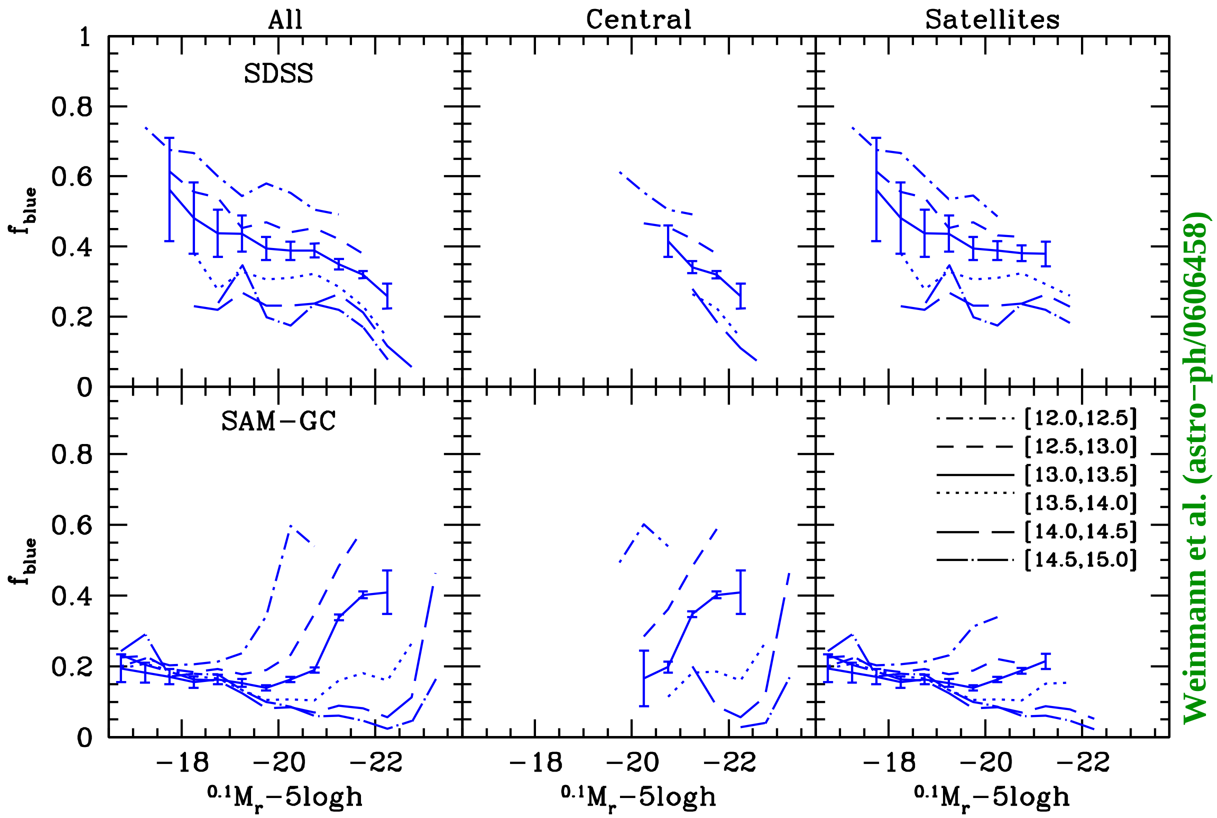
Comparison of Group Occupation Statistics with Semi-Analytical Model of Croton et al. 2006. Includes 'radio-mode' AGN feedback.



- **SAM matches global statistics of SDSS**
- **LF, bimodal color distribution, and overall blue fraction**
- **But what about statistics as function of halo mass?**

Constraining Star Formation Truncation

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



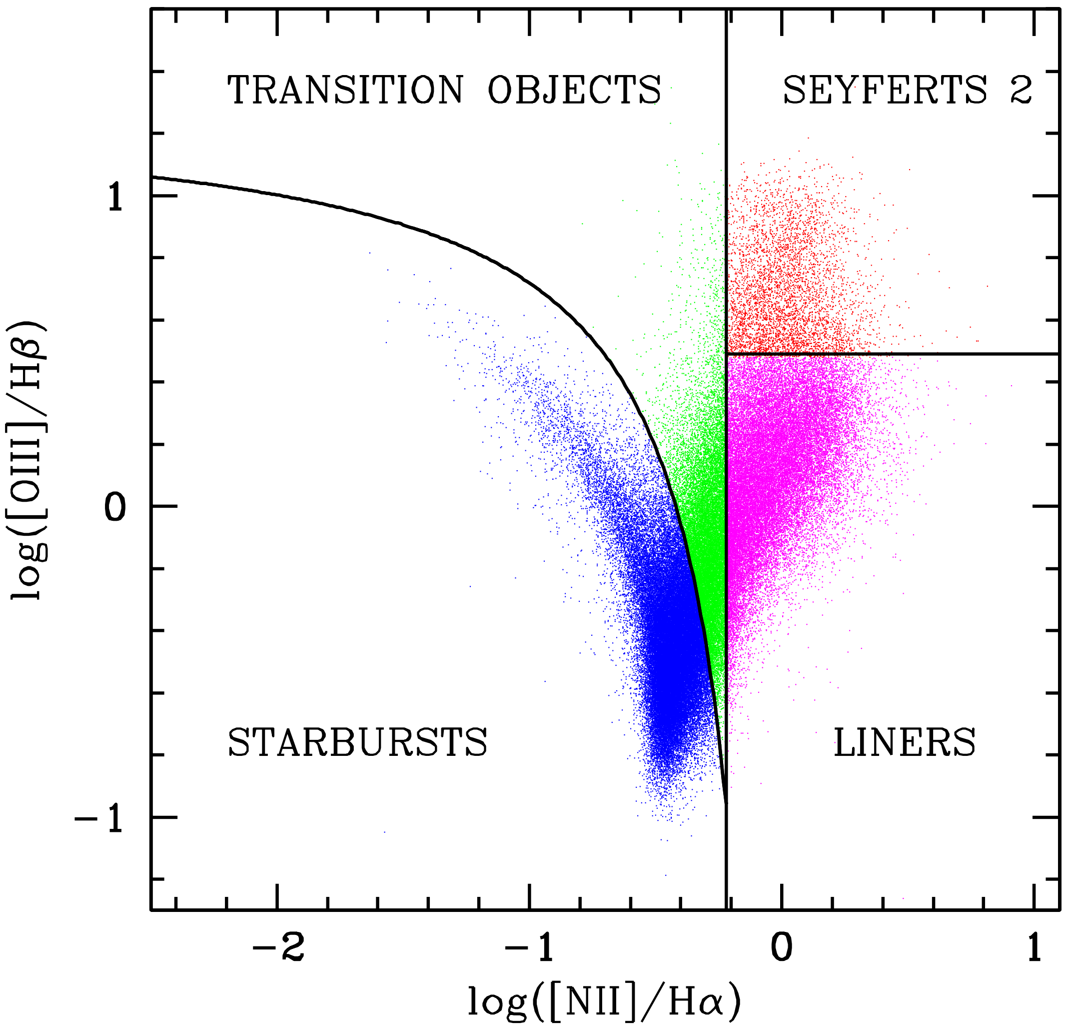
Satellites: red fraction too large: ▷ **strangulation too efficient**

Centrals: $f_{\rm blue}(L|M)$ **wrong:** ▷ **Problem with AGN feedback or dust**

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

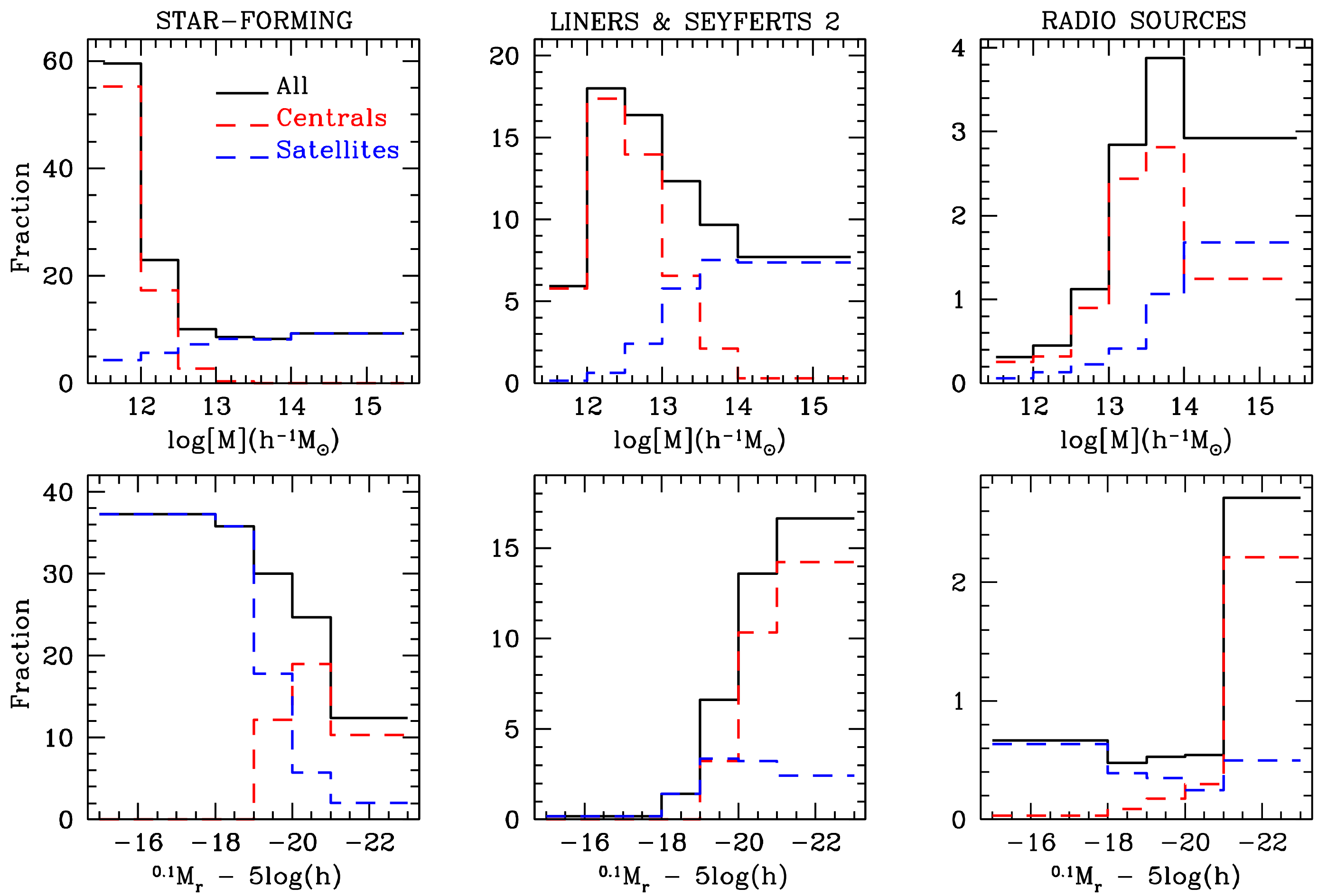
Defining Activity Classes

Galaxies can be classified in Seyferts, Liners and Starbursts using emission line ratios. We also use Radio detections (FIRST+NVVS).



Pasquali, vdB, et al. 2007, in prep.

Ecology of AGN and Starbursts



- **Central SB activity truncated at** $M \sim 10^{12} h^{-1}\ \mathrm{M}_{\odot}$
- **Central AGN activity peaks at** $M \sim 3 \times 10^{12} h^{-1}\ \mathrm{M}_{\odot}$
- **Radio-mode AGN activity peaks at** $M \sim 10^{14} h^{-1}\ \mathrm{M}_{\odot}$

Pasquali, vdB, et al. 2007, in prep.

Stochasticity and Stacking

To measure satelite kinematics or the weak lensing shear around galaxies, one needs to stack the signal of many galaxies.

Typically one stacks (central) galaxies in a narrow luminosity bin.

Unless $P(M|L_{\rm cen})$ is very narrow, this means stacking haloes of different masses, and signal does not reflect $\langle M\rangle(L_{\rm cen})$.

Proper interpretation of satelite kinematics and galaxy-galaxy lensing requires knowledge of $\sigma_{\rm logM}$.

How can we constrain the scatter in $P(M|L_{\rm cen})$?

- **Use 'predictions' from semi-analytical models for galaxy formation**
- **Compute from CLF:** $P(M|L_{\rm cen}) = \frac{\Phi_c(L|M)\, n(M)}{\Phi_c(L)}$ *(Bayes Theorem)*
- **Use satellite kinematics; host-weighting *vs.* satellite weighting**

Satellite Kinematics

Ecology

Stochasticity

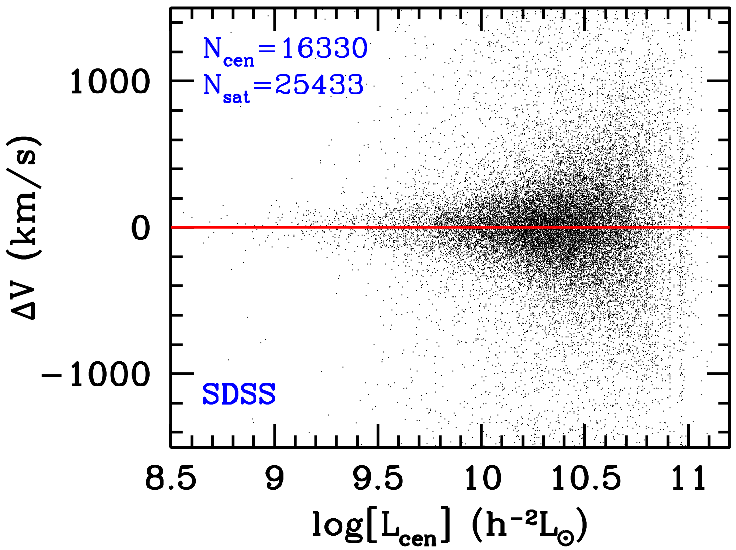
- Stochasticity and Stacking
- Satellite Kinematics
- The Scatter in $P(M|L_{\rm cen})$

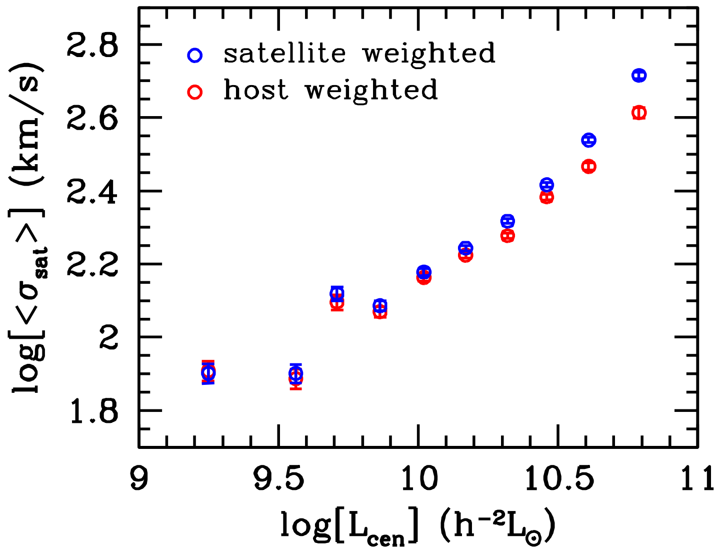
Conclusions

Extra Material

Select **centrals** **and** **satellites** **and determine** $\sigma_{\rm sat}(L_{\rm cen})$**, describing the width of** $P(\Delta V)$ **with** $\Delta V = V_{\rm sat} - V_{\rm cen}$

(More, vdB, et al. 2007, in prep.)





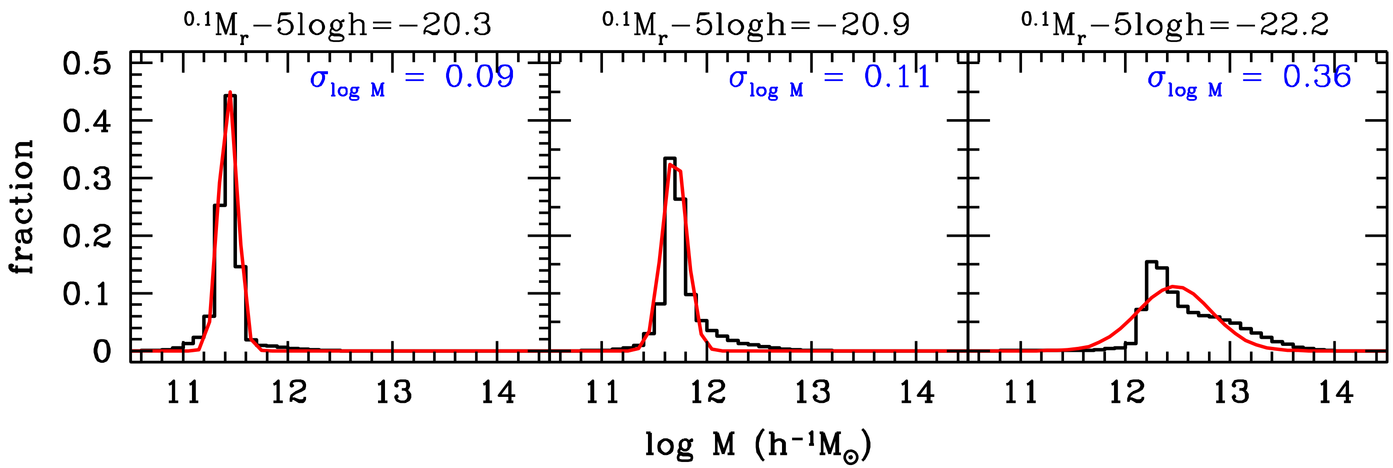
$$\langle\sigma_{\rm sat}\rangle(L_{\rm cen}) = \frac{\int P(M|L_{\rm cen})\,\langle N_{\rm sat}\rangle_M^p\,\langle\sigma_{\rm sat}\rangle_M\,{\rm d}M}{\int P(M|L_{\rm cen})\,\langle N_{\rm sat}\rangle_M^p\,{\rm d}M}$$

- $p = 1$: **satellite-weighted mean** $\langle\sigma_{\rm sat}\rangle_{\rm sw}$
- $p = 0$: **host-weighted mean** $\langle\sigma_{\rm sat}\rangle_{\rm hw}$

Unless $P(M|L_{\rm cen}) = \delta(M - \langle M\rangle)$ **one has that** $\langle\sigma_{\rm sat}\rangle_{\rm sw} > \langle\sigma_{\rm sat}\rangle_{\rm hw}$

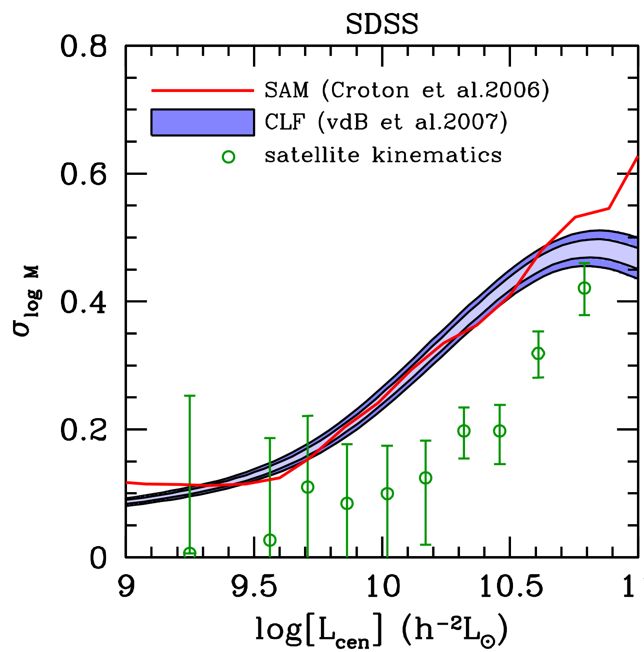
Both $\langle\sigma_{\rm sat}\rangle_{\rm sw}$ **and** $\langle\sigma_{\rm sat}\rangle_{\rm hw}$ **can be determined from data.**

The Scatter in $P(M|L_{\rm cen})$



Assuming that $P(M|L_{\rm cen})$ is a log-normal, the combination of $\langle\sigma_{\rm sat}\rangle_{\rm sw}$ and $\langle\sigma_{\rm sat}\rangle_{\rm hw}$ allows one to compute both $\langle M\rangle$ and $\sigma_{\log M}$ as function of $L_{\rm cen}$.

(More, vdB et al. 2007, in prep.)



All methods agree that scatter in $P(M|L_{\rm cen})$ increases with $L_{\rm cen}$

Conclusions

- **Modern redshift surveys allow the construction of large and well-defined group catalogues.**
- **The ecology of galaxies yields useful constraints on physics of galaxy formation.**
- **The ecology of AGN agrees with a "cold-mode" to "hot-mode" transition at** $M \simeq 10^{12} - 10^{13} h^{-1}\,\mathrm{M}_\odot$
- **Satellite kinematics can be used to probe and quantify the stochasticity in galaxy formation.**
- **Scatter in** $P(M|L_{\rm cen})$ **increases strongly with increasing** $L_{\rm cen}$