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Galaxy evolution in the high-redshift, colour-selected cluster RzCS 052 at $z = 1.02$

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ABSTRACT

We present deep I and z' imaging of the colour-selected cluster RzCS 052 and study the colour–magnitude relation of this cluster, its scatter, the morphological distribution on the red sequence, the luminosity and stellar mass functions of red galaxies and the cluster blue fraction. We find that the stellar populations of early-type galaxies in this cluster are uniformly old and that their luminosity function does not show any sign of evolution other than the passive evolution of their stellar populations. We rule out a significant contribution from mergers in the build-up of the red sequence of RzCS 052. The cluster has a large (∼30 per cent) blue fraction and we infer that the evolution of the blue galaxies is faster than an exponentially declining star formation model and that these objects have probably experienced starburst episodes. Mergers are unlikely to be the driver of the observed colour evolution, because of the measured constancy of the mass function, as derived from near-infrared photometry of 32 clusters, including RzCS 052, presented in a related paper. Mechanisms with clustercentric radial dependent efficiencies are disfavoured as well, because of the observed constant blue fraction with clustercentric distance.

Key words: galaxies: clusters: general – galaxies: clusters: individual: RzCS 052 – galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: formation – galaxies: luminosity function, mass function.

1 INTRODUCTION

The existence of a tight, and apparently universal colour–magnitude relation for galaxies in nearby clusters (e.g. Bower, Lucey & Ellis 1992; Andreon 2003; Lopez-Cruz, Barkhouse & Yee 2004; McIntosh et al. 2005; Eisenhardt et al. 2007 and references therein) implies that the majority of the stellar populations of early-type cluster galaxies were formed at $z \gg 1$ over relatively short time-scales. Studies of clusters at high redshift, then, should allow us to witness the earlier stages of galaxy evolution, leading to the establishment of the present-day luminosity function (LF), colour–magnitude relation and morphological mixtures. A classical example of this kind of studies is the detection of a blueing trend among galaxies in clusters at $z > 0.3$ by Butcher & Oemler (1984).

Until large samples of high-redshift ($z \gtrsim 0.8$) clusters become available, detailed 'case studies' of individual objects may provide useful clues to the evolution of galaxy populations at half the Hubble time and beyond. Several studies have analysed a number of such objects in detail (Blakeslee et al. 2003, Homeier et al. 2005; Blakeslee et al. 2006; Holden et al. 2006; Homeier et al. 2006; Mei et al. 2006a,b), using both ground-based imaging and spectroscopy and high-resolution imaging with the Advanced Camera for Surveys (ACS) on the *Hubble Space Telescope* (*HST*). These observations reiterate that the cluster early-type populations appear to be composed of old stellar populations which were probably in place at high redshift.

Most of the studied high-redshift clusters are selected from the X-ray catalogues, which may pre-select objects that have already formed a deep potential well. An alternative strategy is to use clusters selected via the prominent red sequence of early-type galaxies (Gladders & Yee 2000). Several $z \geqslant 1$ clusters have already been identified using the galaxy colours or their spectral energy distributions (Andreon et al. 2005a; Stanford et al. 2005).

Here we focus on RzCS 052 (J022143−0321.7), a rich (Abell class 2 or 3) cluster selected via a modified red-sequence method, with a measured redshift of 1.016 and a velocity dispersion of 710 ± 150 km s^{-1} and a modest X-ray luminosity of $(0.68 \pm 0.47) \times$

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10^{44} erg s^{-1} in the [1–4] keV band. Details about this objects and its properties may be found in Andreon et al. (2008). Because RzCS 052 is less X-ray luminous than clusters at similar redshift, and therefore does not possess a massive X-ray atmosphere, this object allows us to carry out a study of galaxy evolution in a different cluster environment and isolate the effects of gas on galaxy properties (Moran et al. 2007).

The layout of the paper is as follows. We present the data reduction and analysis in the next section. Section 3 discusses the red-sequence galaxies. Section 4 deals with the blue galaxies in RzCS 052. Finally, we summarize our results in Section 5. We adopt the concordance cosmological parameters $\Omega_M = 0.3, \Omega_\Lambda = 0.7$ and $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. Magnitudes are quoted in their native photometric system (Vega for *RI*, SDSS for z' and instrumental for Megacam data). Results of our stochastic computations are quoted in the form $x \pm \sigma$ where x is the posterior mean and σ is the posterior standard deviation.

2 THE DATA

The data set used here consists of a 2.4-ks *I*-band image and a 1.4-ks z'-band image obtained in 2006 July, as part of the pre-imaging for deep spectroscopy of RzCS 052, using the FOcal Reduction Spectrograph (FORS2) imaging spectrograph at the European Southern Observatory (ESO) 8.2-m Very Large Telescope (VLT, programme 075-A0175). FORS2 has a 7 × 7-arcmin^2 field of view. The typical seeing in these images varies between 0.5 and 0.7 arcsec, with 5σ completeness limits (in 3-arcsec apertures, equivalent to a 24 kpc aperture), computed as in Garilli, Maccagni & Andreon (1999) of $I = 24.5$ and $z' = 24.0$ mag. The data were reduced and calibrated as usual except for the z'-band calibration, which is not part of ESO's routine calibrations. This was bootstrapped from the CTIO z' discovery image for this cluster presented in Andreon et al. (2008), in turn calibrated using z' standard stars (Smith et al. 2002). Both CTIO and FORS2 z' have negligible colour terms (if any) with respect to the standard z' system, as verified by observing a Sloan Digital Sky Survey (SDSS) region with CTIO and with FORS2.

Additional high-resolution imaging for RzCS 052 was obtained from the *HST* archive, which contains a 12-ks z-band (F850LP) ACS image of this object (PID: 10496). The image was retrieved from the archive and processed through the Multidrizzle algorithm to remove hot pixels and cosmic rays (Koekemoer et al. 2002). The area sampled by ACS is about 2.2 Mpc^2, and one-fifth of the FORS2 area. These data are used for our morphological study of galaxy populations in RzCS 052. Morphologies are estimated by eye (by S. Andreon), as usual. For this reason, 20 per cent of the estimated types are in error, on average (Couch et al. 1994; Dressler et al. 1994; Andreon & Davoust 1997). Our magnitude limit for morphological typing, $z' = 22.5$ mag, is conservatively set at about 1.5 mag brighter than similar works (e.g. Blakeslee et al. 2006; Mei et al. 2006a,b) to limit the incidence of typing errors.

Successful spectroscopy for around 54 galaxies, 21 of which turn out to be cluster members (have a velocity offset less than twice the computed cluster velocity dispersion), was obtained from VLT and Gemini GMOS spectra (see Andreon et al. 2008 for details). The morphology of the 16 confirmed members that are in the ACS image is shown in Fig. 1.

The spectroscopic sample is far from complete and, for our purposes, we need to discriminate statistically against foreground and background interlopers. In order to avoid systematic biases introduced by the use of heterogeneous observational data for cluster

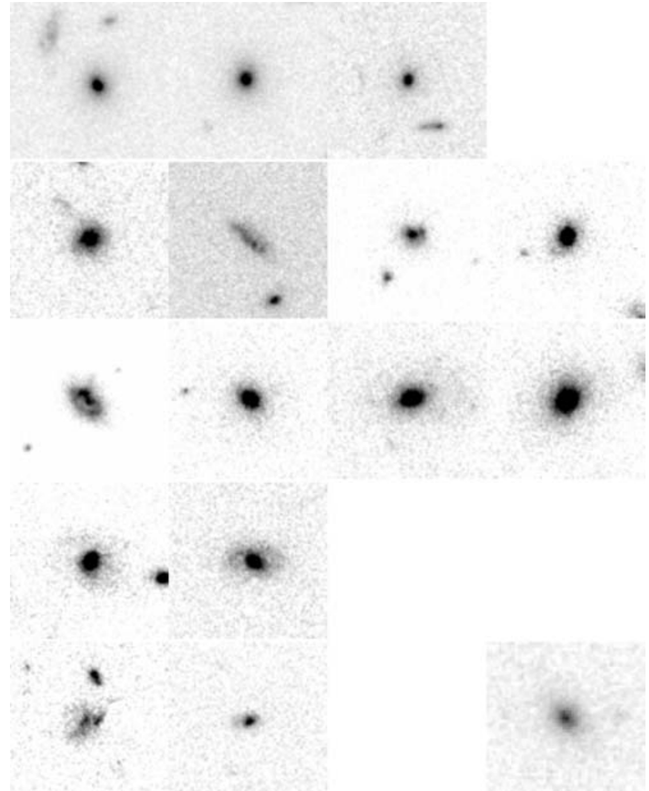

Figure 1. Gallery of *HST* images of spectroscopically confirmed galaxies. The top row shows early-type galaxies. The second to fourth rows show red ($I - z' > -0.12$ mag) late-type galaxies. Last row shows blue ($I - z' < -0.12$ mag) late-type galaxies (two leftmost panels) or unclassified galaxy (rightmost panel). Each panel is 5 arcsec wide.

and control field (see e.g. Andreon et al. 2006b), we use two *I* and z' FORS2 fields (programme 073.A-0564) having similar depth and seeing to our pre-imaging frames. In order to calibrate the z'-band photometry we make use of a third archival programme (072.C-0689) which acquired some z'-band imaging of a region overlapping the SDSS (also including standard stars) during the same nights.

Finally, in order to provide a local ($z \sim 0$) reference, we use our u^*, g', r', z' observations of Abell 496 at $z = 0.032$ (Struble & Rood 1999) taken (for another project) in 2005 December with Megacam (Boulade et al. 2003) at Canada–France–Hawaii Telescope (CFHT) under photometric conditions. Megacam has a field of $1^\circ \times 1^\circ$, and our images have seeing between 0.7 and 1.0 arcsec FWHM. As for RzCS 052, the statistical discrimination of interlopers is performed by using a control field, which observations have been interspersed to Abell 496 observations. Data are reduced as usual and are at least 5 mag deeper than needed for this project.

We produce the object catalogue and carry out photometry using the Source Extractor software (SExtractor – Bertin & Arnouts 1996). For RzCS 052, photometry is carried out in 3 arcsec (diameter) apertures, while colours are computed in 2 arcsec (diameter) apertures. Abell 496 photometry uses, instead, isophotal corrected magnitude (as 'total mag' proxy) and 3-arcsec aperture for colours. Colours are corrected for minor differences (0.05 mag, or less) in seeing, as in Andreon et al. (2004).

Table 1 lists coordinates, z' magnitude, $I - z'$ colour and morphology of RzCS 052 spectroscopic members.

Table 1. J2000 coordinates, z' magnitude, $I - z'$ colour and morphology of RzCS 052 spectroscopic members.

RA	Dec.	z'	$I - z'$	Morphology
02:21:36.21	−03:24:56.0	21.71	0.29	
02:21:37.08	−03:24:28.4	21.41	0.25	
02:21:37.60	−03:21:38.0	22.00	0.04	Late
02:21:38.85	−03:23:40.7	22.47	−0.10	Late
02:21:39.60	−03:22:00.9	21.50	0.34	Early
02:21:40.32	−03:19:03.4			
02:21:40.46	−03:18:35.6			
02:21:41.13	−03:24:41.2	23.13	−0.70	
02:21:41.73	−03:23:35.2	22.72	−0.37	Compact
02:21:42.04	−03:21:54.1	21.90	0.25	Late
02:21:42.14	−03:20:07.0	21.65	0.15	Late
02:21:42.52	−03:22:43.6	22.81	−0.25	Late
02:21:42.81	−03:22:48.8	22.16	0.32	Late
02:21:43.15	−03:21:15.2	21.16	0.09	Late
02:21:43.87	−03:21:06.0	21.35	0.27	Early
02:21:43.96	−03:20:27.9	23.21	0.17	Late
02:21:44.85	−03:22:04.3	21.10	0.32	Late
02:21:44.90	−03:21:44.5	21.34	0.25	Late
02:21:45.21	−03:21:25.5	21.78	0.27	Late
02:21:45.24	−03:20:44.3	22.31	0.29	Early
02:21:48.33	−03:20:48.6	21.82	0.16	Late

Some galaxies have no morphological type or colour because they are outside the ACS or FORS2 field of view.

3 THE RED-SEQUENCE GALAXIES OF RZCS 052

The left-hand panel of Fig. 2 shows the $I - z'$ versus z' colour–magnitude diagram of galaxies within 1.5 arcmin of the cluster centre. This is equivalent to the rest-frame $B - V$ versus V. The familiar red sequence and the blue cloud of star-forming galaxies can be clearly identified, even without marking the spectroscopic members. It is easier to identify these features in the colour histogram shown in the right-hand panel of Fig. 2. The narrow peak above the normalized background at $I - z' \sim 0.35$ mag represents the red sequence, while the broad feature at bluer colours is due to the blue cloud galaxies.

The line in the left-hand panel of Fig. 2 is the predicted colour–magnitude relation from Kodama & Arimoto (1997), assuming a formation redshift of $z_f = 5$ and total stellar masses between 0.5 and 2×10^{11} $M_\odot$. These models provide a good fit not only to the present $I - z'$ relation, but also to the $R - z'$ relation in the discovery image and to the $R - z'$ colour–magnitude relations of the 18 $0.3 < z < 1.05$ clusters analysed by Andreon et al. (2004). This implies that red-sequence galaxies in RzCS 052 appear to be dominated by old stellar populations, similar to those in other high-redshift clusters, although the precise z_f can vary between 2 and 11 depending on model assumptions (see section 3.3 of Andreon et al. 2004).

The intrinsic scatter about the colour–magnitude relation provides a further clue to the star formation history of these objects. We calculate the dispersion for the 13 galaxies classified as early-type from the *HST* images and having $I - z' > -0.12$ mag (see Fig. 3) using three methods: (i) from the measured interquartile range without any outlier clipping; (ii) using the biweight estimator of scale (Beers, Flynn & Gebhardt 1990) and (iii) by fitting an Student t_4 distribution, i.e. by Bayesian-fitting an overdispersed version of the Gaussian, in order to account for outliers (Gelman et al. 2004). Once corrected for the photometric errors, as measured by SExtractor, the intrinsic scatter is about 0.03–0.04 mag, which is consistent with the local values (e.g. Bower et al. 1992; Andreon 2003; Eisenhardt et al. 2007). Following Mei et al. (2006a,b) we can transform this scatter into a mean luminosity-weighted age corresponding to $z_f = 2.5$–3 for both galaxy formation scenarios considered by Mei et al. (2006a,b). This is consistent with the usual interpretation that the majority of the stellar populations in the red-sequence galaxies were formed during rapid starbursts at high redshift.

It is important to emphasize that the colour range over which the slope and scatter of the colour–magnitude relation are computed must not be too narrow, otherwise this will result in an artificial low value of the intrinsic scatter. For instance, a sample of galaxies uniformly distributed in colour, i.e. neither old nor synchronized at all, is selected in a 0.3 mag colour range (as in the ACS cluster survey, e.g. Mei et al. 2006a,b), which has an effective (accounting for the colour–magnitude slope) width of 0.2 mag, then the measured dispersion is 0.06 mag ($= 0.2/\sqrt{12}$). Finding a colour scatter that is small but compatible with a uniform distribution is, therefore, inconclusive about the star formation history in samples severely colour pre-selected. Our estimate of the colour scatter in RzCS 052 is unaffected by the colour pre-selection, because we have considered galaxies up to 10σ away from the colour–magnitude relation.

Fig. 3 shows the colour–magnitude diagram of galaxies classified as early-type (left-hand panel) and late-type (right-hand panel). The difference in the colour scatter is notable between the two morpho-

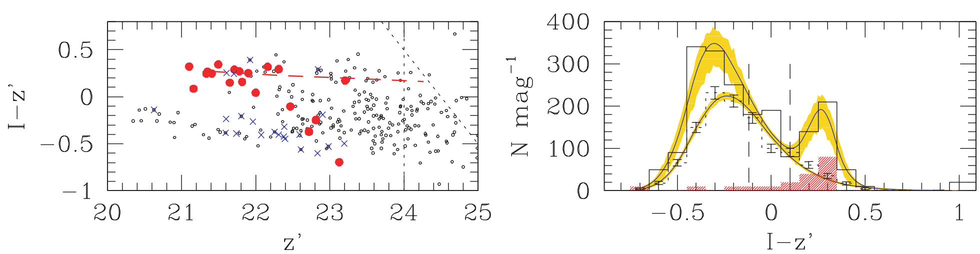

Figure 2. Left-hand panel: colour–magnitude diagram. Galaxies with unknown membership within 1.5 arcmin of the cluster centre are shown as open circles, known RzCS 052 members are marked with (red) closed circles. Spectroscopic non-members are marked with (blue) crosses. The dashed (red) line is the expected colour–magnitude relation at the cluster redshift, from Kodama et al. (1997), without any parameter tuning. Right-hand panel: histogram of the colour distribution of galaxies within 1.5 arcmin of the cluster centre (solid histogram) and in the 72 arcmin^2 control fields (dashed – normalized to the cluster area). The shaded histogram is the colour distribution of confirmed cluster members. The shaded areas around the smooth function show the 68 per cent highest posterior credible intervals for cluster and background colour distributions, modelling them as a mixture of a Pearson type IV function (for background galaxies) and of two Gaussian's (for cluster galaxies), following Bayesian methods (e.g. appendix B of Andreon et al. 2008). Finally, the two vertical (long-dashed) lines mark the boundary of the two 'red' definitions considered in this work.

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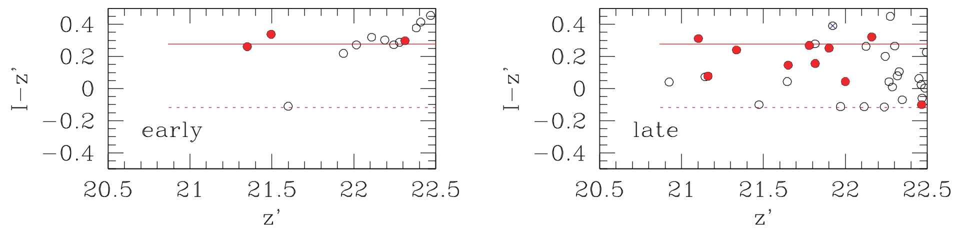

Figure 3. Colour–magnitude diagram of galaxies in the *HST* field of view, having $I - z' > -0.12$ mag (marked by a dotted line), for morphological early-types (left-hand panel) and late-types (right-hand panel) galaxies. Colours are corrected for the slope of the colour–magnitude relation. From control field data, we estimate that late-type galaxies with red colour are a mix of interloper and member galaxies. Spectroscopic members and non-members are marked with (red) closed circles and with (blue) crosses, respectively.

logical classes, even in the restricted colour range studied. Many of the red late-type galaxies are spectroscopic members (marked by solid points), many, from control field observations, are expected to be interlopers. The RzCS 052 red spirals may be analogues of the anaemic spirals encountered in low-redshift clusters (e.g. Andreon 1996 and reference therein) or of the massive discs of old stars at $z \sim 2$ described by Stockton, Canalizo & Maihara (2004). It is however unclear whether this represents evidence of morphological evolution on the red sequence, because there are several spirals also lying on the red sequence in the Coma cluster (Andreon 1996; Terlevich, Caldwell & Bower 2001), even inside the cluster core. We are presently investigating their nature (Covone et al., in preparation).

Even if the stellar populations of red-sequence galaxies are uniformly old, it is still possible that these objects are built via dissipationless mergers of low-mass spheroids (the so-called 'red' or 'dry' mergers). Pairs of close spheroids have been identified in MS1054.3−03 by van Dokkum et al. (1999) and Tran et al. (2005) or in RDCS 0910+54 by Mei et al. (2006a). However, if red mergers are important in the build-up of the red sequence, we should observe a gradual increase in the mean mass of red galaxies with decreasing redshift. According to De Lucia et al. (2006) galaxies more massive than $\sim 10^{11}$ $M_\odot$ accrete about one half of their mass since $z = 0.8$, which should make their luminosity fainter than the passively evolved local value by about 0.8 mag at $z = 1$ (and also change the faint end slope, α).

In order to test for the luminosity evolution, we derive the rest-frame *V*-band luminosity and mass function of red galaxies in RzCS 052. Red galaxies are defined as being redder than $I - z' > -0.12$, but we note that adopting the valley between red and blue clouds ($I - z' = 0.10$ mag, see right-hand panel of Fig. 2) identical results are found. Magnitudes were evolved to $z = 0$ assuming a Bruzual & Charlot (2003, hereafter BC03) single stellar population (SSP) 11.3-Gyr old at $z = 0$ (i.e. $z_f = 3$) and a Salpeter initial mass function. We also compute a (stellar) mass function using the same BC03 model. The LF is calculated following Andreon, Punzi & Grado (2005b), accounting for the background contamination, estimated from control fields, and performing the LF computation without binning the data and computing errors without the restrictive hypothesis that they (only) add up in quadrature.

Fig. 4 shows the rest-frame *V*-band LF of RzCS 052 and compares it with the LFs of 16 clusters (see figure for details). There are 42 red statistical members in the RzCS 052 LF.

In our sample of 16 clusters, we find no evidence of evolution in the luminosity (and mass) function of red galaxies to $M^* + 2$ once the passive evolution of the stellar populations is accounted for, as also found by many previous studies (e.g. De Propris et al. 1999; Andreon 2006a; De Propris et al. 2007), but for a sample dominated and not entirely composed by red galaxies. We can therefore *rule out* a significant contribution from mergers to the build-up of the red sequence for galaxies with $M < M^* + 2$ at $z \leqslant 1$ in our cluster sample as the majority of their stellar mass is already in place. We emphasize once more that we assumed a star formation history to convert luminosity to mass, but any assembly history: the conversion

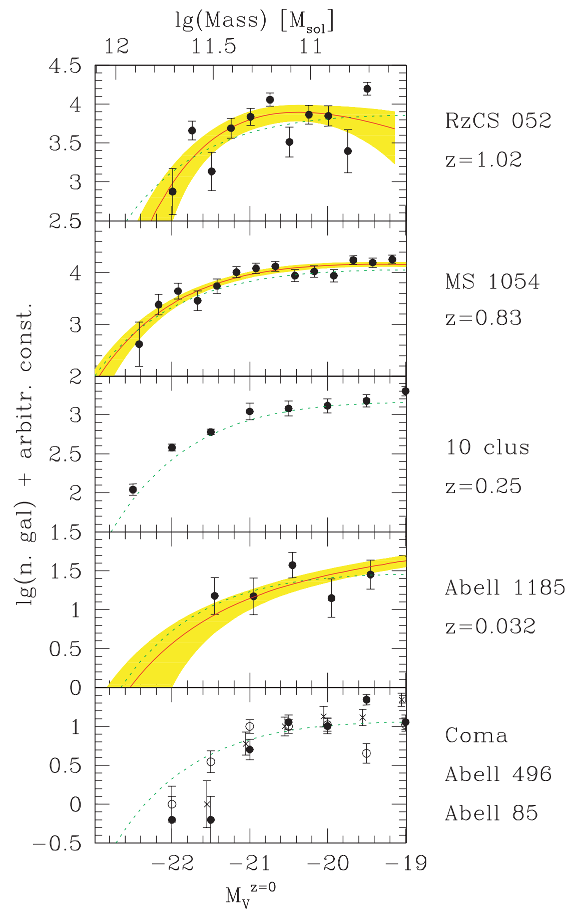

Figure 4. LF of red galaxies in RzCS 052 (this paper), MS1054 (Andreon 2006a), a composite LF of 10 galaxies at $z = 0.25$ (Smail et al. 1998) and the local LF of Abell 1185 (Andreon et al. 2006b), Abell 1656 (crosses: Secker, Harris & Plummer 1997; solid dots: Terlevich et al. 2001), and the composite LF of Abell 496 and Abell 85 (open points), as derived by us from McIntosh et al. (2005) data. The points marks the LF as usually derived in the astronomical literature, whereas the continuous (red) curve and the shaded area mark LF and 68 per cent confidence errors LFs derived following Andreon et al. (2005b) for RzCS 052, and their Bayesian analogous for MS1054 and Abell 1185, as described in those papers. The green line shows a reference LF with $\alpha = -1.0$ and $M^*_V = -21.3$ mag. All magnitudes were transformed to $z = 0$ (lower abscissa) or in mass (upper abscissa) using the procedure described in the text.

from luminosity to stellar mass holds whether galaxies formed monolithically or assembled hierarchically. A factor of 2 increase in mass due to mergers should move points 0.75 mag to the left-hand side in Fig. 4 going from top to bottom.

Our finding, based on mass estimates derived from V-band rest-frame magnitudes of a red-selected sample, is in good agreement with previous studies. For example, in the field, Wake et al. (2006) find no evidence for any additional evolution in the LF of luminous red galaxies beyond that expected from a simple passive evolution model. Bundy, Ellis & Conselice (2005) find little evolution at the high-mass end of the mass function of morphological early-type galaxies (≈50 per cent of which with photometric redshifts): in particular the M^* value of early-type galaxies is the same at the highest and lowest redshift bin.

One caveat is that our sample consists of just two high-redshift clusters (MS1054 and RzCS 052); however, in both cases, cluster galaxies are more massive than the predictions of hierarchical assembly models and have luminosities consistent with early assembly and no subsequent growth, via merging or star formation. At the very least, models must accommodate both merger-driven and merger-free red-sequence build-up.

There is moderate evidence that RzCS 052 data points fluctuate too much around the best fit model, i.e. that the Poisson model for the likelihood should be updated with a more complex model that allows its variance to be different from (larger than, in our case) its mean. However, such complex (and yet to be determined) statistical model will not considerably move the RzCS 052 LF to the right-hand side by about 0.75 mag, because the new model will change the width of point error bars, not the value of points themselves, i.e. it will not make our high-redshift galaxies twice fainter and less massive, which is what we need to reconcile data with a merger-driven evolution. In particular, many red galaxies in the first magnitude bin are spectroscopic members (see Fig. 2), and any analysis intricacy can make these red massive galaxies disappear from the sample.

4 THE BLUE CLOUD GALAXIES IN RzCS 052

We now focus on the blue cloud galaxies. We characterize these objects via the traditional blue fraction. Our definition of the blue fraction differs, however, from the conventional definition by Butcher & Oemler (1984) subsequently used by most studies. We define a galaxy as blue if it is bluer than a BC03 model with $z_f = 3$ and $\tau = 3.7$ Gyr. This galaxy will be bluer by 0.2 mag in $B - V$ than red-sequence galaxies at the present epoch (which would be a blue galaxy by the original definition). We also require that this galaxy be brighter than exponential declining (τ) or SSPs models having $M_V = -19.27$ mag at the present epoch (this avoids objects momentarily brightened by starbursts).

The rationale behind this choice is described in detail in Andreon et al. (2006a) but in essence we attempt to account for the different star formation histories of galaxies of different masses. To understand this better, let us consider a cluster of galaxies formed at the same time, but with star formation histories (i.e. e-folding times) dependent on galaxy mass, as in the original downsizing picture of Heavens et al. (2004). It is obvious that the blue fraction in this cluster will change with redshift even if there is no increase in the star formation rate due to the cluster environment. Our approach attempts to identify 'extra' star formation above and beyond the increase in the blue fraction due to the younger mean age of the Universe and the secular increase in the star formation rate with redshift.

We compute the blue fraction accounting for background galaxies (i.e. in the line of sight, and not belonging to the cluster) using our control fields following the Bayesian methods introduced in Andreon et al. (2006a), for both a luminosity selected sample and a mass selected sample. For the latter we adopt a mass threshold of $4 \times 10^{10}\,M_\odot$, and a definition of mass given by the integral of the star formation rate over $0 \leqslant t \leqslant \infty$.

We computed the blue fraction for RzCS 052 members and also for two nearby galaxy clusters Abell 496 ($z = 0.032$) and Abell 85 ($z = 0.055$), in order to make a comparison with $z = 0$. These two clusters have velocity dispersions, and thus masses, almost identical to RzCS 052: $\sigma_v = 721^{+35}_{-20}$ (Rines et al. 2005) and $\sigma_v = 692^{+55}_{-45}$ (Rines & Diaferio 2006). For Abell 496 we both used our Megacam data, and U and V catalogues published by McIntosh et al. (2005), also used to derive the blue fraction of Abell 85. All virial radii are consistently derived from σ_v using equation (1) in Andreon et al. (2006a).

The two independent determinations of Abell 496 turn out to agree each other and agree with the blue fraction of Abell 85 (see Fig. 5).

Fig. 5 shows that the blue fractions of RzCS 052, Abell 496 and Abell 85 members do not show a large change with radius (both if

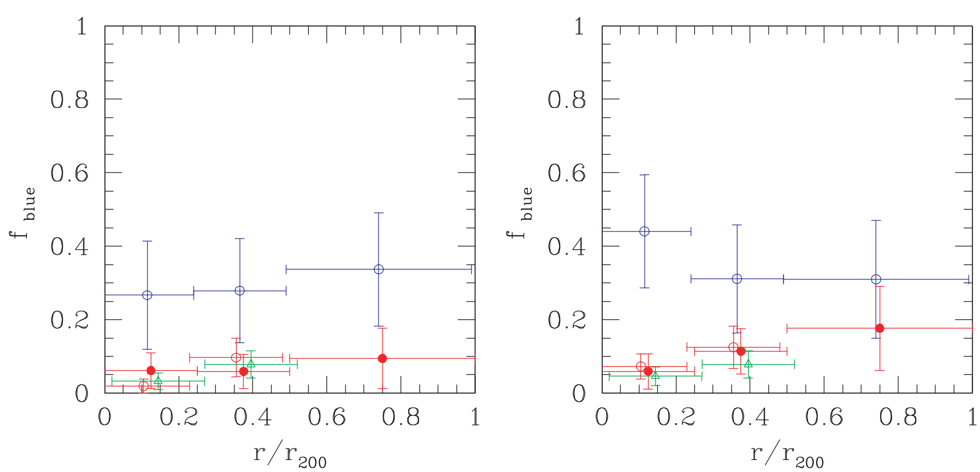

Figure 5. Fraction of blue galaxies, as a function of clustercentric distance expressed in units of virial radii: RzCS 052 (upper open blue points); Abell 496 from Megacam data (closed red points); Abell 496 from McIntosh et al. (2005) photometry (lower open red points) and Abell 85 (green open triangles, also from McIntosh et al. 2005 data). Fractions are computed for mass-selected (left-hand panel) or luminosity-selected (right-hand panel) samples. Points are slightly displaced horizontally for clarity. Error bars mark the posterior rms, not the 68 per cent confidence interval.

the sample is luminosity or mass selected). This result suggests that, whatever mechanism is changing the galaxy properties, it seems to affect in a similar way all the environments within one virial radius. Therefore, mechanisms with a substantial different efficiency at the centre and at one virial radius are disfavoured. Among them, we mention tidal compression of galactic gas (e.g. Byrd & Valtonen 1990), which by interaction with the cluster potential can alter the star formation rate, and tidal truncation of the outer galactic regions by the cluster potential (e.g. Merritt 1983, 1984), which should remove the gas supply, after eventually a last episode of star formation.

The fraction of blue galaxies is similar for mass- and luminosity-selected samples in all three clusters, and is lower in nearby clusters than in RzCS 052. A redshift-dependent blue fraction is favoured, with respect to redshift-independent one, with ∼10:1 odds, i.e. there is positive evidence of a change in the blue fraction between $z = 0$ and 1. Abell 496 has $f_b = 0.03 \pm 0.03$ and $f_b = 0.08 \pm 0.04$ for luminosity- and mass-selected sample within r_{200}, whereas the respective values for RzCS 052 are $f_b = 0.28 \pm 0.10$ and $f_b = 0.32 \pm 0.11$.

The observed evolution in the blue fraction from $z = 1$ to 0 does not take place because the fraction of red galaxies decreases with redshift (as shown above, the mass function of the red galaxies is consistent with pure passive evolution). The change of the blue fraction is therefore related to the blue population itself, and it is not a reflex of a change in the red population.

Due to the particular definitions of blue fraction adopted in this work, our finding is qualitatively different from other (apparently similar) claims of a large fraction of blue galaxies at high redshift (e.g. Butcher & Oemler 1984) that, instead, does not account for the increase in the blue fraction due to the younger mean age of the Universe and the secular increase in the star formation rate with redshift. We are stating that we observe a blueing in excess to the one expected in a younger universe, and thus some more mechanism is working *in addition to the flow of the time* to make galaxies blue.

Blue galaxies might merge to form galaxies on the red sequence, but this would conflict with both the observed evolution of the mass function of galaxies on the red sequence presented in the previous section and the constant mass function of galaxies in 32 clusters, including RzCS 052, at $0.29 < z < 1.25$, which is the unique scenario not excluded by Andreon (2006a), and the preferred scenario in other studies (e.g. De Propris et al. 1999, 2007). The only remaining possibility is that the blue galaxy evolution is faster than our library of models used to describe their star formation history (τ models), i.e. that blue galaxies in RzCS 052 are experimenting a vigorous star formation history, possibly involving starbursts (perhaps short lived). This same suggestion is pointed out by the analysis of the rest-frame blue LF of 24 clusters at $0.3 < z < 1.05$ in Andreon et al. (2004): M^* values are not aligned on a common evolutionary track (see their fig. 8), but scatter off as much as 1 mag, a clear indication of a complex star formation history.

Since RzCS 052 has a low X-ray emission (see Andreon et al. 2008) than other clusters with an X-ray bright intracluster medium, gas-related quenching mechanisms, such as ram pressure stripping (e.g. Gunn & Gott 1972; Byrd & Valtonen 1990; Quilis, Moore & Bower 2000), turbulent and viscous stripping (Nulsen 1982), thermal evaporation (Cowie & Songaila 1977) and pressure-triggered star formation (Dressler & Gunn 1983), will be much less efficient (e.g. Treu et al. 2003), making unlikely that something that lacks, the gas, play a role in making RzCS 052 galaxies bluer than expected. On the other side, an opposite conclusion can be drawn: the relative lack of gas in RzCS 052 (and therefore less effective quenching) compared to the X-ray bright clusters allows for more extended and vigorous star formation and therefore RzCS 052 has a large blue fraction because the lack of the gas that ultimately ends star formation in infalling galaxies.

5 CONCLUSIONS

We presented new results on morphology, mass assembly history, role of environment and colour bimodality of galaxies in the colour selected, modest X-ray emitter, cluster RzCS 052 at $z = 1.02$, as derived from VLT, *HST* and optical data, supplemented by a coarser analysis of a large sample of about 45 clusters, from $z = 0$ to 1.22 (16 in the context of the evolution of red galaxies shown in Fig. 4, and 32 used to constraint the fate of the blue population in Section 4).

We found that the colour distribution of RzCS 052 is bimodal. Analysis of the morphological mix, slope and intercept of the colour–magnitude relation, and of the mass function shows that RzCS 052 red galaxies differs only by age from their local counterparts and that mergers play a minor role in building massive (down to $M^* + 2$) red galaxies in studied clusters, from $z = 1$ to today.

The situation is remarkably different for blue galaxies. The blue fraction, once accounted for the younger age of stellar populations at high redshift and for the higher star formation rate there, is larger in RzCS 052 than in nearby similar clusters, highlighting perhaps for the first time that something, in addition to the flow of the time, is making galaxies bluer at high redshift.

Mergers are unlikely to be the driver of the observed colour evolution between $z = 1$ and 0, because of the measured constancy of the mass function, as derived from Spitzer photometry of 32 clusters in Andreon (2006a). Mechanisms requiring a substantial intracluster medium, such as ram pressure stripping, are ruled out as well as direct driver, because of the very modest X-ray emission in RzCS 052. Mechanisms with a substantial different efficiency at the centre and at one virial radius are strongly disfavoured, because of the observed constant blue fraction.

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