# The central stellar populations of brightest cluster galaxies

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**Abstract.** In this proceedings we investigate the central stellar populations of brightest cluster galaxies (BCGs), more specifically to determine whether the stellar populations can shed any light on the formation and evolution of these galaxies. The high signal-to-noise ratio, long-slit spectra of a sample of BCGs were fitted against the Pegase.HR and Vazdekis-Miles synthesis stellar population models of the *ULySS* software package. We use the full spectrum fitting abilities of *ULySS* and fit each spectrum against a single stellar population (SSP) and a composite stellar population (CSP). The CSPs generally consist of 2 or 3 SSPs, and can be divided according to their ages into young, intermediate and old components. Monte-Carlo simulations are used to assess the relevance of the solutions, and $\chi^2-$maps aid in the selection of the most probable star formation histories of the BCGs. We investigate whether any correlations can be found between the derived parameters and the internal properties of the galaxies and the properties of the host clusters, more specifically whether the presence of cooling flows (CFs) had any detectable influence on the stellar population components of the galaxies. We found an indication that the CF clusters, located closer to the centre of the clusters, housed galaxies consisting of populations with intermediate ages. The opposite was true for the CF clusters located further away from the cluster centre, more specifically the populations had older ages. The non–CF clusters, closer to the centre of the clusters contained galaxies consisting of intermediate and old ages. The non–CF clusters located further away from the centre contained galaxies consisting of populations with older ages. From the fact that both the CF and non–CF clusters experienced star formation epochs it follows that at least some of the star formation, but not all of the activities might be due to the presence of CFs.

## 1. Introduction

The centre of galaxy clusters contains rather unique, massive and luminous galaxies. The most luminous and massive of these early-type galaxies (ETGs) are called *brightest cluster galaxies* (BCGs) and are located very close to or at the centre of the clusters. BCGs have luminosities of $\sim 10L_\star$ with $L_\star = 1.0 \times 10^{10} h^2 L_\odot$ and a mass of $\sim 10^{13}\, M_\odot$ [1]. It was suggested by [2] that these BCGs are well-aligned with the host cluster galaxy distribution, which implies that the BCGs are located at the bottom of the cluster gravitational potential well. This indicates that the origin of BCGs are closely related to the formation of the host cluster because it is widely accepted that the stars have settled to the bottom of these potential wells. Initially it was thought that the special location of BCGs could be regarded as the cause for the properties that distinguished BCGs from ordinary galaxies [3] but it was later found that BCGs dominate the massive end of the galaxy luminous function [4], which in turn implies that the properties of these galaxies can be influenced by their large mass as well as by the environment of the host cluster. This further complicates the formation and evolution theories of BCGs [5]. It was proposed by [6] that the location of the BCGs at the bottom of these potential wells are responsible for the distinct properties of these galaxies, for example the high luminosities, the diffuse and extended structures of these galaxies. These properties in turn indicates that the formation and evolution of these galaxies are closely linked to that of their parent clusters, but the mechanisms behind these formations are still not fully understood.

The formation theories of BCGs is summarised by [2] as follows:

**Theory 1:** Star formation due to *cooling flows* (CFs) are expected to occur in the dense, cool centres of X–ray clusters [7]. These CFs present researchers with a plausible formation theory since clusters with CFs have extremely high luminosities and large central galaxies, but the connection between the cooling of the X–ray gas and the formation of the BCGs are still not clear. It was stated by [6] that BCGs are more frequently found in the centre of clusters containing CFs. This implies that if the density in the core of the clusters are high enough, then stars will form at the bottom of the gravitational well. The presence of blue cores and ultraviolet excess in some BCGs are taken as an indication of recent star formation [8, 9, 10, 4] but this is inconsistent with the fact that these galaxies have a red photometric color, which implies that BCGs contain old stellar populations.

**Theory 2:** A second theory is called *galactic cannibalism*, which is the accretion of existing galaxies through dynamical friction and tidal stripping. This theory was first proposed by [11] and developed by [12]. Through this process, a central galaxy is formed through the mergers/capturing of less massive objects [13]. [14] found that tidal stripping reduced the mass of the clusters to such a degree that the timescales over which the dynamical friction took place were too long to be considered a viable formation theory. The study conducted by [15] found that the stars in BCGs formed very early on in the formation of these galaxies. By using numerical simulations, [16] found that BCGs, contained in clusters with redshifts higher than $z \sim 1$ experienced a significant number of mergers. The nature of these mergers were dissipationless, therefore no new stars were formed during these mergers and the BCGs are expected to consist of old stellar populations.

**Theory 3:** [17] proposed another theory – primordial origin, also known as *galaxy merging*. This process took place in the early history of the formation of the cluster, as predicted by the hierarchical cosmological models. The failures of the galactic cannibalism theory pointed to the fact that BCGs must have had an earlier origin than that determined through the dynamical friction timescales. This meant that mergers could have taken place during the collapse of a cosmological hierarchy and therefore offered up another formation theory [2] i.e. that galaxies were formed through the merger of smaller objects that were dragged into the centres of the clusters by dynamical friction. A study conducted by [15] found that most of the stars in BCGs formed very early on in the star formation histories (SFHs) of the BCGs and that mergers took place in the final stages of the BCG evolution where nearly all the gas was converted into stars. Hence, these mergers were dissipationless and no significant star formation are expected to take place in the BCGs.

Studies regarding the SFHs of BCGs are further complicated due to several aspects:

(i) It is difficult to find progenitors of these ETGs by means of direct observations, which is a tough requirement to satisfy even with the current generation of telescopes because large amounts of observational time is needed [13].

(ii) The properties used in the analysis of the formation histories of these ETGs are effected by the high mass of these galaxies and also by the cluster environment [18].

It is for these reasons that researchers were forced to divert to other methods to obtain meaningful information about the SFHs of the BCGs, more specifically to study the SFHs of nearby galaxies by analysing the stellar populations of these galaxies in terms of their ages and metallicities ([Fe/H]).

Little is known about the properties of the stellar populations of BCGs [19]. A study was recently undertaken by [3] in which 625 brightest group and cluster galaxies was taken from the Sloan Digital Sky Survey; their stellar population properties were compared with those of elliptical galaxies with the same mass. This study can be regarded as a point of reference in the investigation of stellar populations in BCGs. However, this study did not include any spatial information about the BCGs. The merger history of a galaxy determines the kinematical and stellar population properties and these properties can be used in an analysis of the formation history of the galaxies.

In this proceedings we investigate whether any correlations can be found between the derived parameters and the internal properties of the galaxies and the properties of the host clusters, more specifically whether the presence of CFs have any detectable influence on the stellar population components of the galaxies.

## 2. Sample Selection and Observations

### *2.1. Sample*

The sample of galaxies analysed in this paper is based on the sample of BCGs analyzed by [20], where they initially selected cD galaxies (a special sub–class of BCGs) by using astronomical databases, for example the NASA/IPAC Extragalactic Database (NED)[1] and literature. For a more detailed description of the methods used in identifying these cD galaxies and for the BCG sample identification, refer to [20] and [13]. In summary, the sample consist of 41 galaxies where:

(i) [20] contained 31 BCGs, as classified by either NED (classified as cD galaxies in the morphological notes or in notes from previous observations) and/or have surface brightness profiles breaking the de Vaucouleurs law ($r^{\frac{1}{4}}$). In addition, NGC 4946 (an elliptical galaxy) was also observed with the same instrumental setup as the BCGs and included in the sample. Here it should be noted that only the galaxies, observed with the Gemini Telescopes (GTs) were included in the BCG sample studied in this proceeding.

(ii) [13] contained eight additional BCGs which were observed with the Gemini South Telescope during July 2007 to January 2008.

Here we note that we refer to the galaxies contained in the sample as the BCG sample.

### *2.2. Observations*

Please refer to [20] for the GT observation setup used to observe the galaxies in the BCG sample.

## 3. Method

High signal-to-noise ratio, long-slit spectra for the sample were obtained on the GTs. Out of this sample, 31 galaxies lacked emission line and ten galaxies showed the presence of weak emission lines (hereafter referred to as emission galaxies). The spectra of the emission galaxies were analysed with the GANDALF routine [21] to accurately separate the stellar and emission line contributions to the observed spectra.

The method followed for this data analysis, is the same as outlined in [22]. In summary: Each galaxy in the sample was fitted against the *ULySS* software which contains the Pegase.HR (P.HR) and Vazdekis-Miles synthesis stellar population models. The models were elaborated on by defining additional fitting parameters, i.e. the error spectra, velocity dispersions, redshifts, line spread functions and a wavelength of (3800, 6000) Å were chosen to include all the important spectral feature elements, for example $H_\beta$ and Fe5270. Each observed spectrum was fitted against a single stellar population (SSP) as well as composite stellar population (CSP). The CSP models were limited to three star formation epochs (refer back to [22] for more detail on why this was done). Monte-Carlo simulations were then used to assess the relevance of the solutions and thereby aided in the selection of the most probable SFHs of the respective BCGs. The $\chi^2$−statistical test assisted in choosing the most probable SSP model, more specifically whether the BCGs could be presented more accurately by a SSP or CSP model.

[1] `http://www.ipac.caltech.edu/`.

## 4. Results and Discussions

NGC 6173 was excluded from further analysis because the observed spectrum provided a visibly poor fit to the models. As previously determined in [22], the analysis indicated that the P.HR model gave the most accurate representation of the SFHs for the majority of the BCGs. The results obtained from this model showed that at least some of the galaxies in the sample underwent periods of recent star formation and could therefore be represented by CSPs. This in turn indicated that the BCGs had a more complex evolution than first thought.

The derived parameters were tested against the internal galaxy properties (the velocity dispersions and absolute K-band magnitudes) and the properties of the host cluster environment (the X–ray temperatures, luminosities, offsets and CFs) to determine whether any correlations could be derived to shed light on the formation and evolution of the BCGs. The internal galaxy and host cluster properties used in these comparison can be found in table 7 of [13]

In table 1 the clusters in the sample with CFs are given. The other clusters in the sample either did not have CFs or no indication in the literature could be found to suggest that CFs were present.

**Table 1.** The CFs contained in the BCG sample. Columns 1 and 2 give the names of the galaxies and host clusters in the sample which contained CFs while Column 4 gives the references to the literature from which this conclusion was derived.

| Object name | Cluster | Ref. |
|---|---|---|
| ESO349-010 | A4059 | [24, 6, 27] |
| ESO488-027 | A0548 | [28] |
| ESO541-013 | A0133 | [24, 26, 27, 28] |
| GSC555700266 | A1837 | [28] |
| IC1101 | A2029 | [24, 26, 27, 28] |
| IC5358 | A4038 | [24] |
| MCG-02-12-039 | A0496 | [6, 26, 28] |
| NGC 1399 | FORNAX-A | [28] |
| NGC 2832 | A0779 | [28] |
| NGC 3311 | A1060 | [24, 28] |
| NGC 6160 | A2197 | [25, 28] |
| PGC026269 | A0780 | [6] |
| PGC044257 | A1644 | [28] |
| PGC072804 | A2670 | [28] |

The young aged stellar populations were characterised by the ages $-2.0 < \mathrm{Log(Age)} < 0.0$, the intermediate aged stellar populations by $0.0 \leqslant \mathrm{Log(Age)} < 0.8$ and the old aged stellar populations by the ages $0.8 \leqslant \mathrm{Log(Age)} < 1.3$.

## 5. Conclusions

Several studies, i.e. [29, 4, 30] have proposed possible sources for the gas fuelling the star formation detected in some BCGs, for example: (i) CFs, (ii) the re-use of matter ejected in stellar ejections and (iii) the accretion of other stellar matter i.e satellites. It has long since puzzled astronomers as to whether there existed a connection between the presence of these CFs and the star formation epochs in these BCGs.

From this analysis it followed that 14 clusters in a sample of 40 contained CFs. Ten of these CFs were hosted in clusters which had galaxies which could accurately be represented by 1 SSP and were comprised of intermediate stellar populations (ISPs). The remaining four CFs were hosted in clusters

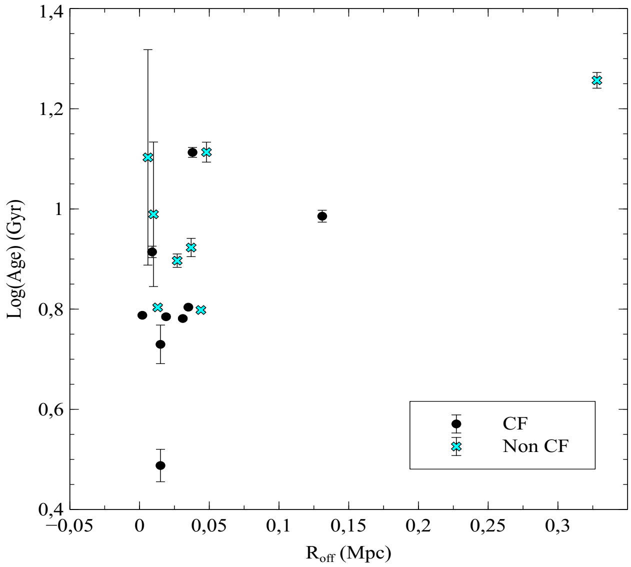


**Figure 1.** Age versus the X–ray offset for the CF and non–CF clusters which had BCGs for which the SFH could accurately be represented by 1 SSP.

which had galaxies which were accurately represented by 2 SSPs and comprised out of ISPs and old stellar populations. The fact that the majority of the CF clusters contained intermediate or young BCGs, indicated that a possible connection might exist between the presence of the CFs and recent star formation periods.

No clear correlations could be derived between the ages and [Fe/H] of the 1 and 2 SSP cases and the velocity dispersions of the BCGs and the host clusters and also for the absolute K–band magnitudes of the galaxies. This was also true for the X–ray luminosities and the temperatures.

The galaxies in CF clusters were located at higher X–ray luminosities than the galaxies in non–CF clusters. [30] found that very luminous systems harbored very massive CFs and contributed more than 70% of the cluster's bolometric luminosity.

As shown in figure 1, a correlation between the ages of the 1 SSP galaxies and the offset between the BCG and the X–ray peak could be detected. This followed due to the fact that the CF clusters, located closer to the centres of the clusters, contained galaxies consisting of populations with intermediate ages, while the opposite was true for the CF clusters located further away from the centres; these clusters contained galaxies consisting of populations with older ages. When analysing the non–CF clusters it followed that the clusters located closer to the centre of the clusters, contained galaxies consisting of populations with intermediate and old ages. The galaxies in the non–CF clusters, located further away from the centre, were comprised out of populations with older ages. The fact that both the CF and non–CF clusters experienced star formation epochs gave an indication that not all the star formation activities in these clusters might be explained due to the presence of CFs. [20] suggested that the gas fuelling the star formation activity in these galaxies had to originate from mergers because the merging/capturing of less massive galaxies are enhanced due to the unique location of the BCGs in the cluster potential well.

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## References


[1] Katayama H, Hayashida K I, Takahara F and Fujita Y 2003 *Astrophys. J.* **585** 687–93
[2] Dubinski J 1998 *Astrophys. J.* **502** 141–9
[3] Von der Linden A, Best P N, Kauffmann G and White S D M 2007 *Mon. Not. R. Astron. Soc.* **379** 867–93
[4] Liu F S, Mao S and Meng X M 2012 *Mon. Not. R. Astron. Soc.* in press
[5] Brough S, Proctor R, Forbes D A, Couch W J, Collins C A, Burke D J and Mann R G 2007 *Mon. Not. R. Astron. Soc.* **378** 1507–30
[6] Edwards L O V, Hudson M J, Balogh M L and Smith R J 2007 *Mon. Not. R. Astron. Soc.* **379** 100–10
[7] Fabian A C 1994 *Annu. Rev. Astron. Astrophys.* **32** 277–318
[8] Bildfell C, Hoekstra H, Babul A and Mahdavi A 2008 *Mon. Not. R. Astron. Soc.* **389** 1637–54
[9] Crawford C S, Allen S W, Ebeling H, Edge A C and Fabian A C 1999 *Mon. Not. R. Astron. Soc.* **306** 857–96
[10] McNamara B R, Rafferty D A, Bîrzan L, Steiner J, Wise M W, Nulsen P E J, Carilli C L, Ryan R and Sharma M 2006 *Astrophys. J.* **648** 164–75
[11] Ostriker J P and Tremaine S D 1975 *Astrophys. J.* **202** L113–7
[12] Ostriker J P and Hausman M A 1977 *Astrophys. J.* **21** L125–9
[13] Loubser S I, Sánchez-Blázquez P, Sansom A E and Soechting I K 2009 *Mon. Not. R. Astron. Soc.* **398** 133–56
[14] Merritt D 1985 *Astrophys. J.* **289** 18–32
[15] De Lucia G and Blaizot J 2007 *Mon. Not. R. Astron. Soc.* **375** 2–14
[16] Gao L, Loeb A, Peebles P J E, White S D M and Jenkins A 2004 *Astrophys. J.* **614** 17–25
[17] Merritt D 1983 *Astrophys. J.* **264** 24–48
[18] Barrena R, Girardi M, Boschin W and Mardirossian F 2012 *Astron. Astrophys.* in press
[19] Loubser S I 2009 PhD thesis Univ. Central Lancashire
[20] Loubser S I, Sánchez-Blázquez P, Sansom A E, Soechting I K and Bromage G E 2008 *Mon. Not. R. Astron. Soc.* **391** 1009–28
[21] Sarzi M, Falcón-Barroso J, Davies R L, Bacon R, Bureau M, Cappellari M, de Zeeuw P T, Emsellem E, Fathi K, Krajnović D, Kuntschner H, McDermid R M and Peletier R F 2006 *Mon. Not. R. Astron. Soc.* **366** 1151–200
[22] Viljoen D N and Loubser S I 2011 Brightest Cluster Galaxies Simple or composite stellar populations? *Proc. J. Phys.: Conf. Series* (University of South Africa, Pretoria, 2011)
[23] Du W, Luo A L, Prugniel Ph, Liang Y C and Zhao Y H 2010 *Mon. Not. R. Astron. Soc.* **409** 567–81
[24] Chen Y, Reiprich T H, Bohringer H, Ikebe Y and Zhang Y Y 2007 *Astron. Astrophys.* **466** 805–12
[25] Giovannini G, Liuzzo E and Giroletti M 2008 *Proc. Approaching Micro–Arcsecond Resolution with VSOP–2: Astrophysics and Technology* ed Y Hagiwara et al.
[26] McCarthy I G, Balogh M L, Babul A, Poole G B and Horner D J 2004 *Astrophys. J.* **613** 811–30
[27] Rafferty D A, McNamara B R, Nulsen P E J and Wise M W 2006 *Astrophys. J.* **652** 216–31
[28] White D A, Jones C and Forman W 1997 *Mon. Not. R. Astron. Soc.* **292** 419
[29] Edge A C, Stewart G C and Fabian A C 1992 *Mon. Not. R. Astron. Soc.* **258** 177–88
[30] Peres C B, Fabian A C, Edge A C, Allen S W, Johnstone R M and White D A 1998 *Mon. Not. R. Astron. Soc.* **298** 416–32