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MASS-SIZE RELATION AT HIGH REDSHIFT IN DIFFERENT ENVIRONMENTS

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Abstract. We study cluster early-type galaxies (ETGs) from the HAWK-I cluster survey in the redshift range $0.8 < z < 1.5$. Comparing them to a sample of field ETGs, we are able to analyze the environmental dependence of the mass-size relation and size evolution of passive ETGs. We find no evidence for an environmental effect within 1σ level for passive ETGs with stellar masses above 3×10^{10} $M_{\odot}$.

Keywords: Galaxies: elliptical, Galaxies: clusters: general, Galaxies: evolution, Galaxies: high redshift

1 Introduction

Many studies have already shown that massive passive galaxies at high redshift ($z \sim 2$) are more compact than their local counterpart at low redshift (Daddi et al. 2005; Trujillo et al. 2006; Buitrago et al. 2008; van Dokkum et al. 2008; Saracco et al. 2011; Newman et al. 2012, and references therein). Even if those results have been controversial for a few years, they are now well established because of independent measurements. Martinez-Manso et al. (2011); van de Sande et al. (2011) and Newman et al. (2012) have confirmed the compact nature of high redshift galaxies through dynamical mass measurements.

Two main mechanisms can theoretically explain this growth in size. One involves dry mergers (Naab et al. 2009; Shankar et al. 2012, and references therein) which allow the galaxy to increase its size by spreading stars in the outer parts after a merger event. The other involves AGN feedback and is called the puffing-up scenario (Fan et al. 2008, 2010): AGN expulses gas from the galaxy and the stars rearrange themselves thus increasing the radius. According to the hierarchical model, galaxies populating the most massive halos, experience on average more mergers and thus are expected to be larger by a factor of a few (Shankar et al. 2012, and 2013, in preparation). So, if the merger scenario is correct, we could observe a different evolution in different environments such as clusters and the field: cluster galaxies are expected to be more evolved, hence larger.

From the observational point of view, there are still some controversies. Papovich et al. (2012) and Cooper et al. (2012) found larger galaxies in cluster environment whereas Raichoor et al. (2012) found the opposite trend. Other studies do not find any trend with the environment (Maltby et al. 2010; Rettura et al. 2010; Huertas-Company et al. 2012). However, these results have been obtained at different redshifts, with different galaxy selection criteria (such as morphology, color, star formation activity, masses threshold...), with different way to measure the environment and with low statistics so that it might explain the differences.

In this work, we study the dependence of the mass-size relation of passive early-type galaxies (ETGs) on environment at $z = 0.8 - 1.5$, an epoch where massive cluster galaxies are assembling (Rettura et al. 2010; Lidman et al. 2012).

2 Data and Sample selection

2.1 Cluster selection

We selected nine clusters having at least 10 spectroscopically confirmed cluster members, beyond $z = 0.8$ and covering a broad redshift interval, imaged with the *Advanced Camera for Surveys* (ACS) on the *Hubble Space Telescope* (HST) in at least two bands and having deep ground-based images in the the near-IR.

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Eight of the nine clusters in this paper were targeted in the HAWK-I[i] cluster survey (HCS: Lidman et al. in prep). The HCS is a near-IR imaging survey that targeted nine well known high redshift galaxy clusters between $z = 0.8$ and 1.5. The aim of the survey was to obtain deep, high-resolution images of a sample of clusters for the purpose of studying the impact of environment on the evolution of cluster members. The ninth cluster in our sample, RDCS J1252-2827, was imaged with ISAAC (Infrared Spectrometer And Array Camera, Lidman et al. 2004). For some clusters, we add J-band data from SofI[ii].

2.2 Analysis

We use GALAPAGOS (Barden et al. 2005) to estimate sizes the ACS/HST z_{850}-band which is the closest available to the B rest-frame filter at the redshifts we consider. This code uses GALFIT (Peng et al. 2002) to model the galaxy light profile using a 2D Sersic profile with a fixed sky value previously estimated. The accuracy of our size estimates is assessed through extensive simulations in which we drop mock galaxies in real background images. Sizes can be recovered with a systematic error lower than 0.1 and a dispersion lower than 0.30 up to $z_{850} = 24$ AB mag (see Delaye et al. 2012, in prep).

We estimate stellar masses through spectral energy distribution (SED) fitting using the spectral library of Bruzual & Charlot (2003) (hereafter, BC03) and the LePhare code (Arnouts et al. 1999; Ilbert et al. 2006). The models were generated using a Chabrier (2003) IMF, three different metallicities ($Z = [0.004, 0.008, 0.02 \text{ (solar)}]$), exponentially declining star formation histories $\psi(t) \propto e^{-t/\tau}$ with a characteristic time $0.1 \leq \tau$ (Gyr) ≤ 30, and no dust extinction. We fixed the redshift at the cluster redshift to better constrain the stellar mass (see Delaye et al. in prep).

To determine the morphology, we use GalSVM, a non-parametric code based on support-vector machines (Huertas-Company et al. 2008, 2009, 2011) on the HST/ACS F850LP images. The local training sample used is a catalogue from the SDSS DR7 of about 14,000 galaxies visually classified (Nair & Abraham 2010). We define as ETGs the galaxies having a probability greater than 0.5 of being early-type (see Huertas-Company et al. 2012, and Delaye et al. (in prep) for details). We also made a visual classification to confirm our results.

2.3 Sample selection

This work is focused on red-sequence massive ETGs. We consider only galaxies with $z_{850} < 24$ AB mag in order to have accurate size estimates and morphologies and make several further selections to build our final sample of cluster members. For each cluster, we perform an iterative sigma-clipping fit to the red sequence in the $(i_{775} - z_{850})$-z_{850} plane, using only spectroscopically confirmed members and then select objects within 3σ of the best fit.

Among the selected red-sequence population, we select ETGs based on our automated morphological classification. We remove from the final sample, objects for which the Sersic fits did not converge (only 5 for the whole sample). We consider that the fitting procedure has converged if z_{850} brighter than 24 mag, $0.1'' < R_{\text{eff}} < 1.6''$ and $1 < n < 8$. Finally, we keep only ETGs more massive than the completeness limit, $M_{\text{lim}} = 3 \times 10^{10}$ $M_{\odot}$.

3 Field comparison sample

In order to measure the environmental effects on the size evolution of passive ETGs, we define a field sample from a combination of four different datasets to be compared with our main clusters sample.

A first set of galaxies is built by putting together all foreground and background galaxies detected in the cluster fields with spectroscopic redshifts ($z - z_{cl} > 0.02$). We apply the same color selection than for cluster galaxies and all derived quantities (stellar masses, sizes and morphologies) are obtained with the same methods described for the cluster sample.

We add a sample of galaxies from the COSMOS survey (Schinnerer et al. 2007; Bondi et al. 2008) with photometric redshifts between $z = 0.7$ and $z = 1.6$ taken from the catalog described in Huertas-Company et al. (2012) and Georges et al. (2012). Passive galaxies are selected using the color selection $\text{NUV} - R > 3.5$ (Ilbert et al. 2010) corrected from dust extinction. Sizes are estimated using GALAPAGOS on the HST/ACS F814W images. Stellar masses were estimated using the LePhare code with BC03 library, a Chabrier IMF and the

[i]High Acuity Wide-field K-band Imager

[ii]Son of ISAAC

30 available filters in COSMOS field. Finally morphologies were derived automatically (see Huertas-Company et al. 2012, for a detailed description).

Twenty-four additional field galaxies in the redshift range $1.1 < z < 1.4$ with published sizes, stellar masses and morphologies (Raichoor et al. 2012) from the GOODS-CDF-S field (Giavalisco et al. 2004) are also considered. Stellar masses were measured with an SED fitting code (different from LePhare) using BC03 models and a Salpeter IMF ($\log(M_{\rm Chabrier}) = \log(M_{\rm Salpeter}) - 0.25$, Bernardi et al. 2010). Sizes were computed on the HST/ACS F850LP image using GALFIT with a fixed sky value. Galaxies were visually classified in the F850LP images (see Raichoor et al. 2011, for a detailed description).

Finally, we add galaxies in the redshift range $0.7 < z < 1.6$ from the CANDELS survey with published stellar masses and sizes by (Newman et al. 2012). Galaxy sizes are also derived with GALFIT (see Newman et al. 2012, for detail) in the optical rest-frame band. Stellar masses were computed through SED fitting using Bruzual (2007) models and a Salpeter IMF. To convert into Chabrier IMF, we applied the same correction than above and to convert from CB07 to BC03 models, we applied: $\log(M_{\rm BC03}) = \log(M_{\rm CB07}) + 0.05 \times z$ (Newman, private communication) where z is the redshift. Galaxies in this sample were selected to be quiescent with SSFR< 0.02 Gyr^{-1} and no detection in the MIPS 24μm channel (Newman et al. 2012), but no morphological information is provided.

4 Mass-size relation and size evolution

In the following, we gather all passive ETGs in clusters and all passive ETGs in the field in 3 redshift bins ($0.7 \leq z < 0.9$, $0.9 \leq z < 1.1$ and $1.1 \leq z < 1.6$).

In Figure 1, we show the mass-size relation (MSR) of passive ETGs in clusters and in the field in the three different redshift bins as well as the best fit power law models. Slopes of the MSRs of ETGS in clusters and in the field are consistent within 1σ at all redshifts between 0.7 and 1.6.

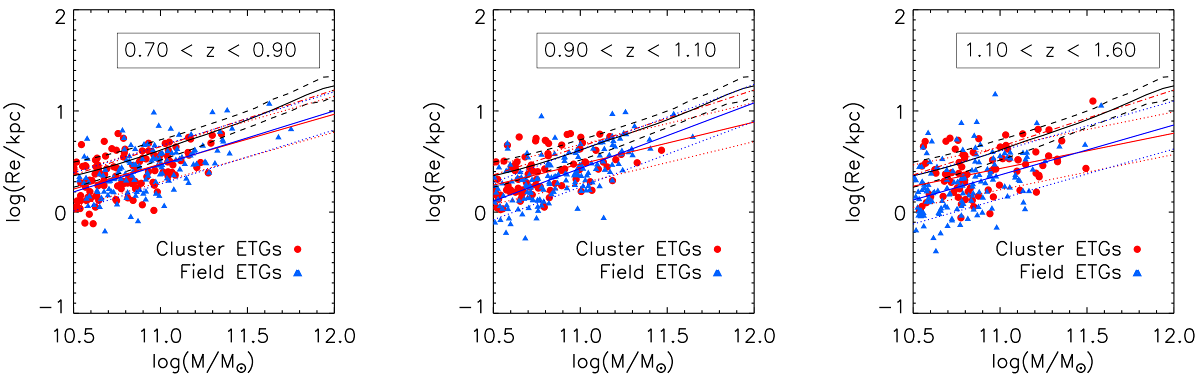

Fig. 1. Mass-size relation of passive field (blue triangles) and cluster (red circles) early-type galaxies. Blue and red lines correspond respectively to the best fit for field and cluster MSR $\pm 1\sigma$ (dotted lines). The local MSR of Bernardi et al. (2010) is in black lines.

To study the size evolution, we compute the mean mass-normalized ($R_e/M_{11}^{0.57}$ with $M_{11} = 10^{11}$ M$_\odot$, Newman et al. (2012); Cimatti et al. (2012)) radius in each of the 3 redshift bins. Mean sizes are estimated by fitting a gaussian function on the size ratio distribution; so that the reported values are the positions of the peaks of the best-fit. Errors are estimated through bootstrapping. Results do not change if we consider a median or a 3-sigma clipped average.

We include a local comparison sample from the SDSS built by cross-correlating the morphological catalog by Huertas-Company et al. (2010) with the group catalog by Yang et al. (2007) updated to the DR7. Sizes come from Sersic fits performed by Meert et al. (2012, submitted). We selected ETGs ($P(ETG) > 0.7$) and divided the sample in field ($\log M_h < 12.5$) and clusters ($\log M_h > 14$).

Figure 2 represents the mass normalized radius evolution of passive ETGs in cluster and in the field for masses above 3×10^{10} M$_\odot$. No significant differences are observed in the size evolution. Field ETGs follow $R_e/M_{11}^{0.57} \propto (1+z)^\alpha$ with $\alpha = -1.05 \pm 0.04$ and cluster ETGs have a similar α value ($\alpha = -1.02 \pm 0.06$). Our results are consistent with size evolution found by Newman et al. (2012); Cimatti et al. (2012); Damjanov et al. (2011).

Finally, we can conclude that, with $M \geq 3 \times 10^{10}$ $M_{\odot}$, field and cluster passive ETGs evolve in the same way taking into account the large uncertainties.

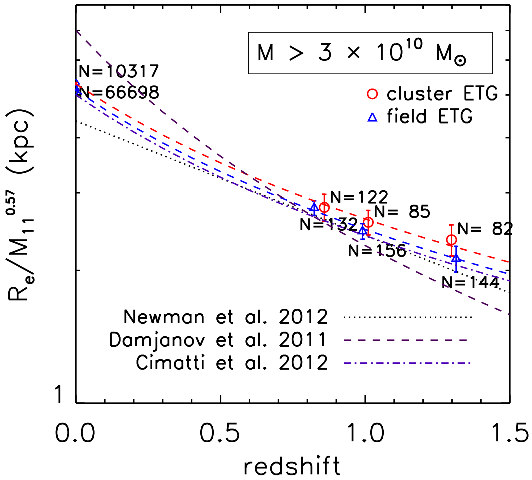

Fig. 2. Size evolution in function of redshift for passive ETGs with $\log(M/M_{\odot}) \geq 10.5$ in clusters (red circles) and in the field (blue triangles). Radius are normalized to $M_{\star} = 10^{11}$ $M_{\odot}$ using the slope $R_e \propto M_{\star}^{0.57}$. Black dotted line corresponds to the fit of Newman et al. (2012). Dashed line is the size evolution fit of Cimatti et al. (2012) and dash-dotted line the one of Damjanov et al. (2011).

5 Conclusion

We have studied a large sample of cluster and field passive early-type galaxies between $z = 0.7$ and $z = 1.6$. We estimated the stellar masses with SED fitting method using BC03 stellar population model and sizes fitting a 2D Sersic profile to the HST/ACS F850LP images. Comparing these two environments, we do not find differences in the mass-size relation and size evolution of passive ETGs at 1σ level. The size evolution we found for both environment is consistent with previous works of Damjanov et al. (2011); Newman et al. (2012) and Cimatti et al. (2012). These results might depend on morphology and galaxy mass range as discussed in Huertas-Company et al. (2012). We will discuss this in our paper Delaye et al. (in prep) as well as a comparison with hierarchical model predictions.

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