

Effects of Early Forming Massive Stars

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- *How* gas is removed (rapidly, or slowly) may affect cluster structure.²

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- Gas evacuation (via stellar feedback) is crucial to the completion of star cluster assembly.¹
- *How* gas is removed (rapidly, or slowly) may affect cluster structure.²
- What about *when* massive stars form? Using our computational model we test the effects of early forming massive stars.

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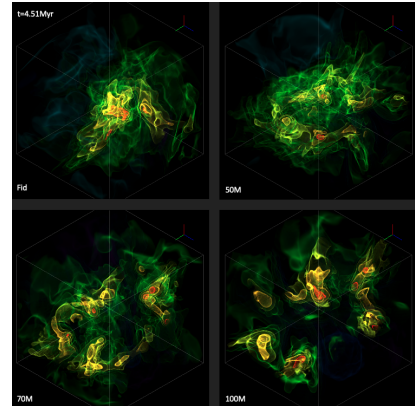
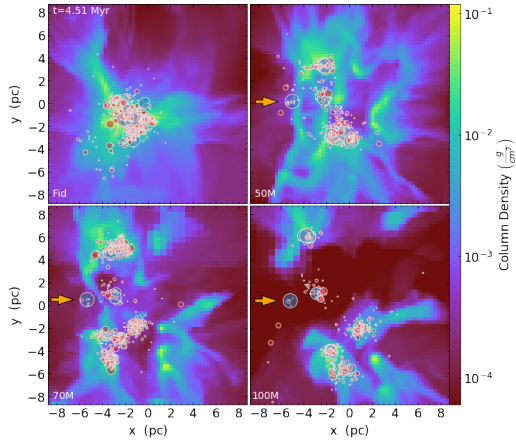
Torch

Stars from gas

- Couples N-body, stellar evolution, and feedback in AMUSE with self-gravitating magnetized gas in MHD code FLASH.
- Resolved dynamics of stars and gas; study star cluster formation within collapsing GMCs.
- Form stars from sink particles which each have a randomized star mass list sampled from the Kroupa IMF.^[3]

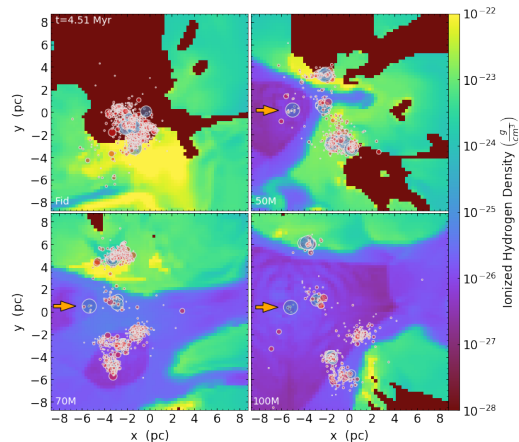
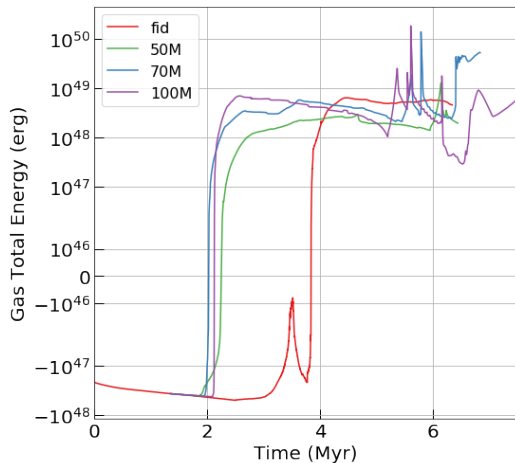
³Kroupa 2001

A Controlled Experiment



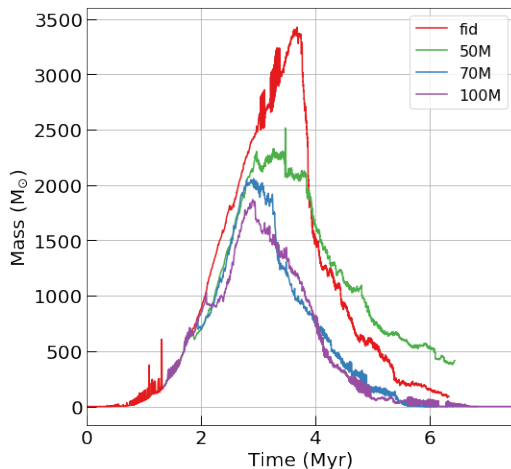
Lewis et al. 2023

Effects on Gas Energy

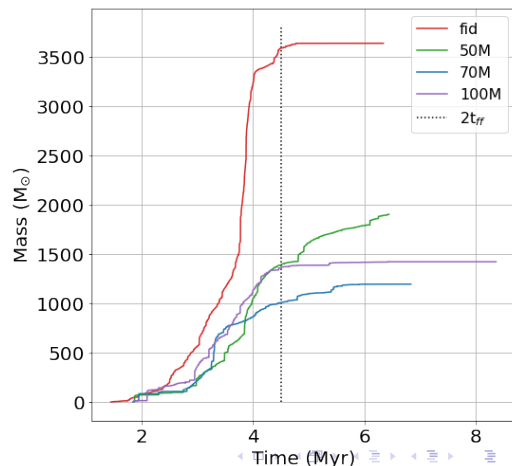


Effects on Gas Accretion and Star Formation

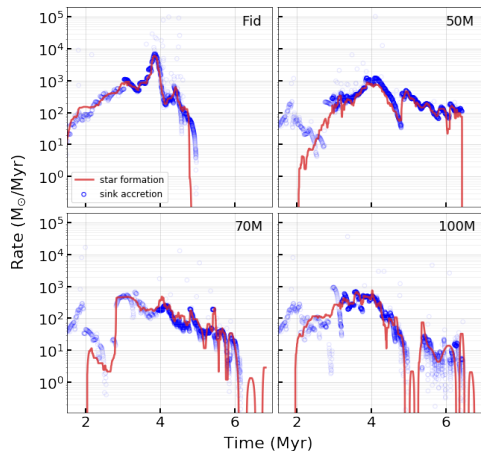
Gas Satisfying Jeans Criterion



Cumulative Stellar Mass

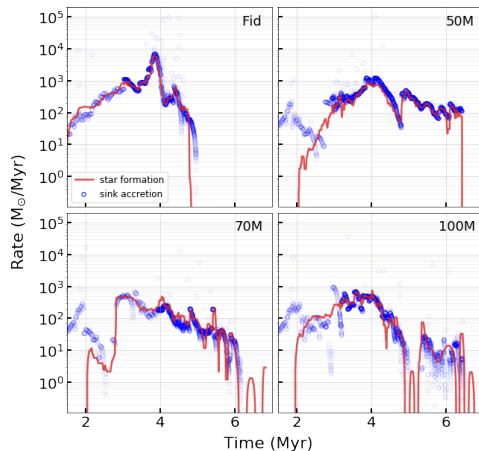


Effects on Gas Accretion and Star Formation



Early forming massive stars reduces sink accretion and star formation rates.

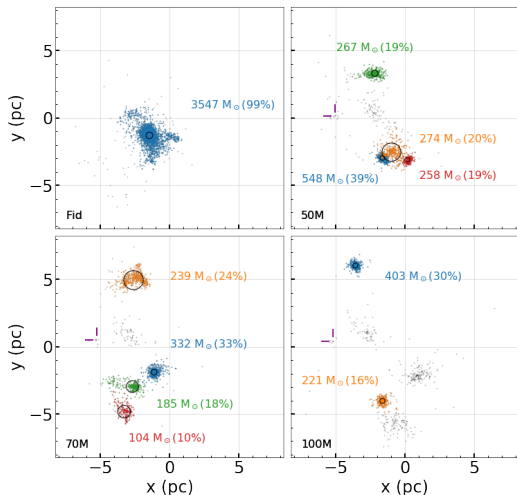
Effects on Gas Accretion and Star Formation



Early forming massive stars reduces sink accretion and star formation rates.

Run	$\langle \epsilon_{ff} \rangle$
Fid	0.23
50M	0.08
70M	0.03
100M	0.04

Effects on Star Clustering, Cluster Assembly



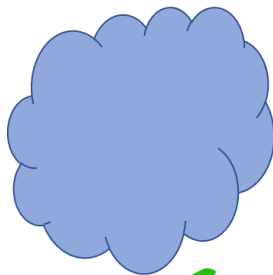
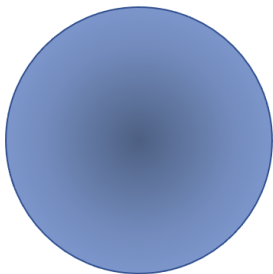
- DBSCAN to identify cluster with at least 50% bound members and $100 M_{\odot}$ at $2\tau_{\text{ff}}$.
- Clusters in runs with early massive stars are less massive and more fragmented compared to the fiducial run.

Run	Mass in Clusters $10^3 M_{\odot}$	Frac Mass M_c / M_{tot}	r_h MMC pc	E_{bind} MMC 10^{46} erg
Fid	3.6	0.99	0.25	-140
50M	1.4	0.97	0.17	-12
70M	0.86	0.85	0.21	-4.2
100M	0.62	0.46	0.18	-3.8

Effects of Early Forming Massive Stars

- Significantly disrupt the natal gas structure, resulting in premature unbinding of GMC.
- The star formation rate per free-fall time is suppressed by up to a factor of seven, reducing the total mass of stars formed.
- Stifle the hierarchical assembly process of massive star clusters, instead promoting the formation of spatially separate and more loosely bound subclusters.

The Problem with Initial Conditions



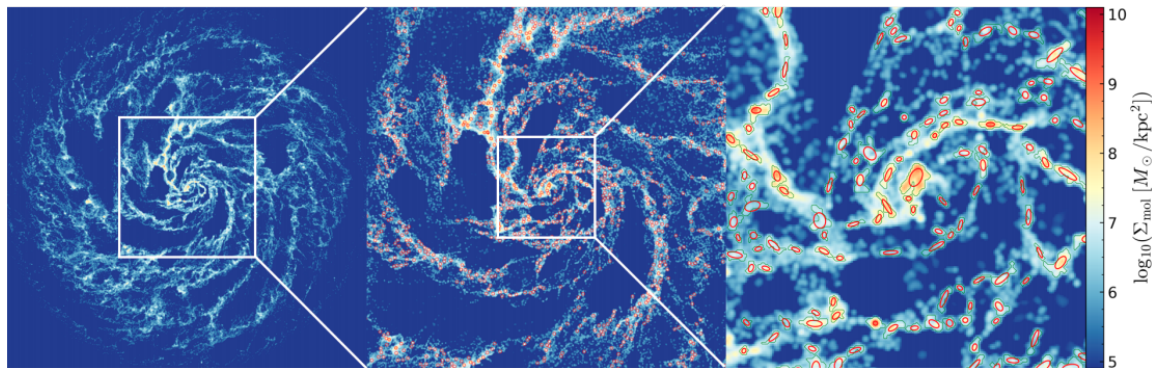
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- Creating our own isolated clouds from scratch? “Creative liberties...”

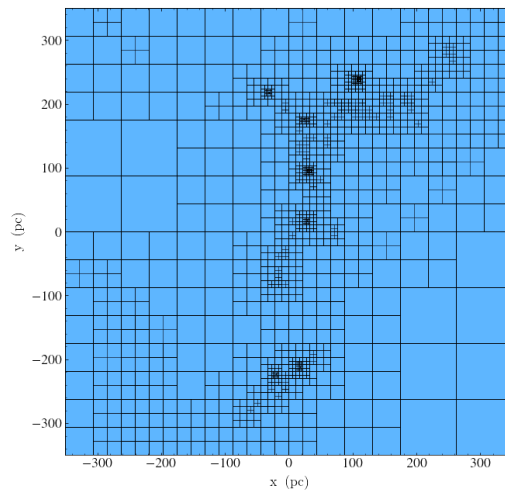
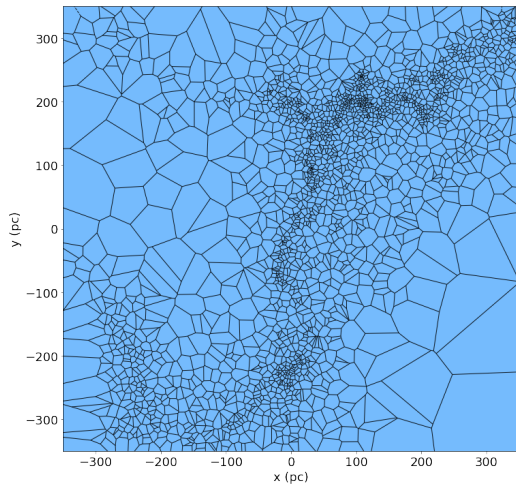
Clouds from Galactic Simulations

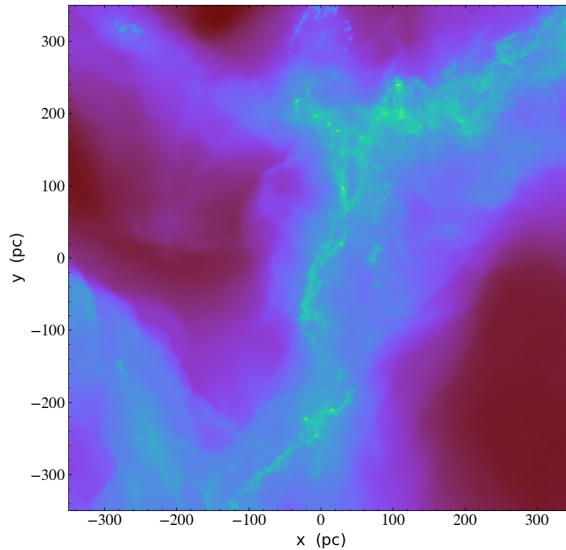


GMC identification⁴

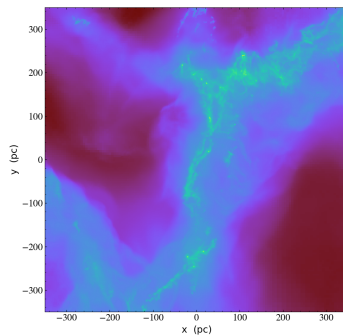
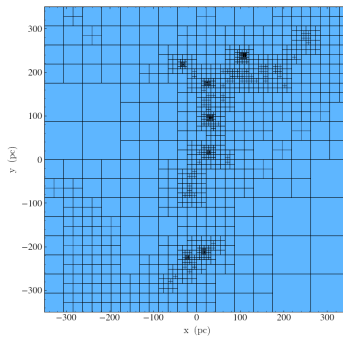
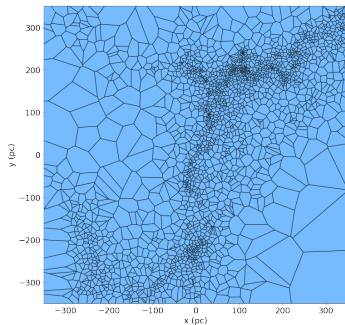
⁴Li, H. et al. 2020

Voronoi Mesh to AMR Grid

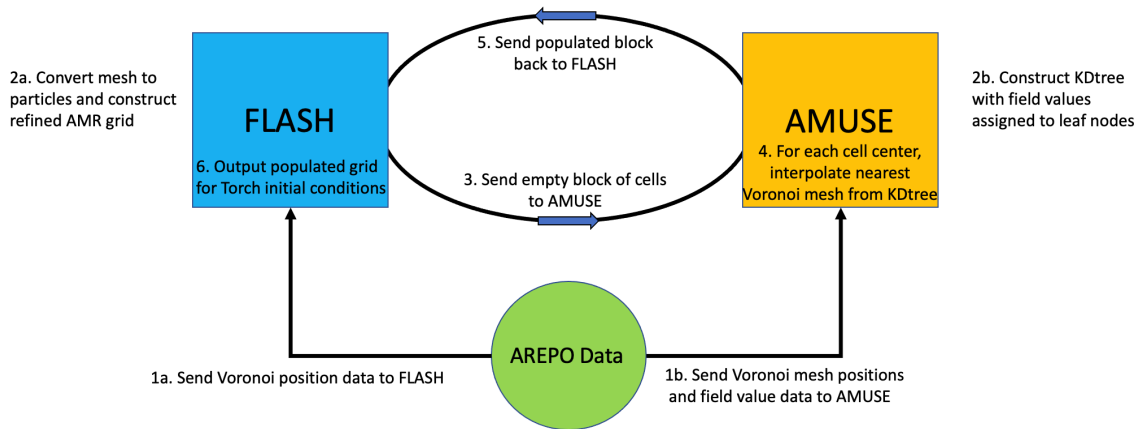




Voronoi Mesh to AMR Grid



VorAMR: Logic path



VorAMR: The Big Wins

- Provides a novel way to visualize Voronoi mesh-based hydrodynamical data.
- Represents a critical linkage in the star cluster simulation pipeline which will allow Torch to use realistic GMC initial conditions.
- Provides an avenue for increased collaboration between entrenched research groups.

Thank You!
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Questions?

Appendix

$$\epsilon_{\text{ff}} = \dot{M}_* \frac{t_{\text{ff}}}{M_g} \quad (1)$$