Searching for New Physics at Cosmic Dawn

JULIAN B. MUÑOZ

Based on:

Sabti, JBM, Kamionkowski PRL 2023

Verwohlt, Mason, JBM+ arXiv 2024

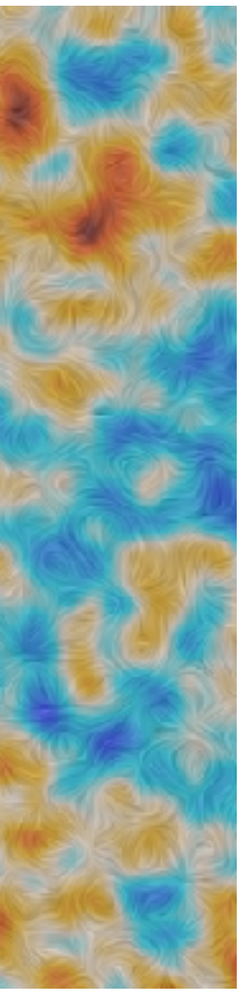
JBM, Mirocha, Chisholm, Furlanetto, Mason arXiv 2024

Cruz, JBM+ arXiv 2024

CREDIT: NASA/STSCI/CEERS/TACC/
FINKELSTEIN/M. BAGLEY/R. LARSON/Z. LEVAY

How does cosmology measure things?

Cosmic Microwave Background



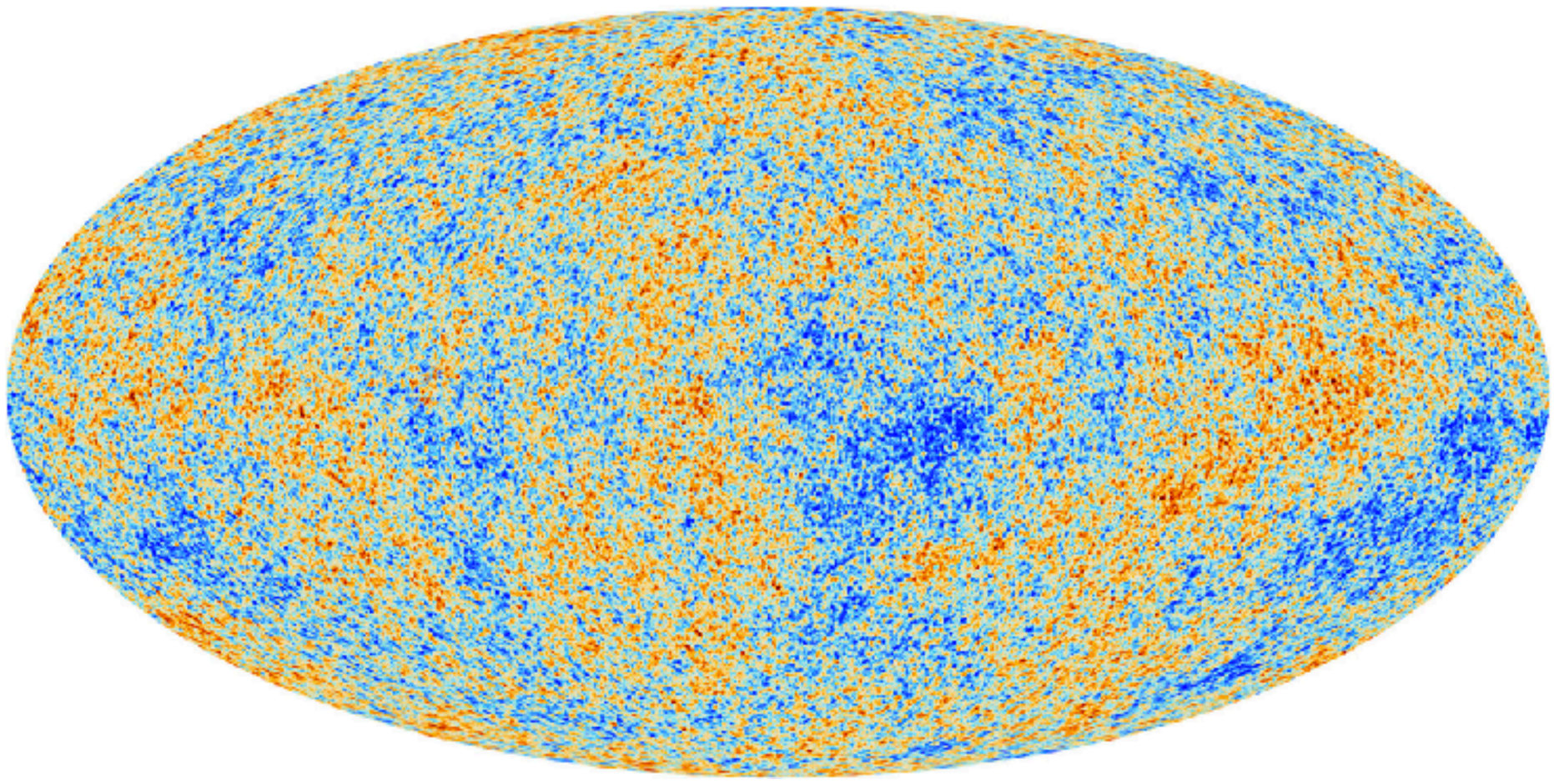
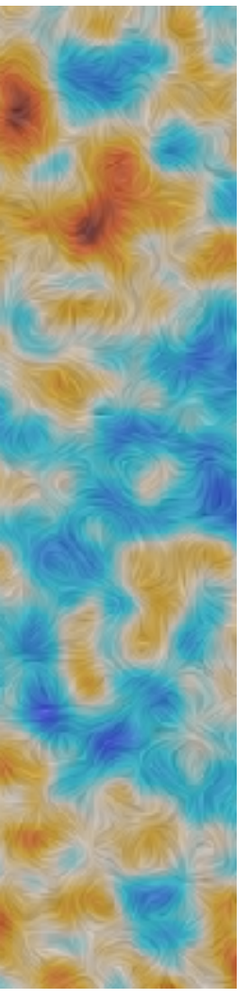


Image: ESA

How does cosmology measure things?

Image: ESA

CMB



$z \approx 10^3$

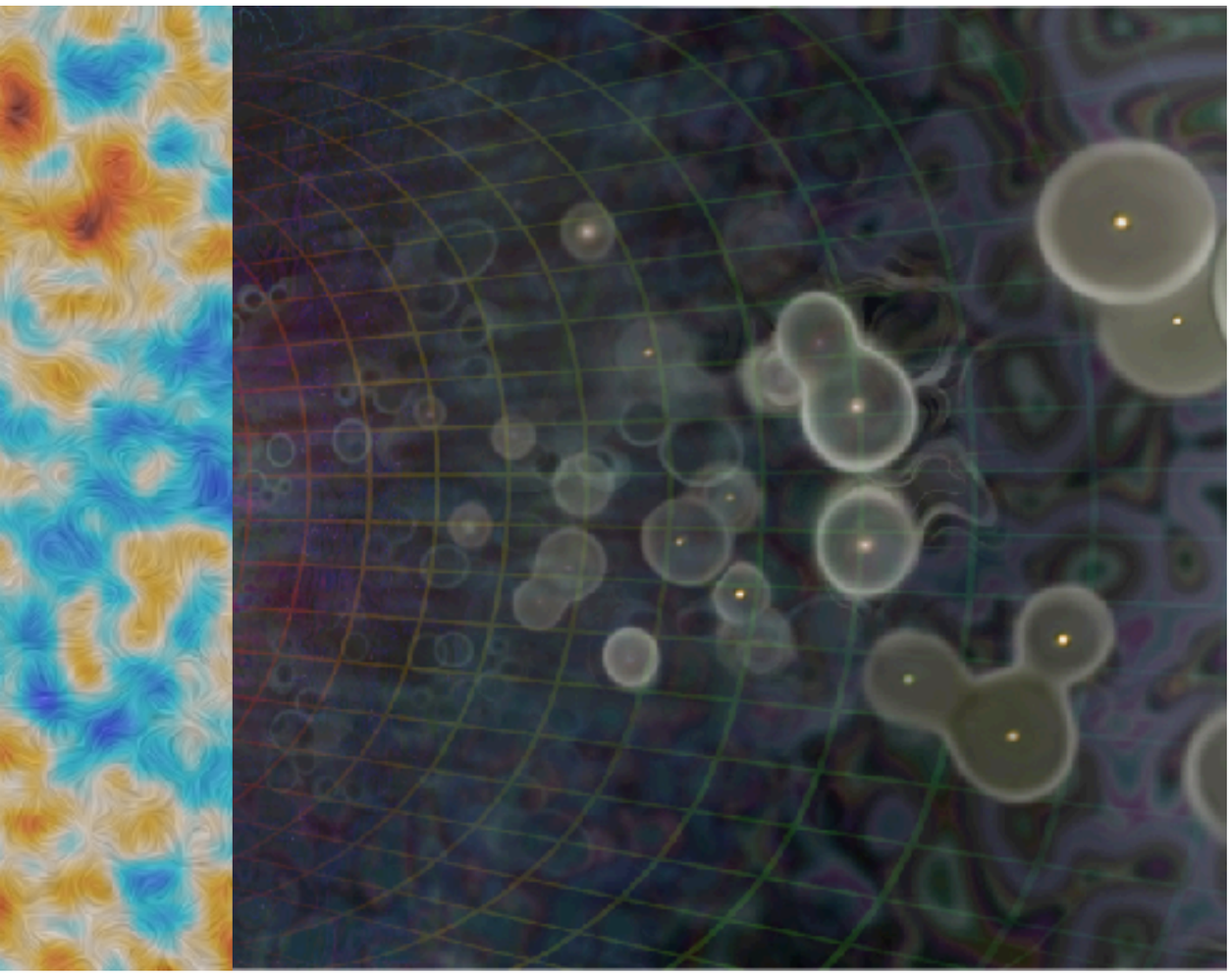
400,000

cosmic time [yr]

How does cosmology measure things?

Image: NASA/
CXC/M.WEISS

CMB **Cosmic Dawn**



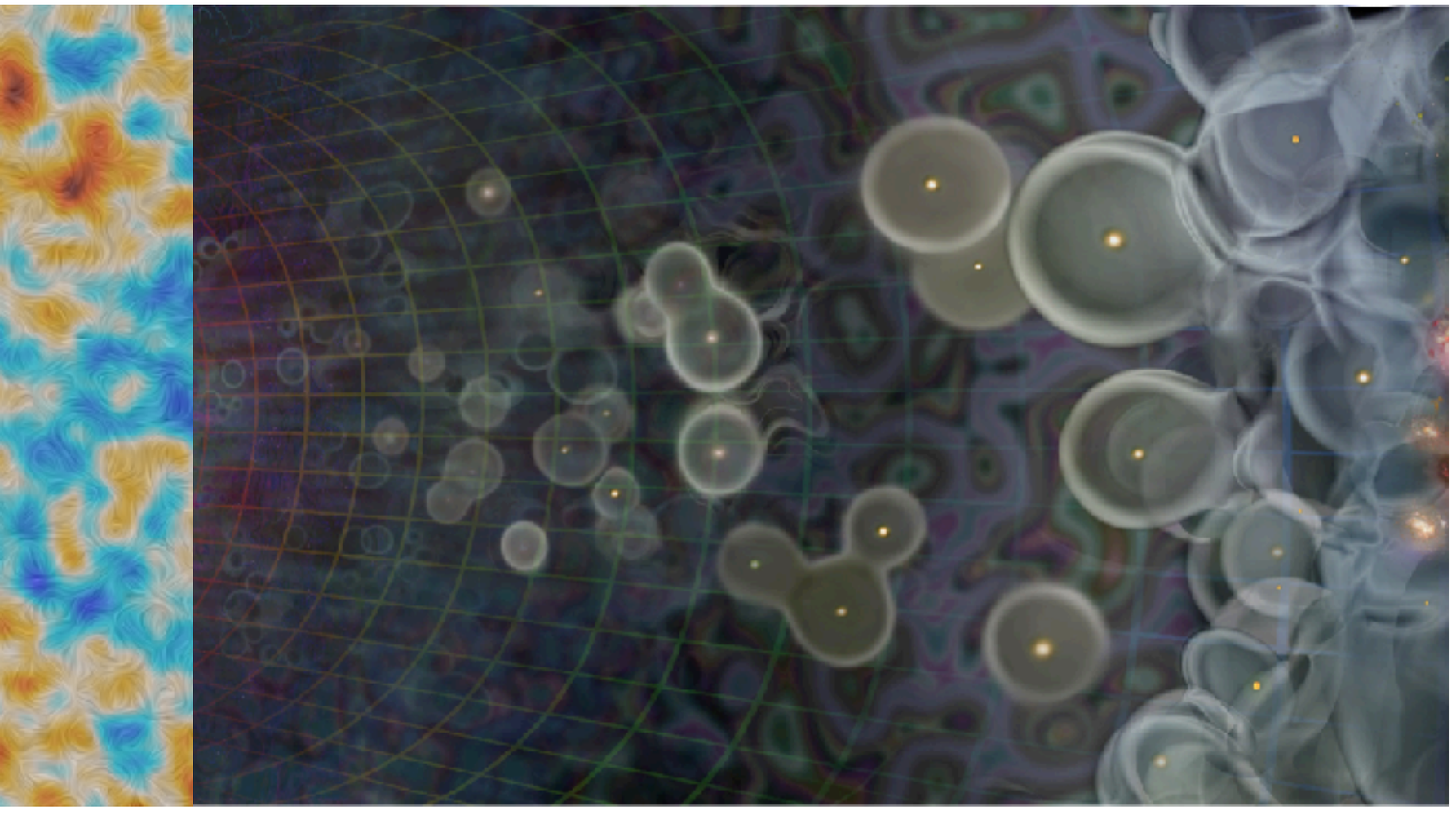
$z \approx 10^3$ $z \approx 30$

400,000 100 Myr cosmic time [yr]

How does cosmology measure things?

Image: NASA/
CXC/M.WEISS

CMB Cosmic Dawn **Reionization**



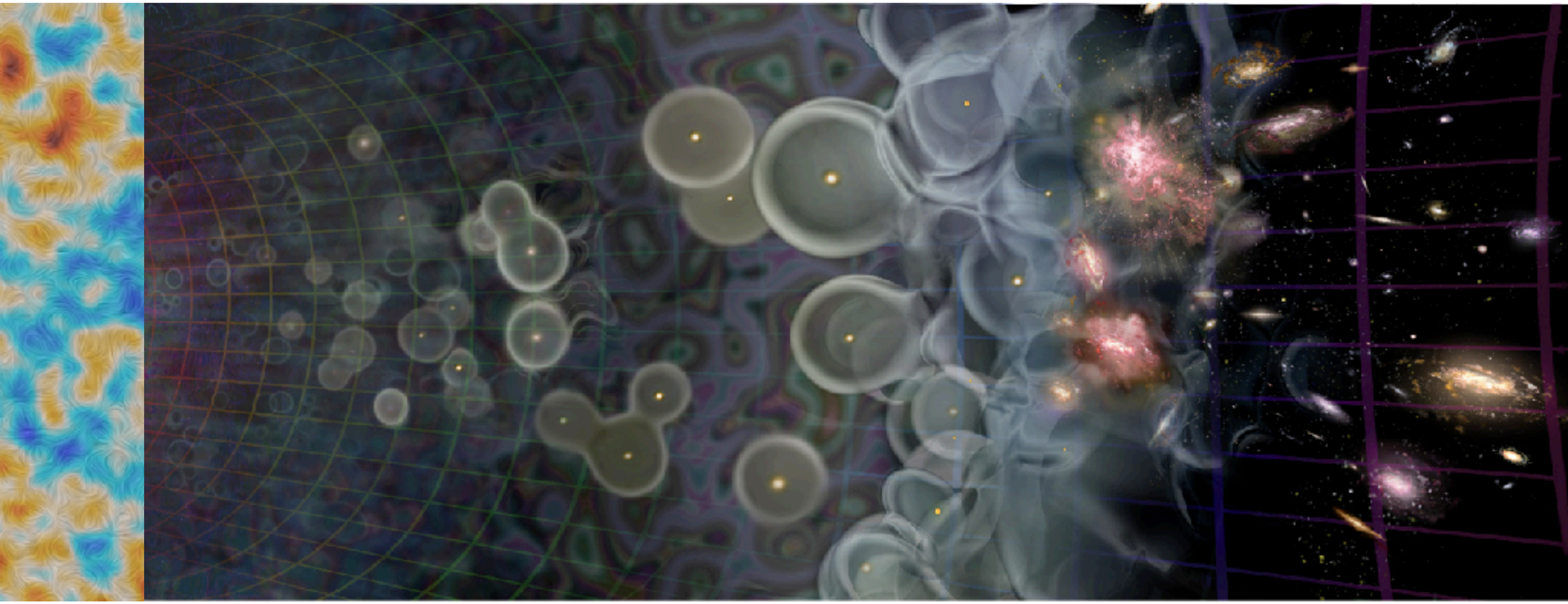
$z \approx 10^3$ $z \approx 30$ $z \approx 5$

cosmic time [yr]

400,000 100 Myr 1 Byrs

Image: NASA/
CXC/M.WEISS

CMB | Cosmic Dawn | Reionization | **Today**

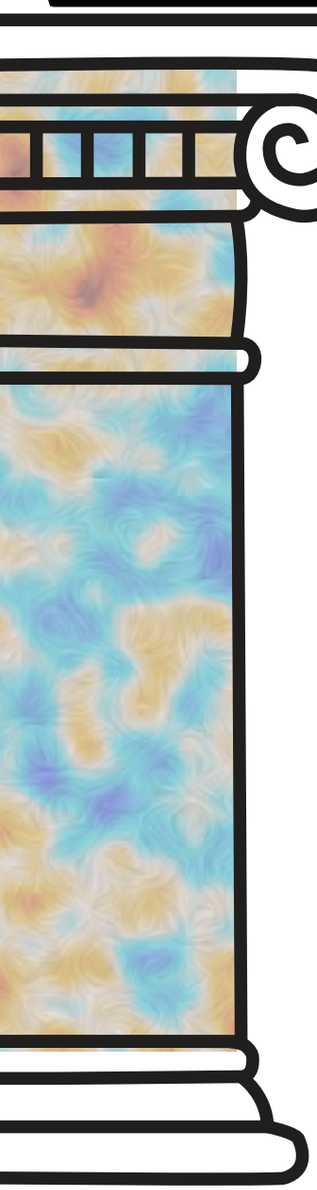


$z \approx 10^3$ | $z \approx 30$ | $z \approx 5$ | $z = 0$

cosmic time [yr]

400,000 | 100 Myr | 1 Byrs | 14 Byrs

Cosmology



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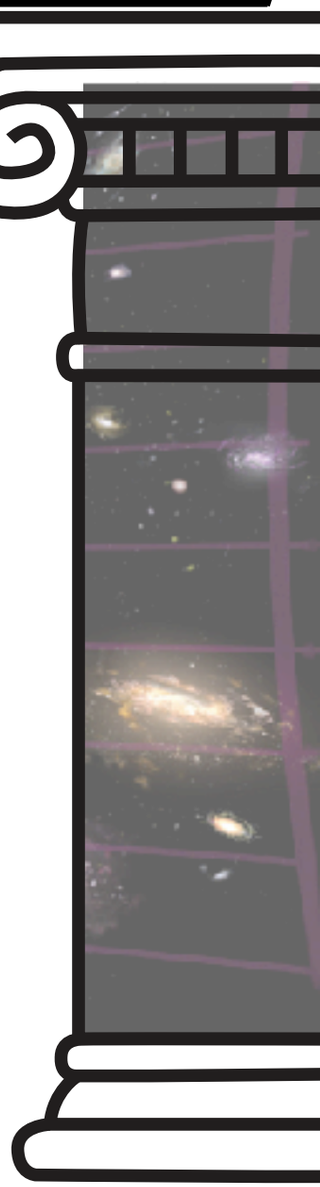
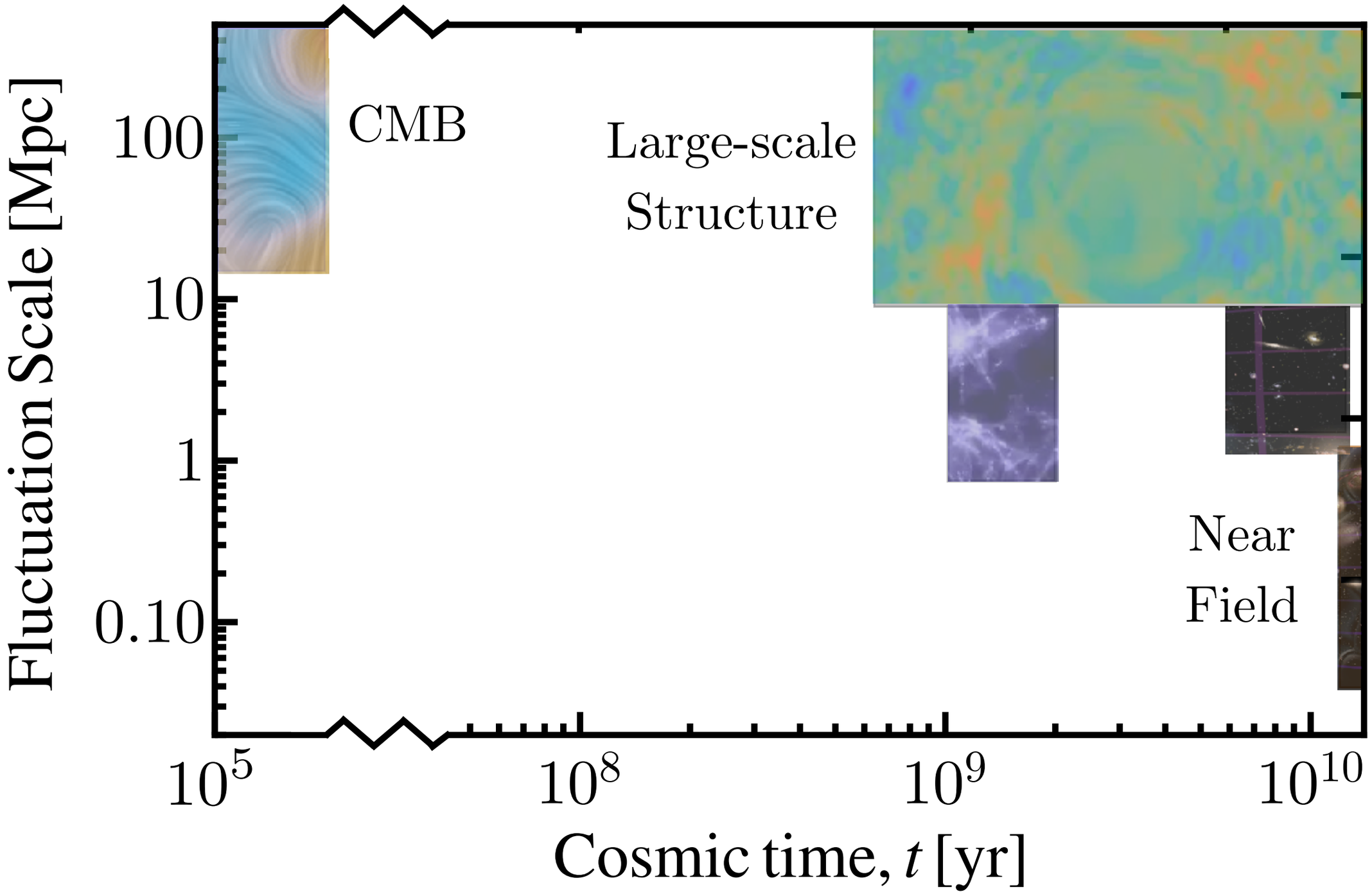
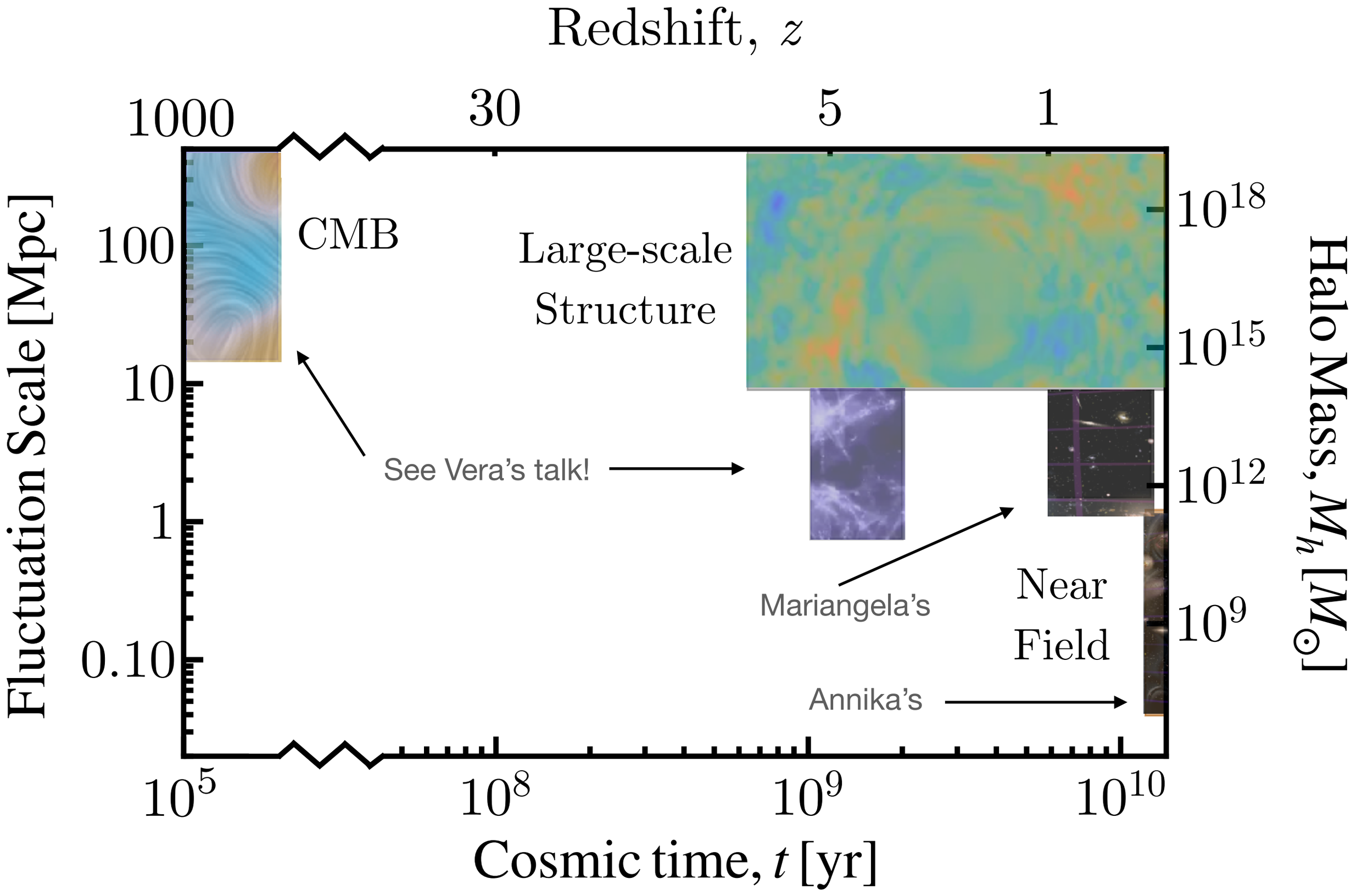


Today

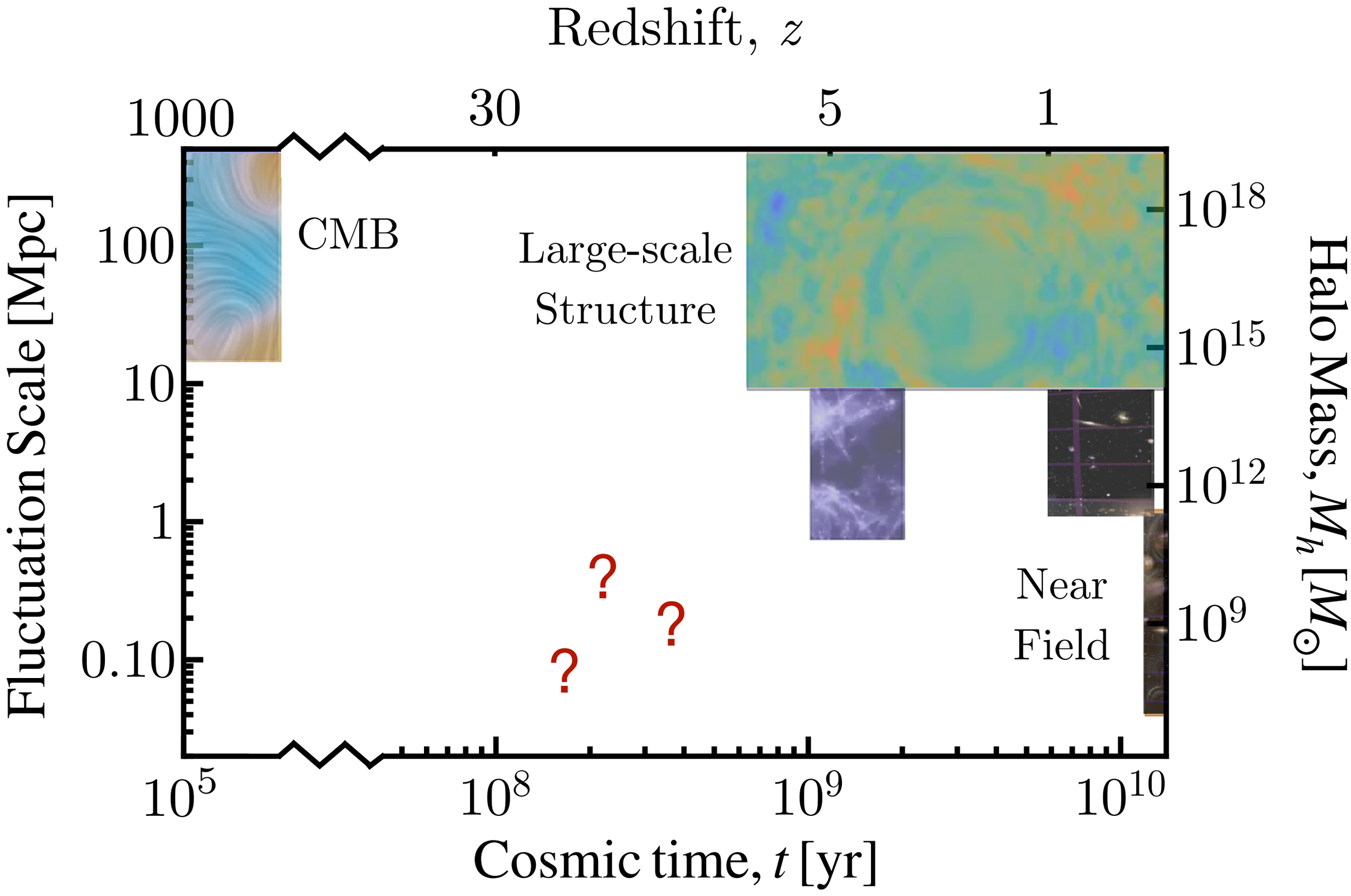
DM is cold ...


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

DM is cold ...

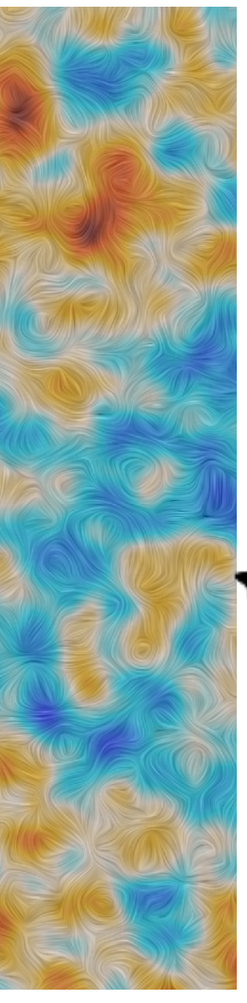

Redshift, z
1000
30
5
1
Fluctuation Scale [Mpc]
100
10
1
0.10
CMB
Large-scale Structure
See Vera's talk!
Mariangela's
Near Field
Annika's
10^{18}
10^{15}
10^{12}
10^{9}
Halo Mass, M_h [$M_\odot$]
10^5
10^8
10^9
10^{10}
Cosmic time, t [yr]

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



New lampposts

CMB

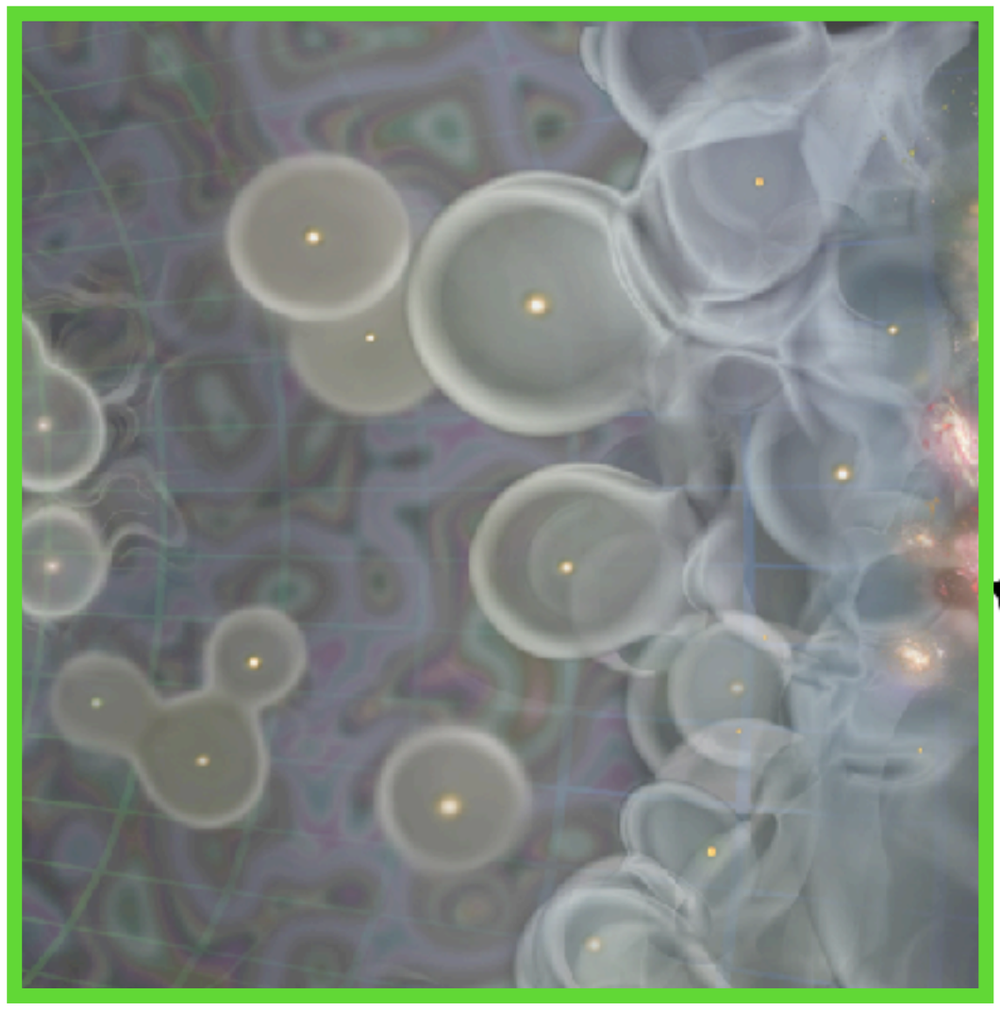


$z \approx 10^3$

Cosmic Dawn

$z \approx 30$

Reionization



$z \approx 5$

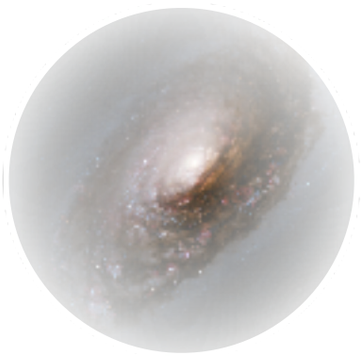
Today

$z = 0$

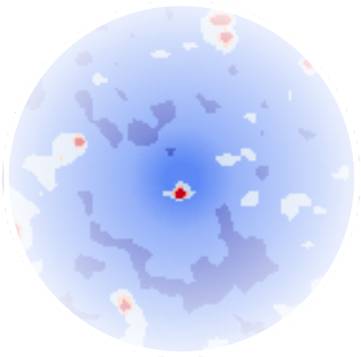
JWST, 21-cm → New Physics

Plan:

“Universe-breaking” galaxies?

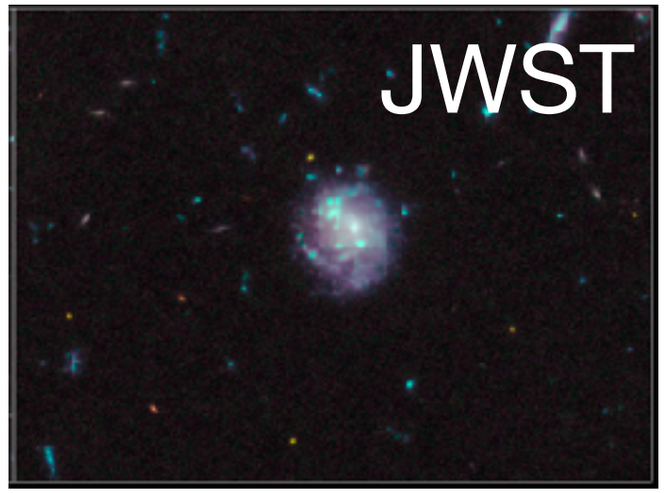


Too many photons at reionization



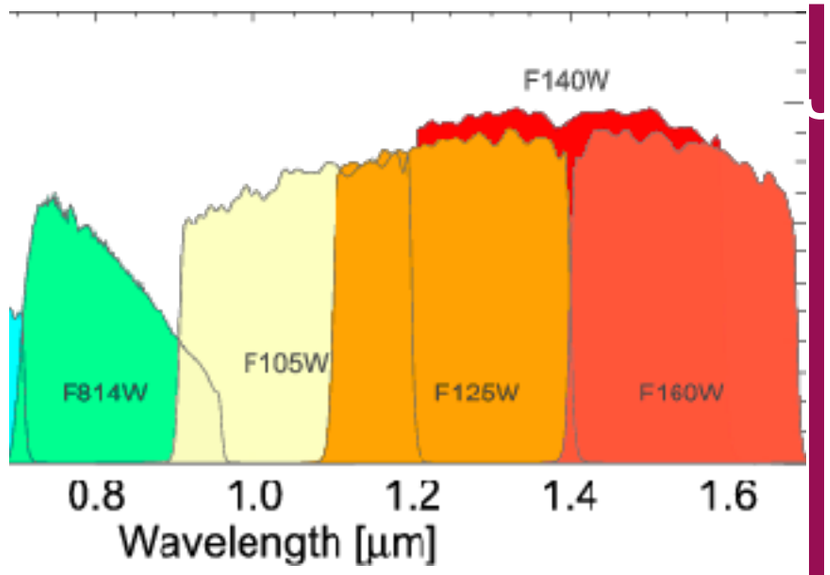
New physics beyond JWST

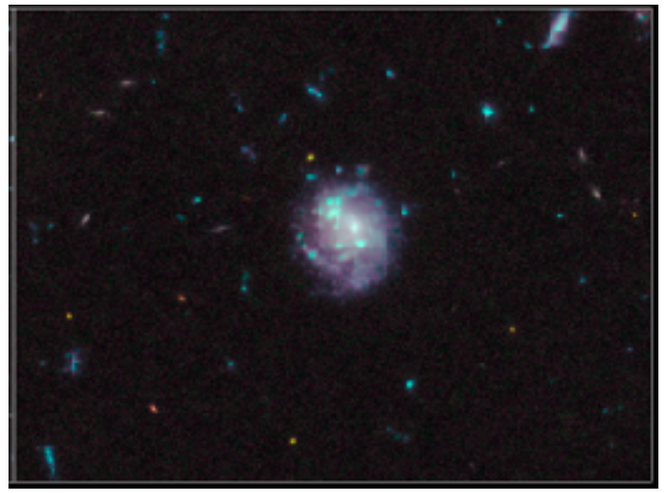
JWST for theorists



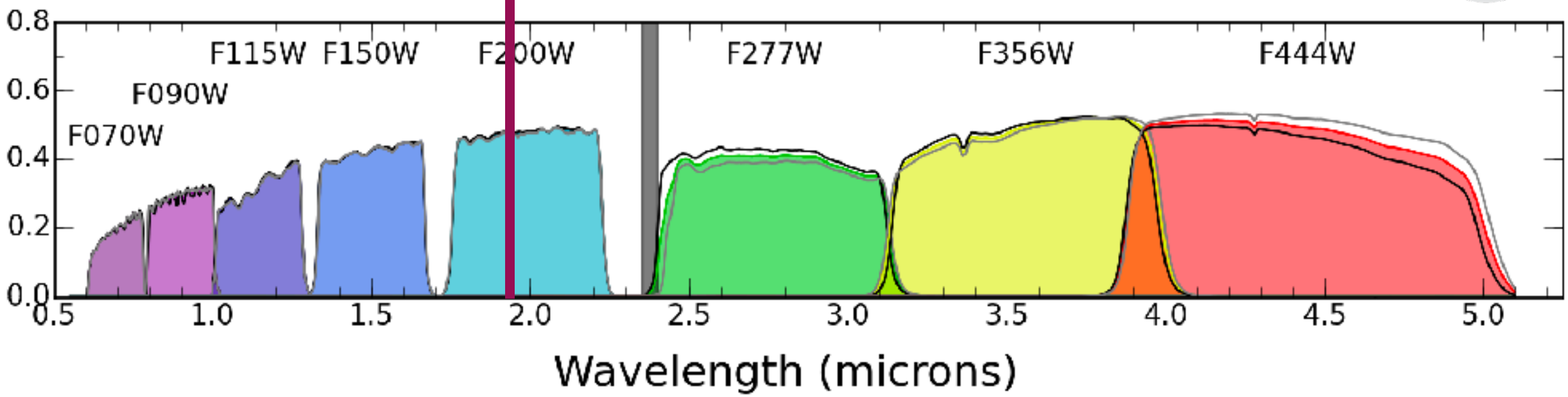
JWST for theorists

HST

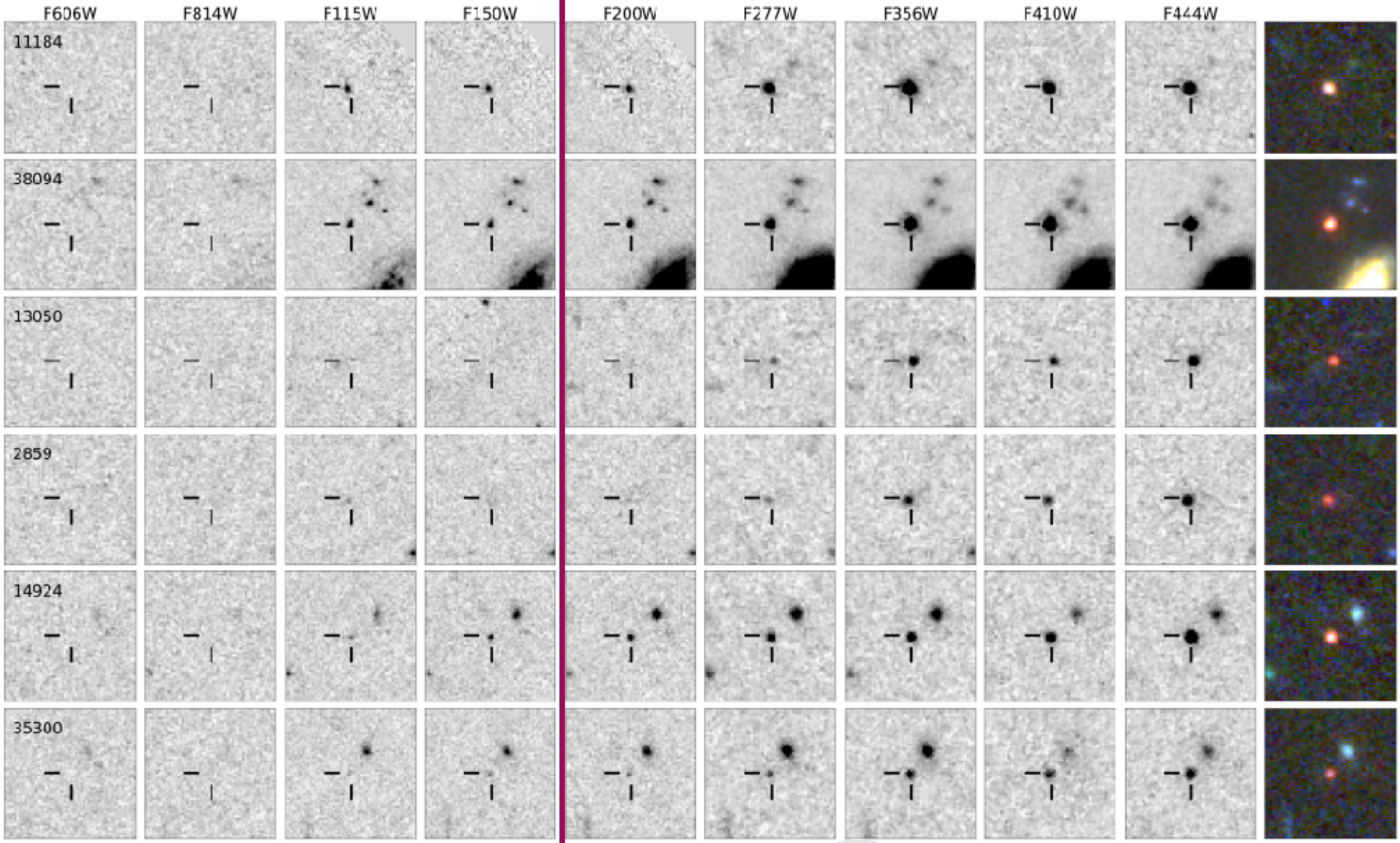




JWST



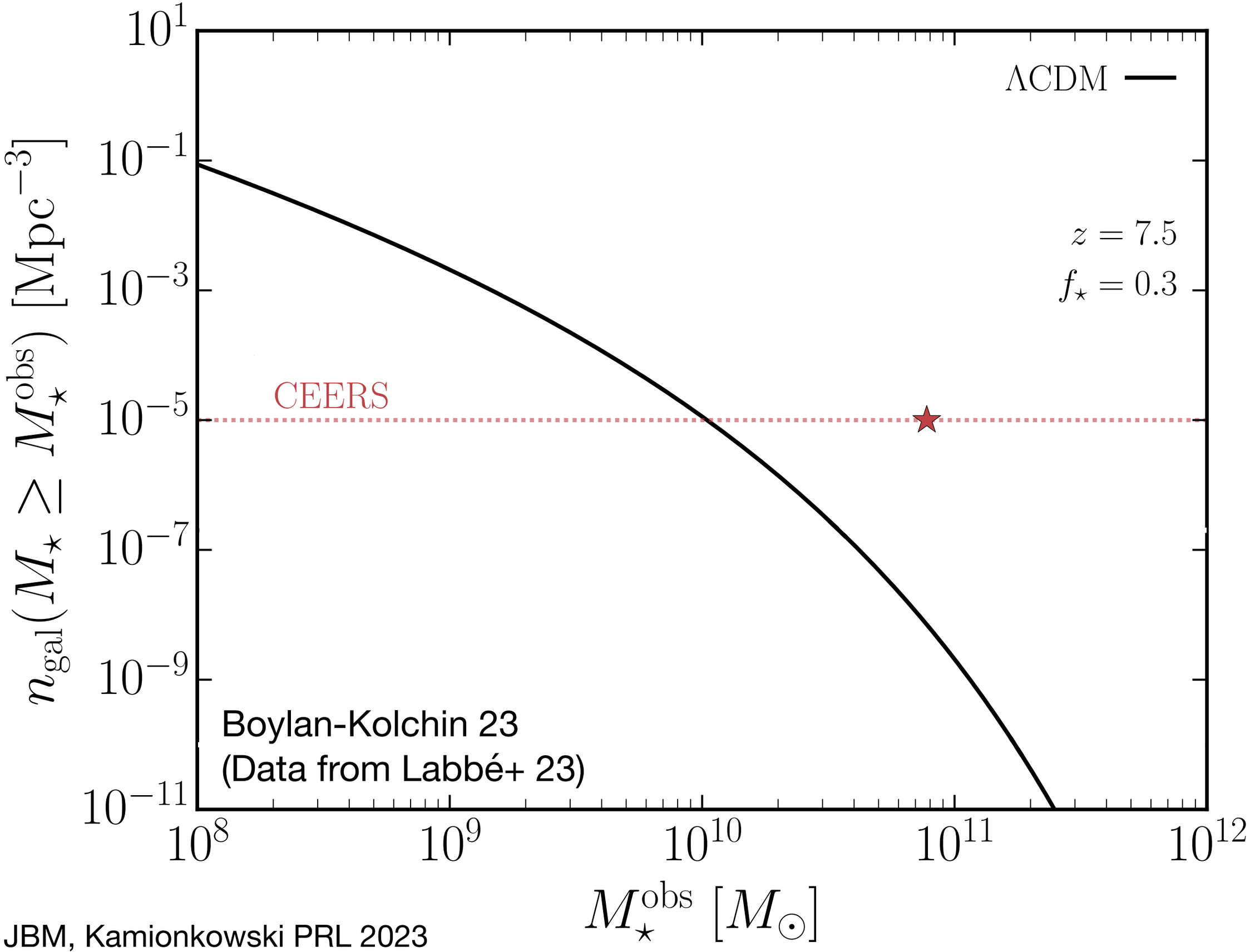
Ultramassive galaxies at high z



HST

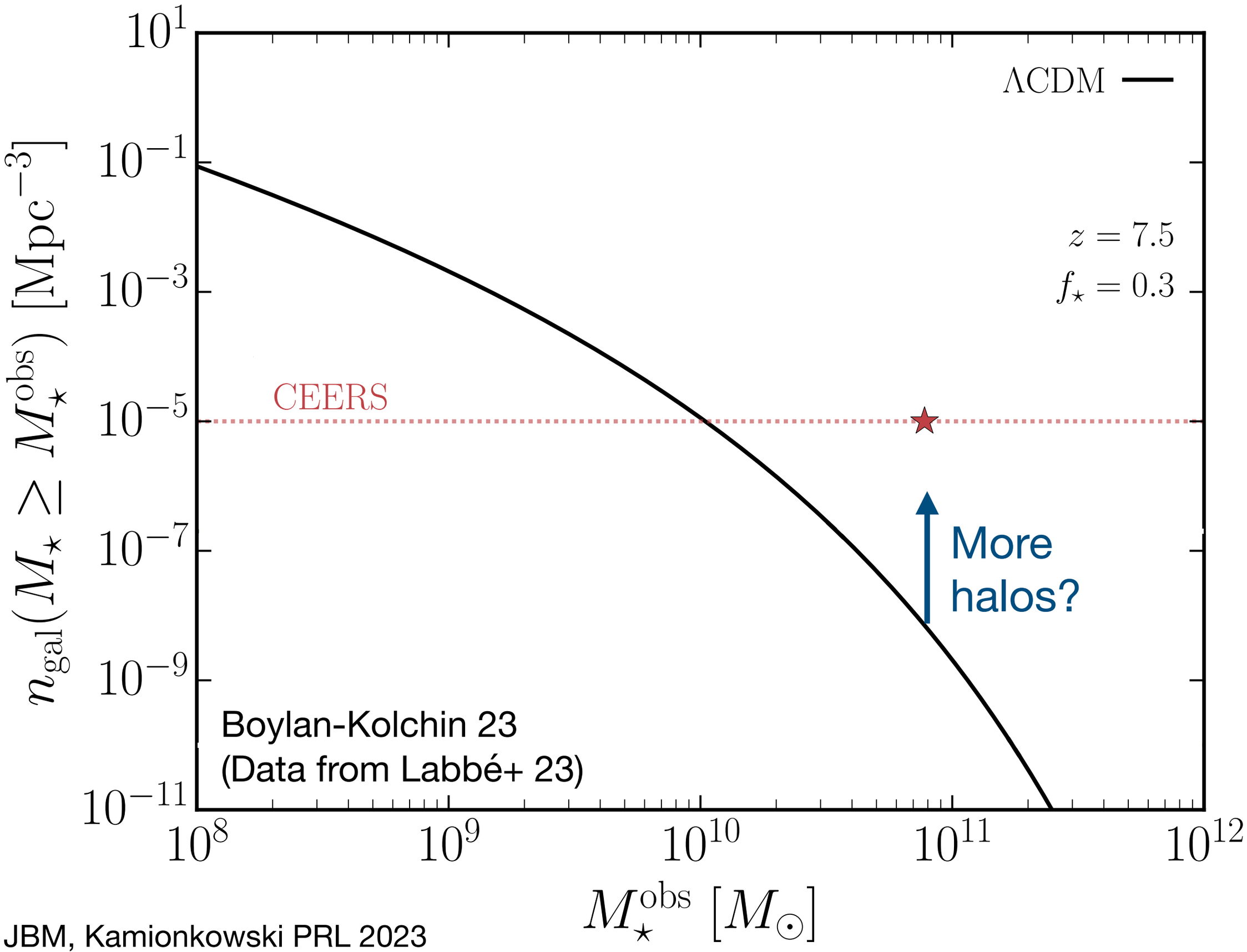
JWST

Labbe+ 23



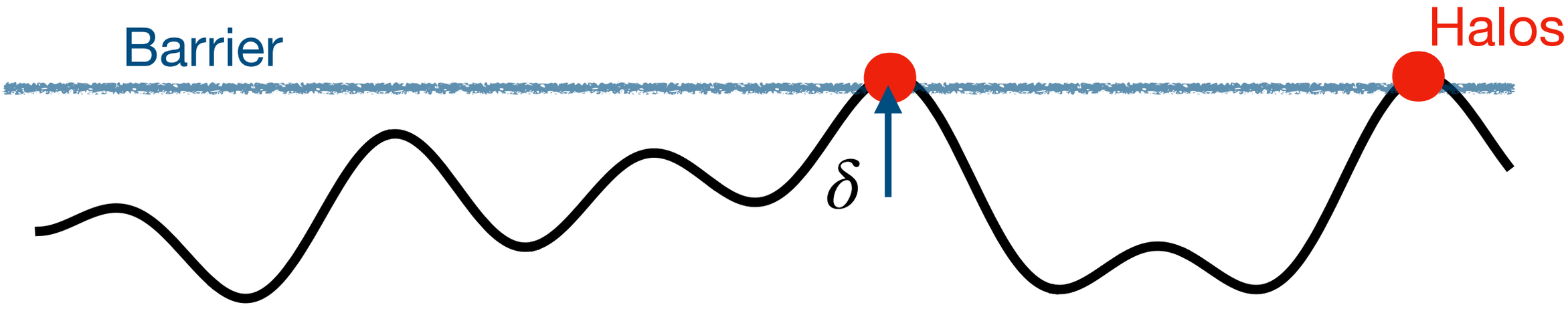
Sabti, JBM, Kamionkowski PRL 2023

Do they break cosmology?



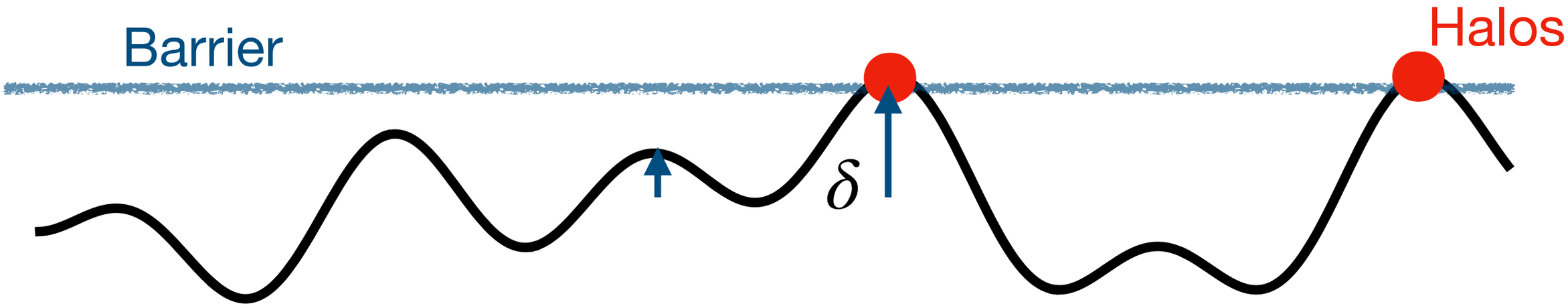
Sabti, JBM, Kamionkowski PRL 2023

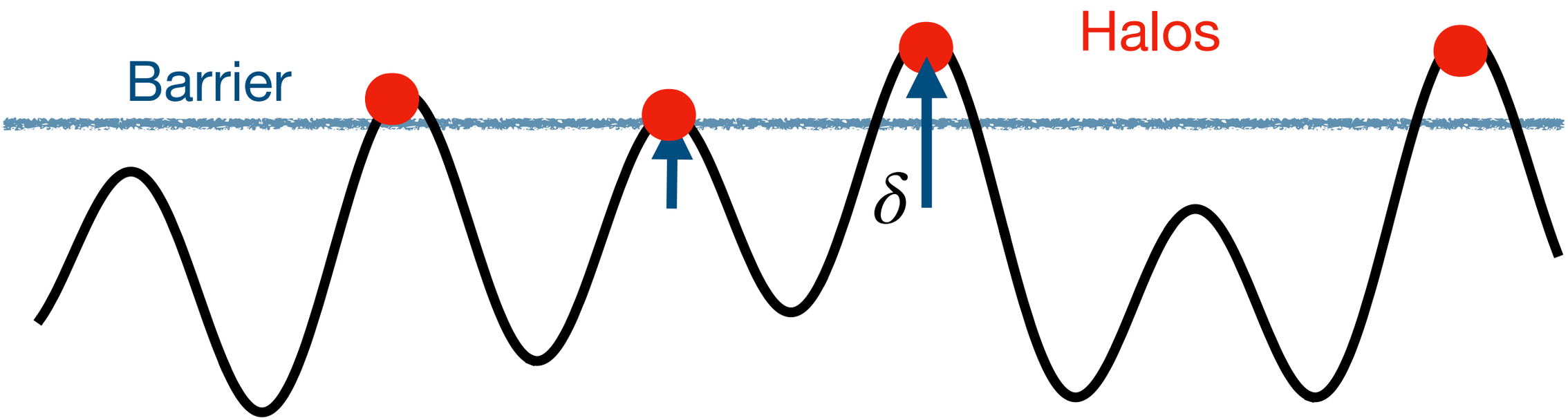
Halos from primordial fluctuations



See, eg Peacock

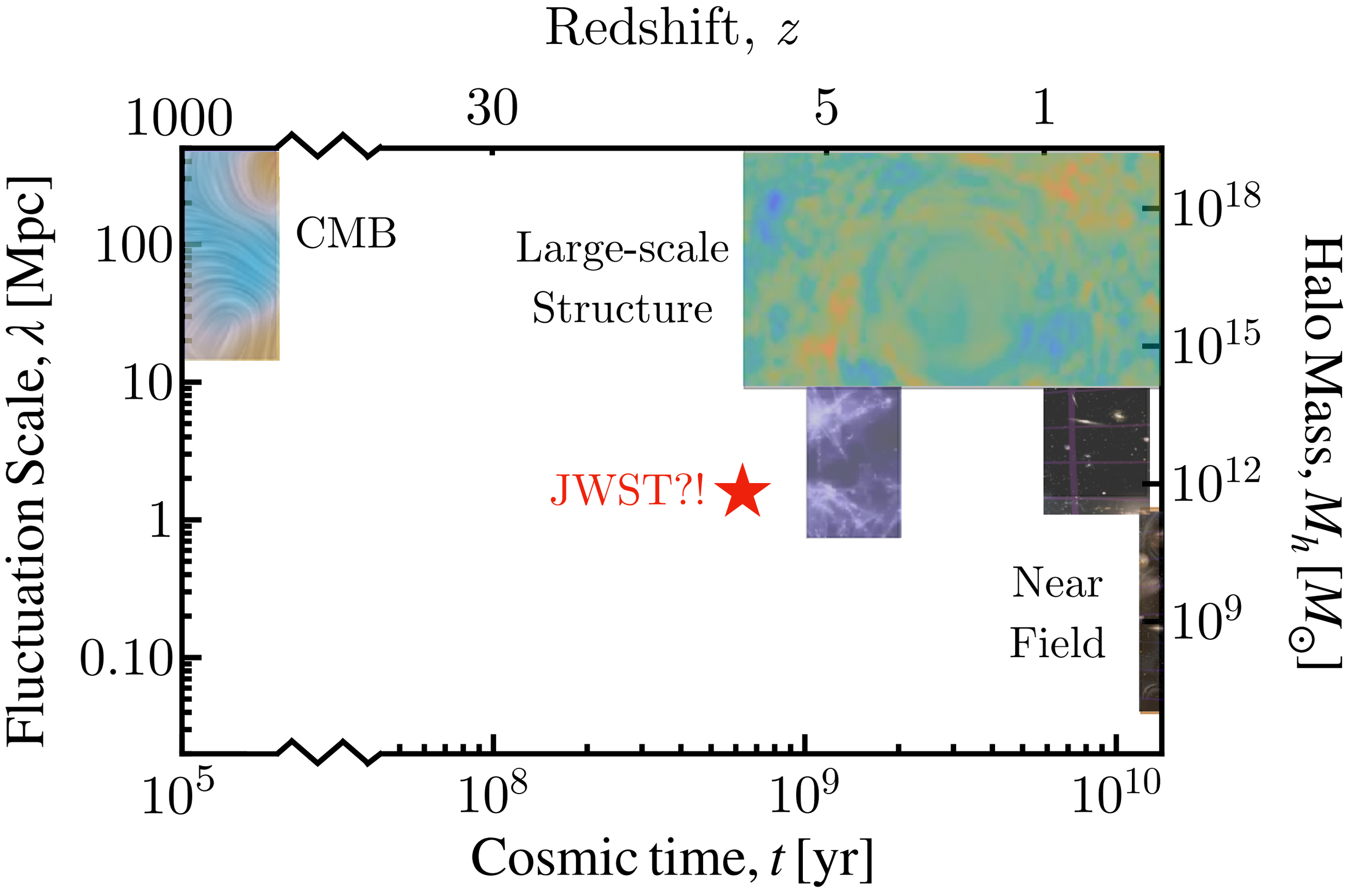
Halos from primordial fluctuations



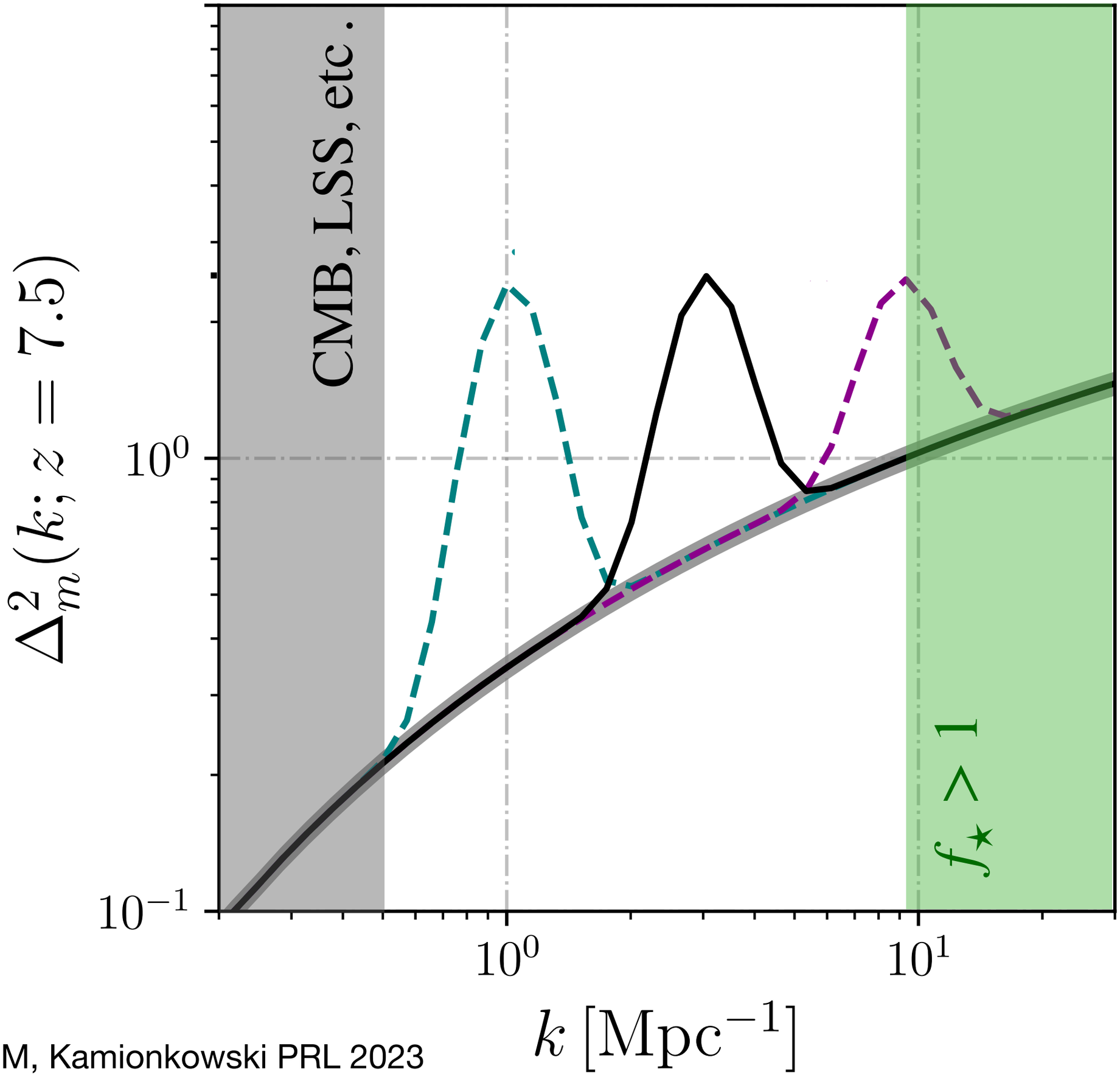


See, eg Peacock

Have we tested there?

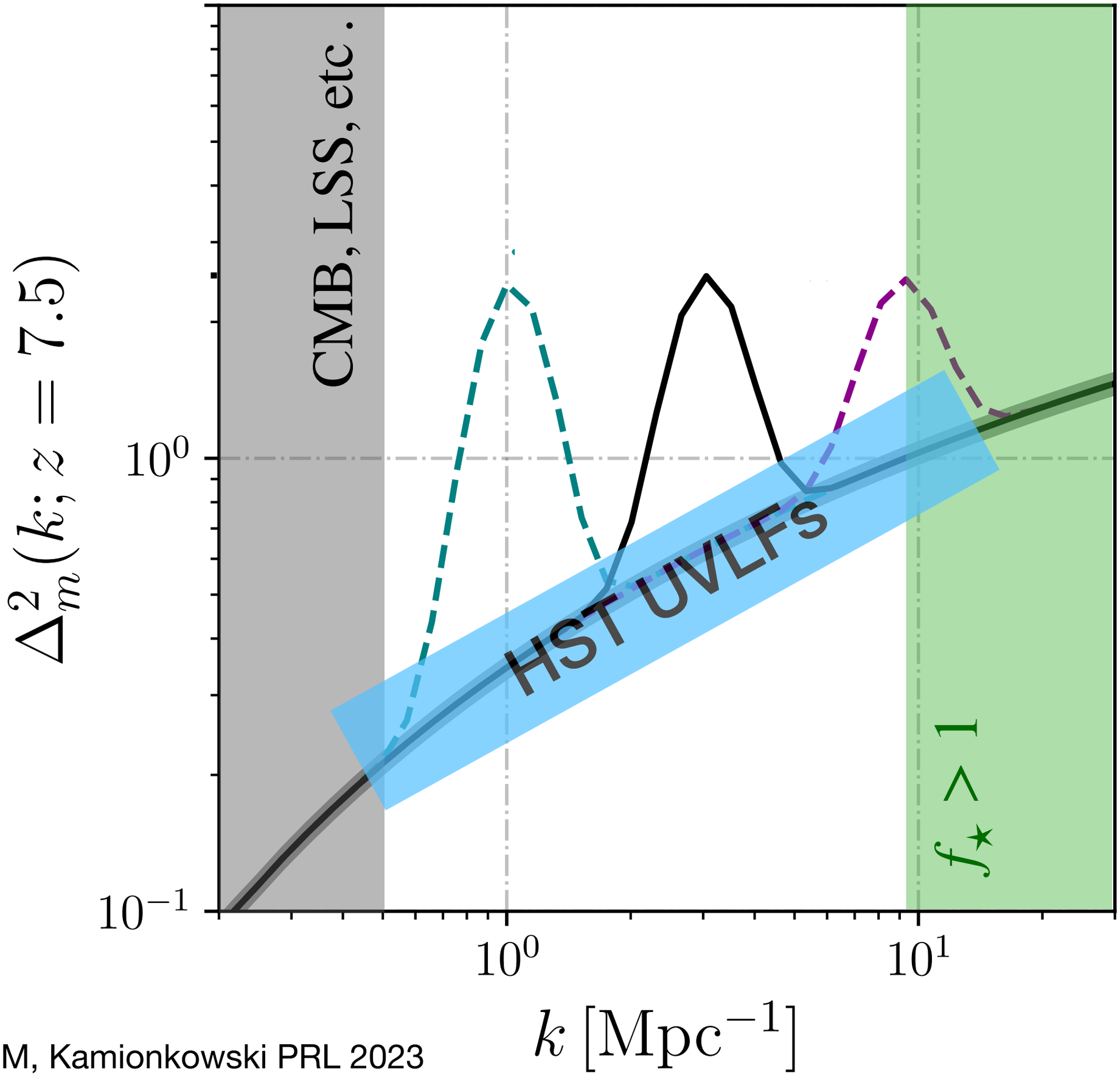


Is there more power?



Sabti, JBM, Kamionkowski PRL 2023

Is there more power?



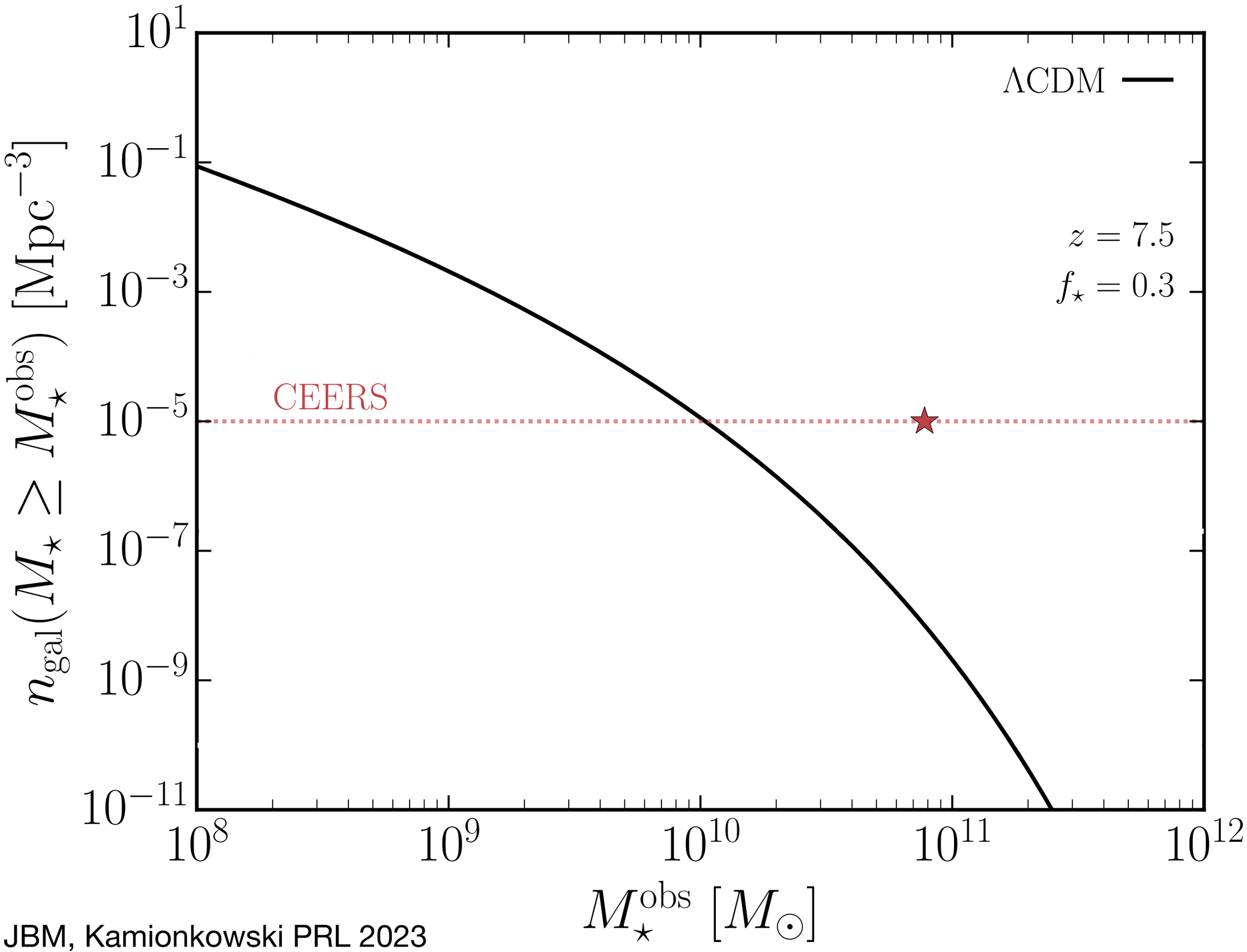
Sabti, JBM, Kamionkowski PRL 2023

Is there more power?

HST UVLFs

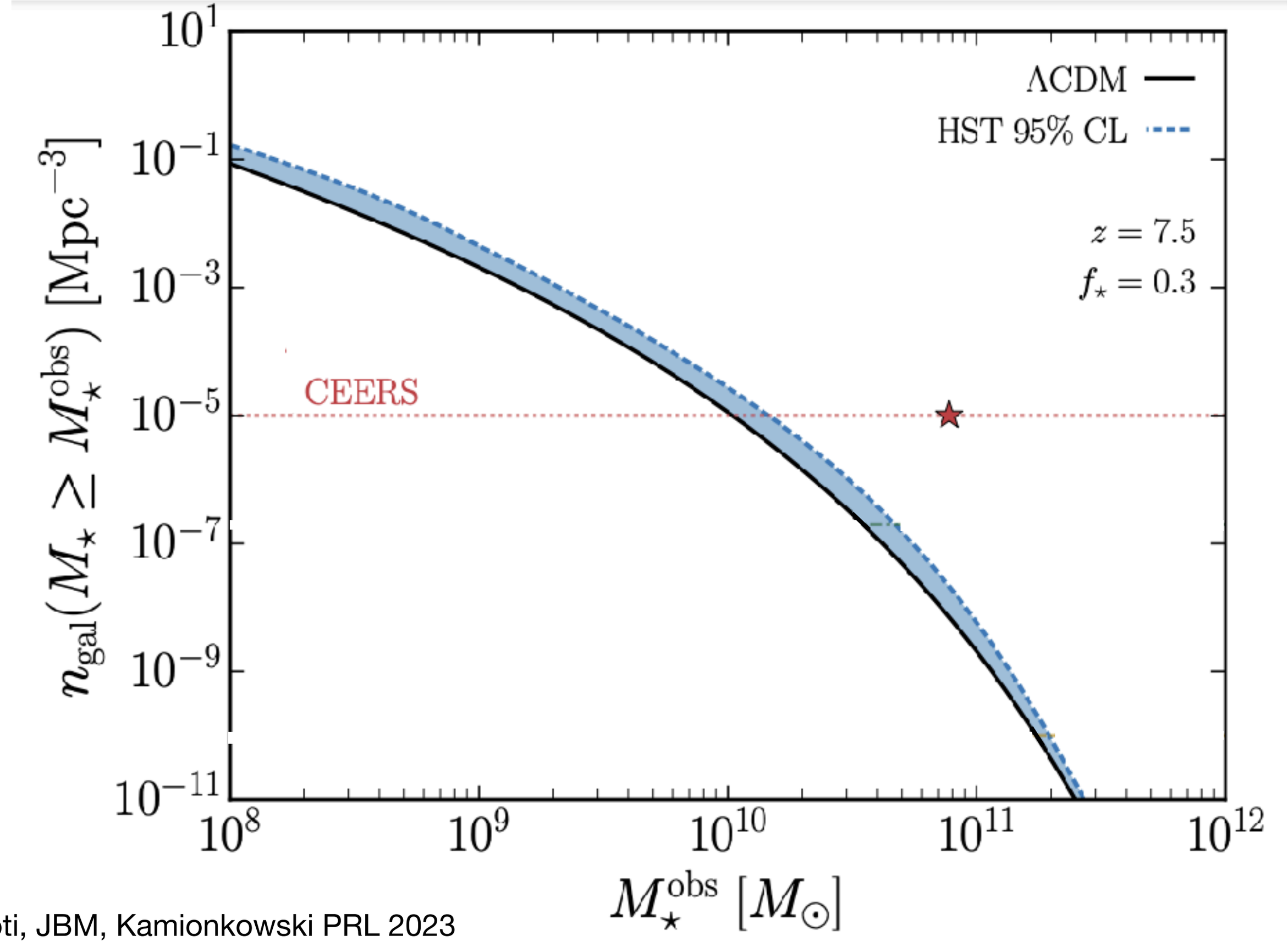
HUDF, StSci

Is there more power?



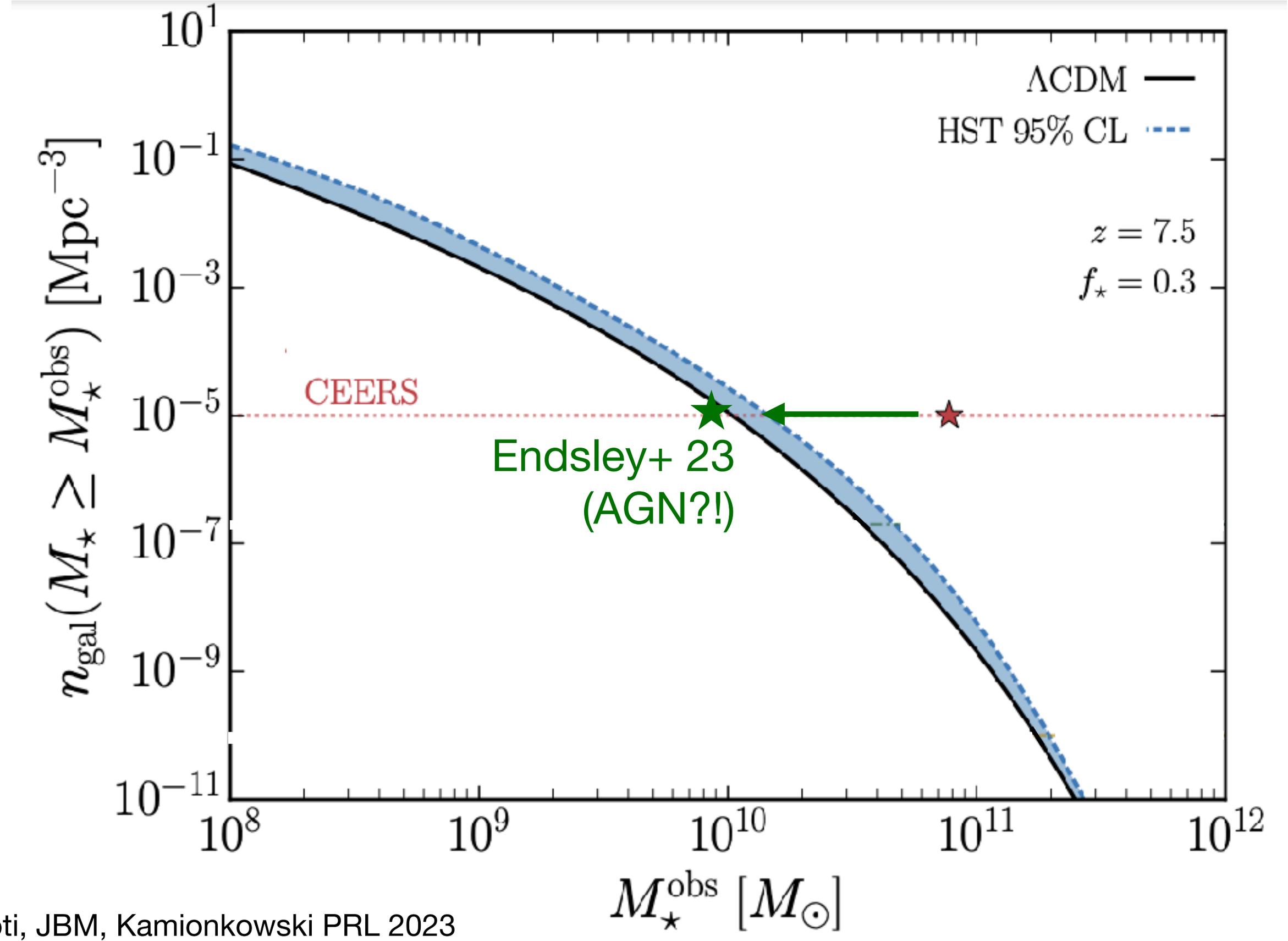
Sabti, JBM, Kamionkowski PRL 2023

Is there more power?



Sabti, JBM, Kamionkowski PRL 2023

So what gives?



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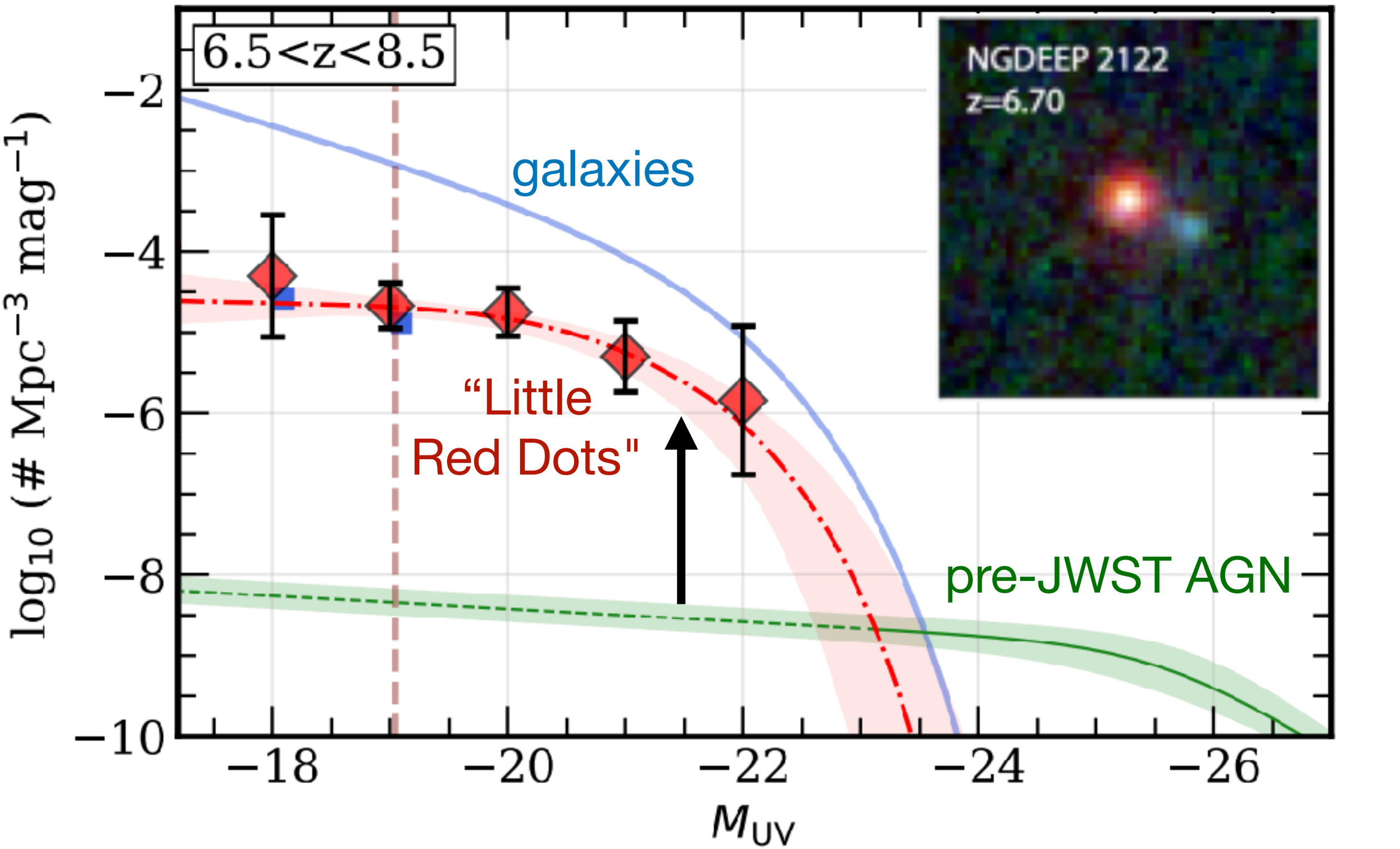
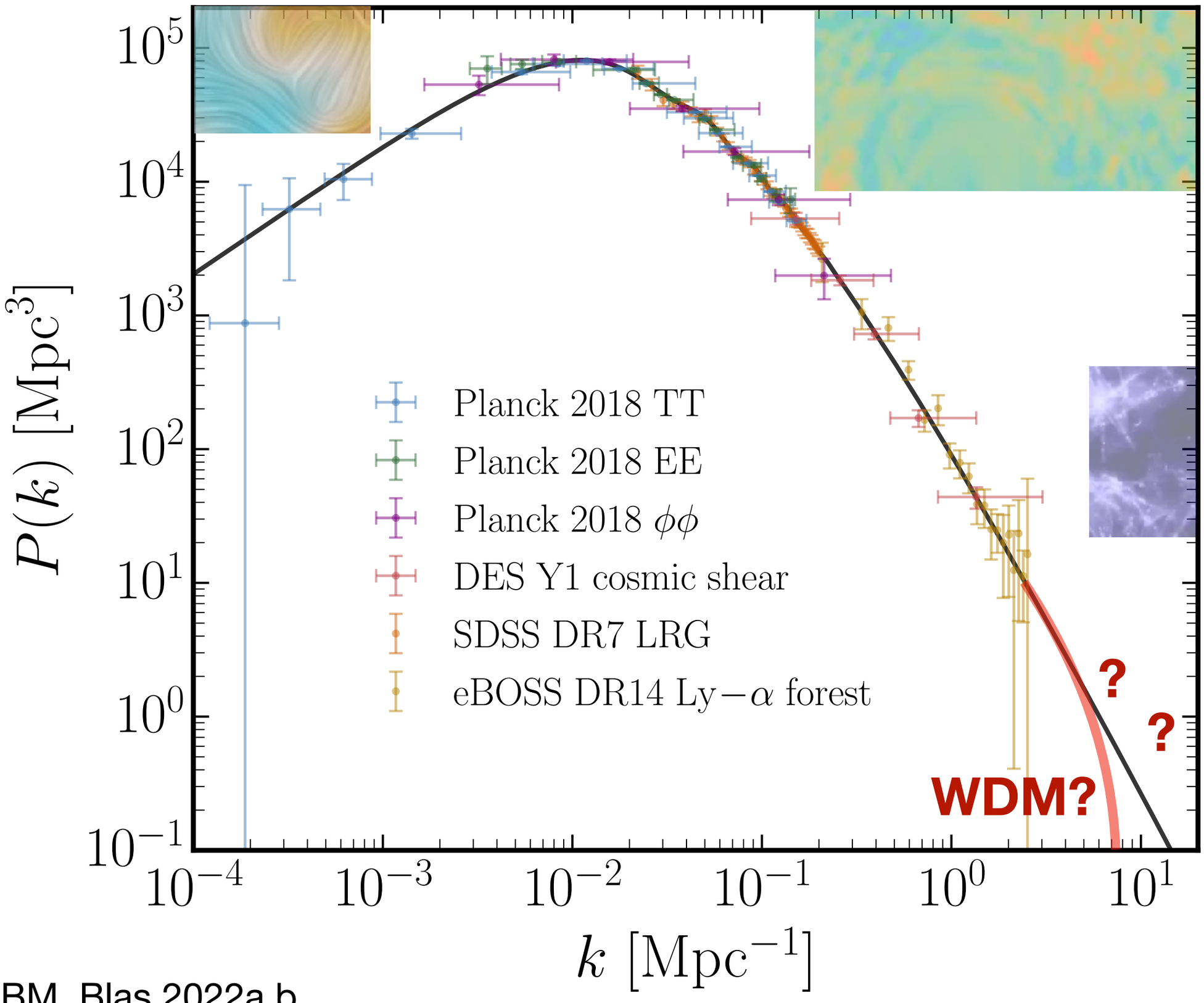
Detour: SMBHs??

Detour: SMBHs??



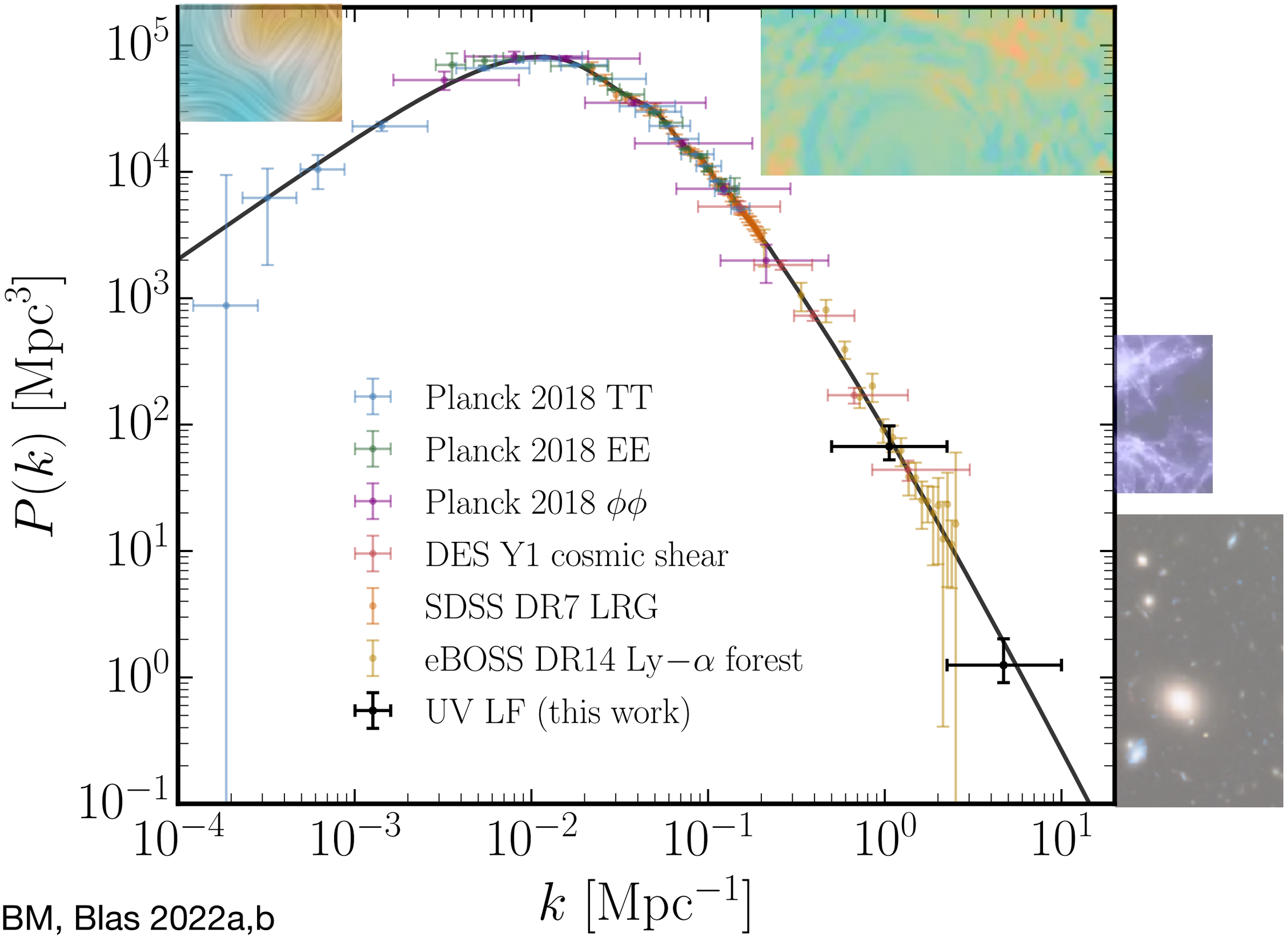
Kokorev+2024

More broadly:



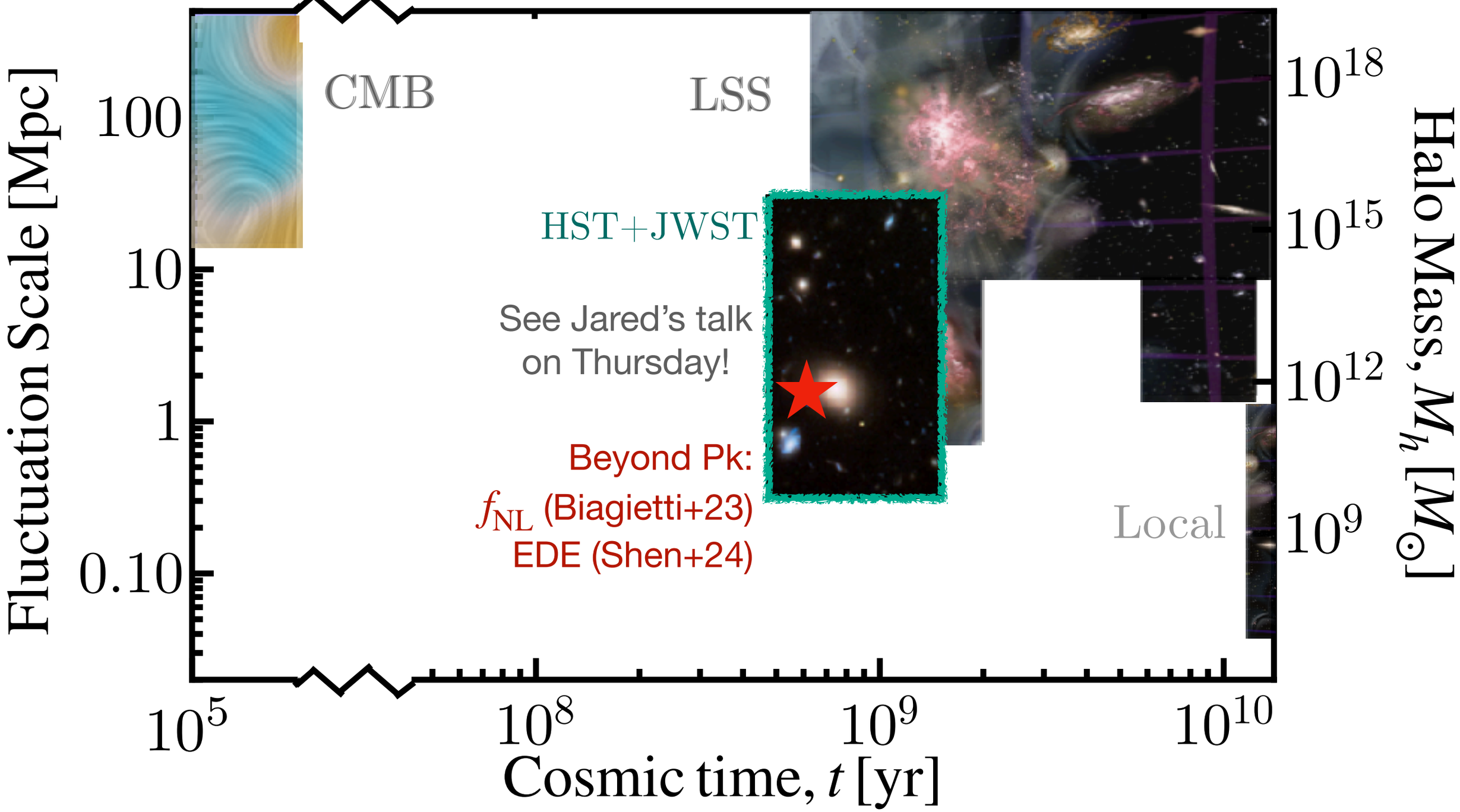
Sabti, JBM, Blas 2022a,b

More broadly:



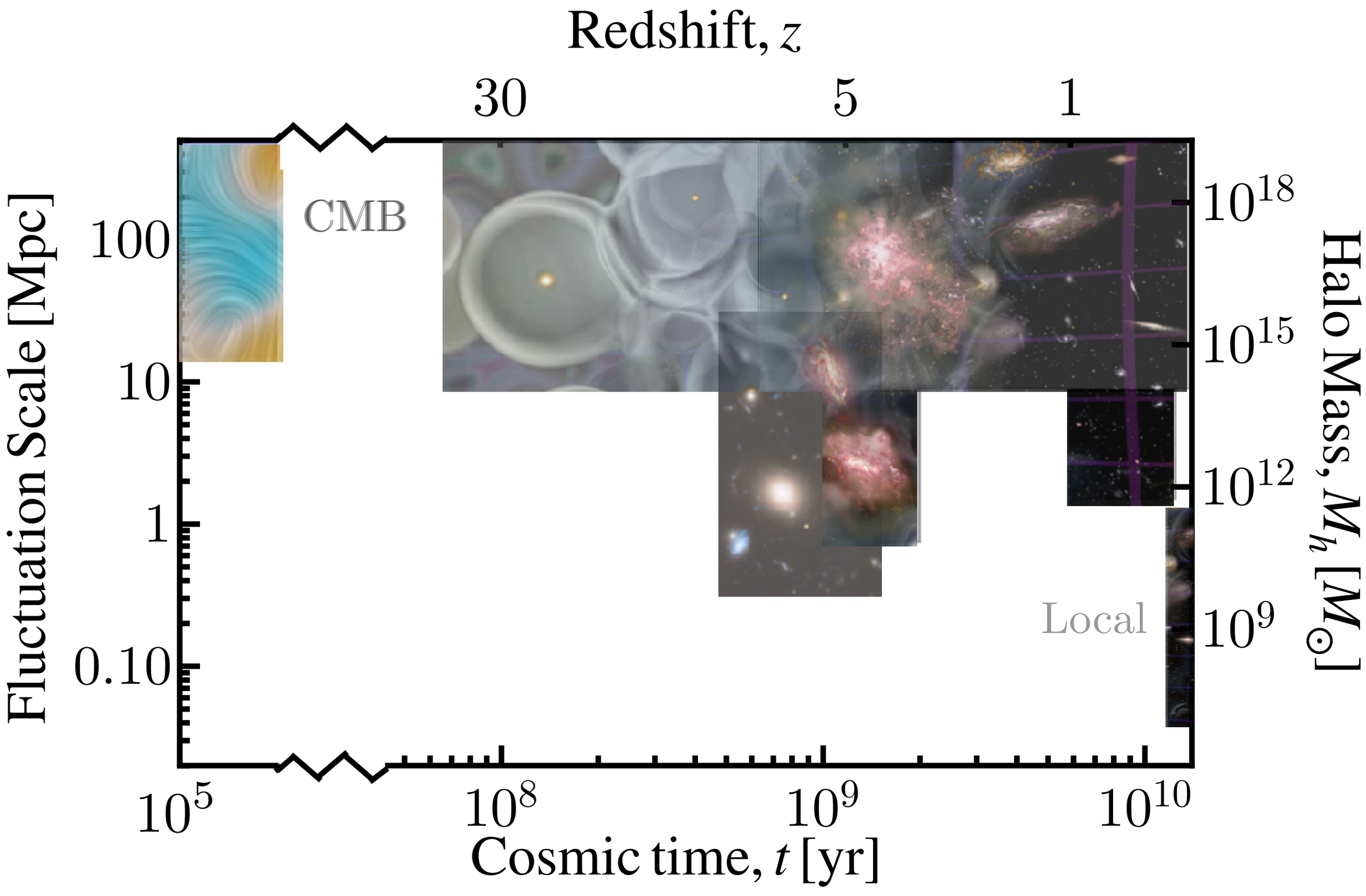
Sabti, JBM, Blas 2022a,b

More broadly:

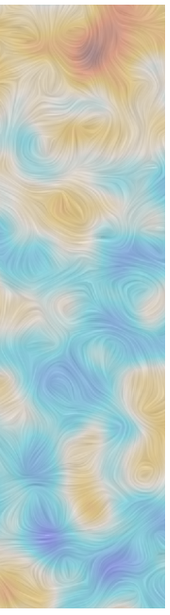


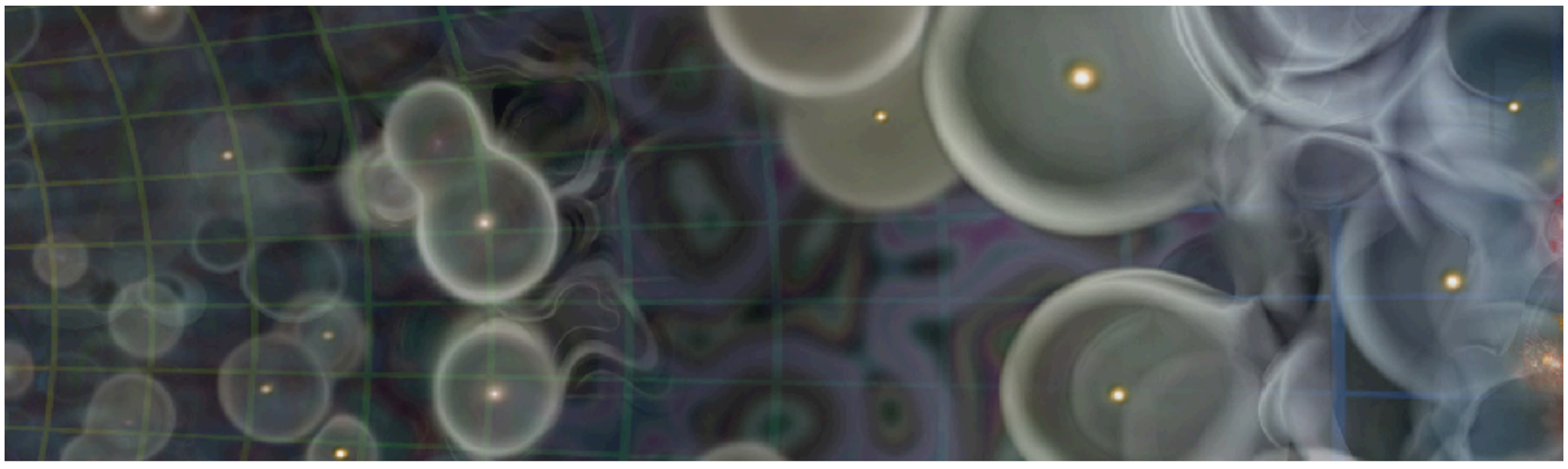
Sabti, JBM, Kamionkowski 23

What's the status of reionization?

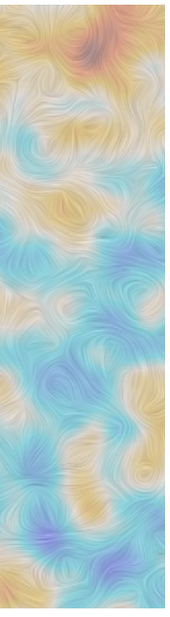


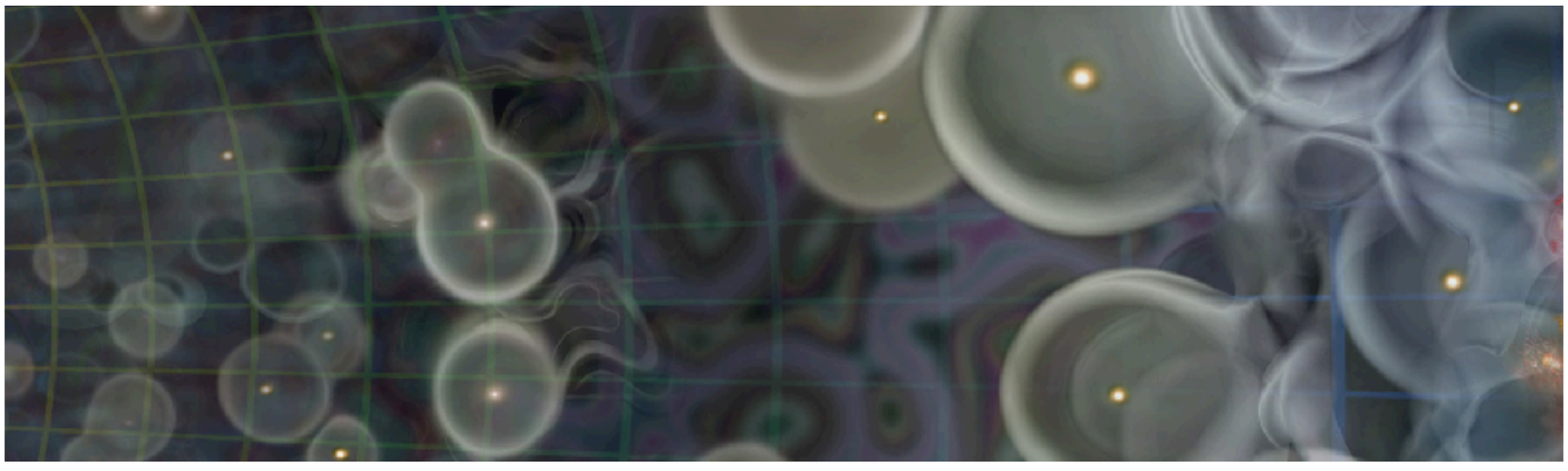
Reionization is topologically complex



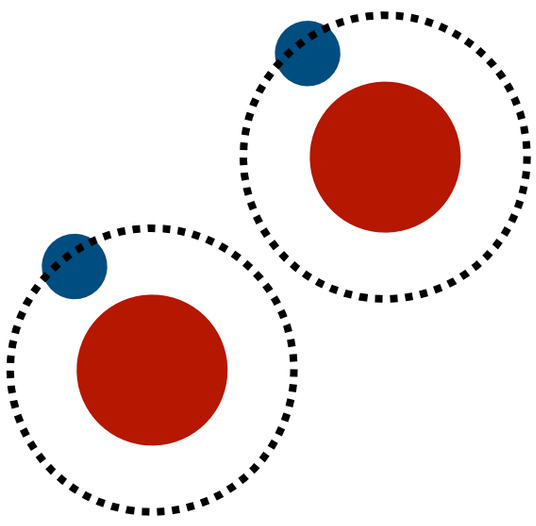


Reionization is topologically complex

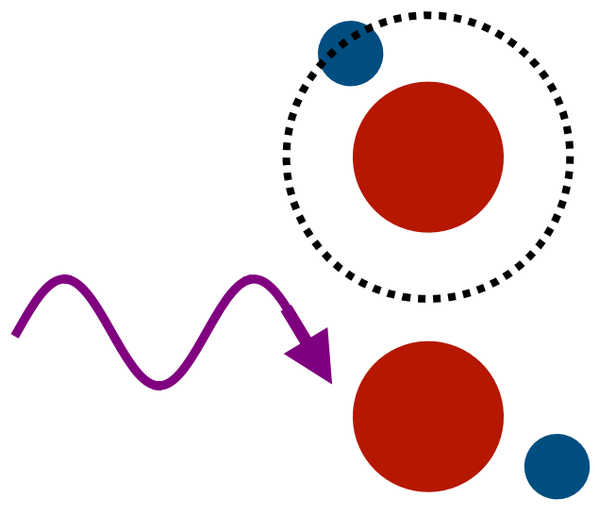




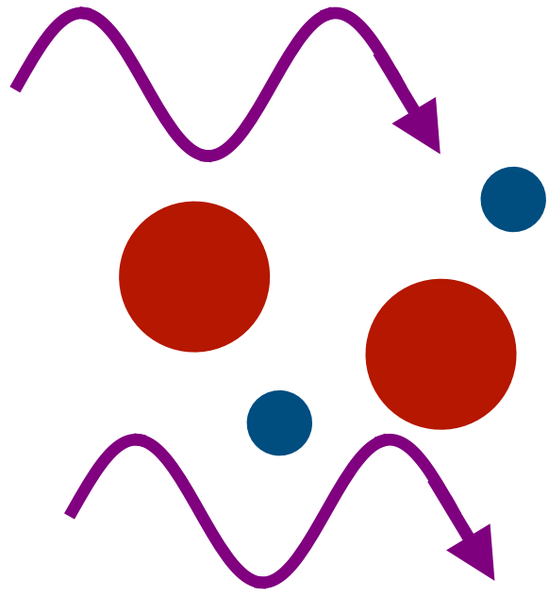
But globally simple



$x_{\mathrm{HI}} = 1$

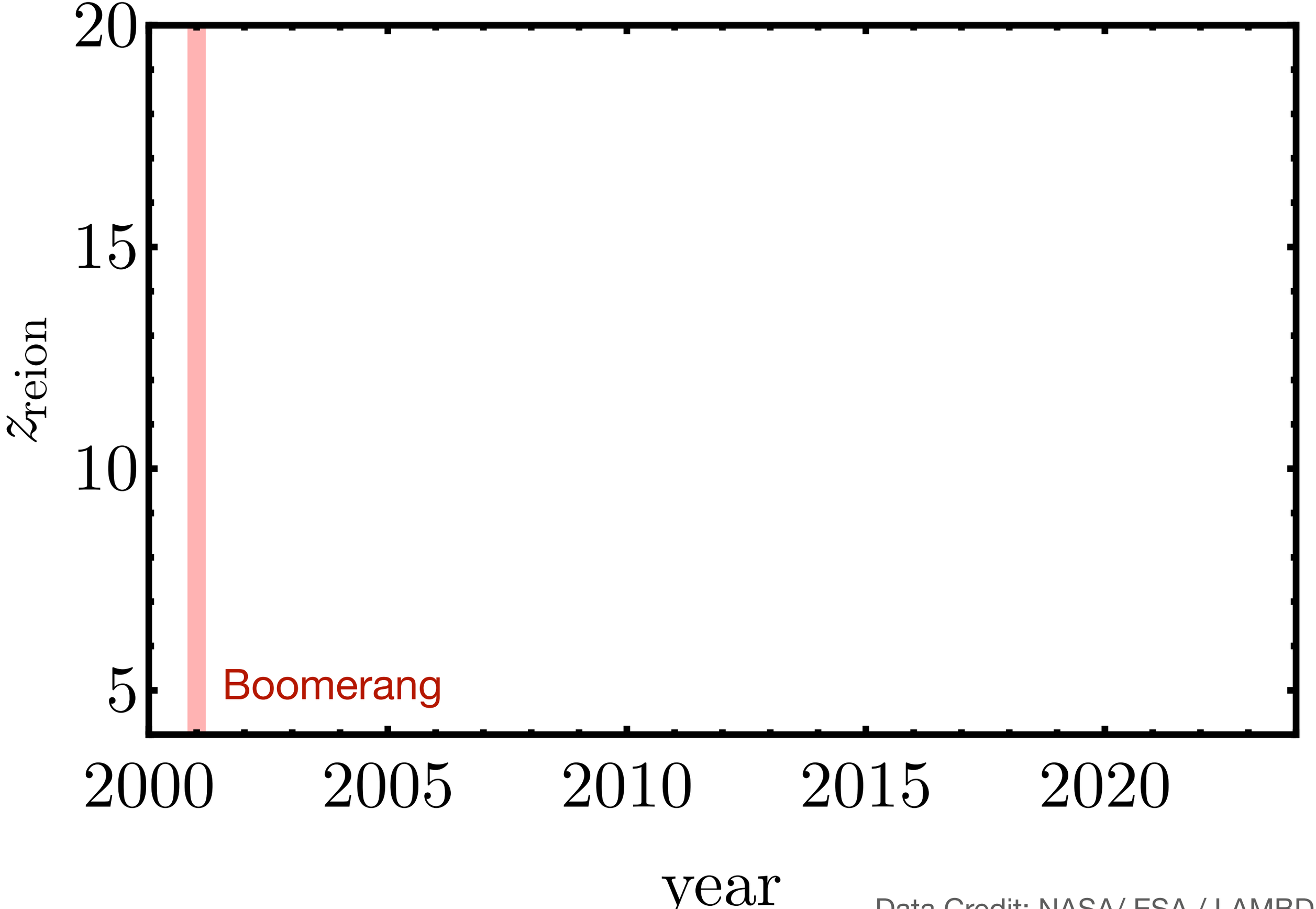


$x_{\mathrm{HI}} = 0.5$



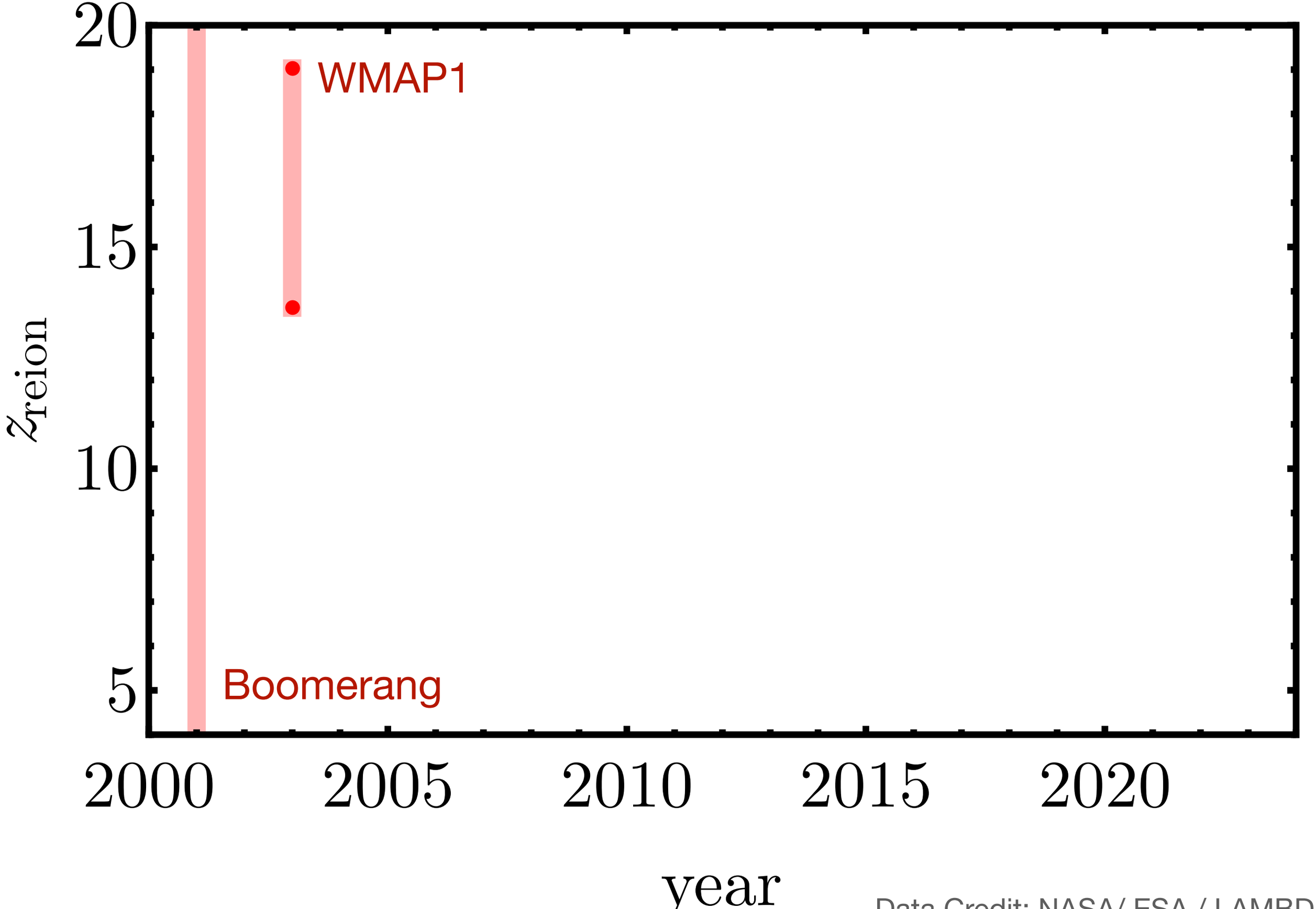
$x_{\mathrm{HI}} = 0$

Reionization circa 2000:



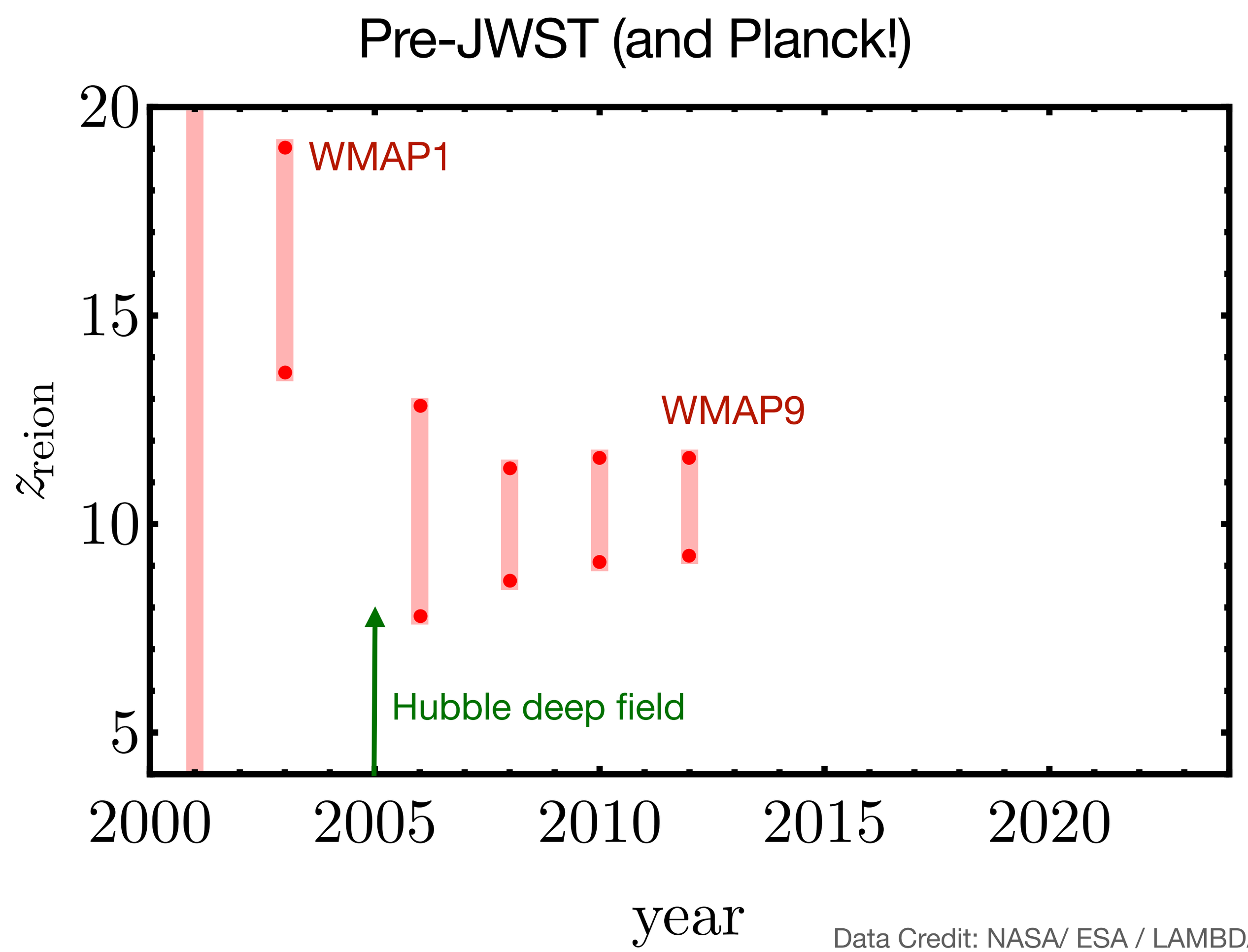
Data Credit: NASA/ ESA / LAMBDA

Pre-JWST (and Planck!)



Data Credit: NASA/ ESA / LAMBDA

Pre-JWST (and Planck!)



Data Credit: NASA/ ESA / LAMBDA

Post-Planck (but still pre-JWST)

20
15
10
5

$z_{\rm reion}$

WMAP9

Planck

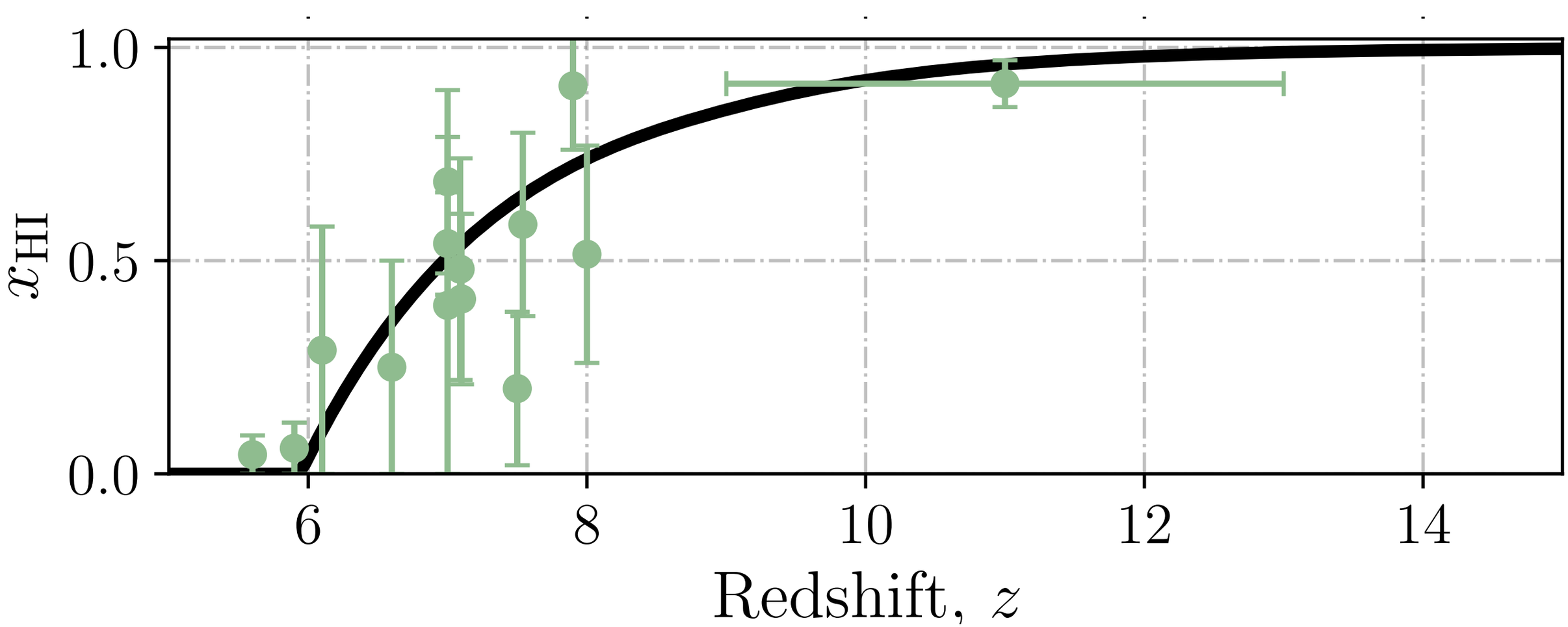
Hubble ultra deep field

2000
2005
2010
2015
2020

year

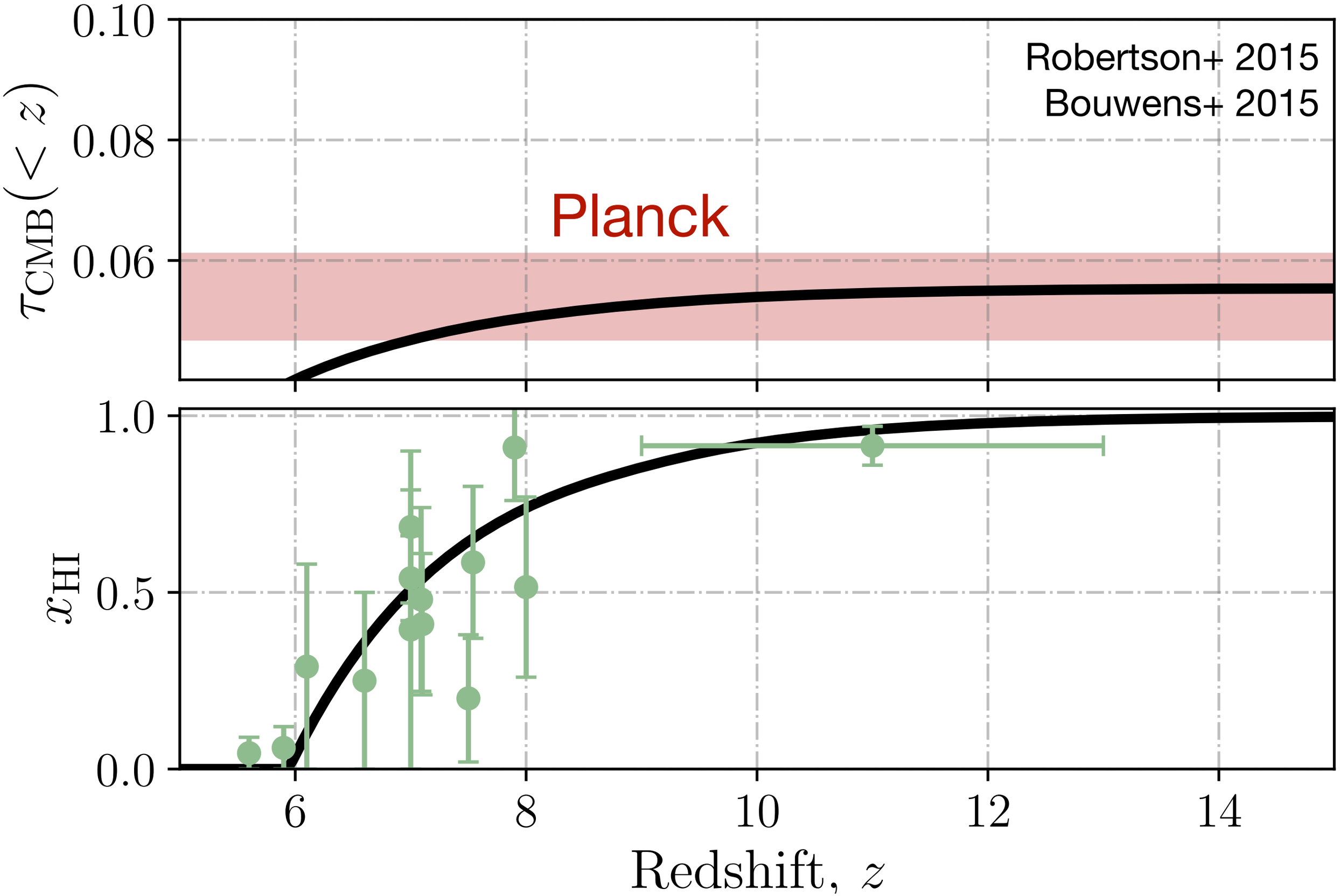
Data Credit: NASA/ ESA / LAMBDA

Circa 2015 (Pre-JWST but post-Planck)

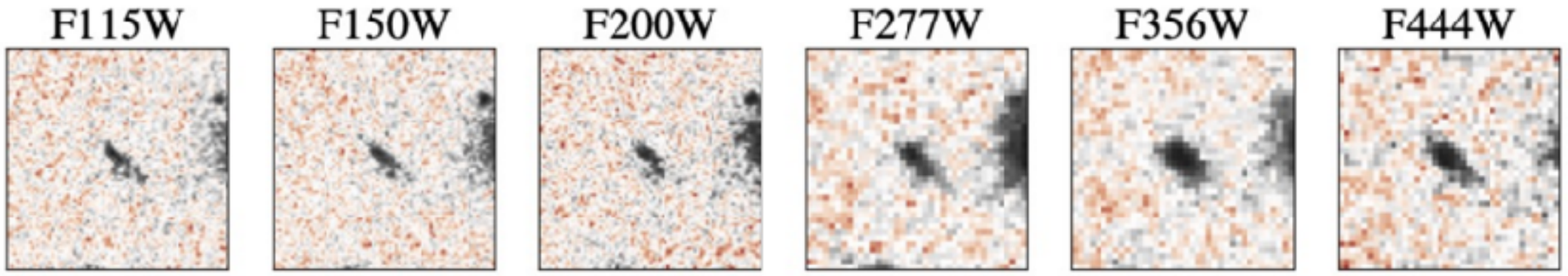


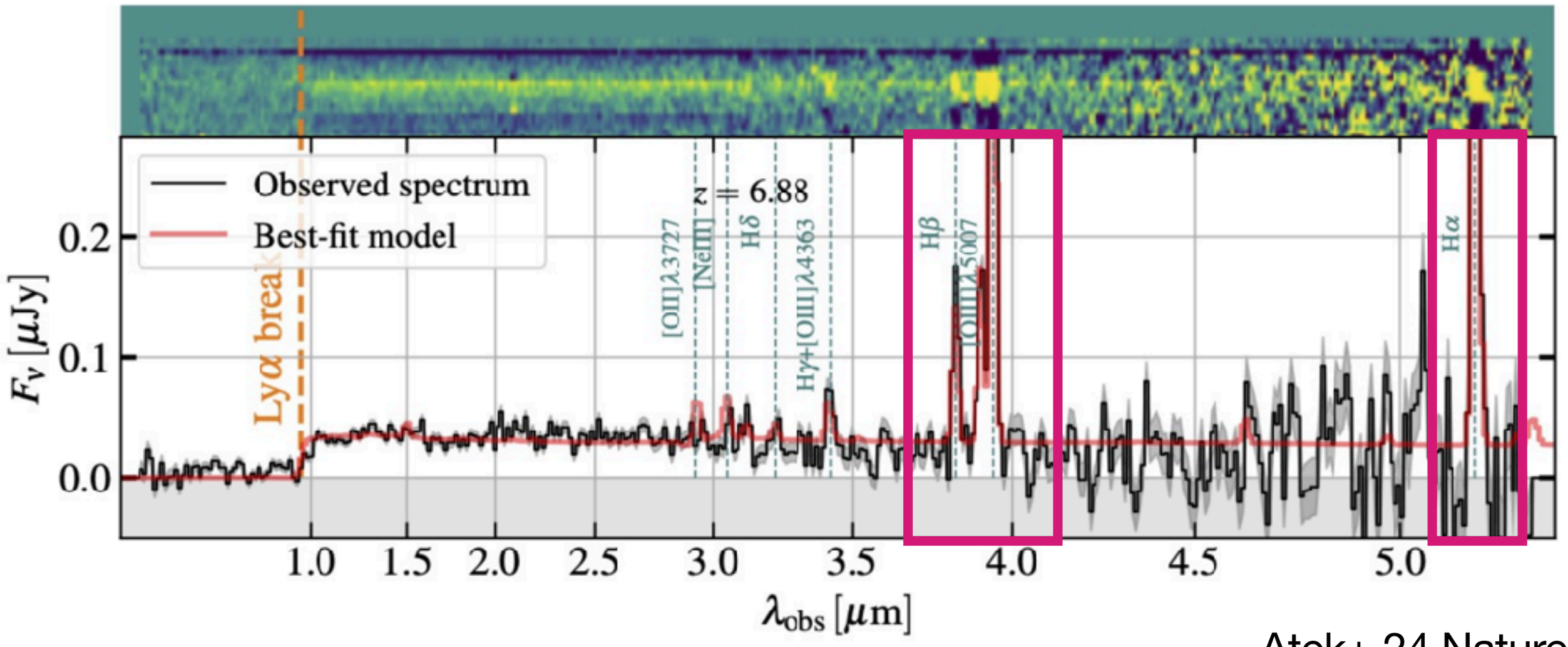
see Madau+15 for AGN

Circa 2015 (Pre-JWST but post-Planck)



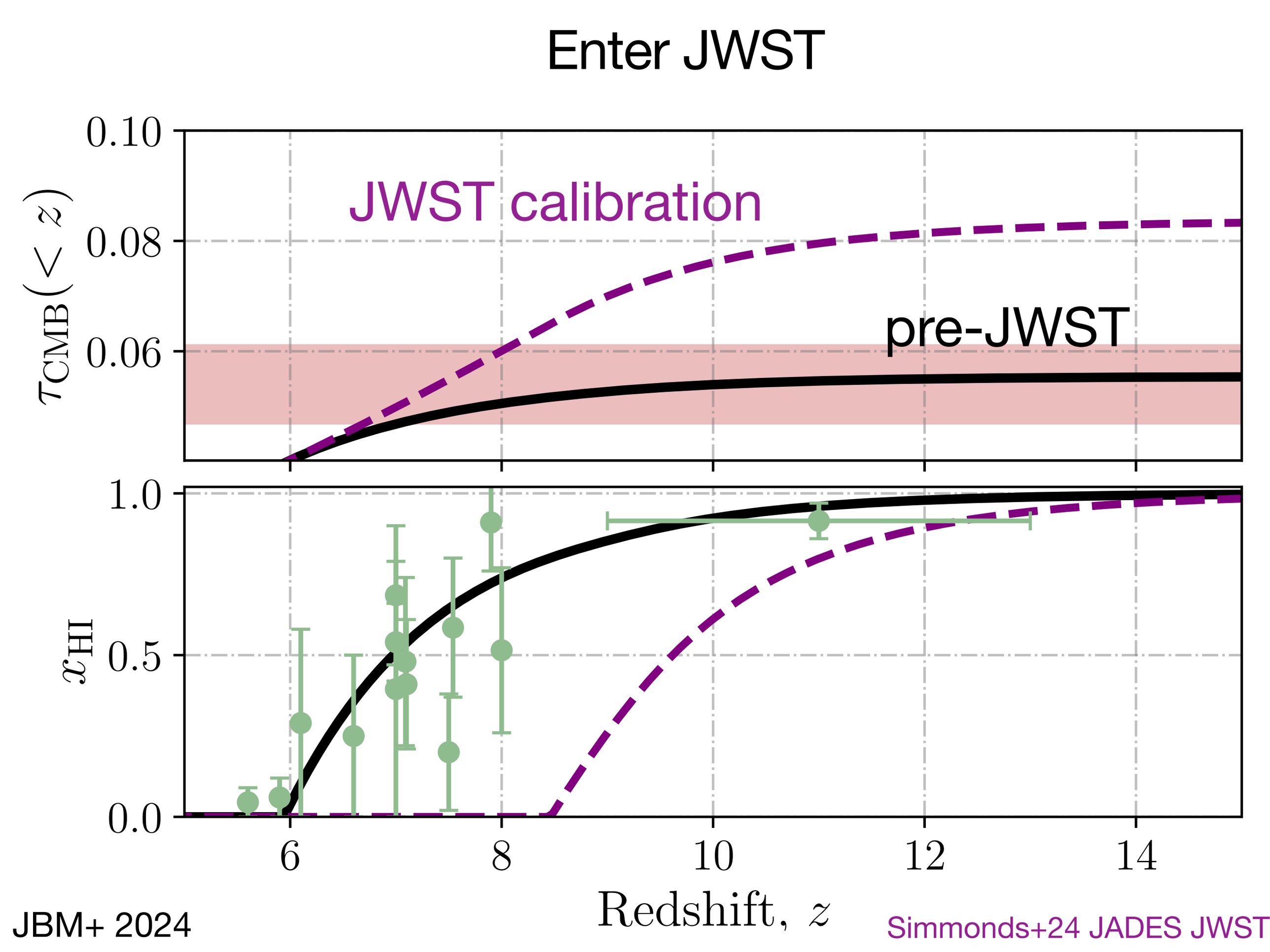
Enter JWST





Atek+ 24 Nature

Enter JWST



JBM+ 2024

Simmonds+24 JADES JWST

M64, Credit: NASA (Smartt, Richstone)

$\gamma_{\rm ion}$

$\gamma_{\rm ion}$

$\gamma_{\rm ion}$

$f_{\rm esc}$?

With JWST + low-z studies

+low-z $f_{\rm esc}$

Planck

JWST

pre-JWST

$\tau_{\rm CMB}(<z)$

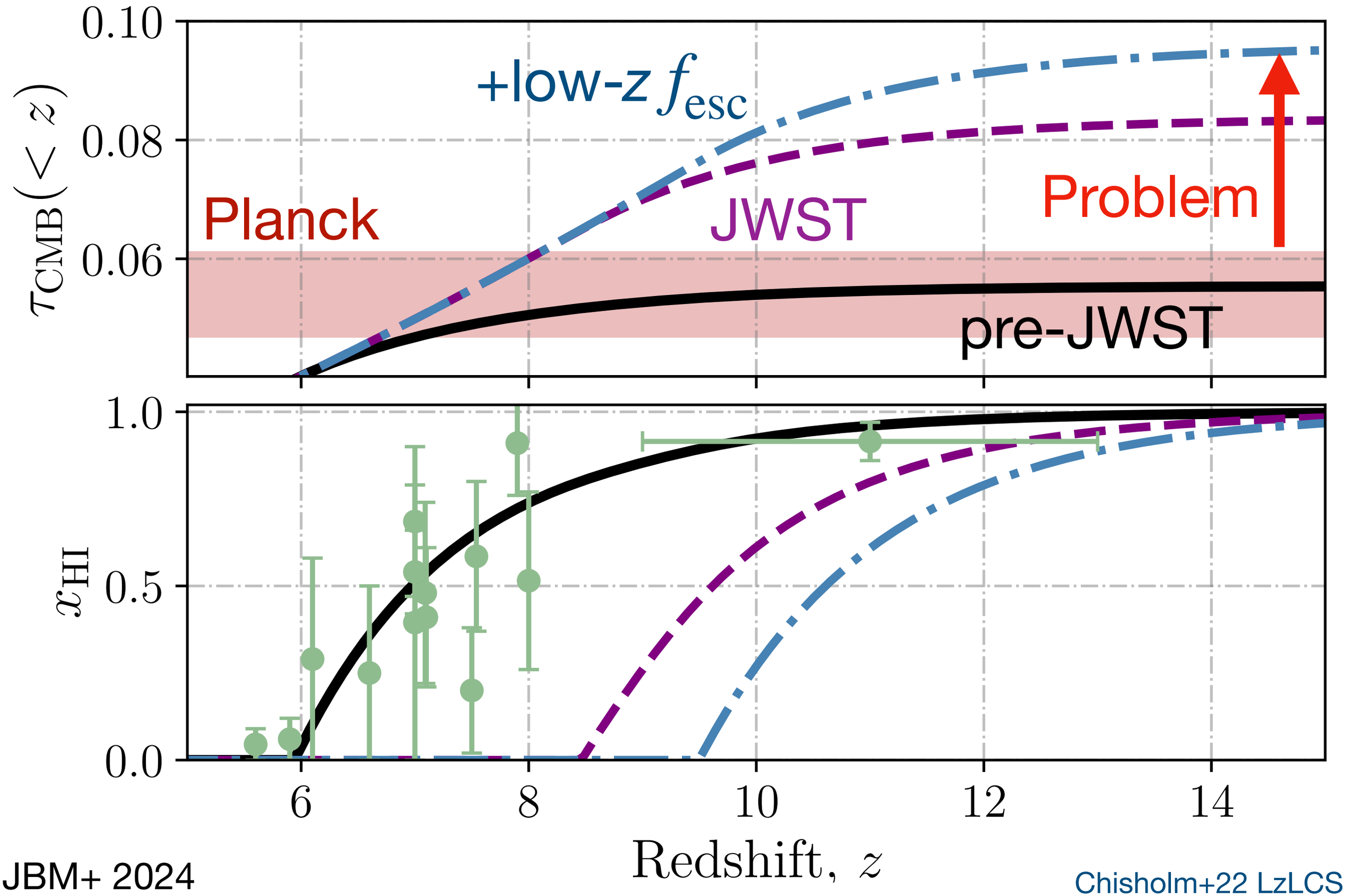
$x_{\rm HI}$

Redshift, z

JBM+ 2024

Chisholm+22 LzLCS

With JWST + low-z studies



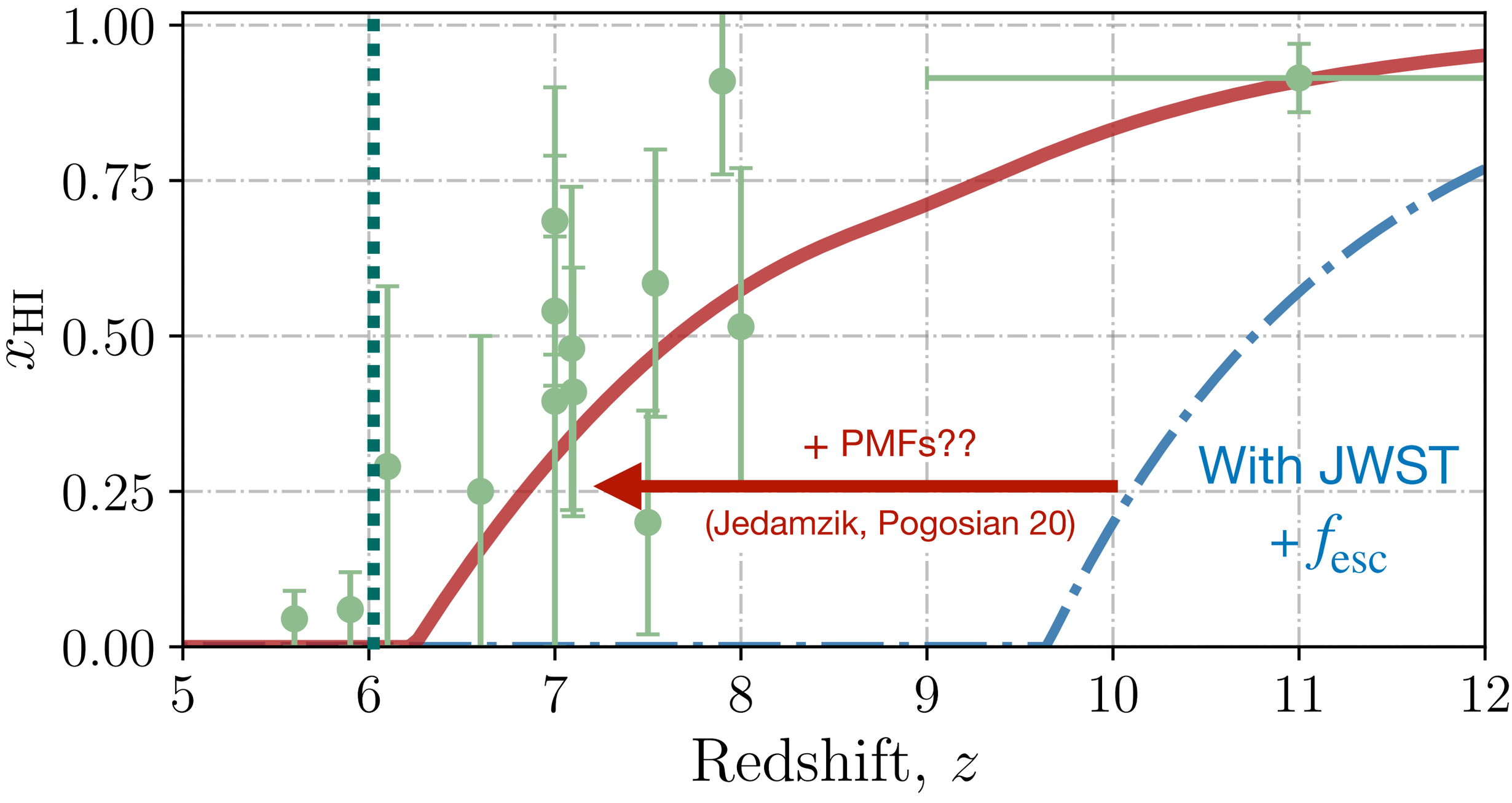
JBM+ 2024

Chisholm+22 LzLCS

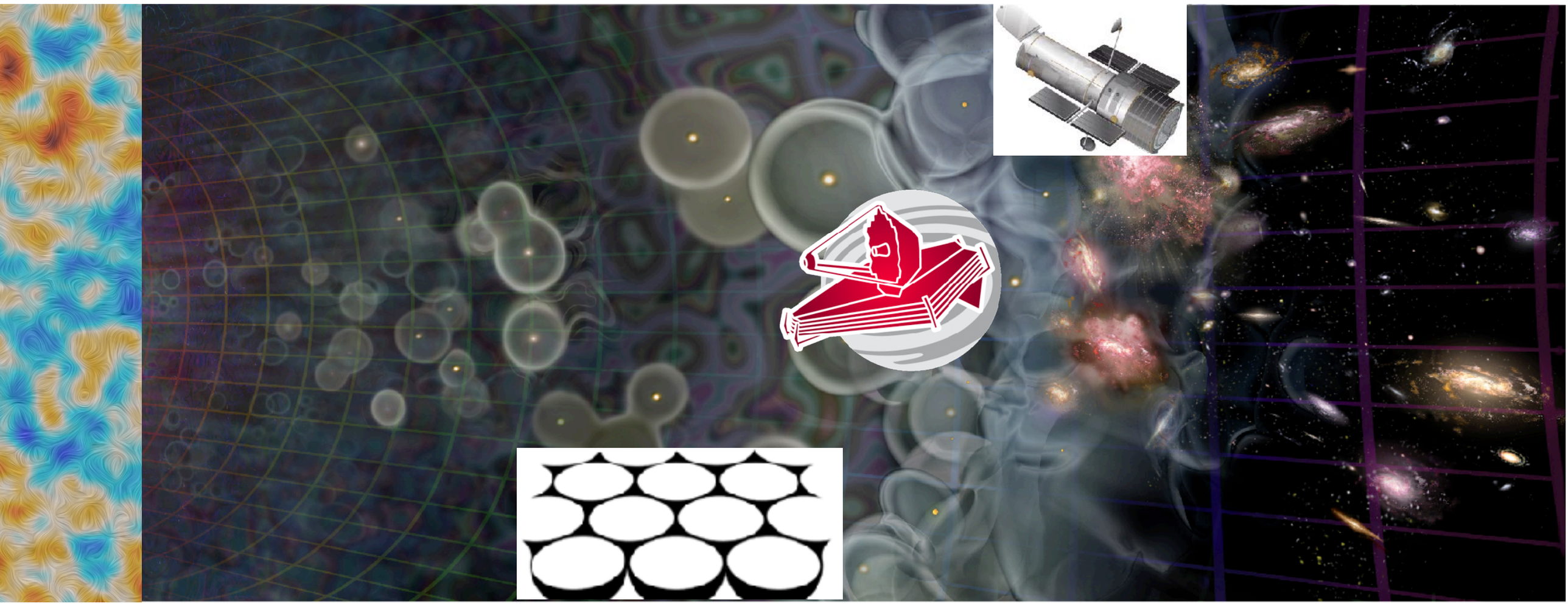
Ways out:

Observational biases?

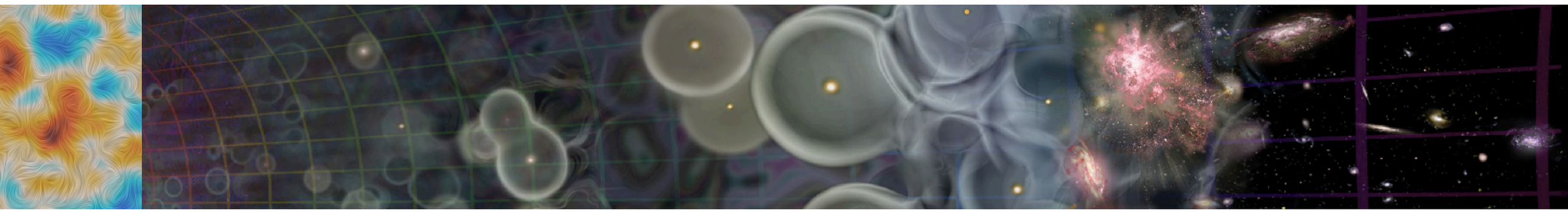
Maybe there are more recombinations?



What about the future?

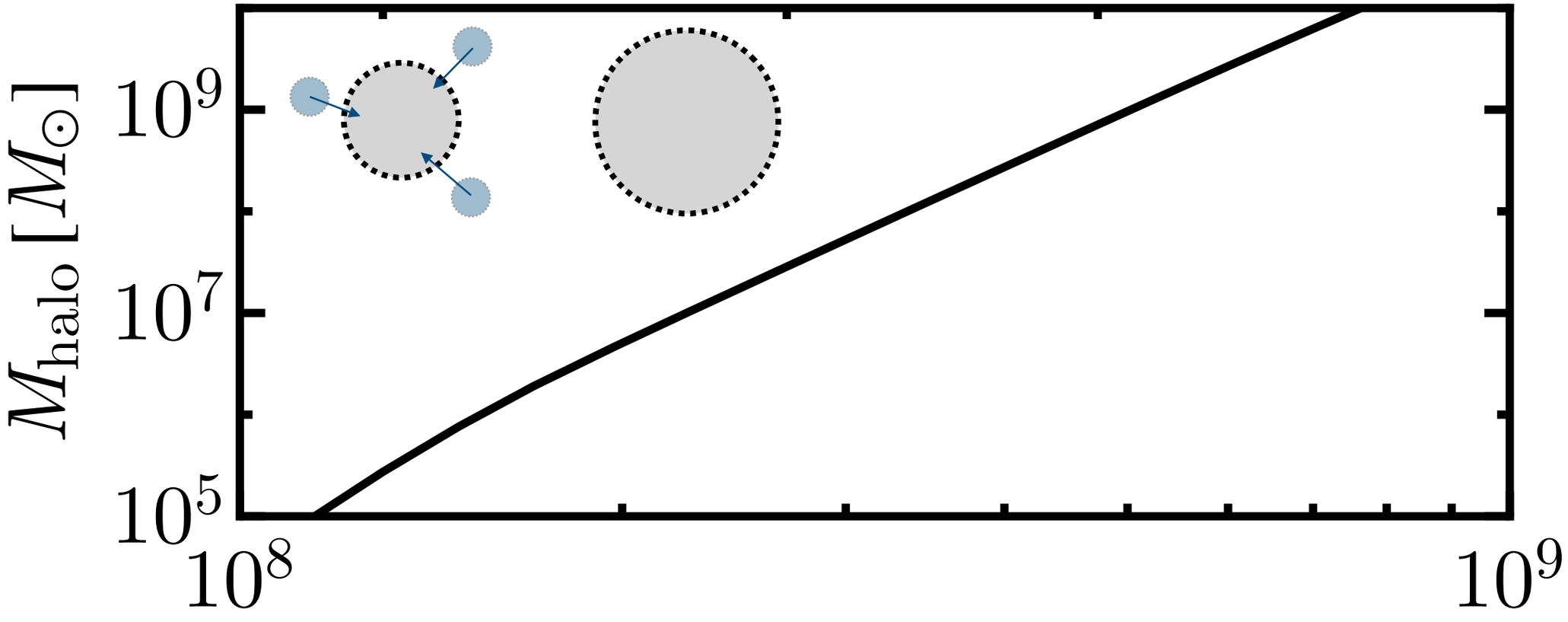


How small were the first galaxy halos?

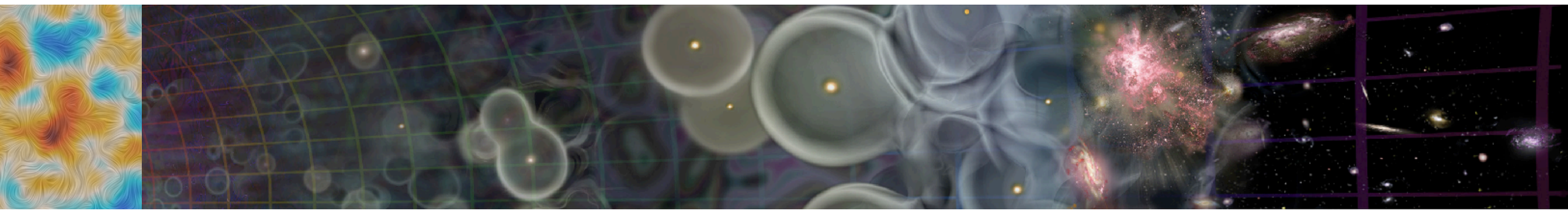


Redshift, z

25 15 10

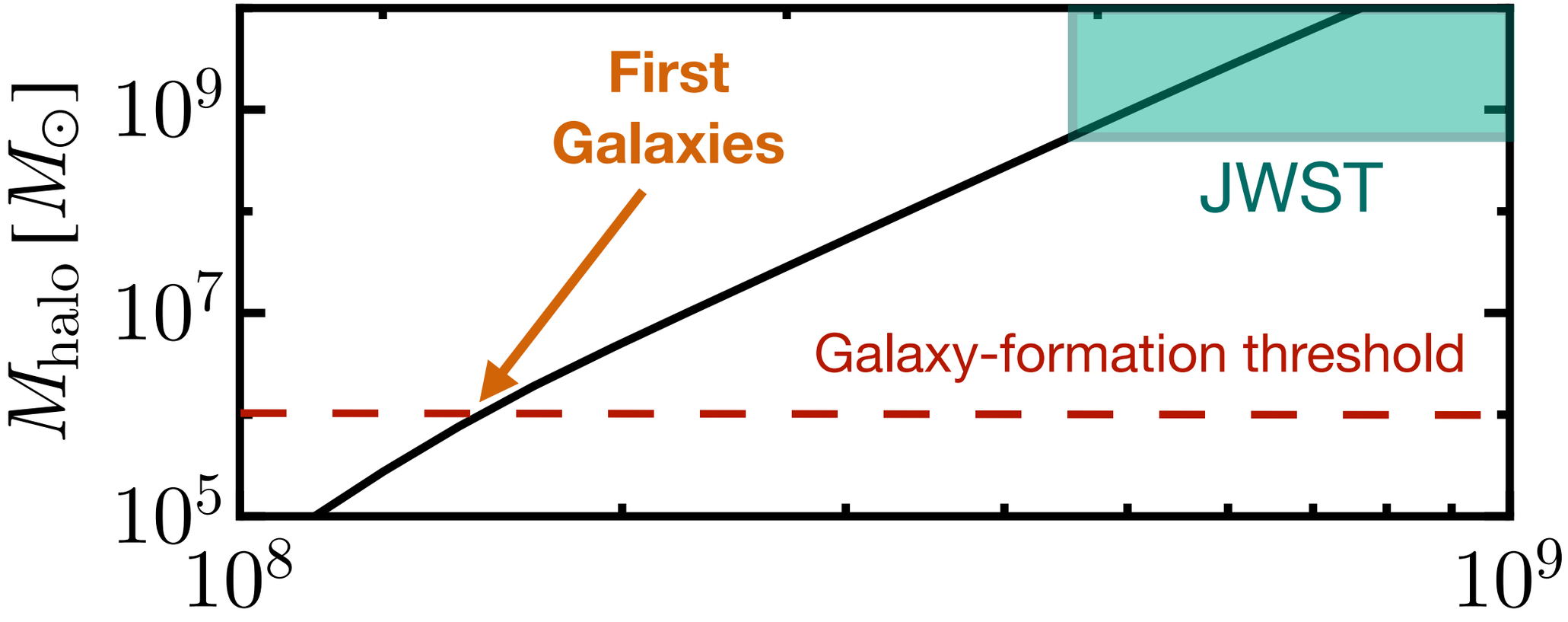


How small were the first galaxy halos?



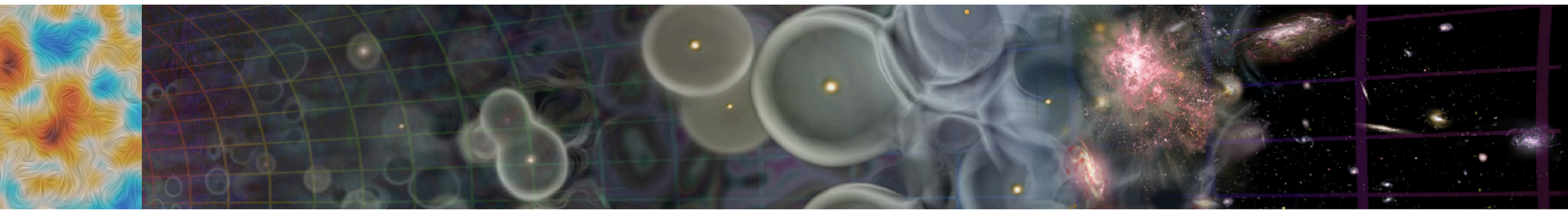
Redshift, z

25 15 10



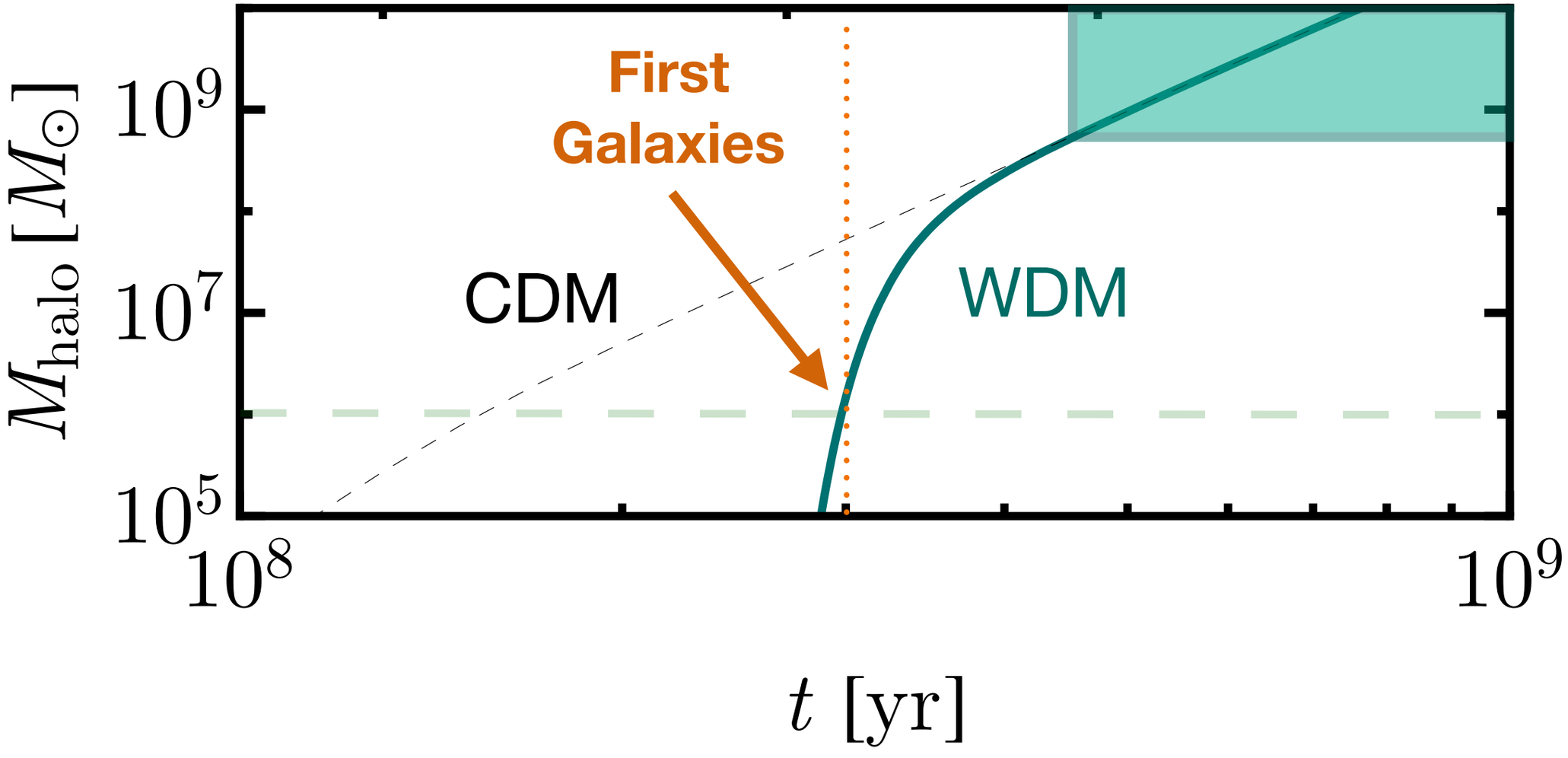
t [yr]

How small were the first galaxy halos?



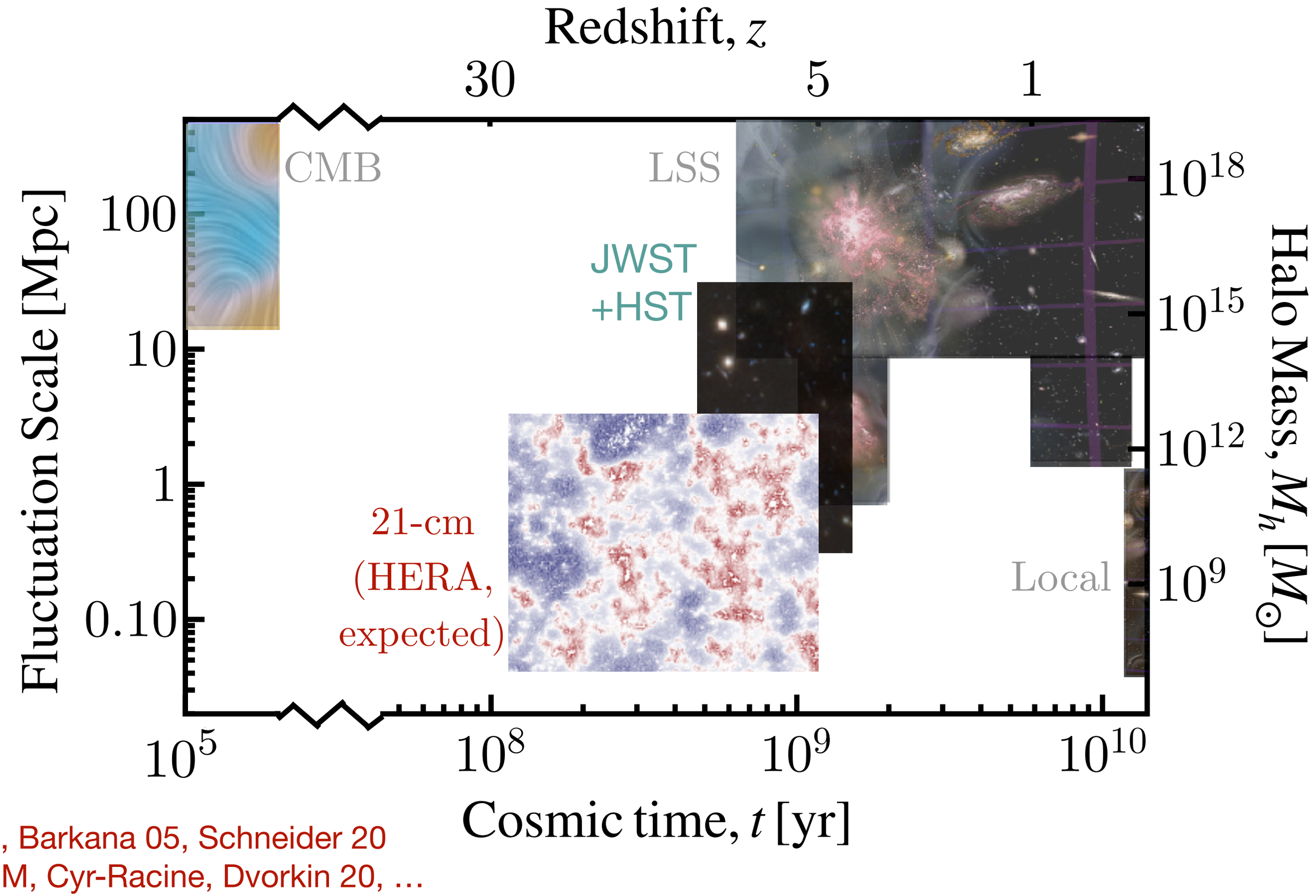
Redshift, z

25 15 10



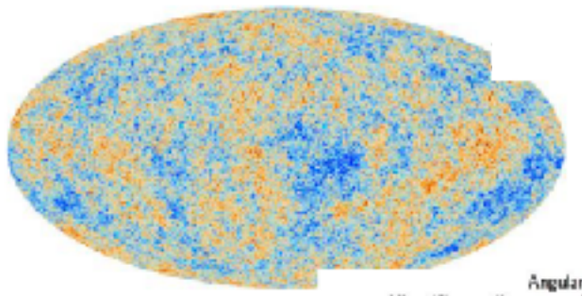
What about the future?

See Wenzer's and Tracy's talks!



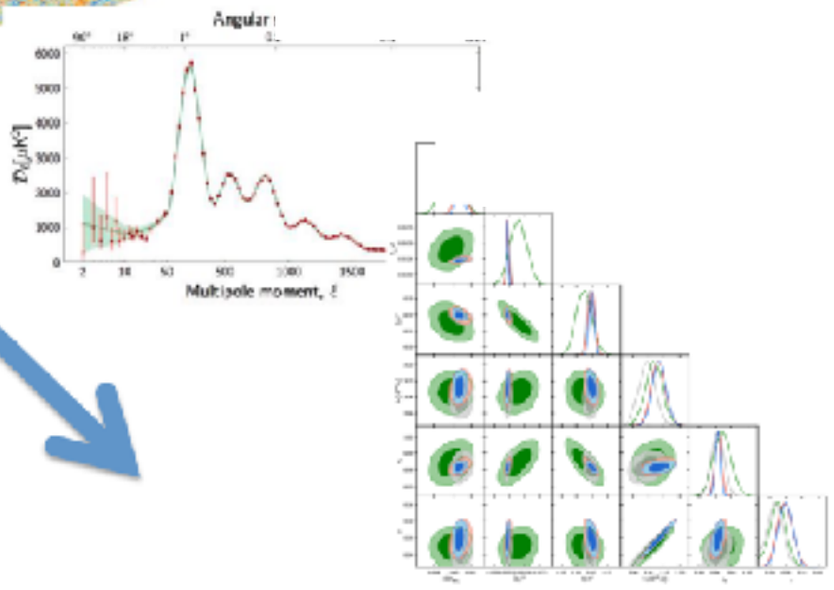
Eg, Barkana 05, Schneider 20
JBM, Cyr-Racine, Dvorkin 20, …

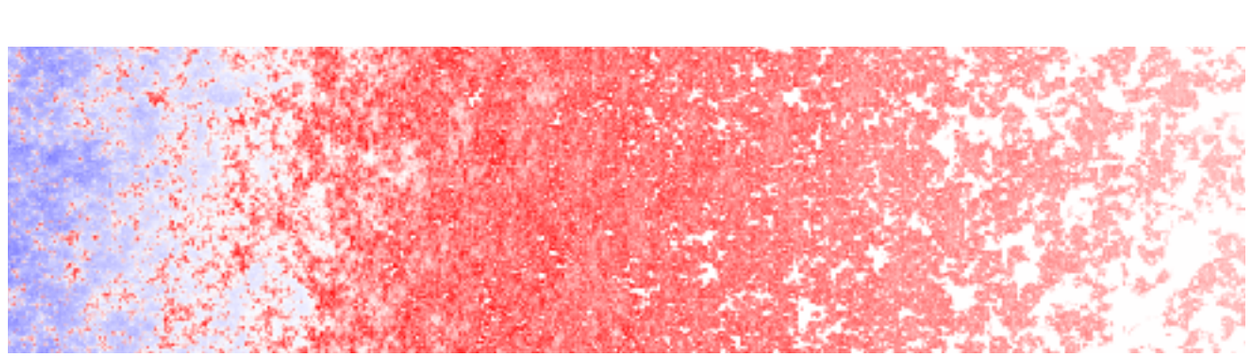
How to decode this information?



CMB (~2D)

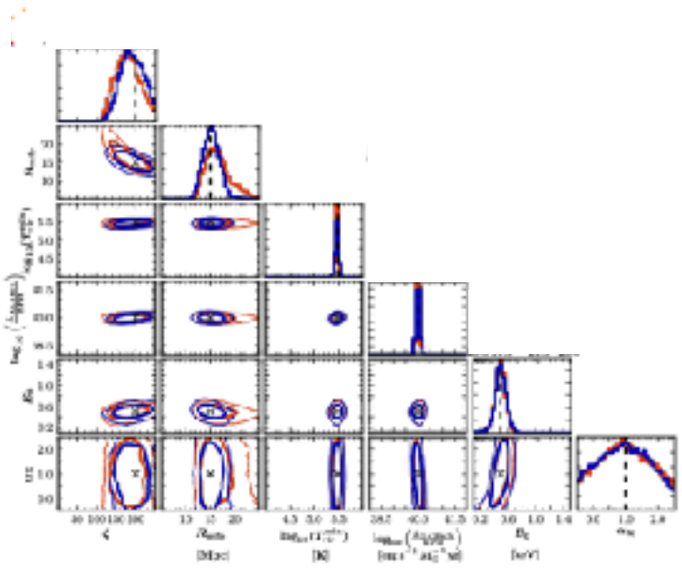
Theory is robust, <1s/point





21-cm (~3D)

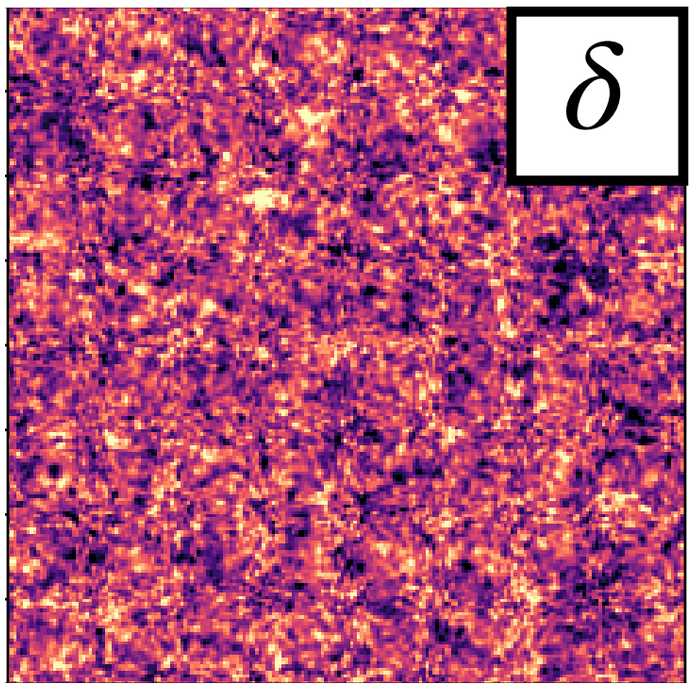
Theory is uncertain, ~1hr/point

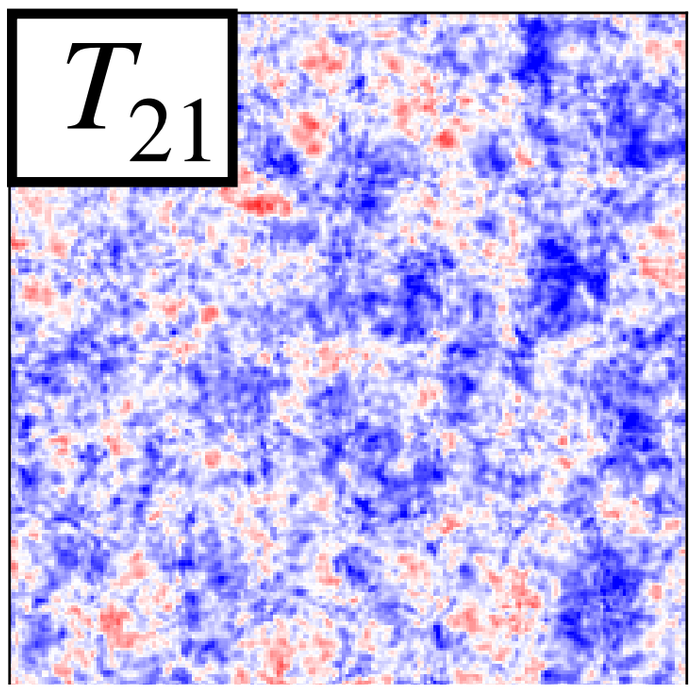


Mesinger 1801.02649

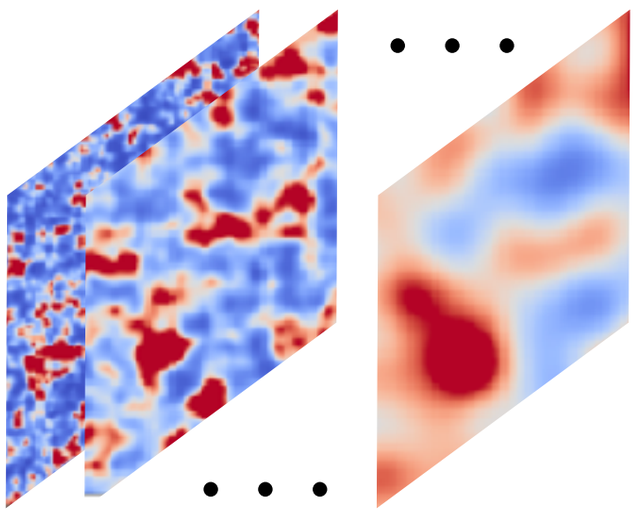
Zeus21

https://github.com/JulianBMunoz/Zeus21

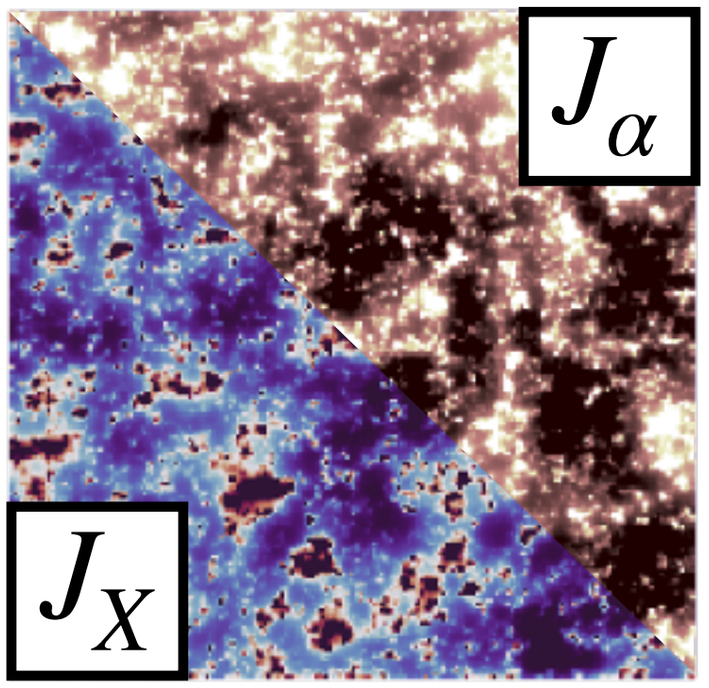




(in ~sec)



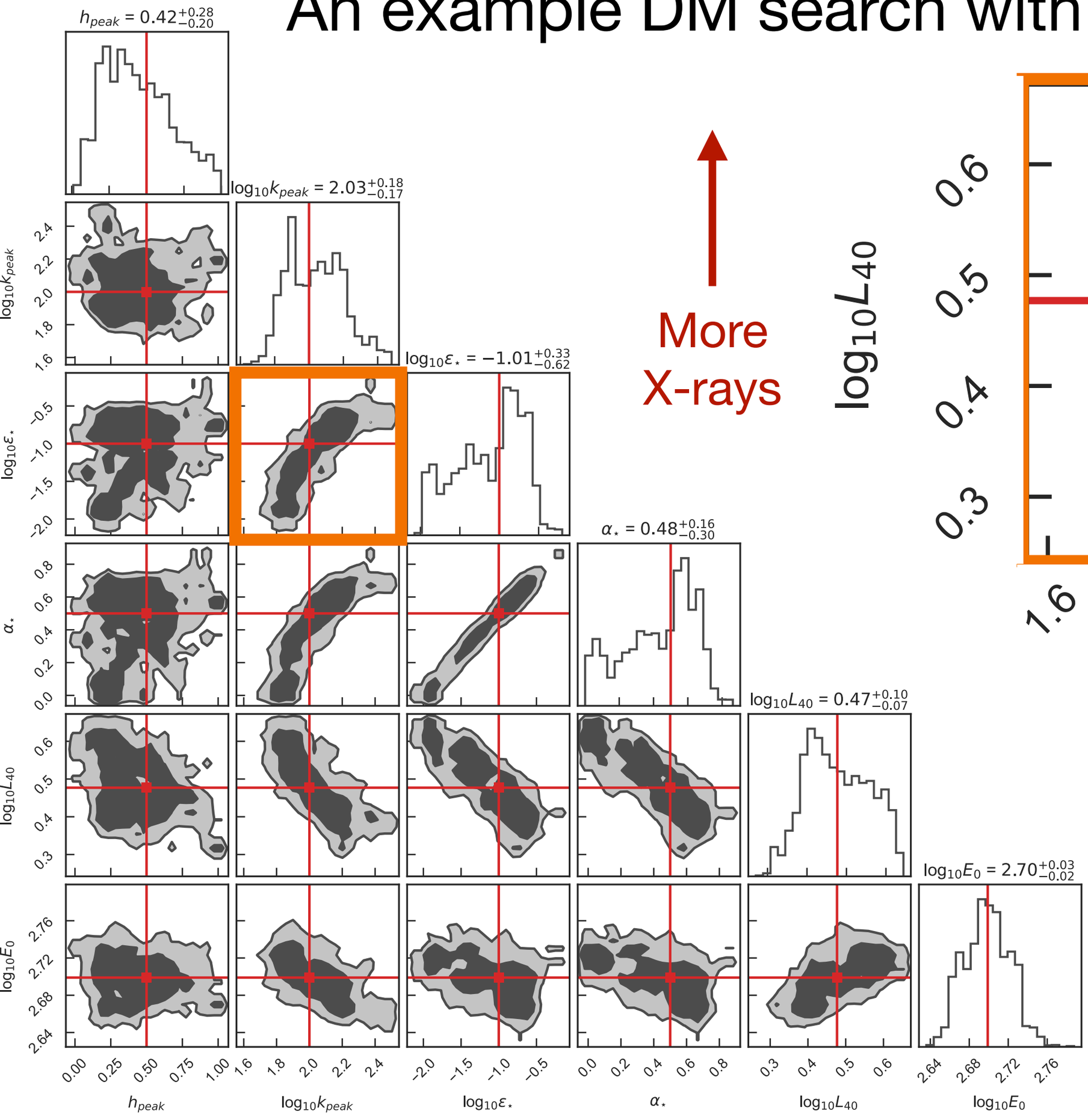
$$\mathrm{SFRD}(\delta_R) \propto e^{\gamma_R \delta_R}$$



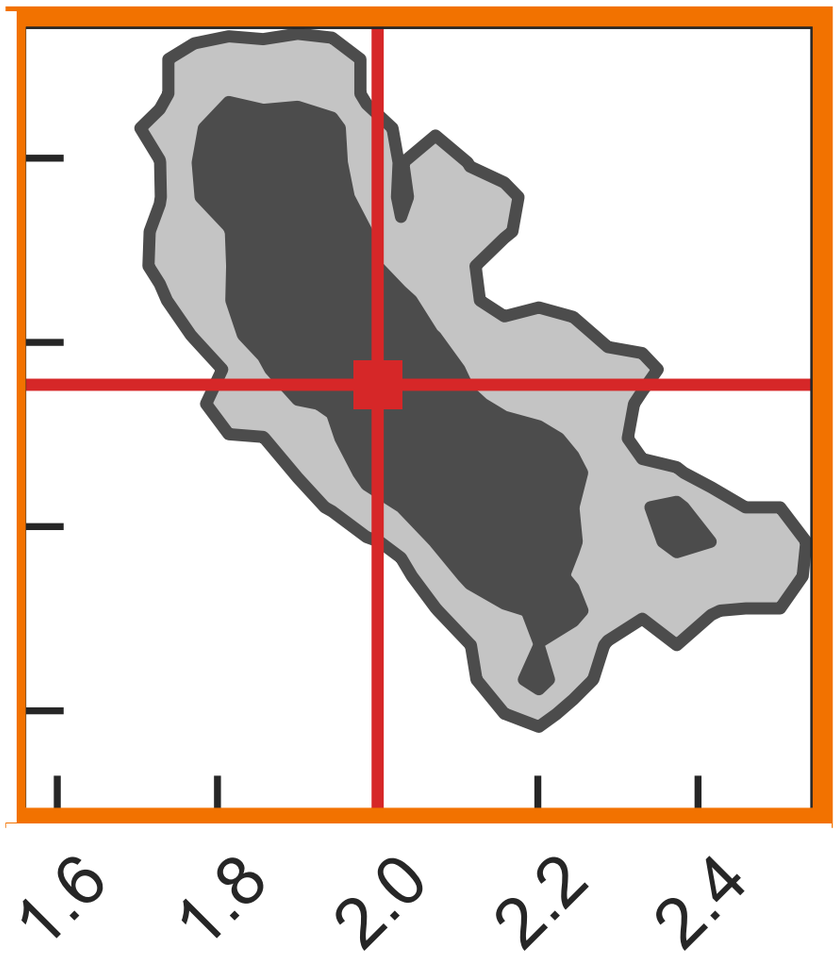
JBM 2023

Cruz, JBM+ 2024

An example DM search with Zeus21



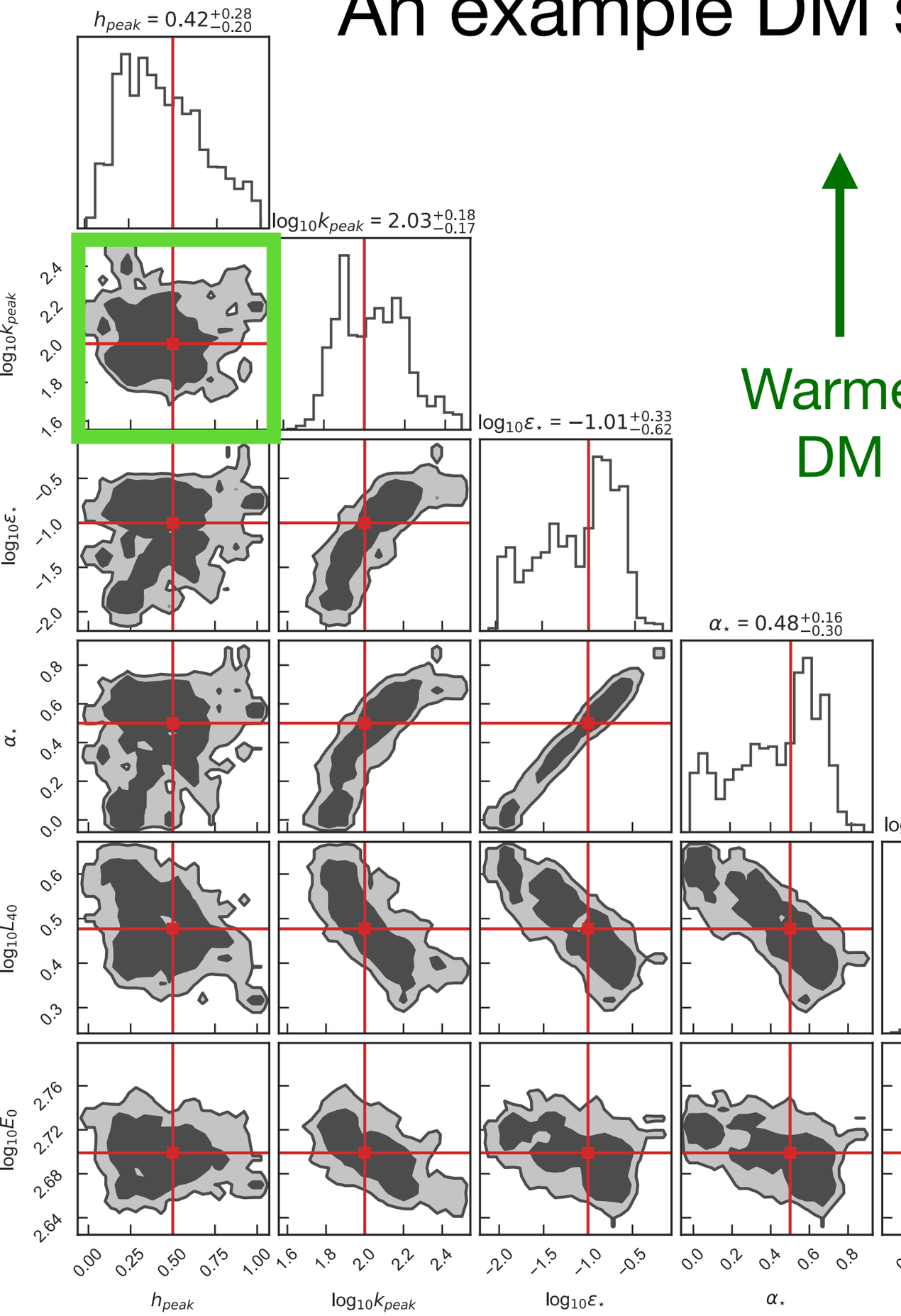
More X-rays



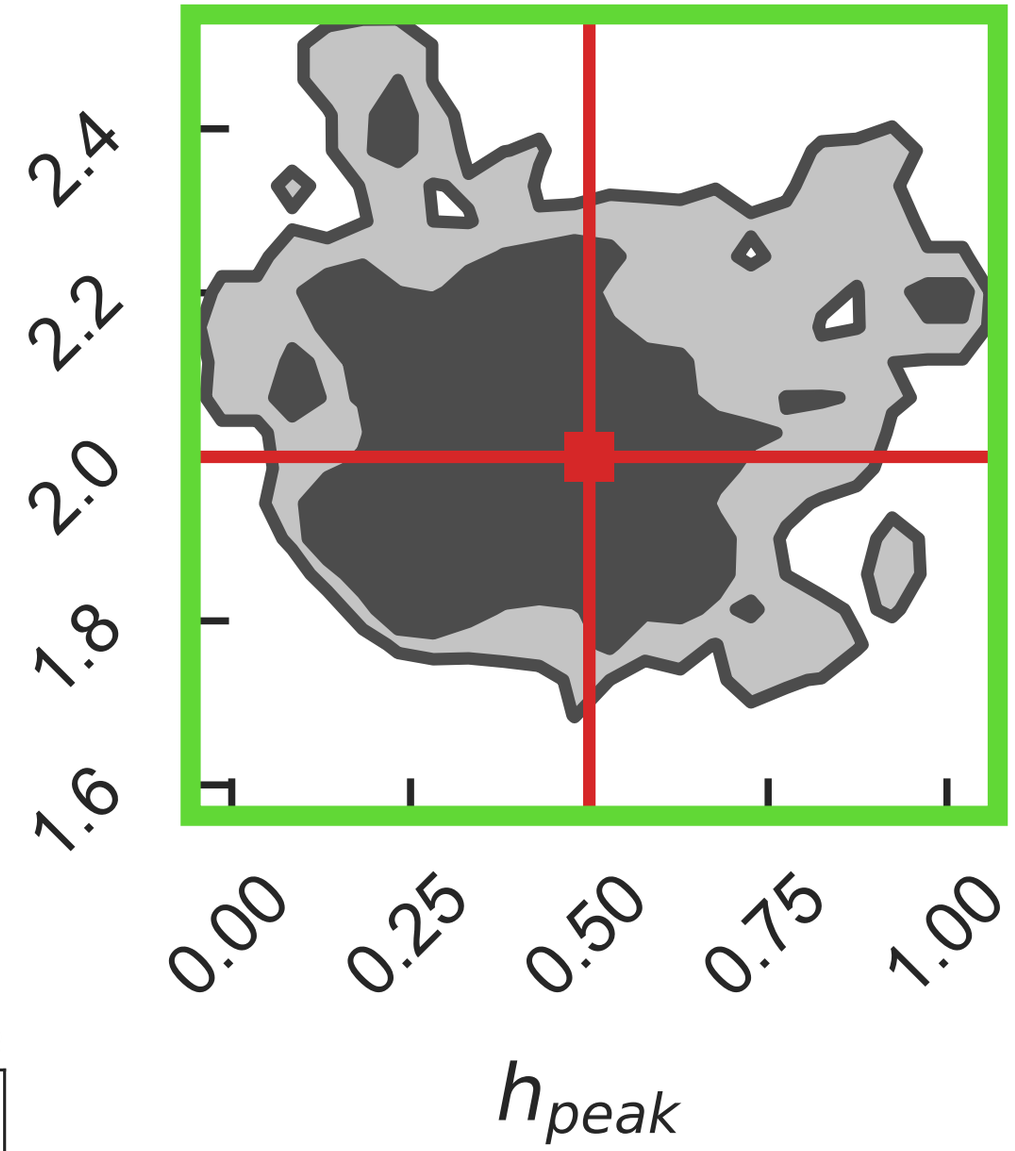
← Warmer DM

Verwohlt+ ETHOS coll. (2404.17640)

An example DM search with Zeus21



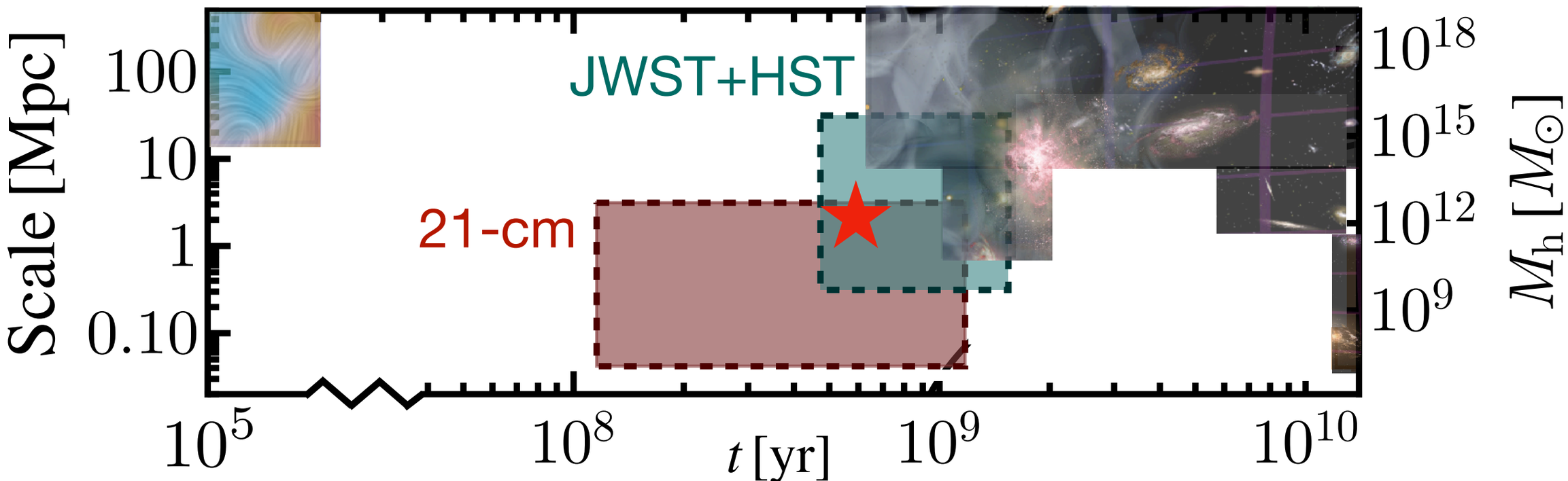
Warmer DM



More DM-DR

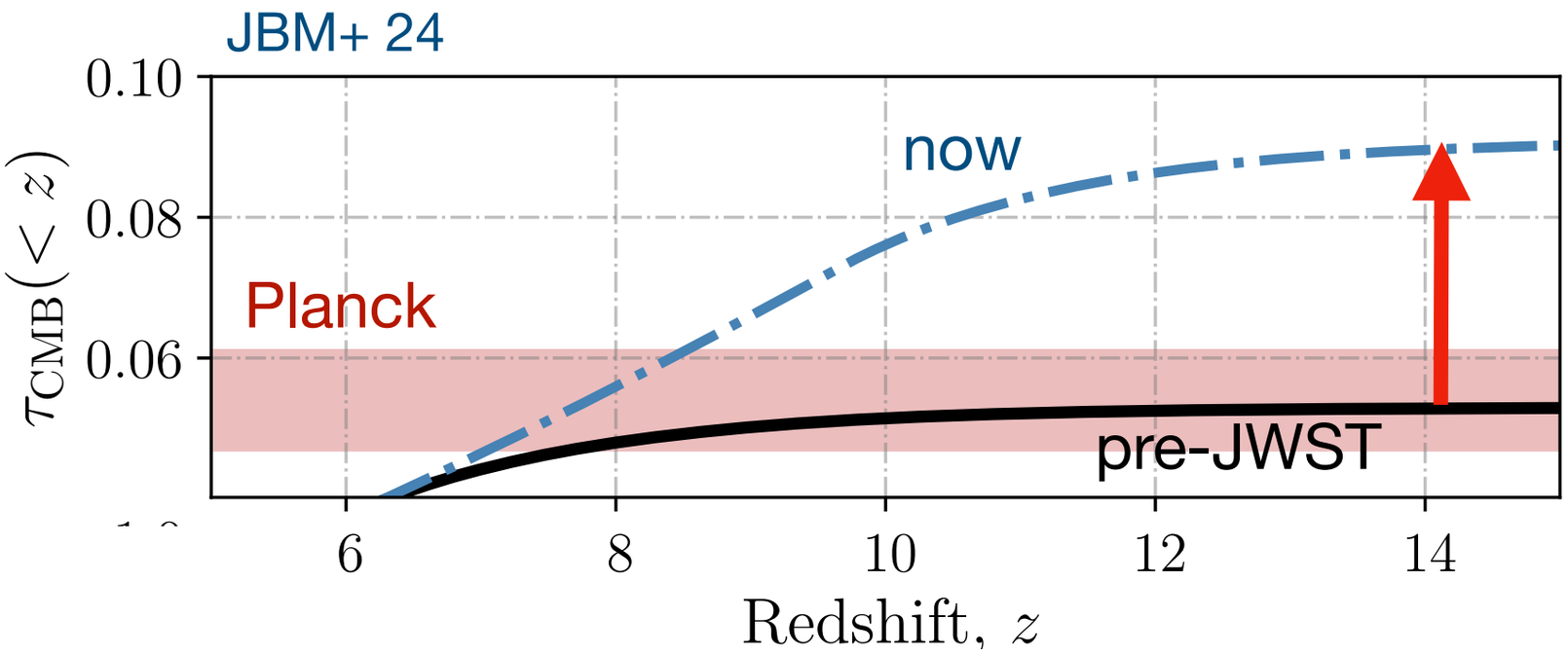
Verwohlt+ ETHOS coll. (2404.17640)

To summarize



Sabti, JBM, Kamionkowski 23

JBM+ 20, **Verwohlt**+ 24



Cruz, JBM+ 24