

DARK MATTER AT COSMIC DAWN

JULIAN B. MUÑOZ

CENTER FOR

ASTROPHYSICS

HARVARD & SMITHSONIAN

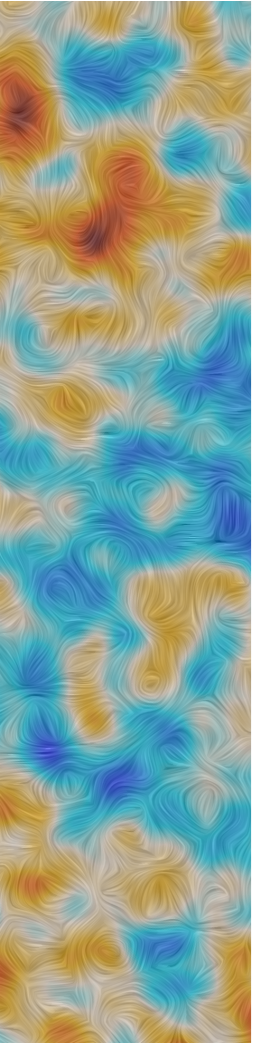
w/ Blas, Bohr, Cyr-Racine, Dvorkin, HERA Coll.,
Loeb, **Sabti**, Vogelsberger, Zavala



How does cosmology measure things?

Image: ESA

CMB



$$z \approx 10^3$$



cosmic time [yr]

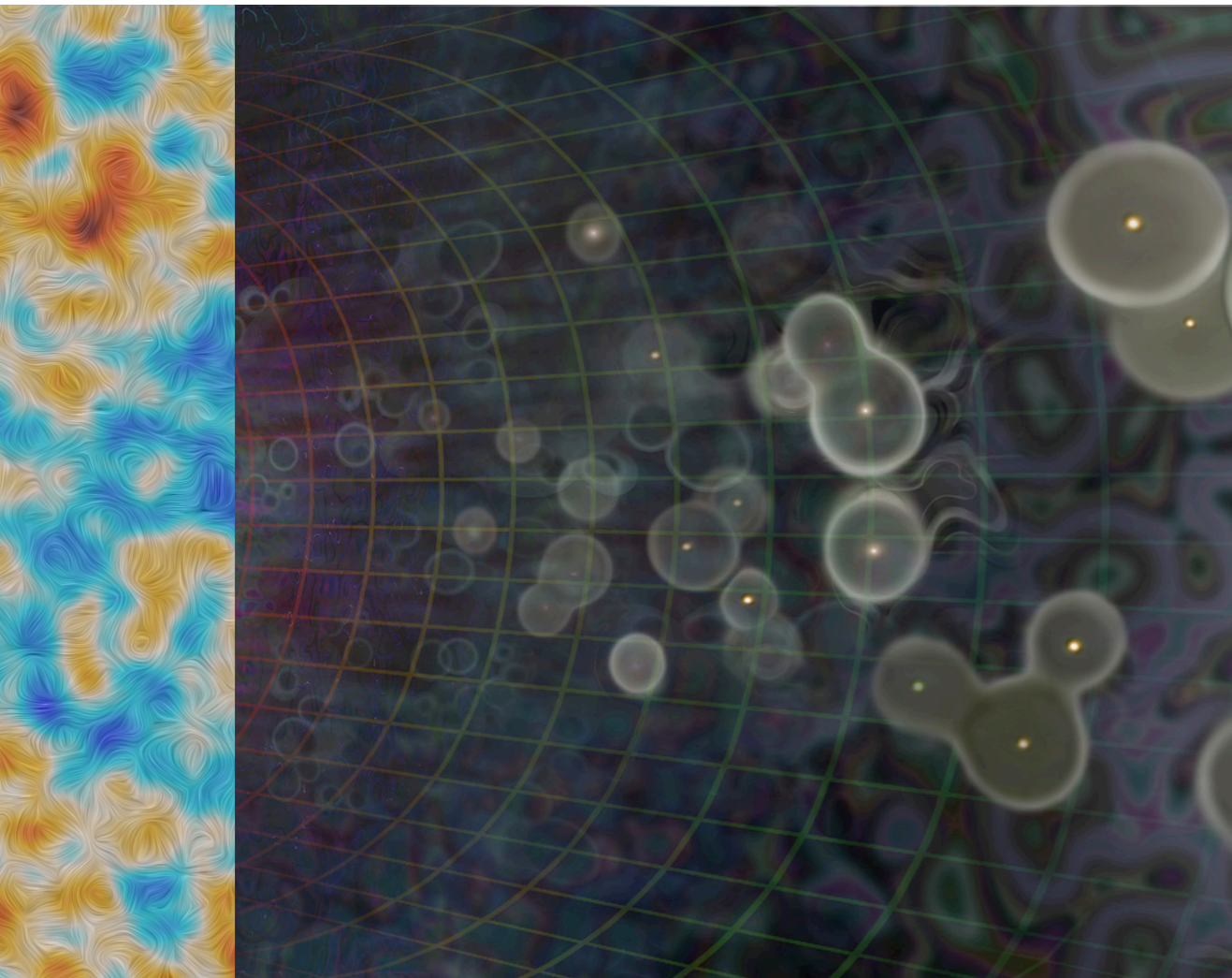
$$4 \cdot 10^5$$

How does cosmology measure things?

Image: NASA/
CXC/M.WEISS

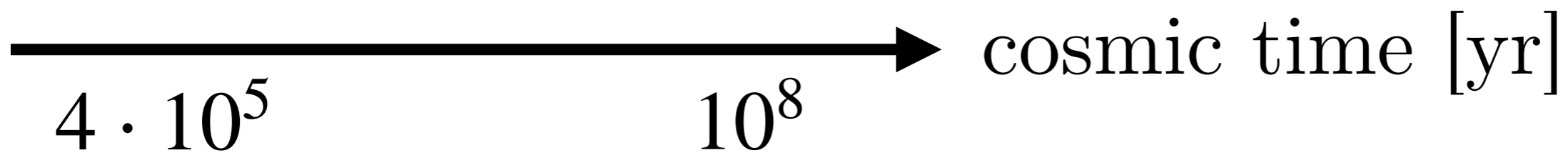
CMB

Cosmic Dawn



$$z \approx 10^3$$

$$z \approx 30$$



$$4 \cdot 10^5$$

$$10^8$$

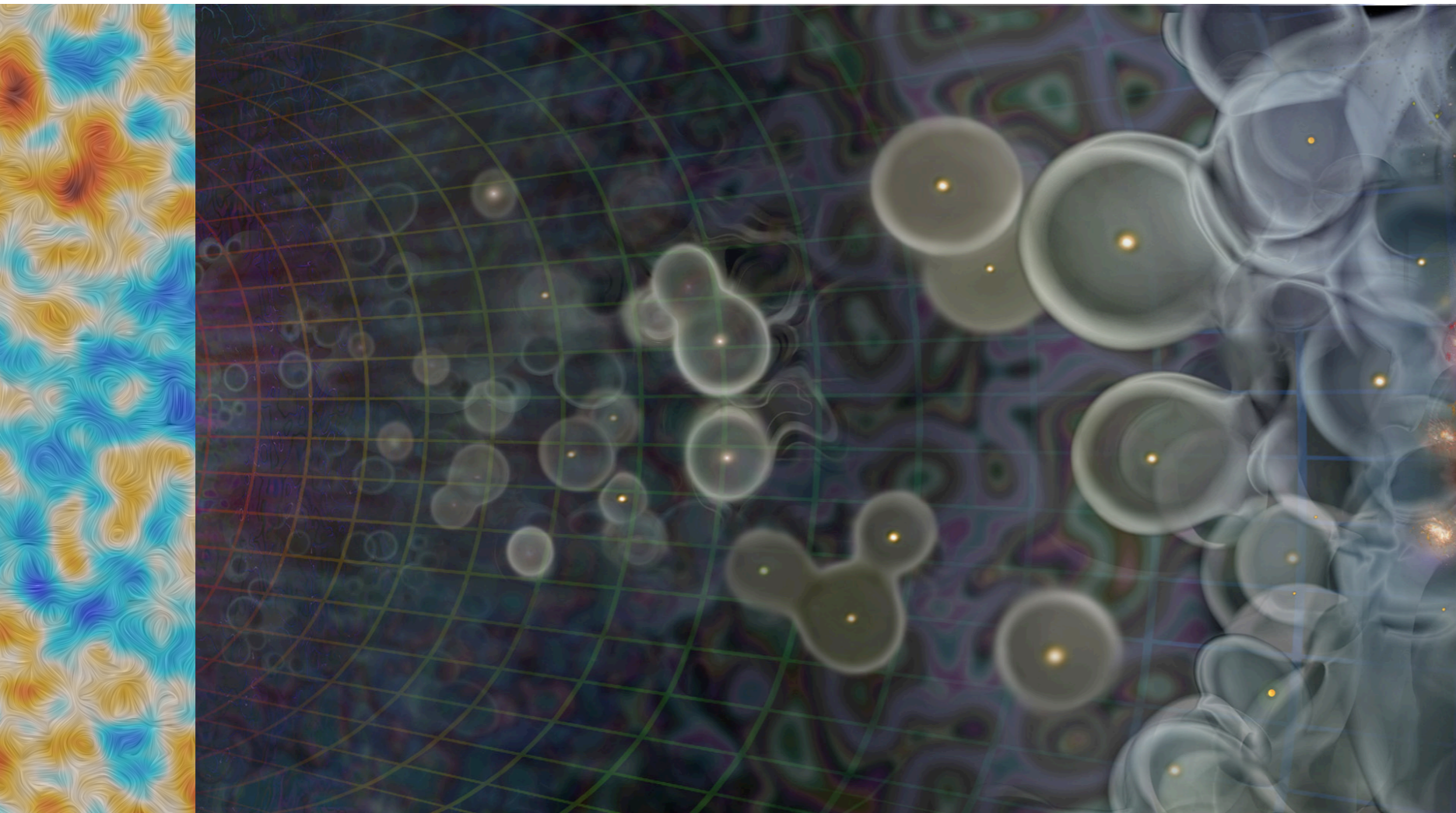
How does cosmology measure things?

Image: NASA/
CXC/M.WEISS

CMB

Cosmic Dawn

Reionization



$$z \approx 10^3$$

$$z \approx 30$$

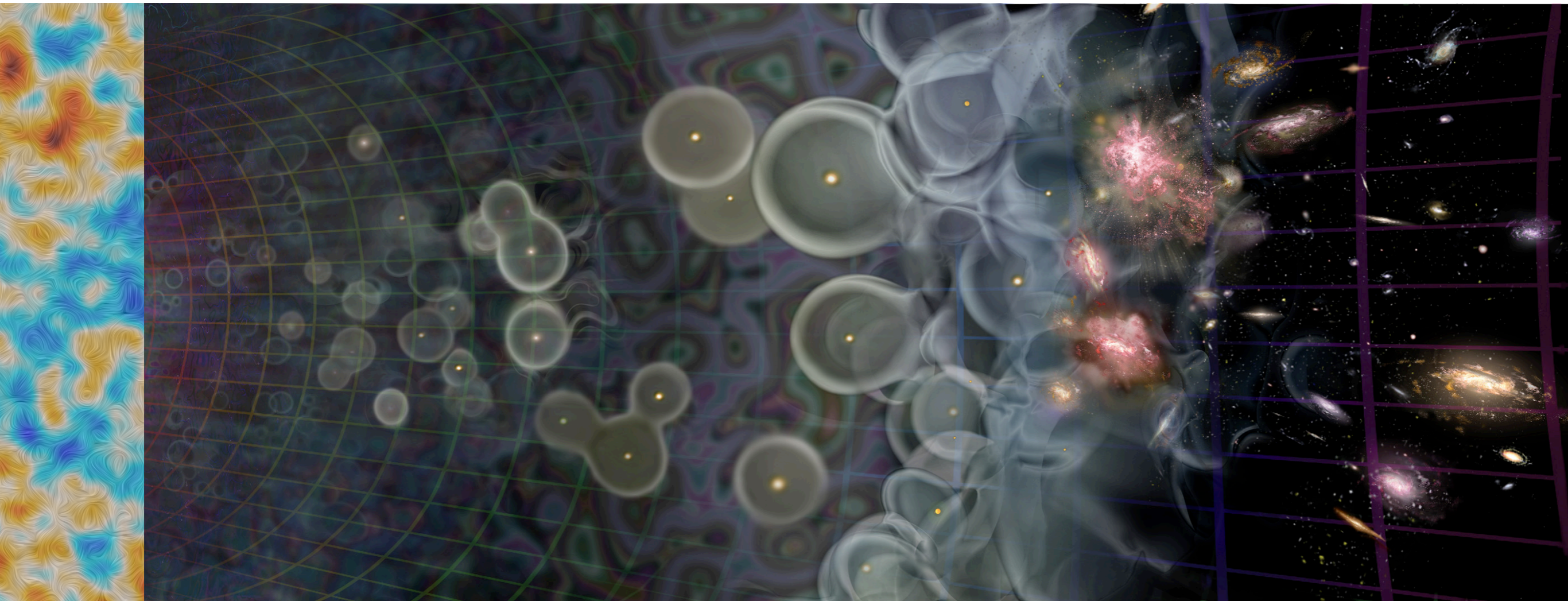
$$z \approx 5$$



How does cosmology measure things?

Image: NASA/
CXC/M.WEISS

CMB **Cosmic Dawn** **Reionization** **Late Universe**



$$z \approx 10^3$$

$$z \approx 30$$

$$z \approx 5$$

$$z = 0$$

cosmic time [yr]

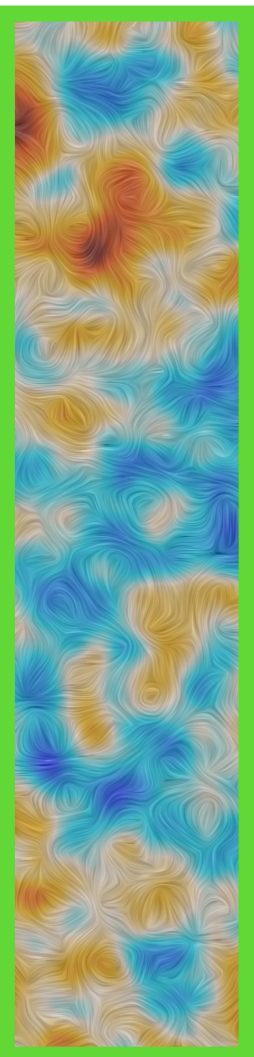
$$4 \cdot 10^5$$

$$10^8$$

$$10^9$$

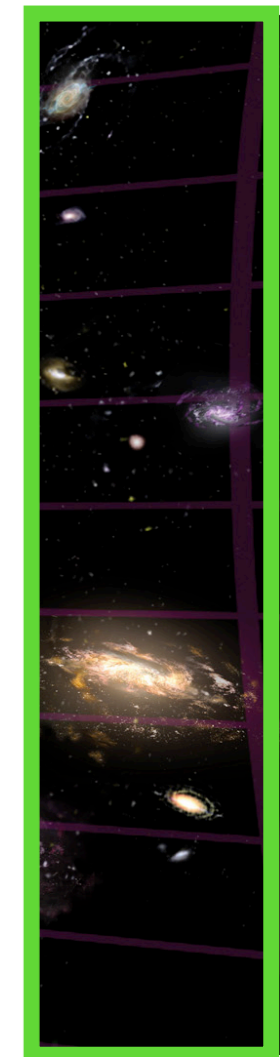
$$10^{10}$$

CMB



$$z \approx 10^3$$

Late Universe



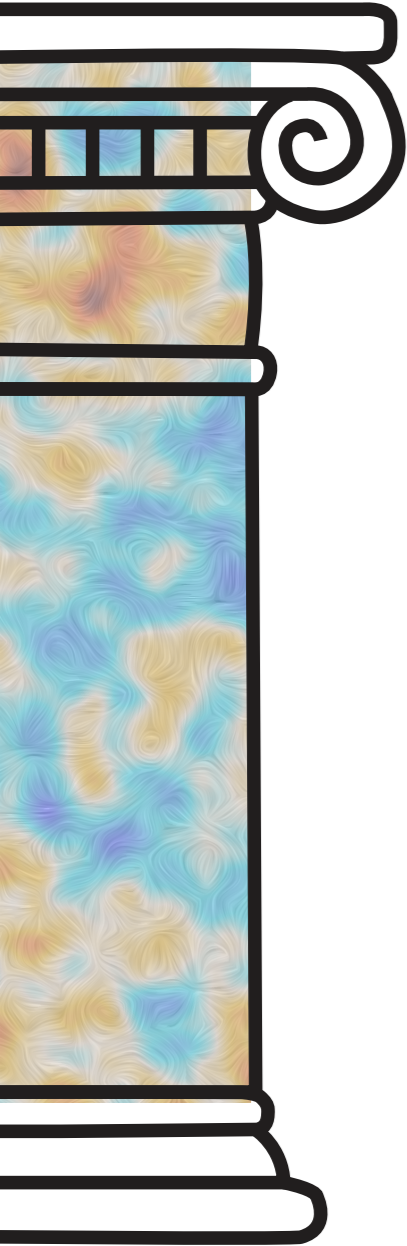
$$z = 0$$

cosmic time [yr]

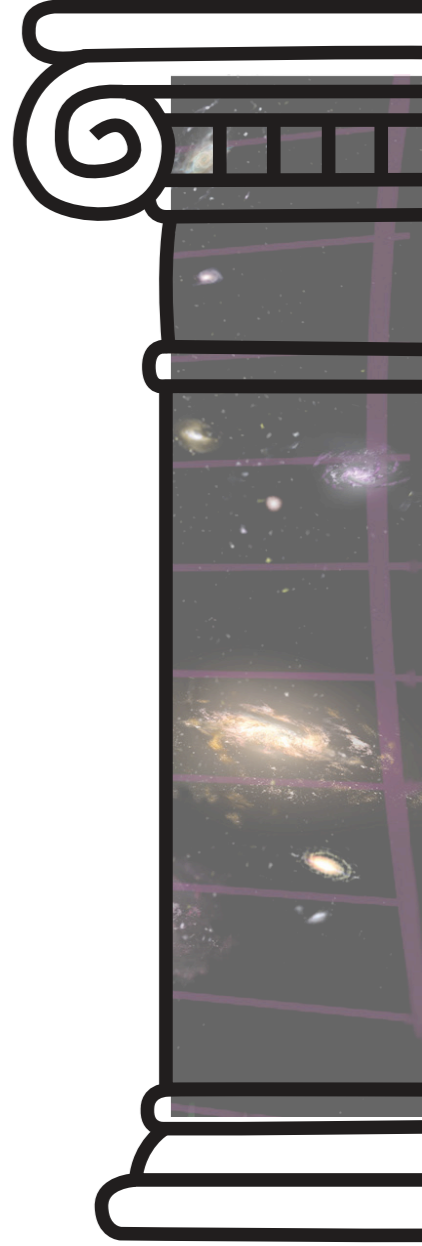
$$4 \cdot 10^5$$

$$10^{10}$$

Cosmology

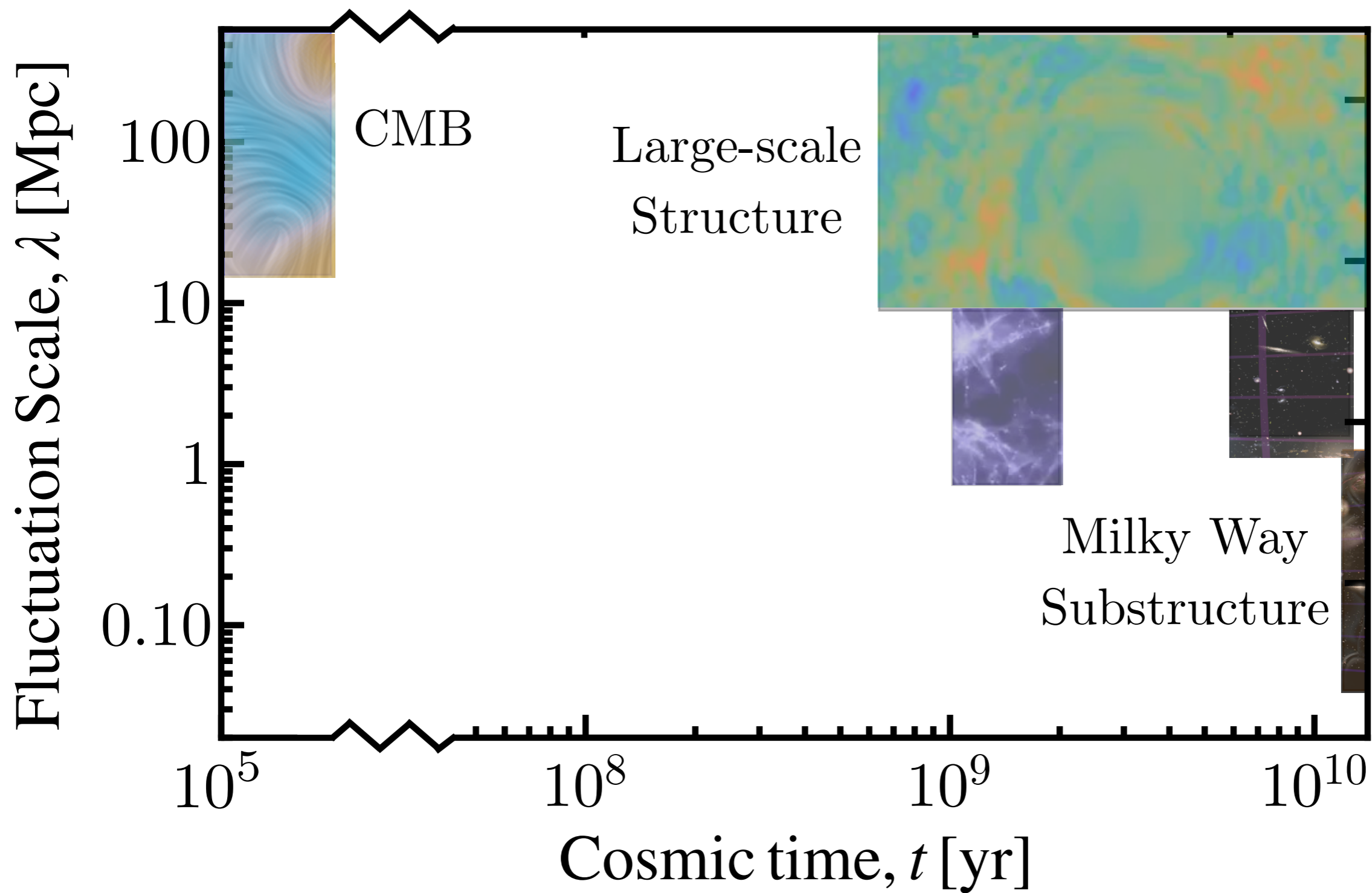


CMB

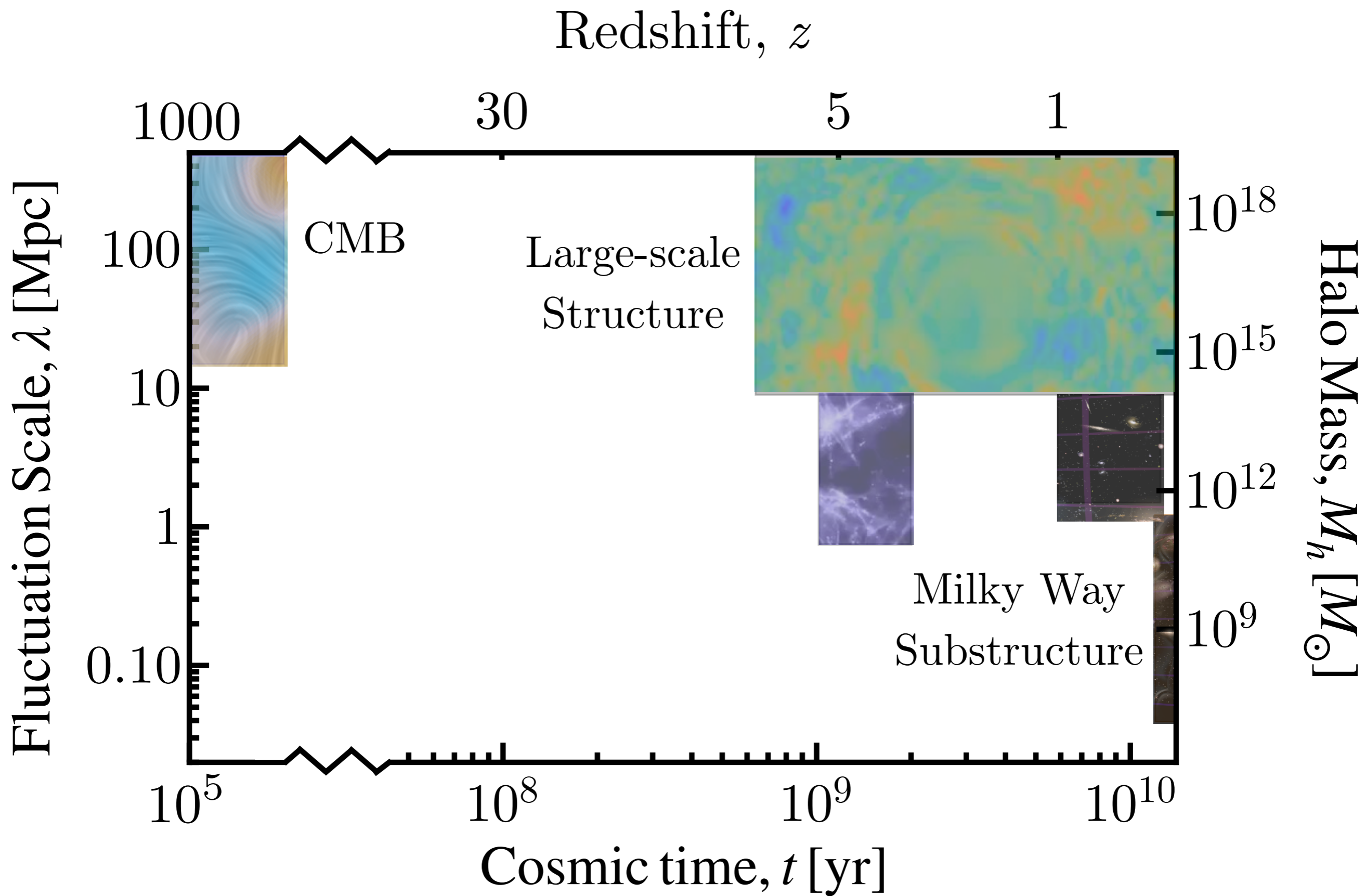


Local
Universe

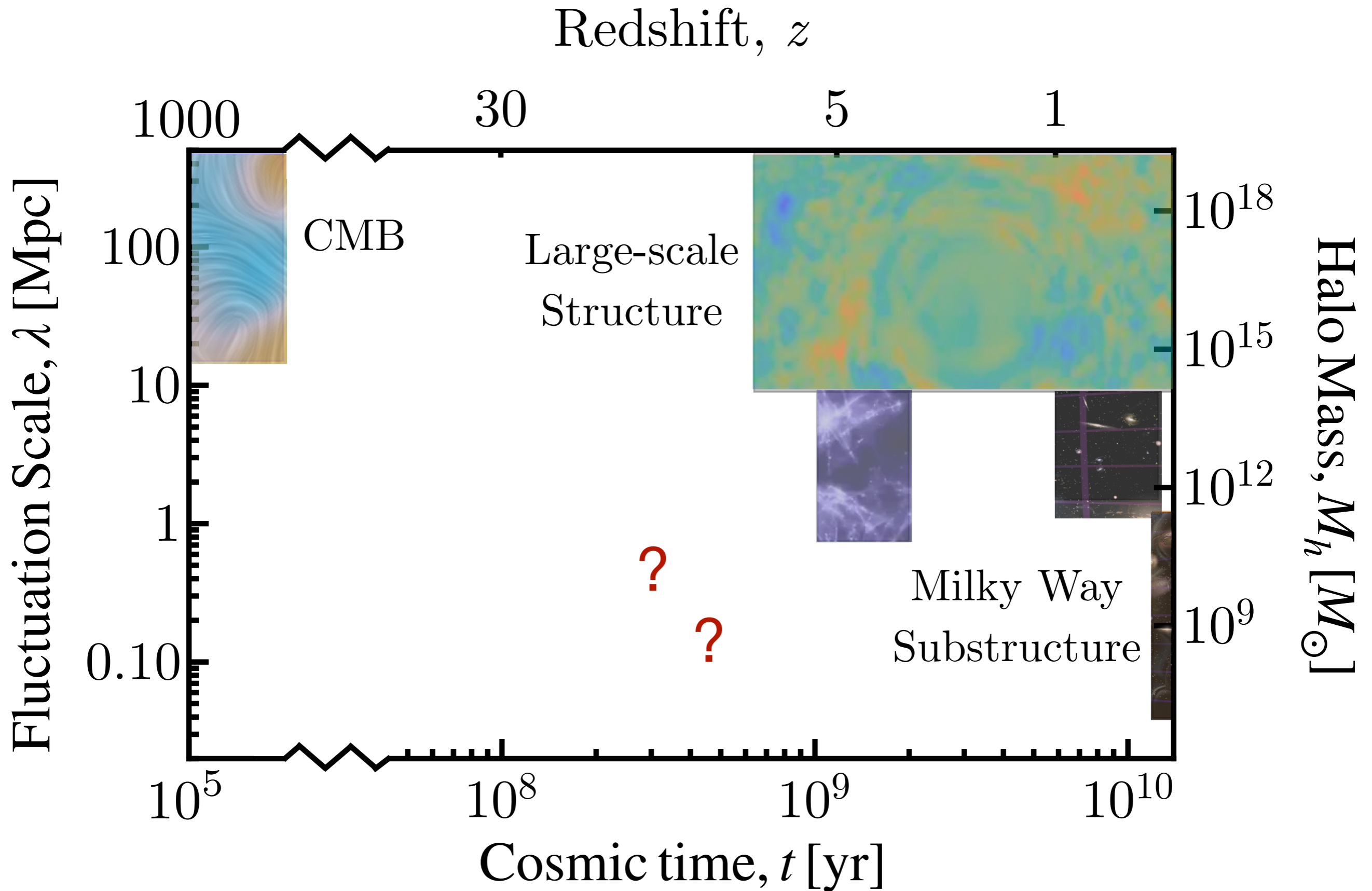
DM is cold ...



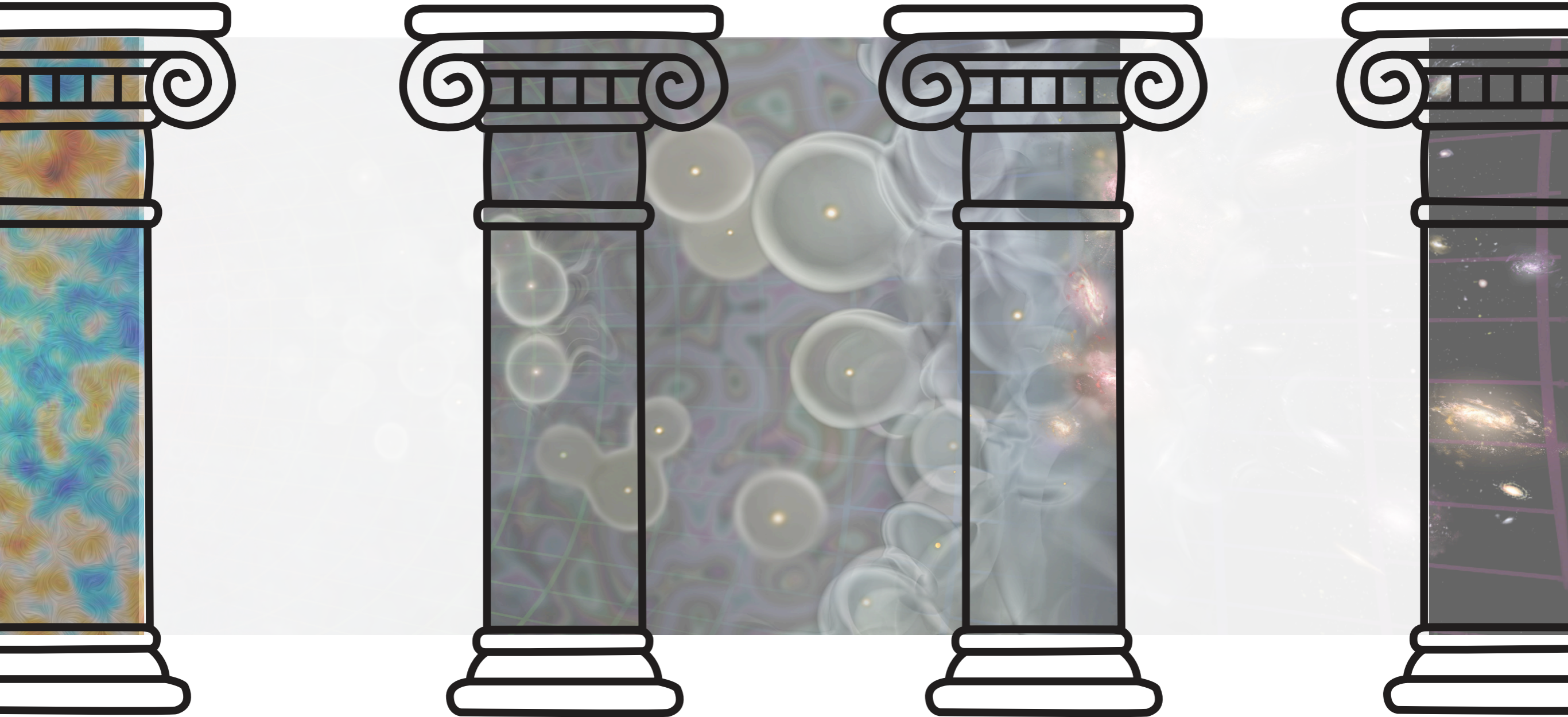
DM is cold ...



DM is cold as far as we can tell



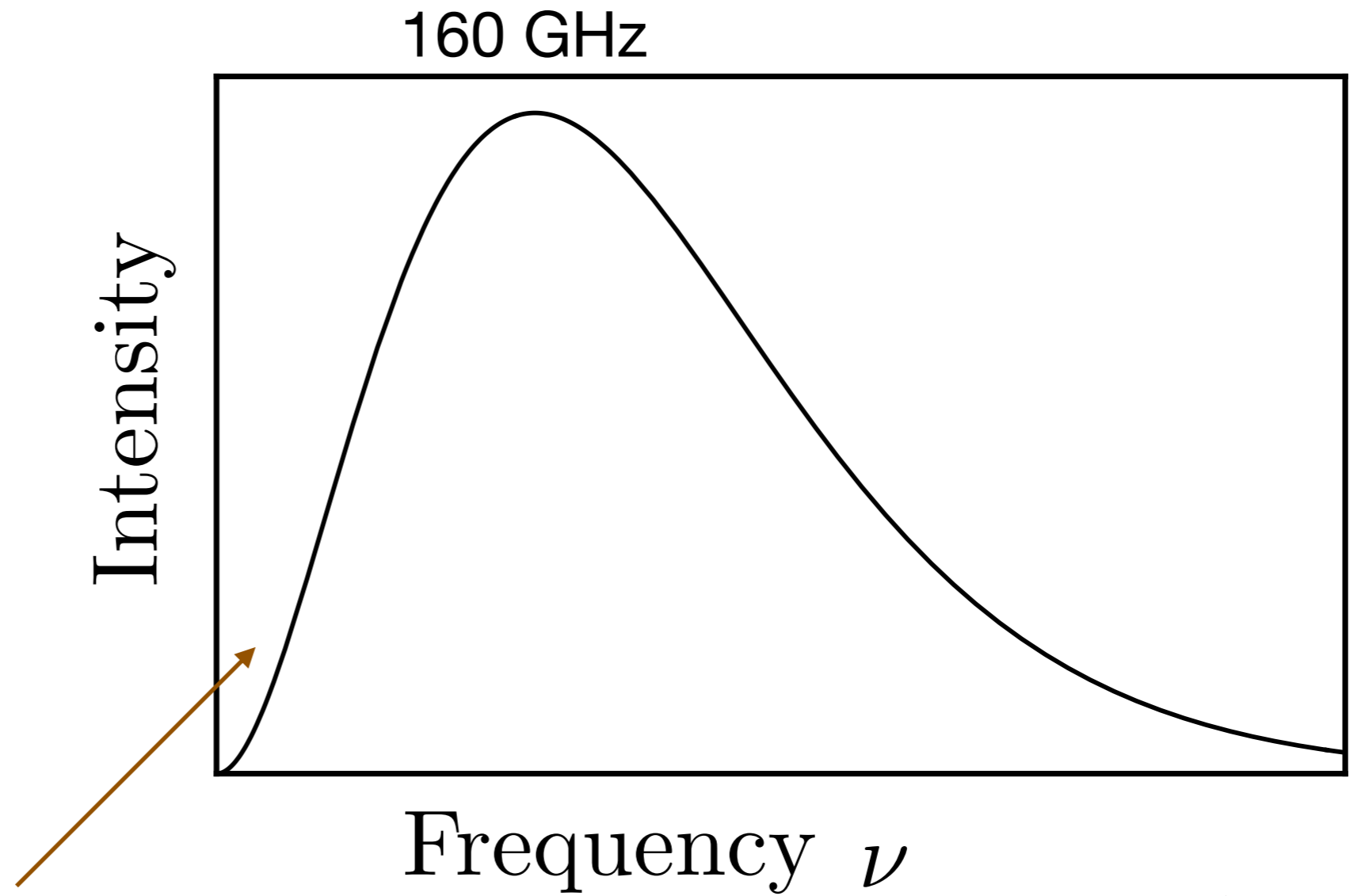
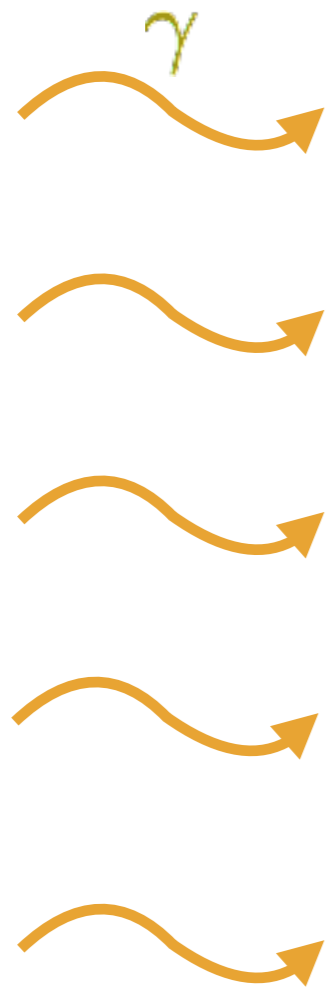
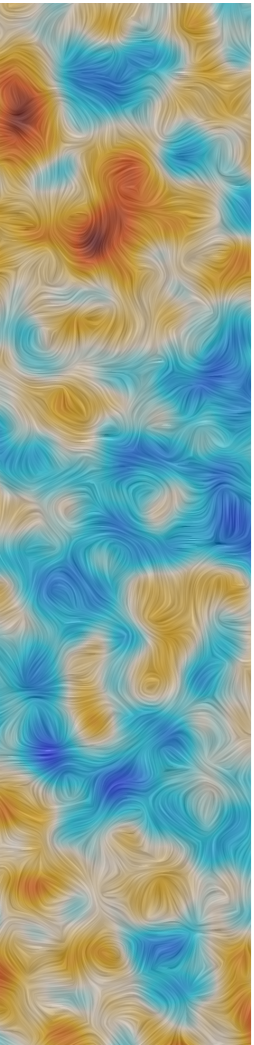
New pillars of cosmology



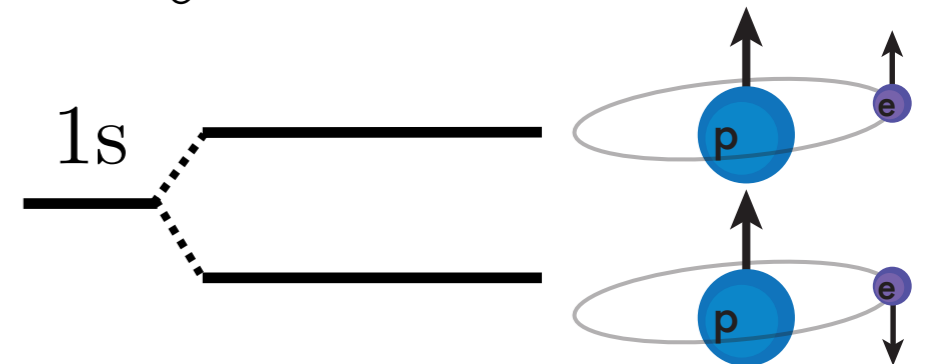
Cosmic Dawn and Reionization

21-cm cosmology super-summarized

CMB

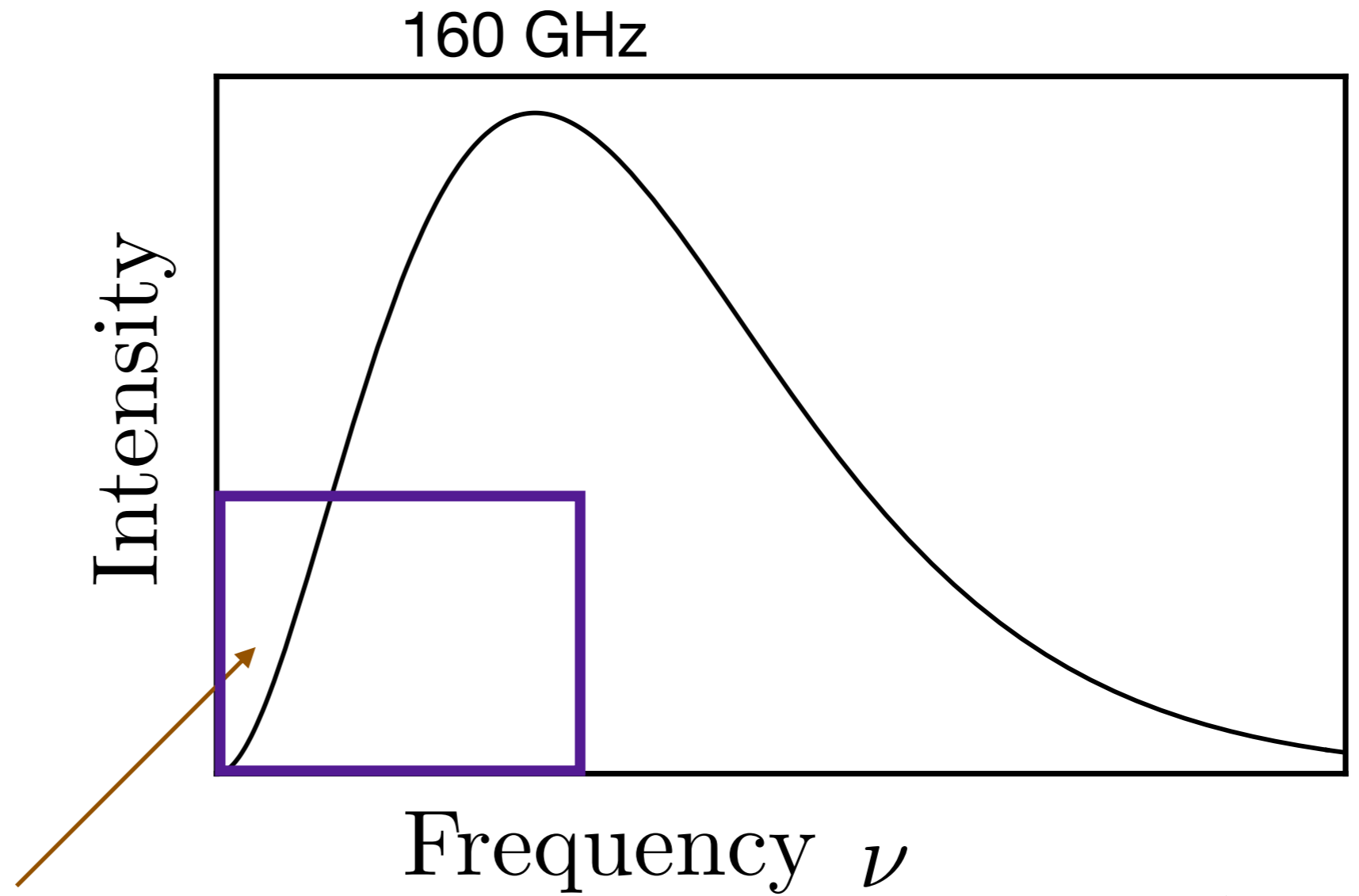
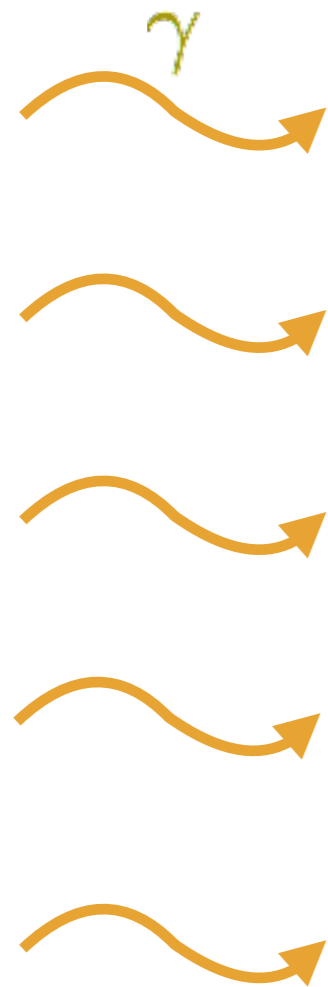
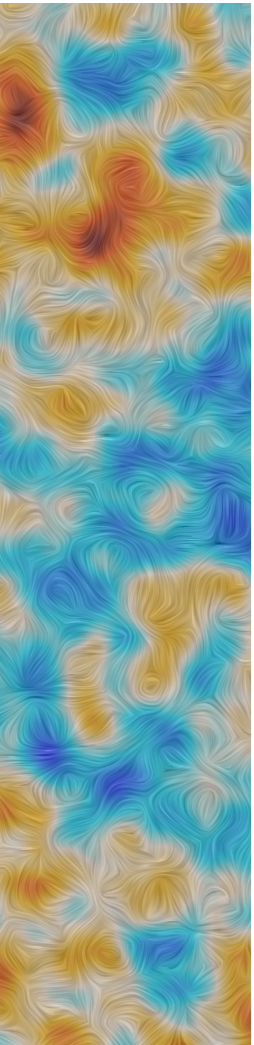


21-cm frequency: 1.4 GHz

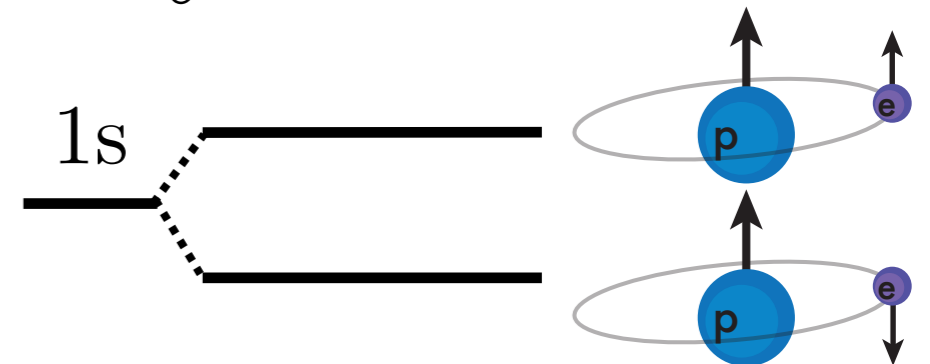


21-cm cosmology super-summarized

CMB



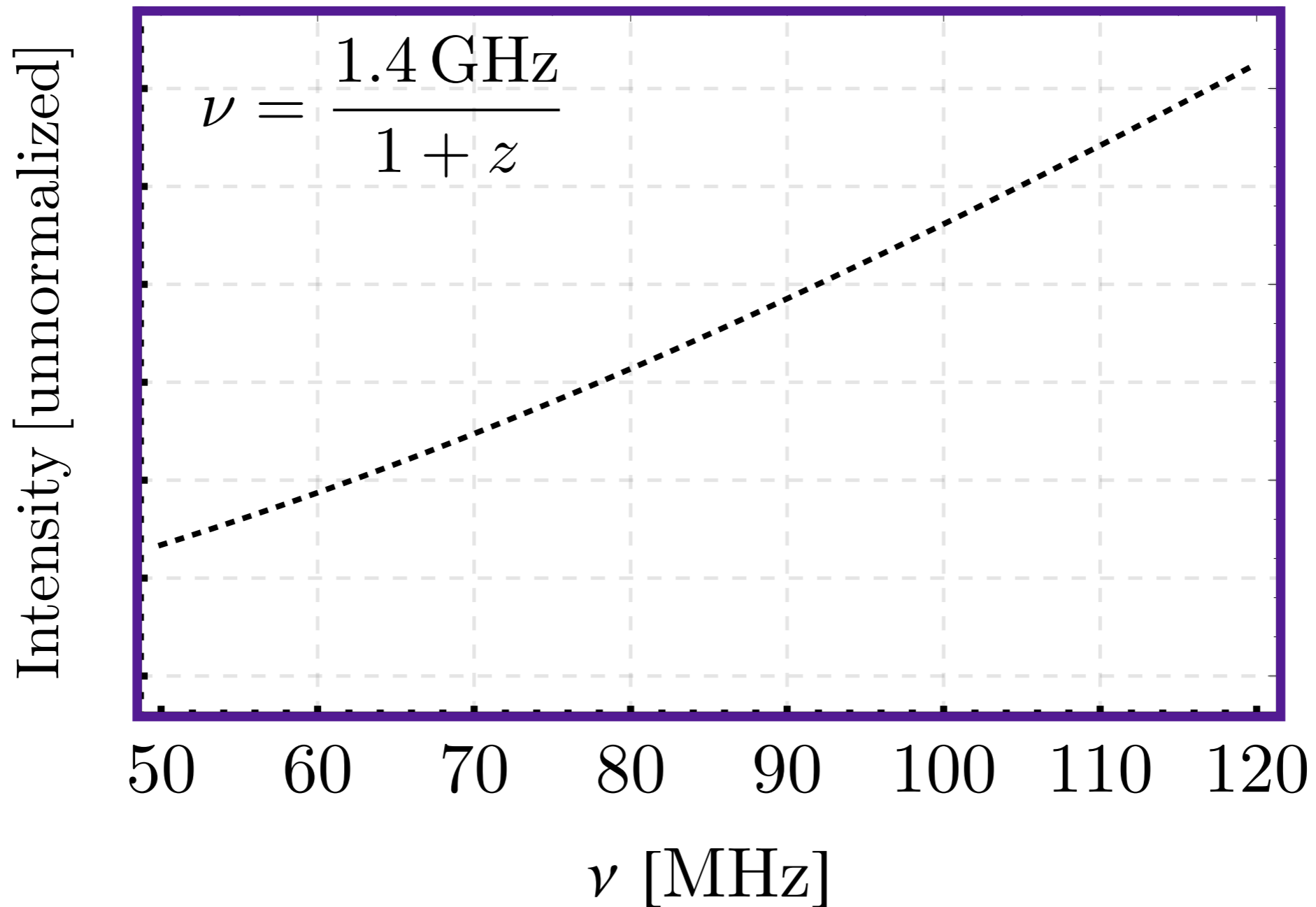
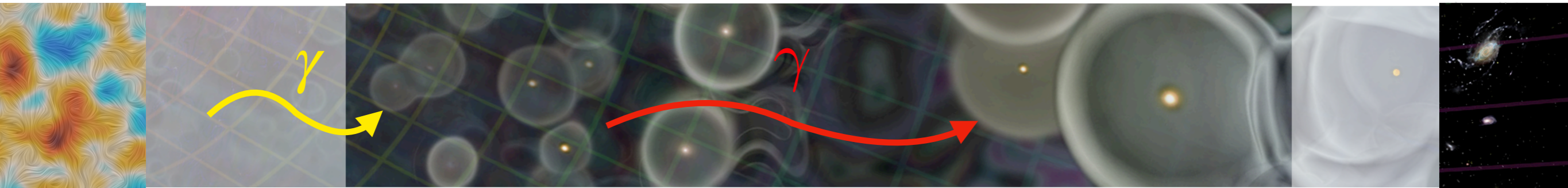
21-cm frequency: 1.4 GHz



$z = 27$

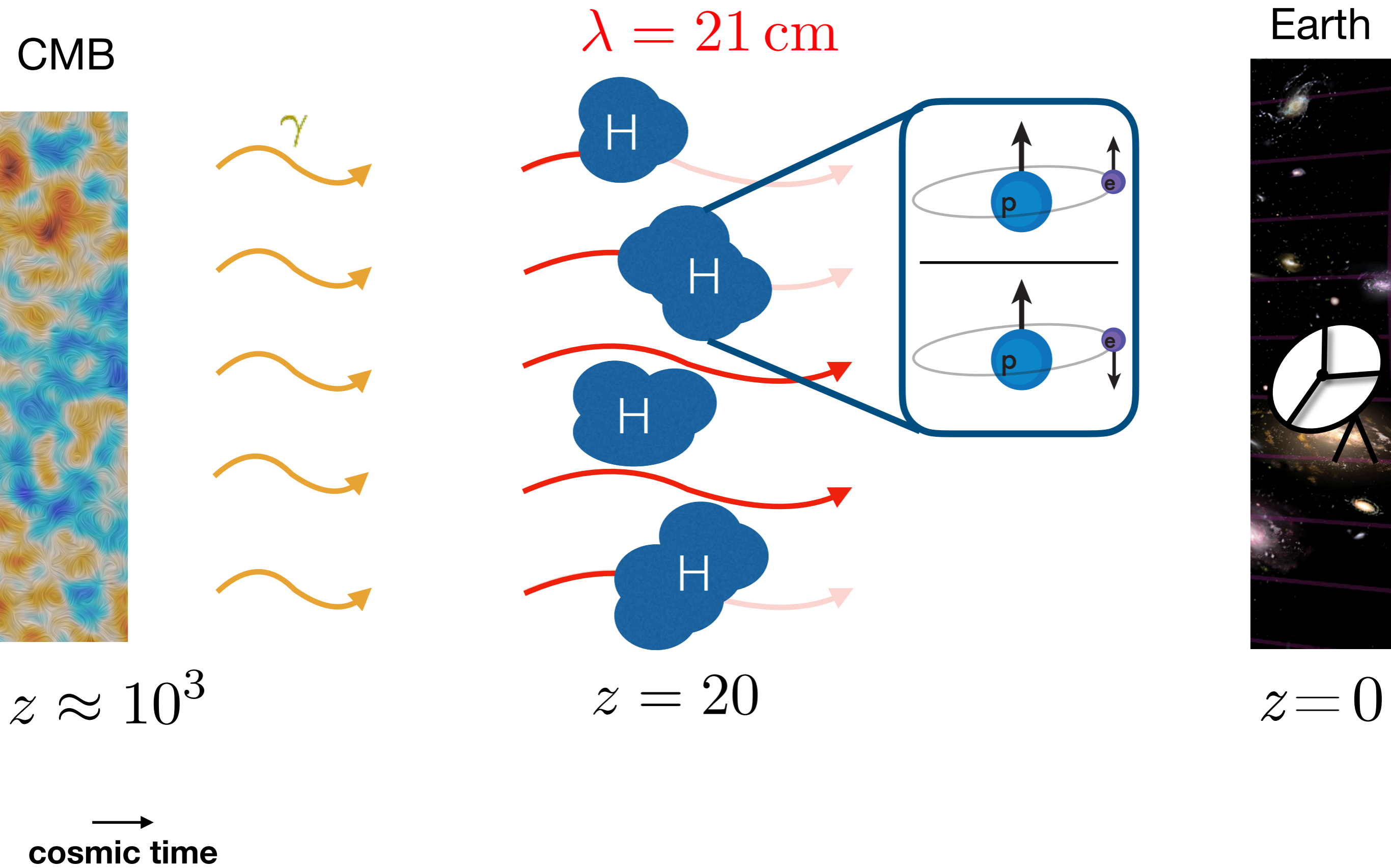
→
cosmic time

$z = 11$



E.g., Pritchard & Loeb 2012

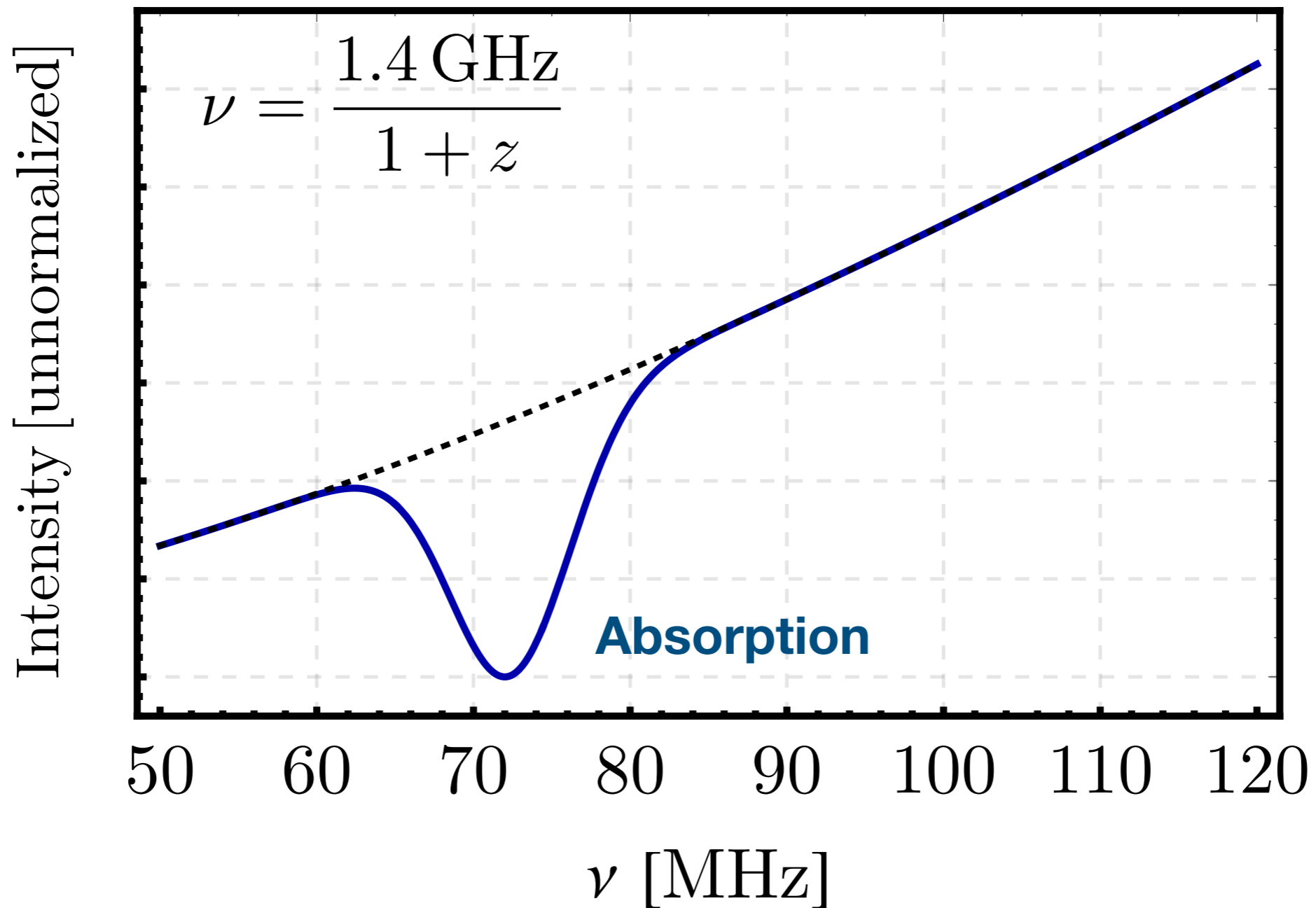
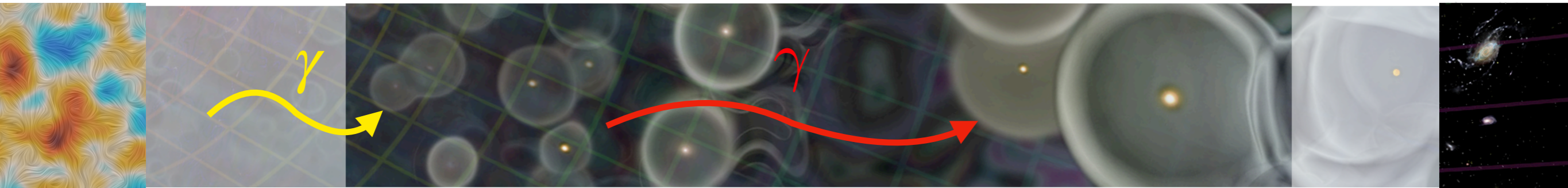
The basics of 21-cm: Absorption



$z = 27$

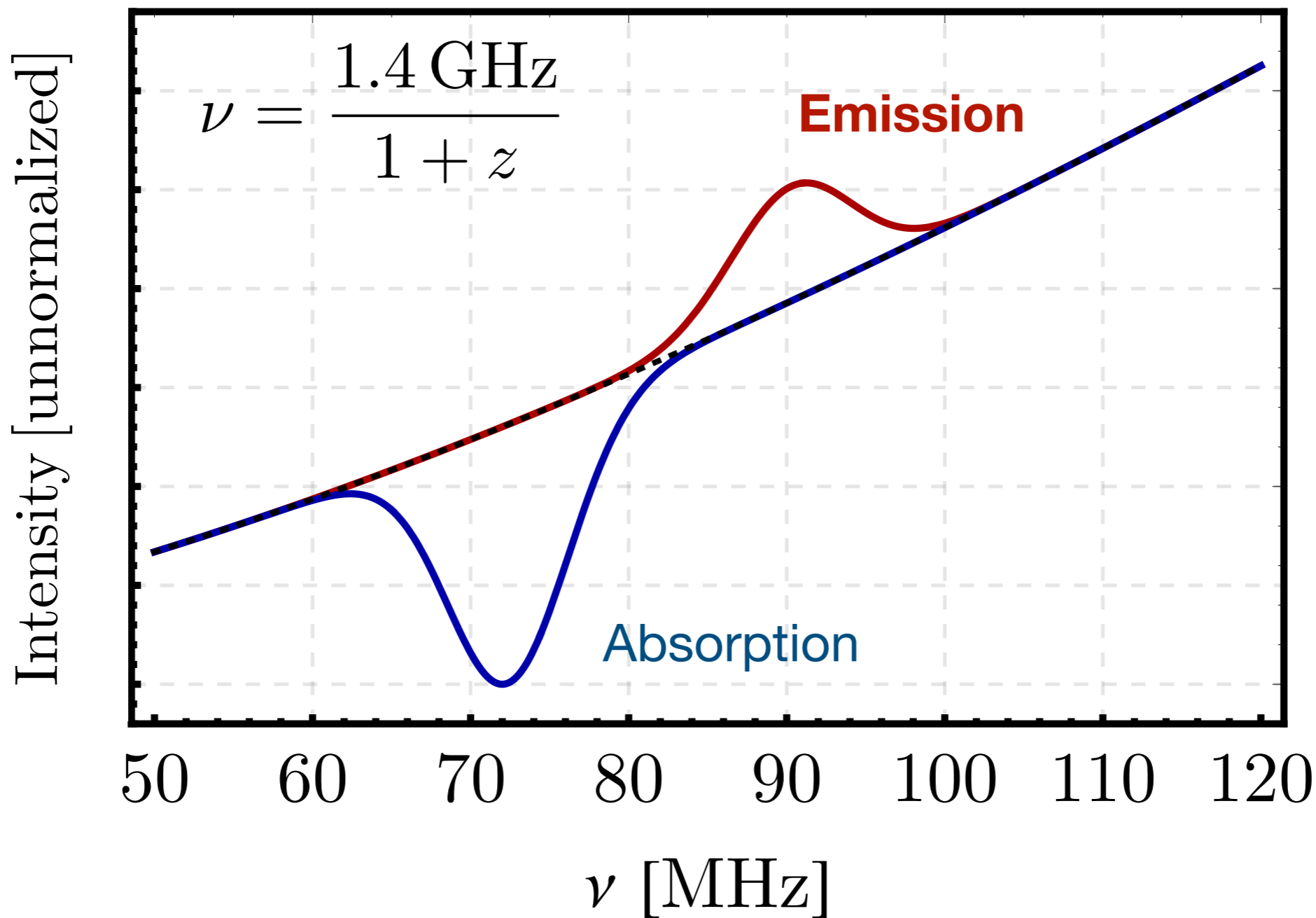
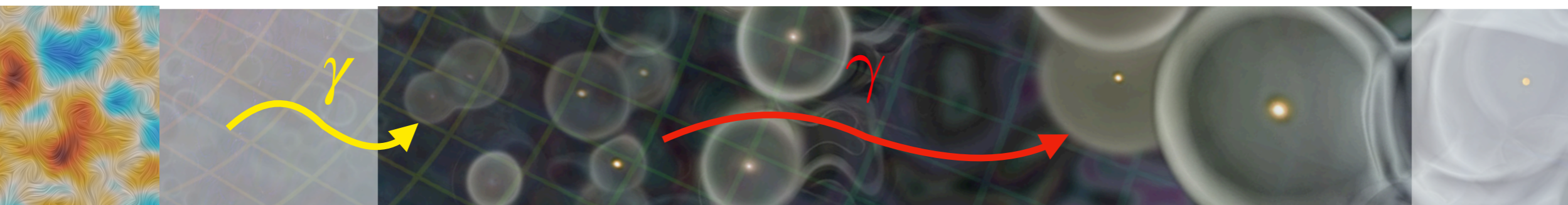
→
cosmic time

$z = 11$



$z = 27$

→
cosmic time

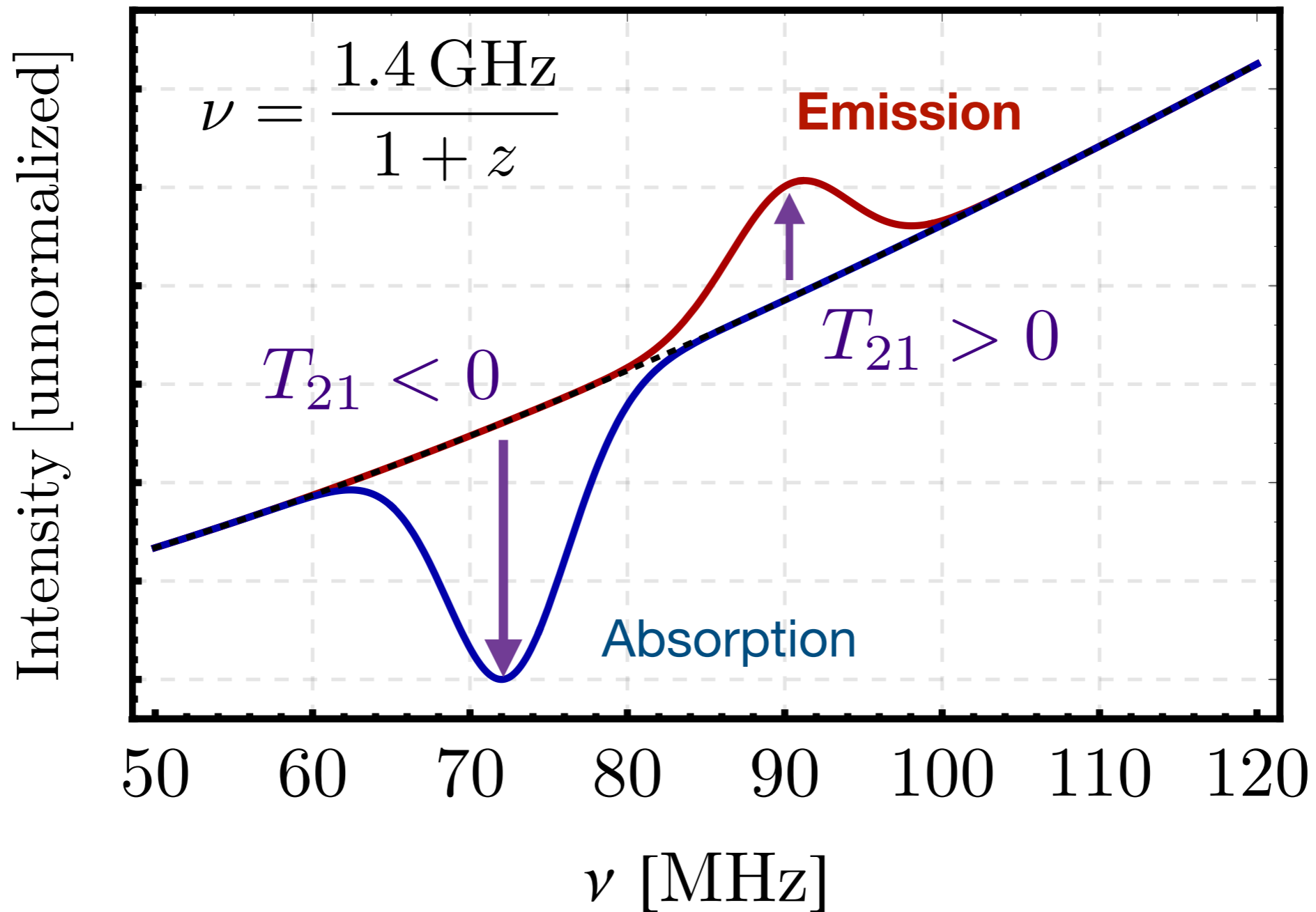
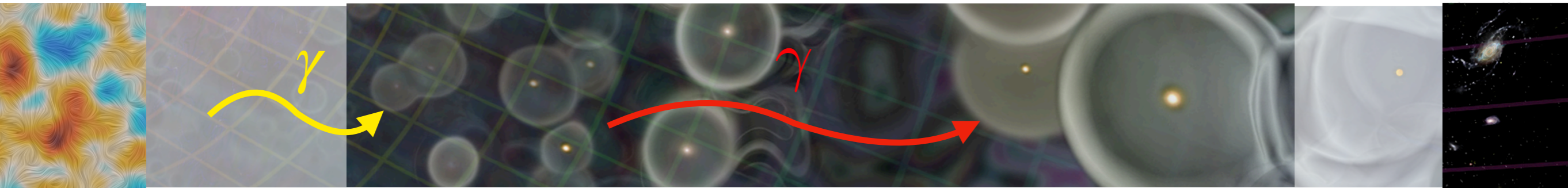
 $z = 11$ 

E.g., Pritchard & Loeb 2012

$z = 27$

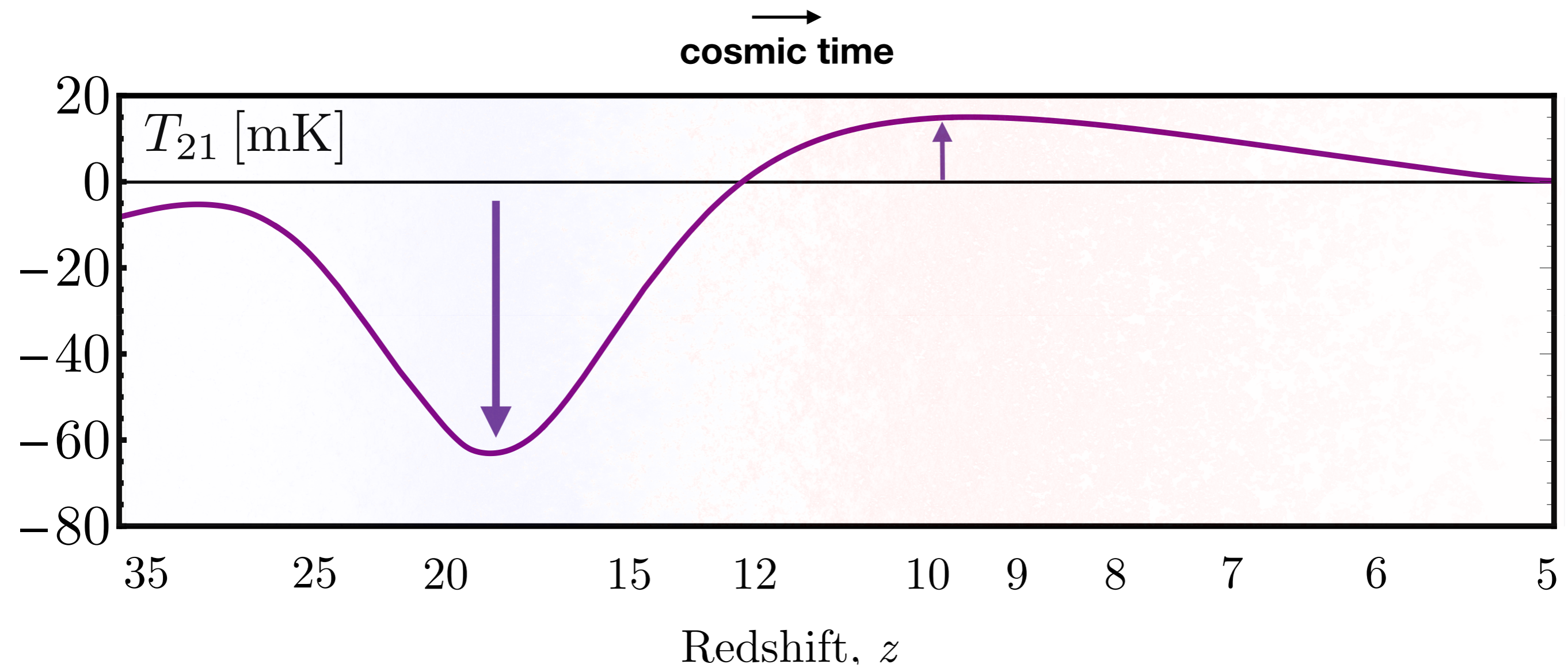
→
cosmic time

$z = 11$



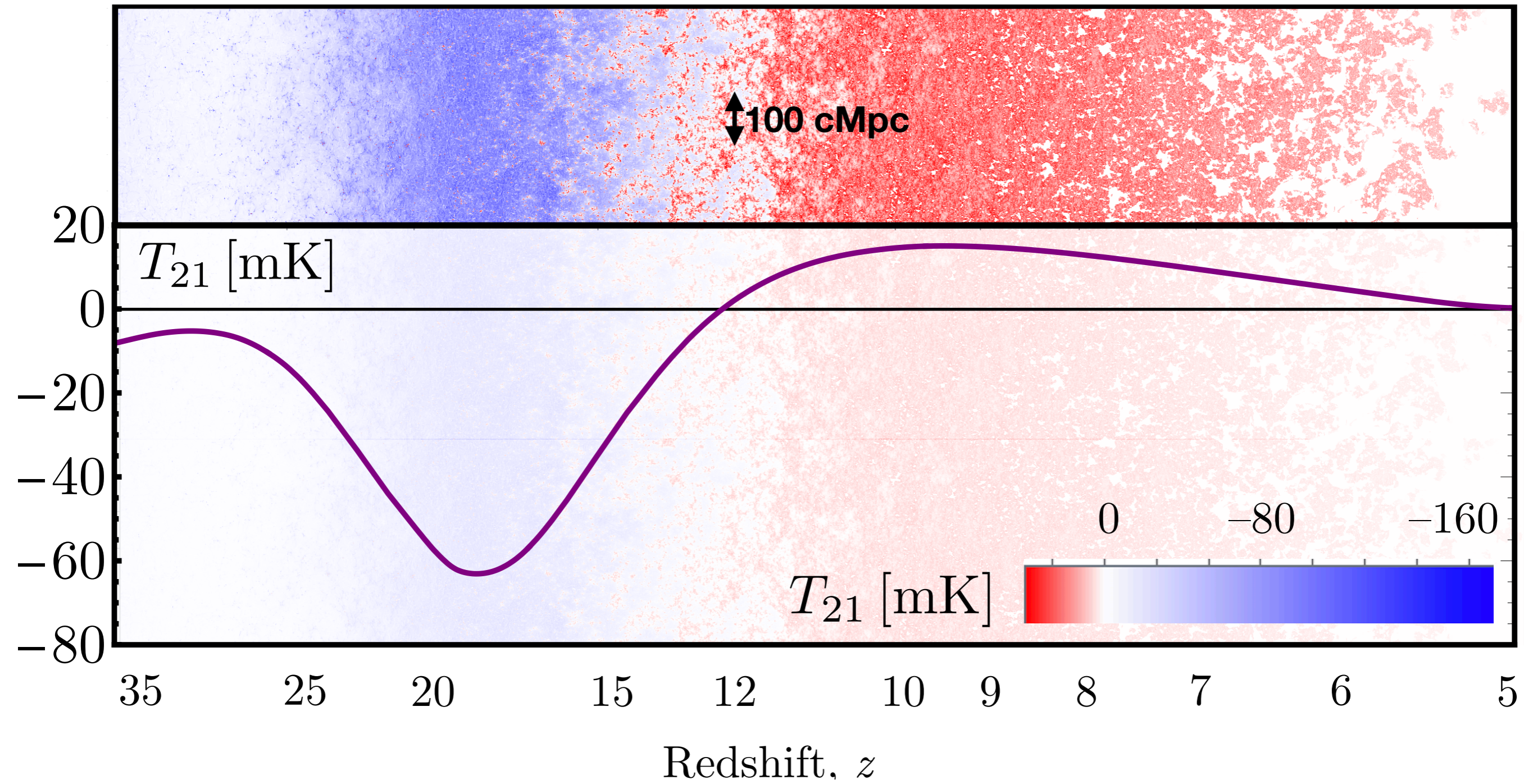
E.g., Pritchard & Loeb 2012

What would we see?

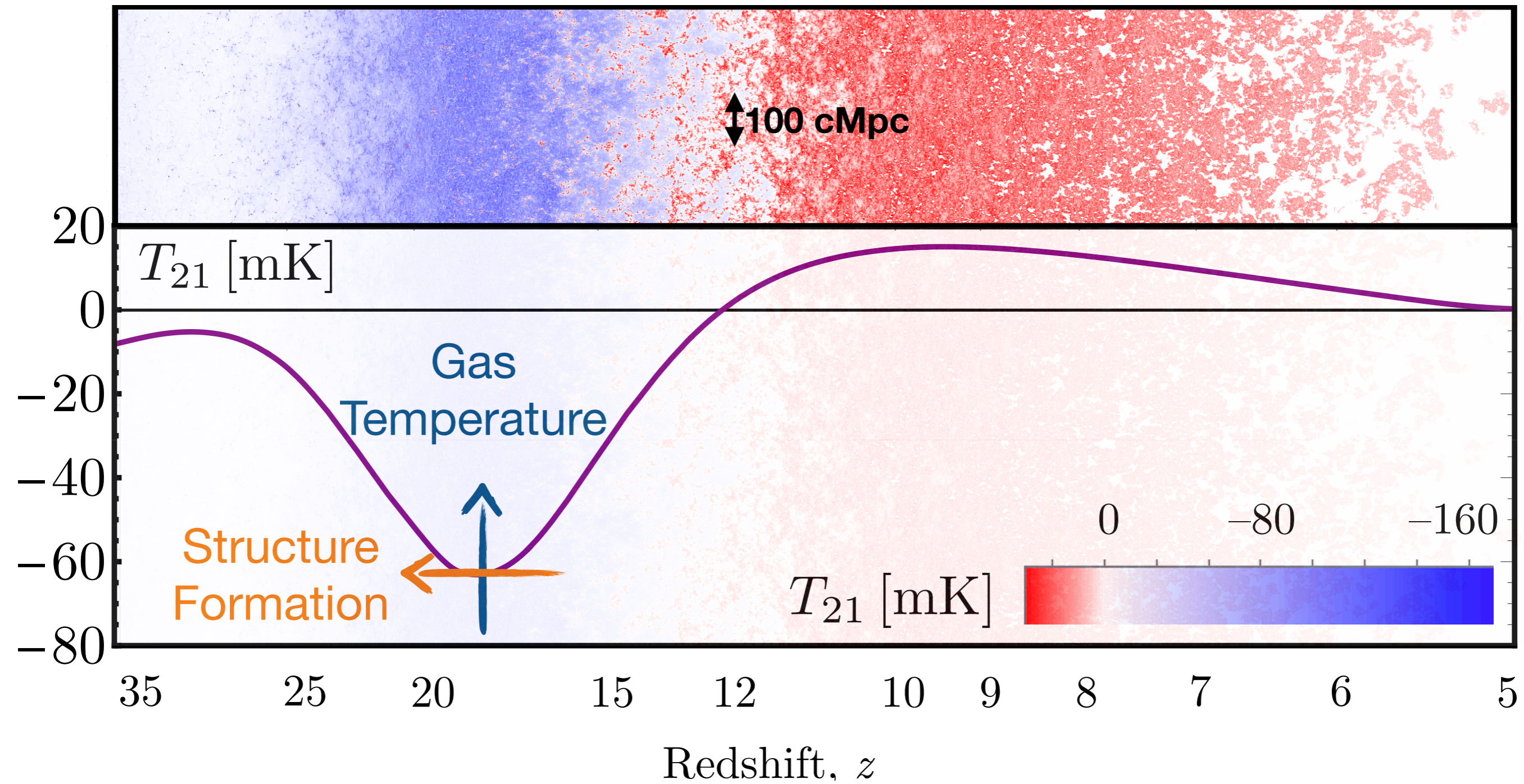


→
cosmic time

↕ 100 cMpc

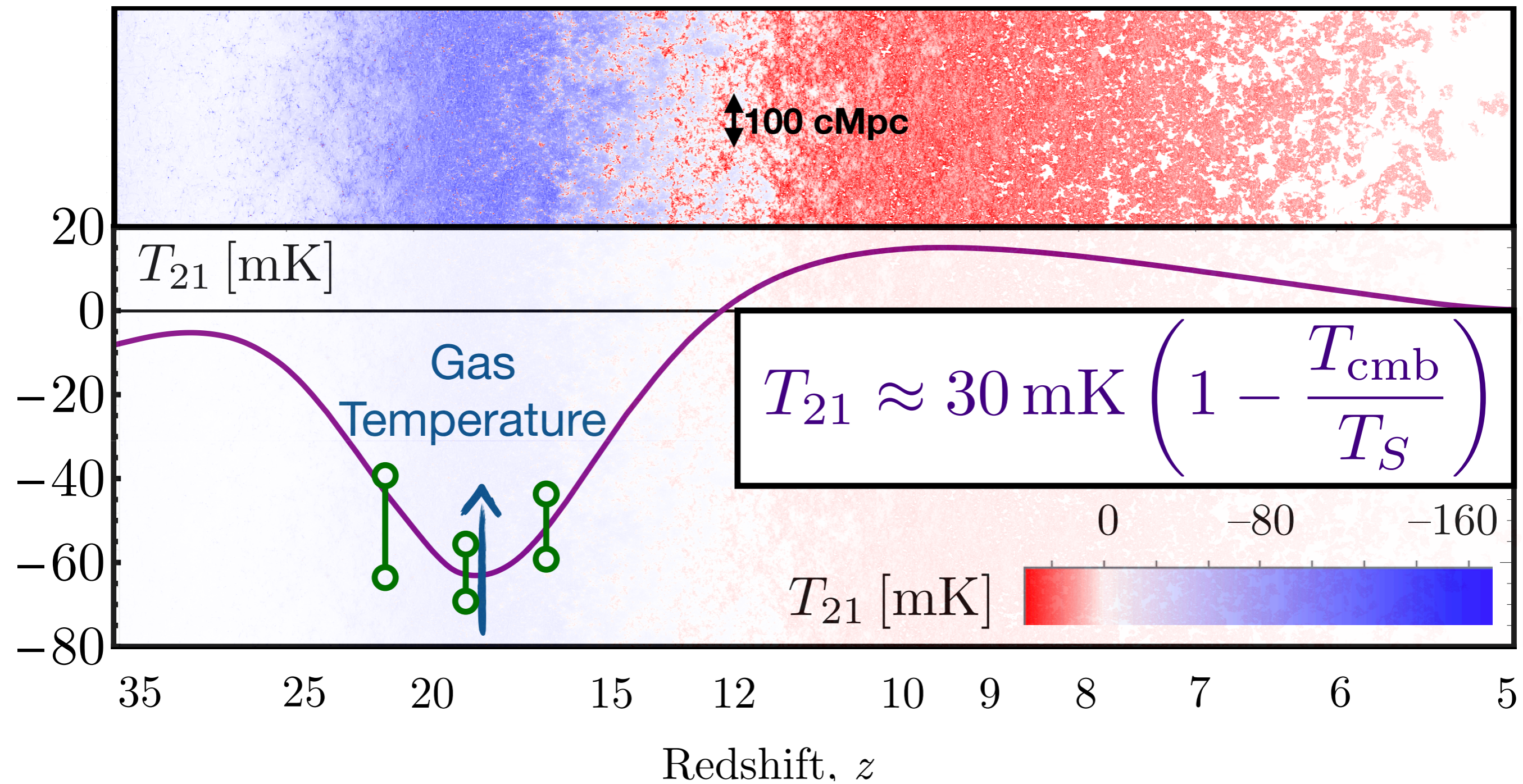


→
cosmic time

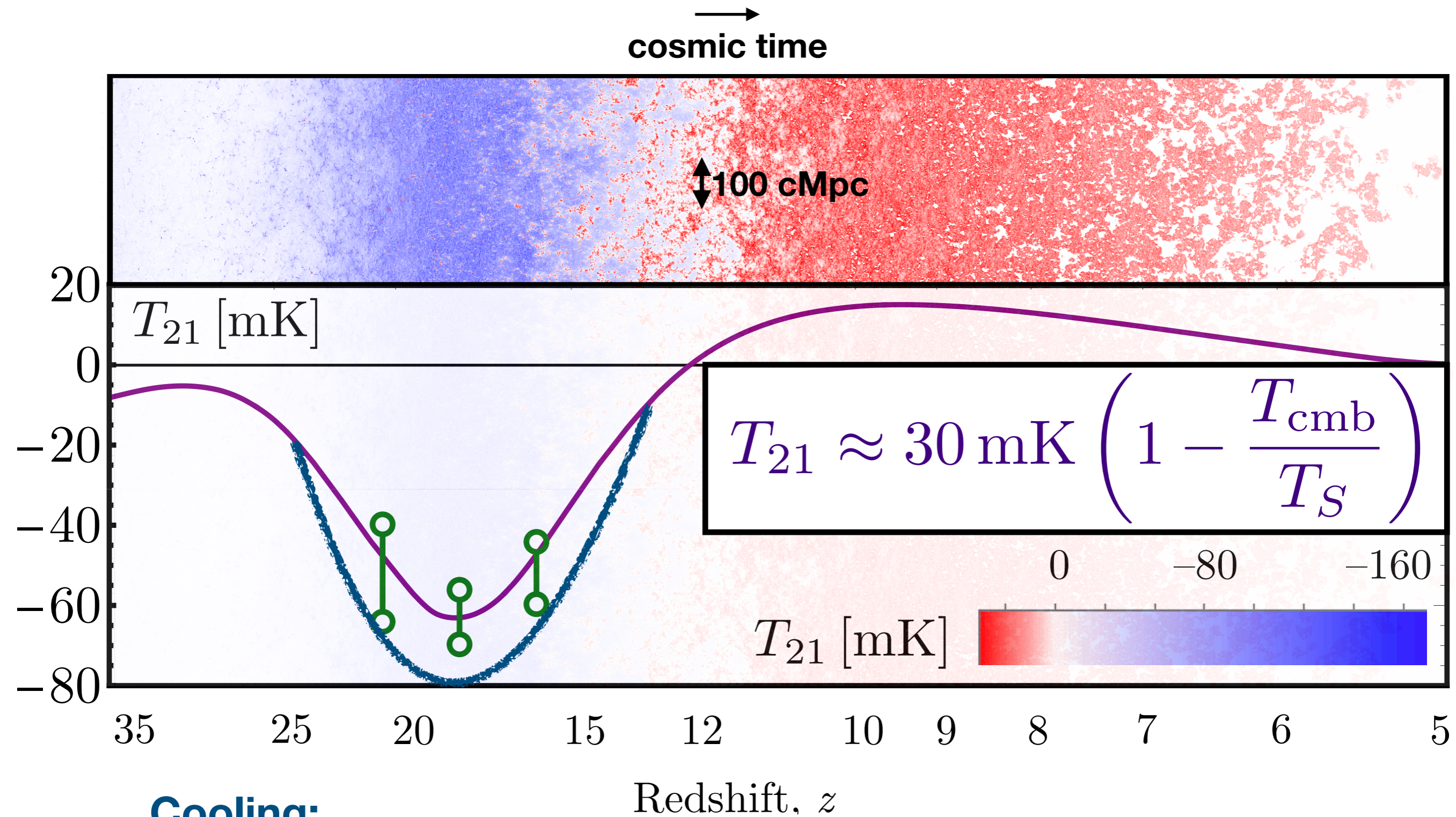


21-cm as a **thermometer** at high z

→
cosmic time



21-cm as a **thermometer** at high z



Cooling:

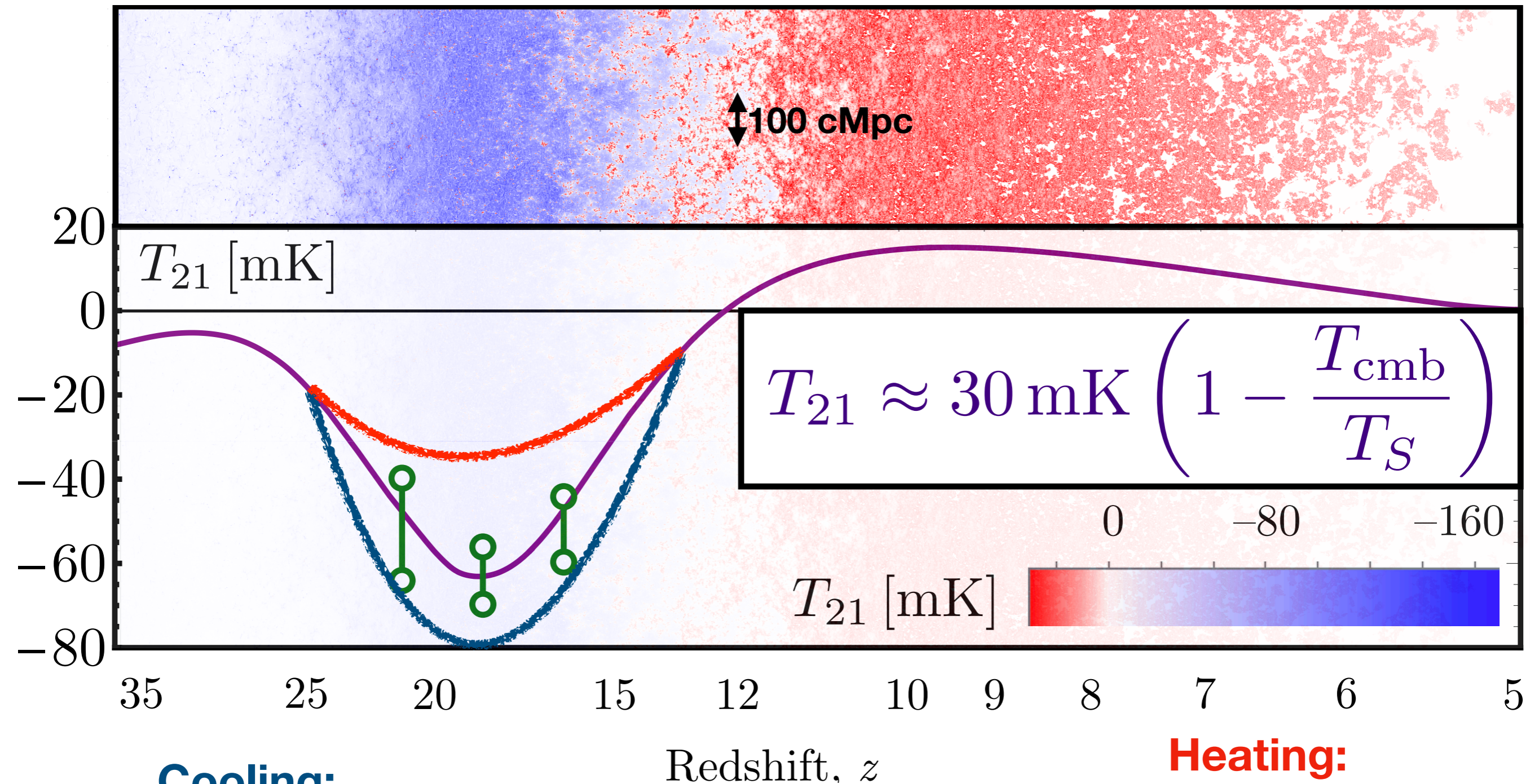
5th force: Tashiro+, **JBM**, Ali-Haimoud & Kovetz 15, Barkana 18

mQ: **JBM** & Loeb, Barkana+, Berlin+ 18, Liu+ 19...

Radio: Ewall-Wice+, Fraser+, Pospelov+ 18, Caputo+21...

21-cm as a thermometer at high z

→
cosmic time



5th force: Tashiro+, **JBM**, Ali-Haïmoud & Kovetz 15, Barkana 18

mQ: **JBM** & Loeb, Barkana+, Berlin+ 18, Liu+ 19...

Radio: Ewall-Wice+, Fraser+, Pospelov+ 18, Caputo+21...

WIMP: Lopez-Honorez+ 16

Liu & Slatyer, D'Amico+ 18

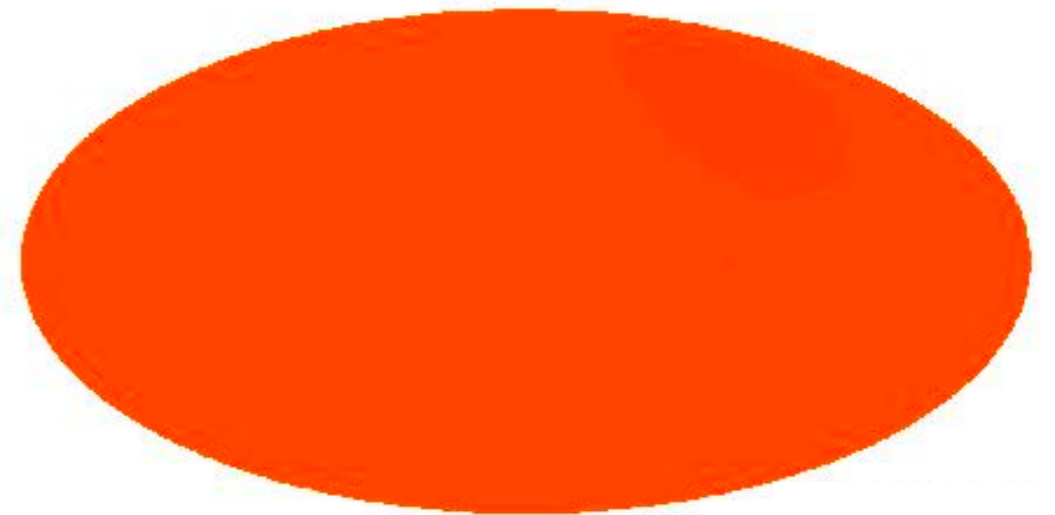
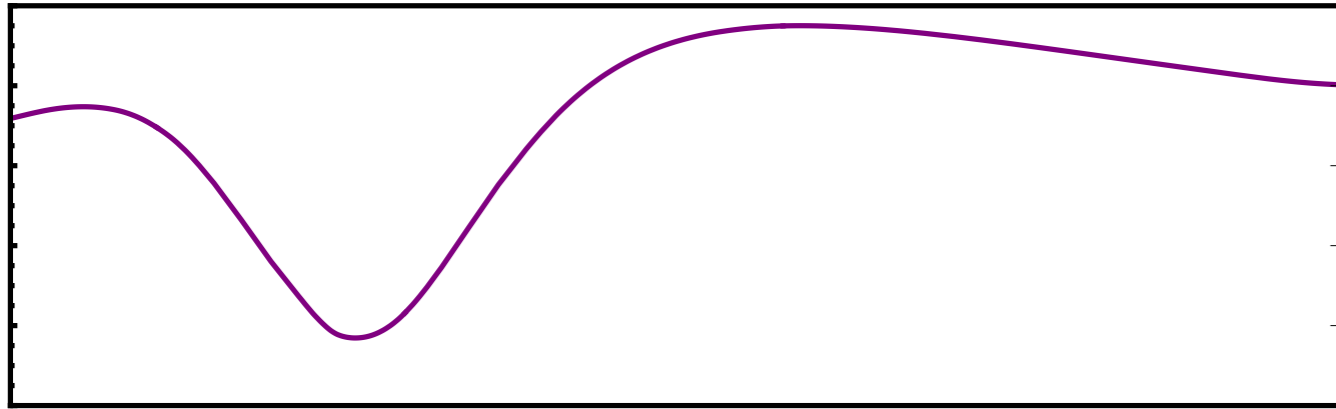
PBHs: Clark+ 18,

A' DM: Kovetz, Cholis, Kaplan 18

21-cm Global Signal
(EDGES, SARAS, PRIZM, MIST,...)

=

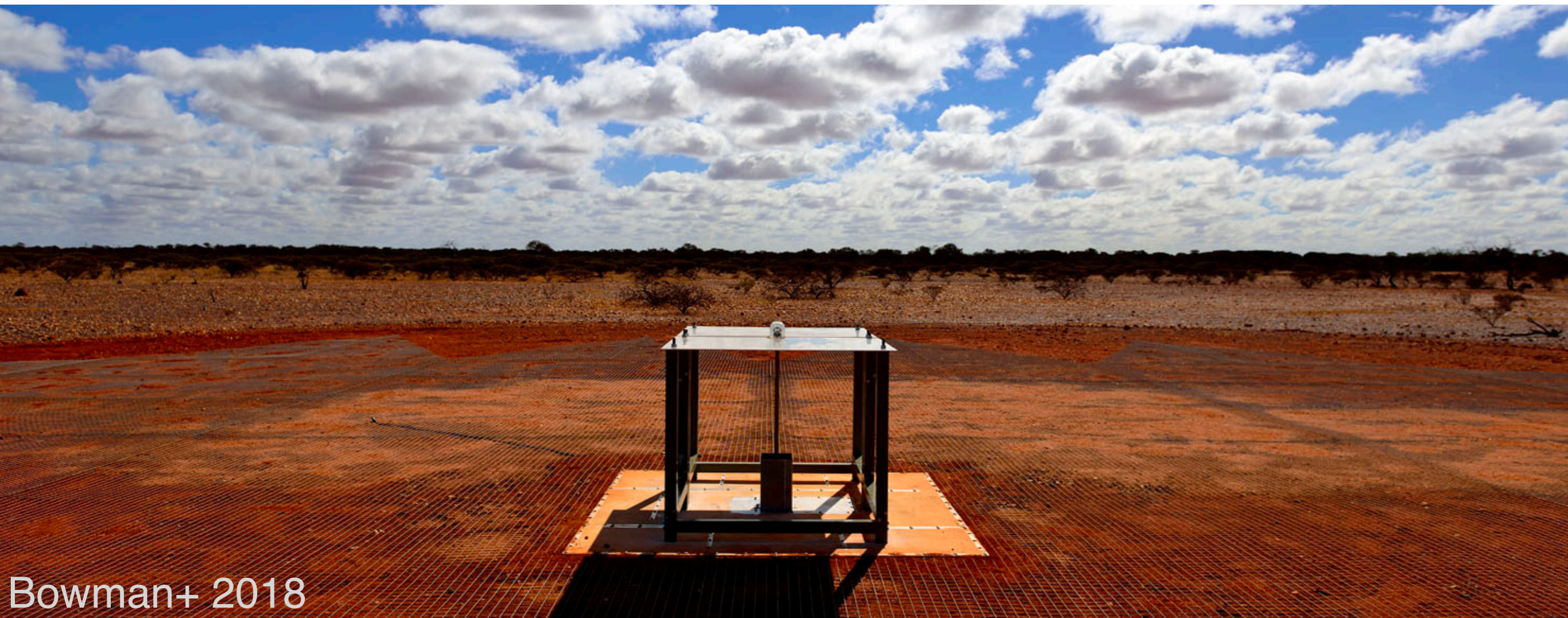
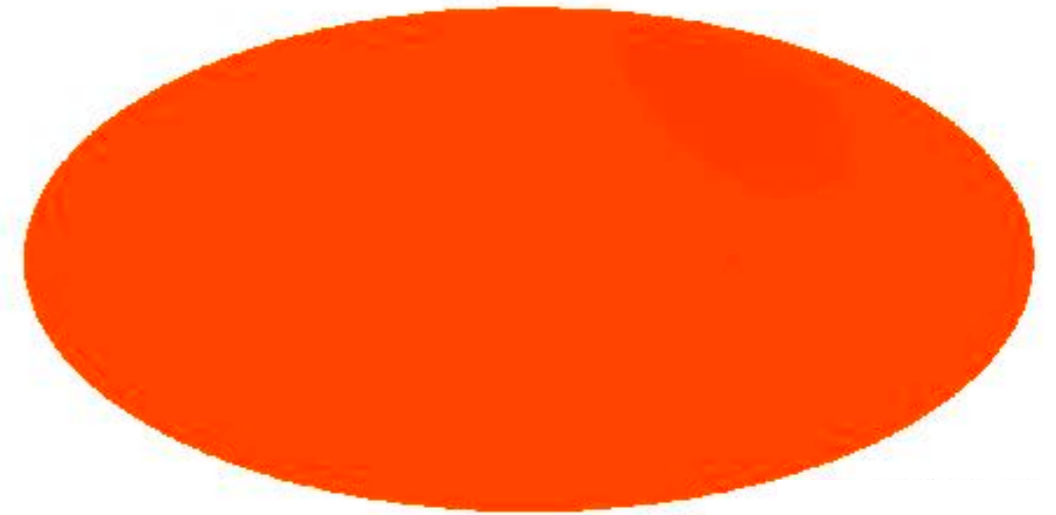
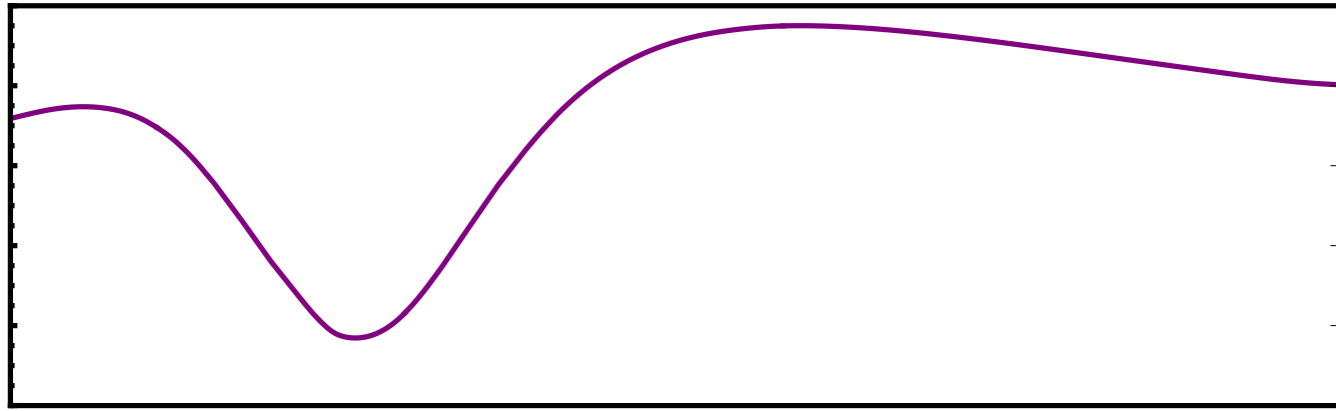
CMB Monopole



21-cm Global Signal
(**EDGES**, SARAS, PRIZM, MIST,...)

=

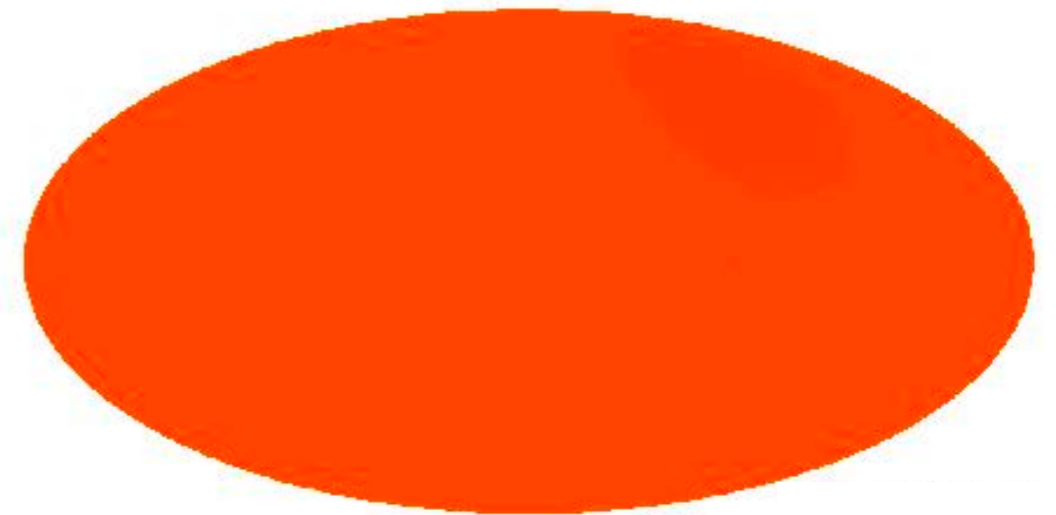
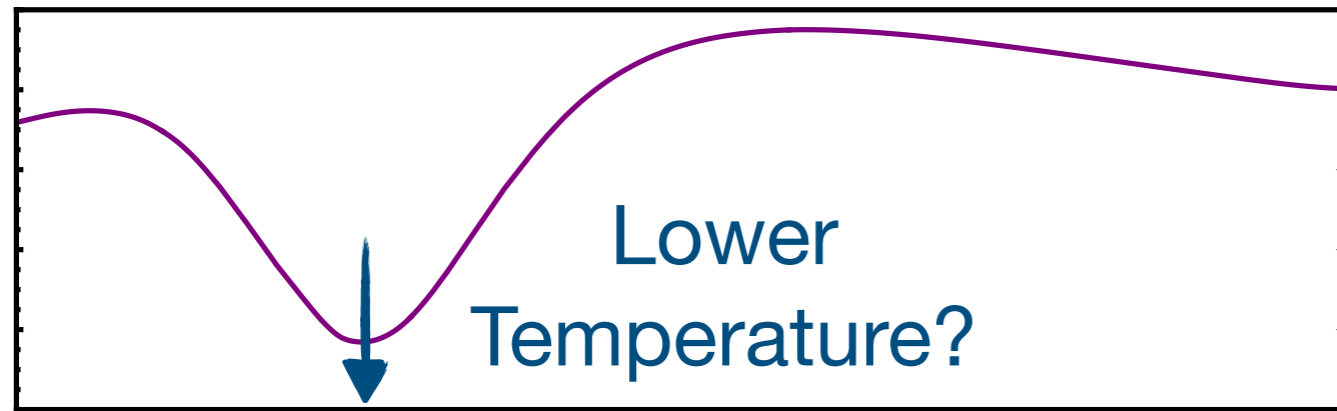
CMB Monopole



21-cm Global Signal
(**EDGES**, SARAS, PRIZM, MIST,...)

=

CMB Monopole



First detection? However, **foregrounds**....

Systematics?

EDGES
(Bowman+ 2018)

Hills+ 2018

SARAS 3
(Singh+ 2021)

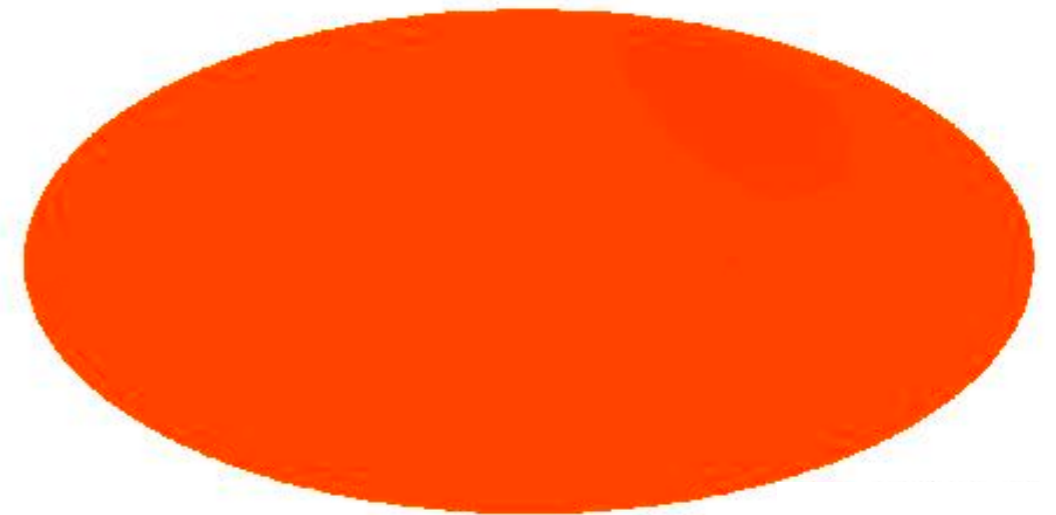
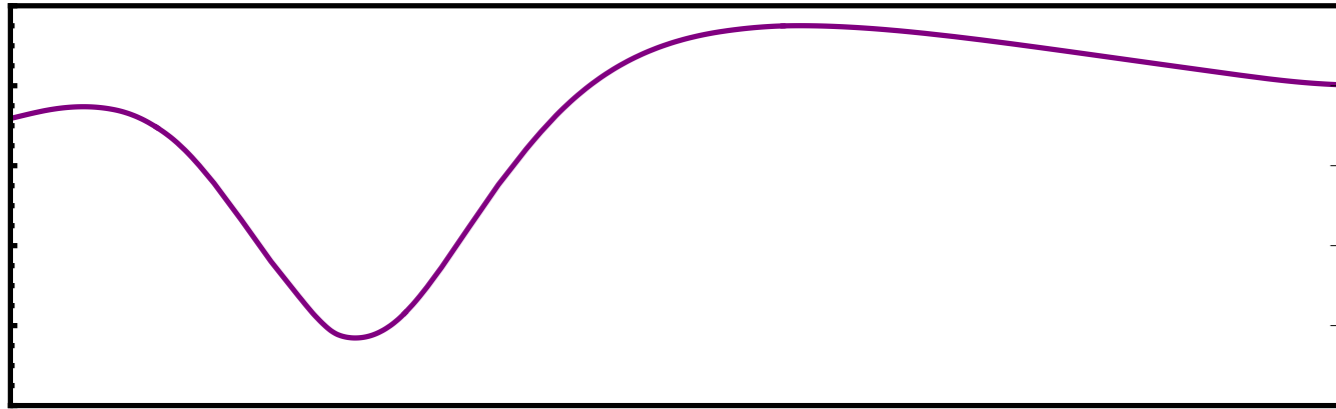
Dark-matter interactions?

mQ: **JBM** & Loeb 18, Barkana+, Berlin+ 18, Liu+ 19...

21-cm Global Signal
(EDGES, SARAS, PRIZM, MIST,...)

=

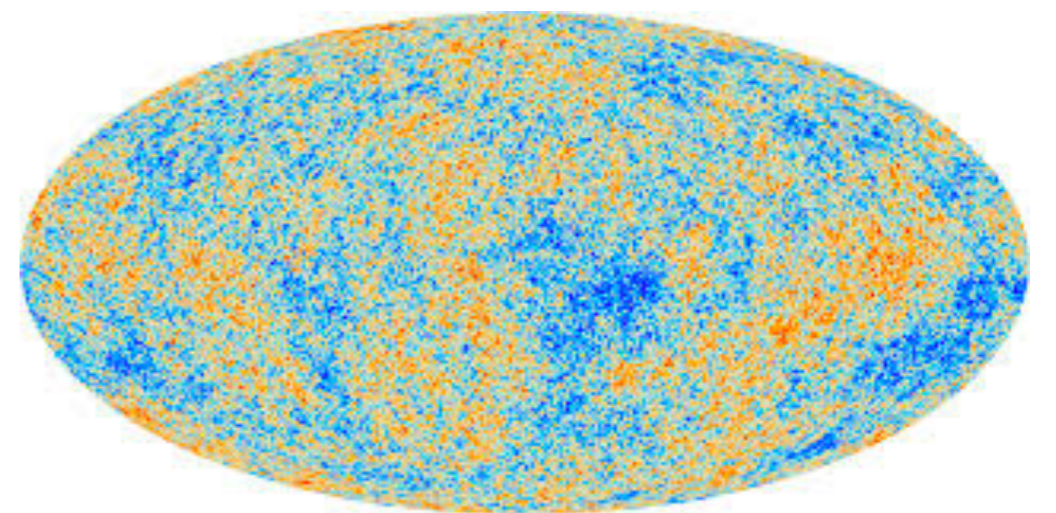
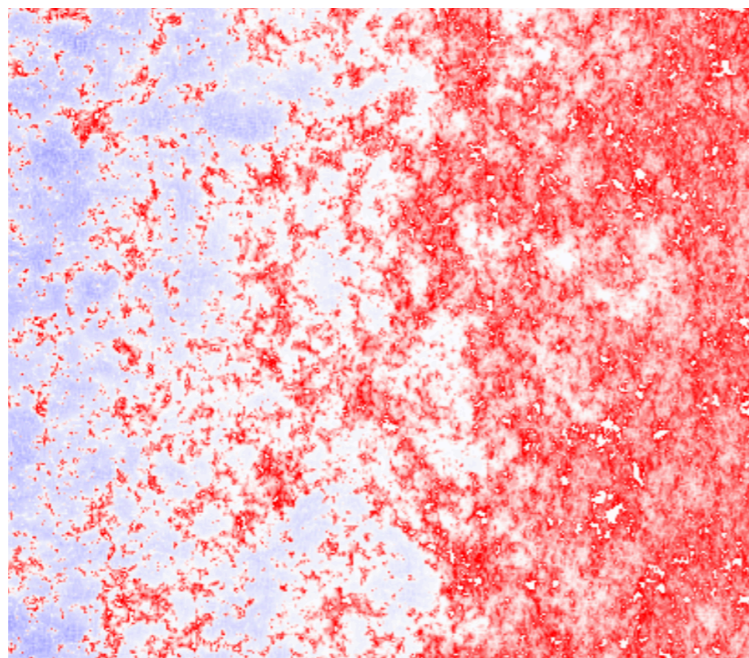
CMB Monopole

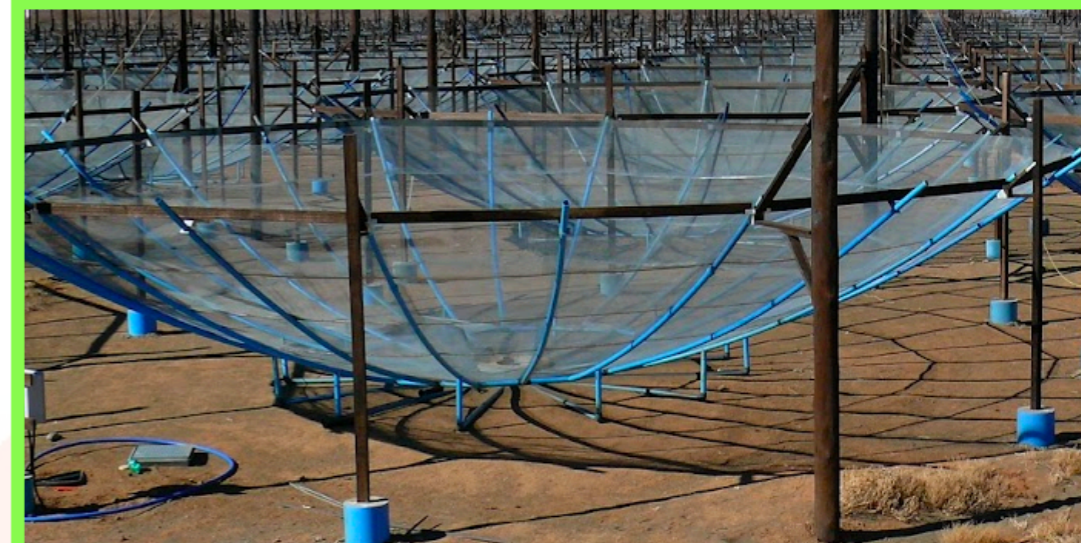


21-cm Fluctuations
(**HERA**, MWA, LOFAR, PAPER, SKA,...)

=

CMB Anisotropies

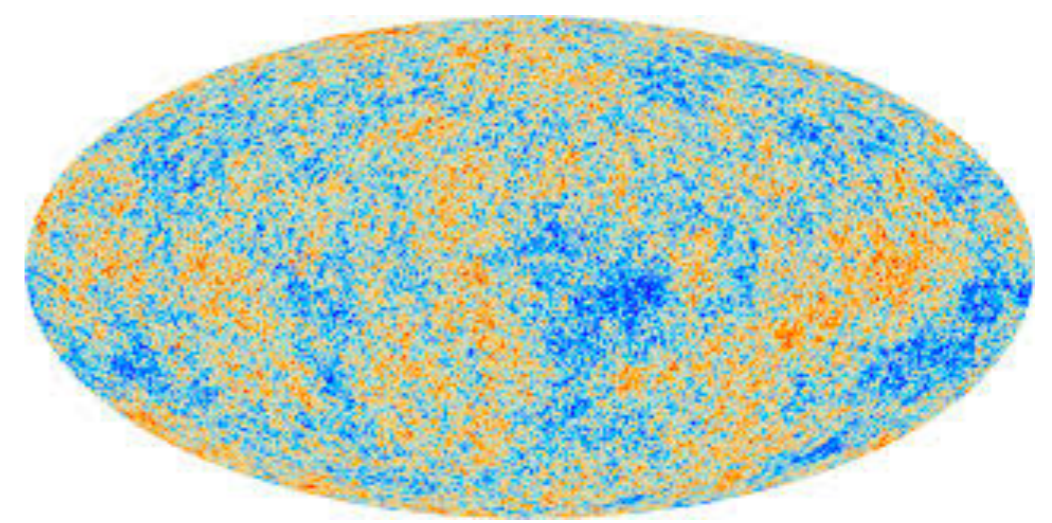
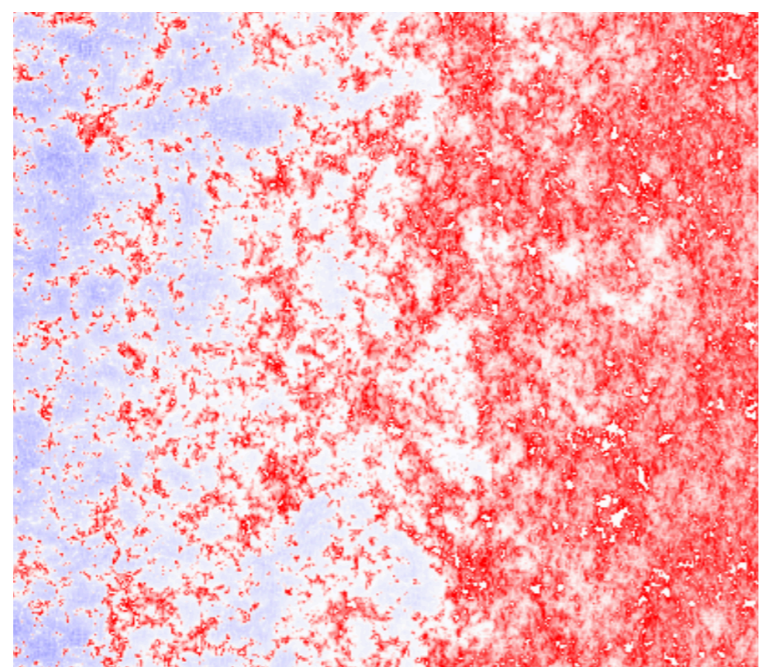




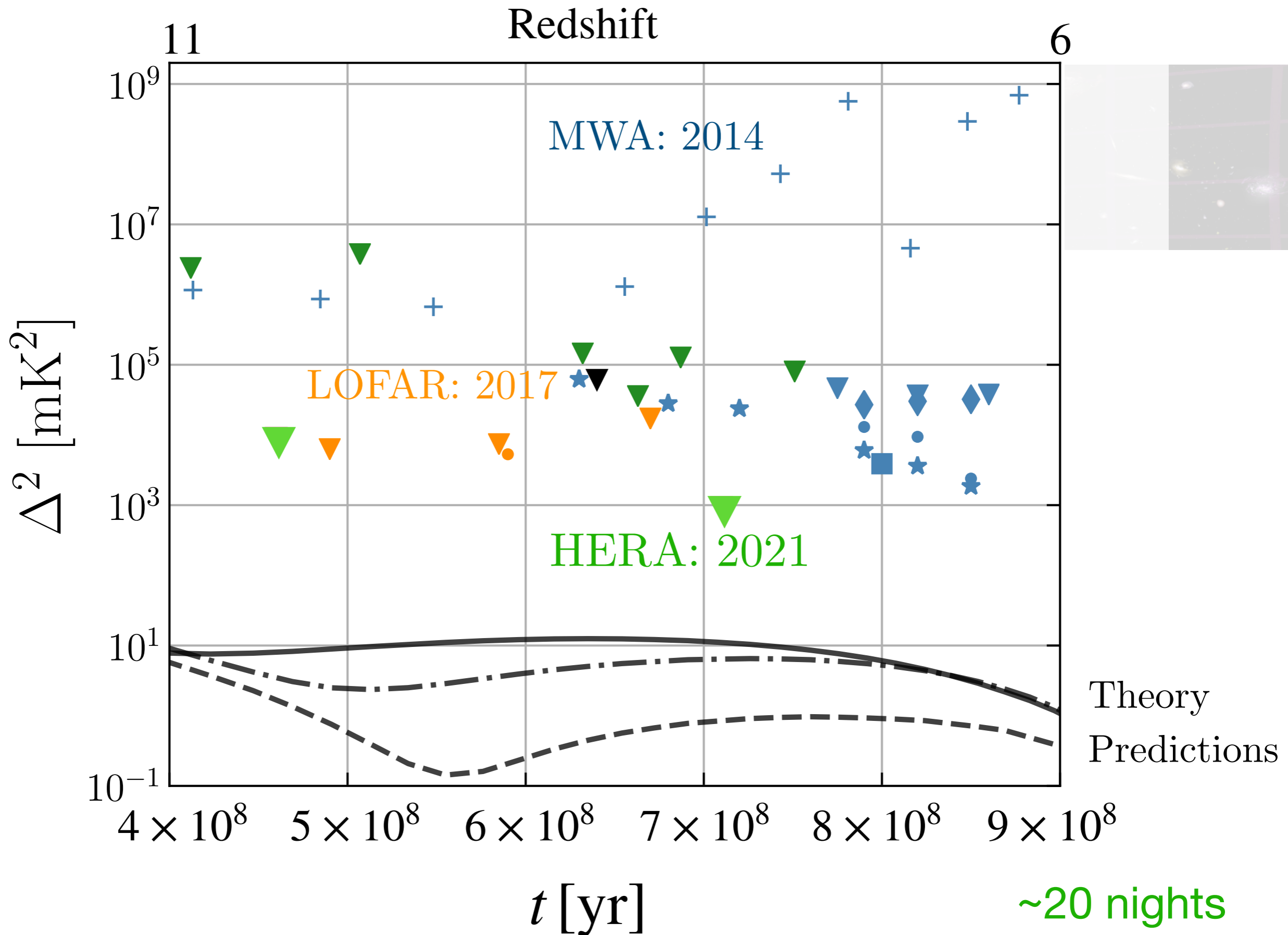
21-cm Fluctuations
(**HERA**, MWA, LOFAR, PAPER, SKA,...)

=

CMB Anisotropies

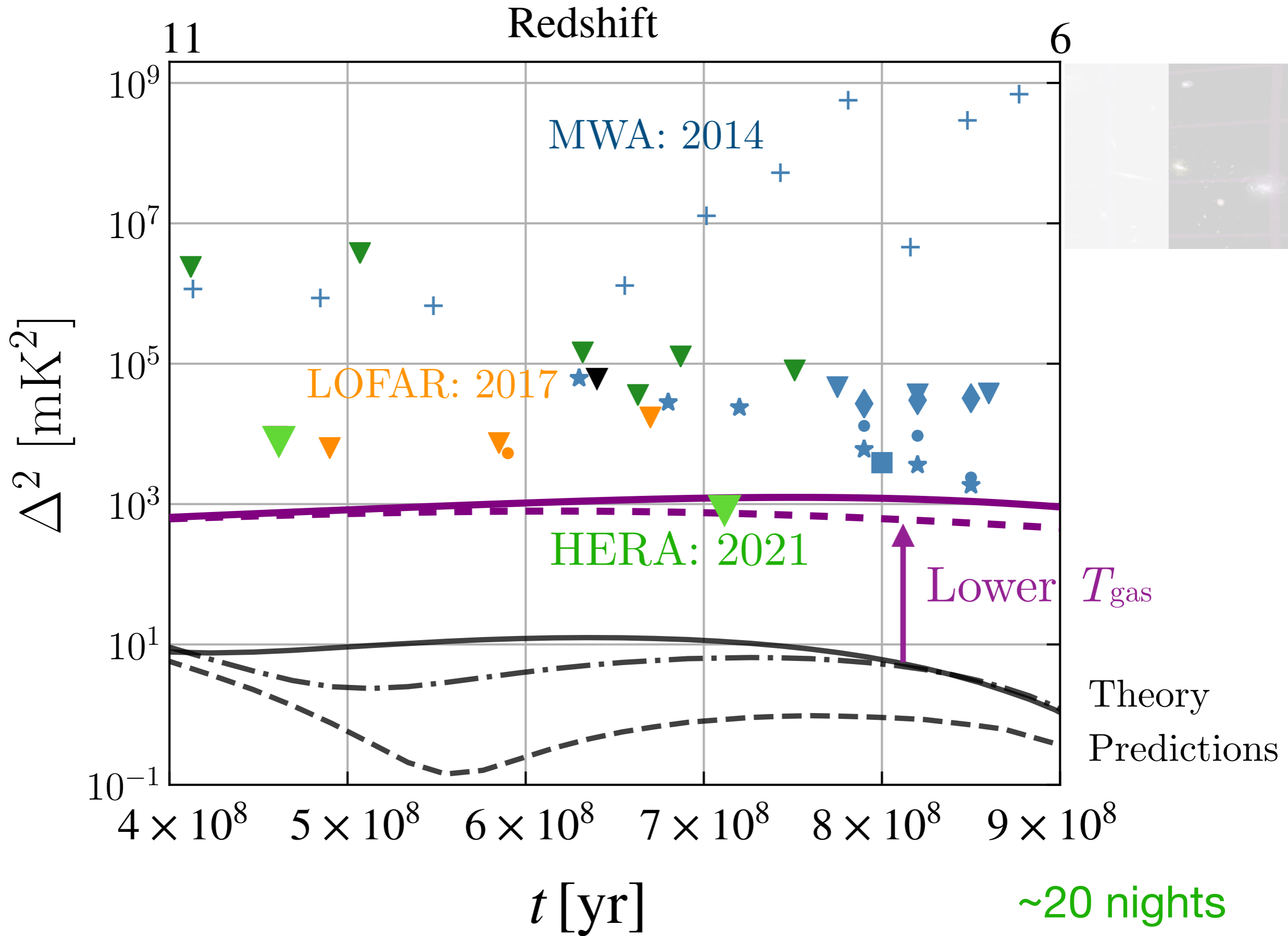


The status of 21-cm data



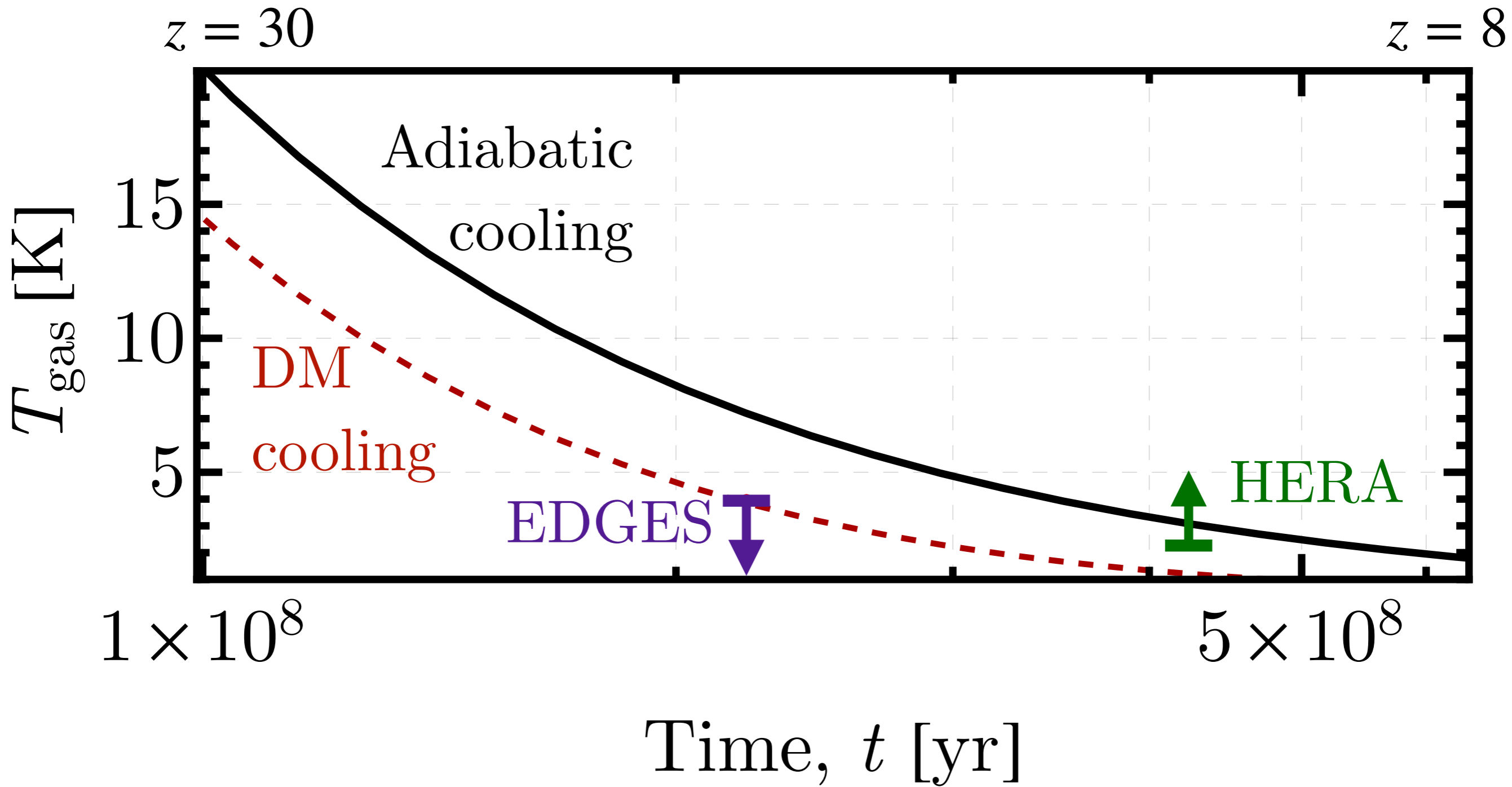
HERA coll. 2021 (Incl. **JBM**)

HERA vs EDGES

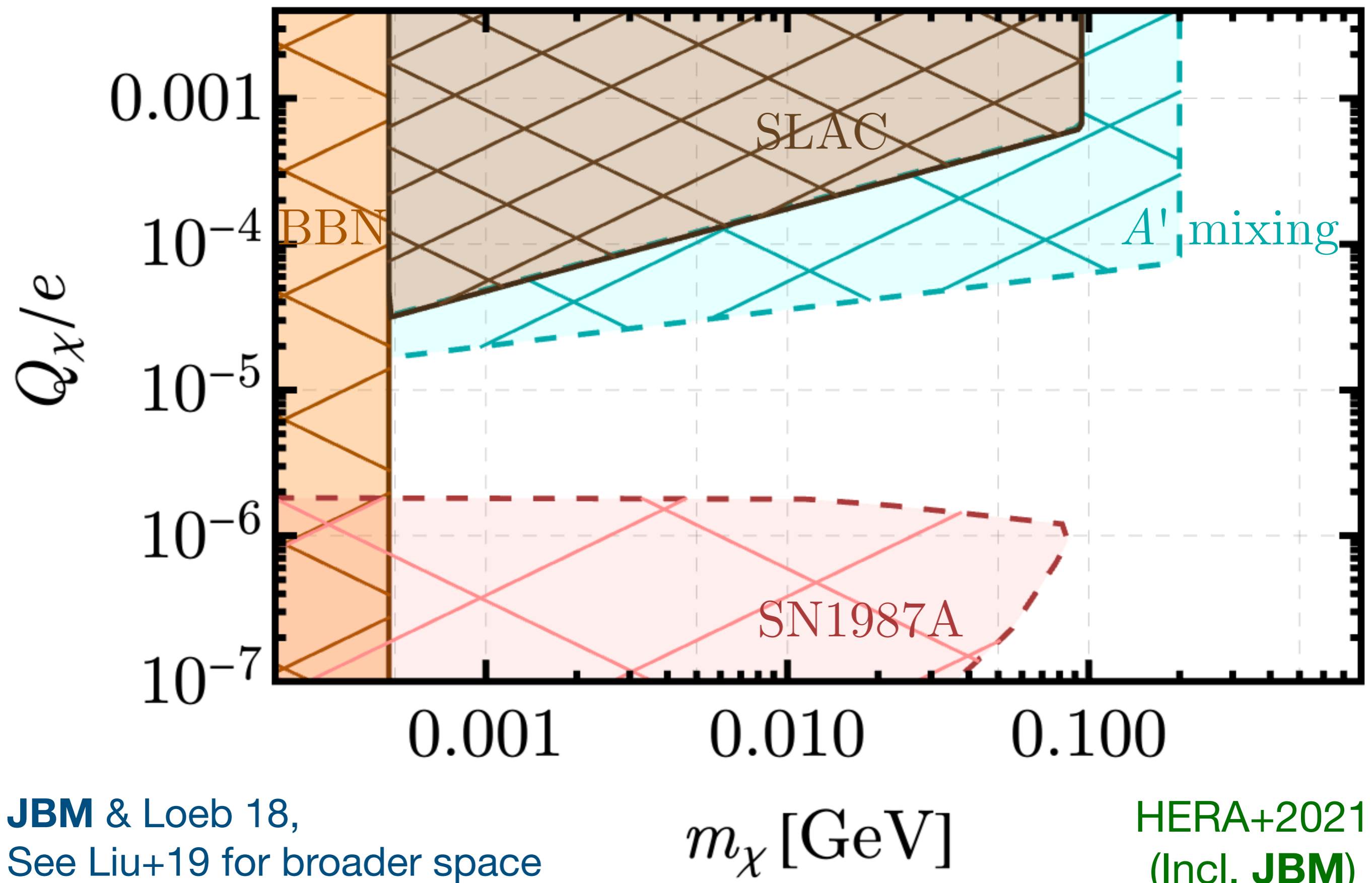


HERA coll. 2021 (Incl. **JBM**)

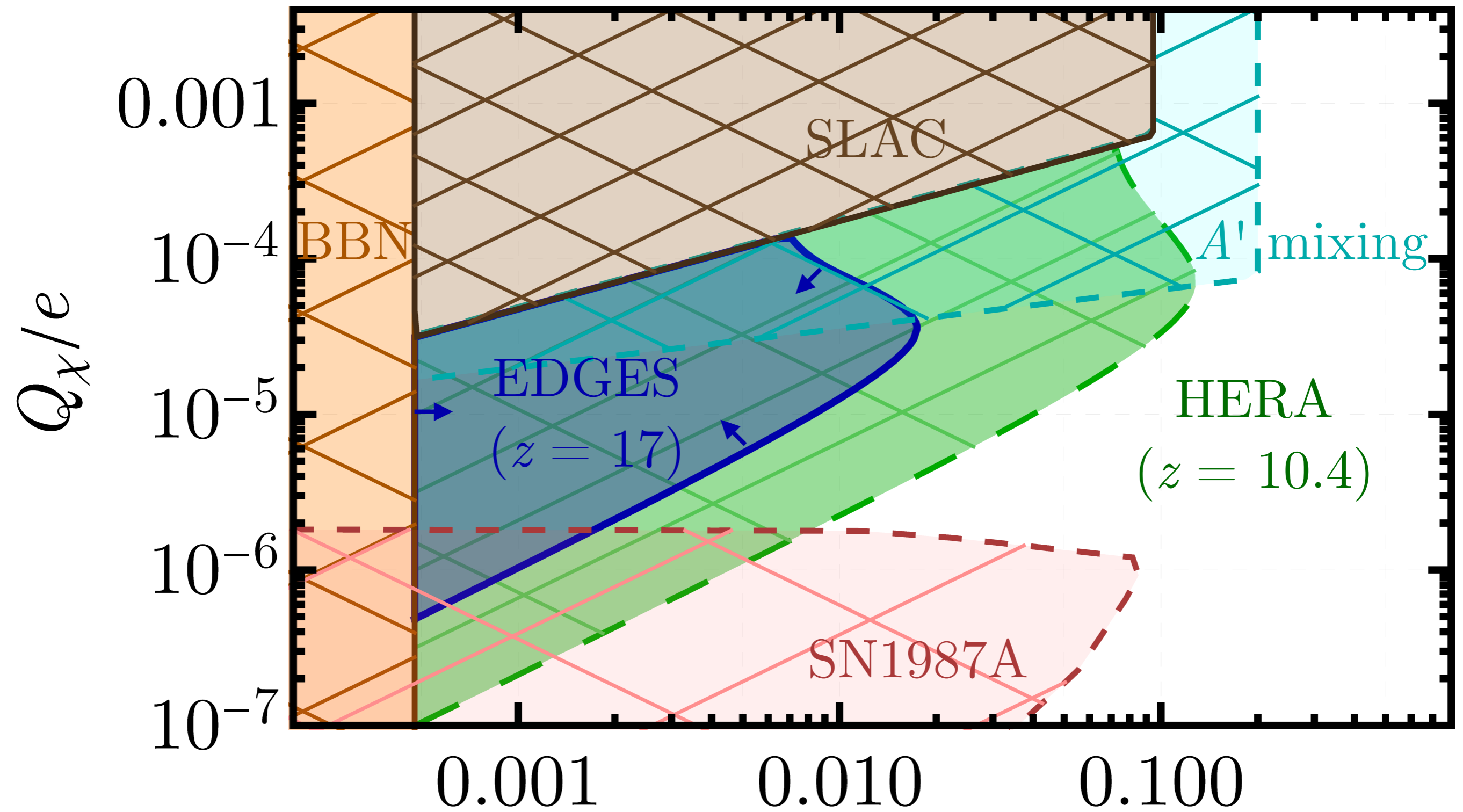
HERA vs EDGES



HERA vs EDGES



HERA vs EDGES



JBM & Loeb 18,
See Liu+19 for broader space

m_χ [GeV]

HERA+2021
(Incl. **JBM**)

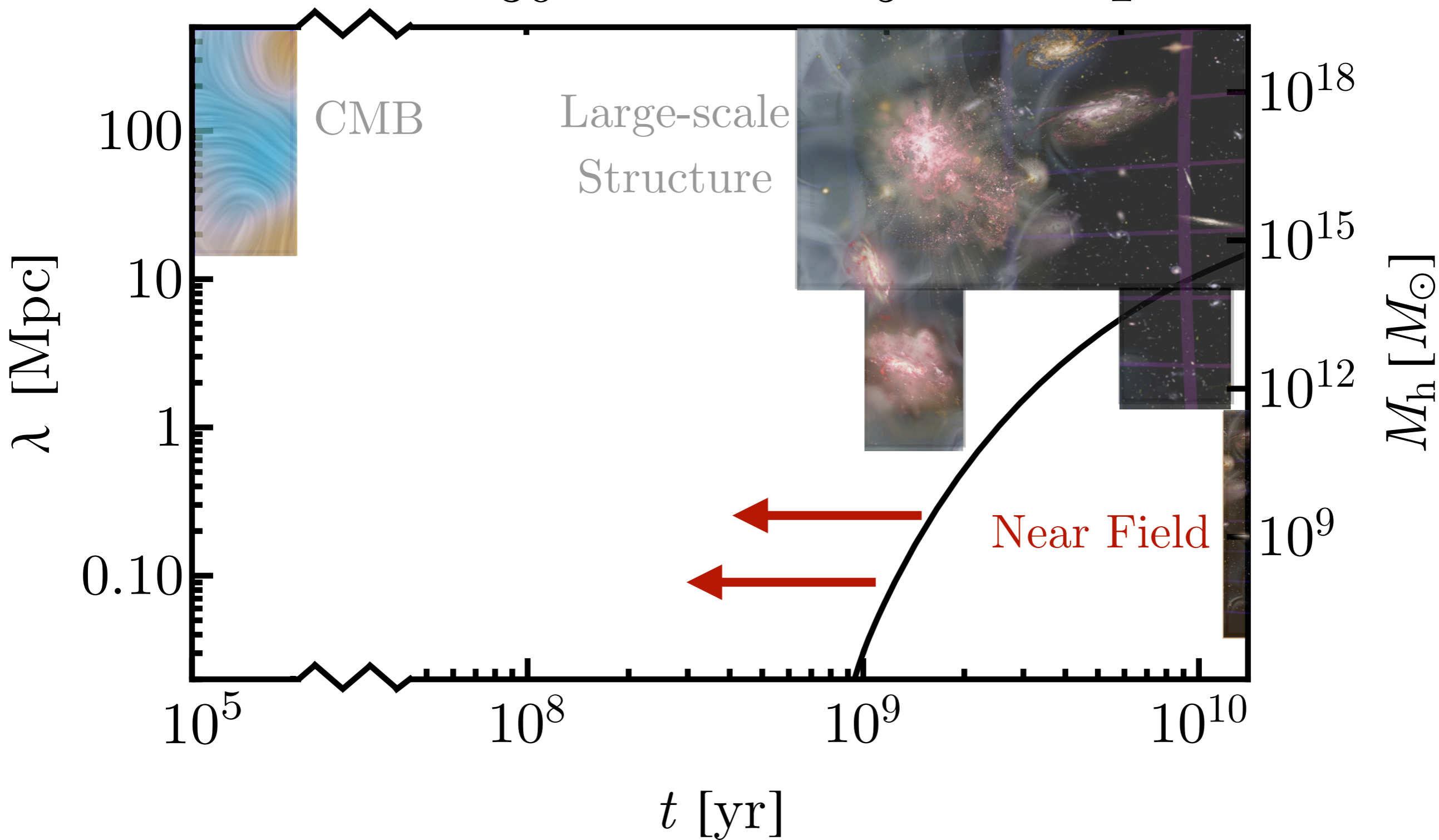
Probing the uncharted

Redshift, z

30

5

1



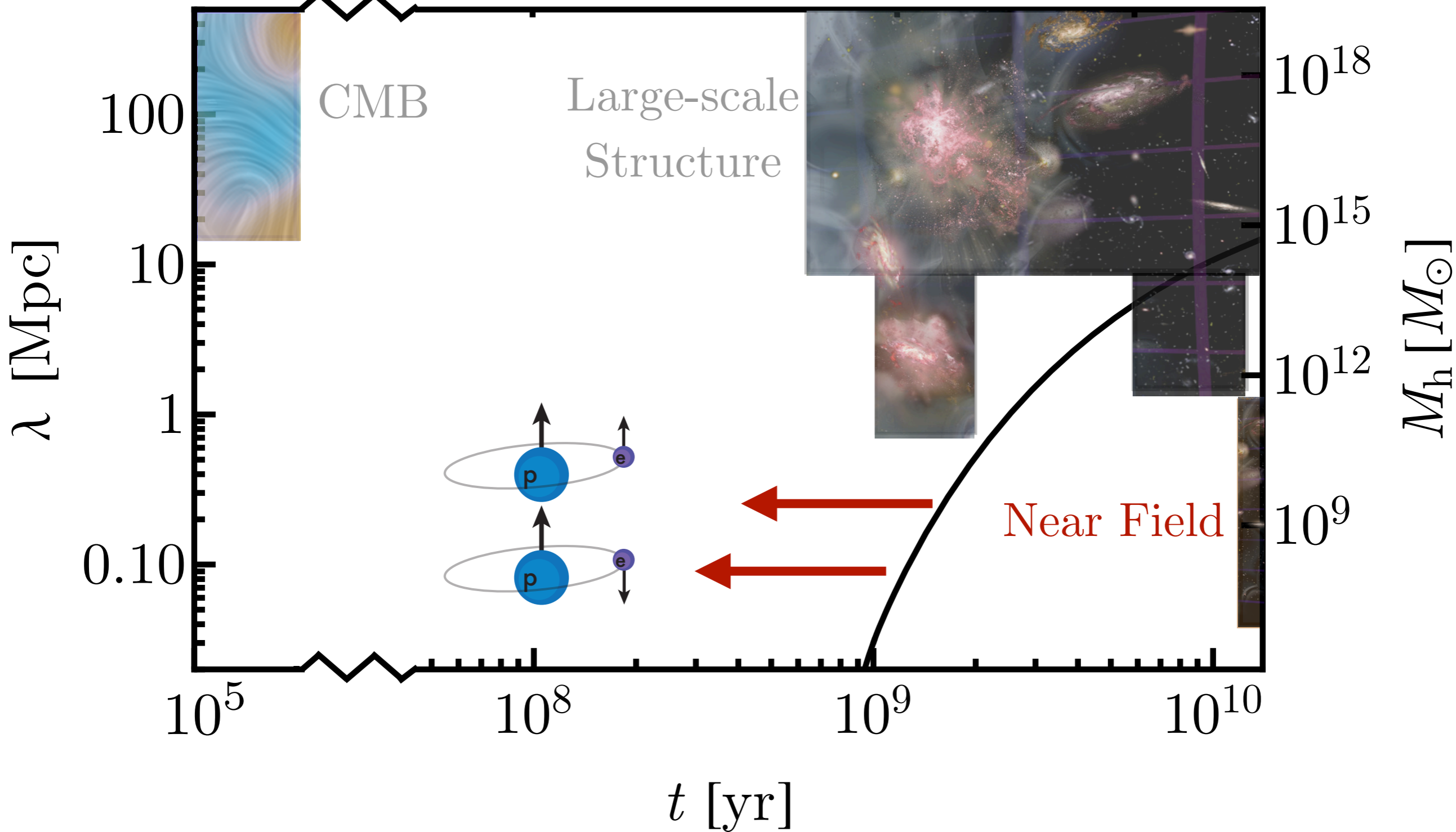
Probing the uncharted

Redshift, z

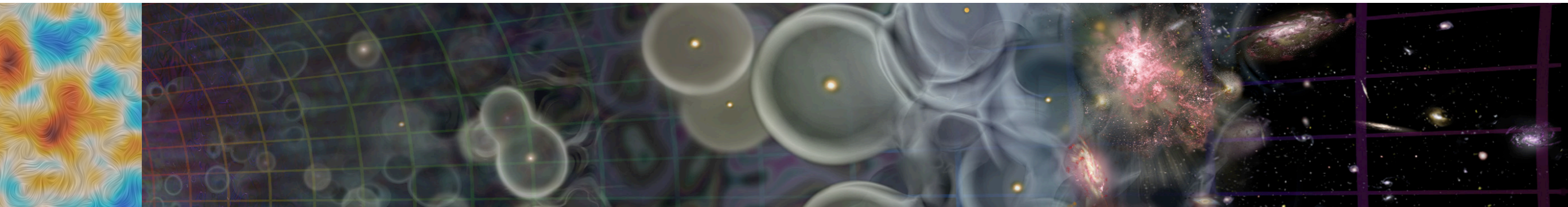
30

5

1



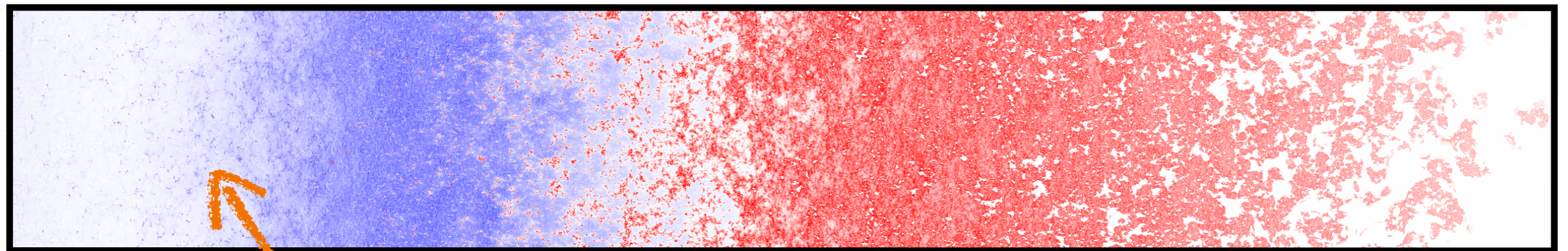
How does 21-cm help us with DM?



10^8 yr

→
cosmic time

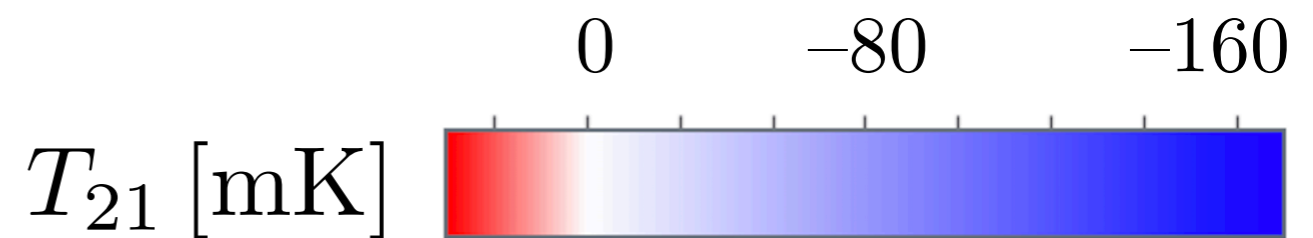
10^9 yr



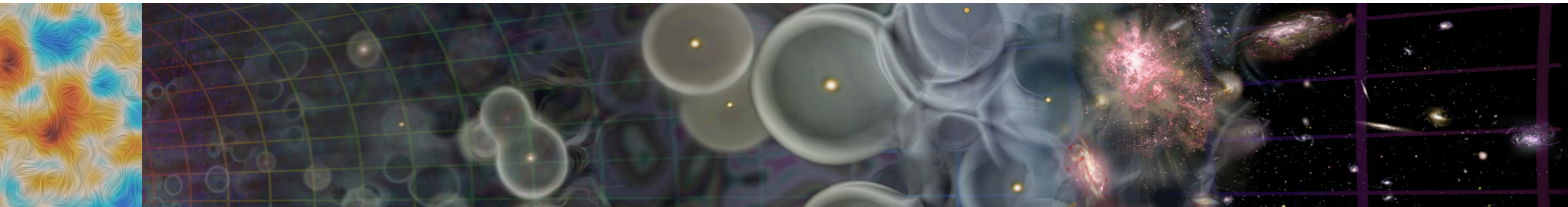
35 25 20 15 12 10 9 8 7 6 5

Redshift, z

First
Galaxies



The first galaxies and DM

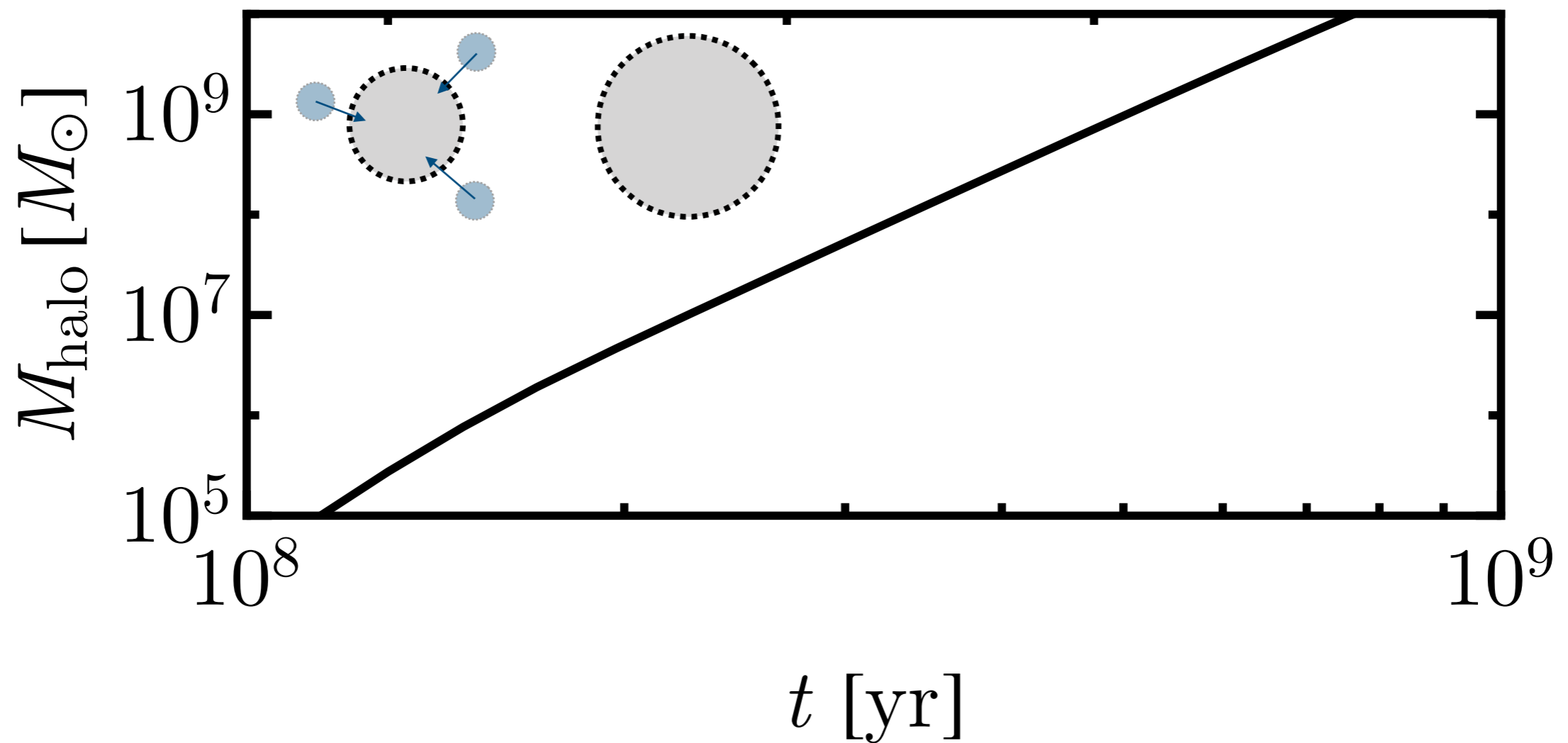


Redshift, z

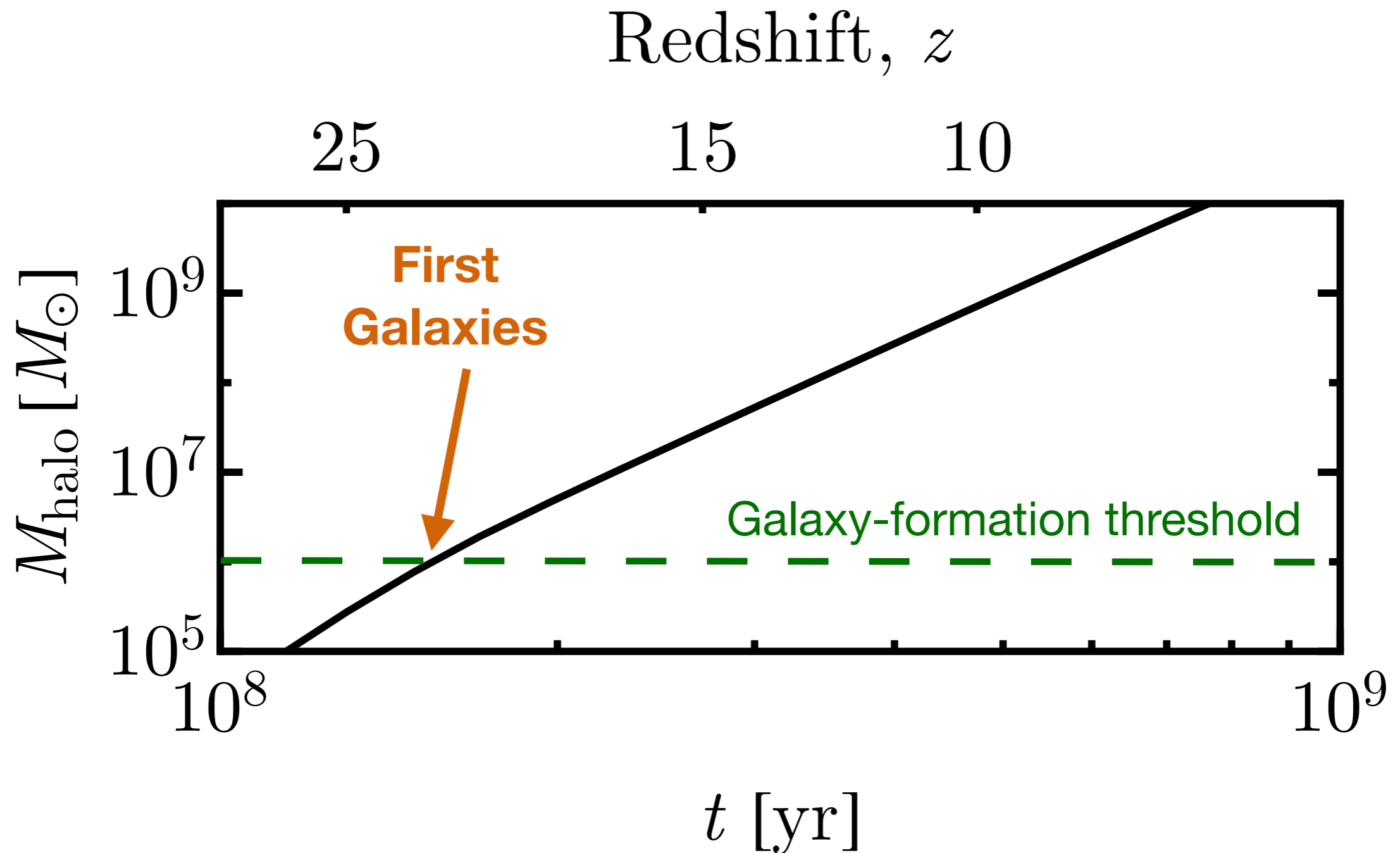
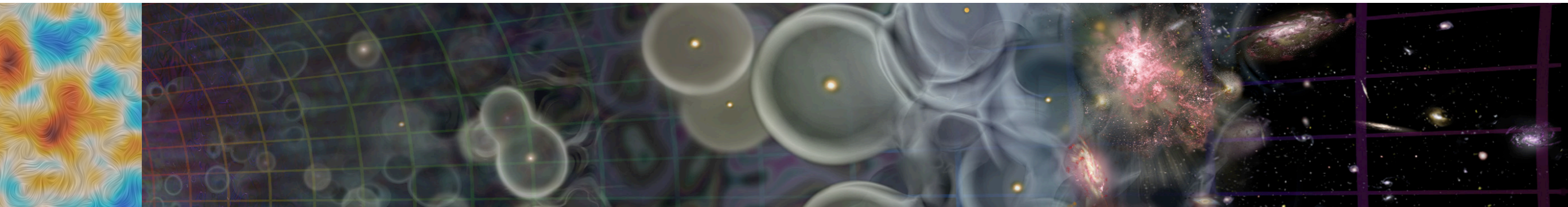
25

15

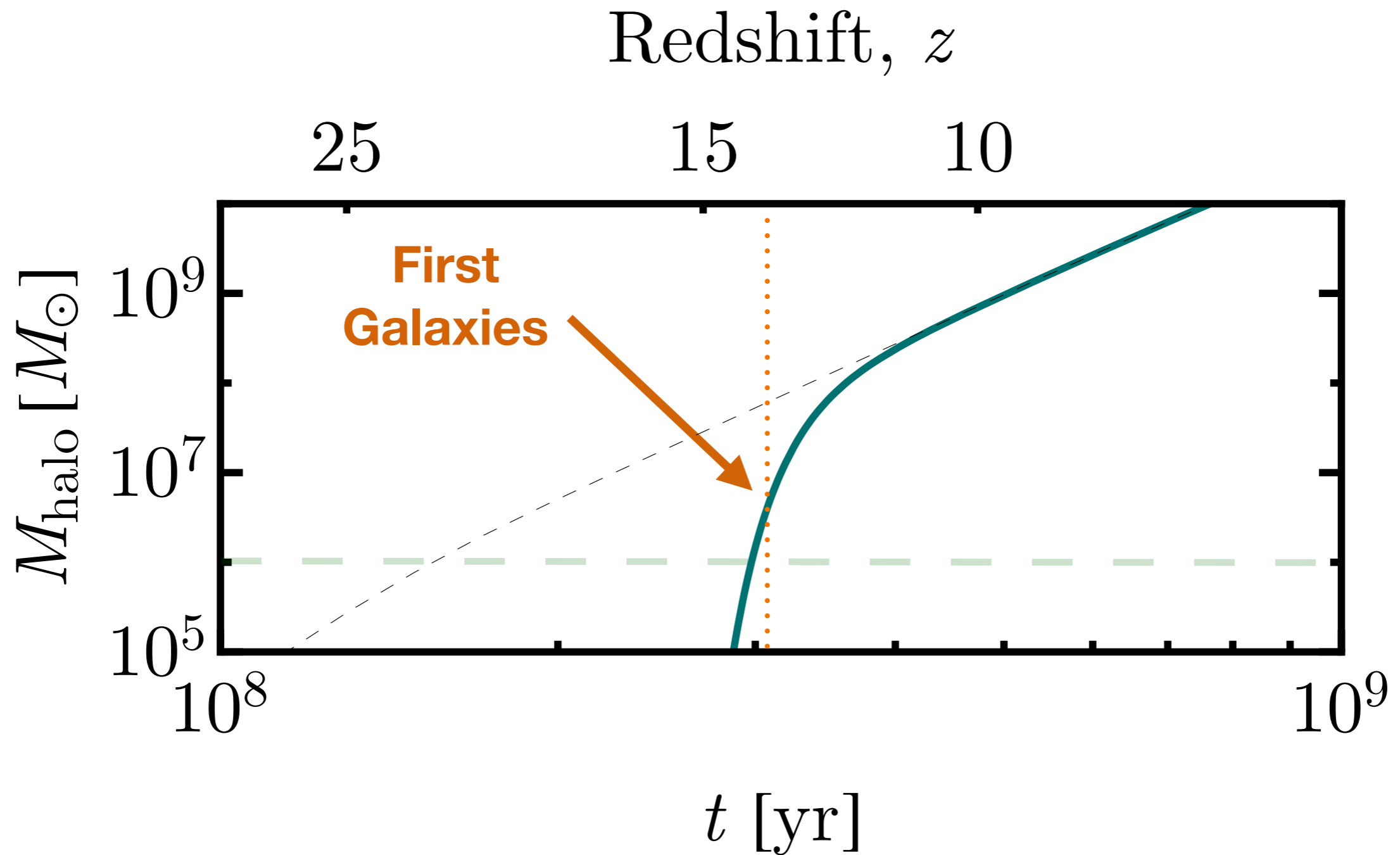
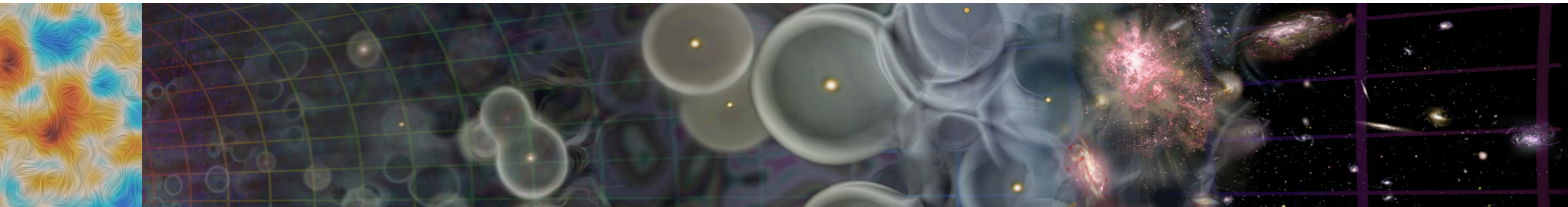
10



The first galaxies and DM

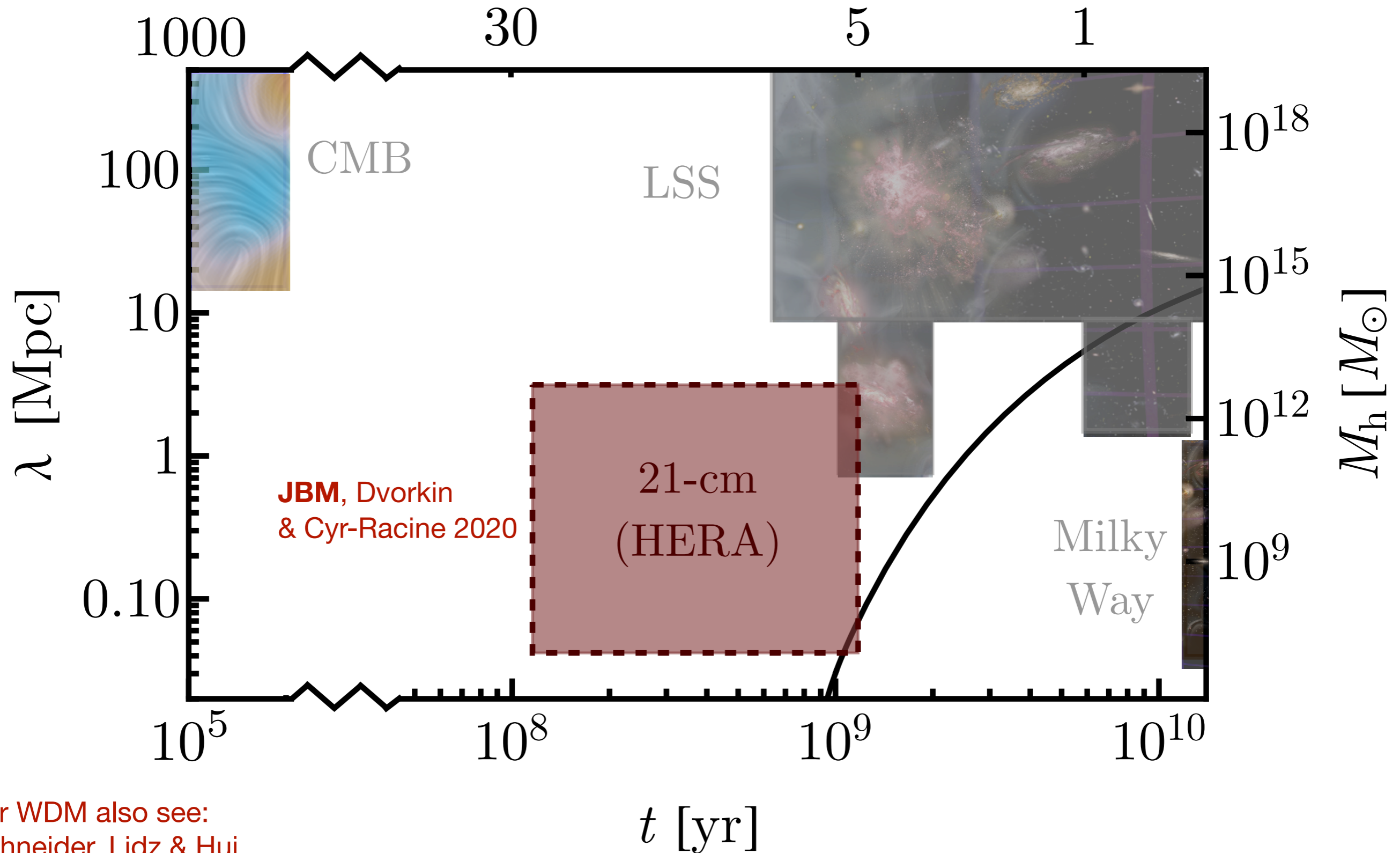


How does 21-cm help us with DM?



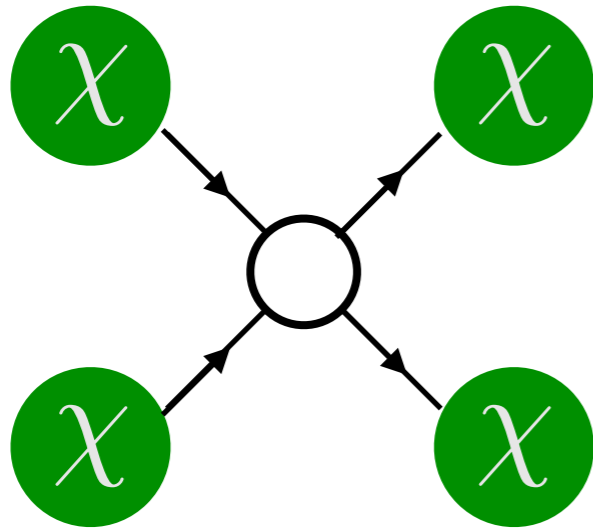
Probing the uncharted

Redshift, z

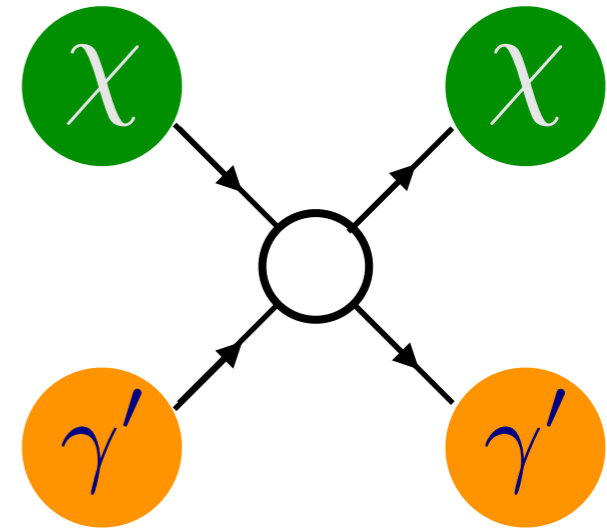


For WDM also see:
Schneider, Lidz & Hui,
Boyarisky+, Yoshiura+ 2018

Effective Theory of Structure Formation: **ETHOS**

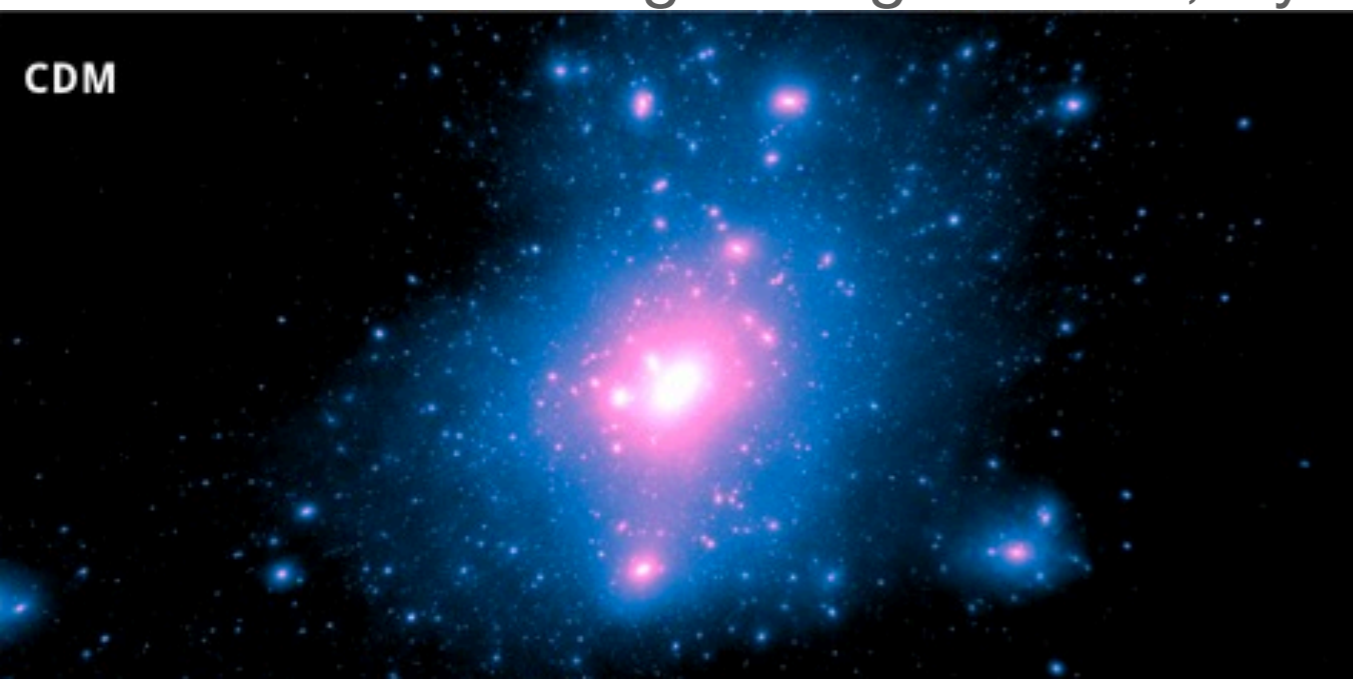


DM-DM:
Halo profiles, etc.

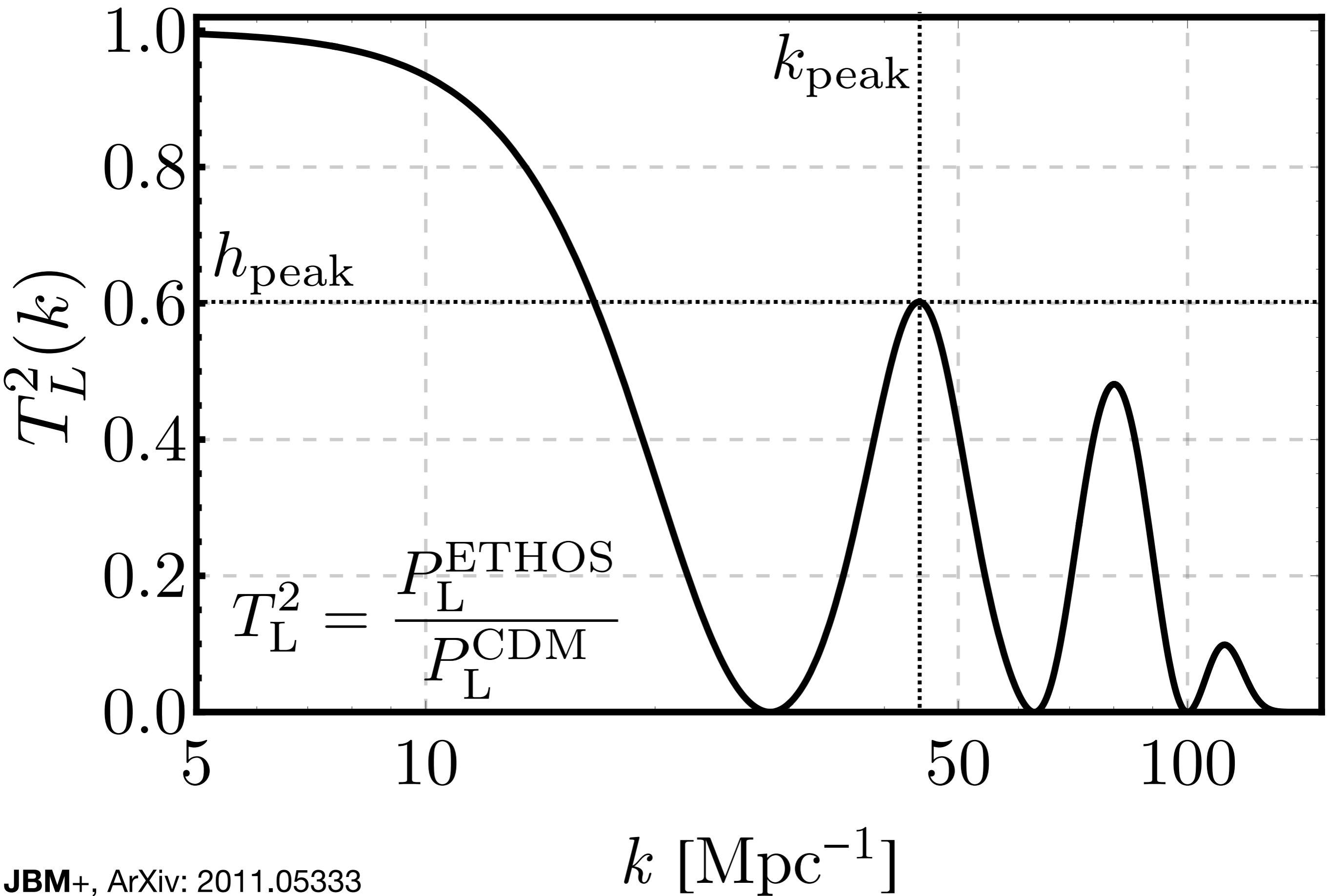


DM-DR:
Power Spectrum

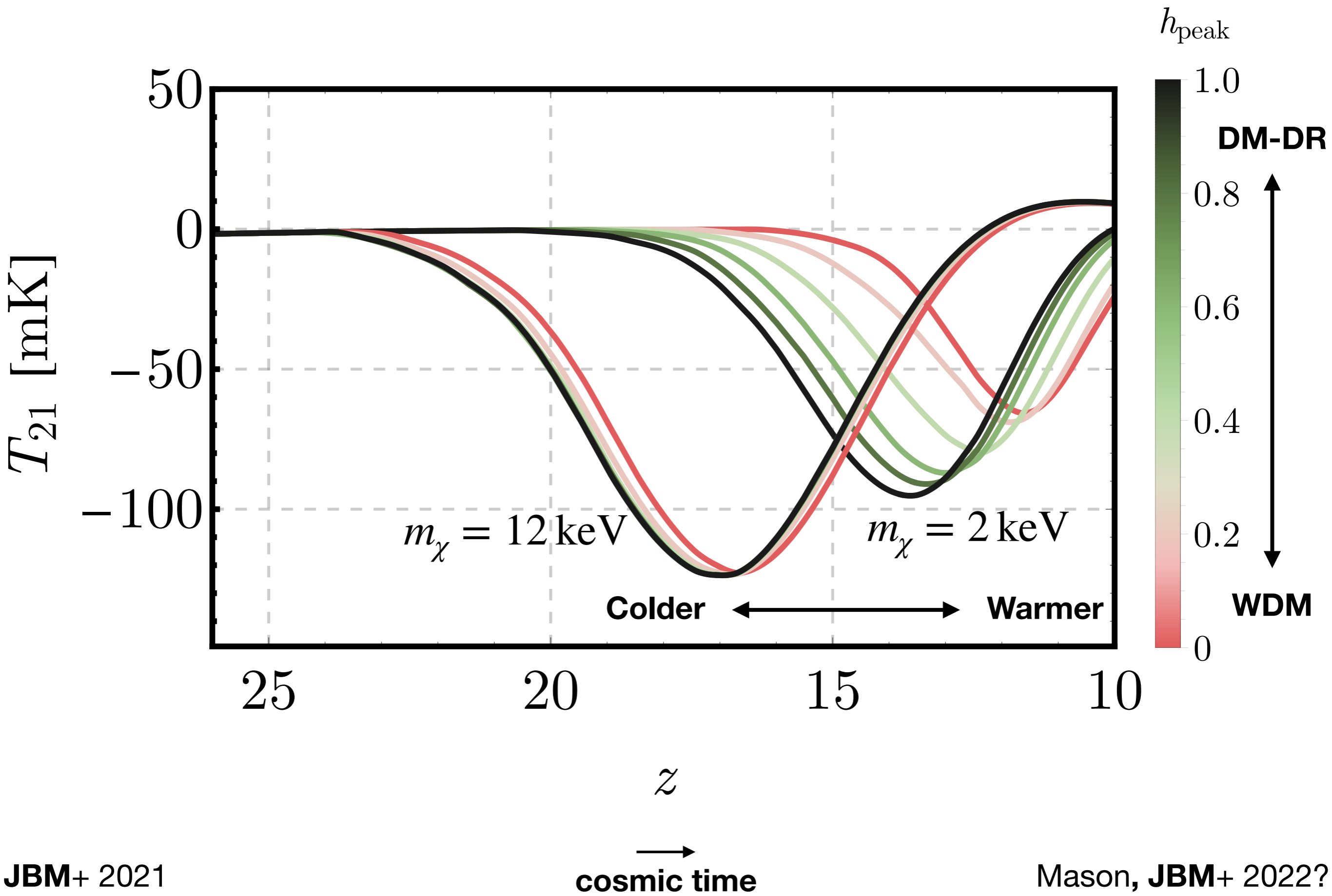
Vogelsberger+ 2016, Cyr-Racine+2016, **JBM+** 2021



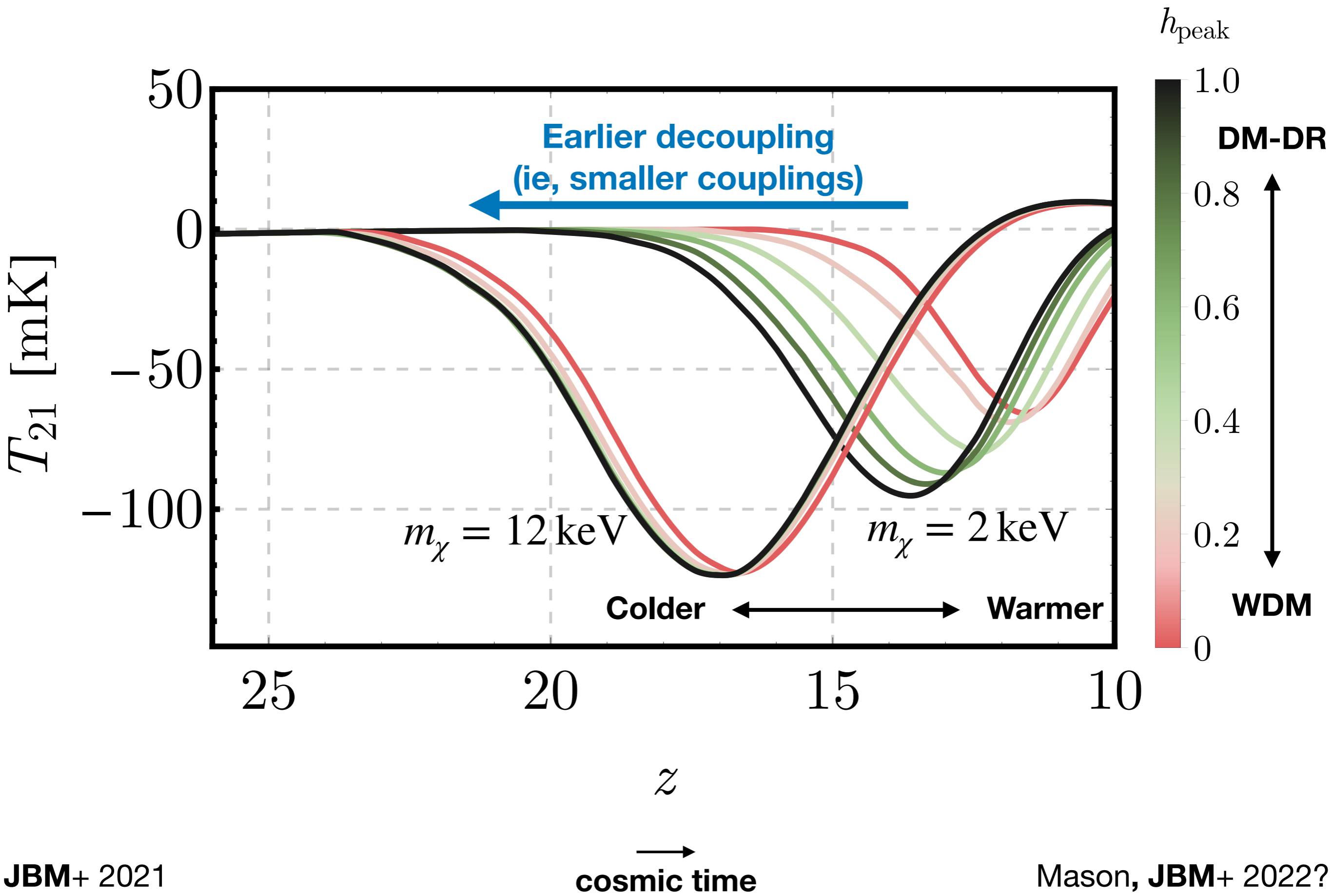
A two-parameter model



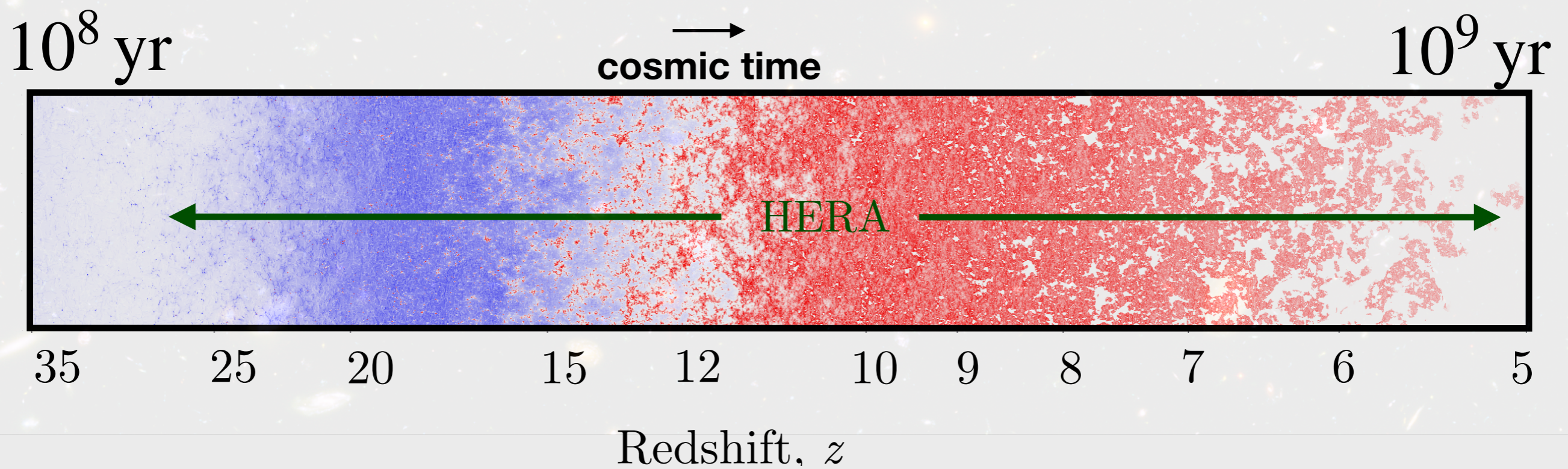
The 21-cm global signal in ETHOS



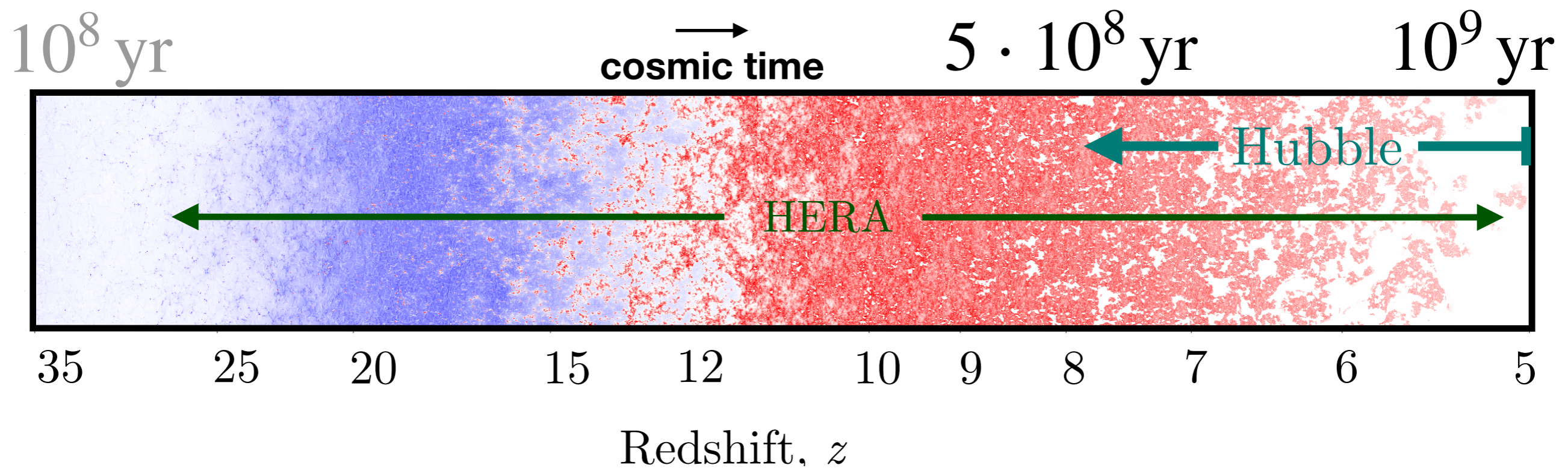
The 21-cm global signal in ETHOS



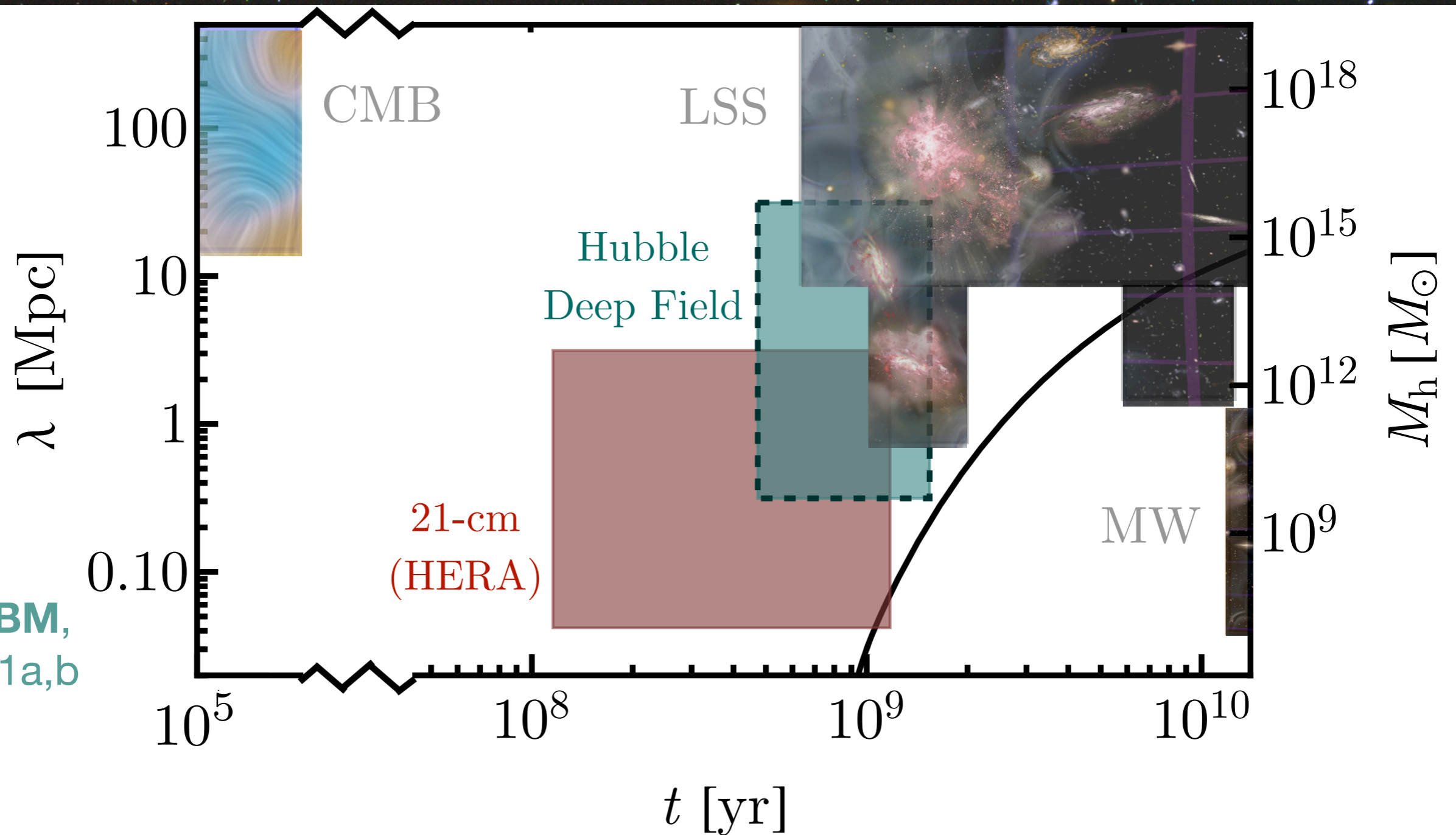
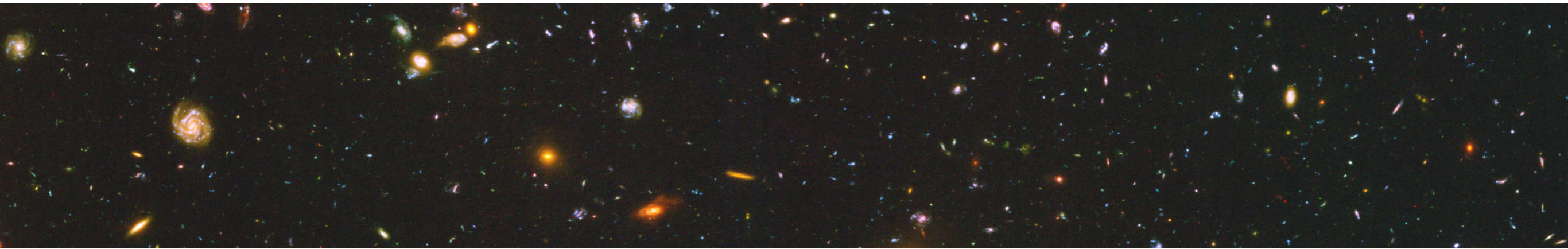
What can we say now?



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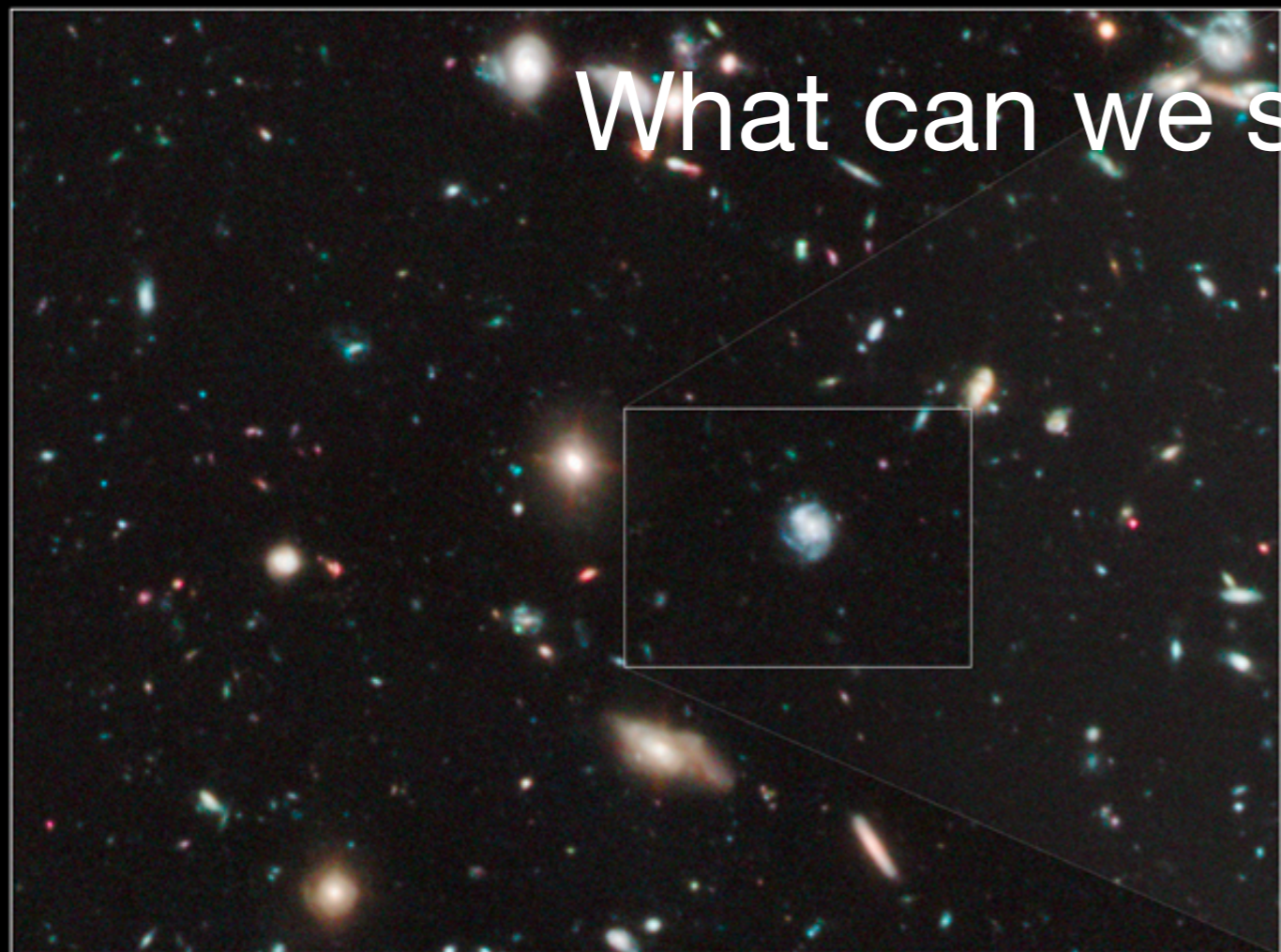
What can we say now?



Sabti*, JBM,
Blas 2021a,b



What can we say in ~a year?

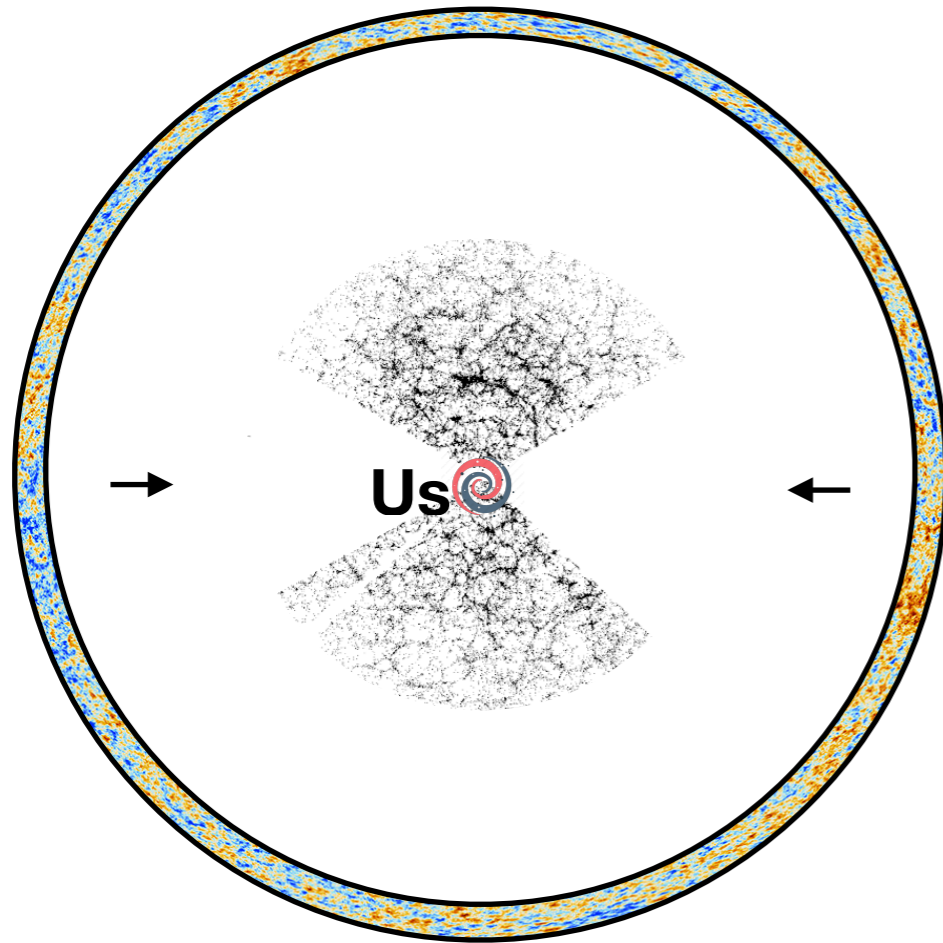


HST



JWST

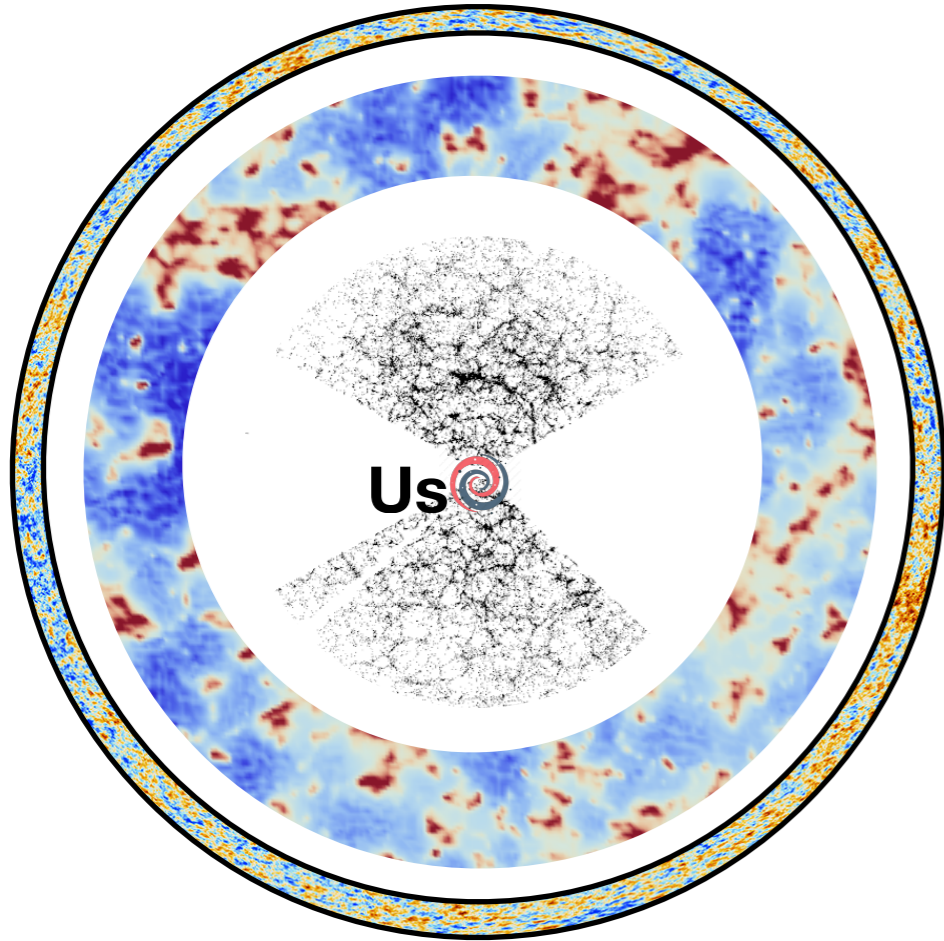
Summary



-We have not observed most of the Universe (yet)

Summary

Data: SDSS/Planck

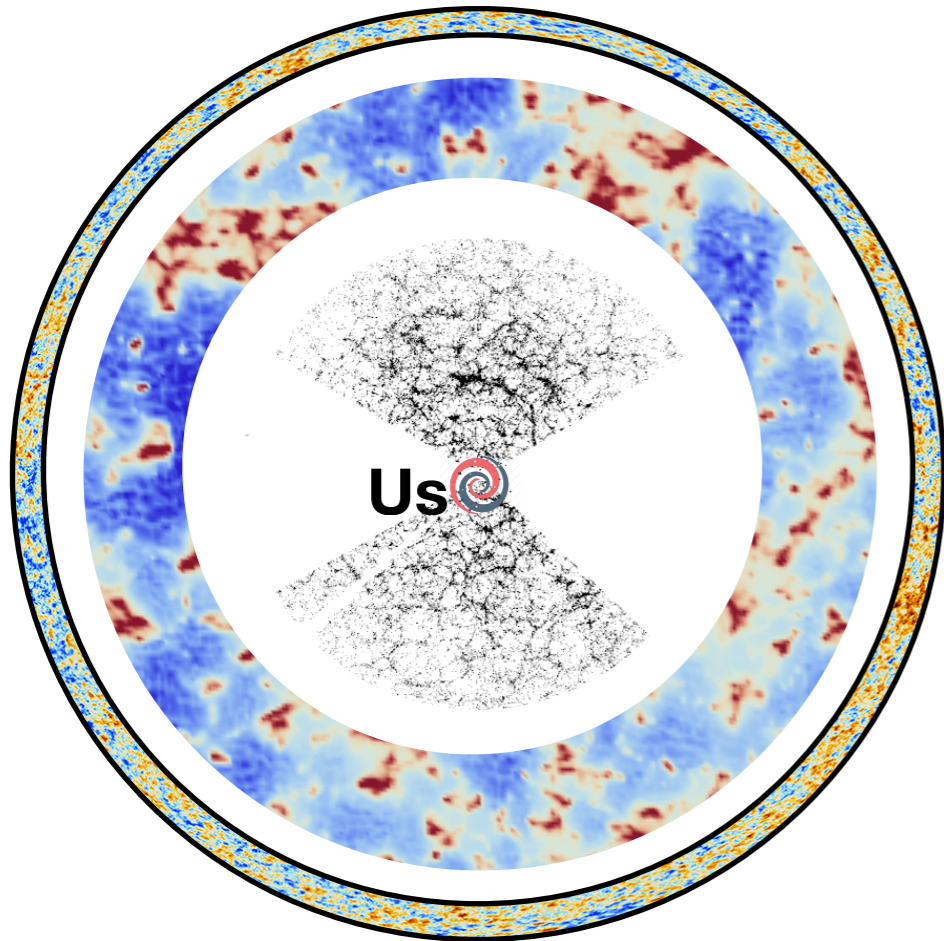


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Data: SDSS/Planck



-We have not observed most of the Universe (yet)

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-New lamppost for Dark Matter!

