Mutual Destruction on FIRE

How Simulated Associated Star Clusters Destroy and are Destroyed by GMCs in Cosmological Simulations

Sarah R. Loebman (UC Davis)

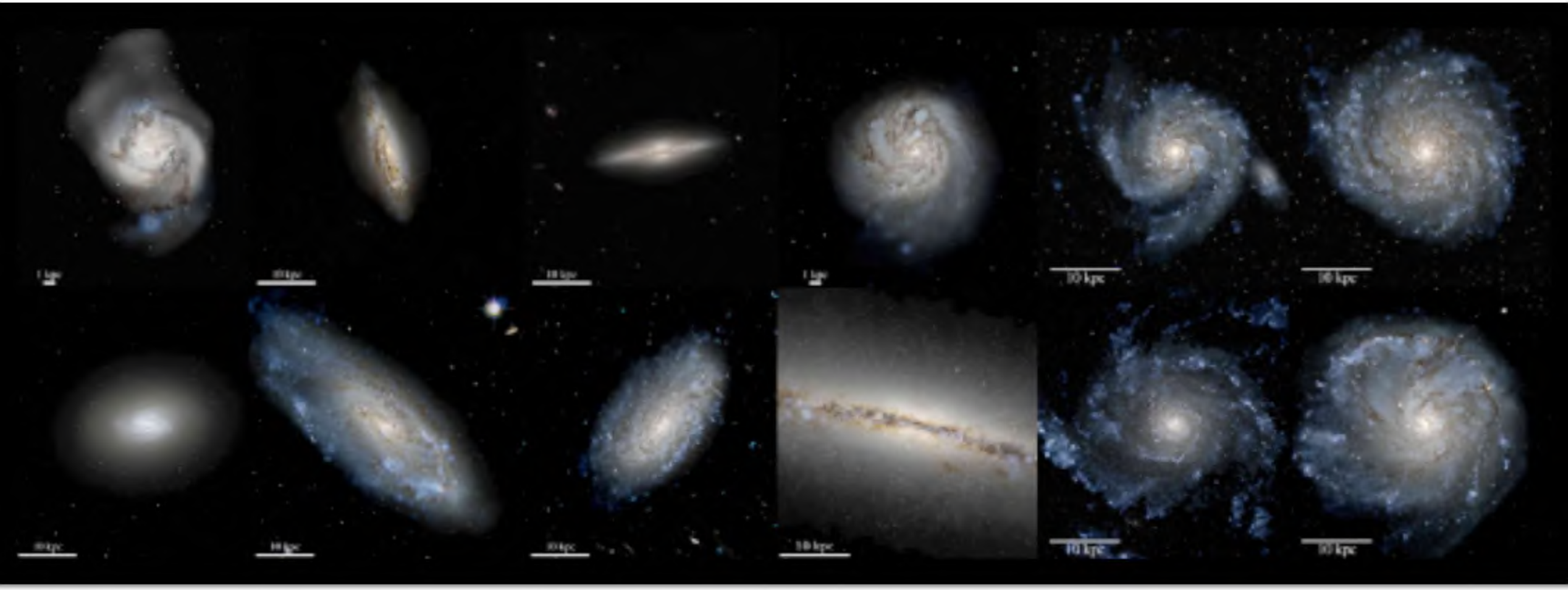
with Sam Benincasa, Andrew Wetzel, and the FIRE Collaboration

Star formation is a multi-scale problem

Only recently have we gotten to the point where we can resolve from ISM scales to galactic scales in cosmological zoom-in simulations

many Mpc	10 kpc	100 pc	~1 pc
			
large-scale structure	galaxy	giant molecular clouds	young stellar clusters

The Latte Cosmological Zooms



Wetzel, et al. (2016)

Study star formation and the ISM in a fully cosmological context:

- 8 Milky Way-mass systems + 2 Local Group pairs
- 7100 $M_\odot$ mass resolution for gas —> rerun 880 $M_\odot$
- adaptive spatial resolution (max: 1 pc, ISM avg: 20 pc)
- 2.2 Myr temporal resolution —> rerun 1 Myr

Star Formation & Feedback in Latte

The goal is to model dense, multi-phase gas, star formation & feedback in a cosmological setting

To form stars, gas must be:

- self-gravitating
- dense (above 1000 cm^{-3})
- molecular (following Krumholz & Gnedin 2011)

A high density threshold and self-gravity criteria for star formation, combined with high spatial resolution, enables the formation of spatially correlated **star clusters**.

GIZMO

Star Formation & Feedback in Latte

The goal is to model dense, multi-phase gas, star formation & feedback in a cosmological setting

supernovae
- core collapse
- type 1a

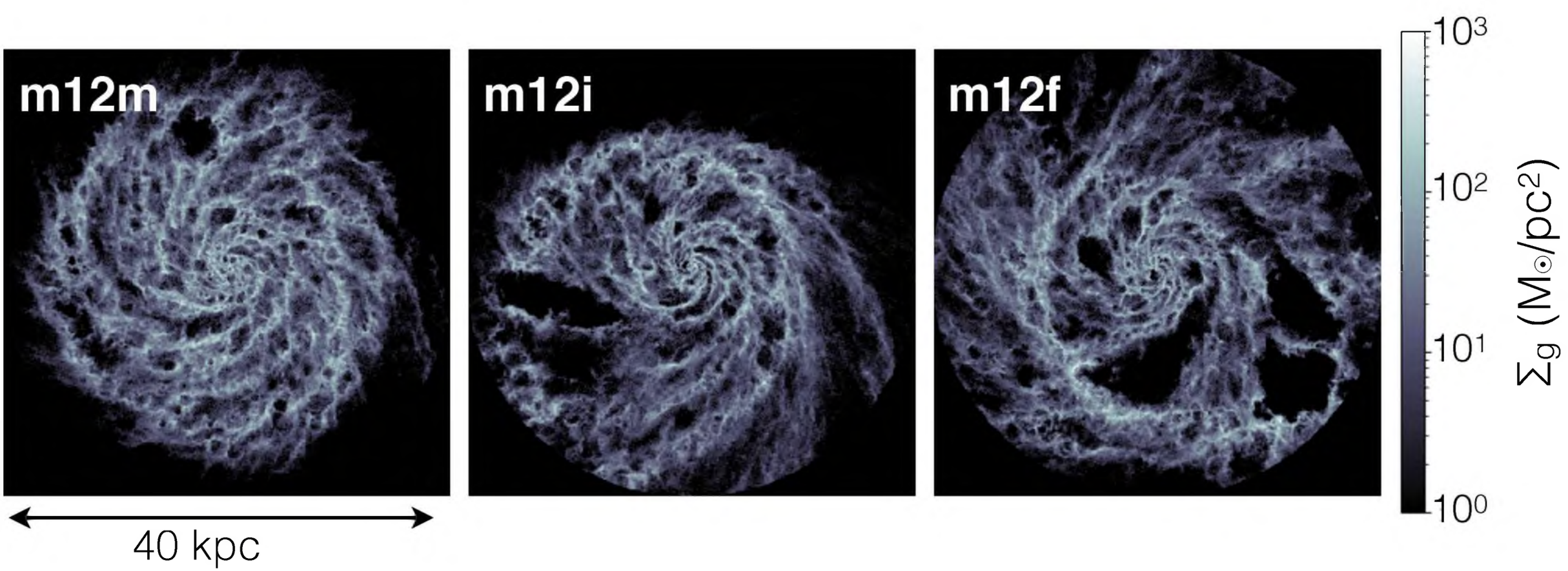
stellar radiation
- radiation pressure
- photoionization heating (HII regions)
- photoelectric heating (via dust)

stellar winds
- massive O & B stars (prompt)
- AGB stars (delayed)

GIZMO

Latte Disks at Present Day

Select 3 galaxies with Milky Way-mass halos run using the ‘standard’ FIRE-2 physics

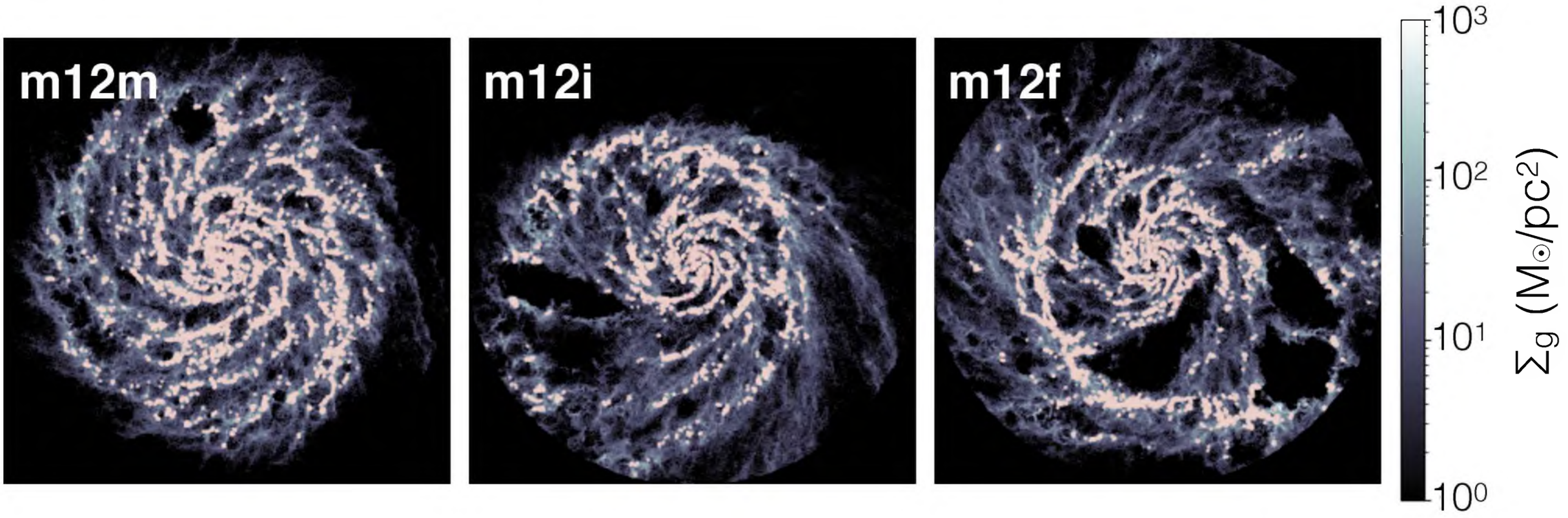


Access the data yourself! Redshift 0 simulation output and synthetic Gaia catalogs can be found at **ananke.hub.yt** (Sanderson et al. 2018)

Finding GMCs and Young Stellar Clusters

Identify GMCs using a friends-of-friends algorithm requiring:

- choosing a linking length (20 pc)
- making optional cuts on density (10 cm^{-3}) and temperature (10^4 K)



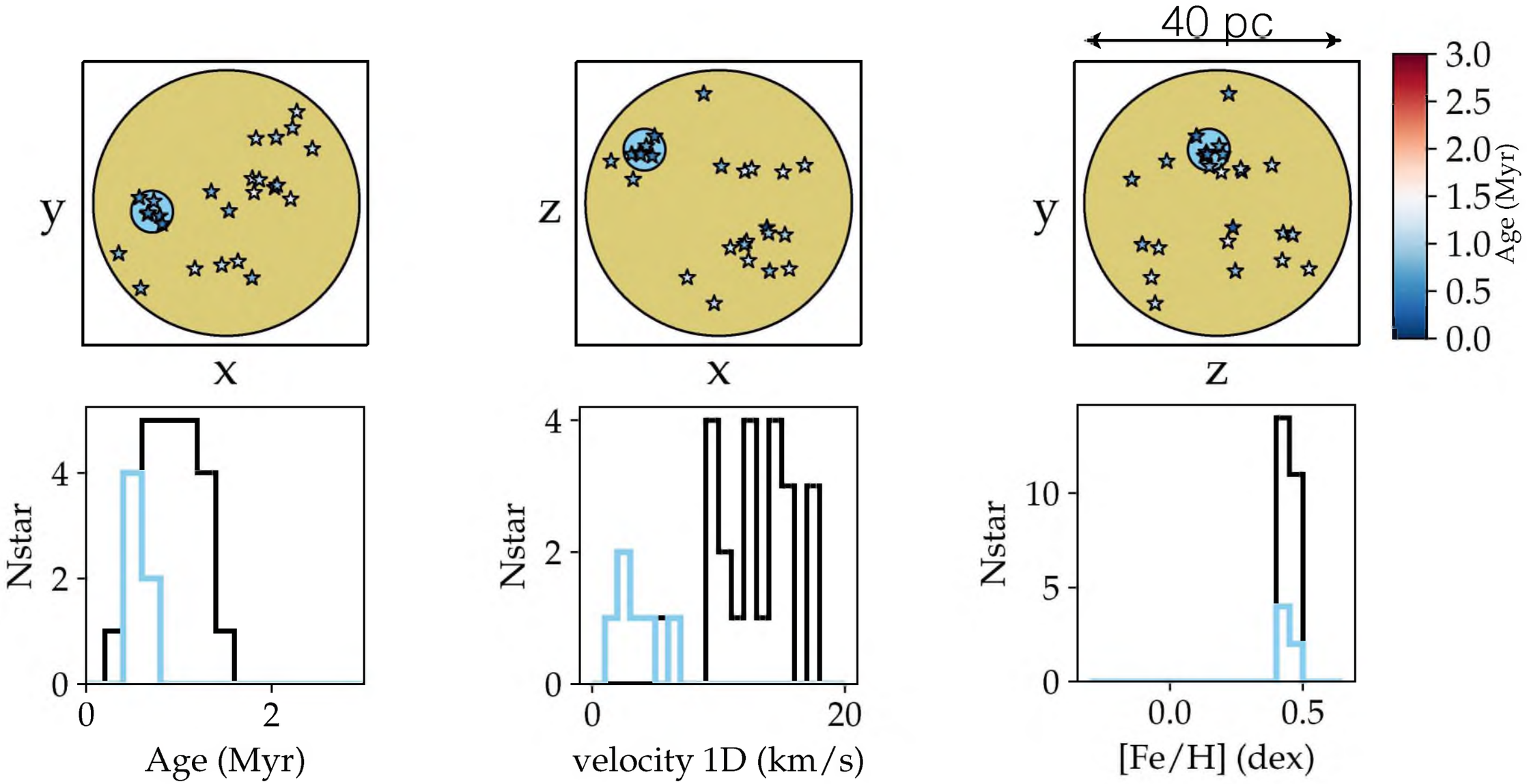
This is a pathfinder to develop a **pipeline** to use on more galaxies in the Latte sample and on **higher resolution zooms** coming this fall

Benincasa, Loebman, et al. (in prep.)

Finding GMCs and Young Stellar Clusters

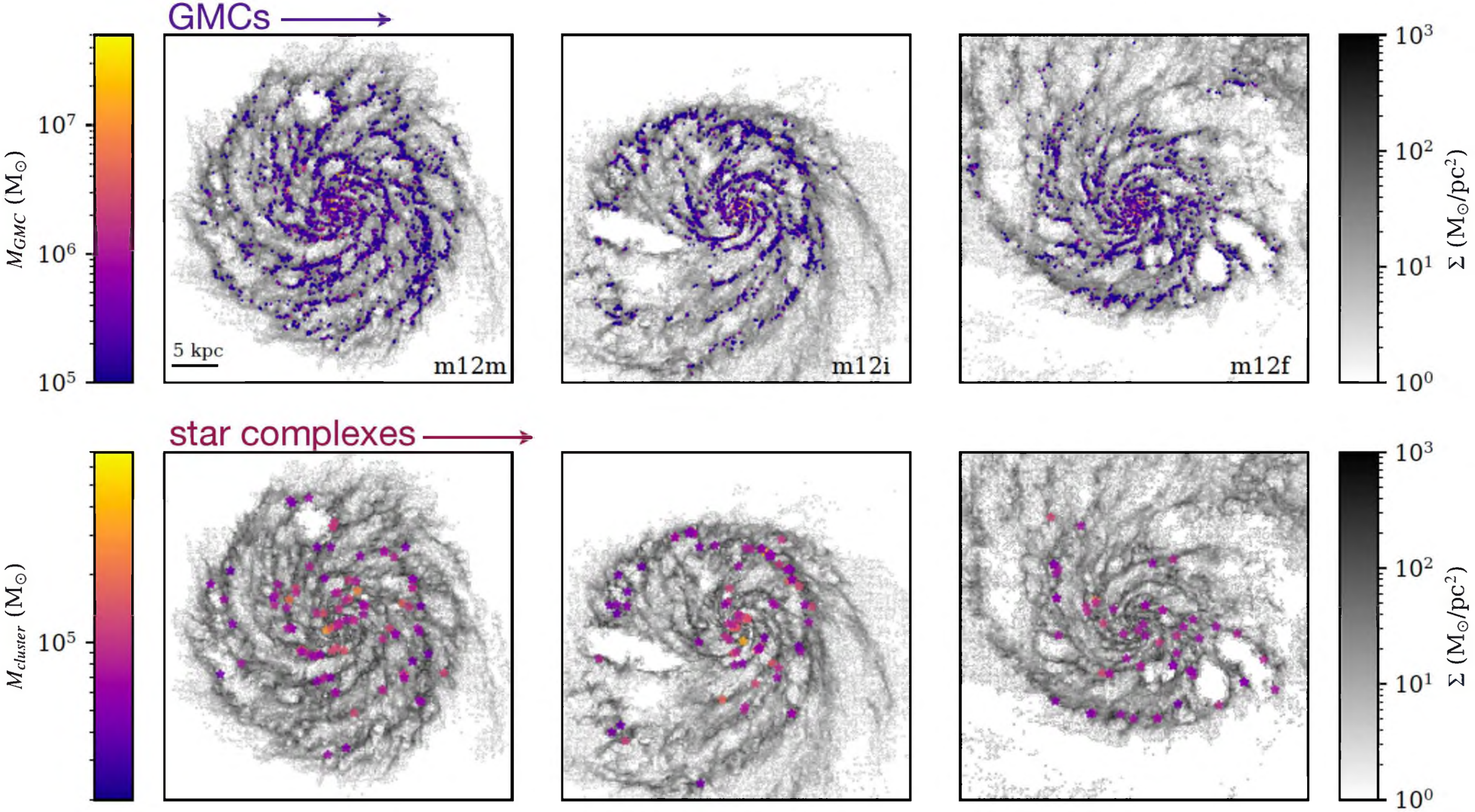
Identify star clusters using a friends-of-friends algorithm requiring:

- linking length of 10 pc, 20 pc for clusters & complexes
- use only stars younger than 3 Myr



Loebman, Benincasa, et al. (in prep.)

Finding GMCs and Young Stellar Clusters



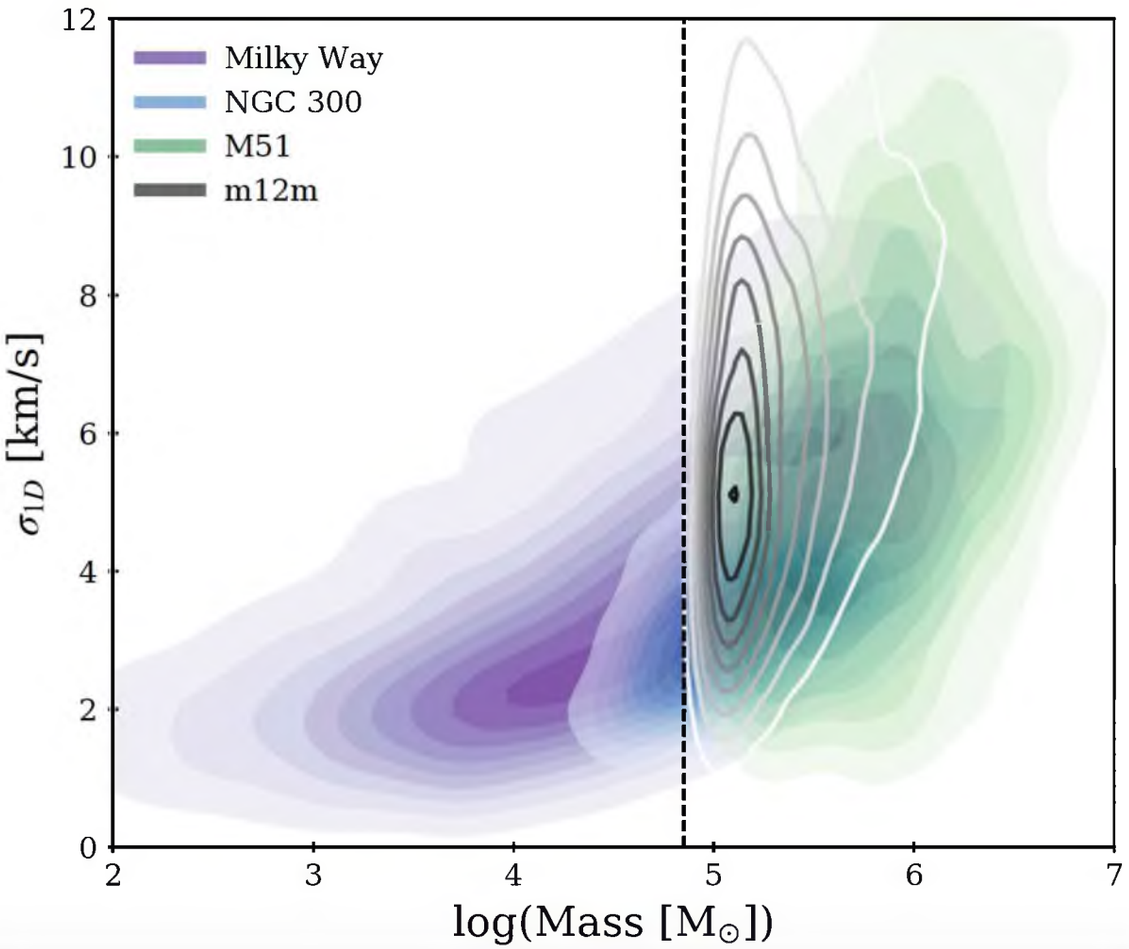
Star clusters & complexes are closely spatially associated with GMCs.
At any time, between 22% and 27% of GMCs host star clusters.

Loebman, Benincasa, et al. (in prep.)

Summary of Global Properties

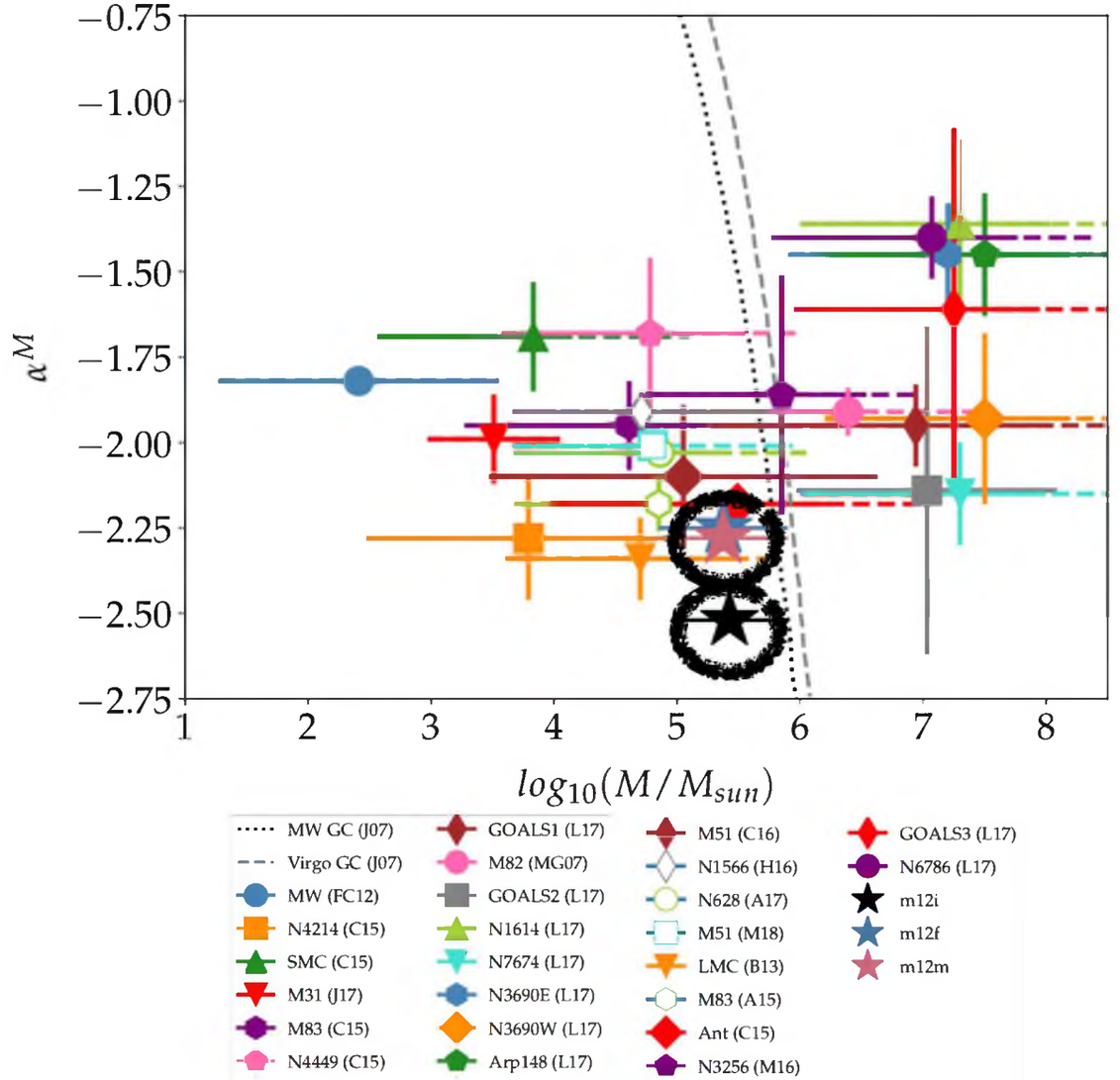
At current resolution, we probe the high mass end of the star cluster and GMC mass distribution.

Giant Molecular Clouds



Benincasa, Loebman et al. (in prep)
see also Lakhlani et al. (in prep.)

Star Clusters



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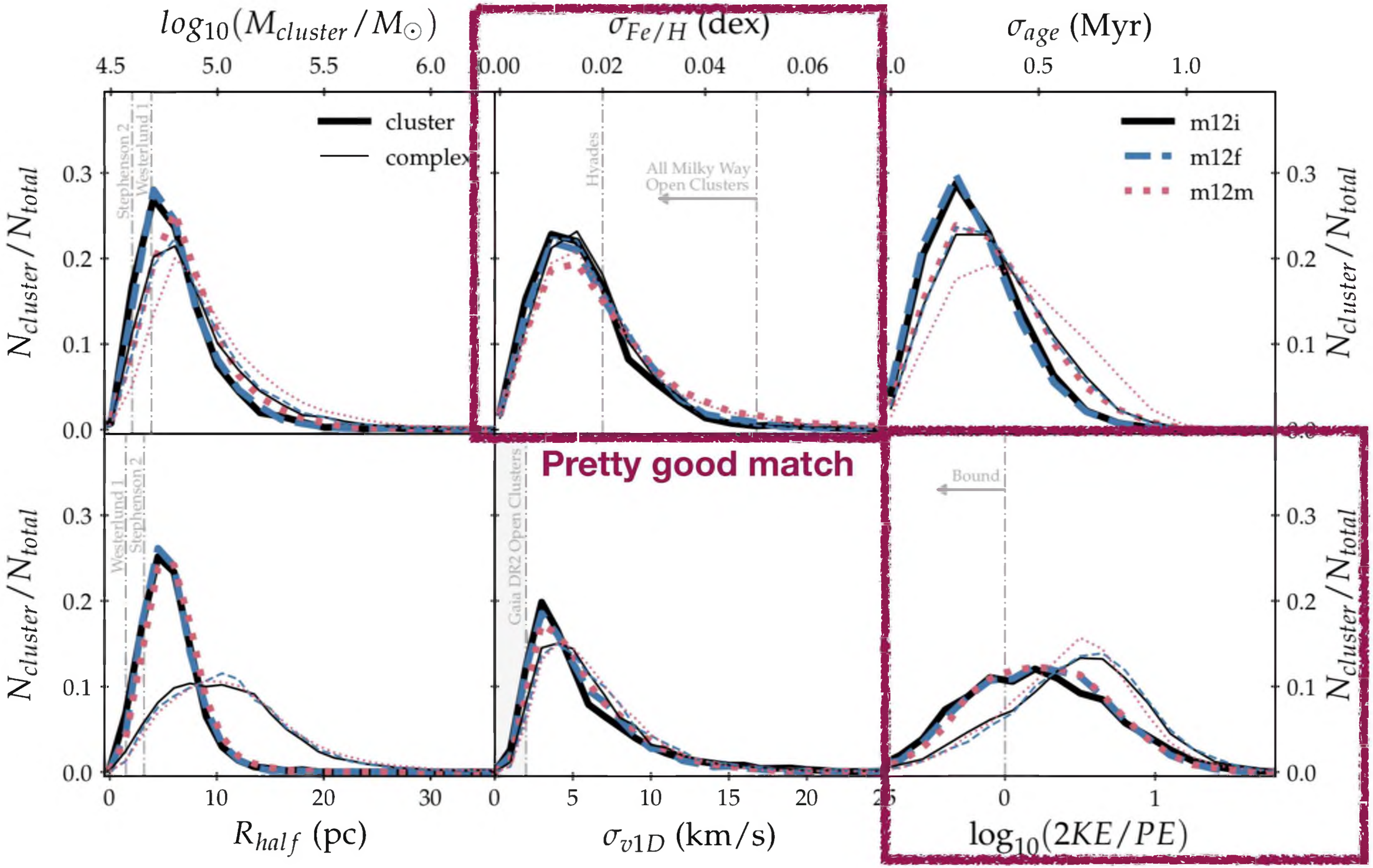

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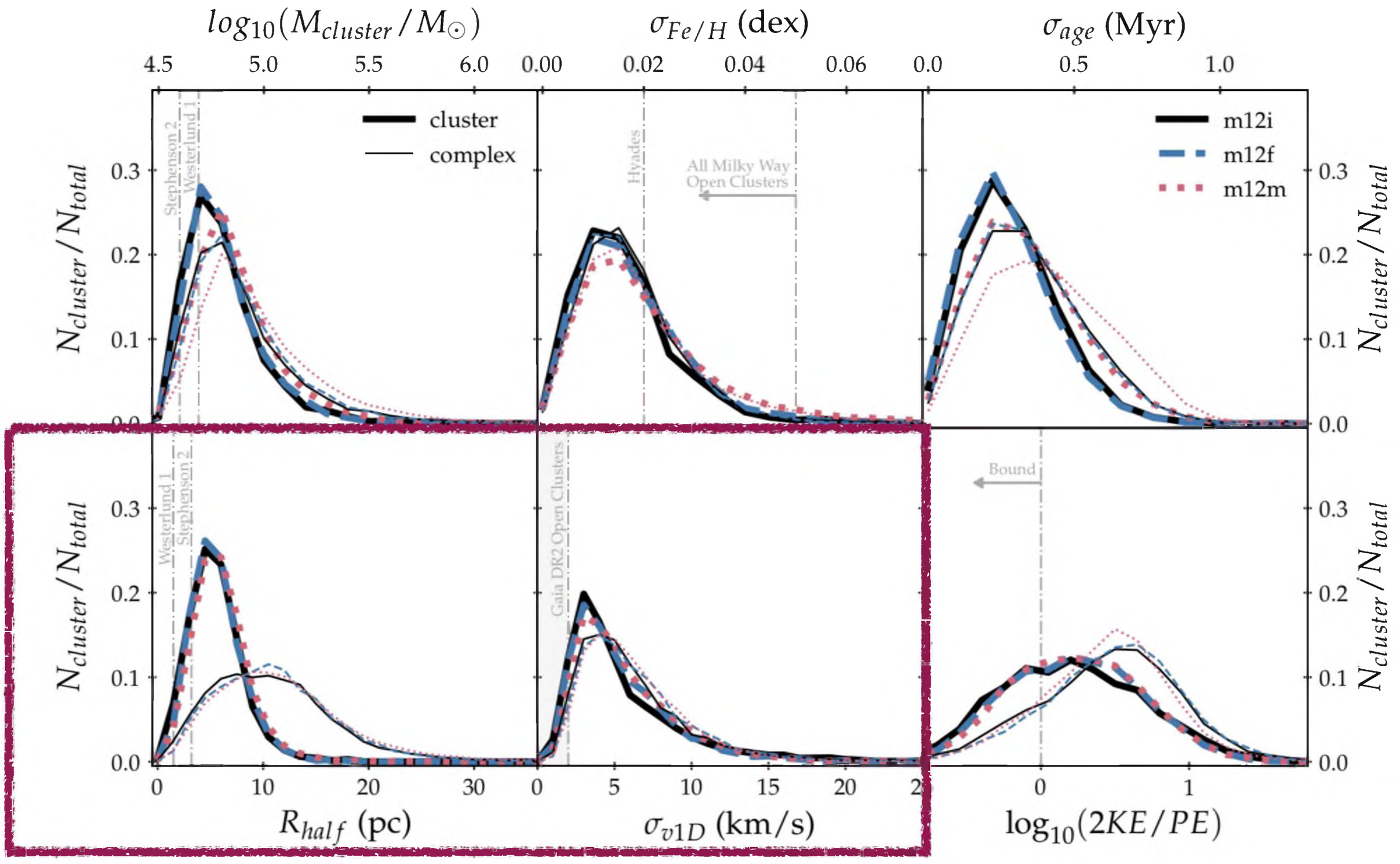
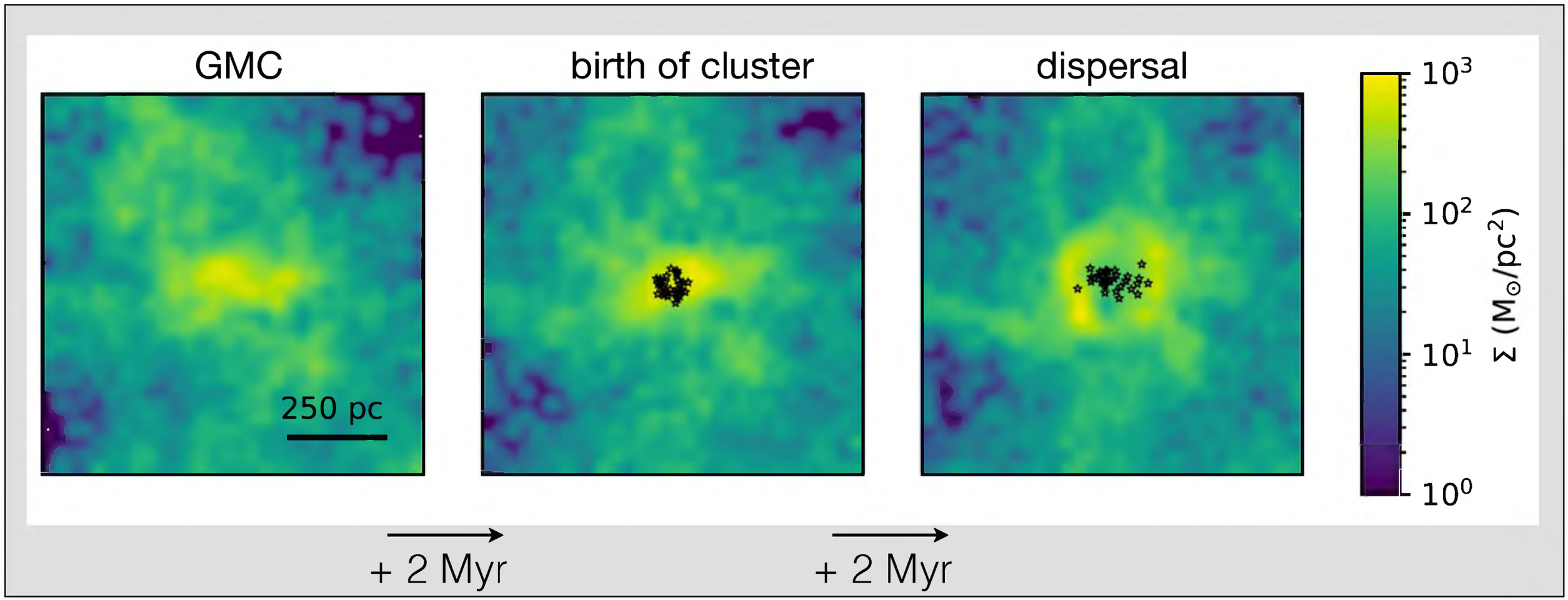


Need to do better!

Loebman, Benincasa et al. (in prep)

Destruction Timescale for GMCs

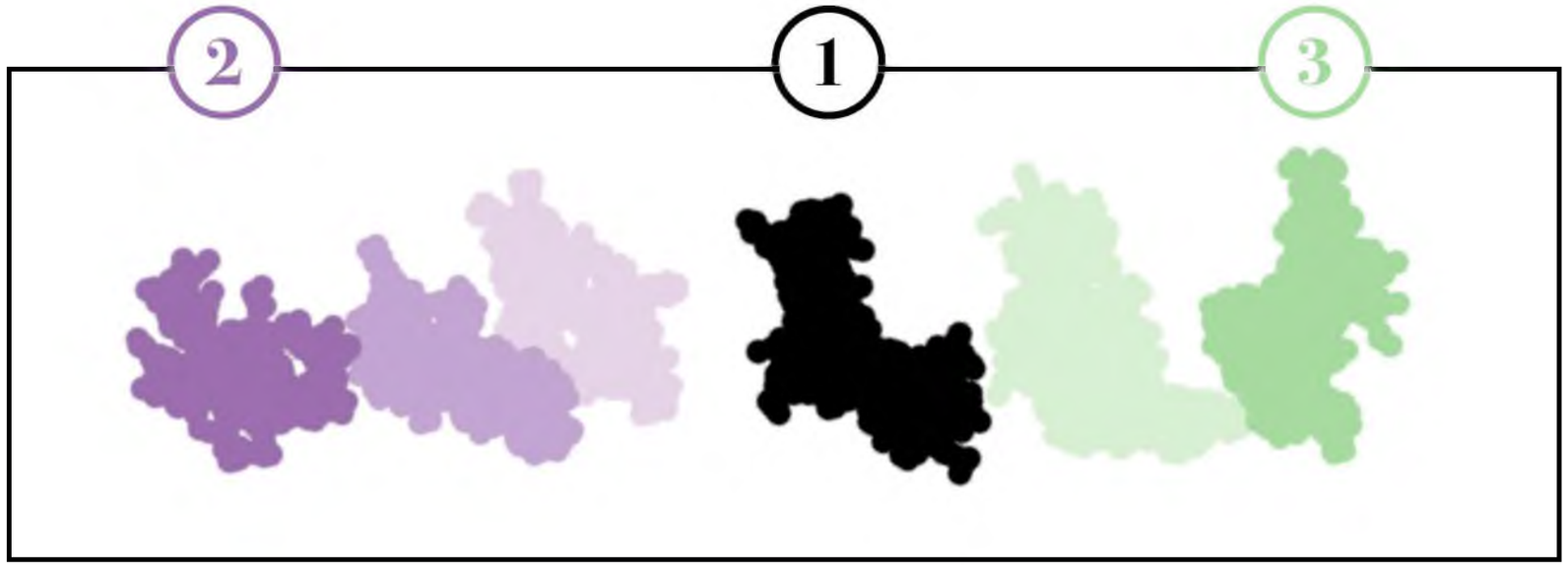
Considering only the clouds associated with clusters, only 18% of those clouds survive longer than ~2 Myr after a cluster formation event



Supernovae begin to go off only after 3 Myr. In our simulations, it appears cloud destruction is driven by early forms of stellar feedback

Benincasa, Loebman, et al. (in prep.)

Measuring GMC Lifetimes in Latte



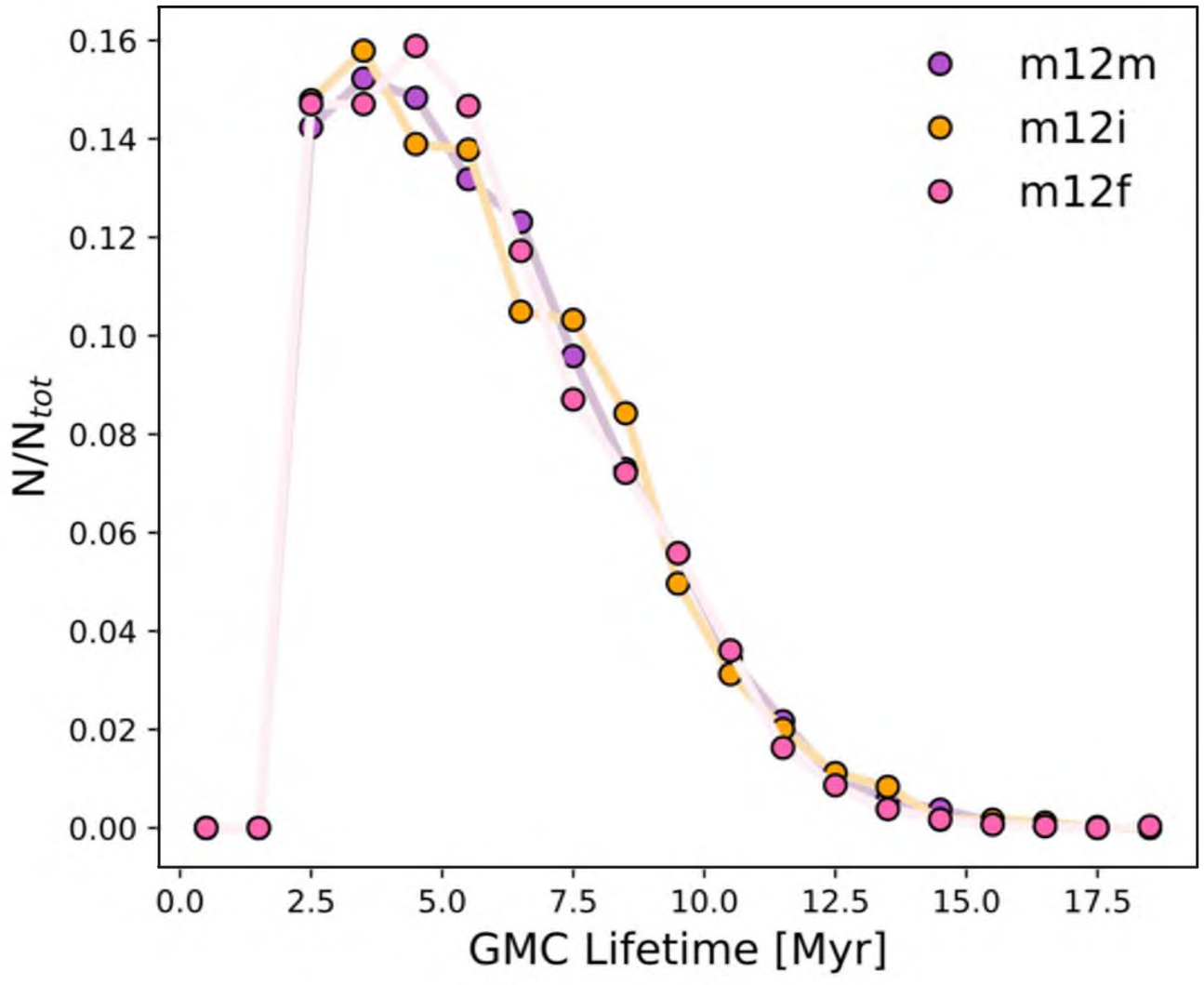
1. identify a GMC at an arbitrary timestep

2. track the cloud **forward** and **backward** until it has lost 50% of its original mass or its particles are no longer the main constituent after a merger (following Dobbs et al. 2013)

Measuring GMC Lifetimes in Latte

Cosmological zoom simulations present us with a laboratory to study GMC lifetimes where we can

- build a statistically diverse galaxy sample
- include different physics (cosmic rays, MHD, rad-hydro, etc…)



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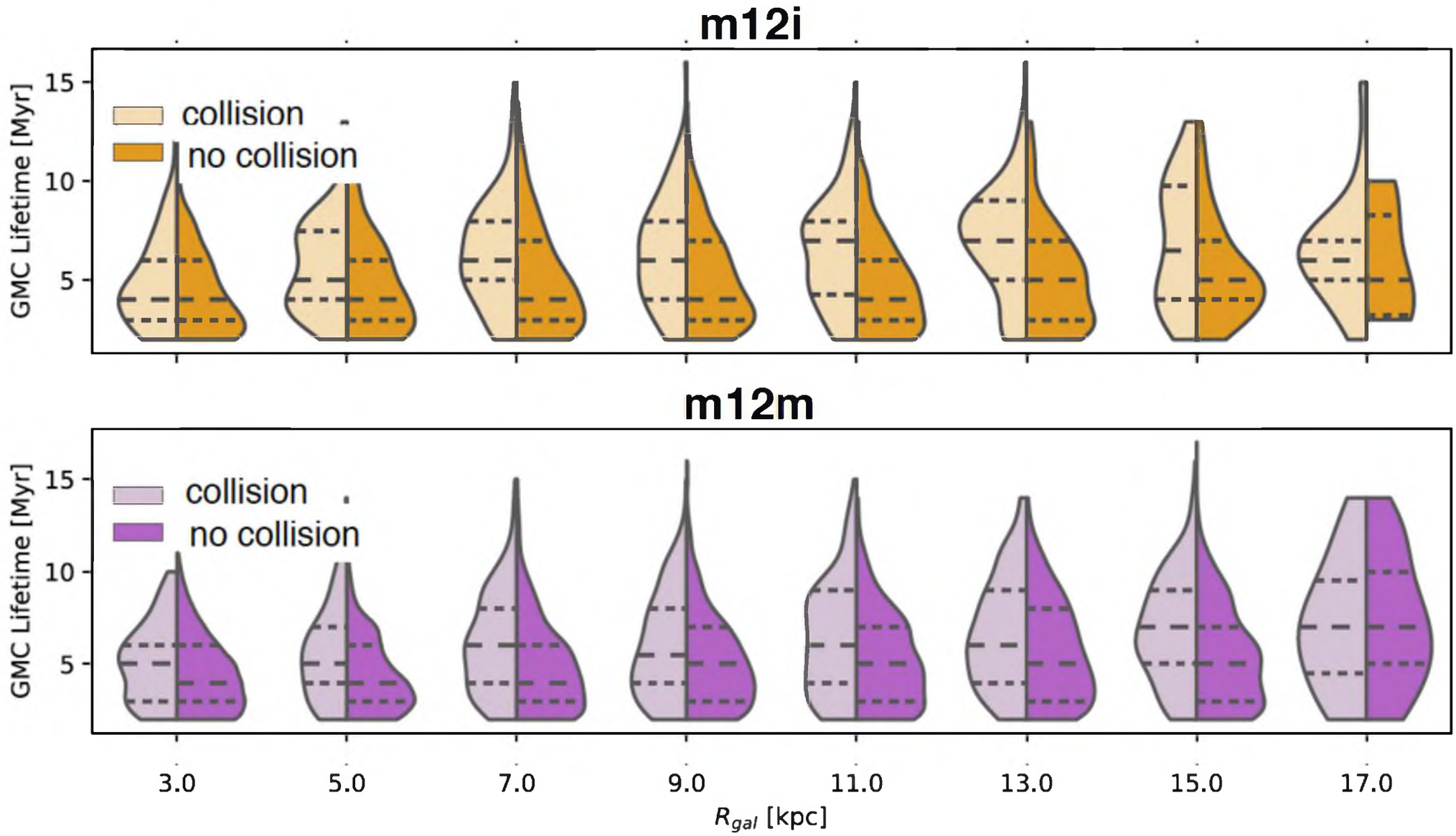
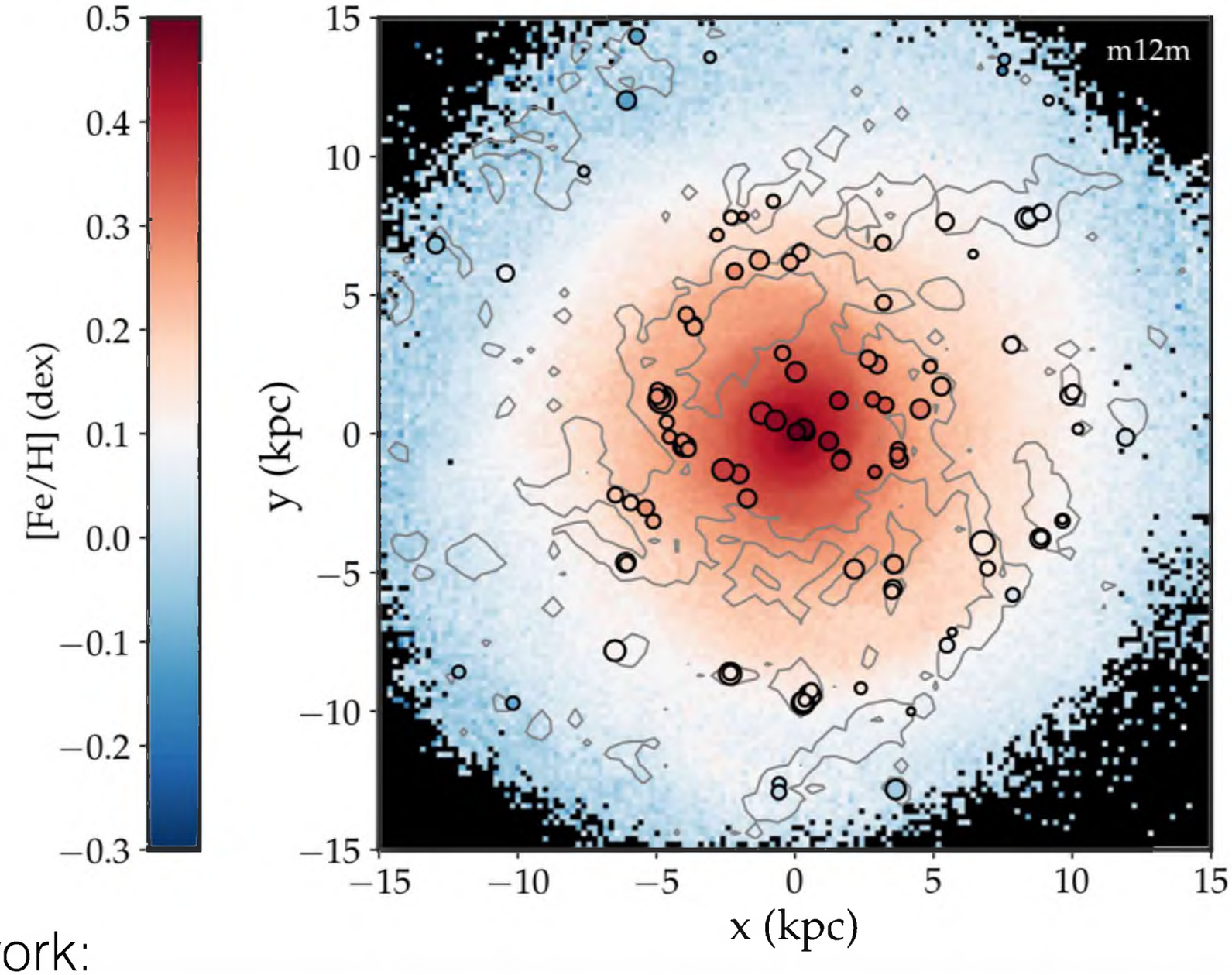


The mean lifetime of GMCs tends to increase with increased Galactic radius. However, cloud lifetime roughly constant for GMCs that don't experience collisions, regardless of where they are found.

Early feedback driven?

Benincasa, Loebman, et al. (in prep.)

Role of Galactic Environment in Latte

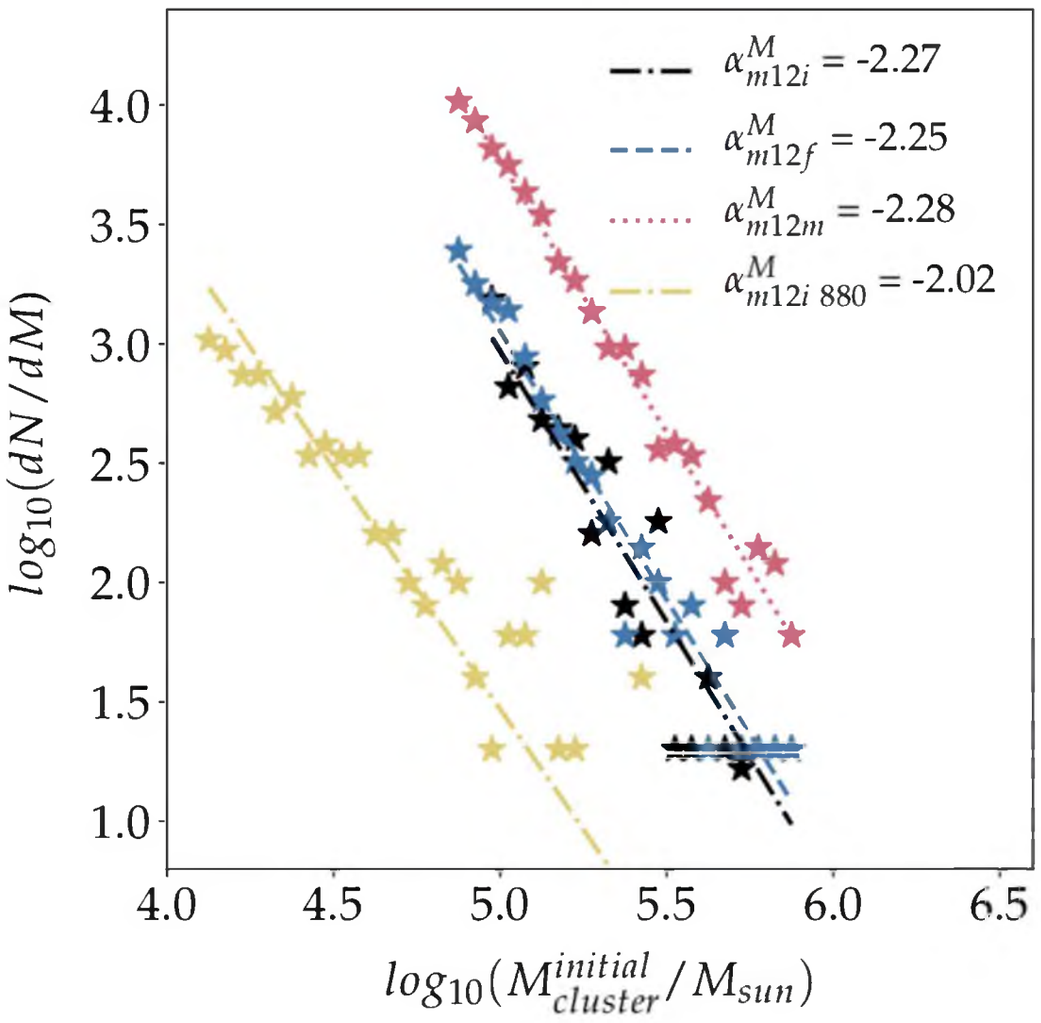


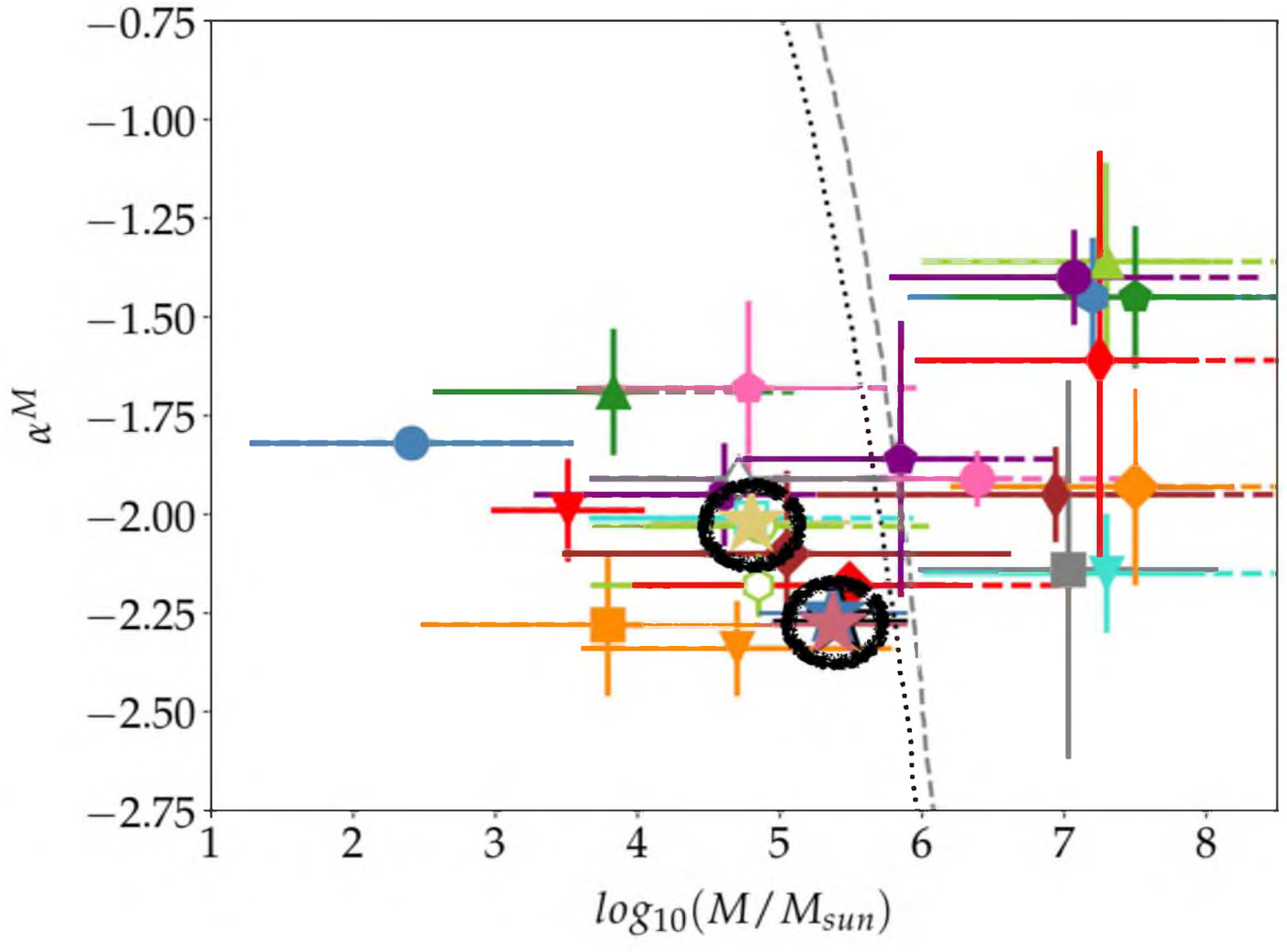
Near term work:

1. Connection between spiral structure lifetime & cluster formation?
2. How does variation in large scale environment (surface density, pressure, shear) impact GMC & cluster lifetimes and dispersal?

Loebman, Benincasa et al. (in prep)

Role of Galactic Environment in (Triple) Latte





New ultra-high resolution runs with 8x mass improvement: 880 $M_\odot$

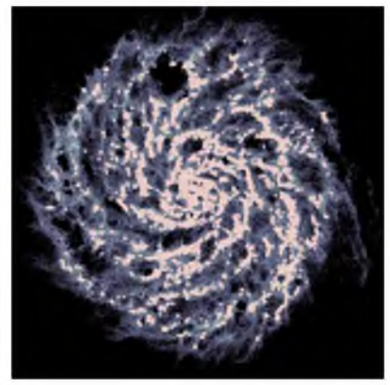
Push down the mass function to resolve star clusters ~10^4 $M_\odot$

Initial comparisons to Latte show promising agreement. Stay tuned!

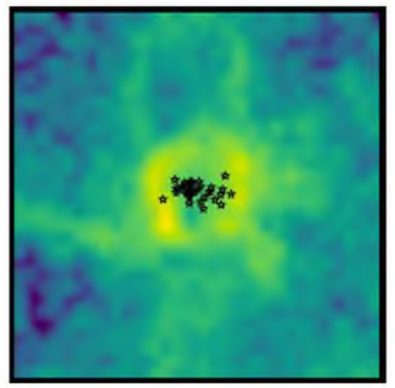
Loebman, Benincasa et al. (in prep)

Conclusions

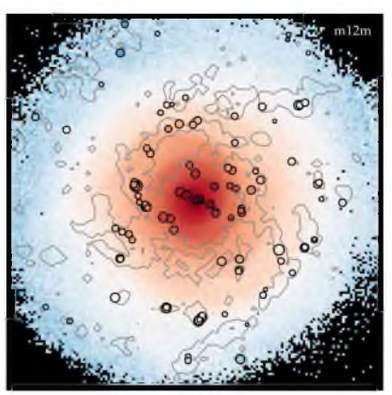
We are able to produce realistic GMCs and star clusters that probe the massive end of the Milky Way distribution in Latte.



We find that after a star cluster formation event, clouds are quickly dispersed. This is likely due to early forms of stellar feedback from young clusters.



In these simulations, GMC lifetime < 17.5 Myr.
In near future, we will explore the role of Galactic environment on star cluster & GMC lifetimes using ultra high resolution cosmological simulations.



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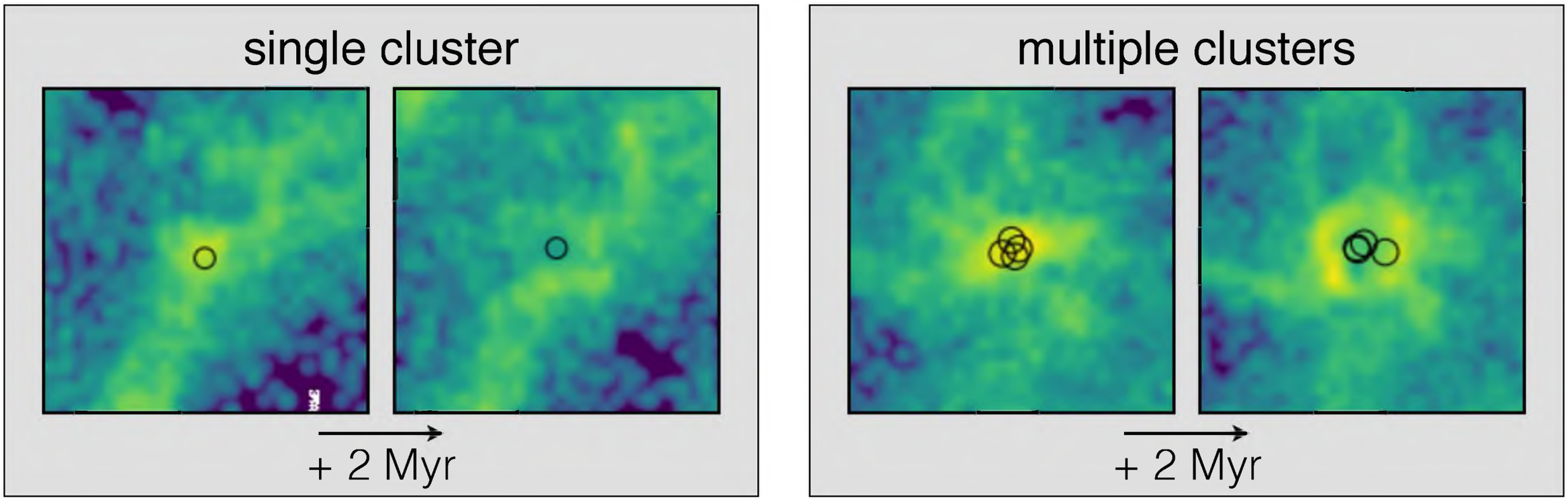

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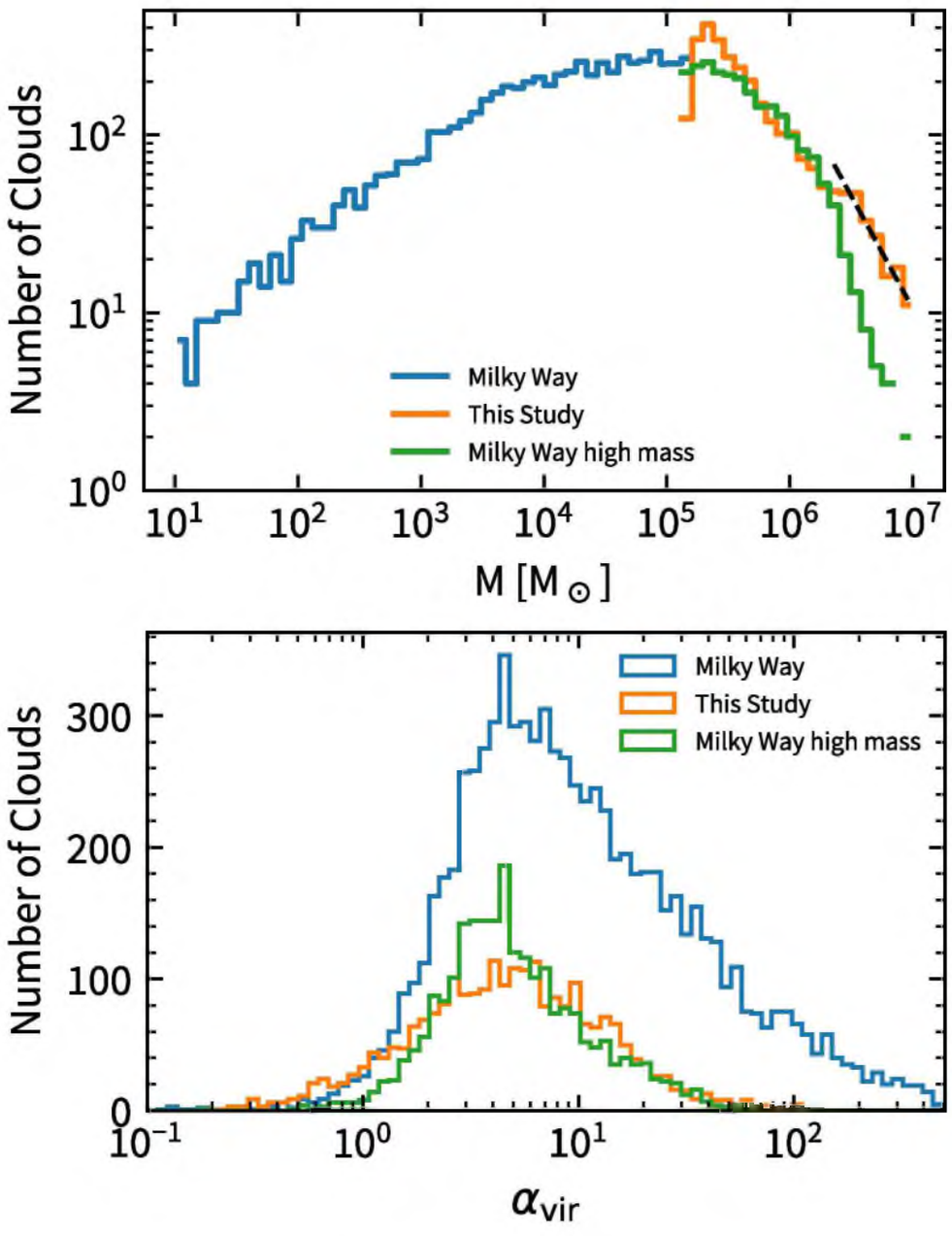
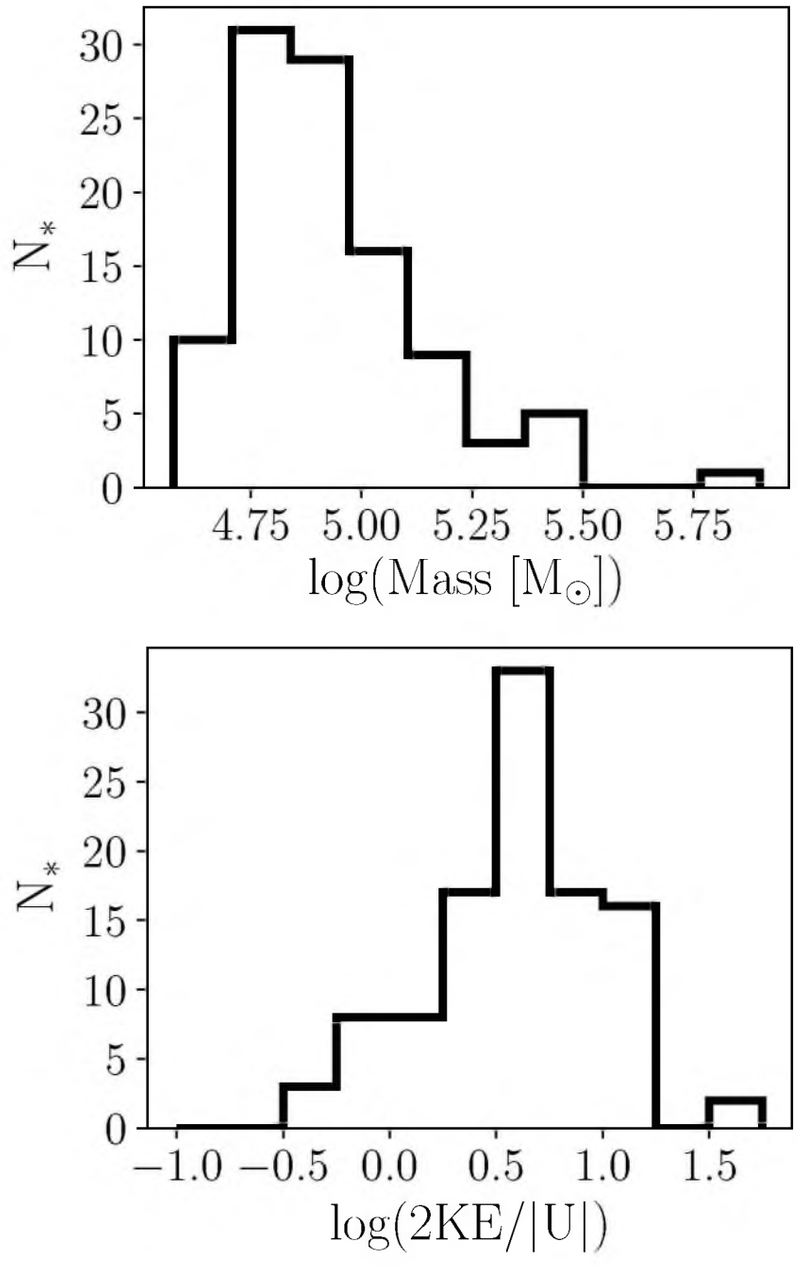


Lakhlani et al. (in prep.)

Star Clusters



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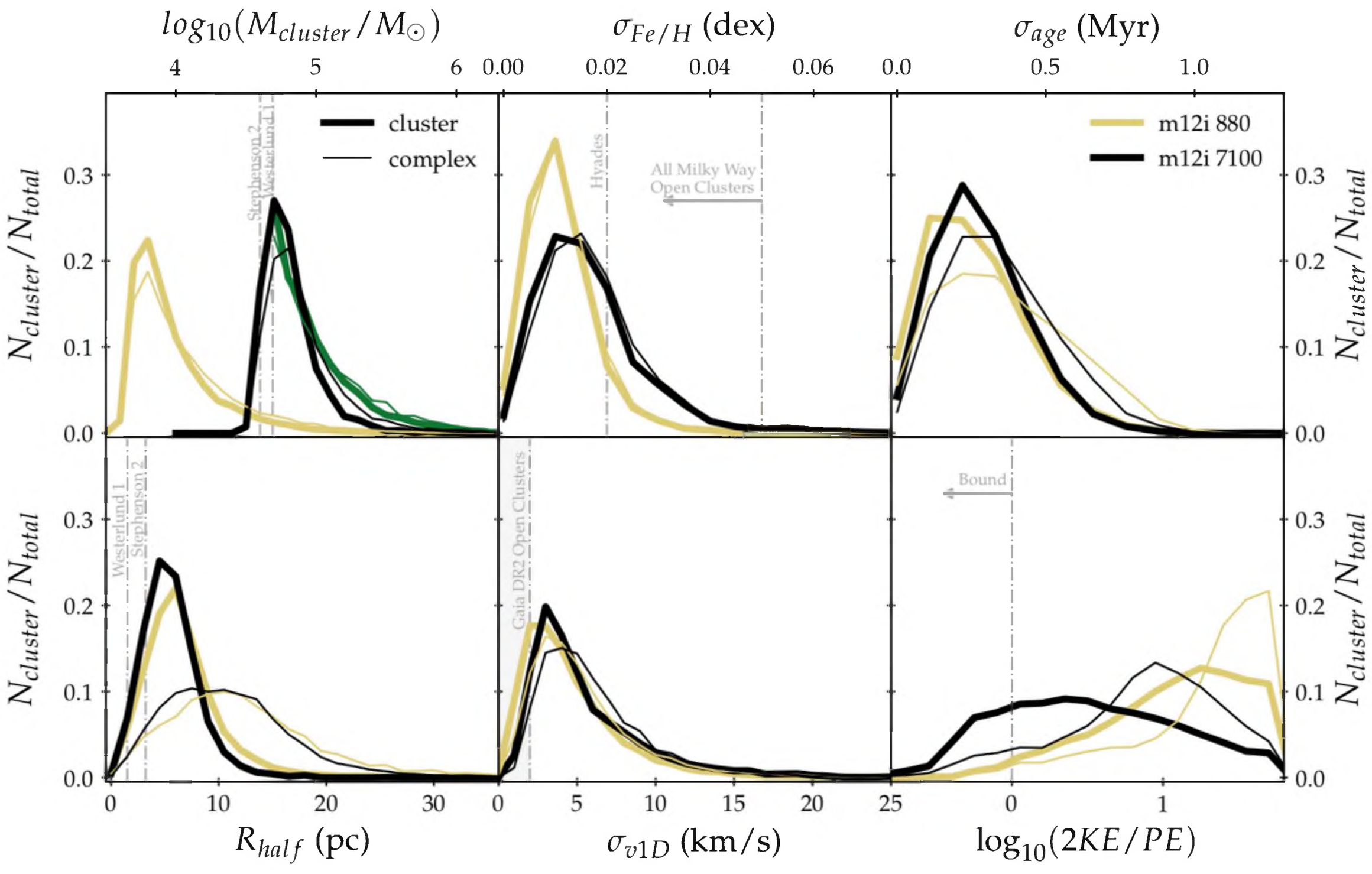

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