Title: Dark matter at high redshifts with JWST

Speakers: Julian Munoz

Collection: Dark Matter, First Light

Date: February 26, 2024 - 1:30 PM

URL: https://pirsa.org/24020071

Abstract: The launch of the James Webb Space Telescope (JWST) has ignited a revolution in our understanding of the early universe. Its exquisite infrared capabilities have allowed observers to find galaxies at higher redshifts than before and to measure their stellar masses. I will describe how we can use these observations to shed light on the nature of dark matter. For the JWST galaxies to form they ought to reside in dark-matter halos, allowing us to measure the clustering of dark matter in an unexplored region. I will discuss the JWST observations of ultra-massive galaxies recently argued to "break LCDM", and how we recently disfavored a cosmological solution using HST data at the same redshifts. If time allows, I will review the path forward to measuring dark-matter clustering down to the first galaxies through 21-cm observations.

What is JWST telling us about cosmology?

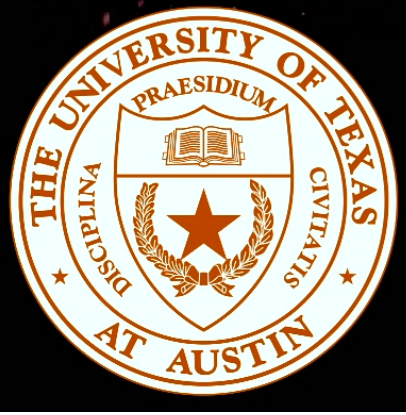
JULIAN B. MUÑOZ

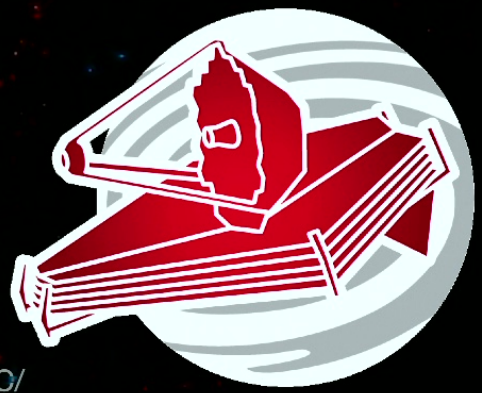
Based on:

Sabti, **JBM**, Blas, PRD + ApJL 2022

Sabti, **JBM**, Kamionkowski PRL 2024

JBM, Cyr-Racine, Dvorkin, ETHOS PRD 2021, 2022





CREDIT: NASA/STSCI/CEERS/TACO/
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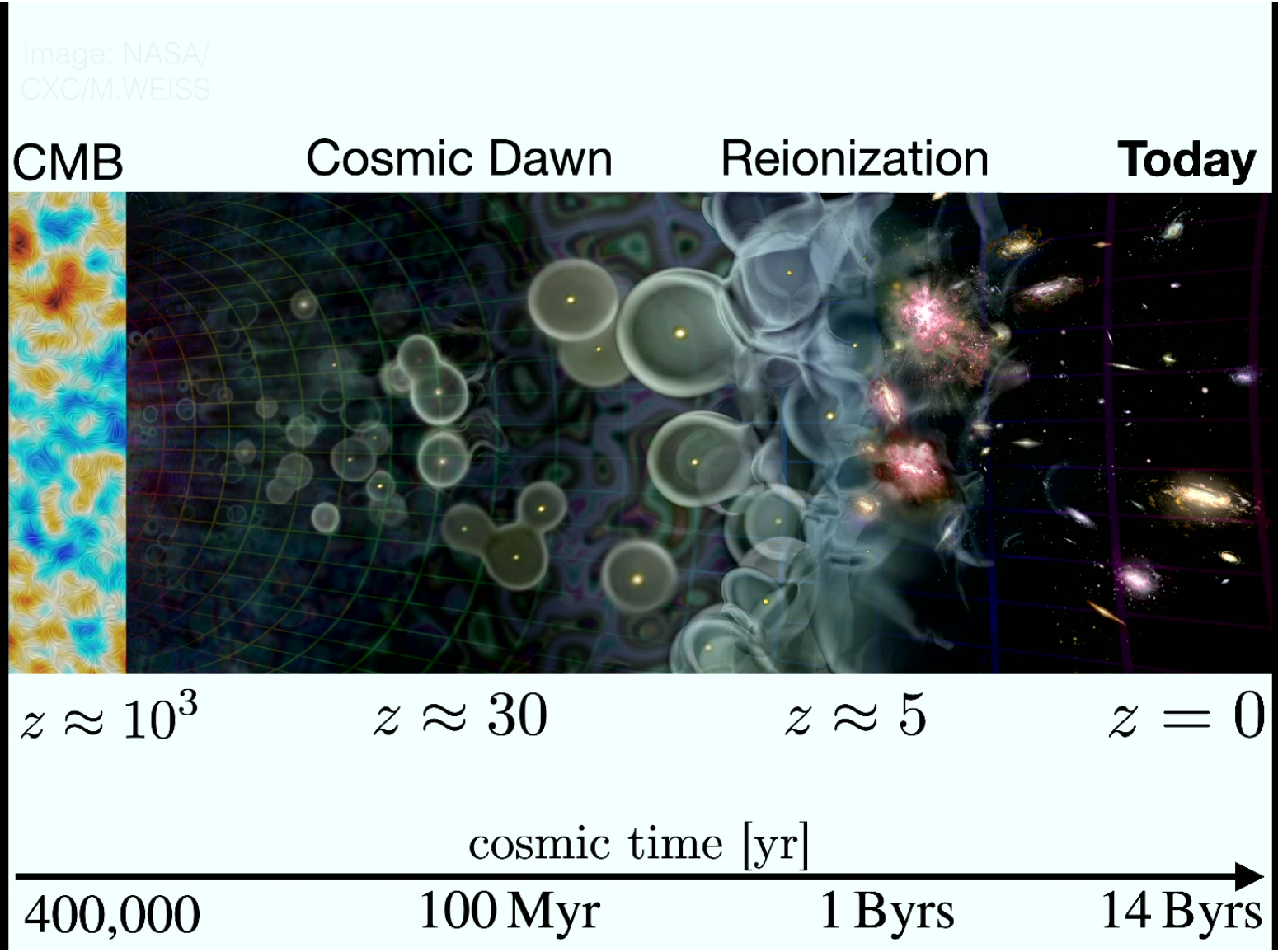
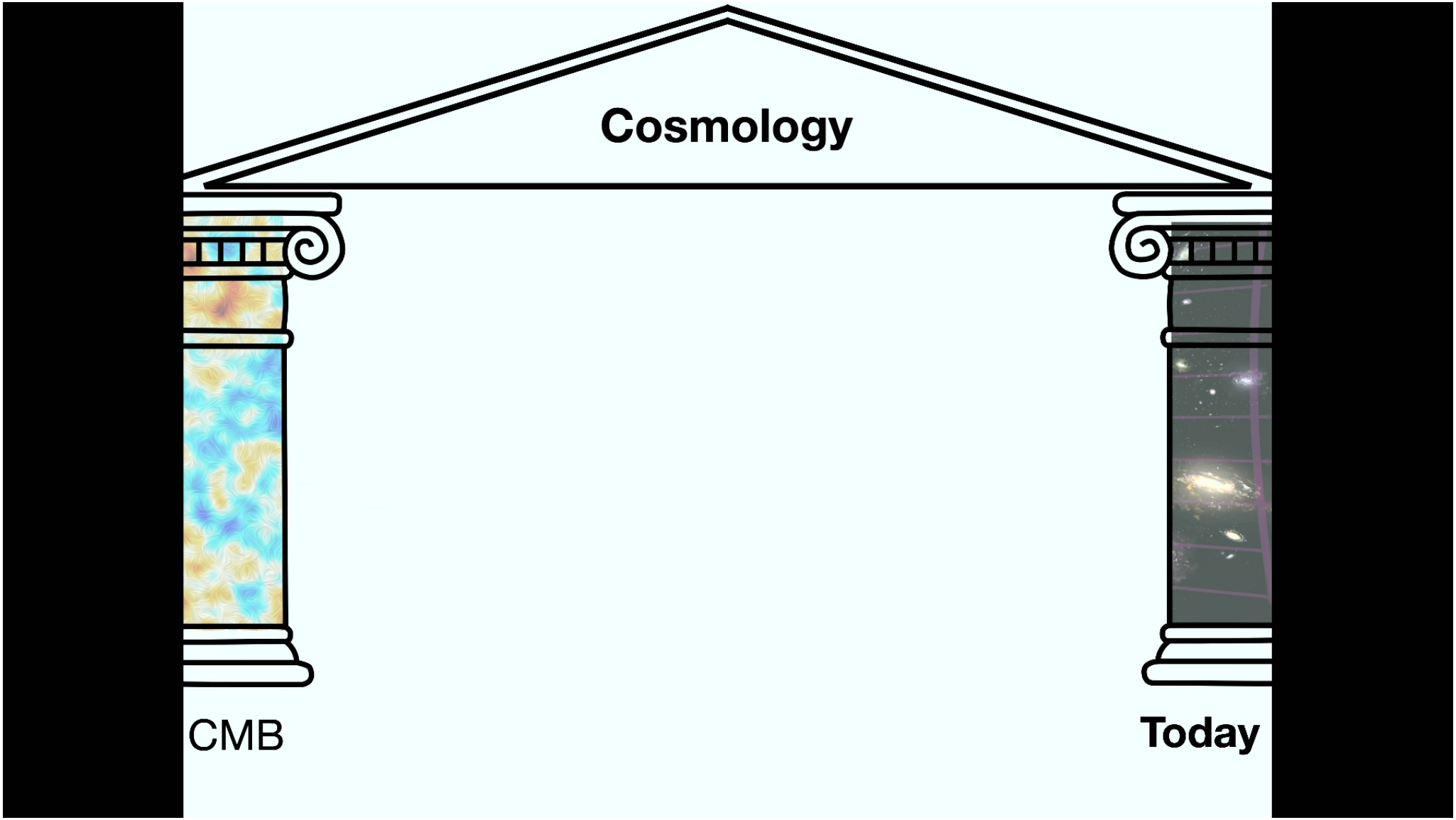
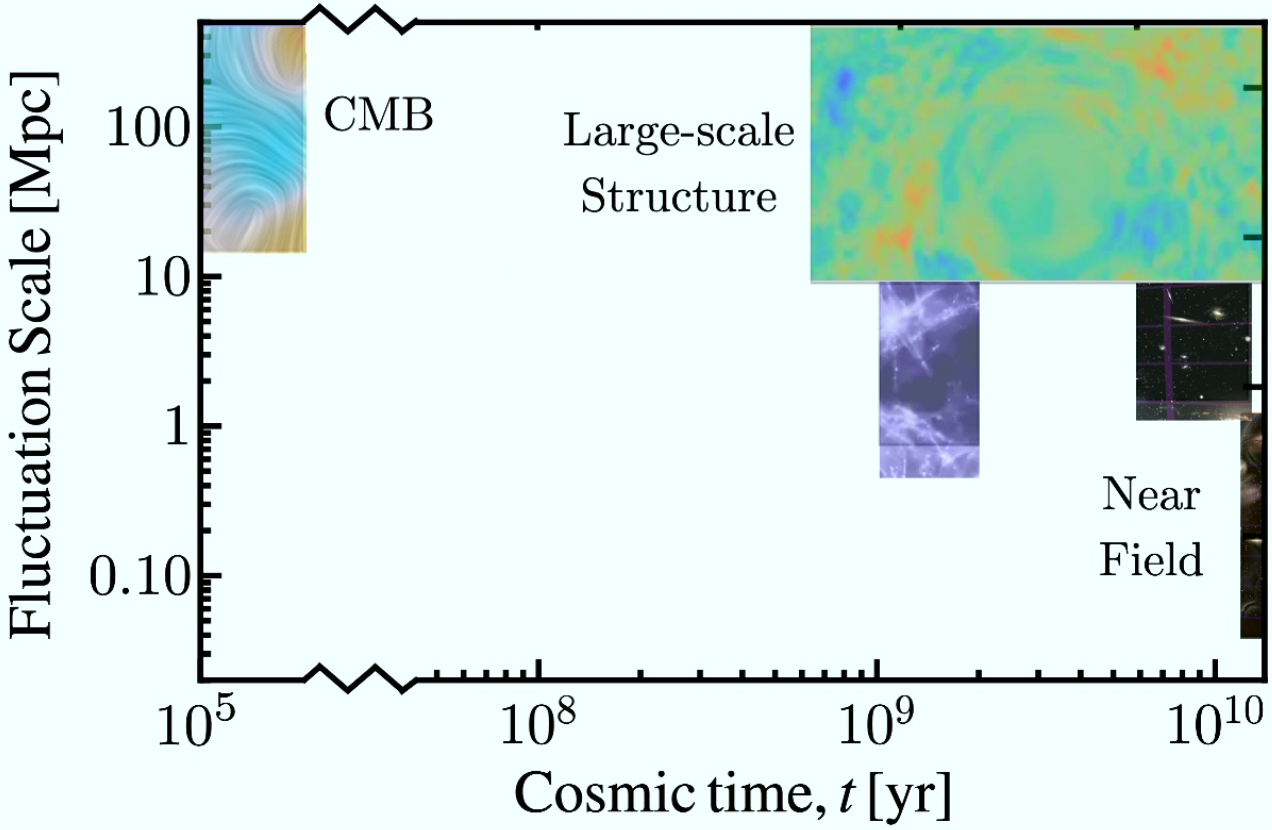


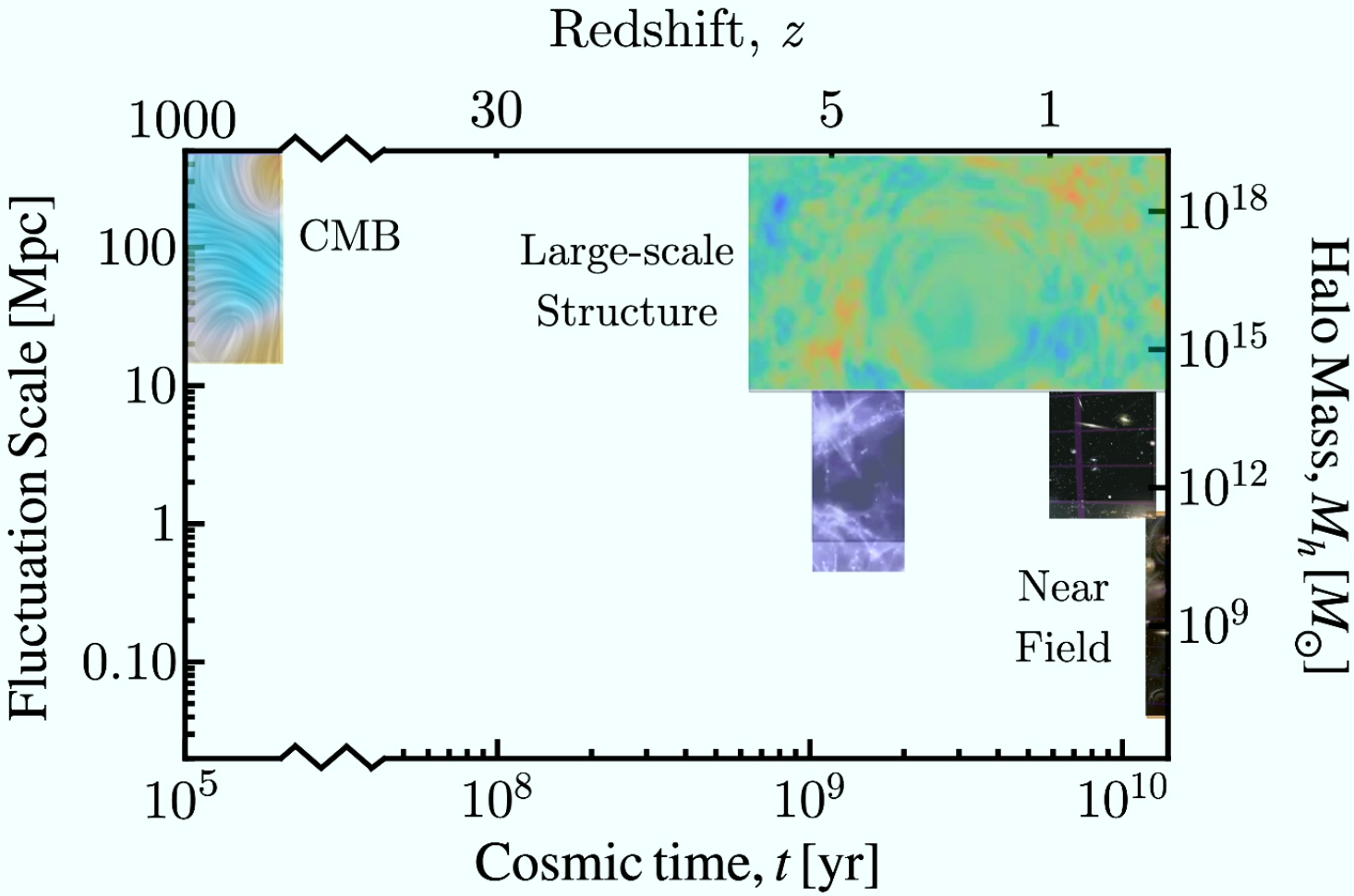
Image: NASA/
CXC/M.WEISS
CMB
Cosmic Dawn
Reionization
Today
$z \approx 10^3$
$z \approx 30$
$z \approx 5$
$z = 0$
cosmic time [yr]
400,000
100 Myr
1 Byrs
14 Byrs


Cosmology
CMB
Today

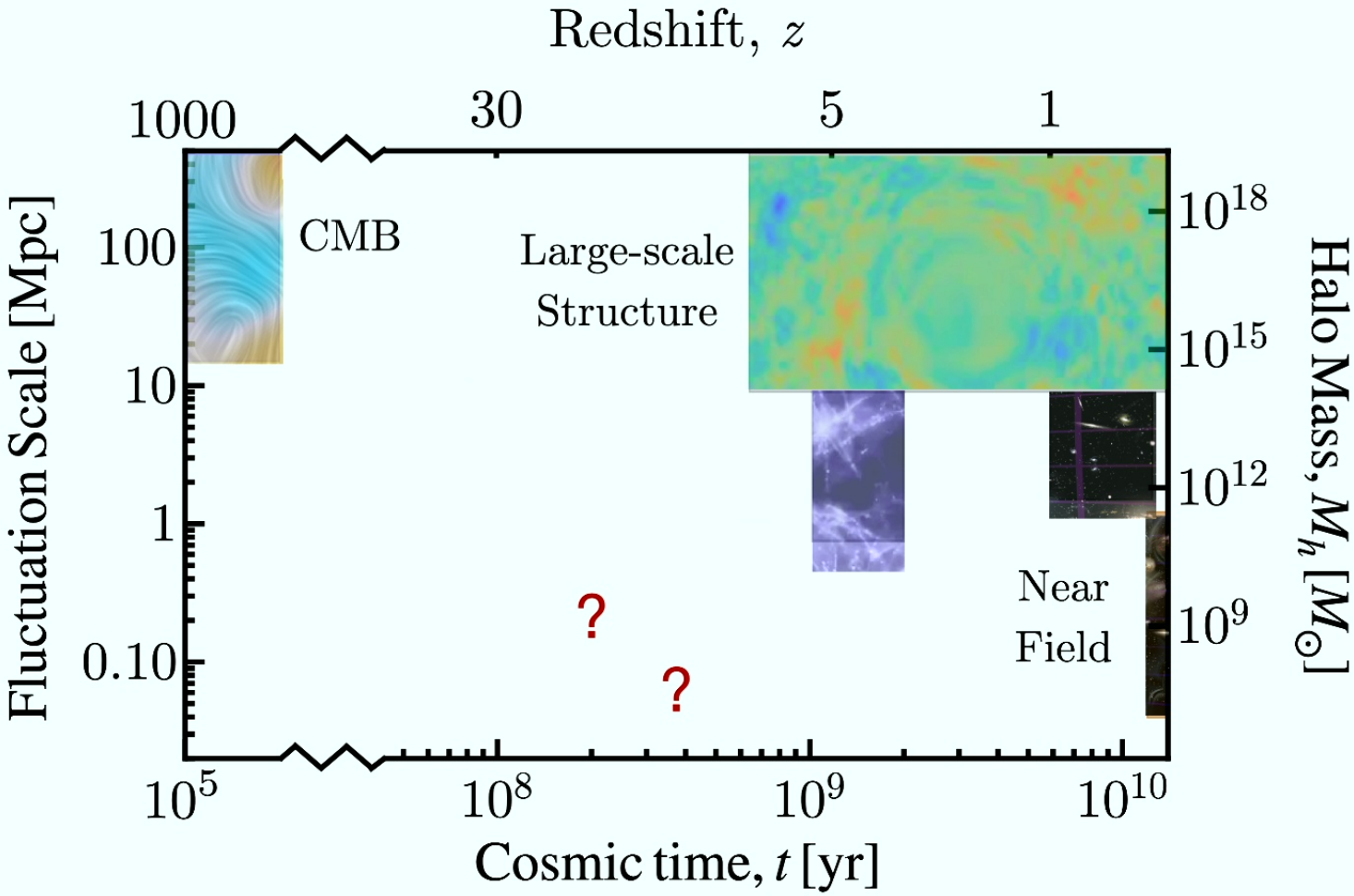
DM is cold ...

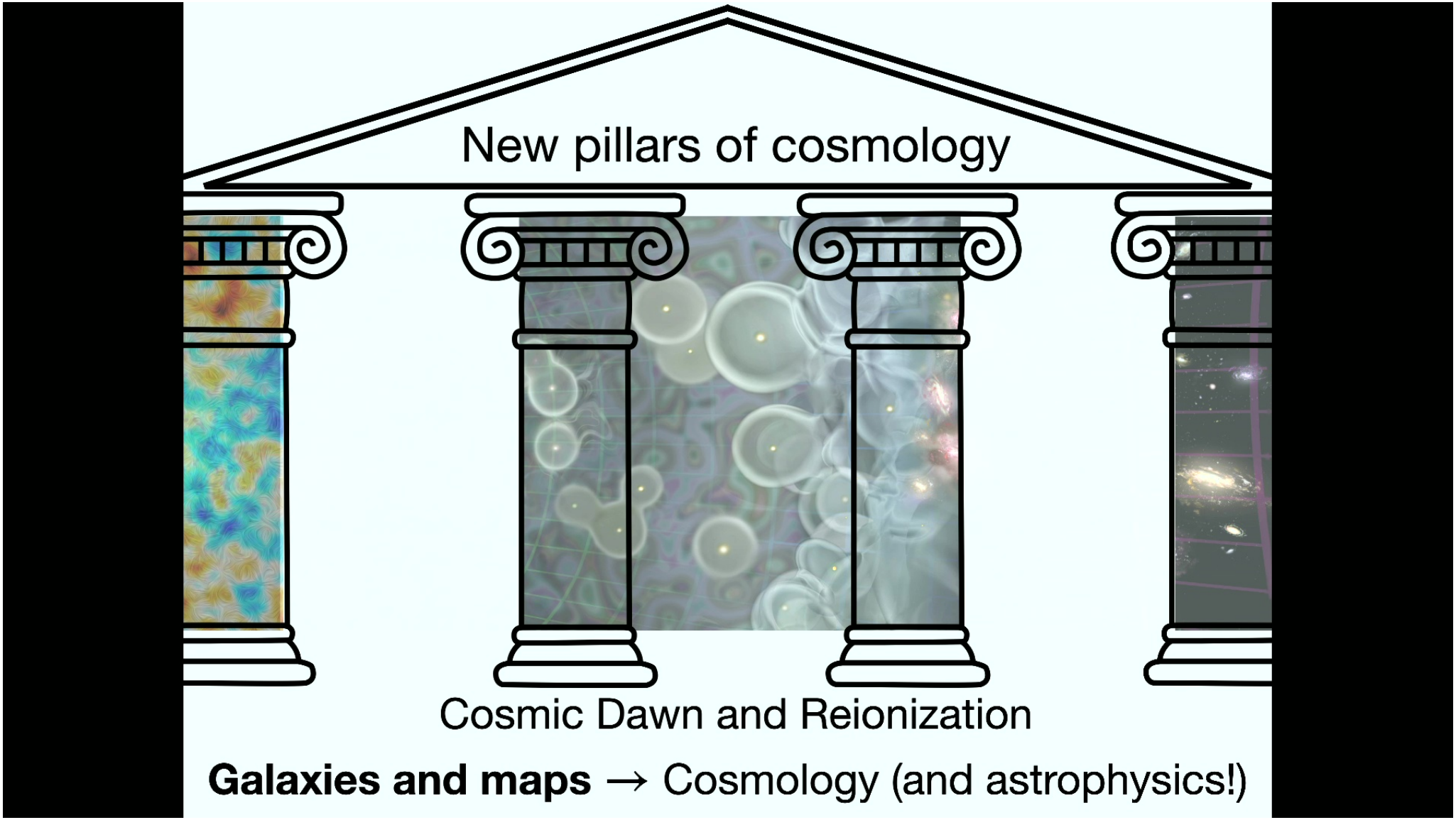

CMB
Large-scale
Structure
Near
Field
100
10
1
0.10
Fluctuation Scale [Mpc]
10^5
10^8
10^9
10^{10}
Cosmic time, t [yr]

DM is cold ...


Redshift, z
1000
30
5
1
CMB
Large-scale
Structure
Near
Field
100
10
1
0.10
Fluctuation Scale [Mpc]
10^{18}
10^{15}
10^{12}
10^{9}
Halo Mass, M_h [$M_\odot$]
10^5
10^8
10^9
10^{10}
Cosmic time, t [yr]

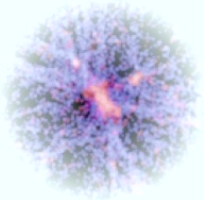
DM is cold **as far as we can tell**




New pillars of cosmology
Cosmic Dawn and Reionization
Galaxies and maps → Cosmology (and astrophysics!)

Outline

Does JWST break LCDM?



DM substructure in HST/JWST

The first halos in 21cm

A story in two headlines

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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?

BY JONATHAN O'CALLAGHAN

A story in two headlines

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The James Webb Space Telescope's first images of the distant

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FEBRUARY 9, 2024 | 6 MIN READ

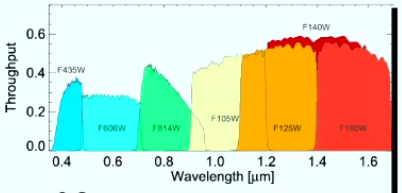
JWST's Puzzling Early Galaxies Don't Break Cosmology—But They Do Bend Astrophysics

Rather than ripping up our fundamental models of the universe, the unexpectedly big and bright galaxies spied in the early universe by JWST probably have astrophysical explanations

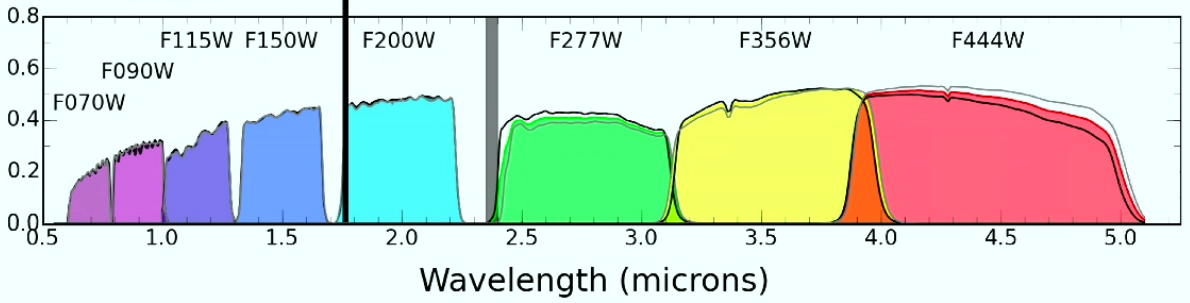
BY JONATHAN O'CALLAGHAN

As a theorist, what does JWST do for us?

HST



JWST



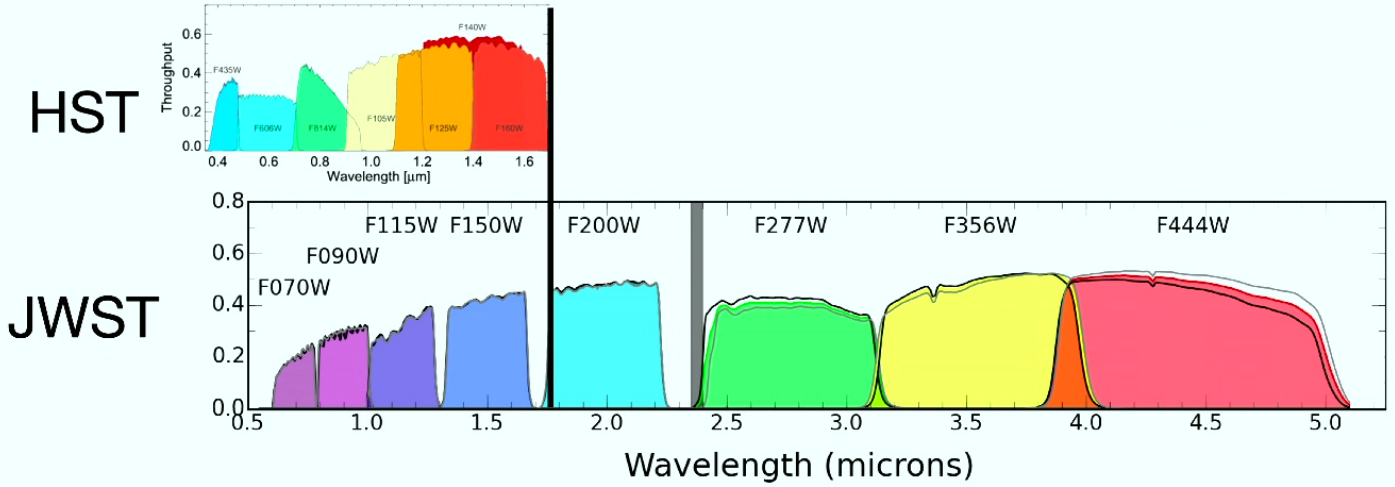
As a theorist, what does JWST do for us?

Measure rest-frame visible $\rightarrow M_\star, M_{\rm BH}, \ldots$

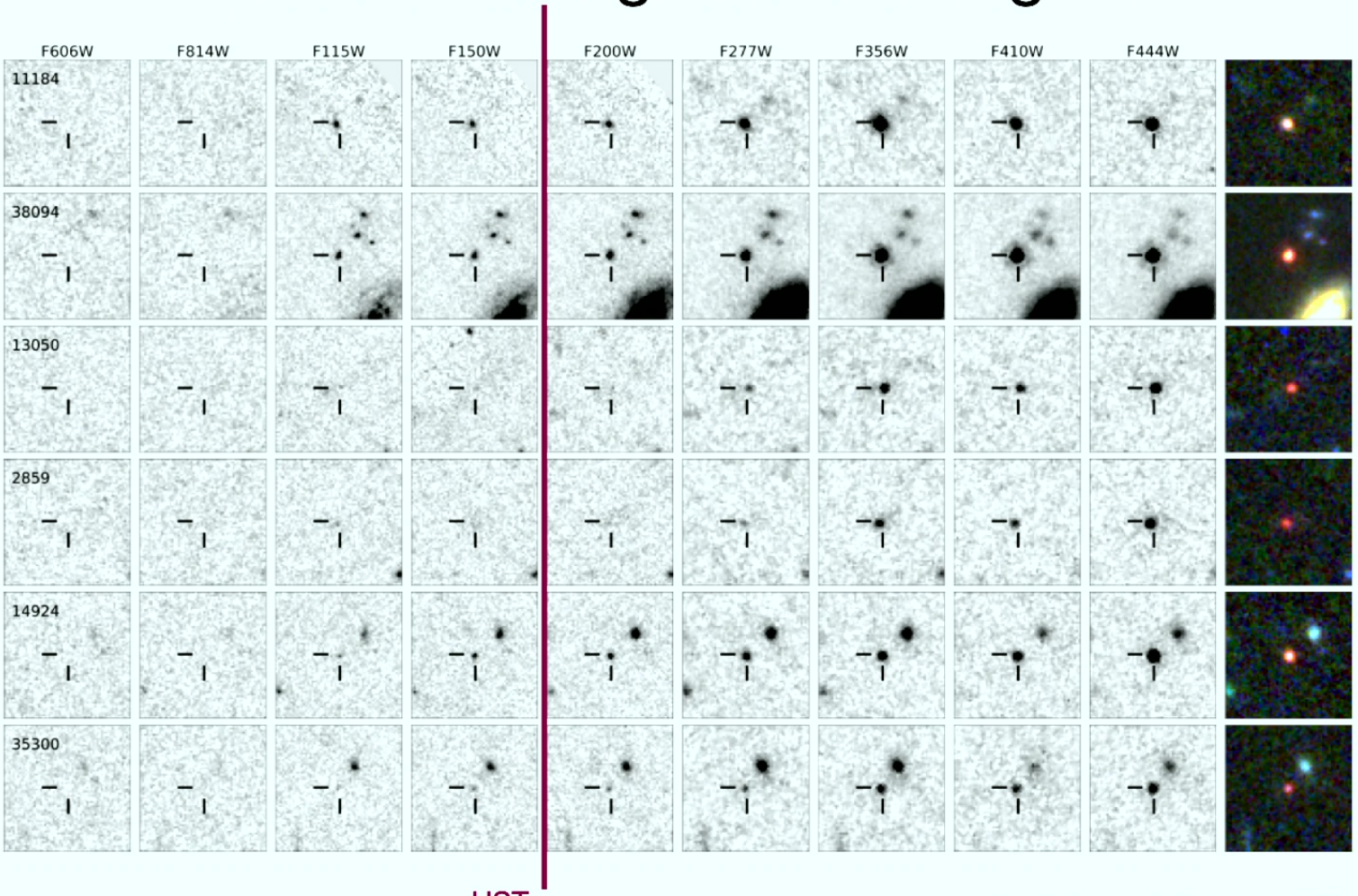
Reach higher redshifts $\rightarrow$ UV at higher z

HST

JWST

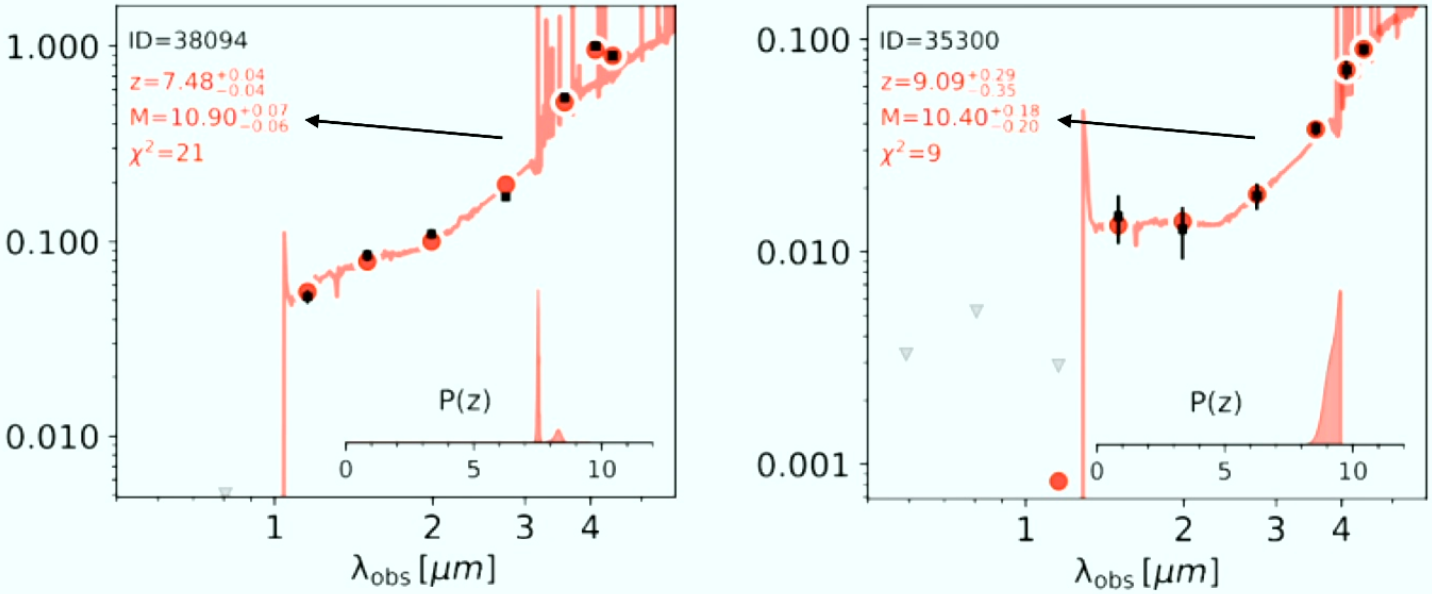


Ultramassive galaxies at high z



Labbe+ Nature 23

Ultramassive galaxies at high z

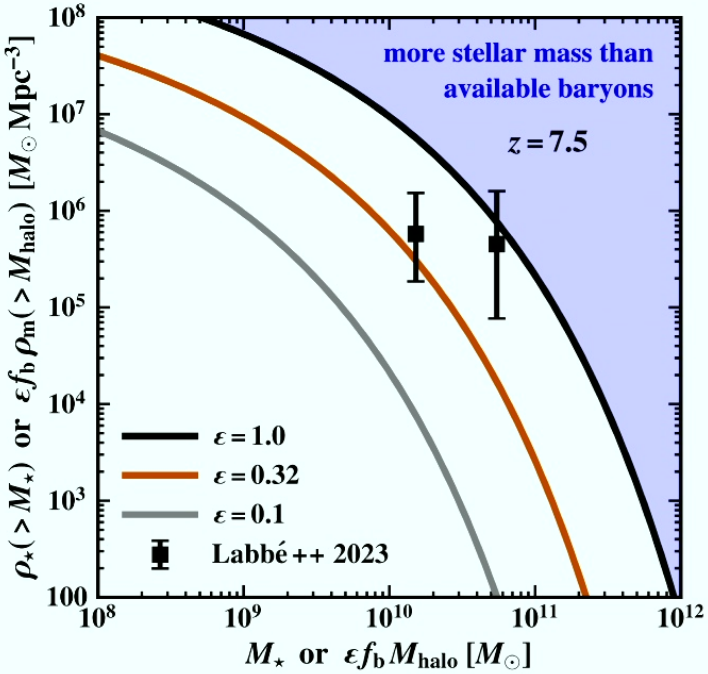


Top 2 massive galaxies. Only photometry*

Balmer break?

Labbe+ Nature 23

Do they break LCDM?

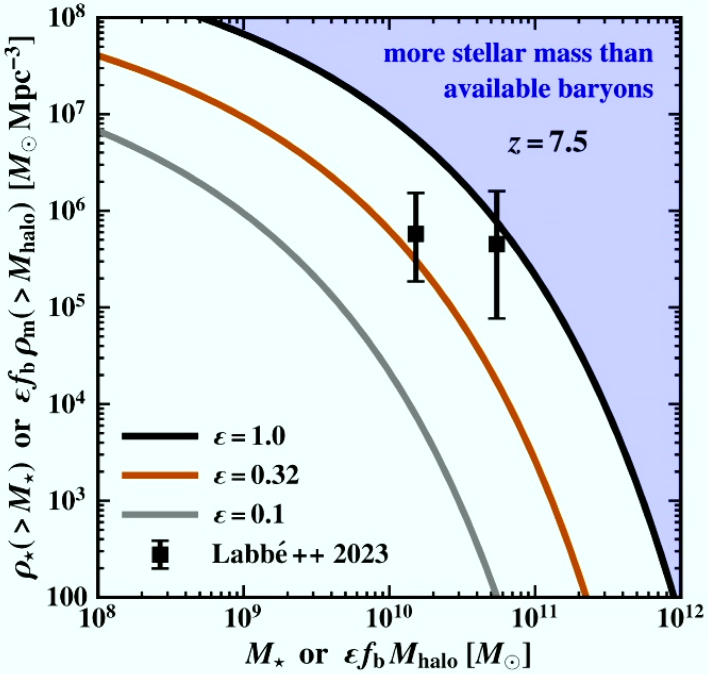


Boylan-Kolchin 23
(Data from Labbé+ 23)

$$N_{\rm gal}(>M_\star) = {\rm Vol} \times n_{\rm gal}$$

$$n_{\rm gal} = \int_{M_{h,\rm min}} dM_h \frac{dn}{dM_h}$$

Do they break LCDM?



Boylan-Kolchin 23
(Data from Labbé+ 23)

$$n_{\rm gal} \gtrsim 10^{-8}\,{\rm Mpc}^{-3}$$

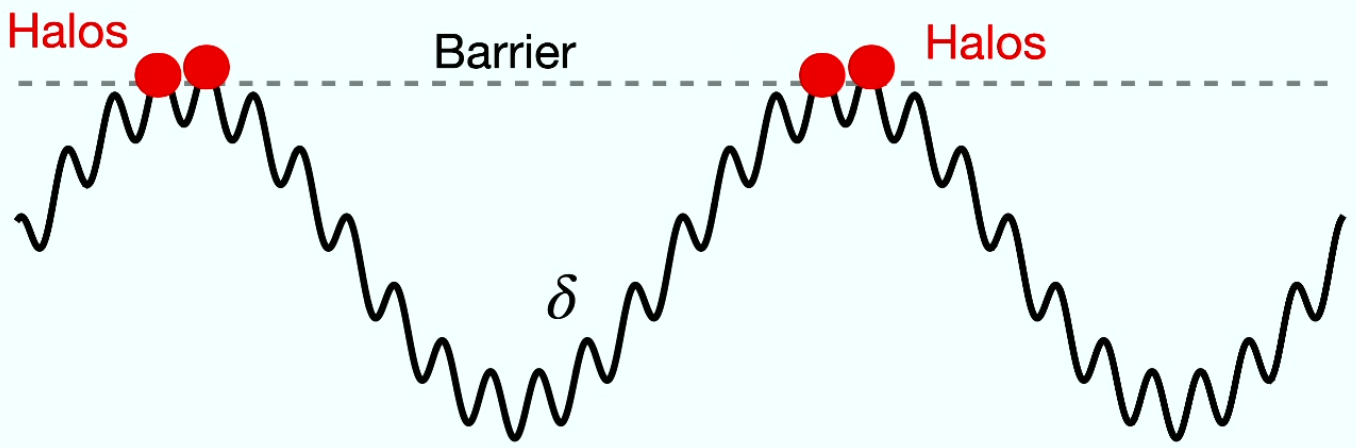
$$\mathrm{Vol} \approx 10^5\,{\rm Mpc}^{-3}$$

Need more halos??

$$N_{\rm gal}(>M_\star) = \mathrm{Vol} \times n_{\rm gal}$$

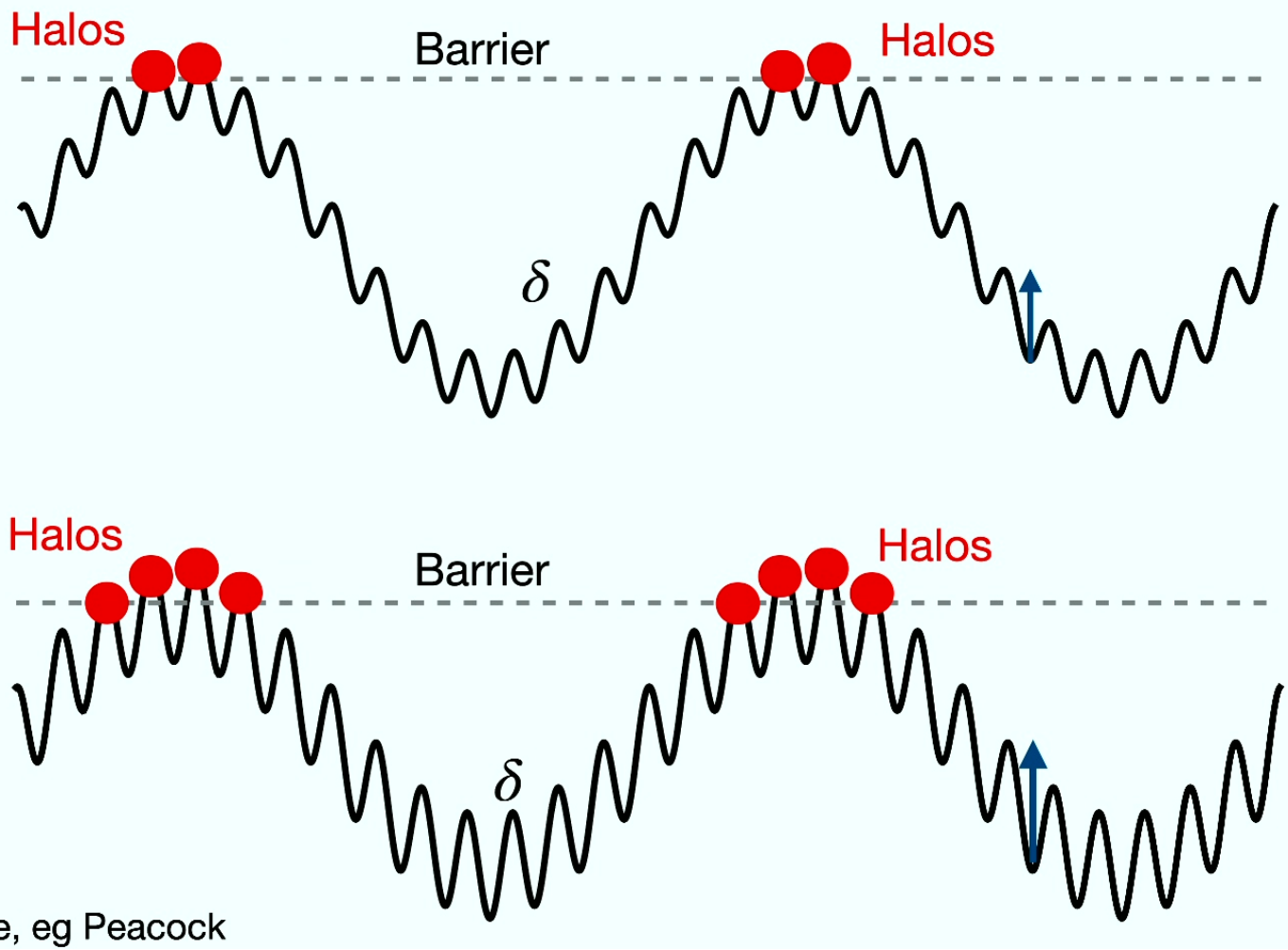
$$n_{\rm gal} = \int_{M_{h,\rm min}} dM_h \frac{dn}{dM_h}$$

Halos from fluctuations



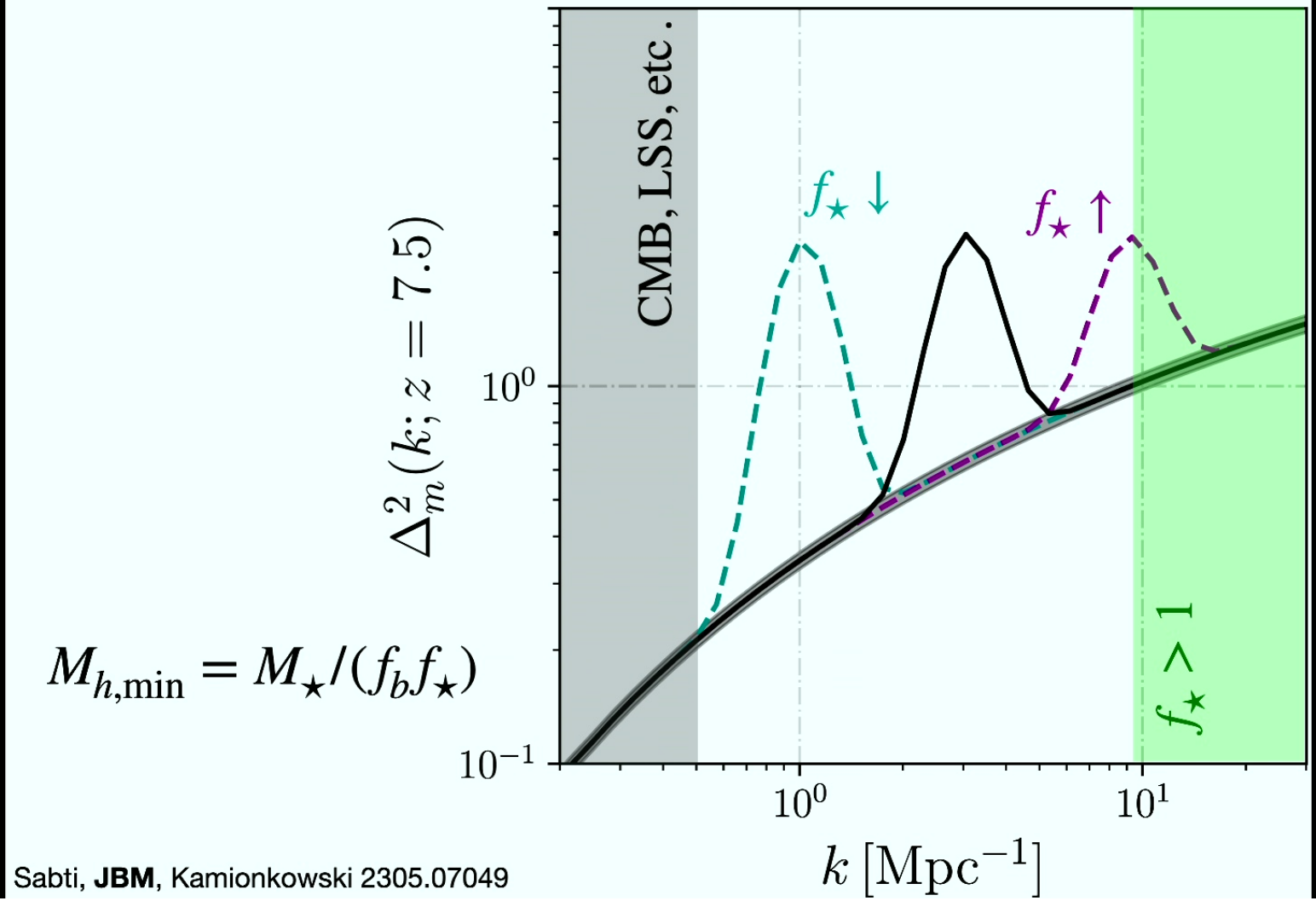
See, eg Peacock

Halos from fluctuations



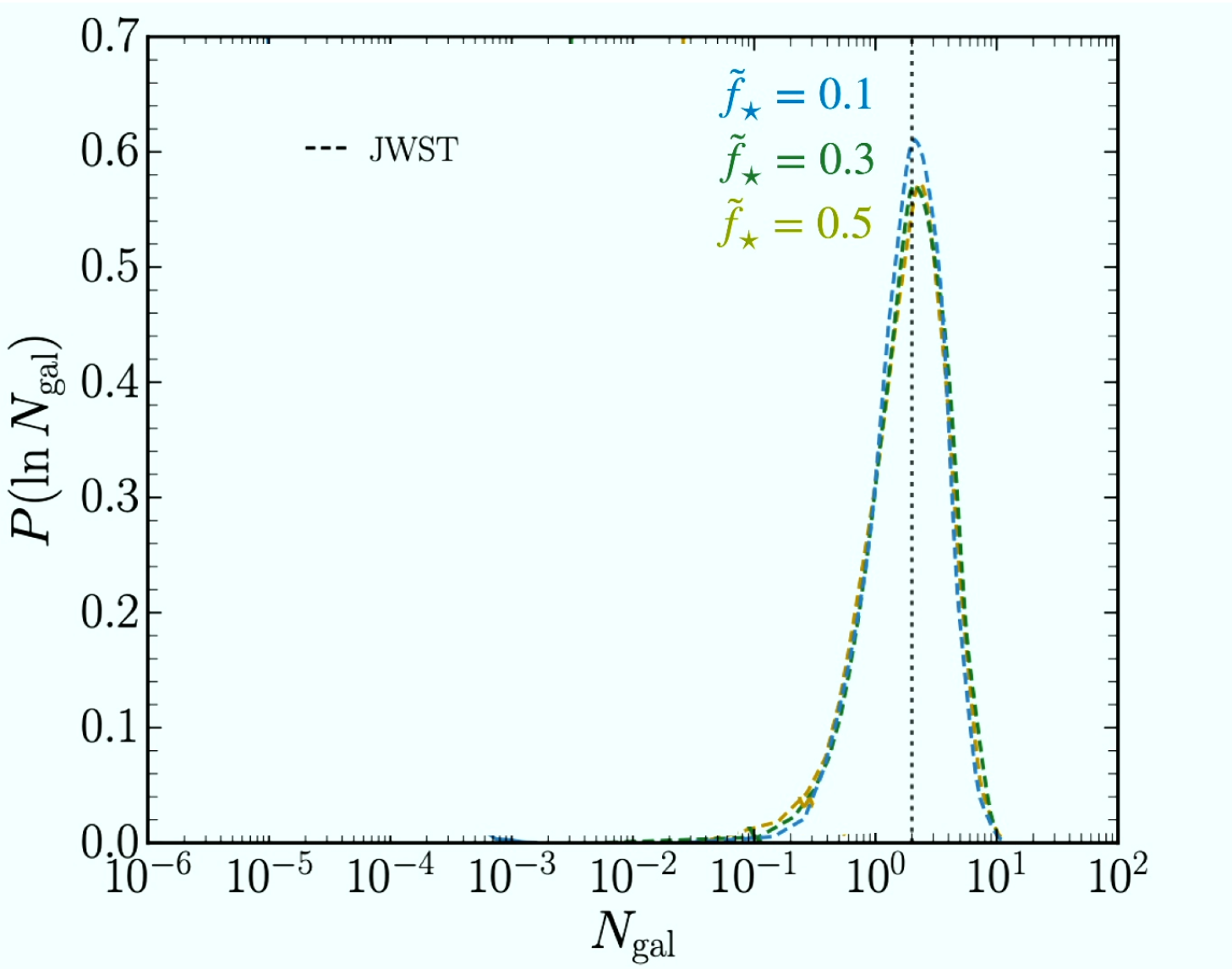
See, eg Peacock

Is there more power?

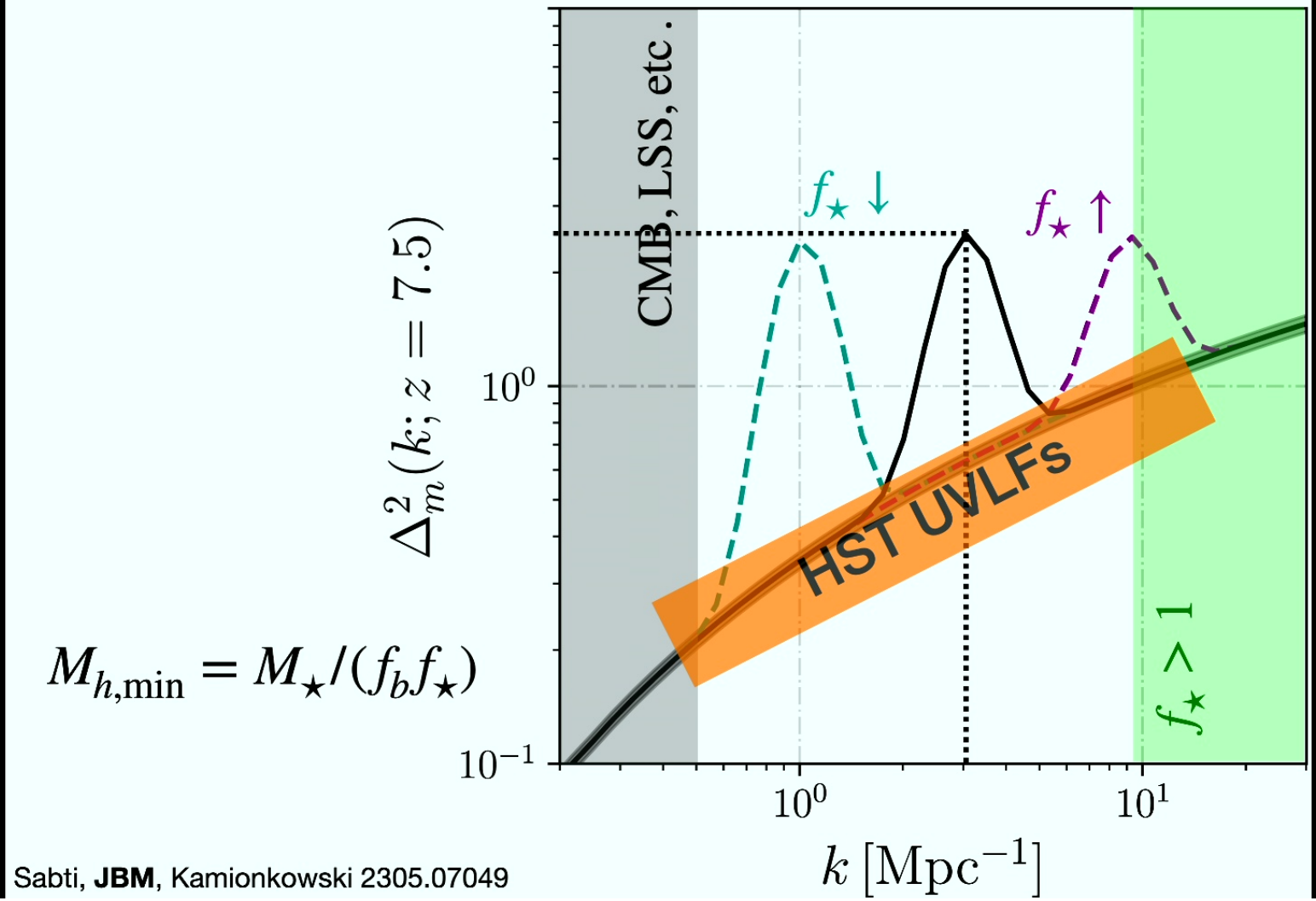


$$M_{h,\mathrm{min}} = M_\star/(f_b f_\star)$$

Sabti, **JBM**, Kamionkowski 2305.07049

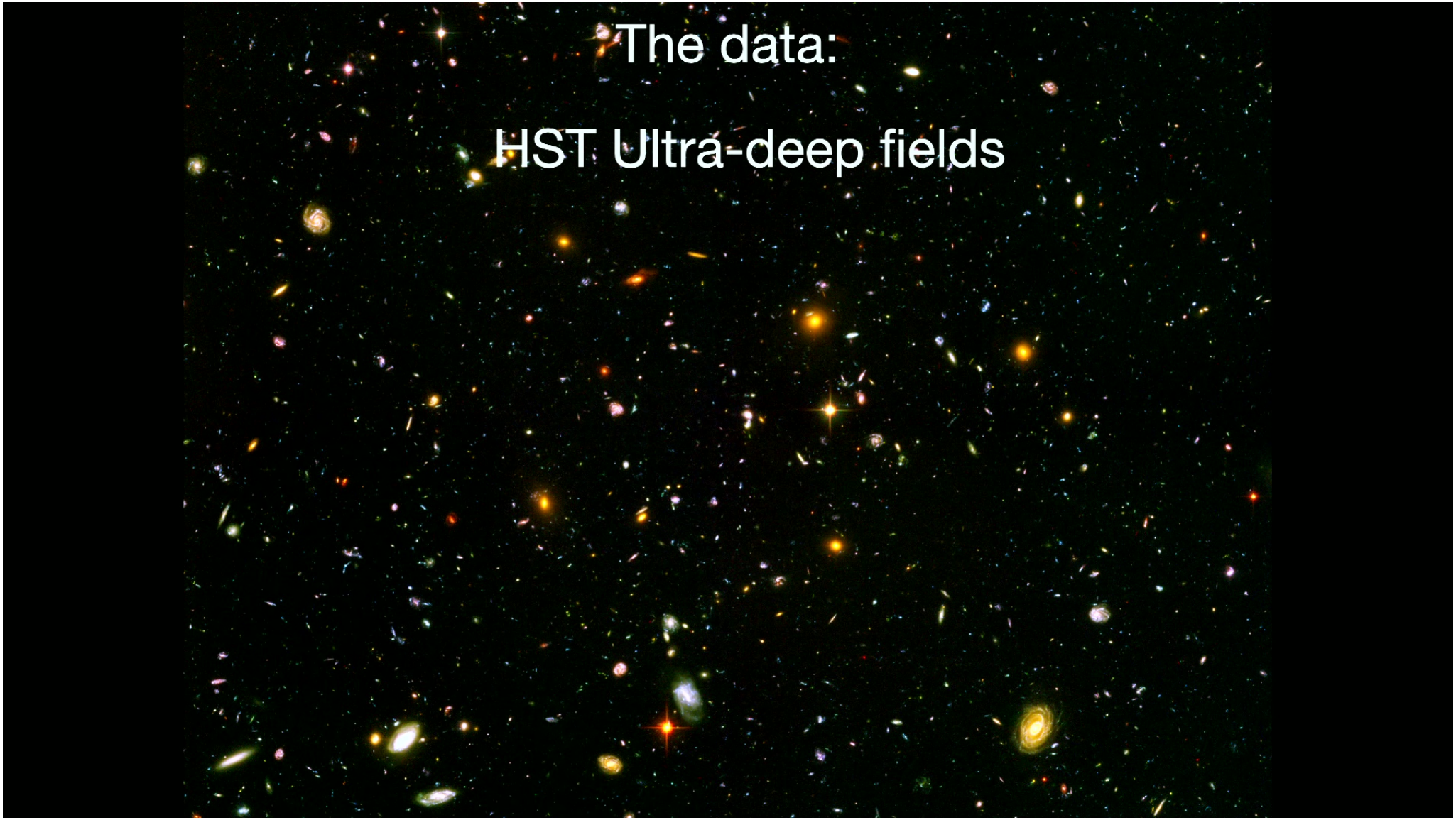

0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
$P(\ln N_{\rm gal})$
--- JWST
$\tilde{f}_\star = 0.1$
$\tilde{f}_\star = 0.3$
$\tilde{f}_\star = 0.5$
10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}
$N_{\rm gal}$

Is there more power?

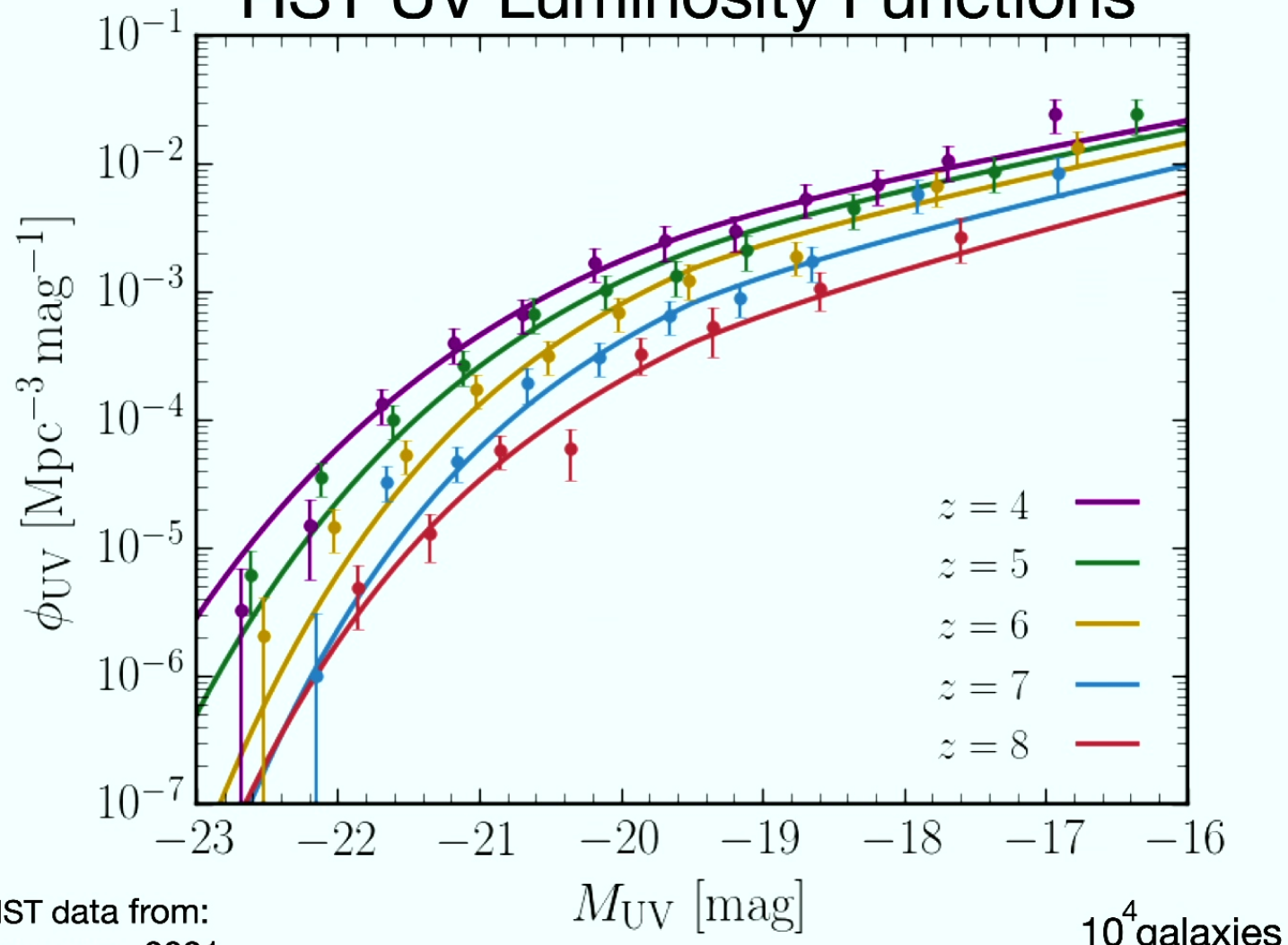


$$M_{h,\mathrm{min}} = M_\star/(f_b f_\star)$$

Sabti, **JBM**, Kamionkowski 2305.07049


The data:
HST Ultra-deep fields

HST UV Luminosity Functions

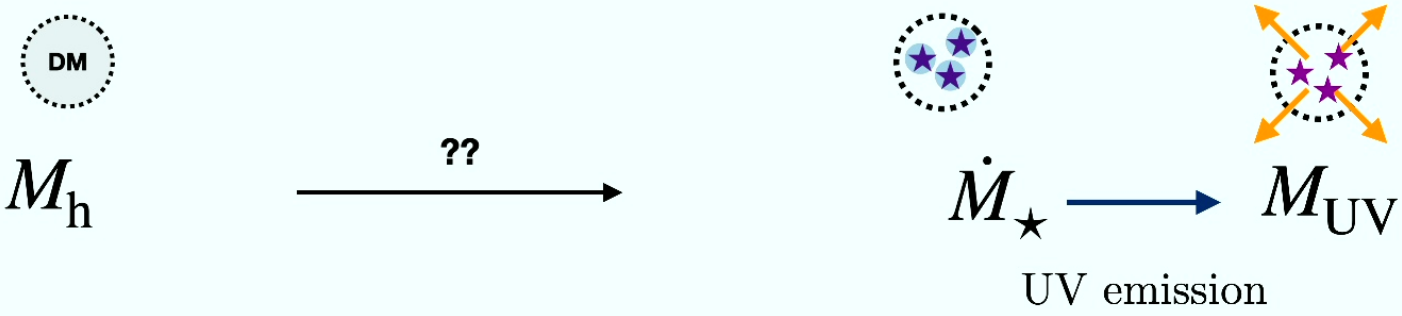


HST data from:
Bouwens+ 2021

10^4 galaxies

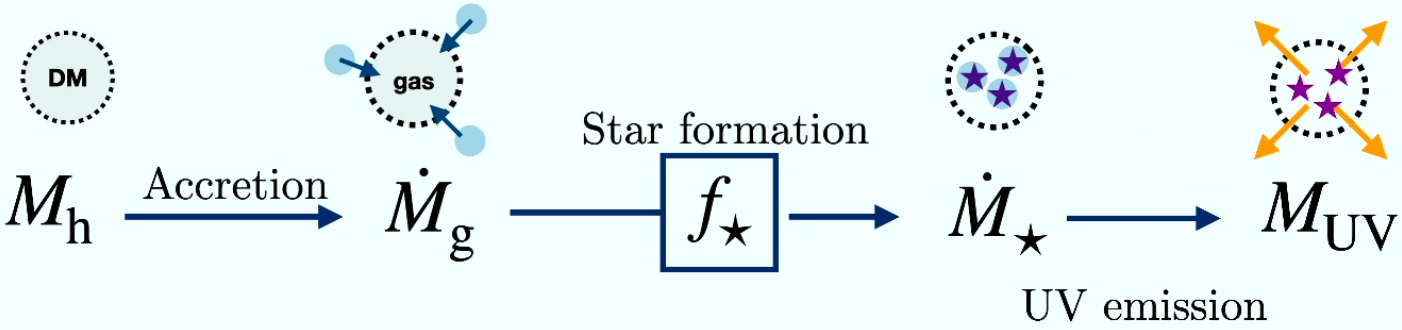
HST UV Luminosity Functions
(**Simple** theoretical model)

Assumption 1: UV light comes from young stars

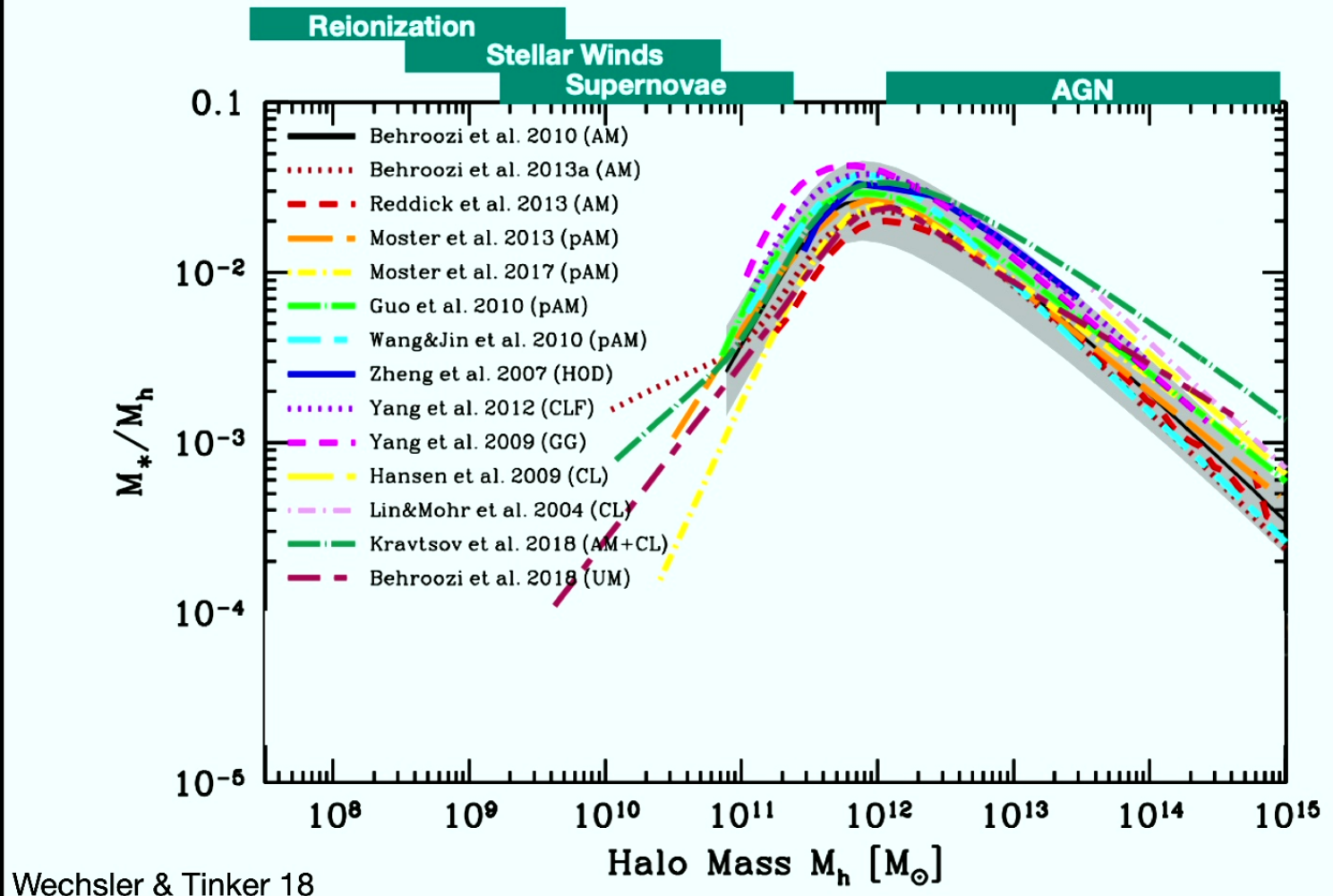


HST UV Luminosity Functions
(**Simple** theoretical model)

Assumption 2: $\dot{M}_*$ is a parametric function of $\dot{M}_h$

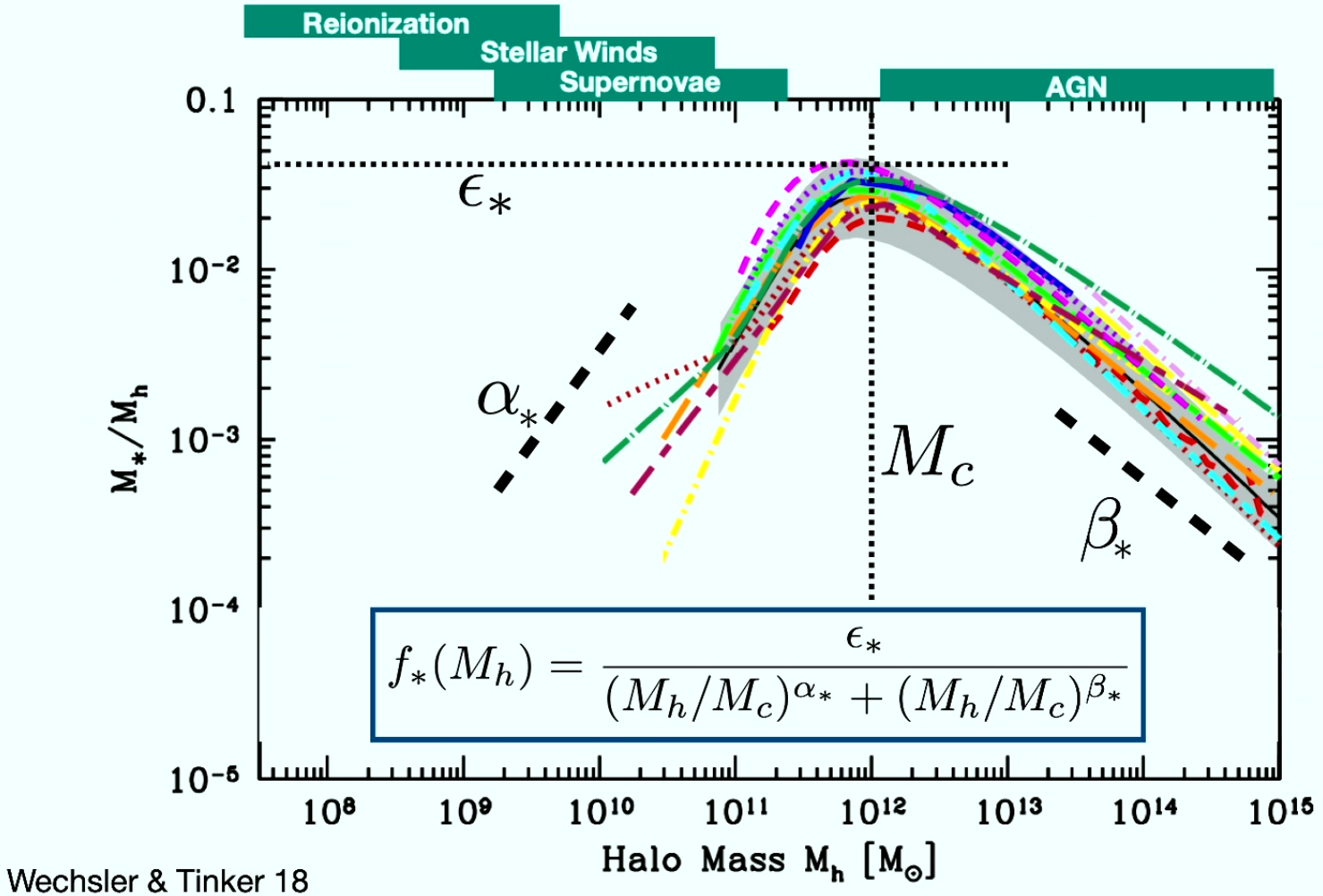


Halo-galaxy connection



Wechsler & Tinker 18
(based on Behroozi+18)

Halo-galaxy connection: a SAM



Wechsler & Tinker 18
(based on Behroozi+18)

GALLUMI

https://github.com/NNSSA/GALLUMI_public

Fast (~10 ms) SAM + likelihood

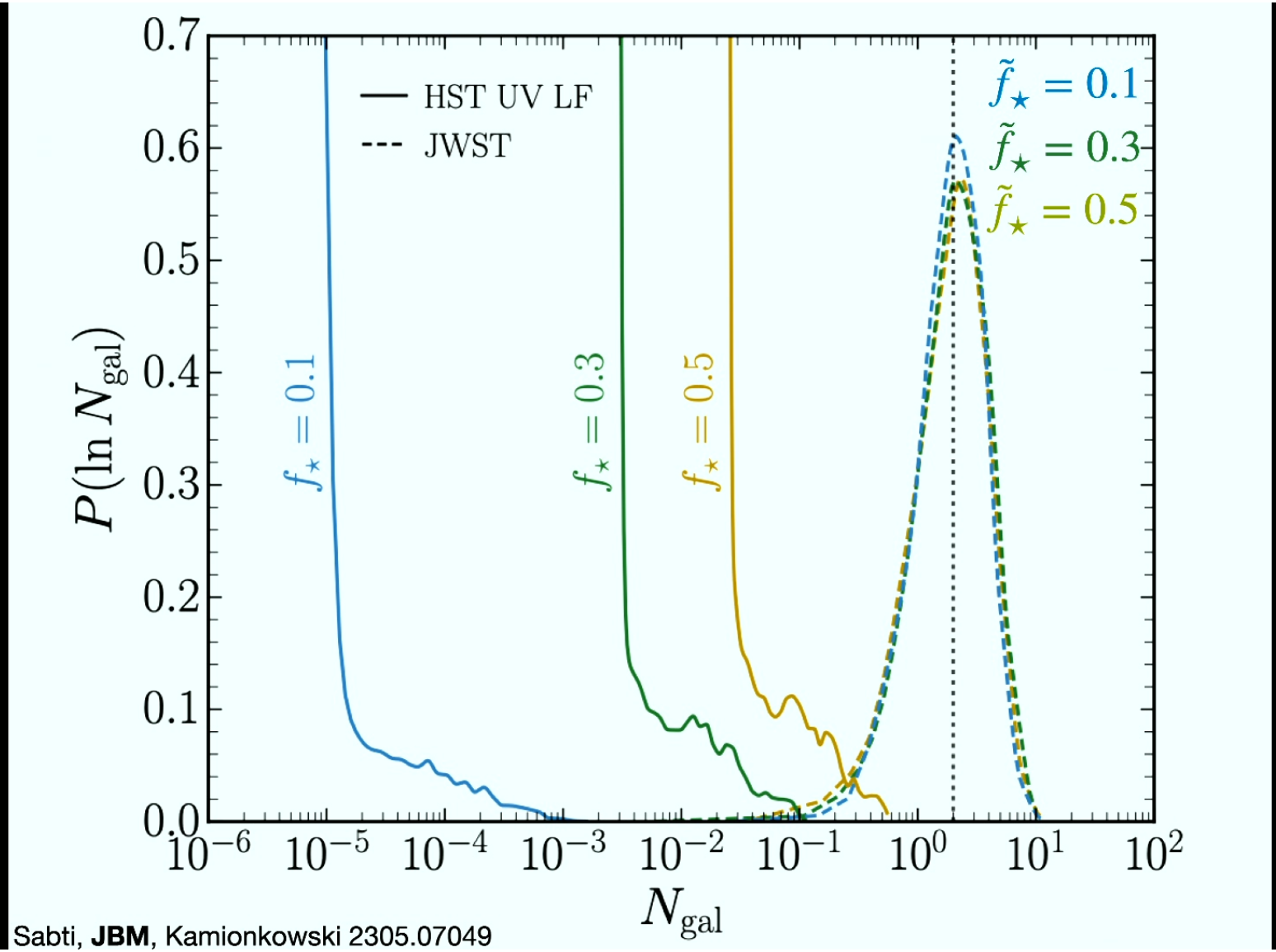
$$M_{\rm h} \rightrightarrows M_{\rm UV}$$

Three halo-galaxy connections, with stochasticity

Different dust assumptions

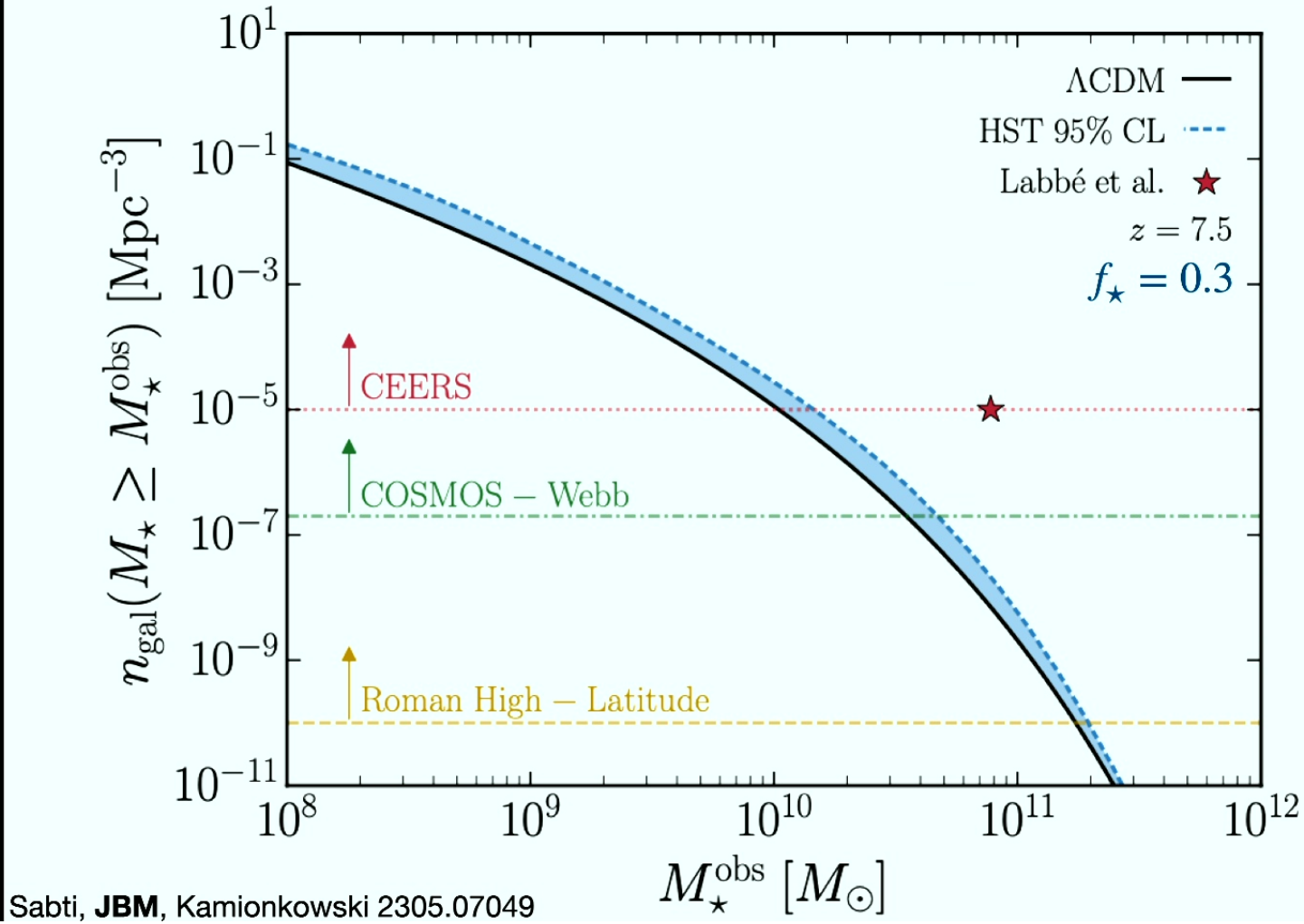
Talks to Montepython 3 + public

Sabti*, **JBM**, Blas 2021a,b



Sabti, **JBM**, Kamionkowski 2305.07049

How many massive galaxies?



Sabti, **JBM**, Kamionkowski 2305.07049

A lower mass from spectra

(At z~9)

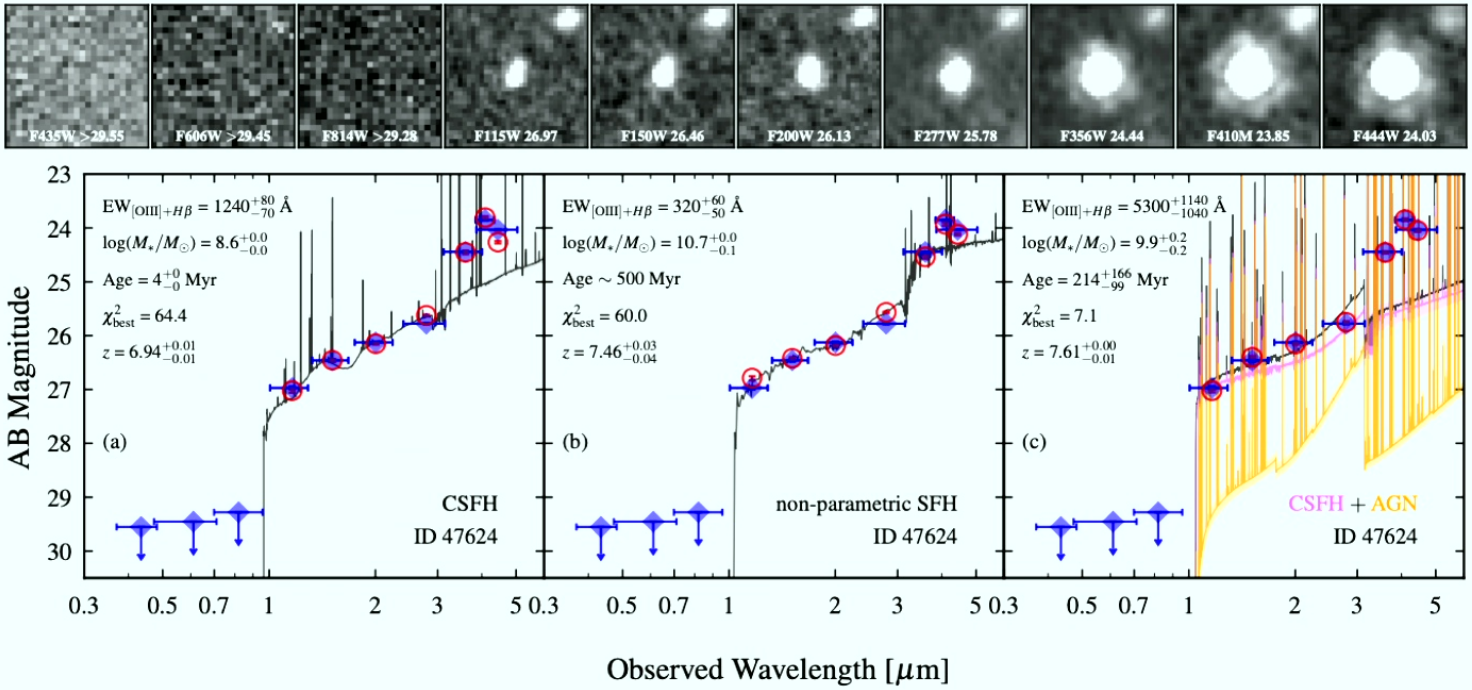
Table 2. Physical Properties of the NIRCam CEERS galaxies confirmed at $z \simeq 8-9$

MPT-ID	$z_{\rm spec}$	$M_{\rm UV}$ (mag)	$E(B-V)$ (mag)	SFR ($M_\odot$ yr^{-1})	$M_{\rm star}$ ($10^8 M_\odot$)	$f_{\rm burst}$	EW([OIII]5008) (Å)	EW(Hβ) (Å)	R3	O32	Mode
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
2	8.807	-20.44	$0.03^{+0.03}_{-0.02}$	$3.2^{+1.1}_{-0.5}$	$1.2^{+0.8}_{-0.6}$	$0.12^{+0.18}_{-0.08}$	372 ± 112	< 150	> 2.5	> 8.2	P
3	8.005	-20.47	$0.15^{+0.04}_{-0.07}$	$9.8^{+2.9}_{-3.2}$	$2.0^{+1.7}_{-0.8}$	$0.25^{+0.21}_{-0.16}$	1022 ± 129	163 ± 62	6.3 ± 2.3	> 8.1	P
4	7.9932	-19.44	$0.33^{+0.12}_{-0.09}$	$16.3^{+21.0}_{-8.1}$	$8.7^{+6.3}_{-4.4}$	$0.10^{+0.18}_{-0.07}$	430 ± 69	< 166	> 2.6	$\cdots$ †	M
7	8.876	-20.75	$0.03^{+0.03}_{-0.02}$	$3.9^{+1.1}_{-0.6}$	$1.2^{+0.9}_{-0.6}$	$0.13^{+0.25}_{-0.09}$	895 ± 436	350 ± 194	2.6 ± 0.8	> 5.5	M
20	7.769	-18.55	$0.61^{+0.02}_{-0.18}$	$64.3^{+18.6}_{-50.8}$	$30.6^{+19.7}_{-13.0}$	$0.08^{+0.13}_{-0.06}$	109 ± 19	50 ± 16	2.2 ± 0.8	> 6.1	P
23	8.8805	-18.38	$0.06^{+0.1}_{-0.04}$	$0.8^{+0.7}_{-0.3}$	$0.2^{+0.2}_{-0.1}$	$0.21^{+0.23}_{-0.14}$	1195 ± 200	208 ± 121	5.8 ± 3.3	> 6.5	M
24	8.998	-19.08	$0.09^{+0.08}_{-0.06}$	$2.7^{+1.5}_{-1.0}$	$0.6^{+0.6}_{-0.3}$	$0.23^{+0.22}_{-0.15}$	989 ± 131	173 ± 51 ††	5.7 ± 1.7	> 5.0	M

Fujimoto+ 23

Perhaps one of them hosts a QSO?

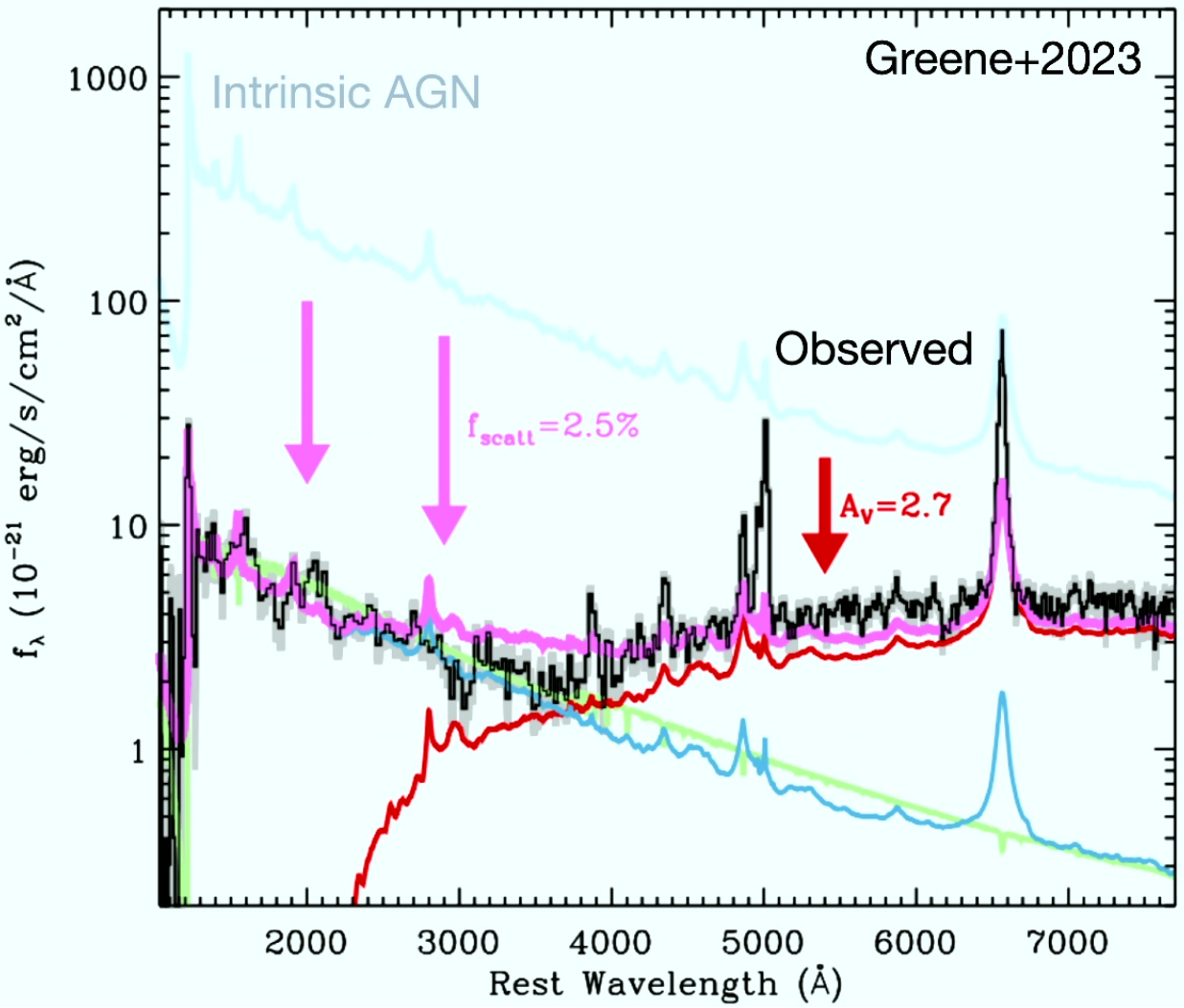
(At z~7.5)



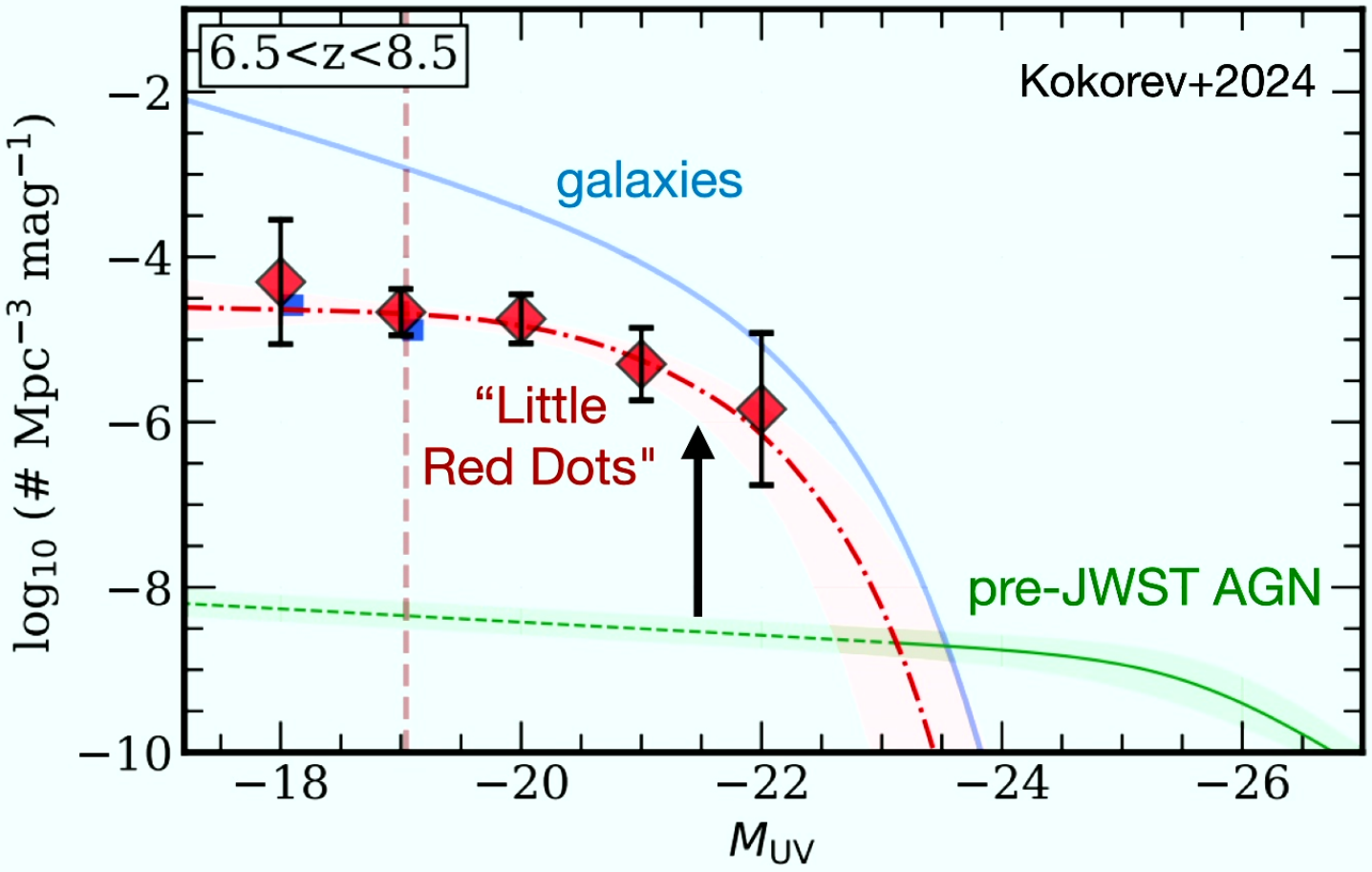
Endsley+ 22

Detour: SMBHs??

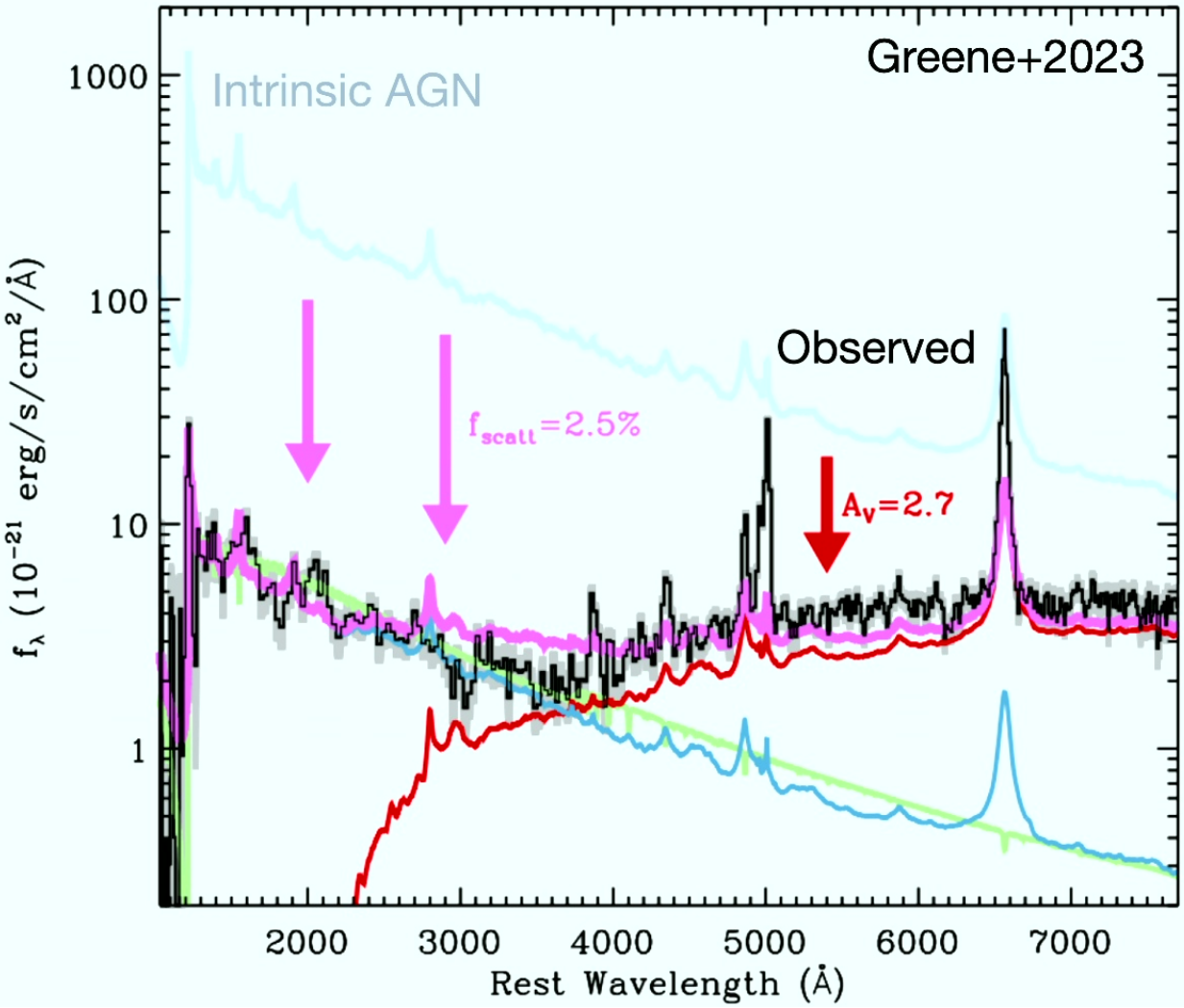
Detour: SMBHs??



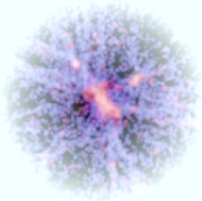
Detour: SMBHs??



Detour: SMBHs??



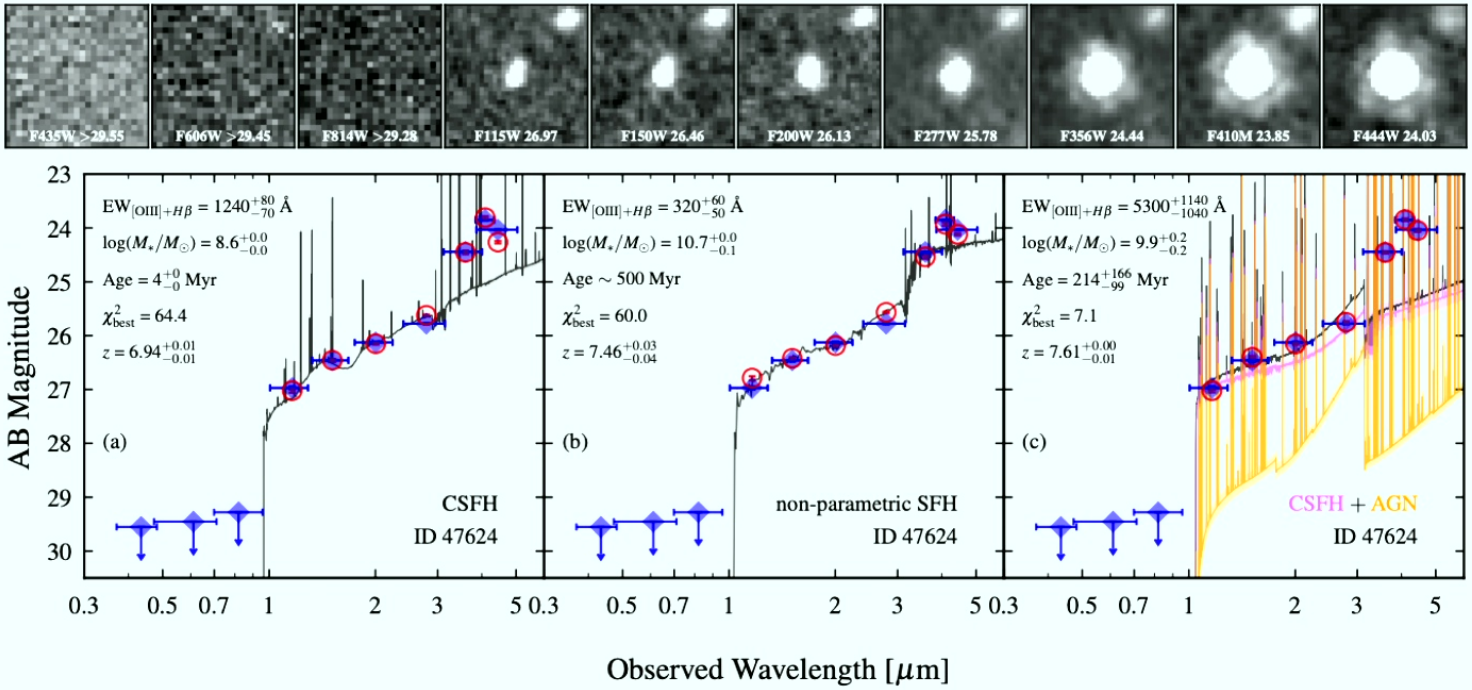
Outline



DM substructure in HST/JWST

Perhaps one of them hosts a QSO?

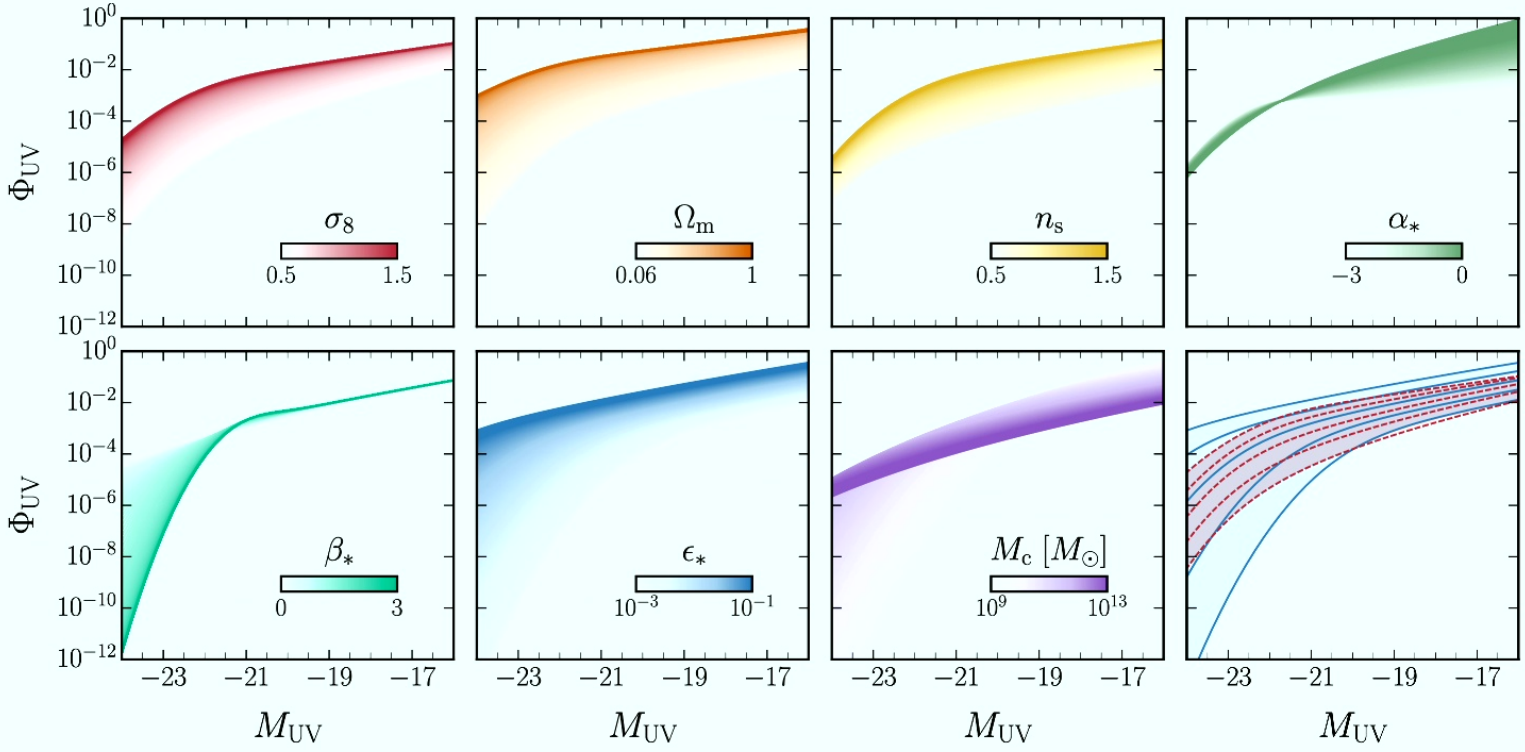
(At z~7.5)



Endsley+ 22

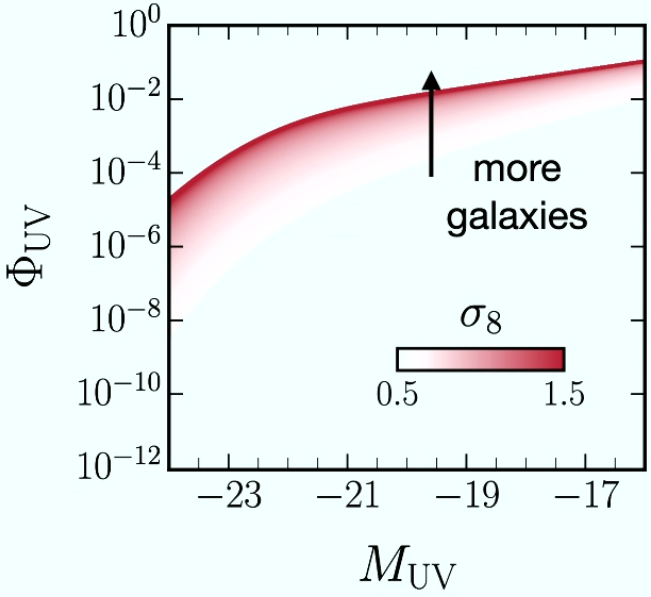
What other cosmology can we learn?

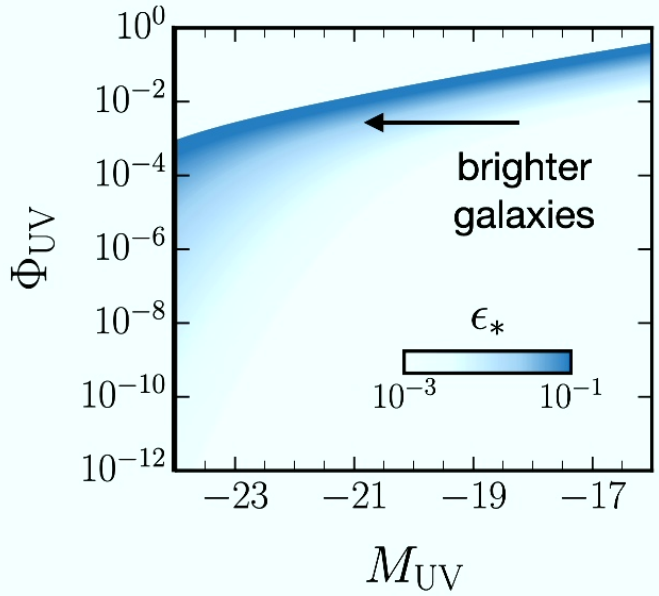
Astro vs Cosmo parameters



Sabti, JBM, Blas 2022a,b

What other cosmology can we learn?

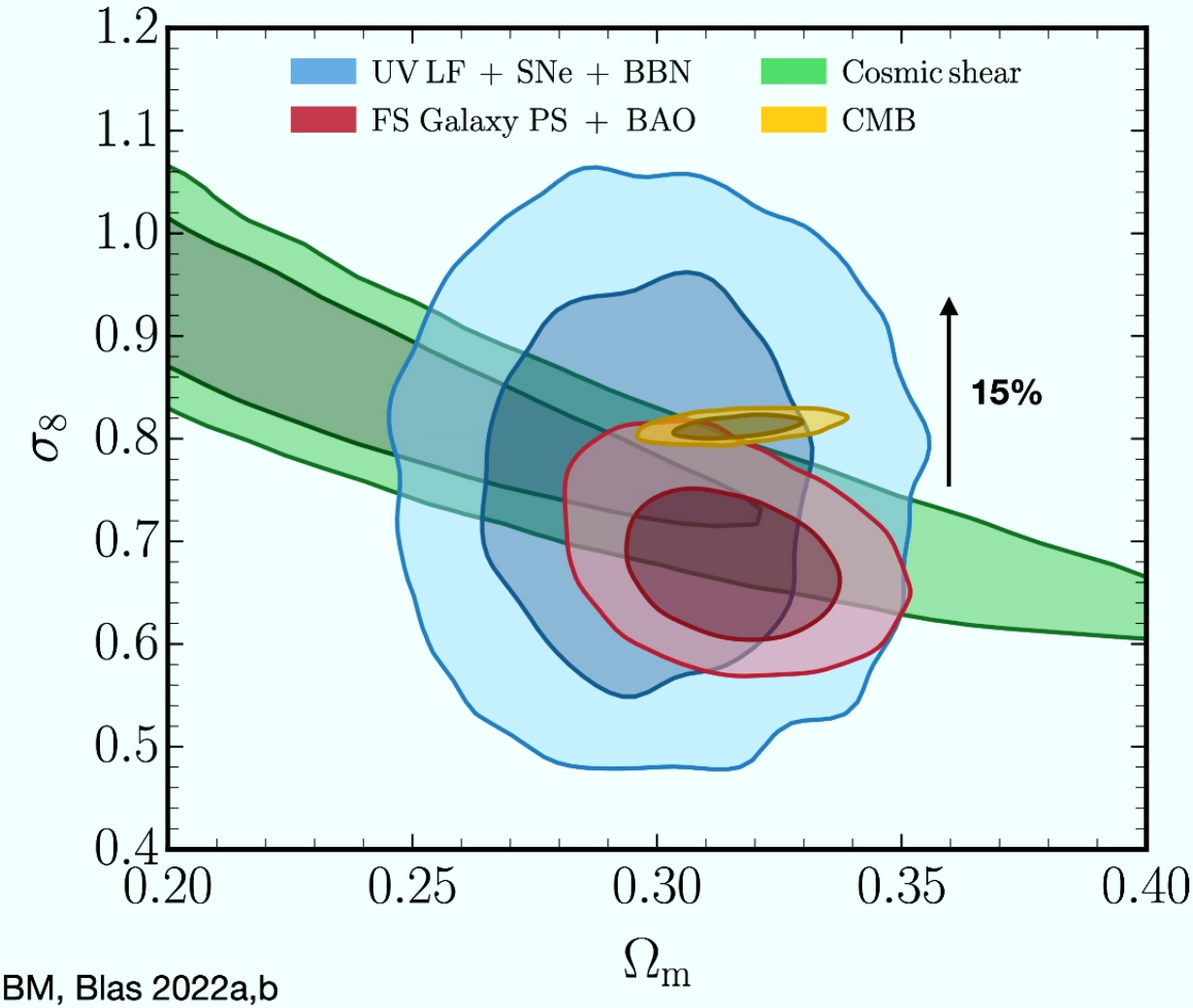




-Separate cosmology from astrophysics?

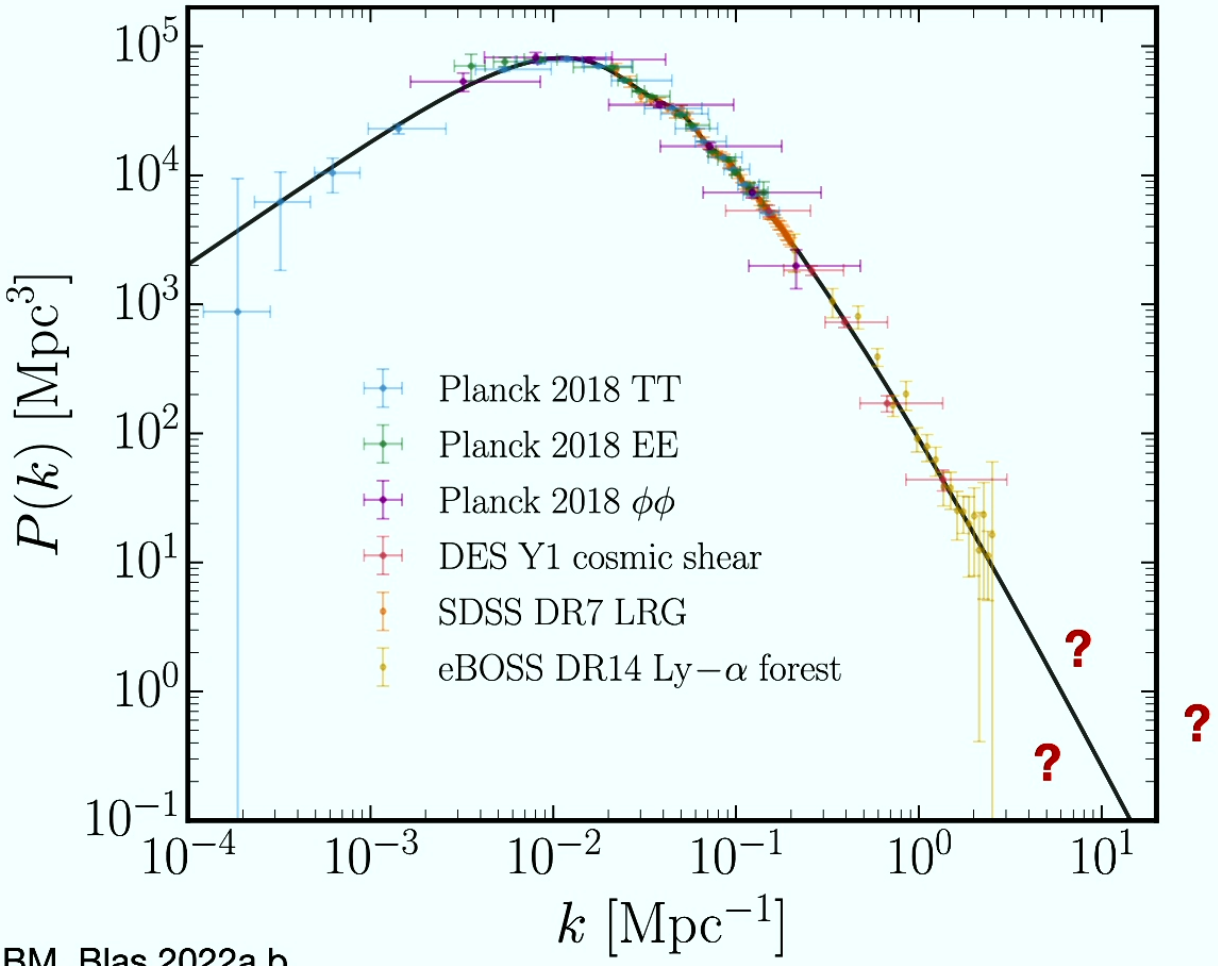
Sabti, JBM, Blas 2022a,b

More broadly, what can we learn?



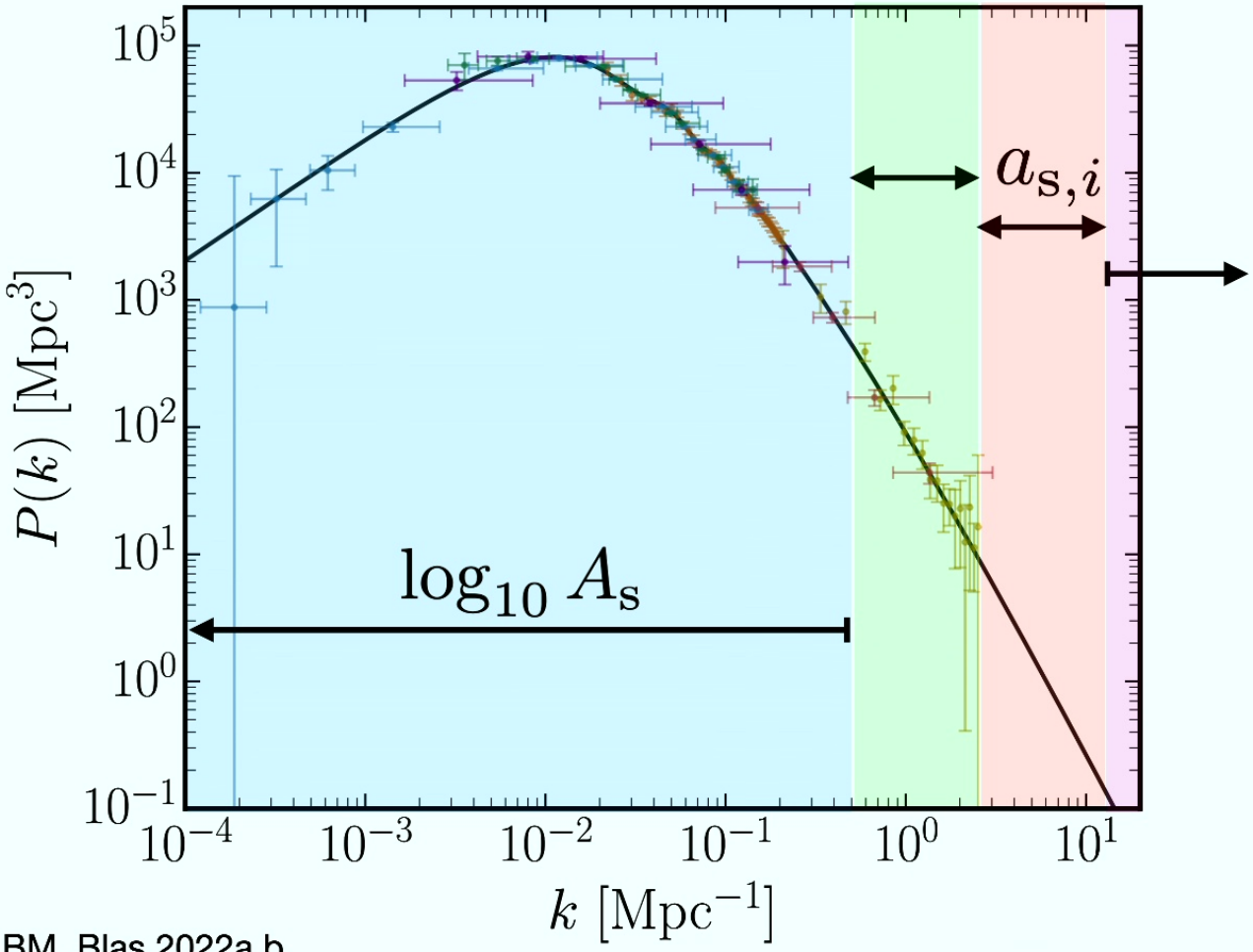
Sabti, JBM, Blas 2022a,b

Smaller galaxies -> higher k



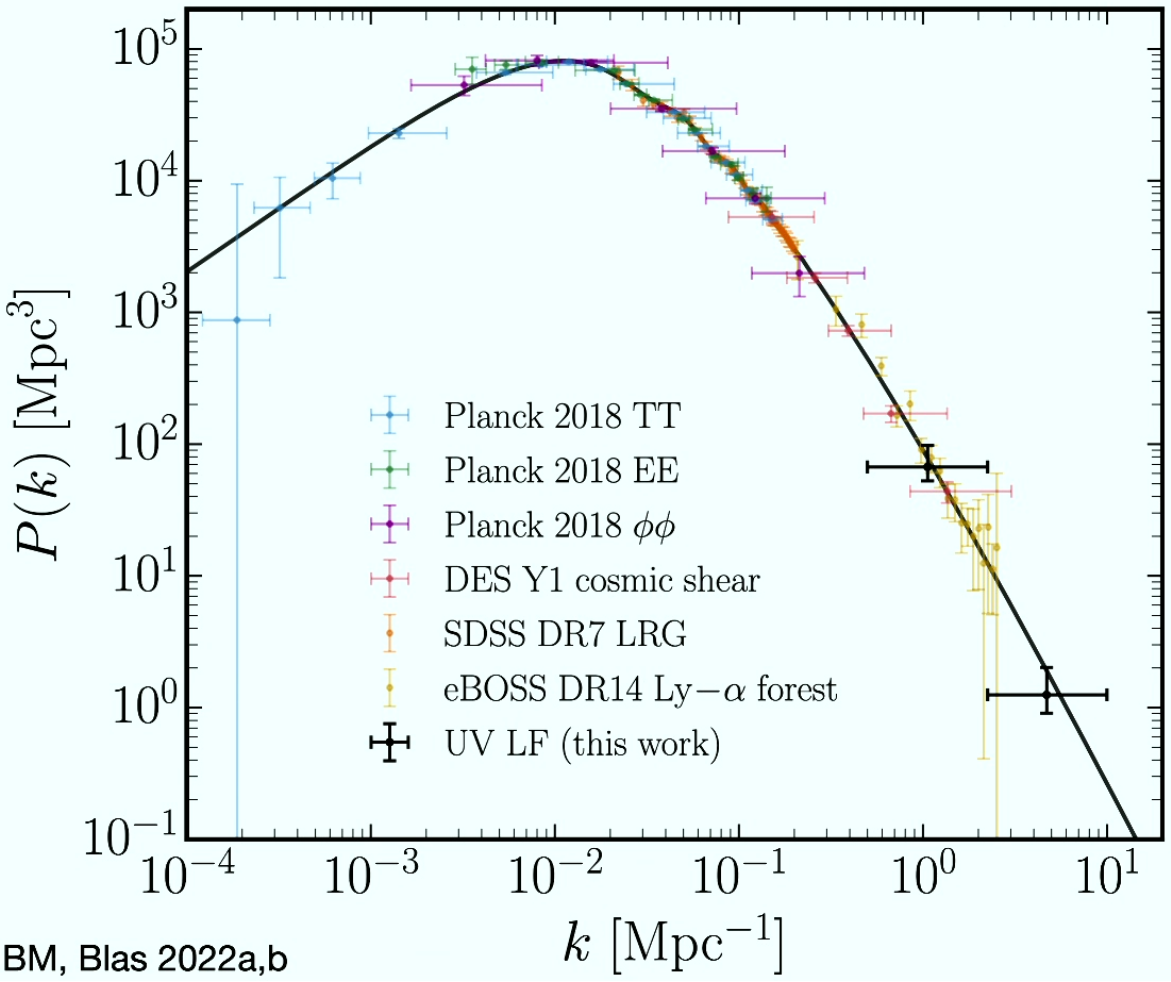
Sabti, JBM, Blas 2022a,b

Smaller galaxies -> higher k



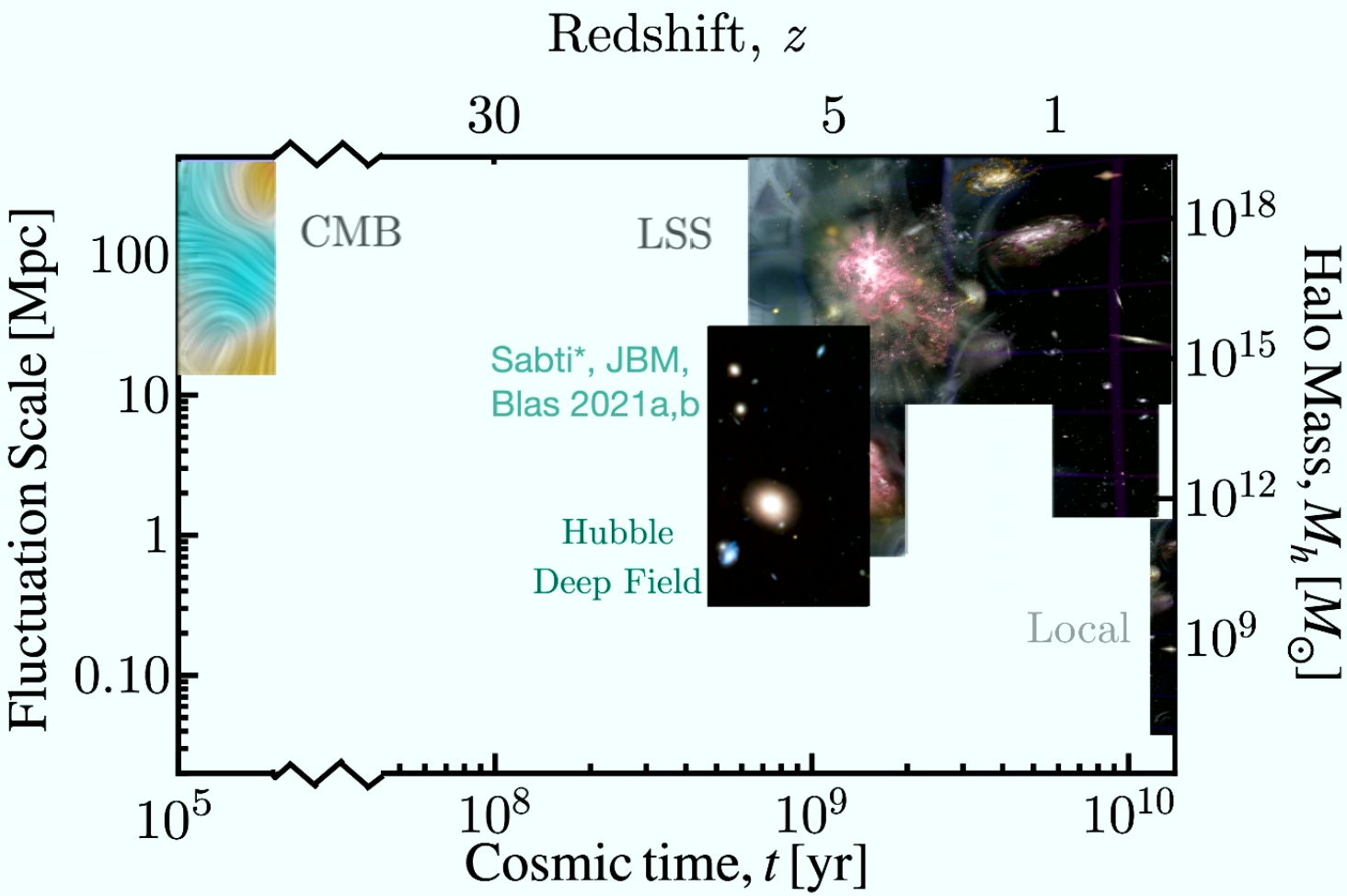
Sabti, JBM, Blas 2022a,b

Smaller galaxies -> higher k



Sabti, JBM, Blas 2022a,b

Smaller galaxies -> higher k

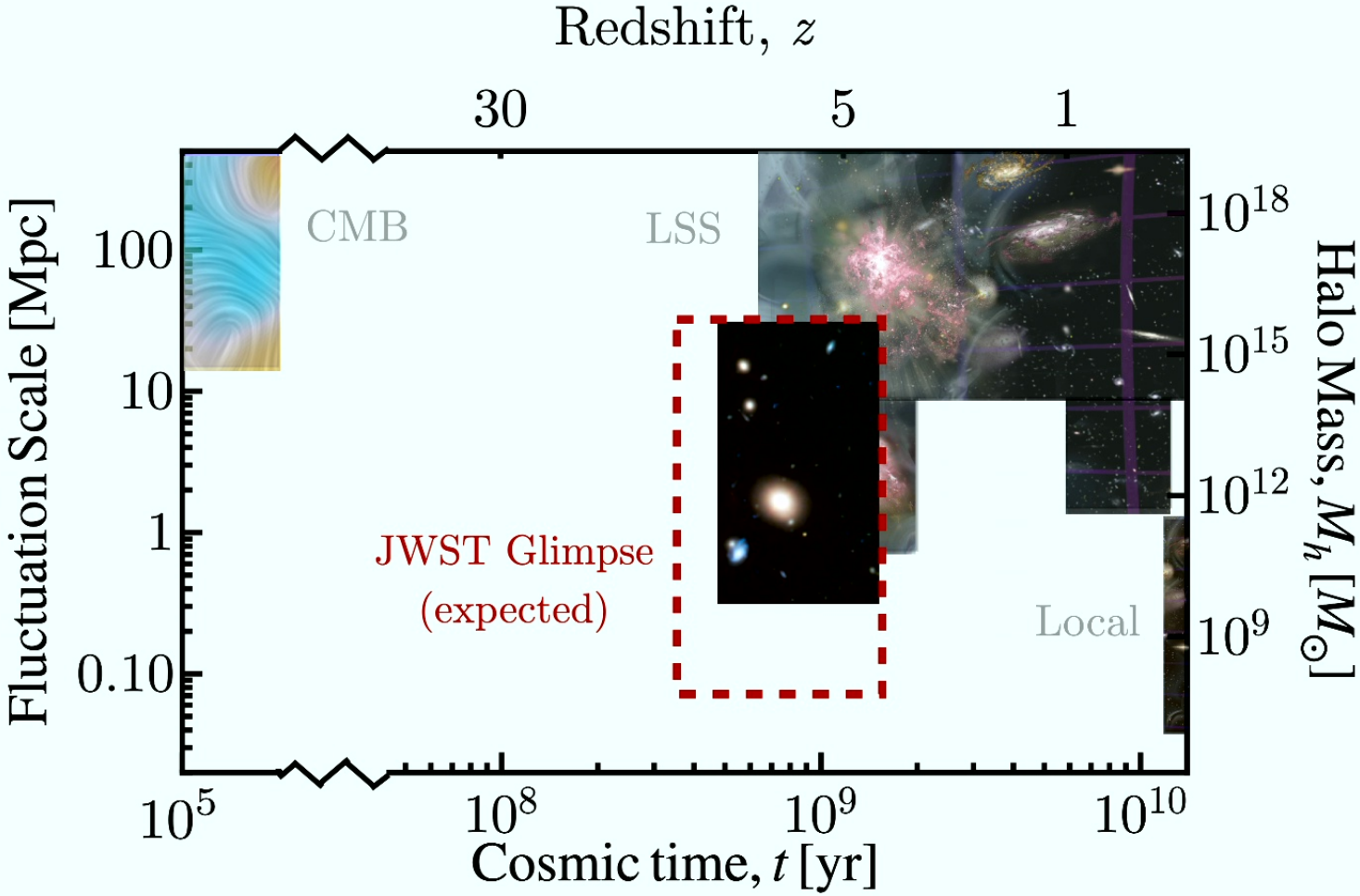


A Glimpse of the future

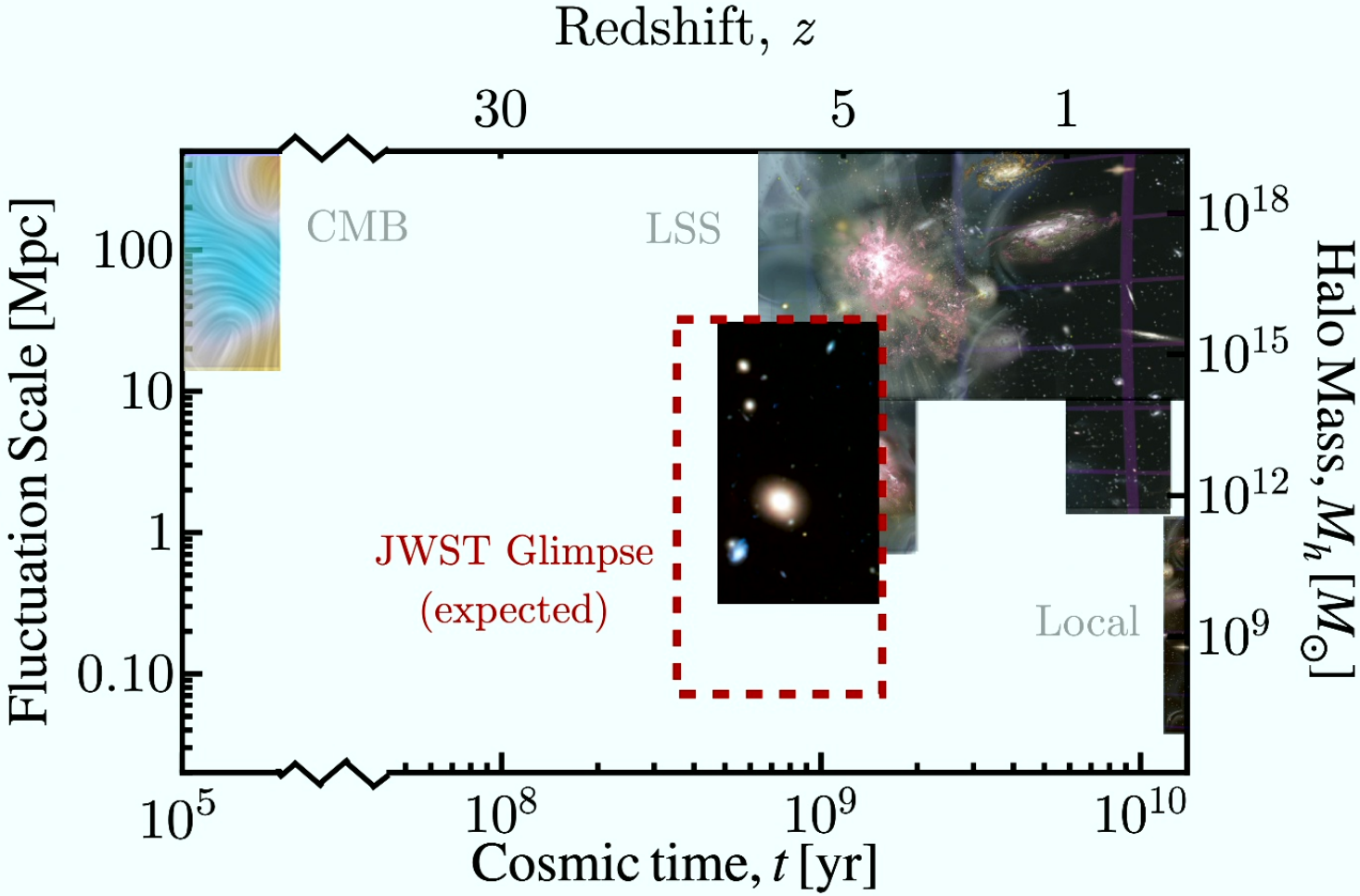
GLIMPSE
Abell S1063
JWST Cy2,
(PIs: Atek, Chisholm)

Expected to reach ~10-30x fainter

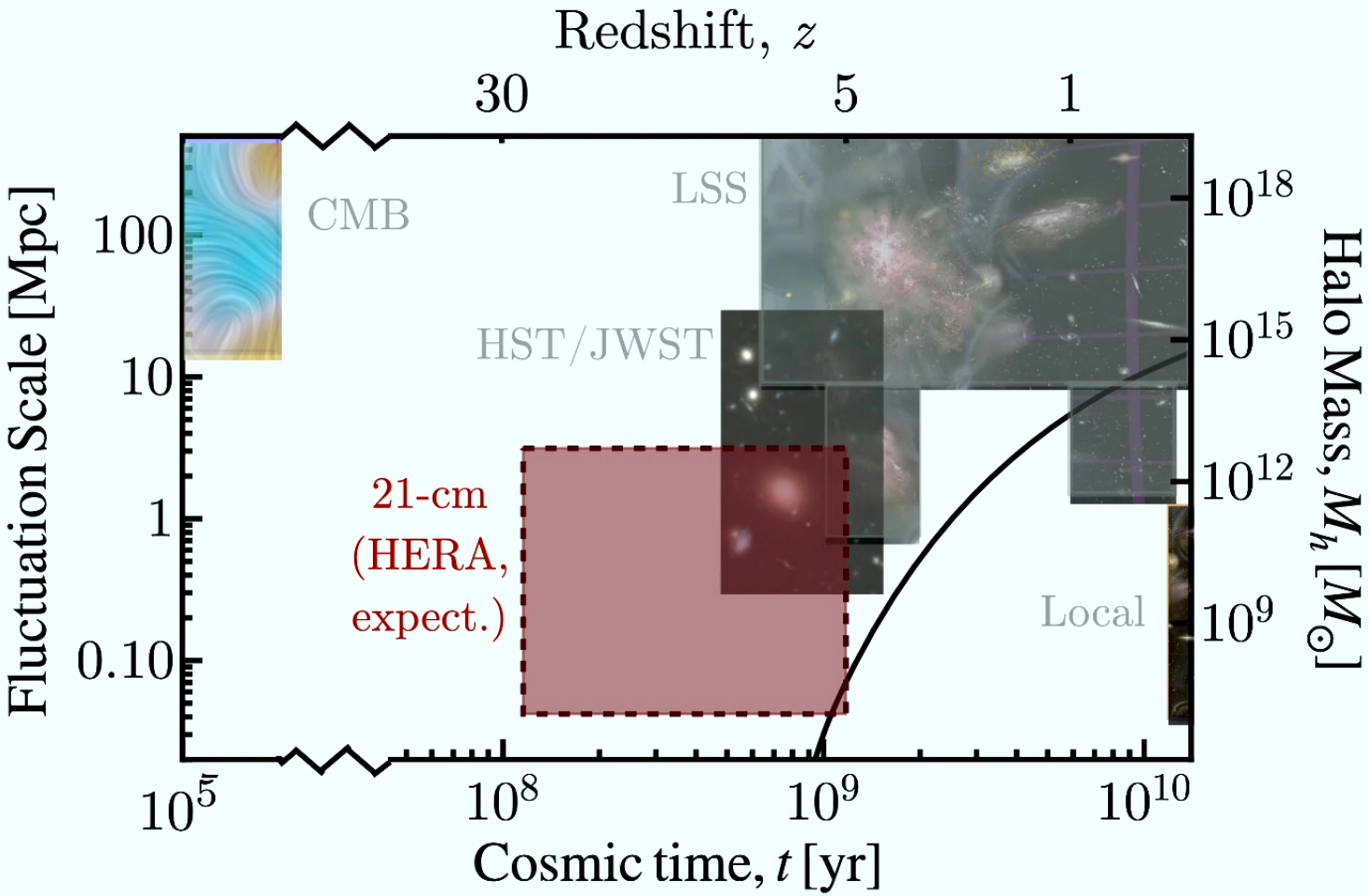
A *Glimpse* of the future



A *Glimpse* of the future



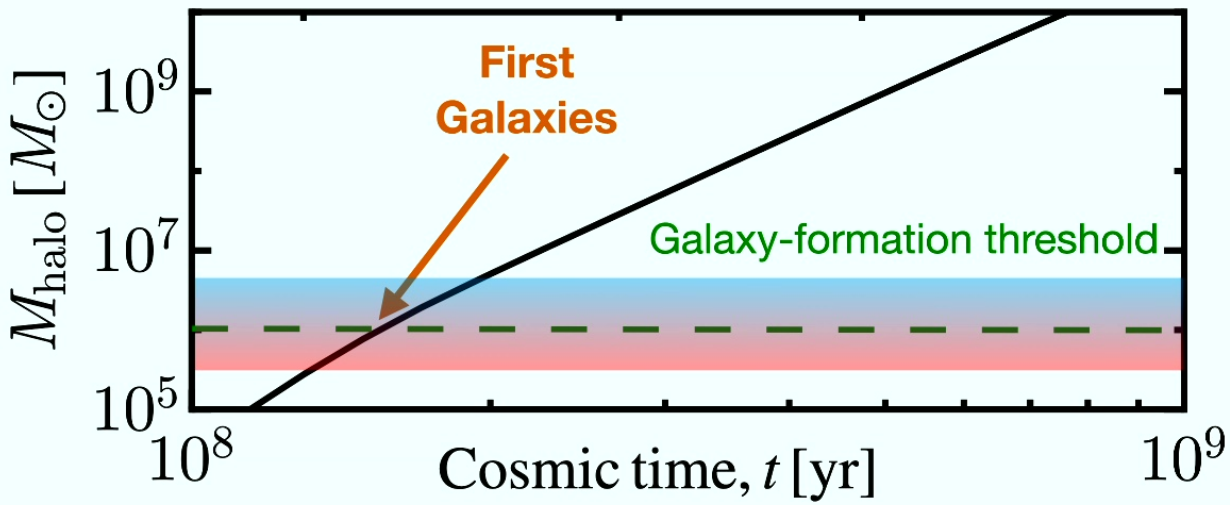
Probing the uncharted



JBM+ 2011.05333

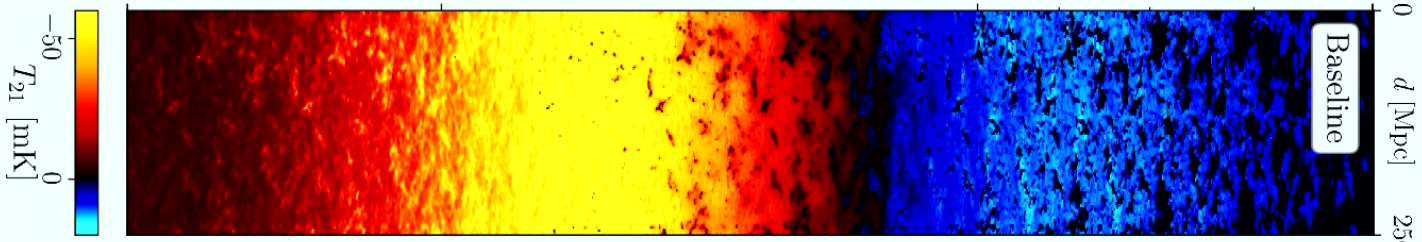
DM can also change threshold

See Wenzer's talk!



And the thermal state of the gas

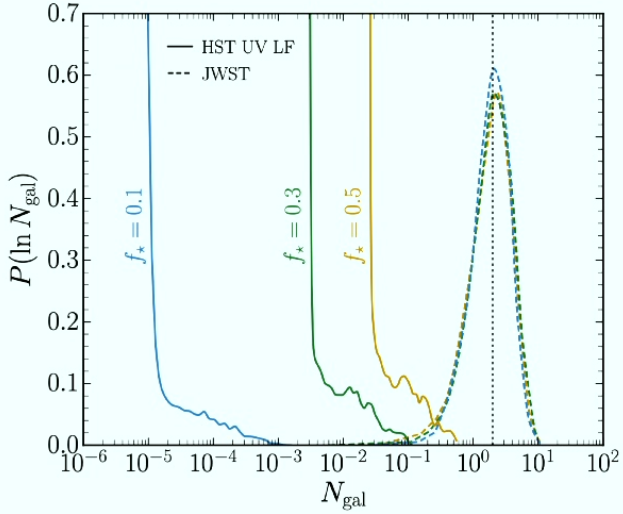
See Yitian's talk!



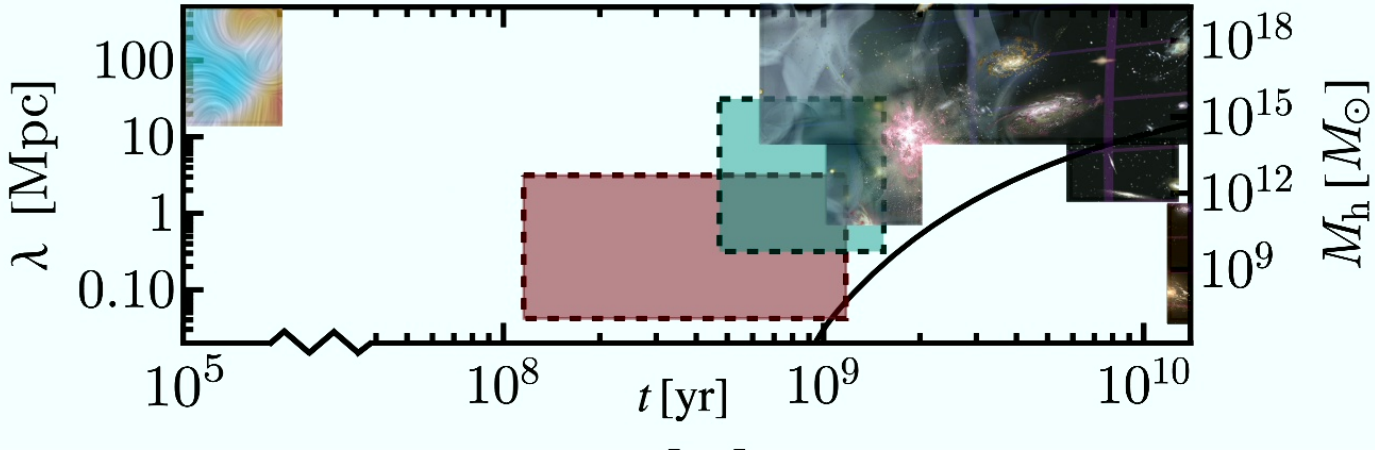
To summarize

Too massive for LCDM?

Sabti, **JBM**, Kamionkowski 2305.07049



JBM+ 2011.05333
Sabti, **JBM**, Blas 2110.13161
Verwohlt, Mason, **JBM**+ (2403.?????)

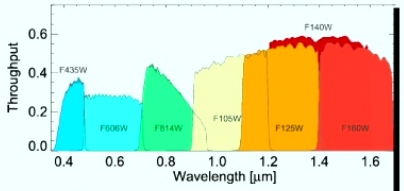


As a theorist, what does JWST do for us?

Measure rest-frame visible $\rightarrow M_\star, M_{\rm BH}, \ldots$

Reach higher redshifts $\rightarrow$ UV at higher z

HST



JWST