Could merged star-clusters build up a small galaxy?

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Abstract. We investigate the behaviour of a cluster of young massive star clusters (hereafter super-cluster) in the tidal field of a host galaxy with a high-resolution particle-mesh code, Superbox. Specifically we want to establish if and how such super star-clusters merge and carry out a detailed study of the resulting merger-object. This merger-object shows either the properties of a compact spherical object or the elongated (‘fluffy’) shape of dSph-galaxies depending on the initial concentration of the super-cluster.

1. Introduction

Interacting galaxies like the Antennae (NGC 4038/4039; Whitmore & Schweizer 1995) or Stephan’s Quintet (HCG 92; Hunsberger 1997) show much star-burst activity in their tidal features. High resolution images from the HST resolve these regions into many compact groups of young massive star clusters (i.e. super-clusters) and/or tidal-tail dwarf galaxies, with typical radii of 100–500 pc. Here we aim to study the future fate of these super-clusters.

We begin with an overview of the numerical method and explain the setup of our simulations. We then show results obtained so far and conclude with an outlook on future work we intend to pursue.

2. Superbox

Superbox is a hierarchical particle-mesh code with high-resolution sub-grids focusing on the cores and the star-clusters as a whole, and moving with them through the simulation area (Fellhauer et al. 2000). The code has, for particle-mesh codes, a highly-accurate force-calculation based on a nearest grid-point (NGP) scheme. The main advantages of Superbox are it’s speed and the low memory requirement which makes it possible to use a high particle number with high grid-resolution on normal desktop computers.

3. Setup

As a model for our massive star-clusters we use, for each, Plummer-spheres with 100,000 particles, a Plummer-radius $R_{\text{pl}} = 6$ pc and a cutoff radius $R_{\text{cut}} = 15$ pc,
giving a total mass of $10^6 \, M_\odot$ and crossing time of 1.4 Myrs. Twenty of these clusters are placed in a compact group orbiting in a logarithmic potential of the parent galaxy,

$$
\Phi = \frac{1}{2} v_{\text{circ}}^2 \ln \left( \frac{R^{2}_{\text{gal}}}{r^2} \right),
$$

with $R_{\text{gal}} = 4 \, \text{kpc}$ and $v_{\text{circ}} = 220 \, \text{km/s}$. The case $v_{\text{circ}} = 0$ is dealt with in Kroupa (1998). The distribution of the super-cluster is also Plummer-like with different Plummer-radii (Table 1). The tidal radius is $\approx 2.4 \, \text{kpc}$ at apo-galacticon and $1.2 \, \text{kpc}$ at peri-galacticon. The orbits have the same eccentricity in all cases, and begin at apo-galacticon ($x = 60 \, \text{kpc}$, $y, z = 0$) with $v_y = 150 \, \text{km/s}$ ($v_x = v_z = 0$).

Table 1. Radial scale-length and crossing time for the different runs

| simulation | scale-length | $T_{\text{cr}}$ |
|------------|--------------|-----------------|
| run6       | 300 pc       | 108.4 Myr       |
| run5       | 150 pc       | 38.3 Myr        |
| run7       | 75 pc        | 13.5 Myr        |

4. First Results

4.1. Global properties of the Super-Cluster

In all runs some of the clusters merge very rapidly within the first 100 Myrs as seen in Fig. 1. The number of surviving clusters drops with increasing concentration of the super-cluster (SC). The orbits of the clusters inside their super-cluster also change rapidly due to the very short relaxation-time of the SC.
Merged star-clusters

4.2. Internal properties of merger-objects

In those cases where the SC has a low concentration initially, the resulting merger-system is an extended object (several kpc) with a low density and an off-centre nucleus (Fig. 3). The radial density profile follows an exponential distribution (Fig. 4). The velocity-dispersion in these objects drops to $\approx 5$ km/s (Fig. 5), which is comparable with the measured dispersions of dSph-galaxies in the Milky Way, and is slightly anisotropic. In the case of the most concentrated SC, the merger-object is a dense compact spheroidal object (Fig. 3) with a high density core ($\approx 10^4 M_\odot/pc^3$). The density profile follows a power-law with $r^{-3}$ out to 0.8-1.0 kpc (Fig. 4). The velocity-dispersion of this spheroidal dwarf galaxy is anisotropic and around 15 km/s (Fig. 5). It has a half-mass radius of about 300 pc. The size of this object is too large in comparison with even the biggest of the globular clusters, and the central density is far too high to be comparable with any dE-, dIrr- or dSph-galaxy. However, it has properties similar to the initial satellites studied by Kroupa (1997), and is thus likely to evolve to a dSph-like satellite. But further investigation of this issue is necessary.
5. Conclusion and Outlook

We found that even if new high resolution images show that most of the so-called tidal dwarf galaxies are clusters of young compact massive star clusters they are likely to merge within a short time-scale. The properties of the merger-objects differ with the scale-length of their initial distribution. We found large fluffy objects with similar properties as the local dSph-galaxies as well as very
compact and massive spheroidal objects, which, however, may be similar to the progenitors of some of the local present-day dSph satellites.

In the course of future work we intend to investigate the influence of the choice of orbit around the parent galaxy and how this alters the results. We will focus on the transition between bound and unbound objects, and look for a region in the space of parameters where 2 merger-objects (binary system) are more likely to form. Our further research will also address the future fate of the merger-objects and their possible counterparts in reality.

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U. Fritze von Alvesleben: It would be interesting to try and see if the age distribution among clusters that are clustered is different (younger) from that of YSCs distributed more homogeneously. What do you expect to happen with the merged clusters that you compared to a dSph. Isn’t it bound to sink into the core of the merger remnant by dynamical friction ? The bulk of the YSCs is at $d \leq 10$ kpc from the nucleus of NGC 4038, i.e. not further away than NGC 4039 (nucleus)!
**Answer:** We assume that at least some of the tidal-tail dwarfs seen to form in outer (> 30 kpc) tidal arms are composed of clusters of young massive star clusters. For our models we use an analytic galactic potential, because in the mass range of the merger-object of about $10^7 M_\odot$, dynamical friction does not play a significant role.

**E. Grebel:** Could you comment on how the merged clusters will resemble a dSph galaxy in their properties (E.g. dSph don’t show rotation, have very low density and surface brightness, etc.)?

**Answer:** It is too early to quantify the reply in detail, but we expect the merged object to show properties that could make it look similar to the progenitors of some of the dSph satellites. The merged object is spheroidal, and has a high specific frequency of globular clusters, and low angular momentum, which however depends on the initial conditions. It’s stellar population contains stars from the mother galaxy, as well as stars formed during the star burst, and maybe stars (and clusters) formed during a possible later accretion event of a co-moving gas cloud. Many of these issues are discussed in Kroupa (1998).

**J. Gallagher** (comment): Since super-star-clusters are often born in groups – the luminous clumps – destruction via cluster merging is of general interest. For example, if this process reduces the survival rate of massive-star-clusters, it might help to explain why intermediate age examples seem to be rare.

**D. McLaughlin:** What evidence is there that the clustered clusters in the Antennae will actually merge? There are $\approx 10^9 M_\odot$ clouds of gas in this system, so it may be that young clusters are clustered because several form in any given cloud, but they disperse after gas-loss. With no information on either the cluster-cluster velocity dispersion or the time when the parent cloud was disrupted, it would be difficult to rule out this possibility.

**Answer:** This is an important issue, and very similar to the problem of forming bound star clusters. While not disproving rapid dispersal entirely, the argument which makes rapid dispersal less likely is as follows: The cluster-cluster velocity dispersion, $\sigma_{clcl}$, is either small, which will lead to a bound merger object. If $\sigma_{clcl}$ is near to virial for the stellar mass in the super-cluster, then our models take care of that. If, however, $\sigma_{clcl}$ is virial for the stars and a much larger mass in gas, then $\sigma_{clcl} > 20 \text{ km/s}$ assuming a star-formation efficiency of 20 per cent and a pre-gas removal super-cluster configuration as in run5 here. Thus, within 10 Myr, the object will have expanded to a radius of at least 350 pc. Since many of the super-clusters are still very concentrated, and about 10 Myr old, rapid expansion does not appear to be taking place, especially so since there are at least about 10 observed super clusters and they would have had to start in unrealistically concentrated configurations for them to appear with the sizes they have now. This is further discussed in (Kroupa 1998).