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THE ENVIRONMENTAL DEPENDENCE OF THE FRACTION OF 'UNCONVENTIONAL' GALAXIES: LUMINOUS LATE-TYPES AND FAINT EARLY-TYPES

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RESUMEN

Usamos la muestra principal, limitada en volumen, del Sloan Digital Sky Survey Data Release 7 (SDSS DR7), para explorar la dependencia ambiental de la fracción de galaxias 'no convencionales', esto es, galaxias luminosas de tipo tardío, y galaxias débiles de tipo temprano. Encontramos que la fracción de galaxias tempranas débiles aumenta significativamente al aumentar la densidad local, y que la fracción de galaxias tardías luminosas decrece un poco al aumentar la densidad local. Esto muestra que existe una dependencia ambiental de la morfología, además de la luminosidad.

ABSTRACT

Using the volume-limited main galaxy sample constructed from the Sloan Digital Sky Survey Data Release 7 (SDSS DR7), we have explored the environmental dependence of the fraction of 'unconventional' galaxies: luminous late-types and faint early-types. It is found that the fraction of faint early-types increases substantially with increasing local density, and that the fraction of luminous late-types weakly decreases with increasing local density. This shows that there is an environmental dependence for morphology beyond that for luminosity.

Key Words: galaxies: fundamental parameters — galaxies: statistics

1. INTRODUCTION

It has been known for a long time that high-luminosity galaxies are preferentially "early -types" and redder (e.g., Bower, Lucey, & Ellis 1992; Strateva et al. 2001; Blanton et al. 2003; Baldry et al. 2004; Balogh et al. 2004; Kelm, Focardi, & Sorrentino 2005), which is correct for the majority of galaxies. But the differences between the luminous and early-type fractions imply the existence of substantial populations of 'unconventional' galaxies: luminous late-types and faint early-types. The galaxy samples can also be classified by other galaxy properties, for example, color and morphologies. Similarly, the majority of the red population corresponds to early-type galaxies, and the majority of the blue population corresponds to late-types. Thus, red late-types and blue early-types also are defined as 'unconventional' populations. The majority of galaxies show concordant classification, being either luminous, red, early-type and passive galaxies or faint, blue, late-type and star-forming galaxies. For example, Mignoli et al. (2009) found that about 85% of the galaxies show a fully concordant classification, being either quiescent, red, bulge-dominated galaxies or star-forming, blue, disk-dominated galaxies. 'Unconventional' galaxies are special and rare galaxies in the universe. Although most authors would like to explore galaxies with concordant classification, the study of 'unconventional' galaxies is genuinely interesting. 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. (2009c) reached the same conclusions. Mahajan & Raychaudhury (2009) explored red star-forming and blue passive galaxies in clusters.

The purpose of this paper is to explore the environmental dependence of the fraction of 'unconventional' galaxies: luminous late-types and faint early-types. For this purpose, the selection of local density estimator is a key step. There are many ways to measure local density, and no one way is more correct than another. Each method has its limitations. Some authors select the projected local density $\sum_5$ which is computed from the distance to the 5th nearest neighbor within a redshift slice ± 1000 km s^{-1} of each galaxy (e.g., Goto et al. 2003; Balogh et al. 2004), which is seriously influenced by projection effects. To decrease projection effects, a simple and direct method is to use the three-dimensional density estimator, which is computed in a comoving sphere around each galaxy whose radius is the distance to the 5th nearest galaxy. Unfortunately, the three-dimensional density estimator is severely biased by the peculiar velocity of the galaxy, especially in a dense region. As indicated as Deng et al. (2008, 2009c), in the volume-limited main galaxy sample, the influences of biases of the two density measures on the conclusions are less important. Thus, in this paper, we only measure the three-dimensional local density.

Our paper is organized as follows. In § 2, we describe the data used. The environmental dependence of the fraction of 'unconventional' galaxies is discussed in § 3. Our main results and conclusions are summarized in § 4.

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

2. DATA

Many of survey properties of the SDSS were discussed in detail in the Early Data Release paper (Stoughton et al. 2002). Like Deng (2010) did, we use the main galaxy sample (Strauss et al. 2002) of the SDSS DR7(Abazajian et al. 2009). The data were downloaded from the Catalog Archive Server of the SDSS Data Release 7 by the SDSS SQL Search(with the SDSS flag: bestPrimtarget&64>0) with high-confidence redshifts (Zwarning $\neq 16$ and Zstatus $\neq 0,1$ and redshift confidence level: zconf>0.95)[1].

From the main galaxy sample of the SDSS DR7, Deng (2010) constructed two volume-limited samples above and below the value of M_r^* found for the overall Schechter fit to the galaxy luminosity function. The luminous volume-limited main galaxy sample contains 120362 galaxies at $0.05 \leq z \leq 0.102$ with $-22.5 \leq M_r \leq -20.5$. The faint volume-limited sample includes 33249 galaxies at $0.02 \leq z \leq 0.0436$ with $-20.5 \leq M_r \leq -18.5$. It is widely accepted that luminous galaxies tend to reside in the densest regions of the universe, while faint galaxies tend to reside in low density regions. For example, Park et al. (1994) noted that high-density regions preferentially include bright galaxies, low density regions tend to harbor only faint galaxies. Blanton et al. (2003) showed that the most luminous galaxies tend to reside in the densest regions of the universe. But Norberg et al. (2001) and Deng et al. (2009b) showed that for galaxies fainter than M_r^*, the change of the clustering amplitude of galaxies with absolute magnitude or the environmental dependence of the galaxy luminosity is very weak, while for luminous galaxies it is quite strong. In this work, we attempt to define galaxies as 'luminous' and 'faint', by the environmental dependence of the galaxy luminosity. Because the environmental dependence of the galaxy luminosity in the faint volume-limited sample is fairly weak, we only use the luminous volume-limited main galaxy sample constructed by Deng (2010).

3. ENVIRONMENTAL DEPENDENCE OF THE FRACTION OF 'UNCONVENTIONAL' GALAXIES

A traditional method of morphological classification is to visually inspect the galaxy images according to Hubble's classification scheme (Sandage 1961). However, the visual inspection procedure is very labor-intensive. Thus, it is highly desirable to find automated morphological classification schemes in order to classify a huge number of galaxies into early and late types. There are a number of parameters, such as concentration index, color, spectral features, surface brightness profile, structural parameters or some combination of these, that exhibit a strong correlation with morphological type and can be used to classify galaxies (e.g., Shimasaku et al. 2001; Strateva et al. 2001; Abraham, van den Bergh, & Nair 2003; Nakamura et al. 2003; Kauffmann et al. 2004; Park & Choi 2005; Yamauchi et al. 2005; Conselice 2006; Sorrentino, Antonuccio, & Rifatto 2006; Scarlata et al. 2007).

R_{50} and R_{90} are the radii enclosing 50% and 90% of the Petrosian flux, respectively. The concentration index $Ci = R_{90}/R_{50}$ is known to correlate with the morphological type (Morgan 1958; Doi, Fukugita, & Okamura 1993; Abraham et al. 1994; Shimasaku et al. 2001; Nakamura et al. 2003; Park

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

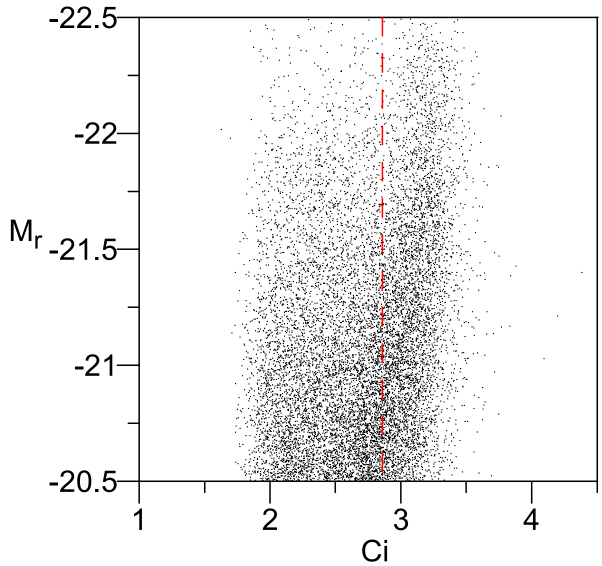

Fig. 1. Distribution in the concentration index vs. luminosity plane of the volume-limited main galaxy sample. The symbol frequency is 10 (only one out of ten points is plotted).

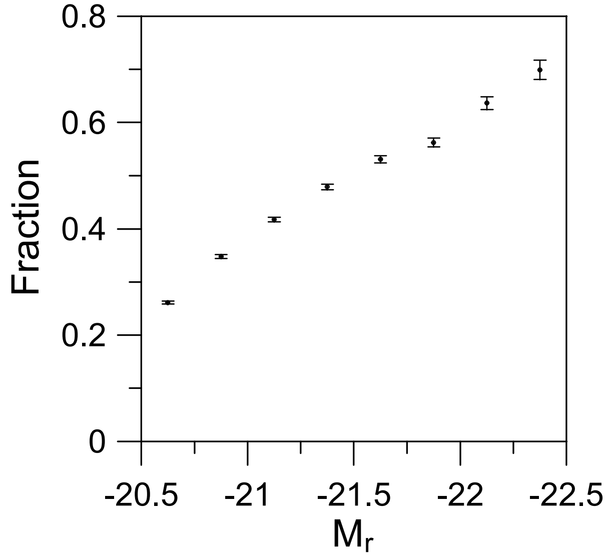

Fig. 2. The fraction of early-type galaxies in different luminosity bins for the volume-limited main galaxy sample.

& Choi 2005). Shimasaku et al. (2001) showed that the (inverse) concentration index $C = R_{50}/R_{90}$ correlates tightly with the morphological type; this index is useful for automated classification of early- and late-type galaxies, if one is satisfied with a completeness of ≃70–90%, allowing for a contamination of ≃15–20%. Shimasaku et al. (2001) also examined the correlations of visual morphology with a number of parameters measured by the photometric pipeline, and found that the concentration index shows the strongest correlation with visual morphology, and that a combination of the concentration index with other parameters, such as surface brightness, color and asymmetry parameter, does not appreciably enhance the correlation. So, Shimasaku et al. (2001) concluded that the concentration index is perhaps the best parameter to be used to classify morphology of galaxies, which is consistent with the conclusion obtained by Doi et al. (1993) and Abraham et al. (1994). Nakamura et al. (2003) separated galaxies into early and late types according to $C < 0.35$ and $C > 0.35$, which corresponds to a division at S0/a. When the visually classified sample is taken as the reference, the early-type and late-type galaxy samples classified by Nakamura et al. (2003) shows an 82% completeness and an 18% contamination from the opposite sample. Park & Choi (2005) used the color versus color gradient space as the major morphology classification tool and the concentration index as an auxiliary parameter. Early-type galaxies strongly concentrate within a spot centered at (2.82, −0.04) in the $u-r$ and $\Delta(g-i)$ plane, and centered at (2.82, 0.3) in the $u-r$ color-concentration index space. In the upper panel of Figure 1 of Park & Choi (2005), we can note that the concentration index is still a relatively good and simple parameter to be used to classify the morphology of galaxies; most of the early-type galaxies have concentration index $C = R_{50}/R_{90} < 0.35$.

In this paper, we use the concentration index $Ci = R_{90}/R_{50}$ to separate early-type ($ci \geq 2.86$) galaxies from late-type ($ci < 2.86$) galaxies. Figure 1 shows the distribution in the concentration index vs. luminosity plane of the volume-limited main galaxy sample. Figure 2 presents the fraction of early-type galaxies in different luminosity bins for the volume-limited main galaxy sample. As seen from Figure 2, the fraction of early-type galaxies rises considerably with increasing luminosity.

Due to the bimodality of the $u-r$ color distribution, Strateva et al. (2001) developed a divider (the observed $u-r$ color = 2.22) and classified galaxies above and below this divider as 'red' and 'blue', respectively. But so far, there has not been a luminosity divider above and below which galaxies can be classified as 'luminous' and 'faint', respectively. In fact, we must confess that whether a galaxy is

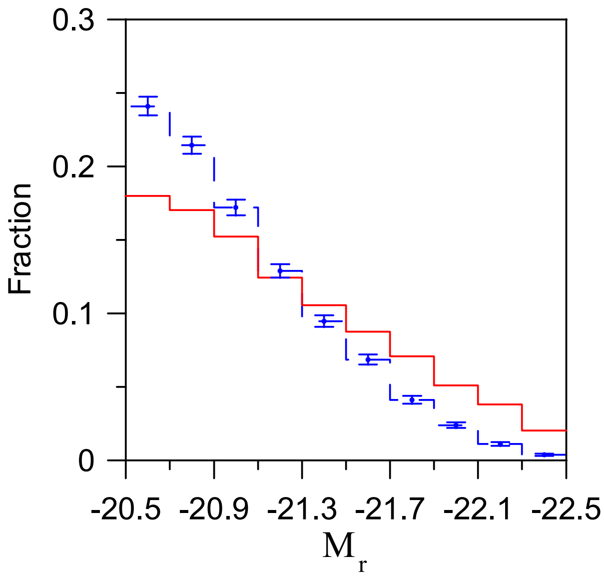

Fig. 3. The luminosity distribution at both extremes of density for the volume-limited main galaxy sample: red solid line for the subsample at high density, blue dashed line for the subsample at low density. The error bars of blue lines are 1σ Poissonian errors. Error-bars of red lines are omitted for clarity. The color figure can be viewed online.

termed 'luminous' or 'faint' is often relative. In this study, we intend to give a clear and physical definition of 'luminous' or 'faint'.

For each galaxy, we calculate the three-dimensional distance to the 5th nearest galaxy, like Deng et al. (2008) did. The local three-dimensional galaxy density is defined as the number of galaxies ($N = 5$) within this distance divided by the volume of the sphere with the radius of the distance to the 5th nearest galaxy. Like Deng et al. (2008), we arrange galaxies in density order from the smallest to the largest, select about 5% galaxies (6018 galaxies), and construct two subsamples at both extremes of the density. We compare the distribution of galaxy luminosity in the lowest density regime with that in the densest regime. As seen from Figure 3, 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; the level of significance is at least 3σ, which is consistent with the widely accepted conclusion: luminous galaxies exist preferentially in the densest regions of the universe, while faint galaxies are located preferentially in low density regions. Thus, we define galaxies with luminosity $M_r \geq -21.1$ as 'faint', and galaxies with luminosity $M_r \leq -21.5$ as 'luminous'. In our volume-limited sample, the luminous early-type class contains 14935 galaxies, the luminous late-type class 11218 galaxies, the faint late-type class 44665 galaxies and the faint early-type class 20604 galaxies.

Figure 4 shows the fraction [n('unconventional' galaxies)/n(all) in each density bin] of 'unconventional' galaxies: luminous late-types (a), and faint early-types (b) as a function of the three-dimensional local density LD (galaxies Mpc^{-3}) for the volume-limited sample. The LD-axis of this figures is logarithmic. We bin the sample in steps of 0.25 over the range $-4 < \log_{10}\ LD < 0$. As seen from Figure 4, the fraction of faint early-types increases substantially with increasing local density, and the fraction of luminous late-types weakly decreases with increasing local 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. From Table 1, we can obtain the same conclusion as from Figure 4. For the concordant classification, being either luminous early-type galaxies or faint late-type galaxies, the fraction of luminous early-type galaxies rises considerably with increasing local density, and the fraction of faint late-type galaxies declines substantially with increasing local density. Table 1 also shows that the proportions of luminous galaxies and early-type 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 early -type galaxies exist preferentially in the densest regions of the universe, while faint or late-type galaxies are located preferentially in low density regions.

As seen from Table 1, in the subsample at high density, the majority of the luminous population corresponds to early-type galaxies, but in the subsample at low density this preference does not exist. In two subsamples at both extremes of density, we note that the majority of the early-type population does not correspond to luminous galaxies. At least in this study, it is difficult to conclude that luminous galaxies are preferentially early-types, and that early-type galaxies are preferentially luminous, which was widely accepted in the past. But Table 1 still shows that faint galaxies are preferentially late-types, and that late-type galaxies are preferentially faint. In fact, 'luminous' and 'faint', as mentioned above, are relative concepts. The most luminous galaxies in a sample may likely be fainter than the faintest galaxies in another sample. So, we should accept such conclusions with caution. But from Figure 2, we can

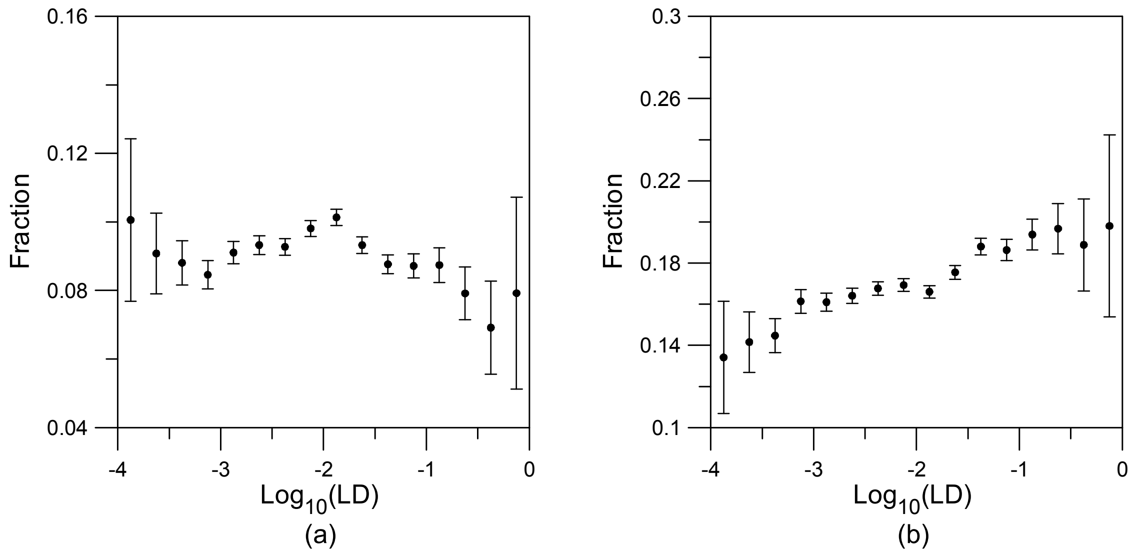

Fig. 4. Fraction of 'unconventional' galaxies: luminous late-types (a) and faint early-types(b) as a function of the three-dimensional local density of galaxies for the volume-limited main galaxy sample. The error bars are 1σ Poissonian errors.

TABLE 1

NUMBER OF GALAXIES OF DIFFERENT CLASSES FOR TWO SUBSAMPLES AT BOTH EXTREMES OF DENSITY

Classes	Subsample at low density N (%)	Subsample at high density N (%)
Luminous early-types	376 (6.25)	1102 (18.31)
Luminous late-types	518 (8.61)	508 (8.44)
Faint late-types	2854 (47.42)	1863 (30.96)
Faint early-types	924 (15.35)	1162 (19.31)

conclude that the more luminous a galaxy is, the more preferentially early-type it is.

Deng et al. (2009c) 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. As is well-known, red or early-type galaxies exist preferentially in dense environments. The environmental dependence of galaxy morphology and color shows that the transformation of galaxies is due to environmental mechanisms. For example, some mechanisms have been proposed for the transformation of spiral galaxies into early-types in dense environments (Boselli & Gavazzi 2006). Bamford et al. (2009) believed that the environmental dependence for color beyond that for morphology shows that a transition from blue to red in dense environments is not generally accompanied by a transition from spiral to early-type, which means that the environmental transformation of galaxies from blue to red must occur on significantly shorter timescales than the transformation from spiral to early-type. In this study, we find that the fraction of faint early-types increases substantially with increasing local density, and that the fraction of luminous late-types weakly decreases with increasing local density. This shows that there is an environmental dependence for morphology beyond that for luminosity. Deng et al. (2009a) investigated the dependence of luminosity and $g-r$ color on environment for the same morphological types, and also found that the dependence of luminosity on local environment is mainly due to the dependence of galaxy morphologies on local environment and the correlation between morphologies and luminosity.

4. SUMMARY

In this work, we use a volume-limited main galaxy sample of the SDSS DR7 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 late-types and faint early-types. It is found that the fraction of faint early-types increases substantially with increasing local density, and that the fraction of luminous late-types weakly decreases with increasing local density. This shows that there is an environmental dependence for morphology beyond that for luminosity.

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