THE ENVIRONMENTAL DEPENDENCE OF THE FRACTION OF ‘UNCONVENTIONAL’ GALAXIES: FAINT RED AND LUMINOUS BLUE

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ABSTRACT

Using the volume-limited Main galaxy sample constructed from the Sloan Digital Sky Survey Data Release 7 (SDSS DR7), we explore the environmental dependence of the fraction of ‘unconventional’ galaxies: luminous blue and faint red. It is found that the fraction of faint red increases apparently with increasing local density, and the fraction of luminous blue declines substantially with increasing local density, which shows that there is an environmental dependence for color beyond that for luminosity.

Key words : Galaxies: fundamental parameters — galaxies: statistics

1. INTRODUCTION

Galaxy properties tend to be easily described as a bimodal distribution, such as color, morphology, and star formation rates. These bimodal properties are correlated with each other. Red galaxies are preferentially early-type and have little or no current star formation, while blue galaxies are preferentially late-type and ongoing star formation (e.g., Strateva et al. 2001; Deng et al. 2009a; Mignoli et al. 2009; Deng et al. 2010). Galaxies with concordant classification, being either red, early-type and passive galaxies or blue, late-type and star-forming galaxies, have been interesting samples for investigation of the properties of galaxies as a function of environment. For example, Skibba et al. (2009) showed that red early-types tend to be located in very dense environments, while blue spirals tend to reside in sparse environments. But in recent years, some works have also shed light on the study of ‘unconventional’ galaxies, such as red late-types and blue early-types (e.g., Schawinski et al. 2007; Bamford et al. 2009; Deng et al. 2009a; Schawinski et al. 2009). Schawinski et al. (2007) showed that the fraction of blue early-types declines with increasing local galaxy density. Bamford et al. (2009) found that the fraction of red spirals rises considerably with increasing local density, and that the fraction of blue early-type galaxies declines substantially with increasing local density. Using the volume-limited Main galaxy sample (Strauss et al. 2002) of the Sloan Digital Sky Survey Data Release 6 (SDSS DR6) (Adelman-McCarthy et al. 2008), Deng et al. (2009a) arrived at the same conclusions.

Red, early type galaxies are likely to be more luminous (e.g., Bower et al. 1992; Strateva et al. 2001;

Blanton et al. 2003; Baldry et al. 2004; Balogh et al. 2004; Kelm et al. 2005). Such a preference is correct for the majority of galaxies. But, there also are exceptions. This implies the existence of substantial populations of ‘unconventional’ galaxies: faint red and luminous blue. In this work, we attempt to explore the environmental dependence of the fraction of ‘unconventional’ galaxies: luminous blue and faint red. Such a study can show which parameter in color and luminosity has stronger environmental dependence. Strateva et al. (2001) reported the bimodality of the $u - r$ color distribution, and developed a divider (the observed $u - r$ color = 2.22) which is used for classifying galaxies as ‘red’ and ‘blue’. But luminosity, being distributed in a continuous, unimodal fashion, is rather different from color or morphology, which display a bimodal distribution. One particular problem is that the definitions of ‘luminous’ and ‘faint’ refer to different criteria in different papers. In most conditions, the choice of the word luminous over faint and vice versa is somewhat arbitrary. In fact, we must confess that whether a galaxy is termed ‘luminous’ or ‘faint’ is often in a relative sense. Luminous galaxies exist preferentially in the densest regions of the universe, while faint galaxies are located preferentially in low density regions (e.g., Park et al. 1994; Blanton et al. 2003; Deng et al. 2007, 2009b). According to such a correlation, Deng et al. (2012) define a criterion to classify luminous and faint galaxies. Deng et al. (2012) compared the distribution of galaxy luminosity in the lowest density regime with that in the densest regime and found that the subsample at low density apparently has a higher proportion of faint galaxies ($M_r \geq -21.1$) and a lower proportion of luminous galaxies ($M_r \leq -21.5$) than the subsample at high density. Thus, Deng et al. (2012) defined galaxies with the luminosity $M_r \geq -21.1$ as ‘faint’, and galaxies with

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Fig. 1.— Distribution in $u-r$ color vs. luminosity plane of the volume-limited Main galaxy sample.

Fig. 2.— The fraction of red galaxies in different luminosity bins for the volume-limited Main galaxy sample.

the luminosity $M_r \leq -21.5$ as ‘luminous’.

In this paper, we use a volume-limited Main galaxy sample (Strauss et al. 2002) of the SDSS DR7 (Abazajian et al. 2009), and explore the environmental dependence of the fraction of ‘unconventional’ galaxies: faint red and luminous blue. Our paper is organized as follows: In section 2, we describe the data used. The environmental dependence of the fraction of ‘unconventional’ galaxies is discussed in section 3. Our main results and conclusions are summarized in section 4.

In calculating the co-moving distance, we used a cosmological model with a matter density $\Omega_0 = 0.3$, cosmological constant $\Omega_\Lambda = 0.7$, Hubble’s constant $H_0 = 100 h \text{ km} \cdot \text{s}^{-1} \cdot \text{Mpc}^{-1}$ with $h = 0.7$.

2. DATA AND SAMPLE

Many of survey properties of the SDSS were discussed in detail in the Early Data Release paper (Stoughton et al. 2002). Galaxy spectroscopic tar-

gets were selected by two algorithms. The Main galaxy sample (Strauss et al. 2002) comprises galaxies with r -band apparent petrosian magnitude brighter than 17.77 mag. This sample has a median redshift of 0.10 and few galaxies beyond $z = 0.25$, in which most galaxies are within the redshift region $0.02 \leq z \leq 0.2$. In our work, the data were downloaded from the Catalog Archive Server of SDSS Data Release 7 (Abazajian et al. 2009) by the SDSS SQL Search (with SDSS flag: `bestPrimgalaxy&64>0`) with high-confidence redshifts ($Z_{\text{warning}} \neq 16$ and $Z_{\text{status}} \neq 0, 1$ and redshift confidence level: $z_{\text{conf}} > 0.95$)*.

Schawinski et al. (2007) indicated that at $z < 0.05$, SDSS spectroscopy begins to be incomplete for bright galaxies. Thus, we construct a volume-limited Main galaxy sample which contains 120362 galaxies at $0.05 \leq z \leq 0.102$ with $-22.50 \leq M_r \leq -20.50$. The absolute magnitude M_r is calculated from the r -band apparent Petrosian magnitude, using a polynomial fit formula (Park et al. 2005) for the mean K -correction within $0 < z < 0.3$:

$$K(z) = 2.3537 \times (z - 0.1)^2 + 1.04423 \times (z - 0.1) - 2.5 \times \log(1 + 0.1). \quad (1)$$

Using the divider (the observed $u-r$ color=2.22) developed by Strateva et al. (2001), we classify galaxies as ‘red’ and ‘blue’, respectively. Like Deng et al. (2012) did, we define galaxies with the luminosity $M_r \geq -21.1$ as ‘faint’, and galaxies with the luminosity $M_r \leq -21.5$ as ‘luminous’. In our volume-limited sample, luminous red class contains 20883 galaxies, luminous blue class 5270 galaxies, faint blue class 25249 galaxies and faint red class 40020 galaxies. We note that the majority of the luminous population corresponds to red galaxies, but the majority of the faint population does not correspond to blue galaxies. Correlations between galaxy colors and luminosity shows that luminous galaxies are preferentially red, while faint galaxies are preferentially blue (e.g., Baum 1959; de Vaucouleurs 1961; Faber 1973; Visvanathan & Sandage 1977; Sandage & Viswanathan 1978; Bower et al. 1992; Aragon-Salamanca et al. 1993; Stanford et al. 1995, 1998; Ellis et al. 1997; Terlevich et al. 2001; Bell et al. 2004; Holden et al. 2004; Hogg et al. 2004; Cool et al. 2006; Chang et al. 2006). But in a study of ‘luminous’ and ‘faint’ galaxies, one particular problem is that ‘luminous’ and ‘faint’ can often be relative, the most luminous galaxies in one sample likely are fainter than the faintest galaxies in another sample. In addition, the fraction of red galaxies may be largely different from each other. In our volume-limited sample, the fraction of red galaxies is fairly high (67.26%), which leads to higher proportion of faint red galaxies. Fig. 1 shows the distribution in $u-r$ color vs. luminosity plane of the volume-limited Main galaxy sample. The red vertical line is $u-r$ color=2.22, corresponding to the divider of color. The blue and green horizontal lines are

*<http://www.sdss.org/dr7/>

Fig. 3.— $u - r$ color distribution of the volume-limited Main galaxy sample. The red vertical line also is $u-r$ color=2.22.

$M_r = -21.1$ and $M_r = -21.5$, respectively. Fig. 2 presents the fraction of red galaxies in different luminosity bins for the volume-limited Main galaxy sample. As seen from Fig. 2, the fraction of red galaxies rises considerably with increasing luminosity, which shows that the more luminous a galaxy is, the more preferentially red it is. Fig. 3 also shows $u-r$ color distribution of the volume-limited Main galaxy sample.

3. ENVIRONMENTAL DEPENDENCE OF THE FRACTION OF ‘UNCONVENTIONAL’ GALAXIES

For each galaxy, we calculate the three-dimensional distance to the 5th nearest galaxy. The local three-dimensional galaxy density LD (Galaxies Mpc^{-3}) is defined as the number of galaxies ($N=5$) within this distance to the volume of the sphere with the radius of the distance to the 5th nearest galaxy. Fig. 4 shows fraction $[n(\text{‘unconventional’ galaxies})/n(\text{all})]$ in each density bin of ‘unconventional’ galaxies: luminous blue (a) and faint red (b) as a function of the three-dimensional local density of galaxies for the volume-limited sample. The x-axis of these figures is logarithmic. We bin the sample in steps of 0.25 over the range $-4 < \log_{10} LD(\text{Galaxies } \text{Mpc}^{-3}) < 0$. As seen from Fig. 4, the fraction of faint red increases apparently with increasing local density, and the fraction of luminous blue declines substantially with increasing local density. Red galaxies prefer dense regions, while faint galaxies prefer less dense regions. Similarly, blue galaxies prefer less dense regions, while luminous galaxies prefer dense regions. So, our result that, faint red galaxies prefer dense regions and luminous blue galaxies prefer less dense regions, shows that the environmental dependence of color is stronger than the one of luminosity.

Similar to what Deng et al. (2008a, 2009a) did, we arrange galaxies in a density order from the smallest to the largest, select about 5% galaxies (6018 galaxies),

and construct two subsamples at both extremes of density according to the density. Table 1 lists the galaxy number of different classes of two subsamples at both extremes of density for the volume-limited Main galaxy sample. In Table 1, we can get the same conclusions showed in Fig. 4. For the concordant classification, being either luminous red galaxies or faint blue galaxies, the fraction of luminous red galaxies rises considerably with increasing local density, and that the fraction of faint blue galaxies declines substantially with increasing local density. Table 1 also shows that the proportions of luminous galaxies and red galaxies in the subsample at high density are much higher than the ones in the subsample at low density. This further confirms the widely accepted conclusion: luminous or red galaxies exist preferentially in the densest regions of the universe, while faint or blue galaxies are located preferentially in low density regions (e.g., Park et al. 1994; Blanton et al. 2003; Tanaka et al. 2004; Balogh et al. 2004; Hogg et al. 2004; Park et al. 2007, 2009; Deng et al. 2007, 2008a-b, 2009b).

Deng et al. (2009a) found that the fraction of red late-type galaxies rises considerably with increasing local density, and that the fraction of blue early-type galaxies declines substantially with increasing local density. This is in good agreement with the conclusion obtained by other authors (Schawinski et al. 2007; Bamford et al. 2009). Bamford et al. (2009) claimed that this trend shows that there is an environmental dependence for color beyond that for morphology, and suggested that the environmental transformation of galaxies from blue to red must occur on significantly shorter timescales than the transformation from spiral to early-type. Deng et al. (2012) also showed that there is an environmental dependence for morphology beyond that for luminosity. In this study, we find that the fraction of faint red increases apparently with increasing local density, and the fraction of luminous blue declines substantially with increasing local density, which shows that there is an environmental dependence for color beyond that for luminosity. Deng et al. (2009c) investigated how other properties of galaxies depend on environment at fixed color, and also found that the environmental dependence of luminosity is mainly due to the environmental dependence of galaxy color and the correlation between color and luminosity.

4. SUMMARY

From the SDSS DR7 (Abazajian et al. 2009), we construct a volume-limited Main galaxy sample which contains 120362 galaxies at $0.05 \leq z \leq 0.102$ with $-22.50 \leq M_r \leq -20.50$, and measure the three-dimensional local density, to explore the environmental dependence of the fraction of ‘unconventional’ galaxies: luminous blue and faint red. It is found that the fraction of faint red increases apparently with increasing local density, and the fraction of luminous blue declines substantially

Fig. 4.— Fraction of ‘unconventional’ galaxies: luminous blue (a) and faint red (b) as a function of the three-dimensional local density of galaxies for the volume-limited Main galaxy sample. The error bars are 1σ Poissonian errors.

Table 1.

The galaxy number of different classes for two subsamples at both extremes of density in the volume-limited Main galaxy sample.

Classes	Subsample at low density N (%)	Subsample at high density N (%)
Luminous red	607 (10.09)	1432 (23.80)
Luminous blue	287 (4.77)	178 (2.96)
Faint blue	1897 (31.52)	656 (10.90)
Faint red	1881 (31.26)	2369 (39.37)

with increasing local density, which shows that there is an environmental dependence for color beyond that for luminosity.

Luminous red class contains 20883 galaxies, luminous blue class 5270 galaxies, faint blue class 25249 galaxies and faint red class 40020 galaxies. This shows that the majority of the luminous population corresponds to red galaxies, but the majority of the faint population does not correspond to blue galaxies, which is not consistent with the widely accepted conclusion: faint galaxies are preferentially blue. One possible explanation is that in such a study, ‘luminous’ and ‘faint’ are only relative, and that the fraction of red galaxies in our volume-limited sample is fairly high (67.26%).

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