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Investigating the Color Distribution of Young and Old Galaxies Using Observations from SDSS

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Abstract

This research aims to investigate the color distribution of a huge sample of 613654 galaxies from the Sloan Digital Sky Survey (SDSS). Those galaxies are at a redshift of 0.001 - 0.5 and have magnitudes of g = 17 - 20. Five subsamples of galaxies at redshifts of (0.001 - 0.1), (0.1 - 0.2), (0.2 - 0.3), (0.3 - 0.4) and (0.4 - 0.5) have been extracted from the main sample. The color distributions (u-g), (g-r) and (u-r) have been produced and analysed using a Matlab code for the main sample as well as all five subsamples. Then a bimodal Gaussian fit to color distributions of data that have been carried out using minimum chi-square in Microsoft Office Excel. The results showed that the color distributions of the main sample and all subsamples are bimodal. This indicates that the color distribution is an ideal tool to differentiate between young and old galaxies. The young and blue star-forming galaxies are represented by one of the two peaks, while the old and red non-star-forming galaxies are represented by the other peaks of the color distribution.

Keywords: Galaxies, Color Distribution, Photometric Data, Redshift, Formation and Evolution of Galaxies

التحقق من التوزيع اللوني للمجرات الناشئة والقديمة باستخدام ارصاداتSDSS

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الخلاصة

يهدف هذا البحث للتحقق من التوزيع اللوني لعينة ضخمة من 613654 مجرة من مسح Sloan الرقمي للسماء (SDSS). هذه المجرات تقع ضمن مدى زحزحة نحو الأحمر بين 0,001 و 0,5 ولها اقدار حزمة g ضمن المدى (17−20). تم استخلاص خمس عينات ثانوية للمجرات ضمن مديات زحزحه نحو الأحمر (0,001 −0,1)، (0,1− 0,2)، (0,2 −0,3)، (0,3 −0,4)، (0,4 −0,5). من العينة الرئيسية للمجرات. تم رسم وتحليل التوزيعات اللونية (u−g)، (g−r)، (u−r) للعينه الرئيسية وكذلك جميع العينات الثانوية الخمسة باستخدام برنامج تم كتابته في الماتلاب. ثم تم انجاز ملائمة المنحني الكاوسي ثنائي القمة لبيانات التوزيعات اللونية للمجرات باستخدام طريقة اقل قيمة لـ Chi−square في برنامج مايكروسوفت اوفس اكسل .النتائج اظهرت ان التوزيعات اللونية للعينة الرئيسية وكل العينات الثانوية هي ثنائية القمة. وهذا يدل على ان التوزيع اللوني

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للمجرات هي اداة فعالة للتمييز بين المجرات الناشئة والقديمة. حيث تتمثل المجرات الناشئة الزرقاء والمكونة للنجوم بإحدى القمتين بينما تتمثل المجرات القديمة الحمراء وغير المكونة للنجوم بالقمة الثانية للتوزيع اللوني.

1. Introduction

Galaxies are complicated structures in the universe that contain a wide range of different objects, such as stars, gas, dust and dark matter. The physical properties of galaxies provide clues on the formation and evolution of galaxies. One of the most important properties is the color distribution. Several previous studies were carried out to examine the colors of galaxies. For instance, in 2001, a group of researchers studied the optical color of 147192 galaxies with magnitudes brighter than g = 21 using observations of galaxies in five bands of Sloan Digital Sky Survey (SDSS). They found that the early-type galaxies are redder than the late-type galaxies[1]. In 2004, the color distribution of galaxies was studied by means of observations from the Sloan Digital Sky Survey (SDSS). They used a sample of more than 24,000 galaxies and divided it into two colors, red and blue. The authors of this study found that, within virialized regions of clusters, the fraction of old galaxies does not depend significantly on velocity dispersion. They also proposed that the evolution of blue galaxies is independent of their environment[2]. In 2005, another group of astronomers compared observations of the color distribution of galaxies with that computed from a model of hierarchical galaxy formation considering different luminosities. They found that the model is consistent with observational data, particularly, the fraction of red galaxies is found to be larger in denser environments [3]. Two years later, a study was carried out to analyze a sample of galaxies from SDSS that matched with the detections in the near-ultraviolet and far-ultraviolet. Their results confirmed the bimodality feature of the color distribution of galaxies [4]. Furthermore, a study that was published in 2011 used a sample of galaxies from SDSS to investigate the dependence of their clustering on color and luminosity [5]. In 2014, several researchers conducted a research using the observation of 300000 face-on galaxies from SDSS to analyse their distributions in the color magnitude diagram, for which they used two methods of Gaussian fitting [6]. Another study that was published in 2016 used a sample of 5853 galaxies in a couple of superclusters. The analysis of this sample of galaxies revealed that ellipticals show no color gradients, regardless of their mass. Spirals, on the other hand, are found to have a steeper gradient in their color profiles for higher masses [7]. In 2017, the photometric observational data of the galaxy NGC 3351 were analysed and the results revealed that such data can be used efficiently to study the overall structure of galaxies and their morphological types [8]. A couple of years later, a group of astronomers investigated the color distribution of galaxies using COSMOS/Ultra VISTA field measurements of the spatial clustering of rest-frame UV-selected large galaxies at $0.5 \leq z \leq 2.5$. Their results, based on the rest-frame extinction-corrected UV colors, showed that three galaxy populations were distinguished: red sequence, blue cloud, and green valley [9]. In the same year, a sample of 300000 galaxies at redshifts between 0 and 0.15 from SDSS confirmed that the color distribution of galaxies was indeed bimodal [10]. In 2021, the color distributions U-V and V-J for star-forming galaxies were investigated using a model with only two free parameters. The results showed that the inclination of galaxies has an impact on dust attenuation [11].

In addition, investigating the chemical composition in galaxies provides information on the physical processes in galaxies, which can be achieved by studying the abundance of gas and other elements in galaxies [12-14]. In 2018, a study was carried out to investigate the photometric and morphological properties for a couple lenticular galaxies using SDSS pipeline [15]. It is essential to point out that investigating the properties of galaxies leads to a better understanding of larger structures like clusters of galaxies. Galaxy clusters can be probed using various methods, such as gravitational lensing [16-17].

The focus in this research is on the color distribution of galaxies and using it to distinguish between different groups of galaxies for a huge sample at redshifts between 0.001 and 0.5. The remainder of this article is organised as follows: the next sections present information on the data collected followed by calculations and results and finally the conclusions are presented.

2. Data Collection

The photometric and redshift data of 613654 galaxies at redshifts between 0.001 and 0.5 have been collected from SDSS [18]. Particularly, the data that have been collected in this research are magnitudes in five different bands u (ultraviolet), g(blue-green), r (red), i (far red), and z' (near infrared). Those magnitudes have effective wavelengths of 3500, 4800, 6250, 7700 and 9100 Å, respectively [19]. The photometric data and redshift of a subsample of 20 galaxies are listed in Table (1). In this article, the magnitude in the z band is referred to as z' to avoid confusion with the symbol z that refers to the redshift. For a full description of the SDSS 14th data release, readers are referred to [20].

Table 1: A subsample of photometric data of 20 galaxies

u	g	r	i	z'	z
18.94659	17.00586	16.15642	15.73315	15.40911	0.054926
19.23904	17.18665	16.14616	15.7115	15.27712	0.091359
19.38708	18.19326	17.8012	17.4931	17.41196	0.065651
19.18054	17.21457	16.28468	15.84518	15.48317	0.049544
19.24709	18.06945	17.57615	17.21119	16.99933	0.066615
19.65639	18.21134	17.61543	17.27651	17.09	0.040701
21.07664	19.66887	19.22633	18.59864	18.32925	0.072912
19.51663	18.11949	17.45229	17.0184	16.75874	0.079599
19.332	17.59563	16.82751	16.35124	16.0485	0.083068
18.74242	17.55478	17.00429	16.6149	16.40302	0.080652
19.44556	18.27106	17.8715	17.58861	17.48755	0.047349
18.8783	17.11285	16.22971	15.8557	15.58644	0.09752
18.38426	17.27011	16.80836	16.46696	16.33492	0.085004
19.10344	17.07944	16.09792	15.66684	15.33062	0.087571
19.91919	17.9929	17.06082	16.64746	16.31562	0.084517
18.28989	17.06703	16.60662	16.30549	16.1497	0.054309
20.46617	18.4138	17.44937	16.87278	16.49128	0.057528
21.54881	19.28476	18.10109	17.49347	16.97114	0.094576
19.4064	17.54558	16.6301	16.22255	15.89212	0.072739
19.30902	18.53376	18.38342	18.09463	18.10676	0.08213

3. Calculations and Results

The color of galaxies has been determined from the difference between the magnitudes in two different bands. In this research, (u-g), (g-r) and (u-r) have been determined for the whole sample of galaxies and five different subsamples at redshift ranges of (z = 0.001 - 0.1, z = 0.1 - 0.2, z = 0.2 - 0.3, z = 0.3 - 0.4 and z = 0.4 - 0.5). The most important color is (u-r) because it is one of the colors that is more sensitive to stellar ages.

A Matlab code has been written in this research in order to produce the color distributions (u-g), (g-r) and (u-r) for the main sample as well as all five subsamples. Then Microsoft Office Excel was used to fit two Gaussians to the data of each color distribution. The fitting procedure employed the minimum chi-square method using the solver feature in Excel. The fitting equation of the two Gaussians is written as follows:

$$Y = A_1 e^{-\left(\frac{(x-B_1)^2}{2C_1^2}\right)} + A_2 e^{-\left(\frac{(x-B_2)^2}{2C_2^2}\right)} \quad (1)$$

Where

A1, A2: are the amplitudes of the two peaks

B1, B2: are the positions of the two peaks on the horizontal axis

C1, C2: are the Full Width at Half Maximum (FWHM) of the two peaks

The fitting coefficients of the color distributions for the whole sample and all subsamples are outlined in Tables (2 to 4). Figure 1 shows a block diagram of the calculations' steps in this research. The color distributions (u-g), (g-r) and (u-r) of the main sample are shown in Figure (2). Similarly, the three color distributions for the five subsamples are shown in Figures (3 to 7). In those figures, the histogram represents the distribution that has been plotted using Matlab, while the orange and yellow peaks represent the results of the bimodal Gaussian fitting.

Table 2: Fitting coefficients of color distributions (u-g).

z	A1	B1	C1	A2	B2	C2
0.001-0.5	39804.52927	1.275117708	0.225375574	67976.49	1.913601	0.202255
0.001-0.1	22712.4299	1.44720999	0.22054504	25229.58	1.847186	0.15736
0.1-0.2	17269.3092	1.57002377	0.25223124	38036.81	1.953035	0.173305
0.2-0.3	756.0611091	0.897873768	0.456088663	7715.322	2.083385	0.137374
0.3-0.4	323.284	0.48838	0.21526	776.009	2.07247	0.55892
0.4-0.5	192.833267	0.33979814	0.10652839	20.84733	1.160937	1.147579

Table 3: Fitting coefficients of color distributions (g-r).

z	A1	B1	C1	A2	B2	C2
0.001-0.5	39358.82031	0.900525508	0.284636309	10361.31	1.502528	0.08053
0.001-0.1	14554.60205	0.669394169	0.197114263	25428.9	0.900783	0.074845
0.1-0.2	10076.8141	0.74323702	0.13344362	31605.31	1.053242	0.134711
0.2-0.3	1017.753	0.825073	0.20536	14000	1.45	0.1
0.3-0.4	129.9101	0.684976	0.339201	2273.602	1.649755	0.104758
0.4-0.5	65.60385	0.359461	0.041553	34.6275	1.644807	0.045907

Table 4: Fitting coefficients of color distributions (u-r).

z	A1	B1	C1	A2	B2	C2
0.001-0.5	21504	1.917814026	0.3733947703	41741	2.930707	0.411321
0.001-0.1	13061.6866	2.02374331	0.41184639	17363.55	2.685959	0.210913
0.1-0.2	10079.93	2.264	0.377001	28000	3	0.27
0.2-0.3	977.76663	1.575	0.4375	7295.77	3.52901	0.10703
0.3-0.4	127.7593197	1.208593185	0.309078166	796	3.7	0.5
0.4-0.5	85.43715	0.587026	0.050729	13.10403	2.405922	4.245844

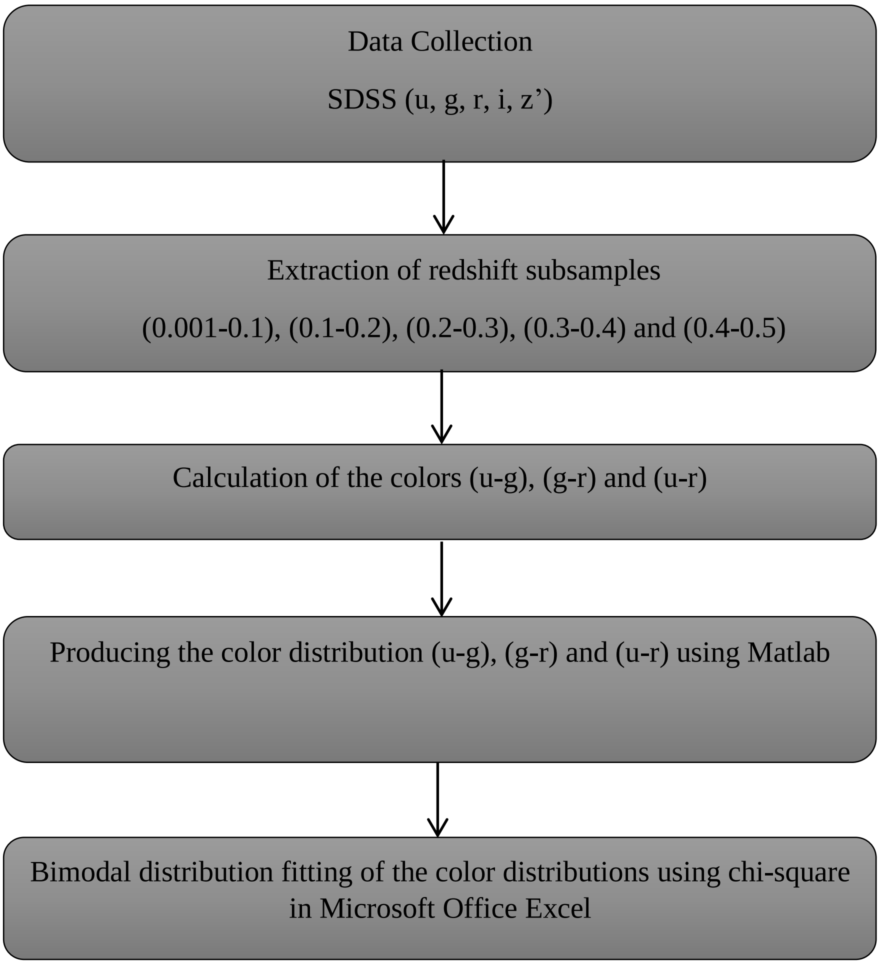

Figure 1: A block diagram of the calculation steps.

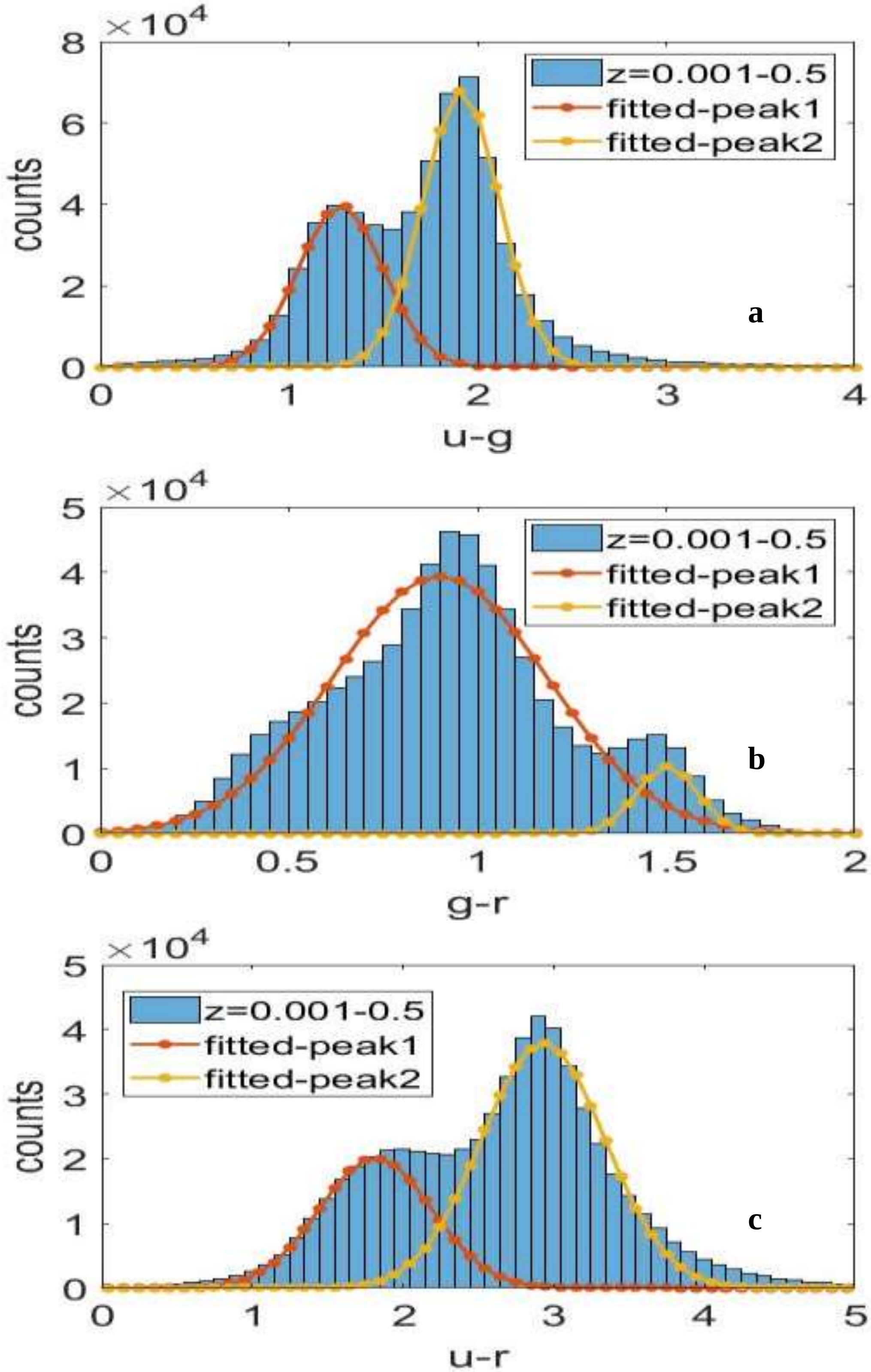

Figure 2: The color distributions of the main samples: u-g (a), g-r (b), and u-r (c).

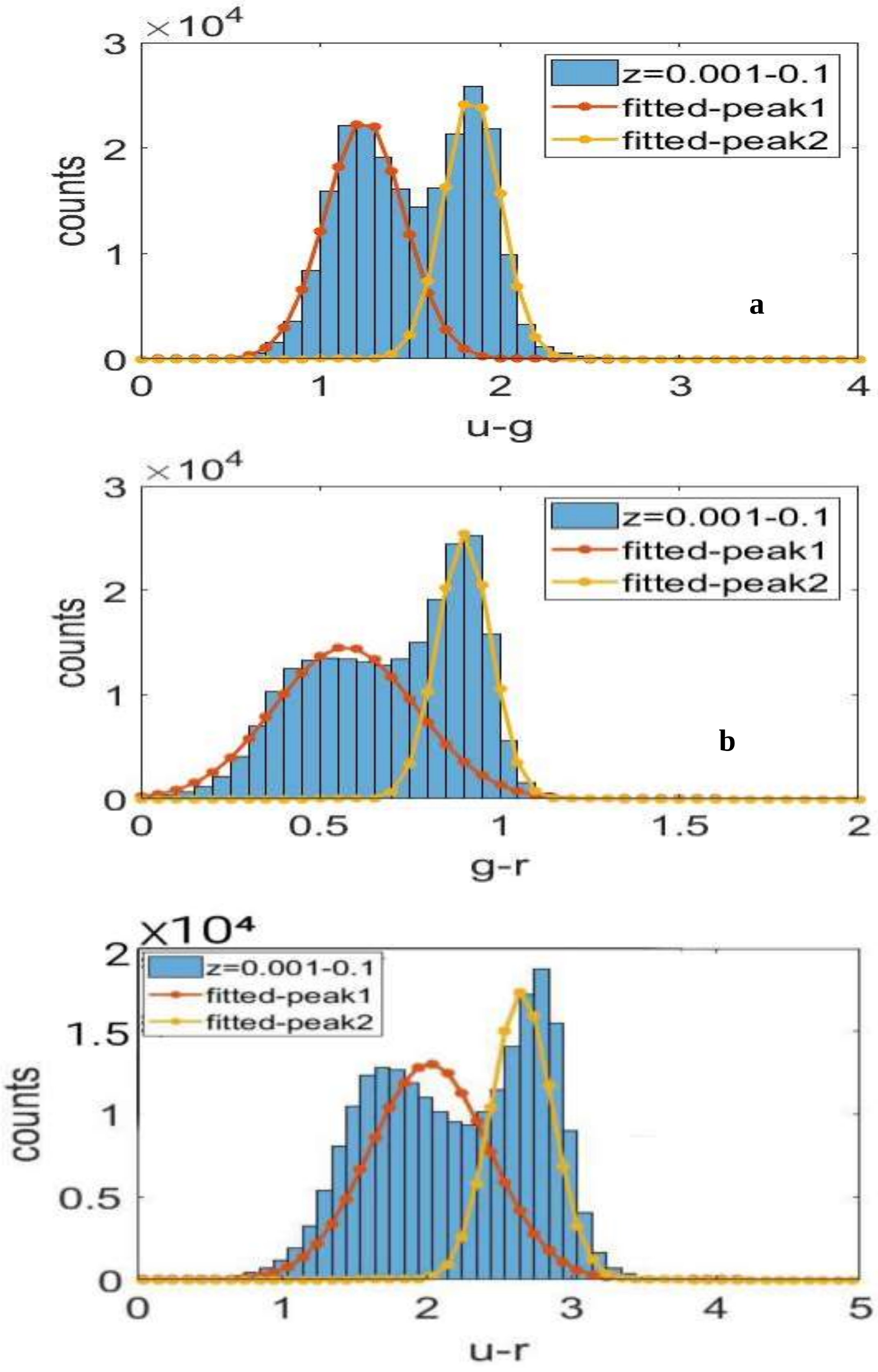

Figure 3- The color distributions of subsamples in the redshift range (0.001-0.1**)**: u-g (a), g-r (b), and u-r (c).

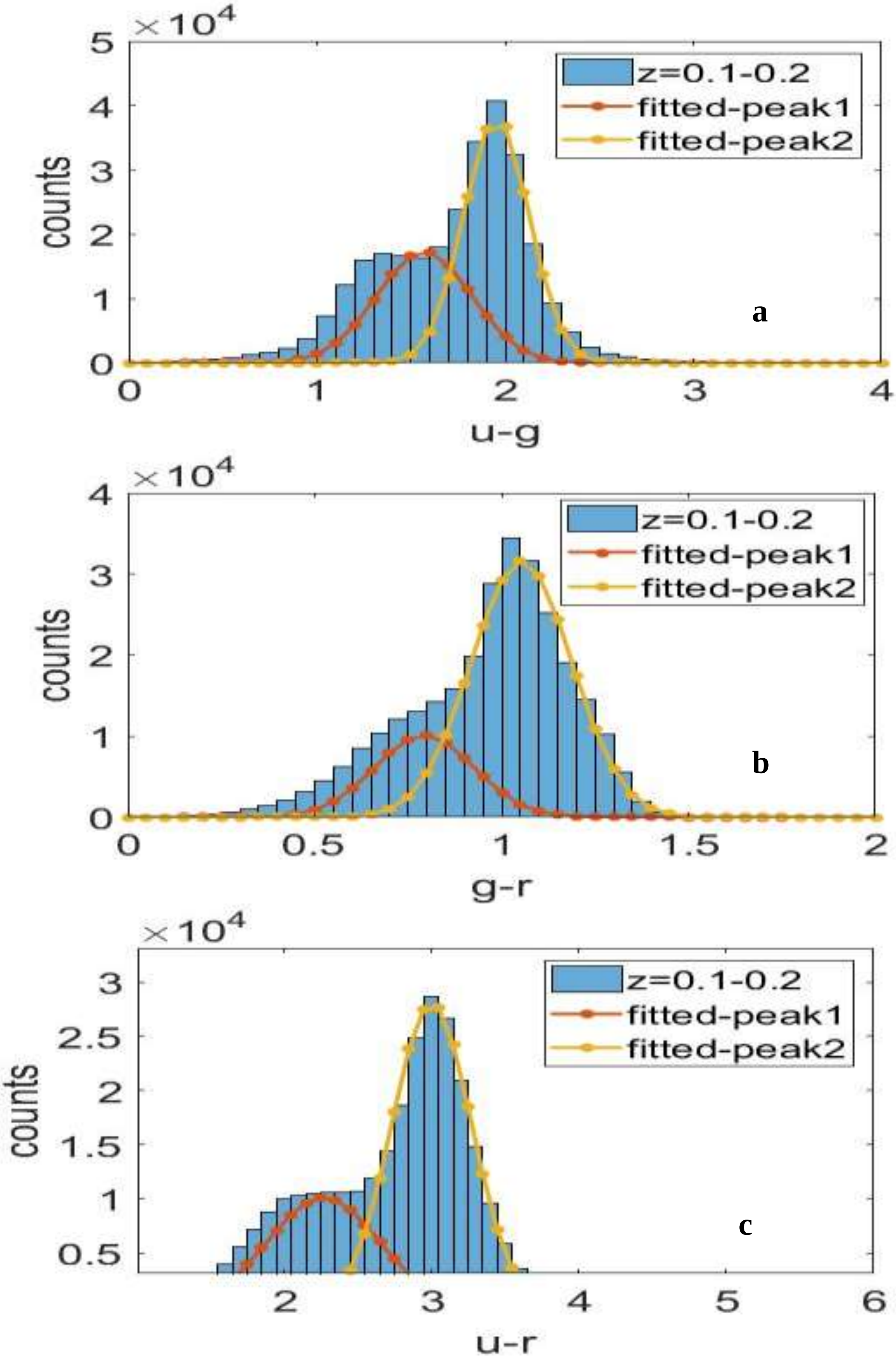

Figure 4: The color distributions of subsamples in the redshift range (0.0.1-0.2**)**: u-g (a), g-r (b), and u-r (c).

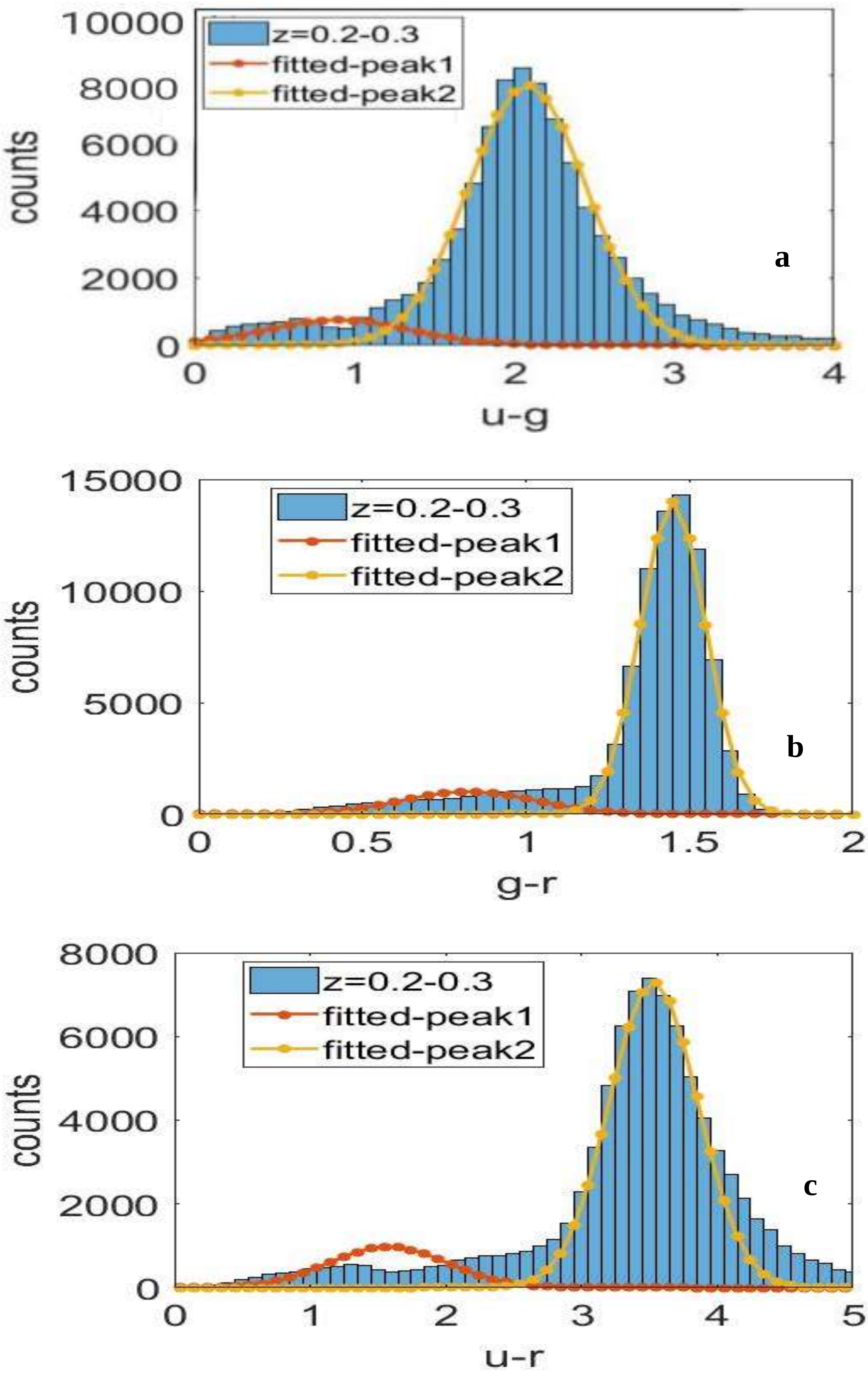

Figure 5: The color distributions of subsamples in the redshift range (0.2-0.3**)**: u-g (a), g-r (b), and u-r (c).

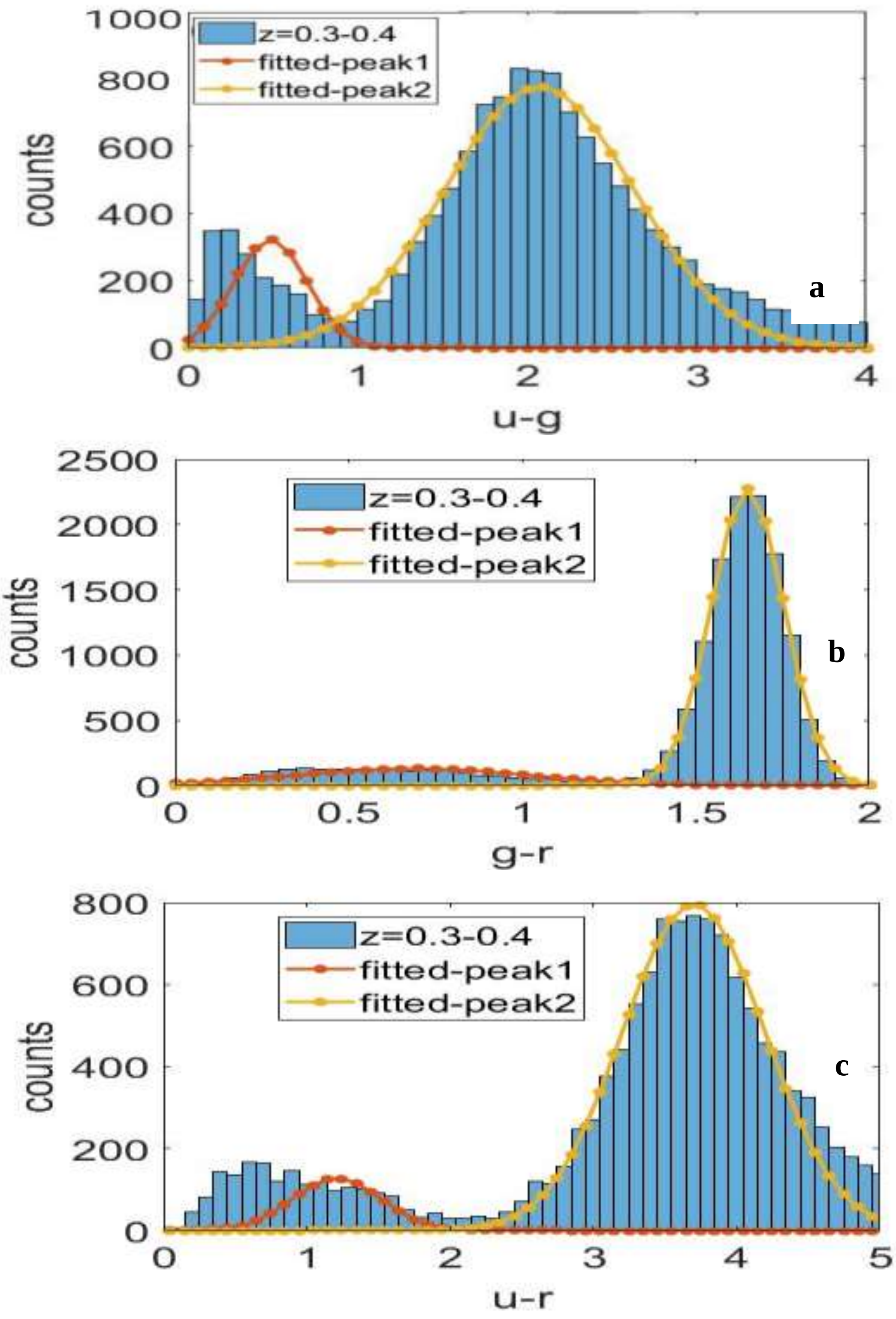

Figure 6: The color distributions of subsamples in the redshift range (0.3-0.4**)**: u-g (a), g-r (b), and u-r (c).

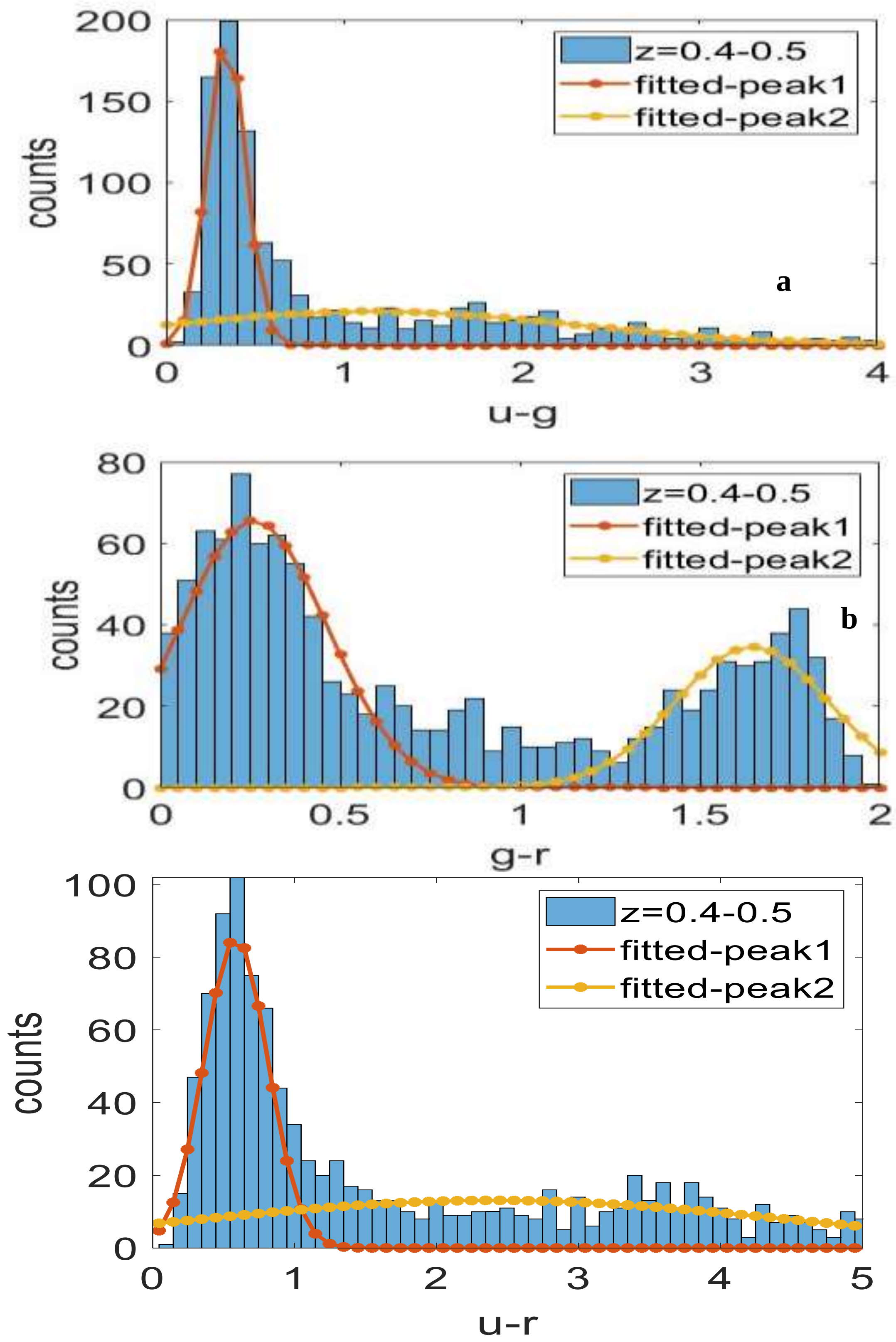

Figure 7: The color distributions of subsamples in the redshift range (0.4-0.5**)**: u-g (a), g-r (b), and u-r (c).

4. Discussions and Conclusion

In this research, photometric data of magnitudes (u,g,r,i,z’) for a huge sample of galaxies from SDSS has been collected and analysed in order to investigate the colors of galaxies. The redshift range of those galaxies is between 0.001 and 0.5. In addition, this sample of galaxies has been subdivided into five groups of galaxies at different redshift ranges. The color distributions of all galaxies and all five subsamples have been produced using a Matlab code. The key findings of this research showed that the color distributions of the whole sample and the five subsamples are bimodal. This behaviour of color distribution provides information on the processes of star formation in galaxies. The young galaxies tend to be bluer in color and belong to one of the two peaks of the color distribution, whereas the old galaxies tend to be redder in color and belong to the second peak. The young galaxies are star-forming galaxies and hence their color is blue, while the old galaxies are non-star-forming galaxies and hence their color is red. In conclusion, the color distribution of galaxies can be considered as an efficient tool for classifying galaxies into two groups, young and old galaxies. Blue galaxies reach their first peak, while the red galaxies reach their second peak. This means that blue and red galaxies can be distinguished from one another based on their color distributions. The variation in star populations within the galaxies is what causes the variation in color of the galaxies. While the stars in red galaxies are old, the stars in blue galaxies are young. Overall, the bimodality feature seen in the color distribution of galaxies is due to the two distinct populations of galaxies that are produced by two different sets of star formation processes. It is worth pointing out here that a future work is suggested to study the relationship between the color of galaxies and their morphological classification.

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