



# Annual Review 2021

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06/29/21

# Background:

What is Sean working on again?

- Star formation process
- Computational models to simulate:
  - Giant molecular clouds collapse gravitationally to form stars,
  - stellar feedback,
  - stellar N-body dynamics
  - MHD grid code FLASH integrated into AMUSE framework –**Torch**
- **Early forming massive stars suppress gas collapse and star formation.**
- **AND hierarchical cluster assembly.**

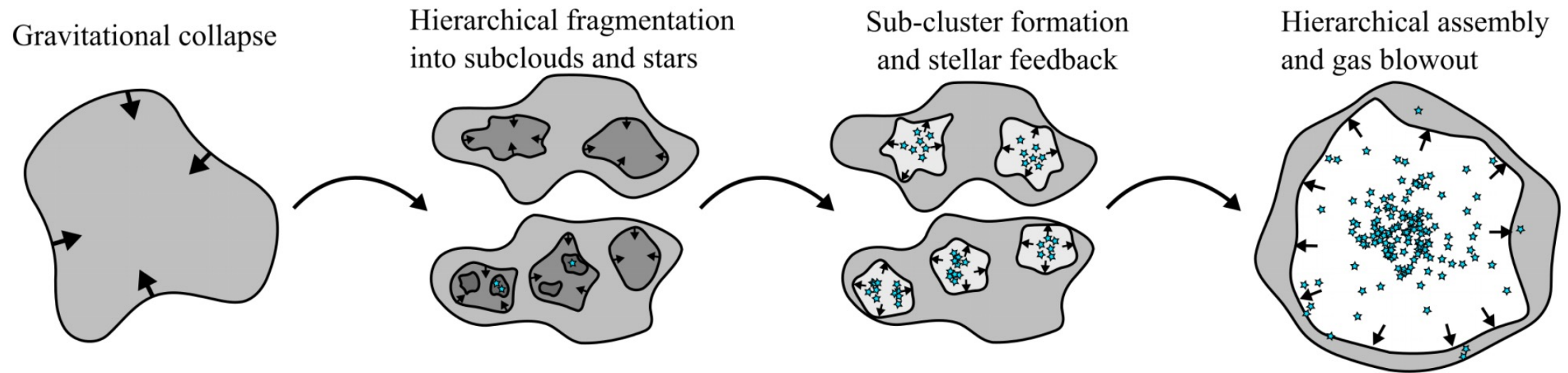
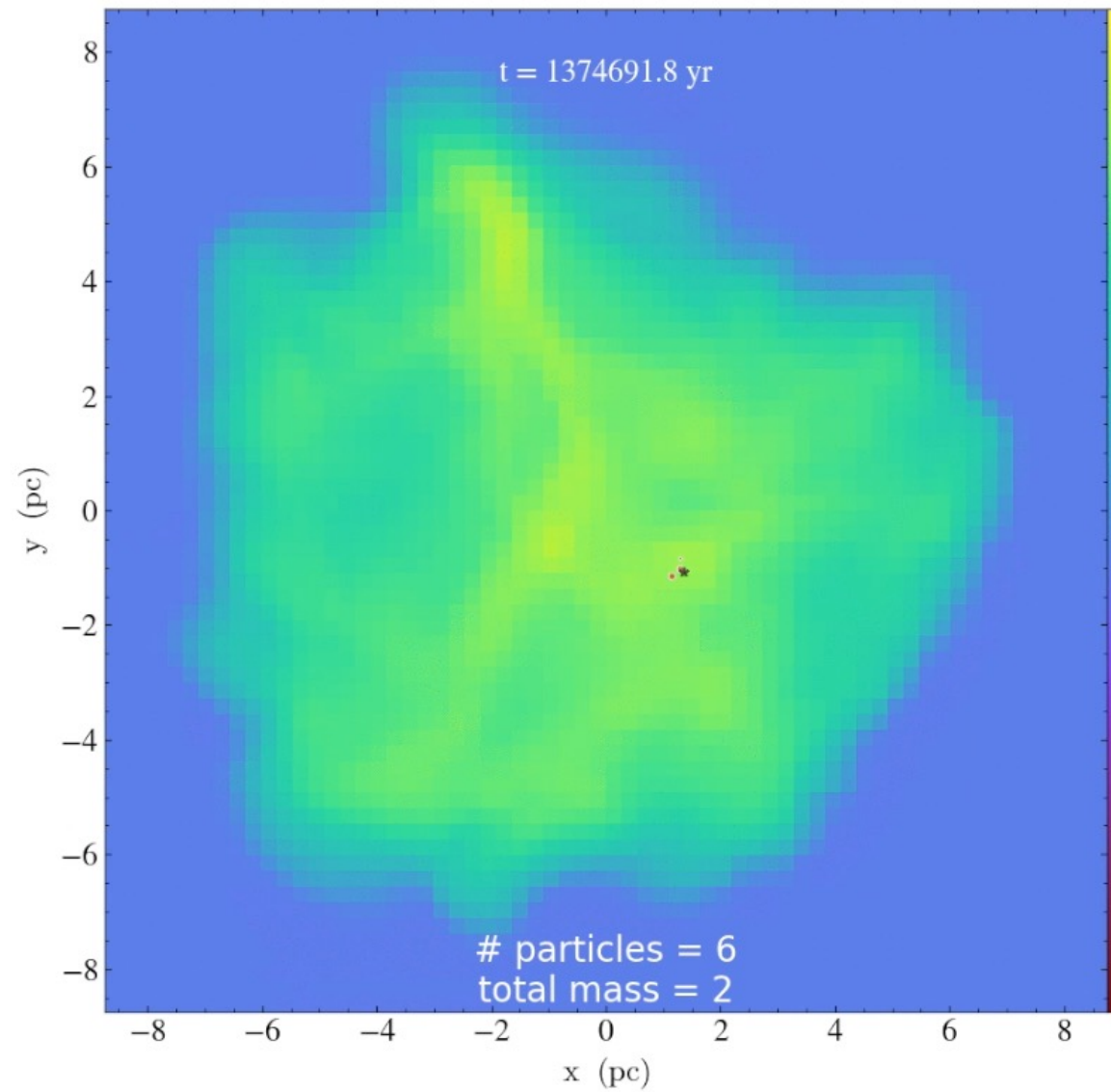
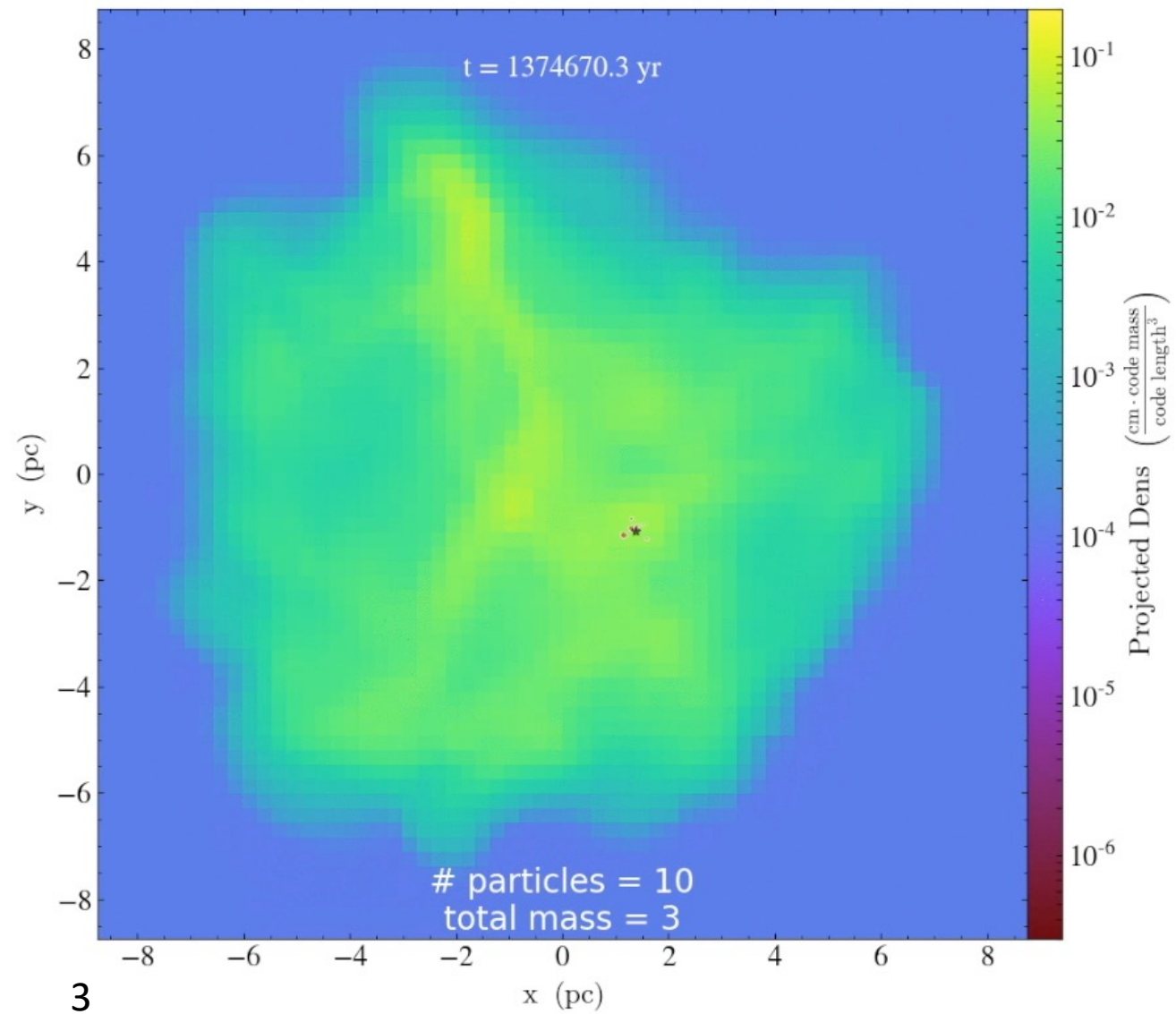


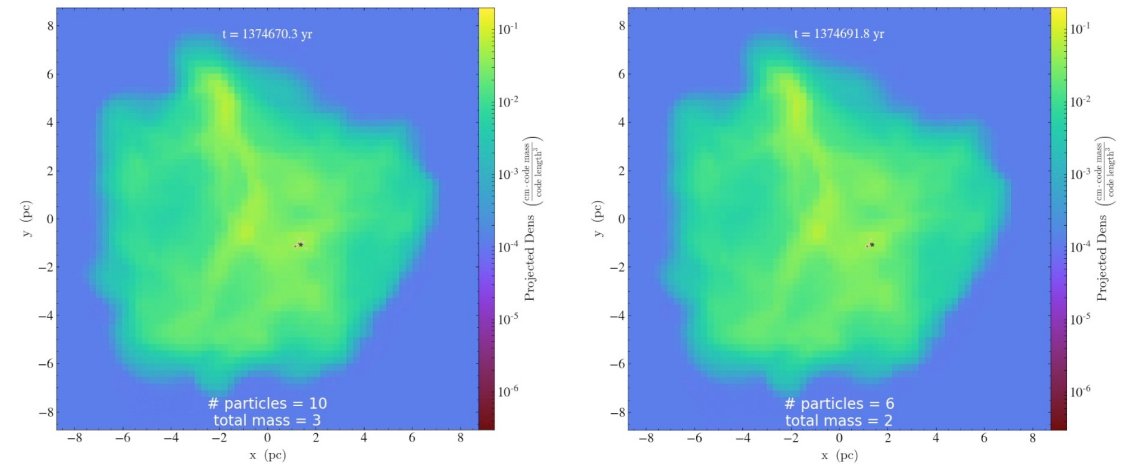
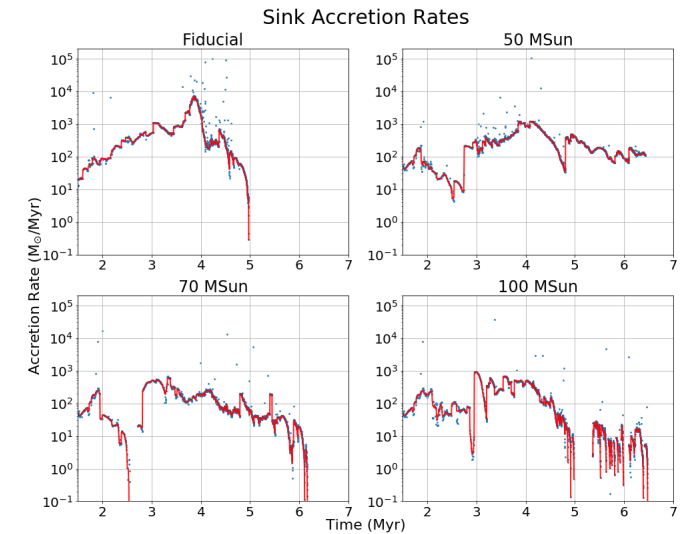
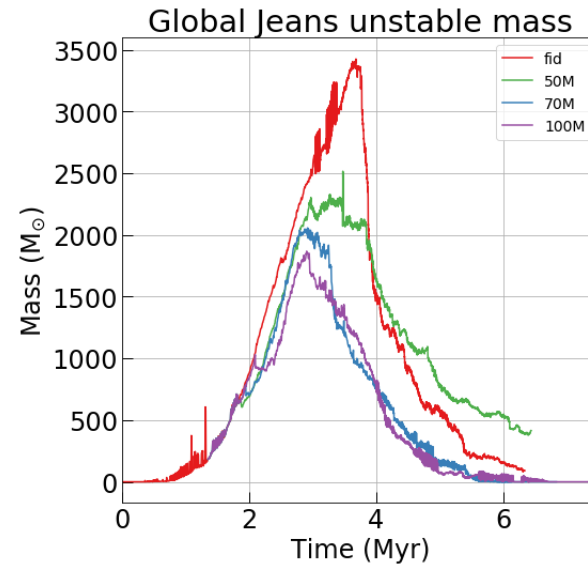
Image Credit: Grudić et al. 2019



# Paper 1 – Results

## Early Forming Massive Stars:

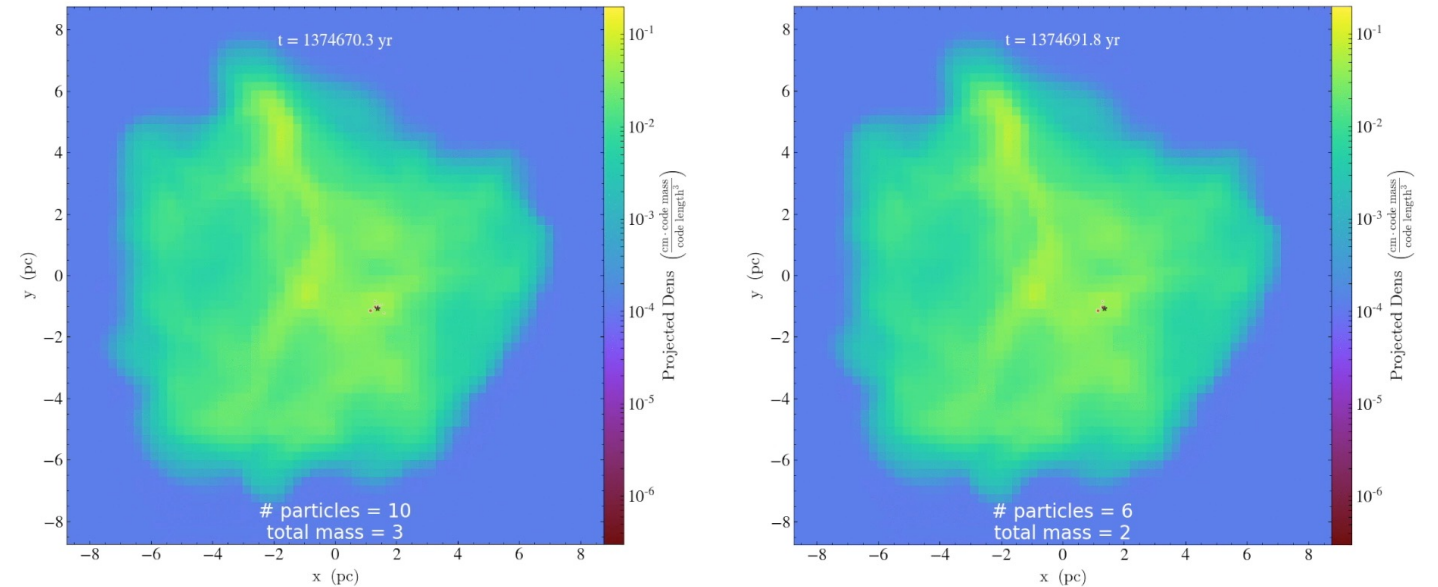
- Globally unbind gas  $\sim 2$  Myr sooner
- Remove gas & stars from computational domain
- Suppress total eligible star forming gas
- Suppress accretion onto sink particles
  - Limits conversion of gas into stars
- Promote formation of several internally bound subclusters that are not bound to most massive cluster on grid



# Paper 1 – Future Progress Timeline

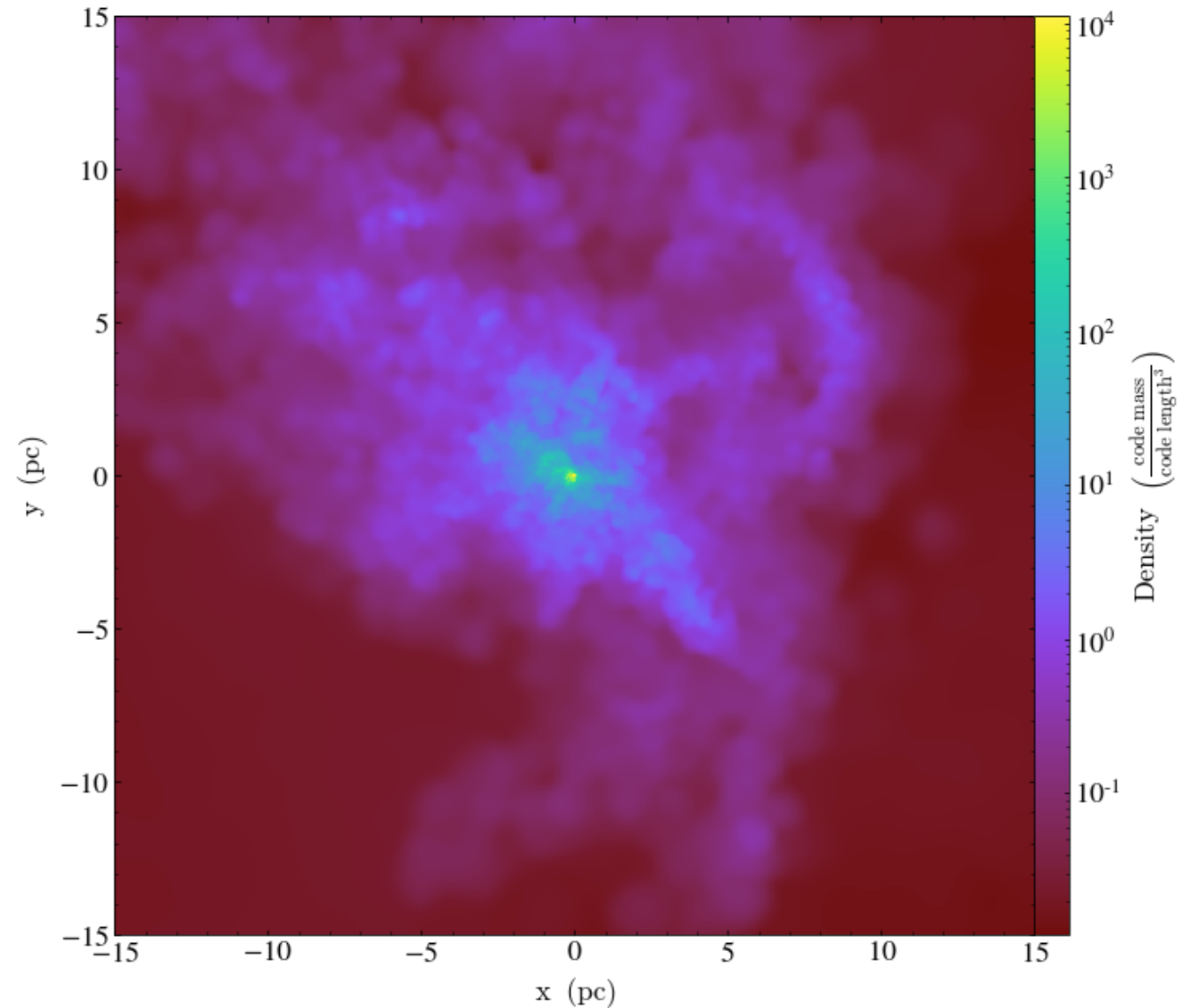
## “Early Forming Massive Stars Suppress Hierarchical Cluster Assembly”

- Expand parameter space by completing and analyzing set of simulations without stellar winds.
- Refine analysis of cluster dynamics to show prevention of large single star cluster forming.
- Curate cluster data for other graduate students to analyze.
- Paper draft writing begins now, completed and submitted by end of Summer.



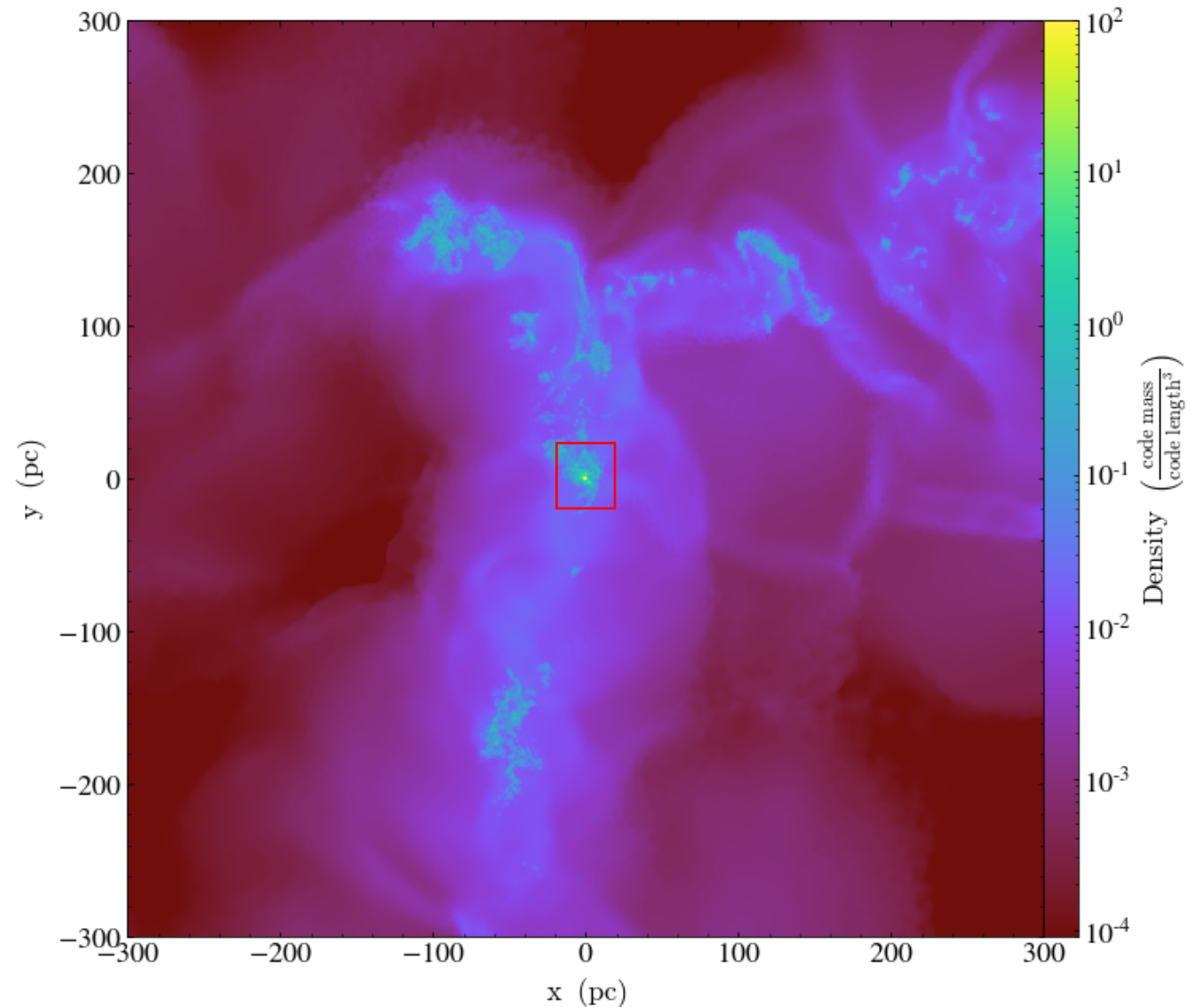
## AREPO-Torch Port

- AREPO: MHD finite volume moving mesh code.
- Star formation simulations have a scale problem.
- Torch simulations (so far) have a spherical cow problem.
- Would rather evolve GMCs that formed in a galactic environment.
- Have access to Hui Li's data (Columbia Univ.): snapshots of clouds formed in a galaxy.



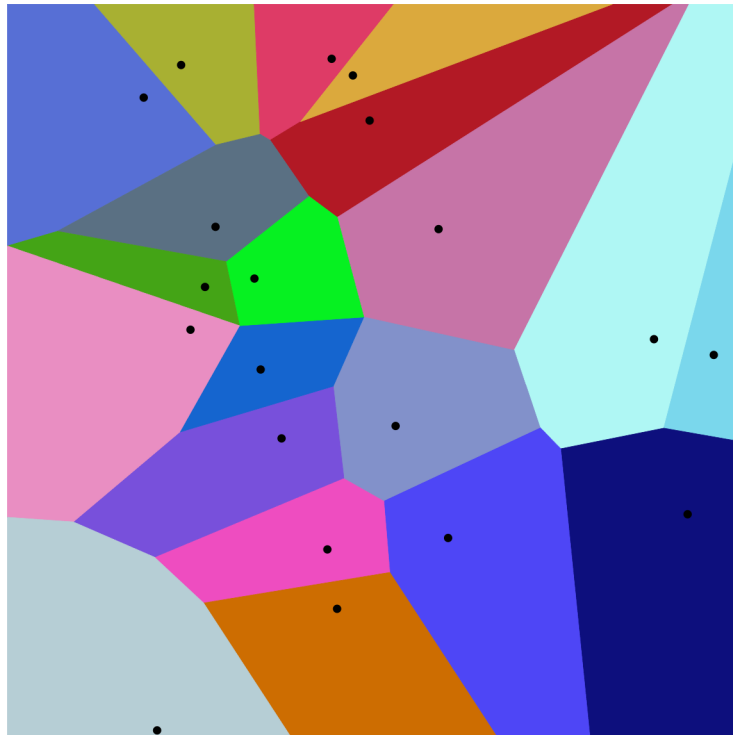
## AREPO-Torch Port

- Also have larger context of environment around GMC: gas and galaxy.
- Goal: use these runs as initial conditions in Torch.
  - Take advantage of AMUSE integration for stellar evolution and N-body dynamics.
- To what accuracy can AREPO output data be converted FLASH input?

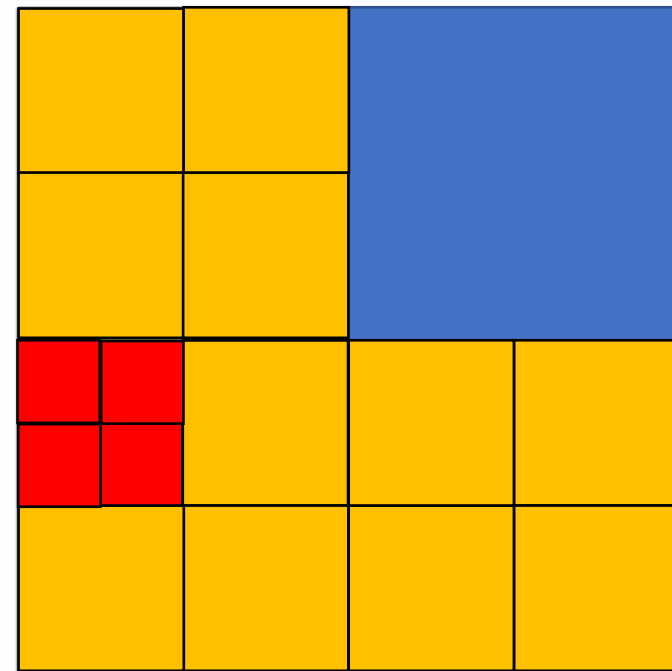


## Paper 2 – AREPO to FLASH method

- To what accuracy can AREPO data be converted to FLASH input using native FLASH routines?
- Provides a new avenue of software integration across large/popular code bases.
- Conversion of moving mesh to FLASH has not been done before.
- Conversion will take place entirely within FLASH and so can be integrated into the larger FLASH public distribution.



AREPO moving mesh

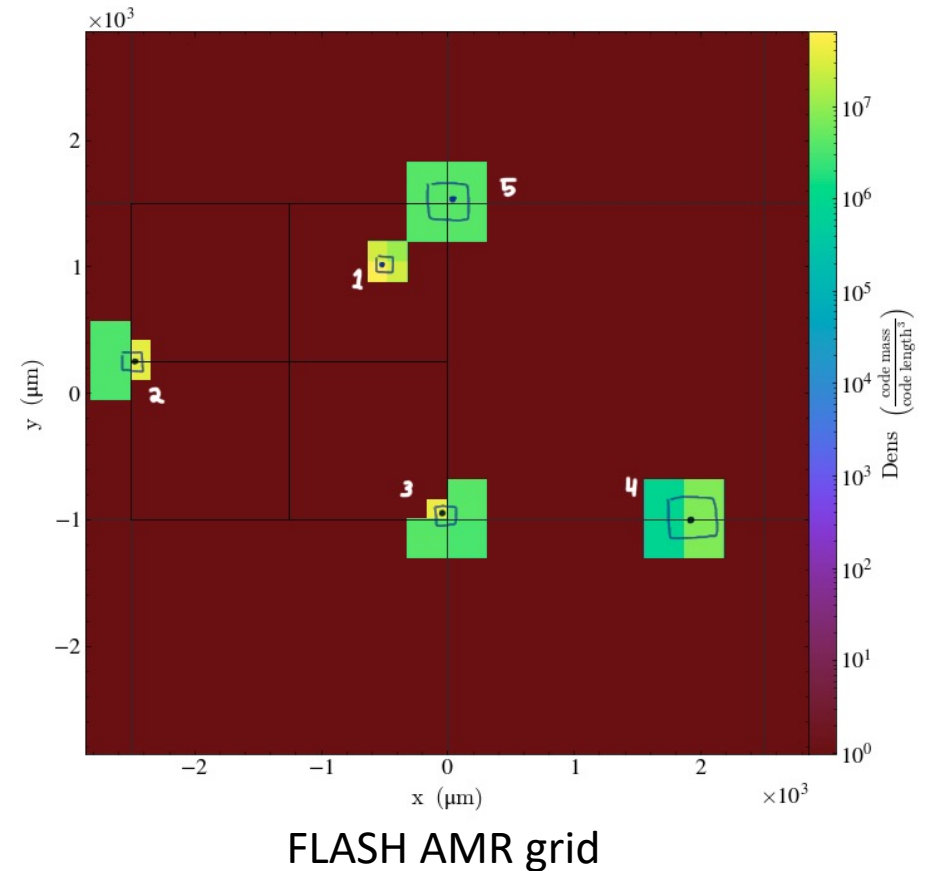
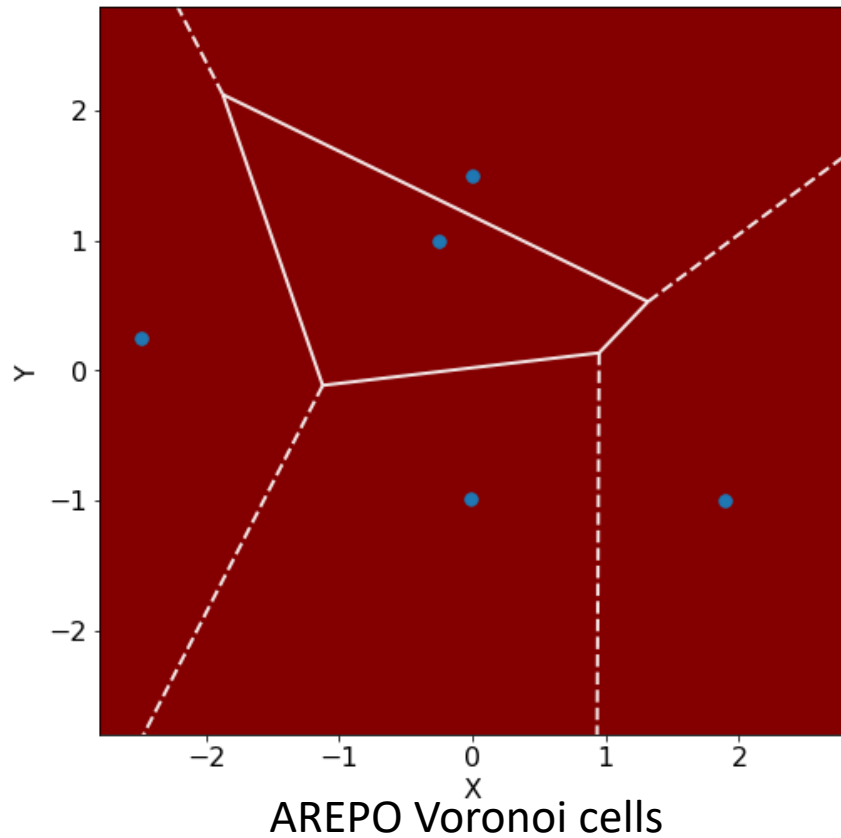


FLASH AMR grid



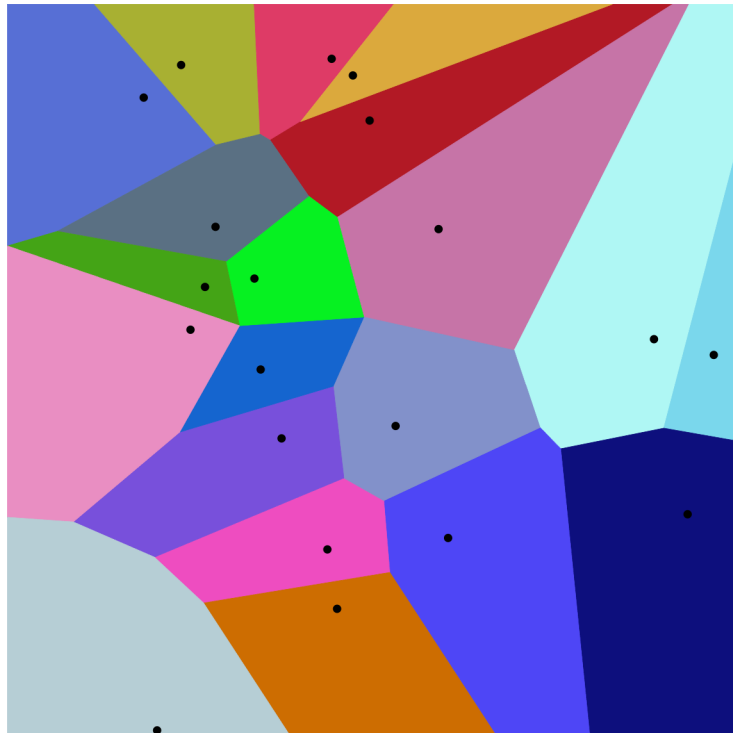
# Paper 2 – AREPO to Torch method

- AREPO moving mesh Voronoi cells
- FLASH AMR grid
- What I can do now:
  - Convert AREPO cells to particles, pass to FLASH grid, refine on particles, map particle data to refined grid.

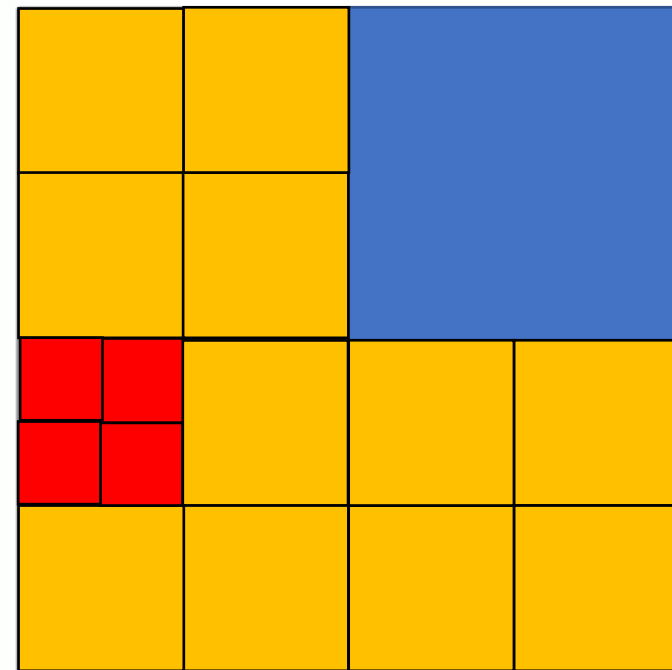


## Paper 2 - Timeline

- Development of AREPO-Torch port: Now – Winter 2022
  - Coherence testing, simplified models.
- Begin Writing: End of Fall 2021
- Submit: Spring 2022 (SciPost, New Astronomy)



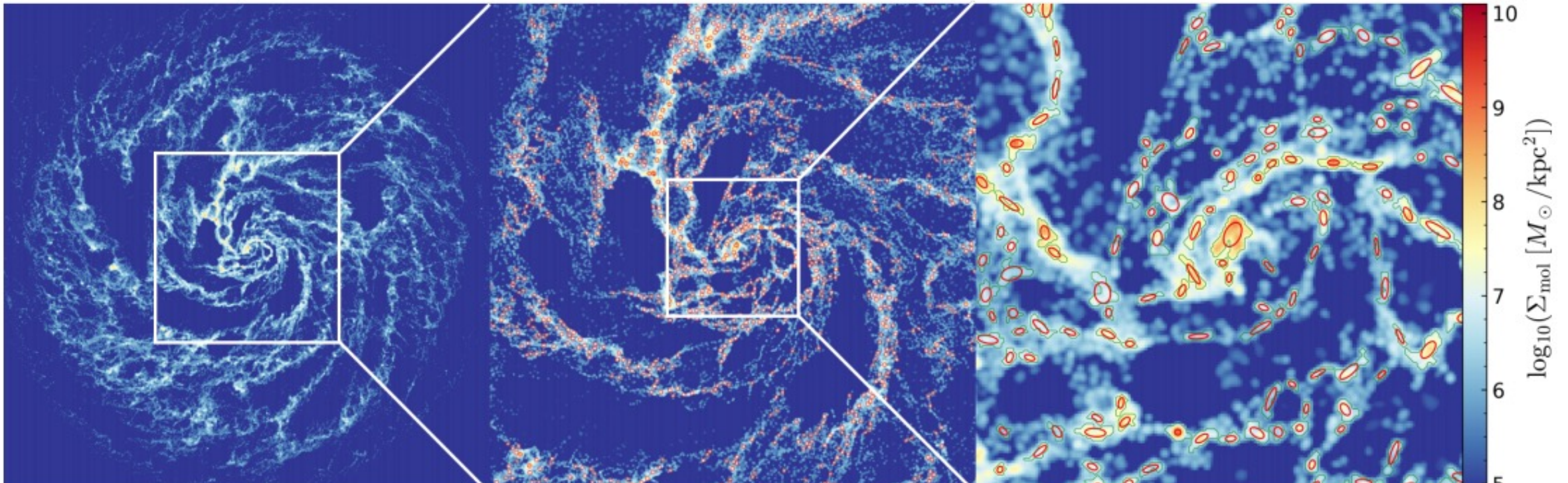
AREPO moving mesh



FLASH AMR grid

# Paper 3 – Star Formation in Galactic Context

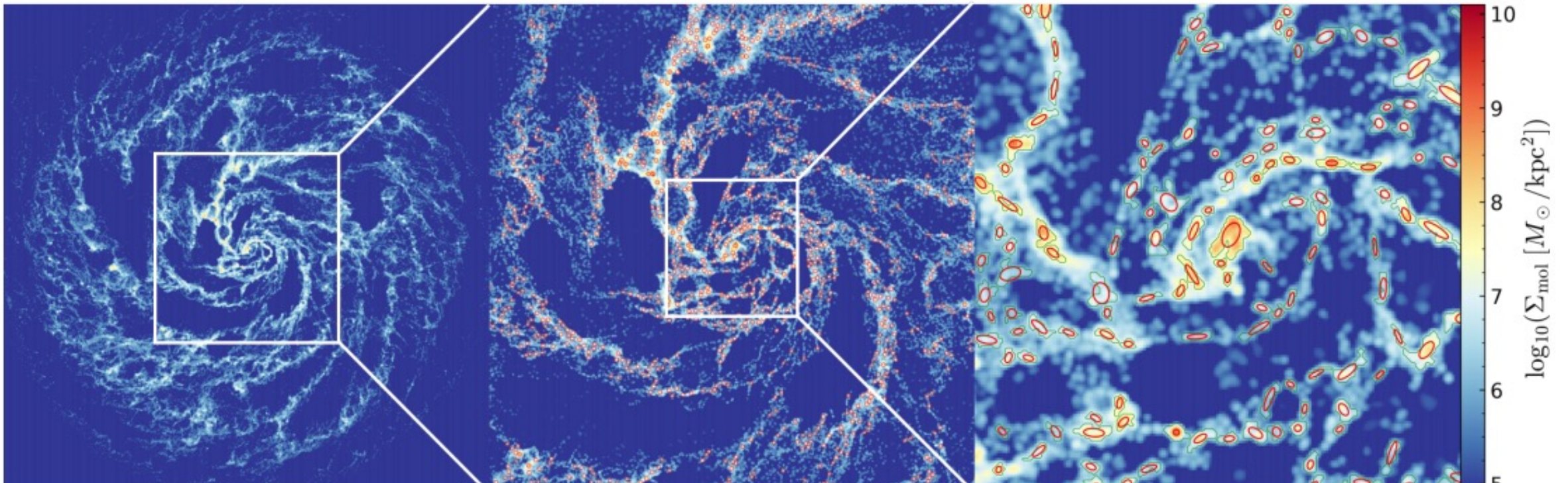
- Torch was the “[...] bridge between gas dynamics and fully collisional N-body dynamics [...]”. (Wall+19)
- How do star formation efficiencies in these GMCs compare to observations?
- What are the characteristics of star clusters formed in galactic GMCs, how do the structure and assembly compare to other idealized simulations and observations.



GMC identification in galaxy simulation [Li et al. 2020]

## Paper 3 – Timeline

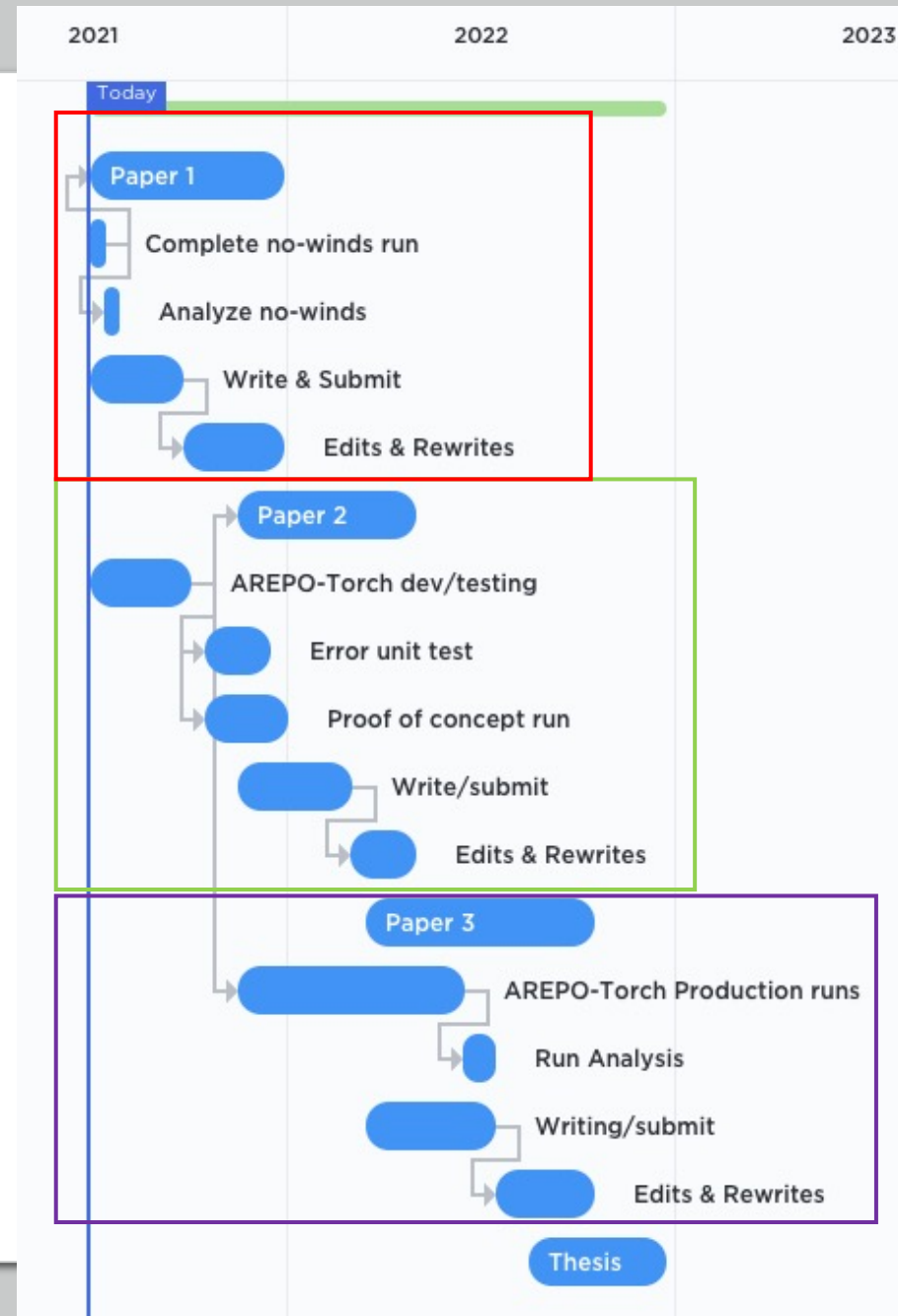
- Development of AREPO-Torch port: Now – Fall Winter 2022
- First production runs: Fall 2021
- Analysis: Spring quarter 2022
- Begin Writing: Spring quarter 2022
- Submit: Summer/Fall 2022



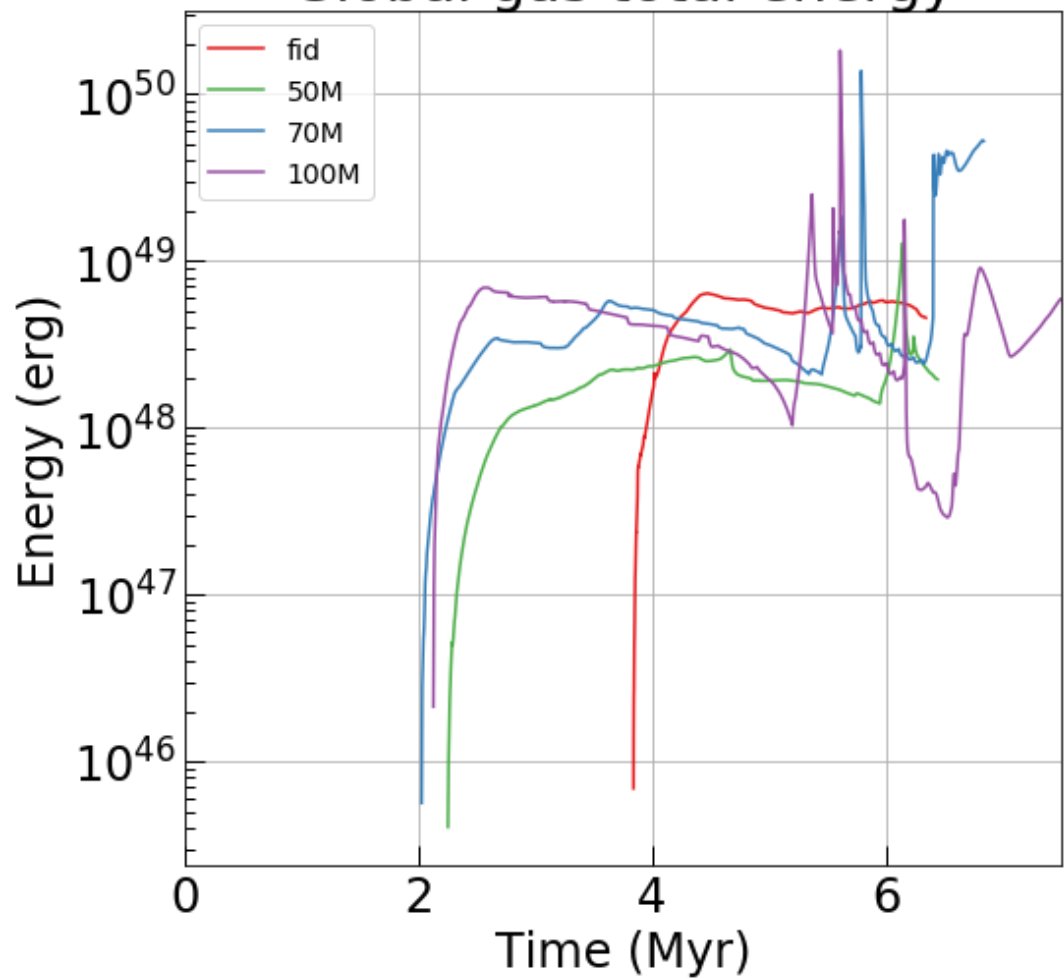
GMC identification in galaxy simulation [Li et al. 2020]

# Timeline and Other Future Items

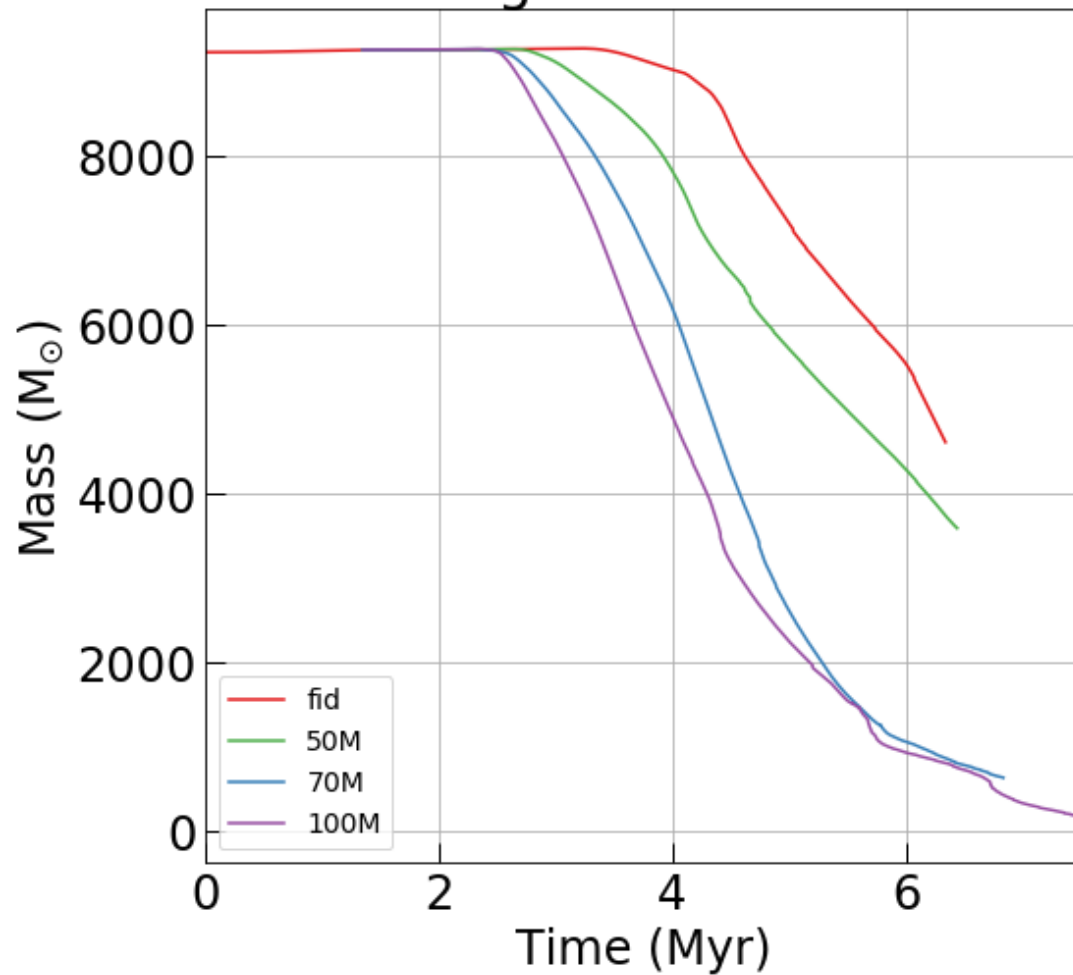
- Keep consistent with AAS meetings
  - Present talk at next winter/summer session
  - Focus on networking
- Public outreach presentations at Philadelphia Academy of Natural Sciences, Franklin Institute, AMNH



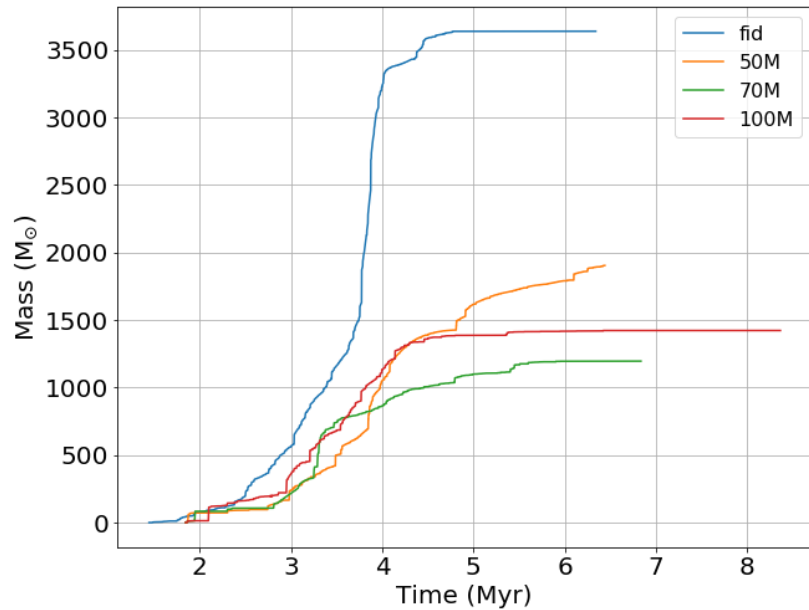
### Global gas total energy



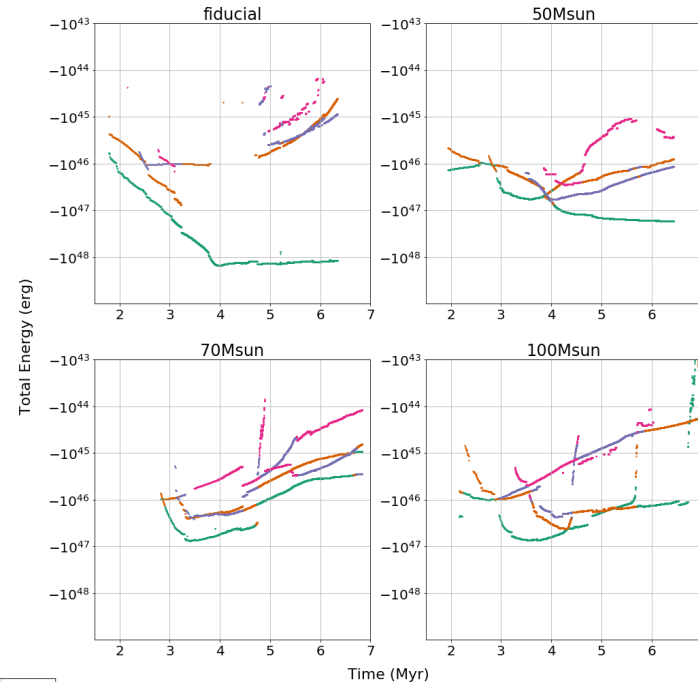
### Global gas + stars mass



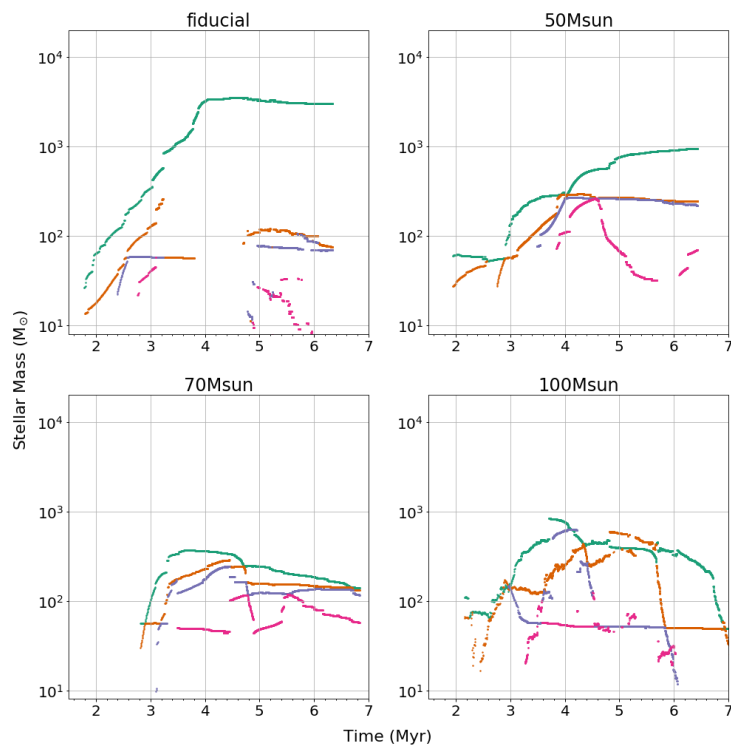
### Cumulative Stellar Mass



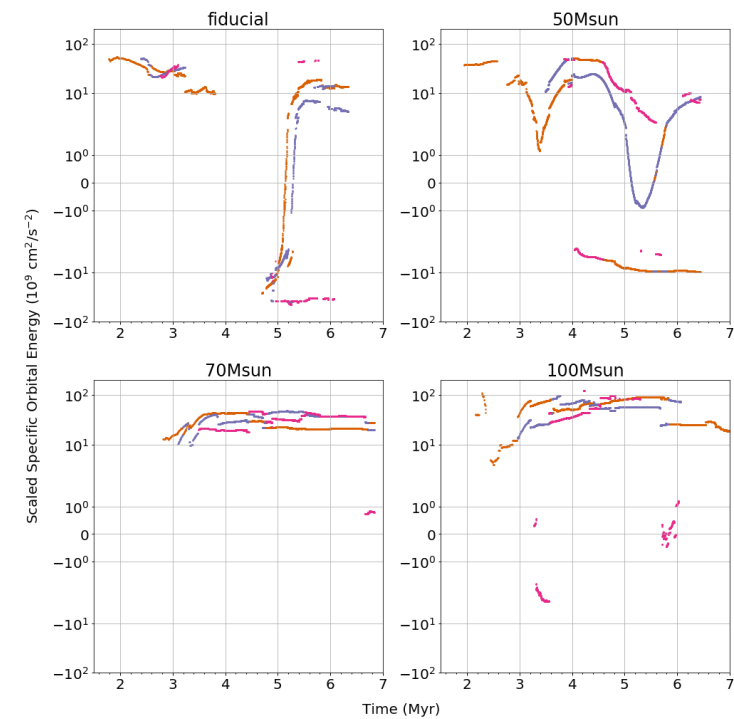
### Cluster Total Binding Energies



### Cluster Stellar Masses



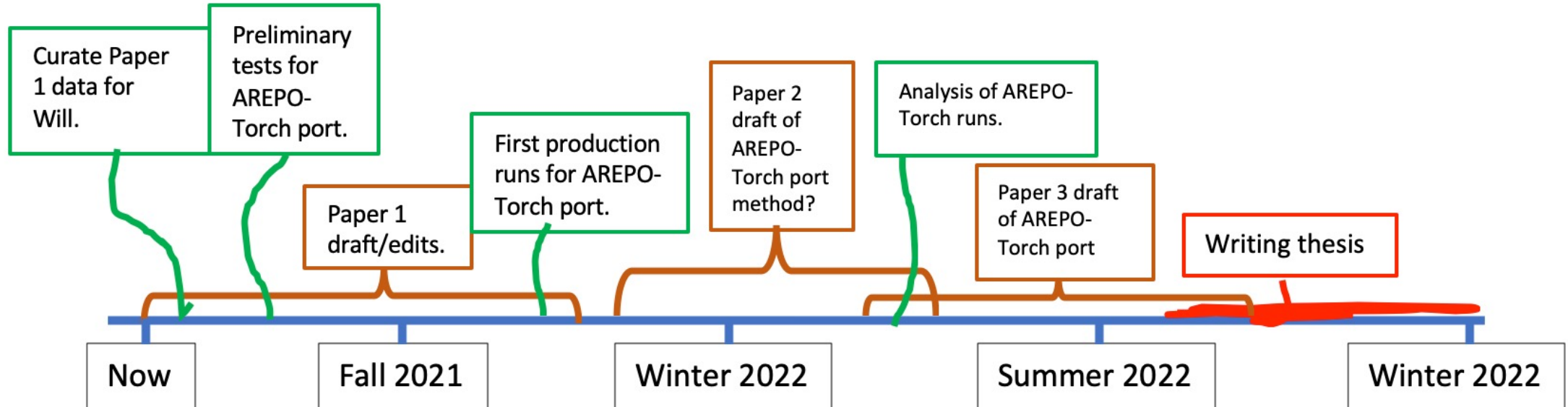
### Boundedness to Most Massive Cluster



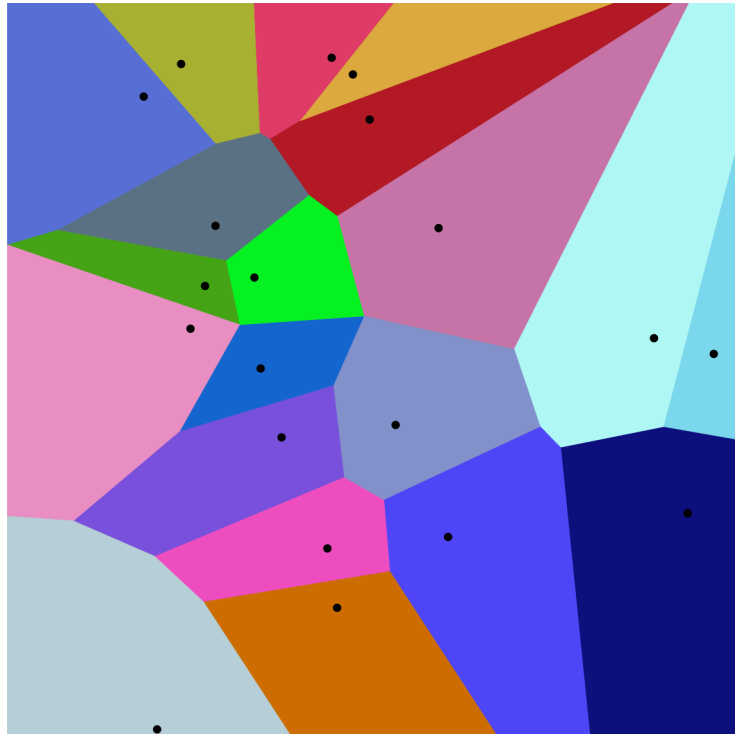
# Timeline

## OTHER FUTURE ITEMS

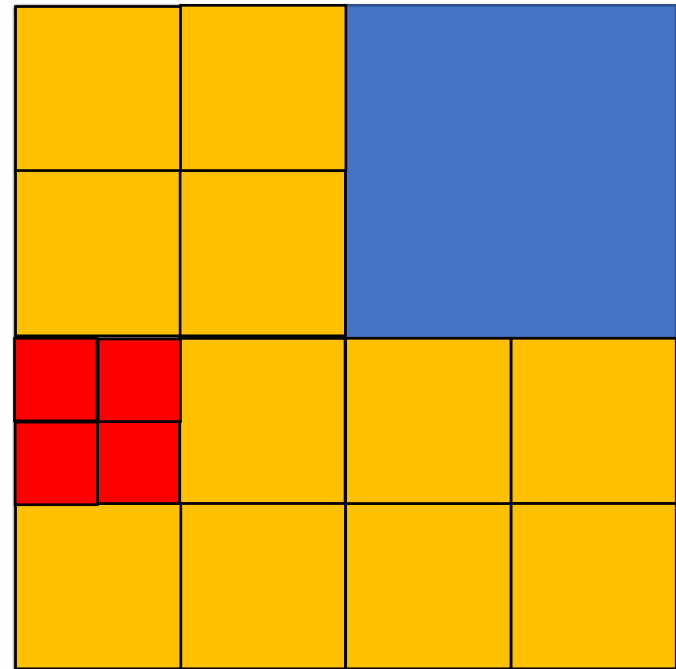
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AREPO moving mesh



FLASH AMR grid