SF2A 2024
M. Béthermin, K. Baillié, N. Lagarde, J. Malzac, R.-M. Ouazzani, J. Richard, O. Venot, A. Siebert (eds)

EMBEDDED CLUSTER DYNAMICAL EVOLUTION

Y. Bernard[1] and E. Moraux[1]

Abstract. This poster aims to present a new simulation framework to model the dynamical evolution of very young stellar clusters. This new simulations are light to compute which will allow to perform enough runs to produce robust statistical results on these very stochastic objects.

Keywords: Star formation, Embedded cluster, Stellar Feedback

1 Introduction

Studies on star formation show evidences that stars in the galaxy are mainly produced in groups within large collapsing molecular clouds, forming what is called an embedded cluster(Lada & Lada 2003). Stellar dynamics inside star clusters has been studied for decades now (Kroupa 1995) and mechanisms leading to the dilution of clusters in the galactic field are well known. However, their early dynamical evolution is much more complex due to gravity and stellar feedback coupling. To improve this picture, we built a hybrid model that manages gas and stars dynamics in parallel within a cluster, from its formation to the complete gas expulsion. We take into account interactions between gas and stars, i.e., the gravitational force as well as feedback processes like HII region expansion around massive stars.

In this poster, we present the new implementations we added to the SPH code `Phantom` (Price et al. 2018) to produce highly accurate simulations of embedded clusters. First, we describe the star formation prescription, using sink particles, that is capable of generating realistic stars and gas distributions from a molecular cloud collapse. Second, we discuss how we implemented feedback interactions between gas and stars in the form of HII region expansion around the massive stars. And finally, we introduce the algorithms needed to accurately follow the stellar dynamics that we have recently added to `Phantom`.

2 Model

2.1 Star formation prescription

In this section, we present a new star formation prescription to generate embedded cluster in star forming region. This method is based on dynamical sink particles (Bate et al. 1995) creation. Each sink particle formed into the simulation is considered as a core with a raidus of 4000 au. Each core is able to accrete surrounding infalling gas during a maximum fixed period of $\tau_{acc} = 0.5\,\mathrm{Myr}$. Once this time is reached, the core disappears freeing the stars that formed within it. The number of stars is randomly chosen between one and five following observational results like Sadavoy & Stahler (2017). The total core mass is randomly shared between the stars and their positions and velocities are chosen using a virialised Plummer sampling (Aarseth et al. 1974). The motion of each star is then followed using stellar dynamics integration methods.

2.2 Stellar feedbacks

Massive stars ($> 8M_\odot$) produce high energetic radiations around them. These radiations heat up the surrounding medium creating expanding bubbles of really hot gas. This hot gas pushes the cold one and reveals star clusters created by the star formation process inside molecular cloud. We implemented a simple prescription

---

[1] Univ. Grenoble-Alpes, CNRS, IPAG, 38000 Grenoble, France

to model this feedback process within the SPH code `Phantom`. Following similar works as Hopkins et al. (2012) and Fujii et al. (2021), this prescription computes the Strömgren radius (Strömgren 1939) :

$$R_{\rm st} = \left(\frac{3Q}{4\pi\alpha_B n_H^2}\right)^{\frac{1}{3}}, \tag{2.1}$$

where Q is the ionising rate of the massive star, α_B is the recombination factor and n_H is the proton number density. All SPH gas particles inside this radius are ionised with a temperature set to $10,000\,\mathrm{K}$.

2.3 Stellar dynamics

Motion of stars within a stellar cluster is usually spread over a huge timescale. Integrating such systems can be really challenging. We implemented two new algorithms from stellar dynamics codes (Wang et al. 2020) and chosen to be compliant with `Phantom` to handle these very large time scale. First we replaced the inefficient and less accurate Leapfrog integrator by a forward symplectic fourth order scheme (FSI) (Rantala et al. 2021). This one has a better accuracy and minimises the number of integration steps. It also has the great advantage to avoid backward steps which can be problematic for dissipative forces.

The other and most effective optimization of stellar dynamics that we implemented is the subgrouping of stars. Binaries and stable multiple systems can be grouped to be integrated separately using specific integration methods. Such systems can have very strong constraint on the simulation timestep to correctly sample their orbits. In that case, regularization method Mikkola & Aarseth (2002) can integrate motion of stars even during close encounters or periapsis approach while relaxing this timestep constraint. Slow-down method (Mikkola & Aarseth 1996) can relax even more this constraint by slowing down weakly perturbed hard binaries or binaries in multiple system. This slow-down integration looses the orbital phase but correctly conserves orbital parameters.

3 Conclusions

To conclude, the hydrodynamical code `Phantom` is now ready to compute efficiently embedded cluster simulations from their formation to their emergence from their natal region. A first study is underway to compare the outcomes of the simulations using our new star formation prescription with observational constraints, such as the star formation efficiency and the stellar mass function. The results will be published in an upcoming paper. The next study will focus on dynamical evolution characterization. To do so, we will compute a large set of simulations with different initial conditions in order to construct robust statistical results. These results shall then be compared with observational results.

References

Aarseth, S. J., Henon, M., & Wielen, R. 1974, A&A, 37, 183

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

Fujii, M. S., Saitoh, T. R., Hirai, Y., & Wang, L. 2021, PASJ, 73, 1074

Hopkins, P. F., Quataert, E., & Murray, N. 2012, MNRAS, 421, 3522

Kroupa, P. 1995, MNRAS, 277, 1507

Lada, C. J. & Lada, E. A. 2003, ARA&A, 41, 57

Mikkola, S. & Aarseth, S. 2002, Celestial Mechanics and Dynamical Astronomy, 84, 343

Mikkola, S. & Aarseth, S. J. 1996, Celestial Mechanics and Dynamical Astronomy, 64, 197

Price, D. J., Wurster, J., Tricco, T. S., et al. 2018, PASA, 35, e031

Rantala, A., Naab, T., & Springel, V. 2021, MNRAS, 502, 5546

Sadavoy, S. I. & Stahler, S. W. 2017, MNRAS, 469, 3881

Strömgren, B. 1939, ApJ, 89, 526

Wang, L., Iwasawa, M., Nitadori, K., & Makino, J. 2020, MNRAS, 497, 536