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A simple way to convert sink particles into stars

R. G. Tress[1], M. C. Sormani[1], R. S. Klessen[1,2], and S. C. O. Glover[1]

[1] Institut für Theoretische Astrophysik, Zentrum für Astronomie der Universität Heidelberg, Albert-Ueberle-Str. 2, D-69120 Heidelberg, Germany
e-mail: robin.tress@uni-heidelberg.de

[2] Interdisziplinares Zentrum für Wissenschaftliches Rechnen, Universität Heidelberg, Im Neuenheimer Feld 205, D-69120 Heidelberg, Germany

Abstract. Star formation is often unresolved in hydrodynamical simulations of the interstellar medium (ISM). A common technique for dealing with this problem is to replace the centre of collapse with a Lagrangian sink particle which conceals the complexity of stellar formation that cannot be resolved by the simulation. Given the total mass of gas accreted onto a sink particle we describe a simple statistical method to assign a stellar content to the sink. With our method the stellar population will always be a good representation of the Initial Mass Function (IMF) given as an input. The method does not restrict the mass range of the sink and naturally deals with subsequent gas accretion making it a compelling alternative to other methods used in the literature.

1. Introduction

Massive stars are very important for determining the properties and dynamics of the ISM. However simulations lack the dynamical range to resolve the formation of these stars and thus sub-grid models have to be employed to model their complex interactions with the environment. Simulations often replace collapsing regions with sink particles when the resolution limit is reached. The problem then arises of how to assign an actual stellar content to the sink which then has to be used to model stellar feedback etc. (e.g. Howard et al., 2014; Gatto et al., 2017). We present here a new simple method to assign a realistic stellar population to sink particles.

2. The method

Given a sink particle of mass M, let us define its stellar population as the vector $\mathbf{n} = \{n_1, n_2, \ldots, n_N\}$, where $n_i \in \mathbb{N}$ is the number of stars having mass m_i. We then say that the probability of the sink having a stellar population $\mathbf{n}$ is $P(\mathbf{n}) = P_1(n_1)P_2(n_2)\ldots P_N(n_N)$, where

$$P_i(n_i) = e^{-\lambda_i} \frac{\lambda_i^{n_i}}{n_i!}\,, \tag{1}$$

and

$$\lambda_i = f_i \frac{M}{m_i}\,. \tag{2}$$

Here f_i defines the fraction of stars having mass m_i. Given an IMF $f(m)$ where $f(m)\mathrm{d}m$

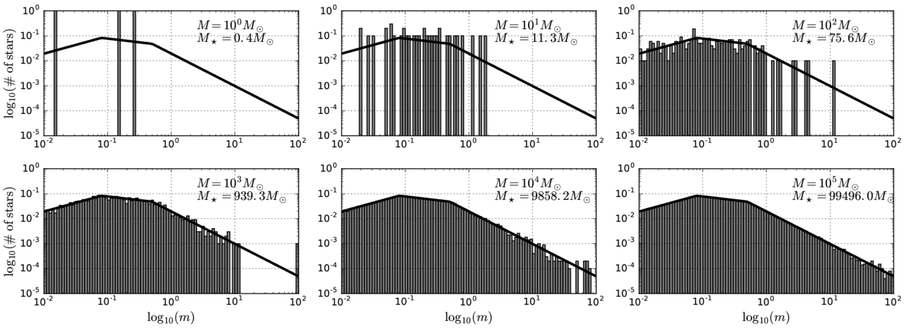

Fig. 1. Different realisations of our method given an increasing (from left to right, top to bottom) mass of the parent sink particle. The number of stars in each mass bin are shown and compared to the expected number given Kroupa's IMF (solid line) (Kroupa, 2002).

is the number of stars in the mass interval $(m, m + \mathrm{d}m)$, f_i is given by

$$f_i = \frac{\int_i m f(m) \mathrm{d}m}{\int_{M_{\min}}^{M_{\max}} m f(m) \mathrm{d}m} \tag{3}$$

and

$$m_i = \frac{\int_i m f(m) \mathrm{d}m}{\int_{M_{\min}}^{M_{\max}} m f(m) \mathrm{d}m}. \tag{4}$$

For a general partition of the mass interval $[M_{\min}, M_{\max}]$, $\int_i$ denotes the integral over the ith mass interval so that m_i is the mean mass of the stars in this interval. Note that equation 1 can be identified as a Poisson distribution of the variable n_i with mean λ_i.

3. Properties

It can be easily shown that on average the mass of the stellar population created with our method is equal to the mass of the sink particle. In some situations the mass in stars may in principle be greater than the available mass of gas of the sink (see Fig. 1). This is not a problem however if star formation efficiency is not assumed to be 100% for the sink, which is almost never the case, and if the mass of the sink is large enough so that the variance is small. It can also be shown that the IMF is always recovered with this method, in fact we have that the average mass in stars of type i is:
$\langle M_{\star,i} \rangle = \sum_{\mathbf{n}} m_i n_i P(\mathbf{n}) = f_i M$.

Finally, since the sum of two Poisson distributions still is a Poisson distribution with the sum of the original distribution's means as its mean, we note that assigning a stellar population separately given two sink masses M_1 and M_2 is statistically equivalent to directly assign the stellar content to a single sink of mass $M_1 + M_2$. This ensures that the stellar population only depends on the final mass of the sink and the method can be safely applied again any time new mass is accreted.

4. Conclusions

We presented a simple statistical method to assign stars to sink particles. Our method always reproduces the IMF given as an input, easily deals with subsequent gas accretion, works for any sink mass regime and does not put any constraints on how the IMF is binned. A shortcoming might be that the mass in stars is not always equal to the mass of the sink, however this might become a problem only for low mass sinks.

For more information see Sormani et al. (2017).

References

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