АСТРОФИЗИКА

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THE CORRELATIONS AMONG COLOR, MORPHOLOGY AND LUMINOSITY FOR THE LUMINOUS RED GALAXY (LRG) SAMPLE OF THE SDSS DATA RELEASE 5

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We have investigated the correlations among color, morphology and luminosity for all LRGs, cut I LRGs, cut II LRGs and Main galaxies which are also classified as LRGs, respectively. It is found that the morphology of LRGs is tightly correlated with luminosity. The rest-frame $u-g$ color of cut I LRGs and cut II LRGs is nearly independent of luminosity, but the color of Main galaxies is correlated with luminosity. For cut I LRGs and Main galaxies, the early-type proportion apparently changes with color: at the rest-frame $u-g<1.3$ it increases strongly with increasing color, while at the rest-frame $u-g>1.3$ it decreases with increasing color. We also notice that the morphology of cut II LRGs is only weak function of color.

Key words: *galaxies: fundamental parameters: statistics*

1. *Introduction*. It has long been known that there are strong correlations among physical properties of galaxies. The correlation between morphological type and luminosity of galaxies is that high-luminosity galaxies are preferentially "early type", and that the late (early) type fraction decreases (increases) strongly with increasing luminosity [1-4]. The type of galaxies also correlate with other properties, such as colors [5]. By investigating the optical colors of 147920 galaxies of the Sloan Digital Sky Survey (SDSS) (brighter than $g=21$), Strateva et al. [5] found that the color distribution of galaxies is strongly bimodal, with an optimal color separator of $u-r=2.22$, and that the two peaks correspond roughly to early (E, S0, Sa) and late (Sb, Sc, Irr) type galaxies. This indicated that the blue galaxies are indeed dominated by late types while the red galaxies are dominated by early types.

The most well-studied relation is correlation between color and luminosity of galaxies, the so-called color-magnitude relation (CMR) [1,2,6-13]. Galaxy colors (at least of early-type) depend strongly on luminosity, in the sense that more luminous galaxies are redder [12,14-25]. The tight color-magnitude relation for early-type galaxies often be established as a metallicity-luminosity correlation: more massive, and thus more luminous, galaxies retain more metals than less massive ones [26-28]. Furthermore, these properties of galaxies are also related with the environment [4,12,29-44]. In short, different physical properties of galaxies are closely related to each other.

The SDSS galaxy data contains two interesting samples: the MAIN Galaxy sample [45] and the Luminous Red Galaxy (LRG) [46]. The Main Galaxy sample has a median redshift of 0.10 and few galaxies beyond $z=0.25$, while the LRG sample are located at higher redshift and contains intrinsically red galaxies. Some studies showed these two samples may have different properties, for example, LRGs show stronger clustering on smaller scales [47,48], while in the MAIN Galaxy sample there is the existence of super-large-scale structures such as the Great Wall of galaxies [49,50]. In this paper, we use the Luminous Red Galaxy (LRG) sample of the SDSS Data Release 5 [51] and investigate the correlations among color, morphology and luminosity. Our paper is organized as follows. In section 2 we describe the galaxy data to be used. Correlations among color, morphology and luminosity are discussed in section 3. Our main results and conclusions are summarized in section 4.

2. *Data*. The SDSS observes galaxies in five photometric bands (u, g, r, i, z) centered at (3540, 4770, 6230, 7630, 9130 Å). York et al. [52] provided the technical summary of the SDSS. The imaging camera was described by Gunn et al. [53], while the photometric system and the photometric calibration of the SDSS imaging data were roughly described by Fukugita et al. [54], Hogg et al. [55] and Smith et al. [56] respectively. Pier et al. [57] 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 [58]. Galaxy spectroscopic target selection of SDSS can be implemented by two algorithms. The Main galaxy sample [45] targets galaxies brighter than $r < 17.77$ (r-band apparent Petrosian magnitude). Most galaxies of this sample are within redshift region $0.02 \le z \le 0.2$. The Luminous Red Galaxy (LRG) algorithm [46] selects galaxies to $r < 19.5$ that are likely to be luminous early-types, based on the observed colors. These LRGs are intrinsically red and at higher redshift. In order to extract LRGs, Eisenstein et al. [46] used different selection cuts above and below $z \approx 0.4$: cut I (the low-redshift cut) and cut II (the highredshift cut).

We download data from the Catalog Archive Server of the SDSS Data Release 5 [51] by the SDSS SQL Search (http://www.sdss.org/). Eisenstein et al. [46] showed that the LRG spectroscopic sample contains luminous and red galaxies with early-type spectra out to $z \approx 0.55$, and strongly advised the researcher that LRGs should be selected at $z > 0.15$. Thus, in redshift region: $0.16 < z < 0.55$, we extract 81392 LRGs (with SDSS flag: Primtarget_Galaxy_

Red, redshift confidence level: zconf > 0.95): 73707 cut I LRGs and 7685 cut II LRGs. At $z \leq 0.3$ the LRG sample will include some galaxies that are bright enough to be in the Main galaxy sample. We totally select 19849 Main galaxies which are also classified as LRGs.

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 km s^{-1} Mpc^{-1} with $h = 0.7$.

3. *Correlations among color, morphology and luminosity.*

3.1. *Correlations between morphology and luminosity.* Because the LRG sample spans a wide range of redshifts, the interpretations of the sample often require the application of K-corrections and stellar population evolution corrections (K + e corrections) for comparison of photometry at different redshifts. As described in Appendix B of Eisenstein et al. [46], we use the measured redshift and the observed r_{petro} magnitude to construct the rest-frame, passively evolved g_{petro} absolute magnitude M_g. In this paper, we have selected the "nonstar-forming" model presented in Appendix B of Eisenstein et al. [46] and normalized to M_g at $z = 0$. Fig.1 shows the distribution of the g_{petro} absolute magnitude for all LRGs.

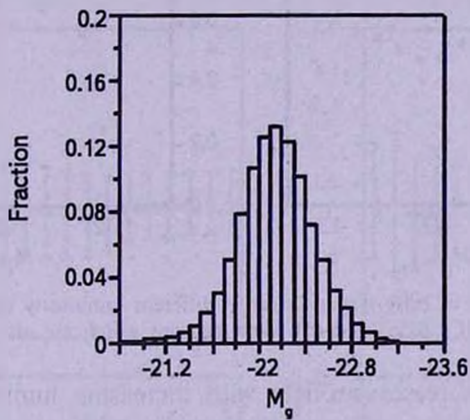

Fig.1. The luminosity distribution of all LRGs of SDSS5.

In this paper, the concentration index $c_i = R_{90}/R_{50}$ is used to separate early-type (E/S0) galaxies from late-type (Sa/b/c, Irr) galaxies [59]. R_{50} and R_{90}, are the radii enclosing 50% and 90% of the Petrosian flux, respectively. As is well-known, the galaxy morphology is closely correlated with many other parameters, such as color and concentration index. Naturally, these parameters can be used as the morphology classification tool [5,59-62]. The concentration parameter is a good and simple morphological parameter. Nakamura et al. [63] study showed that $c_i = 2.86$ separates galaxies at S0/a with a completeness of about 0.82 for both late and early types. Fig.2 illustrates the proportion of early-type galaxies as a function of luminosity for all LRGs, cut I LRGs, cut II LRGs, and Main galaxies which are also classified as LRGs, respectively. The absolute magnitude region is divided into 16 bins of width 0.2. The proportion of early-type galaxies in each absolute magnitude bin is calculated. As seen from Fig.2, the proportion of early-type galaxies increases with increasing luminosity at low luminosity region $M_g > -22$. This result further confirms previous conclusion:

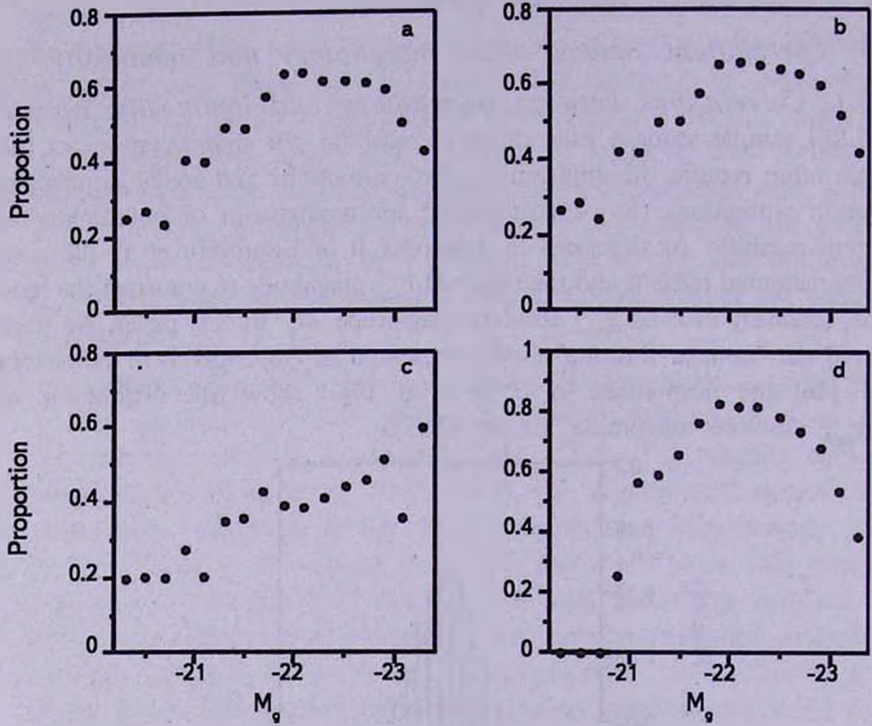

Fig.2. The proportion of early-type galaxies in different luminosity bins for (a) all LRGs, (b) cut I LRGs, (c) cut II LRGs, and (d) Main galaxies which are also classified as LRGs.

early type fraction increases strongly with increasing luminosity [1-4]. For example, using photometry and spectroscopy of 144609 galaxies from the Sloan Digital Sky Survey, Blanton et al. [1] found that highly luminous galaxies are more concentrated, and thus have higher S'ersic indices, than lower luminosity galaxies. But at high luminosity region $M_g < -22$, early type fraction decreases strongly with increasing luminosity for cut I LRGs and Main galaxies-especially for Main galaxies. This is also in qualitative agreement with results found by Blanton et al. [1]. Blanton et al. [1] indicated that the reddest galaxies (according to the correlation between color and luminosity, these galaxies are also the most luminous galaxies) are in optical colors exponential galaxies (S'ersic index $n < 1.5$), not concentrated galaxies (S'ersic index $n > 3$).

We notice that at high luminosity region $M_r < -22$, early type fraction still increases strongly with increasing luminosity for cut II LRGs. This shows that there is the existence of the difference of statistical properties between cut I LRGs and cut II LRGs, which was also found in other works. For example, Eisenstein et al. [46] showed that the luminosity of cut II LRGs is approximately independent of rest-frame color, whereas cut I LRGs have a strong correlation between the two. We are not clear whether this difference is due to selection effect or a physical effect.

3.2. *Correlations between color and luminosity*. Because the observed g and r bands at the typical redshift of the LRG sample are close to the rest-frame u and g bands respectively, we use the observed $g-r$ color to compute the rest-frame $u-g$ color in this paper. As the same as Eisenstein et al. [46], all colors refer to differences of model magnitudes.

In Fig.3, we present the mean color and the standard deviation in different absolute magnitude bins (bin = 0.2) for all LRGs, cut I LRGs, cut II LRGs and Main galaxies which are also classified as LRGs, respectively. In the LRG sample, few galaxies have abnormal color (abnormally large or small) which results in abnormally large standard deviation in some absolute magnitude bins. So, we exclude objects with the rest-frame $u-g>3$ or $u-g<1$. As seen from

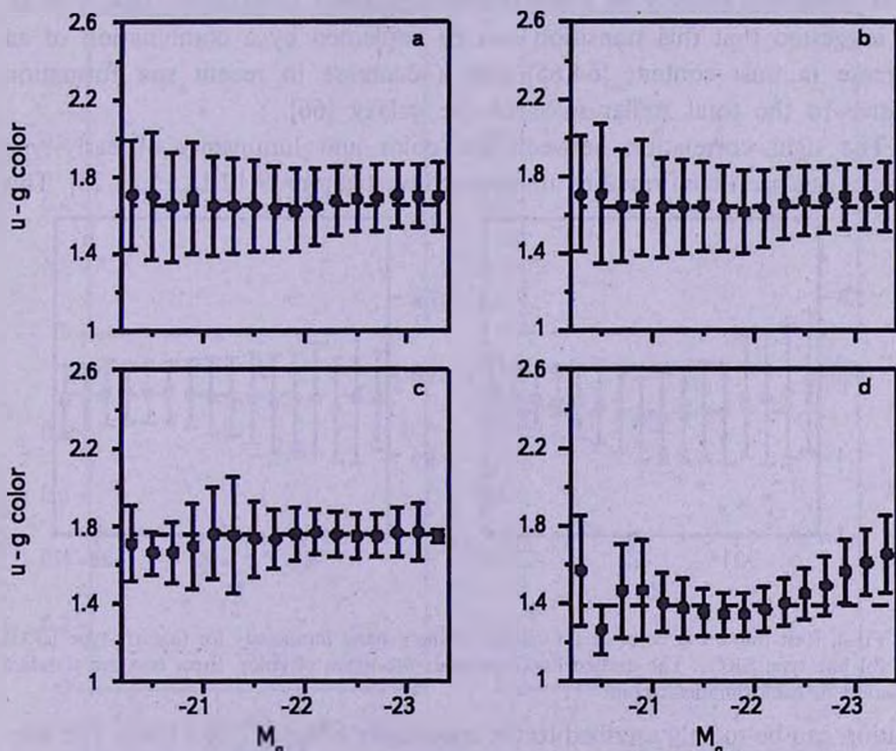

Fig.3. Rest-frame u - g color as a function of the g-band luminosity for (a) all LRGs, (b) cut I LRGs, (c) cut II LRGs and (d) Main galaxies which are also classified as LRGs.. The dashed line represents the mean of color. Error bars are standard deviation in each luminosity bin.

Fig.3, the color of cut I LRGs and cut II LRGs is nearly independent of luminosity, which is not consistent with previous conclusion: more luminous galaxies are redder[12,14-25]. This does not also agree with that found by Eisenstein et al. [46]. Eisenstein et al. [46] showed that the luminosity of cut II LRGs is approximately independent of rest-frame color, whereas cut I LRGs have a strong correlation between the two.

But in Fig.3d we also notice that the rest-frame $u-g$ color of Main galaxies increases strongly with increasing luminosity at $M_g < -22$, while the color for faint galaxies (i.e. $M_g > -22$) have weak correlation with the luminosity. This is agreement with that found by Baldry et al. [2]. Using a low redshift sample of galaxies from the Sloan Digital Sky Survey, Baldry et al. [2] obtained color-magnitude(CM) relations ($u-r$ vs. M_r) for red and blue distributions (early- and late-type). For each distribution, the mean $u-r$ color increases contiguously with luminosity. Further, in different luminosity regions, the slope of color-magnitude (CM) relations is different. For the low-luminosity blue-distribution galaxies ($M_r \geq -19$), Baldry et al. [2] found a shallow CM relation slope that is consistent with a metallicity-luminosity correlation. Over the luminosity range from $M_r = -19.5$ to $M_r = -22$, the CM relation slope becomes too steep to be explained entirely by a metallicity-luminosity correlation. Baldry et al. [2] suggested that this transition can be explained by a combination of an increase in dust content [64,65] and a decrease in recent star formation relative to the total stellar mass of the galaxy [66].

The tight correlation between the color and luminosity of early-type galaxies has been confirmed by numerous investigators [9,12,13,15,24,25]. This

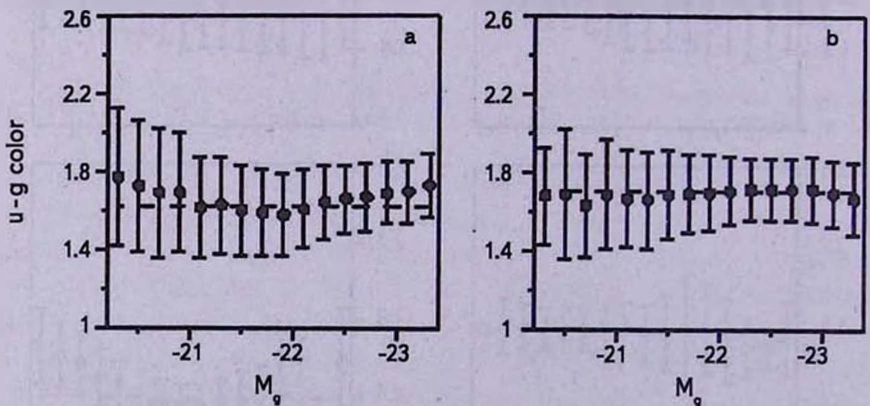

Fig.4. Rest-frame u-g color as a function of the g-band luminosity for (a)early-type LRGs and (b) late-type LRGs. The dashed line represents the mean of color. Error bars are standard deviation in each luminosity bin.

relation can be mainly ascribed to the metallicity effect [27,28,67,68]. For late-type galaxies the color is also closely correlated with luminosity [65,66,69-71]. Because massive galaxies may have older and higher metallicity stellar populations than less massive galaxies, Chang et al. [71] suggested that the CMRs of late-type galaxies are the combined results of stellar mean age and metallicity. In our work, we divide all LRGs into two groups: early-type and late-type and calculate color-magnitude(CM) relations for early-type and late-type distributions. As seen from Fig.4, for each distribution, colors of LRGs are weak functions of luminosity. Clearly, this is not consistent with above results.

3.3. *Correlations between morphology and color.* The principal relationship between color and morphology [5] is that early types are generally redder than more late types. Due to this relation, many authors even assume that the red and blue distributions correspond in general to the morphological definitions of early and late types. Fig.5 illustrates the proportion of early-type galaxies as a function of the rest-frame $u-g$ color for all LRGs, cut I LRGs, cut II LRGs and Main galaxies which are also classified as LRGs, respectively. We again notice the difference of statistical properties between cut I LRGs and cut II LRGs. For cut I LRGs there is a tight correlation between color and morphology, while the morphology of cut II LRGs is weak function of color. Additionally, on the average, the early-type proportion of cut I LRGs is apparently higher than that of cut II LRGs. At the rest-frame

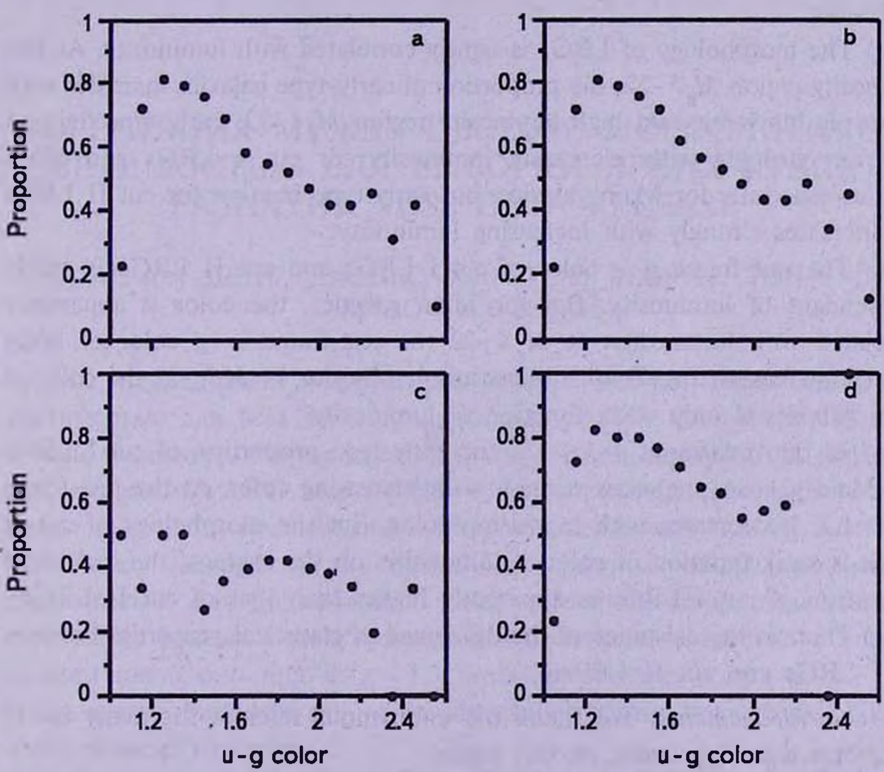

Fig.5 The proportion of early-type galaxies as a function of colors for (a) all LRGs, (b) cut I LRGs, (c) cut II LRGs and (d) Main galaxies which are also classified as LRGs.

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$u-g<1.3$, the early-type proportion of cut I LRGs and Main galaxies increases strongly with increasing color. This is consistent with above relationship between color and morphology: early types are generally redder than more late types. Blanton et al. [1] ever found that the reddest galaxies are in optical colors exponential galaxies (S'ersic index $n<1.5$), not concentrated galaxies(S'ersic index $n>3$). In Fig.5, we also notice that at the rest-frame $u-g>1.3$, the early-type proportion of cut I LRGs and Main galaxies decreases strongly with increasing color. In this paper, the concentration index $c_i=R_{90}/R_{50}$ is used to separate early-type galaxies from late-type galaxies. When developing a selection criterion $c_i=2.86$, Nakamura et al. [63] only used nearby bright galaxies. It has been known for a long time that concentration index is very sensitive to seeing as shown in Blanton et al. [1]. Above abnormality suggests that we should not use concentration index for classification of galaxies at wide range of redshift like this study.

4. *Summary*. Using the LRG sample of the SDSS Data Release 5, we have investigated the correlations among color, morphology and luminosity for all LRGs, cut I LRGs, cut II LRGs and Main galaxies which are also classified as LRGs, respectively. The main conclusions can be summarized as follows:

1) The morphology of LRGs is tightly correlated with luminosity. At low luminosity region $M_g>-22$, the proportion of early-type galaxies increases with increasing luminosity. At high luminosity region $M_g<-22$, early type fraction decreases strongly with increasing luminosity for cut I LRGs and Main galaxies-especially for Main galaxies, but early type fraction for cut II LRGs still increases strongly with increasing luminosity.

2) The rest-frame $u-g$ color of cut I LRGs and cut II LRGs is nearly independent of luminosity. But for Main galaxies, the color is apparently correlated with luminosity: at $M_g<-22$ the rest-frame $u-g$ color of Main galaxies increases strongly with increasing luminosity, at $M_g>-22$ the color of Main galaxies is only weak function of luminosity.

3) At the rest-frame $u-g<1.3$, the early-type proportion of cut I LRGs and Main galaxies increases strongly with increasing color. At the rest-frame $u-g>1.3$, it decreases with increasing color. But the morphology of cut II LRGs is weak function of color. Additionally, on the average, the early-type proportion of cut I LRGs is apparently higher than that of cut II LRGs.

4) There is the existence of the difference of statistical properties between cut I LRGs and cut II LRGs.

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КОРРЕЛЯЦИЯ МЕЖДУ ЦВЕТОМ, МОРФОЛОГИЕЙ И СВЕТИМОСТЬЮ ДЛЯ ВЫБОРКИ ЯРКИХ КРАСНЫХ ГАЛАКТИК SDSS DATA RELEASE 5

КСИН-ФА ДЕНГ, ДЖИ-ЖУ-ХИ, ПЕНГ ДЖЯНГ, ПИНГ ВУ, ХИАО-ХИА КИАН

Мы исследовали корреляцию между цветом, морфологией и светимостью для всех LRG, подвыборки I LRG, подвыборки II LRG и Main галактик, которые также классифицированы как LRG. Найдено, что морфология LRG тесно коррелирована со светимостью. В системе покоя $u-g$ цвета подвыборки I LRG и подвыборки II LRG почти не зависят от светимости, но цвета Main-галактик коррелированы со светимостью. Для подвыборки I LRG и Main-галактик относительное количество ранних типов, по-видимому, меняется с цветом: с покраснением цвета оно при $u-g<1.3$ резко возрастает, а при $u-g>1.3$ - уменьшается. Видно также, что морфология галактик подвыборки II LRG слабо зависит от цвета.

Ключевые слова: *галактики:фундаментальные параметры:статистика*

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