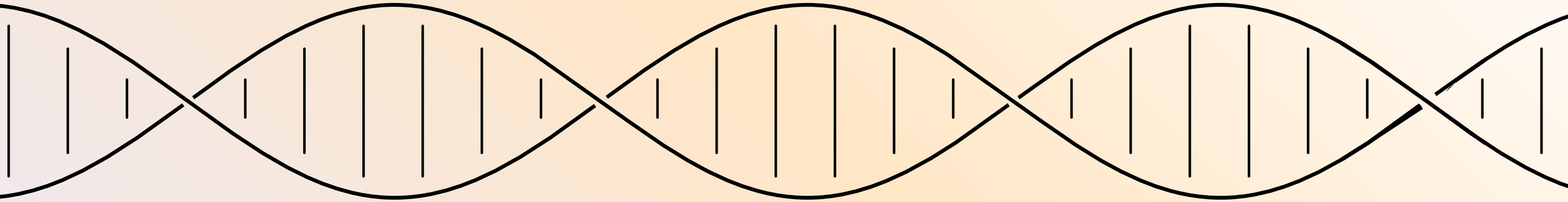

A new approach to cosmological simulations

Andrew Pontzen, UCL
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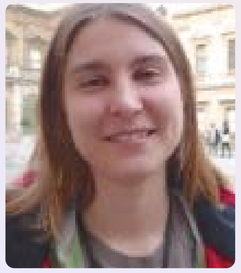
Nina Roth,
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Stephen Stopyra,
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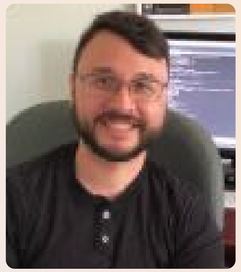
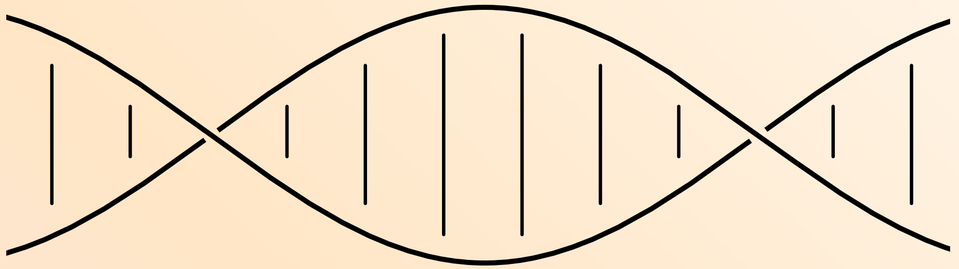
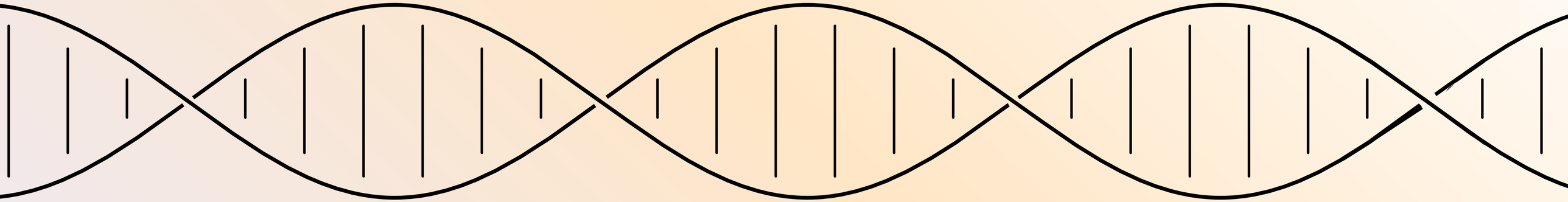

Michael Tremmel,
Yale



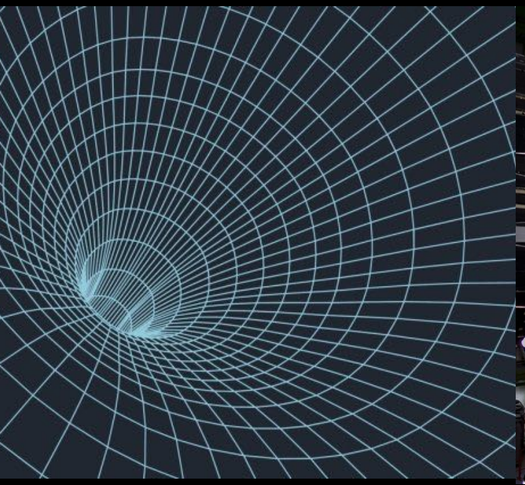


Part 1: Why dwarf galaxies are interesting

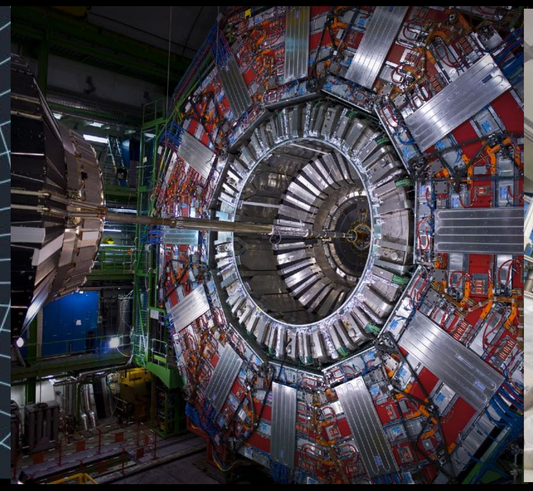
Part 2: “Genetically modified” simulations

Part 3: Results / predictions

Ingredients of ΛCDM cosmology

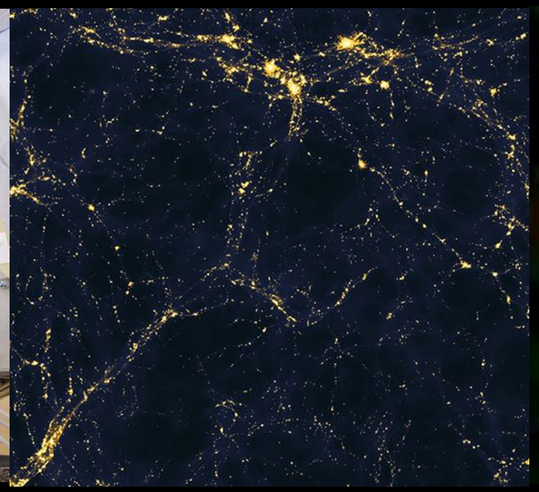


General relativity



Standard model of particle physics

Cold dark matter (CDM)

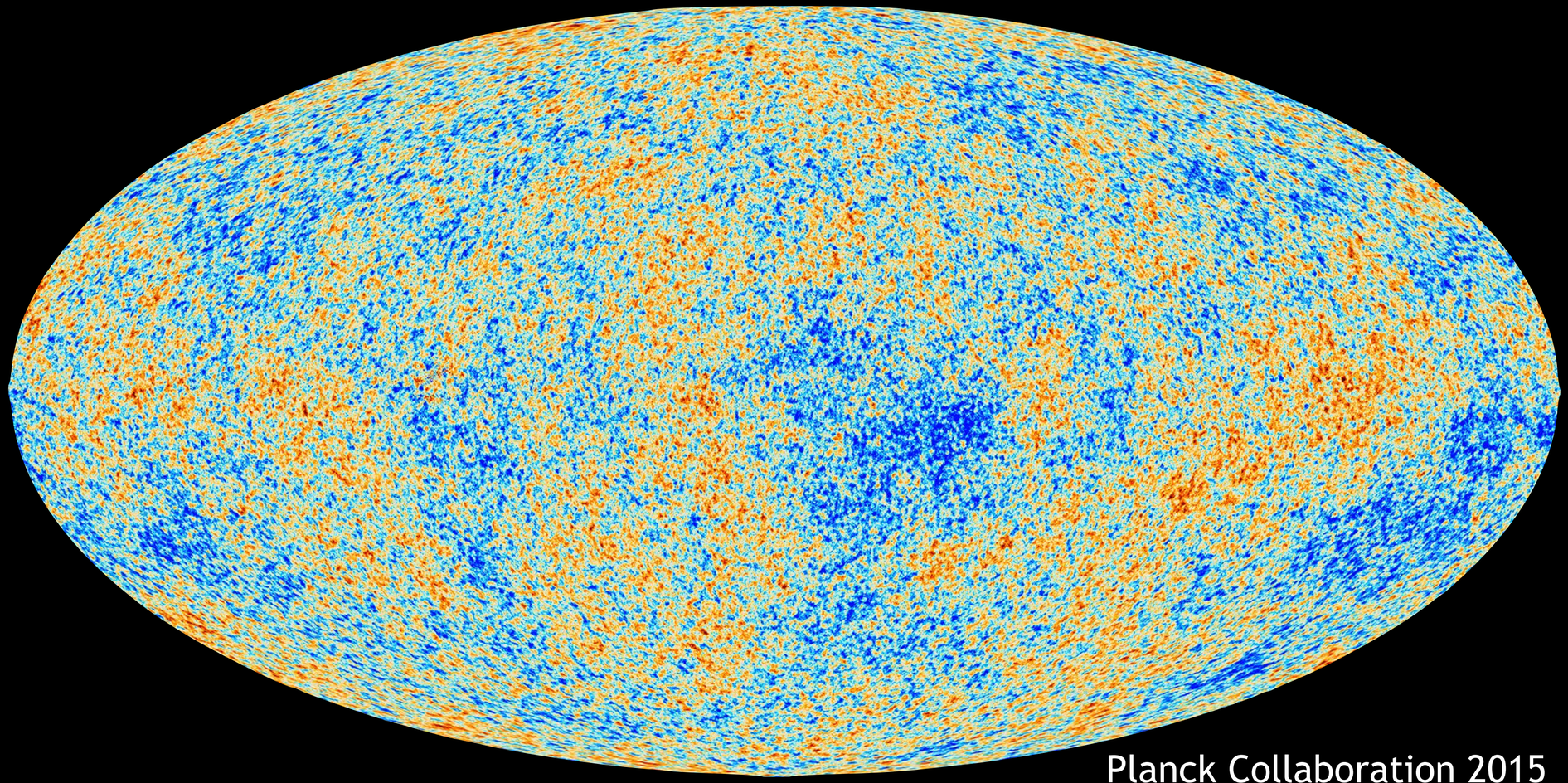


Dark energy (Λ)

Inflation

Highly successful phenomenology

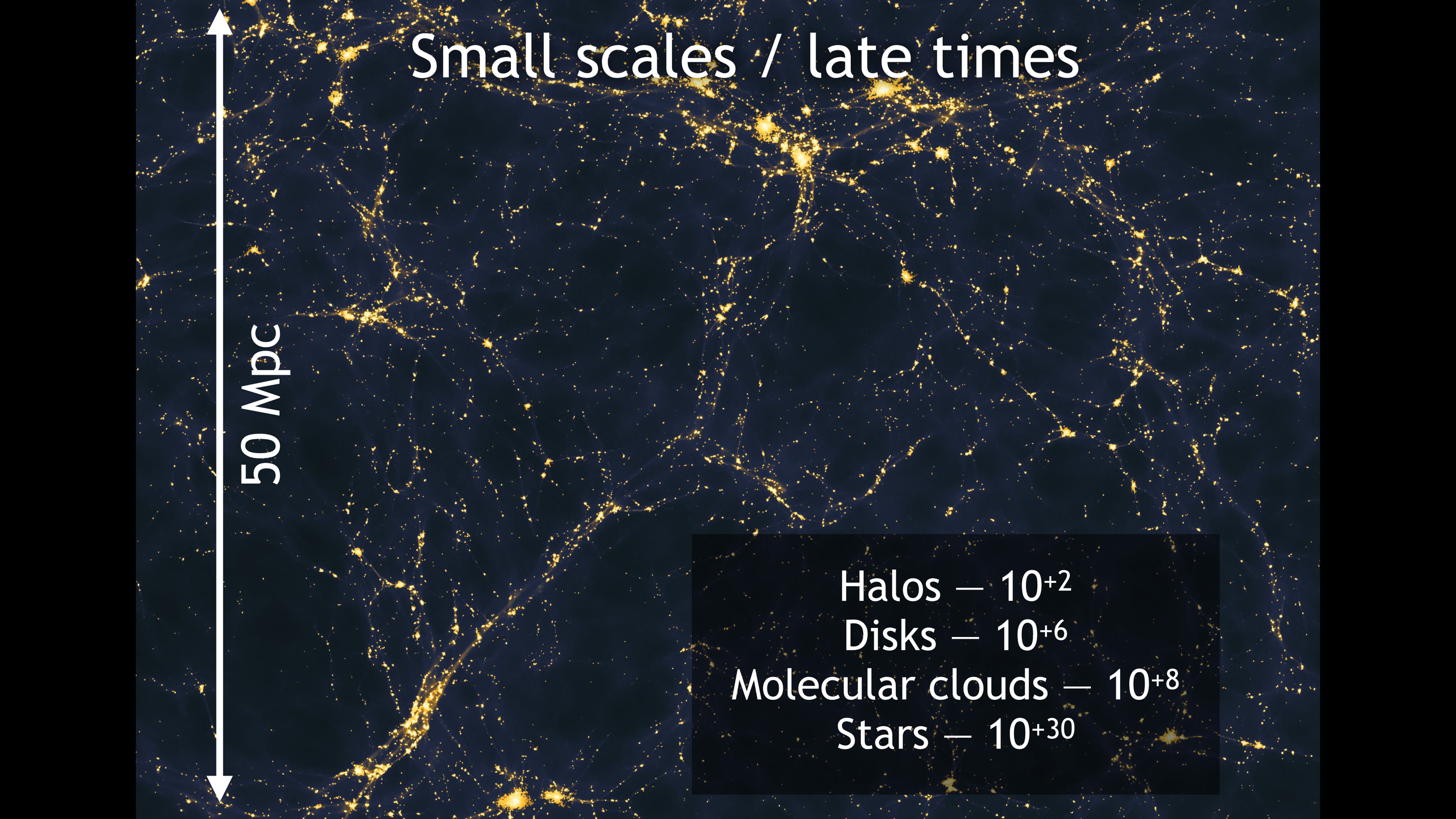
Large scales/early times

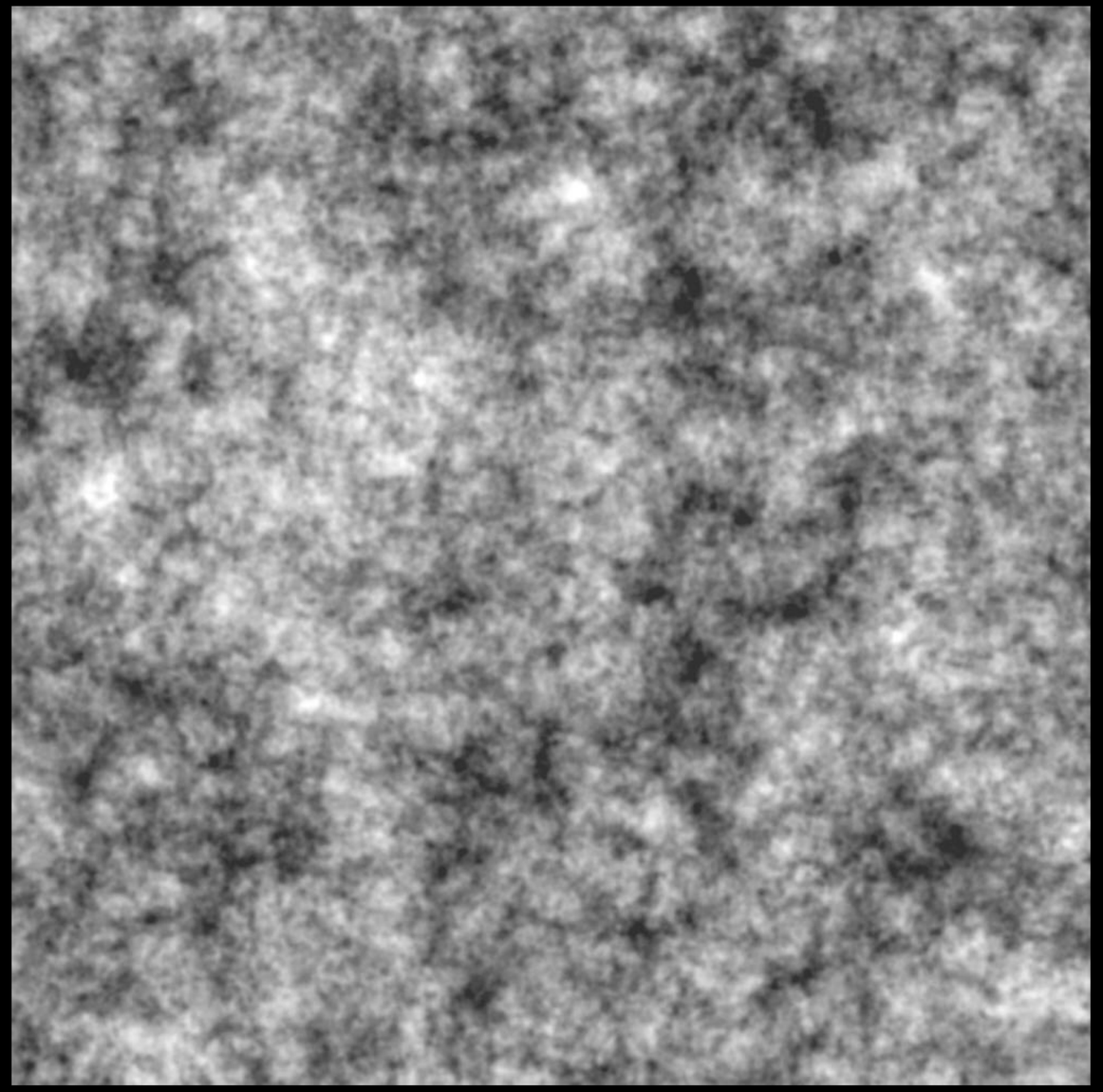


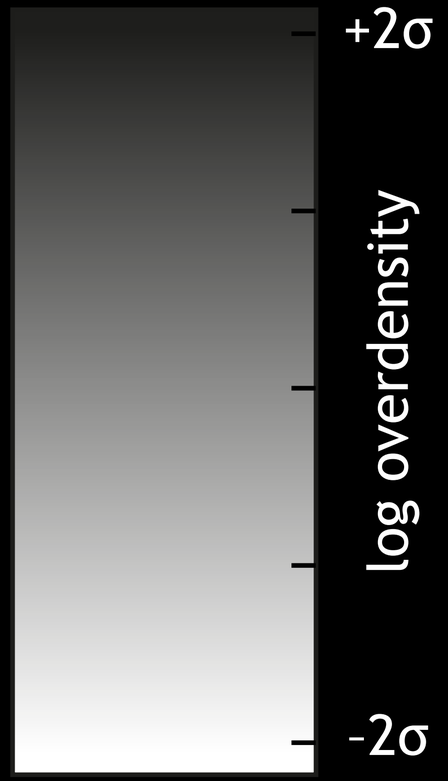
Planck Collaboration 2015

$2\pi d_A$=90 Gpc comoving

Fluctuation scale: 10^{-5}


Small scales / late times
50 Mpc
Halos — 10^{+2}
Disks — 10^{+6}
Molecular clouds — 10^{+8}
Stars — 10^{+30}



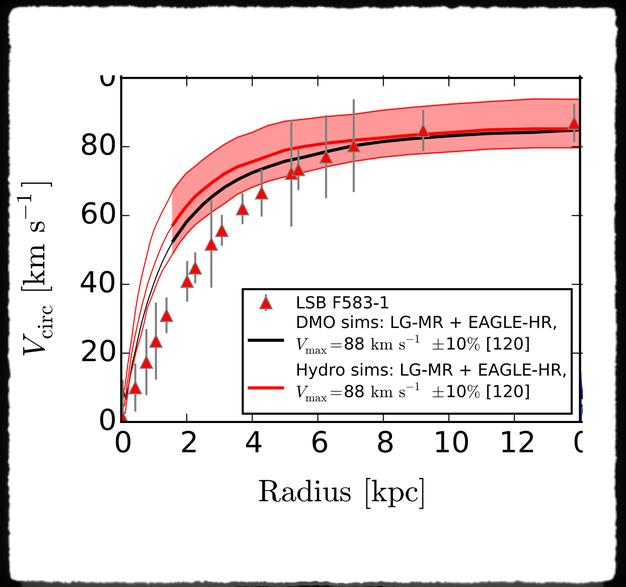


Pontzen+ 1511.04090

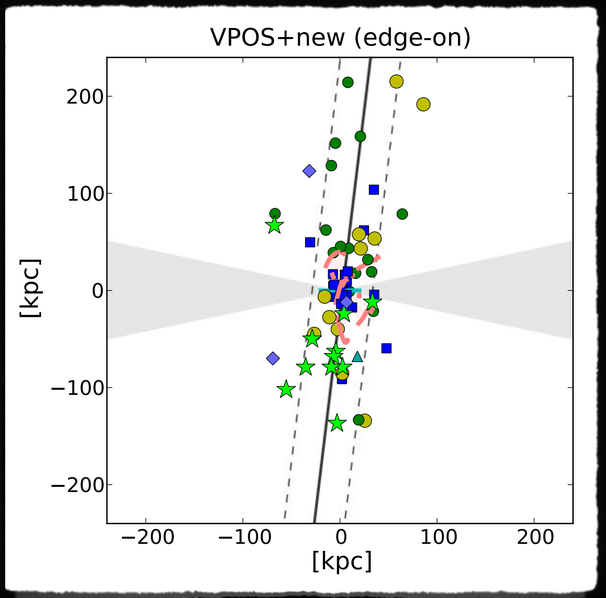
Why dwarf galaxies challenge ΛCDM

Dynamical masses

Abundance

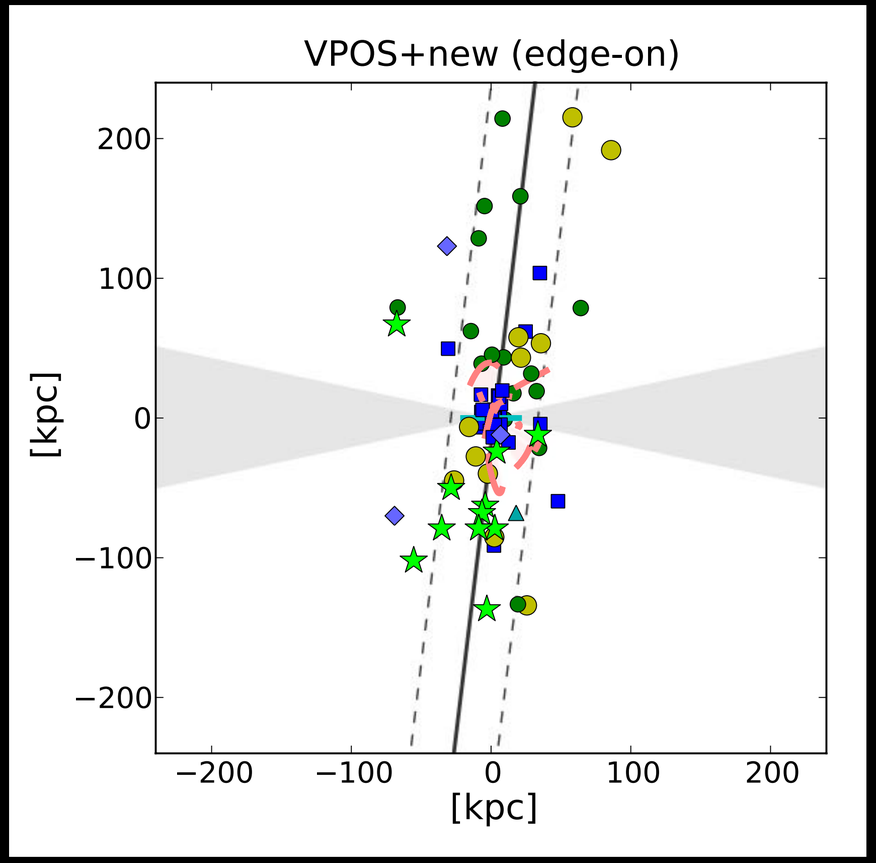


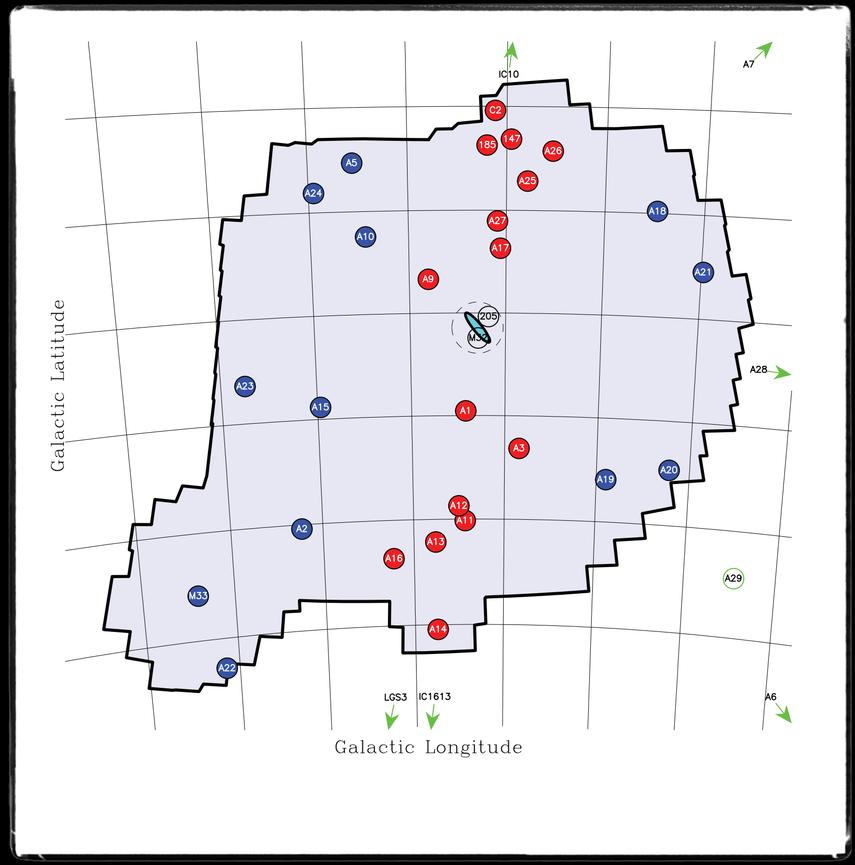
Central densities



Alignments

Alignments





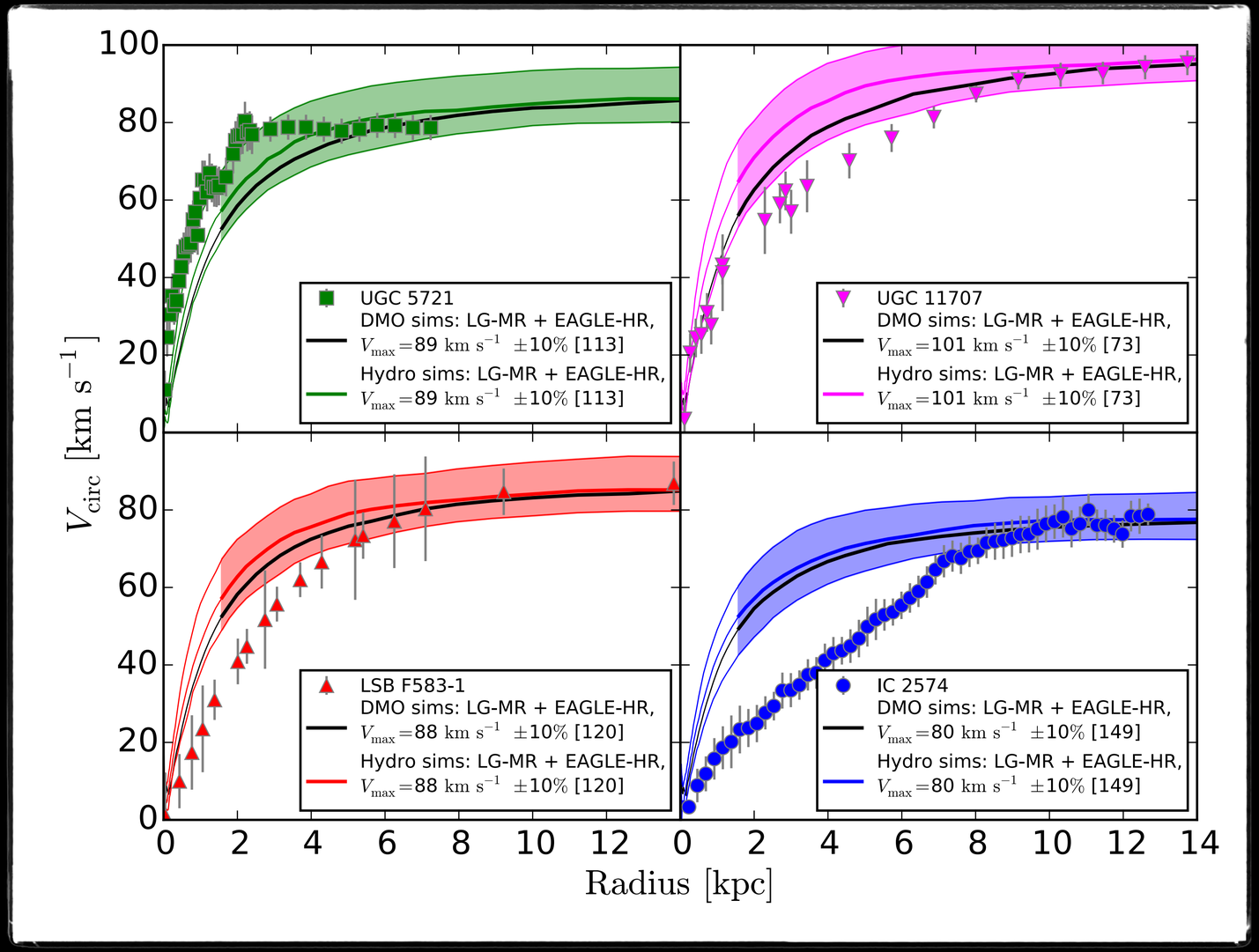
MW e.g. Pawlowski, McGaugh & Jerjen 15

M31 e.g. Ibata+ 2013

Jury still out on whether this is a problem or not

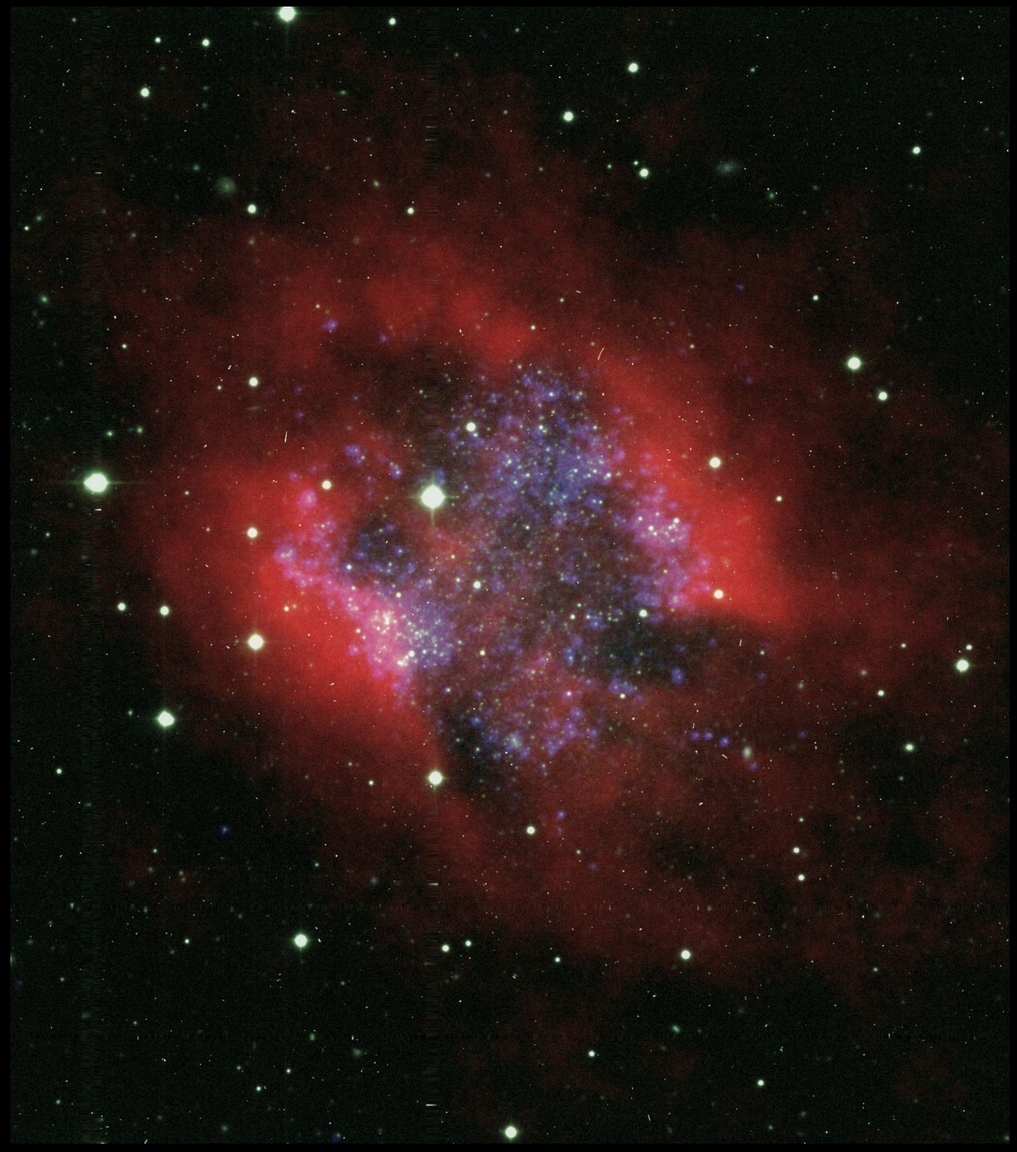
e.g. Libeskind+ 2009; Buck, Dutton & Macciò 2016; Santos-Santos+ 2021

Central densities



Oman+ 2015

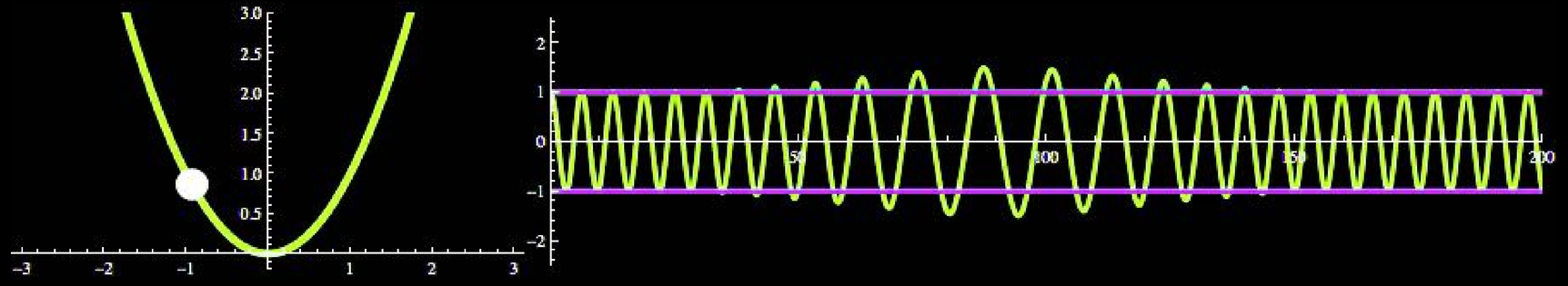
Central densities



DDO 75
“Little THINGS” survey
Hunter+ 2012

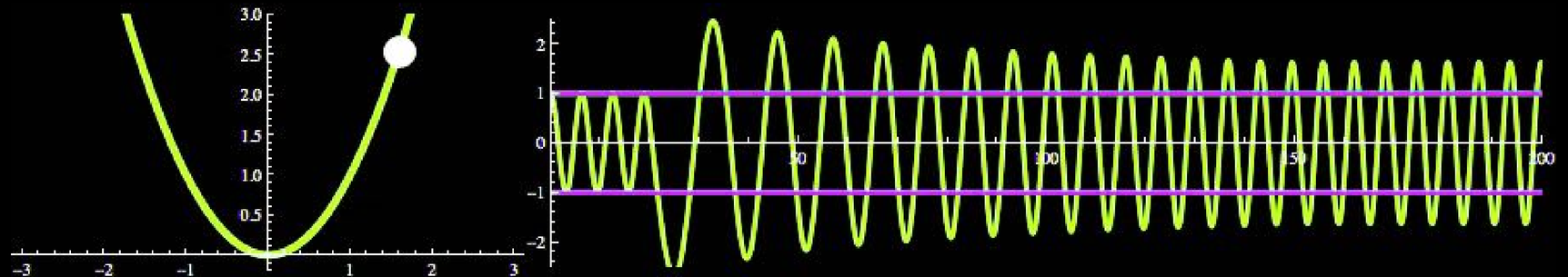
Composite image by
Lauren Hill

Central densities: slow vs fast feedback



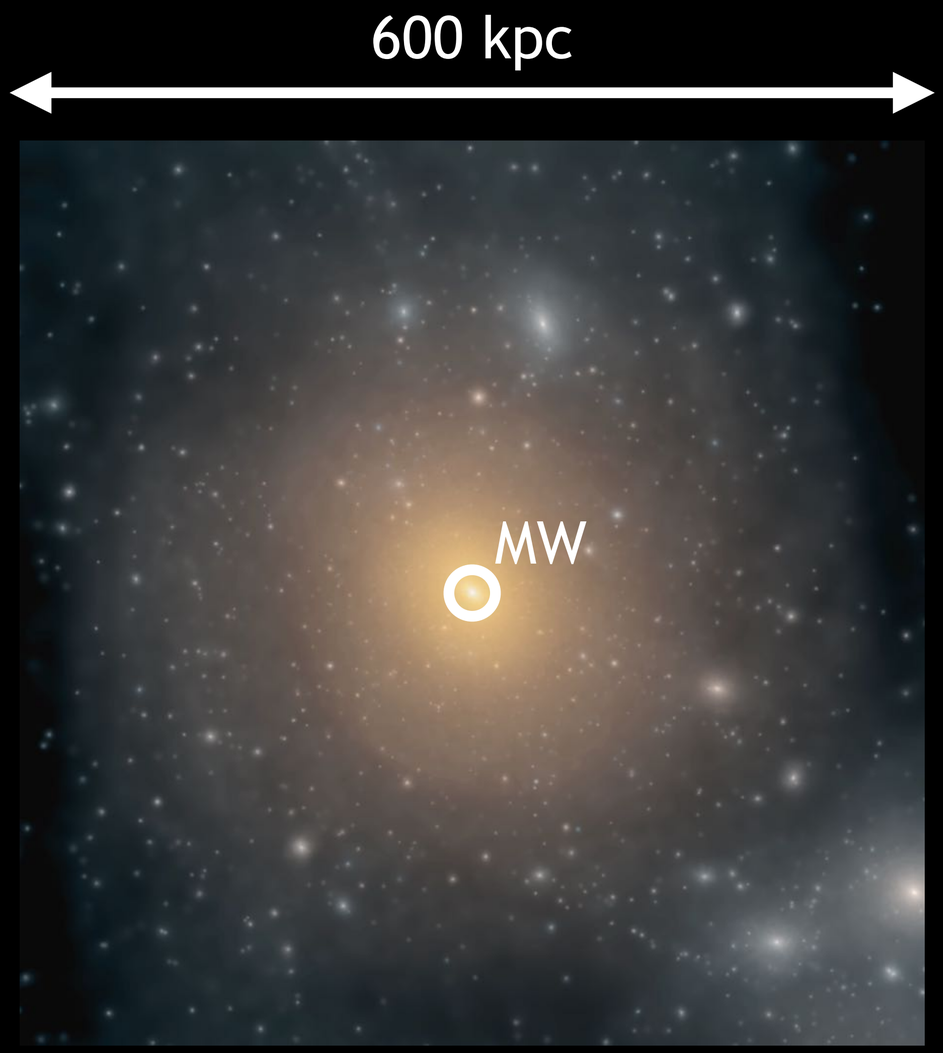
Slow outflows (adiabatic) $E_f = E_i$

Fast outflows (impulsive) $\frac{\langle E_f \rangle}{E_i} = \frac{1}{2}\left(\frac{\omega_1}{\omega_0} + \frac{\omega_0}{\omega_1}\right)$

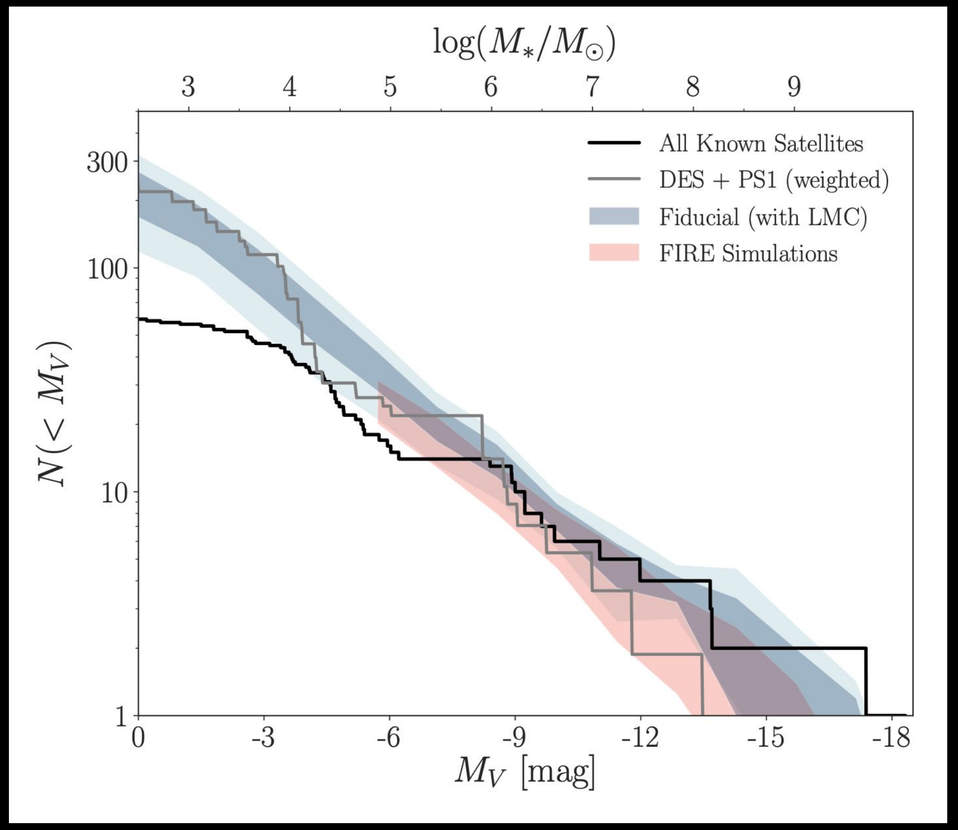


Pontzen & Governato 2012

Missing satellites

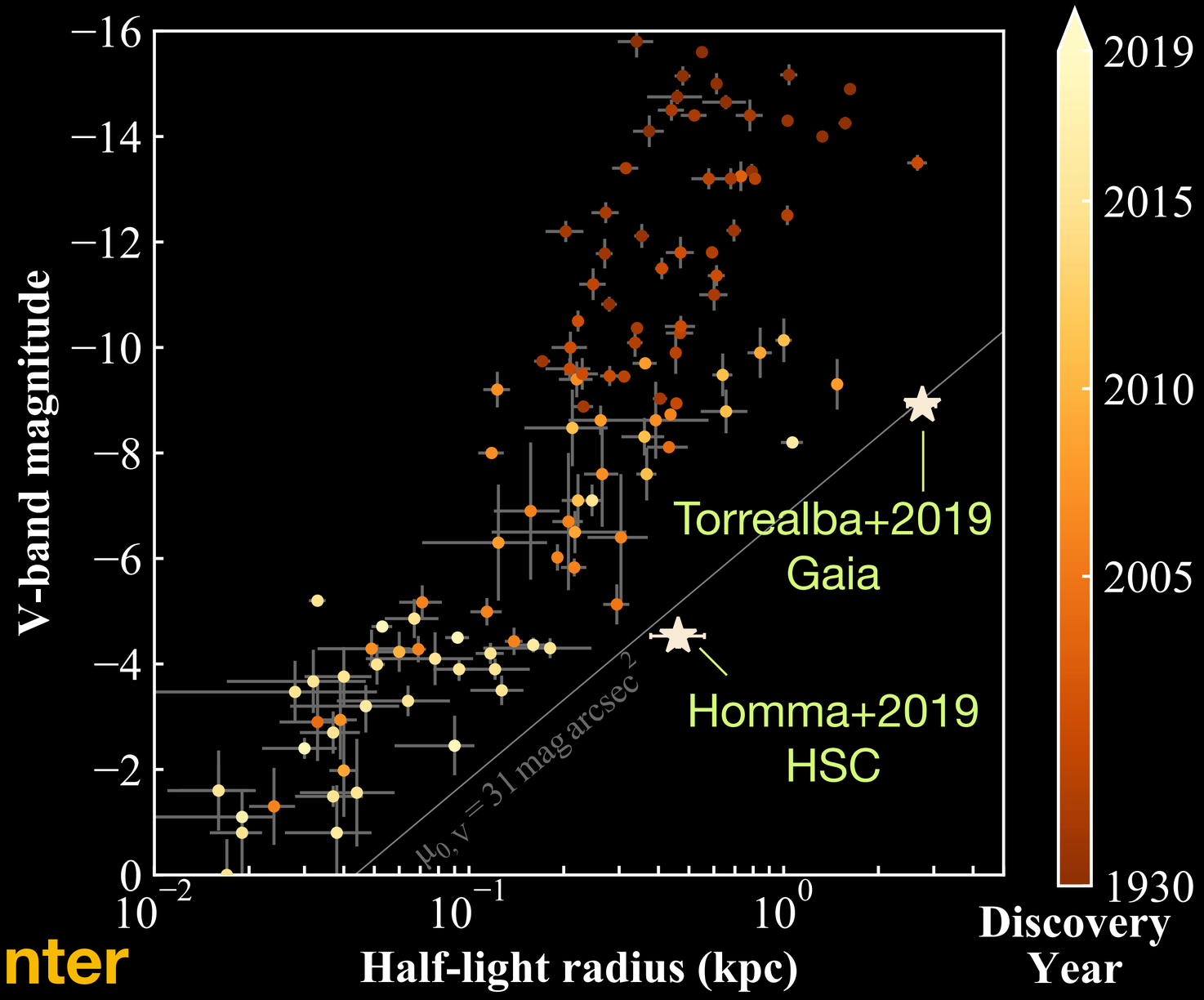


Pontzen+ 2013



Nadler+ 2020

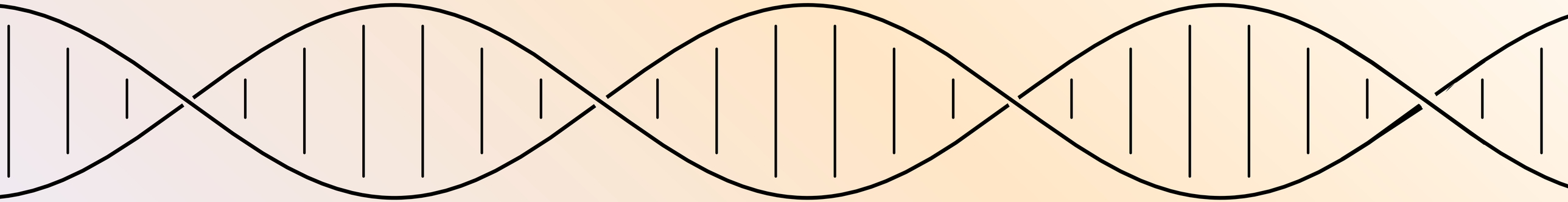
Discovery space



Fainter

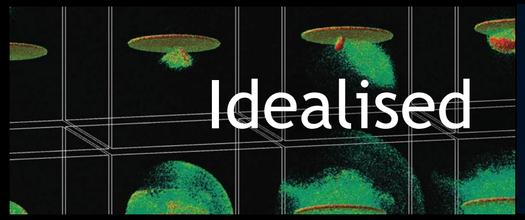
Larger

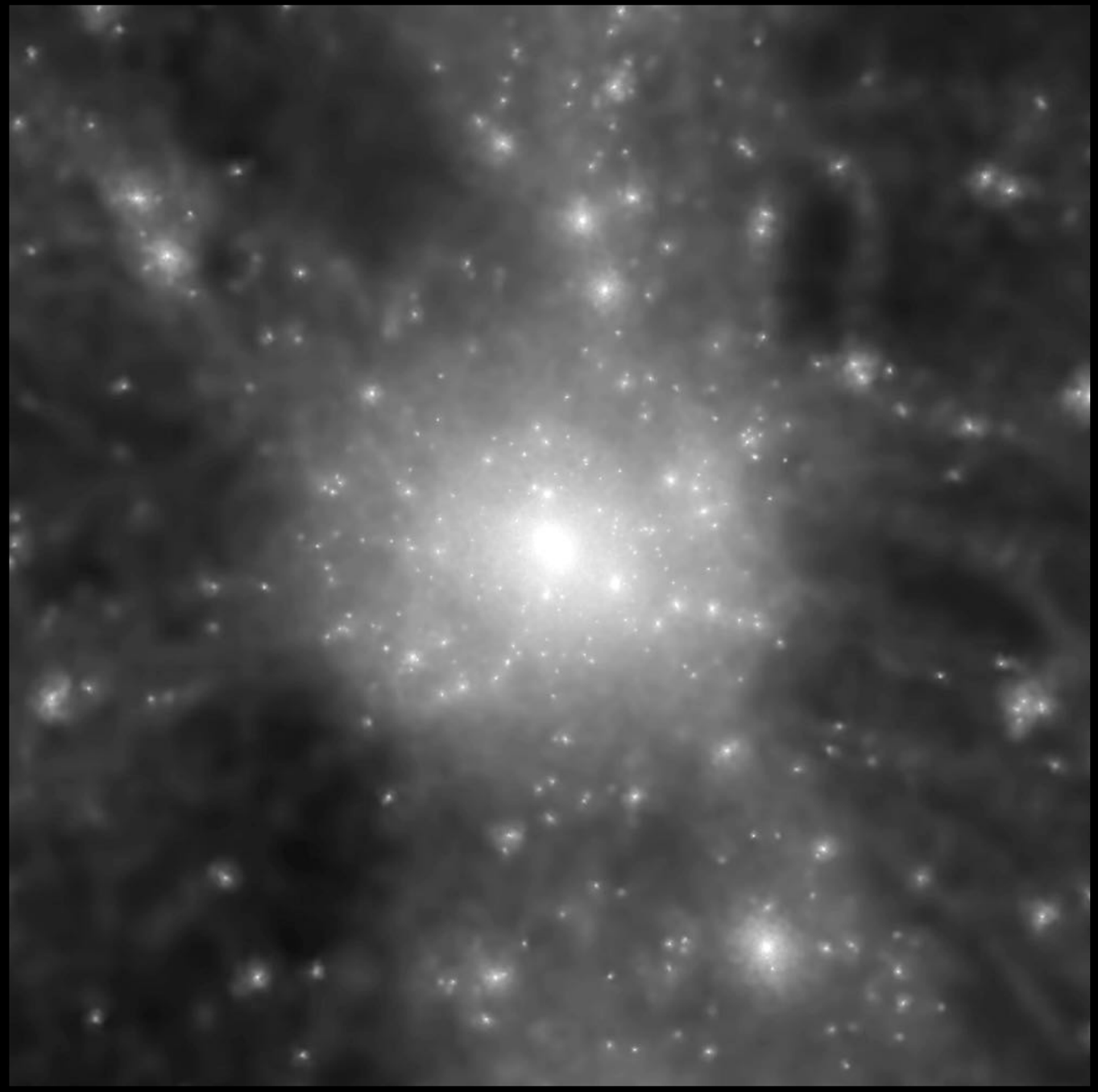
Rey+ 19



Part 2: “Genetically modified” simulations

Simulation Pros & Cons

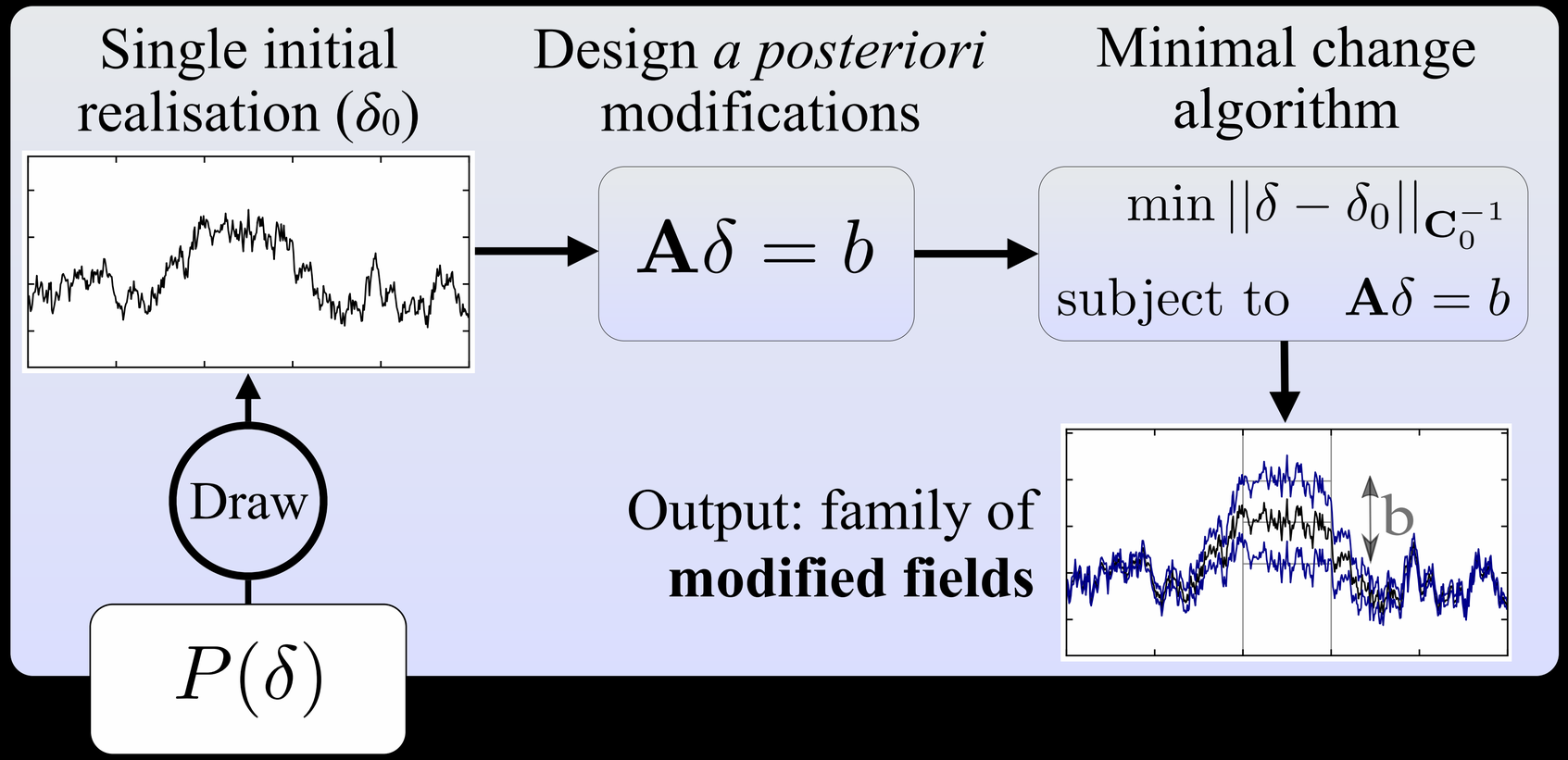
	Cosmology	Resolution	Control
 Volume	😀	😢	😢
 Zoom	😀	😀	😐
 Idealised	😢	😀	😀
 GM	😀	😀	😊



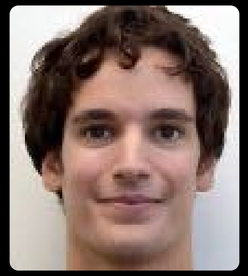
1 cMpc
(full box is 50 cMpc)

Formation of a dwarf galaxy halo

“Genetic modification” of early Universe

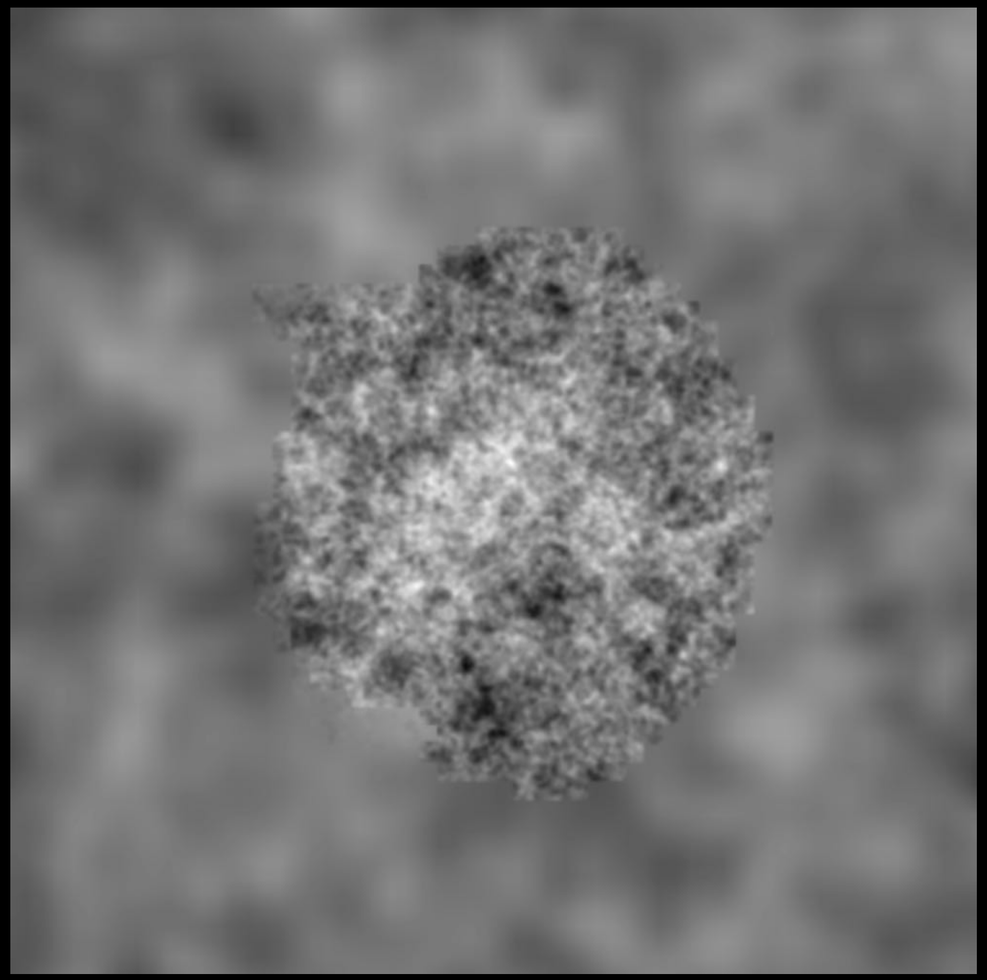


Rey+ 18



Modifications are tiny and smooth

Maintain consistency with ΛCDM



10 cMpc
(full box is 50 cMpc)

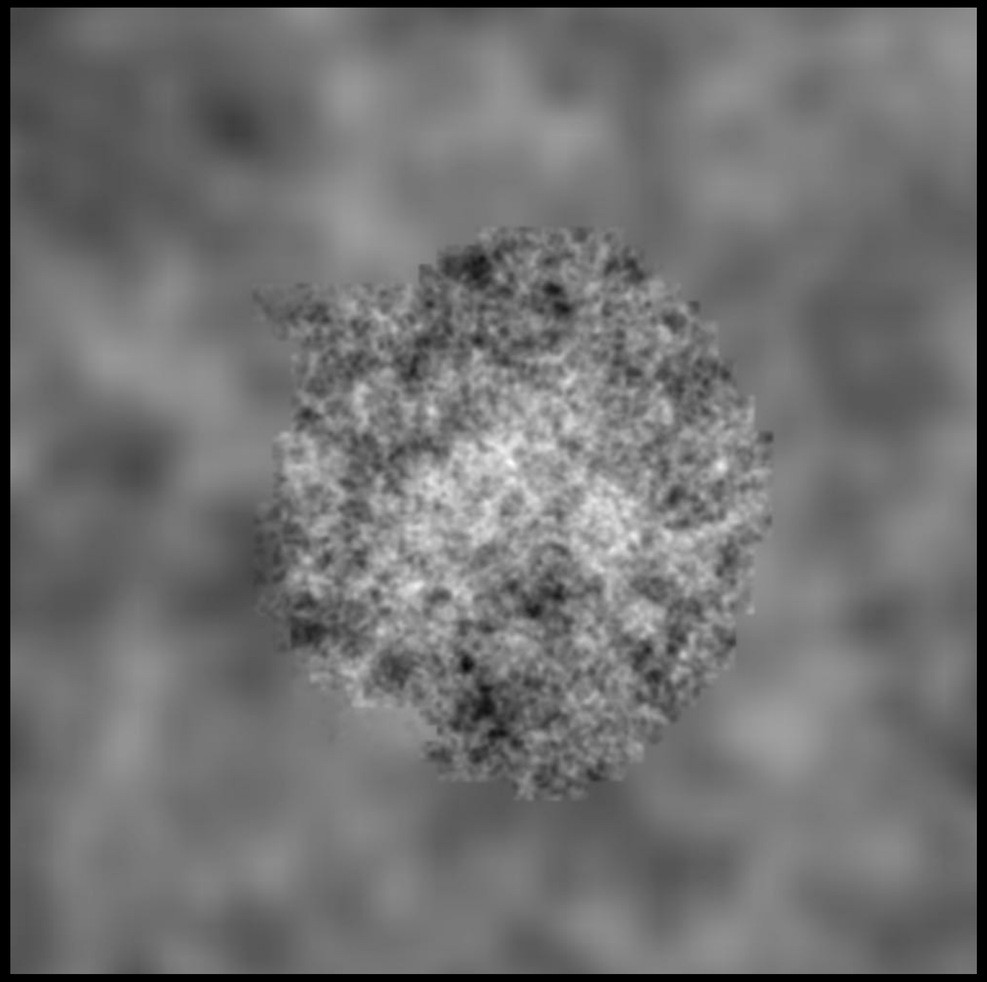
Unmodified

z=99

Roth+ 2016

Modifications are tiny and smooth

Maintain consistency with ΛCDM

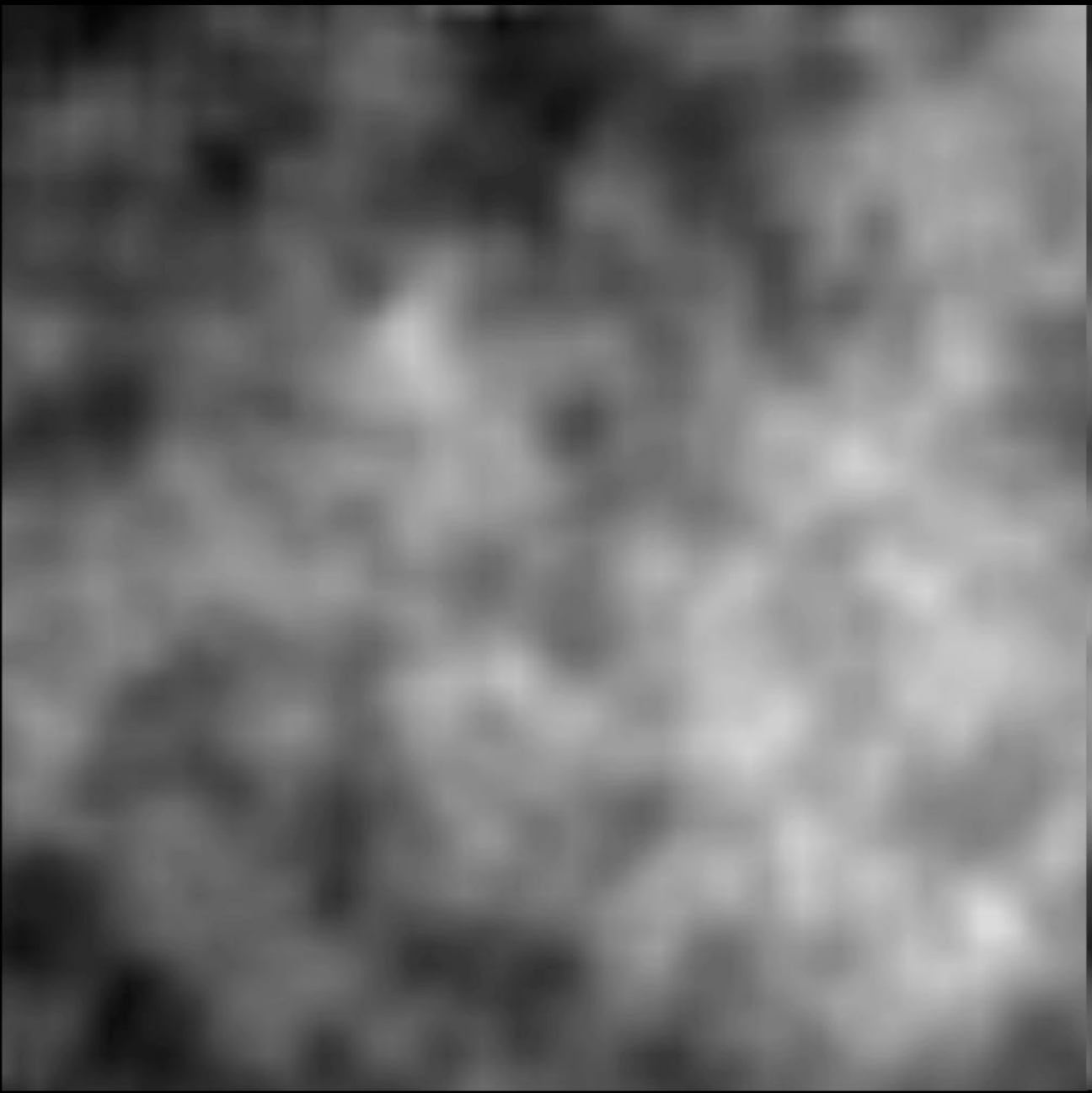


10 cMpc
(full box is 50 cMpc)

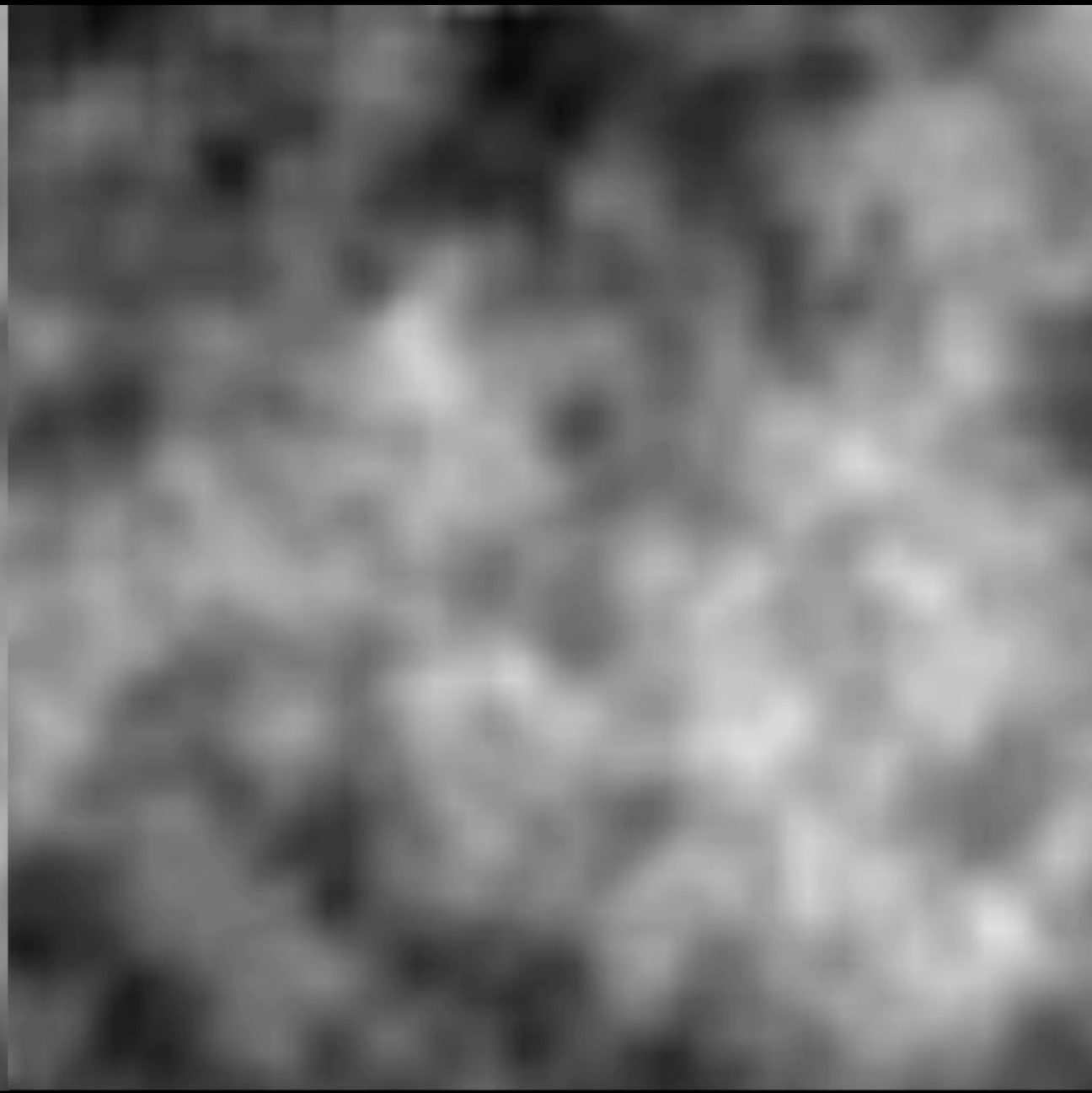
GM late formation z=99

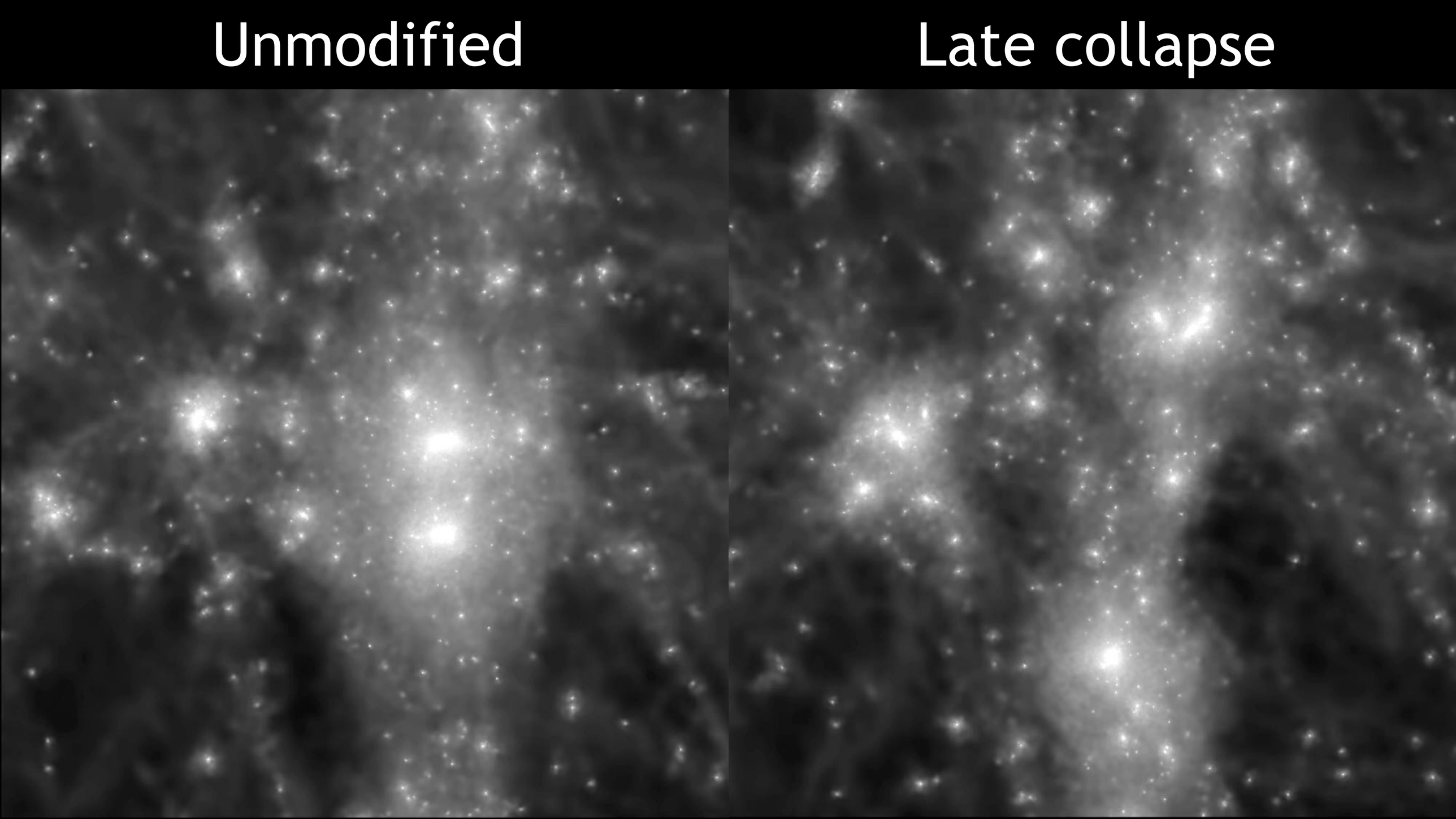
Roth+ 2016

Unmodified

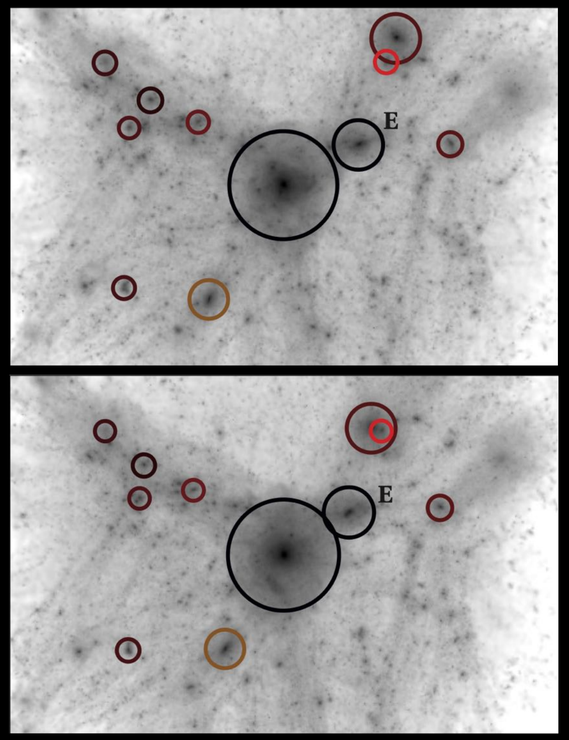


Late collapse



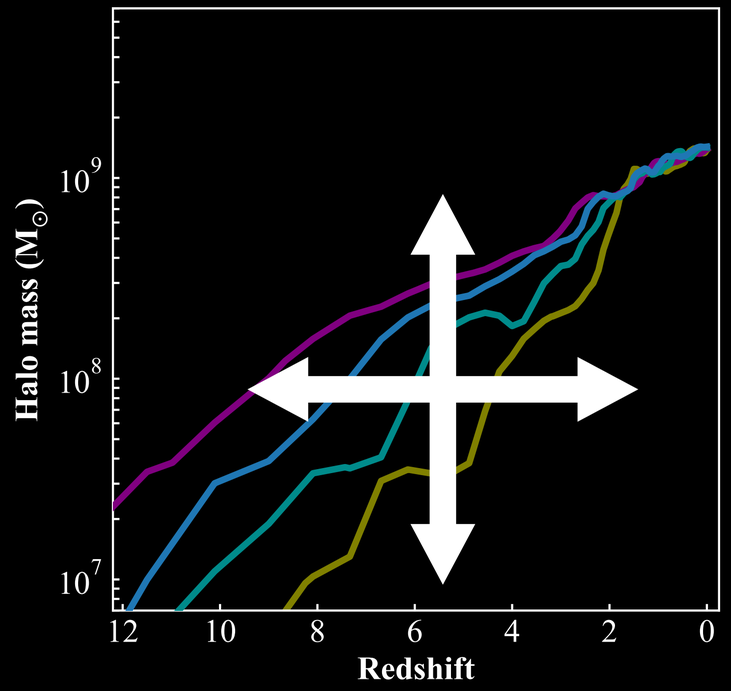

Unmodified
Late collapse

Why is this good?



Consistent environment

no confusion from random sampling



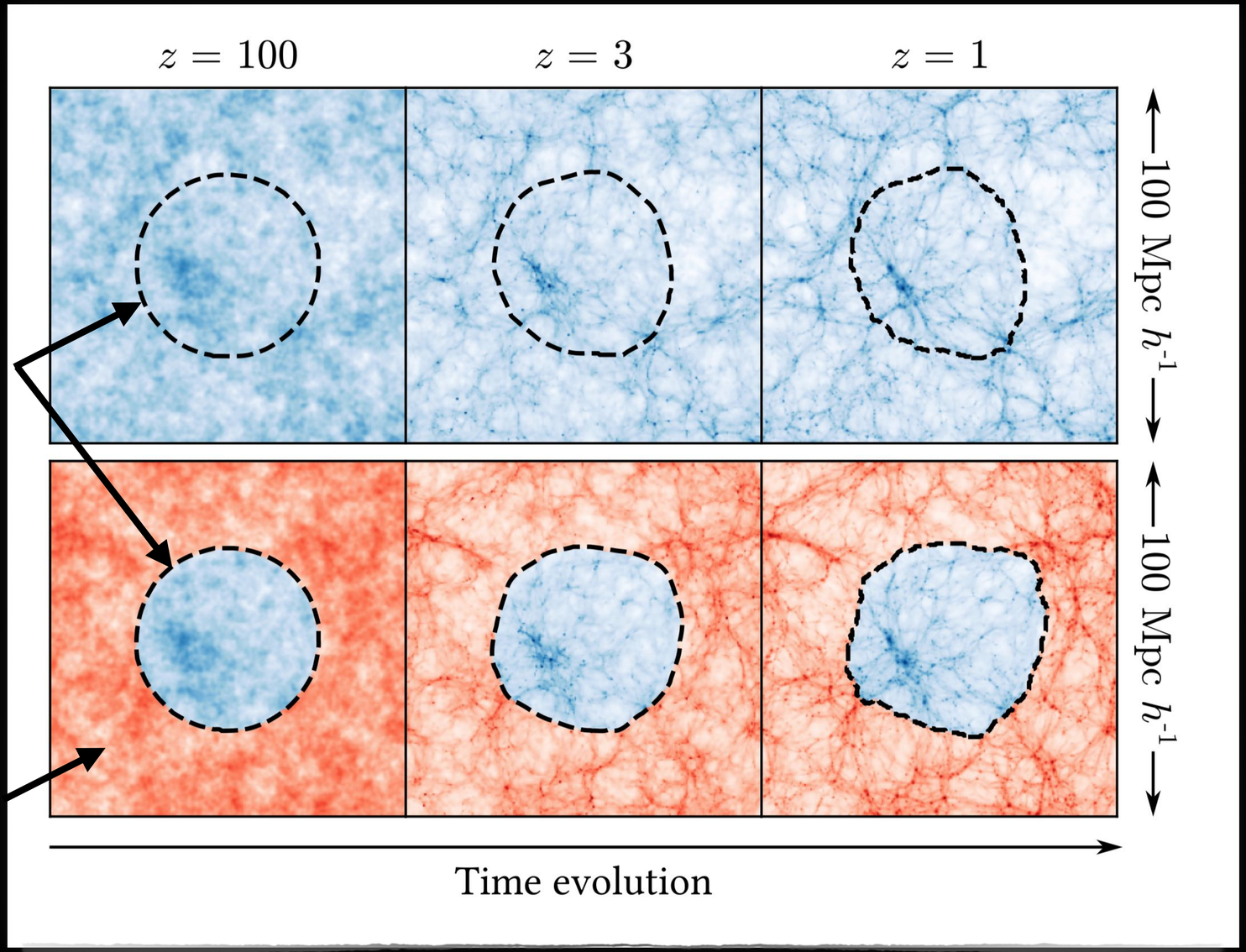
Infinite tunability

pose and test hypotheses

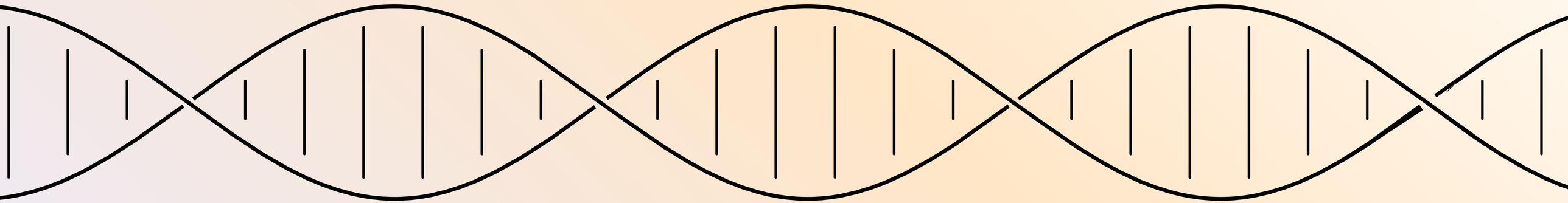
Also: “Gene Splicing”

same inner field

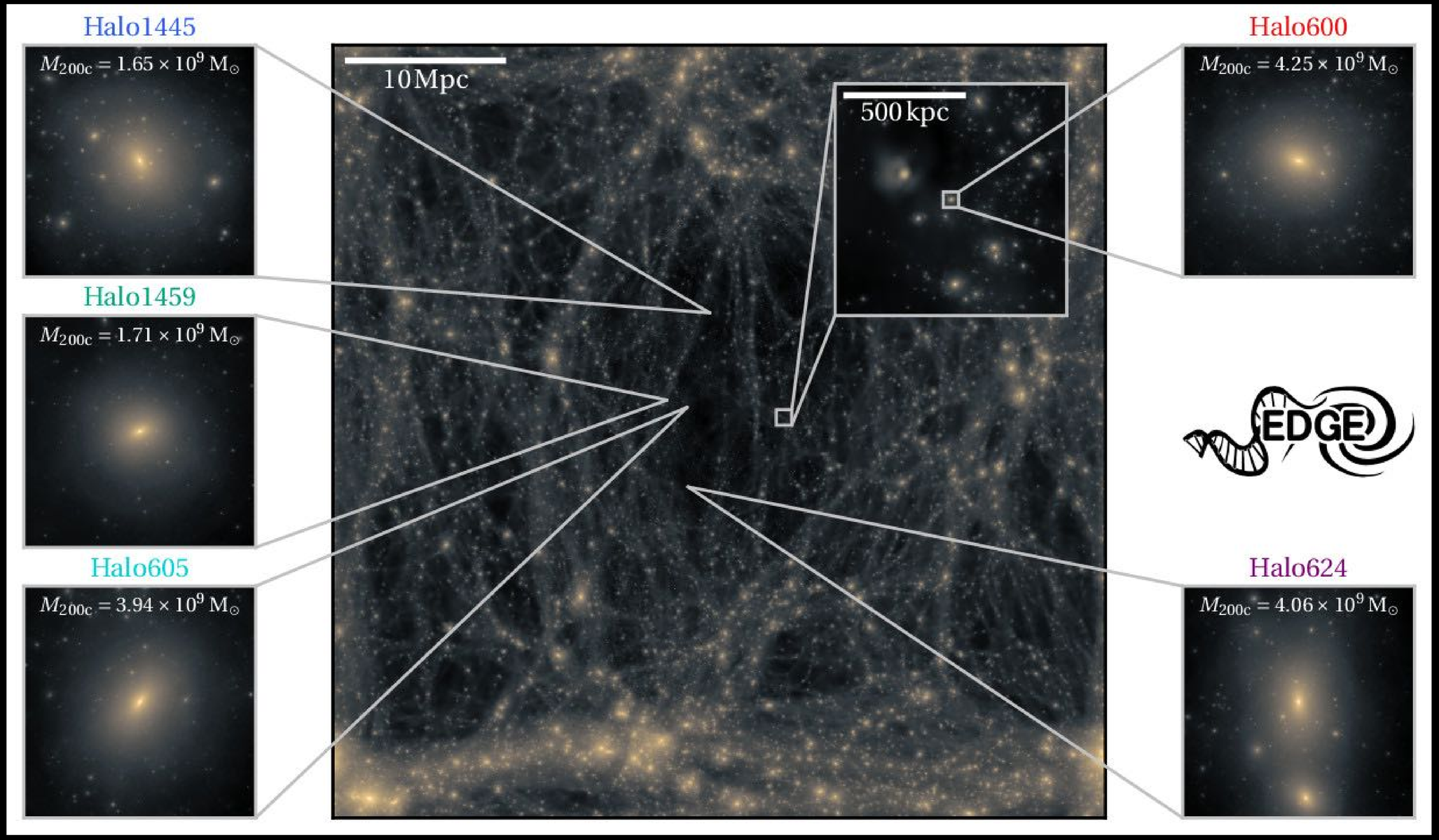
different outer field



Cadiou+ 21

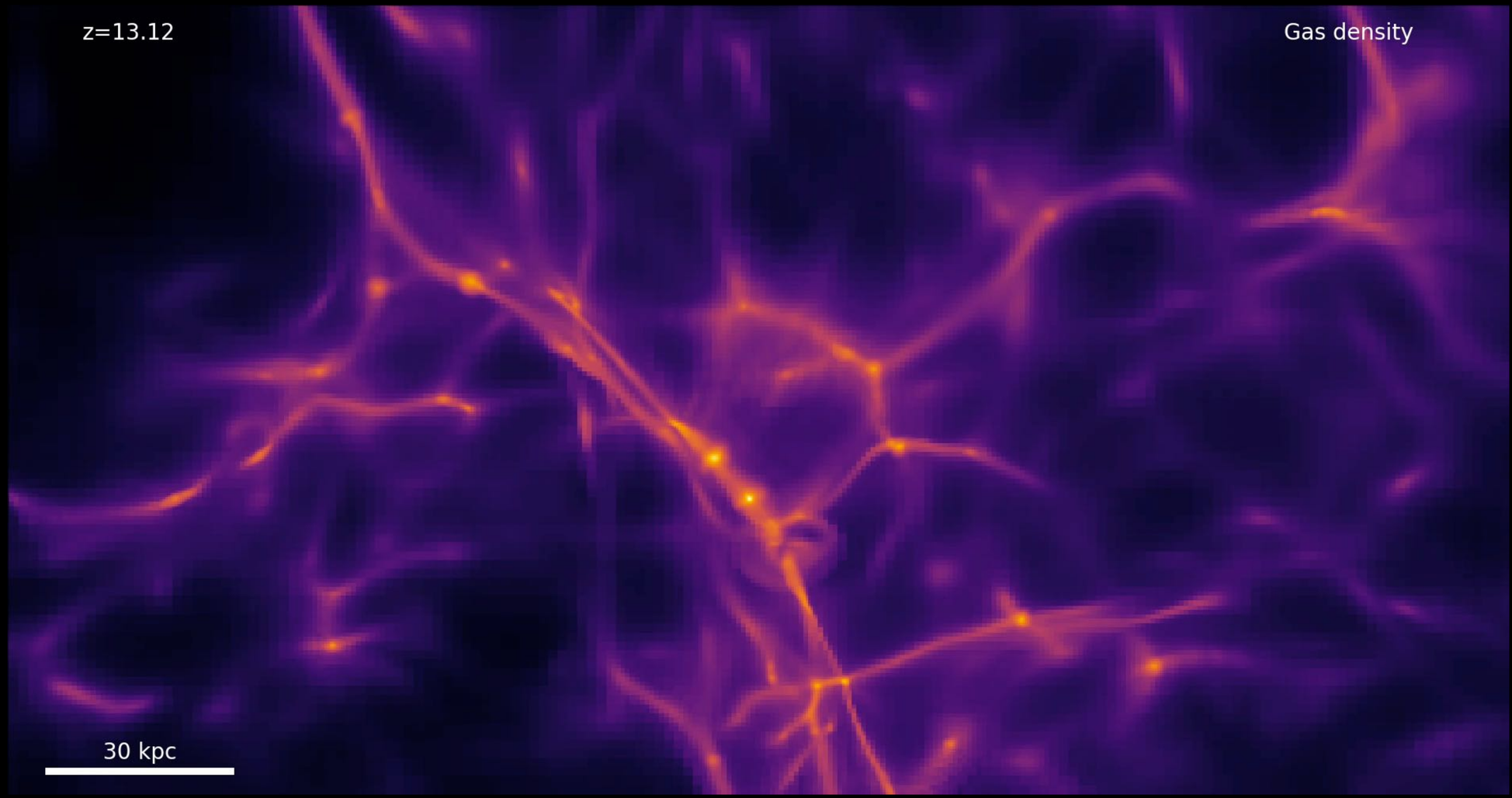


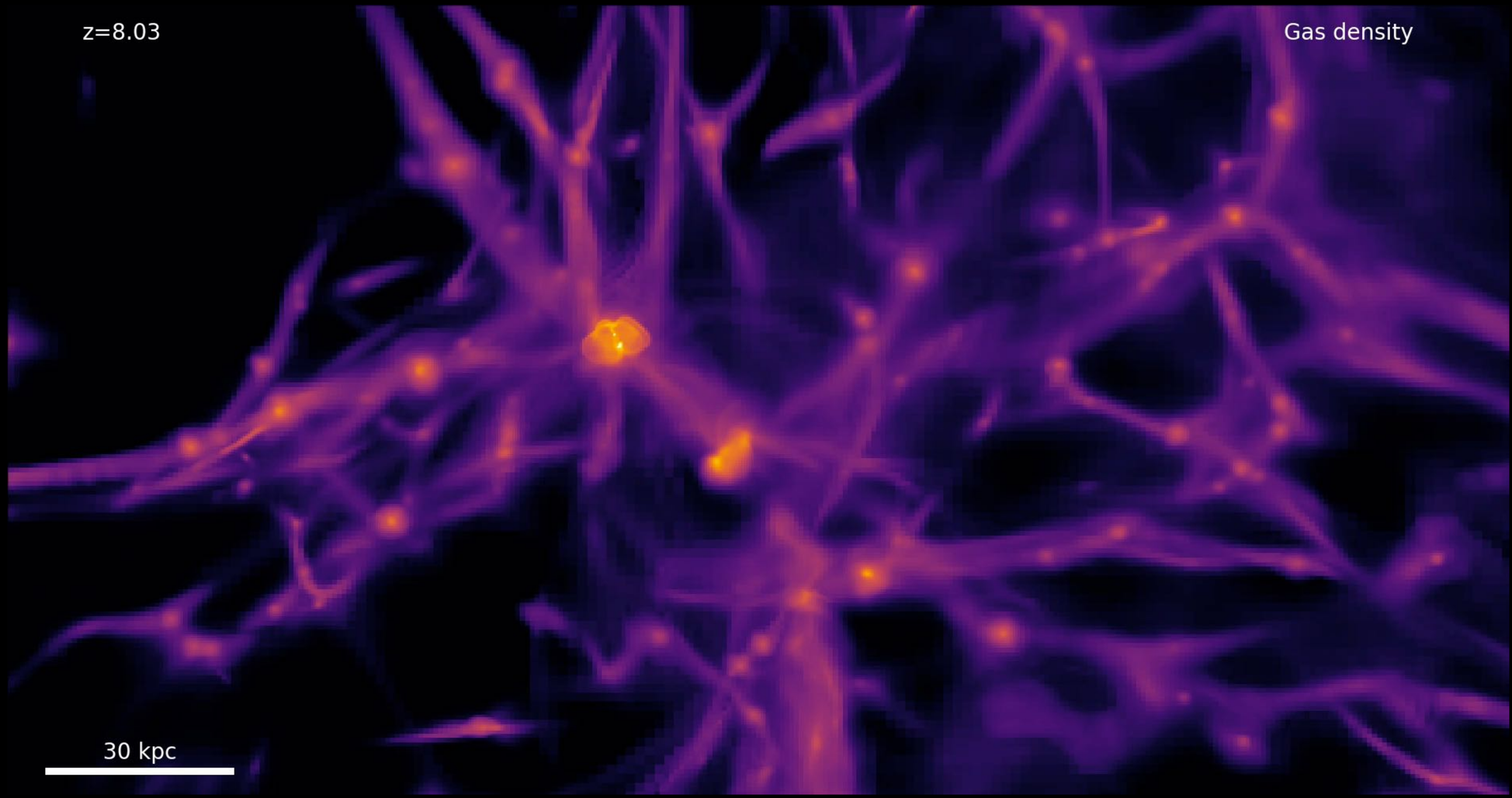
Part 3: Results / predictions

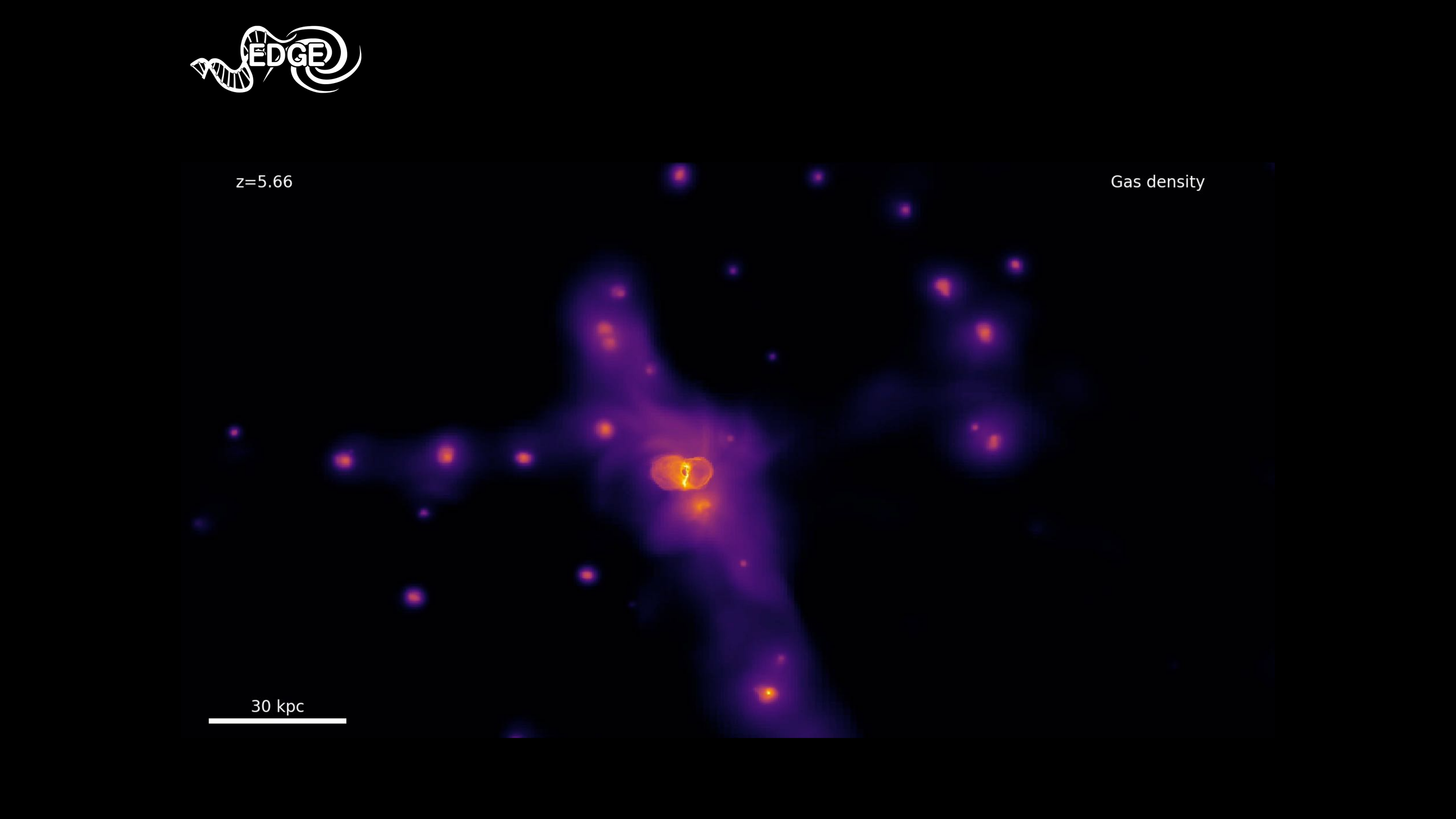


UCL/Surrey/Lund Universities

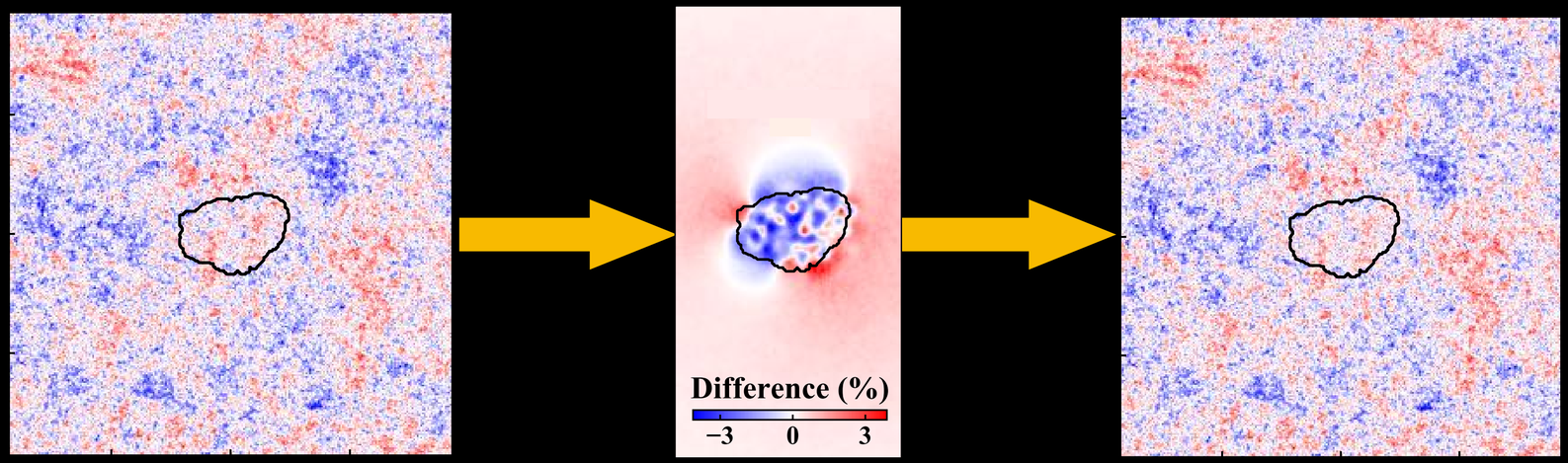
Image by Matt Orkney

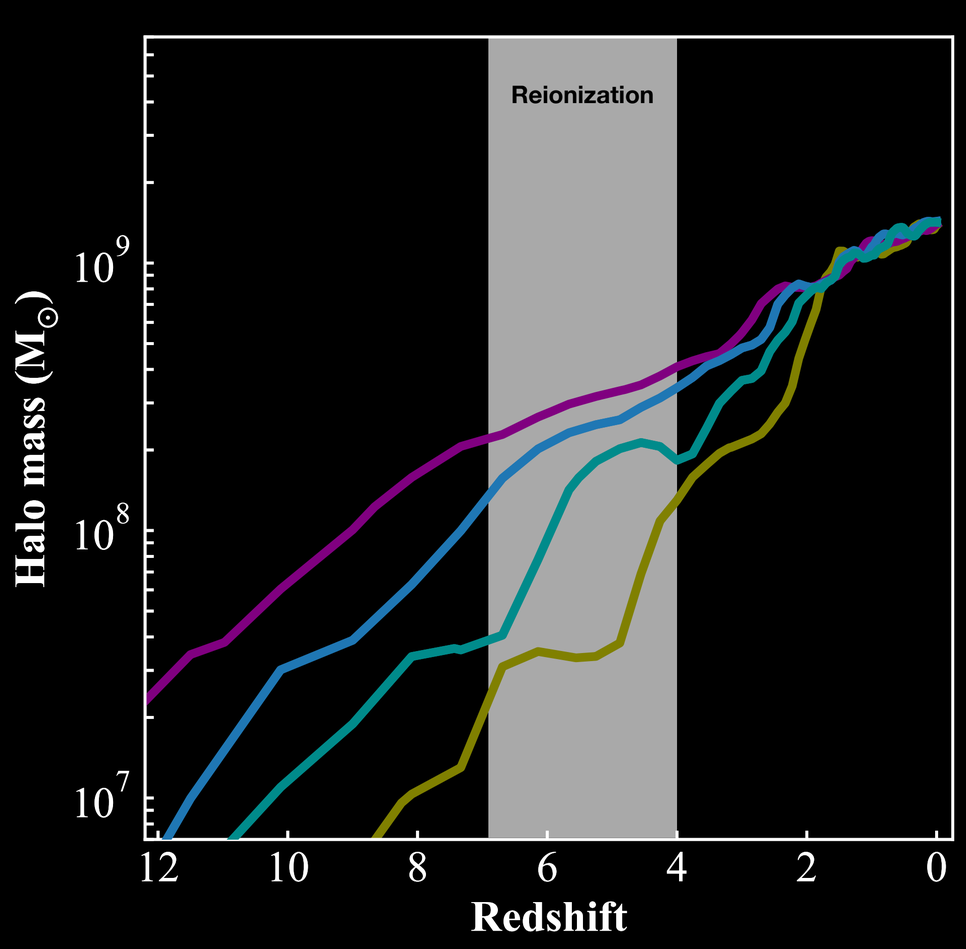

z=13.12
Gas density
30 kpc

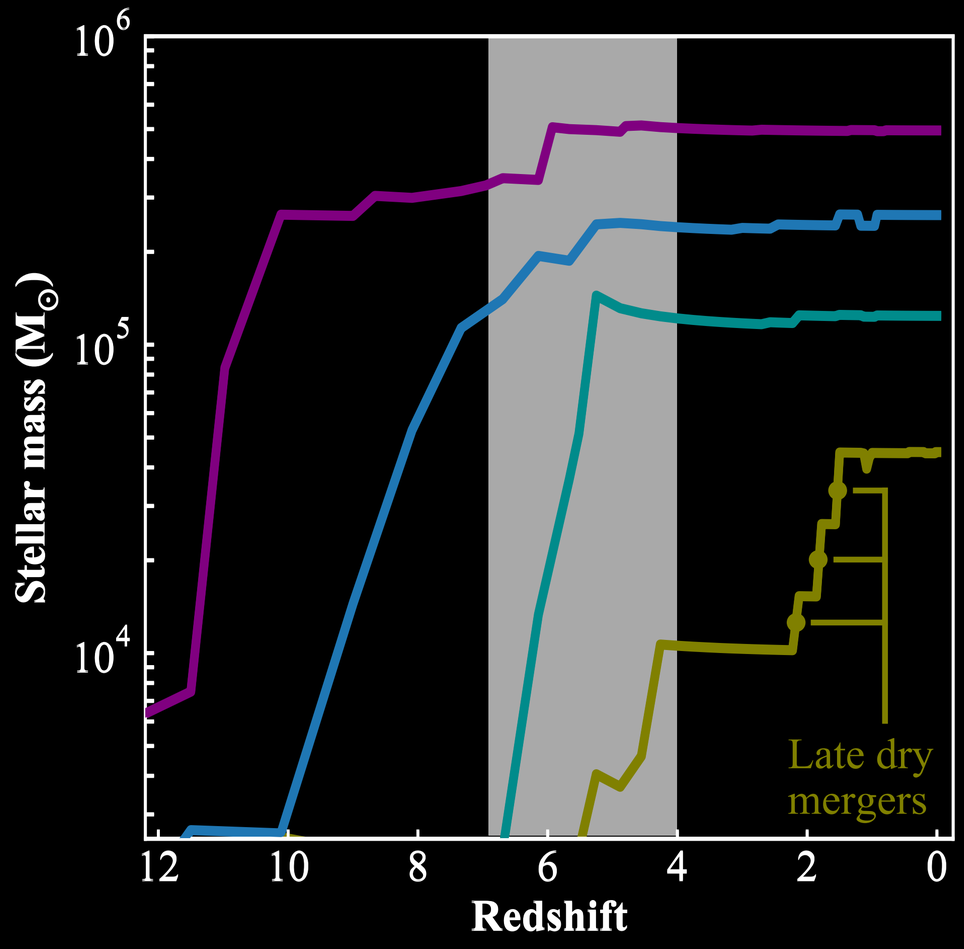

z=8.03
Gas density
30 kpc


EDGE
z=5.66
Gas density
30 kpc

“Genetic modification” of early Universe



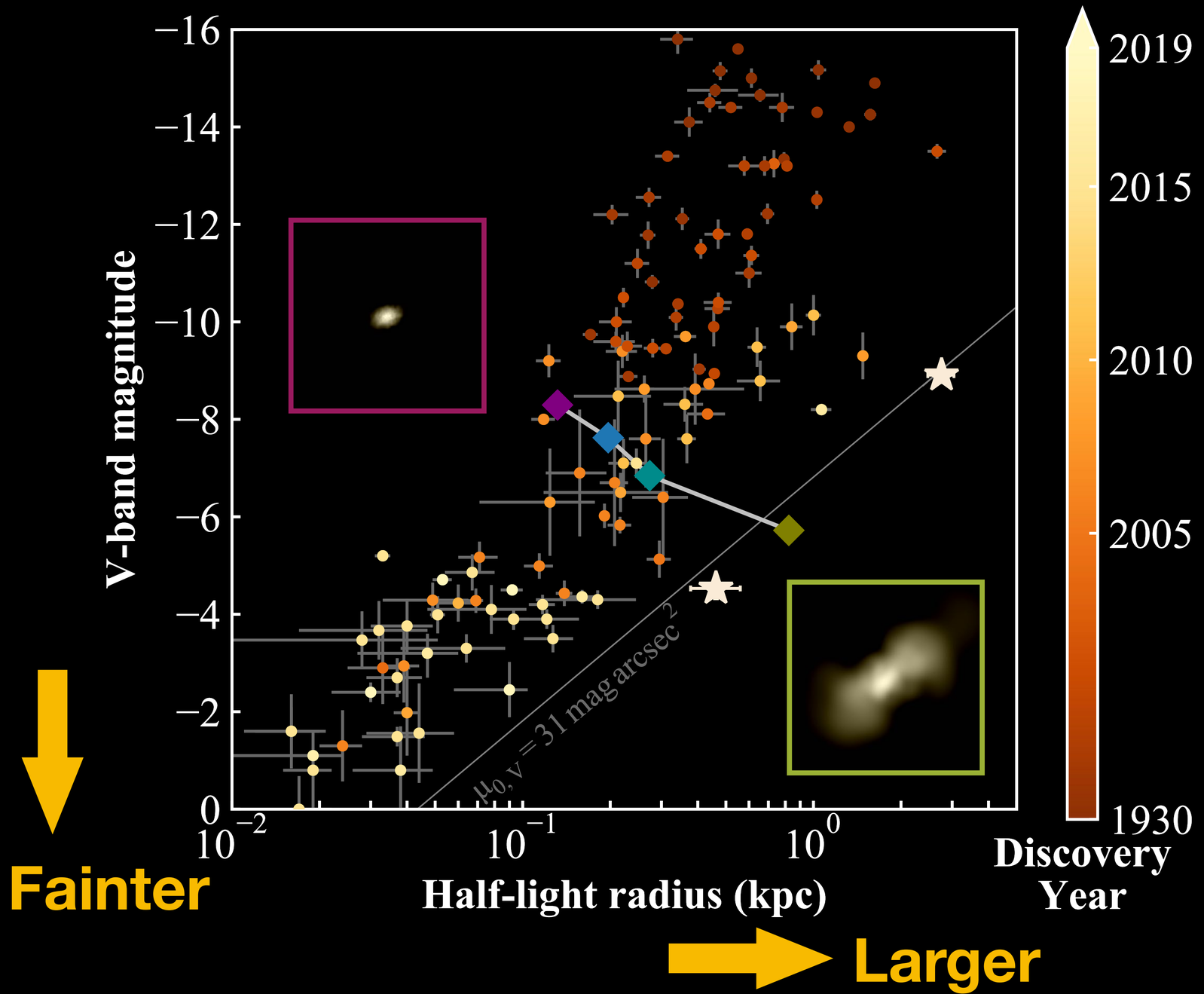




Earlier forming ultra-faint have higher stellar mass, at fixed halo mass today.

Rey+ 19

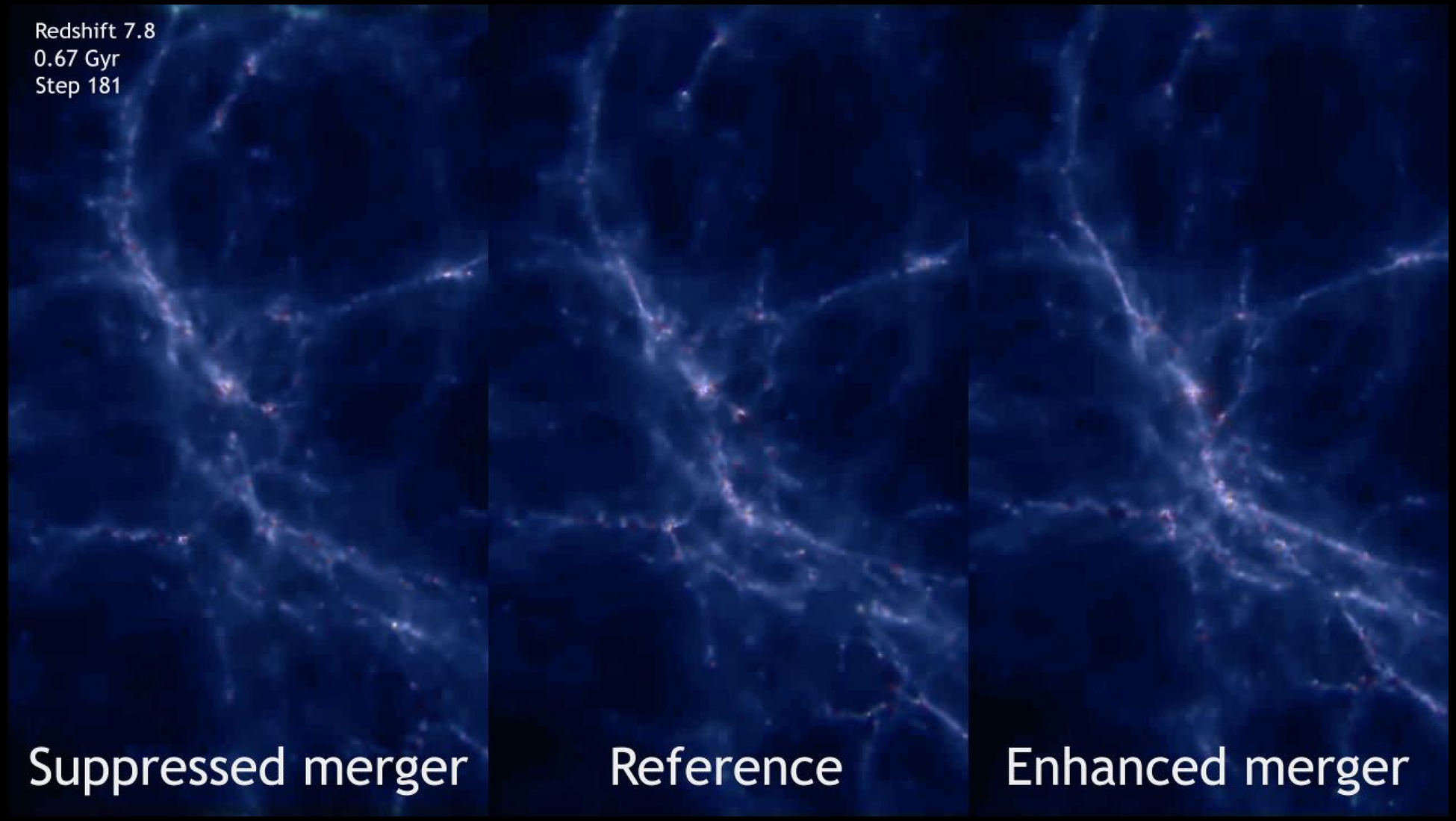
Finding dwarfs



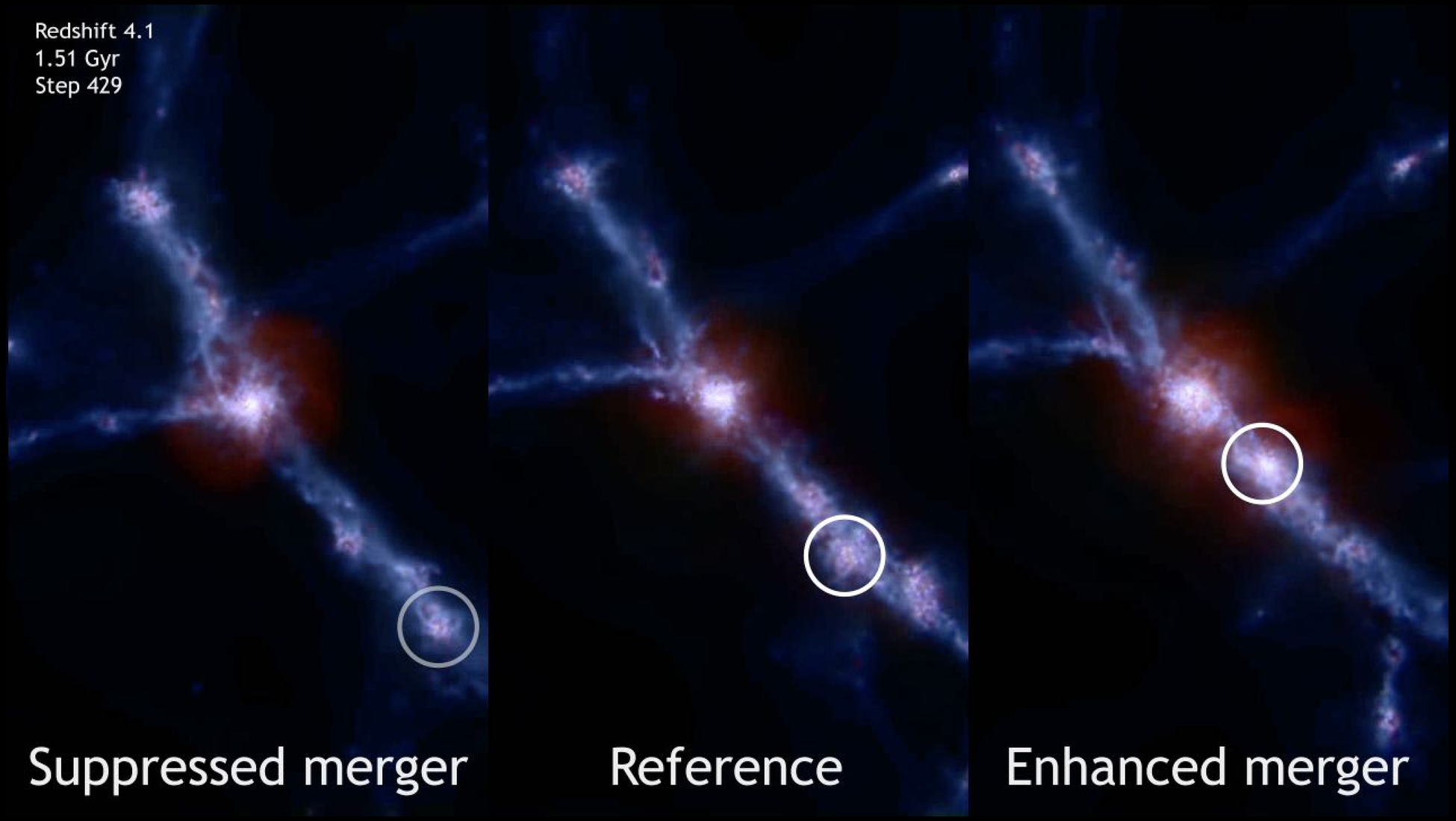
Fainter

Larger

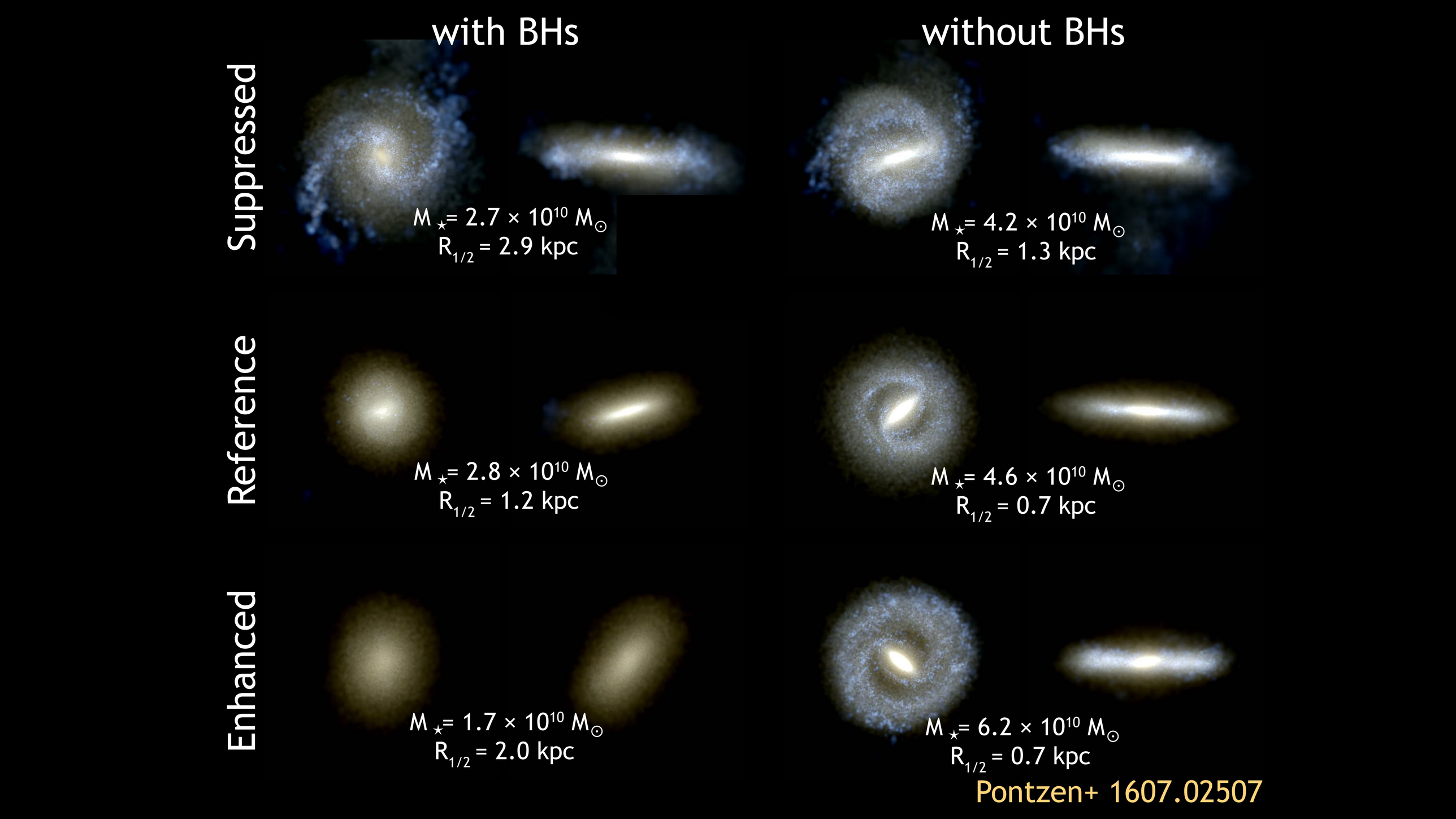
Rey+ 19

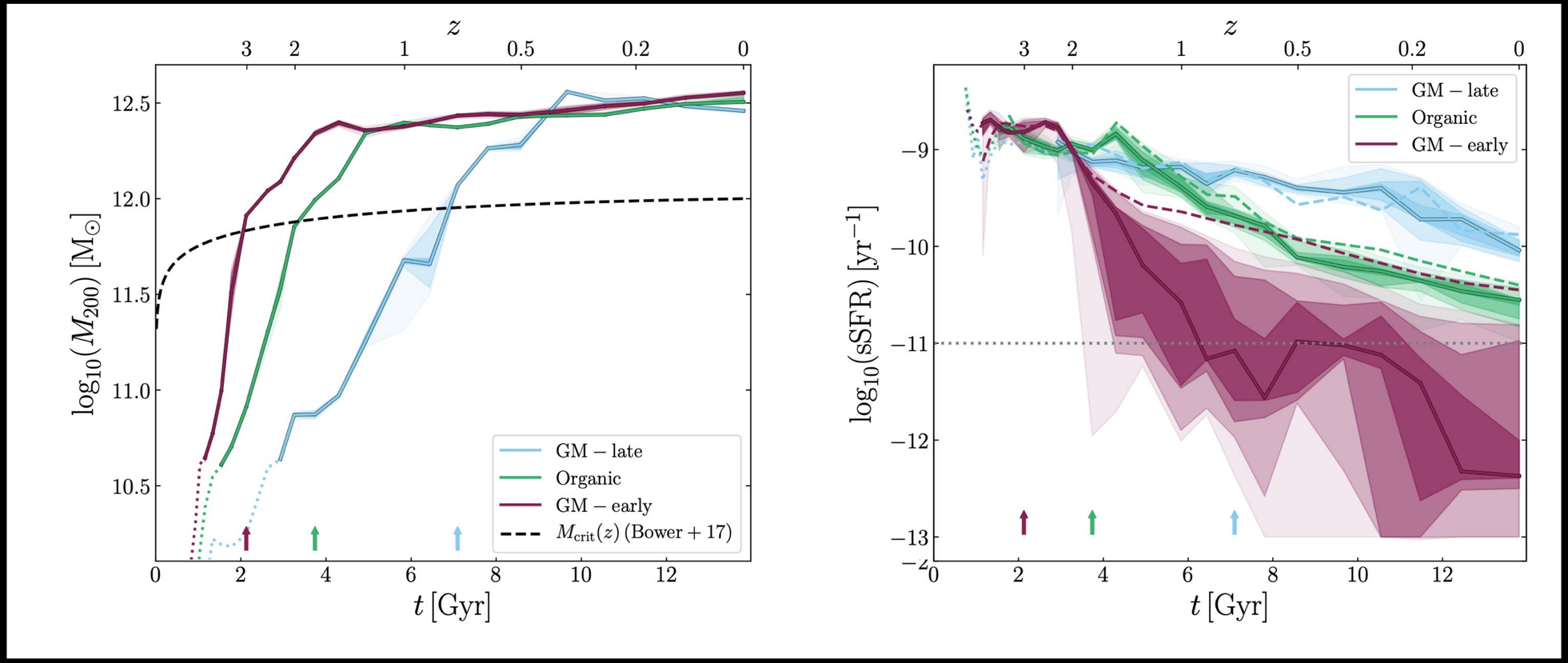


Pontzen+ 1607.02507; Tremmel+ 1607.02151



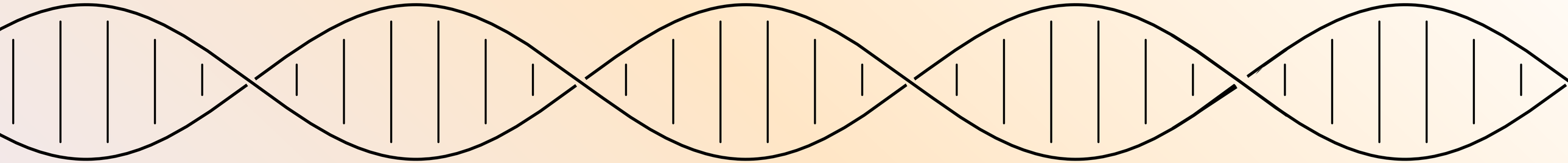
Pontzen+ 1607.02507; Tremmel+ 1607.02151


with BHs
without BHs
Suppressed
Reference
Enhanced
M ⋆= 2.7 × 10^10 M⊙
R1/2 = 2.9 kpc
M ⋆= 4.2 × 10^10 M⊙
R1/2 = 1.3 kpc
M ⋆= 2.8 × 10^10 M⊙
R1/2 = 1.2 kpc
M ⋆= 4.6 × 10^10 M⊙
R1/2 = 0.7 kpc
M ⋆= 1.7 × 10^10 M⊙
R1/2 = 2.0 kpc
M ⋆= 6.2 × 10^10 M⊙
R1/2 = 0.7 kpc
Pontzen+ 1607.02507



History + Feedback + Stochasticity
= Galaxy Formation

Davies+ 2020



- Dwarf galaxies: an exciting laboratory where we are trying to make predictions for forthcoming surveys (e.g. LSST)
- Crucial that we take advantage of this moment to make some predictions (e.g. low surface brightness dwarfs)
- “Genetic modification” — alternative versions of galaxies; controlled, cosmological numerical experiments

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gmgalaxies.org