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ENVIRONMENTAL DEPENDENCE OF ALL FIVE BAND LUMINOSITIES FOR SDSS-III/BOSS GALAXIES IN THE SDSS DR9

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RESUMEN

Utilizamos la muestra CMMASS con corrimientos al rojo entre 0.44 y 0.59 para investigar la dependencia ambiental de las luminosidades en cinco bandas de esta muestra proveniente del Sloan Digital Sky Survey Versión 9 (SDSS DR9). Para disminuir el efecto de selección radial dividimos la muestra CMASS en diferentes submuestras con corrimientos al rojo agrupados en celdas con $\triangle z = 0.01$ y analizamos para cada submuestra la dependencia ambiental de las luminosidades en cinco bandas. Encontramos que todas las luminosidades están débilmente correlacionadascon el ambiente local.

ABSTRACT

Using the CMASS sample with a redshift of $0.44 \leq z \leq 0.59$, we investigate the environmental dependence of all five band luminosities in the CMASS sample of the Sloan Digital Sky Survey Data Release 9 (SDSS DR9). To decrease the radial selection effect, we divide the CMASS sample into several subsamples with a redshift binning size of $\triangle z = 0.01$, and we analyze the environmental dependence of the five band luminosities of subsamples in each redshift bin. It is found that all five band luminosities are very weakly correlated with the local environment.

Key Words: galaxies: fundamental parameters — galaxies: statistics

1. INTRODUCTION

The study of the environmental dependence of galaxy properties is beneficial to understanding the formation and evolution of galaxies. The link between halo properties and galaxy properties likely leads to the variation of galaxy properties with their environment (Harker et al. 2006). In the last several decades, many works have focused on the correlation between galaxy luminosity and their environment (Davis et al. 1988; Hamilton 1988; White et al. 1988; Park et al. 1994; Loveday et al. 1995; Guzzo et al. 1997; Willmer et al. 1998; Norberg et al. 2001, 2002; Zehavi et al. 2002; Blanton et al. 2003, 2005; Hogg et al. 2003; Berlind et al. 2005; Zandivarez et al. 2006; Park et al. 2007; Deng et al. 2007, 2008a, 2008b, 2009, 2012a, 2012b; Deng & Zou 2011; Deng 2012). The hierarchical models of galaxy formation predict a close correlation between galaxy luminosity and the clustering strength or the environments of galaxies (e.g., White et al. 1987; Kauffmann et al. 1997). Many statistical results of observational data also support this standpoint. In the local Universe, it is widely accepted that luminous galaxies tend to reside in dense environments, while faint galaxies tend to reside in low density regions (e.g., Park et al. 1994; Norberg et al. 2001; Blanton et al. 2003, 2005; Zandivarez et al. 2006; Deng et al. 2007, 2008a, 2008b, 2009). However, this is a complicated matter because Deng & Zou (2011), Deng (2012) and Deng et al. (2012a, 2012b) have shown, using different statistical methods, that in the Main galaxy sample (Strauss et al. 2002) of the SDSS, the environmental dependence of galaxy luminosities does not follow a single trend for different bands, even in different luminosity regions. For the u-band, an opposite trend is observed: luminous galaxies in the u-band exist preferentially in low density regions, while faint galaxies in the u-band are located preferentially in high density regions. Thus, this issue merits further investigation.

The environmental dependence of galaxy properties is likely different in different redshift regions. In the local Universe, for example, galaxy colors strongly depend on the local environment (e.g., Brown et al. 2000; Zehavi et al. 2002; Blanton et al. 2005; Deng et al. 2008a, 2008b, 2009), while in intermediate and high redshift regions, this dependence is very weak (e.g., Cucciati et al. 2006; Grützbauch et al. 2011a, 2011b; Deng 2014). Thus, it would be of great interest to explore the environmental dependence of galaxy luminosities in intermediate and high redshift regions. The Baryon Oscillation Spectroscopic Survey (BOSS) of the Sloan Digital Sky Survey III (SDSS-III; Eisenstein et al. 2011) will carry out a redshift survey of 1.5 million luminous red galaxies (LRGs) at $0.15 < z < 0.8$ over

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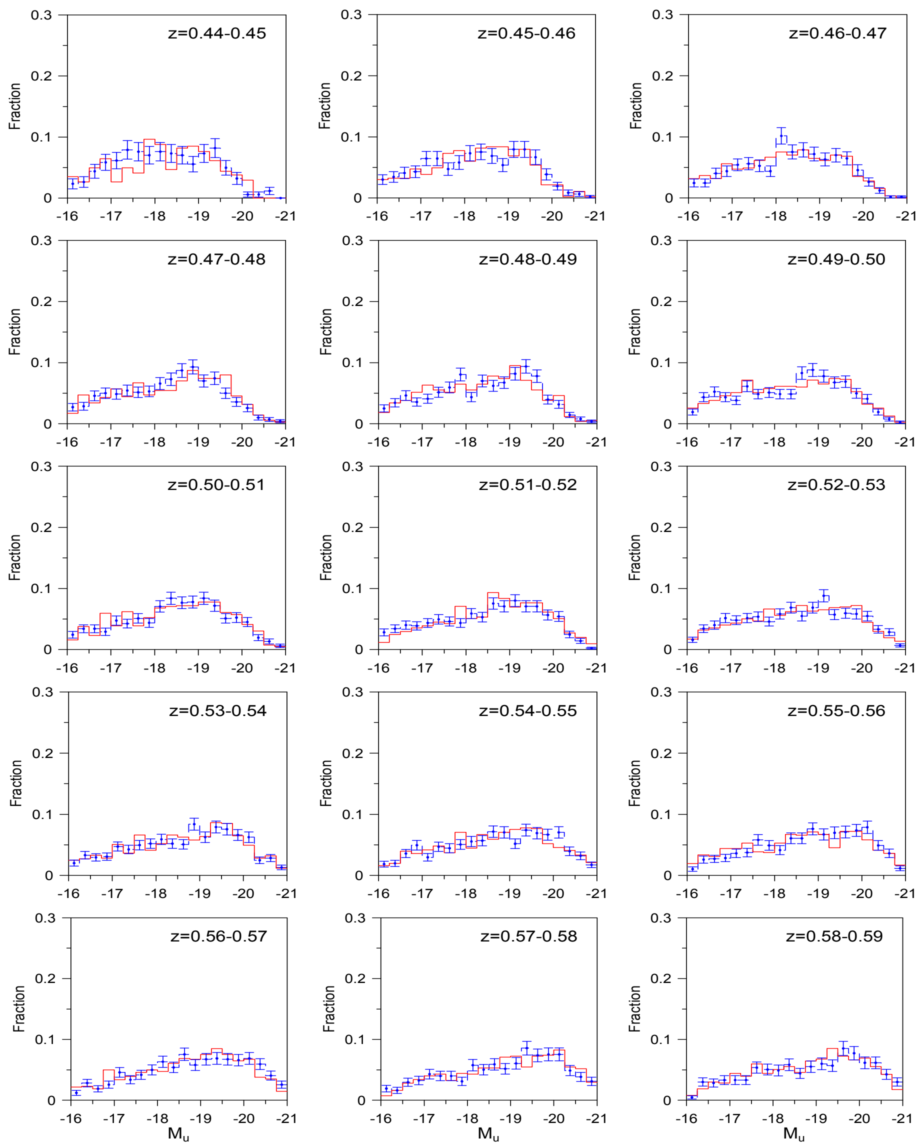

Fig. 1. U-band absolute magnitude distribution at both density extremes in different redshift bins: the red solid line represents the sample at high density, the blue dashed line represents the sample at low density. The error bars of the blue lines are 1 σ Poissonian errors. The error-bars of the red lines are omitted for clarity. The color figure can be viewed online.

10,000 square degrees. Undoubtedly, the BOSS galaxy sample is a valuable sample for intermediate redshifts. Here, we investigate the environmental dependence of all five band luminosities of BOSS galaxies.

Our paper is organized as follows. In § 2, we describe our sample. The statistical method is described in § 3. In § 4, we present statistical results. § 5 summarizes our conclusions.

In calculating the distance, we used a cosmological model with a matter density of $\Omega_0 = 0.3$, a cosmological constant of $\Omega_\Lambda = 0.7$, a Hubble's constant of H_0=70 km s^{-1} Mpc^{-1}.

2. SAMPLE

The ninth data release (DR9) (Ahn et al. 2012) of the SDSS is the first public release of spectroscopic data from the SDSS-III Baryon Oscillation Spectroscopic Survey (BOSS), which includes 535,995 new galaxy spectra (median $z \sim 0.52$), 102,100 new quasar spectra (median $z \sim 2.32$), and 90,897 new stellar spectra, along with the data presented in previous data releases.

The BOSS galaxy sample is divided into two principal samples at $z \simeq 0.4$: "LOWZ" and "CMASS". The LOWZ sample, a low redshift sample with a median redshift of $z = 0.3$, is a simple extension of the SDSS I and II LRG samples (Eisenstein et al. 2001) and can be used for comparison with them. The CMASS sample is a nearly complete sample of massive galaxies above $z \simeq 0.4$, in which most galaxies are located at $0.43 < z < 0.7$. Such a sample is a good representative of intermediate-redshift galaxy samples. Deng (2014)

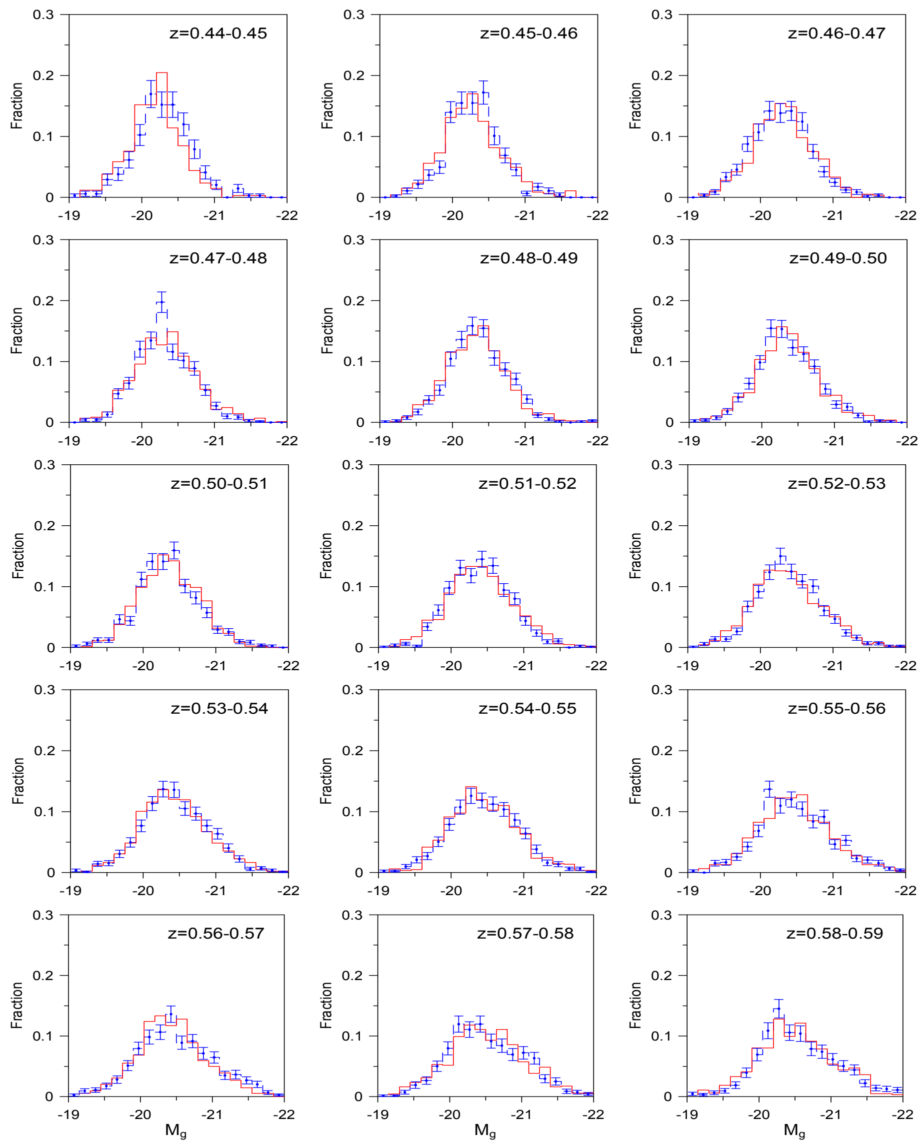

Fig. 2. Same as Figure 1, but for the g-band absolute magnitude distribution at both density extremes in different redshift bins. The color figure can be viewed online.

studied the environmental dependence of galaxy colors in the CMASS sample and found that galaxy colors are weakly correlated with the local environment. In considering the serious radial selection effect of the CMASS sample at $z > 0.6$ (Maraston et al. 2013; Anderson et al. 2012; Dawson et al. 2013), Deng (2014) restricted his study to a CMASS sample with a redshift of $0.44 \leq z \leq 0.59$ that contains 212,911 CMASS galaxies. We also use this CMASS sample.

3. STATISTICAL METHOD

Within redshift $0.44 \leq z \leq 0.59$, the CMASS galaxy sample still suffers from the radial selection effect. A good choice for removing this effect is to use the volume-limited galaxy sample. Unfortunately, the CMASS galaxy sample is not simply flux-limited, making it difficult to construct an ideal volume-limited sample from it.

We proceed with the same approach used by Deng (2012). § 3 of Deng (2012) describes this method in detail, but we briefly summarize the key points here.

Following Deng (2012), we measure the projected local density $\sum_5$, which is computed from the distance to the 5th nearest neighbor within a redshift slice of ± 1000 km s^{-1} of each galaxy (e.g., Goto et al. 2003; Balogh et al. 2004a, 2004b). The CMASS galaxy sample is then divided into subsamples with a redshift binning size of $\triangle z = 0.01$. Then, the environmental dependence of all five band luminosities of the subsamples in each redshift bin is analyzed.

As in Deng et al. (2008a), for each subsample we arrange galaxies in a density order from smallest to largest. We select approximately 5% of the galaxies,

TABLE 1

KS PROBABILITIES OF ALL FIVE BAND LUMINOSITIES, WHERE TWO SAMPLES AT BOTH DENSITY EXTREMES ARE DRAWN FROM THE SAME DISTRIBUTION

Redshift bins	Galaxy number	P(u-band)	P(g-band)	P(r-band)	P(i-band)	P(z-band)
0.44−0.45	6833	0.266	0.000174	0.0518	0.0420	0.163
0.45−0.46	9291	0.403	0.317	0.555	0.244	0.665
0.46−0.47	11420	0.536	0.828	0.401	0.134	0.323
0.47−0.48	13970	0.0708	0.0930	0.274	0.838	0.798
0.48−0.49	15146	0.627	0.460	0.982	0.995	0.902
0.49−0.50	15650	0.482	0.339	0.183	0.0190	0.00505
0.50−0.51	16444	0.870	0.475	0.0129	0.0151	0.00135
0.51−0.52	16984	0.0176	0.535	0.0543	0.0702	0.0543
0.52−0.53	17475	0.829	0.235	0.515	0.155	0.0683
0.53−0.54	16938	0.995	0.573	0.910	0.295	0.219
0.54−0.55	16204	0.544	0.923	0.428	0.0522	0.0681
0.55−0.56	15491	0.0668	0.642	0.475	0.0443	0.0112
0.56−0.57	14834	0.278	0.0373	0.142	0.614	0.827
0.57−0.58	13546	0.738	0.862	0.555	0.182	0.0732
0.58−0.59	12685	0.281	0.468	0.426	0.251	0.0312

construct two samples at both density extremes according to the density, and compare the distributions of galaxy luminosities in the lowest density regime with those in the densest regime. In each redshift bin, the radial selection effect is less important.

We use model magnitudes. In all cases, galactic extinction corrections are applied, but without K-corrections. In this study, each subsample is limited to the redshift bin $\triangle z = 0.01$. As indicated in Deng (2012), K-corrections are less important and can be ignored in such a small redshift range.

4. RESULTS

Deng (2012) argued that in such a study the environmental dependence of galaxy luminosity in each subsample is likely to be greatly decreased due to each subsample being limited to a small redshift range, $\triangle z = 0.01$. However, Deng (2012) still found that in each redshift bin, the u-, g-, r-, i- and z-band luminosities are apparently correlated with the local environment. Using the same galaxy sample and statistical method, Deng et al. (2012c) also demonstrated that there is a strong environmental dependence of stellar mass, star formation rate (SFR), specific star formation rate (SSFR, the star formation rate per unit stellar mass) and fraction of active galactic nuclei (AGNs) in nearly all redshift bins. These studies showed that in redshift bin $\triangle z = 0.01$, the environmental dependence of galaxy properties can still be observed if it exists.

Figures 1–5 show u-, g-, r-, i- and z-band absolute magnitude distributions at both density extremes in different redshift bins for the CMASS galaxy sample. As seen from these figures, all five band luminosities are weakly correlated with the local environment, which is inconsistent with the hierarchical models of galaxy formation (e.g., White et al. 1987; Kauffmann et al. 1997).

We also perform the Kolmogorov-Smirnov (KS) test to investigate whether two independent distributions are similar or different by calculating a probability value. A large probability implies that it is very likely that the two distributions are derived from the same parent distribution. Conversely, a low probability implies that the two distributions are different. Table 1 lists the probability of the two distributions coming from the same parent distribution, which is much larger than that obtained by Deng (2012) and Deng et al. (2012c) (see Table 1 of Deng 2012 and Deng et al. 2012c) and it is even much larger than 0.05 (5% is the standard in a statistical analysis) in many redshift bins. Such a result is in good agreement with the conclusion obtained by the step figures.

Deng & Zou (2009) demonstrated that at fixed color, the environmental dependence of galaxy luminosity is greatly decreased, and Deng et al. (2011a) reported that at fixed luminosity, strong environmental dependences of g-r color still can be observed. These results imply that the environmental dependence of galaxy luminosity is likely mainly driven by the color-density relation. A strong environmental dependence of galaxy luminosities in the
Main galaxy sample (Strauss et al. 2002) of the SDSS is a combination of a tight color-luminosity relation and a strong color-density relation. Deng & Zou (2011) argued that in the Main galaxy sample of the SDSS,

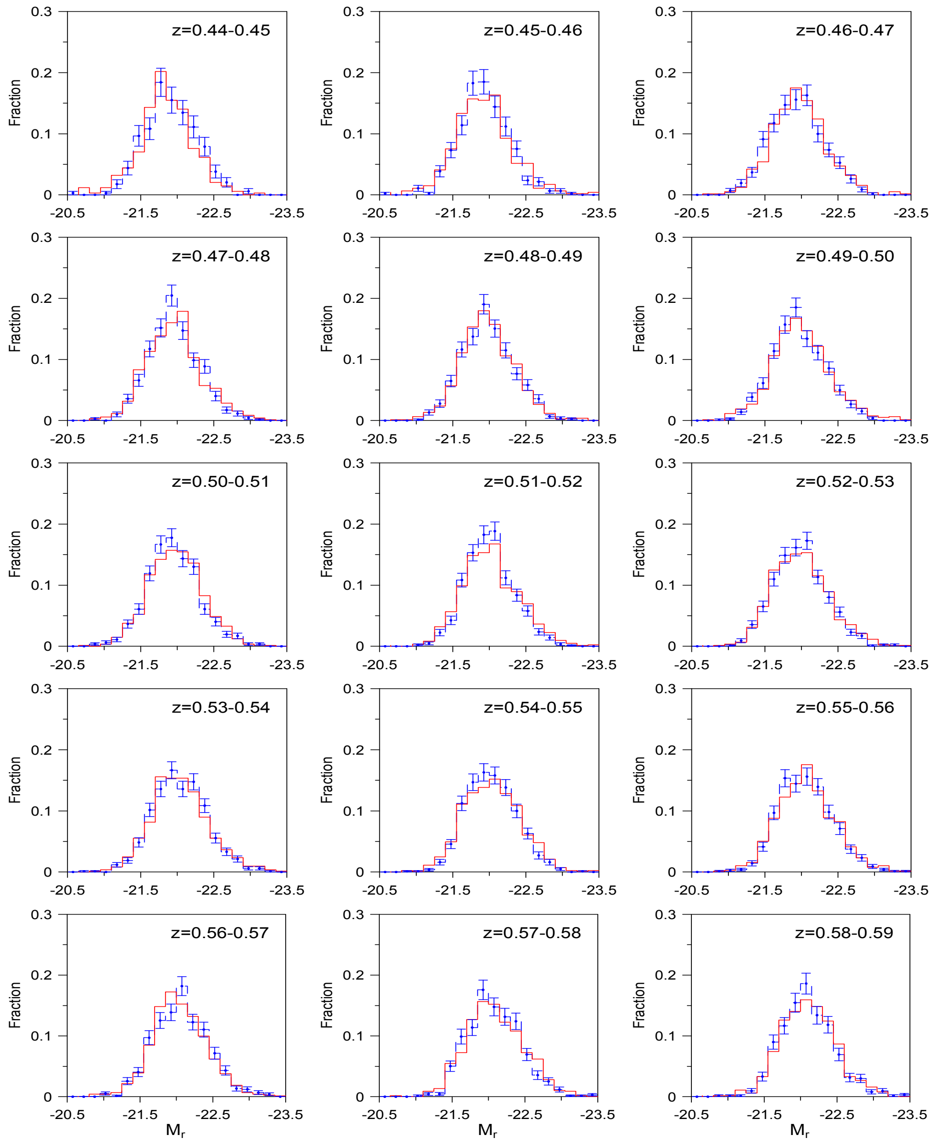

Fig. 3. Same as Figure 1, but for the r-band absolute magnitude distribution at both density extremes in different redshift bins. The color figure can be viewed online.

the opposite trend for the environmental dependence of u-band luminosity may be due to the abnormal correlation between colors and luminosity (e.g., Deng et al. 2008c). In intermediate and high redshift regions. the color-density relation is likely very weak. Cucciati et al. (2006) showed that the color-density relation at $0.25 < z < 0.60$ progressively disappears with higher redshift until it is undetectable at $z \simeq 0.9$. Grützbauch et al. (2011a) demonstrated that there is a weak correlation of galaxy color with local number density in the redshift range of $0.4 < z < 1$, which becomes weaker with higher redshift and is not detectable at $z \simeq 1$. Grützbauch et al. (2011b) did not observe a strong influence of the local environment on galaxy colors up to a redshift of $z \simeq 3$. Thus, it is not surprising that all five band luminosities of CMASS galaxies weakly depend on the environment.

As indicated above, the strong environmental dependence of galaxy colors in the local Universe cannot be extended to intermediate- and high-redshift regions. Similarly, the environmental dependence of stellar mass is fairly strong in the local Universe (e.g., Kauffmann et al. 2004; Li et al. 2006; Deng et al. 2011b, 2012c), but it is very weak in the SDSS LRG and BOSS galaxy samples (e.g., Deng et al. 2012d; Deng & Zou 2014). At intermediate redshifts, Grützbauch et al. (2011a) also found a weak stellar mass dependence on the environment and claimed that the weak color-density relation at intermediate redshifts is a combination of a strong color-stellar mass relation and a weak stellar mass-density relation. Considering that the colors of galaxies are strongly correlated with stellar mass at redshifts up to $z \simeq 3$, Grützbauch et al. (2011b) argued that stellar mass is

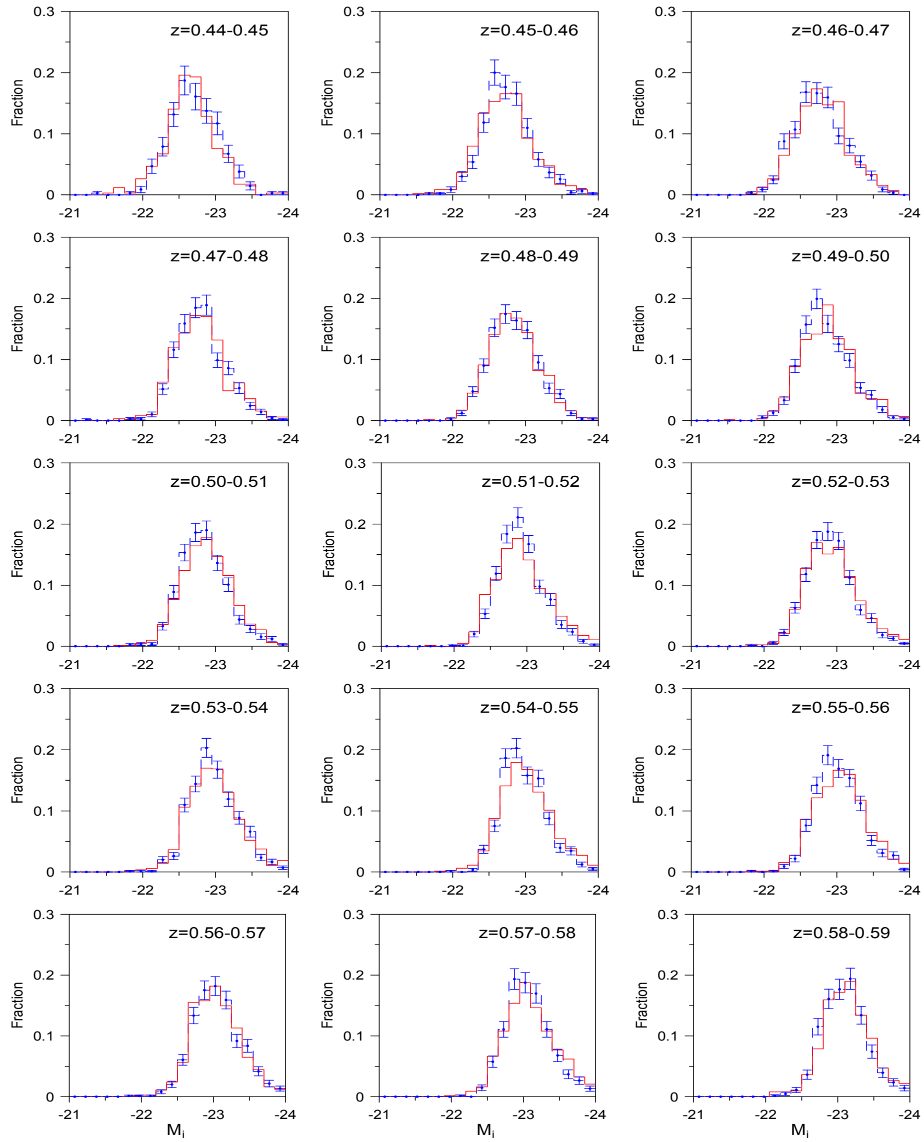

Fig. 4. Same as Figure 1, but for the i-band absolute magnitude distribution at both density extremes in different redshift bins. The color figure can be viewed online.

the most important factor in determining the colors of galaxies in the early universe up to $z \simeq 3$ and that the local density likely has a small additional effect, but only at the most extreme overdensities. Grützbauch et al. (2011b) explained that the environmental processes that exert the main influence on galaxy properties proceed slowly over cosmic time. Moreover, some of the most influential high-density environments may still be in the process of developing and cannot yet affect galaxy colors. It is likely that the weak environmental dependence of CMASS galaxy luminosities is due to a similar mechanism.

Grützbauch et al. (2011a) argued that the color difference largely disappears when stellar mass selected samples are used. Cooper et al. (2007) demonstrated that the strong color-density relation still exists at $z > 1$. Grützbauch et al. (2011a) claimed that the strong relation between color and local density obtained by Cooper et al. (2007) might be partly caused by their sample selection, which is rest-frame B-band luminosity limited. The galaxy sample selection also likely leads to different environmental dependences of galaxy luminosities. This question clearly merits further studies.

5. SUMMARY AND CONCLUSIONS

The strong environmental dependence of some typical galaxy properties (such as colors and stellar mass) in the local Universe cannot extend to intermediate- and high-redshift regions. Thus, it is necessary to explore the environmental dependences of galaxy luminosities in intermediate and high redshift regions. Such information can provide model tests for the formation and evolution of galaxies.

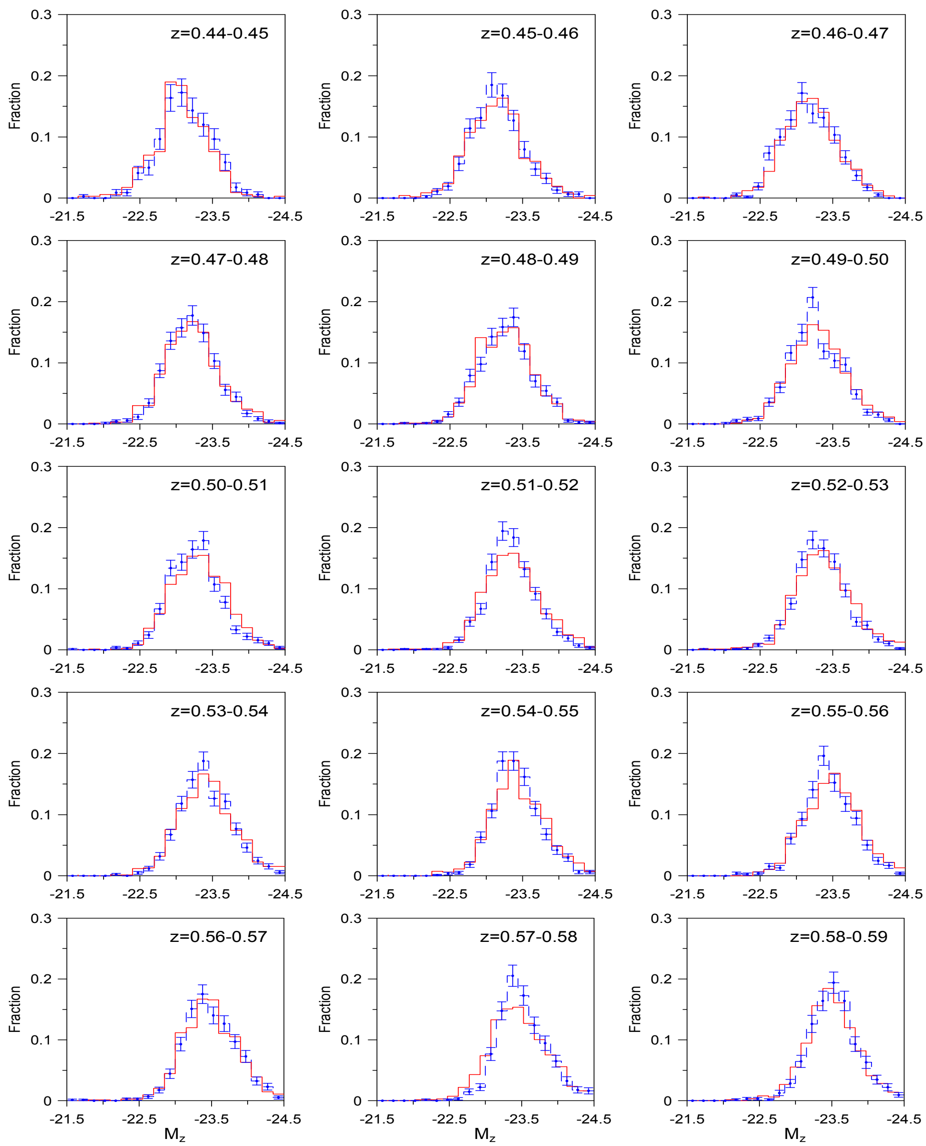

Fig. 5. Same as Figure 1, but for the z-band absolute magnitude distribution at both density extremes in different redshift bins. The color figure can be viewed online.

Using the CMASS sample with a redshift of $0.44 \leq z \leq 0.59$, we investigate the environmental dependence of all five band luminosities in the CMASS sample of the SDSS DR9 (Ahn et al. 2012). Following Deng (2012), to decrease the radial selection effect we divide the CMASS sample into several subsamples with a redshift binning size of $\triangle z = 0.01$, and we analyze the environmental dependence of the five band luminosities of subsamples in each redshift bin. As seen in Figures 1–5, all five band luminosities are very weakly correlated with the local environment, which is inconsistent with the results obtained in the local Universe. Such a result cannot be explained by previous models, such as the hierarchical models of galaxy formation. A possible interpretation of this result is that the environmental processes that exert the main influence on galaxy properties proceed slowly over cosmic time and that some of the most influential high-density environments may still be in the process of developing and cannot yet affect galaxy luminosities. Another possible explanation is that the galaxy sample selection may lead to different environmental dependences of galaxy luminosities.

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