Star Clusters: From the Milky Way to the Early Universe
Proceedings IAU Symposium No. 351, 2019
A. Bragaglia, M. Davies, A. Sills & E. Vesperini, eds.

doi:10.1017/S1743921319007841

GEP I: A globular cluster in the center of the dwarf spheroidal galaxy Andromeda XXV?

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Abstract. Looking for variable stars in the M31 dwarf spheroidal satellite Andromeda XXV (And XXV), which we have observed with the LBC at the LBT, we serendipitously discovered a clustering of stars (Gep I) of 12 arcsec in diameter, near the center of And XXV. This is one of the very few clusters known to be associated with a dwarf spheroidal galaxy. The half light radius (r_h) of Gep I at the distance of And XXV corresponds to 25 pc in linear extension. Radius and absolute V ($M_V \sim -4.9$ mag) magnitude place Gep I in the region of the M_V-r_h plane that seems to be forbidden to ordinary globular clusters (GCs). The seeing-limited resolution of our photometry could resolve only a few bright stars in Gep I. The CMD of these sources is compatible with an old stellar population placed at a heliocentric distance of ∼750–800 kpc, thus confirming a real concentration of old stars. The ground-based CMD of Gep I is severely incomplete. Future high resolution imaging and spectroscopy of the brightest stars will permit to disentangle the puzzle on the real nature of Gep I.

Keywords. galaxies: star clusters: general; galaxies: star clusters: individual: Gep I

1. Introduction

Since 2011 we are conducting a survey with the Large Binocular Camera (LBC) at the Large Binocular Telescope (LBT) to study the nature and origin of Andromeda's satellites and relate it to the global context of merging and accretion episodes occurring in M31 (Cusano *et al.* 2013, 2017). In our study targeted on Andromeda XXV (Richardson *et al.* 2011), we have serendipitously discovered a concentration of stars near And XXV's photometric center (Cusano *et al.* 2016). Visual inspection of the deep image obtained by stacking all $B-$band LBC frames reveals this roughly spherical assembly of stars to be centered around coordinates R.A.=00^h:30^m:10.579^s dec.=+46°:51′:05.58″ and to be of ∼ 12 arcsec in diameter. A snapshot of Gep I from our deep $B-$band image with the LBT is shown in Figure 1. There is no known globular cluster (GC) in the Revised Bologna Catalogue of the M31 GCs (Galleti *et al.* 2004), nor any other known extended source within 20 arcsec of Gep I center coordinates.

2. Phyical properties

The r_h of Gep I at the distance of And XXV corresponds to 25 pc in linear extension. Assuming the distance modulus and reddening of And XXV (Cusano *et al.* 2016), we obtain an absolute magnitude $M_V \sim -4.9$ mag. Radius and absolute V magnitude place Gep I in the region of the M_V-r_h plane that seems forbidden to ordinary GCs. Only the M31 Extended Clusters (Huxor *et al.* 2011) and the less luminous among the Milky Way Palomar GCs are found to lie in this region (see Figure 2 adapted from Figure 10 of

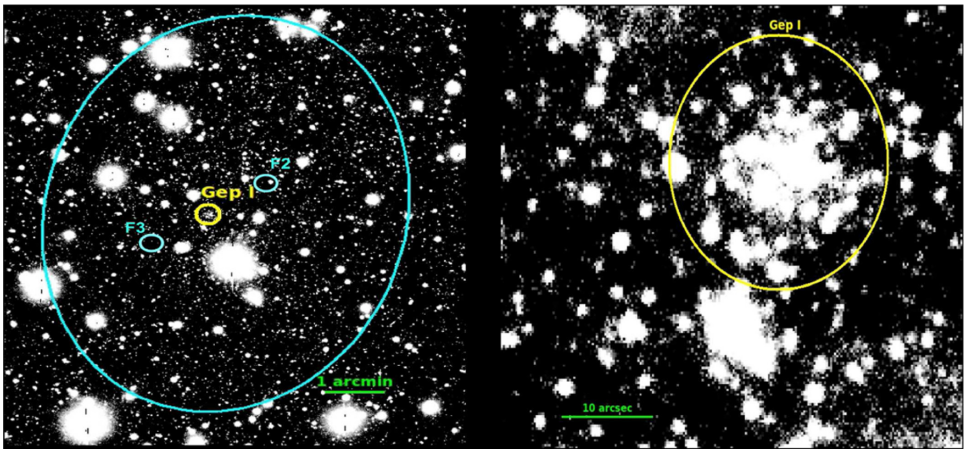

Figure 1. Left: Image obtained by stacking all B-band LBC frame in the field of And XXV. The position of Gep I is highlighted with a yellow circle. The cyan ellipse show the area delimited by 1 r_h of And XXV. Right: a zoom in to Gep I.

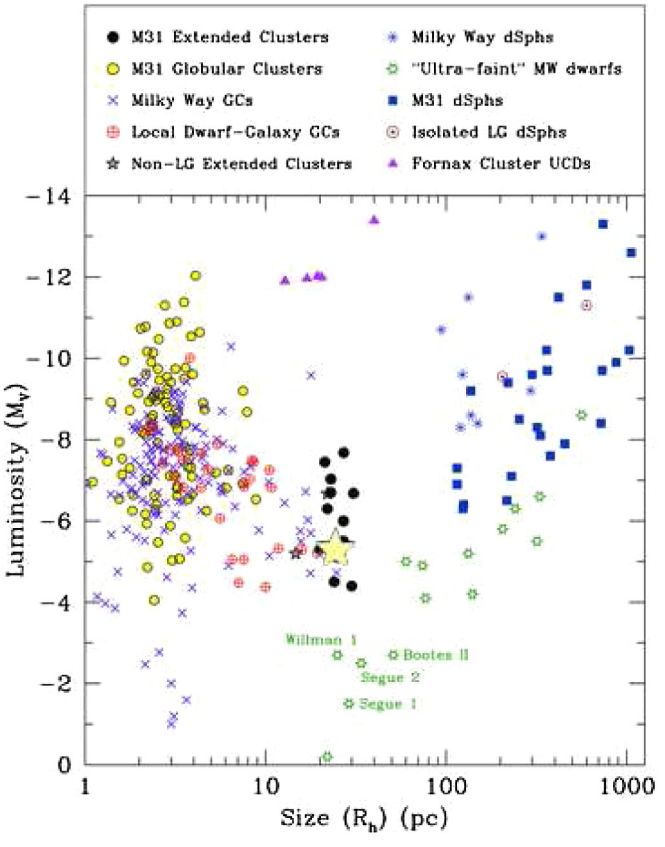

Figure 2. Luminosity vs. size relation for compact object in the MW and M31 adapted from Huxor *et al.* (2011). Gep I (big yellow star) lies in the region of extended clusted in M31.

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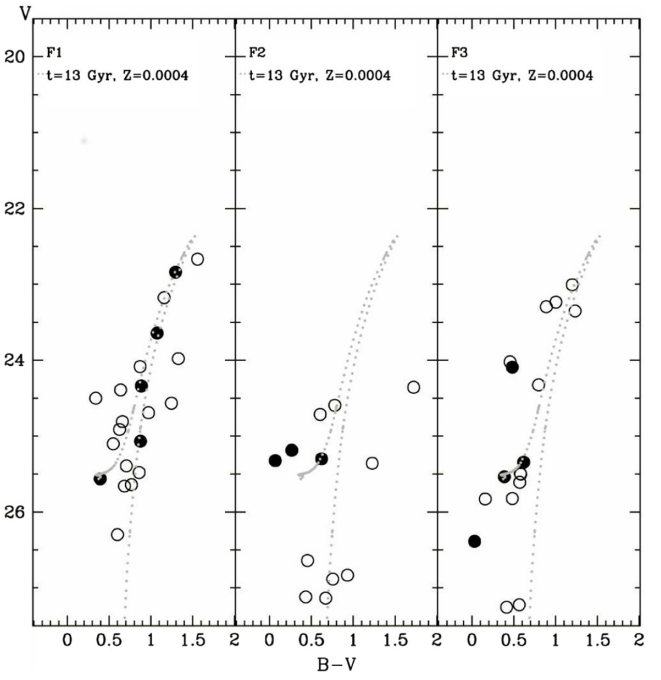

Figure 3. CMD of stars in a circular area within a radius of 12 arcsec from the center of Gep I (field F1). The grey dashed line is an isochrone with t = 13 Gyr and Z = 0.0004 (Bressan *et al.* 2012). Center: same as in the left panel but for sources in F2. Right: same as in the left panel but for stars in F3.

Huxor *et al.* 2011). There are few stars that our photometry could resolve in this cluster and their position in the CMD is shown in the left panel of Figure 3. This CMD was performed by taking all the objects in a circular area of 12 arcsec in radius from the center of the stellar association (field F1, Figure 1). These stars are mostly red giants, with only one or two HB stars. Their location in the CMD is compatible with an old population placed at a Heliocentric distance of ∼750–800 kpc. The center and right panels of Figure 3 show, for a comparison, the CMDs of sources in two circular regions F2 (central panel) and F3 (right panel) with a radius equal to twice the estimated r_h of Gep I, but centered 1 arcmin to the northwest and 1 arcmin to southeast with respect to the F1 center, respectively. The positions of F2 and F3 in the LBC FOV are marked with cyan circles in Figure 1. The CMDs of fields F2 and F3 show no clear evidence of a single old stellar population similar to the one observed in field F1, thus confirming that in F1 there is a real concentration of old stars.

3. The importance of central cluster in dSph galaxy

Zaritsky *et al.* (2016) have suggested that most GCs may be hosted by undetected faint galaxies. Our discovery in And XXV, along with Crnojevic *et al.*'s (2016) discovery of the central cluster in Eridanus II, may lend support to Zaritsky *et al.*'s (2016) claim and provide hints on the connection between GCs and dwarf galaxies. In addition Vanzella *et al.* (2019) linked the presence of a cluster like Gep I to the formation scenario of dwarf galaxies. The authors claimed that Gep I could be one of the few examples in the local universe of a star cluster and its environment (or hosting dwarf) survived for

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the entire cosmic time. Moreover based on simulations Amorisco (2017) and Contenta *et al.* (2017) raise the question of whether clusters with such low densities can survive the tidal field of cold dark matter haloes with central density cusps. Using both analytic arguments and a suite of collisionless N-body simulations, they show that these clusters are extremely fragile and quickly disrupted in the presence of central cusps. They find that these clusters are long lived only in cored haloes. Amorisco (2017) finally stated that star cluster like Gep I near the center of ultra-faint dwarf galaxies can be the "first unambiguous evidence for physics beyond cold DM". Clearly, our ground-based study of Gep I is severely incomplete. To unveil the nature of Gep I we will propose follow up Hubble Space Telescope and LBT observations in order to resolve and characterize its stellar populations and precisely measure its distance.

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