Decomposing galaxy color bimodality at z~1 in VIPERS

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The study of the VIPERS galaxy UBV and $NUVrK$ colour distributions in narrow redshift and stellar mass bins display the bimodality very well approximated by the sum of two Gaussian functions. We show that galaxy number excess over the sum of two Gaussians in the green valley regionis statistically significant only when a wide redshift and/or stellar mass range is considered. We found that the crossing time across the green valley region is not longer than 1.5 Gyrs.

1 Introduction

The bimodal colour distribution of galaxies is well correlated with the physical galaxy properties. The blue cloud objects are dominated by the star-forming galaxies whereas the red sequence galaxies are passive (e.g. Fritz et al., 2014). In the local Universe the rest-frame colours of each main galaxy population are well modelled by a single Gaussian distribution. The area of intermediate colours between two peaks, the green valley, is considered to be a possible transition zone from the active to the quiescent populations. In this work we study galaxy colour bimodality up to $z \sim 1$.

The study is based on the data from the spectroscopic galaxy survey VIPERS (Guzzo et al., 2014; Garilli et al., 2014). We analyse $\sim 55,000$ galaxies with the highest quality of the measured redshift. The spectroscopic data were replenished with multiband photometry (Moutard et al., 2016).

2 Method and results

Based on the $(U-B)$ vs $(B-V)$ and $(NUV-r)$ vs $(r-K)$ rest-frame colour-colour distributions the UBV (Krywult et al., 2017) and $NUVrK$ (Krywult, 2019) colours were defined. The detailed colour bimodality analysis was carried out in four equally spaced redshift bins in the range $z = [0.5, 0.95]$ and 14 stellar mass (M_*) bins from $10^{9.10}$ to $10^{11.15}\,\mathrm{M}_\odot$, covering the VIPERS area in 50 volume-limited subsamples of galaxies. The observational data were statistically normalised to take into account the incompleteness of the VIPERS survey, and $V_{\max}$ correction was applied.

The analysis shows strong bimodality of UBV and $NUVrK$ colour distributions very well approximated by the sum of two Gaussian functions in each of redshift and stellar mass bin with no statistically significant galaxy number excess in the green valley region above the Gaussians sum. The bottom plots of Fig. 1 present the Gaussian components in colour coded M_* bins for the $NUVrK$ rest-frame colour. It demonstrates that the proportions of blue and red galaxies change significantly with

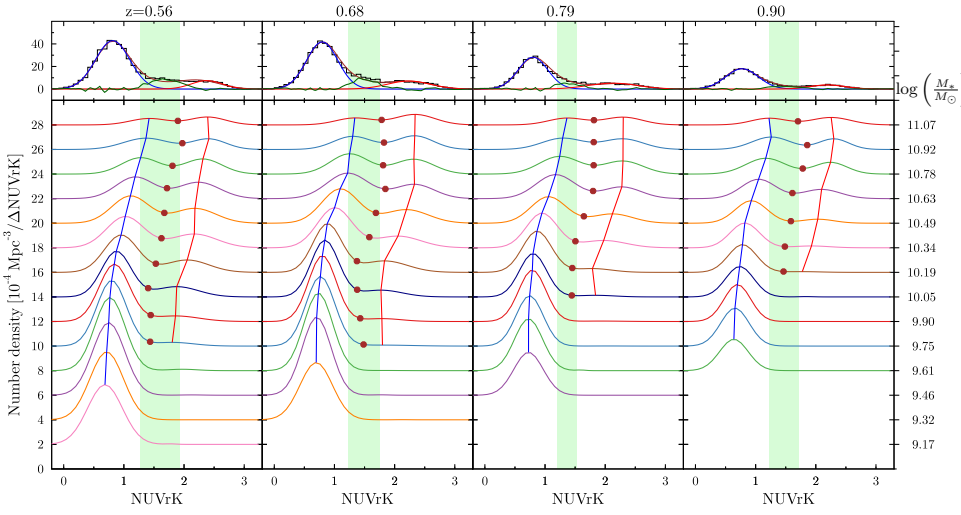

Fig. 1: Bottom plots present the sum of two Gaussian functions approximating the observed $NUVrK$ colour distribution in each redshift and colour coded stellar mass $\log(M_*/\mathrm{M}_\odot)$ bin, vertically shifted for clarity. Blue and red lines connect the maxima position of the distributions of the blue cloud and red sequence galaxies. Top plots show the sum of the $NUVrK$ colour distributions in each redshift bin. The green line shows a number density excess of galaxies over the sum of two Gaussians (blue and red lines), black line presents the observed distribution. The vertical green strip shows the average green valley location in each redshift bin.

redshift and stellar mass. While in the whole studied redshift range the populations with the low $\log(M_*/\mathrm{M}_\odot)$ are dominated by the blue galaxies, with the increasing stellar-mass the population of the blue galaxies decreases and red sequence emerges more strongly. We find that in the lower stellar mass bins, the red galaxy population is too weak to be statistically significant. The established mean lower mass limit of bimodality corresponds to $\log(M_*/\mathrm{M}_\odot) = 8.2 + 2.1z$. Less massive galaxies form an unimodal star-forming population.

The brown line in the top row of Fig. 1 shows the reconstruction of the $NUVrK$ colour obtained by summing up all bi-Gaussians in each redshift bin, while the blue and red lines correspond to the Gaussian distributions of the blue cloud and red sequence. The difference between the observed $NUVrK$ colour distribution (black histogram) and the fitted sum is shown as the green line. In contrast to the previous case the excess in the galaxy number in the region of the green valley in comparison to the sum of two Gauss functions is no more negligible. This galaxy number excess is a result of summing up galaxy populations with a varied position of minima between them for a wide galaxy stellar mass range.

To test homogenity of the green valley population across the redshift range $0.5 < z < 1$ we plotted the UBV and $NUVrK$ colours centra positions of the blue cloud, red sequence and green valley in Fig. 2. The crossing point of two main populations divides galaxies in each redshift bin into the blue objects dominated region located below this line and red galaxy region above it. The analysis shows that the green valley is an actually heterogeneous mix of the blue cloud and red

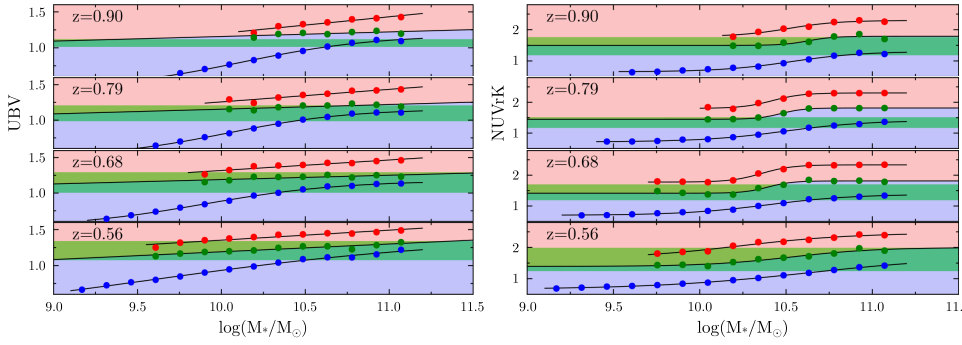

Fig. 2: UBV (left panel) and $NUVrK$ (right panel) colour – mass relation for the blue cloud, red sequence and the green valley centre galaxies marked by blue, red and green dots, respectively. The backgroud colour corresponds to the dominated population of the blue or red galaxies. The green strip marks the green valley region.

sequence galaxies. In all redshift bins the massive blue galaxies, $\log(M_*/\mathrm{M}_\odot) > 10.5$, dominate in the intermediate objects population. Only at redshift $z = 0.56$ low massive red galaxies, $\log(M_*/\mathrm{M}_\odot) < 10$, play an important role in the green valley composition. Howeover, we find rapid intermediate galaxy type chemical transformation at $z = 0.79$ when for galaxies of transition mass $\log(M_*/\mathrm{M}_\odot) \approx 10.5$ the $NUVrK$ colour redden faster.

3 Conclusions

The study of the UBV and $NUVrK$ rest-frame colours of $\sim 55,000$ intermediate redshift galaxies from the spectroscopic survey VIPERS shows that in sufficiently narrow redshift and stellar mass ranges a bimodal Gaussian distribution can very well model both rest-frame colour distributions, with virtually no residua. We found that the existence of the galaxy number excess over the sum of two Gaussians in the intermediate green valley region in the case of the colour distributions becomes statistically significant only when a sufficiently wide range of redshift and/or stellar masses is considered. We conclude that galaxies present in this intermediate region can well belong to elongated tails of blue and red galaxy populations while timescales for galaxies to cross the green valley are very short, not exceeding $1 - 1.5$ Gyr.

Acknowledgements. We acknowledge support from the Polish National Science Centre grant UMO-2018/30/M/ST9/00757 and MNiSW DIR/WK/2018/12.

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