The globular cluster system of nearby spirals through multi-band surveys: Improving the photometric catalogue

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Received: 09 February 2024 / Accepted: 11 April 2024

Resumen / Los relevamientos fotométricos multi-banda permiten estudiar los sistemas de cúmulos globulares de un amplio número de galaxias cercanas en forma homogénea. El procesamiento de estos datos y la construcción de catálogos fotométricos, es crucial para determinar una muestra de candidatos a partir de métodos estadísticos. En el presente trabajo exploramos alternativas al procedimiento de reducción aplicado en trabajos previos de este proyecto, que permiten mejorar el catálogo de objetos puntuales.

Abstract / Photometric multi-band surveys are useful for studying the globular cluster systems for a large number of nearby galaxies in an homogeneous manner. The data processing and further catalogues build-up are important in obtaining a sample of likely candidates by means of statistical methods. In the present work we test some alternatives to the photometrical procedure applied in previous studies from this project, to improve the catalogue of point-sources.

Keywords / galaxies: star clusters: general — galaxies: star clusters: individual — galaxies: stellar content — galaxies: groups: individual (M81)

1. Introduction

The Sloan Digital Sky Survey (York et al., 2000) has represented a turning point for modern astronomy, which is entering an era dominated by large surveys. In particular, photometric multi-band surveys, like the Large Synoptic Survey Telescope (Ivezic et al., 2008) or the Javalambre Photometric Local Universe Survey (J-PLUS, Cenarro et al., 2019), provide useful data for a large variety of astronomical topics with low telescope time. The amount of data released by these surveys allows homogeneous studies of large samples of targets, but it also leads to challenges when processing the data that have to be addressed in an automated manner.

In particular, the study of globular clusters (GCs) in nearby galaxies is relevant for our knowledge of galaxy evolution. They are present in the majority of the galaxies with masses above $\approx 10^9\,M_{\odot}$, spanning different morphologies and environments (e.g. Harris et al., 2015). The formation and later evolution of GCs, as well as the build-up of globular cluster systems (GCSs), are related to the mergers experienced by their host galaxies (e.g. Kruijssen et al., 2019; Li & Gnedin, 2019), and their properties provide evidences about the host galaxy, including the amount of dark matter (e.g. Hudson et al., 2014; Forbes et al., 2018), the relevance of the accretion processes (e.g. De Bórtoli et al., 2022), and the mechanisms that rule the disruptions of substructure in the inner regions (e.g. Caso et al., 2024). This article presents preliminary results from a project devoted to the study of the GCSs in nearby spirals, through observations from J-PLUS, and continues the analysis carried by Chies-Santos et al. (2022) and Caso et al. (2023) of the M 81 triplet, chosen as a test bench for our project. Its distance ($D \approx 3.6$ Mpc, Tully et al., 2013), and the existence of previous studies on the GCSs of M 81 (Perelmuter et al., 1995; Nantais et al., 2010; Nantais et al., 2011; Ma et al., 2017) make it an excellent target for our purposes. The triplet is conformed by the spiral M 81, the dominant galaxy in the group, the starburst spiral M 82 and the irregular NGC 3077. There is evidence of interactions, including emission in HI (de Blok et al., 2018) and low surface-brightness substructure in optical bands (Smercina et al., 2020) that seems to connect the galaxies.

2. Observations and photometry

The dataset is conformed by processed images in twelve filters, from u to z (see Cenarro et al. 2019 for information about the filters system) for three pointings that cover the entire region of the triplet, and span to the

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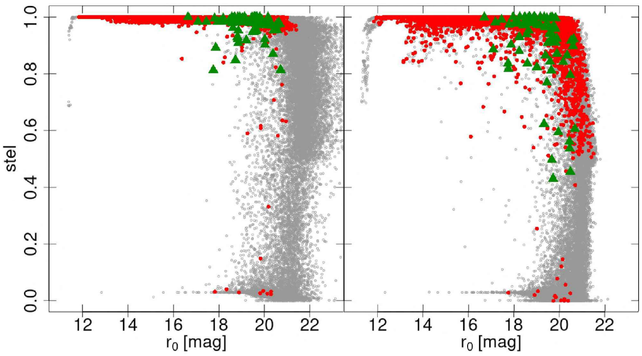

Fig. 1. Stellarity index from SourceExtractor against r_0 magnitude for sources in the field containing M 81. In the *left panel*, the detection of the sources and its stellarity index are obtained from the composite image described in Section 2.1. The *right panel* is analogue, but the detection and stellarity index are based on the r image. The red circles correspond to sources with proper motions larger than 3 m.a.s. per year, from Gaia DR3, and assumed as Galactic stars. The green triangles correspond to confirmed GCs from the literature.

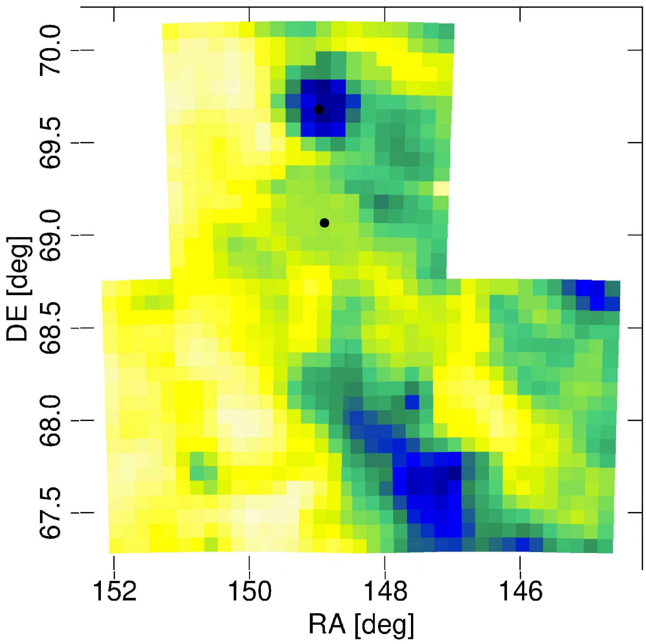

Fig. 2. Reddening map (E_{B-V}) for the three pointing included in this analysis. It is built from the extinction calculators from the NASA/IPAC Infrared Science Archive and the extinction coefficients for the J-PLUS filters. The colour gradient moves towards larger E_{B-V} values, from light yellow to dark blue.

South. The images are publicly available at the J-PLUS collaboration website*.

2.1. Photometry

In order to increase the signal-to-noise for faint sources, we perform the detection on a composite image, built from the addition of the images corresponding to broad bands g, r, i and z, plus the narrow band images from filters $J0515$, $J0660$ and $J0861$. Bluer filters are not used to build the composite image, since the spectral energy distribution for old GCs drops in flux for wavelengths below 5000 Å (e.g. Brodie & Strader, 2006). The aperture photometry in the twelve filters is carried using SourceExtractor (Bertin & Arnouts, 1996) in dual mode, with the composite image as the reference one, and using a Gaussian filter to classify the sources. The background is measured locally, with a mesh size of 32 pixels, large enough to not affect the photometry. Typically, the mean effective radii of extragalactic GCs is $\approx 3-4$ pc (e.g. Peng et al., 2008; Caso et al., 2014). Considering the distance to the triplet and the typical seeing in these images (above 1 arcsec), GCs can be treated as point-sources. Finally, a selection of point sources is made based on the SourceExtractor parameters, FWHM and stellarity index, obtained from the composite image. This procedure allows us to reach fainter magnitudes, and to improve the selection of sources (see Fig. 1). Point sources lacking photometric measurements in more than one filter are excluded, as well as those presenting uncertainties above 0.5 mag in the broad bands (except for the u filter). Finally, the definite catalogue is matched with Gaia DR3 (Gaia Collaboration et al., 2021) to add information on proper motions.

2.2. Photometric corrections

The zero points for each filter are calculated from the crossmatch of the point sources with the J-PLUS photometric catalogue, for the corresponding aperture radius. Besides, aperture corrections are obtained from several bright and isolated stars in different sections of the fields. In contrast to what was performed in Chies-Santos et al. (2022), the extinction corrections are calculated for each source with a E_{B-V} map built from the extinction calculators of the NASA/IPAC Infrared Science Archive**, and used to correct the photometry of the extinction coefficients for the J-PLUS filters from López-Sanjuan et al. (2019). Figure 2 shows the map with the gradient of colours representing increasing values of reddening, from 0.04 mag (light yellow) to 0.14 mag (dark blue). It should be emphasised that sources embedded in the disk of both spirals could still be affected by their intrinsic extinction.

2.3. Exclusion of contaminants

The data publicly available from Gaia DR3 are useful to identify Galactic stars in the photometric catalogue. This is particularly helpful for points sources brighter than $g = 20.5$ mag, for which more than 50 per-cent have proper motion measurements (μ, and 90 per-cent if the threshold is set at $g = 19$ mag). In Chies-Santos et al. (2022), the criterion was to reject all the sources with $\mu > 3.6\,\mathrm{mas\,yr^{-1}}$, based on the proper motion measurements of confirmed GCs from the literature. In Fig. 3

*http://www.j-plus.es/datareleases/data_release_dr2

**https://irsa.ipac.caltech.edu/applications/DUST/

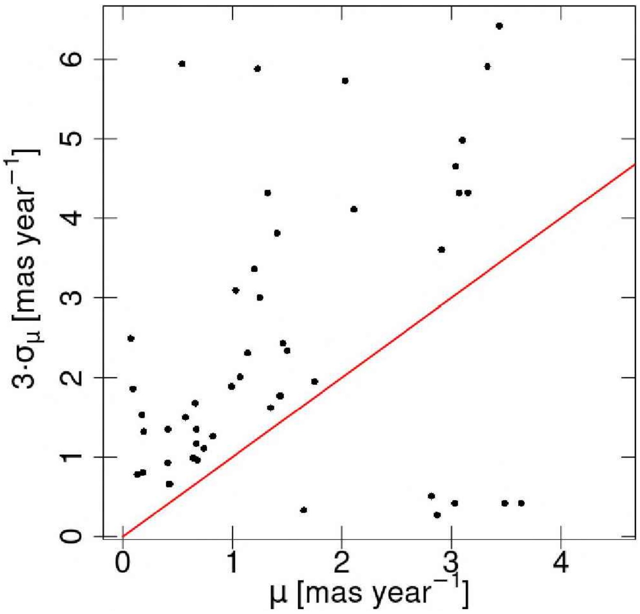

Fig. 3. Proper motions from Gaia DR3 (μ) and three times their uncertainties, for confirmed GCs of M 81. The red line represents the identity relation.

the proper motion measurements for confirmed GCs of M 81 from the literature, and three times their corresponding uncertainties are shown . It is noticeable that, although many GCs present non-negligible proper motions, the vast majority of them do not surpass the $3 \cdot \sigma$ value. A few GCs from Perelmuter et al. (1995) exceed this limit, but they lack ACS photometry confirming their extended nature, and their flux excess from Gaia (i.e., the ratio between the fluxes derived from the spectra of the object and its point-spread function in the astrometric CCD) range $1.15 - 1.25$, which is expected for point sources. Hence, our rejection criterion is $\mu > 3{\cdot}\sigma_{\mu}$.

Finally, radial velocities from SDSS DR16 (Ahumada et al., 2020) are included, discarding those objects with heliocentric velocities $> 1000\,\mathrm{km\,s^{-1}}$, based on the heliocentric velocities of the galaxies of the triplet. The resulting catalogue has $\approx 11,900$ objects.

3. Conclusion

A better segregation of point-like sources in our photometry, plus more a restrictive criterion for proper motion measurements, produce a final catalogue with fewer contaminants. Although it is limited to bright sources, the spectroscopic survey from SDSS DR16 is also helpful for this goal. This procedure is intended to provide an improved input catalogue for statistical methods, as the one applied in Chies-Santos et al. (2022), leading to a better selection of GC candidates.

Acknowledgements: This work was funded with grants from Consejo Nacional de Investigaciones Científicas y Técnicas de la República Argentina, Agencia Nacional de Promoción Científica y Tecnológica, and Universidad Nacional de La Plata (Argentina). This research was supported in part by Perimeter Institute for Theoretical Physics. Research at Perimeter Institute is supported by the Government of Canada through the Department of Innovation, Science and Economic Development and by the Province of Ontario through the Ministry of Research and Innovation. ACS acknowledges funding from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the Rio Grande do Sul Research Foundation (FAPERGS) through grants CNPq-403580/2016-1, CNPq-11153/2018-6, PqG/FAPERGS-17/2551-0001, FAPERGS/CAPES 19/2551-0000696-9, L'Oréal UNESCO ABC Para Mulheres na Ciência and the Chinese Academy of Sciences (CAS) President's International Fellowship Initiative (PIFI) through grant 2021VMC0005

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