



# The Origin of Galaxy Bimodality

*what makes galaxies red & dead?*

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in collaboration with

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# The Bi-Modal Distribution of Galaxies

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- The Bi-Modal Distribution of Galaxies
- The Standard Paradigm
- Galaxy Transformations
- Outstanding Questions

## Centrals vs. Satellites

## Environment Dependence

## Conclusions

### Early-Types



**Spheroidal Morphology**

**Old Stellar Populations**

**No or Little Cold Gas**

**Red Colors**

### Late-Types



**Disk-like Morphology**

**Young Stellar Populations**

**Abundant Cold Gas**

**Blue colors**

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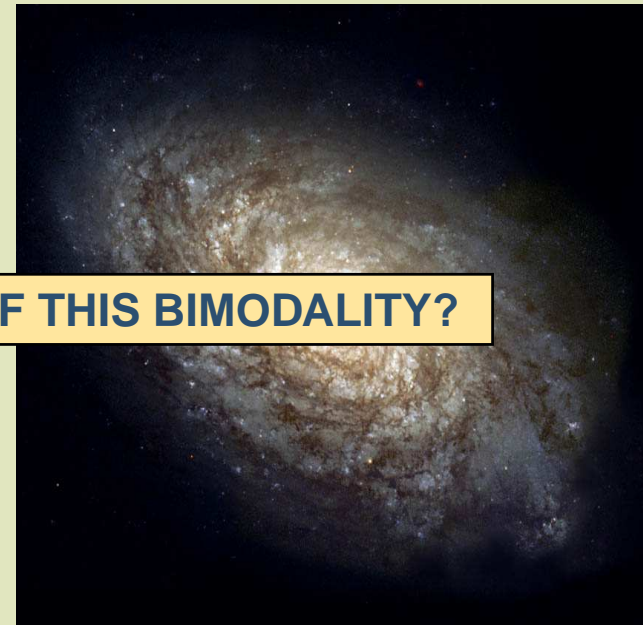
**Spheroidal Morphology**

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**Disk-like Morphology**

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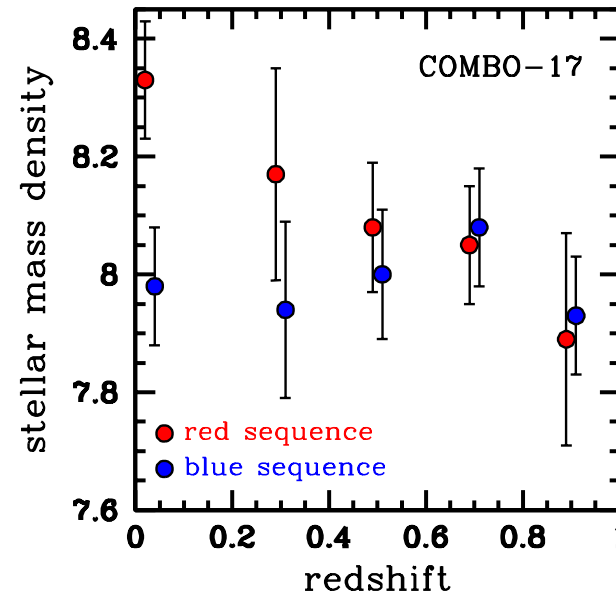
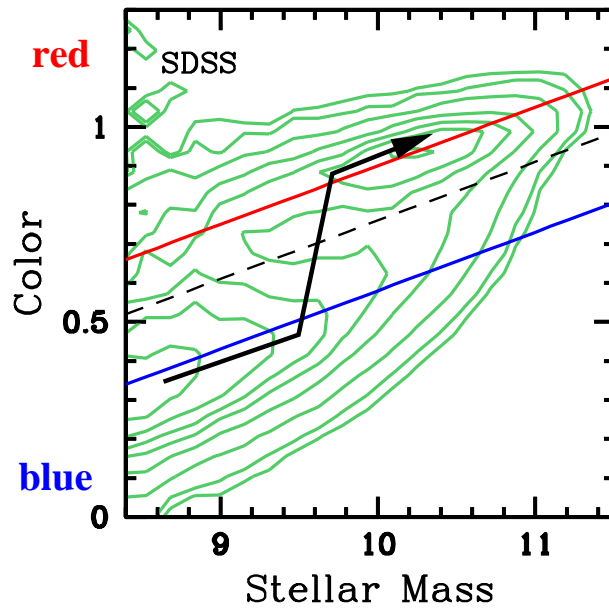
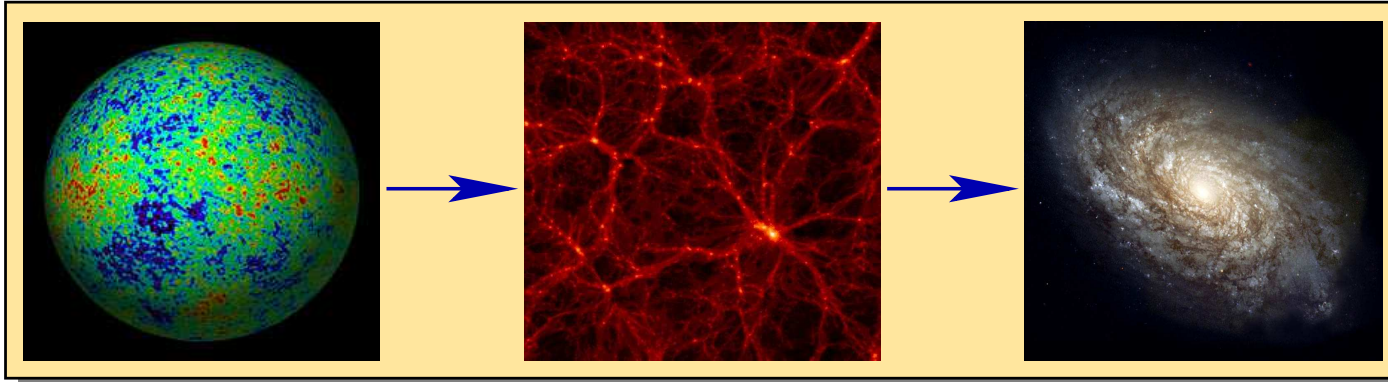
**Abundant Cold Gas**

**Blue colors**

**WHAT IS THE ORIGIN OF THIS BIMODALITY?**

# The Standard Paradigm

**PARADIGM:** All galaxies originally form as central disk galaxies.



(Wolf et al. 2003; Bell et al. 2004; Borch et al. 2006)

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# Galaxy Transformations

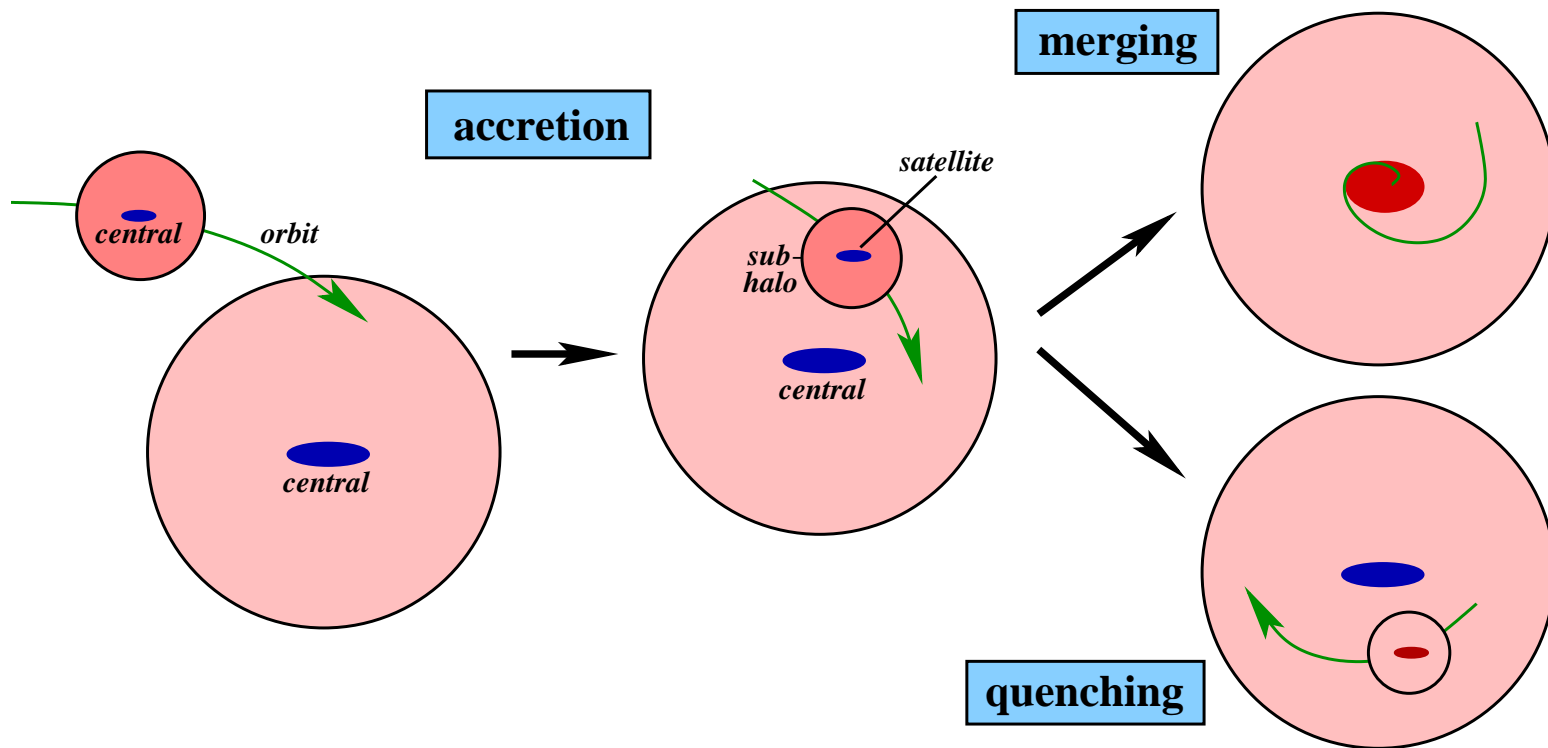
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In  $\Lambda$ CDM cosmology dark matter haloes grow hierarchically.

A **major merger** between disk galaxies results in an early-type remnant.

There are also several **satellite-specific** transformation processes:

- **Strangulation**                      stripping of hot gas atmosphere
- **Ram-pressure stripping**        stripping of cold gas
- **Galaxy Harassment**              impulsive encounters with other satellites



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- **What fraction of the red-sequence satellites underwent their transformation as a satellite?**
- **Which Transformation Process is Most Important?**
- **In what Environment (dark matter halo) do Galaxies undergo their Transformation?**
- **To what extent are Satellite-Specific Transformation Processes responsible for Environment Dependence of Galaxy Population?**



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To address these questions we constructed SDSS **galaxy group catalog**

(Yang et al. 2005, 2007)

This allows us to split galaxy population in **centrals** and **satellites**, and to study galaxy properties as function of **halo mass**

(vdB et al. 2005, 2007; Weinmann et al. 2006; Yang et al. 2006; Moster et al. 2007)

We study impact of **satellite-specific** transformation processes by comparing satellites to centrals of the same stellar mass,  $M_*$

# Centrals vs. Satellites: matched in stellar mass

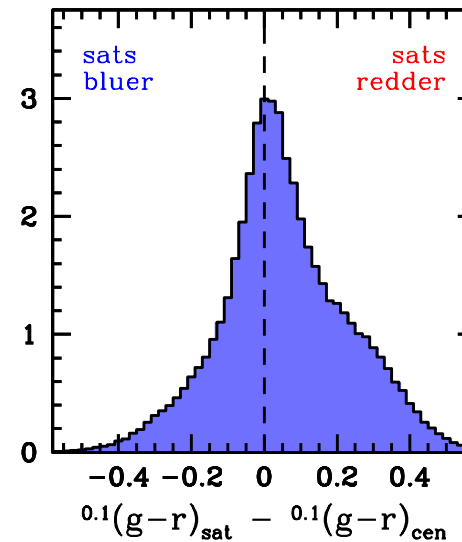
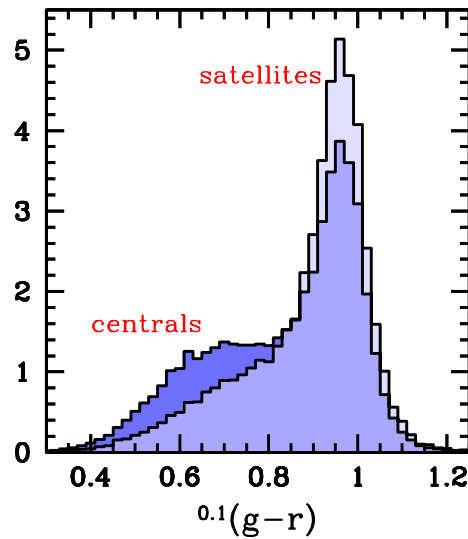
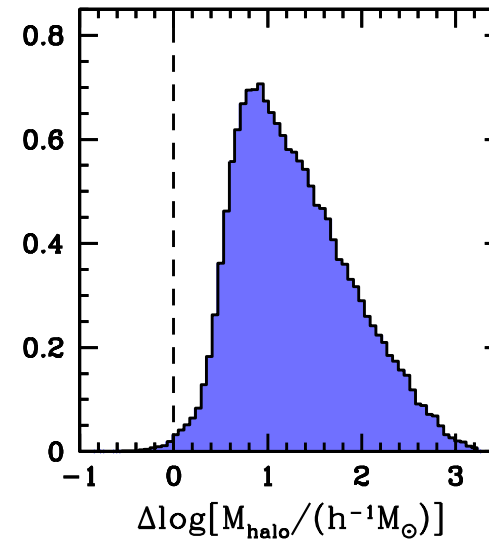
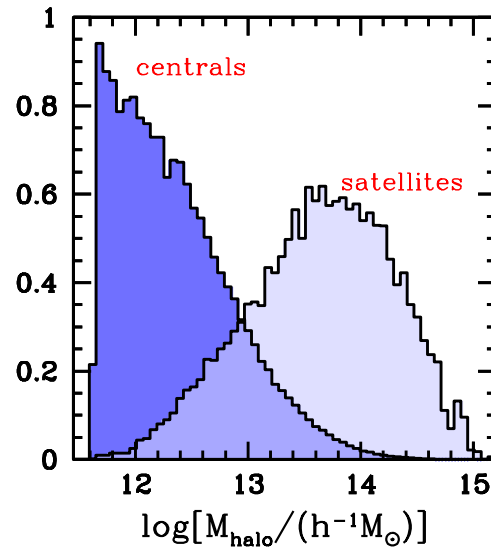
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- Centrals vs. Satellites: matched in stellar mass
- Stellar Mass Dependence
- Blue-to-Red Transition Fractions

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Sats are marginally **redder** than centrals of same  $M_{star}$



# Stellar Mass Dependence

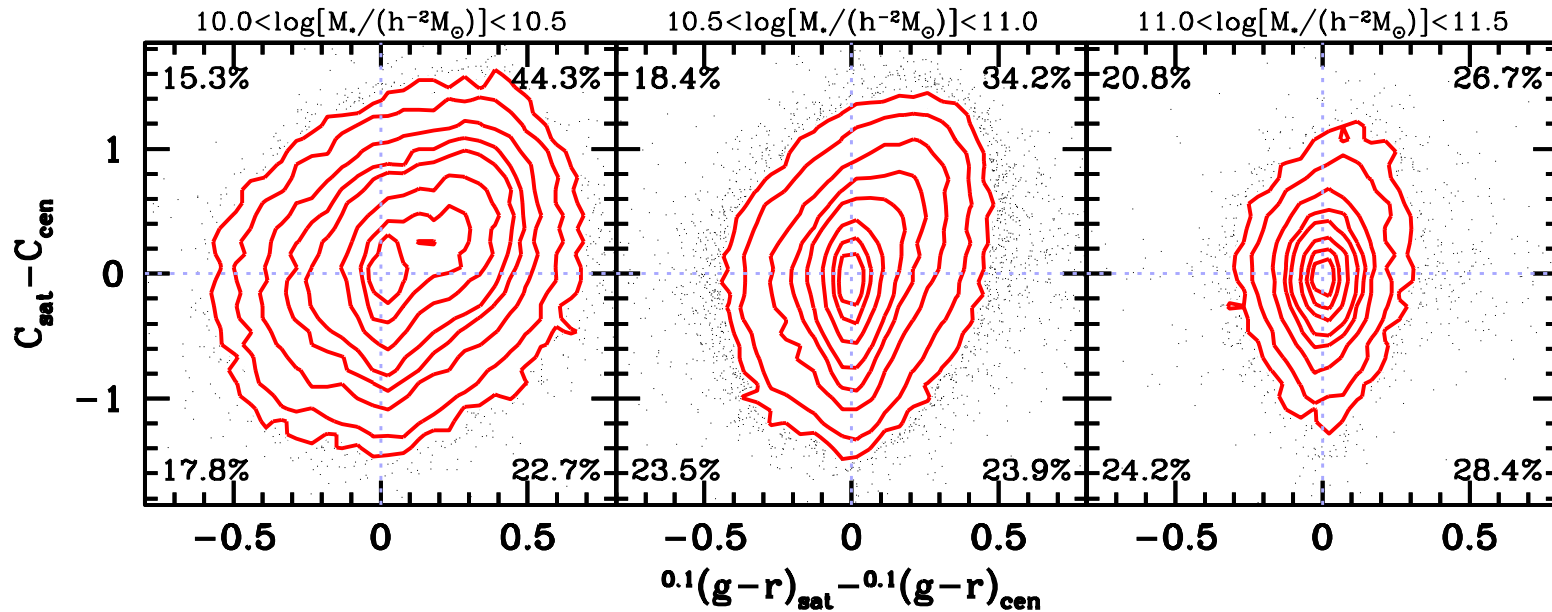
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- **Stellar Mass Dependence**
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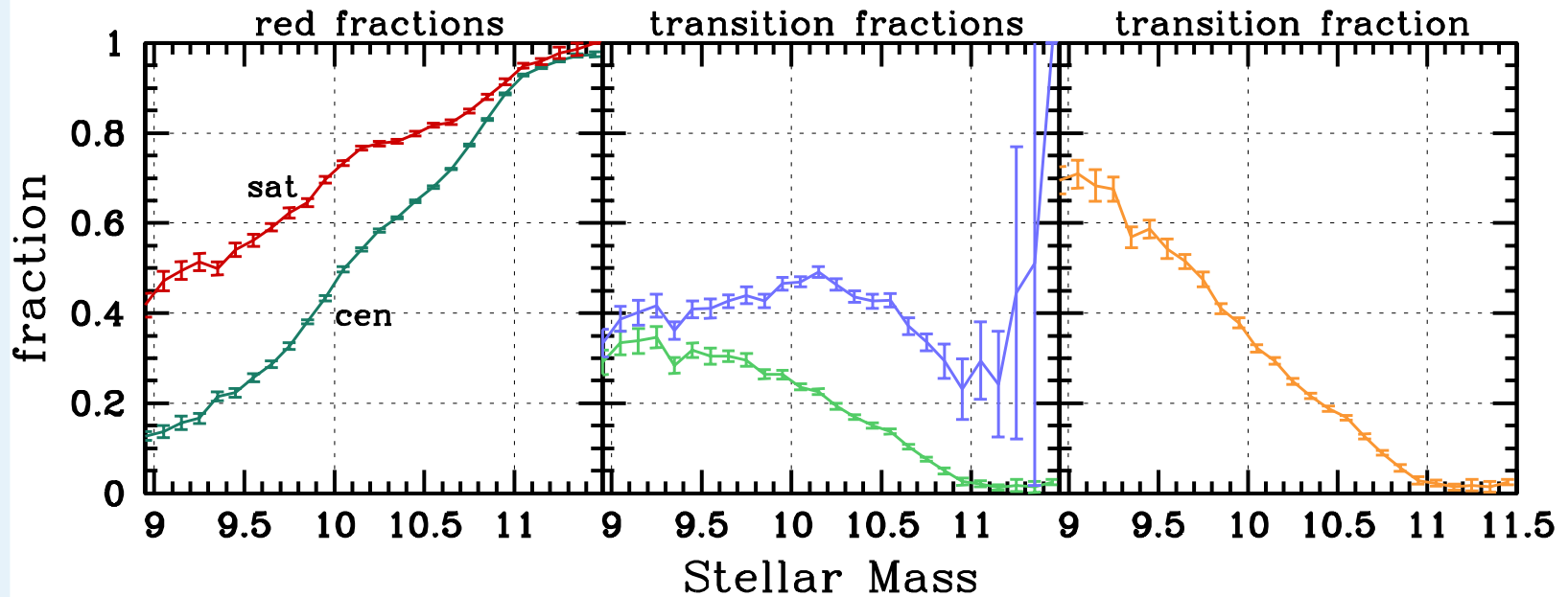
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- Low mass galaxies ( $M_{\text{star}} < 10^{11} M_\odot$ ) become redder and more concentrated after having been accreted
- Massive galaxies ( $M_{\text{star}} > 10^{11} M_\odot$ ) show no sign of undergoing a transformation after being accreted

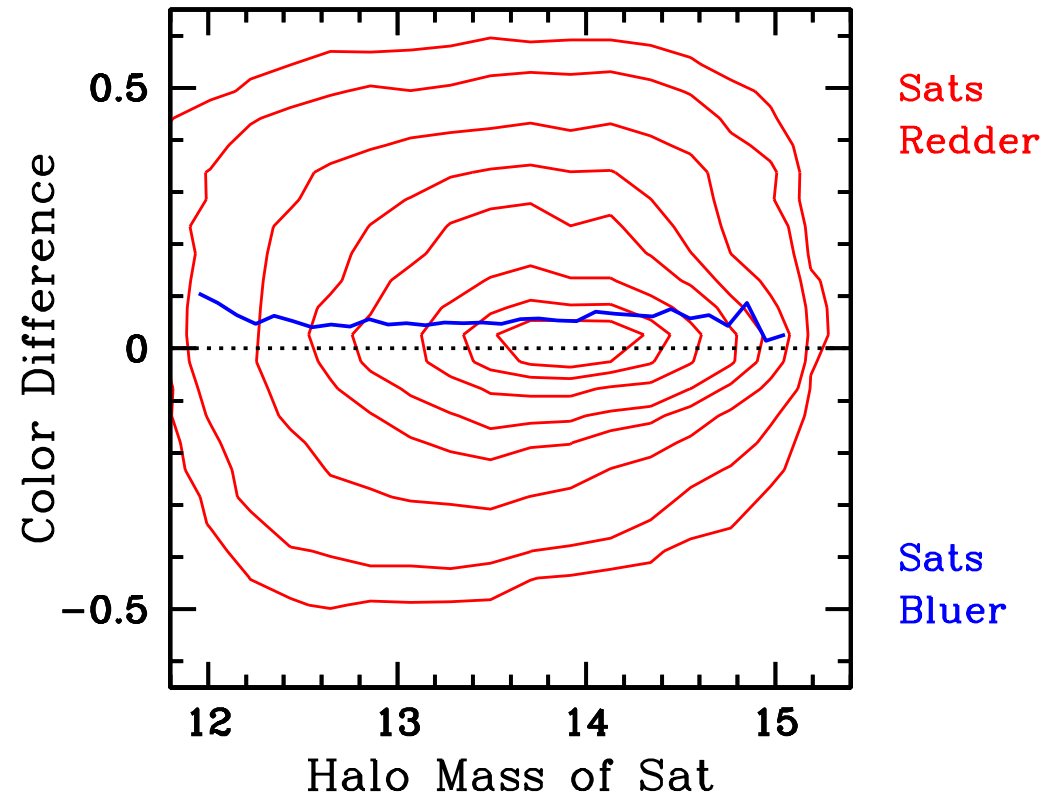
# Blue-to-Red Transition Fractions



- The **red** fraction of SATs is higher than that of CENs of same  $M_{\text{star}}$ .
- Roughly 40% of SATs that are **blue** at accretion undergo transition.
- Above  $10^{10} h^{-2} M_{\odot}$  majority of SATs were already **red** at accretion.

Satellite transformation processes only important at low  $M_{\text{star}}$

# Dependence on Halo Mass



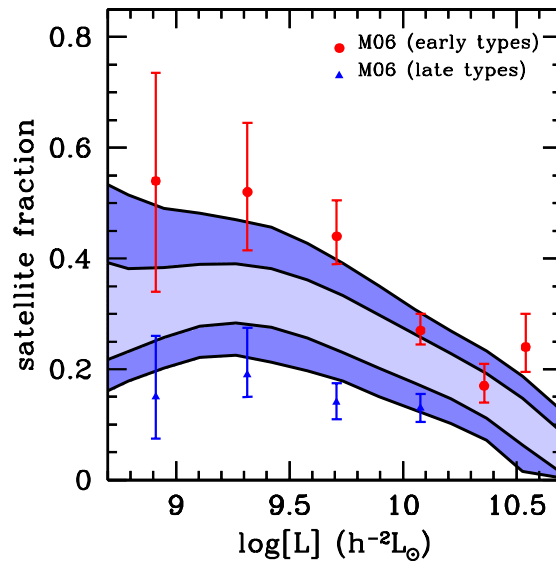
- Color difference is independent of halo mass of satellite
- Transformation efficiency is independent of halo mass

**Strangulation is main satellite-specific transformation mechanism**

# Satellite Ecology

Most transformation mechanisms only work on **satellite galaxies**:

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



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

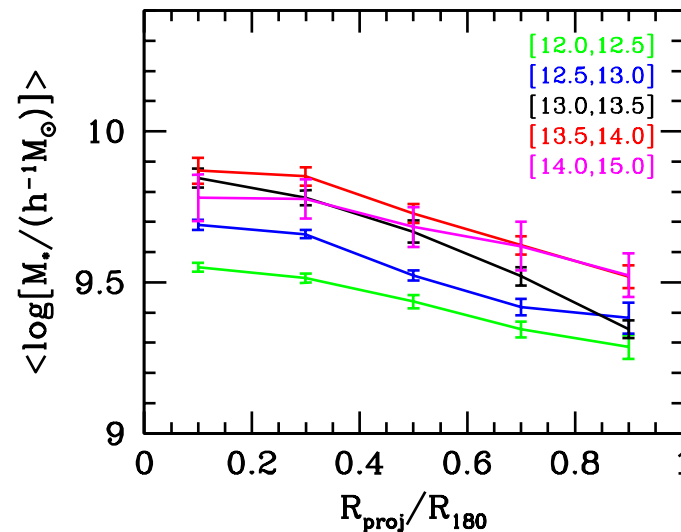
Central galaxies can wash out environment signal

(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  $R_{proj}$

(vdB et al. 2007, in preparation)



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● Dependence on Halo Mass

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● Average Colors of Satellite Galaxies

● Average Satellite Concentrations

● Beyond the First Moments

● Beyond the First Moments

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# Average Colors of Satellite Galaxies

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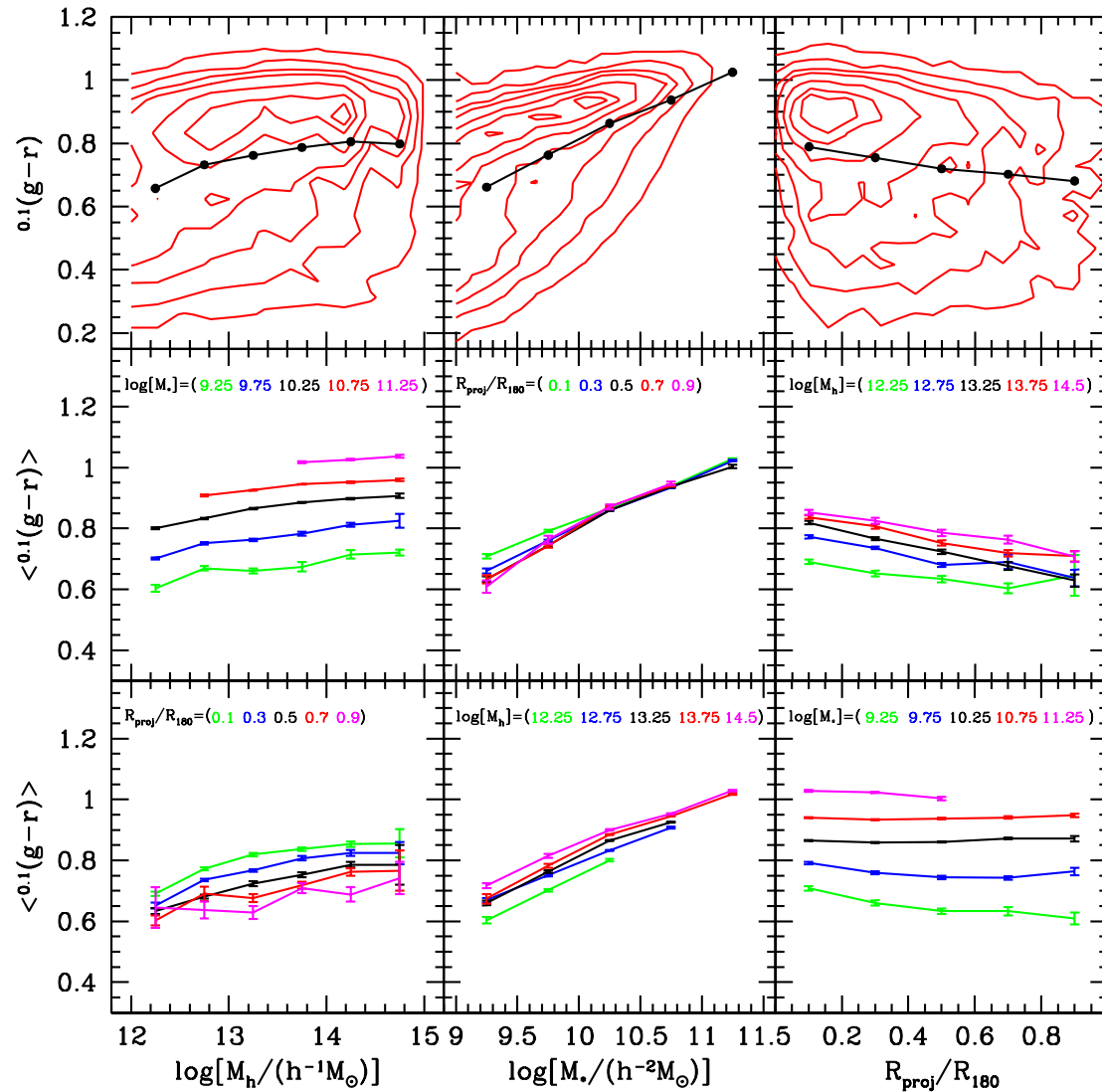
● Average Satellite

Concentrations

● Beyond the First Moments

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At fixed  $M_*$ , average satellite color independent of environment

# Average Satellite Concentrations

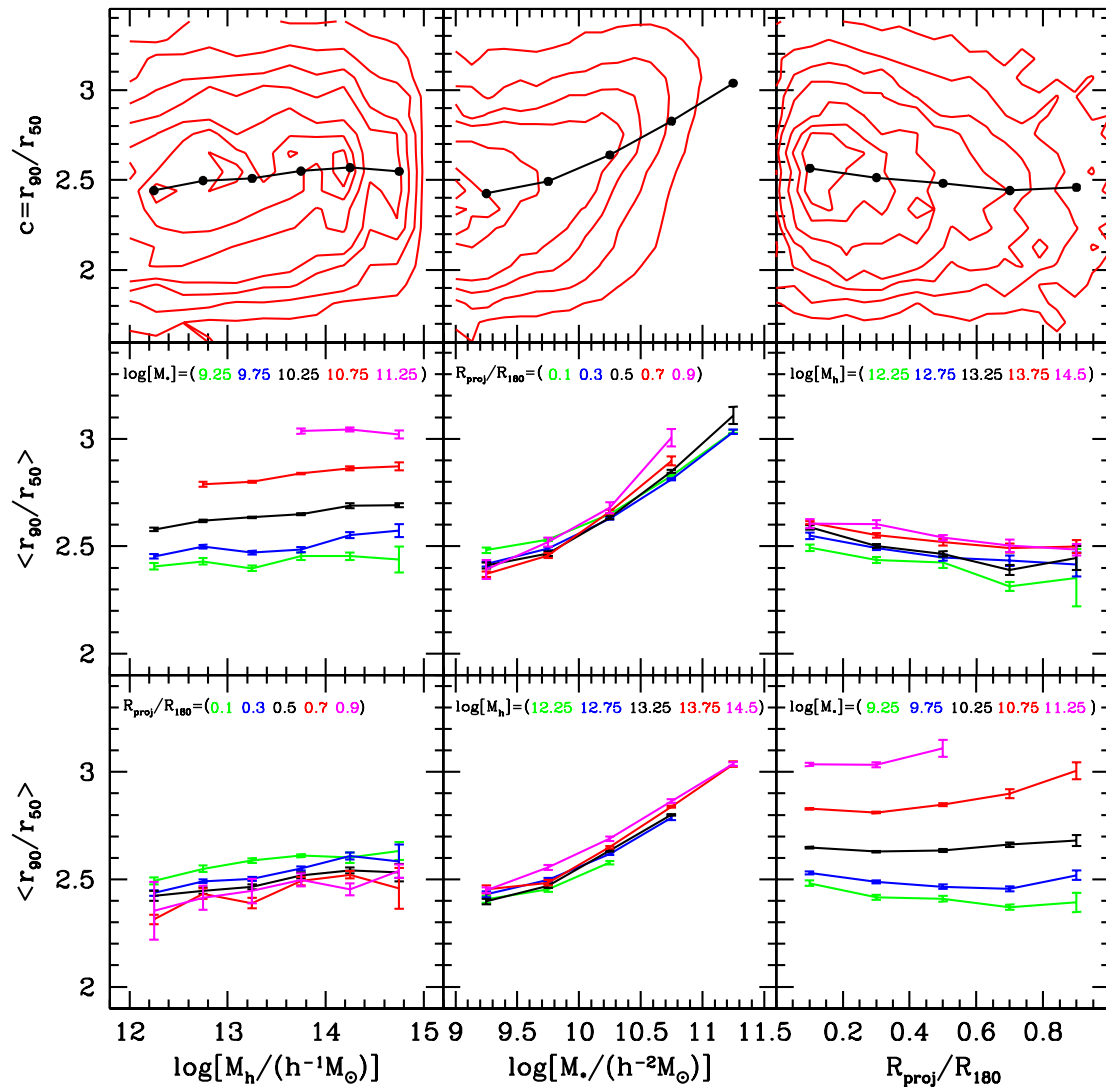
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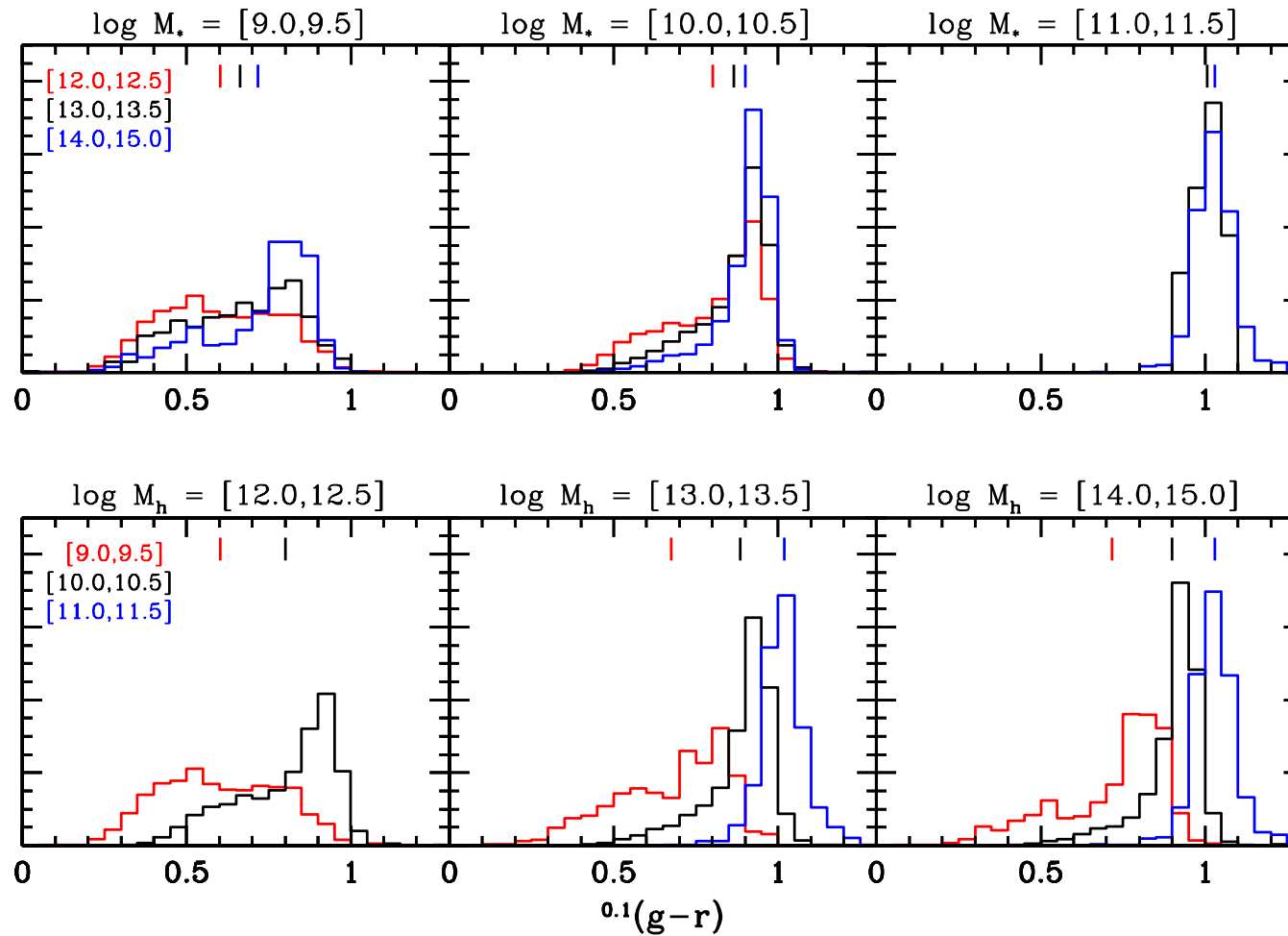
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- Beyond the First Moments

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**At fixed  $M_*$ , average satellite concentration independent of environment**

# Beyond the First Moments



**Satellite colors depend only very weakly on environment**

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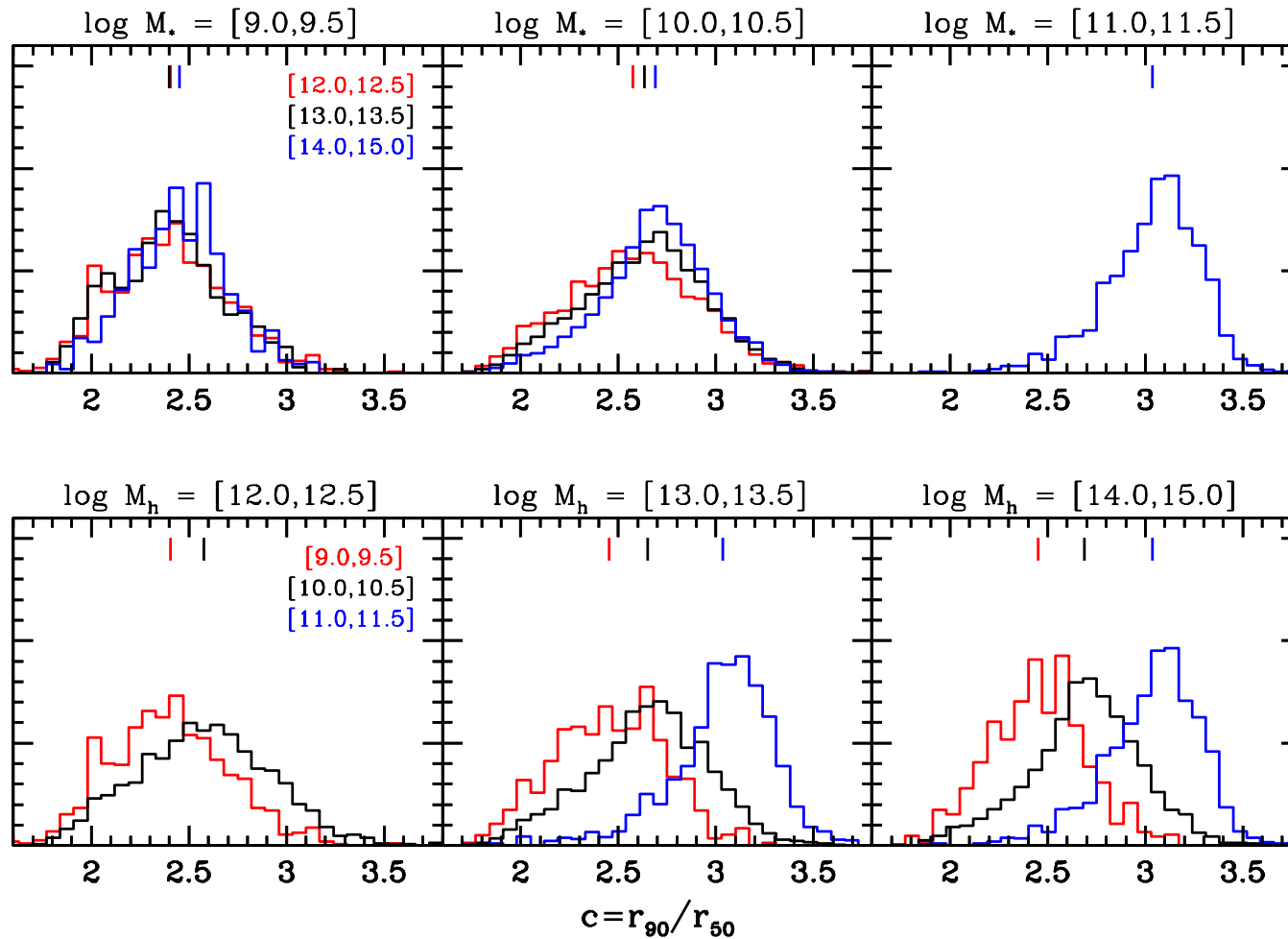
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**Satellite concentrations are independent of environment**





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**From 70% at  $\log(M_*) = 9$  to 0% at  $\log(M_*) = 11$**

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**In all haloes of all masses**

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**There is no environment dependence**

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