Looking for prints of interaction processes in the globular cluster system of NGC 3640

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Resumen / Existen muchas relaciones entre las propiedades de los sistemas de cúmulos globulares y las de las galaxias que los hospedan, lo cual convierte a los cúmulos globulares en buenos trazadores de la historia evolutiva de las galaxias de tipo temprano. Las fusiones y los eventos de acreción pueden alterar la distribución espacial de los cúmulos, así como sus colores. Presentamos el estudio del sistema de cúmulos globulares de la galaxia elíptica NGC 3640, usando observaciones de GMOS/Gemini. En nuestro análisis encontramos evidencia de interacción entre NGC 3640 y su compañera, NGC 3641, en la aparente presencia de un puente compuesto por cúmulos globulares que conecta ambas galaxias.

Abstract / There are many connections between the properties of globular cluster systems and those of the galaxies that host them, making them useful tracers of the evolutionary history of early-type galaxies. Mergers and accretion events may alter the spatial distribution of the system, as well as their colours. We present a study of the globular cluster system of the elliptical galaxy NGC 3640, using observations from GMOS/Gemini. In our analysis, we find evidence of an interaction between NGC 3640 and its companion, NGC 3641, in the form of an apparent trail of globular clusters between the two galaxies.

Keywords / galaxies: evolution — galaxies: elliptical and lenticular, cD — galaxies: star clusters: individual (NGC 3640)

1. Introduction

The assembly of early-type galaxies (ETGs) is understood as a two-phase process: first, there is in-situ star formation caused by the initial gas collapse; then, the mass of the galaxy continues to increase steadily through accretion processes (Oser et al., 2010). Throughout the evolution of a galaxy, the environment has been shown to play an important role (e.g. Yoon et al., 2017), but its relation with the evolutionary processes a galaxy undergoes is not yet fully understood. In the second phase of galaxy evolution, mergers and interactions contribute greatly to the growth of the galaxy's mass, and they alter its stellar populations. Thus, characterizing stellar populations of ETGs across different environments is a key step towards understanding galaxy evolution and its connection to the environment a galaxy inhabits. In galaxies at large distances, resolving individual stars is not possible, and we require tracers to analyse the properties of the galaxy. Globular clusters are powerful discrete tracers, since they are intrinsically bright and compact, which makes them detectable as point-like sources, and their properties are closely linked to those of the underlying stellar population. Because they are linked to old stellar populations (Dotter et al., 2010; Hansen et al., 2013), they can provide information about the early stages of star formation of galaxies, as well as about the processes the galaxy has undergone.

NGC 3640 is an elliptical galaxy, at a distance of 27 Mpc (obtained using the surface brightness fluctuation method by Tully et al. 2013). It belongs to a loose group, comprised of eight galaxies, among which is its close companion, the compact elliptical (cE) NGC 3641 (de Vaucouleurs et al., 1976). The morphology of NGC 3640 presents a number of tidal features, shown in Prugniel et al. (1988), which are considered to be remnants of a major merger. In addition to this, NGC 3640 presents extremely boxy isophotes (Michard & Prugniel, 2004), a dust lane along its minor axis and high rotation velocity along its major axis (Prugniel et al., 1988), which are all thought to be signatures of recent interactions. Most of the works that mention NGC 3640 consider it a result of a major merger, but many of these signs of interactions could also be attributed to an interaction by tidal stripping with NGC 3641, a possibility which is acknowledged in several of these studies. In order to untangle the relation between NGC 3640 and its neighbour, we present an analysis of their globular cluster systems.

2. Observations

In this work we use data obtained with the Gemini Multi-Object Spectrograph Camera (GMOS) on Gemini North (Program GN-2016A-Q-69, P.I. Lilia Bassino), in imaging mode, in the $g'r'i'$ filters. We use a binning of 2×2, which results in a resolution of 0.146 arcsecpix^{-1}.

We observed two fields (Figure 1), one containing the galaxies, and an adjacent one with the goal of covering the full extension of the GCS. We also observed a field

Poster contribution

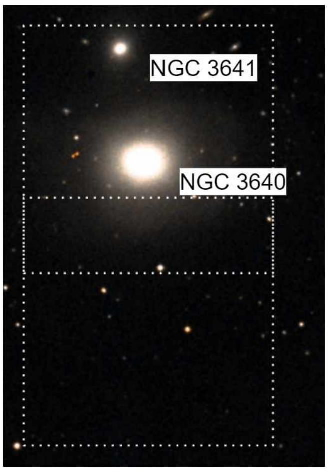

Figure 1: Digital Sky Survey 2 image showing both galaxies, with the observed fields marked with dotted white lines. South points up, East to the left.

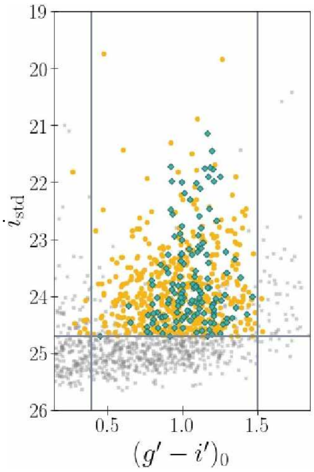

Figure 2: Colour-magnitude diagram for all sources present across both fields (grey crosses). The yellow dots represent the GC candidates attributed to NGC 3640, while the green diamonds represent GC candidates attributed to NGC 3641.

of standard stars on the same night, used to convert instrumental magnitudes to standard ones using the equations provided by the Gemini website and to estimate the aperture size used for aperture photometry.

3. Data reduction and source selection

3.1. Data reduction

The first steps of data reduction consisted of correcting the observations using BIAS and FLAT-FIELD images and tasks from the Gemini package in IRAF, followed by combining all of the images from each field in each filter. Then, we subtracted the integrated light from both galaxies with the FMEDIAN task in IRAF, making it possible to detect point-like sources in the central regions. On these residual images we used SExtractor to detect point-like sources, for which we obtained aperture photometry with tasks in the DAOPHOT package. From this first catalogue, we selected 30 of the brightest objects to build the point-spread function (PSF) corresponding to these observations, and then used it to obtain PSF photometry of all our catalogue.

With the ALLSTAR task, we fitted the PSF to each source, obtaining in return an instrumental magnitude, and statistical parameters that characterize the goodness of the fit, specifically, sharpness and chi-squared. The final catalogue was obtained after applying constraints to these parameters.

We performed a completeness analysis by adding artificial sources to the image and carrying out the steps mentioned above to obtain the fraction of recovered sources. From this analysis, we established a limiting magnitude of $i' = 24.75$ corresponding to an $\sim 80\%$ completeness.

Finally, using the observations of the field of standard stars, we obtained the equations to transform our instrumental magnitudes to standard ones.

3.2. Source selection

Following Bassino & Caso (2017), we used colour limits to identify GC candidates in the three classic colour combinations ($g' - i'$, $g' - r'$ and $r' - i'$). We also limited the magnitude in the faint end, corresponding to the result from the completeness analysis. In Figure 2 we show the colour-magnitude diagram for all point-like sources, highlighting those we attributed preliminarily to each galaxy. The separation was done considering only closeness to the center, since we cannot estimate radial velocities based on photometry.

4. Analysis

4.1. Colour distributions

In Figures 3 and 4 we show the colour distributions for the GC candidates attributed to NGC 3640 and NGC 3641, respectively.

In the case of NGC 3640, we show the distribution for the whole sample and then for two different regions, separating those closest to the center of the galaxy and those of the outskirts. The distribution of the sample extends across the entire expected colour range for GCs, covering both the "red" (more metallic) and the "blue" (less metallic) subpopulations. The middle and bottom panels show that most objects in the inner region belong to the red subpopulation, with very few objects towards the blue extreme, while the blue subpopulation dominates the outskirts. Though it is typical for the red subpopulation to be more concentrated toward the center while the blue one is usually more extended, the lack of blue objects in the central region is peculiar.

On the other hand, the colour distribution of NGC 3641 presents a very narrow range of colours, mostly concentrated towards the red.

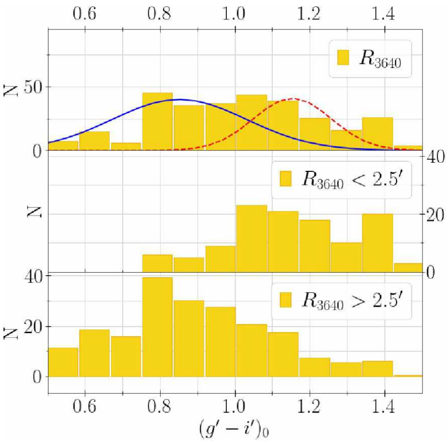

Figure 3: Background corrected colour distribution for GC candidates attributed to NGC 3640. *Top panel:* The entire sample. *Middle panel:* GC candidates in the inner region. *Bottom panel:* GC candidates in the outer region.

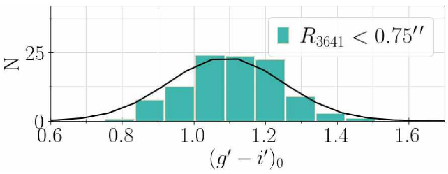

Figure 4: Background corrected colour distribution of the GC candidates attributed to NGC 3641.

4.2. Spatial distributions

In Figure 5 we show the residual images from which the surface brightness of NGC 3640 was subtracted, with the density contours corresponding to the smoothed density of blue and red GCs shown in solid lines. The colour gradient of the line indicates a larger density towards darker colours. The residual surface brightness from the galaxy reveals the underlying substructures in its morphology, in the shape of shells and feathers. The blue subpopulation of GCs seems to be aligned with these substructures, presenting an irregular spatial distribution which could be the consequence of having been displaced from their original position due to the same evolutionary process that caused the shell on the bottom right. In the case of the red subpopulation, there is a concentration towards the region between NGC 3640 and NGC 3641. This overdensity forms a bridge between the two of them, which can be interpreted as a sign of undergoing or recent interaction between them.

5. Summary and conclusions

We presented the preliminary results for the photometrical analysis of the GCS of NGC 3640 and its companion, NGC 3641, in which we find prints of the evolutionary processes undergone by the galaxy.

- The colour distribution of NGC 3640 appears to be bimodal since it covers the entire range of colours expected for GCs while presenting slight peaks which approximately match the expected means for the blue and red subpopulation, though the statistical analysis does not return conclusive results. This is likely due to the presence of GCs from NGC 3641, either because the systems are superposed or because they were tidally stripped. The presence of an intermediate-age population seems unlikely.
- Blue GCs usually extend towards the outskirts of galaxies, where their spatial distribution is more easily affected by interactions. In the case of NGC 3640, an event seems to have pushed both blue GCs and the underlying stellar population in the same direction.
- The GCS of NGC 3641 appears to present mostly red GCs. It is possible that it had blue GCs which were tidally stripped by NGC 3640, though there is no clear evidence for this specifically. However, the overdensity of red GCs that connects both galaxies does hint at an accretion process that is still ongoing.

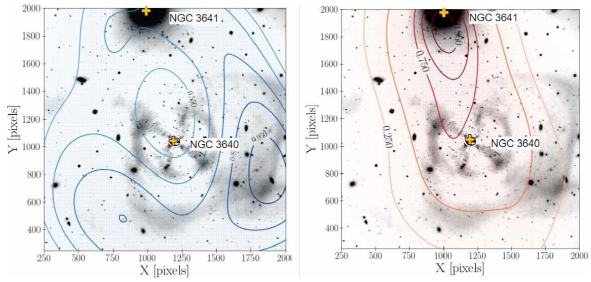

Figure 5: Smoothed spatial distribution of the "blue" (*left panel*) and "red" GC candidates (*right panel*), shown in contours over the residual image resulting from subtracting the surface brightness of NGC 3640. The shells and feathers in the figure are features of the surface brigthness distribution of NGC 3640.

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