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THE ENVIRONMENTAL DEPENDENCE OF THE STELLAR VELOCITY DISPERSION OF ACTIVE GALACTIC NUCLEUS (AGN) HOST GALAXIES AND DEPENDENCE OF THE CLUSTERING PROPERTIES OF AGN HOST GALAXIES ON THE STELLAR VELOCITY DISPERSION

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We use two volume-limited active galactic nucleus (AGN) host galaxy samples constructed by Deng & Wen [47], and explore the environmental dependence of the stellar velocity dispersion in these two volume-limited AGN host galaxy samples. In the luminous volume-limited AGN host galaxy sample, the stellar velocity dispersion of AGN host galaxies apparently depends on local environments: AGN host galaxies with large stellar velocity dispersion exist preferentially in high density regime, while AGN host galaxies with small stellar velocity dispersion are located preferentially in low density regions. But in the faint volume-limited AGN host galaxy sample, this dependence is fairly weak. We also examine the dependence of the clustering properties of AGN host galaxies on the stellar velocity dispersion by cluster analysis, and find that in the luminous volume-limited AGN host galaxy sample, AGN host galaxies with small stellar velocity dispersion preferentially form isolated galaxies, close pairs and small groups, while AGN host galaxies with large stellar velocity dispersion preferentially inhabit the dense groups and clusters. In the faint volume-limited AGN host galaxy sample, although the fraction of isolated galaxies with small stellar velocity dispersion is apparently higher than the one with large stellar velocity dispersion, the trend in the luminous volume-limited sample is very difficultly observed. This likely is due to the galaxy number of the faint volume-limited AGN host galaxy sample being too small to ensure an ideal statistical analysis.

Keywords: *cosmology: large-scale structure of universe - galaxies: fundamental parameters*

1. *Introduction*. In the last several decades, the study of active galactic nuclei (AGNs) has been a very important issue of astrophysics [1-8]. Dressler et al. [1] and Miller et al. [2] examined the local environmental dependence of the presence of active galactic nuclei (AGNs). Krumpe et al. [3] measured the clustering amplitudes of both X-ray-selected and optically selected SDSS broad-line AGNs. Krumpe et al. [4] explored the cause of the X-ray luminosity dependence of the clustering of broad-line, luminous AGNs at $0.16 \le z \le 0.36$. In anticipation of upcoming wide-field X-ray surveys that will allow quantitative analysis of AGN environments, Ballantyne [5] presented a method to observationally constrain the conditional luminosity function (CLF) of AGN at a specific z. By investigating

2727 galaxies observed by MaNGA, Wylezalek et al. [6] developed spatially resolved techniques for identifying signatures of AGNs. Zou et al. [7] confirmed the prediction of the unified model of AGNs. Koulouridis & Bartalucci [8] 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.

It has been known for a long time that many galaxy parameters strongly depend on local environments [9-20]. For example, Blanton et al. [13] observed that local density is a strong function of luminosity: the most luminous galaxies tend to reside in the densest regions of the universe. Kauffmann et al. [17] reported that the stellar mass distribution of galaxies shifts by almost a factor of two towards higher masses between low and high density regions. Blanton et al. [14] argued that galaxy color is the galaxy property most predictive of the local environment. Some authors found that there is a close correlation between stellar velocity dispersion and masses of supermassive black holes (BHs) at galaxy centers [21-28], which showed that stellar velocity dispersion also is a fairly important galaxy parameter. In the Main galaxy sample [29] of the SDSS DR10 [30], Deng [31] found that the stellar velocity dispersion of galaxies strongly depends on their local environments: galaxies with large stellar velocity dispersion tend to reside in the dense regions of the universe, whereas galaxies with small stellar velocity dispersion tend to reside in low-density regions.

As is well-known, the clustering properties of galaxies depend on various galaxy parameters [9,11,12,18,32-41]. For example, Norberg et al. [11,33] demonstrated that the clustering amplitude of the correlation function of galaxies increases with absolute magnitude. Zehavi et al. [12] examined $u-r$ color dependence of galaxy clustering, and showed that the red galaxies exhibit a stronger and steeper real-space correlation function than do the blue galaxies. Li et al. [18] studied the two-points correlation function as a function of stellar mass and found that more-massive galaxies cluster more strongly than less-massive galaxies. Deng et al. [41] investigated the dependence of the clustering properties of the SDSS Main galaxies [29] on stellar velocity dispersion by cluster analysis [42]. It was found that in the luminous volume-limited Main galaxy sample, except at $r=1.2$, richer and larger systems can be more easily formed in the large stellar velocity dispersion subsample, while in the faint volume-limited Main galaxy sample, at $r \geq 0.9$, an opposite trend is observed. According to statistical analyses of the multiplicity functions, Deng et al. [41] concluded in two volume-limited Main galaxy samples: small stellar velocity dispersion galaxies preferentially form isolated galaxies, close pairs and small groups, while large stellar velocity dispersion galaxies preferentially inhabit the dense groups and clusters. However, Deng et al. [41] also noted the difference between two volume-limited Main galaxy samples: in the faint volume-limited Main galaxy sample, at $r \geq 0.9$, the small stellar velocity dispersion subsample has a higher proportion of galaxies in superclusters ($n \geq 200$) than the large stellar velocity dispersion subsample.

The primary goal of this study is to explore the environmental dependence of the stellar velocity dispersion for the AGN host galaxy samples, and examine the dependence of the clustering properties of AGN host galaxies on the stellar velocity dispersion. The outline of this paper is as follows. In Section 2, we describe the AGN host galaxy samples. We present statistical results in Section 3 and Section 4. Our main results and conclusions are summarized in Section 5.

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 $H_0 = 70$ km s^{-1} Mpc^{-1}.

2. *Data*. Data Release 12 (DR12) [43] 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 [29] was downloaded from the Catalog Archive Server of SDSS Data Release 12 [43] by the SDSS SQL Search (with SDSS flag: LEGACY_TARGET1 & (64|128|256) > 0). We extract 631968 Main galaxies with the spectroscopic redshift $0.02 \leq z \leq 0.2$. The data set of stellar velocity dispersion measurements was downloaded from the EmissionlinesPort table.

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. [44]:

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 the lower line in Fig.1 of Brinchmann et al. [44]. This lower line is taken from equation (1) of Kauffmann et al. [45].

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. [44]. The upper line has been taken from equation (5) of Kewley et al. [46].

AGN. The AGN population consists of the galaxies above the upper line in Fig.1 of Brinchmann et al. [44]. This line corresponds to the theoretical upper limit for pure starburst models.

Low S/N AGNs. They have [NII] 6584/H$\alpha > 0.6$ (and S/N > 3 in both lines) [45], and still are classified as an AGN even if their [OIII]5007 and/or Hβ 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 Hα 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.

In this work, we use the volume-limited AGN host galaxy samples of Deng & Wen [47]. Deng & Wen [47] selected C, AGN and Low S/N AGN populations and constructed an apparent magnitude-limited AGN sample which contains 122923 AGN host galaxies. When constructing volume-limited samples, Deng & Wen [47] used the K-correction formula of Park et al. [48]: $K(z)=2.3537(z-0.1)^2+$ $+1.04423(z-0.1)-2.5\log(1+0.1)$. The luminous volume-limited AGN host galaxy sample is constructed by selecting 39373 AGN host galaxies with the r-band absolute magnitudes $-22.5 \le M_r \le -20.5$, in the redshift range $0.05 \le z \le 0.102$; the faint volume-limited AGN host galaxy sample is constructed by selecting 5148 AGN host galaxies with $-20.5 \le M_r \le -18.5$ and $0.02 \le z \le 0.0436$.

3. *Environmental dependence of the stellar velocity dispersion of AGN host galaxies.* Like Deng [49] did, we measure the local three-dimensional galaxy density (Galaxies Mpc^{-3}) which is defined as the number of galaxies ($N=5$) within the three-dimensional distance to the 5th nearest galaxy to the volume of the sphere with the radius of this distance. For each sample, we arrange galaxies in a density order from the smallest to the largest, select approximately 5% of the galaxies, construct two subsamples at both extremes of density according to the density, and compare the distribution of the stellar velocity dispersion in the lowest density regime with that in the densest regime.

Fig.1 shows the stellar velocity dispersion distribution at both extremes of density for the faint (left panel) and luminous (right panel) volume-limited AGN host galaxy samples. As shown by this figure, in the luminous volume-limited AGN host galaxy sample, the stellar velocity dispersion of galaxies apparently

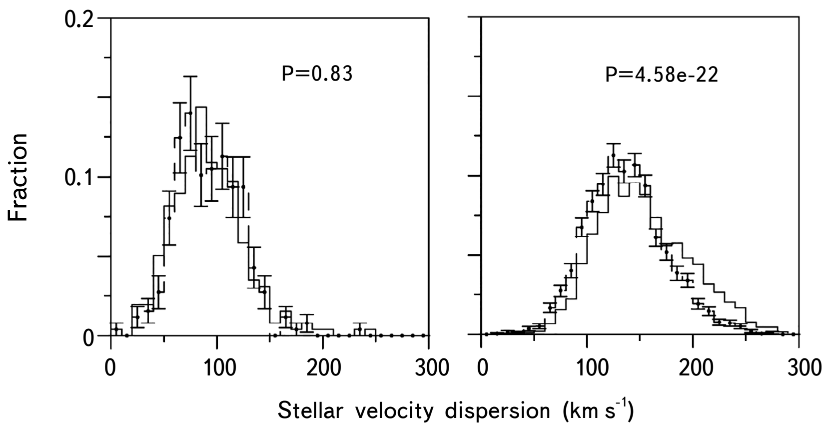

Fig.1. Stellar velocity dispersion distribution at both extremes of density for the faint (left panel) and luminous (right panel) volume-limited AGN host galaxy samples: solid line represents the subsample at high density, dashed line represents the subsample at low density. The error bars of the dashed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

depends on local environments: AGN host galaxies with large stellar velocity dispersion exist preferentially in high-density regime, while AGN host galaxies with small stellar velocity dispersion are located preferentially in low-density regions. But in the faint volume-limited AGN host galaxy sample, the environmental dependence of the stellar velocity dispersion of AGN host galaxies is fairly weak.

We also conduct the Kolmogorov-Smirnov (K-S) test, which can examine the measure of similarity or dissimilarity of two independent distributions 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 at the right upper corner of each figure. K-S probability of the left panel in Fig.1 is 0.83, which even is much larger than 0.05 (5% is the standard in a statistical analysis), while K-S probability of the right panel in Fig.1 only is 4.58e-22. Apparently, such an result is in good agreement with the conclusion obtained by the step figure.

To examine the environmental dependence of stellar velocity dispersion in the local universe, Deng [31] constructed two volume-limited Main galaxy samples with the same redshift and luminosity ranges as ones of two volume-limited AGN host galaxy samples used in this work, and got the same conclusion in two volume-limited Main galaxy samples: the stellar velocity dispersion of galaxies strongly depends on local environments. Similarly, Deng [50] demonstrated strong environmental dependence of galaxy age in two volume-limited Main galaxy samples, but Deng & Wen [47] reported that in the faint volume-limited AGN host galaxy sample, the environmental dependence of the age is fairly weak. Zheng et al. [51] presented the stellar age and metallicity distributions for 1105 galaxies on the SDSS-IV MaNGA (Mapping Nearby Galaxies at APO) [52] integral field spectra, and also found that the galaxy age depends on local density. Thus, Deng & Wen [47] believed that the environmental dependence of the age of AGN host galaxies is likely different from the one of general galaxies, which merits further studies.

Deng et al. [53] demonstrated that the galaxy luminosity strongly depends on local environments only for galaxies above the value $M_r^* \approx -20.5$ found for the overall Schechter fit to the galaxy luminosity function [54], but this dependence is very weak for galaxies below the value M_r^*. Deng & Wen [47] also showed that M_r^* is an important characteristic parameter for the environmental dependence of the age of AGN host galaxies. In this work, we again note that the environmental dependence of the stellar velocity dispersion of AGN host galaxies is fairly different between galaxies above and below the value M_r^*.

4. *Dependence of the clustering properties of AGN host galaxies on the stellar velocity dispersion*. Following Deng & Wen [47], we use cluster analysis [42] to explore the dependence of the clustering properties of AGN host galaxies on the stellar velocity dispersion. The key step of the cluster analysis is how to select a neighbourhood radius *r* for identifying various systems of objects. By such a method, the galaxy sample can be separated into galaxy systems of different sizes and density contrast, such as isolated galaxies, galaxy pairs, galaxy groups or clusters and superclusters. This approach was used by some authors to explore superclusters [42,55-57] and compiled catalogs of galaxy groups [e.g., 58,59].

It is important to keep in mind that when performing comparative studies of clustering properties between two subsamples with different number densities by cluster analysis, richer and larger systems can be more easily found in a subsample with larger number densities. Deng et al. [60] claimed that although dimensionless radii are used to express distances, this replacement can not completely correct such a bias. Considering this factor, when exploring the clustering properties of galaxies on galaxy parameters by cluster analysis, the volume-limited galaxy samples often be divided into two subsamples with nearly same number density of galaxies by an galaxy parameter [e.g., 41,47]. Thus, the influence of the difference of the number density between two subsamples on statistical conclusion is completely removed. In this work, to investigate the dependence of the clustering properties of AGN host galaxies on the stellar velocity dispersion, we also divide each volume-limited AGN host galaxy sample into two subsamples: large stellar velocity dispersion and small stellar velocity dispersion, and then perform comparisons between them. Table 1 lists some parameters of the subsamples. The stellar velocity dispersion thresholds in each volume-limited AGN host galaxy sample are selected for ensuring that the number density of the two subsamples must be nearly the same.

Table1

THE NUMBER OF GALAXIES IN THE TWO SUBSAMPLES OF EACH VOLUME-LIMITED AGN HOST GALAXY SAMPLE

Sample	Subsamples	Number of galaxies	Poisson radius R_0 (Mpc)
Luminous volume-limited AGN host galaxy sample	Large stellar velocity dispersion (≥ 140 km/s)	19701	8.766
	Small stellar velocity dispersion (<140 km/s)	19672	8.770
Faint volume-limited AGN host galaxy sample	Large stellar velocity dispersion (≥ 90 km/s)	2568	7.561
	Small stellar velocity dispersion (<90 km/s)	2580	7.549

The Poisson radius is the one of the spheres with unit population, and is defined as $R_0 = [3V/4\pi N]^{1/3}$, where N and V are the number of galaxies in the sample and the volume of the sample, respectively. Following Deng & Wen [47], the neighborhood radius is expressed in dimensionless units, $r = R/R_0$. Table 1 lists the Poisson radius (comoving distance) of each subsample. For the cluster analysis, it is difficult to define a proper neighborhood radius for the identification of galaxy systems. Here, we work with the dimensionless radii range of $r = 0.5 \rightarrow r = 1.3$, as Deng & Wen [47] did.

The multiplicity functions, giving the fraction of the galaxies in systems with membership between n and $n + dn$, can describe the distribution of galaxy systems

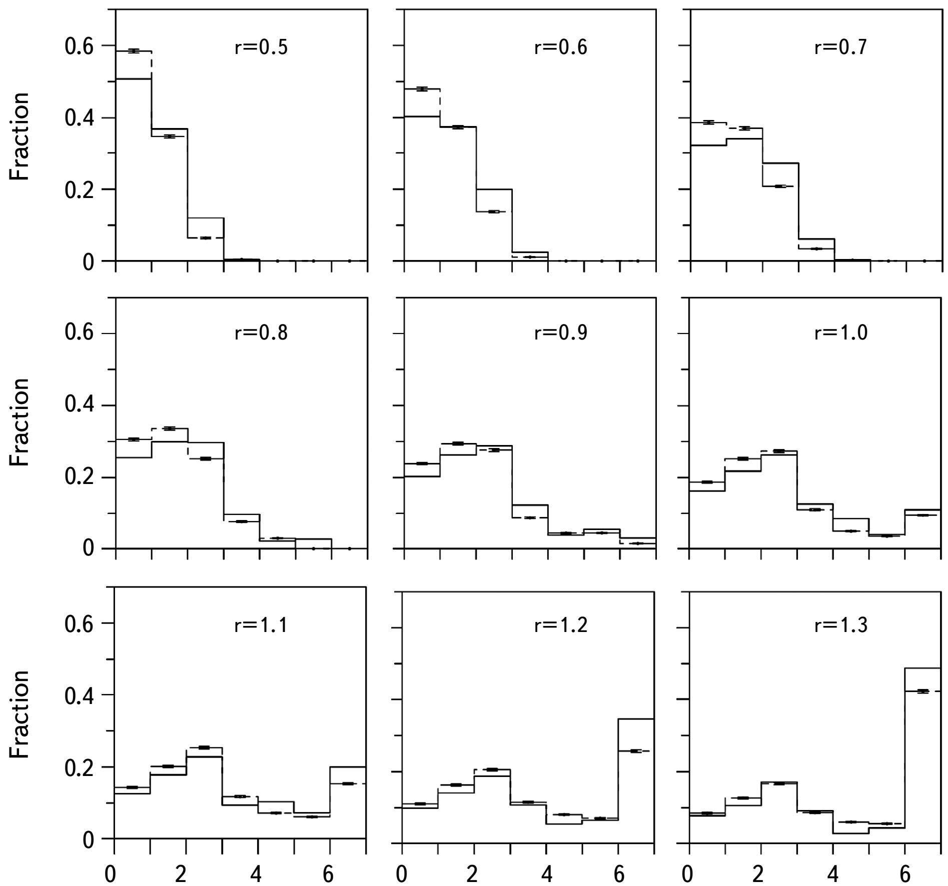

Fig.2. Histograms of the multiplicity functions for large stellar velocity dispersion (solid line) and small stellar velocity dispersion (dashed line) AGN host galaxies in the luminous volume-limited AGN host galaxy sample for dimensionless radii ranging from $r = 0.5$ to $r = 1.3$. The error bars on the dashed histograms are 1σ Poissonian error. The error bars on the solid histograms are omitted for clarity.

of different size and density contrast in the galaxy sample, which depend on the neighbourhood radius of the cluster analysis. This function often was plotted as histograms. Following Deng & Wen [47], we divide the whole interval from 1 to N (the total number of galaxies in the sample) into 7 subintervals: $n=1$; $2 \le n < 5$; $5 \le n < 20$; $20 \le n < 50$; $50 \le n < 100$; $100 \le n < 200$ and $n \ge 200$, and show histograms of the multiplicity functions from dimensionless radii $r=0.5$ to $r=1.3$, to follow the multiplicity functions in detail.

Deng et al. [41] applied the multiplicity functions in two volume-limited Main galaxy samples, and concluded: small stellar velocity dispersion galaxies preferentially form isolated galaxies, close pairs and small group, while large stellar velocity dispersion galaxies preferentially inhabit the dense groups and clusters. This actually demonstrated that there is a close clustering-stellar velocity dispersion

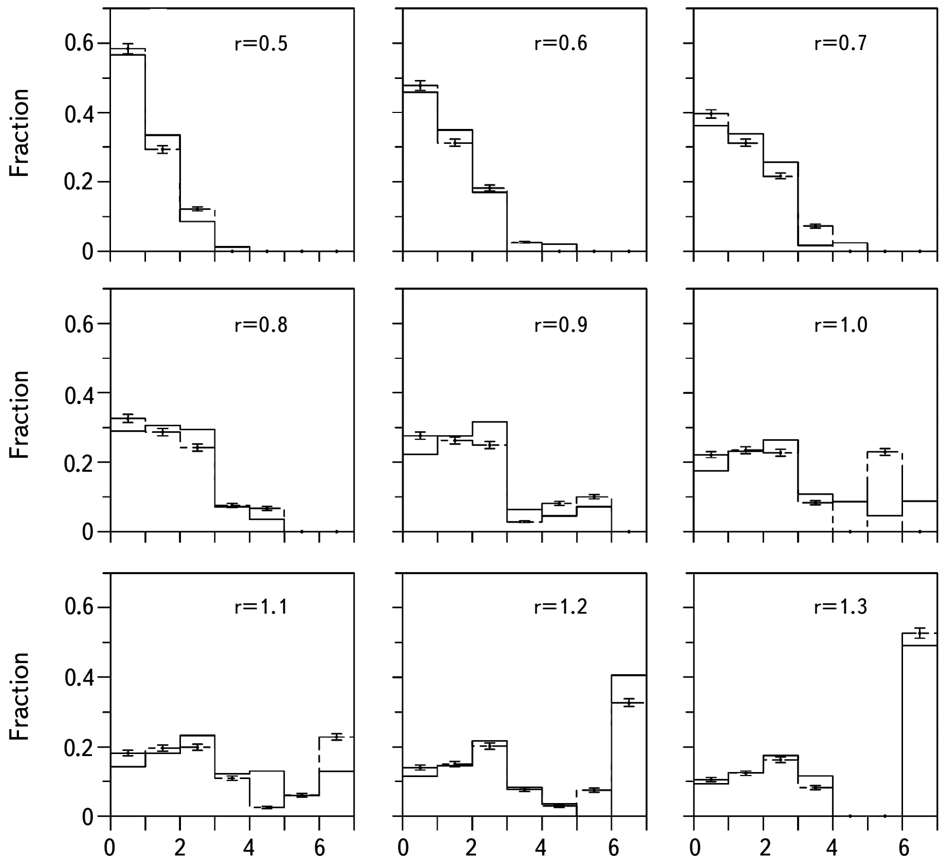

Fig.3. Same as Fig.2, but for histograms of the multiplicity functions for large stellar velocity dispersion (solid line) and small stellar velocity dispersion (dashed line) AGN host galaxies in the faint volume-limited AGN host galaxy sample for dimensionless radii ranging from $r=0.5$ to $r=1.3$.

dependence in normal galaxies, which is also in good agreement with the above-mentioned environmental dependence of the stellar velocity dispersion [31].

Fig.2 shows histograms of the multiplicity functions for large stellar velocity dispersion and small stellar velocity dispersion galaxies in the luminous volume-limited AGN host galaxy sample for dimensionless radii of $r=0.5$ to $r=1.3$. As shown by Fig.2, at all scales, AGN host galaxies with small stellar velocity dispersion preferentially form isolated galaxies, close pairs and small groups, while AGN host galaxies with large stellar velocity dispersion preferentially inhabit the dense groups and clusters. This further confirms the clustering-stellar velocity dispersion dependence of galaxies. When exploring the similar subject, previous works often focused on the cluster/field comparisons. Considering that the selection of the linking length for defining the cluster is often somewhat arbitrary, here, we examine the difference of clustering properties between large stellar velocity dispersion and small stellar velocity dispersion galaxies at all scales, thereby avoiding ambiguity related to the definition of a cluster.

Fig.3 demonstrates histograms of the multiplicity functions for large stellar velocity dispersion and small stellar velocity dispersion galaxies in the faint volume-limited AGN host galaxy sample for dimensionless radii of $r=0.5$ to $r=1.3$. Although the fraction of isolated galaxies with small stellar velocity dispersion is apparently higher than the one with large stellar velocity dispersion, the trend in the luminous volume-limited sample is very difficultly observed. This likely is due to the galaxy number of the faint volume-limited AGN host galaxy sample being too small to ensure an ideal statistical analysis.

5. *Summary*. We use two volume-limited active galactic nucleus (AGN) host galaxy samples constructed by Deng & Wen [47], and explore the environmental dependence of the stellar velocity dispersion in these two volume-limited AGN host galaxy samples. As shown by Fig.1, in the luminous volume-limited AGN host galaxy sample, the stellar velocity dispersion of galaxies apparently depends on local environments: galaxies with large stellar velocity dispersion exist preferentially in high-density regime, while galaxies with small stellar velocity dispersion are located preferentially in low-density regions. But in the faint volume-limited AGN host galaxy sample, the environmental dependence of the stellar velocity dispersion of AGN host galaxies is fairly weak.

By comparing AGN host properties with those of normal galaxies, Kauffmann et al. [45] concluded that AGN hosts have properties similar to that of early-type galaxies. Deng et al. [61] reported that AGN host galaxies have preferentially higher concentration indices than the whole galaxy sample, especially in the faint volume-limited sample. Some authors claimed the environmental dependence of galaxy parameters of early type galaxies is fairly weak [62-64]. Ball et al. [63]

found that for the red/early-type population color of galaxies does not change significantly with density; for the blue/late-type population, the color of galaxies becomes redder with increasing density. Park et al. [62] showed that when the local density varies from $\rho/\overline{\rho} \approx 15$ to ≈ 0.37, the color of galaxies changes only by 0.03 for early types and by 0.11 for late types. Deng et al. [64] examined the age distribution at both extremes of density for early-types and late-types in the luminous and faint volume-limited Main galaxy samples. In two volume-limited Main galaxy samples, Deng et al. [64] got the same conclusions: the environmental dependence of galaxy age is stronger for late type galaxies. Thus, it is not surprising that in the faint volume-limited AGN host galaxy sample, the environmental dependence of the stellar velocity dispersion of AGN host galaxies is fairly weak.

An alternative approach is to examine the dependence of the clustering properties of AGN host galaxies on the stellar velocity dispersion by cluster analysis. We divide each volume-limited AGN host galaxy sample into two subsamples (small stellar velocity dispersion and large stellar velocity dispersion) with nearly the same number density and then perform comparisons between them. The multiplicity functions in the dimensionless radii range of $r = 0.5 \rightarrow r = 1.3$ are analyzed, enabling the clustering properties to be explored on all relevant scales. Fig.2 shows histograms of the multiplicity functions for large stellar velocity dispersion and small stellar velocity dispersion galaxies in the luminous volume-limited AGN host galaxy sample for dimensionless radii of $r=0.5$ to $r=1.3$. As can be seen from Fig.2, in the luminous volume-limited AGN host galaxy sample, at all scales, AGN host galaxies with small stellar velocity dispersion preferentially form isolated galaxies, close pairs and small groups, while AGN host galaxies with large stellar velocity dispersion preferentially inhabit the dense groups and clusters. In the faint volume-limited AGN host galaxy sample, although the fraction of isolated galaxies with small stellar velocity dispersion is apparently higher than the one with large stellar velocity dispersion, the trend in the luminous volume-limited sample is very difficultly observed. This likely is due to the galaxy number of the faint volume-limited AGN host galaxy sample being too small to ensure an ideal statistical analysis.

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ЗАВИСИМОСТЬ ДИСПЕРСИИ ЗВЕЗДНЫХ СКОРОСТЕЙ РОДИТЕЛЬСКИХ ГАЛАКТИК С АКТИВНЫМ ГАЛАКТИЧЕСКИМ ЯДРОМ (АЯГ) ОТ ОКРУЖАЮЩЕЙ СРЕДЫ И ЗАВИСИМОСТЬ СВОЙСТВ КЛАСТЕРИЗАЦИИ РОДИТЕЛЬСКИХ ГАЛАКТИК С АЯГ ОТ ДИСПЕРСИИ ЗВЕЗДНЫХ СКОРОСТЕЙ

ЮН СИНЬ, КСИН-ФА ДЭНГ

Использованы две выборки родительских галактик с активными ядрами (АЯГ) с ограниченным объемом, построенные Денгом и Веном, и исследована зависимость дисперсии звездных скоростей от окружающей среды в этих двух выборках родительских галактик ограниченного объема. В выборке сравнительно ярких родительских галактик АЯГ с ограниченным объемом дисперсия звездных скоростей родительских галактик АЯГ, по-видимому, зависит от локального окружения: родительские галактики АЯГ с большой дисперсией звездных скоростей наблюдаются преимущественно в областях с высокой плотностью, в то время как родительские галактики АЯГ с малой дисперсией звездных скоростей - с низкой плотностью населения. Но в выборке слабых родительских галактик АЯГ, ограниченных по объему, эта зависимость довольно слабая. Изучена также зависимость свойств кластеризации родительских галактик АЯГ от дисперсии звездных скоростей с помощью кластерного анализа и обнаружено, что в выборке ярких родительских галактик АЯГ с ограниченным объемом родительские галактики АЯГ с малой дисперсией

звездных скоростей предпочтительно образуют изолированные галактики, близкие пары и небольшие группы, в то время как галактики с большой дисперсией звездных скоростей преимущественно населяют плотные группы и скопления. Несмотря на то, что в выборке слабых галактик, ограниченных по объему, доля изолированных галактик с малой дисперсией звездных скоростей, по-видимому, выше, чем с большой, тренд наблюдается с трудом. Вероятно, это связано с тем, что число галактик в выборке слабых галактик с ограниченным объемом слишком мало для обеспечения идеального статистического анализа.

Ключевые слова: *космология: крупномасштабная структура Вселенной - галактики: фундаментальные параметры*

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