EXTREMELY RED GALAXIES AT z~1

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Abstract.

In this paper we use optical and near infrared photometrical (R, I, J, K) data and morphological data for the galaxies in the fields of 3C 184 (z=0.996), 3C 210 (z=1.169) and RX J0848+4453 (z=1.273), in order to determine the cumulative number of Extremely Red Galaxies (ERGs), the surface density and the fraction of ERGs with respect to the entire galaxies from each studied field. The radial trends of the ERGs, the clustering tendency of galaxies and ERGs are also revealed. The presence of the red sequence in the color-magnitude diagram and the morphology of the galaxies are analyzed.

1. Introduction

Extremely Red Galaxies (ERGs) are characterized by extreme properties such as very red optical to near-infrared (NIR) colors (R-K)>5, (I-K)>4, (J-K)>1.8 and moderately faint NIR magnitudes (K~17.5-20). As the 4000Å break falls between R (or I, J) band and K band, at z ~1 the old passively-evolving galaxies should be characterized by red optical-NIR colors, representing redder colors than most galactic stars and field galaxies.

The red colors of ERGs population are consistent with two classes of galaxies:

a) old passively evolving elliptical galaxies at z~1;
b) high-redshift dusty starburst galaxies, characterized by high star formation rates, or AGN reddened by strong dust extinction.

ERGs represent a mix of dusty star-forming galaxies, edge-on spiral galaxies and early type galaxies, therefore it is necessary to combine the color selected samples of ERGs with morphological information about them.

2. Galaxies and ERGs studied samples

In this paper we present the results of a ***photometrical*** and ***morphological*** study of galaxies and ERGs in the field of 3C 184 (z = 0.996, 35 gal. in a 6.2 arcmin^2 field); 3C 210 (z = 1.169, 57 gal. in a 6.2 arcmin^2 field); RX J0848+4453 (z=1.273, 70 gal. in a 6.2 arcmin^2 field)

using optical and NIR photometrical data and HST/WFPC2 morphological data [1]. The photometrical data are derredened for Galactic extinction. The fields are centred on the brightest cluster galaxy (BCG).

From the morphological point of view the ERGs elliptical galaxies are compact, regularly shaped objects and starburst galaxy present a much more irregular shape (if the starburst is triggered by a merger or if a large amount of irregularly distributed dust is present in the galaxy).

The general color selection criteria for the ERGs are (R-K)>5, (I-K)>4 and (J-K)>1.8.

The HST /WFPC2 morphology of galaxies in:

- *3C 184 field*: 15 E/S0, 7 Sa/Sb, 5 Sc/Sd, 5 Irr/disturbed galaxies and 3 galaxies outside the WFPC2 field;
- *3C 210 field*: 23 E/S0 , 6 Sa/Sb, 6 Sc/Sd, 22 Irr/disturbed galaxies;
- *RX J0848+4453 field*: 14 E/S0, 14 Sa/Sb, 6 Sc/Sd, 18 Irr/disturbed galaxies, 15 galaxies outside the WFPC2 field, 3 stars.

The HST /WFPC2 morphology and the total surface density of ERGs in:

- *3C 184* field: 12 ERGs with 6 E/S0, 1 Sa/Sb, 2 Sc/Sd, 1 Irr/disturbed galaxies, 2 outside the WFPC2 field. ERGs are determined for (J-K)>1.8 color selection criterion and the total surface density is 1.93 gal/arcmin^2.
- *3C 210* field: 24 ERGs with 11 E/S0, 3 Sa/Sb, 1 Sc/Sd, 9 Irr/disturbed galaxies. ERGs are determined for (I-K)>4 and (J-K)>1.8 color selection criteria and the total surface density is 3.87 gal/arcmin^2.
- *RX J0848+4453*: 31 ERGs with of 13 E/S0, 4 Sa/Sb, 2 Sc/Sd, 5 Irr, 1 merger and 6 ERGs outside the WFPC2 field of view (i.e. without morphology). The total surface density is 5 gal/arcmin^2.

In the Table 1 we present the results on the multi color selected ERGs subsamples of 3C 210 and RX J0848+4453 fields. We present in column 2 the cumulative number of ERGs (ERG) and the cumulative number of galaxies from the fields (Gal.) selected at each K limiting magnitude. For each color criteria we determine the cumulative number of ERGs selected at each K limiting magnitude (Nr), the surface density (D), in $\text{objects} / \text{arc}\,\text{min}^2$, and the fraction of ERGs with respect to the entire galaxies from the fields (Fr.).

Table 1

RX J0848+4453										3C 210		
	ERG (Gal.)	R-K>5 I-K>4		R-K>5 J-K>1.8		I-K>4 J-K>1.8		R-K>5 I-K>4 J-K>1.8		Gal.	I-K>4 J-K>1.8	
K<		Nr	D (Fr.)	Nr	D (Fr.)	Nr	D (Fr.)	Nr	D (Fr.)		Nr	D (Fr.)
17										5	2	0.322
												0.4
17.5	1 (4)							1	0.161	9	3	0.483
									0.25			0.33
18	3 (9)							3	0.483	12	4	0.645
									0.33			0.33
18.5	4 (11)							4	0.645	24	10	1.612
									0.363			0.417
19	14(24)	1	0.161			2	0.322	11	1.774	31	17	2.741
			0.042				0.083		0.458			0.548
19.5	16(31)	2	0.322	1	0.161	2	0.322	11	1.774	42	19	3.064
			0.065		0.032		0.065		0.355			0.452
20	25(50)	2	0.322	2	0.322	2	0.322	19	3.065	57	24	3.87
			0.04		0.04		0.04		0.38			0.421
20.5	31(70)	3	0.483	3	0.483	2	0.322	23	3.709			
			0.043		0.043		0.028		0.328			

3. Radial trends of the ERGs number density

The 3C 184, 3C 210 and RX J0848+4453 fields' densities as function of radial projected distance from the brightest field galaxy are analyzed. The galaxy density was calculated in successive annuli of $10^{"}$ wide, centered on the BCGs. Fig. 1 presents radial density profiles of the galaxies (diamonds with solid line) and the ERGs sample (circles with solid line) from the studied fields. The theoretical radial cluster profile, determined with the following formula:

$$\rho(\mathrm{r}) = \frac{\rho_0}{\left[1 + (r/R_{core})^2\right]^{0.75}} \ ,$$

where $R_{core} = 20^{"}$ represents the core radius and ρ_0 is the corresponding surface density, is also drown using dashed lines. The radial density profiles reveal a strong concentration of the galaxies in the central region of the fields [2]. **ERGs** are located in the inner region of the fields, close to BCG and with **clustering tendency.**

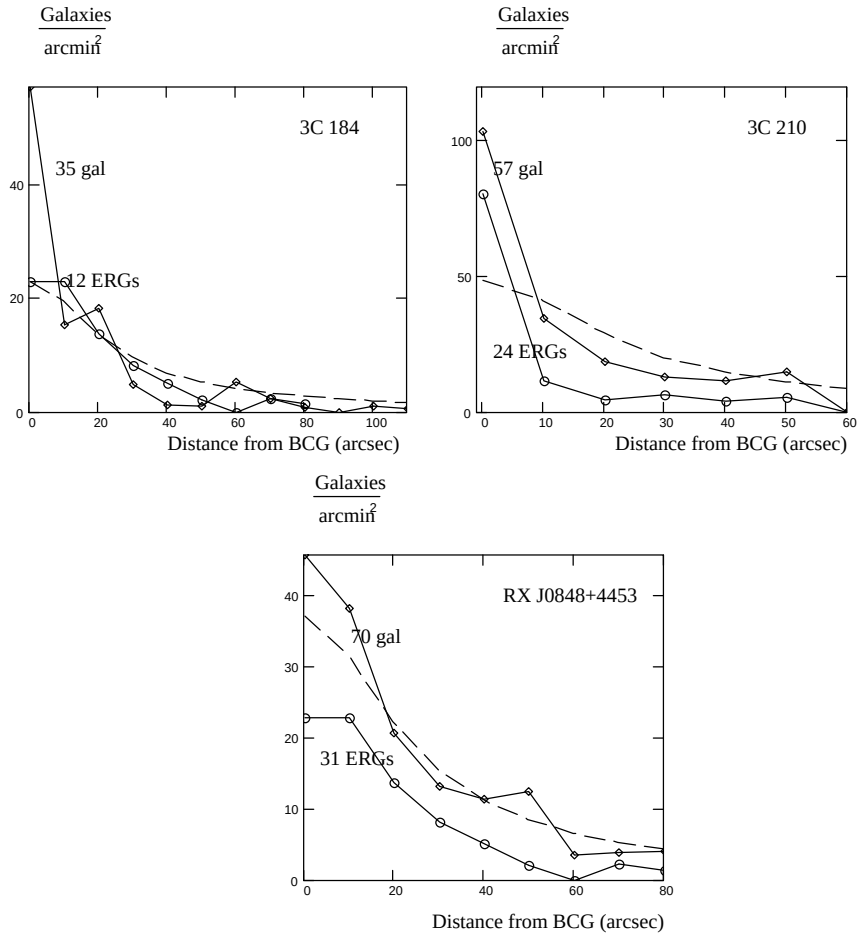

Fig. 1 – Radial density profiles of the galaxies and ERGs

4. (J-K)-K color-magnitude diagram and the morphology of z~1 red sequence galaxies

The (J-K)-K color-magnitude diagrams for the 3C 184 (Fig.2 top), 3C 210 (Fig.2 bottom) and RX J0848+4453 (Fig. 3) fields are presented. The solid lines represent the loci of the color-magnitude relations at the considered redshifts, predicted by the passive evolution models of Kodama et al. [3]. The lower dashed lines represent the adopted cut between red sequence and blue galaxies. Galaxies redder than these lines represent the red sequence galaxies and the majority of these galaxies are **morphologically early-type** (E/S0 and even Sa) - see the figures.

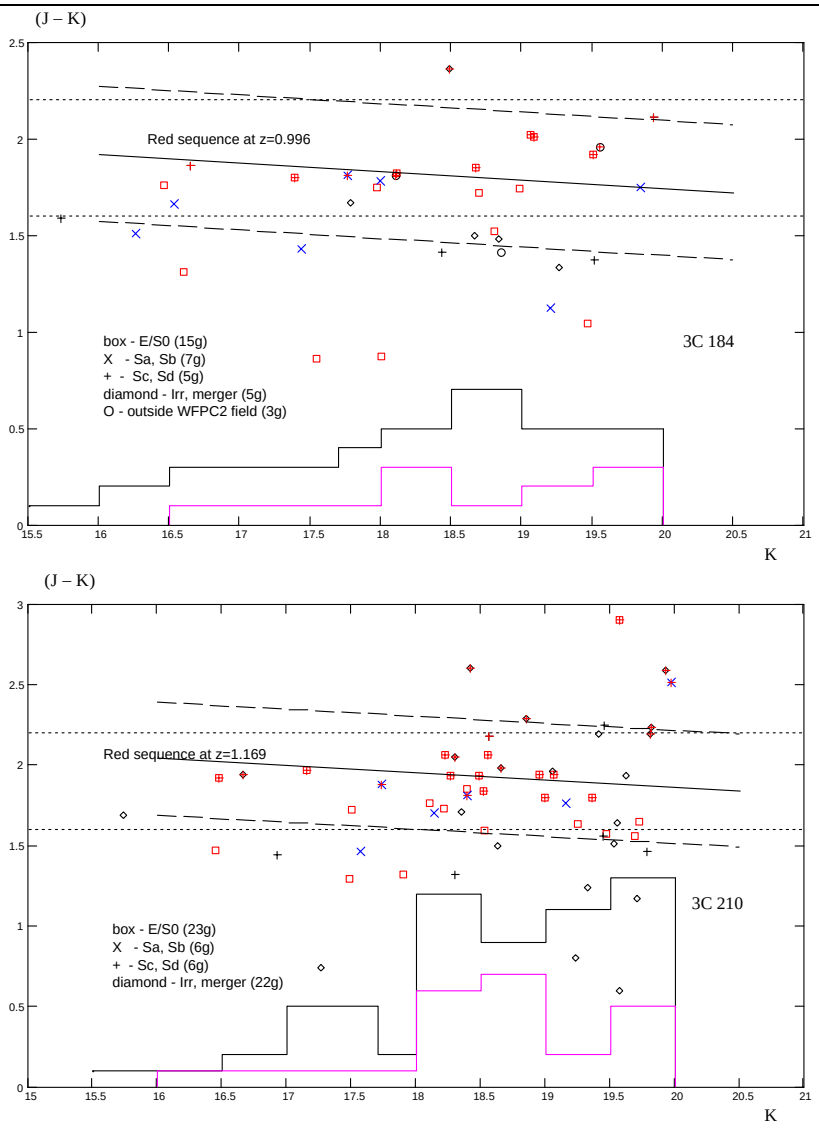

Fig. 2 - (J-K)-K color-magnitude diagrams

The upper horizontal dotted line represents the color cut (J-K) = 2.2 , above the red color-magnitude sequence of the possible cluster members. In this way is avoided the contamination with red background galaxies. Objects bluer than (J-K) = 1 are considered stars or foreground galaxies. The solid (dotted) histogram represents the (number of galaxies)/10 (ERGs/10) function of K magnitude.

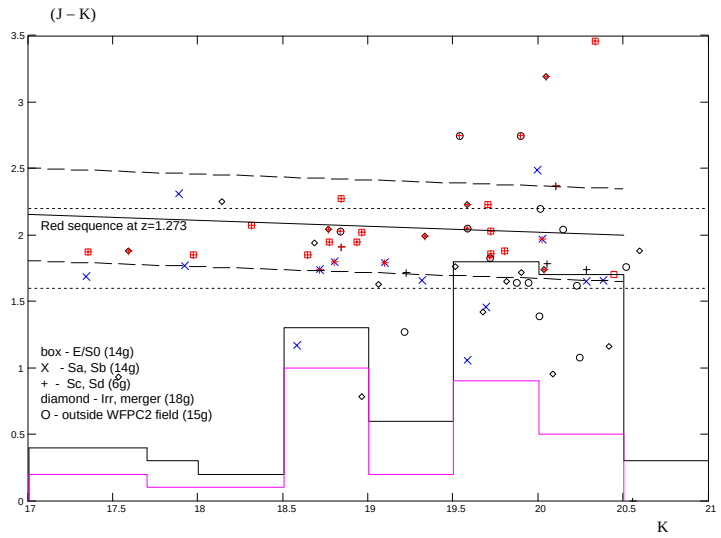

Fig. 3 - (J-K)-K color-magnitude diagram for RX J0848+4453

The 3C 184, 3C 210 and RX J0848+4453 cluster candidates belong to the sequence of red galaxies, near the passive evolution prediction at the considered redshifts, **confirming the presence of massive clusters**. The majority of these galaxies consists of **ERGs** (represented with overlapped cross on the existing symbols).

5. Conclusions

The selection criteria of the passively evolving elliptical galaxies by means of red optical and near-infrared colors contribute to the identification of galaxies clusters at z ~1. We studied the galaxies and ERGs clustering **function of colors and morphology**, specially the clustering properties of (R-K), (I-K) and (J-K) red galaxies. We determined the **presence of an excess of ERGs in the field of 3C 210** and **RX J0848+4453**, representing extremely rich samples of galaxies with extremely red colors.

References

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