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Population III Sink Particle Resolution Study

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ABSTRACT
The Population III initial mass function (IMF) is currently unknown, but recent studies agree that fragmentation of primordial gas gives a broader IMF than the initially accepted singular star per halo. Sink particles introduced at high densities can prevent artificial fragmentation of the gas once the mesh stops refining, but an incorrect choice of sink particle creation density will effect the resulting IMF. We present the evolution of the total number of sinks formed and the total mass of the combined sinks, for five different sink creation densities, and the difference in velocity power spectra just before sink creation. This study also introduces sink mergers into AREPO.

Key words: keyword1 – keyword2 – keyword3

1 INTRODUCTION

The first stars, known as Population III (Pop III) stars, are responsible for the first ionising radiation which began the epoch of reionisation, and when they died as supernovae, they injected the interstellar medium (ISM) with the first metals, which would go on to form the next generation (Pop II) of stars. During their formation, the primordial magnetic seed field was amplified via the small-scale magnetic dynamo (REF), which may have been the first step in converting the small scale chaotic fields into the coherent, large scale galactic magnetic fields observed today. Evidently the initial mass function (IMF) of Pop III stars has a huge effect on the evolution of the Universe. Initially it was thought that Pop III stars formed in isolation, and were massive (REF), yet further studies showed they were susceptible to fragmentation in the presence of subsonic turbulence (REF). Since then, numerical studies have attempted to improve the picture of Pop III star formation by including feedback mechanisms (REF), live dark matter (DM) potentials (REF) and magnetic fields (REF). Despite this, the Pop III IMF is still in dispute, and there are still many factors left to study.

The Jeans length λ_J of a structure of given density and temperature marks the maximum size it can achieve before thermal pressure cannot resist against gravitational collapse. Hence artificial fragmentation occurs in hydrodynamic codes if the local λ_J falls below the size of mesh cells Δx. To prevent this, the mesh refines itself based on the local λ_J, which depends on the temperature and density of the gas. The Truelove condition (REF) requires a Jeans number $\Delta x/\lambda_J$ of 0.25, corresponding to at least 4 cells spanning across any λ_J to prevent artificial fragmentation. Numerical simulations cannot refine indefinitely as the gas gets denser, and at higher densities (smaller λ_J), it becomes computationally expensive to refine further. Sink particles (REF: Bate 1995) provide an alternative to indefinite refinement, they are non-gaseous particles that contain all of the mass within the area they occupy and can accrete matter from their surrounding cells. As they cannot fragment, either naturally or artificially, their implementation at high densities overcomes the Jeans refinement criteria. In present day star formation simulations, the sink creation density is chosen to be $\sim 10^{10} gcm^{-3}$ (e.g. REF), corresponding to the first adiabatic core (REF). During an adiabatic collapse , the radial density profile is flat within the central λ_J (REF: Larson69), so the radius of the of sink particle is chosen to be the Jeans length at the creation density and temperature. In primordial star formation, there is no clear 'first core' (REF Omiki graph), and so the appropriate time to introduce a sink particle is unclear. Sink particles are not a perfect solution to the indefinite refinement problem, and authors choice of sink particle creation density will change the morphology of the resulting cluster. This paper explores the effect of varying the sink particle creation density within the frame of primordial Pop III gas collapse. The most important parameters to track are the total number of sinks formed and the total combined mass of the sinks.

2 METHOD

The radius of a sink particle is chosen to be λ_J corresponding to the sink creation density, given by

$$\lambda_J = \sqrt{\frac{k_B T}{G\rho_{sink}(\mu m_p)}}. \tag{1}$$

where k_B is the Boltzmann constant, T is the temperature, $\rho_s ink$ is the sink creation density, μ is the mean molecular weight and m_p is the mass of a proton. To estimate λ_J before running the simulation, an estimate of T at ρ_{sink} is needed. To achieve

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Table 1. Sink creation density, temperature, sink radius, minimum cell size and minimum gravitational softening lengths used in the study.

ρ_{sink} $[gcm^{-3}]$	T [K]	λ_J [cm]	V_{min} [cm^3]	L_{soft} [cm]
10^{-10}	2	3	4	e
10^{-9}	4	6	8	e
10^{-8}	5	7	9	e
10^{-7}	e	e	e	e
10^{-6}	e	e	e	e

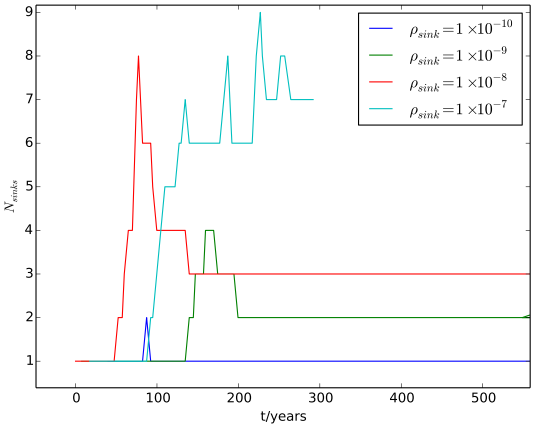

Figure 1. This is an example figure. Captions appear below each figure. Give enough detail for the reader to understand what they're looking at, but leave detailed discussion to the main body of the text.

this, a lower resolution simulation was performed without turbulence, resulting in 1 central star. The simulation was run up until the maximum creation density testing in this study was reached, figure REF shows the resulting relationship between density and temperature. This gives an effective relationship between ρ and λ_J using equation 1. The ρ_{sink}, T, λ_J, minimum cell volume and minimum gravitational softening lengths are given in table 1.

3 CONCLUSIONS

The last numbered section should briefly summarise what has been done, and describe the final conclusions which the authors draw from their work.

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DATA AVAILABILITY

The inclusion of a Data Availability Statement is a requirement for articles published in MNRAS. Data Availability Statements provide a standardised format for readers to understand the availability of data underlying the research results described in the article. The statement may refer to original data generated in the course of the study or to third-party data analysed in the article. The statement should describe and provide means of access, where possible, by linking to the data or providing the required accession numbers for the relevant databases or DOIs.

APPENDIX A: SOME EXTRA MATERIAL

If you want to present additional material which would interrupt the flow of the main paper, it can be placed in an Appendix which appears after the list of references.

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