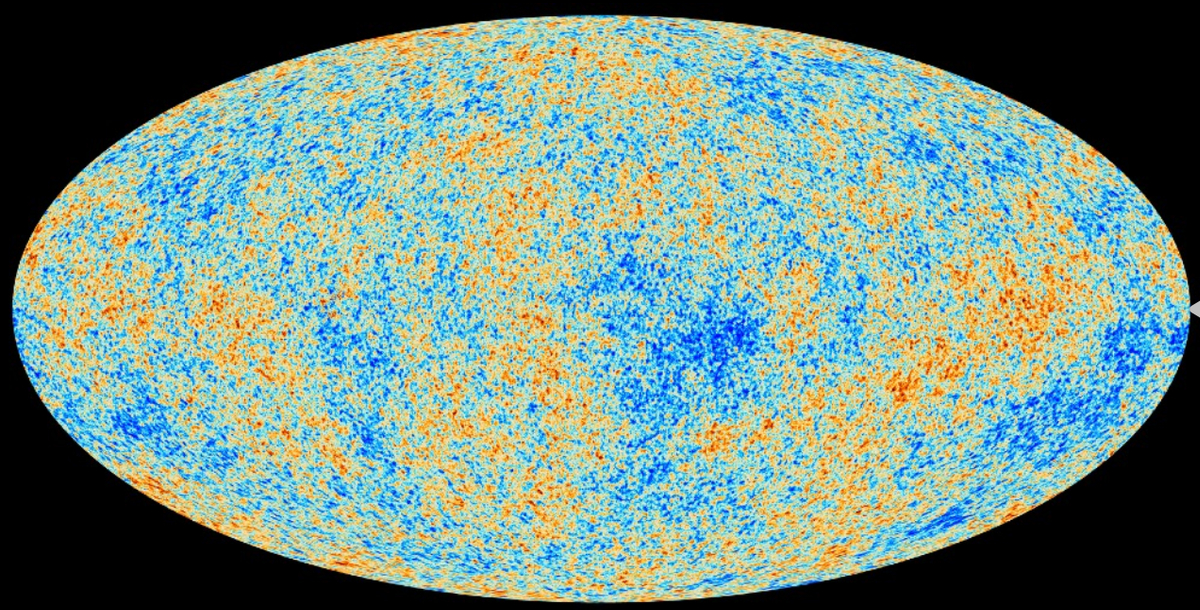
Cosmological Tensions in the JWST Era

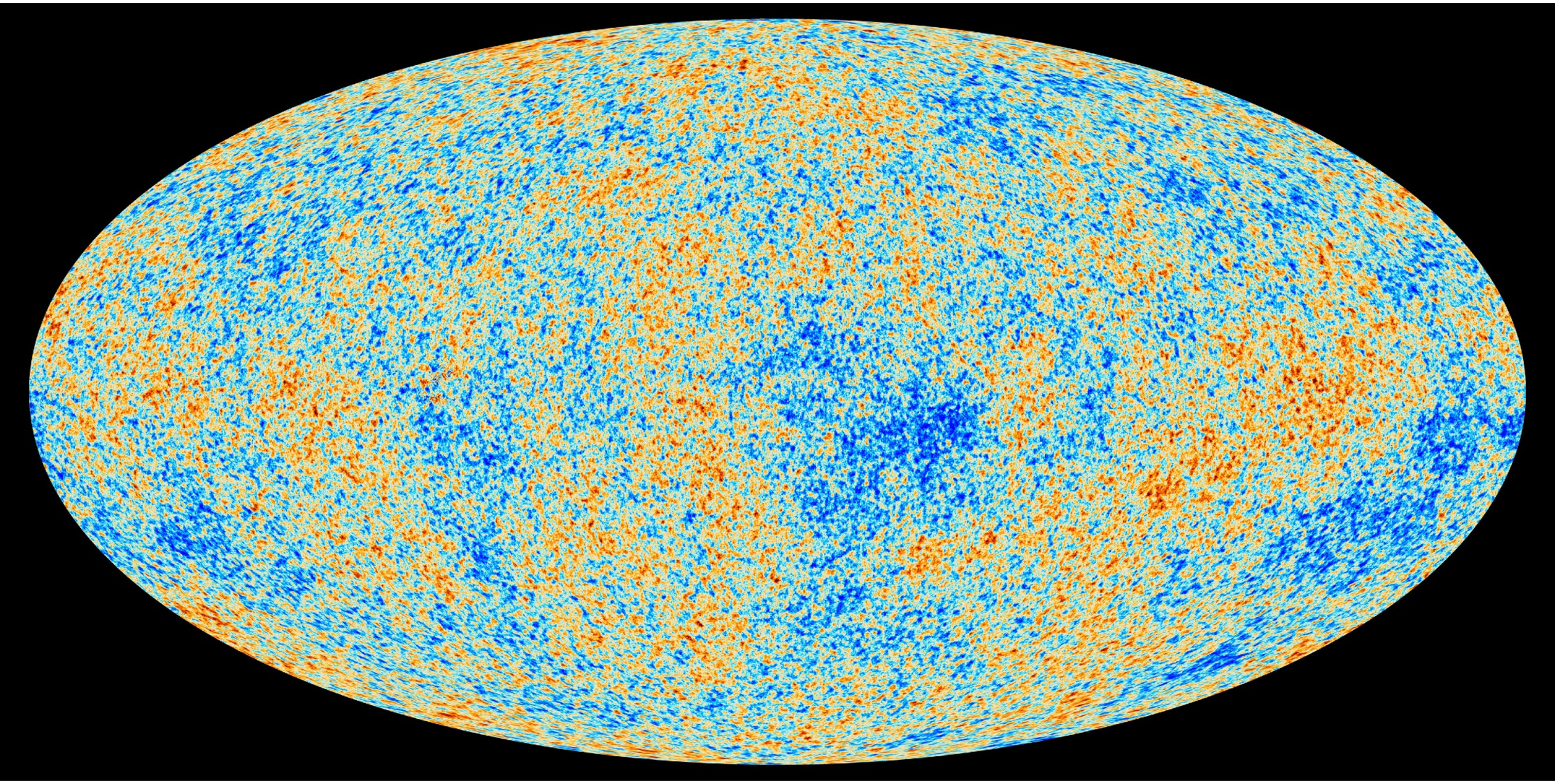


Mike Boylan-Kolchin

@mbkplus

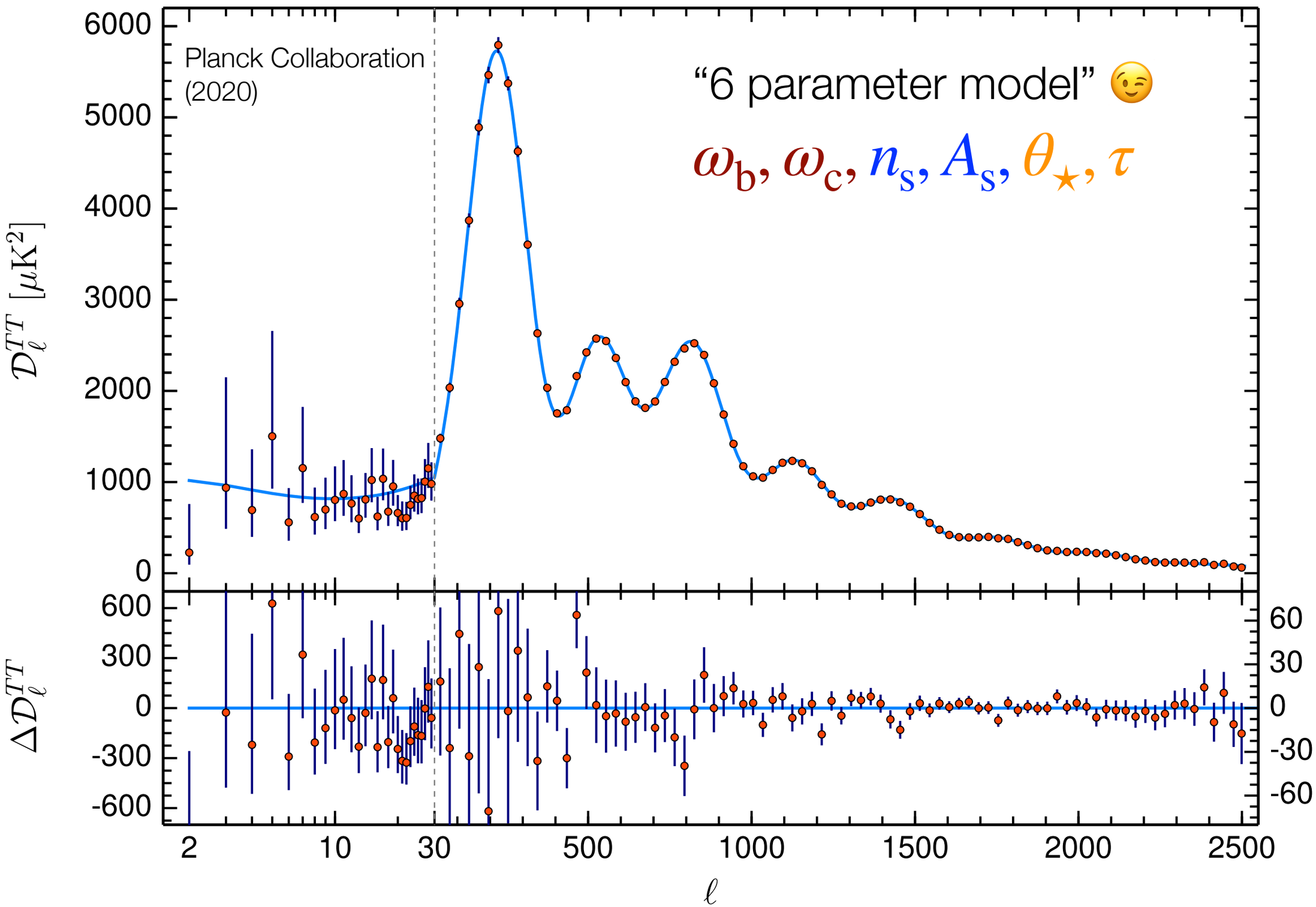
The University of Texas at Austin

The ΛCDM Cosmology



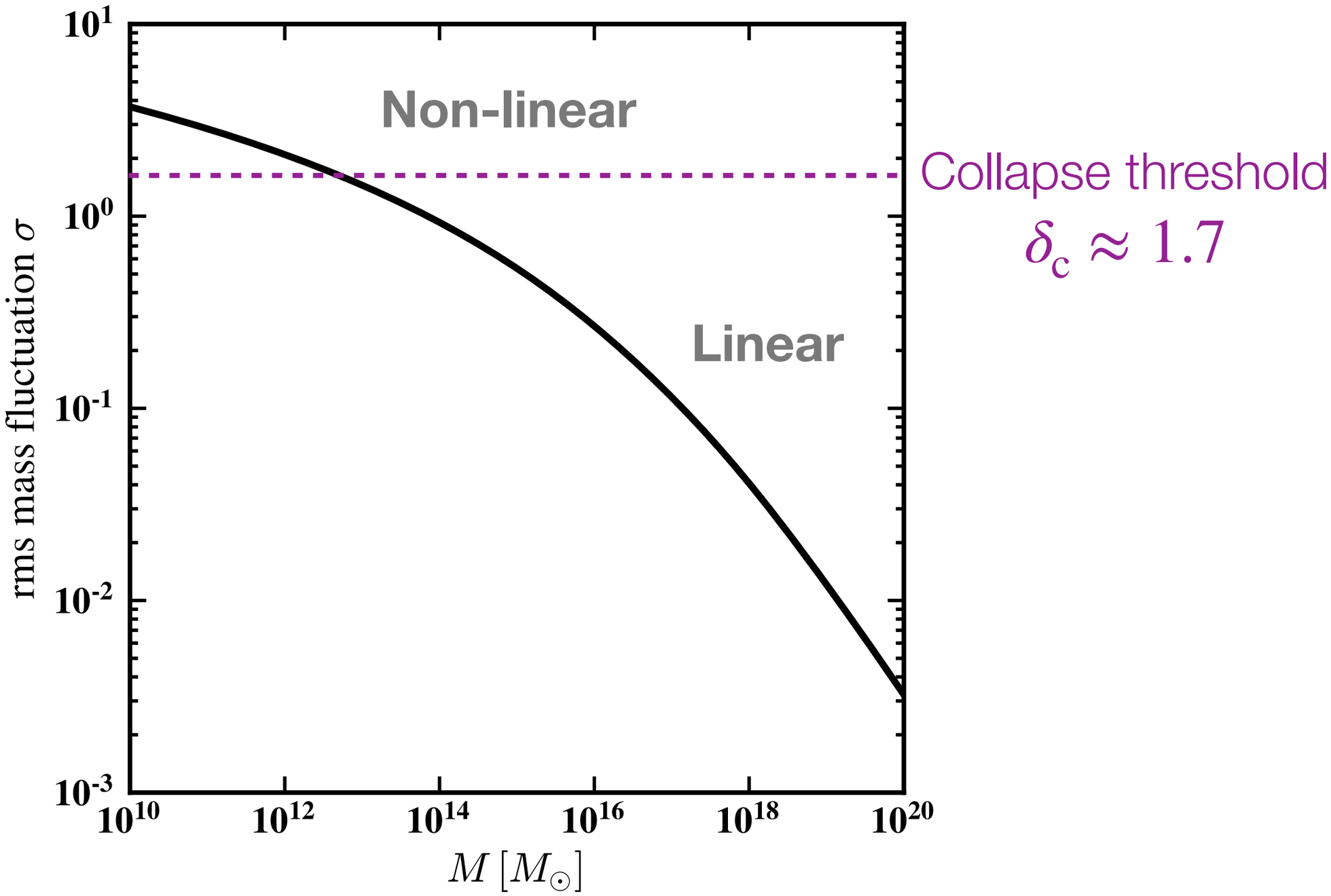
Planck Collaboration (2018)

The ΛCDM Cosmology



The ΛCDM Cosmology

Base ΛCDM model fully described by $\omega_b, \omega_c, n_s, A_s, \theta_\star, \tau$



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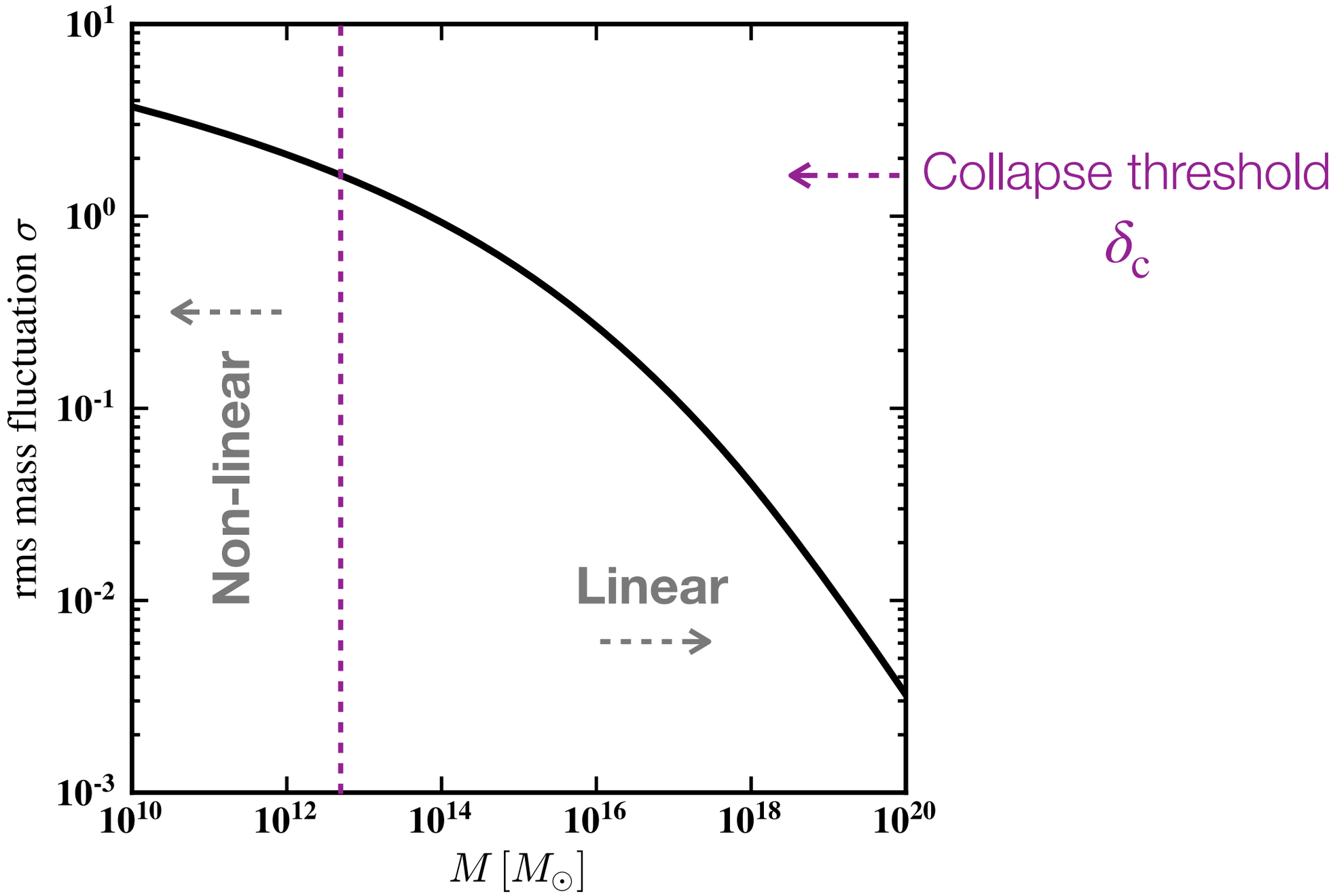

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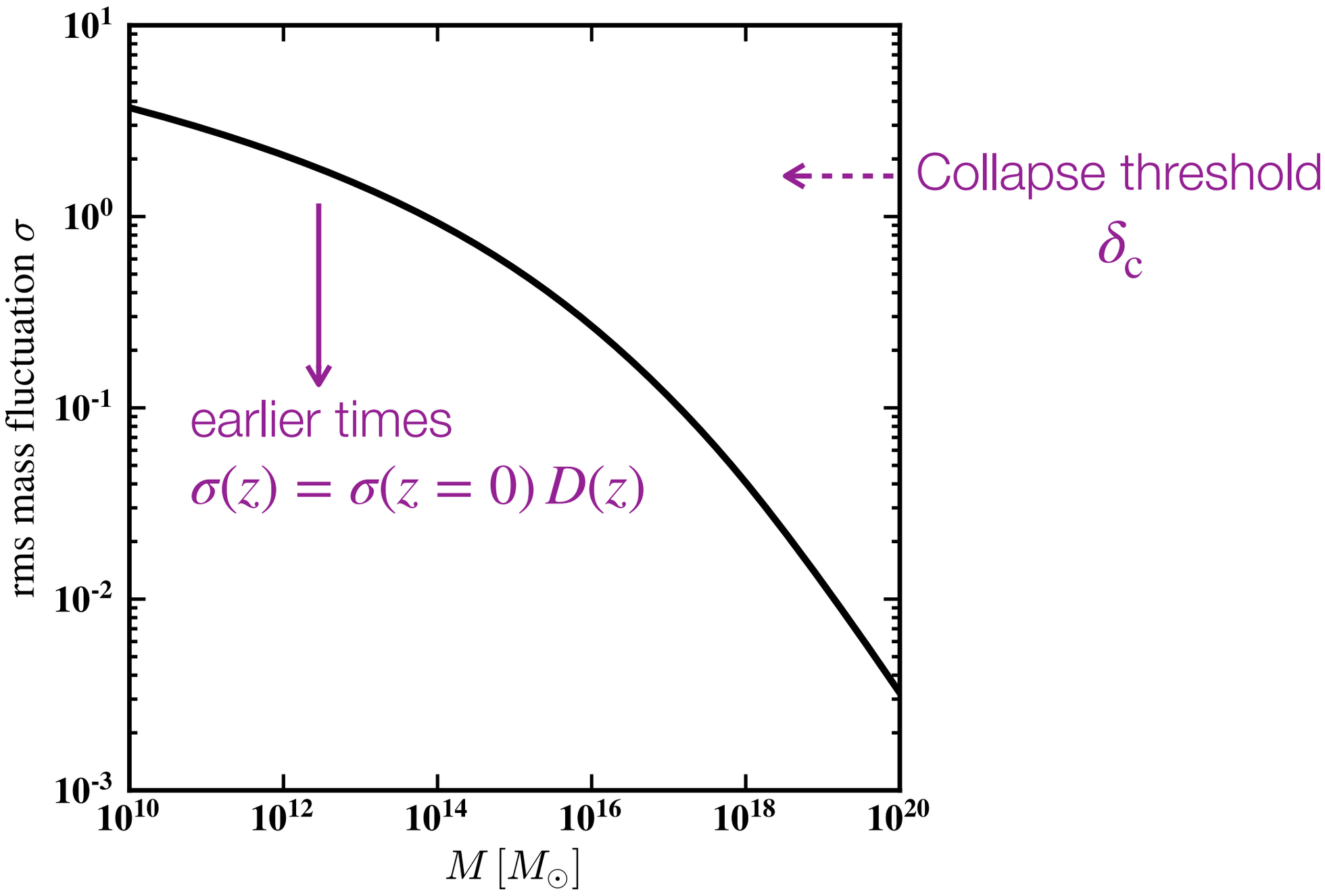

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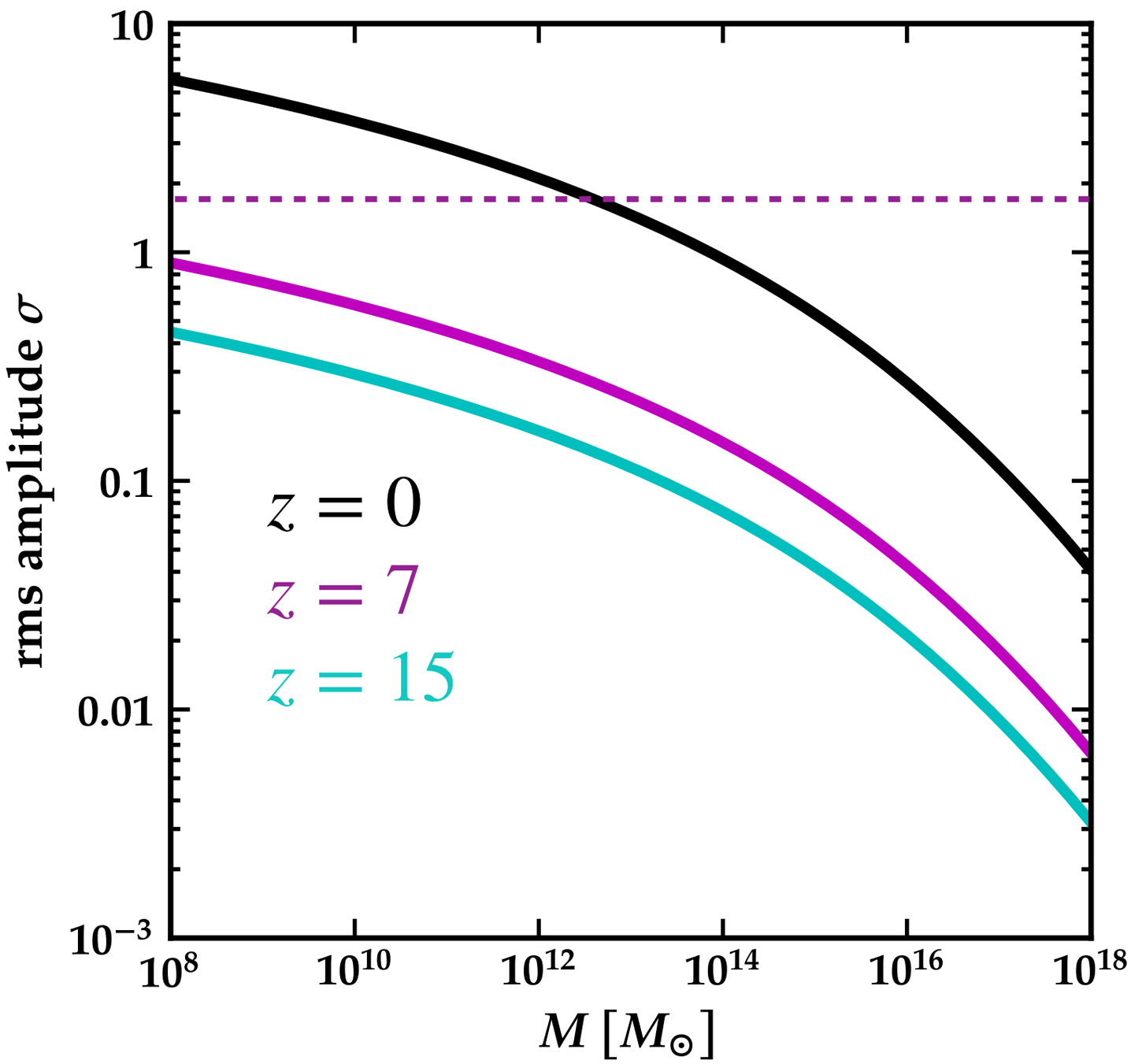


Collapse threshold

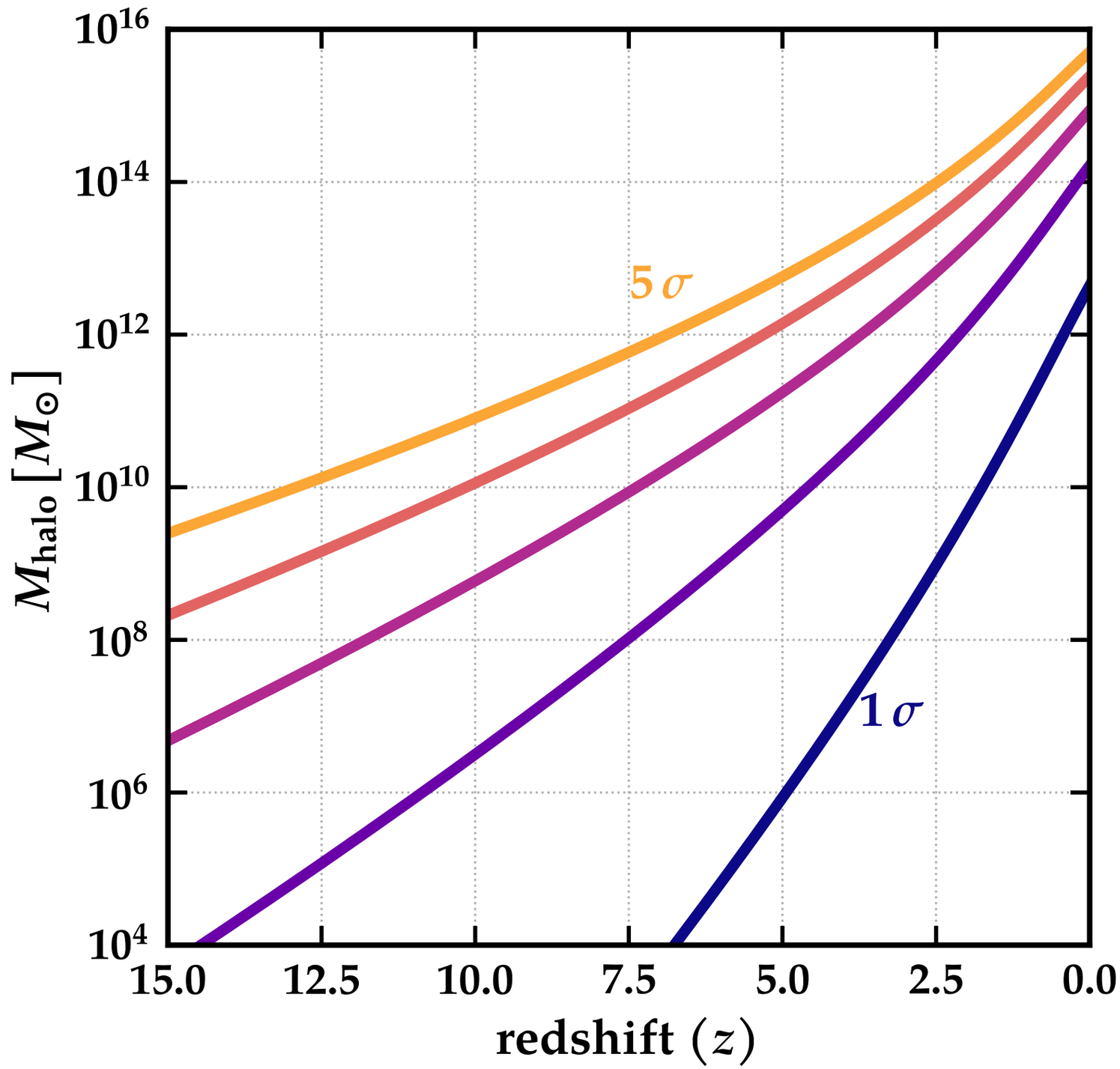
$\delta_{\rm c} \approx 1.7$

Peak height:

$$\nu = \frac{\delta_{\rm c}}{\sigma(M, z)}$$

The ΛCDM Cosmology

Base ΛCDM model fully described by $\omega_b, \omega_c, n_s, A_s, \theta_\star, \tau$



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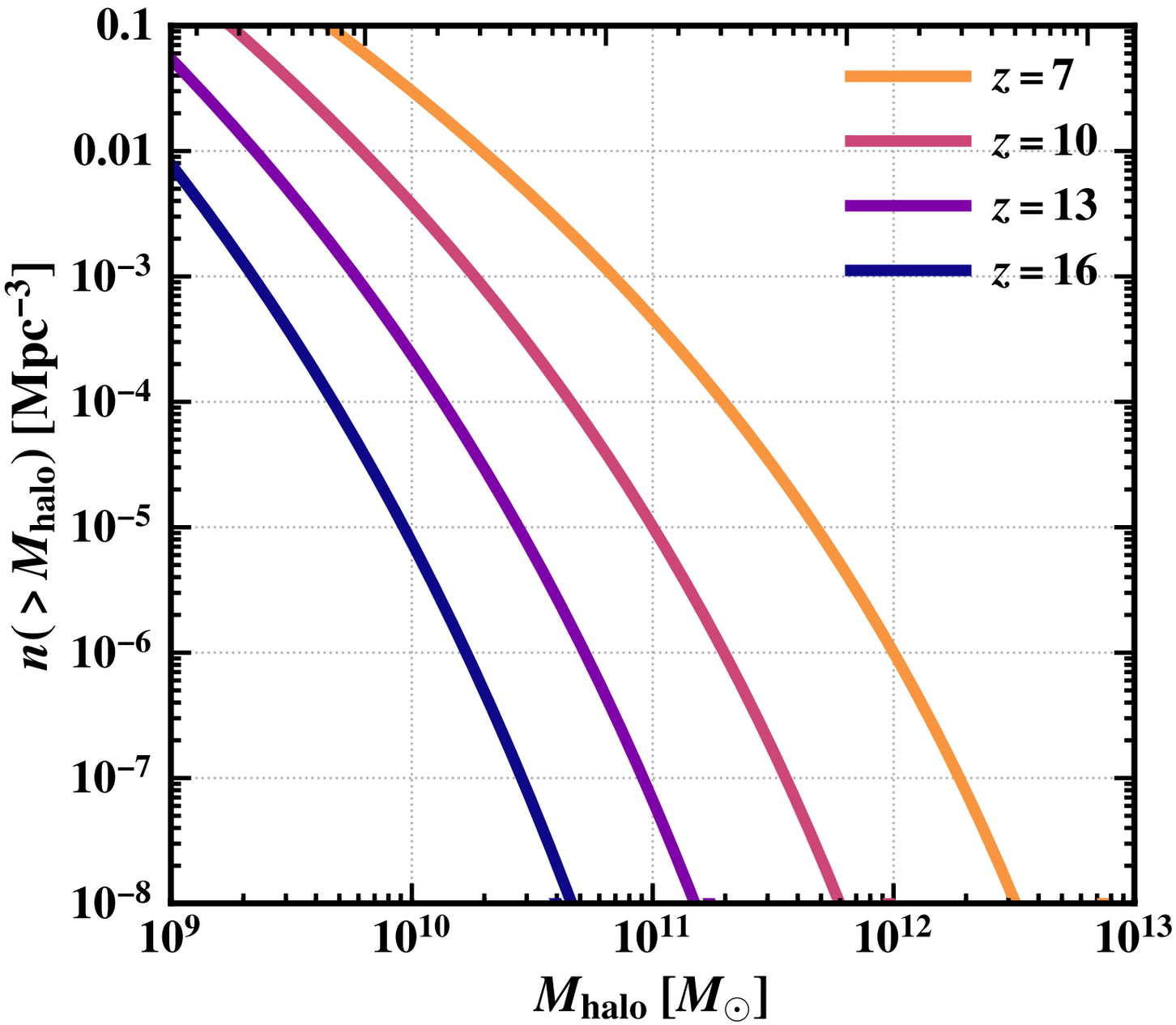
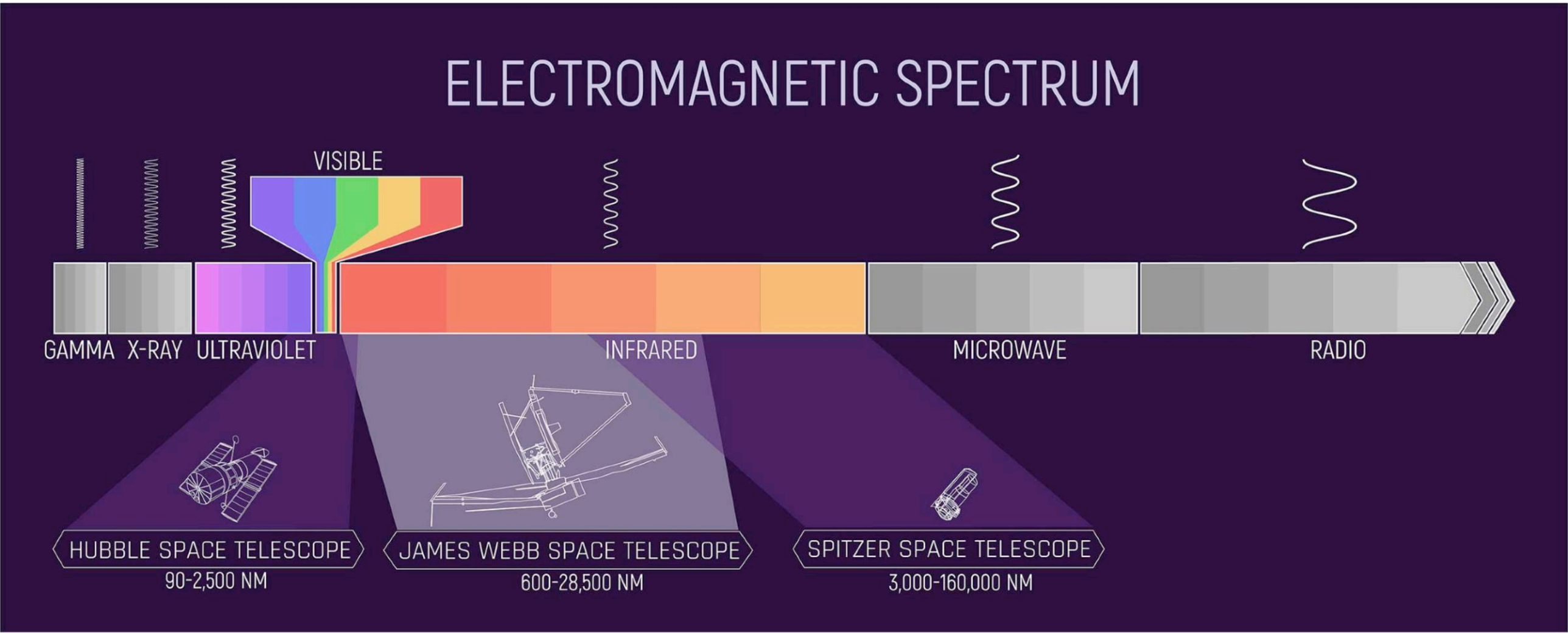


JWST: optimized to push the high-redshift frontier

Infrared coverage captures rest-frame UV (hot, young stars) at $z \gtrsim 7 - 10$

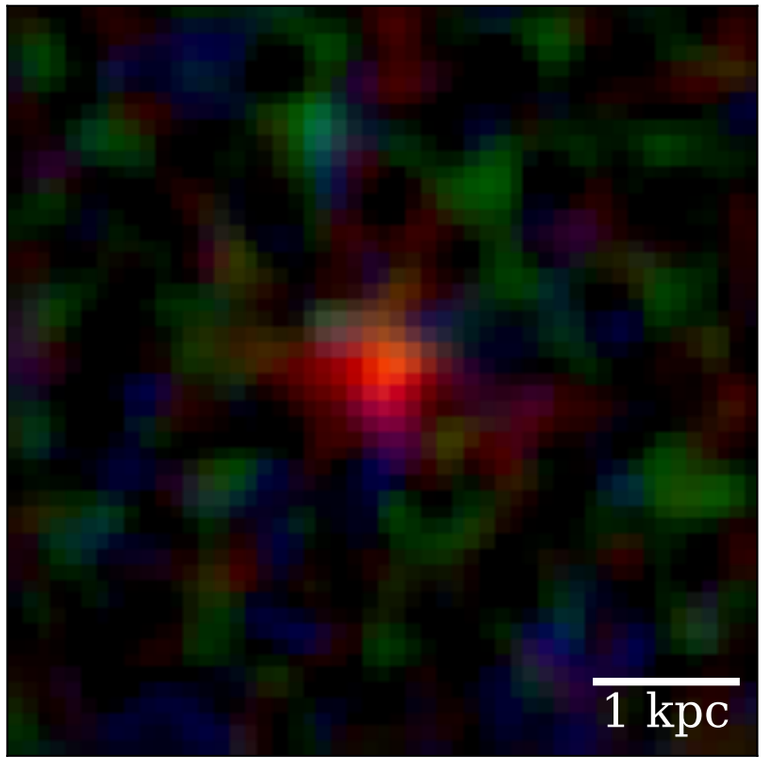


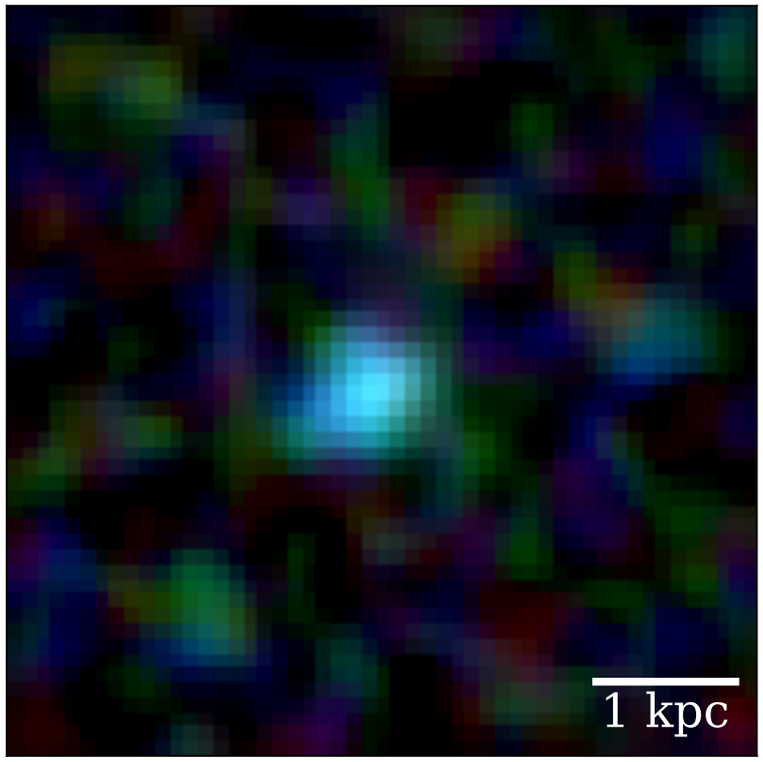
$$\lambda_{\rm obs} = (1+z)\,\lambda_{\rm emit}$$

NASA and J. Olmsted [STScI]

First results from JWST: galaxies everywhere!

- **Expectation:** first observations will help us understand instrument, find galaxies at distance seen by Hubble (z~10) or just beyond
- **What happened:** a shocking number of galaxy candidates were quickly discovered out to z~20 (~200 million years after the big bang)





Finkelstein et al. 2022

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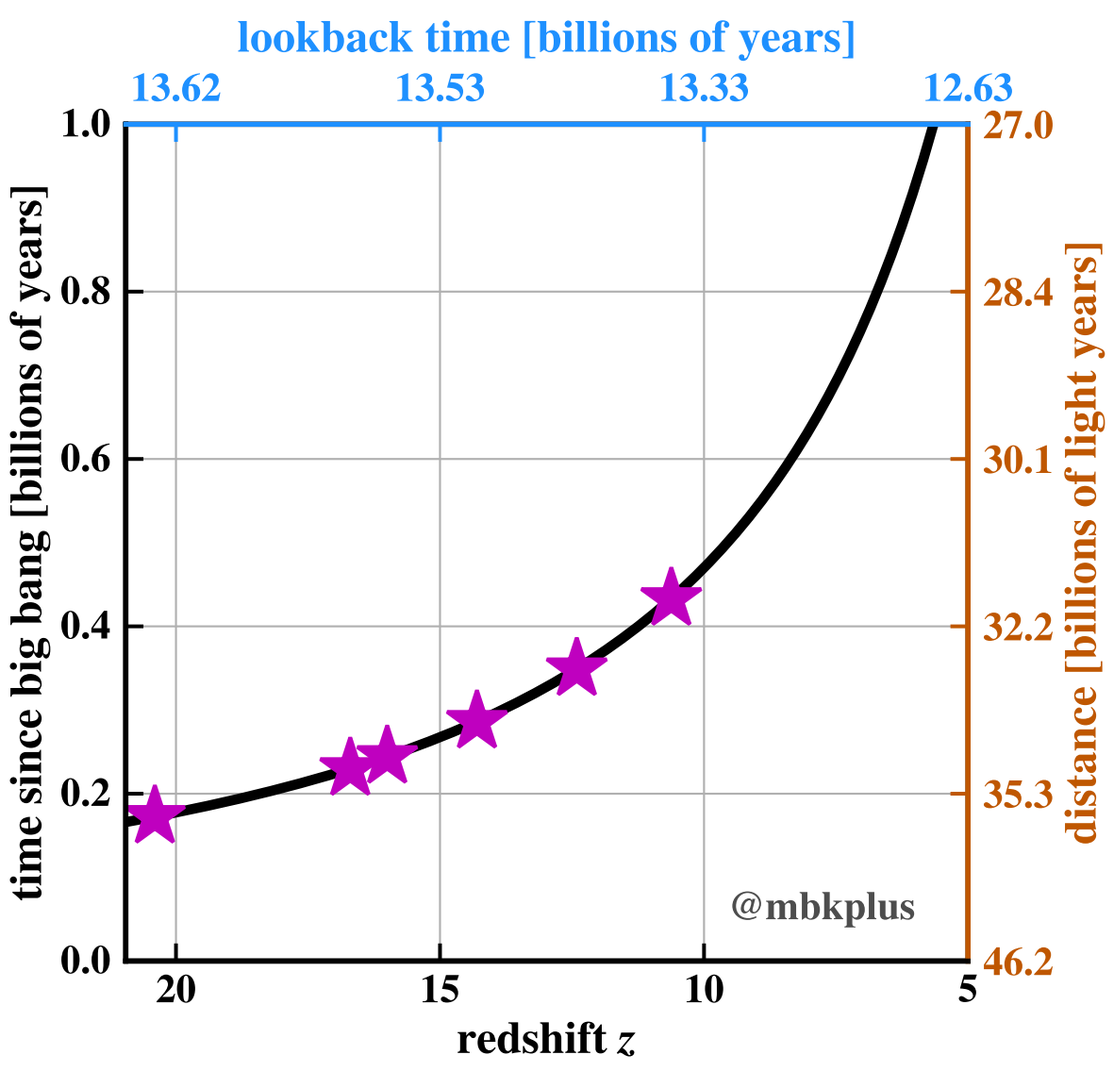


Webb telescope reveals unpredicted bounty of bright galaxies in early universe

Star formation after the big bang appears much faster than models had forecast

GALAXIES

WEBB TELESCOPE SHATTERS DISTANCE RECORDS, CHALLENGES ASTRONOMERS

BY: GOVERT SCHILLING | AUGUST 10, 2022 | 7

Distant galaxies in Webb images suggest we need to rethink star and galaxy evolution in the early universe.

JWST's First Glimpses of Early Galaxies Could Break Cosmology

The James Webb Space Telescope's first images of the distant universe shocked astronomers. Is the discovery of unimaginably distant galaxies a mirage or a revolution?

The Big Bang didn't happen

What do the James Webb images really show?

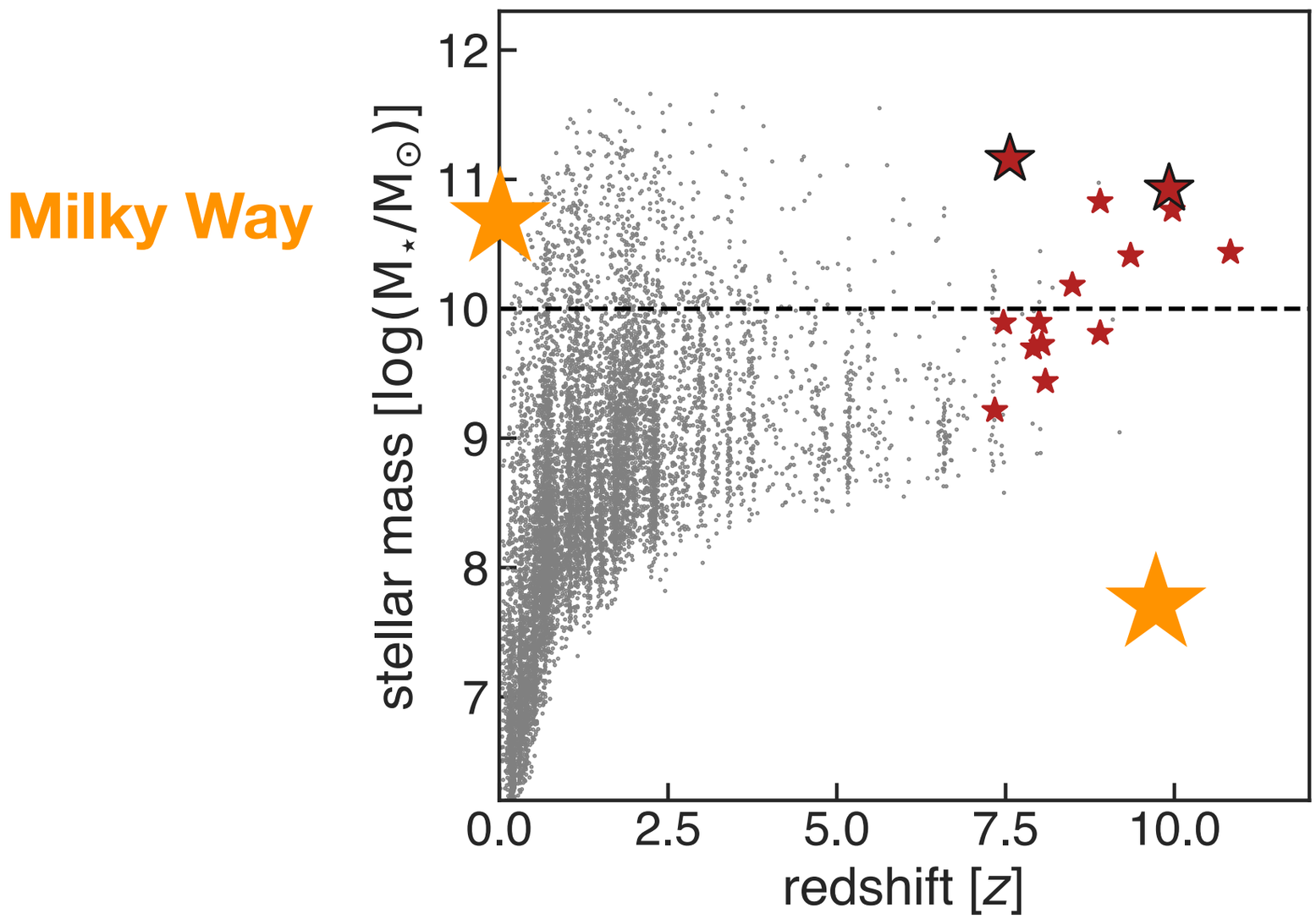
The James Webb Space Telescope never disproved the Big Bang. Here's how that falsehood spread.

By Keith Cooper published September 07, 2022

The Big Bang theory is still on solid ground, despite pseudoscientific attempts to twist JWST's findings

First results from JWST: massive early galaxies

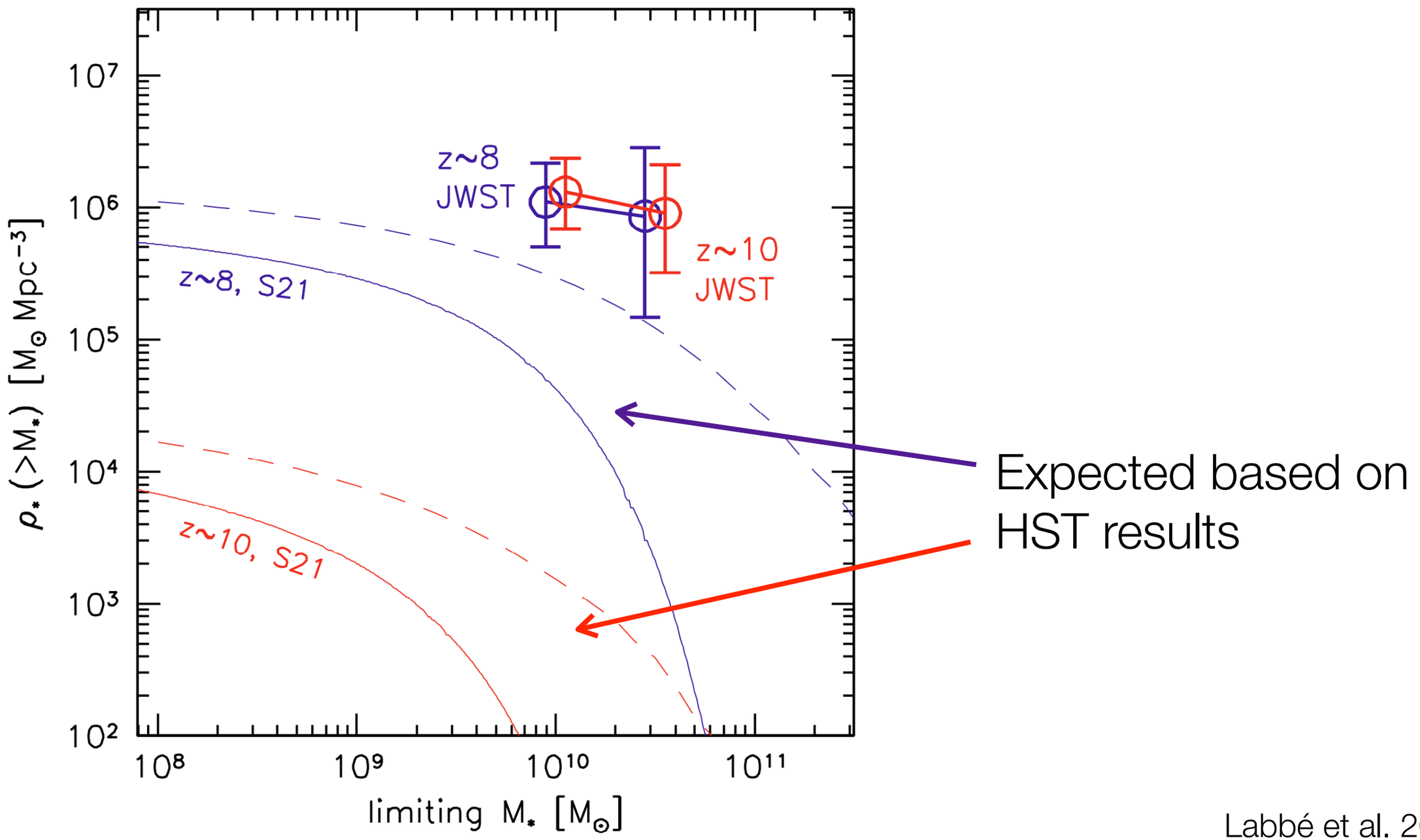
One of the most surprising results: galaxies with $M_\star \approx 10^{10.5-11}\, M_\odot$ at redshift 8-10



Labbé et al. 2022

First results from JWST: massive early galaxies

Galaxies with $M_\star \approx 10^{10.5-11}\, M_\odot$ at redshift 8-10 imply *thousands* of times more stars than was expected based on Hubble

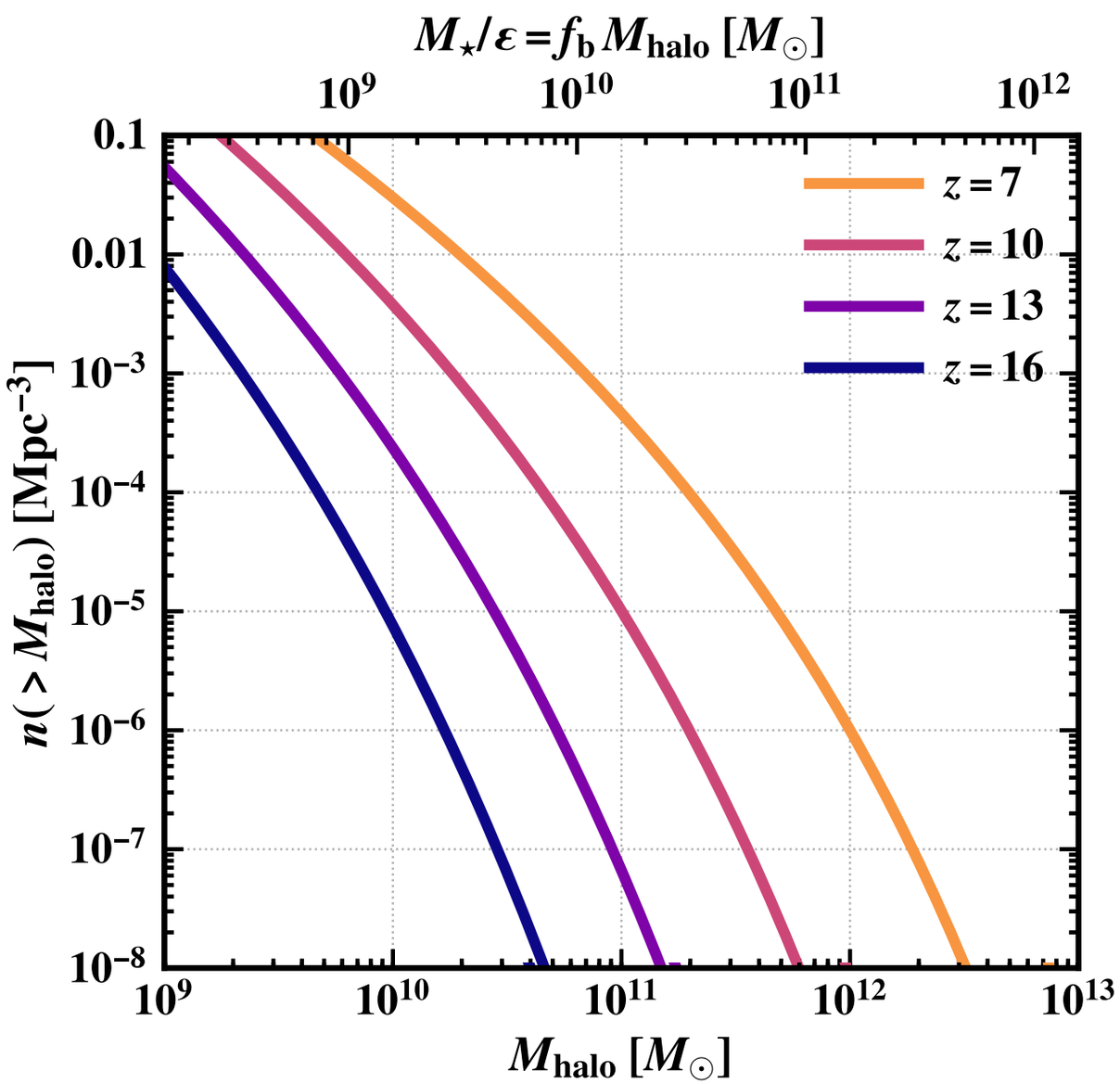


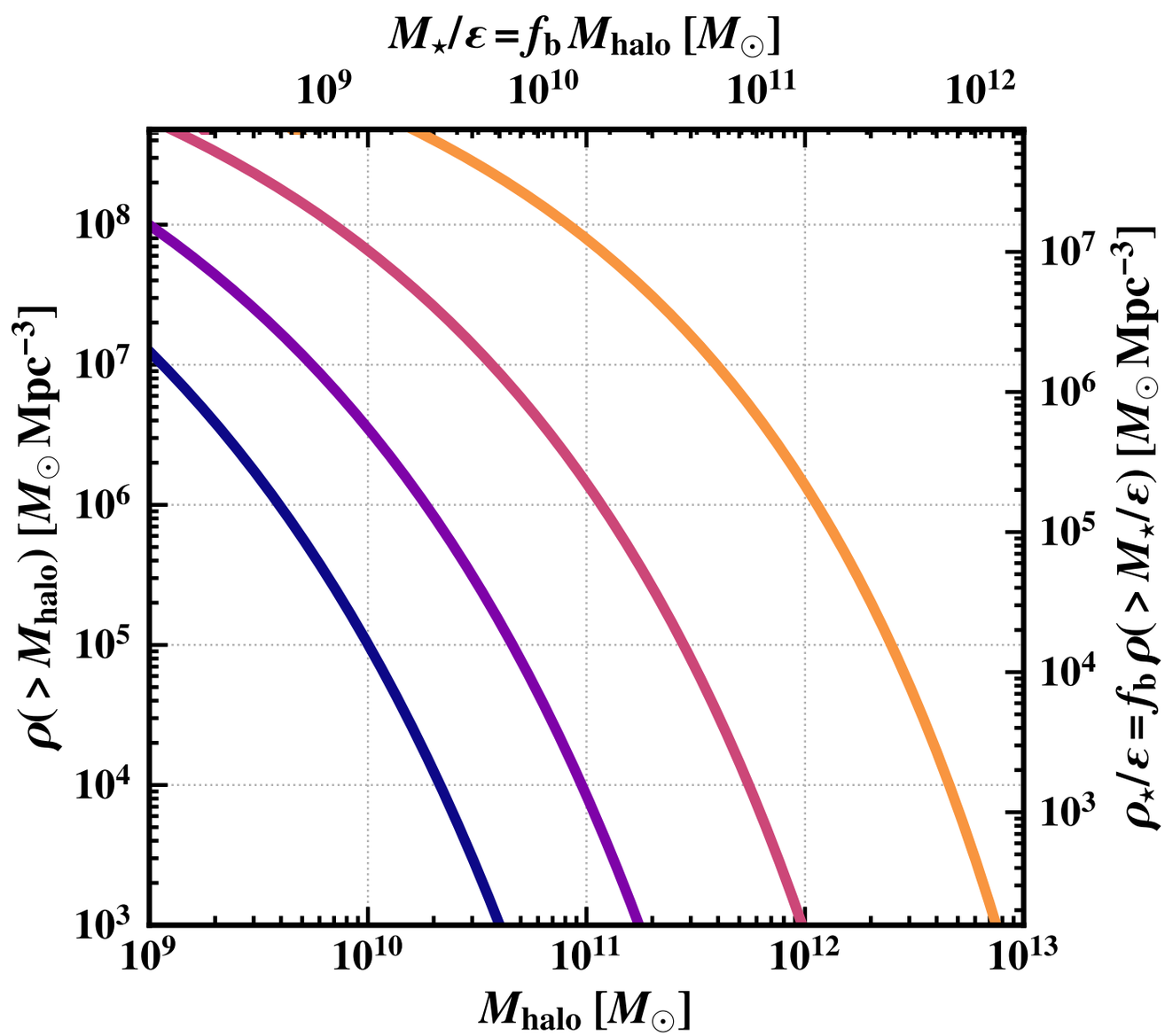
Labbé et al. 2022

What should we have expected?

$$M_{\rm baryon} = \frac{\Omega_{\rm b}}{\Omega_{\rm m}} M_{\rm halo} = f_{\rm b} M_{\rm halo}$$

$$M_\star = \epsilon_\star f_{\rm b} M_{\rm halo} \leq M_{\rm baryon}$$

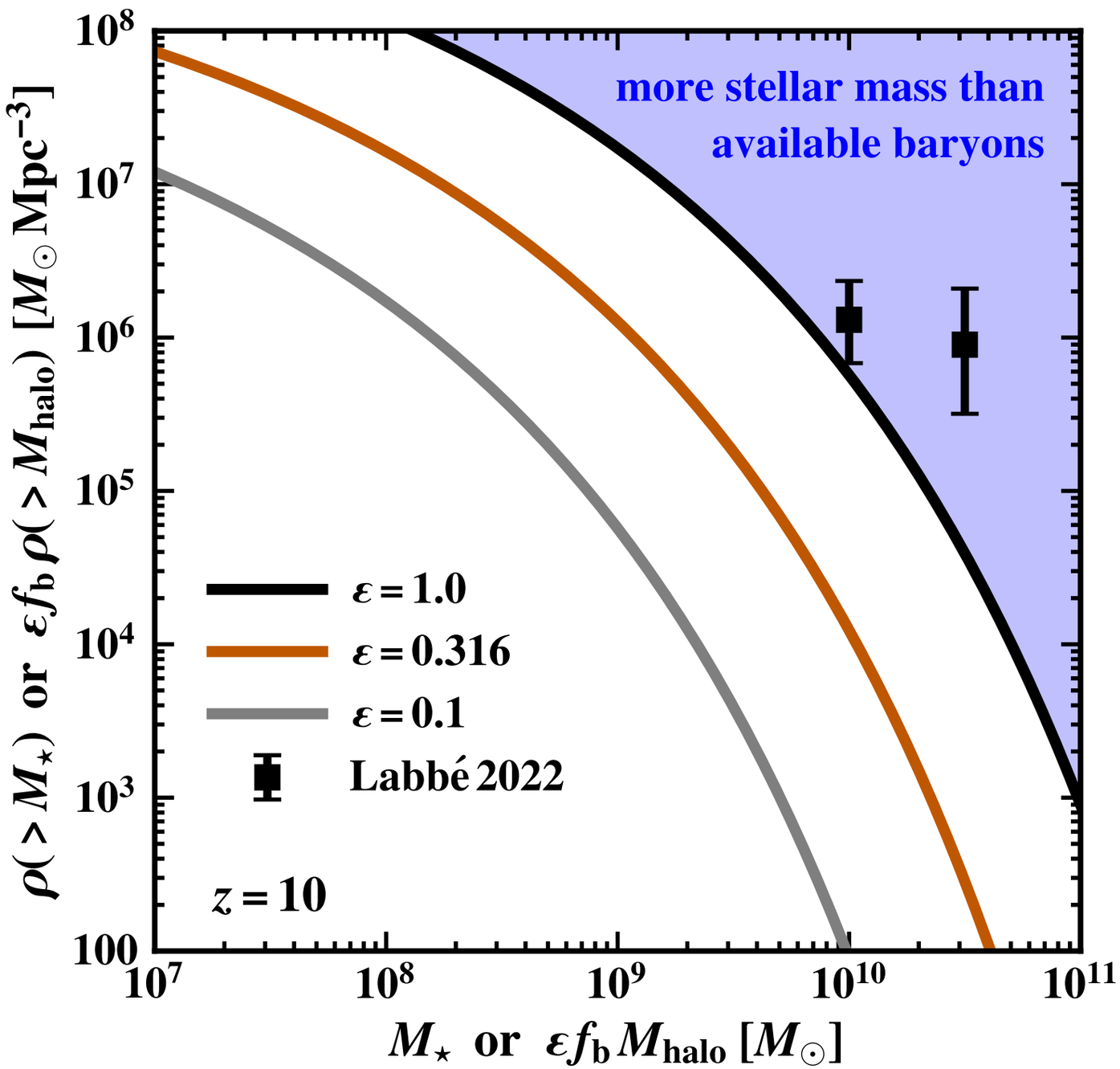




Boylan-Kolchin 2022

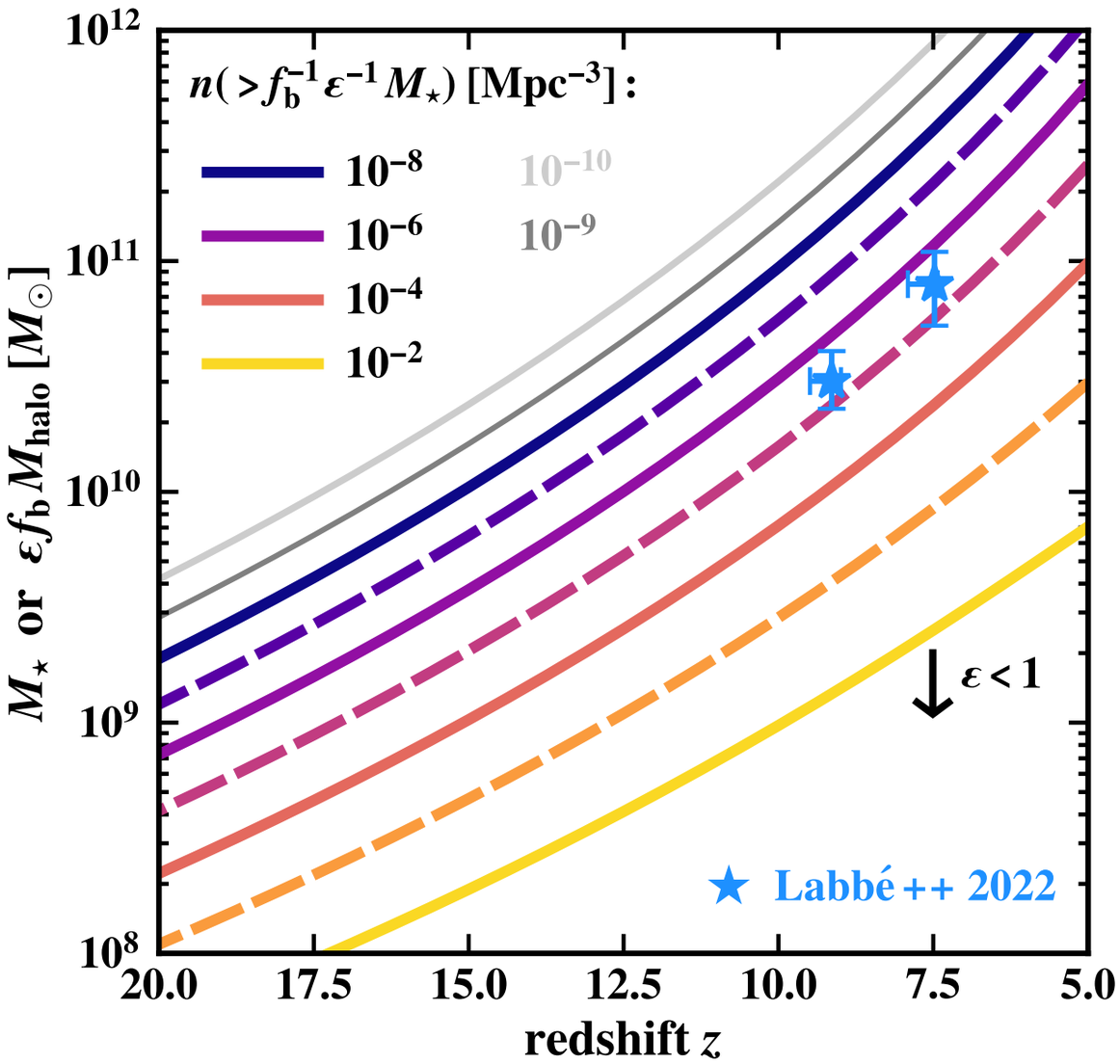
What should we have expected?

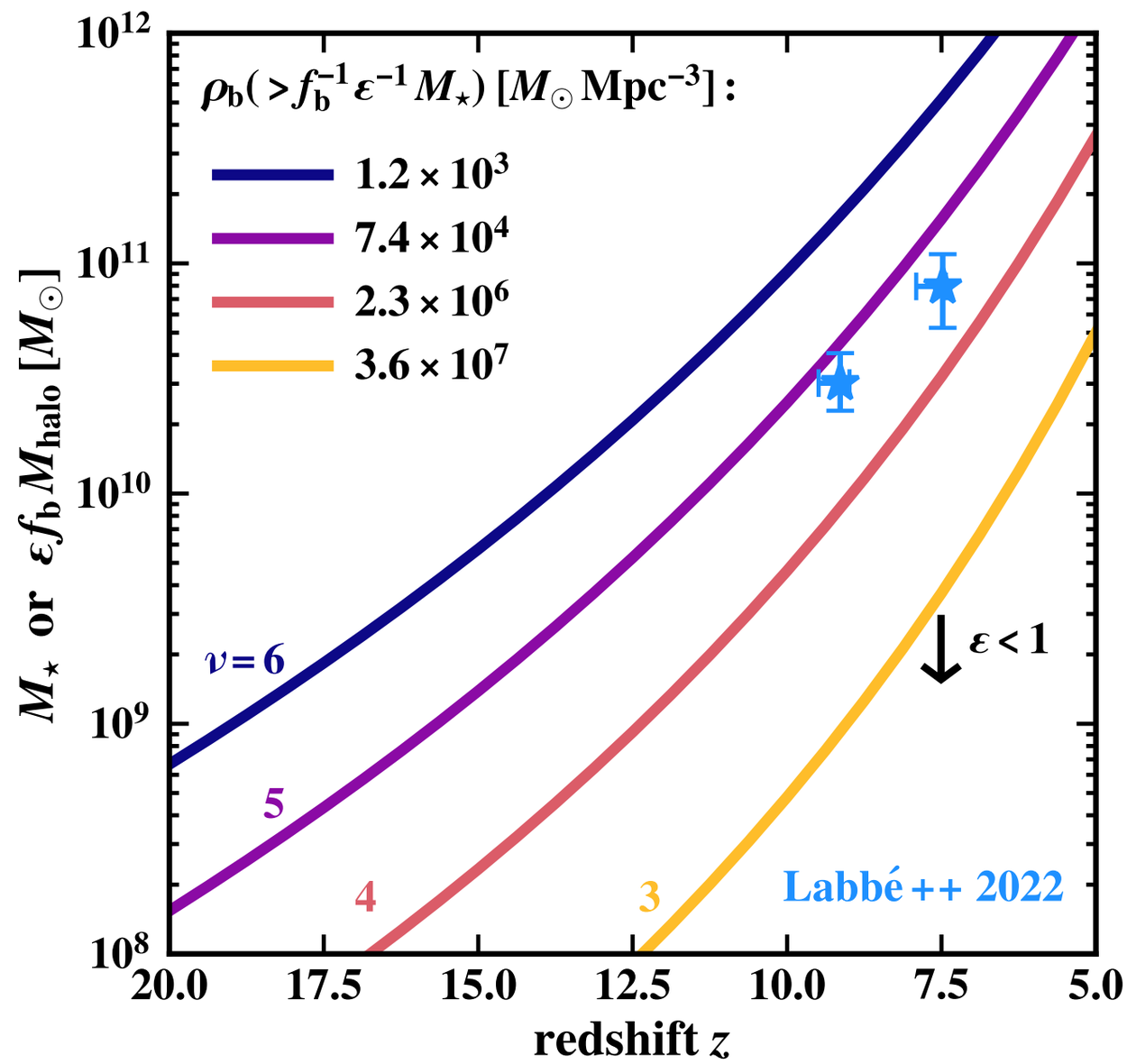
Problem: this implies more stars than material available to make stars in the standard ΛCDM cosmology



Boylan-Kolchin 2022

The implied dark matter hosts are *very* rare





Boylan-Kolchin 2022

Too many stars too early in JWST data?

Problem: this implies **more stars** than **material available** to make stars in the standard ΛCDM cosmology

Implications: either the inferred **galaxy properties are wrong**, the observed portion of the Universe is **highly atypical**, or there is an issue with our successful **cosmological model**

Too many stars too early in JWST data?

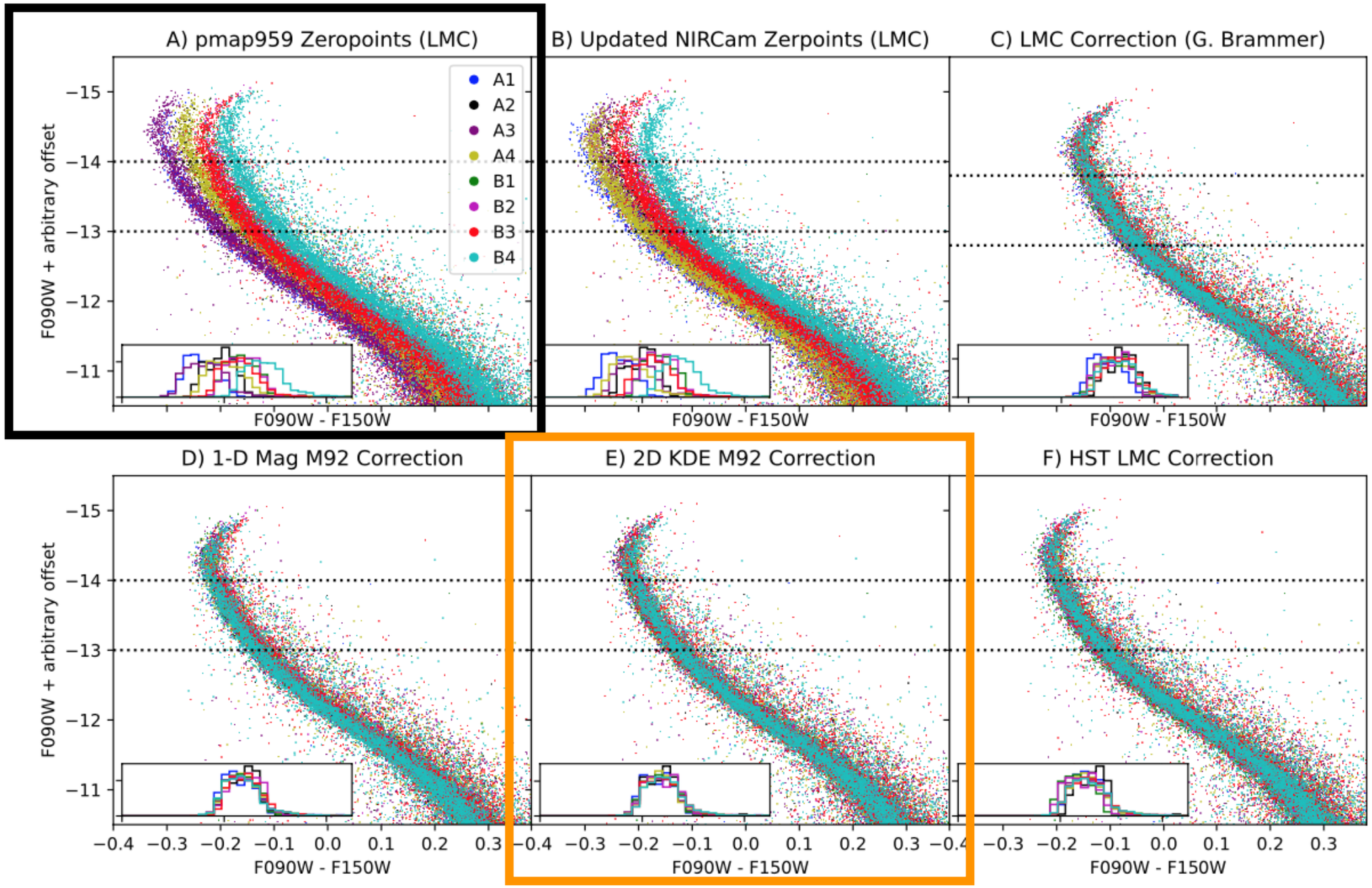
(1) galaxy properties are wrong:

Need to understand the performance of NIRCam accurately

- Calibrations are still ongoing

Calibrations of NIRCam are still ongoing

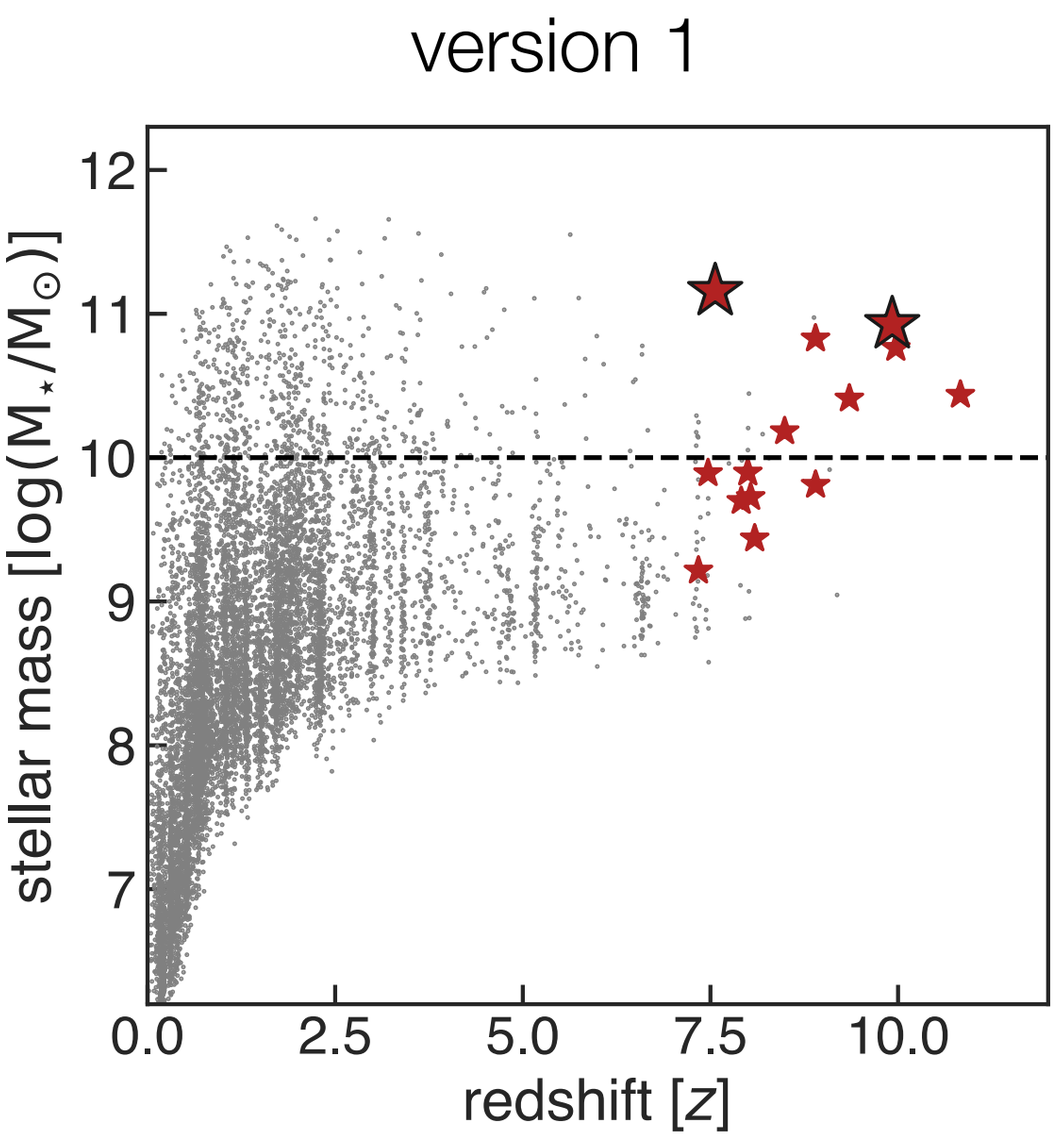
Original



Updated

Boyer et al. 2022 (M92 globular cluster)

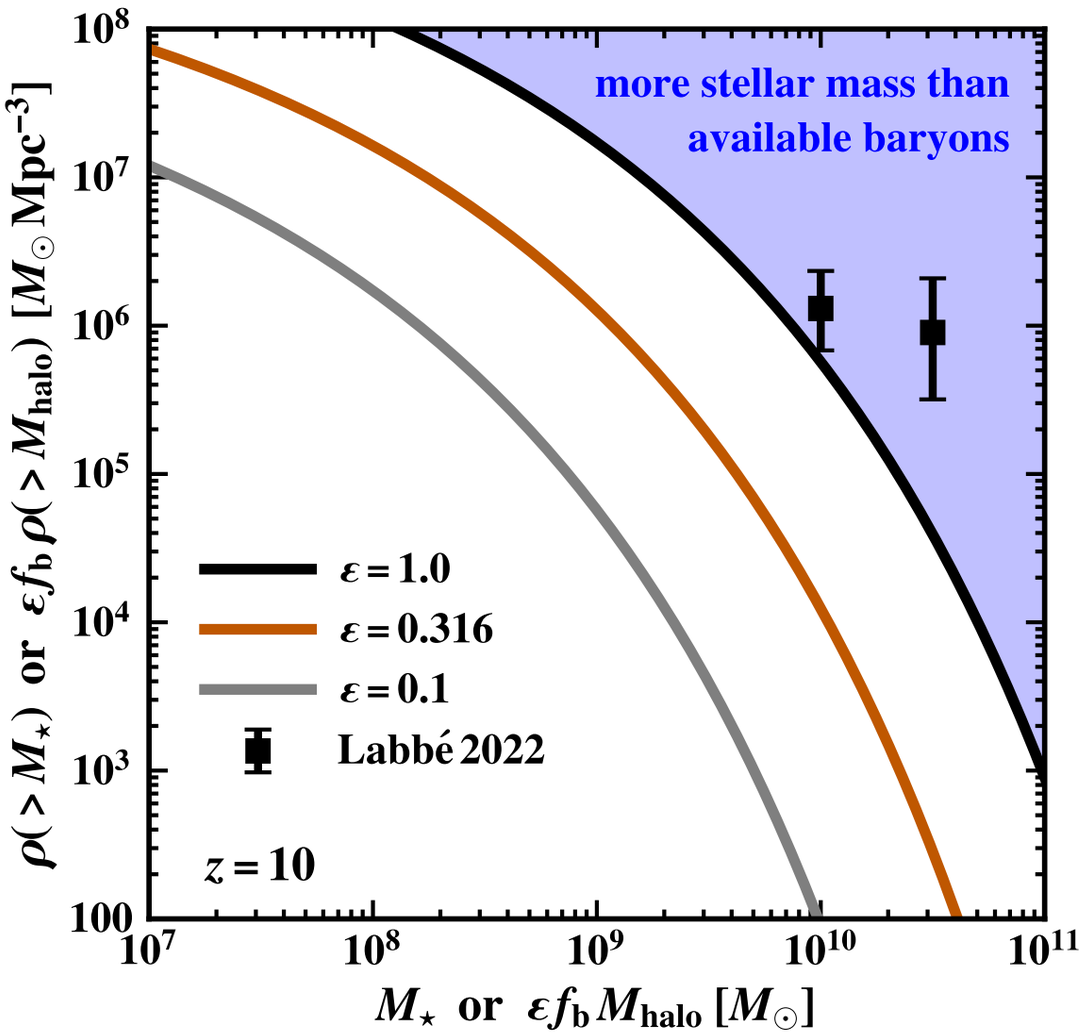
With newest calibrations: masses are still high!

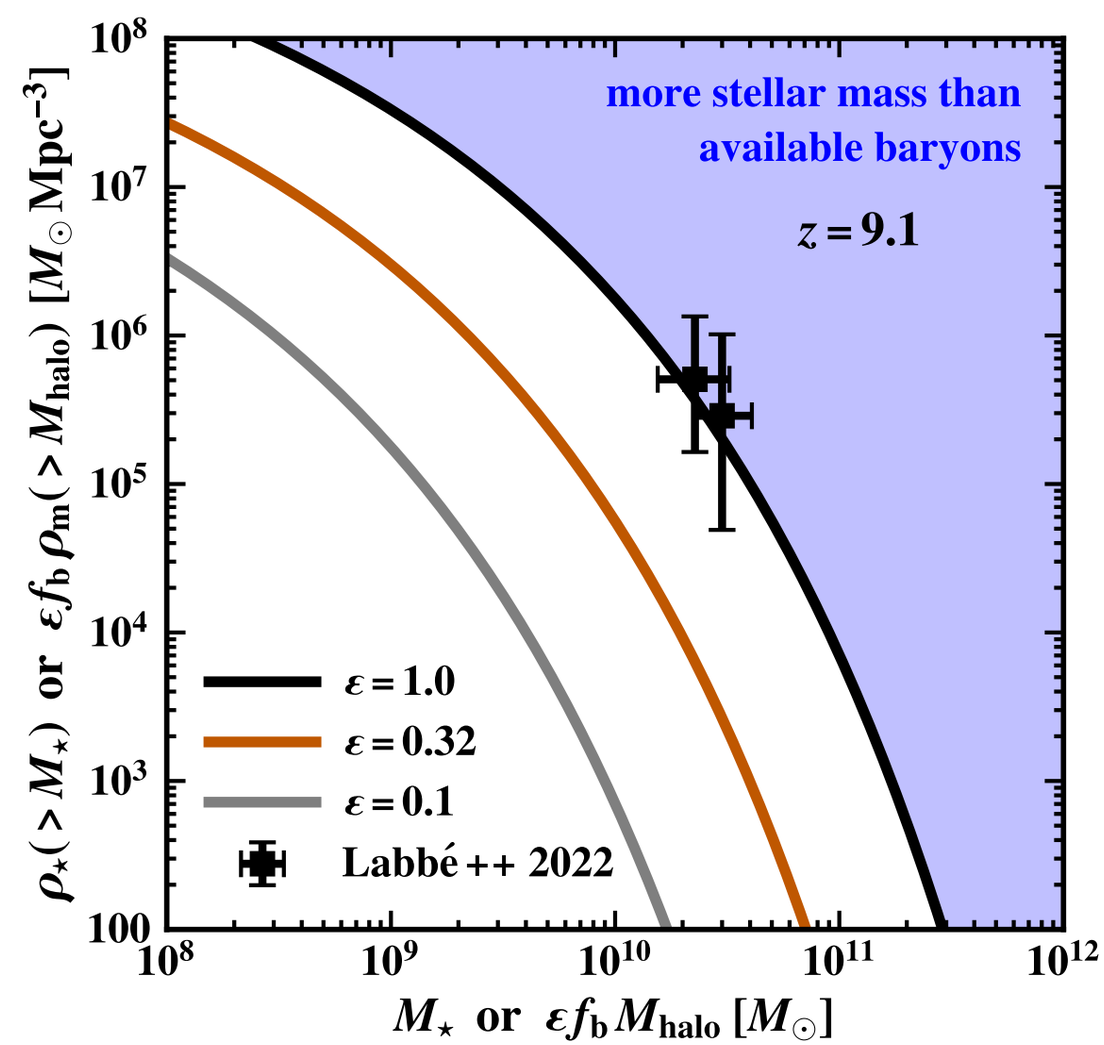


!Preliminary!

Labbé et al. 2022

Tension still present, though decreased





expectation: $\epsilon \approx 0.33$ corresponds to ***very*** efficient conversion; the Milky Way today sits at peak of galaxy formation efficiency with $\epsilon \approx 0.2$

Boylan-Kolchin 2022

What could be going on?

(1) galaxy properties are wrong:

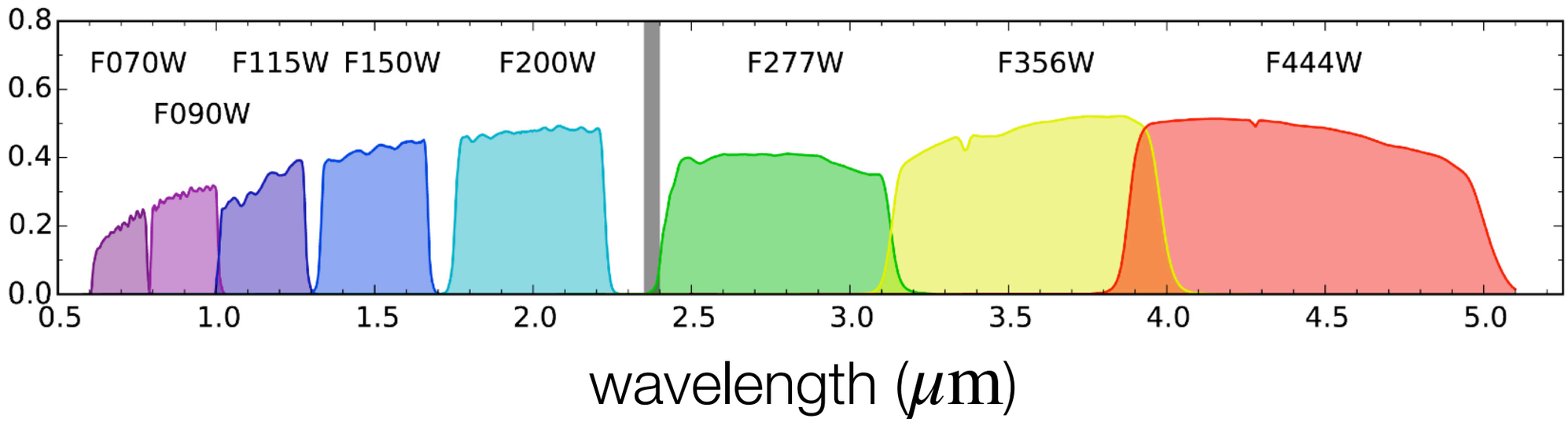
Need to convert from **observed light** to **stellar mass**, which depends on assumed stellar initial mass function, star formation history, etc.

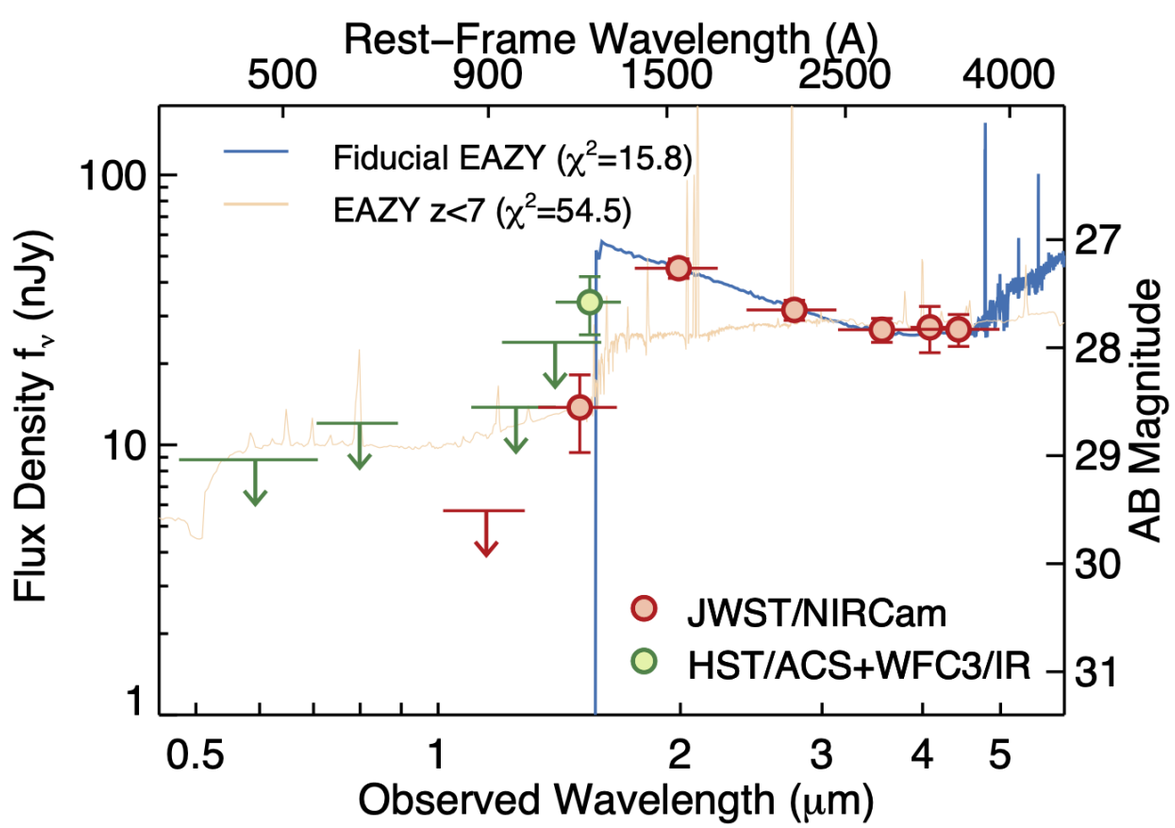
Need to be sure we really are measuring the galaxy redshift correctly

- Evidence for confusion with galaxies at much lower redshift (z~5)?

Current results based solely on imaging

NIRCam filters





Finkelstein et al. 2022

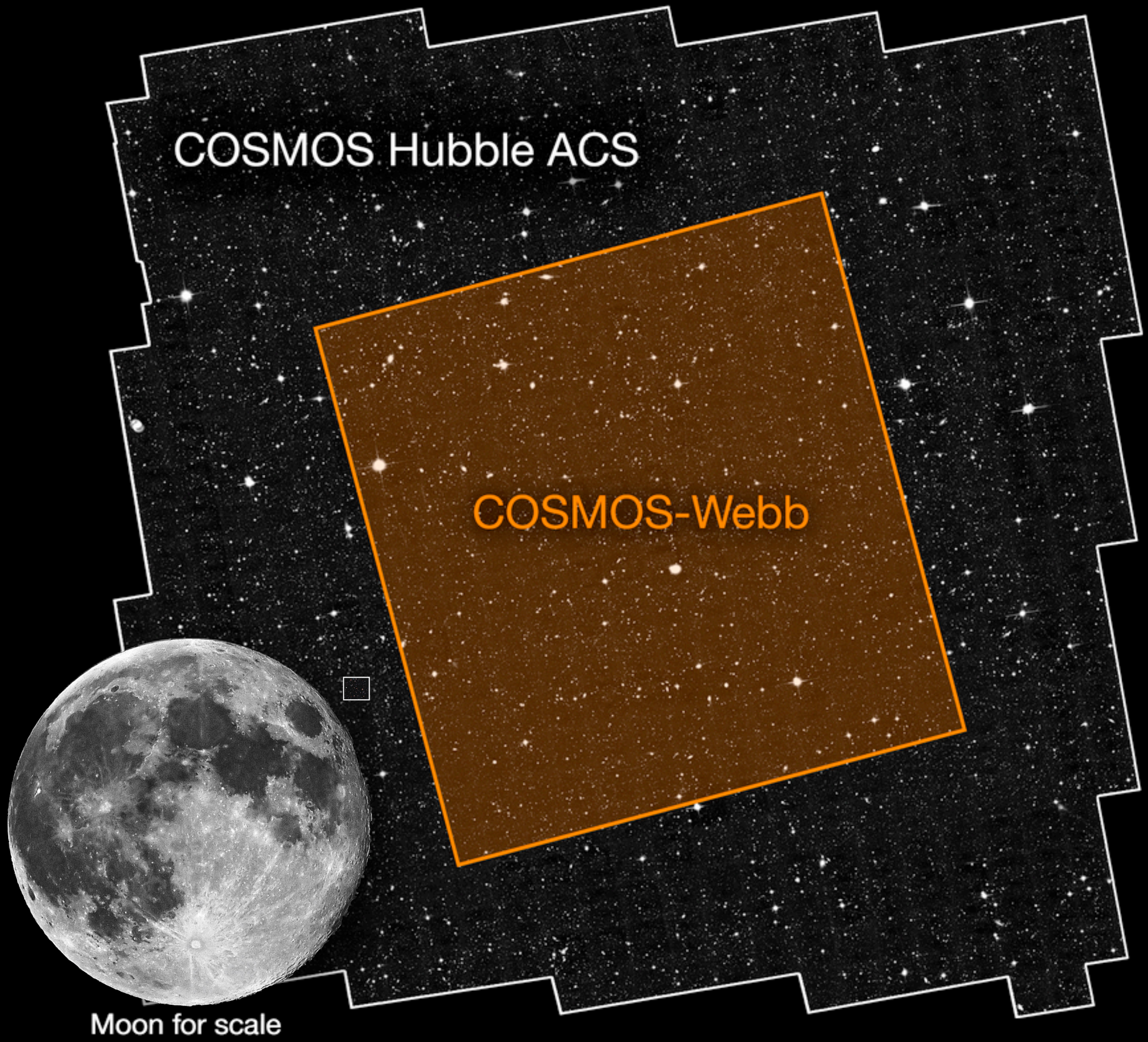
Star-forming galaxies at very early cosmic times or **quiescent galaxies** at "low redshift" ($z \sim 5$)?

What could be going on?

(2) the observed portion of the Universe is **highly atypical**

If the observations just happen to be in a **very over-dense part** of the Universe, then the problem goes away

- Naive expectation: we would need to survey ~1000x more sky to see galaxies like this


COSMOS Hubble ACS
COSMOS-Webb
Moon for scale

What could be going on?

(3) there is an issue with our successful **cosmological model**

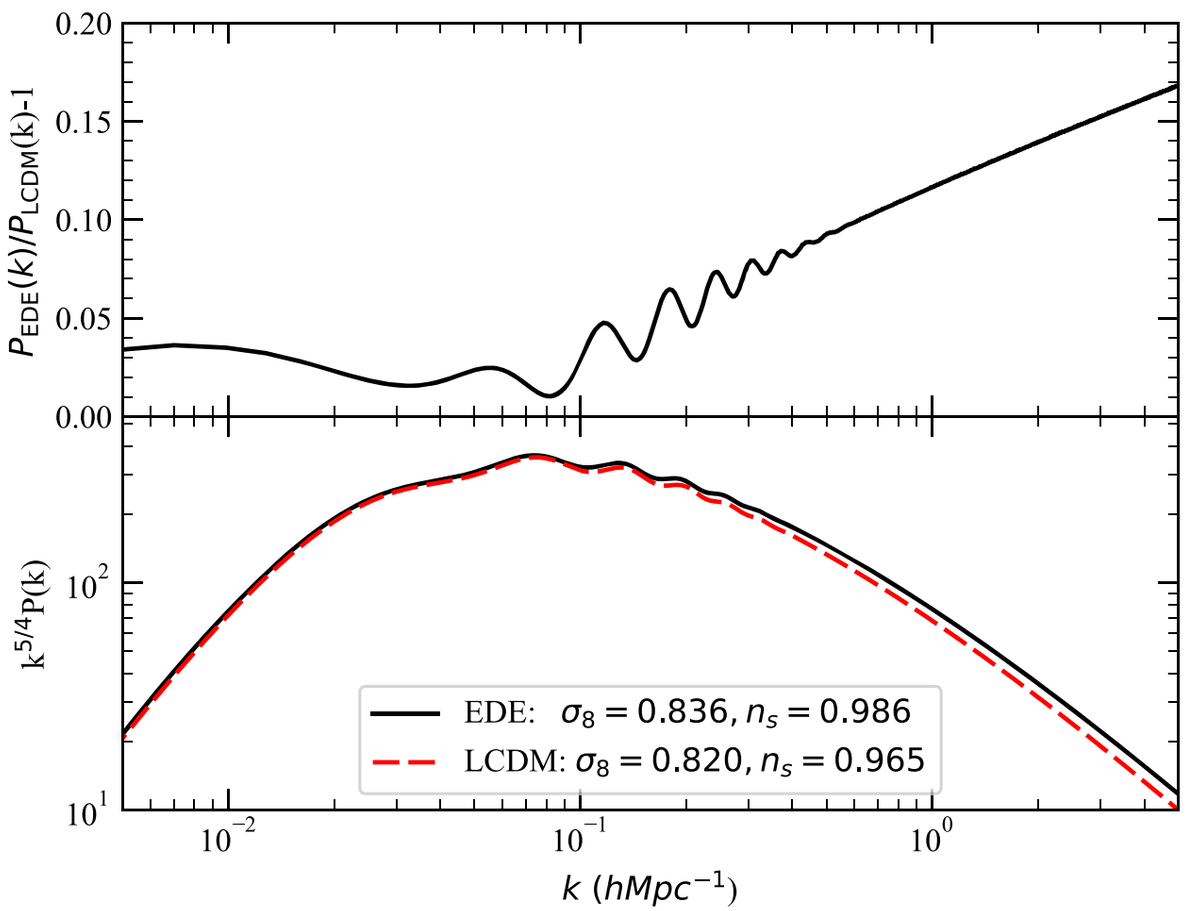
If none of the other explanations hold up:
we will have to **re-examine the ΛCDM model**

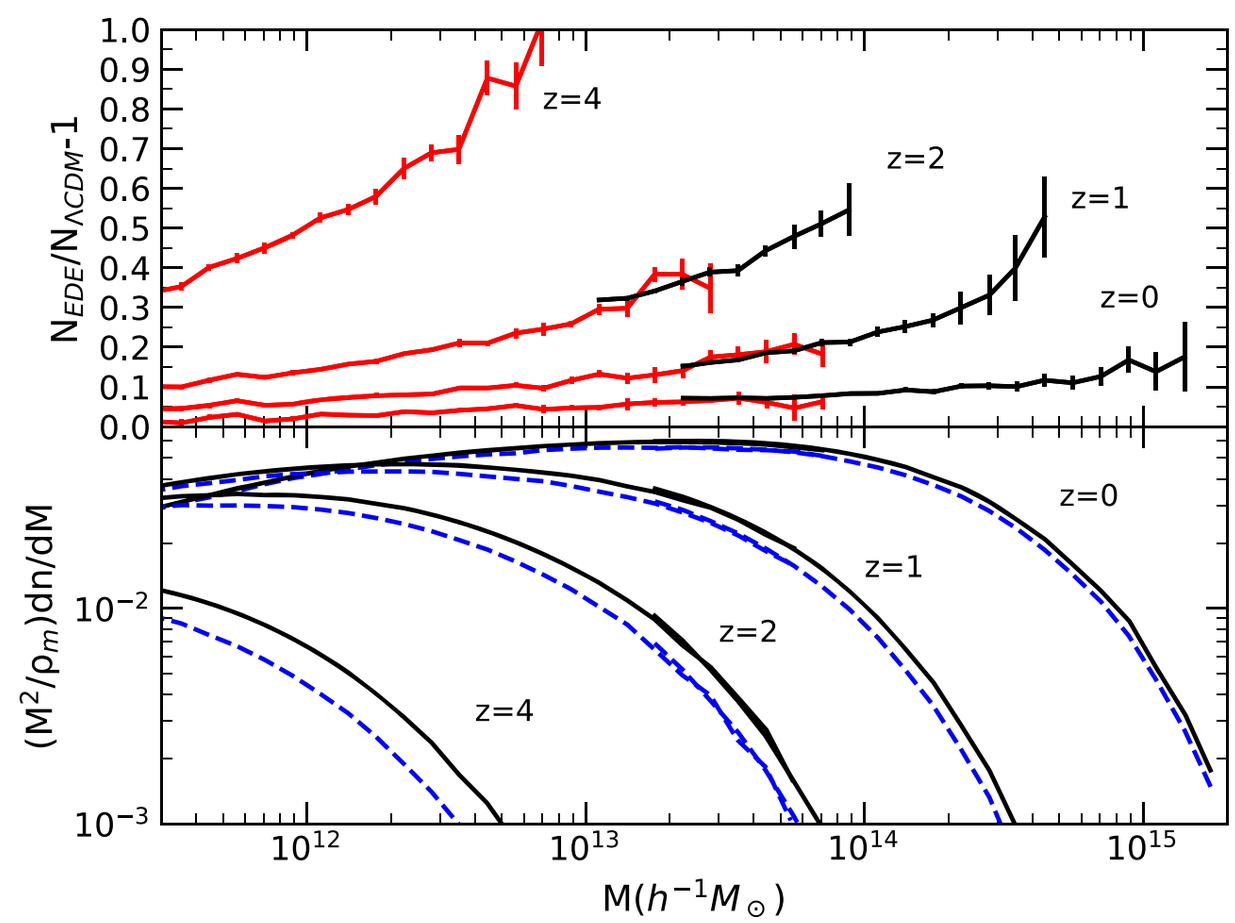
Example: *Early Dark Energy* allows for more and faster earlier formation of cosmological structure. Could this also explain the JWST observations?

- EDE: contributes ~10% of the energy density at $z \sim 3500$ (and less at all other times); decreases sound horizon by decreasing $t(z_\star)$, lowers inferred H_0

EDE leads to enhanced high-z structure formation

EDE: requires higher $\omega_{\rm m}$ and $n_{\rm s}$ than base Planck model

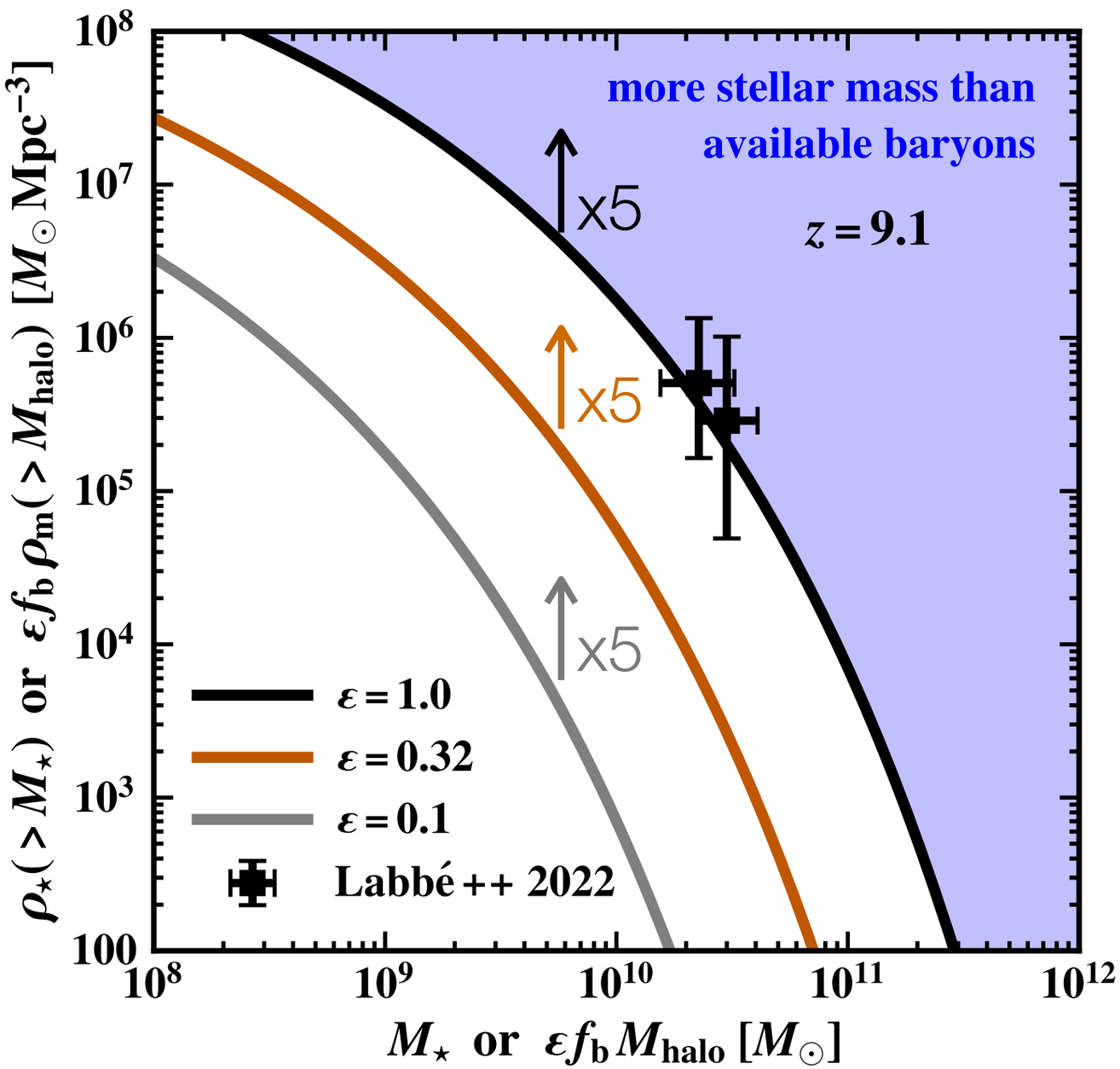




Klypin et al. 2021

EDE leads to enhanced high-z structure formation

EDE: requires higher $\omega_{\rm m}, \sigma_8$ and $n_{\rm s}$ than base Planck model



Boylan-Kolchin 2022

Issue(?): higher $\omega_{\rm m}$ & σ_8 will worsen the S_8 tension

Also: EDE results in $t_0 \approx 12.8\,{\rm Gyr}$ versus base ΛCDM value of **13.8 Gyr**. Inconsistent with GC ages? (Boylan-Kolchin & Weisz 2021)

Outlook

JWST is revolutionizing our understanding of the earliest phases of galaxy formation

Striking early results:

- an unexpected treasure trove of galaxy candidates in the early Universe (z~15-20)
- **very** massive galaxies at z~8-10

These results are challenging our inference of **galaxy properties**, our understanding of **galaxy formation**, or our **cosmological model**

- more baryons in stars than baryons present in halos massive enough to host the observed galaxies in base ΛCDM
- **if** it is an issue with cosmology, could it be related to the Hubble tension & EDE?

Observations over wider areas & with spectroscopy will point the way forward → exciting times for cosmology and galaxy physics with JWST