SIZES OF CONFIRMED GLOBULAR CLUSTERS IN NGC 5128: A WIDE-FIELD HIGH-RESOLUTION STUDY

Matías Gómez
Grupo de Astronomía, Departamento de Física, Universidad de Concepción, Casilla 160-C, Concepción, Chile; matias@astro-udec.cl

Kristin A. Woodley
Department of Physics and Astronomy, McMaster University, Hamilton, ON L8S 4M1, Canada; woodleka@physics.mcmaster.ca

Received 2007 September 7; accepted 2007 October 8; published 2007 October 30

Abstract

Using Magellan/IMACS images covering a 1.2 \times 1.2 deg\(^2\) field of view with seeing of 0.4"–0.6", we have applied convolution techniques to analyze the light distribution of 364 confirmed globular clusters in the field of NGC 5128 and to obtain their structural parameters. Combining these parameters with existing Washington photometry from Harris et al., we are able to examine the size difference between metal-poor (blue) and metal-rich (red) globular clusters. For the first time, this can be addressed on a sample of confirmed clusters that extends to galactocentric distances about 8 times the effective radius, \(R_{\text{eff}}\), of the galaxy. Within 1\(R_{\text{eff}}\), red clusters are about 30\% smaller on average than blue clusters, in agreement with the vast majority of extragalactic globular cluster systems studied. As the galactocentric distance increases, however, this difference becomes negligible. Thus, our results indicate that the differences between the effective radii, \(r_e\), of the clusters could be explained purely by projection effects, with red clusters being more centrally concentrated than blue ones, and by an intrinsic \(r_e-R_{\text{eff}}\) dependence, like the one observed for the galaxy.

Subject headings: galaxies: elliptical and lenticular, cD — galaxies: individual (NGC 5128) — galaxies: star clusters — globular clusters: general

Online material: color figure

1 INTRODUCTION

Since the sizes and structural parameters of globular clusters (GCs) in different GC systems (GCSs) have first been obtained, it has become clear that some of these properties correlate with the global properties of their host galaxies (see, e.g., Jordán et al. 2005 and Brodie & Strader 2006). The existence of the so-called fundamental-plane relation in an increasing number of studied GCSs seems to confirm that GCs populate a narrow region in this parameter space (Djorgovski 1995; McLaughlin 2000; McLaughlin & van der Marel 2005; Barmby et al. 2007). However, we are still awaiting the confirmation of some puzzling trends that need to be addressed by the use of larger samples of GCs.

It is necessary to study the structural parameters of GCs and GC-like objects in different environments before definitive statements can be made regarding their formation. Among the structural parameters that can be studied, the effective (or half-light) radius is of particular importance. Models have shown that this quantity remains fairly constant throughout the entire GC lifetime (Spitzer & Thuan 1972; Aarseth & Heggie 1998), making it a good indicator of proto-GC sizes that are still observable today. A decade ago, Hubble Space Telescope (HST) observations unveiled a systematic size difference between red and blue GCs (Kundu & Whitmore 1998). Since then, multiple studies have found that the blue GCs are between 17\% and 30\% larger than their metal-rich counterparts in both spiral and early-type galaxies (Kundu et al. 1999; Puzia et al. 1999; Larsen et al. 2001a, 2001b; Kundu & Whitmore 2001; Barmby et al. 2002; Jordán et al. 2005). However, most of these studies have made use of HST observations and examine only the innermost regions of the galaxy or small fields in regions at galactocentric distances greater than the galaxy’s effective radius.

According to Larsen & Brodie (2003), the systematic size difference between red and blue GCs is caused merely by a projection effect. Since red (metal-rich) GCs are found to be more centrally concentrated in early-type galaxies than blue (metal-poor) GCs are (Côté et al. 2001; Dirsch et al. 2003; Woodley et al. 2005), the red GCs will appear to lie, on average, at a smaller galactocentric distance. On average, the red clusters will be smaller than the blue clusters, assuming that both types shares the same relation between GC size and galactocentric distance. The relation \(r_e \sim R_{\text{eff}}\) was first found in the Milky Way by van den Bergh et al. (1991). In this scenario, the difference between the cluster sizes should be most apparent at a small galactocentric distance and should decrease strongly beyond 1 galaxy effective radius (Larsen & Brodie 2003).

Alternatively, Jordán (2004) suggests that this effect could be explained by an intrinsic difference between metal-rich and metal-poor GCs. Assuming half-mass radii that are independent of metallicity, Jordán (2004) proposed that the effects of mass segregation, combined with a metallicity-dependent stellar lifetime, should lead to different sizes between the blue and red clusters. The brightest stars would be more massive and more centrally concentrated for the metal-rich GCs. This scenario should have little or no effect on a cluster’s distance from the center of its parent galaxy.

In a recent study, Spitler et al. (2006) analyzed the GCS of NGC 4594 (Sombrero, at a distance of \(\sim 9\) Mpc) using a six-image mosaic from the Advanced Camera for Surveys (ACS) on HST. They confirm that within the inner 2′ (2.2\(R_{\text{eff}}\)), the metal-rich GCs are, on average, 17\% smaller than the metal-poor GCs. However, the size difference becomes negligible at \(\sim 3′\), corresponding to \(\sim 3.4 R_{\text{eff}}\), where \(R_{\text{eff}} = 0.89′\) (Baggett et al. 1998).

To further understand the sizes of red and blue clusters, we need a homogeneous survey of a GCS; this study should have the ability to eliminate contaminating sources, it should be of a high-resolution, so that we can measure the structural parameters of the GCS, and it should be over a large range in galactocentric distance.

NGC 5128 is the nearest giant elliptical galaxy, at a distance of 3.8 Mpc (McLaughlin et al. 2007). Its GCs are thus easily...
resolvable with subarcsecond seeing (Harris et al. 2006). In this Letter we present effective-radius results for 337 GCs from the Woodley et al. (2007) catalog that are either confirmed GCs by radial velocity measurements from various studies (see the references in Woodley et al. 2007) or resolved by HST/ACS images (Harris et al. 2006). We also present the effective radii of 27 GCs newly confirmed through radial velocity measurements by the Baade 6.5 m telescope, with the use of the low-dispersion survey spectrograph 2 (LDSS-2; data in preparation for publication). This list represents a clean sample of confirmed clusters. All of these also have ellipticities of less than 0.4 and effective radii of less than 8 pc, both of which are consistent with normal GC properties in NGC 5128. We find that only an additional 2.4% of GCs from the Woodley et al. (2007) catalog have effective radii greater than the 8 pc boundary that we have imposed here (to be discussed in detail in M. Gómez & K. A. Woodley 2008, in preparation). Those few GCs are not considered here, as our purpose is to establish the effective-radius trends within the bulk of the GC population.

2. OBSERVATIONS

On the night of 2006 April 9, 25 fields were imaged with the Magellan 6.5 m telescope using the Inamori Magellan Areal Camera and Spectrograph (IMACS). In the highest imaging resolution, IMACS offers a field of view of 15.4′ on a side, composed of a mosaic of eight 2K × 4K CCDs with a scale of 0.111″ pixel−1. Our observational material will be fully discussed in G. L. H. Harris et al. (2008, in preparation). The total field of view of our images is roughly 1.2 × 1.2 deg2, and the average seeing is about 0.5″ across the entire field, with individual frames ranging from 0.35″ to 0.7″. Images were acquired through B (on 16 of the 25 fields) and R (on all 25 fields) filters, with both 10 and 300 s exposures to avoid saturation of the brightest clusters.

We have identified all GCs in the catalog of Woodley et al. (2007) on our IMACS frames.2 We have run the code ISHAPE (Larsen 1999, 2001) individually on each GC in our R-filtered IMACS frames, using a stellar point-spread function (PSF) modeled from the chip in which the cluster is located. For this, typically 20–30 stars were chosen in each frame and were

2 Note that the positions of two GCs have been corrected: GC0001 with a corrected right ascension of 13h25m 1.16s (J2000) and GC0002 with corrected declination of −43°02′42.9″ (J2000).
measured with standard tools in IRAF. ISHAPE convolves the PSF with analytical profiles and compares the result with the input image, until a best match is achieved.

As the analytical model, we chose King (1962) profiles, because of their simplicity and because they are known to provide a good fit to a large family of GCs in different environments. Moffat functions were also tried, but they do not improve the fits, except for a handful of large and very elliptical sources that we are not considering for the present study. They will be discussed as special cases in a forthcoming paper. Possible systematic effects in the sizes, arising from the choice of a particular model, are discussed in Larsen (1999). However, the effective radius seems to be independent of the model for sources that have a similar extension to the stellar PSF, as in our case. For a recent comparison between different models, the reader is referred to Barmby et al. (2007) and McLaughlin et al. (2007).

King (1962) profiles are defined by a core radius $r_c$ and a concentration index, which we define here as $c = r_e/r_c$, where $r_e$ is the tidal radius of the cluster. Usually, the concentration parameter is the most uncertain one to constrain (Larsen 2001), but given the high spatial resolution of our IMACS images, we were able to fit it, along with the ellipticity, position angle, and $r_c$.

The sizes quoted by ISHAPE were transformed into effective radii by use of the approximation $r_e/r_c \approx 0.547c^{0.486}$, which is good to $\pm 2\%$ for $c > 4$ (Larsen 2001). The median value for the concentration parameter, for GCs in NGC 5128, was $c = 39.4 \pm 10.2$. Uncertainties in the effective radius were estimated by the standard deviation of the determined value by use of King profiles with fixed concentration indices of 15, 30, and 100. These concentration parameters were chosen on the basis of the typical values observed in our Galaxy as well as on the concentration parameters that were fit freely with ISHAPE for the NGC 5128 data. The $r_e$ values determined for any given cluster with varying concentration parameters does not vary more than $\sim 10\%$ for the average GC. The concentration parameter, $c$, is the most uncertain of the fitted parameters. The extension of the GC is a secondary uncertainty. A GC at the distance of NGC 5128, with an effective radius of 6 pc, would span a diameter of 0.6', marginally larger than the typical stellar FWHM. For smaller or more compact objects, the intrinsic size can be as small as 0.1'' (i.e., completely blurred, even with subarcsecond imaging).

3 RESULTS

We have 69 GCs that are also in the HST/ACS structural parameter study of Harris et al. (2006). Their $r_e$ values, derived by an isophotal analysis of the resolved clusters and discussed fully in McLaughlin et al. (2007), serve as an external comparison and as a quality test for our measurements. Figure 1 shows clearly that there is good agreement in the $r_e$ values determined by these independent techniques. We have also examined our measured differences between the $r_e$ values as a function of ellipticity and luminosity and have found no notable correlation.

In an upcoming paper (M. Gómez & K. A. Woodley 2008, in preparation), we will discuss the structural parameters in detail as well as the new GCs discovered with the Baade 6.5 m telescope (mentioned above) that have been used in this study. Here we focus on the dependence of the GC sizes as a function of galactocentric radius, $R_g$, for the GC subpopulations. A metallicity break has been chosen to represent the red or metal-rich ([Fe/H] $> -1$) and blue or metal-poor ([Fe/H] $< -1$) subpopulations of clusters, following the studies of Larsen & Brodie (2003), Harris et al. (2004), Woodley et al. (2005, 2007), and Gómez et al. (2006). The [Fe/H] values were obtained from a

![Figure 4](image-url)

Figure 4.—Effective radius, $r_e$ in parsecs, as a function of projected galactocentric radius, $R_g$, in kiloparsecs, for the GCs in NGC 5128 (open circles) and in the Milky Way (MW, crosses), for both the metal-poor GCs ([Fe/H] $< -1$) on the top and metal-rich GCs ([Fe/H] $> -1$) on the bottom. The Milky Way GC data are taken from Harris (1996), with the projected galactocentric radius defined as $R_g = (\alpha^2 + \epsilon^2)^{1/2}$ and $R_g = 2.7$ kpc (de Vaucouleurs & Pence 1978). Best-fit curves of the form $r_e = c(R_g/R_{\text{eff}})^{\alpha}$ yield ($c = 3.22 \pm 0.12$, $\alpha = 0.05 \pm 0.05$) and ($c = 2.76 \pm 0.14$, $\alpha = 0.26 \pm 0.06$) for the metal-poor and metal-rich GCs in NGC 5128 (dashed curves), along with ($c = 3.02 \pm 0.17$, $\alpha = 0.17 \pm 0.04$) and ($c = 3.16 \pm 0.21$, $\alpha = 0.36 \pm 0.07$) for the metal-poor and metal-rich GCs in the Milky Way (solid curves). [See the electronic edition of the Journal for a color version of this figure.]
in the metal-rich GCs. The Milky Way data, on the other hand, have been shown to host the $r_{\text{eff}}-R_e$ relationship for both metallicity populations, first noted by van den Bergh et al. (1991) using a three-dimensional $R_e$. However, in projection, the metal-poor GCs in the Milky Way do not appear vastly different from those in NGC 5128.

4. DISCUSSION

The existence of a systematic difference between the effective radii of blue and red clusters has been extensively studied in other galaxies, with blue clusters typically found to be 17–30% larger than red ones (see § 1). However, in NGC 5128, Harris et al. (2002) did not find any correlation between color and size in a sample of 27 GCs, by the use of the Wide Field Planetary Camera 2 on HST. In a subsequent study, Gómez et al. (2006) found the red GCs to have larger median sizes compared with the blue clusters, in a sample of 38 objects, by the use of Magellan/MagIC. Both studies were based on small field images, involved small sample sizes, and were centered at large $R_e$. (At the smallest $R_e$, this was more than 2 times farther than the $R_{\text{eff}}$ of the galaxy light.) According to Larsen & Brodie (2003), the average sizes of red and blue clusters should be similar at about $1R_{\text{eff}}$, and beyond, if projection effects are to account for the size difference. The results from Harris et al. (2002) and Gómez et al. (2006) are consistent with this scenario, bearing in mind the low number statistics of their studies.

This work and Spitler et al. (2006) are the only two studies thus far with a large enough sample of GCs that also extends beyond $1R_{\text{eff}}$. Both studies show that the red clusters are smaller within $1R_{\text{eff}}$ than the blue clusters and that they are identical in size beyond this distance. In the ACS Virgo Cluster Survey, Jordán et al. (2005) have studied the sizes of GCs in 67 early-type galaxies. Their analysis reaches about 3 times the effective radius of the massive ellipticals studied, and these GCSs dominate their sample. However, their results, which find red clusters to be consistently smaller than blue clusters, are dominated by the inner GCs in these galaxies.

Our sample consists of only confirmed GCs that have been analyzed homogeneously and that span a projected galactocentric distance of up to 50 kpc (i.e., 8 times the effective radius, $R_{\text{eff}}$) of the galaxy. Thus, we are able to draw conclusions about the origin of the size difference by use of a sample that is both uncontaminated and much more spatially extended than in previous studies.

As is evident from Figures 2, 3, and 4, metal-poor clusters do not show an $r_{\text{eff}}-R_e$ relationship. Jordán et al. (2005) analyze this trend for metal-poor clusters in their samples and conclude that they are too shallow, compared with the Galaxy, for the projection effects to account for the size difference. Our results for NGC 5128 agree with this but, at the same time, make it clear that the metal-poor subpopulation does not represent the global $r_{\text{eff}}-R_e$ trend. In fact, only metal-rich clusters show this trend. Therefore, projection effects can account for the observed size differences, without the need of intrinsic formation and destruction mechanisms between red and blue clusters.

5. CONCLUSIONS

Using a contaminant-free sample of 364 GCs in NGC 5128, confirmed with radial velocity measurements or by resolved HST images, we have measured effective radii with ISHAPE. Our results indicate that the blue or metal-poor clusters do not show any significant $r_{\text{eff}}-R_e$ relation. However, the red or metal-rich GCs do show a steep relation, in which red clusters within $1R_{\text{eff}}$ of the galaxy’s light are 30% smaller than the blue clusters. Beyond this distance, there is no indication of a size difference between the two metallicity populations. This finding in NGC 5128, not previously seen in any other early-type galaxy, supports the more tentative findings of the Sombrero galaxy’s GCS (Spitler et al. 2006). Both studies support the idea that the size differences are most likely caused by projection effects (Larsen & Brodie 2003) and not the result of intrinsic physical differences between the two subgroups.

M. G. and K. A. W. thank Dean McLaughlin for use of his HST structural parameters in advance of publication. M. G. thanks the Department of Physics and Astronomy at McMaster University, especially Bill and Gretchen Harris for their hospitality. K. A. W. thanks NSERC and Bill Harris for financial support, and also the Departamento de Física at the Universidad de Concepción, especially Doug Geisler for his hospitality. We thank the anonymous referee for her/his valuable suggestions and comments.

REFERENCES

Aarseth, S. J., & Heggie, D. C. 1998, MNRAS, 297, 794
Baggett, W. E., Baggett, S. M., & Anderson, K. S. 1998, AJ, 116, 1626
Barmby, P., Holland, S., & Huchra, J. P. 2002, AJ, 123, 1937
Barmby, P., McLaughlin, D. E., Harris, W. E., Harris, G. L. H., & Forbes, D. A. 2007, AJ, 133, 2764
Brodie, J. P., & Strader, J. 2006, ARA&A, 44, 193
Côté, P., et al. 2001, ApJ, 559, 828
de Vaucouleurs, G., & Pence, W. D. 1978, AJ, 83, 1163
Dirsch, B., Richtler, T., Geisler, D., Forte, J. C., Bassino, L. P., & Gieren, W. P. 2003, AJ, 125, 1908
Djorgovski, S. 1995, ApJ, 438, L29
Gómez, M., Geisler, D., Harris, W. E., Richtler, T., Harris, G. L. H., & Woodley, K. A. 2006, A&A, 447, 877
Harris, G. L. H., Harris, W. E., & Geisler, D. 2004, AJ, 128, 723
Harris, W. E. 1996, AJ, 112, 1487
Harris, W. E., & Harris, G. L. H. 2002, AJ, 123, 3108
Harris, W. E., Harris, G. L. H., Barmby, P., McLaughlin, D. E., & Forbes, D. A. 2006, AJ, 132, 2187
Harris, W. E., Harris, G. L. H., Holland, S. T., & McLaughlin, D. E. 2002, AJ, 124, 1435
Jordán, A. 2004, ApJ, 613, L117
Jordán, A., et al. 2005, ApJ, 634, 1002
King, I. R. 1962, AJ, 67, 471
Kundu, A., & Whitmore, B. C. 1998, AJ, 116, 2841
Kundu, A., & Whitmore, B. C. 2001, AJ, 121, 2950
Kundu, A., Whitmore, B. C., Sparks, W. B., Macchetto, F. D., Zepf, S. E., & Ashman, K. M. 1999, ApJ, 513, 733
Larsen, S. S. 1999, A&AS, 139, 393
Larsen, S. S. 2001, AJ, 122, 1782
Larsen, S. S., & Brodie, J. P. 2003, ApJ, 593, 340
Larsen, S. S., Brodie, J. P., Huchra, J. P., Forbes, D. A., & Grillmair, C. J. 2001a, AJ, 121, 2974
Larsen, S. S., Forbes, D. A., & Brodie, J. P. 2001b, MNRAS, 327, 1116
McLaughlin, D. E. 2000, ApJ, 539, 618
McLaughlin, D. E., Barmby, P., Harris, W. E., Harris, G. L. H., & Forbes, D. A. 2007, MNRAS, submitted
McLaughlin, D. E., & van der Marel, R. P. 2005, ApJ, 616, 304
Puzia, T. H., Kissler-Patig, M., Brodie, J. P., & Huchra, J. P. 1999, AJ, 118, 2734
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Spitler, L. R., Larsen, S. S., Strader, J., Brodie, J. P., Forbes, D. A., & Beasley, M. A. 2006, AJ, 132, 1593
Spitzer, L., Jr., & Thuan, T. X. 1972, ApJ, 175, 31
van den Bergh, S., Morby, C., & Pazder, J. 1991, ApJ, 375, 594
Woodley, K. A., Harris, W. E., Beasley, M. A., Peng, E. W., Bridges, T. J., Forbes, D. A., & Harris, G. L. H. 2007, AJ, 134, 1994
Woodley, K. A., Harris, W. E., & Harris, G. L. H. 2005, AJ, 129, 2654