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ENVIRONMENTAL DEPENDENCES OF STAR FORMATION RATE (SFR), SPECIFIC STAR FORMATION RATE (SSFR) AND STELLAR MASS AT FIXED LUMINOSITY

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RESUMEN

Empleamos cuatro muestras limitadas en volumen de galaxias principales del Sloan Digital Sky Survey, versión 8 (SDSS DR8) para investigar la dependencia del medio ambiente de la tasa de formación estelar (SFR), la tasa específica de formación estelar (SSFR) y la masa en estrellas a una luminosidad fija. Aún fijando la luminosidad, se observa una fuerte dependencia ambiental de la SFR, la SSFR y de la masa en estrellas: las galaxias en la región de más baja densidad tienden a tener mayores SFR y SSFR, y masa en estrellas menores que las galaxias en la región de más alta densidad. Este resultado sugiere que al fijar la luminosidad no se altera apreciablemente la dependencia ambiental de la SFR, la SSFR y la masa en estrellas de las galaxias, lo cual muestra que la luminosidad no es un parámetro fundamental en las correlaciones entre las propiedades galácticas y el ambiente.

ABSTRACT

Using four volume-limited Main galaxy samples of the Sloan Digital Sky Survey Data Release 8 (SDSS DR8), we have investigated the environmental dependences of the SFR, SSFR and stellar mass at fixed luminosity. At fixed luminosity, we still observe strong environmental dependences of the SFR, SSFR and stellar mass of galaxies: galaxies in the lowest density regime preferentially have a higher SFR or SSFR and lower stellar mass than galaxies in the densest regime. This result suggests that the limitation or fixation of luminosity does not exert substantial influence on the environmental dependences of the SFR, SSFR and stellar mass of galaxies, which further shows that luminosity is not a fundamental parameter in correlations between galaxy properties and the environment.

Key Words: galaxies: fundamental parameters — galaxies: statistics

1. INTRODUCTION

In the last several decades, much progress has been made in discovering the correlations between the properties and local environments of galaxies (e.g., Postman & Geller 1984; Dressler et al. 1997; Hashimoto & Oemler 1999; Fasano et al. 2000; Tran et al. 2001; Blanton et al. 2003, 2005; Goto et al. 2003; Helsdon & Ponman 2003; Hogg et al. 2003, 2004; Treu et al. 2003; Balogh et al. 2004a, 2004b; Kauffmann et al. 2004; Tanaka et al. 2004; Berlind et al. 2005; Blanton & Berlind 2007; Capak et al. 2007; Deng et al. 2007a–e, 2008a,b, 2009a, 2010, 2011a,b, 2012; Deng & Zou 2009; Deng 2010, 2012; Park et al. 2007; Bamford et al. 2009; Pannella et al. 2009; Skibba et al. 2009; Tasca et al. 2009; Iovino et al. 2010; Lee et al. 2010; Wilman et al. 2010; Grützbauch et al. 2011a,b,c). Statistical results often have been interpreted in the framework of the current models of formation and evolution of galaxies. Hierarchical models of galaxy formation predict the existence of correlations between galaxy luminosity and the clustering strength or environments of galaxies (e.g., White et al. 1987; Kauffmann, Nusser, & Steinmetz 1997). Harker et al. (2006) argued that the variation of galaxy properties with environment could be explained by considering a likely link between the halo properties and the galaxy properties.

When exploring such an issue, one should account for correlations among the physical properties of galaxies (e.g., Bower, Lucey, & Ellis 1992; Strateva et al. 2001; Blanton et al. 2003; Baldry et al. 2004; Balogh et al. 2004a; Kelm, Focardi, & Sorrentino 2005). Correlations between some galaxy properties and the local environments are likely due to correlations between other galaxy properties and the local environments. Some authors focused on the environmental dependences of other galaxy properties at a fixed parameter (e.g., Balogh et al. 2004a; Kauffmann et al. 2004; Blanton et al. 2005; Park et al. 2007; Deng et al. 2010, 2011a,b, 2012), to explore which parameter is fundamental in the correlations between galaxy properties and the environment.

Deng et al. (2009a) and Deng & Zou (2009) demonstrated that at a given galaxy morphology or fixed color, the environmental dependence of galaxy luminosity is greatly decreased, implying that luminosity is not fundamental in correlations between galaxy properties and the environment. Deng et al. (2011b) investigated how $g-r$ color, concentration index and morphology of galaxies depend on the environment at fixed luminosity, and found that at fixed luminosity, strong environmental dependences of $g-r$ color, concentration index and morphology of galaxies still can be observed. This result further shows that luminosity is not fundamental

Stellar mass, the star formation rate (SFR) and the specific star formation rate (SSFR) (defined as the star formation rate per unit stellar mass) are important physical parameters of galaxies that are strongly correlated with local environments (e.g., Balogh et al. 1998; Hashimoto et al. 1998; Lewis et al. 2002; Gómez et al. 2003; Kauffmann et al. 2004; Tanaka et al. 2004; Li et al. 2006; Patel et al. 2009; Deng 2010; Deng et al. 2011a). For example, Gómez et al. (2003) argued that the SFR of galaxies strongly depends on the local (projected) galaxy density. Kauffmann et al. (2004) found that the stellar mass distributions of galaxies in low-density regions differ significantly from the stellar mass distributions of galaxies in high-density regions. Other works further studied the environmental dependences of these galaxy properties at a fixed parameter. For example, Deng (2010) demonstrated that the environmental dependences of the SFR and SSFR of galaxies remains true when the morphology was fixed: the SFR and SSFR of galaxies in the densest regime are still preferentially lower than the ones in the lowest density regime with the same morphological type. Deng et al. (2011a) explored the environmental dependences of the SFR, SSFR and stellar mass for blue and red galaxies and found that the environmental dependences of the SFR, SSFR and stellar mass for red galaxies are still fairly strong, but the environmental dependences of these parameters for blue galaxies are very weak. Deng et al. (2011a) argued that the strong environmental dependences of these parameters for red galaxies are mainly due to the one in the red late-type sample. In this work, we investigate the environmental dependences of the SFR, SSFR and stellar mass at fixed luminosity.

Our paper is organized as follows. In § 2, we describe the data used. The environmental dependences of SFR, SSFR and stellar mass at fixed luminosity are discussed in § 3. Our main results and conclusions are summarized in § 4.

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

2. DATA

In this work, following Deng et al. (2012), we used the Main galaxy sample (Strauss et al. 2002) of the eighth data release(DR8) (Aihara et al. 2011) and downloaded the data from the Catalog Archive Server of DR8 using the SDSS SQL Search (with SDSS flag: `bestPrimtarget&64>0`) within the redshift range $0.02 < z < 0.2$[1]. DR8 is the first data release of SDSS-III (Eisenstein et al. 2011). DR8 contains a number of galaxy physical parameters derived by the MPA-JHU group[2], such as BPT classification, stellar mass, nebular oxygen abundance, star formation rates (SFRs) and specific SFR (SSFR). Our Main galaxy sample contains 582625 galaxies. From this flux-limited Main galaxy sample, we construct four volume-limited samples with different luminosity, labeled S1 to S4. The definitions for all samples are summarized in Table 1. The absolute magnitude M_r is calculated from the r-band apparent Petrosian magnitude, using a polynomial fit formula (Park et al. 2005) for the mean K-correction within $0 < z < 0.3$:

$$K(z) = 2.3537 \times (z-0.1)^2 + 1.04423 \times (z-0.1) \\ -2.5 \times \log(1+0.1).$$

Norberg et al. (2001) and Deng et al. (2009b) showed that there is a characteristic parameter M_r^*: for galaxies fainter than M_r^*, the variation in the clustering amplitude of galaxies with absolute magnitude or the environmental dependence of the galaxy luminosity is very weak, while for galaxies brighter than M_r^*, it is quite strong. Thus, we pay special attention to the difference between two types

[1] `http://www.sdss3.org/`.

[2] `http://www.mpa-garching.mpg.de/SDSS/DR7/`.

TABLE 1

VOLUME-LIMITED SAMPLES

Name	Absolute Magnitude	Redshift	Number of galaxies
S1	$-18.5 > M_r > -19.5$	$0.02 < z < 0.0436$	18619
S2	$-19.5 > M_r > -20.5$	$0.02 < z < 0.0672$	50738
S3	$-20.5 > M_r > -21.5$	$0.02 < z < 0.1023$	109324
S4	$-21.5 > M_r > -22.5$	$0.02 < z < 0.1528$	105038

of galaxy samples with absolute magnitudes above and below M_r^*. In this work, the S1 and S2 samples are fainter than M_r^*, whereas the S3 and S4 samples are brighter than M_r^*.

3. THE ENVIRONMENTAL DEPENDENCES OF THE SFR, SSFR AND STELLAR MASS AT FIXED LUMINOSITY

In the past, many authors often used different density estimators. Grützbauch et al. (2011a) claimed that nearest neighbor density is widely used. The key step of this density estimator is the best choice of the number of neighbor to count, n, which is still a subject of debate. Values from $n = 3$ (Cooper et al. 2006) up to $n = 10$ (Dressler 1980) have been used in different studies. Cooper et al. (2005) argue that the choice of n does not change the resulting densities significantly. In this study, the five neighbor ($n = 5$) are used, in concordance with many other studies (e.g., Goto et al. 2003; Balogh et al. 2004a,b; Yee et al. 2005; Ball, Loveday, & Brunner 2008; Deng et al. 2008a, 2009a,b,c, 2010, 2011a,b, 2012; Deng & Zou 2009; Deng 2010, 2012). Deng et al. (2008a, 2009c) demonstrated that in the volume-limited Main galaxy sample of the SDSS, the local three-dimensional galaxy density and the projected local density $\sum_5$ (e.g., Goto et al. 2003; Balogh et al. 2004a,b) can produce the same conclusions. Thus, we only measure the three-dimensional local density in a comoving sphere with a radius equal to the distance to the 5th nearest galaxy for each galaxy (e.g., Deng et al. 2008a, 2009c). Following Deng et al. (2008a), we arrange galaxies in a density order from the smallest to the largest, select approximately 5% of the galaxies and construct two subsamples at both density extremes according to the density for each sample.

Deng & Zou (2009) showed that at fixed color, the environmental dependences of other galaxy properties, such as luminosity, concentration index and morphologies, are greatly decreased. Skibba et al. (2009) found that at fixed morphology, galaxy colors are still strongly correlated with the environment, but the correlations between morphology and the environment are extremely weak at fixed color. Deng et al. (2011a) argued that when color is limited, the environmental dependences of the SFR, SSFR and stellar mass are also substantially decreased. Taken together, these results suggest that color is fundamental in correlations between galaxy properties and the environment and that many of the other galaxy properties-density relation are likely due to the relation between color and density.

As is well known, galaxy luminosity is strongly correlated with local environment (e.g., Davis et al. 1988; Hamilton 1988; White, Tully, & Davis 1988; Park et al. 1994; Loveday et al. 1995; Guzzo et al. 1997; Willmer, da Costa, & Pellegrini 1998; Norberg et al. 2001; Zehavi et al. 2002; Blanton et al. 2003, 2005; Hogg et al. 2003; Berlind et al. 2005; Zandivarez, Martínez, & Merchán 2006; Park et al. 2007; Deng et al. 2007b, 2008a,b, 2009b). The question naturally arises as to whether luminosity is fundamental in correlations between galaxy properties and the environment. The answer to this question is a subject of debate. Deng et al. (2009a) and Deng & Zou (2009) argued that at a given galaxy morphology or at a fixed color, the environmental dependence of galaxy luminosity is greatly decreased. Deng et al. (2011b) further investigated how $g - r$ color, concentration index and morphology of galaxies depend on the environment at fixed luminosity, and found that at fixed luminosity, $g - r$ color, concentration index and morphology of galaxies still strongly depend on the local environment. Deng et al. (2011b) argued that much of the correlation between luminosity and the environment indeed is due to the relation between galaxy morphology or color and density. However, Balogh et al. (2004a) demonstrated that at fixed luminosity the mean color of blue galaxies or red galaxies is nearly independent of the environment. Blanton et al. (2005) showed that at fixed luminosity and color, density is not closely re-

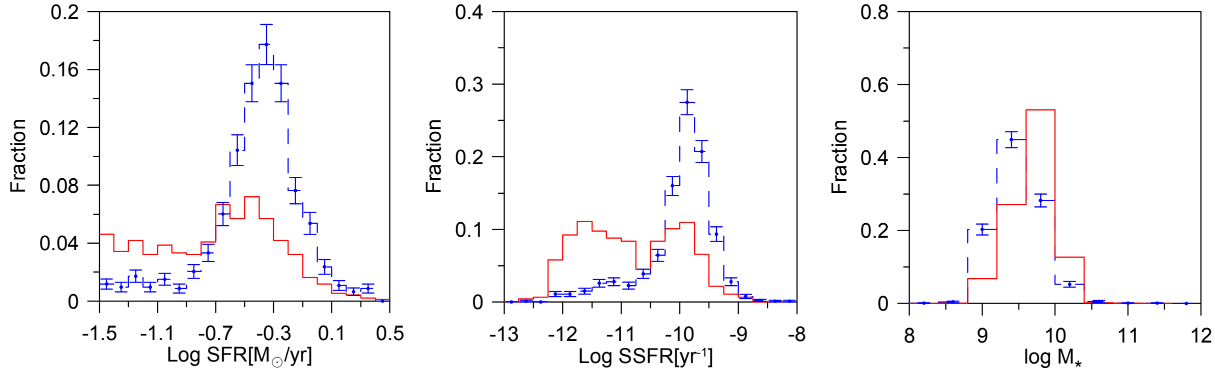

Fig. 1. SFR, SSFR and stellar mass distributions at both density extremes for the S1 sample. The red solid line represents the subsample at high density, and the blue dashed line represents the subsample at low density. The error bars of the blue lines are 1σ Poissonian errors. The error bars of the red lines are omitted for clarity. The color figure can be viewed online.

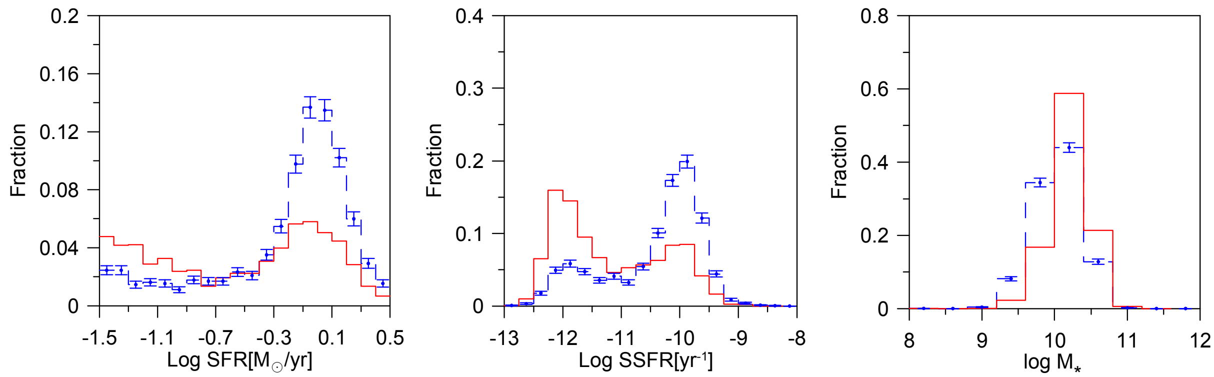

Fig. 2. As Figure 1 but for the S2 sample. The color figure can be viewed online.

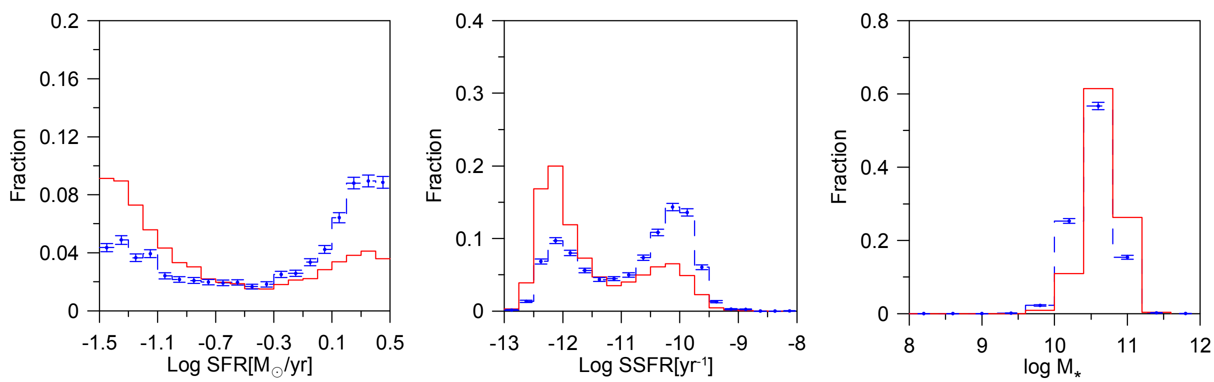

Fig. 3. As Figure 1 but for the S3 sample. The color figure can be viewed online.

lated to surface brightness or to the Sérsic index (a measure of galaxy structure). Park et al. (2007) also found that color, color-gradient, concentration, size, velocity dispersion, and star formation rate are nearly independent of the local density when morphology and luminosity are fixed. These results imply that luminosity is likely a fundamental parameter in correlations between galaxy properties and the

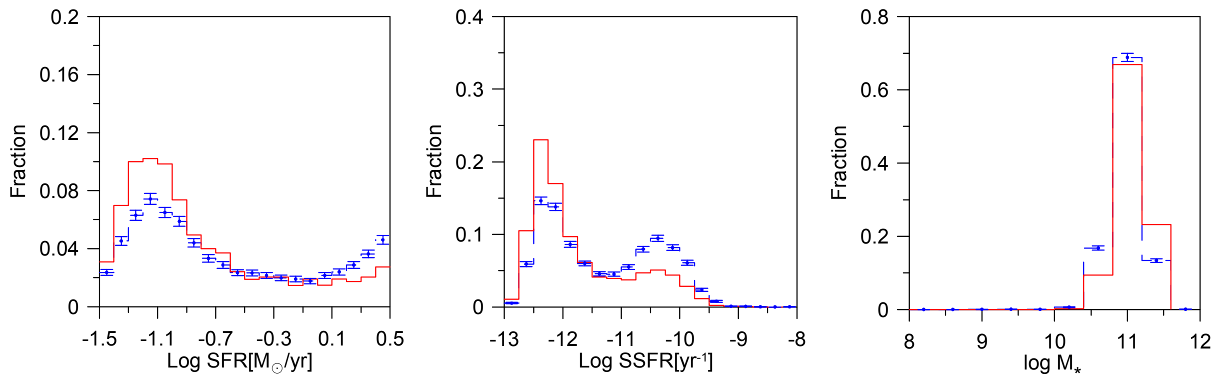

Fig. 4. As Figure 1 but for the S4 sample. The color figure can be viewed online.

environment. Deng et al. (2011b) argued that the result of Balogh et al. (2004a) may be due to using a statistically incorrect method. Considering tight correlations among galaxy properties, other parameters may be limited to a fairly small region when two parameters are fixed. Thus, it is not surprising that there are no apparent correlations between other parameters and the local density.

Deng et al. (2010) demonstrated that the environmental dependence of luminosity for High Stellar Mass galaxies and Low Stellar Mass galaxies is much weaker than that obtained in the volume-limited Main galaxy sample. Figures 1–4 present the SFR, SSFR and stellar mass distributions at both density extremes for S1–S4. As seen from these figures, when luminosity is fixed, the environmental dependences of the SFR, SSFR and stellar mass of galaxies are still fairly strong: galaxies in the lowest density regime preferentially have a higher SFR or SSFR and lower stellar mass than galaxies in the densest regime. Thus, we can conclude that the limitation or fixation of luminosity does not exert substantial influence on the environmental dependences of the SFR, SSFR and stellar mass of galaxies, which further shows that luminosity is not a fundamental parameter in correlations between galaxy properties and the environment.

The Kolmogorov-Smirnov (KS) test is used to check the similarity of the two independent distributions in each of our figures by calculating a probability value. The lower the probability value is, the less likely the two distributions are similar. Conversely, the higher or more close to 1 the value is, the more similar the two distributions are. The probability of the two distributions coming from the same parent distribution is listed in Table 2. As seen from Table 2, the KS probability of all figures is nearly

TABLE 2

K-S PROBABILITIES THAT TWO SUBSAMPLES AT DENSITY EXTREMES STEM FROM THE SAME DISTRIBUTION

Sample	P(SFR)	P(SSFR)	P(stellar mass)
S1	0	0	3.50E-43
S2	0	0	0
S3	0	0	0
S4	0	0	0

0. This result leads us to reject the null hypothesis, thus we can conclude that the two independent distributions in each figure completely differ, which is in good agreement with the conclusion obtained by the step figures.

Due to tight correlations between galaxy luminosity and other galaxy properties, we need to distinguish between two simple scenarios: (1) the environmental dependence of galaxy luminosity is only due to the environmental dependences of other galaxy properties and tight correlations between luminosity and these galaxy properties or (2) galaxy luminosity is correlated with its environment as well as with other galaxy properties. The statistical results of this study and previous work (e.g., Deng et al. 2009a, 2010, 2011b; Deng & Zou 2009) support the first scenario, which can rule out certain hypothetical physical mechanisms regarding the influence of environment on galaxy luminosity.

We do not observe significant statistical differences between the samples fainter than M_r^*(S1 and S2) and the samples brighter than M_r^*(S3 and S4), which is consistent with the conclusion obtained by Deng et al. (2011b).

According to the work of Kauffmann et al. (2003), we can infer that there is a close correlation between stellar mass and luminosity: more luminous galaxies are preferentially high mass. In Figures 1–4, we also observe such a trend.

4. SUMMARY

Using four volume-limited samples with luminosity bins $-18.5 > M_r > -19.5$, $-19.5 > M_r > -20.5$, $-20.5 > M_r > -21.5$ and $-21.5 > M_r > -22.5$, we have investigated the environmental dependences of the SFR, SSFR and stellar mass at fixed luminosity. For each sample, we measure the local three-dimensional galaxy density in a comoving sphere with a radius equal to the distance to the 5th nearest galaxy for each galaxy, select approximately 5% of the galaxies and construct two subsamples at both density extremes. The results suggest that when luminosity is fixed, the environmental dependences of the SFR, SSFR and stellar mass of galaxies are still fairly strong: galaxies in the lowest density regime preferentially have a higher SFR or SSFR and lower stellar mass than galaxies in the densest regime. Thus, we can conclude that the limitation or fixation of luminosity does not exert substantial influence on the environmental dependences of the SFR, SSFR and stellar mass of galaxies, which further shows that luminosity is not a fundamental parameter in correlations between galaxy properties and the environment.

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