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The Extended Profiles of Brightest Cluster Galaxies

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Abstract

We present preliminary results from our systematic program to quantify the structural properties of a sample of nearby brightest cluster galaxies (BCGs). This study is one of the first to measure BCG surface brightness profiles out to large radii ($r > 200 h^{-1}$kpc), placing limits on any radially symmetric component of intracluster light. Utilizing drift-scan data and new techniques we have developed for analyzing low surface brightness features, we are extending upon previous work by modelling the profiles down to $\mu_I \simeq 27.5$ mag arcsec^{-2} (5-σ) for a sample of 31 clusters $z \simeq 0.1$. In this proceeding we give an overview of our approach and present initial findings from this work.

1.1 Introduction

Brightest cluster galaxies (BCGs) are the largest, most luminous stellar systems in the universe. In the context of hierarchical structure formation, the prevailing view is that these galaxies are assembled relatively late (z<1) via the disruption and accretion of smaller cluster galaxies (e.g., see Dubinski 1998). It has been realized in recent years that quantitative measurements of the present day stellar populations and structural properties of these galaxies can be used to constrain their assembly history, and in the process elucidate the associated process of cluster formation.

With the current program we focus upon quantitative measurement of the structure of nearby BCGs on scales from 2-300 h^{-1} kpc. Starting with initial work by Matthews, Morgan, & Schmidt (1964), numerous groups have noted that some BCGs appear to have excess emission at large radii relative to a simple de Vaucouleurs ($r^{1/4}$) profile (Oemler 1973, 1976; Schombert 1986, 1988), possibly due to debris from tidally disrupted cluster members (Merritt 1984). The work of Schombert (1986, 1988) serves as the foundation for much of what is known about the extended profiles of BCGs, but recent studies of individual galaxies have highlighted the need for new systematic studies of the BCG population based upon CCD photometry rather than photographic data. These programs have largely failed to find distinct cD envelopes at large radii, reviving debate on the frequency of these envelopes (Uson et al. 1991; Scheick & Kuhn 1994; Gonzalez et al. 2000; Feldmeier et al. 2002).

The issue of the structure of this diffuse emission is timely because numerical simulations are just beginning to reach the stage of providing quantitative predictions for both the distribution and amount of diffuse emission in cluster cores (Willman et al., this meeting). The combination of improved numerical simulations, increased computational power, and new analysis techniques are yielding a renaissance of interest in the structural and stellar properties of BCGs at low surface brightness levels. Our program is one of three ongoing, largely complementary, studies of diffuse cluster emission; the other two are also described in this volume (Feldmeier et al. 2004; Krick et al. 2004).

With this program we plan to quantify the structure of a sample of 31 nearby BCGs ($0.05<z<0.13$), with the aim of providing a statistical sample for comparison with upcoming simulations. The specific goals of our program are (1) to determine the best parametric model for the profiles and the degree of variation among these galaxies, (2) to measure the basic structural parameters, (3) to quantify the amount of non-axisymmetric residual emission, and (4) to test for correlations between the observed structural parameters and global cluster properties. In this proceedings I outline our analysis procedure and discuss the first of these four goals.

1.2 Data and Procedure

For this study we obtained drift-scan imaging of a sample of 31 BCGs at $z = 0.05-0.13$ using the Great Circle Camera on the Swopes 1 m at Las Campanas Observatory. These galaxies reside in Abell, ACO, and APM clusters, which we chose to span a range of masses and dynamical states. We also define the redshift range of our sample to optimally match the detector field-of-view to the physical scale of these systems. Total exposure times are 600-900 seconds per target, with typical seeing of $1.5''$ and a plate scale of $0.7''$ per pixel.

The image reduction procedure is analogous to that described in Gonzalez et al. (2000). We remove flatness variations using an iterative procedure that yields residual variations of less that 0.1%. A low order polynomial fit is used to remove temporal sky variations in the drift scan data, and large-scale sky variations are modelled and subtracted using a wavelet decomposition. We also subtract saturated stars from the images to avoid contamination from light in the extended wings of the stellar PSF. Finally, we employ extensive masking of all objects other than the BCG to further minimize contamination of the BCG surface brightness profile.

To model the profiles we use GALFIT 1.6b (Peng et al. 2002), a two-dimensional galaxy fitting code capable of simultaneously fitting multiple components. We generate a unique stellar PSF for each image, which is input to GALFIT for convolution with the model profiles. The modelling is performed on a 300×300 pixel ($\sim300\times300h^{-1}$ kpc) square region centered on the galaxy. For each galaxy we test a suite of models, both fixing the sky level and allowing it to vary as a free parameter. The models tested include:

(1) A simple Sersic ($r^{1/n}$) model.

(2) A model with two de Vaucouleurs profiles.

(3) A model with an inner de Vaucouleurs and outer Sersic profile.

(4) A model with two Sersic profiles.

The motivation for testing different two-component models is simply to assess whether the Sersic index significantly alters the quality of the fit. Physically, the form of the profile at large radii may be expected to deviate from an $r^{1/4}$ law depending on the assembly history of the galaxy.

1.3 Results

Modelling is presently complete for roughly 50% of the sample, and all results are currently tentative. Nevertheless, several comments can be made based upon the preliminary data.

1.3.1 Form of the Profile

For a simple Sersic model we find that large Sersic indices (n) typically provide the best fits to the profiles, with a wide scatter in n between different galaxies. This result is similar to the work of Graham et al. (1996); however, with our greater radial baseline (by about a factor of 5) it is evident that a single Sersic profile is not the optimal parametric model for this class of galaxies.

Instead, we find several lines of evidence that strongly favor two-component parametric models. First, many BCGs are observed to have strong radial ellipticity gradients (e.g. Garilli et al. 1997). These gradients cannot be reproduced by a single component model, but can be naturally generated if the observed profile is modelled as a superposition of two components with different ellipticities. This is illustrated in Figure 1, which shows a two-component fit for the BCG in Abell 0122. Second, a direct comparison of χ^2 values for the Sersic and the two-component models strongly argues for the superiority of the two-component models. The double de Vaucouleurs model for example, which has 5 additional degrees of freedom, yields χ^2 values that on average are lower by $\Delta\chi^2 = 1300$.

Which of the two-component models is superior? Additional work is required before we can definitively answer this question, including generation of mock galaxies to quantify biases in the derived parameters. What can be said at the moment is that (1) the outer profile appears to be best modelled as a Sersic, and (2) the resolution of the data is likely insuffcent to warrant use of a Sersic rather than $r^{1/4}$ profile for the inner component. In roughly half of the sample the effective radius of the inner component is comparable to the FWHM of the point spread function, which precludes robust determination of n. Finally, we note that none of the galaxies analyzed thus far exhibit strong breaks in their profiles comparable to the canonical cD galaxies from Schombert (1986, 1988). We observe more gradual transitions (Figure 1).

1.3.2 Magnitudes

All of the two-component models yield consistent total magnitudes, independent of whether the sky level is held fixed or treated as a free parameter. The average absolute magnitude is $M_I = -24.2 \pm 0.5$. In subsequent work we hope to test whether the scatter in absolute magnitudes is correlated with cluster velocity dispersion. The fits for the individual components in these models typically imply that 80% of this luminosity is in the outer component; however, physical interpretation of the individual components is premature.

1.3.3 Effective Radii

For the two component models the inner components typically have effective radii between 1 and 20 h^{-1} kpc. The effective radii of the outer components span a larger range of 15-300h^{-1} kpc.

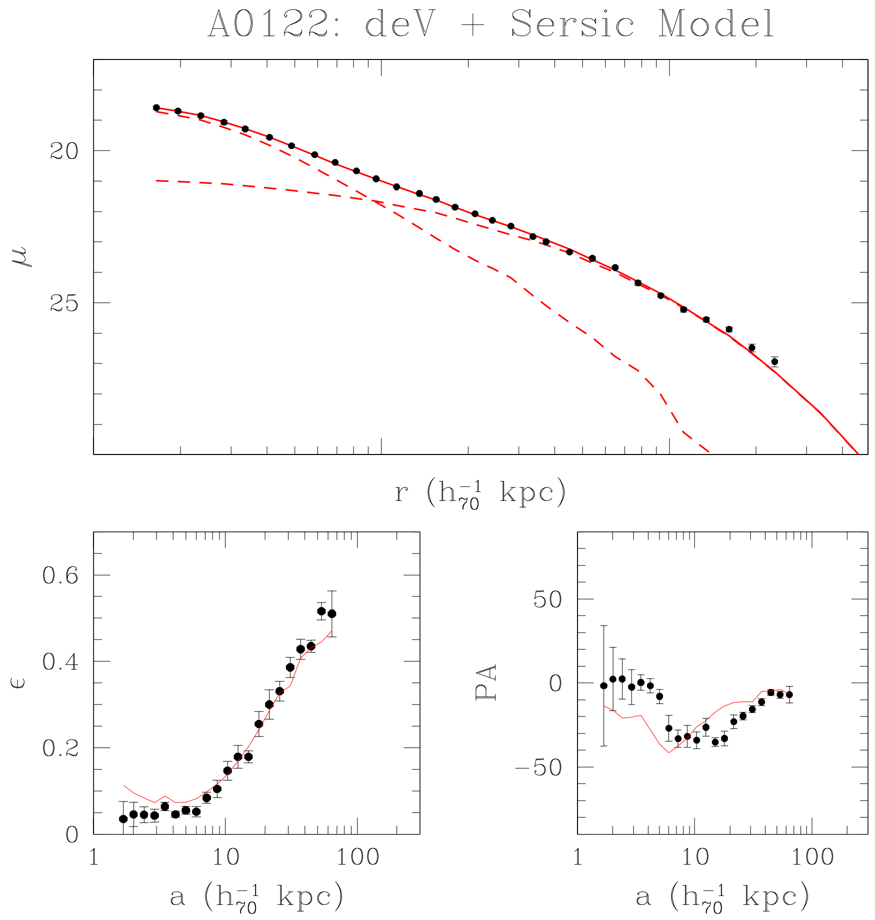

Fig. 1.1. The top panel shows the radially averaged surface brightness profile for the BCG in Abell 0122. The overlaid model consists of two components – an inner $r^{1/4}$ profile and an outer Sersic. The solid line corresponds to the composite model, while the dashed lines correspond to the inner components. This model is statistically a much better fit than the single Sersic ($\Delta\chi^2 = 3541$ for 6 additional degrees of freedom in the dimensional fit). The lower panels show the observed galaxy ellipticity and position angle as a function of radius, overlaid with the same model. The two-component model reproduces well the large ellipticity gradient observed in this galaxy, which is not possible with a single Sersic model.

1.3.4 Sersic Indices

With the current data our leverage on the inner components is limited. As mentioned above, robust Sersic indices cannot be derived for half of the galaxies because their effective radii are comparable to the seeing. Those with larger effective radii are on average consistent with a de Vaucouleurs profile.

The best fits for the outer components yield Sersic indices that on average are slightly steeper than a de Vaucouleurs model, $n \simeq 3.4 \pm 1$. This result, which contrasts sharply with the values obtained for a single Sersic model, is robust to the parameterization of the inner component. If the inner and outer components can indeed be interpreted as physically distinct entitites, then this result argues that each component independently has a form very similar to a normal elliptical galaxy.

1.4 Conclusions and Future Work

The program described in this proceedings is very much work in progress. When complete this project will yield the largest existing sample of BCGs with CCD surface brightness profiles extending to $r > 200h^{-1}$kpc. The most interesting thing to emphasize at this point is that two-component models provide *significantly* improved fits to the data compared to a single Sersic model. Interestingly, a comparison of the two indicates that the high values of n quoted for Sersic fits by previous authors are primarily due to a steepening of the profile within roughly the inner 10 h^{-1} kpc. When a second component is added to model this inner region, then the outer profiles are found to be well described by models with Sersic indices similar to those of typical ellipticals. A second interesting note from the work thus far is that the scatter in the total absolute magnitudes is rather small (0.5 mag). Metric magnitudes have in the past been shown by various authors to yield small scatter (e.g. Sandage 1972*ab*; Postman & Lauer 1995); however, it is not *a priori* obvious that the same should hold true for total magnitudes. We are conducting a complementary program to obtain velocity dispersions for these clusters, and it will be interesting to see whether part of the remaining dispersion arises from a correlation between BCG magnitude and cluster mass.

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