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Internal Dynamics of ABCG 209 at z∼ 0.21

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Abstract. We report the results about the internal dynamics of the rich galaxy cluster ABGC 209 on the basis of new spectroscopic and photometric data. ABCG 209 is a peak of 112 detected member galaxies at z= 0.209, characterised by a high value of the line–of–sight velocity dispersion, $\sigma_v \sim 1400$ km s^{-1}. The cluster shows evidence of relevant substructure and dynamical segregation, and is characterised by a preferential SE–NW direction. The observational scenario suggests that ABCG 209 is a strongly evolving cluster, possibly in an advanced phase of merging.

Key words. Galaxies: clusters: general – Galaxies: clusters: individual: ABCG 209 – Galaxies: redshifts – Cosmology: observations

1. Introduction

In order to gain insight into the physics of the formation of clusters of galaxies, we carried out a spectroscopic and photometric study of the cluster ABCG 209, at z ∼ 0.21 (Fetisova 1981), which is a rich, very X–ray luminous and hot cluster (richness class R = 3, Abell et al. 1989; $L_X(0.1-2.4 \text{ keV}) \sim 14\ h_{50}^{-2}\ 10^{44}$ erg s^{-1}, Ebeling et al. 1996; $T_X \sim 10$ keV, Rizza et al. 1998). The first evidence for its complex dynamical status came from the significant irregularity in the X–ray emission, characterized by a trimodal peak (Rizza et al. 1998).

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2. Observations

The data were collected at the ESO New Technology Telescope (NTT) with the ESO Multi Mode Instrument (EMMI) in October 2001. The spectroscopic sample consists of 166 spectra, randomly selected by using preliminar R–band images. 112 galaxies turned out to be cluster members (seven of which observed twice). A field of $9.2' \times 8.6'$ (1.2×1.1 Mpc^2 at z=0.209, $H_0 = 100$ h km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$.) was observed in B–, V– and R–bands, pointed to the center of the cluster. Two additional adjacent fields were observed in V–band in order to sample the cluster at large distance from the center (out to ∼ 1.5 Mpc).

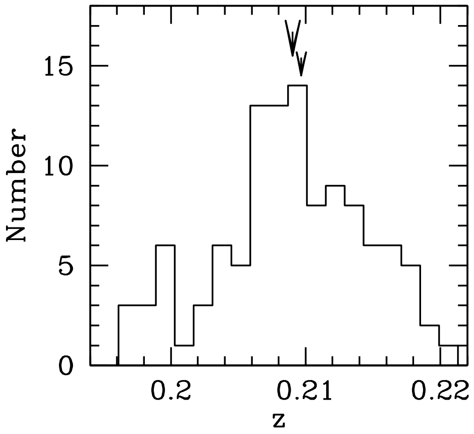

Fig. 1. Distribution of redshifts of the cluster members. The big and small arrows indicate the mean cluster redshift and the redshift of the cD galaxy, respectively.

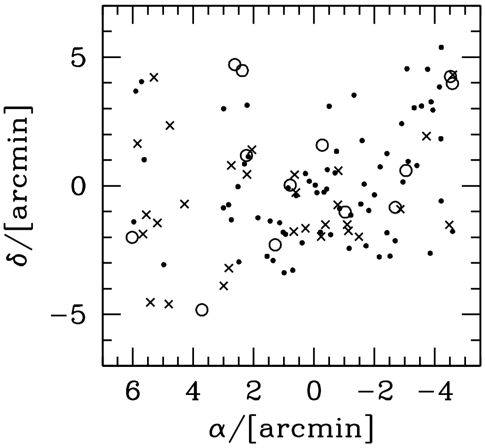

Fig. 2. Distribution of member galaxies centered on the cluster center. Dots, open circles, and crosses indicate low–, intermediate–, and high–velocity clumps respectively.

3. Dynamical analysis

3.1. Redshift distribution

The analysis of the redshift distribution based on the one–dimensional adaptive kernel technique (Pisani 1993, Fadda et al. 1996 and Girardi et al. 1996) confirms that ABCG 209 is characterised by a peak at z $\sim$ 0.209 (cf. Fig. 1). We estimated the line–of–sight (LOS) velocity dispersion $\sigma_{\rm v} = 1394^{+88}_{-99}$ km s^{-1}, where errors were estimated with the bootstrap method. The value of $\sigma_{\rm v}$ leads to a value of the radius of the collapsed, quasi–virialized region $\mathrm{R_{vir}} \sim 1.78$ $\mathrm{h_{100}^{-1}}$ Mpc (cf. Eq. (1) of Girardi & Mezzetti 2001) and of the virial mass $\mathrm{M}(<\mathrm{R_{vir}}) = 2.25^{+0.63}_{-0.65} \times 10^{15}$ $\mathrm{h_{100}^{-1}}$ $\mathrm{M_\odot}$, assuming the dynamical equilibrium.

According to the KMM algorithm (cf. Ashman et al. 1994), we found that a mixture of three Gaussians (of $\mathrm{n_1} = 13$, $\mathrm{n_2} = 70$, and $\mathrm{n_3} = 29$ members at mean redshift $\mathrm{z_1} = 0.1988$, $\mathrm{z_2} = 0.2078$, and $\mathrm{z_3} = 0.2154$) is a better description of velocity distribution (at 91.2% c.l.). For the clumps we estimated a velocity dispersion of $\sigma_{\rm v1} = 337$ km s^{-1} , $\sigma_{\rm v2} = 668$ km s^{-1} , and $\sigma_{\rm v3} = 545$ km s^{-1} . Figure 2 shows the spatial distributions of the three clumps. The second and the third clumps are clearly spatially segregated.

3.2. Substructures

We found an evidence (c.l. 95.2%) for the presence of a velocity gradient in the direction SE–NW, at position angle PA= 141^{+29}_{-37} degrees (cf. Fig. 3).

In order to check for the presence of substructure, we combined velocity and position information by computing the Δ–statistics [1] devised by Dressler & Schectman (1988) . The significance of substructure was checked by running 1000 Monte Carlo simulations, randomly shuffling the galaxy velocities, obtaining a sig-

[1] For each galaxy, the deviation δ is defined as $\delta^2 = (11/\sigma^2)[(\overline{\rm v}_l - \overline{\rm v})^2 + (\sigma_l - \sigma)^2]$, where subscript l denotes the average over the 10 neighbours of the galaxy. Δ is the sum of the δ of the individual galaxies.

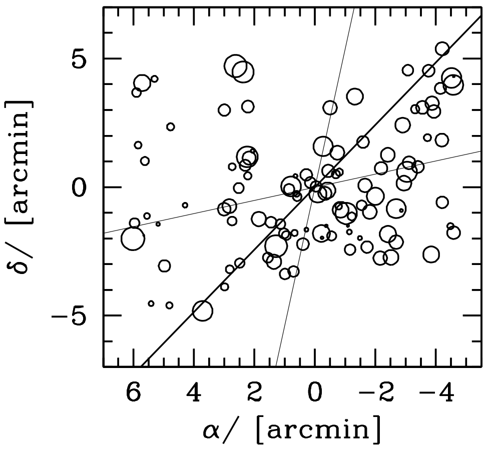

Fig. 3. Spatial distribution of member galaxies centered on the cluster center. Circle radius is proportional to the radial velocity. The solid and the thin lines indicate the position angle of the cluster velocity gradient and relative errors, respectively.

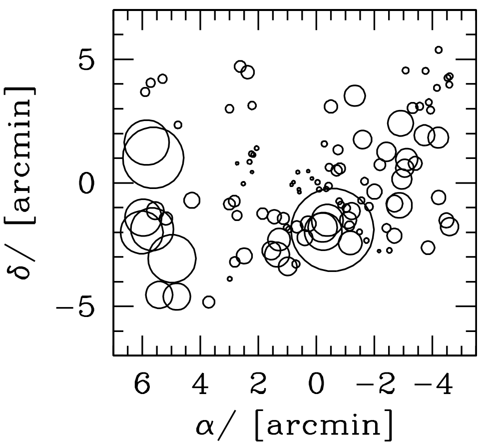

Fig. 4. Spatial distribution of the cluster members. The radii of the circles are proportional to the deviation δ of the local parameters from the global cluster parameters. The plot is centered on the cluster center.

nificance level of 98.7%. This indicates that the cluster has a complex structure.

In Fig. 4, we can see a group of galaxies with high velocity that is the cause of large values of the deviation δ of the individual parameters (position and velocity) from the mean cluster parameters, in the external East cluster region. The other possible substructure lies in the well sampled cluster region, closer than 1 arcmin SW to the cluster center .

4. Luminosity Segregation and X–Ray analysis

We performed a two–dimensional analysis to detect subclumps using the photometric sample of galaxies for which we have B–R colours. Galaxies were selected using the B–R vs. R colour–magnitude relation, determined on the spectroscopically confirmed cluter members. The projected galaxy distribution is clustered and elongated in the SE–NW direction. Galaxies brighter than R=19.5 (upper panel of Fig. 5), are centered around the cD, while galaxies fainter than R=19.5 (lower panel of Fig. 5) show some clumps aligned in the SE–NW direction. In particular, the main clump, eastward with respect the cD galaxy, coincides with the secondary peak found in the analysis of the Chandra X–ray data.

The X–ray analysis of ABCG 209 was performed by using the Chandra archive[2] data. In order to detect possible substructures in ABCG 209 we ran the task CIAO/Wavdetect. We found two significant substructures: the principal one, located at α= 01 31 52.7 and δ= -13 36 41, is centered on the cD galaxy; the second is a structure located at α= 01 31 55.7 and δ= -13 36 54, about 50 arcseconds (∼120 h_{100}^{-1} kpc) East of the cD, well coincident with the clump found in the distribution of faint galaxies (see Fig. 5, lower panel).

[2] http://asc.harvard.edu/cda/

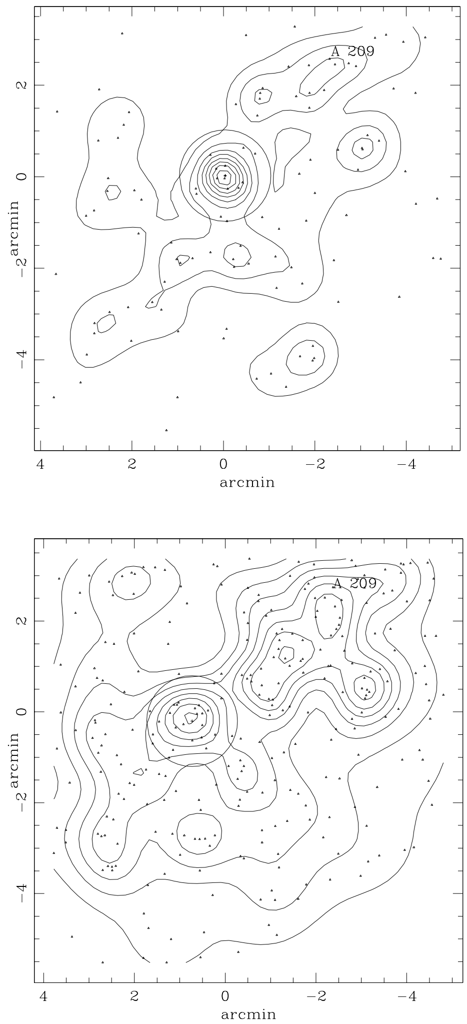

Fig. 5. Spatial distribution on the sky and relative sodensity contour map of cluster members selected on the basis of the B–R colour–magnitude relation, recovered by adaptive–kernel method (cf. Pisani 1993, 1996). The plots are centered on the cluster center. Upper panel: bright (R< 19.5) galaxies. The 1 arcmin circle is centered on the cD galaxy position. Lower panel: fainter (R> 19.5) galaxies. The 1 arcmin circle is centered on the secondary X–ray peak. In the figures the isodensity contours are spaced by $5 \cdot 10^{-5}$ galaxies/arcsec^2.

5. Summary and conclusions

The dynamical analysis shows that ABCG 209 is characterised by a high value of the LOS velocity dispersion, $\sigma_{\rm v} \sim 1400$ km s^{-1} and by a preferential SE–NW direction. There is evidence of significant substructure and of a strong luminosity segregation of colour–selected members. All these facts suggests that ABCG 209 is presently undergoing strong dynamical evolution with the merging of two or more sub-clumps along the SE–NW direction, possibly in an advanced phase.

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