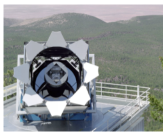
A Halo Model of Galaxy Colors and Clustering in the SDSS

And a Comparison to SDSS Galaxy Group Catalogs



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1. Introduction

In standard ΛCDM cosmological models, cold dark matter halos form from the gravitational collapse of dark matter particles, and they assemble hierarchically, such that smaller halos merge to form larger and more massive halos. There is a correlation between the formation and abundances of halos and large-scale structure (Mo & White 1996; Sheth & Tormen 2002), and halo properties, especially their masses, are correlated with their environments. According to the current paradigm of galaxy formation, galaxies form within halos, due to the cooling of hot gas, and halos and galaxies evolve simultaneously. Observational studies have shown that galaxy properties are correlated with their environments: luminous, red, and elliptical galaxies tend to be more strongly clustered than their faint, blue, spiral counterparts (*e.g.*, Blanton & Berlind 2007, Tinker et al. 2007, Li et al. 2007). If a galaxy's properties are determined by the mass and formation history of its host halo, this entails that the **correlation between halo properties and environment induces correlations between galaxy properties and environment** (Skibba et al. 2006).

We use the **halo occupation distribution as a function of luminosity** in the SDSS (Zehavi et al. 2005, Zheng et al. 2007), and **extend the model to galaxy colors, by exploiting the bimodal distribution of galaxy color** as a function of luminosity. The model predicts the **environmental dependence of color, quantified by the color mark correlation function**, and we compare these predictions to measurements with SDSS galaxy catalogs. We show they are in excellent agreement, **indicating that the correlation between halo mass and environment is the primary driver for correlations between galaxy colors and environment**. We also compare the model to the colors of central and satellite galaxies in SDSS group catalogs, and find good agreement between them.

2. Marked Statistics

We utilize a versatile set of tools known as marked statistics (Beisbart & Kerscher 2000), which have been shown to provide sensitive probes of environmental effects (Sheth, Connolly & Skibba 2005). Rather than measuring clustering by treating galaxies as points without attributes, marked clustering statistics allow us to describe the clustering of the galaxy properties themselves, thus allowing us to **probe the environmental dependence of those galaxy properties**. A '**mark**' is a weight or attribute associated with each galaxy in a catalog, and it can be any observable property, such as color in this work, or luminosity, star formation rate, morphology likelihood, etc. The simplest marked statistic is the **marked two-point correlation function**, which is the ratio of the weighted correlation function *W(r)*, where each galaxy is weighted by its property normalized by the mean property, and the regular unweighted correlation function *ξ(r)*:

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

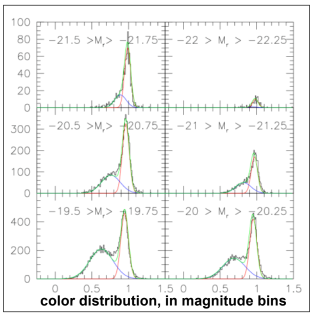
- **if *M(r)* = 1 ⇒ mark is not correlated with the environment at *r* scales**
- **if *M(r)* > 1 ⇒ higher values of mark tend to be located in denser *r*-scale environments**

3. Bimodal Galaxy Color Distribution in SDSS

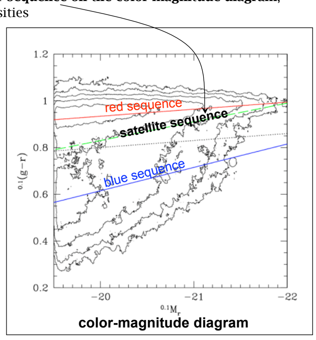
- galaxy color distribution at fixed luminosity, *p(c|L)*, is bimodal (*e.g.*, Baldry et al. 2004), fit well as the sum of two Gaussian components (left plot)
- mean and rms of red sequence and blue sequence, and the red fraction, all vary with luminosity, as can be seen from color-magnitude distribution (right plot)

Our model is based on luminosity dependence of galaxy clustering, and we extend the model for the color dependence with only two additional assumptions:

- the bimodal color distribution at fixed luminosity is independent of halo mass
- **satellite galaxies tend to follow a particular sequence on the color-magnitude diagram**, approaching the red sequence at bright luminosities



color distribution, in magnitude bins



color-magnitude diagram

The **halo model** is the framework currently used to interpret measurements of galaxy clustering (see Cooray & Sheth 2002), and it **describes mark clustering statistics when the environmental correlations of galaxy properties arise entirely from the statistical correlation between halo mass and environment**. We incorporate the halo-model description of luminosity mark statistics of Skibba et al. (2006) and extend it in order to develop a description of color mark statistics.

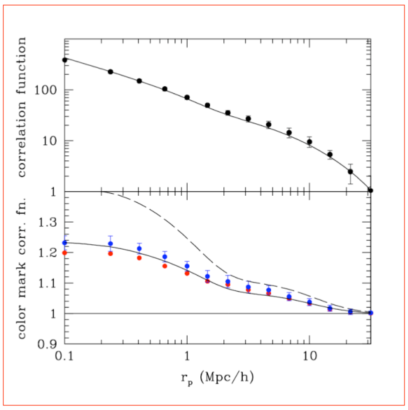
The most important components of the halo model for this work:

- **halo mass function** (Sheth & Tormen 2002) & **halo density profile** (Navarro, Frenk, White 1997)
- **luminosity-dependent halo occupation distribution** (HOD): probability of *M*-mass halos containing *N* 'central' & 'satellite' galaxies brighter than some threshold (Zheng et al. 2007)
- **color mark**: relationship between halo mass and central & satellite galaxies' colors

4. Main Results

Model predictions are compared to measurements from volume-limited galaxy catalog with $-23.5<M_r<-19.5$, $0.017<z<0.082$, in SDSS Data Release 5 (Adelman-McCarthy et al. 2007)

Color mark correlation function (lower panel): halo model **(solid curve)** *vs.* SDSS measurements with Petrosian colors (**blue points**) & model colors (**red points**)



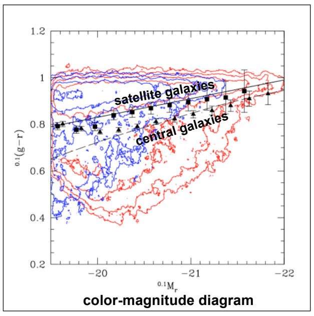
- **Conclusion #1**: excellent agreement between halo model prediction and SDSS measurements ⇒ **The environmental dependence of color is primarily driven by the environmental dependence of halo mass.** Effect of 'assembly bias' is relatively small.
- **Conclusion #2**: **some satellite galaxies are still blue**, especially at faint luminosities. **The star formation quenching by 'strangulation' of faint satellites is still on-going.**

5. Comparison of the Model and SDSS Galaxy Group Catalogs

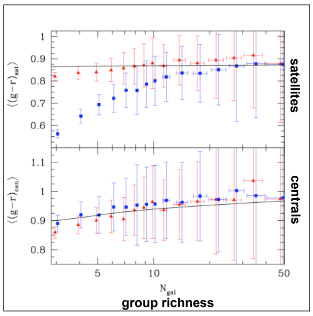
Our model implies that central and satellite galaxies tend to follow particular relations on the color-magnitude diagram. We compare these relations to a SDSS galaxy group catalog (Yang et al. 2008), and find good agreement between them (**left plot**).

Our model implies that the colors of central and satellite galaxies are correlated with halo mass in a particular way. We compare the colors as a function of group richness to Yang et al. (blue) and Berlind et al. (2006, red) and generally find agreement between them (**right plot**). See Skibba (2008) for details.

- **Conclusion #3: Central galaxies are *bluer* than satellites at fixed luminosity, but central galaxies are redder than satellites at fixed halo mass.**



color-magnitude diagram



group richness

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