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Letter

The Brazil–Argentina Gemini Group for the Study of Globular Cluster Systems (BAGGs GCs): FLAMINGOS-2 and GMOS Data for NGC 1395

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Abstract: In this letter, we present preliminary results of the analysis of Flamingos-2 and GMOS-S photometry of the globular cluster (GC) system of the elliptical galaxy NGC 1395. This is the first step of a long-term Brazilian–Argentinian collaboration for the study of GC systems in early-type galaxies. In the context of this collaboration, we obtained deep NIR photometric data in two different bands (*J* and *Ks*), which were later combined with high quality optical Gemini + GMOS photometry previously obtained by the Argentinian team. This allowed us to obtain different color indices, less sensitive to the effect of horizontal branch (HB) stars for several hundreds of GC candidates, and to make an initial assessment of the presence or absence of multiple GC populations in colors in NGC 1395.

Keywords: early-type galaxies; globular cluster; galaxy halos

1. Introduction

Globular clusters (GCs) are powerful probes to study the evolutionary histories of galaxies, as they are good tracers of galactic star forming episodes. They are found around all major galaxies and can be easily observed far beyond the Local Group [1]. As GCs are intrinsically old objects, their integrated properties could give us information about the physical conditions in the interstellar medium at the moment of formation of their host galaxies.

GC systems in massive galaxies are known to present a bimodal optical color distribution ([2,3]). This phenomenon has been identified in different galaxies and it has been shown that this effect is more clearly detectable when metallicity-sensitive color indices (such as $(g' - z')$ or $(C - T_1)$) are used ([4,5]). Therefore, color bimodality is usually interpreted as evidence for the existence of two GC sub-populations: the "blue" subpopulation (metal-poor clusters associated with the halo) and the "red" one (metal-rich clusters linked to bulge/disc). These sub-populations would have been formed in at least two stages (e.g., [6,7]): blue GCs would have been a primordial population formed at high redshifts in protogalactic fragments (e.g., [8,9]), while the red GCs would have formed later, during a gas-rich merging of these fragments (e.g., [10]).

However, it was suggested that the bimodality may be an artifact arising from the non-linearity in the color–metallicity (C–M) relation of GCs ([11,12]). In the [12] scenario, the morphology of the horizontal branch (HB) produces a "wavy" pattern in the C–M relation in such a way that it is possible to obtain a bimodal color distribution from a unimodal metallicity distribution. Despite several empirical C–M calibrations have been published in the last decade, there is still a lot of controversy about the existence of the alleged "wavy" pattern, i.e., how strong it is, and how much it influences our interpretation of multiple GC populations based on broad-band colors ([13–16]).

Although the combination of optical and NIR colors is expected to help to mitigate the "age–metallicity degeneracy" ([17]), it is still not clear how to interpret the lack of multi-modality in some systems observed with optical/NIR filters ([18]). The study of NGC 3115 by [15] (multi-band photometry and spectra centered on the CaT), suggests that if the underlying metallicity bimodality is real, it should be detected in all colors as well as in metal-sensitive indices. This means that, if the bimodality appears only in some colors, it would be due to the "wavy" pattern in the C–M relation.

In the framework of our BAGGs GCs collaboration, we are involved in obtaining deep optical and NIR multi-band photometry, as well as deep MOS spectroscopy, of GC systems belonging to massive early-type galaxies. We expect that this data, combined with different single stellar population models (SSP), helps to mitigate the age–metallicity degeneracy and allows us to measure several color-indices less sensitive to the effect of HB stars. By combining kinematics and color–metallicity measurements of GC systems in a self-consistent manner, we hope to be able to recover the evolutionary histories of the galaxies and shed light on the assembly history of the halos of the galaxies.

As a first step of our collaboration's observing campaign, in semester 2015B, we obtained data of the GC system of the giant elliptical galaxy NGC 1395 (D $\sim$ 21.4 Mpc, $M_B = -21.02$ mag), one of the dominant galaxies of the Eridanus group. This galaxy harbors thousands of GCs and shows a clear bimodal optical color distribution (Escudero+, in prep.). Here, we present preliminary results of an analysis of deep NIR photometric images taken in two different photometric bands (J and Ks), obtained with Gemini+Flamingos-2. The photometry obtained from these images was combined with high quality optical photometry from previous Gemini+GMOS runs.

2. Data

Within the BAGGs GCs collaboration, we obtained NIR images of two fields of the elliptical galaxy NGC 1395 using Gemini + Flamingos-2 in the J and Ks bands (Program GS-2015B-Q-38). The total on-source exposure times were 30 $\times$ 50 s in both fields for the J band, and, in the Ks band, 302 $\times$ 12 s on-source for the field containing the galaxy and 277 $\times$ 12 s on-source for the other field. The results presented here are based on a preliminary reduction performed with THELI ([19]). We used DAOPHOT ([20]) to obtain psf photometry of all the detected sources in the fields. The NIR photometry was calibrated using 2MASS objects present in our fields.

We also worked on a mosaic of four image fields of NGC 1395, previously obtained with Gemini+GMOS by the Argentinian team (Figure 1). These optical images were observed in the g' (4 $\times$ 180.5 s), r' (4 $\times$ 120.5 s), i' (4 $\times$ 150.5 s) and z' (4 $\times$ 150.5 s) bands, using 2 $\times$ 2 binning which gives a scale of 0.146″/pix (Programs GS-2012B-Q-44 and GS-2014B-Q-28). In this work, we present the results obtained from the two fields that overlap with the NIR fields. The reduction of this data set was performed through the Gemini/GMOS IRAF package in the usual way (see [21] for more details). The detection and classification of the sources was made using a combination of SExtractor ([22]) and different IRAF tasks as is explained in [23]. Finally, we obtained DAOPHOT photometry in each band and we calibrated our final photometric catalogue using Sloan standard stars observed on the same night as our target. The complete optical photometric analysis will be presented in Escudero+ (in prep.).

We used RA and DEC coordinates to match the optical candidates and to build a master catalogue which includes all the unresolved sources detected and measured in the g', r', i', z', J and Ks bands. In order to obtain a clean sample of GC candidates as possible and to have reliable colors in all the bands, we cut the photometric sample in the range $18 < g' < 24$ mag with color cuts similar to those in Escudero+ (2015a). The final catalogue includes 650 candidates detected in all the bands (red circles in Figure 1).

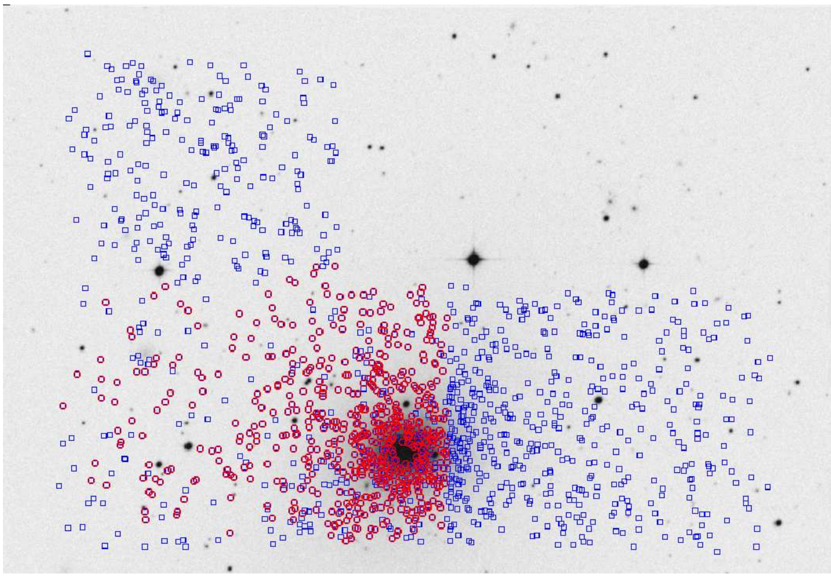

Figure 1. DSS red image of NGC 1395 showing the optical globular cluster (GC) candidates (blue squares). The GC candidates detected in the NIR images (∼650) are shown in red. The size of this image is 12 × 17 arcmin. North is up and east is to the left.

3. Results

Our first goal is to try to identify the presence of different color GC subpopulations. To this aim, we built several color histograms and color–color diagrams. As an example, in Figure 2, we present the different color histograms obtained by combining g' magnitudes with the rest of our photometric bands. At this stage of our work, we did not apply any statistical test but rather made a preliminary identification of the modal peaks of the different colors. As in other giant early-type galaxies, the $(g' - z')$ color distribution of NGC 1395 looks bimodal ([24]). Two main peaks are clearly identified in modal colors of $(g' - z')$ = 0.93 and $(g' - z')$ = 1.33 mag. However, the appearance of the color distribution strongly depends on the combined bands. All the optical, optical-NIR and most of the purely NIR color distributions show signs of multiple subpopulations. Some of them, such as $(g' - i')$, $(g' - z')$ and $(g' - K_s)$, look strongly bimodal with possible substructures. As previously noticed by other authors (e.g., [25]), in the particular case of colors involving only NIR bands, the situation is not so clear.

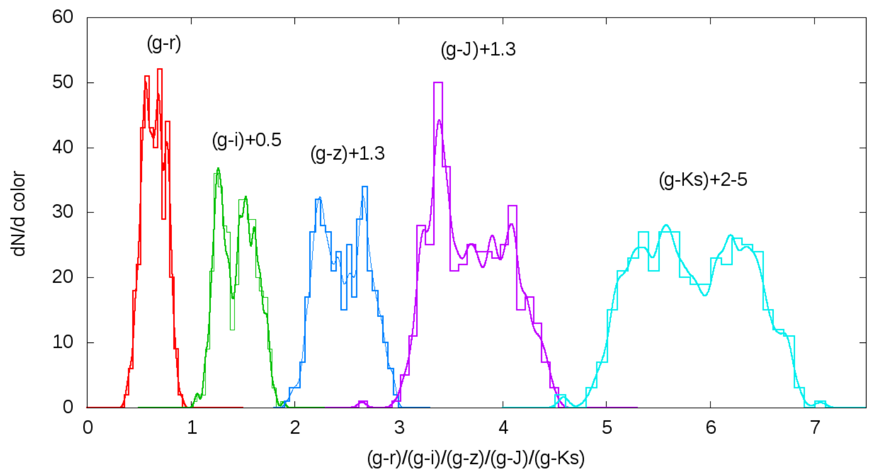

Figure 2. Histograms and density color distributions for different band combinations and for objects with $g' < 24$ mag. The considered bins are in the range 0.04–0.1 mag. The density distributions were built using a Gaussian kernel with $0.02 < \sigma < 0.05$ mag. To avoid superposition, we shifted some histograms by a constant value, as indicated in the figures.

The color–color diagrams show signs of different degrees of non-linearity. As an example, Figure 3 shows a $(g' - K_s)$ vs. $(g' - z')$ diagram with evidence of a slight non-linearity which is in good agreement with the results of previous studies ([26–28]). Interestingly, most of the smoothed diagrams obtained from our photometry suggest that, at least, two main subpopulations in color are present.

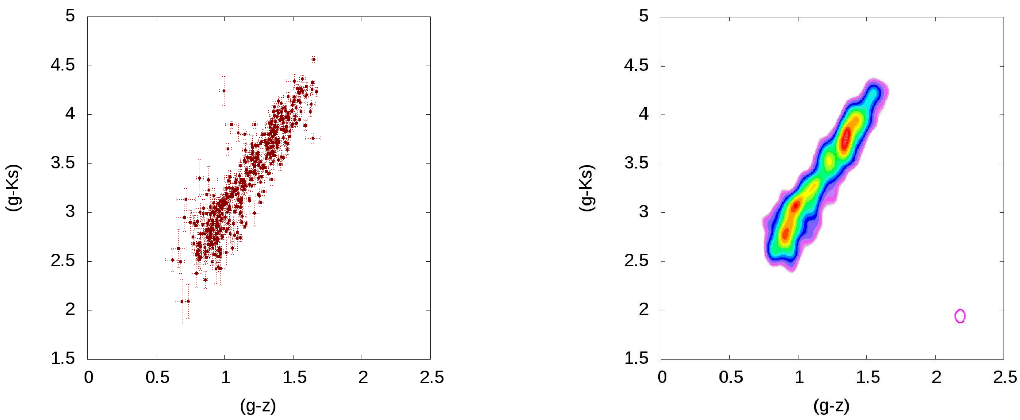

Figure 3. (**Left**): Color–color $(g' - K_s)$ vs. $(g' - z')$ diagram built from our optical and NIR photometric sample (objects with $g' < 24$ mag); (**Right**): Smoothed version of the same diagram as that on the left. The elliptical symbol depicts the kernel used to smooth the original diagram.

4. Discussion

As it has already been noticed by other authors, in some galaxies, the usual description of color histograms on unimodal or bimodal bases by fitting Gaussian distribution seems to be simplistic. For example, [29] has shown that the $(g' - z')$ color distributions of the GCs of several galaxies in Virgo and Fornax seem to display a common and synchronized multi-population pattern. Furthermore, [16] proposed that in some massive galaxies, the metallicity distribution might be thought of as the result of a rapid sequence of individual GC formation events leading to an apparent "continuous" metallicity distribution. In the particular case of NGC 1395, though preliminary, our results seem to fit in these pictures. That is, they seem to present a bimodal color distribution in some photometric band combinations, but show evidence of substructures in these color patterns.

To clarify all these issues, high-quality multi-band photometry and deep spectroscopy for a large sample of GCs belonging to different systems, are clearly needed. In the framework of our BAGGs GCs collaboration, we expect to obtain deep spectroscopy for a sub-sample of GC candidates in order to determine spectroscopic ages and metallicities to test the photometric results.

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Conflicts of Interest: The authors declare no conflict of interest.

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