N-body simulation on survival possibility of Population III stars

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ABSTRACT

It has been argued that the low-mass primordial stars ($M_* \leq 0.8\,M_\odot$) are likely to enter the main sequence and hence possibly be found in present-day Galaxy. However, due to limitation in existing numerical capabilities, three-dimensional (3D) simulations of disk fragmentation are capable of following only a few thousands of years of evolution after the formation of first protostar. Here we address the issue of their survival probability following a combination of 3D-simulations and semi-analytical methods with Bondi-Hoyle flow. We explore that a number of evolving protostars formed within fast-rotating clumps accretes a small amount of mass before they are ejected from the cluster.

MOTIVATION

• What did happen with the newly formed Population III protostars in the cluster? Do they merge with the central star, or do they move away from the cluster after their dynamical interaction with each other and with the surrounding gas?

• A fully computational approach that follows the non-linear process starting from initial collapse of primordial gas upto the formation of disk and its fragmentation is not feasible due to limitations of resources at our disposal and the complexity of the processes at work.

• Thus, the final fate of these fragments remains unclear and needs more investigation.

NUMERICAL METHOD

We use our previous simulations set-up from Dutta (2016) once the protostellar system evolve up to the epoch ~3000 years, and implement it as initial conditions for post-processing of semi-analytical model using Runge Kutta fourth order method along with adaptive time stepping scheme following Dutta et al. (2020). We follow these steps:

• Performing a suite of SPH GADGET-2 (Lagrangian) simulations to follow the collapse of rotating self-gravitating primordial gas clumps upto the formation of a number of protostars as a result of disk fragmentation.

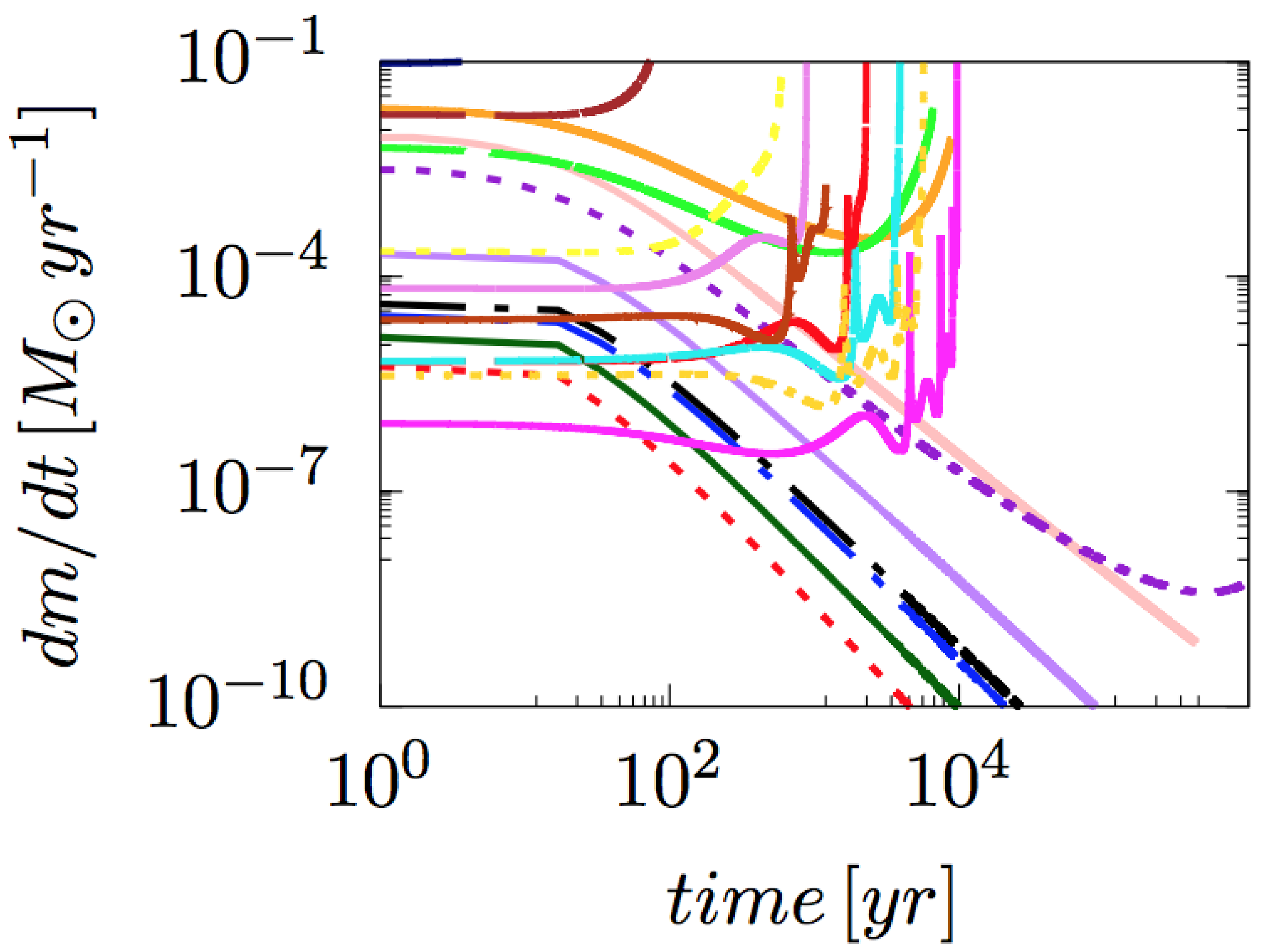
• Modelling the ambient density (using the results from 3D simulation as initial condition)

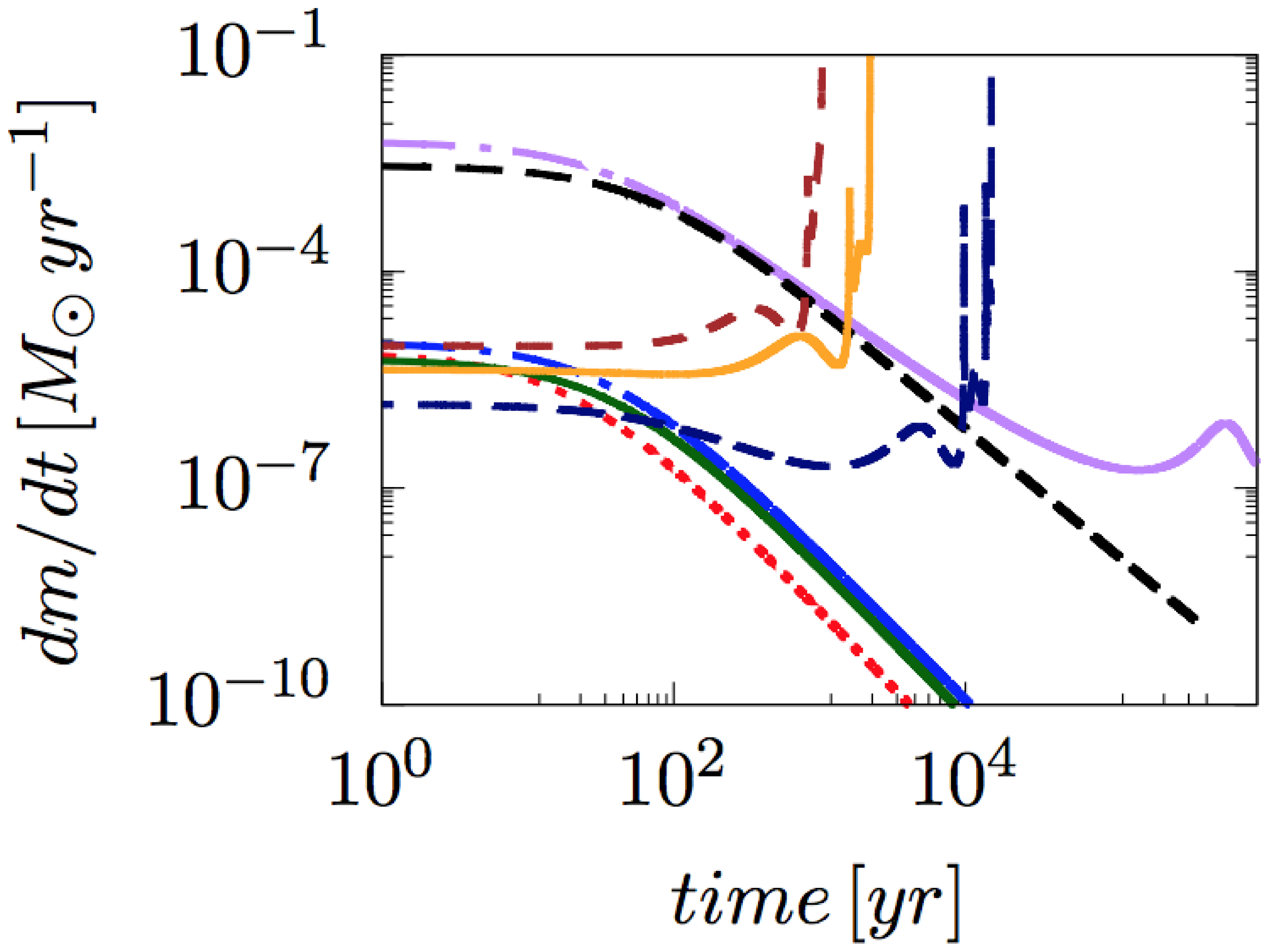
• We replace each protostar with a point mass particle with characteristic properties that are incorporated with spherical Bondi-Hoyle flow.

• We then model the dynamics of protostars (N-body method coupled with gravity)

• The system of equations are numerically solved in spherical-polar coordinates using the standard Runge-Kutta fourth order method. The dynamical time uses adaptive time step and satisfies the Courant - Friedrichs - Lewy criteria.

EVOLUTION OF ACCRETION RATE OF EACH PROTOSTARS WITHIN TWO COLLAPSING CLUMPS





DISCUSSION

• A fraction of the protostars for fast-rotating clumps directly travel at the periphery at around million of years, and even go away from their parent clumps. Protostars that escape the cluster earlier tend to have higher radial velocity (slightly steeper curve for the rotation parameter ≥ 0.05.

• There exist another possibility of merging. Depending on the initial mass, spin and angular momentum of the protostars, they may also continue to orbit within the central dense regime and gradually gain a sufficient amount of gas to end up becoming massive stars.

• Even if the initial mass function of protostars does not contain very massive stars, accretion can lead to a substantial increase in mass. Such evolving protostars may potentially prompt to initiate Pair-instability supernovae and also results in early development of black holes.

• In future studies, we plan to include radiative feedback as well as amplification of magnetic field, and it is possible that many body interactions lead to a more nuanced understanding.

CONCLUSION

For the first time to the best of our knowledge, we have shown that the first generation of stars might have formed in a broad range of masses depending on the strength of clump's rotation within minihalos. Some protostars are expected to remain in the main sequence as low-mass stars, whereas protostars for slow-rotating clumps keep on accreting to form massive stars in the absence of radiative feedback.

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