PROCEEDINGS OF SCIENCE

How star clusters could survive low star formation efficiencies

Michael Fellhauer*
Sternwarte, Univerity of Bonn, Germany
E-mail: mike@astro.uni-bonn.de

Pavel Kroupa
Sternwarte, University of Bonn, Germany
E-mail: pavel@astro.uni-bonn.de

After the stars of a new, embedded star cluster have formed they blow the remaining gas out of the cluster. Especially winds of high mass stars and definitely the on-set of the first super novae can remove the residual gas from a cluster. This leads to a very violent mass-loss and leaves the cluster out of virial equilibrium. Standard models predict that the star formation efficiency (SFE) has to be about 33 per cent for sudden (within one crossing-time of the cluster) gas expulsion to retain some of the stars in a bound cluster. If the efficiency is lower the stars of the cluster disperse completely.

Recent observations reveal that in strong star bursts star clusters do not form in isolation but in complexes containing dozens and up to several hundred star clusters (super-clusters). By carrying out numerical experiments we demonstrate that in these environments (i.e. the deeper potential of the star cluster complex and the merging process of the star clusters within these super-clusters) the SFEs could be as low as 20 per cent, leaving a gravitationally bound stellar population. We demonstrate that the merging of the first clusters happens faster than the dissolution time therefore enabling more stars to stay bound within the merger object.

Such an object resembles the outer Milky Way globular clusters and the faint fuzzy star clusters recently discovered in NGC 1023.

Baryons in Dark Matter Halos
5-9 October 2004
Novigrad, Croatia

*Speaker.

PoS(BDMH2004)101

1. Results

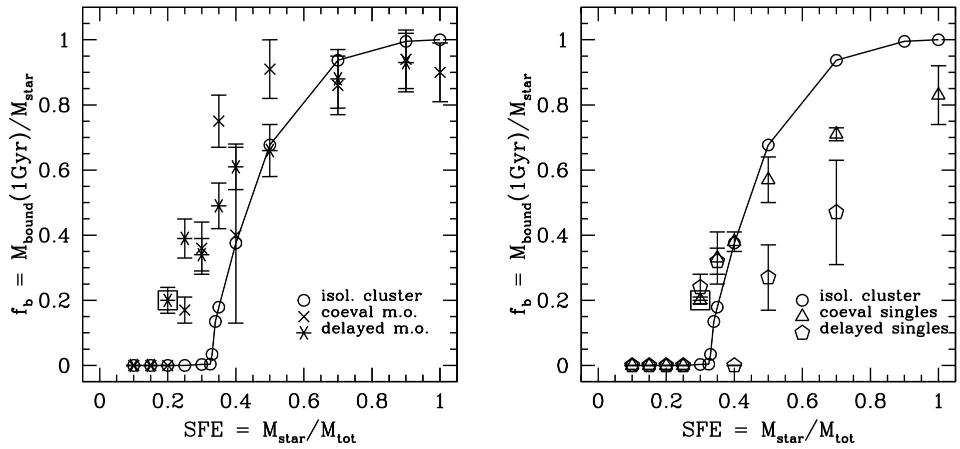

Figure 1: The fraction f_b of bound particles (stars) after 1 Gyr of evolution is plotted versus the the star formation efficiency (SFE), i.e. the fraction of mass in the embedded cluster which is transformed into stars. The remaining gas is blown out within a cluster crossing time. Large open circles show the results of the isolated clusters. These results agree with previous results in the literature. The star cluster complex contains 20 star clusters, each modelled as a Plummer sphere with 100000 particles, and is modelled as a Plummer distribution, with the star clusters as 'particles'. This Plummer distribution is given a Plummer radius of 20 pc, a cut-off radius of 100 pc and a crossing time of 5.9 Myr. This is a very dense configuration which will lead to a fast merging of the star clusters into one massive merger object, and resembles some of the cluster complexes observed in the Antennae galaxies. The mass-loss due to gas-expulsion is modelled by all particles loosing a fraction of their mass linearly over a crossing-time of the single star cluster. We consider two mass-loss models. In the coeval model every star cluster starts immediately and at the same time to loose mass and in the delayed model the star clusters start to loose their mass randomly during the first crossing time of the super-cluster. The star cluster complex orbits circularly at a distance of 10 kpc around an analytical galactic potential with a flat rotation curve of 220 kms^{-1}. Crosses are the merger objects of the simulations with coeval gas-expulsion, six-pointed stars denote the merger objects in the simulations with randomly delayed gas expulsion (left panel). Small open triangles and small open pentagons are surviving and escaped star clusters in the coeval and the delayed case respectively (right panel). Almost all clusters which do not end up inside the merger object have a smaller bound mass than in the isolated case. There are even star clusters dissolving completely when the SFE is 70 per cent. On the other hand there are rare cases where single clusters escape and survive even at low star formation efficiencies. Two single clusters escape and survive the coeval simulation with a SFE of 30 per cent. The building up of a merger object with its deeper potential well favours the survival of a bound object that retains more of its stars than an isolated single cluster would, as long as the SFE is below 60 per cent. If the SFE is higher destructive processes during the merging process lead to a mass-loss, i.e. stars that are expelled as a result of the kinetic energy surplus produced during the merging of the clusters (the stars are then found in the tidal tails), leaving the remaining object with a smaller bound mass fraction than the star clusters would have had if they would have formed in isolation. However, as a major result we find that cluster formation in complexes allows star clusters to survive even if the SFE is as low as 20 per cent. In a dense star cluster complex the crossing time of the star clusters through the super-cluster, and therefore the merging time-scale, is short enough that some star clusters have already merged before they expel their gas. The much deeper potential wells of these merger objects are able to retain the stars more effectively than isolated clusters would.