Better Living Through Computation

Connecting the first stars in the universe to the Milky Way using cosmological simulations

Berkeley TAC seminar
November 6, 2017

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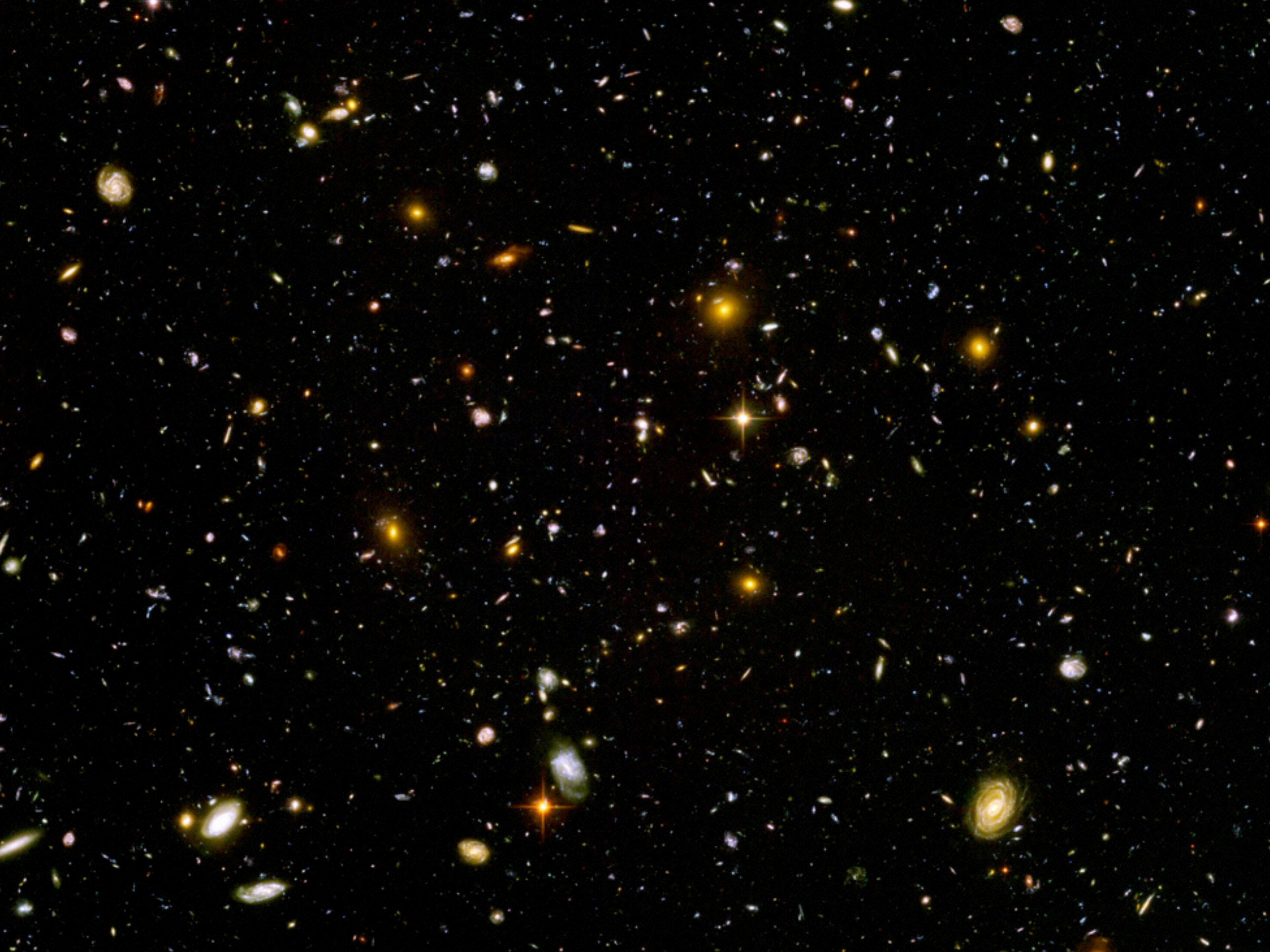
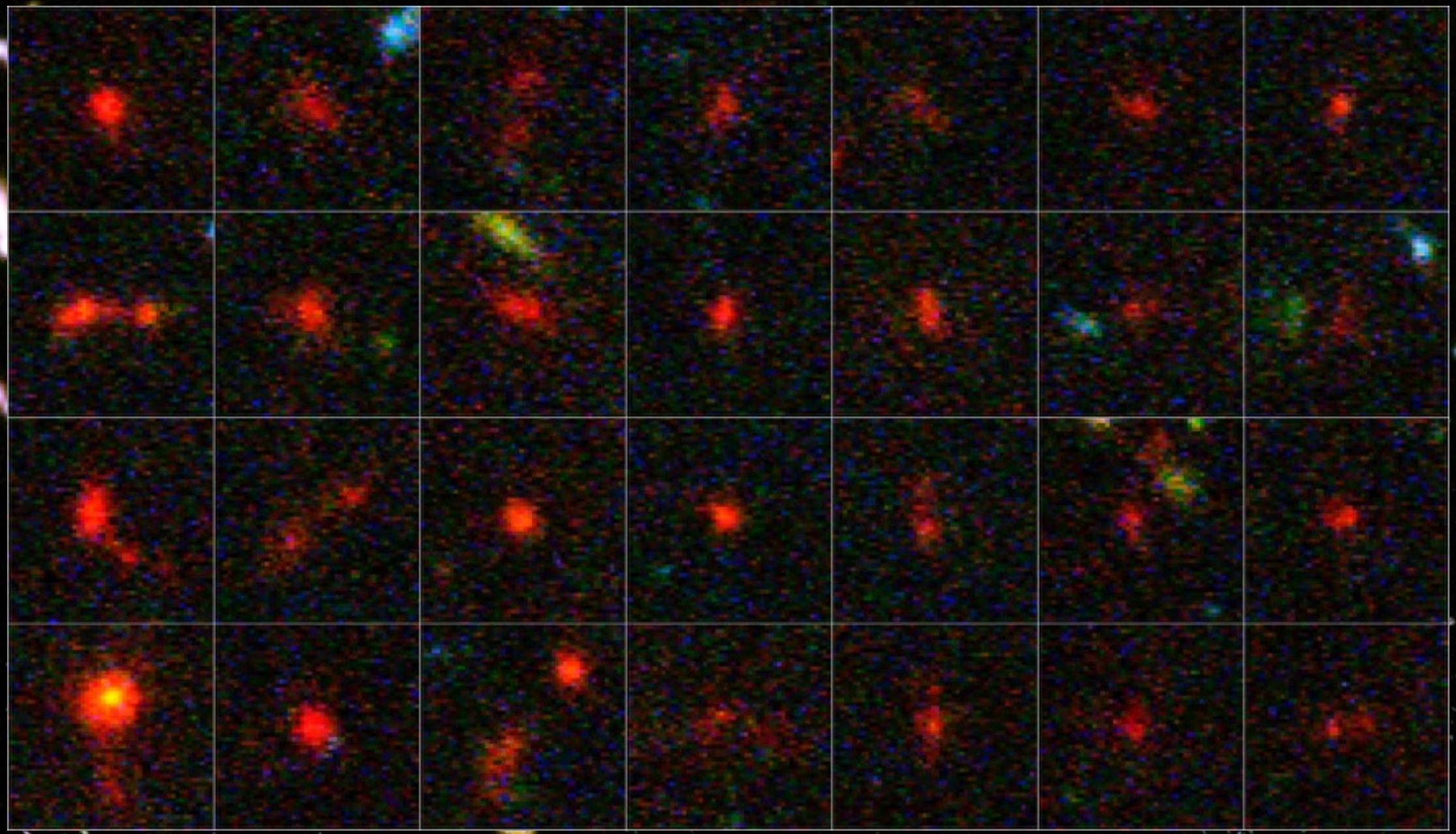
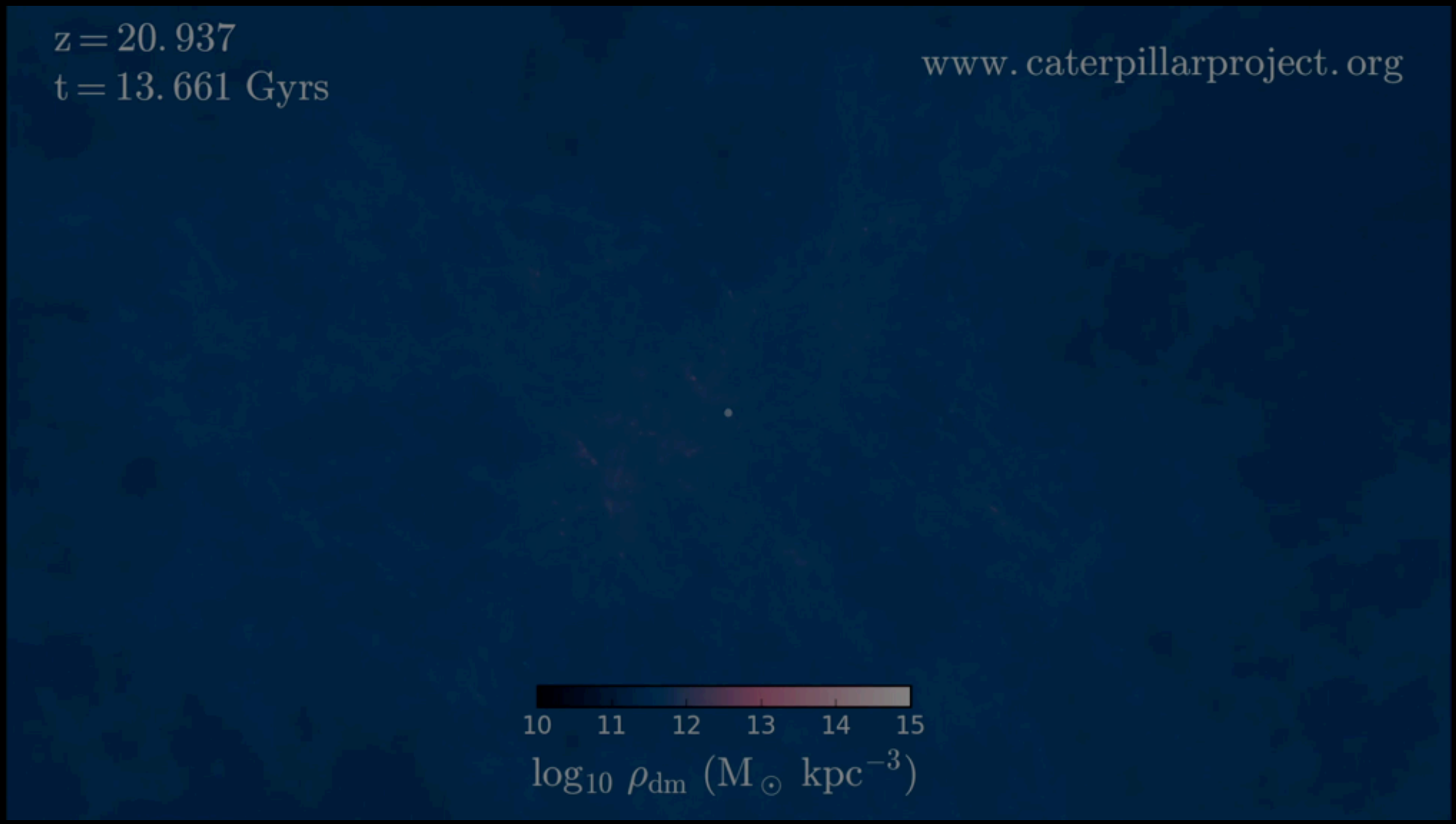






Movie c/o Brendan Griffen, MIT (Caterpillar Project:
Griffen, Frebel, O'Shea et al.)

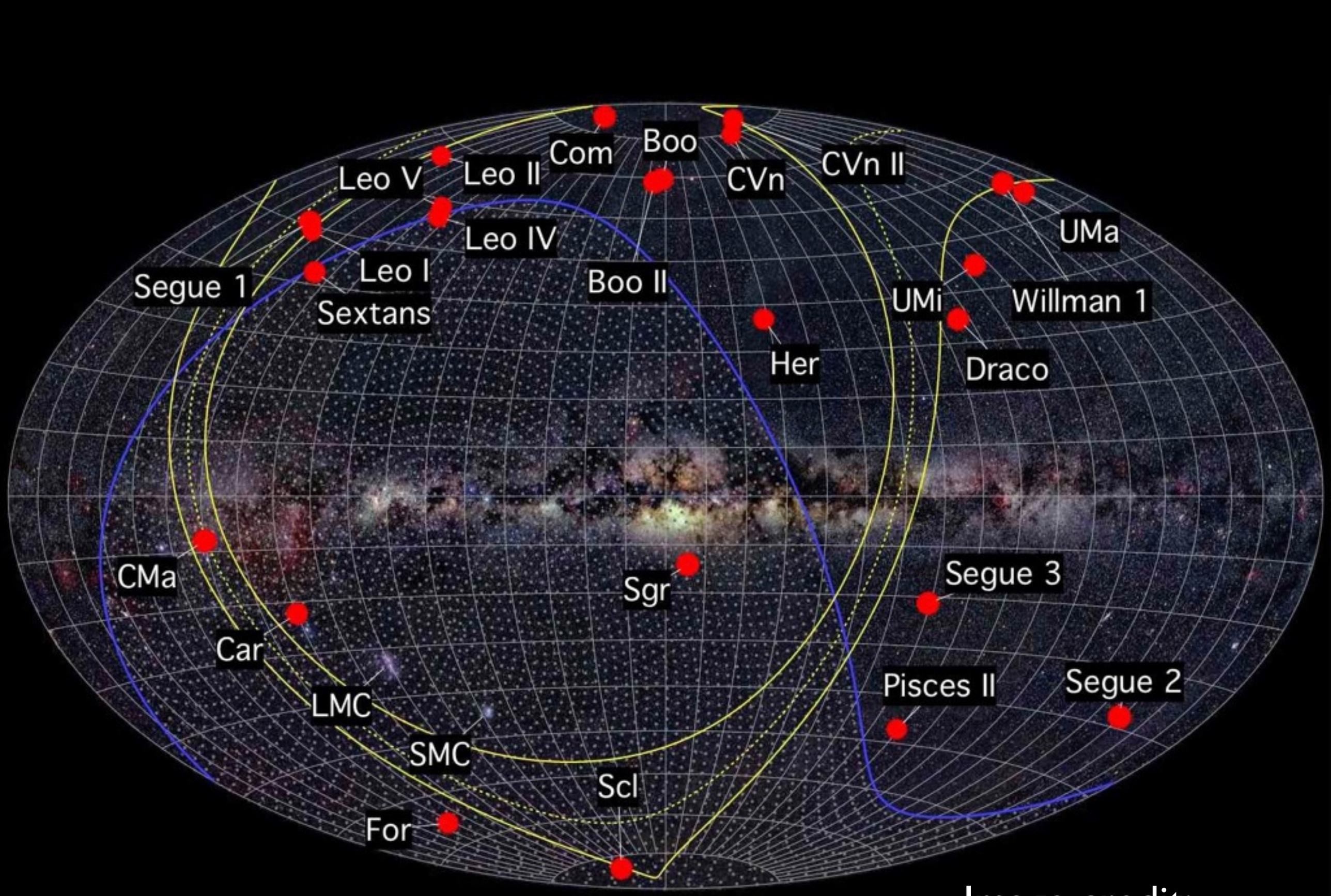


Image credit:
Anna Frebel (MIT)

redit:
Frebel (MIT)

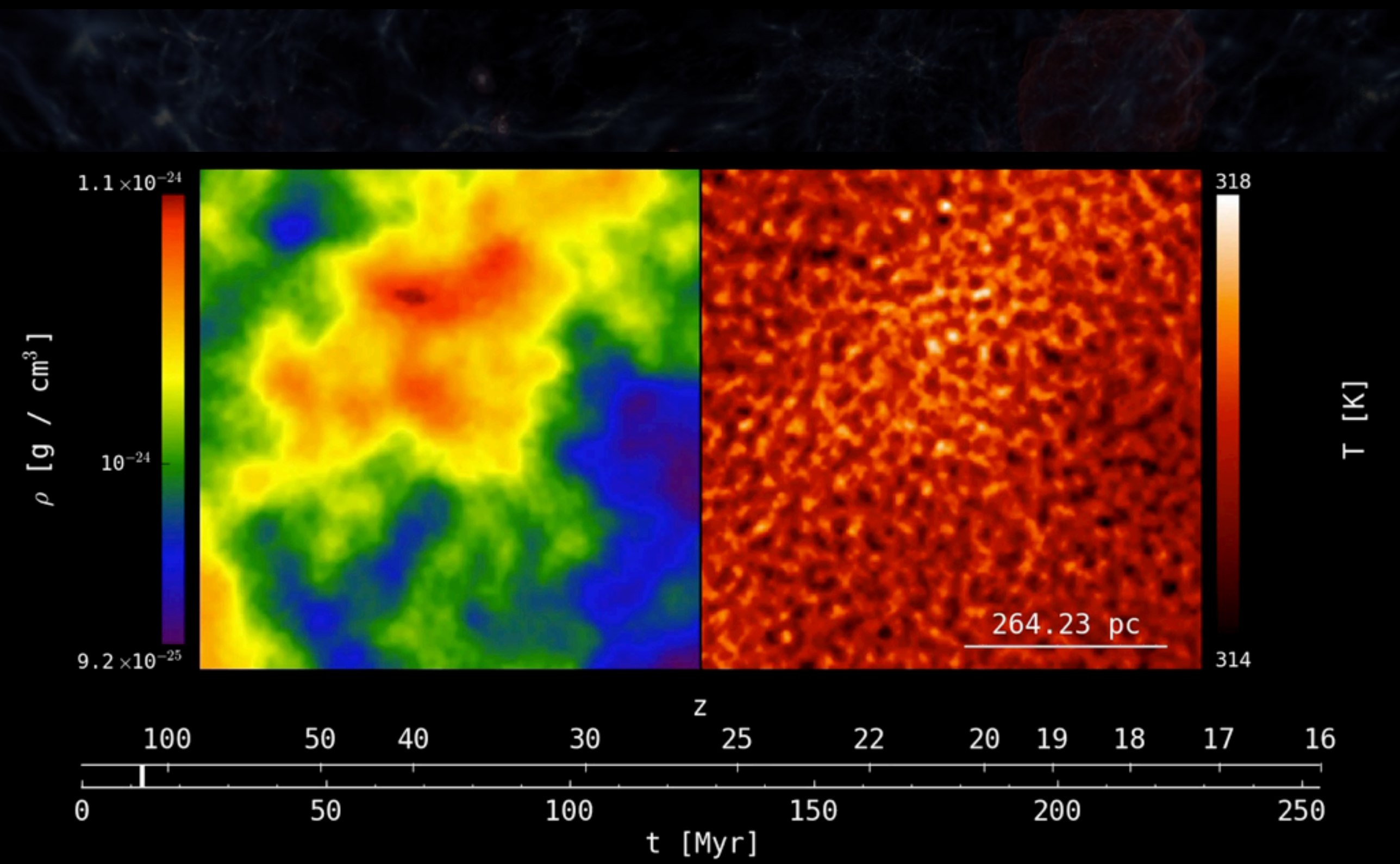
Big questions

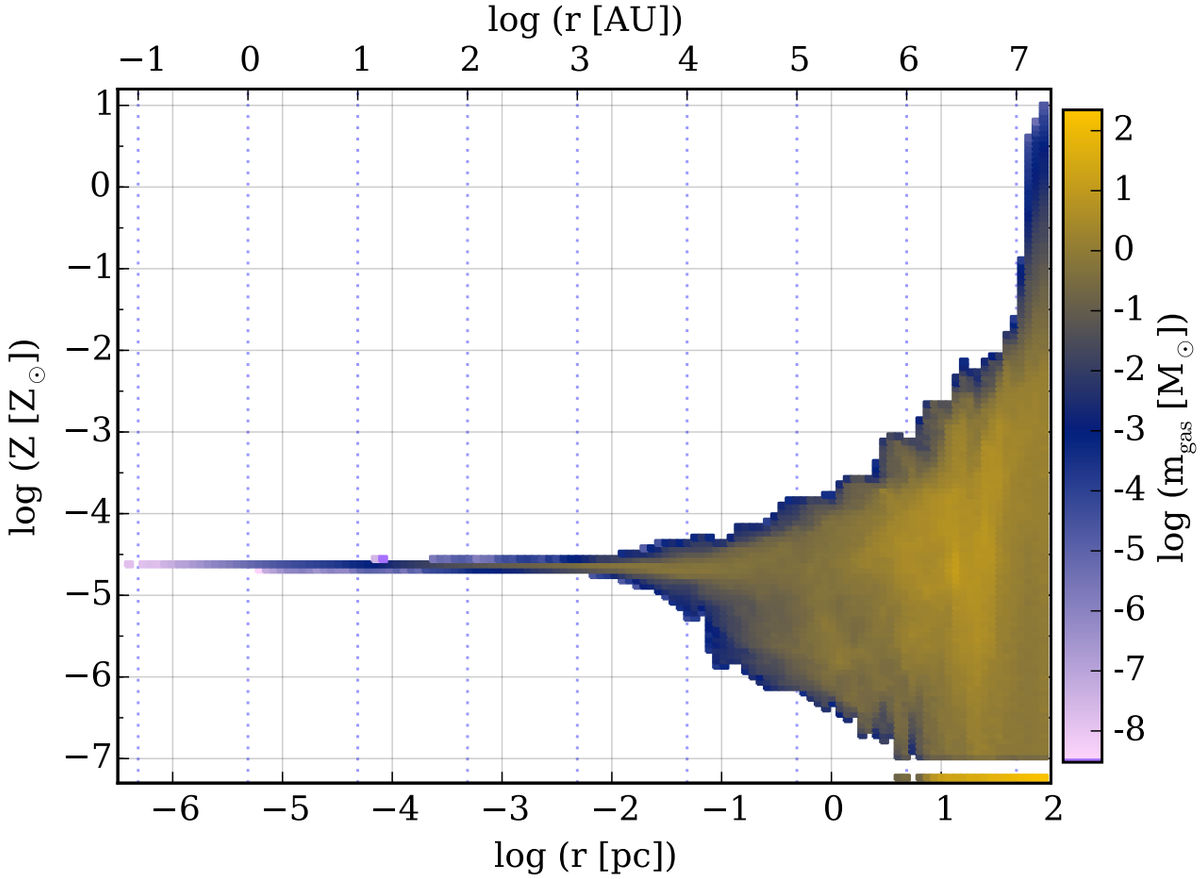
- How do the first stars affect later generations of galaxies?
- What are the observable properties of the earliest galaxies?
- How do the earliest galaxies relate to the Milky Way and its environments?

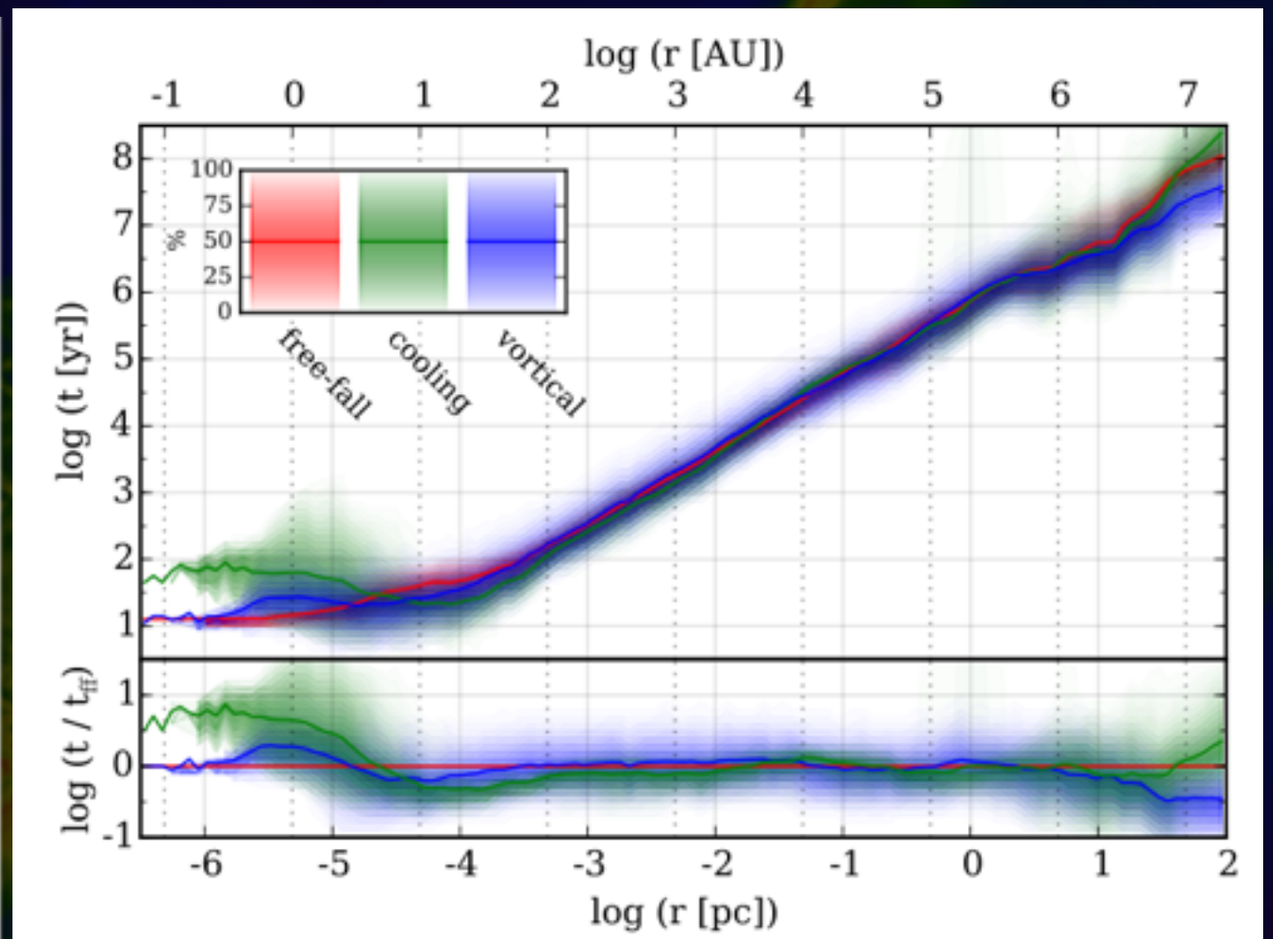
What do we find?

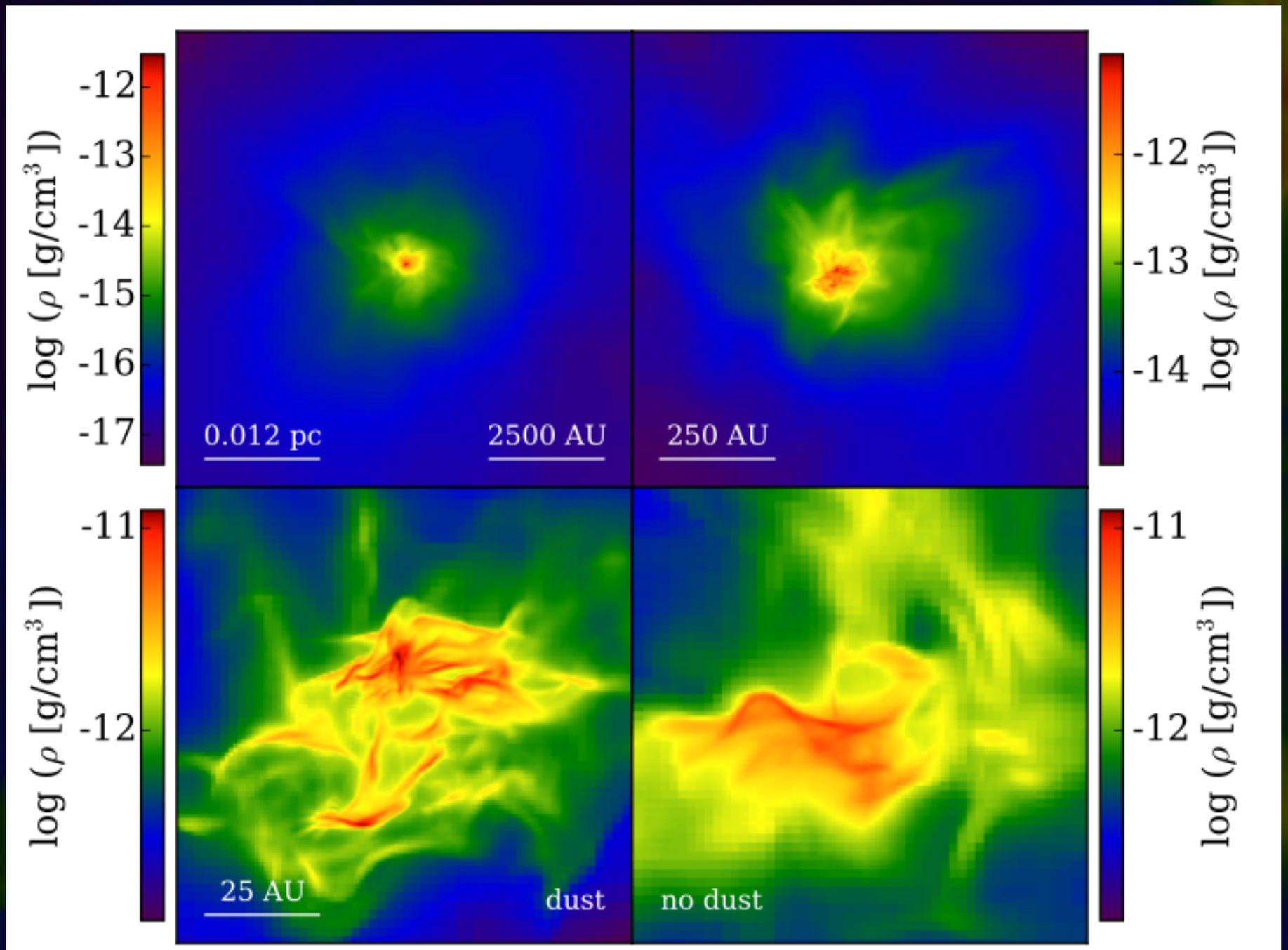
The very first (metal-enriched) stars

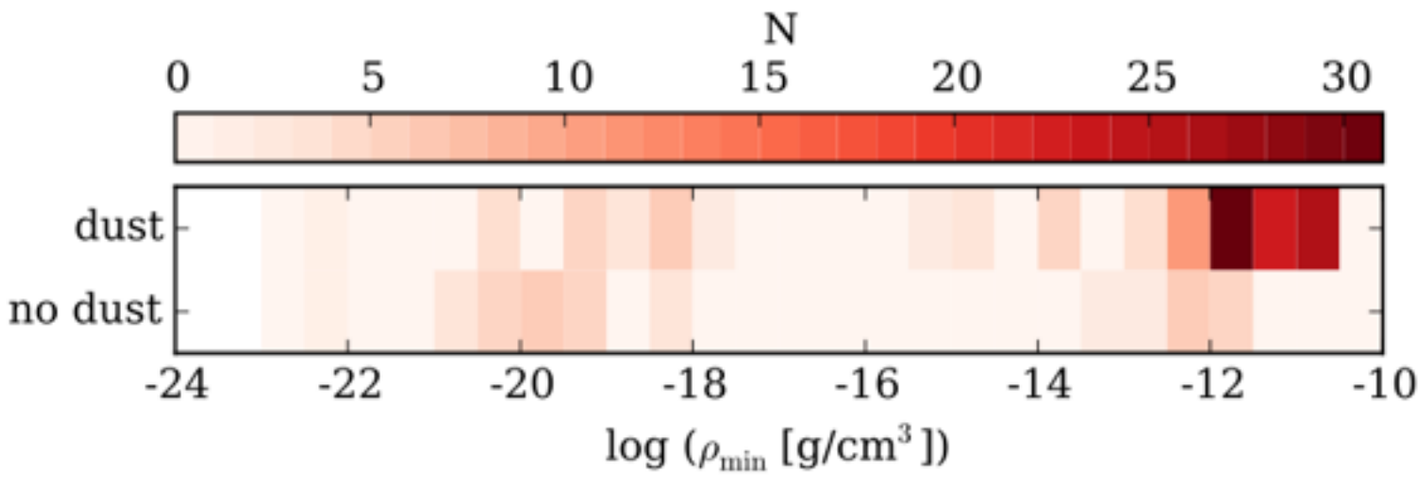
B. Smith et al. 2015, MNRAS, 452, 2822
B. Smith et al. 2017, in prep
O'Shea et al. 2017, in prep.

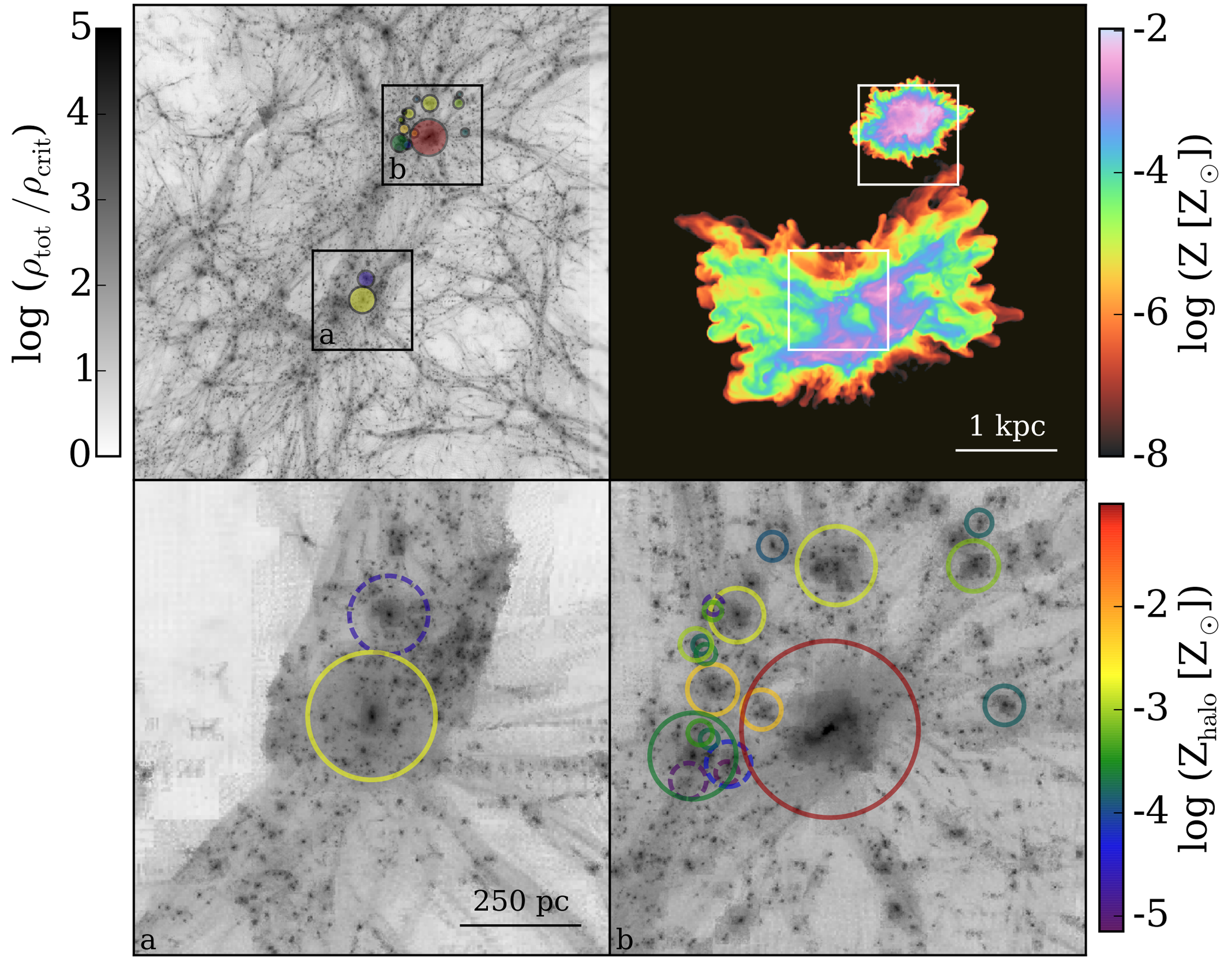

1.1 ×10^−24
10^−24
9.2 ×10^−25
ρ [g / cm^3]
318
314
T [K]
264.23 pc
z
100
50
40
30
25
22
20
19
18
17
16
0
50
100
150
200
250
t [Myr]

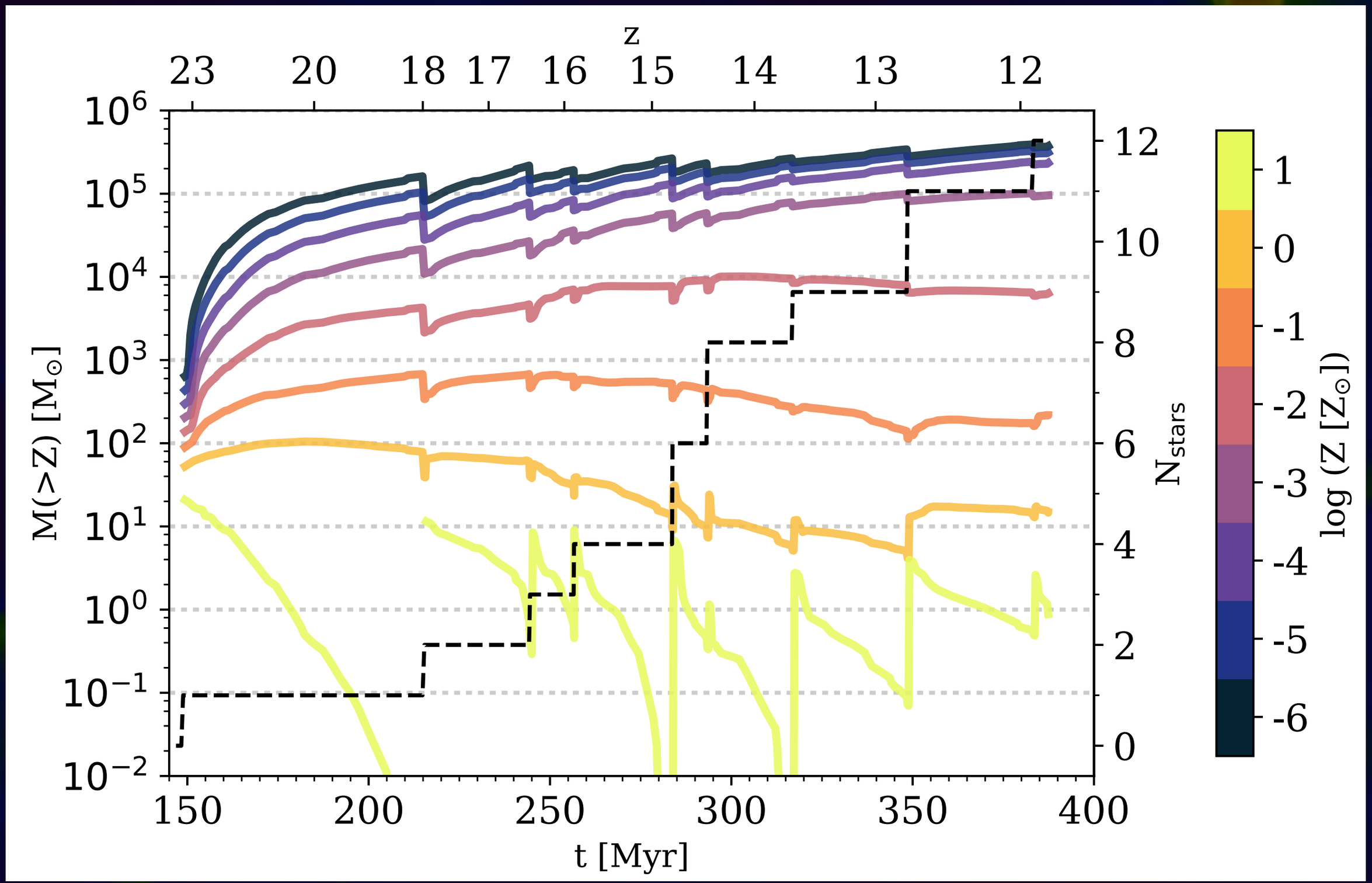

log (r [AU])
log (Z [Z⊙])
log (m_gas [M⊙])
log (r [pc])

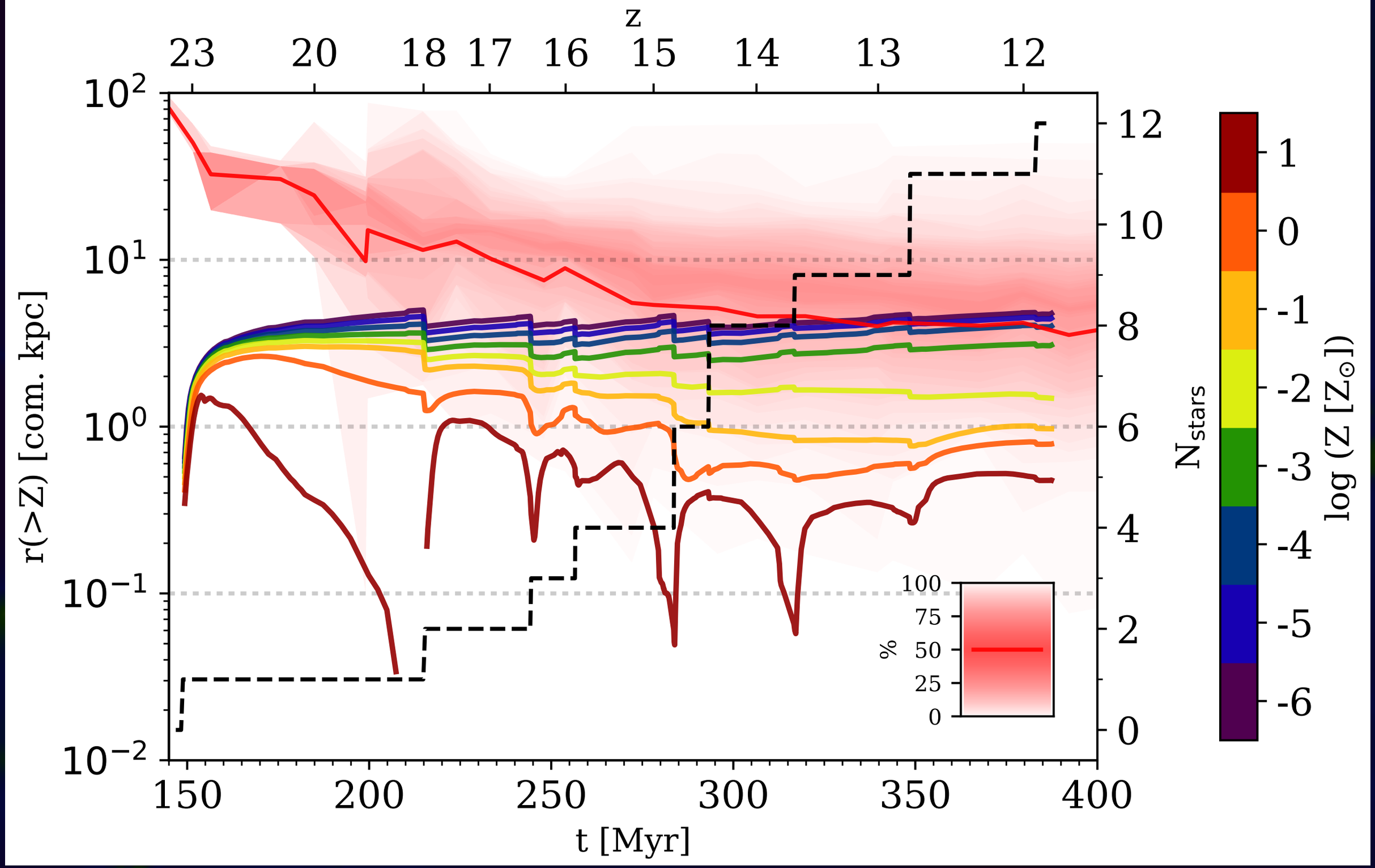

log (r [AU])
log (t [yr])
%
free-fall
cooling
vortical
log (t / t_ff)
log (r [pc])


log (ρ [g/cm^3])
-12
-13
-14
-15
-16
-17
0.012 pc
2500 AU
250 AU
log (ρ [g/cm^3])
-11
-12
25 AU
dust
no dust
log (ρ [g/cm^3])
-11
-12


N
0
5
10
15
20
25
30
dust
no dust
-24
-22
-20
-18
-16
-14
-12
-10
log ($\rho_{\rm min}$ [g/cm^3])

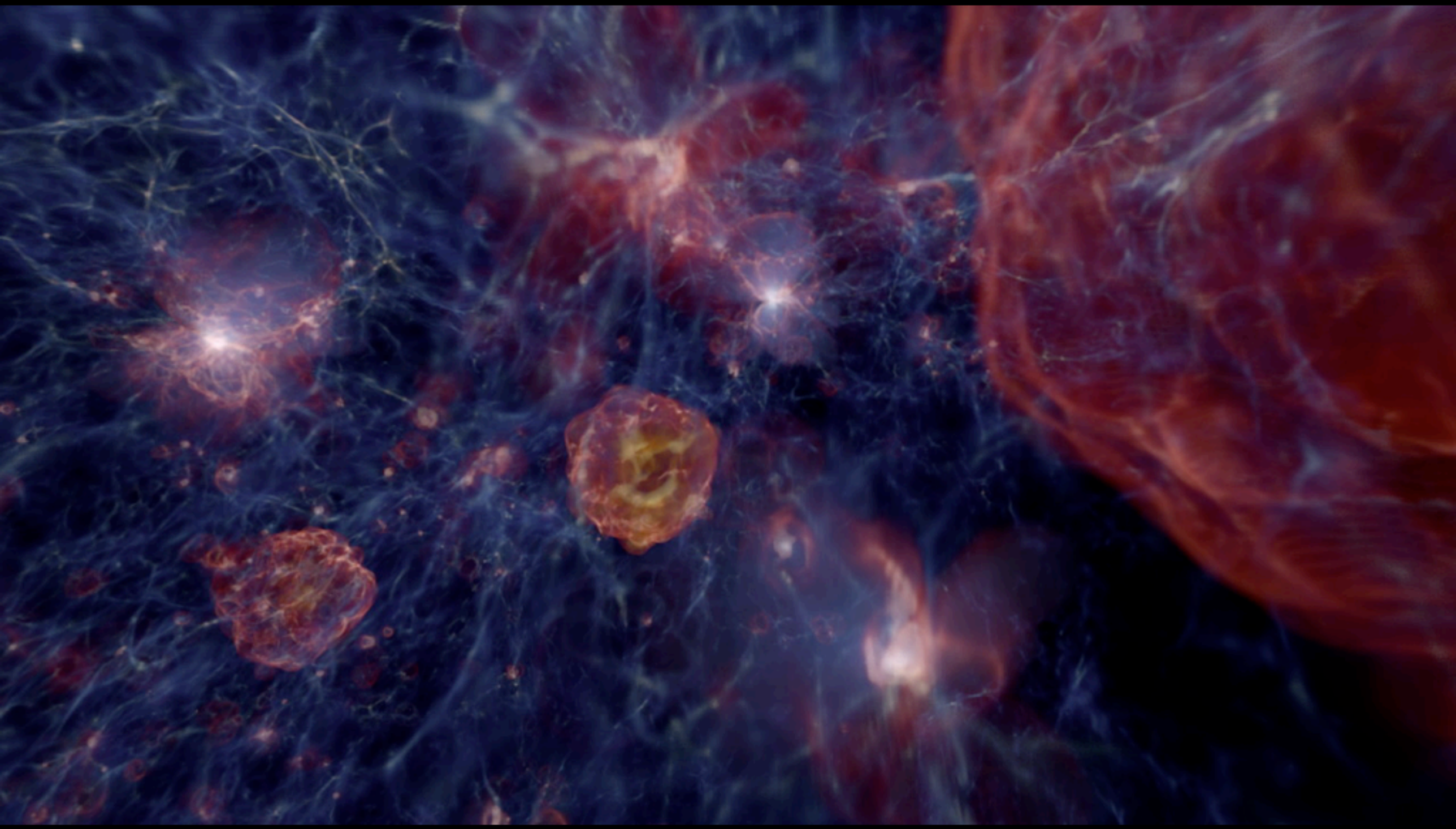

log ($\rho_{\rm tot}$ / $\rho_{\rm crit}$)
5
4
3
2
1
0
b
a
1 kpc
250 pc
a
b
log (Z [$Z_\odot$])
-2
-4
-6
-8
log ($Z_{\rm halo}$ [$Z_\odot$])
-2
-3
-4
-5


z
23
20
18
17
16
15
14
13
12
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
M(>Z) [$M_\odot$]
12
10
8
6
4
2
0
N_{stars}
1
0
-1
-2
-3
-4
-5
-6
log (Z [$Z_\odot$])
150
200
250
300
350
400
t [Myr]


z
23
20
18
17
16
15
14
13
12
10^2
10^1
10^0
10^{-1}
10^{-2}
r(>Z) [com. kpc]
12
10
8
6
4
2
0
100
75
50
25
0
%
150
200
250
300
350
400
t [Myr]
N_{stars}
1
0
-1
-2
-3
-4
-5
-6
log (Z [$Z_\odot$])

Early galaxy populations

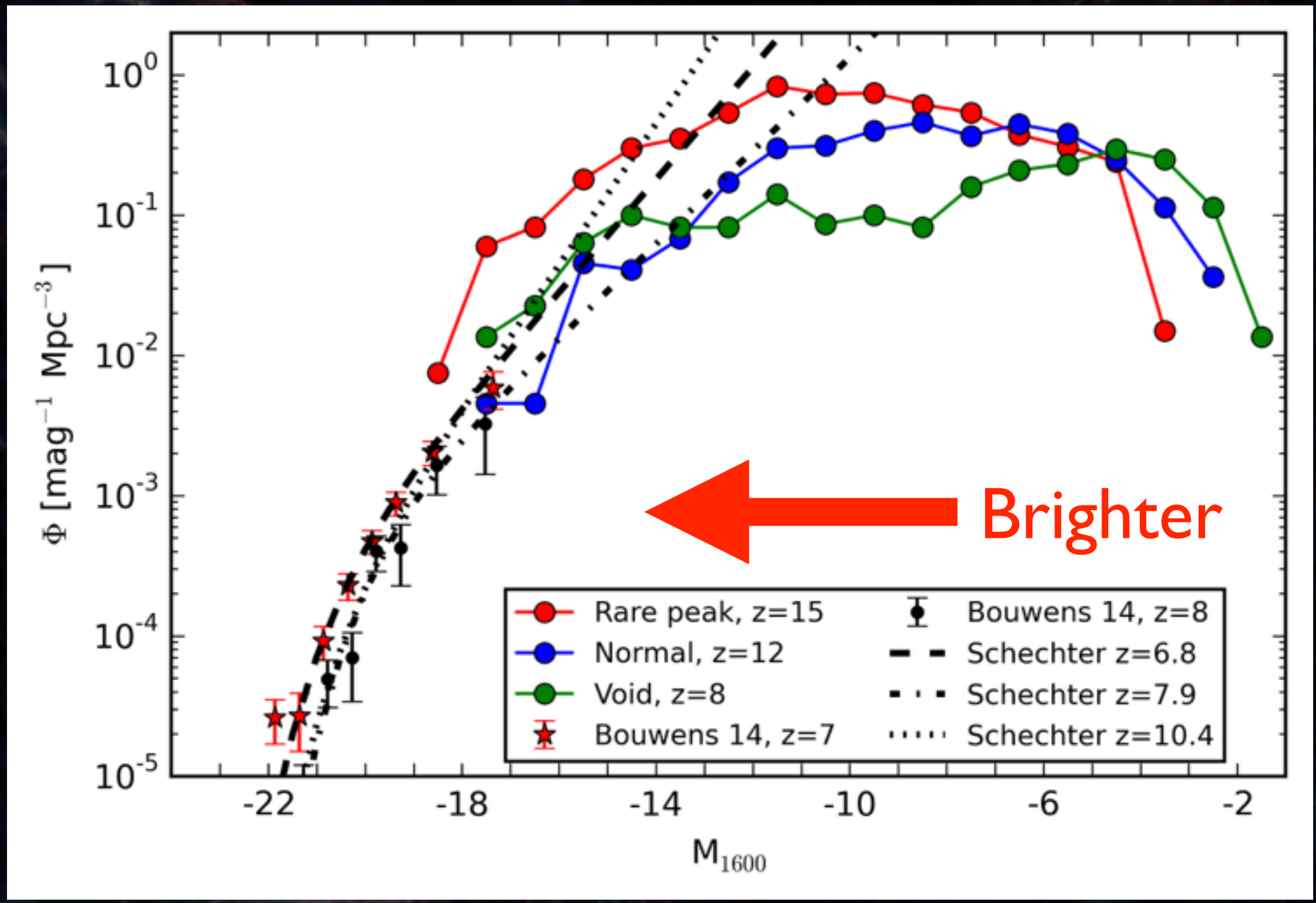
Hao Xu et al. 2014, 15, 16; Chen et al. 2014;
O'Shea et al. 2015, 2017



Movie c/o Bob Patterson, NCSA Advanced Visualization Laboratory

Luminosity function of early galaxies

$$\frac{d^2N}{dMdV}$$

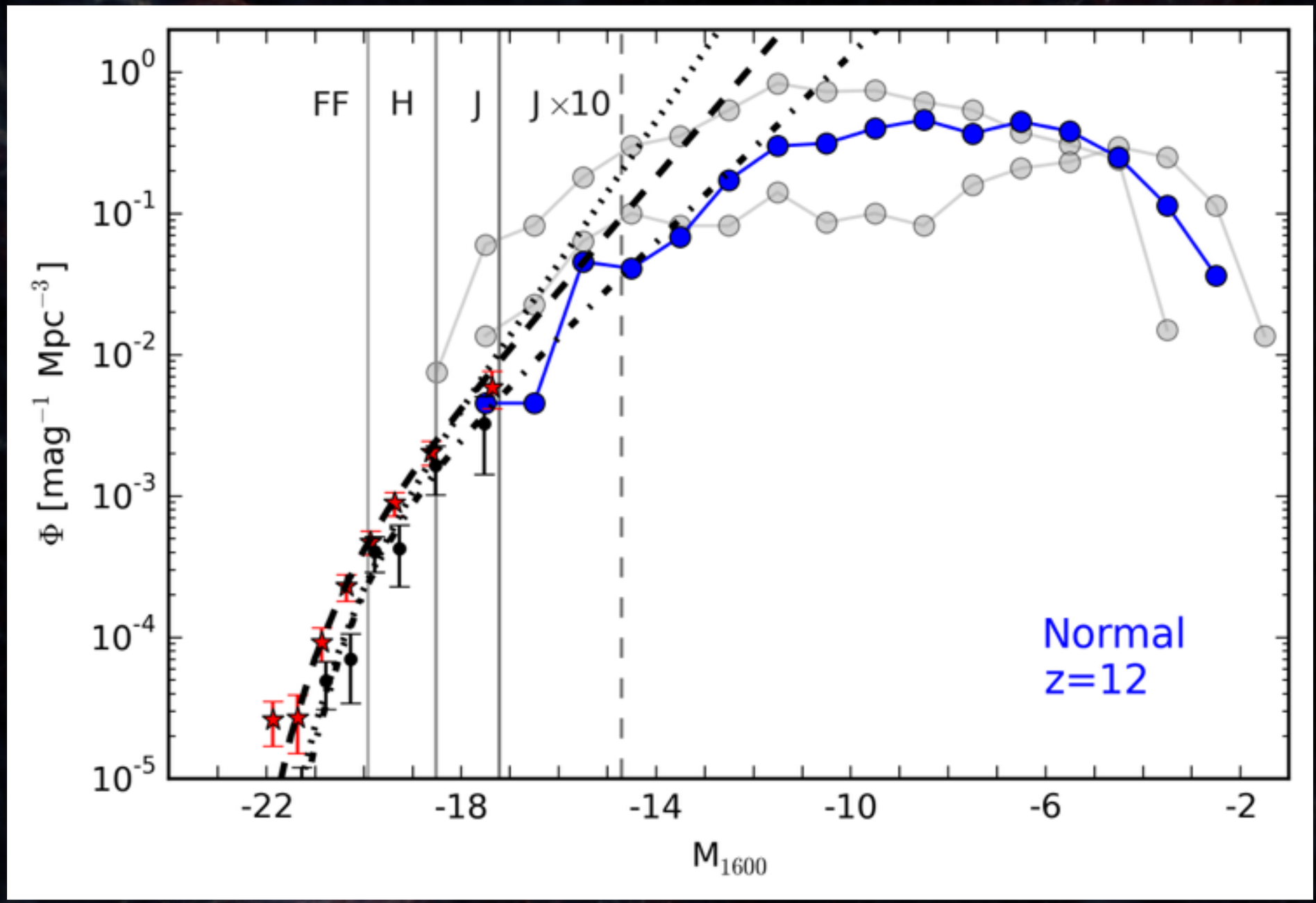


More per volume

O'Shea et al. 2015

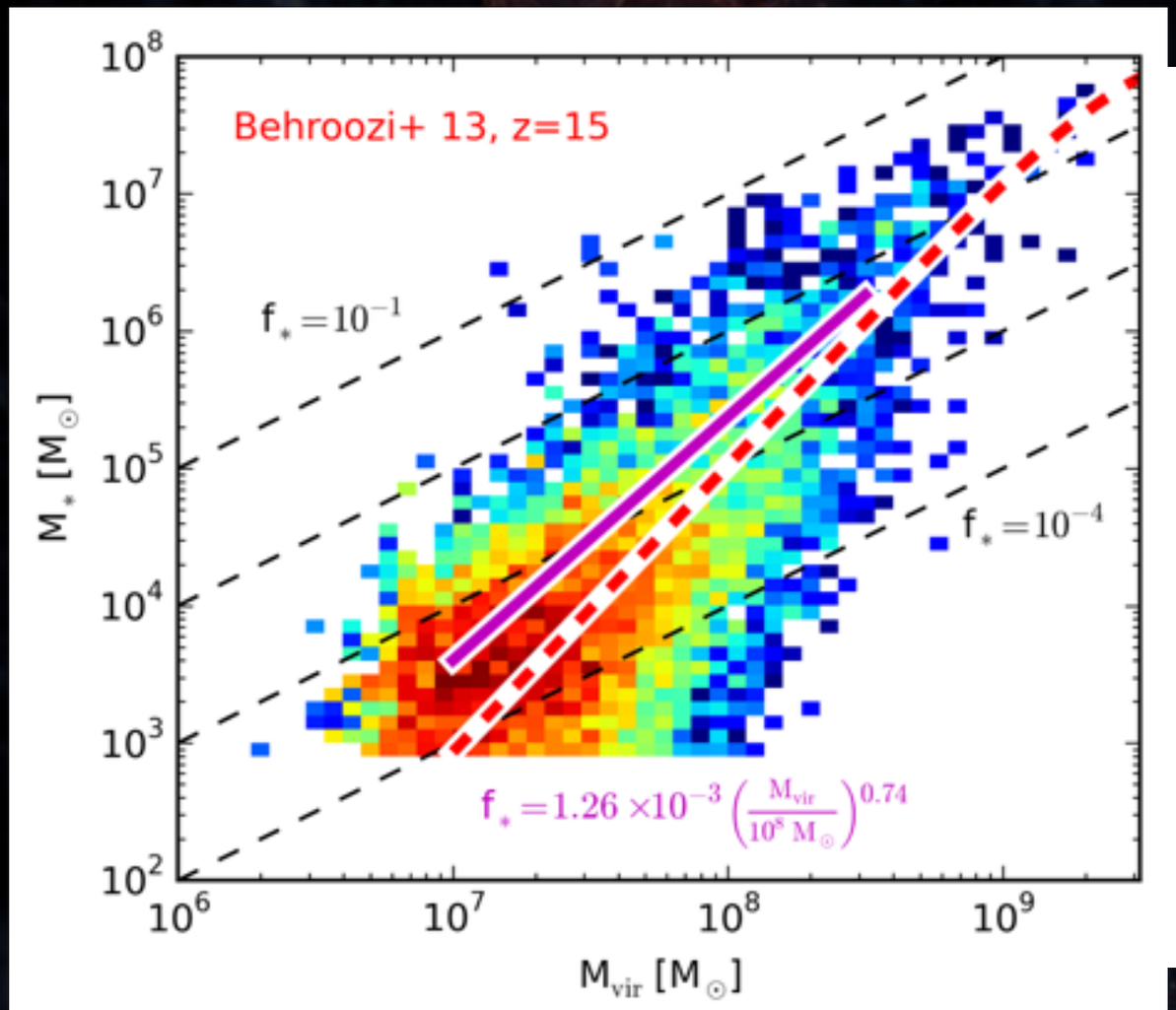
Luminosity function of early galaxies

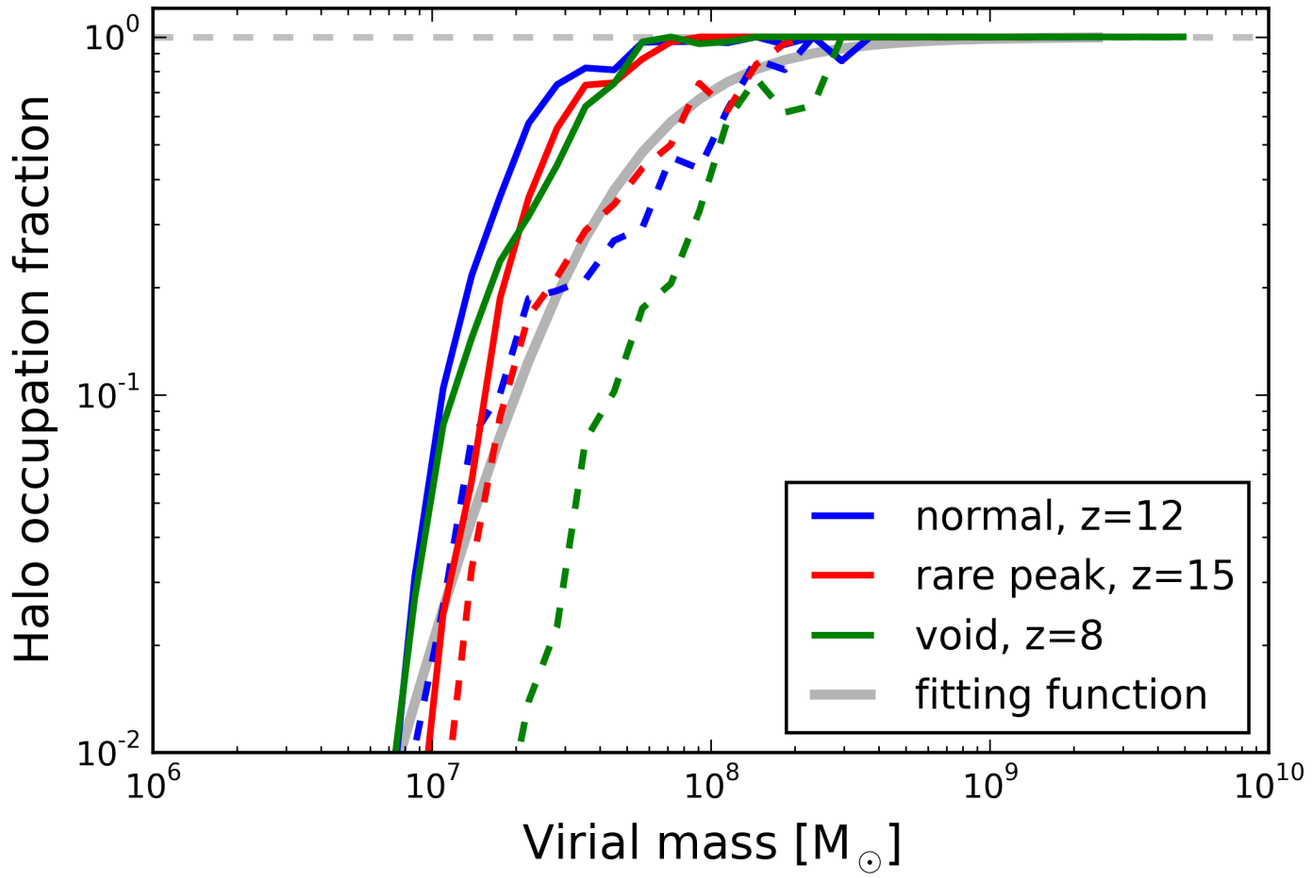
$$\frac{d^2N}{dMdV}$$



O'Shea et al. 2015

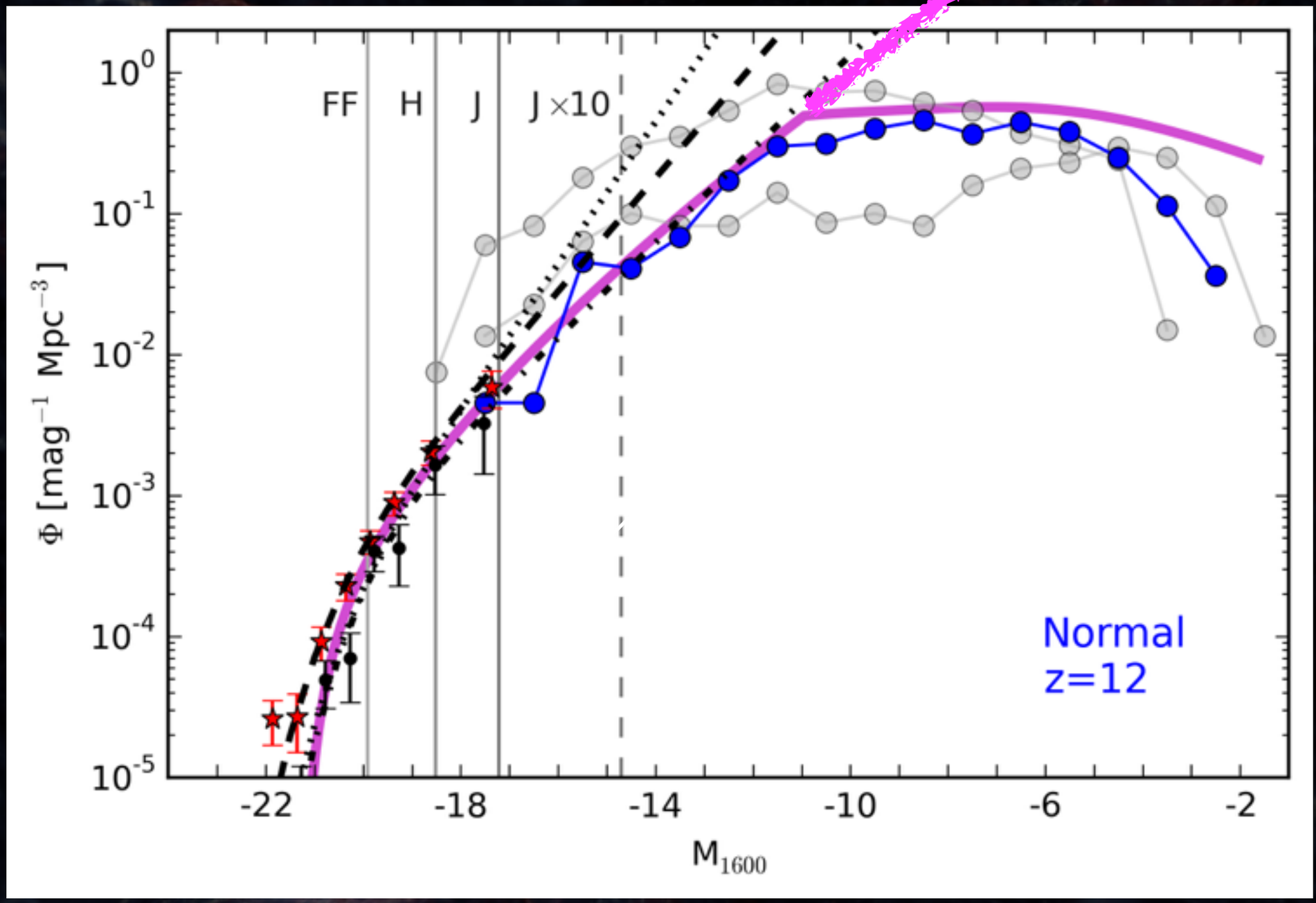
Luminosity function of early galaxies





O'Shea et al. 2015

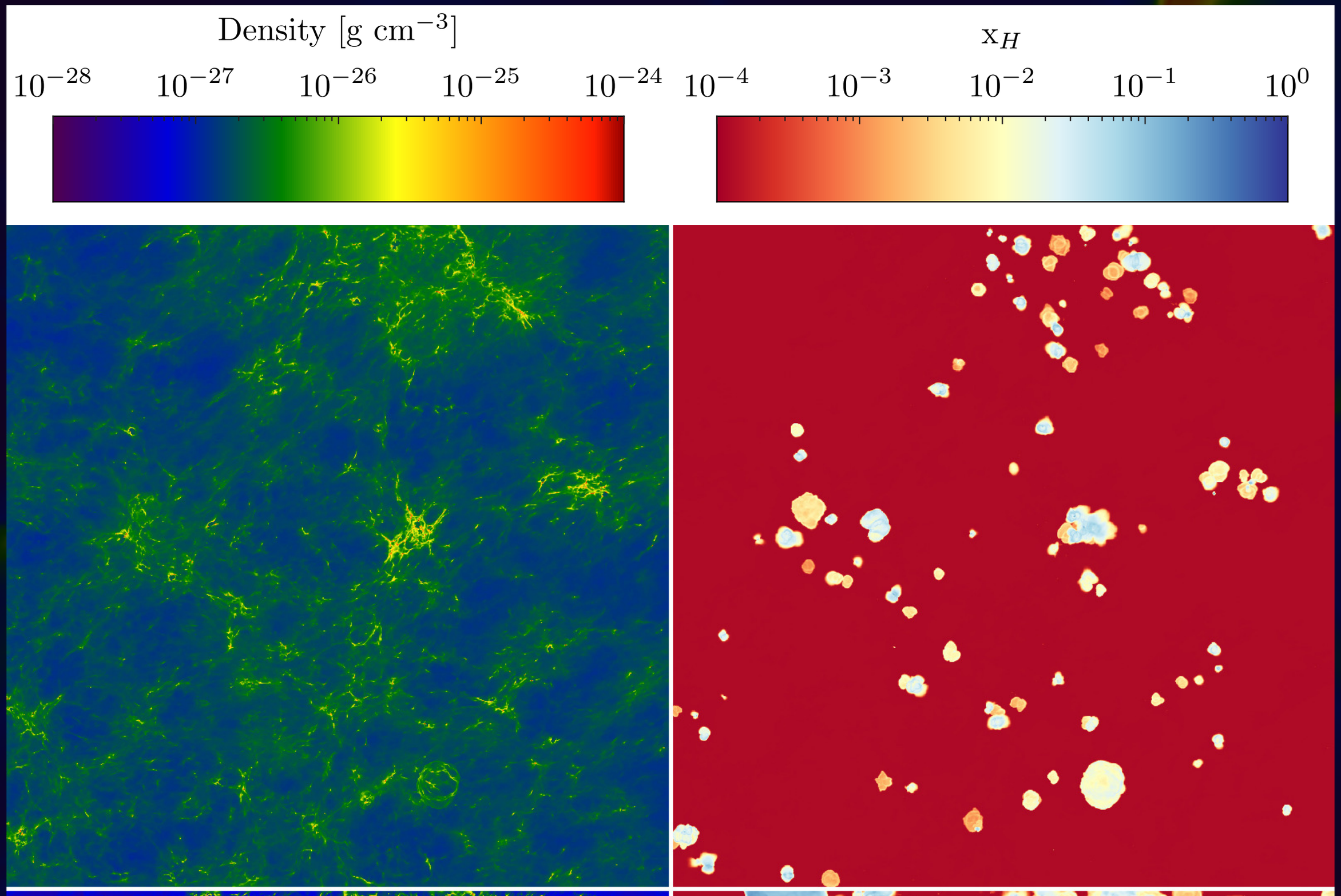
Luminosity function of early galaxies

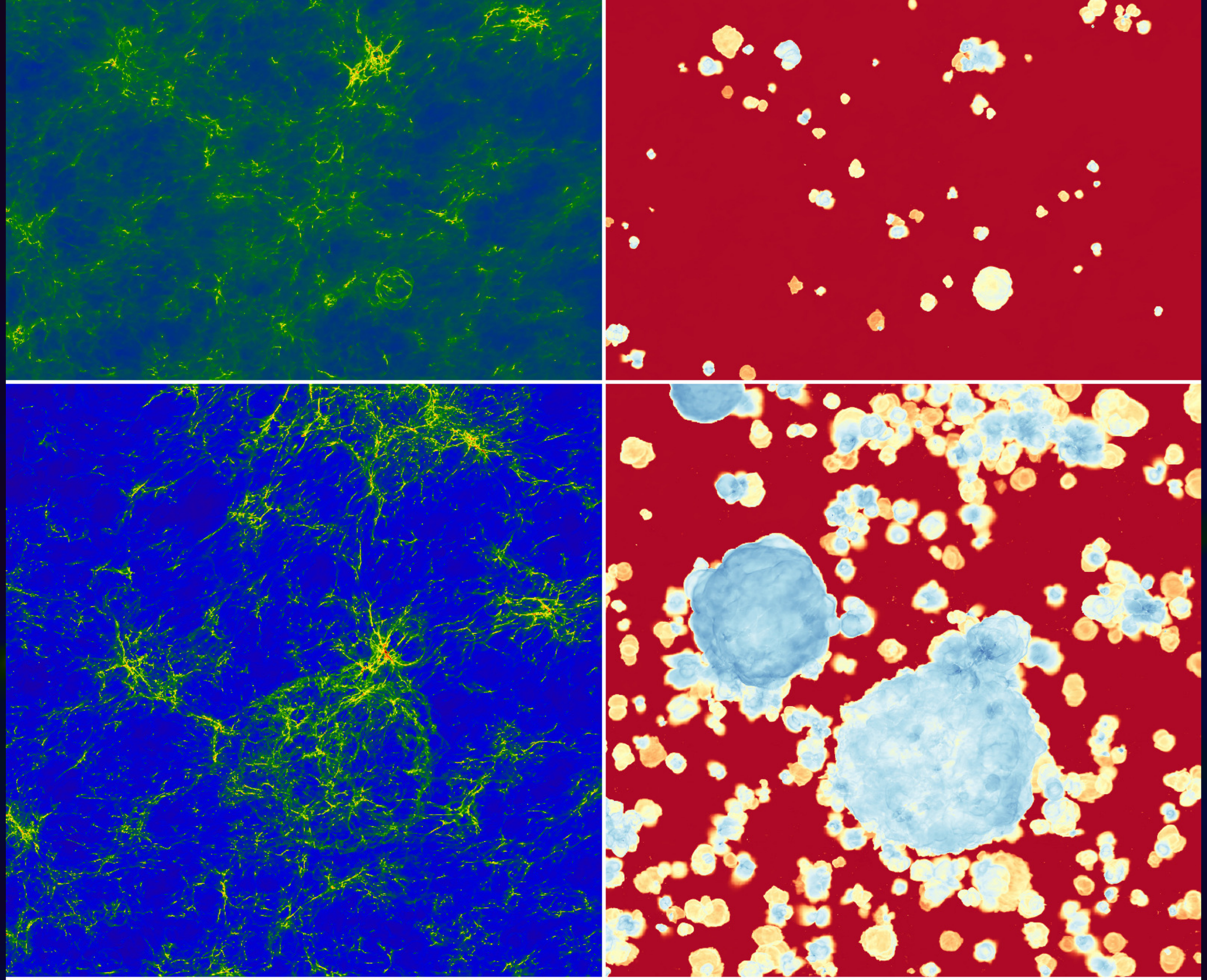


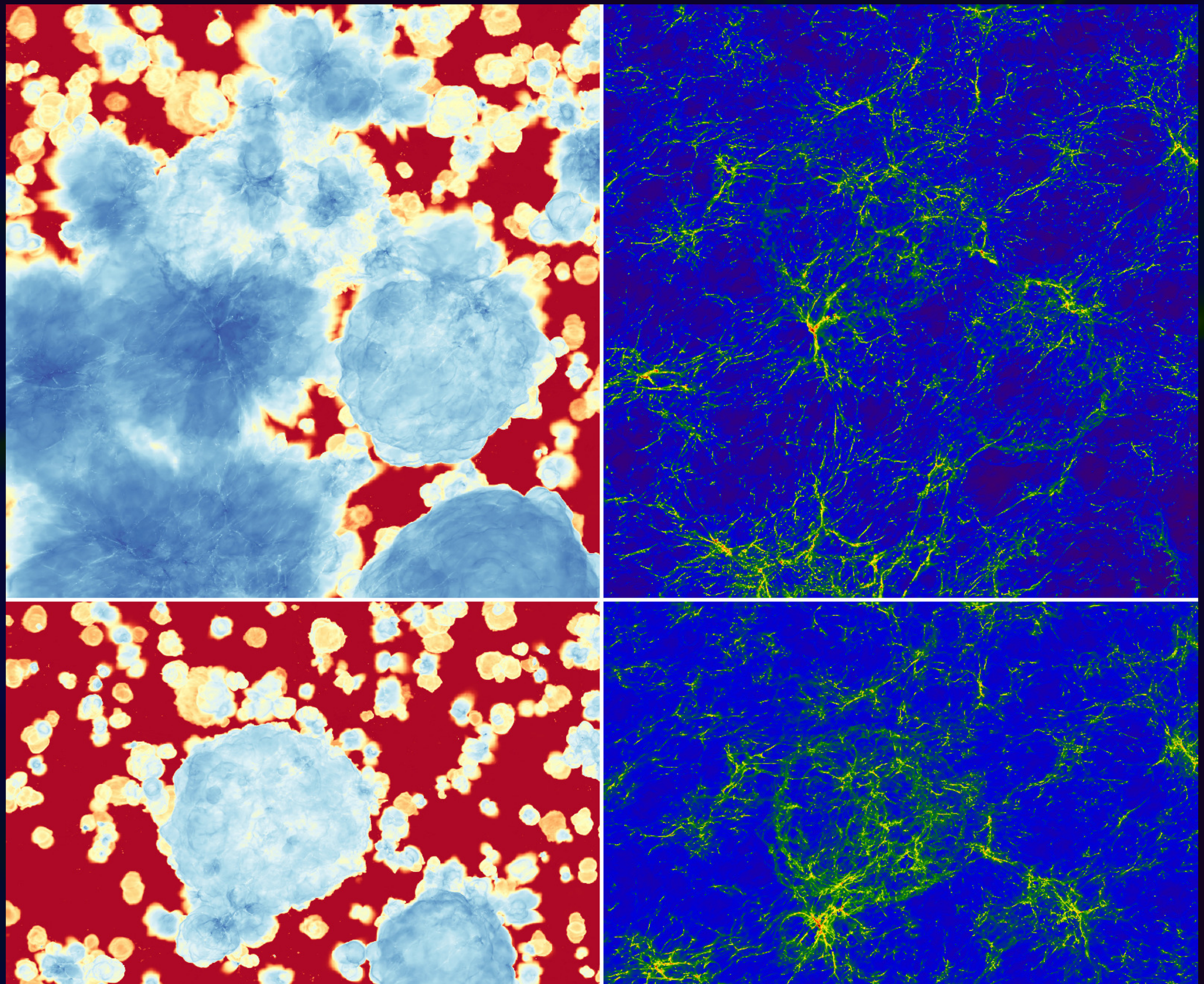
O'Shea et al. 2015

O'Shea et al. 2017; NCSA Advanced Viz. Lab

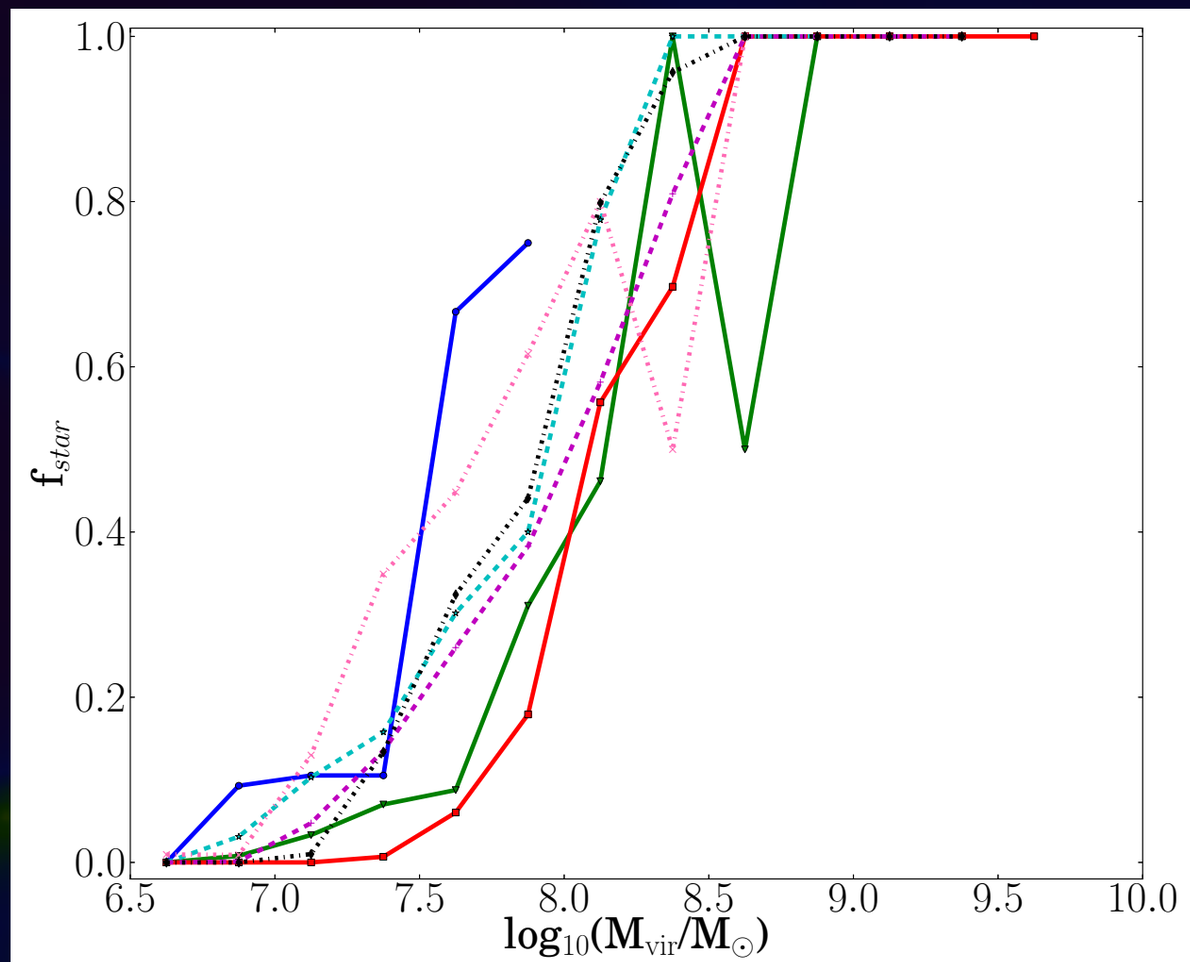
Escape fraction of ionizing radiation



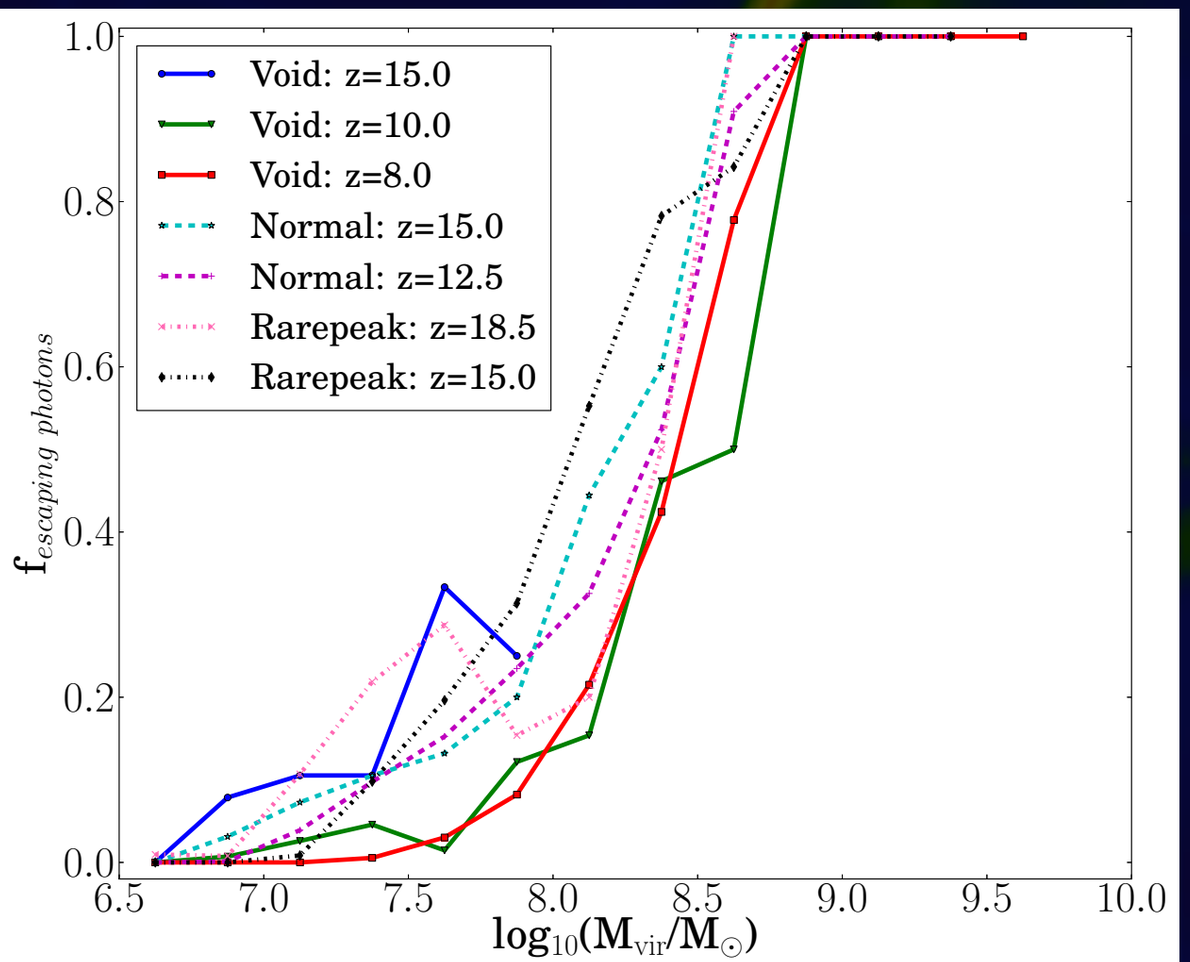




Escape fraction of ionizing radiation



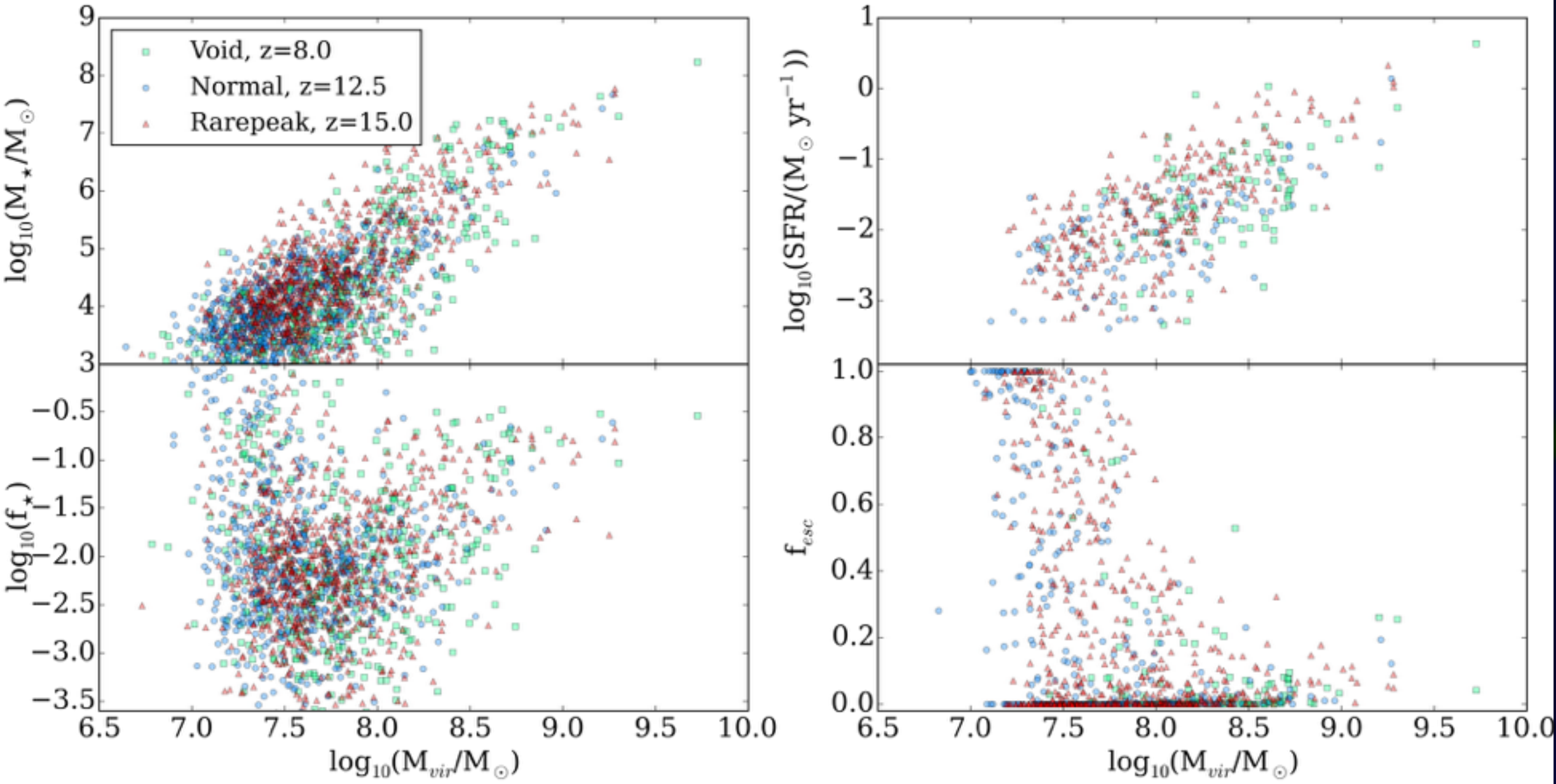
Fraction of halos
w/active star formation



Fraction of halos
w/escaping photons

Xu et al. 2016

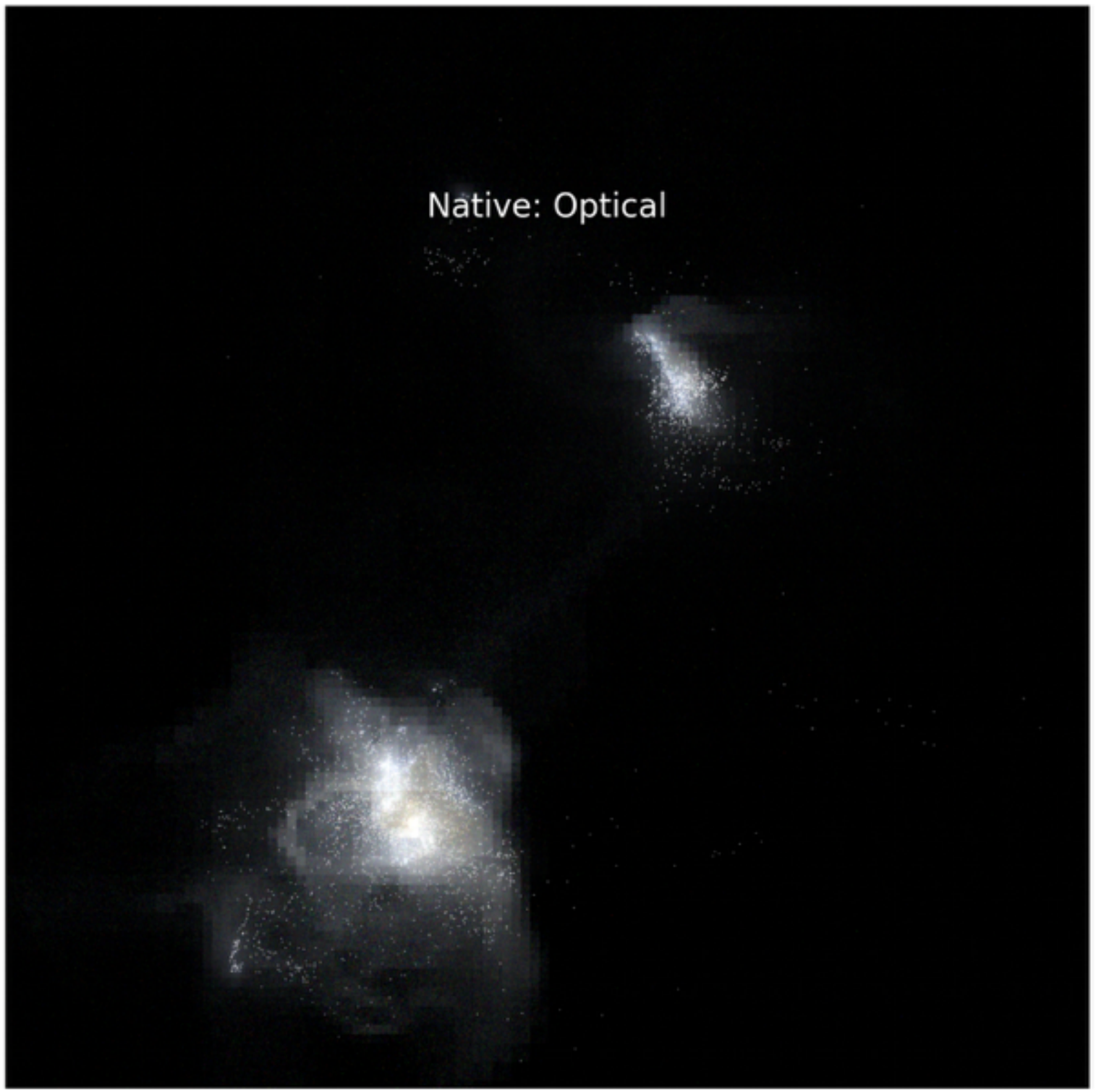
Escape fraction of ionizing radiation

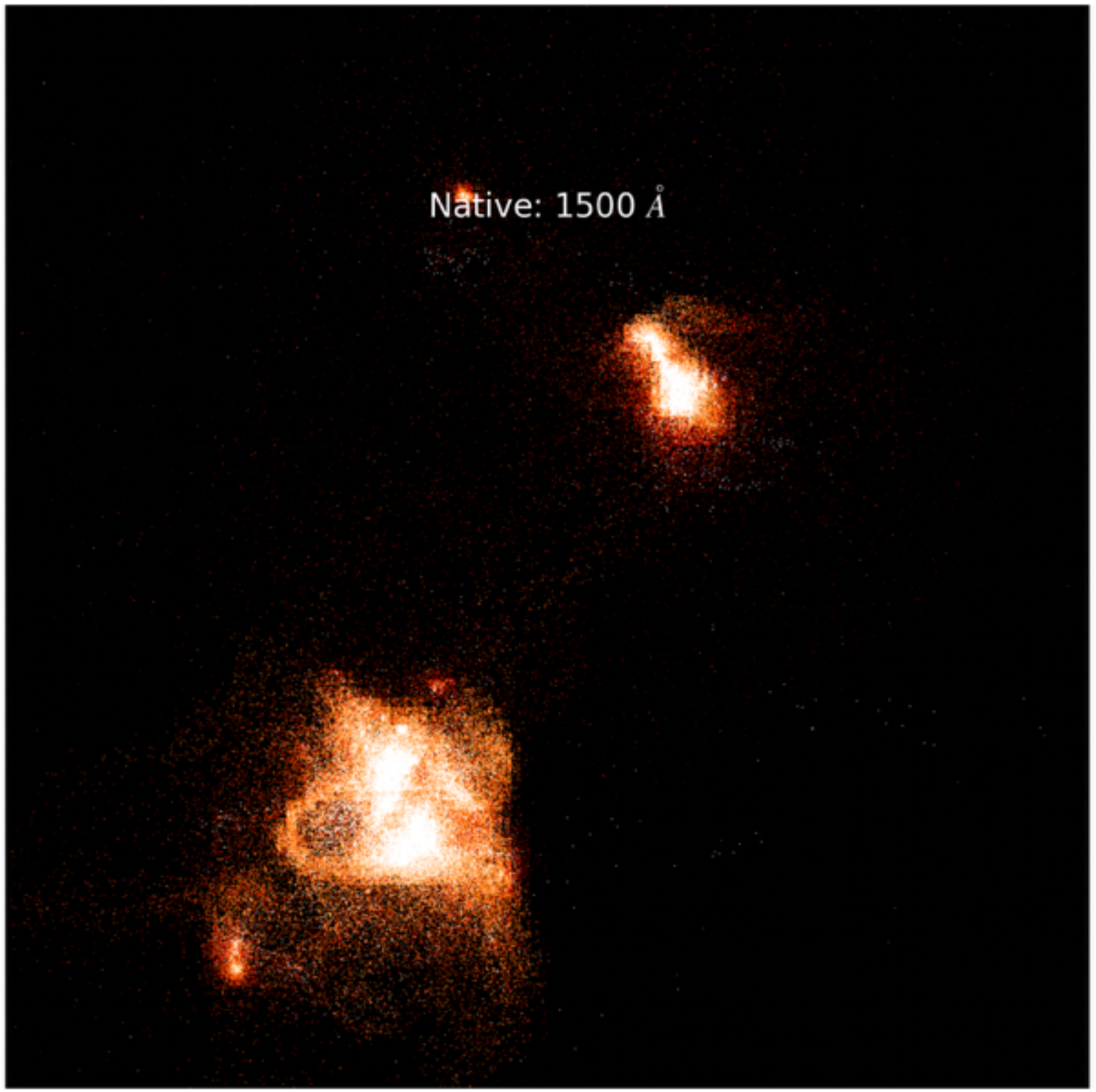


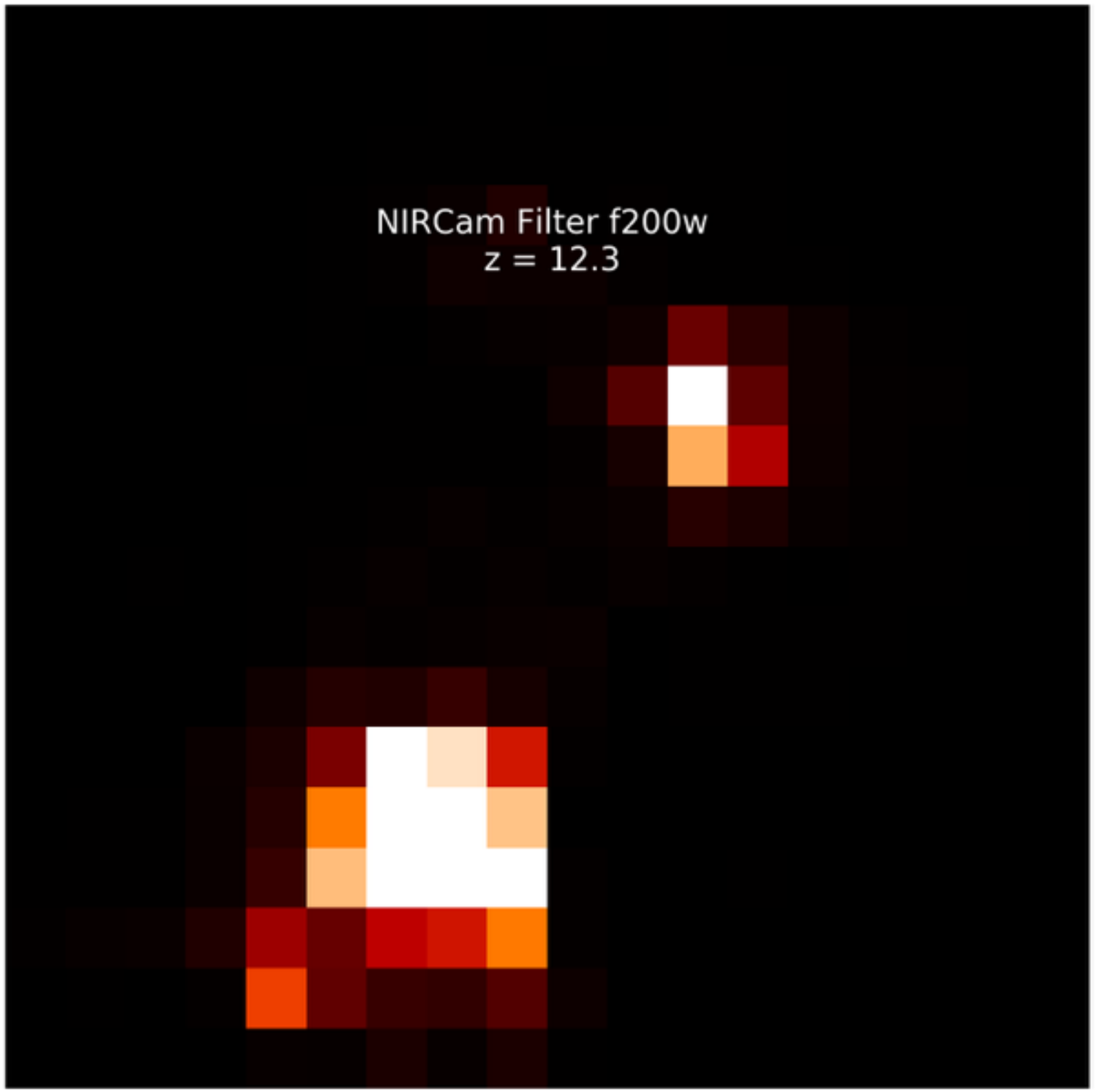
Xu et al. 2016

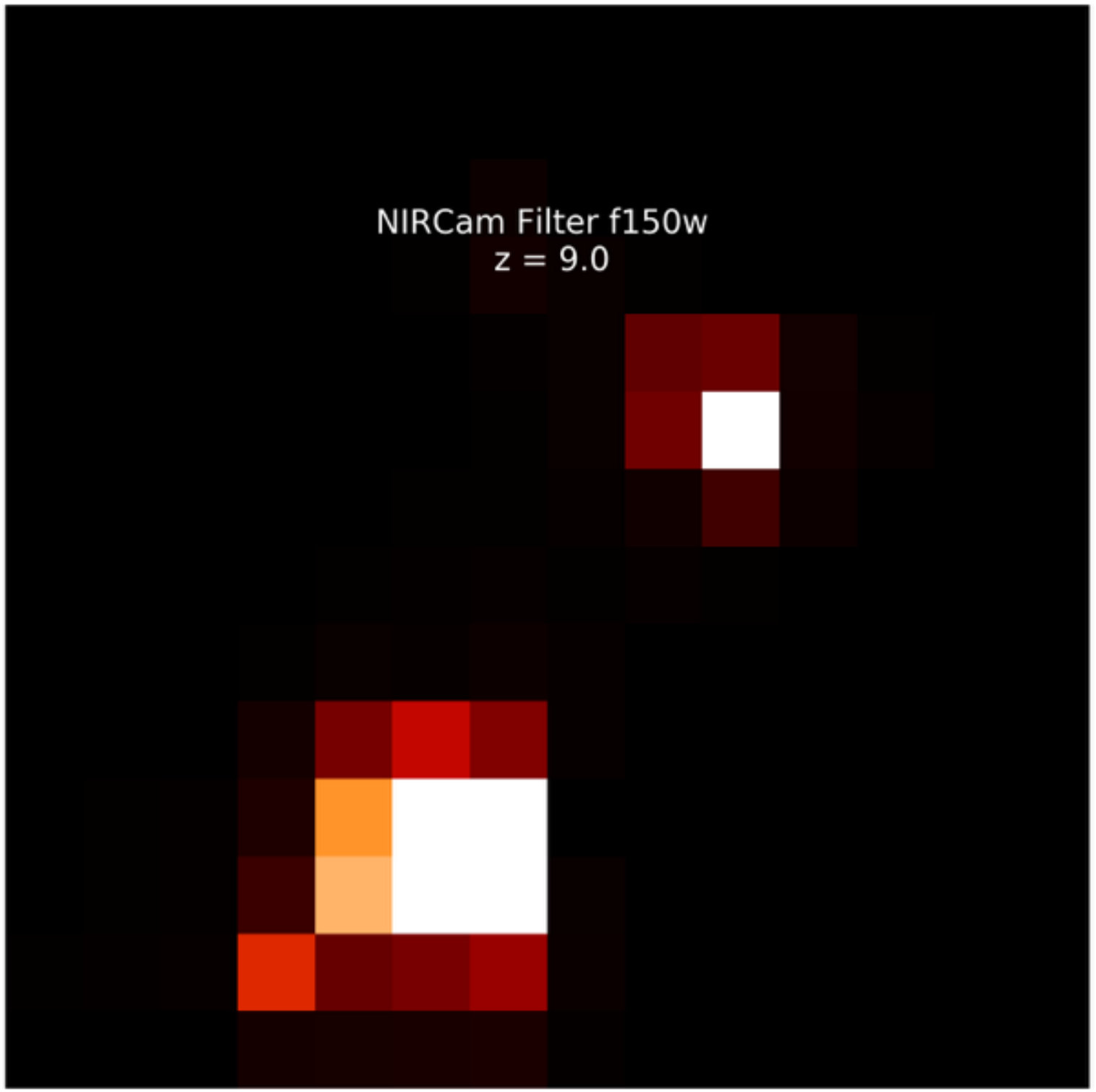
Observations of high-z galaxies with JWST

Barrow et al. 2017, MNRAS, 469, 4864
Barrow et al. 2017, submitted (arXiv:1709.04473)


Native: Optical


Native: 1500 $\AA$


NIRCam Filter f200w
z = 12.3


NIRCam Filter f150w
z = 9.0

Connecting high redshift galaxies to the Milky Way

Griffen et al. 2016, ApJ, 818, 10
Griffen et al. 2017, ApJ accepted (arXiv:1611.00759)
Côté et al. 2017, submitted (arXiv:1710.06442)

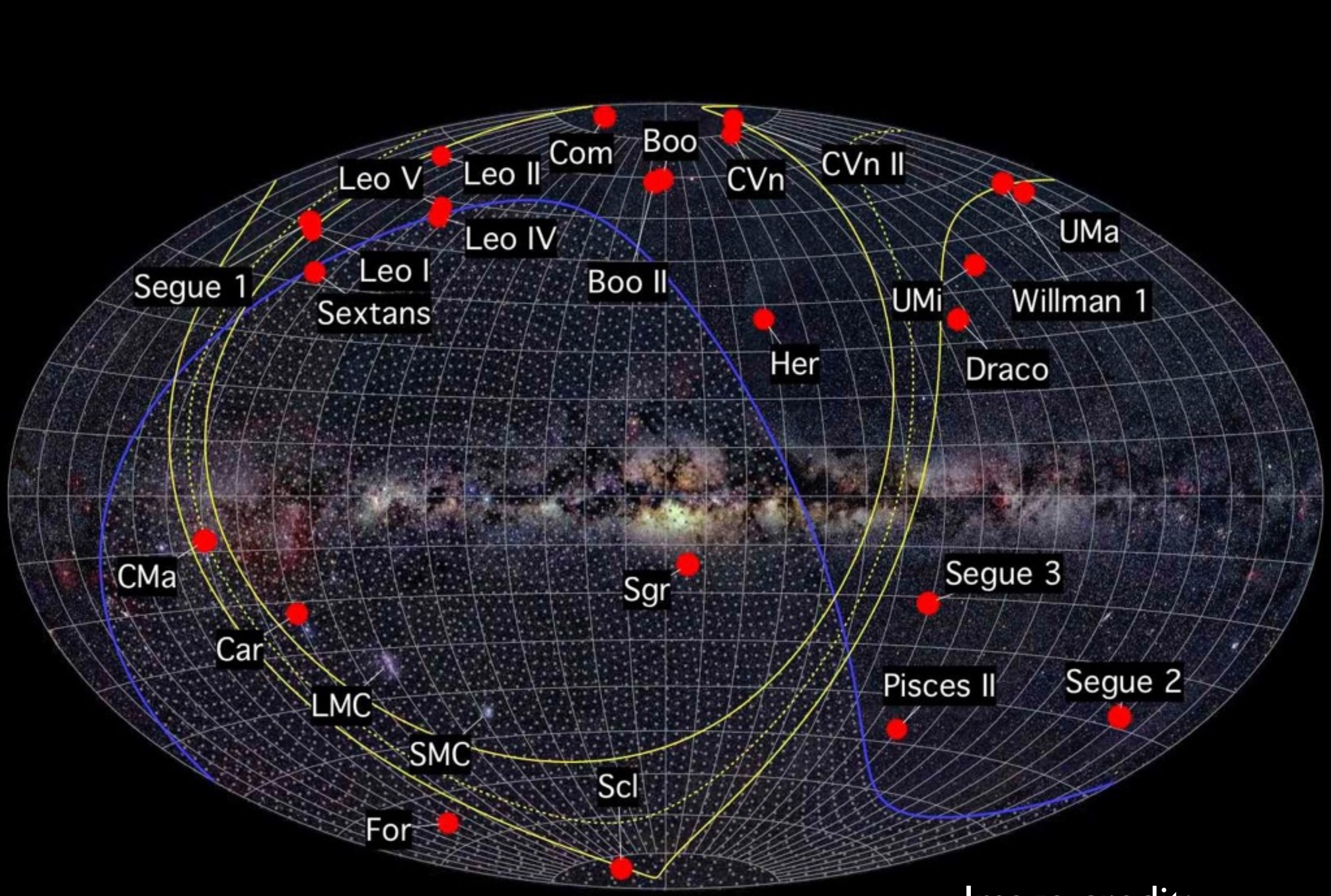


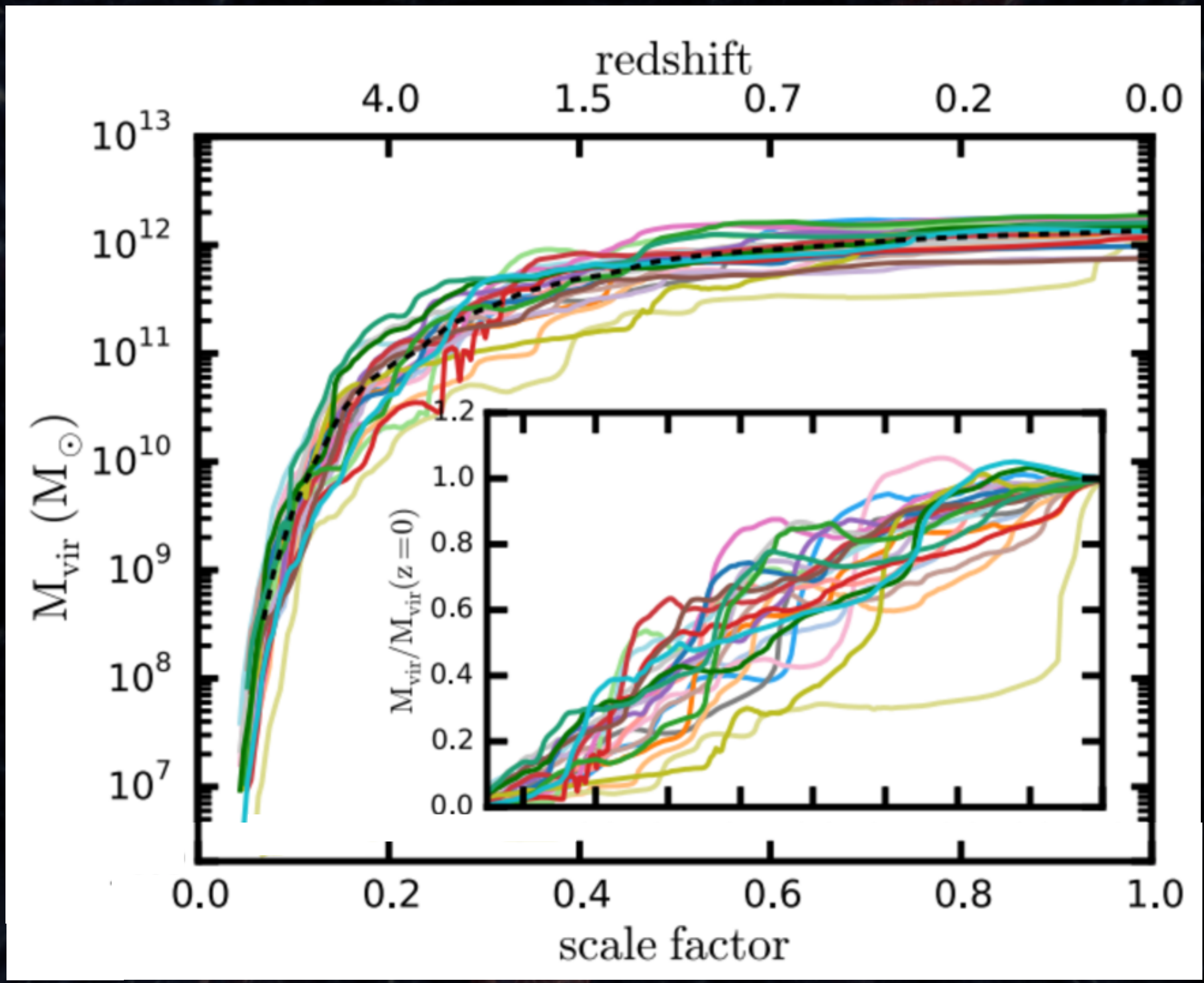
Image credit:
Anna Frebel (MIT)

redit:
Frebel (MIT)

Two challenges:

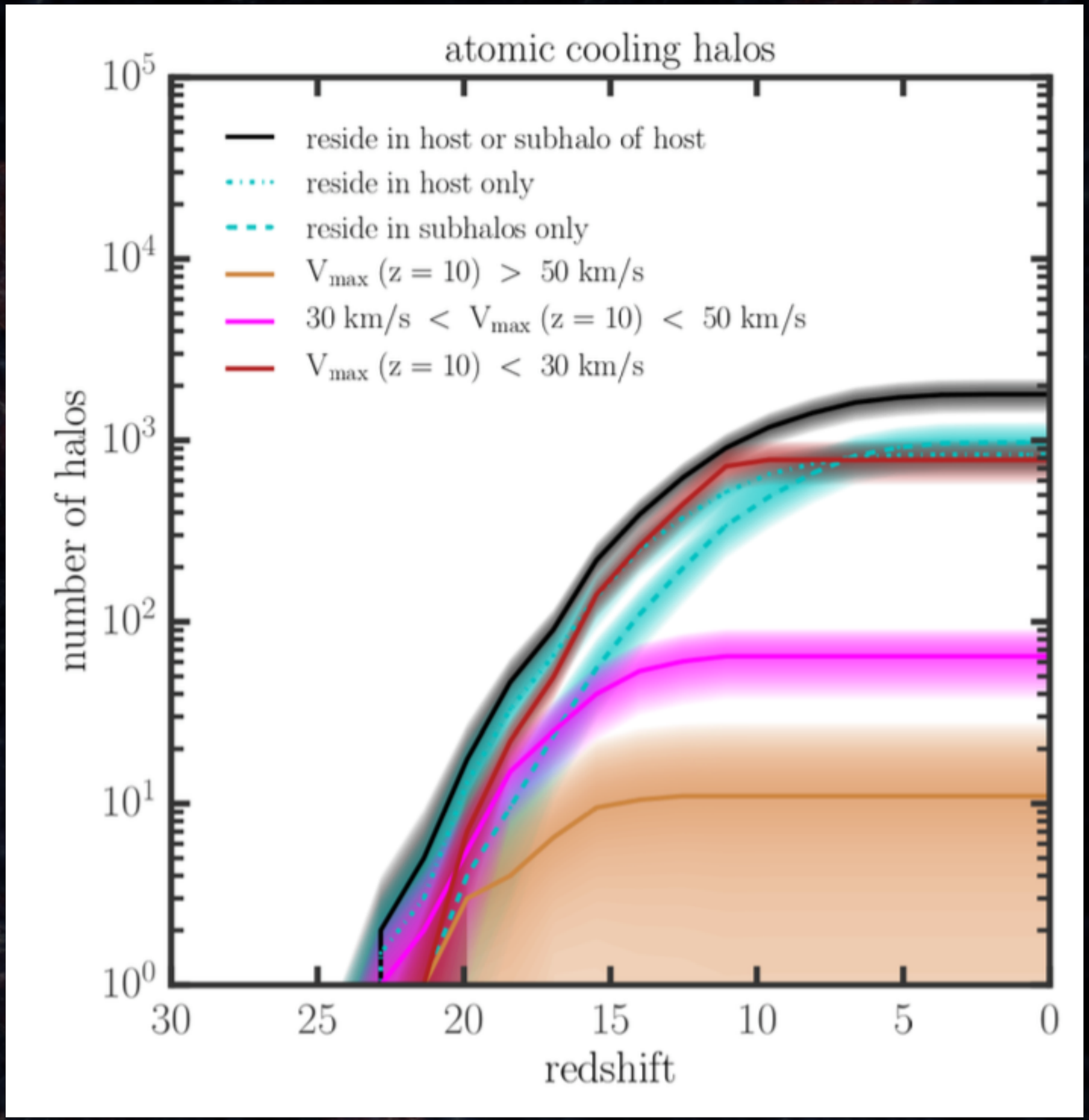
1. We don't know some critical information about the Milky Way!

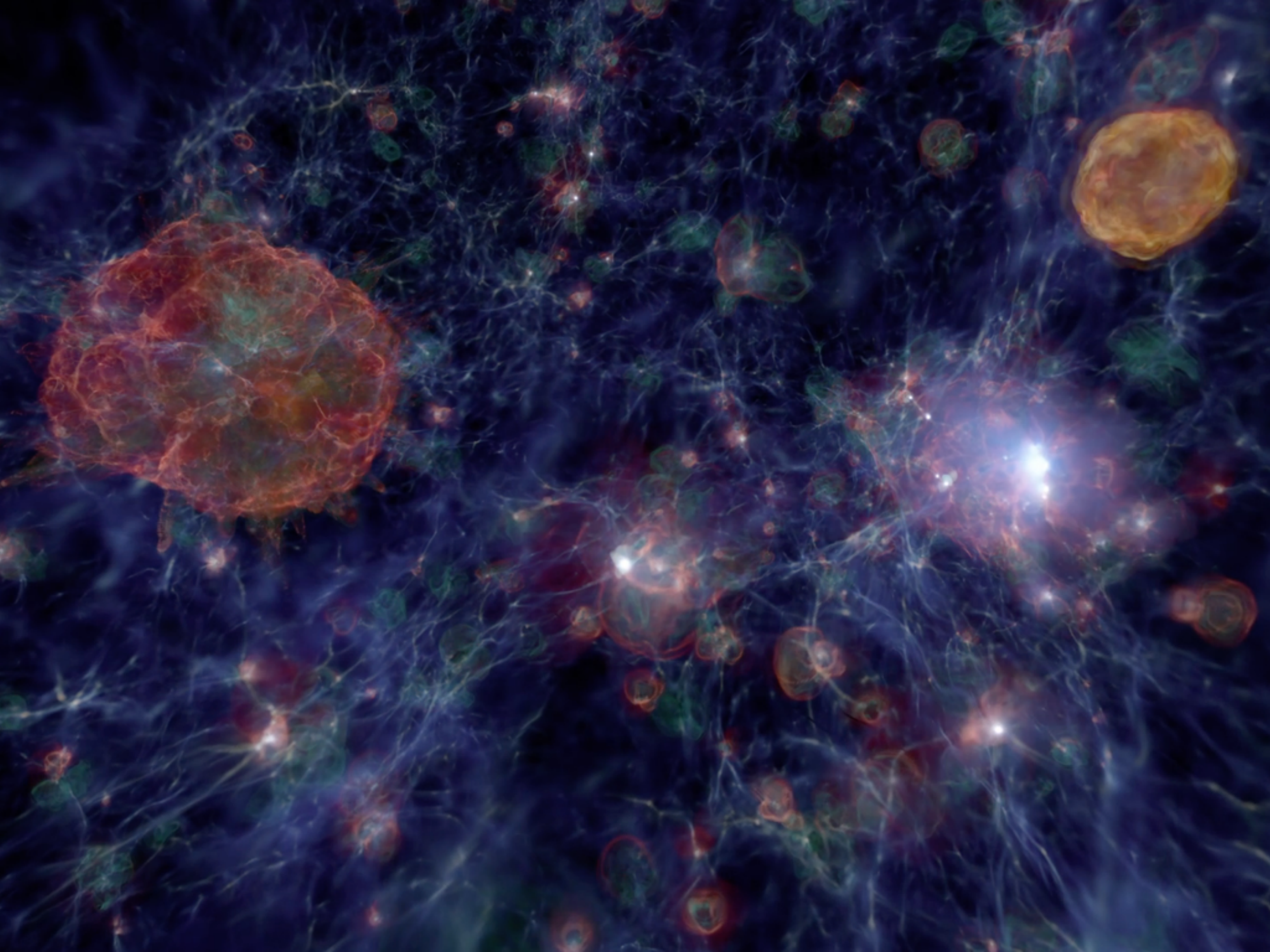
2. Doing physics-rich simulations of the Milky Way that encompass mini-halos and all physics to z=0, is impossible (for a while)

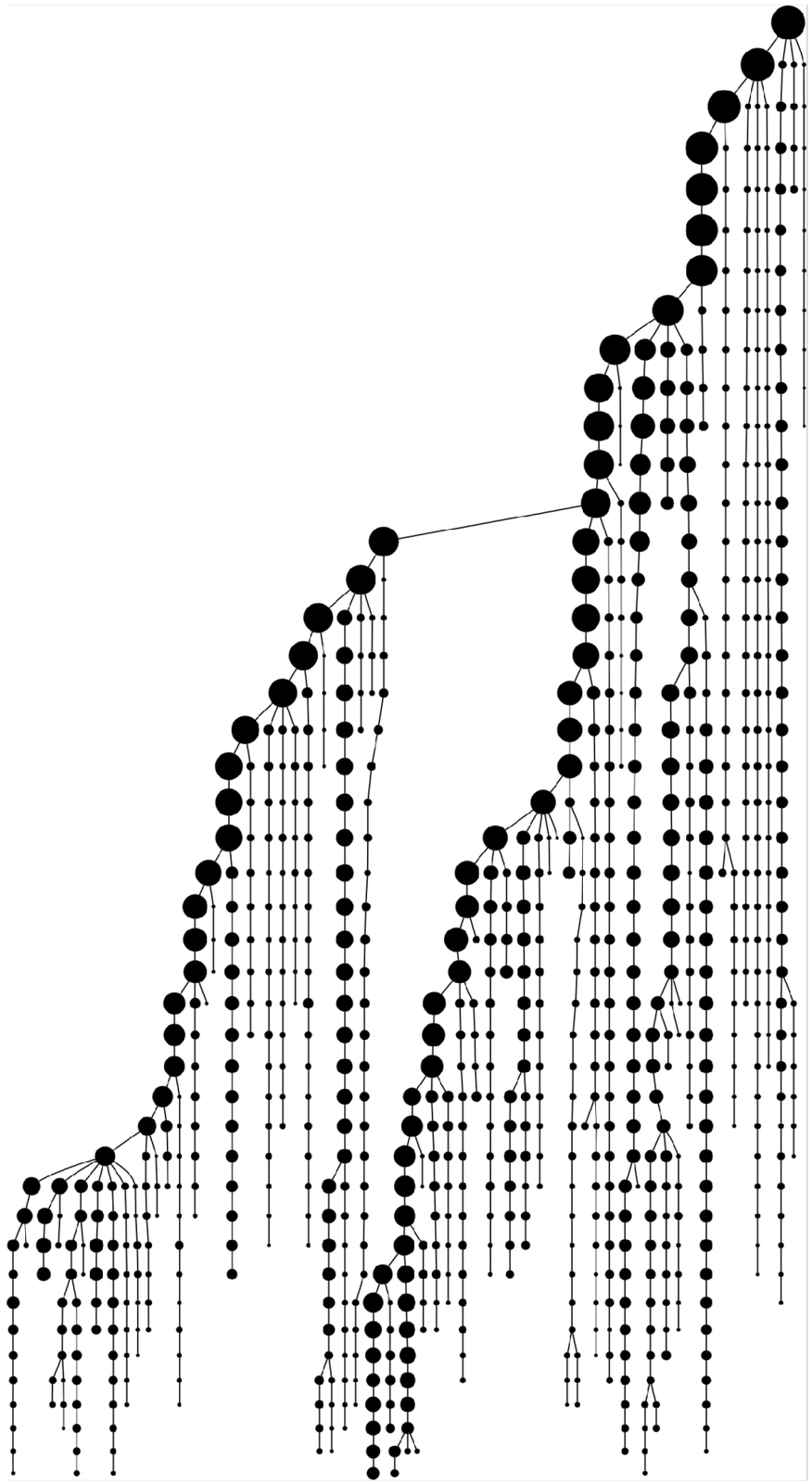


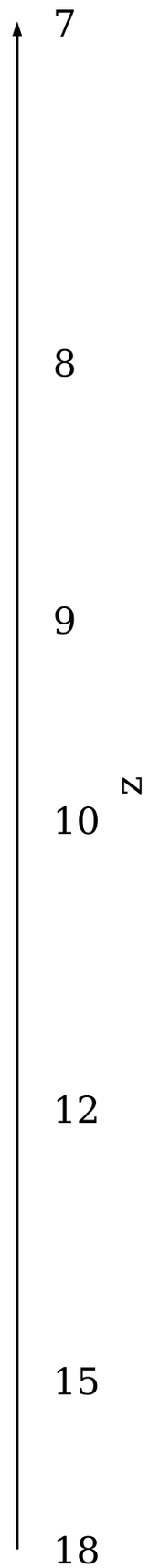
Griffen+ 2016

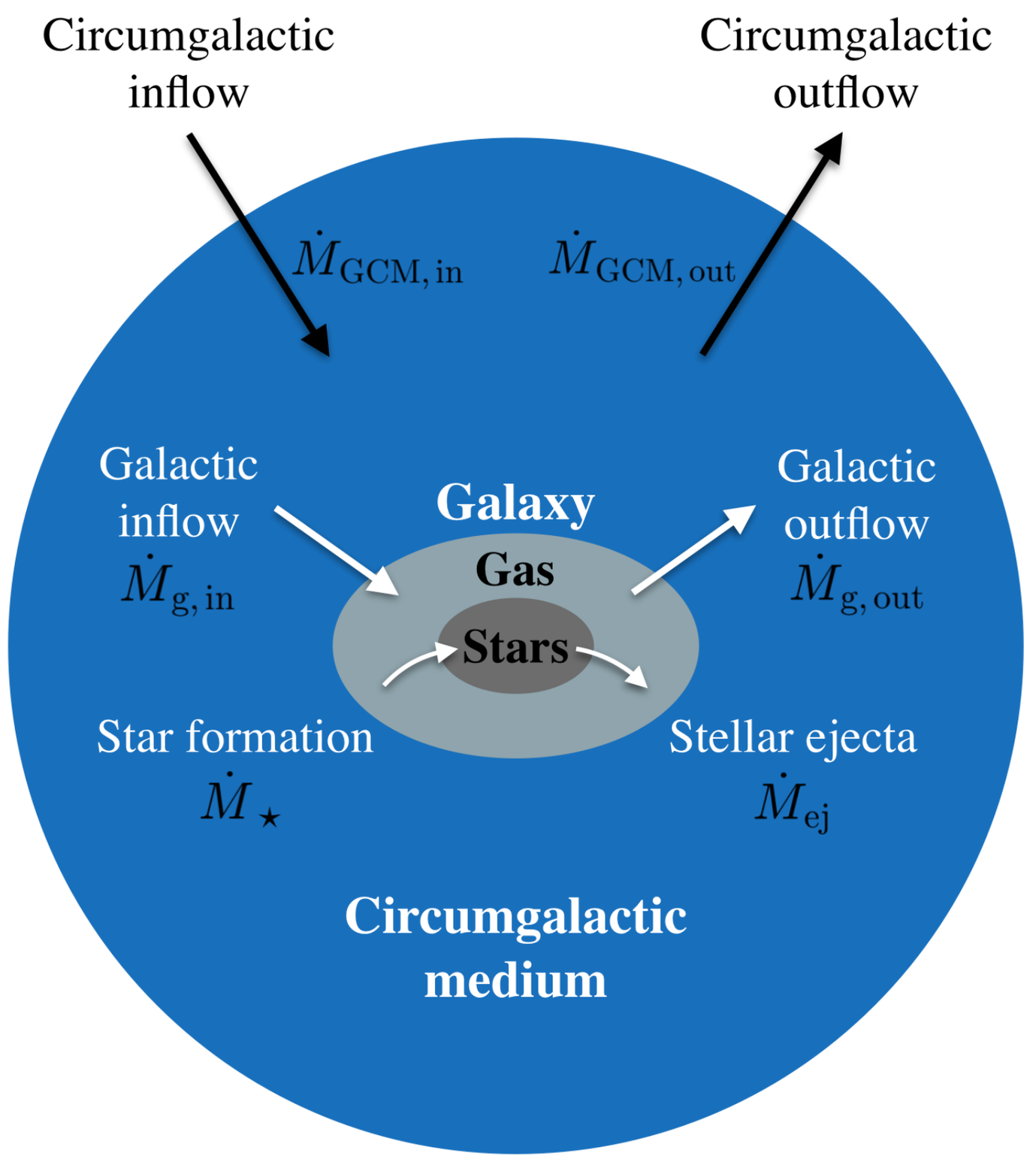
Griffen+
2017











Côté et al. 2017

Takeaways

- Simulating galaxies is challenging due to complex physics, dynamic range, and statistics.
- The transition between primordial and metal-enriched star formation is locally complex.
- Star formation is inefficient in small, early galaxies - neighbors quench each other!

Takeaways

- Simulating galaxies is challenging due to complex physics, dynamic range, and statistics.
- The transition between primordial and metal-enriched star formation is locally complex.
- Star formation is inefficient in small, early galaxies - neighbors quench each other!
- We're working on making connections to the Milky Way and its neighbors in the Local Group! (Stay tuned!)