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The Bimodal Color Distribution of Galaxies at Redshift of z=0-0.15 from the Sloan Digital Sky Survey (SDSS)

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Abstract

This work aims to use the color distribution of galaxies to differentiate between blue and red galaxies. The photometric data of 300000 galaxies at redshift of z = 0 – 0.15 were collected from the Sloan Digital Sky Survey (SDSS). Three redshift ranges were considered for the purpose of this work: 100000 galaxies at z = 0-0.05, 100000 galaxies at z = 0.05-0.1 and 100000 galaxies at z = 0.1-0.15. The color distributions for all redshift ranges were determined. The results have clearly shown that the color distributions for all redshift ranges are bimodal. One of the two peaks corresponds to the blue galaxies (young and star-forming galaxies), whereas the other peak corresponds to the red galaxies (old and non-star-forming galaxies). Therefore, the color distribution of galaxies can be considered as an efficient tool to distinguish between blue and red galaxies.

Keywords: Classification of Galaxies, Formation and Evolution of Galaxies, Photometric Data.

الخلاصة

يهدف هذا العمل لاستخدام توزيع اللون للمجرات لغرض التمييز بين المجرات ذات اللون الازرق والمجرات ذات اللون الاحمر. البيانات الفوتومترية لـ ٣٠٠٠٠٠ مجرة تم تجميعها من موقع Sloan Digital Sky Survey. ثلاثة مديات مختلفة للزحزحة نحو الاحمر تم اعتمادها لغرض تحقيق هدف هذا العمل: ١٠٠٠٠٠ مجرة ذات زحزحة نحو الاحمر z = 0-0.05، ١٠٠٠٠٠ مجرة ذات زحزحة نحو الاحمر z = 0.05-0.1 و ١٠٠٠٠٠ مجرة ذات زحزحة نحو الاحمر z = 0.1-0.15. تم تحديد توزيع اللون لكل مديات الزحزحة نحو الاحمر. بينت النتائج بصورة واضحة وجلية بأن توزيع اللون لكل مديات الزحزحة نحو الاحمر هي توزيعات ثنائية القمة (تحتوي على قمتين). احدى القمتين تتوافق مع المجرات الزرقاء (المجرات الفتية والقادرة على ولادة نجوم جديدة)، بينما القمة الاخرى فهي تتوافق مع المجرات الحمراء (المجرات القديمة وغير القادرة على ولادة نجوم جديدة). لذلك فأن توزيع اللون للمجرات يمكن ان يعتبر اداة فعالة للتفريق بين المجرات الزرقاء والمجرات الحمراء.

Introduction

Different types of galaxies have different physical properties. Therefore, it is useful to classify galaxies into different groups. The first morphological classification of galaxies was proposed by Hubble in the twenties of last century [1]. Hubble classified galaxies into three main types: elliptical, lenticular and spiral galaxies. His scheme of classification is now known as Hubble tuning fork diagram. Elliptical galaxies are usually denoted by the letter E followed by a number that represents the degree of ellipticity. On the other hand, spiral galaxies can be subdivided into two groups: normal spirals (Sa, Sb, Sc) and barred spirals (SBa, SBb, SBc). The intermediate galaxies between ellipticals and spirals are referred to as lenticular galaxies (S0). A recent description of the Hubble classification scheme of galaxies was also presented in the second edition of Schneider's book that was published in 2015 [2].

Several previous studies showed that the color of galaxies provides wealth of information about their morphological types and ages. For example, a study that was published in 2001 showed that the color distribution of a sample of 147920 galaxies is bimodal [3]. Another study that was published in 2008 showed that the evolution of galaxies can be studied as a function of their color. They also confirmed that the color distribution of galaxies is bimodal [4]. It was pointed out in a previous work that the bimodality arises due to two natural features: 1- star formation histories of massive red galaxies that are formed in biased high density regions, and are peaked at higher redshift as compared to lower mass galaxies; and 2- the existence of a non-gravitational mass scale [5]. Simulated galaxies from IllustrisTNG were used recently to investigate the bimodality of color distributions of galaxies. An excellent agreement was found between the simulated color distributions of galaxies and the observed counterparts from the SDSS survey [6]. On the other hand, a few recent studies have shown that the morphological classification of galaxies can be achieved with high accuracy using modern machine learning algorithms [7, 8]. Computer vision and pattern recognition techniques were also used to analyze the morphological types of about 3 million galaxies taken from SDSS survey. These techniques were found to be effective and accurate [9]. The goal of this work is to classify galaxies into two types: blue and red galaxies using the photometric data of three large samples of galaxies from SDSS survey. The collection of photometric data from SDSS was discussed in the following section. Then we present the calculations, results and discussion followed by the conclusions drawn from the results of this work.

Data collection from SDSS

The Sloan Digital Sky Survey (SDSS) is a large spectroscopic and imaging survey that uses a 2.5 m telescope at Apache Point Observatory. A description of the SDSS telescope was published in 2006 [10] and a description of the fourteenth data release of SDSS has been published recently [11].

The photometric data of three samples of galaxies at three different redshift intervals: z = 0-0.05, z = 0.05-0.1, z = 0.1-0.15 were collected from the SDSS survey. Each sample has a size of 100000 galaxies.

The data used in this work are the magnitudes of galaxies in five bands between 3000 Å and 10000 Å (u, g, r, i, z). The central wavelengths and full widths at half maximum of all bands are listed in Table 1. The data of a sub-smaple of 30 galaxies at redshifts from 0 to 0.05 were listed in Table 2.

Table 1: The properties of SDSS bands (u, g, r, i, z) [12]

Band	λ_c (Å)	FWHM (Å)
u (ultraviolet)	3500	600
g (blue-green)	4800	1400
r (red)	6250	1400
i (far red)	7700	1500
z (near infrared)	9100	1200

Table 2: The photometric data of sub-sample of 30 galaxies at redshift of z = 0 – 0.05.

u	g	R	i	z
19.38905	18.24496	17.58728	17.20807	16.90905
18.72268	17.3852	16.81134	16.51803	16.29502
21.15835	19.97747	19.44971	19.12359	19.07743
17.54884	15.75164	15.031	14.66728	14.36099
20.65226	19.77637	20.11424	19.77093	19.80214
17.61444	16.17125	15.52131	15.15564	14.86996
19.46874	18.18264	17.59063	17.26436	16.95295
24.20345	24.53743	21.62383	20.44507	20.40582
22.19689	19.6663	18.3876	17.53941	17.1504
23.9199	20.93173	19.40141	18.01012	17.23484
22.40952	21.54809	21.41933	21.24093	21.25659
20.26043	19.02534	18.56368	18.32345	18.17825
18.73592	17.4272	16.80908	16.47318	16.18574
19.39842	18.40464	18.17116	18.03709	17.93543
23.98771	21.11526	19.73831	18.50679	17.80876
18.82219	17.61563	17.08038	16.80011	16.65407
18.97349	17.54252	17.04639	16.81821	16.66867
20.6244	19.47523	18.96804	18.66734	18.48407
18.29589	16.52947	15.61466	15.09457	14.63546
19.16749	18.55299	17.69763	17.3443	17.09744
18.80279	17.16058	16.46665	16.05672	15.76566
20.88138	19.82068	19.30403	19.03388	18.85489
22.01575	22.19654	21.11957	20.49259	20.24918
23.18928	20.90349	19.58338	18.96074	18.63707
19.3949	17.55328	16.67647	16.23977	15.92742
25.67104	22.6802	21.25917	20.26896	19.56991
19.03764	17.41195	16.69575	16.31307	16.03388
18.52316	16.42145	15.39282	14.8915	14.48816
17.86614	15.8951	14.91003	14.40679	14.0132
20.61522	18.63779	17.72062	17.16121	16.71248

Results and Discussions

The data of the three samples of galaxies mentioned in the previous section were used to determine the color distribution of galaxies and differentiate between young and old galaxies. The color of galaxies can be determined from the difference between the magnitudes in two different bands. It was found that the (u-r) color is one of the colors that are more sensitive to stellar ages (see e.g. [13]. In addition, the (u-r) color is widely used to study the physical properties of astronomical objects and their environments (see e.g. [14]). Therefore, the difference between magnitudes in u and r bands is used for the purpose of this work. The (u-r) color is calculated for the three samples of galaxies and histograms are plotted in Figures 1, 2 and 3. The three figures reveal that the color distributions are bimodal for all redshift intervals. The results of this work are found to be consistent with those published by previous works (see e.g. [3, 15 and 16]).

The first peak is for blue galaxies while the other peak for the red galaxies. This means that the color distribution can be used to classify galaxies into two types: blue and red galaxies. The difference in the color of galaxies is due to the difference in the population of stars within the galaxies. The stars in blue galaxies are young and contain light elements such as hydrogen, whereas the stars in red galaxies are old and contain heavy elements such as iron. Bimodal Gaussian distributions were fitted to the histograms. The fittings were performed using *QtiPlot* on a *linux system*. The formula of the bimodal Gaussian distribution is written as follows:

$$f(x) = \frac{a_1}{\sigma_1}\sqrt{\frac{2}{\pi}}e^{-2(x-\mu_1)^2/\sigma_1^2} + \frac{a_2}{\sigma_2}\sqrt{\frac{2}{\pi}}e^{-2(x-\mu_2)^2/\sigma_2^2} \quad \ldots\ldots (1)$$

where a_1, μ_1 and σ_1 are the amplitude, mean, and standard deviation of the first peak, and a_2, μ_2 and σ_2 are the amplitude, mean and standard deviation of the second peak.

The histograms with fitted curves are plotted in Figures 4, 5 and 6. The fitting parameters of the bimodal Gaussian distributions for all redshift intervals are listed in Table 3.

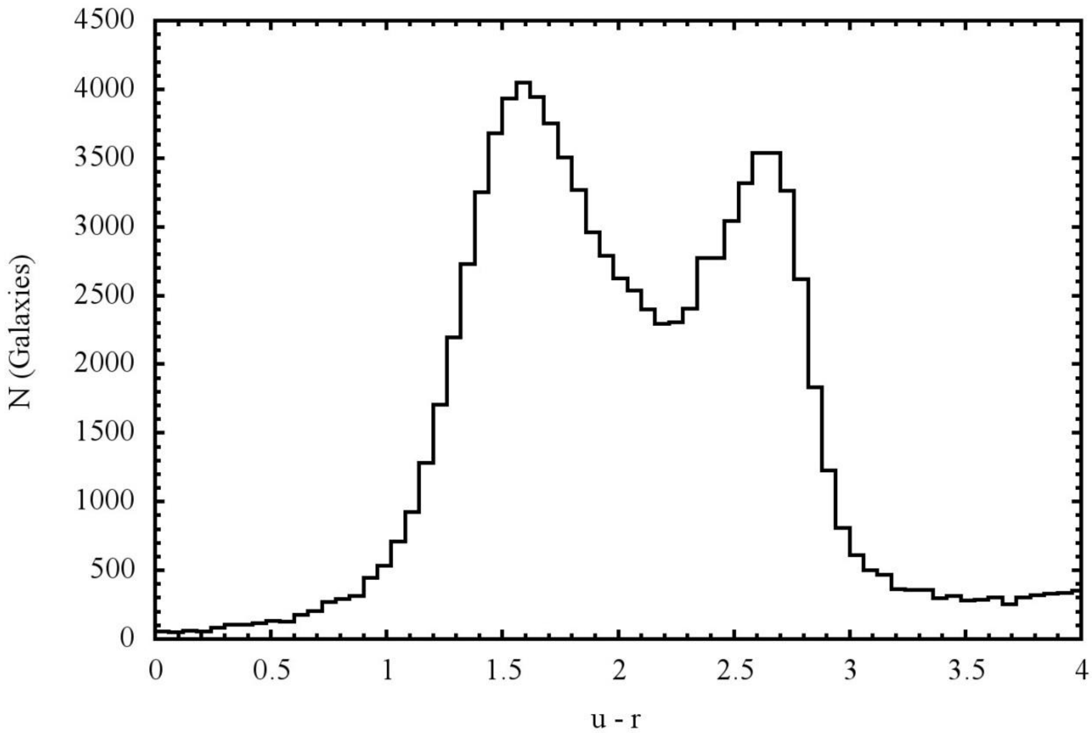

Figure 1: The histogram of color for a sample of 100000 galaxies at redshift of z = 0 – 0.05.

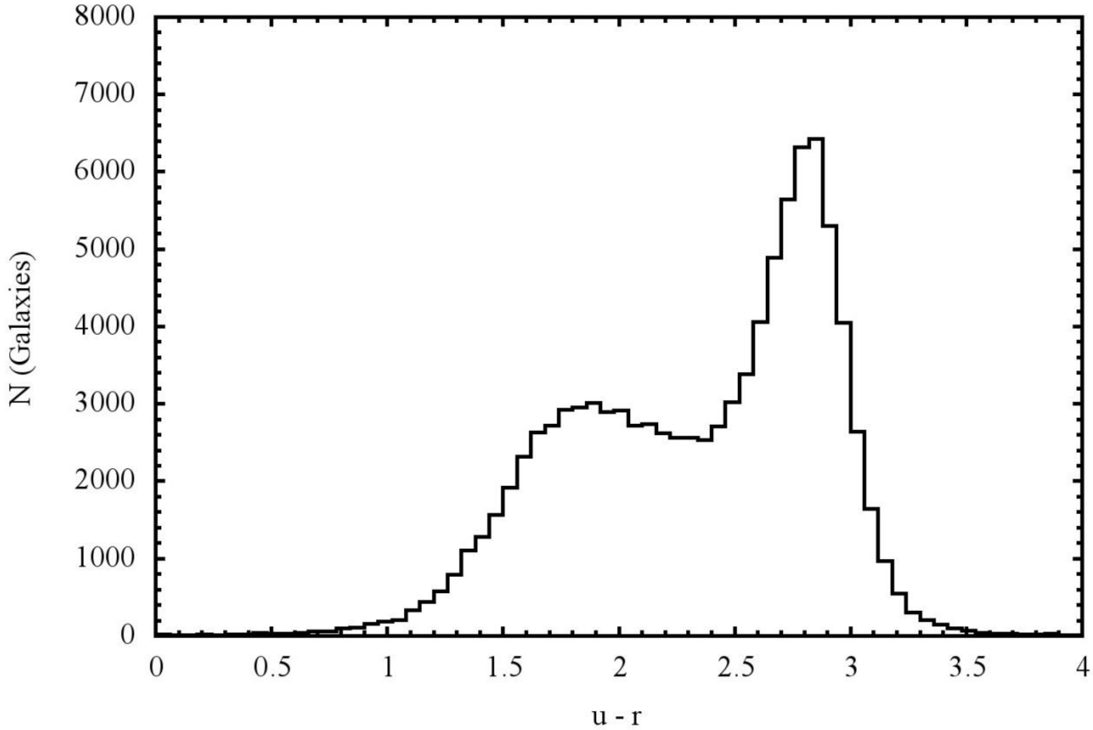

Figure 2: The histogram of color for a sample of 100000 galaxies at redshift of z = 0.05 – 0.1.

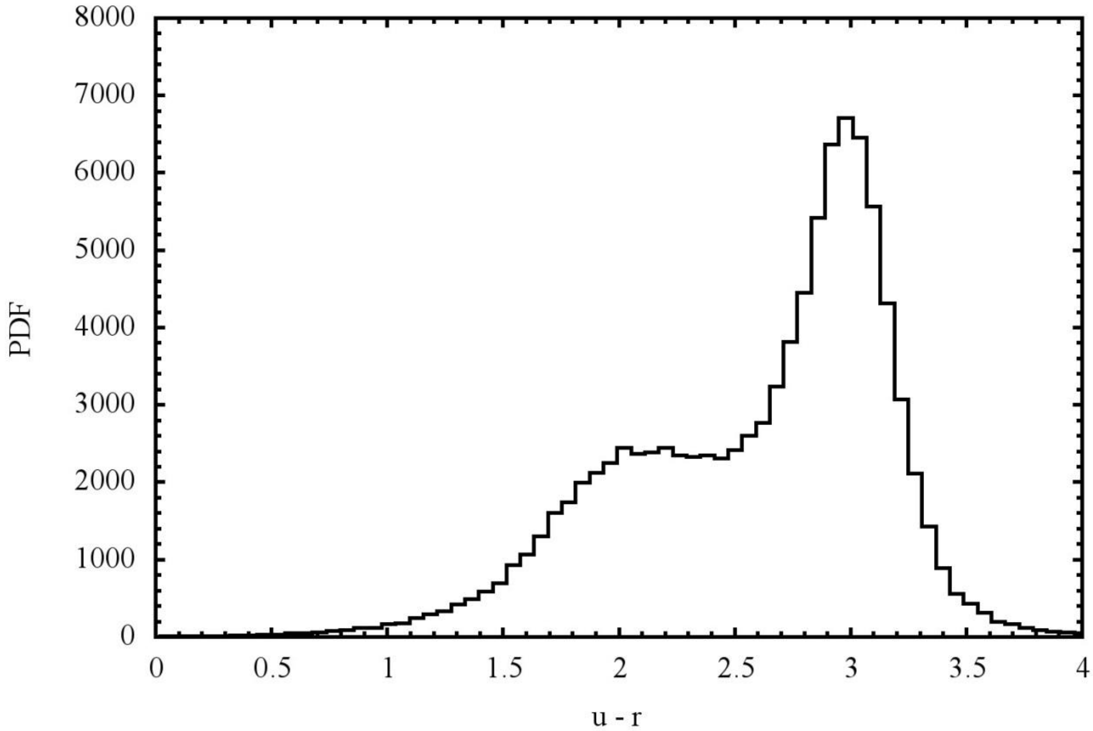

Figure 3: The histogram of color for a sample of 100000 galaxies at redshift of z = 0.1 – 0.15.

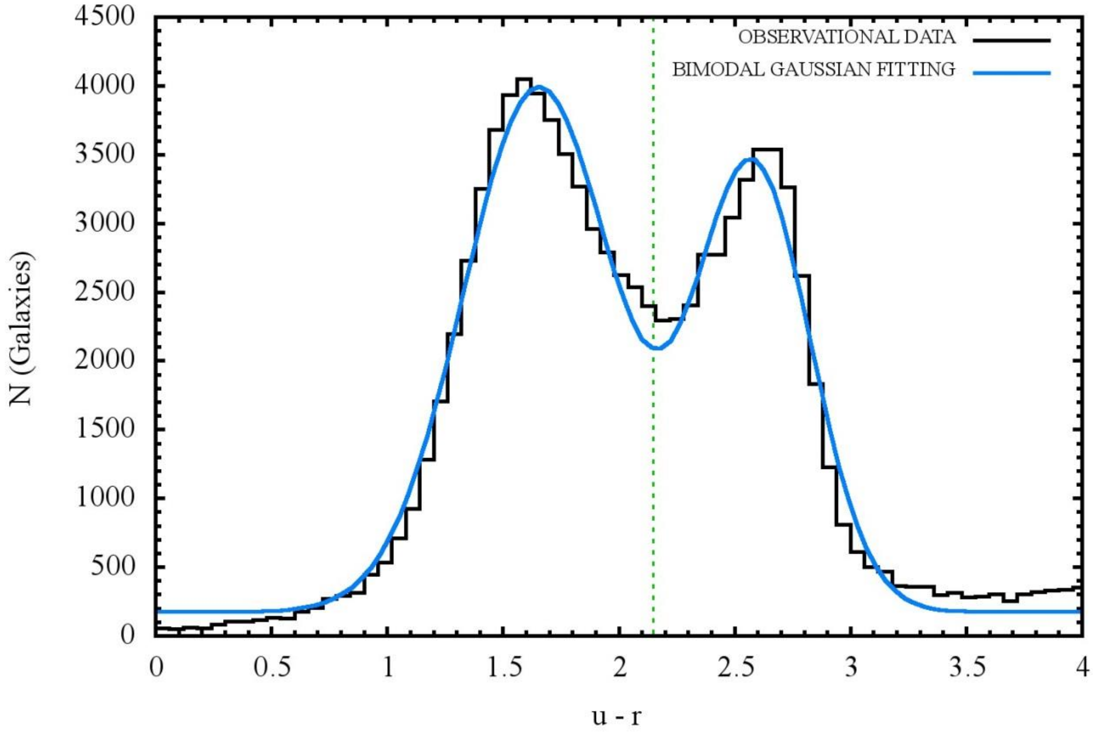

Figure 4: The fitted bimodal Gaussian curve of the color distribution for a sample of 100000 galaxies at redshift of z = 0 – 0.05.

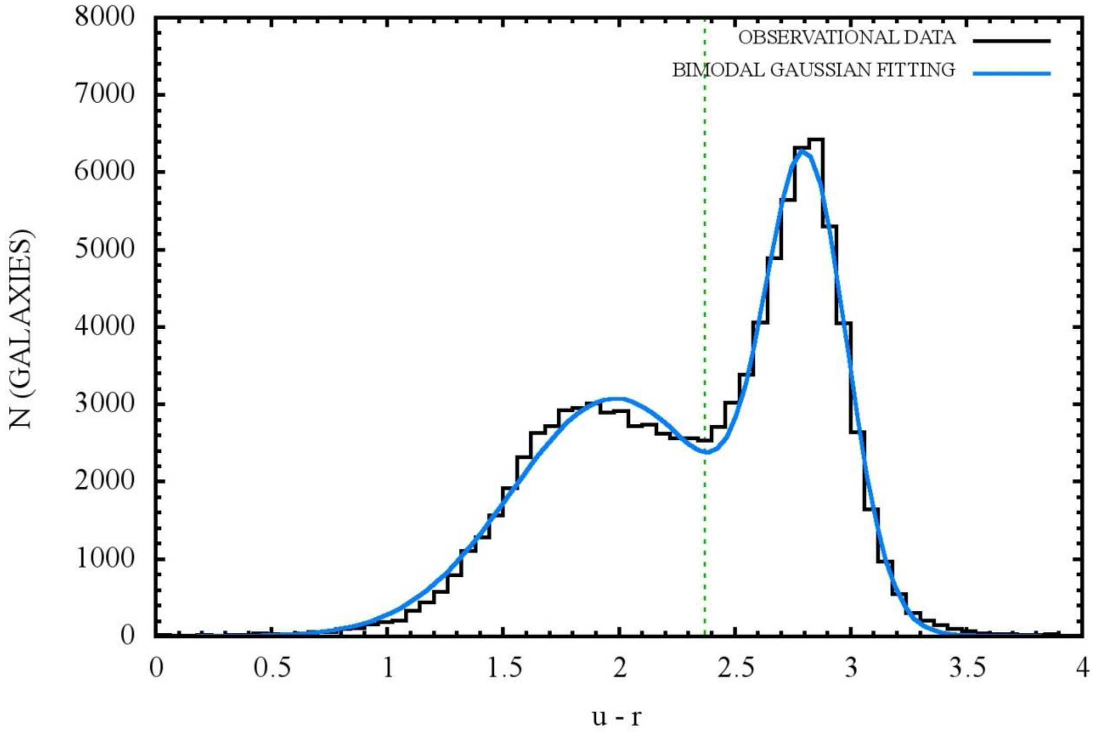

Figure 5: The fitted bimodal Gaussian curve of the color distribution for a sample of 100000 galaxies at redshift of z = 0.05 – 0.1.

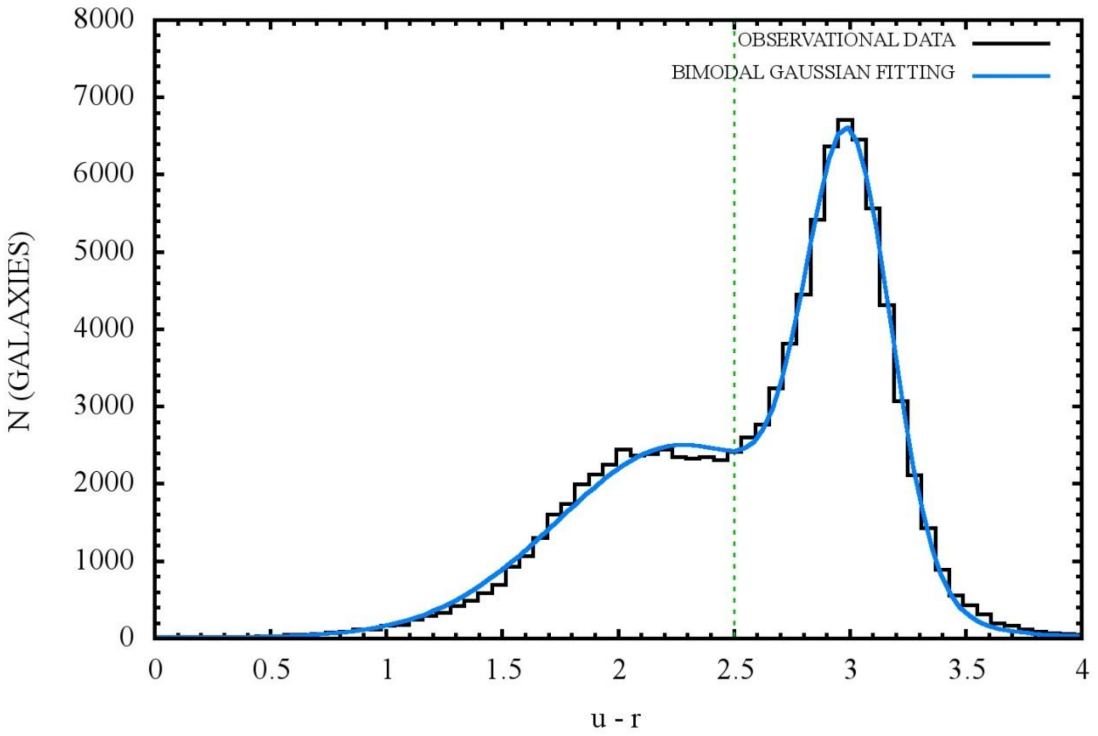

Figure 6: The fitted bimodal Gaussian curve of the color distribution for a sample of 100000 galaxies at redshift of z = 0.1 – 0.15.

Table 3: The fitting coefficients of the bimodal color distributions of galaxies.

z	a_1	μ_1	σ_1	a_2	μ_2	σ_2
0 – 0.05	3110.465 ± 0.492	1.653 ± 5.116 × 10^{-5}	0.650 ± 1.126 × 10^{-4}	2007.259 ± 0.424	2.579 ± 5.358 × 10^{-5}	0.496 ± 1.069 × 10^{-4}
0.05 – 0.1	3454.907 ± 0.706	1.984 ± 9.148 × 10^{-5}	0.897 ± 1.991 × 10^{-4}	2519.357 ± 0.496	2.810 ± 2.317 × 10^{-5}	0.352 ± 5.117 × 10^{-5}
0.1 -0.15	3354.679 ± 0.115	2.277 ± 1.864 × 10^{-4}	1.076 ± 3.308 × 10^{-4}	2530.173 ± 0.780	2.998 ± 2.154 × 10^{-5}	0.362 ± 6.667 × 10^{-5}

Conclusions

The color distributions of three samples of galaxies at redshifts from 0 to 0.15 were determined using photometric data from the SDSS survey. The key result of this work is that the color distributions are found to be bimodal for all redshift ranges considered in this work. This is due to the star formation processes in galaxies that have an impact on the color of galaxies. Blue galaxies are star-forming galaxies, whereas red galaxies are non-star-forming galaxies because they contain heavier elements. Therefore, the color distribution can be considered as an ideal tool for classifying galaxies according to their colors. In addition, it can be used to improve our understanding about the formation and evolution of galaxies. This also means that the difference in the morphological types of galaxies is due to differences in their intrinsic physical properties.

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