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Environmental dependence of stellar velocity dispersion in the Main galaxy sample of SDSS DR10

Abstract: The aim of this work is to examine the environmental dependence of stellar velocity dispersion in local galaxies. In studies that likely suffer from the radial selection effect, one has a preference for the use of volume-limited samples. Two volume-limited samples with different redshift and luminosity ranges were constructed from the Main galaxy data of the Sloan Digital Sky Survey Data Release 10 (SDSS DR10). Considering some drawbacks of volume-limited samples, the apparent magnitude-limited Main galaxy sample was also applied. Statistical analyses in these different galaxy samples can reach the same conclusion: galaxies with large stellar velocity dispersions exist preferentially in high density regimes, while galaxies with small stellar velocity dispersions are located preferentially in low density regions, which is inconsistent with that obtained at intermediate redshifts.

Keywords: Galaxy: fundamental parameters; galaxies: statistics

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1 Introduction

Some works have demonstrated that there is a close correlation between stellar velocity dispersion and masses of supermassive black holes (BHs) at galaxy centres [3, 12, 40, 42, 45, 46, 52, 77]. Thus, stellar velocity dispersion was shed light on by many works. Matković and Guzmán [59] studied the luminosity- velocity dispersion relation and the colour- velocity dispersion relation for 69 faint early-type galaxies in the core of the Coma cluster. Van Dokkum et al. [80] measured the stellar velocity dispersion of a massive compact galaxy at a redshift of z = 2.186. Van de Sande et al. [79] reported a velocity dispersion of 294±51 km/s of a compact quiescent galaxy at z = 1.80 using X-Shooter on the VLT. Bernardi et al. [9] presented fits to the distribution of stellar velocity dispersion as a function of concentration index and morphological type in the SDSS. Gruel et al. [49] measured the stellar velocity dispersion of 5 Luminous Compact Galaxies at z = 0.5 − 0.7, and found that these galaxies have velocity dispersions $\sigma \simeq 137 - 260$ km/s, which is in good agreement with the value characteristic of early-type spiral galaxies today. Martinez-Manso et al. [58] claimed that velocity dispersions of 4 compact and massive early-type galaxies in the Groth Strip Survey range from $\simeq 156$ km/s to 236 km/s. Wake et al. [81] explored correlations between a galaxy's rest-frame colour and some other galaxy parameters, and concluded that velocity dispersion is the best indicator of a galaxy's typical colour.

Many galaxy parameters, such as galaxy luminosity, colour, morphological type, stellar mass and star formation rate (SFR), strongly depend on local environments [10, 11, 13, 16–19, 25, 29, 30, 36, 39, 43, 50, 51, 53, 57, 61, 63, 64, 78, 83, 84]. For example, dense environments lead to galaxies having suppressed star formation rates (SFRs) [4, 21, 29, 43, 50, 56, 63, 73]. Galaxies in dense environments also are older than galaxies in low-density environments [7, 41, 54, 60, 65–70, 74–76, 82]. Statistical results of such studies can provide tests of models of formation and evolution of galaxies. In this work, the environmental dependence of stellar velocity dispersion in the Main galaxy sample of the SDSS is explored.

The paper is organized as follows. The galaxy sample is described in section 2. Statistical results are presented in section 3.

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

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2 Sample

Stoughton et al. [71] expained the survey properties of the SDSS in detail. In the SDSS I and II, galaxy spectroscopic targets were selected by two algorithms. The Main galaxy sample [72] includes galaxies brighter than r_{petro} = 17.77 (r-band apparent Petrosian magnitude). The Luminous Red Galaxy (LRG) algorithm [37] selects galaxies to r_{petro} < 19.5 that are likely to be luminous early-types. The Main galaxy sample is the largest and the most valuable galaxy sample in the local Universe. It 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≤ z ≤ 0.2.

In this work, the environmental dependence of stellar velocity dispersion in the Main galaxy sample of the SDSS is explored. The tenth data release (DR10) [2] is the newest one of the SDSS-III. The data of the Main galaxy sample was downloaded from the Catalog Archive Server of SDSS Data Release 10 [2] by the SDSS SQL Search (http://www.sdss3.org/dr10/), 633172 Main galaxies with the redshift 0.02≤ z ≤ 0.2 [the Main galaxy sample corresponds to LEGACY_TARGET1 & (64 | 128 | 256) > 0] are extracted, and an apparent-magnitude limited Main galaxy sample is constructed.

Following Deng [21], the K-correction formula of Park et al. [62] is used: $K(z) = 2.3537\times(z-0.1)^2+1.04423\times(z-0.1)-2.5\times\log(1+0.1)$, the r-band absolute magnitude M_r, is calculated, and two volume-limited Main galaxy samples with different redshift and luminosity range are constructed, to see the influence of galaxy sampling on statistical results. The luminous volume-limited Main galaxy sample contains 129515 galaxies at 0.05 ≤ z ≤ 0.102 with −22.5 ≤ M_r ≤−20.5; the faint volume-limited sample includes 34573 galaxies at 0.02 ≤ z ≤ 0.0436 with −20.5 ≤ M_r ≤−18.5.

3 Results

The same approach as used by Deng et al. [17] is proceeded with. Section 3 of Deng et al. [17] describes this method in detail, but the key points is briefly summarized here.

The projected local density Σ_5 (Galaxies Mpc^{-2}) is defined as $\Sigma_5 = N/\pi d_5^2$ where d_5 is the distance to the 5th nearest neighbour within ±1000 km s^{-1} in redshift [5, 6, 44]. For each sample, galaxies are arranged in a density order from the smallest to the largest, approximately 5% of the galaxies are selected, two subsamples at both extremes of density are constructed according to the density, and distribution of stellar velocity dispersion in the lowest density regime is compared with that in the densest regime.

Projected local density ranges (Galaxies Mpc^{-2}) are $1.30\times10^{-3} \longrightarrow 1.28\times10^{4}$ for the faint volume-limited sample and $9.82\times10^{-4} \longrightarrow 6.89\times10^{3}$ for the luminous volume-limited sample. Figure 1 shows the stellar velocity dispersion distribution at both extremes of density for the faint (left panel) and luminous (right panel) volume-limited Main galaxy samples. As shown by this figure, in these two volume-limited Main galaxy samples, stellar velocity dispersion of galaxies strongly depends on local environments: galaxies with large stellar velocity dispersions exist preferentially in high density regimes, while galaxies with small stellar velocity dispersions are located preferentially in low density regions. The Kolmogorov-Smirnov (KS) test is made. The probability of the two distributions in the left panel of Figure 1 coming from the same parent distribution is 6.328e-31, the one in the right panel of Figure 1 is nearly 0, which further shows that the above-mentioned statistical conclusion is robust.

Norberg et al. [61] and Deng et al. [19] reported that when studying the correlation between the galaxy luminosity and environment, M_r^* found for the overall Schechter fit to the galaxy luminosity function merits close attention. Galaxies brighter than M_r^* have a fairly strong correlation between the galaxy luminosity and environment, while for galaxies fainter than M_r^* it is very weak. However, some works demonstrated that other properties of galaxies strongly depend on local environments for all galaxies with different luminosities [19, 21, 26, 27, 32]. Deng et al. [19] argued that M_r^* is only a characteristic parameter dealing with the environmental dependence of galaxy luminosity. Deng et al. [31] even found that M_r^* is not an important characteristic parameter for the environmental dependence of the U-band luminosity. The U-band luminosity of galaxies still strongly depends on local environments in the faint volume-limited sample, like that in the luminous volume-limited sample. In this work, it is again noted that stellar velocity dispersion of galaxies strongly depend on local environments for all galaxies with different luminosities.

The radial selection effect in galaxy samples is a serious problem. In the past, one often used the volume-limited galaxy samples to remove this effect. Deng [28] argued that the use of volume-limited samples has the following two drawbacks: (1) a large fraction of the data becomes useless; and (2) due to being defined in a narrow luminosity region and a redshift limit Z_{max}, overall characters of the whole galaxy sample cannot be presented. Deng [28] tried another new method, and applied the apparent magnitude-limited galaxy sample for his statisti-

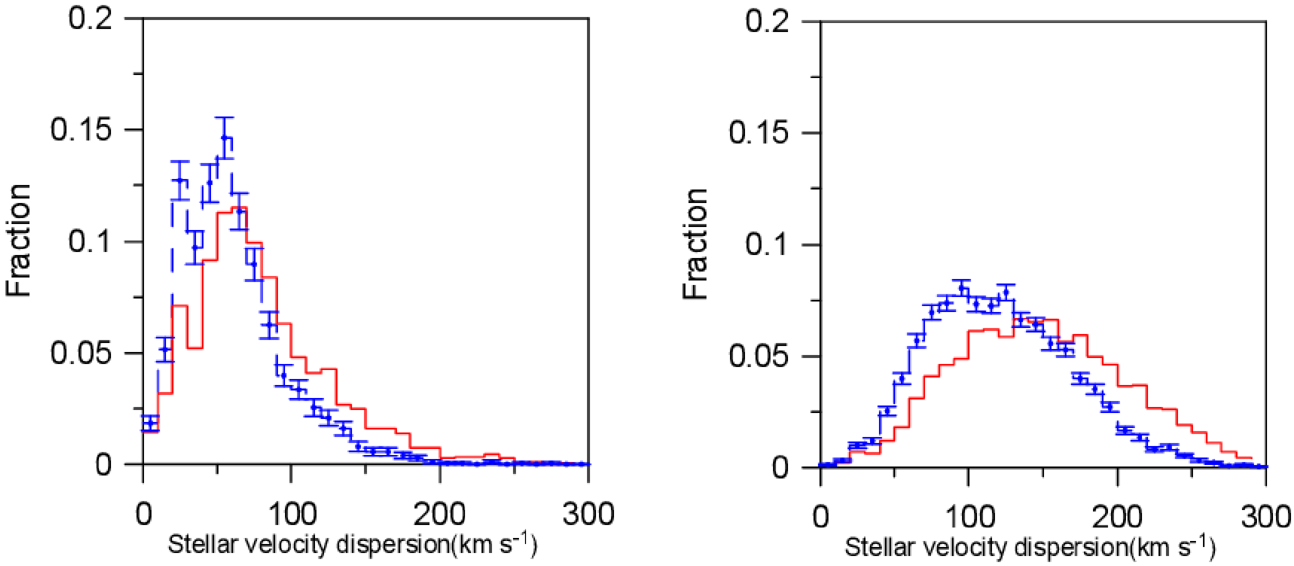

Figure 1: Stellar velocity dispersion distribution at both extremes of density for the faint (left panel) and luminous (right panel) volume-limited Main galaxy samples: red solid line represents the subsample at high density, blue dashed line represents the subsample at low density. The error bars of the blue lines are 1 σ Poissonian errors. The error-bars of the red lines are omitted for clarity.

cal analysis. In the study of Deng [28], the entire apparent magnitude-limited Main galaxy sample was divided into some subsamples with a redshift binning size of Δz = 0.01. Then, a statistical analysis of the subsamples in each redshift bin was performed. Apparently, in each subsample with a redshift binning size of Δz = 0.01, the radial selection effect should be less important. 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 [28, 29, 33]. For example, Deng et al. [29] demonstrated that there is a strong environmental dependence of the stellar mass, star formation rate (SFR), specific star formation rate (SSFR, the star formation rate per unit stellar mass) in nearly all redshift bins.

Following Deng [28], the projected local density Σ_5 is measured. The Main galaxy sample of the SDSS DR10 is then divided into subsamples with a redshift binning size of Δz = 0.01. Then, the environmental dependence of stellar velocity dispersion of the subsamples in each redshift bin is analyzed. Figure 2 shows stellar velocity dispersion distributions at both extremes of density in different redshift bins for the apparent magnitude-limited Main galaxy sample. Table 1 lists the Kolmogorov-Smirnov (KS) test probability in each redshift bin. As shown by Figure 2 and Table 1, the stellar velocity dispersion of Main galaxies strongly depends on the local environment in nearly all redshift bins. It is noteworthy that the environmental dependence of galaxy properties becomes weak in high redshift bins, especially in the redshift range of z = 0.17 – 0.20 [28, 29, 33]. Deng et al. [29] argued that this is likely due to galaxies in the high redshift region being restricted in a fairly narrow high-luminosity region. Considering the tight correlation between other galaxy properties and luminosity, one can infer that the galaxy property difference in the high redshift region largely disappears, which results in the environmental dependence of these galaxy properties being greatly reduced.

The BOSS project of the Sloan Digital Sky Survey III (SDSS-III [38]) provide a valuable sample with intermediate redshifts for studies of galaxies. At z ≃ 0.4, one can divide the BOSS galaxy sample into "LOWZ" and "CMASS" samples. The LOWZ sample, a low redshift sample with a median redshift of z = 0.3, is a simple extension of the SDSS I and II LRG samples [37]. The CMASS sample is a nearly complete sample of massive galaxies above z ≃ 0.4, in which most galaxies are located at 0.43 < z < 0.7. Using the same statistical method as Deng [28], Deng [34] investigated the environmental dependence of stellar velocity dispersion in the CMASS sample of the Sloan Digital Sky Survey Data Release 9 (SDSS DR9) [1], and found that the stellar velocity dispersion of CMASS galaxies are very weakly correlated with local environment in all redshift bins. In fact, the strong environmental dependence of some galaxy properties in the local Universe cannot be extended to intermediate- and high-redshift regions. For example, galaxy colours strongly depend on environment in the local Universe [5, 8, 10, 11, 13, 17–20, 22–24, 51, 55, 73, 84]. However, some authors did not observe a strong environmental dependence of galaxy colours in intermediate- and high-redshift regions [15, 35, 47, 48].

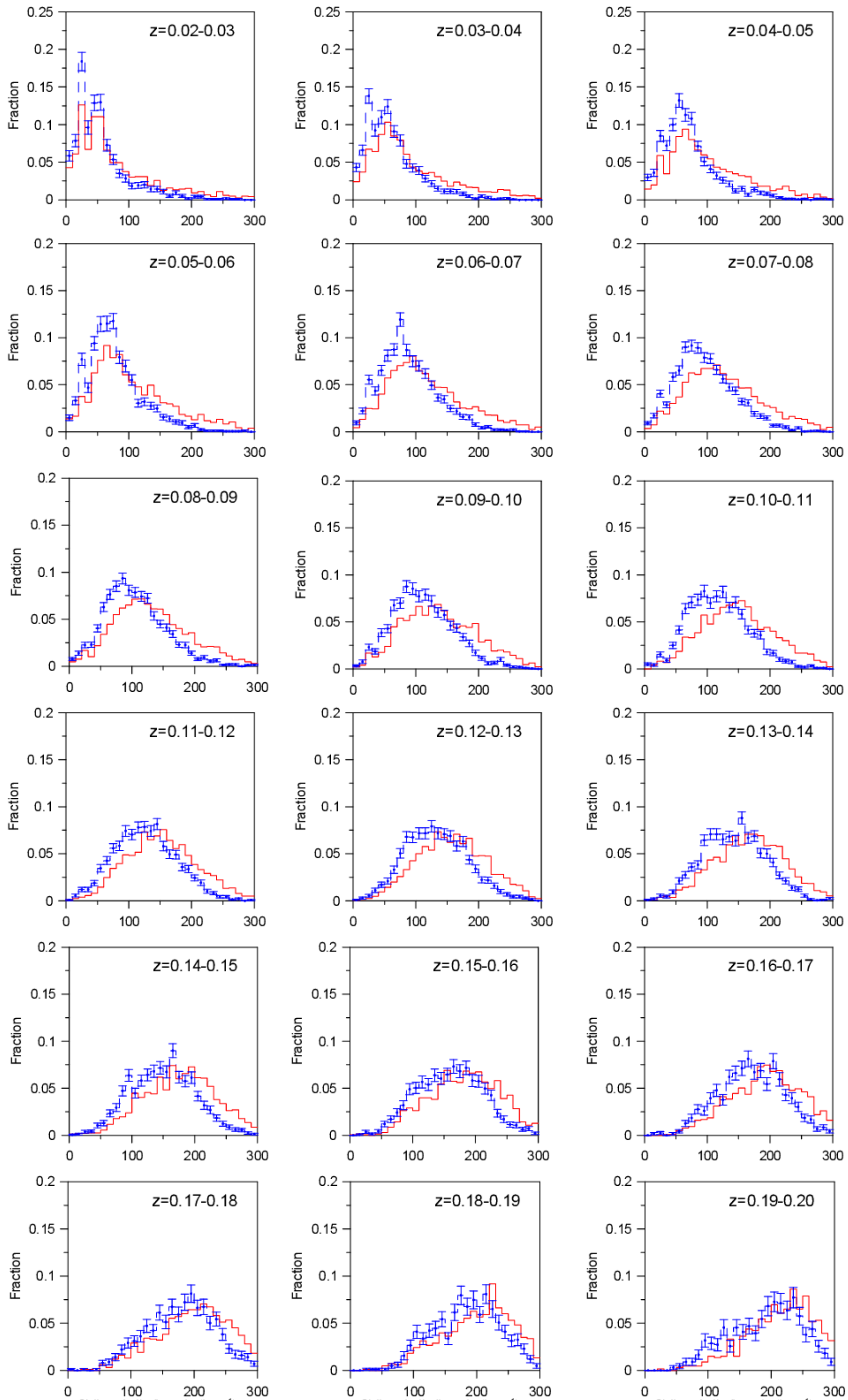

Figure 2: Stellar velocity dispersion distribution at both extremes of density in different redshift bins: red solid line for the sample at high density, blue dashed line for the sample at low density. The error bars of blue lines are 1 σ Poissonian errors. Error-bars of red lines are omitted for clarity.

Table 1: The Kolmogorov-Smirnov (KS) test probability that the two independent distributions in each redshift bin of Figure 2 are drawn from the same parent distribution.

Redshift bins	Galaxy number	**Projected local density range (Galaxies Mpc^{-2})**	P
0.02-0.03	23921	$1.12\times10^{-2} \longrightarrow 1.90\times10^{4}$	5.423e-16
0.03-0.04	29694	$1.27\times10^{-2} \longrightarrow 2.47\times10^{4}$	2.425e-27
0.04-0.05	32242	$1.34\times10^{-3} \longrightarrow 3.21\times10^{4}$	1.212e-38
0.05-0.06	36381	$2.61\times10^{-3} \longrightarrow 6.85\times10^{3}$	3.572e-38
0.06-0.07	46951	$3.31\times10^{-3} \longrightarrow 6.81\times10^{3}$	8.184e-43
0.07-0.08	57414	$2.01\times10^{-3} \longrightarrow 5.76\times10^{4}$	0
0.08-0.09	54994	$2.16\times10^{-3} \longrightarrow 2.42\times10^{4}$	0
0.09-0.10	44316	$1.46\times10^{-3} \longrightarrow 6.01\times10^{3}$	1.766e-41
0.10-0.11	44033	$9.18\times10^{-4} \longrightarrow 1.02\times10^{4}$	0
0.11-0.12	46890	$1.27\times10^{-3} \longrightarrow 4.01\times10^{3}$	2.803e-45
0.12-0.13	41224	$1.18\times10^{-3} \longrightarrow 1.31\times10^{4}$	2.960e-35
0.13-0.14	40729	$1.42\times10^{-3} \longrightarrow 4.27\times10^{3}$	2.198e-36
0.14-0.15	32660	$5.14\times10^{-4} \longrightarrow 1.32\times10^{3}$	4.829e-34
0.15-0.16	28188	$3.67\times10^{-4} \longrightarrow 1.89\times10^{2}$	2.436e-20
0.16-0.17	23868	$3.49\times10^{-4} \longrightarrow 4.28\times10^{2}$	7.026e-20
0.17-0.18	19895	$3.92\times10^{-4} \longrightarrow 3.06\times10^{2}$	1.925e-12
0.18-0.19	16582	$2.93\times10^{-4} \longrightarrow 1.93\times10^{2}$	3.363e-12
0.19-0.20	13190	$1.29\times10^{-4} \longrightarrow 70$	4.269e-09

Grützbauch et al. [47] also found a weak stellar mass dependence on the environment at intermediate redshifts and claimed that the weak colour-density relation at intermediate redshifts is due to a tight colour-stellar mass relation and a weak stellar mass-density relation. Grützbauch et al. [48] noted that the galaxy colours are tightly correlated with the stellar mass at redshifts up to $z \simeq 3$, and concluded that stellar mass exerts the most important influence on the galaxy colours, while the environment of galaxies likely has a minor influence but only at the densest environments. Grützbauch et al. [48] explained that the environmental processes that essentially change galaxy properties proceed slowly over cosmic time, and that some of the most influential dense environments may still be in the process of developing and cannot yet influence galaxy colours. Another possible explanation is that the galaxy sample selection also likely lead to completely different conclusions. Cooper et al. [14] observed a strong colour-density relation at z>1. Grützbauch et al. [47] indicated that such a strong colour-density relation obtained by Cooper et al. [14] might be partly caused by their sample selection. Cooper et al. [14] used a rest-frame B-band luminosity limited sample, while in stellar mass selected samples the colour difference becomes very small. Maybe the weak environmental dependence of stellar velocity dispersion in the CMASS sample is due to a similar reason? This question merits further study.

4 Summary

Two volume-limited samples with the luminosity $-20.5 \le M_r \le -18.5$ and $-22.5 \le M_r \le -20.5$ respectively, were constructed from the Main galaxy data of SDSS DR10. The environmental dependence of stellar velocity dispersion in these two volume-limited Main galaxy samples is examined. Statistical analyses in these two volume-limited Main galaxy samples can reach the same conclusion: galaxies with large stellar velocity dispersions exist preferentially in high density regimes, while galaxies with small stellar velocity dispersions are located preferentially in low density regions.

Considering drawbacks of volume-limited samples, the apparent-magnitude limited Main galaxy sample was also applied. Following Deng (2012), the Main galaxy sample of the SDSS DR10 is divided into subsamples with a redshift binning size of $\Delta z = 0.01$, then the environmental dependence of stellar velocity dispersion of subsamples in each redshift bin is analyzed. As shown by Figure 2 and Table 1, the stellar velocity dispersion of Main galaxies strongly depends on the local environment in nearly all redshift bins. Apparently, the result of this work is inconsistent with that obtained at intermediate redshifts.

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