BRIGHTEST CLUSTER MEMBERS

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Abstract

A review of the structural properties of BCM's in poor and rich clusters is presented in order to define the morphological types gE, D and cD in ellipticals. Although the difference between bright field ellipticals and BCM's is subtle (primarily an enlargement in characteristic radius for BCM's) it is quantifiable on the fundamental plane for ellipticals. Various indirect arguments, plus direct comparison to N-body simulations, demonstrate that these structural differences are the result of a past history of early mergers plus late accretions of lesser clusters members. Although present day tidal stripping is evident in some clusters, cD envelopes must have their origin before cluster virialization.

1 Introduction

The purpose of this conference is to debate the usefulness of the morphological classification of galaxies and whether it should be replaced by a scheme based on the physical properties of galaxy types. In either case, one example of where morphological classification has been very successful is in the understanding of first-ranked ellipticals in clusters, i.e. the brightest cluster members (BCM's). In this incidence, I define successful in the sense that the morphological classification of BCM's alerted the astronomical community of their special nature and, with further study, led to a substantial contribution to our understanding of dynamical evolution. In this review I will summarize the morphological classes of BCM's, outline the structural meaning of these classes, particularly in differentiating the interior versus halo properties of BCM's, and demonstrate that the interior properties of BCM's are due to a history of mergers, while the extended envelopes are primordial in origin.

BCM's are extreme examples of a class of very homogeneous objects, elliptical galaxies. They are extreme in their luminosities ($L > 10^{11} L_\odot$, $H_0 = 100\,\mathrm{km\,sec^{-1}Mpc^{-1}}$ assumed throughout this review), being the brightest objects in the Universe that emit light strictly from stellar photospheres. They are extreme in their absolute sizes with some cD galaxies measuring over 1.0 Mpc in radius (Oemler 1976, Schombert 1984). They are also extreme in the environment in which they reside, the cores of rich clusters. In modern astrophysics it is generally perceived that special objects imply a special process of formation or evolution, and the process most often invoked is one of growth of

BCM's from the cannibalism of lesser galaxies by dynamical friction. Note that there are certain dynamical reasons to believe this effect would not be strong in present-day clusters since, although the cross section for galaxy interactions are high in the cores of a rich cluster, those encounters are fast and not typical of the bound, merging orbits (see Merritt 1985).

2 BCM Morphological Types

The most extensive morphological classification of BCM's is from the catalogs of Struble and Rood (1984). Within these catalogs BCM's are represented in a variety of forms; gE (giant elliptical), B (binary galaxy); Bp (peculiar binary, usually relating to a common envelope), cD (a gE with evidence of a diffuse and extended halo) and cD, (a "nested" cD of several multiple nuclei embedded in the primary's core). Sketches of several examples are shown in Figure 1, taken from Struble and Rood (1984). Although BCM's come in a variety of flavors, a majority are of the plain cD or the multi-nuclei cD variety where the embedded companions are sufficiently small enough to be ignored for structural analysis. For the rest of this review, I will concentrate on the parent body or primary mass concentration of BCM's, however, one should not forget that a significant fraction of BCM's are of the dumbbell variety (e.g. A400) where the companion is of comparable size and luminosity. An excellent study of the binary BCM's was performed by Valentij n and Casertano (1988).

It is instructive to remember that classification of BCM's is usually performed by visual examination of wide-field photographic plates (e.g glass copies of the Palomar Sky Survey), involving the material from a non-linear detector using a logarithmic device. This places a high weight, in the classification, on the mid-regions of an elliptical's halo. The centers are usually too high in density with little contrast to the eye and the faint, outer envelopes are below eye detection. Thus, it is not too surprising, as detailed in the following section, that a BCM's classification. is strongly influenced by the slope of the radial luminosity distribution at 5 to 10% of sky brightness (Malumuth 1983).

3 Classification by Surface Photometry

Upon examining luminosity distributions, it is found that BCM's are generally distributed into three morphological types; gE, D and cD. A normal elliptical is represented by a smooth manifold of surface photometric profiles. On the low mass end of the sequence these profiles are exponential in shape (Binggeli, Sandage and Tarenghi 1984). On the high mass end these profiles become approximately $r^{1/4}$ shaped. The transition from exponential to power-law is smooth and an interested reader can view template profiles for ellipticals in Figure 1 of Schombert (1987). At the extreme end in luminosity of the normal elliptical sequence are, by my nomenclature, giant ellipticals. They are a natural extension of the elliptical sequence, being roughly $r^{1/4}$ in appearance, and lie on the same fundamental plane of structural and kinematic properties (Djorgovski and Davis 1987) as normal ellipticals. I simply delineate them from other ellipticals by their size ($R \approx 75\,\mathrm{to}\,100$ kpc) and magnitude ($M_{\mathrm{v}} < -22$). On the other hand, the D class galaxies, similar in luminosity, size and mean surface brightness as gE's, display special properties with respect to normal ellipticals on the fundamental plane. For example, their surface brightness profiles are

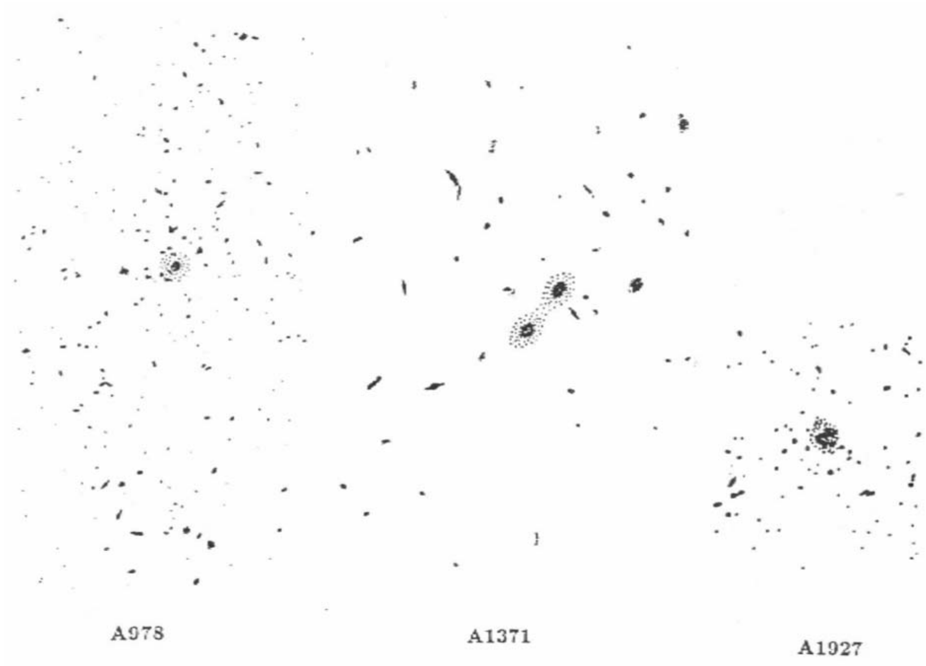

Figure 1: Examples of BCM's from Struble and Rood (1984), A978 is a flat cluster (F-type) with a D galaxy, A1371 is a B_p cluster and A1927 is an example of a nested cD galaxy.

more extended at a characteristic radius than normal ellipticals causing a shallower profile slope (see below). The cD class is recognized by D-like interiors plus a large, low surface brightness ($\bar{\mu} = 26\,\mathrm{to}\,27\,\mathrm{mag\,arcsec}^{-2}$) envelope (Oemler 1976). All three types are shown in Figure 2 along with a intermediate luminosity elliptical. The manifold of profiles for gE and D type galaxies overlap; however, the brightest D galaxies are more luminous than the brightest gE types.

Individual examples of surface brightness profiles of all these morphological classes can be found in Figure 2 of Schombert (1987). Most notable of these examples are some "classical" cD galaxies, such as the BCM in A2029, which, although being a very large D galaxy, does not have the extended envelopes that I associate with the cD class. Extreme cD examples are seen with the BCM's in A1413 ($L_{env} = 7 \times 10^{11} L_\odot$) and the southern cluster Shapley 8 ($L_{env} = 2 \times 10^{12} L_\odot$). Homology merger theory (Hausman and Ostriker 1978) predicts that cD galaxies should have depressed central surface brightnesses; however, as noted by Oemler (1976), most D and cD galaxies have high central surface brightnesses (central refers to the inner 2 kpc, not a core value).

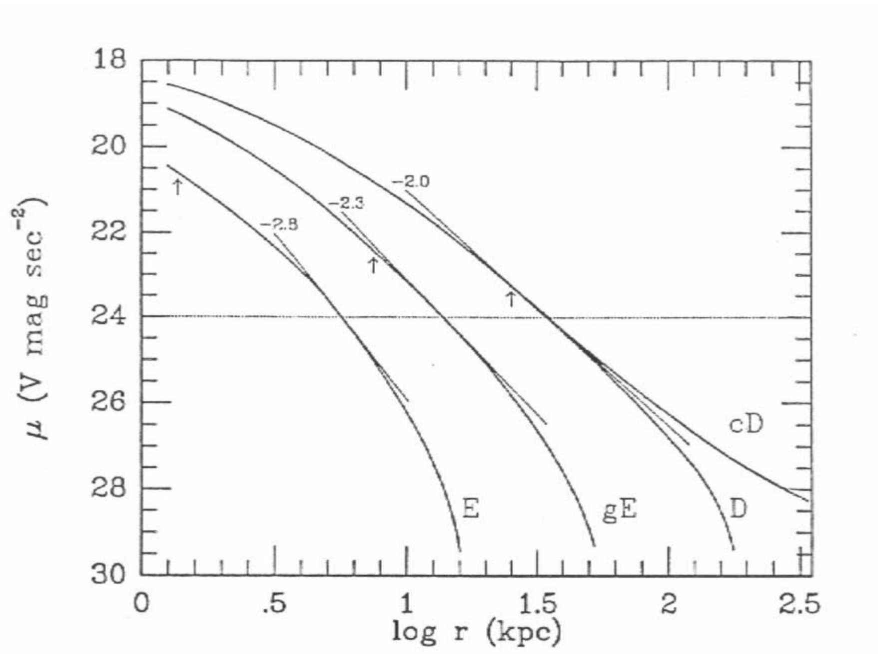

Figure 2: Surface brightness profiles for the four classes of BCM's, normal elliptical, giant elliptical, D and cD. The dotted line indicates the region of a profile most strongly weighted in visual classification.

Nonetheless, there does exist a sub-sample of cD galaxies with depressed central surface brightness (e.g., A85 and NGC 6166 in Schombert 1987). These objects are rare, but it is interesting to note that most are associated with emission lines, IRAS emission and other evidence of recent star formation in their cores.

Several characteristics are common to BCM's evidenced through comparison of their surface brightness types. The first is that almost all BCM's are of the D or cD class. This is true for poor clusters (Thuan and Romanishin 1981) as well as rich clusters (Malumuth 1983, Schombert 1987). A second point is that cD envelopes are not detected by eye (most being below 1% of sky brightness). The "diffuseness" seen for BCM's is not the extended cD envelope, but rather the slope of the profile around the 24 V mag arcsec^{-2} level. This is an important distinction since I reserve the cD class for objects with extended envelopes only, a matter for deep surface photometry, and that the "diffuseness" is a characteristic independent of the existence of a cD envelope. This is seen in Figure 3, where the morphological type by surface photometry is compared to the morphological type as determined by visual classification of Struble and Rood (1954). What Struble and Rood would call a cD galaxy is equally divided into the D and cD classes meaning their definition of cD had nothing to do with extended envelopes, but rather depended on profile slope. Fortunately, as I will prove in the following section, this shallow profile is a merger signature and, therefore, the cD classification by Struble and Rood still has merit with respect to the galaxy type. Also, very few gE's are called cD by Struble and Rood. Sometimes, as in NGC 6034, cD galaxies are misidentified as SO galaxies, probably due to a high elongation combined with a shallow profile which simulates the appearance of a disk. Lastly, not all D or cD galaxies are BCM's; however, no D or cD type galaxies have been found in the field despite an extended search of bright, field ellipticals from redshift surveys (Schombert 1987) and all are positioned on local cluster density enhancements (Beers and Geller 1983).

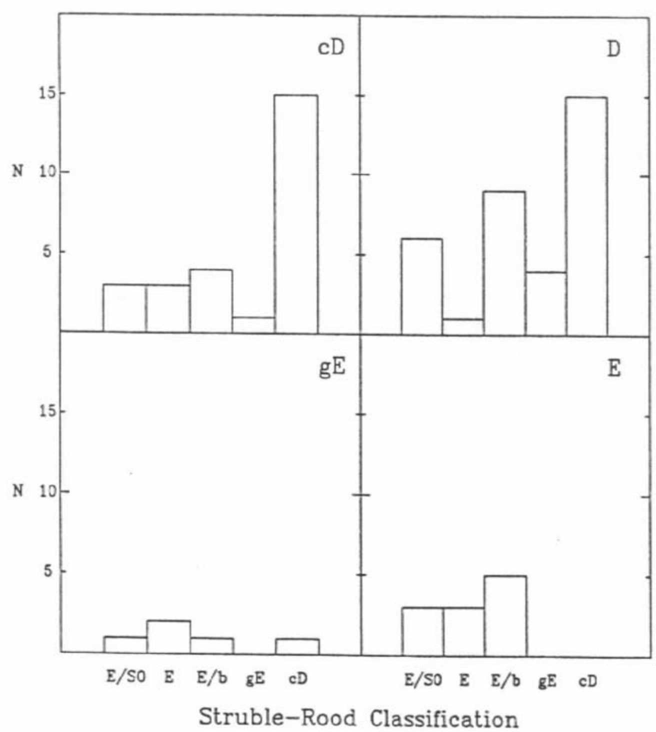

Figure 3: Comparison of morphology from Struble and Rood versus classification based on surface photometry profiles as shown in Figure 1.

4 Are BCM's an Extension of the Normal Elliptical Sequence?

In the next two sections I will to address two questions. One concerns the interior properties of BCM's and the second concerns the origin of cD halos. The first question comes down to the problem of whether BCM's are a simple extension of the elliptical sequence, in terms of luminosity and structural properties, or whether they are special objects whose formation or evolution is due to some external factor, such as mergers or accretions. At first glance, the naive answer to this question is that BCM's have many properties in common with normal ellipticals. The profiles of D galaxies and the interiors of cD galaxies are basically $r^{1/4}$ in shape and there is no discontinuity in luminosity from gE and D type galaxies. The diffuse appearance of BCM's, as compared to gE's, is a difficult attribute to quantify. On the other hand, BCM's exhibit luminosity characteristics that imply a two population interpretation (Schneider, Gunn and Hoessel 1983, Bhavsar 1989) as well as external differences from other galaxies, such as their location on density enhancements beyond a mere morphology-density relationship (Beers and Geller 1983).

A crude technique, but still enlightening, is a test of three structural properties mass (aperture luminosity), scale length (characteristic radius) and density (surface brightness), three of the four segments of the fundamental plane. These three diagrams are reproduced in Figures 4, 5 and 6 from the work of Schombert (1987). Figure 4 displays a plot of aperture magnitude (M_{16kpc}) versus a characteristic scale length, in this case the half-light radius, r_e, from $r^{1/4}$ fits. Although BCM's appear to follow a different relationship from normal ellipticals, closer inspection of this diagram shows that the bright field ellipticals also deviate from the $L \propto r^{1.6}$ line above $M_V = -21.5$. I interpret this to mean that the kinematic properties of bright ellipticals (rotators below $M_V = -21.5$ and velocity supported above) are reflected in the structural relationship of mass and scale length. In Figure 5, mass versus density is represented by magnitude and an inner metric surface brightness (μ at the 2 kpc radius). Similarly in this diagram, BCM's are not strongly deviant, although the majority appear overly bright for their inner luminosity densities. On the other hand, the special nature of BCM's can clearly be seen in a plot of density (effective surface brightness, μ_e) versus scale length (r_e again) in Figure 6. Here 87% of the BCM's lie above the normal sequence, where even the brightest gE galaxies follow the relationship established by Kormendy (1980). I consider this diagram to be the strongest evidence for structural difference between BCM's and normal ellipticals. And, I interpret this difference to be that BCM's are enlarged (have larger effective radii) for a given surface brightness (rather than higher luminosity density for a given radii) which is also consistent with a "diffuse" appearance from morphology. Thus, D and cD galaxies are not in the same sequence as the elliptical template profiles from Schombert (1987), although they are very similar with BCM's being slightly shallower in profile slope than gE of the same scale length or magnitude. Lastly, a recent analysis of the fourth leg of the fundamental plane (velocity dispersion for BCM's and field ellipticals (Djorgovski et al. 1990), from Malumuth and Kirshner (1985) data, confirms the above conclusions finding that BCM's follow different scaling relations.

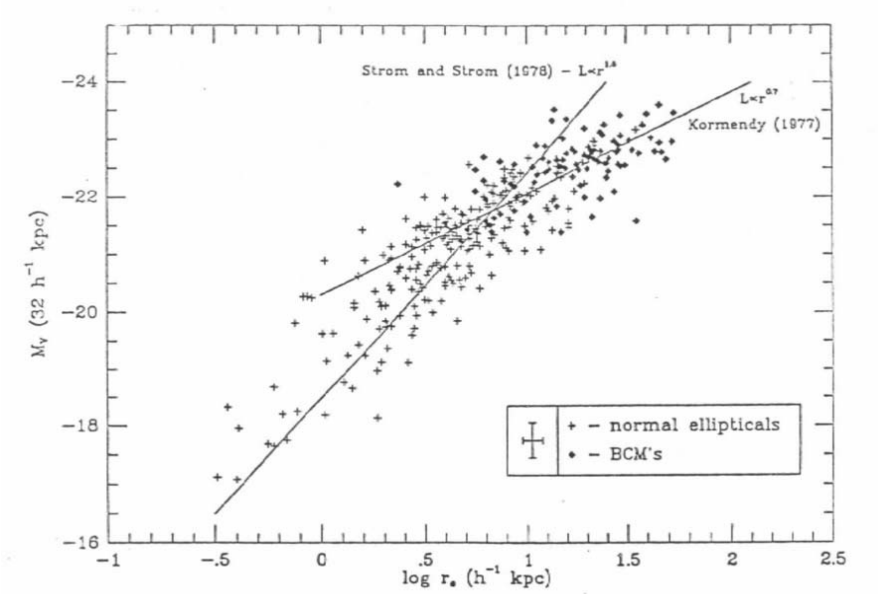

Figure 4: Aperture magnitude versus effective radius for normal ellipticals and BCM's. The two lines are relationships taken from early work on ellipticals.

I have argued in previous papers that these differences on the fundamental plane are exactly what is predicted from N-body merger and accretion simulations. I am particularly influenced by the series of papers by Farouki et al. (1983) for equal mass mergers and hierarchical accretions in which they publish surface density profiles for their remnant objects after each stage of mergers. Sifting through these models and others in the literature (Villumsen 1982, White 1982, May and van Albada 1984) has led me to propose the following scenario for BCM formation and evolution. At the time of galaxy formation there were a range of protogalactic lumps from dwarf sized to 1 or 2 L_* sized bodies formed by a dissipative collapse processes (see Larson 1990 for a review of these galaxy building processes). Immediately after this early epoch, all objects which will become bright ellipticals (either field or cluster members) are formed as the product of hierarchical mergers between these early lumps (White and Rees 1978, Tinsley and Larson 1979).

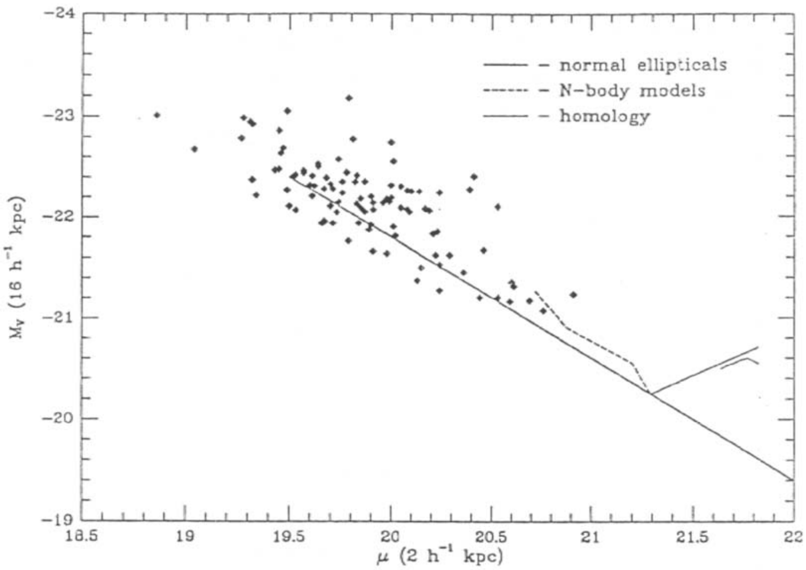

Figure 5: Aperture magnitude versus surface brightness for BCM's. BCM's tend to scatter above the relationship for normal ellipticals.

One argument for this particular origin to all bright ellipticals is shown in Figure 4 where the transition from exponential to $r^{1/4}$ shaped profiles occurs at the same point where there is a break in the M_{16kpc} vs r_e diagram, Figure 4. May and van Albada (1954) argue that a $r^{1/4}$ profile is a natural result from merging and the simulations of Farouki et al. also note the tendency for an $r^{1/4}$ profile to form in the remnant. However, to maintain the mass-metallicity relation and the old stellar population observed today, this merging must be at or before the epoch of first star formation. After this early merger epoch, the field and cluster population diverge as the cluster ellipticals continue the process of cannibalizing their neighbors. The field ellipticals, on the other hand, have no neighbors from which to continue this process and, thus, promotes the expectation that cluster ellipticals will depart from the field population only in the degree of dynamical evolution. At this stage, seed cluster ellipticals (ones which will become the BCM's) are located in small subclusters which will later coalesce to form a rich cluster. Within this subgroup, the relative velocities are low and dynamical friction speeds the accretion process. However, unlike hierarchical mergers which led to equalpartition of internal energy and loss of identity of the two original components, later accreting objects will, in all probability, be smaller in mass. Their fate is such that, as they fall into the BCM their outer envelopes are disrupted, placing their stellar material in orbit near the effective radii of BCM's. The remaining small, tightly bound core survives to reach the center of the BCM and increase its central surface brightness (White 1982).

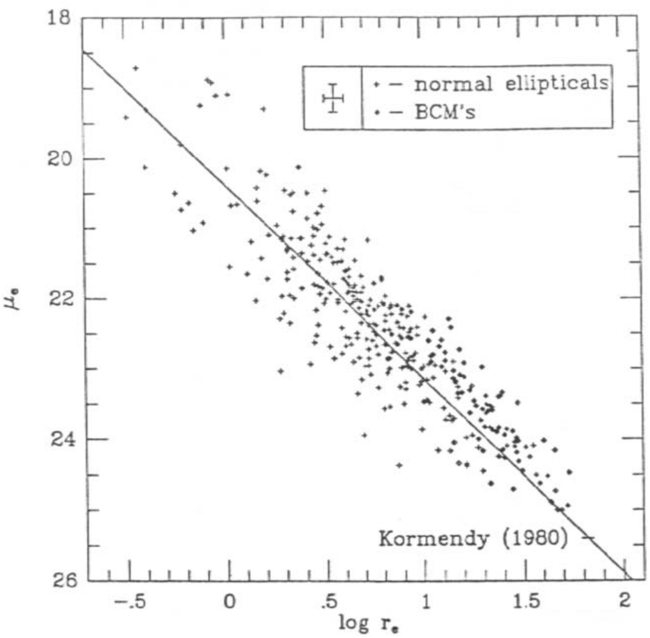

Figure 6: Surface brightness versus effective radius for normal ellipticals and BCM's. Most BCM's lie to the right of the normal elliptical relationship as defined by Kormendy (1980).

After a crossing time (the orbital period at the effective radius), the cannibalized material redistributes into a smooth core and halo $r^{1/4}$ appearance. The result is that the BCM grows mostly in size due to the fact that the accreting material is located in the outer regions (diffuseness). There is little change in the core surface brightness, relate to other bright ellipticals of the same size or aperture magnitude, while a $r^{1/4}$ shape is maintained. An interesting special case is if the victim galaxy is not centrally concentrated (e.g. a disk galaxy). In this scenario, the BCM consumes the object yet no core exists to increase the central density of the BCM. The result is a low central surface brightness BCM with dissipating gas collecting in the core, which would be visible as emission gas, if heated by infall, or compressed to ignite star formation. These are precisely the characteristics exhibited by A85 and NGC 6166, our two best examples of low central surface brightness cD's.

5 Are cD Envelopes Primordial in Origin?

The shape of cD envelopes is most easily understood by a simple two component model of a galaxy potential on top of a more extended cluster potential indicating that envelopes surrounding cD galaxies are structurally independent of the underlying galaxy. Figure 7 shows one attempt to model the envelope of A2670 (Schombert 1988). The major limitations to this method are an unresolved cluster core value, r_h, and lack of velocity dispersion data on cD envelopes. However, adequate models are produced from typical cluster core radii and velocity dispersions, lending support to the idea that cD envelopes are a "'sea" of stars bound not to the underlying galaxy, but to the cluster potential as a whole. The underlying galaxy is simply at rest with respect to the cluster's potential and benefits from its unique position with the adhesion of the surrounding cluster light as a cD envelope. This argues that we should decouple the properties of cD envelopes from the underlying galaxy. The discovery of cD envelopes either independent of an underlying galaxy (cluster light) or with non-concentric isophotes (such as the starpile in A545, Struble 1988) supports this idea.

Since cD envelopes are cluster-sized entities, it would not be surprising to find correlations between envelope properties, such as occurrence and luminosity. and global cluster properties, such as cluster morphological type. However, Figure 8 shows that, this is not as pronounced as expected. Both the occurrence and luminosity of cD envelopes are shown with respect to cluster Rood-Sastry type (a pleasure of the dynamical state of the cluster, where cD and B type cluster are assumed to be highly evolved and L/F/I clusters are irregular and in a pre-collapse state) and Bautz-Morgan type (a measure of the dominance of the BCM, also reflecting the dynamical state of a cluster). Although there is a tendency for more and brighter cD envelopes to occur in advanced cluster types, there are still significant numbers of envelopes in unevolved clusters with comparable brightnesses.

Comparing the physical properties of clusters to cD envelopes is even less edifying: the correlations are weak to non-existent. In Figures 9 and 10, the cD envelope luminosity is plotted against two cluster properties, richness and total X-ray luminosity. If the stripping of cluster galaxies by the mean tidal field is the source of light for cD envelopes, then one would expect a direct correspondence between number of cluster members and envelope luminosity. Figure 9 shows there is a relationship (a correlation coefficient of 0.72), similar to the $L_{env} \propto N^2$ trend predicted by Malumuth and Richstone (1984), although weak. An equivalent weak relation exist between X-ray and envelope luminosity as shown in Figure 10.

Additional evidence as to the origin of cD envelopes comes from inspection of their broadband colors (i.e. a measure of the dominant stellar population). Although color information at the surface brightnesses typical for cD envelopes is extremely difficult, requiring long integrations with CCD's that have excellent flattening characteristics. I have examined several cD galaxies with various filter schemes and have concluded that no color gradients are visible through the transition from galaxy to envelope light, and the mean colors are the same as an old elliptical-like population. This is somewhat surprising in view of the fact that Bothun and Schombert (1990) found evidence for truncated galaxies in the present-day cD clusters. Even if most of these truncated galaxies are ellipticals, one would expect, from the color-magnitude relation for galaxies ($B-V=0.9$ for low luminosity ellipticals) plus any blue disk material stripped from spiral, a minimal change of 0.1 to 0.2 $B-V$ gradients.

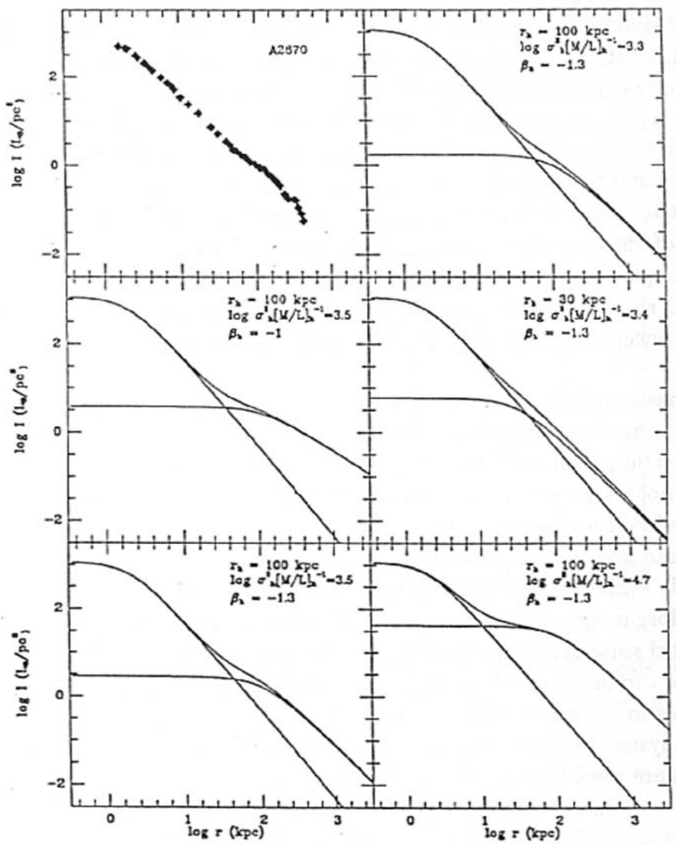

Figure 7: A two component cD envelope model for A2670. Various values of halo radius and velocity dispersion, as well as halo M/L and power-law slope β, are shown.

It is difficult to draw a strong conclusion of dynamical origin to cD envelopes while lacking clear cluster correlations. Combined with the stellar population information, I believe that the formation of cD envelopes was an early process, from one of two scenarios : (1) the envelopes have their origin in tidal stripping of protogalactic material of subcluster members or (2) as Merritt suggests, the envelope is a remnant of the special location of the BCM; all galaxies initially had large envelopes, but were stripped by the cluster mean tidal field *except* the BCM's. This latter view is attractive since then the parallel evolution of mergers for the BCM's interior and stripping for envelopes both reflect, to some

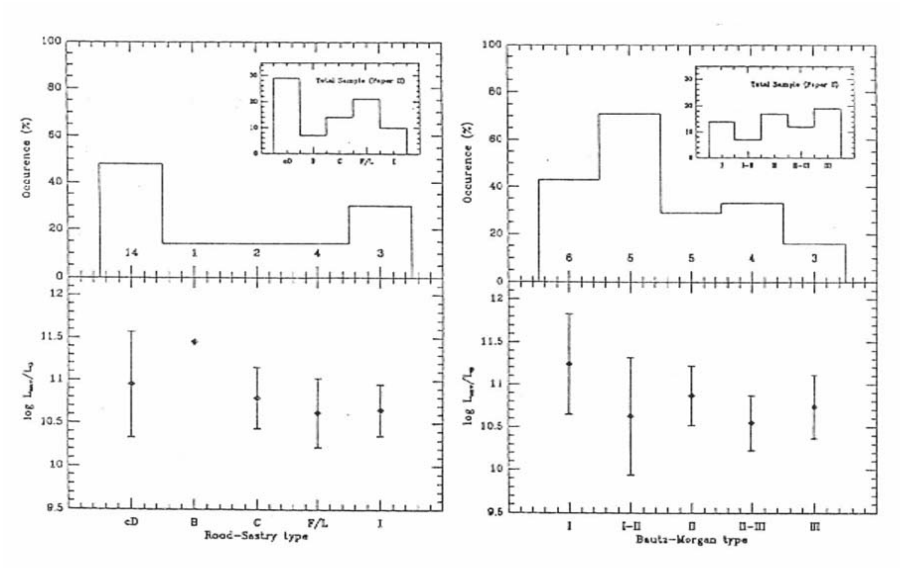

Figure 8: Rood-Sastry and Bautz-Morgan cluster type versus cD envelope ocurrence and luminosity. Although a majority and the brightest cD envelopes ocurr in the evolved cluster types, a significant number exist in unevolved clusters.

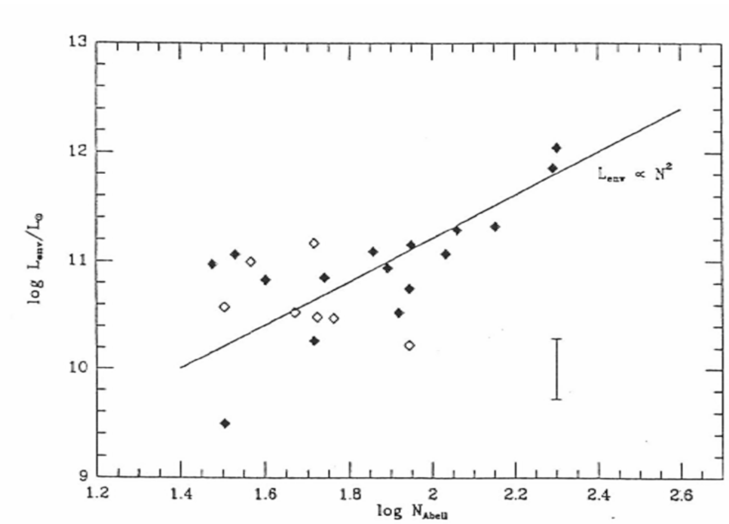

Figure 9: Cluster richness versus cD envelope luminosity.

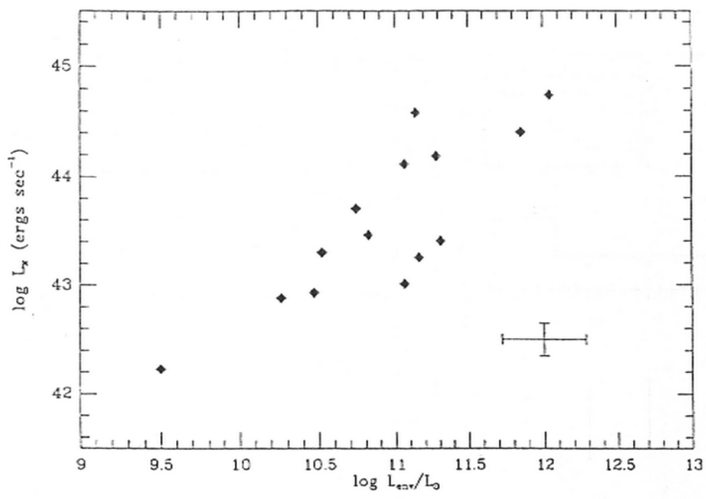

Figure 10: X-ray luminosity versus cD envelope luminosity.

degree the richness and mass concentration of the initial subcluster and, thus, are partially reflecting in present-day global cluster correlations. However, this scenario would also predict that all BCM's should be cD's and does not explain where all the excess material from early tidal stripping is today (e.g., not in the form of stars). In addition, Bothun and Schombert (1990) have shown strong evidence of ongoing dynamical friction and tidal stripping in present day clusters. The amount of material available may be insufficient to form cD envelopes, which would further support an earlier epoch for envelope formation.

6 Summary

The morphological classification of BCM's, when augmented with quantitative surface photometry, leads to the conclusion that BCM's are special objects, beyond being mere extrapolations of the luminosity function. Morphology paved the way for an examination of these objects and has led to an interpretation of their properties within the context of dynamical evolution, mergers and cannibalism. When the structural information is combined with kinematics of the underlying galaxies, dynamics of cluster cores and color information about the component stellar populations, we are persuaded that the evolution of BCM's has two primary elements. The first is that the interior properties of BCM's are determined by a long history of hierarchical merging (i.e. the cannibalism of smaller cluster members). The "diffuseness" of BCM's and their enlarged characteristic radii are all signatures of past mergers. These conclusions define the class of D galaxies and are drawn from parameters that are independent of the cD envelopes found around some BCM's. The second process in the evolution of BCM's is the occurrence of cD envelopes, a feature in BCM's which is invisible to the eye and, thus, morphological classification. All evidence points to the origin of cD envelopes as primordial, before cluster collapse, at the same epoch of star formation that produced the populations in galaxies. Whether all galaxies had cD envelopes to be later stripped off by the cluster mean tidal field, or whether they developed from stripping other cluster members in local subgroups before cluster collapse, remains unknown.

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Discussion

BURSTEIN : Many of your E galaxy luminosity profiles show deviations from an $r^{1/4}$ law at faint surface brightnesses. Can you prove that such deviations *cannot* be due to sky subtraction? Sky subtraction is a problem we have to deal with at the 1-2% level in the data on E galaxies being taken for our own survey. It is a straightforward test to make.

SCHOMBERT : Of course I cannot *prove* that the deviations at faint surface photometry levels are indeed real. The behavior of elliptical profiles at the 27 to 28 mag arcsec^{-2} level is in the realm of 0.5% of sky brightness and are very sensitive to proper sky subtraction as you noted. However, there is a great deal of overlap in surface photometry in the literature; i.e. same galaxy from different telescopes and observers. A comparison shows that there is very good agreement down to 28 mag arcsec^{-2}. In other words, faint surface photometry is repeatable. I believe everyone in this field has be very careful and very honest about their techniques. The burden of proof here is for someone to show that there is a legitimate reason to believe that everyone has been systematically wrong in their sky subtraction.

SURMA : At Heidelberg Observatory we have performed a study of deep surface photometry of E's, where we also looked at the galaxies in Kormendy's 'tidal class' galaxy sample. What we have found is that the occurrence of so-called 'tidal halos' is *strongly* coupled with the problem of accurate sky subtraction. M. Cappaccioli has been emphasizing the importance of sky subtraction in order to reach the faint outer regions of E's, SO's and also cD's. It is evident that you need a sky subtraction accurate to $\ll$1% if you want to reach brightness levels of 24 mag arcsec^{-2}, and this is the region you need to reach in order to see cD envelopes! I wonder how much of the discussion about cD's is influenced by these problems.

SCH0MBERT : First, I strongly disagree with your statement that better than 1% sky is need to obtain the 24 arcsec^{-2} photometry level. A sky of 1% (in the Johnson V band) corresponds to 26 not 24 mag arcsec^{-2}. The exact shape of the outer halos of ellipticals is certainly open to debate and new work; however, CCD's have achieved 0.1% flattening, on average, for many years now. And many observers, with different telescopes and detectors, using different techniques and software, have time and time again proven the repeatability of faint surface photometry. I cannot accept the claim that everyone has performed their sky subtraction incorrectly for 20 years. cD envelopes have been known for 15 years and *cannot* be the result of sky errors.

KENT : D and gE galaxies have identically shaped profiles (i.e. $r^{1/4}$). Hence, they can only differ in the value of μ at r_e. Is your "diffuse" characteristic of D galaxies another way of saying that they have lower μ_e?

SCHOMBERT : No, D galaxies are noted by their shallower $r^{1/4}$ fits. This places them larger and brighter in the $\mu_e - r_e$ diagram (see Figure 6). I prefer to interpret this as enlarged r_e as predicted by N-body simulations.

BUTA : What are the three-dimensional shapes of cD's, particularly the envelopes?

SCHOMBERT : Alan Porter's thesis (Caltech 1988) addresses this problem more fully. His answer is that cD isophotes become more flattened with radius, presumably shifting from the galaxy potential to the cluster potential. However, it is an excellent future project, with the advent of reimaging cameras, to study the behavior of cD envelopes with respect to twisting and central shifts.

D JORGOVSKI : Two more bits of information come from Porter's thesis. First, BCM's show systematic ellipticity gradients, in the sense of becoming flatter outwards, whereas the normal ellipticals show no such trend. Second, the envelopes tend to be well aligned with the parent clusters (the Binggeli effect). To me, this also suggests that the origin of envelopes is at the epoch of cluster formation. The BCM galaxy and the cD envelope may be independent entities, sharing the same special location (i.e. the bottom of the cluster potential well).

KING : I didn't understand your argument that the extended envelopes must be primordial. Can you distinguish against the case of a merger of galaxies that already consisted only of old stars? In answering, please note that the merging process favors massive galaxies, which have colors like those of cD envelopes. Also, w'th regard to Djorgovski"s arguments about the alignment of cD envelopes with the major axis of their cluster, this could be simply due to the greater velocities of galaxies in this direction.

SCHOMBERT : If tidal stripping is the origin of cD envelopes, then a majority of their luminosity must be taken from low luminosity members of the cluster. The mass-metallicity relation predicts that this material will be bluer than the stellar population of the cD parent body. Although only a handful of cD envelopes have been studied by myself (in Johnson B and V plus a Stromgren narrow band system) all show very flat color profiles. The merging of bright ellipticals can maintain a red cD interior, but the outer envelope is going to be influenced by lower luminosity E's and, of course, any disk galaxies in the cluster. I agree that the elongation of the cD envelope could be due to the orbits of galaxies being stripped if that is the mechanism of formation. However, a more likely explanation is that the cD envelope is reflecting the shape of the cluster potential in which it was born which, if galaxies are on strongly radial orbits, is the same statement.

MELNICK : I disagree with your statement that there is no correlation between cluster parameters and cD envelopes. I see in your plots a rather strong correlation which, of course, eventually disappears if one eliminates critical data (such as the brightest envelopes). My question is, is there any physical or statistical arguments to eliminate the points that give a strong correlation?

SCHOMBERT : I agree that the extreme points in these diagrams are the "best" cD galaxies, but a simple correlation test gives only marginal significance. My statement is not that the correlations do not exist, but that they are surprising weak, and, therefore, have been partially erased during cluster collapse.

MERRITT : Is there any evidence that the presence of a cD galaxy correlates with the dynamical properties of a cluster, such as its velocity dispersion?

SCHOMBERT : A comparison of cD envelope properties with cluster dynamical properties (velocity dispersion, Bautz-Morgan type, etc...) is an exploration into the world of bad statistics. The correlations exist, but they are only marginally significant, strongly weighted by the very few brightest cD's. I argue that this merely reflects the early cluster state into the present epoch, and that cD envelopes are linked to the local conditions (i.e. its original subcluster) at birth as you predicted in 1955.

MERRITT : Does this fact argue for a primordial origin of the cD's, as well as for the diffuse envelopes?

SCHOMBERT : There is only a weak correlation between the underlying galaxy luminosity and the cD envelope luminosity. Therefore, I don't believe we can conclude that the merging that produced the parent galaxy was only primordial. In fact, bound populations exist today with dynamical friction timescales of only 5 $\times 10^9$ yrs, so the process of dynamical evolution must still be ongoing. My interpretation of the parent to envelope correlations is that parallel dynamical formation processes are being echoed from early epochs (i.e. mergers versus tidal stripping)

NIETO : Can you comment on the flat central profiles of BCM's? Are they intrinsically flat or is your material resolution limited?

SCHOMBERT : Due to the large variety of surface photometry for the sample; some from CCD's, others from large scale photographic plates, I cut the inner limit at 2 kpc and, therefore, can say very little on the core properties of BCM's.