Formation, evolution, and survival of massive star clusters
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From a star cluster ensemble to its formation history

Christine Schulz[1] **and Michael Hilker**[1]

[1]European Southern Observatory (ESO),
Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany
email: `cschulz@eso.org, mhilker@eso.org`

Abstract. The present-day sample of ultra-compact dwarf galaxies (UCDs) and globular clusters (GCs) around NGC 1399 is interpreted to be composed of individual star cluster (SC) populations. It is assumed that such an SC population forms at a constant star-formation rate (SFR), and its mass distribution is described by the embedded cluster mass function (ECMF) up to the upper limit $M_{\max}$. The GCs and UCDs probably formed in interactions of the progenitor galaxies during the assembly of the central Fornax galaxy cluster which is why we use them as tracers of those events. After some corrections, the overall GC/UCD mass function is decomposed into separate SC populations, each described by an ECMF. $M_{\max}$ of each ECMF is converted to an SFR according to the SFR-$M_{\max}$ relation, revealing the SFRs reached during the assembly of galaxies in the central Fornax galaxy cluster.

Keywords. galaxies: clusters: individual (NGC 1399), galaxies: star clusters, globular clusters: general, methods: analytical

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1. The background

We assume that present-day GCs and UCDs are accumulated from many individual SC formation events which can be described as follows (Schulz *et al.* 2015, accepted to A&A):

(*a*) Each SC formation epoch has a constant length δt (Table 1) during which the total mass of the SC population, $M_{\rm ECMF}$, is formed at a constant SFR: $M_{\rm ECMF} = {\rm SFR} \cdot \delta t$.

(*b*) The ECMF, $\xi_{\rm ECMF}(M) \propto (M/M_{\max})^{-\beta}$, describes the SC mass distribution of each population. $M_{\max}$ is the upper mass limit, and $\beta \approx 2.0$ is the index of the ECMF.

2. The observed GC and UCD samples in Fornax

(*a*) Spectroscopic sample ('UCD sample', orange in Fig. 1): A spatially complete sample of massive UCDs and GCs down to $\log(M) \approx 6.7$ within 83 kpc around NGC 1399 whose membership is confirmed by radial velocity measurements.

(*b*) Photometric sample ('GC sample', purple in Fig. 1): A statistically robust sample of GCs from HST/ACS observations (Jordan *et al.* 2007) within 150 kpc around NGC 1399 with masses down to $\log(M) \approx 4.5$, but without complete spatial coverage.

We scale the photometric sample at $\log(M) = 6.7$ to match the spectroscopic sample to obtain an accurate number distribution across the whole mass range. The cumulative number distribution of the combined GC/UCD sample is plotted in red in Fig. 1.

Consistency check I: The combined GC/UCD sample includes 11 615 objects, which agrees very well with the estimate of 11 100 ± 2 400 GCs/UCDs by Gregg *et al.* (2009).

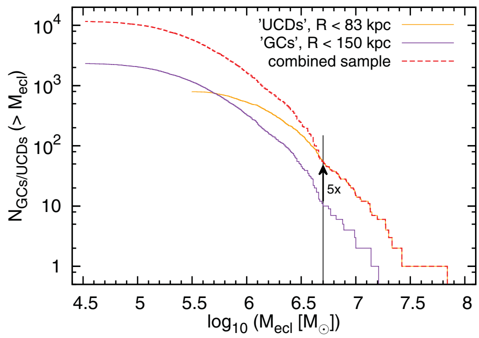

Figure 1. Cumulative 'GC sample' (purple), 'UCD sample' (orange), and the combined GC/UCD sample (red).

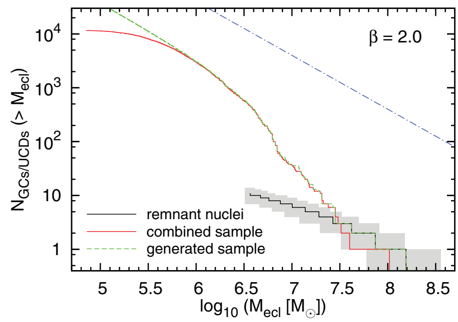

Figure 2. Cumulative combined GC/UCD sample (red) vs. generated sample (green) for $\beta = 2.0$.

3. The analysis

Before the analysis, we have to apply some corrections:

• SCs lose roughly 1/3 of their initial mass due to stellar evolution.

• Remnant nuclei of dwarf galaxies whose envelope was stripped away by the tidal field may contribute to the combined GC/UCD sample at high masses. Their cumulative number estimate by Pfeffer *et al.* (2014) is shown in black in Fig. 2, with the standard deviation in gray.

Considering only objects above the remnant nuclei sample, the combined GC/UCD sample is reproduced iteratively:

(*a*) Find the most massive SC, $M_{\max}$. $M_{\max}$ fully determines the ECMF.

(*b*) Generate all other SCs of the population according to this ECMF.

(*c*) Accumulate all SCs.

Finally, the generated sample (green) and the remnant nuclei sample (black) together match the combined GC/UCD sample (red) as shown for $\beta = 2.0$ in Fig. 2.

Table 1. Results for all β.

β	δt [Myr]	$t_{\rm tot}$ [Gyr]	$M_{\rm tot}$ [10^{10} $M_\odot$]
1.5	0.42	1.64	1.39
1.6	0.55	1.59	1.57
1.7	0.77	1.56	1.84
1.8	1.11	1.65	2.34
1.9	1.70	1.74	3.26
2.0	2.80	2.05	5.32
2.1	4.94	2.37	10.05
2.2	9.31	2.62	22.35
2.3	18.57	4.55	62.67
2.4	38.77	8.53	190.51
2.5	83.77	15.25	598.01
2.6	185.82	29.92	2 011.71

4. The result

$M_{\max}$ of each formation epoch is converted to an SFR according to the SFR-$M_{\max}$ relation (Weidner *et al.* 2004). We calculated the total SC formation time, $t_{\rm tot}$, and the total mass of all SC ever formed, $M_{\rm tot}$, as a function of β in Table 1 (Schulz *et al.* in prep.).

Consistency check II: The GCs and UCDs are older than 10 Gyr, so that $t_{\rm tot}$ should not exceed several Gyr. All results for $\beta \lesssim 2.3$ are reasonable.

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