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ENVIRONMENTAL DEPENDENCE OF DIFFERENT COLORS FOR THE APPARENT MAGNITUDE-LIMITED MAIN GALAXY SAMPLE OF THE SDSS DR7

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Abstract. The apparent magnitude-limited Main galaxy sample of the Sloan Digital Sky Survey Data Release 7 is used to investigate the environmental dependence of u–r, u–g, g–r, r–i and i–z colors. All the five colors strongly correlate with the local environment: red galaxies tend to be located in dense regions, while blue galaxies tend to be located in low density regions. We also note that with increasing of redshift, the environmental dependence of galaxy colors becomes weaker, especially in the high redshift region (z between 0.17 and 0.20). This can be explained accepting that subsamples with high redshifts contain only luminous and red galaxies.

Key words: galaxies: fundamental parameters – galaxies: statistics

1. INTRODUCTION

In the past it was widely believed that luminous galaxies tend to reside in the densest regions of the Universe, while faint galaxies tend to reside in the low density regions (e.g., Park et al. 1994; Blanton et al. 2003; Zandivarez et al. 2006; Deng et al. 2007a, 2008a,b, 2009a). However, recent studies showed that the environmental dependence of galaxy luminosity likely has different trends in different photometric passbands. Deng & Zou (2011) reported that the above-mentioned trend of the luminosity-density relation is indeed seen for r, i and z bands of the SDSS Main galaxy sample (Strauss et al. 2002), but for the u band the luminosity-density relation has an opposite trend. Deng (2012), using the apparent magnitude-limited Main galaxy sample of the SDSS DR7 (Abazajian et al. 2009), investigated the environmental dependence of all the five band luminosities again, and reached the same conclusion. Deng & Zou (2011) claimed that the opposite trend for the environmental dependence of u-band luminosity likely is due to the abnormal correlation between colors and luminosity (Deng et al. 2008c). Considering that the luminosity-density relation is a combination of the color-luminosity relation and the color-density relation (e.g., Deng & Zou 2009b), we now believe that the environmental dependence of different galaxy colors merits further investigation.

The color-density relation for a long time has been studied in detail (Brown et al. 2000; Zehavi et al. 2002; Bernardi et al. 2003; Blanton et al. 2003, 2005; Balogh et al. 2004a; Hogg et al. 2004; Lee et al. 2004; Tanaka et al. 2004; Cooper et al. 2006, 2007, 2010; Cucciati et al. 2006; Cassata et al. 2007;

Gerke et al. 2007; Bamford et al. 2009; Pannella et al. 2009; Tasca et al. 2009; Iovino et al. 2010; Deng et al. 2007b, 2008a,b, 2009a, 2010a,b,c; Skibba et al. 2009; Lee et al. 2010; Wilman et al. 2010; Grützbauch et al. 2011a,b). Brown et al. (2000) and Zehavi et al. (2002) demonstrated that clustering of galaxies strongly depends on color. Blanton et al. (2003) found that local density is a strong function of all colors. Blanton et al. (2005) argued that galaxy color is a property mostly predictive from the local environment. Investigations in the local Universe show that red galaxies tend to reside in the densest regions of the Universe, while blue galaxies tend to reside in low density regions. For example, Deng et al. (2007b) reported that mean colors of galaxies in compact groups (CGs) are redder than those of galaxies in the random groups. Deng et al. (2008b) demonstrated that isolated galaxies have a higher proportion of blue galaxies and a lower proportion of red galaxies than the member galaxies of CGs. However, in the intermediate and high redshift regions statistical analyses from different surveys have yielded contradictory results. Cooper et al. (2006) found that the environmental dependence of galaxy colors at $z \approx 1$ mirrors that seen in the local Universe. Grützbauch et al. (2011a) demonstrated that galaxy color is weakly correlated with the local number density in the redshift range $0.4 < z < 1$.

The SDSS has revolutionized the studies of galaxies in the local Universe. In this paper, our goal is to further investigate the environmental dependence of different colors of galaxies in the SDSS Main galaxy sample. When investigating the data of the SDSS Main galaxies, most authors transform apparent magnitude-limited samples to the volume-limited samples which are constructed by the r-band luminosity (e.g., Deng et al. 2007b, 2008a,b, 2009a). An important reason of this choice is that the use of the volume-limited galaxy sample can remove the radial selection effect in galaxy samples. However, Deng (2012) argued that the volume-limited galaxy samples also have some drawbacks. For example, in this case a large fraction of the data becomes out of use. Deng (2012) also indicated that the volume-limited galaxy sample is defined in a narrow luminosity region and a redshift limit $Z_{\max}$, which cannot show overall properties of the whole sample of galaxies. In addition, the r-band luminosity selection can induce biases in the luminosity functions of other bands, which lead to different biases for different colors.

When exploring properties of galaxies, different galaxy samples are often used and different statistical methods are applied. In this study, we use the apparent magnitude-limited Main galaxy sample of the SDSS DR7 (Abazajian et al. 2009) to investigate the environmental dependence in different colors. An advantage of the apparent magnitude-limited sample is the maximum use of observational data. However, the apparent magnitude-limited sample seriously suffers from the Malmquist bias (Malmquist 1920; Teerikorpi 1997). This means that an observer will see an increase in the averaged luminosity with increasing distance, caused by the fact that less luminous galaxies at large distances will not be detected. To decrease such an effect we divide the whole apparent magnitude-limited Main galaxy sample into many subsamples with redshift binning size $\Delta z = 0.01$, and analyze the environmental dependence of different colors of subsamples in each redshift bin.

Our paper is organized as follows. In Section 2, we describe the data used. The statistical method is described in Section 3. In Section 4 we discuss the environmental dependence of different colors in the apparent magnitude-limited

Main galaxy sample of the SDSS DR7. The main results and conclusions are summarized in Section 5.

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

2. DATA

The properties of SDSS were described in detail by Stoughton et al. (2002). In this survey, there are two galaxy samples: the Main galaxy sample (Strauss et al. 2002) and the Luminous Red Galaxy (LRG) sample (Eisenstein et al. 2001), which are selected by different algorithms. The Main galaxy sample with a median redshift of 0.10 includes galaxies brighter than $r_{\mathrm{petro}} = 17.77$. Here r_{petro} is the r-band apparent Petrosian magnitude in which most galaxies are located within the redshift range $0.02 \leq z \leq 0.2$. The LRG algorithm contains galaxies to $r_{\mathrm{petro}} < 19.5$ that are luminous galaxies of early types, intrinsically red and with higher redshifts.

The data of the Main galaxy sample were downloaded from the Catalog Archive Server of SDSS Data Release 7 by the SDSS SQL Search with high-confidence redshifts[1]. This apparent sample contains 565 029 Main galaxies in the redshift range $0.02 \leq z \leq 0.2$.

In this study, all analyses are limited in the redshift bin $\Delta z = 0.01$. As indicated as Deng (2012), in such a small redshift range, K-corrections are less important and can be ignored. Being restricted by a small distance range, each subsample is also insensitive to the Malmquist bias.

In most cases, K-corrections should be applied. But it is important to bear in mind that there are inherent uncertainties in K-corrections due to lack of knowledge of the spectral energy distributions (SEDs). The gap between the g and r bands gives a considerable freedom in constructing SEDs. This means that the application of K-corrections will result in new biases and assumptions. In fact, Blanton et al. (2003) emphasize that K-corrections are not always necessary or appropriate. In many cases the observed colors without K-corrections were used. For example, many authors applied the observed colors and classified galaxies above and below the divider (the observed u–$r = 2.22$), identified by Strateva et al. (2001) as the 'red' and 'blue' samples, respectively.

3. STATISTICAL METHOD

The nearest neighbor densities are widely used in the literature to characterize the local galaxy environment (Grützbauch et al. 2011b). The number of neighbors to count, n, is still a subject of debate, but many authors would like to use $n = 5$ (e.g., Goto et al. 2003; Balogh et al. 2004a,b; Yee et al. 2005; Ball et al. 2008; Deng et al. 2008a, 2009a, 2010b,c; Deng 2012). Cooper et al. (2005) demonstrated that the choice of n does not change the resulting densities significantly.

Following Deng (2012), we measure the projected local density $\Sigma_5 = N/\pi d_5^2$, where d_5 is the distance to the 5th nearest neighbor within $\pm\,1000\ \mathrm{km\,s^{-1}}$ in redshift (e.g., Goto et al. 2003; Balogh et al. 2004a,b). Considering that in the apparent magnitude-limited Main galaxy sample of SDSS the number-density of galaxies dramatically drops with increasing redshift due to the Malmquist bias

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[1] http://www.sdss.org/dr7/.

(see Fig.1 of Deng 2012), we divide the whole sample into subsamples with redshift binning size $\Delta z = 0.01$.

Like Deng et al. (2008a), for each subsample we arrange galaxies in a density order from the smallest to the largest, select approximately 5% of the galaxies, construct two samples at both extremes of density, and compare the distributions of galaxy colors in the lowest density sample with those of galaxies in the densest sample. Apparently, in each redshift bin, the radial selection effect is less important.

4. ENVIRONMENTAL DEPENDENCE OF DIFFERENT COLORS IN THE APPARENT MAGNITUDE-LIMITED MAIN GALAXY SAMPLE

Figures 1–5 show u–r, u–g, g–r, r–i and i–z color distributions at both extremes of density in different redshift bins for the apparent magnitude-limited Main galaxy sample. It is seen that all the five colors strongly correlate with local environment: red galaxies tend to be located in dense regions, while blue galaxies tend to be located in low density regions. This is a conclusion widely accepted in the past.

In the figures we also note that with increasing redshift the environmental dependence of galaxy colors becomes weak, especially in the high-redshift region $0.17 \leq z \leq 0.20$. Due to the Malmquist bias in the apparent magnitude-limited sample, the average luminosity of galaxies dramatically increases with increasing redshift. Thus, subsamples with high redshifts likely contain only luminous and red galaxies, and are limited in a narrow luminosity and color region, which leads to reduced environmental dependence of galaxy colors in these subsamples.

The Kolmogorov-Smirnov (KS) test allows to verify if two independent distributions are similar or different by calculating the probability values. 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. The application of the KS test to our sample gives the probabilities of the two distributions, coming from the same parent distribution in the redshift region $0.05 \leq z \leq 0.14$, close to zero. This shows that the two distributions of colors at both extremes of density are completely different. In the high redshift region, this probability apparently is larger than zero. Such a result is in good agreement with the conclusion obtained by the histograms.

In the past it was widely believed that the correlation between colors and luminosities is tight: more luminous galaxies are redder (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). Our results show that the environmental dependence of different galaxy colors has the same trends. If the environmental dependence of all the five band luminosities is due to the environmental dependence of galaxy colors and the correlation between colors and luminosities, the environmental dependence of different band luminosities should have a single trend: luminous galaxies exist preferentially in the densest regions of the Universe, while faint galaxies are located preferentially in low density regions.

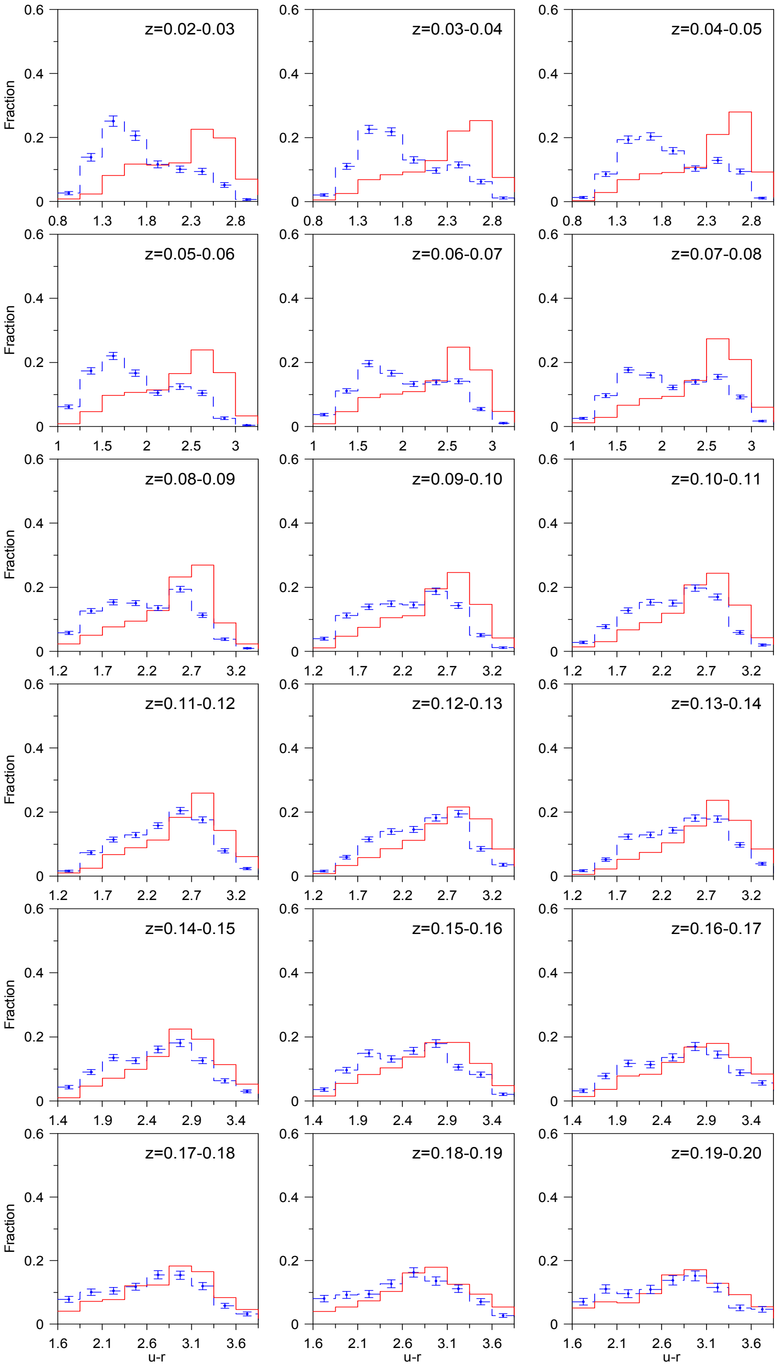

Fig. 1. Distribution of u–r colors at both extremes of density in different redshift bins: the red solid line is for the sample at high density, and the blue dashed line is for the sample at low density. The error bars of blue lines are $1\,\sigma$ Poissonian errors. The error bars of red lines are omitted for clarity.

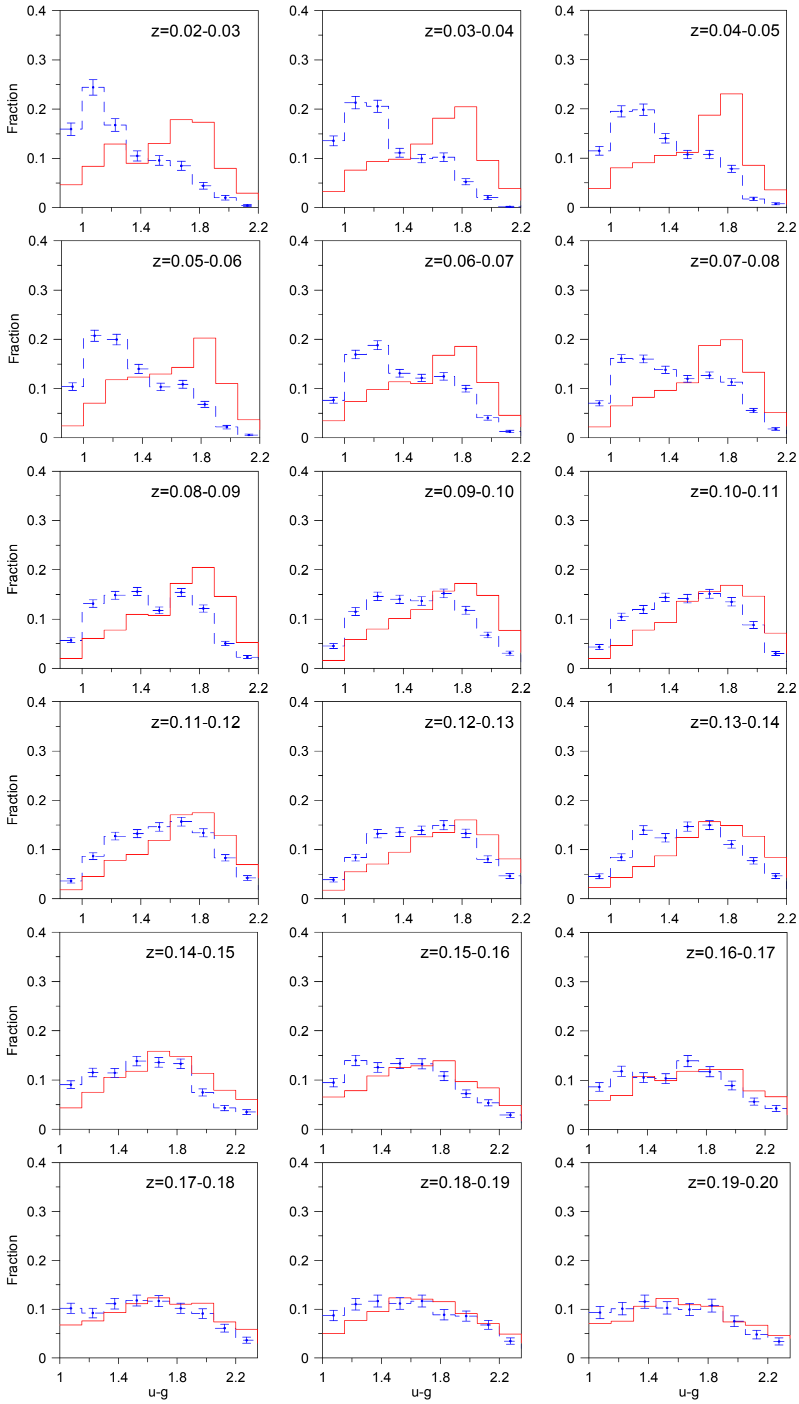

Fig. 2. Distribution of u–g colors. Designations are the same as in Figure 1.

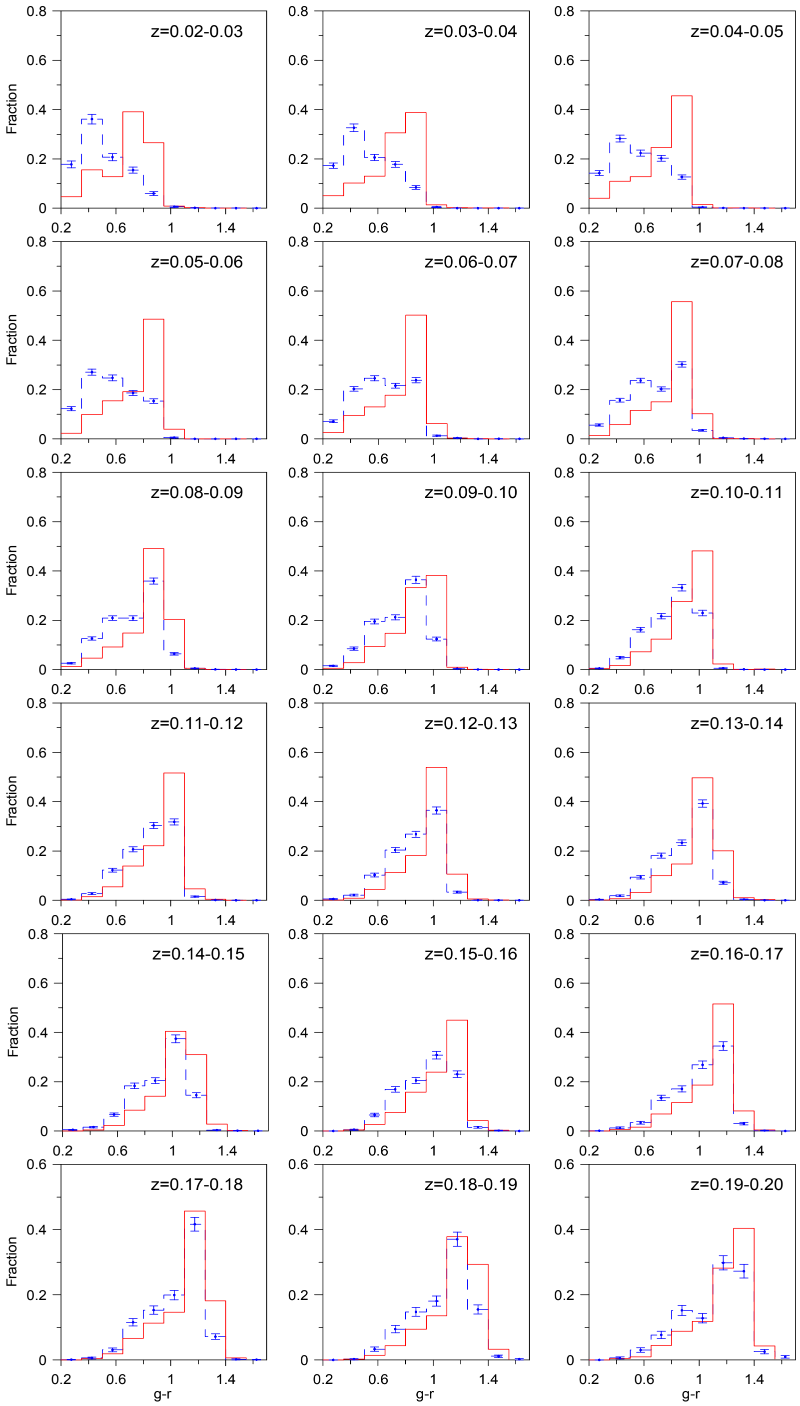

Fig. 3. Distribution of g–r colors. Designations are the same as in Figure 1.

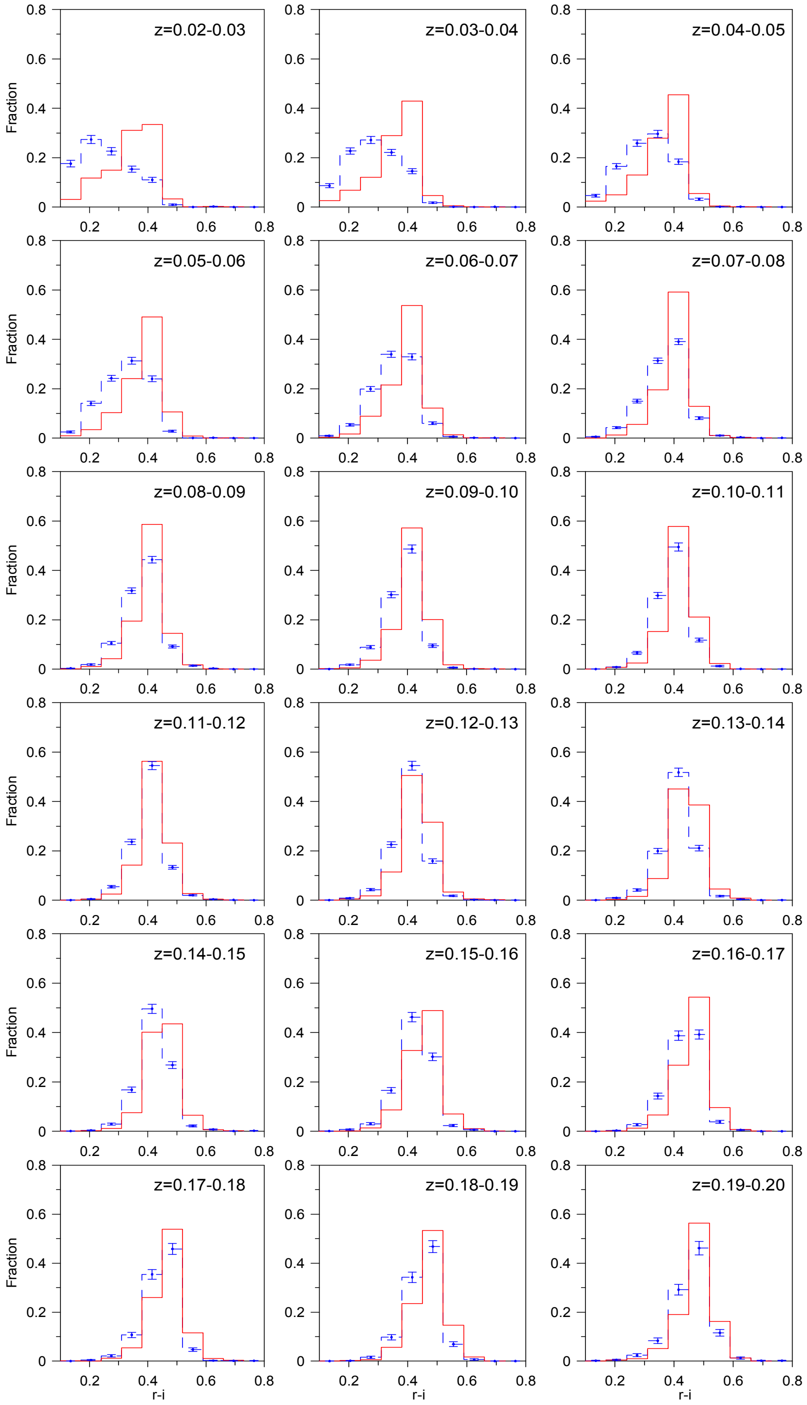

Fig. 4. Distribution of r–i colors. Designations are the same as in Figure 1.

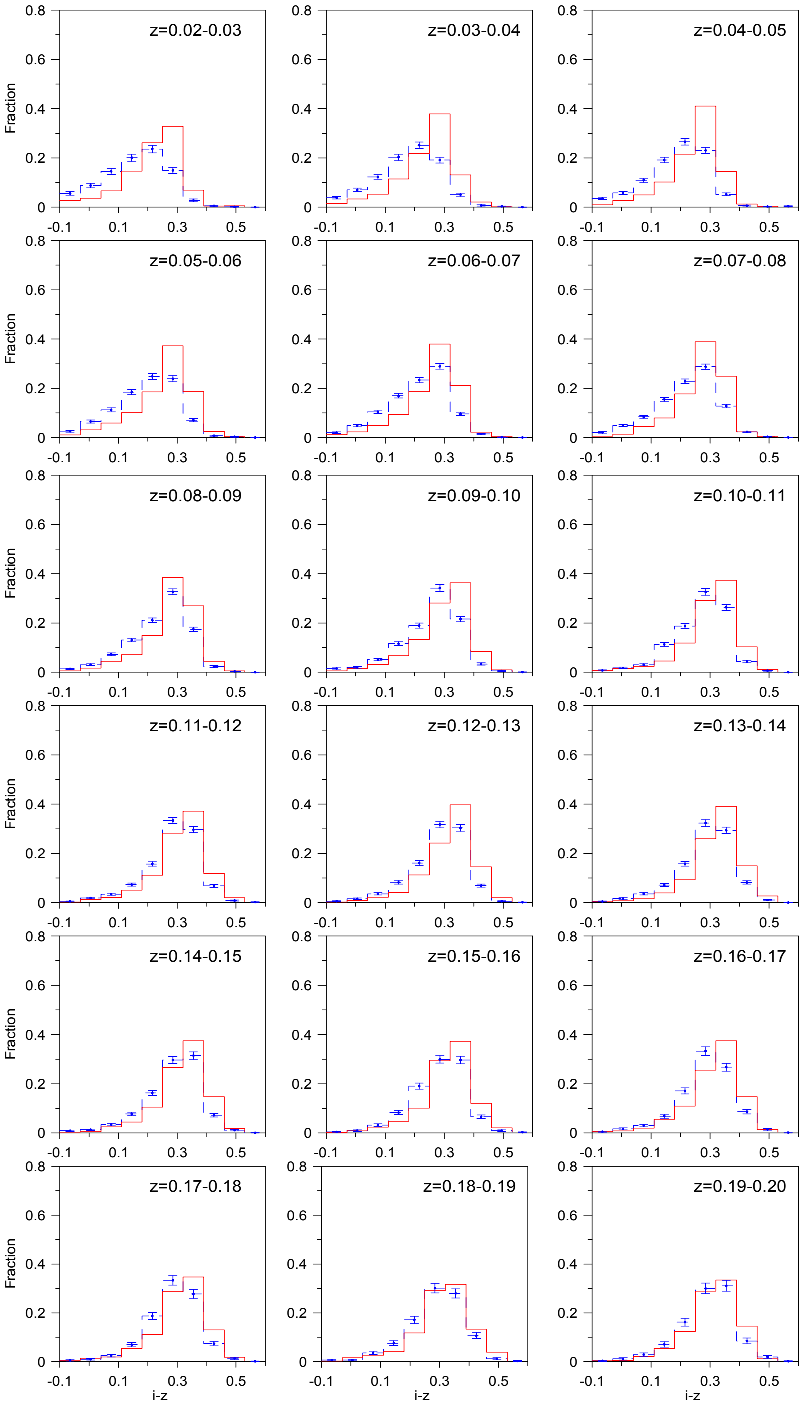

Fig. 5. Distribution of i–z colors. Designations are the same as in Figure 1.

However, the correlation between colors and luminosities is complicated. Deng et al. (2008c) reported that the mean colors of galaxies become bluer with increasing luminosity in the u band. Due to such correlation between colors and luminosities, one can expect abnormal behavior of the environmental dependence of the luminosity in the u band.

Due to close correlations between physical properties of galaxies (e.g., Bower et al. 1992; Strateva et al. 2001; Blanton et al. 2003; Baldry et al. 2004; Balogh et al. 2004a; Kelm et al. 2005), when exploring the environmental dependence of a galaxy property, one needs to distinguish between two simple scenarios: (1) the environmental dependence of this galaxy property is only due to the environmental dependence of other galaxy properties and the correlation between this galaxy property and other galaxy properties; or (2) the environmental dependence of this galaxy property is fundamental in the correlations between galaxy properties and their environment. Some studies showed that galaxy colors likely are fundamental in correlations between galaxy properties and environment. For example, Skibba et al. (2009) found that at fixed morphology, galaxy colors are correlated with the environment, but the correlations between morphology and environment are extremely weak at the fixed color. They concluded that much of the morphology-density relation is due to the relation between color and density. So, when exploring the environmental dependence of galaxy colors, its statistical conclusion should not be influenced by correlations between physical properties of galaxies.

5. CONCLUSIONS

In this work, we used the apparent magnitude-limited Main galaxy sample of the SDSS DR7 to investigate the environmental dependence of u–r, u–g, g–r, r–i and i–z colors. Like Deng (2012), to decrease the radial selection effect, we divided the whole apparent magnitude-limited Main galaxy sample into many subsamples with redshift binning size $\Delta z = 0.01$, and analyzed the environmental dependence of colors of the subsamples in each redshift bin. As it is seen form Figures 1–5, all the five colors strongly correlate with the local environment: red galaxies tend to be located in dense regions, while blue galaxies tend to be located in low density regions. We also note that with increasing redshift, the environmental dependence of galaxy colors becomes weak, especially in the high redshift region, $0.17 \leq z \leq 0.20$. This is likely due to subsamples with high redshifts containing only luminous and red galaxies. Thus, they are limited in a quite narrow luminosity and color range, which leads to the environmental dependence of galaxy colors in these subsamples being greatly decreased.

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