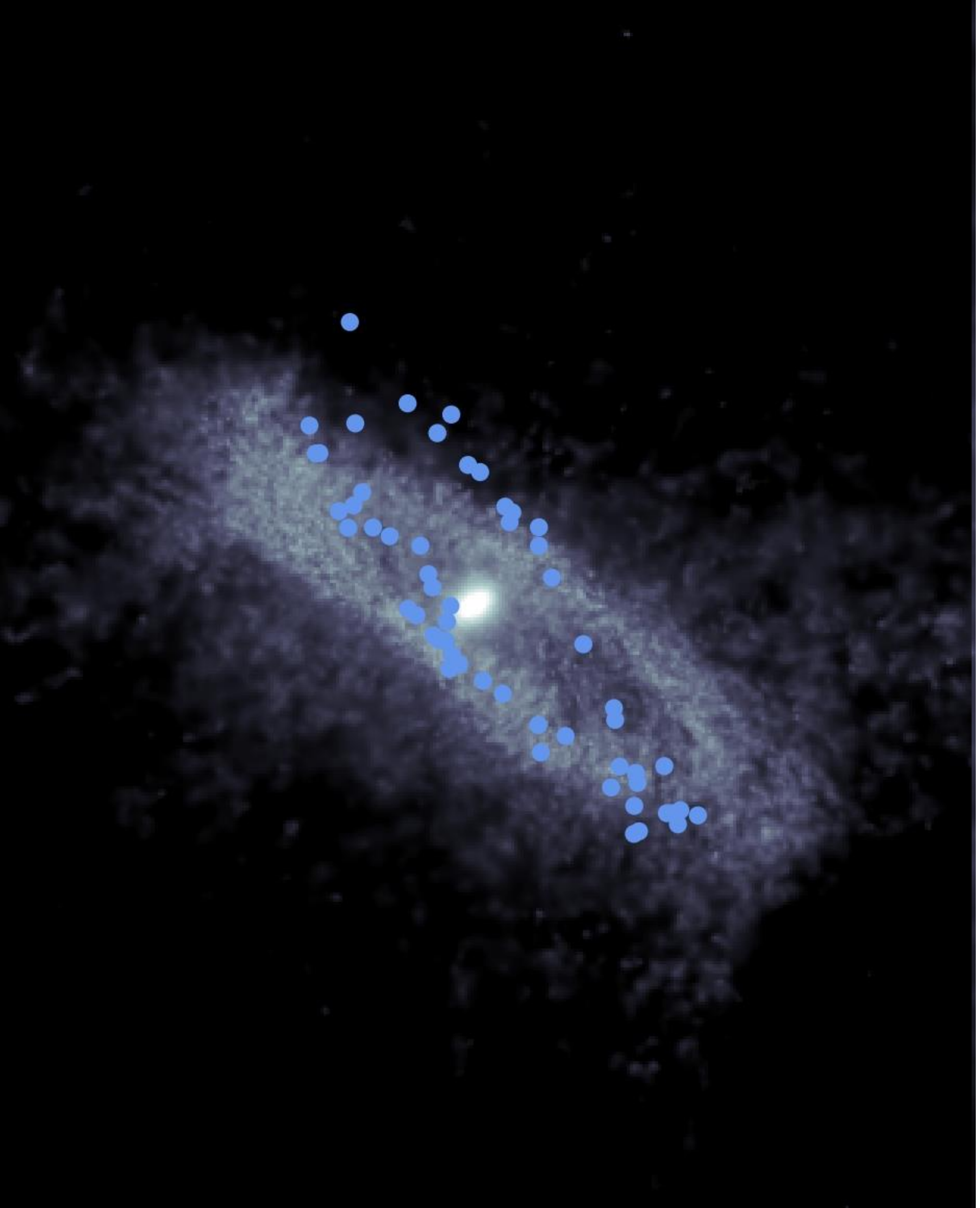

The GigaEris Simulation:

Stellar clusters in Milky Way-sized galaxies at z>4

MODEST-24: Exploring Dense Stellar Systems Across Cosmic Time

23rd of February 2024

Floor van Donkelaar
floor.vandonkelaar@uzh.ch

In collaboration with:
Lucio Mayer, Pedro R. Capelo, Tomas Tamfal, Thomas R. Quinn & Piero Madau

University of Zurich UZH

GigaEris

First billion SPH particles "zoom-in" cosmological simulation of a MW-like galaxy

No major merger at z > 4, selected in 90 cMpc volume at z=0.

Constructed to reach down z=0, with a lagrangian volume of ~2 Mpc on a side. Currently at **z=4.4**

Run using **ChaNGa**

- N-body smoothed-particle hydrodynamics code
  - hydro resolution of a 1-10 pc
  - Baryon resolution 798 $M_{\odot}$ (43 pc softening)
  - $m_{gas} = 1099\ M_{\odot}$, $n_{gas} = 1.1 \times 10^7$
  - $m_{star} = 798\ M_{\odot}$, $n_{star} = 3.9 \times 10^7$

Tamfal et al. 2022

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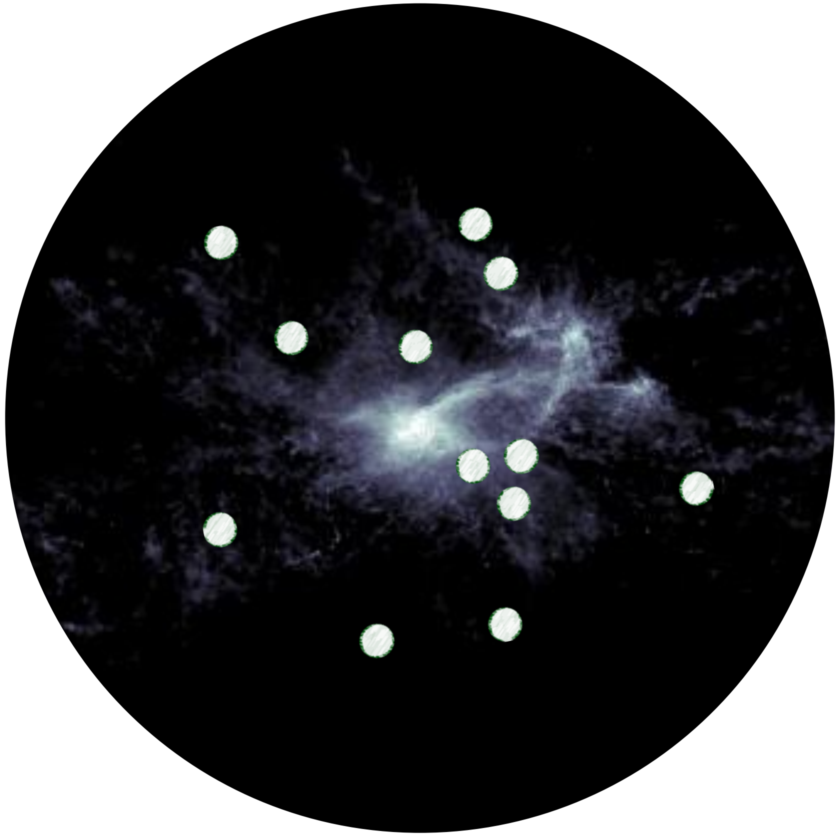
We can the constrain the lower mass GC using multiple particles!

Tamfal et al. 2022

AMIGA Halo Finder

- Minimum 64 baryonic particles
- 0 substructures within halos
- Bound



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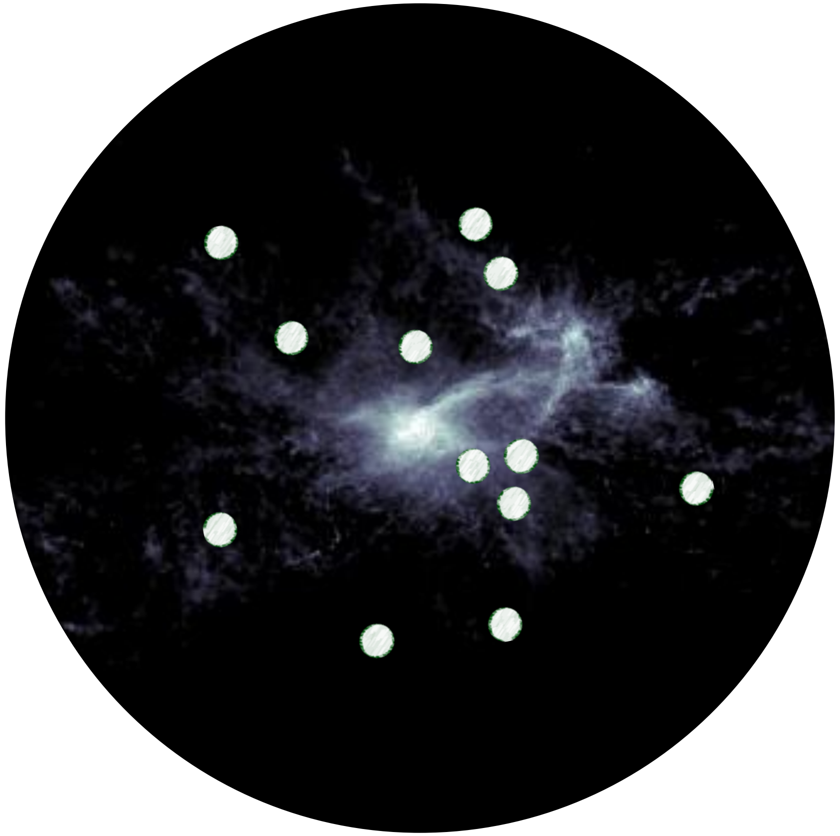

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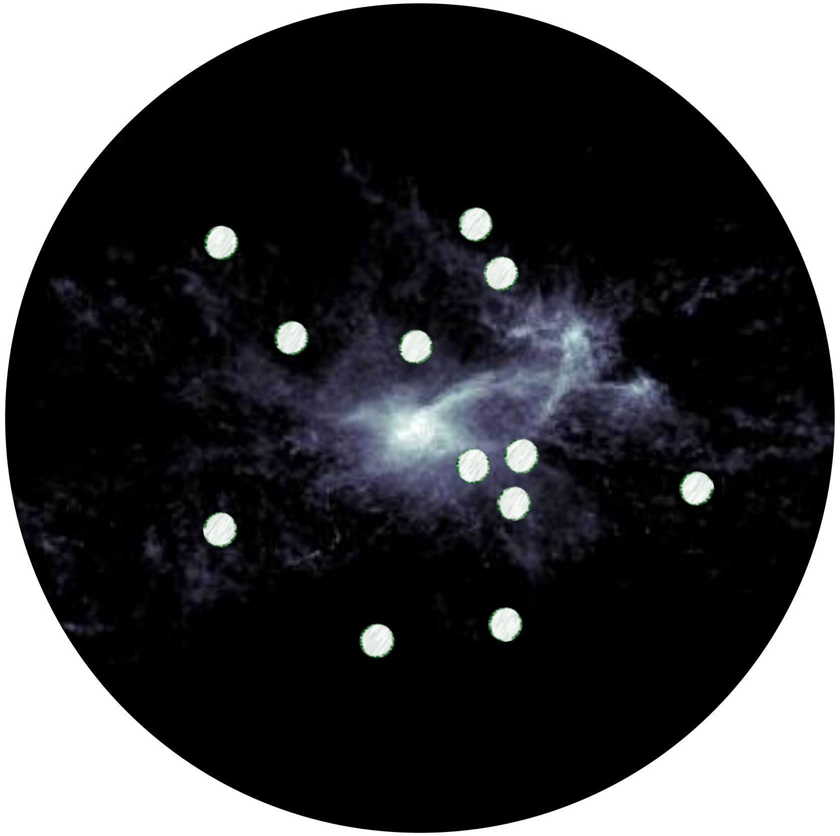
Globular Clusters

arXiv:2210.04915



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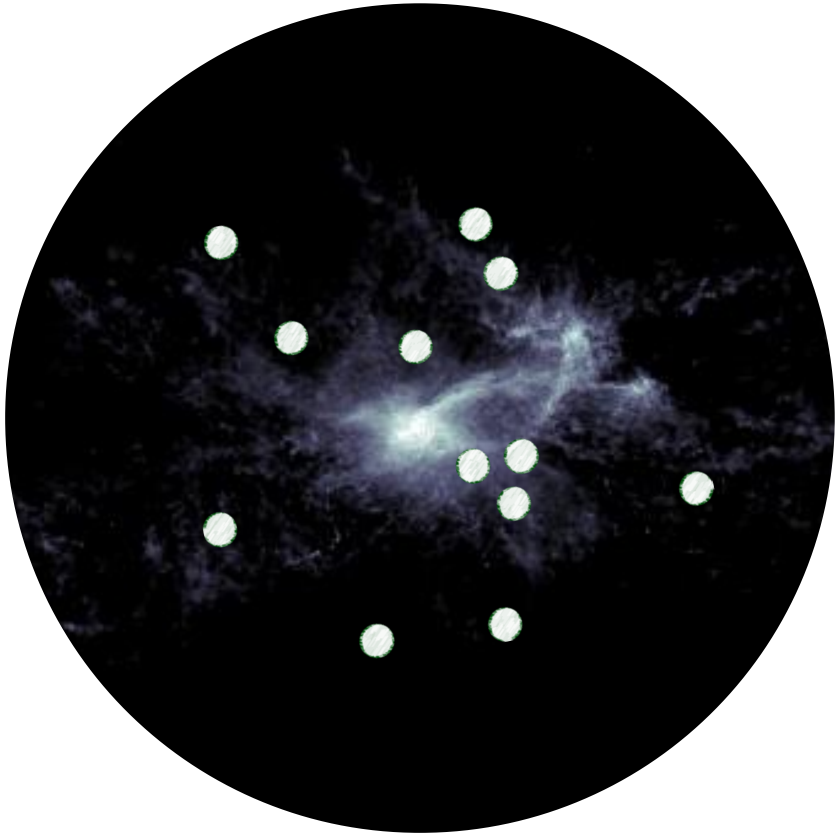

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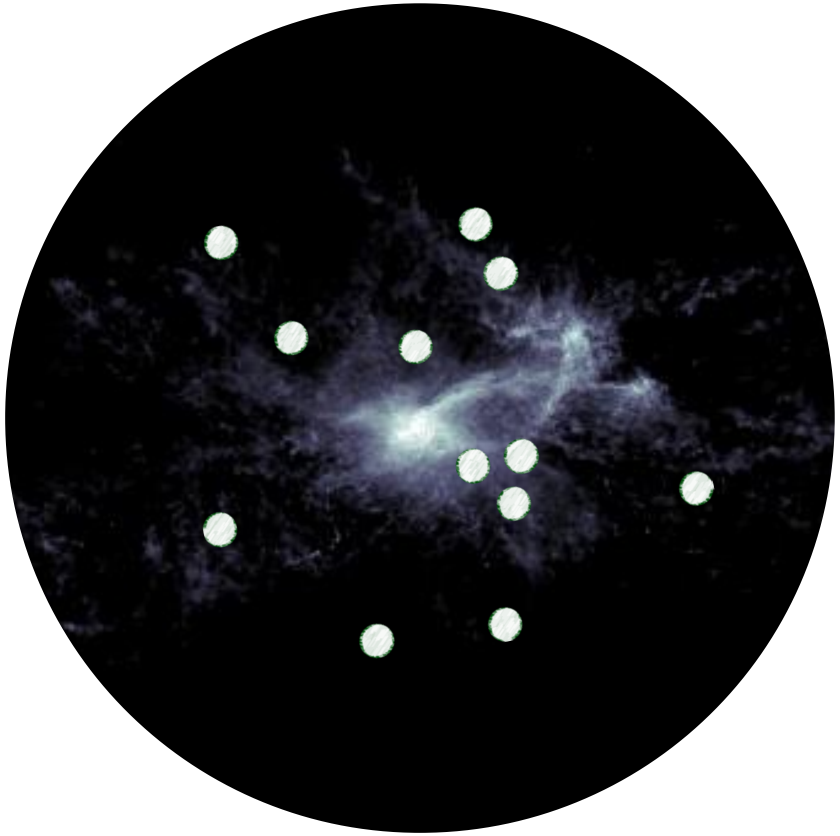
Wandering IMBHs arXiv:2404.15404



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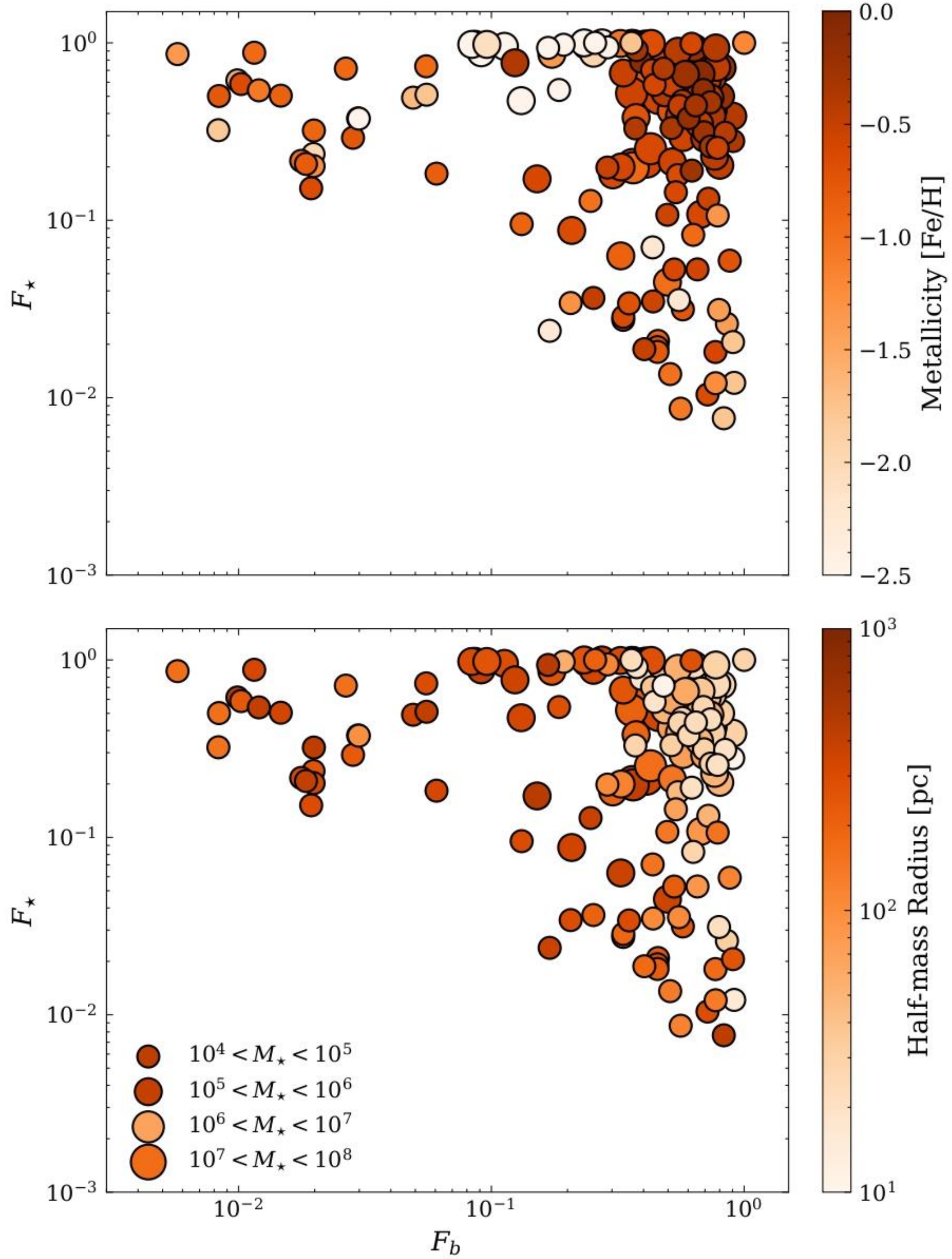
Globular Clusters — arXiv:2210.04915

Nuclear Star Cluster — arXiv:2303.12828

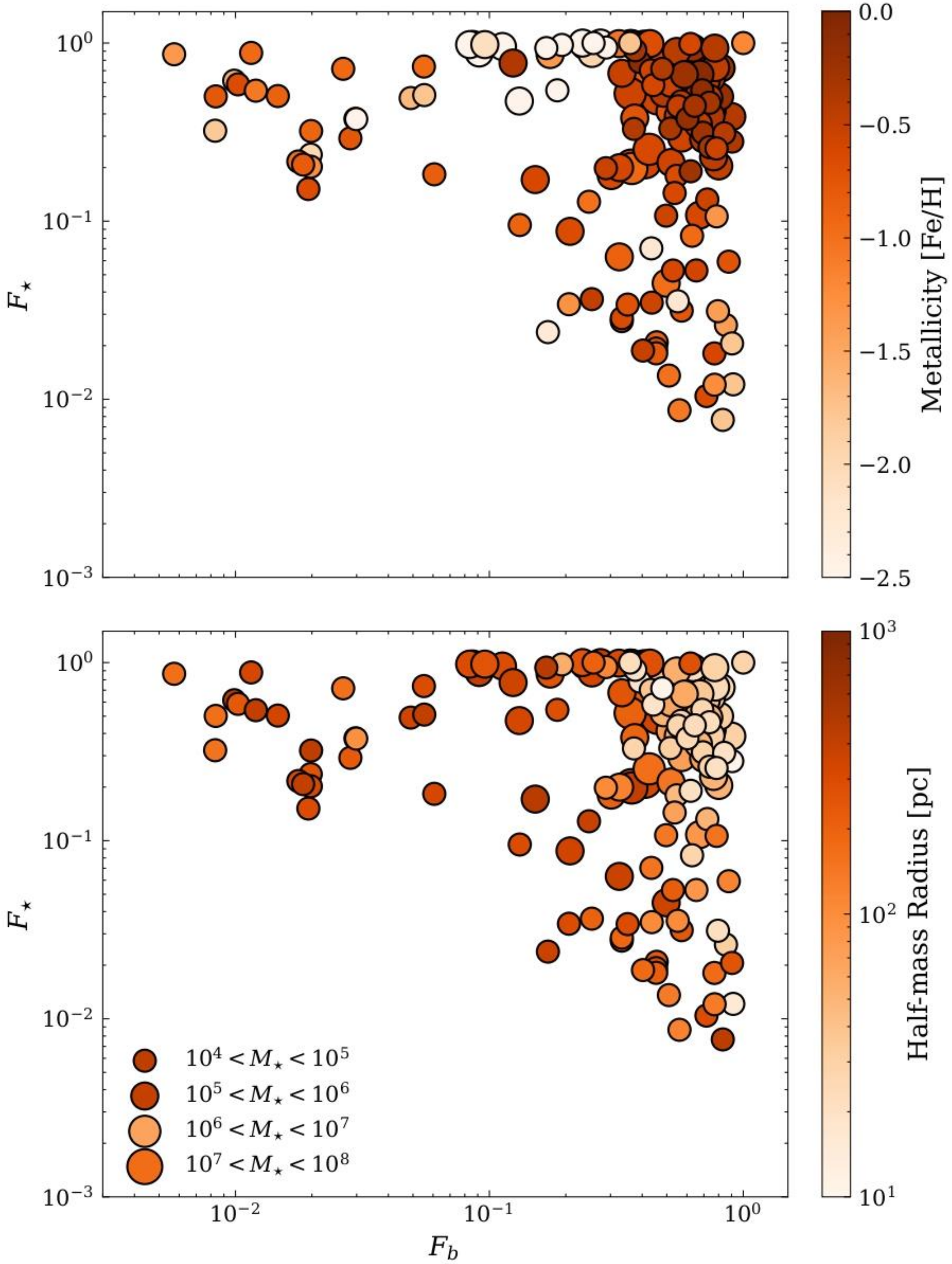
Wandering IMBHs — arXiv.2404.15404

Globular Clusters

arXiv.2210.04915



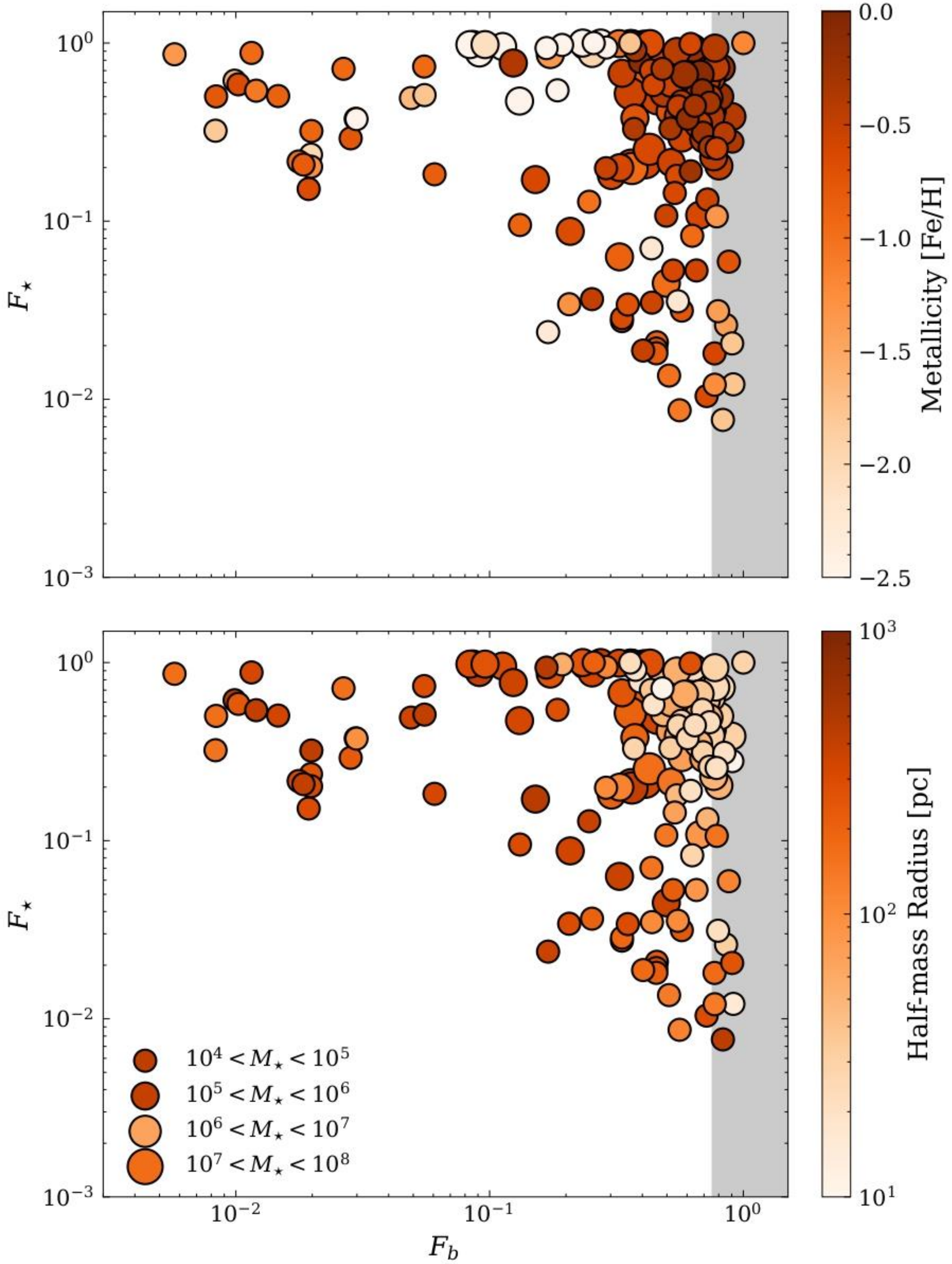
What can we classify as a proto-GC?



What can we classify as a proto-GC?

- Gravitationally bound

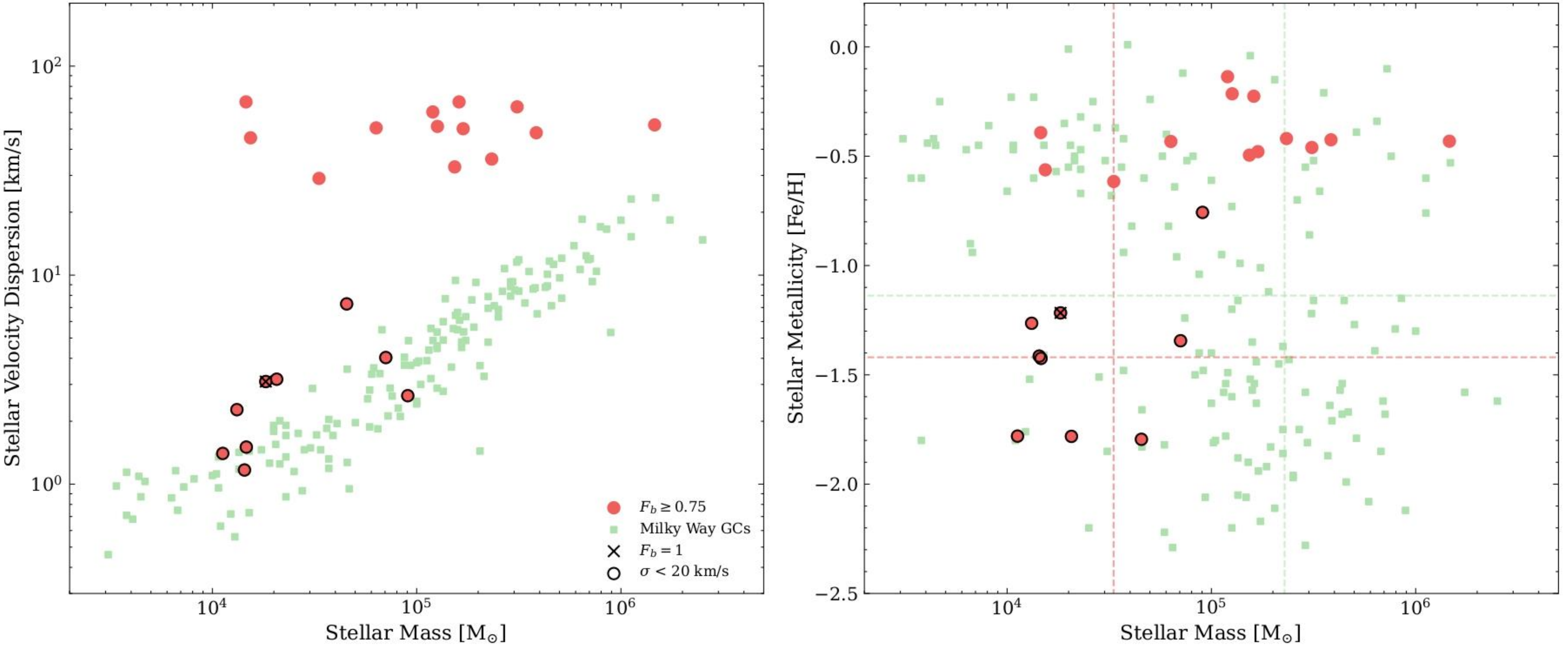
N = 174



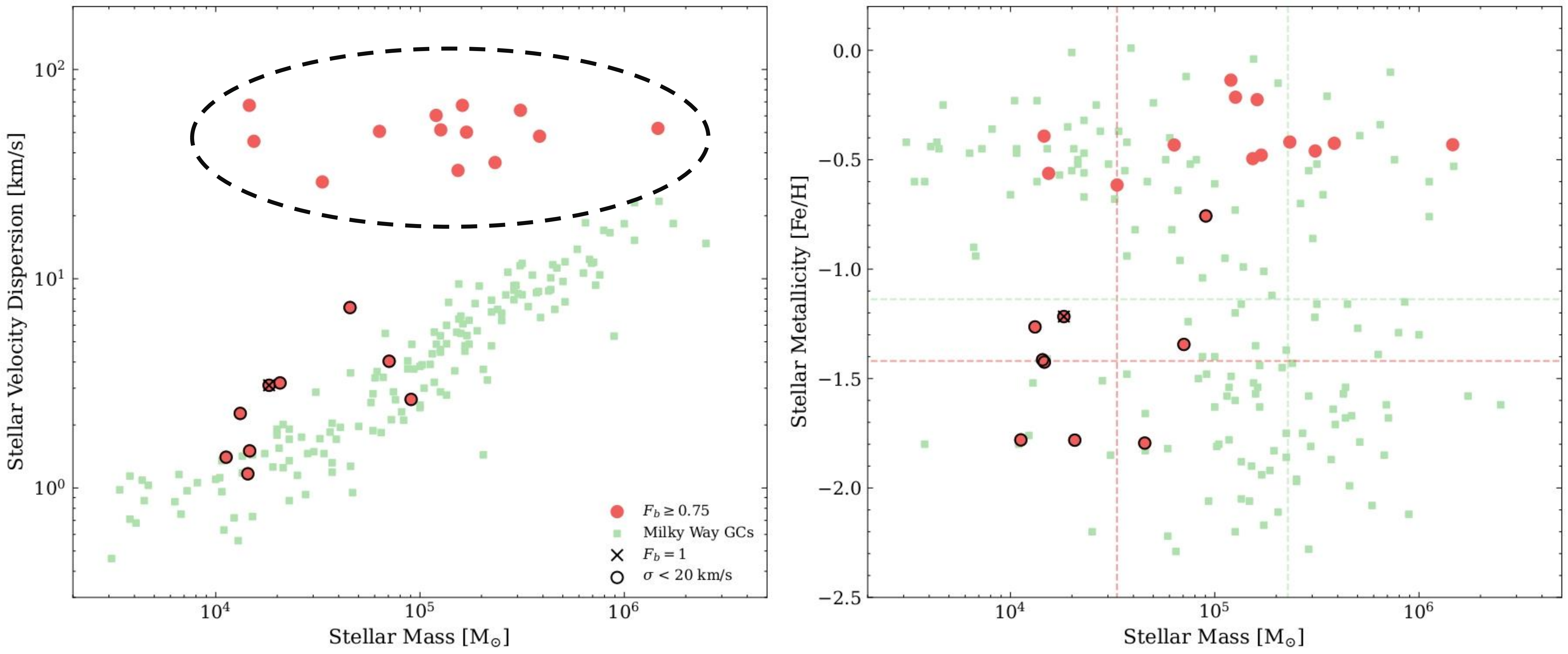
What can we classify as a proto-GC?

- Gravitationally bound
- Baryon dominated, $F_b \geq 0.75$

N = 22



McLaughlin & van der Marel (2005)



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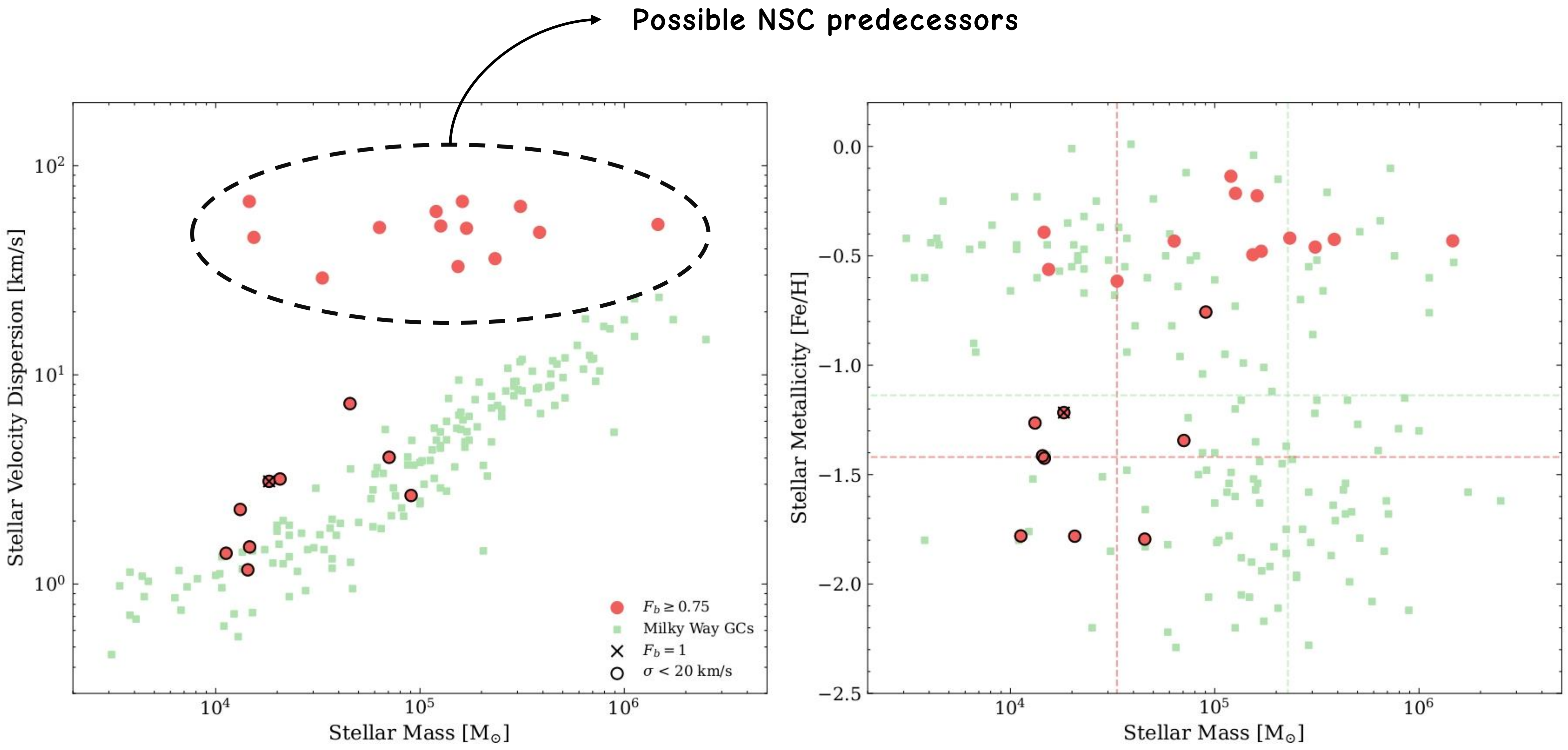
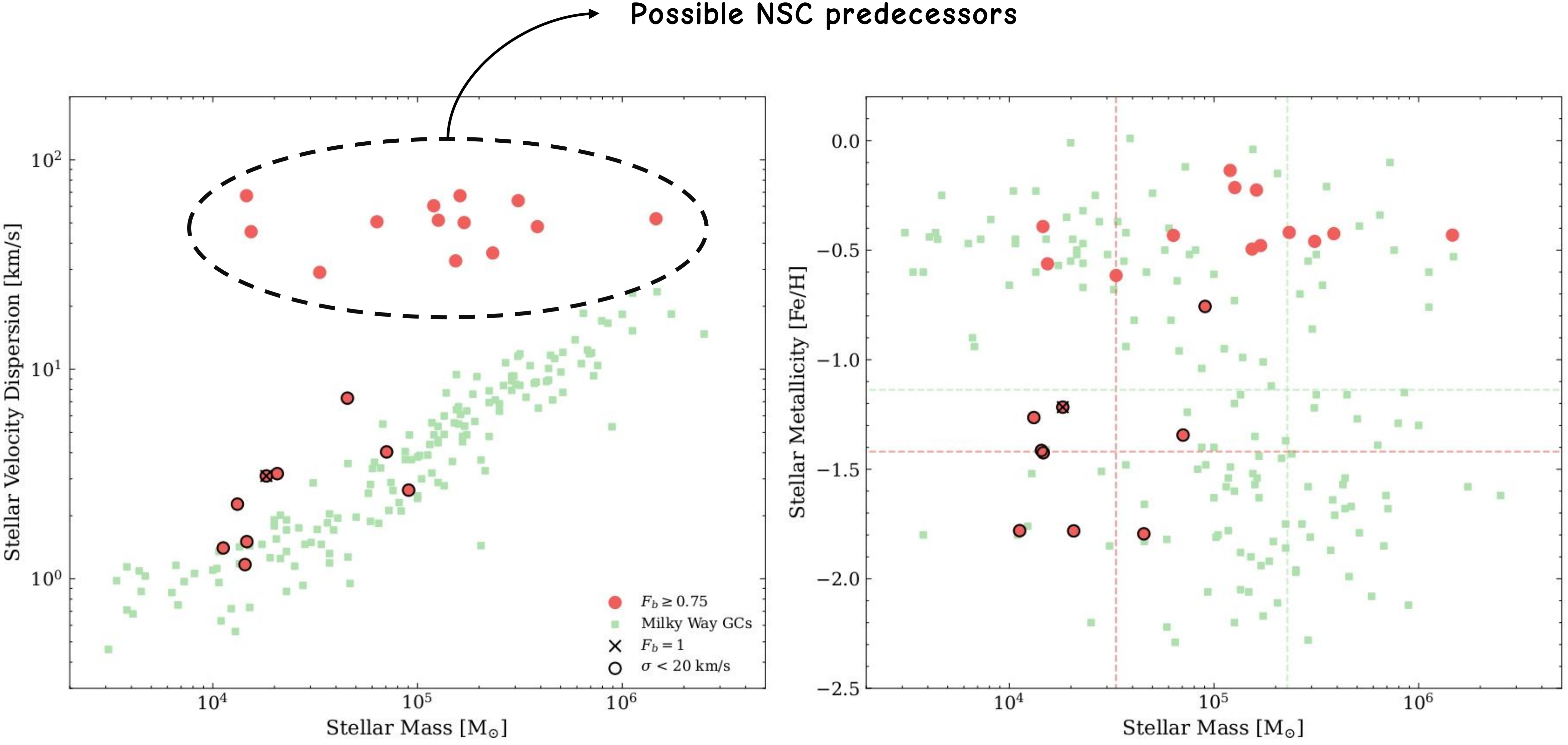


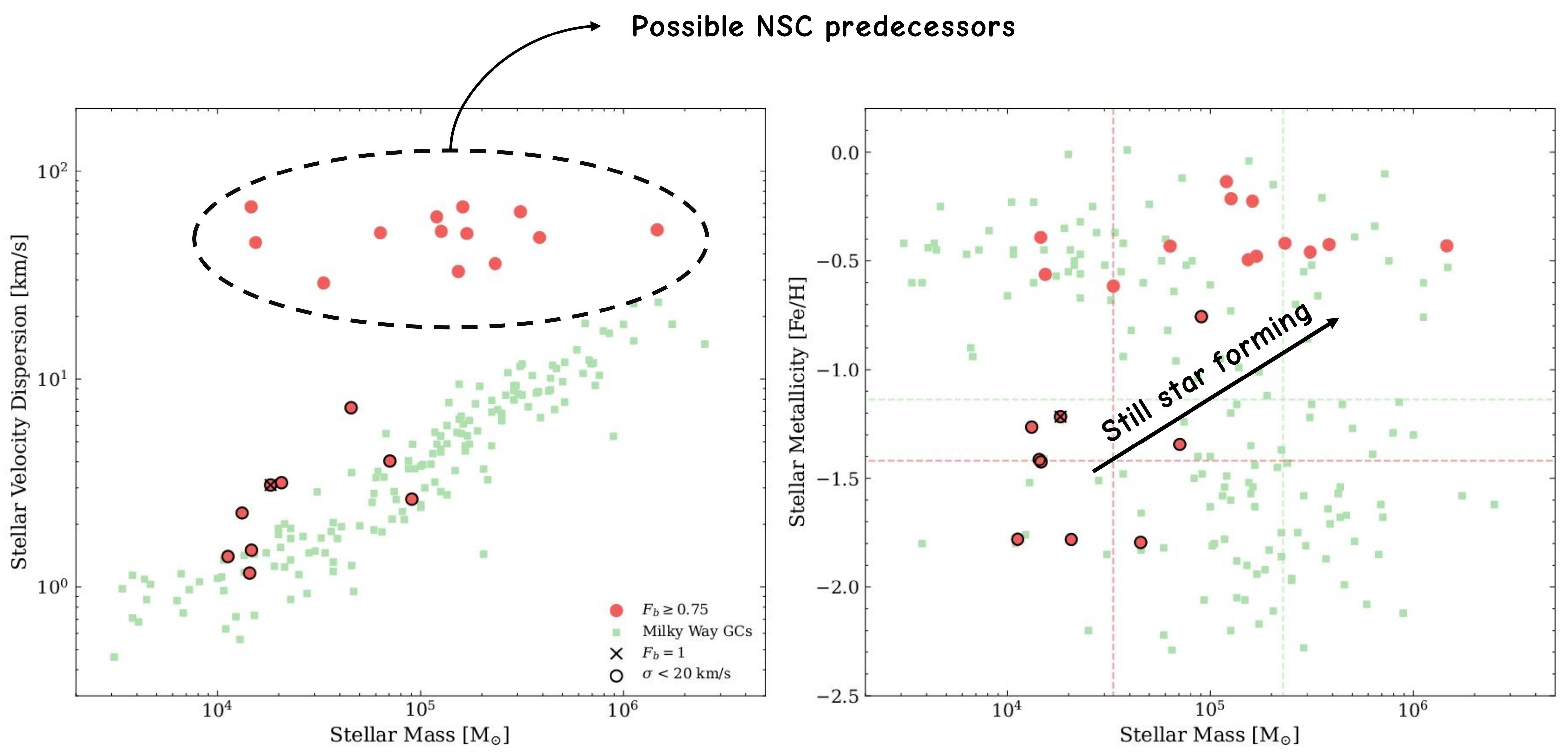
McLaughlin & van der Marel (2005)

Possible NSC predecessors



N = 9

McLaughlin & van der Marel (2005)



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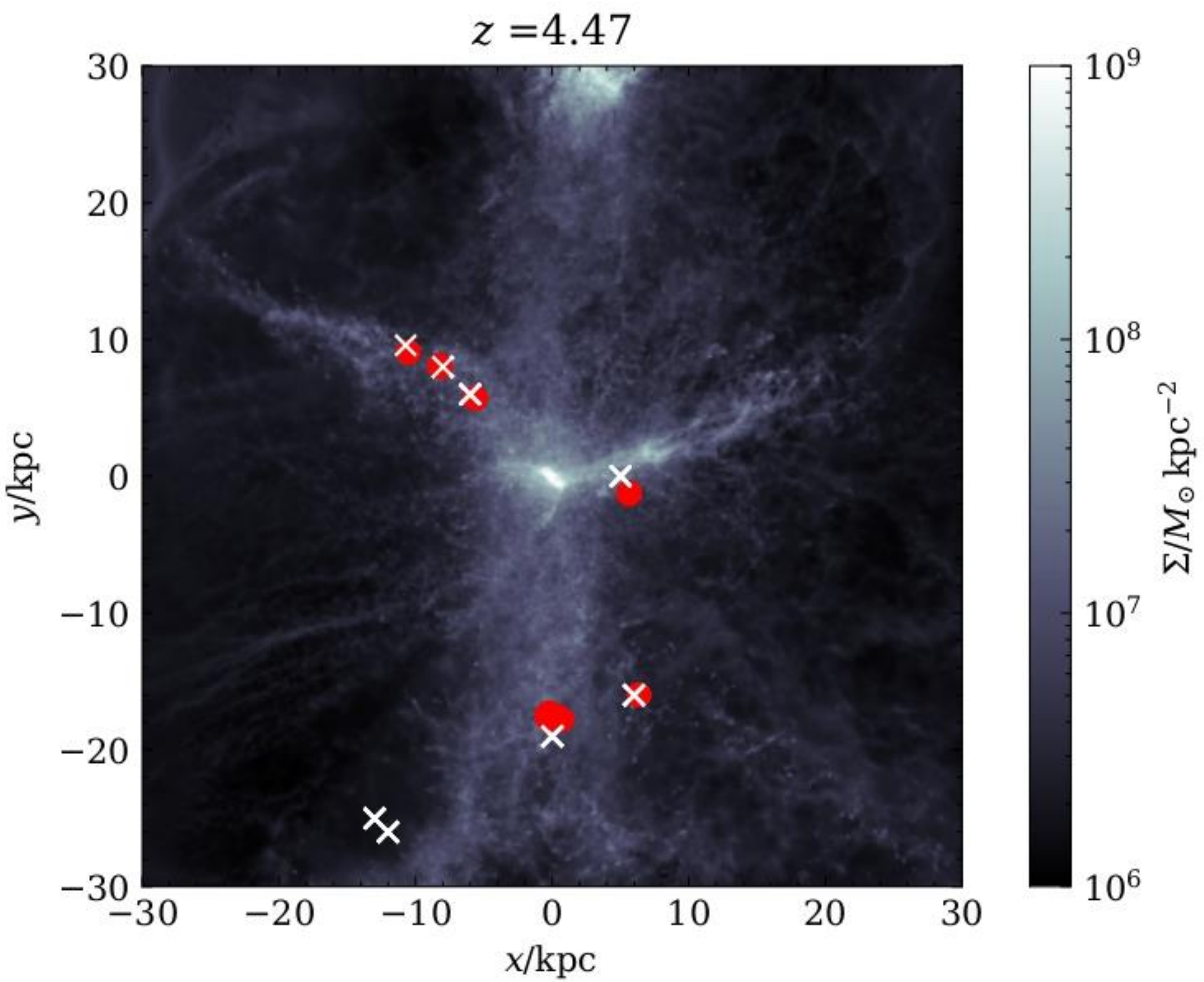
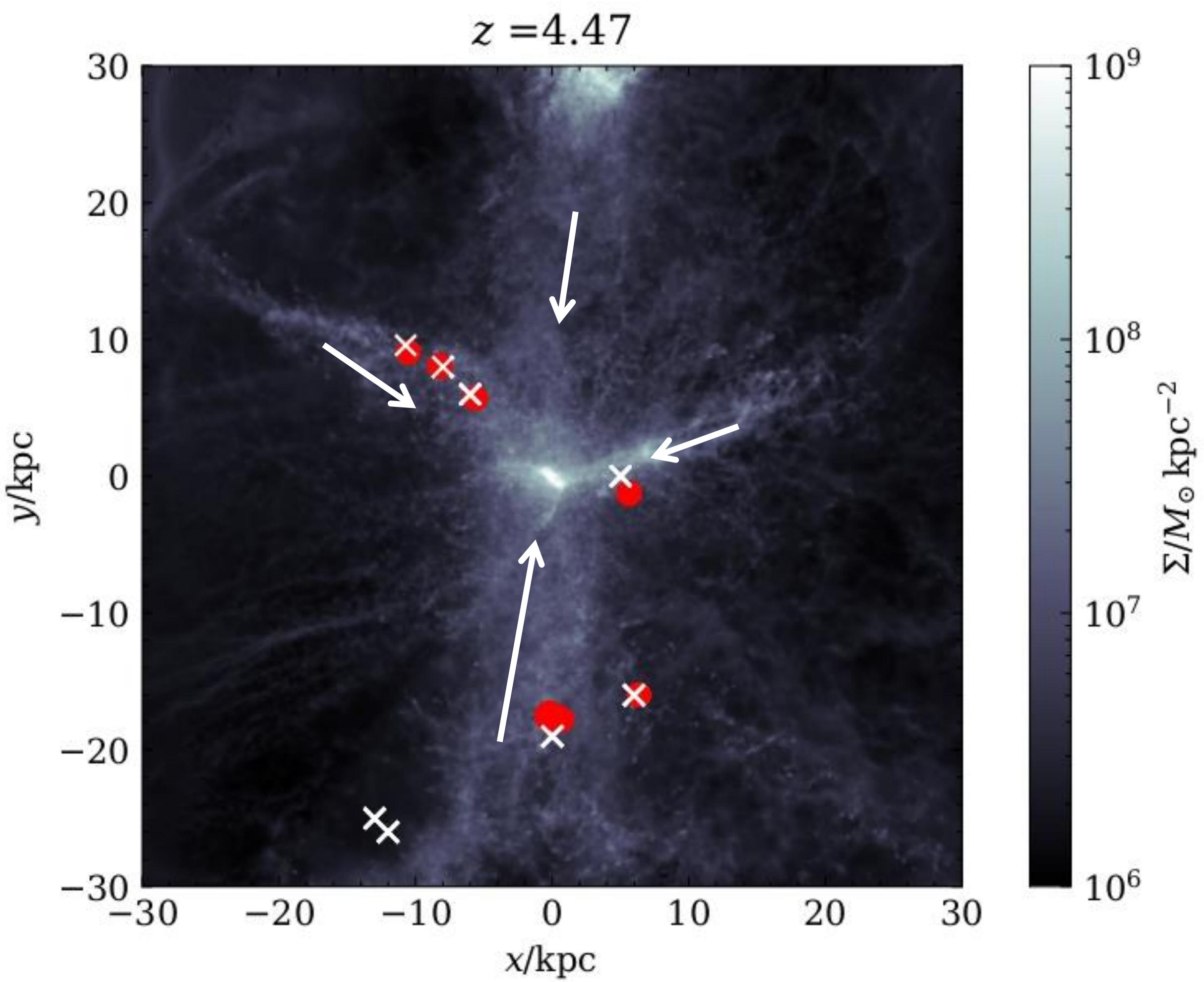


8 of these objects form
between z = 4.64 and z = 4.47



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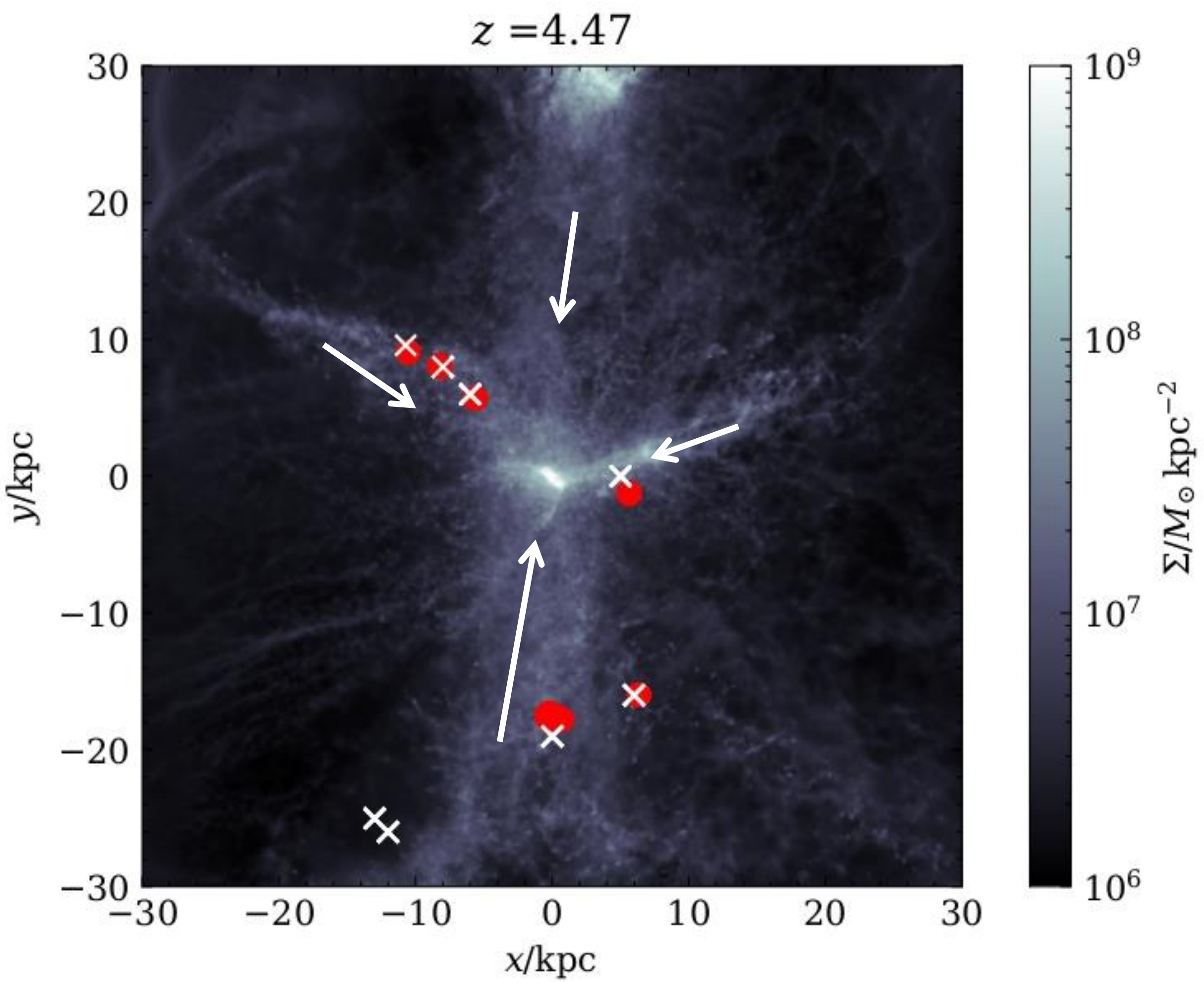

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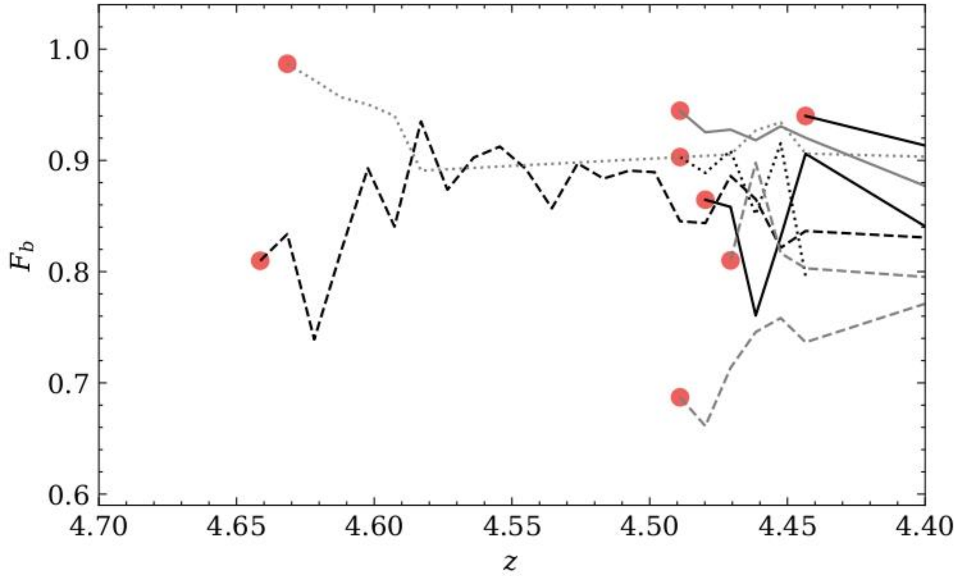
Gas inflow through filaments



$$F_b = \frac{(M_\star + M_{gas})}{M_{total}}$$

8 of these objects form between z = 4.64 and z = 4.47

↓

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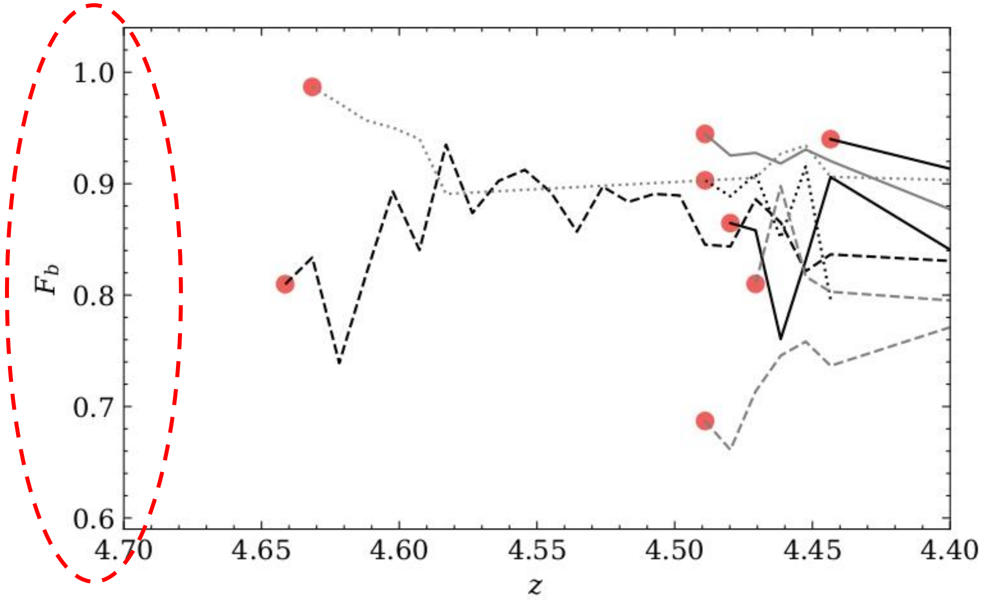

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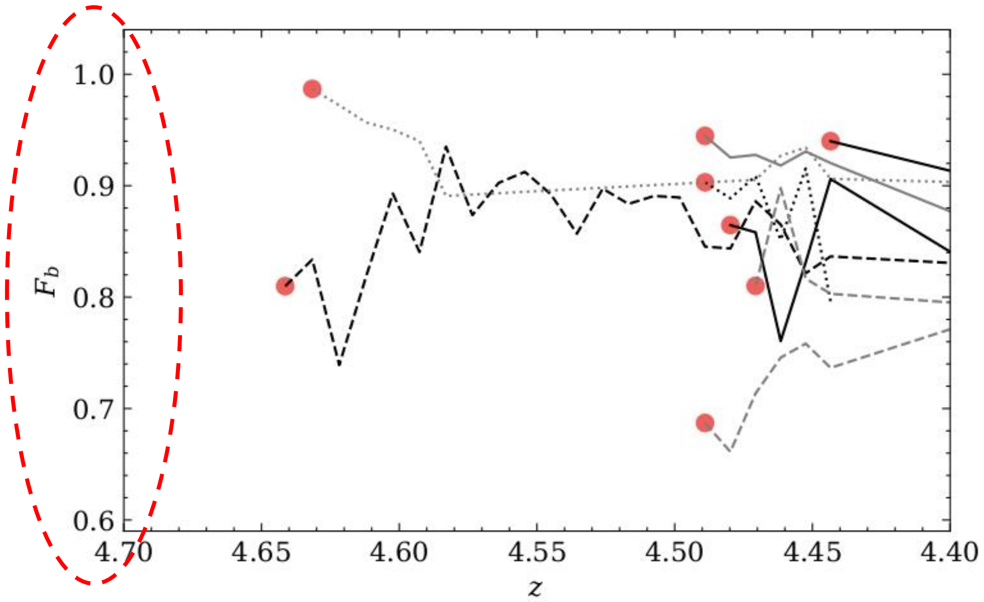
8 of these objects form between z = 4.64 and z = 4.47

Gas inflow through filaments

Formed high, stays high



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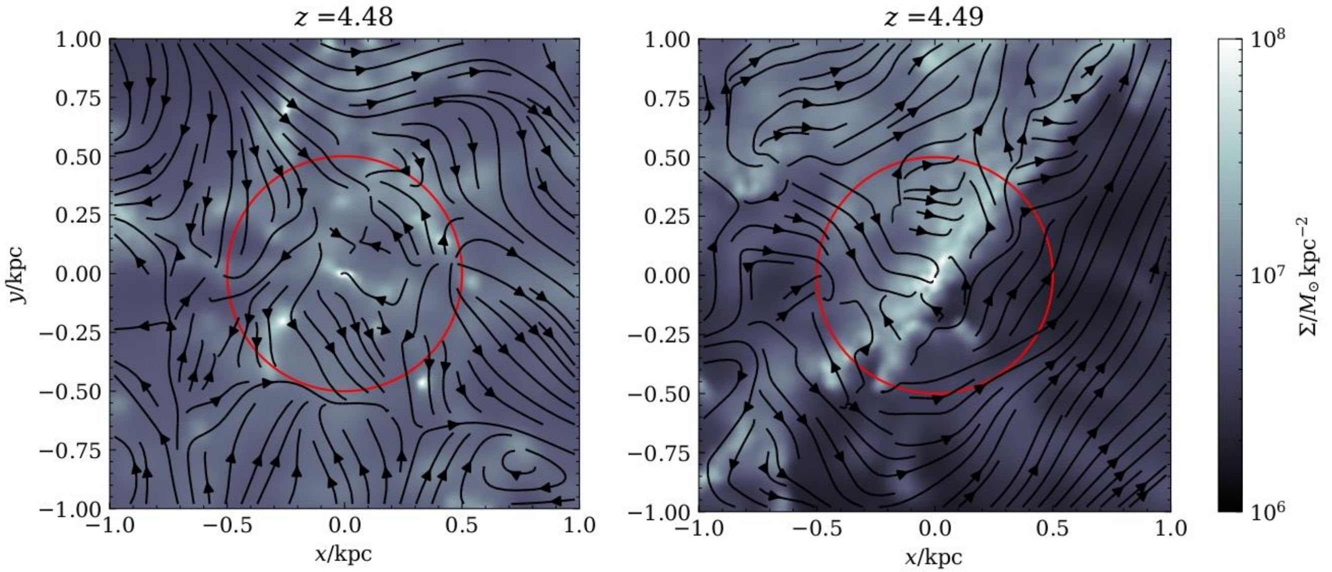
Gas inflow through filaments

On smaller scale:



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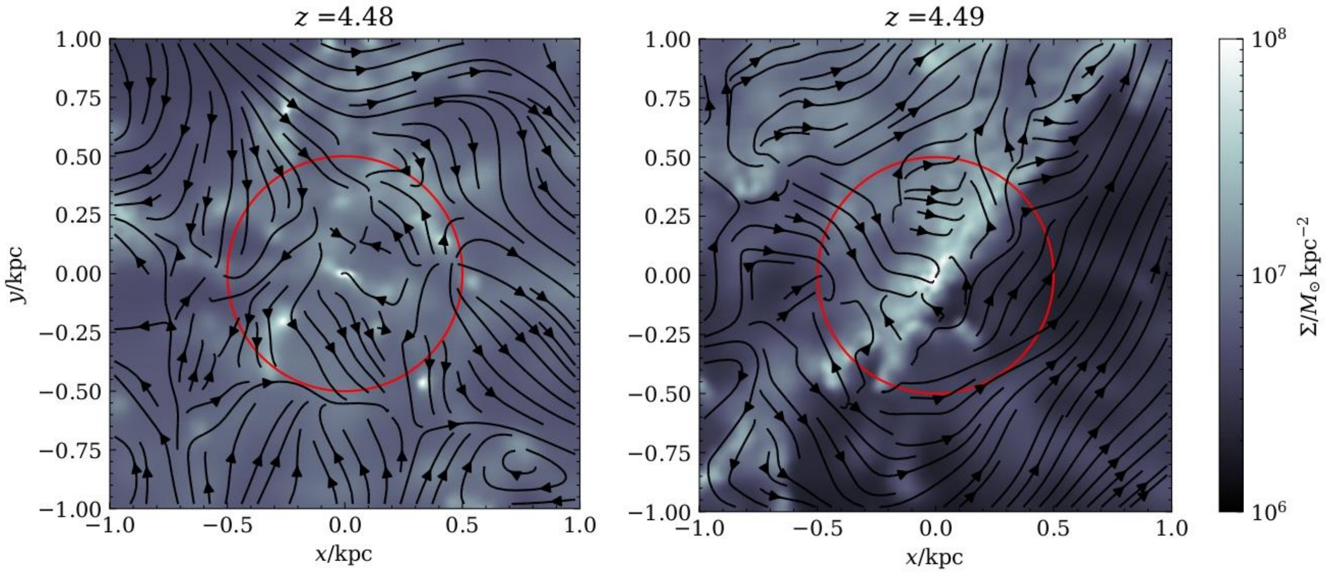
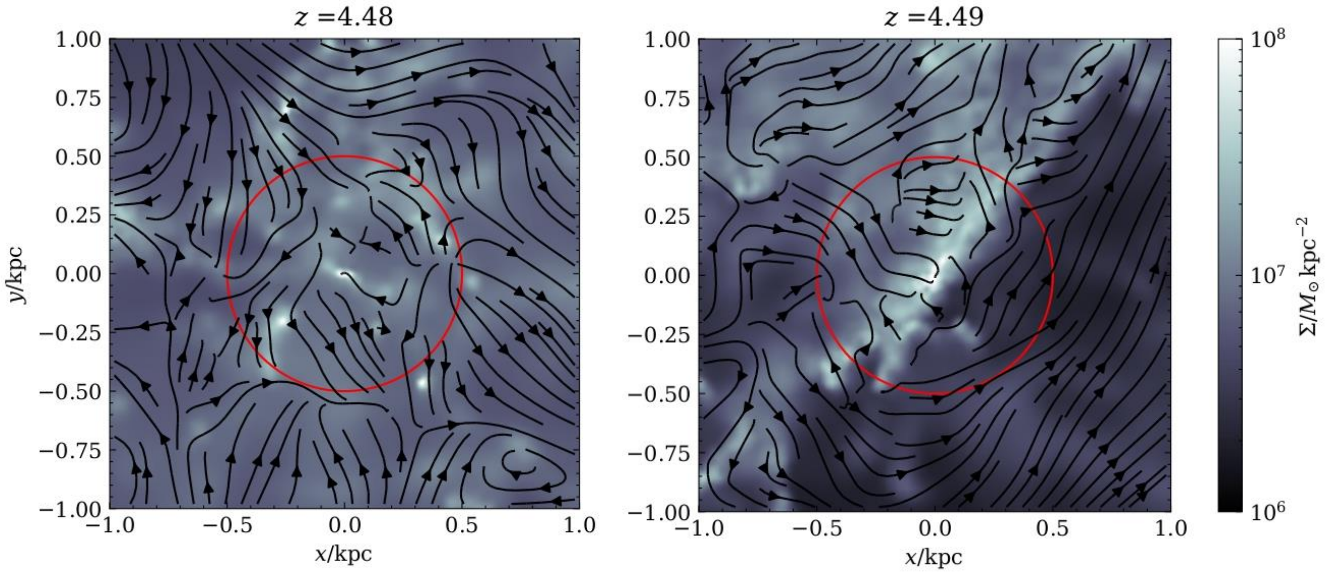


- Surrounded by gas
- No specific inflowing filaments visible

On smaller scale:



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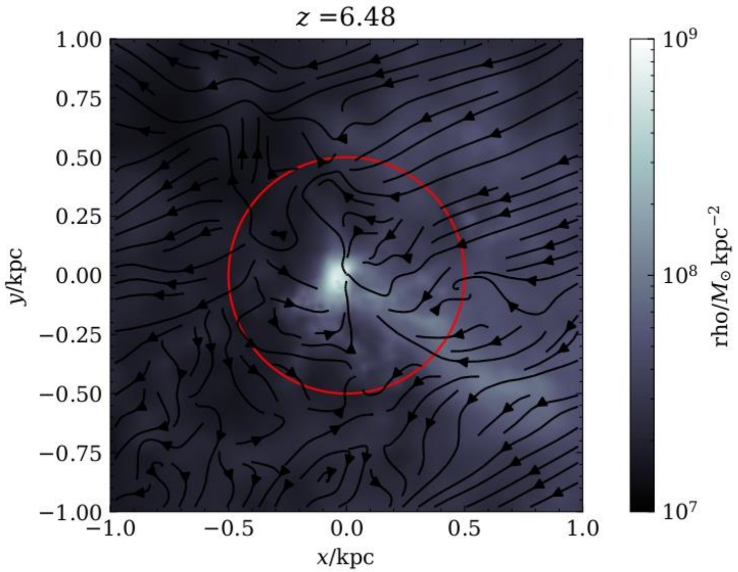

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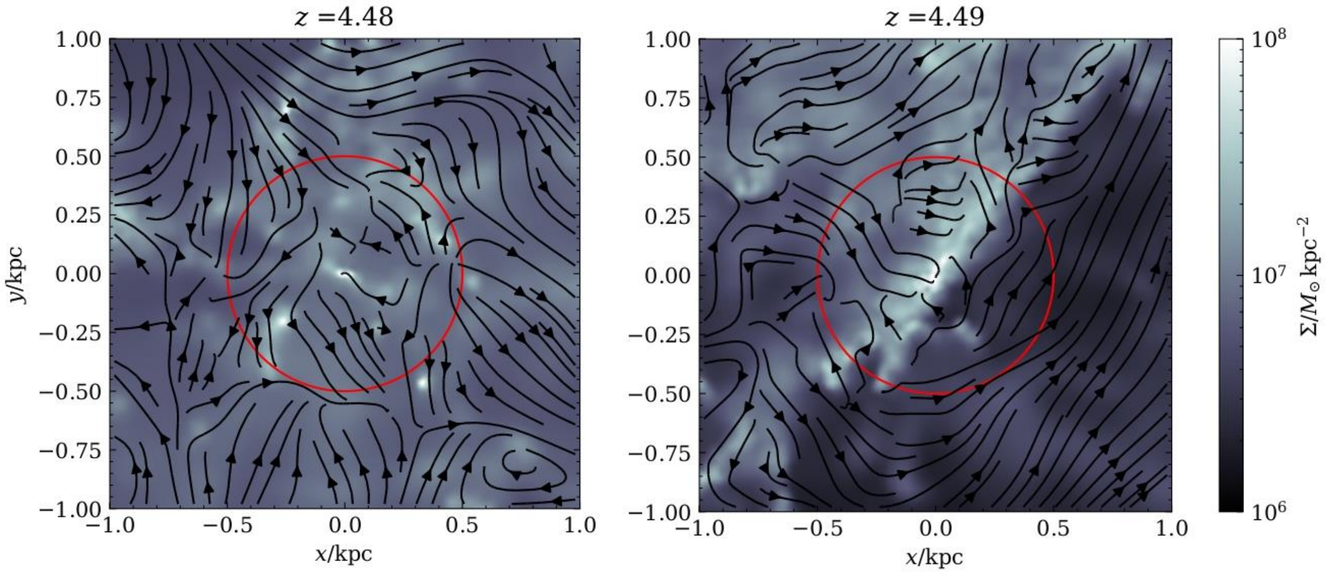

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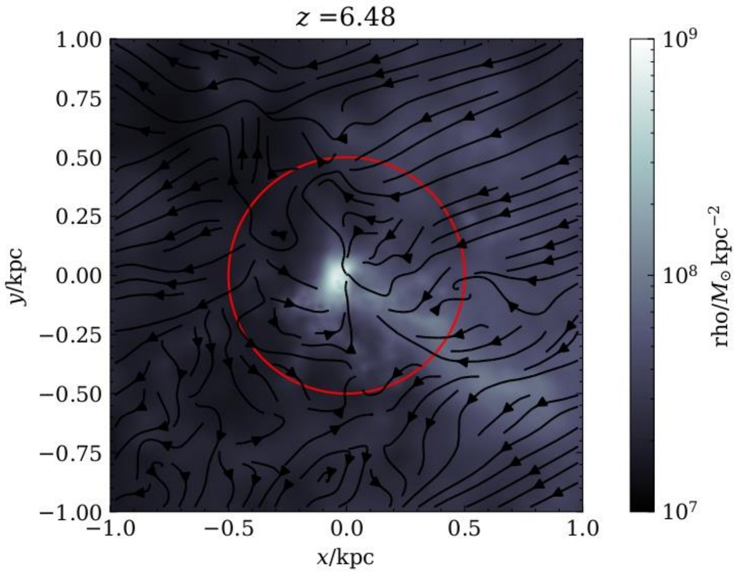
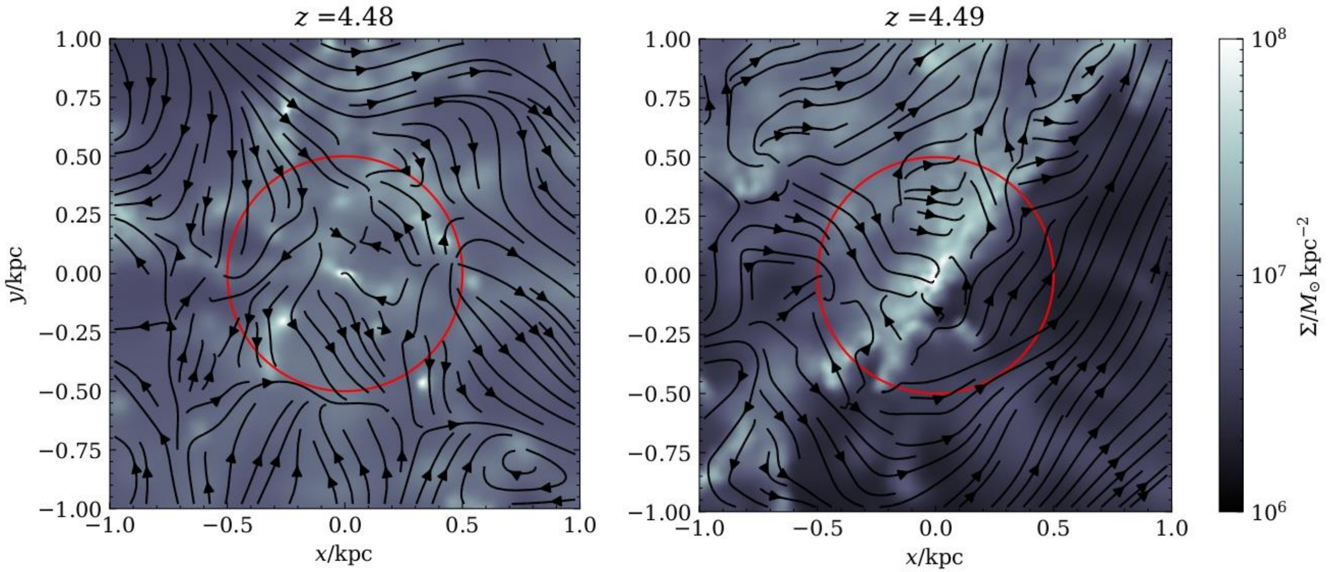


- Formed at higher z
- Isolated
- Inflowing tail of gas

On smaller scale:



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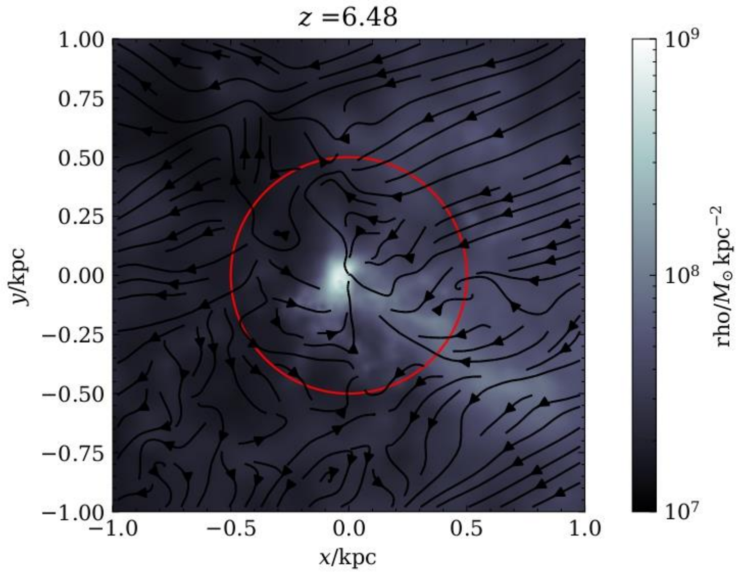
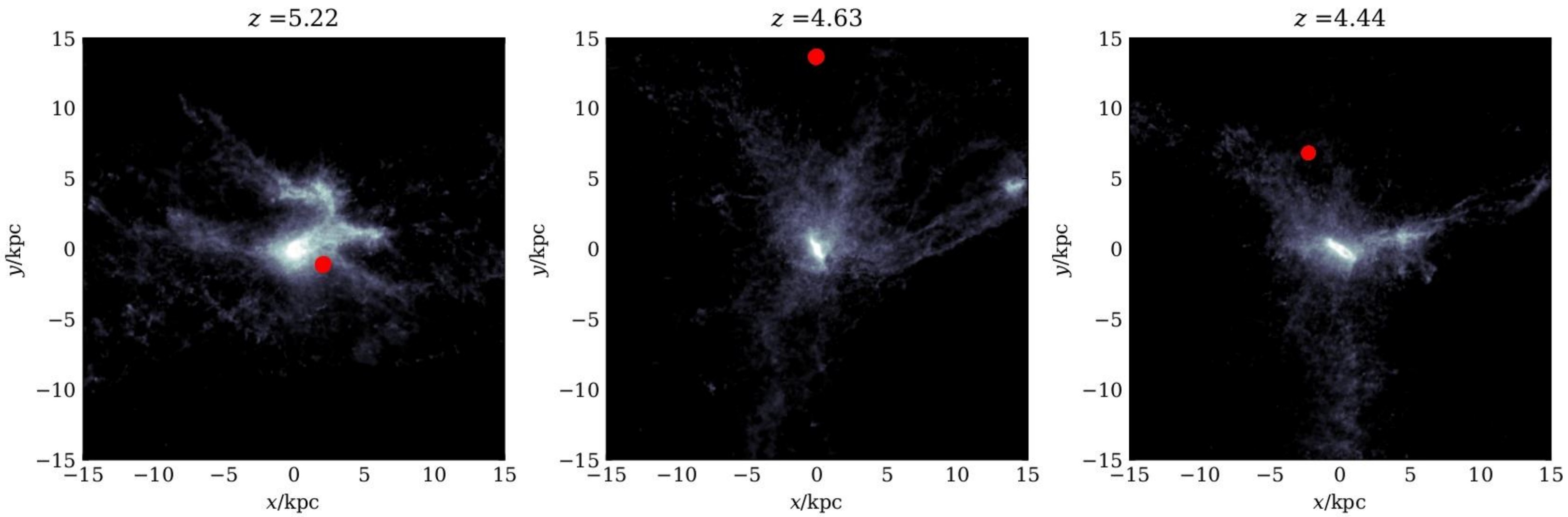


- Formed at higher z
- Isolated
- Inflowing tail of gas

The imposter

- Older
- More isolated during formation
- $F_\star = 1.00$, $F_b = 1.00$



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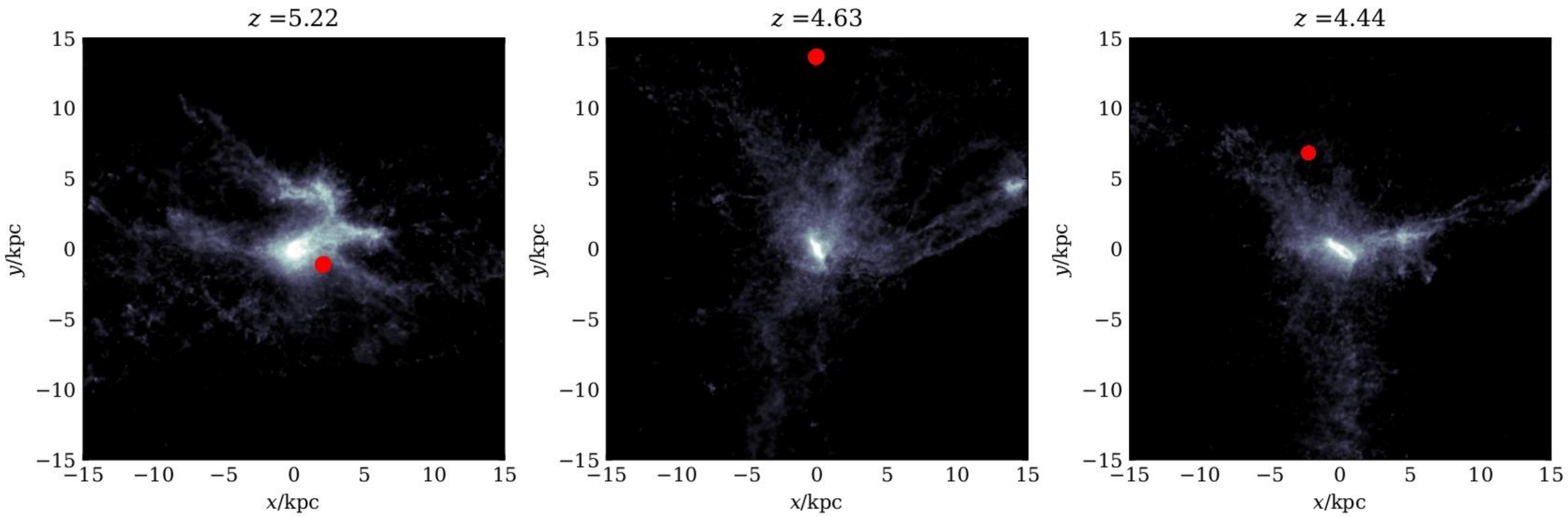

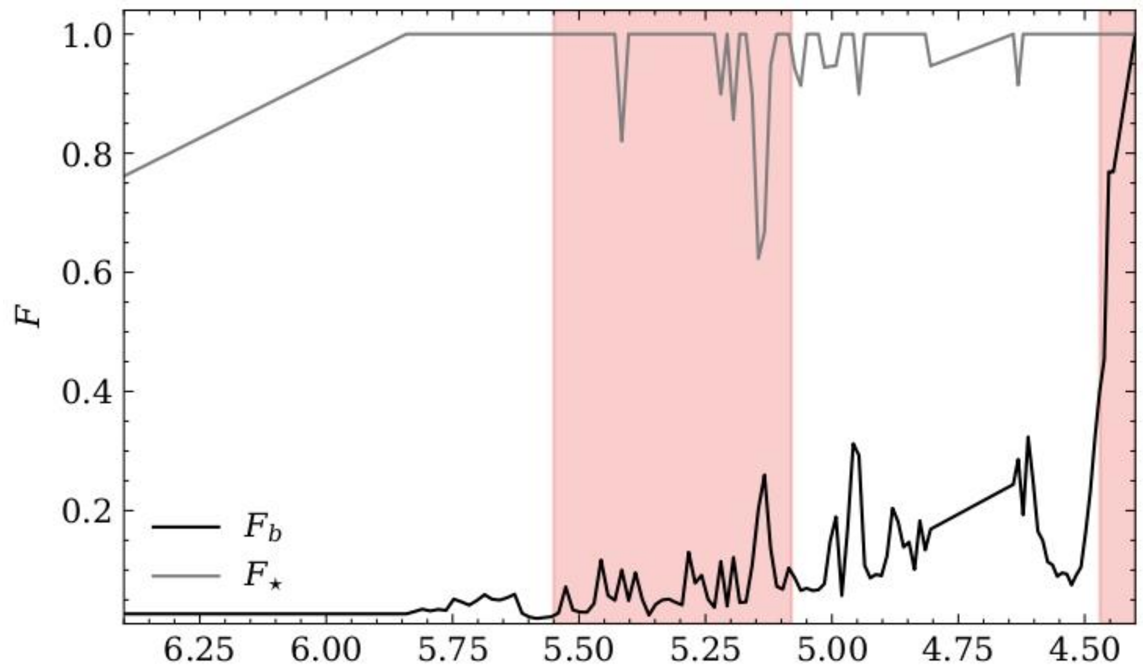

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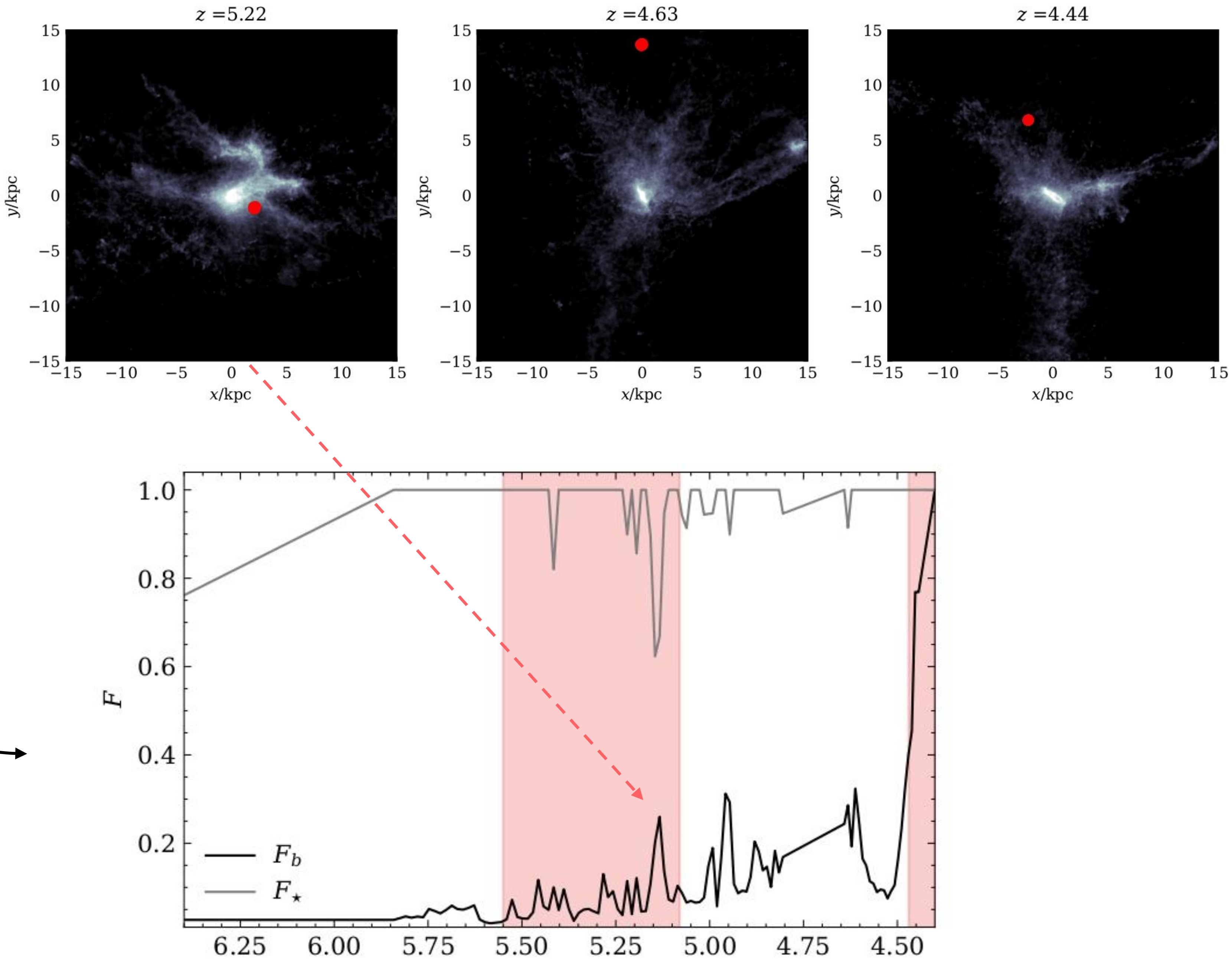

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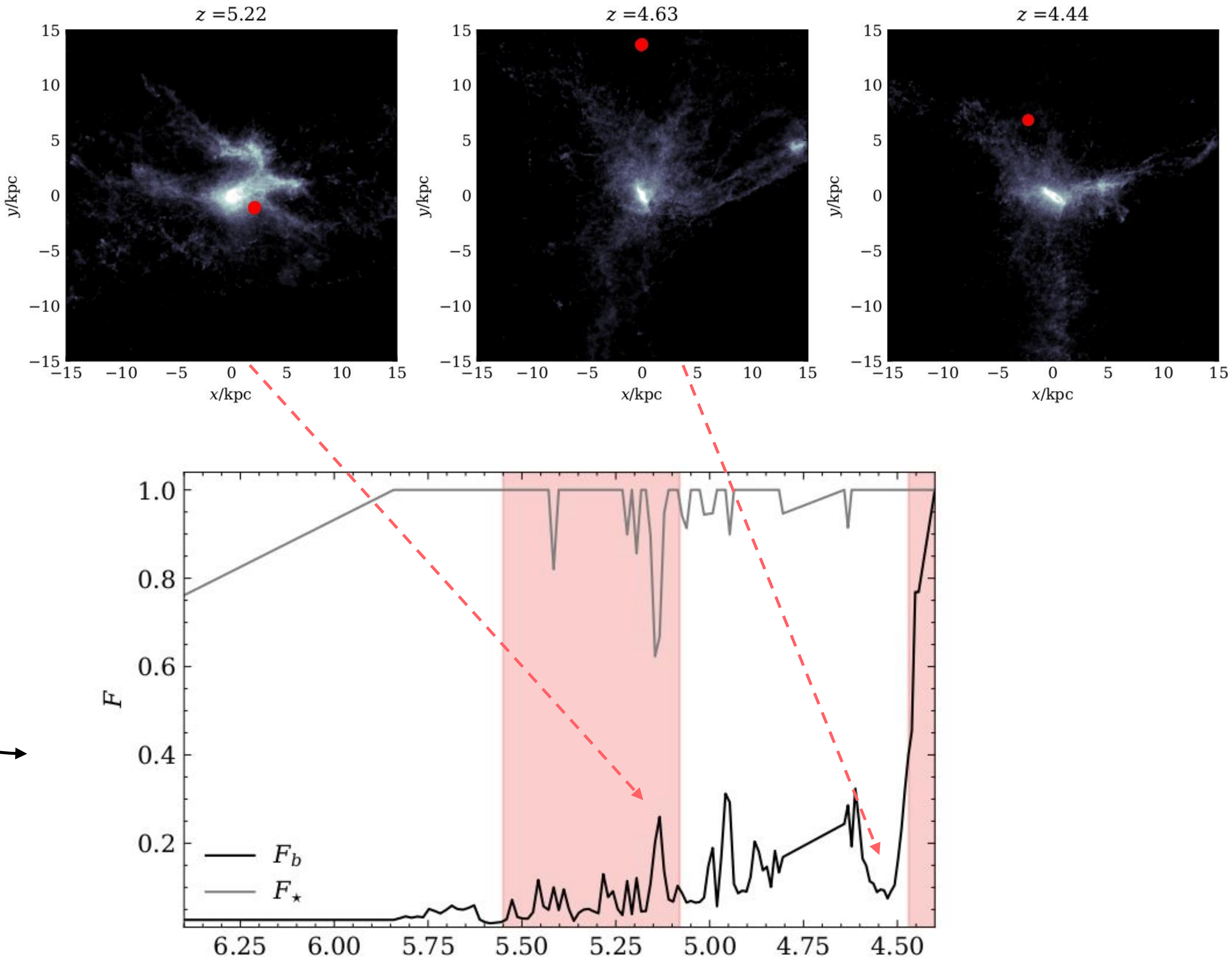

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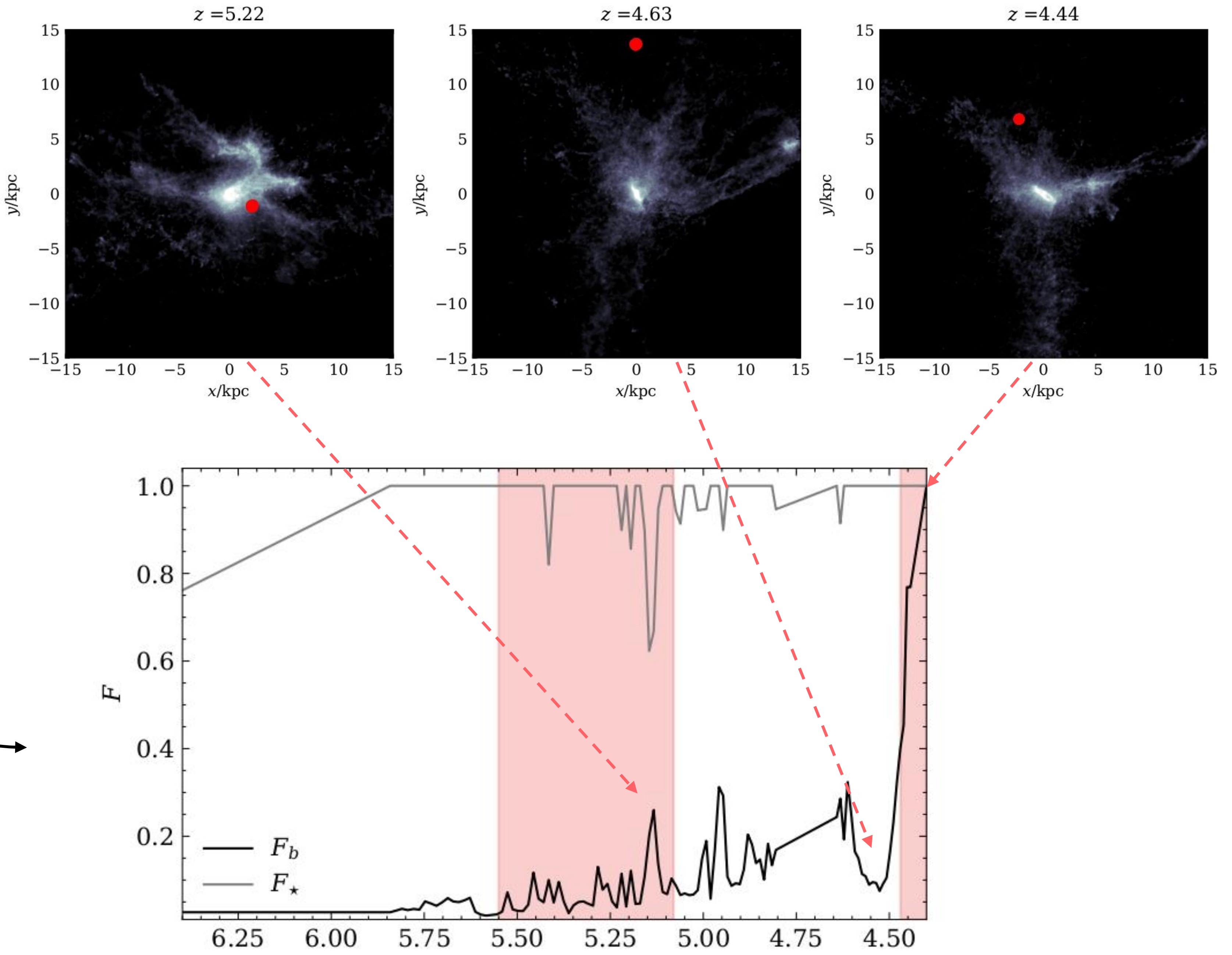
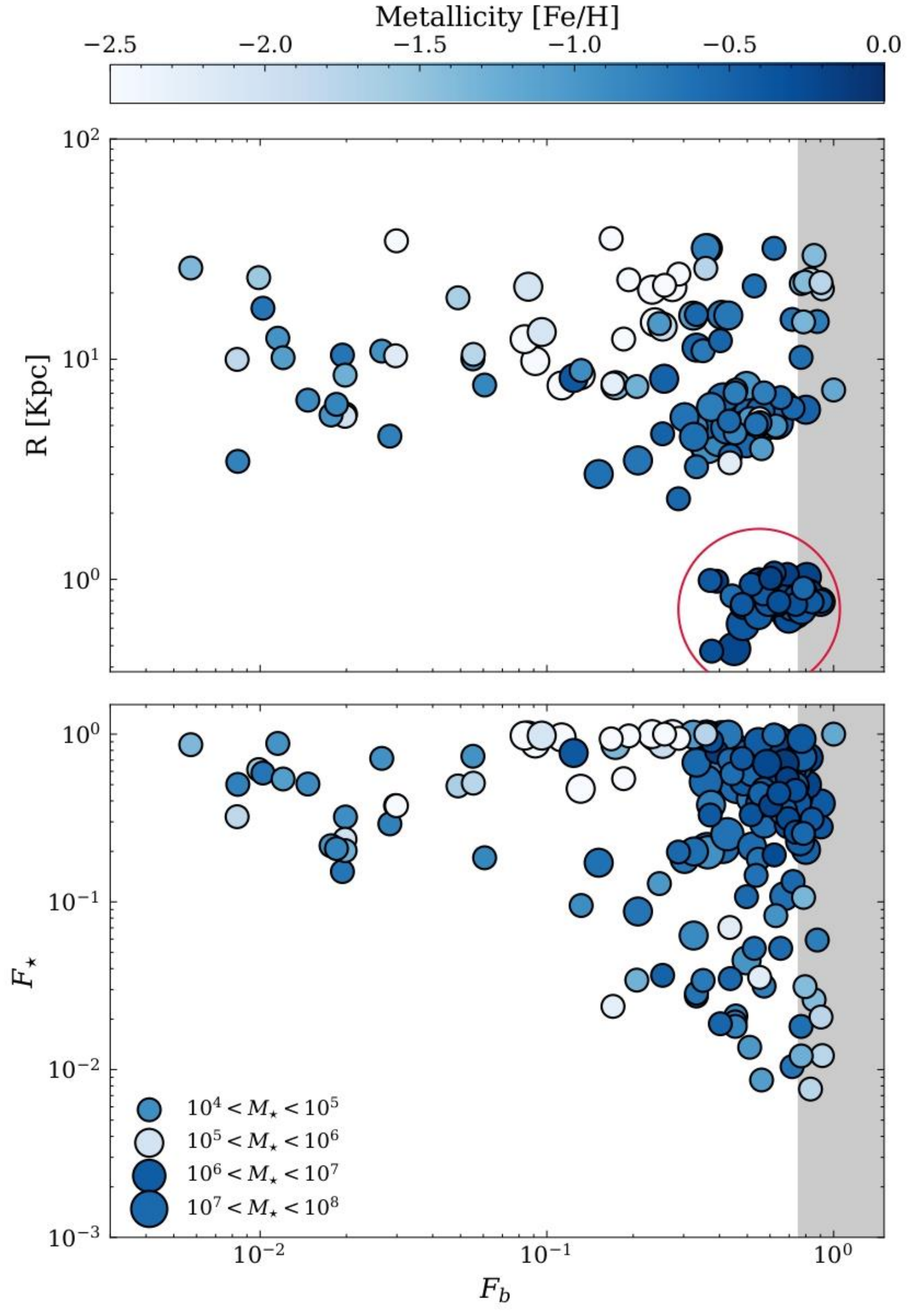
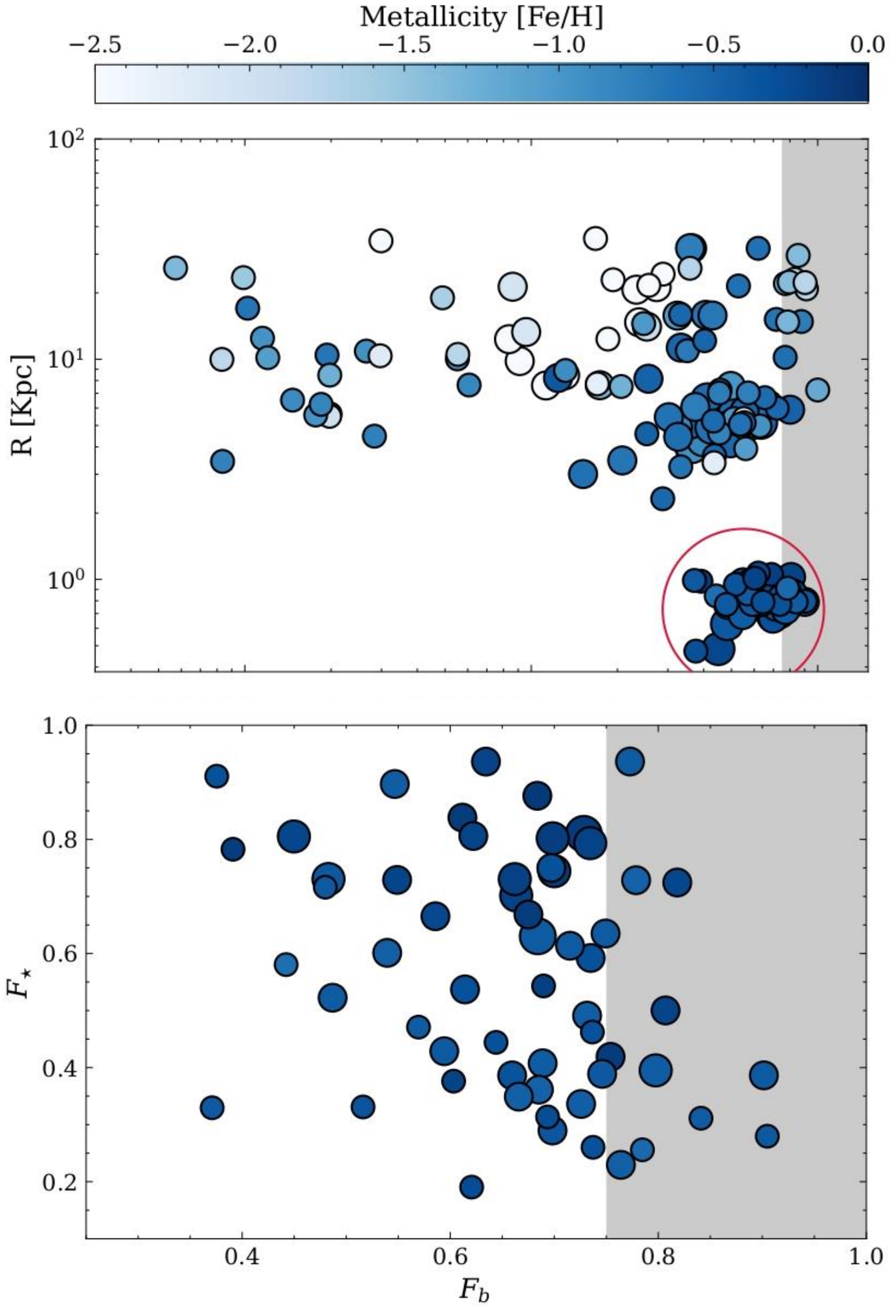


Nuclear Star Cluster

arXiv.2303.12828



Metallicity [Fe/H]
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
10^2
10^1
10^0
R [Kpc]
10^0
10^{-1}
10^{-2}
10^{-3}
$F_\star$
$10^4 < M_\star < 10^5$
$10^5 < M_\star < 10^6$
$10^6 < M_\star < 10^7$
$10^7 < M_\star < 10^8$
10^{-2}
10^{-1}
10^0
F_b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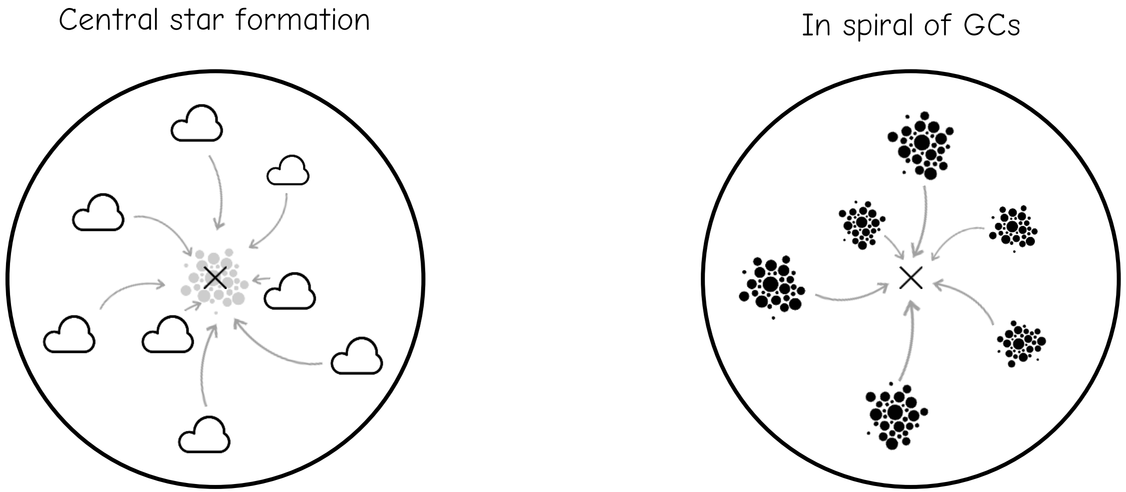
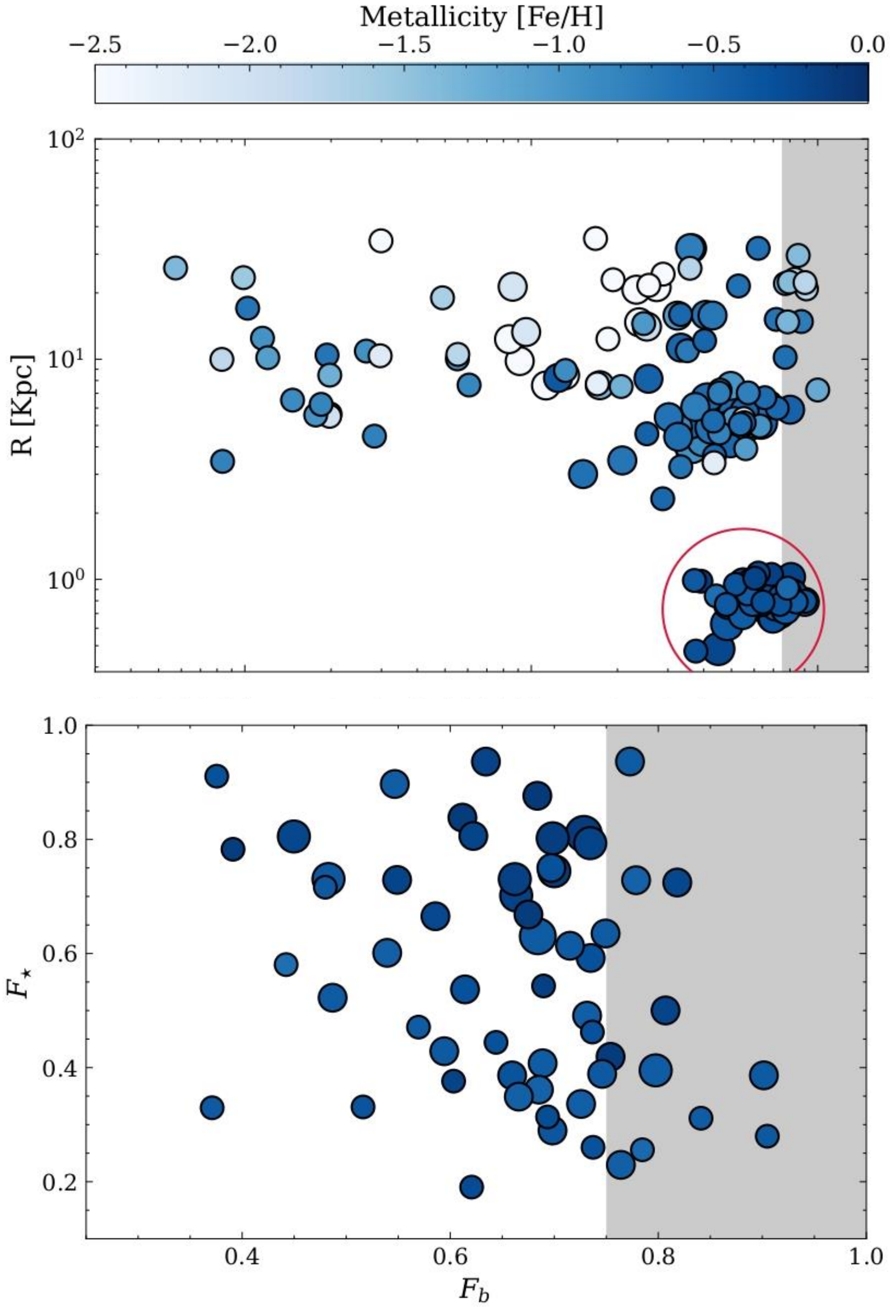
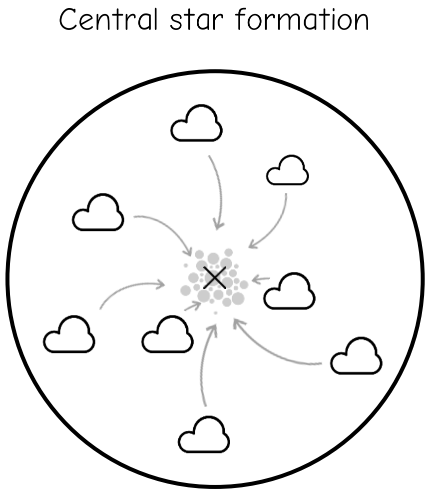
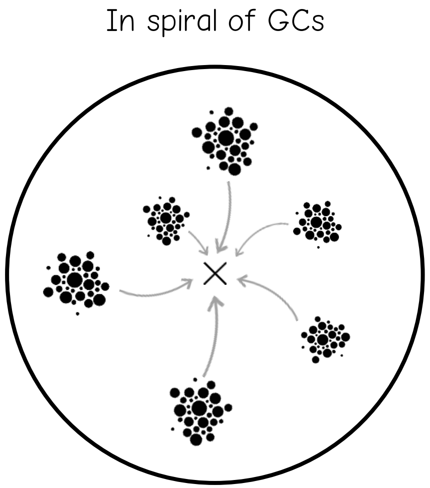
R [Kpc]
10^2
10^1
10^0
1.0
0.8
0.6
0.4
0.2
$F_\star$
0.4
0.6
0.8
1.0
F_b


Central star formation
In spiral of GCs

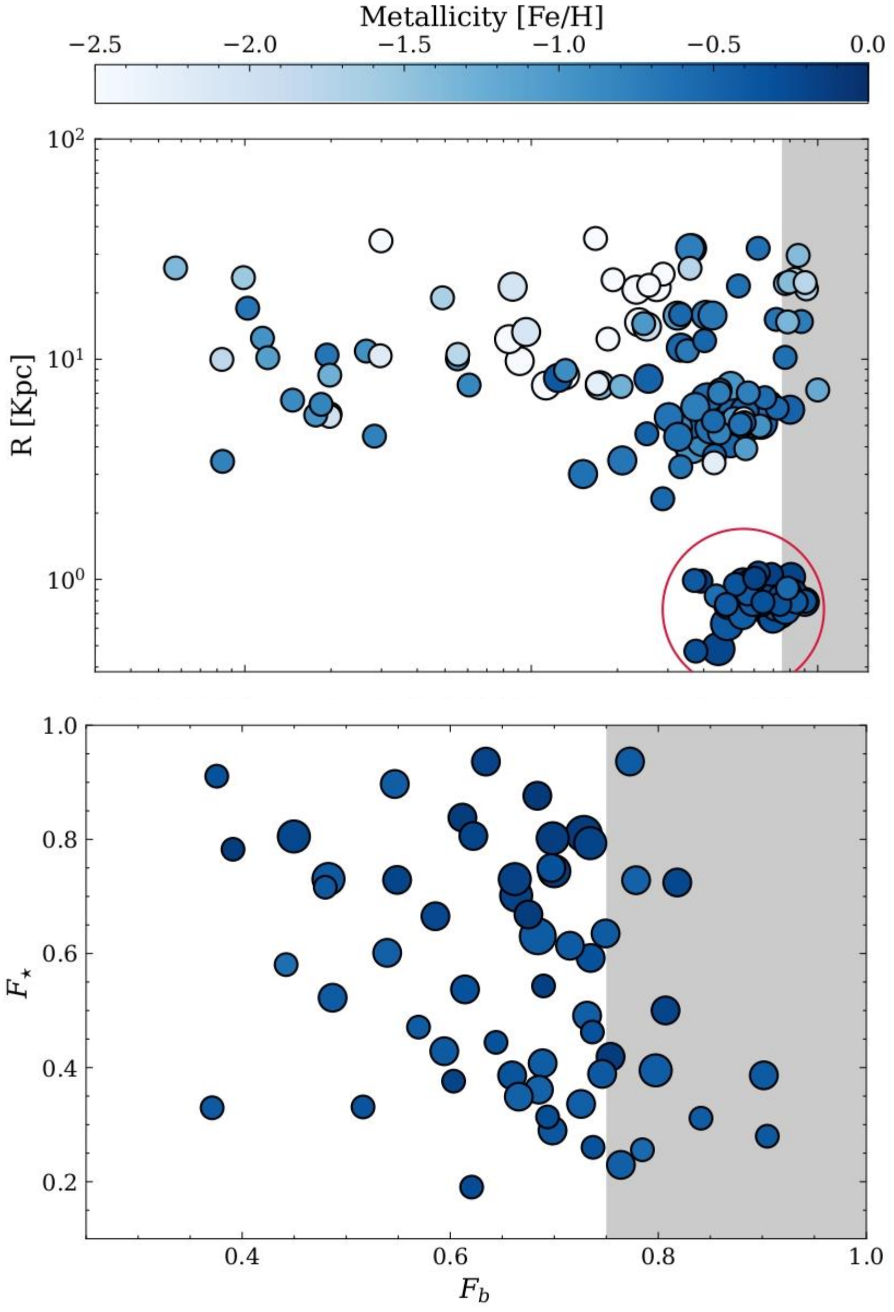






Reflects properties typical of GCs

- Simple SFHs
- Low Metallicity
- High fraction of Old stars



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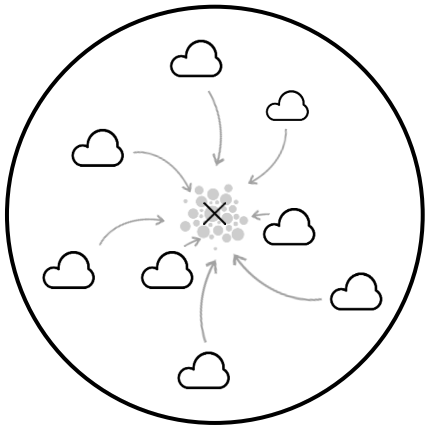
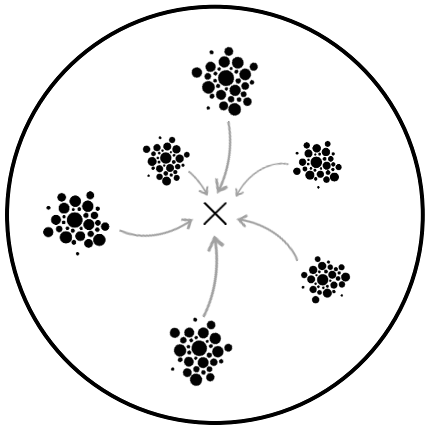


In spiral of GCs



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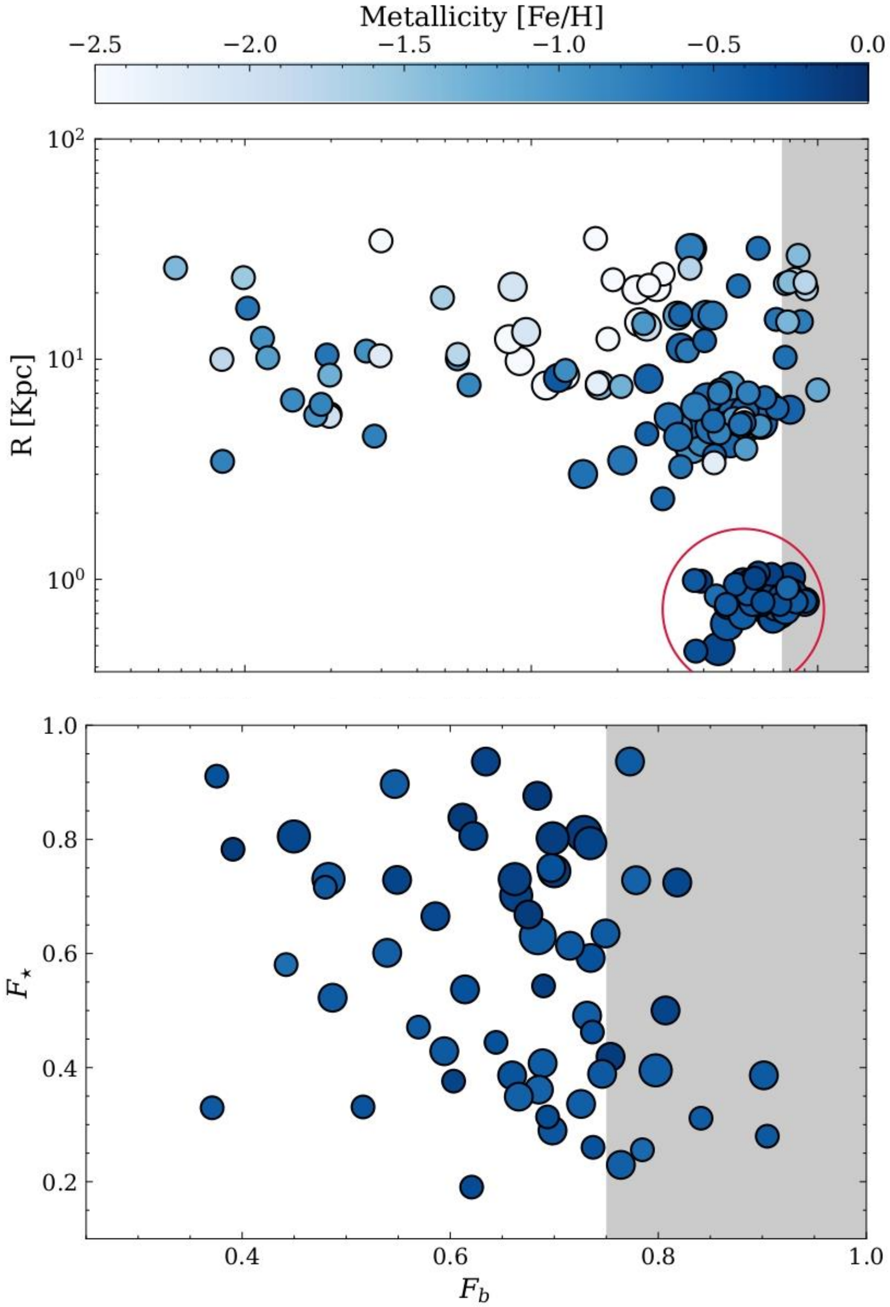
} **F_{omp}**



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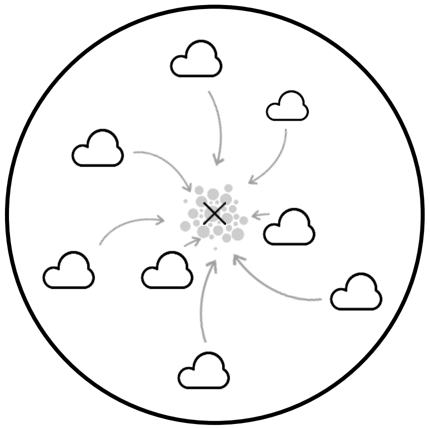
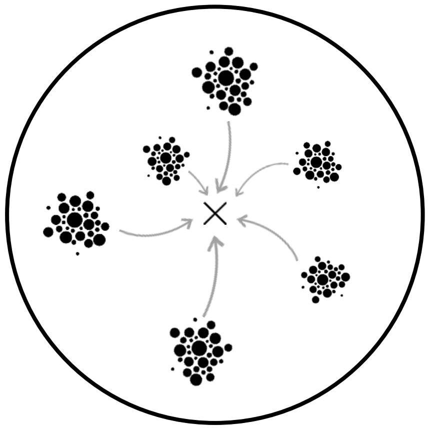


In spiral of GCs



Reflects properties typical of GCs

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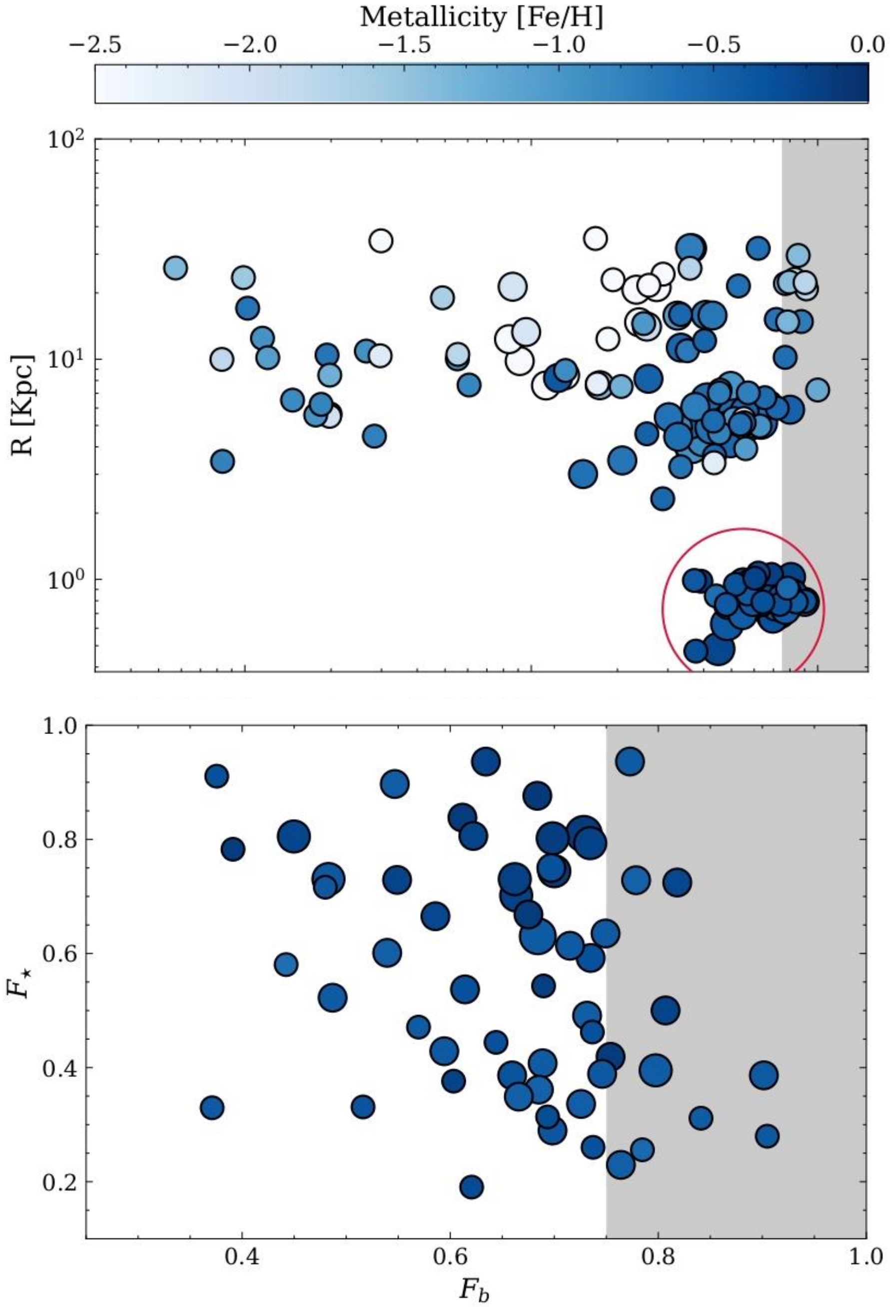
} **F_{omp}**

In-situ SF

- More complex SFH
- Low F_{omp}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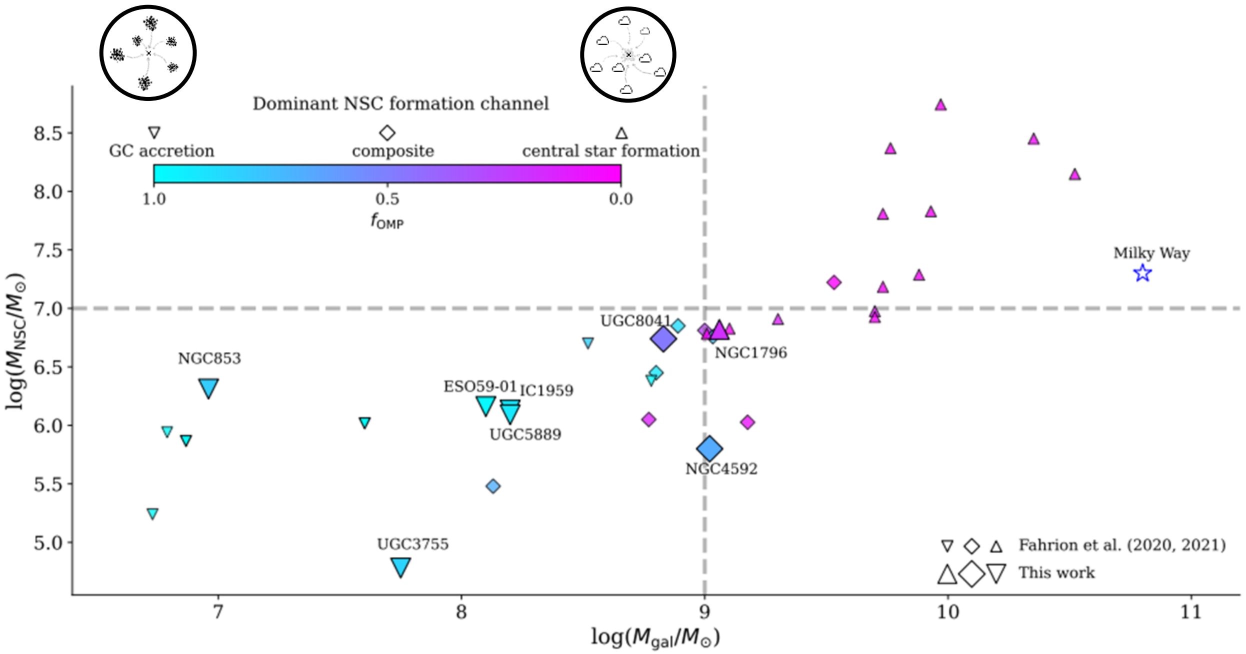
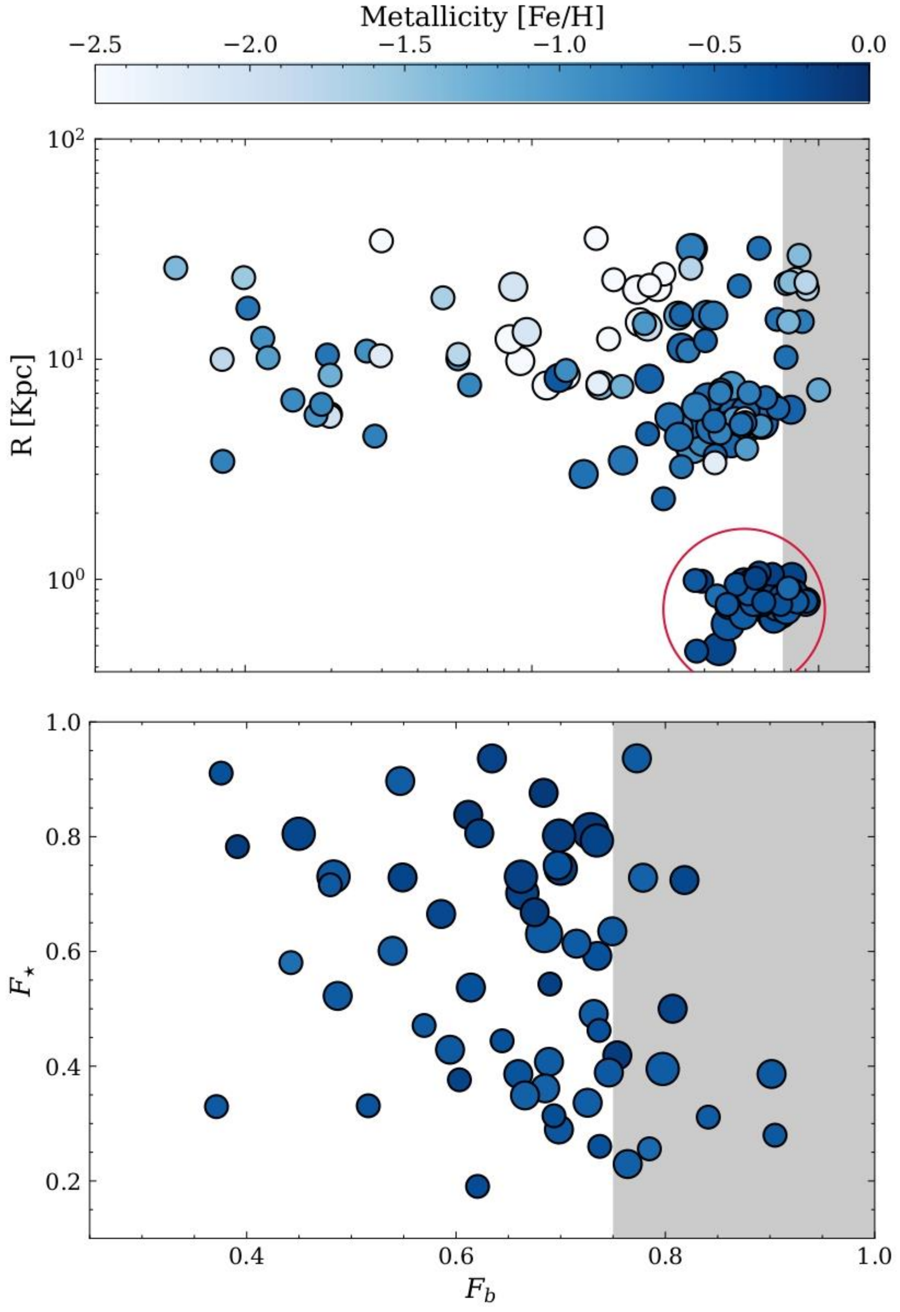
0.2
0.4
0.6
0.8
1.0
F_b


Dominant NSC formation channel
GC accretion
composite
central star formation
1.0
0.5
0.0
$f_{\rm OMP}$
$\log(M_{\rm NSC}/M_\odot)$
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
Milky Way
UGC8041
NGC1796
NGC853
ESO59-01
IC1959
UGC5889
NGC4592
UGC3755
Fahrion et al. (2020, 2021)
This work
7
8
9
10
11
$\log(M_{\rm gal}/M_\odot)$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0.8
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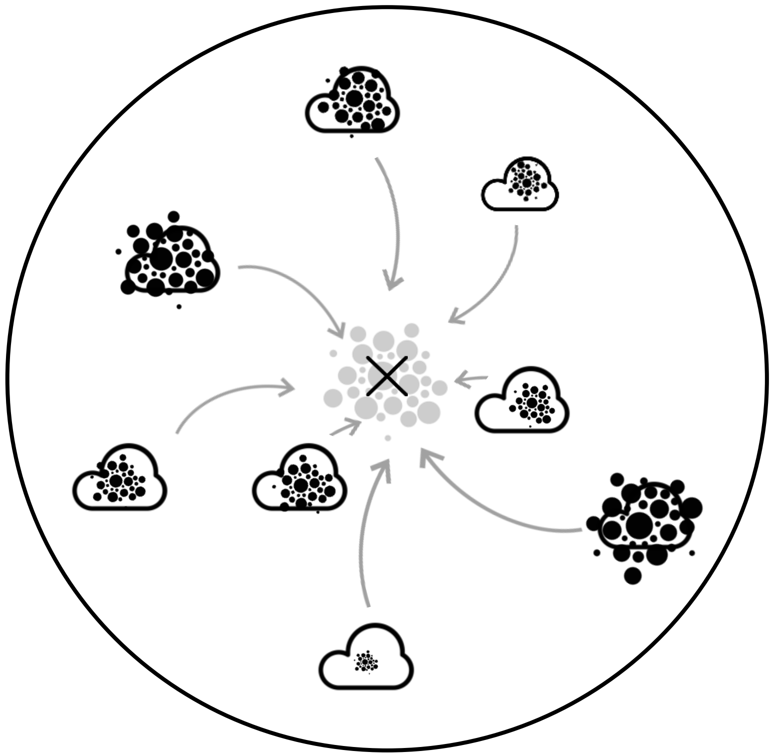
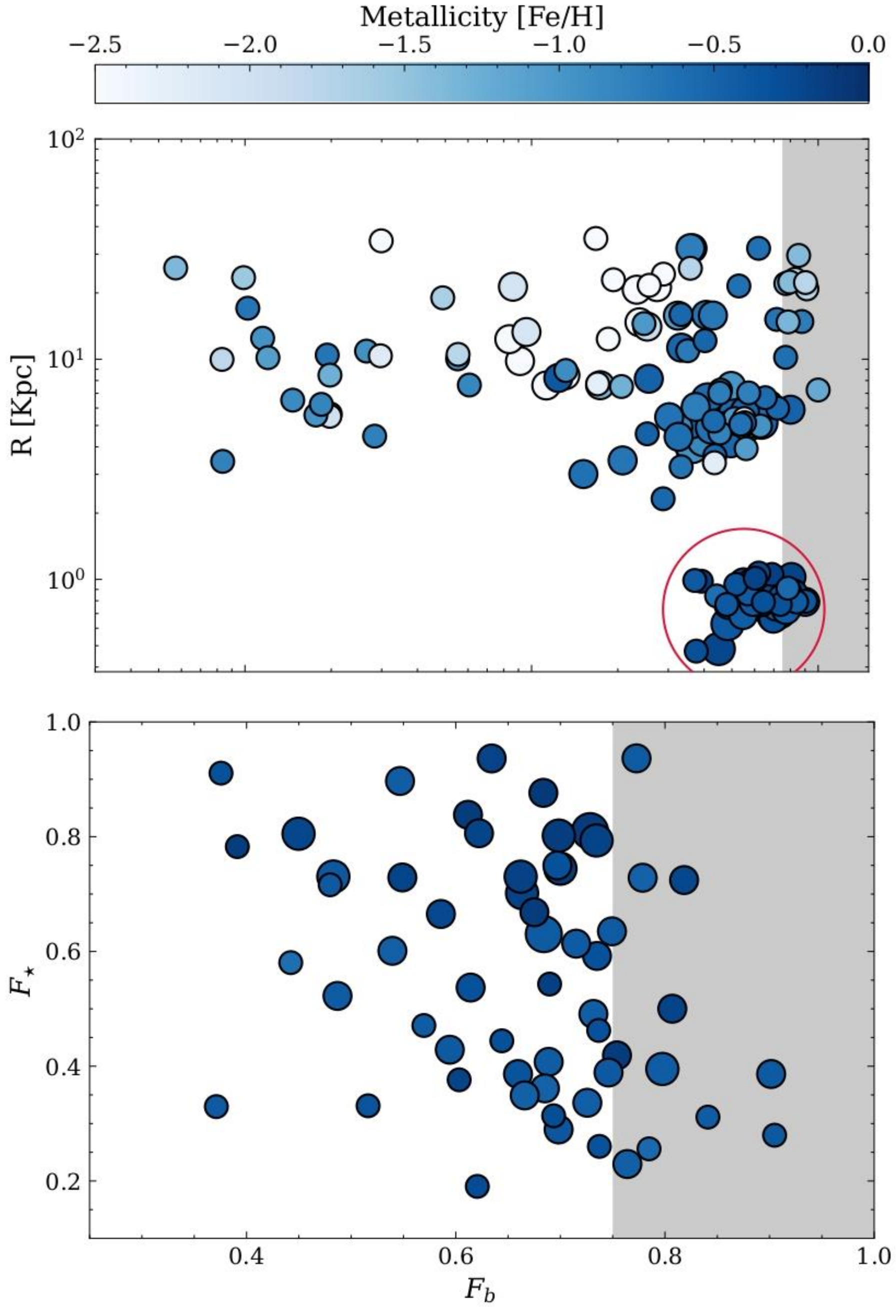
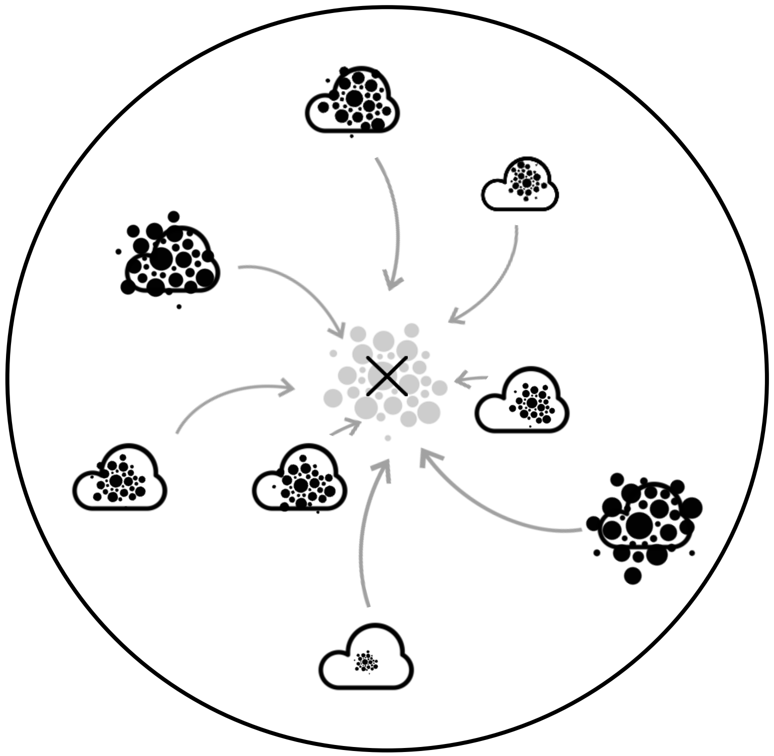
0.4
0.2
0.4
0.6
0.8
1.0
F_b

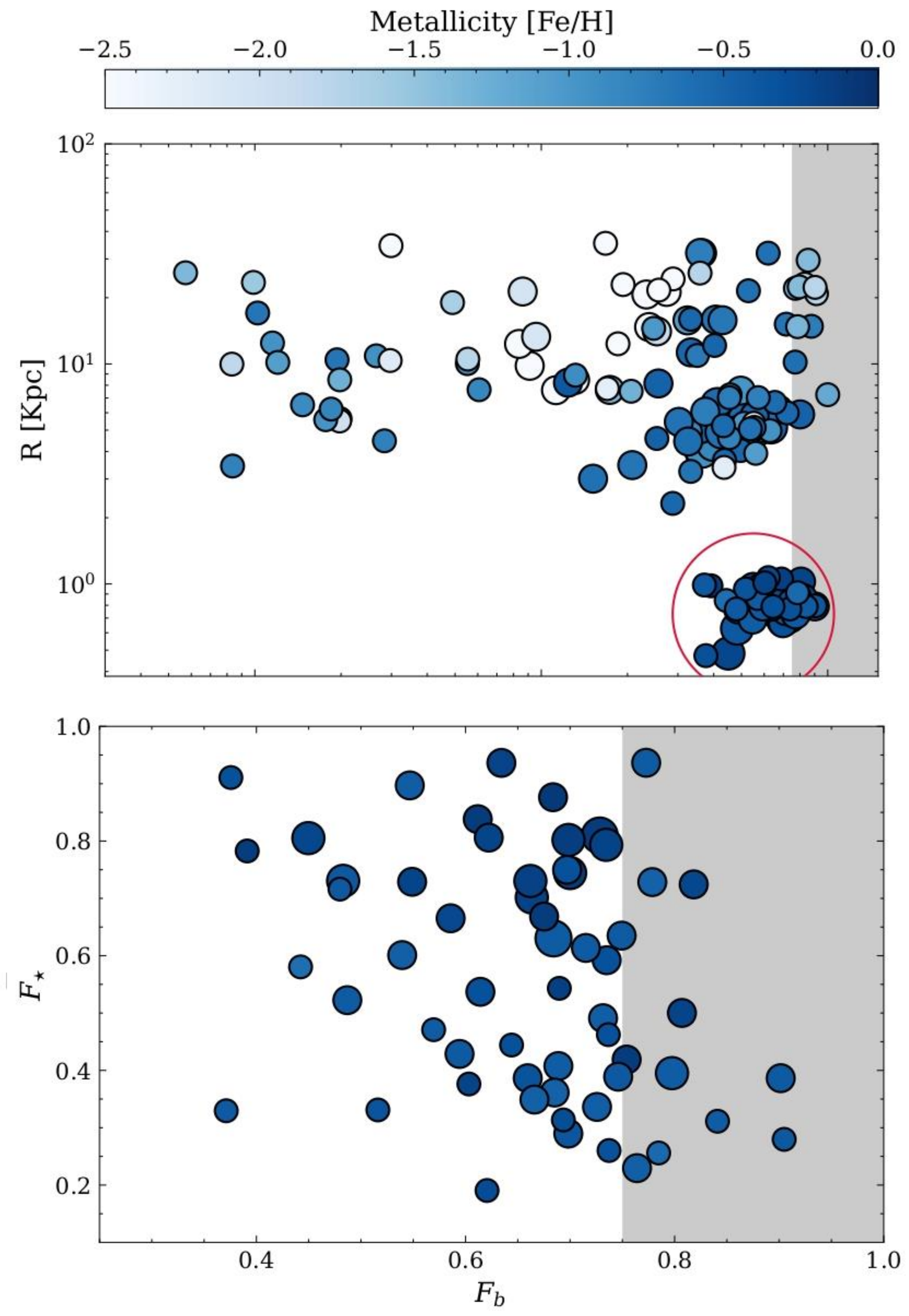


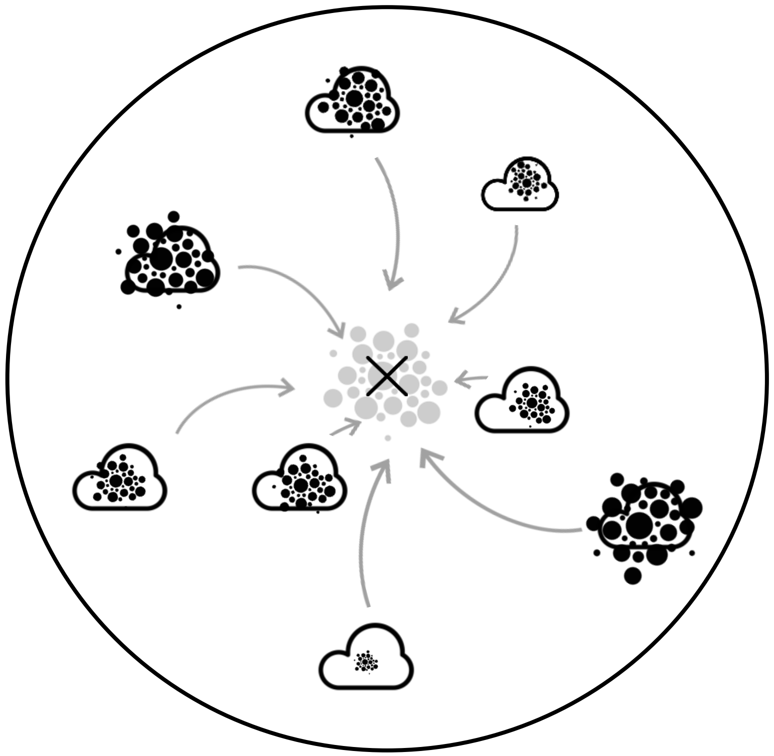




For this theory to be true

- Clusters should fall into the system before the simulation reaches z=0





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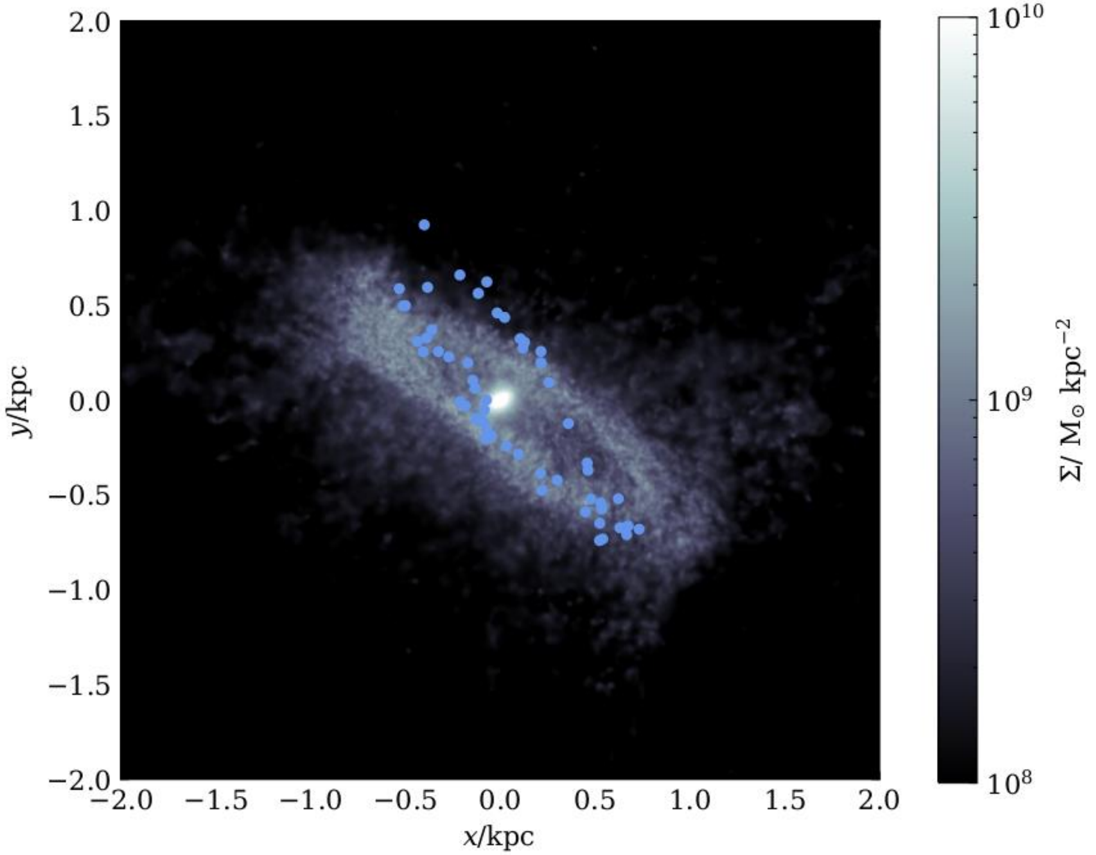

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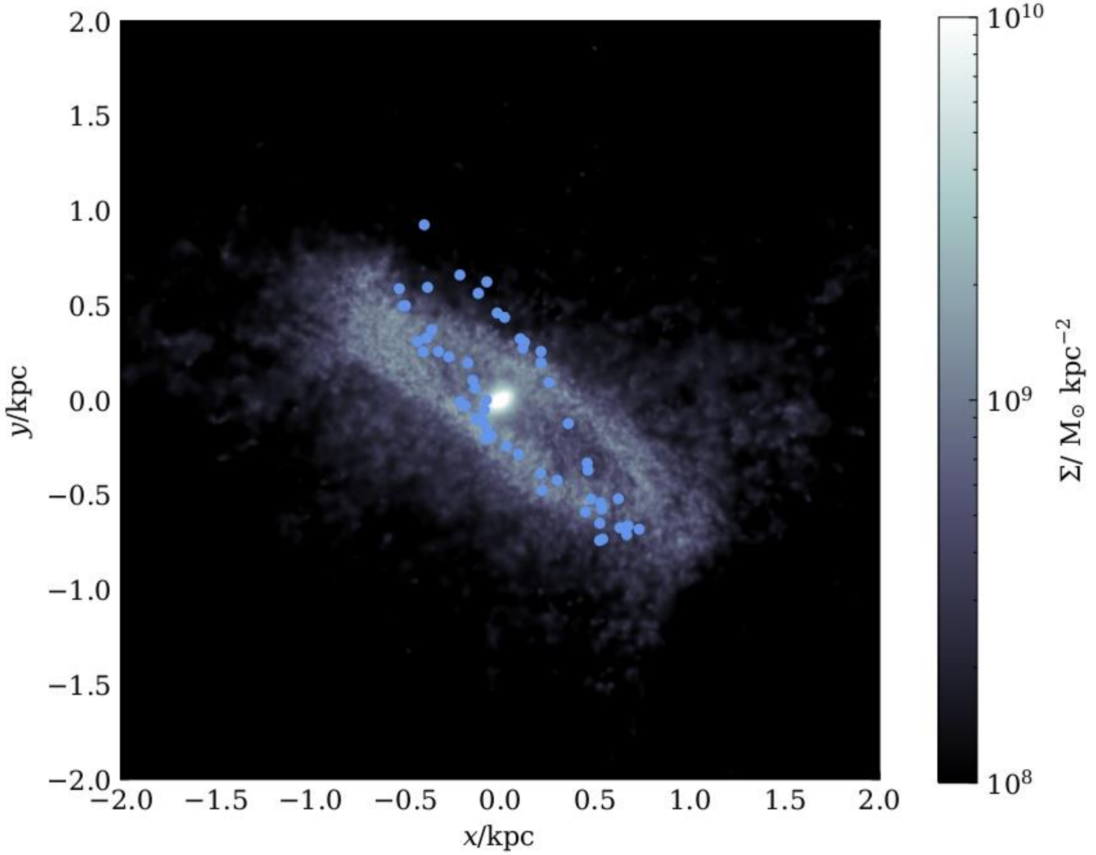

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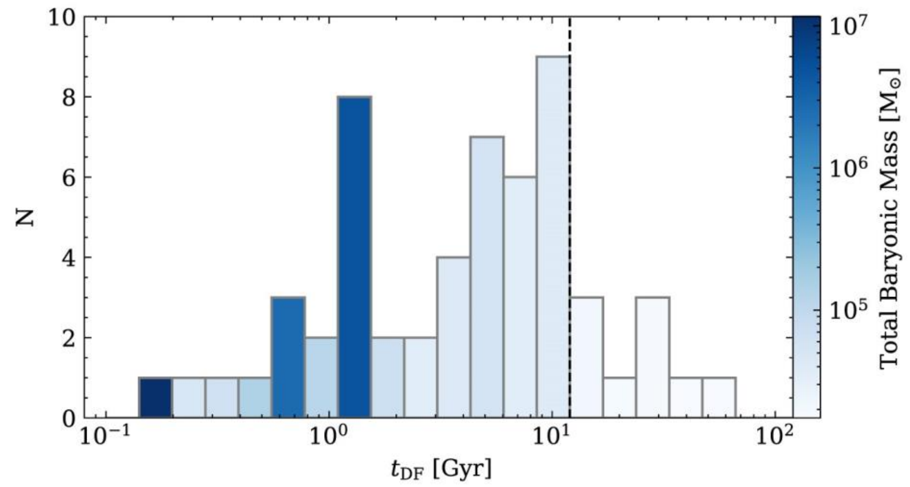

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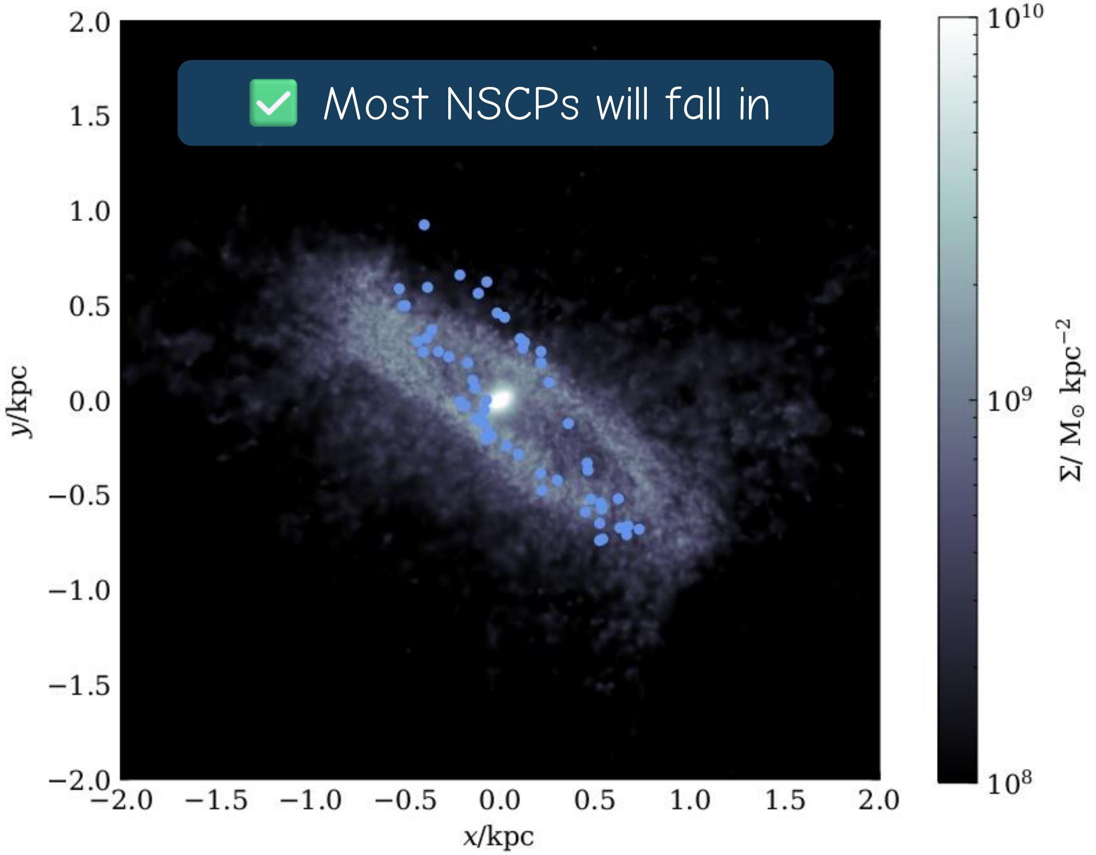

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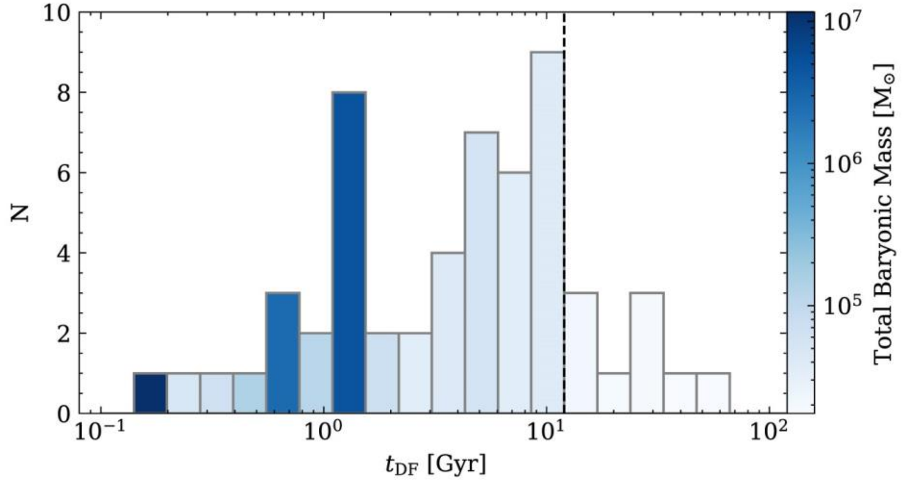
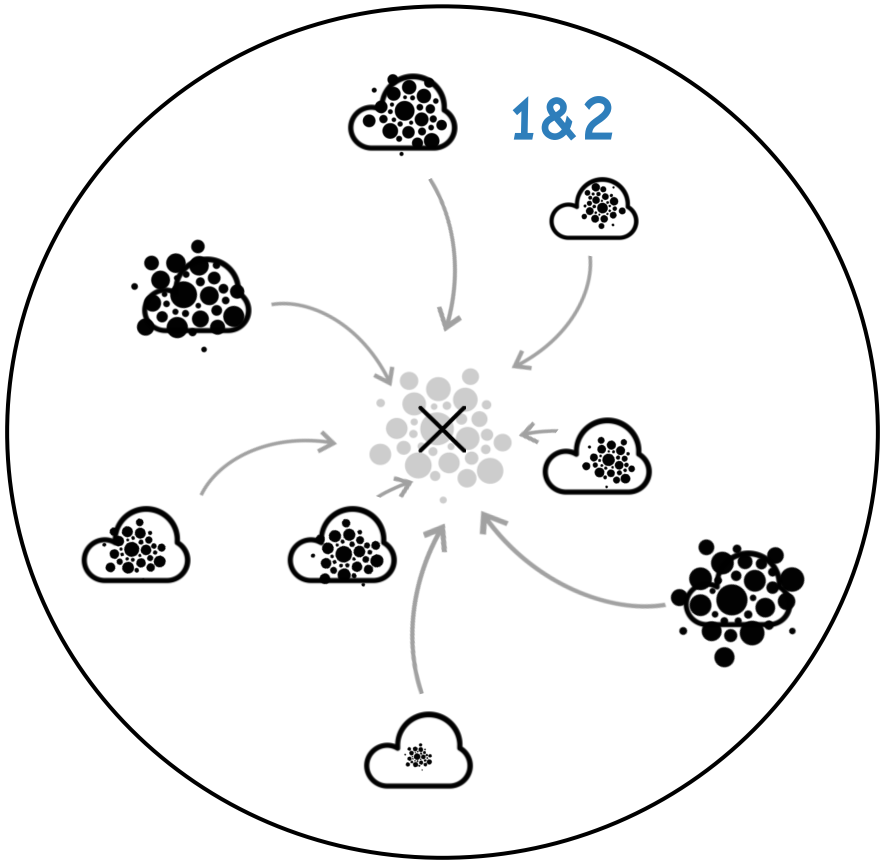


Formation Scenarios of NSC



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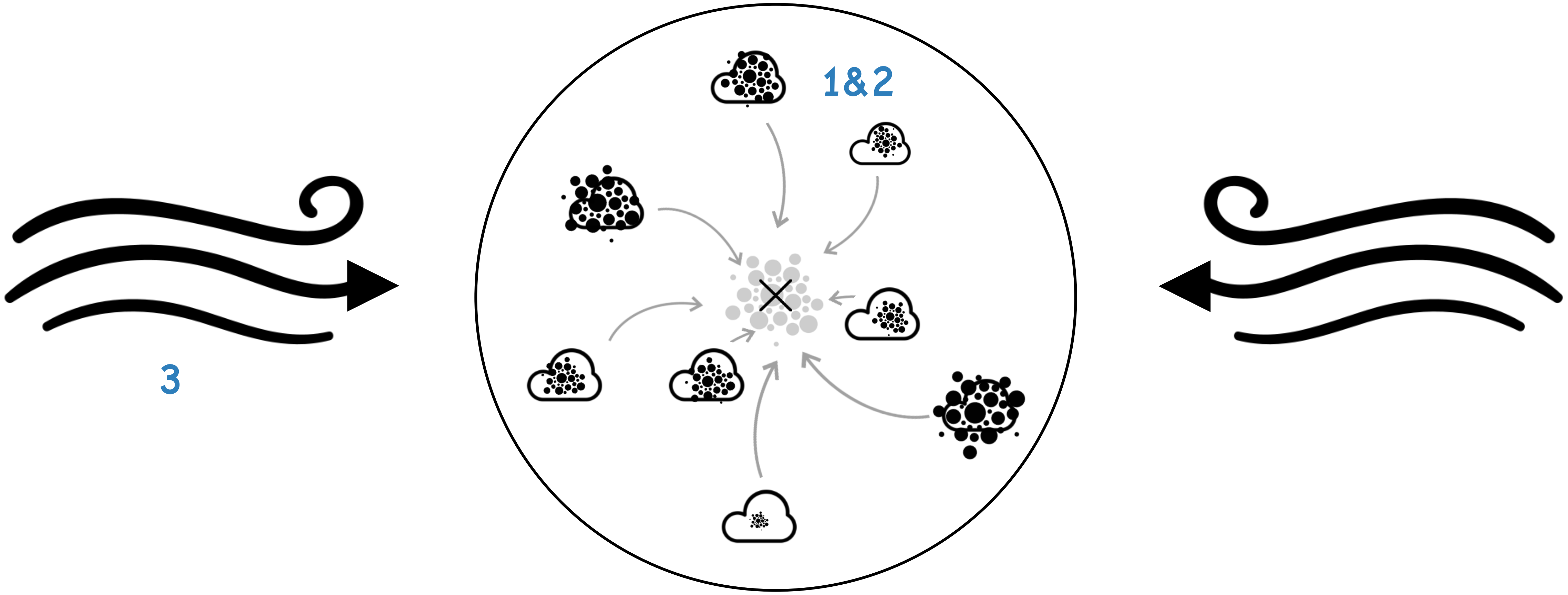

In a barred galaxy system, the bar efficiently funnels gas toward to center, where it settles

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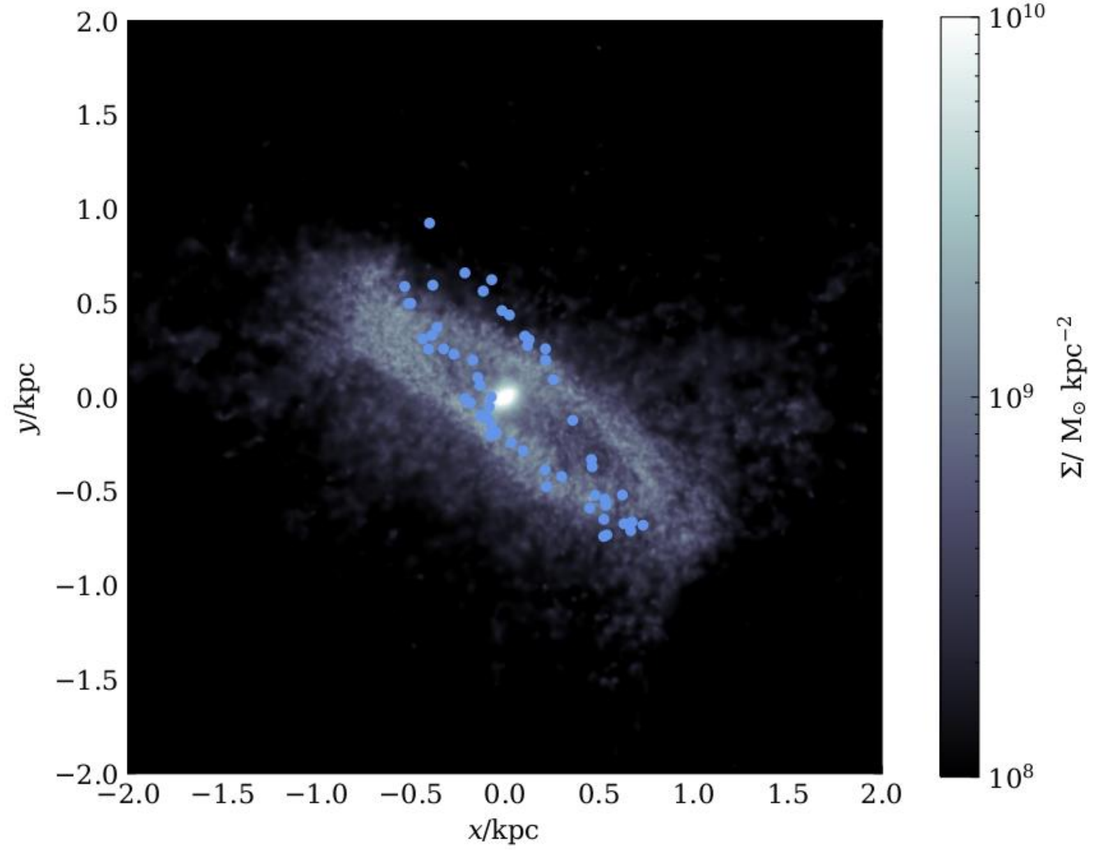

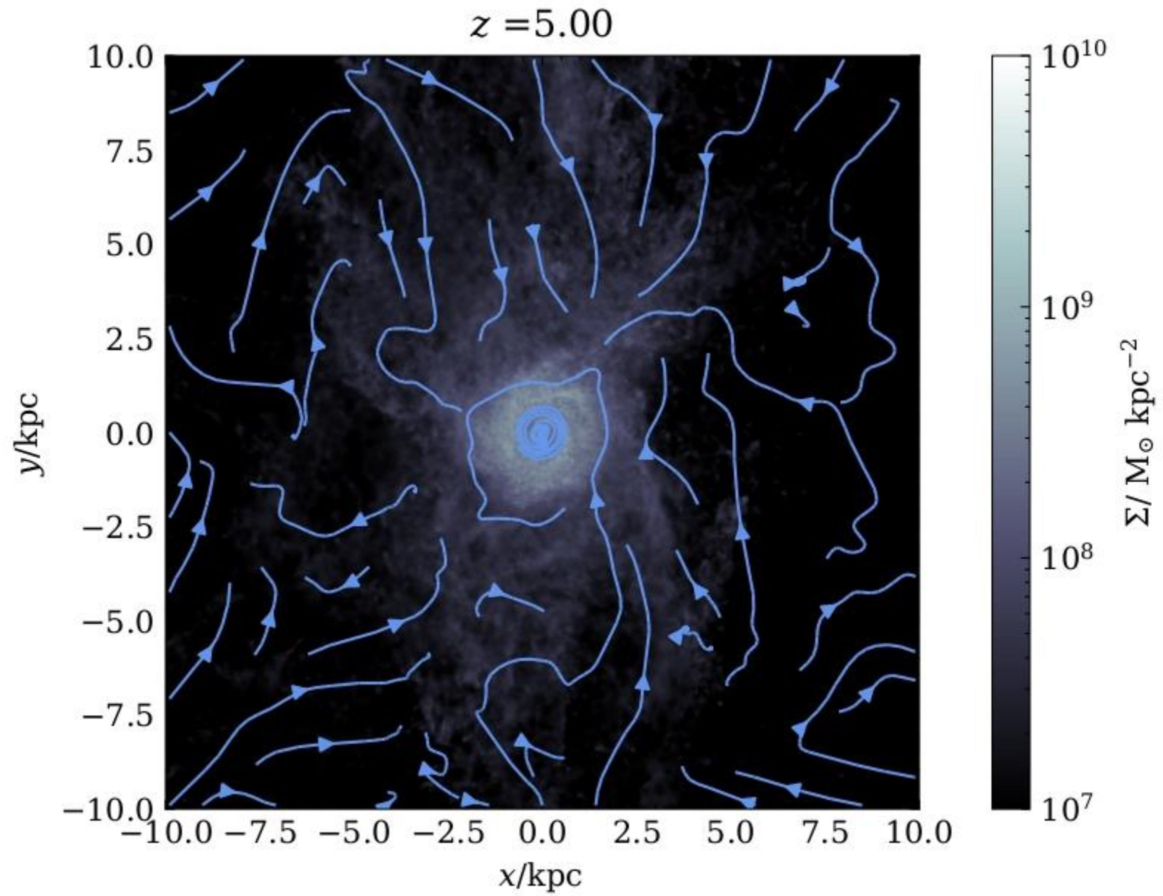

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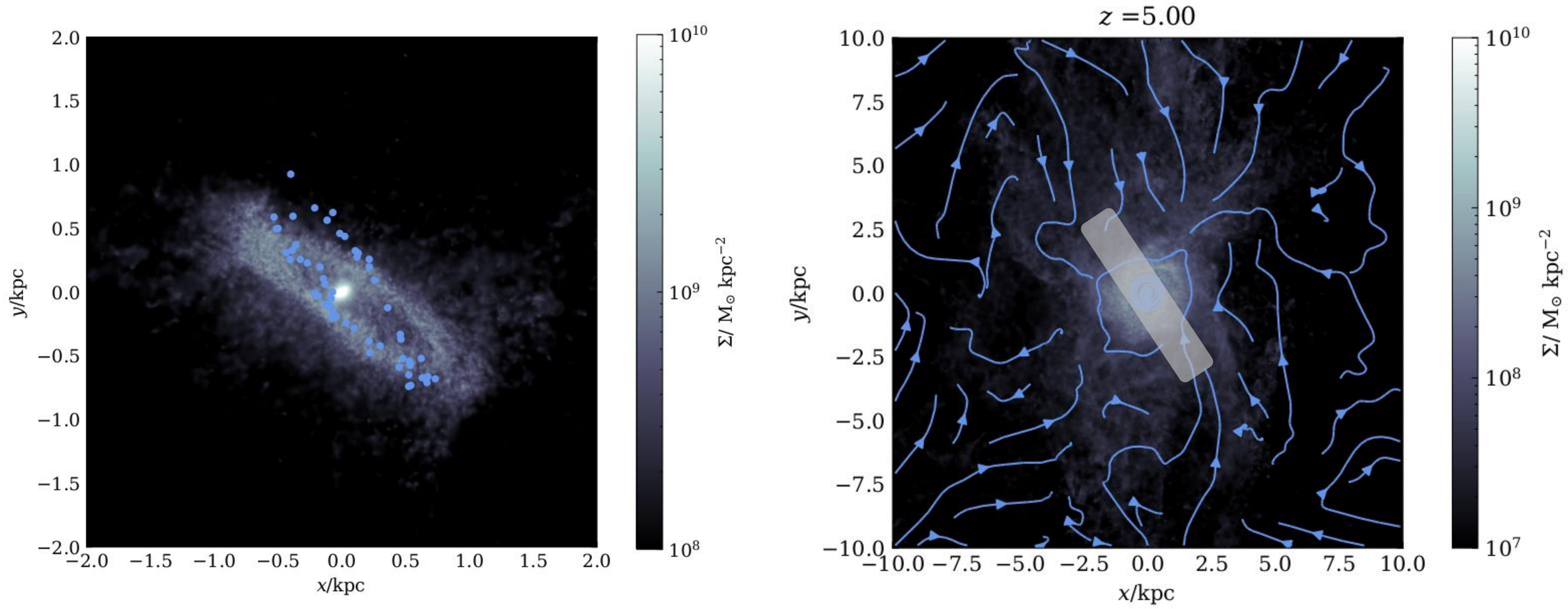

Thank you for listening

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arXiv:2210.04915
arXiv:2303.12828
arXiv.2404.15404

Star Clusters in the Milky Way

Thank you for listening

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Star Clusters in the Milky Way

- **Proto-GCs** form through **gas inflows** in the main galaxy halo and are born with a **high baryon fraction**.

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