On The Nature of Fossil Galaxy Groups

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Abstract. We present a new sample of 25 fossil groups (FGs) at $z < 0.1$, along with a control sample of seventeen bright ellipticals located in non-fossil systems. Both the global properties of FGs (e.g. X-ray luminosity) as well as the photometric properties (i.e. isophotal shape parameter, $a_4$) and spectroscopic parameters (e.g. the $\alpha$-enhancement) of their first-ranked ellipticals are consistent with those of the control sample. This result favors a scenario where FGs are not a distinct class of systems, but rather a common phase in the life of galaxy groups. We also find no evidence for an evolutionary sequence explaining the formation of galaxies in fossil systems through the merging of galaxies in compact groups.

1. Introduction

A fossil group consists of an isolated, luminous early-type galaxy embedded in an extended X-ray halo. The origin of such systems is still a matter of debate, with three main scenarios proposed in the literature. First, FGs may be the end-product of merging galaxies in normal loose groups at high redshift (Ponman et al. 1994; Jones et al. 2000; Khosroshahi, Jones & Ponman 2004). The main motivation for this idea is that the merger time scales for $L > L^*$ group galaxies are much shorter than the cooling time scales for the hot gas component in which they are embedded (e.g. Barnes 1989, Ponman & Bertram 1993). In this simplistic view, FGs can be used to trace the mechanisms driving the coalescence of galaxies in the not-so-high-redshift Universe. Alternatively, FGs may originate in regions that inhibit the formation of $L^*$ galaxies, leading to an atypical galaxy luminosity function (Mulchaey & Zabludoff 1999). An intermediate picture is also plausible, whereby the atypical luminosity function of FGs is a transient yet common phase in the evolution of groups, ending with the infall of fresh galaxies from the surroundings (von Benda-Beckmann et al. 2008). In this paper, we compare the properties of bright ellipticals in fossil and non-fossil systems, homogeneously selected from the same dataset, together with those of galaxies in Hickson Compact Groups (HCGs). The FG sample is
described in Sec. 1, while Sec. 2 compares the properties of the fossil, non-fossil, and HCG samples. Conclusions are drawn in Sec. 3.

2. The Fossil Group sample from SDSS+RASS

We select FGs using spectroscopy and photometry from SDSS-DR4, and RASS X-ray imaging. We define a volume-limited sample consisting of all galaxies in SDSS with r-band Petrosian magnitude $M_r < -20$ and spectroscopic redshift in the range of 0.05 to 0.095 (Sorrentino et al. 2006). A galaxy is defined as an FG optical candidate if it has early-type morphology and no companion galaxies within a magnitude gap of $\Delta M_{\text{min}} = 1.75$ mag inside a cylinder (parallel to the line-of-sight) with a radius of $D_{\text{max}} = 0.35 h^{-1}_{75}$ Mpc and a semi-height of $\Delta(cz_{\text{max}}) = 300$ km/s (see La Barbera et al. 2009, hereafter LdC09, for details). We further exclude galaxies hosting an AGN, classified using the diagnostic diagrams of Kewley et al. (2006), as well as FG candidates closer than $1.5 h^{-1}_{75}$ Mpc to a rich ($R > 0$) Abell cluster. For each optical candidate, we measure the X-ray luminosity $L_X$ (0.5 – 2.0 keV) from the RASS. A source is considered to have an X-ray counterpart if there is an X-ray detection whose position is matched to that of the optical source within 1 FWHM and whose luminosity is $3 \sigma$ above background. We classify the FG X-ray sources as extended if the extension parameter is greater than zero at the $2 \sigma$ level. The extension parameter is measured by subtracting in quadrature the FWHM of the RASS PSF from the FWHM of the FGs. Our final sample consists of 25 FGs. Fig. 1 shows three FG examples of X-ray contours from the RASS, with the positions of the optical sources overlaid.

3. Bright ellipticals in fossil vs. non-fossil systems

We select a control sample (hereafter CS) of bright ellipticals from SDSS+RASS following the same procedure as for the FGs, but without applying the cylinder test for bright companions around the first-ranked galaxy. This yields a sample of 17 CS ellipticals (against $N = 25$ FGs). Fig. 2 compares the distributions
Figure 2. Distribution of $L_X$ (left panel) and $a_4$ (right panel) for FGs (filled circles) and control sample ellipticals (empty symbols; normalized to the total number of FGs). Error bars are 1σ Poissonian errors (from LdC09).

of $L_X$ and $a_4$ (describing the deviation of the galaxy isophotes from purely elliptical shapes) for the FG and CS systems. The $L_X$ distributions are fully consistent (using the KS test). Since FGs and CS ellipticals have similar optical luminosities (by construction), the consistency of $L_X$ implies that fossils do not have enhanced X-ray luminosity compared to non-fossil galaxies, in contrast to the results of Khosroshahi et al. (2007) and Jones et al. (2003), but in agreement with Voevodkin et al. (2009). The distributions of $a_4$ values are also consistent, with FG and CS galaxies presenting both disky ($a_4 > 0$) and boxy ($a_4 < 0$) isophotes. This result is in disagreement with that of Khosroshahi et al. (2006), who concluded that FG systems have preferentially boxy isophotes (for a sample of seven FGs). On the other hand, the fact that FG ellipticals can have a variety of isophotal shapes agrees with the predictions of N-body simulations from Díaz-Giménez et al. (2008). We also investigate the stellar population properties of the FG and CS samples - age, metallicity, and $\alpha$-enhancement, $[\alpha/Fe]$ (see LdC09 for details). The twenty elliptical galaxies in Hickson compact groups (HCGs), studied by de la Rosa et al. (2007), are also included in the analysis. Fig. 3 shows $[\alpha/Fe]$ as a function of the central velocity dispersion, $\sigma_0$, for galaxies in the three samples. We find that the stellar population properties of FG galaxies are very similar to those of bright ellipticals in non-fossil systems while ellipticals in HCGs have lower $[\alpha/Fe]$ relative to both FG and CS galaxies.

4. Conclusions

We find a striking consistency between fossil and non-fossil galaxies. This similarity indicates that FGs are not a separate class of systems, but represent a common phase in the evolutionary history of galaxy groups, which can undergo fossil phases at different cosmic epochs, with these phases ending with an infall of gas rich galaxies from their surroundings (von Benda-Beckmann et al. 2008). Our results suggest that generally there is no evolutionary link between fossil and compact group (CG) galaxies. In fact, dry mergers of ellipticals in CGs would not increase their $\alpha$-enhancement, and cannot therefore generate
Figure 3. The $\alpha/Fe$ is plotted as a function of the central velocity dispersion, $\sigma_0$, for first-ranked galaxies in FGs (filled circles); ellipticals in the control sample (empty circles); and ellipticals in HCGs (filled triangles). The dashed line is the best-fit line for field galaxies (see LdC09).

the higher $\alpha/Fe$ observed in most of the FG galaxies (see Fig. 3). On the other hand, wet mergers also seem not to play a major role, since we do not find any excess of first-ranked ellipticals with either disky isophotes or positive internal color gradients (see LdC09). However, if ellipticals in CGs at intermediate redshifts have different properties from those in CGs at $z \sim 0$ (de Carvalho et al. 2005; Mendes de Oliveira & Carrasco 2007), our results can not rule out an evolutionary sequence between the higher-$z$ CGs and low-$z$ FGs.

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