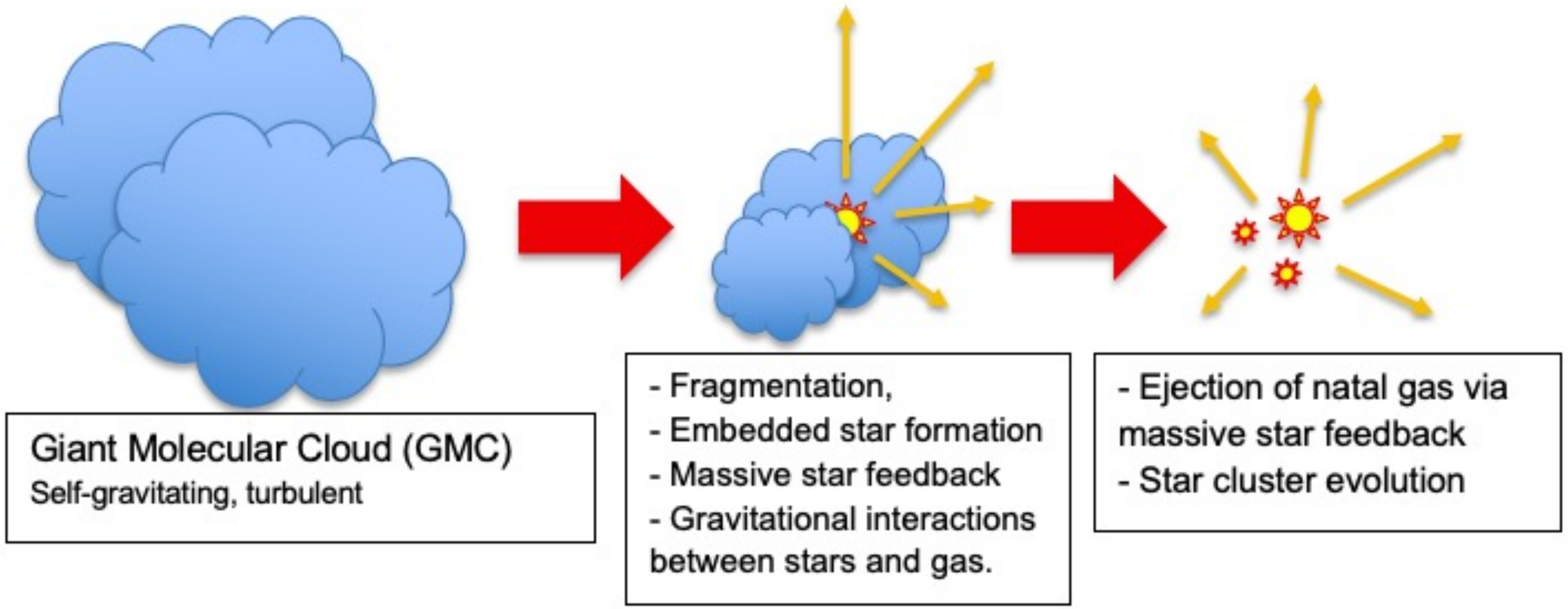
Characterizing Massive Star Feedback

Sean Lewis

06/15/20

Thesis Proposal

Star Formation: An Overview



Gaseous Environment

- Cold Neutral Medium (CNM)
  - 10 K; star-forming
- Warm Neutral Medium (WNM)
  - 10^4 K
- Shocked Gas
  - $10^6 – 10^7$ K
- Warm Ionized Medium (WIM)
  - 10^4 K

Radiation & Winds

Ionizing radiation

Creates parsec-scale regions of ionized hydrogen.

Destruction of dense CNM via photoevaporation.

Strömgren Sphere

$$r_S = \left(\frac{3S\mu^2 m_H^2}{4(1.1)\pi\alpha_B\rho_0^2} \right)^{1/3} = 2.8 S_{49}^{1/3} n_2^{-2/3} \mathrm{pc}$$

Stellar Winds

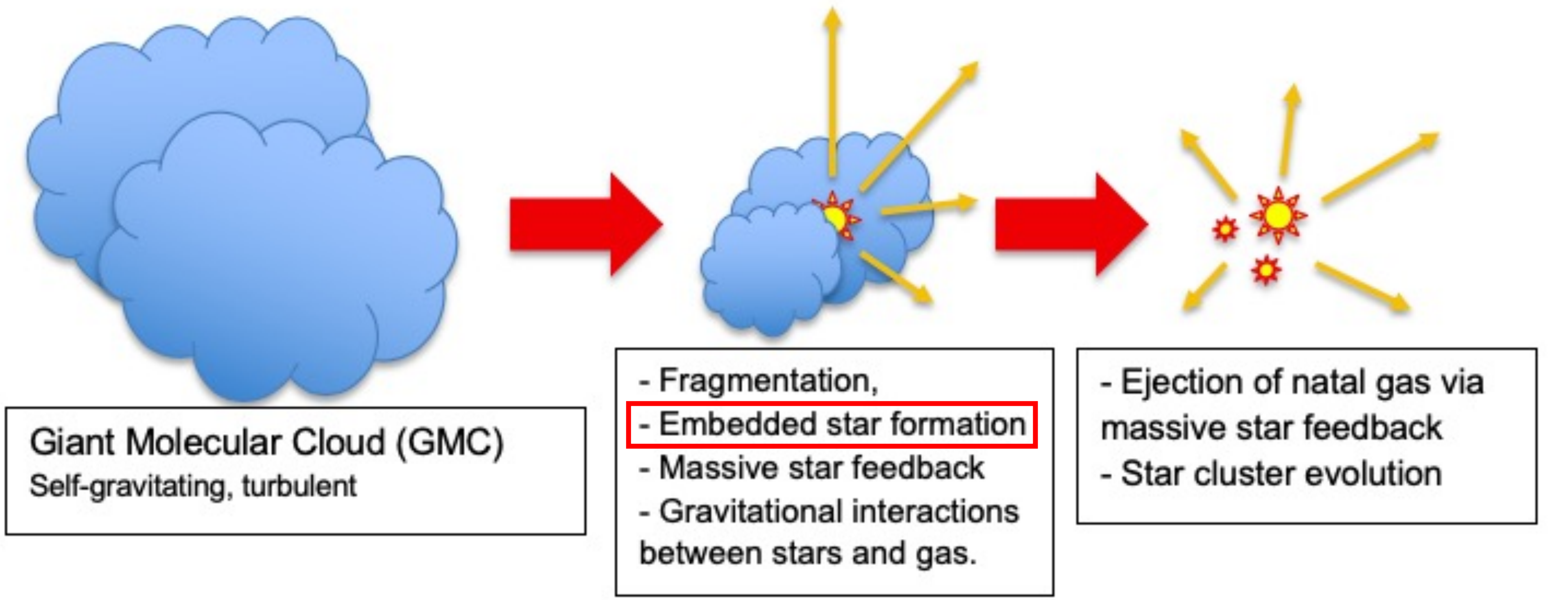
- Deposit matter into surrounding medium
- Momentum injection comparable to radiation
- High velocity injection shocks surrounding gas to 1e6 – 1e7 K

Both are present throughout massive star’s life.

Supernova

- Rapid ejection of matter up to 30,000 km/s
- Occur at least 3 Myr after onset of star formation event.
- Injection of high mass elements into interstellar medium.

Star Formation: An Overview



~10 Myr

The entire star formation process cannot be observed on a human timescale.

How important are the feedback mechanisms?

My Research: Torch

FLASH

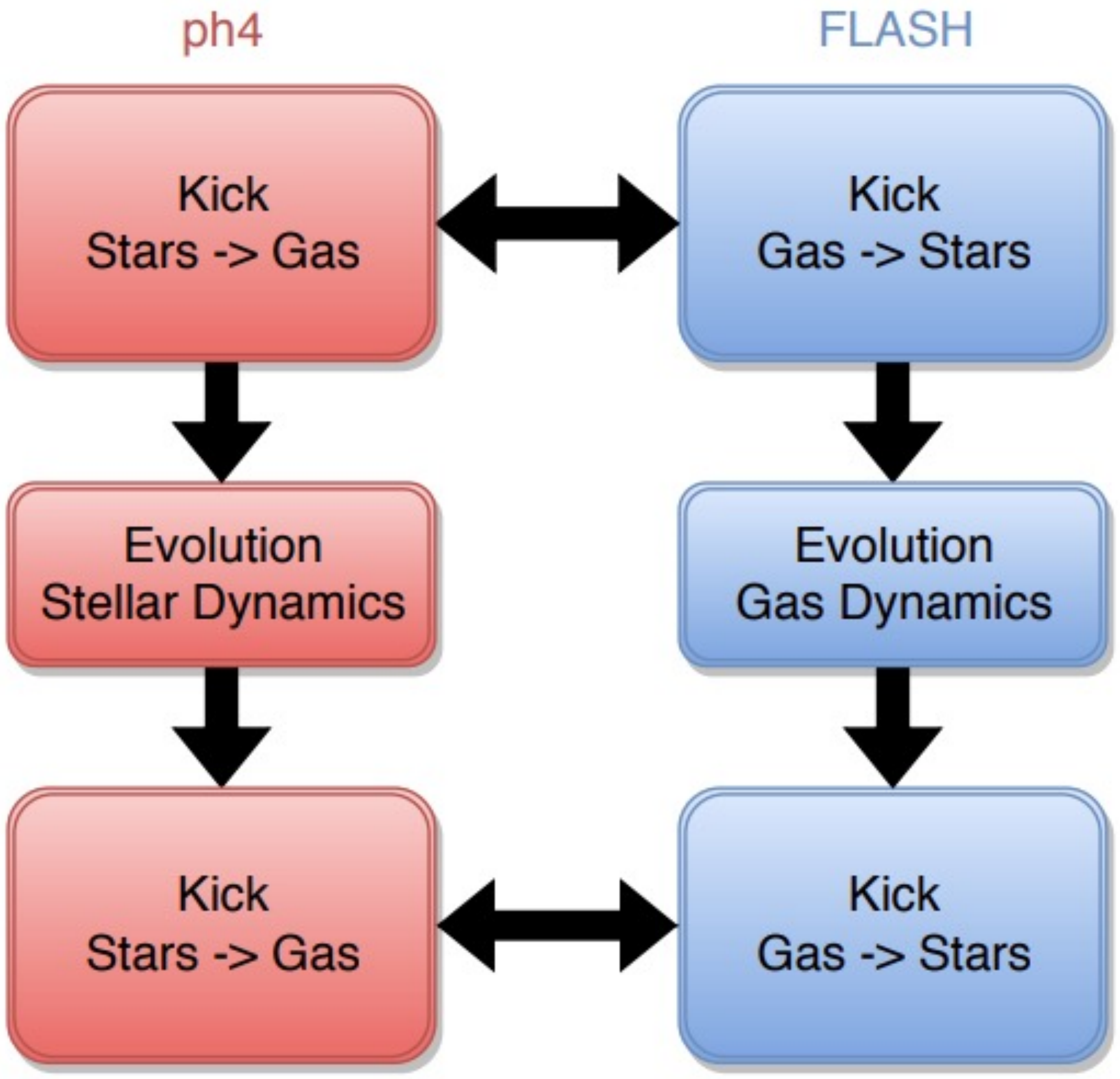
- Magnetohydrodynamics
- Radiation transfer
- Adaptive mesh refinement (AMR) grid simulation space
- Sink particles

AMUSE

- N-body dynamic solvers for star particles (ph4)
- Stellar evolution (SeBa)

Torch

- Python wrapper driving and communicating between the two.

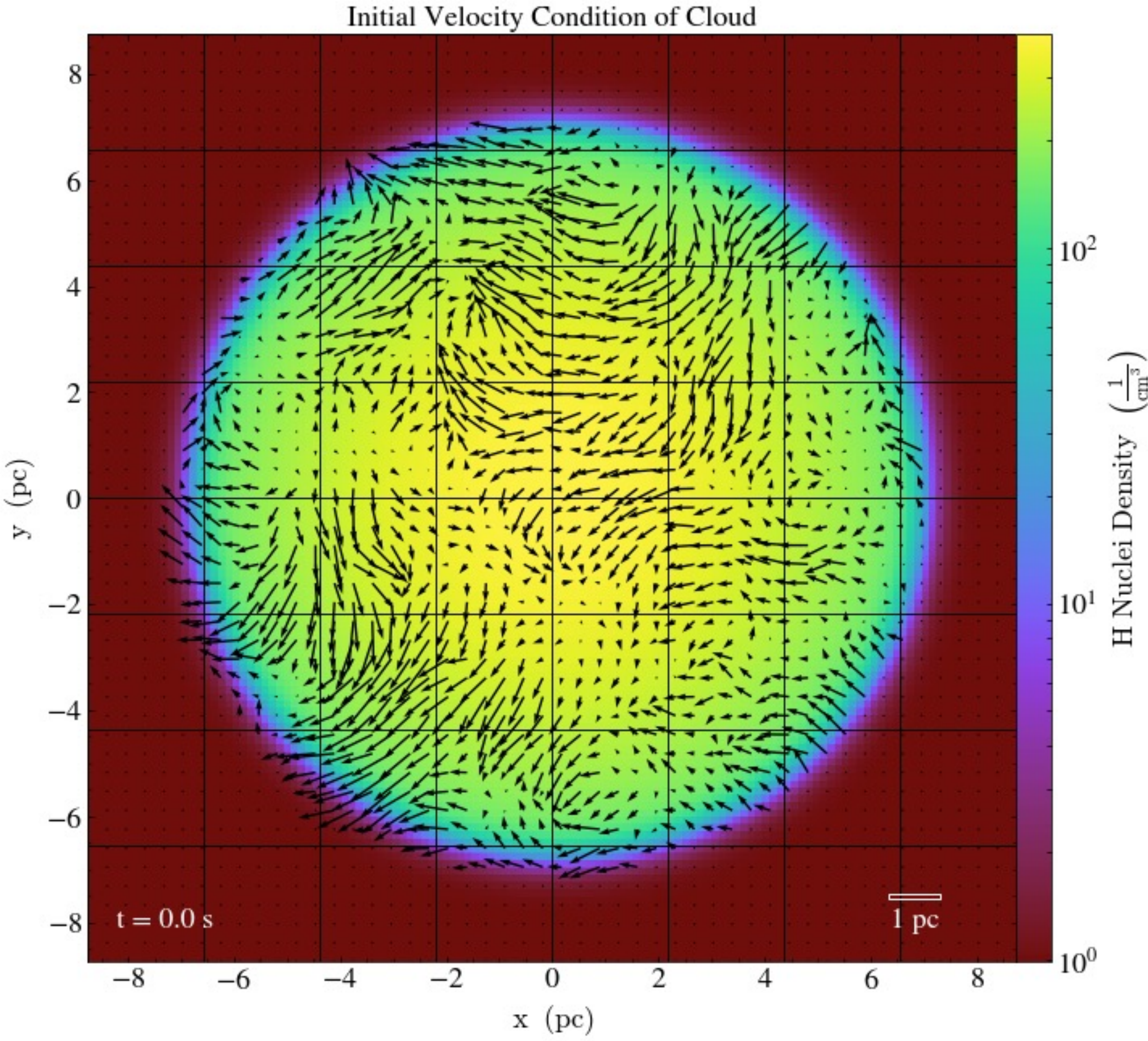


My Research:

- CNM sphere $10^4\,M_\odot$
- Pressure equilibrium with WNM.
- Supersonic turbulence

- Refine on Jeans Length
    - Identify star forming regions: sink particles.

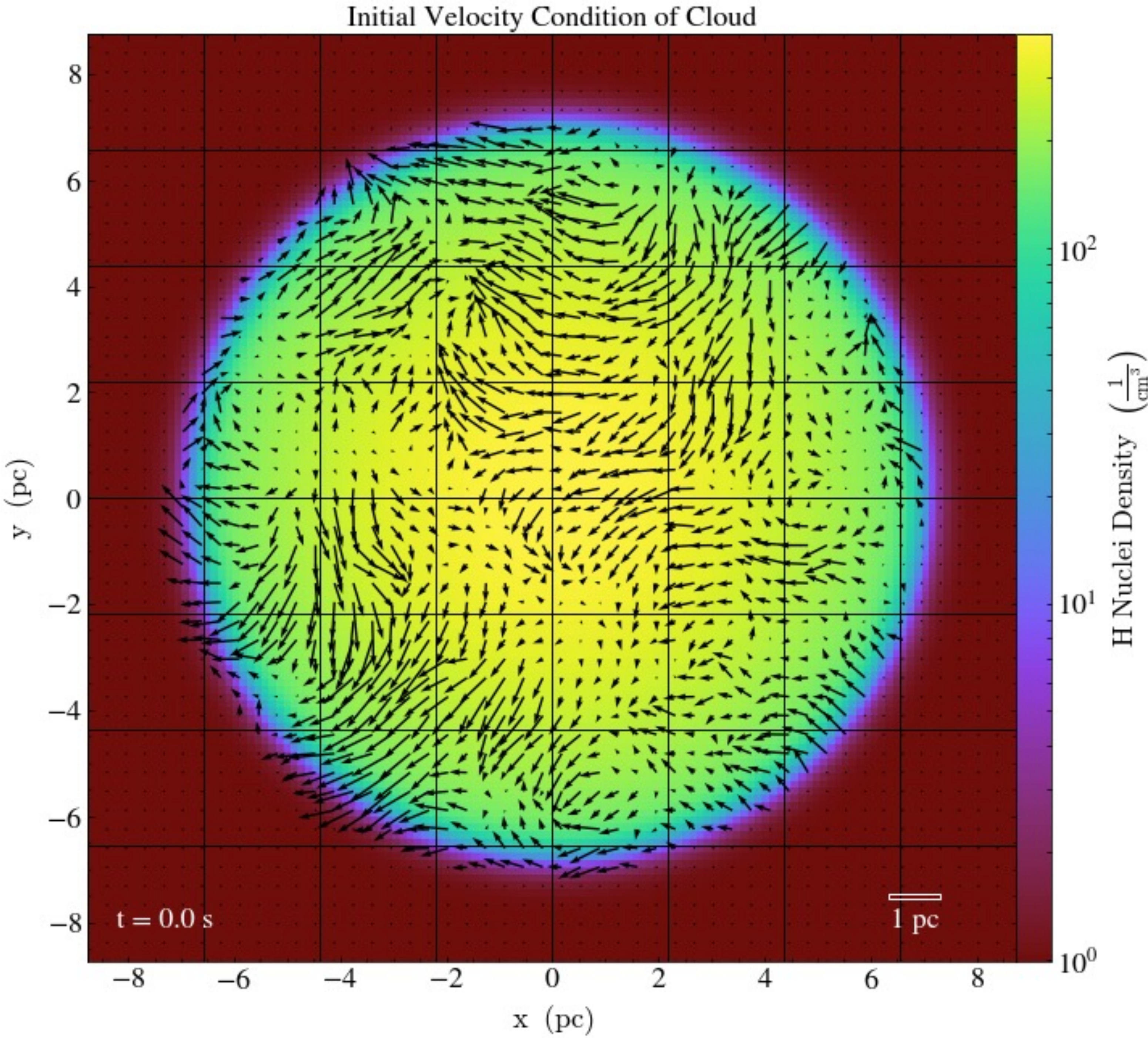
Star particles placed once sink particles accrete enough mass.



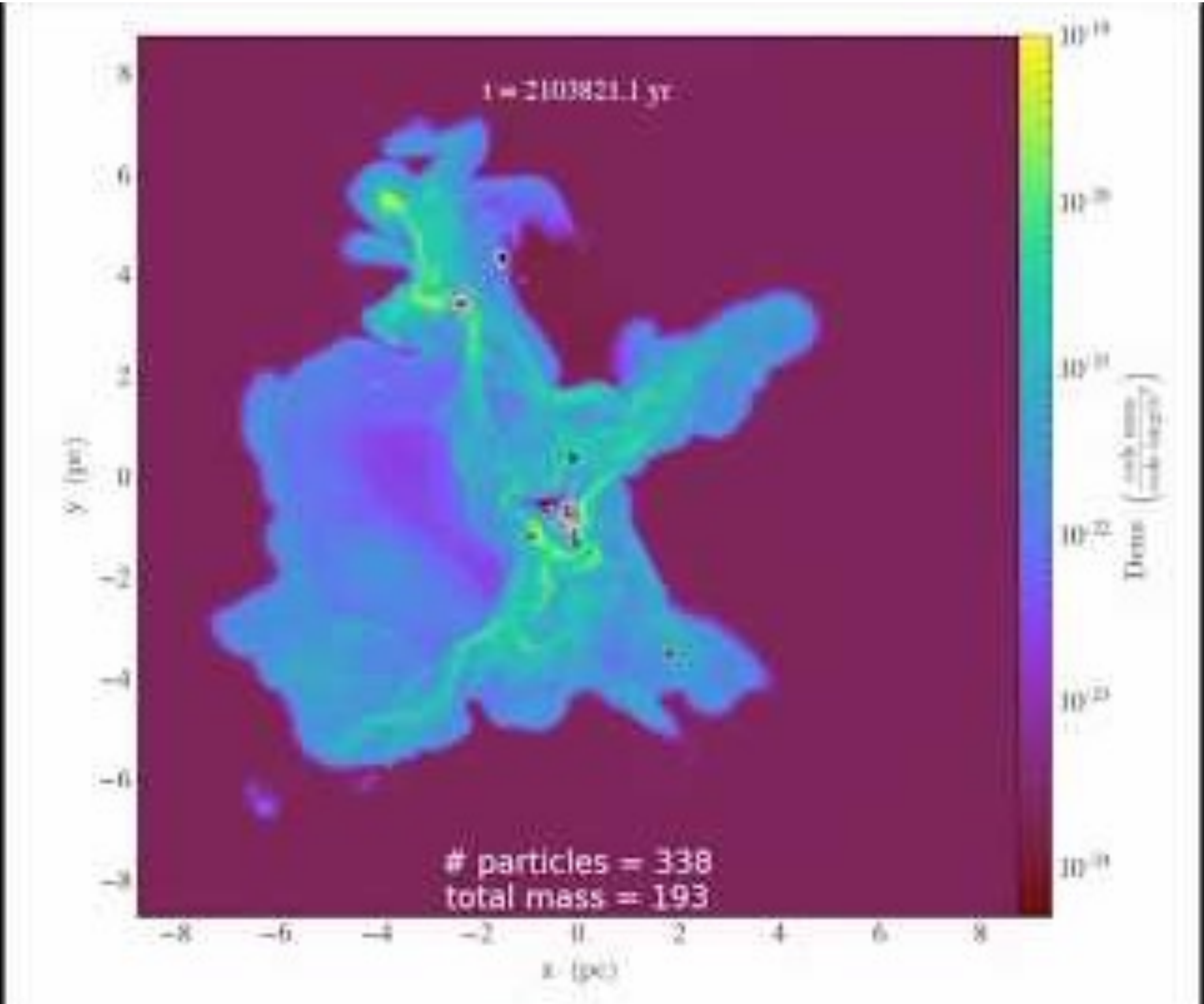
My Research: A Controlled Experiment

Three Simulations

- Identical cloud initial conditions.
- 8, 20, 50 solar mass stars are forced to begin forming at 1.32 Myr (0.43 global free-fall times).
- Each simulation evolves, placing the massive star, and the gas and star cluster dynamics can be examined.



Simulations: 50 $M_{\odot}$



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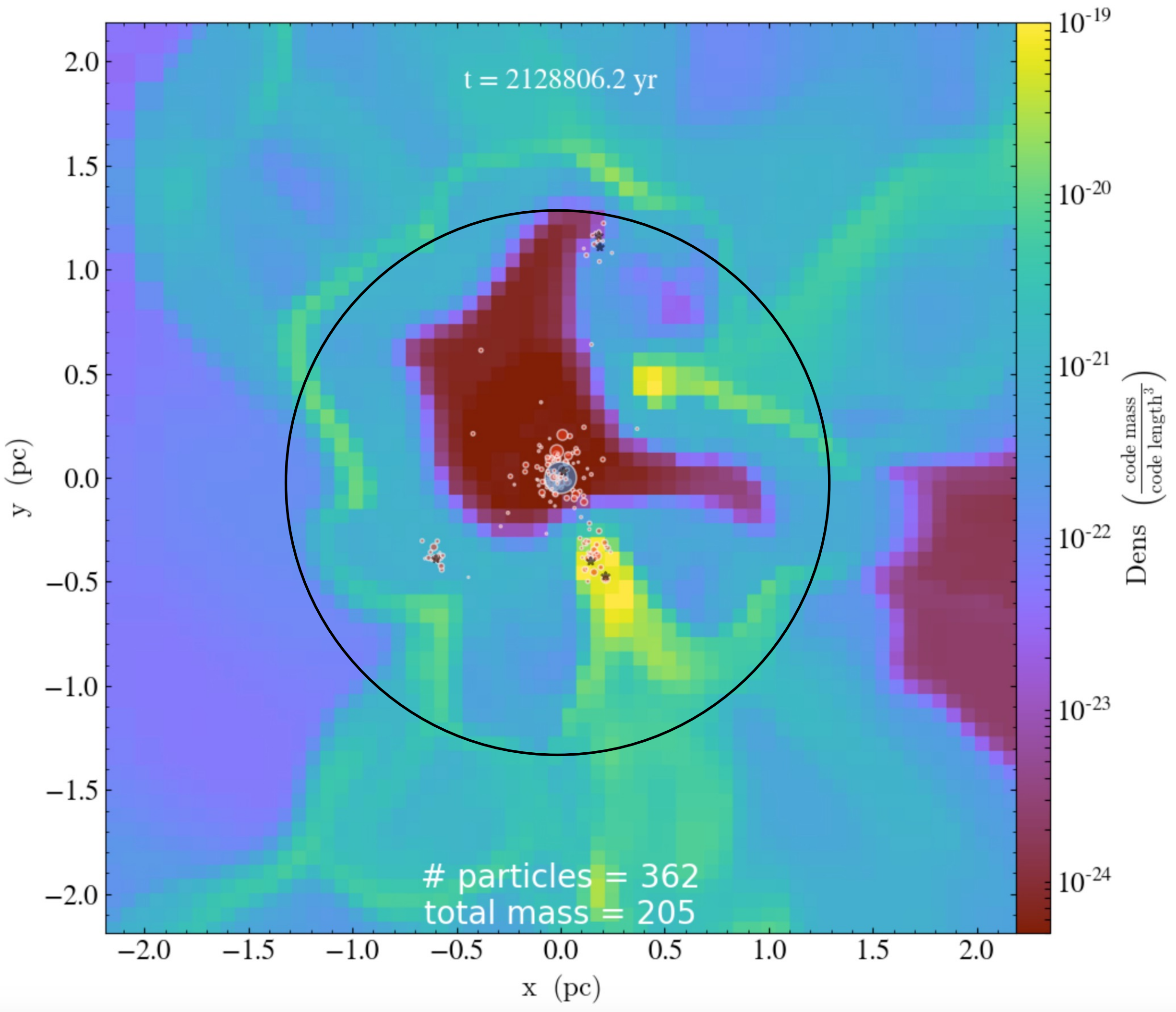
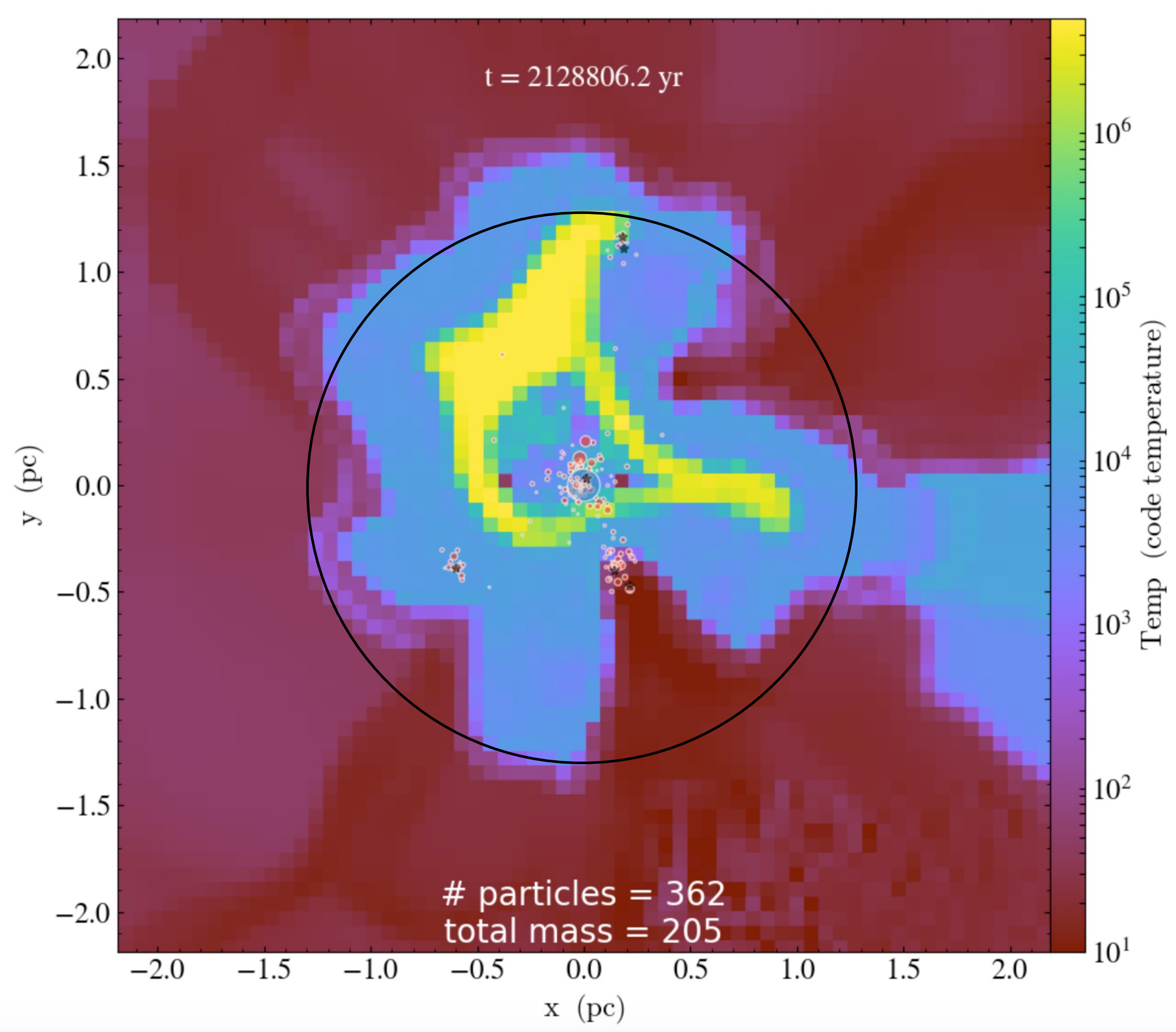




Phase plots: 50 $M_\odot$

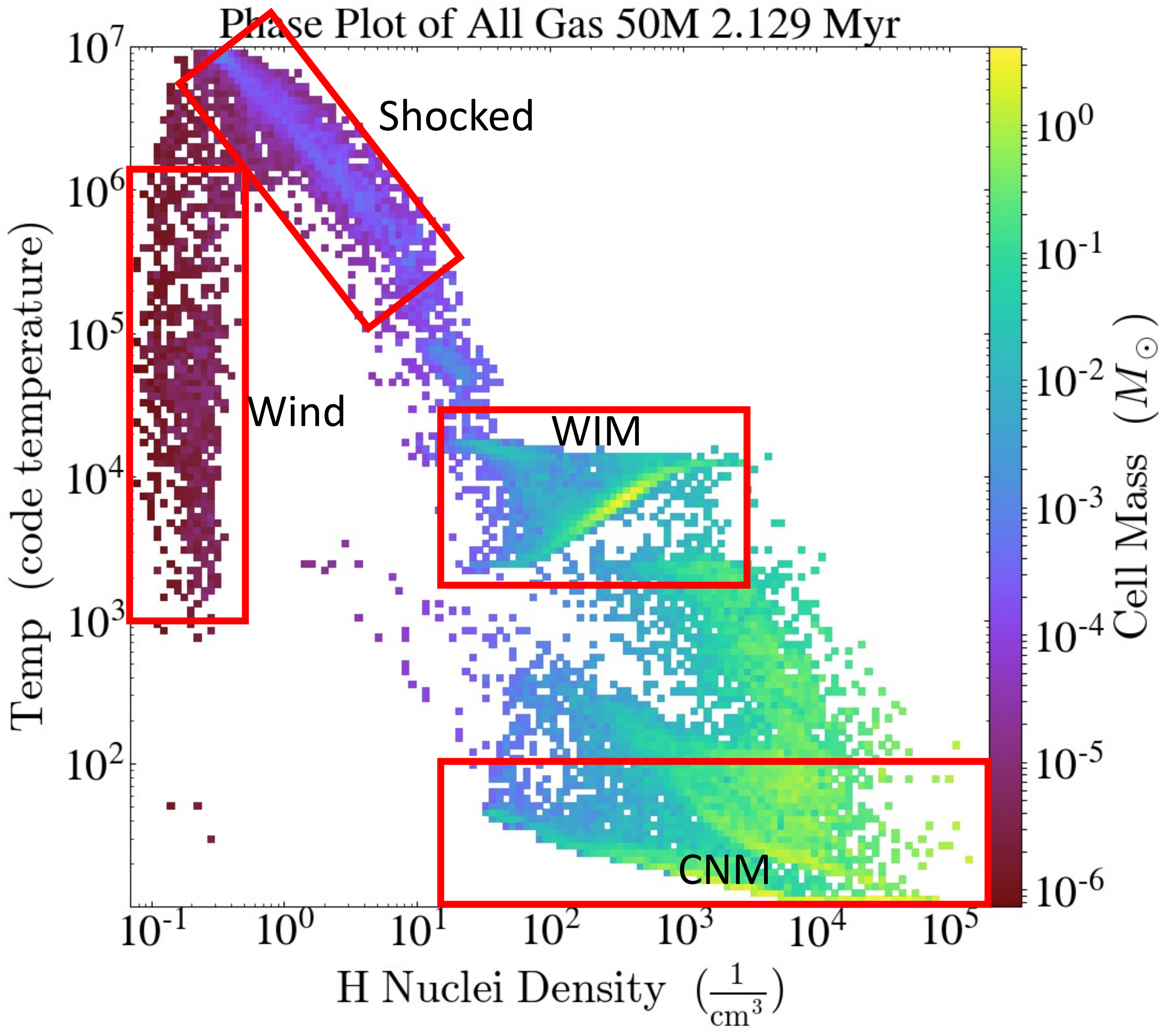
0.12 Myr after formation

Cold Neutral Medium

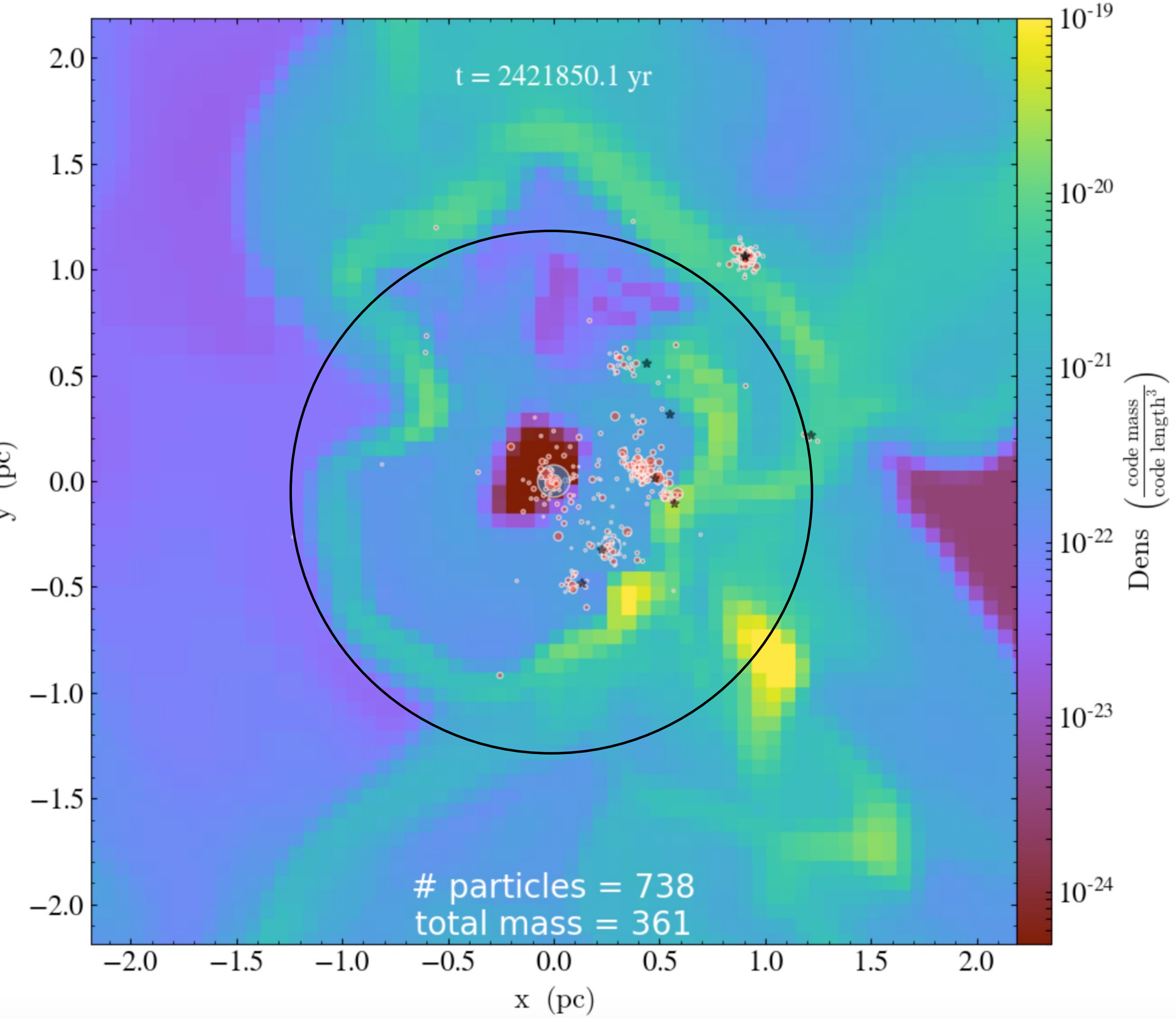
Warm Ionized Medium

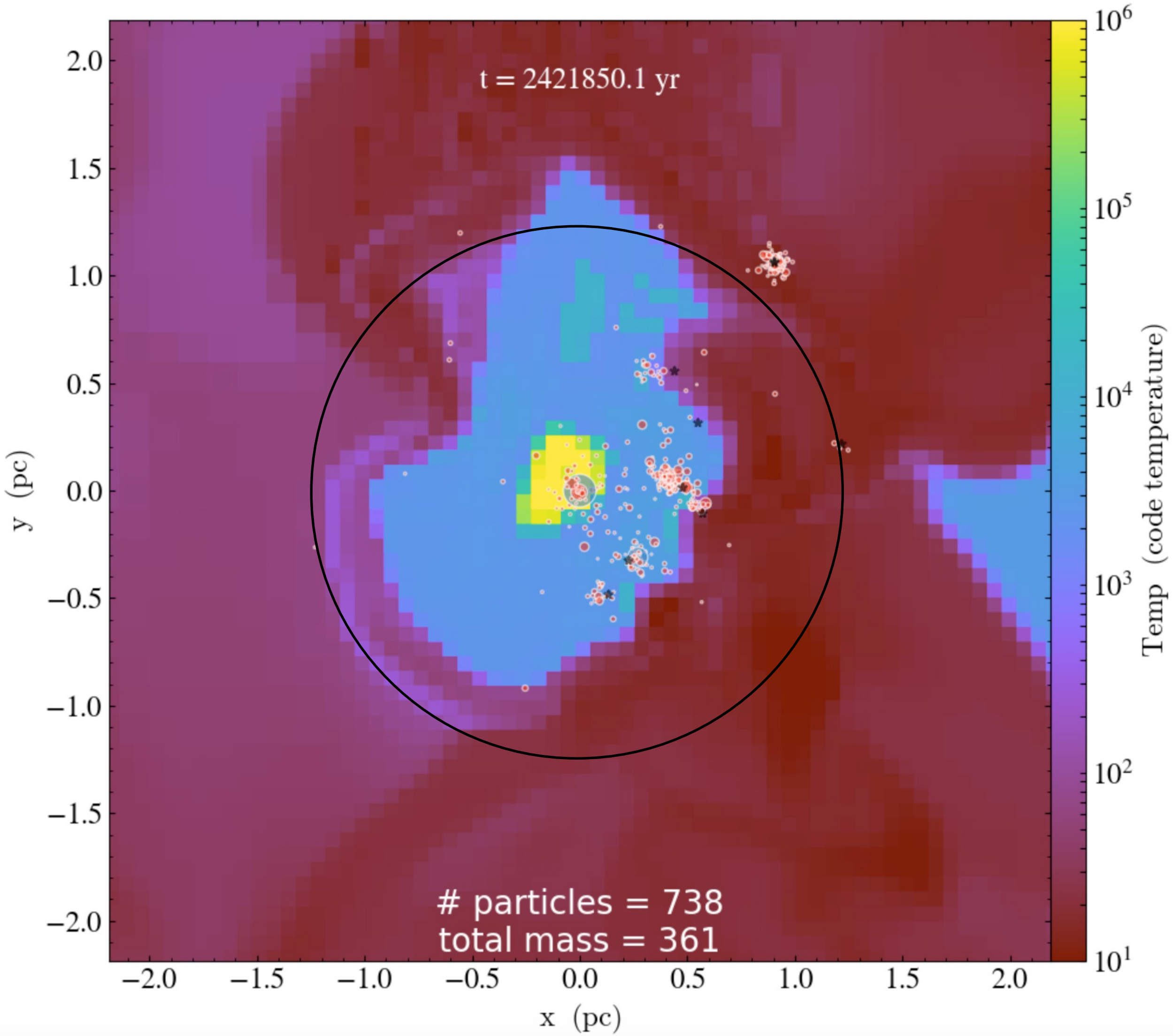
Shocked gas

Free-flowing wind bubble



Simulations 20 $M_\odot$





Phase plots: 20 $M_\odot$

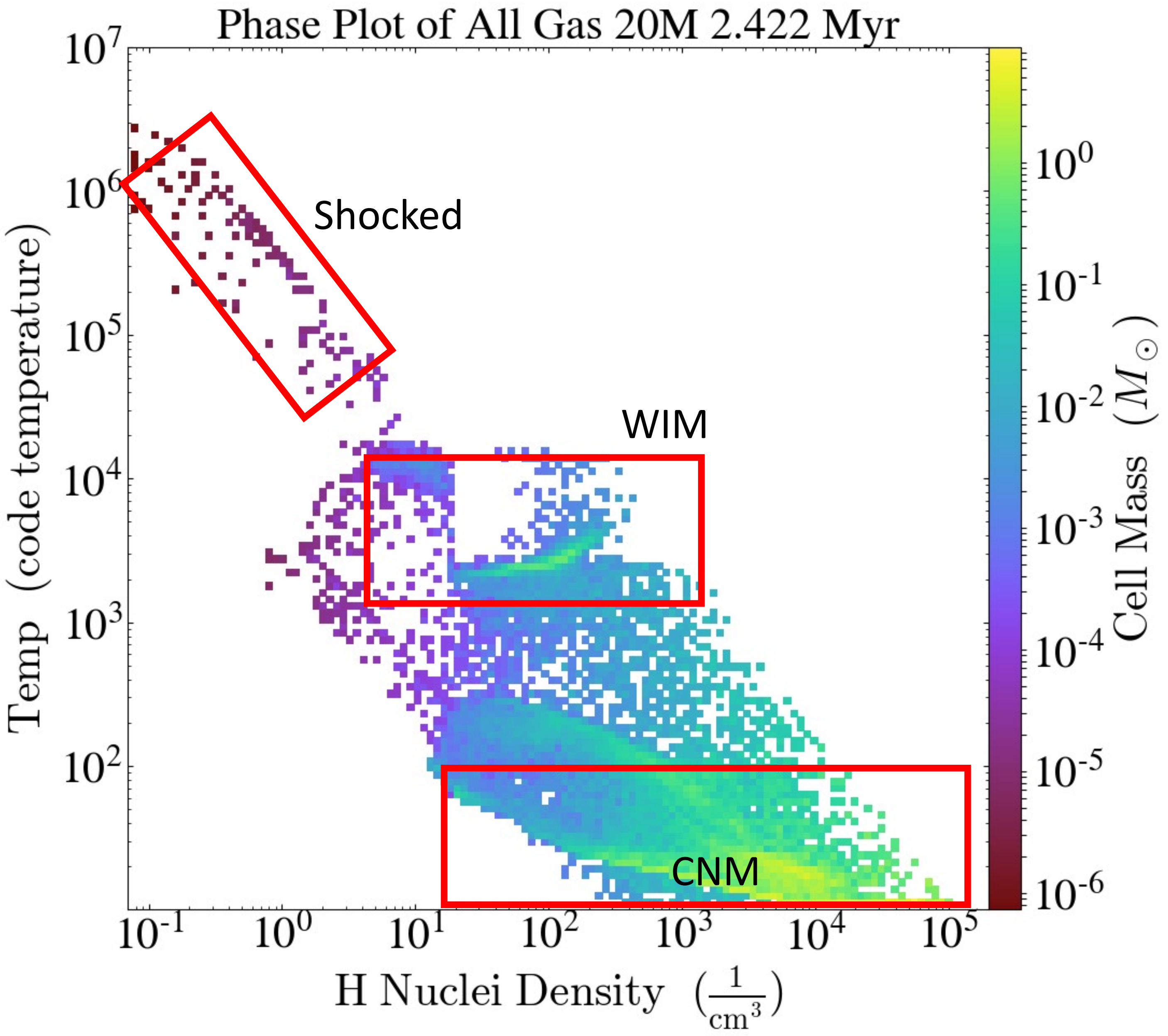
0.58 Myr after formation

Cold Neutral Medium

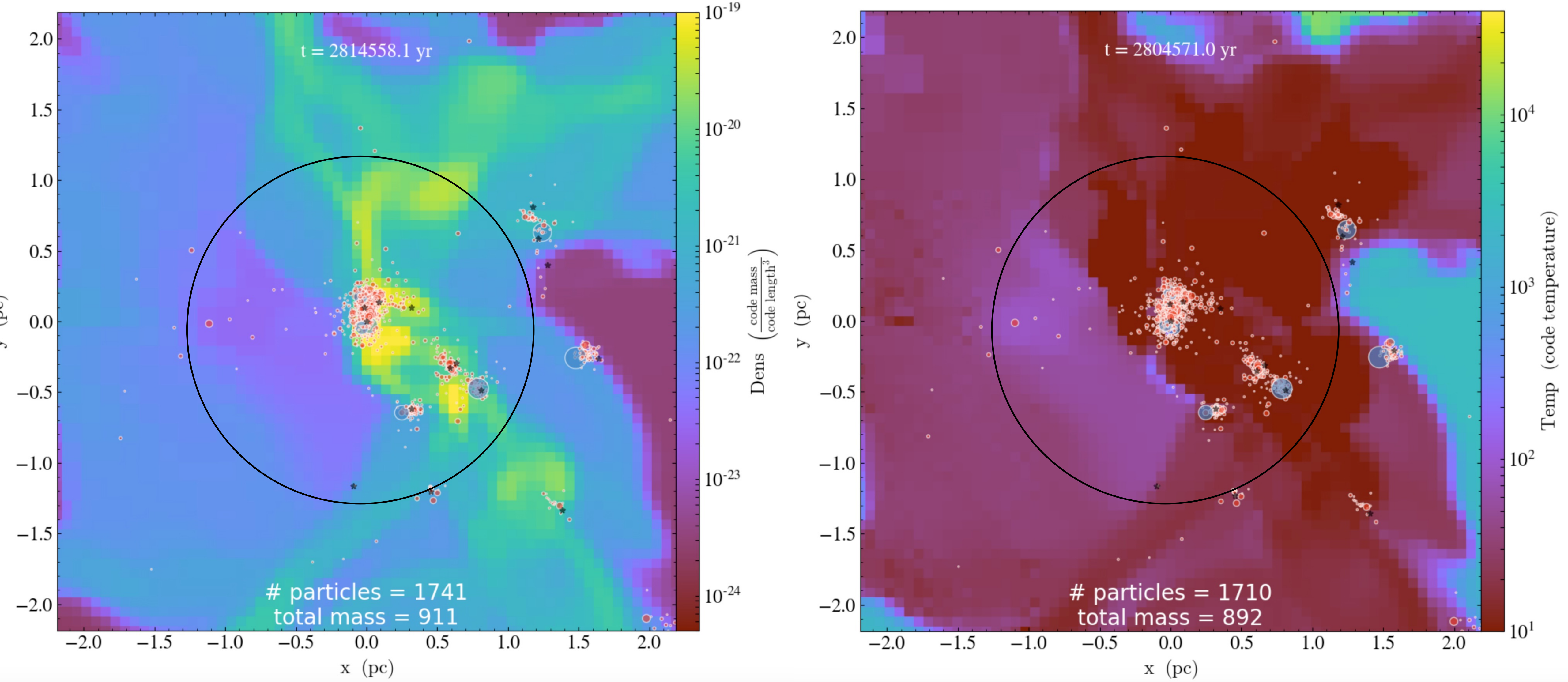
Warm Ionized Medium

Shocked gas

No resolved wind bubble



Simulations 8 $M_\odot$

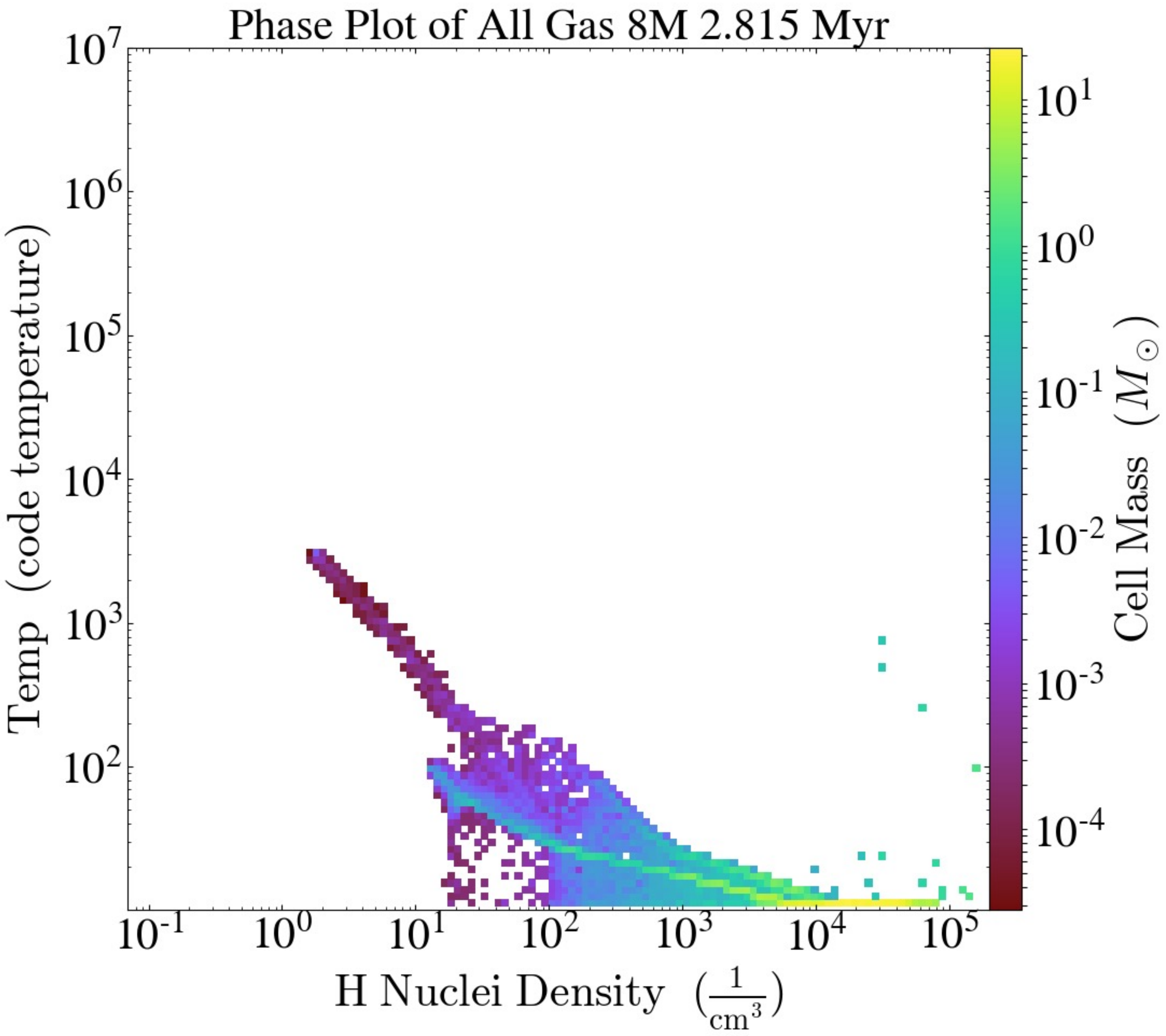


Phase plots: 8 $M_\odot$

- No warm ionized medium
- No shocked gas
- No resolved wind bubble

Strömgren sphere ~1/10th of 1 grid cell.

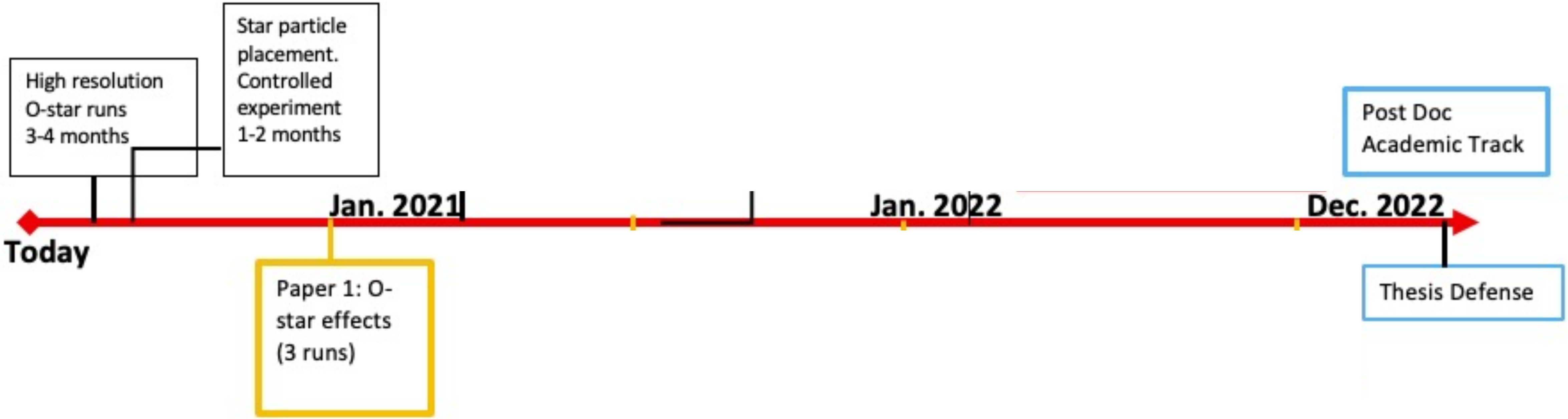
Ultra compact HII region.



Expanding Analysis Further

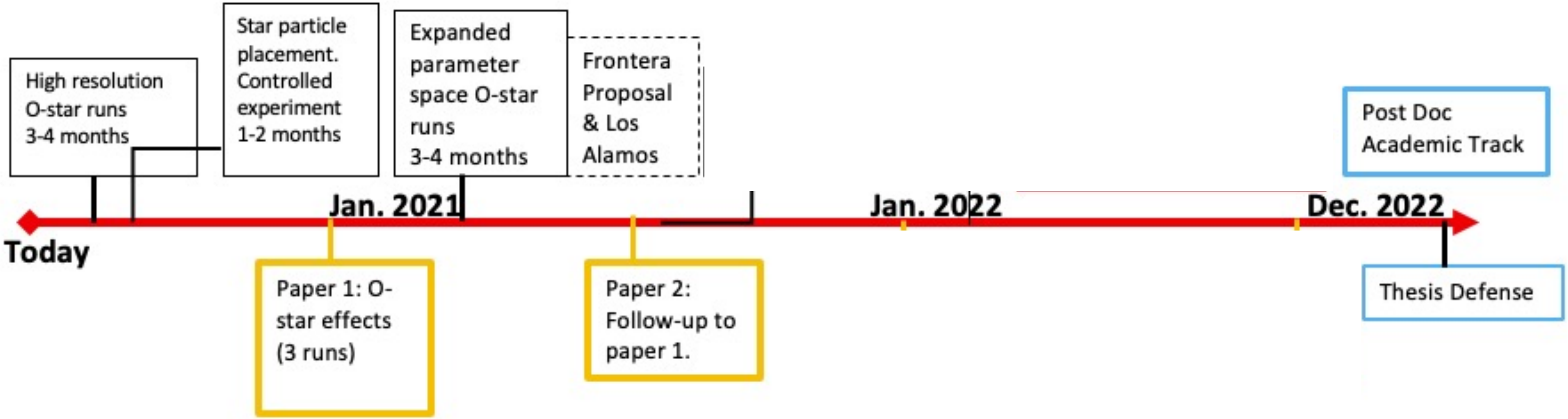
- Time series analysis of gas ejection/inflow behavior.
- Fractional gas mass above/below density threshold.
- Quantify fraction of gas in CNM, WIM, Shocked phases.
- Analysis of stellar dynamics in most affected regions.

Timeline



High resolution O-star runs 3-4 months
Star particle placement. Controlled experiment 1-2 months
Post Doc Academic Track
Jan. 2021
Jan. 2022
Dec. 2022
Today
Paper 1: O-star effects (3 runs)
Thesis Defense

Timeline



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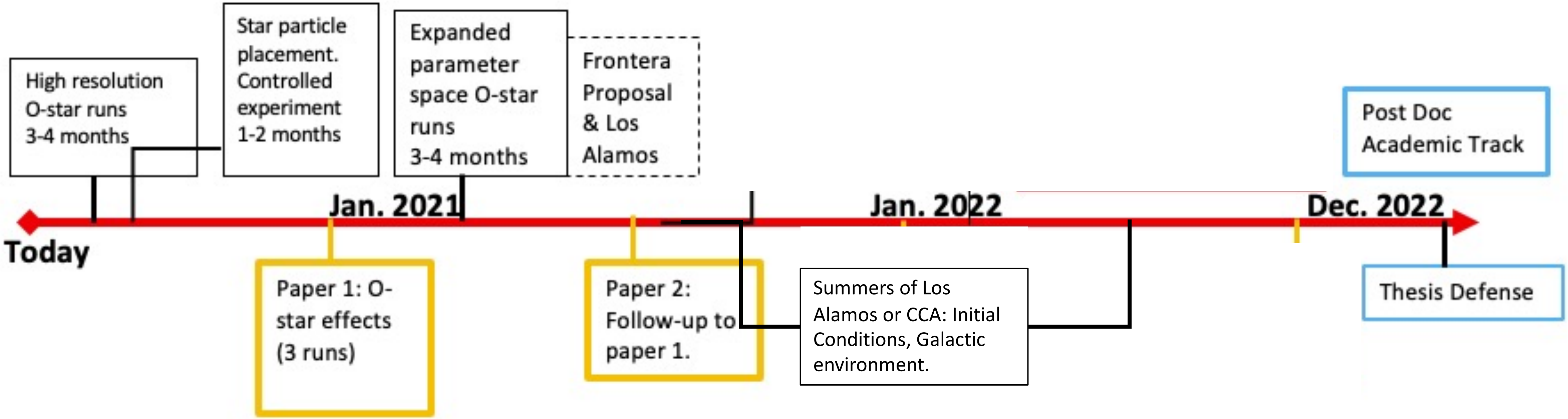

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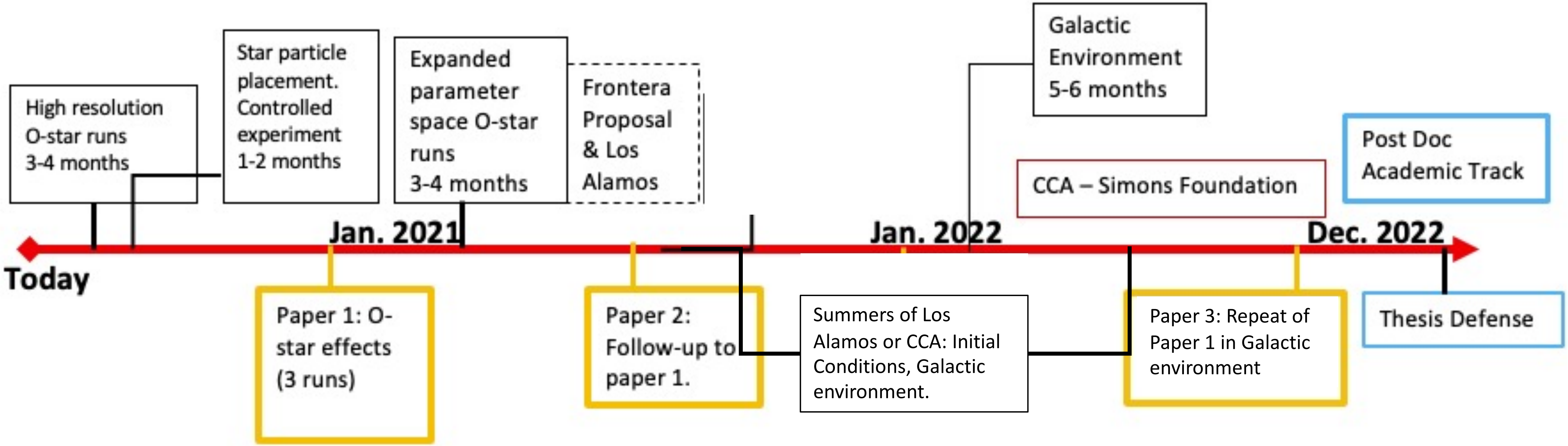
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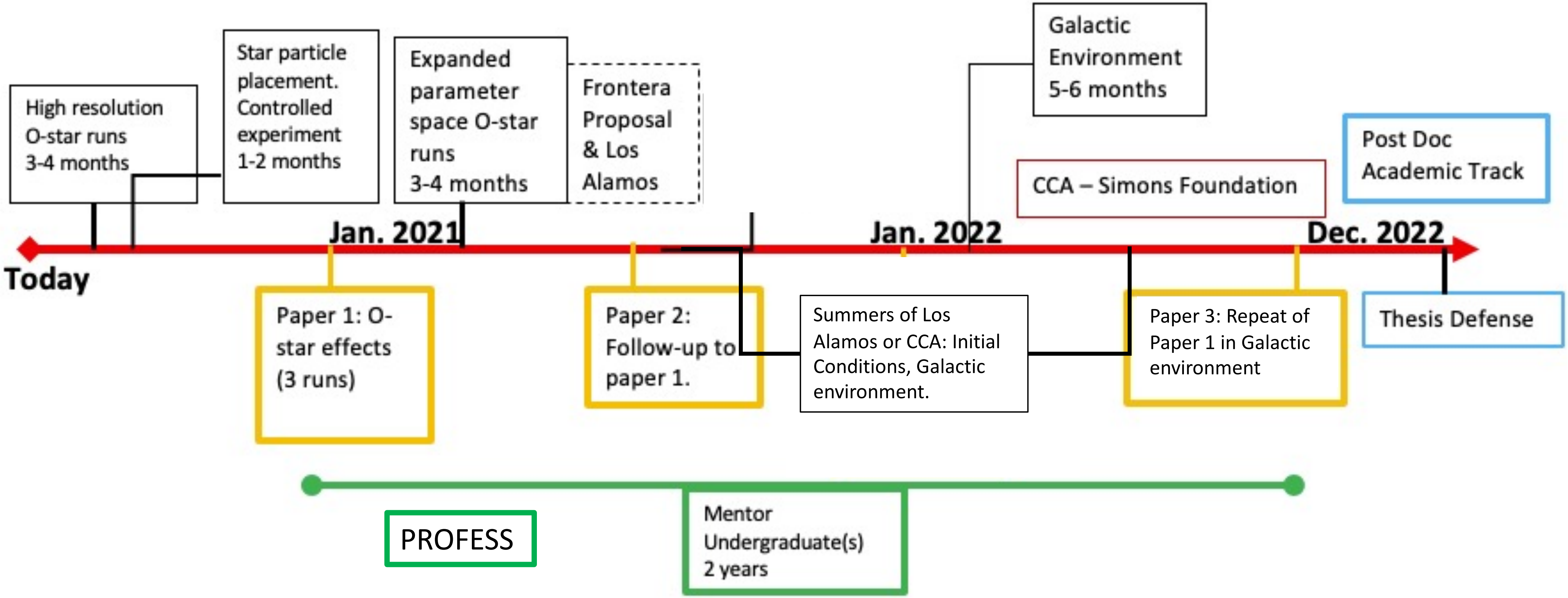
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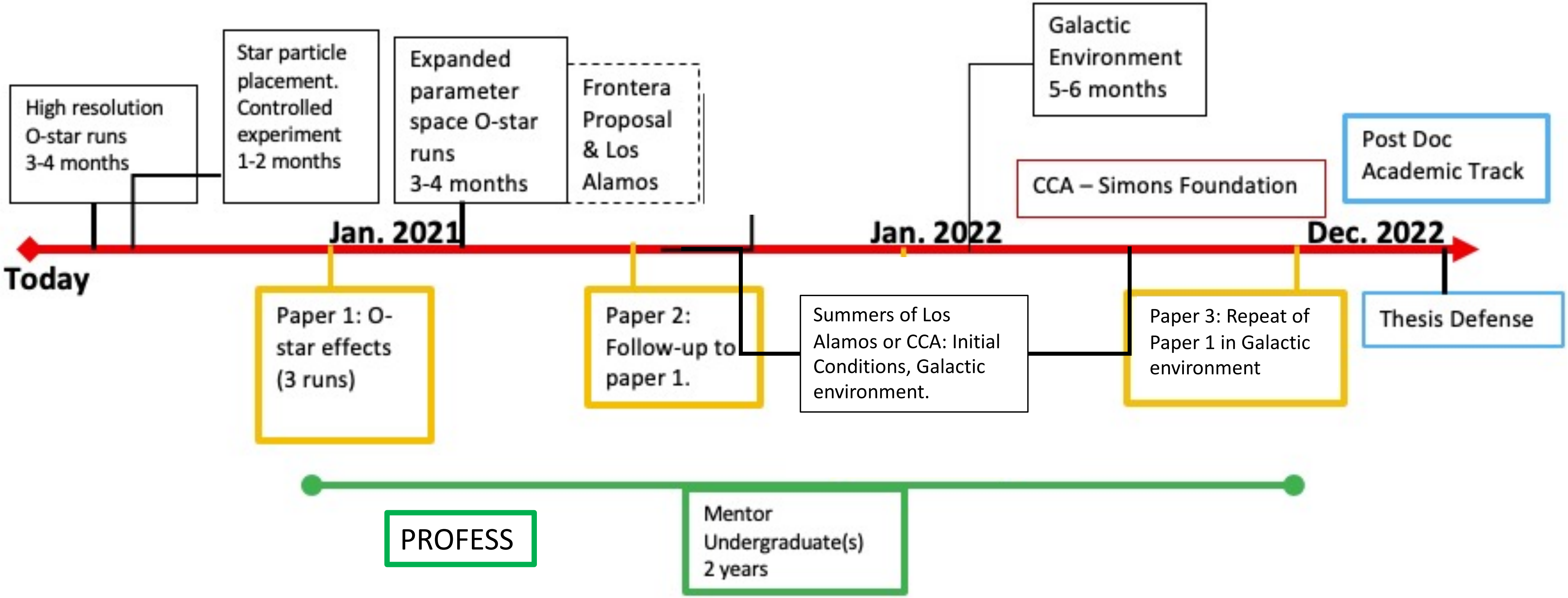
PROFESS
Mentor Undergraduate(s) 2 years

Timeline



- Continued collaborative efforts with graduate students and faculty.
- Moving into more responsible role as lead Torch user at Drexel.

Stellar Feedback

Massive stars are major players in the removal of gas.

- Radiation
- Winds

Present throughout star's life.
Scale strongly with star mass.

- Supernova

Single event at $t > 3$ Myr.
Consistent over star mass range.

Radiation

Ionizing radiation

Creates parsec-scale regions of ionized hydrogen.

Penetrates into CNM.

Can limit star formation far from star.

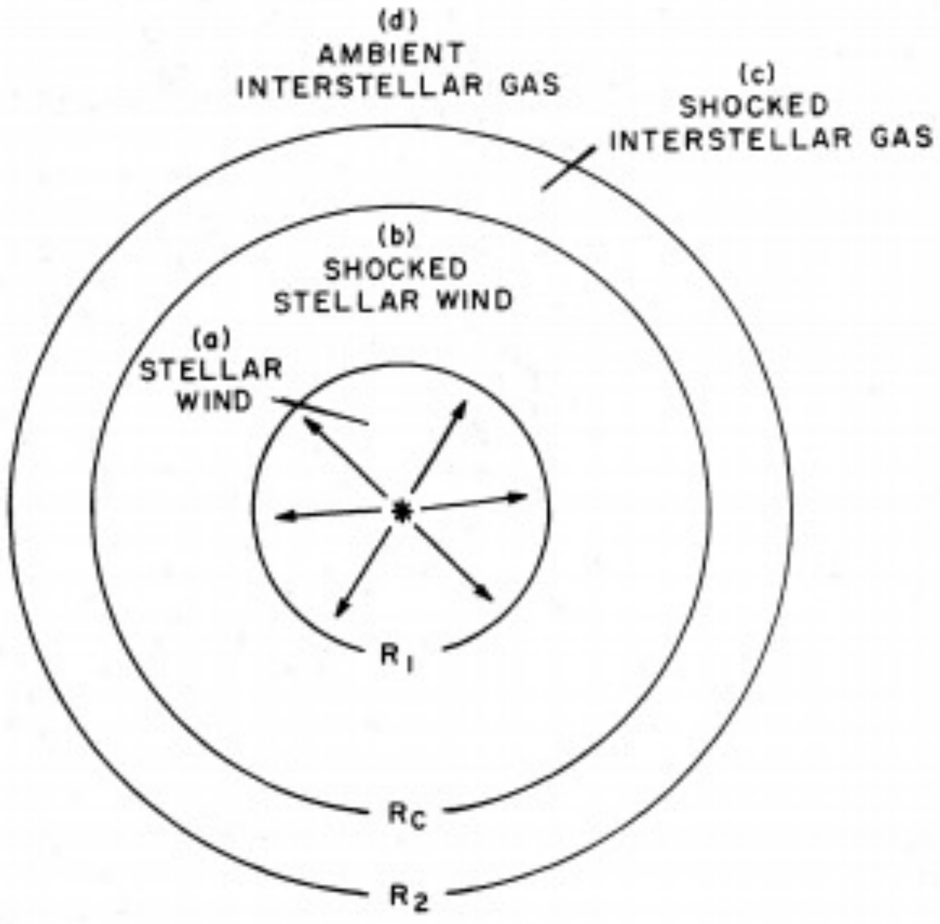
Strömgren Sphere

$$r_S = \left(\frac{3S\mu^2 m_H^2}{4(1.1)\pi\alpha_B\rho_0^2} \right)^{1/3} = 2.8 S_{49}^{1/3} n_2^{-2/3} \mathrm{pc}$$

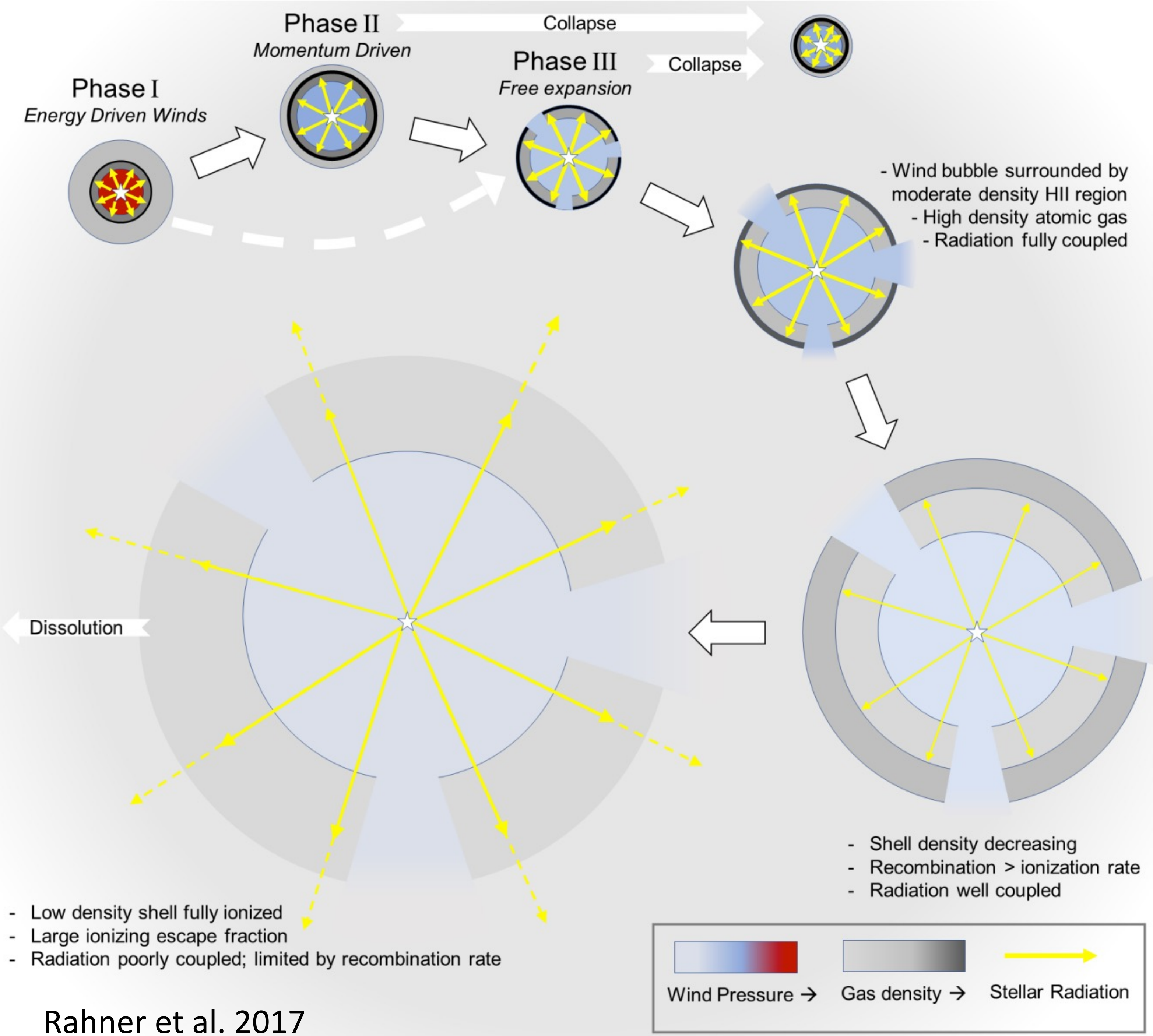
Winds

- Deposit matter into surrounding medium
- Momentum injection comparable to radiation
- High velocity injection shocks surrounding gas to 1e6 – 1e7 K

Winds



Weaver et al. 1977



Rahner et al. 2017

Stellar Feedback

- Role of stellar feedback is not well understood
  - Gas must be removed from clusters
  - But which mechanisms are important?

- 90% of local star clusters have been disrupted *before* gas-removal (Lada & Lada, 2003)
- Need to model massive star feedback, hydrodynamics of the gas, N-body dynamics of the stars.

Prior Studies

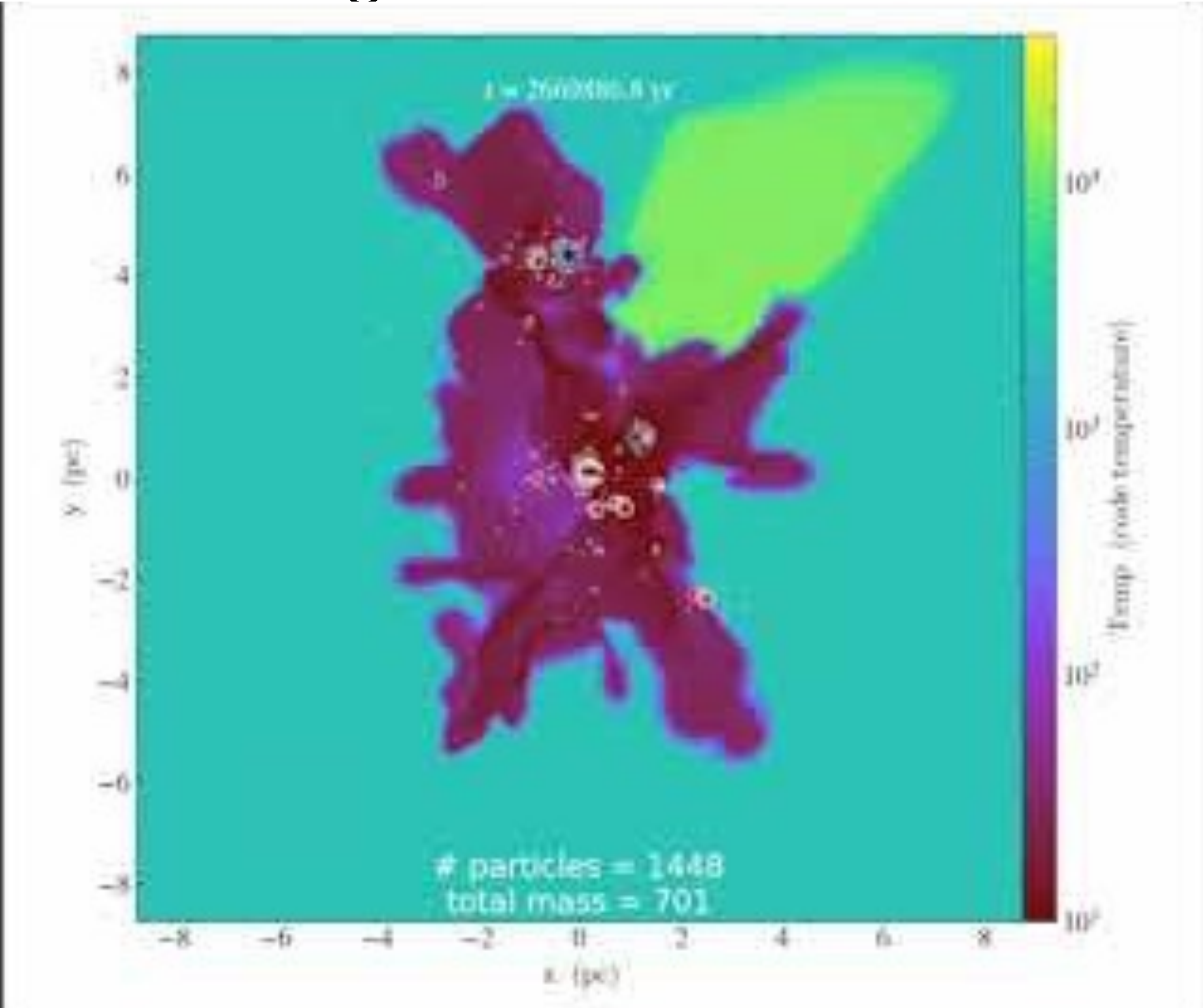
- Kroupa 2001 examines cluster structure in radially AND time dependent potential mimicking the removal of gas via feedback
  - No self-consistent interaction between feedback and gas
- (Dale et al. 2012a, 2014) Ionization and Ionization + winds
  - No N-body, represents entire star clusters as a single particle
- Gonzales et al. 2020 models gas, stellar feedback AND forms individual stars from the gas but only $M_* > 0.3$ Msun

The 10 pc^3 around the stars

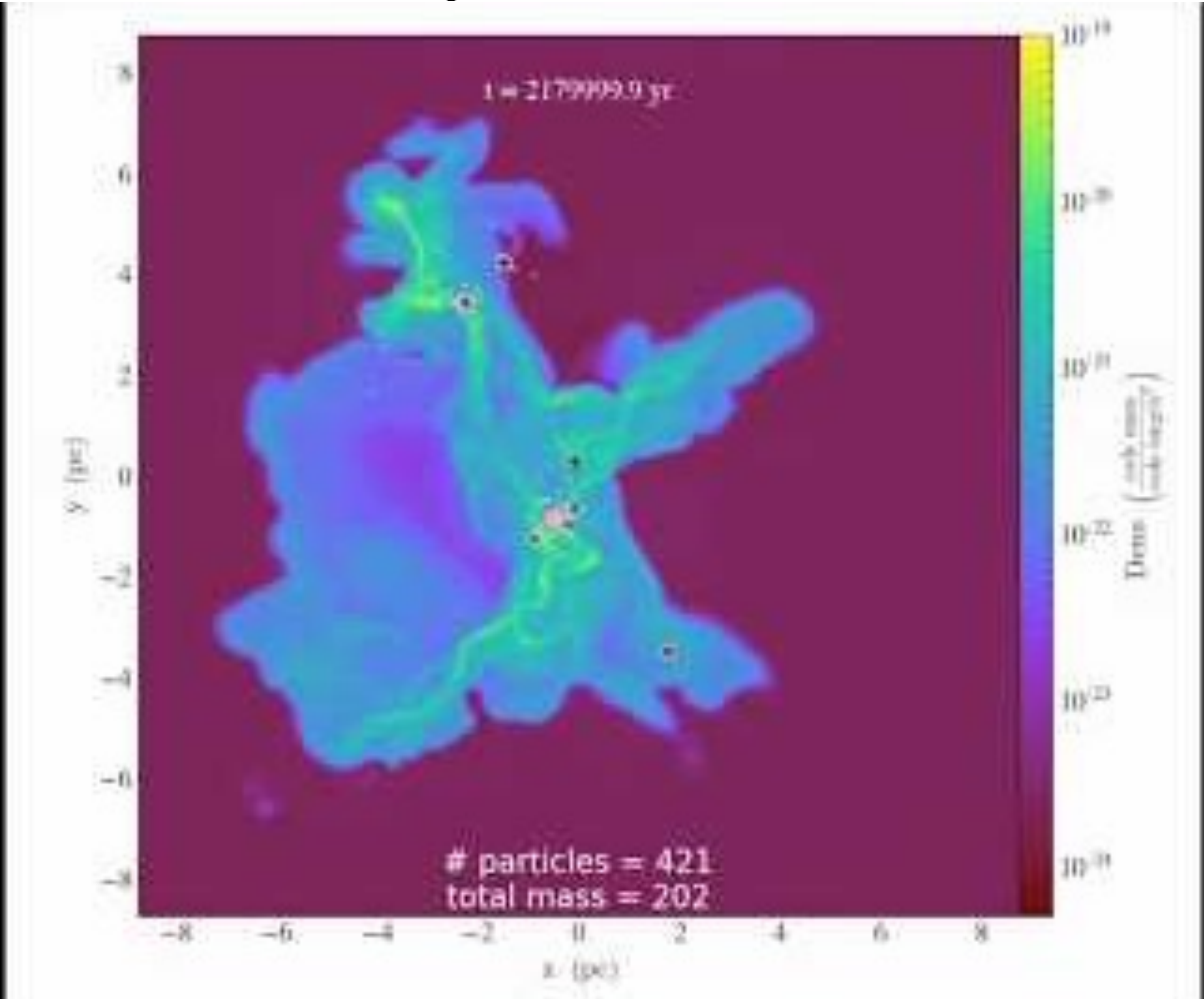
Simulation	Change in Mass	Ionized material	Time after formation
50 $M_\odot$	-3.7% (15 $M_\odot$)	11.4 % (46.0 $M_\odot$)	0.12 Myr
20 $M_\odot$	+12.7% (47.3 $M_\odot$)	0.46% (1.94 $M_\odot$)	0.12 Myr
8 $M_\odot$	+ 4.5% (16.3 $M_\odot$)	0.027% (0.0096 $M_\odot$)	0.12 Myr

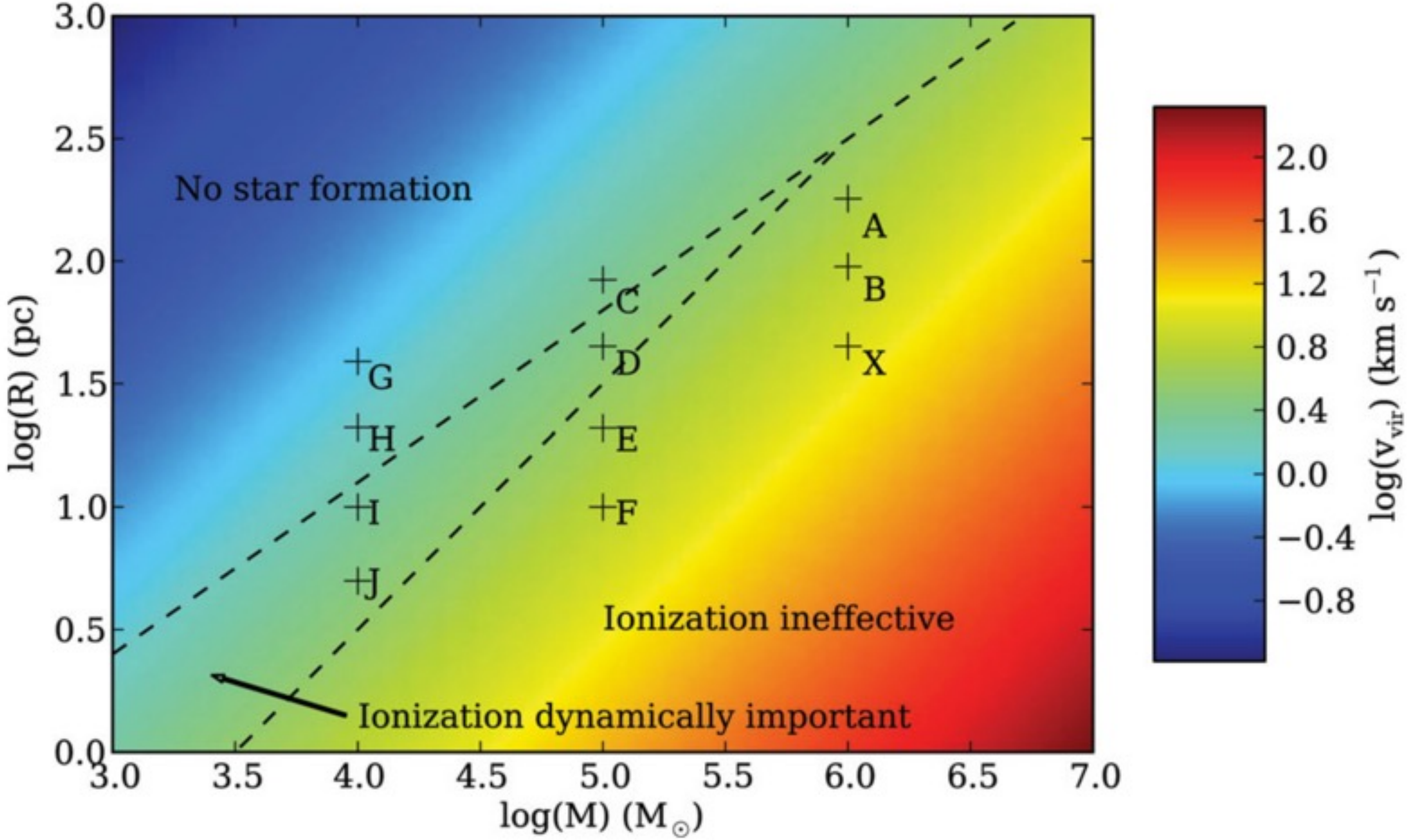
Simulation	Change in Mass	Ionized material	Time after formation
50 $M_\odot$	-3.7% (15 $M_\odot$)	11.4 % (46.0 $M_\odot$)	0.12 Myr
20 $M_\odot$	+22.8% (84.9 $M_\odot$)	1.76% (8.03 $M_\odot$)	0.58 Myr
8 $M_\odot$	+ 79.8% (287.3 $M_\odot$)	0.025% (0.015 $M_\odot$)	1.12 Myr

Simulations: 8 $M_\odot$



Simulations: 20 $M_{\odot}$





No star formation
Ionization ineffective
Ionization dynamically important
A
B
C
D
E
F
G
H
I
J
X
log(R) (pc)
log(M) ($M_\odot$)
$\log(v_{vir})$ (km s^{-1})
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
2.0
1.6
1.2
0.8
0.4
0.0
−0.4
−0.8

Other

- PROFESS

$$\rho_{thresh} = \frac{\pi c_s^2}{G\lambda_J^2} = \frac{\pi c_s^2}{G(2 * 2.5\Delta x)^2}$$

5 pc^

- f

Simulation	Change in Mass	Ionization Mass	Time after formation
50 Msun	-27.3 % (76.3 Msun)	12.1% (24.5 Msun)	123 kyr
20 Msun	+ 9.4 % (24.3 Msun)	0.7 % (1.93 Msun)	123 kyr
8 Msun	+ 4.3 % (10.6 Msun)	0.024% (0.006 Msun)	123 kyr

Simulation	Change in Mass	Ionization Mass	Time after formation
50 Msun	-27.3 % (76.3 Msun)	12.1% (24.5 Msun)	123 kyr
20 Msun	+ 5.6 % (14.6 Msun)	2.62 % (7.16 Msun)	582 kyr
8 Msun	+ 78.4 % (191.8 Msun)	0.027% (0.012 Msun)	1120 kyr