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ON THE PRECURSORS OF FOSSIL GROUPS

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RESUMEN

Comparamos las magnitudes absolutas en la banda K de las galaxias más brillantes en cúmulos de Bautz-Morgan tipo I con las de las galaxias brillantes de grupos fósiles. Demostramos que las galaxias más brillantes en grupos fósiles son, en promedio, más débiles que sus contrapartes en los cúmulos. Además, mostramos que la luminosidad de la galaxia más brillante depende de la riqueza del cúmulo. Concluimos que los precursores de grupos fósiles fueron en promedio cúmulos pobres.

ABSTRACT

We compare the absolute magnitudes in the K-band of the brightest galaxies in clusters of Bautz-Morgan type I with those of the fossil group brightest galaxies. It is found that the brightest galaxies in fossil groups are on average fainter than the brightest galaxies in clusters. It is also shown that the brightness of the brightest galaxy depends on the cluster richness. It is concluded that the precursors of fossil groups were on average poor clusters.

Key Words: galaxies: clusters: general — galaxies: elliptical and lenticular, cD

1. INTRODUCTION

Fossil groups (FGs), discovered by Ponman et al. (1994), consist of a very bright galaxy surrounded by low luminosity companions and have an extended and luminous X-ray halo. Jones et al. (2003) defined that the difference in absolute magnitude in the R-band between the brightest and the second brightest galaxy located within half the projected virial radius of the FG must be $\Delta M_{12} > 2$ mag. The common opinion is that the brightest fossil group galaxy (BFGG) was formed by cannibalism. Ponman et al. (1994), Jones, Ponman, & Forbes (2000), Jones et al. (2003) assumed that the precursors of FGs were normal groups of galaxies. Meanwhile, Vikhlinin et al. (1999) and Mulchaey & Zabludoff (1999) expressed the idea that FGs could be formed by the complete merging of galaxies in compact groups, as it followed from numerical simulations (Barnes 1989). On the other hand, Mendes de Oliveira & Carrasco (2007) and Mendes de Oliveira et al. (2009) mention that a compact group may hardly evolve into a FG, and that the precursor of FGs was rather a cluster. Also, Zibetti, Pierini, & Pratt (2009) point out that the luminosity function of FGs is consistent with that of normal clusters.

In this paper we present arguments in favor of the formation of BFGGs in relatively poor clusters of galaxies through merging of most of its members to a single, bright galaxy.

2. THE DATA AND THE ANALYSIS

2.1. *The Data*

We compare the absolute stellar magnitudes of the BFGGs with the brightest cluster galaxies (BCGs) in Bautz-Morgan (BM) (Bautz & Morgan 1970) type I clusters in order to find possible precursors of FGs. The BM type I clusters, as FGs, contain a single very bright galaxy. The clusters of BM type I are taken form Abell, Corwin, & Ollowin (1989, hereafter ACO). The BCGs in these clusters are predominantly of E or S0 type, as the brightest members of FGs. The inspection of images of these clusters shows that clusters A447, A1468, A1508, A1775, A2025 mentioned as of BM type I in ACO, do not contain a single very bright galaxy. Therefore, they were excluded from the compiled list. Also, we found that the radial velocities of bright galaxies in A1631 and A1654 differ significantly from those of the corresponding clusters. So these clusters are not of BM type I. We also excluded the clusters A85, A1177 and A2029 which according to Andernach et al. (2005) consist of separate projected clusters. We used the list of FGs compiled by Mendes de Oliveira, Cypriano, & Sodré (2006) and also the list of candidate FGs compiled by Santos, Mendes de Oliveira, & Sodré (2007).

Absolute stellar magnitudes M_k of BFGGs and BCGs were determined in the K-band which is more appropriate for our study, since it encompasses the light of the predominantly red population in early-type galaxies. We used the apparent magnitudes $\mathrm{K}_{\mathrm{s-total}}$ from 2MASS (Jarrett et al. 2000). Note that 2MASS magnitudes have problems (e.g. Bell et al. 2003) in detecting the low surface brightness parts of the observed objects, such as halos of BCG galaxies (e.g. Schombert 1988). In addition, Lauer et al. (2007) demonstrated that the 2MASS photometry is likely to underestimate the total light from the BCGs, and showed also that the 2MASS photometry is free from possible errors which may be caused by sky background substraction and crowding. The most important inconsistency may be produced by the extrapolation scheme to generate "total magnitudes" (Jarret et al. 2000). Meanwhile, Lin & Mohr (2004) used a correction scheme to extrapolate isophotal magnitudes to "total" magnitudes and showed that this scheme is consistent with the extrapolation scheme used by Jarret et al. (2000). Summing up, we may assume that the mentioned problems of 2MASS magnitudes will not introduce systematic errors in our study, and we may use them for comparison of BFGGs with BCGs. Note that the 2MASS magnitudes have been widely used in galactic studies (e.g. Temi, Brighenti, & Mathews 2008; Courteau et al. 2007; Masters, Springob, & Huchra 2008, etc.).

The M_k absolute magnitudes of BCGs were deduced using the redshift of the corresponding clusters in which they reside. The redshifts were taken mainly from a compilation by Andernach & Tago (private communication from H. Andernach, see Andernach et al. 2005). For distance determinations $H_0 = 72$ km s^{-1} Mpc^{-1} was adopted. The Galactic extinction was corrected by the value taken from the NED according to Schlegel, Finkbeiner, & Davis (1998), and the K-correction was applied according to Kochanek et al. (2001).

The list of BFGGs from Mendes de Oliveira et al. (2006) and Santos et al. (2007) with measured by 2MASS $K_{\mathrm{s-total}}$ apparent magnitudes and known redshift is presented in Table 1. The list of 54 BCGs in ACO clusters is presented in Table 2, in which the redshifts, the M_k magnitudes and the Abell number count N_A of corresponding clusters are given. The number count N_A characterizes the cluster richness. It is the number of galaxies more luminous than m_{3+2} mag, where m_3 is the apparent photored magnitude of the third most luminous cluster member located within one Abell radius R_c of the cluster center. N_A values are taken from Struble & Rood (1987).

TABLE 1

ABSOLUTE MAGNITUDES M_K OF BFGGS

FG	z	M_k
Mendes de Oliveira et al. (2006)		
NGC 1132	0.023133	−25.74
RX J0454.8-1806	0.031405	−26.40
ESO 306-G017	0.035805	−26.37
RX J1119.7+2126	0.060550	−24.52
RX J1159.8+5531	0.060550	−26.67
RX J1256.0+2556	0.232000	−27.75
RX J1331.5+1108	0.079000	−25.24
RX J1340.6+4018	0.171853	−26.41
RX J14116.4+4018	0.138000	−27.29
RX J1552.2+2013	0.136000	−26.90
NGC 6034	0.03388	−25.38
NGC 6482	0.013129	−25.40
Santos et al. (2007)		
J015241.95+010025.5	0.229744	−27.45
J075244.19+455657.3	0.051799	−25.38
J080730.75+340041.6	0.207888	−26.95
J084257.55+362159.2	0.282265	−28.13
J084449.07+425642.1	0.05410	−25.91
J104302.57+005418.2	0.125563	−25.79
J111439.76+403735.1	0.20207	−26.16
J114128+055829.5	0.187803	−27.02
J114647.57+095228.1	0.221403	−27.23
J114803.81+565426.6	0.104617	−25.43
J114915.02+481104.9	0.282933	−27.39
J124742.07+413137.6	0.155396	−26.87
J130009.36+444301.3	0.23316	−27.17
J141004.19+414520.8	0.093761	−24.53
J145359.01+482417.1	0.146164	−26.45
J152946.28+440804.2	0.147824	−26.97
J153950.78+304303.9	0.097077	−26.49
J161431.10+264350.3	0.184287	−27.45
J171811.93+563956.1	0.113598	−25.84
J235815.10+150543.5	0.17843	−25.71

TABLE 2

ABSOLUTE MAGNITUDES M_K OF BCGS IN ABELL CLUSTERS OF BM-I TYPE

Abell	z	M_K	N_A
21	0.0955	−27.32	56
22	0.1417	−27.37	141
42	0.1115	−26.66	154
77	0.0717	−26.64	50
122	0.1138	−27.43	64
136	0.1610	−27.41	99
146	0.1878	−27.47	70
180	0.1350	−26.25	33
192	0.1219	−27.00	89
214	0.1593	−27.41	71
261	0.0473	−25.94	63
360	0.2176	−27.70	107
394	0.2087	−27.52	58
401	0.0735	−27.06	90
496	0.0326	−26.06	50
505	0.0555	−26.74	39
586	0.1711	−27.61	190
690	0.0803	−27.42	52
733	0.11547	−26.90	64
734	0.0719	−26.01	71
882	0.1408	−25.69	48
1068	0.1382	−27.08	71
1146	0.1412	−28.10	222
1277	0.2435	−27.65	62
1391	0.1546	−27.80	90
1413	0.1417	−27.69	196
1468	0.0872	−25,67	50
1576	0.2972	-28.35	158
1597	0.1102	-26.51	54
1602	0.1940	-27.72	59
1738	0.1173	-27.47	85
1795	0.0627	-26.63	115
1839	0.1295	-26.18	63
1954	0.1810	-28.45	120
1991	0.0589	-26.32	60
2107	0.0416	-26.38	51
2124	0.0667	-26.80	50
2199	0.0309	-26.49	88
2271	0.0586	-26.38	35
2283	0.1830	-28.15	65
2364	0.1473	-26.24	72
2397	0.2190	-28.11	146
2416	0.2086	-27.59	57
2420	0.0852	-27.10	88
2456	0.0754	-25.71	50
2521	0.1361	-26.39	103
2533	0.1114	-27.33	59
2577	0.1257	-26.35	73
2579	0.1107	-26.71	66
2589	0.0419	-26.33	40
2666	0.0281	-26.09	34
2631	0.2778	-27.29	136
2667	0.2331	-26.89	165
2694	0.0974	-27.27	132

2.2. *Dependence of the BCG brightness on the cluster richness.*

The distribution of M_k absolute magnitudes of BCGs in clusters of BM class I against redshift is shown in Figure 1. The dotted lines represent the locus of absolute magnitudes of galaxies with $K_{\rm s-total}$ apparent magnitudes equal to 9^m and 14^m respectively. The K-correction (Kochanek et al. 2001) to apparent magnitudes was applied. The absence of galaxies to the right of the $K_{\rm s-total} = 14^m$ line is caused by the selection effect, since fainter objects are below the detection limit of 2MASS. The sample of 38 BCGs (marked by filled circles) in Figure 1 is volume-limited. BCGs marked by open circles are outside the limiting distance $z = 0.1500$ denoted by the vertical line. Figure 1 shows that the brightness of the brightest BCGs gradually increases with redshift. The increase of brightness with redshift for the distance limited sample is not due to the Malmquist bias.

It is widely accepted that BCGs are formed by cannibalism (e.g. Boylan-Kolchin, Ma, & Quataert 2006; Bernardi et al. 2007). The rate of merging is inversely proportional to the cube of the cluster velocity dispersion, which is high in rich clusters. Also, the time-scale in rich cluster is longer due to dynamical friction. However, one may assume that BCGs will be on average brighter in rich clusters, since the probability of encounter and merging depends also on the number density of galaxies in the cluster, and eventually on the cluster richness. The richer the cluster, the more members could be cannibalized in the potential well of the cluster by the forming BCG. In Figure 2 the plot $\log N_A - M_k$ for the distance limited sample of BCGs is presented. It shows that indeed there is a certain correlation be-

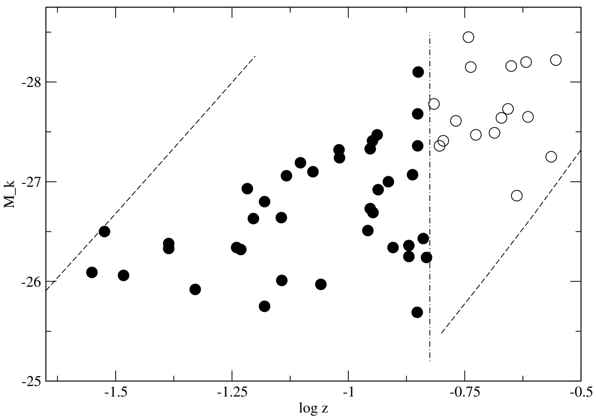

Fig. 1. The distribution of M_k, the absolute magnitudes of BCGs in Abell clusters of BM type I, against redshift. The galaxies of the distance limited sample are shown by filled circles . Galaxies located farther than the distance limit are shown by open circles.

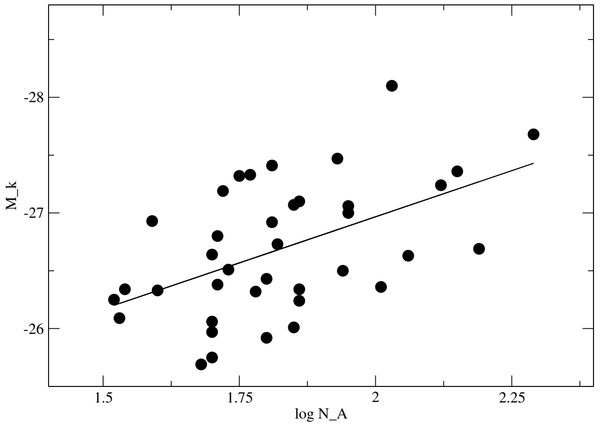

Fig. 2. The dependence of the absolute magnitude M_k of BCGs in the distance limited sample of ACO clusters of BM type I on the Abell number count N_A. The straight line is the least squares best fit.

tween the number count N_A and the absolute magnitude M_k of the BCG. Note that the richness of clusters depends on the distance. This is demonstrated on the graph $z - N_A$ (Figure 3), which was plotted using the same distance limited sample of clusters. Figure 3 shows that poor groups are observed almost uniformly at all distances, while rich clusters are observed at higher redshifts only. Consequently, in a distant rich cluster more members may be cannibalized, and the formed BCG will be brighter.

We estimated the number N_m for merged galaxies, which formed the observed BCG, by assuming that BCGs are formed by merging of ordinary

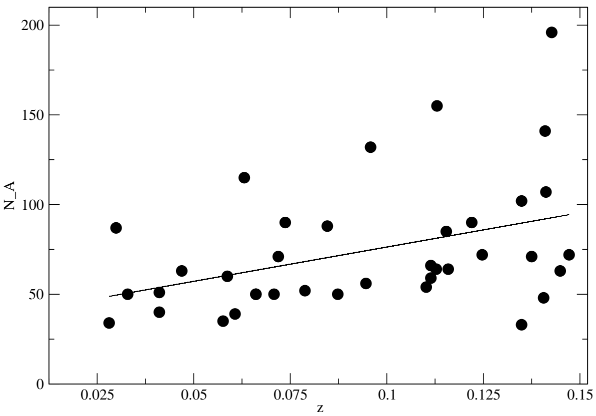

Fig. 3. The dependence of the Abell number count N_A on the redshift of the distance limited sample of ACO clusters of BM type I. The straight line is the least squares best fit.

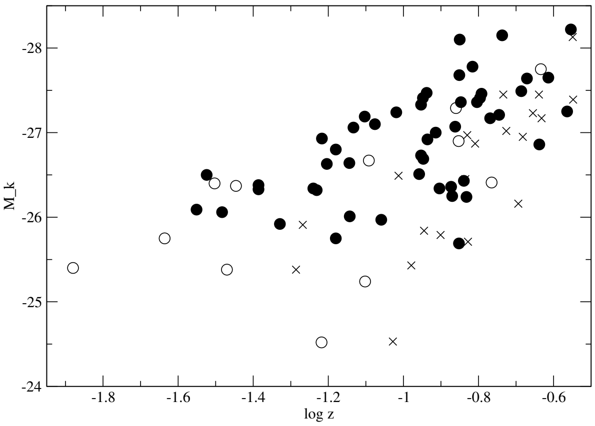

Fig. 4. The distribution against redshift of M_k, the absolute magnitudes of BCGs in Abell clusters of BM type I (filled circles), the BGs in FGs (Mendes de Oliveira et al. 2006) (open circles) and in candidate FGs (Santos et al. 2007) (crosses).

galaxies. For the absolute magnitude of an ordinary galaxy we used $M_{\mathrm{k(isol)}} = -22.68^m$ found by Tovmassian, Plionis, & Andernach (2004) for an isolated E/S0 or spiral galaxies in groups. The number N_m of merged galaxies is determined by the formula $N_m = \mathrm{antilog}[(M_{\mathrm{k(isol)}} - M_k)/2.5]$. For example, the faintest BCG with $M_k \approx -26^m$ is formed by the merging of about 20 galaxies with a mean brightness of an isolated galaxy. Meanwhile, the brightest BCG with M_k equal to about -28^m is formed by the merging of about 130 ordinary E/S0 or spiral galaxies.

TABLE 3

THE COMPARISON OF THE MEAN ABSOLUTE MAGNITUDES OF BCGS IN BM-I TYPE CLUSTERS AND BFGGS

z	0.023-0.044	0.044-0.093	0.093-0.158	0.158 - 0.286
$<M_k>$ (BM-I)	-26.27 ± 0.19 (5)	26.51 ± 0.48 (11)	-26.93 ± 0.62 (24)	-27.50 ± 0.41 (11)
$<M_k>$ (FG)	-25.97 ± 0.50 (4)	25.53 ± 0.86 (07)	-26.36 ± 0.68 (9)	-27.19 ± 0.56 (11)
ΔN_m	6	21	20	21

2.3. *Comparison of the Brightness of the Brightest Galaxies in Clusters of Galaxies and FGs*

In Figure 4 the distribution of M_k, the absolute magnitude against the redshift for three different samples of galaxies, BCGs (filled circles), FGs (open circles) and candidate FGs (crosses) is plotted. Figure 4 shows that the bright galaxies in FGs and candidate FGs are, on average, fainter than the BCGs at all redshifts. In Table 3 the mean absolute magnitudes M_k of BCGs and BFGGs (of both samples) in four redshift ranges are presented. The standard deviations and the number of galaxies in each sample (in parentheses) are also shown. Table 3 shows that FGBCs are fainter in comparison to BCGs in all four redshift ranges. In the third row of Table 3 the differences between the numbers of the supposedly merged galaxies for formation of the mean BCGs and BFGGs at corresponding redshift intervals are presented. The number of merged galaxies which formed the BCG for the three distant samples is on average by 20 galaxies larger than that for the formation of the BFGGs. The difference in the number of merged galaxies is only 6 in the case of nearby objects at redshifts $0.023 - 0.044$. Here there are no rich clusters and, therefore, BCGs can not grow much. It is also worth to note that in the very nearby space there is one FG at $z = 0.013$ and there is no cluster with a BCG (Figure 4).

We found that the brightness of the brightest galaxy in a cluster depends on the cluster richness (Figure 2). The faintness of BFGGs in comparison to BCGs allows us to conclude that the former were, on average, formed in systems poorer than typical BM-I type clusters. Thus, the precursor clusters of FGs are not rich ones. This finding proves the conclusion made by Mendes de Oliveira et al. (2006); Cypriano, Mendes de Oliveira, & Sodré (2006); Khosroshahi, Ponman, & Jones (2007); Mendes de Oliveira et al. (2009); and Díaz-Giménez, Muriel, & Mendes de Oliveira (2009) that FGs were formed in low mass clusters or in massive versions of compact groups (Mendes de Oliveira 2006).

Khosroshahi et al. (2007) mentioned the absence of recent merger processes in FGs, which is considered to be a result of their early formation. D'Onghia et al. (2005), Dariush et al. (2007) and von Benda-Beckmann et al. (2008) also concluded that FGs are older in comparison with clusters of about the same mass, so they had more time for merging processes. We assume that due to a relatively small number of precursor cluster members, the majority of them have already been merged to a BFGG.

3. CONCLUSIONS

We show that the brightness of the BCGs in clusters of BM type I depends on the cluster richness characterized by the Abell number count N_A. The comparison of the absolute stellar magnitudes M_k of BCGs in ACO clusters of BM type I with those of the brightest galaxies in FGs (Mendes de Oliveira et al. 2006; Santos et al. 2007) showed that the latter are systematically fainter. We conclude that the precursors of FGs were relatively poor clusters, the majority of members of which have already been cannibalized.

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