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The properties of bright globular clusters, ultra-compact dwarfs and dwarf nuclei in the Virgo core: hints on origin of ultra-compact dwarf galaxies (UCDs)

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Abstract. Based on the data from the Next Generation Virgo cluster Survey (NGVS), we statistically study the photometric properties of globular clusters (GCs), ultra-compact dwarfs (UCDs) and dwarf nuclei in the Virgo core (M87) region. We found an obvious negative color ($g-z$) gradient in GC system associate with M87, i.e. GCs in the outer regions are bluer. However, such color gradient does not exist in UCD system, neither in dwarf nuclei systemaround M87.

In addition, we found that many UCDs are surrounded by extended, low surface brightness envelopes. The dwarf nuclei and UCDs show different spatial distributions from GCs, with dwarf nuclei and UCDs (especially for the UCDs with visible envelopes) lying at larger distances to the Virgo center. These results support the view that UCDs (at least for a fraction of UCDs) are more tied to dwarf nuclei than to GCs.

Keywords. galaxies: dwarf; galaxies: nuclei; galaxies: star clusters: general; globular clusters: general

1. Introduction

Since the discovery of the ultra-compact dwarf galaxies (UCDs) around 2000 (Hilker *et al.* 1999, Drinkwater *et al.* 2000), it has not been clear exactly what they are. There are two main formation scenarios have been proposed: (1) UCDs are just larger, more massive, otherwise normal GCs (e.g., Mieske *et al.* 2002, Fellhauer & Kroupa 2002); (2) UCDs are the remnant nuclei of stripped nucleated dwarf galaxies (e.g., Bekki *et al.* 2001, Binggeli *et al.* 1985). In the past few years, people found many pieces of evidence which support the tidal stripping scenario (e.g., Pfeffer *et al.* 2013, Seth *et al.* 2014, Liu *et al.* 2015a, Liu *et al.* 2015b, Mihos *et al.* 2015, Zhang *et al.* 2015, Voggel *et al.* 2016, Ahn *et al.* 2017, Afanasiev *et al.* 2018, Ahn *et al.* 2018, Schweizer *et al.* 2018, Zhang *et al.* 2018). Thanks to the high quality images from Next Generation Virgo cluster Survey (NGVS, see Ferrarese *et al.* 2012), we have homogeneous sample of bright GCs, UCDs and dwarf nuclei simultaneously. In this contribution, we will directly compare the properties of these three type of objects in Virgo core (M87) region and give hints on UCD origin.

2. Data and sample

The data we used is drawn from NGVS, which is a deep multi-wavebands (u^*, g, r, i and z) imaging survey (see Ferrarese *et al.* 2012), and NGVS-IR, which is a near-infrared (J and K_s) imaging survey (see Muñoz *et al.* 2014). Both these two surveys were carried out with CFHT. In this contribution, we only use the data in Virgo core region.

Bright GC sample. The GC selection is mainly based on color-color diagrams and concentration parameters (see Peng *et al.* 2018, in preparation). To compare the properties with UCDs, we only use bright GCs in the magnitude range $18.5 < g < 21.5$ mag. We have a total of 548 GC candidates in the bright GC sub-sample.

UCD sample. The UCD candidates are selected using a combination of several criteria including magnitude ($18.5 < g < 21.5$ mag), half-light radius ($11 < r_h < 100$ pc), color-color diagram ($u - i$ vs. $i - K_s$), surface brightness, and visual inspection. We found 92 UCD candidates associated with M87 (see Liu *et al.* 2015b).

Dwarf nuclei. The nucleated dwarf ellipticals (dE,Ns) are from either Binggeli *et al.* 1985 or Ferrarese *et al.* (2018, in press). There are 38 dwarf nuclei in the magnitude range $18.5 < g < 21.5$ mag in M87 region. We compare the properties of nuclei of these dE,Ns (not the whole galaxy) with GCs and UCDs.

3. Results

Color distribution. It is well known that GC systems in massive elliptical galaxies exhibit bimodal color distribution (e.g. Peng *et al.* 2006). As we can see in right panels of figure 1, not only the bright GCs, but also the UCDs and nuclei show bimidal color ($g - z$) distribution. As in Liu *et al.* (2015b), we divide UCDs, bright GCs and nuclei

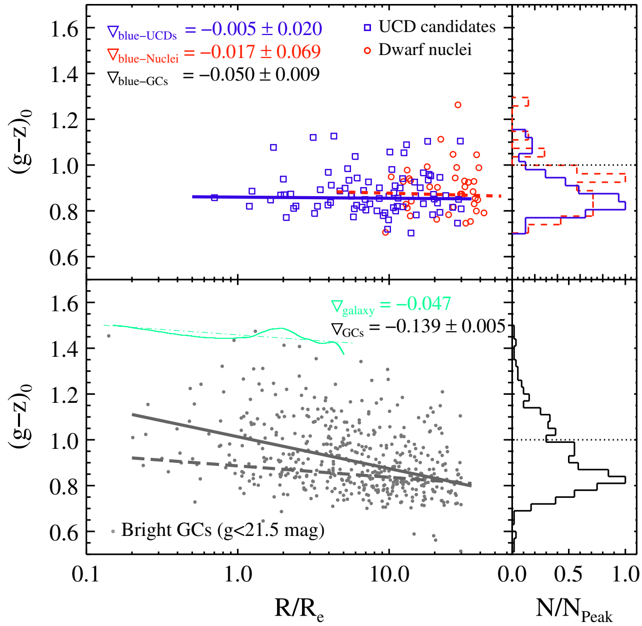

Figure 1. Color distributions (right panels) and color gradients (left panels) for UCDs (blue histogram and blue squares), dwarf nuclei (red histogram and red circles) and bright GCs (black histogram and dark gray dots). We show the color profile for M87 itself (green lines) as well.

into blue and red sub-populations at $(g-z) = 1.0$. The fractions of blue sub-populations for three type of objects are $f_{\rm blue-GCs} = 73.3\%$, $f_{\rm blue-UCDs} = 89.0\%$, $f_{\rm blue-Nuclei} = 89.5\%$ respectively. The blue fraction of UCDs and nuclei are approximately equal, while the blue GCs fraction is 15 percentage points smaller.

Color gradients. Since most of the UCDs and nuclei are blue, we only measure and compare the color gradients for the blue sub-populations. The corresponding color gradients are $\nabla_{\rm blue-GCs} = -0.050 \pm 0.009$, $\nabla_{\rm blue-UCDs} = -0.005 \pm 0.020$ and $\nabla_{\rm blue-Nuclei} = -0.017 \pm 0.069$. Again, GCs show different properties from UCDs and nuclei. The blue GC system show an obvious negative gradient ($\sim 5\sigma$) which is consistent with previous studies (e.g., Liu *et al.* 2011). But neither blue UCD system nor blue nuclei system exhibit significant color gradients. We notice that the M87 itself has an obvious negative color gradients as well (see green lines in figure 1). The most straightforward interpretation of the color gradient is that GCs were formed together with the host galaxy but UCDs and dE,Ns were formed in a different way.

Spatial distribution. We found that many UCDs are embedded in extended, low surface brightness envelopes (see images in figure 2), which should be the feature of dE,Ns. We divide UCDs into two sub-samples according to whether they have visible envelopes or not. Now we have four types of objects: GCs, UCDs, UCDs with envelopes and dwarf nuclei. The lower-left panel of figure 2 shows the cumulative distribution of project distances to M87 for these four types of objects. The mean distance for dwarf nuclei is the largest, followed by UCDs with visible envelope, UCD without visible envelope and GCs. Actually, this is also in order of the size of envelope. It seems that the gravitational potential well governs the envelope structure of UCDs and dwarf nuclei. This result supports the tidal stripping scenario.

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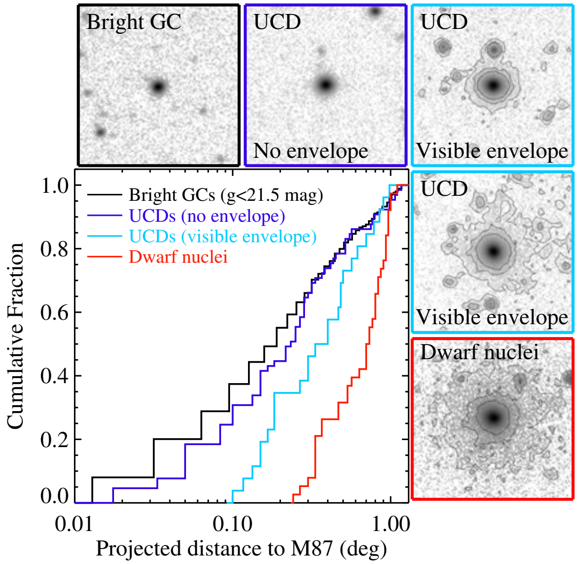

Figure 2. Cumulative distribution of project distances to M87 for bright GCs (black line), UCDs without visible envelope (blue line), UCDs with visible envelopes (cyan line) and dwarf nuclei (red line). The 5 small panels show the selected g band images of 1 bright GC, 3 UCDs and 1 dwarf nucleus. The contours in the right three panels denotes the isophote with constant surface brightness level: 25.0, 25.5, 26 mag arcsec^{-2} respectively.

4. Conclusion

We compare the color distributions, the color gradients and the spatial distributions for bright GCs, UCDs and dwarf nuclei. Statistically, the UCDs show similar properties to dwarf nuclei, and GCs are the outlier. Our results support the tidal stripping scenario. However, we did not rule out any other scenario. It is entirely possible that there are multiple formation pathways.

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