Effects of Early Forming Massive Stars

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- What about *when* massive stars form? Using our computational model we test the effects of early forming massive stars.

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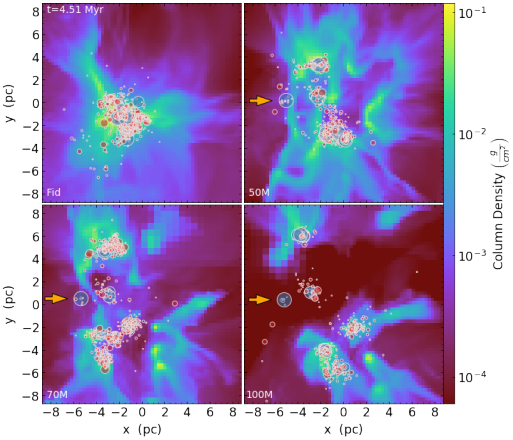
Torch

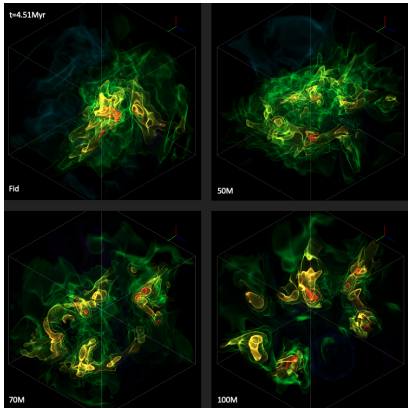
Stars from gas

- 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]

[3] Kroupa 2001

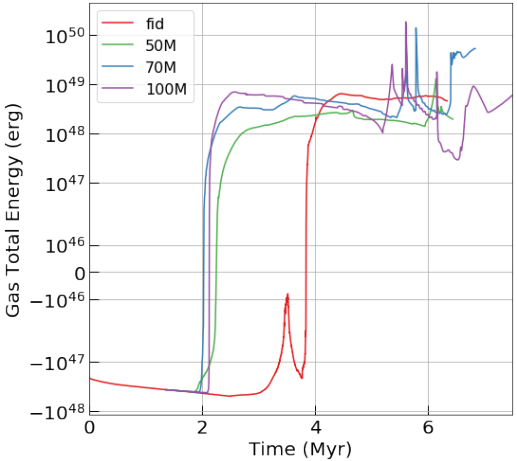
A Controlled Experiment

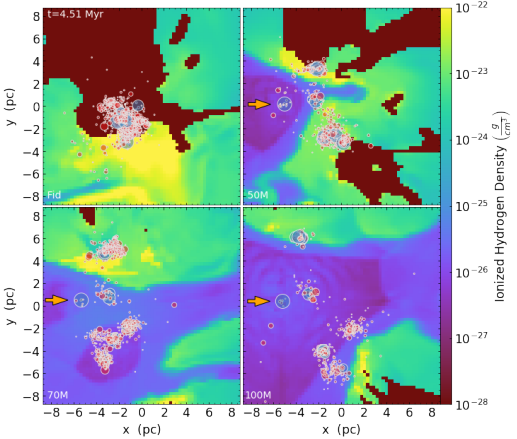




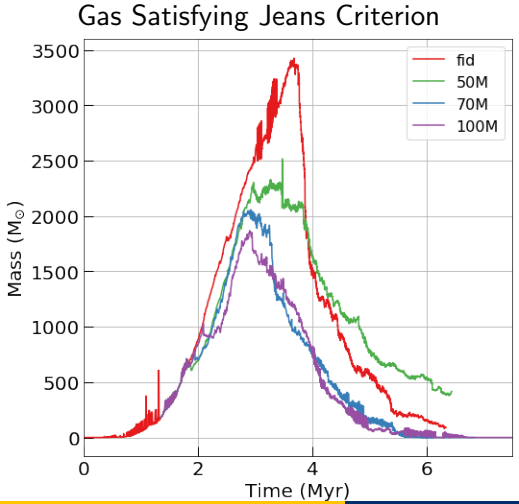
Lewis et al. 2023

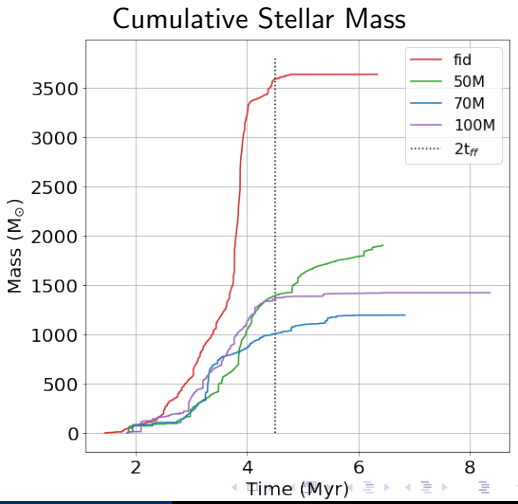
Effects on Gas Energy





Effects on Gas Accretion and Star Formation





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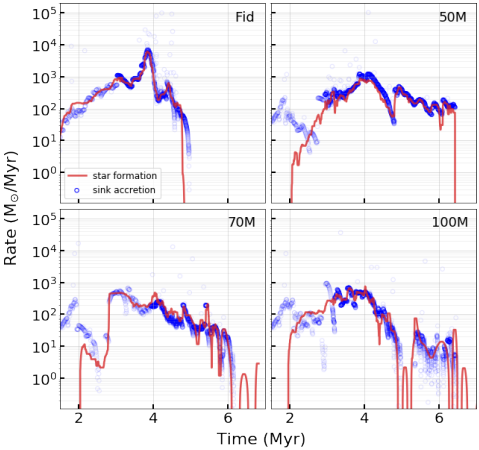
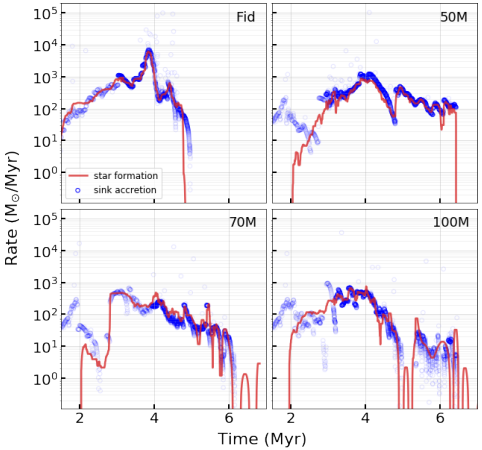


Early forming massive stars reduces sink accretion and star formation rates.

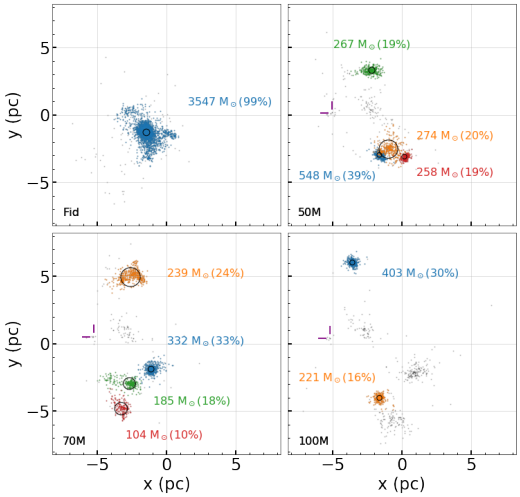
Effects on Gas Accretion and Star Formation



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 $2\tau_{\rm ff}$.
- 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

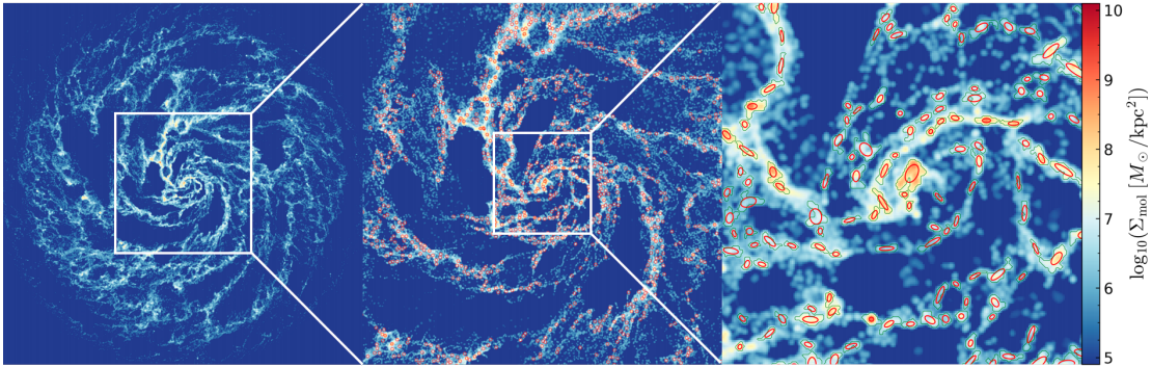
- Significantly disrupt the natal gas structure, resulting in premature unbinding of GMC.
- The star formation rate per free-fall time is suppressed by up to a factor of seven, reducing the total mass of stars formed.
- Stifle the hierarchical assembly process of massive star clusters, instead promoting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

The Problem with Initial Conditions

- Self consistent galactic scale simulations with resolution down to sub-tenth parsec scales and include Nbody individual stellar dynamics and individual stellar feedback all at once? A little tough.

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

Clouds from Galactic Simulations

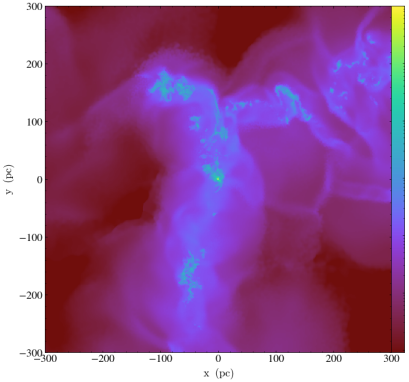


GMC identification[4]

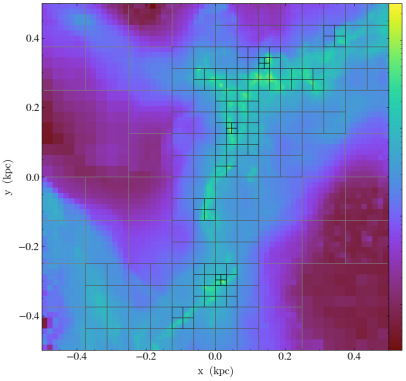
[4] Li, H. et al. 2020

From AREPO to FLASH

Try CIC Mapping?

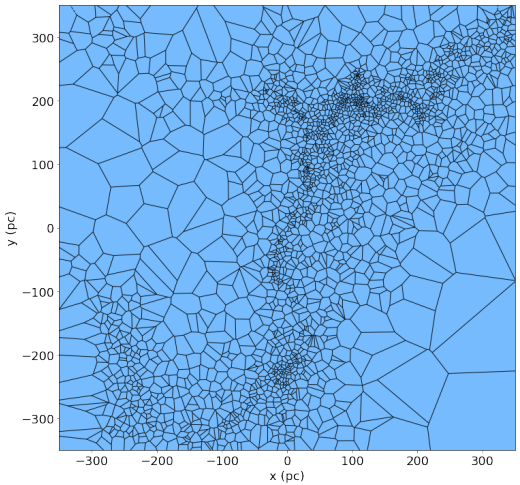


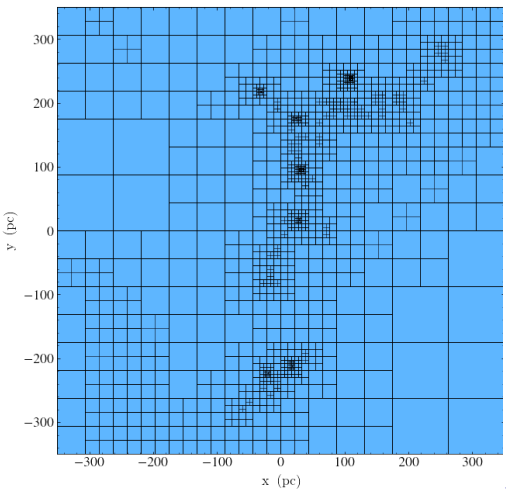
Cloud from raw AREPO data represented using SPH kernels



Cloud-in-cell mapping onto AMR FLASH grid

Voronoi Mesh to AMR Grid





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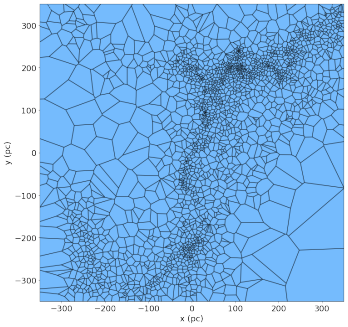
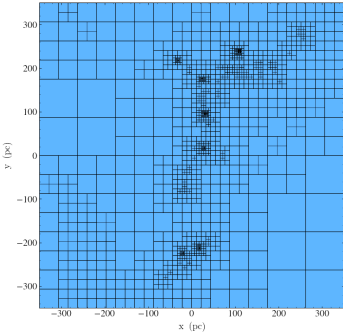
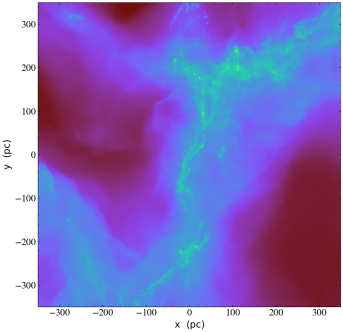
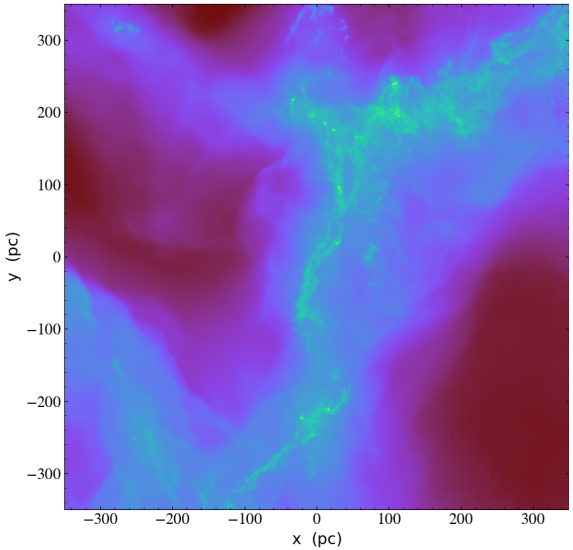
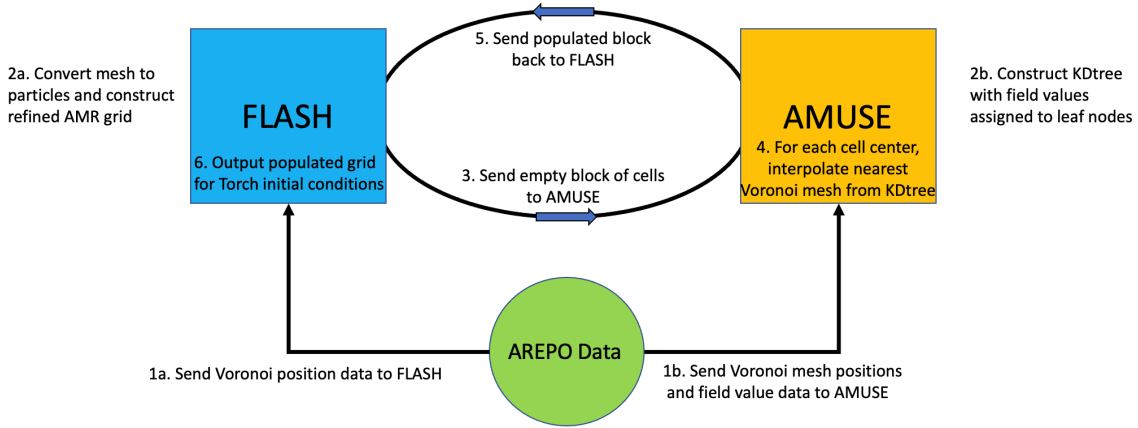







300
200
100
0
−100
−200
−300
y (pc)
−300
−200
−100
0
100
200
300
x (pc)

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

$$\epsilon_{\mathrm{ff}} = \dot{M}_* \frac{t_{\mathrm{ff}}}{M_{\mathrm{g}}} \tag{1}$$