Dynamical Evolution of Dense Stellar Systems
Proceedings IAU Symposium No. 246, 2007
E. Vesperini, M. Giersz & A. Sills, eds.

doi:10.1017/S1743921308016074

Masses and M/L Ratios of Bright Globular Clusters in NGC 5128

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Abstract. We present an analysis of the radial velocities and velocity dispersions for 27 bright globular clusters in the nearby elliptical galaxy NGC 5128 (Centaurus A). For 22 clusters we combine our new velocity dispersion measurements with the information on the structural parameters, either from the literature when available or from our own data, in order to derive the cluster masses and mass-to-light (M/L) ratios. The masses range from $1.2 \times 10^5 \mathrm{M}_\odot$, typical of Galactic globular clusters, to $1.4 \times 10^7 \mathrm{M}_\odot$, similar to more massive dwarf globular transition objects (DGTOs) or ultra compact dwarfs (UCDs) and to nuclei of nucleated dE galaxies. The average M/L_V is 3 ± 1, larger than the average M/L_V of globular clusters in the Local Group galaxies. The correlations of structural parameters, velocity dispersion, masses and M/L_V for the bright globular clusters extend the properties established for the most massive Local Group clusters towards those characteristic of dwarf elliptical galaxy nuclei and DGTOs/UCDs. The detection of the mass-radius and the mass-M/L_V relations for the globular clusters with masses greater than $\sim 2 \times 10^6 \mathrm{M}_\odot$ provides the link between "normal" old globular clusters, young massive clusters, and evolved massive objects.

Keywords. galaxies: star clusters, galaxies: elliptical and lenticular, cD, galaxies: individual (NGC 5128)

1. Introduction

The properties of globular clusters and the observed correlations between their various internal structural and dynamical parameters offer empirical constraints for the formation of globular clusters and for the star formation history of the host galaxy. A large number of empirical relations have been found between various properties (core and half-light radii, surface brightnesses, velocity dispersions, concentrations, luminosities, metallicities, etc.) of the globular clusters in the Milky Way and its satellite galaxies (Djorgovski & Meylan 1994; McLaughlin & van der Marel 2005). Many of them are mutually dependent due to the fact that globular clusters have very simple structures that can be well approximated by isotropic, single-mass King (1966) models.

Ultra compact dwarf galaxies (UCDs) or dwarf globular transition objects (DGTOs) are compact massive objects discovered first in the Fornax cluster (Hilker *et al.* 1999), and later also in Virgo, Centaurus and Hydra clusters (Haşegan *et al.* 2005; Mieske *et al.* 2007; Wehner & Harris 2007). They are more luminous, more massive, and more extended than typical Galactic globular clusters. Their ages are similar to those of old globular clusters (see review by Hilker 2006). Are UCDs/DGTOs related to massive globular clusters, or are they more similar to compact dwarf galaxies?

Young massive clusters (YMCs) form in starbursts and mergers. Their masses are in the range of those of the most massive globular clusters observed around massive elliptical galaxies ($> 10^6$ M$_\odot$), or even comparable to UCDs ($> 10^7$ M$_\odot$). Question is whether they will evolve to become normal massive globular clusters or even more extreme UCDs.

Given the bright magnitudes and large masses of UCDs/DGTOs and YMCs it is appropriate to compare their properties to those of the most massive "normal" globular clusters, which are typically found around elliptical galaxies. While our Galaxy contains only a handful of clusters with masses in excess of 10^6 M$_\odot$, many more are expected to be present in giant elliptical galaxy halos. At the distance of 3.8 Mpc (Rejkuba 2004), the closest giant elliptical galaxy and easiest to observe in detail is NGC 5128 (=Centaurus A). Martini & Ho (2004) presented first measurements of masses and mass-to-light (M/L) ratios of 14 bright clusters in this galaxy. This sample was extended by adding new mass and M/L$_V$ measurements of bright globular clusters observed with UVES echelle spectrograph at ESO VLT, and with EMMI at ESO NTT (Rejkuba *et al.* 2007). We summarize here the main results of that work.

2. Velocity dispersion measurements

We have observed 23 bright clusters in NGC 5128 with UVES Echelle spectrograph at Kueyen VLT, and 10 clusters with EMMI at NTT. Velocity dispersions of these clusters were measured from the observed integrated light spectra using the well established cross-correlation technique. The templates for cross-correlation were bright stellar spectra, obtained during the same observing runs as our bright clusters. The cross-correlation of star-star spectra was used to determine instrumental profiles, and extensive simulations were done to assess the accuracy of the measurements and systematics. According to these simulations our velocity dispersion measurements were accurate to ~ 1 km/s for almost all our targets.

Our target's apparent V-band magnitudes ranged from 17.1 to 19.4, corresponding to absolute magnitudes of $M_V = -11.1$ to -8.9. The measured velocity dispersions were between 5 and 30.5 km/s. For comparison, the central velocity dispersion of the most massive Galactic globular cluster ω Cen is 22 km/s, while G1 in M31 has 27.8 km/s. Due to finite slit width (1") and the seeing of mostly ~ 0.8" during the observations, aperture corrections were small. The measured velocity dispersions were on average $\sim 6\%$ smaller than the central velocity dispersion.

In total we derived velocity dispersions for 22 clusters observed with UVES and 10 clusters observed with EMMI. Five clusters were in common to the two samples, hence we measured velocity dispersions for 27 different clusters. Our measurements are in very good agreement with those of Martini & Ho (2004), for 10 clusters in common, and the measurements for clusters observed with both UVES and EMMI agree within the errors. Nowadays there are in total 31 different globular clusters in NGC 5128 with accurate velocity dispersion measurements.

3. Masses and M/L ratios

Structural parameters, in particular the cluster half-mass radius r_h, are necessary to derive the masses. We have taken the structural parameters from the literature, where available, but for 7 clusters we derived their structural parameters by fitting King profiles to the high resolution FORS1 images (Rejkuba *et al.* 2007). In total we had structural parameters for 22 clusters in our sample.

https://doi.org/10.1017/S1743921308016074 Published online by Cambridge University Press

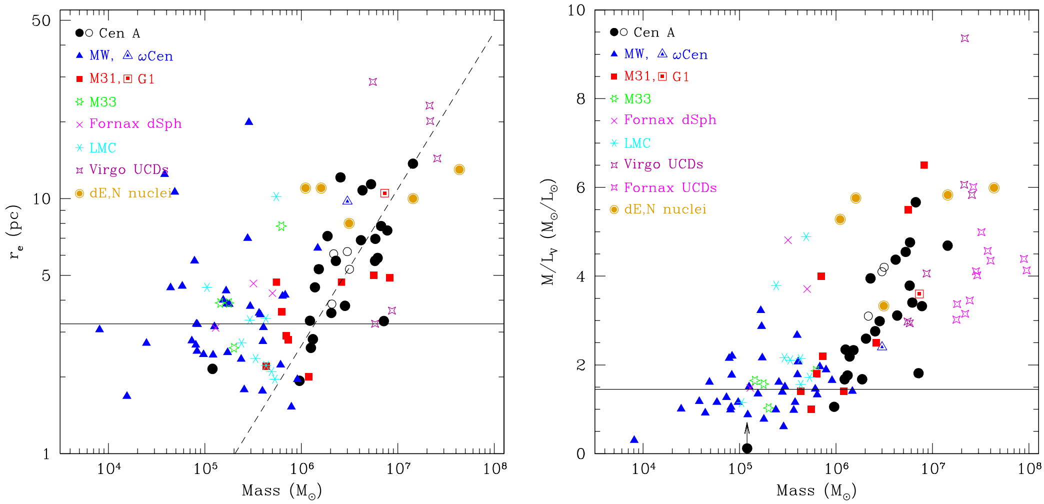

Figure 1. Left: Mass vs. effective (half-light) radius for massive star clusters in NGC 5128 is compared to DGTOs/UCDs and dE,N nuclei, as well as to the less massive globular clusters in the Local Group galaxies: the Milky Way, M31, M33, LMC, and Fornax dSph. A relation consistent with Faber-Jackson relation for hot galaxy sized systems emerges for objects more massive than $1 - 2 \times 10^6$ M$_\odot$. Dashed line shows the dependence for bright elliptical galaxies (Eq. 12 from Haşegan *et al.* 2005), while the solid line represents the median $r_e = 3.2$ pc for Galactic globular clusters. Right: Mass vs. M/L for massive clusters and UCDs. The solid line is the average dynamically determined $M/L = 1.45$ for Galactic globular clusters.

Masses were calculated using the Virial Theorem:

$$M_{vir} \simeq 2.5 \frac{3\sigma^2 r_h}{G} \tag{3.1}$$

where $3\sigma^2$ is the mean square velocity of the stars (assuming an isotropic velocity distribution), and r_h is the cluster half-mass radius, which is related to the half-light (effective) radius r_e through $r_e \approx 3r_h/4$. All the observed targets had radial velocities and structural parameters within the ranges expected for globular clusters belonging to NGC 5128, hence confirming their membership.

The least massive cluster, R122 (Rejkuba 2001), in our sample had 1.2×10^5 M$_\odot$. This mass is typical for Galactic globular clusters, but its magnitude ($M_V = -10.2$) indicates brighter than average cluster. However, its magnitude, structural parameters, and mass have larger errors due to the presence of stellar light, probably from a foreground source, which was visible in the integrated light spectra. The masses of all the other targets ranged from 1×10^6 to 1.4×10^7 M$_\odot$. Only the most luminous Galactic globular clusters have masses in excess of 10^6 M$_\odot$, and the most massive cluster in our Galaxy, ω Cen, has 3×10^6 M$_\odot$. UCDs/DGTOs and some YMCs have masses in the range of $10^6 - 10^8$ M$_\odot$ (Kissler-Patig, Jordán, & Bastian 2006).

Dividing the derived masses with V-band luminosities we derived M/L ratios for our targets. Leaving aside R122, M/L_V ratios range from 1.1 to 5.7, with an average of 3 ± 1, which is larger than average $M/L_V = 1.45$, determined dynamically for the Milky Way globular clusters (McLaughlin 2000).

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4. Correlation relations

We examined relations of central velocity dispersion (σ_0) with luminosity and with mass for the bright clusters in NGC 5128. They are both within the errors similar to those obeyed by the Galactic globular clusters, but the relation between σ_0 and mass shows a small deviation for the most massive objects (for details see Rejkuba *et al.* 2007).

The most remarkable results are shown in Fig. 1. In both panels we compare the properties of massive globular clusters in Cen A with globular clusters and other massive evolved compact objects. The references to the literature data are as follows: filled dots are used for our Cen A sample (Rejkuba *et al.* 2007); open symbols are clusters from Martini & Ho (2004) that are not in common with our sample; old globular clusters of the Milky Way, Fornax dSph, and LMC are from McLaughlin & van der Marel (2005); M33 clusters from Larsen *et al.* (2002); M31 clusters from Dubath & Grillmair (1997); ω Cen and $G1$ data from Meylan *et al.* (1995), and Meylan *et al.* (2001), respectively; Virgo and Fornax UCDs are from Haşegan *et al.* (2005), and Hilker *et al.* (2007); and dE,N nuclei data are from Geha, Guhathakurta & van der Marel (2002).

The left panel shows that the massive globular clusters follow similar mass-effective radius relation as other compact evolved objects. The dashed line (which is not a fit to the data) indicates that this relation is essentially the same one obeyed by the bright ellipticals. The YMCs follow the same mass-radius relation (Kissler-Patig *et al.* 2006).

In the right panel Fig. 1 displays the relation between the mass and M/L ratio for bright globular clusters and UCDs/DGTOs. The ordinary globular clusters in the Milky Way, M31, M33 and other smaller galaxies do not show any dependence of mass on M/L, and the average dynamically determined $M/L_V = 1.45$ for the Galactic globular clusters is shown with the horizontal solid line (McLaughlin 2000). However, the clusters more massive than $1 - 2 \times 10^6$ $M_\odot$, including ω Cen and G1 start obeying a relation where the larger the mass the higher the M/L.

5. Discussion and conclusions

We have explored the possible causes for the increase in M/L_V for the bright massive clusters: (i) the stellar and dynamical evolution of clusters in the tidal field of giant elliptical galaxy; (ii) the metallicity; and (iii) the initial mass function (IMF).

Baumgardt & Makino (2003) have made extensive numerical N-body simulations of the dynamical evolution of star clusters in the tidal field of the Galaxy. They find that the clusters in the last 10% of their lifetime, before being dissolved, increase their M/L ratios very fast. These results were also reproduced by a simple analytical description of the evolution of star clusters in the tidal field by Lamers *et al.* (2005). Therefore, if all the most massive clusters were caught during the last stage of their lifetime, an increase in the M/L ratio could be expected. However, this interpretation has difficulties to reproduce the constant M/L ratios for lower mass clusters, at the same time as an increase for the most massive clusters. It is expected that preferentially first the low-mass clusters are dissolved, but the details depend somewhat on the orbits and the galactic potential. Moreover, the relaxation times for the clusters more massive than 10^6 $M_\odot$ are longer than the Hubble time, and orbits passing extremely closely to the galactic center would be necessary for their disruption in less than 13 Gyr. Given the wide range of galactocentric distances of our targets, ranging up to 23.4 kpc, dynamical evolution cannot reproduce the observed trend of mass vs. M/L_V.

The more metal-rich stellar population is expected to have higher M/L. While on average the observed clusters are more metal-rich than the Milky Way sample, the colors

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of Cen A clusters are not consistently redder for the more massive or for clusters with increasing M/L_V. Instead there is a scatter in the color-M/L_V diagram, showing that some blue, metal-poor clusters have rather high M/L_V ratios of 4–5.

It is possible to select a combination of stellar evolutionary model parameters (IMF, age, metallicity) in order to fit the M/L ratios for Cen A clusters with single stellar population. However, in that case the models do not fit the Galactic globular clusters, indicating that other parameters need to be taken into account when interpreting the M/L and r_{eff} relations with mass.

It is quite probable that these massive objects do not have the simple single-age stellar populations, but that due to higher masses and deeper potential wells, they could retain the gas in the early evolution and have a self-enriched second population. In that case the simple stellar population models that are typically assumed for globular clusters, would not be valid any more, and a more sophisticated modelling would be required. Unfortunately at the distance of NGC 5128, we do not have the possibility to obtain accurate photometry for many stars necessary to detect multiple stellar populations. An observational fact in favour of this possibility is that the globular clusters that are known to have multiple stellar populations, ωCen in our Galaxy, and G1 in the M31, lie along the same mass vs. r_{eff} and mass vs. M/L_V relations as our targets.

Finally we point out that the bright globular clusters in NGC 5128 connect the regions of diagrams occupied by "normal" globular clusters and more massive evolved UCDs/DGTOs indicating perhaps a connection in formation and evolution history between these classes of objects. Also the mass-radius relation in YMCs could survive up to much later times, if these young massive clusters evolve into some of the most massive globular clusters.

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