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COLOR-DENSITY RELATION IN THE LOW Z SAMPLE OF THE SDSS DR10

Xin-Fa Deng

School of Science, Nanchang University, Jiangxi, China

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RESUMEN

El objetivo de este estudio es examinar la dependencia ambiental de los colores $u-r$, $u-g$, $g-r$, $r-i$ e $i-z$ en la muestra de baja z del Sloan Digital Sky Survey Data Release 10 (SDSS DR10). Para disminuir el efecto de selección radial, divido la muestra de baja z en submuestras agrupadas en intervalos de $\triangle z$=0.01 y analizo la dependencia ambiental de los colores para estas submuestras en cada intervalo de corrimiento al rojo. Los resultados estadísticos indican que los cinco colores de la muestra de baja z están levemente correlacionados con las propiedades ambientales locales, lo cual coincide con lo encontrado para galaxias principales a $z > 0.15$ y para galaxias CMASS.

ABSTRACT

The aim of this study is to examine the environmental dependence of the $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors in the loz z sample of the Sloan Digital Sky Survey Data Release 10 (SDSS DR10). To decrease the radial selection effect, I divide the low z sample into subsamples with a redshift binning size of $\triangle z$=0.01 and analyze the environmental dependence of colors for these subsamples in each redshift bin. The statistical results show that all five colors of galaxies in the low z sample are weakly correlated with the local environment, which is consistent with the results of main galaxies at $z > 0.15$ and CMASS galaxies.

Key Words: Galaxies: fundamental parameters — galaxies: statistics

1. INTRODUCTION

Many previous works have focused on the environmental dependence of galaxy colors (e.g., 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, 2010; 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. 2008a-b, 2009a-b, 2013a; Skibba et al. 2009; Wilman et al. 2010; Grützbauch et al. 2011a-b). In the local Universe, galaxy colors have a strong environmental dependence: red galaxies tend to reside in the dense environment, while blue galaxies tend to reside in the sparse environment (e.g., Brown et al. 2000; Zehavi et al. 2002; Blanton et al. 2005; Deng et al. 2008a-b, 2009a). Following (Deng 2012), (Deng et al. 2013a) divided an apparent magnitude-limited main galaxy sample (Strauss et al. 2002) at redshift 0.02≤ z ≤0.2 into subsamples with a redshift binning size of $\triangle z$=0.01 and investigated the environmental dependence of the $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors of the subsamples in each redshift bin. Such a study can demonstrate the variation of the environmental dependence of galaxy colors with redshift. (Deng et al. 2013a) found that strong environmental dependence only exists in the redshift region 0.02≤ z ≤0.15. Their statistical results also implied that the environmental dependence of galaxy colors becomes weak with increasing redshift in the apparent magnitude -limited main galaxy sample. (Deng 2014) examined the environmental dependence of colors in the CMASS sample of the Baryon Oscillation Spectroscopic Survey (BOSS) of the Sloan Digital Sky Survey III (SDSS-III; Eisenstein et al. 2011) and showed that the $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors in this sample are weakly correlated with the local environment. The CMASS sample of the BOSS is a nearly complete sample of massive galaxies mainly located in the redshift range of $0.43 < z < 0.7$. The BOSS also contains a low redshift (low z) sample with a median redshift of $z = 0.3$, which is mainly located in the redshift range of $0.15 < z < 0.43$. To understand the color-density relation in the intermediate redshift regime, it is necessary to investigate the environmental dependence of galaxy colors in the low z sample.

The low z sample is a simple extension of the SDSS I and II LRG samples (Eisenstein et al. 2001) and can be used for comparison with them. Some previous works have shed light on the environmental dependence of galaxy properties or on the dependence of galaxy clustering on galaxy properties in the LRG sample, which is a sample of luminous intrinsically red galaxies that extends farther than the SDSS main galaxy sample. (Zehavi et al. 2005) demonstrated that the clustering properties of LRGs are dependent on the luminosity, with more luminous LRGs being more clustered. (Deng et al. 2008c, 2009b) showed that the $u-g$, $g-r$, $r-i$ and $i-z$ colors of LRGs are nearly independent of the local density. (Deng et al. 2012a) found that the stellar mass, star formation rate (SFR) and specific star formation rate (SSFR) of LRGs are weakly correlated with the local density. When investigating the environmental dependence of galaxy properties, a series of volume-limited samples was often drawn from the apparent magnitude-limited galaxy sample. The chief advantage of this approach is to avoid the complication of modeling the radial selection function in the flux-limited survey. Unfortunately, the LRG sample is not simply flux-limited, making it difficult to construct an ideal volume-limited sample from it. In previous studies, researchers often constructed a relatively uniform LRG sample through a simple redshift limitation. However, in such a sample, the radial selection effect still exists. Here, I apply the method of (Deng 2012) and the newest data release, SDSS DR10 (Ahn et al. 2014), to study the environmental dependence of galaxy colors in the low z sample.

Considering some disadvantages of the use of volume-limited samples, Deng (2012) used the apparent magnitude-limited galaxy sample. To decrease the influence of the radial selection effect on statistical results, (Deng 2012) divided the entire apparent magnitude-limited galaxy sample into many subsamples with a redshift binning size of $\triangle z$=0.01 and performed a statistical analysis of the subsamples in each redshift bin. (Deng 2012) argued that the radial selection effect should be less important in each subsample with a redshift binning size of $\triangle z$=0.01. Although the environmental dependence of galaxy properties in such a small redshift bin is likely to be greatly decreased, it can still be observed if it exists (e.g., Deng 2012; Deng et al. 2012b, 2013a). For example, (Deng et al. 2012b) demonstrated that there is a strong environmental dependence of the stellar mass, SFR and SSFR in nearly all redshift bins. The method of (Deng 2012) can also be used to explore the variation of the environmental dependence of galaxy properties with redshift.

The outline of this paper is as follows. In § 2, I describe the galaxy sample. I present the statistical results in § 3. I summarize my main results and conclusions in § 4.

In calculating the distance, I 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$\cdot s^{-1}\cdot$ Mpc^{-1}.

2. SAMPLE

In this work, the data of the low z galaxy sample were downloaded from the Catalog Archive Server of SDSS Data Release 10 (Ahn et al. 2014) using the SDSS SQL Search (`http://www.sdss3.org/dr10/`). I extract 163,682 low z galaxies with a redshift of $0.15 \leq z \leq 0.43$ (with SDSS flag: BOSS_TARGET1&1>0). Similar to (Deng 2014), the model magnitudes and galactic extinction corrections are used, but k-corrections are not applied.

3. STATISTICAL RESULTS

Following previous works (e.g., Deng 2012, 2014; Deng et al. 2012b, 2013a), I measure the projected local density $\Sigma_5 = N/\pi d_5^2$ (galaxies Mpc^{-2}), where d_5 is the distance to the 5th nearest neighbor within $\pm$1000 km s^{-1} in redshift (e.g., Goto et al. 2003; Balogh et al. 2004a, 2004b) and I divide the low z sample into subsamples with a redshift binning size of $\triangle z$=0.01. In each subsample, I arrange galaxies in a density order from smallest to largest, select approximately 5% of the galaxies, construct two samples at both extremes of density, and compare the distribution of galaxy colors in the lowest density regime with that in the densest regime.

The Kolmogorov-Smirnov (KS) test can show the degree of similarity or difference between two independent distributions 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. Following previous works (e.g., Deng 2012, 2014; Deng et al. 2012b, 2013a), I calculate the KS probability that the two distributions come from the same parent distribution, which is listed in Table 1. (Deng et al. 2013a) demonstrated that the application of the KS test to the apparent magnitude-limited main galaxy sample gives the probabilities of the two distributions originating from the same parent distribution in each subsample with a redshift binning size of $\triangle z$=0.01, which is close to zero in the redshift region $0.02 \le z \le 0.15$, indicating that the two distributions of colors at both extremes of density are completely different in this redshift region. The result of (Deng et al. 2013a) also showed that in the high redshift region, this probability is apparently larger than zero. Thus, they concluded that galaxy colors have strong environmental dependence in the redshift region $0.02 \le z \le 0.15$ and that the environmental dependence of galaxy colors becomes weak with increasing redshift in the apparent magnitude-limited main galaxy sample.

As shown by Table 1, the KS probability of the low z galaxy sample is much larger than that of the apparent magnitude-limited main galaxy sample (see Table 1 of Deng 2012 and Deng et al. 2012b) and it is much larger than 0.05 (5% being the standard in a statistical analysis) in many redshift bins, as in the CMASS galaxy sample (see Table 1 of Deng 2014). This implies that in the low z galaxy sample, all five colors also show minimal correlation with the local environment.

I also plot the $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ color distributions at both density extremes in the different redshift bins for the low z galaxy sample. The redshift range of the low z galaxy sample is somewhat wide, which leads to too many redshift bins. If plotting a panel for each redshift bin, each figure contains too many panels. Considering that the statistical properties of adjacent redshift bins are close, I only select one for plotting from both adjacent redshift bins (except for $0.15 \le z \le 0.16$ and $0.16 \le z \le 0.17$). As shown in Figures 1-5, all five colors indeed only have a weak environmental dependence.

One possible explanation for the weak environmental dependence of the galaxy colors is that the environmental processes 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 (Grützbauch et al. 2011b).

(Grützbauch et al. 2011a) argued that the environmental dependence of galaxy colors is strongest for intermediate mass galaxies ($10.5 < \log M_* < 11$), whereas colors of lower and higher mass galaxies are insensitive to their redshift and environment. (Deng 2014) computed the percentage of intermediate mass galaxies ($10.5 < \log M_* < 11$) in his CMASS galaxy sample and showed that it is only 30.08%. (Deng 2014) claimed that a lower fraction of intermediate mass galaxies likely leads to weak environmental dependence of galaxy colors in his CMASS galaxy sample. Here, I also calculate the percentage of intermediate mass galaxies ($10.5 < \log M_* < 11$) in the low z galaxy sample and find that it is only 24.11%, which is even lower than that in the CMASS galaxy sample.

(Grützbauch et al. 2011a) also found a weak environmental dependence of galaxy color at $0.4 < z < 0.7$ and believed that such a weak color-density relation is a combination of a strong color-stellar mass relation and a weak stellar mass-density relation. (Grützbauch et al. 2011b) further showed that there is a strong color-stellar mass relation at redshifts up to $z \simeq 3$ and argued that stellar mass is 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. However, such conclusions are problematic. Indeed, one should account for correlations among the physical properties of galaxies when exploring the environmental dependence of galaxy properties. A strong color-stellar mass relation in intermediate and high redshift regions only implies that a weak color or stellar dependence on environment is likely due to the environmental dependences of the another parameter and a tight correlation between them. However, one does not know which parameter is fundamental in correlations between galaxy properties and the environment. In fact, in the local universe, some studies have shown that when color is limited or fixed, the environmental dependences of the other galaxy properties are substantially decreased (e.g., Deng and Zou 2009; Skibba et al. 2009; Deng et al. 2011). (Deng et al. 2013b) even concluded that color is fundamental in correlations between galaxy properties and the environment, and that much of the other galaxy property-density relations are likely due to the relation between color and density. If galaxy color still is fundamental in intermediate redshifts, a reasonable explanation for the statistical results of these studies should be that a weak stellar-density relation is a combination of a strong color-stellar mass relation and a weak color-density relation.

(Deng et al. 2012b) noted that the environmental dependence of galaxy properties also becomes weak at $z > 0.15$ in the apparent magnitude-limited main

TABLE 1

K-S PROBABILITIES OF DIFFERENT COLORS THAT TWO SAMPLES AT BOTH EXTREMES OF DENSITY ARE DRAWN FROM THE SAME DISTRIBUTION.

Redshift bins	Galaxy number	P($u-r$)	P($u-g$)	P($g-r$)	P($r-i$)	P($i-z$)
0.15-0.16	1785	0.984	0.984	0.602	0.479	0.276
0.16-0.17	1749	0.0932	0.587	9.447e-06	0.000610	0.0265
0.17-0.18	2006	0.261	0.794	0.0131	6.124e-07	0.000322
0.18-0.19	2140	0.225	0.386	0.167	2.718e-05	0.488
0.19-0.20	2449	0.0936	0.172	0.00998	6.535e-09	0.0936
0.20-0.21	2819	0.306	0.668	0.00176	0.00176	0.00176
0.21-0.22	3503	0.116	0.190	0.190	0.00705	0.190
0.22-0.23	4490	0.764	0.836	0.685	0.116	0.384
0.23-0.24	4903	0.872	0.872	0.119	0.00656	0.180
0.24-0.25	4782	0.491	0.795	0.00776	0.251	0.251
0.25-0.26	5275	0.487	0.776	0.178	0.360	0.178
0.26-0.27	5749	0.216	0.123	0.924	0.475	0.994
0.27-0.28	5584	0.593	0.736	0.456	0.665	0.242
0.28-0.29	5828	0.421	0.186	0.825	0.962	0.0437
0.29-0.30	6458	0.168	0.0960	0.814	0.553	0.553
0.30-0.31	7068	0.0474	0.0582	0.00195	0.854	0.0582
0.31-0.32	7563	0.150	0.474	0.150	0.474	0.474
0.32-0.33	8428	0.828	0.489	0.196	0.489	0.196
0.33-0.34	9232	0.135	0.0983	0.000724	0.717	0.771
0.34-0.35	9274	0.773	0.664	0.0287	0.212	0.500
0.35-0.36	8992	0.261	0.298	0.0136	0.757	0.382
0.36-0.37	8934	0.897	0.806	0.0298	0.641	0.294
0.37-0.38	8828	0.417	0.467	0.958	0.520	0.799
0.38-0.39	8039	0.902	0.938	0.692	0.407	0.107
0.39-0.40	7576	0.656	0.534	0.977	0.777	0.281
0.40-0.41	7230	0.627	0.446	0.297	0.220	0.971
0.41-0.42	6852	0.468	0.468	0.529	0.0785	0.311
0.42-0.43	6146	0.586	0.519	0.250	0.0428	0.519

galaxy sample and argued that this likely is due to a selection effect: galaxies in the high redshift region are restricted to a fairly narrow high-luminosity region due to the Malmquist bias (Malmquist 1920; Teerikorpi 1997), which leads to other galaxy properties being limited to a narrow region. The weak environmental dependence of galaxy colors in the low z galaxy sample is also likely a product of the selection of galaxies. (Grützbauch et al. 2011a) demonstrated that the color difference largely disappears when stellar mass selected samples are used, and argued that the strong color-density relation out to $z > 1$ obtained by (Cooper et al. 2007) might be partly caused by their sample selection, which is rest-frame B-band luminosity limited. LRGs are a group of galaxies that are likely to be luminous, red, and of early type. (Deng et al. 2012a) claimed that the weak environmental dependence of the SFR, SSFR and stellar mass of LRGs is likely associated with the lack of a population of red, late-type galaxies. In the local Universe, (Deng et al. 2011) showed that the strong environmental dependence of galaxy properties for red galaxies is mainly due to that in the red late-type sample. Another possible explanation for the sample selection is that the LRG sample targets a very uniform population of luminous and massive galaxies that mostly reside in high density regions (fairly massive dark matter halos).

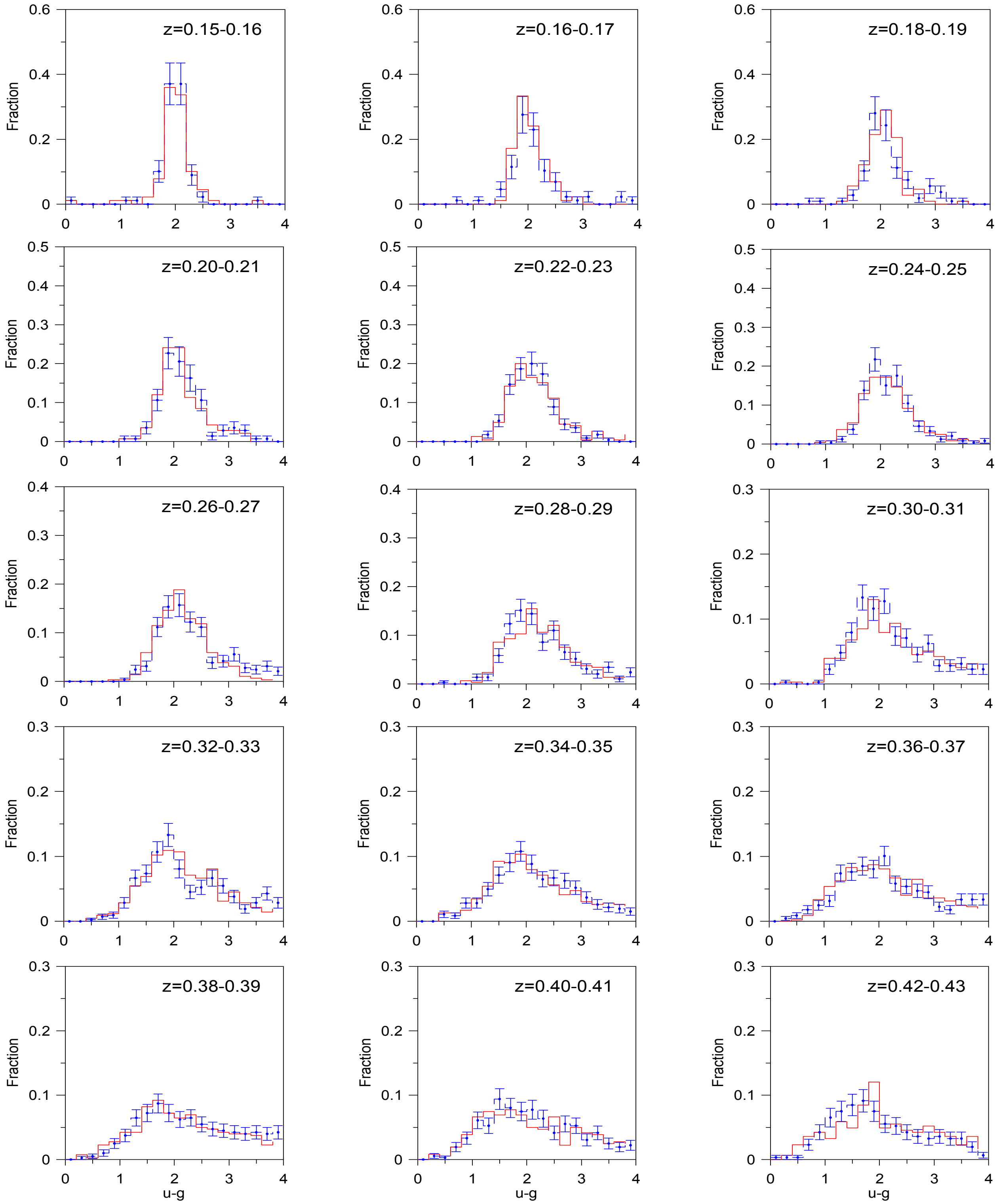

Fig. 1. $u - g$ color distribution at both extremes of density in different redshift bins: red solid lines for the sample at high density, blue dashed lines for the sample at low density. The error bars of the blue lines are 1 σ Poissonian errors. The error-bars of the red lines are omitted for clarity.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

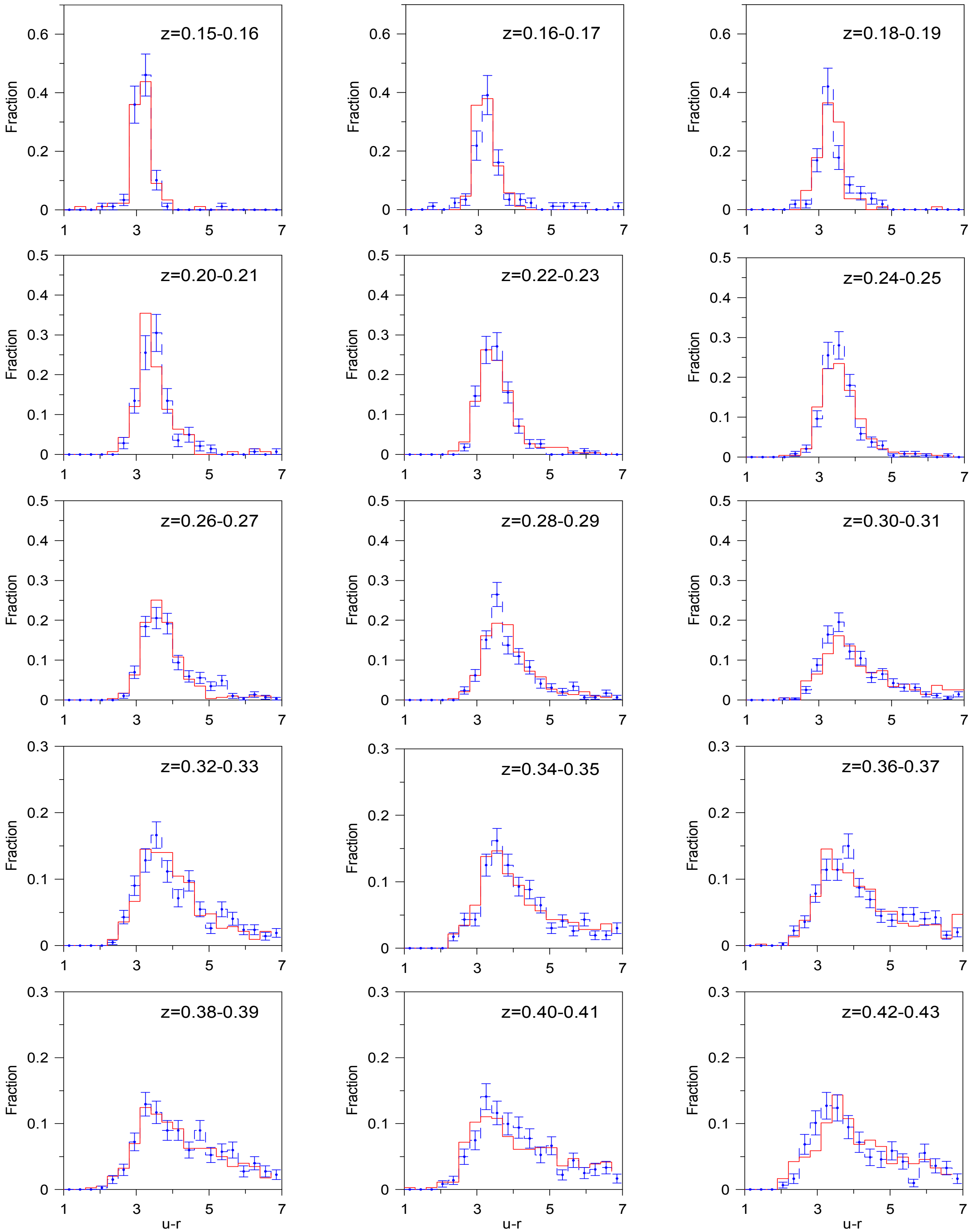

Fig. 2. Same as Figure 1, but for the $u-r$ color distribution at both density extremes in different redshift bins. The color figure can be viewed online.

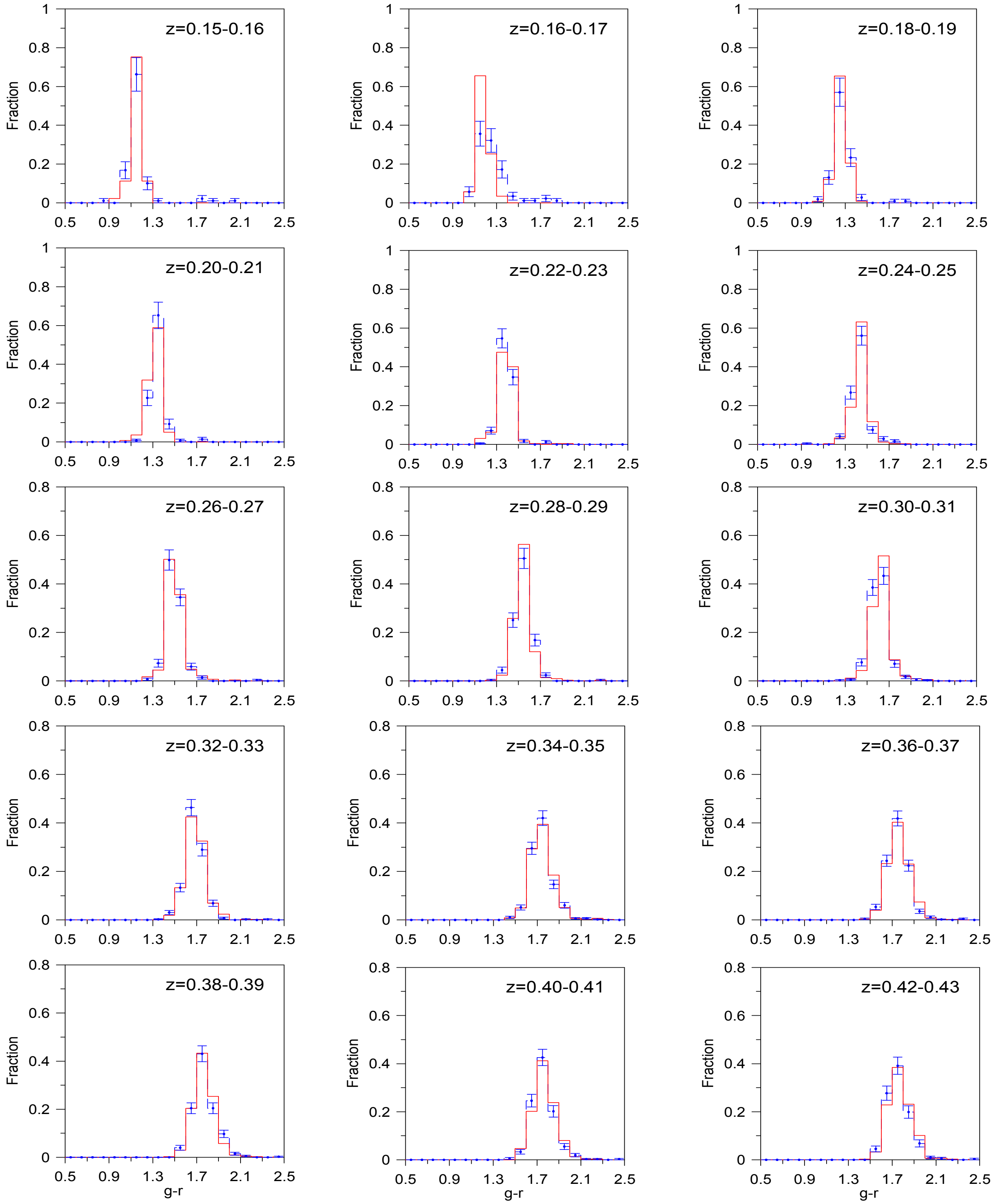

Fig. 3. Same as Figure 1, but for the $g-r$ color distribution at both density extremes in different redshift bins. The color figure can be viewed online.

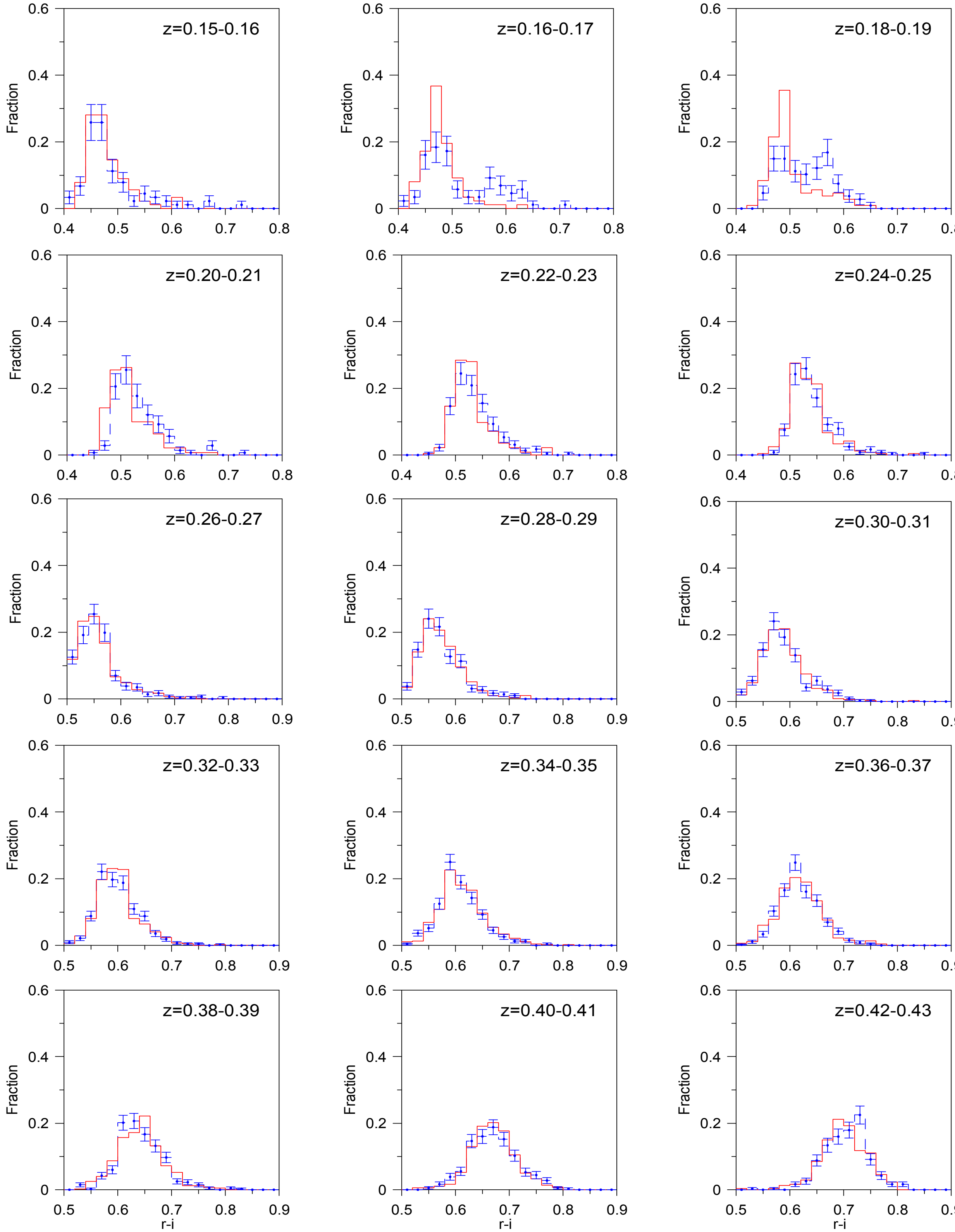

Fig. 4. Same as Figure 1, but for the $r - i$ color distribution at both density extremes in different redshift bins. The color figure can be viewed online.

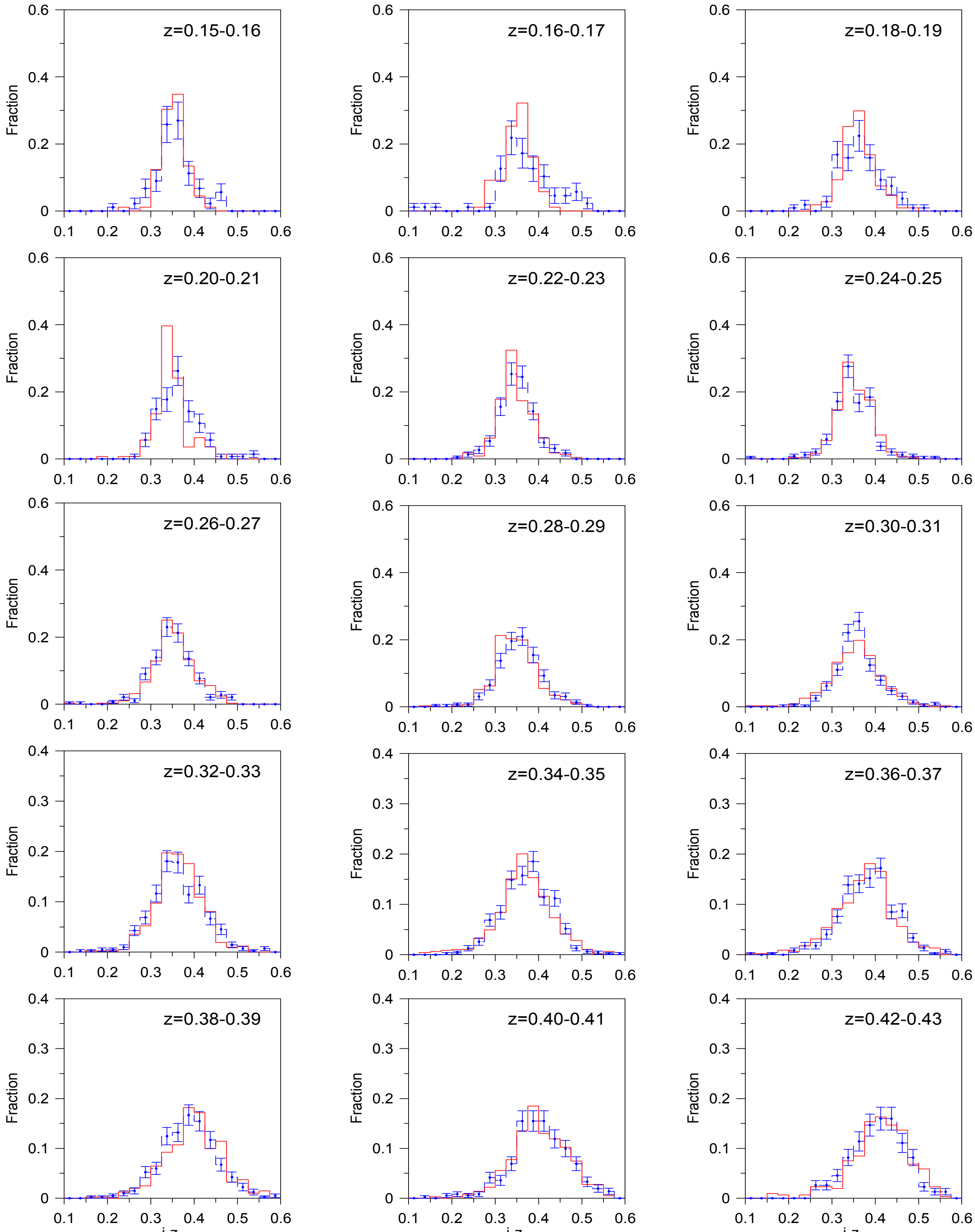

Fig. 5. Same as Figure 1, but for the $i-z$ color distribution at both density extremes in different redshift bins. The color figure can be viewed online.

4. SUMMARY

The BOSS galaxy sample of the SDSS-III can be divided into two principal samples at $z \simeq 0.4$: a low redshift (low z) sample and a constant mass (CMASS) sample. (Deng 2014) studied the environmental dependence of the $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors in the CMASS sample and showed that all five colors in this sample are weakly correlated with the local environment. In this work, using the newest data release, SDSS DR10 (Ahn et al. 2014), I investigate the environmental dependence of these colors in the low z sample. Following (Deng 2014), I apply the method of (Deng 2012), divide the low z sample into subsamples with a redshift binning size of $\triangle z$=0.01, and analyze the environmental dependence of all five colors for these subsamples in each redshift bin. As shown in Table 1 and Figs.1-5, overall, all five galaxy colors in the low z sample are very weakly correlated with the local environment.

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Xin-Fa Deng: School of Science, Nanchang University, Jiangxi, China, 330031(xinfadeng@163.com).