



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

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Resumen / Esta contribución resume el estudio fotométrico de la galaxia elíptica aislada NGC 6411 y su sistema de cúmulos globulares (CGs). Nuestros resultados indican que la galaxia presenta un sistema de CGs pobre, con evidencias de bimodalidad en su distribución de color y una extensión aproximada de 65 kpc. Se ha detectado un exceso de CGs brillantes, fuertemente concentrados hacia la galaxia y de colores intermedios, lo cual podría indicar que NGC 6411 ha experimentado una fusión de edad intermedia.

Abstract / This contribution summarizes a photometric study of the isolated elliptical NGC 6411 and its globular cluster (GC) system. The results point to a poor GC system, with evidence of bimodality and an extension of about 65 kpc. An excess of bright GCs with intermediate colours and strongly concentrated towards the galaxy has been found, suggesting that NGC 6411 experienced an intermediate-age merger.

Keywords / galaxies: elliptical and lenticular, cD – evolution – 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 extremely low density environment they inhabit, isolated ellipticals (iEs) might have experienced less mergers, evolving more quietly. Both observational and numerical studies indicate that they have experienced a larger proportion of late mergers 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 may reveal important clues about the evolution of galaxies. Globular clusters (GCs) formed under environmental conditions achieved during massive star formation episodes (Kruijssen, 2014), driven by galaxy mergers and interactions. This fact implies a direct connection between the formation of GC systems (GCS) and the evolution of their host galaxies.

We present preliminary results of the study of the GCS of the iE NGC 6411. It is a moderately bright galaxy with an estimated distance of 40 Mpc based on surface-brightness fluctuations (SBF Blakeslee et al., 2001). It hosted a Ia supernova (SN 1999da Filippenko, 1999), and spectroscopic analysis reveals that the luminosity in its inner region is dominated by a young and metal-rich population (González Delgado et al., 2015).

2. Observations and data reduction

The data set consists of a field observed with the GMOS camera at Gemini North (programme GN-2015A-Q-70, PI: L.P. Bassino), containing the galaxy, plus science verification observations (programme GN-2001B-SV-67) from the Gemini Observatory Archive (hereafter, CompF). The GMOS field of view is $\approx 5.5 \times 5.5$ arcmin². Both programmes were observed in g' , r' and i' filters with similar exposure times.

The data reduction was carried out with the tasks from the GEMINI-GMOS package, within IRAF. Afterwards, the galaxy light of NGC 6411 was subtracted in order to improve point source detection. Because GCs usually present effective radii smaller than $R_{\text{eff}} = 10$ pc (Brüns & Kroupa, 2012), they should be detected as point sources at the distance of NGC 6411. Hence, the software SExtractor (Bertin & Arnouts, 1996) was used to generate a source catalog of point sources. Then, PSF photometry was carried out with the DAOPHOT package within IRAF.

In order to calculate the photometric completeness, we added in the three filters 20000 artificial stars. We obtained completeness curves for different galactocentric radii, which were used in the analysis (for further details, see Bassino & Caso, 2017).

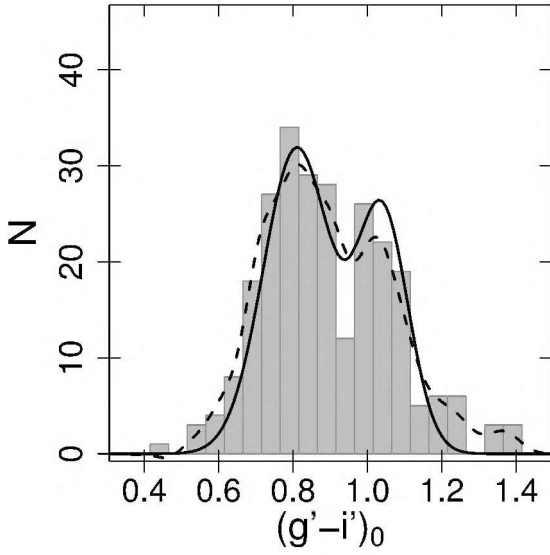


Figure 1: Background corrected colour distribution for GC candidates brighter than $i'_0 = 25.5$ mag. The dashed curve corresponds to a smoothed distribution obtained with a Gaussian kernel. The solid curve represents the fit result.

3. Results

The histogram in Fig. 1 corresponds to the background corrected colour distribution for all GC candidates brighter than $i'_0 = 25.5$ mag. The dashed curve indicates the smoothed distribution obtained with a Gaussian kernel. In order to determine whether the GCS colour distribution is better represented by two Gaussians instead of one, we used the Gaussian Mixture Method algorithm (GMM, Muratov & Gnedin, 2010). We statistically subtracted the contamination contribution from the GC candidates, repeating the process 25 times. In all cases GMM indicated a negative kurtosis and DD larger than 2, pointing to a bimodal distribution. The solid curve in the figure corresponds to the mean parameters for the sum of two Gaussians. From these results, we adopted $(g' - i')_0 = 0.95$ as the limit between blue and red GCs.

Open circles in Fig. 2 show the radial distribution for GC candidates brighter than $i'_0 = 26$, corrected for completeness. The dotted horizontal line indicates the contamination level. Filled symbols show the radial distributions corrected by completeness and contamination for all the GCs brighter than $i'_0 = 26$ (circles), blue GCs (upwards triangles) and red ones (downwards triangles). We fitted modified Hubble profiles to each radial distribution, indicated with a solid curve for the entire population, and dashed and dashed-dotted ones for the blue and red subpopulations, respectively. The dashed-dotted horizontal line corresponds to 30% of the contamination level, a value used in several studies to determine the GCS extension (e.g. Caso et al., 2017). We obtain ≈ 5 arcmin, i.e. ≈ 65 kpc.

The GC luminosity function (GCLF) of early-type galaxies can be represented by a Gaussian distribution with a turn-over magnitude (TOM) in the V -band of $M_{V,TOM} \approx -7.4$ mag (e.g. Jordán et al., 2007). Fig. 3 shows the GCLF of NGC 6411 in terms of the i' magni-

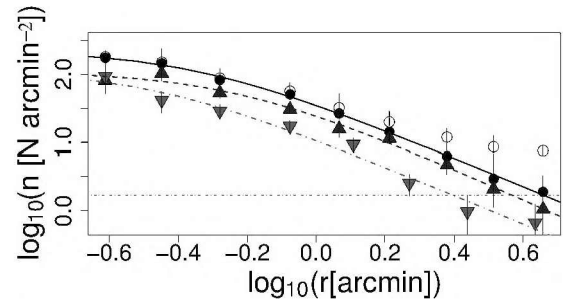


Figure 2: The filled symbols show the background corrected radial distribution for the entire sample (black circles), blue GCs (upwards triangles) and red ones (downwards triangles). The dashed-dotted horizontal line corresponds to the 30% of the contamination level.

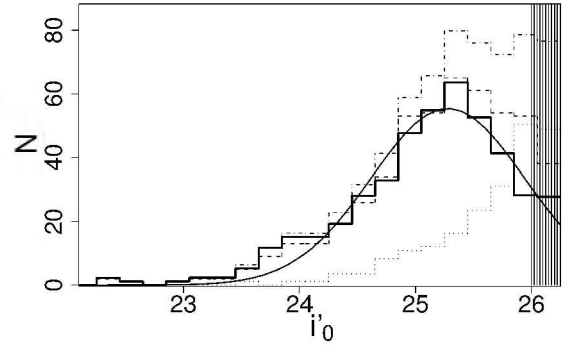


Figure 3: Raw (blue dashed histogram), completeness corrected (dashed-dotted red histogram) and background and completeness corrected (black solid histogram). The grey dotted histogram is the completeness corrected LF for the CompF field. The vertical lines indicate the luminosity range avoided due to completeness drop.

tude. The blue dashed histogram shows the raw GCLF, and the dashed-dotted red histogram is the completeness corrected GCLF. The grey dotted histogram is the completeness corrected LF for the CompF field, and the black solid histogram corresponds to the background and completeness corrected GCLF.

The solid curve is a Gaussian fitted to this latter histogram, resulting $i'_{0,TOM} \approx 25.3$. From Eqs. 1 and 2 of Bassino & Caso (2017), and the mean colour for the GC candidates, $(g' - i')_0 \approx 0.9$, the absolute magnitude of the TOM in the i' -band results $M_{i',TOM} \approx -8$ mag. Then, the distance modulus for NGC 6411 is $m - M \approx 33.3$ mag, in agreement with measurements of Blakeslee et al. (2001) from SBF and the fundamental plane. The numerical integration of the Gaussian indicates that the GCs brighter than $i'_0 = 26$ mag correspond to $\approx 85\%$ of the entire population. From this value and the integration of the Hubble modified profile fitted to the radial distribution, the total population of GCs results in ≈ 700 members.

An excess of GCs brighter than $i'_0 = 24$ mag can be seen in the GCLF. As we might be missing some bright objects with a strict photometric χ^2 -selection, we relax these limits in the three filters. This results in an enlarged sample of GC candidates brighter than $i'_0 = 24$ mag, with marginal changes for the fainter ones (≈ 5

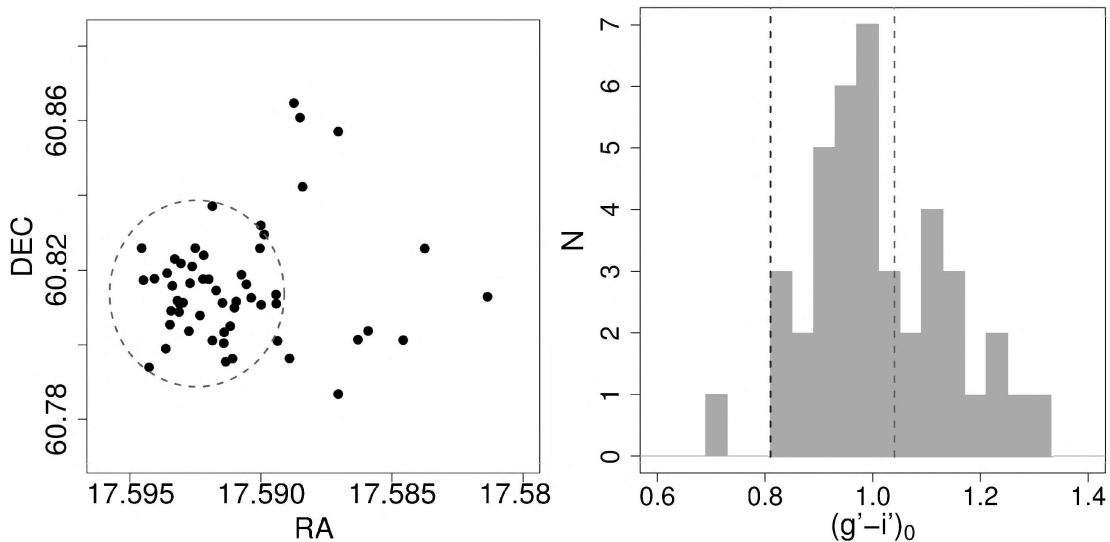


Figure 4: **Left panel:** projected spatial distribution for GC candidates brighter than $i'_0 = 24$ mag. The red dashed circle is centered in the galaxy and its radius is 1.5 arcmin. North is up, East to the left. **Right panel:** colour distribution for GC candidates brighter than $i'_0 = 24$ mag. The vertical lines correspond to the colour peaks for blue and red GCs from Fig. 1.

per cent). We visually inspect the brightness profile and residuals of these bright candidates, but no evidence of saturation or deficient subtraction was found.

The left panel of Fig. 4 shows the projected spatial distribution for the GC candidates brighter than $i'_0 = 24$ mag. The ≈ 76 per cent of these objects are located at galactocentric distances smaller than 1.5 arcmin. This proportion is larger than those corresponding to blue and red GCs fainter than $i'_0 = 24$ mag, at 95% confidence level. A Kolmogorov-Smirnov test (Kolmogorov, 1933) also points to different projected distributions for faint and bright GC candidates. The right panel of Fig. 4 shows the colour distribution for the bright GCs with galactocentric distances up to 1.5 arcmin. The vertical lines indicate the colour peaks for blue and red GC candidates from Fig. 1. The majority of the bright GCs present intermediate colours, around $(g' - i')_0 = 0.95$. From Bressan et al. (2012) SSP models, the bright GCs colours cannot simultaneously match the ages and metallicities derived by González Delgado et al. (2015) for the galaxy. We considered that the starburst that formed these bright GCs was driven by an older event.

4. Summary

- The galaxy does not present evidence of recent merger events, like tidal structures, after subtracting a smoothed surface brightness component.
- The total population of the GCS results in ≈ 700 members, implying a poor GCS, as usually found in low density environments.
- The TOM of the GCLF is in agreement with SBF studies, and the colour distribution resembles those

found in typical bright Es, with old GCS.

- We detect an excess of bright GCs, strongly concentrated towards the galaxy. Their colours are mainly intermediate between those of blue and red GCs and do not agree with ages derived by the spectroscopic studies, pointing to an older event.

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