Galaxy Disks and Disk Galaxies
ASP Conference Series, Vol. 3×10^8, *2000*
J.G. Funes S.J., and E.M. Corsini, eds.

Gas Expulsion from Star Forming Regions and the Formation of Globular Clusters

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Abstract. The effect of gas ejection on the structure and binding energy of newly formed stellar clusters is investigated using numerical N–body and combined N–body & SPH simulations. If the system is in virial equilibrium initially, bound clusters only form in regions where the local star formation efficiency (SFE) is high, or where the gas expulsion timescale is long compared to the dynamical timescale. A small initial velocity dispersion of the stars leads to a compaction of the cluster and reduces the SFE needed to form bound clusters to less than 10%.

1. Introduction

During the formation of star clusters gas expulsion, caused by feedback of young massive stars, like ionizing radiation, stellar winds or supernova explosions, terminates the star formation epoch. It reduces the binding energy of the cluster and can thus unbind the stellar system. Hills (1980) showed analytically that a star formation efficiency (SFE) $\epsilon = M_s/M_c > 0.5$ is needed to obtain bound stellar clusters, where M_s and M_c are the mass of the stellar component and of the initial gas cloud prior to star formation, respectively. As the typical observed SFEs in our Galaxy are less than 10%, the formation of gravitationally bound open clusters and globular clusters is a yet unsolved problem.

Numerical simulations done by Lada, Margulis & Dearborn (1984) showed that open star clusters can remain bound even if the SFE is as low as 30%. Goodwin (1997) extended these simulations to globular clusters. We present new numerical N–body and combined N–body & SPH simulations of the early evolution of young GCs, covering a broad range of SFEs and gas expulsion timescales. See Geyer & Burkert (2000) for a detailed description of our model and the results.

2. Discussion

Our simulations start after the cluster has formed, but before the residual gas has been expelled. In our pure N–body models, stars and gas initially are in virial equilibrium and follow the same King (1966) density distribution. The stars are represented by collisionless, equal mass N–body particles. To model the ejection of the residual gas we use a time variable external potential that linearly decreases in time, similar to the approach of Lada et al. (1984).

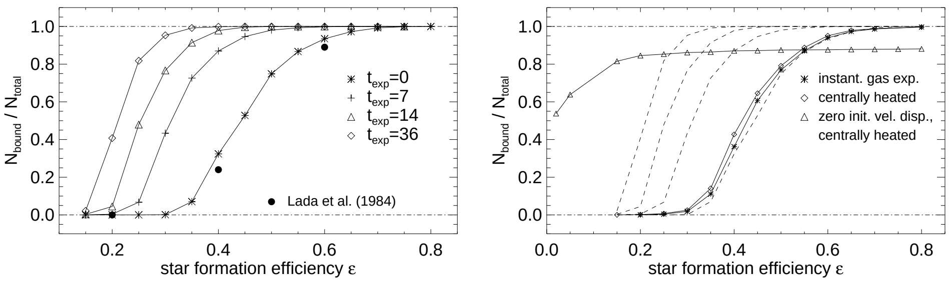

Figure 1. Ratio of the number of bound stars after gas expulsion to the initial number of stars. *Left:* pure N–body simulations (4000 particles). Large dots are results from Lada et al. (1984), using 50(!) particles. *Right:* combined N–body and SPH simulations (2×11045 particles). Dashed lines indicate results from pure N–body simulations.

Fig. 1 (left) shows the ratio of the number of finally bound stars to the initial number of stars for various SFEs and gas expulsion timescales (given in units of the dynamical timescale). In the case of instantaneous gas expulsion, clusters with SFEs greater than $\epsilon = 0.45$ can keep more than 50% of the initial stars. Clusters with SFEs less than $\epsilon = 0.40$ are dissolved. We confirm that gas expulsion timescales which are several times longer than the crossing time of the GC can decrease the SFE needed to sustain bound clusters considerably.

To describe the physics more properly, we extend our simulations using smoothed particle hydrodynamics (SPH) with variable smoothing length, individual particle timesteps (Bate, Bonnell & Price 1995) and collisionless N–body particles. As initial configuration we adopt a pressure–confined, isothermal gas sphere with N–body particles added according to the same density distribution. To expel the gas, we heat up a small inner core, creating an outward propagating shock front disrupting the gas cloud. In order to destroy the whole cloud the gas expulsion must take place on a short timescale. Thus, as shown in Fig. 1 (right), high SFEs are required to obtain bound clusters. Models with stars having an initial zero velocity dispersion lead to a compaction of the cluster and can explain bound systems even in low SFE regions: For SFEs as low as $\epsilon = 0.15$ more than 80% of the stars stay bound (Fig. 1, right). Bound systems are obtained even with SFEs lower than 10%. For future investigations it is essential to know the velocity dispersion of newly born stars in clusters.

Acknowledgments. We thank Matthew Bate for his N–body & SPH code.

References

Bate, M. R., Bonnell, I. A., Price, N. M. 1995, MNRAS, 277, 362

Geyer, M. P., Burkert, A. 2000, astro-ph/0007413

Goodwin, S. P. 1997, MNRAS, 284, 785

Hills, J. G. 1980, ApJ, 225, 986

King, I. R. 1966, AJ, 71, 64

Lada, C. J., Margulis, M., Dearborn, D. 1984, ApJ, 285, 141