# А С Т Р О Ф И З И К А

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# ENVIRONMENTAL DEPENDENCE OF ALL THE FIVE BAND LUMINOSITIES OF ACTIVE GALACTIC NUCLEUS (AGN) HOST GALAXIES


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Using the apparent-magnitude limited active galactic nucleus (AGN) host galaxy sample of the Sloan Digital Sky Survey Data Release 12 (SDSS DR12), we investigate the environmental dependence of $u$-, $g$-, $r$-, $i$- and $z$ -band luminosities of AGN host galaxies. We divide the whole apparent-magnitude limited AGN sample into many subsamples with redshift binning size $\Delta z = 0.01$, and analyse the environmental dependence of all the five band luminosities of subsamples in each redshift bin. It turns out that overall, all the five band luminosities of AGN host galaxies are weakly correlated with the local environment.



Keywords: *galaxies: fundamental parameters - galaxies: statistics*


1. *Introduction.* In the last several decades, the study of active galactic nuclei (AGNs) has been an important subject in the galaxy field [1-8]. Dressler et al. [1] and Miller et al. [2] examined the local environmental dependence of the presence of active galactic nuclei (AGNs). Using two volume-limited main galaxy samples of the SDSS, Deng et al. [3] explored the environmental dependence of the star formation rate (SFR), specific star formation rate (SSFR), and the presence of AGNs for high stellar mass (HSM) and low stellar mass (LSM) galaxies. Komiya et al. [4] showed results of the cross-correlation analysis between AGNs and galaxies at redshift 0.1-1. Davies et al. [5] found that the fraction of these AGN in S0 host galaxies decreases strongly as a function of galaxy group size (halo mass) - which contrasts with the increasing fraction of galaxies of S0 type in denser environments. Bornancini &García Lambas [6] observed different properties of host galaxies of distinct AGNs: Type 1 AGNs reside in blue, star-forming and less massive host galaxies compared to Type 2. Koulouridis & Bartalucci [7] studied the distribution of X-ray detected AGNs in the five most massive and distant galaxy clusters in the Planck and South Pole Telescope (SPT) surveys. Liu et al. [8] presented a new, complete sample of 14,584 broad-line active galactic nuclei (AGNs) at $z < 0.35$.

Galaxy luminosities strongly depend on the environment (e.g., [9-12]). Park et al. [9] claimed that high-density regions preferentially include bright galaxies, low density regions tend to harbor only faint galaxies. Blanton et al. [10] reported that local density is a strong function of luminosity: the most luminous galaxies tend to reside in the densest regions of the universe. Blanton et al. [11] demonstrated that galaxy color and luminosity jointly comprise a pair of properties most predictive of the local environment. Zandivarez et al. [12] computed the luminosity function for several subsamples of galaxies in groups, and observed that the characteristic magnitude is $\approx 0.5$ magnitudes brighter than those obtained for field galaxies. The above-mentioned conclusion is consistent with hierarchical models of galaxy formation which predict that bright galaxies should be more strongly clustered than faint galaxies (e.g., White et al. [13]; Kauffmann et al. [14]).

However, the environmental dependence of luminosity is rather complicated. For example, Norberg et al. [15] showed that the clustering amplitude increases slowly with absolute magnitude for galaxies fainter than $M^*_{bJ} - 5\log_{10} h = -19.7$ (Folkes et al. [16]), but rises more strongly at higher luminosities. Deng et al. [17] demonstrated that the galaxy luminosity strongly depend on local environments only for galaxies above the value of $M^*_r \approx -20.5$ found for the overall Schechter fit to the galaxy luminosity function (Ball et al. [18]), but this dependence is very weak for galaxies below the value of $M^*_r$. Applying different statistical methods, Deng & Zou [19] and Deng [20] explored the environmental dependence of *u*-, *g*-, *r*-, *i*- and $z$-band luminosities in the Main galaxy sample (Strauss et al. [21]) of the SDSS, and demonstrated that the environmental dependence of galaxy luminosities does not follow a single trend for different bands. They paid special attention to the abnormal environmental dependence of *u*-band luminosity: luminous galaxies in the *u*-band exist preferentially in low density regions, while faint galaxies in the *u*-band are located preferentially in high density regions.

The primary goal of this study is to explore the environmental dependence of *u*-, *g*-, *r*-, *i*- and $z$-band luminosities of active galactic nucleus (AGN) host galaxies. The outline of this paper is as follows. In Section 2, we describe the AGN host galaxy sample. We present statistical result in Section 3. Our main results and conclusions are summarize in Section 4.

In calculating the distance, we used 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 $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

2. *Data*. Data Release 12 (DR12) (Alam et al. [22]) of the SDSS is the final public release of spectroscopic data from the SDSS-III BOSS. In this work, the data of the Main galaxy sample [21] was downloaded from the Catalog Archive Server of SDSS Data Release 12 [22] by the SDSS SQL Search (with SDSS flag: LEGACY_TARGET1 & $(64|128|256) > 0$). We extract 631968 Main galaxies

with the spectroscopic redshift $0.02 \le z \le 0.2$.

The galSpecExtra table contains estimated parameters for all galaxies in the MPA-JHU spectroscopic catalogue. BPT classification in this table is based on the methodology of Brinchmann et al. [23]:

**All**. The set of all galaxies in the sample regardless of the S/N of their emission lines.

**SF**. The star-forming galaxies. These are the galaxies with $S/N > 3$ in all four BPT lines that lie below lower line in Fig.1 of Brinchmann et al. [23]. This lower line is taken from equation (1) of Kauffmann et al. [24].

**C**. The composite galaxies. They are the objects with $S/N > 3$ in all four BPT lines that are between the upper and lower lines in Fig.1 of Brinchmann et al. [23]. The upper line has been taken from equation (5) of Kewley et al. [25].

**AGN**. The AGN population consists of the galaxies above the upper line in Fig.1 of Brinchmann et al. [23]. This line corresponds to the theoretical upper limit for pure starburst models.

**Low S/N AGNs**. They have $[\mathrm{NII}]6584/\mathrm{H}\alpha > 0.6$ (and $S/N > 3$ in both lines) (e.g. Kauffmann et al. [24]), and still are classified as an AGN even if their [OIII] 5007 and/or $\mathrm{H}\beta$ have too low S/N. Miller et al. [2] called such AGNs the "two-line AGNs".

**Low S/N SF**. The remaining galaxies with $S/N > 2$ in $\mathrm{H}\alpha$ are considered low S/N star formers.

**Unclassifiable**. Those remaining galaxies that are impossible to classify using the BPT diagram. This class is mostly made up of galaxies with no or very weak emission lines.

Deng & Wen [26] selected C, AGN and Low S/N AGN populations and constructed an apparent magnitude-limited AGN sample which contains 122923 AGN host galaxies. In this work, we use this AGN sample.

3. *Statistical results*. Following [20], we measure the projected local density $\Sigma_5 = N/\pi d_5^2$ (Galaxies $\mathrm{Mpc}^{-2}$), where $d_5$ is the distance to the 5th nearest neighbor within $\pm 1000\,\mathrm{km\,s^{-1}}$ in redshift (e.g., [27-29]) and divide this AGN sample into subsamples with a redshift binning size of $\Delta z = 0.01$. In each subsample, we 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 $u$-, $g$-, $r$-, $i$- and $z$-band luminosities of AGN host galaxies in the lowest density regime with those in the densest regime.

Fig.1-5 show $u$-, $g$-, $r$-, $i$- and $z$-band absolute magnitude distributions at both extremes of density in different redshift bins for the apparent magnitude-limited AGN sample. As seen form these figures, overall, all the five band luminosities of AGN host galaxies are weakly correlated with the local environment.

We further perform the Kolmogorov-Smirnov (KS) test which can show the degree of similarity or difference between two independent distributions in a figure 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 lower probability value indicates that the two distributions are less likely to be similar. The probability of the two distributions coming from the same parent distribution is listed in Table 1, which is much larger than that obtained by Deng (see Table 1 of [20]) and even is much larger than 0.05 (5%, is the standard in a statistical analysis). Such a result shows that two independent distributions in these two figures are very similar. This is in good agreement with the conclusion obtained by the histogram figures.

The redshift ranges of the AGN sample in this work is the same as one of the apparent-magnitude limited Main galaxy sample of the SDSS used by Deng [20]. Using the same method, Deng [20] investigated the environmental dependence of $u$-, $g$-, $r$-, $i$- and $z$-band luminosities in all redshift bins of the apparent-magnitude limited Main galaxy sample. It was found that overall, all the five band luminosities apparently correlate with the local environment. For $r$, $i$ and $z$ bands, luminous galaxies exist preferentially in the densest regions of the

*Table 1*

KS PROBABILITIES OF ALL THE FIVE BAND LUMINOSITIES THAT TWO SAMPLES AT BOTH EXTREMES OF DENSITY ARE DRAWN FROM THE SAME DISTRIBUTION

| Redshift bins | Galaxy number | P($u$-band) | P($g$-band) | P($r$-band) | P($i$-band) | P($z$-band) |
|---|---|---|---|---|---|---|
| 0.02-0.03 | 3433 | 0.512 | 0.353 | 0.287 | 0.353 | 0.287 |
| 0.03-0.04 | 5105 | 0.239 | 0.683 | 0.683 | 0.464 | 0.464 |
| 0.04-0.05 | 6281 | 0.411 | 0.908 | 0.600 | 0.600 | 0.156 |
| 0.05-0.06 | 7757 | 0.385 | 0.385 | 0.096 | 0.0452 | 0.0550 |
| 0.06-0.07 | 10503 | 0.876 | 0.310 | 0.0472 | 0.0192 | 0.00873 |
| 0.07-0.08 | 13062 | 0.00619 | 5.840e-05 | 6.671e-07 | 4.913e-07 | 3.607e-07 |
| 0.08-0.09 | 12860 | 0.0820 | 0.840 | 0.661 | 0.567 | 0.357 |
| 0.09-0.10 | 9824 | 0.0113 | 0.0859 | 0.309 | 0.392 | 0.183 |
| 0.10-0.11 | 8186 | 0.702 | 0.156 | 0.0305 | 0.0103 | 0.00184 |
| 0.11-0.12 | 9109 | 0.203 | 0.487 | 0.981 | 0.903 | 0.389 |
| 0.12-0.13 | 8136 | 0.210 | 0.580 | 0.813 | 0.863 | 0.322 |
| 0.13-0.14 | 7650 | 2.838e-07 | 1.400e-06 | 0.0146 | 0.0525 | 0.330 |
| 0.14-0.15 | 6412 | 0.00734 | 0.00425 | 0.114 | 0.319 | 0.370 |
| 0.15-0.16 | 4787 | 0.00776 | 0.00411 | 0.0545 | 0.0695 | 0.251 |
| 0.16-0.17 | 3445 | 0.782 | 0.0476 | 0.782 | 0.782 | 0.693 |
| 0.17-0.18 | 2710 | 0.222 | 0.129 | 0.543 | 0.645 | 0.748 |
| 0.18-0.19 | 2190 | 0.619 | 0.0666 | 0.506 | 0.734 | 0.840 |
| 0.19-0.20 | 1473 | 0.616 | 0.879 | 0.879 | 0.994 | 0.879 |

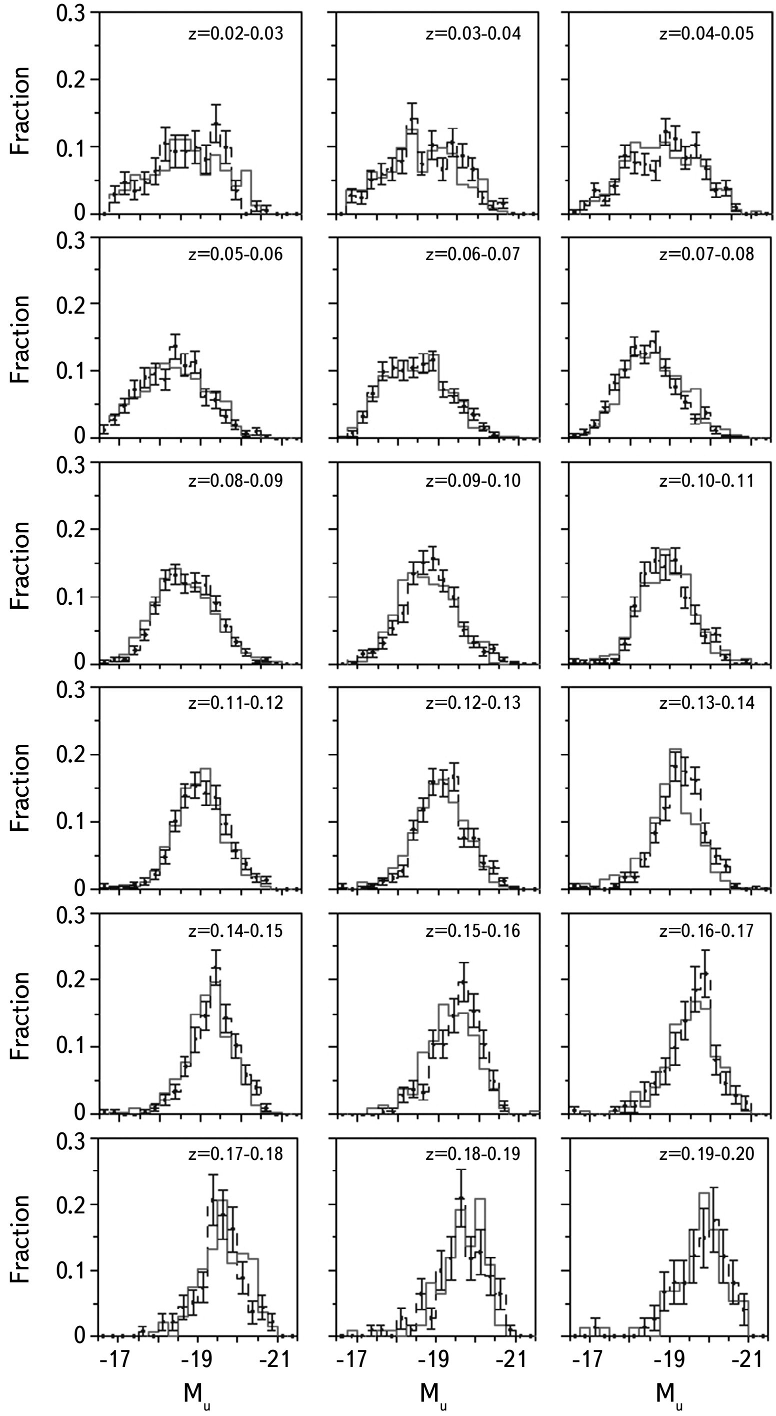


Fig.1. $u$-band absolute magnitude distribution at both extremes of density in different redshift bins: solid line for the sample at high density, dashed line for the sample at low density. The error bars of dashed lines are $1\sigma$ Poissonian errors. Error-bars of solid lines are omitted for clarity.

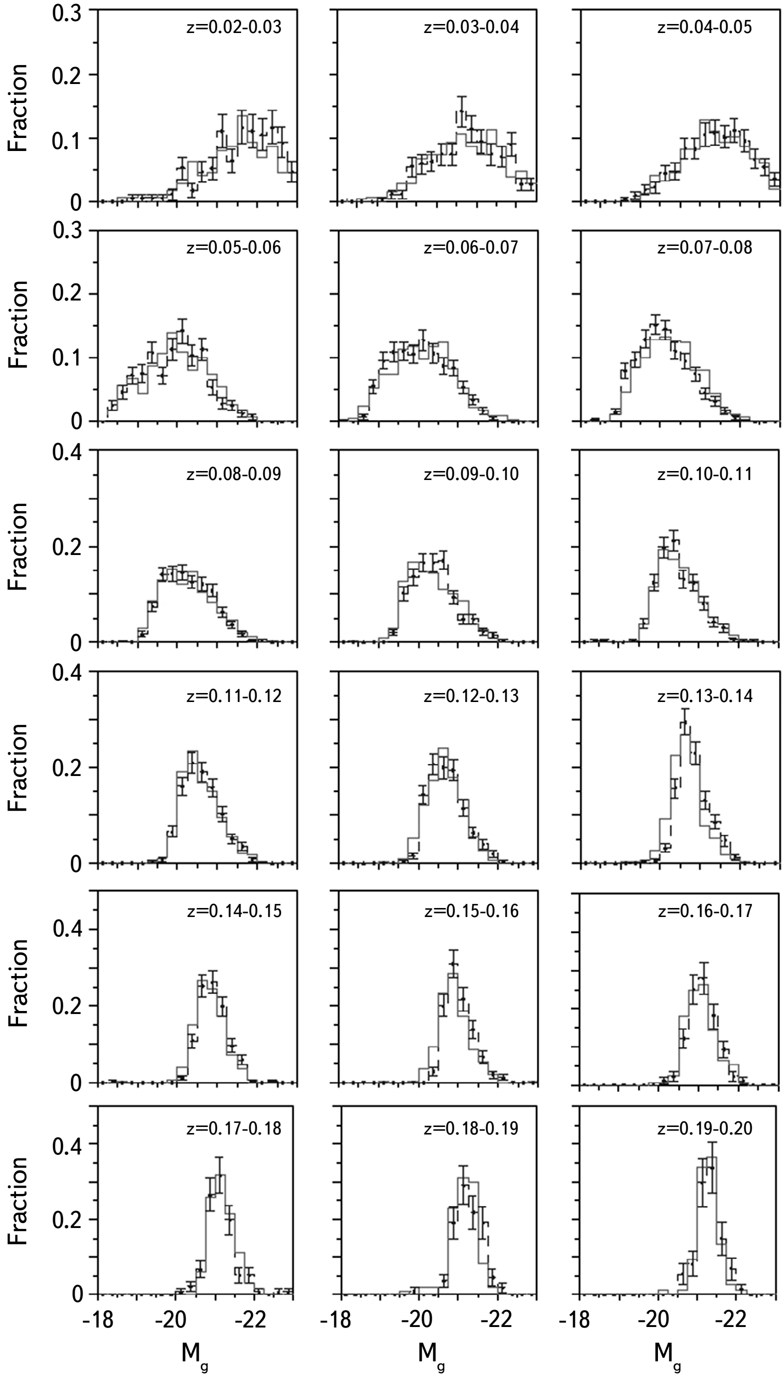


Fig.2. As Fig.1 but for *g*-band absolute magnitude distribution at both extremes of density in different redshift bins.

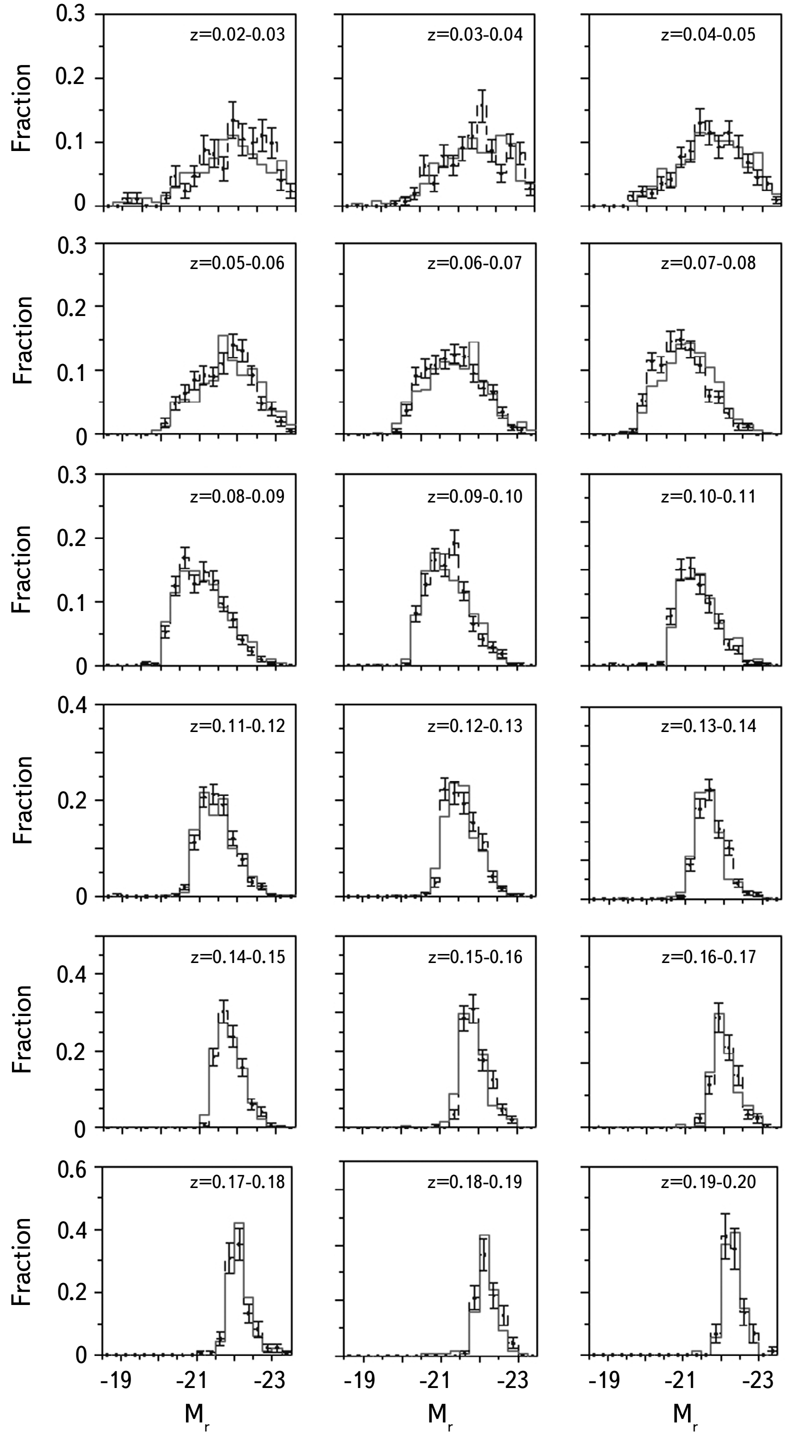


Fig.3. As Fig.1 but for *r*-band absolute magnitude distribution at both extremes of density in different redshift bins.

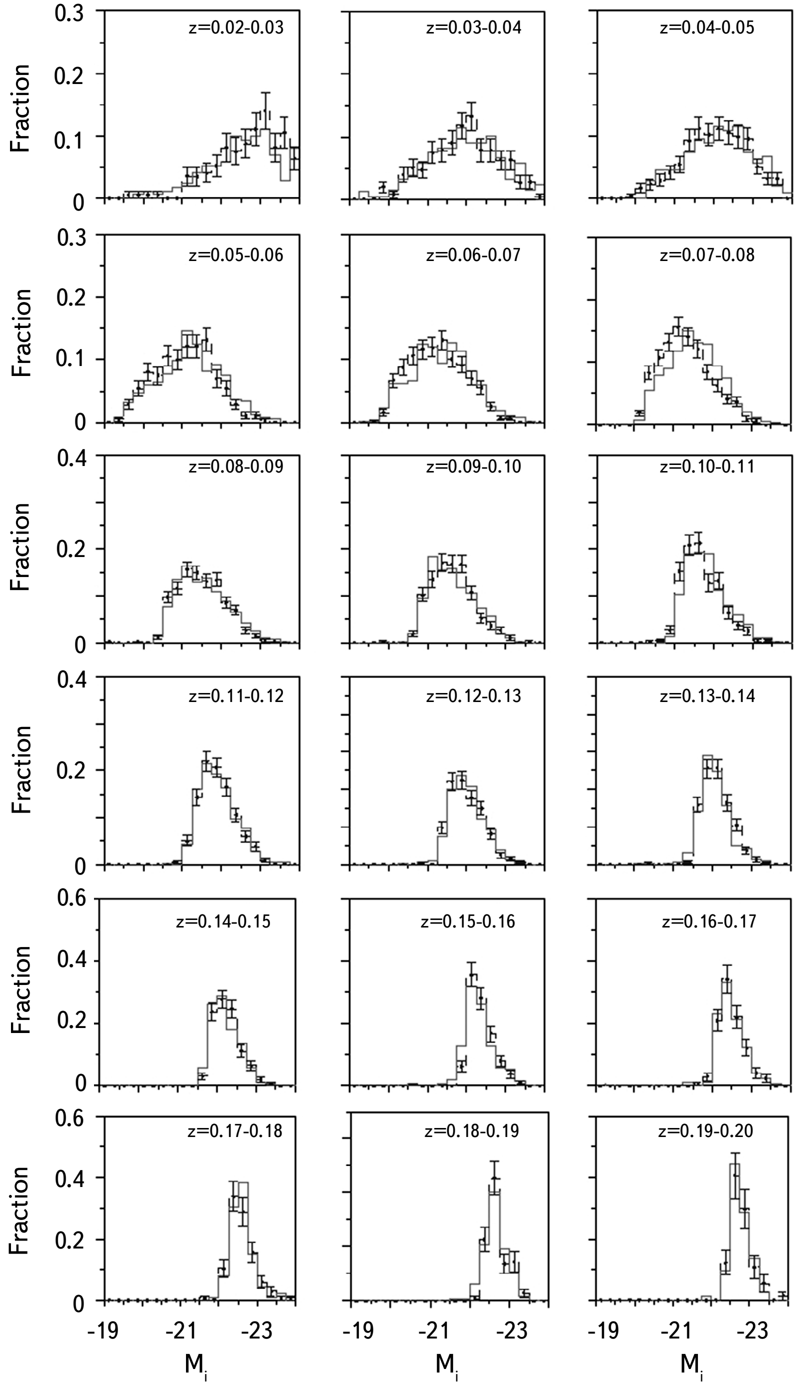


Fig.4. As Fig.1 but for *i*-band absolute magnitude distribution at both extremes of density in different redshift bins.

universe, while faint galaxies are located preferentially in low density regions, which is consistent with the conclusion obtained by Deng & Zou [19]. Deng [20]

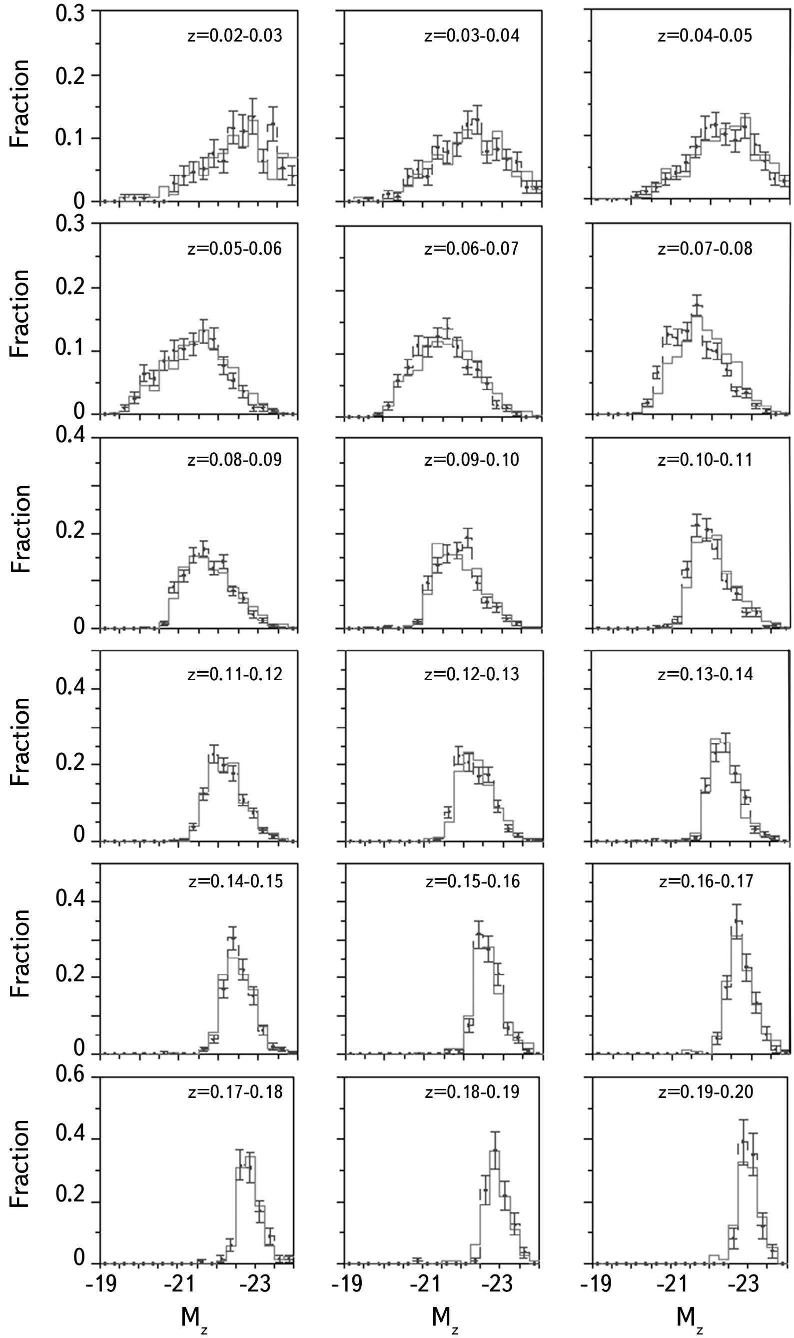


Fig.5. As Fig.1 but for $z$ -band absolute magnitude distribution at both extremes of density in different redshift bins.

also observed that the environmental dependence of all the five band luminosities nearly are the strongest in the redshift bin $0.07 \le z \le 0.08$, in which a super-large-scale structure exists (Gott et al. [30]; Deng et al. [31]). It is noteworthy that luminous galaxies in $M_u$ (the $u$-band absolute magnitude) exist preferentially in low density regions of the universe, while faint galaxies in $M_u$ are located preferentially in high density regions, especially in the redshift range $0.05 \le z \le 0.10$, which is opposite to widely accepted conclusion.

In faint volume-limited Main galaxy sample, galaxy age still strongly depend on environment [32], but in the faint volume-limited AGN host galaxy sample, the environmental dependence of the age is fairly weak (Deng & Wen [26]). Zheng et al. [33] analysed the stellar age and metallicity distributions for 1105 galaxies on the SDSS-IV MaNGA (Mapping Nearby Galaxies at APO) (Bundy et al. [34]) integral field spectra, and also observed that the galaxy age depends on local density. Thus, Deng & Wen [26] believed that the environmental dependence of the age of AGN host galaxies is likely different from the one of genenal galaxies. Here, we again note that the environmental dependence of all the five band luminosities of AGN host galaxies is different from the one of genenal galaxies.

4. *Summary*. In this study, we use the apparent-magnitude limited AGN sample of the SDSS DR12 [21] which contains 122923 AGN host galaxies and investigate the environmental dependence of $u$-, $g$-, $r$-, $i$- and $z$-band luminosities of active galactic nucleus (AGN) host galaxies. Following Deng [20], we divide the whole apparent-magnitude limited AGN sample into many subsamples with redshift binning size $\Delta z = 0.01$, and analyse the environmental dependence of all the five band luminosities of subsamples in each redshift bin. As shown by Figs.1-5, overall, all the five band luminosities of AGN host galaxies are weakly correlated with the local environment. We also perform the Kolmogorov-Smirnov (KS) test. Statistical result is in good agreement with the conclusion obtained by the histogram figures.

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# ЗАВИСИМОСТЬ СВЕТИМОСТЕЙ РОДИТЕЛЬСКИХ ГАЛАКТИК AGN В ПЯТИ ПОЛОСАХ ОТ ОКРУЖАЮЩЕЙ СРЕДЫ

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Используя выборку родительских галактик AGN с ограниченной видимой величиной из Sloan Digital Sky Survey Data Release 12 (SDSS DR12), мы исследовали зависимость светимостей в $u$, $g$, $r$, $i$ и $z$ полосах от окружающей среды родительских галактик AGN. Мы разделили всю выборку AGN с ограниченной видимой величиной на множество подвыборок с размером биннинга красного смещения $\Delta z = 0.01$ и анализировали зависимость светимостей в пяти полосах от окружающей среды для подвыборок в каждой ячейке красного смещения. Оказалось, что для всех пяти полос светимости родительских галактик AGN слабо коррелируют с местным окружением.

Ключевые слова: *галактики: фундаментальные параметры - галактики: статистика*

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