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Impact of a star-formation efficiency profile on the evolution of open clusters

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Abstract. We perform direct *N*-body simulations of cluster violent relaxation within the Galactic tidal field after instantaneous gas expulsion. The residual star-forming gas has a density profile shallower than that of the stars as expected if star formation proceeds with a constant star-formation efficiency (SFE) per free-fall time in a centrally-concentrated clump. We find that the violent relaxation lasts around 20 Myr, independently of cluster mass and global SFE. Our model clusters need a minimum SFE of 15% to survive gas expulsion, which is a factor of 2 smaller than earlier estimates.

1. Introduction

The formation of bound clusters after residual gas removal has been the subject of numerous studies. For instance, Baumgardt & Kroupa (2007) concluded that star clusters need at least 33% global SFE to survive instantaneous gas expulsion. This is higher than the SFEs measured in embedded clusters, which are less than 30%. To match observations different solutions have been developed: adiabatic gas expulsion (Geyer & Burkert 2001), sub-virial clusters (Farias et al. 2015), hierarchically formed clusters (Smith et al. 2011). An interesting solution was proposed by Adams (2000). Based on semi-analytical calculations, he showed that clusters should be able to survive instantaneous gas expulsion despite low SFEs if the stellar component has a steeper density profile than the residual gas. Parmentier & Pfalzner (2013) developed a local-density-driven clustered star formation model which yields exactly that property. Using initial conditions derived from Parmentier & Pfalzner (2013) we model by means of *N*-body simulations the response of star clusters to gas expulsion (for more details see Shukirgaliyev et al. 2017).

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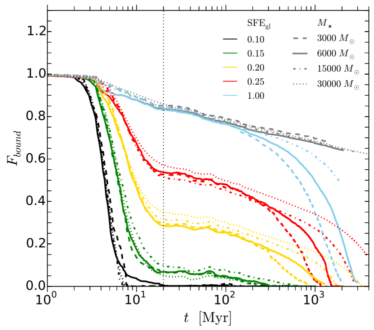

Fig. 1. Evolution of the bound mass fraction of clusters as obtained in our simulations for different cluster initial stellar masses (see the key for the line-coding). Different colours correspond to different global SFEs (see the key). The grey lines show the impact of mass loss caused by stellar evolution alone.

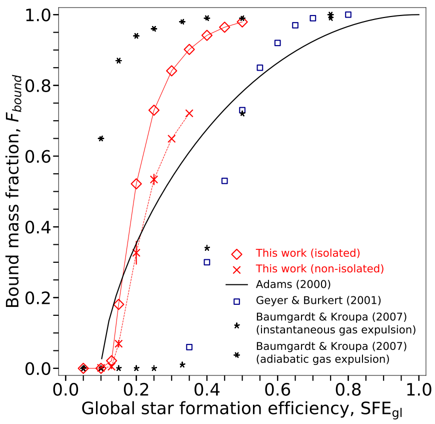

Fig. 2. Bound fraction as a function of global SFE. We compare our results (in red) with previous works. The isolated models are depicted by the red diamonds, and non-isolated models by red crosses.

2. Main results

We have performed N-body simulations of violent relaxation after instantaneous gas expulsion for: 1) isolated single-mass clusters, and 2) non-isolated models, that is, star clusters with stellar evolution and dissolving in the Galactic disk plane. We adopt a circular orbit of radius $R_G = 8$ kpc. We studied the effect of different cluster initial stellar masses $3\times10^3 - 3\times10^4\ M_\odot$ on the evolution of our non-isolated models. The initial stellar mean density was fixed by a given half-mass to Jacobi radius ratio, $r_h/r_J = 0.05$. Based on our simulations, we quantified the bound fraction evolution and the violent relaxation duration (Fig. 1). We found that the violent relaxation duration of non-isolated model clusters depends neither on the cluster initial stellar mass nor on the global SFE, and lasts no longer than 20 Myr. The bound mass fraction of surviving clusters that achieved the same global SFE does not depend on the cluster initial stellar mass.

We also found that the minimum global SFE necessary to form a bound cluster after instantaneous gas expulsion is $\mathrm{SFE_{gl}} = 0.15$. This is a factor of 2 less than the previous estimates of 33% (see Fig. 2).

We have therefore improved the survival likelihood of star clusters after instantaneous gas expulsion. This is caused by the difference in density profiles between the embedded cluster and its residual gas, namely, the stellar density profile has a steeper slope than that of the residual gas. This is a consequence of star formation taking place with a constant SFE per free-fall time in a centrally concentrated molecular clump, as modelled by Parmentier & Pfalzner (2013).

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