Brightest cluster galaxies – single or composite stellar populations?

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Abstract. High signal-to-noise ratio, longslit spectra for a sample of 49 *brightest cluster galaxies* (BCGs) and 2 elliptical galaxies were observed on the WHT and Gemini North and South telescopes during an extensive observational campaign from July 2006 to January 2008.

In this paper we study the stellar populations of these galaxies by fitting their spectra using the software package *ULySS* which has the advantage of full spectral fitting as opposed to fitting specific parts of the spectrum (so called indices) as used up to now. Each galaxy was fitted against a single stellar population (SSP) and two- and three-component (2 and 3 SSPs) models, separately. For the 2 and 3 SSPs fits, the stellar components of the galaxies are divided into groups by ages: a young, intermediate and old component. Each of these SSP components are characterised by their ages and metallicities. A series of 500 Monte-Carlo simulations are then preformed, checking the residual of the fits and assessing the relevance of the solutions, aiding the selection of the most probable star formation histories (SFH) of the BCGs. After this, the χ^2-maps are drawn to assist in understanding the structure of the parameter space. During the fits, two stellar population models, Pegase HR and the Vazdekis-Miles models are used as independent stellar population models.

We find that the stellar population model, Pegase HR represents the SFH of these BCGs more accurately. The Pegase HR model determined that the most significant fit is given by a composite stellar population for some BCGs, indicating that these BCGs have a more complex evolution and formation as first thought.

1. Introduction

Central galaxies in clusters are some of the most massive ellipticals galaxies in the Universe. These galaxies are considered to be unique because they are extremely luminous, diffuse, and have extended structures.

Fabian (1994) [2] defines *brightest cluster galaxies* (BCGs) as strictly the most massive and luminous galaxy in a cluster. However recent literature, for example Loubser (2009) [6], gives a more involved definition which describes these BCGs as central dominant galaxies in clusters, with a typical mass of $\sim 10^{13} M_{\odot}$ (Katayama et al., 2003) [3]. It was suggested by [2] that these BCGs are well aligned with the host cluster galaxy distribution, which consequently implies that these BCGs are located at the bottom of the gravitational potential well. This in turn implies that the origin of the 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 this potential well.

Some BCGs are also called cD galaxies, which indicate that they have an extended stellar halo. This subclass of BCGs are the most luminous, and contain the largest stellar mass of any of the galaxies. They are significantly brighter than $L \sim 10^{10}L_{\odot}$ (Sparke and Gallagher, 2007) [10] and these galaxies are almost always the brightest galaxies in the clusters. The unique and distinctive properties of BCGs create a challenge for astronomers studying galaxy formation.

To study galaxy formation and evolution, we have to study the formation and evolution of the stars these galaxies consist of. The theory of stellar evolution is concerned with the physical and chemical properties of stars and their development with time. Studies done on the evolution of stars play a crucial role in our understanding of the mechanisms responsible for the evolution of the matter created during the Big Bang. As indicated by Burbidge et al. (1957) [1], some of the elements, heavier than helium, are produced in stars and injected into the interstellar medium by the various mass loss processes and explosions. New generations of stars are formed out of this chemically enriched matter and this cycle continues until interstellar gas is available to form these new stars. The stellar evolution theory is therefore paramount in understanding the chemical composition of the present Universe and how it evolved since the Big Bang. Stellar populations can be analysed to provide important information about the age and chemical composition of galaxies, thus providing us with knowledge about their formation and evolution. In this project stellar populations are investigated and used to learn more about the age, metallicity and consequently the formation and star formation histories (SFH) of BCGs.

The question arises whether the SFH of BCGs can accurately be represented by single stellar population (SSP) models, as is widely assumed, or whether a composite stellar population (CSP) model is needed. SSPs describe the most elementary populations of stars consisting of stars or objects born at the same time in a burst of star formation activity, which evolved passively and where the objects all have the same initial chemical composition (Salaris and Cassisi, 2005) [8]. On the other hand, a CSP is defined by [8], as a group of stars formed at different times due to several star formation periods and with different initial chemical compositions.

2. Method

The high signal-to-noise ratio, longslit spectra for a sample of 49 BCGs and 2 elliptical galaxies were observed on the WHT and Gemini North and South telescopes during an extensive observational campaign from July 2006 to January 2008 (Loubser et al., 2008) [7]. Out of this sample, 38 galaxies contained no emission lines, while the remaining 13 galaxies contained emission lines. The spectra of the galaxies with emission lines were analysed with the software package *GANDALF* (Sarzi et al., 2006) [9]. The latter software package accurately separates the stellar and emission line contributions to the observed spectra.

2.1. ULySS - Université de Lyon Spectroscopic analysis Software

The software package *ULySS*[1] described by Koleva et al. (2009) [4] is used in this study. *ULySS* has the advantage of full spectral fitting as opposed to fitting specific parts of the spectrum (so called indices) as used up to now. This software can be used to determine the (i) stellar atmospheric parameters and (ii) star formation and metal enriched history of galaxies. This software can be used to fit SSPs or CSPs.

ULySS fits an observed spectrum against a linear combination of non-linear model components convolved with a instrumental line-of-sight velocity dispersion and multiplied by a polynomial function. The polynomial absorbs the errors in the flux calibration, galactic

[1] *ULySS* is available at `http://ulyss.univ-lyon1.fr` [4].

extinction or any other causes affecting the shape of the spectrum [4]. The advantages of the software package, as stated in Koleva et al. (2010) [5], are that:

- All the pixels are used (weighted by their inverse squared estimated errors).
- All the parameters are simultaneously minimized to give an optimal solution despite degeneracies.

Studies conducted on stellar population synthesis models concluded that the Pegase HR, with the Elodie 3.1 stellar library, and Vazdekis-Miles stellar population models are trustworthy and consistent (see [4], and references there in). These two models were used in this analysis and expanded further by defining additional input parameters, for example the instrumental line-of-sight velocity broadening, the velocity dispersion, the error spectra, redshift and wavelength range of the galaxy being analyzed. The χ^2-statistical test assisted in choosing the most probable fit, more specifically whether the BCG can be presented more accurately by a SSP or CSP. These stellar population components are characterised by their ages and metallicities ([Fe/H]). A series of 500 Monte-Carlo simulations are then preformed, checking the residual of the fits and assessing the relevance of the solutions, aiding the selection of the most probable SFH of the BCGs. After this, the χ^2-maps are drawn to assist in understanding the structure of the parameter space.

3. Results and Discussions

The spectra of each BCG was fitted against each of these models, in addition fitting a SSP and CSP for each of these BCGs. The χ^2-value was then used to determine if the SSP or CSP provided the best fit for each BCG for each of these models. These result are summarized in Table 1 and 2.

Table 1. Stellar populations of BCGs determined by the Pegase HR model.

Components	Gemini No emission	Gemini Emission	WHT No emission	WHT Emission
1 SSP	42%	80%	29%	67%
2 SSP	29%	10%	43%	—
3 SSP	29%	10%	29%	33%

From Table 1 it follows that the results for the BCGs without emission lines are more significant for the composite populations as indicated by the higher combined percentages for the two and three components than for the 1 SSP. On the other hand, the results for the BCGs with emission lines are more significant for the single stellar population.

Table 2. Stellar populations of BCGs determined by the Vazdekis-Miles model.

Components	Gemini No emission	Gemini Emission	WHT No emission	WHT Emission
1 SSP	35%	60%	57%	67%
2 SSP	42%	—	43%	—
3 SSP	23%	40%	—	33%

From Table 2 it follows that the results for the BCGs without emission lines, as observed by Gemini, are more significant for the composite populations as indicated by the higher combined percentages for the two and three components than for the 1 SSP. On the other hand, the results for the BCGs with emission lines, as observed by Gemini and WHT, are more significant for the single stellar population. The results for the BCGs without emission lines, as observed by WHT, are more significant for the single stellar population.

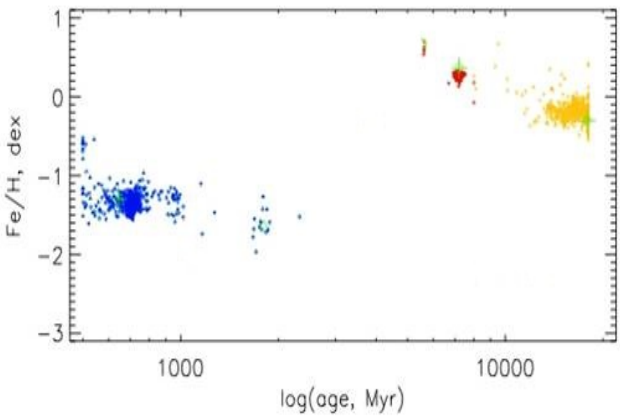

Figure 1. Stellar populations of NGC6160 as determined by the Pegase HR model. The yellow dots indicate the old component, the red dots the intermediate component while the blue dots indicate the young component. The local minima (best fits) are indicated by the green +.

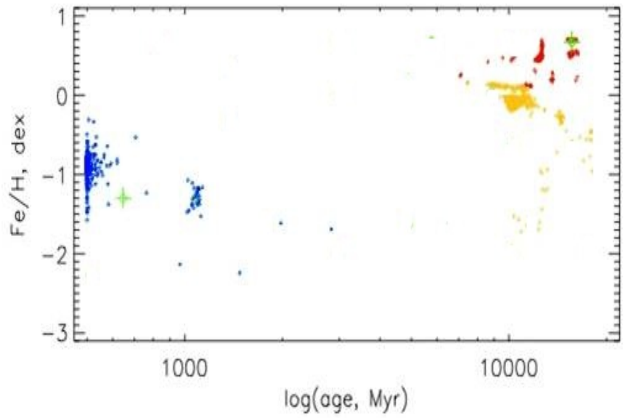

Figure 2. Stellar populations of NGC6160 as determined by the Vazdekis-Miles model. The yellow dots indicate the old component, the red dots the intermediate component while the blue dots indicate the young component. The local minima (best fits) are indicated by the green +.

Figure 1 and 2 show the solutions obtained by the Pegase HR and Vazdekis-Miles models for NGC6160. By comparing the two figures, it follows that the results are more significant for three components which indicate that this BCG is most likely comprised out of composite populations. The CSP fit, determined by the Pegase HR model is the most accurate representation of the SFH of this BCG because the χ^2-value (indicated by the green cross) of each component converges with the spread of the three components. This is not the case in Figure 2.

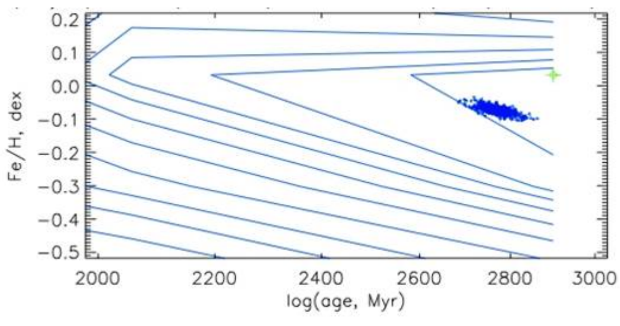

Figure 3. Stellar population of PGC026269 as determined by the Pegase HR model. The local minima is indicated by the green +.

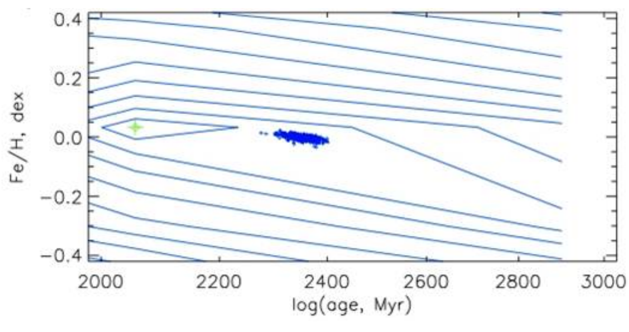

Figure 4. Stellar population of PGC026269 as determined by the Vazdekis-Miles model. The local minima is indicated by the green +.

Figure 3 and 4 show the solutions obtained by the Pegase HR and Vazdekis-Miles models for PGC026269. It is clear from the figures that the results are more significant for one component. By comparing Figure 3 and 4, the results are represented more accurately by the Pegase HR model because the χ^2-value (indicated by the green cross) and the spread of the component are located in the same contour line (indicated by the blue line). Once again this is not the case for Figure 4.

Table 3. The mean ages of each stellar population (in Gyr) as determined by Pegase HR for the BCGs observed by the Gemini and WHT telescopes.

	Component	Gemini No emission	Gemini Emission	WHT No emission	WHT Emission
1 SSP		9.46 ± 0.10	6.10 ± 0.07	5.85 ± 0.09	3.89 ± 0.04
2 SSP	First	4.90 ± 1.70	5.37 ± 0.50	3.48 ± 0.25	—
	Second	15.98 ± 0.48	13.70 ± 0.71	9.20 ± 1.15	—
3 SSP	First	0.56 ± 0.15	1.08 ± 0.55	0.61 ± 0.22	0.23 ± 0.17
	Second	8.25 ± 0.48	5.10 ± 0.25	7.59 ± 0.67	13.48 ± 1.62
	Third	17.59 ± 0.52	14.55 ± 3.17	15.00 ± 2.10	19.47 ± 0.48

Table 3 summarizes the mean ages, in Gyr, for each stellar population of the BCGs as determined by the Pegase HR stellar population model. Only the results obtained by the Pegase HR model is shown here because the results for the stellar populations are more accurately represented by this model (see discussion of Figure 1 to 4).

We point out a few interesting points:

- For the Gemini BCGs, without emission lines, the 2 SSP contains an intermediate and old component while the 3 SSP has a young, intermediate and old component.
- For the Gemini BCGs, with emission lines, the 2 SSP contains an intermediate and old component while the 3 SSP contains a young, intermediate and old component.
- For the WHT BCGs, without emission lines, the 2 SSP contains two intermediate components while the 3 SSP has a young, intermediate and old component.
- For the WHT BCGs, with emission lines, there are no galaxies where 2 SSP components provided the best fit. The 3 SSP contains a young and two old components.

4. Conclussions

Between the two models which were tested, the Pegase HR stellar population model gave the best representation of the SFH of the BCGs sample. An example is shown in Figure 1 and 3 where the local minima (indicated by green +) converges with the spread of the components. Hence only the results of this particular model will be interpreted in further analysis.

The stellar population model, Pegase HR, determined that the most significant fit is given by a CSP for most BCGs, indicating that these BCGs have a more complex evolution and formation as first thought.

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