Disentangling the Environmental Dependence of Morphology and Color

Implications for the Evolution of Central and Satellite Galaxies

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Outline

- Exploring the environmental dependence of galaxy formation, by analyzing correlations between galaxy properties and environment
- Our main tools: mark clustering statistics, with halo occupation modeling and galaxy group catalogs

1. Environmental dependence of galaxy color
   - SDSS measurements, halo model, group catalog
2. Environmental dependence of galaxy morphology, using morphology likelihoods from Galaxy Zoo
   - SDSS measurements
3. Disentangling the environmental dependence of morphology & color
   - SDSS measurements
4. Conclusion

Important Questions

How does galaxy formation depend on environment? In particular, how do galaxy properties depend on the galaxies' small-scale and large-scale environments?

How are galaxies affected by their host dark matter halos? What aspects of galaxy formation and evolution can be explained by halo formation and evolution?

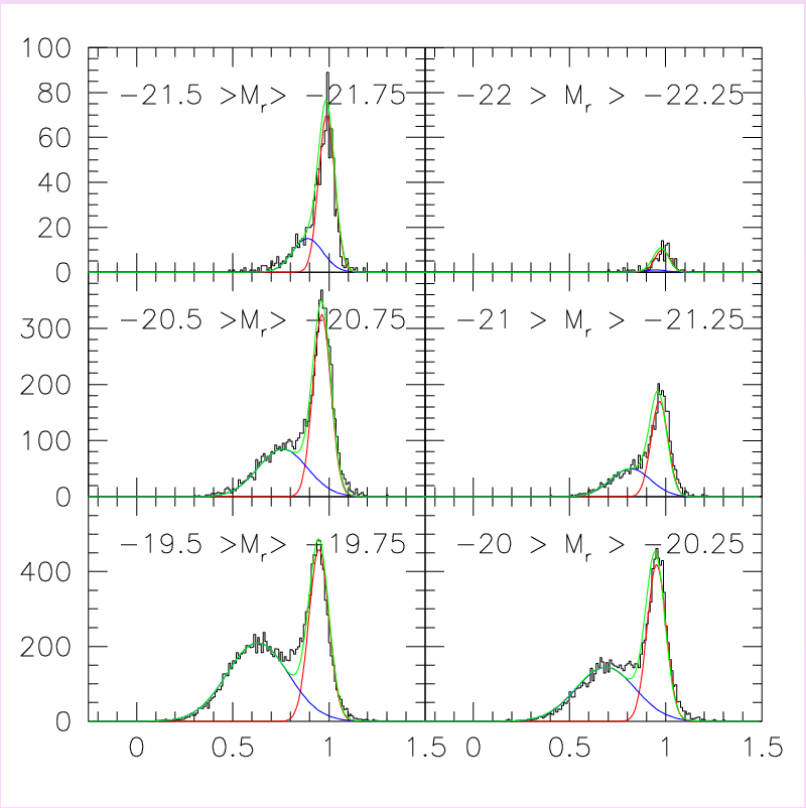
How do central galaxies in halos and satellite galaxies in halo substructures evolve differently?

Modeling the Color-Magnitude Distribution

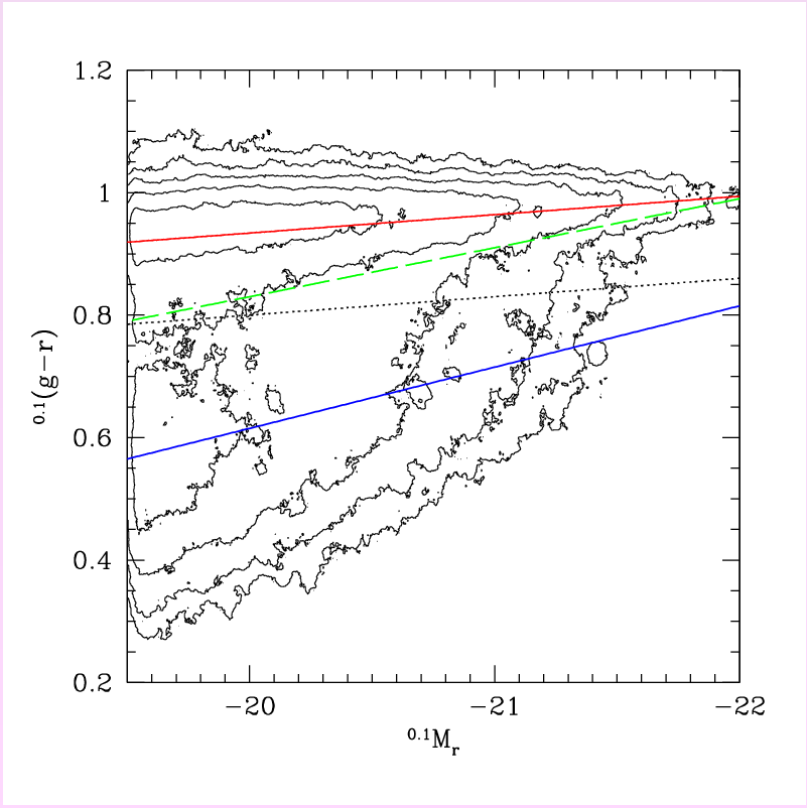
constraints from $P(c|L)$, the color distribution at fixed luminosity (left), which we assume to be independent of halo mass

one additional assumption, that satellite galaxies tend to follow a particular sequence on the color-magnitude diagram (right)

color distribution (at fixed L)



color-luminosity diagram



Skibba & Sheth 2009

Environmental Dependence of Color

Environmental dependence of galaxy properties described by *marked* statistics:

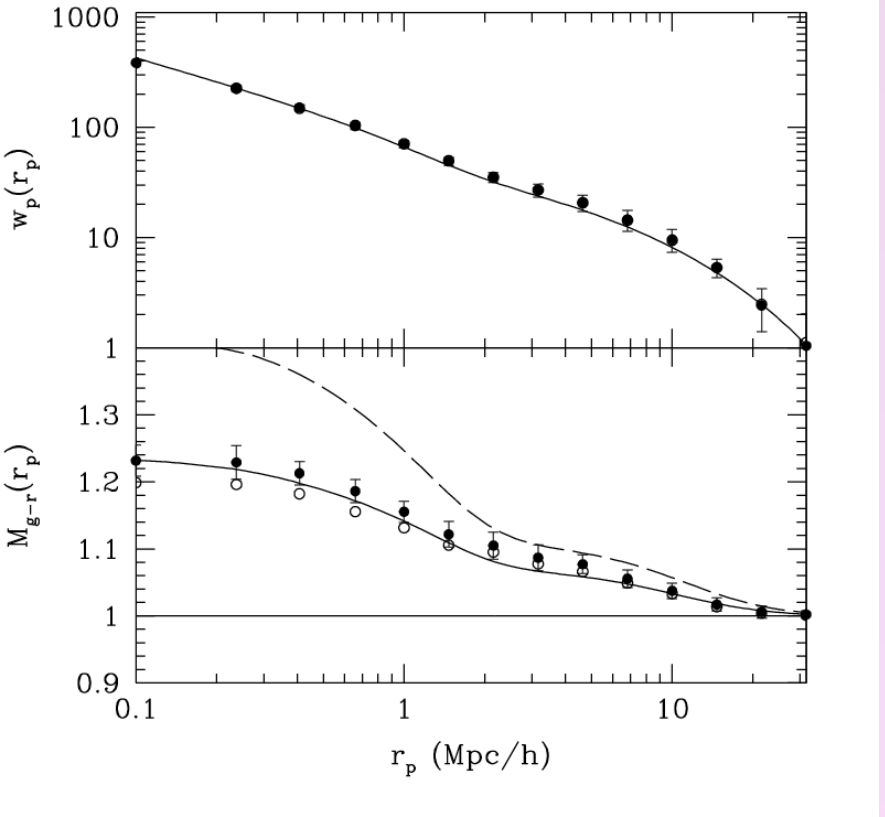
Marked Correlation Function

$$M(r) \equiv \frac{1 + W(r)}{1 + \xi(r)}$$

If $M(r) = 1$, then galaxy property (or 'mark') is uncorrelated w/ enviro

If $M(r) > 1$, larger values of mark tend to occur in denser environments

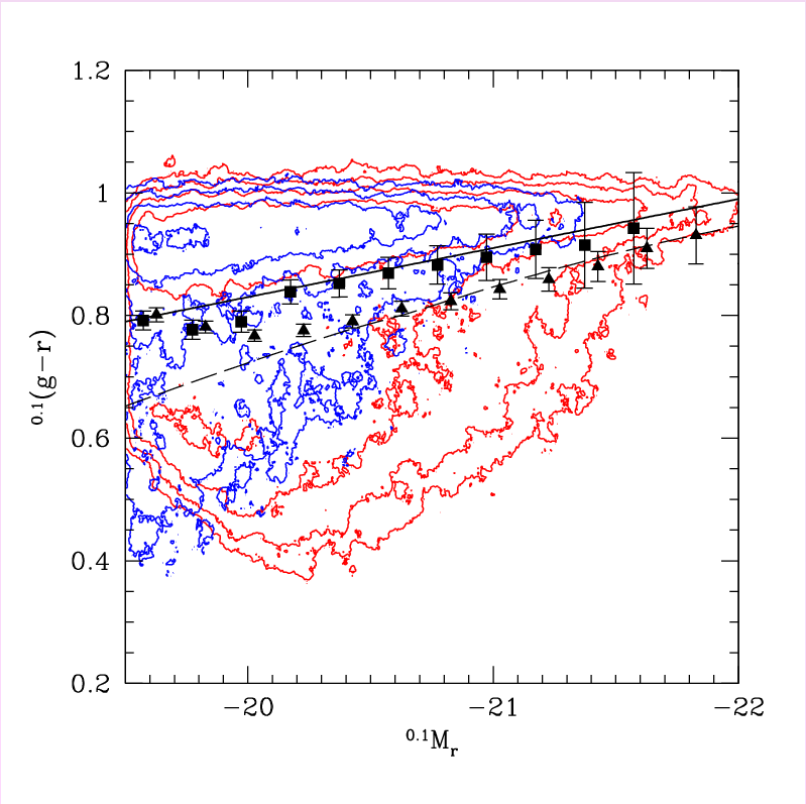
color-marked CF

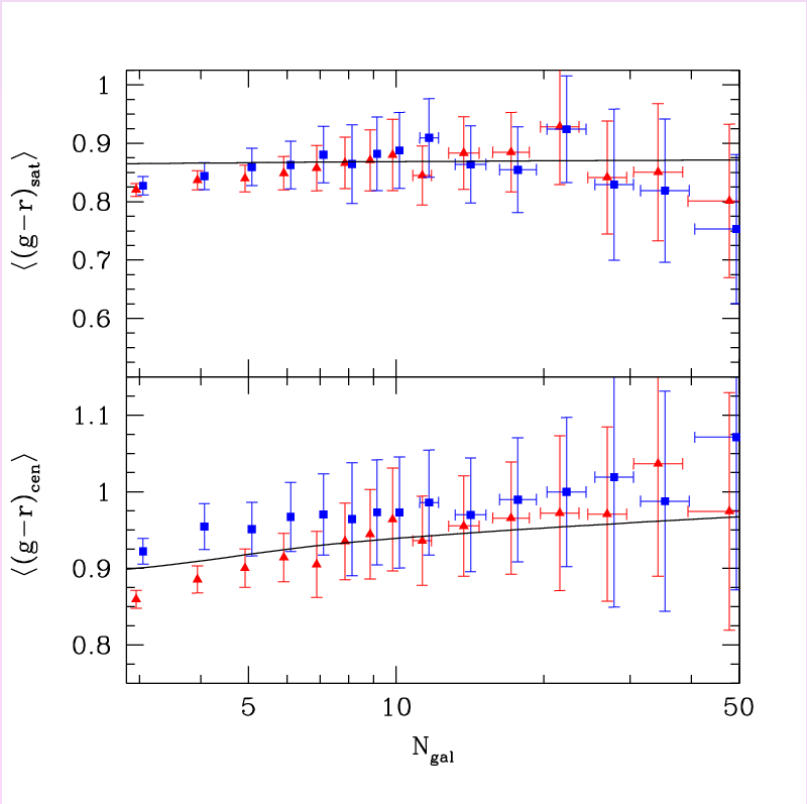


- redder galaxies tend to be located in denser environments
- **environmental dependence of galaxy color explained by that of halo mass**, assuming that satellite galaxy colors approach red sequence at bright luminosities

Colors of Central and Satellite Galaxies

- model predicts central & satellite galaxies tend to follow particular sequences in CMD (left), consistent with group catalog
- satellite galaxies are slightly redder than centrals at fixed luminosity
- central galaxies are the reddest at fixed halo mass/richness (right)
- satellite galaxy color is almost independent of halo mass





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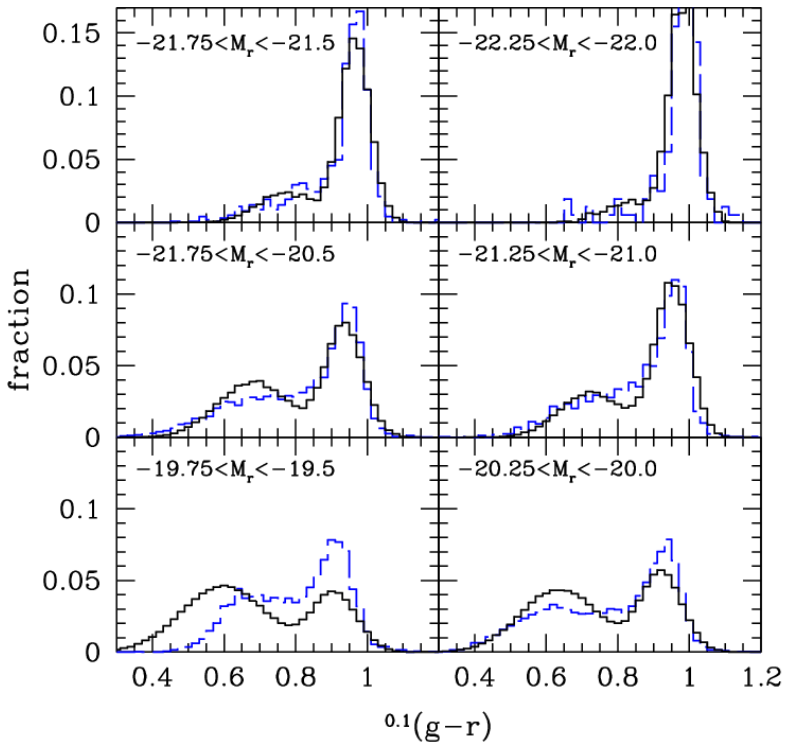
Central & Satellite Color Distributions I

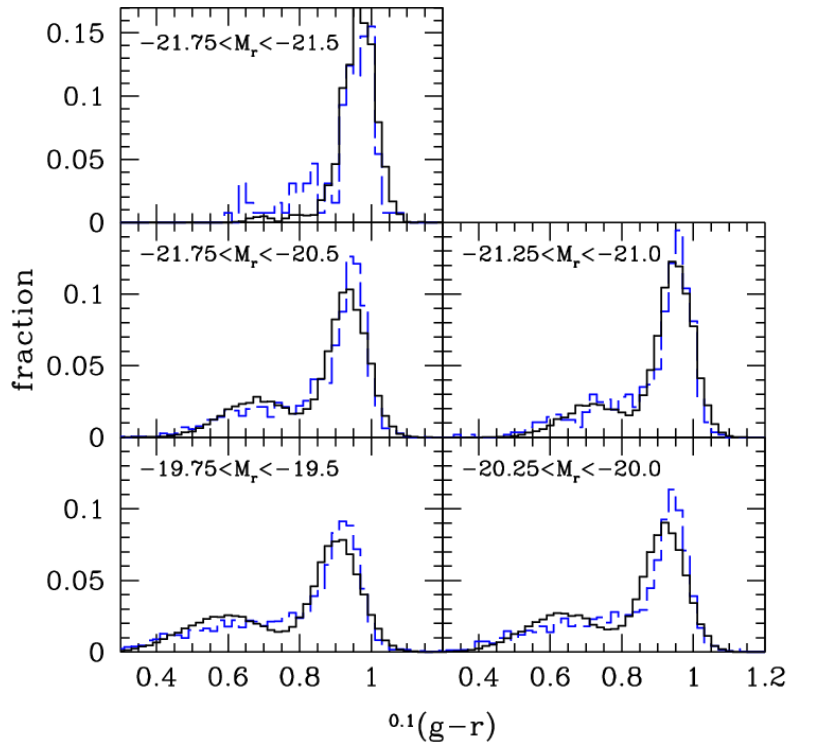
model (black) *vs.* SDSS groups (Yang et al. 2007: blue)

at fixed luminosity, red fraction is larger for satellites than centrals

central galaxies



satellite galaxies



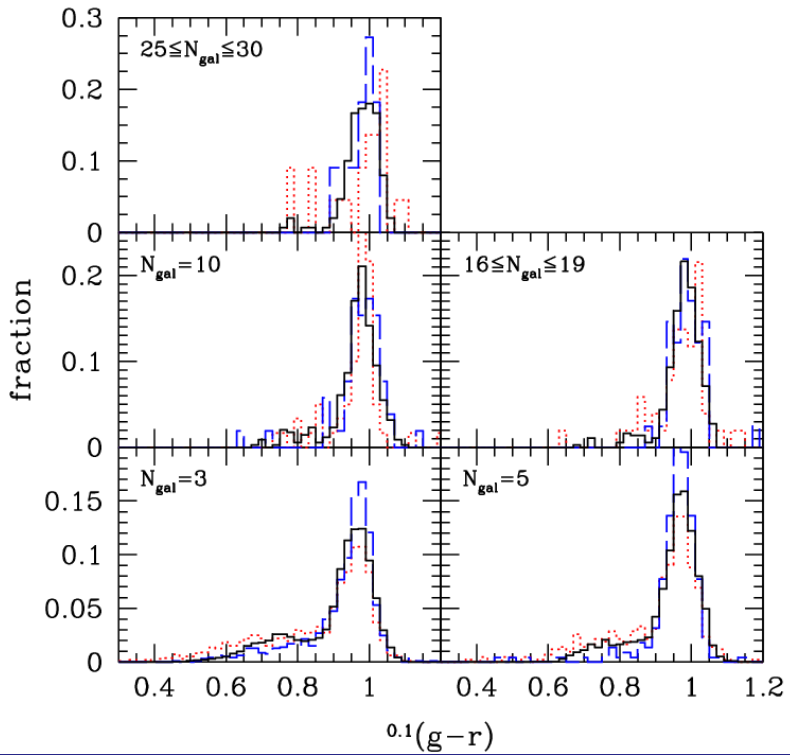
Skibba 2009

Central & Satellite Color Distributions II

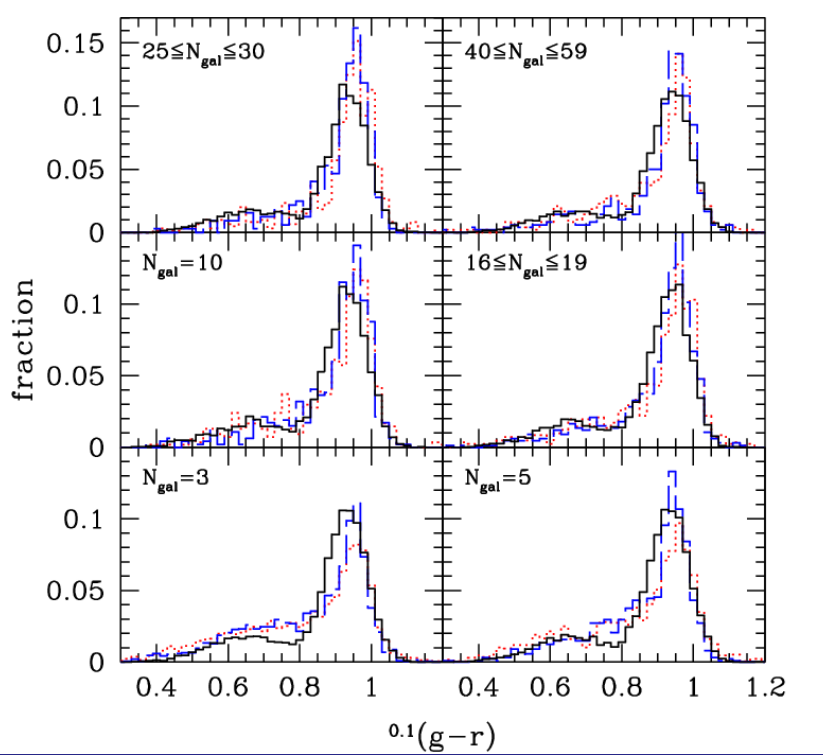
model (black) *vs.* SDSS groups (Yang et al.: blue; Berlind et al.: red)

- **central galaxy blue cloud disappears in richer groups**
- **satellite galaxy color distribution ≈ independent of richness**
- red and blue sequences of centrals are slightly redder than satellites'

central galaxies



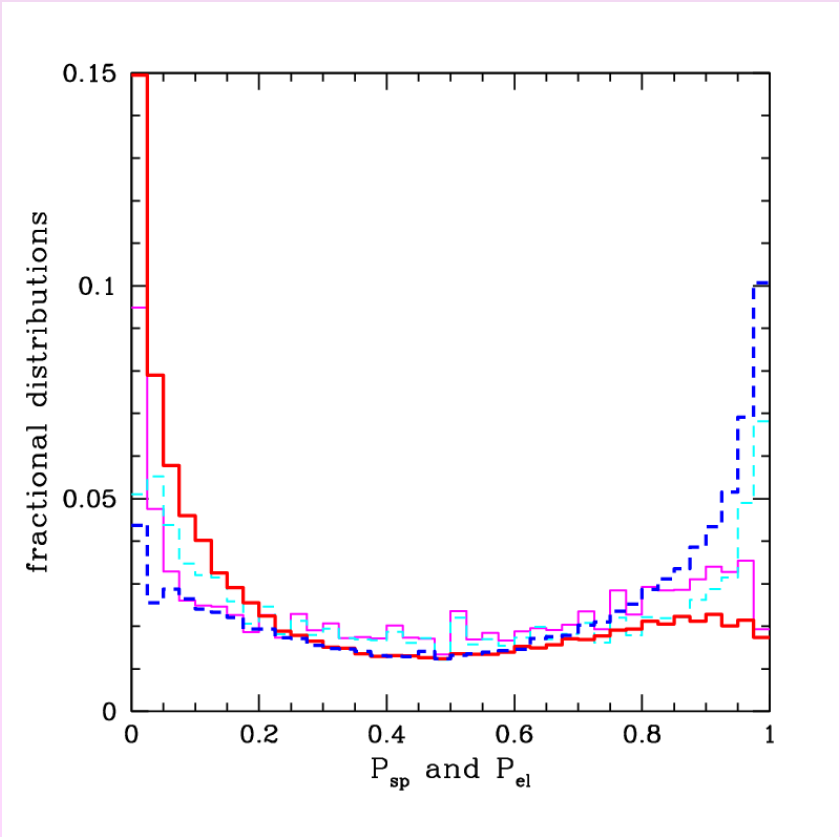
satellite galaxies



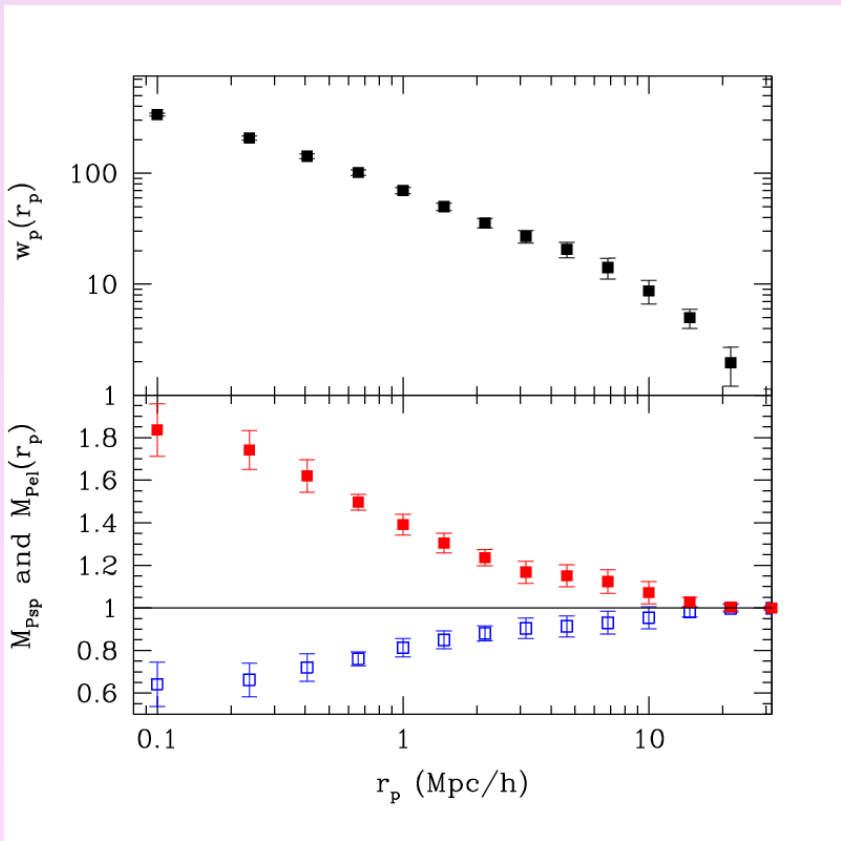
Environmental Dependence of Morphology

$P_{\rm elliptical}$ is strongly and significantly correlated with environment, while $P_{\rm spiral}$ is anti-correlated (right)

GZ morphology mark distributions: spiral & elliptical likelihoods



morphology-marked CF for $P_{\rm el}$ (red) & $P_{\rm sp}$ (blue)



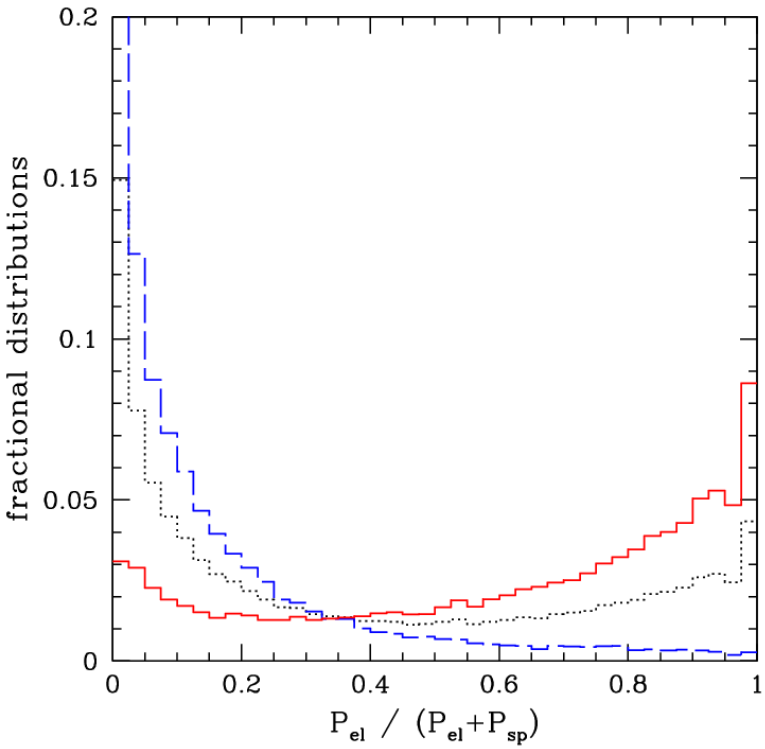
Skibba, Bamford, Nichol, Lintott et al., 2009

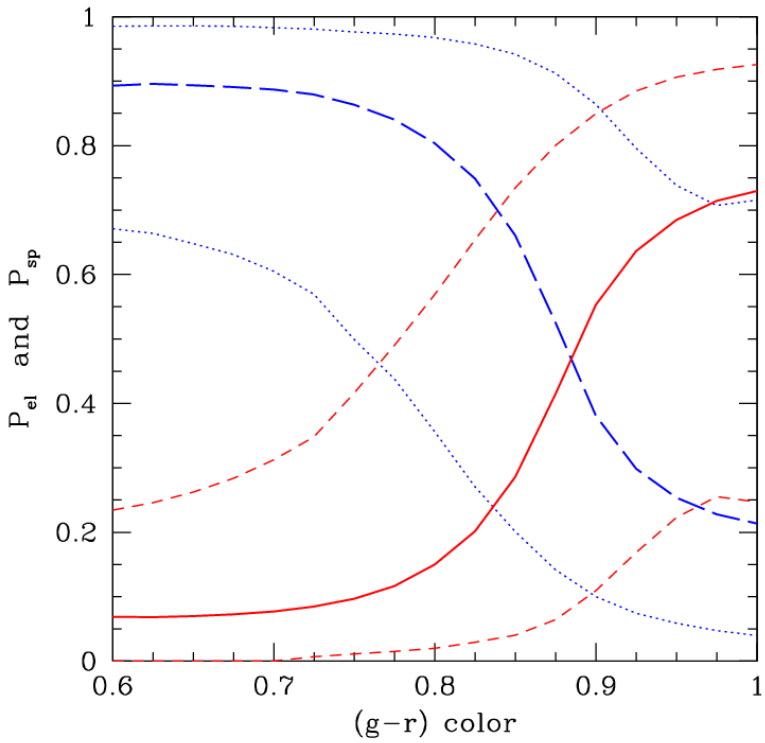
Correlation Between Morphology and Color

$P_{\rm elliptical}$ distribution for red and blue galaxies (left)

$P_{\rm spiral}$ & $P_{\rm elliptical}$ correlation with $g - r$ color (right)

most blue galaxies are spirals, but red galaxies have wide range of morphologies



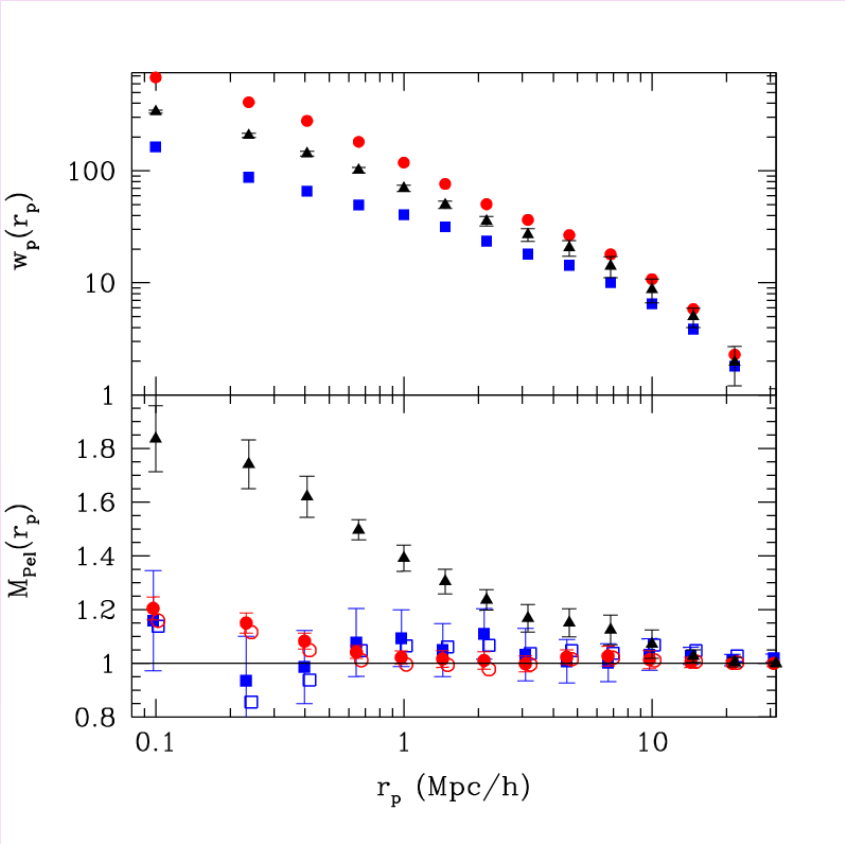


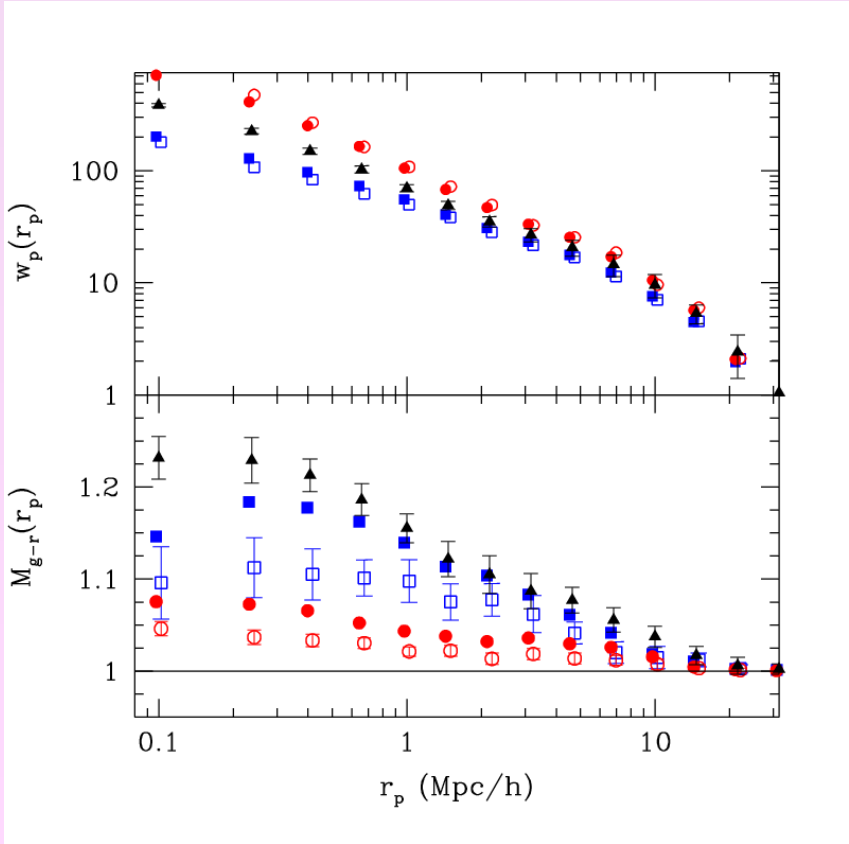
Disentangling Morphology & Color

At fixed color, much of environmental dependence of morphology disappears (left), except for morphology gradient of red galaxies

At fixed morphology, environmental dependence of color remains significant out to large scales (right)

$\Rightarrow$ **environmental dependence of galaxy color explains most of morphology-environment correlation**



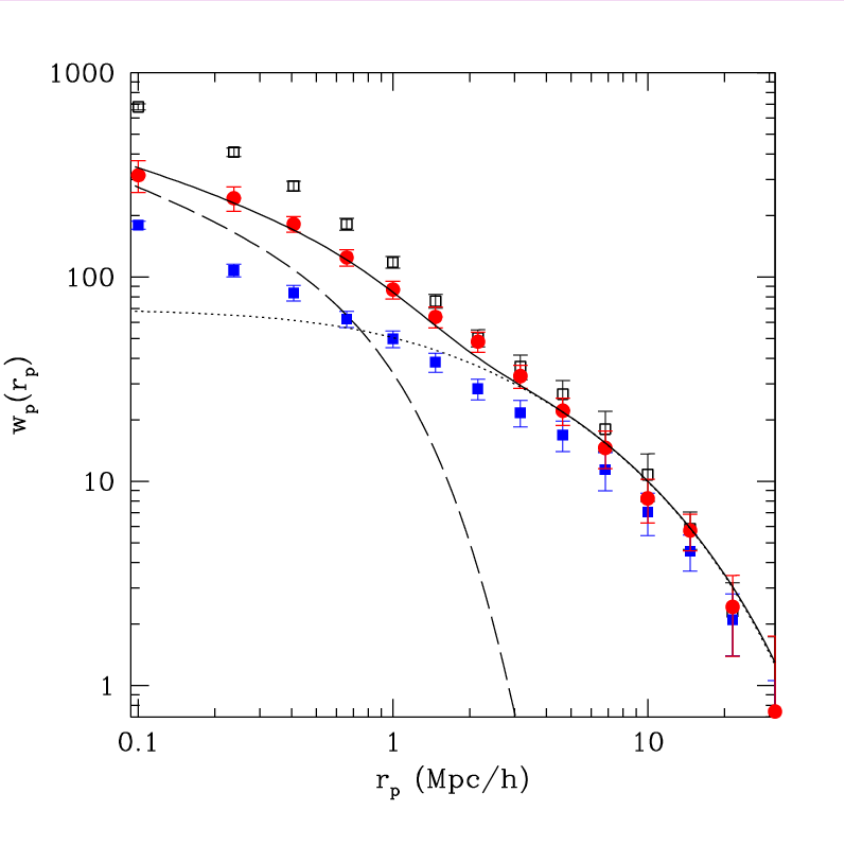


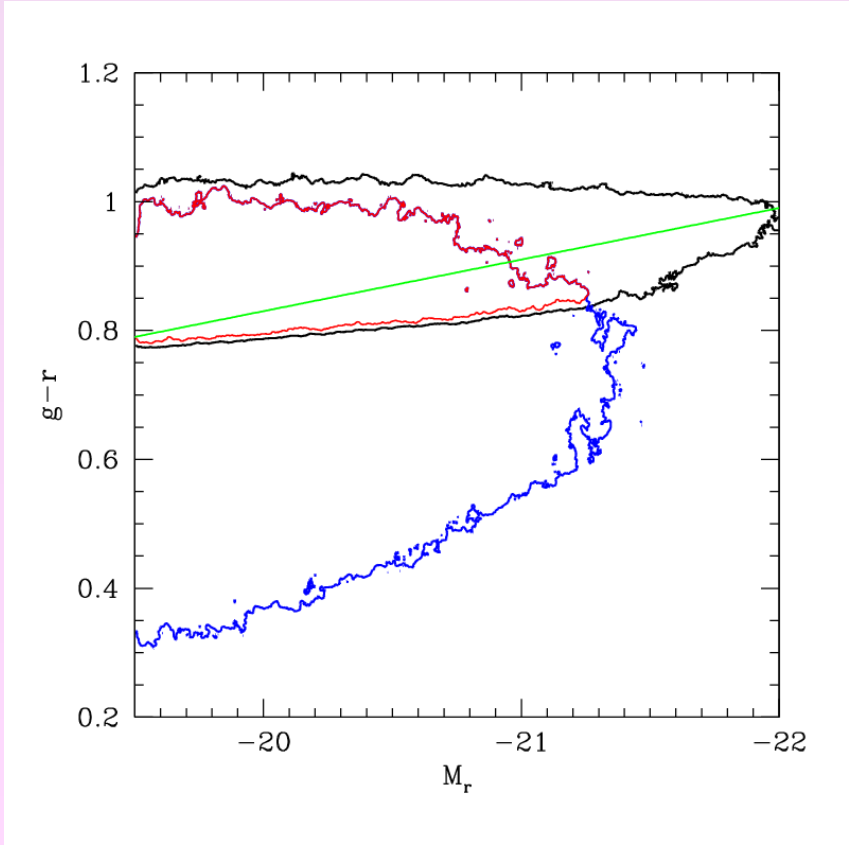
Red Spiral Galaxies

Red Spirals vs. Red and Spiral Galaxies

Red spirals have high satellite fraction ($\approx 32\%$ *vs.* 24%), from halo-modeling of correlation function (left)

Satellite galaxies' mean color-magnitude sequence (Skibba 2009) passes through red spirals' and red early-types' color-magnitude regions (right)





Main Conclusions

- mark clustering statistics identify and quantify the environmental correlations of galaxy properties
- **halo model, with many faint satellites in blue cloud, explains color mark correlations**
- in halo model and group catalogs, **satellite color distribution is $\approx$ independent of halo mass.** due to strangulation?
- at fixed color, environmental dependence of morphology is extremely weak, except for a morphology gradient of red galaxies within halos
- at fixed morphology (and luminosity), environmental dependence of color remains strong
  - $\Rightarrow$ **much of morphology-density relation explained by color-density relation**; different time-scales of morph./color transformation
- **red spirals are abundant and have high satellite fraction**
- implications about evolution of central & satellite galaxies...