Simulating Stellar Feedback from Clusters: Toward Realistic Cluster Formation

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Scientific Goal

We study the formation and early evolution of massive star clusters star by star, ultimately using self-consistent ISM models.

Method

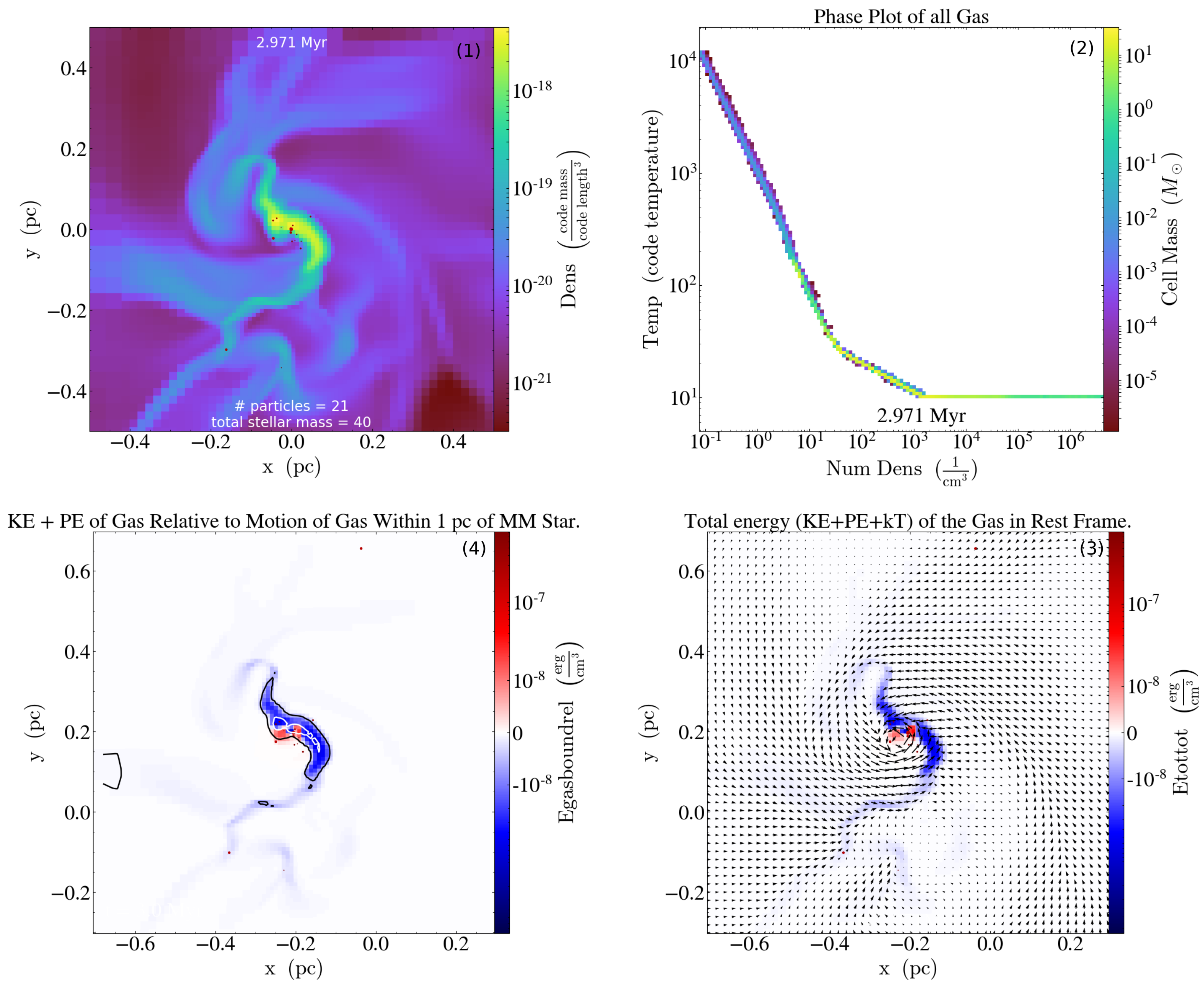
We simulate stellar feedback in the MHD code FLASH [1] and couple this to collisonal stellar dynamics and evolution in the AMUSE [2] software framework. Which includes:

1. 4th order Hermite N-body integrators ph4 [3] and Hermite [4].
2. Stellar and binary evolution using SeBa [5].
3. Stellar ionizing and non-ionizing radiation using a modified version of FERVENT [6].
4. Supernovae implemented as described in [7].
5. Stellar winds module based in part on [7].

We will compare our models with simulations that place cluster members in sink particles such as [8,9]. Each star in our simulation is resolved, injects feedback individually and undergoes collisional dynamics with every other star.

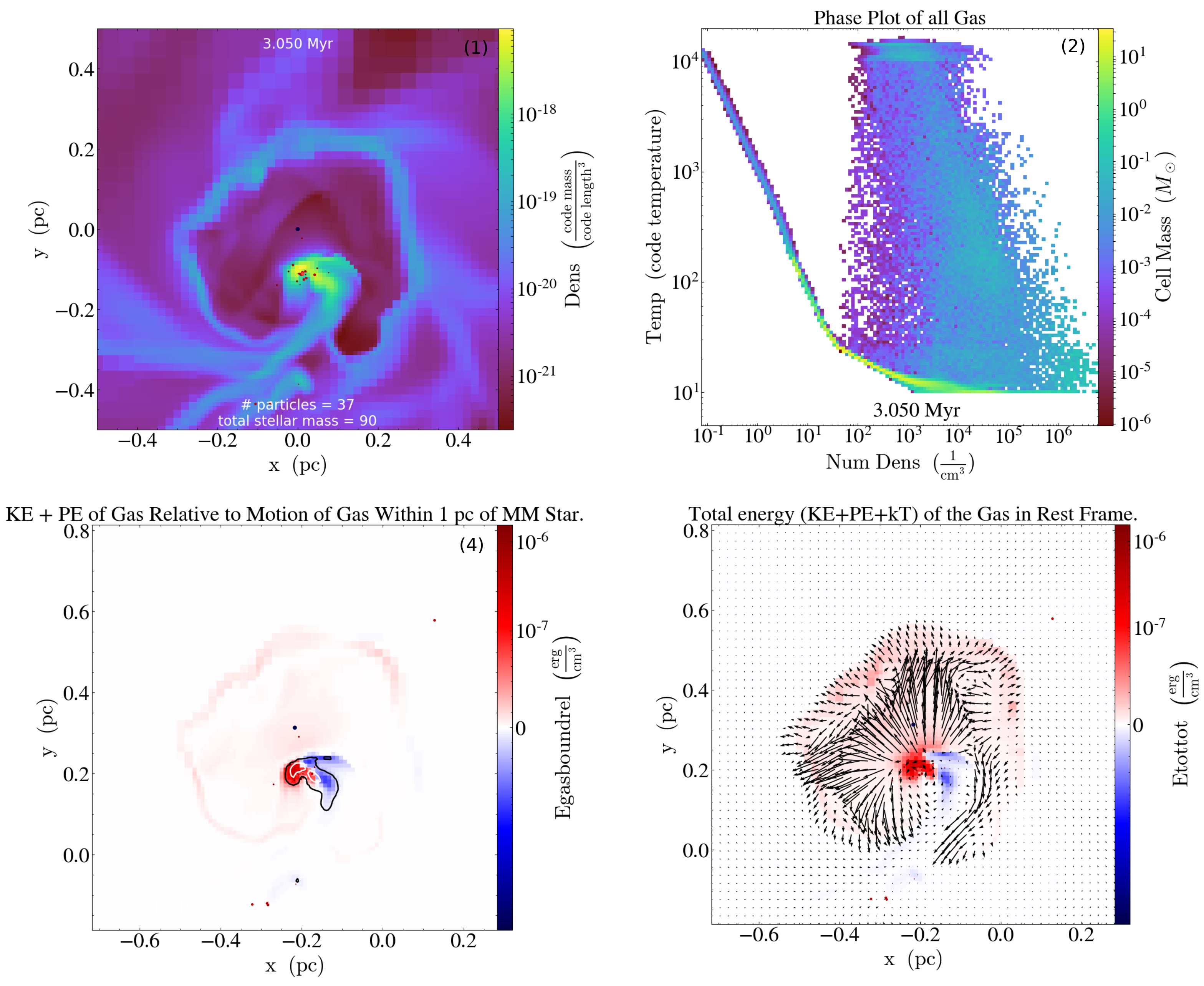
Star Cluster Formation Under Feedback

Here we present a simulation of a 10^3 solar mass turbulent cloud [10] forming a small cluster under the effects of our radiation feedback (photo-ionization and PE heating and pressure) and background PE heating, atomic, molecular and dust cooling. Our domain is 10 pc^3 cubed with 8 refined levels and a max resolution of ~2×10^3 AU.



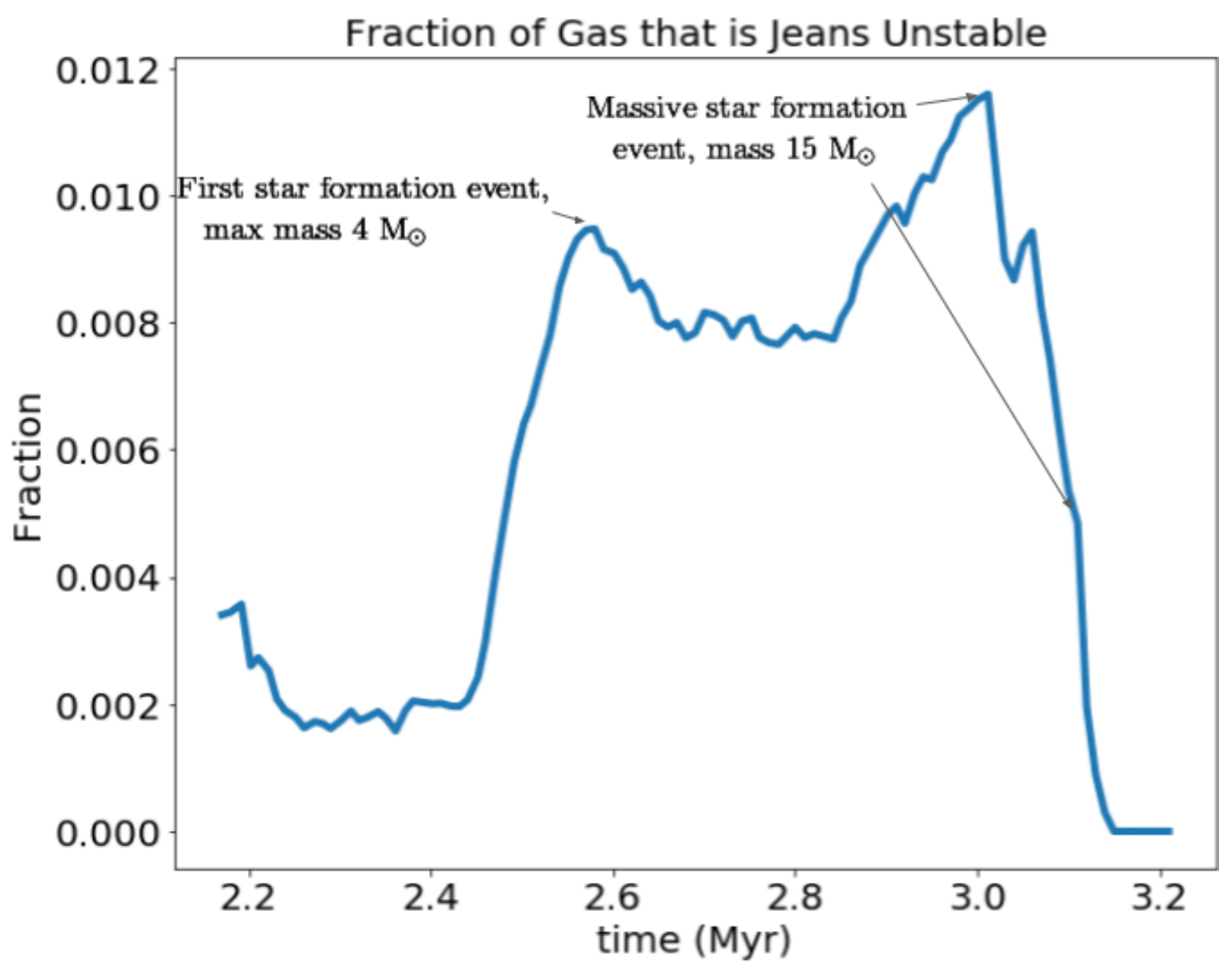
Plots from just after the first burst of star formation. Clockwise from top left: (1) Density slice; (2) Phase plot of temperature vs. density; (3) Total energy density (gas + stars potential + gas kinetic+ gas internal) in the rest frame with gas velocity; (4) Dynamic energy density (gas + stars potential+ gas kinetic) of relative motion within 1 pc of 4 solar mass star at cluster center. Black contour is $n_H > 10^3$ cm^{-3}, white is $n_H > 10^4$ cm^{-3}.

Here a 15 solar mass star has formed and is ionizing the surrounding gas. However a dense clump is able to survive even after the massive star passes through the region, and this clump later forms more stars (including another B star).

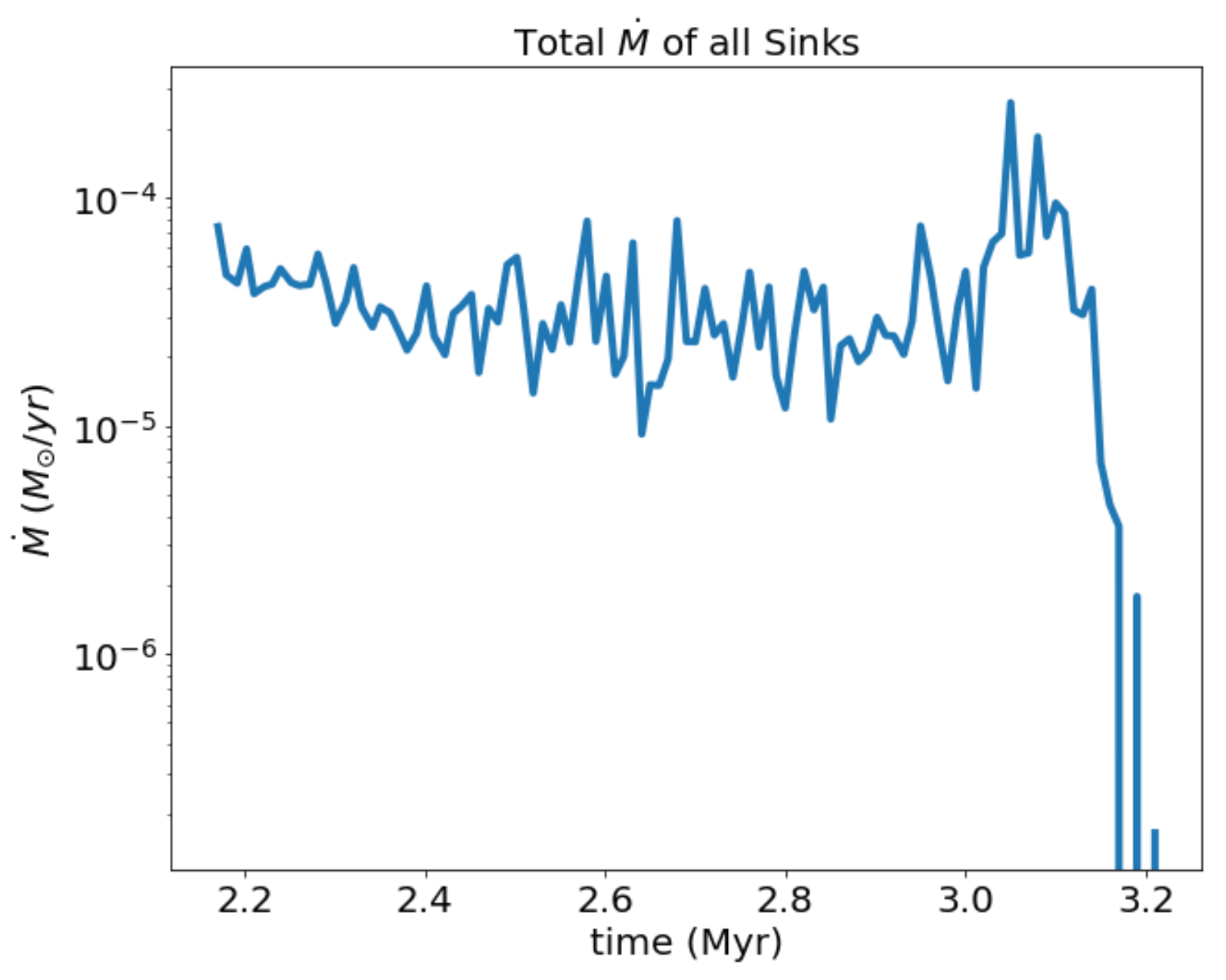


Plots from just after the first massive star forms (15 solar masses). Clockwise from top left: (1) Density slice with gas velocity; (2) Phase plot of temperature vs. density; (3) Density slice after the B star passes by the region of dense gas; (4) Total energy density (gas + stars potential+ gas kinetic+ gas internal) in the rest frame with gas velocity. Black contour is $n_H > 10^3$ cm^{-3}, white is $n_H > 10^4$ cm^{-3}.

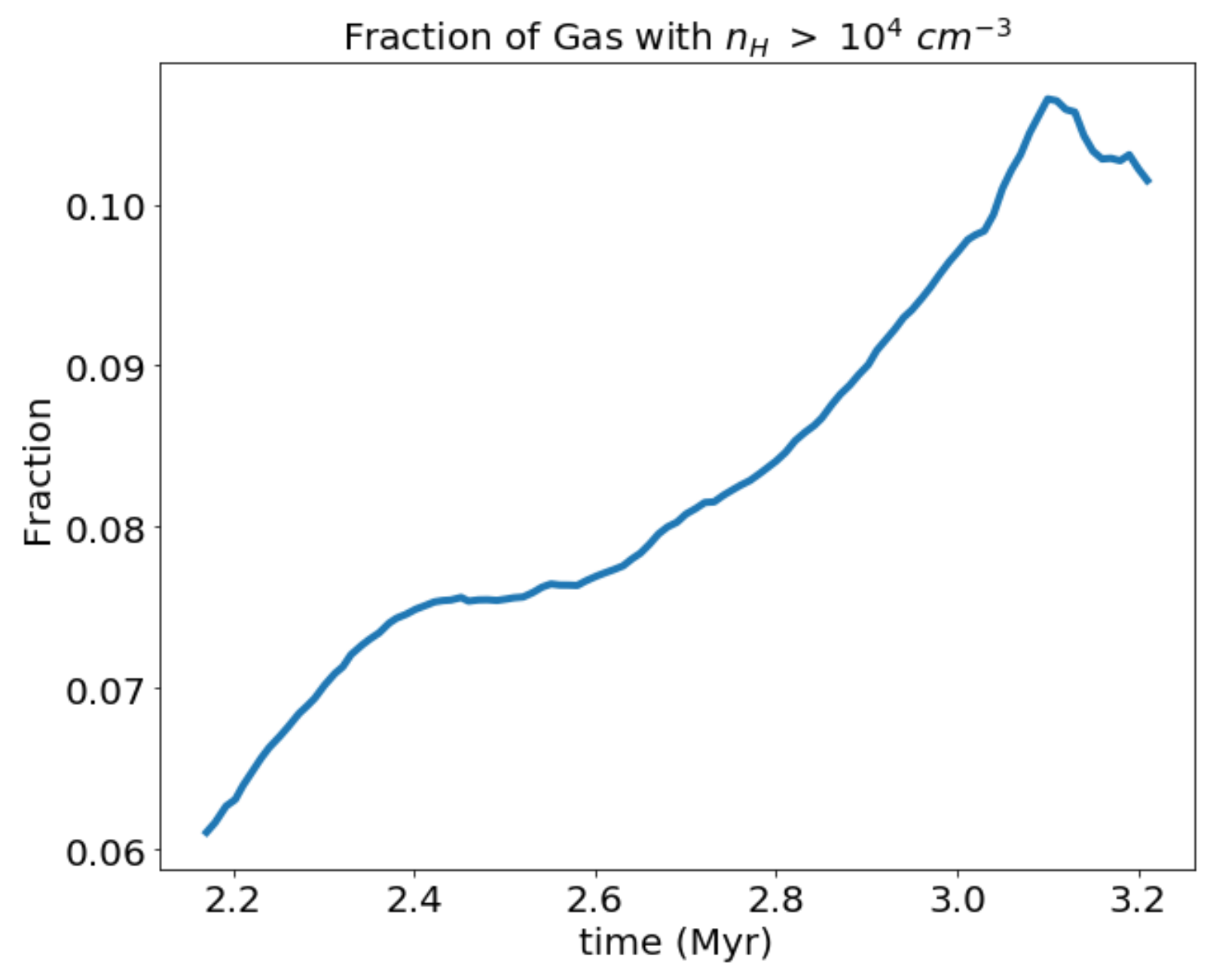
Time Evolution of the System



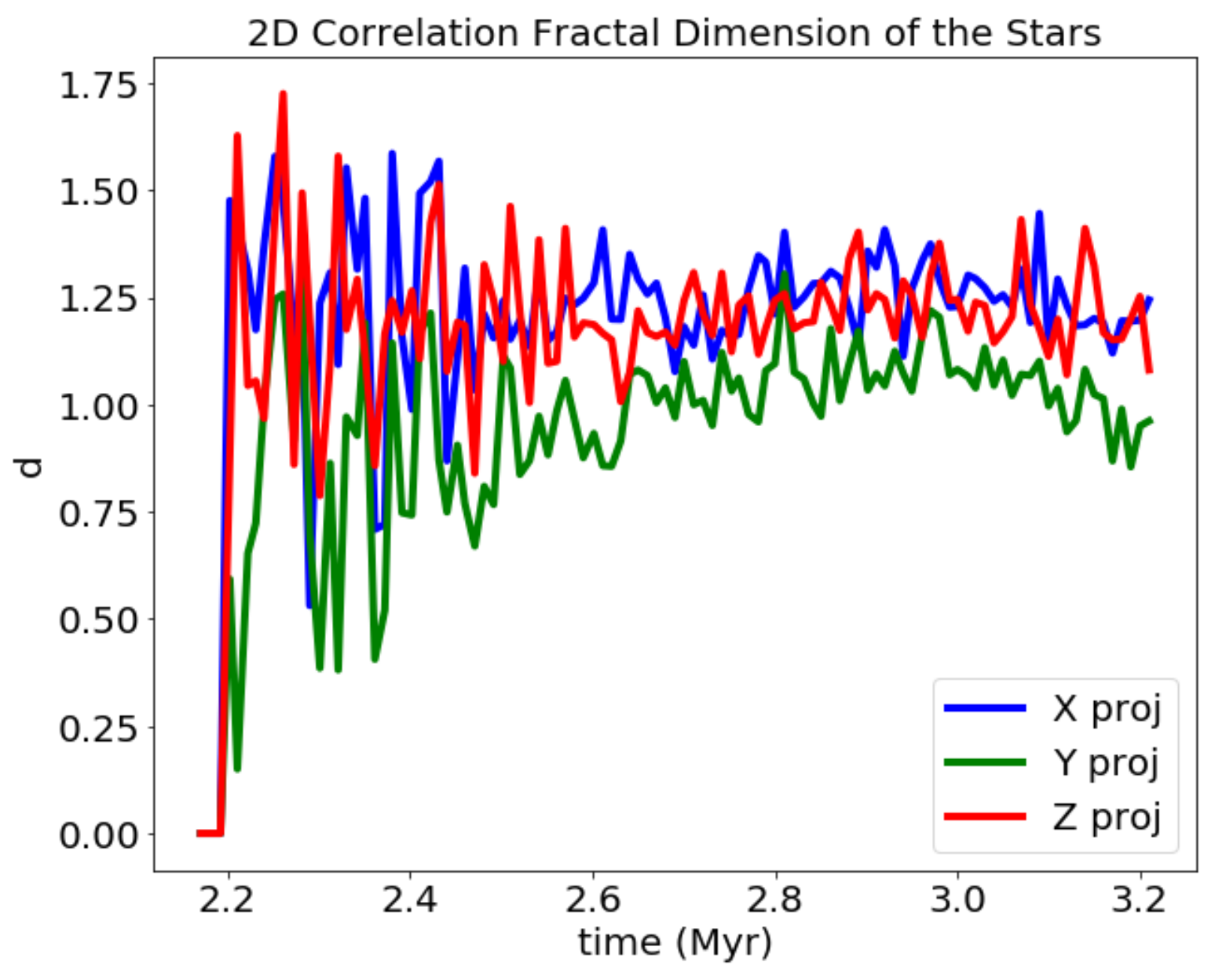
Fraction of gas that is Jeans unstable across the simulation.



Mass accretion rate across all sinks in the simulation. Sinks accrete mass that become individual stars followed with collisional dynamics.

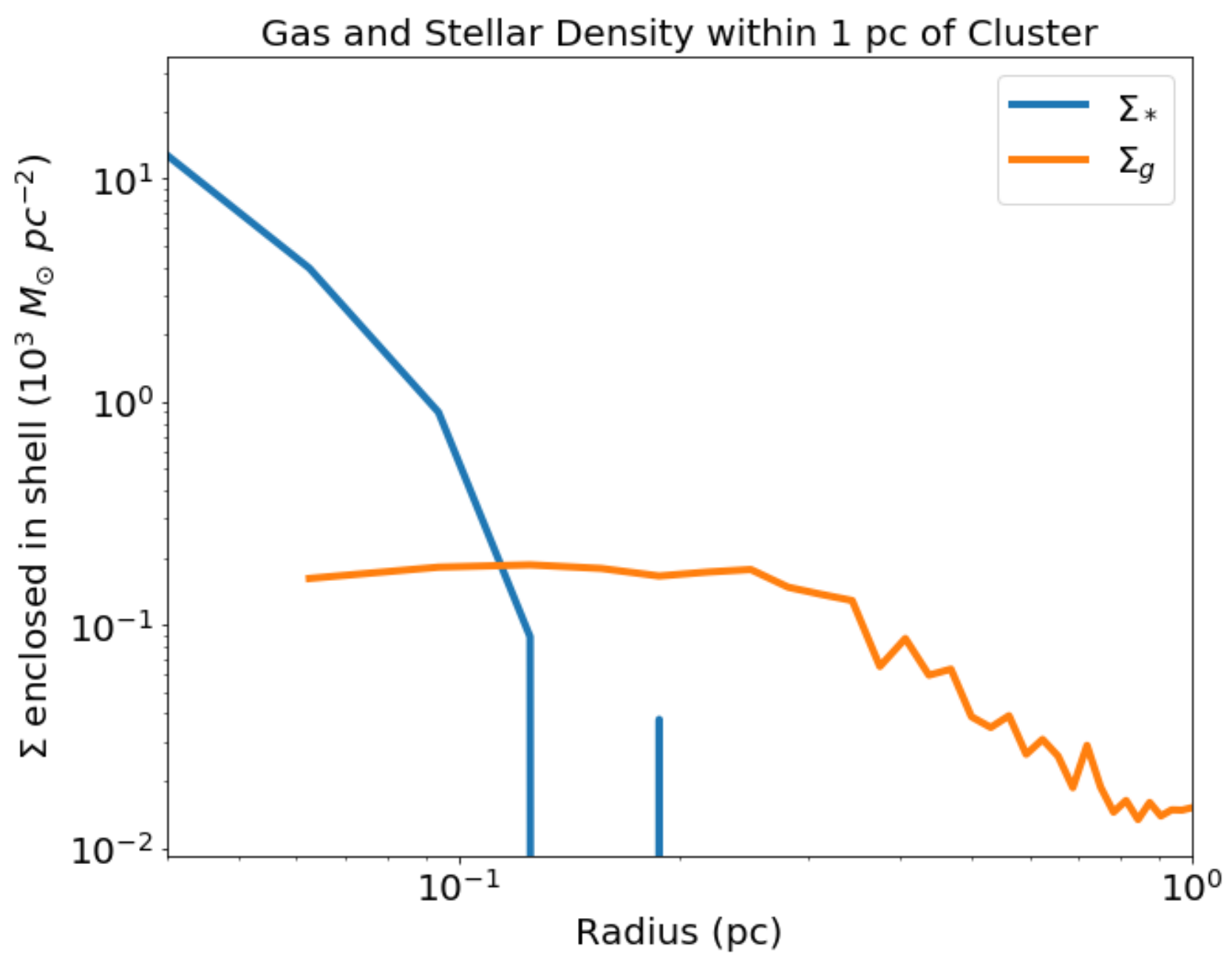


The fraction of gas with $n_H > 10^4$ cm^{-3} over the whole simulation. Density holds even as Jeans length falls, similar to results in [8].

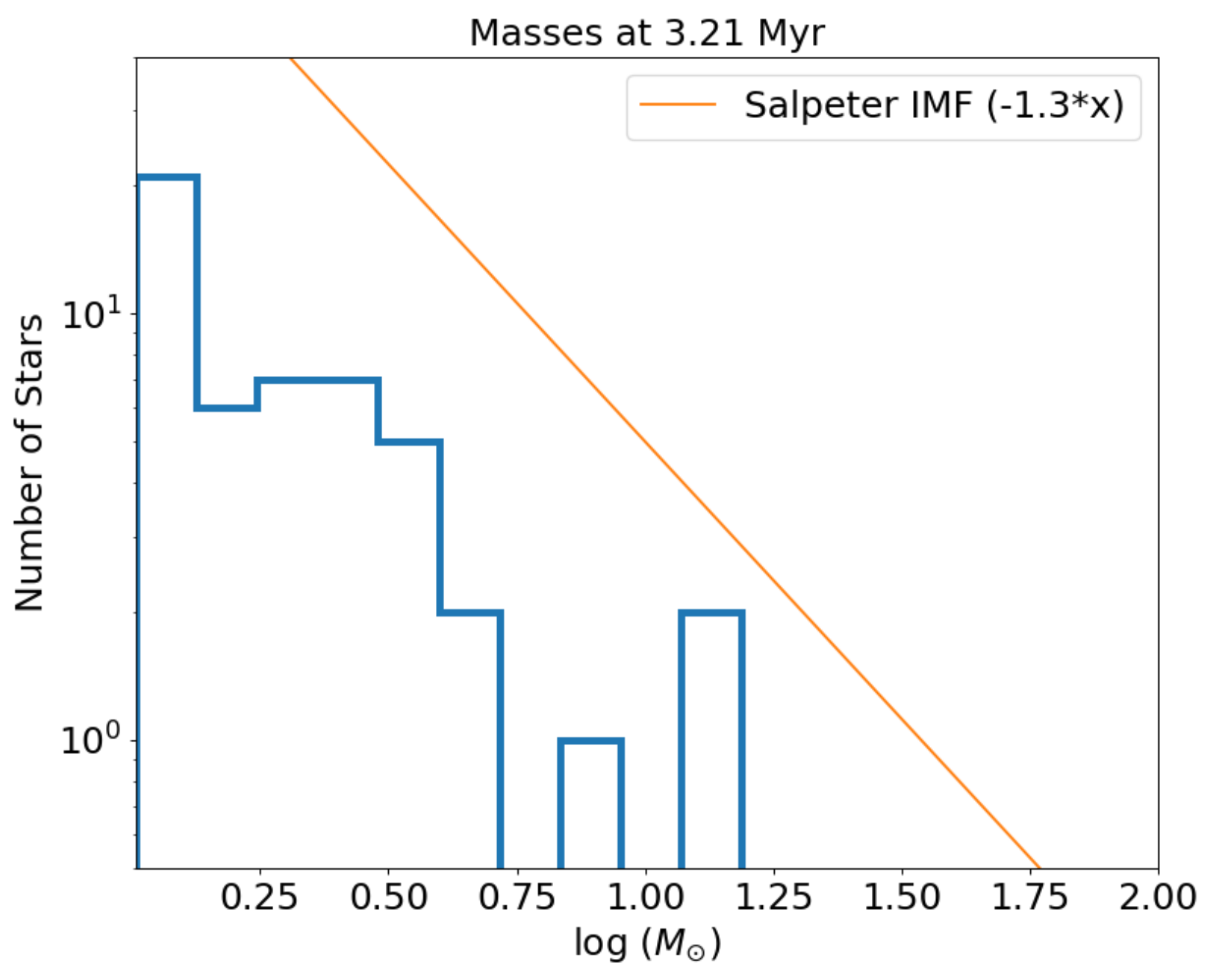


The correlation dimension of the stars in the simulation computed in 2D. Our cluster appears slightly more fractal than expected (~1.6), which could be due to small numbers [11].

Distribution of Gas and Stars

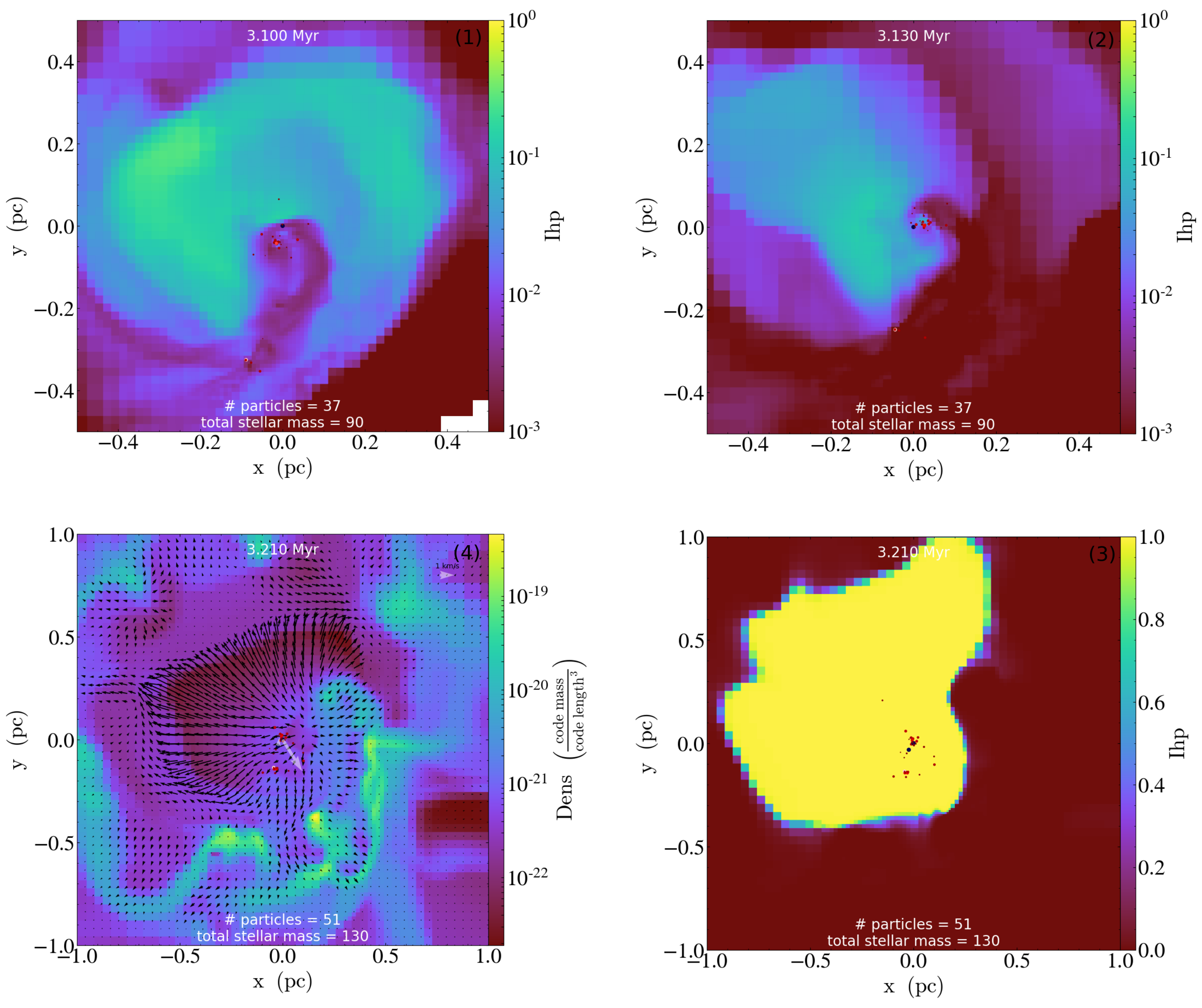


Radial distribution of both stellar and gas mass density within 1 pc of the cluster at 3.21 Myr. Both B stars have merged into the central cluster.



Mass distribution of the cluster just after the formation of the second 15 solar mass star.

Radiation, Ionization and Star Formation



Clockwise from top left: A projection of density-weighted ionization fraction (1) before and (2) after B star passed through the filament with a density of n_H ~10^6 cm^{-3} showing the HII region flickering. Radiation is blocked by this filament, allowing a second star formation event which leads to another 15 solar mass star. Combined effects of both stars are seen in ionization fraction (3) and density with gas velocity in (4).

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