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Globular Clusters as Probes of the Formation History of Elliptical Galaxies: Results for NGC 4472

K.L. Rhode and S.E. Zepf

Yale University Dept. of Astronomy, New Haven, CT, USA

Abstract. We have undertaken a survey of the globular cluster systems of a large sample of elliptical and spiral galaxies in order to test predictions of elliptical galaxy formation models. Here we outline the survey and present a summary of our results for the Virgo elliptical NGC 4472.

1. Introduction

Globular clusters (GCs) are among the oldest readily-observable objects in the Universe and are seen in all types of galaxies, thus serving as useful probes of galaxy formation and evolution. In fact, models describing elliptical galaxy formation make specific predictions regarding the properties of the galaxies' GC systems (e.g., Ashman & Zepf 1992; Forbes, Brodie, & Grillmair 1997; Côté, Marzke, & West 1998). We are carrying out a survey of the GC systems of a large sample of elliptical and spiral galaxies in order to test the predictions of elliptical galaxy formation models. Using wide-field mosaic CCD imagers on the Mayall 4-meter and WIYN telescopes at Kitt Peak National Observatory (KPNO), we have observed 4 ellipticals and 9 edge-on spirals. We aim to quantify the total numbers, spatial distributions, and color distributions of their GC systems out to large radii. In addition to more than doubling the spatial coverage of the best CCD studies, we use 3-filter photometry, image classification analysis, and archival HST data to significantly reduce and account for any contamination present in our GC samples. Due in part to our techniques for reducing contamination, our measured GC specific frequency for the Virgo elliptical NGC 4472 is smaller than previous determinations. Here we summarize the results for NGC 4472; details appear in Rhode & Zepf (2001).

2. Observations & Analysis

NGC 4472 is a giant elliptical located ~4 degrees from the center of the Virgo cluster. *BVR* images of NGC 4472 and 3 other early-type galaxies were taken in March 1999 with the Mosaic Imager on the KPNO 4-m telescope. The Mosaic consists of 8 2048 x 4096 CCDs and on the 4-m has a $36'$ x $36'$ field-of-view. The data were reduced using standard procedures and a stacked image was created in each filter. Photometric calibration was done using WIYN images taken in January 2000. Tests with artificial stars indicate that the 50% completeness limits for the NGC 4472 images are: B = 23.3, V = 23.7, R = 22.8.

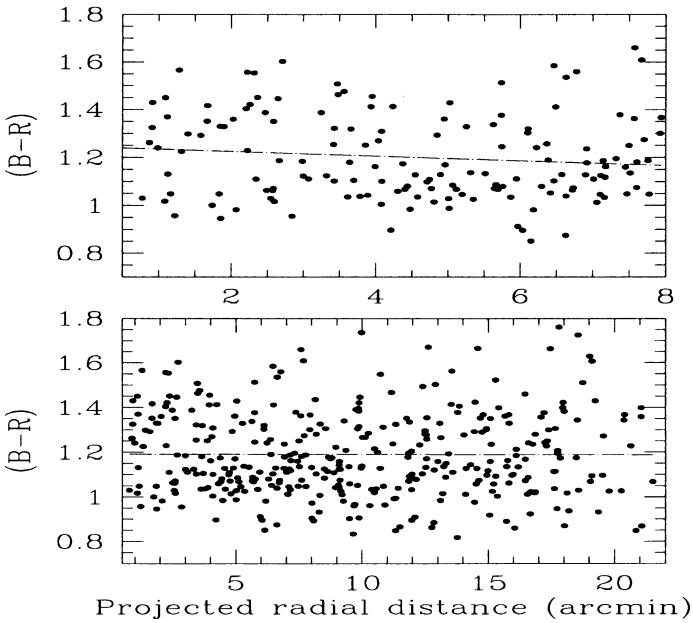

Figure 1. $B - R$ color vs. radius for a subsample of GC candidates around NGC 4472. A color gradient in the inner $8'$ vanishes when the full radial range ($22'$, or ~107 kpc) is included.

GCs at the distance of Virgo (~17 Mpc) are unresolved in our images. To detect them, we removed the galaxy light by subtracting a smoothed version of each image from the original. DAOFIND was used to find ~4000 sources appearing in all 3 filters. About 900 extended objects were then eliminated from this list. Aperture photometry on the remaining objects yielded magnitudes and colors. A list of 1465 GC candidates was produced by selecting objects whose V magnitudes and $B - V$ and $V - R$ colors were in the expected range for GCs.

Contamination from foreground stars or background galaxies poses a problem for ground-based studies of extragalactic GC systems. Using high-resolution imaging and 3-filter photometry significantly reduces the contamination in our GC sample. To quantify how much remains, we used HST images, spectroscopic data and Galactic star count models. The total surface density of contaminating objects in the GC candidate sample is $\lesssim 0.264$ objects per sq. arc minute. This is *an order of magnitude less contamination* compared to previous studies (e.g., Harris 1986; Lee, Kim, & Geisler 1998). Moreover, accurately quantifying the contamination level allows us to better correct for it.

3. Summary of Main Results

Radial profile and local S_N. — Our observed radial profile suggests that NGC 4472's GC system does not extend beyond ~120 kpc (i.e., our measured GC surface density is consistent with zero in the 3 outermost radial bins). Models that

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invoke tidal stripping as the mechanism by which GC systems of giant cluster ellipticals are formed assume a shallow power-law radial profile out to large radius. Our observations do not support this assumption.

Color gradient.— All the models we consider predict or assume that the blue (metal-poor) GC population is more spatially extended than the red (metal-rich) one. At small radii ($<8'$), we observe a color gradient in the GC system due to the increasing ratio of blue to red GCs with radius. The gradient vanishes, however, when the entire radial extent of the data is included (see Fig. 1). The flattening of the color gradient is not consistent with any of the current models.

Specific frequency.— We find a specific frequency (S_N) of 3.6 ± 0.6, compared to past studies that found $S_N \sim 5-6$ (Harris 1986; Lee et al. 1998). We suggest past values were inflated due to contamination by foreground and background objects. Accurately determined S_N values are crucial for testing formation models, since all the models seek to explain the differences in total numbers of GCs for disk galaxies vs. ellipticals. For example, Ashman & Zepf (1992) predict that the mass-normalized numbers of metal-poor GCs around ellipticals and spirals are the same. Even with our smaller S_N, it appears that there are still slightly more metal-poor GCs per unit mass in NGC 4472 than can be accounted for by merging the halo GC populations of spirals like the Milky Way and M31.

4. Future Work

Our Mosaic observations of NGC 4472 pose a challenge in one way or another to all the galaxy formation models we considered. Our goal is to be able to draw more general conclusions by studying more ellipticals, in various environments. Accordingly, we are analyzing Mosaic images of the Virgo elliptical NGC 4406 and two early-type field galaxies, NGC 3379 and NGC 4594. Another objective is to quantify the total numbers, color distributions, and spatial distributions of GCs in a sample of spiral galaxies in order to establish what the typical properties of a spiral GC system are. This will enable us to test models that propose that ellipticals are formed via the merger of two or more disk galaxies. With this in mind, we have observed a sample of 9 edge-on spirals with the WIYN telescope. Stay tuned for more results!

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