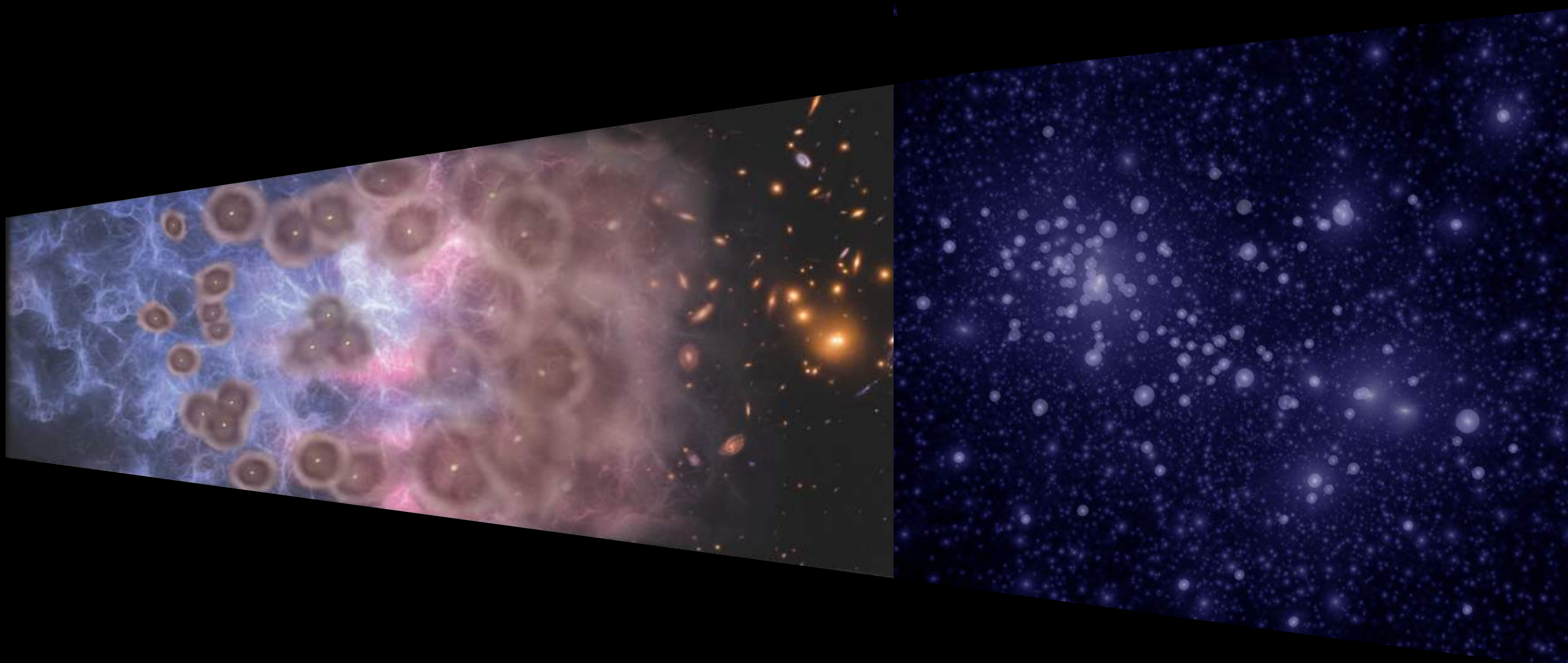
Galaxy Formation Physics Revealed by Faint Stellar Systems Near and Far

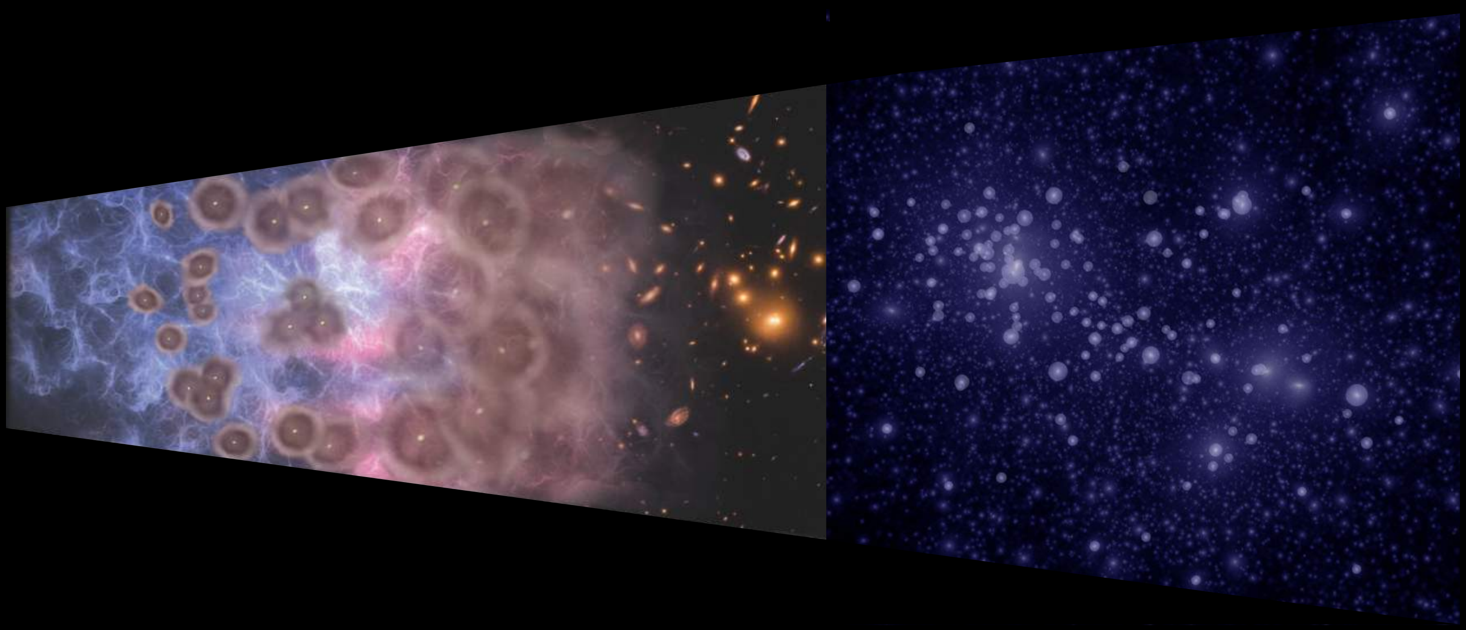


Mike Boylan-Kolchin

The University of Texas at Austin

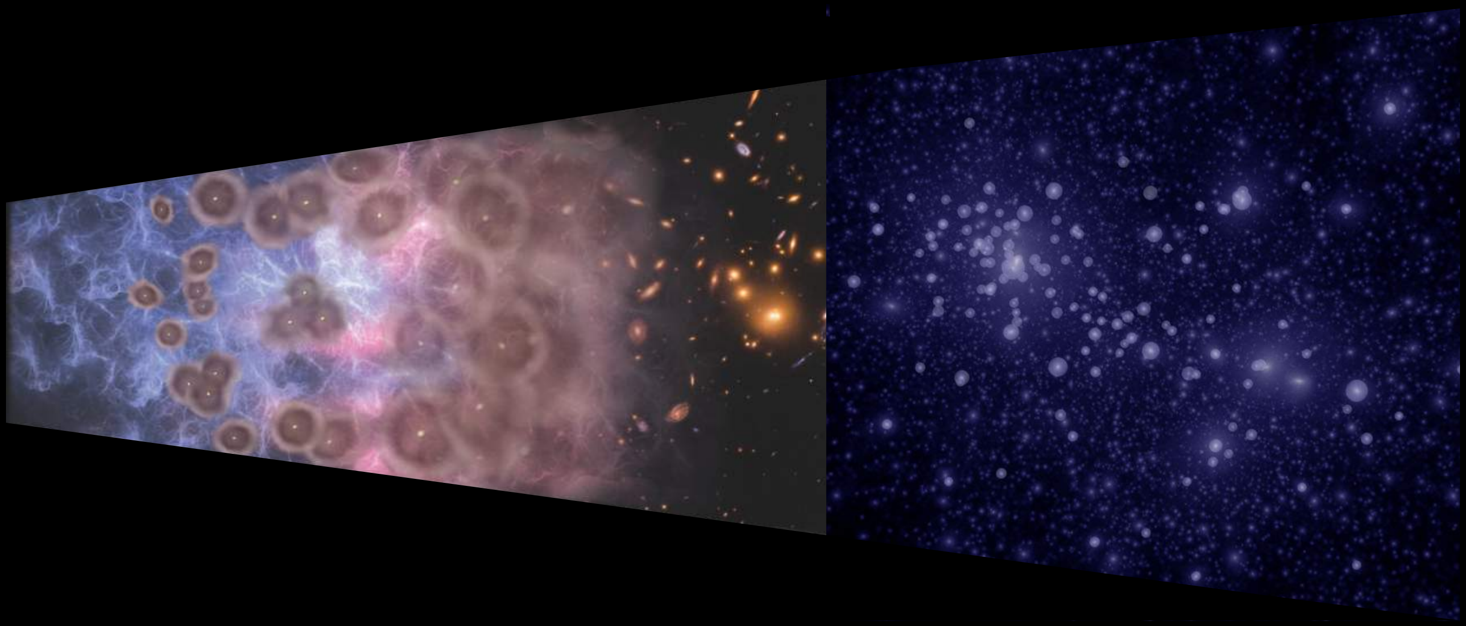
Why look for near-far connections?

- The nearby Universe is the *only* place where we can directly study the faintest stellar systems
- Conditions in the lowest mass, lowest metallicity regions nearby may reflect those of the earliest phases of star formation in the Universe
- These connections give us a way to understand galaxy *evolution*, not just a single snapshot

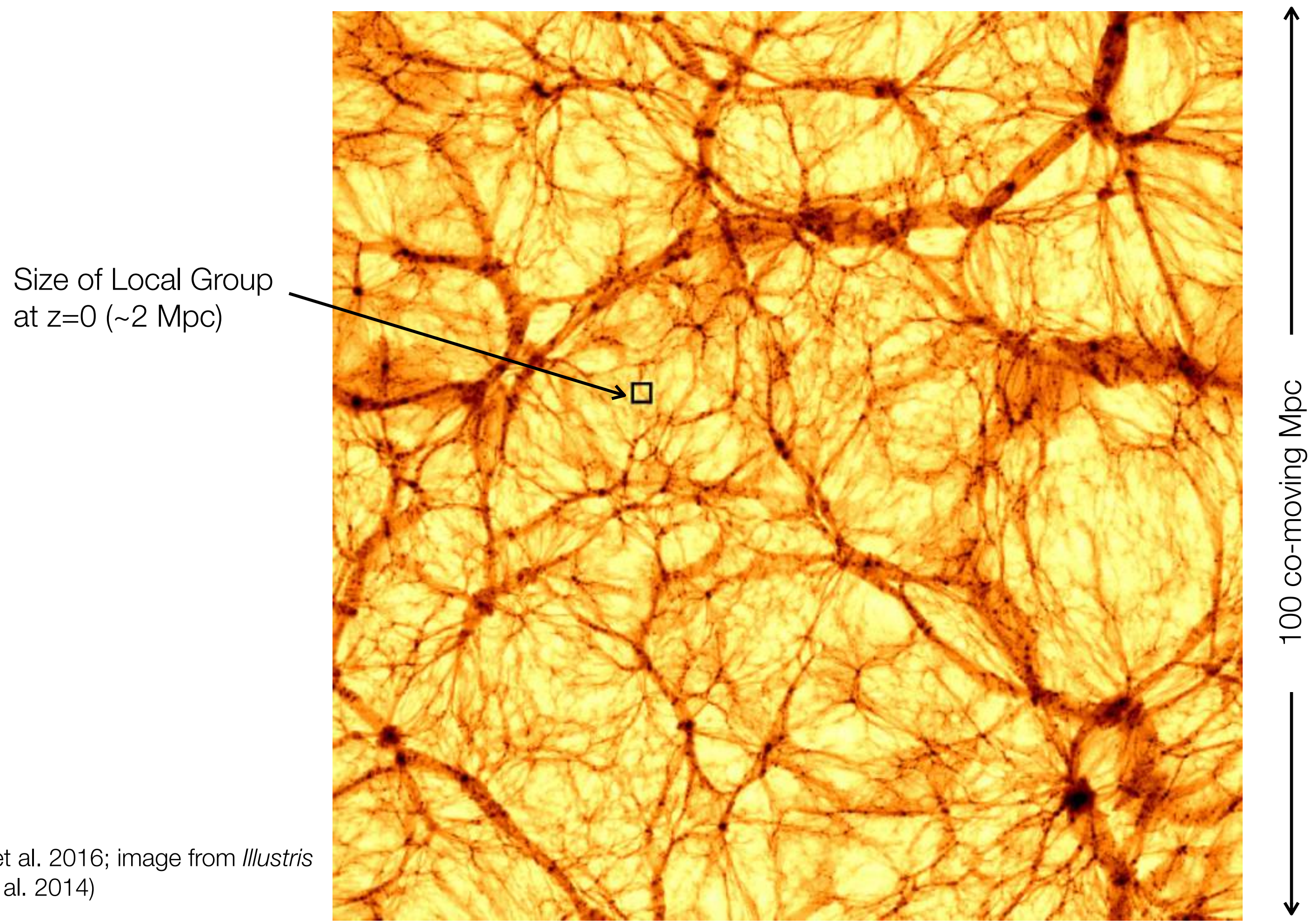


What can we learn by studying near-far connections?

- Reionization's effects on dwarf galaxies and dwarf galaxies' contributions to reionization
- Conditions of star formation leading to systems of similar $M_\star$ but vastly different properties
- Surviving versus disrupted galaxies and star clusters

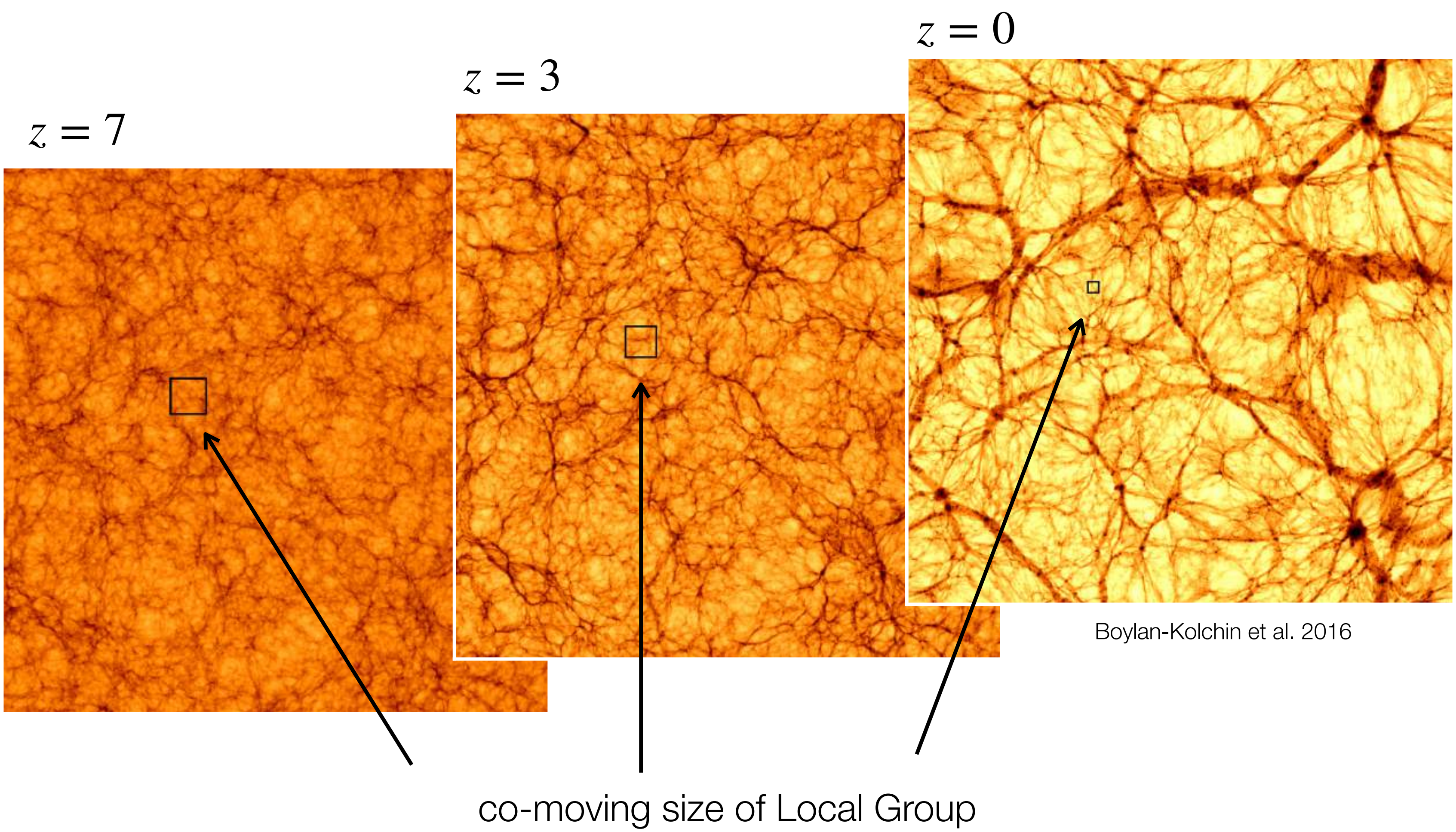


The Local Group at $z = 0$: a highly biased view of the Universe



Boylan-Kolchin et al. 2016; image from *Illustris*
(Vogelsberger et al. 2014)

The Local Group came from matter within a $r \sim 5$ comoving Mpc sphere



Boylan-Kolchin et al. 2016

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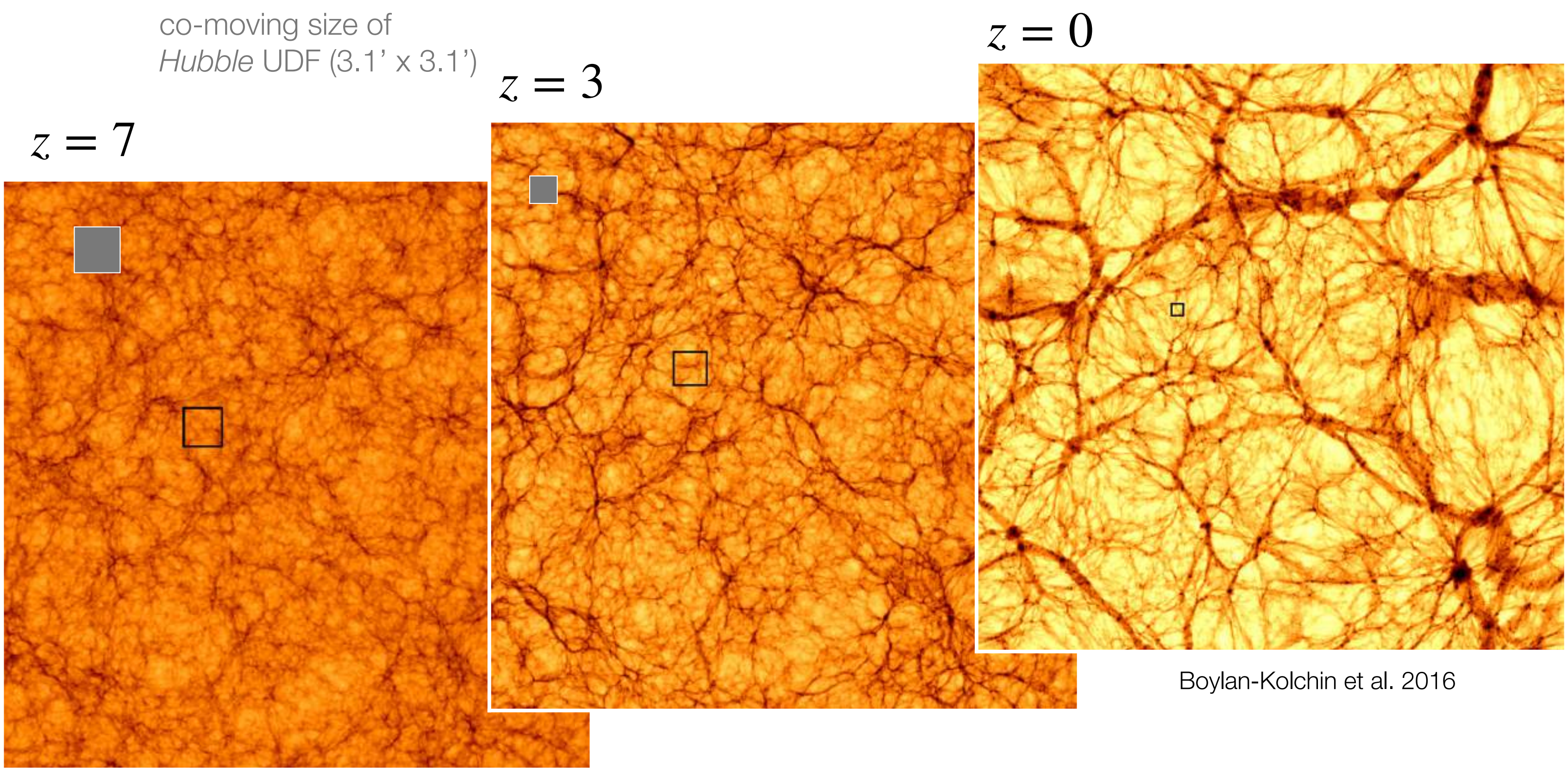
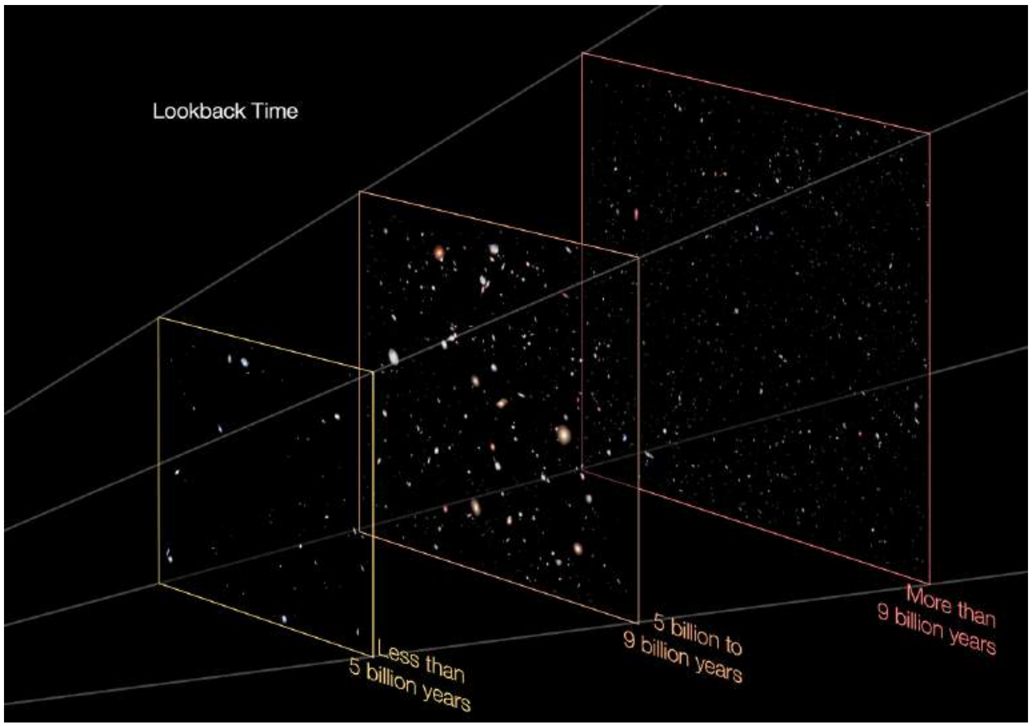


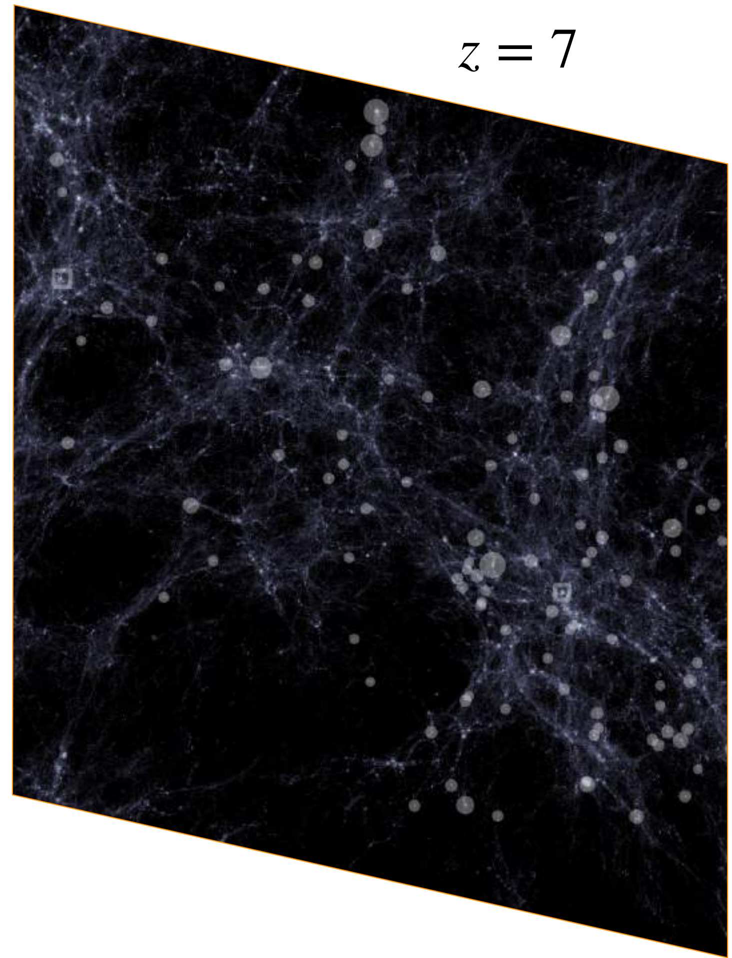
Boylan-Kolchin et al. 2016

For most of the history of the Universe, the progenitors of the Local Group cover a larger area on the sky than the *Hubble* UDF

The Local Group is unique in its ability to reveal galaxy evolution



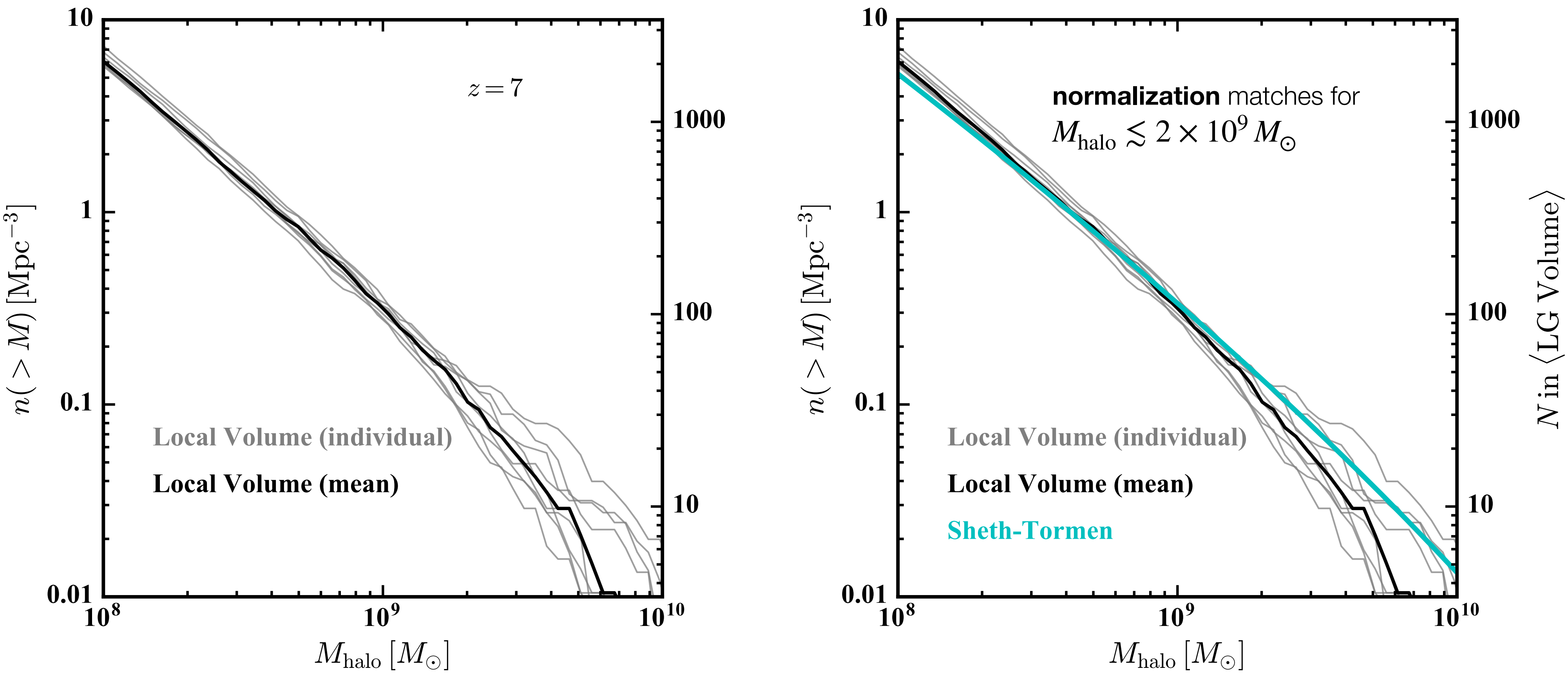
http://www.alternavox.net/wp-content/uploads/heic1214c.jpeg



The Local Group: galaxy evolution on a galaxy-by-galaxy basis in thin z-slices ($\Delta z \sim 0.02$ at $z = 7$) with area similar to HUDF/NIRCam

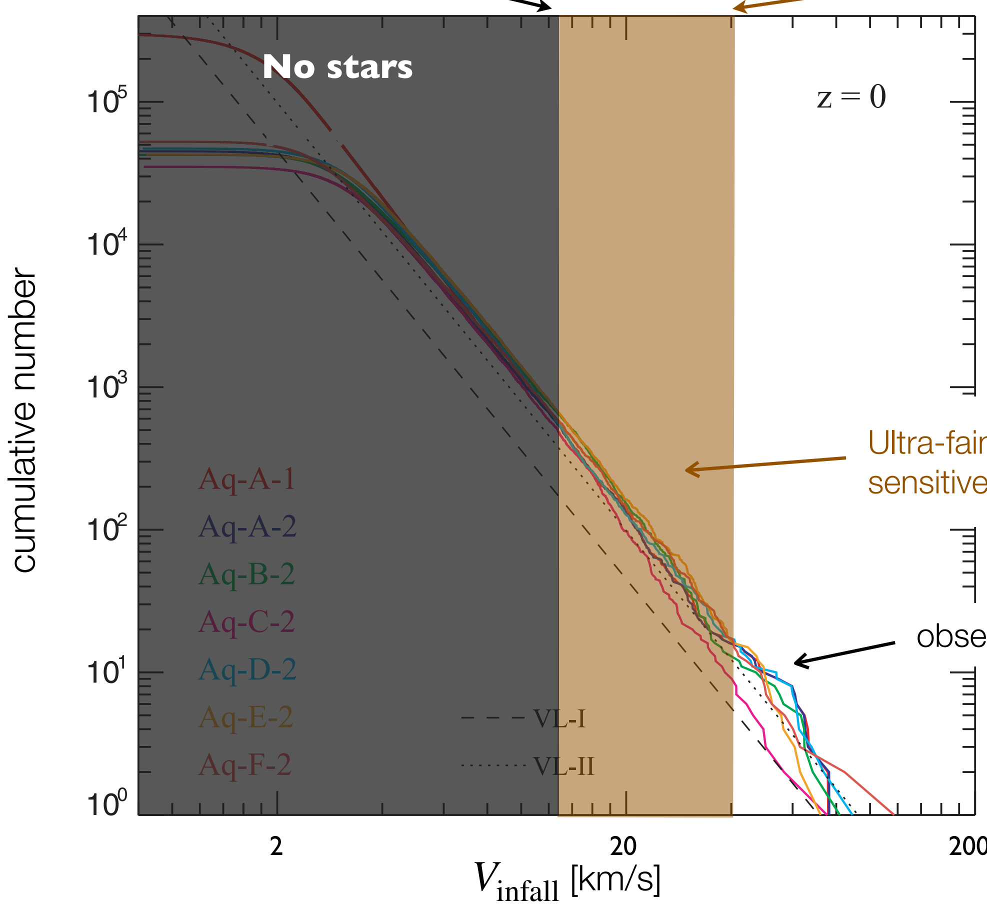
The faint galaxy population of the Local Group is representative* of the Universe

*in some ways; we would like to understand this better



Boylan-Kolchin et al. 2016

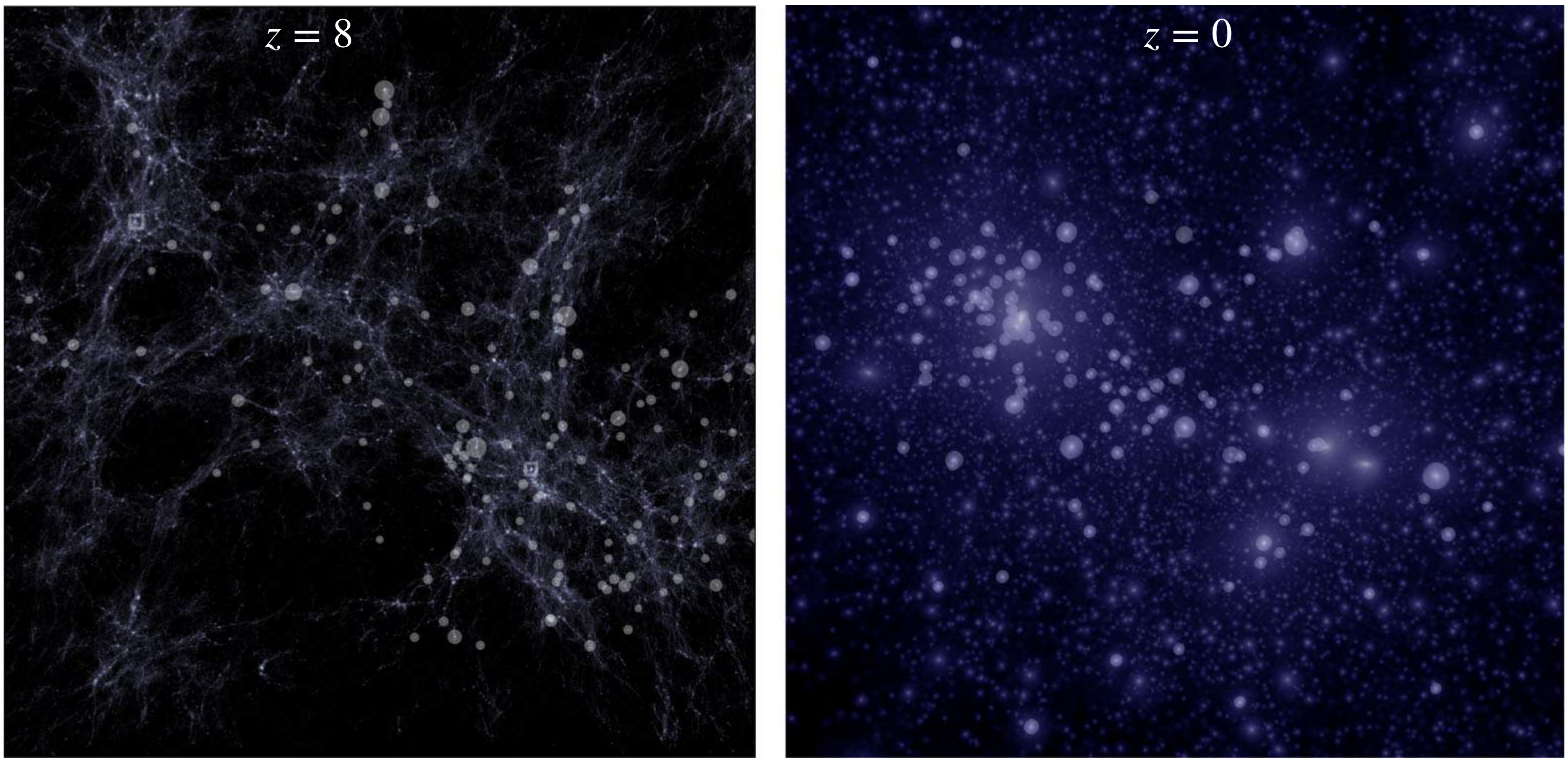
What are the scales relevant for galaxy formation?



Springel et al. 2008 / Aquarius project

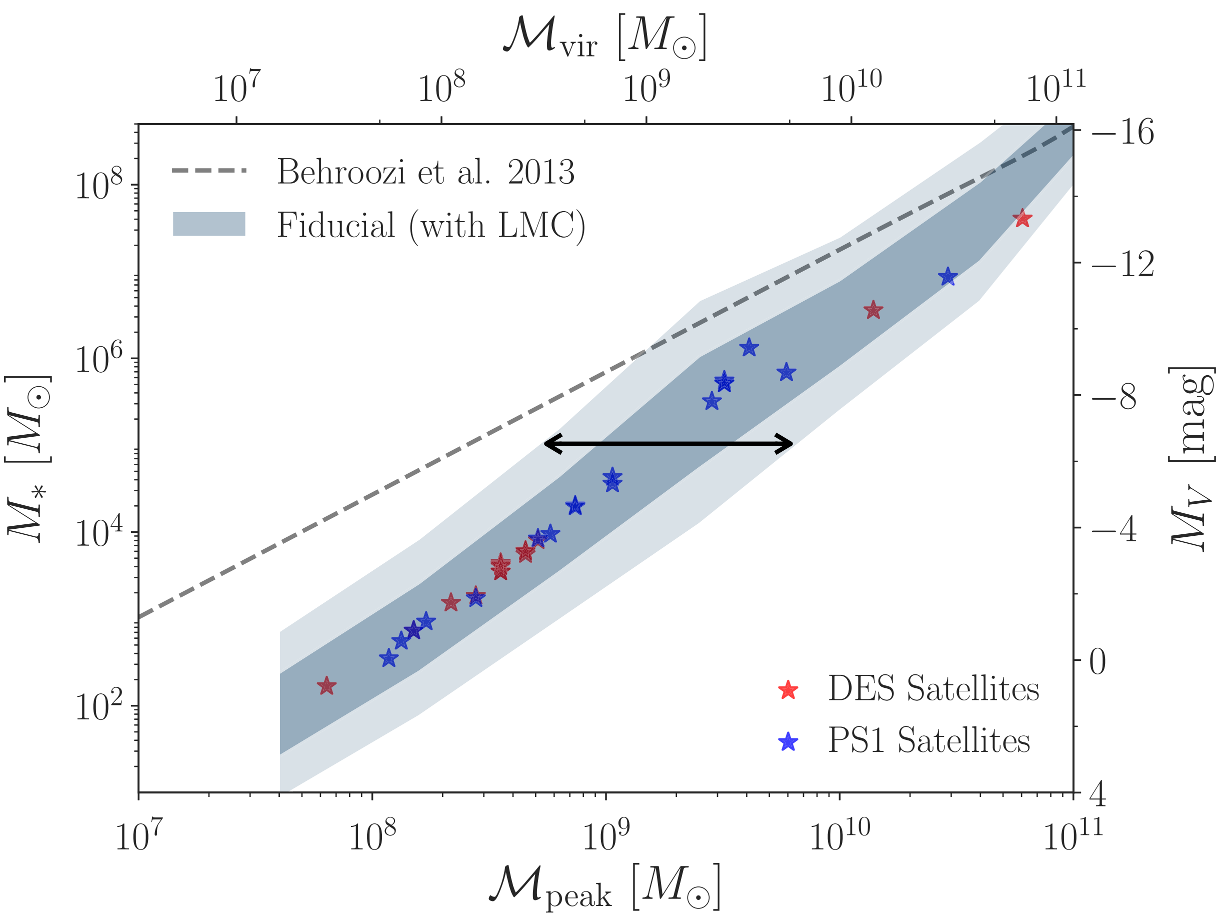
The field should be littered with reionization-quenched ultra-faints

circles: halos above atomic cooling limit at $z = 8$ with a descendant at $z = 0$



Boylan-Kolchin et al. 2015

In theory land, $M_{\rm halo}$ (not $M_\star$) reigns supreme



Nadler et al. 2020

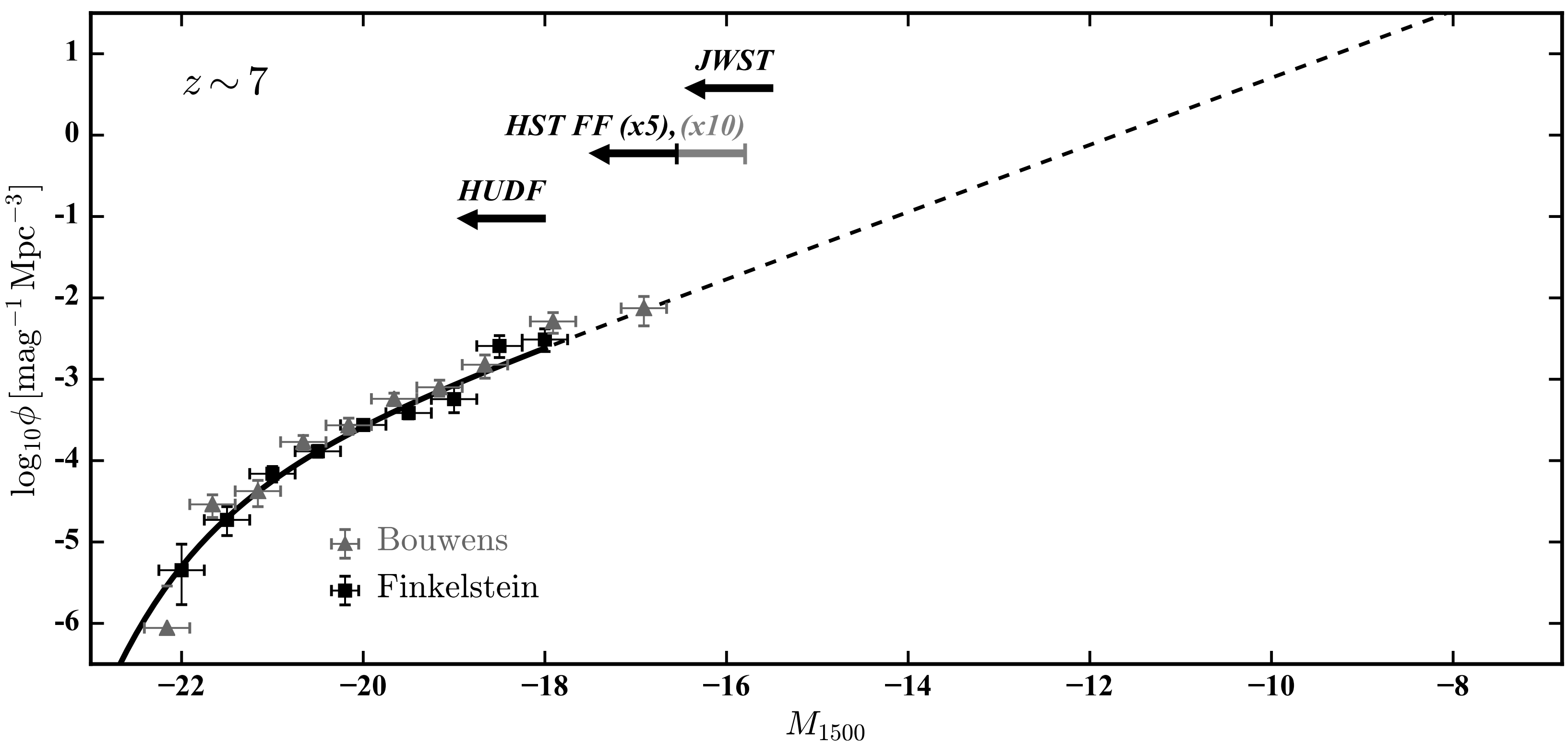
$M_\star = 10^5\,M_\odot$:

spread of factor of 10 in $M_{\rm halo}$

($10^{2/3} \approx 5$ in $T_{\rm vir}$ or Φ_0)

Expect substantial variations in SFHs at fixed $M_\star$

Reconstructing Local Group galaxies at high redshifts



Boylan-Kolchin et al. 2015

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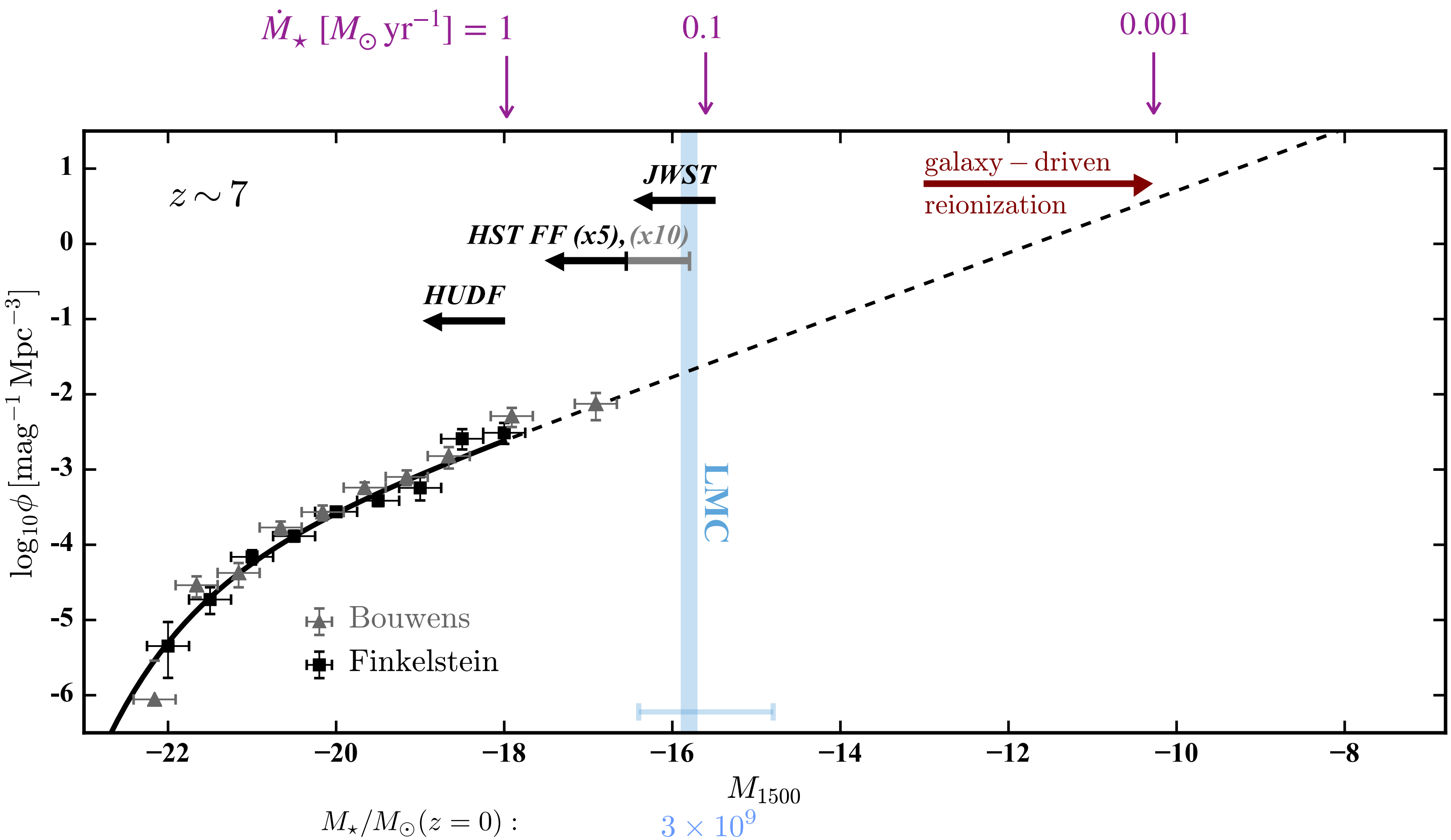
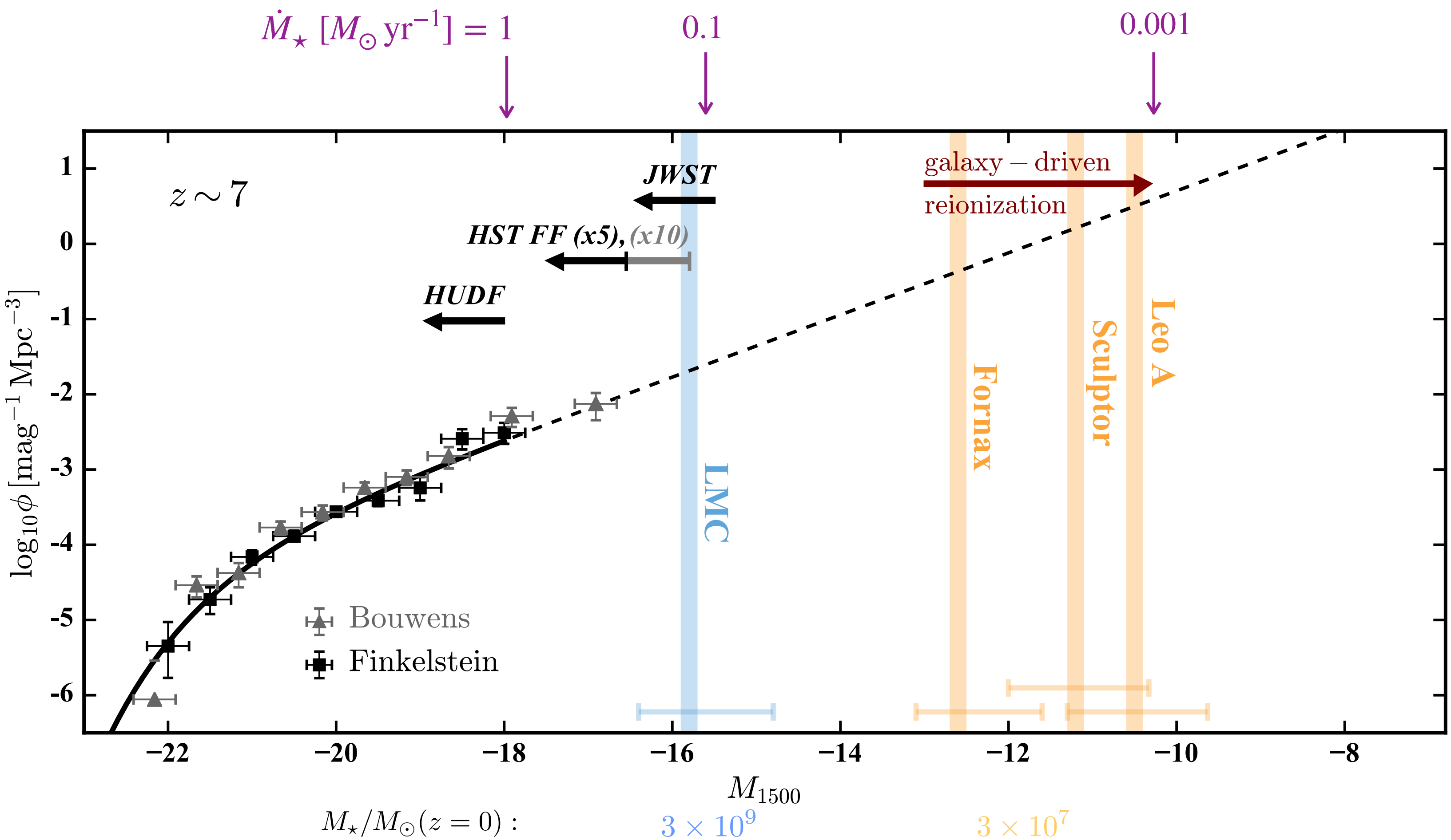


Boylan-Kolchin et al. 2015

Reconstructing Local Group galaxies at high redshifts



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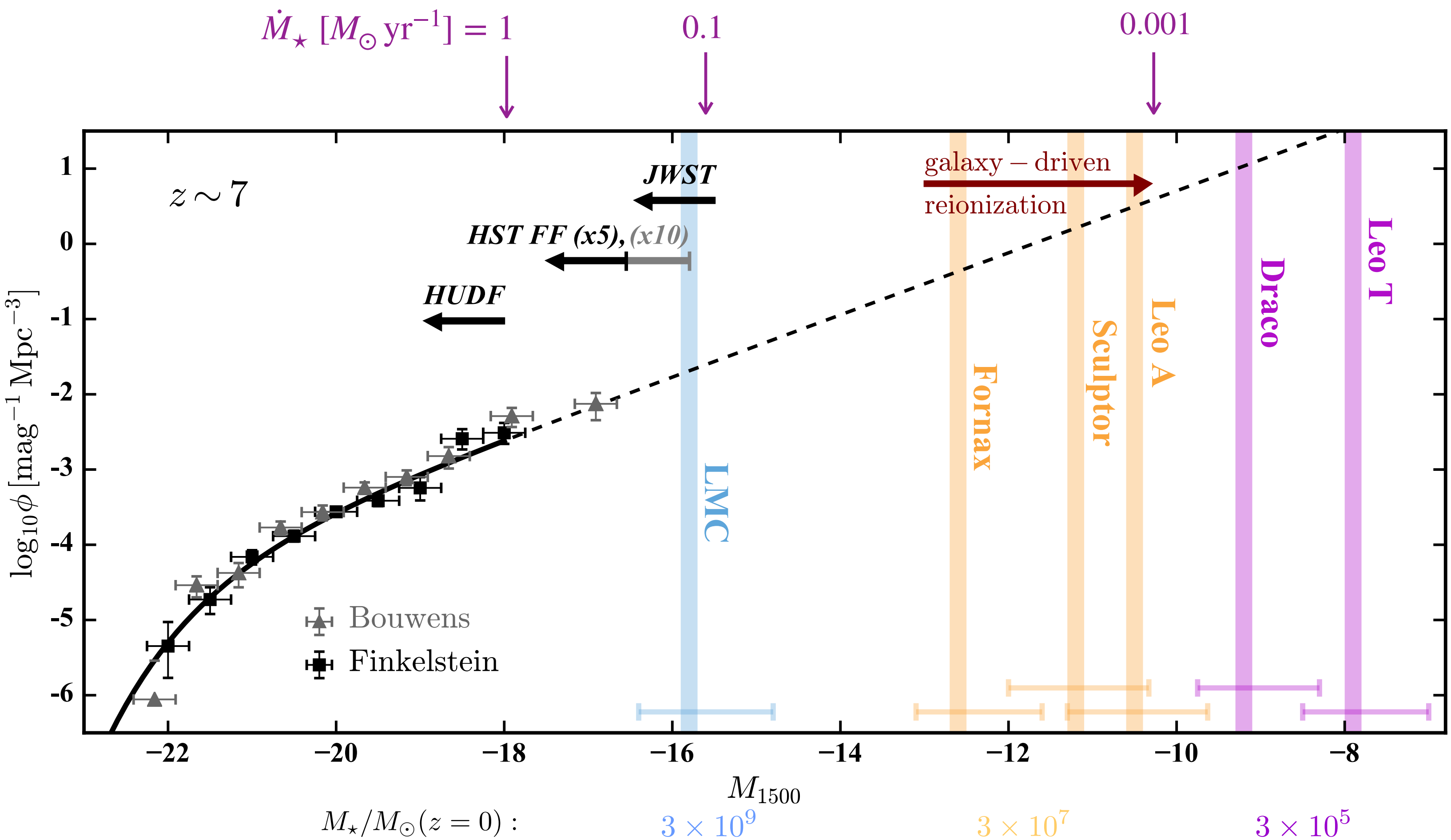
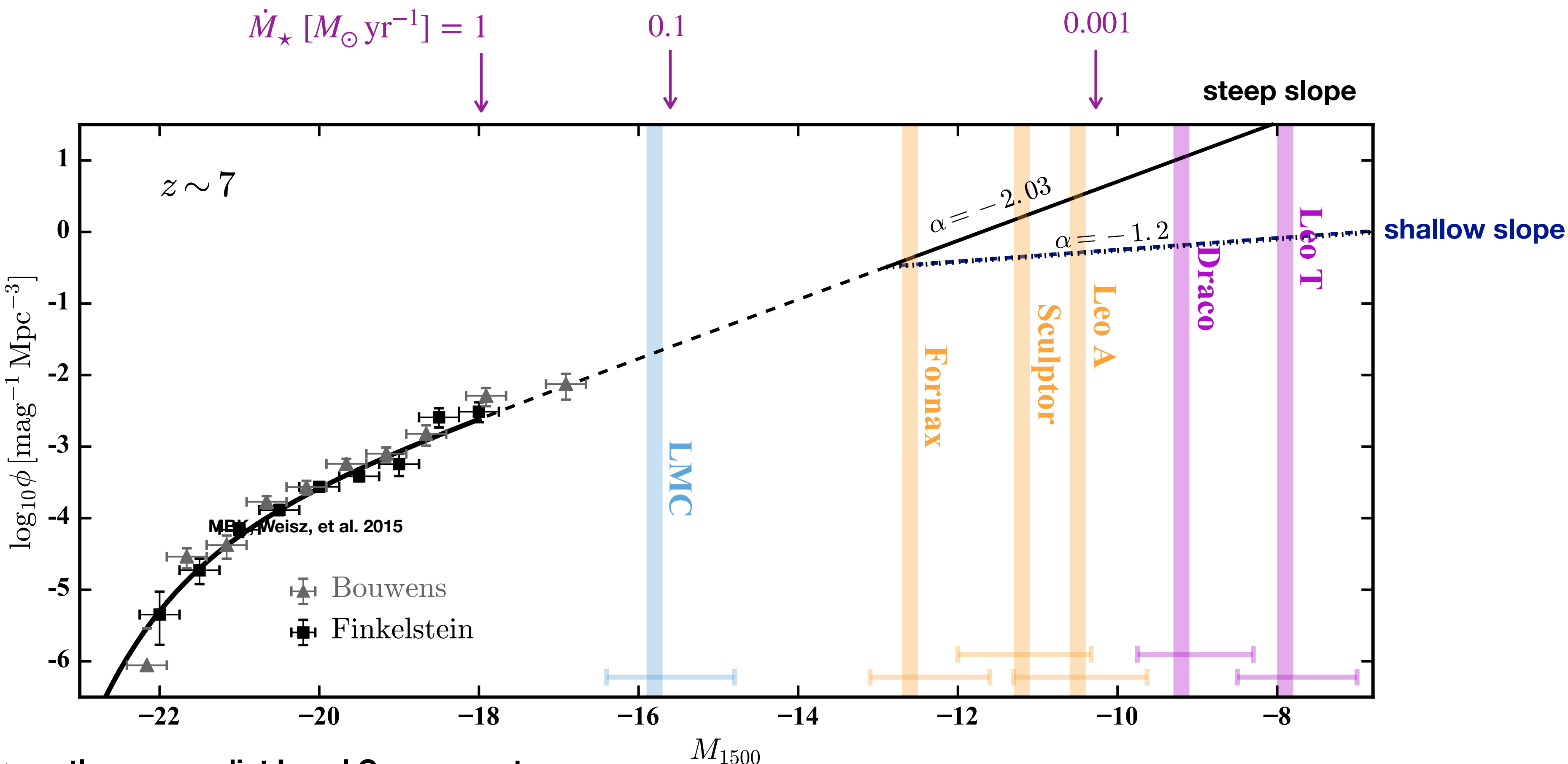
Reconstructing Local Group galaxies at high redshifts



Boylan-Kolchin et al. 2015

Reconstructing Local Group galaxies at high redshifts

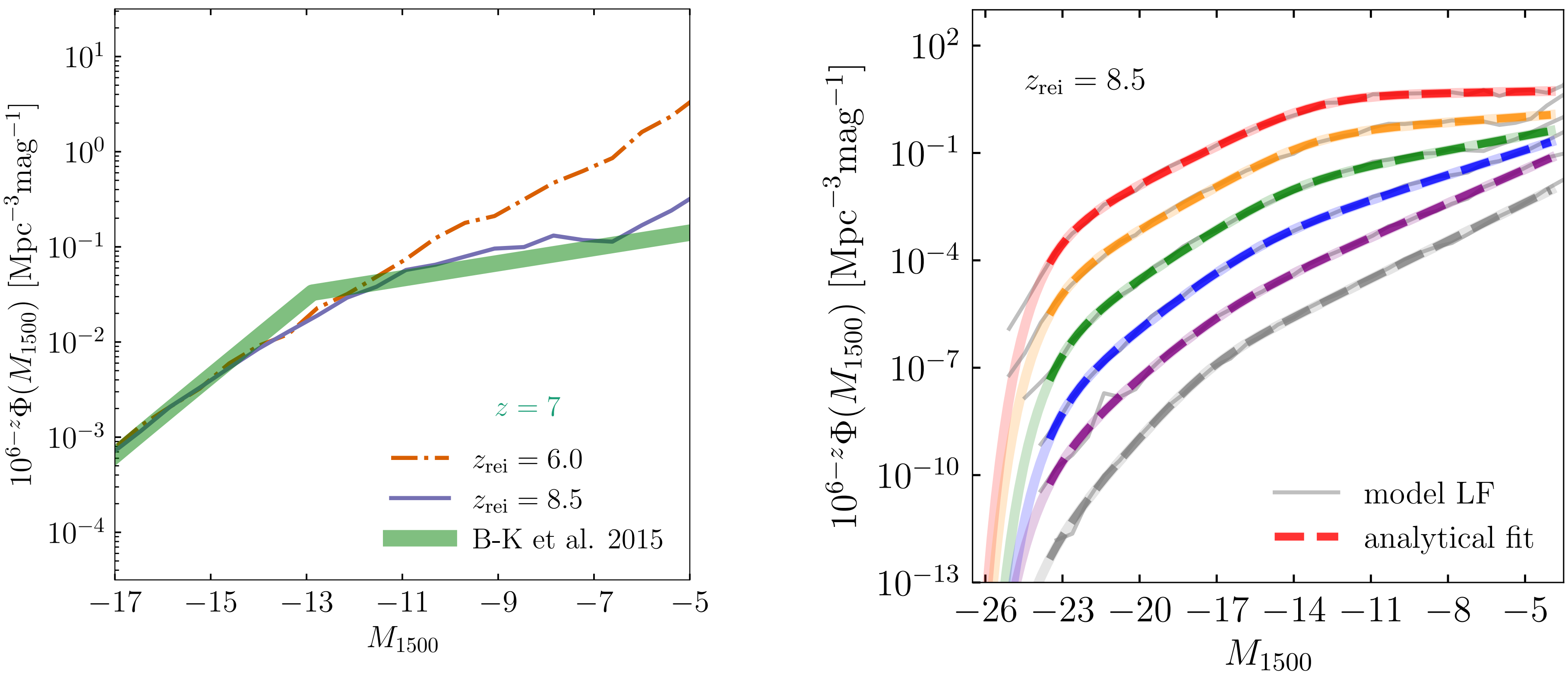


steep slope → vastly over-predict Local Group counts

broken LF → match Local Group counts (still get reionization)

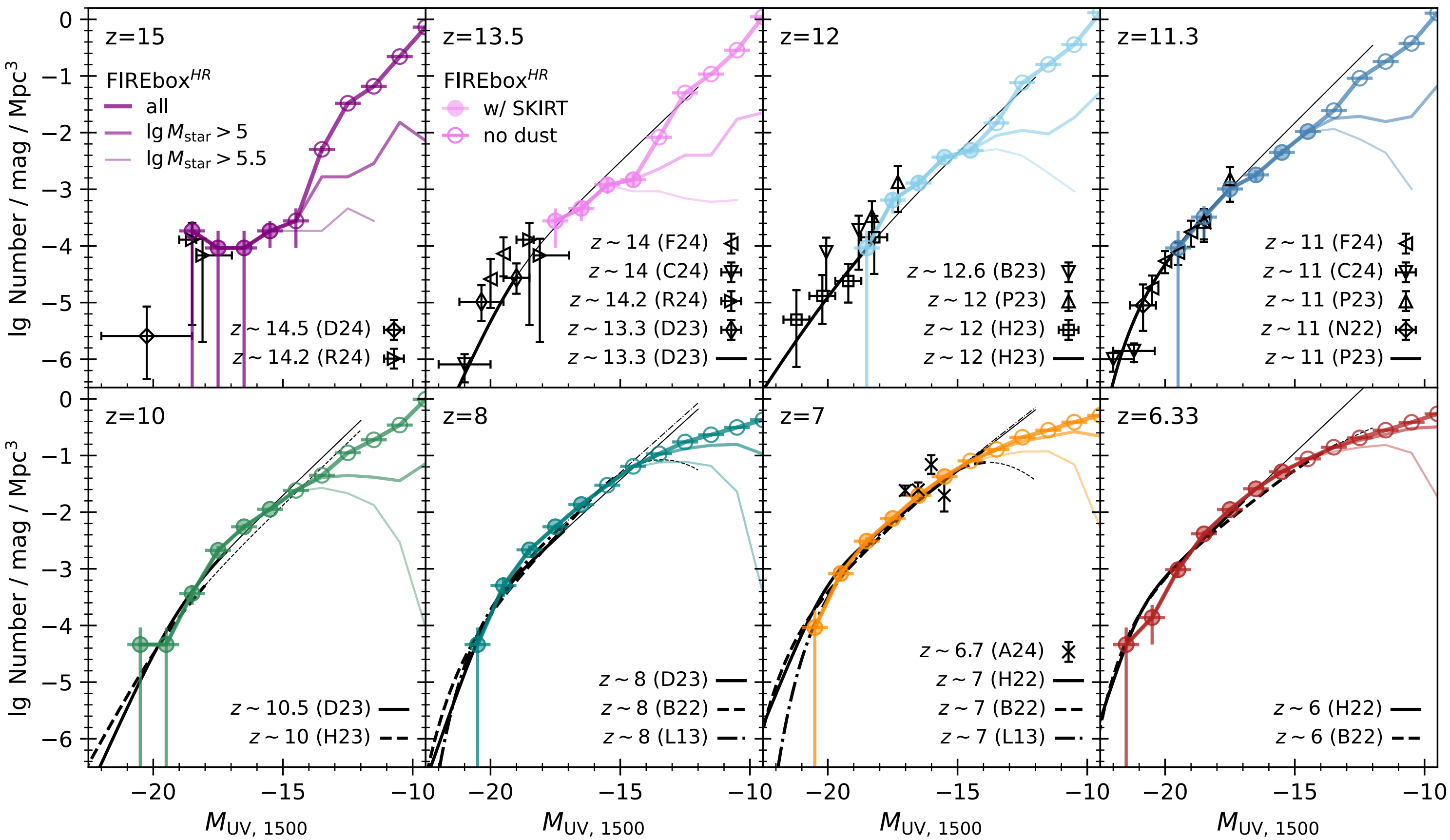
Boylan-Kolchin et al. 2015

Models predict a redshift-dependent flattening



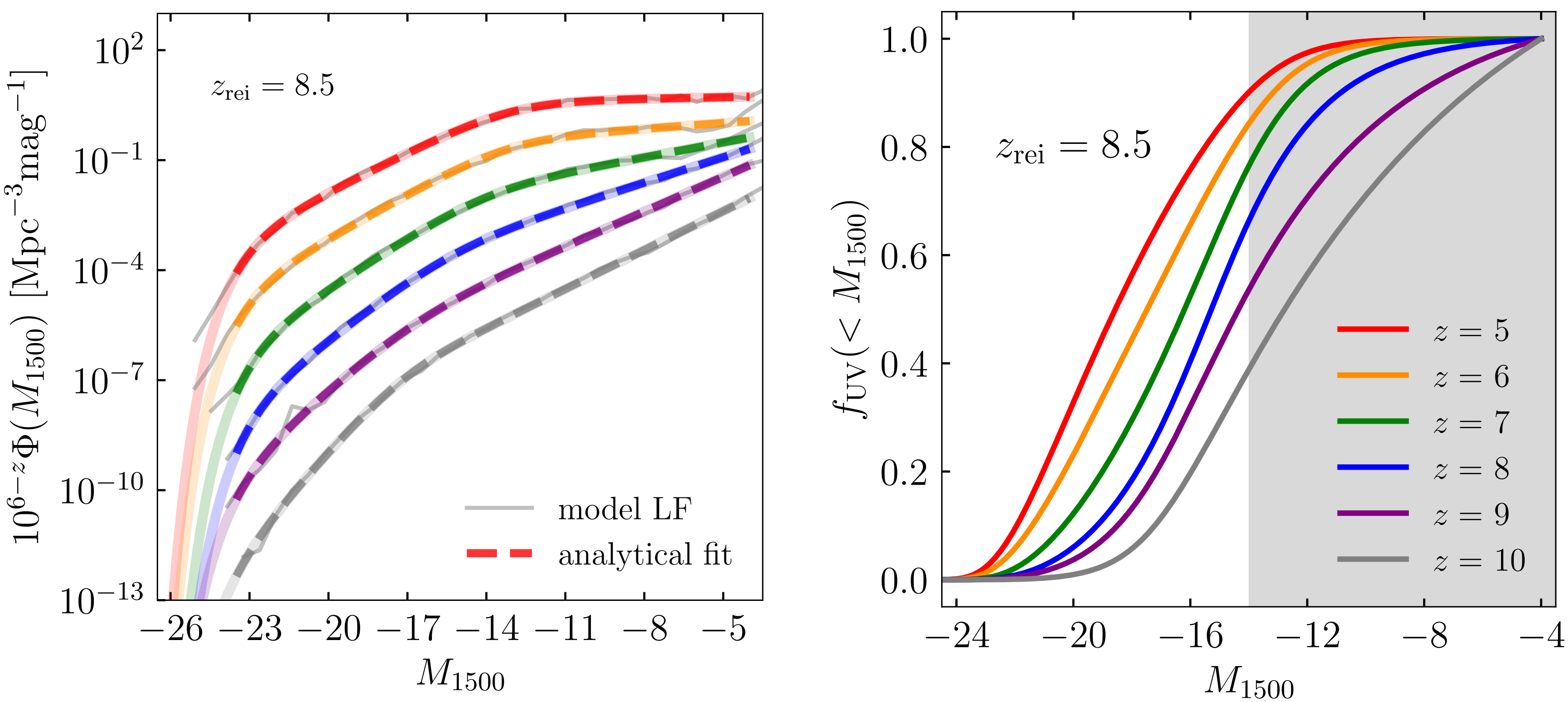
Wu & Kravtsov 2024

Simulations see a redshift-dependent flattening



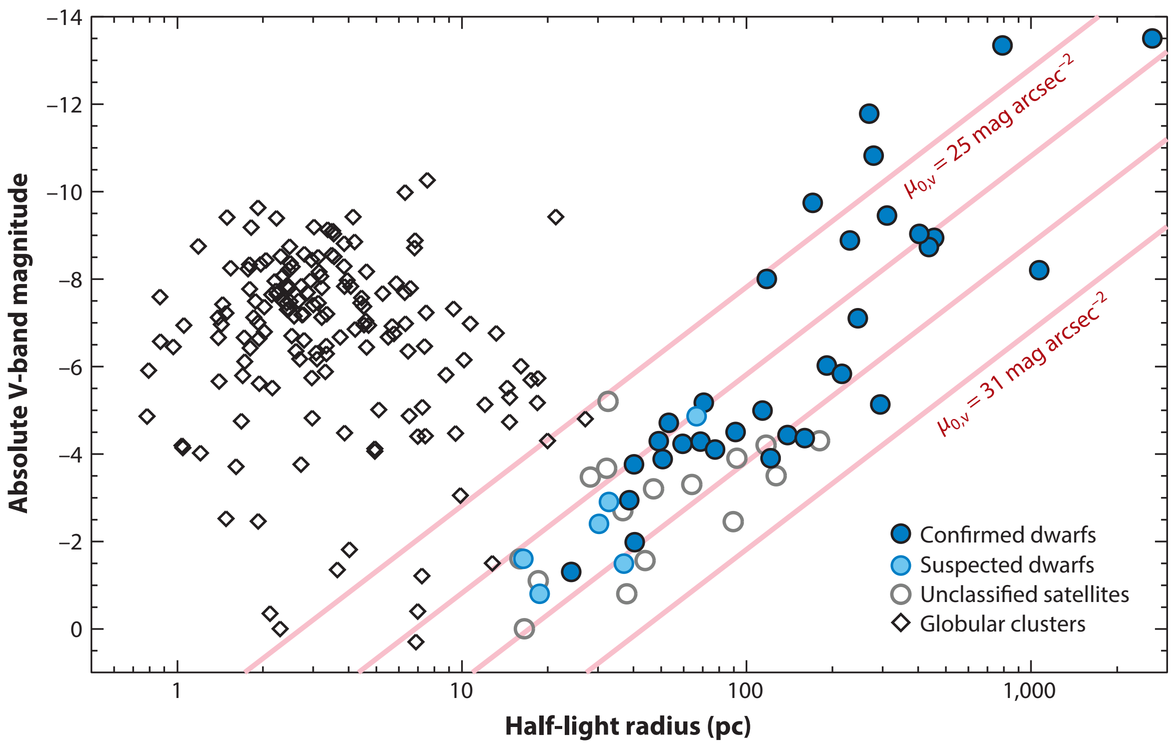
Feldmann et al. 2024

Dwarfs are crucial for the reionization budget



Wu & Kravtsov 2024

What about star clusters?

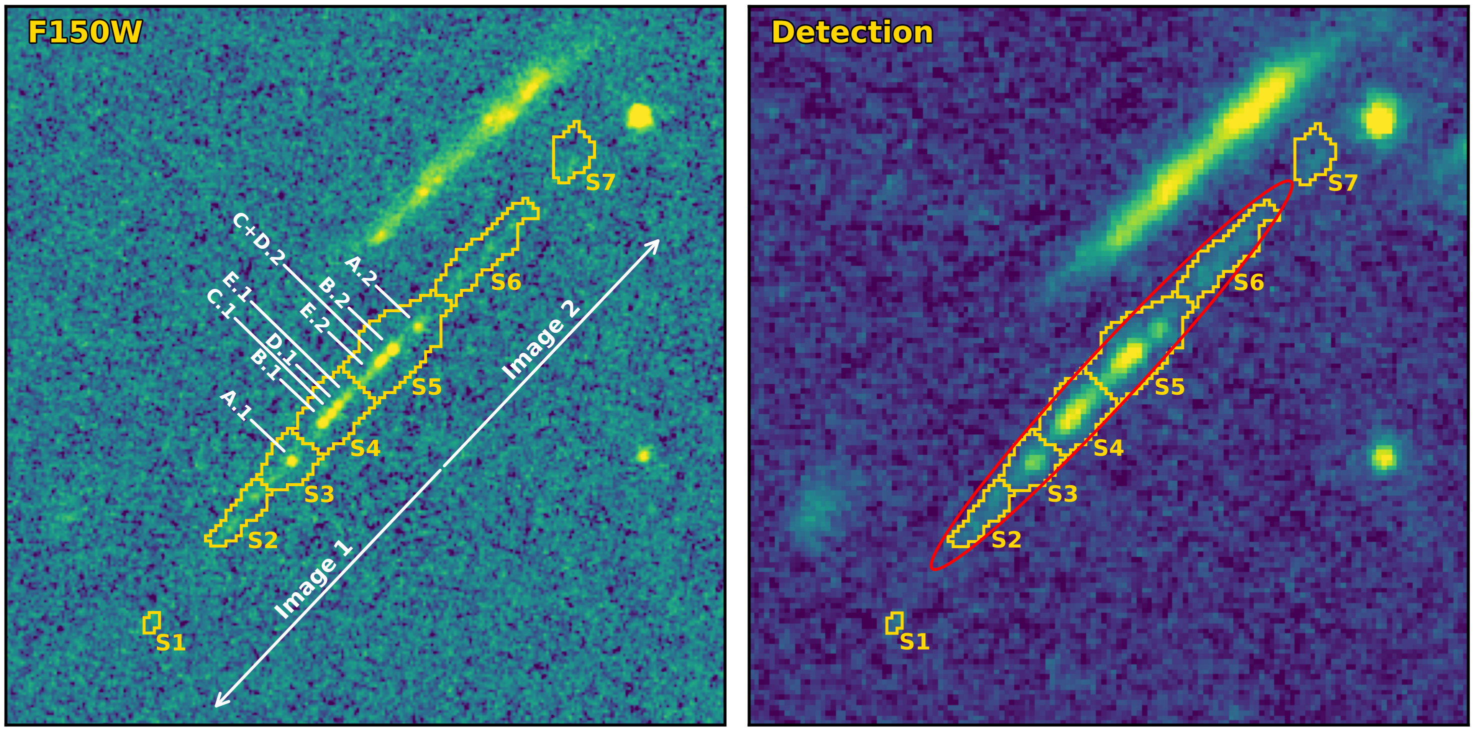


Simon 2019

Globular cluster formation epoch starts early

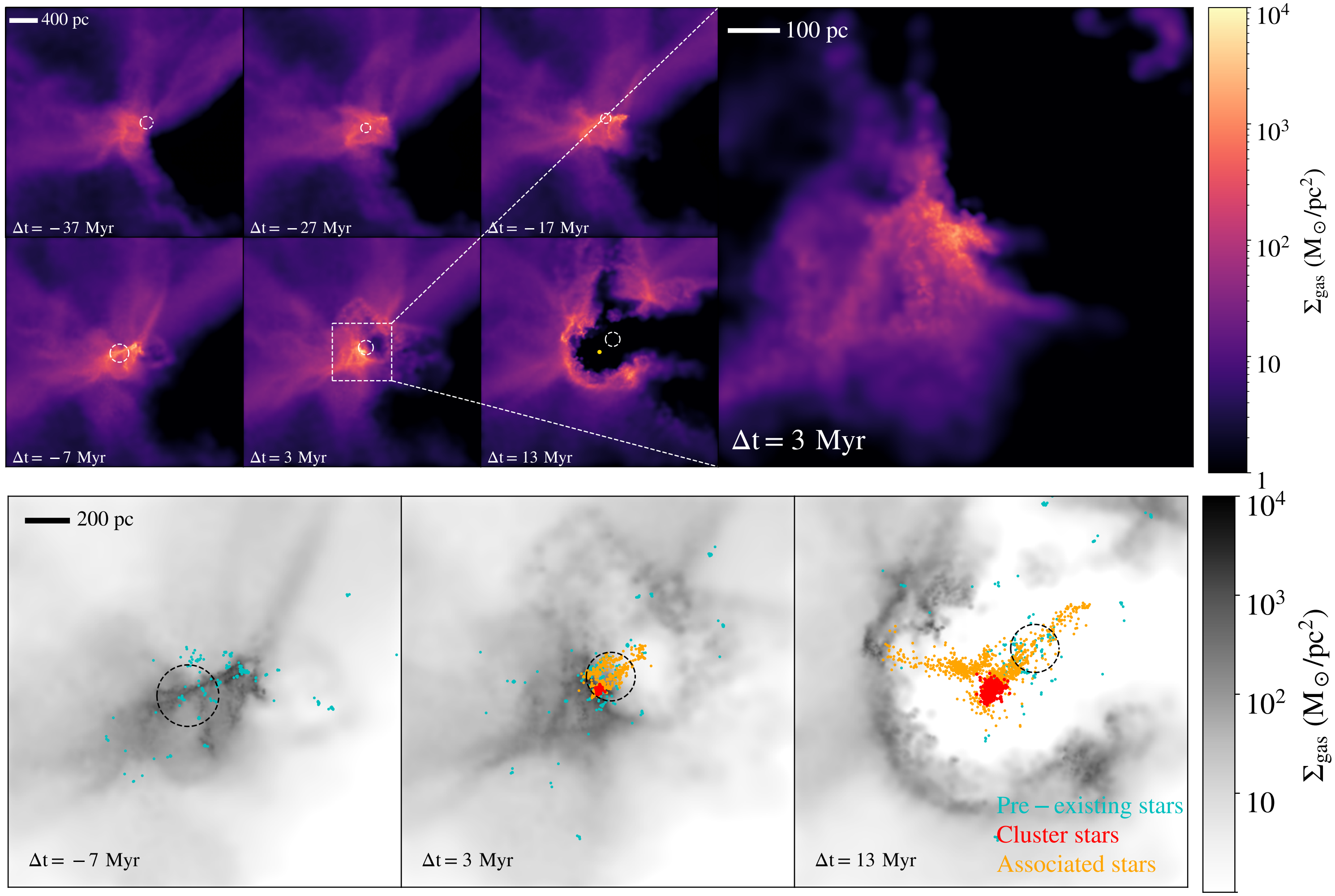
Individual star clusters with $r \sim 1\,\mathrm{pc}$, $M_\star \sim 10^6\,M_\odot$ in a $z = 10$ galaxy

Clusters constitute ~30% of the total stellar mass ($M_{\star,\mathrm{tot}} \approx 2.5 \times 10^7\,M_\odot$)



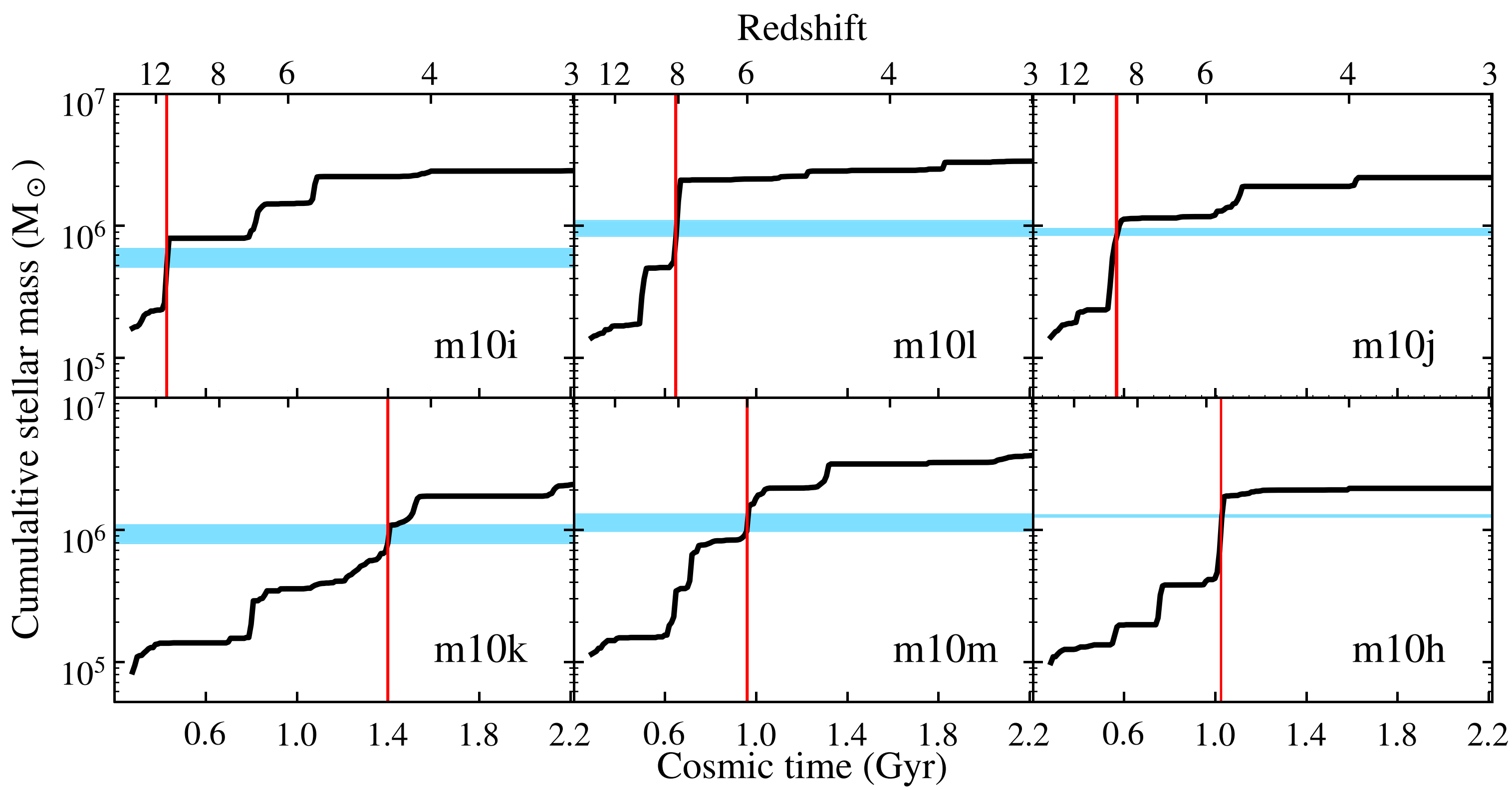
Bradley et al. 2024, Adamo et al. 2024

Formation of a globular cluster (?) in a dwarf galaxy at $z \approx 11$



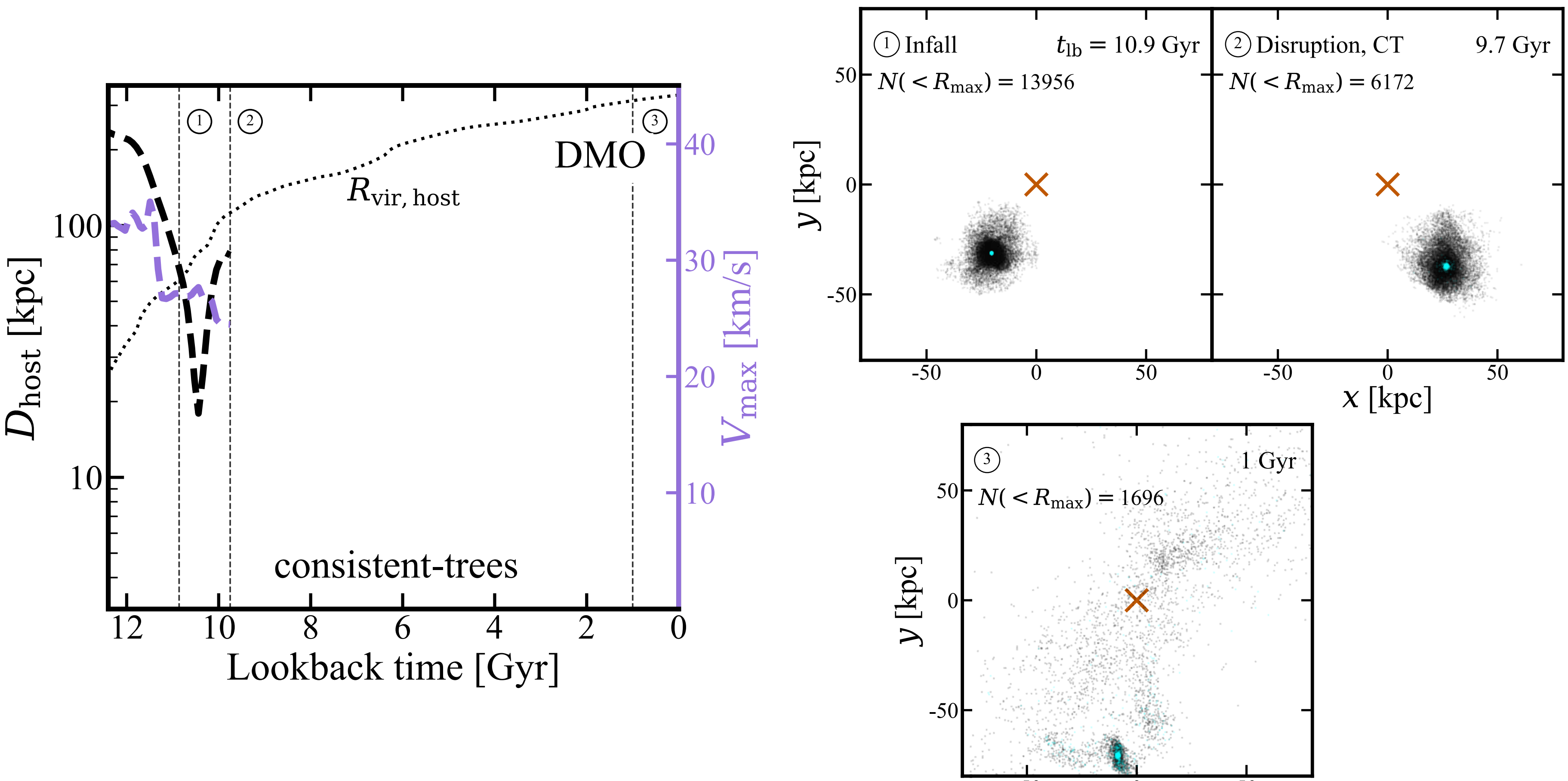
Sameie et al. 2023

Cluster formation precedes galaxy formation



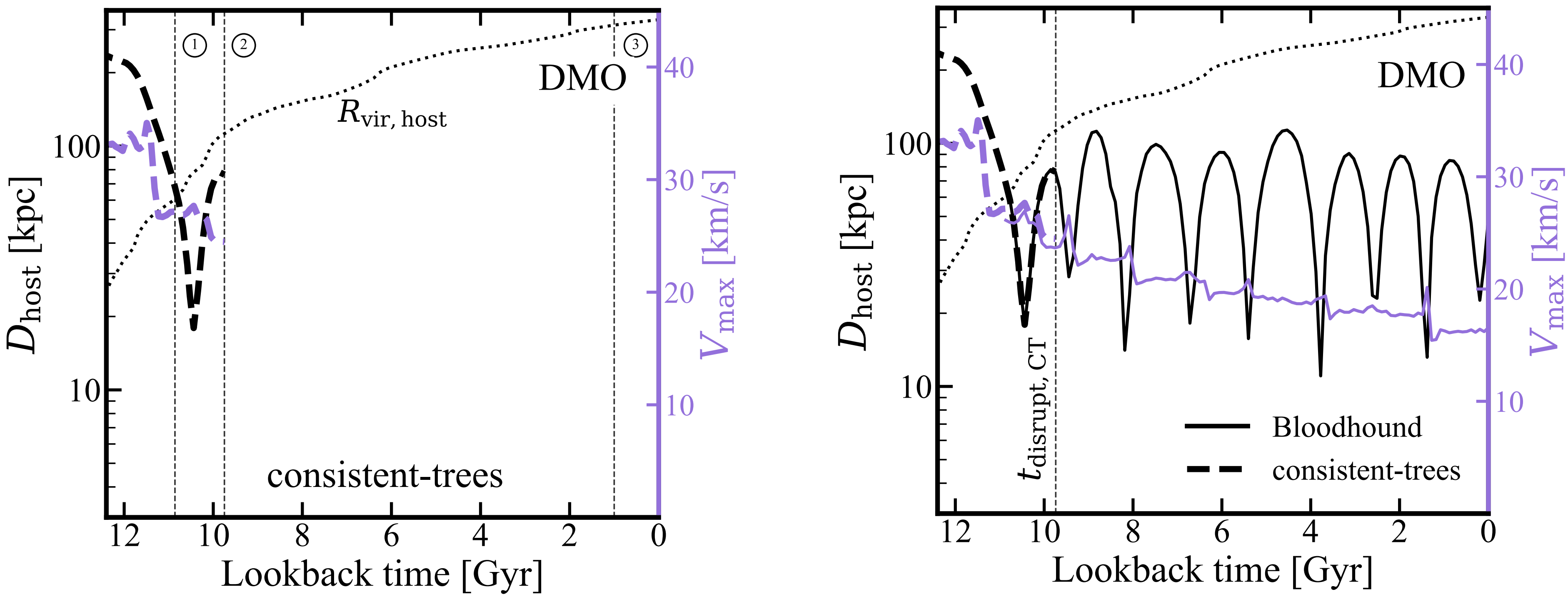
Sameie et al. 2023

How robust are our simulation-based results?



Kong et al. (in preparation)

Halo and galaxy tracking is an issue



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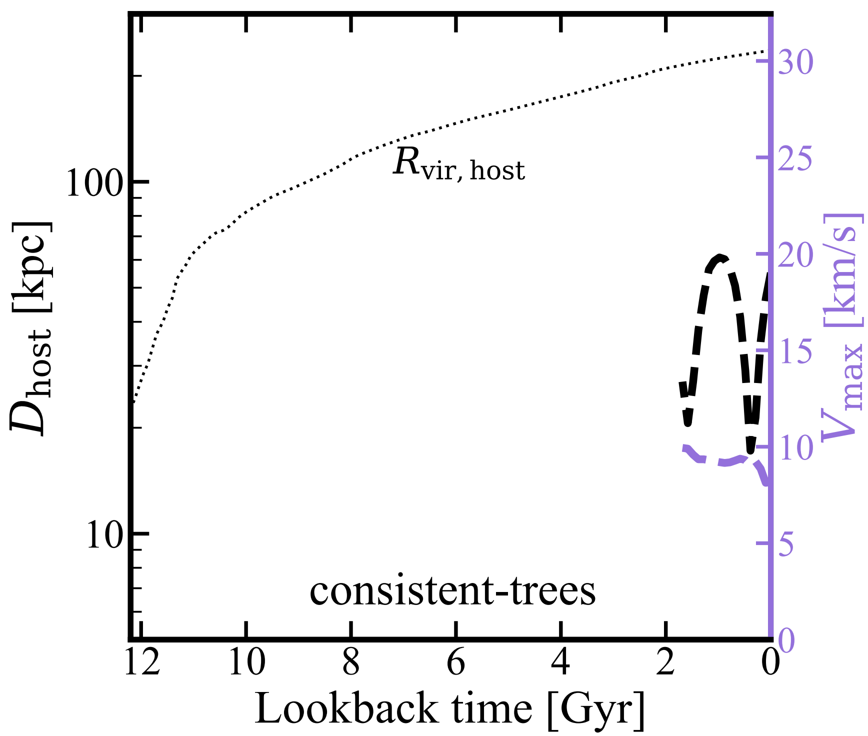

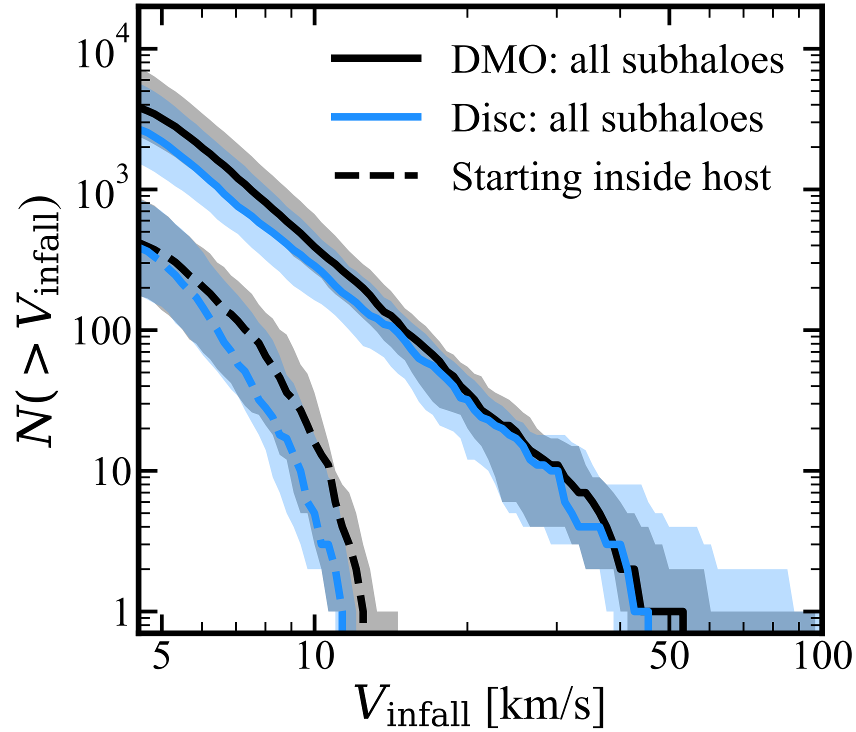

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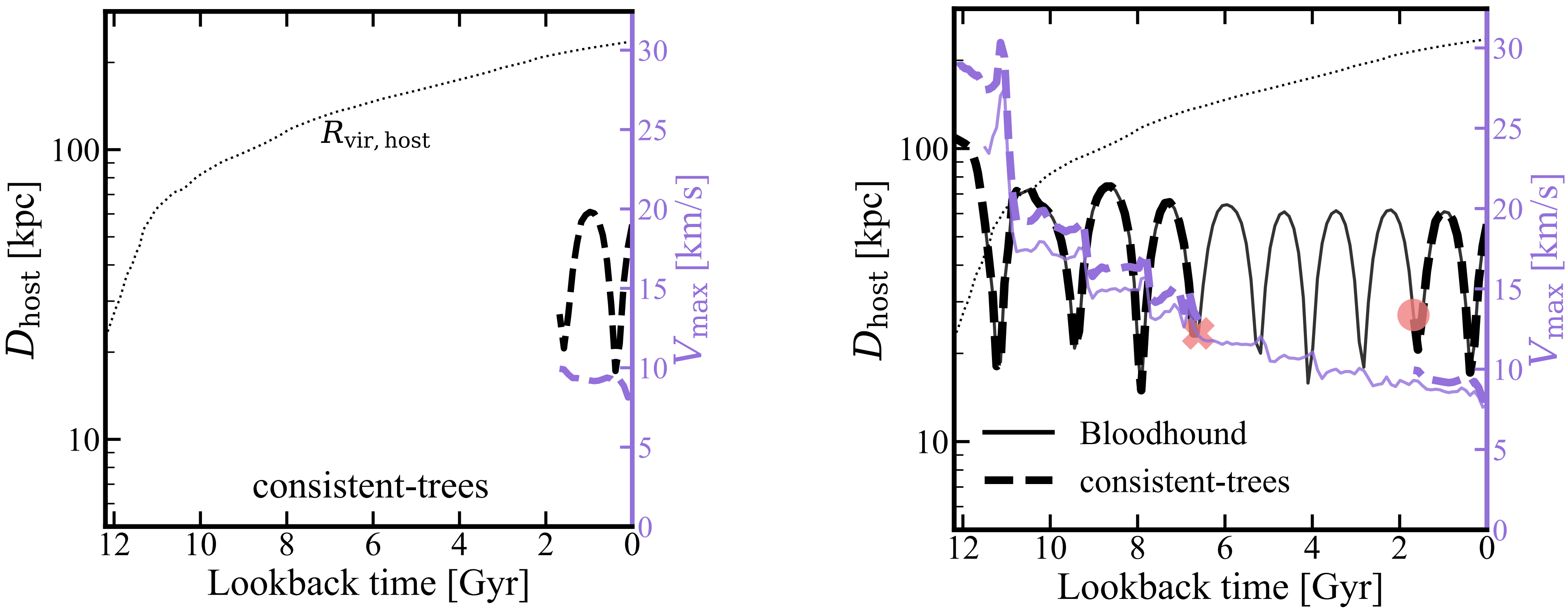
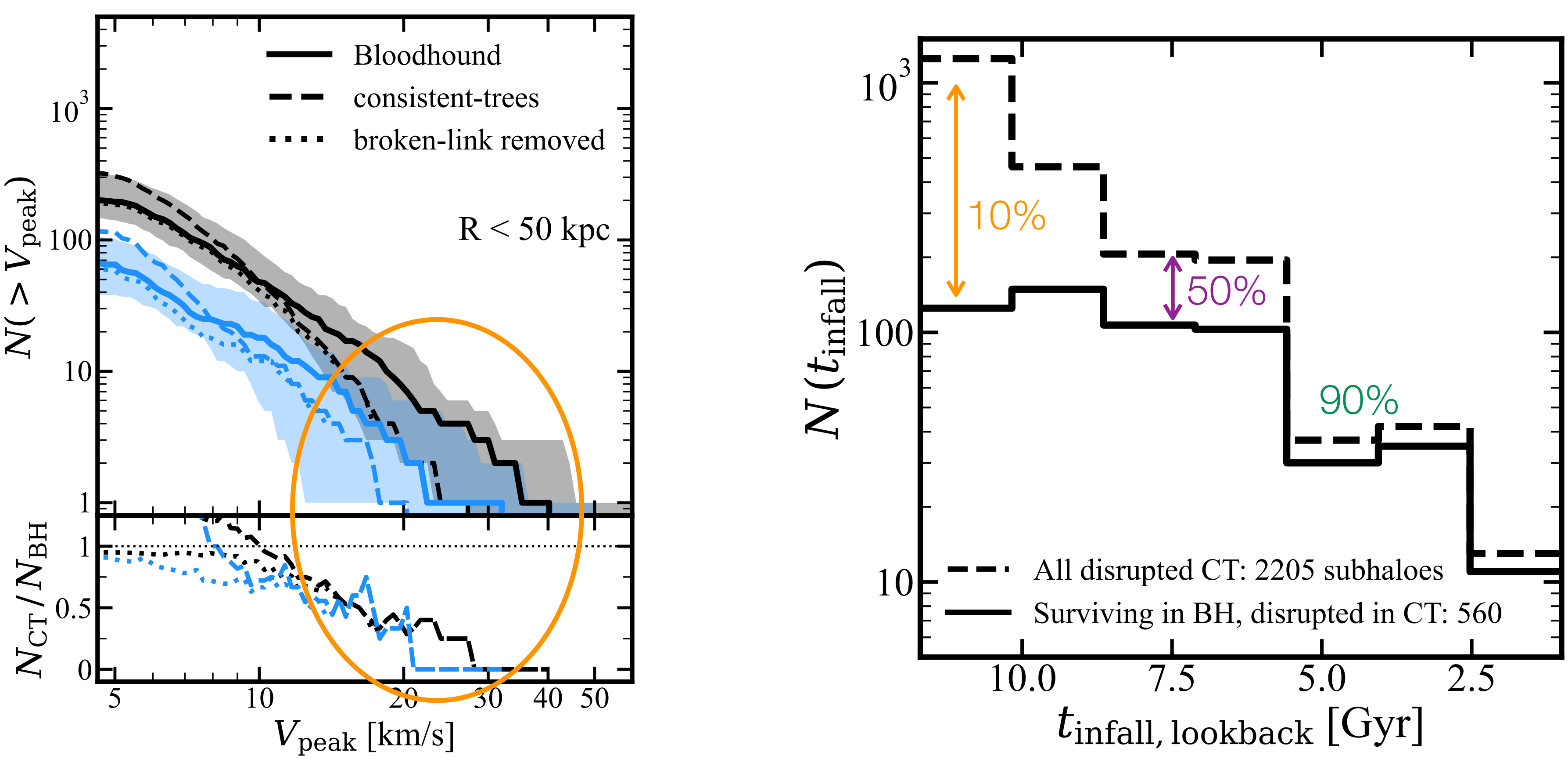


Kong et al. (in preparation)

Affects predictions for massive subhalos near halo centers

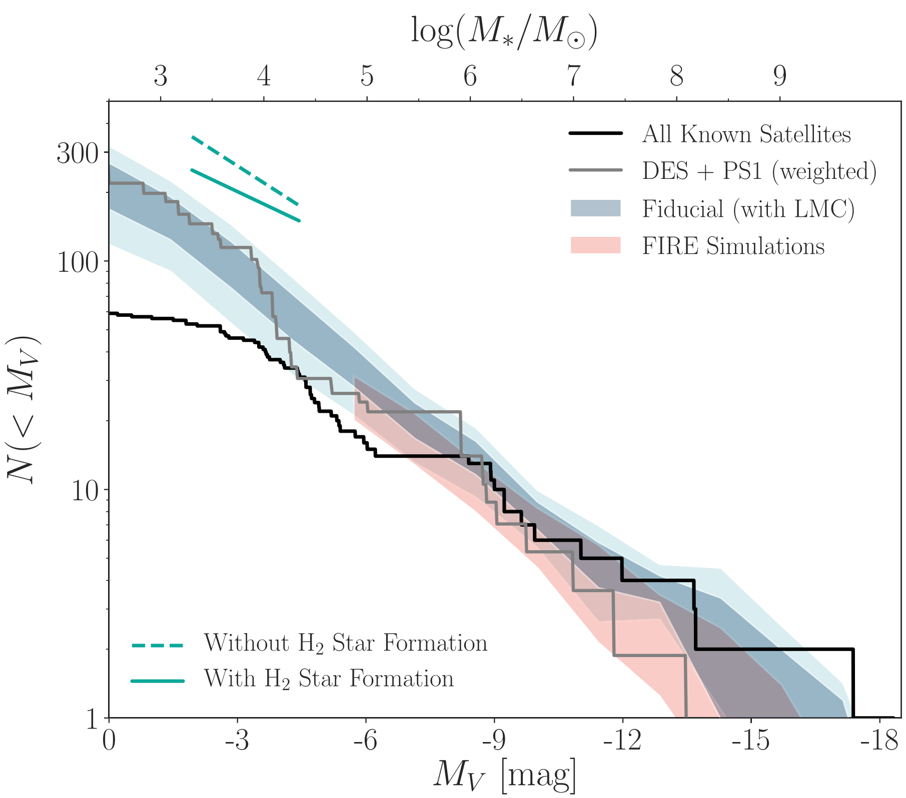


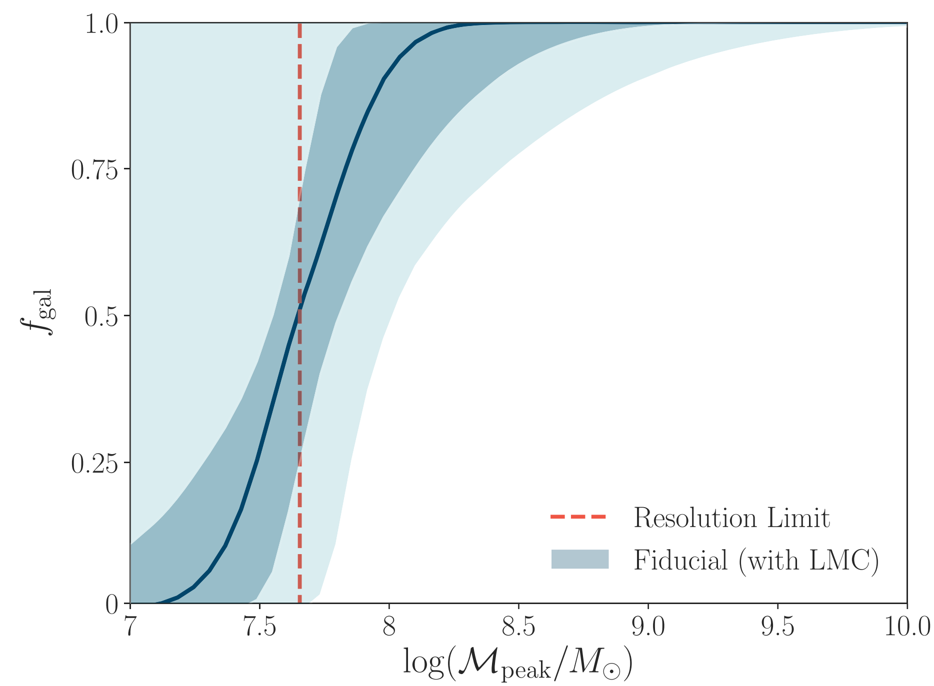
Kong et al. (in preparation)

Some of the major questions (according to me)

- Can we definitively show that reionization suppression explains the missing satellites?
- What leads to two modes of star formation at high redshift in similarly massive systems (GCs and ~Draco-mass dwarfs)?
- Are our standard numerical tools up to the challenge in the LSST era?

What are the scales relevant for galaxy formation?





Nadler et al. 2020