Evolution of Brightest Cluster Galaxies Over the Past 7 Billion Years

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We present a study of the formation and evolution mechanisms of the brightest cluster galaxies (BCGs) over cosmic time. By comparing high-z (z~0.9) massive galaxies in clusters and groups of the Cl1604 supercluster with those in local clusters (z~ 0), we noticed striking differences in the morphologies and structural parameters of these galaxies. This sample, coupled with the results of numerical simulations and semi-analytic models, allows us to directly infer the mechanisms that shape and evolve BCGs over the past ~7 Gyrs.

INTRODUCTION

In the last years, several works have analyzed the brightest cluster galaxies (BCGs) and the most massive cluster galaxies (MMCGs) in galaxy clusters up to moderate redshift (z~ 0.6, *Ascaso et al. 2011*; z~0.25, *Bernardi 2009*) or for limited samples (*Nelson et al. 2002, Vikram et al. 2010*), finding interesting indicators for other evolutionary mechanisms other than major merging. In this work, we consider the BCGs and MMCGs in the z~ 0.9 supercluster CL1604, which contains clusters and groups ranging a wide range in mass, and searched for low-redshift counterpart in the SDSS. We noticed striking differences in their luminosity and mass gaps between the BCG and the next brightest galaxy/the MMCG and the next most massive cluster galaxy between both samples. This gap was nonexistent in many of the cases at z~ 0.9, while is really remarkable at low redshift. Additionally, the BCG/MMCGs at high redshift were, in many cases, either late-type galaxies or were bluer than the red-sequence, in stark contrast to what we observe in the low-redshift SDSS clusters. We are analyzing these samples in order to constrain evolutionary scenarios as a function of cluster mass and redshift. We will complement our observational findings with numerical and semi-analytic simulations.

SDSS sample:

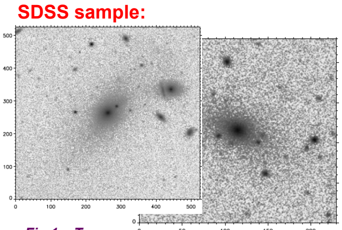


Fig 1a. Two BCGs/MMCGs from the SDSS sample

- Searched for X-ray clusters in the MCMX catalogue (*Piffaretti et al. 2011*) that are contained in the SDSS archive.

- We selected all low-redshift clusters that had comparable (rest-frame) photometry and spectroscopic coverage to the sc1604 supercluster (see right frame).

- The final sample consists of 91 BCGs/ MMCGs.

Cl1604 supercluster sample:

- The Cl1604 supercluster is located at z~0.9 and consists of three galaxy clusters and five groups (*Gal et al. 2008, Lemaux et al. 2012*)

- It is spectroscopically sampled to a completeness limit of Mg=-19.86 and has associated deep F606W/F814W HST ACS imaging.

- The final sample consists of 11 galaxies: five BCGs and 6 MMCGs.

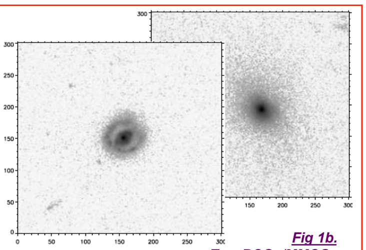
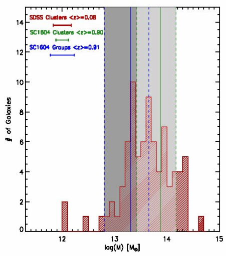


Fig 1b. Two BCGs/MMCGs from the CL1604 supercluster

SAMPLE PROPERTIES

CLUSTER MASS DISTRIBUTIONS



We compiled galaxy clusters in the SDSS with enough spectroscopic confirmed members in order to estimate a reliable velocity dispersion (σ) for the clusters.

In Fig. 2, we show the virial mass distribution for the SDSS sample with the mean values for the high-z clusters and groups marked on them.

***Fig 2.** Virial mass distribution for the SDSS sample (histogram) compared with the CL1604 ranges from clusters (light shaded) and groups (dark shaded)*

We fit the color-magnitude relation for both samples as can be seen in Fig 3. and placed the BCG in the color-magnitude diagram.

The BCG/MMCG was often off the red sequence for the high-z CL1604 sample, whereas it was included in the red sequence in all cases for the lower-z sample, independently of the cluster or group mass.

COLOR-MAGNITUDE DIAGRAMS

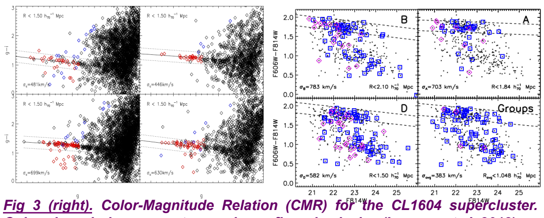
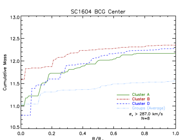


***Fig 3 (right).** Color-Magnitude Relation (CMR) for the CL1604 supercluster. Colored symbols are spectroscopic confirmed galaxies (Lemaux et al. 2012). **(left).** CMR for the SDSS sample. Red symbols refer to spectroscopic confirmed galaxies whereas blue ones are spectroscopic non-members.*

STELLAR MASS RADIAL DISTRIBUTION



We compared how concentrated is the baryonic mass around our BCG/ MMCG sample to account of how much mass these galaxies might have accreted since z~0.9. In Fig 4, we show the cumulative stellar mass relation with radius (centered on the BCG) between both samples, separated between groups and clusters.

Both groups and clusters in the CL1604 supercluster have an increase in their stellar mass content in the first R~0.2R_{vir} that is almost twice that of the SDSS clusters. The results are nearly identical if we still consider the MMCG as the center. This strongly supports a scenario in which multiple mergers have taken place in the BCG/MMCG since z~0.9.

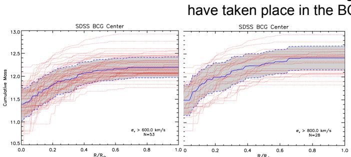


***Fig 4.** Stellar mass cumulative distribution as a function of radius (centered on the BCG) for the SDSS sample (bottom left panel, groups, bottom right, clusters) and for CL1604 sample (top panel). Blue line in the SDSS sample is the median value and shaded region is the sample variance at each radius.*

Comparing BCG/MMCG structural parameters over cosmic time can, in conjunction with stellar mass evolution, constrain evolutionary scenarios, differentiating scenarios involving solely merging from those involving solely adiabatic expansion (*Hopkins et al. 2010*, see also *Ascaso et al. 2011*).

We fit the two dimensional surface brightness (SB) profiles of all the BCGs/MMCGs in the samples with one (Sérsic) and two components (Sérsic+Exponential and Sérsic+Sérsic) by using Galfit (*Peng et al. 2010*). In Fig. 4, we show the Sérsic fits for one of the BCGs in both samples.

We will extract structural parameters from these fits which will provide measurements of the size, concentration, ratio of luminosity to total light ratio evolution, as well as to quantify the differences between the morphologies*)*.

MORPHOLOGY EVOLUTION

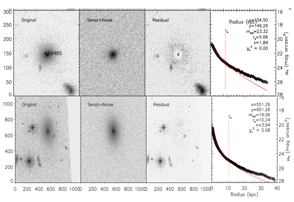


***Fig 5.** Sérsic surface brightness fit for one of the BCGs in the CL1604 sample (top) and the SDSS sample (bottom). Additional Sérsic+Exp and Sérsic +Sérsic fits have been made.*

POSSIBLE EVOLUTIONARY SCENARIOS

The whole observational analysis explained above, together with the stellar mass distribution analysis, will provide the empirical basis to constrain any evolutionary scenario.

To do so, we will use the semi-analytical simulations by *De Lucia & Blaizot (2007)* to track the mass growth of the BCGs during the past 7 Gyrs and compare to our results. We will discuss the possible scenarios for these galaxies to form and evolve such as major merger, minor merger, adiabatic contraction or others. The results are still open-ended.

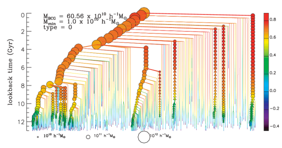


***Fig 6.** BCG merger tree of a semi-analytical simulation by De Lucia & Blaizot 2007. Symbols are color-coded as a function of B-V color. Circles and triangles are used for galaxies that have and have not joined to the group respectively.*

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