АСТРОФИЗИКА

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# THE COLOR PROPERTIES OF COMPACT GROUPS OF MAIN GALAXIES FROM THE SDSS DATA RELEASE 4

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In order to compare color statistical properties of member galaxies in compact groups with those of field galaxies, we use a compact group (CG) sample which contains 4217 CGs extracted from the MAIN galaxy sample of the SDSS Data Release 4 (SDSS4), and construct a random group sample which have the same distributions of redshift and number of member galaxies as those of the CG sample. It turns out that mean colors of galaxies in CGs are redder than those of galaxies in random groups. Additionally, we also find that member galaxies in real CGs have a smaller dispersion of colors than those in random groups - at least for $g-r$, $r-i$ and $i-z$ colors.

Key words: *Galaxy: fundamental parameters - galaxy: large scale structure*

1. *Introduction*. Compact groups of galaxies (CGs) are small and dense systems of several galaxies in the universe. In the clustering hierarchy, they are at an intermediate stage between rich clusters and triplets, pairs and individual galaxies [1-4]. Undoubtedly, studies of compact groups will be beneficial to the understanding of the overall structure of the universe.

Galaxy color is an important quantity that characterizes stellar contents of galaxies. Using 175 CGs identified from the Sloan Digital Sky Survey (SDSS), Lee et al. [5] explored morphology-environment effects in SDSS CGs. They found that the rest-frame colors of CG galaxies indeed differ from those of field galaxies - at least for $M_{u^*}-M_{g^*}$, $M_{g^*}-M_{r^*}$, and even $M_{r^*}-M_{i^*}$, and concluded that SDSSCGs contain a relatively higher fraction of elliptical galaxies than does the field. This indicated that there is strong evidence of interactions and mergers within a significant fraction of SDSS CGs. In this paper, we use a new catalog of CGs, and further explore statistical properties of colors for CGs. Our paper is organized as follows. In section 2, we describe the galaxy data to be used. The group identification algorithm and the CG catalog are discussed in section 3. In section 4, we present statistical properties of colors for CGs. Our main results and conclusions are summarized in section 5.

2. *Galaxy data*. The Sloan Digital Sky Survey (SDSS ) is one of the largest astronomical surveys to date. The completed survey will cover ap-

proximately 10000 square degrees. York et al. [6] provided the technical summary of the SDSS. The SDSS observes galaxies in five photometric bands ($u$, $g$, $r$, $i$, $z$) centered at 3540, 4770, 6230, 7630, 9130 Å. The imaging camera was described by Gunn et al. [7], while the photometric system and the photometric calibration of the SDSS imaging data were roughly described by Fukugita et al. [8], Hogg et al. [9] and Smith et al. [10] respectively. Pier et al. [11] described the methods and algorithms involved in the astrometric calibration of the survey, and present a detailed analysis of the accuracy achieved. Many of the survey properties were discussed in detail in the Early Data Release paper [12]. The MAIN Galaxy sample [13] targets galaxies brighter than $r < 17.77$ ($r$-band apparent Petrosian magnitude [14]). Most galaxies of this sample are within redshift region $0.02 \le z \le 0.2$.

In our work, we consider the Main galaxy sample. The data is download from the Catalog Archive Server of SDSS Data Release 4 [15] by the SDSS SQL Search (with SDSS flag: bestPrimtarget=64) with high-confidence redshifts (Zwarning $\neq 16$ and Zstatus $\neq 0$, 1 and redshift confidence level: zconf$>0.95$) (http://www.sdss.org/dr4/). From this sample, we select 260928 Main galaxies in redshift region: $0.02 \le z \le 0.2$.

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

3. *The CG catalog*. Compact groups are often located within the bounds of loose groups and clusters [16-21]. The best known catalog of compact groups is that of the Hickson Compact Groups (HCGs) [22]. Because Hickson's criteria were mainly based on the angular distribution of galaxies, this CG catalog was actually two-dimensional sample in which CGs are seriously contaminated by background/foreground galaxies. Barton et al. [21] used a different version of the friends-of-friends algorithm and compiled a catalog of 89 redshift-selected compact groups (RSCGs) in a complete magnitude-limited redshift survey. Galaxies having projected separations $\Delta D \le 50\,h^{-1}$ kpc and line-of-sight velocity differences $\Delta V \le 1000\,\mathrm{km\,s^{-1}}$ are connected and the sets of connected galaxies constitute the groups. Apparently, the velocity selection criterion will greatly decrease the contamination by background/foreground galaxies. Unlike Hickson, Barton et al. [21] did not include isolation and luminosity criteria, and also did not defined the minimum number of members of CGs. They only considered the galaxy spatial distribution. Because the criterion of radial distance is far larger than that of the projected separation, this algorithm is actually the quasi-three-dimensional method.

Using different criteria and galaxy catalogs, many other catalogs of compact groups also have been compiled and studied [5,21,23-32]. In this paper, we use the catalog of compact groups identified from the Main galaxy sample of SDSS Data Release 4 [15] by Deng et al. [33]. Deng et al. [33] used the conventional three-dimensional cluster analysis [34] by which the galaxy sample can be separated into individual systems at a given neighbourhood radius $R$. At small radii, most systems are some isolated single galaxies, the rest being close double and multiple galaxies. At larger radii groups and clusters of galaxies and even superclusters will be formed. Deng et al. [33] defined CGs as systems with $4 \leq N < 10$ ($N$ is the number of member galaxies in systems). In order to find the appropriate neighbourhood radius to identify CGs, they analysed the clustering properties of the Main galaxy sample. Finally, systems identified at radius $R = 1.2$ Mpc were selected as the CG sample which contains 4217 CGs (total number of member galaxies is 21166). The selection of this neighbourhood radius mainly depended on two factors: (1) Most groups do not merge into loose groups and clusters (when the neighbourhood radius is larger, many groups will be included into loose groups and clusters). (2) In order to make ideal statistical analyses, we hope that our CG sample is as large as possible.

In the Main galaxy sample, the minimum redshift difference between galaxies is $\Delta z = 0.001$ corresponding to the minimum radial luminosity distance $\Delta D_{rad} \approx 4.4$ Mpc. So, members of CGs identified by the three-dimensional separation $R \leq 1.2$ Mpc actually have the same redshifts. As compared with previous CG samples, this sample has two advantages: (1) Group member galaxies are located at the same redshift. So the contamination by background/foreground galaxies is completely eliminated. (2) Because our seletion criteria are only based on the galaxy spatial distribution, the correlations of some properties among member galaxies of CGs in such a CG sample may be real physical effects.

4. *Statistical properties of color for CGs.* To explore color properties of CGs, we have constructed a field sample by removing member galaxies of CGs from the Main galaxy sample of SDSS4. It contains 239762 Main galaxies. For each CG, we randomly extract a group of galaxies from the field sample and compose a random group which has the same redshift and number of galaxies as those of the CG. All random groups make up a random group sample which will reasonably sample the field with little contamination from CGs. Apparently, it has a redshift distribution completely identical to that of the original 21166 CG galaxies. In this paper, we will compare statistical properties of colors of the CG sample with those of the random group sample.

Main galaxy sample is an apparent-magnitude limited sample in which some properties change with redshift, being due to physical effect or select effect (for example, on the average, with growing redshift $z$ the luminosities of galaxies, sizes of galaxies and the proportion of early-type galaxies increase) [33]. So, we divide the whole redshift region into 18 bins of width 0.01, and perform the comparative studies of color properties between the CG sample and the random group sample in the same redshift bins. Fig.1 respectively show the mean colors of member galaxies as a function of redshift $z$ for the CG sample (dot) and the random group sample (dashed line). Error bars represent standard deviation in each redshift bin for member galaxies of the CG sample. In Fig.1c, abnormally large standard deviation of $r-i$ color in the redshift bin $0.07 \le z < 0.08$ is due to some galaxy having abnormally large $r-i$ color.

Although we do not observe as large statistical difference between the CG sample and the random group sample as Lee et al. [5] results, it is clear that mean colors of CG galaxies are on average redder than those of field galaxies

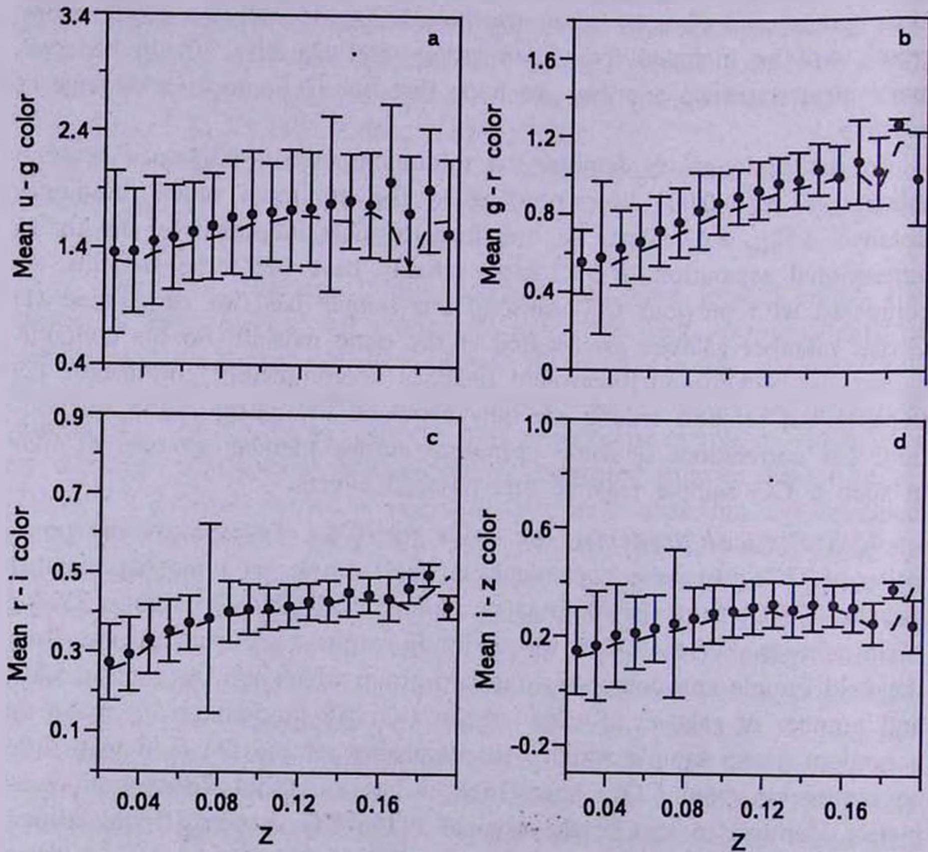


Fig.1. The mean colors of member galaxies as a function of redshift $z$ for the CG sample(dot) and the random group sample(dashed line). Error bars represent standard deviation in each redshift bin for the CG sample.

- at least for $u-g$ color and $g-r$ color. Galaxy colors can be used as a rough indication of morphological type: red galaxies tend to be ellipticals and S0's, while blue galaxies tend to be spirals and irregulars. Lee et al. [5] concluded that SDSSCGs contain a relatively higher fraction of elliptical galaxies than does the field. *N*-body simulations pioneered by Toomre [35] indicated that the end-product of merging spirals can be an elliptical galaxy. So, above conclusion is likely due to the cumulative effect of interactions and mergers over the course of a typical CG lifetime.

In Fig.2, we have also calculated the mean colors of each CG and each random group and show distribution of mean colors of CGs (solid line) and random groups(dashed line) for different color indices. As seen from these figures, the CG sample has higher proportion of groups with redder mean colors than the random group sample for different color indices. This further demonstrates above conclusion.

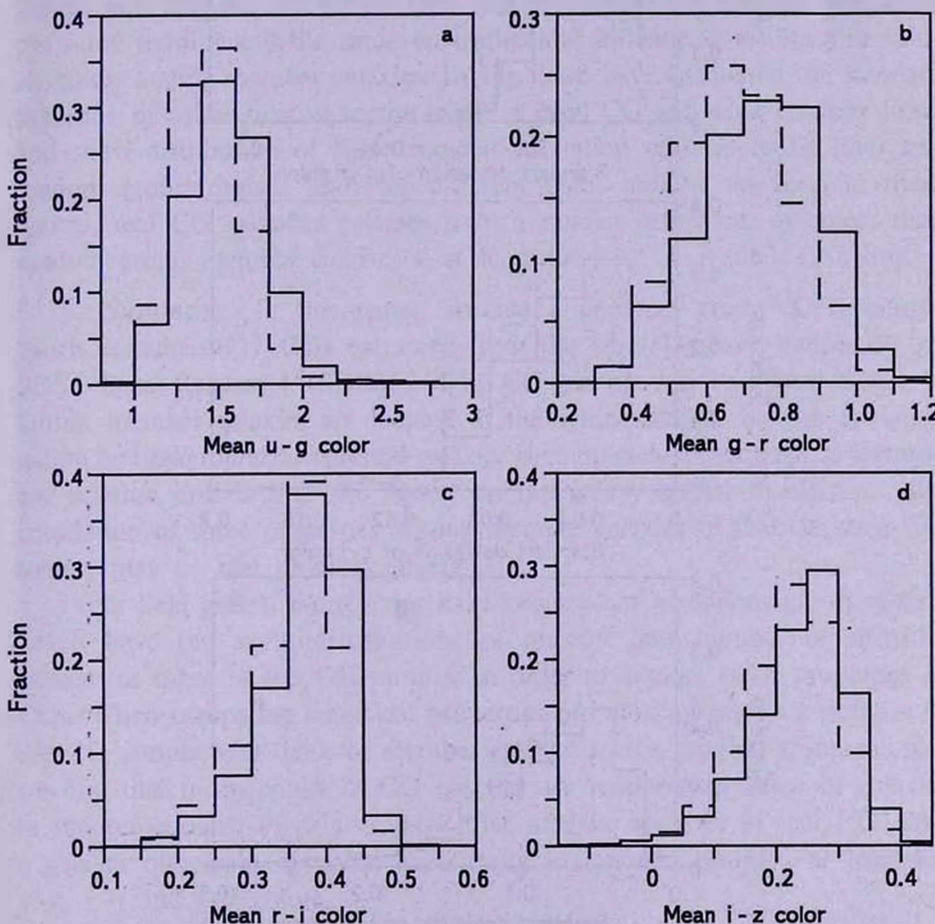


Fig.2. Histograms of distribution for mean colors of CGs (solid line) and random groups (dashed line).

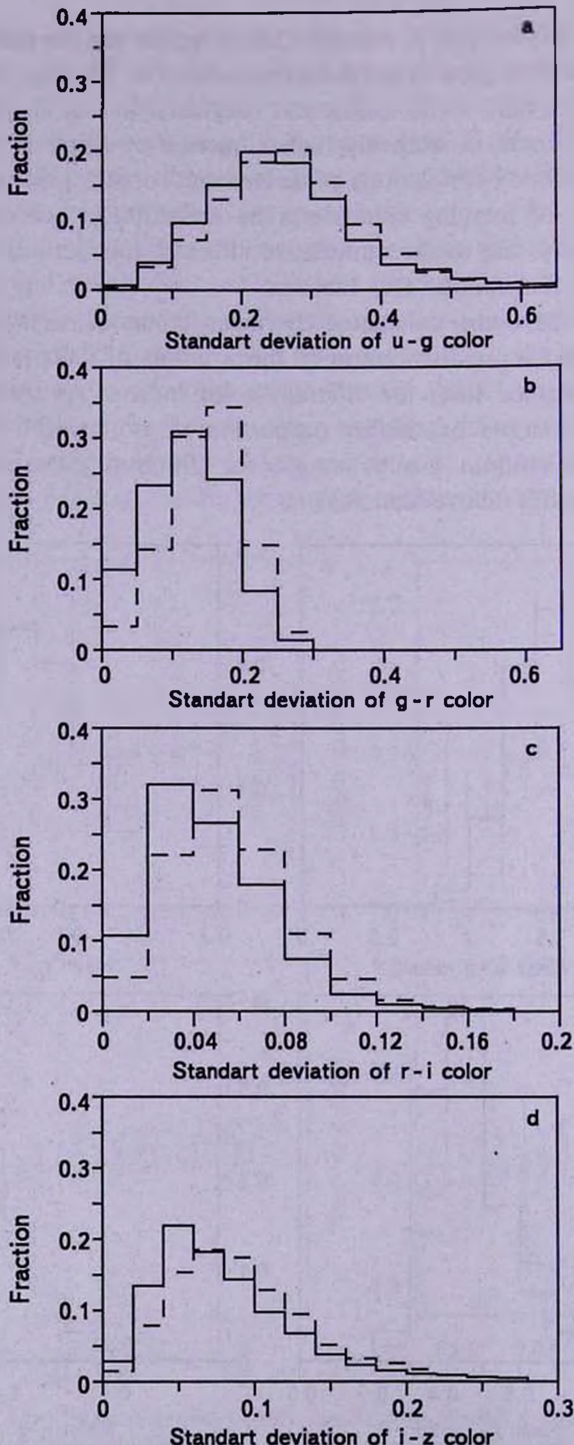


Fig.3. Histograms of distribution for standard deviation of colors of CGs (solid line) and random groups (dashed line).

According Deng et al. [33] analyses, the proportion of early-type galaxies increases with redshift $z$. In Fig.1b, we also notice that there is a significant tendency for $g-r$ color of galaxies to become redder with redshift $z$. This is due to the correlation between color and morphological type. Strateva et al.[36] found that for $u-r$ color distribution the blue galaxies are dominated by late types while the red galaxies are dominated by early types.

Bower et al. [37] observed $U$ and $V$ photometry of spheroidal galaxies in two local clusters, Virgo and Coma, and found a very small scatter, $\delta(U-V) < 0.035$ rms. Similarly, Stanford et al. [38] studied optical-infrared colors $(R-K)$ of early-type (E + S0) galaxies in 19 galaxy clusters out to $z = 0.9$ and observed a very small dispersion in the optical-infrared colors of ~0.1 mag rms. Goto et al. [39] considered that cluster members have similar colors and used color cuts to enhance the contrast of galaxy clusters. Because compact groups are often located within the bounds of loose groups and clusters, we expect that real group member galaxies will share the same redshift and the same environmental influences, resulting in similar colors among member galaxies. In Fig.3, we have calculated the standard deviation of colors relative to the mean in each CG and each random group and show distribution of color standard deviation of CGs (solid line) and random groups(dashed line) for different color indices. As seen in these figures, real CG member galaxies have a smaller dispersion of colors than random group member galaxies - at least for $g-r$, $r-i$ and $i-z$ colors.

5. *Summary*. In this paper, we use a compact group (CG) sample which contains 4217 CGs extracted from the MAIN galaxy sample of the SDSS Data Release 4 (SDSS4). This CG sample has two advantages: 1) Group member galaxies are located at the same redshift. So the contamination by background/foreground galaxies is completely eliminated. 2) Because our seletion criteria are only based on the galaxy spatial distribution, the correlation of some properties among member galaxies of CGs in such CG sample may be real physical effects.

From field galaxy sample, we have constructed a random group sample which have the same distributions of redshift and number of member galaxies as those of the CG sample, in order to explore color properties of CGs. When comparing statistical properties of colors of member galaxies in the CG sample with those of member galaxies in the random group sample, we find that mean colors of CG galaxies are redder than those of galaxies in random groups. Fig.3 also show that member galaxies in real CG have a smaller dispersion of colors than those in random groups - at least for $g-r$, $r-i$ and $i-z$ colors.

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## ЦВЕТОВЫЕ ОСОБЕННОСТИ КОМПАКТНЫХ ГРУПП MAIN ГАЛАКТИК ИЗ SDSS4

КСИН-ФА ДЕНГ, ДЖИ-ЖУ-ХИ, ПЕНГ ДЖЯНГ, КОН ГЕН ХИ, ЧЕНГ-ХОНГ ЛЮО, ПИНГ ВУ

Чтобы сравнить цветовые статистические особенности галактик в компактных группах с теми же особенностями для галактик поля, мы использовали выборку компактных групп (КГ), содержащую 4217 КГ, выведенных из выборки MAIN галактик из SDSS4. Составлена также выборка случайных групп, имеющих одинаковое распределение красных смещений и одинаковое число галактик, что и выборка КГ. Оказалось, что галактики в КГ имеют более красный цвет, чем галактики в случайных группах. Кроме того, мы также нашли, что, по крайней мере, для $g-r$, $r-i$ и $i-z$ дисперсия цветов галактик в реальных КГ меньше, чем для галактик в случайных группах.

Ключевые слова: *Галактики: фундаментальные параметры - галактики: широкомасштабная структура*

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