Homogeneity of early–type galaxies across clusters

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Abstract. We studied the scatter across clusters of the color of the red sequence in a representative and large sample of clusters (more than 200) detected on the Early Data Release of the Sloan Digital Sky Survey (EDR–SDSS) in the redshift range $0.06 < z < 0.34$. We found an extreme degree of homogeneity in the color of the red sequence (the intrinsic scatter is about 0.02 to 0.03 mag) suggesting that either galaxies on the red sequence formed a long time ago ($z > 2$) or else their star formation is universally delayed with preservation of a small spread in age formation. The latter possibility is ruled out by the mere existence of galaxies at high redshift. While the old age of ellipticals was already been claimed for a small heterogeneous collection of clusters, most of which are rich ones, we found that it holds for a ten to one hundred larger sample, representative of all clusters and groups detected on the EDR–SDSS. Hence, we claim the possible universality of the color of the galaxies on the red sequence. Furthermore, the sample includes a large number of very poor clusters (also called groups), not studied in previous works, for which the hierarchical and monolithic scenarios of elliptical formation predict different colors for the brightest ellipticals. The observed red sequence color does not depend on cluster/group richness at a level of 0.02 mag, while a 0.23 mag effect is expected according to the hierarchical prediction. Therefore, the stellar population of red sequence galaxies is similar in clusters and groups, in spite of different halo histories. Finally, since the observed rest–frame color of the red sequence does not depend on environment and redshift, it can be used as a distance indicator, with an error $\sigma_z = 0.018$, a few times better than the precision achieved by other photometric redshift estimates and twice better than the precision of the Fundamental Plane for a single galaxy at the median redshift of the EDR-SDSS.

Keywords: luminosity evolution – ellipticals

1. Introduction

The existence of a relation between color and magnitude for early type galaxies has been known for a long time (e.g. Sandage & Visvanathan 1978). This relation, known as color–magnitude relation, implies a link between the mass of the stellar population and its age or metallicity, with the latter being the presently favored explication, because high redshift clusters have bluer color–magnitude relations with a small scatter (Ellis et al. 1997, Kodama & Arimoto 1997, Andreon, Davoust & Heim 1997, Stanford, Eisenhardt & Dickinson 1998). The color–magnitude relation, often called red sequence, of different clusters shows an homogeneity across clusters, but from the observational point of view the sample studied thus far is a small heterogeneous collection of clusters, and not a representative sample of clusters in the Universe.

At first sight, the early formation of the bulk of stars in cluster galaxies seems a problem for hierarchical scenarios of galaxy formation. However, while star formation occurs late in such models, it is pushed back to early times in clusters (Kauffmann 1996). Hence, the conclusion that the bulk of stars in cluster galaxies is homogeneous and red is not in contradiction with the hierarchical scenario. A natural consequence of hierarchical models would be that the evolution of early–type galaxies should depend on their environment: merging history are likely to have varied from cluster to groups.

2. The data & the analysis

We used the EDR–SDSS galaxy catalog (Stoughton et al. 2002). We detected clusters on the EDR-SDSS in a way not biasing the cluster catalog against (or for) clusters with a normal or unusual color for their galaxies (e.g. with early–type galaxies having unusually red or blue colors). Details are presented in Andreon (2003). The detected clusters span a large range in richness: there are many clusters of very low richness (often call groups), so low that they are not listed in the Abell (1958) catalog (i.e. $R < 0$), and also very rich clusters clusters ($R = 3$ or higher).

Of the ~ 450 clusters detected in the redshift range $0.06 < z < 0.34$, we are able to measure their reshift (using the spectroscopic *galaxy* database of the EDR-SDSS), for about half to two thirds of them. With the most stringent criteria, used hereafter, 212 clusters have spectroscopic redshift. This cluster sample is larger than previous studied samples (by a factor of 10 to 100), and is representative of the whole cluster population detected on the EDR–SDSS in the $0.06 < z < 0.34$ range (except for clusters so rare that their inclusion in our sample is unlikely), because it is a large and random (color unbiased) subsample of the whole sample.

For each cluster, we measure the color of the red sequence (the intercept of the color–magnitude relation), by a method that ensures that the color is measured with a fixed accuracy, independent on the cluster richness (details are presented in Andreon et al. 2003). Finally, we measure the difference between the observed color of the red sequence and the average color at each redshift.

3. Results

Figure 1 shows the difference between observed and average color. The dispersion is 0.054 mag. We checked if part of this scatter is due to systematic effects, such as color drift across the survey. We were unable to see any trend between color residuals and observing run, CCD id, right ascension or declination, hence supporting the non–systematic nature of the scatter. Part of the

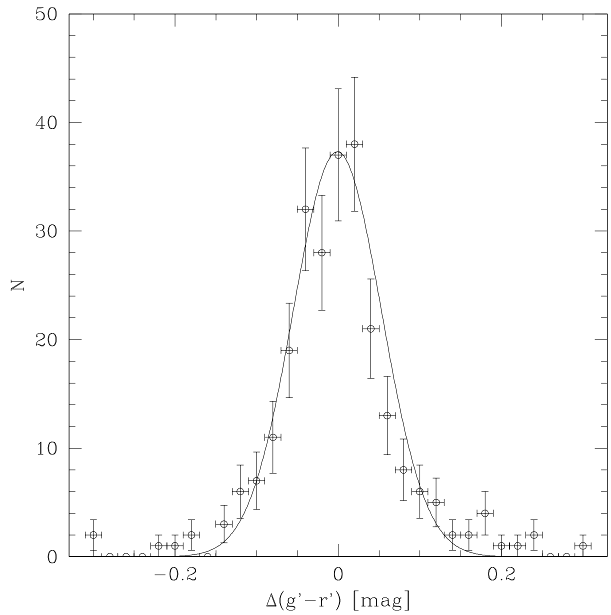

Figure 1. Distribution of the difference between observed and average color of the red sequnce. The curve is a Gaussian of the same median and (robust) dispersion of the data, traced to guide the eye, but never used in the paper. Error bars on data points are $\sqrt{N}$ (in the ordinate direction) and half the bin width (in the abscissa direction)

observed scatter is of observational nature, not intrinsic to variations, from cluster to cluster, of the color of the red sequence. The intrinsic scatter of the color of the red sequence across clusters turns out to be about 0.02-0.03 mag.

We build a model that describes the observations with the aim of putting constrains on the synchronicity or stochasticity of the stellar formation in galaxies on the red sequence. We inspired ourselves on Bower, Lucey & Ellis (1992 and following works): via a stellar population synthesis model we infer the mean age of the last episode of star–formation and its scatter by requiring that the expected color dispersion across clusters matched the observed one. We use the scatter alone, and not the color variation, the former being more robust than the latter to systematic uncertainties of stellar population models. The small scatter implies that either galaxies on the red sequence formed a long time ago ($z > 2$) or else their star formation is universally delayed with preservation of a small spread in age formation. The latter possibility is ruled out by the mere existence of galaxies at high redshift (e.g. Shapley et al. 2001).

While the old age of ellipticals had already been claimed for small heterogeneous collections of rich clusters, we found that it holds for a ten to one hundred larger sample, representative of all clusters and groups detected on the EDR–SDSS. Hence, we claim the possible universality of the color of

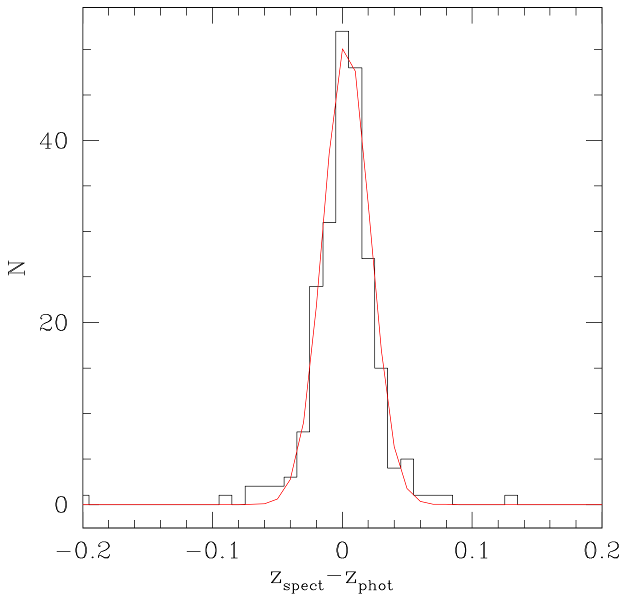

Figure 2. Residual between photometric and spectroscopic redshifts. The curve shows a Gaussian with the same width as the observed distribution and with the same area.

the galaxies on the red sequence at $0.06 < z < 0.34$. Furthermore, the sample includes a large number of very poor clusters (also called groups), not studied in previous works, for which the hierarchical and monolithic scenarios of elliptical formation predict different colors for the brightest ellipticals.

The observed red sequence color does not depend on cluster/group richness at a level of 0.02 mag, while a 0.23 mag effect is expected according to the hierarchical prediction. Therefore, the stellar population of red sequence galaxies is similar in clusters and groups, in spite of different halo histories. As their cousins in clusters, galaxies in groups live an “accelerated" live, in spite of the prediction of the hierarchical scenario.

Since the color of the red sequence does not depend on redshift and environment, it can be used as a distance indicator. The scatter between z_{spect} and z_{photom}, determined from the color of the red sequence, turns out to be 0.018 in z between $0.06 < z_{photom} < 0.30$, as shown in Figure 2. The considered redshift range is a bit smaller than in the remaining of the paper, because the flattening of the color–redshift relation at $z > 0.3$ does not allow to accurately measure z_{photom} at $z > 0.3$. The observed scatter (0.018), computed on about 200 clusters with z_{spect}, outperform by a factor of 3 all photometric redshift precisions published thus far (usually 0.05 or larger) and by a factor two the precision of the Fundamental Plane for a single galaxy (e.g. Jorgensen, Franx, & Kjaergaard 1996, 0.03 at the median redshift of our survey).

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