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The presence of low surface brightness structures in fossil systems as a record of a recent dynamical activity

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Abstract. Fossil systems are defined as groups and clusters of galaxies that have a magnitude gap between the brightest and the second brightest galaxies of $\Delta m_{12} \geq 2.0$ mag inside half virial radius in the R-band and a spatially extended X-ray emission with an X-ray luminosity of $L_{X,\mathrm{bol}} \geq 10^{42} h_{50}^{-2}$ erg s^{-2}. These systems would be the result of an active dynamical existence at high redshift that is now settled like a “fossil structure”; therefore, we expect they are dynamically relaxed. In this work, we show preliminary results of our study of the presence of low surface brightness structures (such as intracluster light, stellar plumes, tidal streams, or the presence of shells in the extended envelope of galaxies) in fossil systems, which can be considered fossil records of dynamical interactions that happened in the past and now can give us information about the dynamical state of these galaxy clusters and groups. We have used deep observations from MegaCam/CFHT (*g* and *r* bands) to study the 2D and 1D brightness of the central galaxies using the software GALFIT and task `ellipse`/IRAF. We analyzed the spatial distribution and color information to characterize the stellar population, and we found morphological features (as shells and plumes) in two fossil groups (NGC 7556 and the well know NGC 1132), which are signals of a recent merger, indicating a contradiction with the fossil systems definition. Doubtless, our study will be fundamental to shed light on the formation and evolution of fossil groups and clusters, complementing the few available results in the literature about the recent dynamical activity in these environments.

Resumo. Sistemas fósseis são definidos como grupos e aglomerados de galáxias que possuem uma diferença de magnitude entre a primeira e segunda galáxia mais brilhante de $\Delta m_{12} \geq 2.0$ mag dentro da metade do raio do virial na banda R, além de uma emissão extensa em raios-X com luminosidade de $L_{X,\mathrm{bol}} \geq 10^{42} h_{50}^{-2}$ erg s^{-2}. Estes sistemas seriam o resultado de uma intensa atividade dinâmica em alto *redshift* e que, atualmente, se estabelece como uma “estrutura fóssil”, ou seja, é esperado que eles sejam dinamicamente relaxados. Neste trabalho, nós mostramos os resultados do estudo da presença de estruturas de baixo brilho superficial (como *intracluster light*, plumas estelares, *tidal streams*, ou a presença de conchas no halo estelar estendido das galáxias) em sistemas fósseis, que podem ser considerados registros fósseis de interações que ocorreram no passado e agora pode nos fornecer informações a respeito do estado dinâmico desses grupos e aglomerados de galáxias. Nós usamos observações profundas da MegaCam/CFHT (nas bandas *g* e *r*) para estudar a distribuição de brilho 2D e 1D das galáxias centrais usando o programa GALFIT e a ferramenta `ellipse`/IRAF. Analisamos a distribuição espacial e a cor a fim de caracterizar as populações estelares, e encontramos estruturas (como conchas e plumas) em dois grupos fósseis (NGC 7556 e a bem conhecida NGC 1132) que são sinais da ocorrência de uma recente fusão, indicando uma contradição com a definição de sistemas fósseis. Sem dúvida, nosso estudo será fundamental para esclarecer as questões a respeito da formação de grupos e aglomerados fósseis, complementando os poucos resultados na literatura sobre atividade dinâmica recente nestes ambientes.

Keywords. Galaxies: photometry – Galaxies: evolution – Galaxies: groups: general

1. Introduction

In the context of the hierarchical cosmological model, Ponman & Bertram (1993) suggest the existence of a new "extreme" class of objects called "fossil groups" which would have a low number of bright galaxies due to the effect of dynamical friction, looking like a field galaxy. However, the main difference between fossil systems and field galaxies is the presence of an extended X-ray emission around the central galaxy. Nowadays, we define fossil systems as groups and clusters of galaxies that have a magnitude gap between the brightest and the second brightest galaxies of $\Delta m_{12} \geq 2.0$ inside half virial radius in the R-band and a spatially extended X-ray emission with an X-ray luminosity of $L_{X,\mathrm{bol}} \geq 10^{42} h_{50}^{-2}$ erg s^{-2} (Jones et al., 2003).

In this work, we aim to study the internal structure of the brightest cluster galaxy (BCG) as well as to detect the intracluster light (ICL) and low surface brightness structures such as stellar plumes, tidal features, or shells, to get information about the dynamical activity history of fossil and non-fossil galaxy clusters and groups. Special care is needed during the acquisition and reduction of data to improve the signal-to-noise ratio of low surface brightness (LSB) features.

2. Methodology

We used deep observations from the Dark Energy Camera (DECam) at the 4 m Victor Blanco Telescope (*g*, *r*, and *i* bands) and MegaCam (*g* and *r* bands) at the 3.6 m Canada France Hawaii Telescope (CFHT) to analyze the 1D and 2D brightness profile of eight central galaxies, taking into account the contribution of the background and point spread function (PSF), besides extracting its internal structural parameters. Our sample is composed of five fossil and three non-fossil systems in order to study the differences in their properties and dynamical activity. However, at the moment we only analyzed the MegaCam/CFHT sample which was processed with the Elixir-LSB data reduction pipeline (Duc et al., 2011), designed for the detection of low surface brightness structures.

In this work, we perform a 2D-decomposition with GALFIT (Peng et al. 2002, 2010), and we extracted the radial brightness profile with the IRAF task `ellipse` (Jedrzejewski 1987; Busko

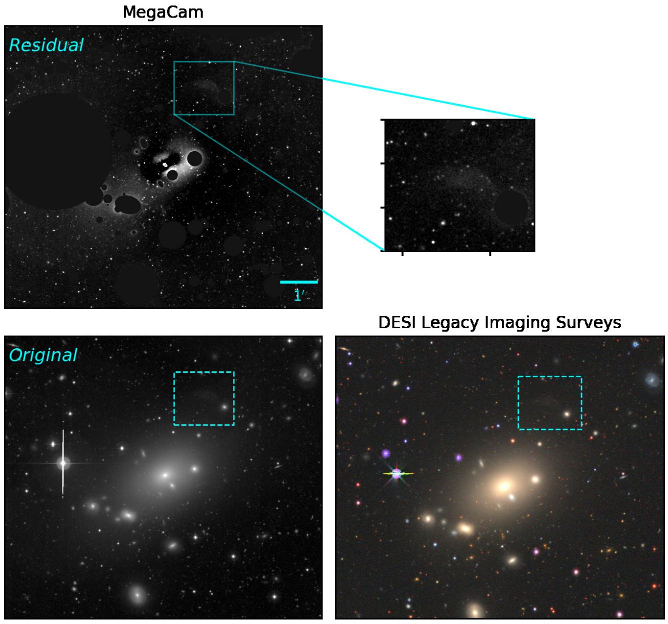

Figure 1. Top: residual image from the GALFIT 2D decomposition of the fossil group NGC 7556 in the r-band. Bottom: MegaCam image (left) and a grz composition image from DESI Legacy Imaging Surveys (right) of NGC 7556.

1996). Following Trujillo et al. (2001), we used the convolution of the Sérsic (1963) profile with the Moffat (1969) function to fit all points of the 1D brightness profile described by:

$$\Sigma_c(\xi,\theta) = (1-\epsilon)\int_0^\infty \xi^{'}\Sigma(\xi^{'})\mathrm{d}\xi^{'}\int_0^{2\pi}\mathrm{d}\theta^{'}\,\mathrm{PSF}(\xi^{'},\theta^{'},\xi,\theta), \qquad (1)$$

where $\Sigma(\xi^{'})$ is the Sersic profile, $\mathrm{PSF}(\xi^{'},\theta^{'},\xi,\theta)$ is the Moffat PSF in elliptical coordinates, ϵ is the isophote ellipticity, $\epsilon = 1-(b/a)$, where a e b are respectively the semimajor and semiminor axes.

We masked all the bright sources that can contaminate the central galaxy light and create observational artifacts. Moreover, we analyzed simultaneously the BCG and ICL in the 1D profiles to avoid the loss of information. Detection of any recent dynamical activity in our sample was done by a morphological (visual inspection) and color analysis ($g-r$ radial color profile).

3. Detection of low surface brightness structures

We found morphological features in two fossil groups NGC 1132 (shells) and NGC 7556 (stellar plume) that indicate a recent merger in these systems. The presence of shell structures in the central galaxy of NGC 1132 was detected for the first time by Alamo-Martínez et al. (2012), but the stellar plume discovered in NGC 7556 (Fig. 1) never was reported before in previous works about this system. Our results indicate a contradiction with what we know about fossil systems (or at least, what we define as a fossil system), because we expect they are dynamically relaxed.

4. 1D brightness profile

Complementing the results of Sec. 3, the inner region of NGC 1132 and NGC 7556 radial brightness profiles was not well fitted by the convolution of the Sérsic profile with the PSF, indicating the possibility of the existence of some perturbation in these systems.

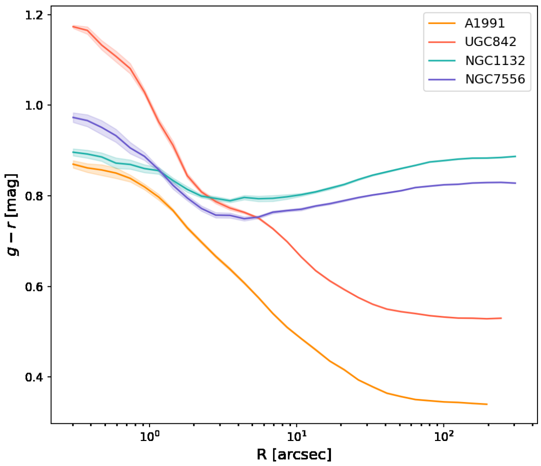

Figure 2. BCG+ICL radial color profile ($g-r$) of MegaCam sample. The shaded area represents 3σ of uncertainties.

5. BCG+ICL radial color profile

We found a negative gradient on the BCG+ICL color profile of the galaxy cluster A1991 and the fossil group UGC 842 (Fig. 2), which indicates that the main formation mechanisms of ICL can be the stellar stripping of L* galaxies or dwarf disruption, and similar results were found in previous works (e.g. DeMaio et al., 2015; Zhang et al., 2019). On the other hand, we found a flattened color profile in NGC 1132 and NGC 7556, suggesting that mergers could have mixed the stellar population of the ICL in these cases.

6. Summary

In this work, we found signals of recent dynamical activity in some fossil groups of our sample, indicating that the definition of fossil systems must be revised. In the future, we will explore other fossil systems and we plan to improve our observational techniques and methodology in order to detect more low surface brightness structures. Doubtless, our study will be fundamental to shed light on the formation and evolution of fossil groups and clusters, complementing the few available results in the literature about the recent dynamical activity in these environments.

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