Globular Clusters in nearby Galaxy Clusters

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Abstract. The discovery of a large population of intra-cluster star clusters in the central region of the Hydra I and Centaurus galaxy clusters is presented. Based on deep VLT photometry (V, I), many star clusters have been identified not only around the early-type galaxies, but also in the intra-cluster field, as far as 250 kpc from the galaxy centres. These intra-cluster globulars are predominantly blue, with a significant fraction being even bluer than the metal-poor halo clusters around massive galaxies. When interpreted as a metallicity effect they would have iron abundances around \([\text{Fe/H}] \simeq -2\) dex. However, they might also be relatively young clusters which could have formed in tidal tails during recent interactions of the central galaxies.

1 Introduction

In galaxy clusters the globular cluster (GC) population of a large variety of galaxies, ranging from giant ellipticals to dwarf galaxies, can be studied. As it turns out, the results of these studies might be very different from that of isolated galaxies in the field.

The most striking discovery in clusters is that the central giant galaxy (mostly a cD elliptical) often possesses an extra-ordinary rich globular cluster system (\(\simeq 6000-10000\) GCs) \([6]\) and also a high specific frequency (\(S_N \simeq 6-10\)) as compared to “normal” ellipticals (\(S_N \simeq 3\)).

To explain these findings various formation scenarios have been proposed. Among them are 1) the merging of major galaxies \([1]\), 2) the accretion of large numbers of dwarf galaxies/small fragments \([7],[3]\), or 3) a large, multiple dissipational collapse without a significant fraction of accretion or merger events \([5]\). One might here object that the true picture probably is very complex and that different mechanisms have been at work and acted at different epochs with changing efficiency. A first step towards a more realistic picture probably is to follow the formation of GC populations within the framework of a cosmologically motivated hierarchical merger tree of dark matter halos \([2]\).

Cosmological simulations for the formation and evolution of galaxy clusters show that the massive central galaxies are built up by continuous accretion of several smaller galaxies, especially in the first Giga years of structure formation \([4]\). However, also presently small groups of galaxies fall into the centres of clusters. It is natural to ask what happened with the globular clusters of the merged and accreted galaxies. How are they distributed today “after all the mess”? Have new clusters perhaps been formed in the interactions? Nearby galaxy clusters provide an ideal laboratory to study these issues in detail.
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Fig. 1. Projected spatial distribution of blue ($0.7 < (V - I) < 1.0$, grey dots) and red ($1.0 < (V - I) < 1.3$, dark dots) globular cluster candidates in the centre of the Centaurus cluster is shown. Ellipses indicate the location of the major galaxies. Circles and boxes mark the selected regions for the colour distribution of globular clusters in Fig. 2.

2 Globular cluster photometry in nearby galaxy clusters

In the following a galaxy cluster shall be defined as ‘nearby’ if it fulfils two conditions: 1) globular clusters are resolved as point sources, and 2) photometry can reach the turnover of the globular cluster luminosity function. Obviously the distance of galaxy clusters where these constraints are valid depends on the telescope one uses and the observing conditions.

Reachable clusters for 4m-class telescopes are the ones within a distance of about 30 Mpc (Virgo, Fornax and Antlia). Wide-field imagers can be used to cover their core area ($r_{\text{core}} \simeq 150$ kpc). Indeed many observations are underway to study the GCSs in these clusters, e.g. Dirsch et al. (this volume).

The GCs in galaxy clusters as far as 50 Mpc can be imaged by 8m-class telescopes. The HST might even reach further out ($\simeq 80$ Mpc, e.g. Coma cluster), but its usefulness is restricted by its small field-of-view. In this contribution, we present the photometric mapping of the core regions of the Hydra I and Centaurus galaxy clusters. Both are located at a distance of about 45 Mpc.
Hydra I and Centaurus were observed at dark time and under photometric conditions in the filters $V$ and $I$ with FORS1 at the VLT (ESO, Paranal). The seeing was in the range 0.5 to 0.7 arcsec, providing well resolved and very homogeneous data. Fig. 1 shows the seven pointings in Centaurus.

The Centaurus cluster is dynamically young with two merging sub-groups, a main cluster component (Cen30) around the cD galaxy NGC 4696 and a smaller group component (Cen45) around NGC 4709 $[9]$. The Hydra I cluster is dynamically evolved, has a regular core shape and an isothermal X-ray gas halo $[10]$. However, a small group of late-type galaxies around the spiral NGC 3312 just seems to cruise through the cluster centre.

## 3 Results for Hydra I and Centaurus

In both galaxy clusters, many star clusters have been identified down to the turnover magnitude of the globular cluster luminosity function at $V \approx 26.0$ mag. They are distributed not only around the early-type galaxies, but also in the intra-cluster field, as far as 250 kpc from the cluster centres (see Figs. 1 and 4). This is well outside the tidal radii of the central galaxies.

In the Centaurus cluster, the intra-cluster star clusters show a tidal tail like structure between the two dominant giant ellipticals (see Fig. 3). In Hydra I,
Fig. 3. Smoothed density maps of all globular cluster candidates (left) and very blue
\((0.7 < (V - I) < 0.85)\) cluster candidates (right) are shown. The ellipses indicate the
faintest measurable isophotes of the major galaxies at a surface brightness of
about \(\mu_V = 27.8\) mag/arcsec\(^2\). There are clear overdensities of clusters outside these
isophotes.

they are distributed asymmetrically around the central galaxy NGC 3311 and
occupy the same space as the abundant (newly found) dwarf spheroidal galaxies
(see Fig. 4). However, in both clusters the spatial coverage of the observations
is not sufficient to draw conclusions about their nature. The overdensity of star
clusters in the intra-cluster field is 3-4 times higher than for objects with the same
selection criteria in a background control field (see Fig. 3). Since the intra-cluster
star light is very faint (> 28 mag/arcsec\(^2\)), the estimated specific frequency of
the intra-cluster globulars is very high \((S_N > 10)\).

When looking at the colour distribution of globular clusters around the giant
ellipticals in Centaurus and Hydra I (Fig. 2), one first recognizes the familiar
bimodality, with peaks around \((V - I) \approx 0.9\) and \((V - I) \approx 1.1\) mag. The
bimodality is more pronounced in the outer parts of the galaxies, see Fig. 2
(middle panels) and Fig. 4 (lower left panel). Also the ratio of blue to red clusters
increases with galacto-centric distance. Already in Fig. 1 one notices that blue
clusters are more widely distributed than the red ones, which are concentrated
towards the galactic bulges.

The colour distributions of the intra-cluster star clusters in Centaurus is
dominated by blue clusters, as expected. But surprisingly, they peak around
\((V - I) \approx 0.8\) mag (see Fig. 3 right panels) which is slightly but noticeably
bluer than the old metal-poor clusters in the halos of the giant galaxies. Also in
the outer halo of NGC 3311 in Hydra I clusters with very blue colours are found
(see Fig. 4). These clusters might have been stripped from the late-type group
of galaxies around NGC 3312 that is passing by the core of Hydra I.
Interpretation of the very blue cluster population

The blue colour of the intra-cluster clusters can be interpreted in two ways. Either they are old and even more metal-poor than the metal-poor halo clusters in massive galaxies, or their blue colour indicates a young age and presumably higher metallicity. How would these clusters, far in the outskirts of the bulges of the central galaxies, fit into the picture of the different formation scenarios as presented in Sect. 1?

First let us suppose that these clusters are old and metal-poor. According to their $(V-I)$ colours their iron abundance would be around $-2.0$ dex. Very metal-poor globular clusters are known to exist around low mass dwarf ellipticals (e.g. Lotz et al., this volume), or might have formed in small proto-galactic fragments that were incorporated into the halo of a larger galaxy before becoming dwarf galaxies themselves. The large extended halo around central cluster galaxies might then have formed via the accretion of a large number of dwarf galaxies whose clusters have been stripped during their infall. In this case one would expect that the metal-poor GCs are distributed quite uniformly around the central galaxy, since any asymmetric accretion of metal-poor dwarfs/fragments at the formation epoch of the halo should have vanished over a Hubble time.
Second let us suppose that the blue clusters are young and rather metal-rich. Several age/metallicity combinations seem possible according to their \((V - I)\) colour only. But how could young clusters exist that far outside the bulges of their host galaxies without any sign of a corresponding young field star population and gas in their vicinity? One might imagine that these clusters have formed from material that has been thrown out in large tidal tails during a major merger. All the gas would have been consumed in this event and/or some rest gas was stripped rapidly and would fall into the centre of the merger remnant. The timescales are short, since any material could travel hundreds of kpc in much less than a Gyr, when assuming a reasonable velocity of few hundreds km/sec. Interestingly, in the Centaurus as well as in the Hydra I cluster, the central galaxy (NGC 4696 and NGC 3311) possesses prominent dust lanes in its centre that point to a rather recent accretion or merging event.

The feasibility of both scenarios makes a further investigation of the intra-cluster stellar population in both clusters very interesting and urgent.

5 What still has to be done

The presented data set still hasn’t been exploited fully. There are several issues in globular cluster astronomy that haven’t been touched yet by our analyses. As next steps we intend to 1) study the specific frequency of intra-cluster GCs as a function of centro-cluster distance, 2) study the individual GCs for all member galaxies down to the dwarf galaxy regime (colours, density profiles, \(S_N\), etc.), and 3) correlate the properties of the central GCs with those of the cD halo, the dwarf galaxy population and the X-ray gas. Moreover, follow-up \(U\) band photometry and multi object spectroscopy are planned to break the age-metallicity degeneracy for the blue clusters and confirm the membership of bright GC candidates and dwarf galaxies.

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