Counting Globular Cluster Candidates in Ultra-diffuse Galaxies

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Abstract

Ultra-diffuse galaxies (UDGs) are high-mass galaxies with low surface brightness. Astrophysicists hypothesize that they have very high dark matter fractions, but their dark matter content is currently undetermined. The mass of a UDG's dark matter halo may be related to its globular cluster (GC) population. We test a method for counting the numbers of GCs in UDGs. We find that, on average, there is an excess of GC candidates on top of the UDGs relative to the background. Counts vary widely among all the UDGs in our sample, but we conclude that the average is 0.94 GCs per UDG. This corresponds to an average dynamical mass of ~$1.3 \times 10^8\ M_\odot$.

Introduction

47 UDGs were discovered in the Coma cluster in 2015 [1]. Shortly after, Koda et al. confirmed the existence of 854 UDGs in the cluster [2]. UDGs have Milky Way-like sizes but the luminosities of dwarfs. They are populous in clusters, where they must have high dark matter content to survive among the strong tidal forces.

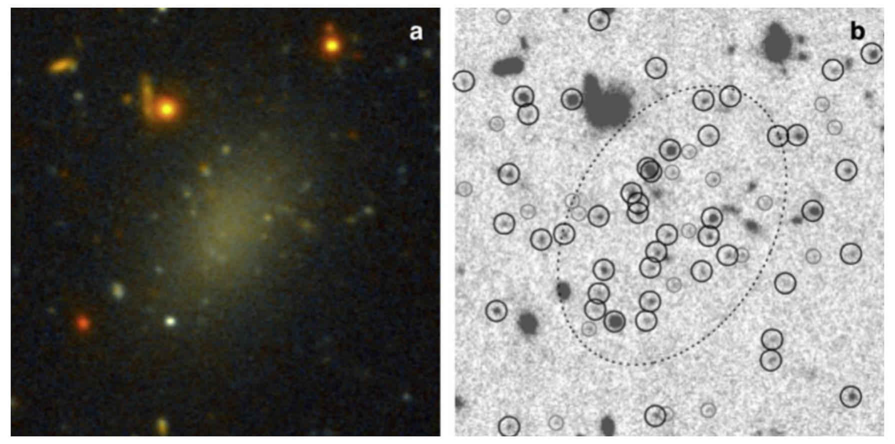

Figure 1. (a) Color image of the UDG Dragonfly 44. (b) Dragonfly 44 with the galactic disk removed from the image. The ellipse outlines the area of the galaxy. The small circled objects are GC candidates [3].

A positive relationship between the total mass of a galaxy's GCs and the mass of that galaxy's dark matter halo has been confirmed in normal galaxies. If this relationship holds in UDGs, it provides a means to determine their amounts of dark matter.

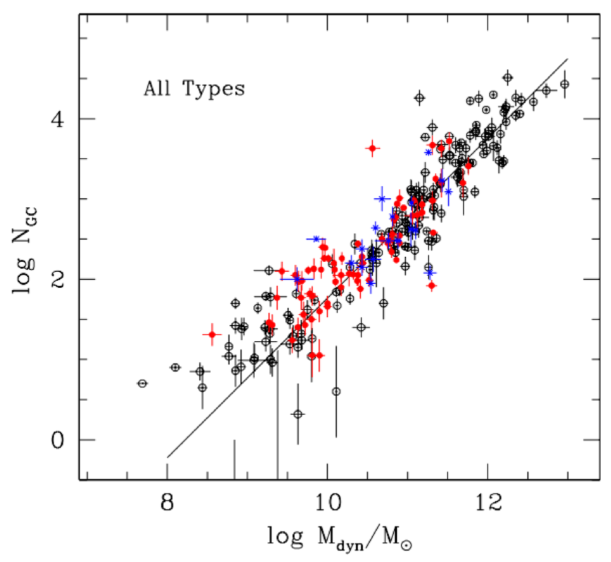

Figure 2. Plot showing number of GCs vs. dynamical mass for elliptical, spiral, and lenticular galaxies. Open circles represent ellipticals, solid red circles represent lenticulars, and blue crosses represent spirals [4].

We estimate the numbers of GCs in UDGs by first identifying GC candidates, and then performing a statistical background subtraction.

Data

The UDGs we examine in this study are in the Coma cluster, imaged by the Subaru Telescope and Hyper Suprime Cam through g- and r-band filters. The Subaru Telescope has an 8.2 m diameter and a 1.5° diameter field of view. This data has the same depth as the data used by Koda et al. in their 2015 study [2]. Our galaxy sample contains 775 UDGs all with effective radii greater than or equal to 1.5 kpc.

Methodology

We remove galaxy models generated by GALFIT [5] from the original images using the parameters derived by Bautista et al. [6]. This enables Source Extractor (SE) [7] to better detect point sources on top of the UDGs. SE outputs a catalog of objects' positions, sizes, and magnitudes. We select GC candidates based on the sizes, colors, magnitudes, and axis ratios typical of GCs in the Coma cluster.

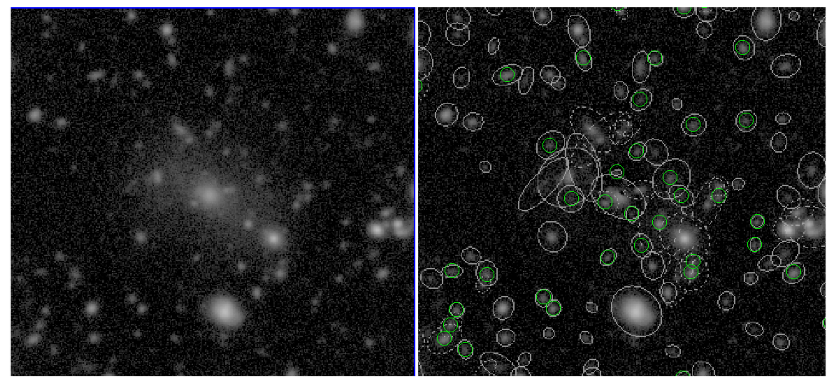

Figure 3. (a) A UDG in the Coma cluster. (b) The same image with the galaxy removed. Grey outlines indicate objects detected by SE. GC candidates are circled in green.

Background Subtraction Steps:

- Calculate the area of the UDG and background
  - For UDGs with $R_e < 7.5$ arcseconds, we took the UDG's radius to be 20 arcseconds.
  - If $3R_e > 20$ arcseconds, we took the UDG's radius to be 30 arcseconds. If $3R_e > 30$ arcseconds, we took the UDG's radius to be 40 arcseconds, etc.
  - The background extends from the edge of the UDG's assumed radius to 4.0 arcminutes.
- Calculate the average object density in the UDG and background
- Subtract the average background density from the average UDG density
- Multiply the difference by the area of the UDG

This calculation provides a lower-limit estimate. Some GCs are too faint to appear in the raw images. The luminosity function of the GCs in a UDG is approximately a normal distribution [3]. By fitting a Gaussian curve to the data after subtracting the background, we can obtain an estimate that accounts for the fainter GCs.

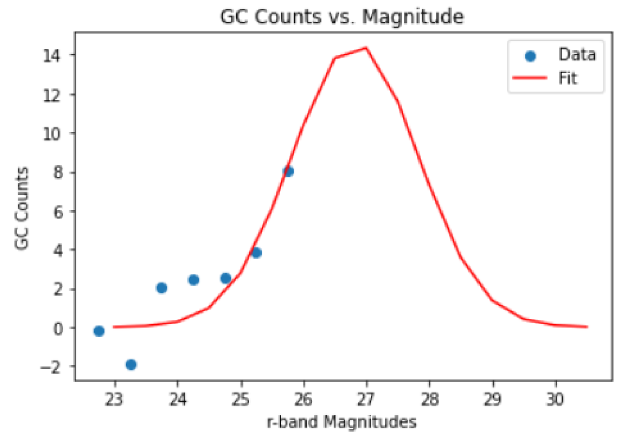

Figure 4. Luminosity function for the GCs in the same UDG as in Fig. 3. The fitted curve is a normal distribution centered on 26.8 mag.

Results

Some UDGs have a higher density of GC candidates than the background; others do not. Plotting the average density vs. distance for all UDGs shows that on average, there is an excess of GCs candidates on top of the UDGs.

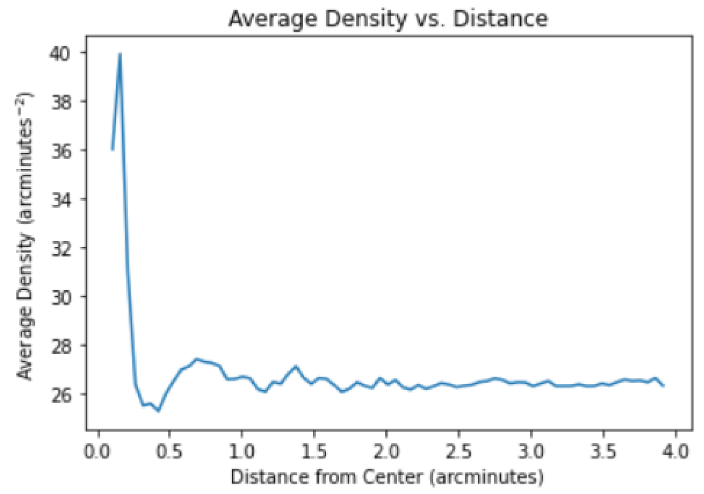

Figure 5. Average density vs. distance for all 775 UDGs.

GC estimates for individual UDGs range from -22.5 to 44.8 Negative estimates result from UDGs with GC candidate densities matching that of the background.

For the UDG in Fig. 3, we find 48 GC candidates on top of the galaxy. After subtracting the background, we conclude that a minimum of 17 are associated with the UDG. Integrating the curve fitted to the luminosity function produces a total estimate of 35.5 GCs. The lower limit is 47.9% of the total estimate. This suggests that the lower-limit estimate for the other UDGs is about 47.9% of the total count.

The average lower-limit of GC candidates for all 775 UDGs is 0.94, or an average dynamical mass of ~$1.3 \times 10^8\ M_\odot$. An average estimate close to zero is mathematically expected based on Fig. 6. For UDGs with GC estimates between 10 and 20, the corresponding dynamical mass is between $2 \times 10^9 M_\odot$ and $2.5 \times 10^9\ M_\odot$. One extreme outlier has a lower-limit GC estimate of 44.8, or a dynamical mass of $3.2 \times 10^9\ M_\odot$

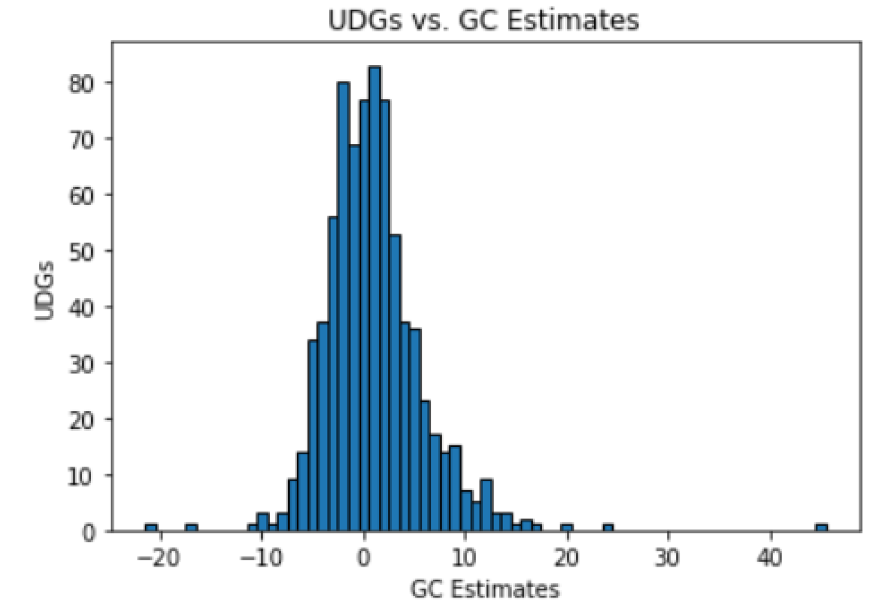

Figure 6. Graph showing the numbers of UDGs with each GC candidate estimate.

423 UDGs have a lower-limit GC estimate above zero, and 351 UDGs have a lower-limit estimate below zero. 1 UDG has an estimate of zero. The distribution of GC estimates for all 775 UDGs in our sample is shaped approximately like a normal distribution centered on 0, with a slight preference toward positive values.

Conclusion

We statistically estimate the numbers of GCs in UDGS and use the GC counts to estimate UDGs' dynamical mass. Dynamical mass calculations follow the assumption that the relationship between M_{dyn} and the number of GCs is the same in UDGs as in normal galaxies. GC estimates vary greatly for individual UDGs. The variety among individual results may be attributable to varying characteristics among the UDGs themselves. For instance, the UDGs in our sample have effective radii ranging from 0.053 to 0.35 arcminutes. Additionally, efficiency at detecting point sources on top of the galaxy varies slightly among UDGs because the GALFIT-based galaxy subtraction leaves some galaxy emission on some UDGs. Improving the galaxy subtraction may improve the accuracy of measurements.

The average lower limit is 0.94 GCs per UDG; this corresponds to a lower dynamical mass limit of $1.3 \times 10^8\ M_\odot$. This result indicates that UDGs have the dark halo masses of dwarfs rather than Milky Way-sized galaxies. The Milky Way has a dynamical mass of about $10^{12} M_\odot$. Even after accounting for the fainter, undetected GCs, and allowing a wide margin of error, UDGs' dynamical masses remain within the range of dwarfs.

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