

EXTRAGALACTIC GLOBULAR CLUSTERS WITH EUCLID AND OTHER WIDE SURVEYS

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Abstract. Globular clusters play a role in many areas of astrophysics, ranging from stellar physics to cosmology. New ground-based optical surveys complemented by observations from space-based telescopes with unprecedented near-infrared capabilities will help us solve the puzzles of their formation histories. In this context, the Wide Survey of the *Euclid* space mission will provide red and near-infrared data over about 15 000 square degrees of the sky. Combined with optical photometry from the ground, it will allow us to construct a global picture of the globular cluster populations in both dense and tenuous environments out to tens of megaparsecs. The homogeneous photometry of these data sets will rejuvenate stellar population studies that depend on precise spectral energy distributions. We provide a brief overview of these perspectives.

Keywords: globular clusters ; surveys

1 Introduction

A refreshing wave of interest is currently pushing globular cluster science ahead, triggered by a growing body of stringent empirical constraints: new formation scenarios are needed to explain the abundance patterns seen among globular cluster stars; galaxy formation scenarios must explain a variety of globular cluster color distributions without endangering the scaling relations between cluster numbers and host galaxy properties; the relationships between globular clusters (hereafter GC), dwarf galaxy nuclei and ultra-compact galaxies remain to be elucidated; direct observations of star forming clumps at high redshift must find their place in the global picture of globular cluster histories. At the same time, GCs remain objects of reference, with comparatively simple stellar populations that can allow us to test our understanding of stellar evolution. For this purpose, at least at distances not yet accessible to detailed spectroscopic observations, homogeneous and deep photometry across the spectrum of stellar photospheres is a must.

The nearby future will see the launch of several astronomical telescopes into space, a few of which will focus on the near-infrared spectral range and thus complement large ground-based optical surveys that are rapidly

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progressing across the globe. The *Euclid* space mission* and the *James Webb Space Telescope*† are next in line for launch. While the second will provide a variety of instruments for pointed observations of small fields of view, the first will operate in survey mode with wide-field cameras in the red part of the optical spectrum (VIS instrument) and in the *Y, J, H* bands of the near-infrared (NISP instrument). The pointed observations of the *James Webb Space Telescope*, later followed by those of the *Nancy Grace Roman Space Telescope*, will extend the volume in which Local Group clusters can be resolved into stars and will also transform our view of high-redshift structure formation. The *Euclid* mission has its place in between these extremes, and will draw a new picture of GC populations at intermediate distances, out to almost 100 Mpc.

Globular clusters are among the targets of the Legacy Science program of the *Euclid* mission plan (Laureijs et al. 2011), and their detection and study is being prepared as a dedicated work package of the Local Universe science working group within the Euclid Consortium. As a consequence of the requirements set by the primary science cases of *Euclid* (dark matter and cosmology studies via tracers such as weak lensing and galaxy clustering; Mellier, this conference), *Euclid* will observe a large part of the darkest skies (almost 15 000 square degrees; Scaramella et al. 2021), with a good spatial resolution ($\simeq 0.15''$ in VIS), a well-characterized point-spread function, and the deep uniform red and near-infrared photometry necessary for photometric redshift measurements. The need for photometric redshifts has led to unprecedented coordination efforts with ground-based optical surveys, in both the Southern and Northern hemispheres.

2 Taking advantage of *Euclid*'s survey specifications

Deep high-resolution observations of extragalactic GC populations obtained over the years with the *Hubble Space Telescope* (HST) have produced high-purity samples of GCs with information on their half-light radii out to about 30 Mpc (e.g. Jordán et al. 2005; Peng et al. 2006; Villegas et al. 2010), and GC candidate photometry out to typically 100 Mpc (e.g. in Coma; Harris et al. 2009; Saifollahi et al. 2021), exceptionally much farther (Alamo-Martínez et al. 2013). However, due to the small field of view of HST cameras, these data sets are not complete but rather restricted to the pointings selected by various observers for their specific purposes. Deep pointed observations from the ground have complemented the HST datasets, again for selected objects; notable examples are the early-type galaxies of the SLUGGS and MATLAS surveys, respectively at $D \leq 27$ Mpc and $D \leq 42$ Mpc (Brodie et al. 2014; Duc & the MATLAS Collaboration 2020). The widest ground-based surveys suitable for extensive GC studies have covered areas of order 10^2 square degrees and targeted the dense environments of nearby galaxy clusters such as Virgo (NGVS; Ferrarese et al. 2012) or Fornax (NGFS; e.g. Ordenes-Briceño et al. 2018; FDS; e.g. Cantiello et al. 2020). *Euclid* will cover almost 15 000 square degrees of sky, and this will allow us to characterize GCs around galaxies of all types in high- and low-density regions, as well as to locate GCs far away from their host (e.g. Jang et al. 2012; Mackey et al. 2019) or associated with extended halo substructures (e.g. Fensch et al. 2020). In these external regions dynamical timescales are longer than near galaxy centers, and the GCs are more direct tracers of galaxy assembly histories.

Before GCs can be studied, they must be found. Here, the spatial resolution of *Euclid*'s VIS camera will be an asset. Any catalog property that reveals the non-point-like nature of a source is instrumental in separating remote GCs from stellar contaminants, as was shown in previous studies from the ground (e.g. Powalka et al. 2016) or using a combination of ground-based and Gaia satellite data (Voggel et al. 2020). The typical 5 pc half-light diameter of a GC will match the VIS pixel size ($0.1''$) at a distance of 10 Mpc (Fig. 1). At a 30 Mpc distance, a cluster at the peak of the GC luminosity function ($M_{\text{VIS}} \simeq -8$ AB mag with some dependence on color and environment‡) will have an apparent AB magnitude of about 24.4, and an expected signal-to-noise ratio above 20 in stacked VIS images (C. Laigle, private communication§). Its non-point-like nature will be detectable. The non-point-like nature of brighter clusters will be recognized up to distances of about 70 Mpc, and this limit will be pushed beyond 100 Mpc for ultra-compact dwarf galaxies (UCDs).

Within the first few Mpc, the grainy aspect of the semi-resolved outer parts of GCs will be a characteristic that the eye and trained machine-learning algorithms will recognize. At larger distances however, the separation between GCs and redshifted compact objects will require the analysis of colors; the ideal combination would include *Euclid* measurements in the red and near-IR parts of the spectrum, and optical and *u*-band data from

*<https://sci.esa.int/web/euclid>

†<https://www.jwst.nasa.gov/>

‡Based on Rejkuba (2012) and the $V - \text{VIS}_{\text{AB}}$ indices of stellar population models.

§Based on simulations for point-sources, Nov. 2020

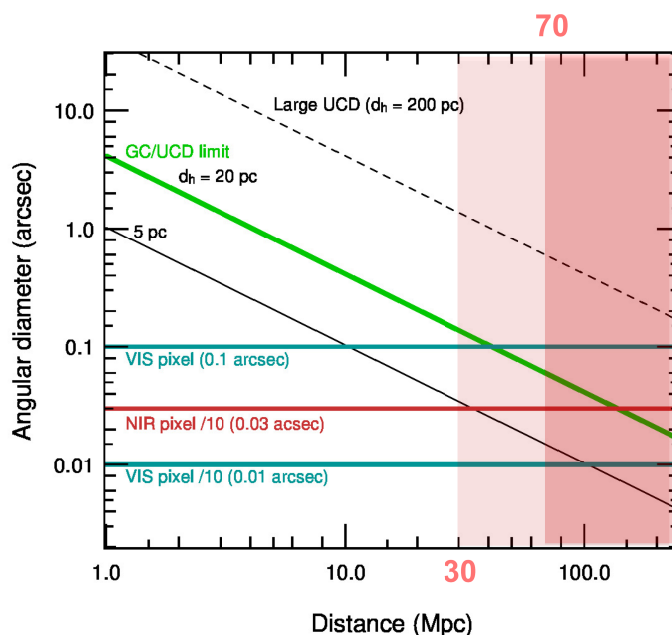


Fig. 1. Properties of globular clusters and ultra-compact dwarf galaxies as seen by the *Euclid* VIS and NIR cameras. The diagonal lines show the angular diameters that correspond to half-light diameters d_h typical of globular clusters or ultra-compact dwarf galaxies. Horizontal lines mark the VIS pixel size, and one tenth of the NIR and VIS pixel sizes. The shaded areas are representative of the limits to which GCs near the peak of the GC luminosity function (light shade), or bright clusters (dark shade) will be recognized as non point-like.

other surveys. Indeed, color-color diagrams that exploit the full photospheric emission spectrum of stellar populations are best suited for this exercise (one now commonly used combination is the *uIK* diagram; Muñoz et al. 2014). The photometric redshift pipelines that are being developed for the core science programs of *Euclid*, and that will use data from ground-based surveys via partnerships, will effectively help rejecting compact background galaxies. We also intend to implement dedicated searches that exploit morphology and colors simultaneously.

As already mentioned, *Euclid* represents a huge step forward in near-infrared photometry, not only by pushing the 5σ detection limit in *Y, J, H* to ~ 24.4 AB mag (Scaramella et al. 2021) but also by ensuring an excellent uniformity over the sky. For the first time, GC spectral energy distributions that include near-infrared data will be comparable across samples, without the need for color transformations. This will give new perspectives to studies of the dependencies between the stellar populations of GCs and their environment. As both the ground-based sky surveys of the near future and the Euclid Consortium strive to improve absolute photometric calibrations, the new data sets will also provide the most accurate GC colors to date, which will allow a critical evaluation of population synthesis model predictions.

3 How many globular clusters?

Estimates of the number of GCs that *Euclid* catalogs will contain depend on the final footprint of the wide survey, on assumptions on GC specific frequencies and their luminosity distributions, and on a number of technical aspects related to the processing of the images with a pipeline designed primarily for the study of galaxies in the distant universe.

For a first estimate, we have used the NED-D catalog of galaxy distances (Steer et al. 2017), total optical magnitudes from the Simbad database at CDS[¶] and a conservative parametrization of the dependence of specific frequencies on galaxy luminosity based on Peng et al. (2008) and Georgiev et al. (2010). The number of GCs expected to lie within the *Euclid* footprint out to 35 Mpc is of several 10^5 , and out to 70 Mpc it exceeds 10^6 . How many of these will indeed be measured remains to be examined, using parameters such as galaxy inclination

[¶]<http://simbad.u-strasbg.fr/simbad/> and <http://cdsxmatch.u-strasbg.fr/>

and pipeline characteristics such as its ability to measure small sources near large host galaxies. Rule of thumb estimates suggest that permissive catalogs of GC candidates will contain a few 10^6 objects. Excluding the nearest 2 Mpc and the largest galaxies in the Virgo and Fornax galaxy clusters (the numerous GCs of which have been extensively studied), the numbers of robust GC candidates with high signal-to-noise photometry are expected to approach 10^5 . Dedicated simulations are being designed to ascertain these preliminary values.

4 Conclusions

The Euclid Wide Survey will provide us with near-infrared photometry of unprecedented precision across vast parts of the sky. The combination of this information with uniform optical photometry from wide ground-based surveys promises a breakthrough in the study of globular clusters, in particular in fields that require reliable spectral energy distributions: the comparison between GC populations in various environments, the validation of stellar evolution models and stellar population synthesis models for these particular astronomical objects. Indeed, systematic errors and color transformation uncertainties had become a limiting factor that the new data will finally push out of the way.

Complete samples will serve to set up spectroscopic follow-up campaigns, leading to new dynamical studies of galaxy halos and of merging histories. In some areas, *Euclid* will open doors for deeper studies with pointed observations, for instance with the *James Webb* Space Telescope or the *Nancy Grace Roman* Space Telescope. This will be the case for instance for the study of GC populations associated with low surface brightness galaxies or galaxy sub-structures that Euclid may find, at distances of 100 Mpc and more, or for the study of the faint end of the GC luminosity function in various environments.

The EC acknowledges the European Space Agency and a number of agencies and institutes that have supported the development of Euclid, in particular the Academy of Finland, the Agenzia Spaziale Italiana, the Belgian Science Policy, the Canadian Euclid Consortium, the Centre National d'Etudes Spatiales, the Deutsches Zentrum für Luft- und Raumfahrt, the Danish Space Research Institute, the Fundação para a Ciência e Tecnologia, the Ministerio de Economía y Competitividad, the National Aeronautics and Space Administration, the National Astronomical Observatory of Japan, the Nederlandse Onderzoekschool Voor Astronomie, the Norwegian Space Agency, the Romanian Space Agency, the State Secretariat for Education, Research and Innovation (SERI) at the Swiss Space Office (SSO), and the United Kingdom Space Agency (cf <http://www.euclid-ec.org>). A.L., P.-A.D., W.C., A.L. acknowledge financial support via grant ANR-19-CE31-0022 of the French Agence Nationale de la Recherche. This work has made use of the SIMBAD database and of the cross-match service operated at CDS, Strasbourg, France.

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