АСТРОФИЗИКА

ТОМ 58 ФЕВРАЛЬ, 2015 ВЫПУСК 1

u-r COLOR DEPENDENCE OF GALAXY CLUSTERING IN THE MAIN GALAXY SAMPLE OF SDSS DR10

FUYANG ZHANG[1], XIN-FA DENG[2]

Recieved 25 March 2014
Accepted 5 December 2014

Using two volume-limited Main galaxy samples of the Sloan Digital Sky Survey Data Release 10 (SDSS DR10), we investigate $u-r$ color dependence of clustering properties of galaxies. We can get the same statistical conclusion in two volume-limited Main galaxy samples: blue galaxies preferentially form isolated galaxies, close pairs and small groups at all scales, whereas red galaxies preferentially inhabit dense groups and clusters.

Key words: *galaxies: fundamental parameters - galaxies: large scale structure*

1. *Introduction.* Galaxy color is strongly correlated with galaxy clustering or environments of galaxies [1-7]. Brown et al. [1] measured the angular correlation function of galaxies in a $B_J \approx 23.5$ multicolor survey of two $5^0 \times 5^0$ fields, and found that the galaxy correlation function depends strongly on color, with red galaxies more strongly clustered than blue galaxies. The Sloan Digital Sky Survey (SDSS) is one of the largest astronomical surveys to date and have revolutionized the studies of many issues of galaxies. Zehavi et al. [2] presented the first measurements of clustering in the SDSS galaxy sample, examined $u-r$ color dependence of galaxy clustering, and demonstrated that the red galaxies exhibit a stronger and steeper real-space correlation function than do the blue galaxies. Zehavi et al. [3] applied $g-r$ color as a separator into blue and red populations, explored color dependence of the galaxy two-point correlation function, and showed that redder galaxies exhibit a higher amplitude and steeper correlation function at all luminosity. Deng et al. [5] divided a volume-limited Main galaxy sample [8] of the SDSS into three subsamples with different $g-r$ color, performed comparative studies of clustering properties between them, and found that the redder galaxies preferentially inhabit the dense groups and clusters. The primary goal of this paper is to investigate $u-r$ color dependence of galaxy clustering, using the newest data of the SDSS and an alternative approach.

The correlation function is a popular statistical method for studying the distribution of galaxies. When investigating such a subject, one often applied it [1-3,9]. However, Börner & Mo [10] reported that the correlation functions are most likely insensitive to structures much larger than the correlation length.

Deng et al. [5] claimed that by correlation function, one can not clearly understand the geometry of the distribution of galaxies. Deng [11] also argued that the correlation function indeed has its own limitations. Deng et al. [5] suggested that different methods should be applied, in order to get more information about the color dependence of clustering properties. Pandey & Bharadwaj [12] presented that the blue galaxies and the spirals have a higher filamentarity than the red galaxies and the ellipticals respectively at large filling factors. In this study, we use cluster analysis [13] that is sensitive to the geometry of the galaxy distribution, like Deng et al. [5,14] and Deng [11] did. By this method, the galaxy sample can be separated into isolated galaxies, close double and multiple galaxies, galaxy groups or clusters and even superclusters. The outline of this paper is as follows. In section 2 we describe the data used. The cluster analysis is discussed in section 3. In section 4 we investigate $u-r$ color dependence of clustering properties. 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 $H_0 = 70\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$.

2. *Data*. The Main galaxy sample [8] of the SDSS is a galaxy sample widely used in recent years, which contains galaxies brighter than $r_{petro} = 17.77$ (r-band apparent Petrosian magnitude). In this work, we study $u-r$ color dependence of clustering properties in this sample. The data was downloaded from the Catalog Archive Server of SDSS Data Release 10 [15] by the SDSS SQL Search (http://www.sdss3.org/dr10/). From an apparent-magnitude limited Main galaxy sample of the SDSS DR10 which contains 633172 Main galaxies with the redshift $0.02 \le z \le 0.2$, we construct a luminous volume-limited Main galaxy sample which contains 129515 galaxies at $0.05 \le z \le 0.102$ with $-22.5 \le M_r \le -20.5$ and a faint volume-limited sample which contains 34573 galaxies at $0.02 \le z \le 0.0436$ with $-20.5 \le M_r \le -18.5$. The absolute magnitude M_r is calculated from the r-band apparent Petrosian magnitude and a polynomial fit formula [16] of K-correction:

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

These two volume-limited Main galaxy samples are located in different redshift and luminosity range.

Galactic extinction correction is applied to this sample. We divide each volume-limited Main galaxy sample into two subsamples (see Table 1): red and blue, and then perform comparative studies between red galaxies and blue galaxies. A drawback of cluster analysis is that there is a preference for richer and larger systems in samples with higher number density. Deng et al. [5] argued that the use of dimensionless radii to express distances cannot entirely correct for this bias. Considering the influence of differences in number density between subsamples on the statistical conclusions, like Deng [11] did, we select the color thresholds in volume-limited samples for ensuring that the number density of the two subsamples must be nearly the same.

Table 1

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

Sample	Subsamples	Galaxy number	Poisson radius R_0 (Mpc)
Luminous volume-limited Main galaxy sample	Red (u-r color ≥ 2.39)	64647	5.899
	blue (u-r color <2.39)	64868	5.892
Faint volume-limited Main galaxy sample	Red (u-r color ≥ 1.85)	17390	3.996
	blue (u-r color <1.85)	17183	4.012

3. *Cluster analysis*. The cluster analysis [13] is often referred to as the friends-of-friends algorithm by which the galaxy sample can be separated into isolated galaxies, close pairs and small galaxy groups, galaxy groups or clusters and even superclusters. Superclusters, the largest virialized systems known, consist of galaxy clusters or groups and galaxy filaments [17,18]. Therefore, by this method, one can present the full range of hierarchical structures in the galaxy distribution.

The cluster analysis algorithm proceeds as follows. Starting from one galaxy of the sample, we search all galaxies within a sphere of radius R around it, and call these close galaxies "friends". These "friends" are assigned to the same system as the starting galaxy. Using the rule "any friend of my friend is my friend", we repeat the above procedure around each new neighbor. When no more new neighbors (friends) can be added, the algorithm terminates and a system is identified. Such a system does not depend on which galaxy we start with or the order in which the galaxies are connected.

As in previous works [5,14], we express the neighborhood radius in dimensionless units, $r = R/R_0$, where $R_0 = [3V/(4\pi N)]^{1/3}$ is the Poisson radius (radius of the sphere with unit population), N is the number of galaxies in the sample, and V is the volume of the sample. Table 1 lists the Poisson radius (comoving distance) of each subsample.

4. *U-r color dependence of clustering properties*. As in Deng et al. [14], we calculate the multiplicity functions, that is the fraction of the galaxies in systems with membership between n and $n + dn$, as a function of the dimensionless radius r. Following Deng et al. [14], we divide the interval from 1 to N (the total number of galaxies) into 7 subintervals: $n=1$; $2 \leq n < 5$; $5 \leq n < 20$; $20 \leq n < 50$; $50 \leq n < 100$; $100 \leq n < 200$ and $n \geq 200$, 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.

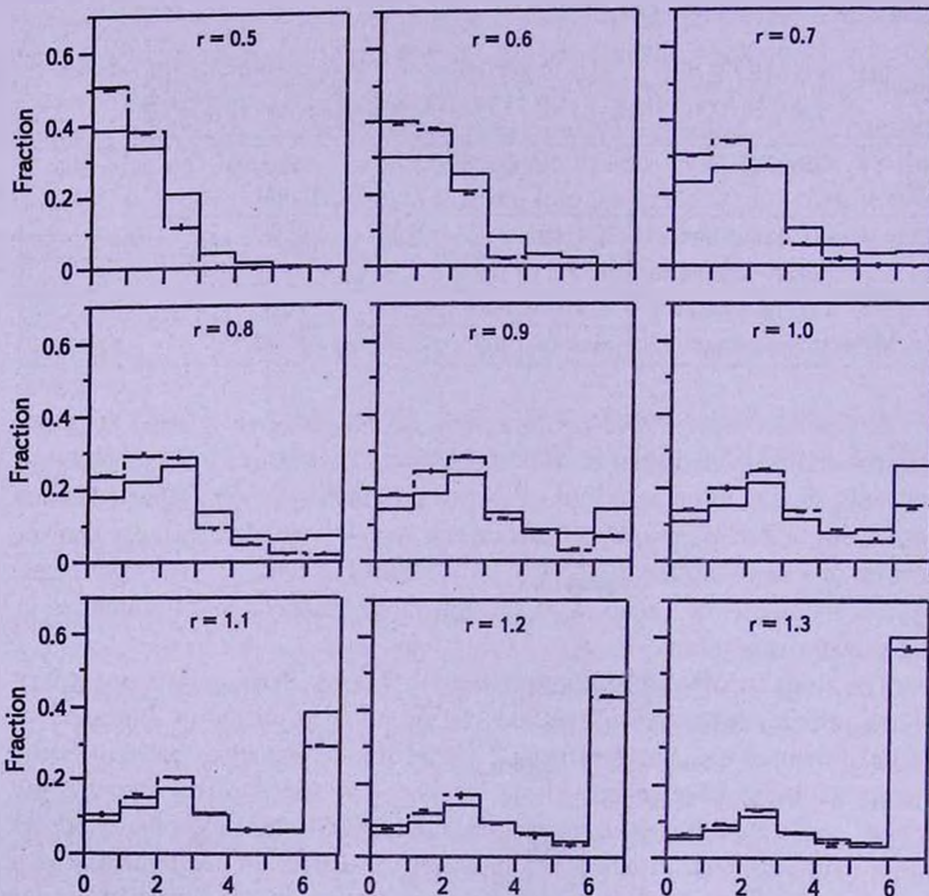

Fig.1. Histograms of the multiplicity functions for red (solid line) and blue (dashed line) galaxies in the luminous volume-limited Main galaxy sample for dimensionless radii ranging from $r=0.5$ to $r=1.3$. The error bars on the dashed histograms are 1σ Poissonian errors. The error bars on the solid histograms are omitted for clarity.

Fig.1 shows histograms of the multiplicity functions for red and blue galaxies in the luminous volume-limited Main galaxy sample for dimensionless radii of $r=0.5$ to $r=1.3$. The 1σ error bars are Poissonian errors. Following previous works [5,14], we define maximum lengths of the systems as the maximum distance between members of this system. At dimensionless radius $r=0.5$, the richest system contains: 31 galaxies in the blue galaxy subsample, and 217 galaxies in the red galaxy subsample; the maximal length of the largest system is: 24.48 Mpc in the blue galaxy subsample, and 57.14 Mpc in the red galaxy subsample. The richest system and the largest system formed in the red galaxy subsample are much larger than those in the blue galaxy subsample. The fraction of galaxies in the first and second bins of histograms of the multiplicity functions is approximately 88.05% in the blue galaxy subsample, and 71.76% in the red galaxy subsample. The most of galaxy systems formed at dimensionless radius $r=0.5$ are isolated, paired and multiple ones. At radius $r=1.3$, the richest system contains: 33821 galaxies in the blue galaxy subsample, and 26518 galaxies in the red galaxy subsample; the maximal length of the largest system is: 729.46Mpc in the blue galaxy subsample, and 619.46 Mpc in the red galaxy subsample; the fraction of galaxies in systems with ≥ 200 galaxies is approximately 56.80% in the blue galaxy subsample, and 59.52% in the red galaxy subsample. The maximal length of the largest system formed at this dimensionless radius is even much larger than the edge length of the sample volume V (the rough estimate of the edge length $L_0 = V^{1/3} = 381.63$ Mpc for the luminous volume-limited Main galaxy sample), which shows that at this dimensionless radius, systems already merge into the entire interconnected supercluster network. As indicated as Deng et al. [14], the clustering properties of galaxies on all relevant scales can be presented in the dimensionless radii range of $r=0.5 \rightarrow r=1.3$.

In the past, many works shed light on the color-density relation [6, 19-32]. Blanton et al. [20] demonstrated that local density of galaxies is a strong function of all colors. Blanton et al. [4] reported that galaxy color is the galaxy property most predictive of the local environment. In the local Universe, it is widely accepted that red galaxies tend to reside in the densest regions of the universe, while blue galaxies tend to reside in low density regions. Deng et al. [7] applied the apparent-magnitude limited Main galaxy sample of the SDSS, studied the environmental dependence of $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors, and found that all the five colors are strongly correlated with local environment. However, it is noteworthy that in intermediate redshift and high redshift region, statistical analyses from different survey have yielded contradictory results. Cooper et al. [22] reported that the environmental dependence of galaxy colors at $z \approx 1$ mirrors that seen in the local Universe. Grützbauch et al. [31] showed that galaxy color weakly depends on local number density in the redshift range of $0.4 < z < 1$.

The volume-limited Main galaxy sample used by Deng et al. [5] actually corresponds to the luminous volume-limited Main galaxy sample of this work. In such a sample, Deng et al. [5] compared clustering properties of three galaxy subsamples with different $g-r$ color, and found that the redder galaxies preferentially inhabit the dense groups and clusters. In this work, we attempt to examine $u-r$ color dependence of clustering properties. As can be seen from Fig.1, we still can reach the conclusions: blue galaxies preferentially form isolated galaxies, close pairs and small groups at all scales, whereas red galaxies preferentially inhabit dense groups and clusters. This shows that the trend of the different color dependence of clustering properties is the same, which is consistent with results regarding the environmental dependence of the different colors.

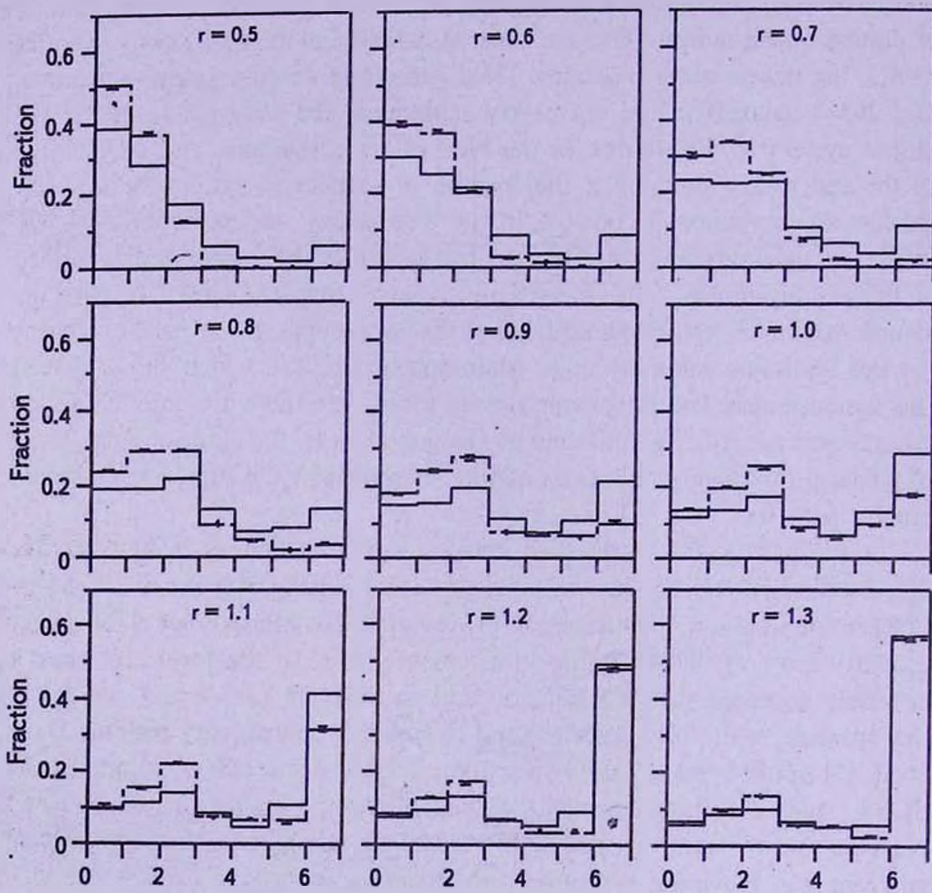

Fig.2. Same as Fig.1, but for histograms of the multiplicity functions for red (solid line) and blue (dashed line) galaxies in the faint volume-limited Main galaxy sample for dimensionless radii ranging from $r = 0.5$ to $r = 1.3$.

Norberg et al. [9] argued that the variation of the clustering properties with luminosity is different for galaxies with different luminosity range. In Fig.2, we plot histograms of the multiplicity functions for blue and red galaxies in the faint volume-limited Main galaxy sample for dimensionless radii of $r = 0.5$ to $r = 1.3$. A strong dependence of the clustering properties on $u - r$ color is observed in the faint volume-limited Main galaxy sample as well as in the luminous volume-limited Main galaxy sample. This shows that the statistical conclusion do not depends on the luminosity range of volume-limited Main galaxy samples, which is consistent with the result obtained by Deng [11].

5. *Summary.* In this study, we aim to investigate $u-r$ color dependence of clustering properties by cluster analysis. We use two volume-limited Main galaxy samples of the SDSS DR10, to see the difference in $u-r$ color dependence of the galaxy clustering properties between the luminous and faint Main galaxy samples. Two volume-limited Main galaxy samples are located in different redshift and luminosity range: a luminous volume-limited Main galaxy sample contains 129515 galaxies at $0.05 \le z \le 0.102$ with $-22.5 \le M_r \le -20.5$ and a faint volume-limited sample includes 34573 galaxies at $0.02 \le z \le 0.0436$ with $-20.5 \le M_r \le -18.5$. We divide each volume-limited Main galaxy sample into two subsamples (red and blue) with nearly same number density and then perform comparative studies of clustering properties between them. As shown by Figs.1-2, the same statistical conclusion can be reached in two volume-limited Main galaxy samples: blue galaxies preferentially form isolated galaxies, close pairs and small groups at all scales, whereas red galaxies preferentially inhabit dense groups and clusters.

Acknowledgements. Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy. The SDSS-III web site is http://www.sdss3.org/.

SDSS-III is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS-III Collaboration including the University of Arizona, the Brazilian Participation Group, Brookhaven National Laboratory, University of Cambridge, University of Florida, the French Participation Group, the German Participation Group, the Instituto de Astrofisica de Canarias, the Michigan State/Notre Dame/JINA Participation Group, Johns Hopkins University, Lawrence Berkeley National Laboratory, Max Planck Institute for Astrophysics, New Mexico State University, New York University, Ohio State University, Pennsylvania State University, University of Portsmouth, Princeton University, the Spanish Participation Group, University of Tokyo, University of Utah, Vanderbilt University, University of Virginia, University of Washington, and Yale University.

[1] School of Information Engineering, Nanchang University, China
[2] School of Science, Nanchang University, China, e-mail: xinfadeng@163.com

ЗАВИСИМОСТЬ СКОПЛЕНИЯ ГАЛАКТИК ОТ u - r ЦВЕТА В ГЛАВНОМ ГАЛАКТИЧЕСКОМ ОБРАЗЦЕ SDSS DR10

Ф.ЦАНГ[1], ХИН-ФА ДЕНГ[2]

Используя два пространственно-ограниченных образца главных галактик в SDSS DR10, мы исследовали зависимость особенности скопления галактик от *u - r* цвета. Мы можем получить одинаковое статистическое заключение в двух пространственно-ограниченных образцах главных галактик: синие галактики предпочтительно формируют изолированные галактики, тесные двойные и маленькие группы во всех масштабах, тогда как красные галактики предпочтительно населяют плотные группы и скопления.

Ключевые слова: *галактики: фундаментальные параметры - галактики: широко-масштабная структура*

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