


Converting sink particles to stars in hydrodynamical simulations

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Abstract. To form stars in hydrodynamical simulations, we introduce the *grouped* star formation prescription to convert the grouped sink particles into stars that follow the IMF. We show that this method is robust in different physical scales. Such methods to form stars are likely to become more important as galactic or even cosmological scale simulations begin to probe sub-parsec scales.

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1. Introduction

Modelling star formation and resolving individual stars in numerical simulations of molecular clouds and galaxies is highly challenging. Simulations on very small scales can be sufficiently well resolved to consistently follow the formation of individual stars, whilst on larger scales sinks that have masses sufficient to fully sample the initial mass function (IMF) can be converted into realistic stellar populations. However, as yet, these methods do not work for intermediate scale resolutions whereby sinks are more massive compared to individual stars but do not fully sample the IMF.

We introduce the *grouped* star formation prescription, whereby sinks are first grouped according to their positions, velocities, and ages, then stars are formed by sampling the IMF using the mass of the groups.

2. Method

Our group assignment prescription is simple. For a new sink to join an existing group, the sink must be within:

- (a) a distance d_g from the group's centre-of-mass (CoM),
- (b) a speed v_g from the group's CoM speed, and
- (c) an age τ_g from the group's oldest member.

Else, the sink creates a new group. Then, a population of stars, sampled from the Kroupa IMF (Kroupa 2001), is introduced for each group of sinks. Similar to Wall et al. (2019), the stars are placed within the sinks and the velocities follow the local gas dispersion. Each group is approximately a star-forming region.

Table 1. The physical scales of the models to test the *grouped* star formation method.

Model	Length (pc)	Speed (km/s)	Age (Myr)	Reference
Isolated cloud	< 1	0	< 1	Bate (2012)
Cloud-cloud collision	~ 10	10	~ 1	Liow & Dobbs (2020)
Isolated cloud	~ 10	0	20	Jaffa et al. (in prep)
Spiral arm	~ 1000	0	~ 1	Rieder et al. (2022)

3. Simulation

We use *Ekster* via *AMUSE* (Rieder & Liow 2021; Rieder et al. 2022), a multiphysical code that combines gas hydrodynamics using *Phantom* (Price et al. 2018), high-performance gravitational dynamics using *PeTar* (Wang et al. 2020), and stellar evolution using *SeBa* (Portegies Zwart & Verbunt 1996). The gravitational dynamics between gas and non-gas is coupled using *Bridge* (Fujii et al. 2007).

We tested the *grouped* star formation prescription on the models of varying length, speed and time scales, as shown in Table 1. For each model, we run several sub-models by varying the grouping parameters d_g , v_g and τ_g to find the optimal values in these different scales.

4. Results

In smaller length scale system (< 1 pc), grouped star formation is essential in reproducing the IMF; on the other hand, forming stars using individual sink mass severely undersamples higher mass stars. Even though greater degree of grouping is better in reproducing the IMF, extreme grouping causes violation of local mass conservation. We find that setting $d_g = 1$ pc, $v_g =$ turbulent velocity dispersion, and $\tau_g =$ free-fall time is optimal.

In intermediate scale system (~ 10 pc), grouped star formation is essential too, although to a lesser extent as compared to the smaller scale system. We find that the grouping parameters described above is suitable in this length scale regardless of the speed and time scales of the system.

Finally, in larger scale system (~ 1 kpc), we verify that there is no need to adopt grouped star formation as each sink is massive enough to sample a full population of stars that is consistent to the IMF.

This work is presented in detail in Liow et al. (2022).

References

- Bate, M. 2012, *MNRAS*, 419, 3115
 Fujii, M., Iwasawa, M., Funato, Y. & Makino, J. 2007, *PASJ*, 59, 1095
 Jaffa, S. E., et al., in preparation
 Kroupa, P. 2001, *MNRAS*, 322, 231
 Liow, K. Y. & Dobbs, C. L. 2020, *MNRAS*, 499, 1099
 Liow, K. Y., Rieder, S., Dobbs, C. L. & Jaffa, S. E. 2022, *MNRAS*, 510, 2657
 Portegies Zwart, S. & Verbunt, F. 1996, *A&A*, 309, 179
 Price, D J., Wurster, J., Tricco, T. S., Nixon, C., Toupin, S., Pettitt, A., Chan, C., Mentiplay, D., Laibe, G., Glover, S., Dobbs, C., Nealon, R., Liptai, D., Worpel, H., Bonnerot, C., and Dipierro, G., Ballabio, G., Ragusa, E., Federrath, C., Iaconi, R., Reichardt, T., Forgan, D., Hutchison, M., Constantino, T., Ayliffe, B., Hirsh, K. & Lodato, G. 2018, *PASA*, 35, 31
 Rieder, S., Dobbs, C. L., Bending, T., Liow, K. Y. & Wurster, J. 2022, *MNRAS*, 509, 6155
 Rieder, S. & Liow, K. Y. 2021, doi:10.5281/zenodo.5520944
 Wall, J. E., McMillan, S. L. W., Mac Low, M.-M., Klessen, R. S., & Portegies Zwart, S. 2019, *ApJ*, 887, 12
 Wang, L., Iwasawa, M., Nitadori, K. & Makino, J. 2020, *MNRAS*, 497, 536