

The LUMINA Simulation & Puzzles of high-redshift galaxies in the Roman era

Pasadena, 07/2026

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<https://xuejianshen.github.io/personal-website/>

with the LUMINA team: Oliver Zier, Aaron Smith, Rahul Kannan,
Mark Vogelsberger, Volker Springel, Rudiger Pakmor, Lars
Hernquist, Rongrong Liu, Sonja Kohler, Teodora-Elena Bulichi,
Meredith Neyer, ...

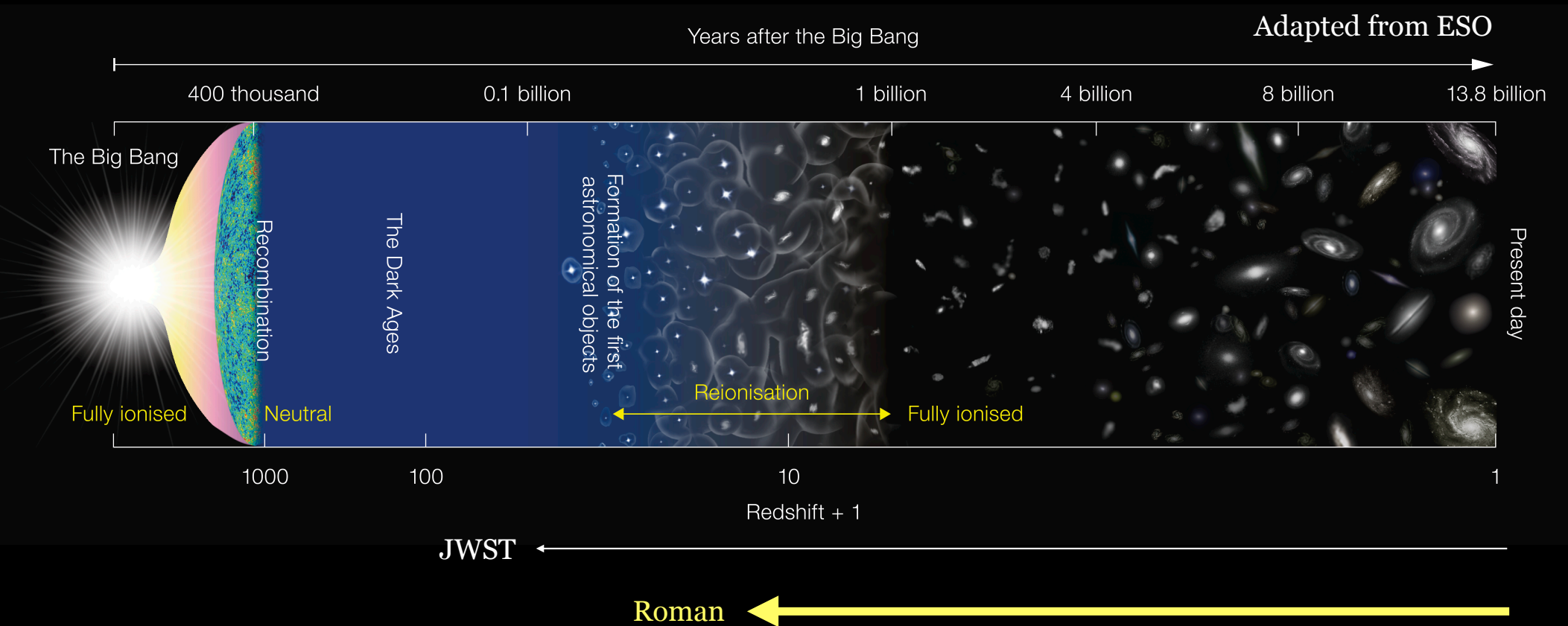
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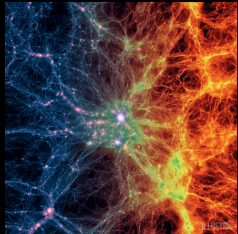
ASTROPHYSICS

HARVARD & SMITHSONIAN



**Massachusetts
Institute of
Technology**





100 cMpc

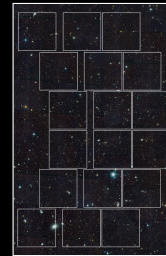
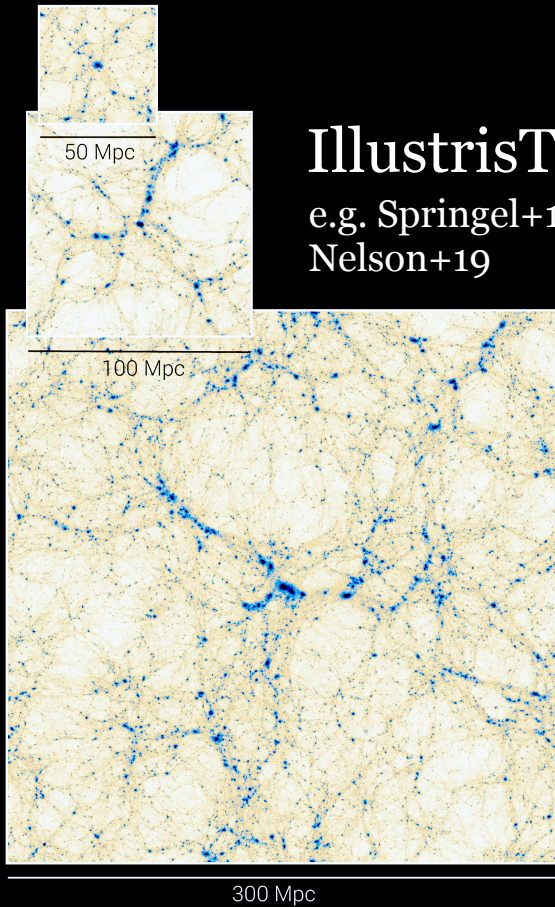
Illustris

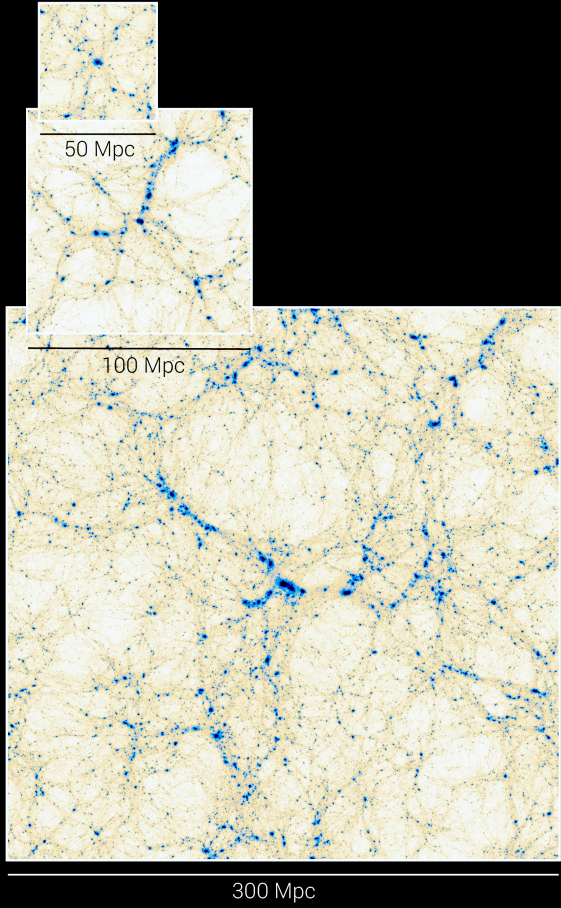
e.g. Vogelsberger+14



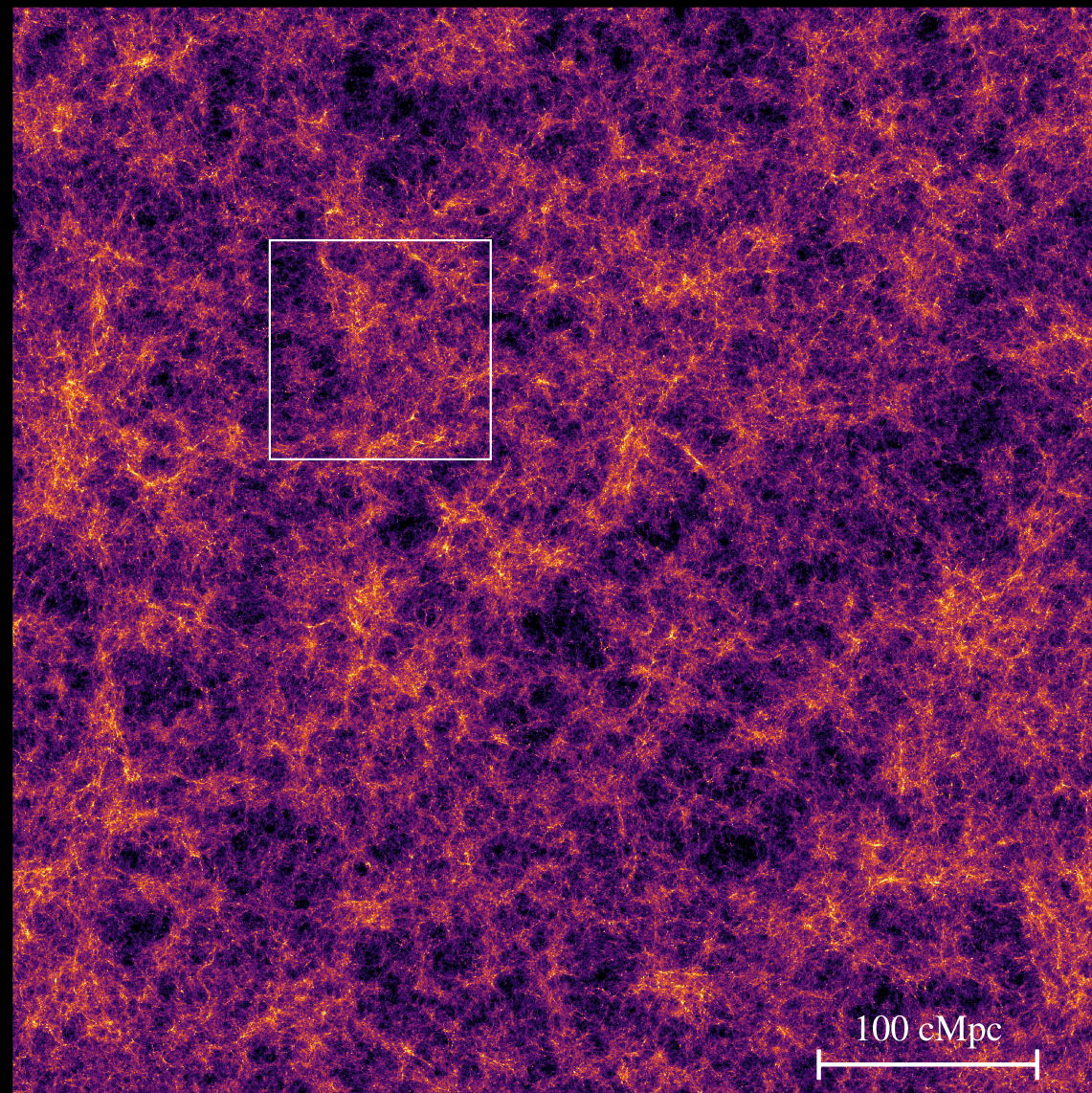
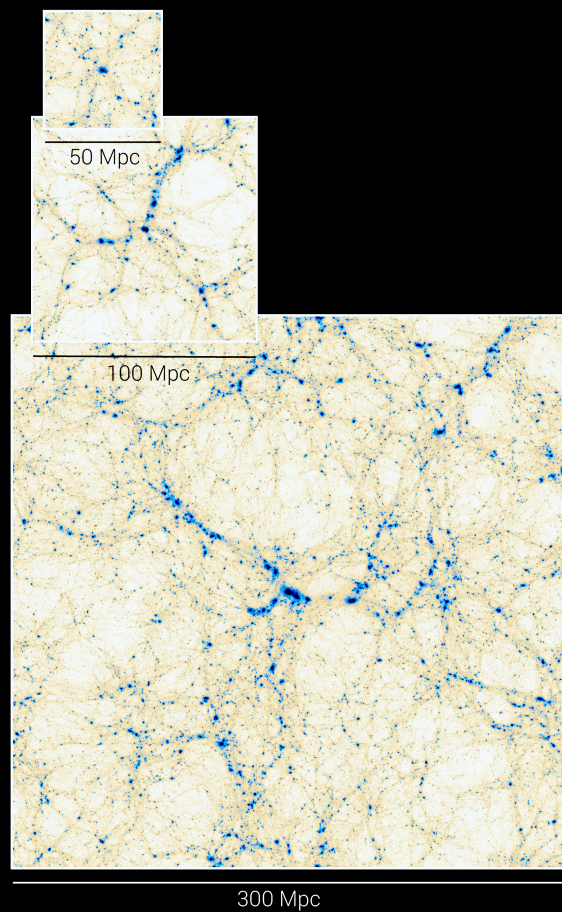
IllustrisTNG

e.g. Springel+18, Pillepich+18,19,
Nelson+19

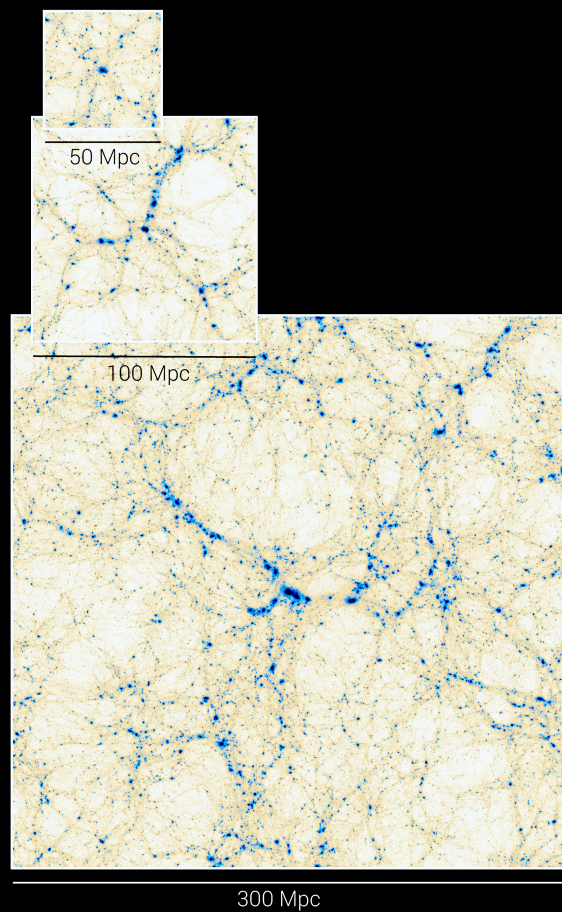




What's next?



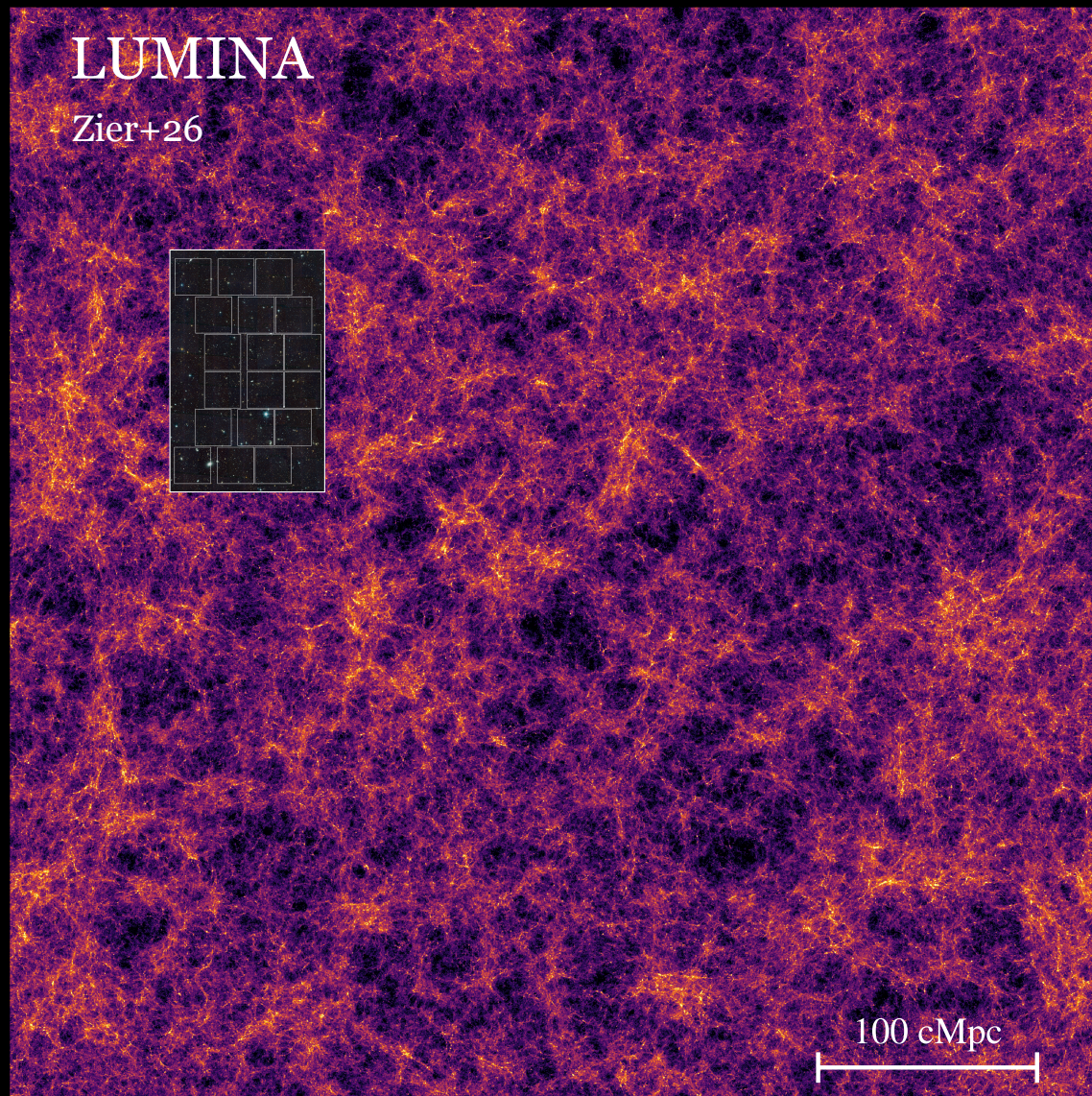
What's next?



500 cMpc

LUMINA

Zier+26



Radiation-Hydrodynamics

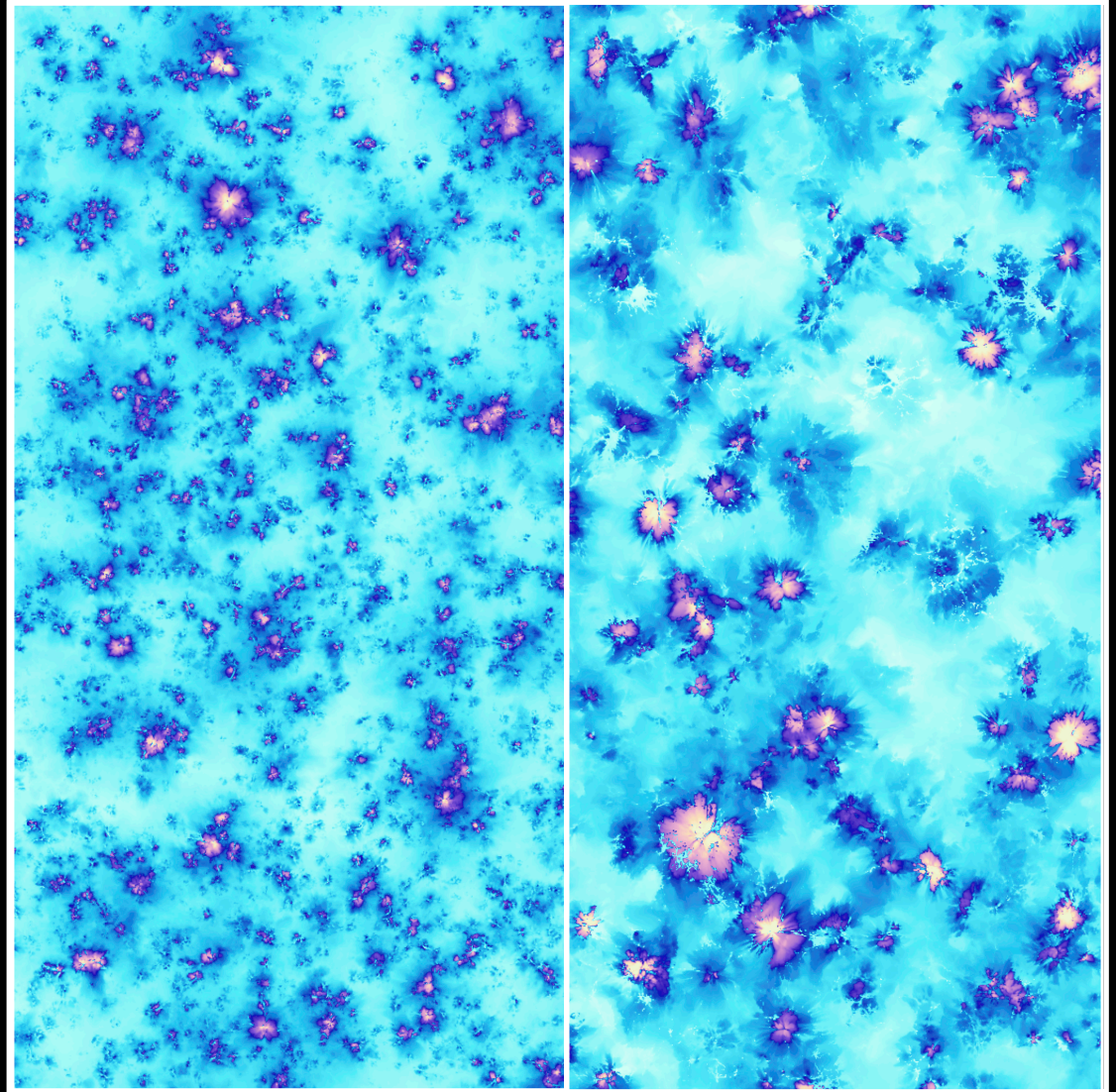
Arepo-RT (GPU)

Reionization + Galaxy Formation
(IllustrisTNG model)

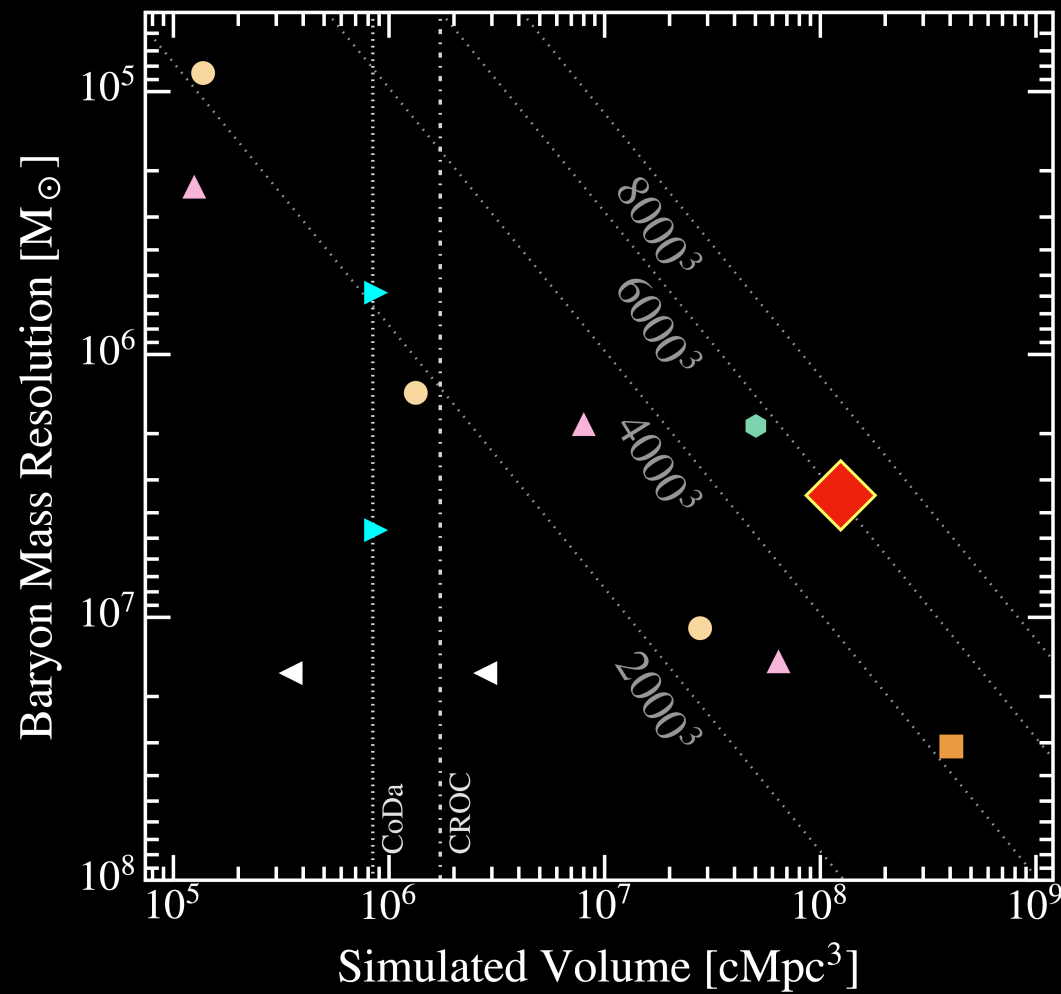
$m_b \sim 3 \times 10^6 M_\odot$, $\epsilon_{\min} \sim 40 \text{ pc}$

evolve to $z \simeq 3$

Hydrogen Reionization



Helium II Reionization



One of the Largest Hydro
Simulation by particle count



The Team



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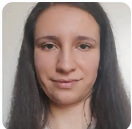
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Prof. Lars Hernquist

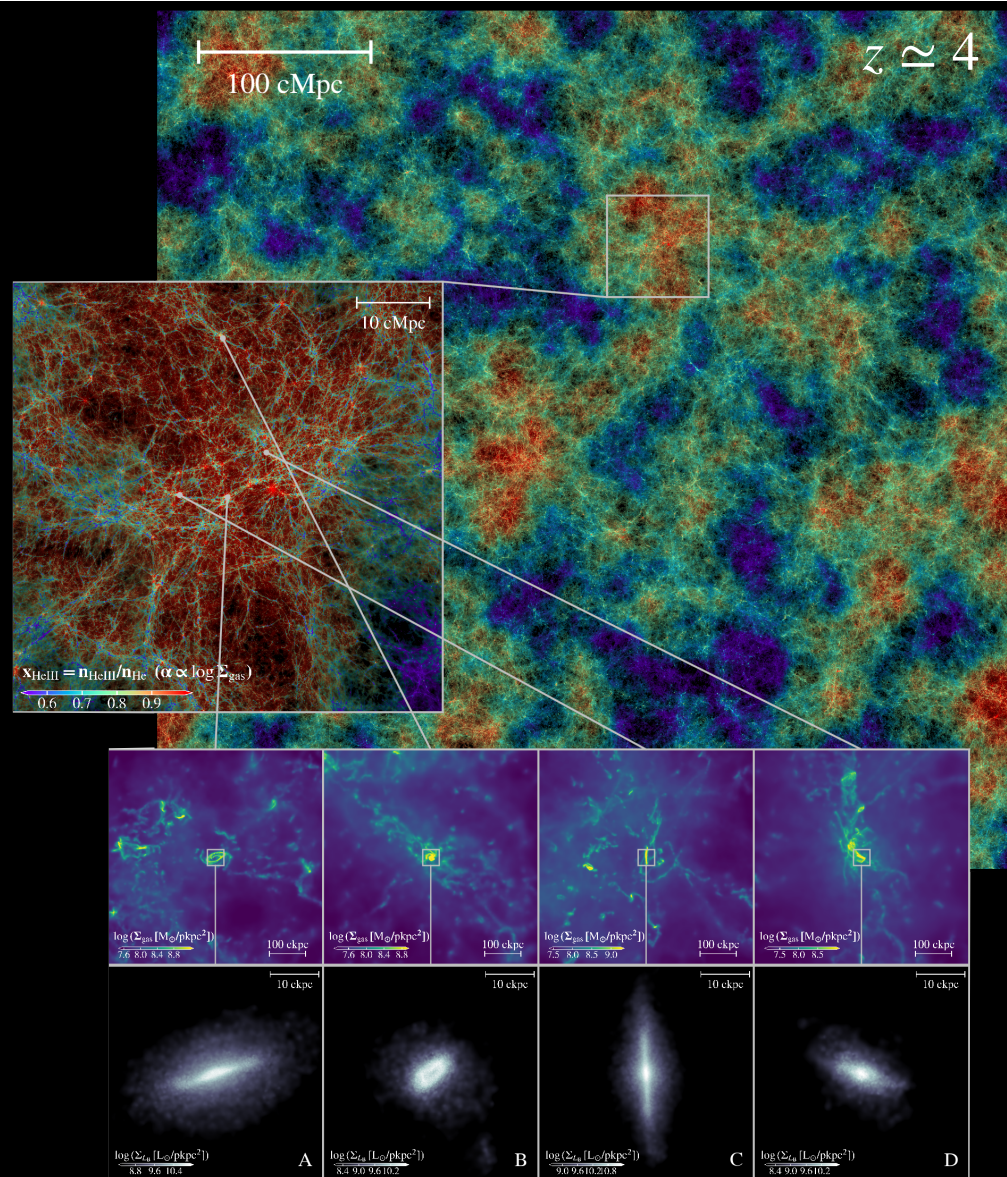
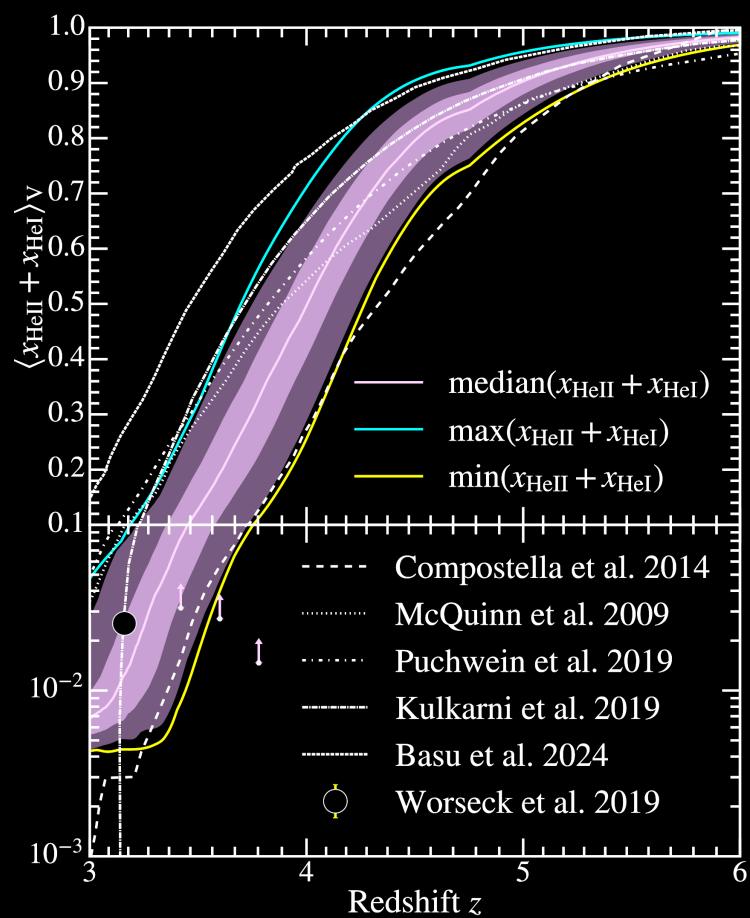
Harvard-Smithsonian CfA

✉ lhernquist@cfa.harvard.edu

Data: <https://lumina-simulation.com/>

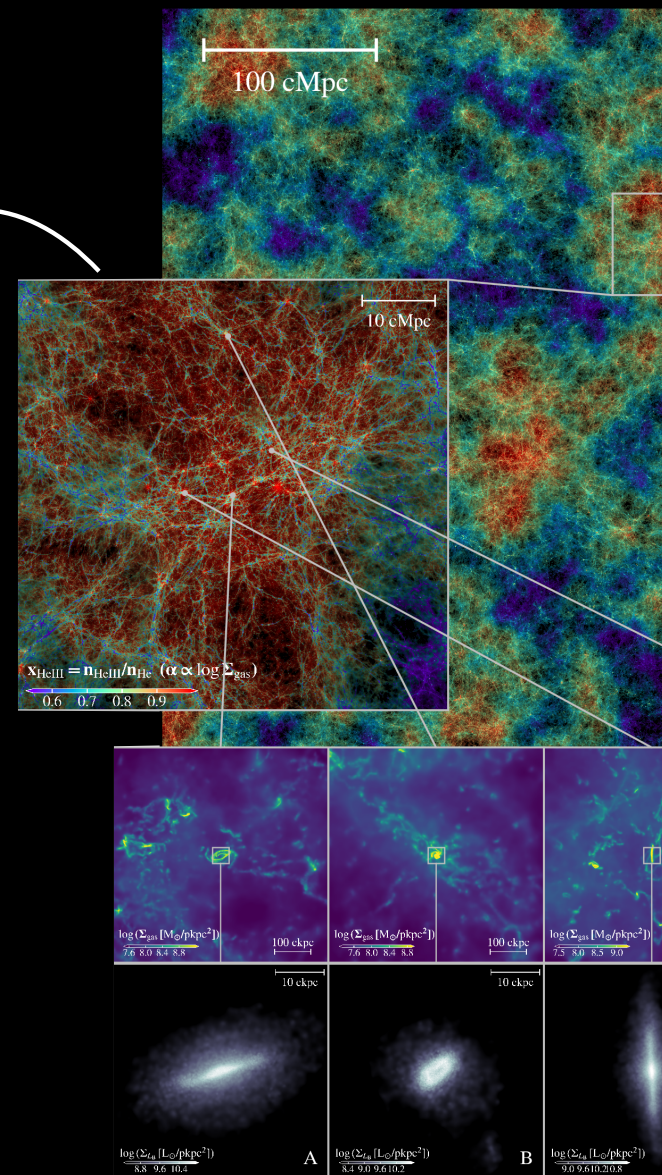
LUMINA — Early Results

Intro paper (Zier+26)



LUMINA — Early Results

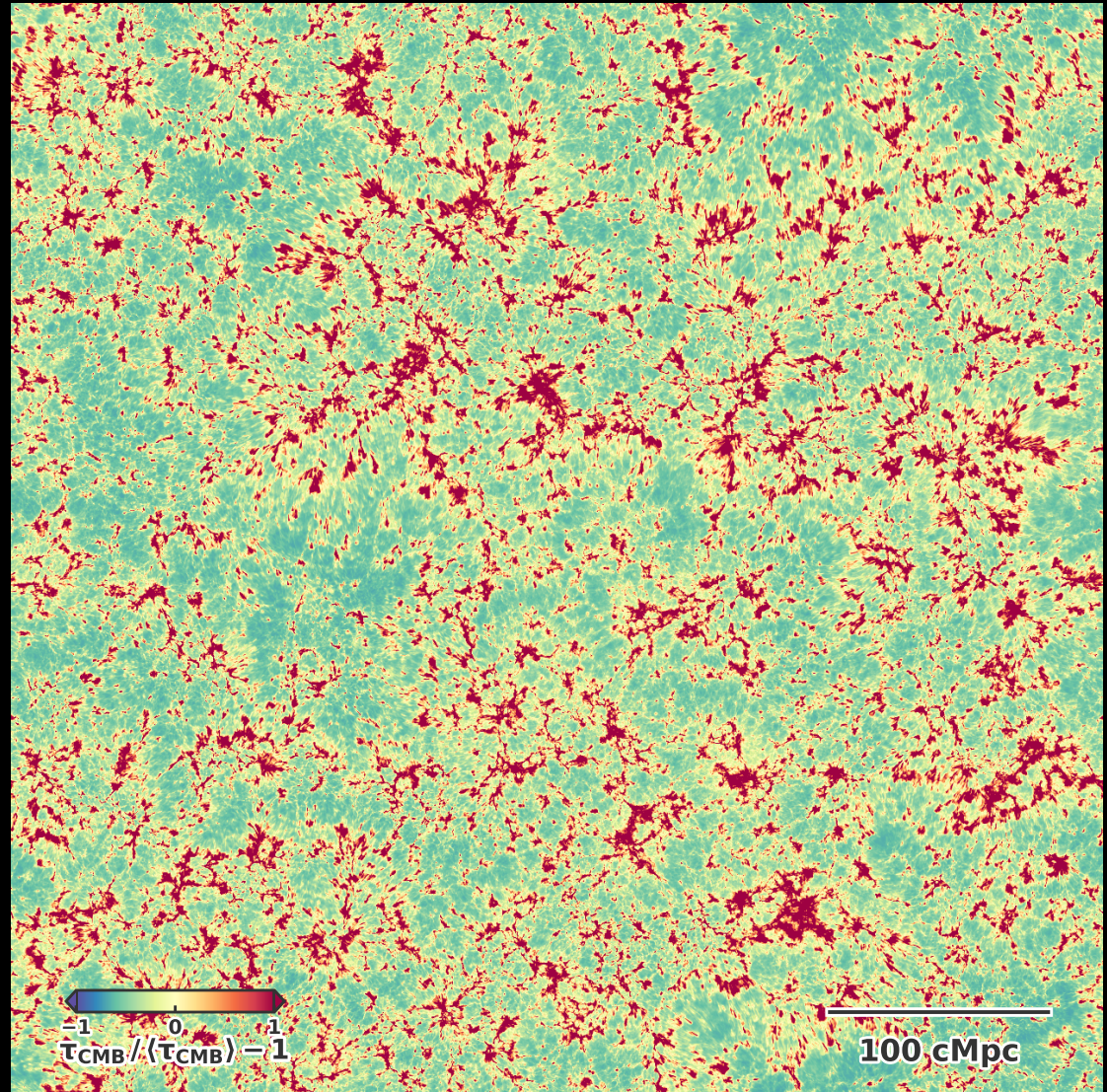
Dark matter density



LUMINA — Early Results

Intro paper (Zier+26)

CMB optical depth (Smith+26)

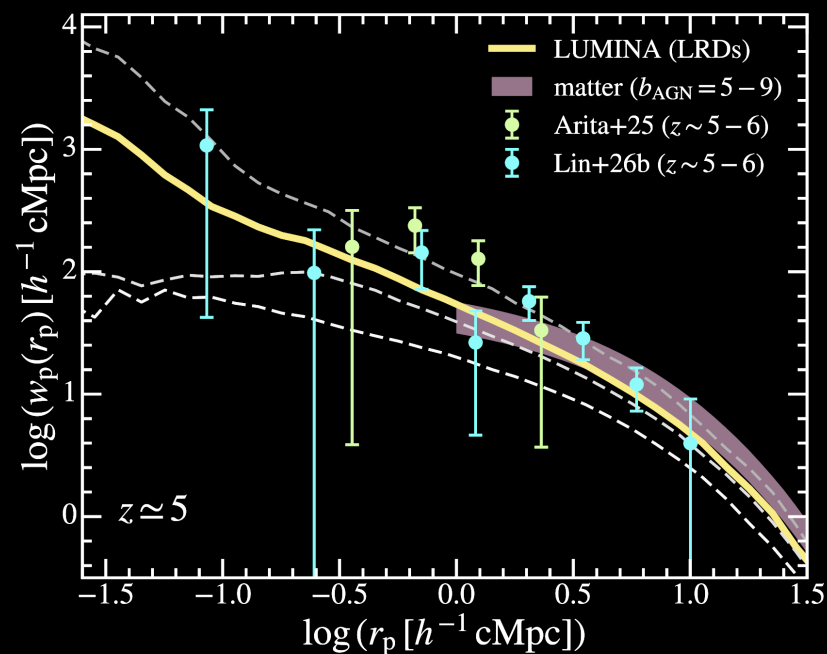
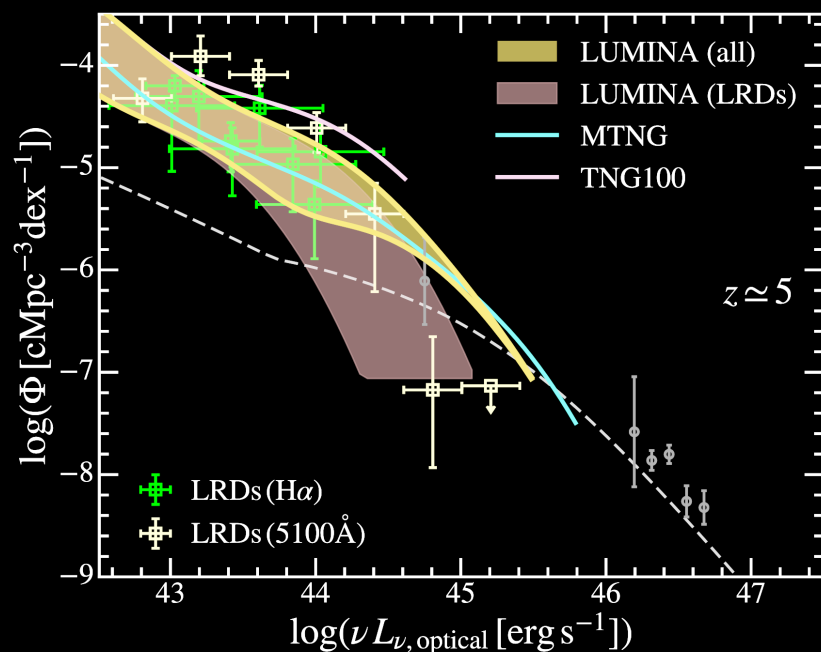


LUMINA — Early Results

Intro paper (Zier+26)

CMB optical depth (Smith+26)

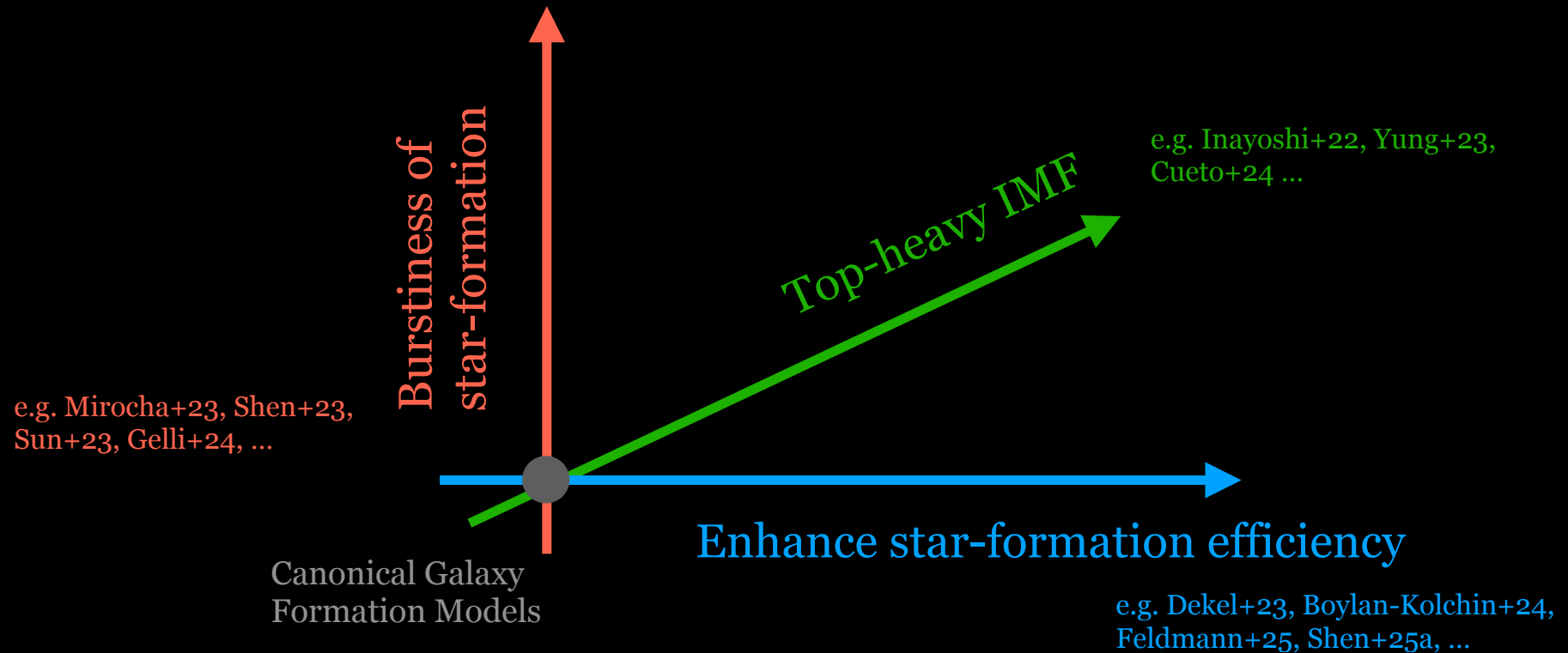
AGN demographics (Shen+26)



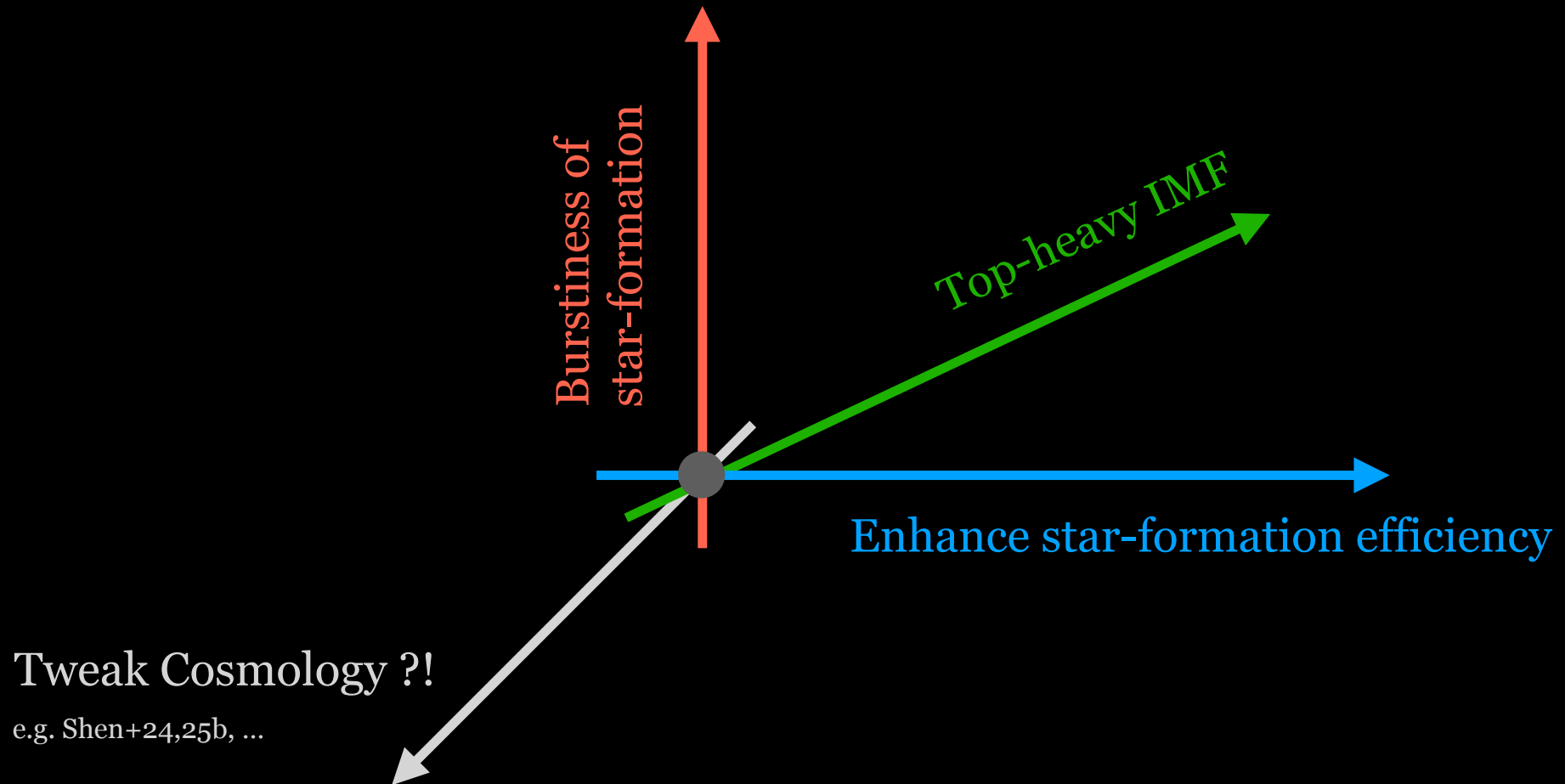
Emerging puzzles signaling a more vibrant early universe

- | | |
|-----------------|--|
| $z \gtrsim 10$ | 1. Too many bright galaxies |
| $z \sim 3 - 12$ | 2. Overly-massive galaxies |
| $z \sim 4 - 7$ | 3. Quench too early |
| $z \sim 5$ | 4. Early massive protoclusters |
| $z \sim 4 - 8$ | 5. Large number of dusty star-forming galaxies |
| $z \sim 7$ | 6. Early disk galaxies |
| $z \sim 4 - 8$ | 7. LRDs |
| $z \sim 6 - 7$ | 8. Massive quasars |
- and more

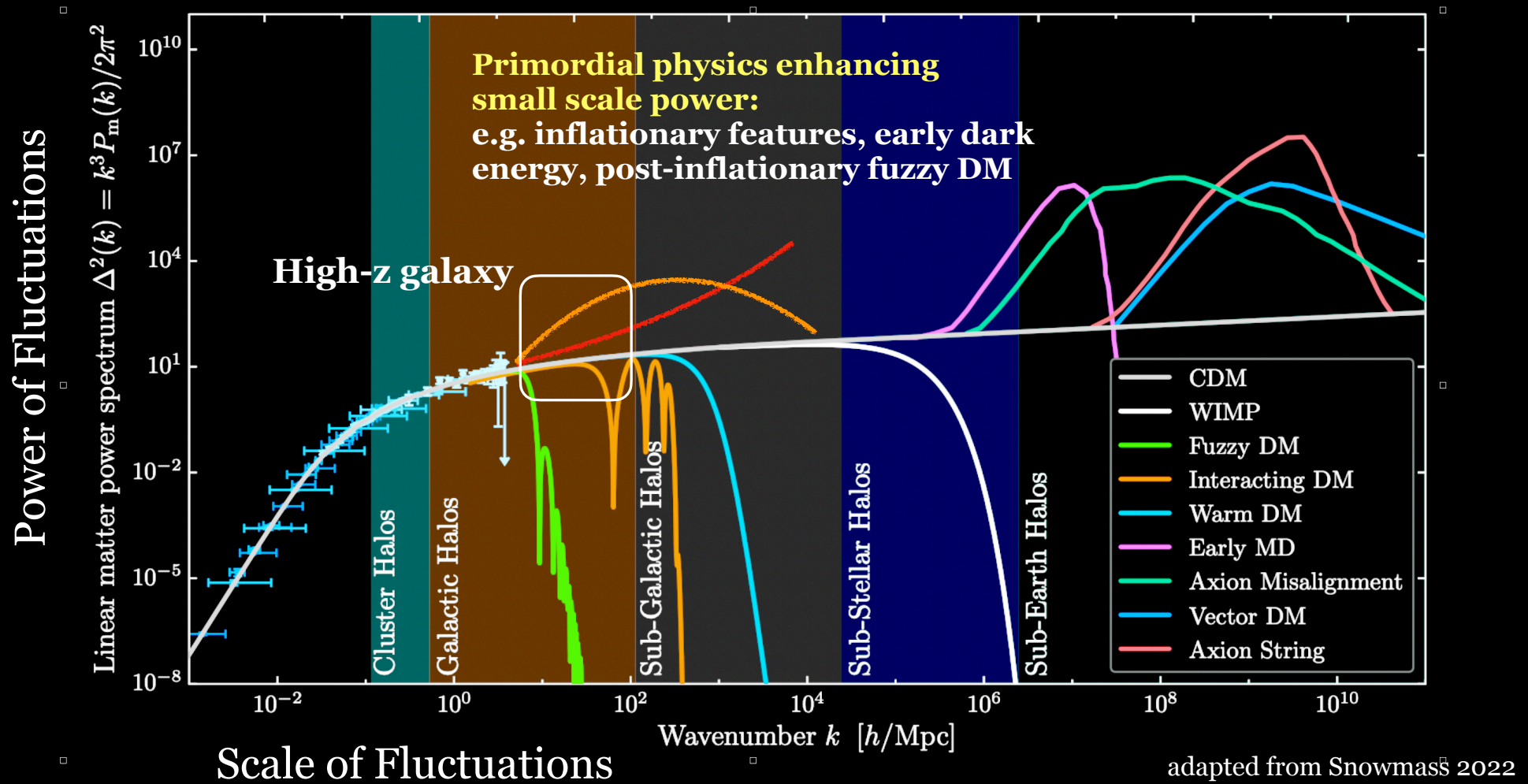
Theory Space of High-redshift Galaxy Formation



Theory Space of High-redshift Galaxy Formation



Echoes from the Primordial Universe?



adapted from Snowmass 2022

Echoes from the Primordial Universe?

One example: **Early Dark Energy** (EDE)

A: solve the Hubble tension!

e.g. Karwal+16, Poulin+18

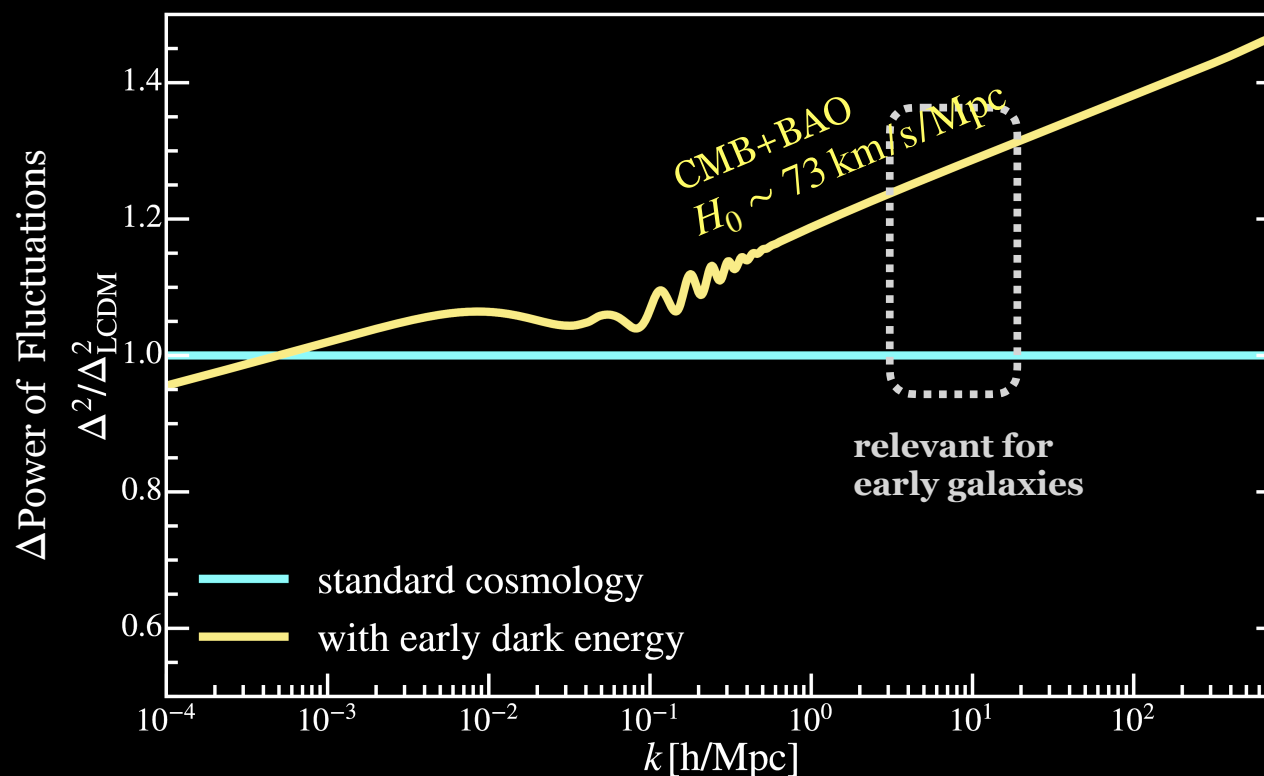
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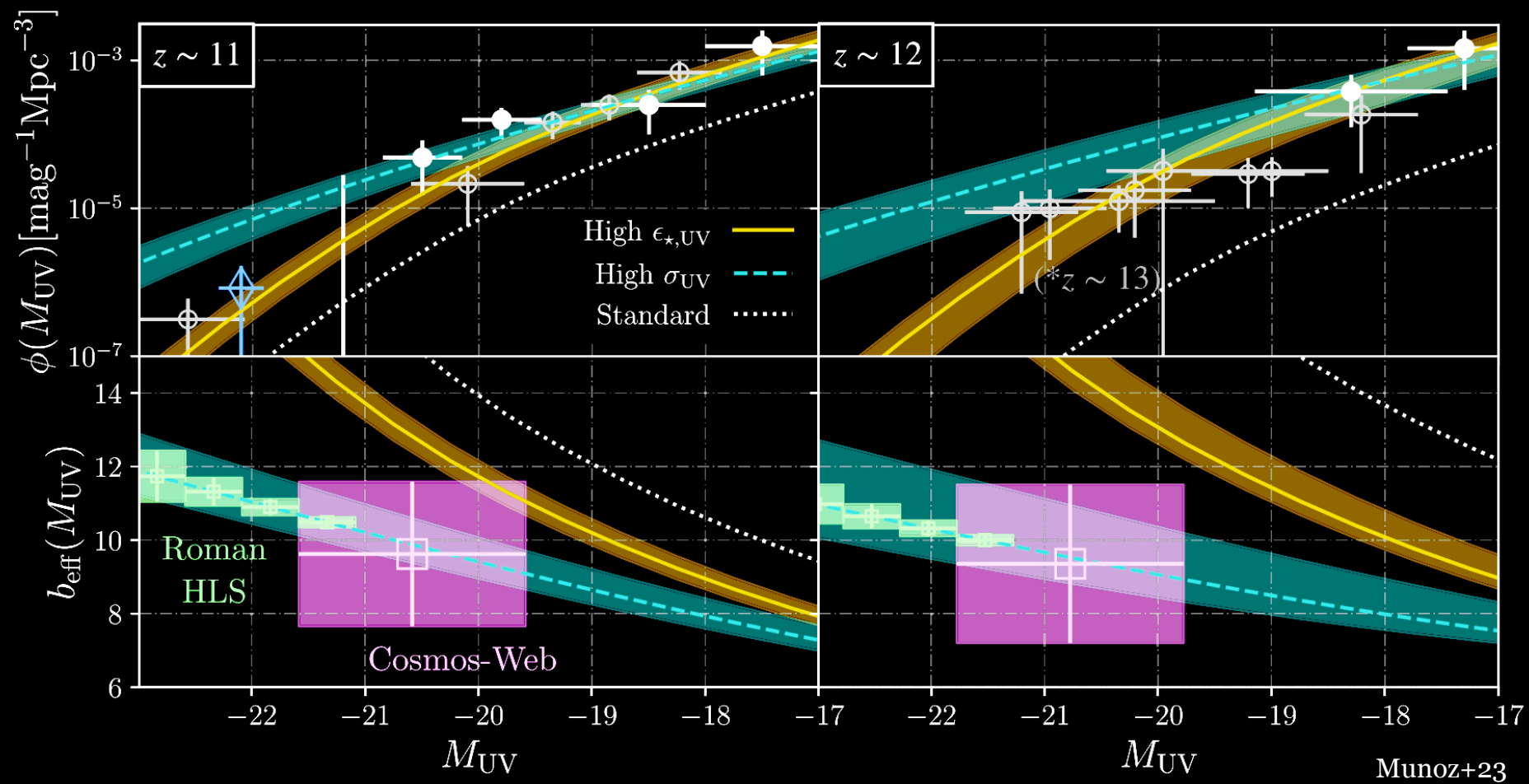
A: solve the Hubble tension!

B: accelerate early structure formation

(Shen+24,25b)



Break the Degeneracy with Clustering



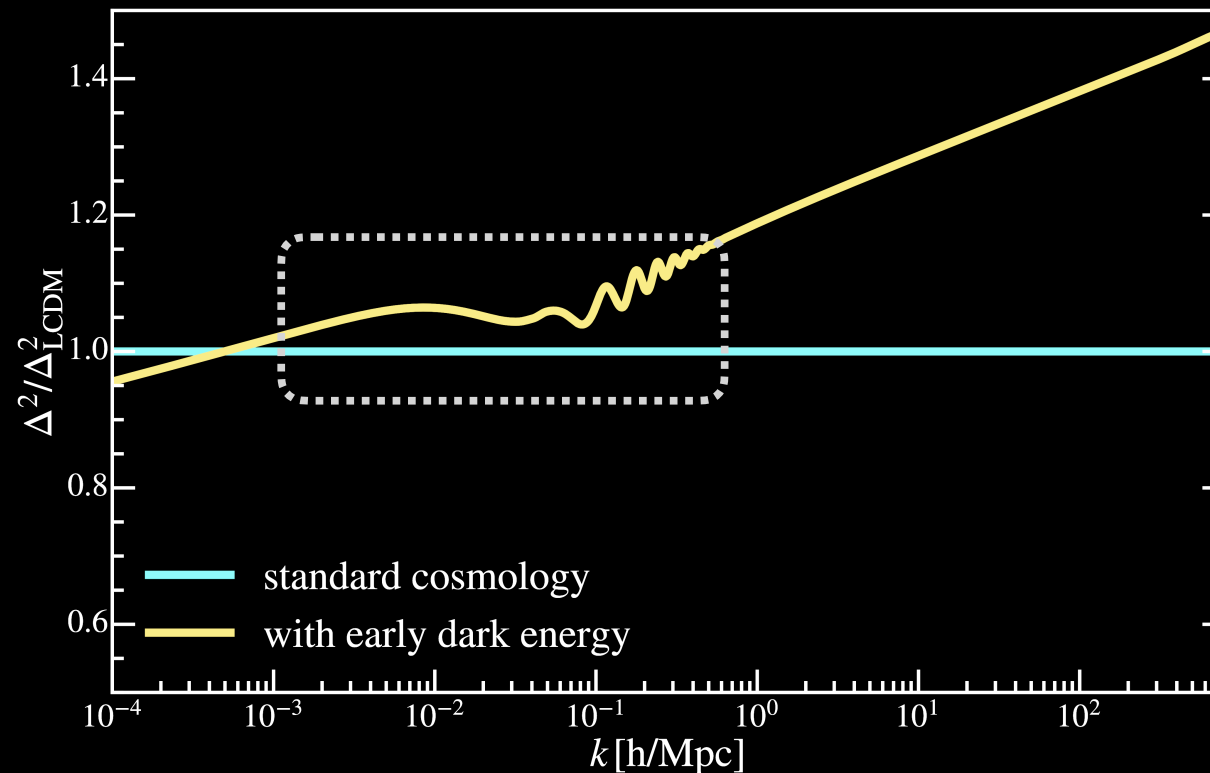
Echoes from the Primordial Universe?

One example: **Early Dark Energy** (EDE)

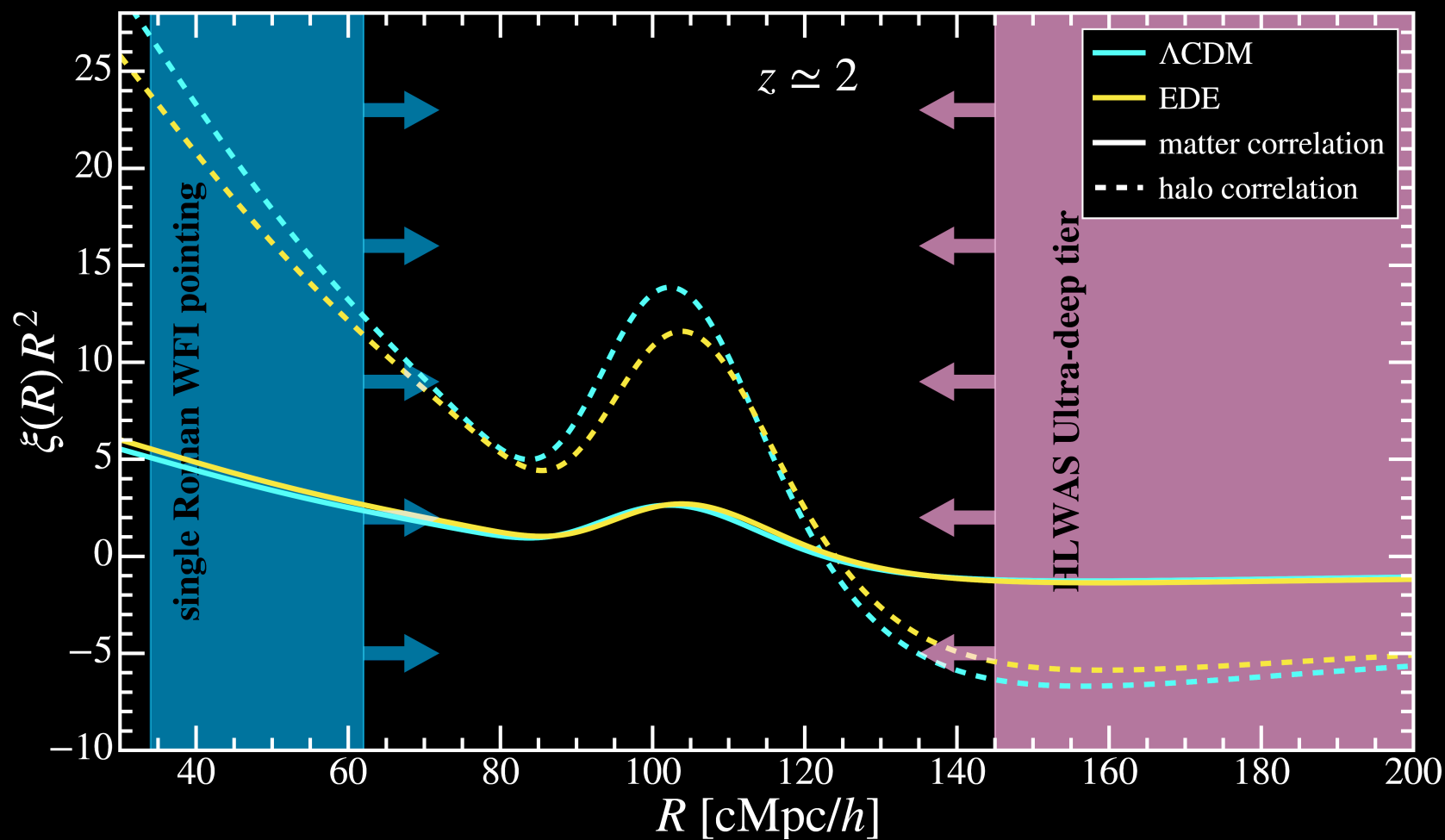
A: solve the Hubble tension!

B: accelerate early structure formation

(Shen+24,25b)



Signatures extends to lower redshifts



LUMINA

$z \simeq 10$

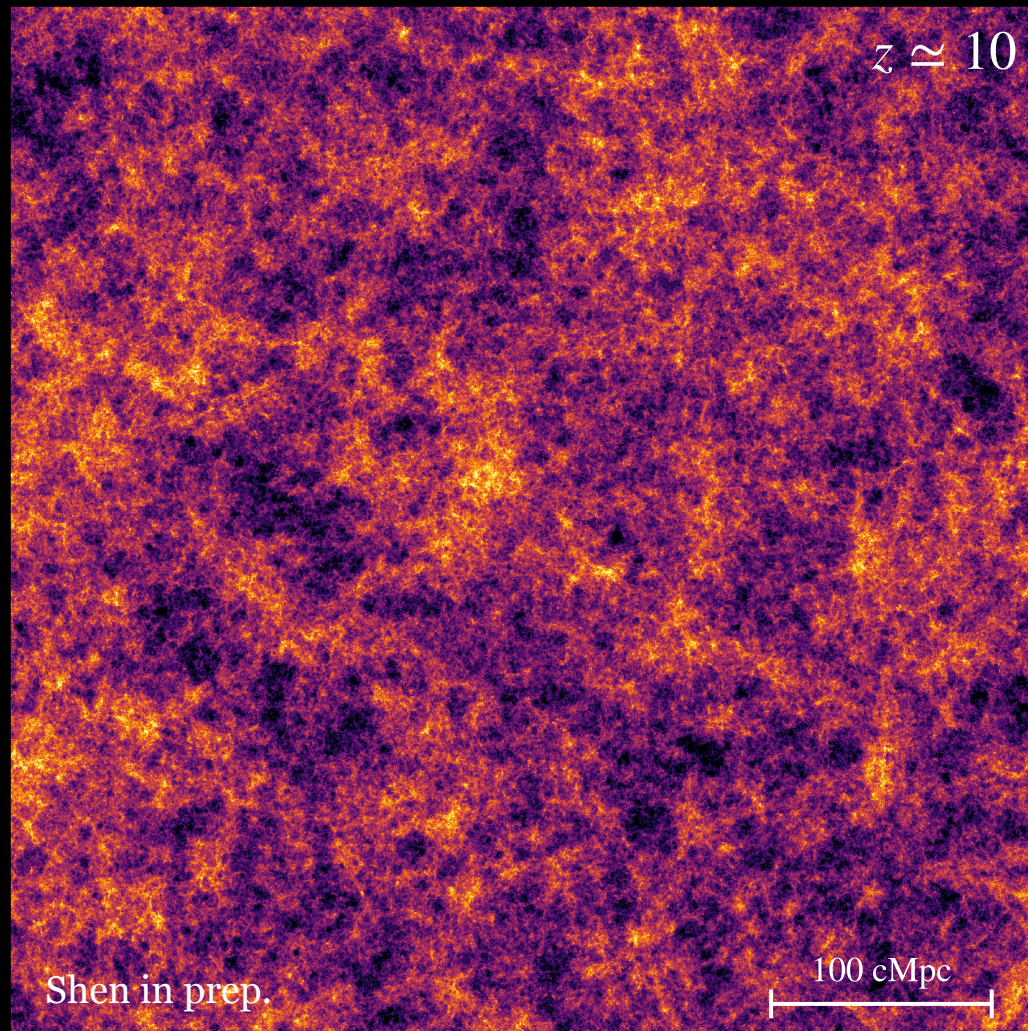
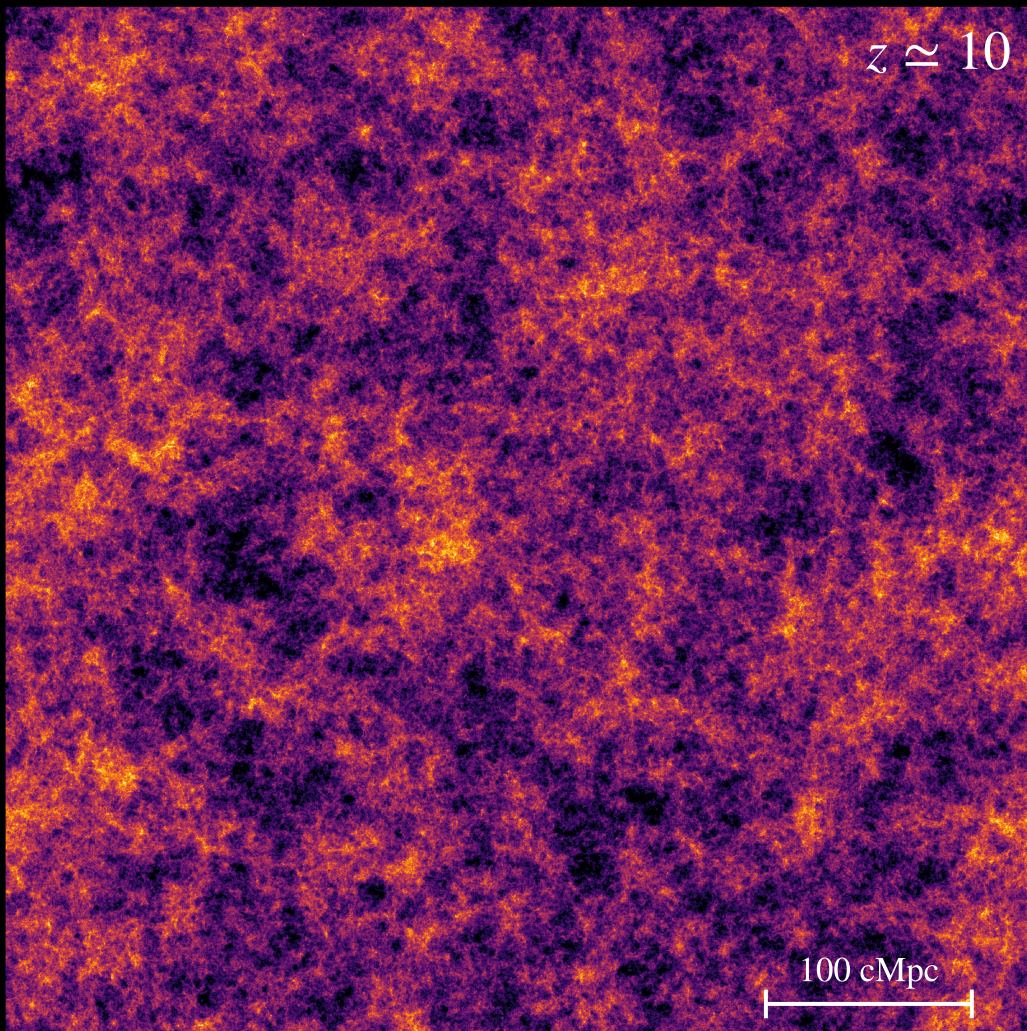
100 cMpc

LUMINA-EDE

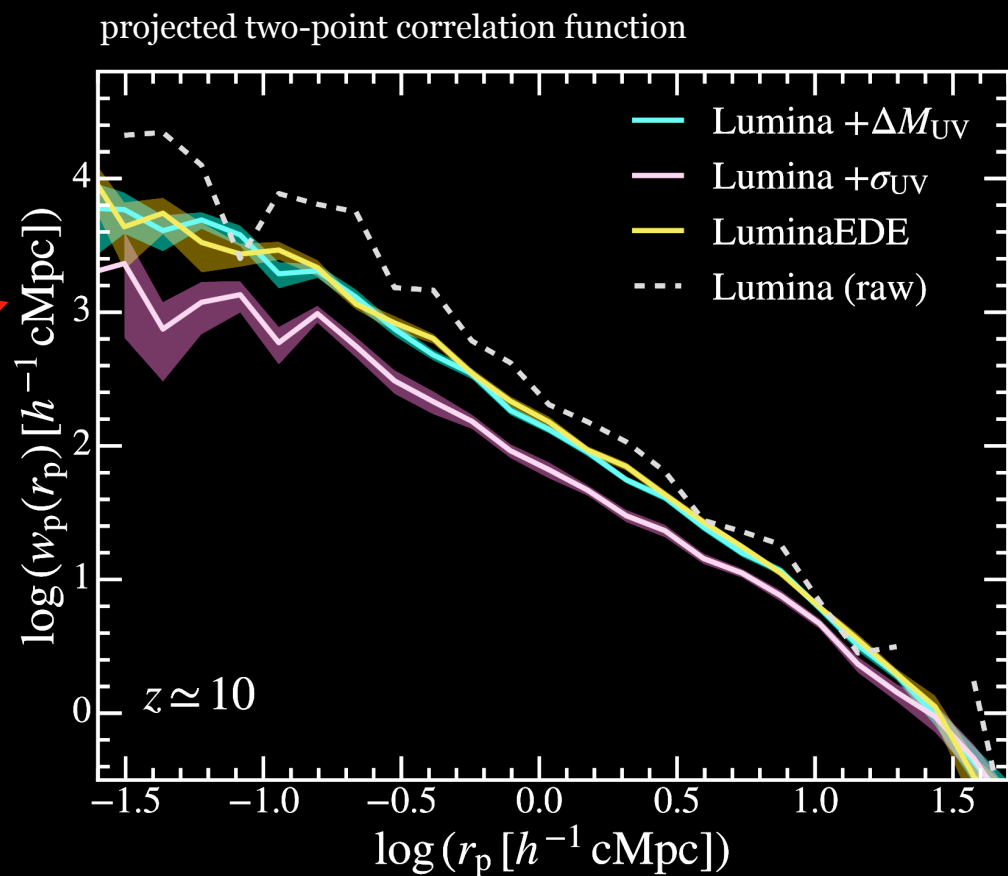
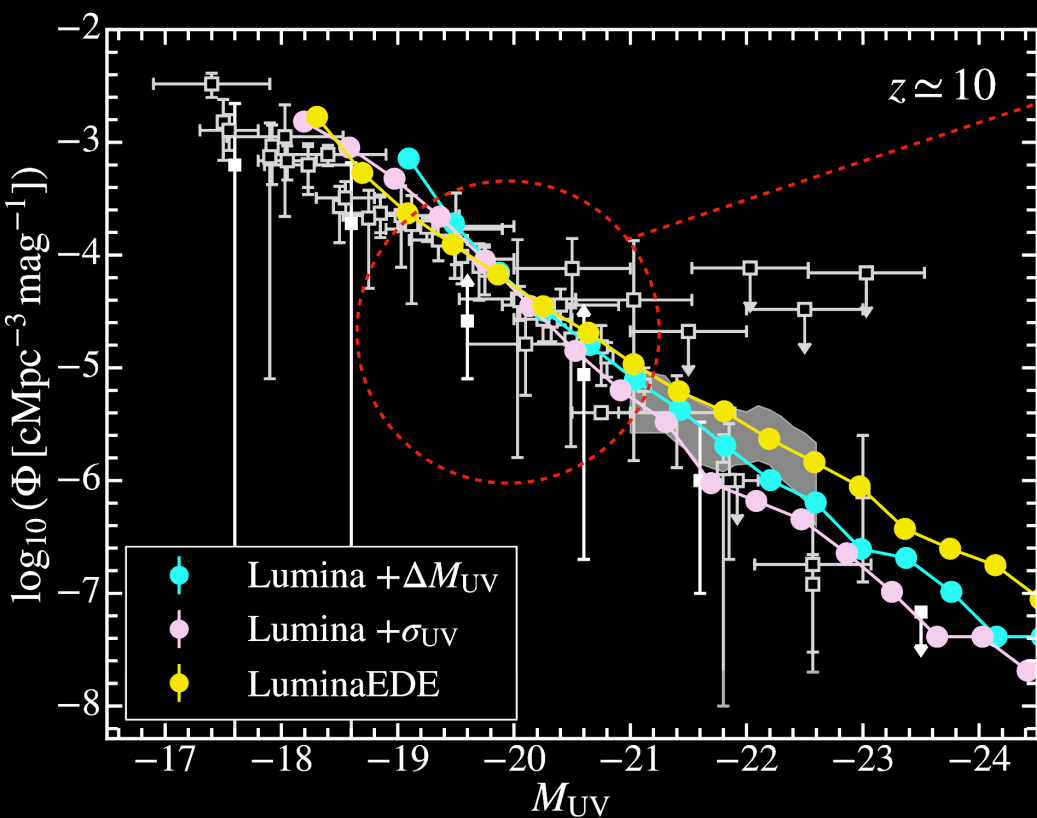
$z \simeq 10$

Shen in prep.

100 cMpc



Clustering



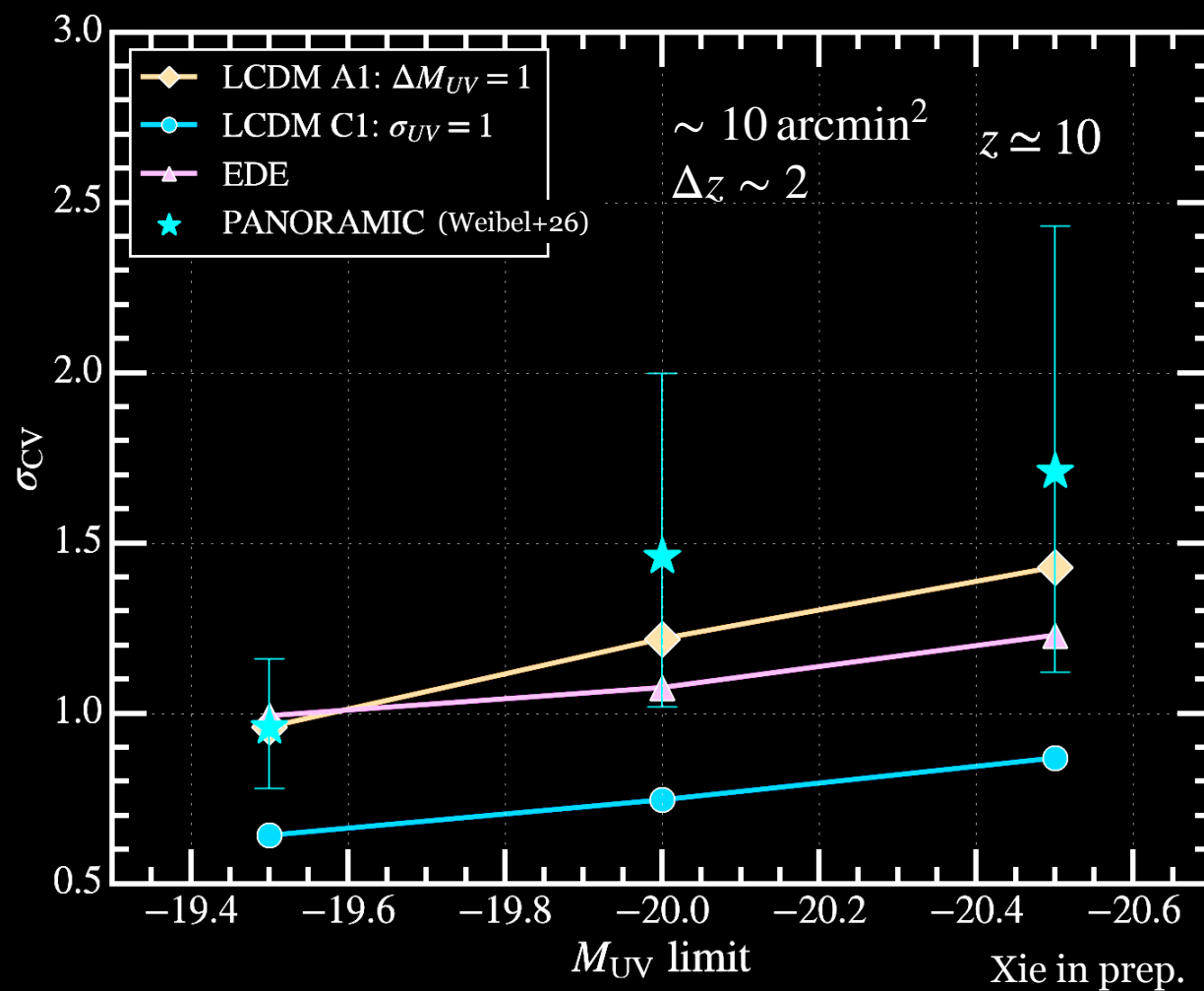
Shen in prep.

Cosmic Variance

$$\sigma_{\text{CV}}^2 \equiv \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle^2} - \frac{\langle N \rangle}{\langle N \rangle^2}$$

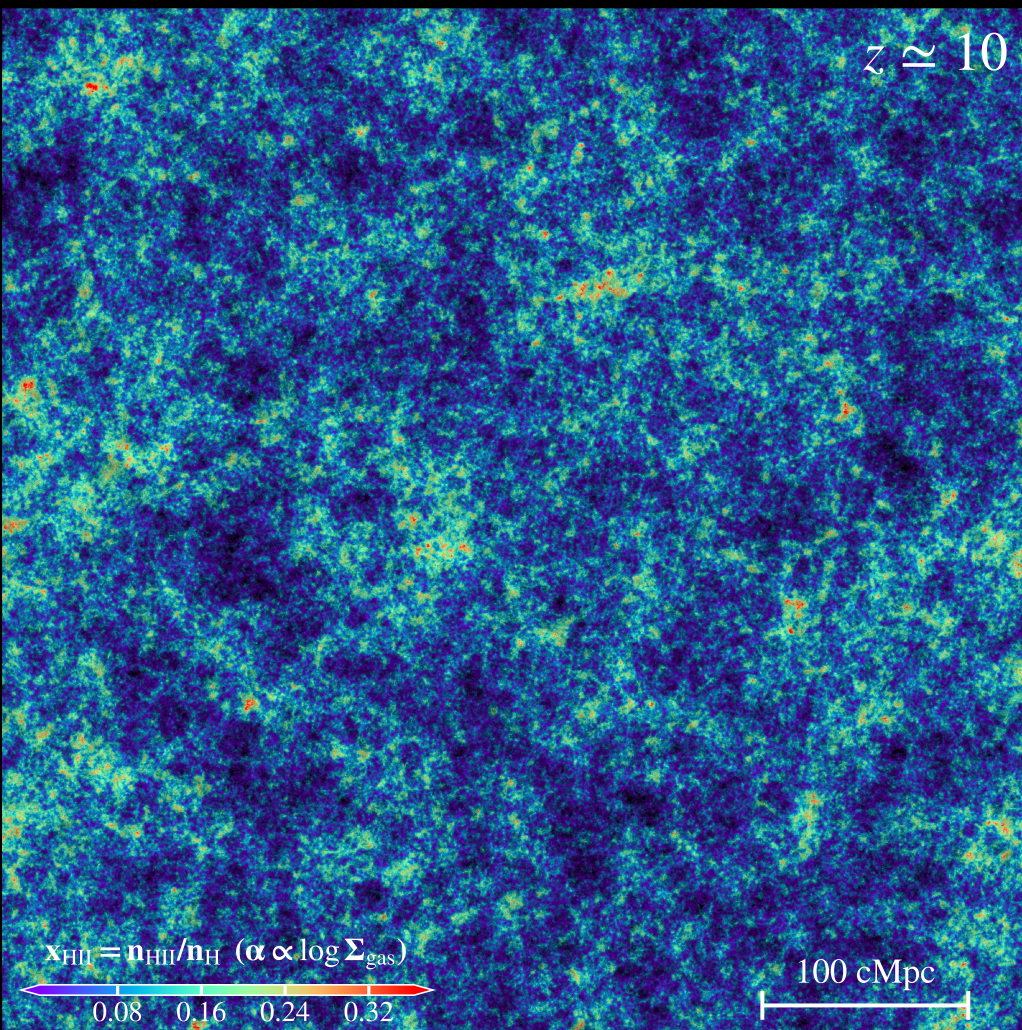


Jiahui Xie (Caltech/Harvard)



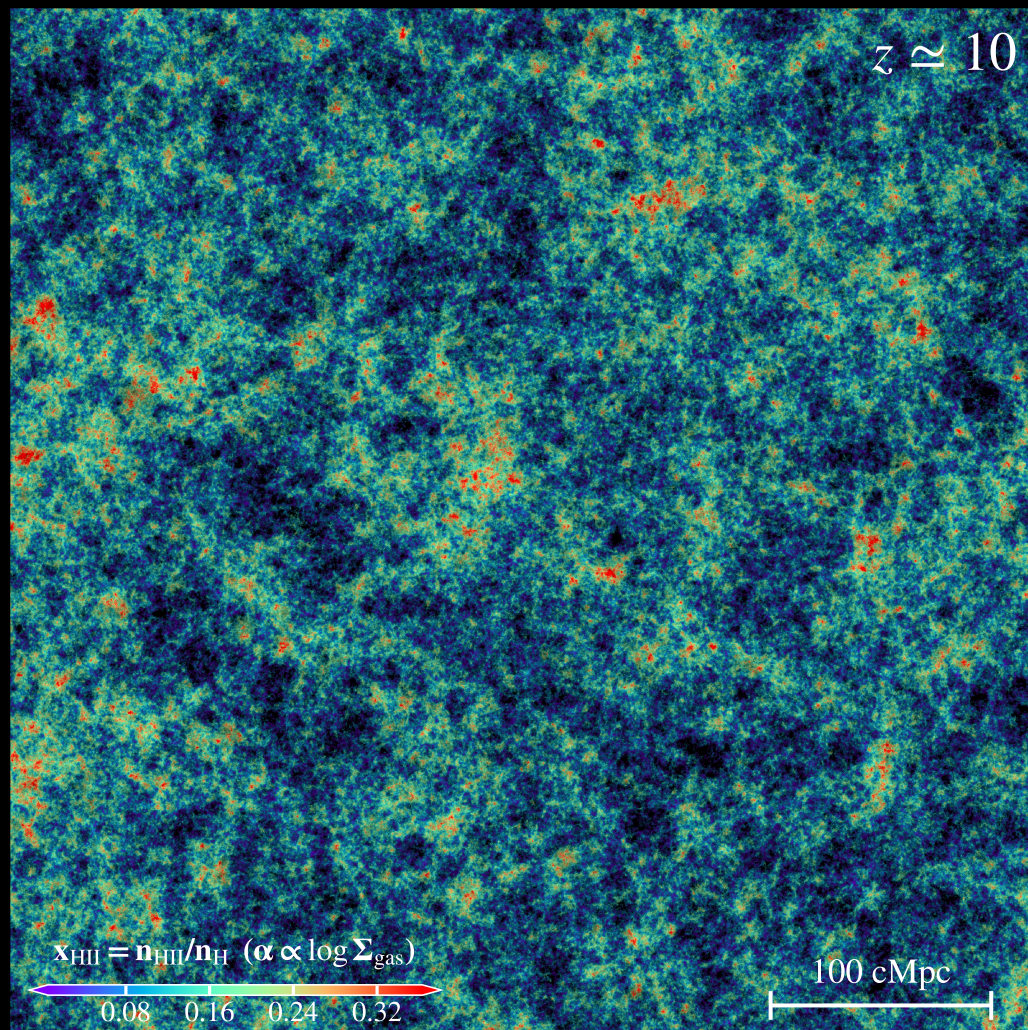
LUMINA

$z \simeq 10$



LUMINA-EDE

$z \simeq 10$



LUMINA

a record-breaking cosmological radiation-hydro simulation

- H and He reionization + Galaxy Formation
- Clustering and cosmic variances of bright high-redshift galaxies. Break the degeneracy between solutions.
- Explore extensions to Λ CDM (e.g. Early Dark Energy; joint constraints from luminosity functions, clustering, cosmic variance, and reionization)