Galaxy Ecology

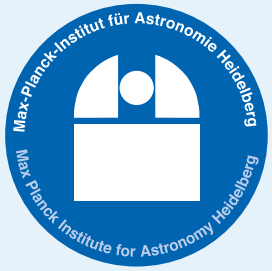
an Environmental Impact Assessment

Frank van den Bosch (MPIA)

in collaboration with

Xiaohu Yang (SHAO), Houjun Mo (UMass), Simone Weinmann (Zürich)

Anna Pasquali (MPIA), Daniel Aquino (MPIA)



Outline of this Talk

ECOLOGY

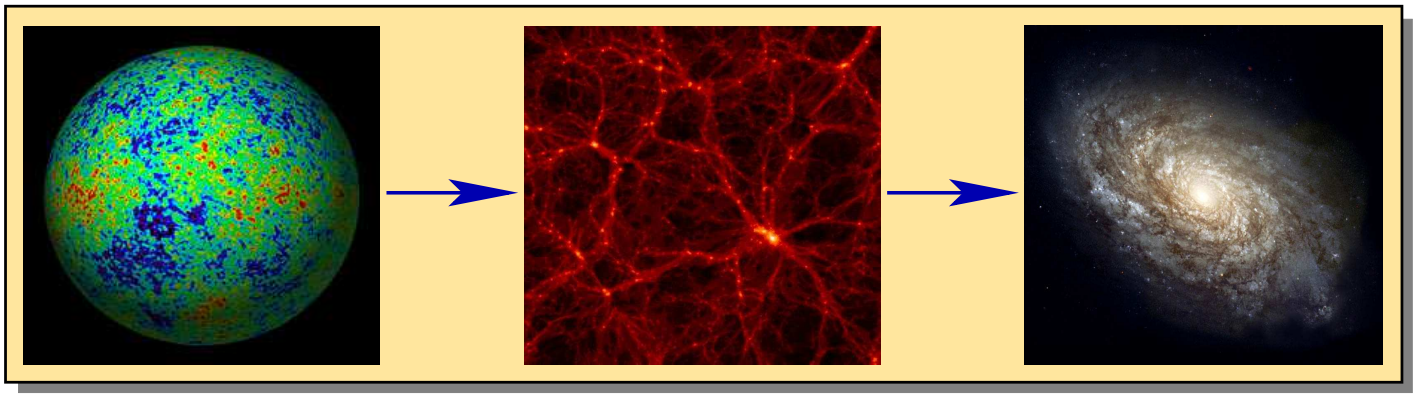
1. a branch of science concerned with the interrelationship of organisms and their environments
2. the totality or pattern of relations between organisms and their environment

(Merriam-Webster's Dictionary)

- Galaxy Transformations
- Overview of Observational Evidence for Environment Dependence
- Studying Galaxy Ecology with SDSS Group Catalogues
- Centrals vs. Satellites: Contraining Transformation Mechanisms
- The Ecology of Satellite Galaxies
- Conclusions

Galaxy Transformations

PARADIGM: All galaxies form as central disk galaxies.



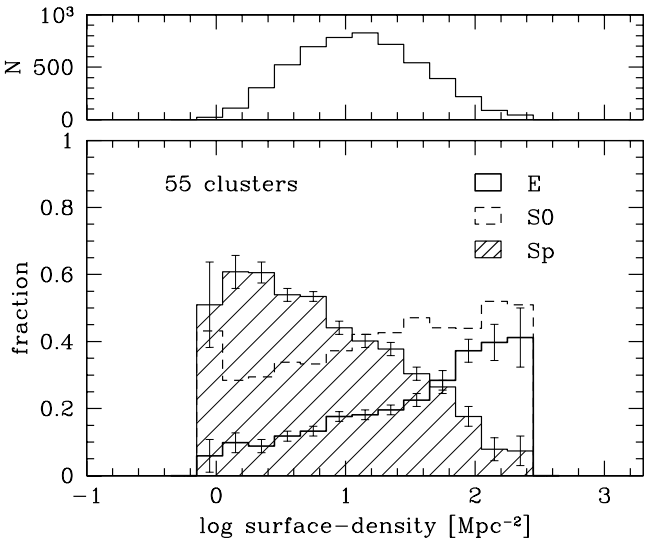
- **Mergers between haloes create satellite galaxies that orbit halo**
- **Dynamical friction causes galaxies to merge $\Rightarrow$ transformation**

Satellite galaxies are subject to several transformation processes:

- **Tidal stripping & heating** — due to tidal field of parent halo
- **Strangulation** — stripping of hot gas atmosphere
- **Ram-pressure stripping** — stripping of cold gas
- **Galaxy Harassment** — impulsive encounters with other satellites

The efficiencies of these processes are environment dependent

The Morphology-Density Relation

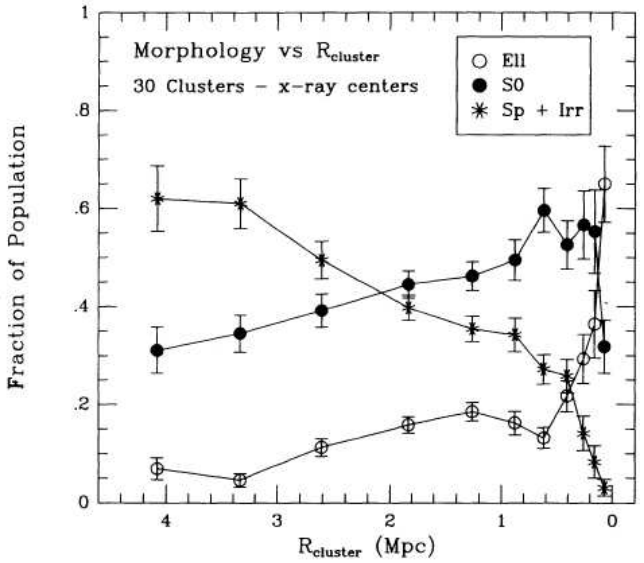


Elliptical galaxies are preferentially found in dense environments (clusters), while spiral galaxies reside predominantly in low density environments (the field).

(Dressler 1980)

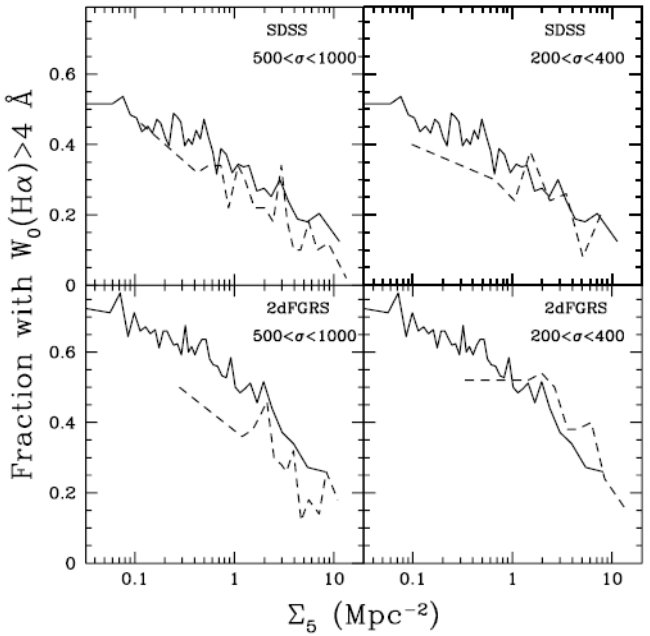
Galaxy Morphologies depend on cluster-centric radius: the spiral fraction is larger at cluster outskirts than at center.

(Whitmore, Gilmore & Jones 1993)



Both trends also clearly present in SDSS (Goto et al. 2003)

Environment Dependence of Star Formation

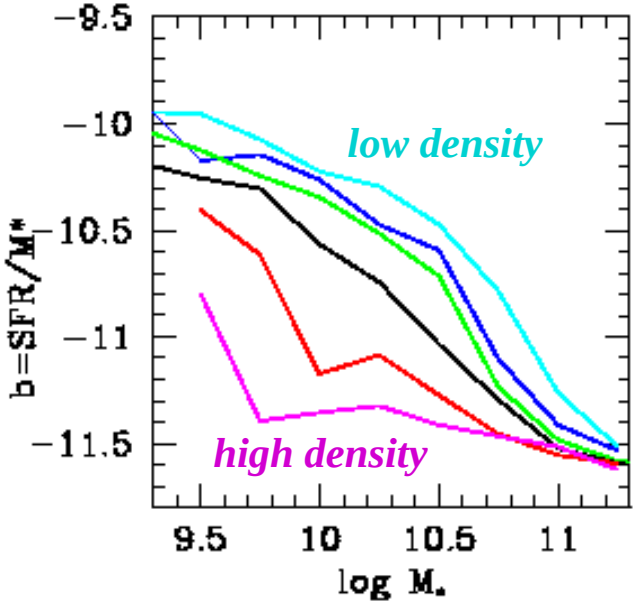


The fraction of star forming galaxies decreases with increasing density of the environment.

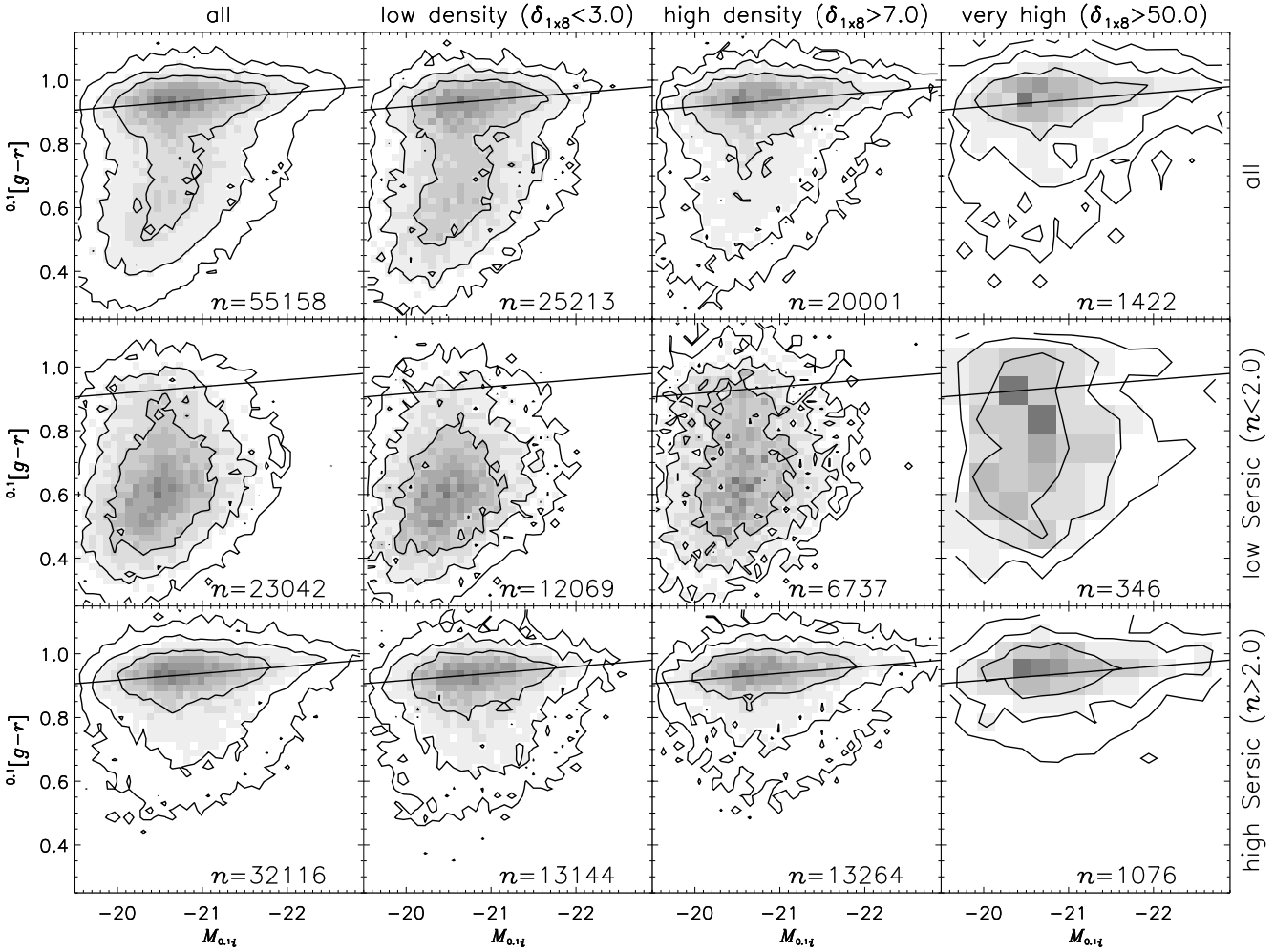
(Balogh et al. 2004)

At fixed stellar mass, galaxies in denser environments have lower (median) specific star formation rates.

(Kauffmann et al. 2004)



Environment Dependence of Galaxy Colors



The Color-Magnitude relation is strongly environment dependent

(Hogg et al. 2004)

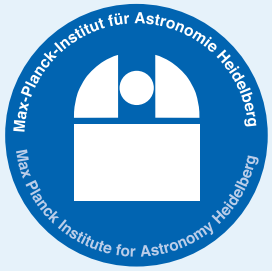
Galaxy Ecology

Galaxies in dense environments are more massive, older, redder, and more concentrated than galaxies in less dense environments

OUTSTANDING QUESTIONS

- Which galaxy properties are most directly related to which environment indicator; which relations are causal?
- What is the characteristic scale of environment dependence?
- What is the physical origin: Nature *vs.* Nurture
- Which mechanism(s) is responsible for transformations

These questions can be addressed by confronting data from the SDSS with galaxy formation models and numerical simulations



How to Quantify Environment?

The environment of a galaxy can be specified in different ways:

Σ_R: Projected number density in circular aperture of radius R
Σ_n: Projected number density out to $n^{\rm th}$ nearest neighbour
$R_{\rm proj}$: Projected distance from group/cluster center
$M_{\rm vir}$: Virial mass of dark matter halo (group)

Latter two are preferred from theoretical point of view, but are very difficult to measure

Former two are observationally accessible, but their physical interpretation is environment dependent:

- In clusters Σ_n measures environment on scales $R < R_{\rm vir}$
- In field Σ_n measures environment on scales $R > R_{\rm vir}$

The halo virial radius is the most natural scale to consider

e.g., Mo et al. 2004; Kauffmann et al. 2004; Blanton et al. 2006

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

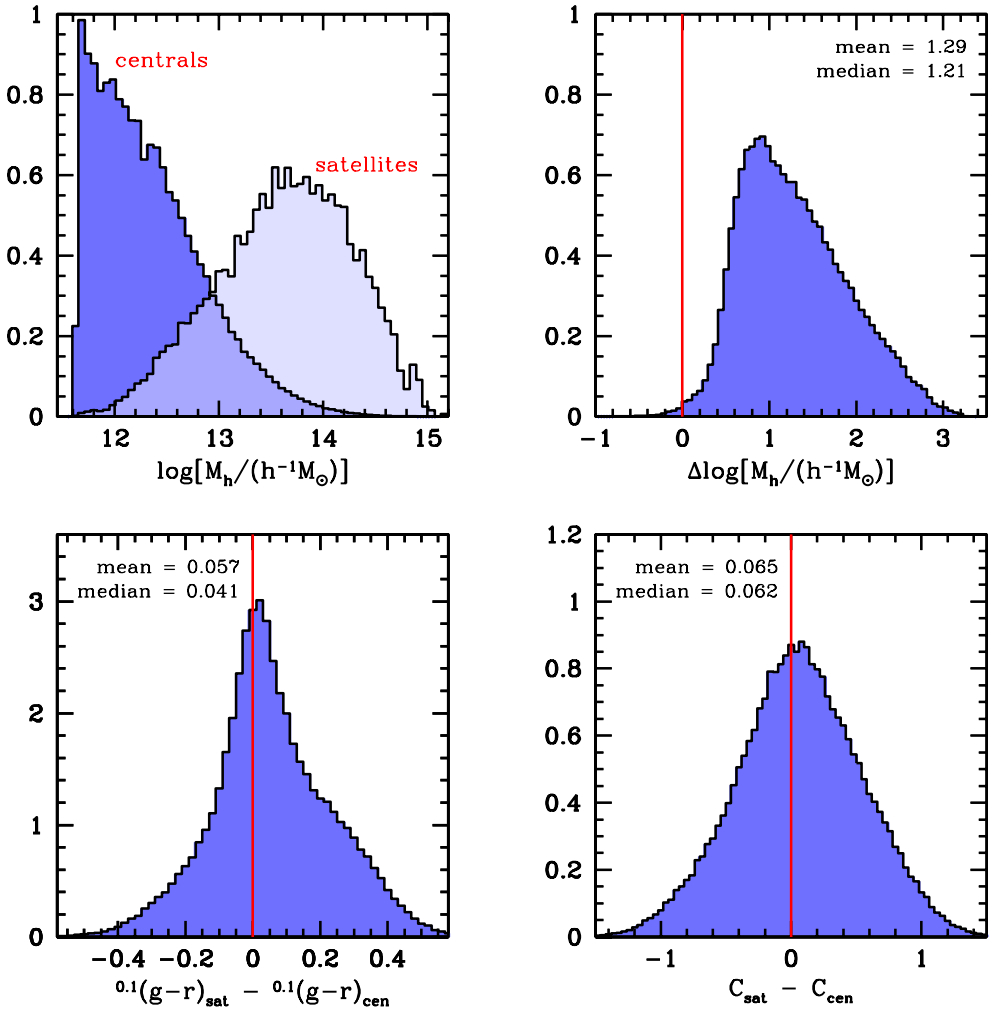
Yang et al. 2005, 2007

- **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 ($11.5 \lesssim \log[M/\,\mathrm{M}_\odot] \lesssim 15$).**

Following results based on SDSS DR4 group catalogue, which consists of $369,447$ galaxies distributed over $301,237$ groups

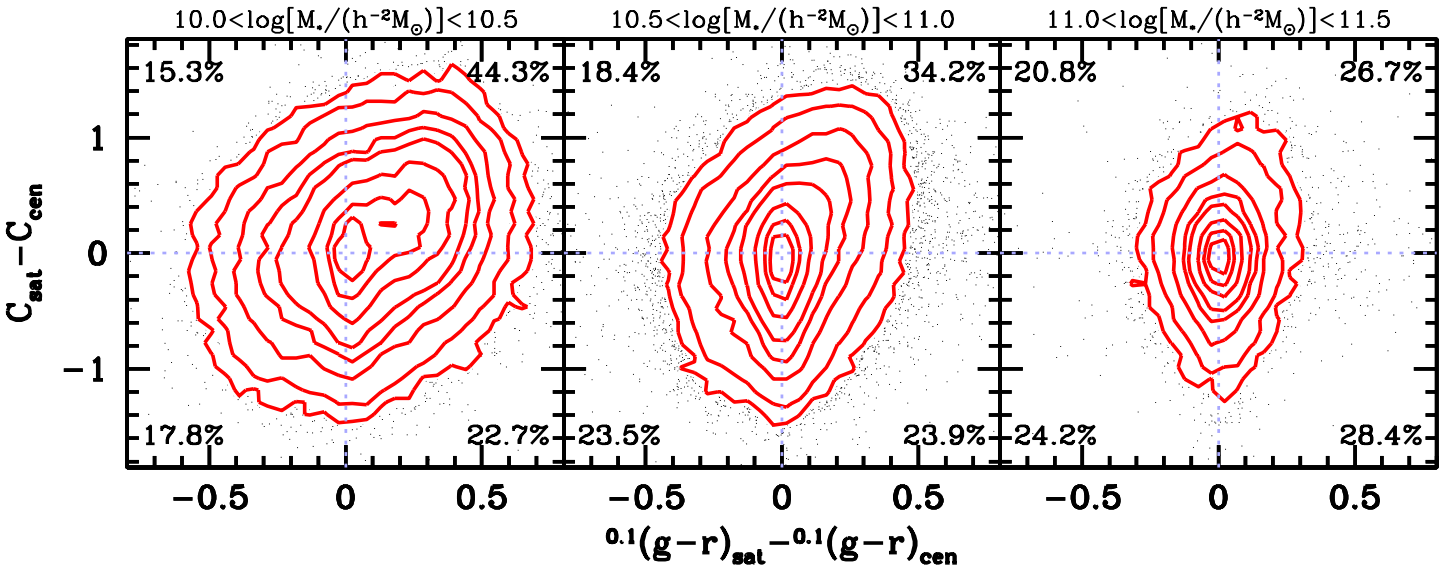
Centrals vs. Satellites: matched in stellar mass

Use group catalogue to split galaxies in centrals, satellites and isolated



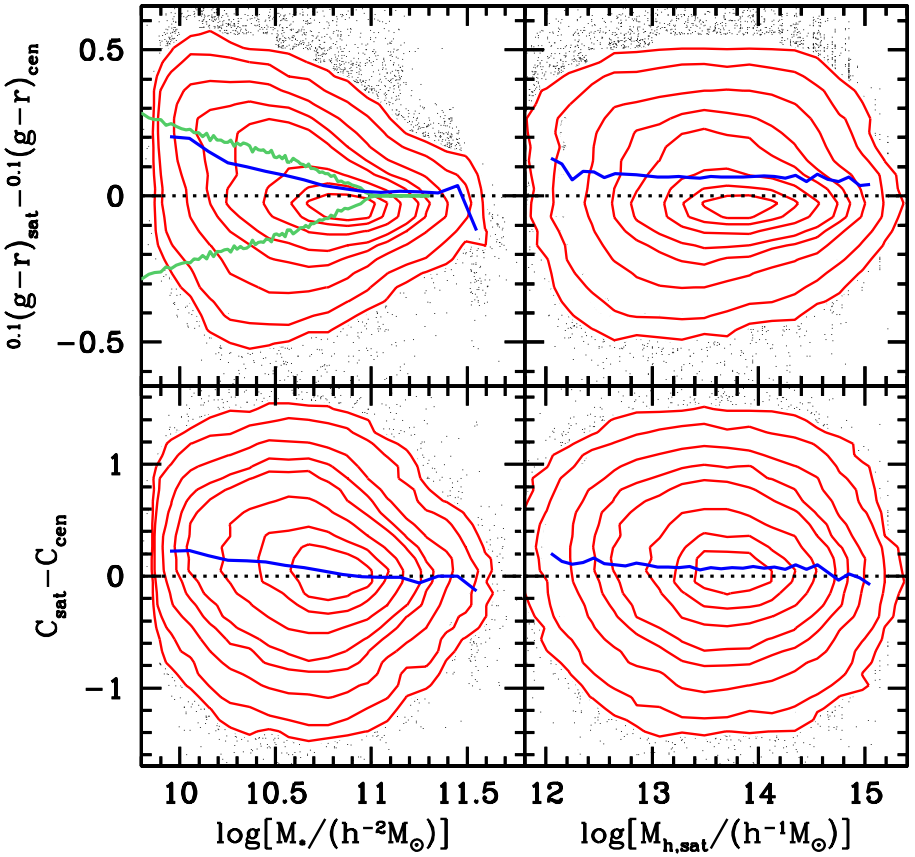
- Sats are ~ 0.06 magn **redder** than centrals of same $M_{\rm star}$
- Sats are marginally **more concentrated** than centrals of same $M_{\rm star}$

Stellar Mass Dependence



- Low mass galaxies ($M_{\rm star} < 10^{11}\,{\rm M}_\odot$) become redder and more concentrated after having been accreted
- Massive galaxies ($M_{\rm star} > 10^{11}\,{\rm M}_\odot$) show no sign of undergoing a transformation after being accreted

Dependence on Halo Mass and Stellar Mass



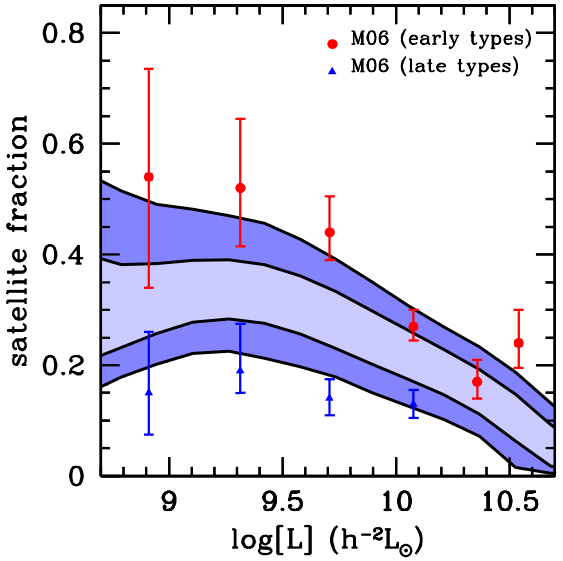
- Color difference at low stellar mass roughly follows bimodality
- There is no dependence on the halo mass of satellite

Transformation efficiency is independent of halo mass

Satellite Ecology

Most transformation mechanisms only work on satellite galaxies:

Strangulation, Ram-pressure stripping, harassement, tidal stripping & heating



Satellite galaxies only account for 20 to 40 percent of entire galaxy population.

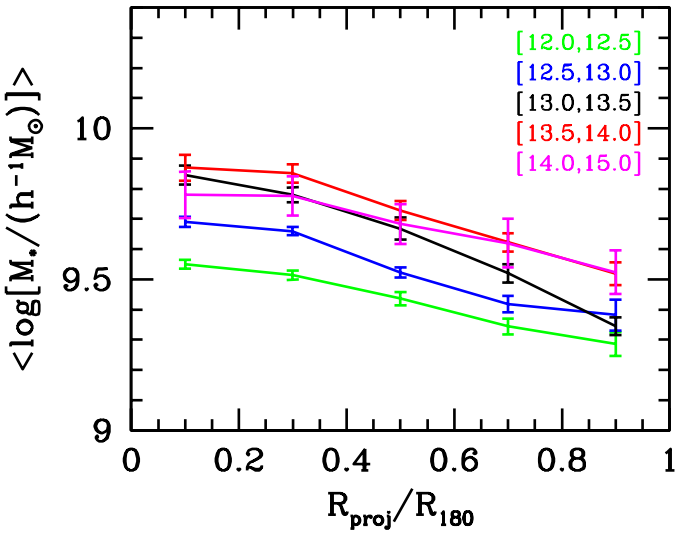
Central galaxies can wash out environment signal

(vdB et al. 2007, MNRAS, 376, 841)

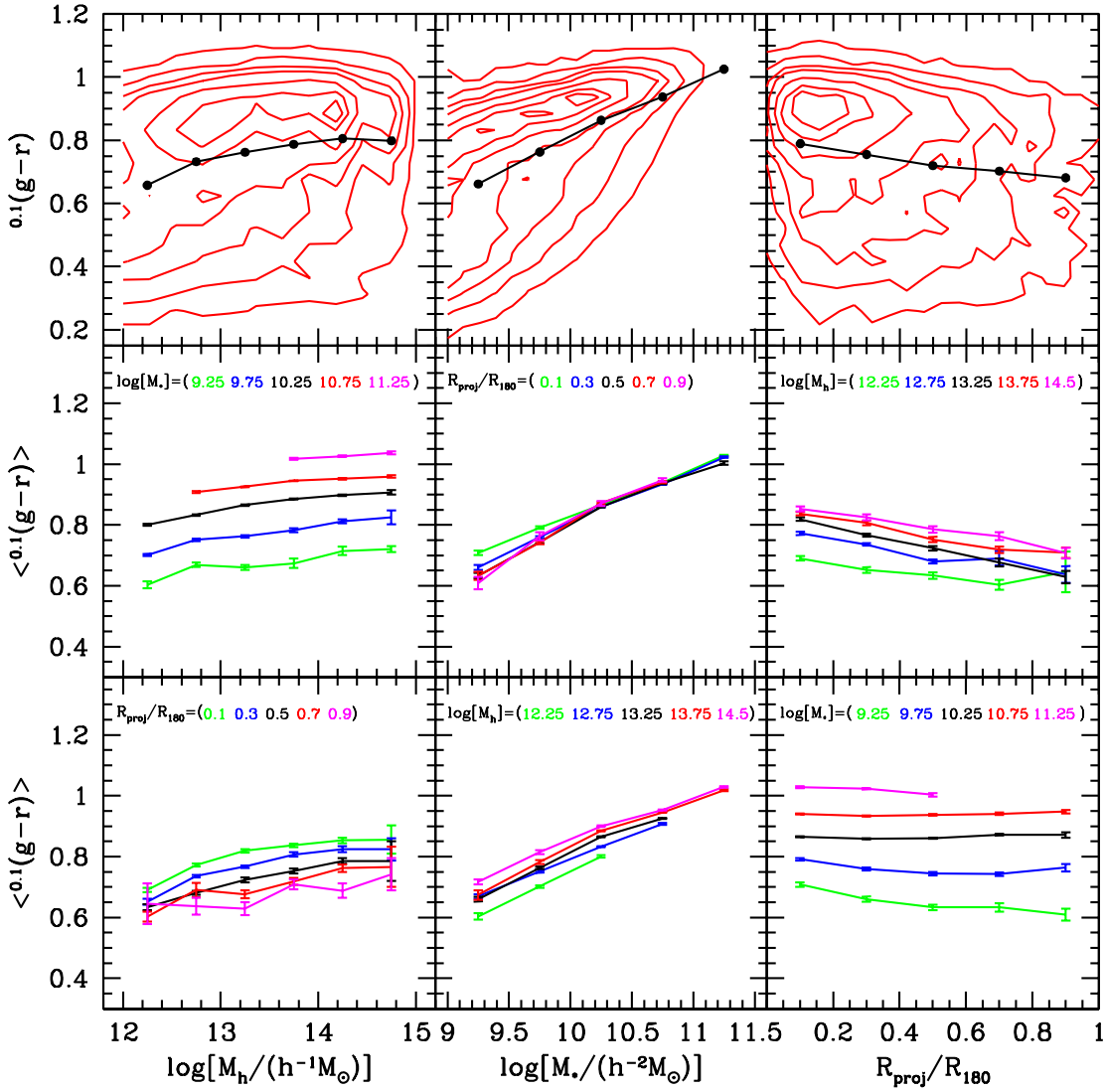
Use group catalogue to only select satellite galaxies

Study color and concentration as function M_h, M_*, and $R_{\rm proj}$

(vdB et al. 2007, in preparation)

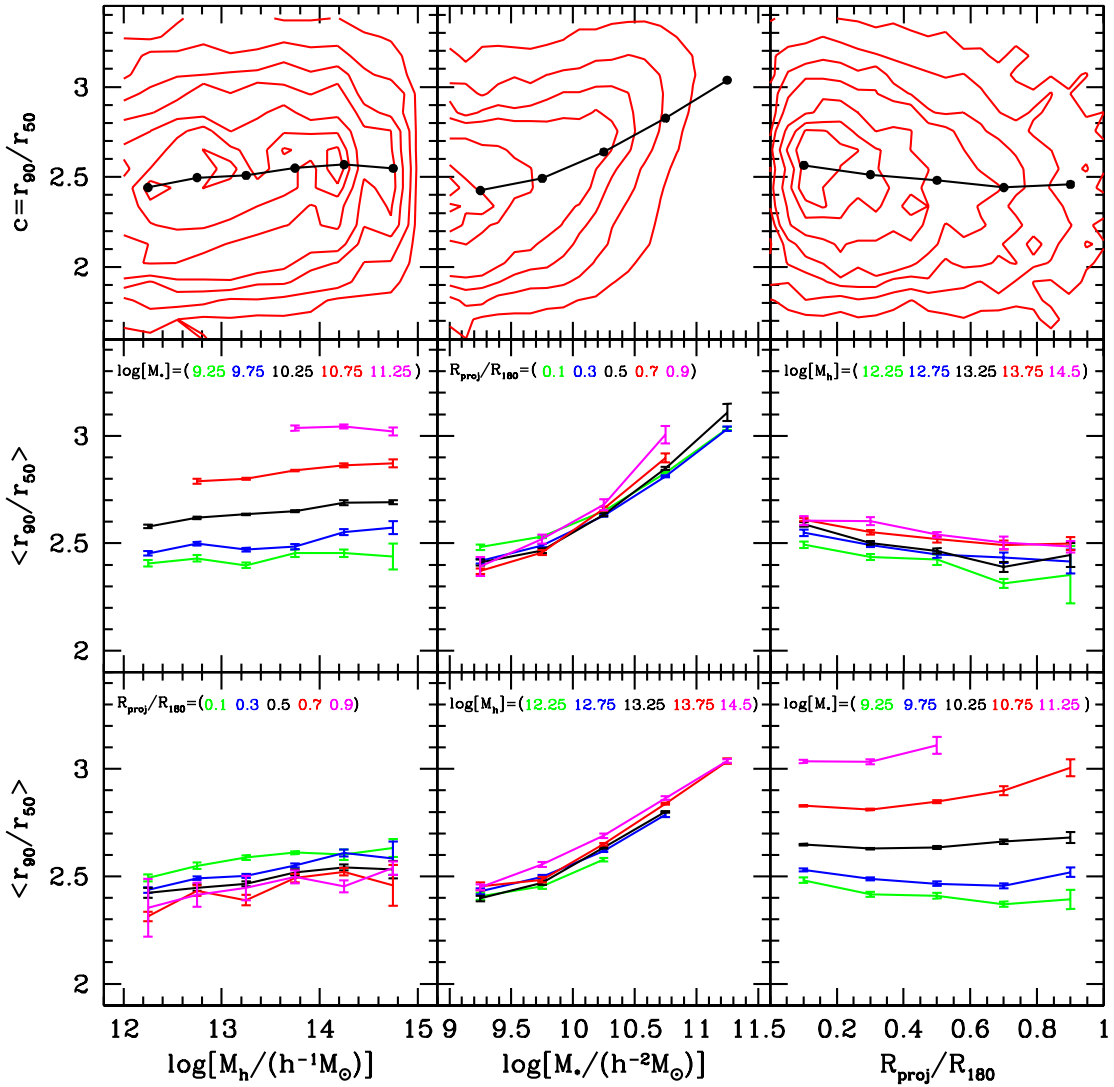


Average Colors of Satellite Galaxies



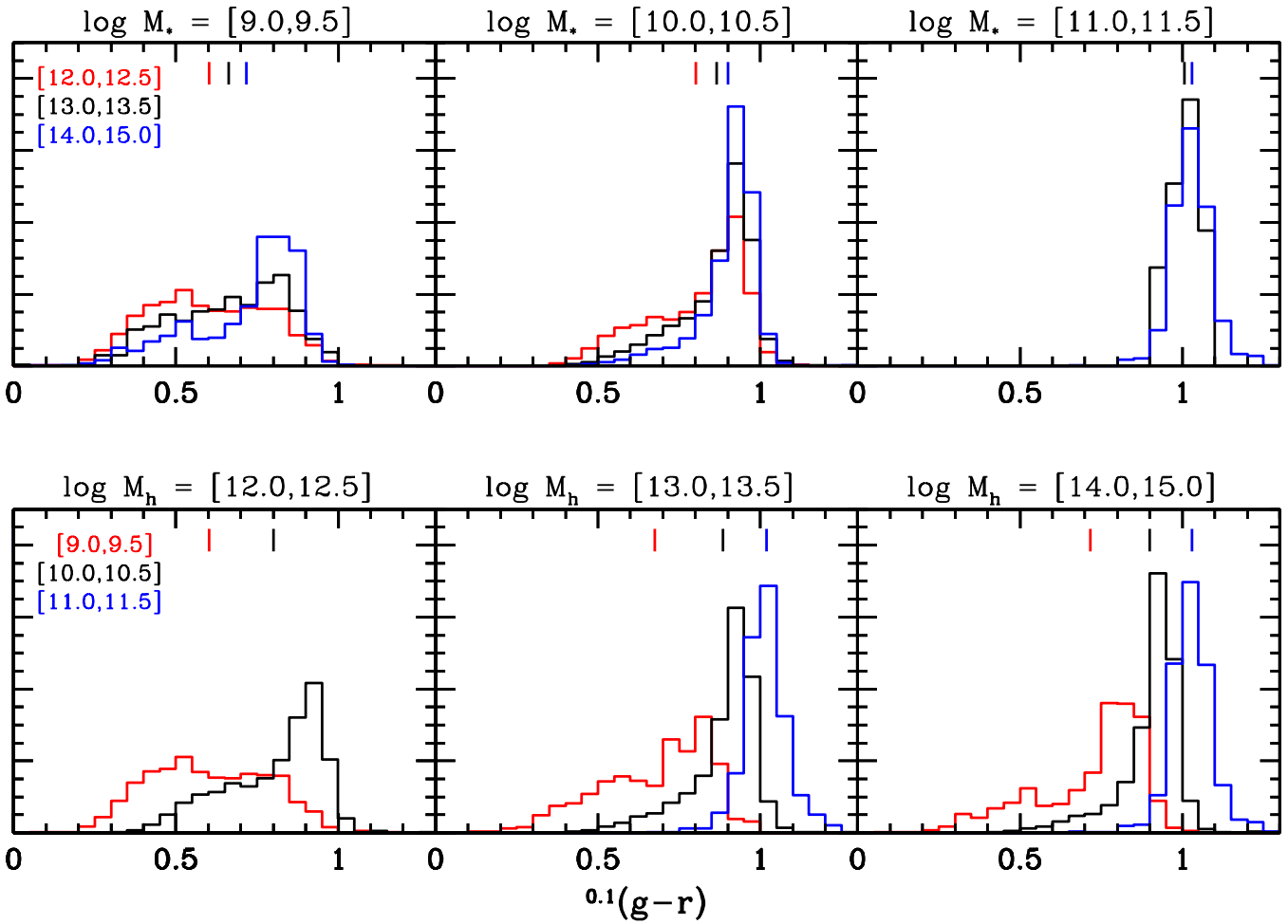
At fixed M_*, average satellite color independent of environment

Average Satellite Concentrations



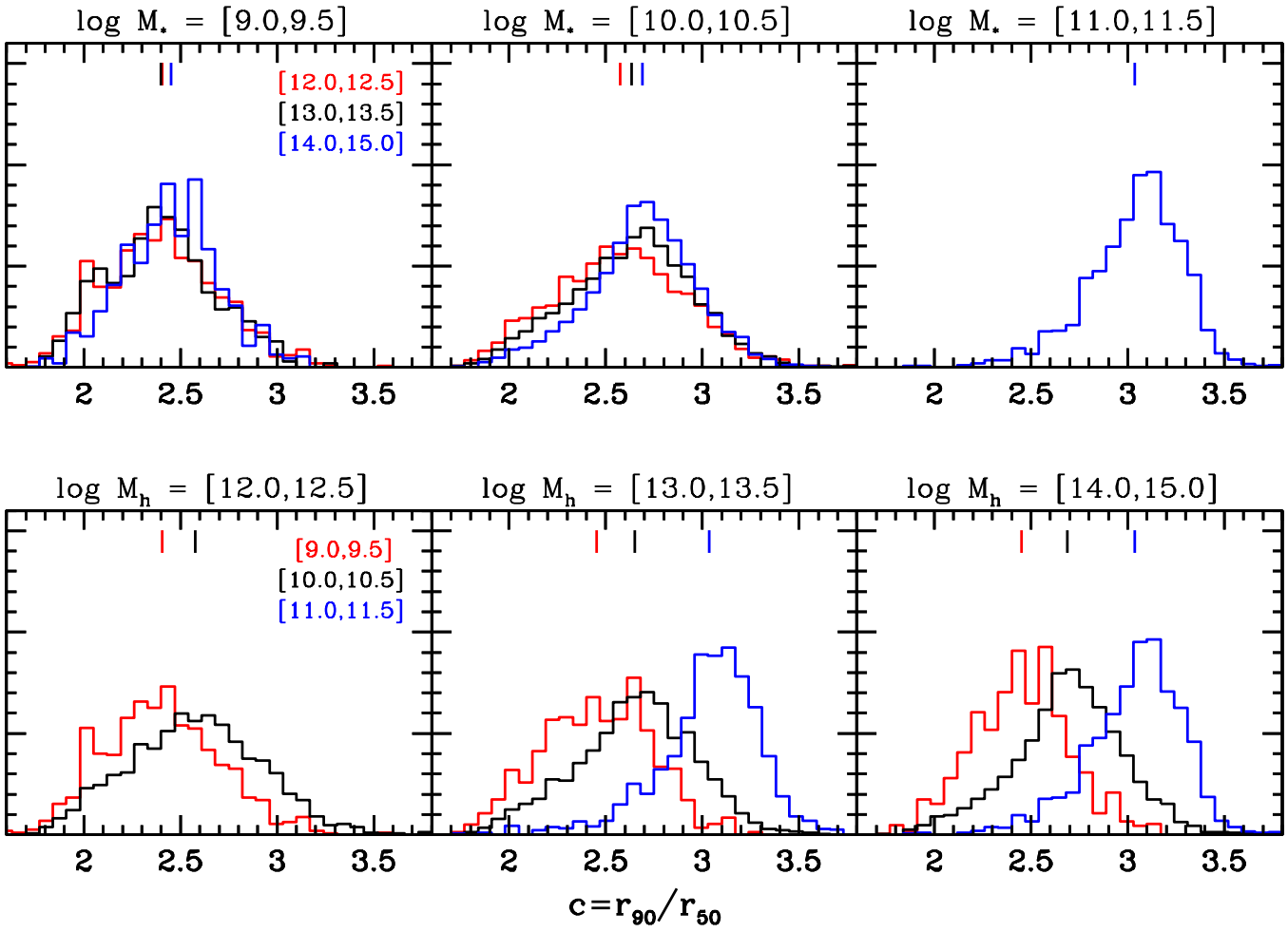
At fixed M_*, average satellite concentration independent of environment

Beyond the First Moments



Satellite colors depend only very weakly on environment

Beyond the First Moments



Satellite concentrations are independent of environment

Conclusions

- Massive galaxies are transformed as **centrals**
  Low mass galaxies are transformed as **satellites**
- Efficiency of transformation mechanism(s) independent of **halo mass**
- **Ram-pressure stripping** can not play an important role
- Satellite galaxies reveal (almost) **no environment dependence**.
  Their colors and concentrations depend only on **stellar mass**.
- Neither clusters nor groups are **special environments**

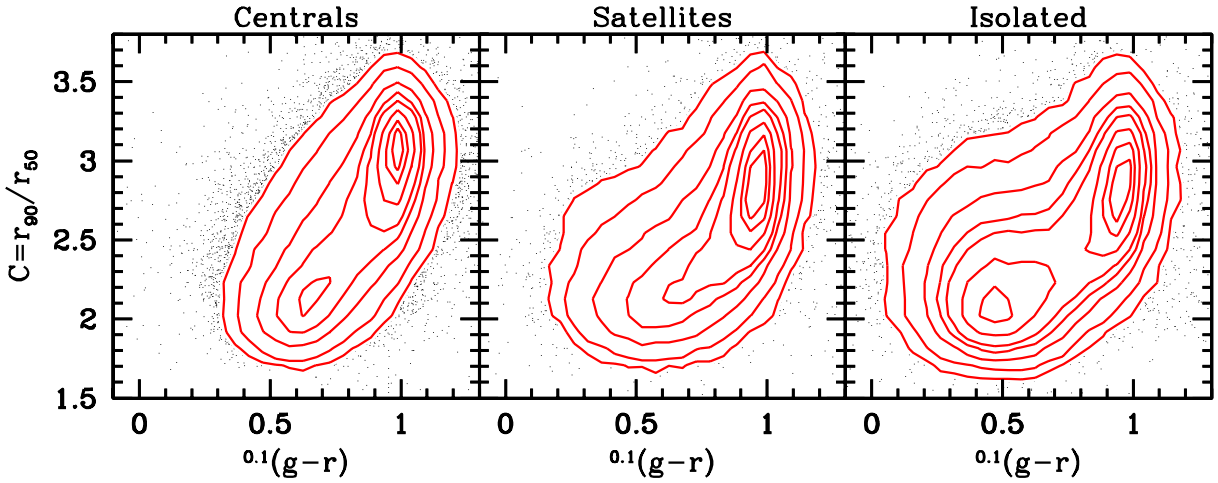
Conclusions

- Massive galaxies are transformed as **centrals**
  Low mass galaxies are transformed as **satellites**
- Efficiency of transformation mechanism(s) independent of **halo mass**
- **Ram-pressure stripping** can not play an important role
- Satellite galaxies reveal (almost) **no environment dependence**.
  Their colors and concentrations depend only on **stellar mass**.
- Neither clusters nor groups are **special environments**

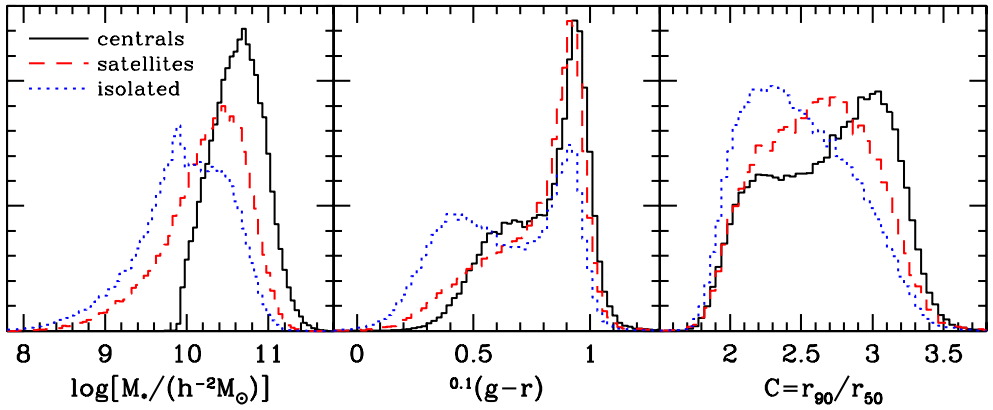
Environment dependence largely vanishes when separating centrals and satellites and when keeping stellar mass fixed.

Centrals vs. Satellites

Use group catalogue to split galaxies in centrals, satellites and isolated



Going from centrals to satellites to isolated galaxies, the fraction of blue, low concentration galaxies increases



Most easily interpreted as stellar mass effect rather than environment