THE CORRELATIONS AMONG COLOR, MORPHOLOGY, AND LUMINOSITY FOR THE MAIN GALAXY SAMPLE OF THE SDSS DATA RELEASE 5

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Using the Main galaxy sample of the SDSS Data Release 5, we have investigated the correlations among color, morphology, and luminosity. We find that only within certain luminosity region the proportion of early-type galaxies significantly increases with increasing luminosity. The CM relations of galaxies also do not present single tendency, for different CM relations or in different luminosity regions, the tendencies of changes of the mean colors with luminosity are different. The mean colors of galaxies significantly increase with increasing luminosity only within certain luminosity region for some CM relations. Within certain color region the proportion of early-type galaxies also increases with increasing colors-especially for g–r color. For very blue galaxies, the proportion of early-type is weak functions of colors except u–g color. For the reddest galaxies the early-type proportion decreases with increasing colors.

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1. Introduction

Many studies showed that there are correlations between galaxy properties and environment, such as ones between morphology and environment (*e.g.*, Oemler 1974; Dressler 1980; Postman, Geller 1984; Whitmore *et al.* 1993; Dressler *et al.* 1997; Hashimoto, Oemler 1999; Fasano *et al.* 2000; Tran *et al.* 2001; Goto *et al.* 2003; Helsdon, Ponman 2003; Treu *et al.* 2003; Deng *et al.* 2006, 2007a, 2007b, 2007c, 2007d; Park *et al.* 2007), ones between star formation rate and environment (*e.g.*, Balogh *et al.* 1997, 1999; Hashimoto *et al.* 1998; Poggianti *et al.* 1999; Lewis *et al.* 2002; Gómez *et al.* 2003; Balogh *et al.* 2004a; Tanaka *et al.* 2004; Kelm *et al.* 2005), and ones between color and environment (*e.g.*,Tanaka *et al.* 2004; Balogh *et al.*

2004b; Hogg *et al.* 2004; Berlind *et al.* 2005; Blanton *et al.* 2005; Park *et al.* 2007; Deng *et al.* 2007e). These correlations will result in correlations among galaxy properties. It has long been known that high-luminosity galaxies are preferentially "early type" (*e.g.*, Blanton *et al.* 2003a; Baldry *et al.* 2004; Balogh *et al.* 2004b; Kelm *et al.* 2005). The type of galaxies also correlates with other properties, such as colors (*e.g.* Holmberg 1958; Roberts, Haynes 1994; Strateva *et al.* 2001). The study of Strateva *et al.* (2001) indicated that the blue galaxies are dominated by late types while the red galaxies are dominated by early types. The most well-studied relation is correlation between color and luminosity of galaxies, the so-called color-magnitude relation (CMR) (Larson *et al.* 1980; Lugger 1984; Zepf *et al.* 1991; Terlevich *et al.* 1999; Bernardi *et al.* 2003, 2005; Blanton *et al.* 2003a; Hogg *et al.* 2004; Baldry *et al.* 2004; López-Cruz *et al.* 2004). Galaxy colors depend strongly on luminosity, in the sense that 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). The tight color-magnitude relation for early-type galaxies often be established as a metalicity-luminosity correlation: more massive, and thus more luminous, galaxies retain more metals than less massive ones (Kodama, Arimoto 1997; De Lucia *et al.* 2004; Kang *et al.* 2005).

Deng *et al.* (2007f) investigated the correlations among color, morphology, and luminosity for the Luminous Red Galaxy (LRG) sample of the SDSS Data Release 5 (Adelman-McCarthy *et al.* 2007). This sample contains cut I LRGs, cut II LRGs, and Main galaxies which are also classified as LRGs. It is found that the morphology of LRGs is tightly correlated with luminosity. The rest-frame u–g color of cut I LRGs and cut II LRGs is nearly independent of luminosity, but the color of Main galaxies is correlated with luminosity. The early-type proportion of cut I LRGs and Main galaxies apparently changes with color, but the morphology of cut II LRGs is only weak function of color. In this paper, we further investigate the correlations among color, morphology, and luminosity for the Main galaxy sample of the SDSS. Our paper is organized as follows. In Section 2, we describe the galaxy data to be used. Correlations among color, morphology, and luminosity for the Main galaxy sample are discussed in Section 3. Our main results and conclusions are summarized in Section 4.

2. Data

The Sloan Digital Sky Survey (SDSS) is one of the largest astronomical surveys to date. Many of the survey properties were discussed in detail in the Early Data Release paper (Stoughton *et al.* 2002). Galaxy spectroscopic target selection can be implemented by two algorithms. The Main galaxy sample (Strauss *et al.* 2002) comprises galaxies brighter than $r_{\rm petro} < 17.77$ (r-band apparent Petrosian magnitude). 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 $0.02 \leq z \leq 0.2$. The Luminous Red Galaxy (LRG) algorithm (Eisenstein *et al.* 2001) selects galaxies to $r_{\rm petro} < 19.5$ that are likely to be luminous early-types, based on the observed colors. These LRGs are intrinsically red and at higher redshift.

We downloaded data from the Catalog Archive Server of the SDSS Data Release 5 (Adelman-McCarthy *et al.* 2007) by the SDSS SQL Search (`http://www.sdss.org/`). The Main galaxy sample contains 332412 galaxies (with SDSS flag: bestPrimtarget = 64, Zwarning $\neq$ 16, Zstatus $\neq$ 0, 1, redshift confidence level: zconf > 0.95, and redshift region: $0.02 \leq z \leq 0.2$).

In calculating the distance we use a cosmological model with a matter density $\Omega_0 = 0.3$, cosmological constant $\Omega_A = 0.7$, Hubble's constant $H_0 = 100\,h$ km s^{-1} Mpc^{-1} with $h = 0.7$.

3. Correlations among color, morphology, and luminosity

3.1. Correlation between morphology and luminosity

Fig. 1 shows the distributions of the absolute magnitude of five photometric bands for the Main galaxy sample. In this paper, we ignore the K-correction (Blanton *et al.* 2003b). As seen from this figure, the distri-

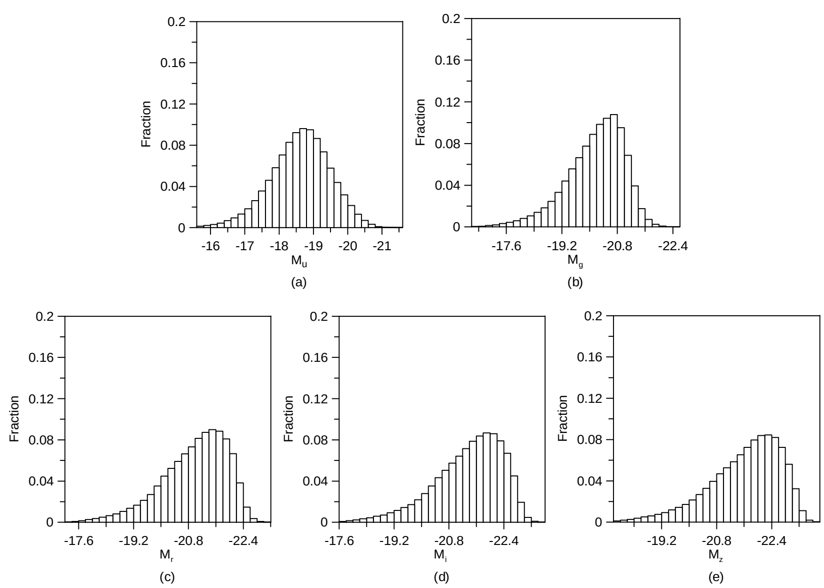

Fig. 1. The luminosity distributions for the Main galaxy sample: (a) u-band, (b) g-band, (c) r-band, (d) i-band, (e) z-band.

bution of u-band is different from ones of other bands. In this paper, the concentration index $c_i = R_{90}/R_{50}$ is used to separate early-type (E/S0) galaxies from late-type (Sa/b/c, Irr) galaxies (Shimasaku *et al.* 2001). R_{50} and R_{90}, are the radii enclosing 50 percent and 90 percent of the Petrosian flux for each band, respectively. As is well-known, the galaxy morphology is closely correlated with many other parameters, such as color and concentration index. These parameters can be used as the morphology classification tool (*e.g.*, Park, Choi 2005; Yamauchi, Goto 2005; Abraham *et al.* 2003; Strateva *et al.* 2001; Shimasaku *et al.* 2001). The concentration index is a simple morphological parameter. Nakamura *et al.* (2003) showed that $c_i = 2.86$ separates galaxies at S0/a with a completeness of about 0.82 for both late and early types.

Fig. 2 illustrates the proportion of early-type galaxies as a function of luminosity(five bands) for the Main galaxy sample. For each band, the absolute magnitude region is divided into 16 bins of width 0.4. The proportion of early-type galaxies in each absolute magnitude bin is calculated. It is

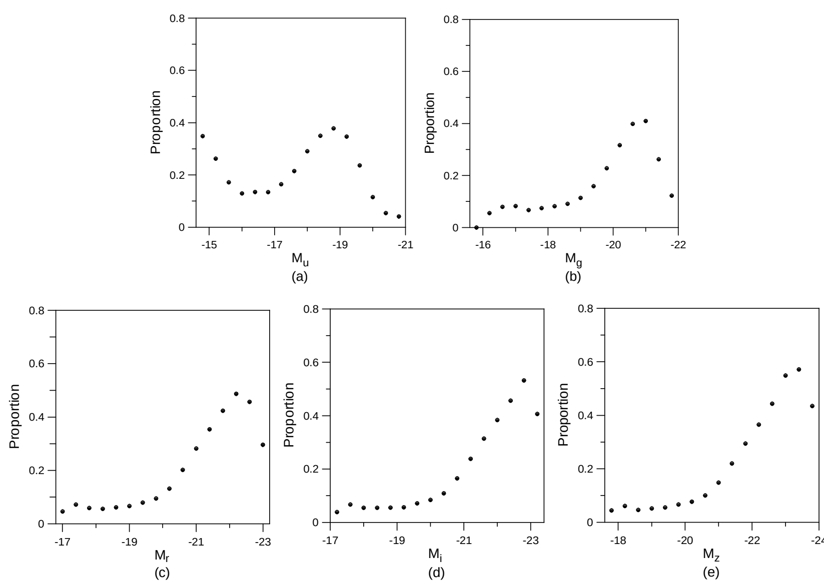

Fig. 2. The proportion of early-type galaxies in different luminosity bins for the Main galaxy sample: (a) u-band, (b) g-band, (c) r-band, (d) i-band, (e) z-band.

widely accepted that galaxy morphology is tightly correlated with luminosity: high-luminosity galaxies are preferentially "early type". Thus, we may expect that the proportion of early-type galaxies increases monotonously with increasing luminosity. But in Fig. 2, we note that this correlation is rather complicated. Only within certain luminosity region, the early-type proportion increases with increasing luminosity. Within low luminosity region, it is almost constant except the u-band luminosity. For the u-band, this proportion even decreases with increasing luminosity in low luminosity region. As indicated found as Norberg *et al.* (2001), the clustering amplitude increases strongly with absolute magnitude only for galaxies brighter than M^*. Accounting for the tight correlation between morphology and environment, it is not surprising that a clear increase of the early-type proportion is found only for the bright galaxies. In addition, we also note that within very high luminosity region, the early-type proportion decreases with increasing luminosity-especially for the u-band luminosity. The Main galaxy sample is an apparent-magnitude limited sample, in which the brightest galaxies often are located in the high redshift region. When developing a selection criterion $c_i = 2.86$, Nakamura *et al.* (2003) only used nearby bright galaxies. It has been known for a long time that concentration index is very sensitive to seeing as shown in Blanton *et al.* (2003a). In the high redshift region, the concentration index may be not suitable for classification of galaxies. For cut I LRGs and Main galaxies which are also classified as LRGs, at high luminosity region $M_g < -22$, the early type proportion also decreases strongly with increasing luminosity, but for cut II LRGs this proportion still increases strongly with increasing luminosity (Deng *et al.* 2007f). Deng *et al.* (2007f) were not clear whether this difference is due to selection effect or a physical effect.

Using photometry and spectroscopy of 144,609 galaxies from the Sloan Digital Sky Survey, Blanton *et al.* (2003a) ever found the similar trend: highly luminous galaxies are more concentrated, and thus have higher Sérsic indices, than lower luminosity galaxies. They also investigated the dependence of Sérsic index n on absolute magnitude for three ranges of ${}^{0.1}(g\text{–}r)$ colors. For very blue galaxies, the Sérsic index n is clearly independent of luminosity. For red galaxies the Sérsic index is a strong function of luminosity. Additionally, They found that the reddest galaxies are in optical colors exponential galaxies (Sérsic index $n < 1.5$), not concentrated galaxies (Sérsic index $n > 3$). As found by many authors, the colors of galaxies depend strongly on luminosity (*e.g.* de Vaucouleurs 1961; Bower *et al.* 1992; Blanton *et al.* 2003a; Baldry *et al.* 2004), in the sense that more luminous galaxies are redder. So, above conclusions are actually consistent with our results.

3.2. Correlation between color and luminosity

Many studies showed that the colors of galaxies depend strongly on luminosity. Using a low redshift sample of galaxies from the Sloan Digital Sky Survey, Baldry *et al.* (2004) obtained color-magnitude(CM) relations (u–r *versus* M_r) for red and blue distributions (early- and late-type). For each distribution, the mean u–r color increases contiguously with luminosity. For each band, we calculate the mean colors and the standard deviations in different absolute magnitude bins (bin = 0.4). In the Main galaxy sample, few galaxies have abnormal colors (abnormally large or small) which results in abnormally large standard deviations in some absolute magnitude bins. So, we delete 724 galaxies having abnormal colors (abnormally large or small) from the Main galaxy sample. Fig. 3–7 respectively show u–g color, g–r color, r–i color and i–z color as a function of luminosity of five-bands. As

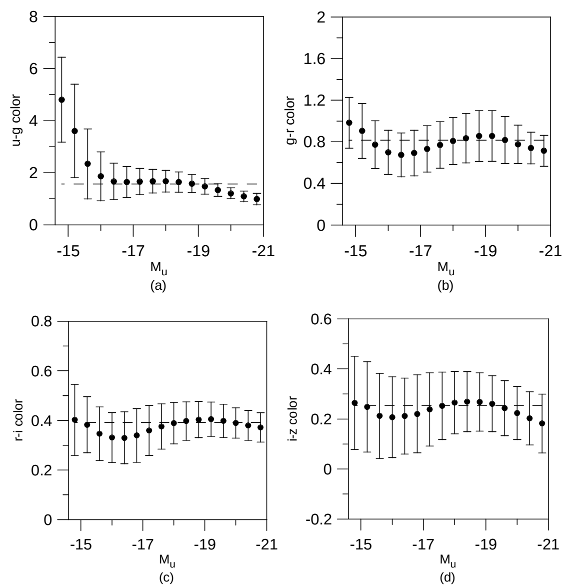

Fig. 3. Colors as a function of the u-band luminosity. The dashed line represents the mean of colors for the Main galaxy sample. Error bars are standard deviation in each luminosity bin: (a) u–g color, (b) g–r color, (c) r–i color, (d) i–z color.

the same as results found by many authors, the mean colors of galaxies increases with increasing luminosity within certain luminosity region except u-band luminosity. For the u-band, we do not observe significant tendency for colors of galaxies to increase with luminosity. Within low luminosity region ($M_u > -16$), the mean colors of galaxies decreases with increasing u-band luminosity-especially for u–g *versus* M–u relation. We are not clear about the physical effect of this kind of abnormal tendency. In the LRG sample, Deng *et al.* (2007f) found that the color of cut I LRGs and cut II LRGs is nearly independent of luminosity, but the rest-frame u–g color of Main galaxies which are also classified as LRGs increases strongly with increasing luminosity at $M_g < -22$.

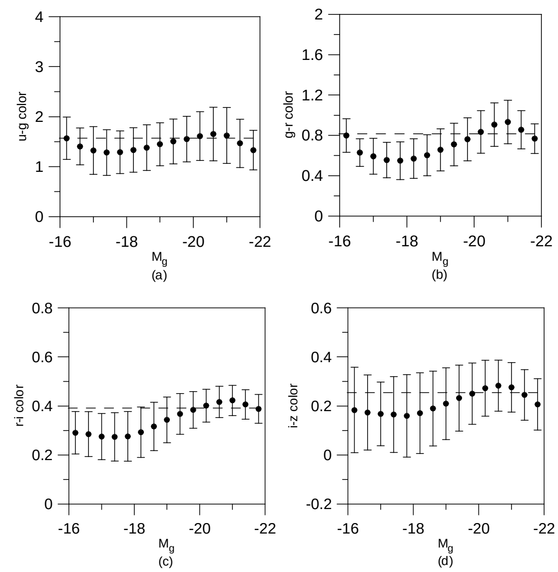

Fig. 4. Colors as a function of the g-band luminosity. The dashed line represents the mean of colors for the Main galaxy sample. Error bars are standard deviation in each luminosity bin: (a) u–g color, (b) g–r color, (c) r–i color, (d) i–z color.

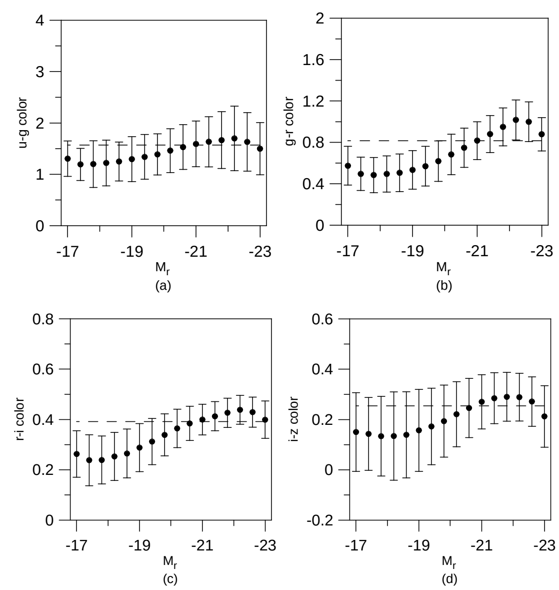

Fig. 5. Colors as a function of the r-band luminosity. The dashed line represents the mean of colors for the Main galaxy sample. Error bars are standard deviation in each luminosity bin: (a) u–g color, (b) g–r color, (c) r–i color, (d) i–z color.

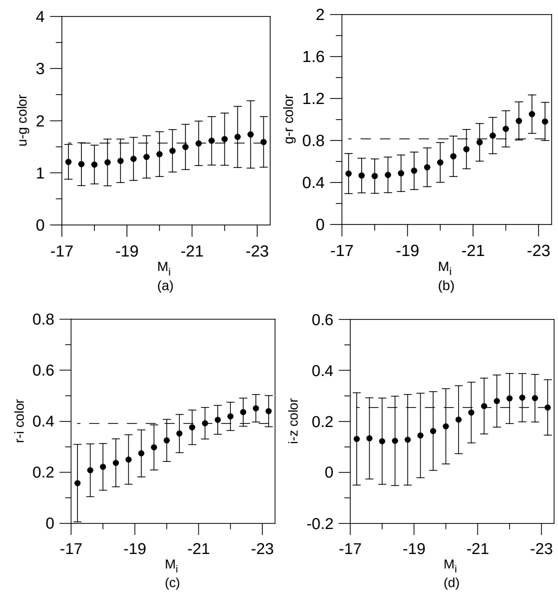

Fig. 6. Colors as a function of the i-band luminosity. The dashed line represents the mean of colors for the Main galaxy sample. Error bars are standard deviation in each luminosity bin: (a) u–g color, (b) g–r color, (c) r–i color, (d) i–z color.

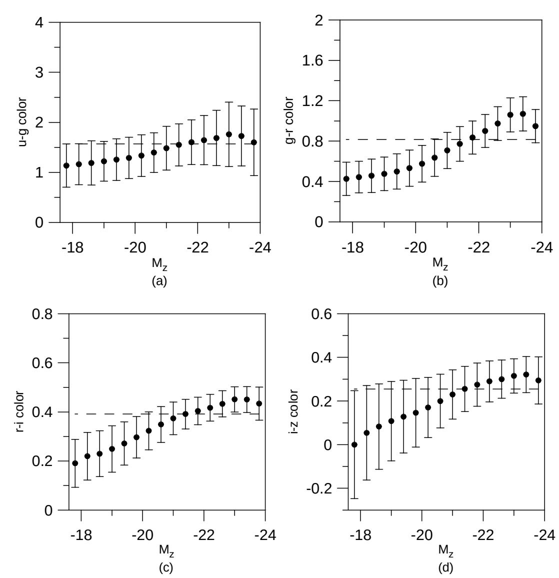

Fig. 7. Colors as a function of the z-band luminosity. The dashed line represents the mean of colors for the Main galaxy sample. Error bars are standard deviation in each luminosity bin: (a) u–g color, (b) g–r color, (c) r–i color, (d) i–z color.

For the low-luminosity blue-distribution galaxies ($M_r \geq -19$), Baldry *et al.* (2004) found a shallow CM relation slope that is consistent with a metalicity–luminosity correlation. Over the luminosity range from $M_r = -19.5$ to $M_r = -22$, the CM relation slope becomes too steep to be explained entirely by a metalicity–luminosity correlation. Baldry *et al.* (2004) suggested that this transition can be explained by a combination of an increase in dust content (Giovanelli *et al.* 1995; Tully *et al.* 1998) and a decrease in recent star formation relative to the total stellar mass of the galaxy (Peletier, de Grijs 1998). In our analyses, some CM relations (for example, g–r *versus* M_i relation) also presents this kind of transition. But we notice that for relations of r–i *versus* M_i, r–i *versus* M_z and i–z *versus* M_z this kind of transition does not exist, and the mean colors of galaxies increases continuously with increasing luminosity from the low-luminosity to the high-luminosity.

For all CM relations, within very high luminosity region the mean colors of galaxies decreases with increasing luminosity. As mentioned above, this transition is also observed in correlations between morphology and luminosity. This indicates that in these correlations there is the existence of characteristic luminosity at which the tendencies of dependencies of galaxy morphology and colors on luminosity change abruptly.

According to above analyses, we find that the CM relations of galaxies do not present single tendency, for different CM relations or in different luminosity regions, the tendencies of changes of the mean colors with luminosity are different. The mean colors of galaxies significantly increases with increasing luminosity only within certain luminosity range for some CM relations. So, when citing this conclusion, we must be especially cautious.

3.3. Correlation between morphology and color

Fig. 8 shows the distributions of u–g color, g–r color, r–i color, and i–z color for Main galaxy sample, respectively. Strateva *et al.* (2001) found that the distribution of galaxies in the g–r *versus* u–g color–color diagram is strongly bimodal, with an optimal color separator of u–$r = 2.22$, and that the two peaks correspond roughly to early (E, S0, Sa) and late (Sb, Sc, Irr) type galaxies. This indicated that the blue galaxies are indeed dominated by late types (spirals) while the red galaxies are dominated by early types (ellipticals).

In Fig. 9 we present the proportion of early-type galaxies as a function of colors for the Main galaxy sample. For each color, the whole color region is divided into 16 bins (width 0.2 for u–g color, 0.1 for g–r color, and 0.05 for r–i color and i–z color). As seen from this figure, only within certain color region the proportion of early-type galaxies apparently increases with

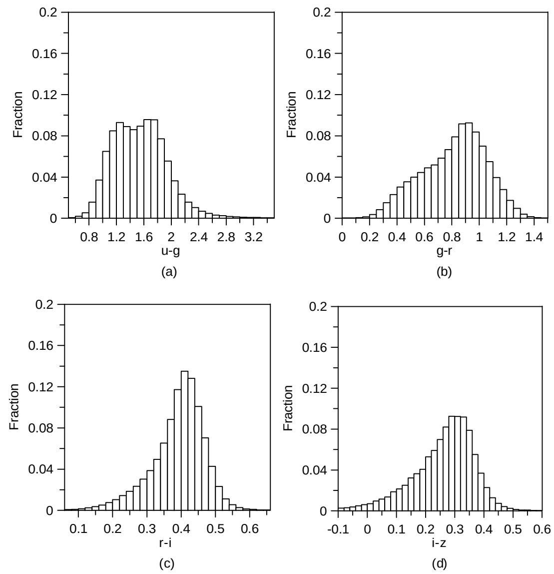

Fig. 8. The color distributions for the Main galaxy sample: (a) u–g color, (b) g–r color, (c) r–i color, (d) i–z color.

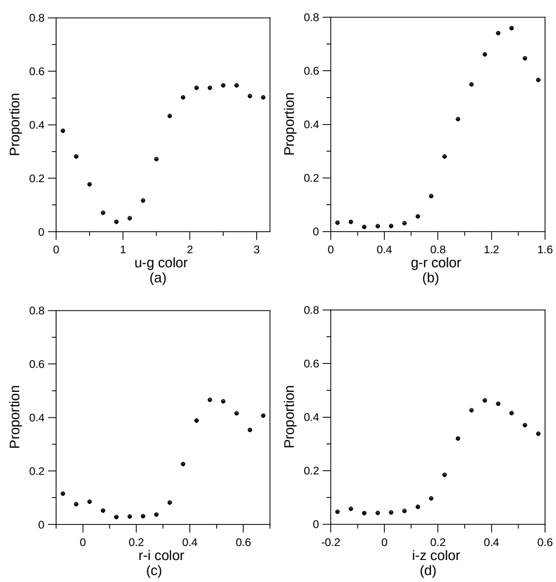

Fig. 9. The proportion of early-type galaxies as a function of colors for the Main galaxy sample: (a) u–g color, (b) g–r color, (c) r–i color, (d) i–z color.

increasing colors — especially for g–r color. For very blue galaxies, the early-type proportion is weak function of colors except u–g color. For the reddest galaxies the early-type proportion decreases with increasing colors that is consistent with results found by Blanton *et al.* (2003a). In addition, we also notice that the early-type proportion of blue galaxies apparently decreases with increasing u–g color. In the LRG sample, Deng *et al.* (2007f) found that there is a tight correlation between color and morphology for cut I LRGs and Main galaxies, but the morphology of cut II LRGs is weak function of color.

4. Summary

It is widely accepted that more luminous galaxies are preferentially "early type" and redder, the blue galaxies are dominated by late types while the red galaxies are dominated by early types. Using the Main galaxy sample of the SDSS Data Release 5, we further investigate the correlations among color, morphology, and luminosity. We find that these correlations are rather complicated, and do not present single tendency. Between the Main galaxy sample and the LRG sample, which are selected by different algorithms, we also find significant differences of these correlations. This suggests that searches for better physical mechanisms to explain these correlations are needed. The main conclusions can be summarized as follows:

(1) The proportion of early-type galaxies increases with increasing luminosity only within certain luminosity range, while within very high luminosity region this proportion decreases with increasing luminosity — especially for the u-band luminosity. Within low luminosity region, the proportion of early-type galaxies is weak function of luminosity except the u-band luminosity.

(2) The CM relations of galaxies do not present single tendency, for different CM relations or in different luminosity regions, the tendencies of changes of the mean colors with luminosity are different. The mean colors of galaxies significantly increases with increasing luminosity only within certain luminosity range for some CM relations.

(3) Only within certain color region the proportion of early-type galaxies apparently increases with increasing colors-especially for g–r color. For very blue galaxies, the early-type proportion is weak function of colors except u–g color. For the reddest galaxies this proportion decreases with increasing colors.

(4) We also perform comparative studies between the Main galaxy sample and the LRG sample, and find significant differences of these correlations.

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