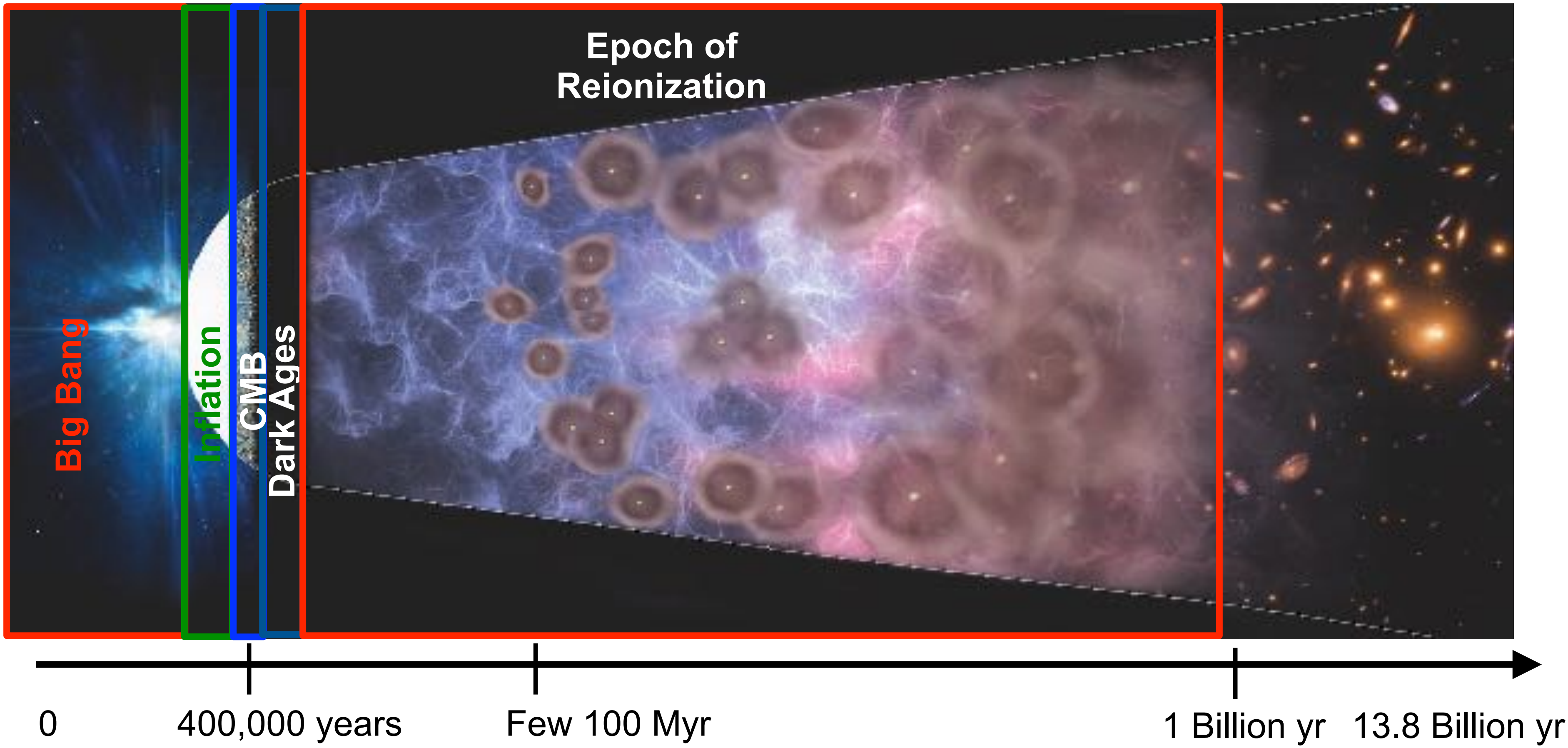
High-redshift galaxy observations with the JWST: advances & implications

Pratika Dayal



rijksuniversiteit groningen

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ODIN NWO

The team in Groningen

Chris Boettner

Giorgos Nikopoulos

Fernanda Pratama

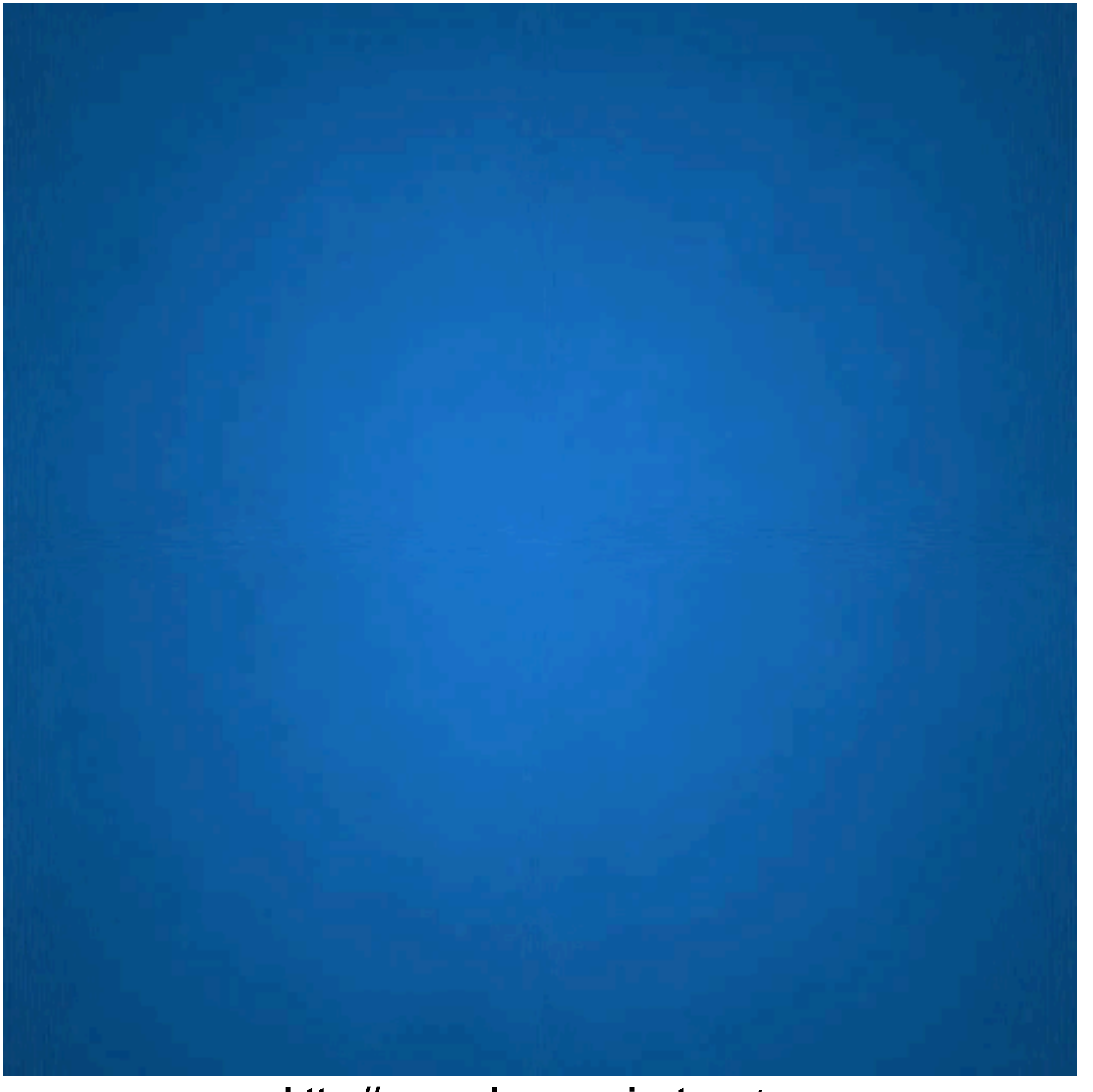
Paula Caceres-Burgos

Valentin Mauerhofer

Maxime Trebitsch

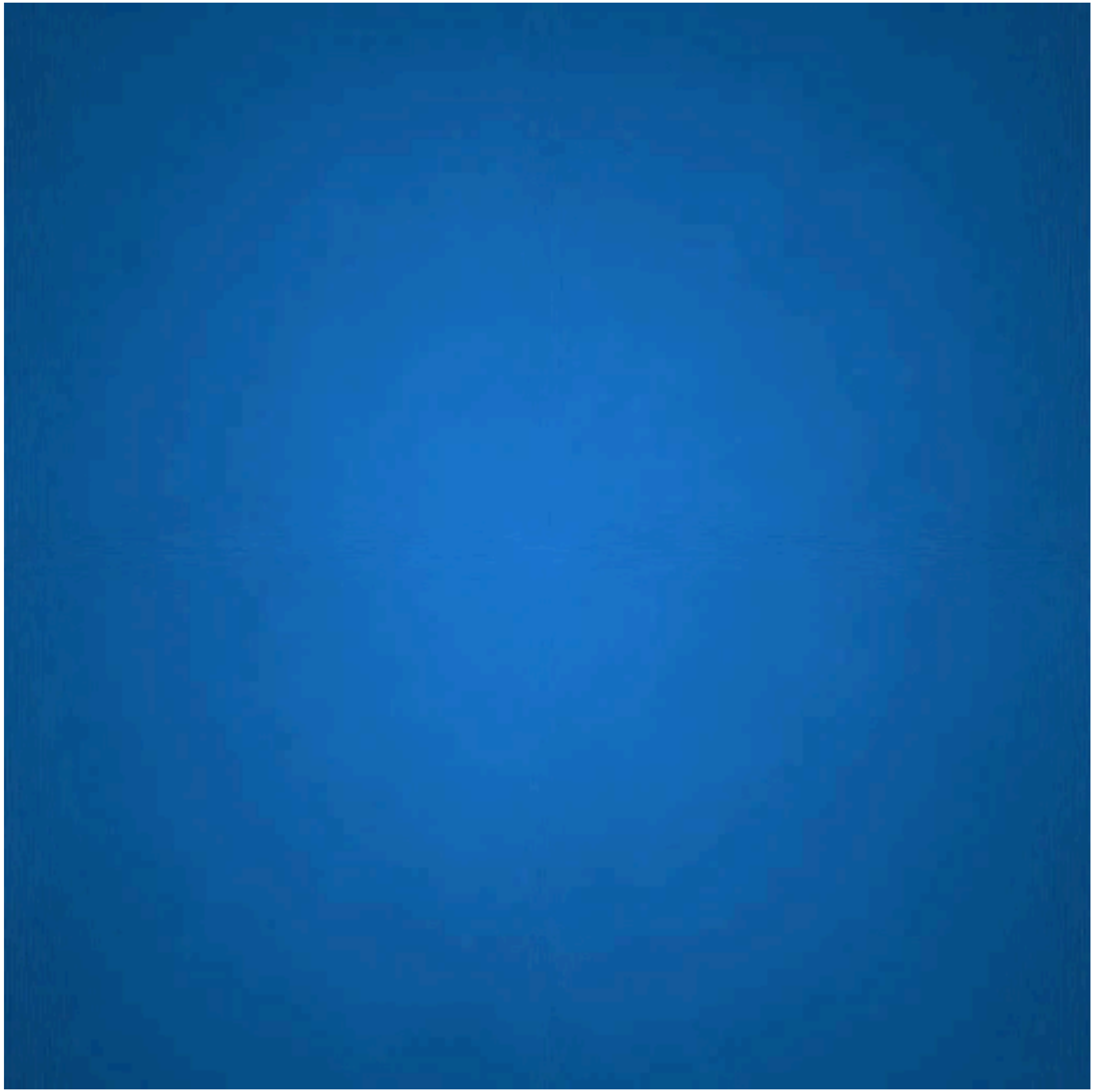
With: the SKA and Euclid theory groups, the ALMA (REBELS) team and JWST teams (Panoramic, Primer, CosmicSpring, Uncover)

The first galaxies - the start of structure formation



http://www.clues-project.org/

The first galaxies - the start of structure formation



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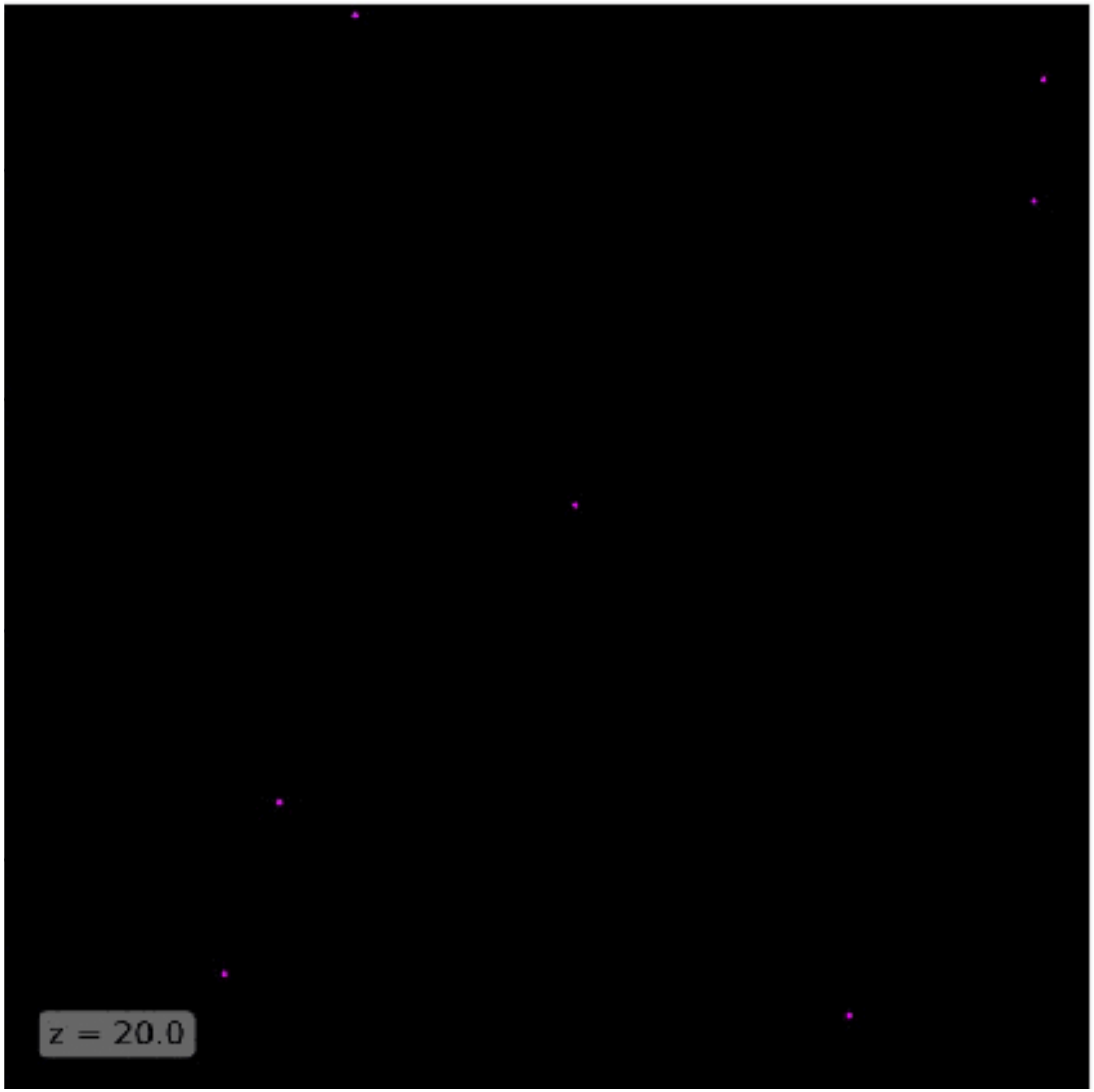
The first galaxies - the start of reionization



Galaxies

Neutral hydrogen

Ionized Hydrogen

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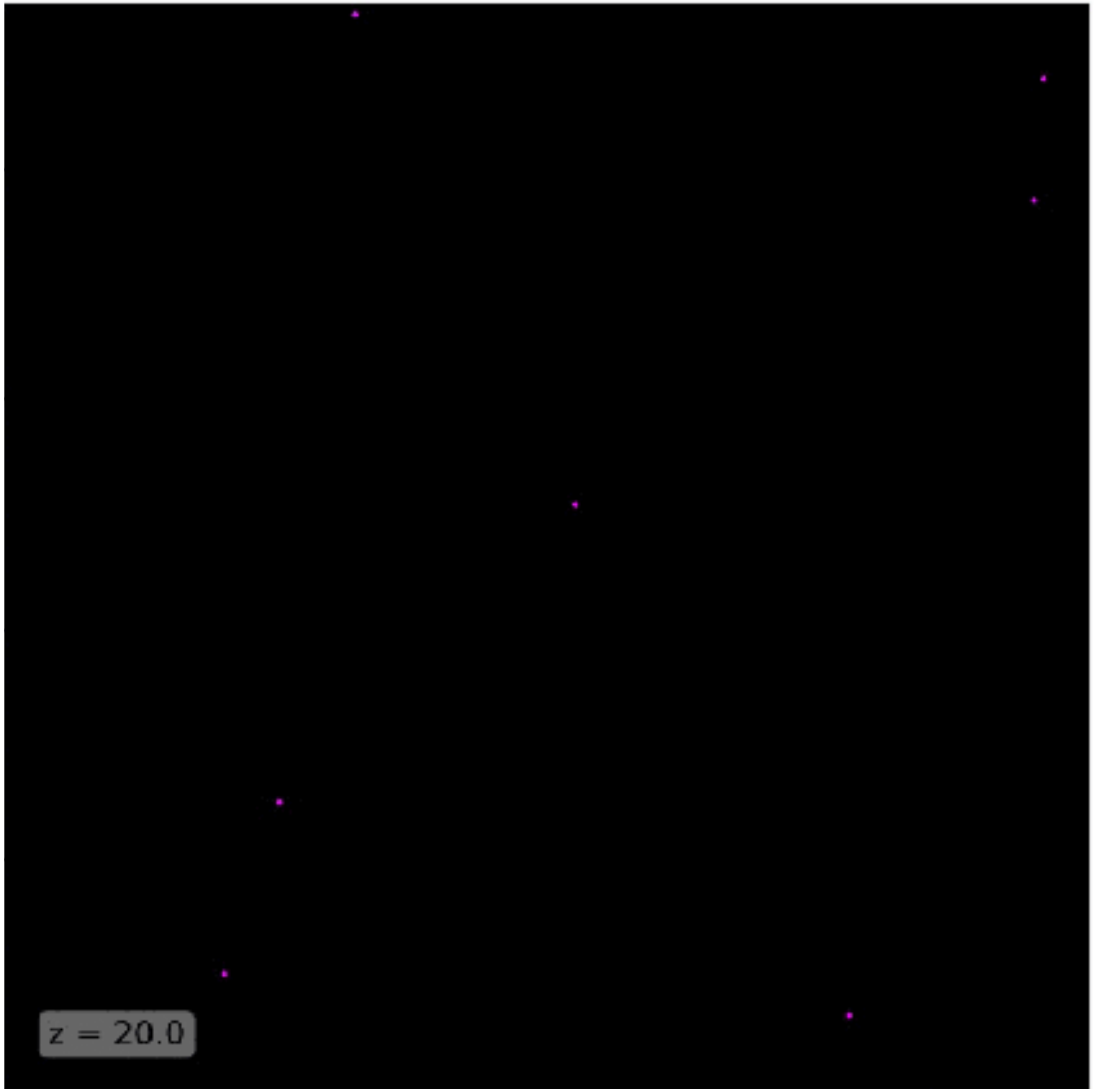
The ASTRAEUS framework; PI:Dayal

The first galaxies - the start of reionization



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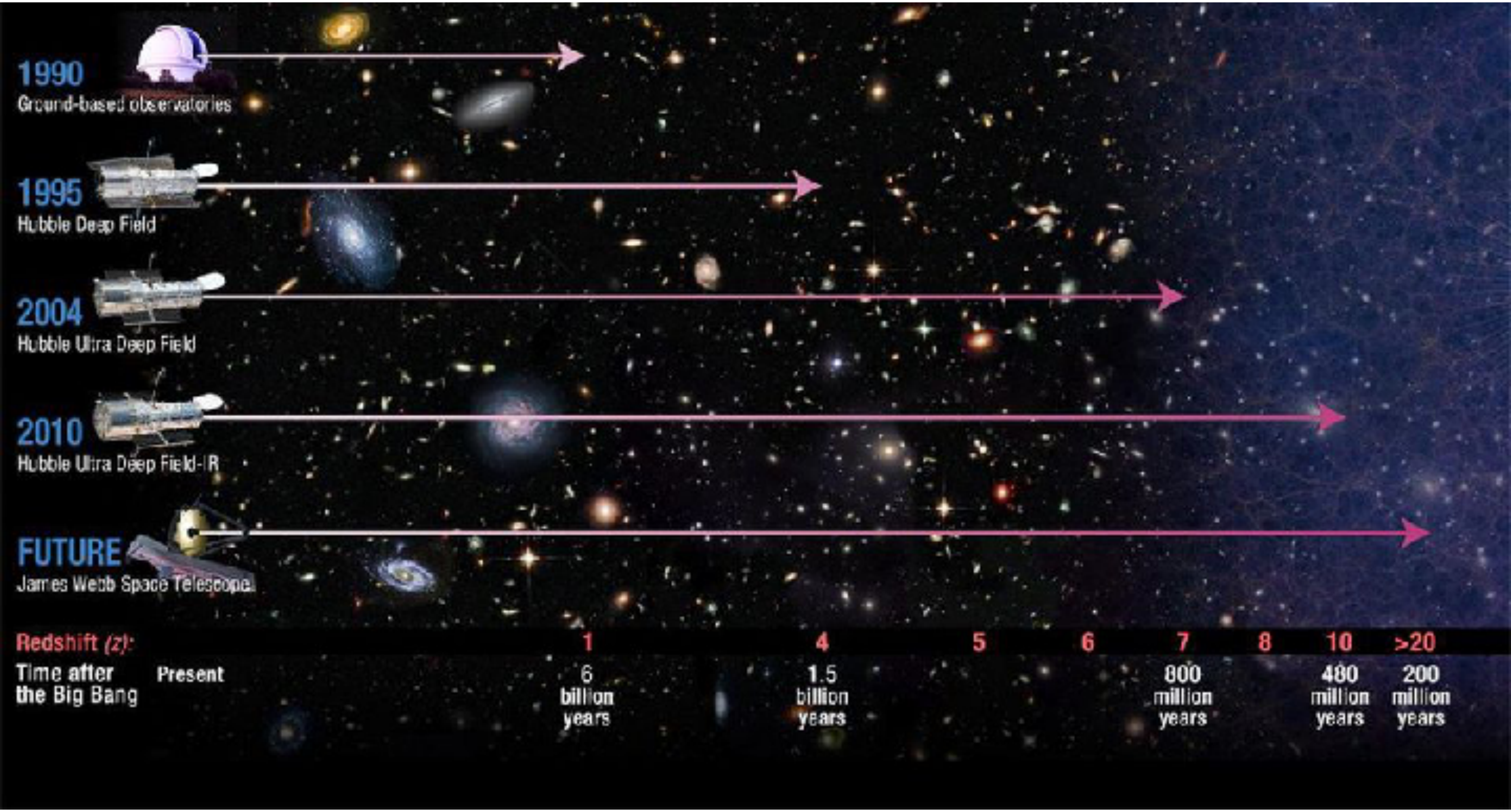
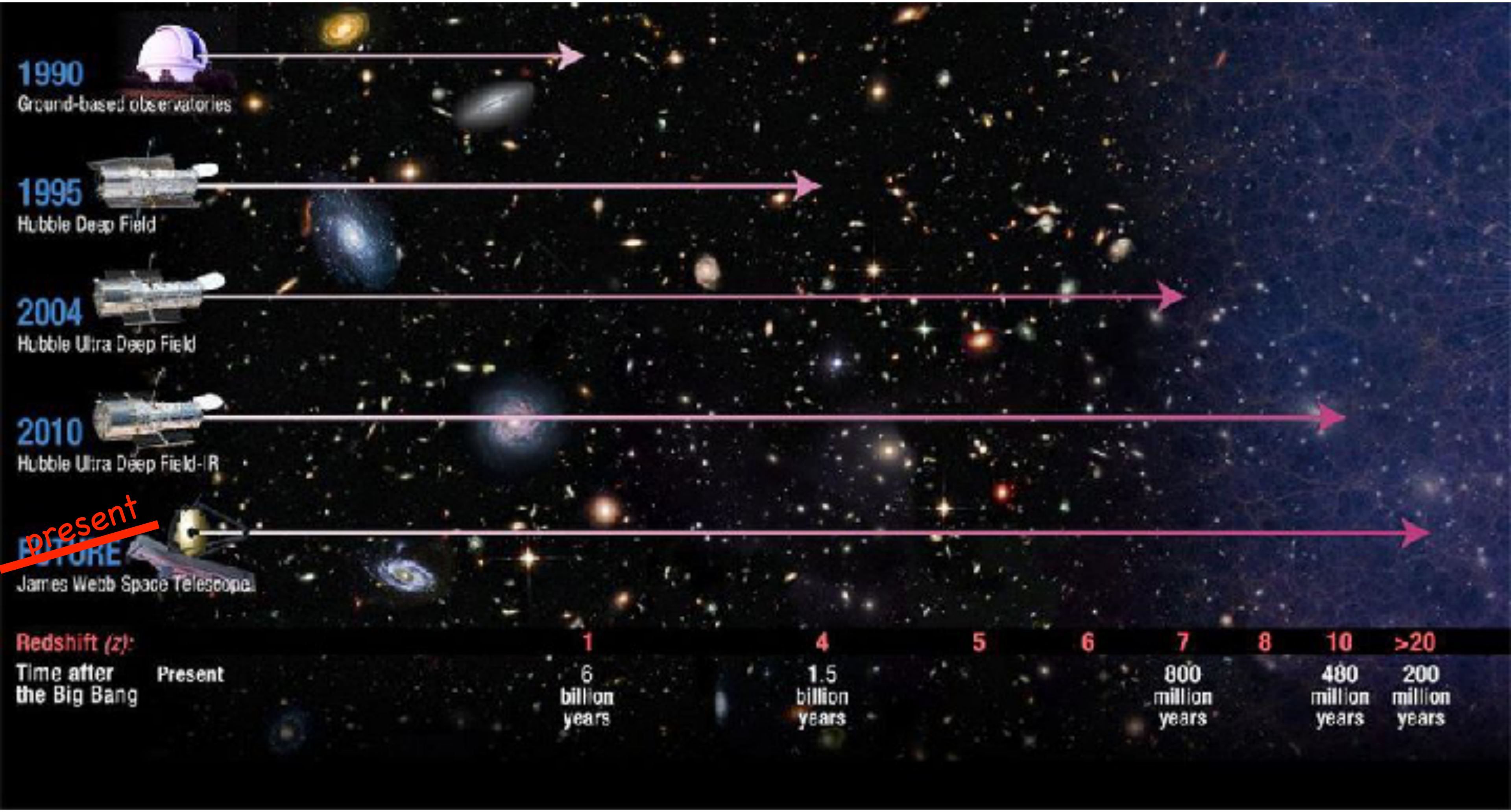
The ASTRAEUS framework; PI:Dayal

Breakthroughs in studying galaxies through cosmic time



NASA / JWST AND HST TEAMS

Breakthroughs in studying galaxies through cosmic time



NASA / JWST AND HST TEAMS

The golden age for observing early galaxies

Number of galaxies of a given luminosity per unit volume as a function of cosmic time (*Luminosity function*)

Total rate of star formation per unit volume (*Star formation rate density*)

Total mass bound in stars per unit volume (*Stellar mass density*)

The dust masses of early galaxies

Sizes and mergers of early galaxies; young star clusters

The open questions

- What were the physical properties of early galaxies?
- How was early galaxy assembly dependent on the environment?
- When & how was the Universe reionized?
- What was the impact of reionization on early galaxy formation?
- What was the role of black holes in early galaxy formation?
- How many gravitational wave events do we expect from the early Universe?
- What can signals from cosmic dawn tell us about cosmology (e.g. nature of dark matter)?

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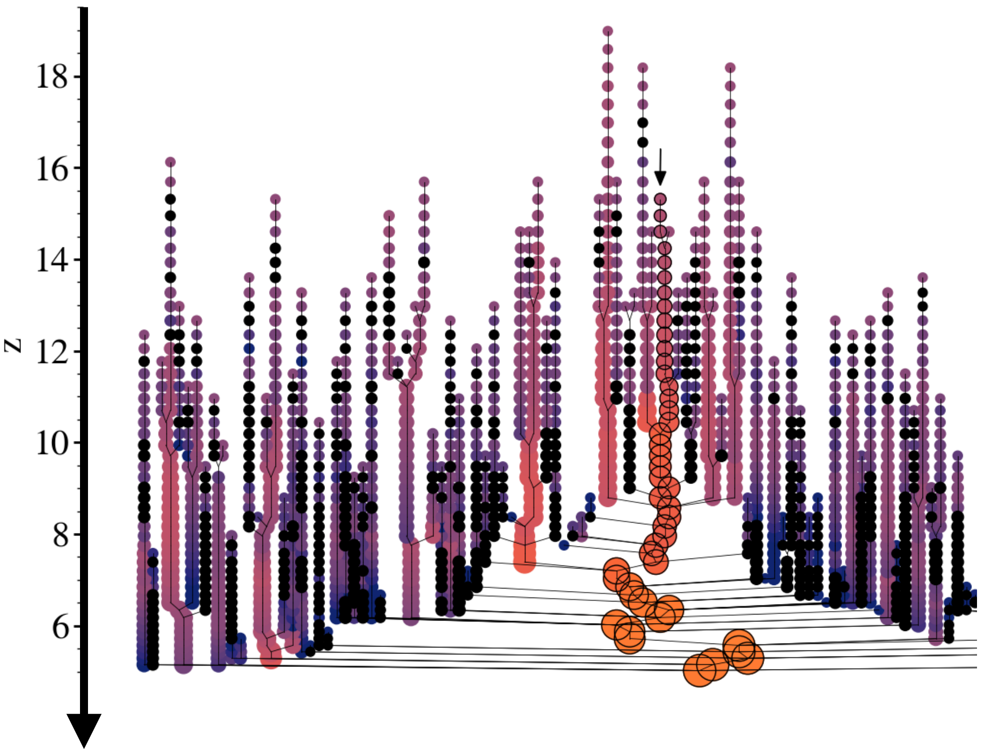
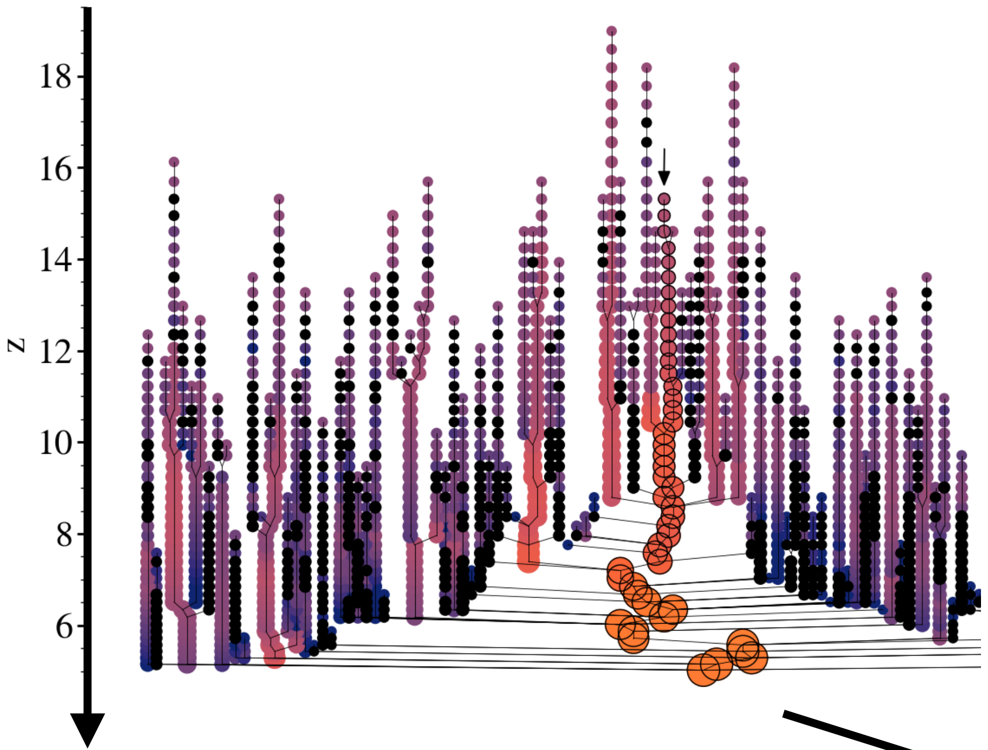
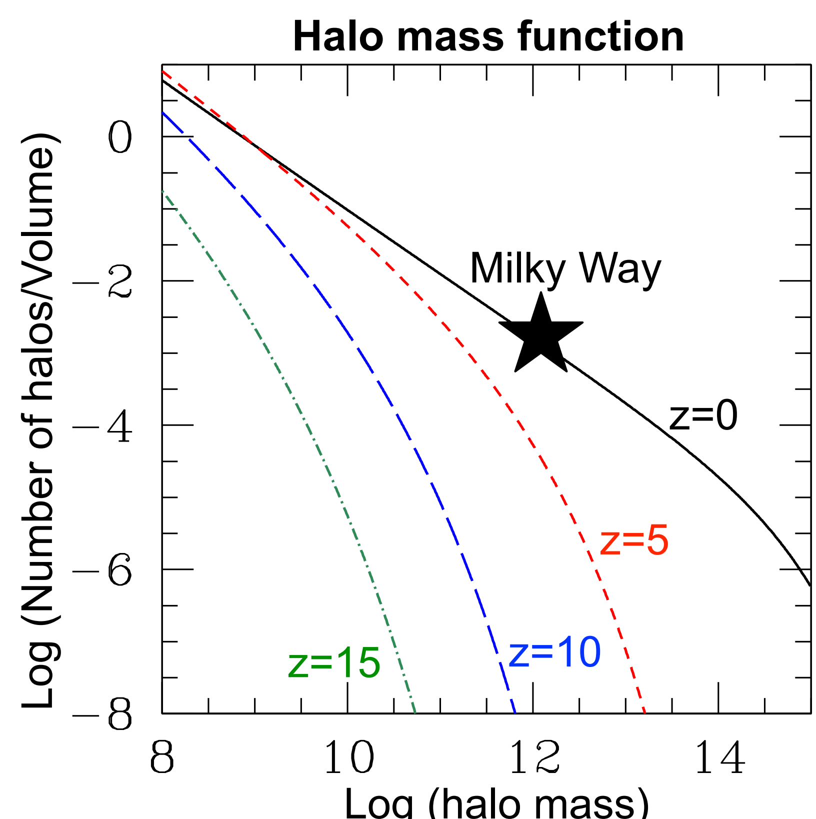
Structure formation in the cold dark matter paradigm

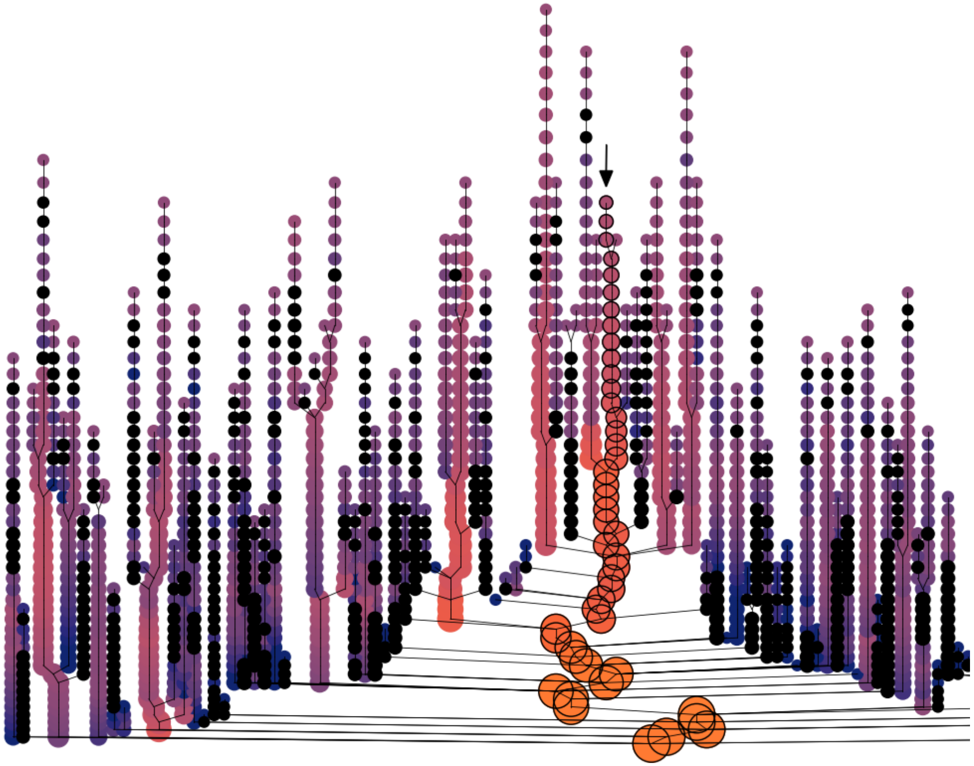


Structure formation in the cold dark matter paradigm

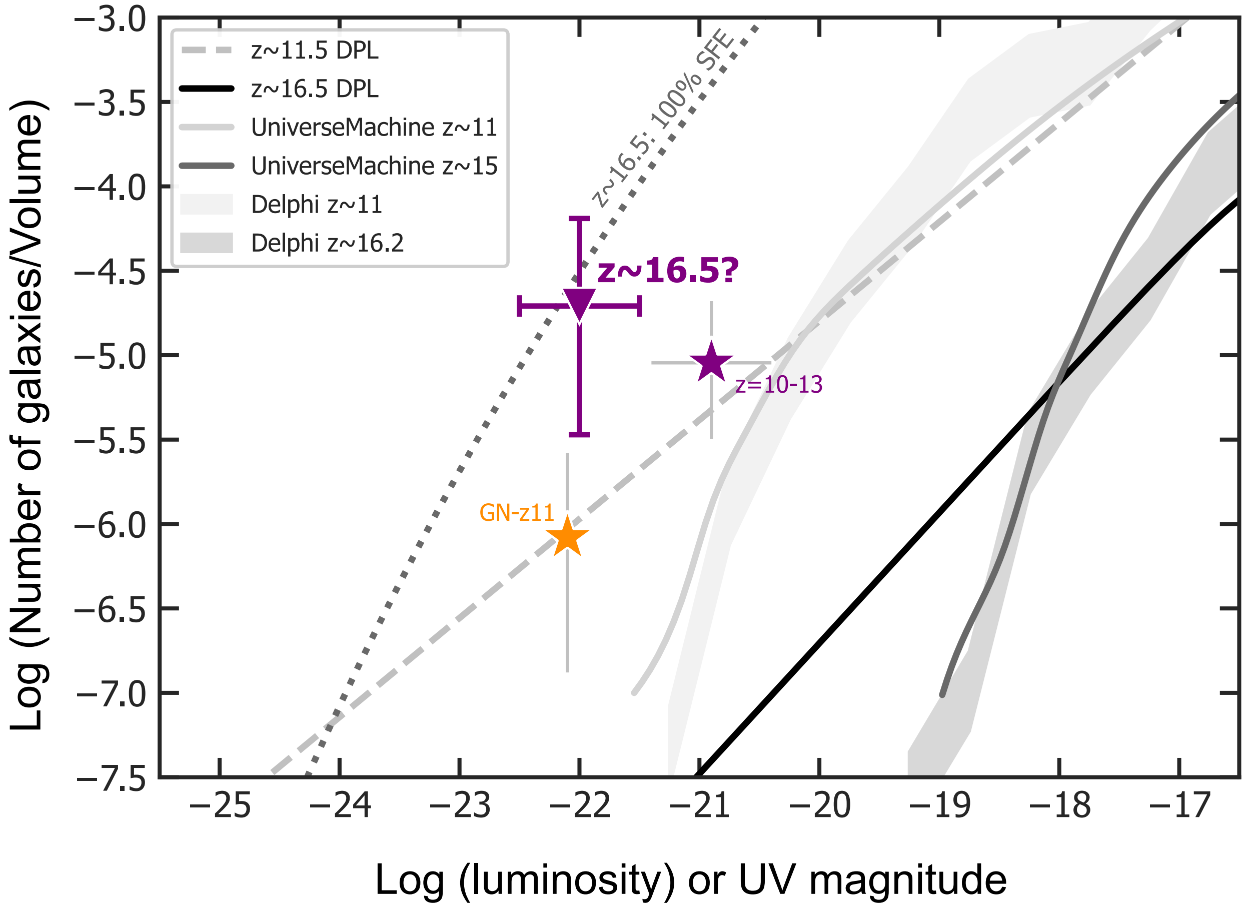




Early galaxy observation implications for the astrophysics/cosmology



An over-abundance of bright systems



Naidu et al. 2022a, b; Atek et al. 2022; Adams et al. 2022; Donnan et al. 2022; also Harikane et al. 2021

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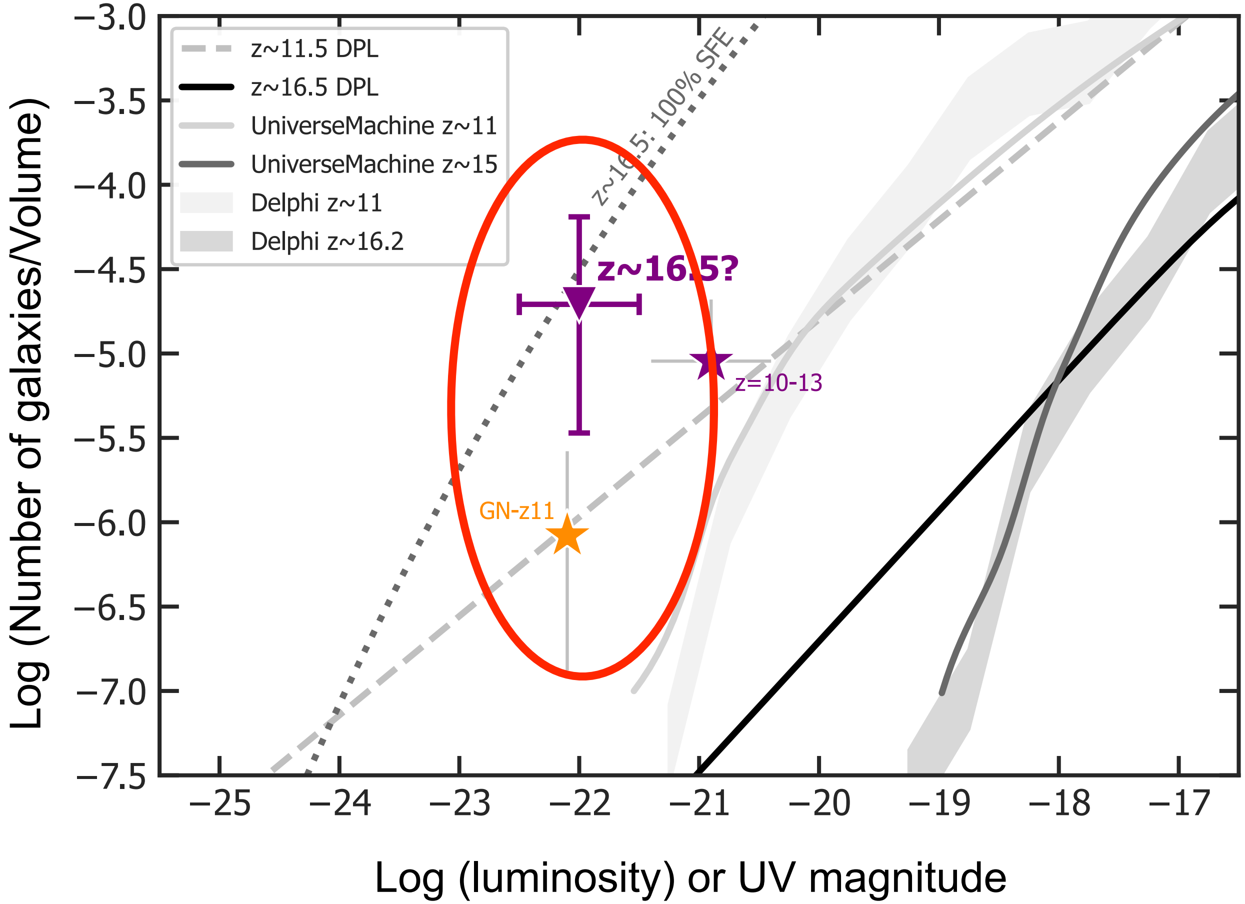
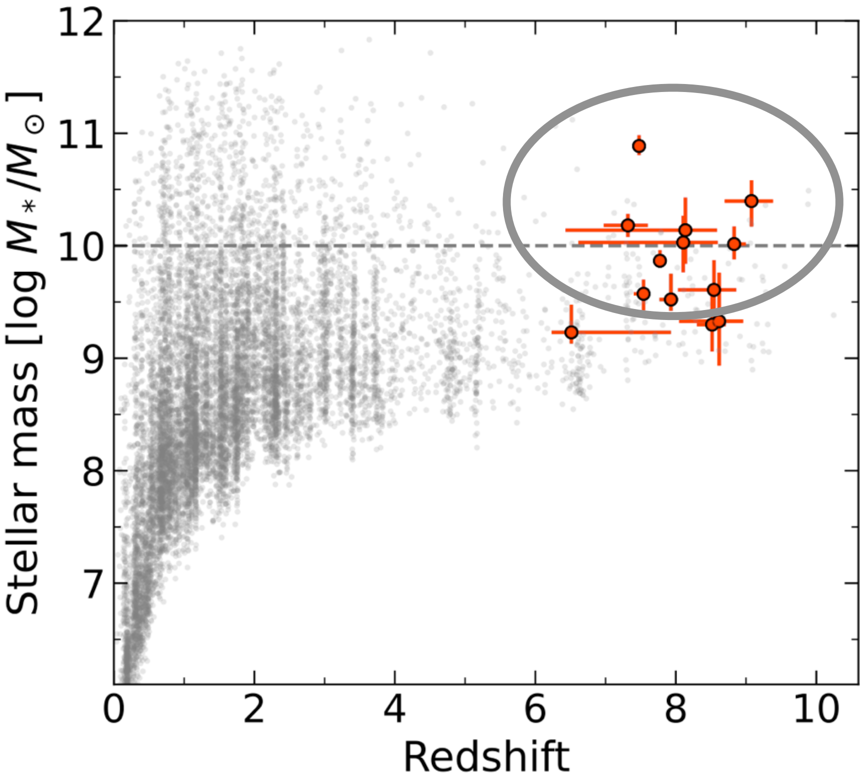


Early observations seem to indicate an over-abundance of luminous systems at all z~11-16. The number density at the observed luminosity is orders of magnitude higher than predicted by any theoretical models and requires a 100% of baryons to be in the form of stars.

Naidu et al. 2022a, b; Atek et al. 2022; Adams et al. 2022; Donnan et al. 2022; also Harikane et al. 2021

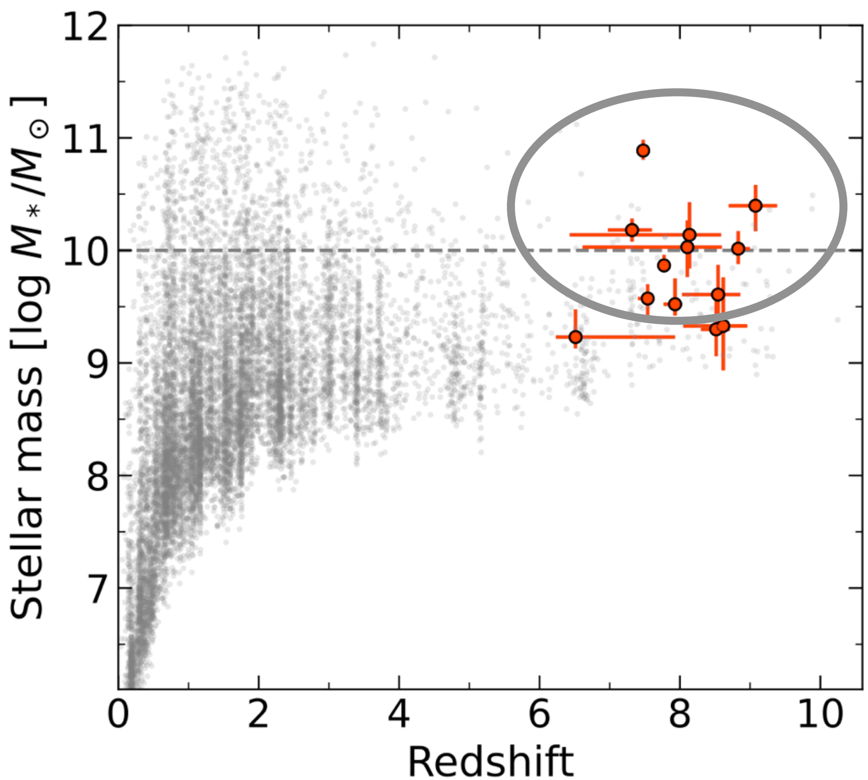
An over-abundance of massive systems

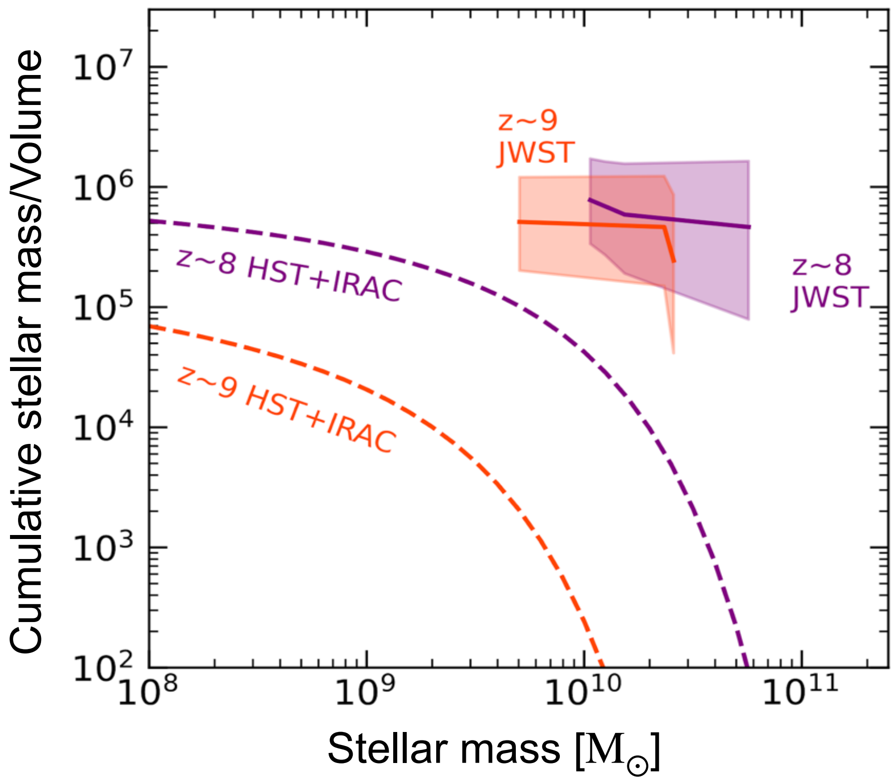


Early observations also seem to indicate an over-abundance of massive systems at all z>7. This results in an inferred stellar mass density that is again orders of magnitude higher than expected at z~10.

Labbe et al. 2023; arXiv: 2207.12446

An over-abundance of massive systems





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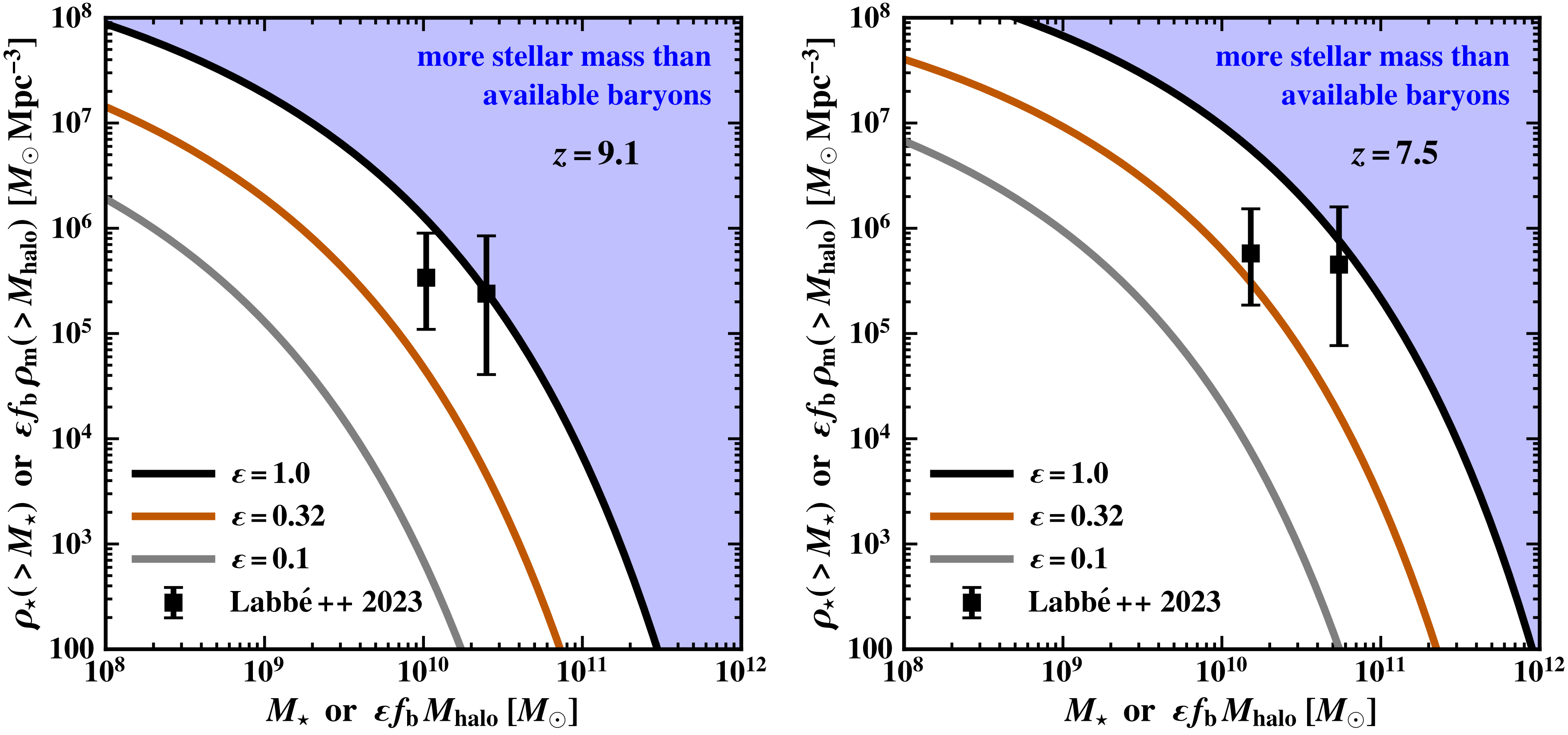
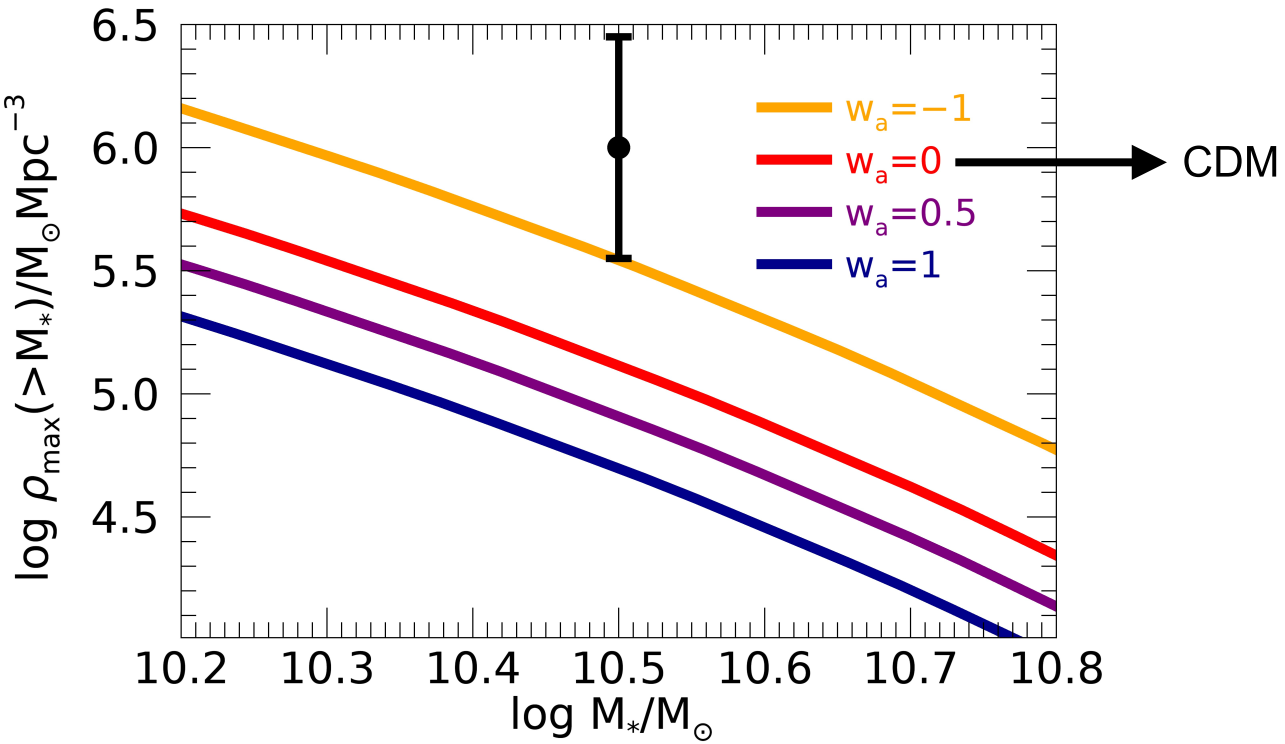
An over-abundance of massive systems - CDM implications



Explaining the stellar mass density at early epochs seems to require galaxies that can convert **ALL** of their baryons into stars

Boylan-Kolchin 2023; arXiv:2208.01611

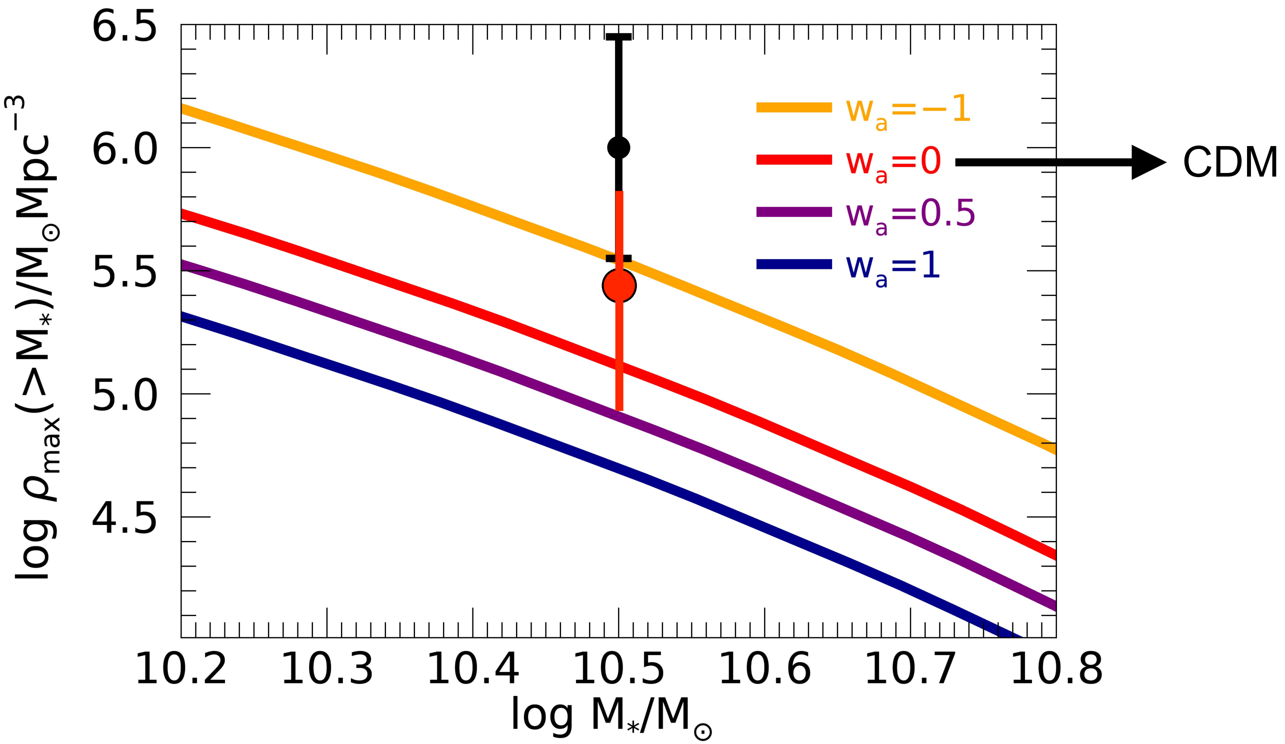
Massive systems to get hints on Dark Energy



The growth of perturbations (and hence the number of halos of a given mass per comoving volume) depend on the cosmic expansion rate that depends on the dark energy equation of state (w). Assuming all baryons to form stars, this can be used to obtain a limit on the dark energy equation of state at high-z.

Menci et al. 2020 (arXiv:2007.12453), 2022 (arXiv: 2208.11471)

Massive systems to get hints on Dark Energy



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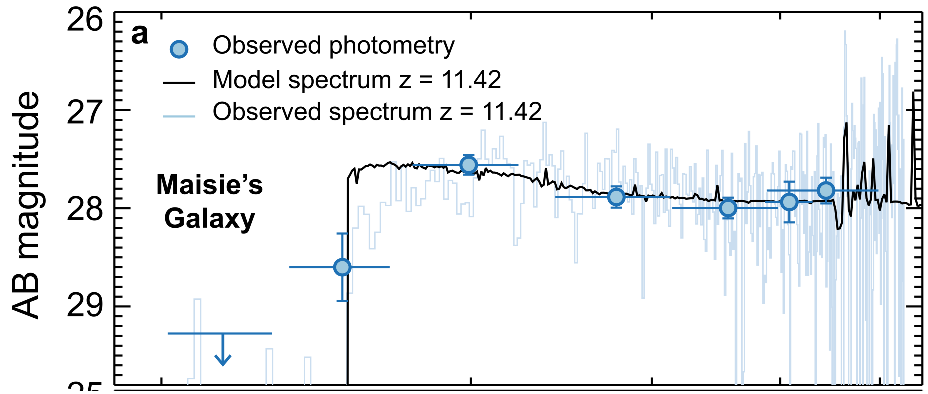
It is crucial to confirm the high-redshift nature of systems



Adams+PD et al. 2022 (arXiv:2207.11217; Arrabal-Haro et al. 2023 (arXiv:2303.15431)

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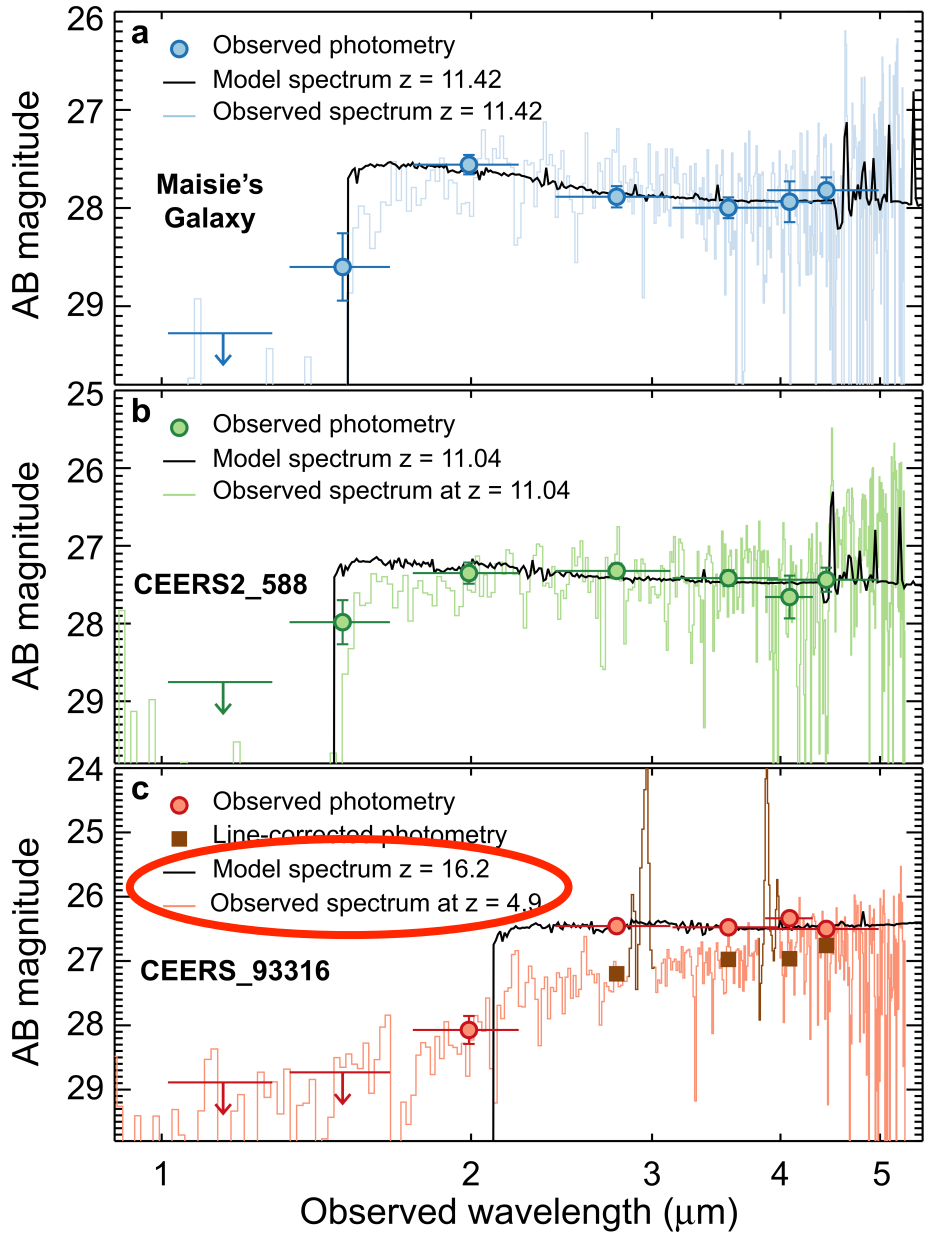

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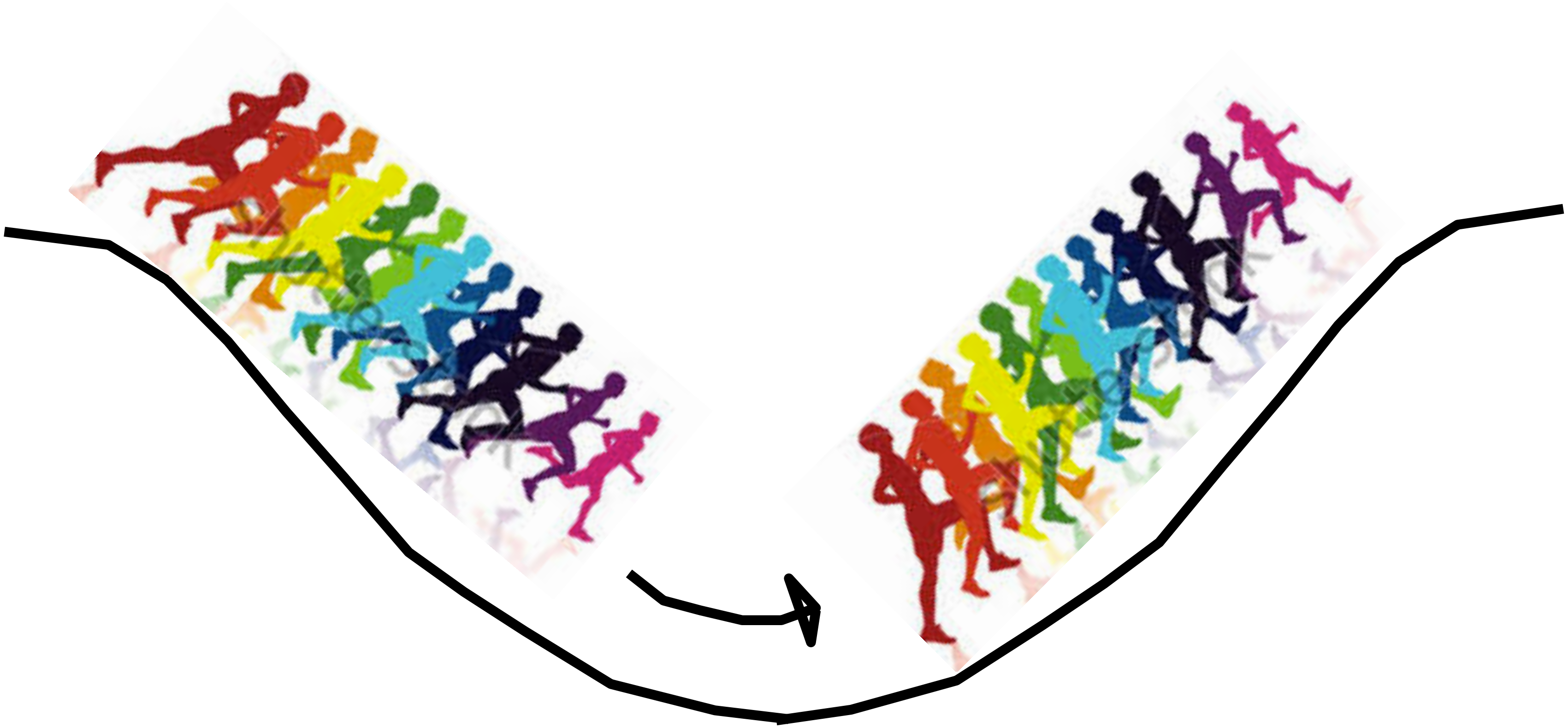
Early galaxy observation implications for the nature of Dark Matter

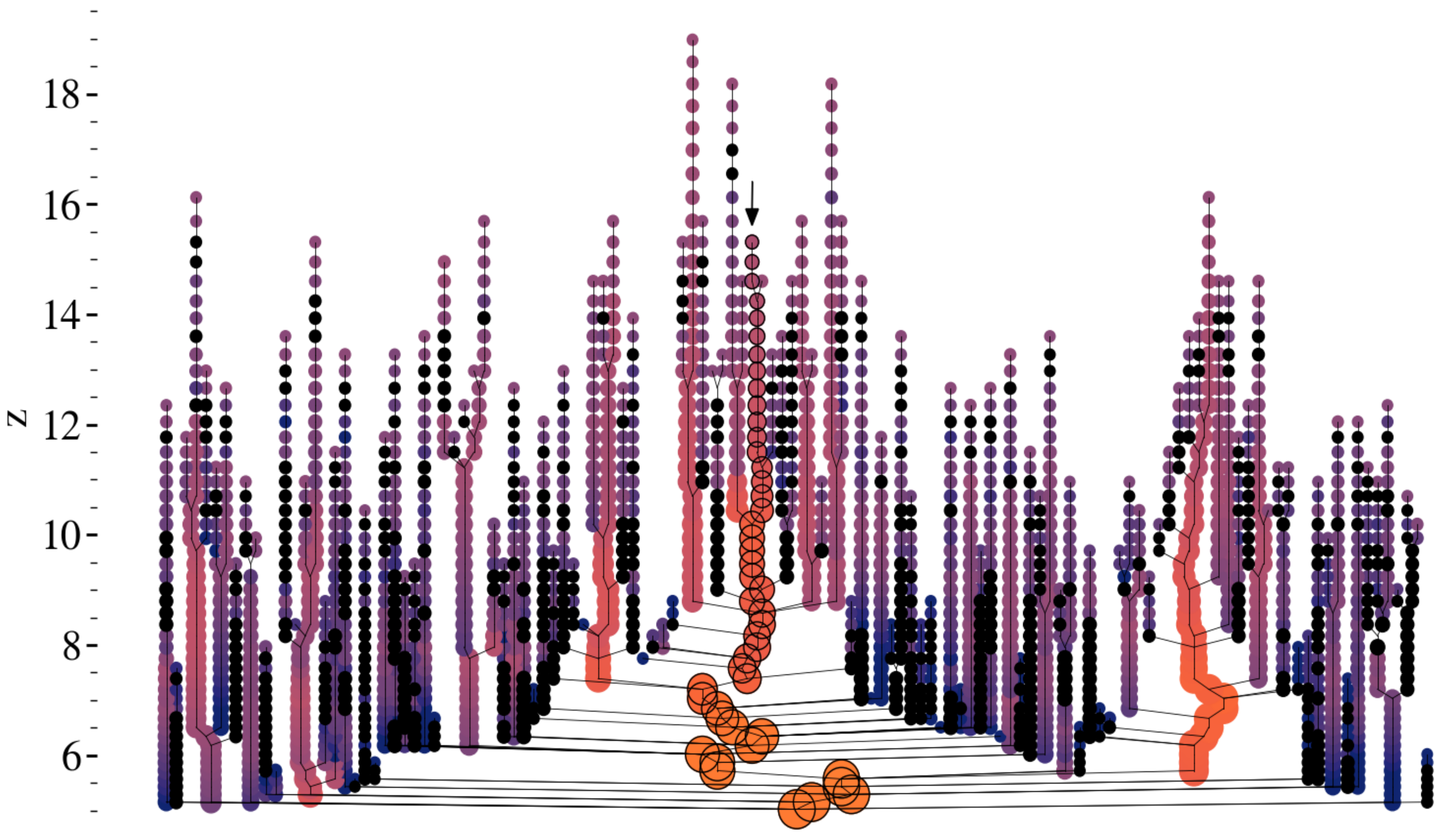


Barkana+2001; Somerville+2003; Yoshida+2003; O'shea+2006; Menci+2012; Yue & Chen2012; Bin & Chen 2012; Pacucci+2013; Sitwell+2013; Lovell+2014; Schultz+2014; Garzilli+2015; Menci+2016, 2017…

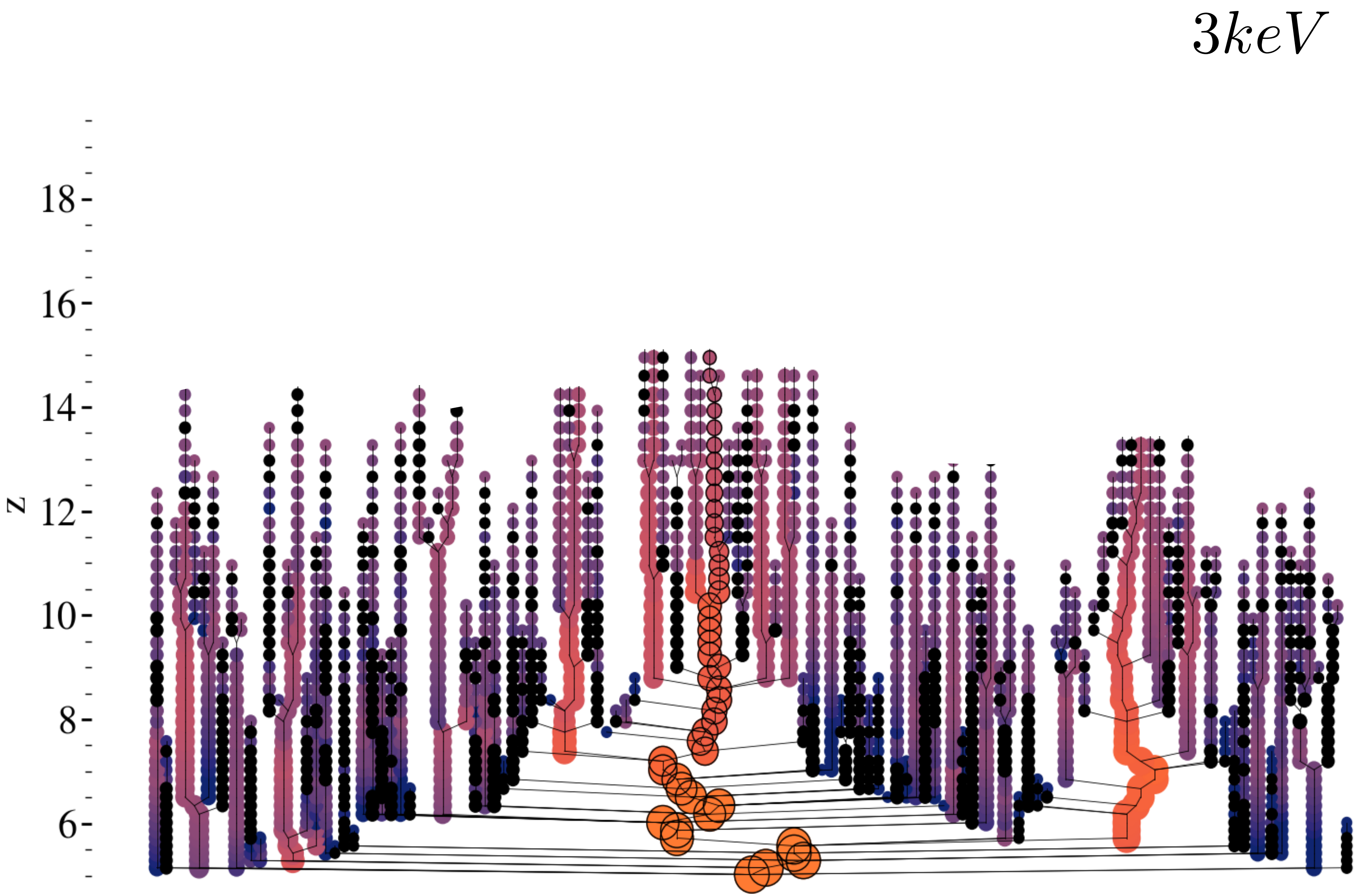
Hierarchical structure formation in CDM

CDM

Mass roughly ~100 GeV

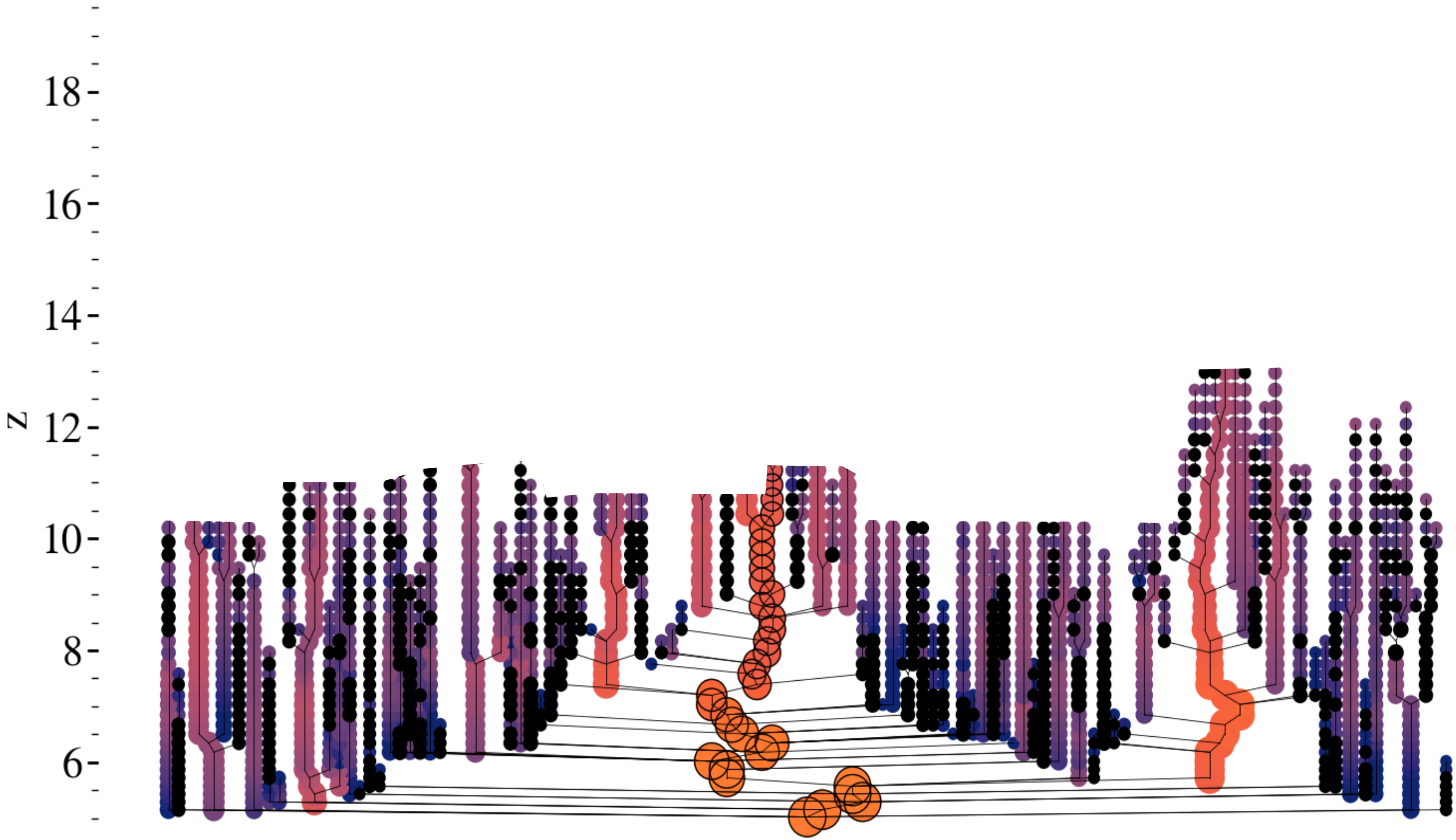


Hierarchical structure formation in WDM

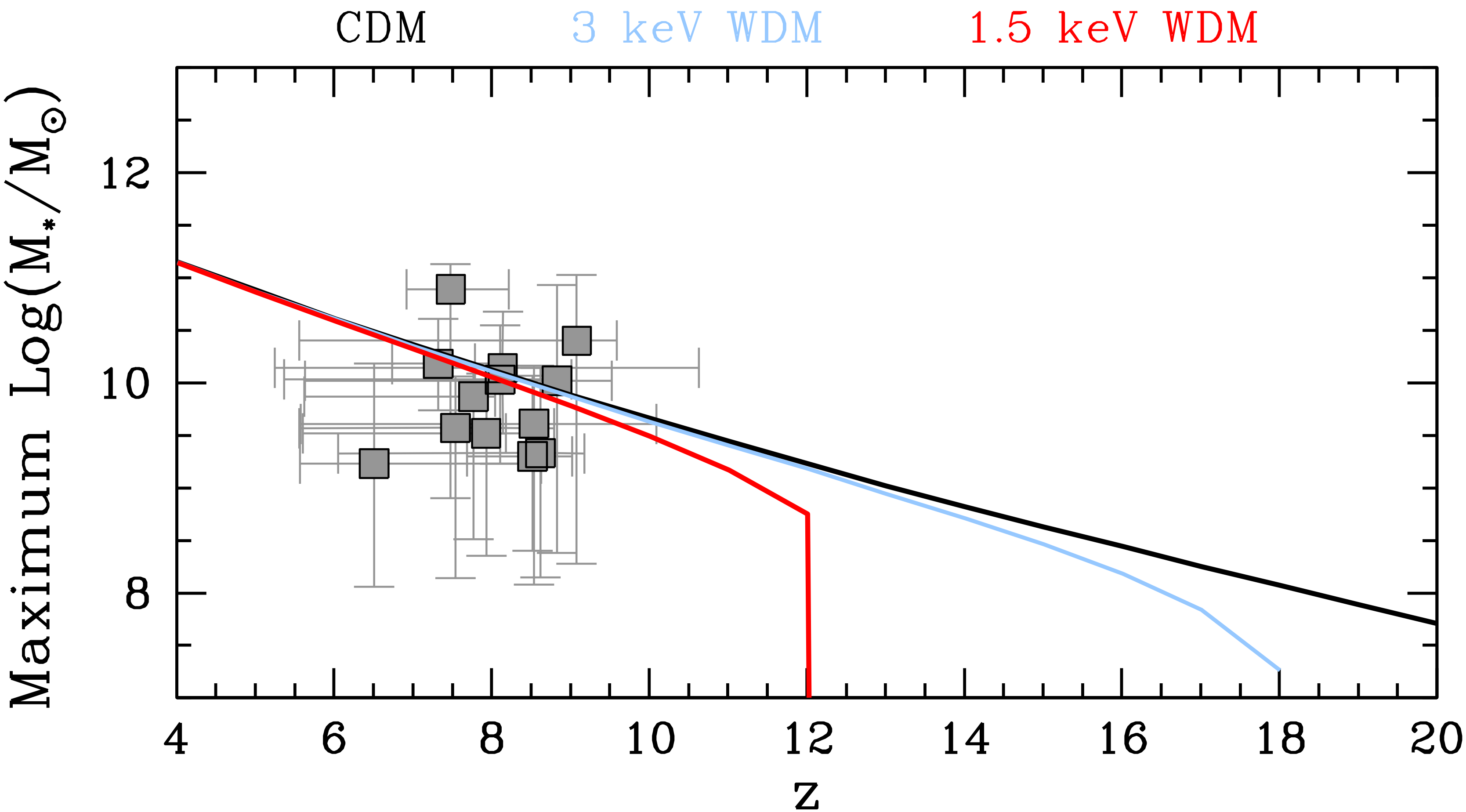


Hierarchical structure formation in WDM

$1.5 keV$



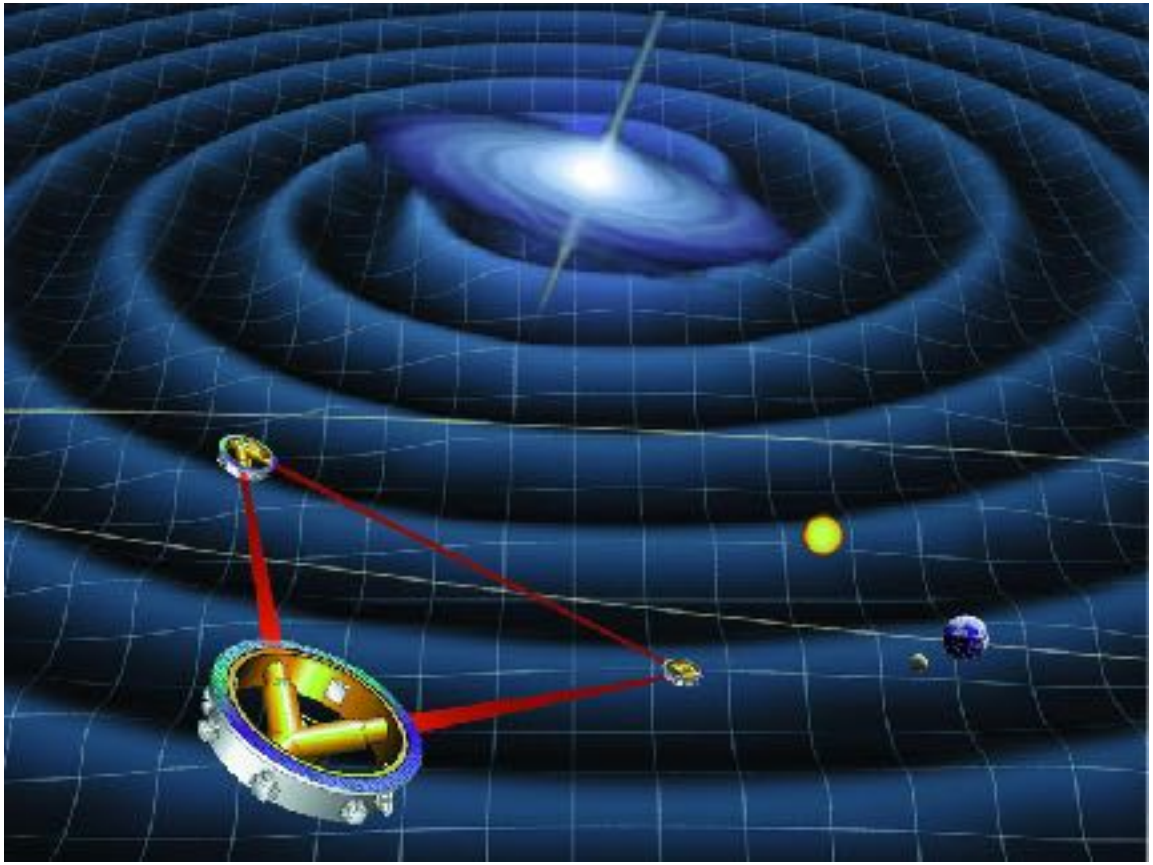
Testing the nature of (warm) dark matter with JWST



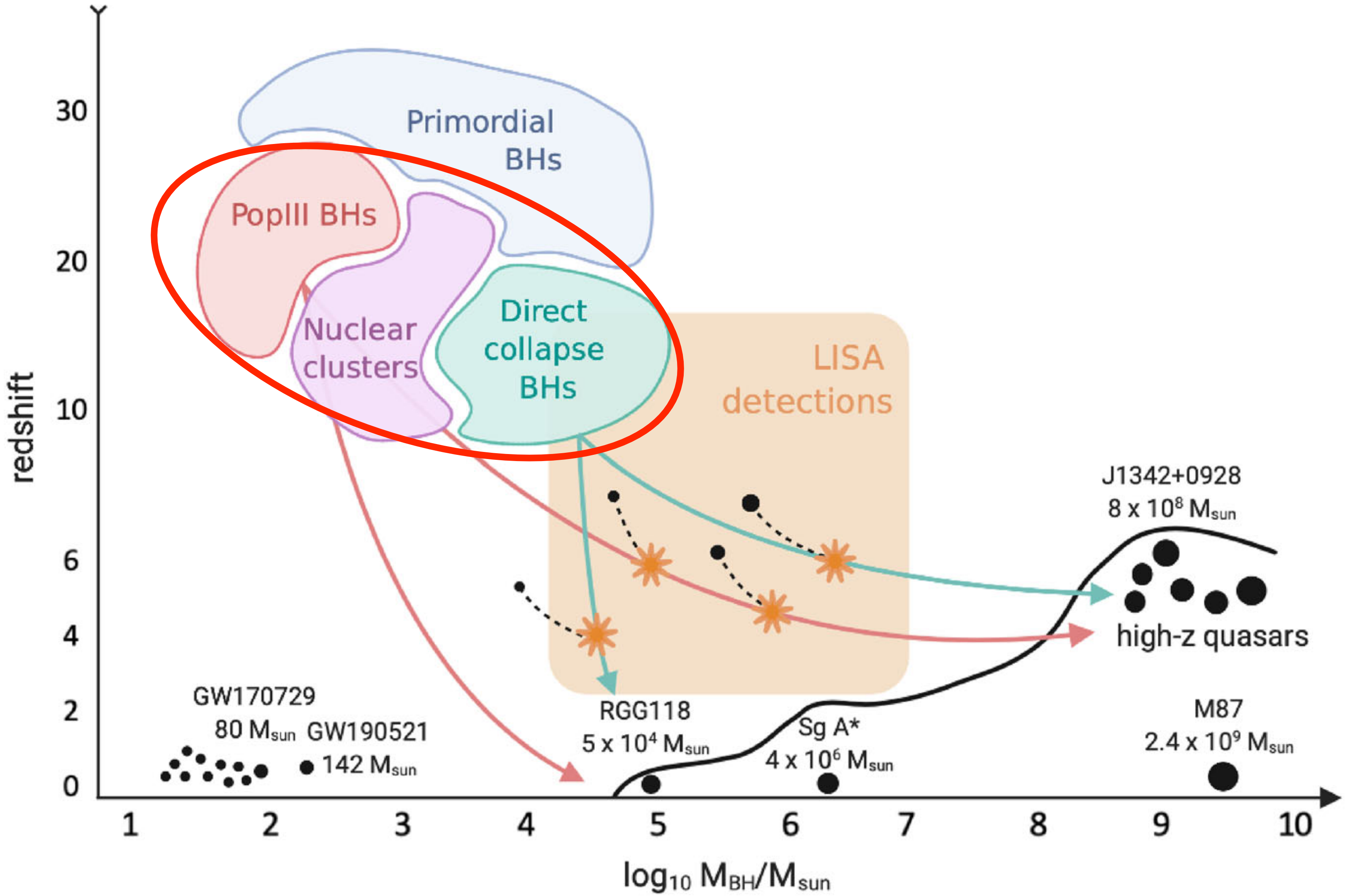
The detection of any galaxies existing in multiple JWST fields can be used to rule out 1.5 keV WDM.

Dayal & Giri, 2023 (arXiv:2303.14239); also PD et al 2015 (arXiv:1408.1102), PD et al. 2017 (arXiv:1501.02823), Maio & Viel 2023 (arXiv:2211.06230)

Early galaxy observation implications for black holes and gravitational waves

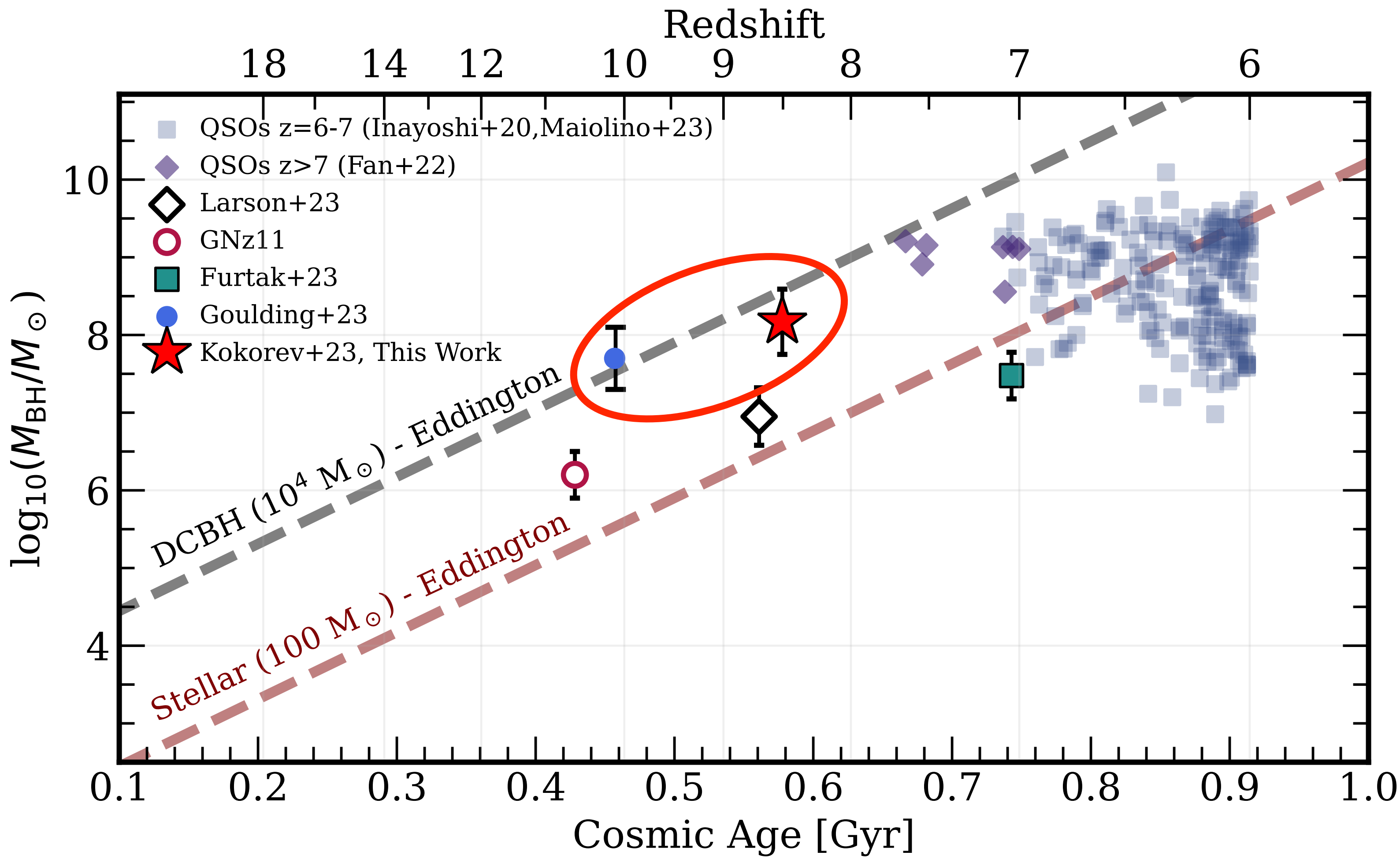


Numerous pathways for black hole seed formation and growth



"Astrophysics with LISA" white paper, 2023, LRR, 26, 2
arXiv:2203.06016

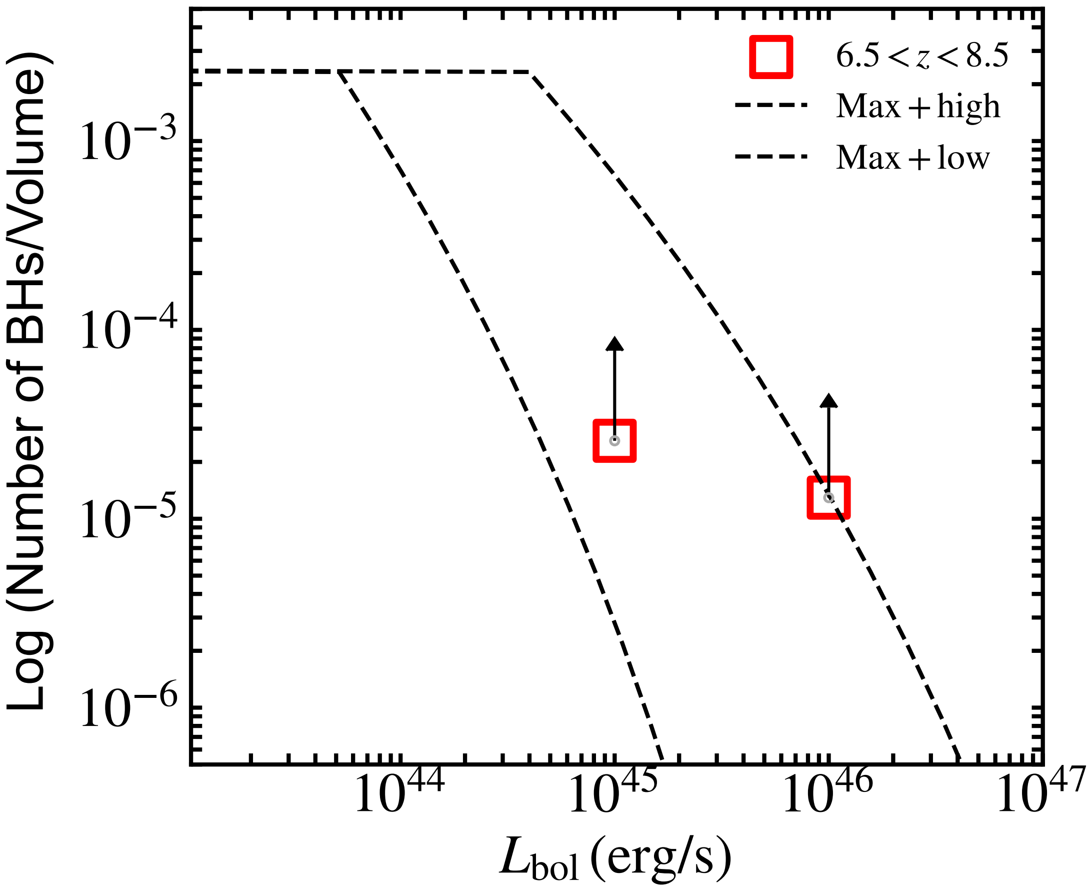
Obese black holes in the first billion years with the JWST



Explaining the supermassive black holes being observed by JWST require unphysical explanations such as super-Eddington accretion onto low-mass seeds or Eddington accretion onto massive (10^4 $M_\odot$) seeds that formed at $z \sim 50$ posing an enormous challenge for all existing theoretical models.

Goulding et al. 2023; Kokorev et al. 2023; Furtak et al. 2023; Greene et al. 2023

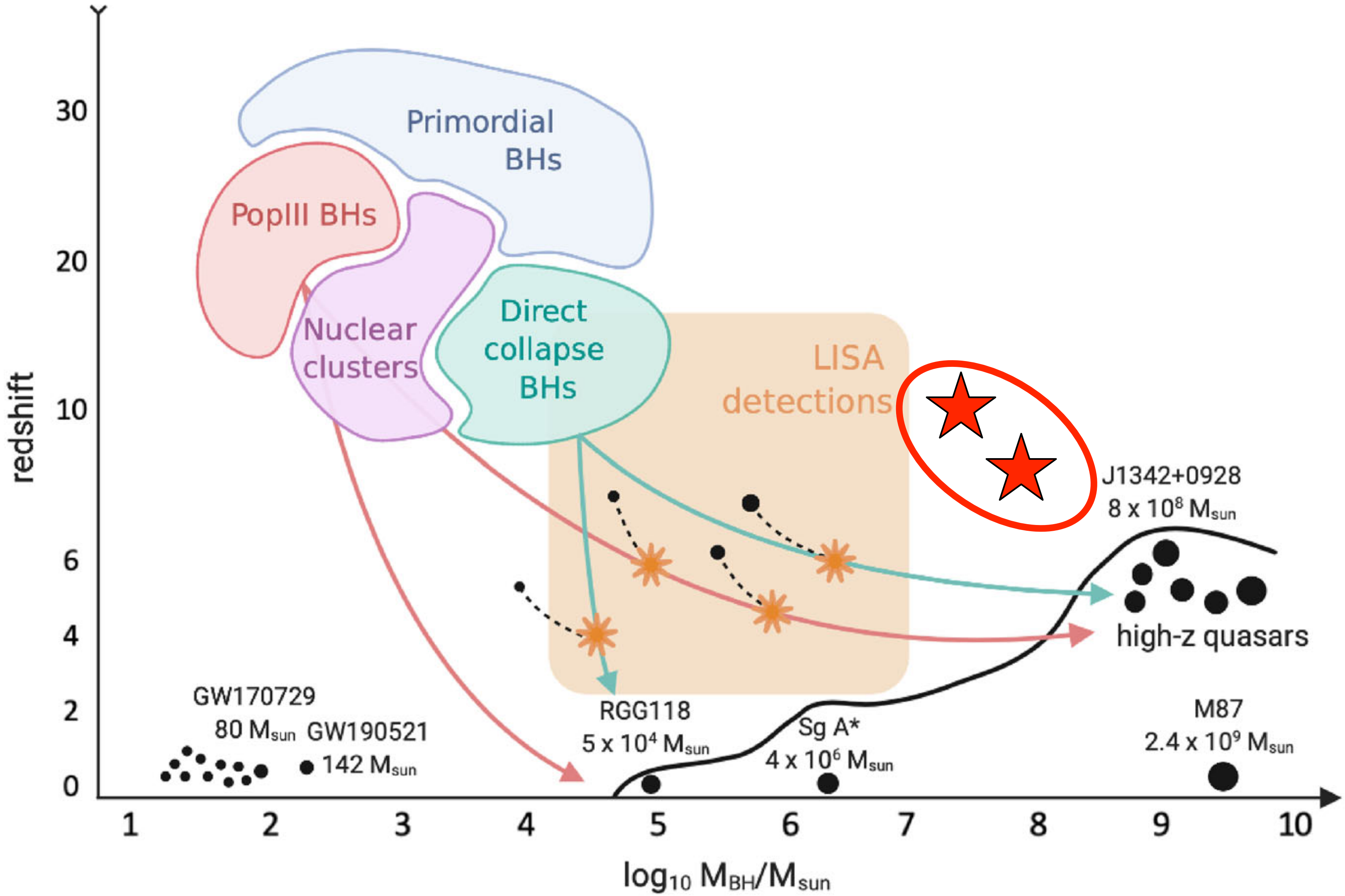
An over-abundance of black holes with the JWST



The JWST indicates at black hole number densities that are at the upper limit of theoretical expectations (each halo has a black hole similar to the local Universe that can accrete at the Eddington rate), specially at z>6.5.

Goulding et al. 2023; Kokorev et al. 2023; Furtak et al. 2023; Greene et al. 2023

A need to revisit black hole seeding and growth pathways



"Astrophysics with LISA" white paper
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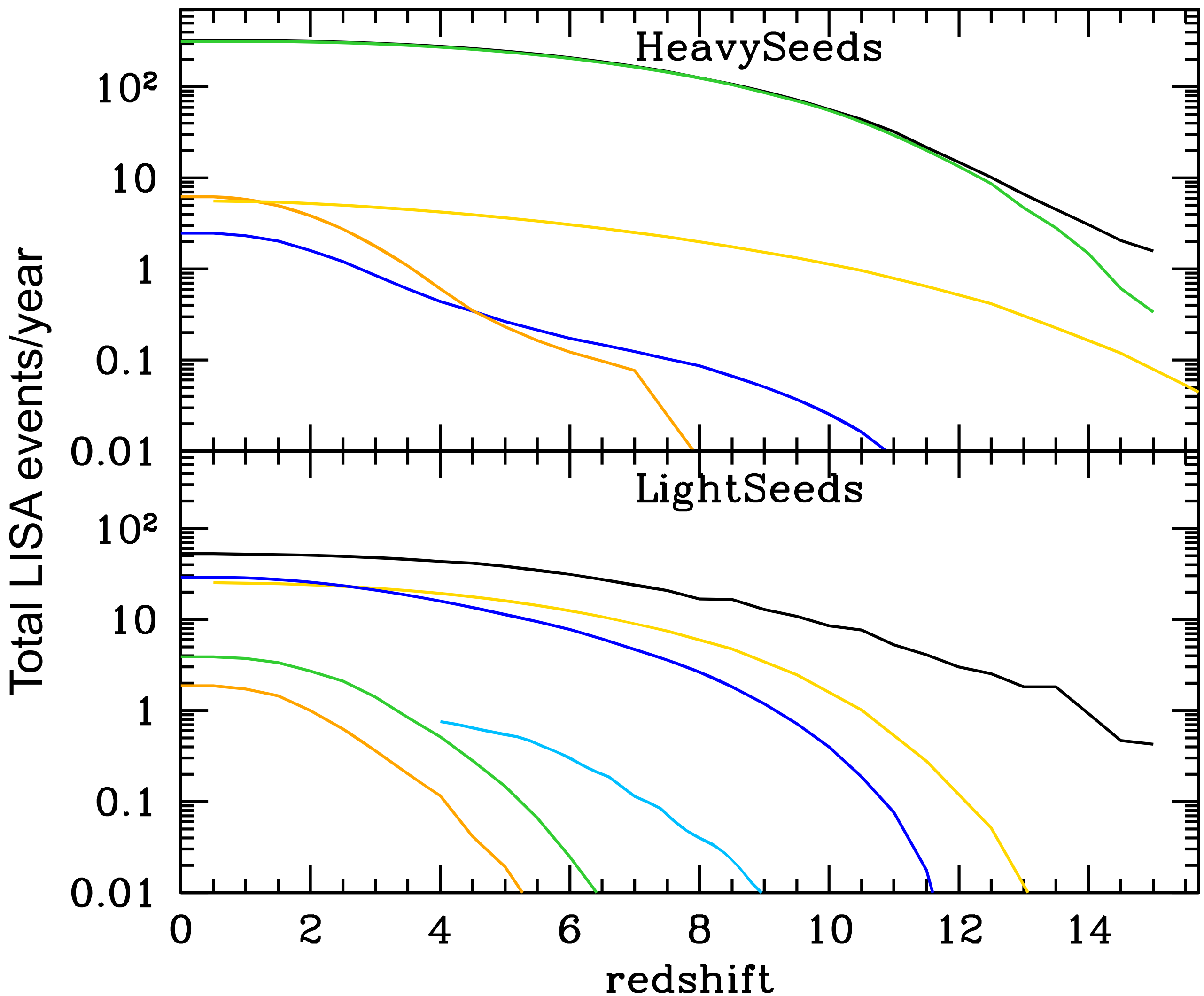
Assumptions on BH seeds masses, feedback and merger timescales crucially determine event rates



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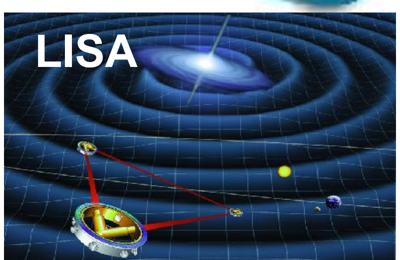
Early galaxy formation: advances & implications



<u>Galaxy populations</u>
link between dark matter and baryons, physical properties of galaxies and their evolution with time

<u>Cosmology</u>
hints on the nature of DM and possibly on the DE EoS

<u>Gravitational wave astronomy</u>
constraints on black hole masses, abundances; constraints on black hole seeding mechanisms and growth channels

<u>21cm cosmology</u>
constraints on source population and its redshift evolution, constraints on topology and history of reionization