Star Clusters: From the Milky Way to the Early Universe
Proceedings IAU Symposium No. 351, 2019
A. Bragaglia, M. Davies, A. Sills & E. Vesperini, eds.

doi:10.1017/S1743921319007191

What do globular clusters tell us about isolated ellipticals? The case of NGC 6411

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Abstract. We summarize the results from a study of the globular cluster (GC) system of the isolated elliptical galaxy NGC 6411, based on Gemini/GMOS g', r', i' photometry. The extent of the globular cluster system is about 70 kpc. It contains ≈ 700 members. The colour distribution and luminosity function are typical of old GC systems. An excess of bright GCs with intermediate colours might evidence an intermediate-age merger.

Keywords. galaxies: elliptical and lenticular; cD – galaxies: evolution – galaxies: star clusters: individual: NGC 6411

1. Introduction

Merging processes are thought to be the main source of mass accretion since $z \approx 2$ (e.g., van Dokkum *et al.* 2010). Due to the low density environment they inhabit, isolated ellipticals (iEs) might have experienced less mergers, evolving more quietly. They often present underlying features typical of late mergers, like shells or plumes (e.g. Tal *et al.* 2009; Bassino & Caso 2017). Both observational and numerical studies indicate that iEs have experienced late mergers in larger proportion than Es in clusters, presenting bluer colours and lighter dark matter haloes (e.g., Niemi *et al.* 2010, Lacerna *et al.* 2016, Richtler *et al.* 2015). Hence, their study might reveal important clues about the evolution of galaxies. Globular clusters (GCs) are formed under environmental conditions achieved during massive star formation episodes (e.g., Kruijssen 2014), driven by galaxy mergers and interactions. This fact implies a direct connection between the formation of GC systems (GCSs) and the evolution of their host galaxy.

NGC 6411 is a moderately bright galaxy ($M_V = -21.6$) with an estimated distance of 40 Mpc based on surface-brightness fluctuations (SBF, Blakeslee *et al.* 2001). It hosted a subluminous SNIa (Filippenko 1999). Spectroscopic analysis from the CALIFA survey indicates that the luminosity in the inner region of NGC 6411 is dominated by an intermediate-age and metal rich population, with $\log(Z/Z_\odot) = 0.28$ and ≈3.5 Gyr (González Delgado *et al.* 2015).

This contribution summarizes part of the results given in Caso *et al.* (2019a).

2. Observations and reduction

The data set consists of a field observed with the GMOS camera at Gemini North, containing the galaxy (hereafter, N6411F), plus science verification observations from the Gemini Observatory Archive (hereafter, CompF). The GMOS field of view (FOV)

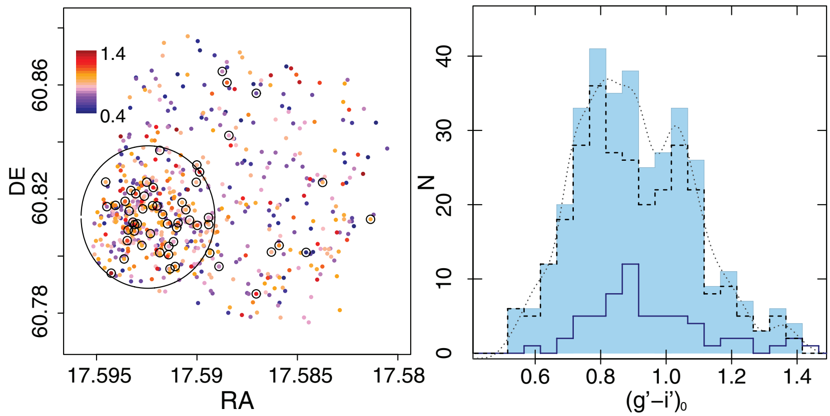

Figure 1. Left panel: Projected spatial distribution of the GC candidates, with the colour bar representing their $(g'-i')_0$ colour. The highlighted objects correspond to those GC candidates brighter than $i'_0 = 24$ mag. North is up, East to the left. **Right panel:** Colour distribution of the entire sample of GC candidates (filled histogram and dotted curve), and split into GCs fainter than $i'_0 = 24$ mag (dashed line histogram) and brighter than this limit (solid line histogram).

is 5.5×5.5 arcmin^2 (1 arcmin$\approx$12 kpc at the assumed distance). Both programmes were observed in g', r' and i' filters with similar exposure times.

The reduction was carried out in the usual manner with the tasks from the GEMINI-GMOS package, within IRAF. The galaxy light was subtracted from the images of the N6411F, using a square median filter. The software SExtractor (Bertin & Arnouts 1996) was applied to the i' images of both fields, to generate an initial source catalogue. Then, the PSF photometry was performed with the DAOPHOT package within IRAF. The definite selection of point sources was based on the χ^2 and sharpness parameters from the task ALLSTAR.

The GC candidates were selected from colour-colour diagrams, assuming similar colour ranges than previous GCs studies (e.g. Faifer *et al.* 2011; Bassino & Caso 2017). From the completeness analysis based on artificial stars, the magnitude limit for both fields was determined as $i'_0 = 26$ mag. For further details on the reduction and selection criteria we refer to Caso *et al.* (2019a).

3. Results

The left panel of Figure 1 shows the projected spatial distribution of the GC candidates in the field N6411F. The colour bar spans the usual $(g'-i')_0$ colour range for old GCs. The large circle is centred in NGC 6411 and its radius is 90 arcsec. The highlighted objects represent GC candidates brighter than $i'_0 = 24$ mag, which are strongly concentrated towards the galaxy. Kolmogorov-Smirnov and proportion tests indicate that the spatial distribution of these bright GC candidates differ from those of both, blue and red subpopulations (see next paragraph).

The filled histogram on the right panel of Figure 1 represents the colour distribution of the entire sample of GC candidates, with the dotted curve indicating its smoothed distribution using a Gaussian kernel. In both cases the colour distribution seems to be bimodal, a usual scenario in bright elliptical galaxies (e.g., Caso *et al.* 2017). The analysis with the software GMM (Muratov & Gnedin 2010) indicates that the colour distribution is better represented by two Gaussians instead of one, with means $(g'-i')_{0,blue} \approx 0.81$

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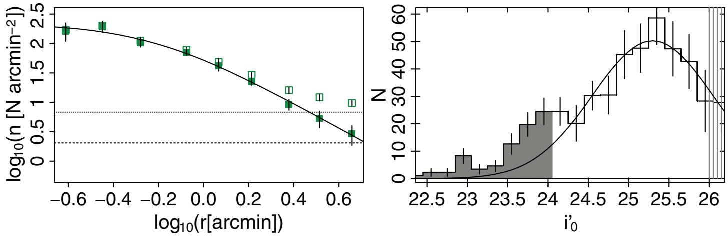

Figure 2. Left panel: radial distribution for the GC candidates, completeness corrected (open symbols), and completeness and contamination corrected (filled symbols). The solid curve represents a modified Hubble profile fitted to the data. The horizontal dotted and dashed lines correspond to the contamination level and its 30%, respectively. **Right panel:** luminosity function of the GCs, completeness and contamination corrected. The solid curve represents the Gaussian profile fitted to GCs fainter than $i'_0 = 24.25$ mag.

and $(g'-i')_{0,red} \approx 1.04$, and a fraction of red GCs ≈0.4. We chose $(g'-i')_0 = 0.95$ as the colour limit to separate both subpopulations. The dashed line histogram shows the colour distribution for GCs fainter than $i'_0 = 24$ mag, with candidates brighter than this limit represented by the solid line histogram. In this latter case the colour distribution lacks signs of bimodality, presenting a single peak in intermediate colours.

The left panel of Figure 2 shows the radial distribution for GC candidates, open (filled) symbols represent the distribution corrected by completeness (completeness and contamination). Concentric elliptical rings were used, assuming the ellipticity and position angle of the galaxy (see Caso *et al.* 2019a). The horizontal dotted and dashed lines correspond to the contamination level and its 30%. This latter value has been used in wide field studies of GCSs to determine their extension (e.g., Bassino *et al.* 2006; Caso *et al.* 2017). A modified Hubble profile was fitted to the distribution and corresponds to the solid curve. The extension of the GCS seems to be ≈70 kpc, considering the previously indicated distance. The extension of the GCS and the exponent of the Hubble profile are in agreement with the expected values for ellipticals with similar stellar mass and GCS population (Caso *et al.* 2019b).

The right panel shows the GC luminosity function (GCLF), completeness and contamination corrected. The grey vertical lines indicate the magnitude range excluded due to the decreasing completeness. The solid curve corresponds to the Gaussian profile fitted to the GCLF for magnitudes fainter than $i'_0 = 24.25$ mag. Considering that old GC populations present a Gaussian GCLF with a nearly universal TOM (e.g. Richtler 2003), the resulting distance modulus from the TOM derived for NGC 6411 is in agreement with SBF measurements (Blakeslee *et al.* 2001), which points to an old GCS. Candidates brighter than $i'_0 = 24$ mag (filled bins) are more numerous than expected, resulting in a GCLF that seems to deviate from the usual behaviour for old GCSs at the bright end. In order to test this latter point, we generated 1000 random samples of GC candidates from a Gaussian profile with the parameters fitted to the GCLF. In any of the cases were obtained ≈40 objects brighter than $i'_0 = 24$ mag which is the number of bright GC candidates at less than 90 arcsec from the galaxy centre.

From the numerical integration of the radial profile and the GCLF, the total population of GCs results ≈700, corresponding to a specific frequency of $S_N \approx 1.7$. This is a rather poor GCS in comparison with bright ellipticals in denser environments, and particularly for the red subpopulation (see Figure 3), which is in agreement with GCS studies of isolated ellipticals (Salinas *et al.* 2015 and references therein).

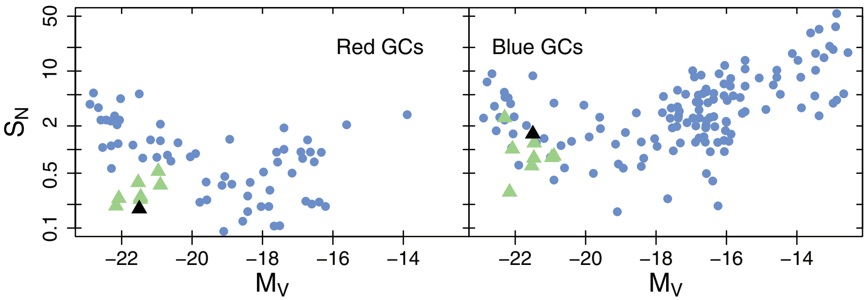

Figure 3. Left panel: specific frequency of GC red subpopulations from a compilation of GCSs in early-type galaxies (Caso 2015). The green triangles represent isolated ellipticals, and the black one highlights the position of NGC 6411. **Right panel:** idem for the blue subpopulation.

4. Summary

We summarize the results presented in this contribution.

• We determined the projected radial profile of the GCS and its size. Results are in agreement with literature compilations. The total population is ≈700 GCs.

• The colour distribution presents evidence of bimodality, except for the brighter GCs. The fraction of red GCs does not differ from those found in bright ellipticals.

• The TOM of the GCLF is in agreement with SBF measurements, a Gaussian profile accurately represents the GCLF for GCs fainter than $i'_0 = 24$ mag. These findings and the bimodality in the colour distribution characterise an old GCS.

• We detect an excess of GCs brighter than $i'_0 = 24$ mag, with intermediate colours and strongly concentrated towards the galaxy.

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