EXTREMELY RED GALAXIES IN THE FIELD OF RX J0152.7–1357 AT $z \sim 0.84$

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Abstract. We study a complete sample of 86 galaxies in the field of the intermediate redshift cluster RX J0152.7-1357, at $z = 0.837$, using the catalog of Blakeslee *et al.* (2006) with optical photometric data, from Hubble Space Telescope Advanced Camera for Surveys (ACS/WFC), spectroscopic and morphological data, combined with the catalog of Demarco *et al.* (2010), with VLT/FORS spectroscopy, ACS/WFC optical data, and NTT/SofI near-IR data. By means of color-color and color-magnitude diagrams of the galaxies in the studied sample, we determine the population of Extremely Red Galaxies (ERGs), and we study their photometric and structural properties.

Key words: galaxy groups and clusters - extremely red galaxies.

1. INTRODUCTION

The study of evolution of galaxy clusters and their interrelationship with the large-scale clusters environment represents the goal of many surveys. The cluster RX J0152.7–1357 is an X-ray luminous intermediate redshift clusters ($z = 0.837$), that was independently discovered in *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).

The properties of the RX J0152.7–1357 cluster were studied by a number of X-ray surveys such as WARPS (Ebeling *et al.*, 2000), *BeppoSAX* (Della Ceca *et al.*, 2000), *XMM-Newton* (Maughan *et al.*, 2006), and *Chandra* (Maughan *et al.*, 2003).

The characteristics of RX J0152.7–1357 cluster were extensively analyzed, with important results on: structure of intracluster medium and X-ray properties from *Chandra* observations (Maughan *et al.*, 2003), red sequence properties (Blakeslee *et al.*, 2006; Patel *et al.*, 2009), cluster dynamics and substructures (Demarco *et al.*, 2005; Girardi *et al.*, 2005), weak-lensing mass structure (Jee *et al.*, 2005), evolution of star-forming galaxies as members of this cluster (Homeier *et al.*, 2005), physical properties of galaxy members (Jorgensen *et al.*, 2005), and large-scale filaments associated with the cluster (Tanaka *et al.*, 2006).

With a dynamically young and complex structure, RX J0152.7–1357 is a result

Romanian Astron. J. , Vol. **23**, No. 2, p. 107–119, Bucharest, 2013

of two subclusters that appear to be in the early stages of merging (Demarco *et al.*, 2005; Girardi *et al.*, 2005) and the hold over of groups from the surrounding filaments (Tanaka *et al.*, 2006). By means of *Chandra* ACIS-I observation, the two subclusters were fully resolved into a northern and southern subcluster and a galaxy group near the cluster to the east (Maughan *et al.*, 2003). The temperatures of the two subclusters were measured separately for the first time from the *Chandra* data, confirming that they are both hot, massive and X-ray luminous. The subclusters have temperatures of 5.5 keV and 5.2 keV, respectively, and their respective masses within the virial radii were 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). According to Jee *et al.* (2005), the mass within 1 Mpc is $M(< 1Mpc) = (4.9 \pm 0.4) \times 10^{14} M_{\odot}$ from a weak-lensing analysis.

The cluster was spectroscopically confirmed at a redshift of $z = 0.83$ (Ebeling *et al.*, 2000; Della Ceca *et al.*, 2000). Based on 100 galaxy members, the mean redshift of the entire system is $z = 0.837$, and considering only the early-type galaxies the mean redshift is $z = 0.834$ (Demarco *et al.*, 2005).

In the frame of the ACS Intermediate Redshift Cluster Survey (Blakeslee *et al.*, 2003), RX J0152.7–1357 has been also studied. In this survey, galaxy clusters in the redshift range $0.8 < z < 1.3$ have been analyzed, using the Wide Field Channel (WFC) of the Advanced Camera for Surveys (ACS) on board of the *Hubble Space Telescope (HST)*. The studies of galaxy colors, morphologies, mass spectra, and star formation properties from ACS photometry and ground-based spectroscopy, together with the study of cluster structure and assembly from weak lensing, represent the targets of this survey.

In the present work we study the environment of RX J0152.7–1357, at $z = 0.837$, using the catalog of Blakeslee *et al.* (2006) with optical photometric data from ACS/WFC and galaxies morphologies, combined with the catalog of Demarco *et al.* (2010) with VLT/FORS spectroscopy, ACS/WFC optical, and NTT/SofI near-infrared data. 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. We study the photometric and morphological properties of the confirmed members of the massive X-ray selected clusters RX J0152.7–1357, especially the properties of the early type galaxies.

Using color-color $(r_{625} - Ks) - (i_{775} - Ks)$ diagram and color-magnitude $(i_{775} - Ks) - Ks$, $(r_{625} - Ks) - Ks$ diagrams of the galaxies in the determined sample, we select the population of Extremely Red Galaxies (ERGs) and analyze their structural properties.

2. OBSERVATIONAL DATA

A complete sample of 86 confirmed members with optical-NIR photometric, spectroscopic, morphological data and spectroscopic redshifts is obtained by combining the catalog of Blakeslee *et al.* (2006) (107 galaxies with HST/ACS/WFC optical photometric data, spectroscopic and morphological data) with the catalog of Demarco *et al.* (2010) (134 galaxies with VLT/FORS spectroscopy, ACS/WFC optical data, and NTT/SofI near-IR data). In both catalogs the magnitudes are on the AB system (Oke, 1974), being corrected for Galactic extinction.

2.1. BLAKESLEE *ET AL.* (2006) CATALOG

The catalog of Blakeslee *et al.* (2006) contains ($F625W$, $F775W$, $F850LP$) optical photometric data, spectroscopic and morphological data for 107 galaxies, in a 42 arcmin^2 field. The RX J0152.7–1357 spectroscopic survey used photometric redshifts obtained by means of (B, V, R, I, J, Ks) color data in order to select possible cluster members, down to a limiting magnitude of $R < 24$. The galaxies in the considered sample include all confirmed cluster members within the area of the ACS/WFC images from the spectroscopic surveys of RX J0152.7–1357 by Demarco *et al.* (2005).

The data from Blakeslee catalog are in the AB photometric system calibrated with the HST/ACS/WFC zero points from Sirianni *et al.* (2005). The magnitudes are corrected for Galactic extinction according to Schlegel *et al.* (1998). The corrections are 0.038, 0.029, and 0.021 mag in $F625W$ (denoted r_{625}), $F775W$ (denoted i_{775}), and $F850LP$ (denoted z_{850}), respectively.

The AB magnitudes and Vega-based magnitudes are denoted with (AB) and (Vega), respectively. In our analysis the following transformation formulae from AB magnitudes to Vega-based magnitudes are considered (Sirianni *et al.*, 2005):

$$r_{625,Vega} = r_{625,AB} - 0.167, \quad (1)$$

$$i_{775,Vega} = i_{775,AB} - 0.398, \quad (2)$$

$$z_{850,Vega} = z_{850,AB} - 0.536. \quad (3)$$

The morphological classification for the sample of galaxies is from Postman *et al.* (2005), who classified all galaxies in these ACS fields down to an AB magnitude limit of $i_{775} < 23.5$. The morphological T-types are those defined in de Vaucouleurs *et al.* (1976): $-5 \leq T \leq -3$ correspond to elliptical (E) galaxies; $T = -2$ corresponds to S0 galaxies; $-1 \leq T \leq 1$ correspond to morphologies between S0 and Sa; $2 \leq T \leq 6$ correspond to later type spiral (Sp) galaxies (type $T = 6$ is associated with an Sd morphology); $6 < T \leq 10$ correspond to irregular (Irr) galaxies. The two AGNs present in this sample have assigned the values of $T = 11$.

2.2. DEMARCO *ET AL.* (2010) CATALOG

The catalog of Demarco *et al.* (2010) contains 134 galaxies with ($F625W$, Ks) optical and near-infrared photometric data, 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.

According to Schlegel *et al.* (1998) the Galactic extinction correction are 0.038 and 0.009 mag in $F625W$ (denoted r_{625}), and Ks, respectively. The scales between the Vega-based magnitudes and the AB magnitudes are given by the formulae (Demarco *et al.*, 2010):

$$Ks_{Vega} = Ks_{AB} - 1.895 \tag{4}$$

$$(r_{625} - Ks)_{Vega} = (r_{625} - Ks)_{AB} + 1.728 \tag{5}$$

3. THE 2D AND 3D DISTRIBUTIONS OF GALAXIES

At the cluster redshift of $z \sim 0.84$, in the cosmological model $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$, $1''$ 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).

Considering the morphological classification presented in the previous section, 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 withdrown from our study.

Fig.1 presents the 2D distribution of galaxies in the RX J0152.7–1357 field for the selected sample of 86 galaxies. In this figure North is up and Est is to the right. The morphological types of galaxies are represented as follows: elliptical galaxies with dots, S0 lenticular galaxies with circles, S0/Sa with diamonds, Sp galaxies with squares, and Irr galaxies with crosses. The center of the field is considered at RA = 01h 52m 41.0s, DEC= –13d 57m 45s (Della Ceca *et al.*, 2000).

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 3D distribution of the galaxies in the RX J0152.7–1357 field function of the position (X,Y) and the spectroscopic redshifts z is presented in Fig.2. The morphological types of galaxies are represented with big dots for elliptical galaxies, small dots for S0 lenticular galaxies, diamonds for S0/Sa, squares for Sp galaxies, and crosses for Irr galaxies.

In Fig.1 and Fig.2, the clustering of elliptical galaxies in the central zone of the RX J0152.7–1357 field is obvious. The distribution of $z \sim 0.84$ galaxies presents two clumpy structures, these two subclusters appearing to be in the early stages of merging. It can be observed the presence of a chain of elliptical galaxies that crosses the central zone of the cluster from NE to SW. In addition, a group of galaxies is present to the east of the southern component, and this structure is infalling into the cluster.

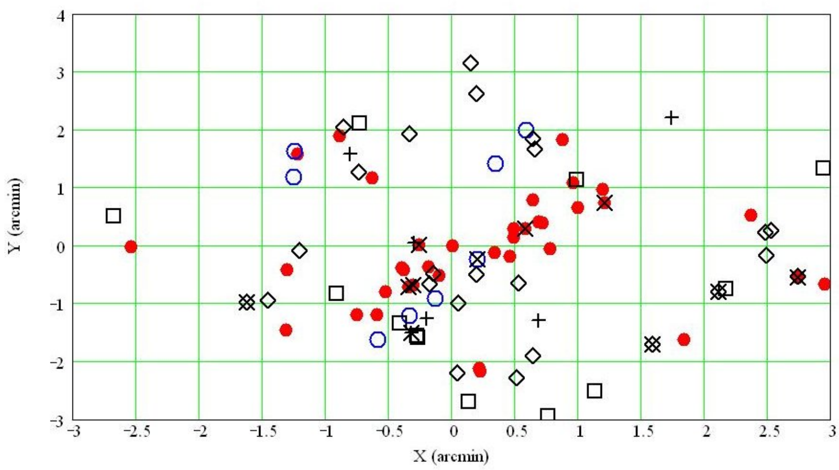


Fig. 1 – The 2D distribution of the galaxies in the RX J0152.7–1357 cluster field.

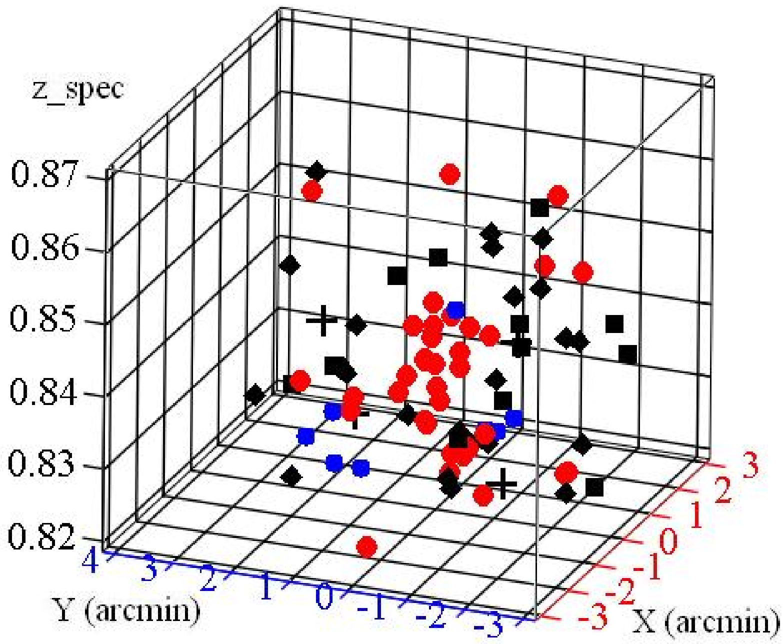


Fig. 2 – The 3D distribution of the galaxies in the RX J0152.7–1357 cluster field as function of the position (X,Y) and the spectroscopic redshifts z.

4. THE CRITERIA OF SELECTION FOR ERGS

Elston *et al.* (1988) first discovered the special population of galaxies denoted extremely red objects (EROs), characterized by very red optical and near-infrared colors, and faint magnitudes. Extremely Red Galaxies (ERGs) represent a subset of EROs, and are difficult to be classified due to their faintness. ERGs are considered to be a mixture of mainly two different populations at redshifts higher than $z = 1$.

Two classes of galaxies are consistent with the red colors of ERGs population:

– passively evolving early-type galaxies (elliptical and S0) with no or very limited recent star formation, in the redshift range $1 < z < 2$;

– dusty starburst galaxies (characterized by high star-formation rates) whose UV luminosities are strongly absorbed by internal dust, or AGN reddened by strong dust extinction, in the redshift range $1 < z < 2$.

Beyond these two classical galaxy types, nowadays the classification of ERGs also contains normal spiral galaxies at slightly lower redshifts (Gilbank *et al.*, 2003; Yan and Thompson, 2003; Moustakas *et al.*, 2004). This category consists of a large fraction of edge-on galaxies, where the inclination plays an important role due to the quantity of dust that is encountered along the line of sight and that reddens the spectral energy distribution (SED).

Also, as we already mention, the galaxies that host an AGN (Alexander *et al.*, 2002; Brusa *et al.*, 2005), and starburst/AGN combinations (Afonso *et al.*, 2001) can be found among the EROs samples. Several other red galaxy populations such as: infrared-detected galaxies (Yan *et al.*, 2004), distant red galaxies (DRGs) (Labbe *et al.*, 2005; Papovich, 2006) and BzK selected galaxies (Daddi *et al.*, 2005; Hayashi *et al.*, 2007), can be found as EROs.

In the identification of galaxies clusters at $z \geq 1$, the selection criteria of the passively evolving elliptical galaxies using red optical and near-infrared colors have been usually used. The basis of these colour techniques resides in the bracketing of the 4000 $\dot{A}$ break, that is shifted into the observed near-infrared bands. The 4000 $\dot{A}$ break being positioned between R- (or I-, J-) band and K band at $z \sim 1$, the old passively-evolving galaxies should be characterized by red optical-near-infrared colors, which are redder than most galactic stars and field galaxies colors.

The considered color and magnitudes thresholds for ERGs are $(R-K)_{Vega} \geq 5$, $(I-K)_{Vega} \geq 4$, $(V-I)_{Vega} \geq 3.5$, and moderately faint near-infrared magnitudes ($K \sim 18-20$) (Roche *et al.*, 2003; Brown *et al.*, 2005). The two ERGs populations can be separated by their morphology, spectra or color. Mannucci *et al.* (2002) studied the color-color diagrams (($R-K$) *vs* ($J-K$) colors) for a sample of 57 ERGs, and separated these two population. The authors found that the two populations have similar abundances.

In order to determine the ERGs sample, the relevant conversions between the AB system and the Vega-based system are the following (Sirianni *et al.*, 2005):

$$(r_{625} - Ks)_{Vega} = (r_{625} - Ks)_{AB} + 1.728 \quad (6)$$

$$(i_{775} - Ks)_{Vega} = (i_{775} - Ks)_{AB} + 1.497 \quad (7)$$

In this paper we define ERGs as objects whose colors satisfy the conditions $(r_{625} - Ks)_{AB} \geq 3.594$ (Hall and Green, 1998; Hall *et al.*, 2001) and $(i_{775} - Ks)_{AB} \geq 2.4$ (Fang *et al.*, 2009). These are the equivalent of the usual definition relations $(R-K)_{Vega} \geq 5$ and $(I-K)_{Vega} \geq 4$.

5. COLOR-MAGNITUDE AND COLOR-COLOR DIAGRAMS FUNCTION OF GALAXIES MORPHOLOGY

According to Stanford *et al.* (1998), it is better to use the Ks band because of its property to trace the rest-frame near-IR light coming from the bulk of the stellar content of galaxies at $z \sim 0.8$, unperturbed by biases due to recent star formation.

In Fig.3 are presented the color-magnitude diagrams $(r_{625} - Ks)_{AB} - Ks_{AB}$ and $(i_{775} - Ks)_{AB} - Ks_{AB}$, function of galaxies morphologies. Fig.4 presents the color-color diagram $(r_{625} - Ks)_{AB} - (i_{775} - Ks)_{AB}$ of galaxies function of their morphologies. The symbols in Fig.3 and Fig.4 are the same as in the previous figures.

The dashed horizontal line in Fig.3 (top panel) represents the threshold $(r_{625} - Ks)_{AB} = 3.594$ for the selection of ERGs, as mentioned in the previous paragraph. In the same panel the locus of the color-magnitude relation (CMR) for the 36 elliptical galaxies is represented by the solid thick line that is obtained by a linear least-squares fit of the elliptical galaxies, in color-magnitude space:

$$(r_{625} - Ks)_{AB} = (-0.229)Ks_{AB} + 7.951 \tag{8}$$

The two dashed lines are positined at ± 0.192 in $(r_{625} - Ks)_{AB}$ from the fitted line. Galaxies redder than the lower dashed line represent the red sequence galaxies, most of them being morphologically early-type (E/S0 and even Sa), and the majority of these galaxies have the colors of ERGs. At $(r_{625} - Ks)_{AB} = 2.6$, the dashed line represents the separation line between red and blue galaxies.

In Fig.3 (bottom panel) the dashed horizontal line is the threshold $(i_{775} - Ks)_{AB} = 2.4$ for the selection of ERGs (Fang *et al.*, 2009). The locus of the color-magnitude relation (CMR) for the 36 elliptical galaxies in $(i_{775} - Ks)_{AB} - Ks_{AB}$ diagram is represented by the solid thick line that is obtained by a linear least-squares fit:

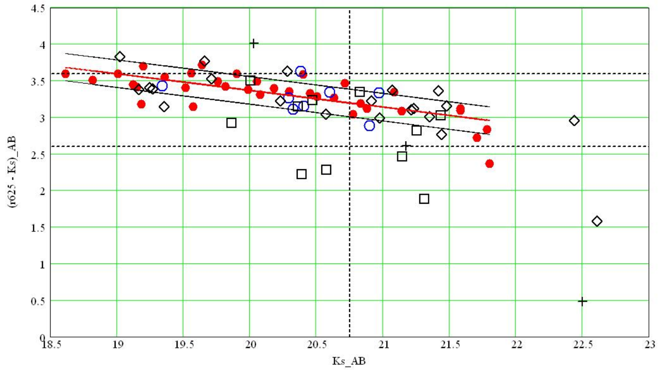
$$(i_{775} - Ks)_{AB} = (-0.184)Ks_{AB} + 5.803 \tag{9}$$

At ± 0.15 in $(i_{775} - Ks)_{AB}$ from the fitted line the two dashed lines are positioned.

In both panels of Fig.3, the vertical dashed line has been set to $Ks = 20.75$ ($\sim K^* + 1$) to divide the red sequence into bright and faint bins. According to Ellis and Jones (2004), $K^* \sim 19.7$ in (AB) system at $z \sim 0.84$, therefore, this separation is settled to be at $\sim K^* + 1$.

The $(r_{625} - Ks)_{AB}$ and $(i_{775} - Ks)_{AB}$ colors deviations from the color-magnitude relation of elliptical galaxy, as a function of galaxy redshift, are presented in Fig.5. Based on Demarco *et al.* (2005), Blakeslee *et al.* (2006), the mean redshifts of the subclusters are determined as follows: the southern clump is centered at $z = 0.830$, the northern clump at $z = 0.838$, the eastern clump at $z \sim 0.845$. A more diffuse clustering of galaxies, with $z \sim 0.866$, is positioned mainly off to the west of the cluster. Although these complex velocity structures exist, no clear trends in the mean colors of the early-type galaxies as a function of redshift are determined.

The red galaxies have colors in the specific range of the old passively evolving galaxies at $z \sim 1$. The presence of an important velocity offset between the early-type and late-type members of the cluster, in RX J0152.7-1357, is the cause of an overall trend of galaxy color to get bluer with velocity (see Fig.5). Also, the concentrations of red galaxies in the two main clumps of galaxies strongly suggest that these clumps



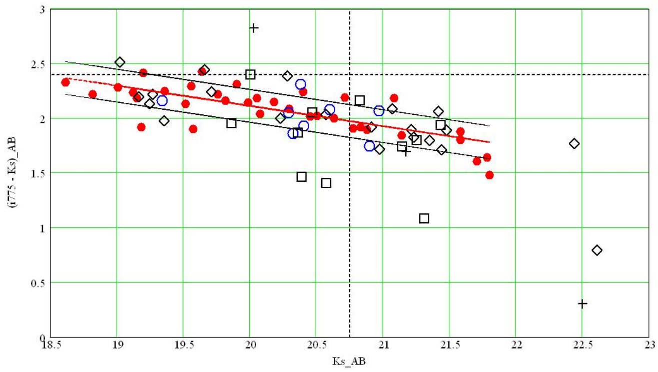


Fig. 3 – The $(r_{625} - Ks)_{AB} - Ks_{AB}$ color-magnitude diagram (top panel); $(i_{775} - Ks)_{AB} - Ks_{AB}$ color-magnitude diagram (bottom panel); The symbols are as follows: big dots - 36 E galaxies ; circles - 8 S0 galaxies; diamonds - 24 S0/Sa galaxies; squares - 12 Sp galaxies; (+) - 4 Irr galaxies.

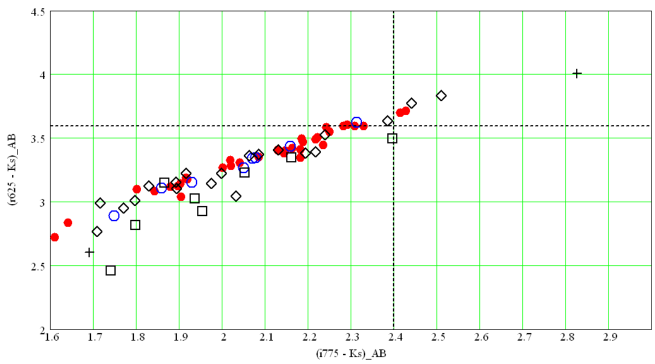


Fig. 4 – The $(r_{625} - Ks)_{AB} - (i_{775} - Ks)_{AB}$ color-color diagram.

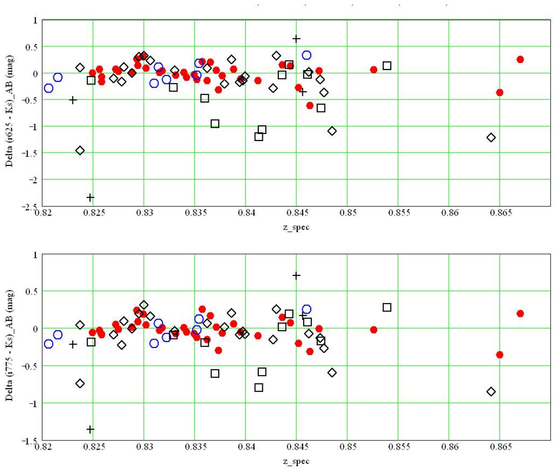


Fig. 5 – The $(r_{625} - Ks)_{AB}$ residuals with respect to the elliptical galaxy color-magnitude relation as a function of redshifts z (top panel); the $(i_{775} - Ks)_{AB}$ residuals with respect to the elliptical galaxy color-magnitude relation as a function of redshifts z (bottom panel); The symbols are as follows: big dots - 36 E galaxies ; circles - 8 S0 galaxies; diamonds - 24 S0/Sa galaxies; squares - 12 Sp galaxies; (+) - 4 Irr galaxies.

are physically bound systems.

6. EXTREMELY RED GALAXY SAMPLE

Based on the $(r_{625} - Ks)_{AB} = 3.594$ threshold (see Fig.3, top panel), a sample of 11 ERGs is determined, representing 13% from the entire sample of galaxies. Using the $(i_{775} - Ks)_{AB} \geq 2.4$ criterion (see Fig.3, bottom panel), only 5 ERGs are determined.

In Fig.1, where the 2D distribution of the 86 galaxies in the RX J0152.7–1357 field is represented, the sample of 11 ERGs is overlapped and depicted with (X). Clustering tendency exists for the ERGs that are positioned in the southern clump (see Fig.1).

Table 1 presents the photometric, morphological and spectroscopic characteristics of the 11 ERGs as follows: ID from Demarco catalog, ID from Blakeslee catalog, K_{AB} magnitude, $(r_{625} - Ks)_{AB}$ color, $(i_{775} - Ks)_{AB}$ color, morphological type (T). Last 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).

We classify as red fraction, the fraction of galaxies that either belong to the red sequence or to the ERGs population (extremely red galaxies). From Table 1, column 7 with the T morphological type, it results that 6 ERGs are early- type galaxies, 4 ERGs are S0/Sa galaxies, and only one is an Irr galaxy. Also, 2 ERG are emission

Table 1

Extremely red galaxy sample

ID D	ID B	K_{AB}	$(r_{625} - Ks)_{AB}$	$(i_{775} - Ks)_{AB}$	z_{spec}	T	EL
598	2949	19	3.594	2.281	0.8315	-5	0
679	4219	18.61	3.595	2.329	0.8342	-5	0
1465	5819	19.9	3.595	2.308	0.8365	-4	0
439	1859	19.56	3.604	2.291	0.8294	-4	0
547	3231	20.38	3.626	2.312	0.846	-2	0
1496	499	20.28	3.633	2.384	0.83	-1	0
131	3941	19.2	3.698	2.414	0.8436	-5	0
387	1808	19.64	3.716	2.427	0.8293	-5	0
258	5292	19.66	3.772	2.441	0.843	-1	0
204	3055	19.02	3.833	2.510	0.8386	1	1
270	1341	20.03	4.007	2.826	0.845	8	1

line galaxies, according to the classification from column 8. According to Smail *et al.* (1999), Wolf *et al.* (2005), the red star-forming sources are dust-enshrouded systems. From Fig.3 we mention that a few of the apparently passive galaxies that belong to the red-sequence could be star-forming systems with the [OII] feature entirely suppressed by a large amount of dust (Smail *et al.*, 1999).

7. CONCLUSIONS

In this paper was analyzed the environment of RX J0152.7–1357, at $z \sim 0.84$, using a complete sample of 86 confirmed members with optical-NIR photometric, spectroscopic, morphological data and spectroscopic redshifts. This sample was obtained by combining the catalog of Blakeslee *et al.* (2006) (107 galaxies with HST/ACS/WFC optical photometric, spectroscopic and morphological data) with the catalog of Demarco *et al.* (2010) (134 galaxies with VLT/FORS spectroscopy, ACS/WFC optical data, and NTT/SofI near-IR data).

In the field of RX J0152.7–1357, the distribution of galaxies presents two main clumpy structures, with other infalling structures in the eastern and western zones of the cluster. By means of the color-magnitude diagrams $(r_{625} - Ks)_{AB} - Ks_{AB}$ and $(i_{775} - Ks)_{AB} - Ks_{AB}$, function of galaxies morphologies, and color-color diagram $(r_{625} - Ks)_{AB} - (i_{775} - Ks)_{AB}$ of galaxies function of their morphologies, a large population of Extremely Red Galaxies (ERGs) was determined. The ERGs positioned in the southern clump present clustering tendency.

REFERENCES

Afonso, J., Mobasher, B., Chan, B., and Cram L.: 2001, *Astrophys. J. Lett.* **559**, 101.
Alexander, D.M., Vignali, C., Bauer, F.E., Brandt, W.N., Hornschemeier, A.E., Garmire, G.P., and

Schneider, D.P.: 2002, *Astron. J.* **123**, 1149.

Blakeslee, J.P., Franx, M., Postman, M., Rosati, P., Holden, B.P., Illingworth, G.D., Ford, H.C., Cross, N.J.G., Gronwall, C., Benitez, N., Bouwens, R.J., Broadhurst, T.J., Clampin, M., Demarco, R., Golimowski, D.A., Hartig, G.F., Infante, L., Martel, A.R., Miley, G.K., Menanteau, F., Meurer, G.R., Sirianni, M., and White, R.L.: 2003, *Astrophys. J.* **596L**, 143.

Blakeslee, J.P., Holden, B.P., Franx, M., Rosati, P., Bouwens, R.J., Demarco, R., Ford, H.C., Homeier, N.L., Illingworth, G.D., Jee, M.J., Mei, S., Menanteau, F., Meurer, G.R., Postman, M., and Tran, Kim-Vy H.: 2006, *Astrophys. J.* **644**, 30.

Brown, M.J.I., Jannuzi, B.T., Dey, A., and Tiede, G.P.: 2005, *Astrophys. J.* **621**, 41.

Brusa, M., Comastri, A., Daddi, E., Pozzetti, L., Zamorani, G., Vignali, C., Cimatti, A., Fiore, F., Mignoli, M., Ciliegi, P., and Rottgering, H.J.A.: 2005, *Astron. Astrophys.* **432**, 69.

Daddi, E., Dickinson, M., Chary, R., Pope, A., Morrison, G., Alexander, D.M., Bauer, F.E., Brandt, W.N., Giavalisco, M., Ferguson, H., Lee, K.-S., Lehmer, B.D., Papovich, C., and Renzini A.: 2005, *Astrophys. J. Lett.* **631**, 13.

Della Ceca, R., Scaramella, R., Gioia, I.M., Rosati, P., Fiore, F., and Squires, G.: 2000, *Astron. Astrophys.* **353**, 498.

Demarco, R., Gobat, R., Rosati, P., Lidman, C., Rettura, A., Nonino, M., van der Wel, A., Jee, M.J., Blakeslee, J.P., Ford, H.C., and R., Postman: 2010, *Astrophys. J.* **725**, 1252.

de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, J. R.: 1976, Second reference catalogue of bright galaxies, Austin: University of Texas Press.

Ellis, S.C., and Jones, L.R.: 2004, *Mon. Not. Roy. Astron. Soc.* **348**, 165.

Fang, G.-W., Kong, X., and Wang, M.: 2009, *Res. Astron. Astrophys.* **9**, 59.

Gilbank, D.G., Smail, I., Ivison, R.J., and Packham, C.: 2003, *Mon. Not. Roy. Astron. Soc.* **346**, 1125.

Girardi, M., Demarco, R., Rosati, P., and Borgani, S.: 2005, *Astron. Astrophys.* **442**, 29.

Hall, P.B., and Green, R.F.: 1998, *Astrophys. J.* **507**, 558.

Hall, P.B., Sawicki, M., Martini, P., Finn, R.A., Pritchet, C.J., Osmer, P.S., McCarthy, D.W., Evans, A.S., Lin, H., and Hartwick, F.D.A.: 2001, *Astron. J.* **121**, 1840.

Hayashi, M., Shimasaku, K., Motohara, K., Yoshida, M., Okamura, S., and Kashikawa N.: 2007, *Astrophys. J.* **660**, 72.

Homeier, N.L., Demarco, R., Rosati, P., Postman, M., Blakeslee, J.P., Bouwens, R.J., Bradley, L.D., Ford, H.C., Goto, T., Gronwall, C., Holden, B., Jee, M.J., Martel, A.R., Mei, S., Menanteau, F., Zirm, A., Clampin, M., Hartig, G.F., Illingworth, G.D., Ardila, D.R., Bartko, F., Benitez, N., Broadhurst, T.J., Brown, R.A., Burrows, C.J., Cheng, E.S., Cross, N.J.G., Feldman, P. D., Franx, M., Golimowski, D.A., Infante, L., Kimble, R.A., Krist, J.E., Lesser, M.P., Meurer, G.R., Miley, G.K., Motta, V., Sirianni, M., Sparks, W.B., Tran, H.D., Tsvetanov, Z.I., White, R.L., and Zheng, W.: 2005, *Astrophys. J.* **621**, 651.

Jee, M.J., White, R.L., Benitez, N., Ford, H.C., Blakeslee, J.P., Rosati, P., Demarco, R., and Illingworth, G.D.: 2005, *Astrophys. J.* **618**, 46.

Jorgensen, I., Bergmann, M., Davies, R., Barr, J., Takamiya, M., and Crampton, D.: 2005, *Astron. J.* **129**, 1249.

Labbe, I., Huang, J., Franx, M., Rudnick, G., Barmby, P., Daddi, E., van Dokkum, P.G., Fazio, G.G., Schreiber, N.M.F., Moorwood, A.F.M., Rix, H.-W., Rottgering, H., Trujillo, I., and van der Werf, P.: 2005, *Astrophys. J. Lett.* **624**, 81.

Mannucci, F., Pozzetti, L., Thompson, D., Oliva, E., Baffa, C., Comoretto, G., Gennari, S., and Lisi, F.: 2002, *Mon. Not. Roy. Astron. Soc.* **329**, L57.

Maughan, B.J., Jones, L.R., Ebeling, H., Perlman, E., Rosati, P., Frye, C., and Mullis, C.R.: 2003, *Astrophys. J.* **587**, 589.

Maughan, B.J., Ellis, S.C., Jones, L.R., Mason, K.O., Cordova, F.A., and Priedhorsky, W.: 2006, *Astrophys. J.* **640**, 219.

Moorwood, A., Cuby, J.-G., and Lidman, C.: 1998, *The Messenger* **91**, 9.
Moustakas, L.A., Casertano, S., Conselice, C.J., Dickinson, M.E., Eisenhardt, P., Ferguson, H.C., Giavalisco, M., Grogin, N.A., Koekemoer, A.M., Lucas, R.A., Mobasher, B., Papovich, C., Renzini, A., Somerville, R.S., and Stern, D.: 2004, *Astrophys. J. Lett.* **600**, 131.
Oke, J.B.: 1974, *Astrophys. J. Suppl.* **27**, 21.
Papovich, C.: 2006, *New Astron. Rev.* **50**, 134.
Patel, S.G., Kelson, D.D., Holden, B.P., Illingworth, G.D., Franx, M., van der Wel, A., and Ford, H: 2009, *Astrophys. J.* **694**, 1349.
Patton, D.R., Carlberg, R.G., Marzke, R.O., Pritchet, C.J., da Costa, L.N., and Pellegrini, P.S.: 2000, *Astrophys. J.* **536**, 153.
Patton, D.R., and Atfield, J.E.: 2008, *Astrophys. J.* **685**, 235.
Patton, D.R., Ellison, S.L., Simard, L., McConnachie, A.W., and Mendel, J.T.: 2011, *Mon. Not. Roy. Astron. Soc.* **412**, 591.
Popescu, N.A.: 2011, *Romanian Astron. J.* **21**, 3.
Popescu, N.A.: 2012, *Romanian Astron. J.* **22**, 95.
Roche, N., Dunlop, J.S., and Almaini, O.: 2003, *Mon. Not. Roy. Astron. Soc.* **346**, 803.
Romer, A.K., Nichol, R.C., Holden, B.P., Ulmer, M.P., Pildis, R.A., Merrelli, A.J., Adami, C., Burke, D.J., Collins, C.A., Metevier, A.J., Kron, R.G., and Commons, K.: 2000, *Astrophys. J. Suppl.* **126**, 209.
Rosati, P., Della Ceca, R., Norman, C., and Giacconi, R.: 1998, *Astrophys. J.* **492L**, 21.
Rosati, P., Tozzi, P., Ettori, S., Mainieri, V., Demarco, R., Stanford, S.A., Lidman, C., Nonino, M., Borgani, S., Della Ceca, R., Eisenhardt, P., Holden, B.P., and Norman, C.: 2004, *Astron. J.* **127**, 230.
Scharf, C.A., Jones, L.R., Ebeling, H., Perlman, E., Malkan, M., and Wegner, G.:1997, *Astrophys. J.* **477**, 79.
Schlegel, D. J., Finkbeiner, D. P., and Davis, M.: 1998, *Astrophys. J.* **550**, 525.
Smail, I., Morrison, G., Gray, M.E., Owen, F.N., Ivison, R.J., Kneib, J.-P., and Ellis, R.S.: 1999, *Astrophys. J.* **525**, 609.
Stanford, S.A., Eisenhardt, P.R., and Dickinson, M.: 1998, ApJ, 492, 461
Yan, H., Dickinson, M., Eisenhardt, P.R.M., Ferguson, H.C., Grogin, N.A., Paolillo, M., Chary, R.-R., Casertano, S., Stern, D., Reach, W.T., Moustakas, L.A., and Fall, S.M.: 2004, *Astrophys. J.* **616**, 63.
Yan, L., and Thompson, D.: 2003, *Astrophys. J.* **586**, 765.
Wolf, C., Gray, M.E., and Meisenheimer, K.: 2005, *Astron. Astrophys.* **443**, 435.
Tanaka, M., Kodama, T., Arimoto, N., and Tanaka, I.: 2006, *Mon. Not. Roy. Astron. Soc.* **365**, 1392.

Received on 29 November 2013