Searching for dark matter signatures in the 21cm signal

Jordan Flitter, Ben-Gurion University of the Negev

with Ely Kovetz

Ben-Gurion University, September 2024

Why do we need 21cm?

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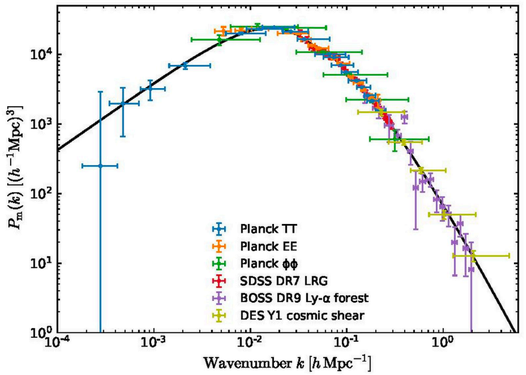
Galaxy surveys



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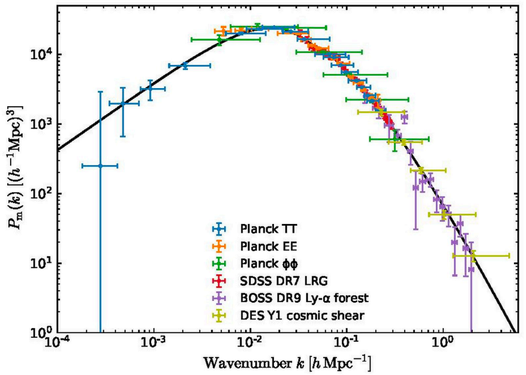
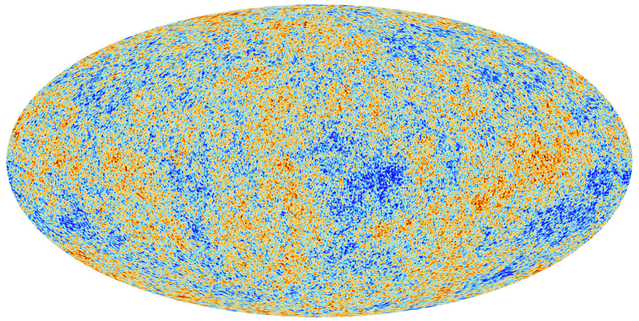
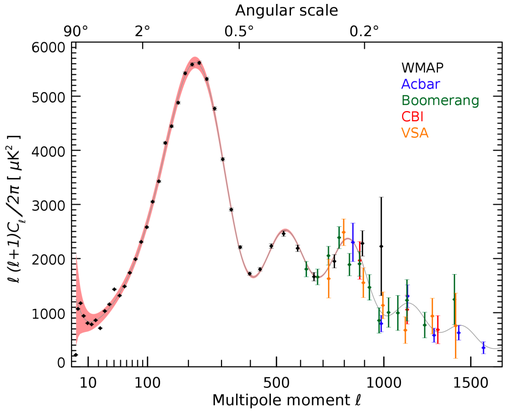


CMB





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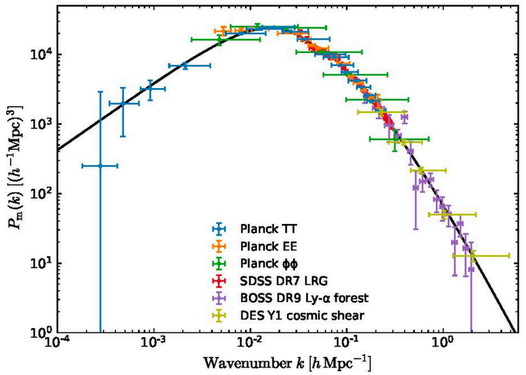

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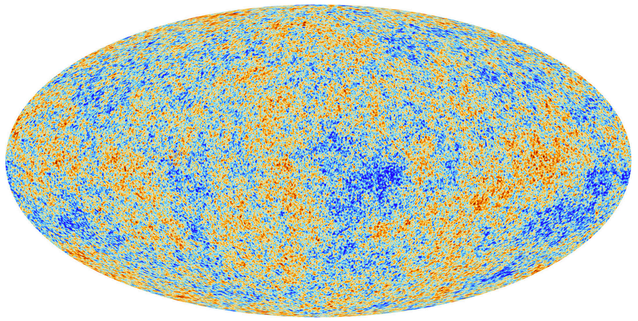

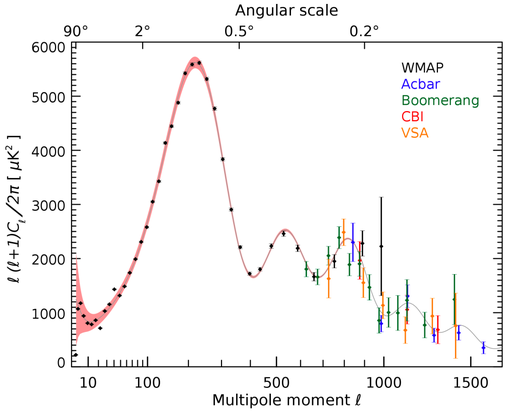

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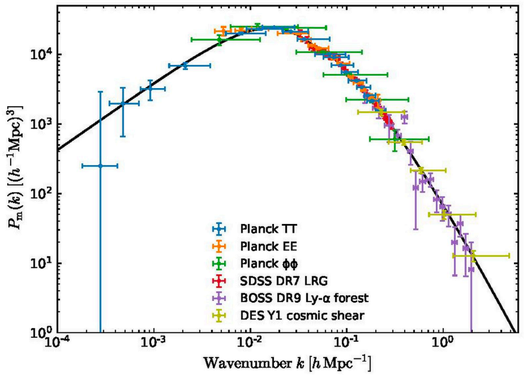

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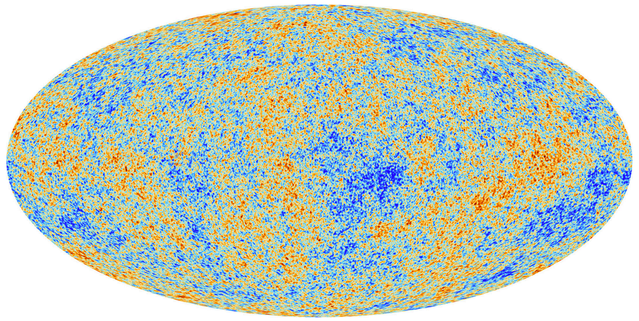
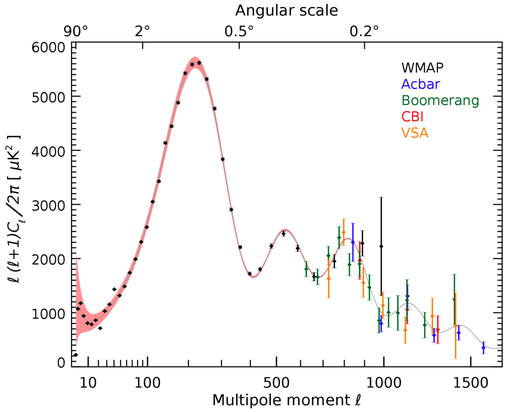
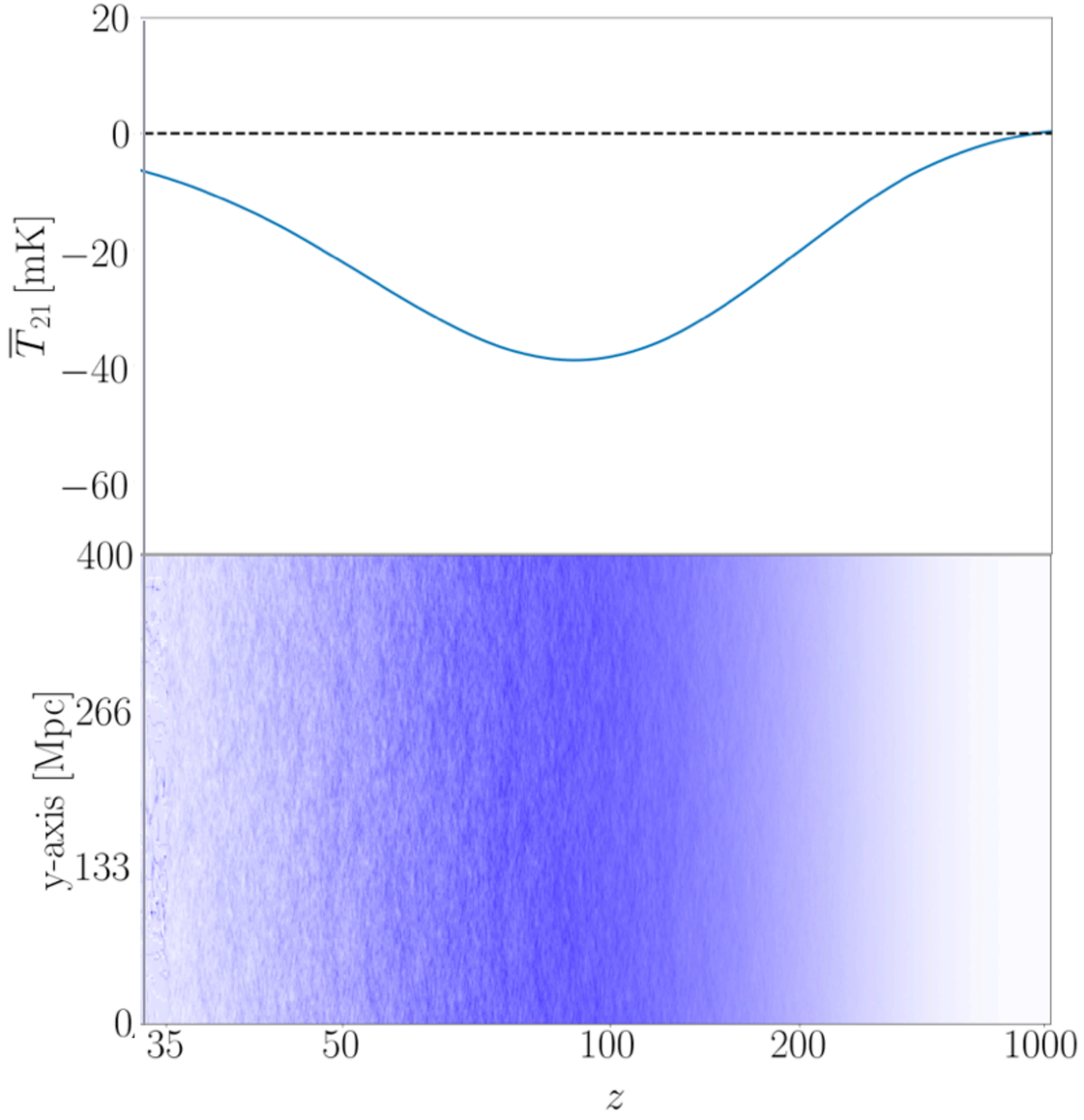
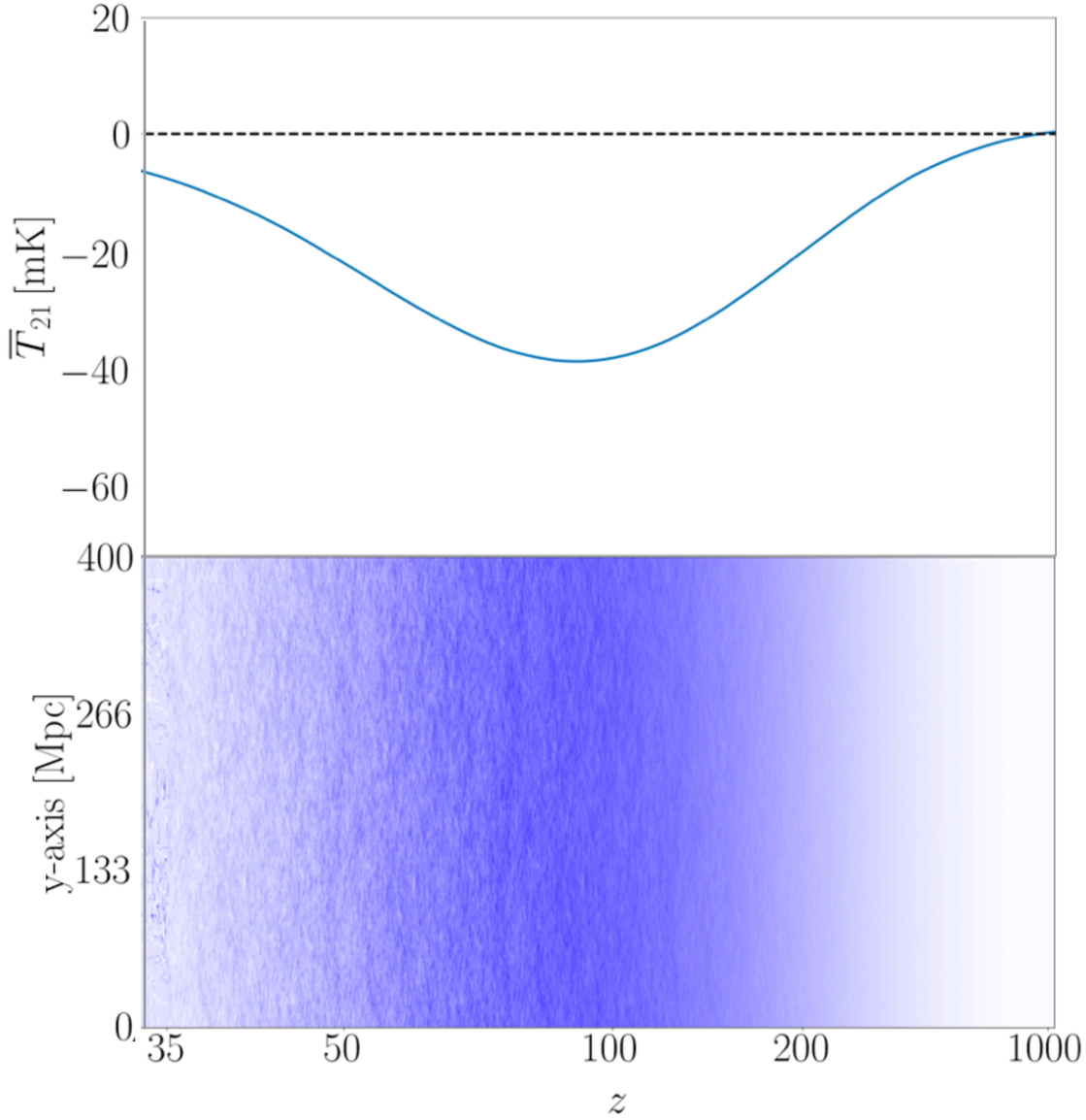
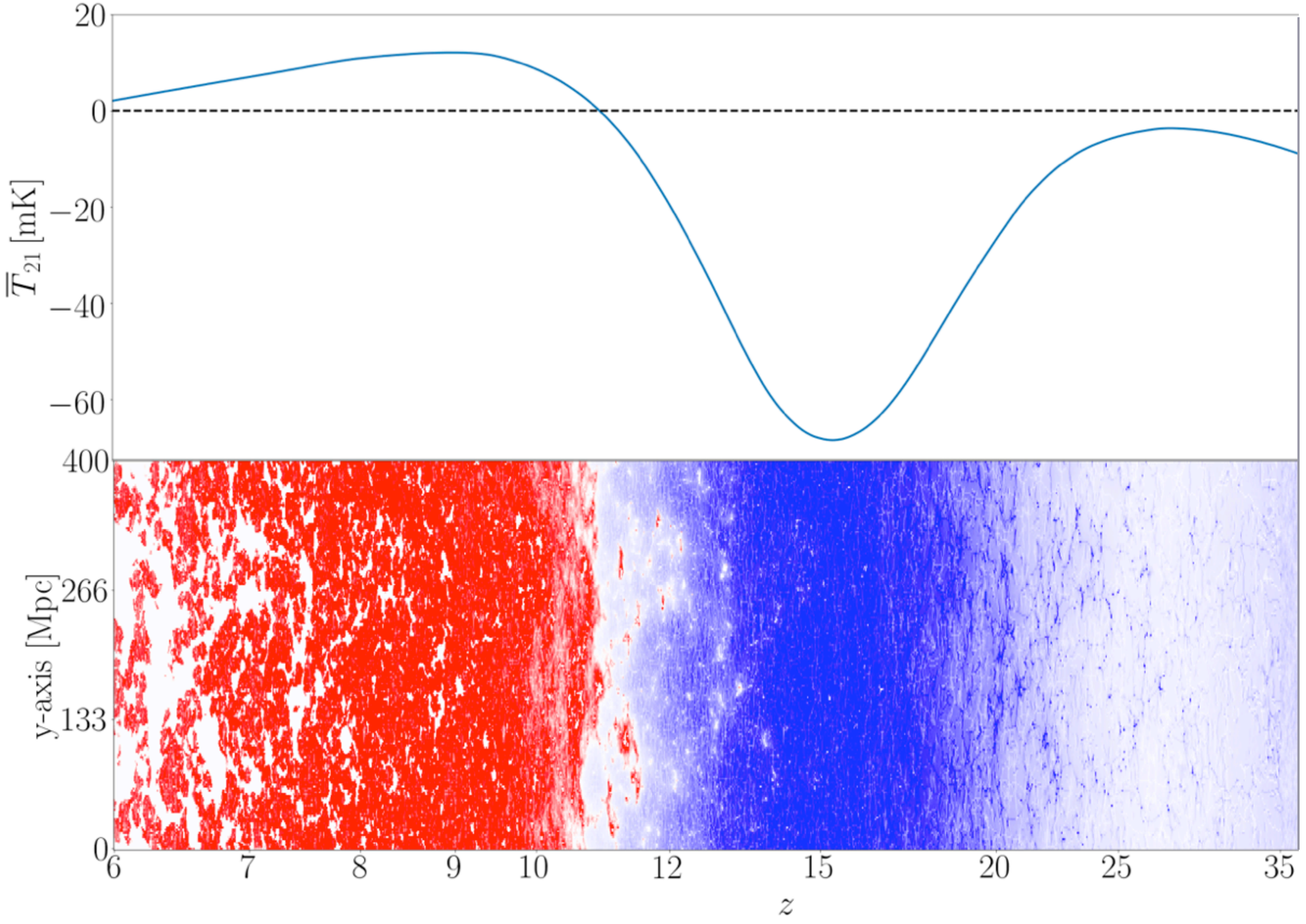





20
0
−20
−40
−60
$\overline{T}_{21}$ [mK]
400
266
133
0
y-axis [Mpc]
35
50
100
200
1000
z



Linear perturbation theory


20
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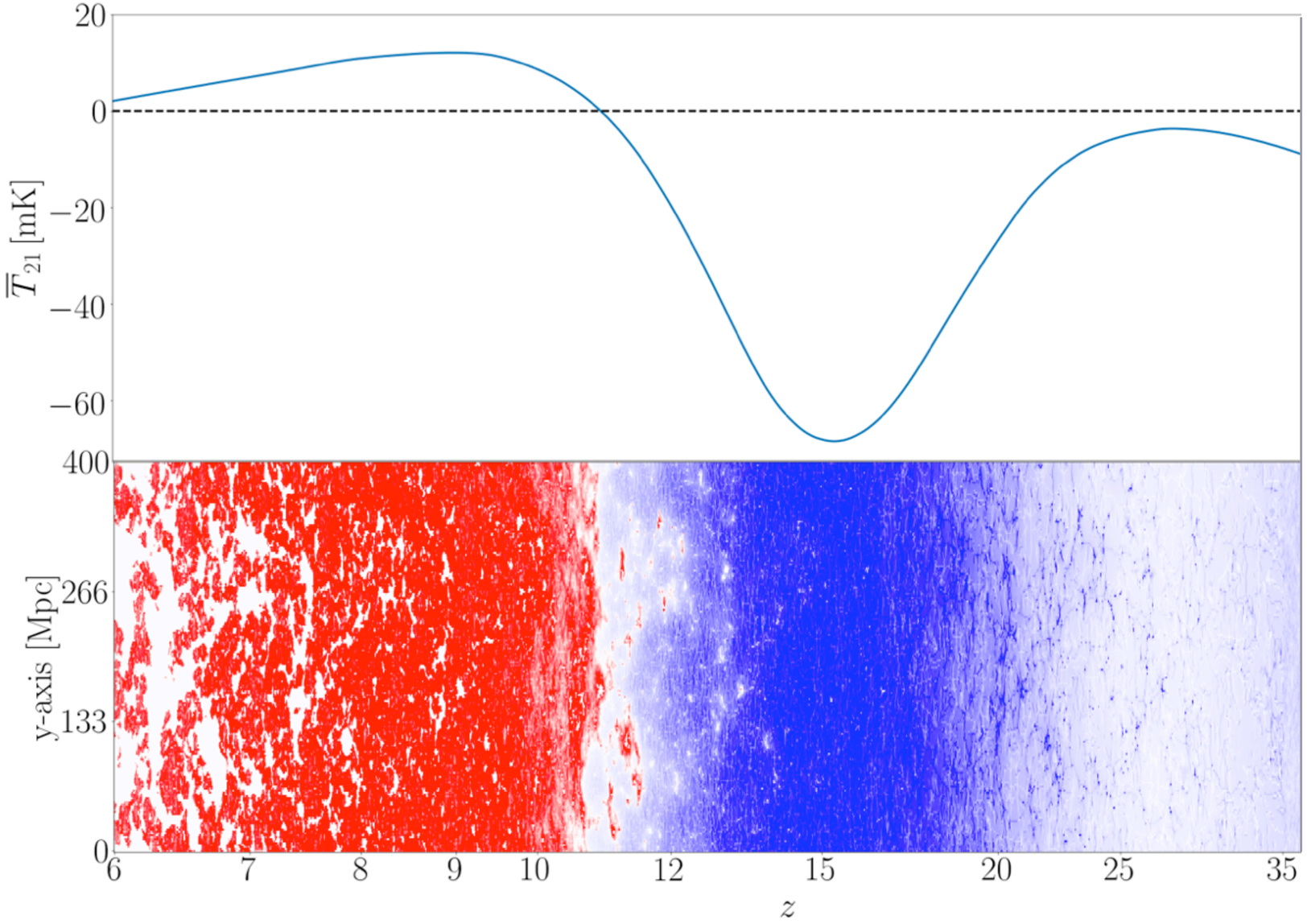
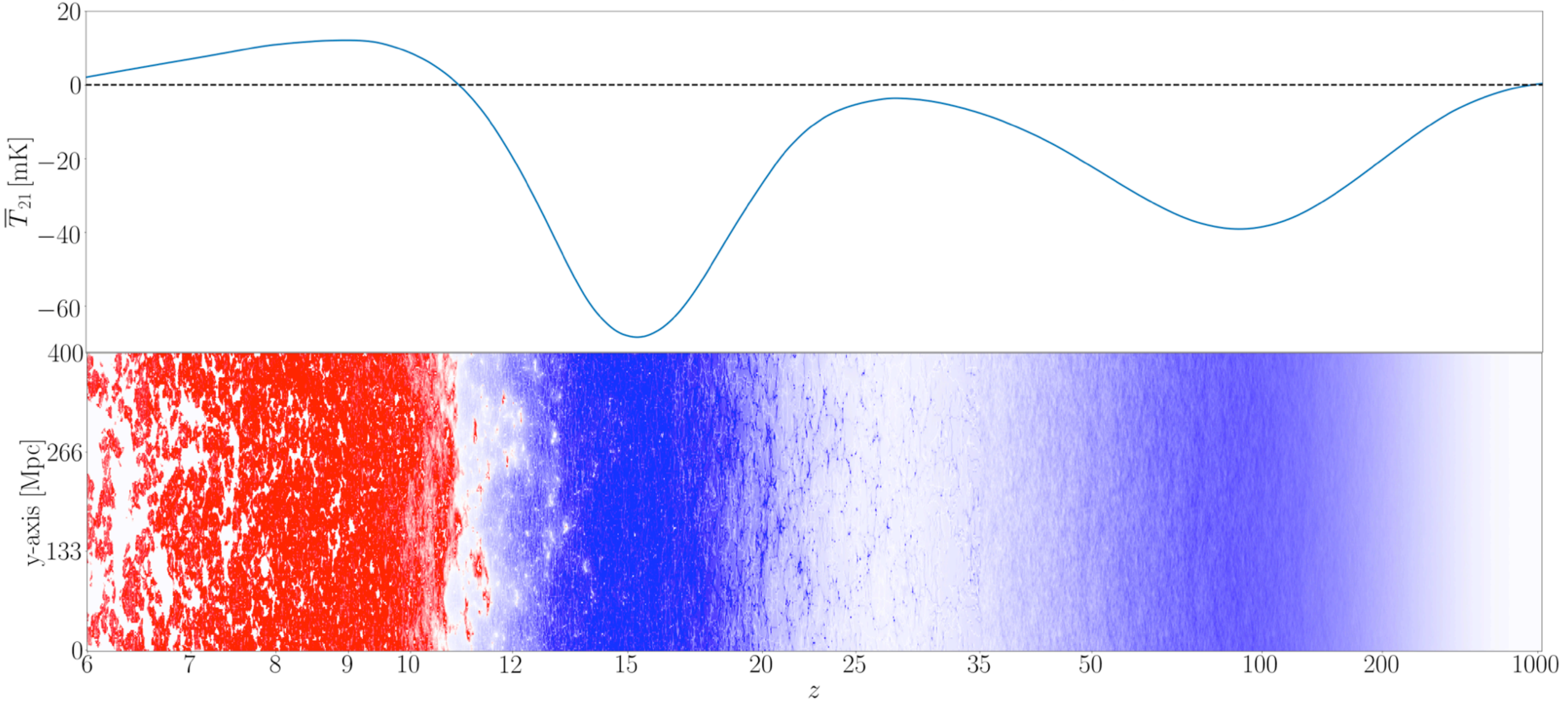


21cmFAST: A Fast, Semi-Numerical Simulation of the High-Redshift 21-cm Signal

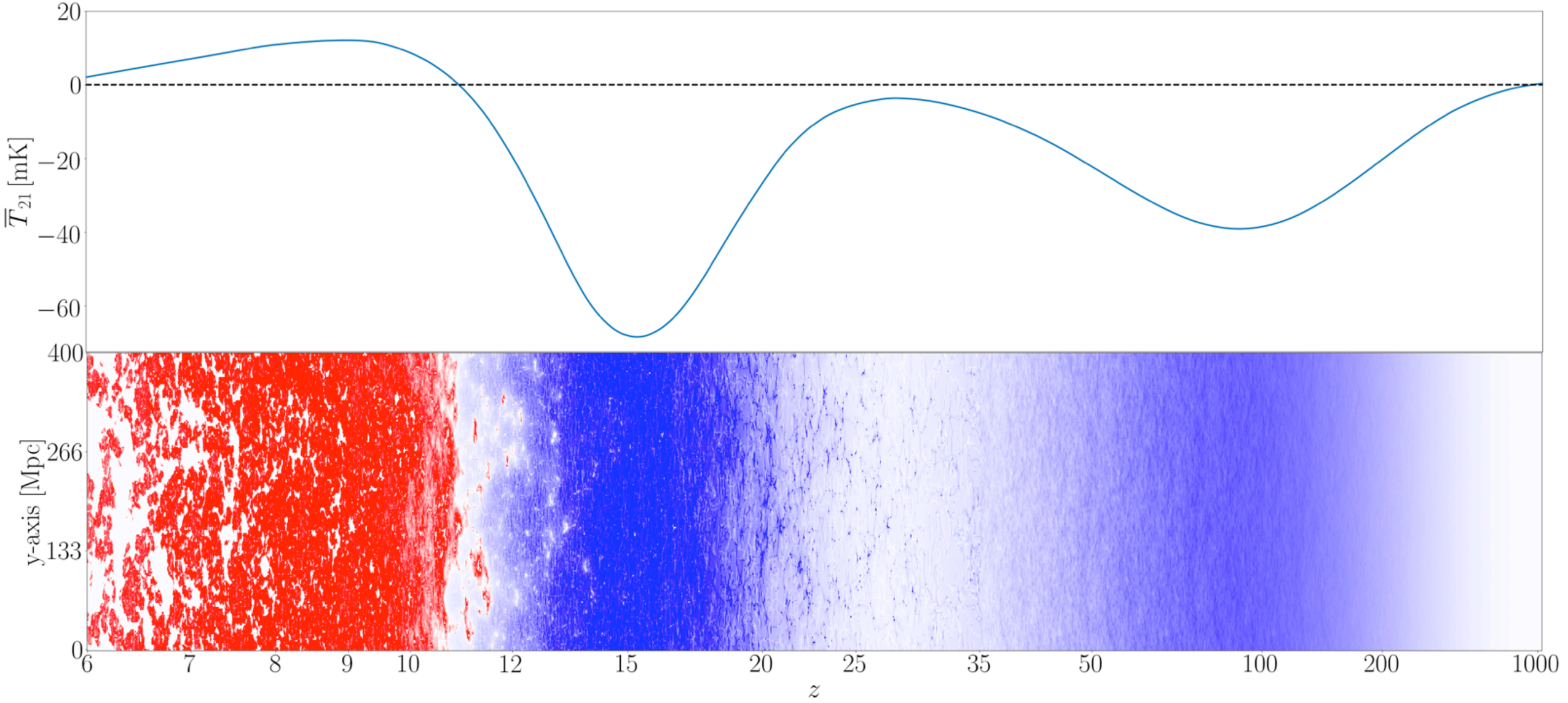
Andrei Mesinger[1⋆], Steven Furlanetto[2], & Renyue Cen[1]
[1]*Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, USA*
[2]*Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA*

Semi-numerical codes

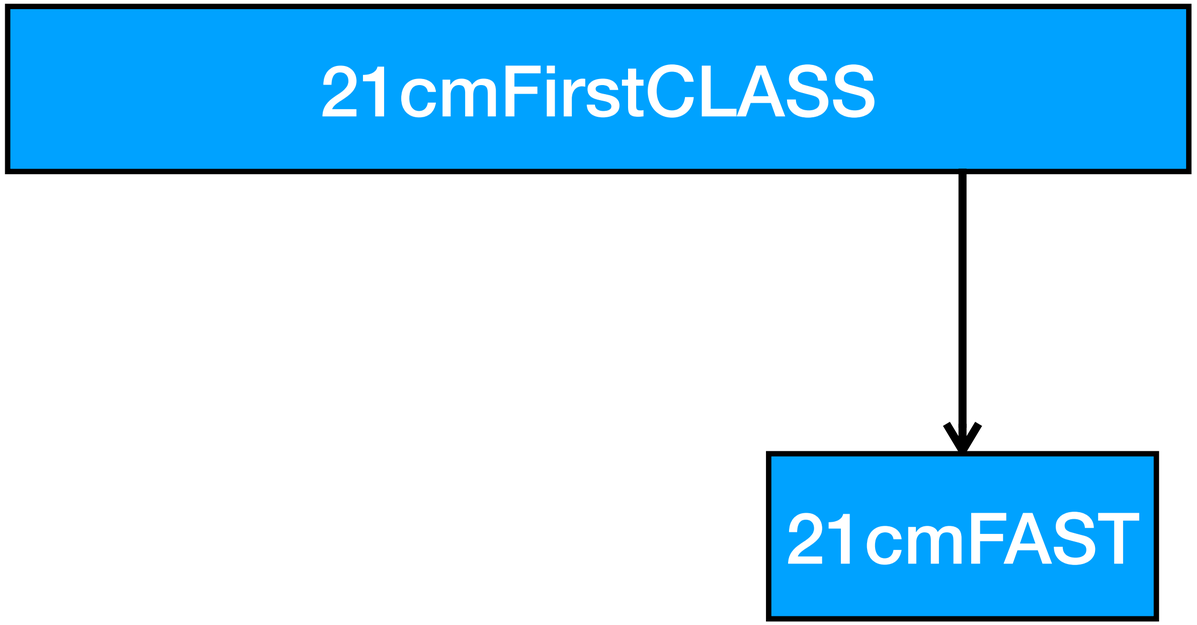
Flitter & Kovetz, *PRD,* 109, 043512 (2023)



Flitter & Kovetz, *PRD,* 109, 043512 (2023)

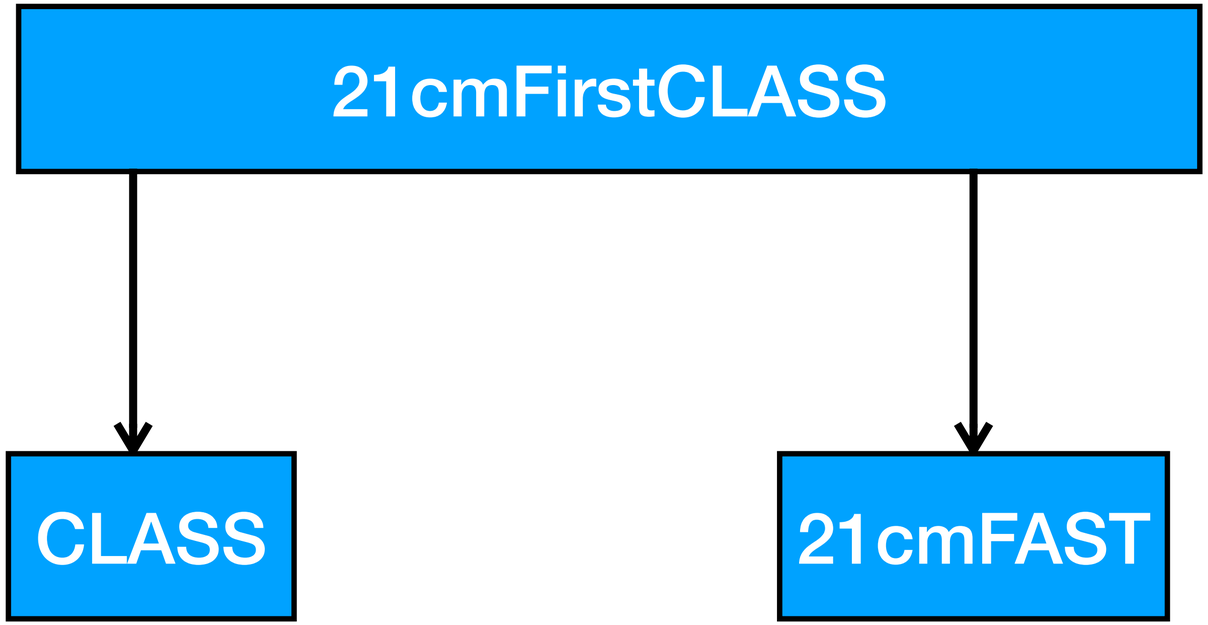


21cmFirstCLASS


21cmFirstCLASS
21cmFAST

The Cosmic Linear Anisotropy Solving System (CLASS) I: Overview

Julien Lesgourgues[a,b,c]



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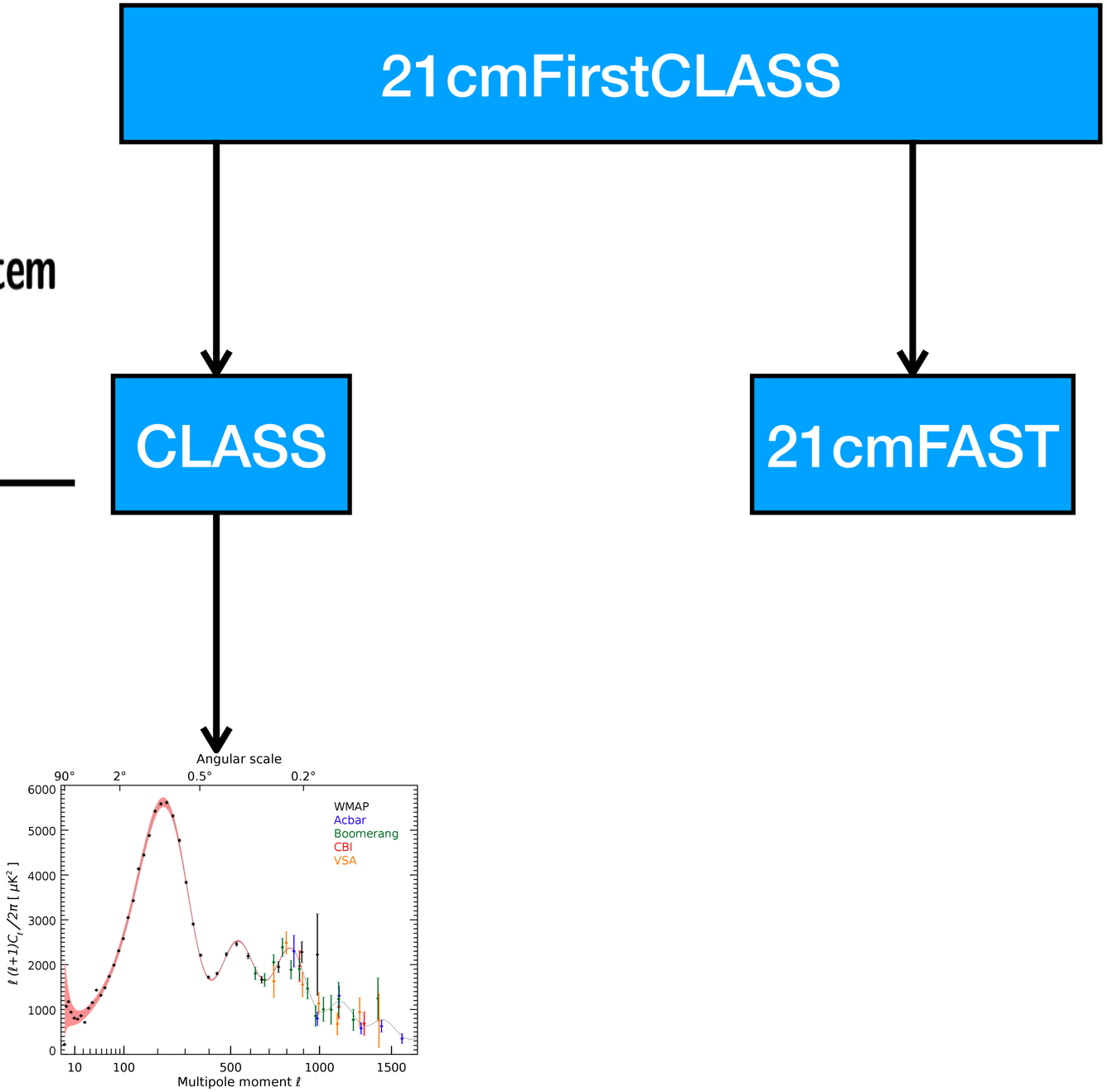
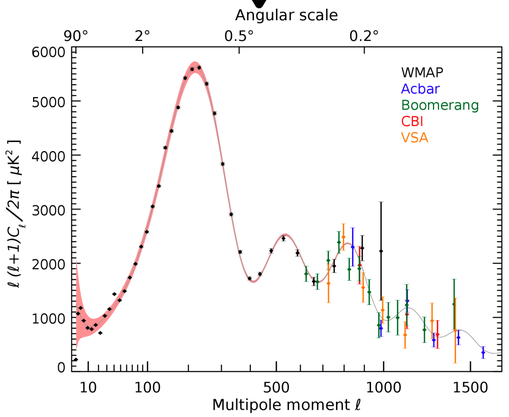


21cmFirstCLASS

CLASS

Initial Conditions

21cmFAST

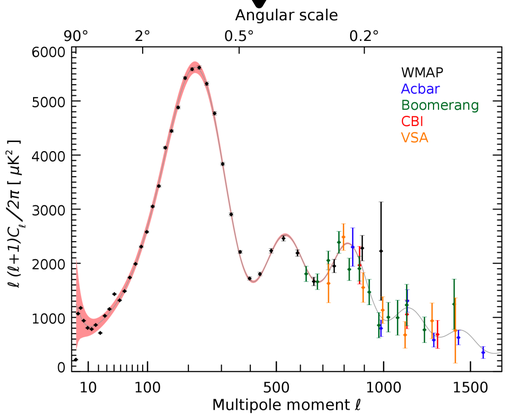


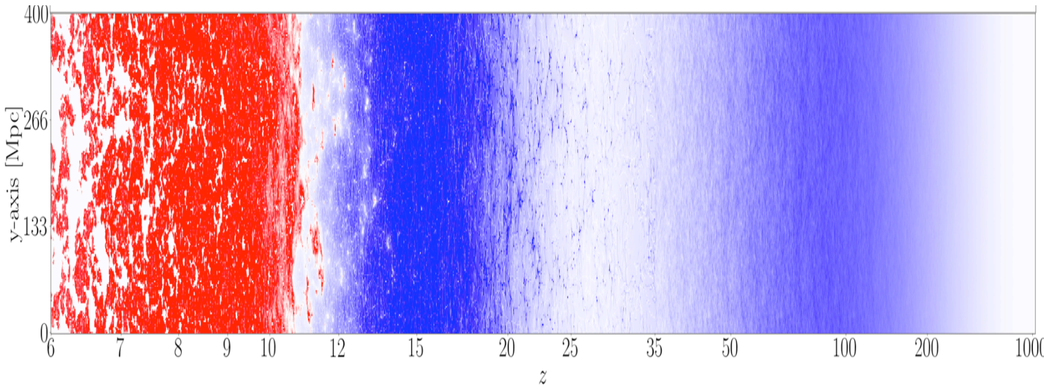
21cmFirstCLASS

CLASS

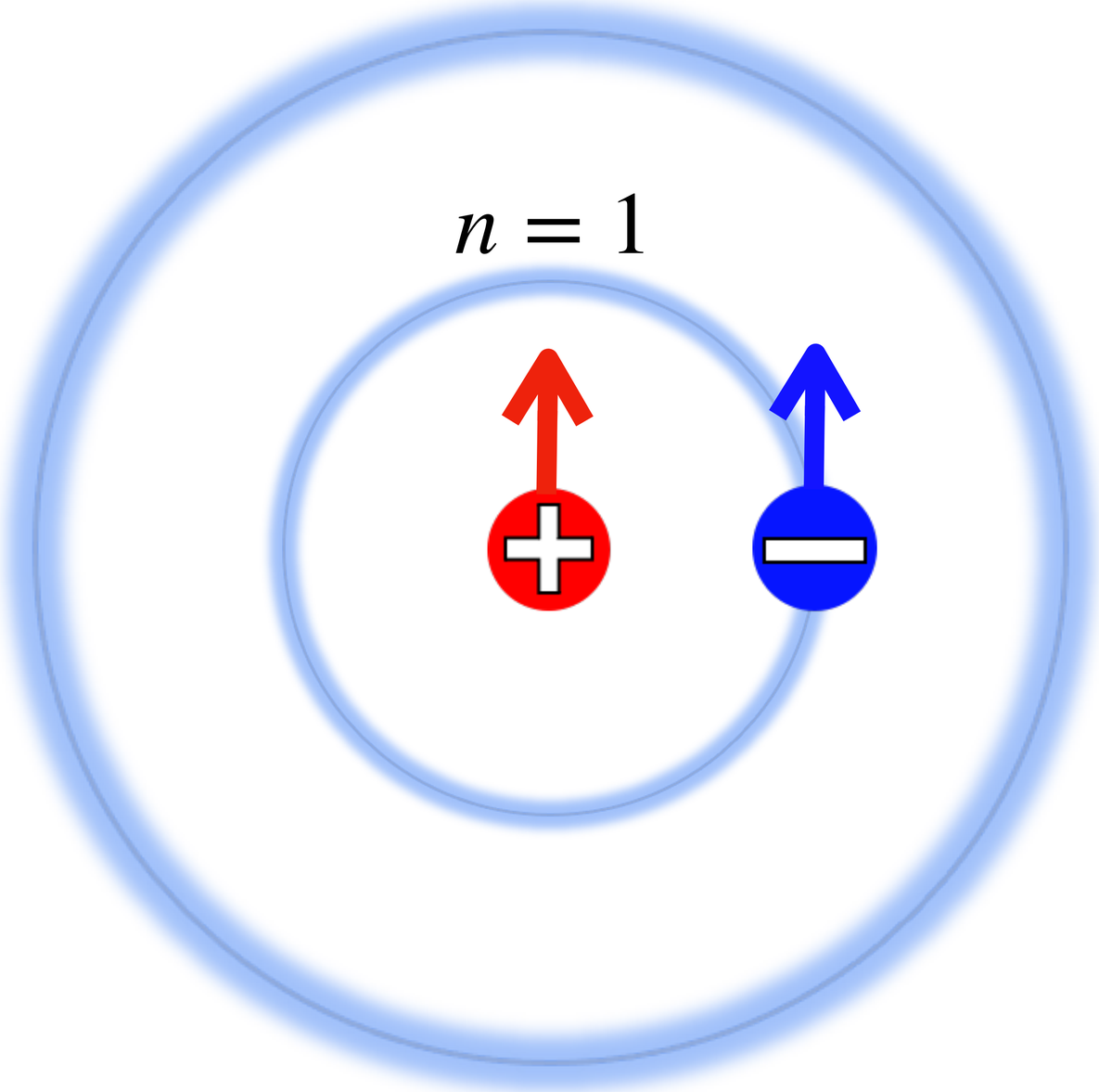
Initial Conditions

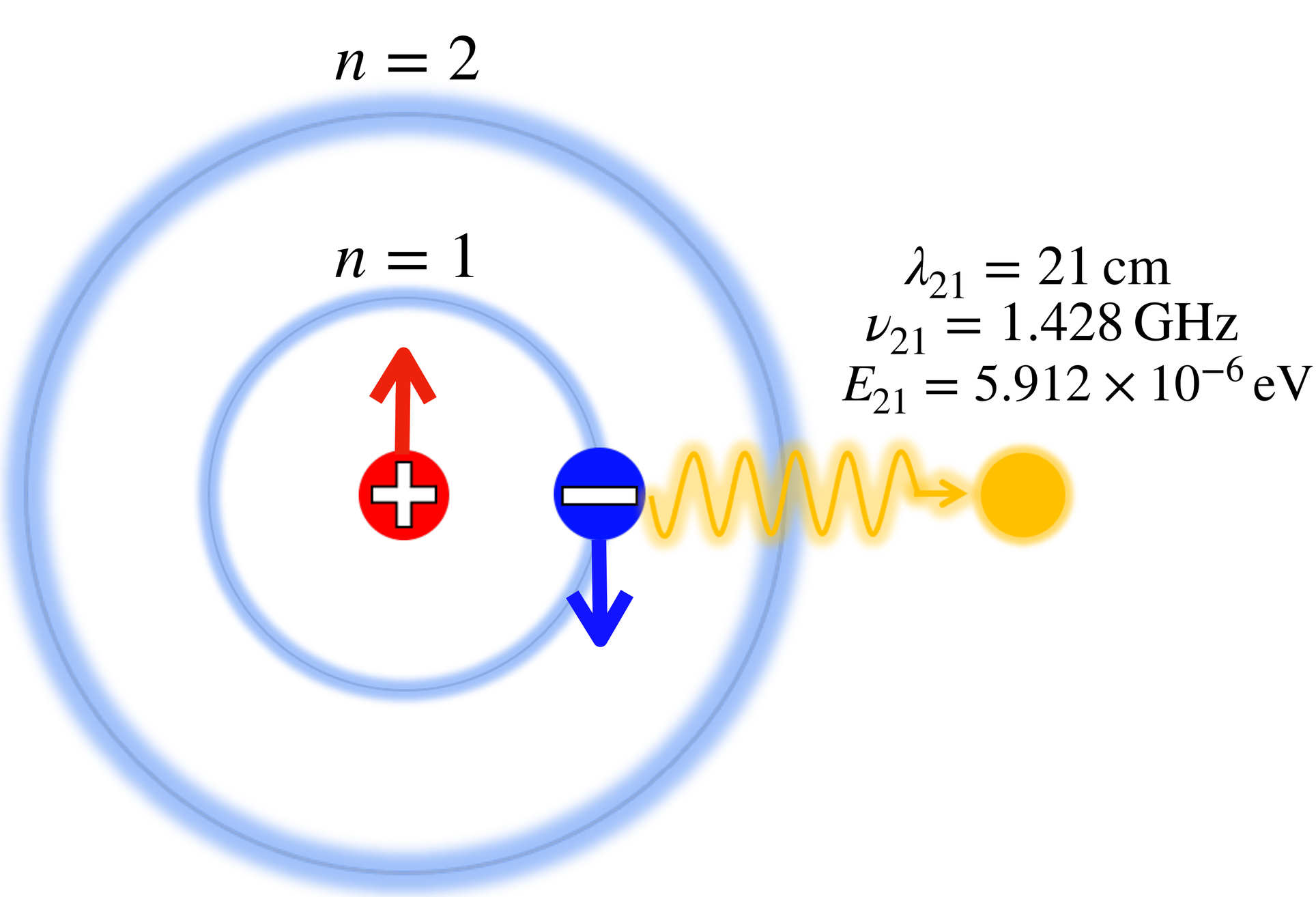
21cmFAST



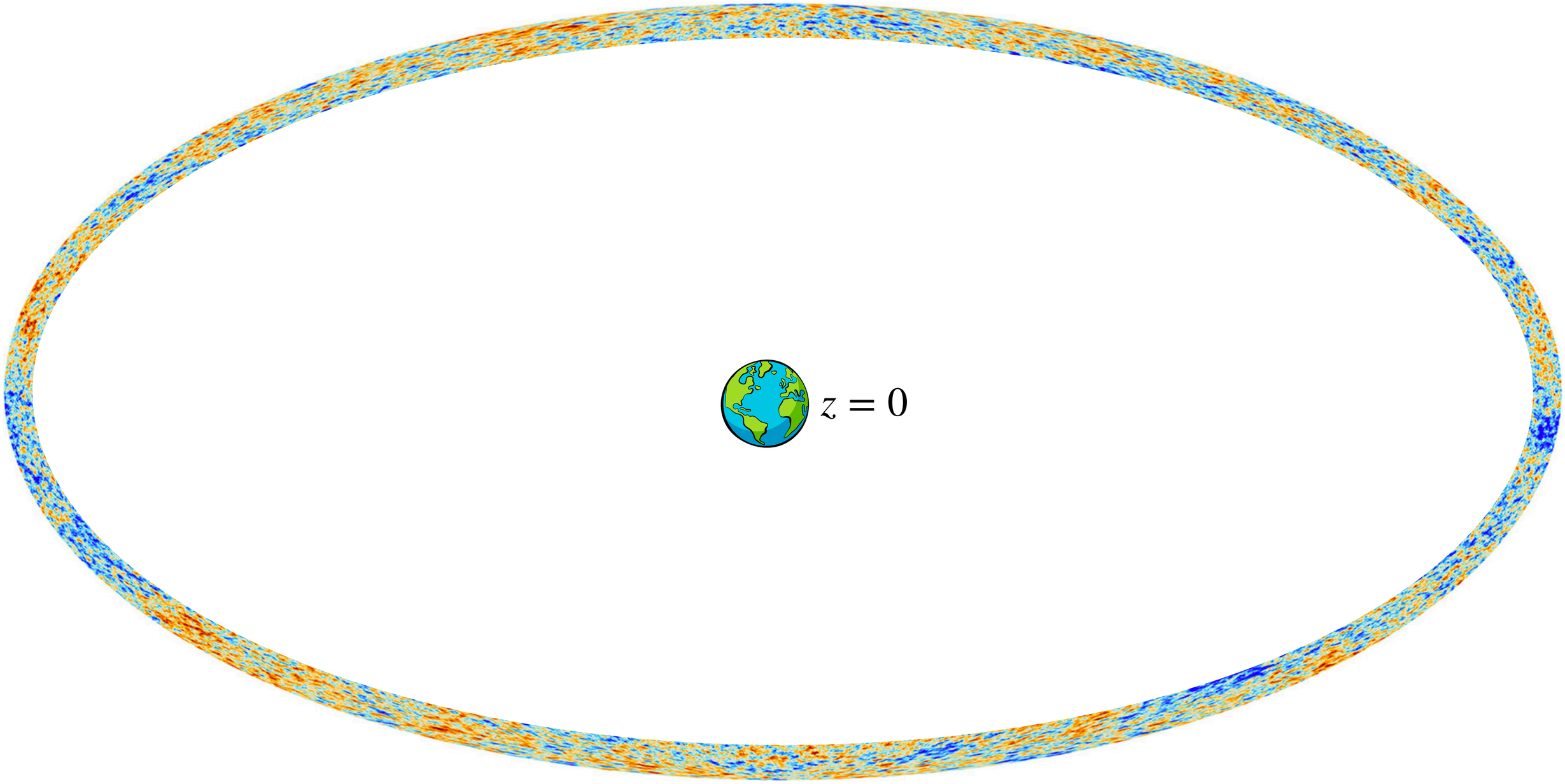


The 21cm signal

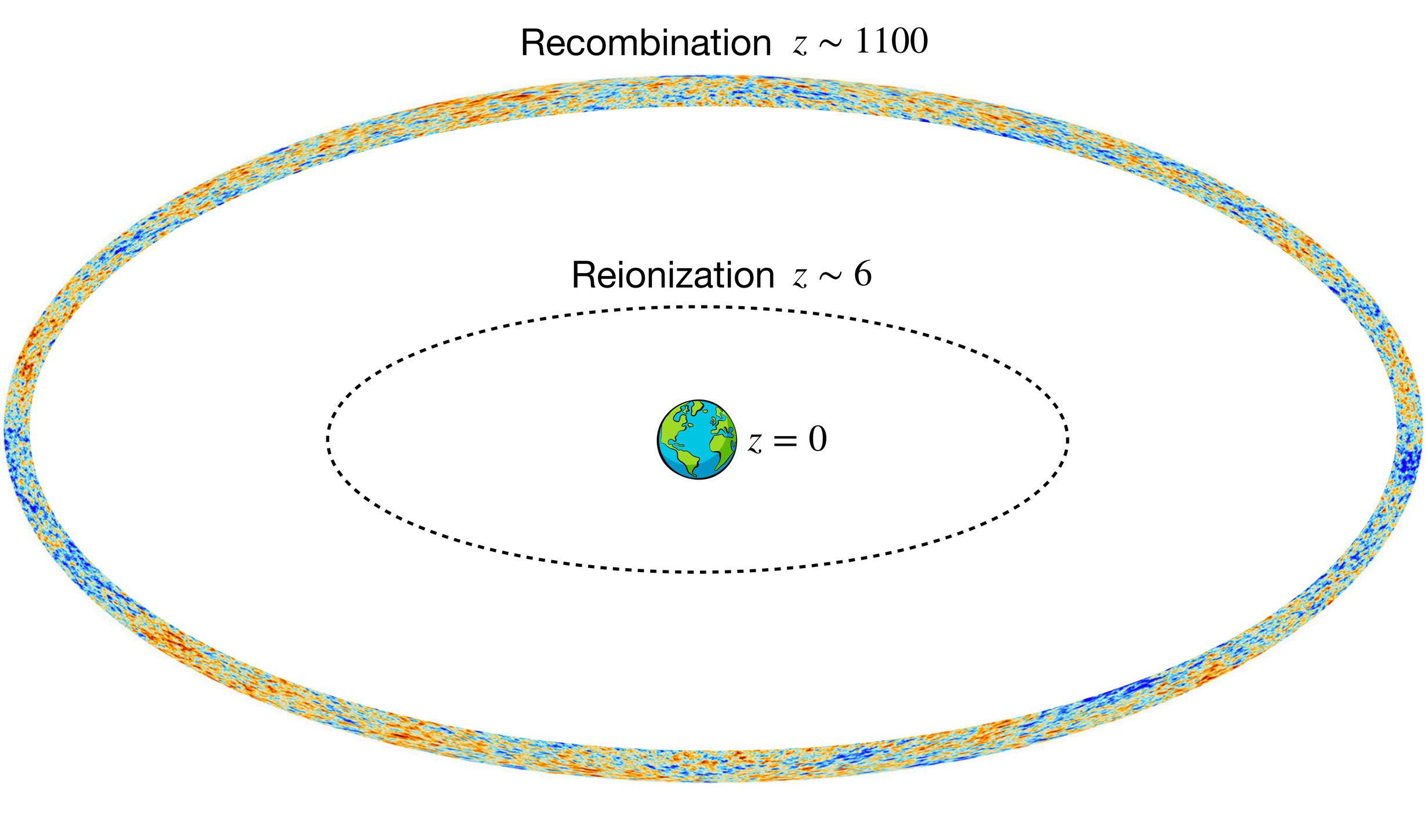

$n = 2$
$n = 1$

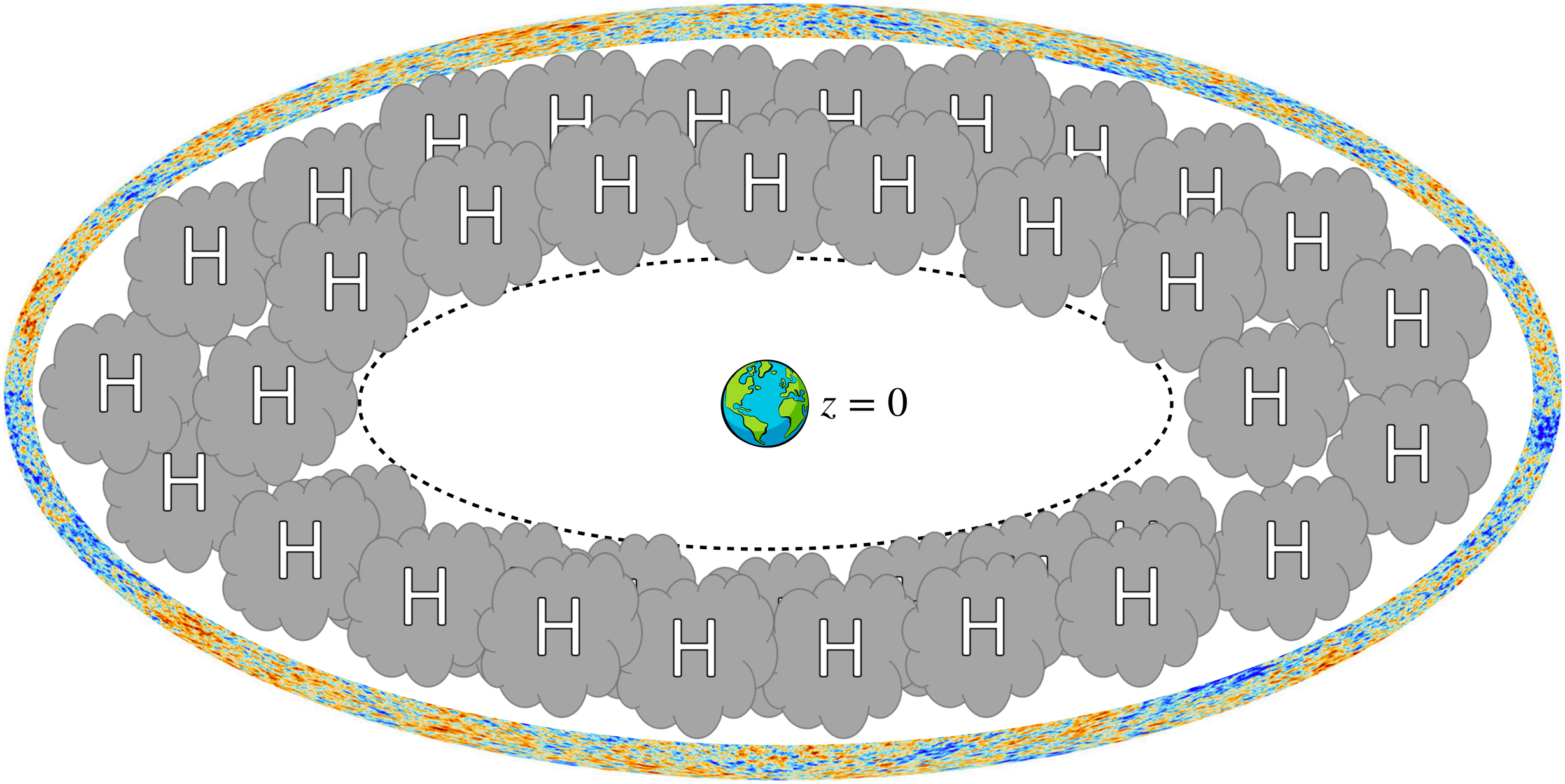

$n = 2$
$n = 1$
$\lambda_{21} = 21\,\mathrm{cm}$
$\nu_{21} = 1.428\,\mathrm{GHz}$
$E_{21} = 5.912 \times 10^{-6}\,\mathrm{eV}$

Recombination $z \sim 1100$

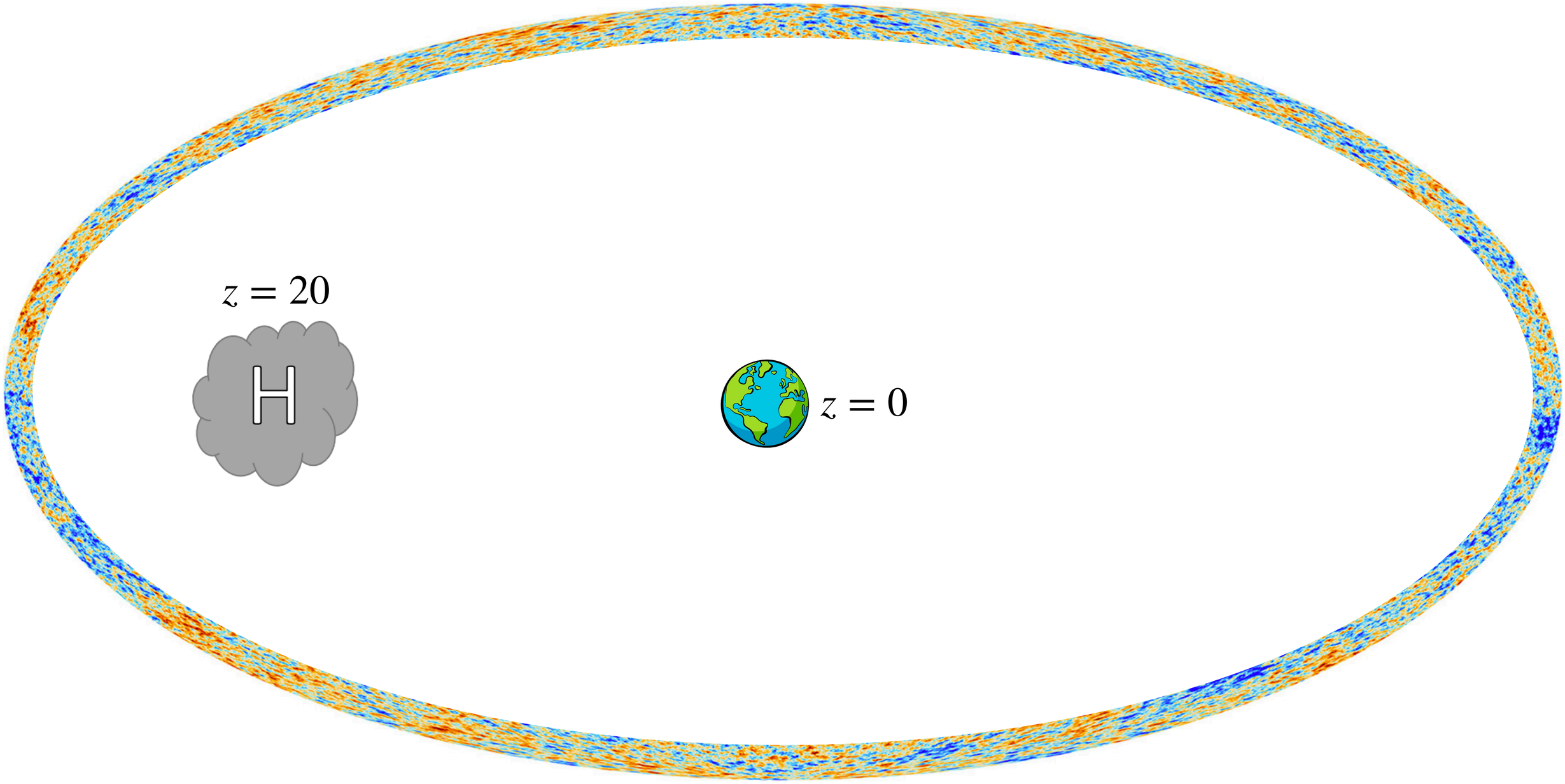


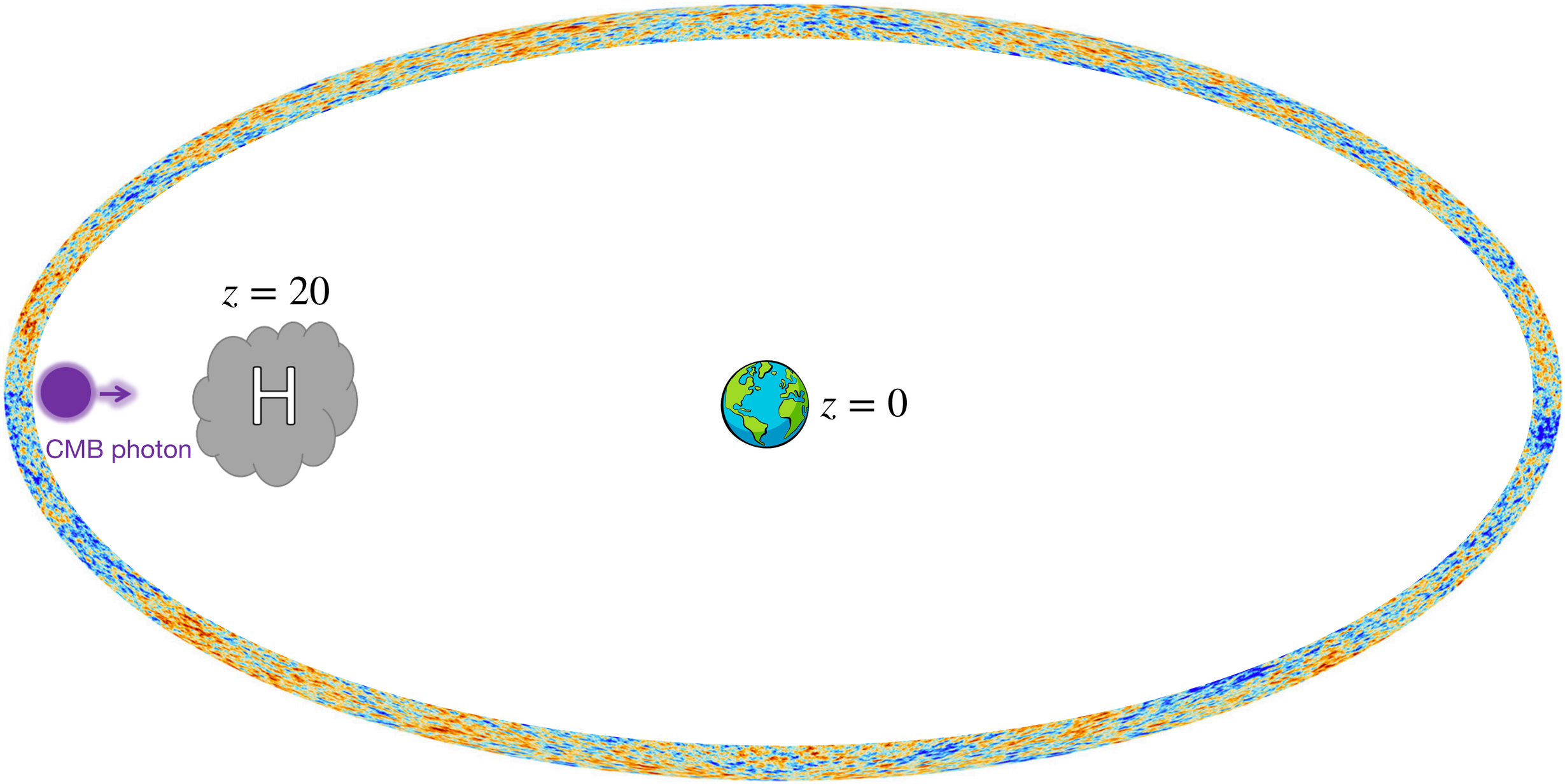
$z = 0$

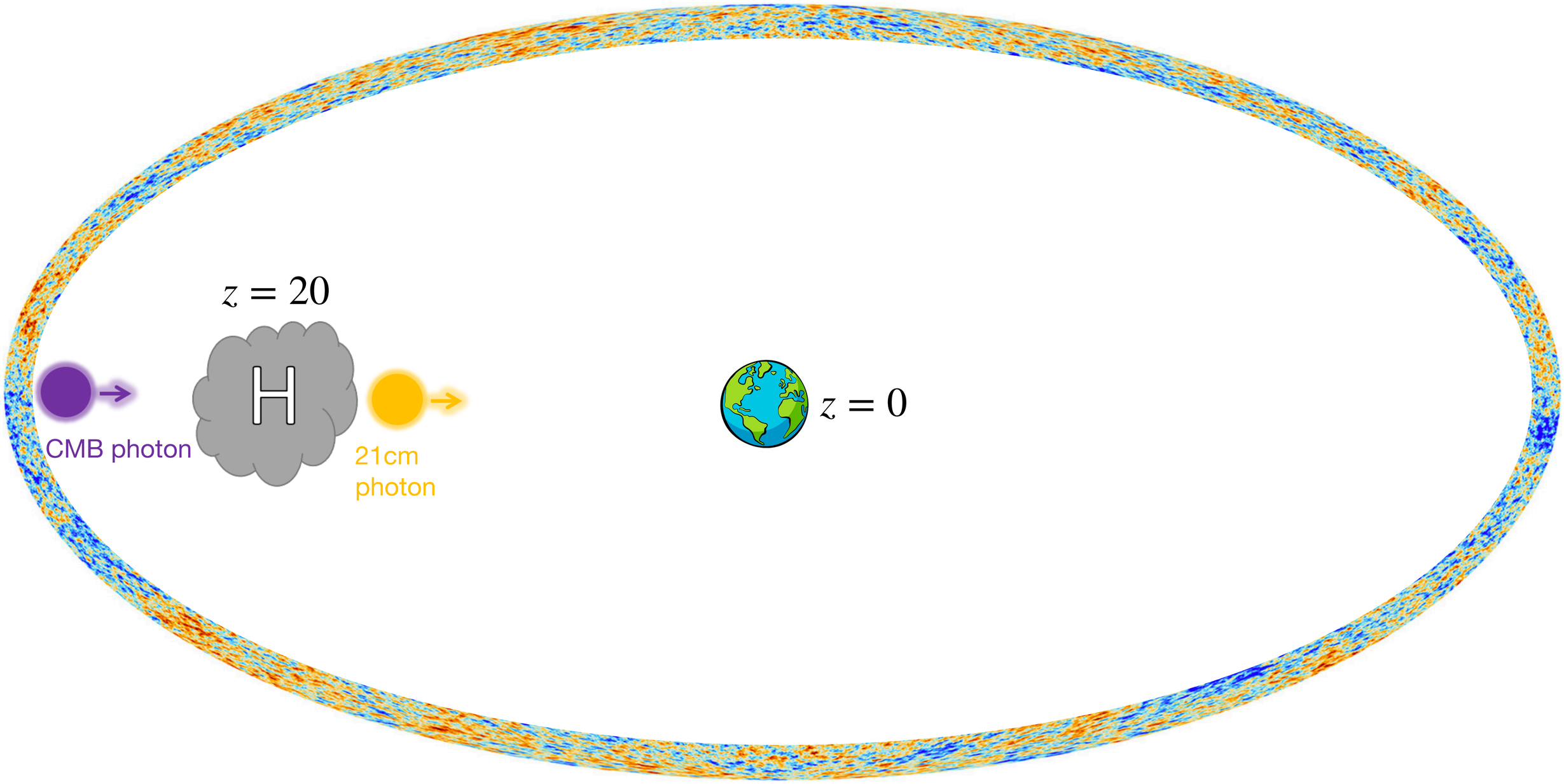

Recombination $z \sim 1100$
Reionization $z \sim 6$
$z = 0$

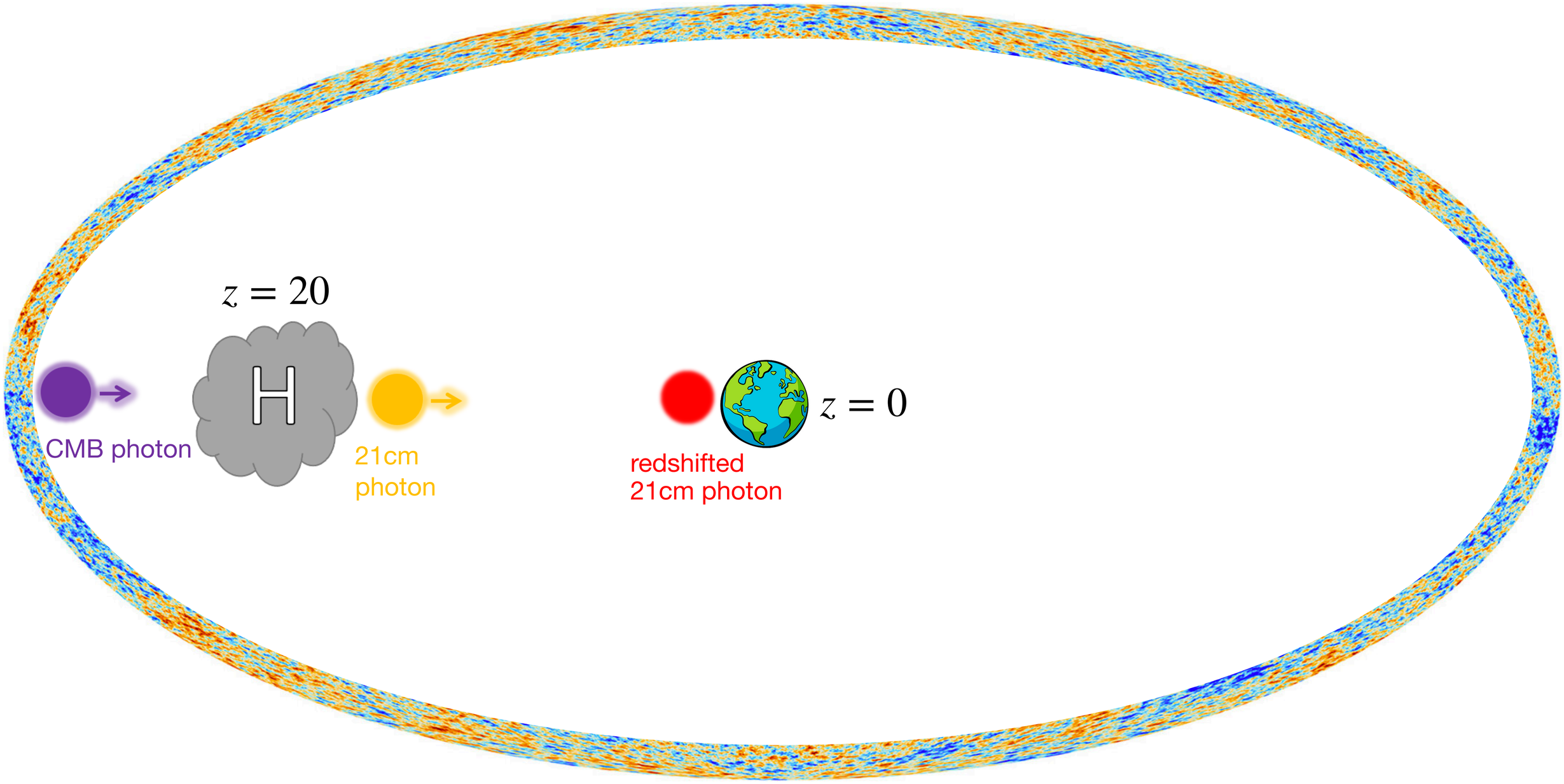

Recombination $z \sim 1100$
H
$z = 0$

Recombination $z \sim 1100$

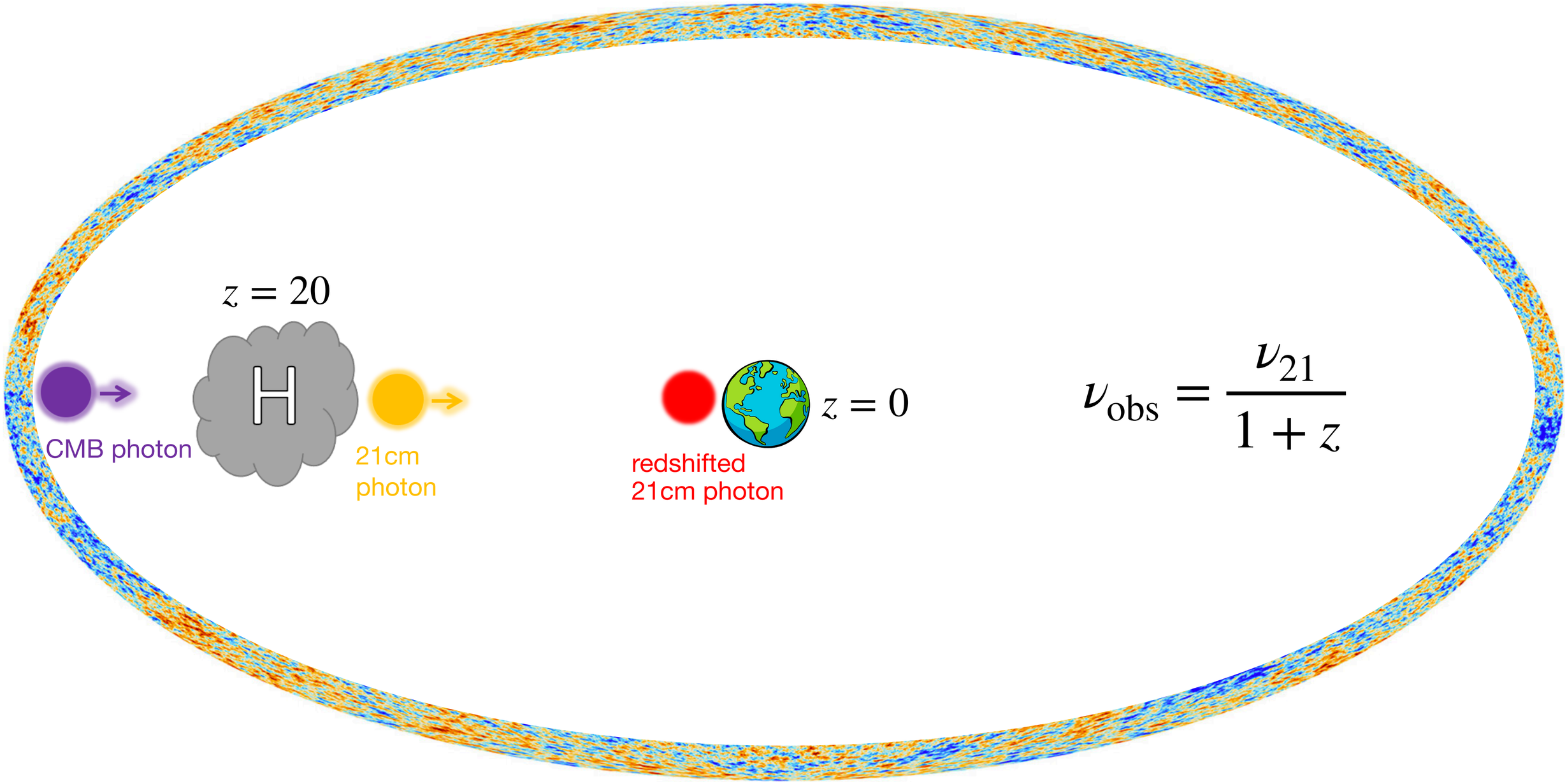


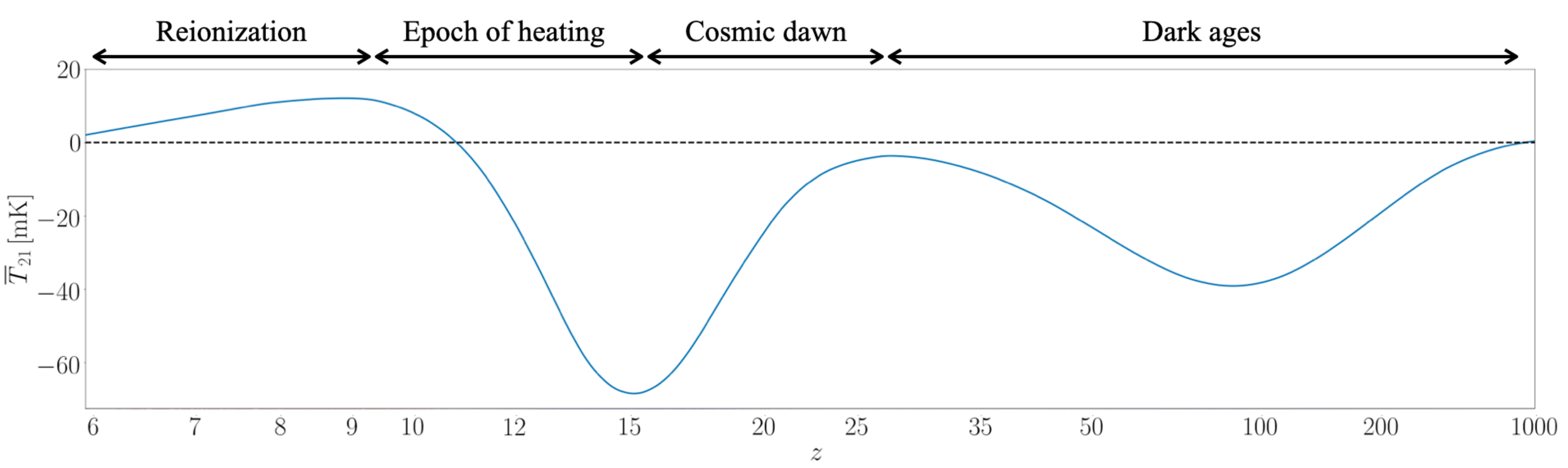

Recombination $z \sim 1100$
$z = 20$
H
CMB photon
$z = 0$

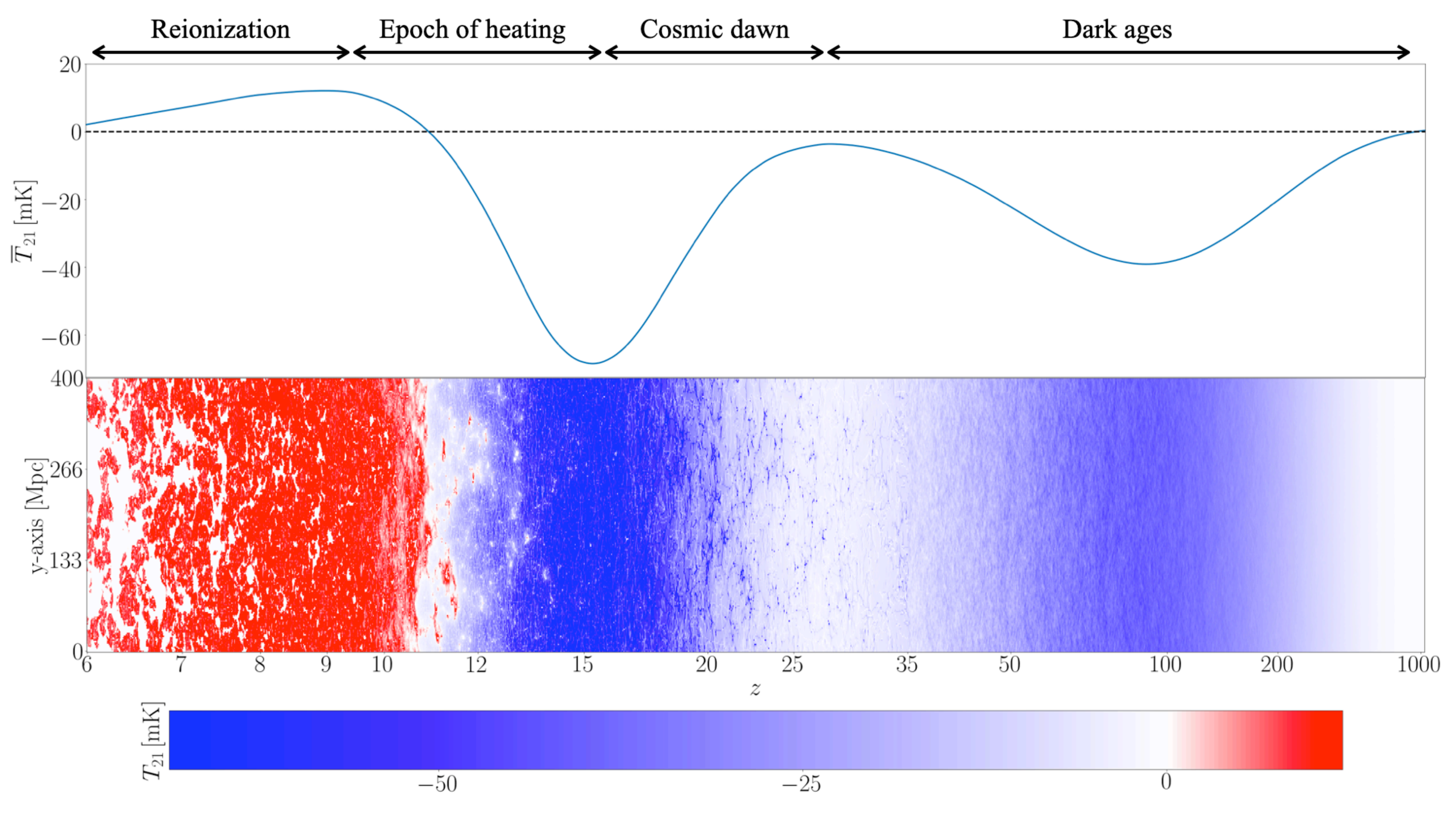

Recombination $z \sim 1100$
$z = 20$
H
CMB photon
21cm
photon
$z = 0$


Recombination $z \sim 1100$
$z = 20$
H
CMB photon
21cm
photon
redshifted
21cm photon
$z = 0$

Recombination $z \sim 1100$




Reionization
Epoch of heating
Cosmic dawn
Dark ages
20
0
−20
−40
−60
$\overline{T}_{21}$ [mK]
6
7
8
9
10
12
15
20
25
35
50
100
200
1000
z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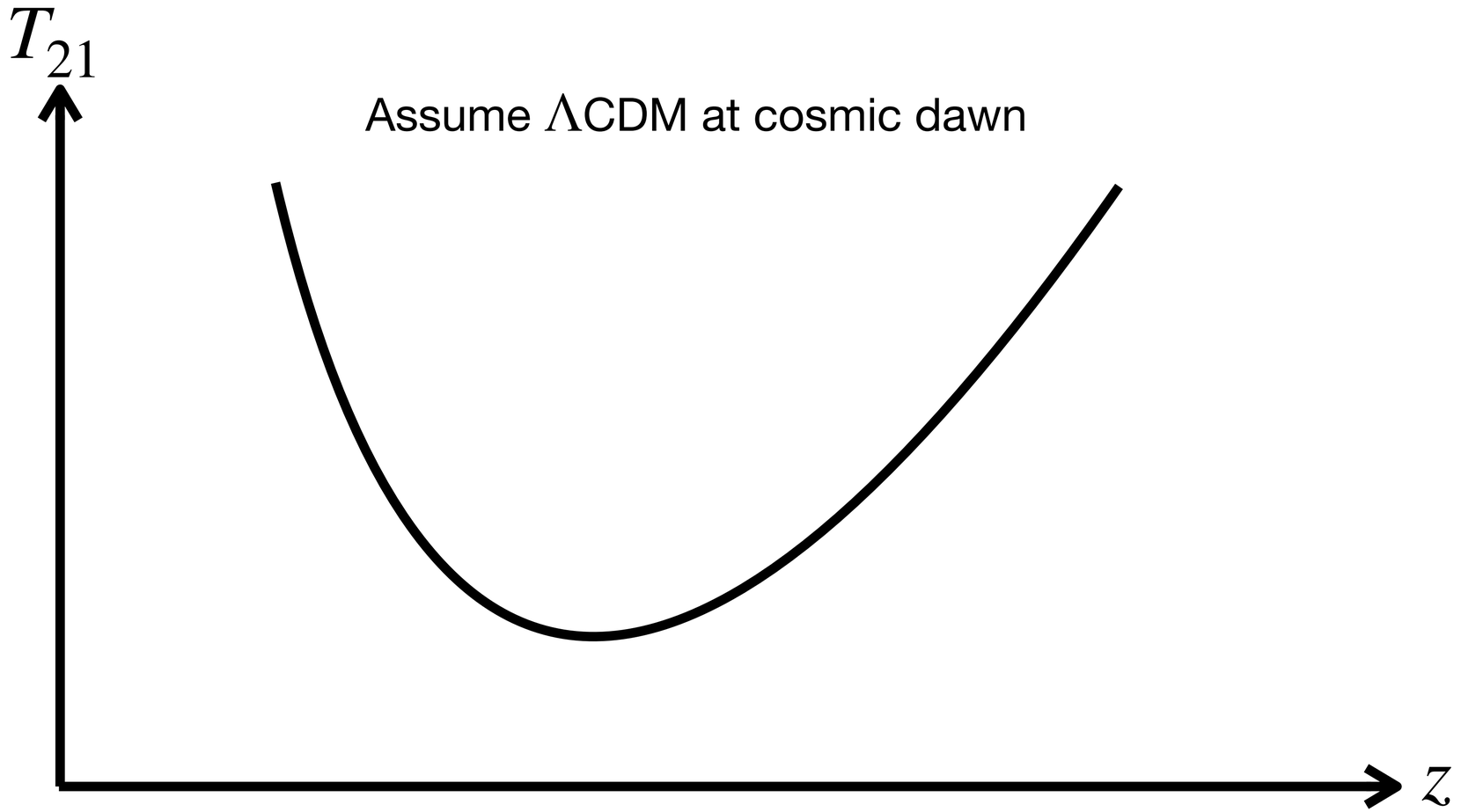
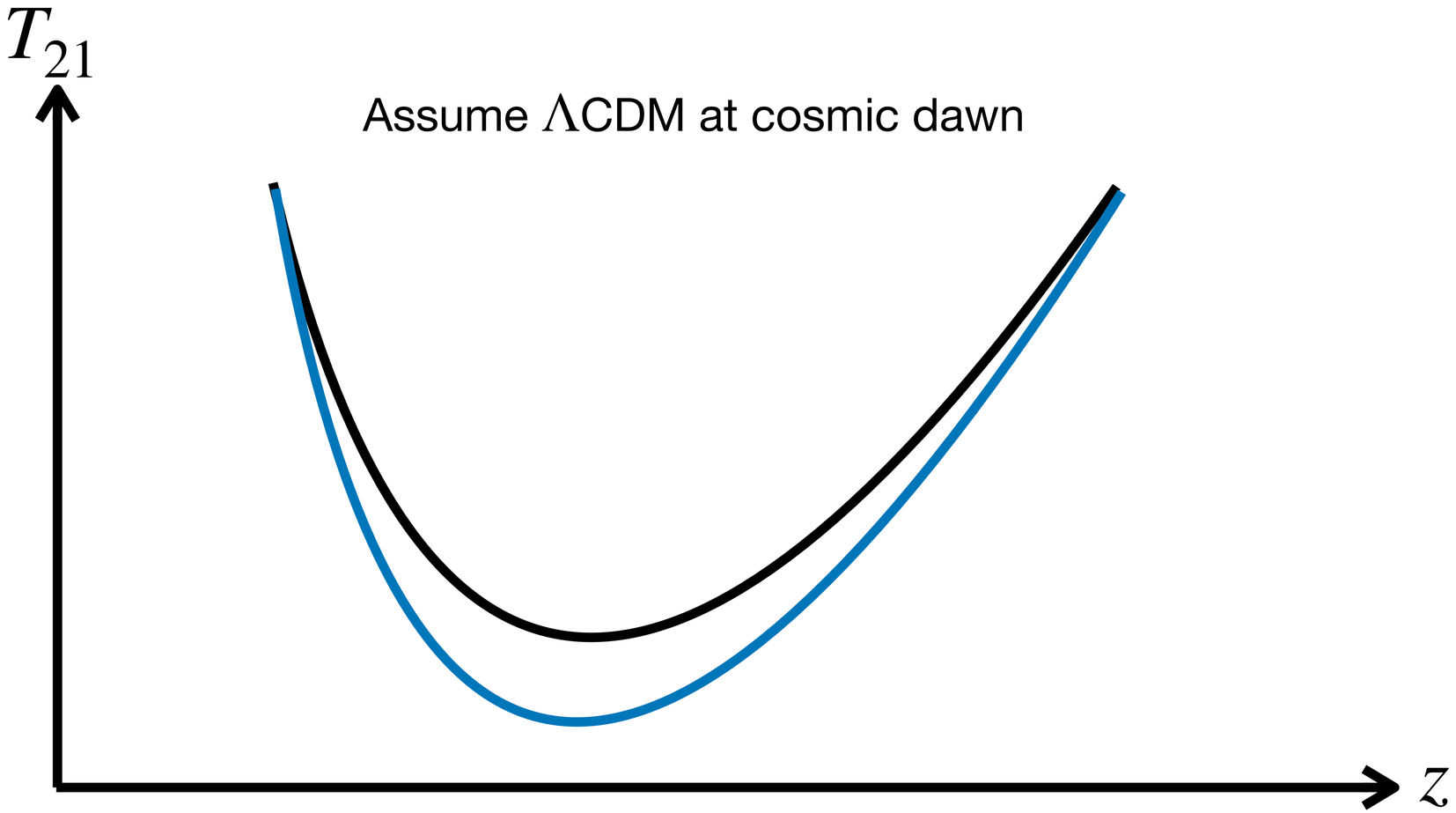
133
0
y-axis [Mpc]
6
7
8
9
10
12
15
20
25
35
50
100
200
1000
z
T_{21} [mK]
−50
−25
0

Dark matter with 21cm

Sensitivity to new physics



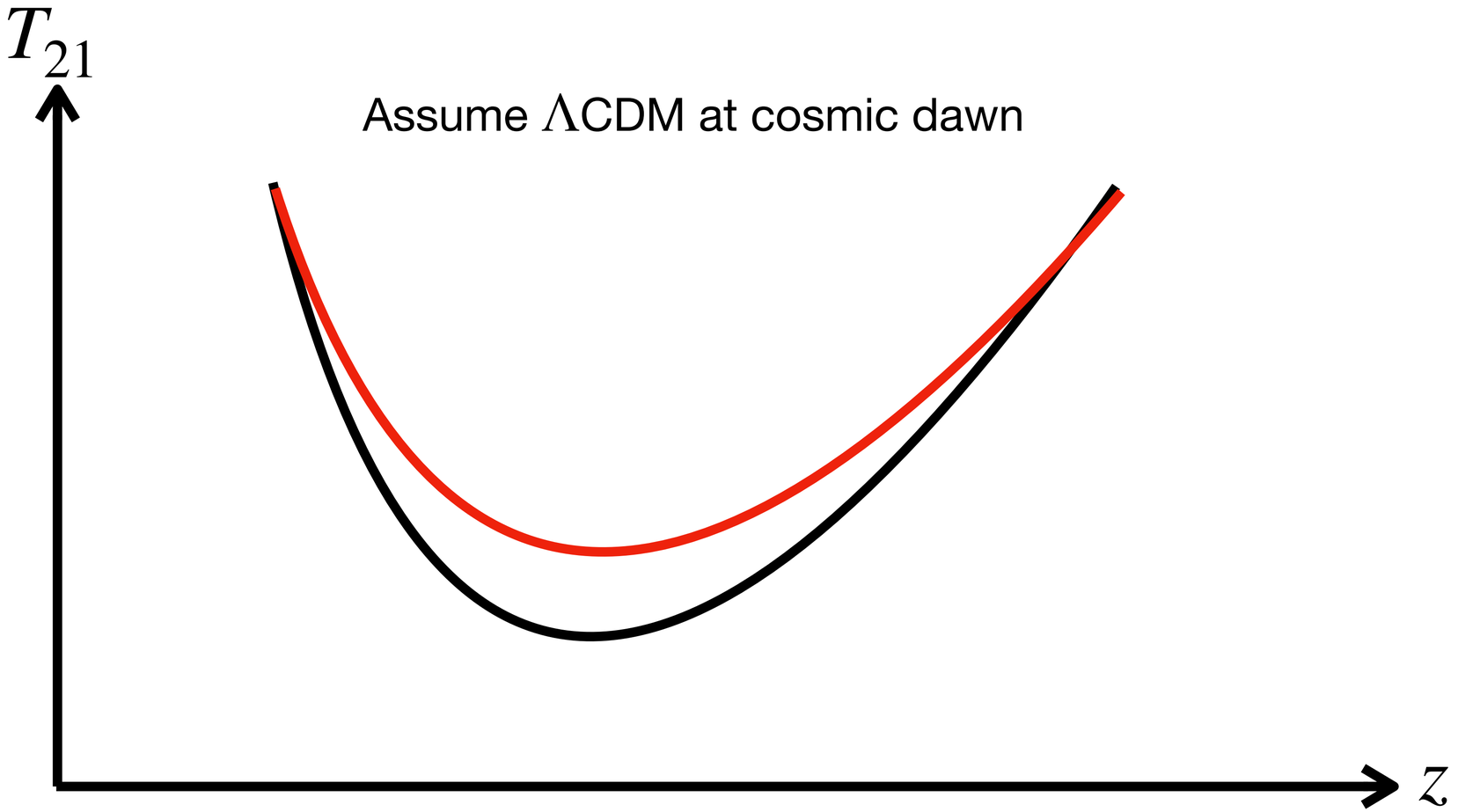
Sensitivity to new physics



"Something" cools down the IGM!

For example: scattering dark matter

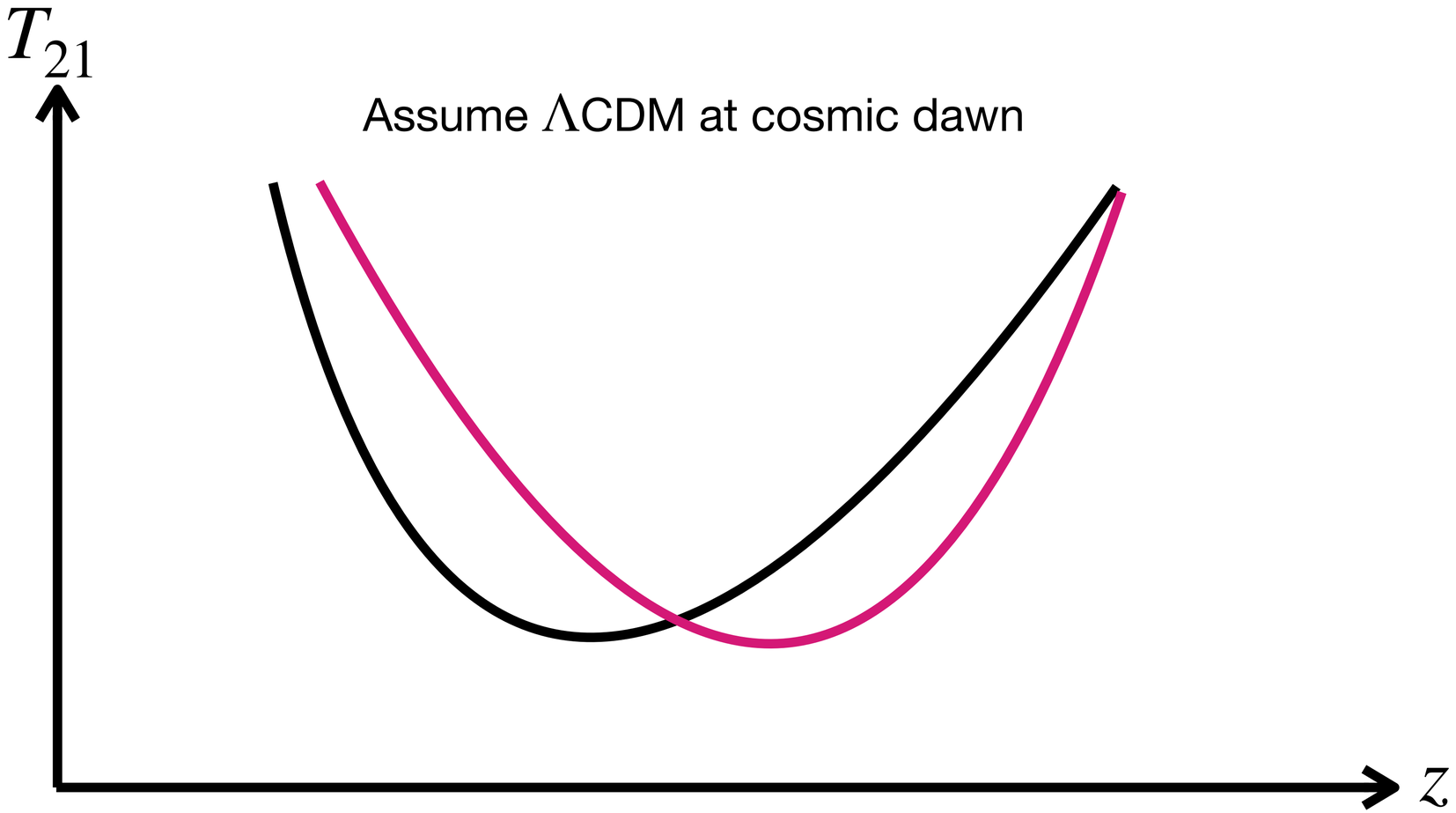
Sensitivity to new physics



"Something" heats up the IGM!

For example: annihilating/decaying dark matter, primordial black holes

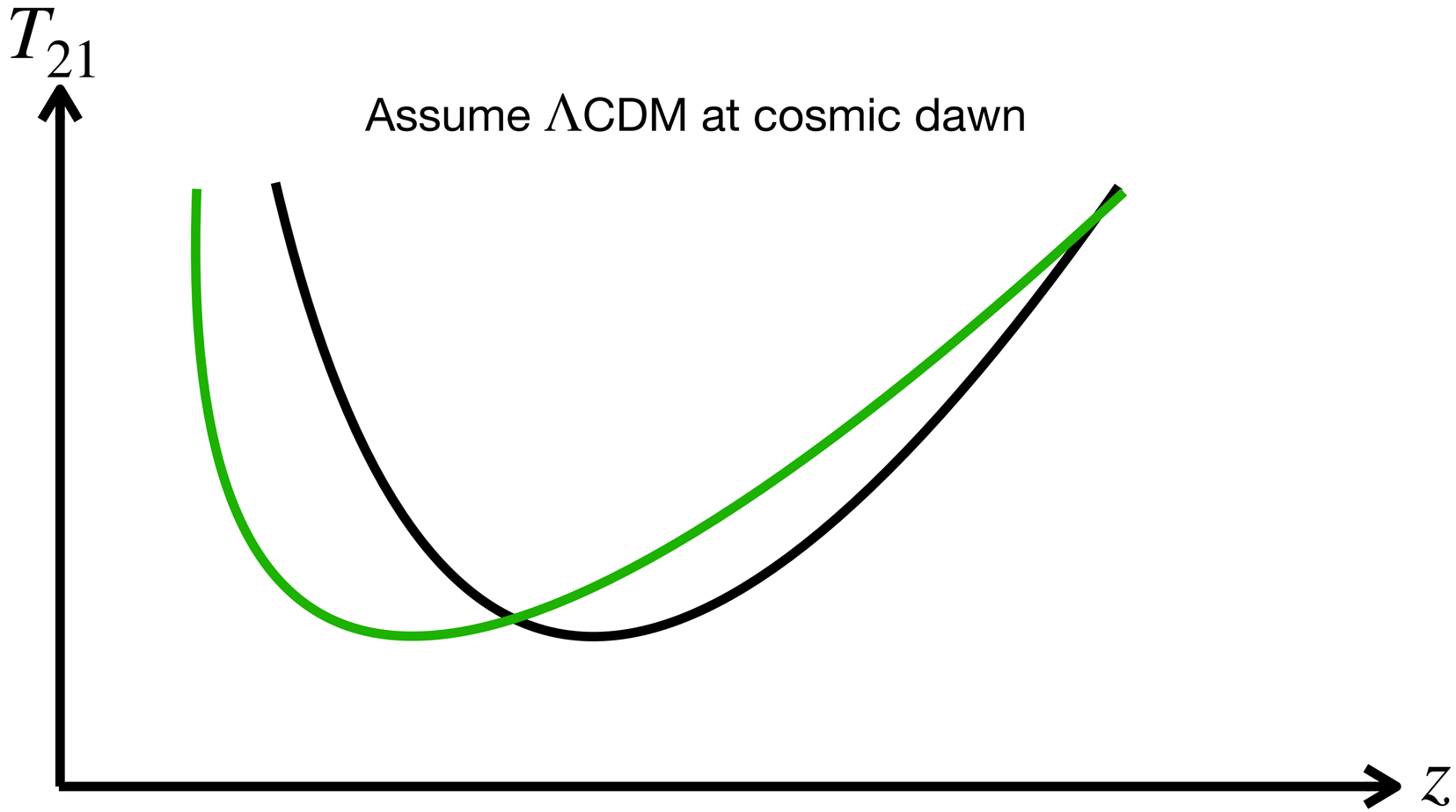
Sensitivity to new physics



"Something" speeds up structure formation!

For example: primordial magnetic fields

Sensitivity to new physics



"Something" delays structure formation!

For example: fuzzy dark matter, ultra light axions

Case study I:
Fuzzy dark matter (FDM)

FDM - How does it affect the 21cm signal?

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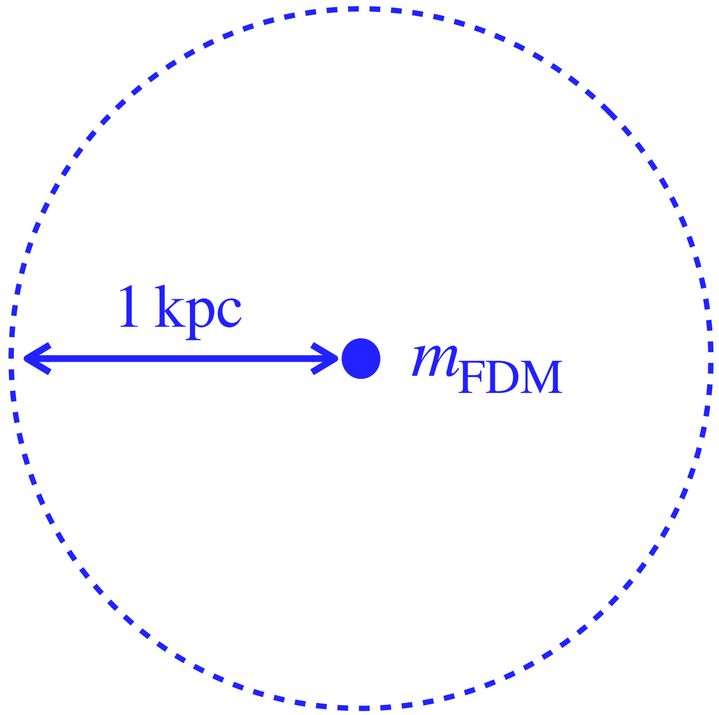
$m_{\rm FDM} \lesssim 10^{-21}\,{\rm eV}$

- $m_{\rm FDM}$

FDM - How does it affect the 21cm signal?

$$m_{\rm FDM} \lesssim 10^{-21}\,{\rm eV} \quad \Rightarrow \quad \lambda_{\rm dB} \gtrsim 1\,{\rm kpc}$$



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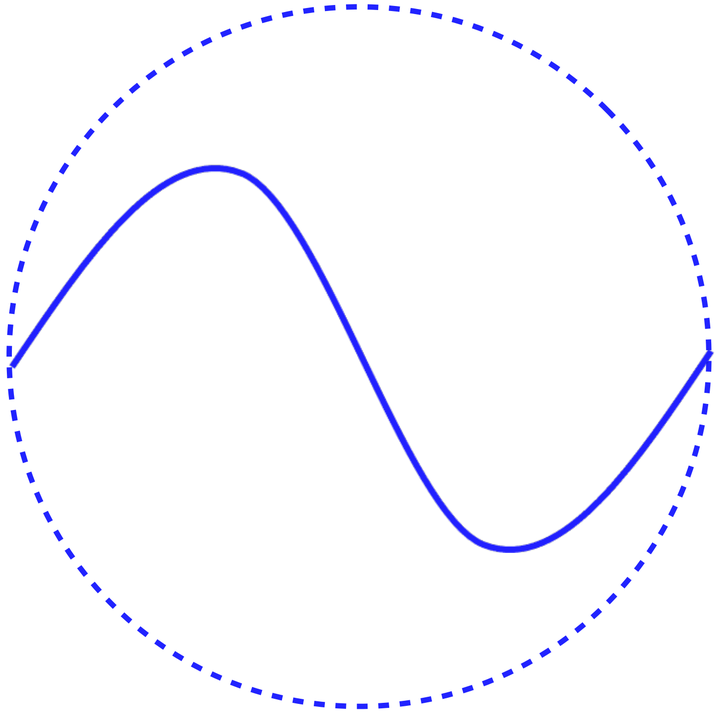

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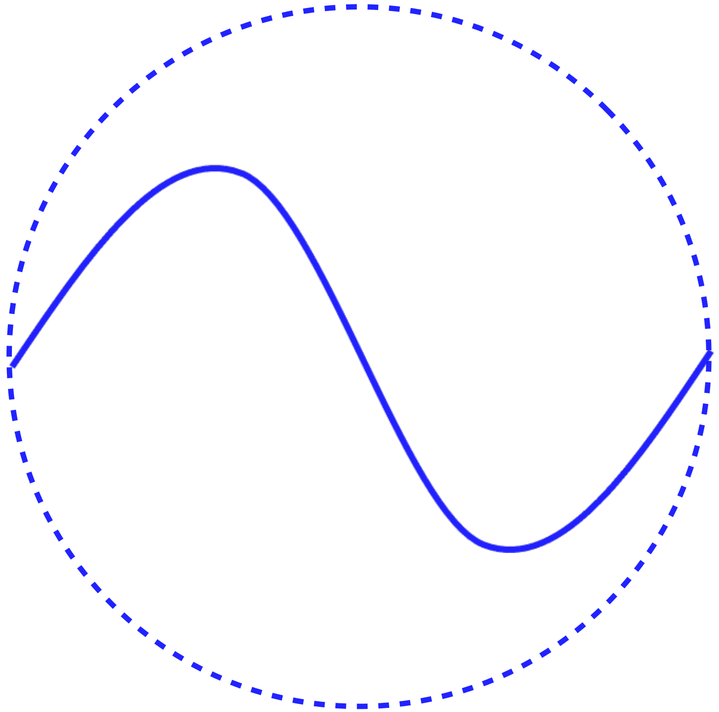

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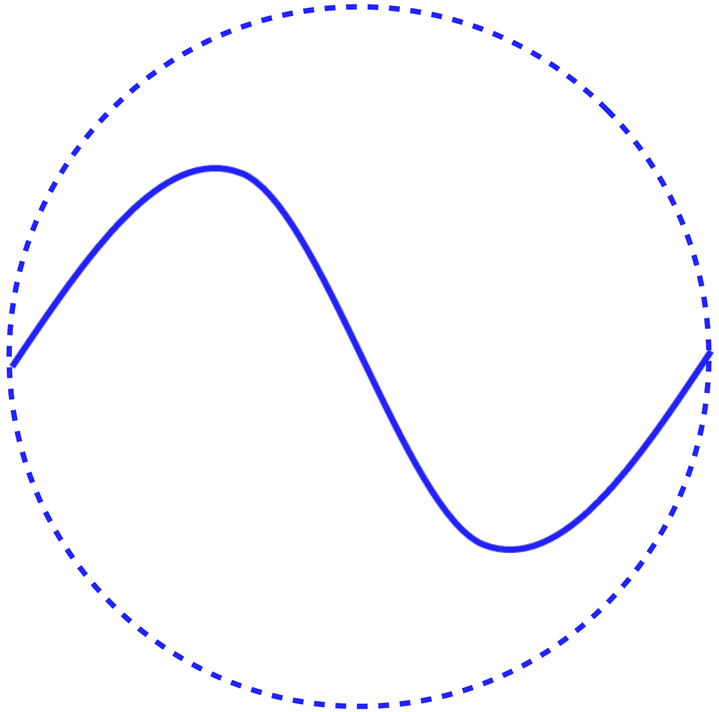
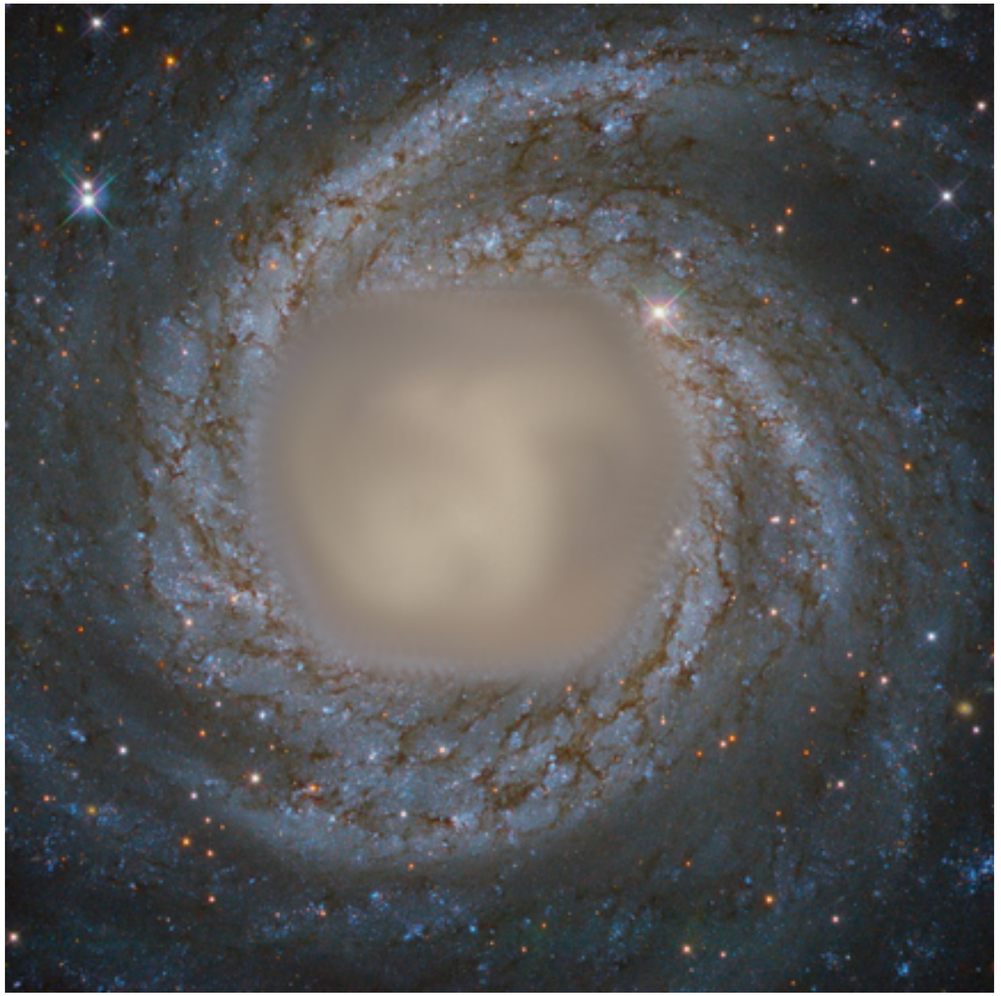
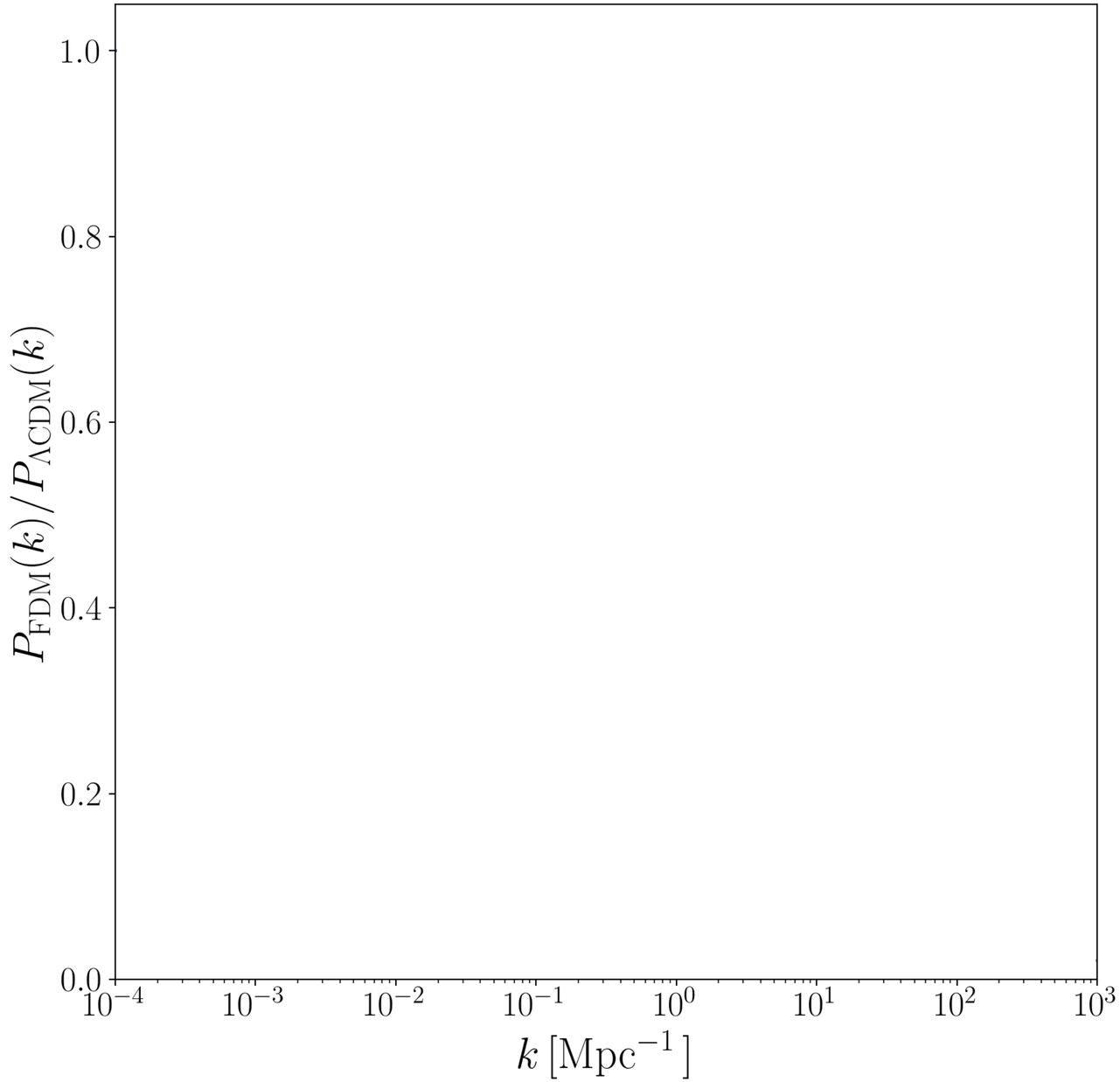
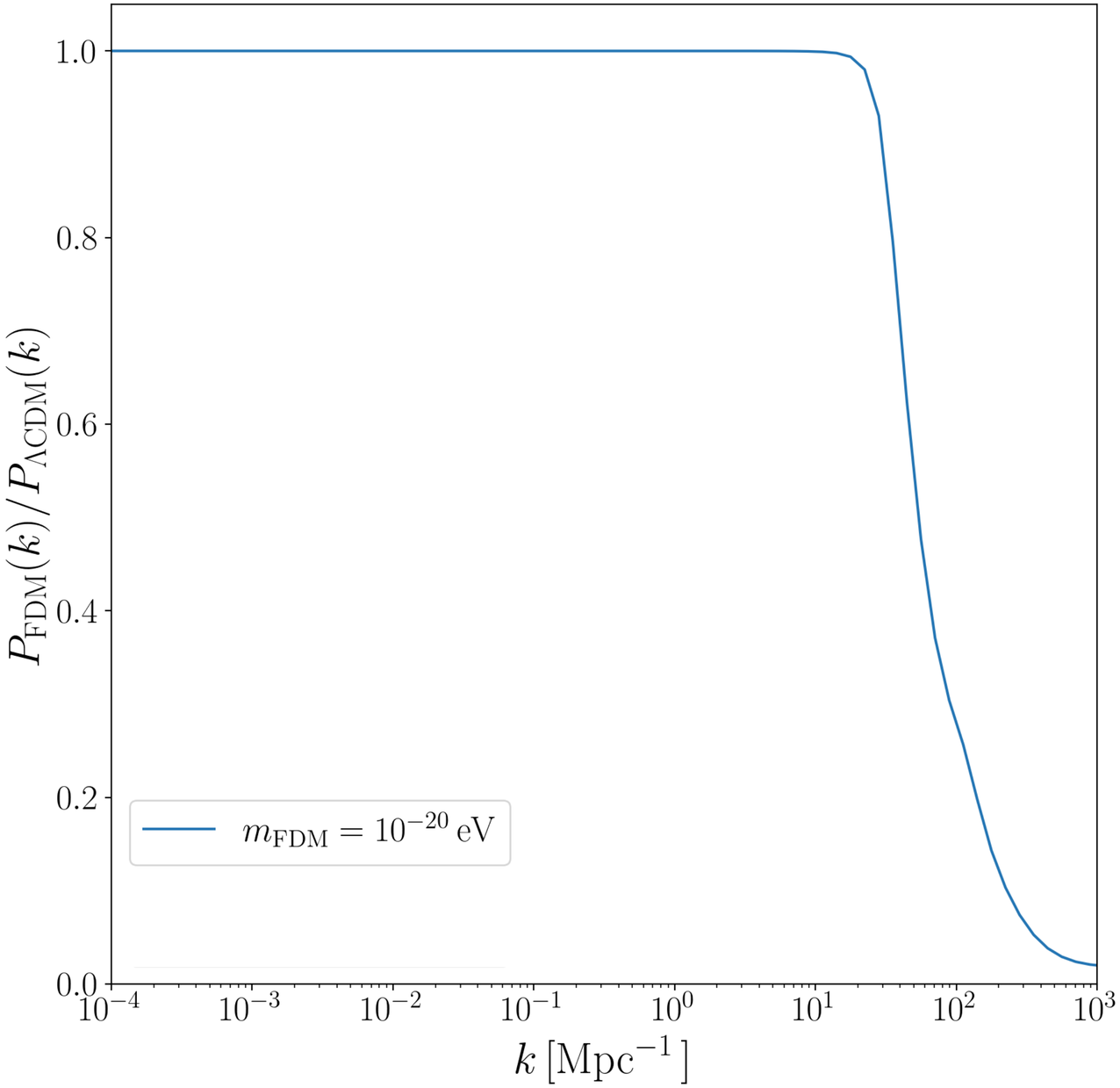





1.0
0.8
0.6
0.4
0.2
0.0
$P_{\rm FDM}(k)/P_{\Lambda{\rm CDM}}(k)$
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
$k\,[{\rm Mpc}^{-1}]$

Solid lines: $f_{\rm FDM} = 30\,\%$



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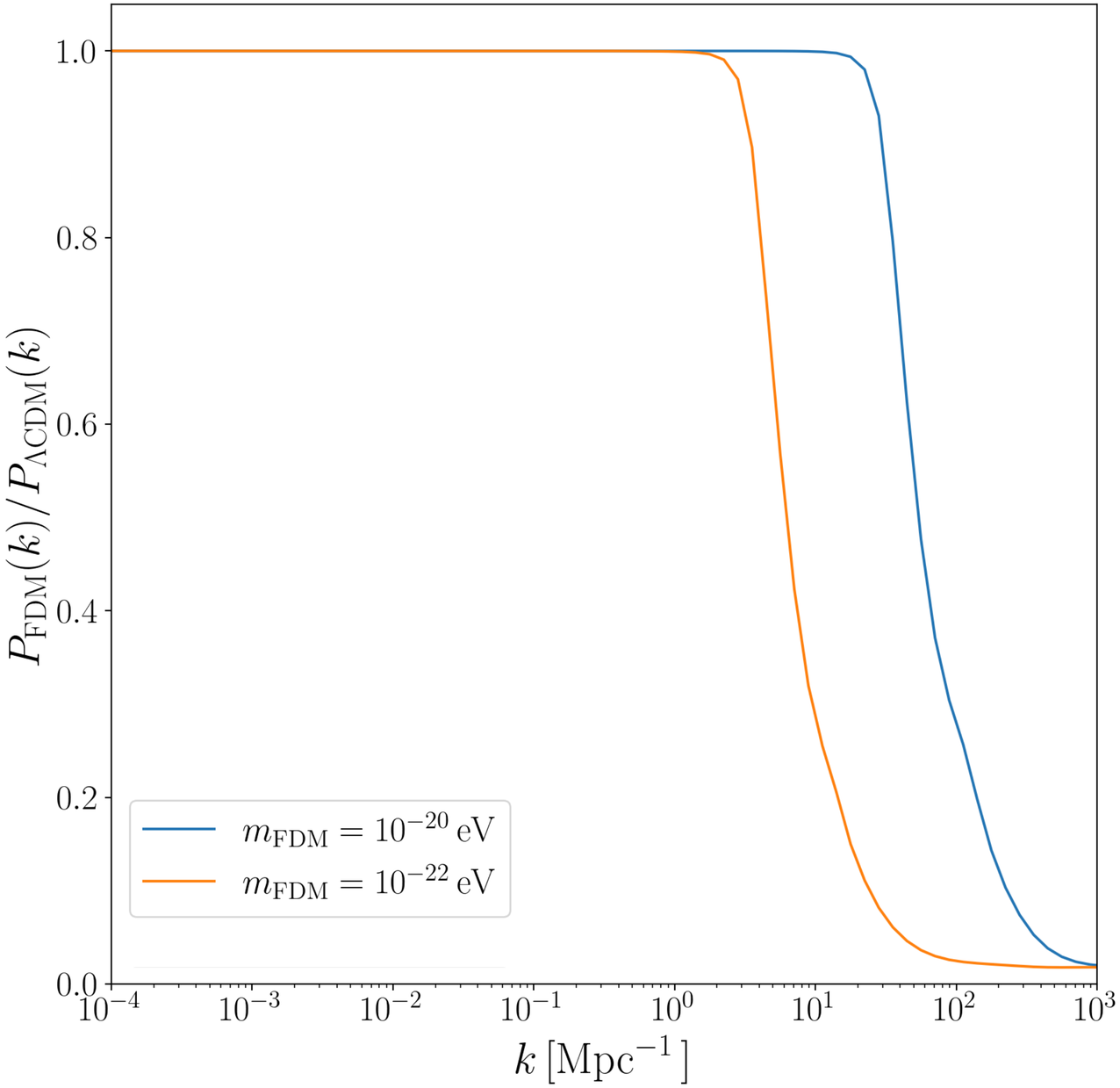
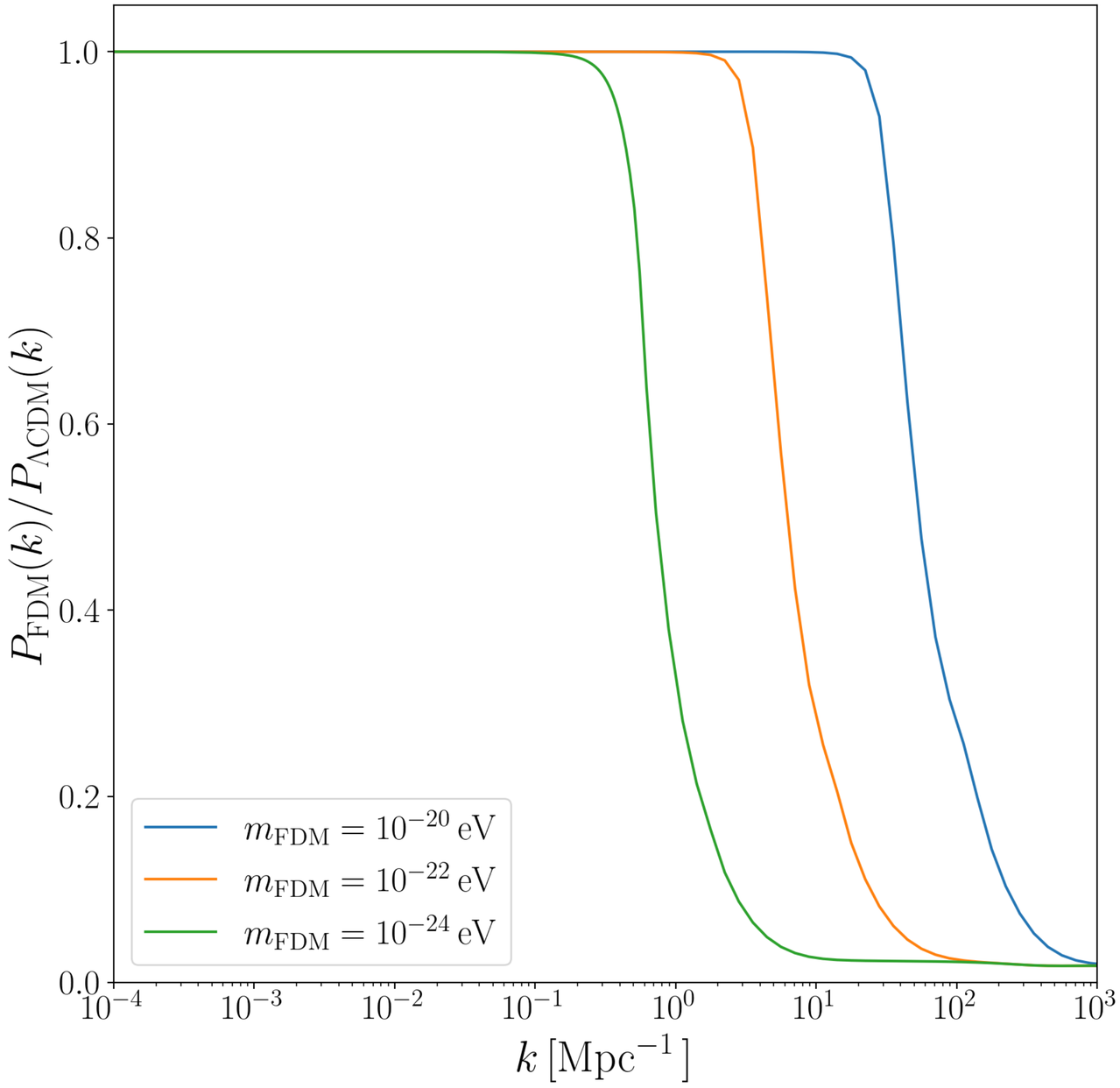
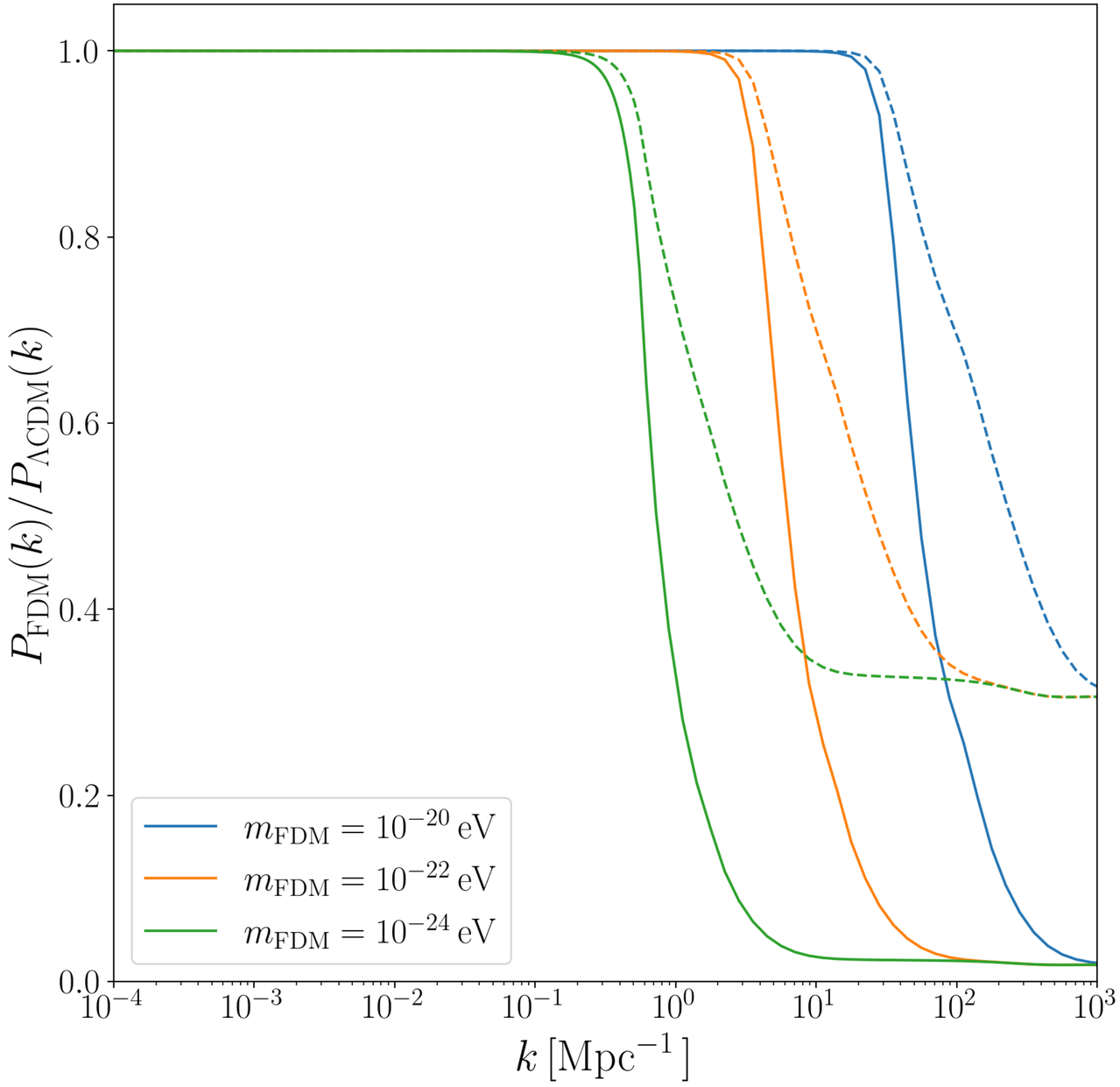


Solid lines: $f_{\rm FDM} = 30\,\%$



Solid lines: $f_{\rm FDM} = 30\,\%$

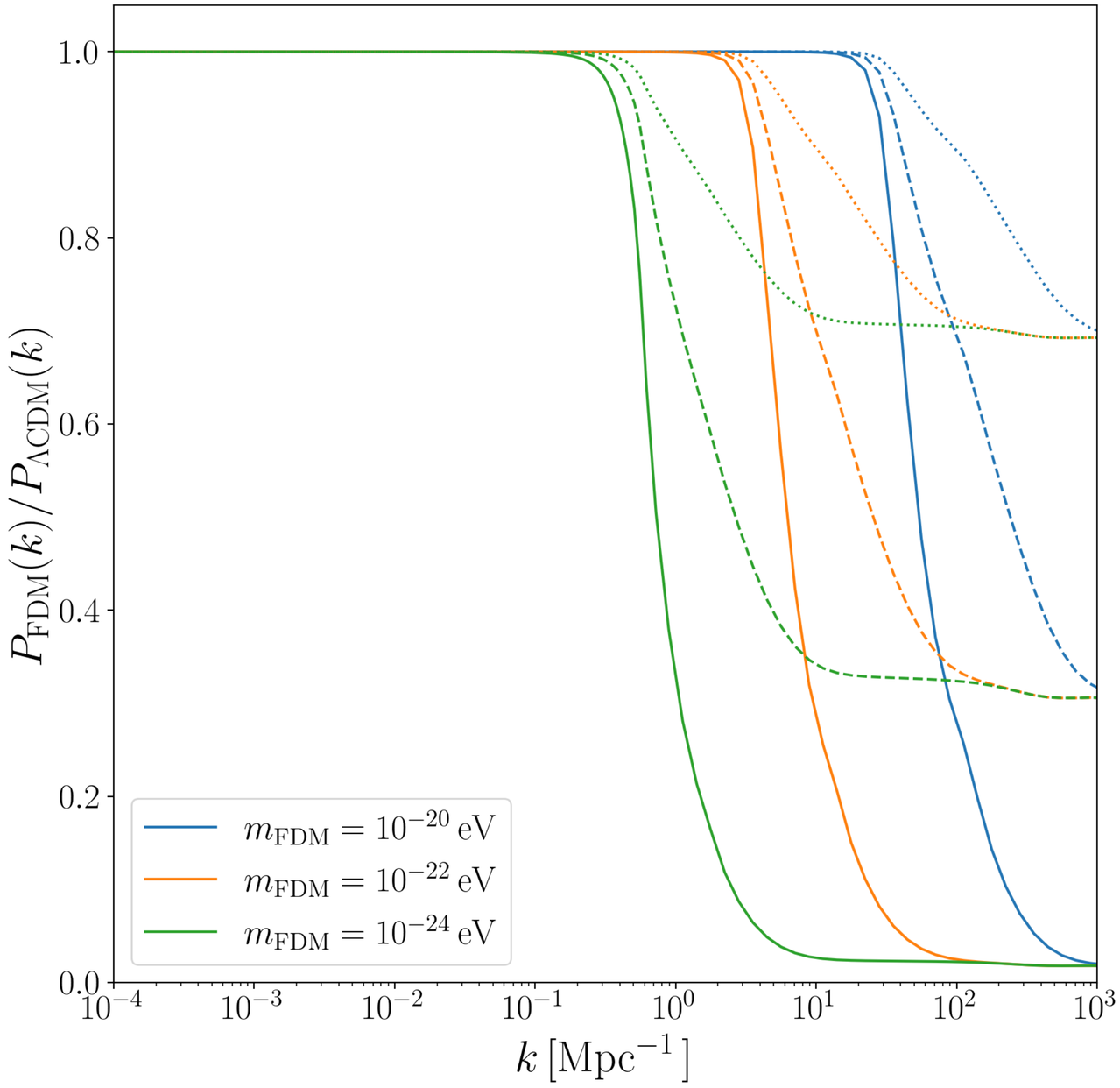
Dashed lines: $f_{\rm FDM} = 10\,\%$



Solid lines: $f_{\rm FDM} = 30\,\%$

Dashed lines: $f_{\rm FDM} = 10\,\%$

Dotted lines: $f_{\rm FDM} = 3\,\%$



FDM - How does it affect the 21cm signal?

$m_{\rm FDM} \lesssim 10^{-21}\,{\rm eV}$ → $\lambda_{\rm dB} \gtrsim 1\,{\rm kpc}$ → washes out structure formation in small scales

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↓

less small mass dark matter halos

← smaller star formation rate

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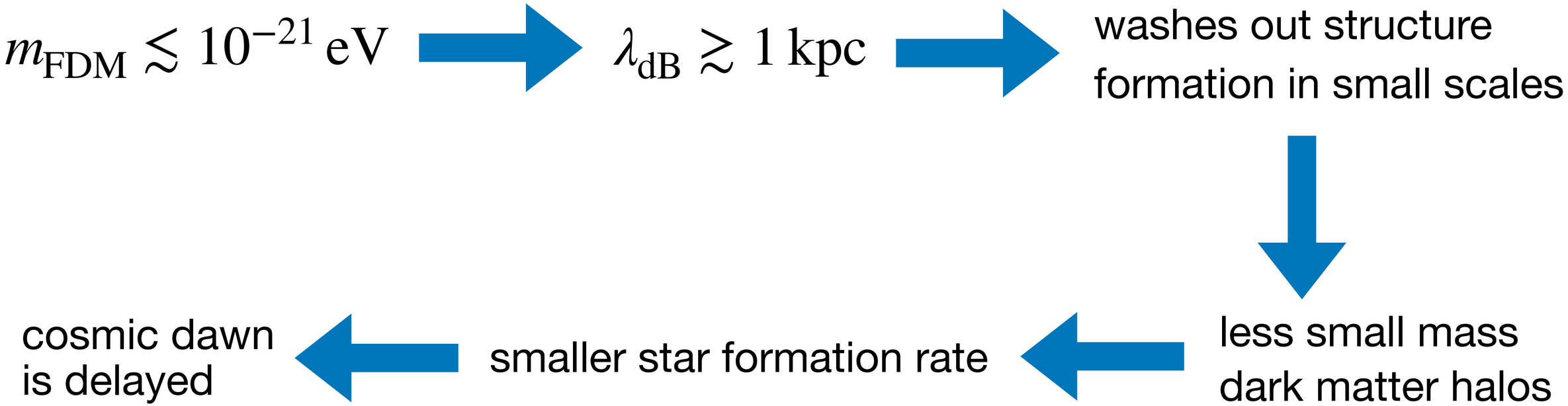
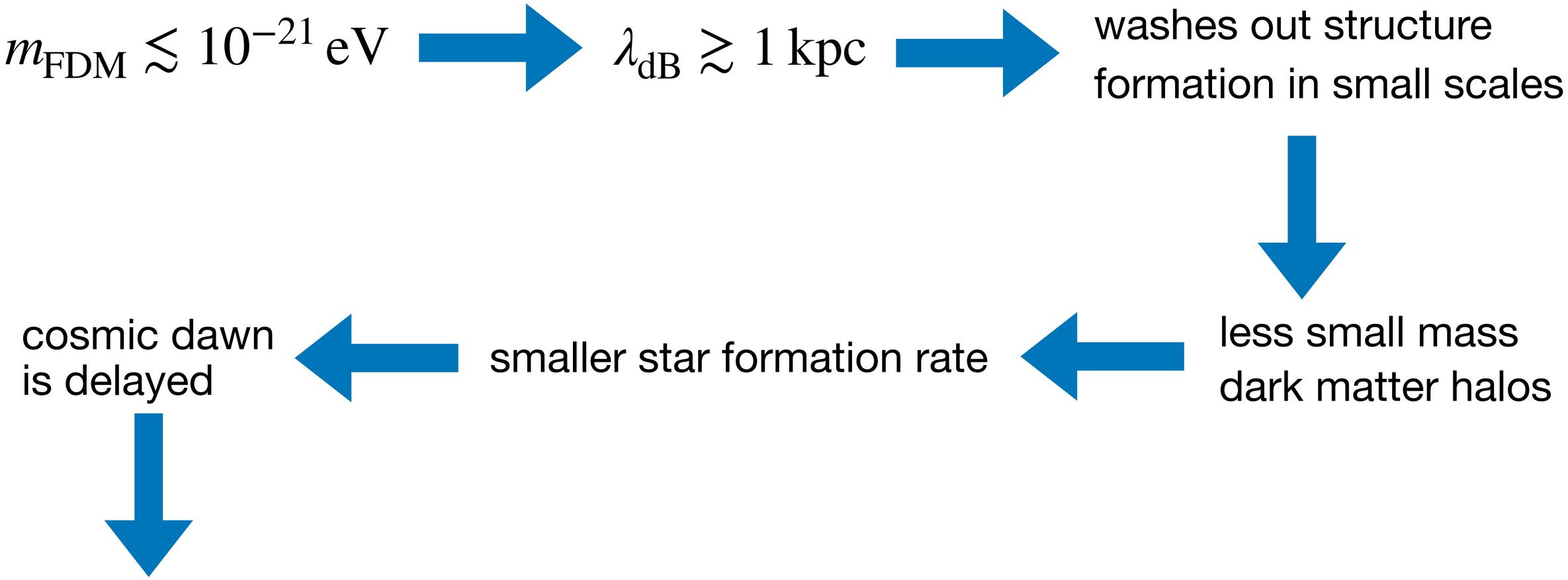
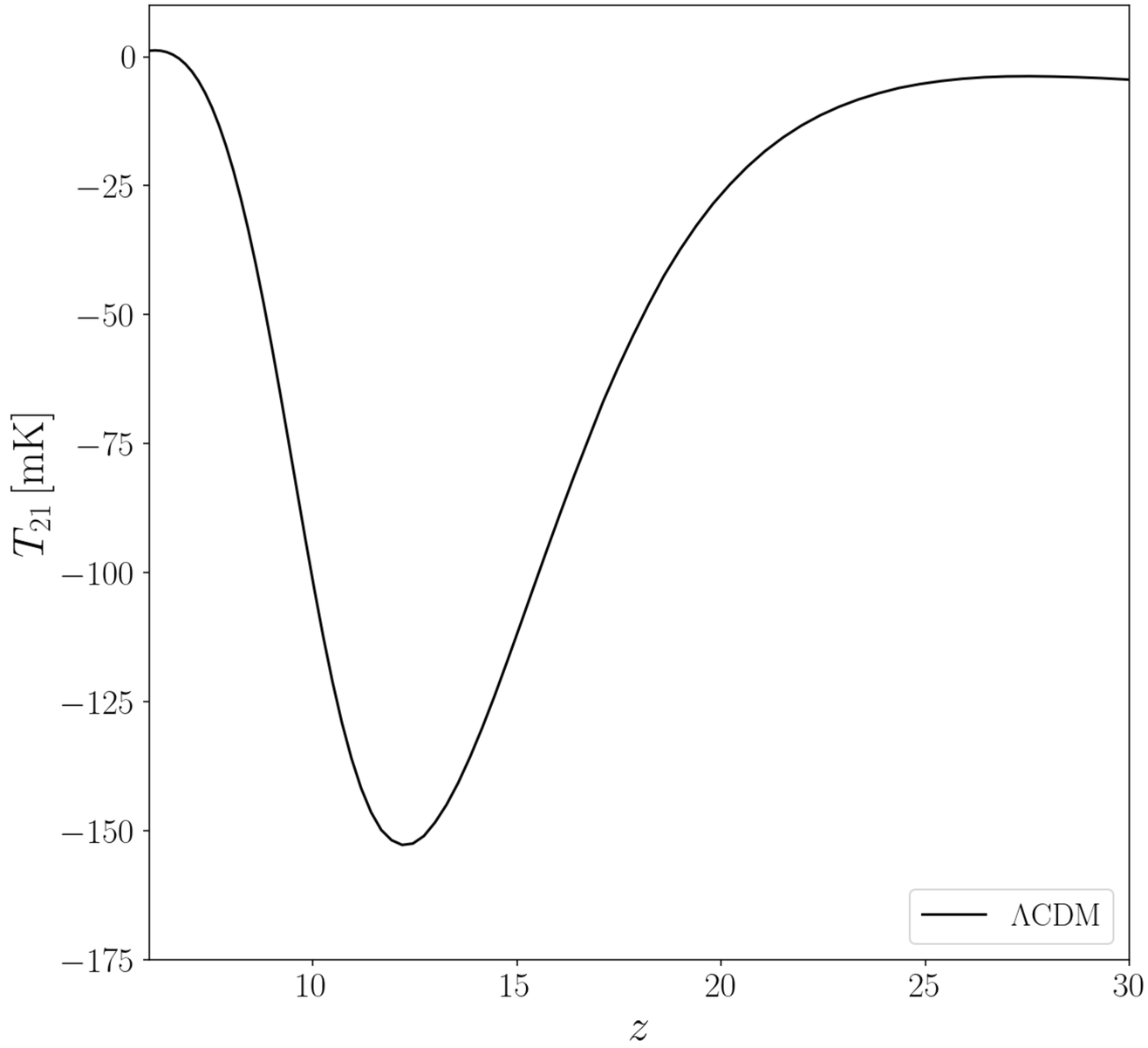


FDM - How does it affect the 21cm signal?

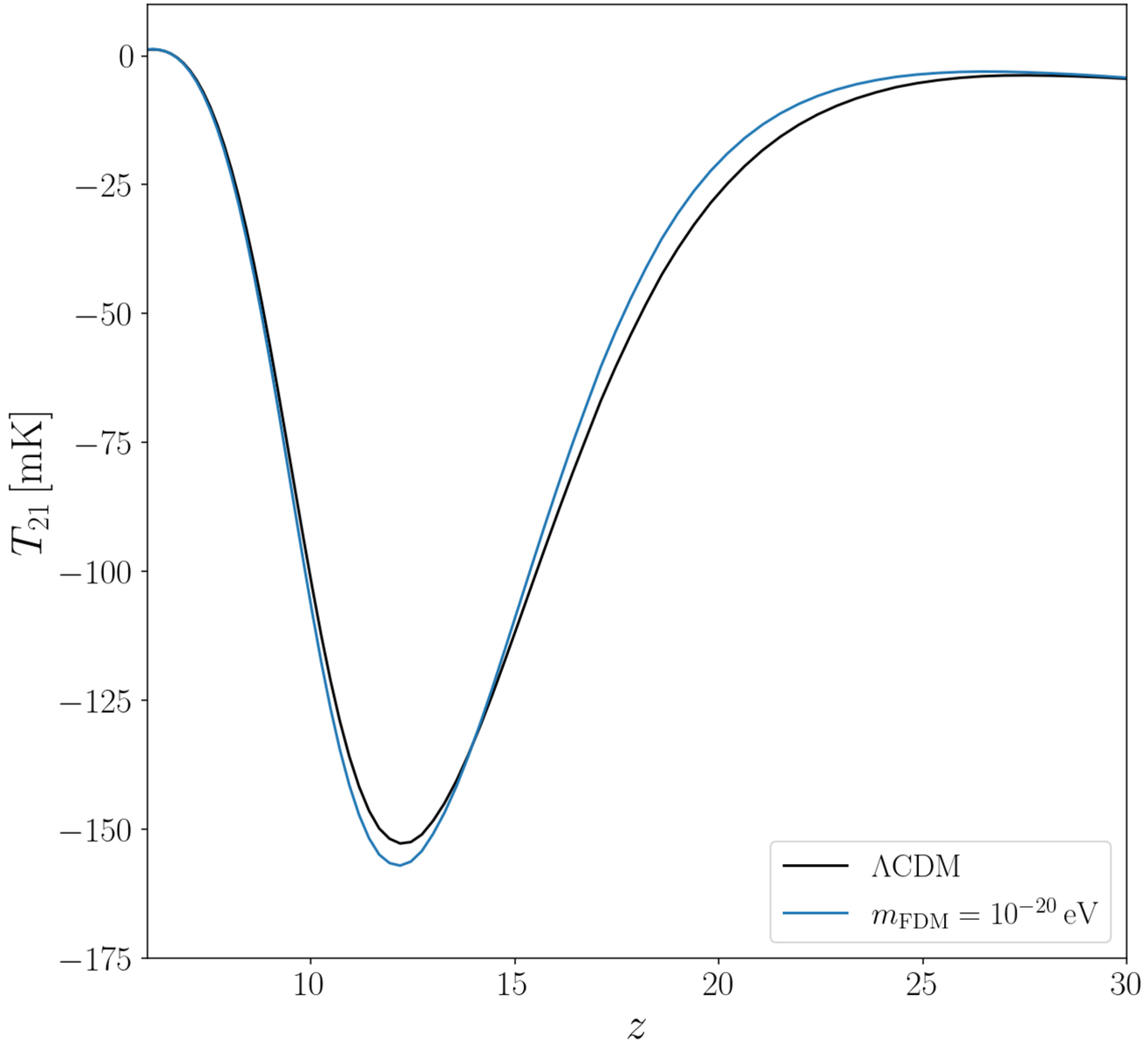


Flitter & Kovetz, *PRD* **106**, 063504 (2022)



Flitter & Kovetz, *PRD* **106**, 063504 (2022)

Solid lines: $f_{\rm FDM} = 10\,\%$



Flitter & Kovetz, *PRD* **106**, 063504 (2022)

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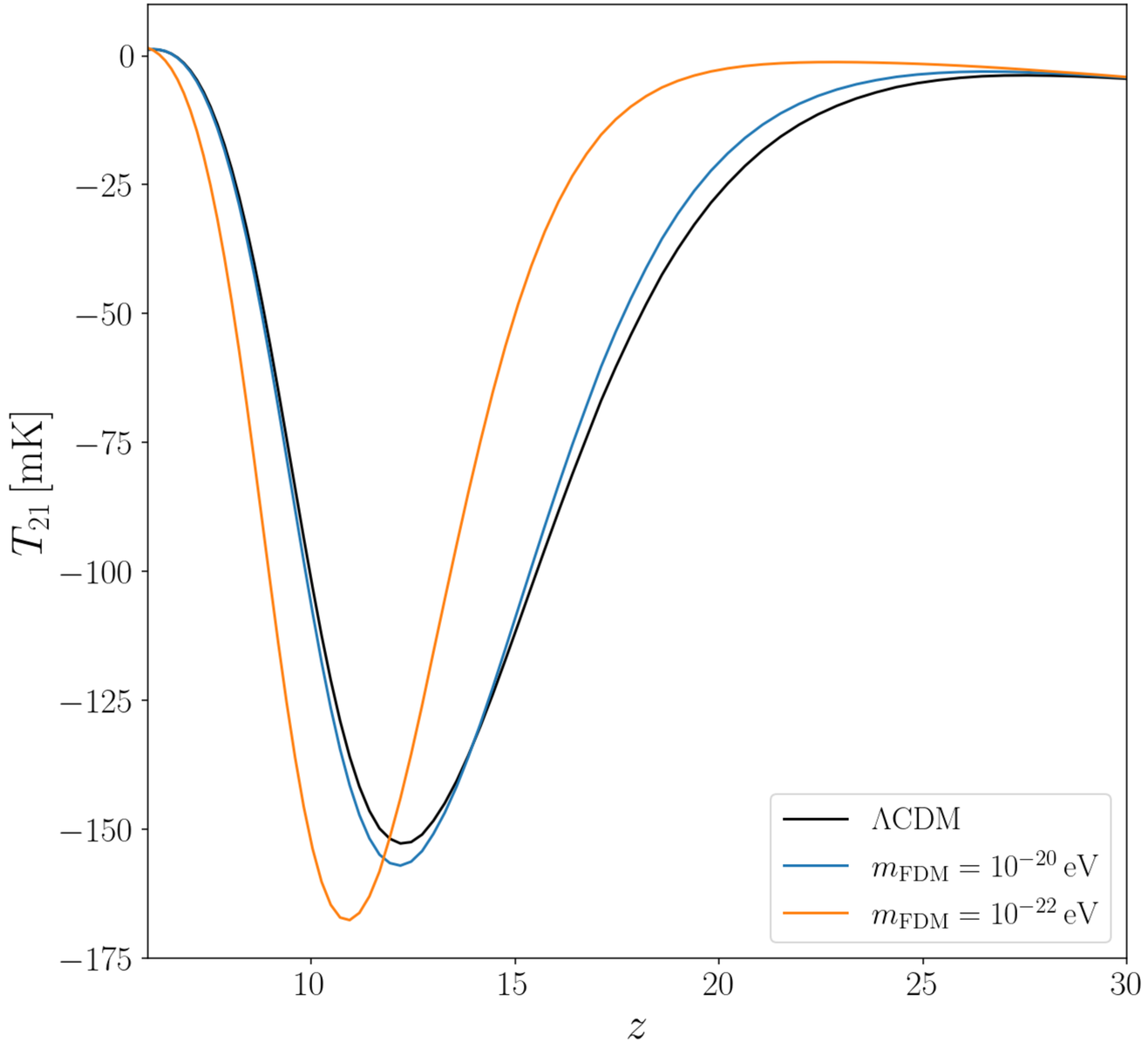

Flitter & Kovetz, *PRD* **106**, 063504 (2022)

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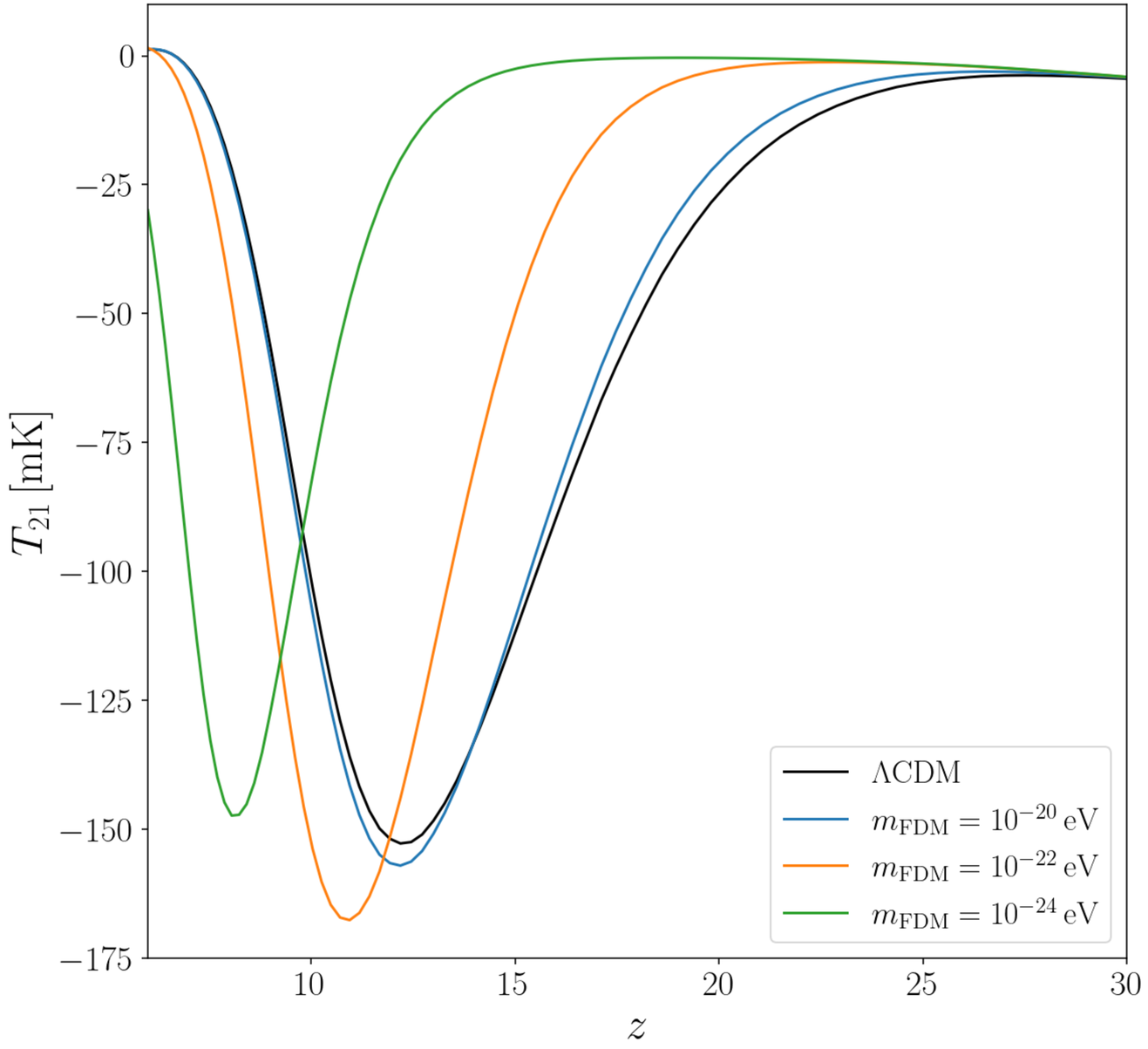

Flitter & Kovetz, *PRD* **106**, 063504 (2022)

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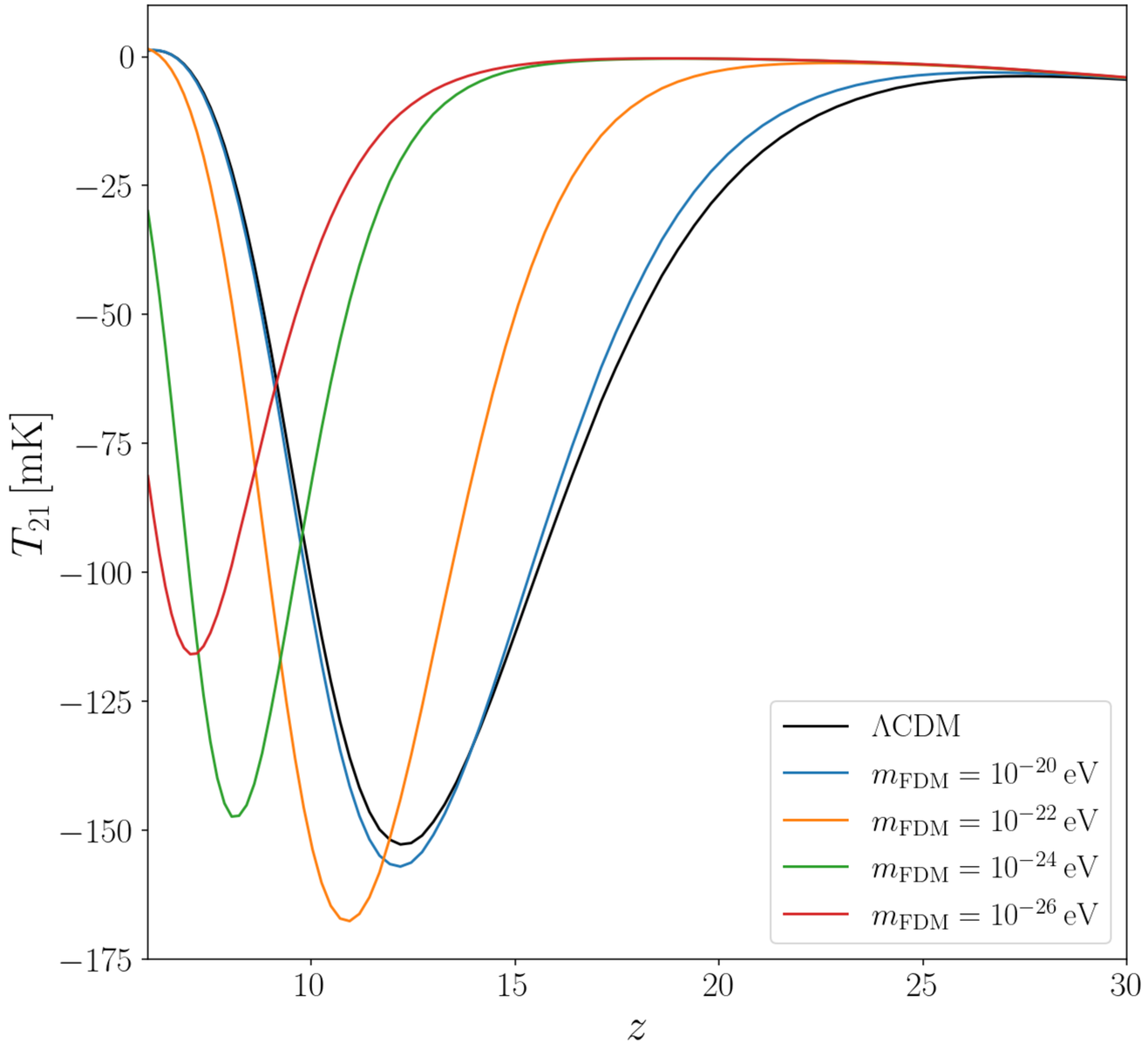
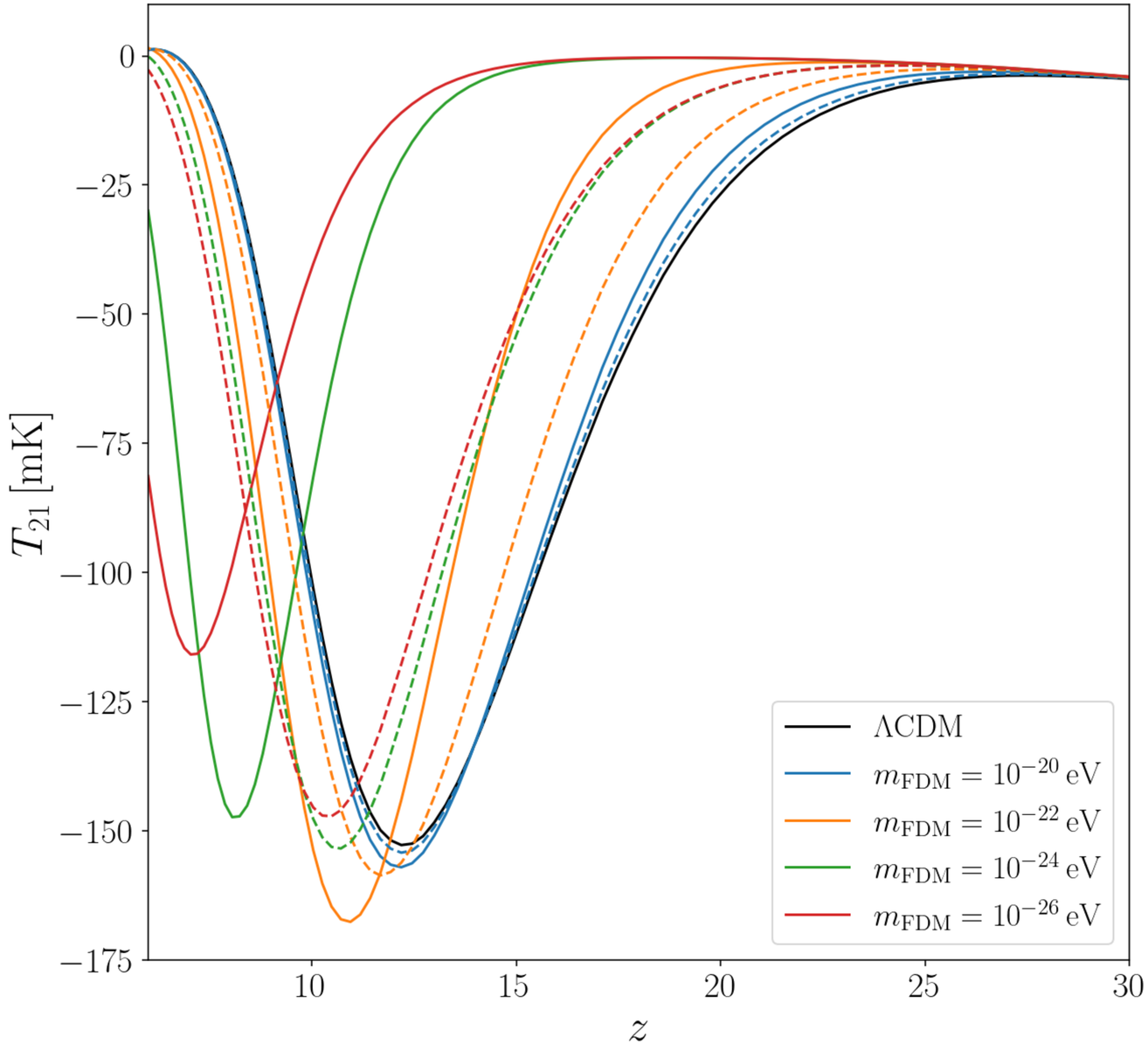


Flitter & Kovetz, *PRD* **106**, 063504 (2022)

Solid lines: $f_{\rm FDM} = 10\,\%$

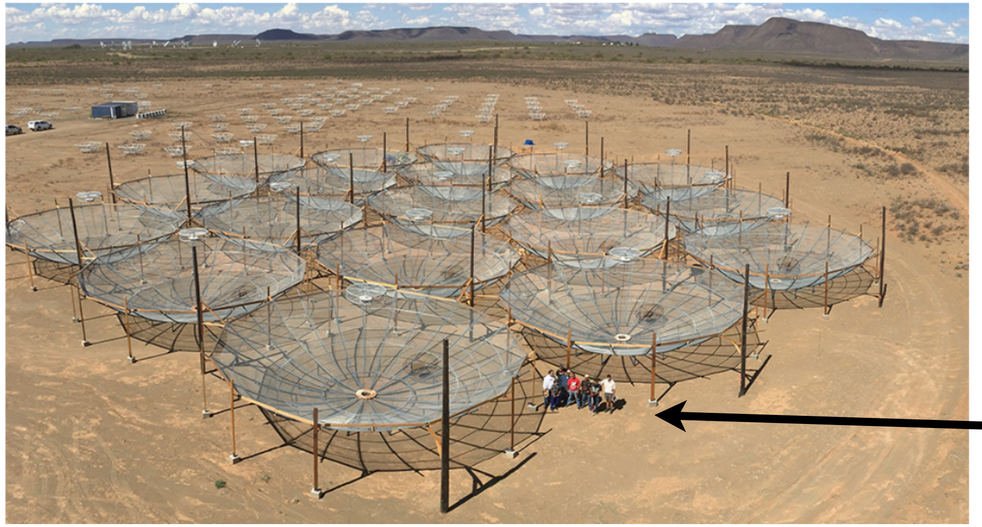
Dashed lines: $f_{\rm FDM} = 3\,\%$



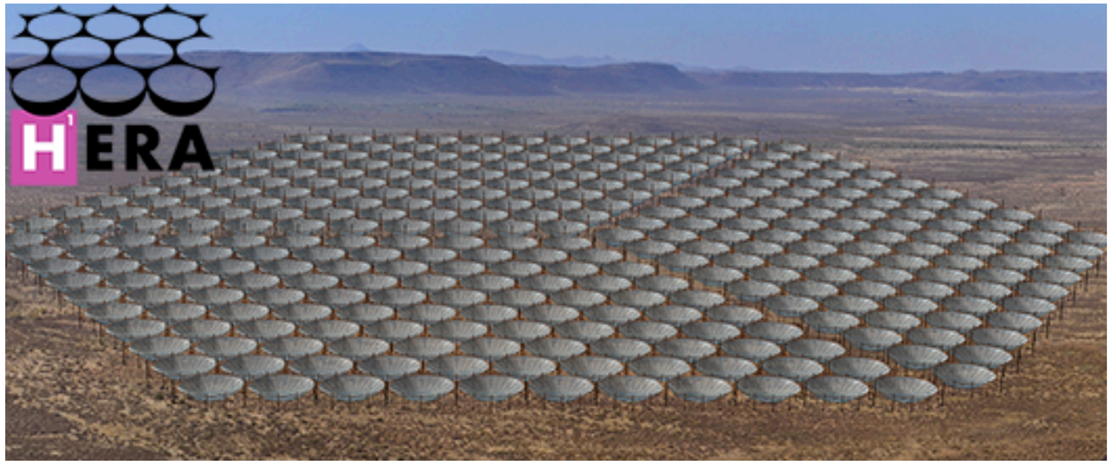
HERA sensitivity to FDM

$$P_{21}\left(k\right) \propto \langle \tilde{T}_{21}\left(k\right)\ \tilde{T}_{21}^{*}\left(k\right)\rangle$$

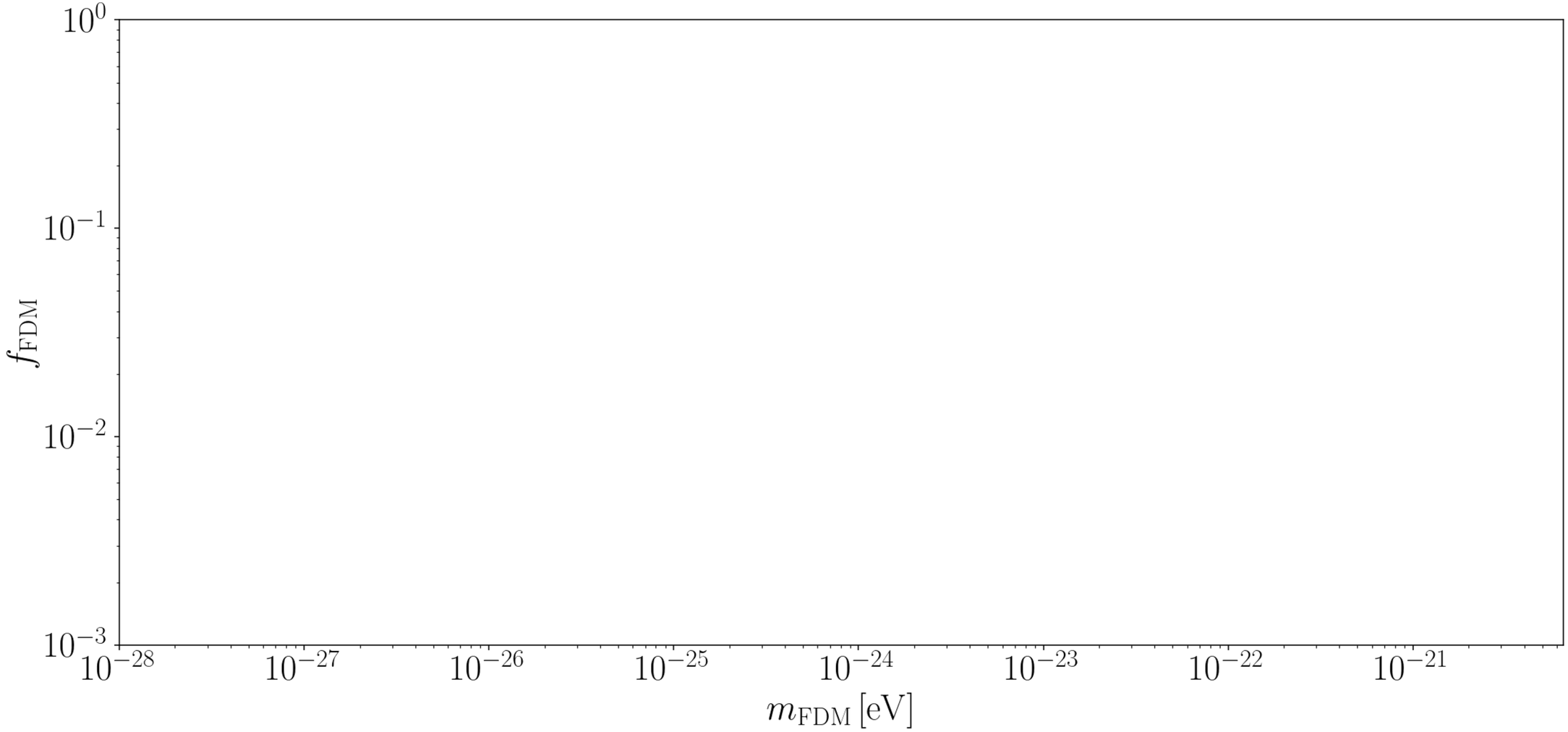
DeBoer et al. (arXiv: 1606.07473)



People in picture

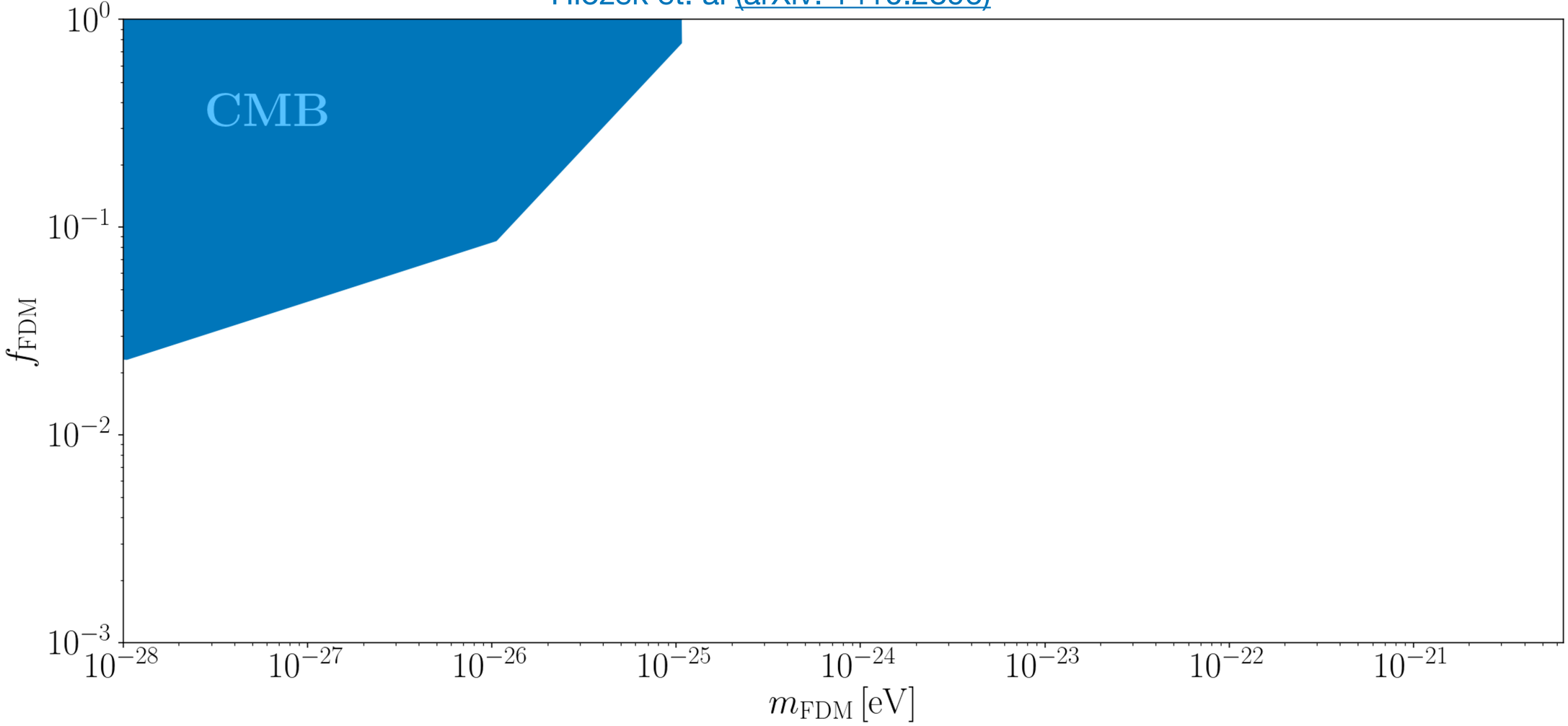


HERA sensitivity to FDM



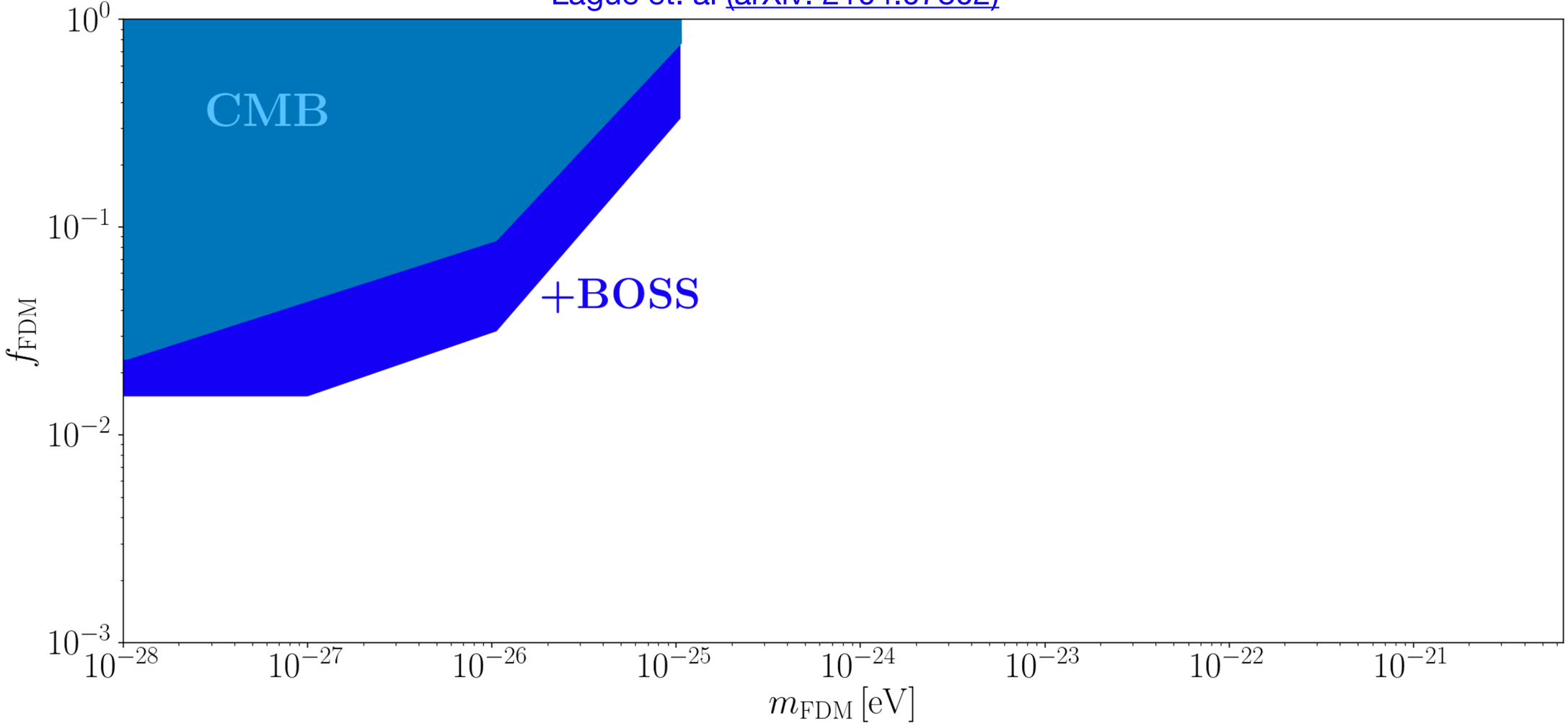
HERA sensitivity to FDM

Hložek et. al (arXiv: 1410.2896)

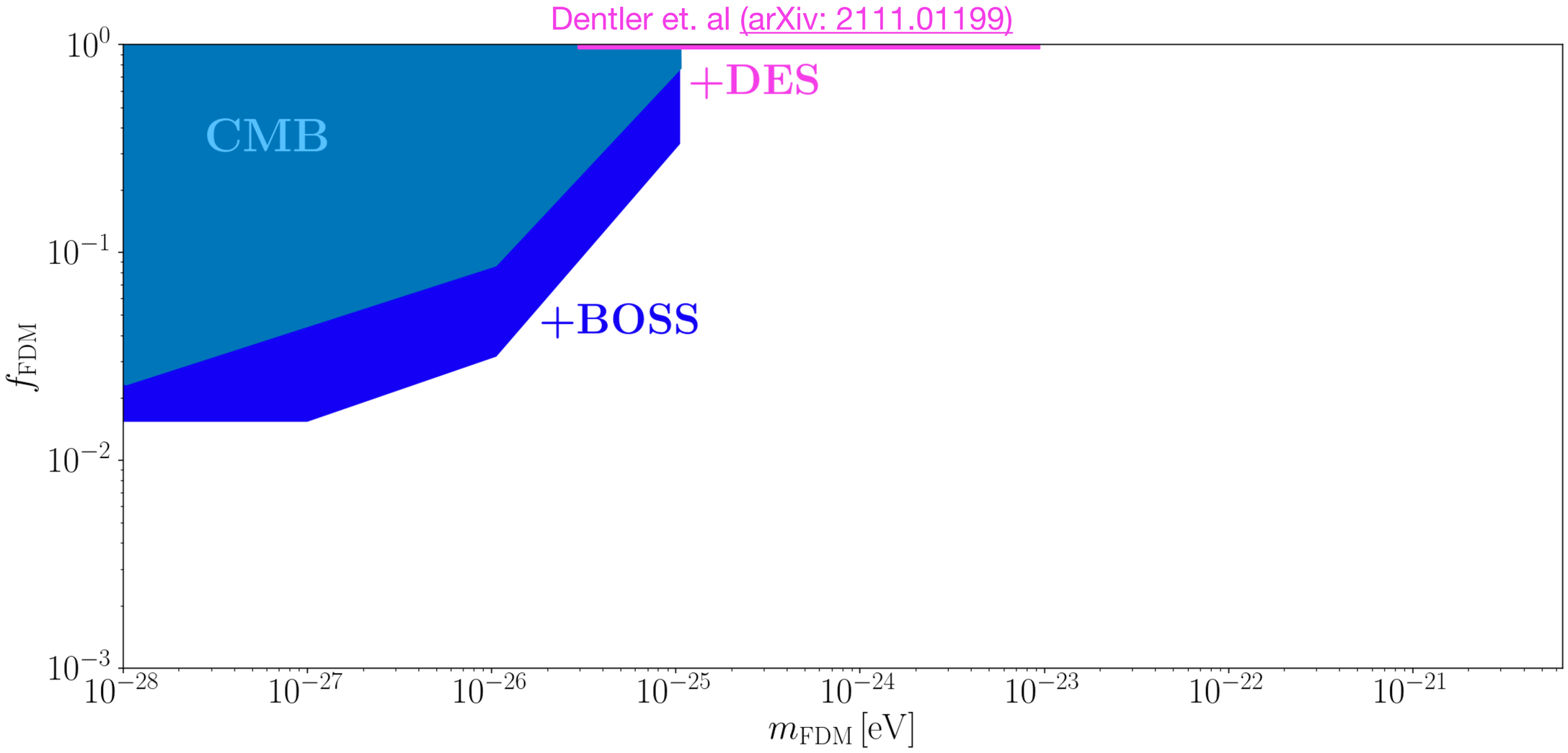


HERA sensitivity to FDM

Laguë et. al (arXiv: 2104.07802)

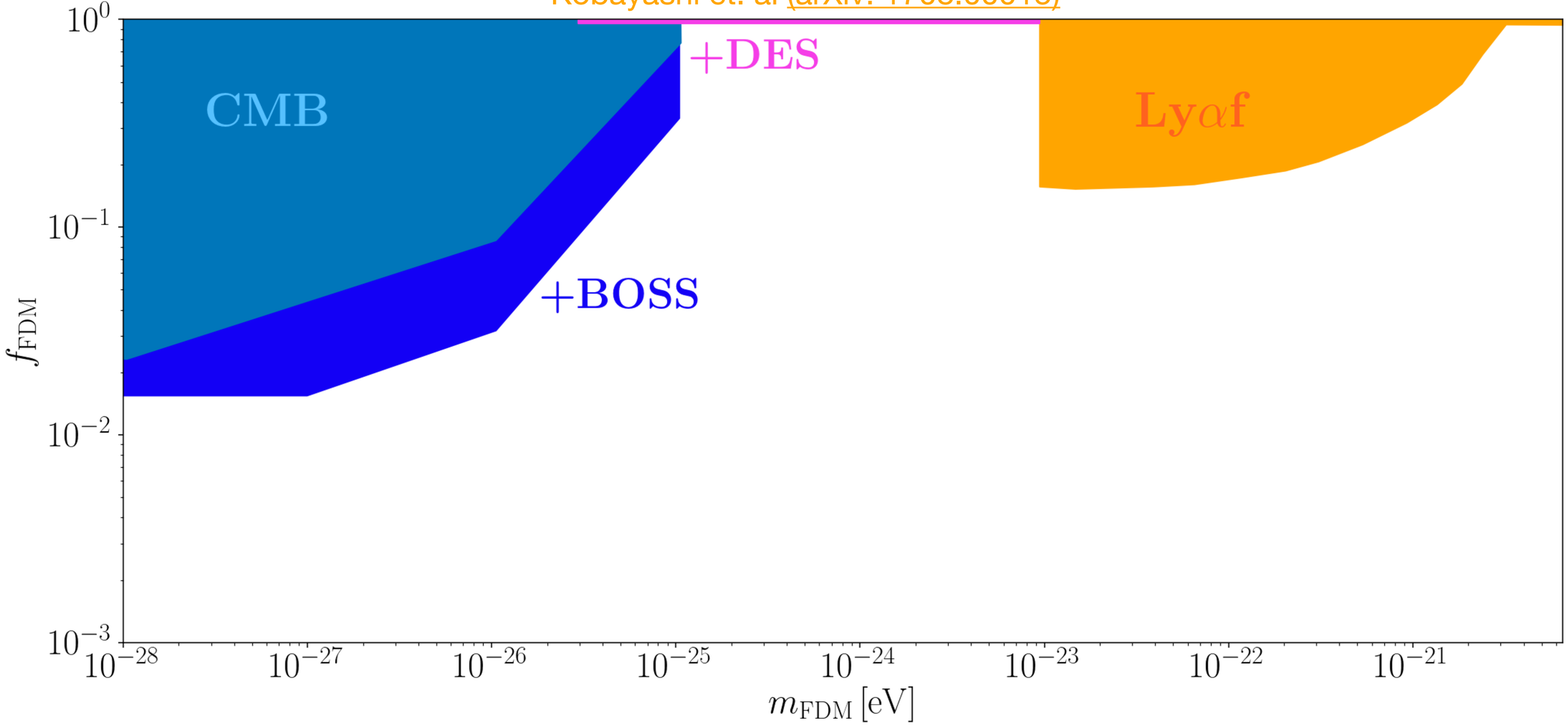


HERA sensitivity to FDM



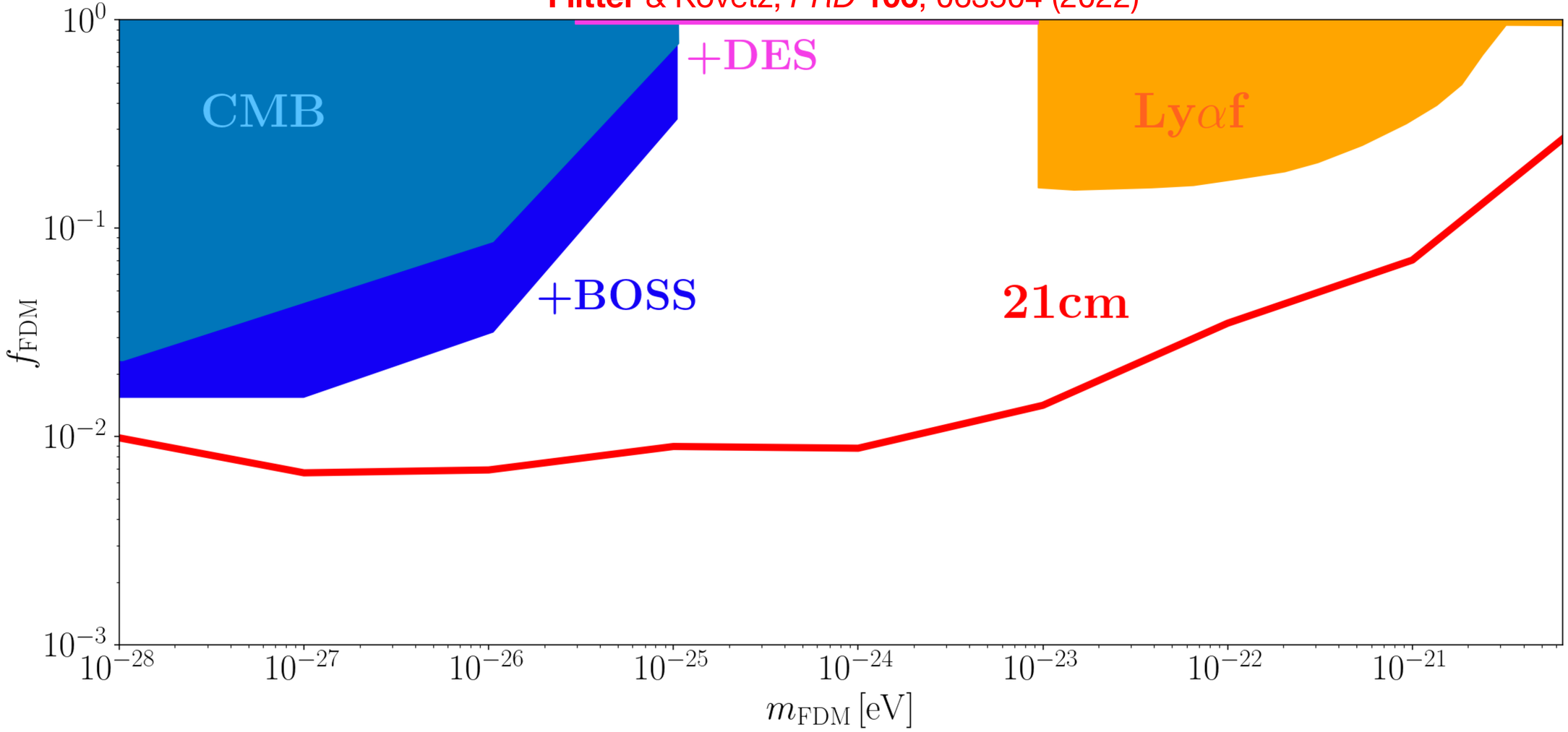
HERA sensitivity to FDM

Kobayashi et. al (arXiv: 1708.00015)



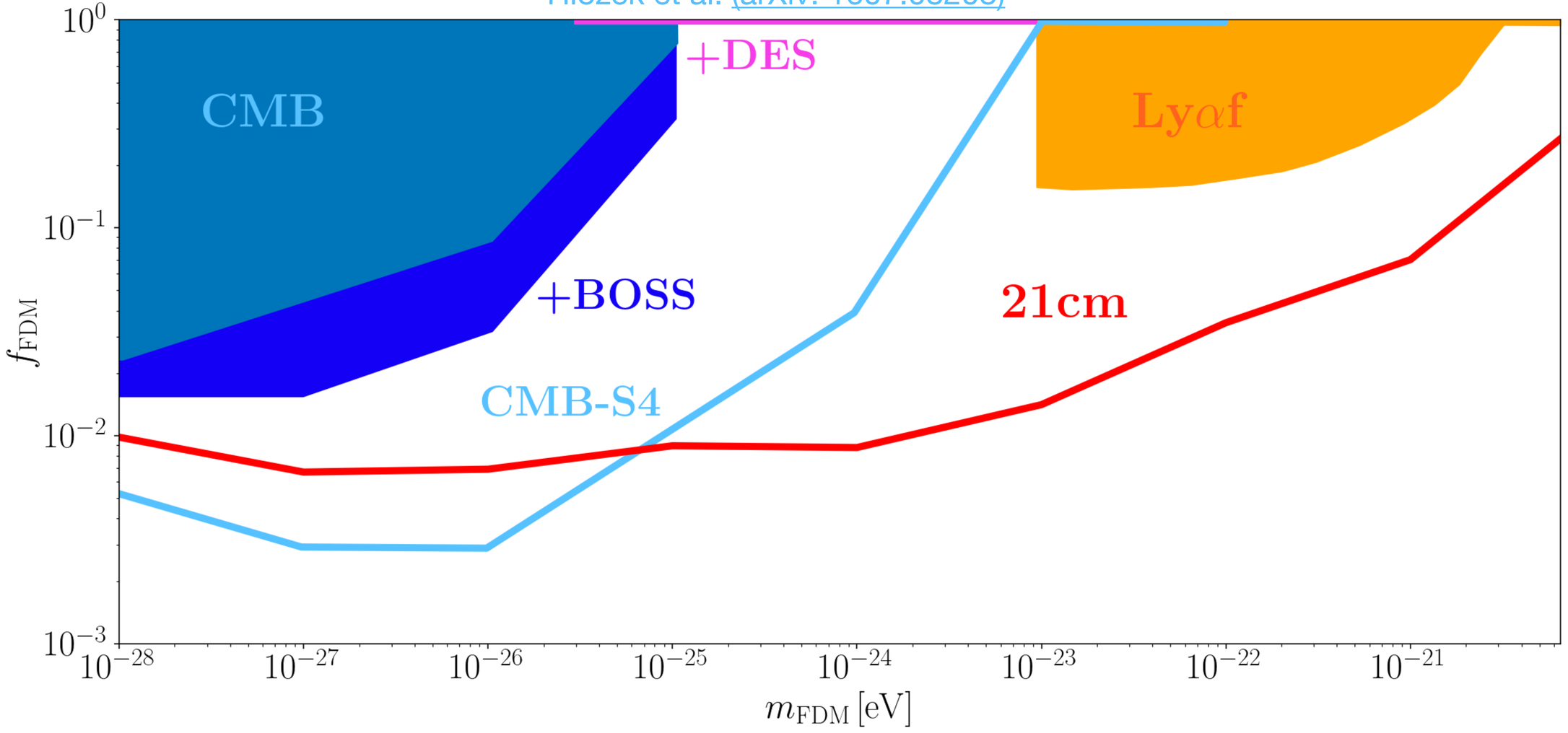
HERA sensitivity to FDM

Flitter & Kovetz, *PRD* **106**, 063504 (2022)



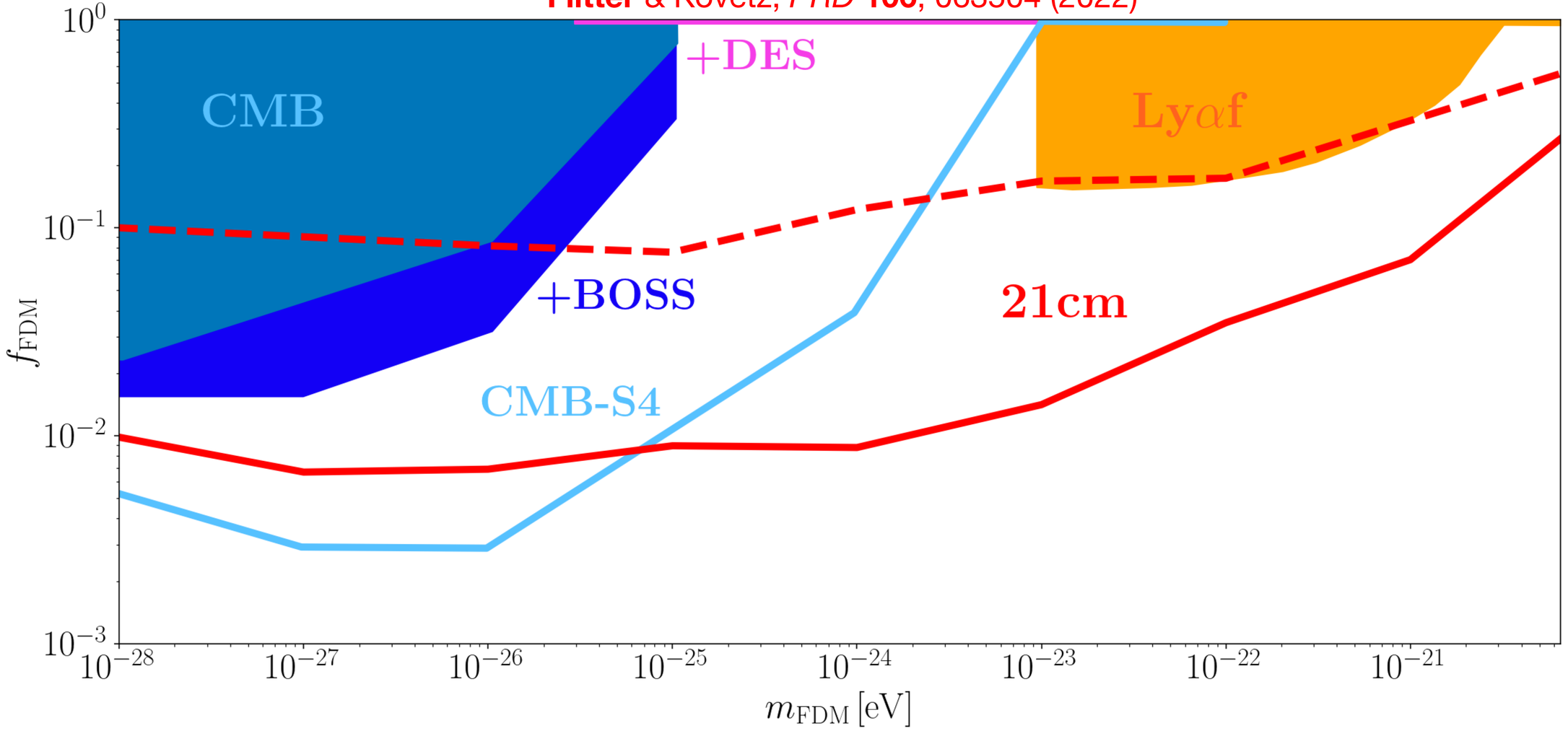
HERA sensitivity to FDM

Hložek et al. (arXiv: 1607.08208)



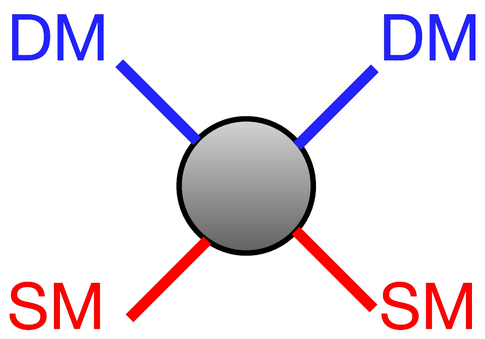
HERA sensitivity to FDM

Flitter & Kovetz, *PRD* **106**, 063504 (2022)



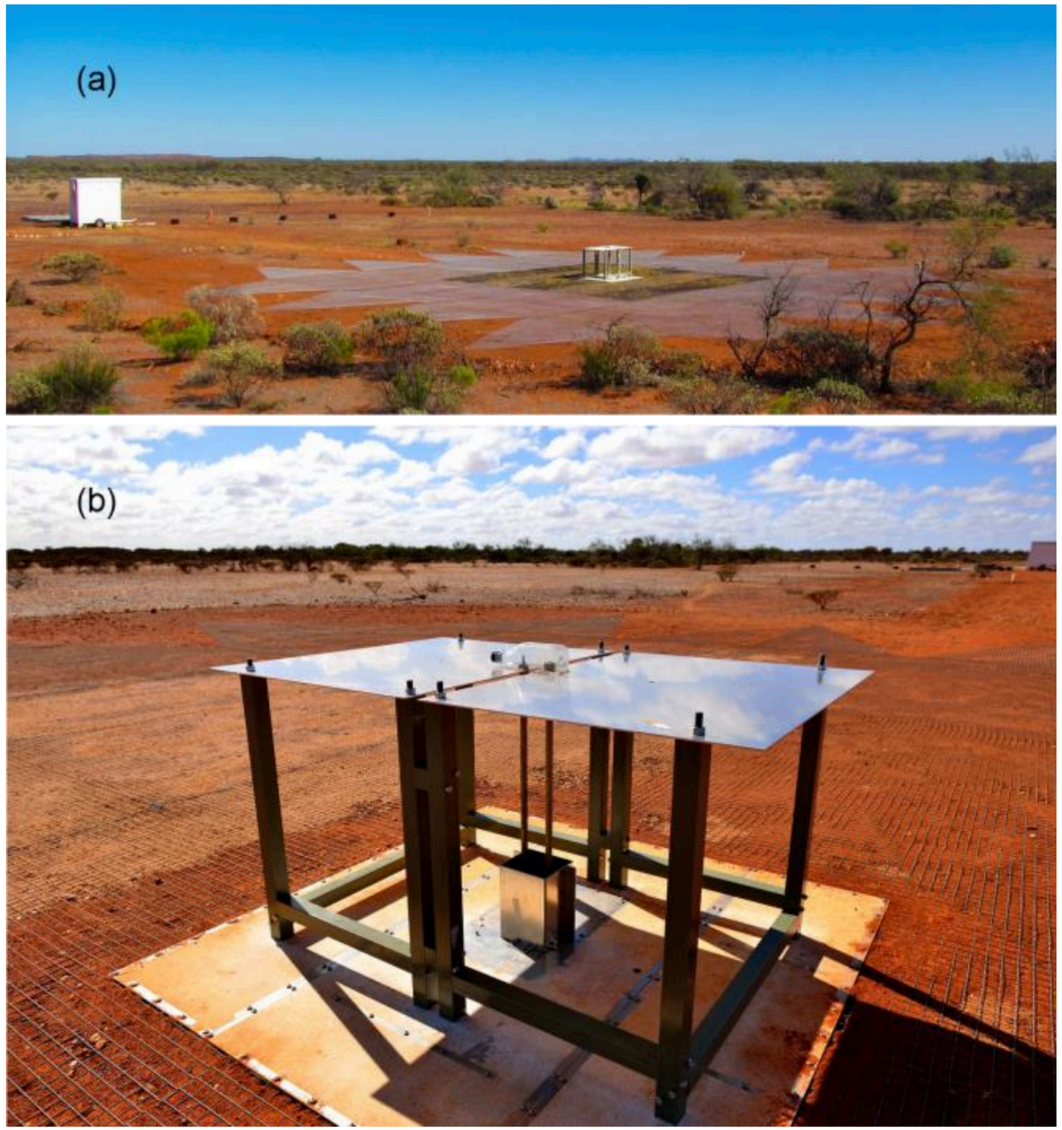
Case study II:
Scattering dark matter (SDM)

Scattering DM



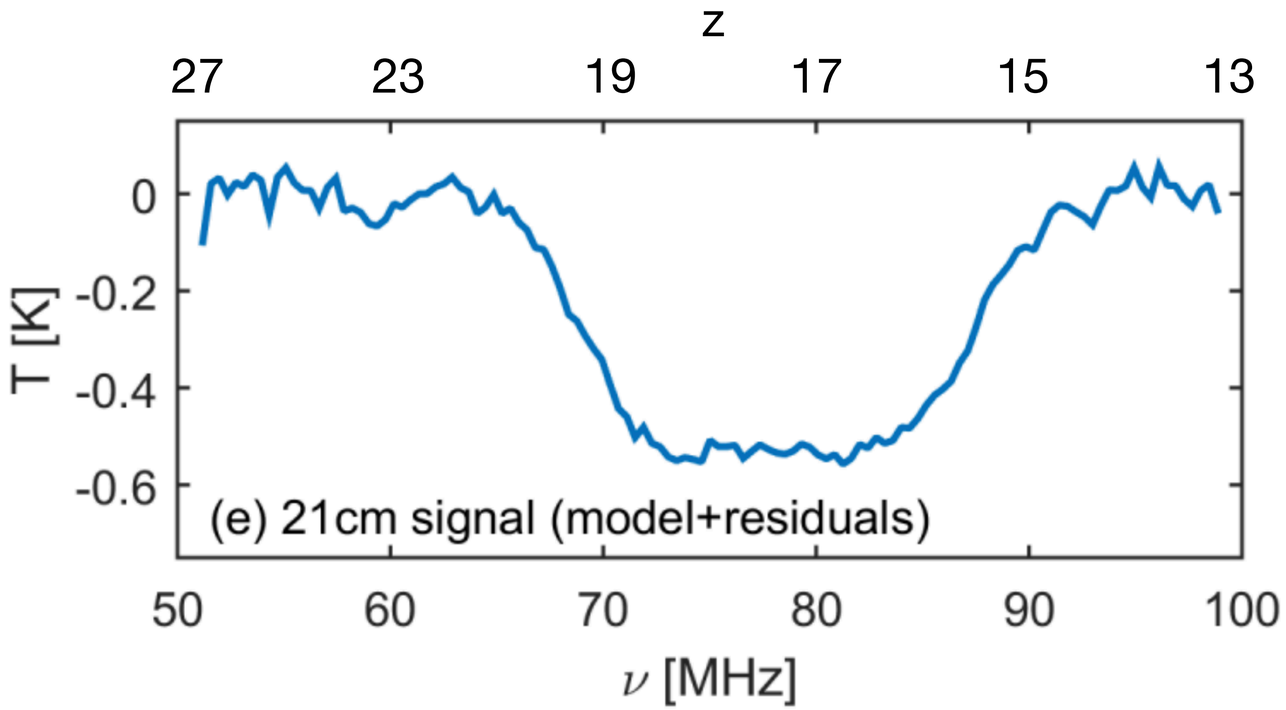
The EDGES experiment

Bowman et al. (arXiv: 1810.05912)



The EDGES experiment

Bowman et al. (arXiv: 1810.05912)



The EDGES experiment

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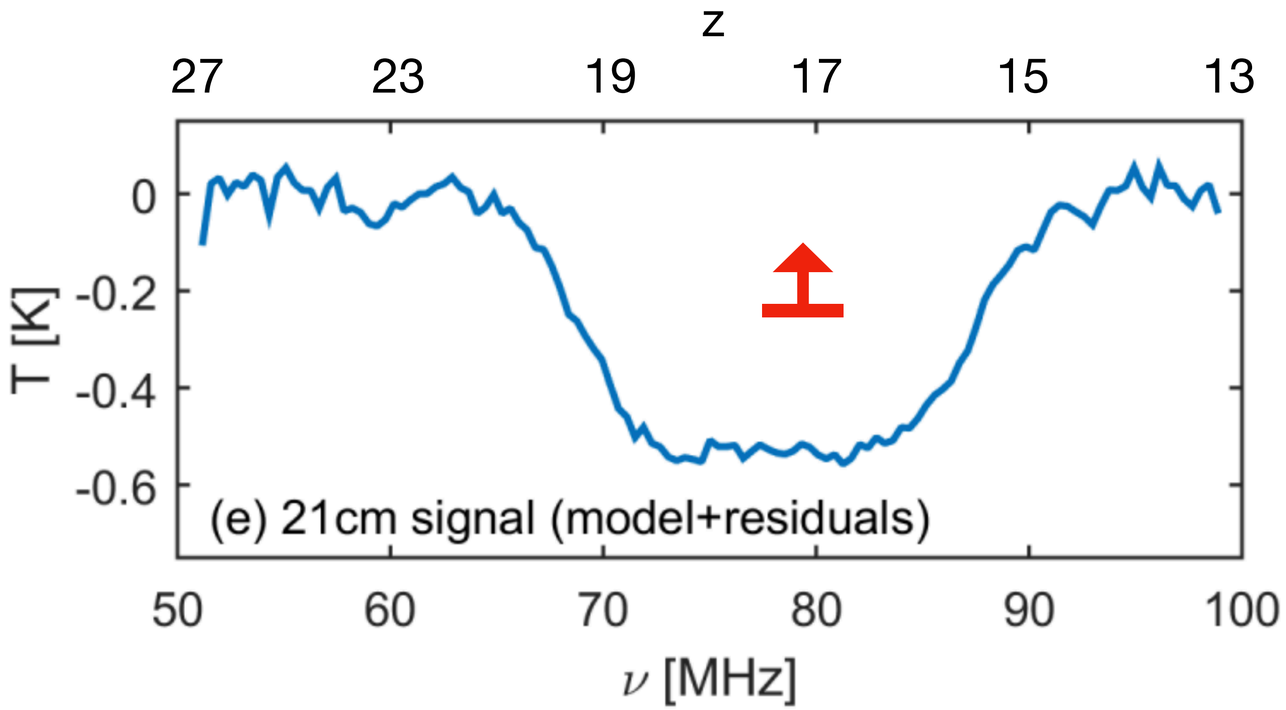
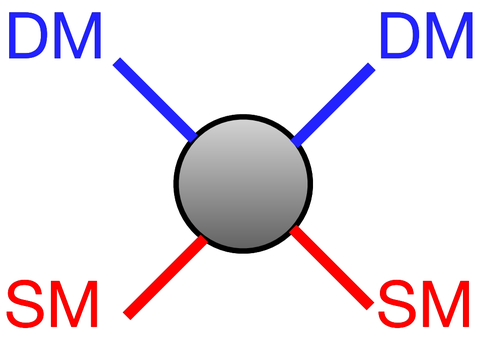
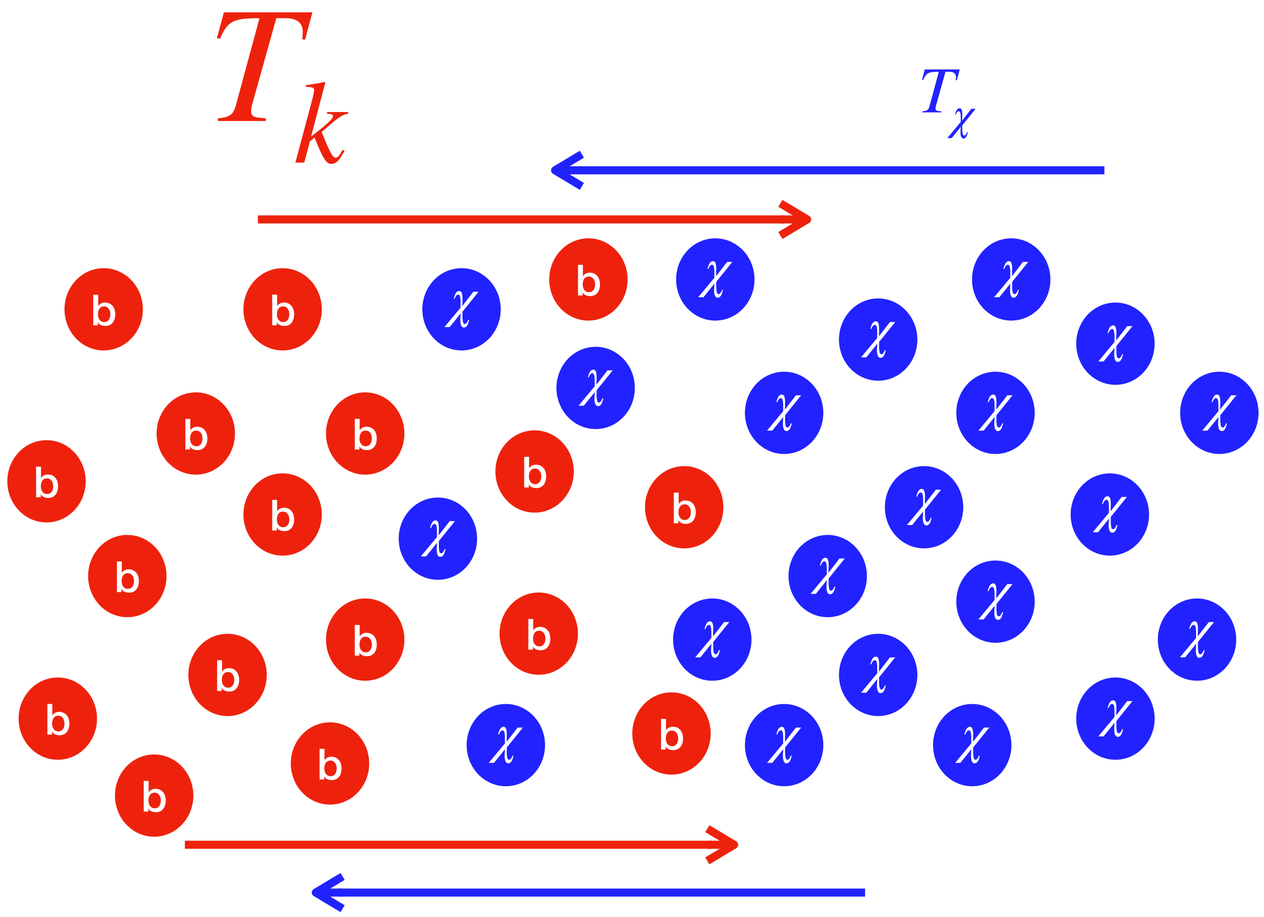


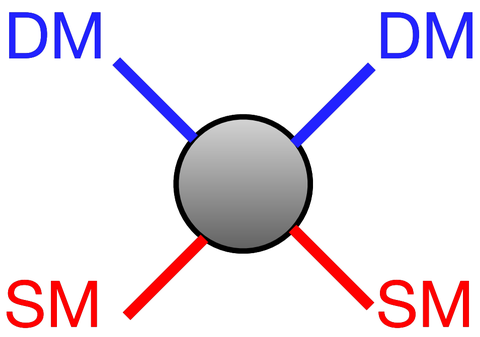
EDGES minimum is 3.8σ below ΛCDM expectation!

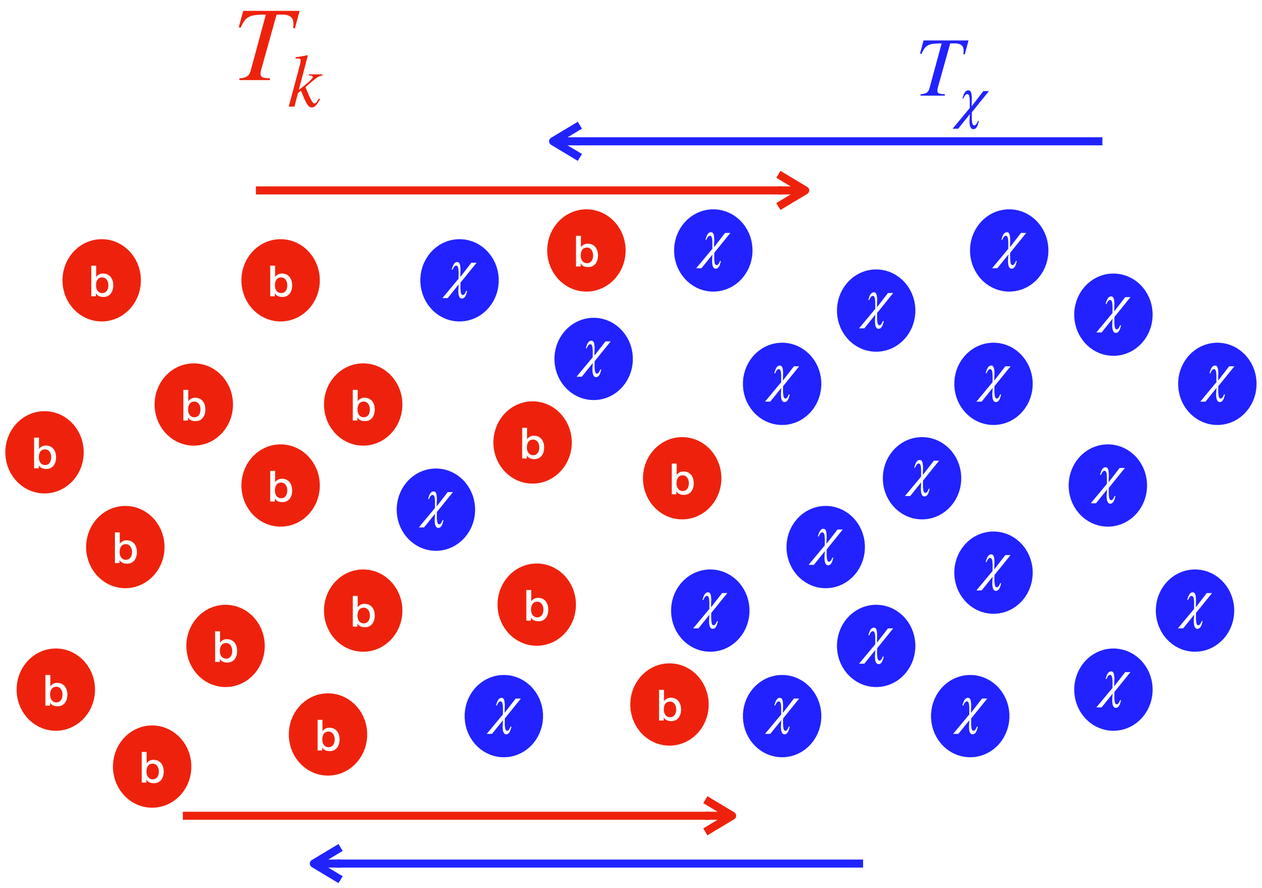
Scattering DM





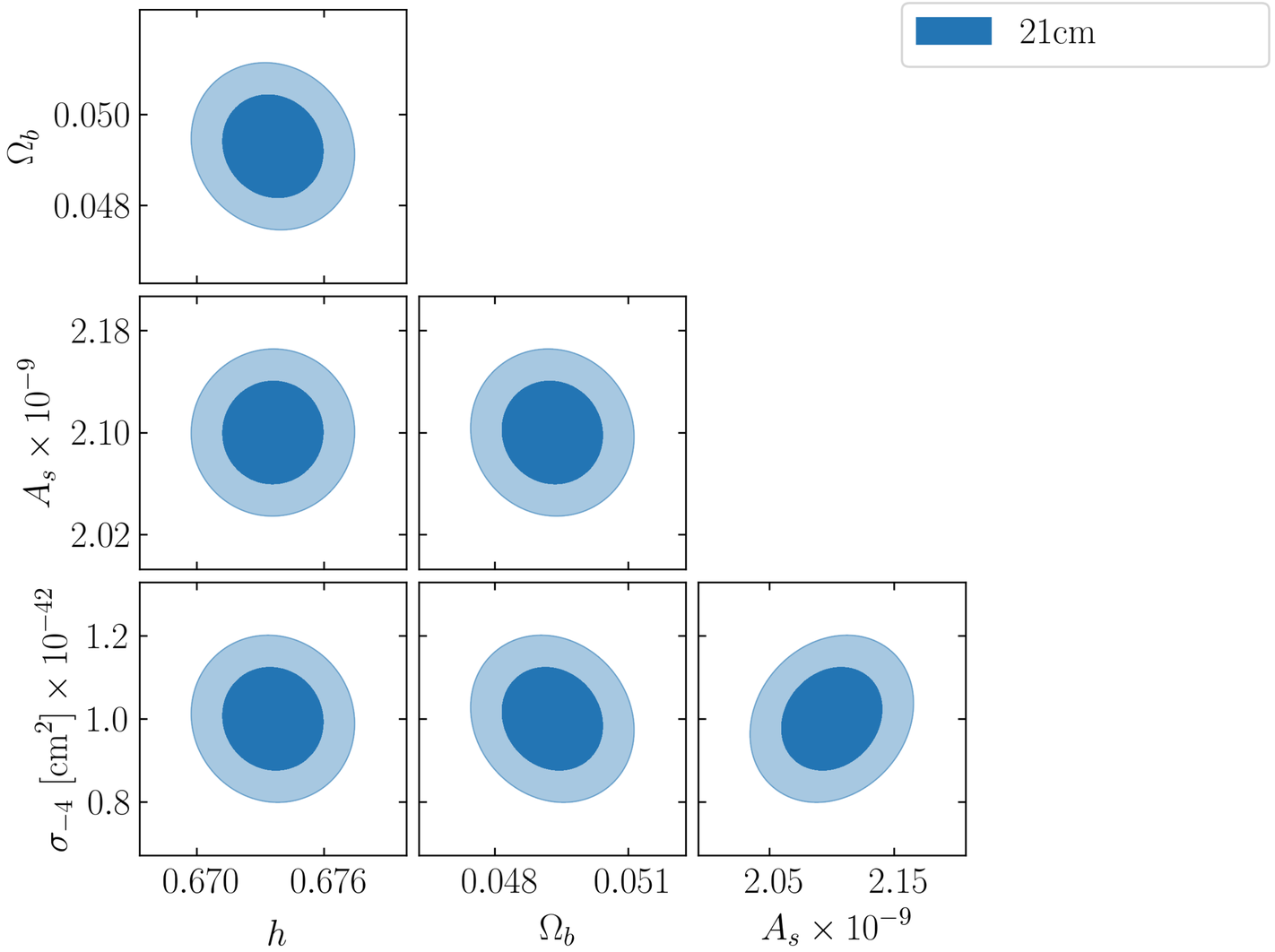
Scattering DM





Scattering DM

Flitter & Kovetz, *PRD,* 109, 043512 (2023)



Scattering DM

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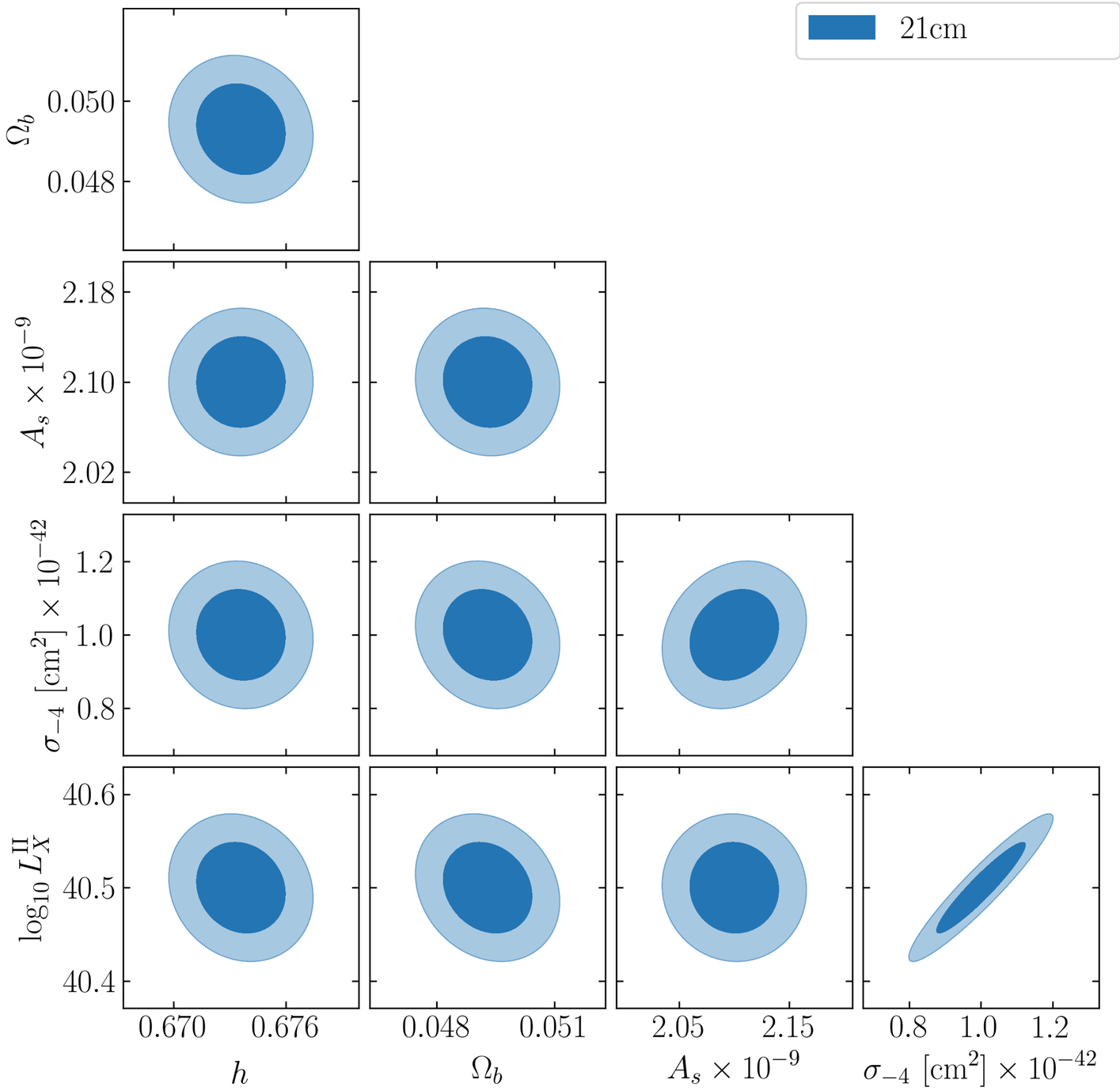
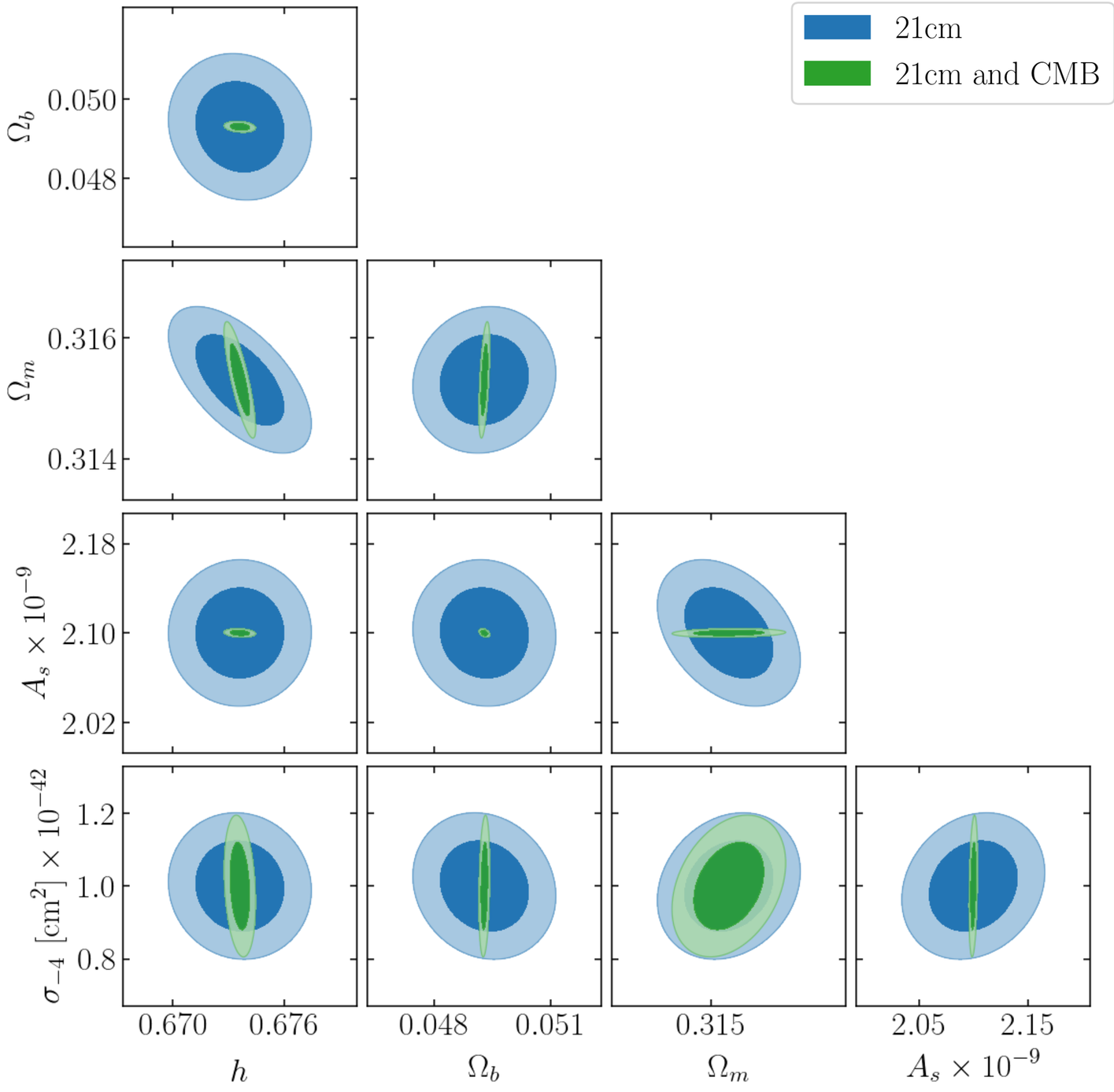


Scattering DM

Flitter & Kovetz, *PRD,* 109, 043512 (2023)



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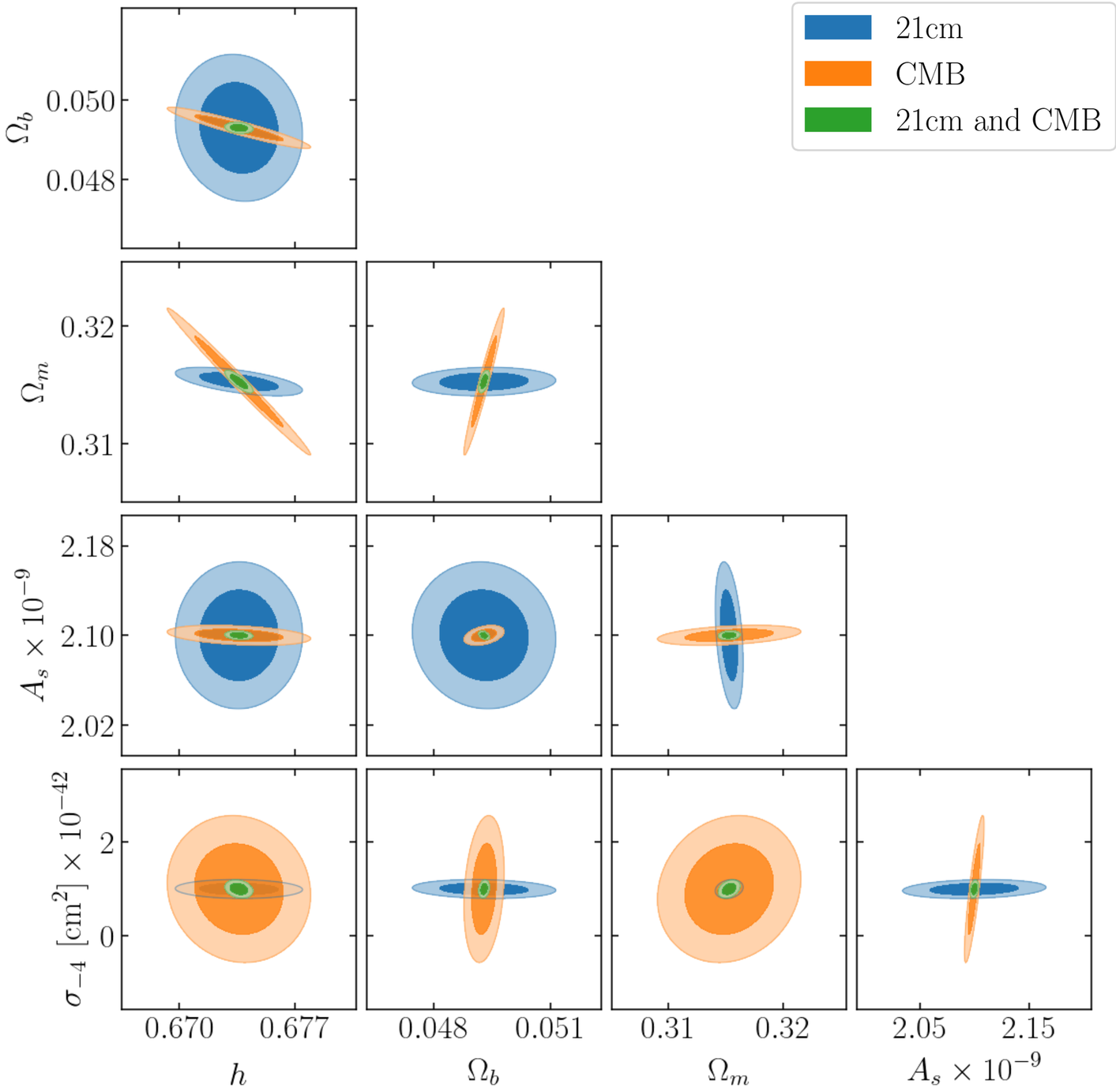
Flitter & Kovetz, *PRD,* 109, 043512 (2023)



Summary

- The 21cm signal is a promising observable for studying dark matter
- In particular, the 21cm signal can constrain (or detect!) FDM and SDM in regions in the parameter space where the CMB is less sensitive
- Joint analysis of 21cm and CMB can relax some of the degeneracies and improve detectability

Thanks!