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Galaxy Populations in the Cluster Abell 209 at z=0.2

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Abstract. We analyse the properties of galaxy populations in the rich Abell cluster ABCG 209 at redshift z~0.21, on the basis of spectral classification of 102 member galaxies. We take advantage of available structural parameters to study separately the properties of bulge-dominated and disk-dominated galaxies. The star formation histories of the cluster galaxy populations are investigated by using line strengths and the 4000 Å break, through a comparison to stellar population synthesis models. The dynamical properties of different spectral classes are examined in order to infer the past merging history of ABCG 209.

Key words. Galaxies: evolution — Galaxies: fundamental parameters (spectral indices, Sersic indices) — Galaxies: stellar content — Galaxies: clusters: individual: ABCG 209

1. Introduction

Studying spectral properties of galaxy populations in rich clusters offers a unique opportunity to observe directly galaxy evolution and environmental effects on star formation, by providing large numbers of galaxies at the same redshift which have been exposed to a wide variety of environments. Episodes of star formation in cluster galaxies can be driven both by the accretion of field galaxies into the cluster and by cluster-cluster merging. Hence it is crucial to relate the star formation history of cluster galaxies to global properties of clusters, such as mass and dynamical state.

2. The data

In order to investigate the effect of environment and dynamics on galaxy properties, in particular on star formation, we have performed a photometric and spectroscopic investigation of galaxies in the cluster ABCG 209 at z=0.21 (Mercurio et al. 2004; and references therein) using EMMI-NTT spectra and archive Canada-France-Hawaii Telescope (CFHT) imaging.

A total of 102 spectra of cluster members with R $\lesssim$ 20.0 were examined in four fields (field of view $5' \times 8.6'$), with different position angles on the sky. Details on spectroscopic data and reduction procedures are described in Mercurio et al. (2003). The photometric data were collected in November 1999 (PI. J.-P. Kneib) using the CFH12K mosaic camera, consisting of B– and R–band wide field images, centred on the cluster ABCG 209 and covering a total field of view of $42' \times 28'$ ($8.6 \times 5.7\ h_{70}^{-2}$ Mpc^2 at the cluster redshift). Reduction procedures, photometric calibration and catalogue extraction are described in Haines et al. (2004).

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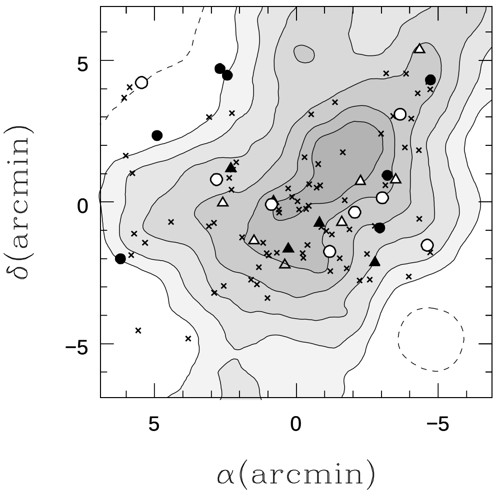

Fig. 1. Spatial distribution of different spectral classes. Filled and open circles, filled and open triangles, and crosses denote ELG, Ab–spiral, HDS_{blue}, HDS_{red} and P galaxies, respectively. The plot is centred on the cluster center. The dashed contour corresponds to the field galaxy number density, while the solid contours correspond respectively to the background subtracted 2, 3.3, 5, 7.5, 10, and 12.5 galaxies $arcmin^{-2}$.

3. Spectral classification

We classified each member galaxy on the basis of the measured equivalent widths of the atomic features [OII], H_δ, [OIII], H_α and of the strength of the 4000 Å break. We also studied the properties of bulge-dominated and disk-dominated galaxies separately, based on the value of the Sersic index *n* in the R band (see La Barbera et al., 2003). We defined five different types of galaxies : i) passive evolving galaxies (P), which exhibit red colours and no emission lines, ii) emission line galaxies (ELG), which are blue and have prominent emission lines, iii) strong blue H_δ galaxies (HDS_{blue}), that are characterized by the presence of strong H_δ absorption lines ($EW(H_\delta) >$ 5 Å) and blue colours , iv) strong red H_δ galaxies (HDS_{red}) galaxies, having $EW(H_\delta) > 3$ Å and red colours; v) anemic spirals (Ab-spirals), that have the same spectral properties of passive evolving galaxies, but are disk-dominated systems.

P galaxies represent ∼ 74% of the cluster population, and lie mainly in high density regions (crosses in Fig. 1). This population has a velocity dispersion fully consistent with that of the whole cluster (see Table 1). HDS_{red} galaxies are distributed along the elongation of the cluster, mainly in intermediate density regions (open triangles in Fig. 1) and have a low velocity dispersion (see Table 1), suggesting that this population could be the remnant of an infalling group. HDS_{blue} galaxies are found in intermediate density regions (filled triangles in Fig.1), in a direction perpendicular to the cluster elongation, that coincides with the elongation of the X-ray contour levels in the Chandra images (see Fig. 14 in Mercurio et al. 2003). This galaxy population is also characterized by high velocity dispersion. ELGs lie in low density regions (filled circles in Fig.1) and have high line–of–sight velocity dispersion, as for the HDS_{blue} galaxies. Both the spatial position and the velocity dispersion suggest that these two populations of galaxies have recently fallen into the cluster from the field. Although both HDS_{blue} and HDS_{red} present strong Balmer lines, their colours and structural parameters show that they are two different galaxy populations. Deriving the Sersic index *n*, we found that HDS_{blue} galaxies are disk-dominated galaxies while HDS_{red} are spheroids. Moreover we have found eight red P galaxies having the Sersic index less than 2. We suggest that they are a population of disk galaxies. We recognize these galaxies as Ab-spiral, assuming that gas has been stripped from the outer parts of these objects, and treat them as a different sample of galaxies from that of ellipticals.

3.1. Star formation histories

In order to follow the evolution of galaxies belonging to different spectral classes, we compare the strengths of various spectral indices in the observed galaxy spectra to stellar population models with different star formation rates and metallicities (Fig 2).

P-galaxies are well described by an exponentially declining star formation with time scale τ=1.0 Gyr. Assuming this SF history and

Table 1. Redshifts and velocity dispersion of different spectral classes.

Class	N_{gal}	Redshift	σ_v
ALL	112	0.2090 ± 0.0004	1394^{+88}_{-99}
P	74	0.2086 ± 0.0005	1323^{+127}_{-94}
HDS_{red}	7	0.2087 ± 0.0005	339^{+91}_{-46}
Ab − spirals	8	0.2107 ± 0.0017	1295^{+340}_{-102}
HDS_{blue}	5	0.2071 ± 0.0044	2257^{+1085}_{-65}
ELG	7	0.2070 ± 0.0038	2634^{+712}_{-53}

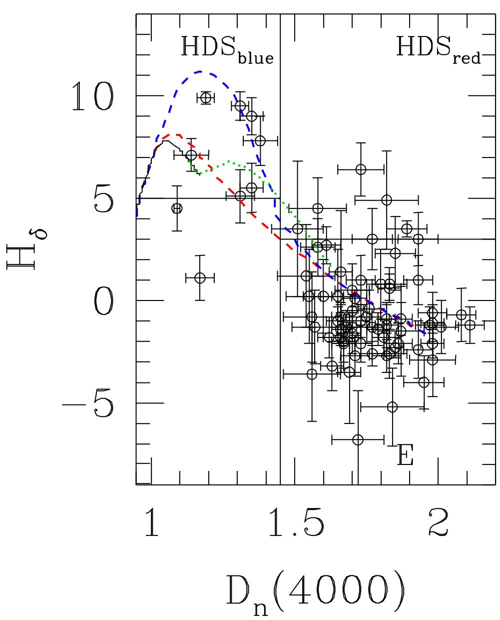

Fig. 2. Equivalent width of H_δ in Å versus the break at 4000 Å for galaxies of different spectral types and GISSEL03 models with Z=1$Z_\odot$. The red line represents a model with exponentially declining SFR with time scale τ=1.0 Gyr while for black continuous and green dotted lines the decay parameter is μ=0.01. For the green line the star formation is truncated at t=10 Gyr. The blue dashed line represents a model with an initial burst of 100 Myr.

metallicities Z=0.4 $Z_\odot$, $Z_\odot$, 2.5 $Z_\odot$, the distribution of ages for early-type galaxies shows that there are two populations of ellipticals, one formed early during the initial collapse of the cluster, at $z_f \gtrsim 3.5$ and another constituted by a younger galaxy population, that could be formed later ($z_f \gtrsim 1.2$) or could have experienced an enhancement in the star formation rate ∼ 8.5 Gyr ago. ELG galaxies can be fitted either by a model with truncated star formation history and by a model with a burst involving the 40% of the total mass. The starburst is assumed to begin at t=9 Gyr lasting for 0.1 Gyr. The strength of the lines and the colour of these galaxies indicate an interruption of the star formation within the last 0.5 Gyr, with a strong starburst preceding the quenching of star formation. HDS_{red} exhibits weaker H_δ equivalent widths. The measured D_n(4000) of these galaxies can be consistent with short starburst models only in presence of a substantial reddening by dust. The measured EW(H_δ) and D_n(4000) imply that these galaxies have experimented a burst no more than 4.5 Gyr ago.

4. Conclusions

All the presented results are understandable in terms of cosmological models of structure formation, in which galaxies form earliest in the highest-density regions corresponding to the cores of rich clusters, while galaxies in the cluster periphery are accreted later. It is suggested an evolutionary scenario in which ABCG 209 is characterized by the presence of two components: an old galaxy population ($z_f \gtrsim 3.5$) and a younger population of infalling galaxies. Moreover, this cluster may have experienced, 3.5-4.5 Gyr ago, a merging with an infalling galaxy group.

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