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Rest-frame color bimodality up to z∼2 in the VIMOS-VLT Deep Survey

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Abstract. We have performed a spectro-photometric analysis of a deep sample of galaxies from the VIMOS-VLT Deep Survey (VVDS), combining photometric and spectroscopic data to obtain galaxy Spectral Energy Distributions (SEDs) which extend from the UV to the near infrared. By fitting these SEDs with synthetic ones derived using PEGASE population synthesis models, we have derived absolute rest-frame magnitudes and colors of each galaxy. In agreement with previous studies at $z\leq1$, we find that rest-frame colors follow a bimodal distribution and this behavior holds up to $z\sim2$. We also study the dependence of rest-frame colors on redshift and on galaxy luminosity.

Key words. Galaxies: evolution - Galaxies: fundamental parameters

1. Introduction

Over the last few years rest-frame color distributions of galaxies in the local universe have been found to be clearly bimodal: it appears that galaxies are naturally divided into two populations, a red one and a blue one. This property has been first noticed by Strateva et al. (2001) on the SDSS galaxies and afterwards many authors have tried to quantify this effect (see, as an example, Baldry et al. 2004). Rest-frame colors distributions have been found to be bimodal also at higher redshifts. Bell et al. (2004) and Weiner et al. (2004) have found the rest-frame color bimodality up to $z\sim1$, respectively in the COMBO-17 and DEEP data.

It is now clear that the color bimodality is an effect of a process controlling the galaxy formation and evolution which produces this discontinuity. This is confirmed by the fact that bimodality has been found to be a characteristic of many other fundamental quantities like the H_α emission (Balogh et al. 2004), the 4000 Å break (Kauffmann et al. 2003), the star formation history (Brinchmann et al. 2004), the clustering (Budavári et al. 2003).

In this work we have used the data from the VIMOS-VLT Deep Survey (VVDS, see Le Fèvre et al. 2005) to analyze the rest-frame color bimodality up to $z\sim2$.

2. The Data

Our working sample is selected from the first epoch VVDS-Deep spectroscopic sample within the VVDS-0226-04 field (hereafter F02) where a very broad multi-wavelength coverage (from radio, far and near infrared, to optical, UV, and X-rays) is available (see Le Fèvre et al. 2005).

The whole 1.2 deg^2 field has been imaged in B, V, R and I with the wide-field 12K mosaic camera at the Canada-France-Hawaii telescope. Data are complete and free from surface brighteness selection effects down to $I_{AB} \leq 24.0$ (see McCracken et al. 2003). U-band data are available for a large fraction of the field (Radovich et al. 2004) while J- and K-band data are available for only a small part of it (Iovino et al. 2005).

The GALEX satellite has observed the F02 field as part of the Deep Imaging Survey (DIS). Observations have been carried out in two band-passes: Far Ultraviolet and Near Ultraviolet (see Arnouts et al. 2005).

Spectroscopic observations for about one third of the objects included in the photometric magnitude limited sample are being carried out with the VIsible Multi Object Spectrograph (VIMOS, see Le Fèvre et al. 2005) on the UT3 unit telescope of the ESO Very Large Telescope. All the data have been reduced with the VIMOS Interactive Pipeline and Graphical Interface software package (VIPGI, see Scodeggio et al. 2005; Zanichelli et al. 2005). The median redshift for the whole spectroscopic sample is $z = 0.75$.

Our sample is composed of all the galaxies with secure redshift measurement up to $z \leq 2.0$. The redshift limitation has been imposed in order to ensure that the observed optical and near-infrared magnitudes provide a reasonably close bracketing for the rest-frame optical magnitudes we use in our analysis.

A total of 6601 galaxies are included in this sample.

3. The method

The idea upon which this work is based was first described in Gavazzi et al. (2002) as part of their analysis of the properties and star formation history (SFH) of Virgo cluster galaxies, and is also quite similar to the one employed by Salim et al. (2005) to analyze the SFH of galaxies in the Sloan Digital Sky Survey.

For each object in the sample the observed Spectral Energy Distribution (SED), limited to the wavelength domain where stellar light is the dominant component, is obtained using all the available photometric magnitudes and the object spectrum. The observed SED is then compared to a set of synthetic galaxy SEDs to find out the one which best reproduces the observed photometric properties of the given galaxy. A very basic fitting procedure has been adopted: age and SFH time scale are considered the interesting parameters.

For each galaxy all the templates are redshifted to the galaxy measured redshift, and then used to derive expected synthetic magnitudes through a standard set of filters and an expected synthetic galaxy spectrum. Expected and observed magnitudes and spectrum are then compared and the SED producing the lowest χ^2 value, within the range of allowed parameters, is then assumed to be representative of the real galaxy. At this point, from the synthetic SED we compute the galaxy absolute magnitudes and rest-frame colors.

4. Results

Figure 1 shows the rest-frame color distributions for the whole sample divided in four redshift bins. Color distributions are clearly non gaussian up to z~2, although the relative intensity of the red tail with respect to the blue

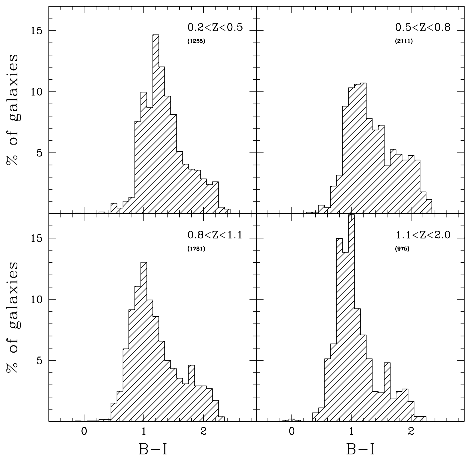

Fig. 1. The B-I rest-frame color distributions in the indicated redshift bins. The total number of objects in each bin is also indicated.

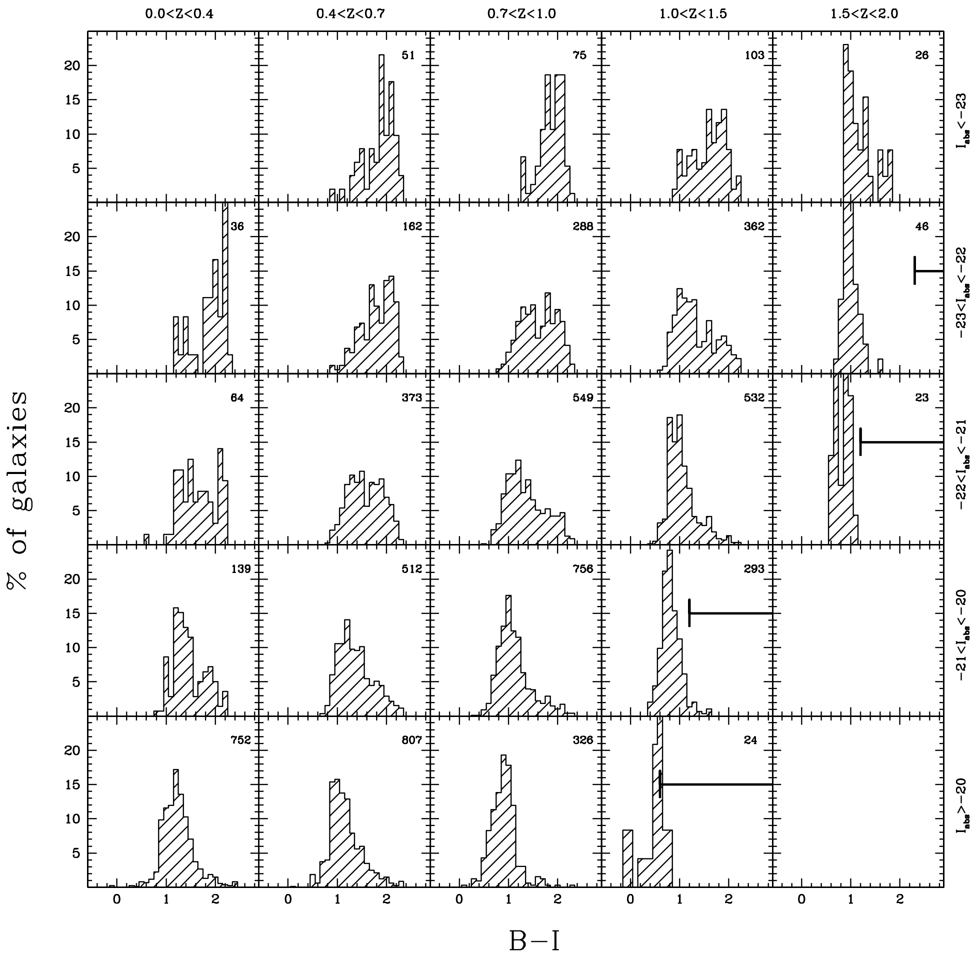

Fig. 2. The B-I rest-frame color distributions divided in absolute magnitude and redshift bins; luminosity increases from bottom to top, redshift from left to right. The total number of objects in each bin is also indicated. The solid T-shaped line plotted in some bins highlights the color regions which are "forbidden" by the VVDS selection criteria.

peak is different at different redshifts. Dividing the sample in narrower redshift bins and in absolute magnitudes bins, bimodality shows up more clearly. As shown in figure 2, in each redshift bin the red peak is strongly dominated by high luminosity galaxies while fainter galaxies populate the blue peak. Moreover, at a given luminosity galaxies become bluer as redshift increases.

To make sure that the observed trends are not produced by sample selection biases we verified that all colors can be reproduced for each redshift-luminosity combination. Secondly we have quantified the bias produced by the magnitude limit of the VVDS: at any given redshift faint red galaxies which are close to the apparent magnitude limit are

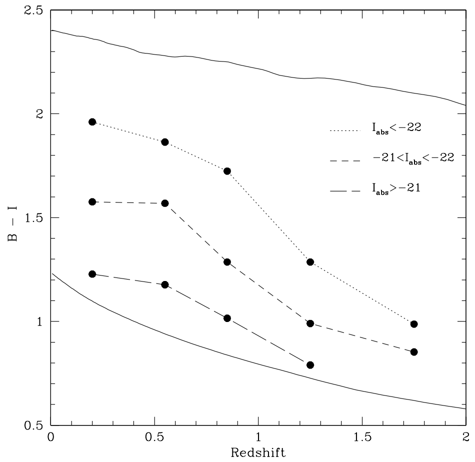

Fig. 3. The median value of each color distribution bin from figure 2 (using only three luminosity bins). For comparison, the two solid lines represent the color evolution of the template which, in our grid, better approximates a constant SFH (bottom line) and a Single Stellar Population (top line).

systematically excluded from the sample. The solid T-shaped line plotted in figure 2 highlights the color regions which are "forbidden" by the VVDS selection criteria. This bias heavily affects only two bins, where distributions are cutted by the line, but it does not invalidate the global picture.

In figure 3 the median values of each color distribution are plotted, using only three luminosity bins. It is clearly visible how galaxies become bluer as redshift increases; the amount of this effect is quite independent from the absolute magnitude. For comparison, the two solid lines represent the color evolution of the template which, in our grid, better approximates a constant SFH (bottom line) and a Single Stellar Population (top line).

All the results have been shown using the B-I rest-frame color; however the same qualitative behaviour is observed in all colors.

5. Conclusions

We have analized the rest-frame color distributions of a subsample of the VVDS spectroscopic survey showing how the color bimodality is present up to $z \sim 2$. The analysis of the color distributions shows that faint galaxies are bluer than the luminous ones at each redshift. Moreover, given a luminosity, galaxies become bluer as redshift increases and the amount of this effect is independent from the luminosity.

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