GALAXY PAIRS IN THE FIELD OF RX J0152.7-1357 AT $z \sim 0.84$

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Abstract. We study the photometric and morphological properties of galaxies in pairs and groups for a complete sample of 86 spectroscopically confirmed members of the cluster RX J0152.7-1357 ($z = 0.837$), combining optical-NIR photometric data, morphological data, and archival images from Hubble Space Telescope Advanced Camera for Surveys (ACS/WFC). We determine a kinematic galaxy pairs sample with 38 galaxies and underline the role of galaxy-galaxy interactions in the modification of color and morphology of galaxy pairs.

Key words: galaxy groups and clusters - galaxy-galaxy interactions - galaxy pairs.

1. INTRODUCTION

The main drivers of galaxy evolution are represented by processes as ram pressure stripping, high speed harassment, tidal heating and galaxy-galaxy interactions. All these processes are very important in shaping the morphologies and stellar populations of galaxies, as well as the relationship between color, morphology and local environment density (groups of galaxies, core or outskirt of galaxy clusters, field). It is now accepted that galaxy-galaxy interactions and mergers represent the main physical processes that trigger substantial star formation in galaxies (Lambas *et al.*, 2003; Barton *et al.*, 2007). Strong modification of galaxy morphologies can be produced by these interactions and even complex structures, such as tidal tails, bridges, plumes can be encountered.

The X-ray luminous intermediate redshift cluster RX J0152.7-1357 ($z = 0.837$) was discovered by different X-ray surveys such as *ROSAT* Deep Cluster Survey (Rosati *et al.*, 1998), Wide Angle *Rontgensatellit (ROSAT)* Pointed Survey (WARPS) (Scharf *et al.*, 1997; Ebeling *et al.*, 2000), and Bright SHARC (Serendipitous High-Redshift Archival *ROSAT* Cluster) Survey (Romer *et al.*, 2000).

Since these discoveries, many authors obtained important results on RX J0152.7-1357 characteristics regarding the dynamics and substructure of the cluster (Demarco *et al.*, 2005; Girardi *et al.*, 2005), the physical properties of galaxy members (Jorgensen *et al.*, 2005), the red sequence properties (Blakeslee *et al.*, 2006; Patel *et al.*, 2009), the structure of intracluster medium and X-ray properties (Maughan *et al.*, 2003), the presence of large-scale filaments associated with this cluster (Tanaka *et*

al., 2006).

RX J0152.7-1357 has a dynamically young and complex structure, with two subclusters (a northern subcluster and a southern one) in the early stages of merging (Demarco *et al.*, 2005; Girardi *et al.*, 2005), a galaxy group near the cluster to the east (Maughan *et al.*, 2003), and the hold over of groups from the surrounding filaments (Tanaka *et al.*, 2006). The two subclusters are both hot (with temperatures of 5.5 keV and 5.2 keV, respectively), massive (the masses within the virial radii are estimated at $(6.1 \pm 1.6) \times 10^{14} M_{\odot}$ and $(5.2 \pm 1.6) \times 10^{14} M_{\odot}$ (Maughan *et al.*, 2003)), and X-ray luminous, these subclusters being separately measured for the first time from the *Chandra* data. The mass within 1 Mpc is $M(< 1Mpc) = (4.9 \pm 0.4) \times 10^{14} M_{\odot}$ from a weak-lensing analysis of Jee *et al.* (2005).

The spectroscopic redshift of $z = 0.83$ was confirmed by Ebeling *et al.* (2000), and Della Ceca *et al.* (2000). Demarco *et al.* (2005) determined the mean redshift of one hundred galaxy members as $z = 0.837$, and the mean redshift of $z = 0.834$ for the early-type galaxies in the sample.

In a previous paper (Popescu, 2013), we analysed the environment of RX J0152.7-1357, at $z = 0.837$, using the combined catalogs of Blakeslee *et al.* (2006) and Demarco *et al.* (2010). The photometric and morphological properties of the confirmed members of the massive X-ray selected cluster RX J0152.7-1357, especially the properties of the early type galaxies and the structural properties of the population of Extremely Red Galaxies (ERGs) have been studied.

In the present work we determine a galaxy-pairs sample of 38 galaxies in the field of the cluster RX J0152.7-1357, and analyse the role of galaxy-galaxy interactions in triggering star formation and strong modification of galaxy morphologies and colors.

2. THE DISTRIBUTION OF GALAXY PAIRS

A complete sample of 86 confirmed members with optical-NIR photometric data, morphological data and spectroscopic redshifts was obtained (Popescu, 2013) by combining the following catalogs:

- the catalog of Blakeslee *et al.* (2006), with ($F625W$, $F775W$, $F850LP$) HST/ACS/WFC optical photometric data, spectroscopic and morphological data for 107 galaxies, in a 42 arcmin^2 field;
- the catalog of Demarco *et al.* (2010), with ($F625W$, Ks) optical and near-infrared photometric data, for 134 galaxies in a 46.24 arcmin^2 field.

These data have been obtained with ACS/WFC (optical data; Moorwood *et al.*, 1998) and SofI on the ESO NTT (near-infrared data; Demarco *et al.*, 2005). The

VLT/FORS spectroscopy has also been provided in this catalog, the galaxies in the considered sample being all confirmed cluster members with spectroscopic redshifts.

In both catalogs the magnitudes are on the AB system (Oke, 1974), being corrected for Galactic extinction according to Schlegel *et al.* (1998). The corrections are 0.038, 0.029, 0.021, and 0.009 mag in $F625W$ (denoted r_{625}), $F775W$ (denoted i_{775}), $F850LP$ (denoted z_{850}), and Ks, respectively.

In the cosmological model $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$, at the cluster redshift of $z \sim 0.84$, $1''$ on the sky corresponds to 7.6 kpc in a physical distance (*i.e.*a linear size of 0.455 Mpc corresponds to $1'$ on the sky). The data from this catalog cover a field of 46.24 arcmin^2 (6.8 arcmin $\times$ 6.8 arcmin), which is equivalent to an area of 3.1 Mpc $\times$ 3.1 Mpc at the cluster redshift.

The 2D distribution of the selected sample of 86 galaxies in the RX J0152.7-1357 field is presented in Fig.1. In this figure North is up and Est is to the left. The morphological types of galaxies are reprezented with: dots for elliptical galaxies (E), circles for S0 lenticular galaxies, diamonds for S0/Sa, (X) for Sp galaxies, and crosses for Irr galaxies. The center of the field is considered at RA = 01h 52m 41.13s, DEC= -13d 57m 43.03s (Tanaka *et al.*, 2006). In Fig.1 the sample of galaxy-pairs is overlapped with large squares symbols on the mentioned above symbols for the studied galaxies.

The galaxies are grouped into two main clumps, one to the north-east of the center of the image (hereafter named northern clump) and the other one to the south-west (hereafter named southern clump). These two clumps are separated by 1.6 arcmin, which corresponds to about 730 kpc at $z \sim 0.84$.

The morphologies of galaxies in the considered ACS field (down to an AB magnitude limit of $i_{775} < 23.5$) have been classified according to Postman *et al.* (2005).

The morphological T-types are those defined in de Vaucouleurs *et al.* (1976):

- for elliptical (E) galaxies $-5 \leq T \leq -3$;
- for S0 galaxies $T = -2$;
- for morphologies between S0 and Sa galaxies $-1 \leq T \leq 1$;
- for later type spiral (Sp) galaxies $2 \leq T \leq 6$ (type $T = 6$ is associated with an Sd morphology);
- for irregular (Irr) galaxies $6 < T \leq 10$.

With the morphological classification presented above, five groups are defined with the following number of galaxies: 36 E ($-5 \leq T \leq -3$); 8 S0 ($T = -2$); 24 S0/Sa

($-1 \leq T \leq 1$, morphologies between S0 and Sa); 12 Sp ($2 \leq T \leq 6$); 4 Irr($6 < T \leq 10$).

Two AGNs with morphological type $T = 11$ are withdrawn from our study.

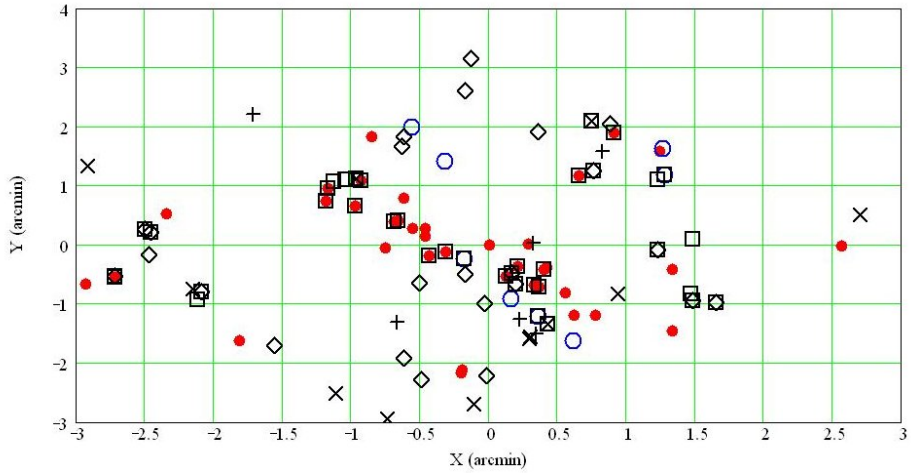

Fig. 1 – The 2D distribution of the galaxies in the RX J0152.7-1357 cluster field, function of morphology. The symbols are as follows: dots for 36 E gal.; circles for 8 S0 gal.; diamonds for 24 S0/Sa gal.; (X) for 12 Sp gal.; crosses for 4 Irr gal.; squares for the overlapped 38 galaxies in pairs.

3. THE KINEMATIC GALAXY-PAIRS SAMPLE

For the detection of our sample of galaxy pairs, we are able to select kinematic pairs, which require accurate spectroscopic redshifts of both pair components in order to reduce the contamination by foreground and background galaxies.

In order to determine the kinematic galaxy pairs in the field of the RX J0152.7-1357 cluster, the following criteria are applied:

(1) For each galaxy in the spectroscopic redshift sample are determined the kinematic companions with a relative line-of-sight velocity difference $|\Delta v| \leq 1000$ km s^{-1} (Barton *et al.*, 2000) and a projected physical separation $r_{proj} \leq 300$ h^{-1} kpc.

(2) In the selected kinematic companions sample, close pairs are considered if they satisfy 10 h^{-1} kpc $\leq r_{proj} \leq 50$ h^{-1} kpc, and $|\Delta v| \leq 500$ km s^{-1} (Lin *et al.*, 2008; Patton and Atfield 2008; Patton *et al.*, 2011).

(3) Wide pairs are determined when the kinematic companions have their projected physical separation in the range 50 h^{-1}kpc $\leq r_{proj} \leq 300$ h^{-1} kpc.

According to Patton *et al.* (2000), galaxy pairs with projected physical separations less than $20h^{-1}$ kpc and velocity differences less than 500 km s^{-1} present disturbed morphologies or signs of interactions, and these galaxies are expected to merge within 0.5 Gyr.

The rest-frame relative velocity along the line of sight is determined with the formula:

$$\Delta v = c|z_C - z_P|/(1+z_P). \quad (1)$$

The linear distance between two galaxies can be obtained using the projected separation $r_{proj} = \theta d_A(z_P)$. In these formulae z_P is the redshift of the principal (more luminous) galaxy in the pair; z_C is the redshift of the companion galaxy; θ is the angular separation of the two galaxies on the sky plane (in arcsec); $d_A(z)$ is the angular scale at redshift z (in kpc/arcsec); c is the speed of light.

Because for the 86 galaxies determined in the combined catalogs of Blakeslee *et al.* (2006) and Demarco *et al.* (2010) (see Popescu, 2013) secure redshifts are available, in the selection of our galaxy pairs we have the redshifts for both members of a pair. In this way the contamination due to unrelated foreground/ background companions is excluded. Thus the intrinsic galaxy properties as a function of projected physical separation and relative line-of-sight velocity can be compared.

Table 1 presents the photometric, morphological and spectroscopic characteristics of the 38 galaxies in the galaxy-pairs sample determined according to the mentioned above criteria, for the galaxies in the field of RX J0152.7-1357 cluster. The columns of the table are as follows: ID from Blakeslee catalog; i_{775} magnitude; morphological type (T); $(i_{775} - z_{850})$ color; ID from Demarco catalog; K_{AB} magnitude; $(r_{625} - Ks)_{AB}$ color; redshift z_{spec}. The ninth column represents the emission line flag (EL), with a value of 0 for passive galaxies, and a value of 1 for emission line galaxies (Demarco *et al.*, 2010). In this sample of 38 galaxies, only four galaxies from Blakeslee *et al.* (2006) have no secure redshifts. Also, two galaxies belong only to the catalog of Demarco *et al.* (2010), these ones being detected on the archival images from Hubble Space Telescope Advanced Camera for Surveys (ACS/WFC), at the Canadian Astronomical Data Center (CADC).

In Fig.2 and Fig.3 are presented the analysed fields of galaxies, each of the two archival images covering a field of 4.767×5.013 arcmin^2 (in $F775W/F625W$ bands), and 4.767×4.047 arcmin^2 (in $F775W/F625W$ bands), respectively (N is up; E is to the left). Inside these two images that cover ~ 43 arcmin^2, we delimited with big circles the existing galaxy pairs, and small groups from Table 1.

Among the 38 galaxies in the sample, we have identified eleven galaxy-pairs, three triplets of galaxies, and a small group of 4 galaxies. Only the pairs formed by galaxies with identification numbers B5495-B5417 (with $r_{proj} = 13.847$ kpc), B3270-B3297 (with $r_{proj} = 46.14$ kpc), B1808-B1859 (with $r_{proj} = 22.656$ kpc),

Table 1

Galaxies-pairs sample properties.

ID B	i_{775}	T	$(i_{775}-z_{850})$	ID D	Ks	$(r_{625}-Ks)$	z_{spec}	EL
5495	20.66	-5	0.679	1466	19.119	3.448	0.8395	0
5417	20.83	-5	0.694	1467	19.147	3.413	0.8412	0
499	22.22	-1	0.668	1496	20.28	3.633	0.83	0
748	23.4	0	0.7	396	22.436	2.952	0.828	0
899	22.27	4	0.376					
1809	22.57	3	0.442					
1898	21.53	1	0.637	551	19.711	3.525	0.8362	1
3270	21.49	-2	0.69					
3297	21.92	-2	0.654	1367	20.288	3.265	0.8352	0
5606	21.15	-5	0.647	1172	19.571	3.143	0.8373	0
5037	21.42	4	0.456	851	19.861	2.923	0.836	1
6434	21.06	1	0.581	1258	19.162	3.381	0.8394	1
6417	21.74	-4	0.704	1338	20.074	3.307	0.8331	0
1355	21.54	3	0.308	295	20.576	2.282	0.837	1
1571	21.95	-2	0.646	332	20.405	3.155	0.8322	0
1808	20.81	-5	0.727	387	19.636	3.716	0.8293	0
1859	21.32	-4	0.76	439	19.556	3.604	0.8294	0
2420	22.81	-1	0.733	455	21.413	3.36	0.8295	0
2412	22.4	-5	0.668	498	20.774	3.041	0.8258	0
2747	22.09	-5	0.729	513	20.504	3.284	0.8275	0
2623	22.54	-1	0.703	477	21.069	3.37	0.8306	0
2569	21.66	-5	0.71	468	19.757	3.492	0.8272	0
3231	22.23	-2	0.772	547	20.377	3.626	0.846	0
3605	21.94	-4	0.755	571	20.051	3.494	0.8444	0
3727	21.99	-4	0.713	548	20.292	3.354	0.8371	0
3941	20.71	-5	0.711	131	19.197	3.698	0.8436	0
3940	21.09	-1	0.691	1501	19.244	3.408	0.8473	0
10164	20.98	1	0.684	1500	19.353	3.142	0.8477	0
10259	22.49	1	0.739	1499	21.229	3.123	0.8462	0
4680	20.67	-4	0.713	701	18.817	3.506	0.8352	0
4219	20.45	-5	0.721	679	18.613	3.595	0.8342	0
4003	22.87	3	0.5	648	21.435	3.022	0.8461	0
10673	21.58	-2	0.718				0.8457	
3956	21.94	-5	0.707	1386	20.179	3.399	0.8388	0
4126	22.72	-5	0.655	663	21.583	3.117	0.8302	0
				1356	21.157	2.977	0.829	0
5292	21.69	-1	0.794	258	19.658	3.772	0.843	0
				5015	21.081	3.189	0.846	0

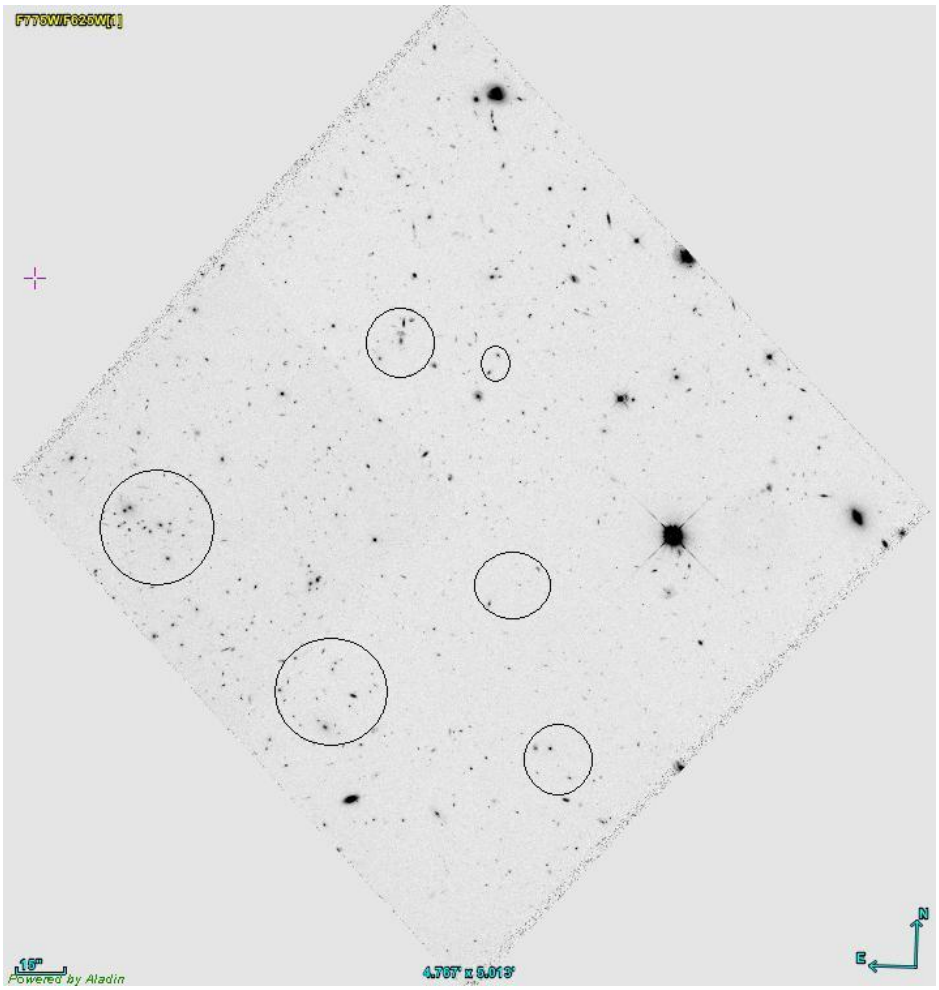

Fig. 2 – The archival image from HST/ACS/WFC of the galaxies in the RX J0152.7-1357 cluster field of 4.767×5.013 arcmin ^{2}.

B2623-B2569 (with $r_{proj} = 27.862$ kpc), B3941-B3940 (with $r_{proj} = 12.555$ kpc), and B10164-B10259 (with $r_{proj} = 28.257$ kpc) have the projected distances less than 50 h^{-1}kpc, and fulfill the criteria for close pairs of galaxies.

The other galaxies represent wide pairs of galaxies, with projected distances in the range 50 h^{-1}kpc $\leq r_{proj} \leq$ 143 h^{-1} kpc.

The final products of the interactions and mergers between different types of galaxies can be essentially different. Thus, in the case of mergers between two gas-poor galaxies (*i.e.dry mergers*) important changes in the star formation rate may not be produced. Dry mergers could influence the stellar mass growth of massive red

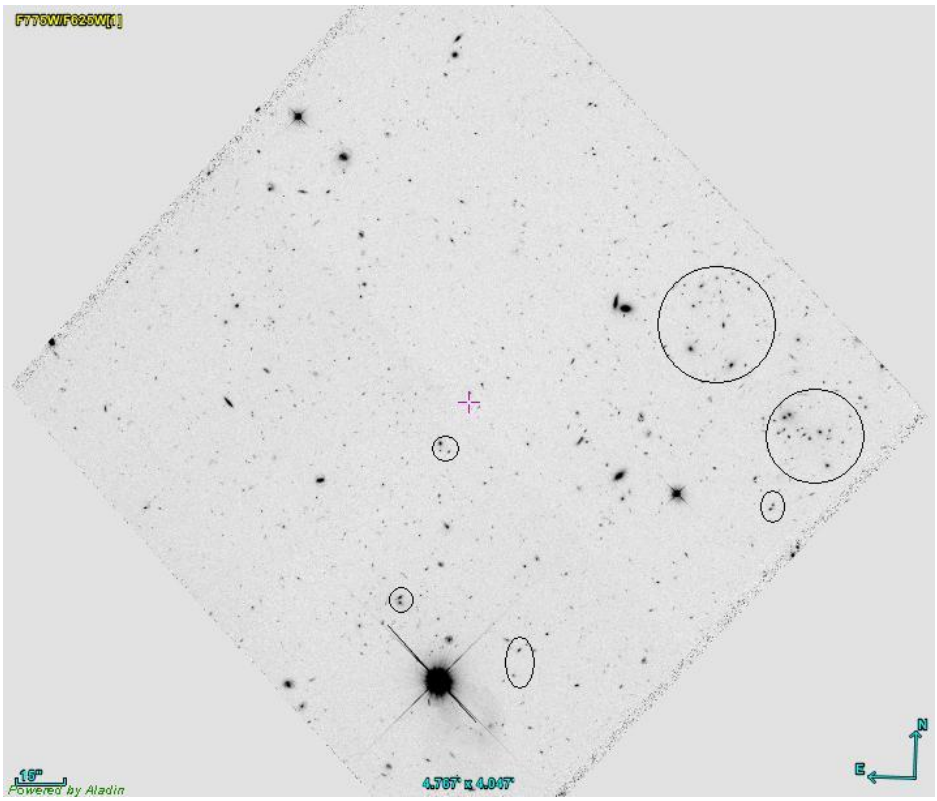

Fig. 3 – The archival image from HST/ACS/WFC of the galaxies in the RX J0152.7-1357 cluster field 4.767×4.047 arcmin ^{2}.

galaxies at the current epoch (Tran *et al.*, 2005; van Dokkum, 2005; Bell *et al.*, 2006).

In our sample, one observes that the galaxies in pairs present obvious features of interactions, with bluer $(i_{775} - z_{850})$ and $(r_{625} - Ks)$ colors, as characteristics of interactions/mergers that trigger star formation activity (see Table 1).

In a forthcoming paper, based on the archival images from HST/ACS/WPC, a detailed analysis of the morphology and colors of the determined galaxy pairs will be presented.

4. CONCLUSIONS

In this paper we analysed the environment of the cluster RX J0152.7-1357 ($z = 0.837$), searching for the galaxy pairs and small groups among the 86 confirmed members with optical-NIR photometric data, morphological data and spectroscopic

redshifts (Popescu, 2013), in two archival images from Hubble Space Telescope Advanced Camera for Surveys (ACS/WFC).

For the galaxies in the field of RX J0152.7-1357 cluster, we determined a sample of 38 galaxies in pairs, according to a strong pair isolation criterion in terms of the apparent angular separation and rest-frame line-of-sight velocity difference. Combining optical-NIR photometric data, morphological data, redshifts and ACS/HST archival images, the analysis of photometric and morphological properties of galaxies in pairs, triplets, and small groups was performed.

A large fraction of red galaxies in pairs, triplets and small groups was determined. The presence of the emission line galaxies in the case of three mixed pairs, and a wet merger is also revealed.

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