reionisation: in the context of small-scale structure

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reionisation: in the context of

small-scale **structure**

the satellites of the Milky Way

the nature of dark matter

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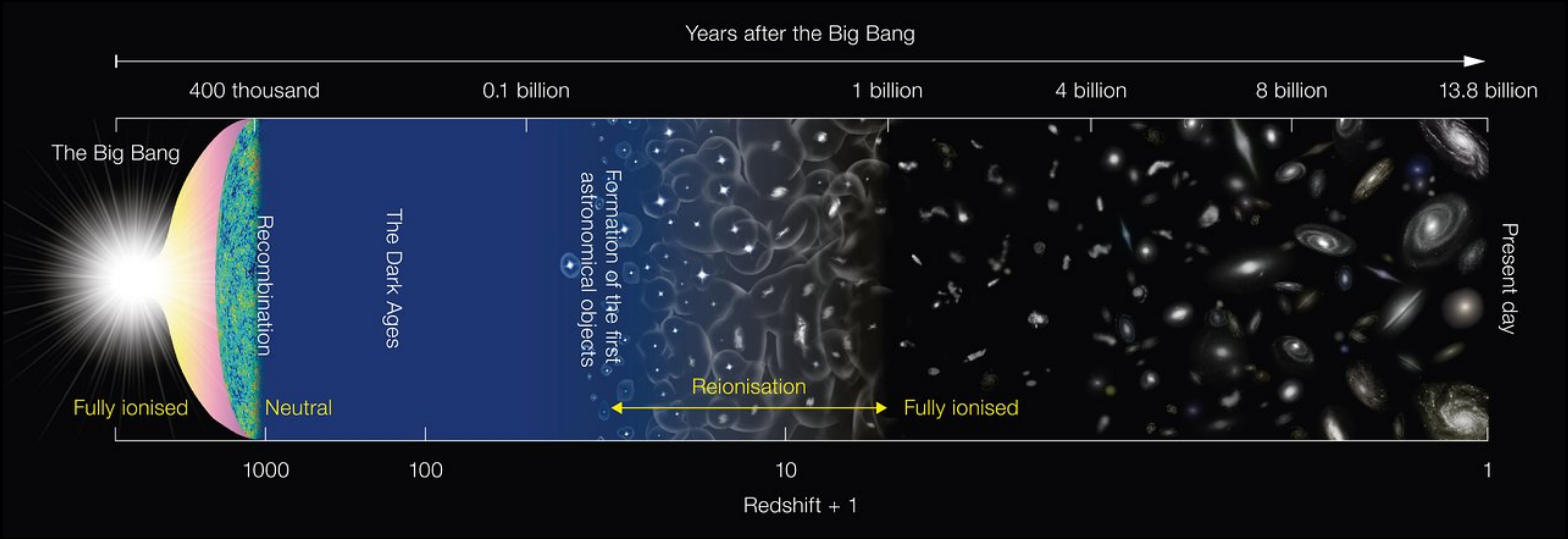
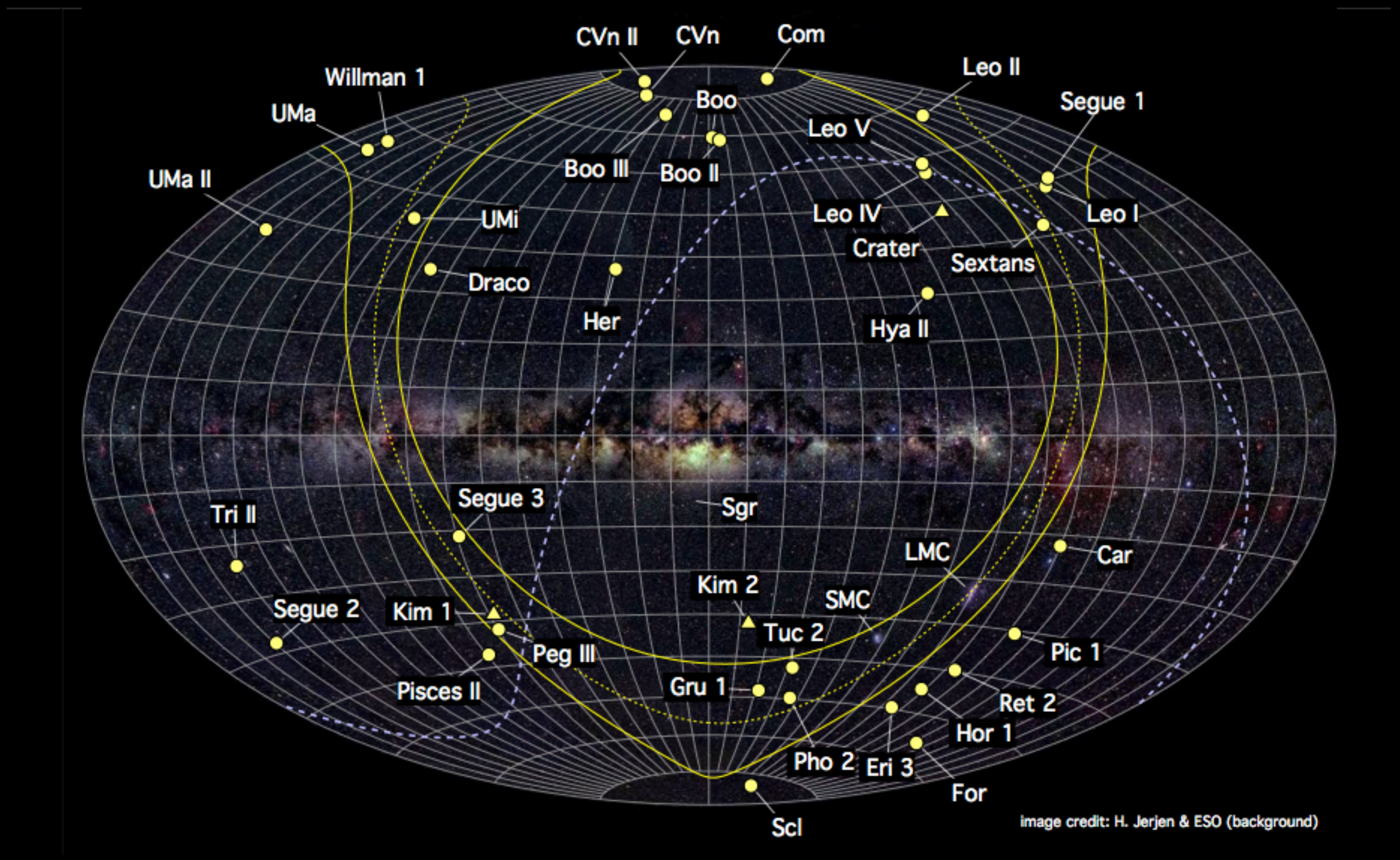
a milestone in the history of the cosmos



[Image credit: NAOJ / ESO]

the missing satellites "problem"

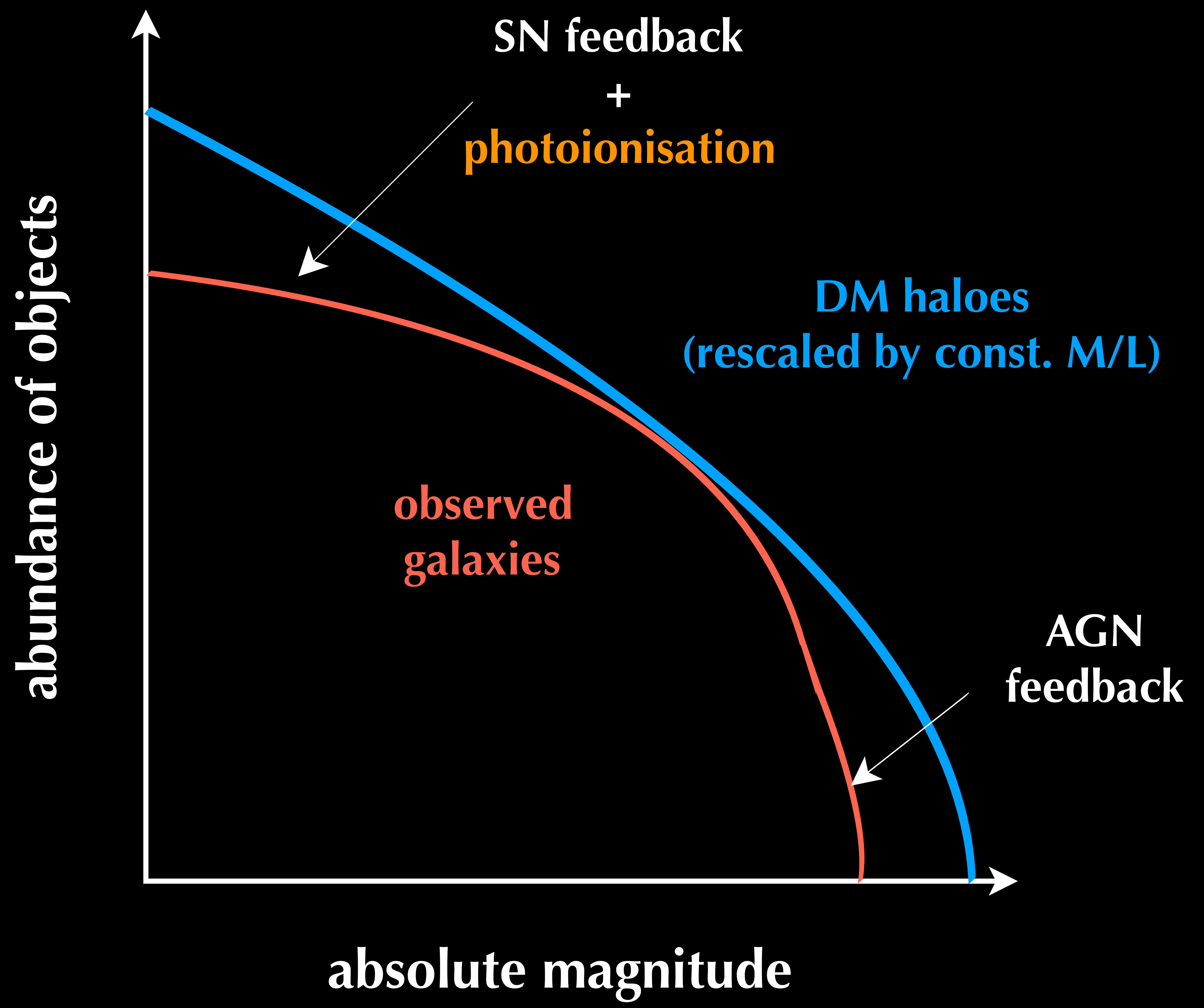


~ 54 satellites known around MW (SDSS+DES)

> 100,000 DM subhaloes predicted by CDM

why do most subhaloes remain dark?

it ain't easy being a galaxy



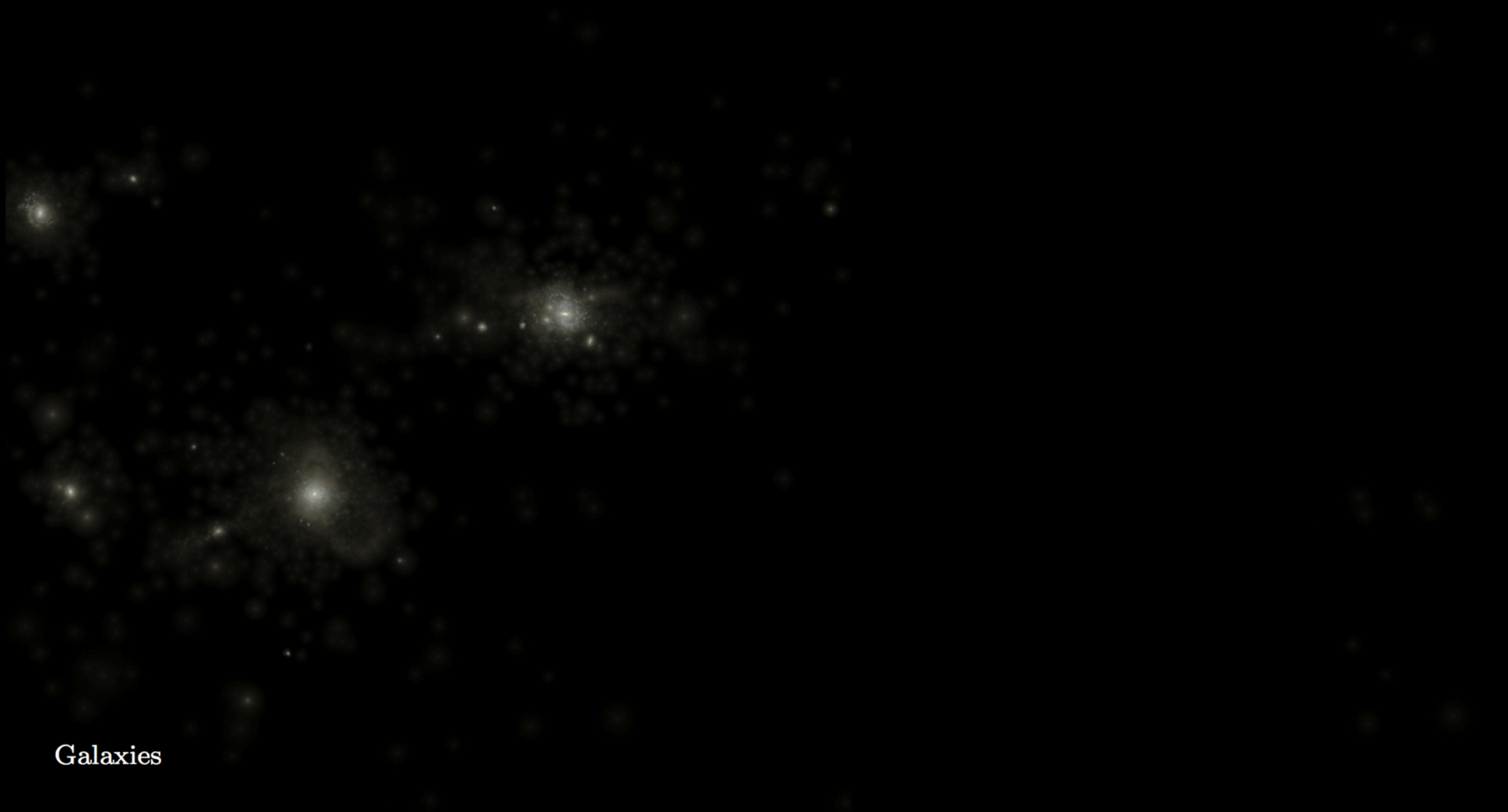
making a galaxy in a small halo
is doubly difficult because:

(1) reionisation heats gas above T_{vir}, preventing cooling, and

(2) SN feedback removes SF gas from haloes

feedback + photoionisation + the impact of the central galaxy

[see also Rees (1986); Efstathiou (1992); Kauffman+ (1993); Loeb & Barkana (2000); Bullock+ (2001); Benson+ (2002); Brooks & Zolotov (2014); Wetzel+ (2016) etc.]



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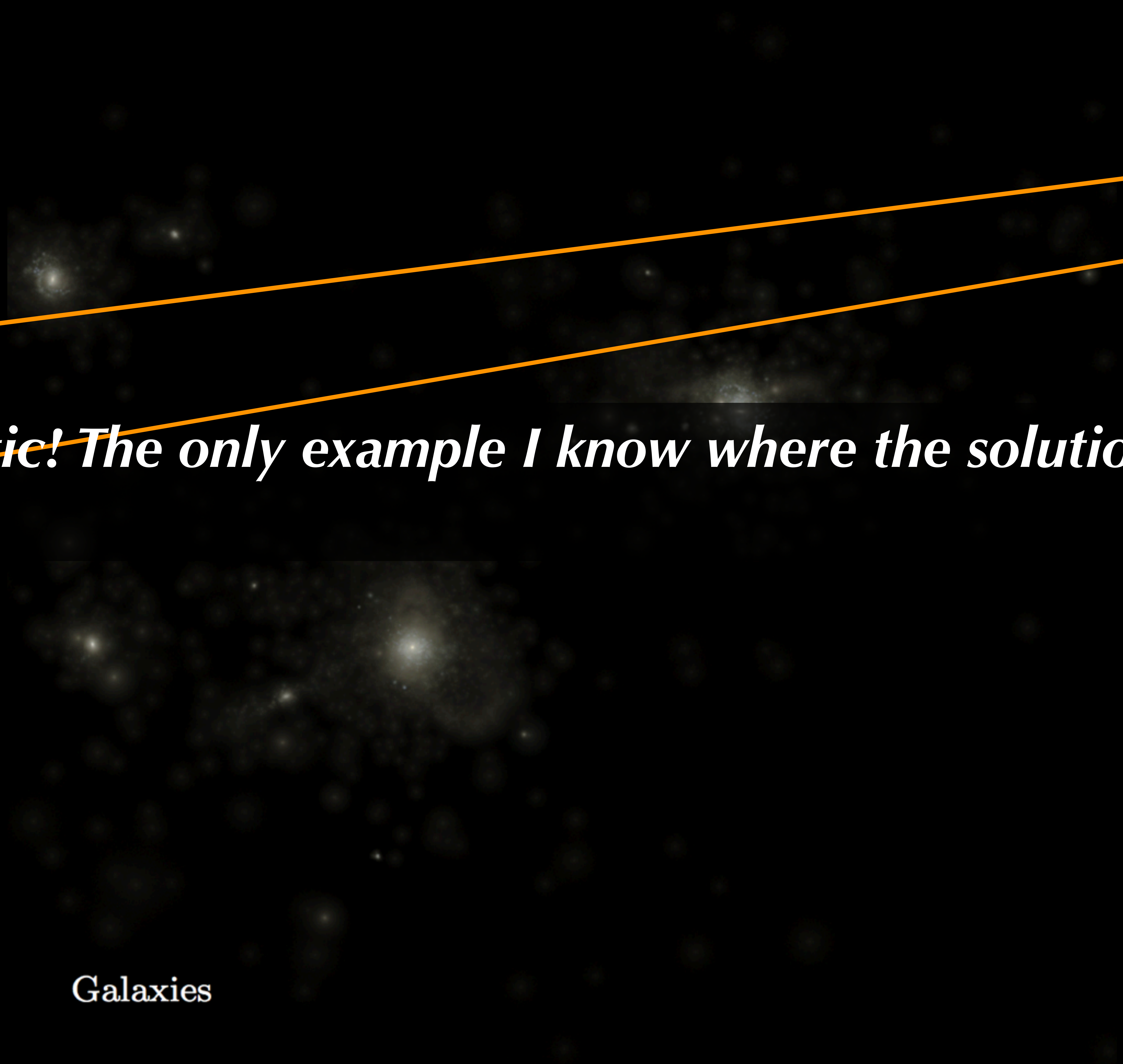
"(It makes me) apoplectic! The only example I know where the solution precedes the problem!"

- Someone in this room



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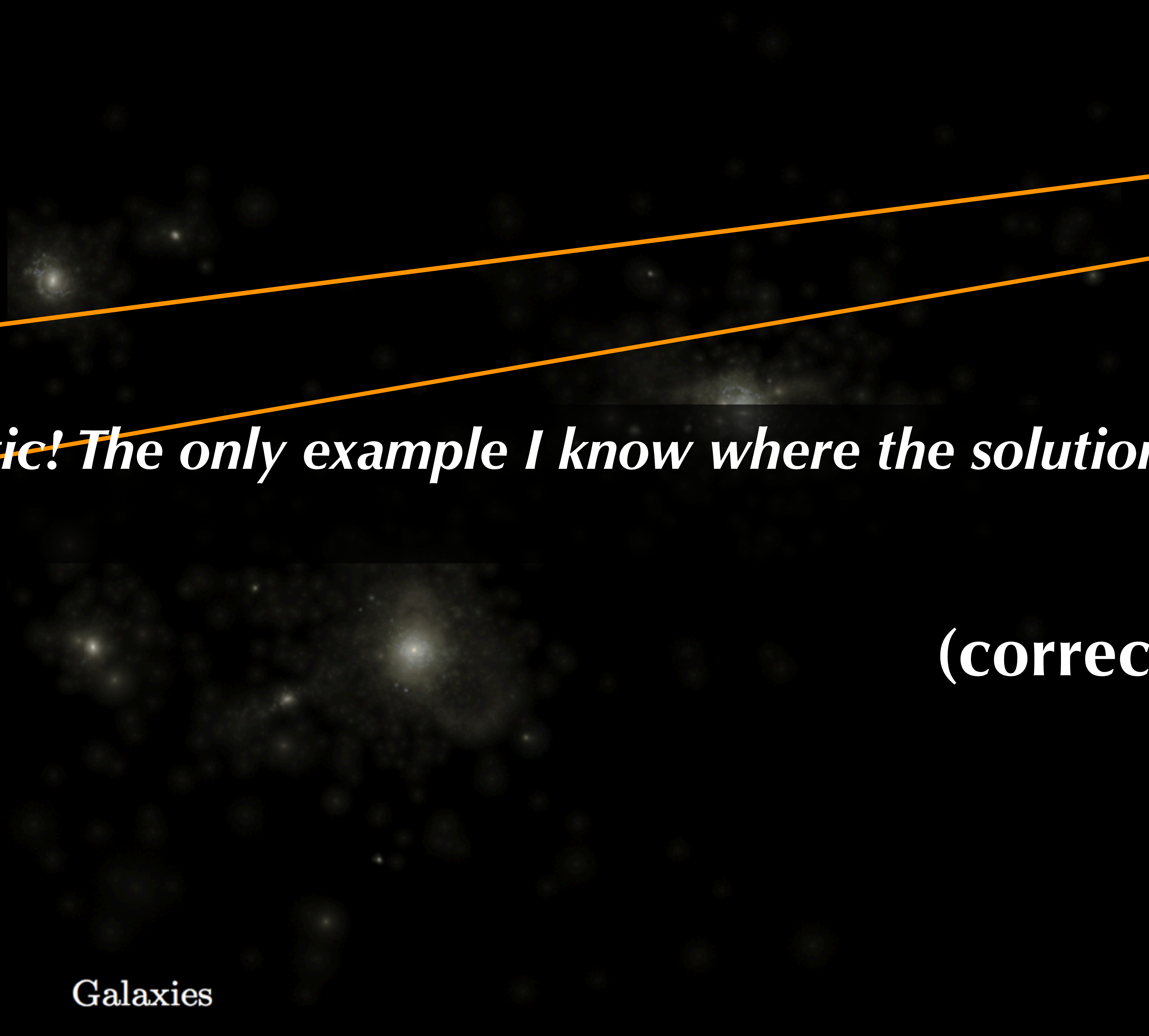
(correct: it was Carlos Frenk)



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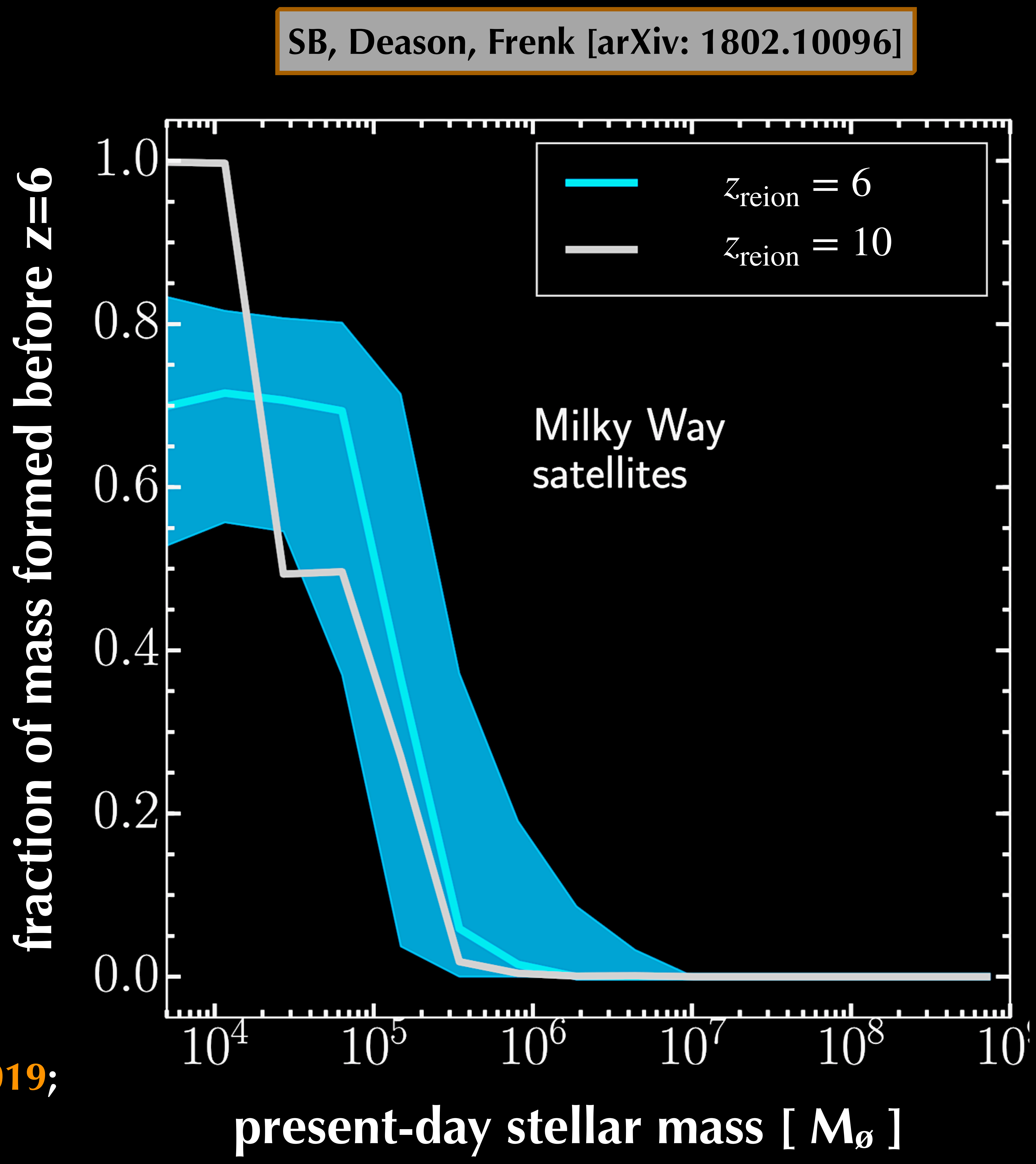
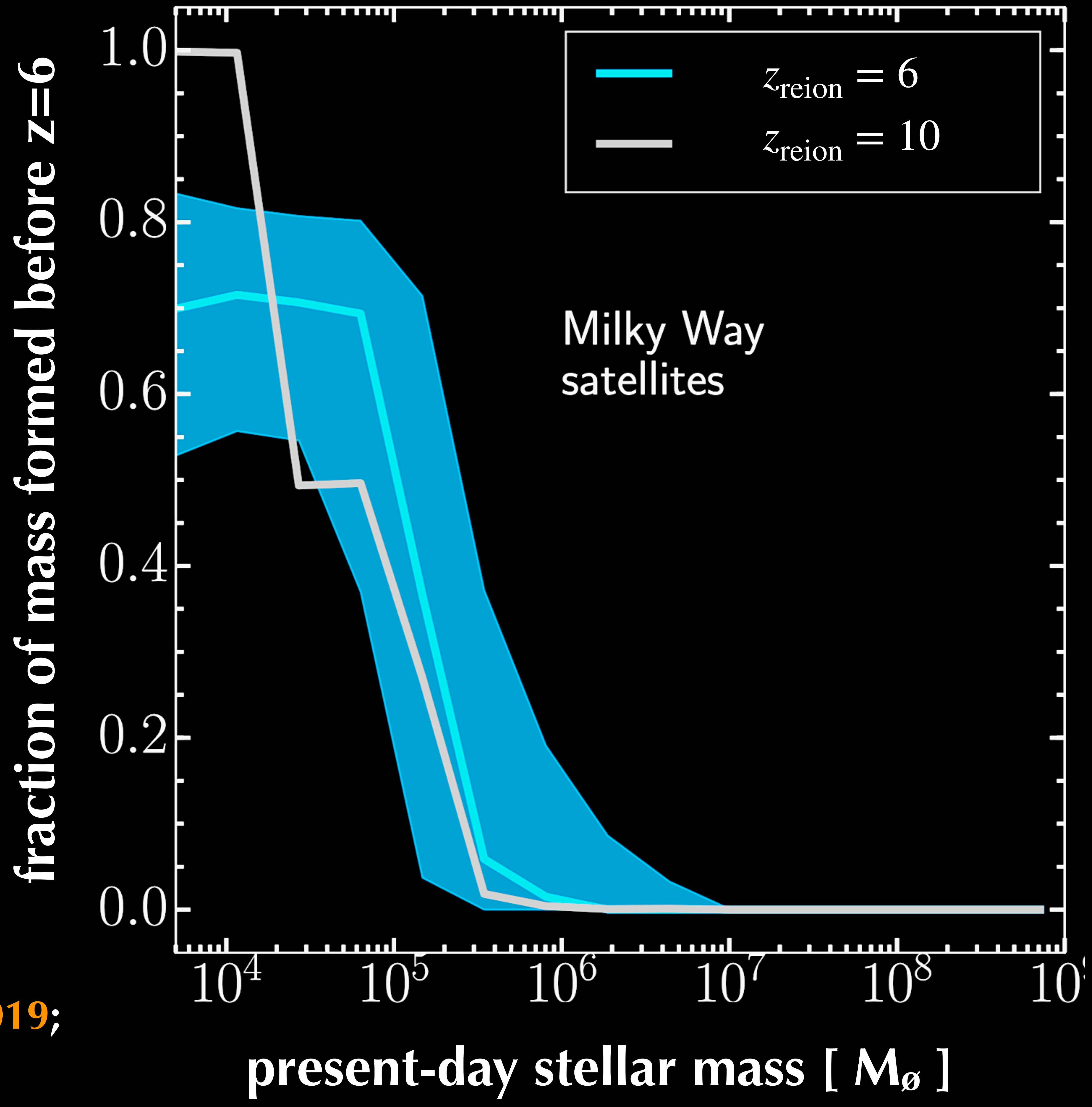


[see also Wheeler+ 2015; Garrison-Kimmel+ 2019; Munshi+ 2019]

faint satellites typically assemble bulk of stellar mass prior to reionisation

SB, Deason, Frenk [arXiv: 1802.10096]



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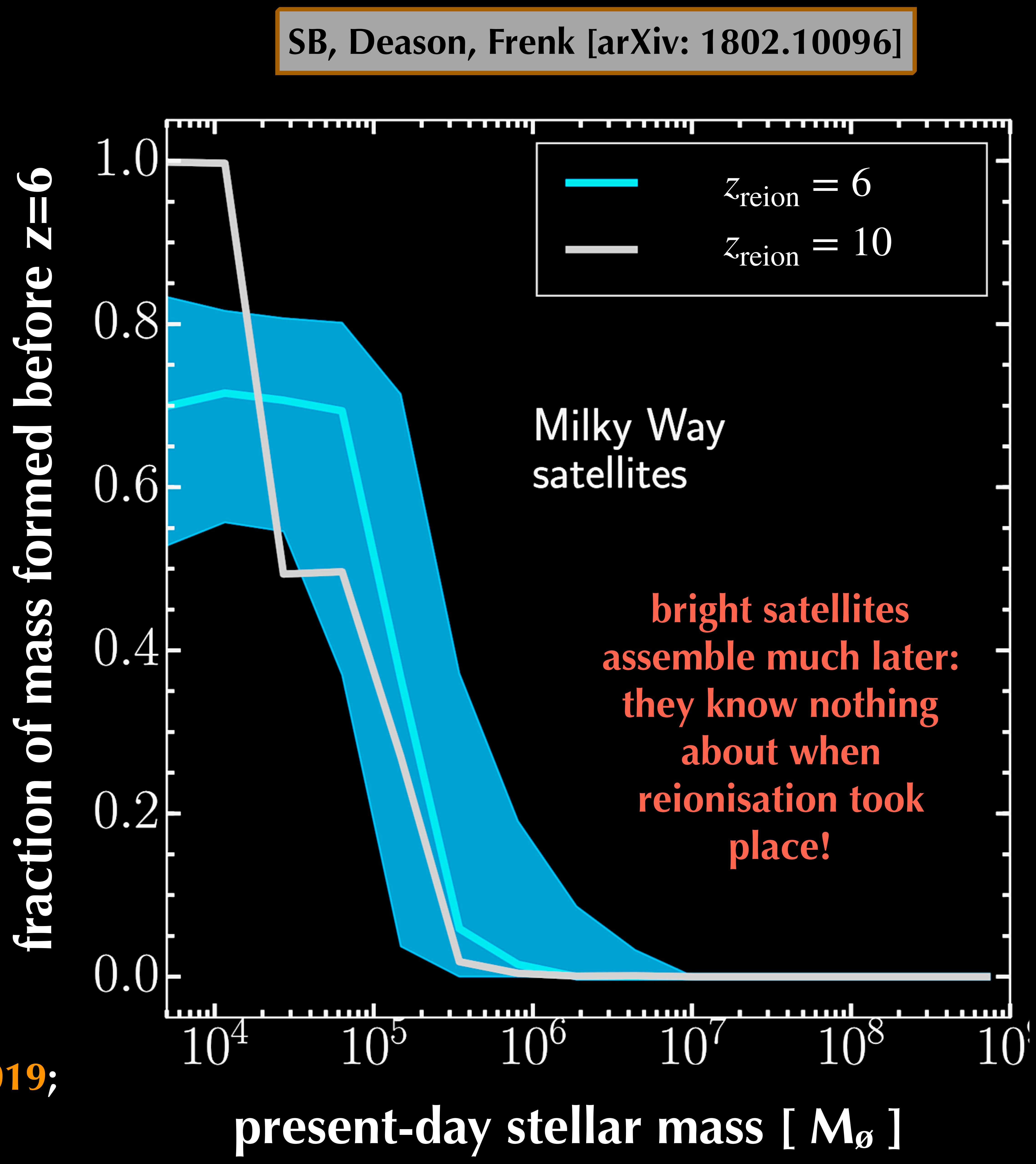

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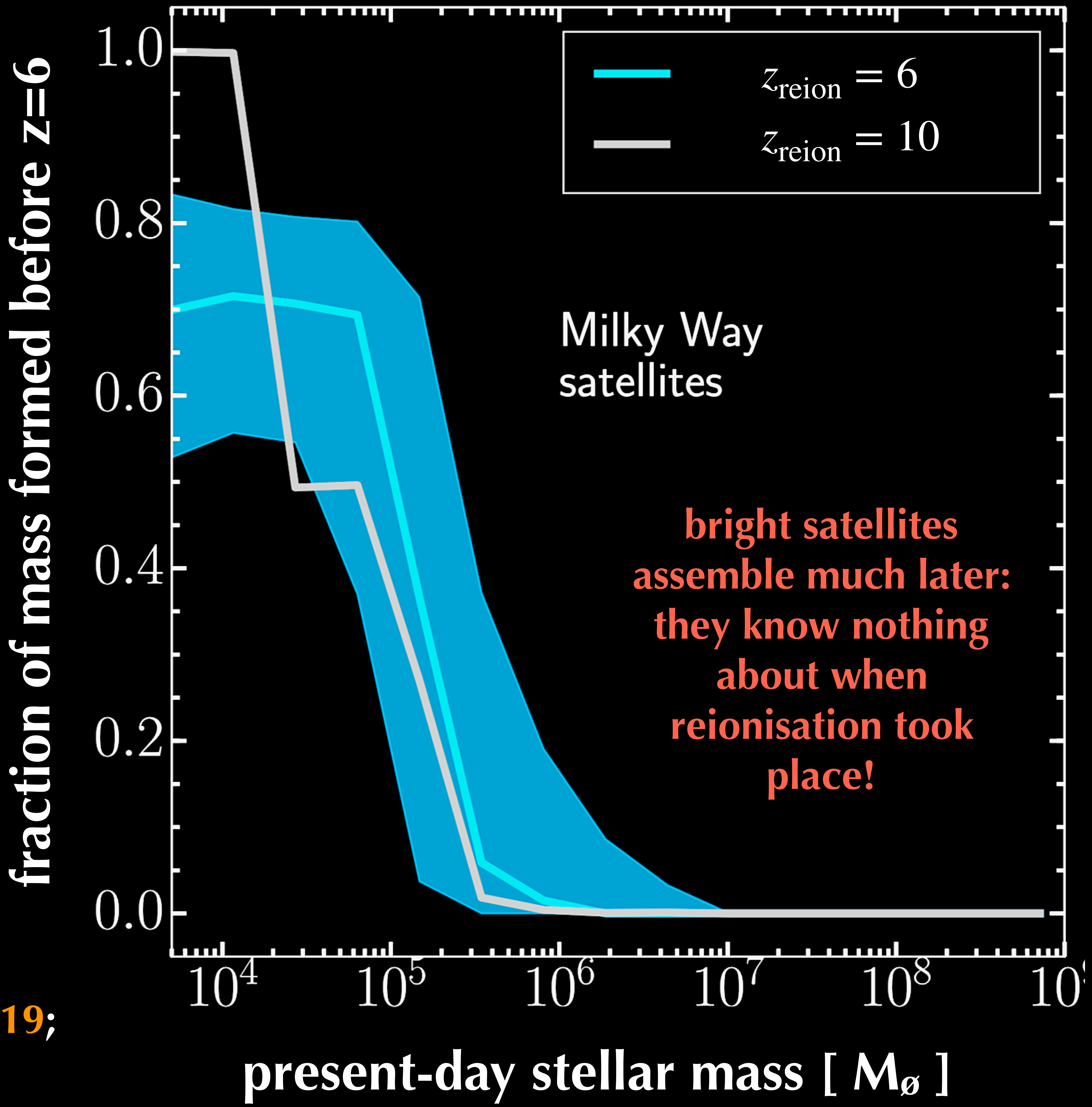
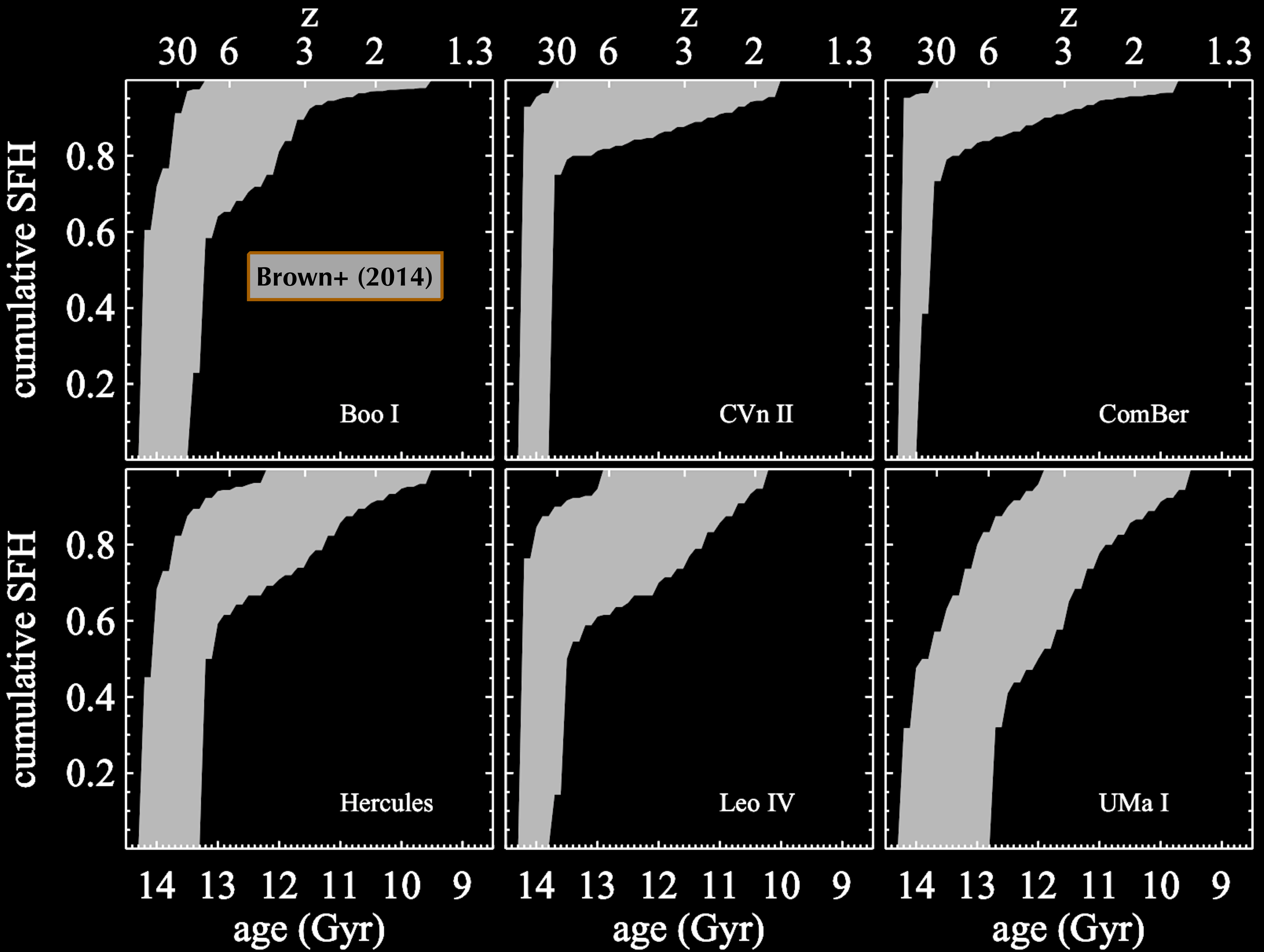


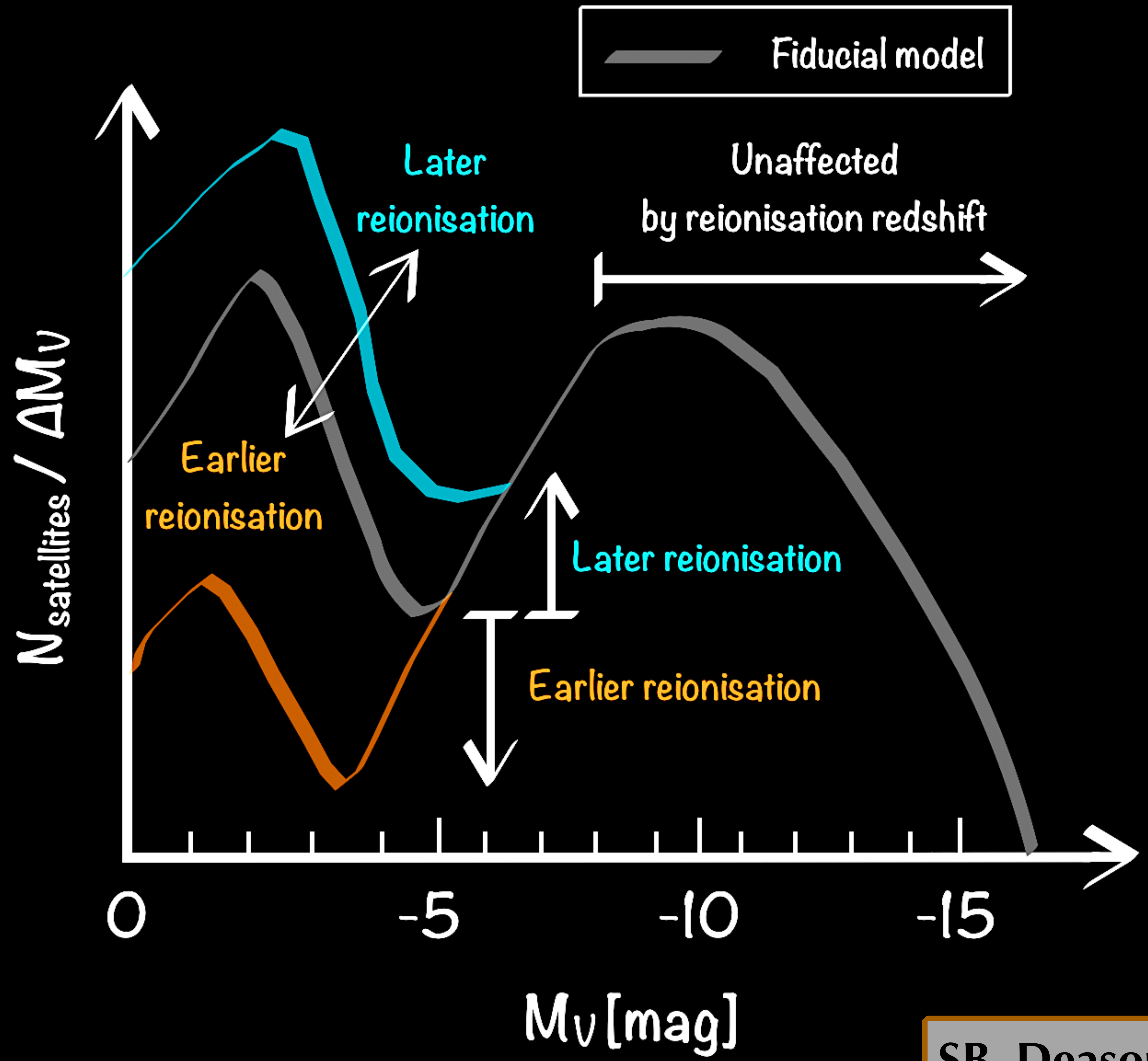
this is what one would expect From the hierarchical growth of structure

[see also Wheeler+ 2015; Garrison-Kimmel+ 2019; Munshi+ 2019]


z
30 6 3 2 1.3
cumulative SFH
0.8
0.6
0.4
0.2
Brown+ (2014)
Boo I
CVn II
ComBer
Hercules
Leo IV
UMa I
14 13 12 11 10 9
age (Gyr)

[see als

a unique imprint in the lf of satellites



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redshift of reionisation

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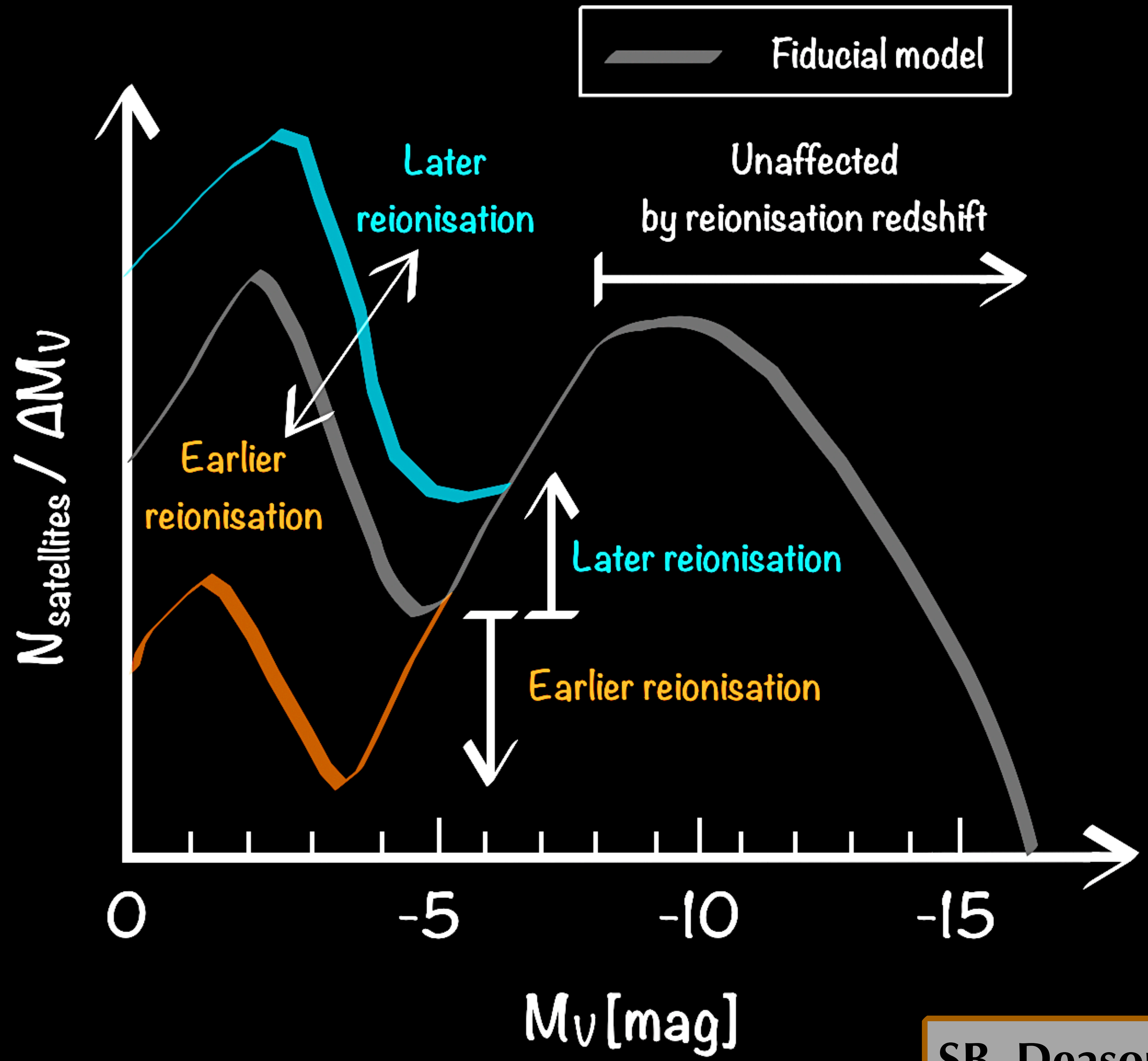

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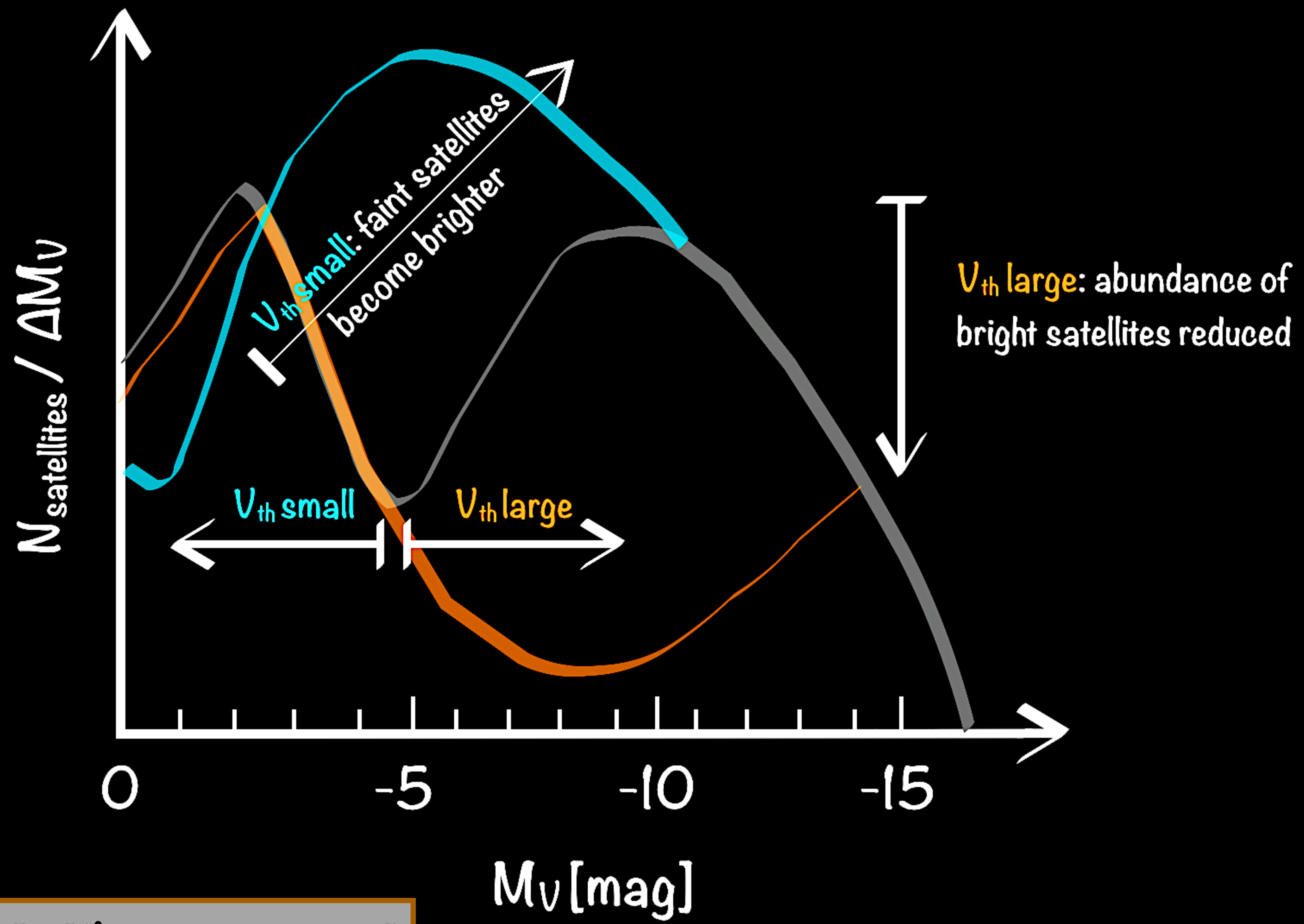


SB, Deason, Frenk [arXiv: 1802.10096]

filtering scale for reionisation

the diversity of ultrafaint abundances

and the diversity of halo growth histories

numerics

parent N-body simulation: COLOR

$$L_{\rm box} = 100\,{\rm Mpc};\, m_p = 8.8 \times 10^6\,{\rm M}_\odot$$

High-resolution zoom-in volume: COCO

$$L_{\rm hr} = 24\,{\rm Mpc};\, m_p = 1.6 \times 10^5\,{\rm M}_\odot$$

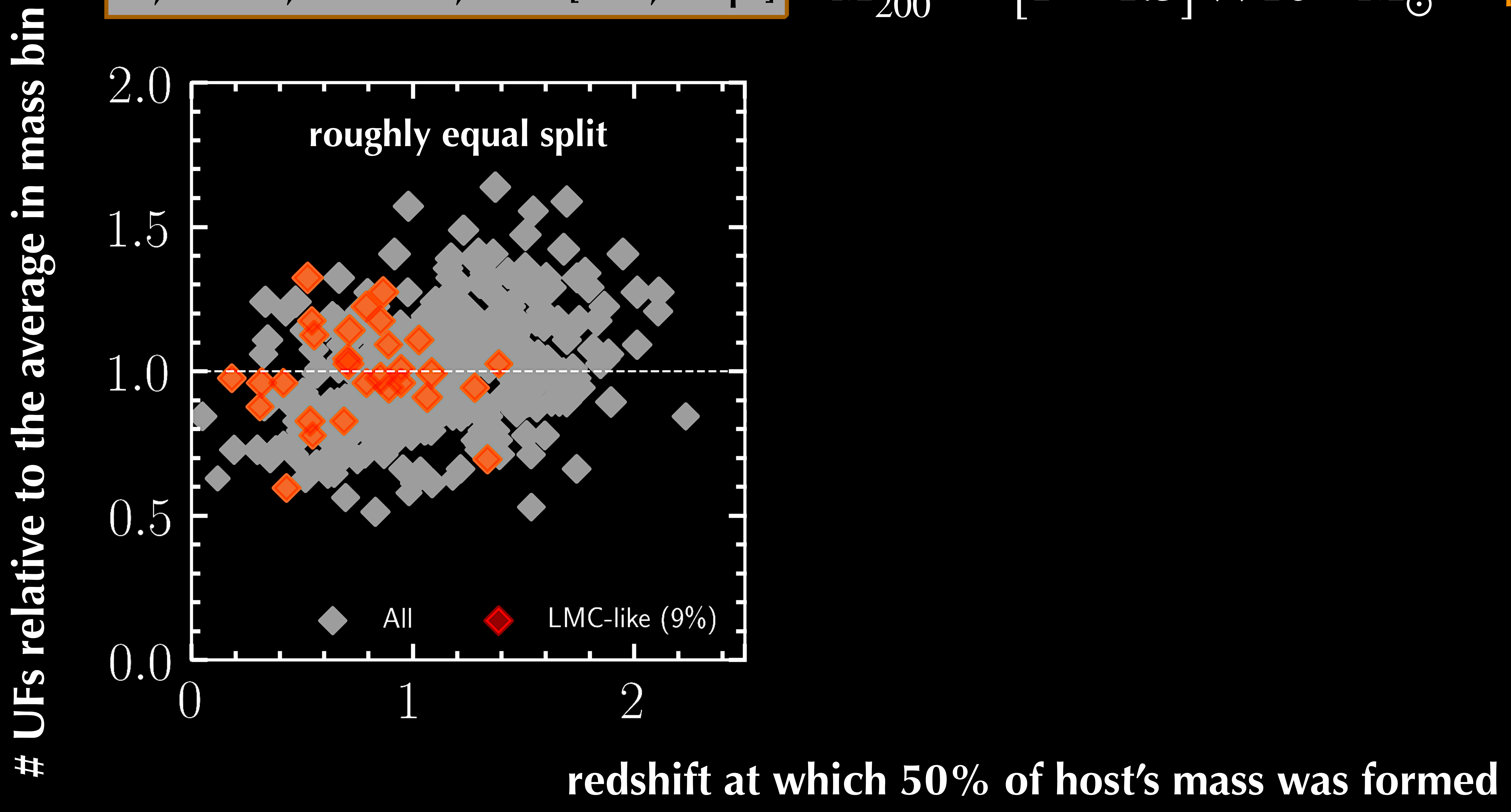
} **semi-analytic model of galaxy formation: GALFORM**

[Cole+ 1994, 2000; Lacey+ 2016]

[Sawala+ 2016; Hellwing, ..., SB+ 2016]

SB, Deason, Belokurov, Frenk [soon, I hope]

$M_{200}^{\rm host} = [1 - 1.3] \times 10^{12}\,{\rm M}_\odot$ [~ 400 objects]



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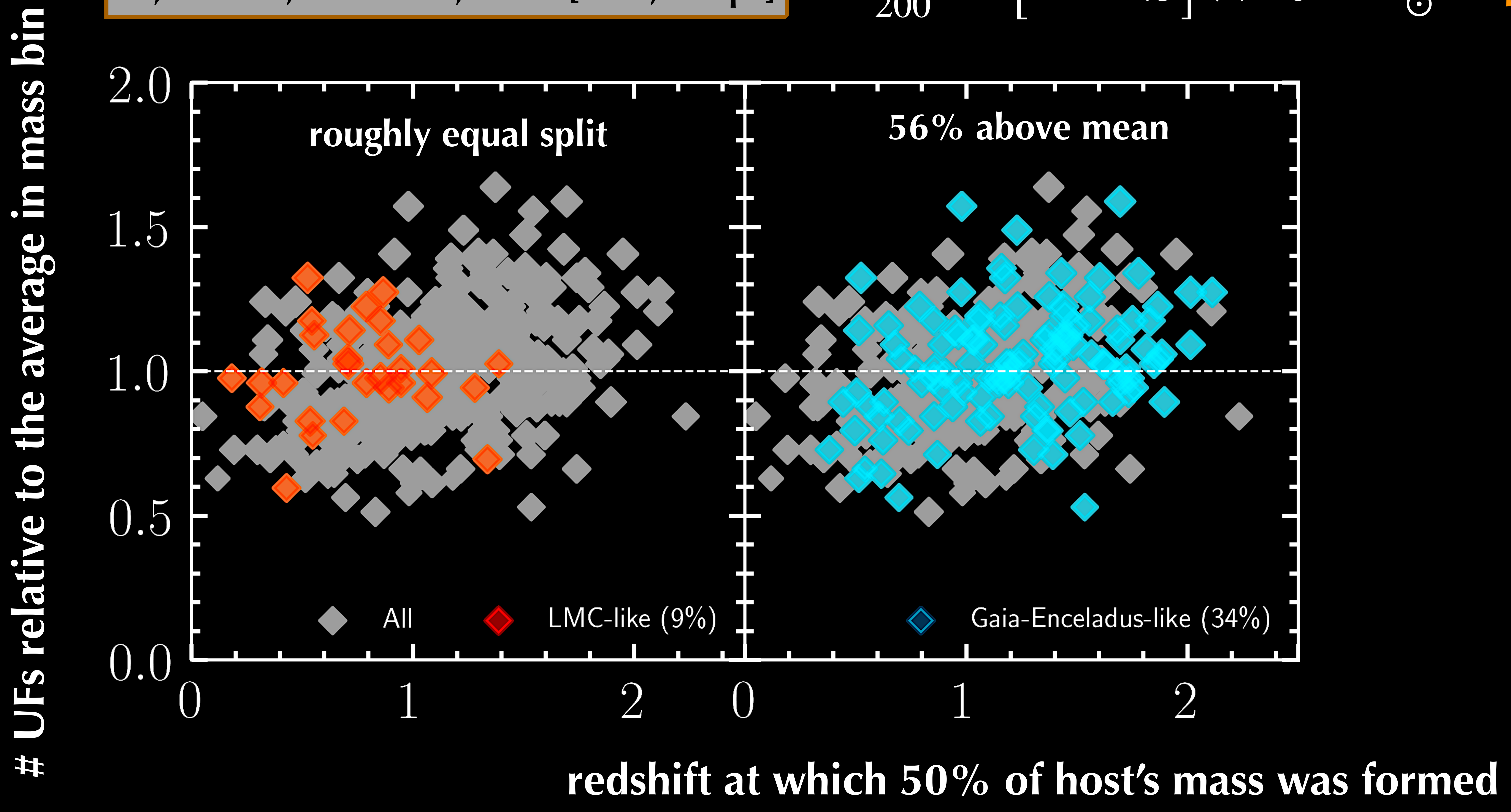

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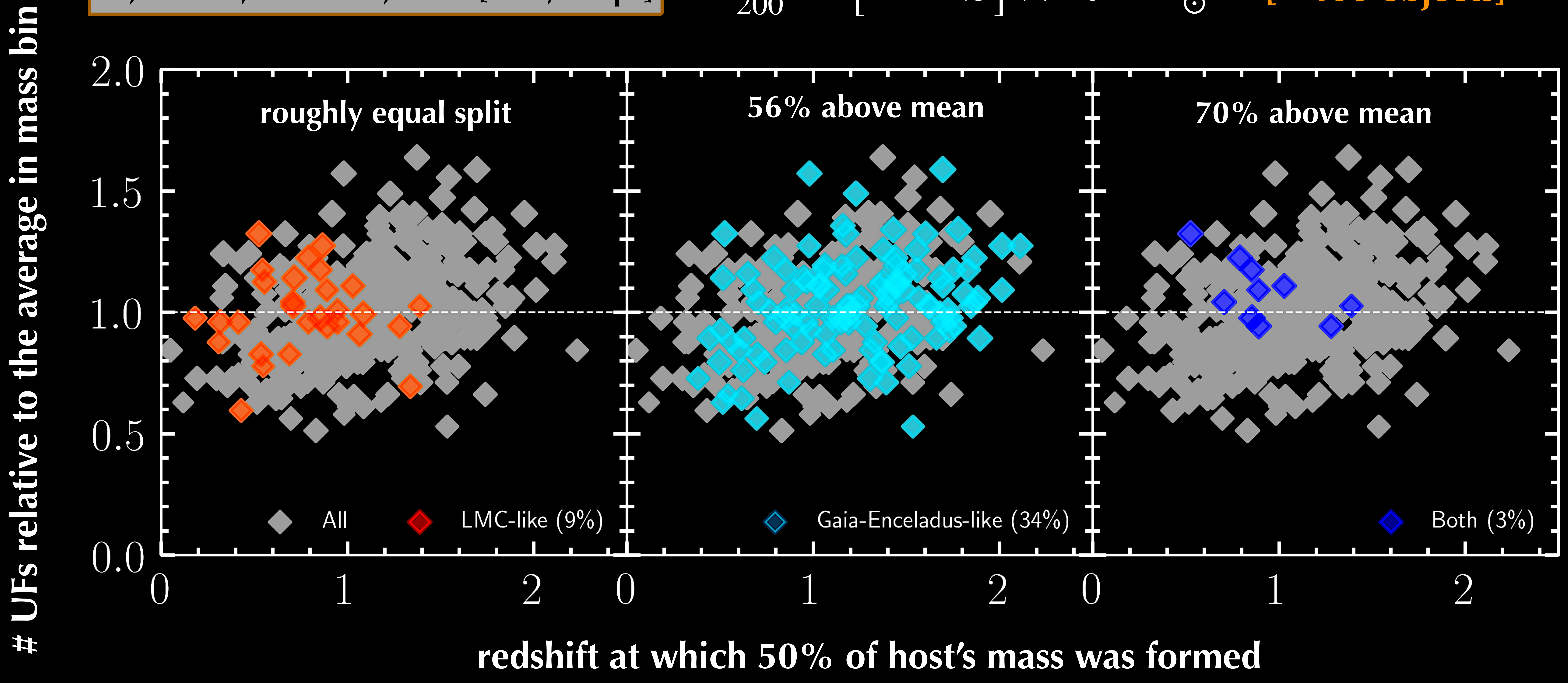
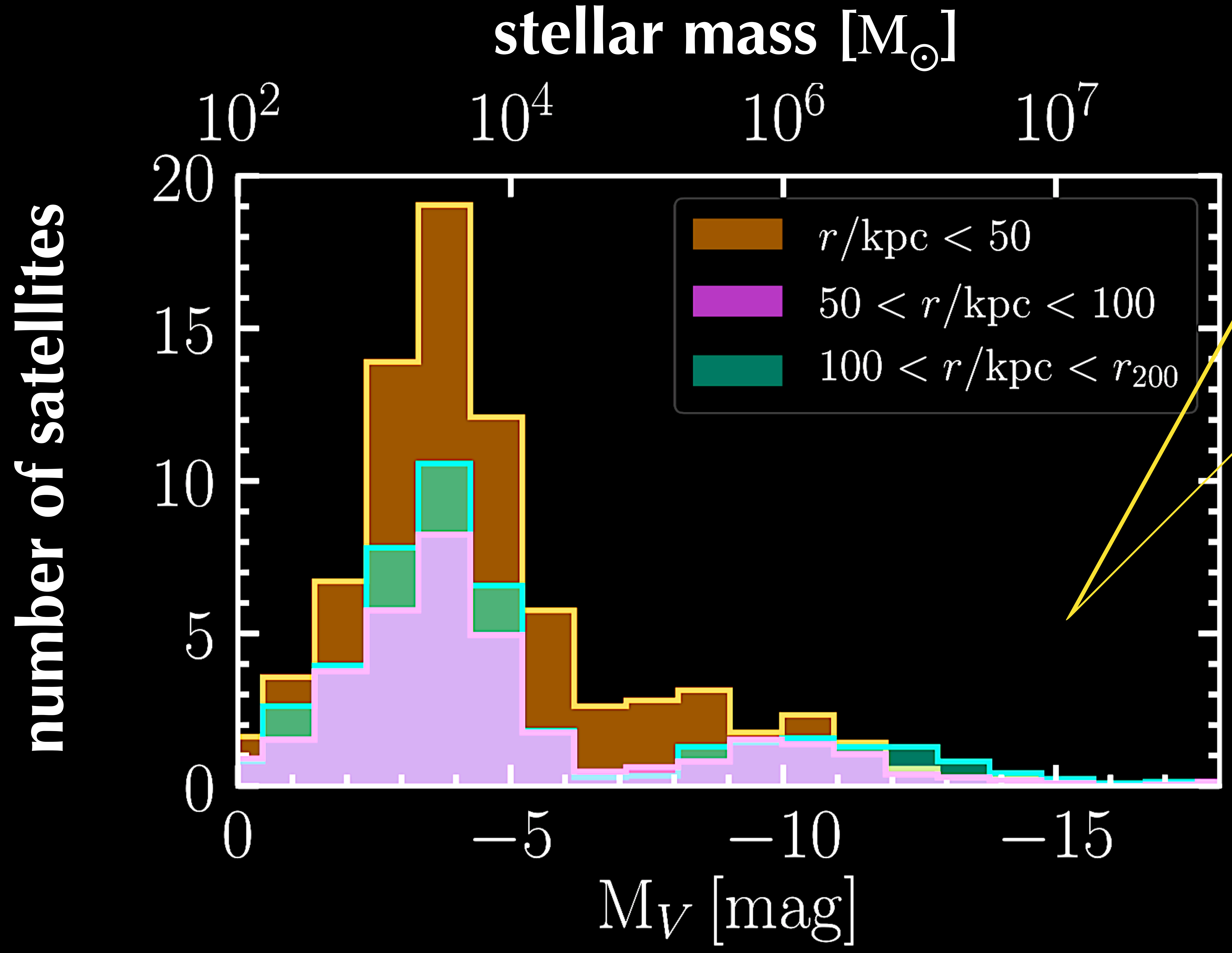


★ our Galaxy's past history and present-day satellite content are pretty unique

★ an ancient accretion event likely dragged in a large number of UFs

where can you find an ultrafaint?

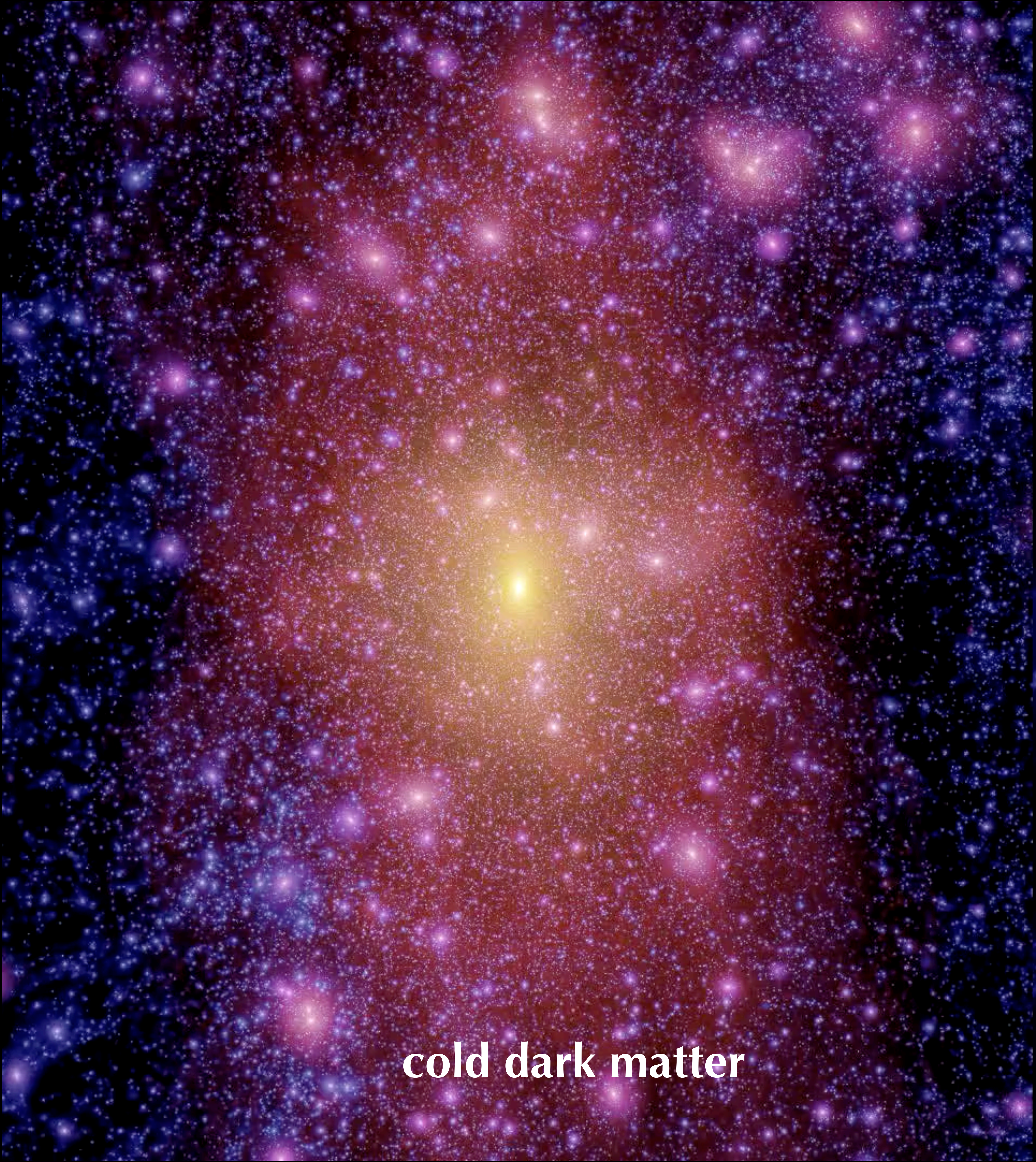


SB, Deason, Belokurov, Frenk [soon, I hope]

- the ultrafaints are generally concentrated pretty centrally
- profiles are more centrally-concentrated in early-forming haloes
- a sizeable proportion (~70%) of these are identified as "orphans" — whose subhaloes have been disrupted below the resolution limit of the simulation [20 particle limit: $3.2 \times 10^6\,M_\odot$]

what if the dark matter isn't CDM?


Movie: Mark Lovell
cold dark matter
warm dark matter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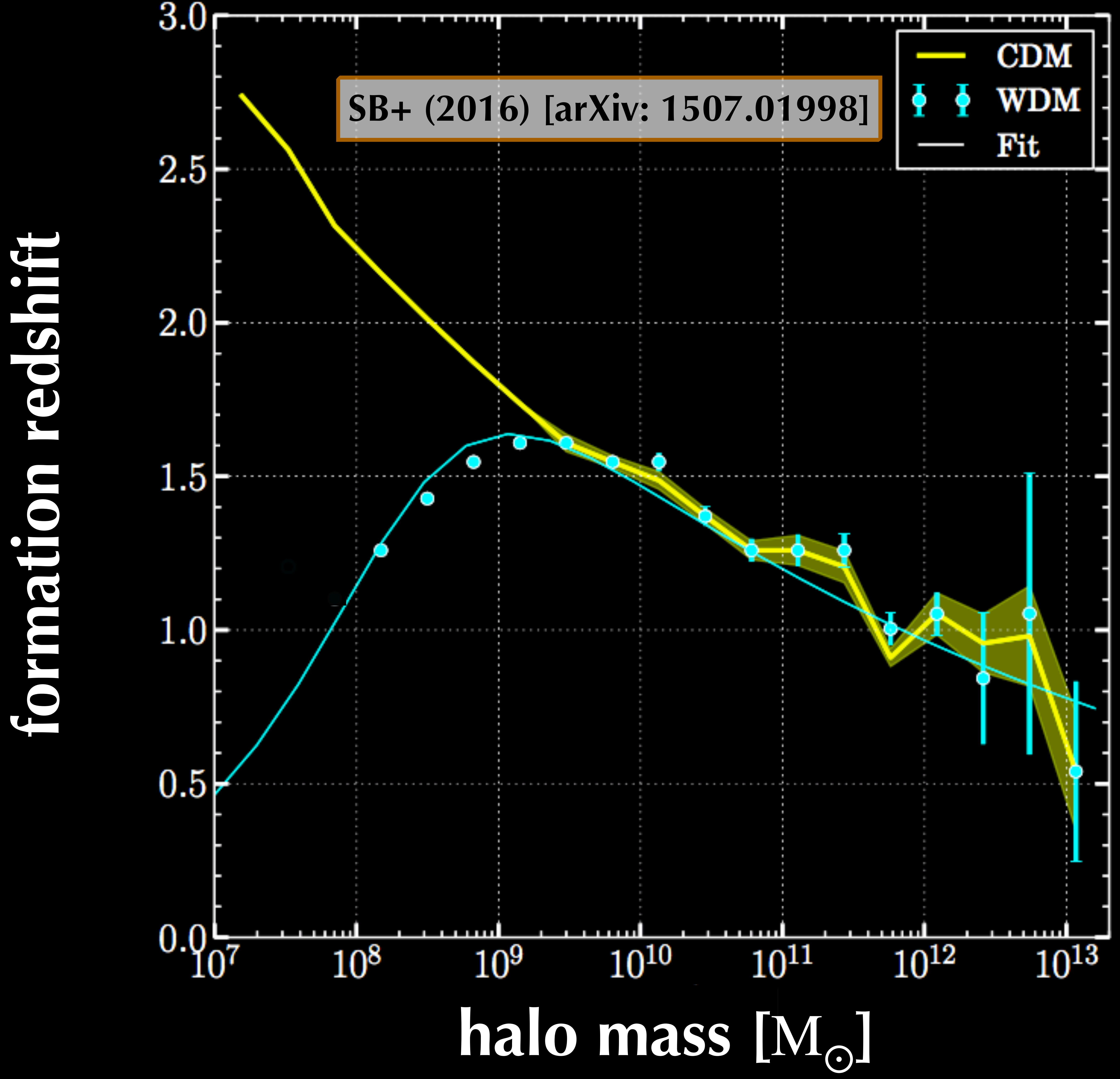
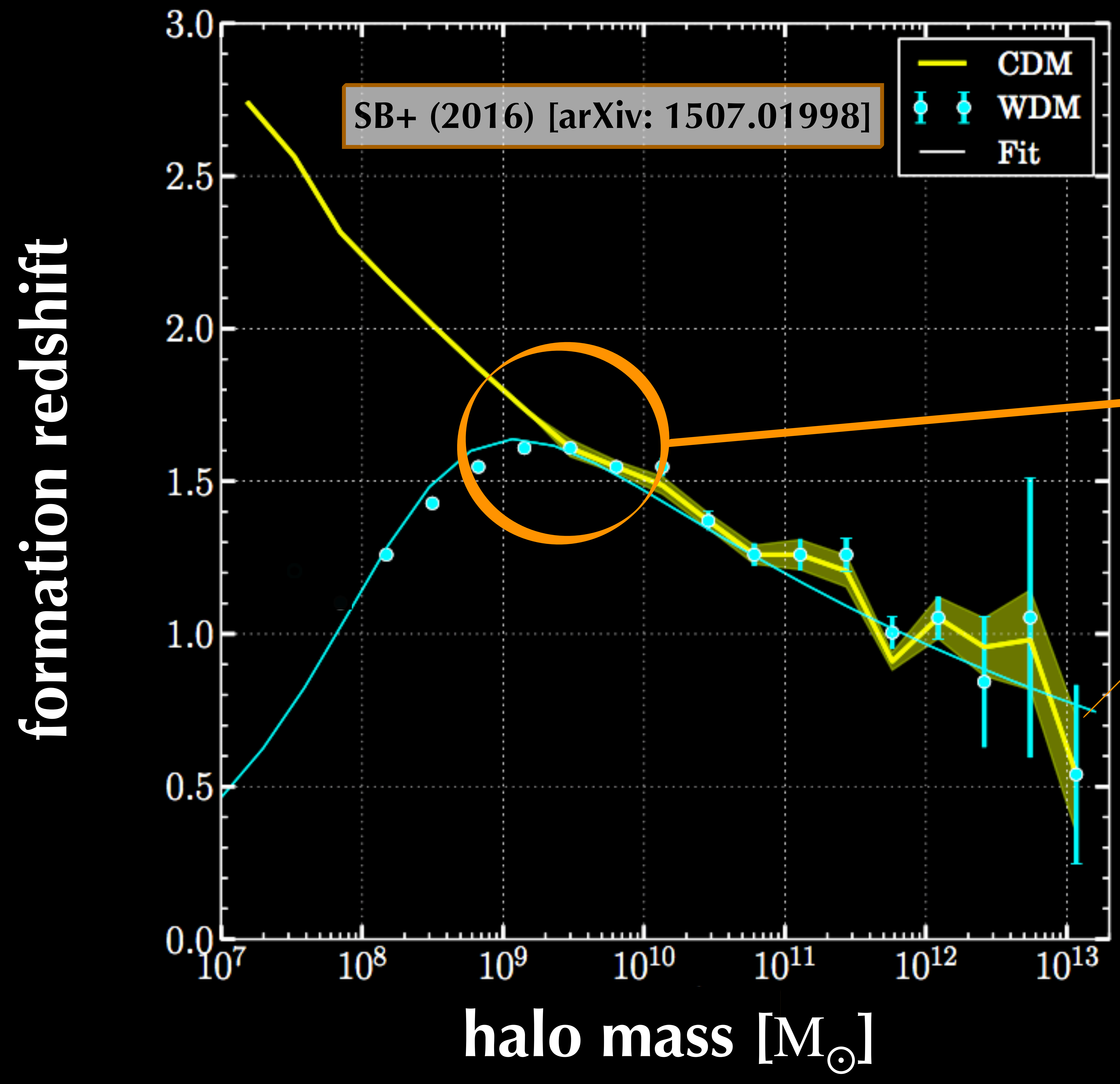
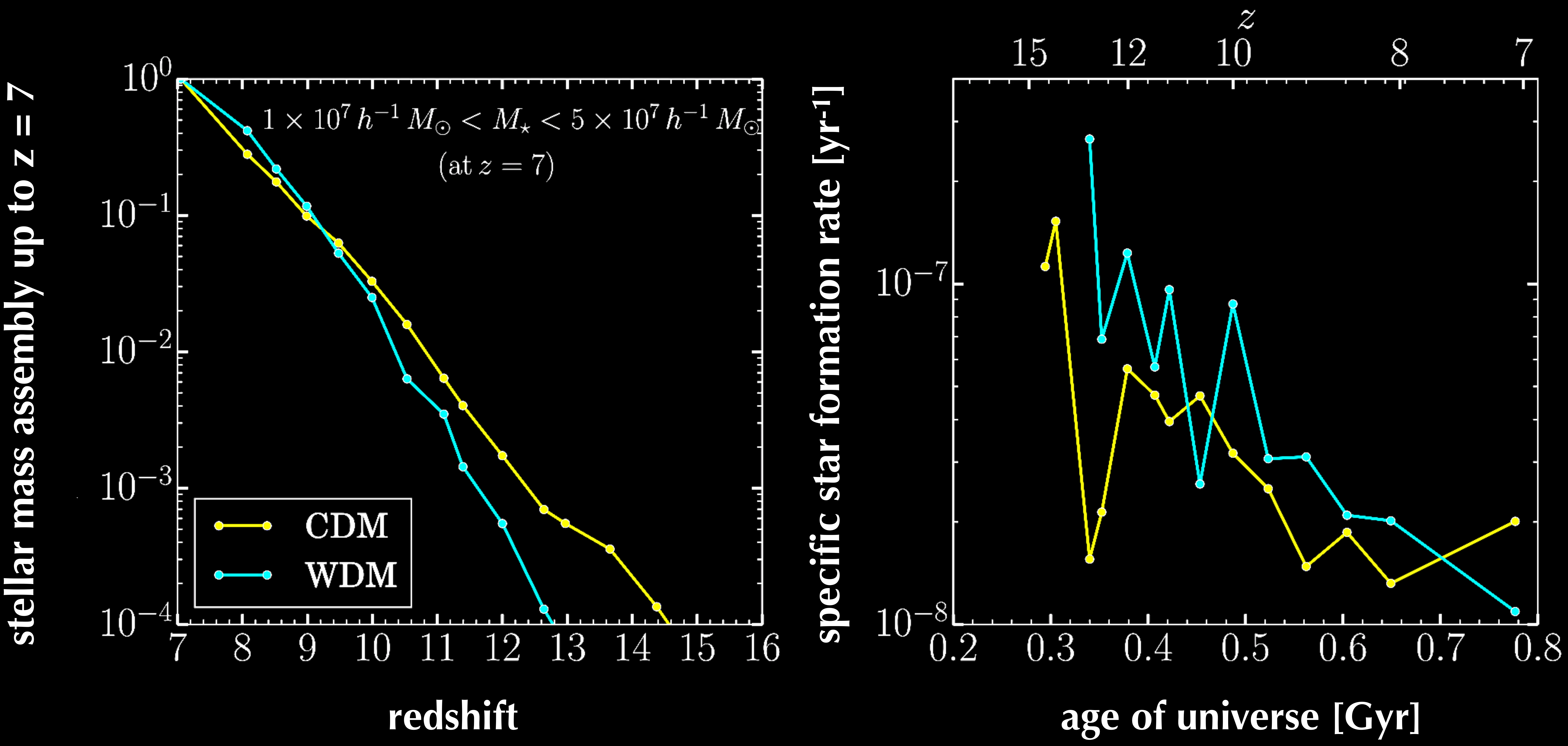

SB+ (2016) [arXiv: 1507.01998]
CDM
WDM
Fit
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
formation redshift
halo mass [$M_\odot$]



below a characteristic scale, halo formation is delayed relative to CDM

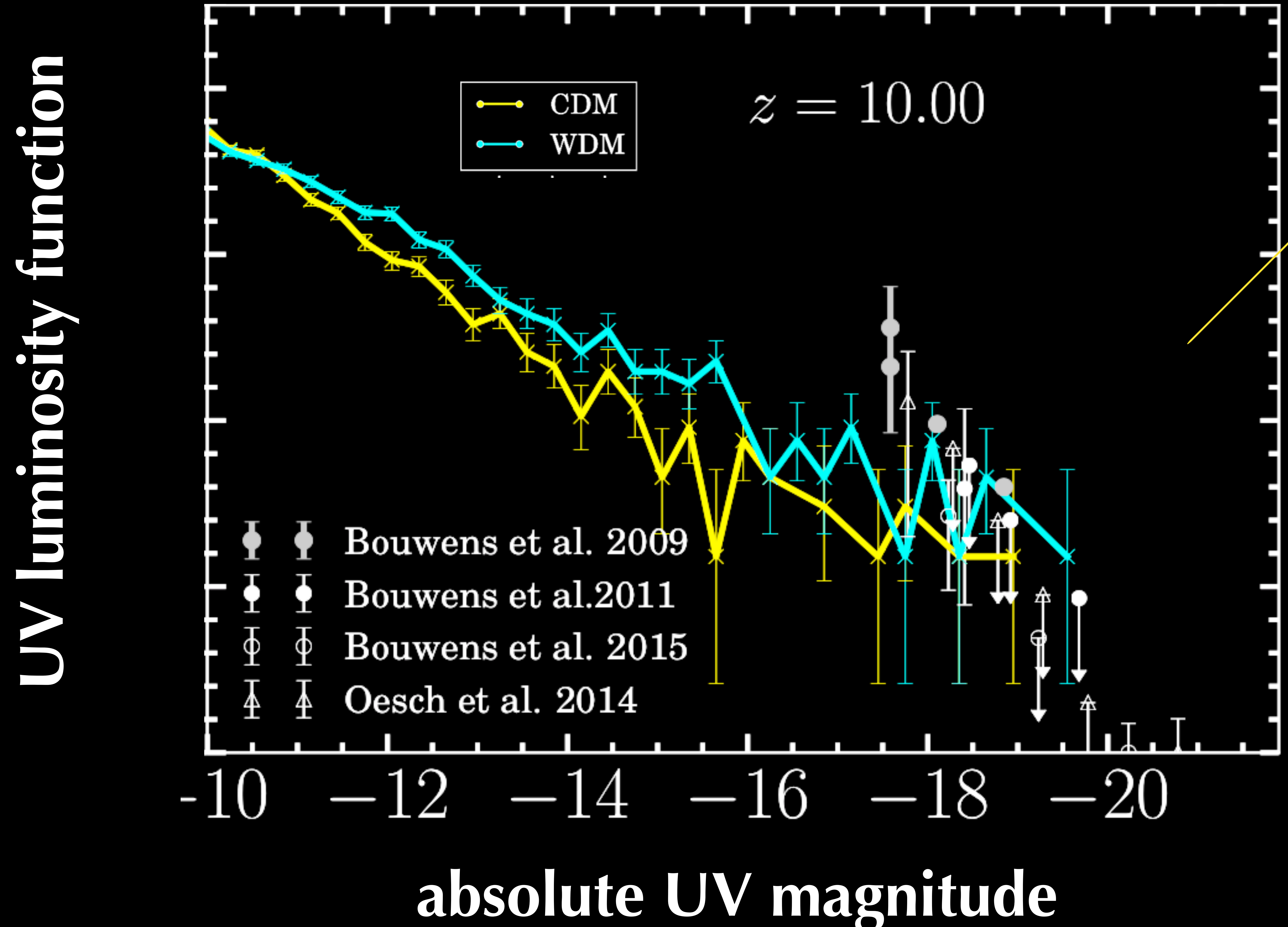
differences driven by this feature



SB+ (2017) [arXiv: 1604.07409]

… and also seen in hydro simulations, Lovell+ (2018)
[Mark's talk from Monday]

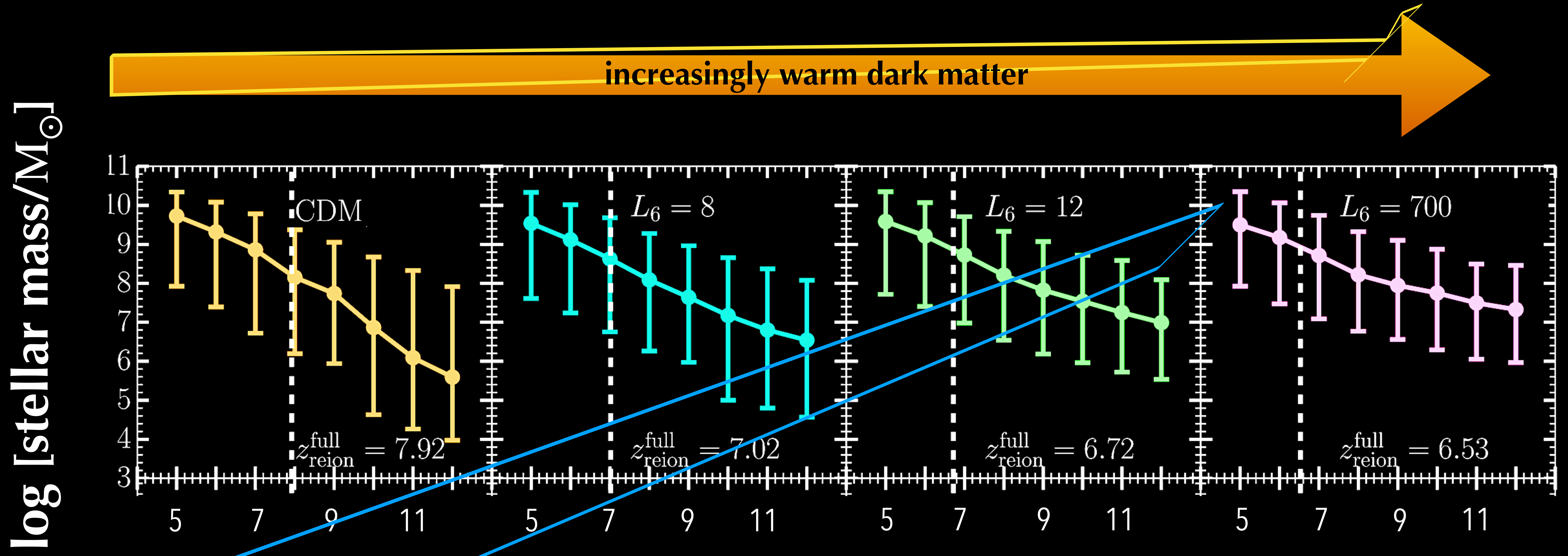
SB+ (2017) [arXiv: 1604.07409]



high-z galaxies form through mostly monolithic collapse and mergers are more gas-rich than in CDM

[see also Wang+ (2017)]

tracing the sources of ionising photons

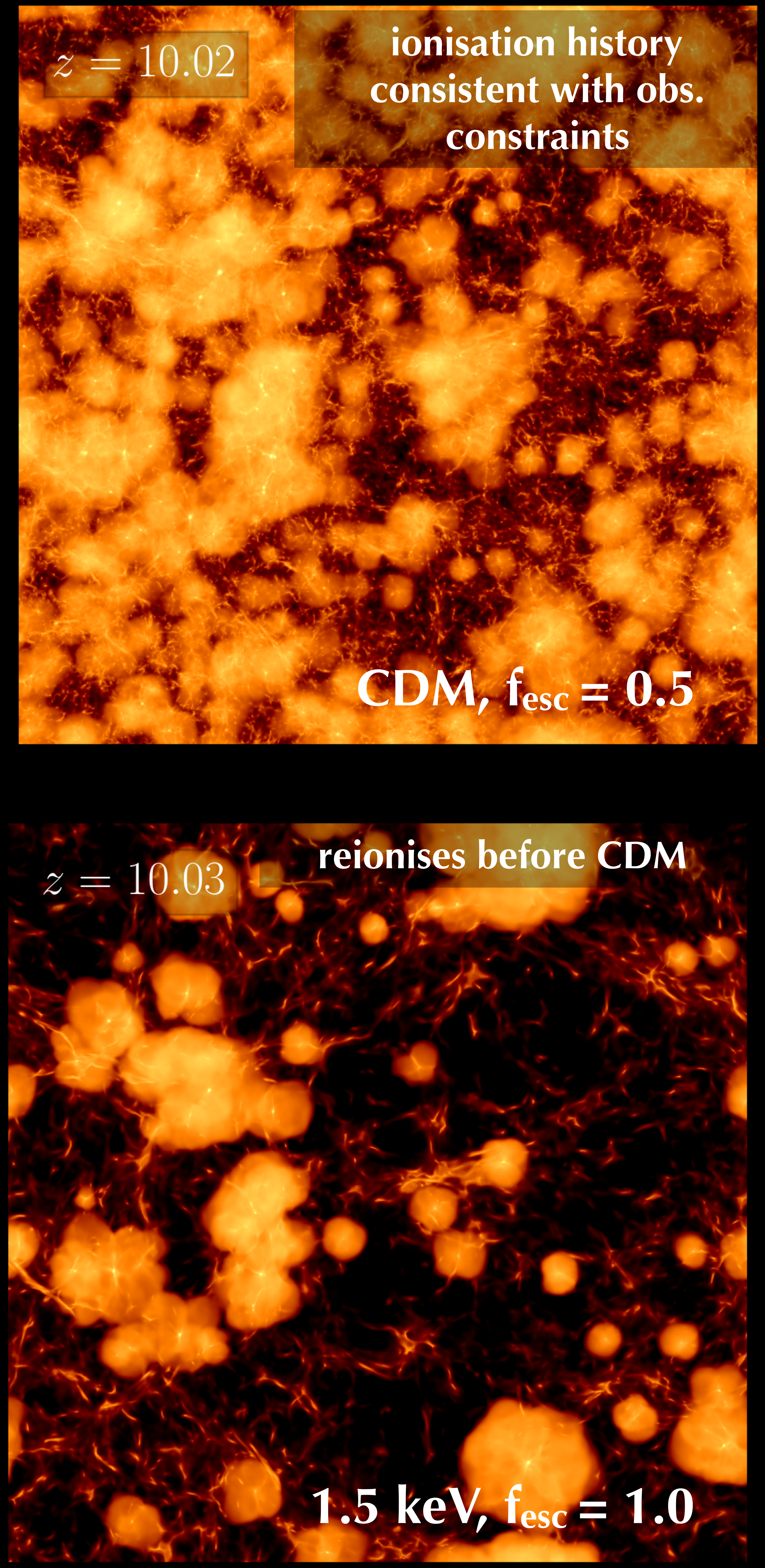


SB+ 2016 [arXiv: 1605.03179]

Compensation: The dominant sources of ionising photons tend to be more massive in sterile neutrino cosmologies than in CDM

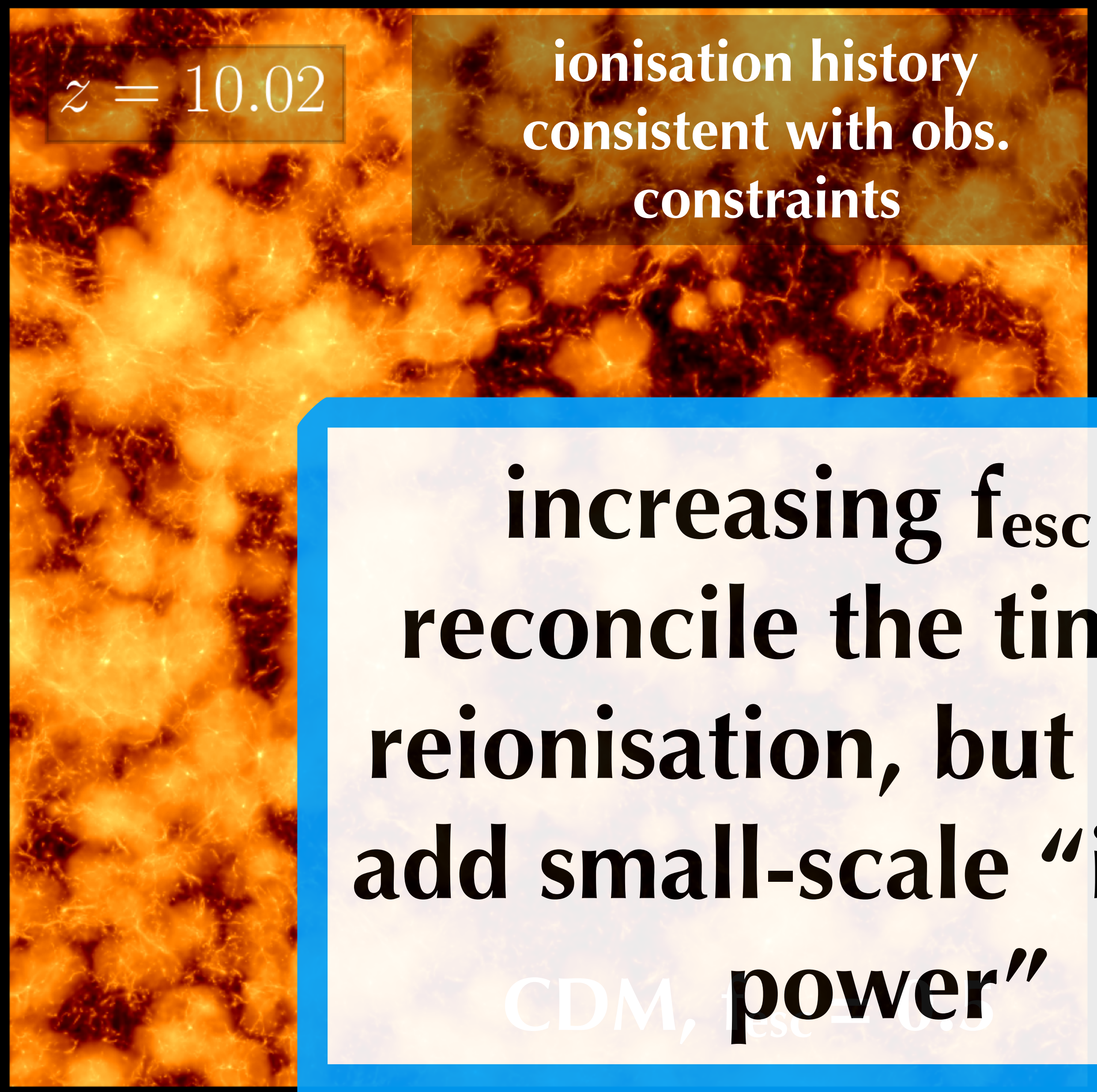
going one step further than averaged quantities

with the **topology** of reionisation

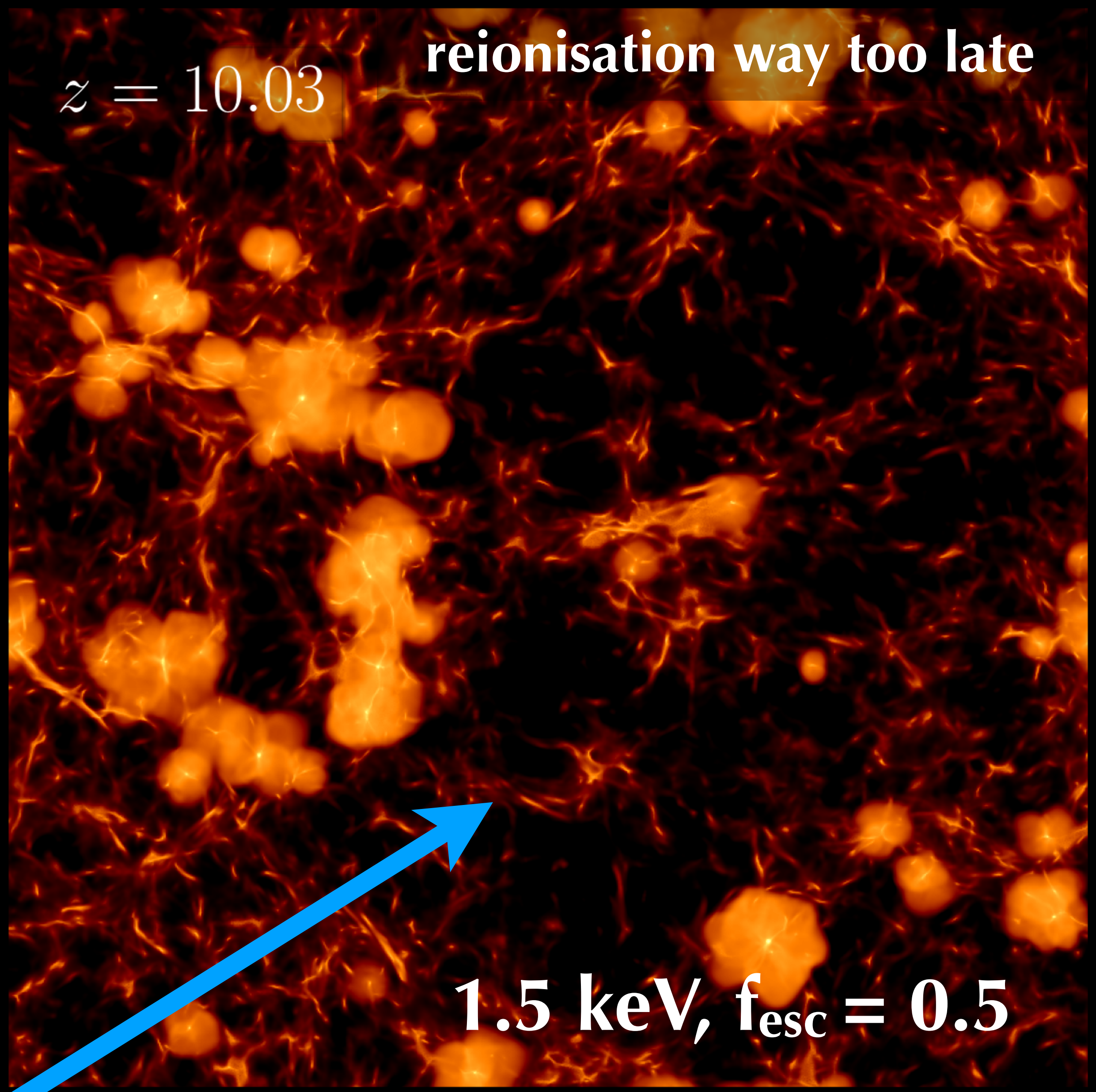


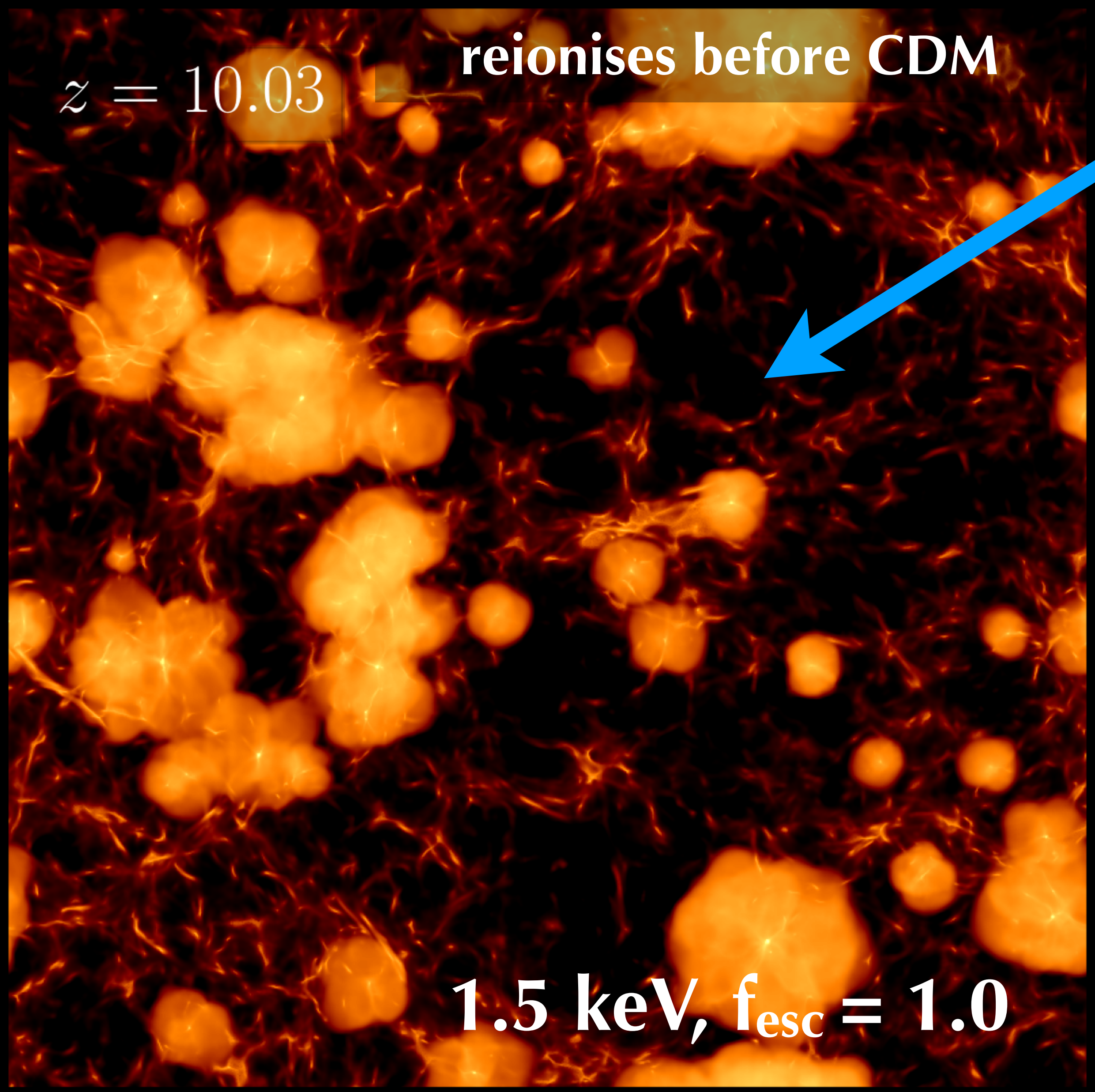
self-consistent reionisation simulations with Arepo-RT (Kannan+2018) with IllustrisTNG physics

SB, Kannan, Mason, Vogelsberger+



increasing f_{esc} can reconcile the timing of reionisation, but doesn't add small-scale "ionising power"





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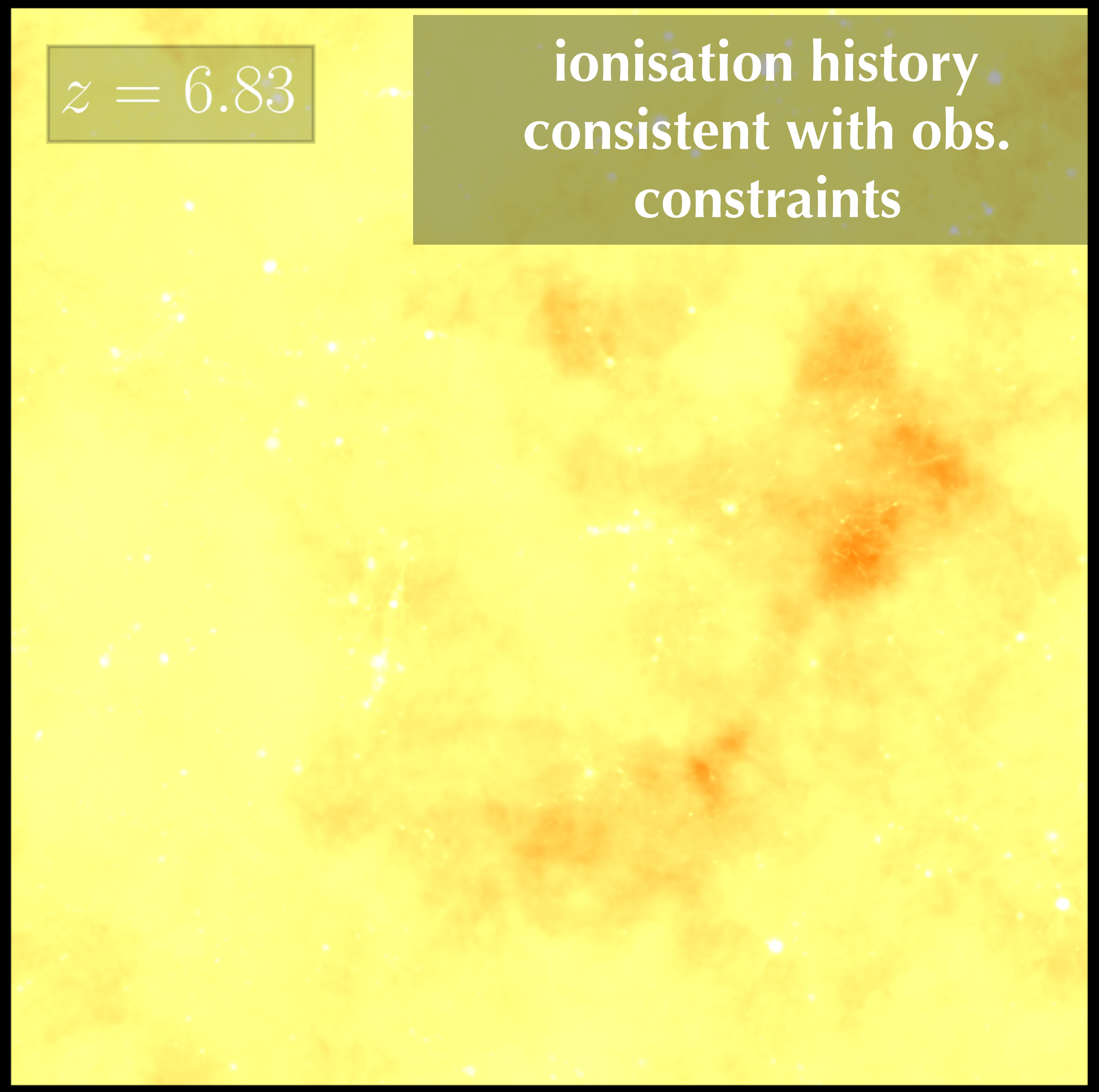

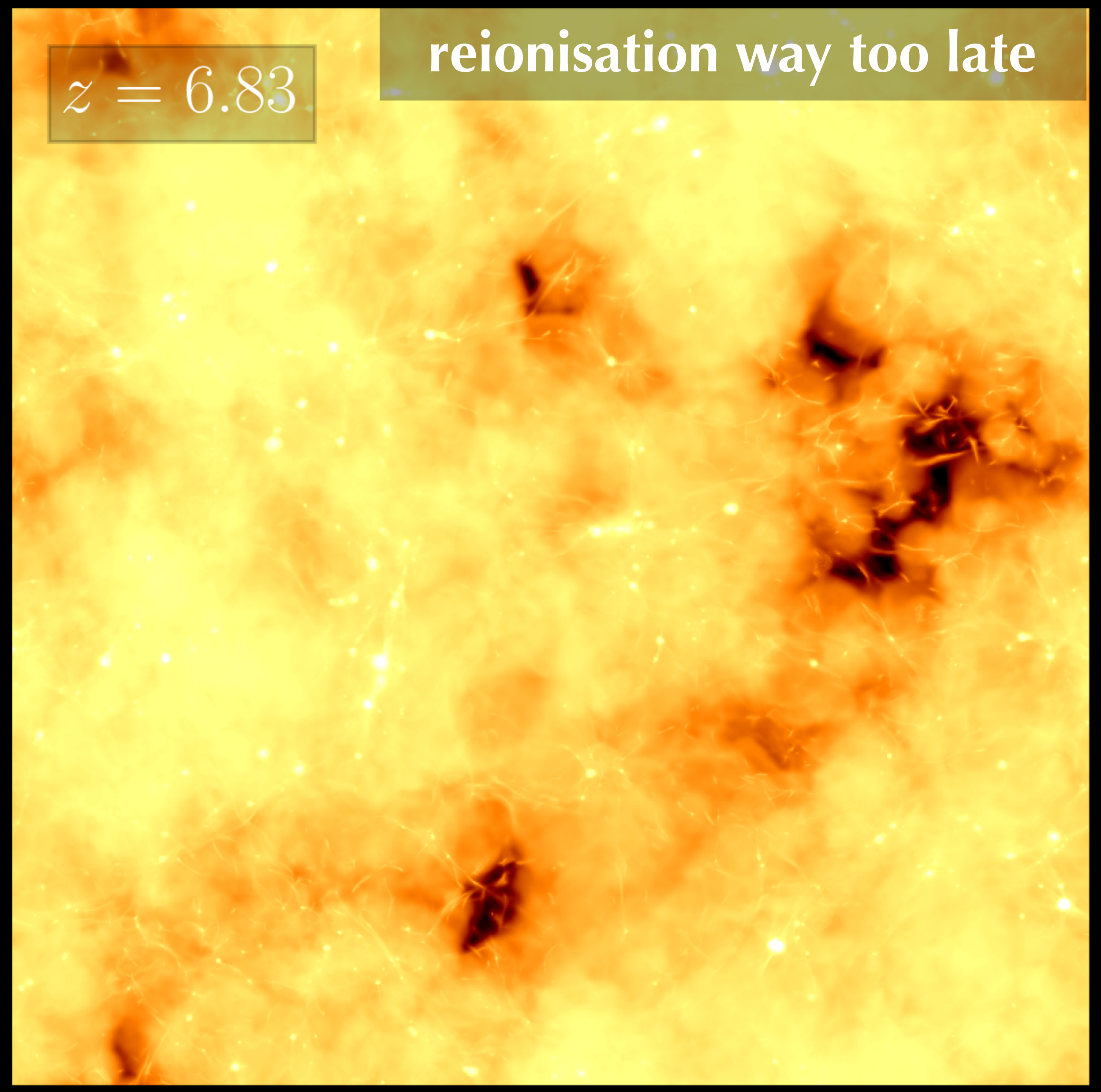

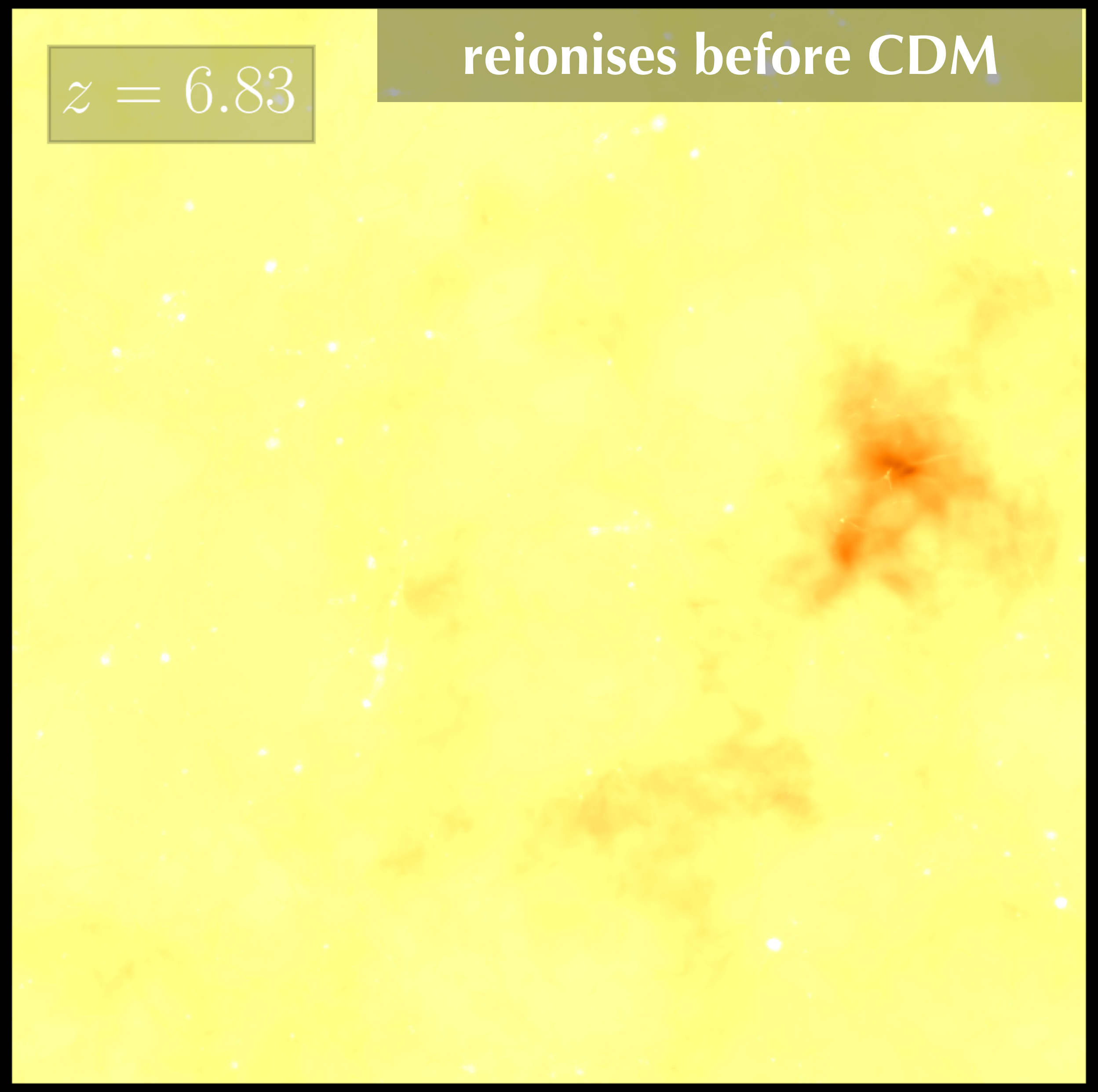

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conclusions

- ultrafaint galaxies are unique: bearing memory of reionisation, the assembly of the host galaxy, and the nature of the dark matter

- at fixed mass, haloes that assemble early contain more UFs — histories similar to that of our Galaxy are quite rare

- a large fraction of these satellites are located within the inner ~ 60 kpc of the host halo at $z = 0$

- despite the absence of low-mass dwarfs, DM models with a free-streaming cutoff have no issues reionising in time: brighter galaxies form efficiently, and carry the burden

- future 21cm experiments may be able to probe the absence of small-scale structure by measuring the size distribution of ionisation fronts

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