COMPARATIVE STUDIES OF CLUSTERING PROPERTIES BETWEEN ACTIVE GALACTIC NUCLEUS (AGN) HOST GALAXIES AND STAR-FORMING ONES

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Using the volume-limited Main galaxy sample of the Sloan Digital Sky Survey Data Release 6 (SDSS DR6), we have explored the difference of clustering properties between Active Galactic Nucleus (AGN) host galaxies and star-forming galaxies. Our results preferentially show that AGN host galaxies have a lower fraction in isolated, close double and multiple systems than star-forming galaxies.

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1. Introduction

The Active Galactic Nuclei (AGNs) and star-forming galaxies are a group of galaxies with relatively strong emission lines, which often are differentiated according to their position on the so-called BPT diagrams [1]. The clustering properties of AGNs and star-forming galaxies were widely studied. Wake *et al.* [2] analysed the two-point correlation function of narrow-line AGNs in the SDSS, and found that the AGN autocorrelation function is consistent with the autocorrelation function of luminous galaxies on scales from 0.2 to 100 h^{-1} Mpc. Gilli *et al.* [3] also investigated the correlation function of X-ray selected AGNs. Magliocchetti *et al.* [4] showed that radio-loud AGNs appear to be significantly more clustered on large scales, which demonstrates that they reside in massive dark matter halos. Li *et al.* [5] explored the clustering differences between AGN hosts and similar but inactive galaxies: on scales larger than a few Mpc, AGNs have almost the same clustering amplitude as the control sample of non-AGN; on scales between 100 kpc and 1 Mpc, AGNs are clustered more weakly than inactive galaxies; on scales lower than 70 kpc, AGNs cluster more strongly than inactive galaxies, but the effect is weak. Li *et al.* [6] studied the clustering properties of a complete sample of 10^5 star-forming galaxies drawn from the SDSS, and showed that on scales lower than 100 kpc, the amplitude of the correlation function of star-forming galaxies exhibits a strong dependence on the specific star formation rate of the galaxy, which is a clear signal that mergers or interactions play an important role in triggering enhanced star formation in galaxies. Deng *et al.* [7] compared the clustering properties of star-forming galaxies with those of passive galaxies, and found that star-forming galaxies preferentially form isolated, close double and multiple systems, while passive galaxies tend to reside in the dense groups and clusters.

Li *et al.* [8] also analysed star forming galaxies and AGNs in exactly the same way, and brought their statistical results on star-forming galaxies and AGNs together, to understand the connection between star formation, AGN activity and galaxy interactions. Here, we attempt to explore the difference of clustering properties between active galactic nucleus (AGN) host galaxies and star-forming galaxies.

Our paper is organized as follows. In Section 2, we describe the data used. In Section 3 we perform comparative studies of clustering properties between active galactic nucleus (AGN) host galaxies and star-forming galaxies. Our main results and conclusions are summarized in Section 4.

In calculating the distance we used a cosmological model with a matter density $\Omega_0 = 0.3$, cosmological constant $\Omega_\Lambda = 0.7$, and Hubble constant $H_0 = 100\,\mathrm{hkm\,s^{-1}\,Mpc^{-1}}$ with $h = 0.7$.

2. Data

Many of survey properties of the SDSS were discussed in detail in the Early Data Release paper [9]. In this study, we use the volume-limited Main galaxy sample [10] of the SDSS Data Release 6 [11] constructed by Deng *et al.* [12], which contains 112 889 galaxies, extends to $Z_{\max} = 0.089$, and is limited to the absolute magnitude interval $-22.40 \le M_r \le -20.16$.

BPT [1] demonstrated that it is possible to distinguish AGNs from star-forming galaxies by considering the classical diagnostic ratios of two pairs of relatively strong emission lines. We use the star-forming galaxy sample constructed by Deng *et al.* [7], which contains 30 926 star-forming galaxies. By the criteria of Kauffmann *et al.* [13], we also identify 11 268 AGNs on this BPT diagram (see Fig. 1 of [7]).

3. Comparative studies of clustering properties between the passive sample and the star-forming sample

Like Deng *et al.* [14] did, we use cluster analysis [15]. The rule "any friend of my friend is my friend" is the key idea of cluster analysis. It is often called the friends-of friends algorithm. By this method, the galaxy sample can be separated into isolated galaxies, close pairs and small galaxy groups, galaxy groups or clusters and even superclusters. So it can present hierarchical structures of galaxy distribution.

The mean density of galaxies is $\bar{\rho} = N/V$ ($N$is the number of galaxies contained in the volume V). The Poisson radius (radius of the sphere with unit population) is $R_0 = (3/(4\pi\bar{\rho}))^{1/3}$. In this paper, we express all distances in dimensionless radii $r = R/R_0$. Poisson radii (comoving distance) are 9.12 Mpc for the AGN sample, and 6.52 Mpc for the star-forming sample.

At dimensionless radius $r = 0.5$, the richest system only contains: 27 galaxies in the star-forming sample, and 13 galaxies in the AGN sample; the maximal length of the largest system is: 17.83 Mpc in the star-forming sample, and 17.34 Mpc in the AGN sample. The maximal length of a system is defined as the maximum distance between members of this system. For small radii, the galaxy systems by cluster analysis consist mostly of isolated galaxies, close double and multiple galaxies, few systems form groups. At radius $r = 1.3$, the richest system contains: 4 237 galaxies in the star-forming sample, and 1 096 galaxies in the AGN sample; the maximal length of the largest system is: 409.48 Mpc in the star-forming sample, and 373.51 Mpc in the AGN sample. At such a large radius, systems begin to merge into filamentary superclusters and finally into the entire interconnected supercluster network or the "cosmic Web". Like Deng *et al.* [7] did, we analyse clustering properties of two samples from dimensionless radii $r = 0.5$ to $r = 1.3$, which can explore clustering properties at all scales.

In order to describe the distribution of systems having different sizes, we analyse the multiplicity functions: the fraction of galaxies in systems of membership from n to $n + dn$, which depend on the dimensionless radii r. We divide the interval from 1 to N (the total number of galaxies) into 7 subintervals: $n = 1$, $2 \le n < 5$, $5 \le n < 20$, $20 \le n < 50$, $50 \le n < 100$, $100 \le n < 200$, $n \ge 200$, and then construct histograms of the multiplicity functions from dimensionless radii $r = 0.5$ to $r = 1.3$. In each histogram, systems which contain one galaxy are in the first bin, systems which contain from 2 to 4 galaxies are in the second bin, systems with 5 to 19 galaxies in the third bin and so on. Fig. 1 shows the multiplicity functions for the star-forming sample and the AGN one. The (1σ) error bars are Poissonian errors. As seen from this figure, AGN host galaxies preferentially form small systems (including isolated, close double and multiple systems), while star-forming galaxies preferentially inhabit the dense groups and clusters.

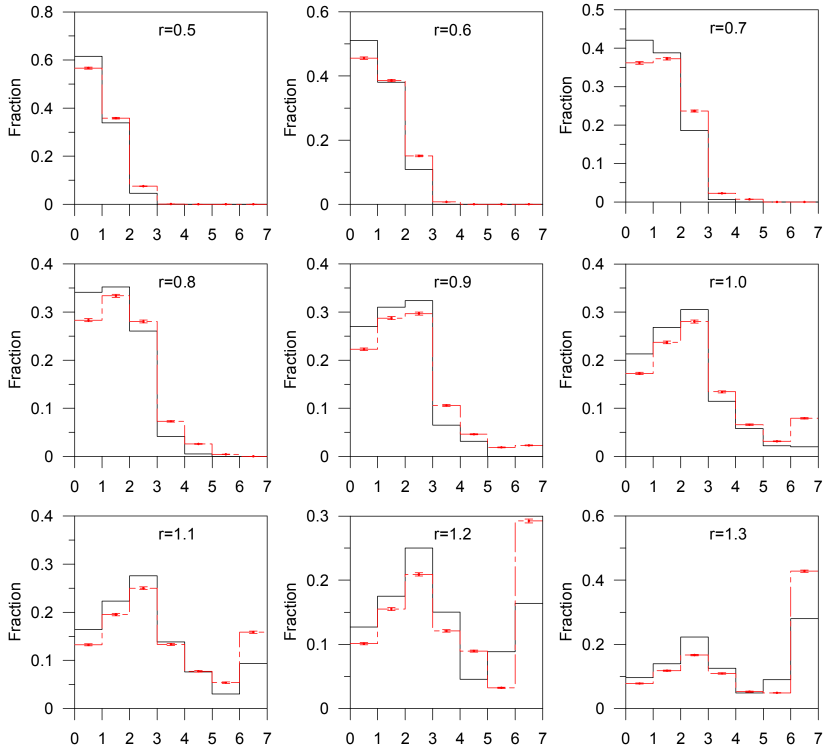

Fig. 1. Histograms of multiplicity functions for the AGN sample (black solid line) and the star-forming sample (red dashed line) from dimensionless radii $r = 0.5$ to $r = 1.3$. The error bars for red dashed line are 1σ Poissonian errors. Error bars for black solid line are omitted for clarity.

The star-forming sample and the AGN one have different number density. Apparently, in a sample with larger number density, richer and larger systems can be more easily found. Deng *et al.* [7, 14] showed that although dimensionless radii are used to express distances, this replacement cannot completely correct the above bias. Like Deng *et al.* [14] did, we randomly extract a subsample from the star-forming sample, which has the same galaxy number and number density as the AGN sample, and again perform the above analyses. As seen in Fig. 2, the random star-forming sample has a higher proportion of small and poor systems than the AGN sample, which is opposite to the conclusion shown in Fig. 1. In the studies of Deng *et al.* [7, 14], such an analysis can get the same conclusion, which shows that their statistical conclusion is robust and real. In this study, the difference of clustering properties between the star-forming sample and the AGN one may be very small. Thus, the influence of methods on statistical conclusion is fairly serious.

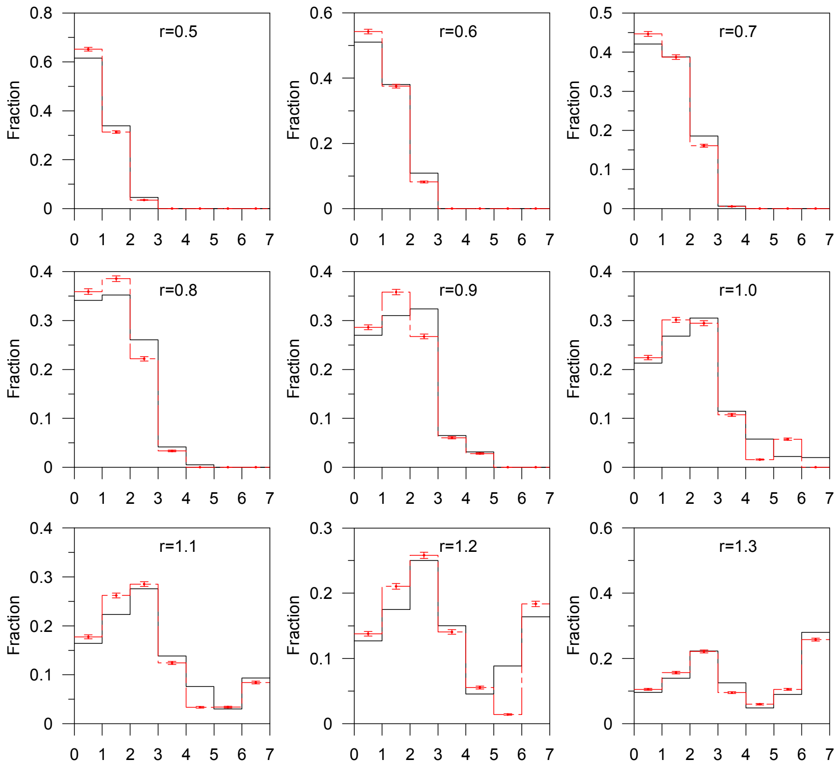

Fig. 2. Histograms of multiplicity functions for the AGN sample (black solid line) and the random star-forming sample (red dashed line) from dimensionless radii $r = 0.5$ to $r = 1.3$. The error bars for red dashed line are 1σ Poissonian errors. Error bars for black solid line are omitted for clarity.

Deng *et al.* [14, 16] showed that early-type and red galaxies have a higher fraction residing in groups and clusters and a lower fraction in isolated, close double and multiple systems than late-type and blue galaxies. With consideration of the bimodality of the u–r colour distribution (*e.g.*, Strateva *et al.* [17]), we classify galaxies above and below the divider (the observed u–r colour = 2.22) as "red" and "blue", respectively. It is found that about 14.25 % star-forming galaxies and 51.90 % galaxies with an AGN are red ones. Like Deng *et al.* [18] did, we also use the concentration index $c_i = R_{90}/R_{50}$ to separate early-type ($c_i \geq 2.86$) galaxies from late-type ($c_i < 2.86$) galaxies ([19, 20]). R_{50} and R_{90} are the radii enclosing 50 % and 90 % of the Petrosian flux, respectively. It turns out that about 6.32 % star-forming galaxies and 21.78 % galaxies with an AGN are early-type ones. As indicated by Deng *et al.* [7], the dependence of clustering properties on some parameters will result in the one on other parameters. If colour and morphology are fundamental, in the dependence of clustering properties on galaxy parameters we can expect that AGN host galaxies have a higher fraction residing in groups and clusters and a lower fraction in isolated, close double and multiple systems than star-forming galaxies. In Fig. 2, we seem to observe such a weak trend.

4. Summary

Using BPT diagram and the criteria of [13], we select 30 926 star-forming galaxies and 11 268 AGNs from the volume-limited Main galaxy sample of the SDSS DR6, to explore the difference of clustering properties between AGN host galaxies and normal star-forming galaxies. Because the two samples have different number density, we randomly extract a subsample from the star-forming sample, which has the same galaxy number and number density as the AGN sample, and again perform the same analyses. Our results preferentially show that AGN host galaxies have a lower fraction in isolated, close double and multiple systems than star-forming galaxies.

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