PHOTOMETRIC PROPERTIES OF LOW-REDSHIFT GALAXY CLUSTERS

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RESUMEN

El levantamiento multicolor para cúmulos de galaxias cercanos LOCOS se realizó para investigar las propiedades generales de los cúmulos y la búsqueda de patrones de evolución galáctica inducida por el medio ambiente. LOCOS incluye la observación de 46 cúmulos cercanos del catálogo de Abell en las bandas R, B, e I del sistema fotométrico Kron-Cousins. LOCOS es uno de pocos levantamientos extensos, donde se ha incluido la contribución de las galaxias enanas. En esta contribución sólo se presentan los resultados concernientes a las variaciones de la Función de Luminosidad (FdeL), otros resultados serán presentados en López-Cruz & Yee (2000a,b). Hemos detectado variaciones en ambas ramas de la FdeL. Dichas variaciones no son totalmente erráticas. Por ejemplo, al investigar la naturaleza de las variaciones en la rama brillante de la FdeL se encontró que la magnitud característica M_R^* para cúmulos cD pobres es más débil que la de los cúmulos cD ricos. Los cúmulos que no tienen galaxias cD parecen que no han afectado y presentan la misma M_R^* dentro de los márgenes de error, mientras que los cúmulos binarios muestran ser una clase en transición al ser, posiblemente, el resultado de la fusión cúmulo-cúmulo.

ABSTRACT

A comprehensive multicolor survey was undertaken to investigate global optical properties of Abell clusters of galaxies. This survey was christened the *Low-Redshift Cluster Optical Survey* (LOCOS). LOCOS was devised to search for patterns of galaxy evolution induced by the environment. The generated data base contains accurate deep CCD photometric measurements (Kron-Cousins R, B and I) for a sample of 46 low-redshift ($0.04 \le z \le 0.18$) Abell clusters. This is one of the few large surveys that included the contribution due to dwarf galaxies (about 5.5 mag deeper than the R characteristic magnitude (M_R^*); $Ho = 50\,h_{50}$ km s^{-1} Mpc^{-1}, qo $= 0$). Due to space restrictions only the main results concerning the variations at the bright-end of the luminosity function (LF) are presented here. Other results are presented elsewhere (López-Cruz & Yee 2000a,b). We have detected clear variations at both the bright end and the faint end of the LF. The nature of the variations at the bright end revealed that poor cD cluster have dimmer M_R^*. We can explain these variations as a result of dynamical friction. On the other hand, non-cD clusters seem to have unaffected LFs. A third class termed as binary clusters seems to be a transition class that might have resulted from cluster-cluster mergers.

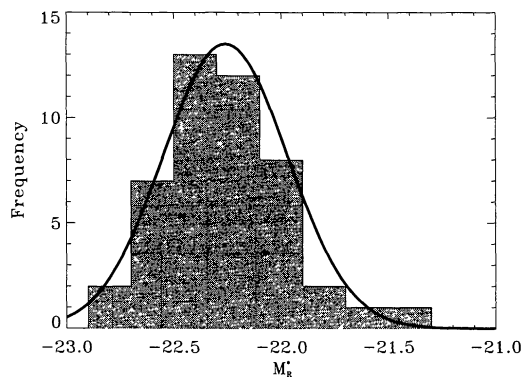*Key Words:* **GALAXIES: CLUSTERS — GALAXIES: ELLIPTICAL AND LENTICULAR, CD — GALAXIES : EVOLUTION**

Fig. 1. The number distribution of M_R^*. A Gaussian distribution with $< M_R^* >= -22.26$ mag and dispersion $\tilde{\sigma} = 0.29$ mag describes the distribution.

1. INTRODUCTION

It is distressing that, up to now, we do not have a clear idea about the true shape of the luminosity function (LF) for galaxies in the field or in clusters. Disagreement has existed ever since the earliest attempts to determine the galaxy LF. Hubble in the 1930's advocated a Gaussian shape LF for bright galaxies, while Zwicky in the late 1950's suggested an exponential increase with decreasing magnitude. It took accurate photometric measurement to show that both descriptions were right. The shape of the LF has a strong dependency on galaxy type and luminosity (Binggeli et al. 1988): a Gaussian function fits the LF of giant galaxies and Zwicky's exponential law fits the LF of dwarf galaxies. One the same grounds the subject of the universality of the LF has always been questioned. Universality was first suggested by Abell (1962) and reintroduced, in an analytical manner, by Schechter (1976). Many photographic and, very few, digital studies have followed since then, but the subject has been far from being settled. For example, no universality was first suggested in the pioneering work of Oemler (1974). However the most recent work of Lumsden et al. (1997) indicates otherwise. One is inclined to think that under the influence of dynamical effects the LF ought to be non-universal (Dressler 1984). Moreover if the mixture of galaxies varies from cluster to cluster, then the universality of the cluster galaxy LF is not expected (Binggeli et al. 1988). The LOCOS sample contains rich Abell clusters that have strong X-ray emission (Jones & Forman 1999). It is one the largest digital cluster surveys to date. The results that are presented below suggest that the non-universality of the LF is due to changes induced by the environment.

2. OBSERVATIONS AND LUMINOSITY FUNCTION GENERATION

The observations were carried out at KPNO with the 0.9m telescope and the T2KA CCD (2048 × 2048) pixels in Kron-Cousins I, R, and B bands with a field of view of 23.2′ × 23.2′ with a scale of 0.68″/pixel. The integration times varied from 900 to 2500 seconds, depending on the filter and the redshift of the cluster. The photometric calibrations were done using stars from Landolt (1992). Control fields are also an integral part of this survey; we observed 5 control fields (in R and B) chosen at random positions in the sky about 5 deg away from a cluster observation. Data preprocessing was done with IRAF, while the object finding, star/galaxy classification, photometry, and the generation of catalogues was done with PPP (Yee et al. 1996). More details are presented in (López-Cruz & Yee 2001a).

The LF functions were generated by background subtraction using the counts from the control fields. The main differences with respect to other studies are that all the photometry and calibrations were based on CCD observations and that color information was used to generate the background subtracted-LF, i.e., galaxies whose colors were too red with respected to the color-magnitude relation were rejected by applying color-cuts in the color-magnitude space. In general, two Schechter functions were used to fit the counts using a χ^2 minimization
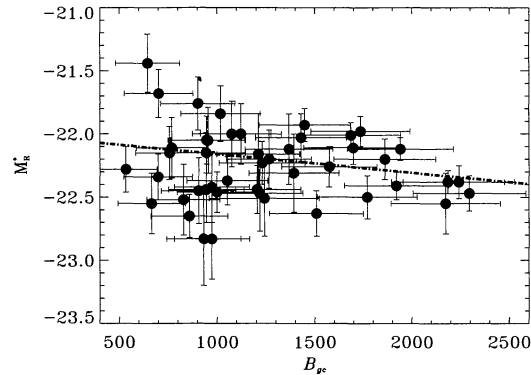
Fig. 2. The variation of the M_R^* with richness (B_{gc}) for the whole sample. There is a weak correlation between M_R^* and B_{gc}.

(see López-Cruz & Yee 1995). The entire cluster sample was combined and a Schechter fit to the bright-end (galaxies with $M_R \leq -20$ mag) of the combined LF gave an slope $\alpha_{com} = -1.04 \pm 0.05$ and a characteristic magnitude $M_{com}^* = -22.53 \pm 0.09 + 5 \log h_{50}$ mag (cf. Gaidos 1997). We proceed to fit the bright-end of the LF of individual clusters with a fixed $\alpha = -1.0$ and the constraint that the total number of galaxies in the resulting fits was equal to the actual total number in the observed LFs (e.g., Dressler 1978; Colless 1989). Full details regarding the generation of the LFs are given in López-Cruz (1997) and López-Cruz & Yee (2001b).

3. LF VARIATIONS AT THE BRIGHT END

Since the effect of contamination by background clusters is small at bright magnitudes, the entire cluster sample can be used to search for variations of M_R^*. The distribution of M_R^* is shown in Figure 1. It is found that the values of M_R^* are normally distributed with mean, $< M_R^* >= -22.26$, and standard deviation, $\tilde{\sigma} = 0.29$. Our $< M_R^* >$ agrees to within 0.2 mag with the mean values previously reported (e.g., Schechter 1976; Dressler 1978; Colless 1989), although a "canonical" $\alpha = -1.25$ was used in their fittings. In Figure 1 we note that there is a slight tail towards faint magnitudes in the distribution. The average error of M_R^* for the whole sample is 0.21 ± 0.07 mag. Hence, the dispersion in the distribution of M_R^* is somewhat larger than that expected from the uncertainties of the measurements, indicating some chance of departure from universality.

In order to investigate whether these variations are associated with intrinsic cluster properties, we compare the values of M_R^* and the richness indicator B_{gc} (Yee & López-Cruz 1999). Figure 2 shows the variations of M_R^* with richness. There is a marginal correlation between M_R^* and B_{gc} (significant at the 15% level). To investigate this possible correlation further, we divide our sample into three groups based on the cluster morphological properties. The first group has objects that have a very strong indication that their brightest cluster members (BCMs) are cD galaxies[2]. These clusters are Rood-Sastry type "cD" and have Bautz-Morgan types between I and I-II. For the second group we select all those objects with Rood-Sastry Type "B". The reason for selecting these objects as a separate class is because binary clusters have indications of recent cluster-cluster merging (Tremaine 1990). The third group is defined, by simply negating the criteria that lead us to select the cD and B clusters, i.e., clusters with Rood-Sastry type different from cD or B, and Bautz-Morgan type later than I-II. We term these clusters non-cD clusters. If cD galaxies are formed by a dynamical evolution mechanism, then non-cD clusters should have properties closer to unevolved clusters. The classes cD and non-cD are well separated, see below. However, we believe that B clusters are a mixture of cD and non-cD clusters. If one or more of the binaries are cD, then we would expect the cluster to have properties similar to cD clusters. But the general properties will be more difficult to characterize because of the recent cluster-cluster merger effects.

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[2]We call cD galaxy a BCM that has the presence of an extended luminous halo, we also recognize two classes: halo, according to Schombert's (1988) criterion for cD-ness, and halo-dominated cDs, as in López-Cruz et al. (1997).
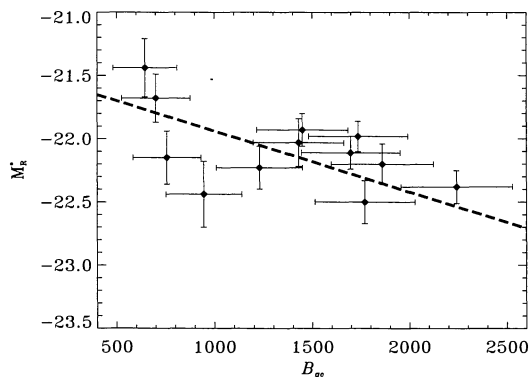
Fig. 3. A significant correlation between M_R^* and B_{gc} is found for cD clusters.

The table below summarizes our group definitions. There are five clusters that do not belong to any of the defined groups: three with ambiguous indication that their BCGs are cDs, A415 (BM II, R-S cD), A665 (B-M III, R-S cD), A1413 (B-M I, R-S C), and two with incomplete morphological information (A1569, A2555).

Group	Bautz-Morgan Type	Rood-Sastry Type	# of clusters
cD	I, I-II	cD	12
non-cD	II, II-III, III	C, F, L,I	23
B		B	6
unclassified			5

3.1. cD Clusters

Figure 3 is a plot of M_R^* vs B_{gc} for cD clusters. It shows that there is a clear trend indicating that M_R^* becomes brighter with richness. We can try to characterize this variation with a linear fit. A least squares fit considering the errors in both variables gives the following:

$$M_R^* = -21.46(\pm 0.20) - 0.428(\pm 0.138)\left(B_{gc}/1 \times 10^3\right).$$ (1)

The correlation coefficient in eq. 1 is $r = -0.55$. For 12 points, the probability of exceeding $|r|$ in a random sample is $P(r, \nu) = 0.07$. Therefore, we conclude that the correlation is significant. We suggest that eq. 1 is consistent with the galactic cannibalism model, in the sense that poorer cD clusters are more effective in depleting their giant galaxies to form a cD galaxy. From the dependence of the time scale for dynamical friction with cluster velocity dispersion $\tau_{df} \propto \sigma_{cl}^3$ (if the cluster potential is a singular isothermal well), and since $\sigma_{cl} \propto 0.4 B_{gc}$ (Yee & López-Cruz 1999). It follows that the orbital decay rate is relatively faster in poor clusters than in the rich ones. Detailed calculations by Merrit (1988) and (Tremaine 1990) show that the decay rates due to dynamical friction are not short enough to produce the total luminosity of cD galaxies (central galaxy + envelope). Eq 1 is consistent with an overall slow rate of orbital decay, because if one or two giant galaxies are cannibalized in a poor cluster, the change in M_R^* is easily detectable. Nevertheless, Figure 3 provides a case for a consequence of cannibalism that is very suggestive and significant. Indeed, the correlation depicted in Figure 3 does not disappear even when the four poorest clusters are removed from the analysis. A more complete picture for cD galaxy formation also involves the disruption of dwarf galaxies (López-Cruz et al. 1997).We note that Dressler (1978) suggested a converse trend. He indicated that a fading of M_R^* with richness was consistent with his data. However, his sample included only five Bautz-Morgan clusters, four of which are part of our cD cluster group (A401, A1413, A2029, A2670). The fifth one is A2218 a Rood-Sastry C cluster. However, Dressler's richness scale, which was based on the central counts scaled by the volume of
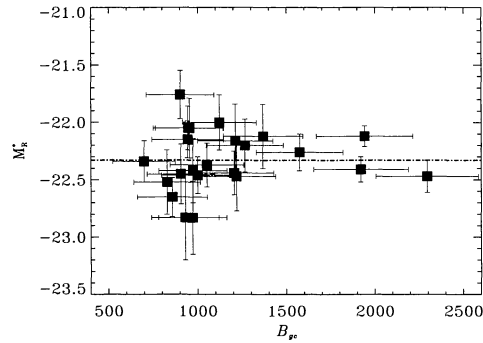
Fig. 4. M_R^* is uniformly distributed with richness (B_{gc})

the cluster core, and ours do not agree, particularly for the cases of A2670, A401 and A1413. The main source of uncertainty in Dressler's richness estimator is the size of the clusters' core. If we use our richness scale, the trend depicted in Dressler's Figure 5 disappears. We should remark that other studies based on photographic material have only reported marginal cases of this kind of variations (e.g., Colless 1989; Lumsden et al. 1997).

3.2. Non-cD Clusters

Apart from the morphological differences between cD clusters and non-cD clusters, in general it is found that non-cD clusters are poorer than cD clusters. Moreover, we found that the non-cD clusters show no correlation with B_{gc} as depicted in Figure 4. Hence, the marginal correlation we see in Figure 1 arises entirely from the cD clusters contribution. Non-cD clusters are normally distributed with $< M_R^* >= -22.33$ mag, and $\tilde{\sigma} = 0.26$ mag, which is smaller than that from the whole sample. Hence, we conclude that non-cD clusters are consistent with having a universal M_R^* within the uncertainties of the observations. Furthermore, a Kolmogorov-Smirnov test shows that the distributions of M^* and B_{gc} for the cD clusters and non-cD clusters are significantly different ($D = 0.36$, $p = 0.21$; $D = 0.41$, $p = 0.10$, respectively). This further, confirms our assertion that these classes are well separated. Most importantly, we also conclude that cD and non-cD clusters must have different dynamical potentials. Therefore, their dynamical evolution should be different. Poor clusters might represent regions that turned around later than cD clusters.

3.3. Binary Clusters

Our idea that binary clusters are an intermediate class is fair. For instance: in the Coma cluster there are three very luminous giant galaxies. Two of those, NGC 4874 and NGC 4839 are halo-cDs. High resolution X-ray images have shown two components of hot gas associated with the galaxies NGC 4874 and NGC 4889, respectively. Based on the galaxy distribution and the X-ray distribution, it was concluded that NGC 4874 and NGC 4889 are the BCGs of two clusters in the process of merging. Indeed, we found that B clusters seem to behave differently from both cD or non-cD clusters. M_R^* fojr binary clusters is consistent with a uniform distribution with B_{gc} ($< M_R^* >= -22.38$), but binary clusters are richer than non-cD clusters on the average. However, with such a small sample of binary clusters, these results should not be overemphasizedy.

4. SUMMARY

We found that the cluster LF is in general *not universal*. As Kormendy & Djorgovski (1989), we also suggest that cD galaxies are formed by special processes. The correlation between M_R^* and B_{gc} suggests that galactic cannibalism contributes in the process of cD galaxy formation. Indeed, if cD galaxies have grown by dynamical processes, we expect a dimming of M_R^* for earlier Bautz-Morgan type; Figure 5 depicts such a trend. The same
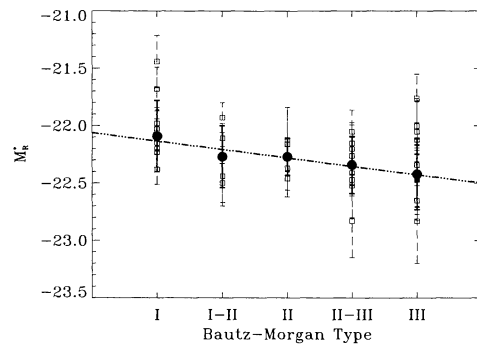
Fig. 5. A significant correlation is found between M_R^* and the Bautz-Morgan type for cD and non cD clusters. M_R^* is about half a magnitude dimmer for type I than for type III clusters. The squares are the individual clusters. The filled circles are the median M_R^* for each B-M type .

trend was suggested by Trèvese et al. (1996). In contrast, we found that the bright end of LF for non-cD cluster is universal and, hence, there is no dependence on the environment. Therefore their properties are closer to that of the field. Finally, we remark that B clusters seem to have properties somewhat intermediate between cD and non-cD clusters. From the results presented here, we propose that the characteristic magnitude may serve as a good distance indicator once the effects of the environment are taken into consideration.

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