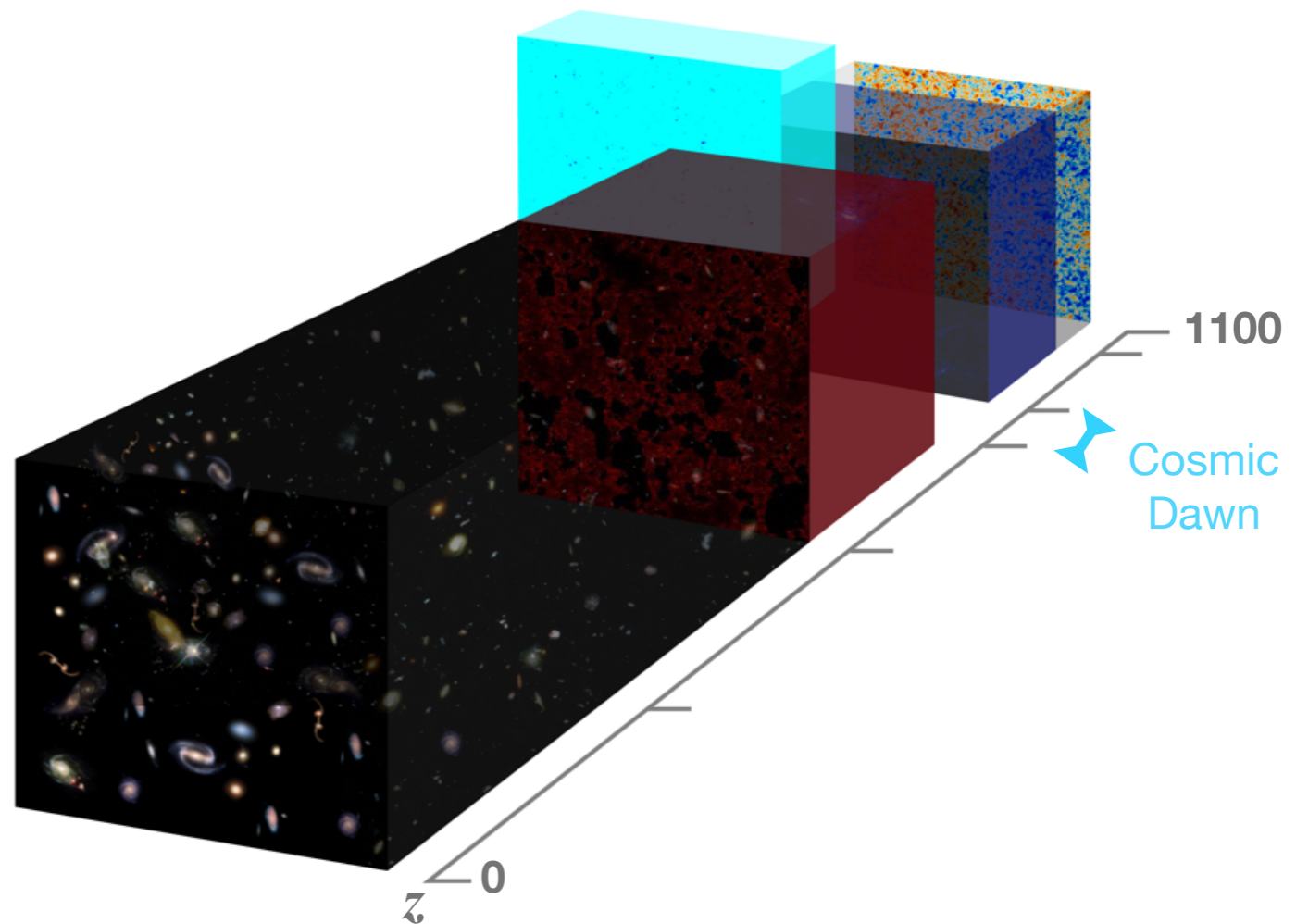
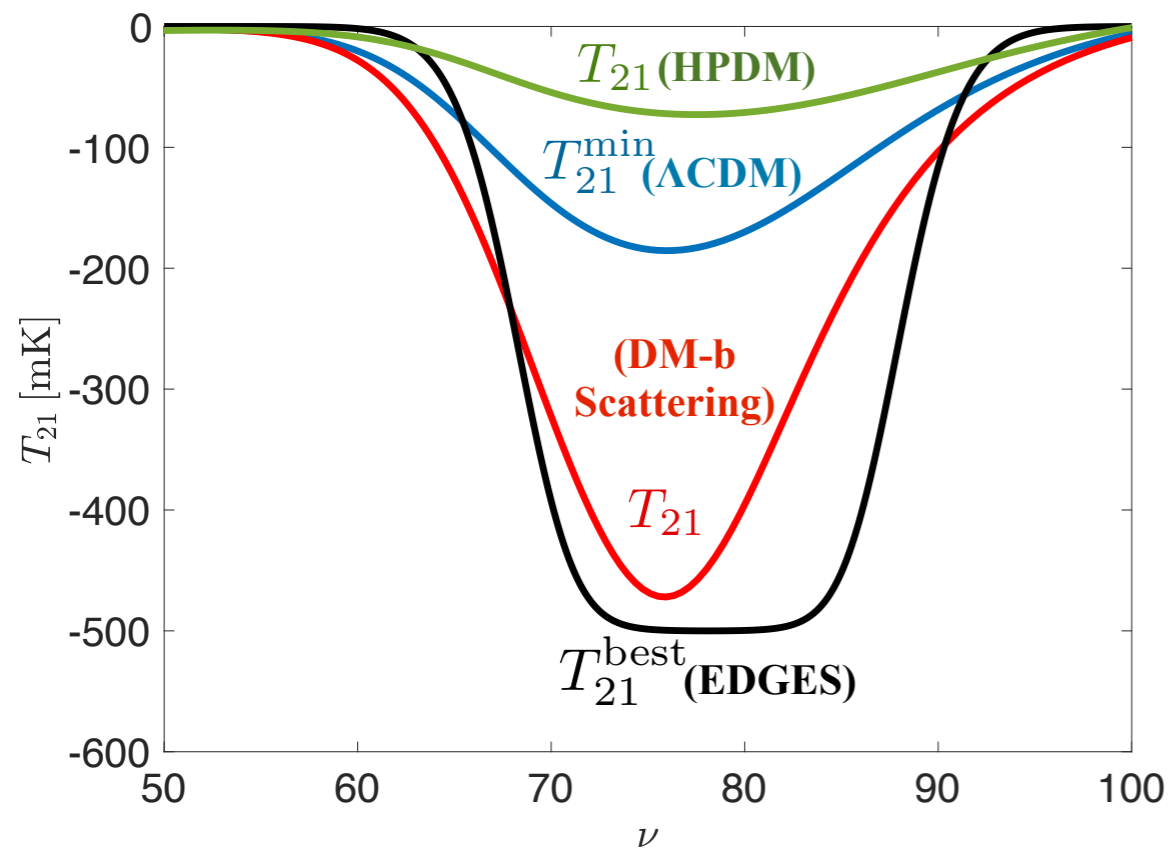


Dark Matter in Light of the 21cm EDGES Signal

Ely D. Kovetz

Johns Hopkins University



Based on arXiv:1509.00029, arXiv:1807.01139, arXiv:1808.00001, arXiv:1809.01139:

Muñoz, EDK and Ali-Haïmoud, “Heating of baryons due to scattering with dark matter during the dark ages”

EDK, Poulin, Gluscevic, Boddy, Barkana and Kamionkowski, “Tighter Limits on Dark Matter Explanations of the Anomalous EDGES 21cm Signal”

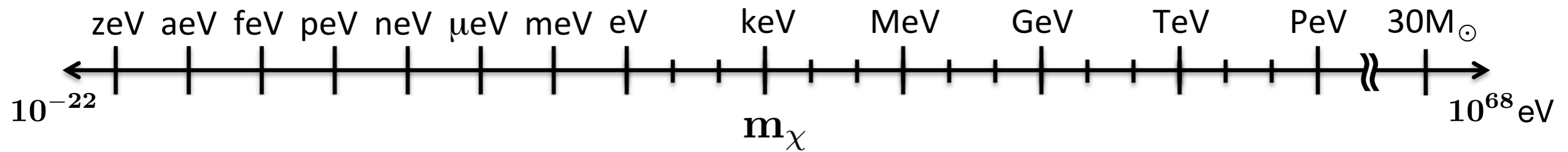
Boddy, Gluscevic, Poulin, EDK, Kamionkowski and Barkana, “A Critical Assessment of CMB Limits on Dark Matter-Baryon Scattering”

EDK, Cholis and Kaplan, “Bounds on Ultra-Light Hidden-Photon Dark Matter from 21cm at Cosmic Dawn”

The Dark Matter Landscape

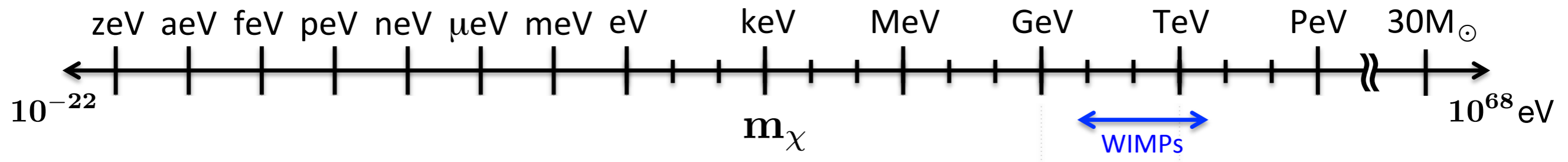
The Dark Matter Landscape

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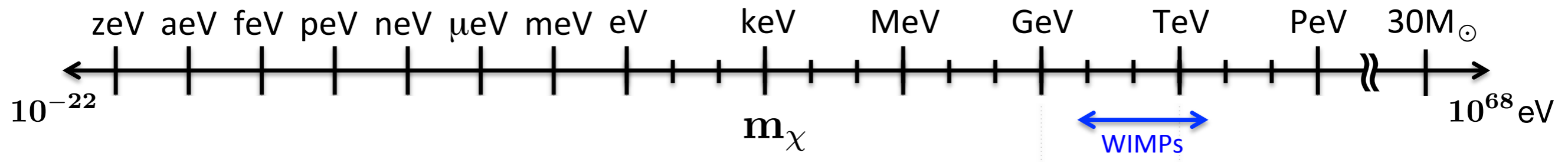
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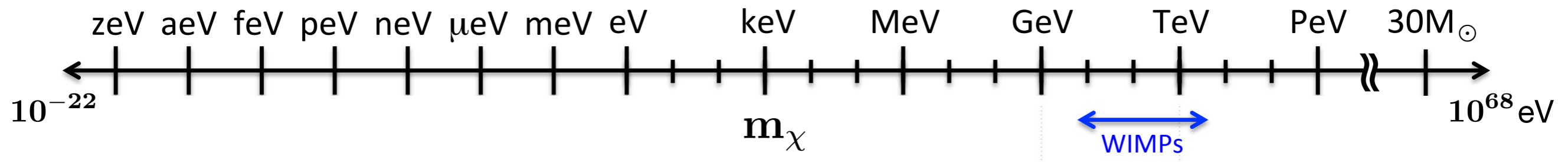
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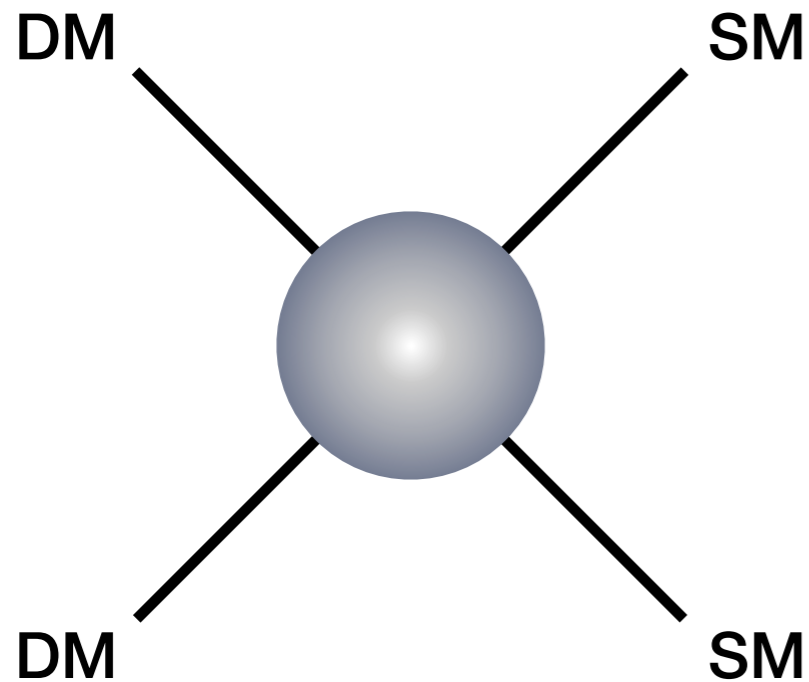
Search techniques:

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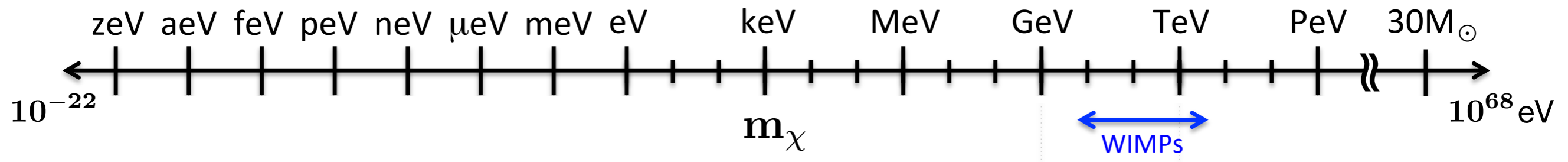


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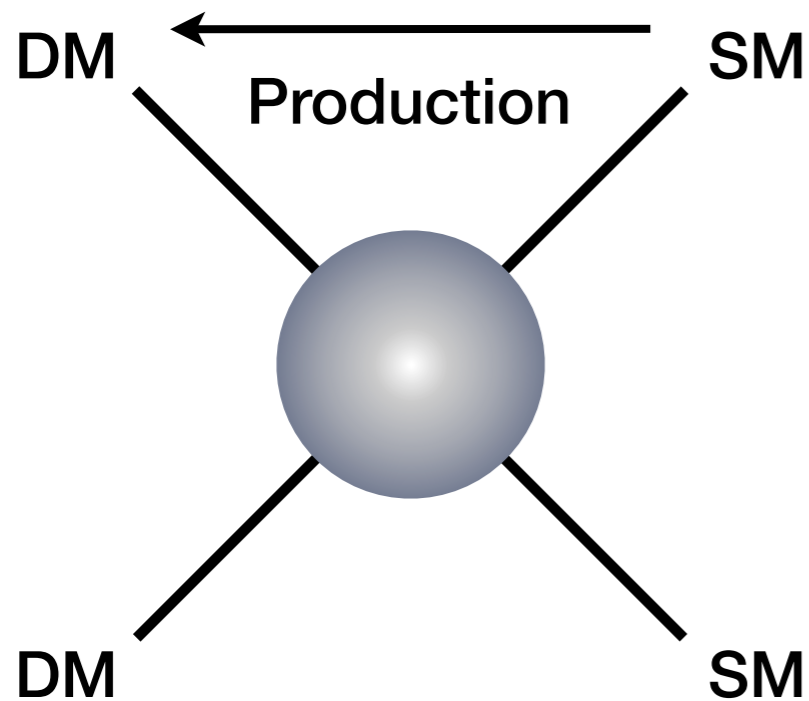


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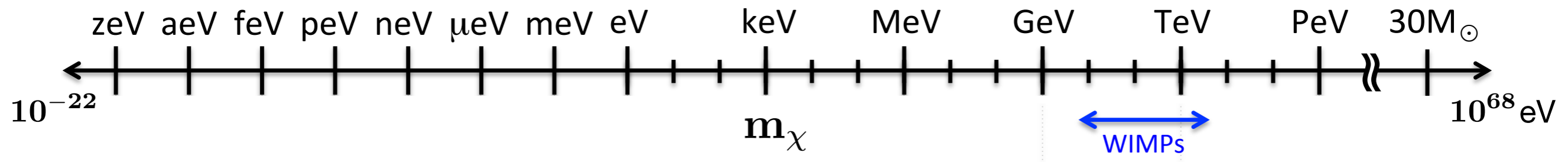


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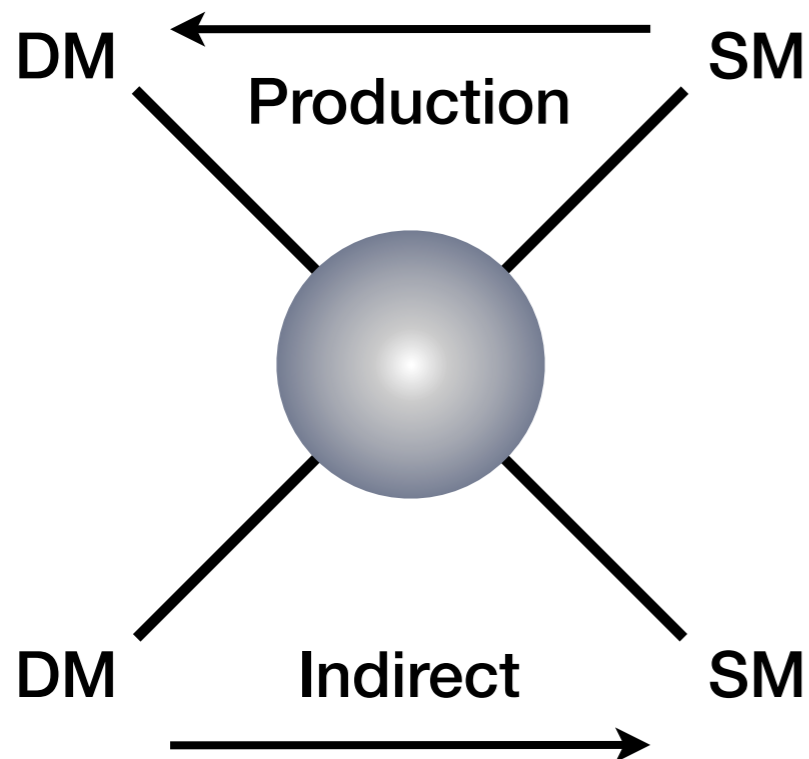


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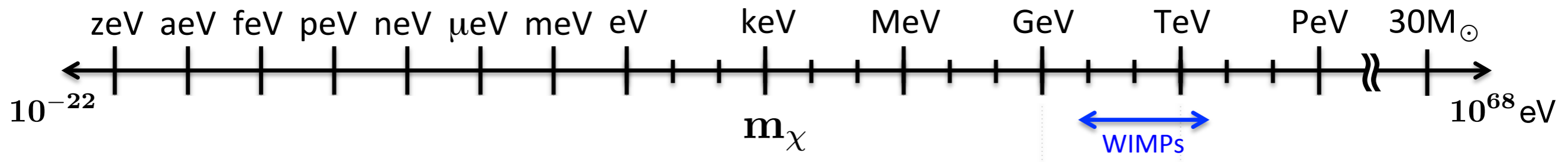


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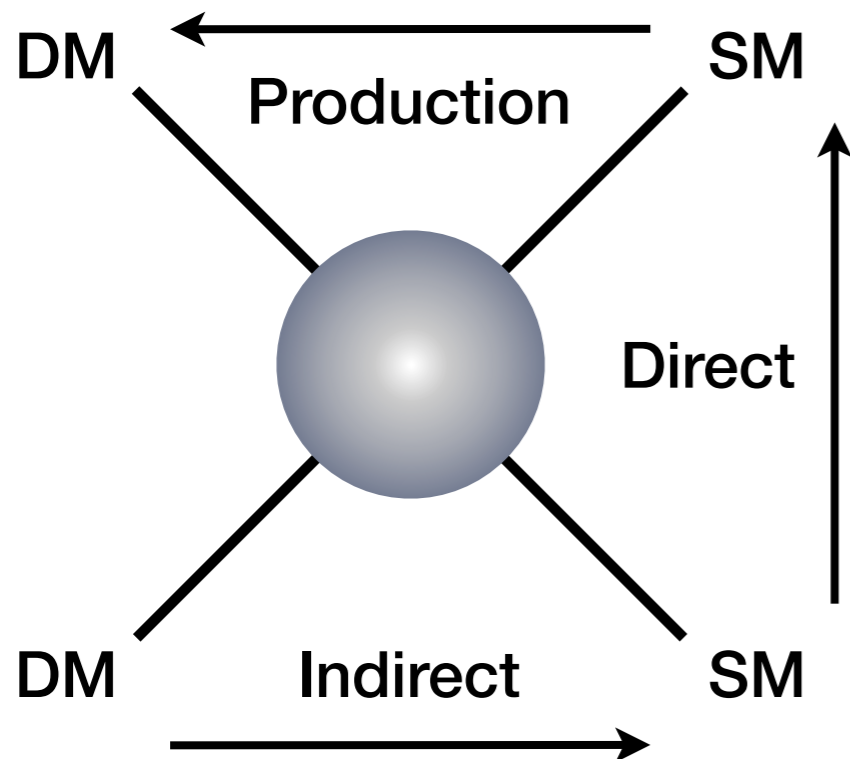


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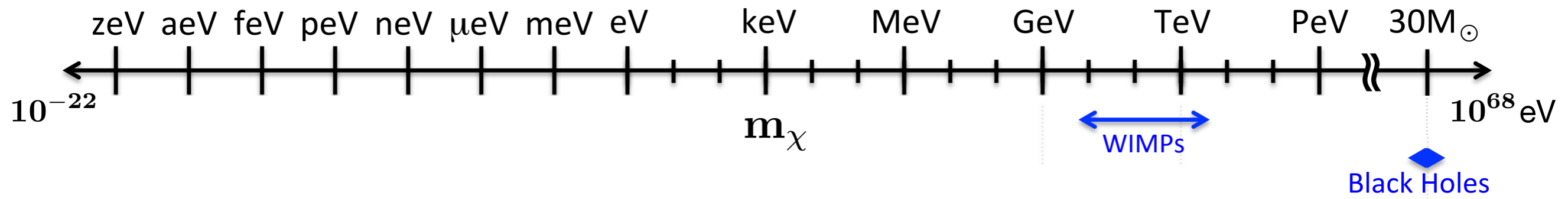


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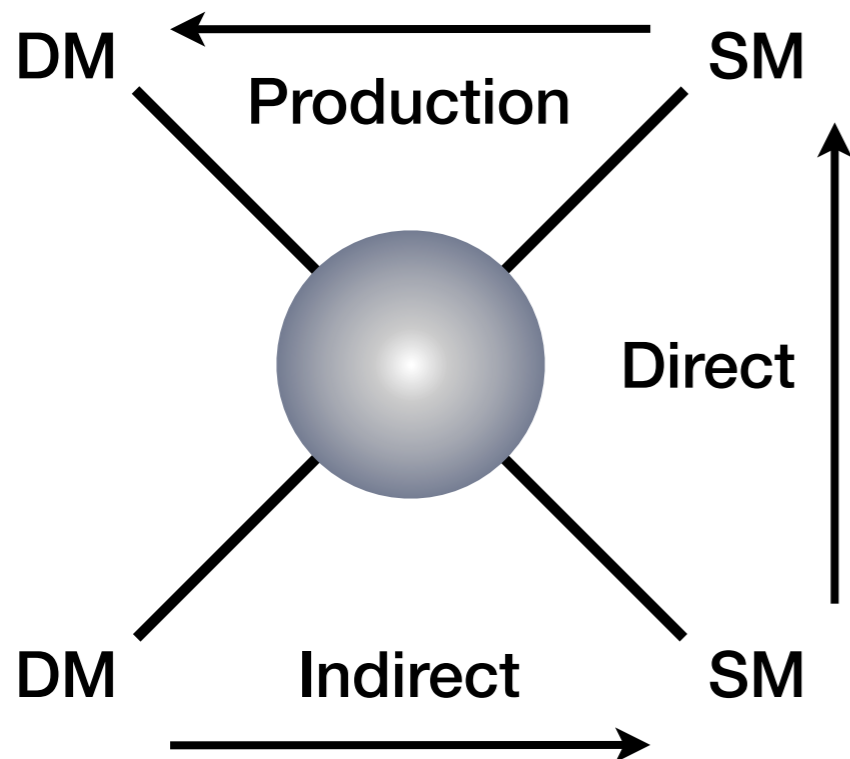


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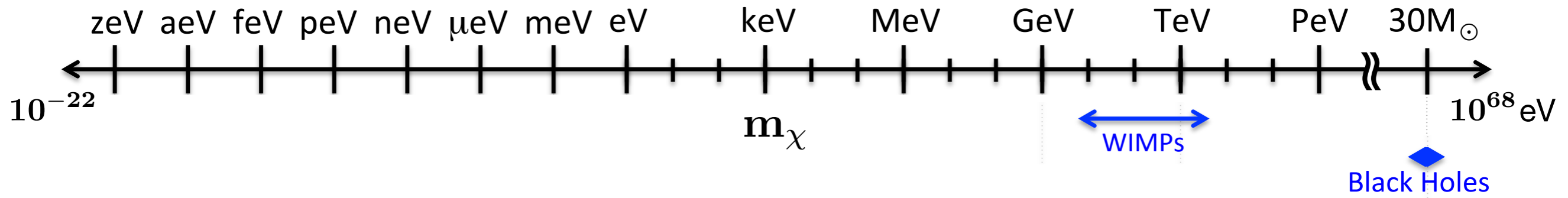


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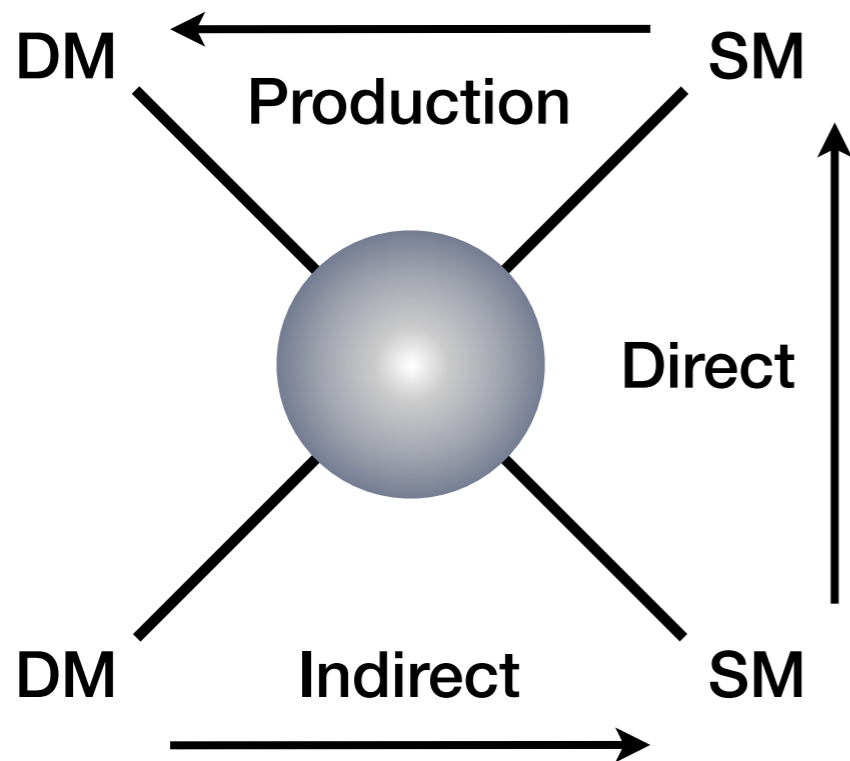


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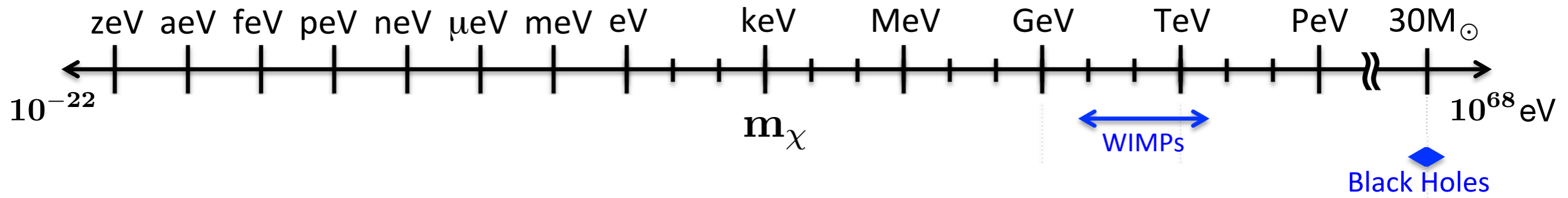
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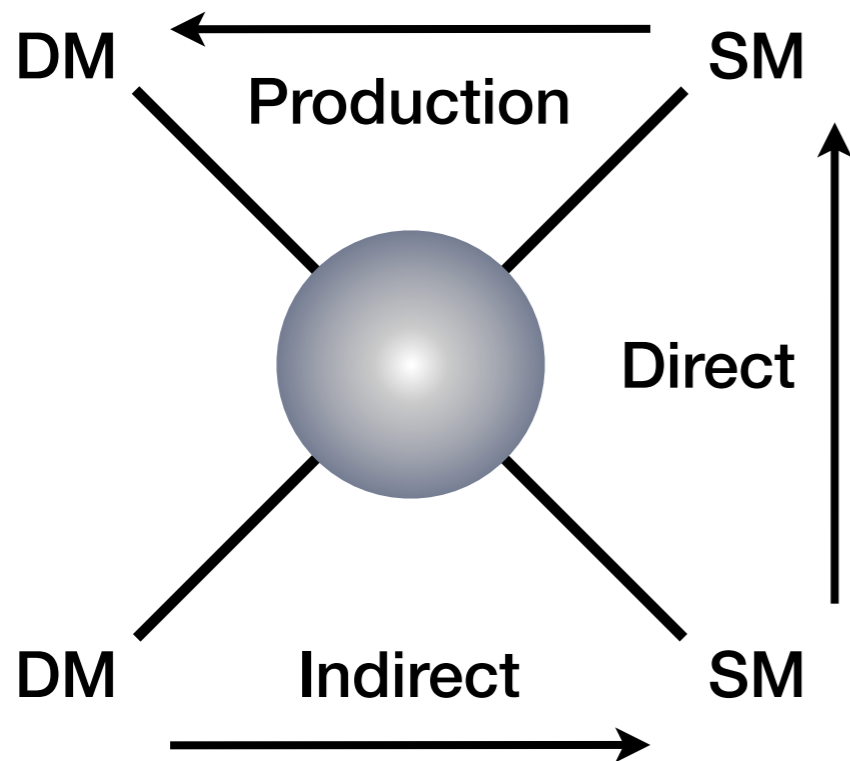
Similarly...

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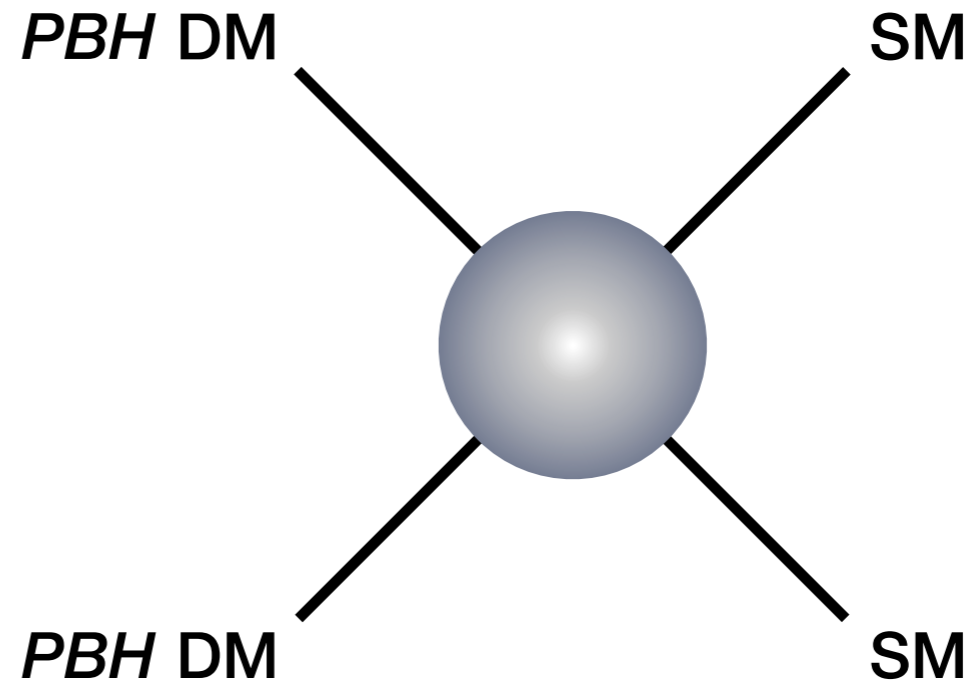


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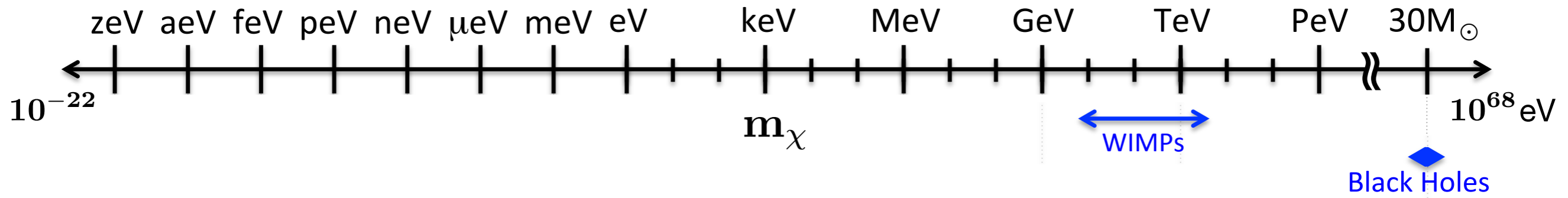
Similarly...

Kovetz, PRL 2017

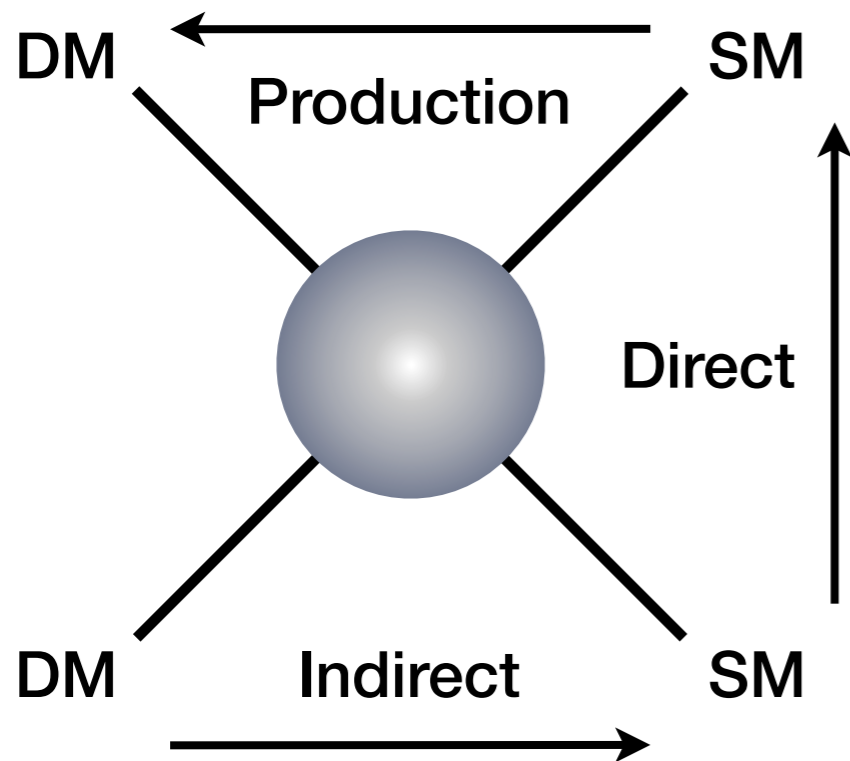


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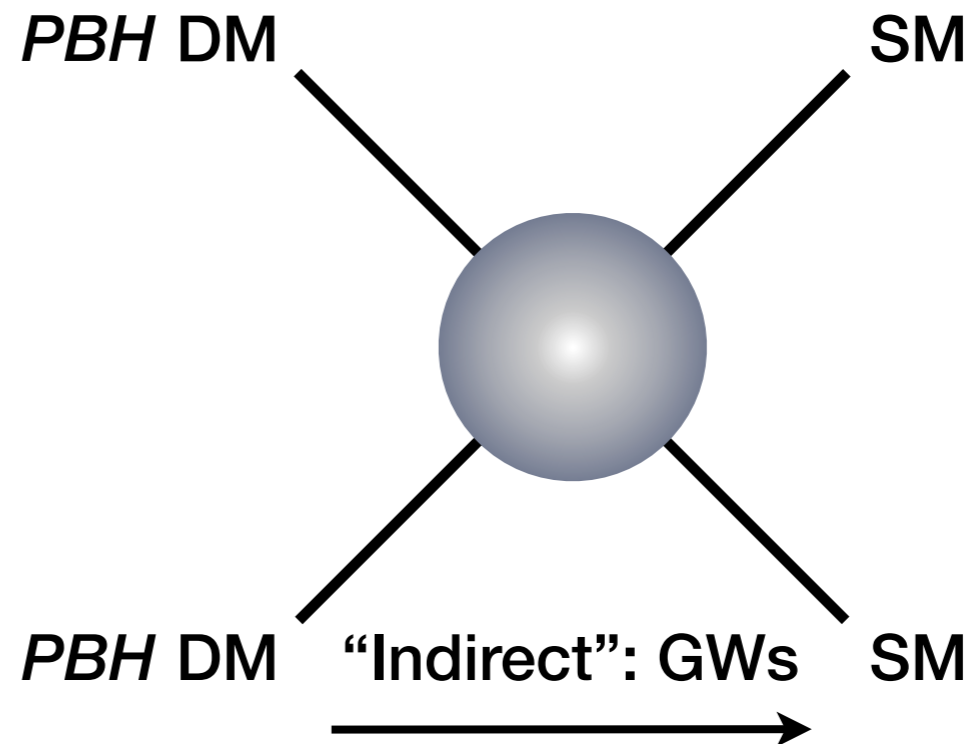


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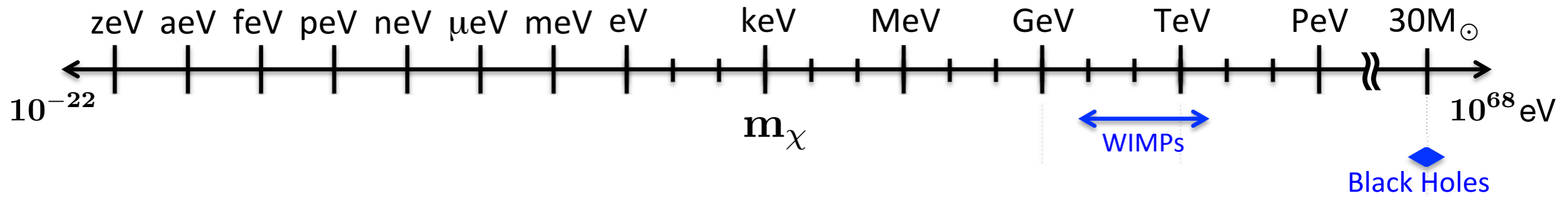
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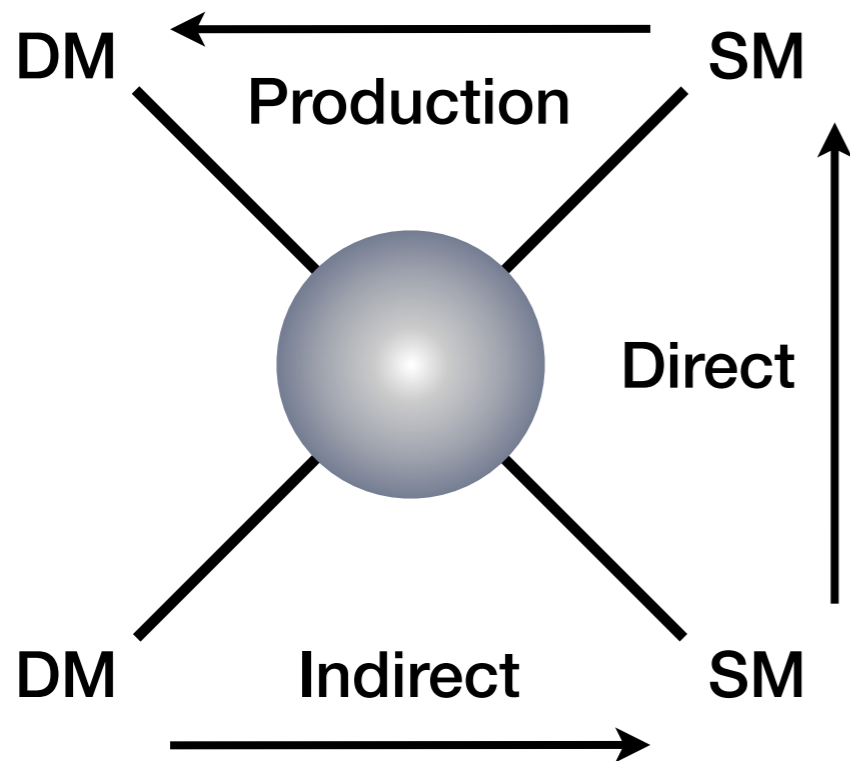


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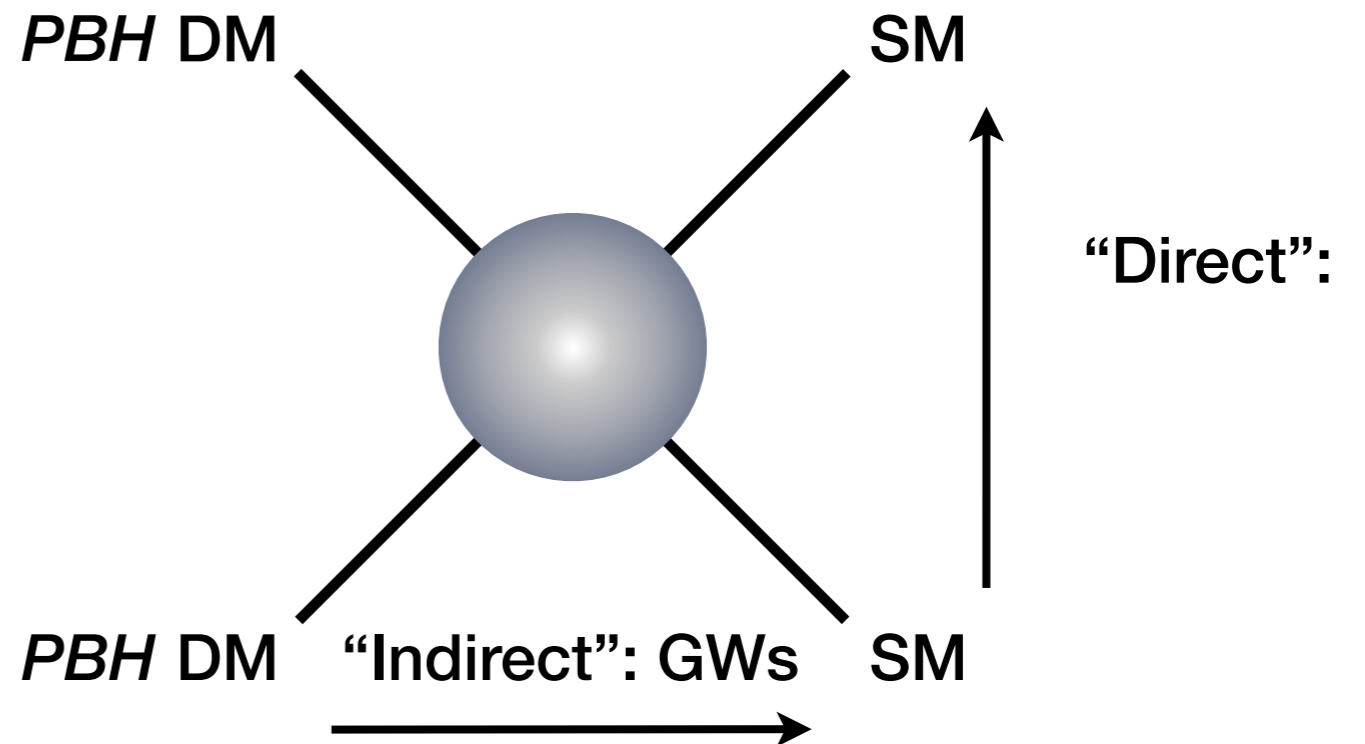


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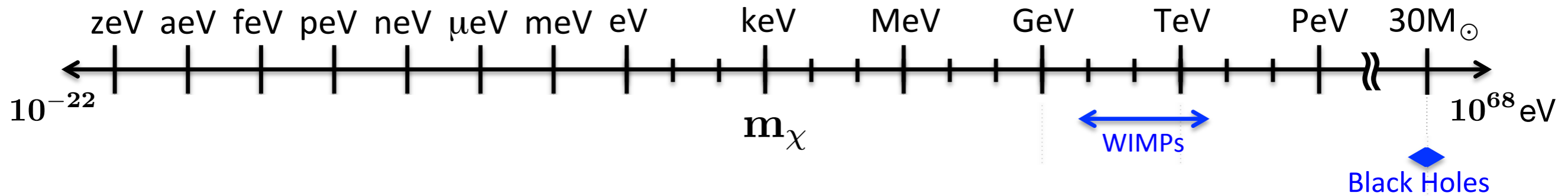
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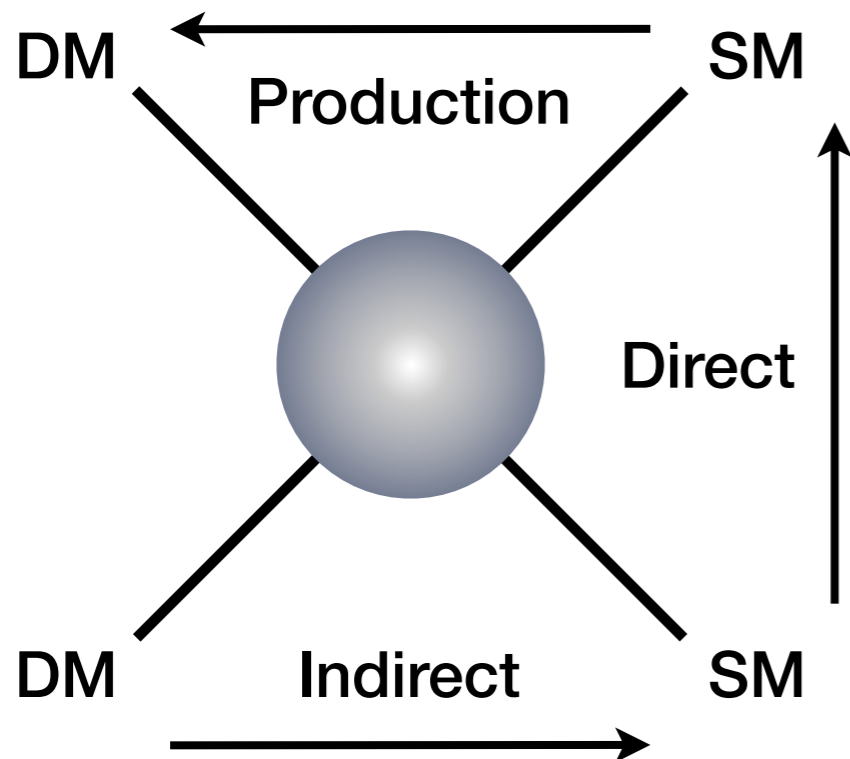


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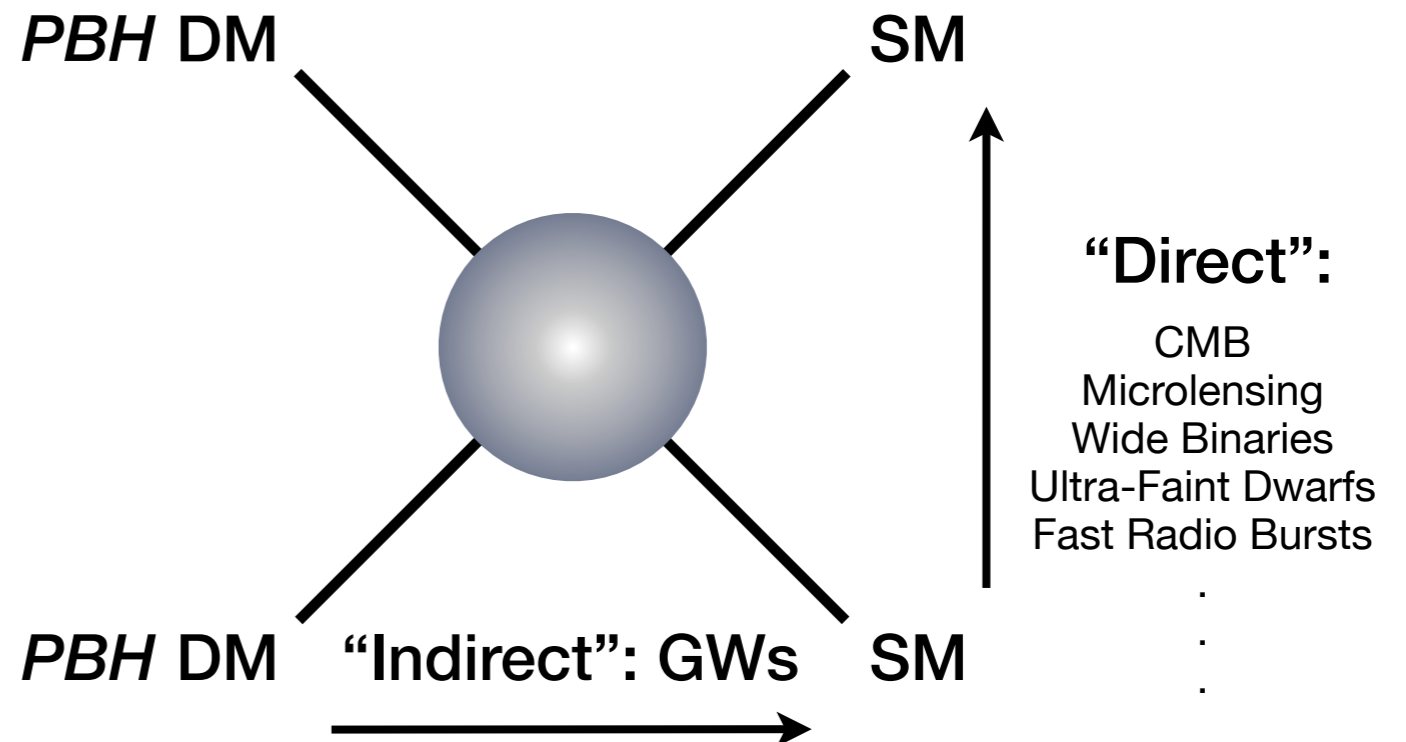


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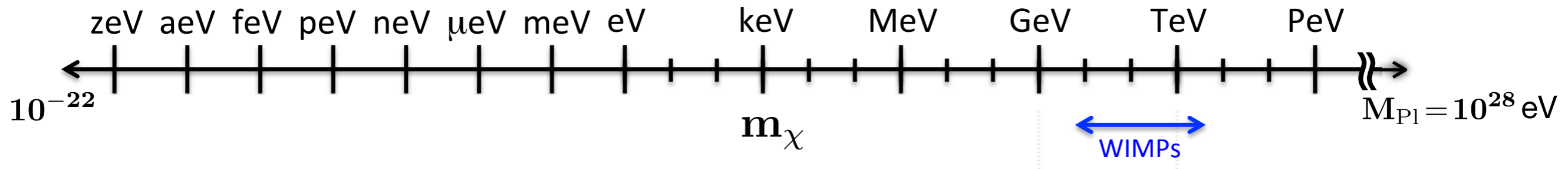
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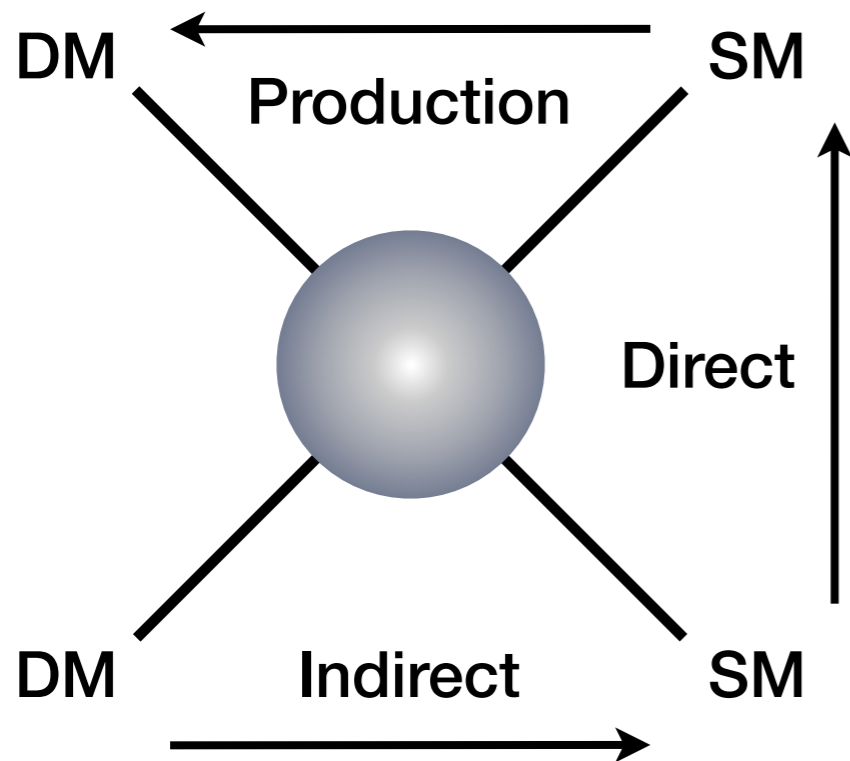


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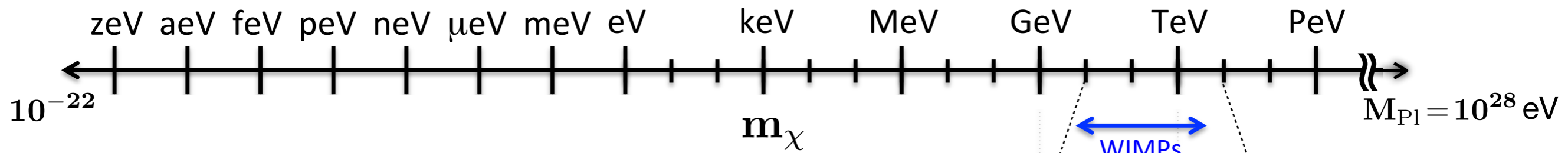


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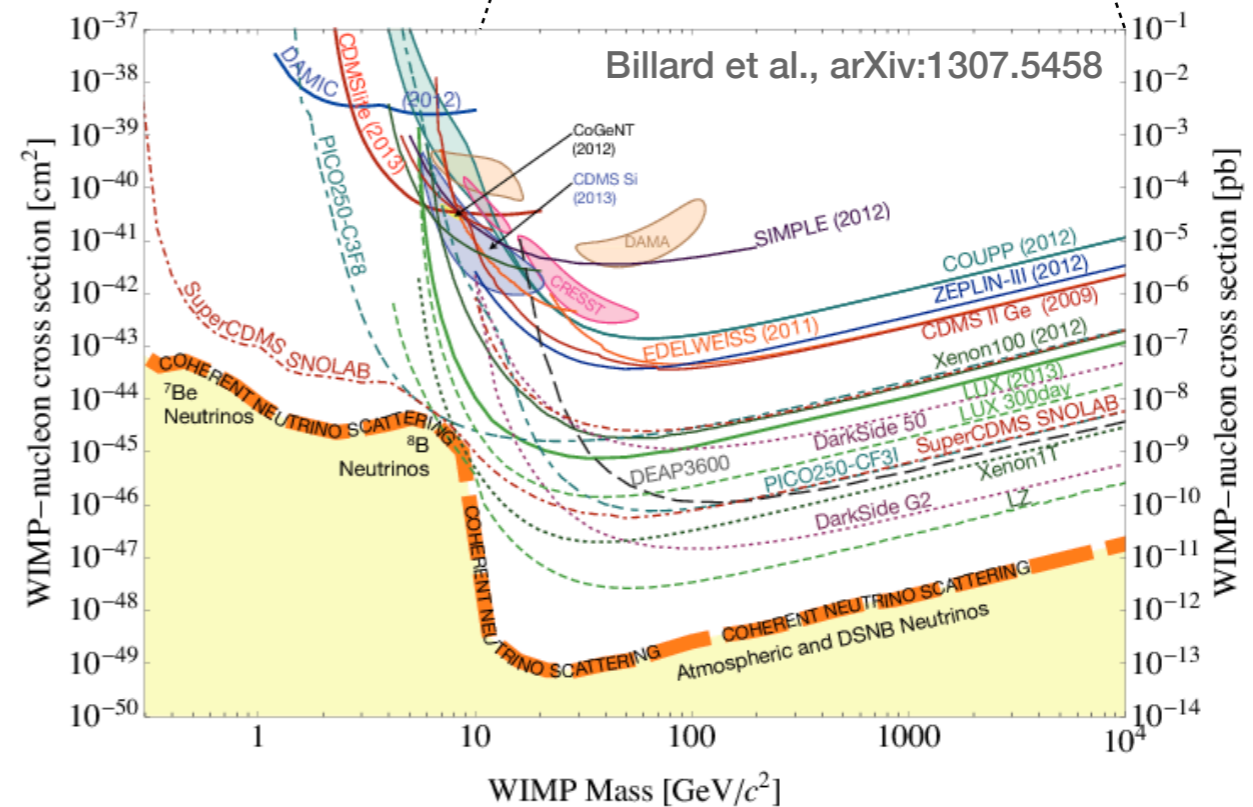
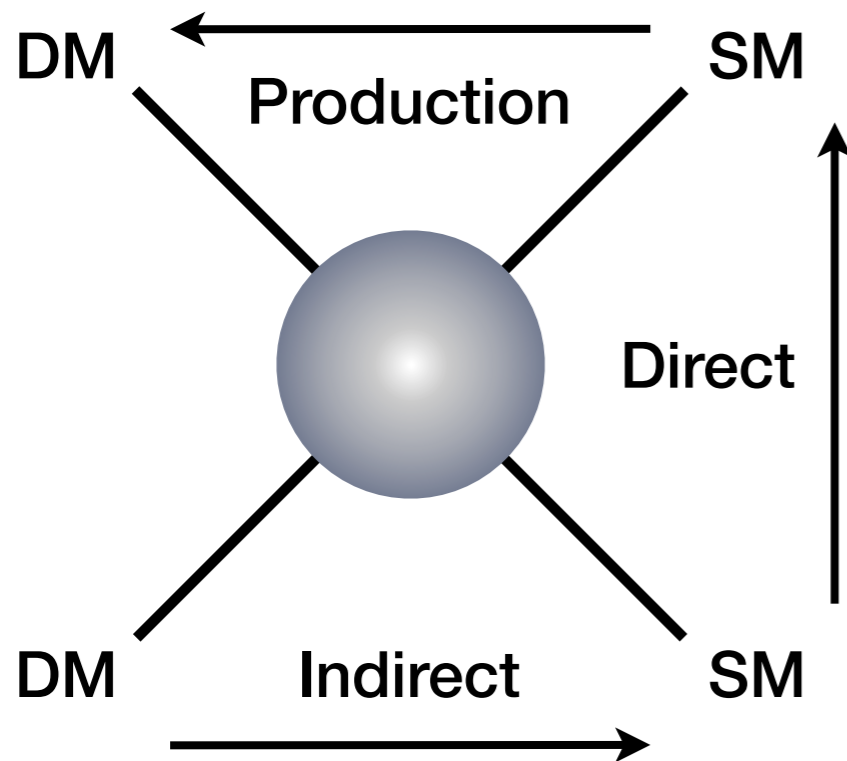


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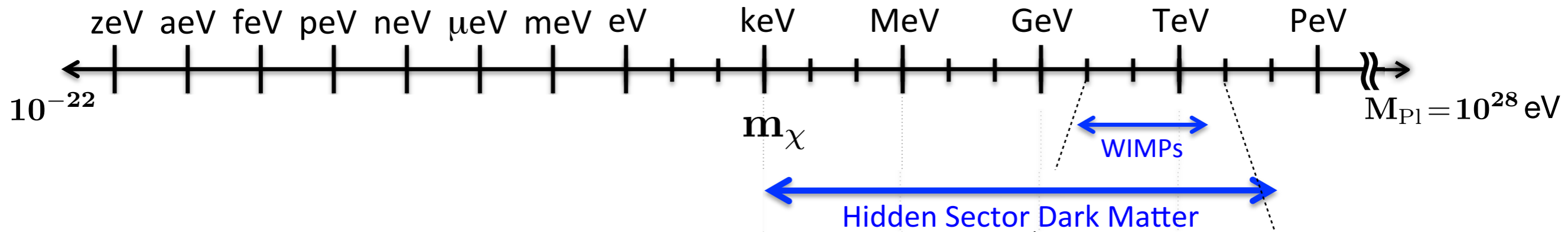


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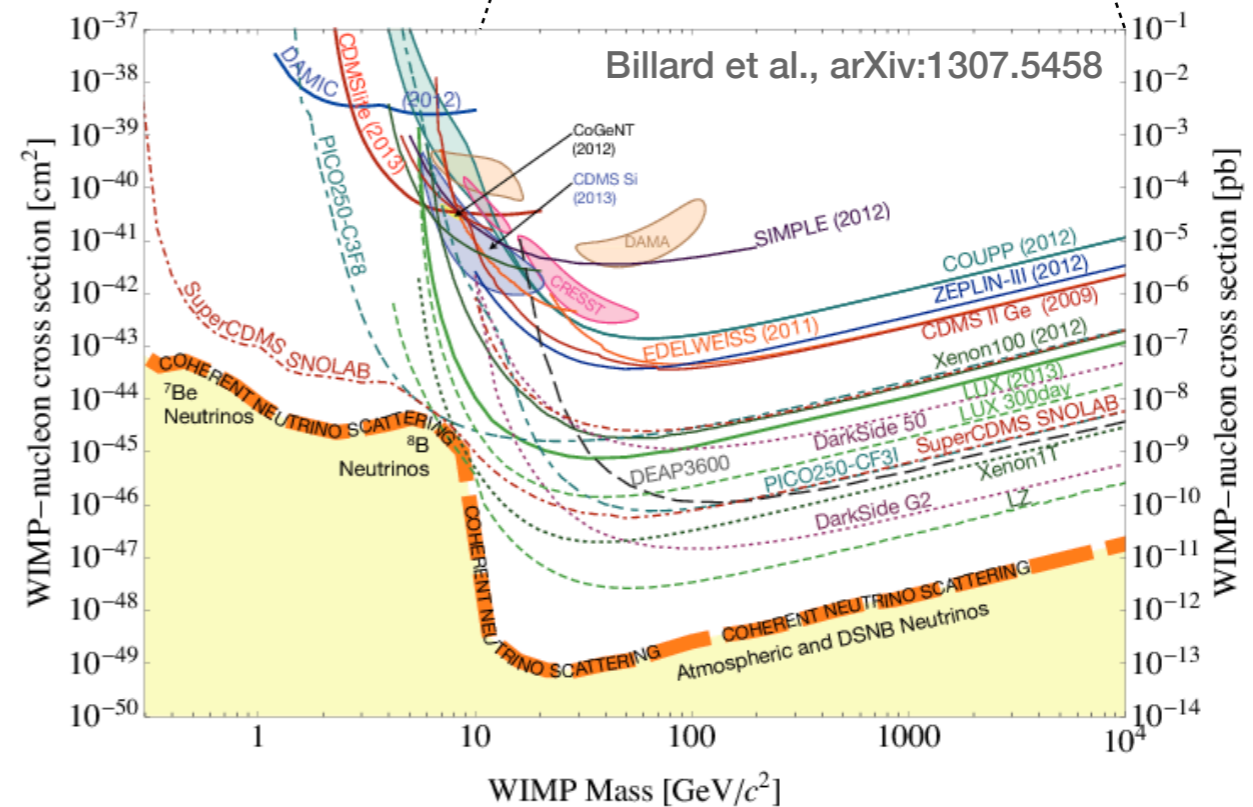
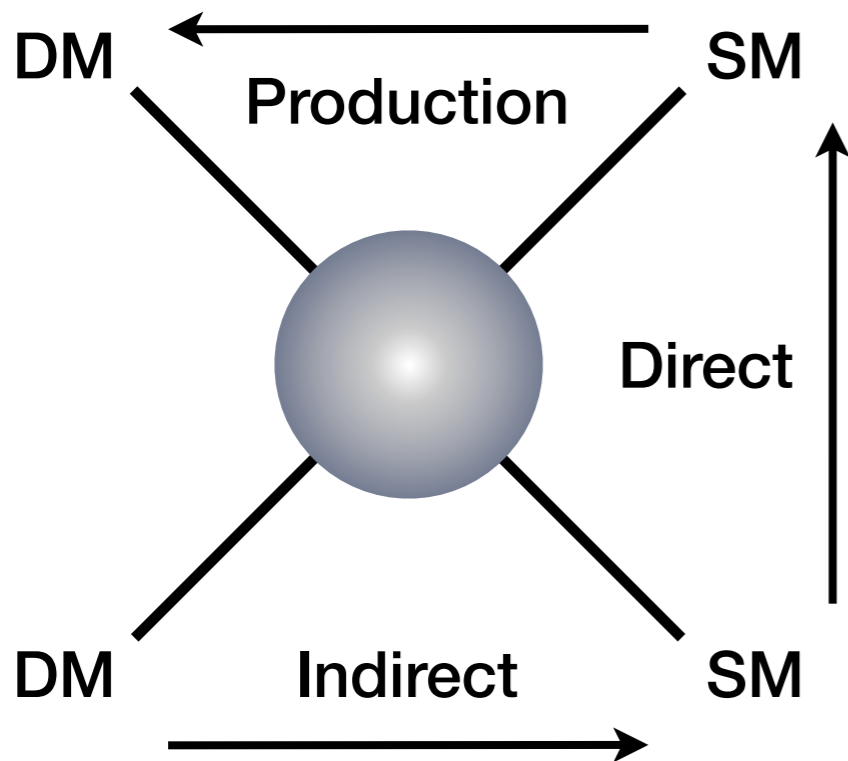


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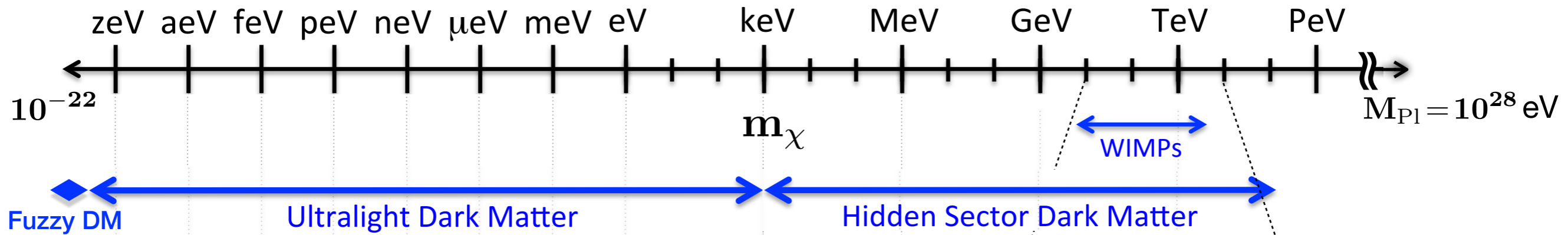


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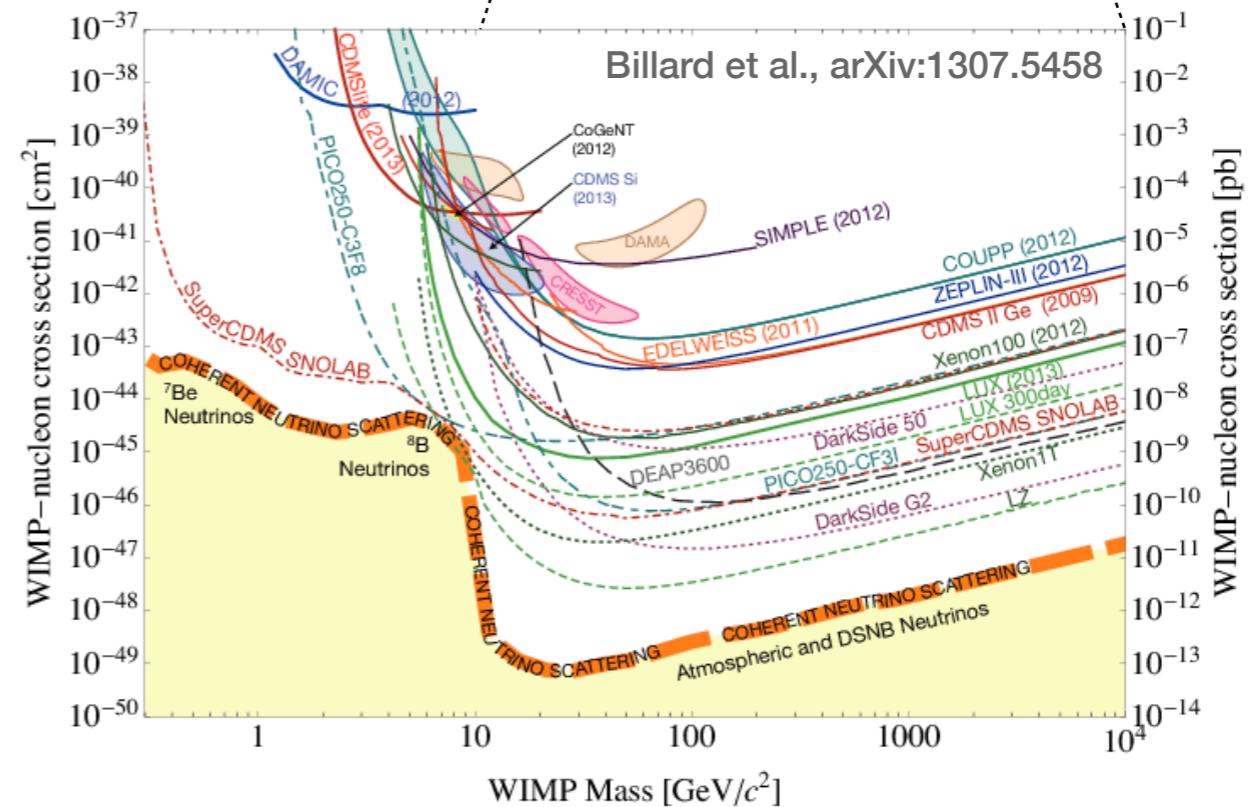
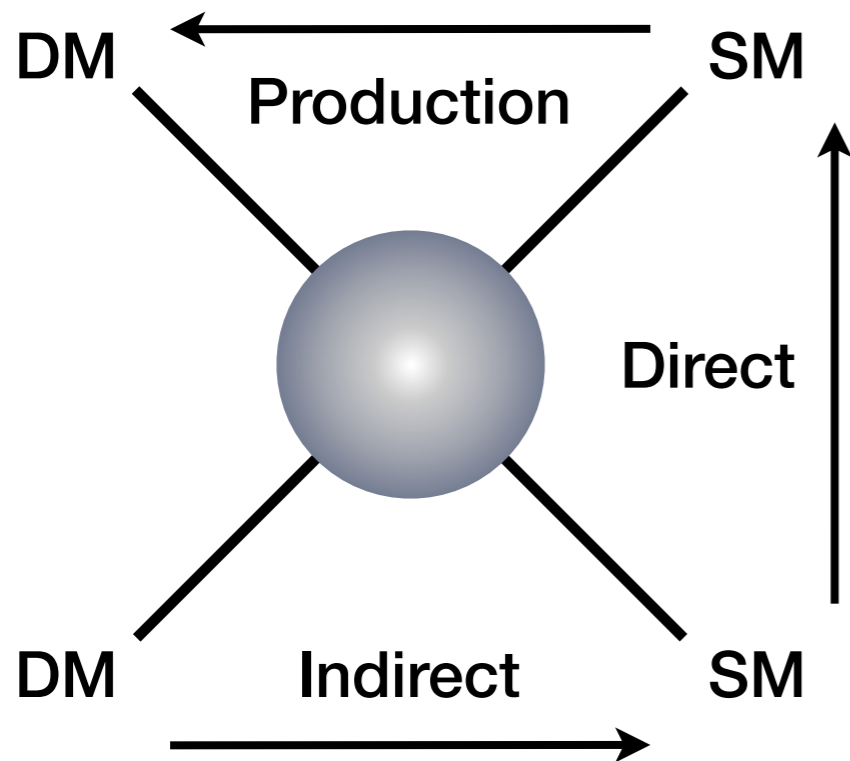


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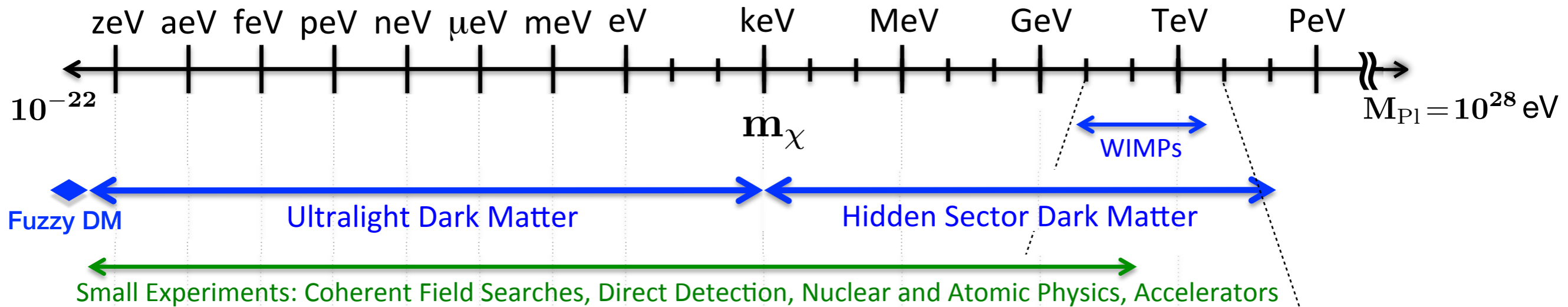


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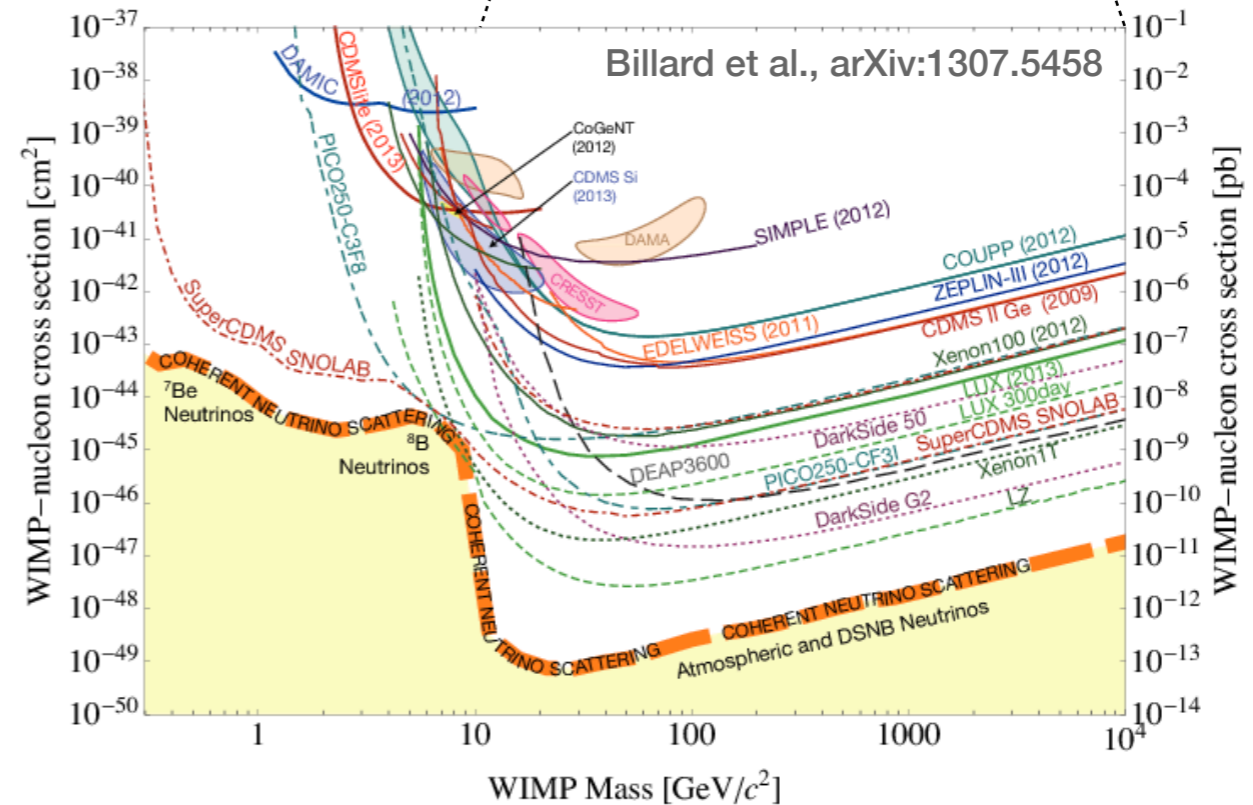
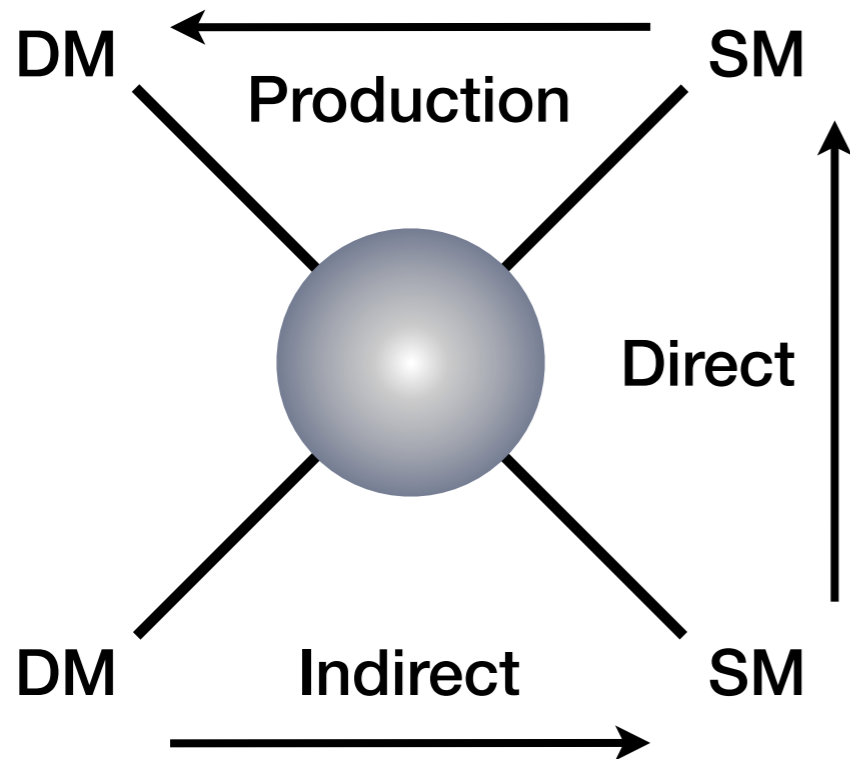


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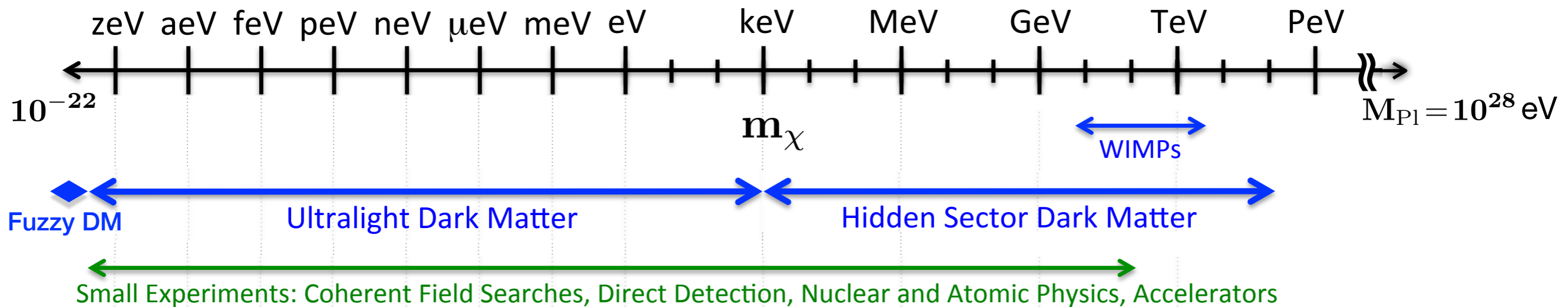


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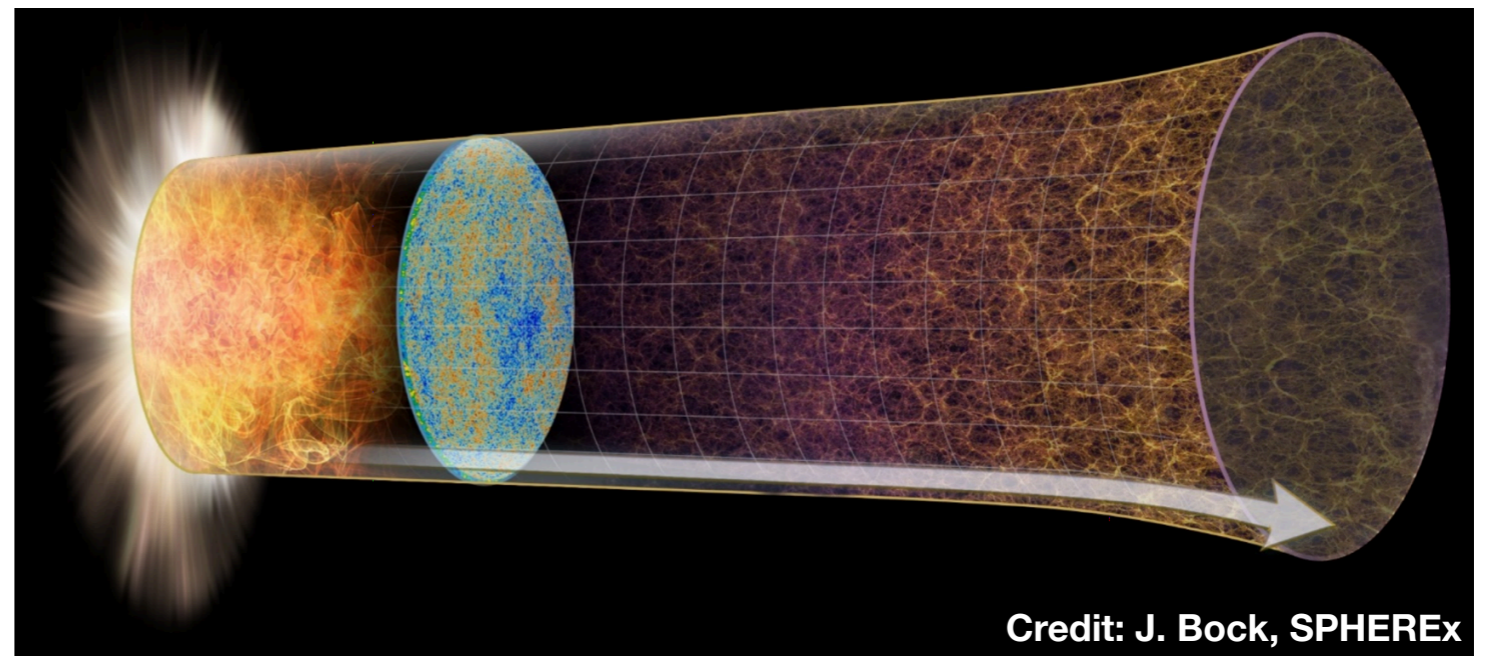
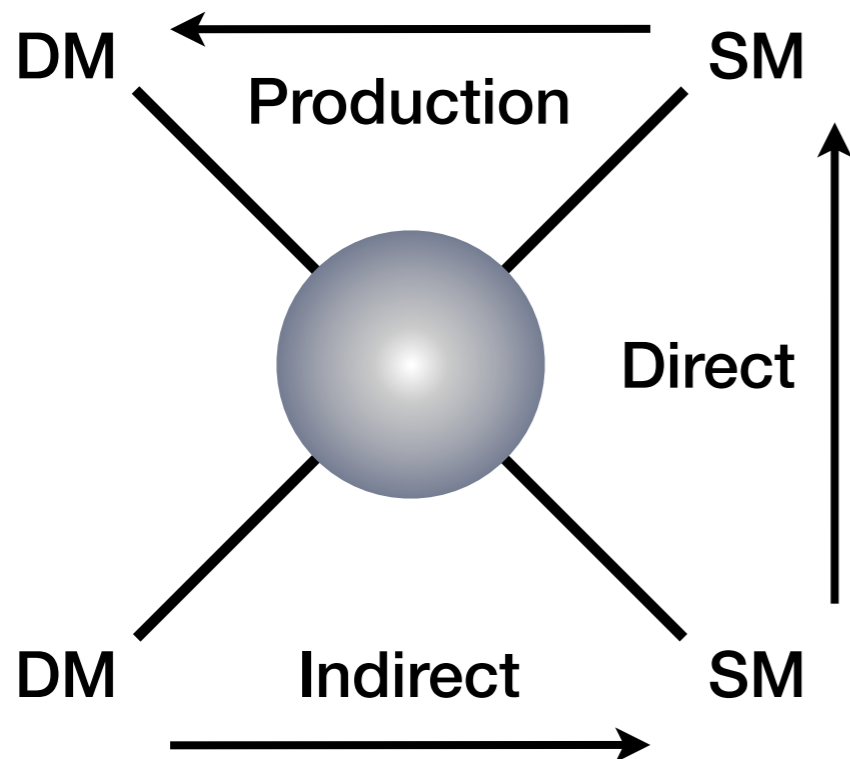


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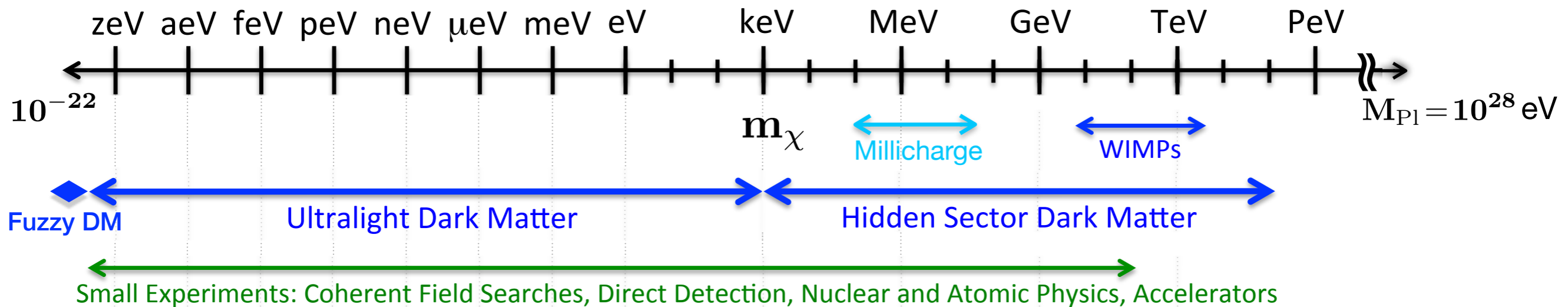
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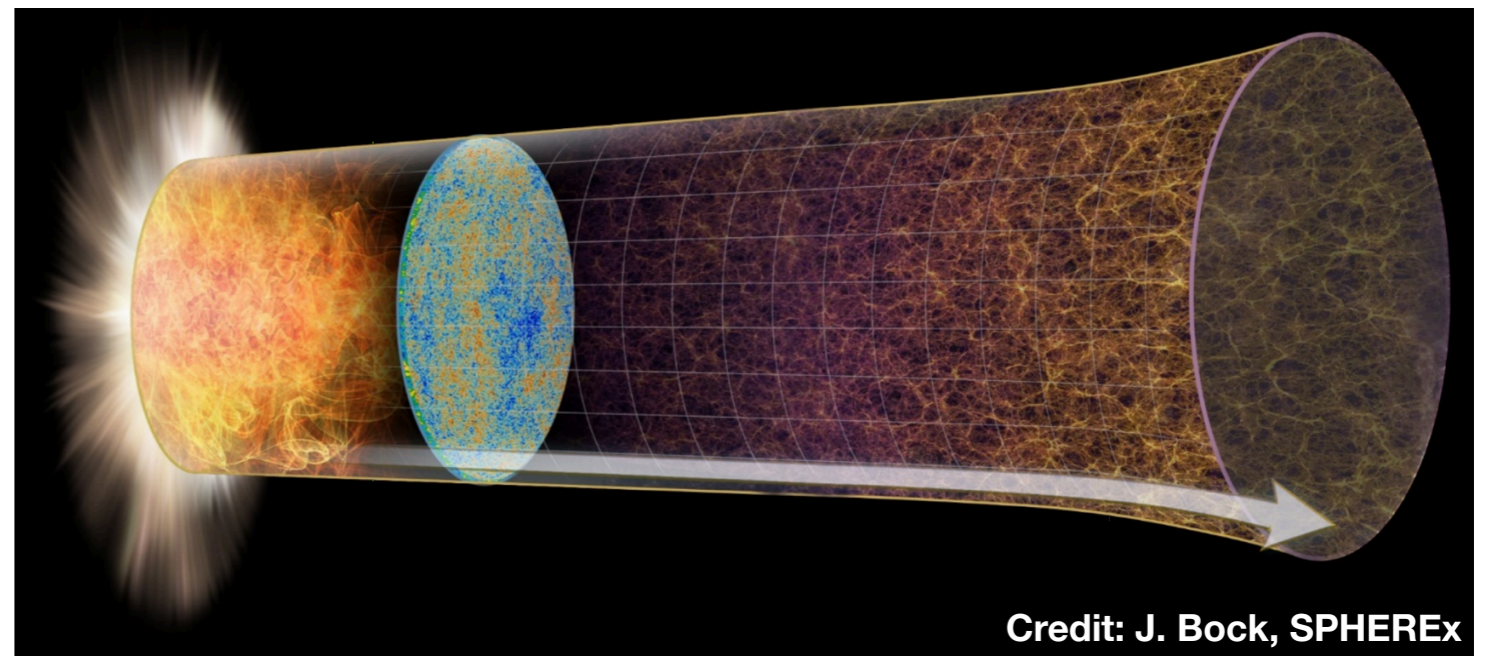
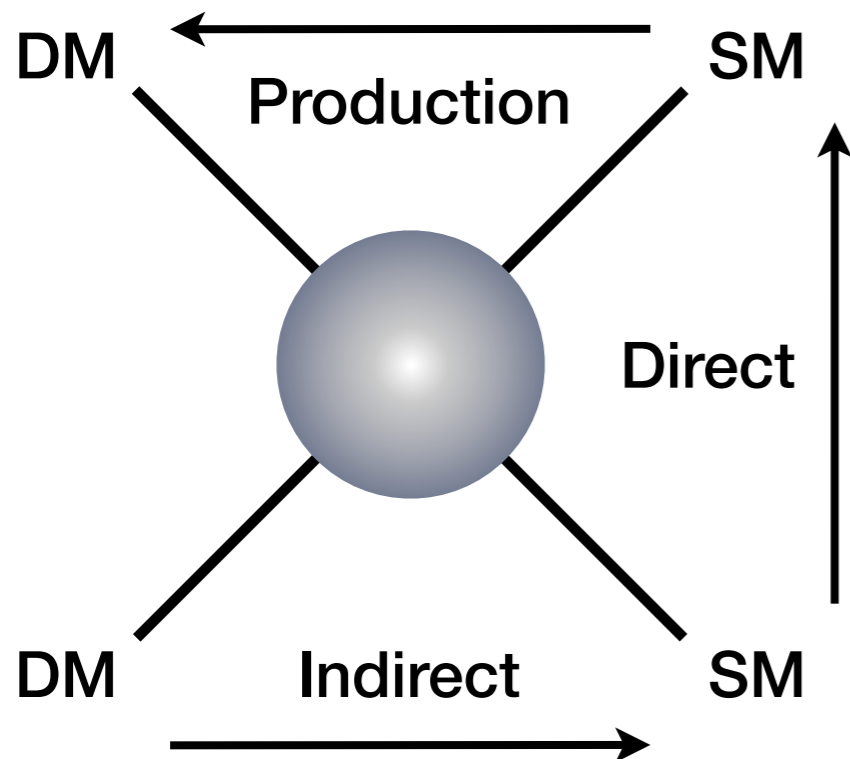
Credit: J. Bock, SPHEREx

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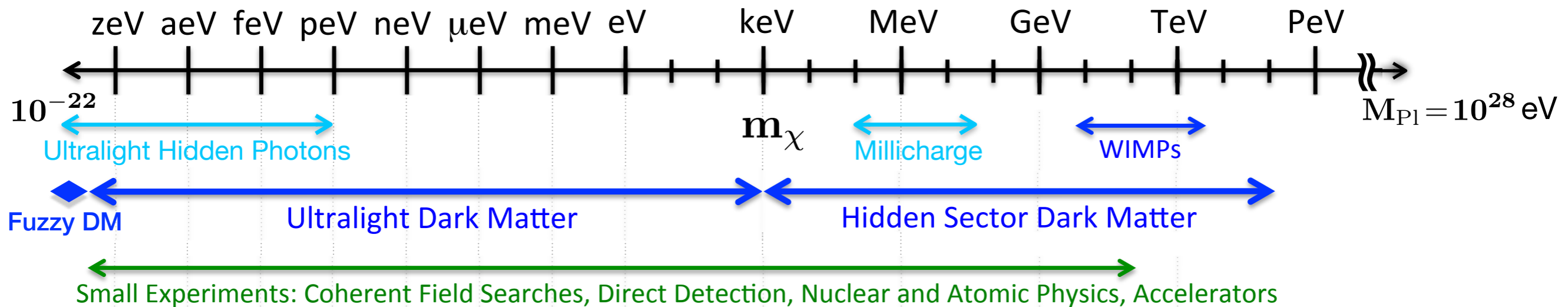
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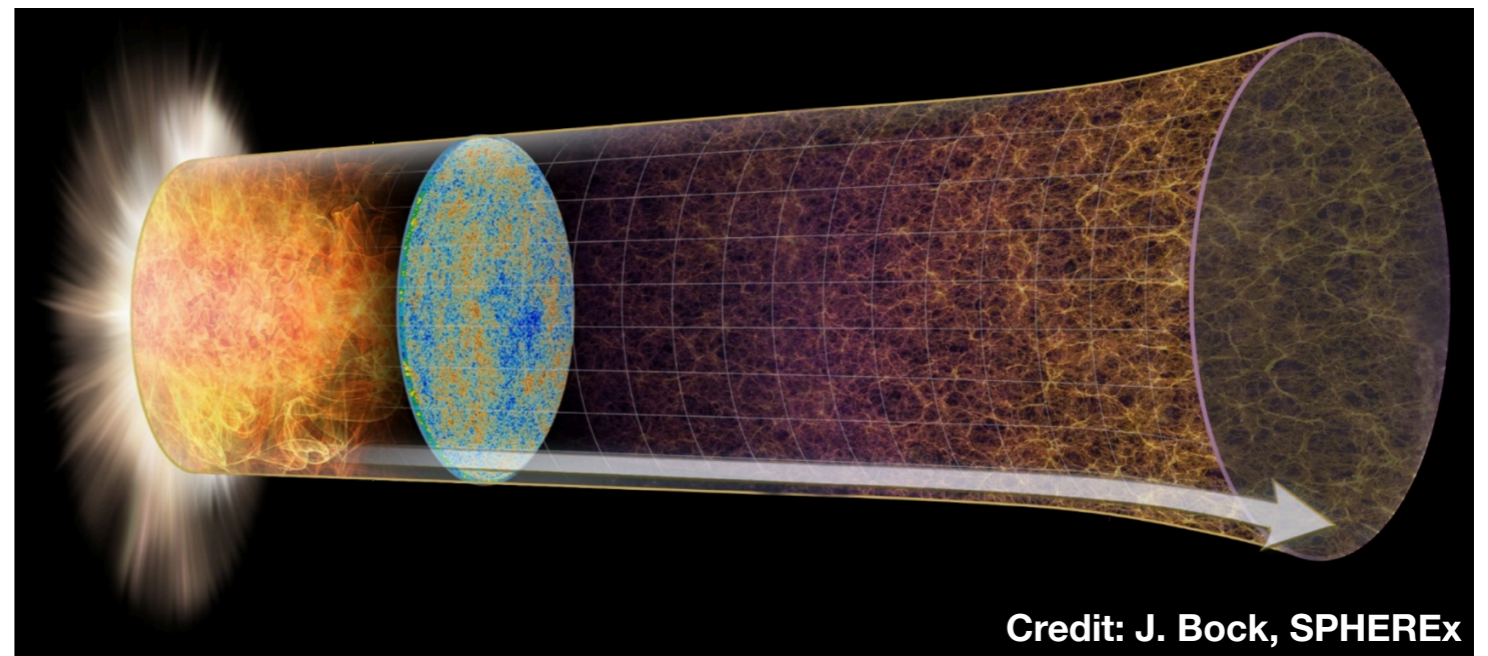
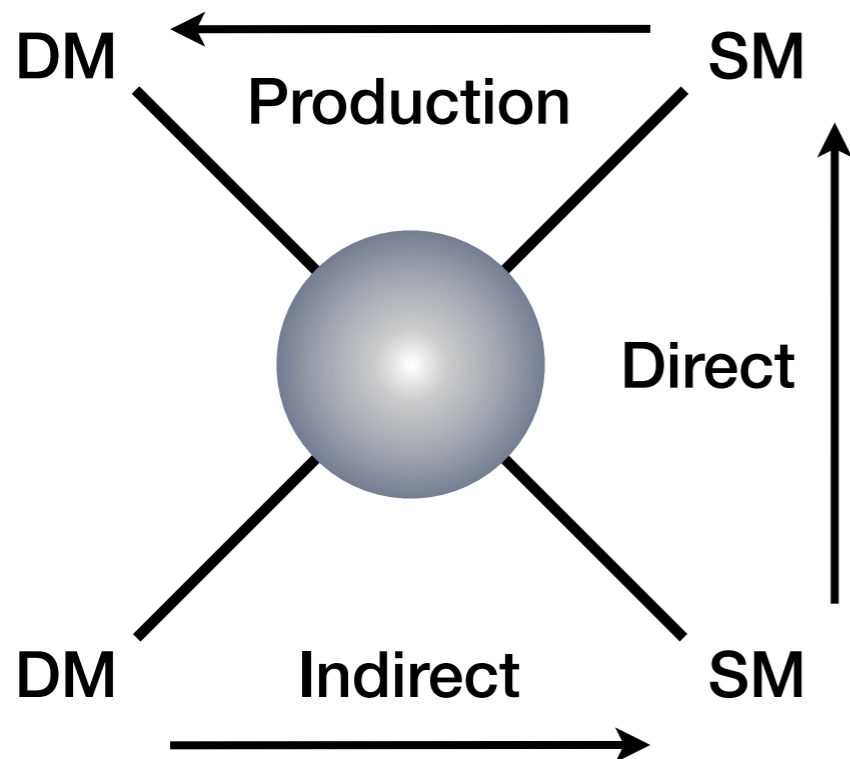
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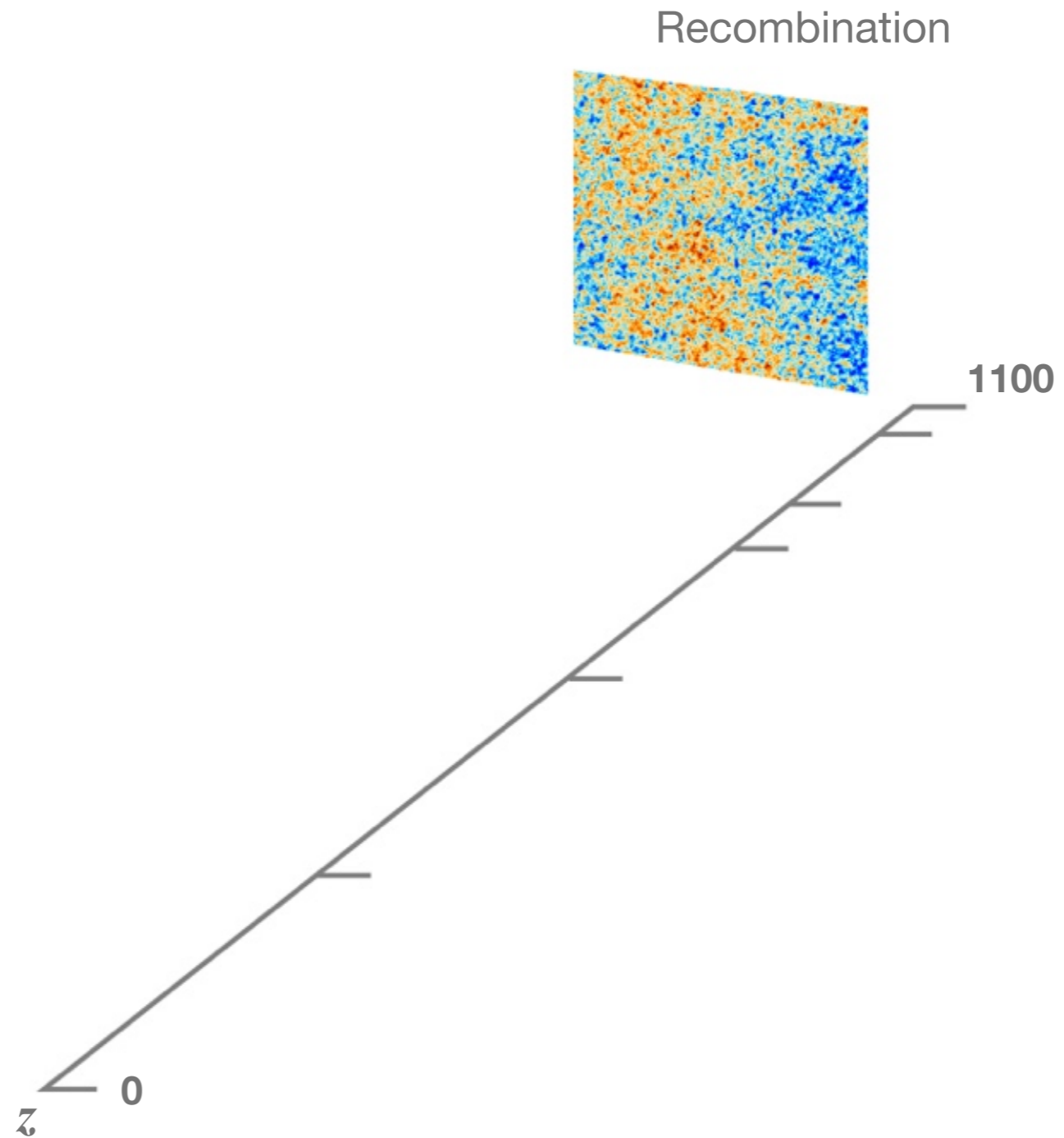


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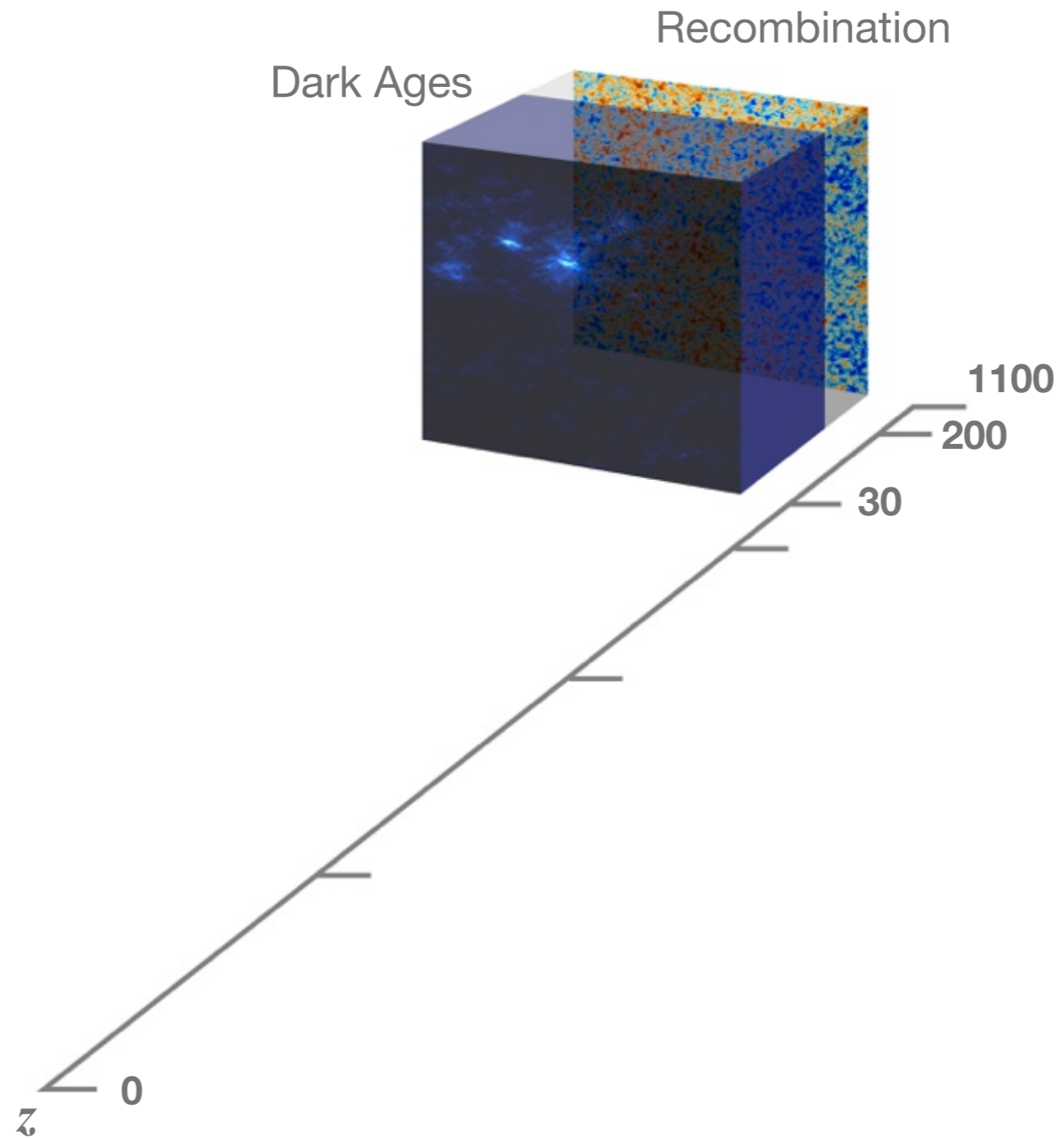


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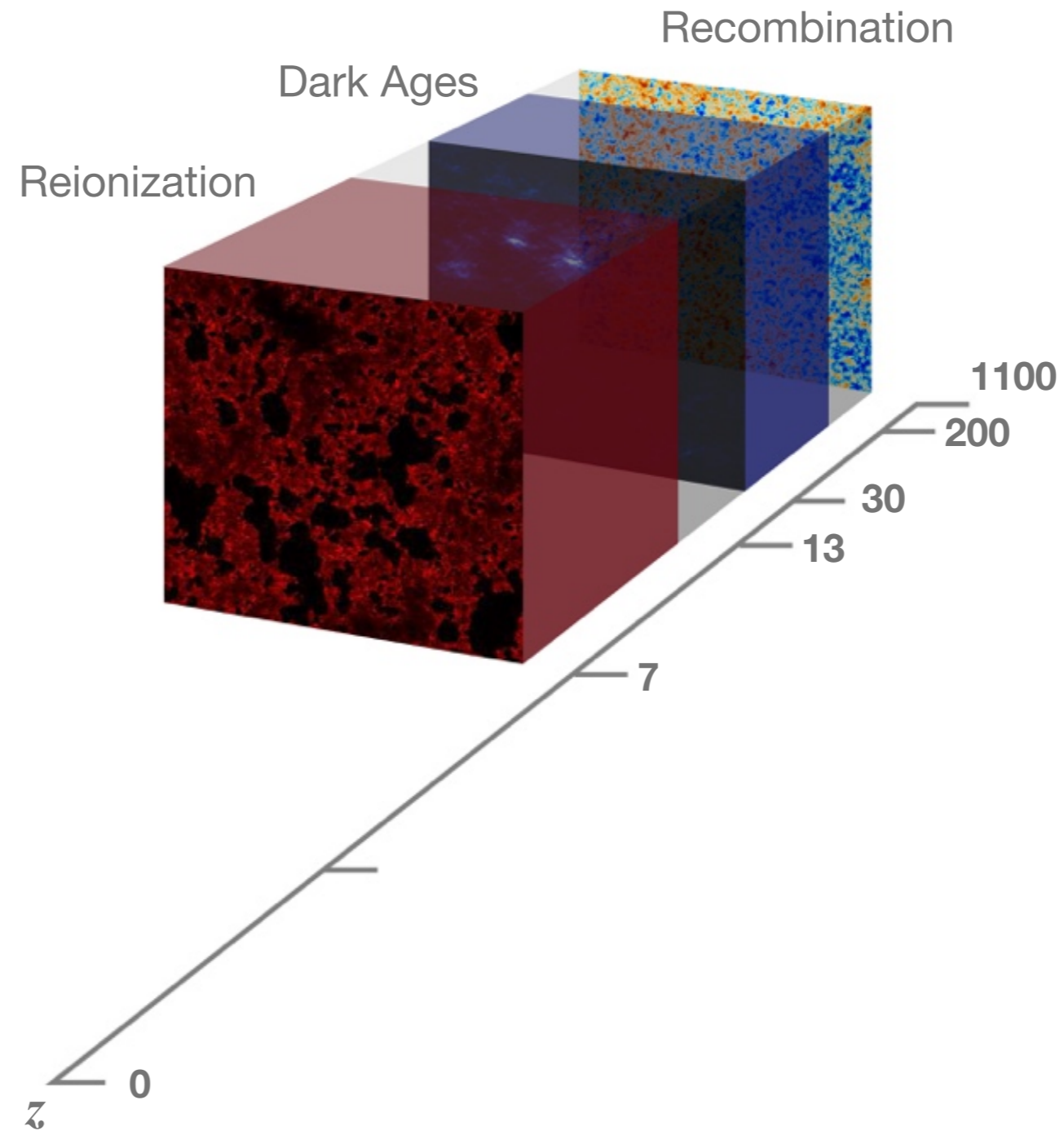
The Observable Universe: A Multi-Layer Detector



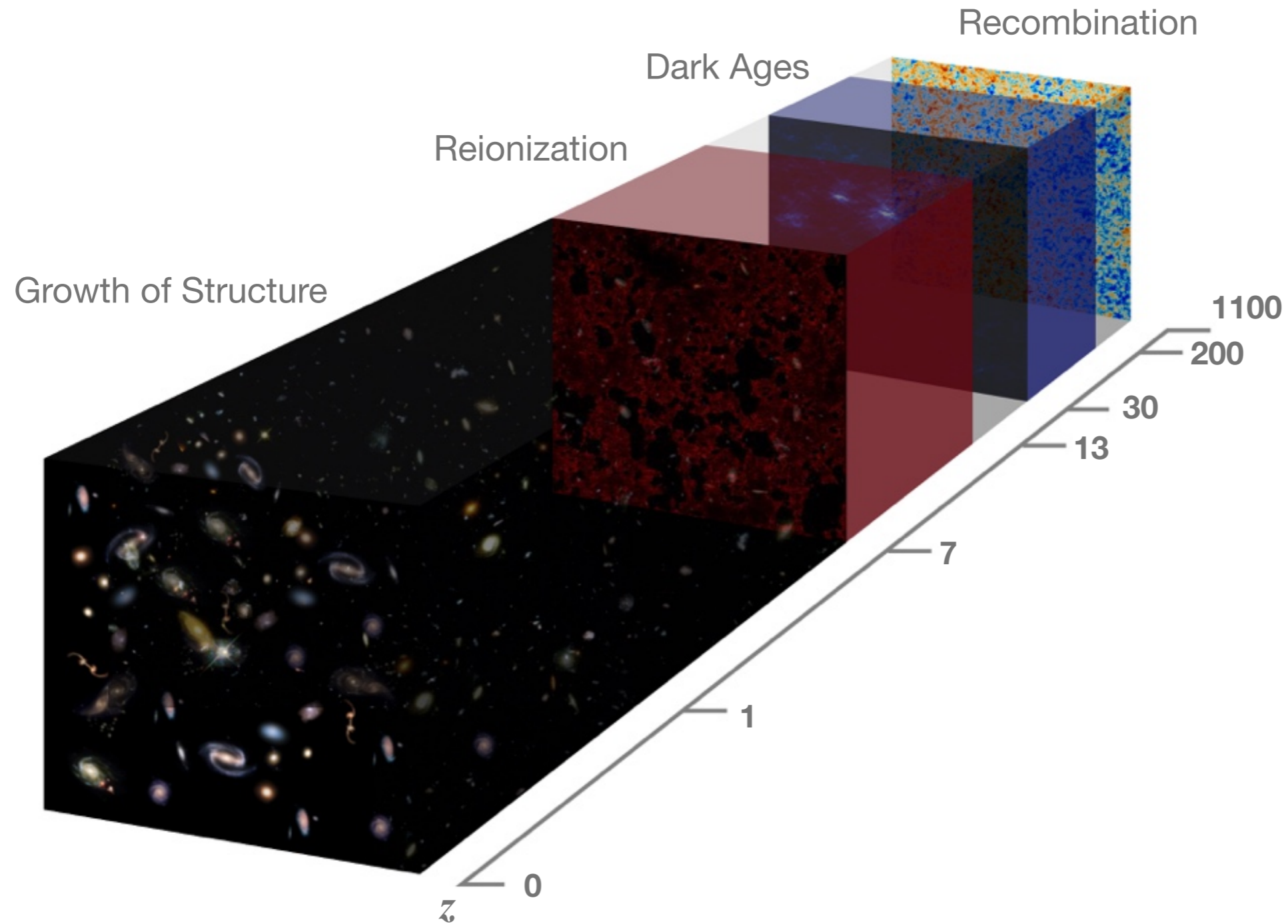
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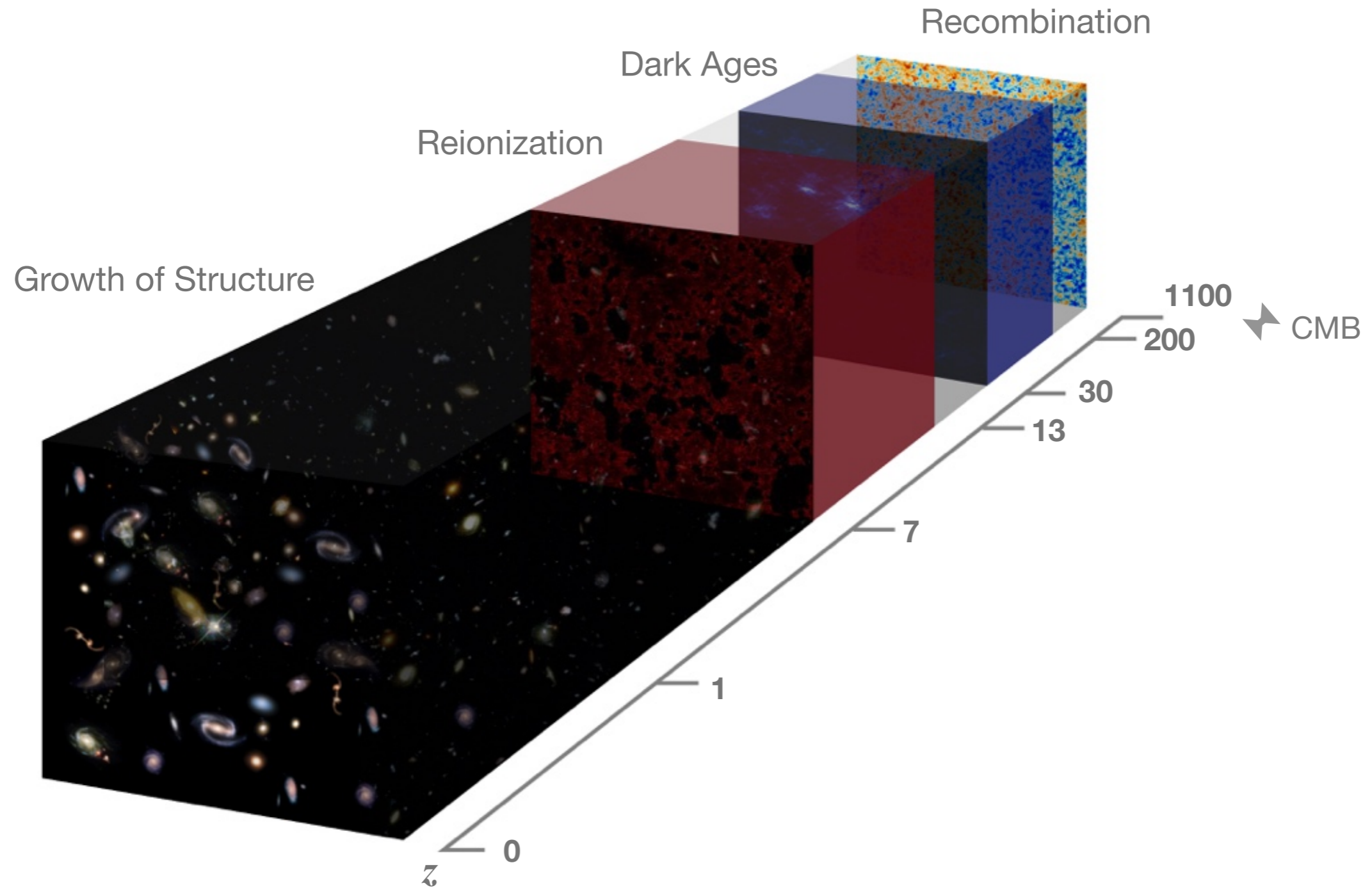
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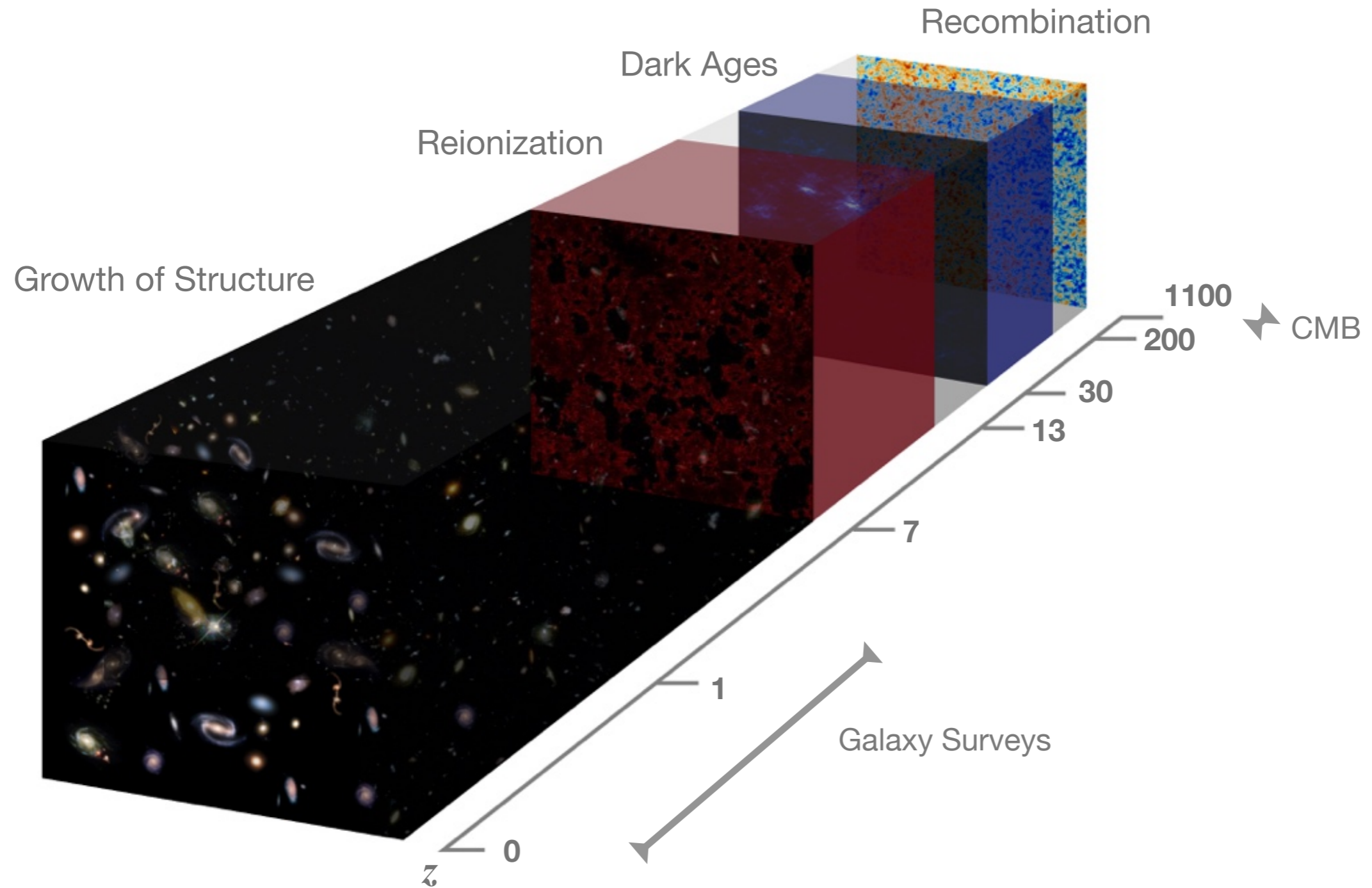
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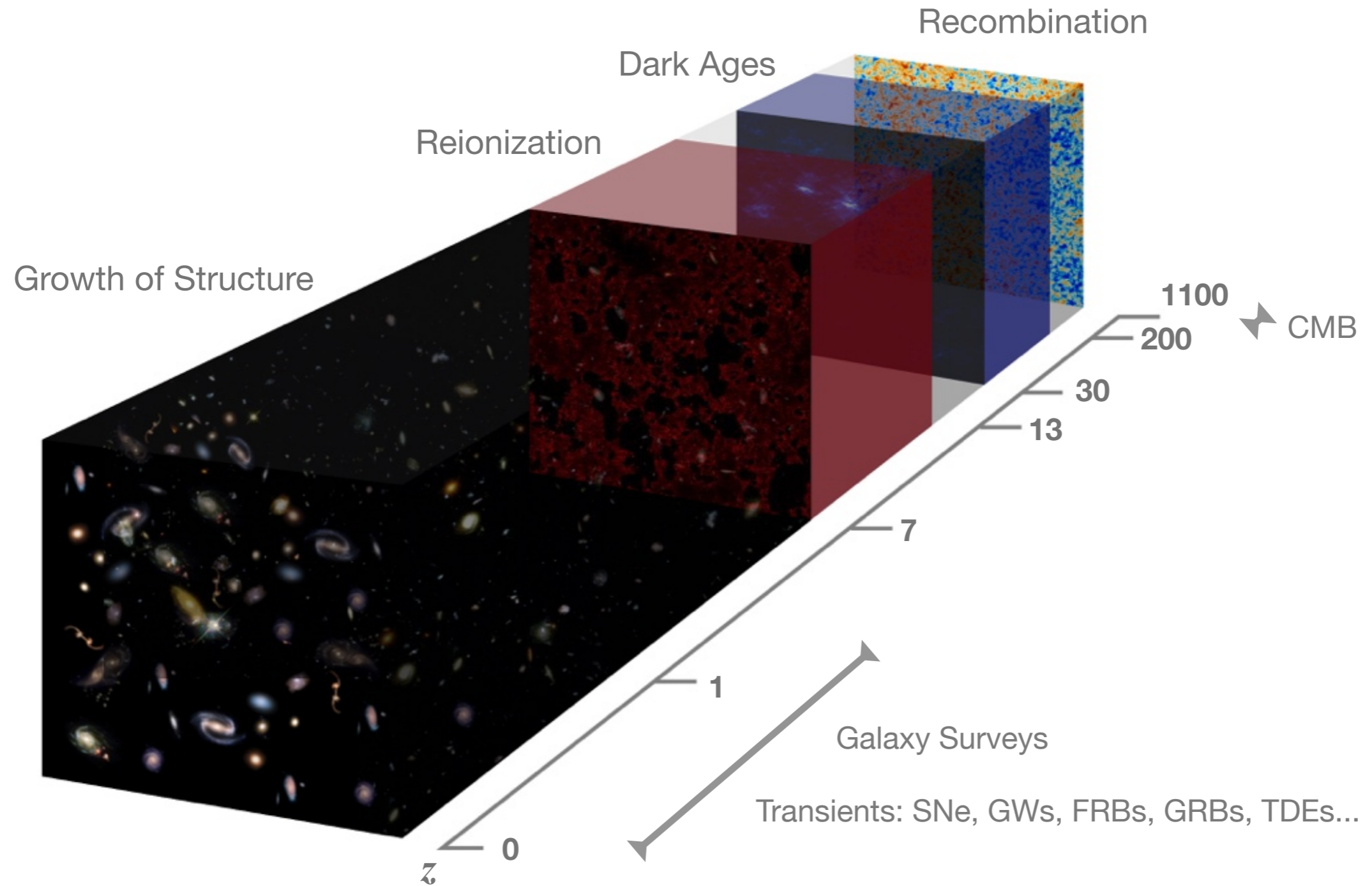
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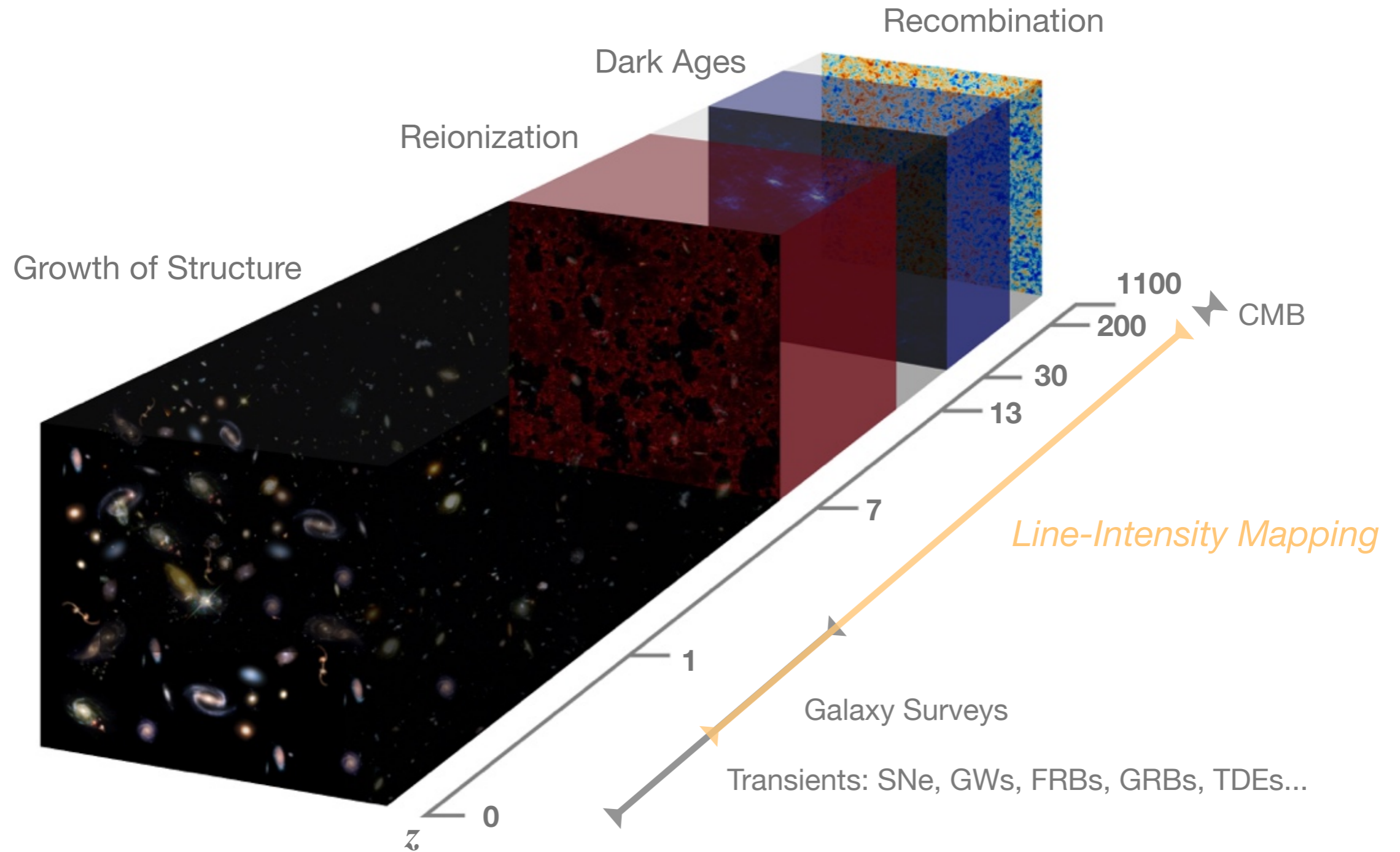
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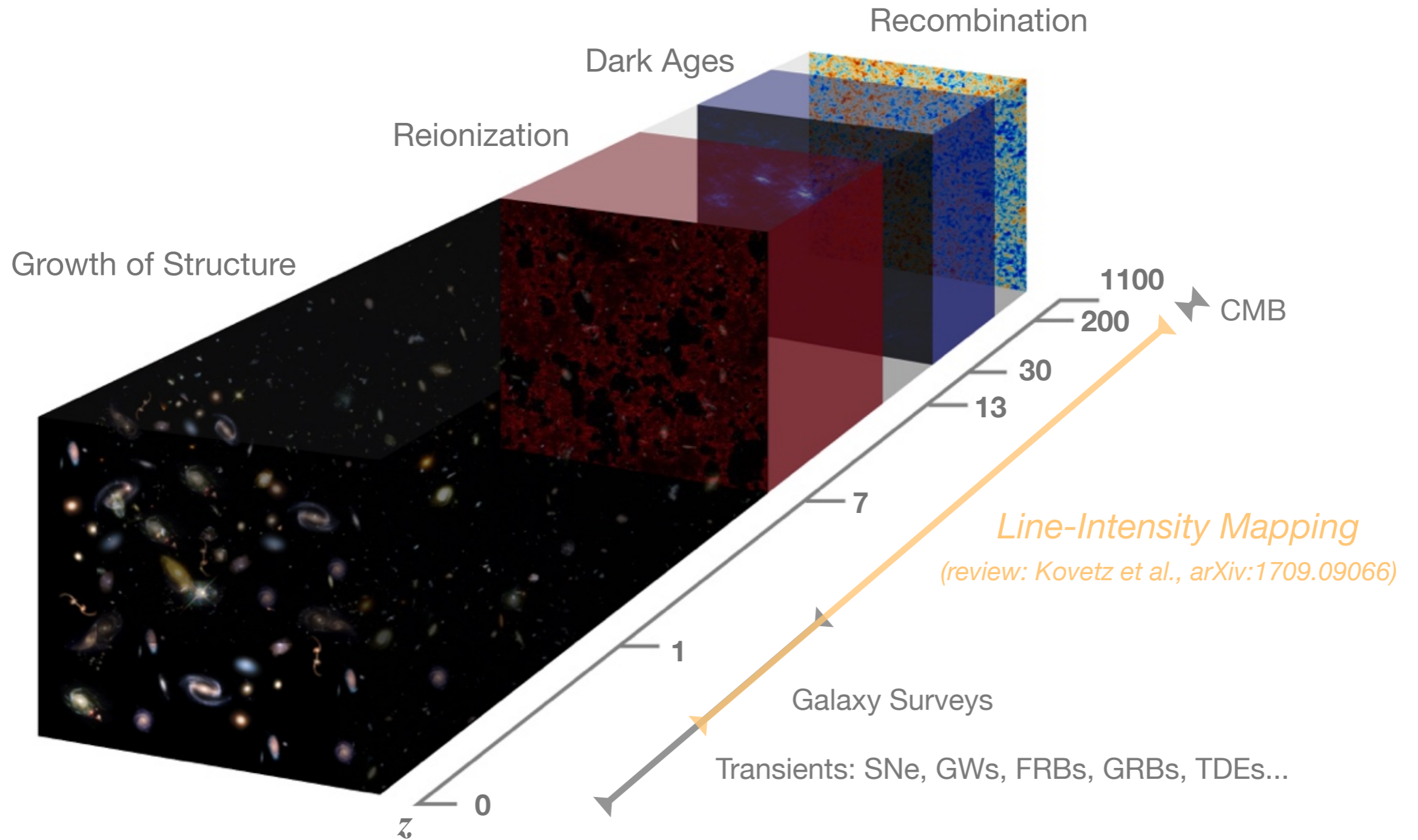
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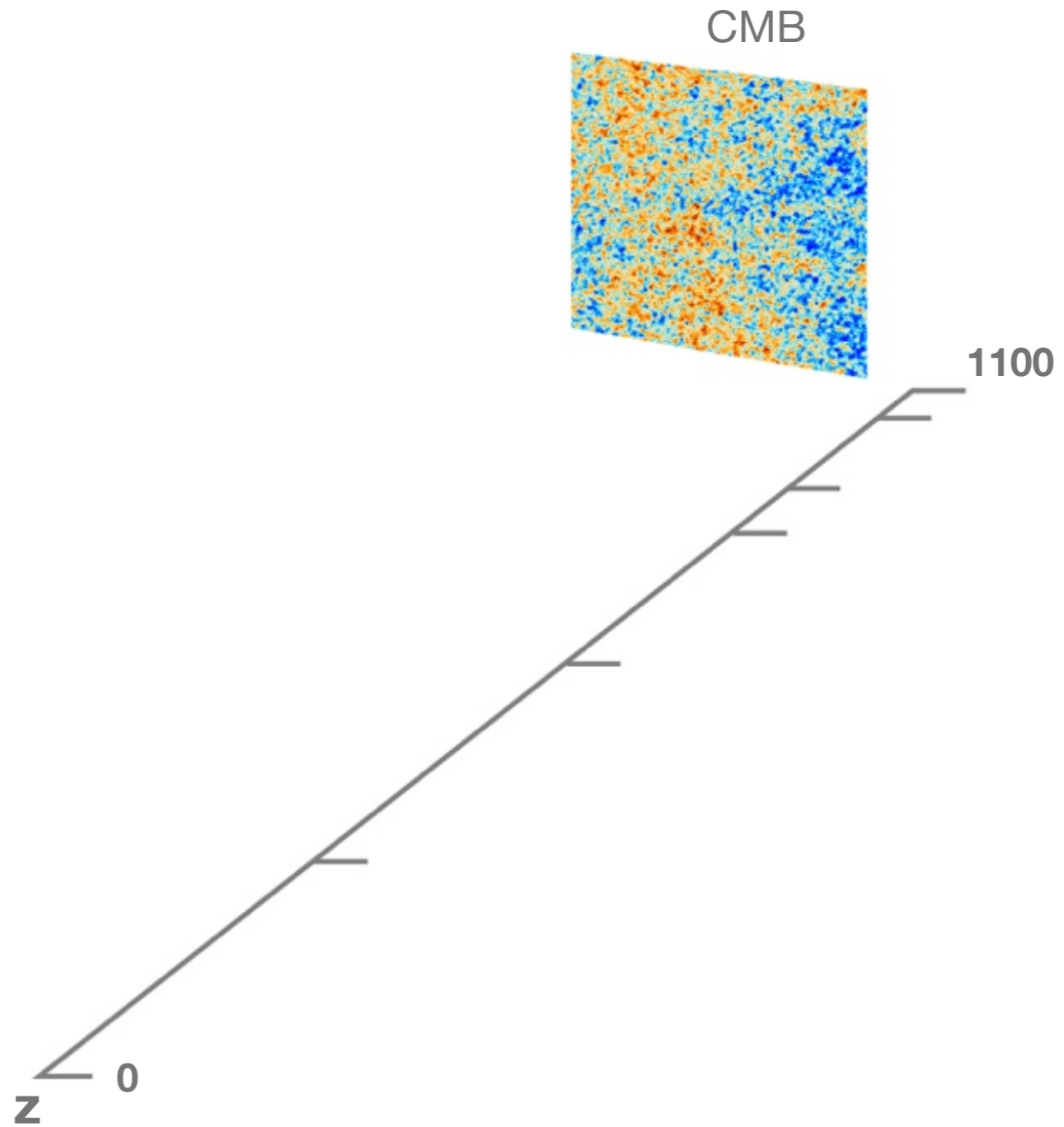


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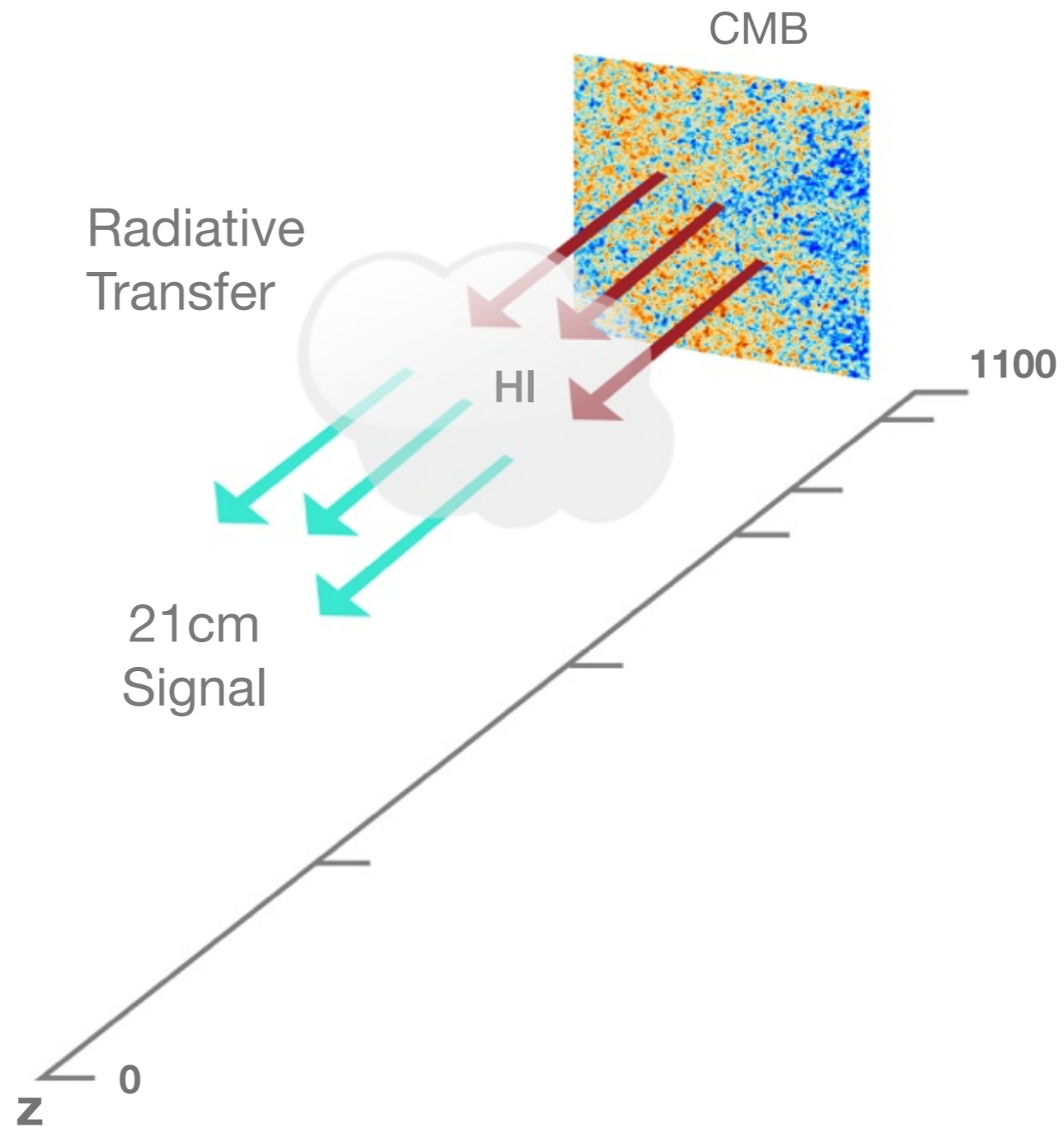


Origin of Cosmological 21 cm Signal

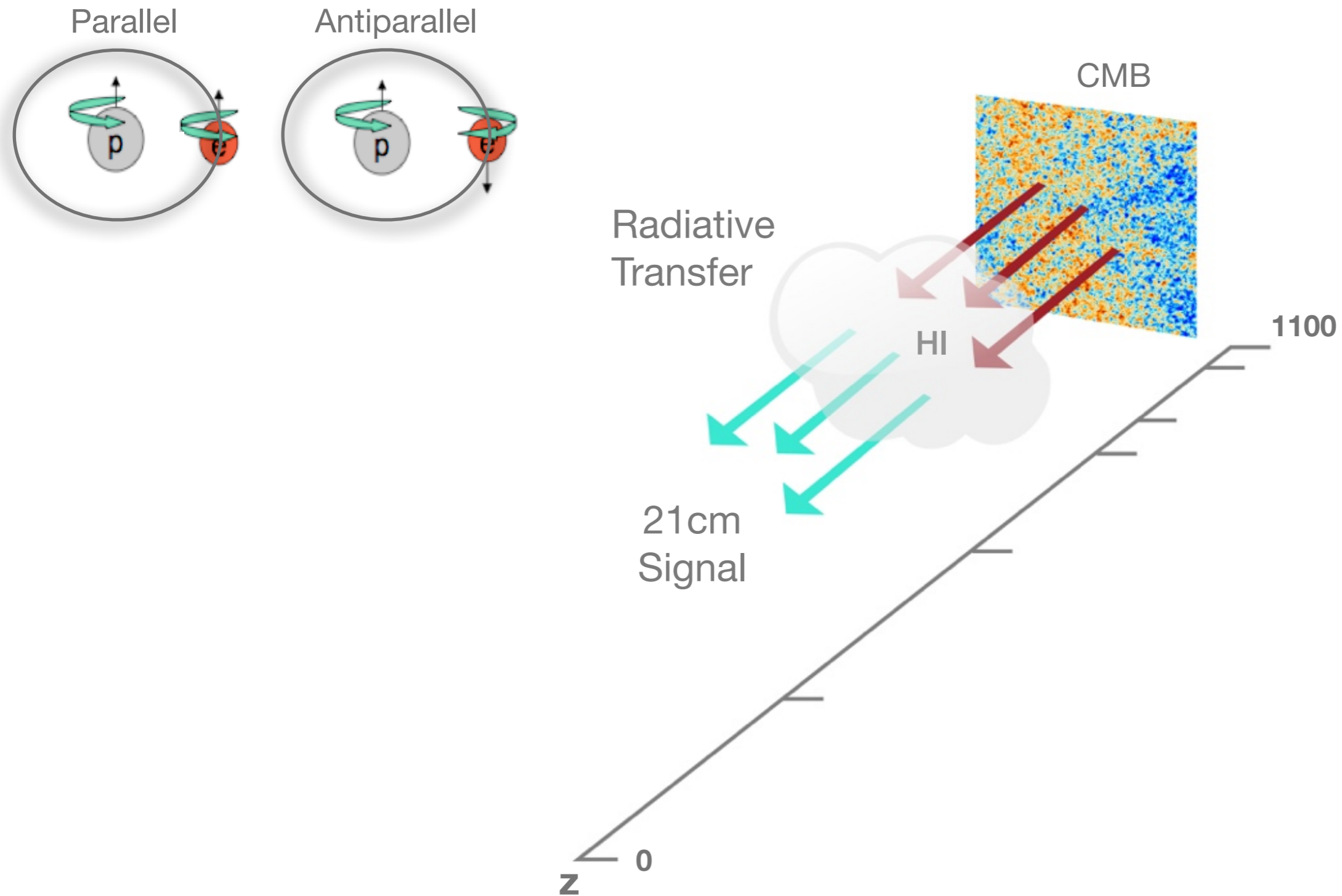
Origin of Cosmological 21 cm Signal



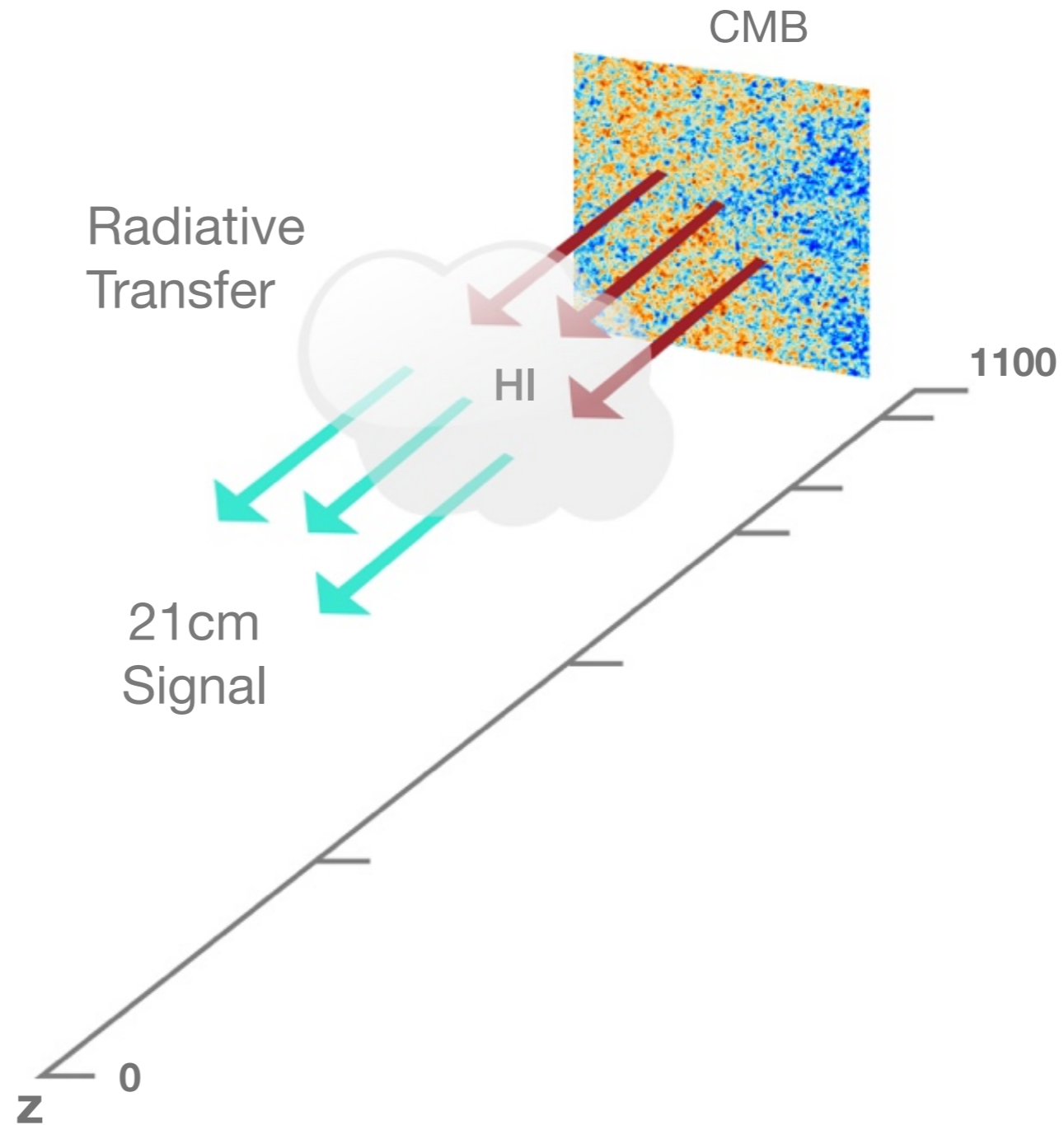
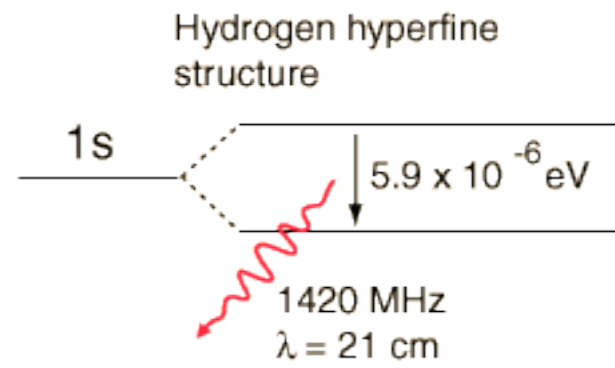
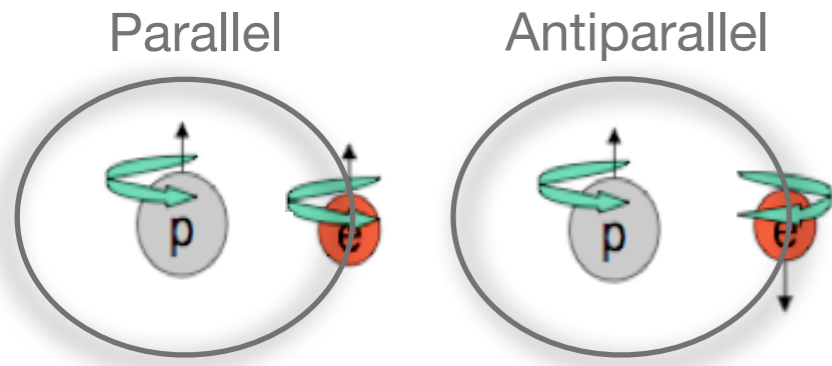
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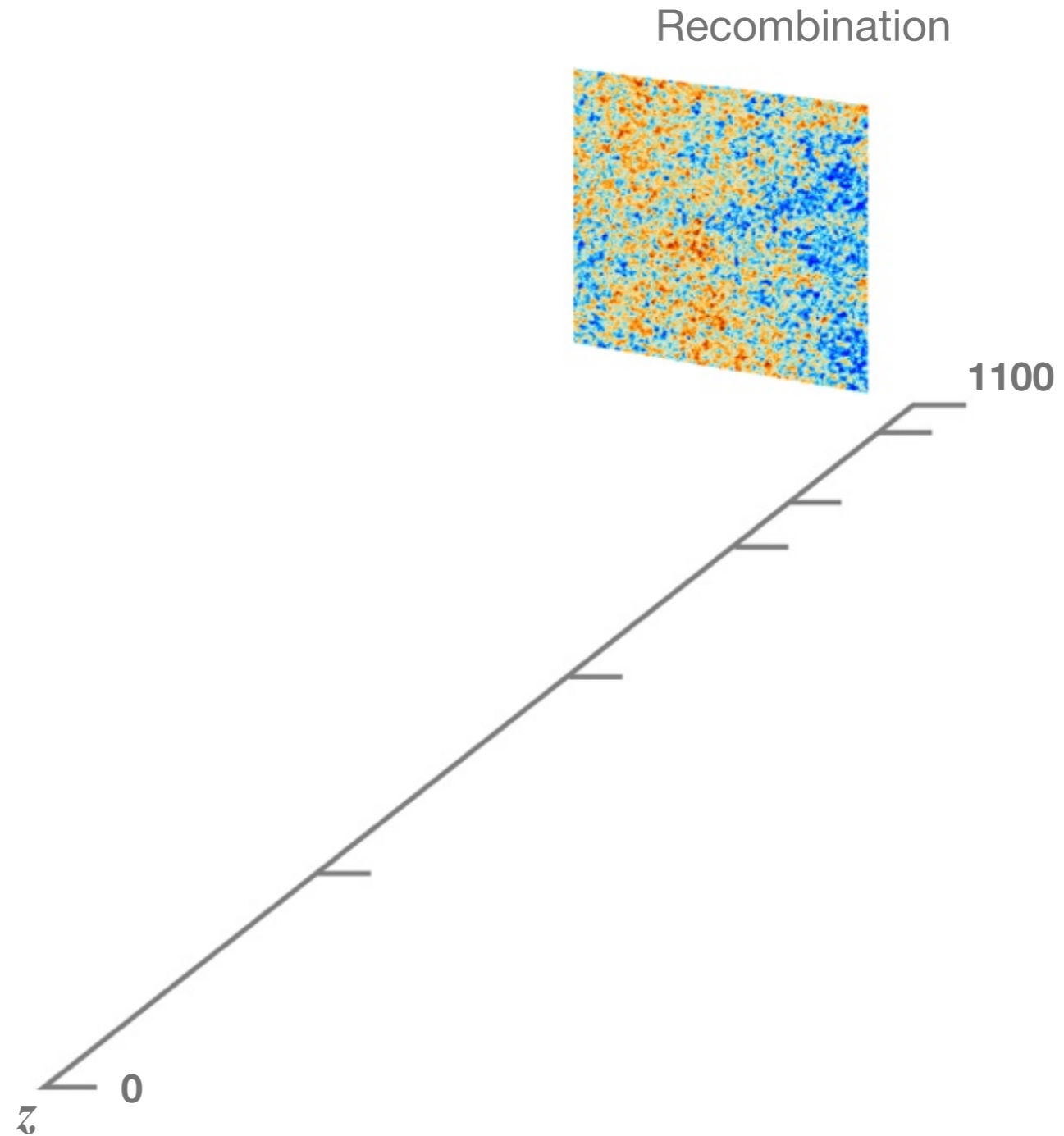
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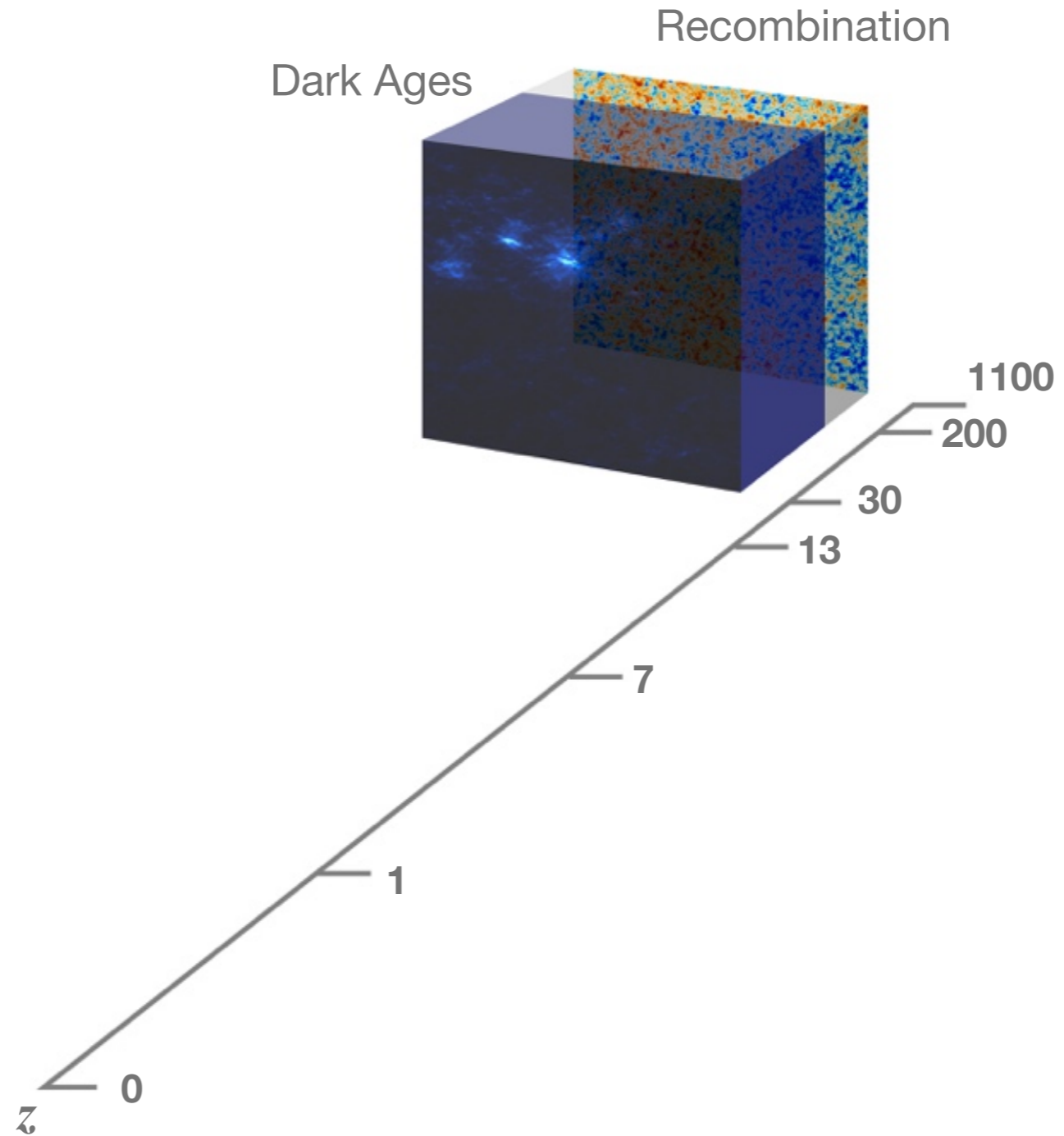
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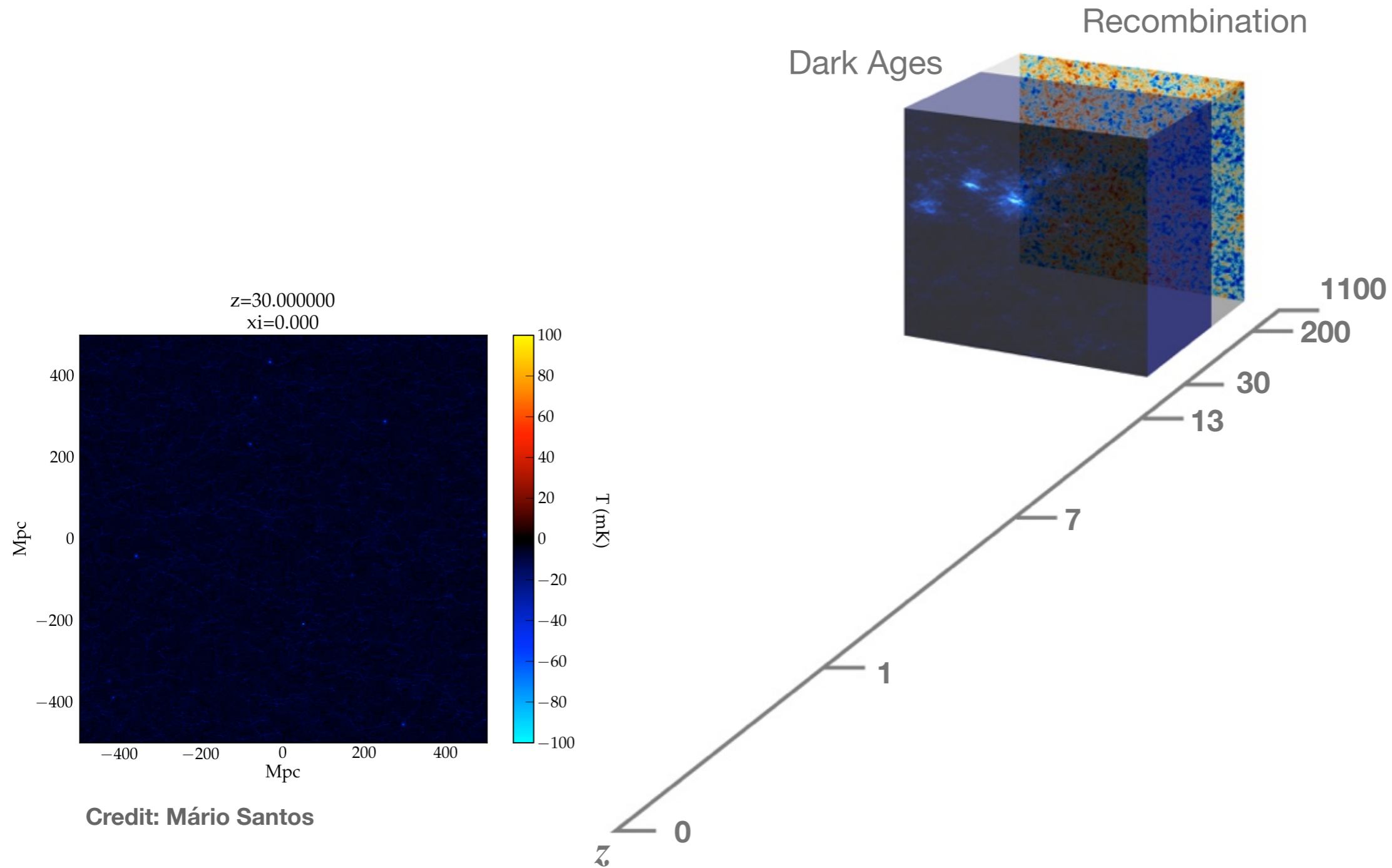
It's Always Darkest before the (Cosmic) Dawn



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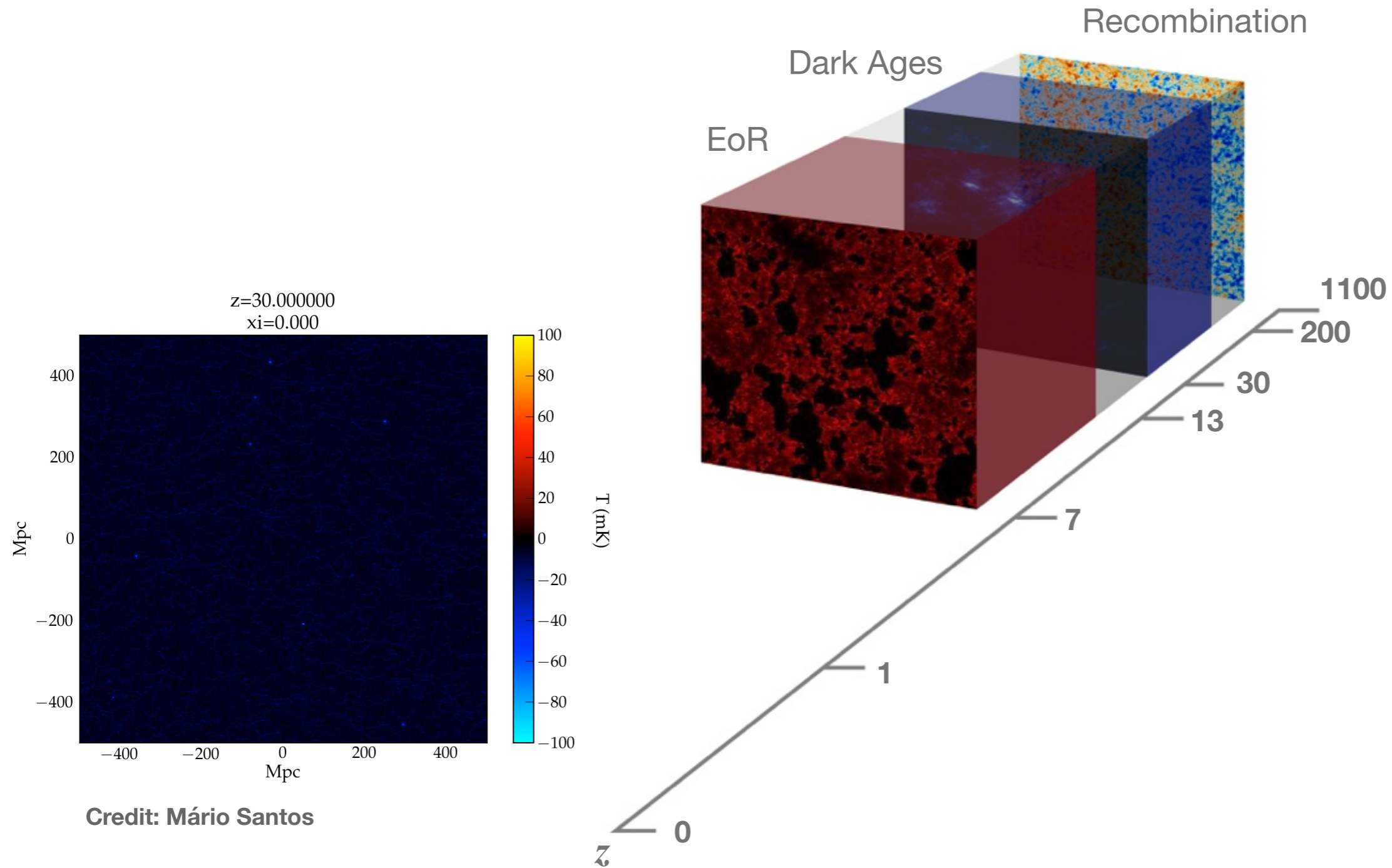


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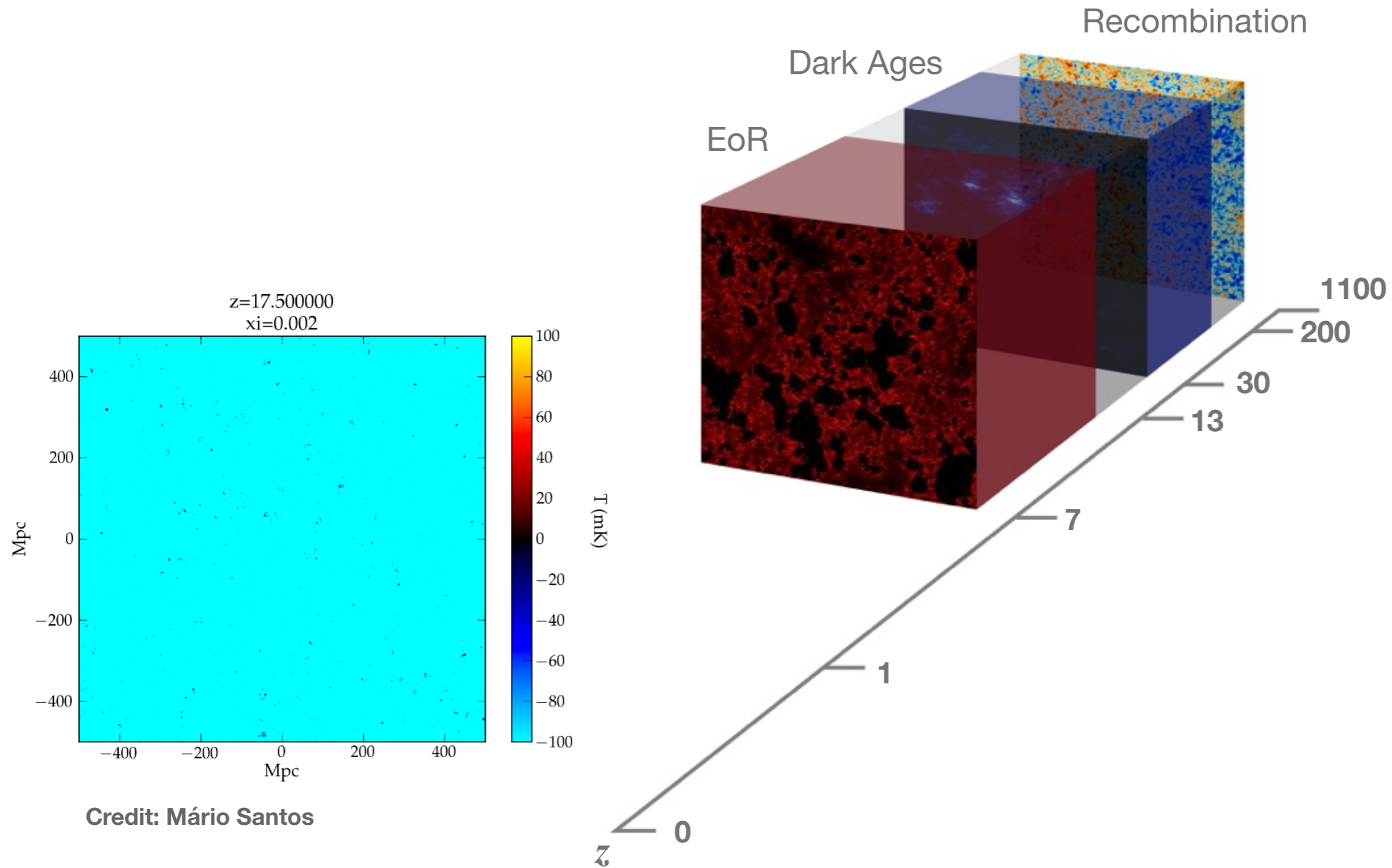


Credit: Mário Santos

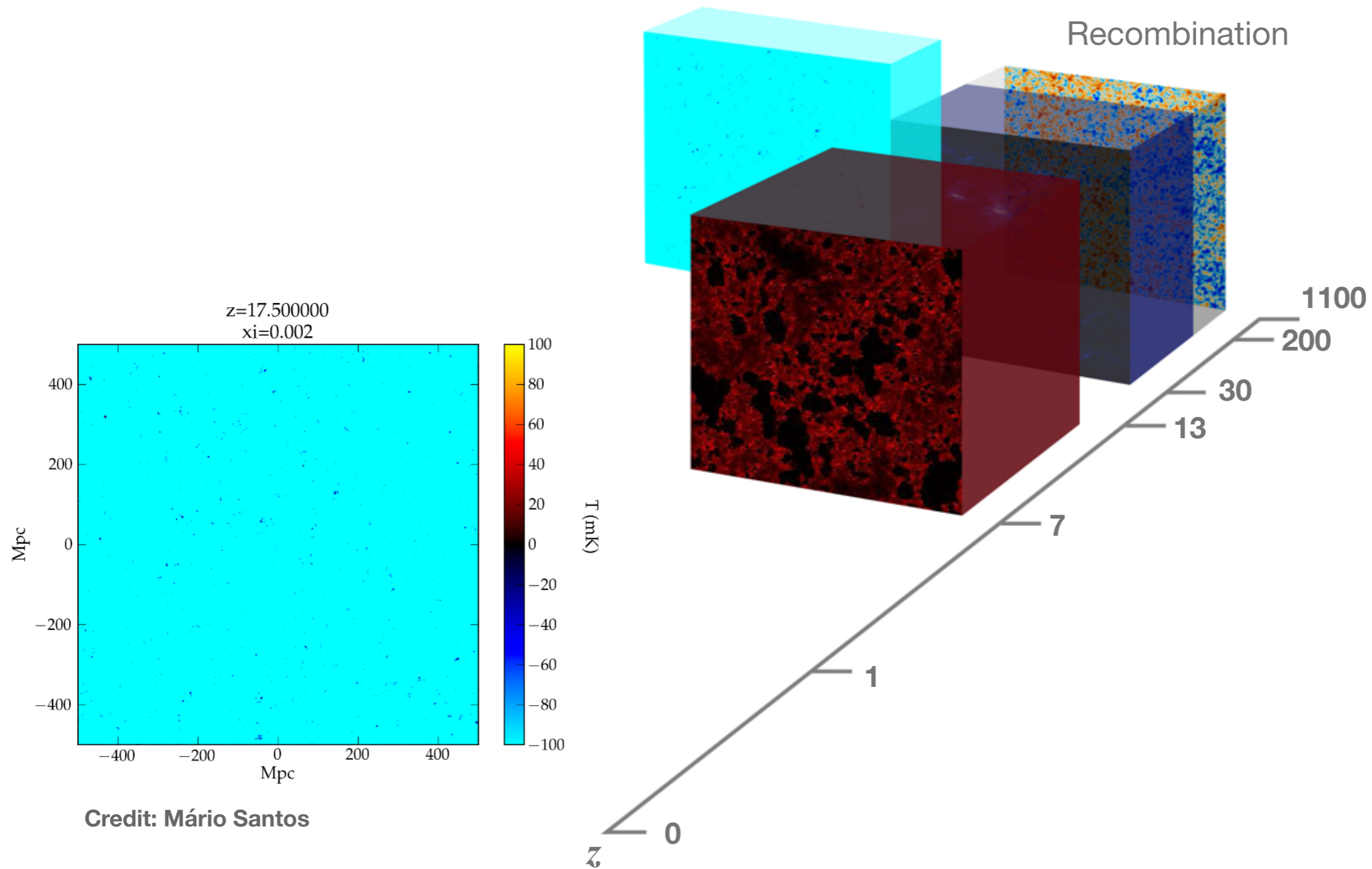
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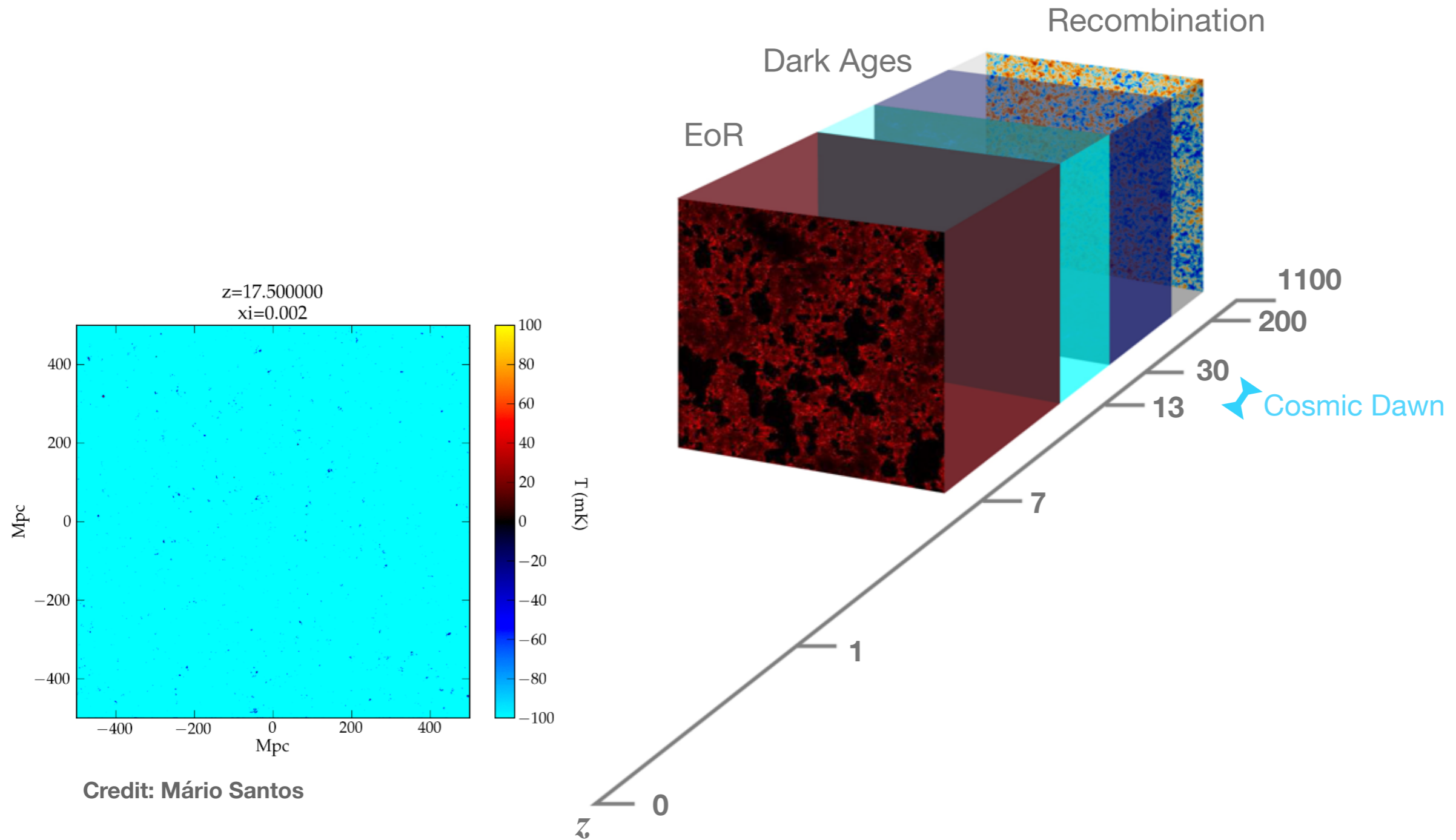


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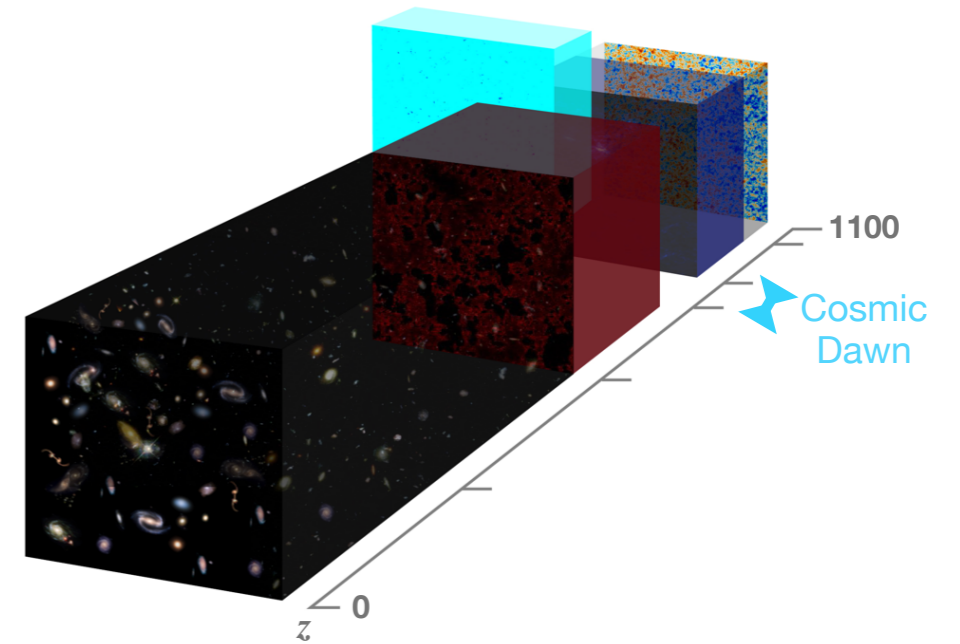


Credit: Mário Santos

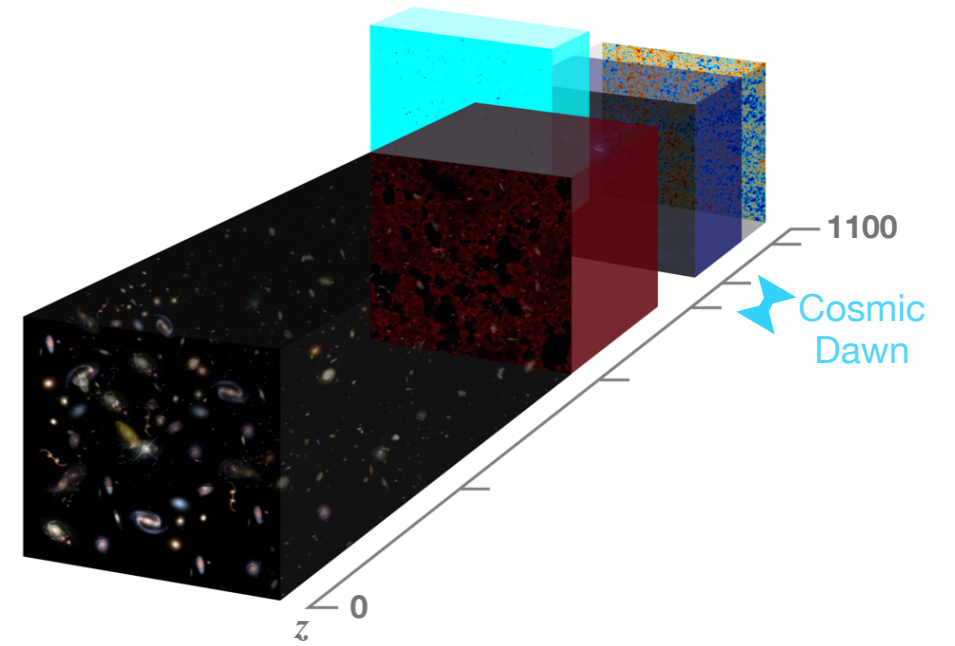
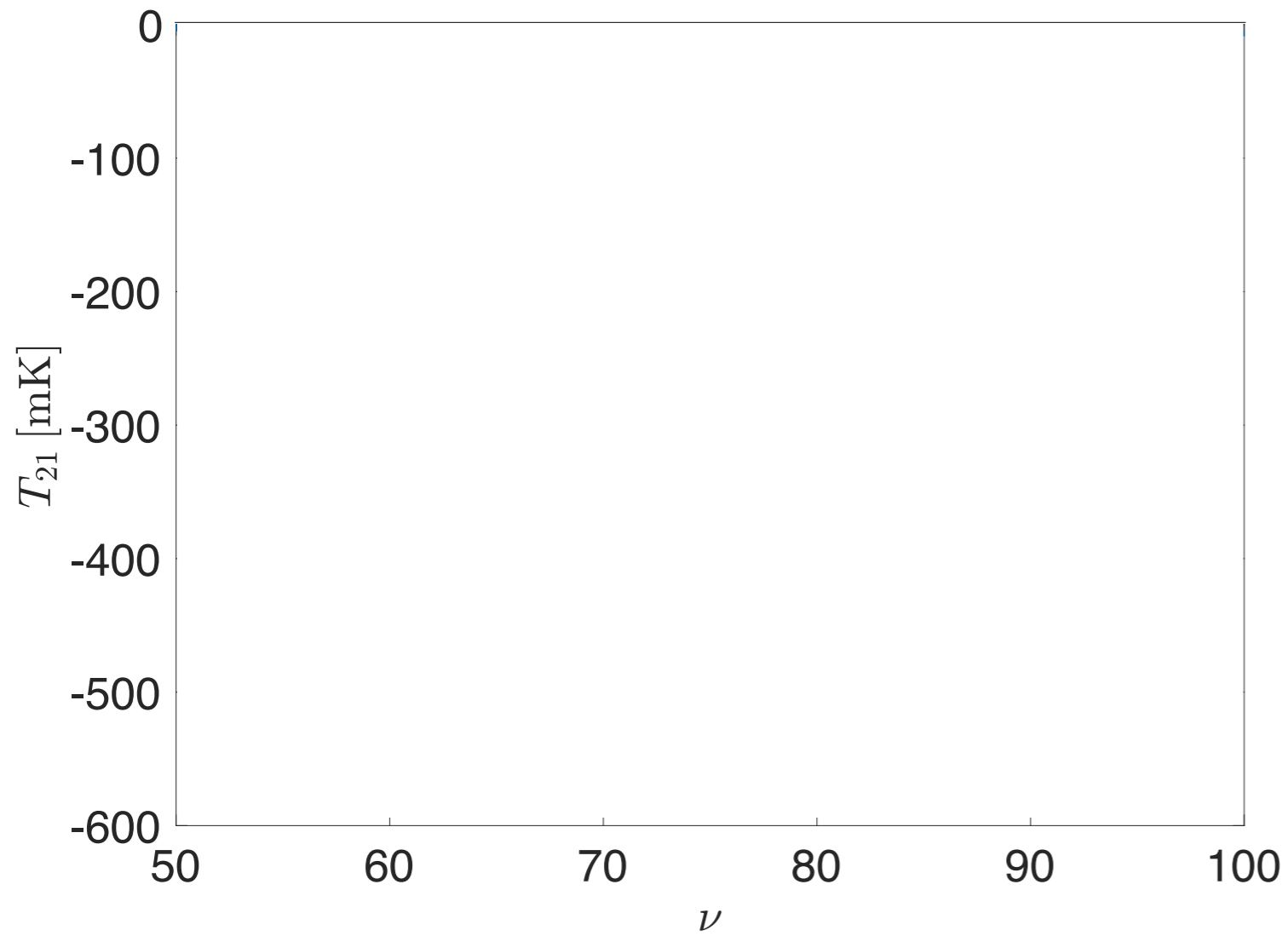
It's Always Darkest before the (Cosmic) Dawn



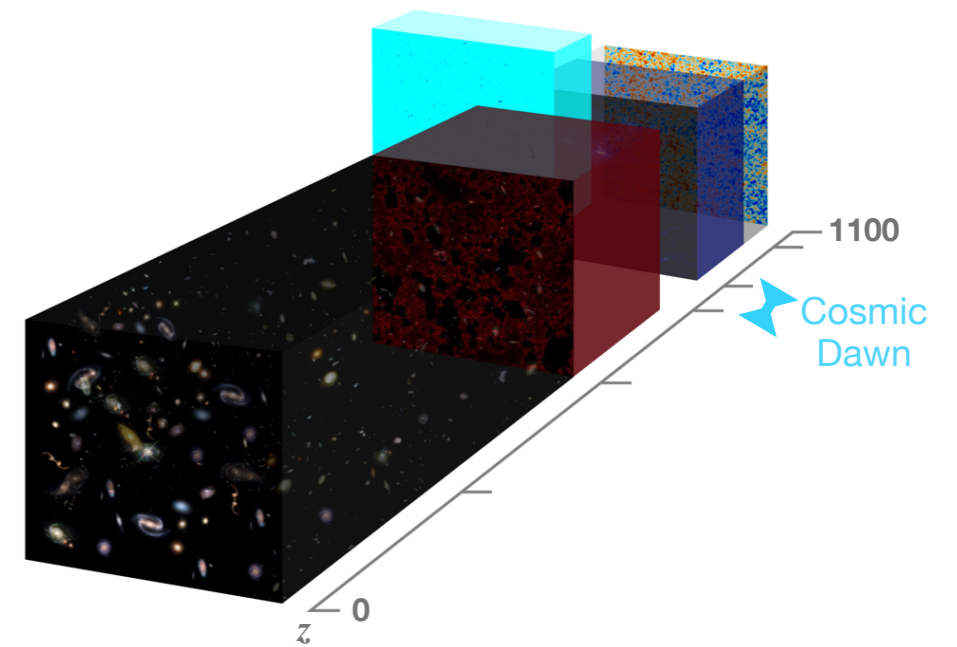
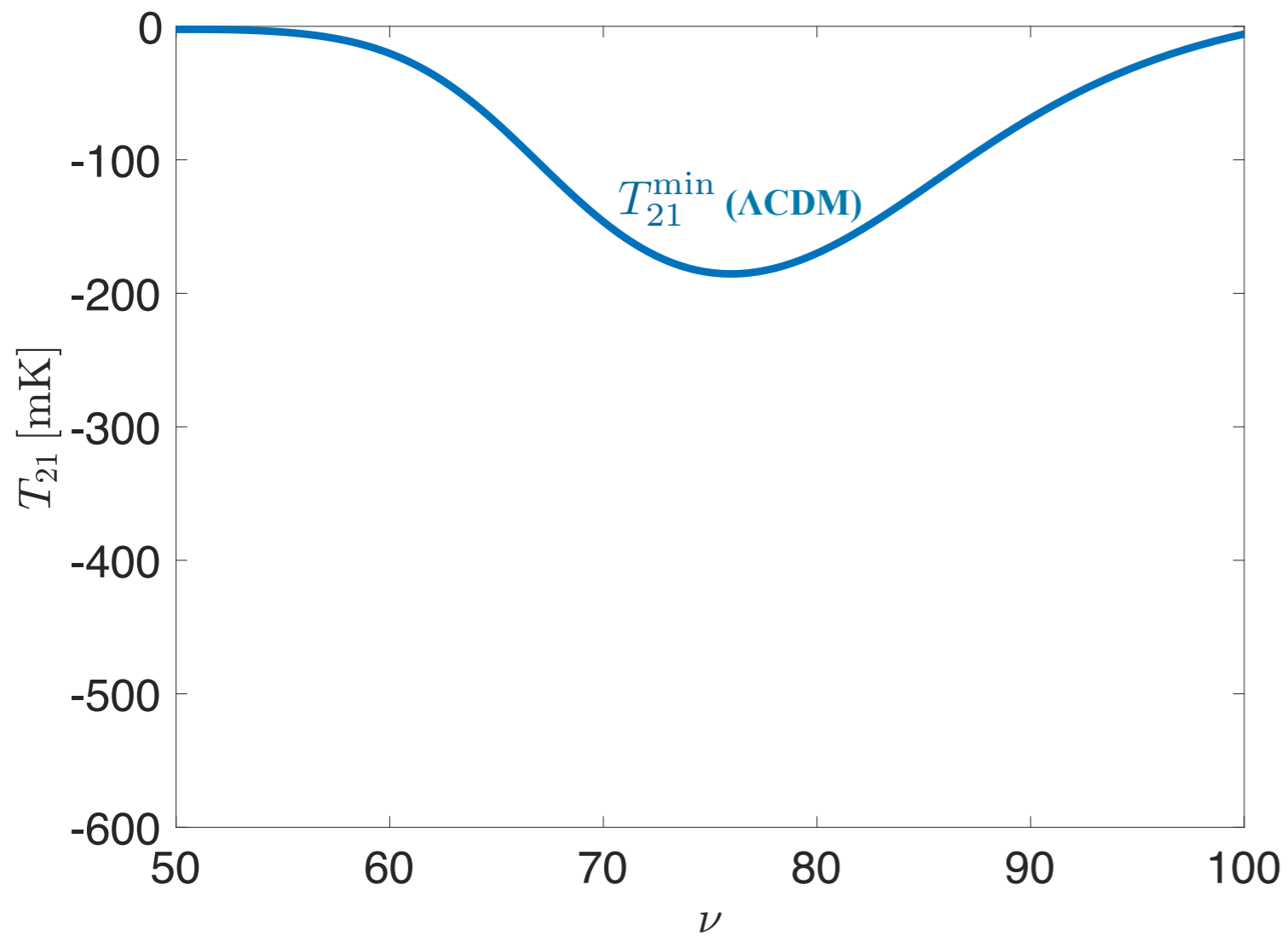
EDGES: First Claimed Detection of Cosmic Dawn



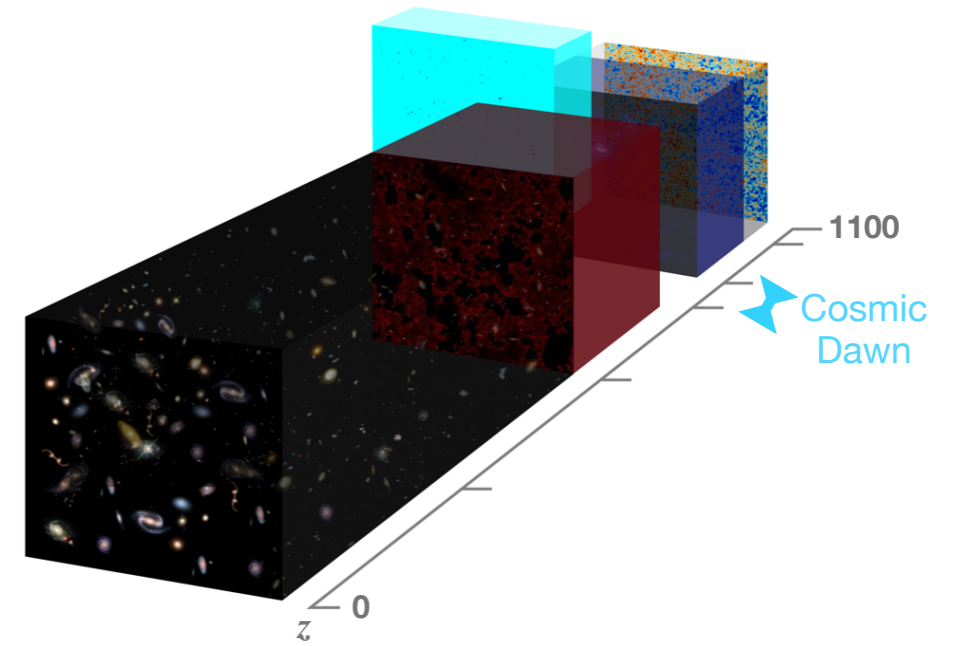
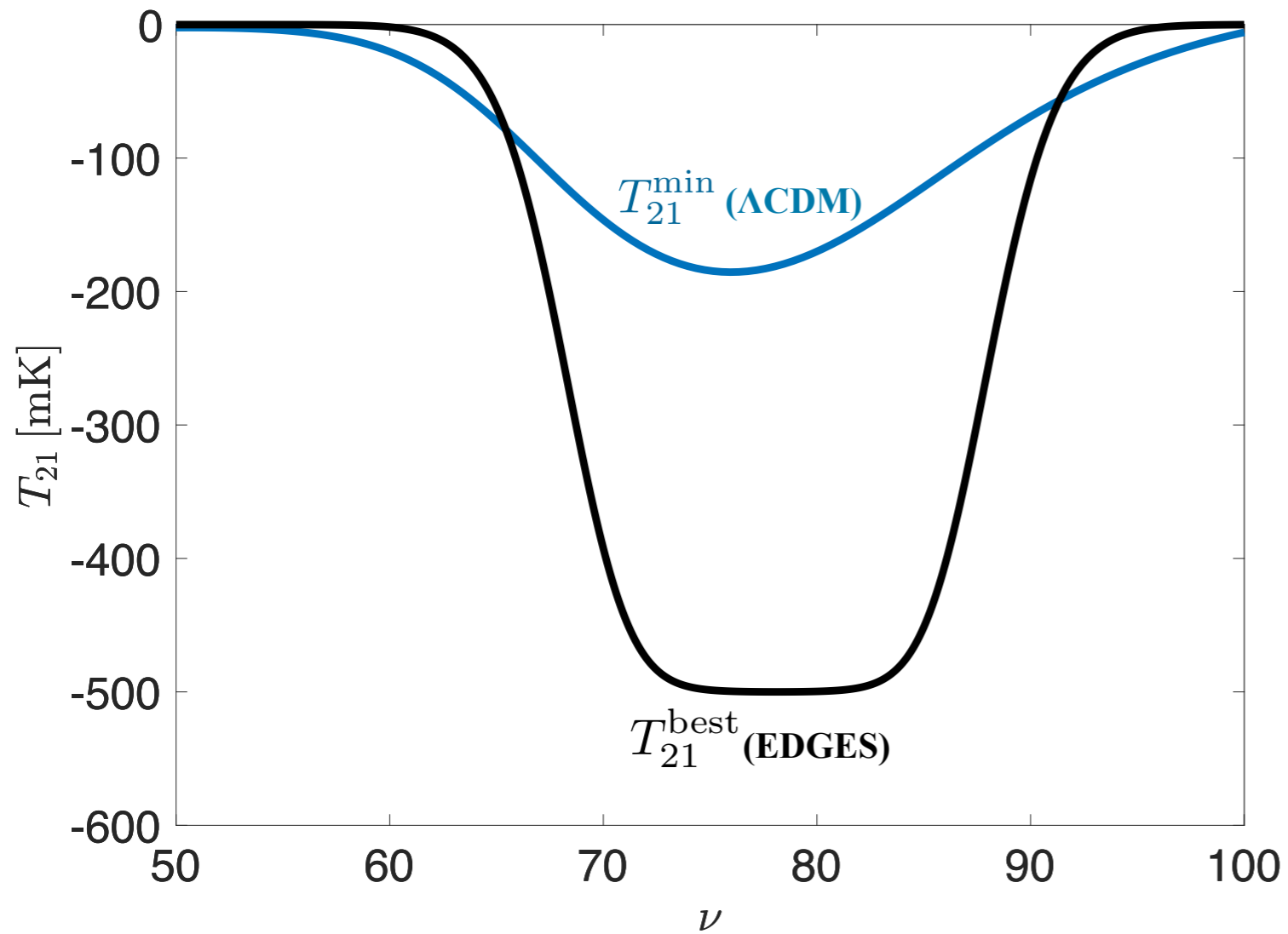
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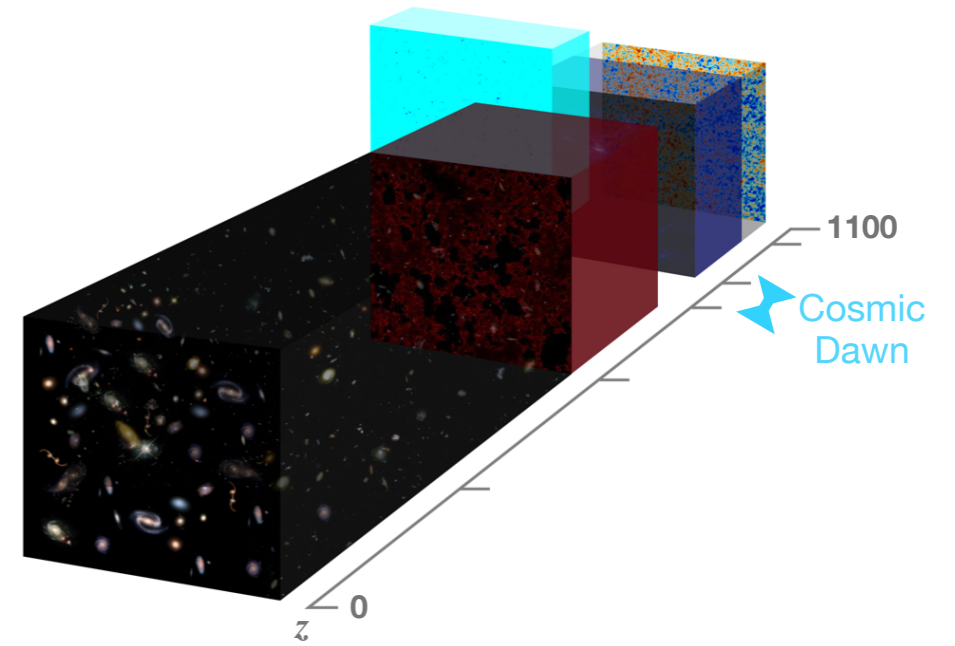
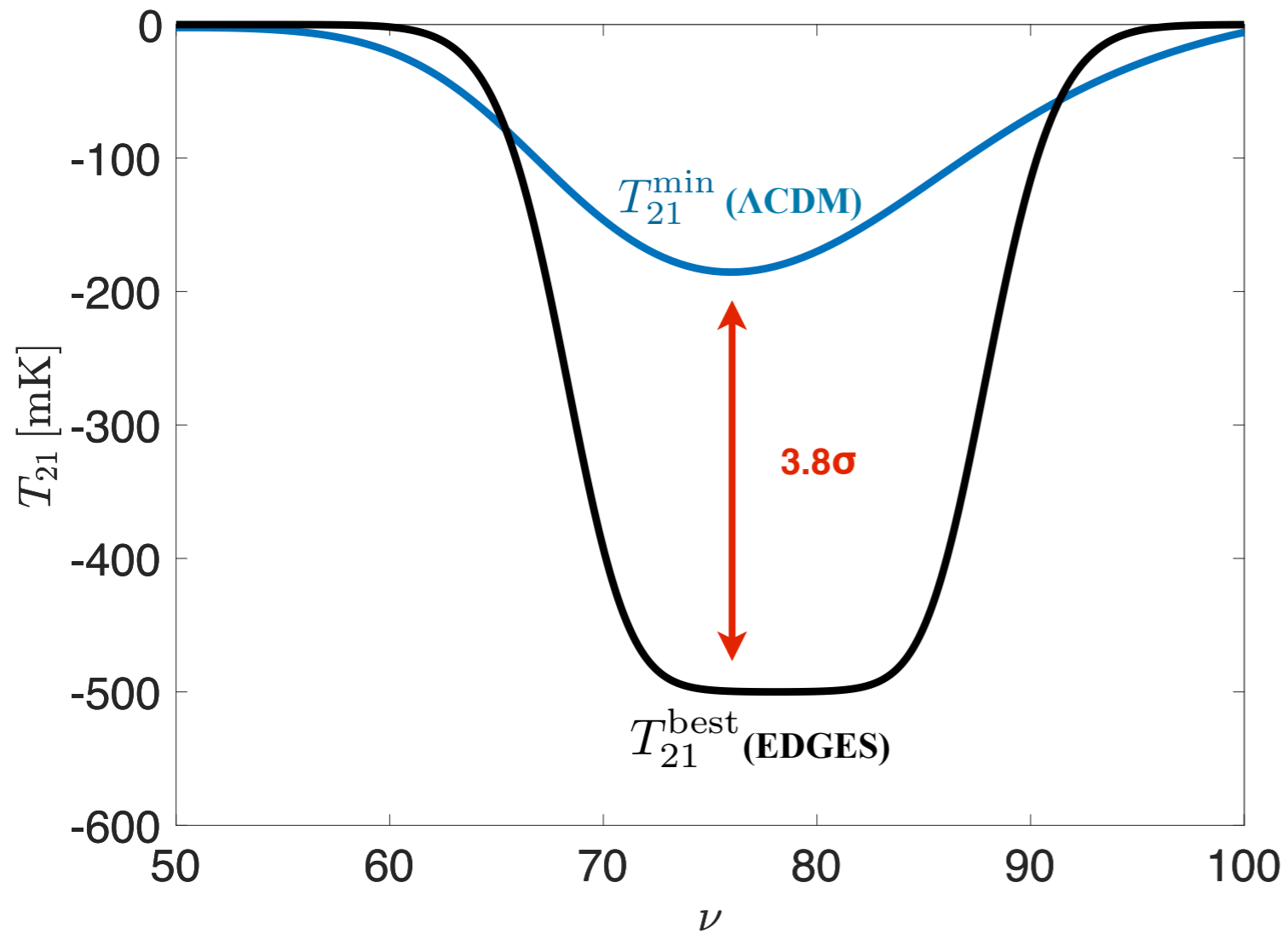
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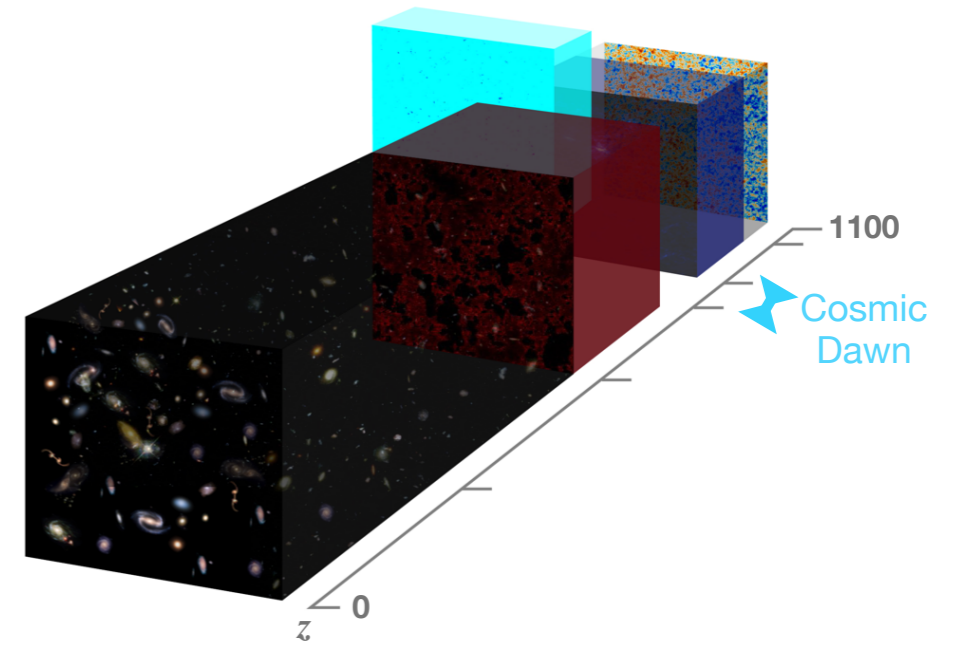
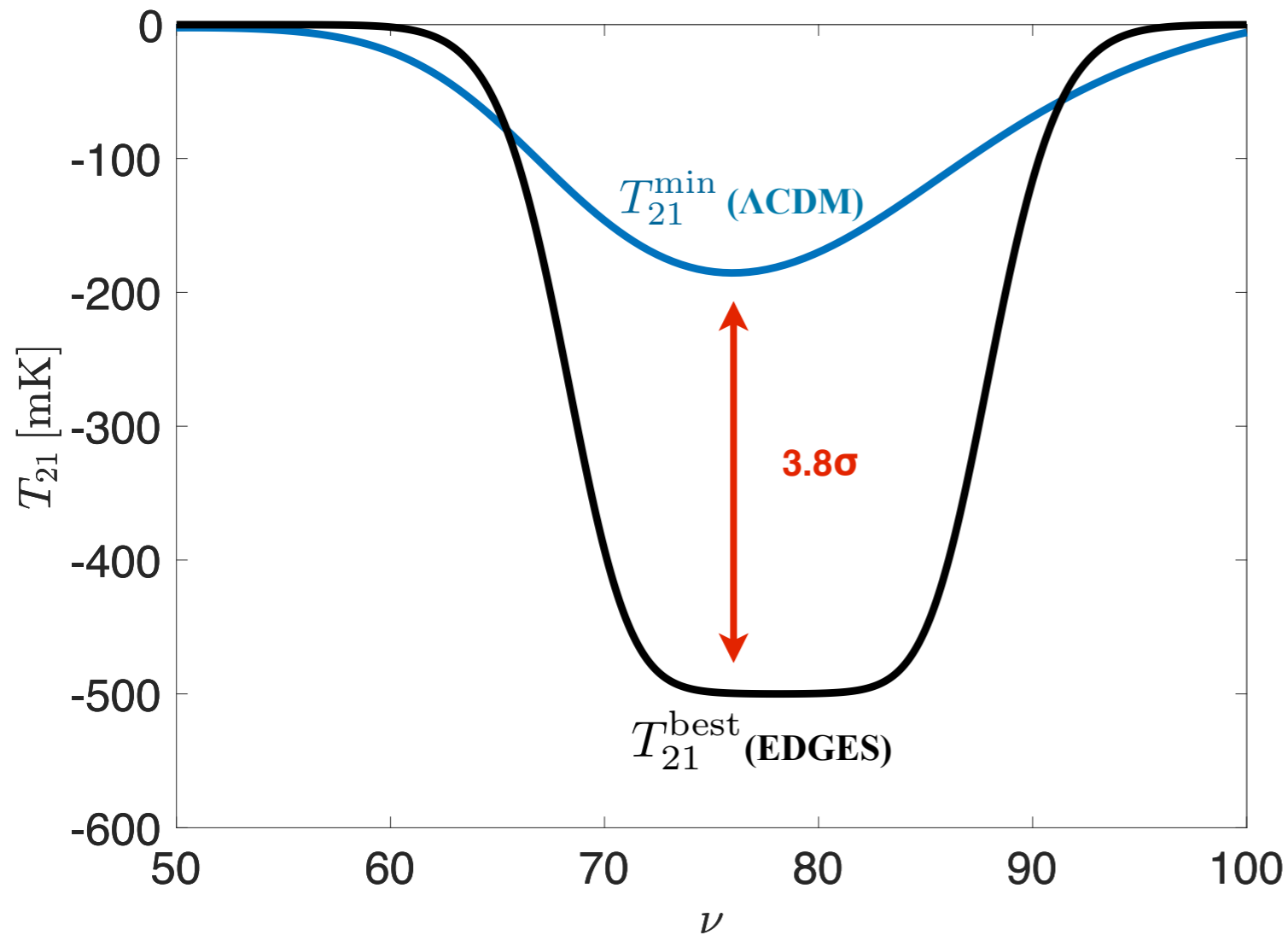


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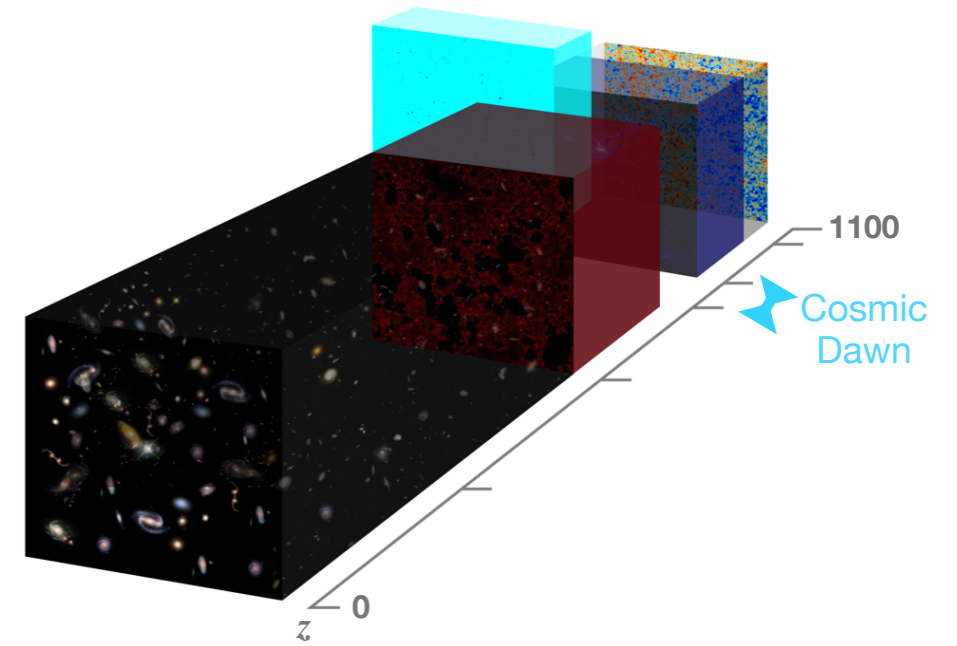
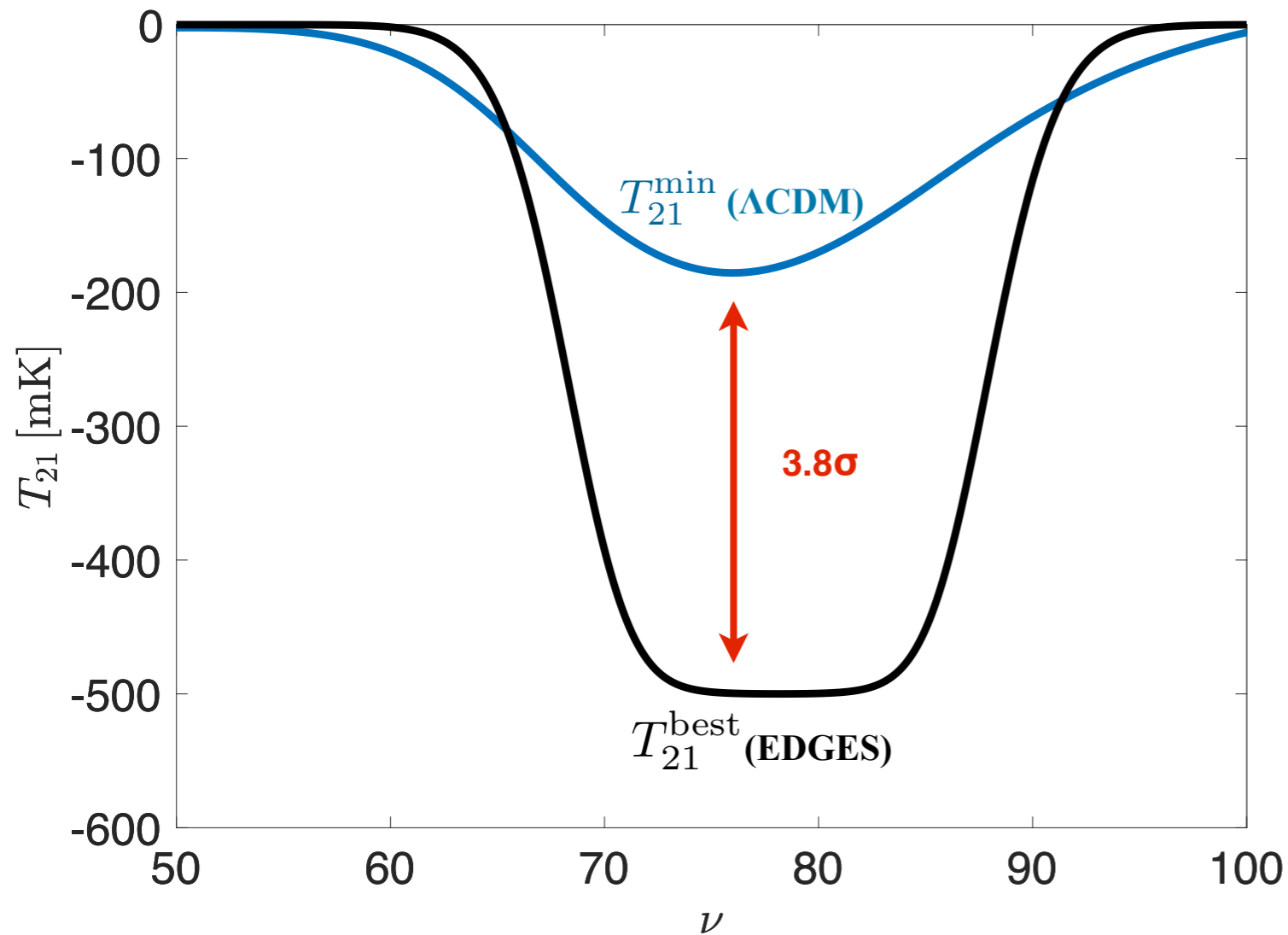
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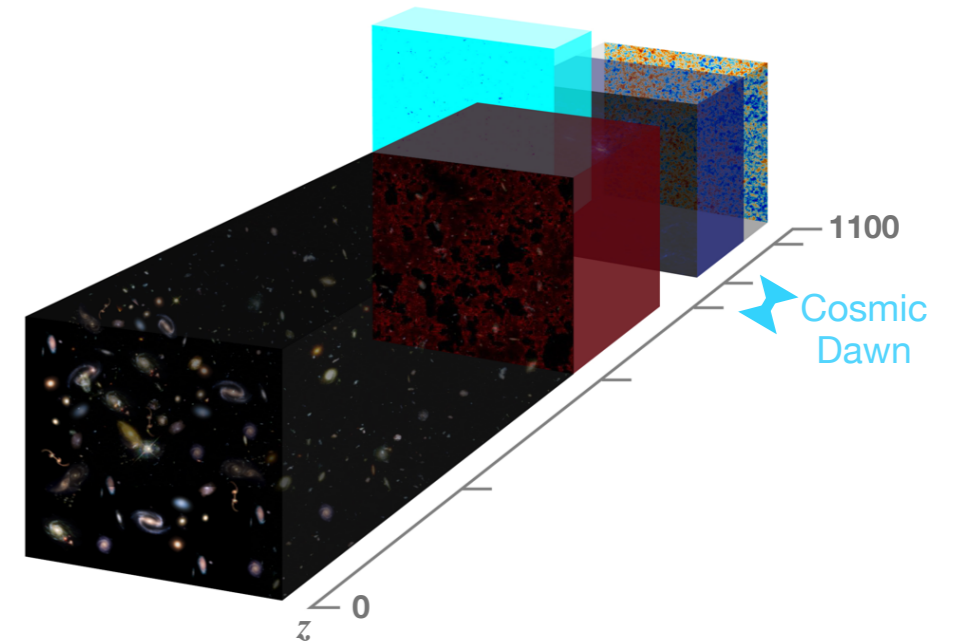
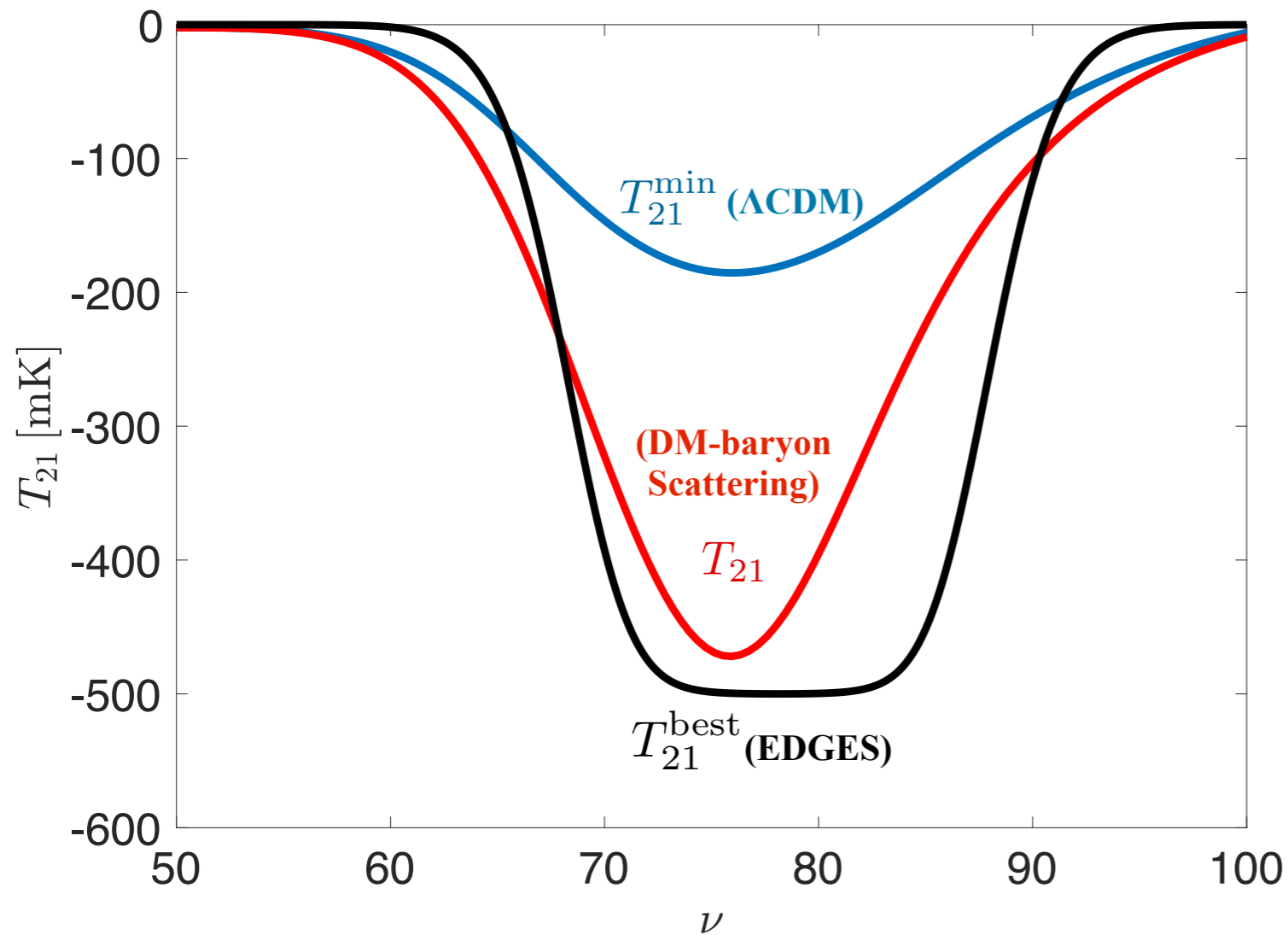
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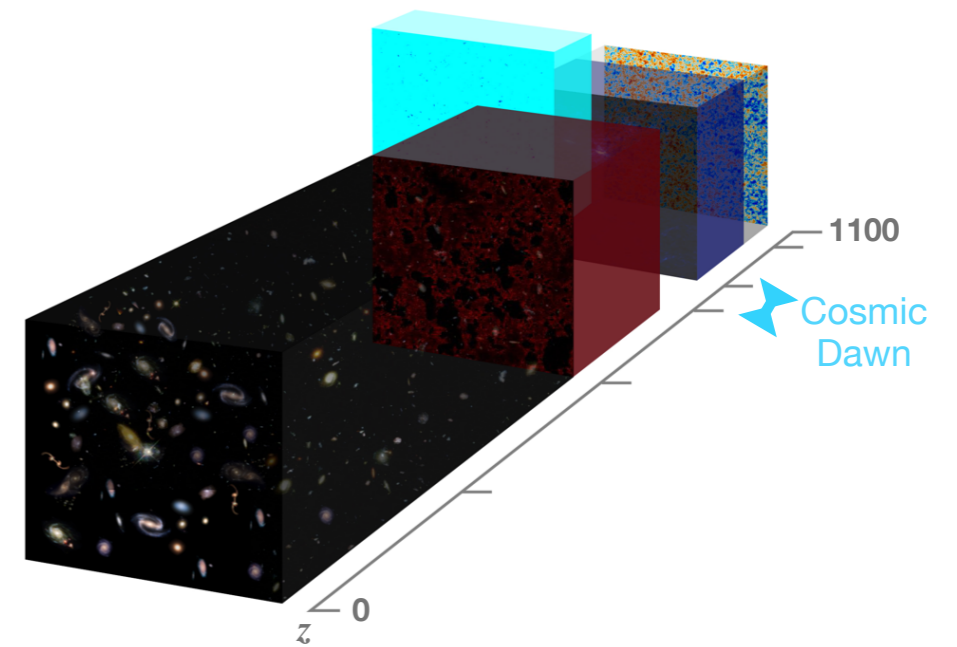
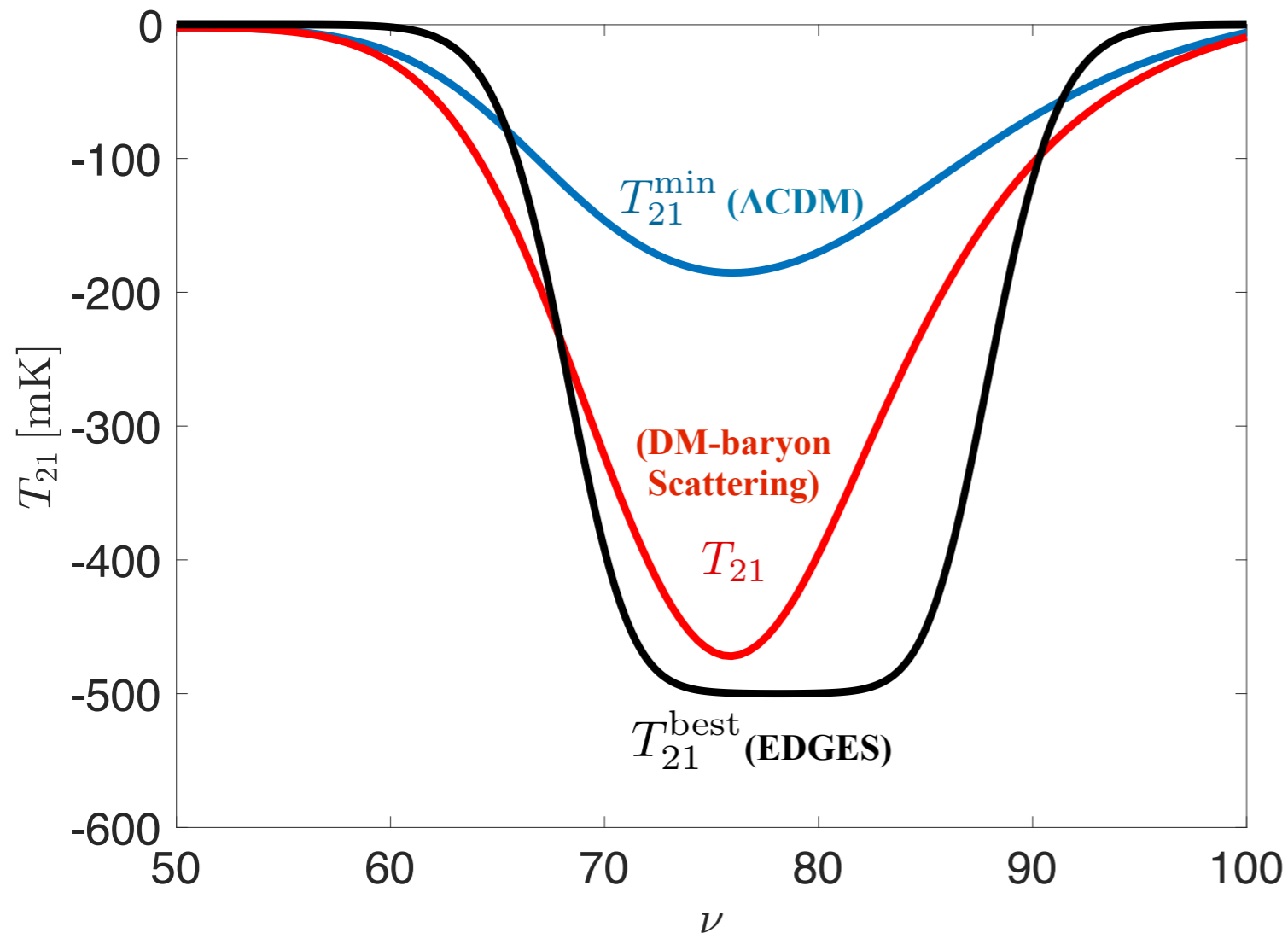


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Q1: Did EDGES detect DM?

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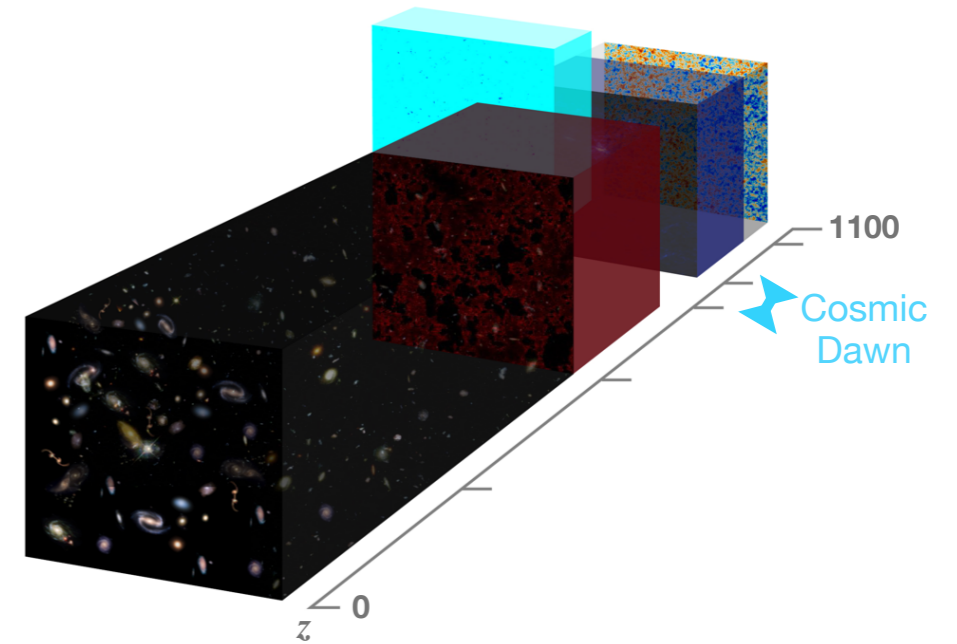
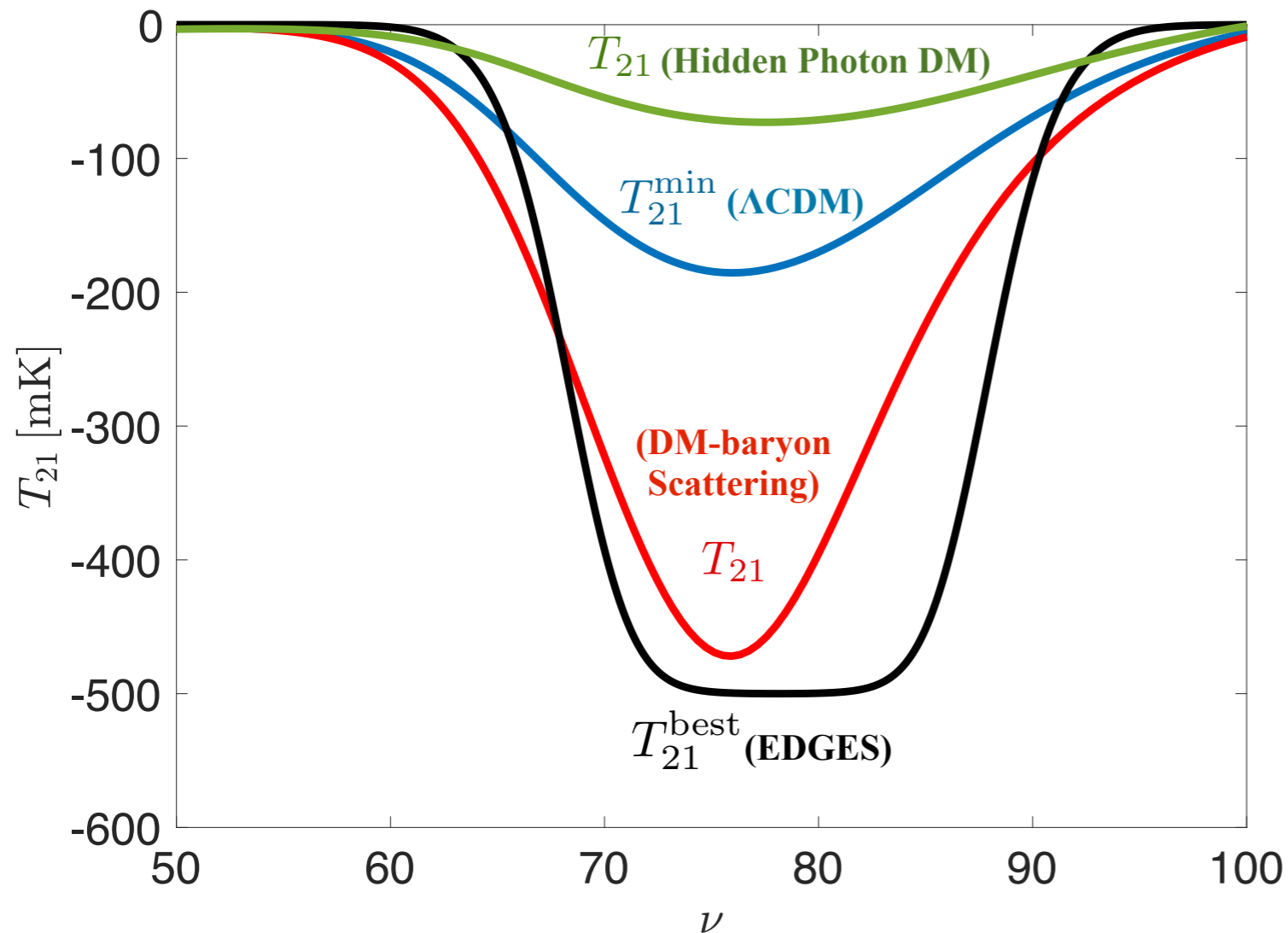


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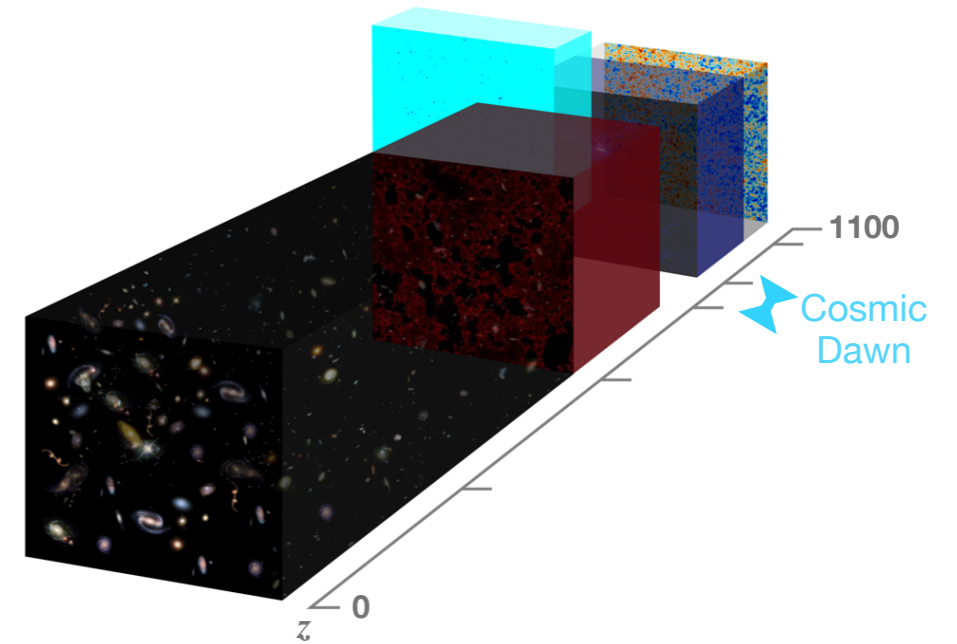
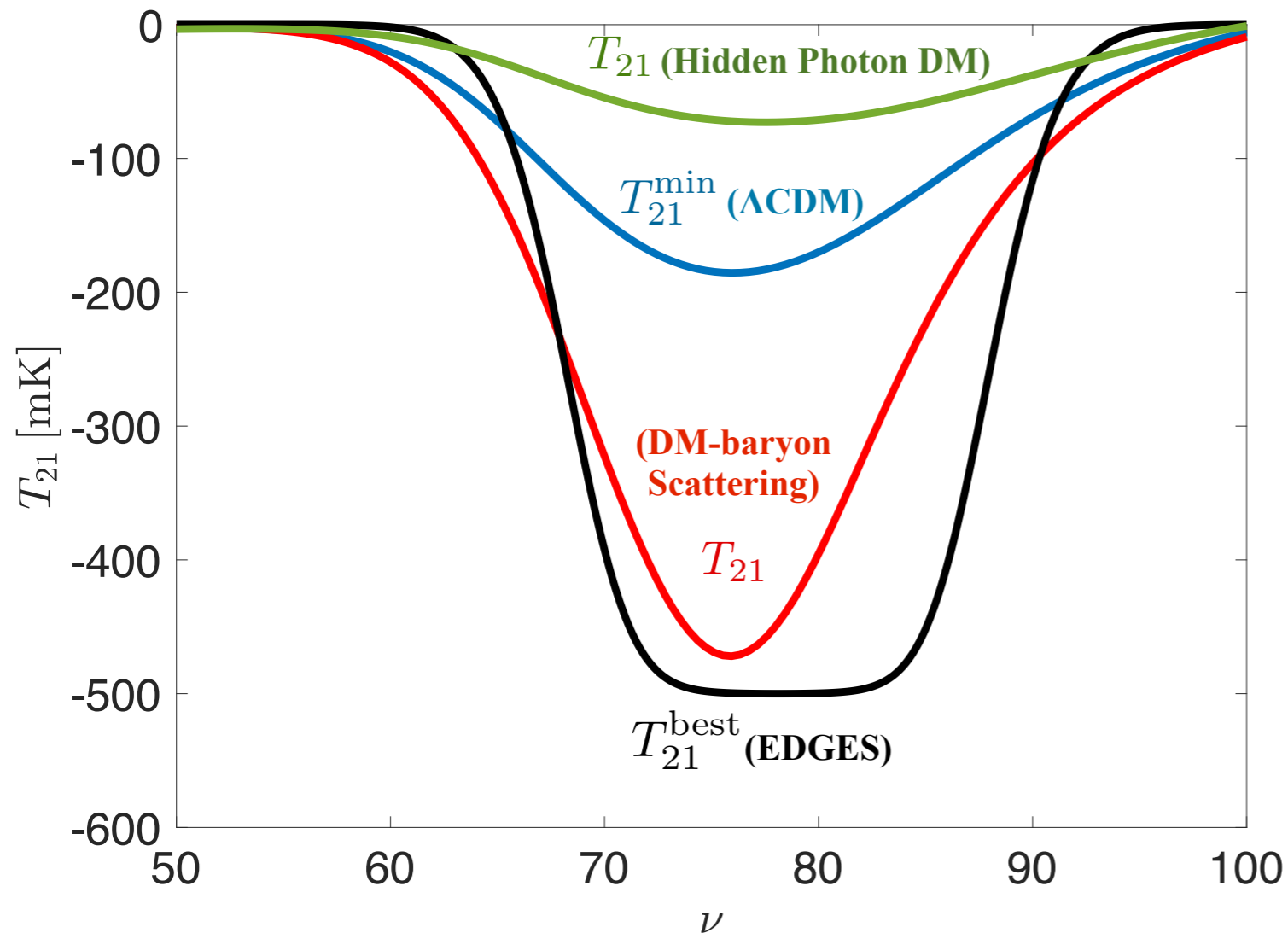
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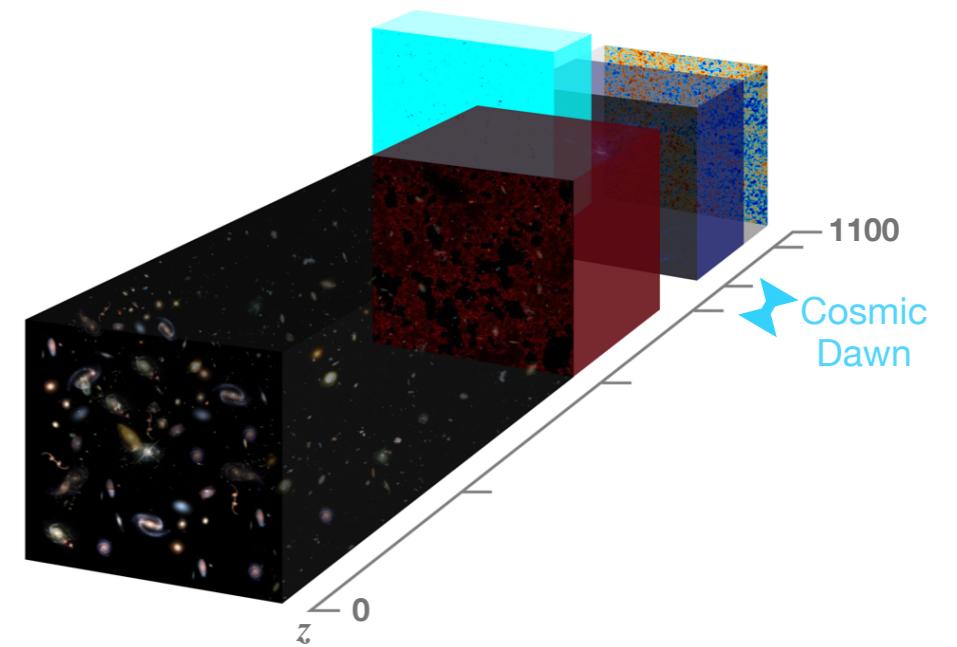
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Message: Prospects of Cosmic Dawn



Outline

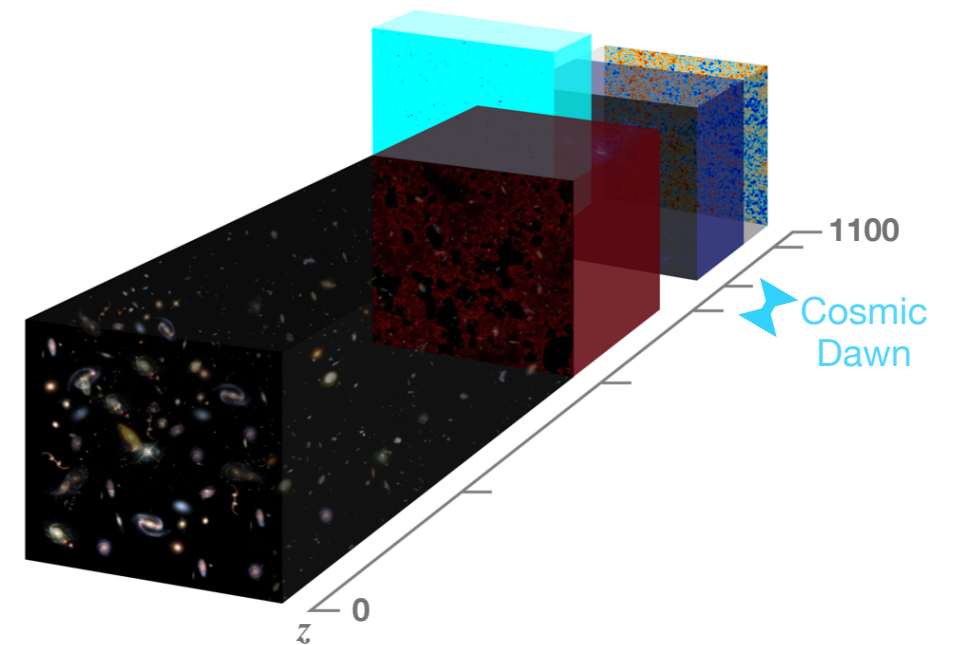
Ely Kovetz
UMD, Sep. 2018



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Ely Kovetz
UMD, Sep. 2018

- Quick Introduction to 21cm at Cosmic Dawn

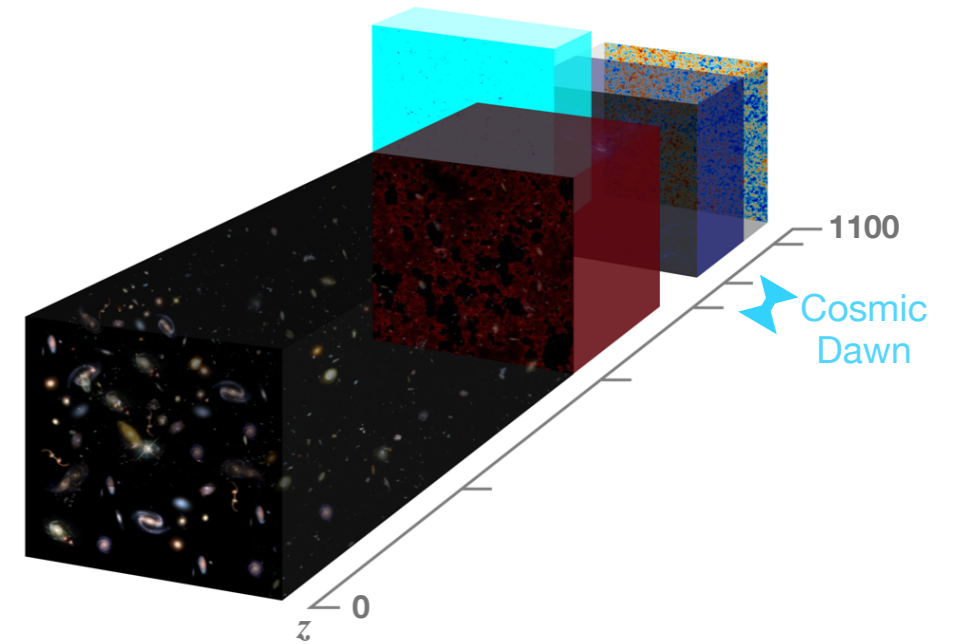


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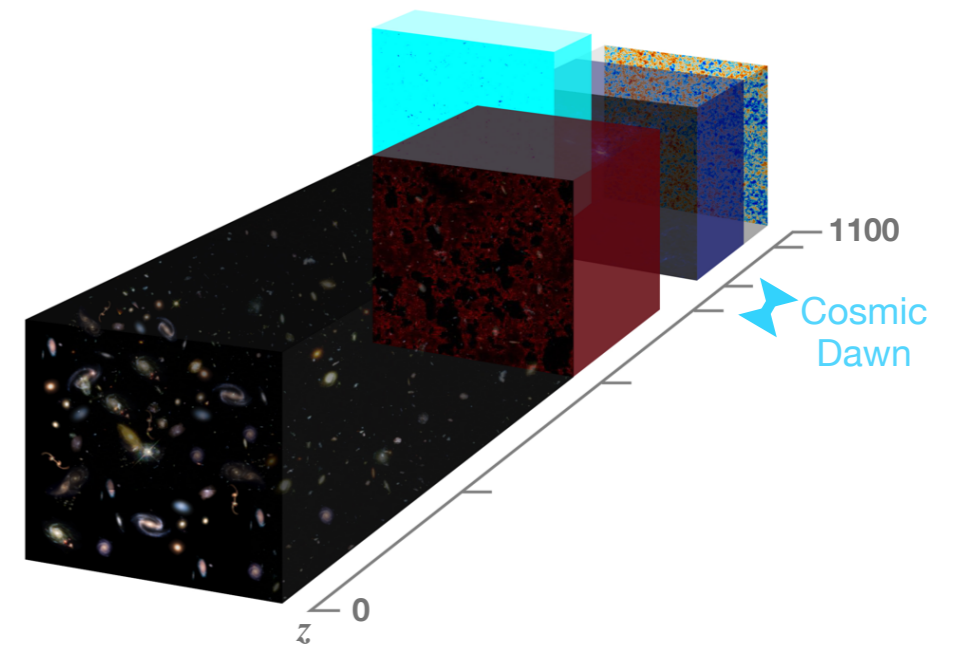
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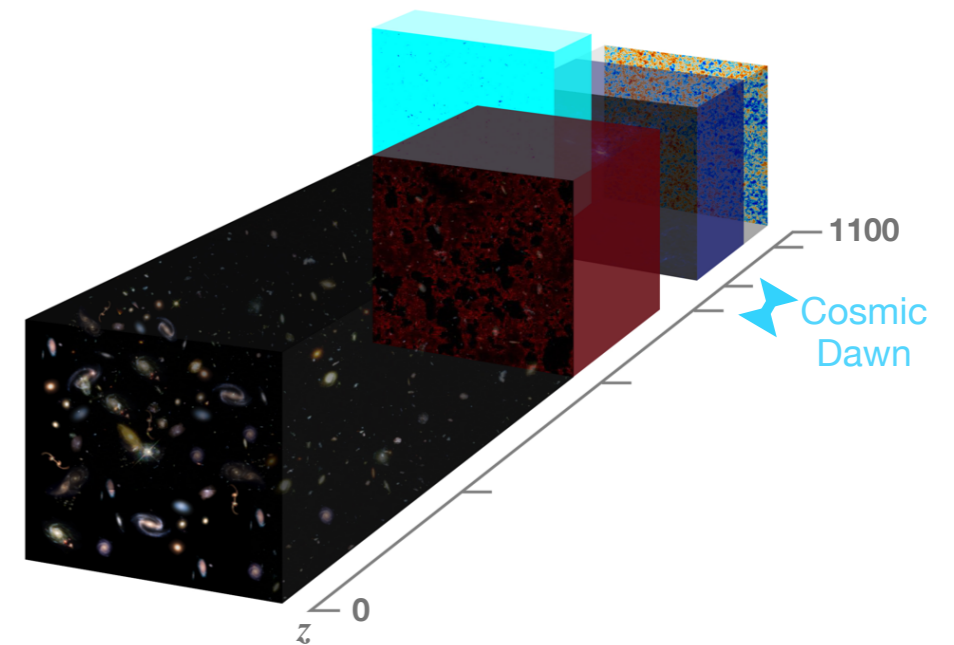
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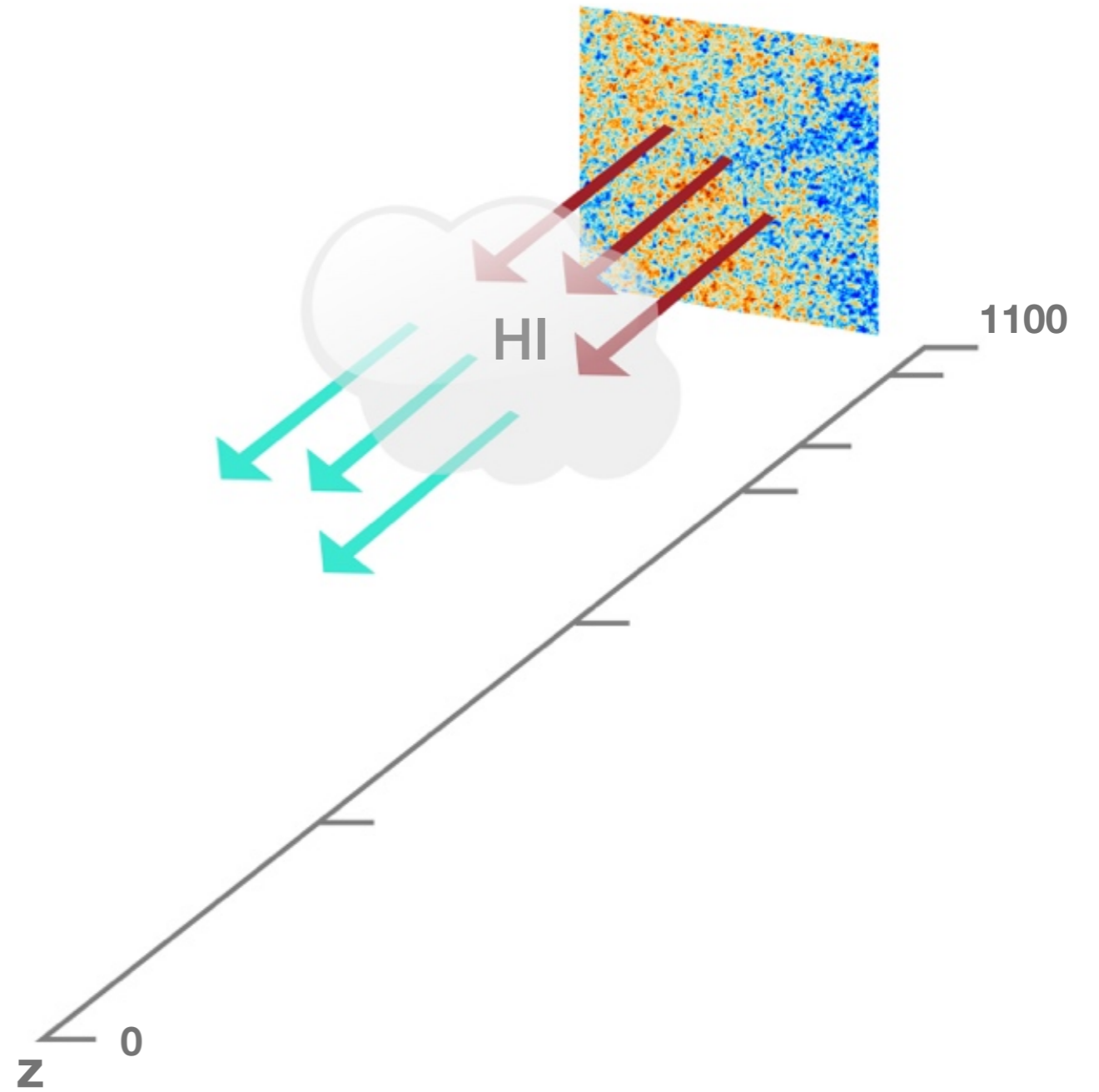
Outline

Ely Kovetz
UMD, Sep. 2018

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- Probing Ultra-Light HPDM

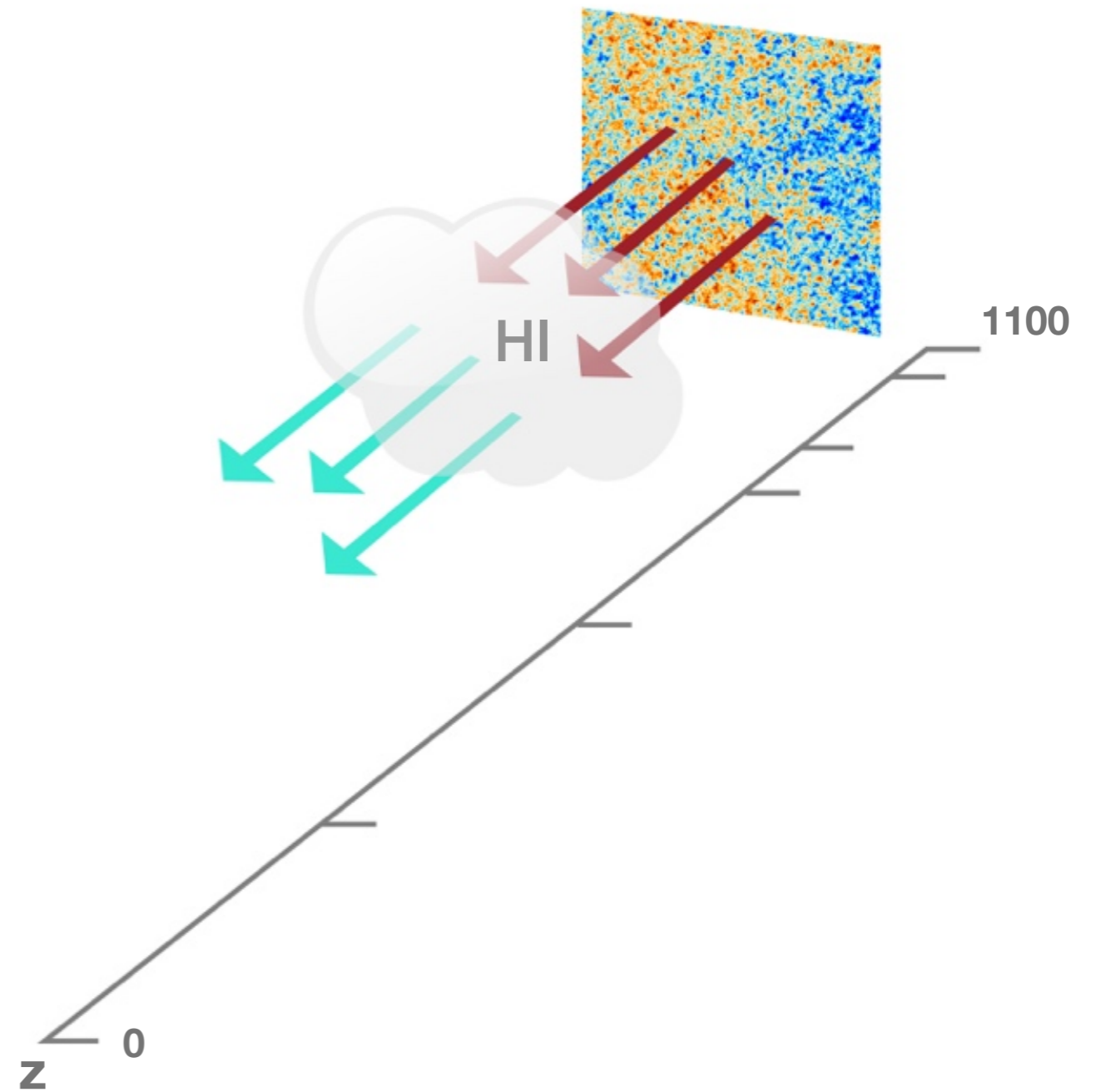


The 21-cm Signal: Lightning Review



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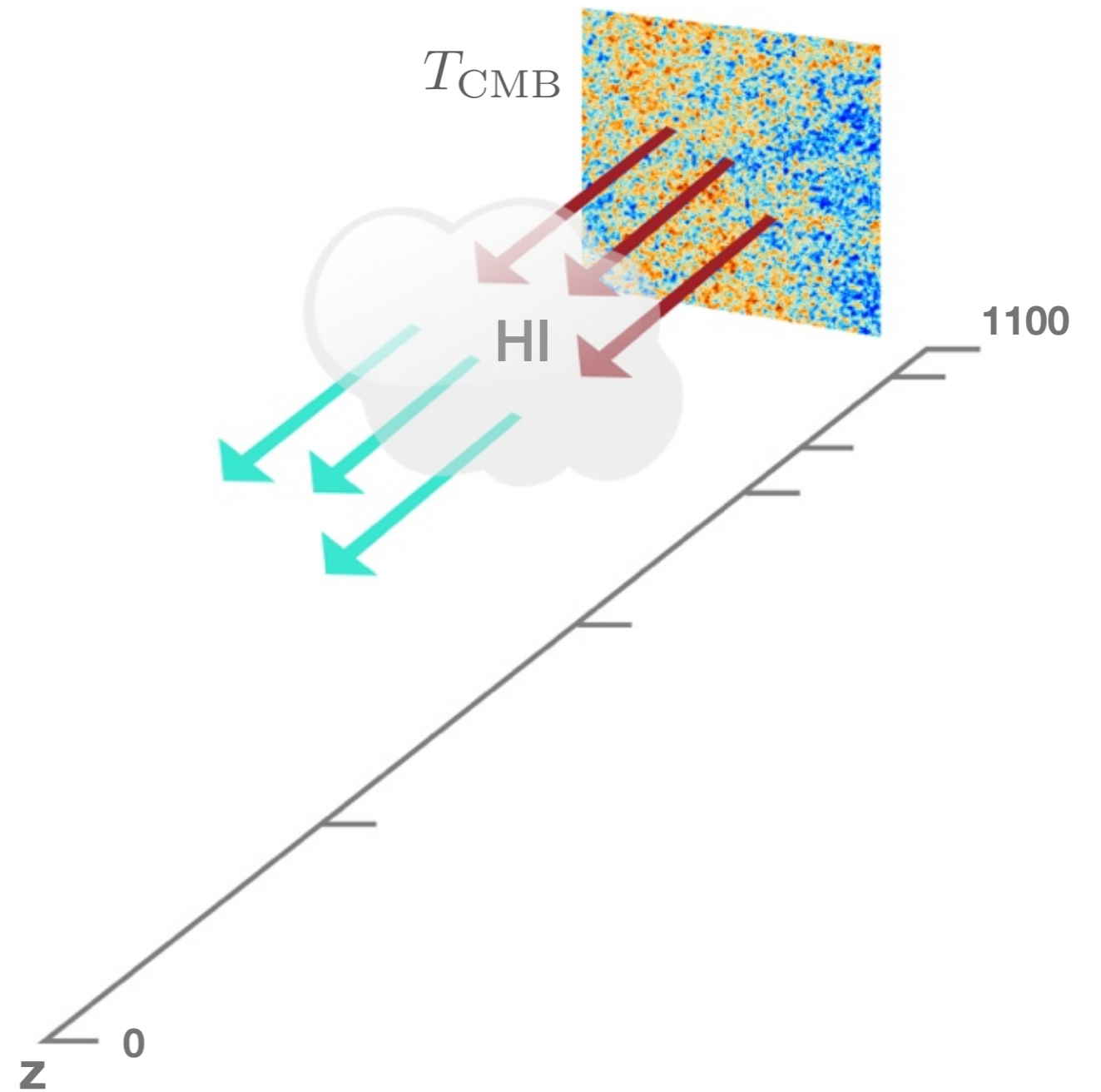
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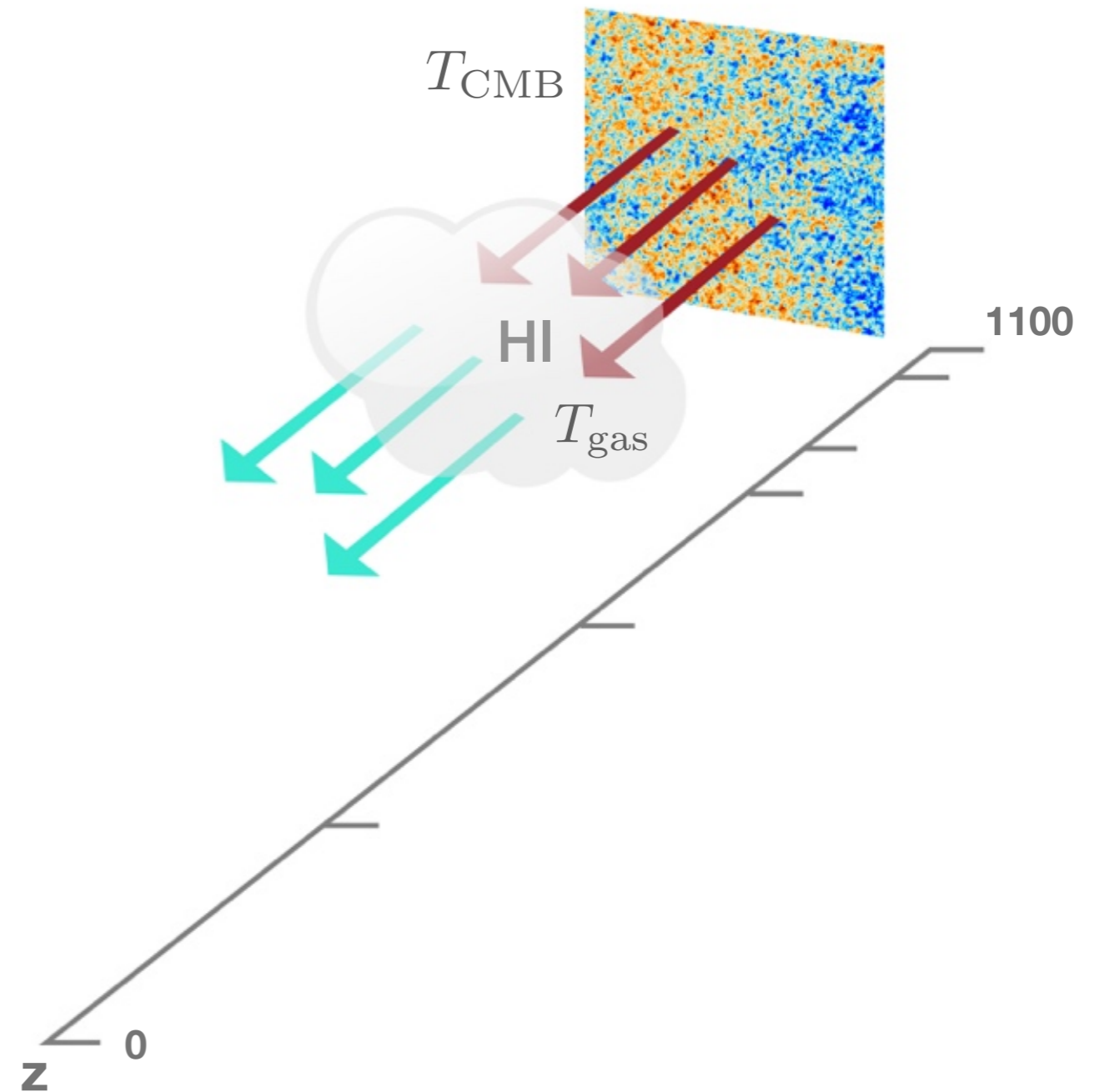
- CMB temperature (background)



The 21-cm Signal: Lightning Review

Game of “Temperatures”:

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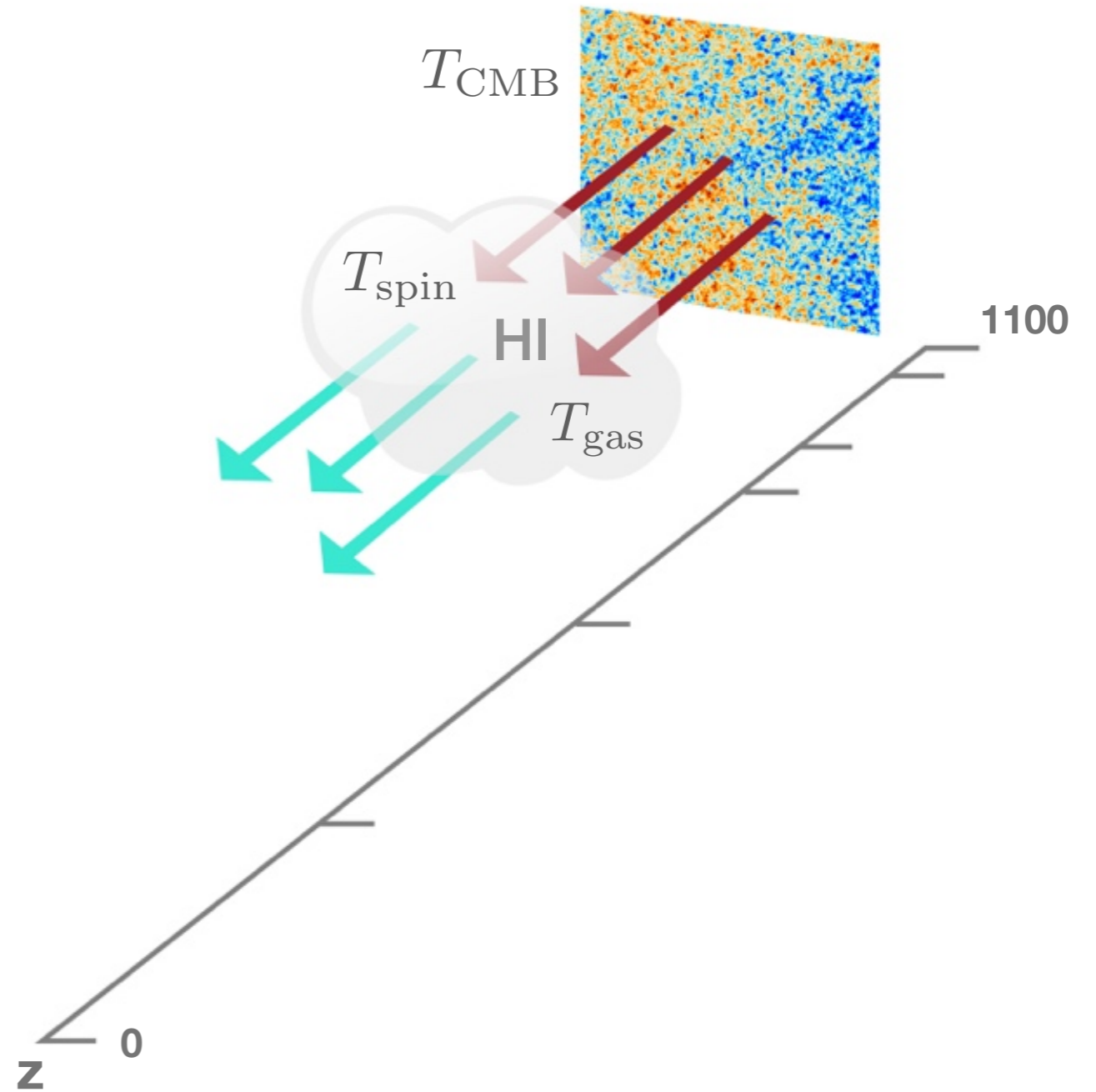


The 21-cm Signal: Lightning Review

Game of “Temperatures”:

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$$\frac{n_1}{n_0} \equiv 3 \exp(-E_{10}/k_B T_{\text{spin}})$$



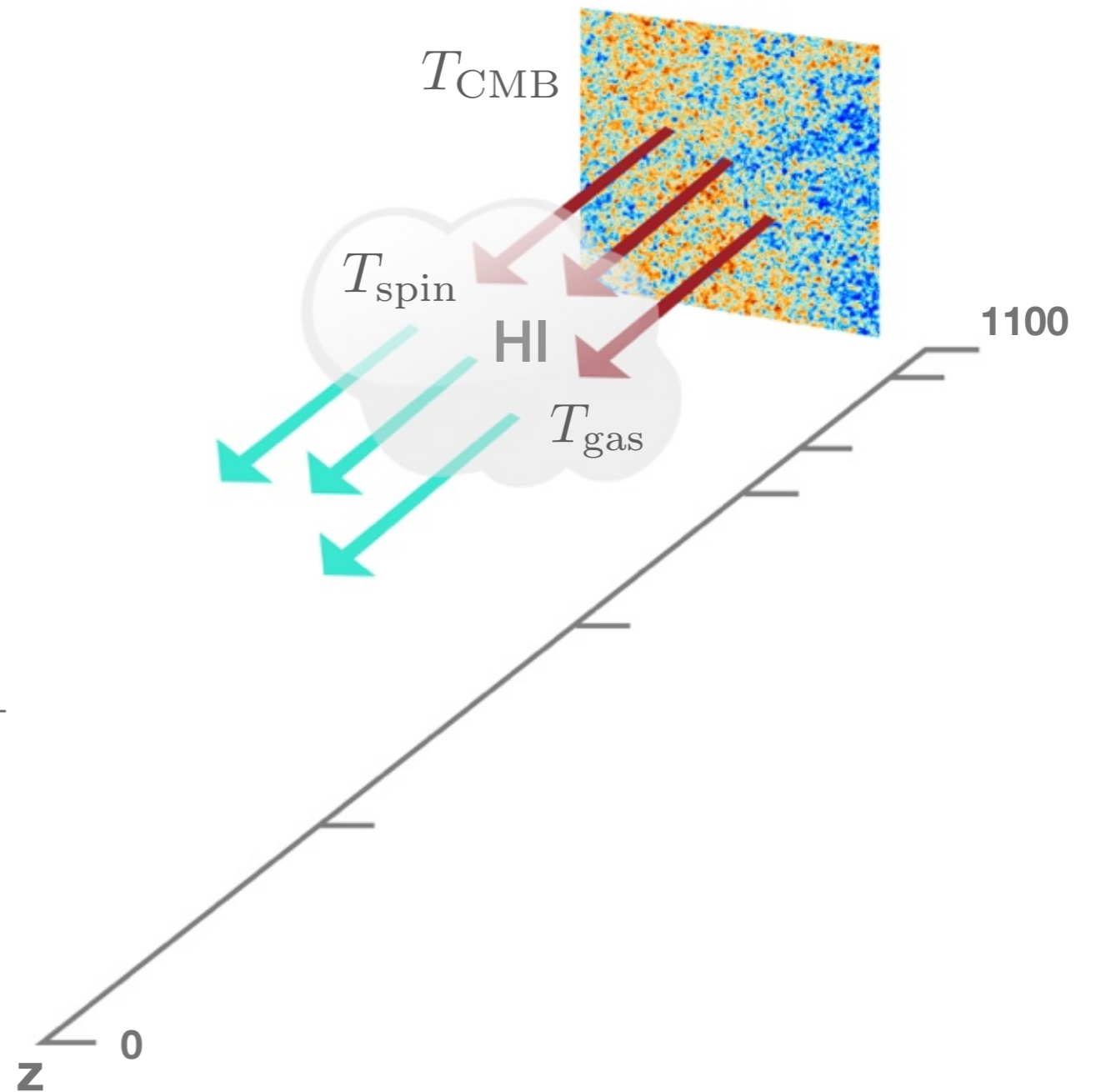
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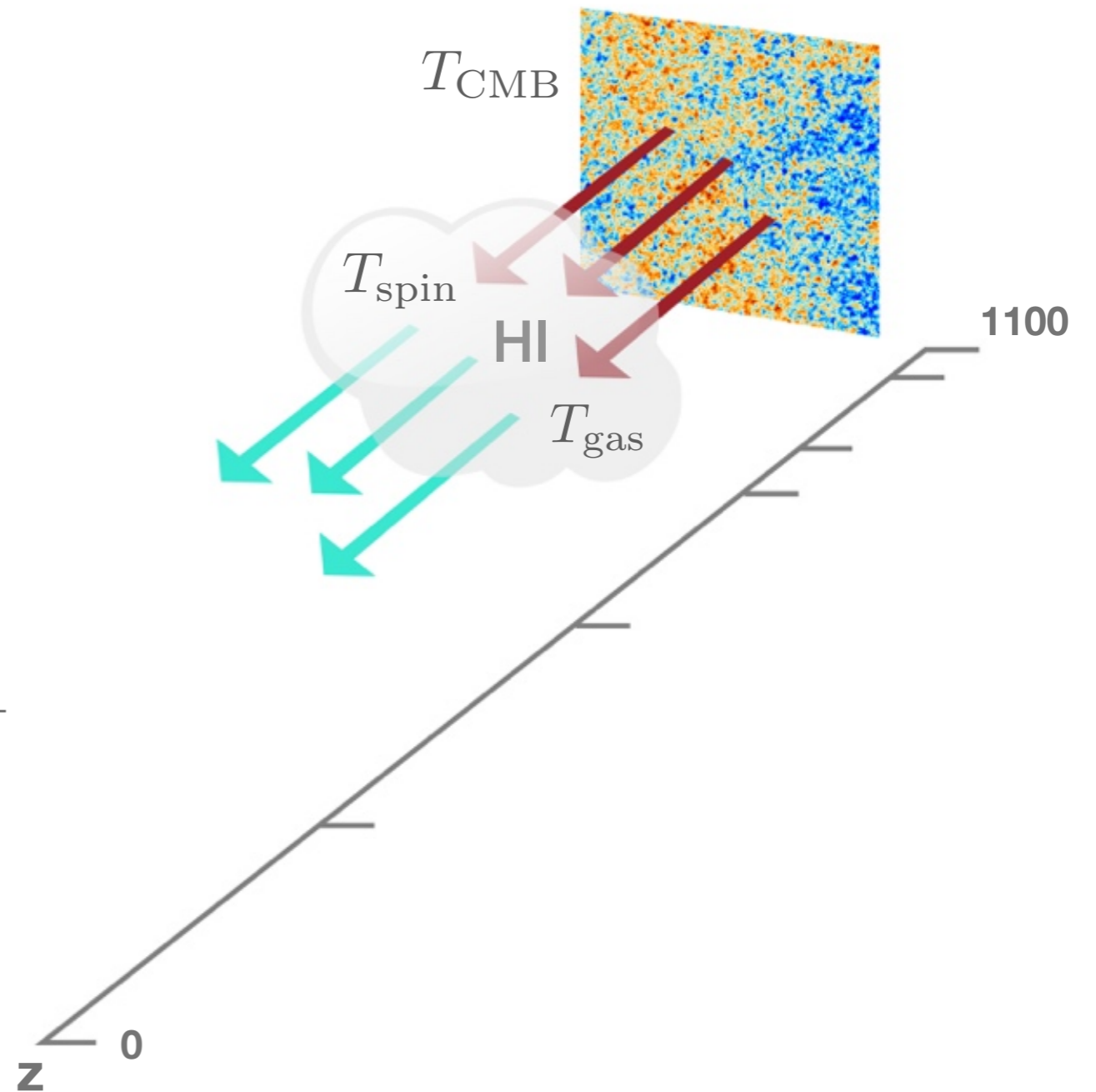
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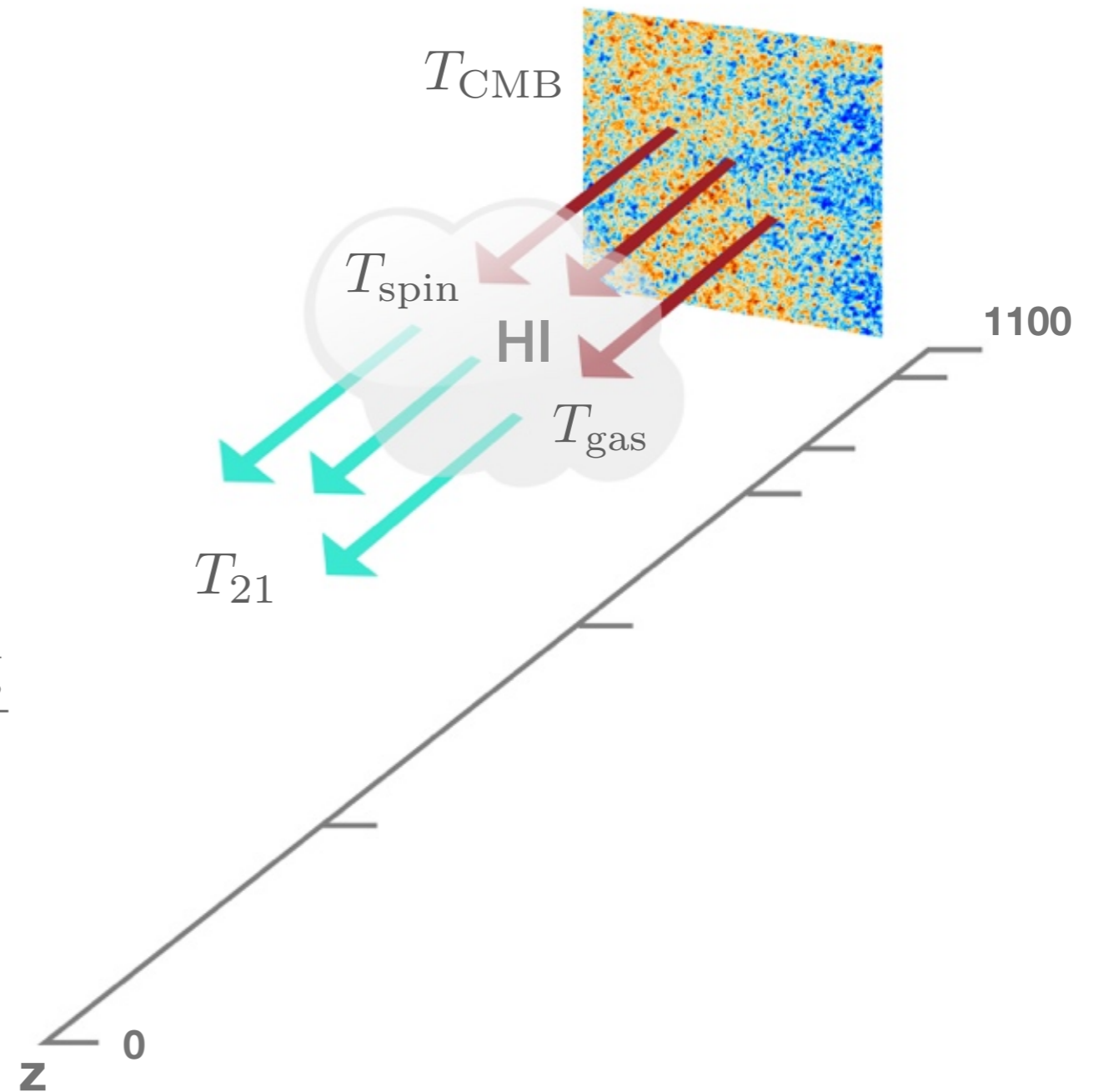
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- Brightness temperature contrast:

$$\delta T_{\text{bright}} \equiv T_{21} \approx \frac{T_{\text{spin}} - T_{\text{CMB}}}{1 + z} \tau$$



The 21-cm Signal: Lightning Review

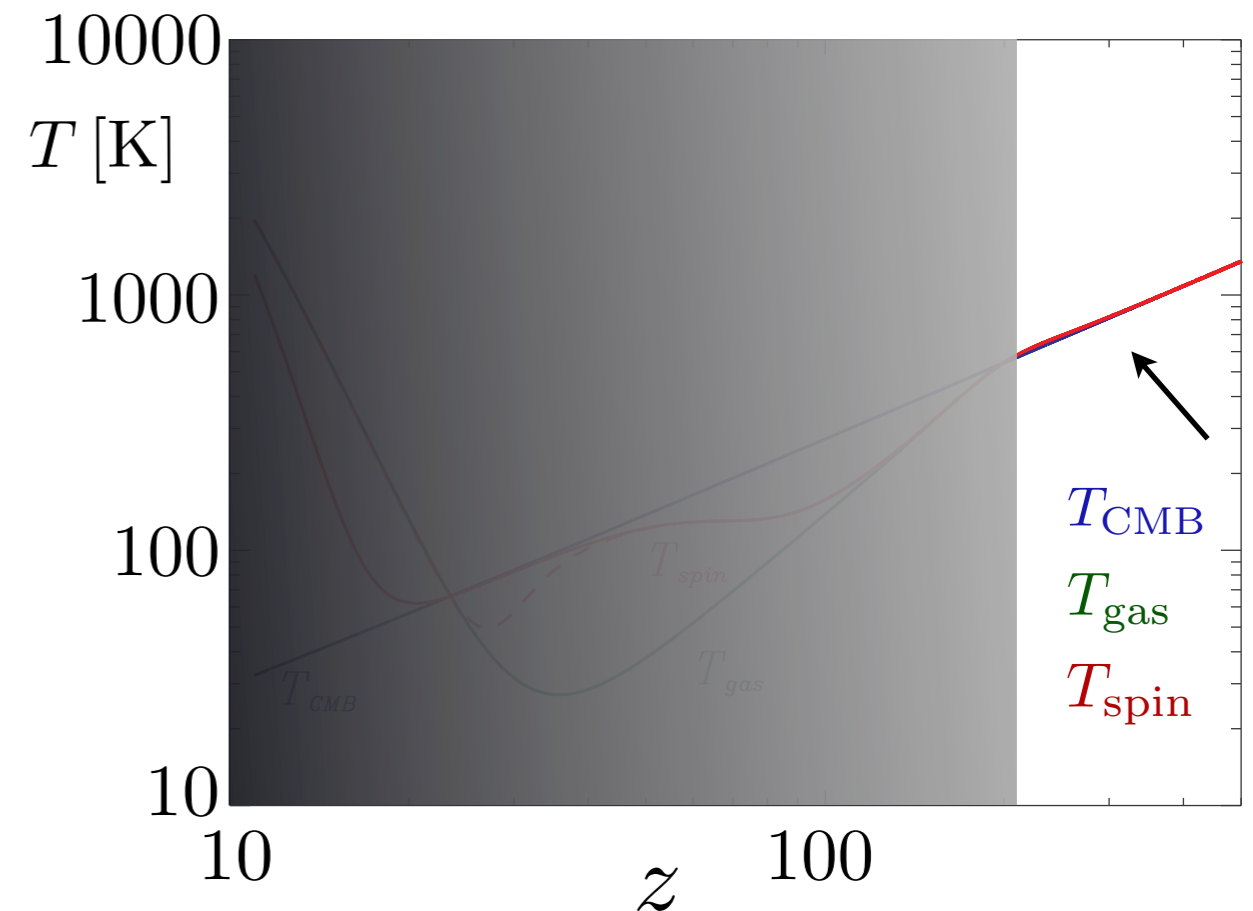
The 21-cm Signal: Lightning Review

Time dependence of different temperatures:

The 21-cm Signal: Lightning Review

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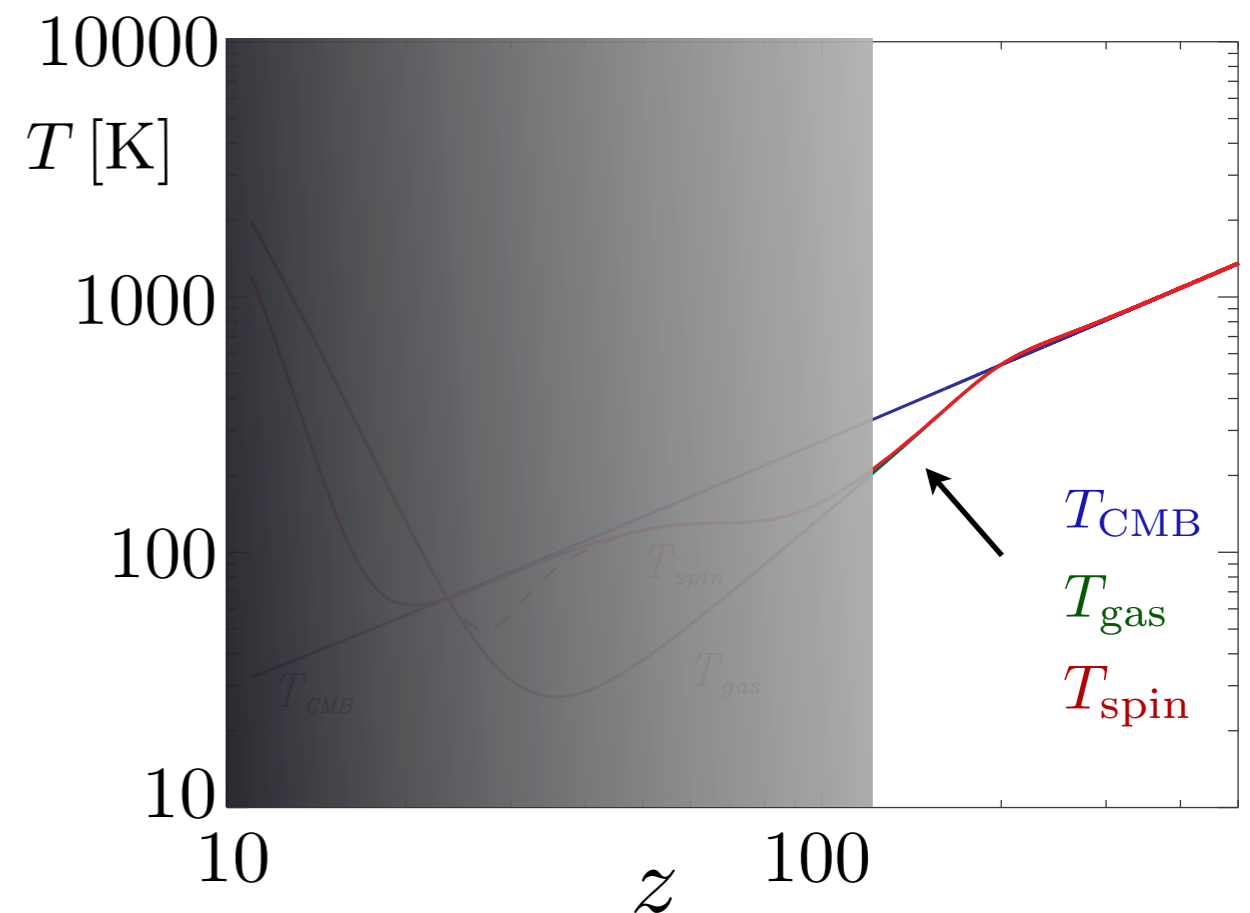


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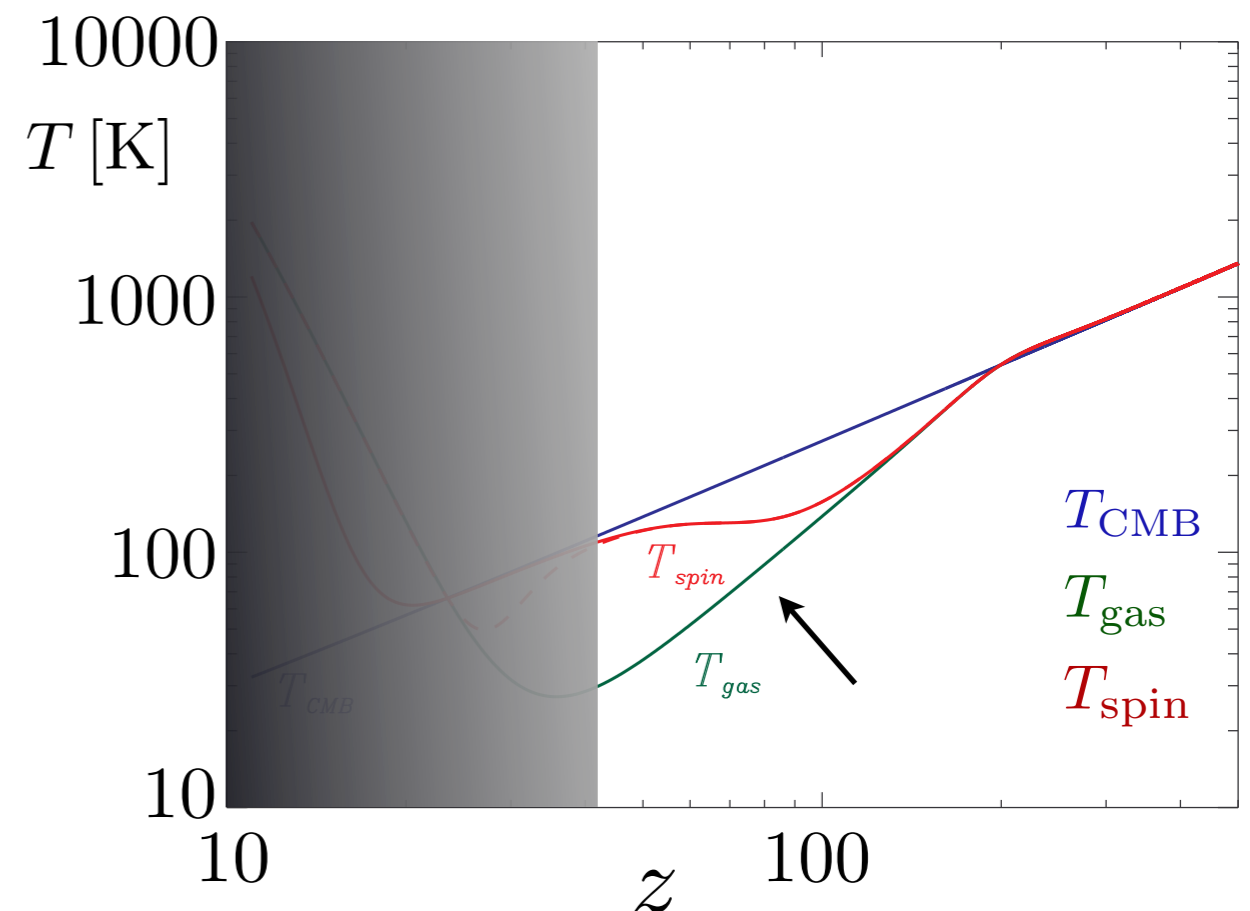
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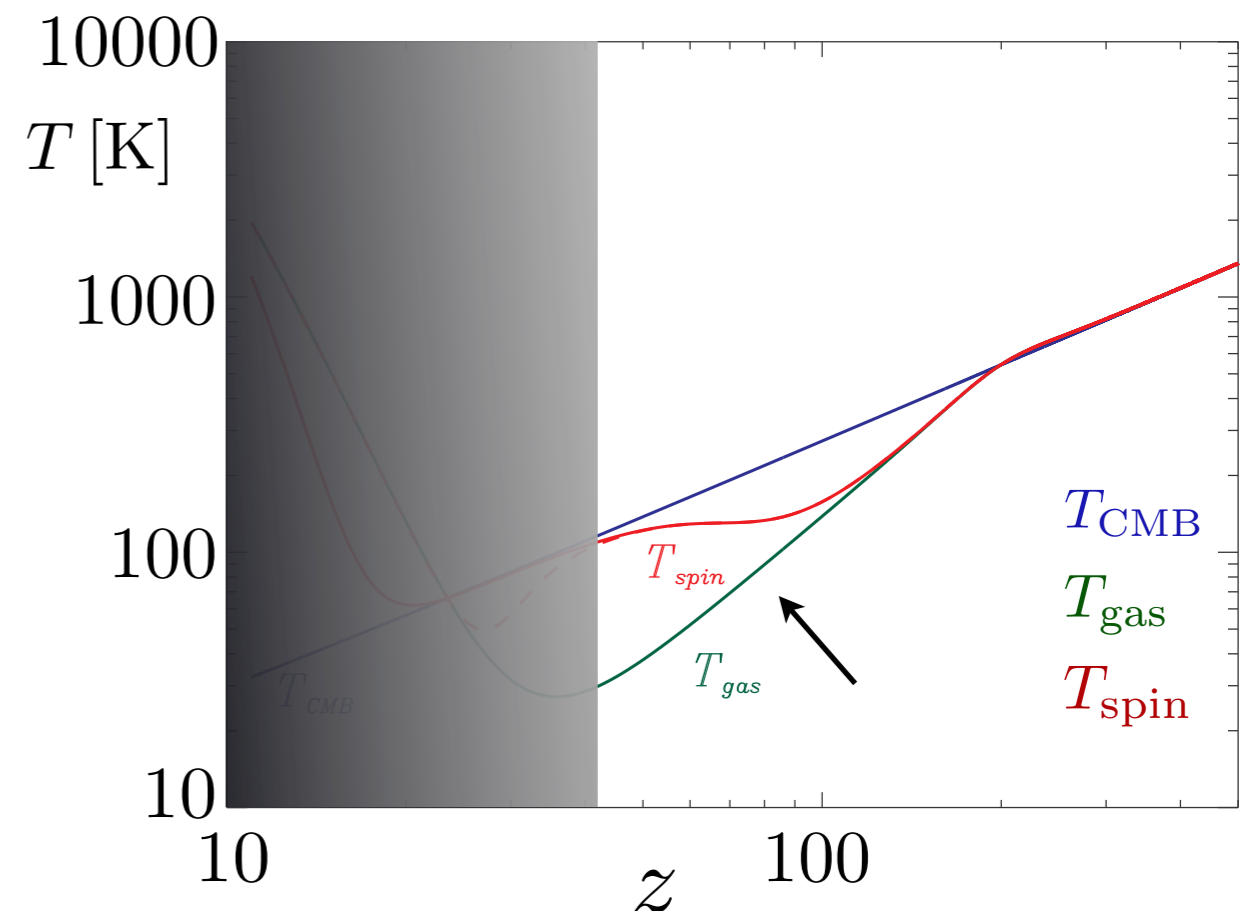
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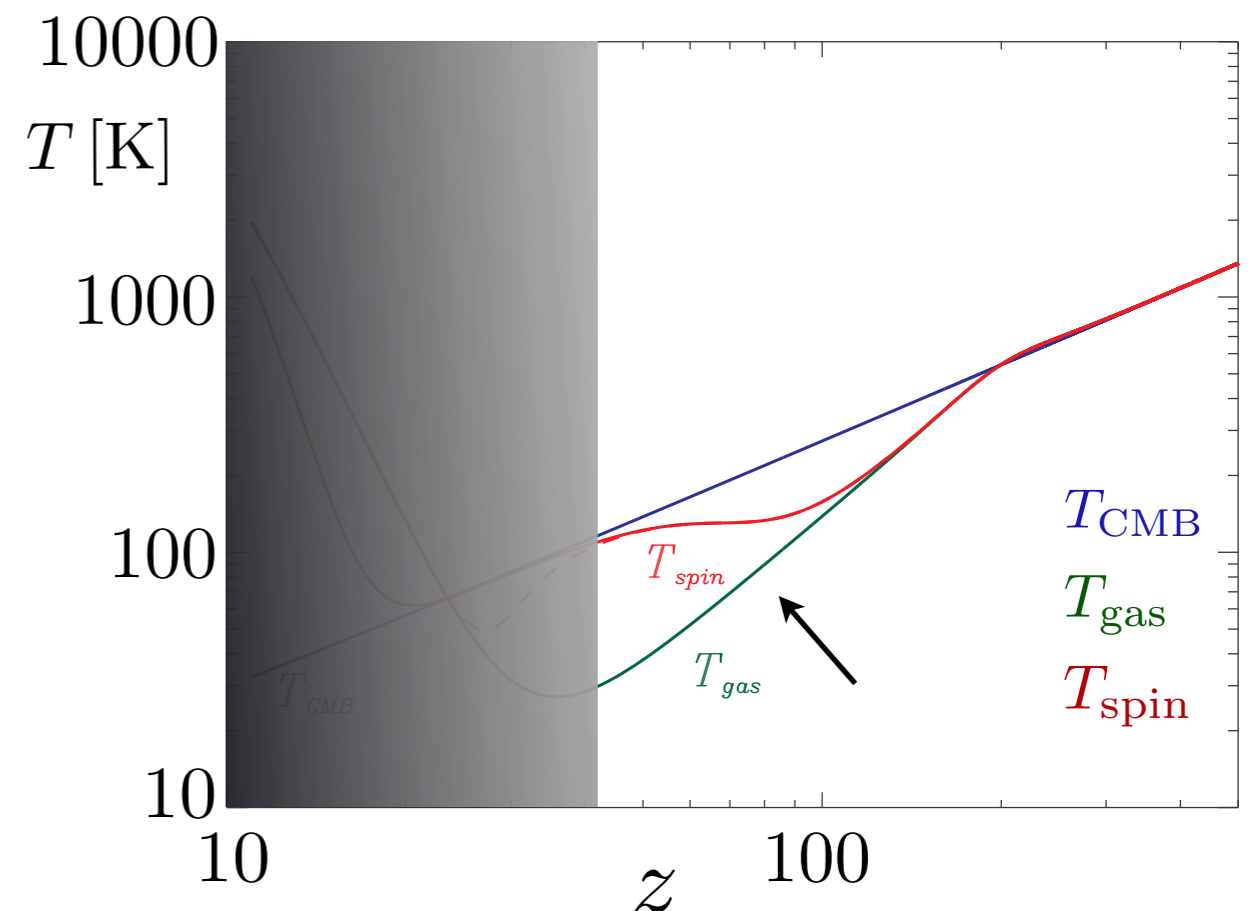
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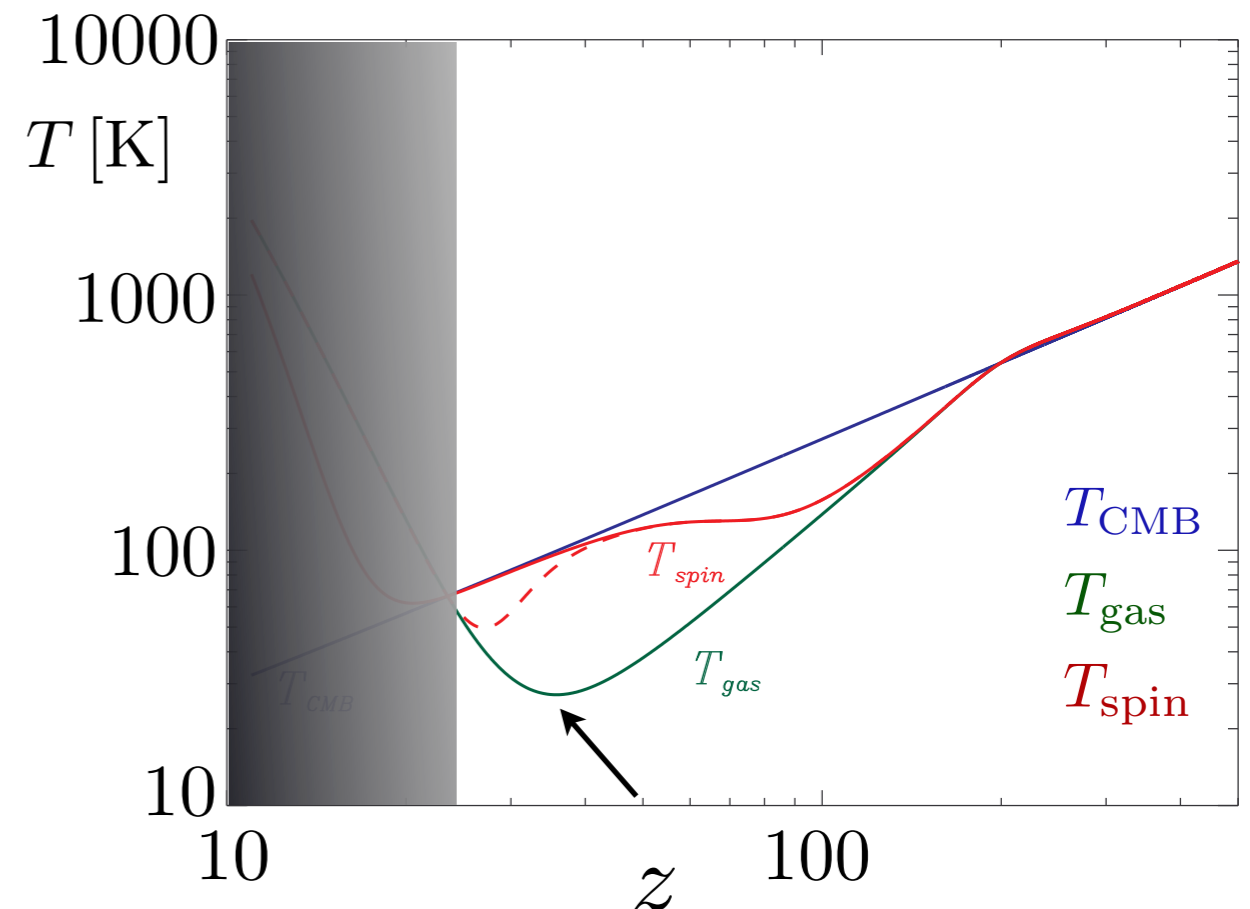
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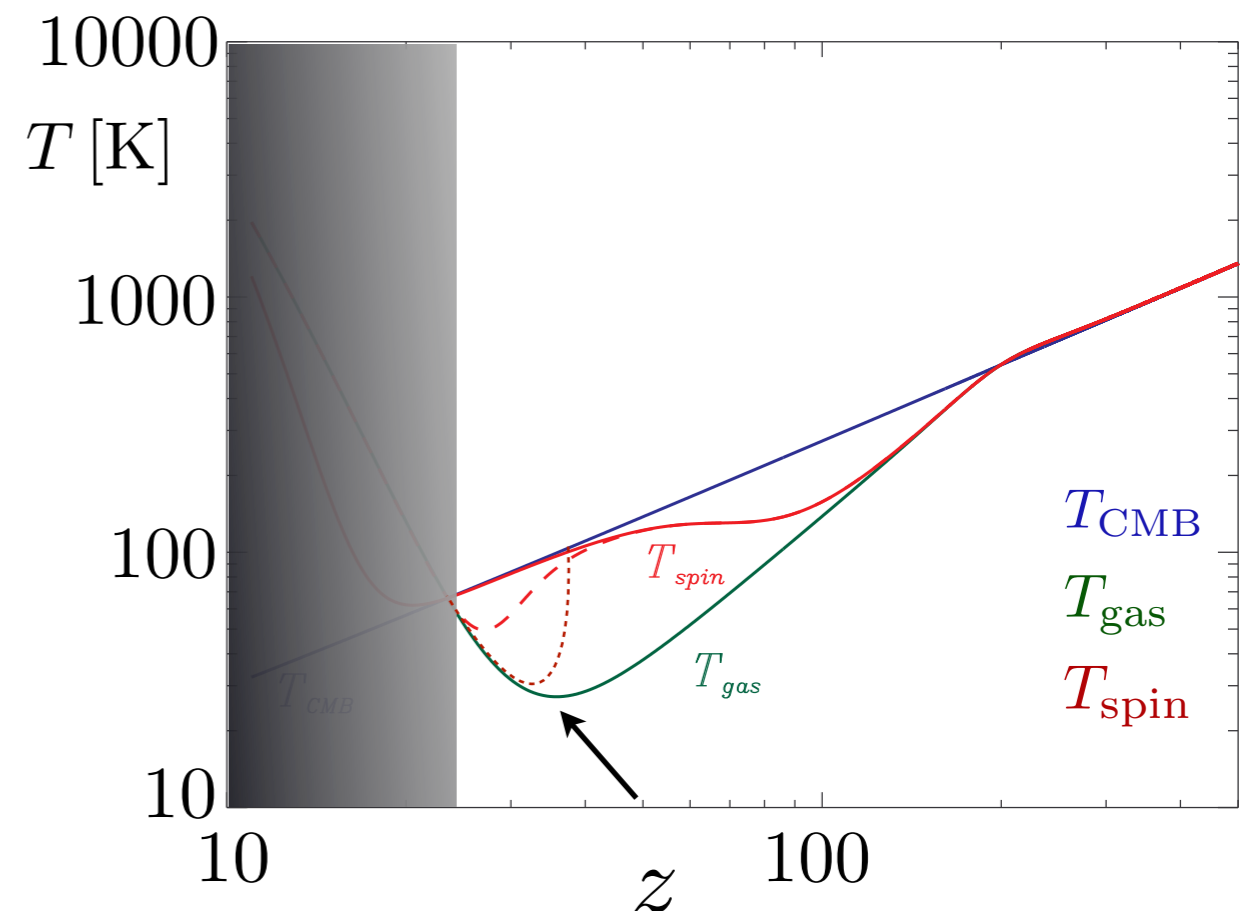
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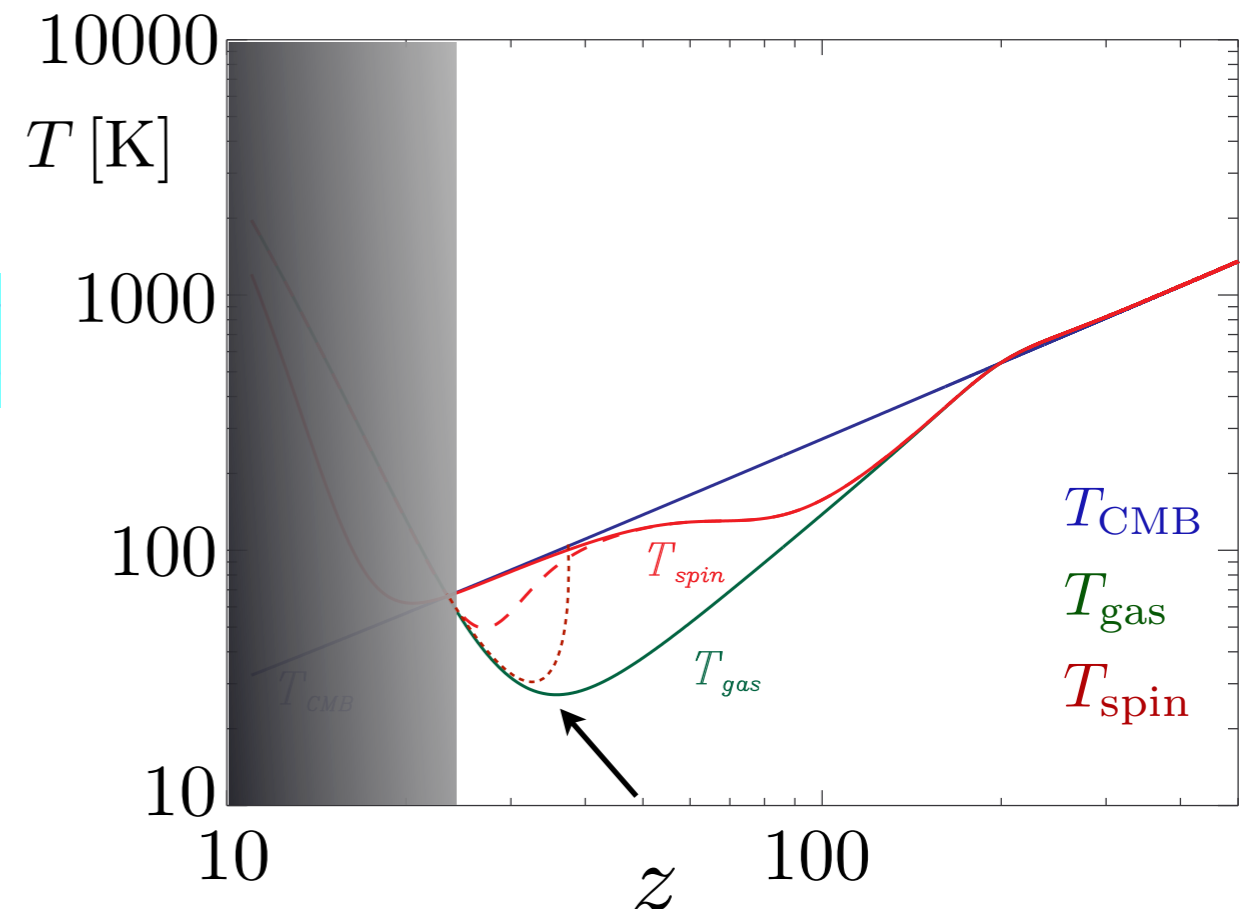
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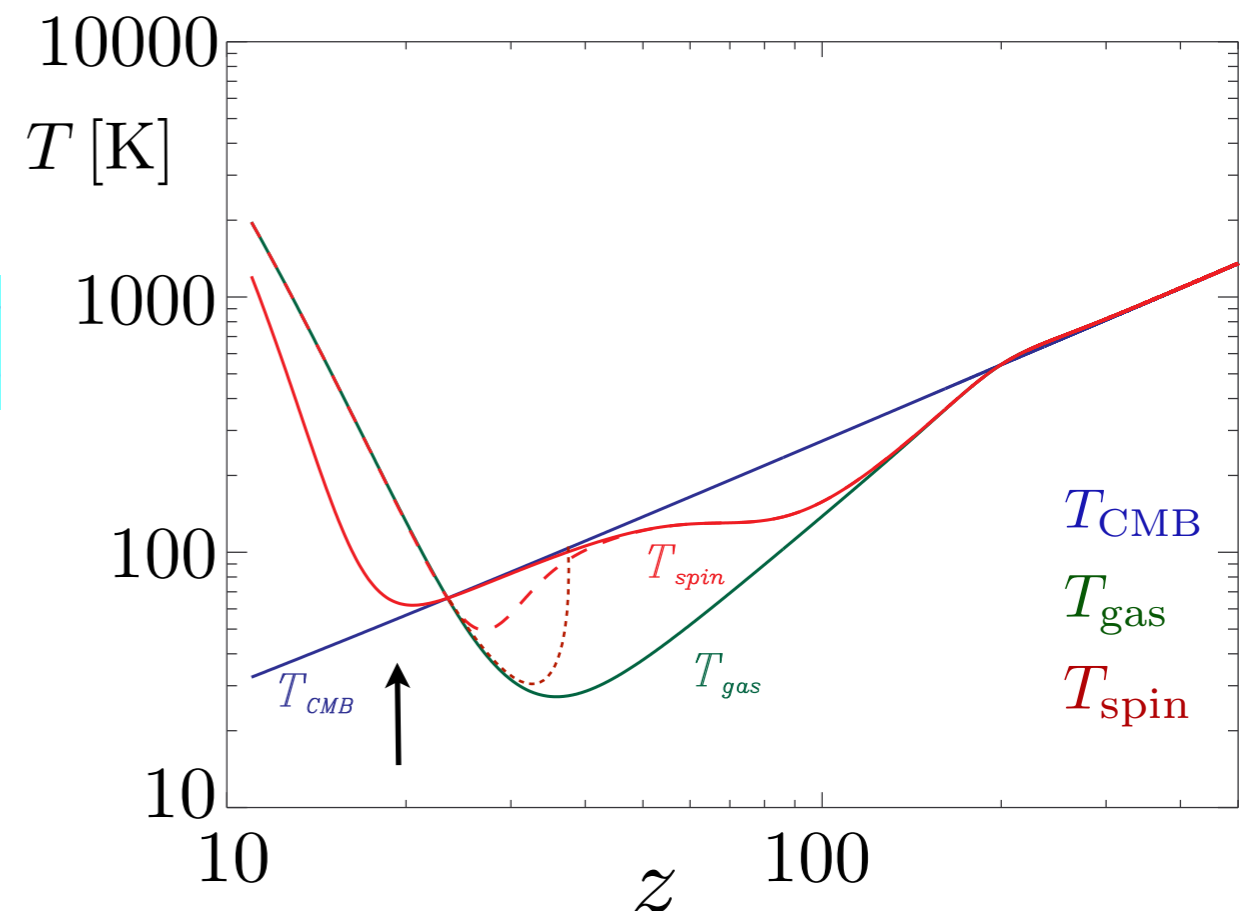
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By $z \sim 13$: remnants heat gas above CMB.



The 21-cm Signal: Lightning Review

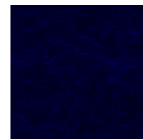
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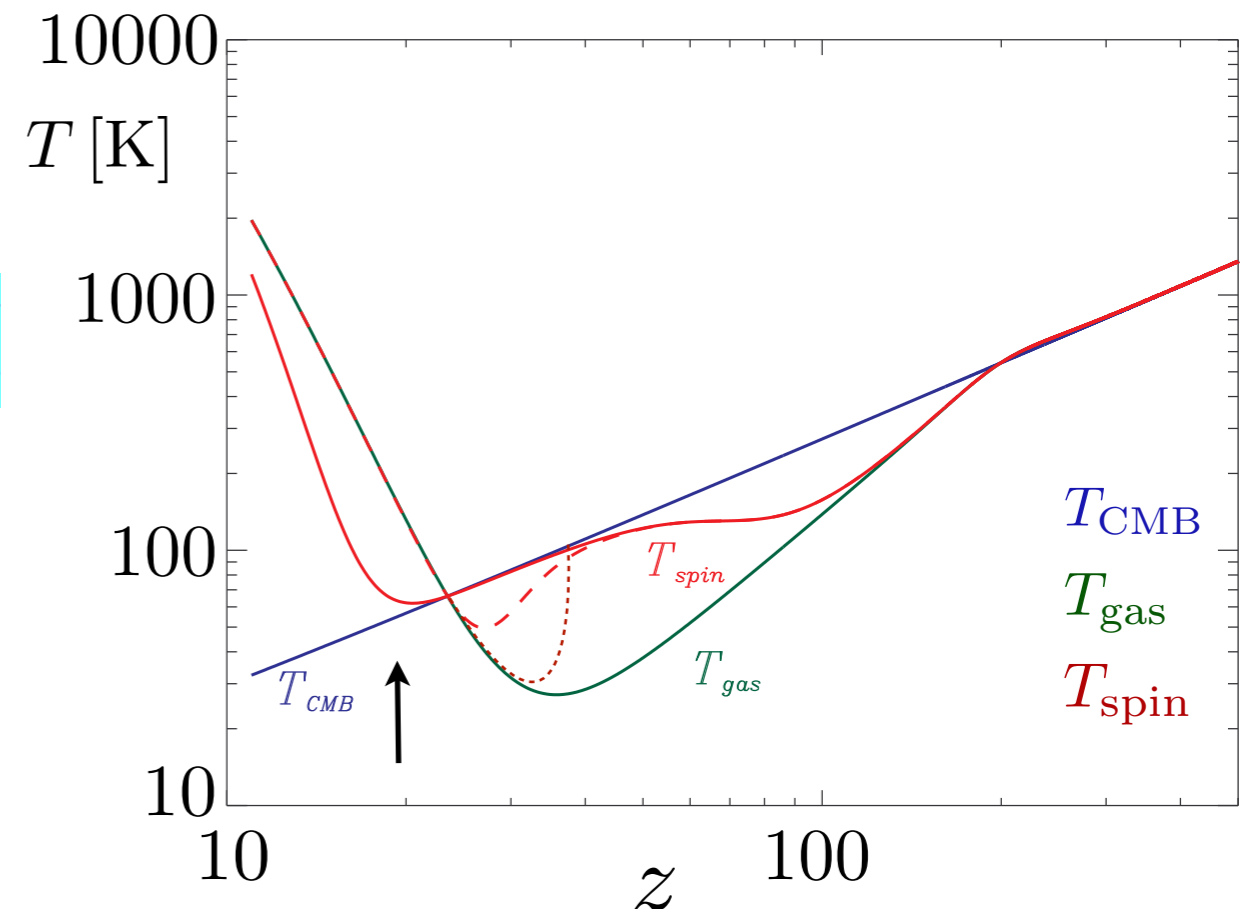
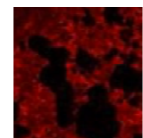
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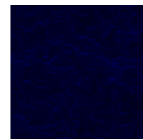
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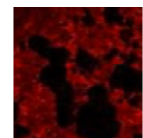
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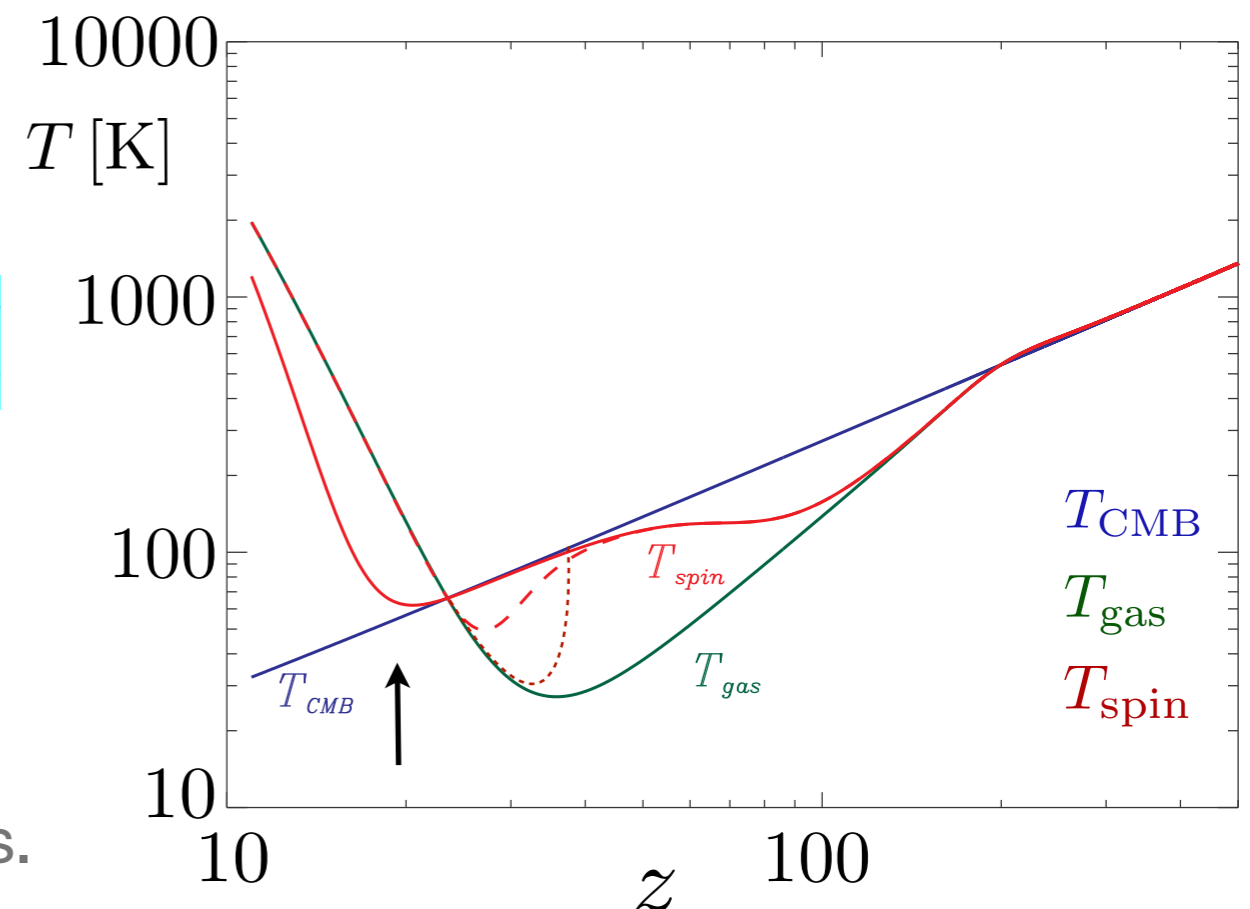


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The 21cm signal cuts off when reionization ends.



The Cosmic Dawn Signal: Global Temperature

The Cosmic Dawn Signal: Global Temperature

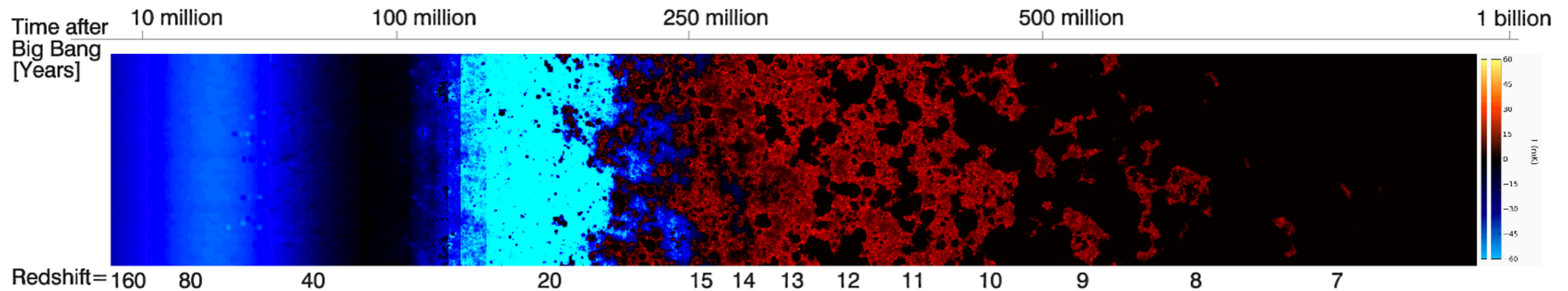
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The Cosmic Dawn Signal: Global Temperature

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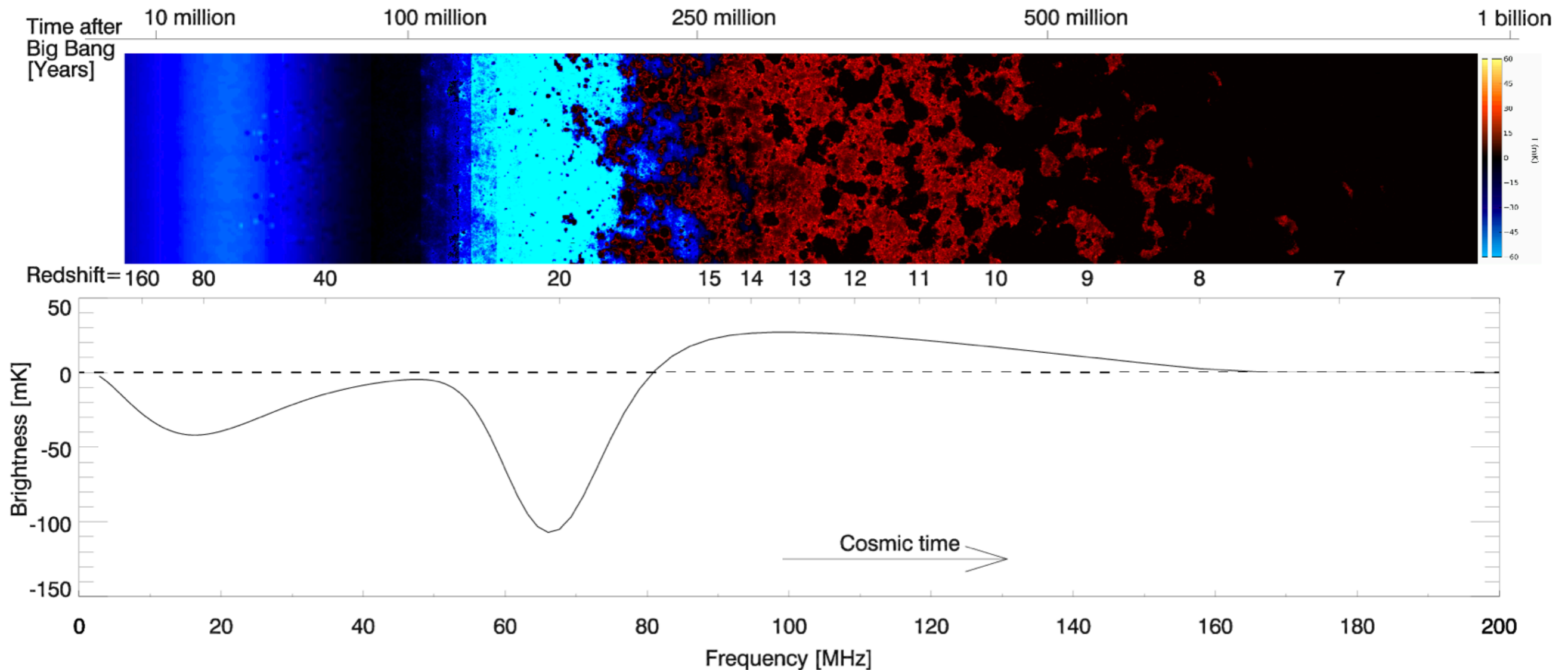
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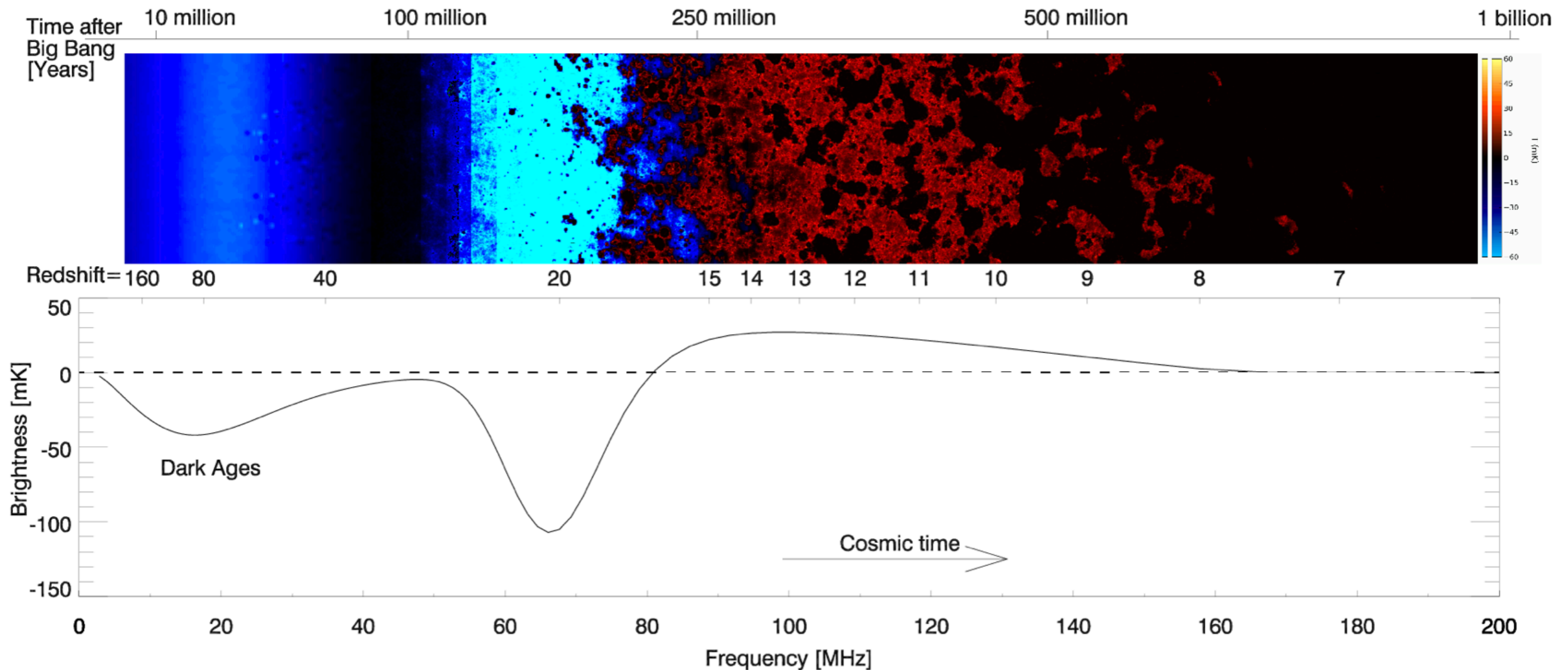


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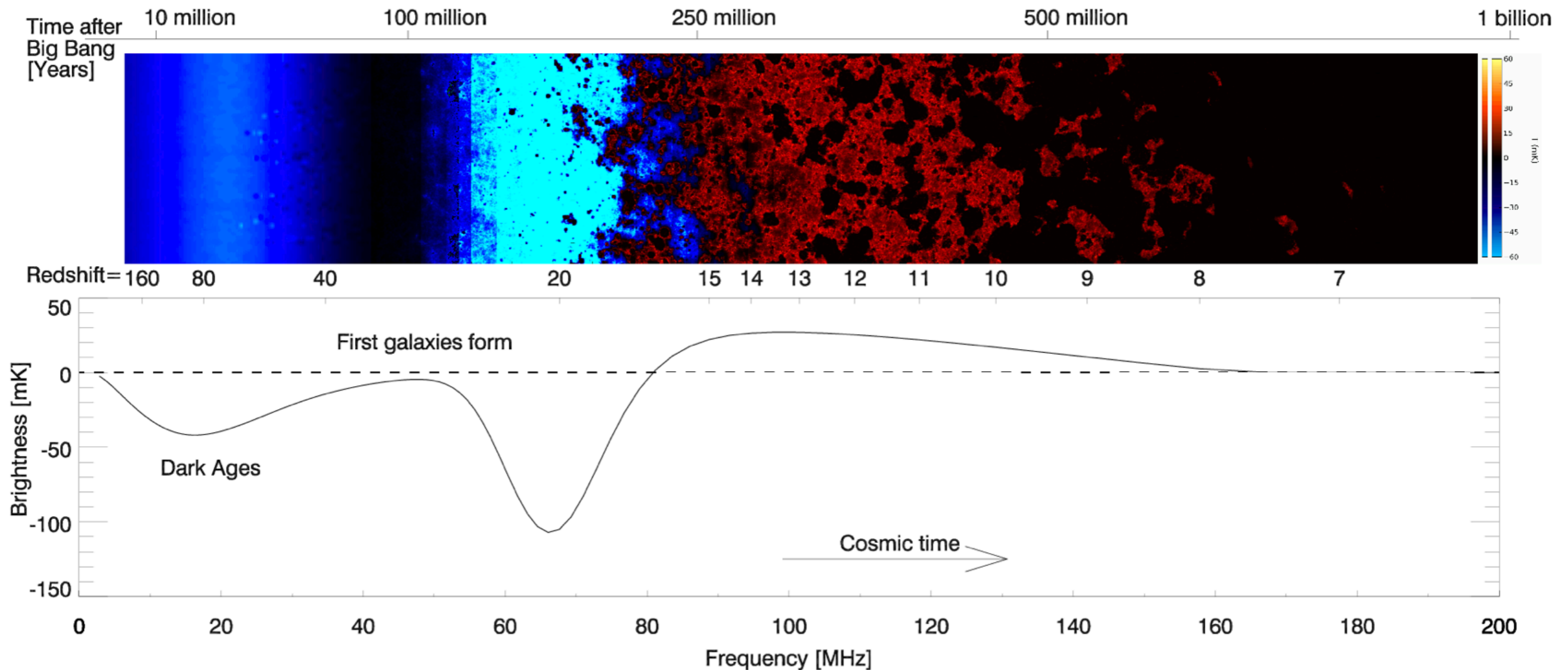


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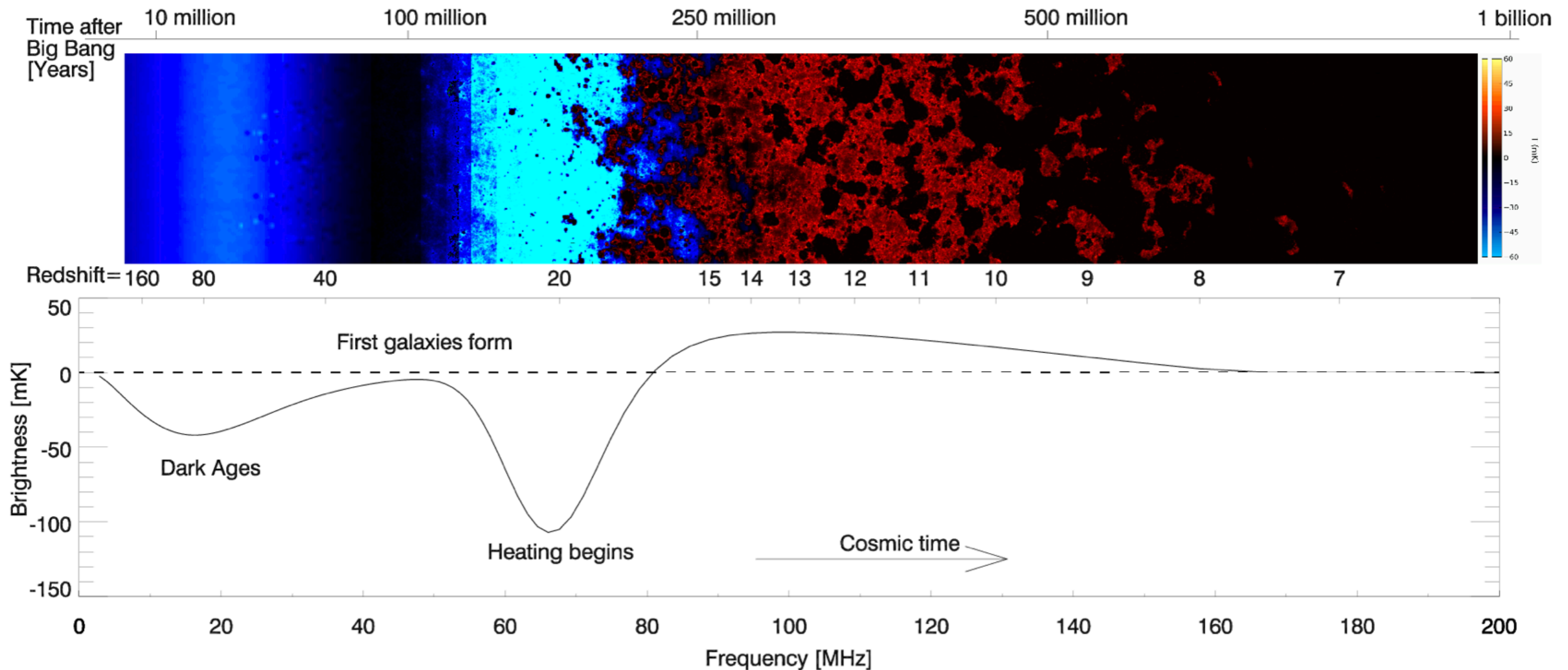


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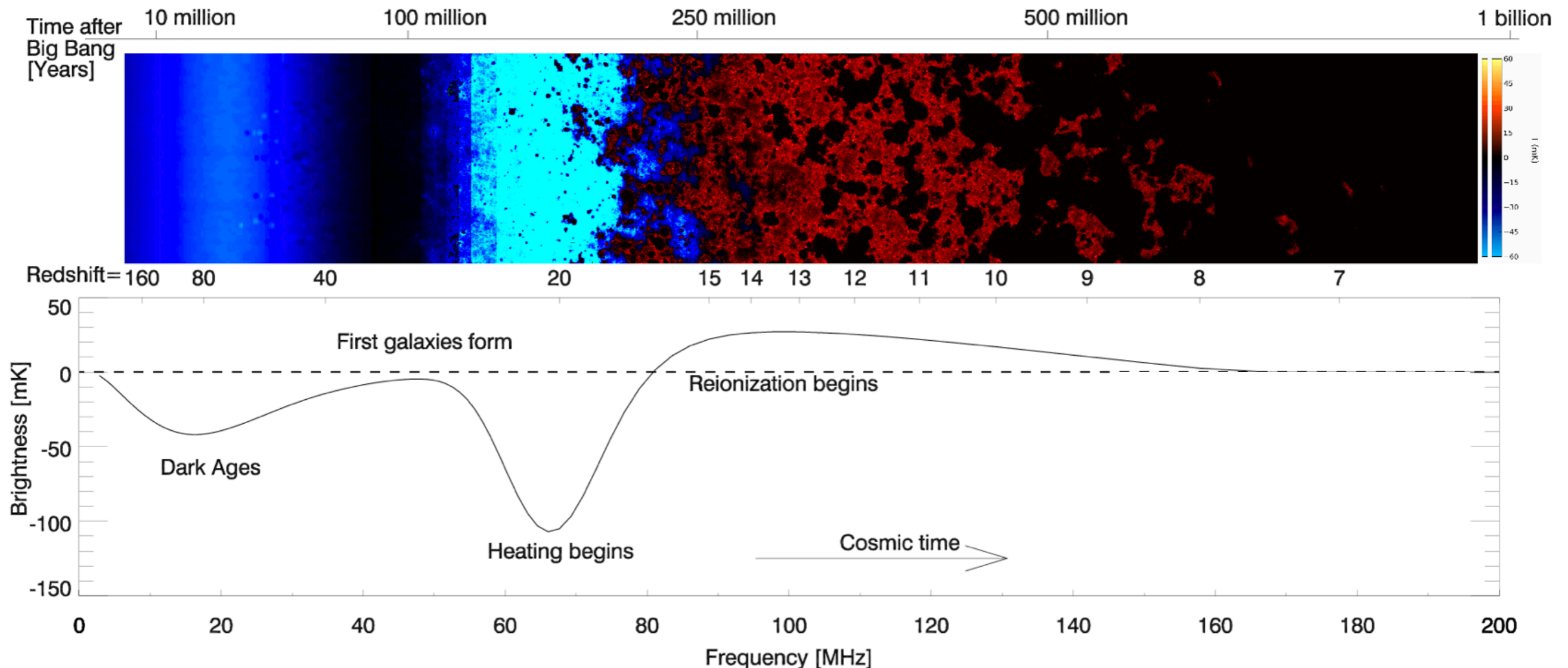


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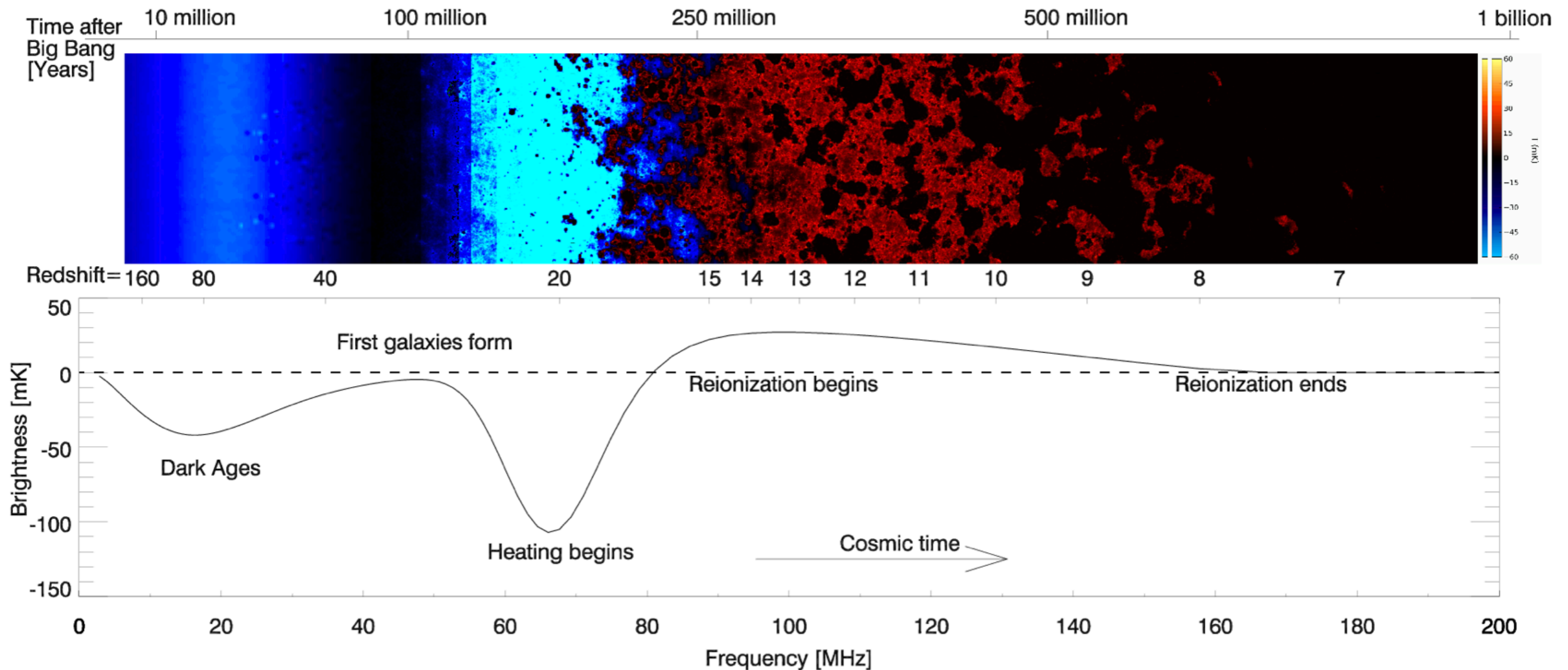


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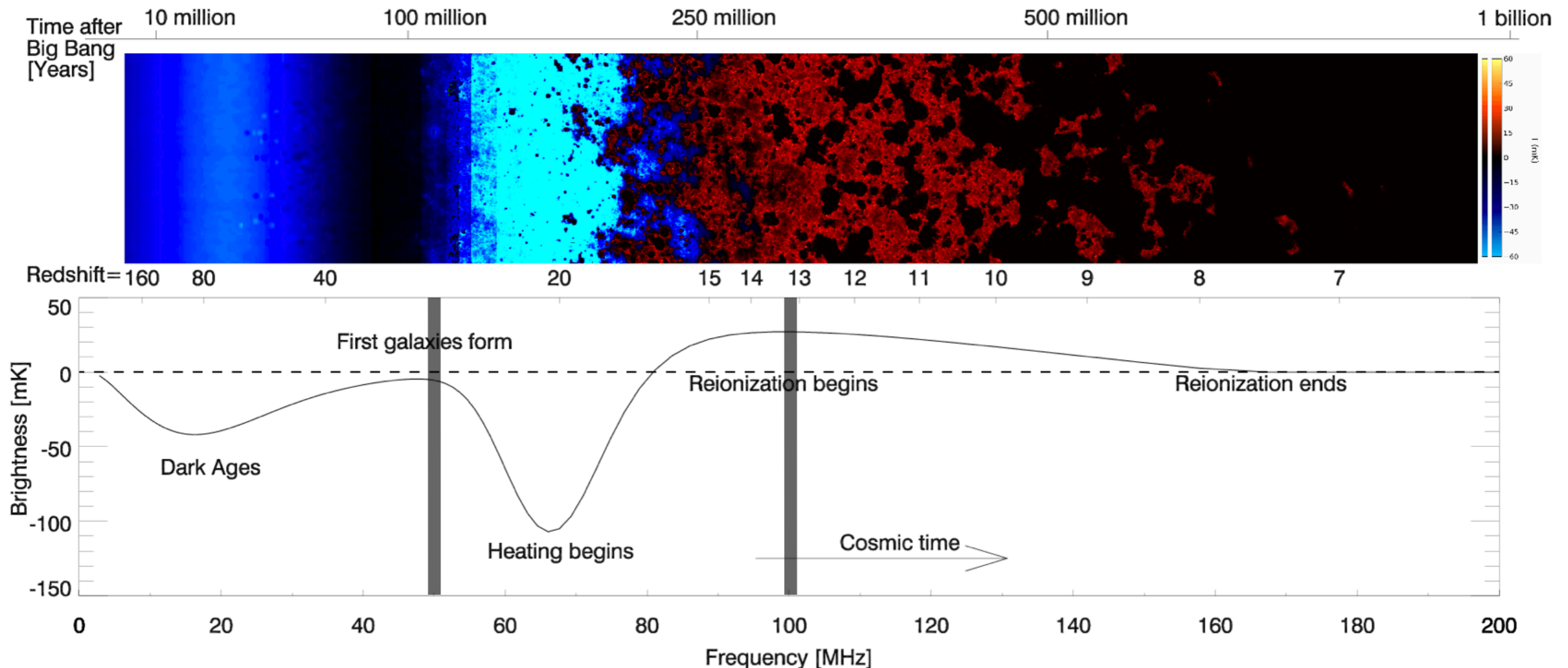


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EDGES Low-Band

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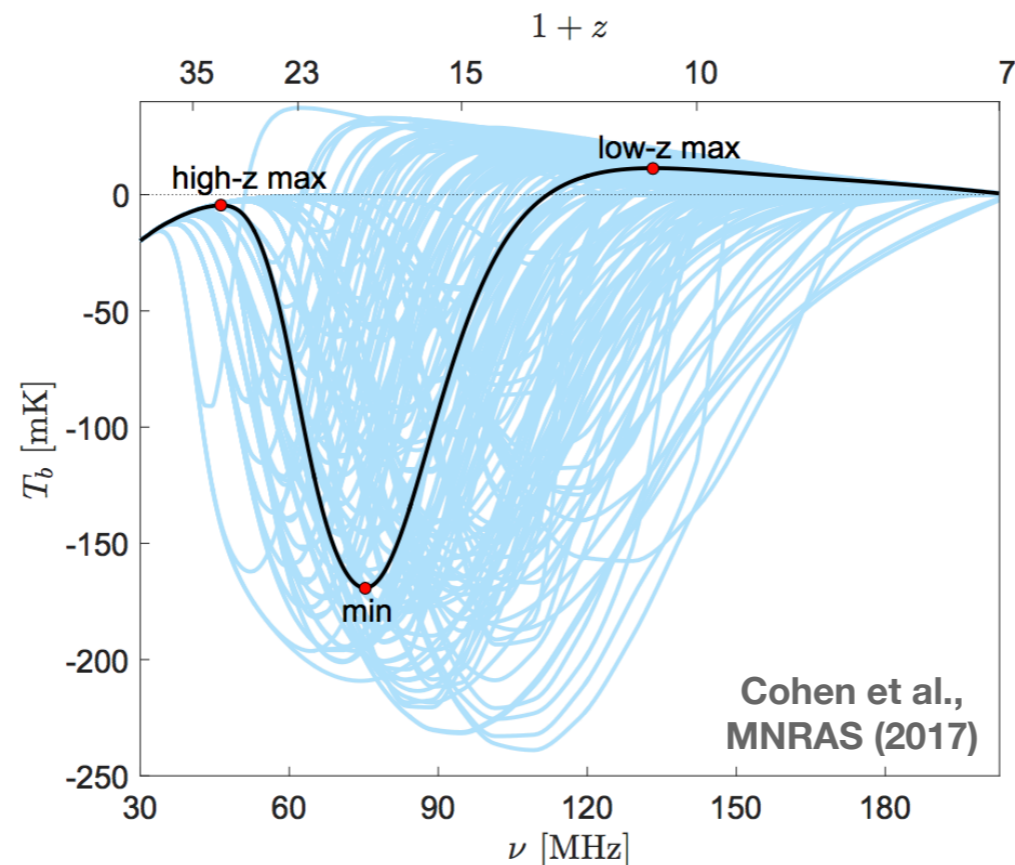
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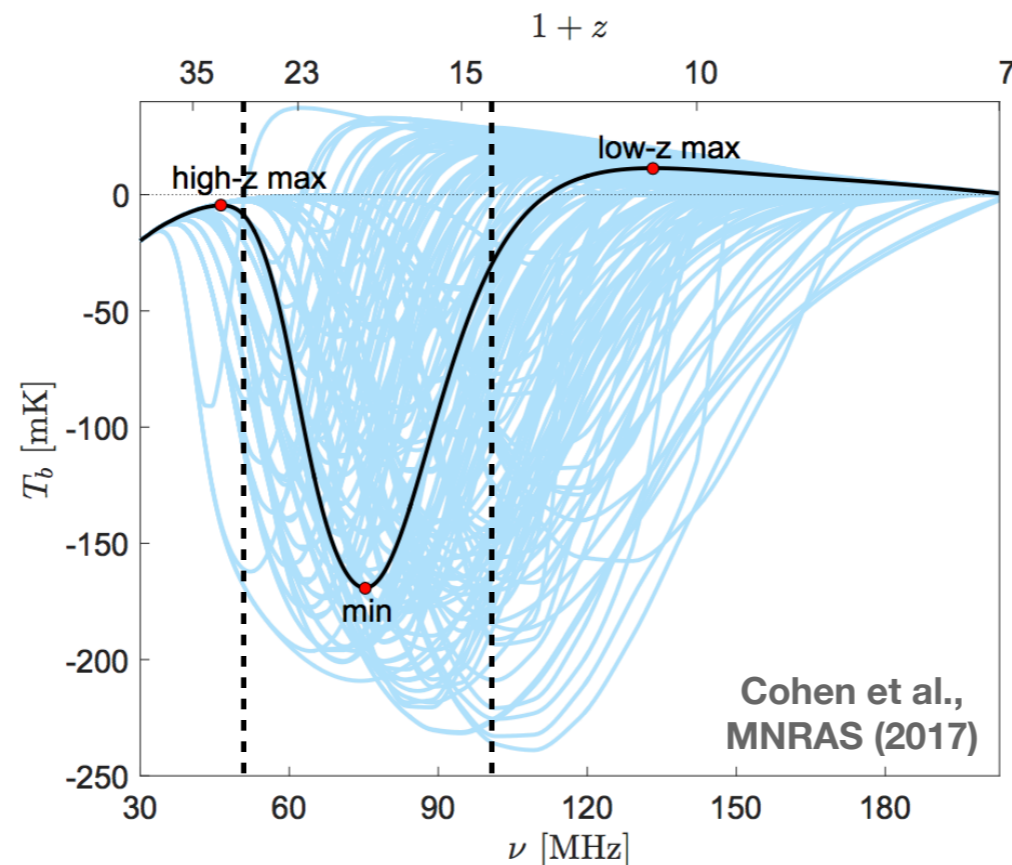


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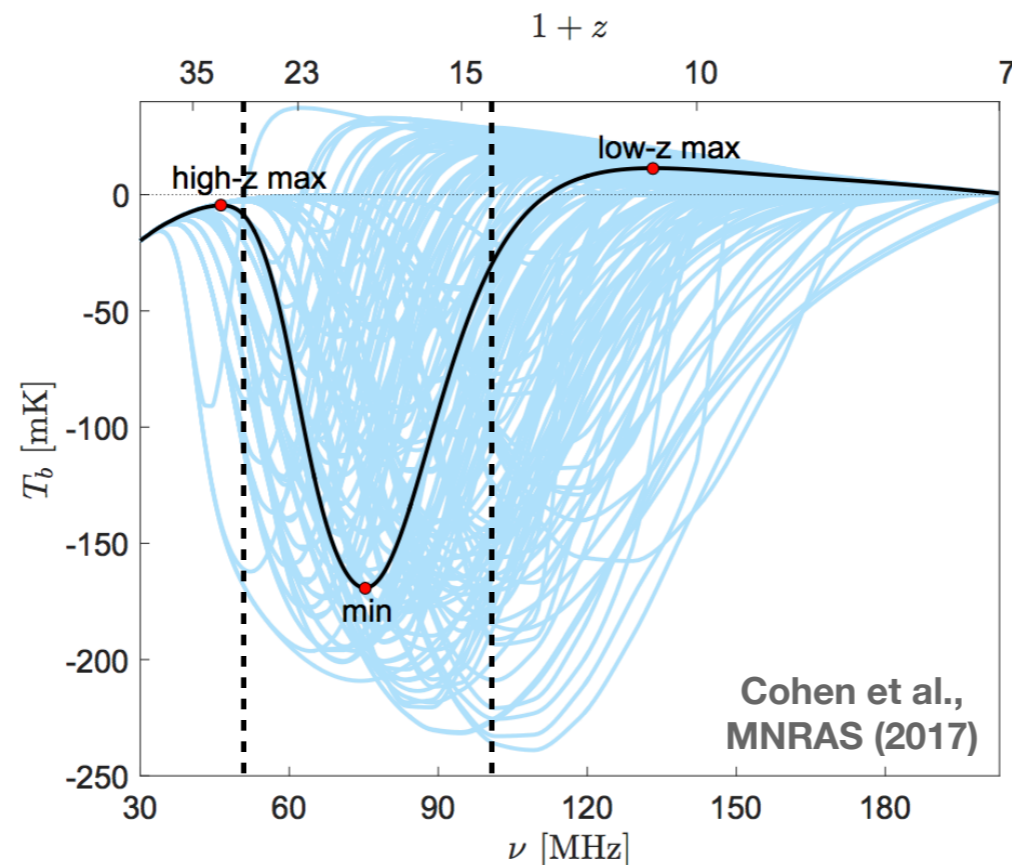


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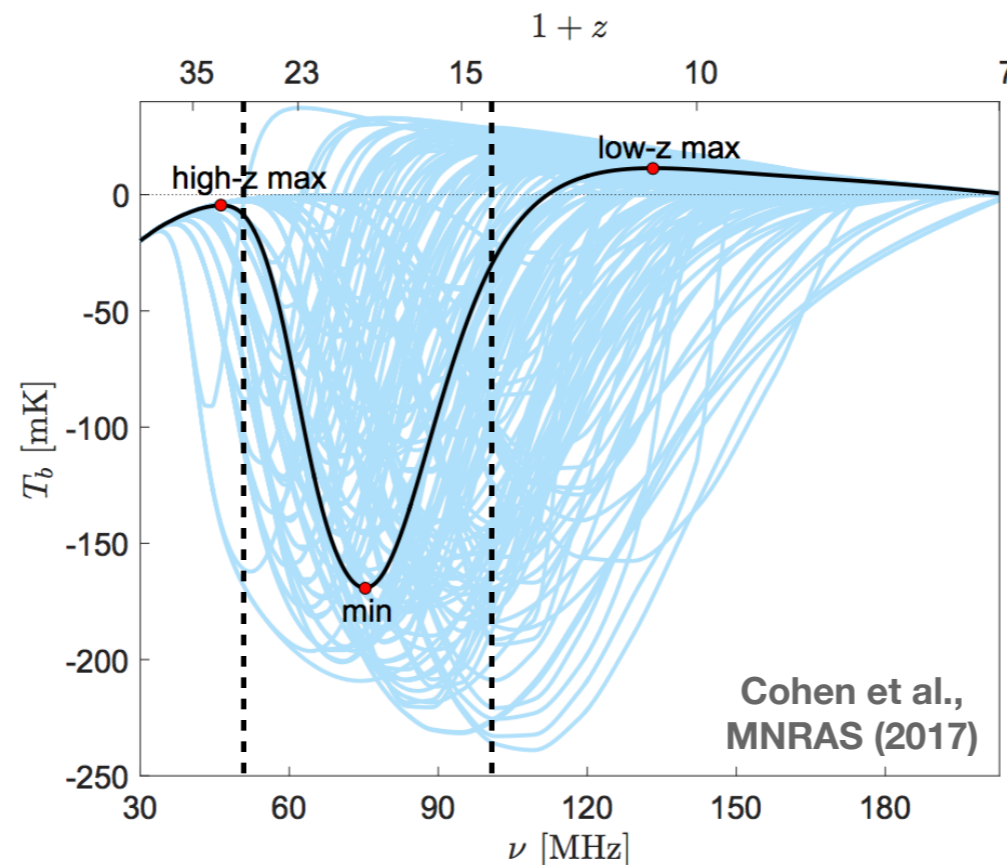
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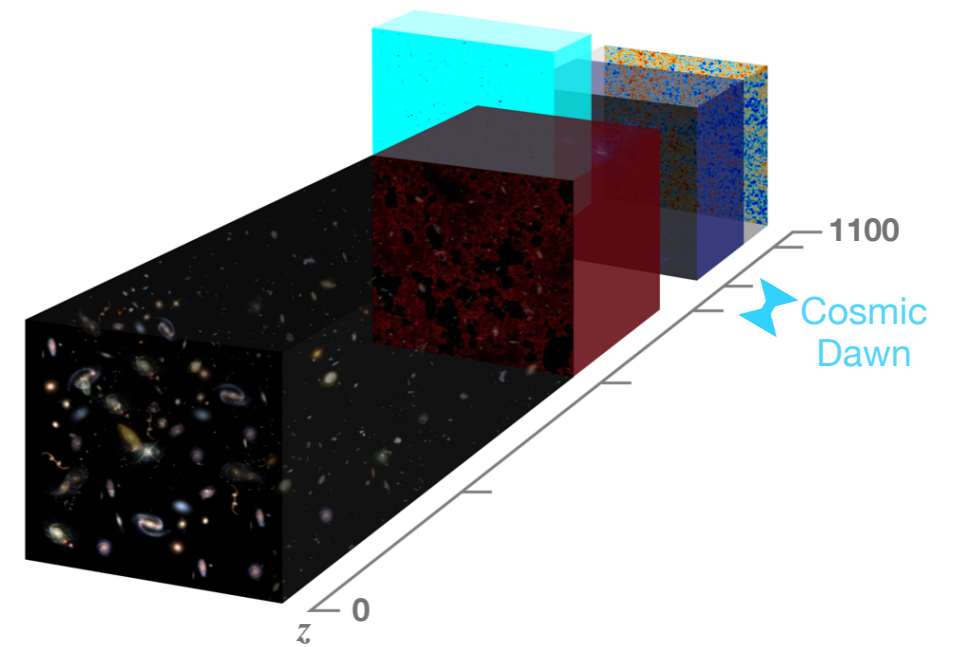
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Ely Kovetz
UMD, Sep. 2018

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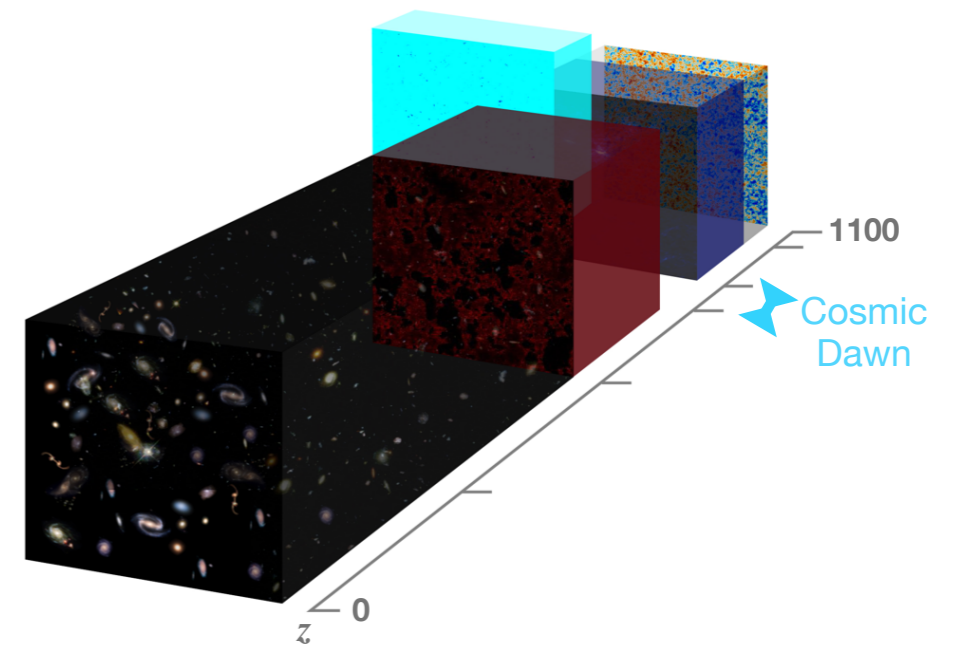


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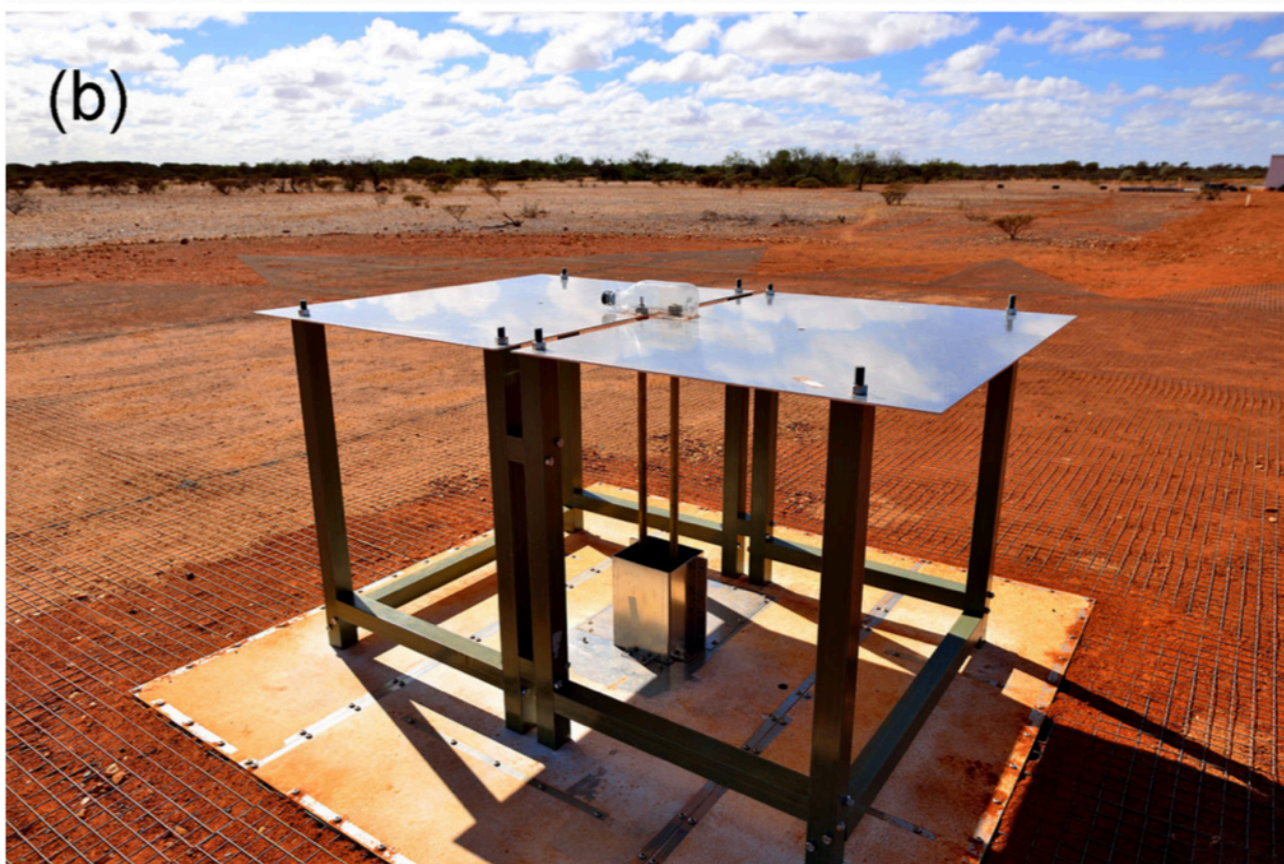
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Experiment to Detect the Global Epoch of Reionization Signature



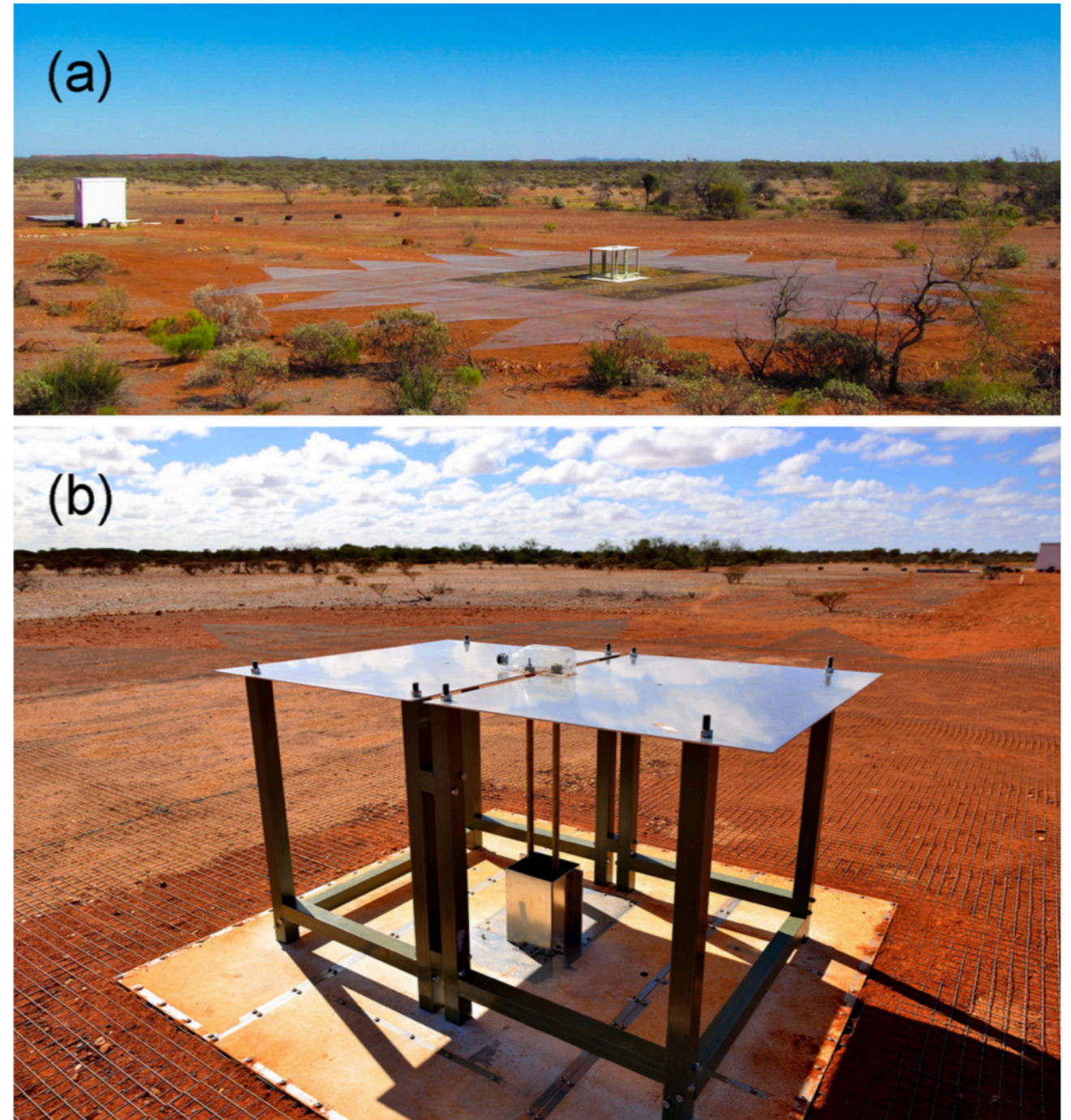
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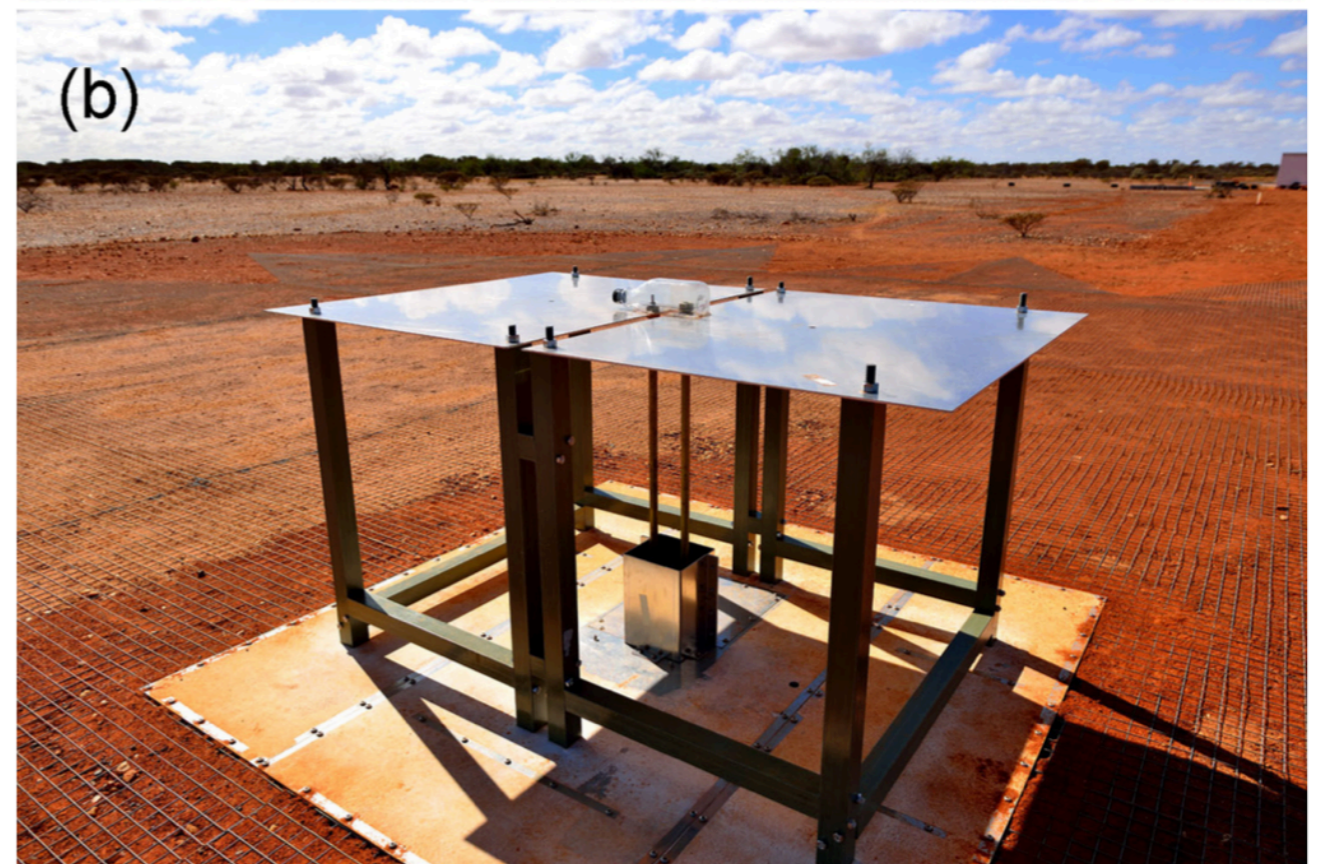


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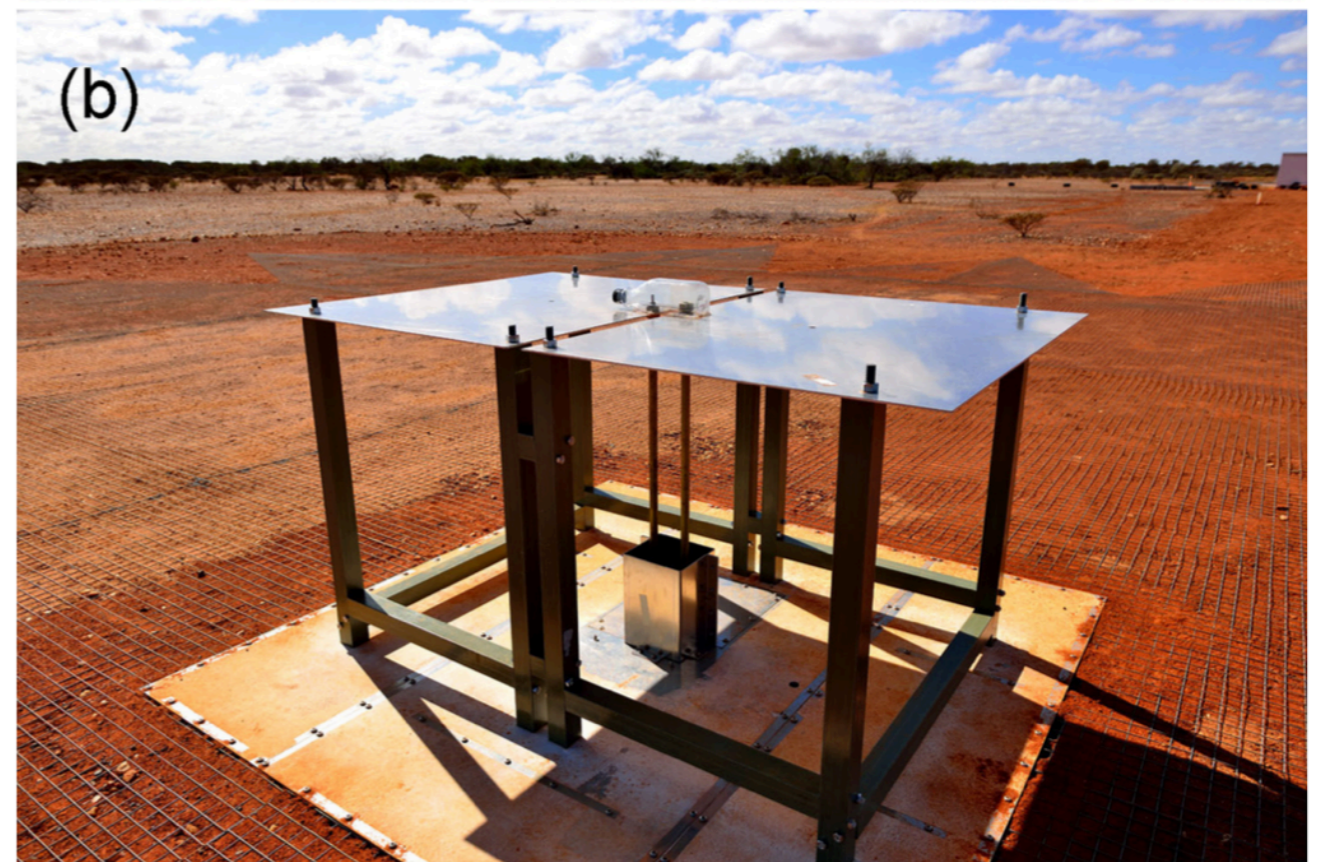


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- Two identical instruments, placed 150m apart



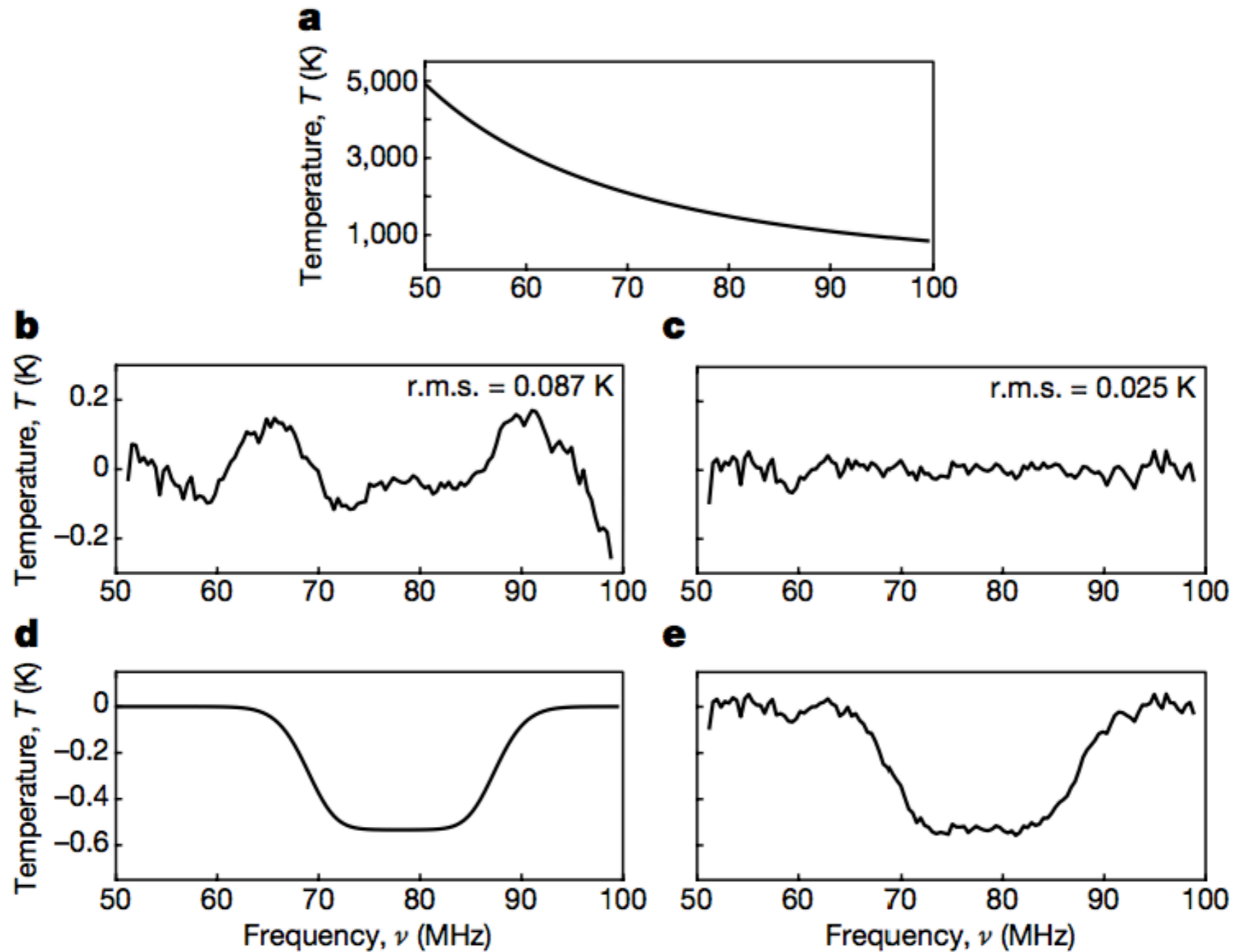
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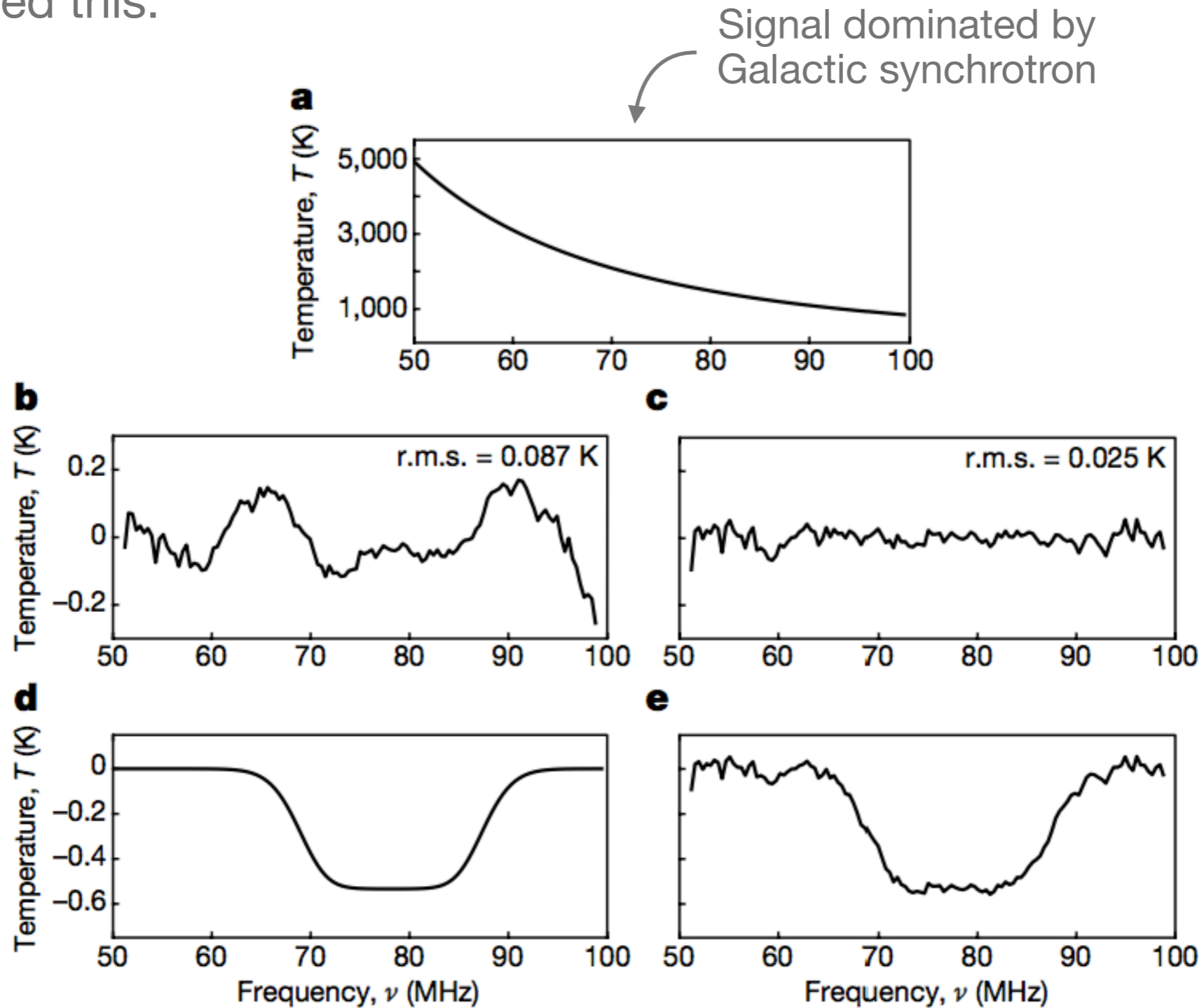
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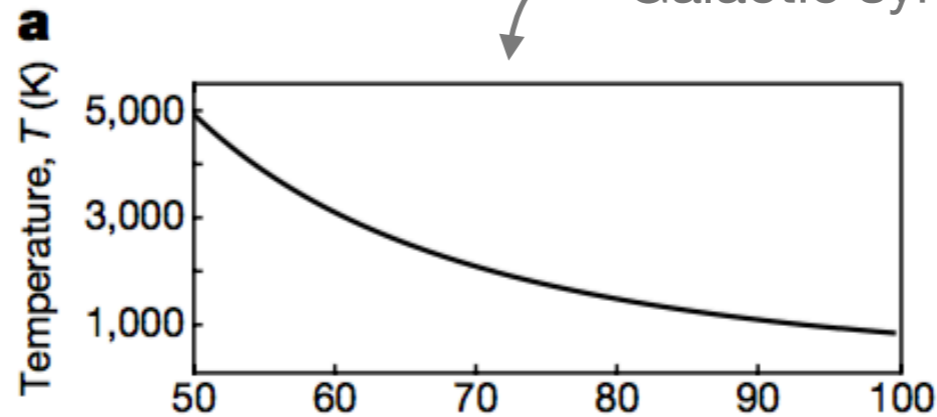
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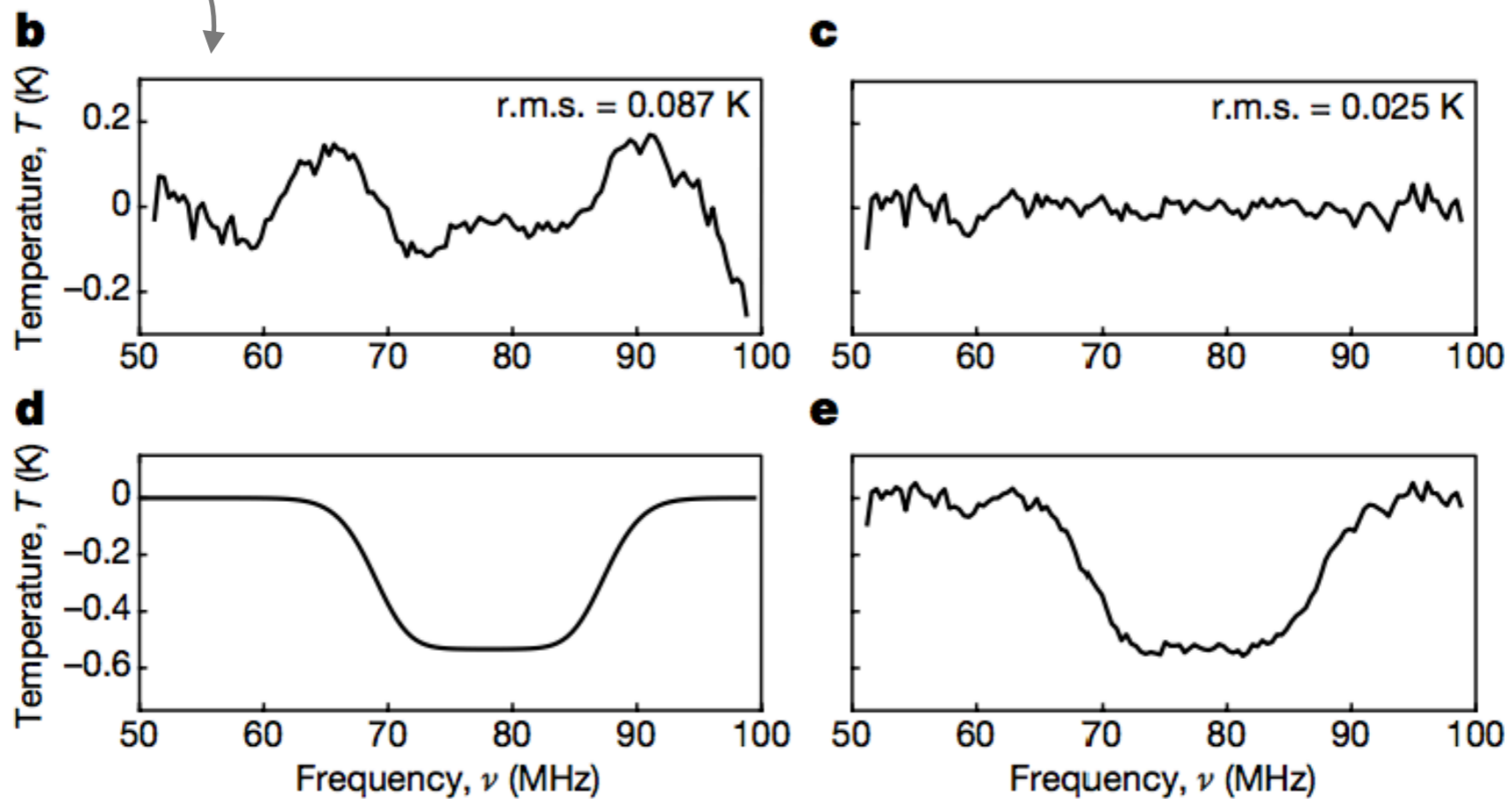
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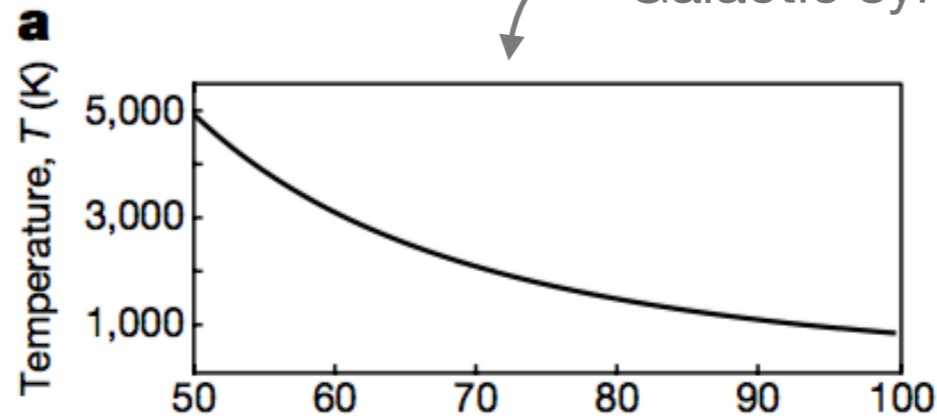
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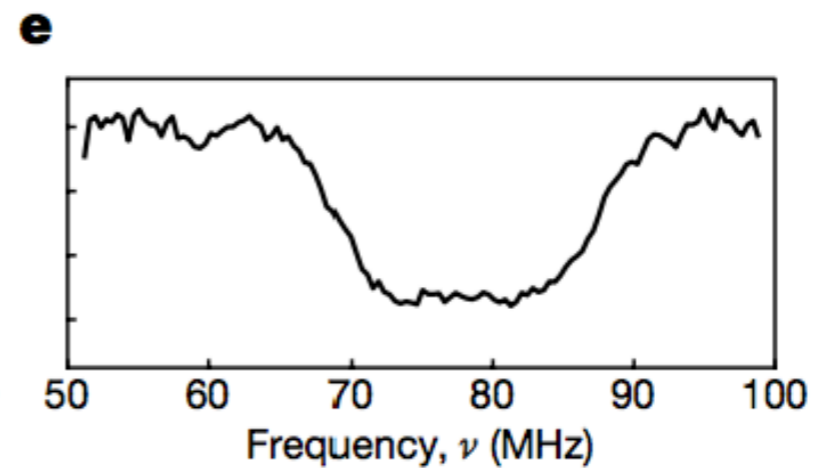
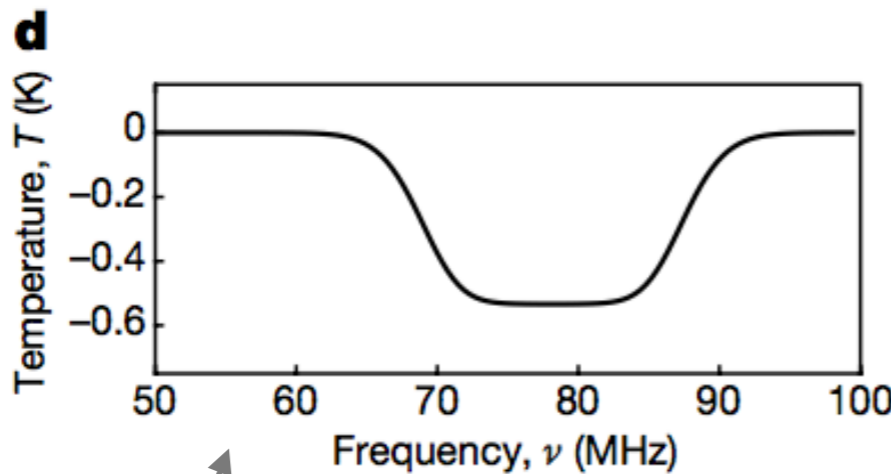
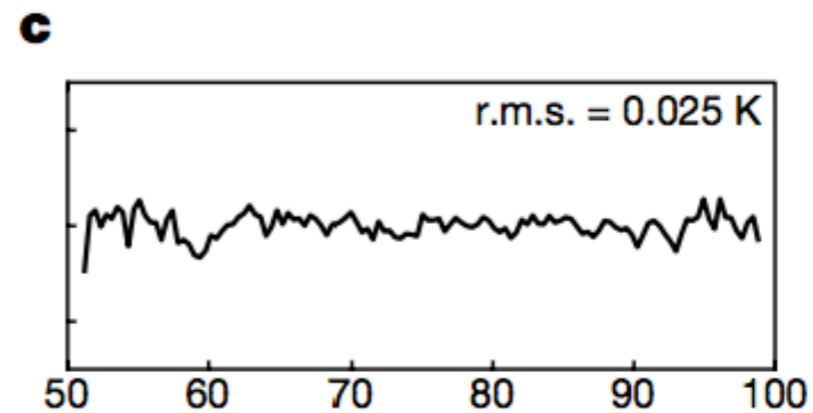
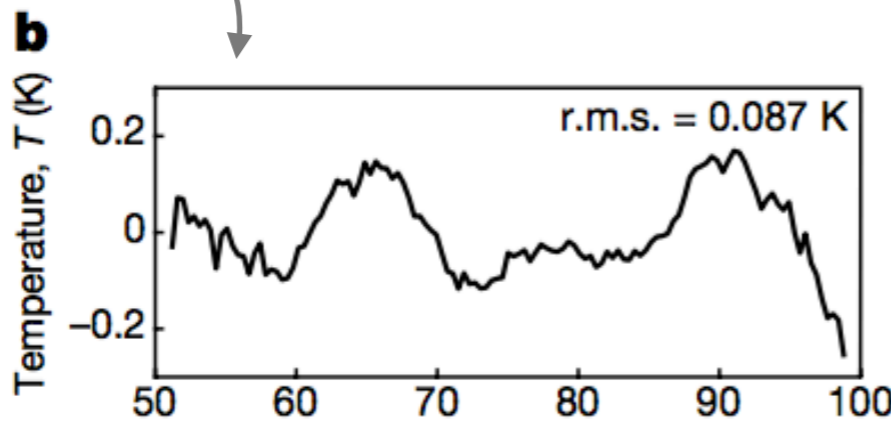
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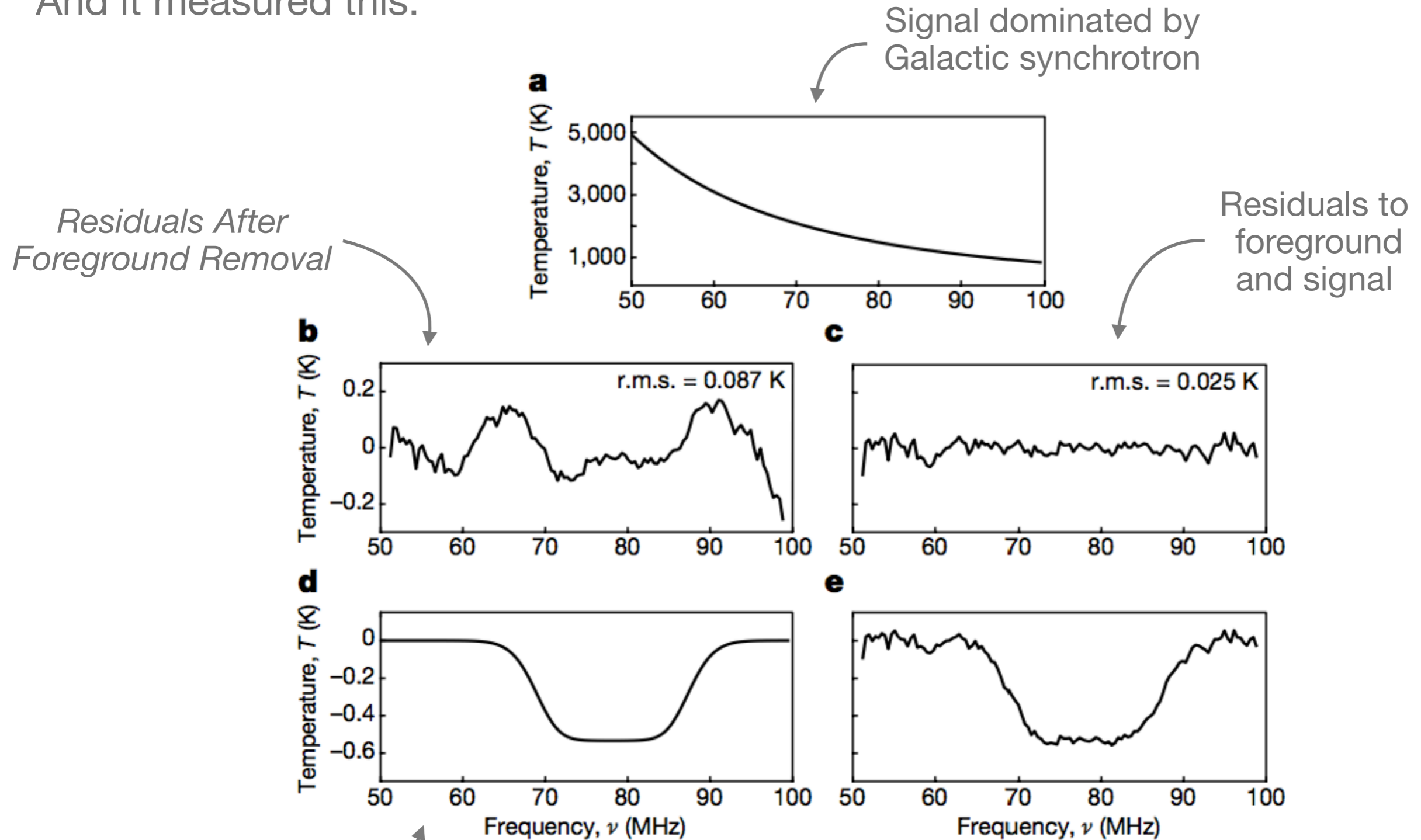


Best-fit 21cm model

Bowman et al., Nature (2018)

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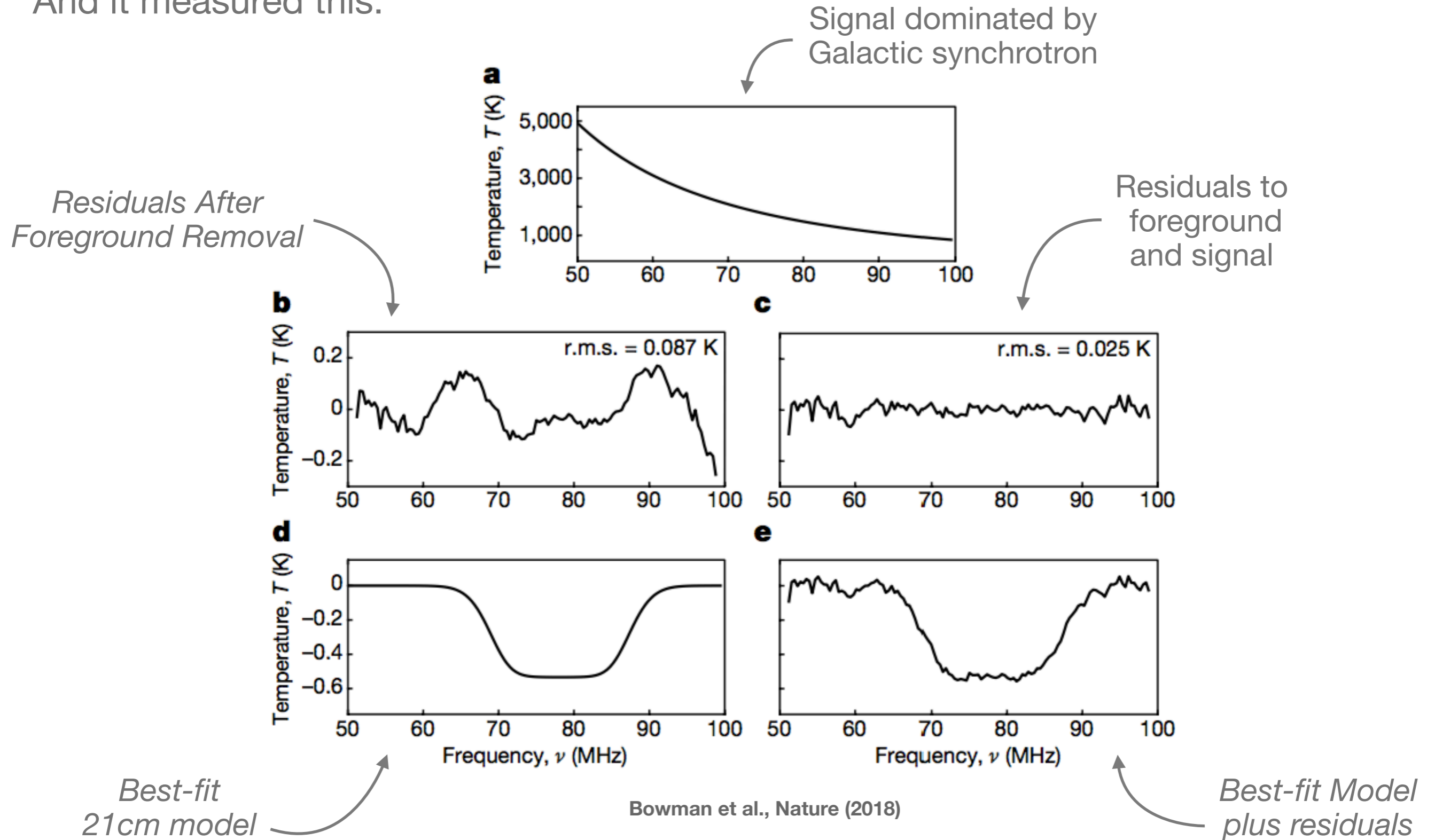
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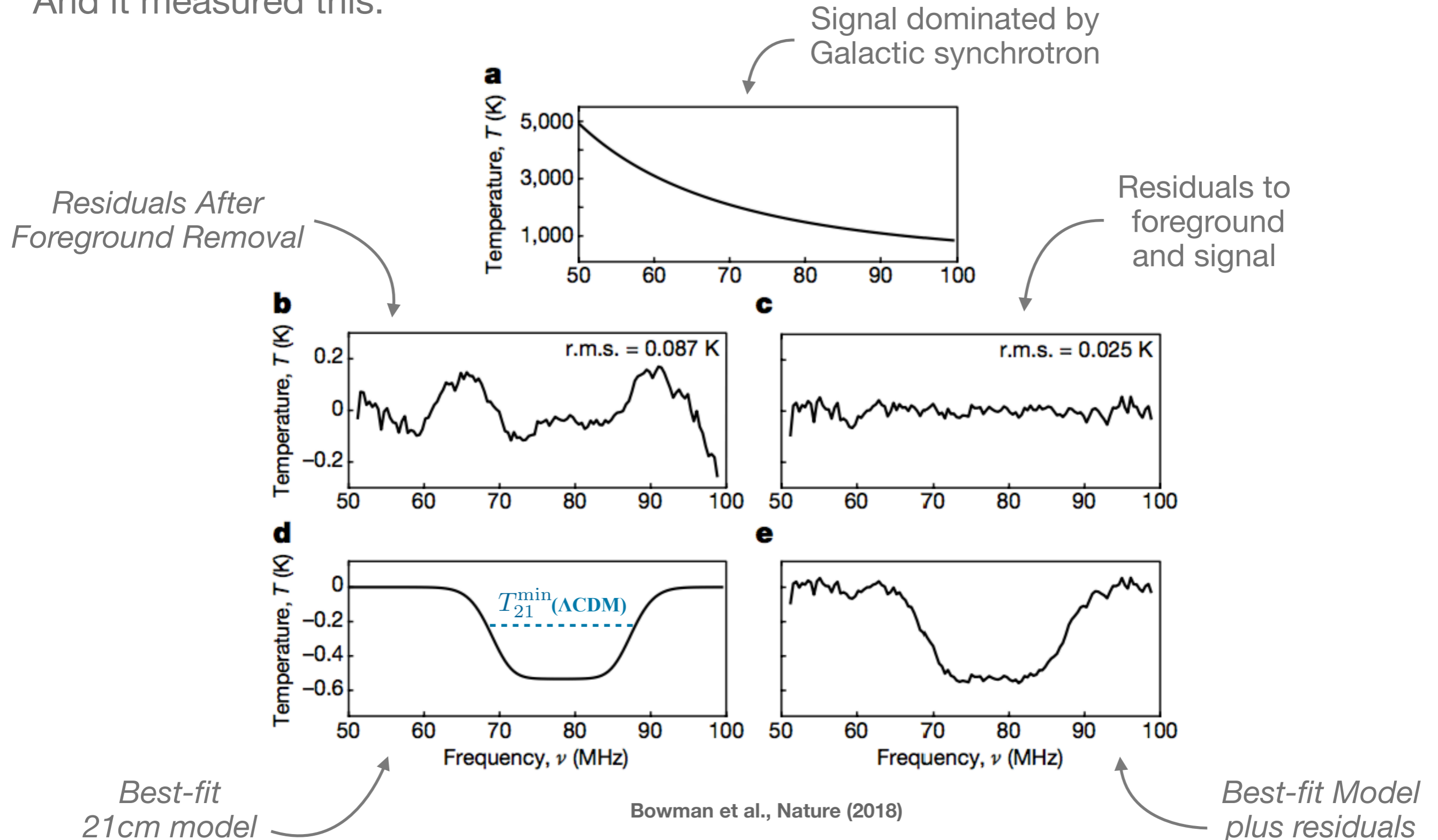
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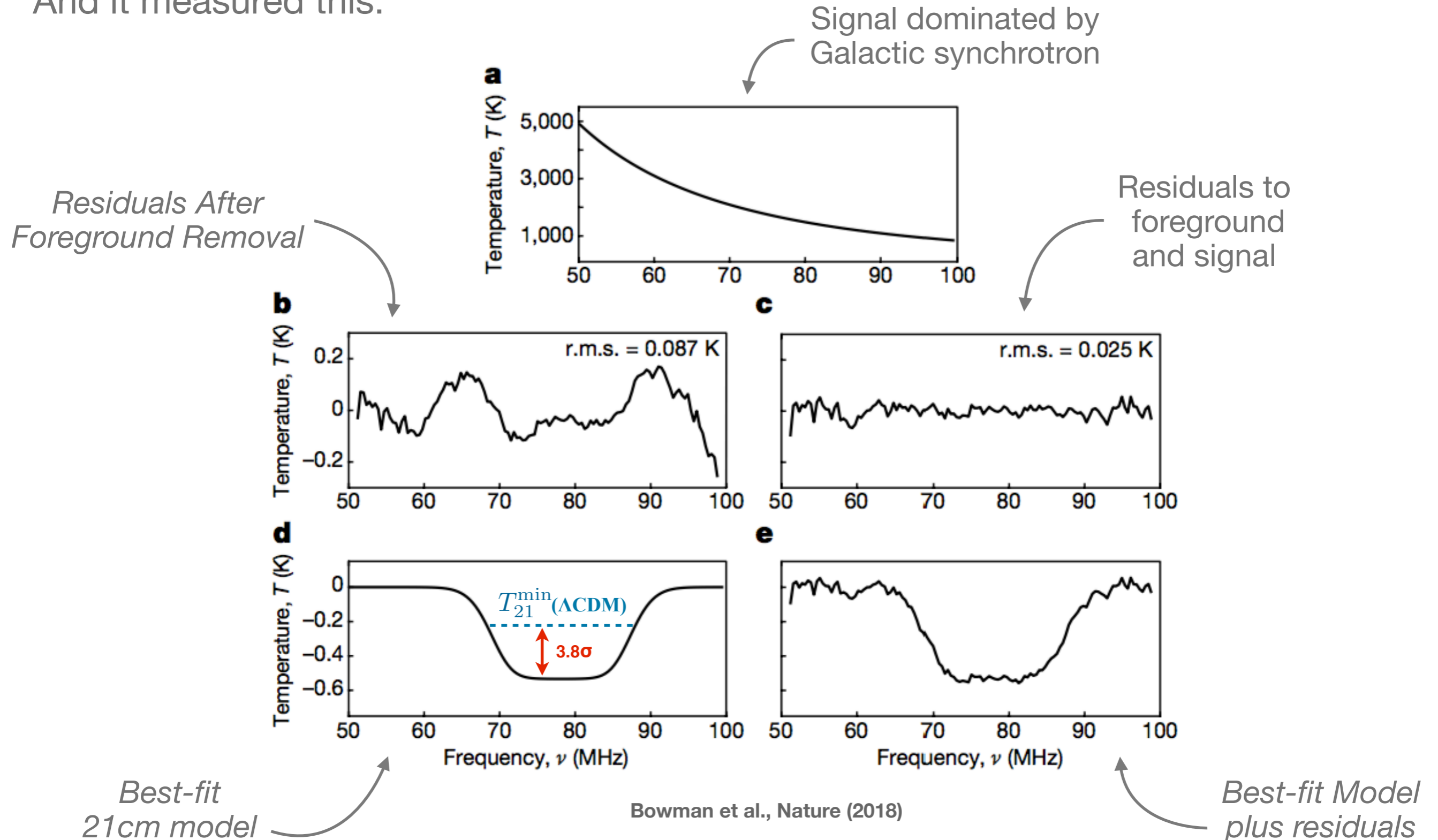
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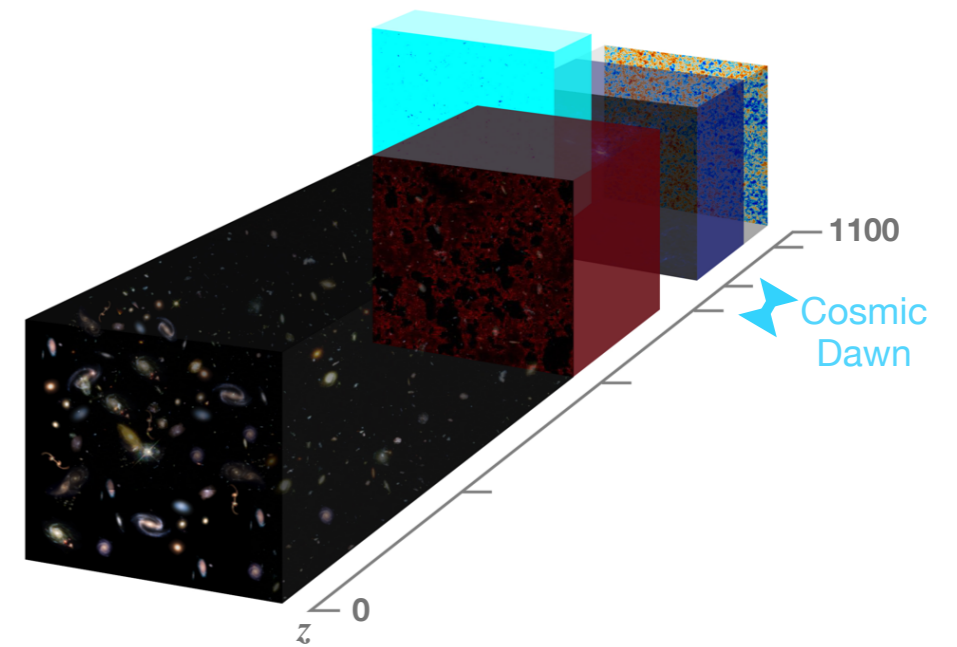
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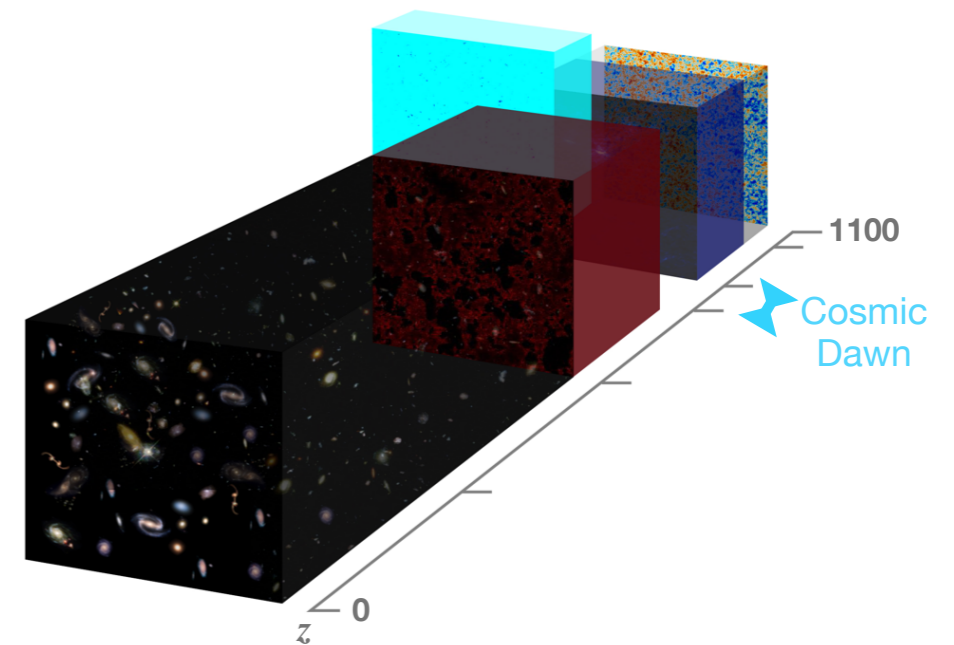
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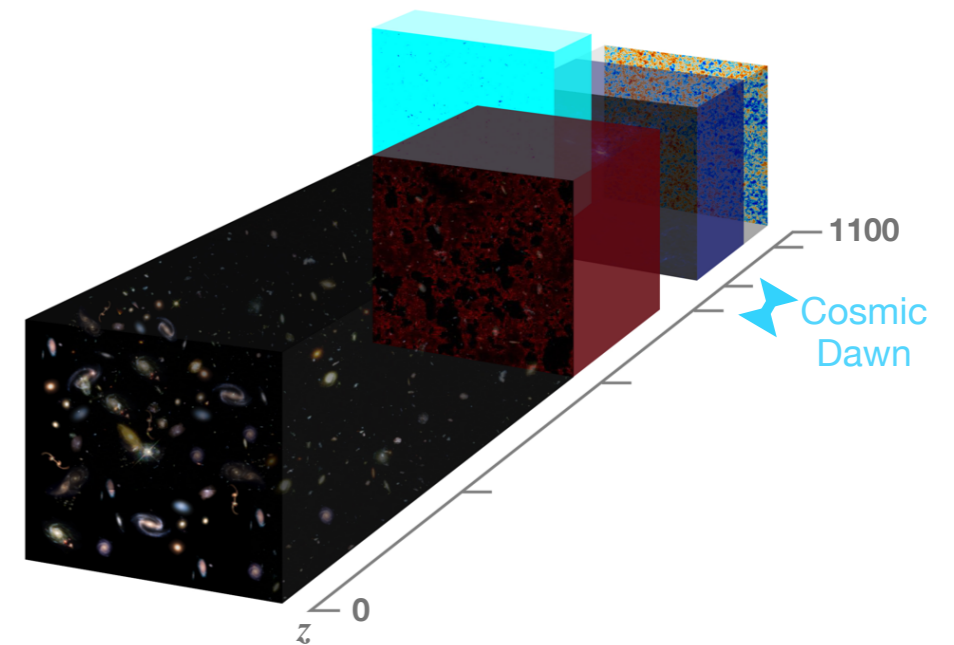
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“Heating of Baryons due to Scattering with Dark Matter During the Dark Ages”

Muñoz, EDK & Ali-Haïmoud, Phys. Rev. D. 92 (2015), arXiv:1509:00029

“Tighter Limits on Dark Matter Explanations of the Anomalous EDGES 21cm Signal”

EDK, Poulin, Gluscevic, Boddy, Barkana and Kamionkowski, arXiv:1807:11482

“A Critical Assessment of CMB Limits on Dark Matter-Baryon Scattering: New Treatment of the Relative Bulk Velocity”

Boddy, Gluscevic, Poulin, EDK, Kamionkowski and Barkana, arXiv:1808:00001

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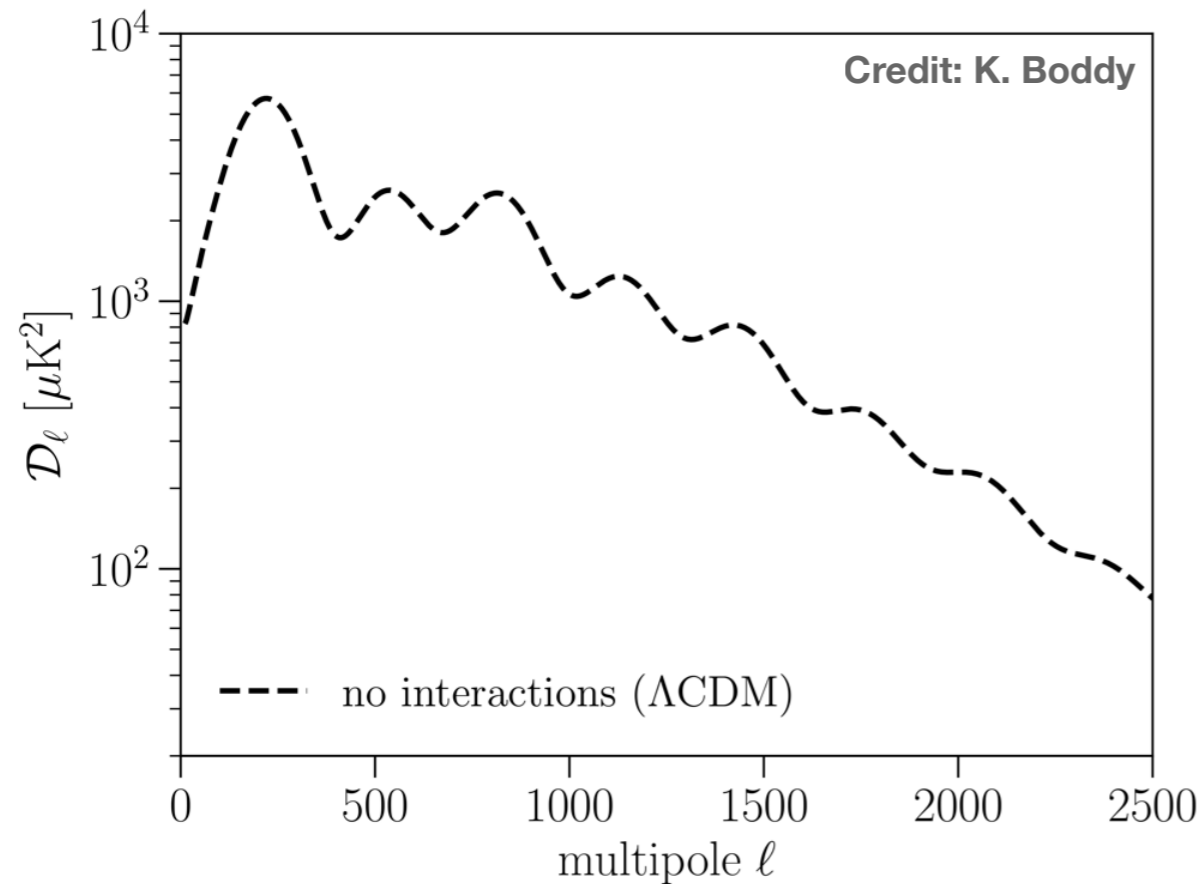
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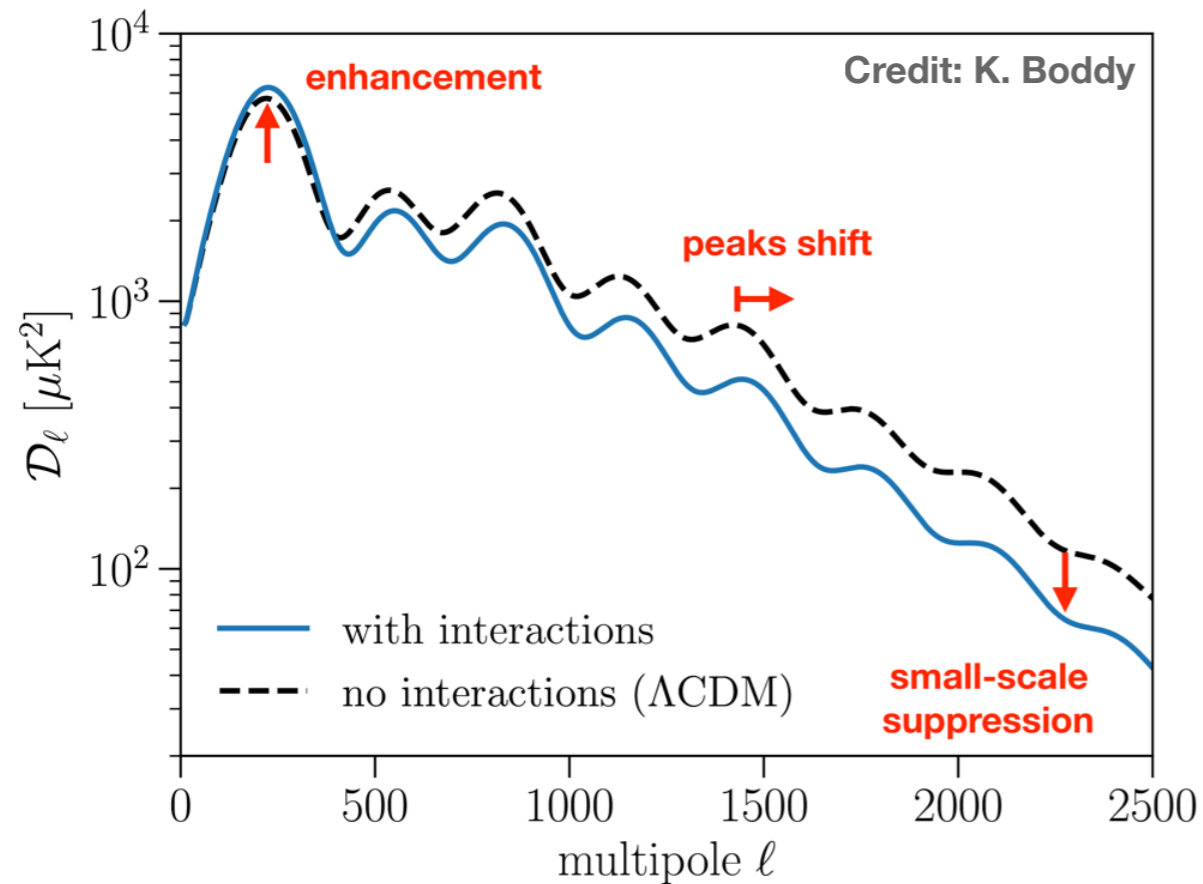


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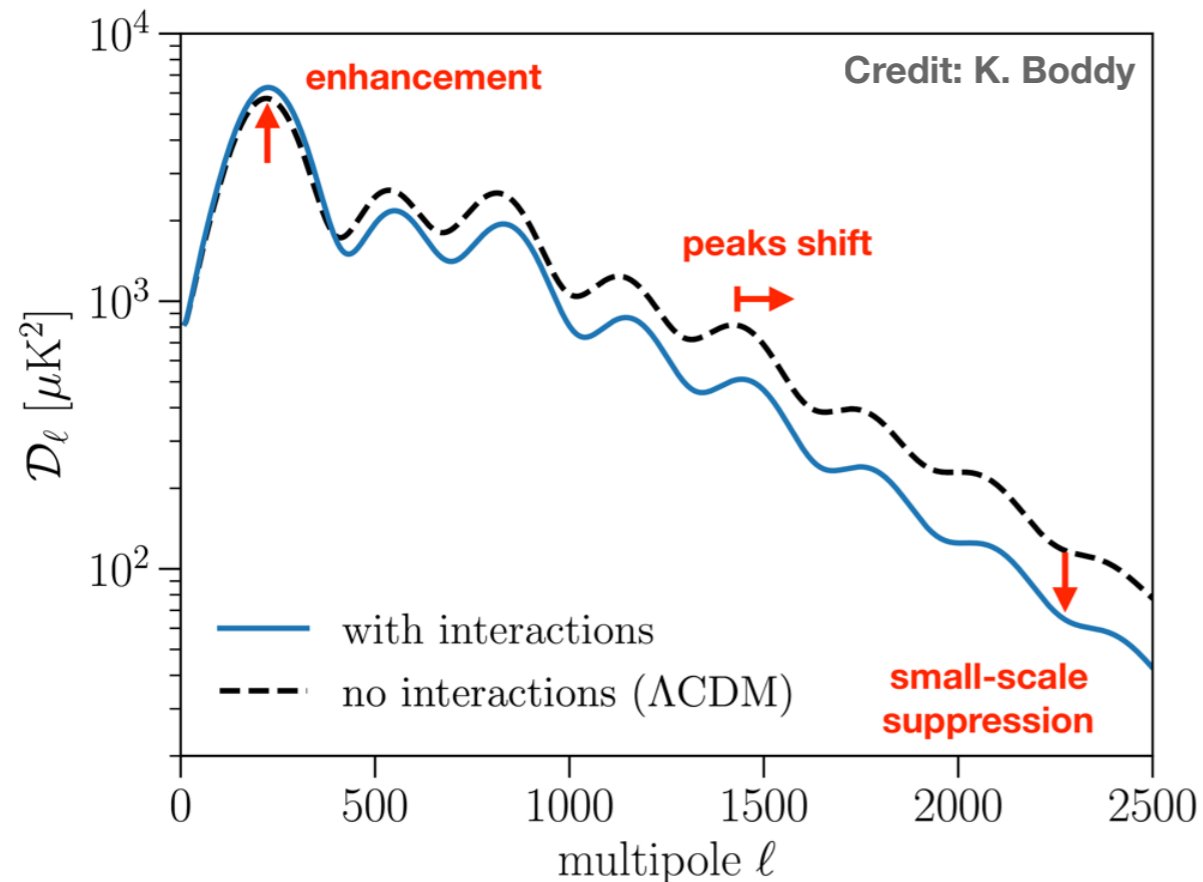


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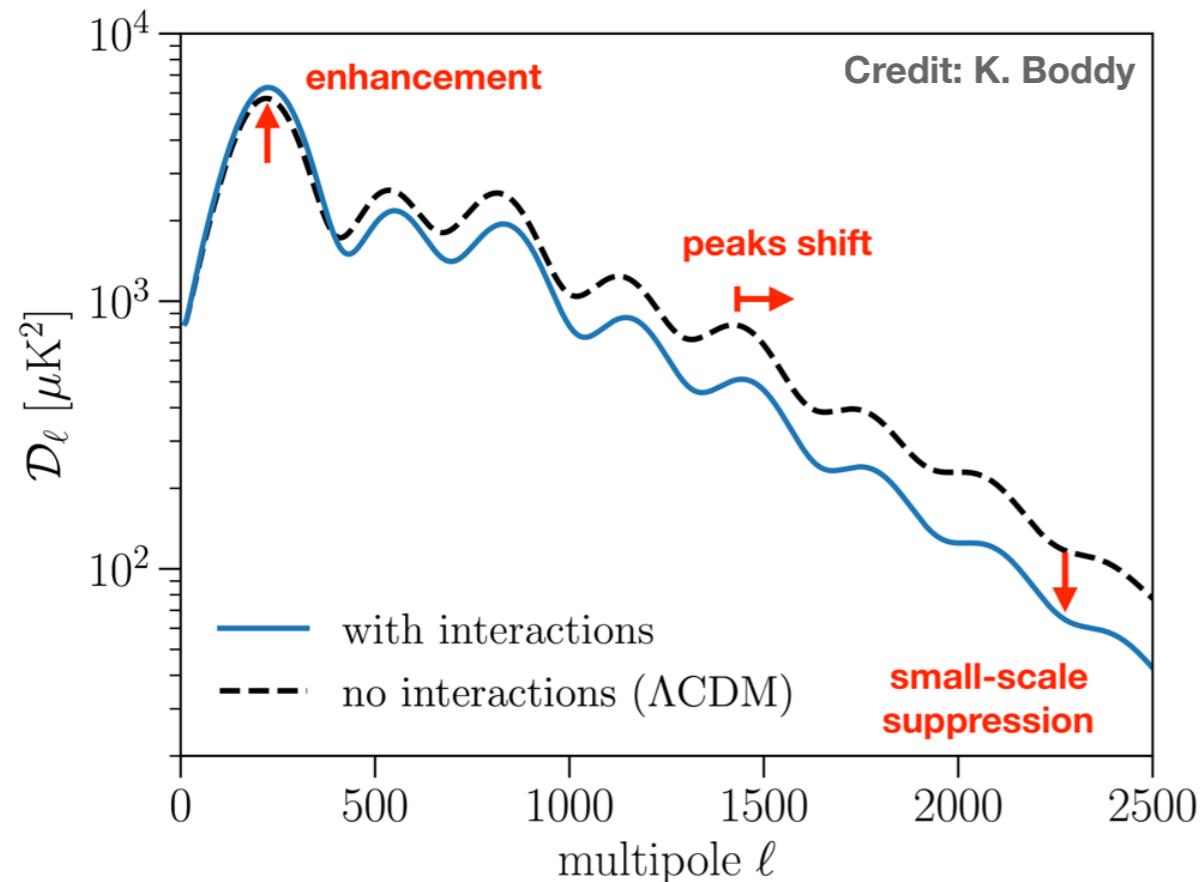
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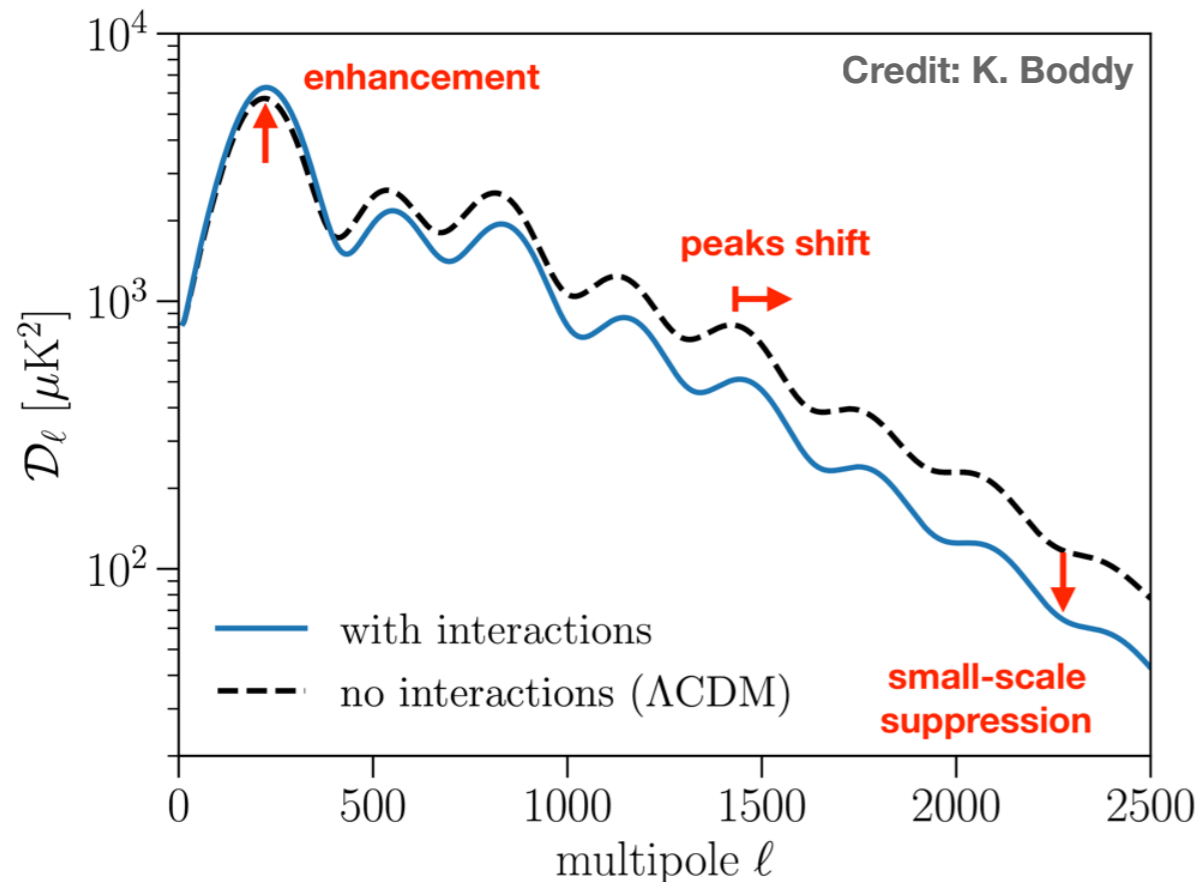
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Let's examine the case: $\sigma(v) = \sigma_c \left(\frac{v}{c}\right)^{-4}$

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(Muñoz, EDK and Ali-Haïmoud, PRD 2015)

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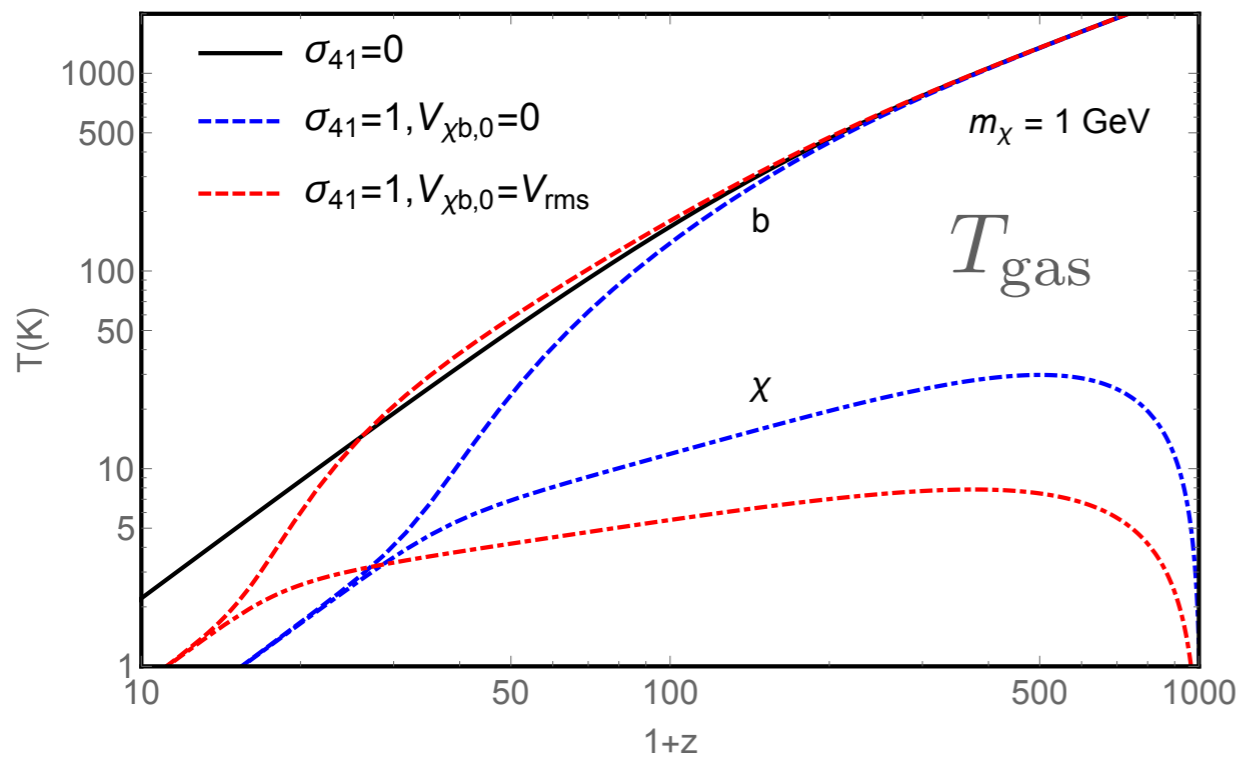
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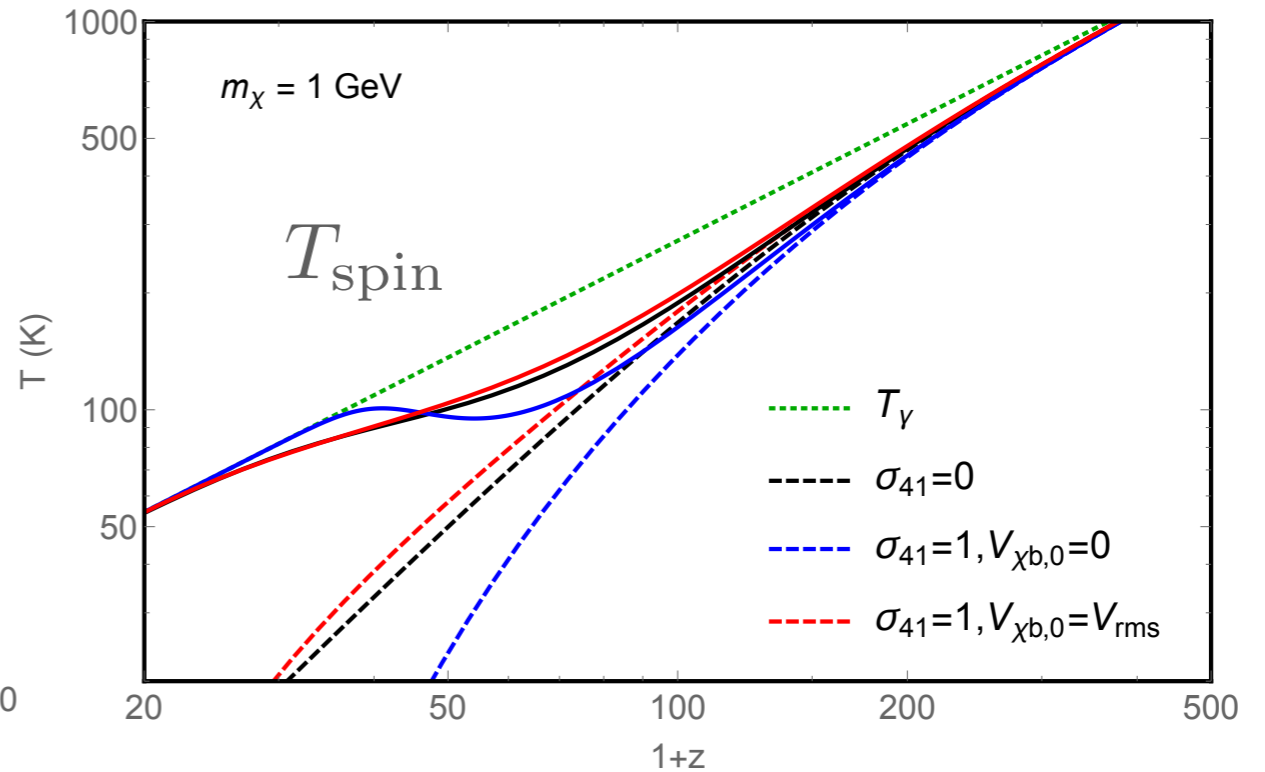
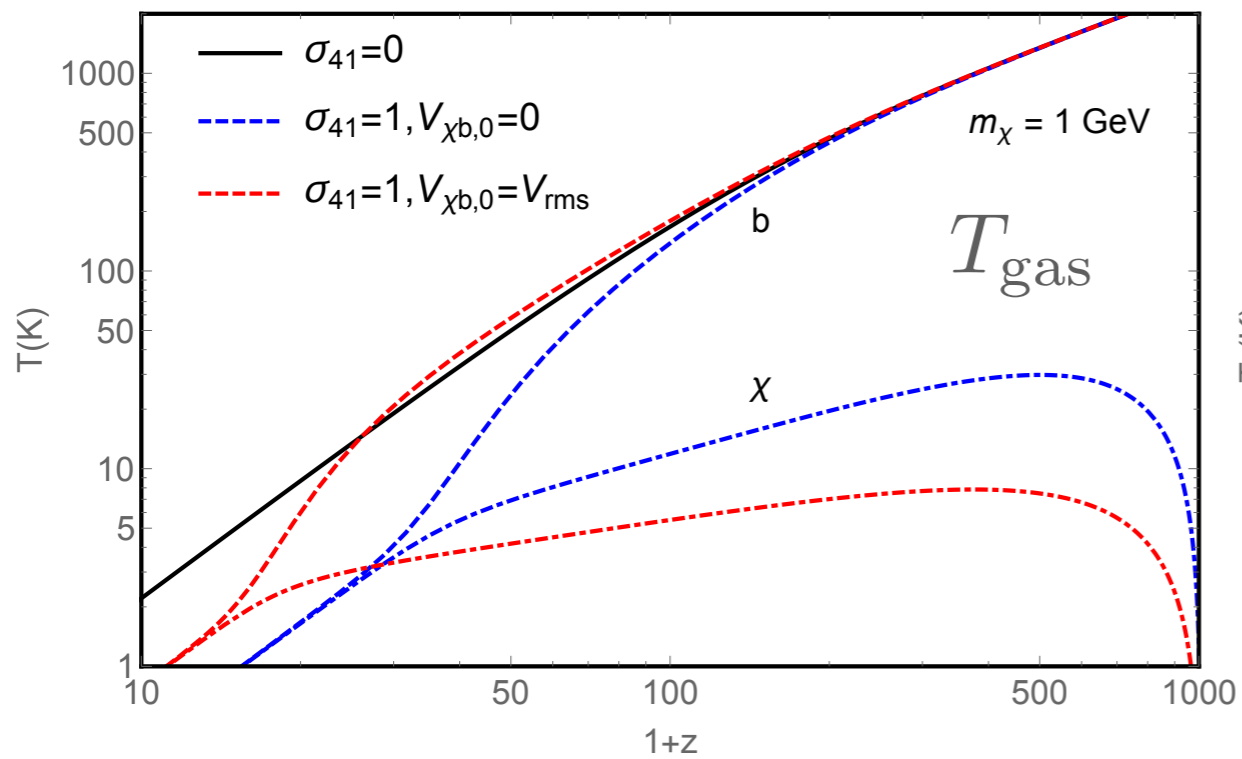
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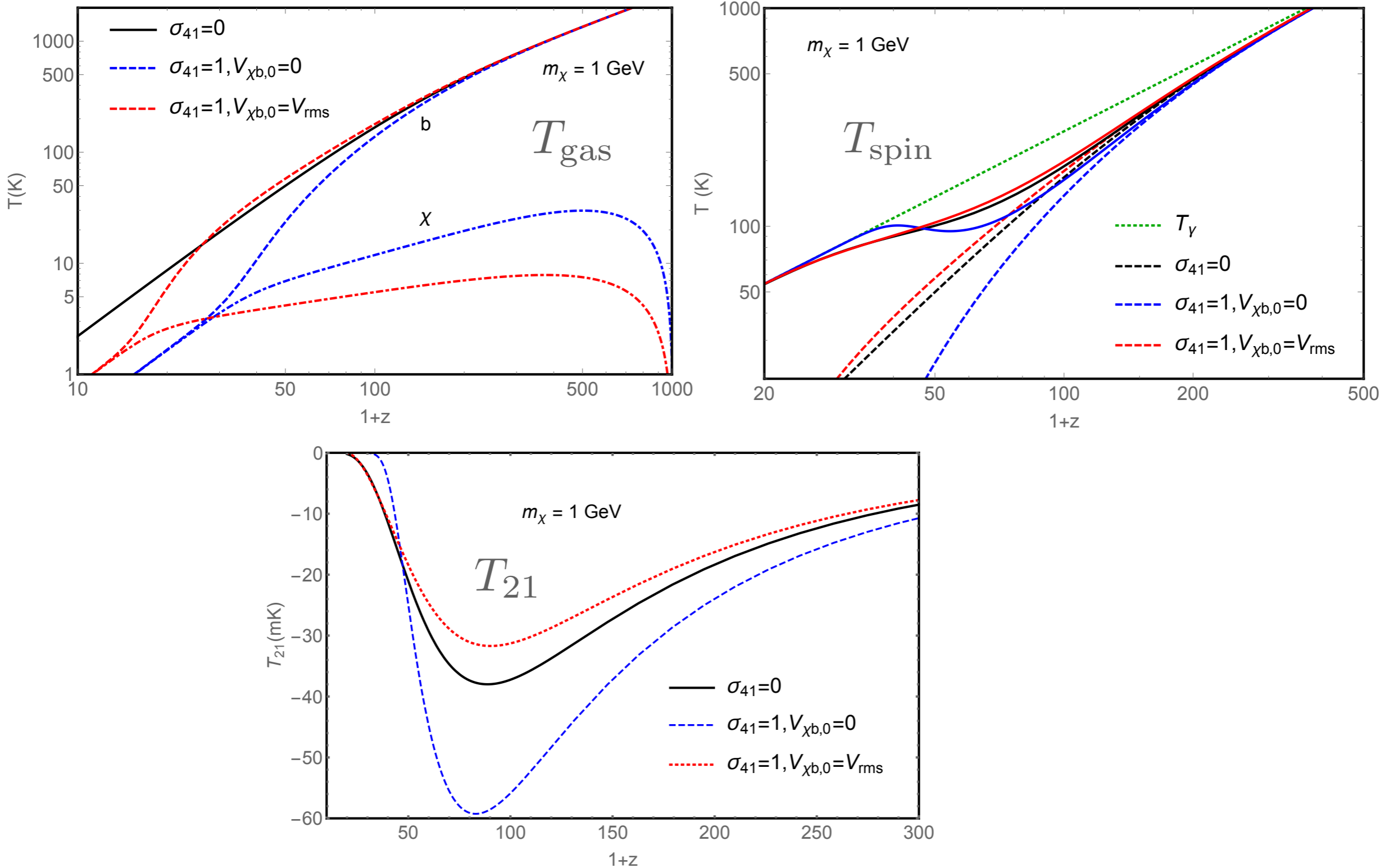
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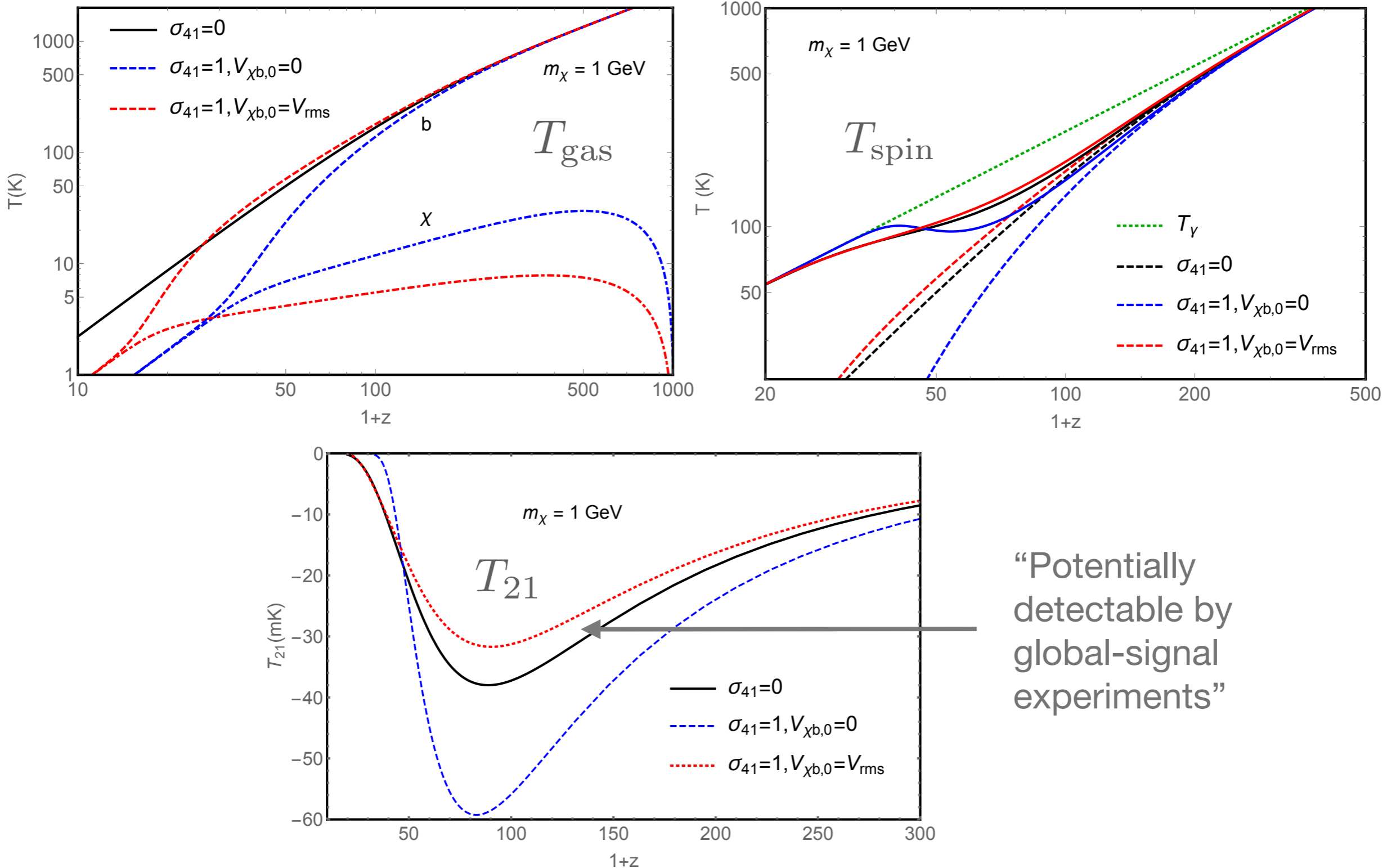
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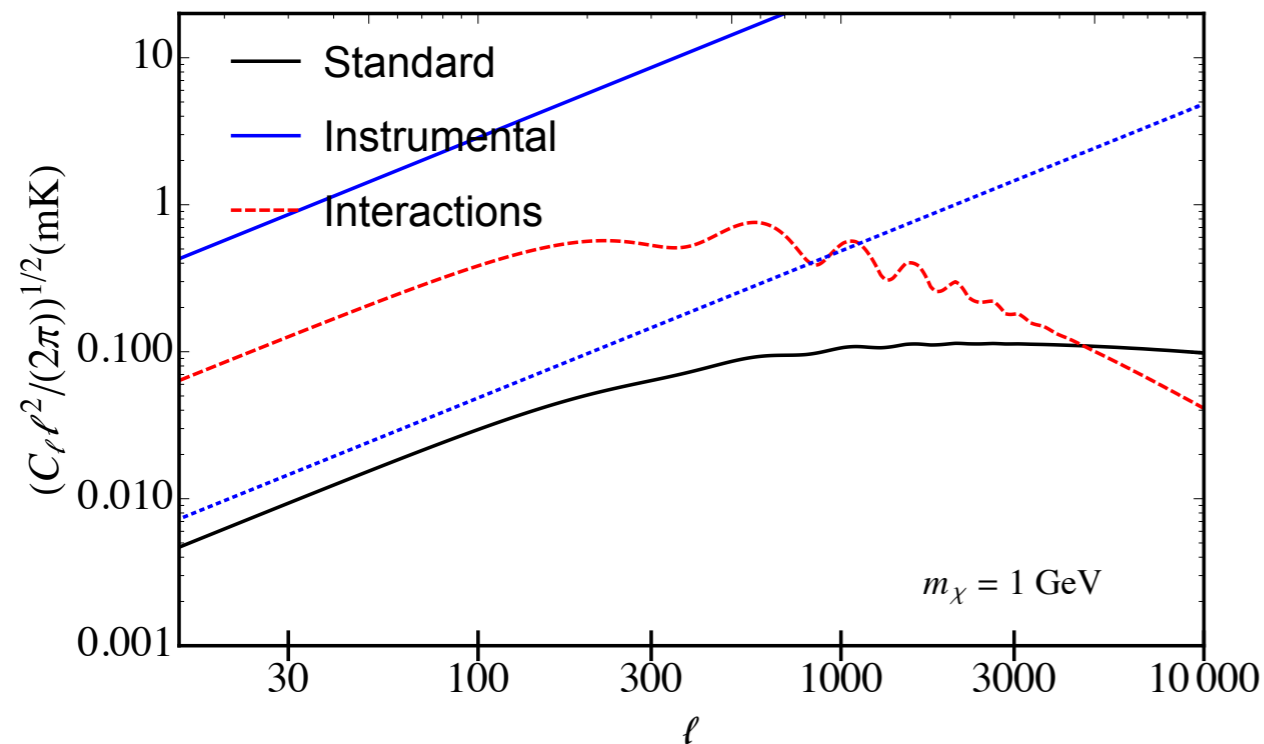
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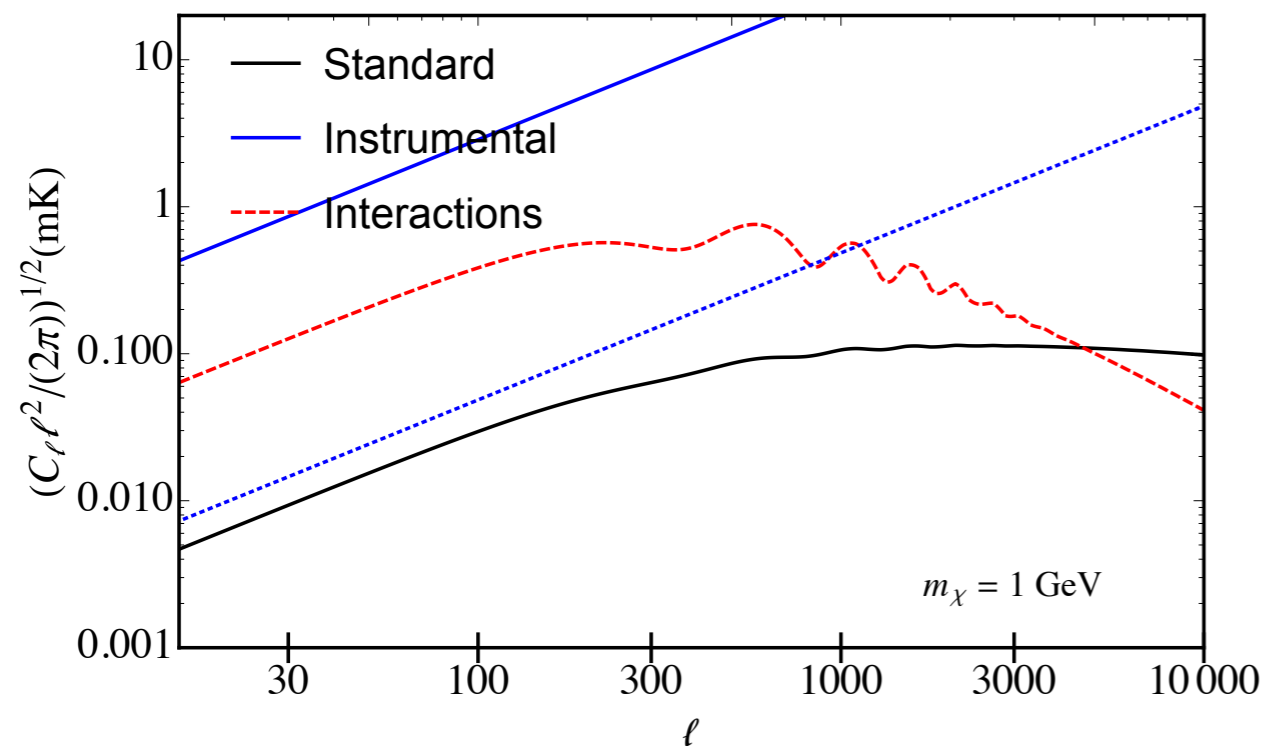
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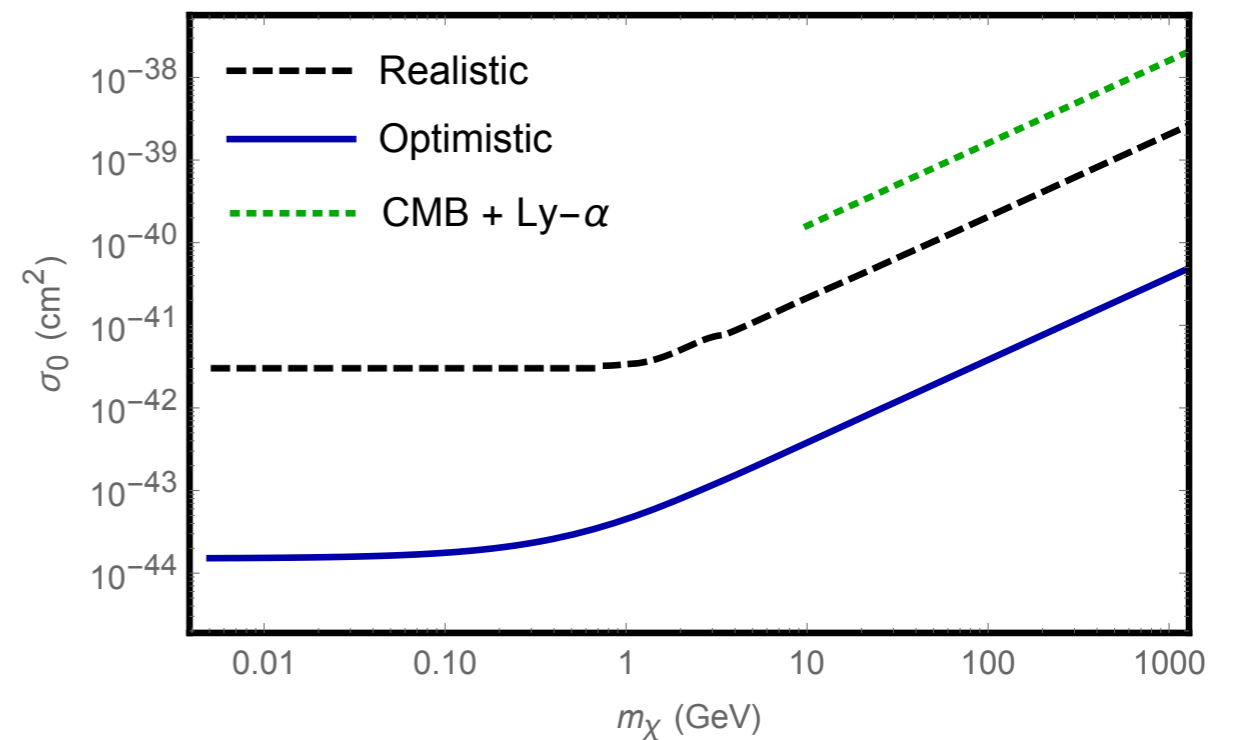
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- Realistic: SKA, 6-km baseline, 2% cover fraction.
- Optimistic: 50-km baseline, 10% cover fraction.
- CMB: from Dvorkin, Blum & Kamionkowski (2014).

DM-B Scattering: What About Cosmic Dawn?

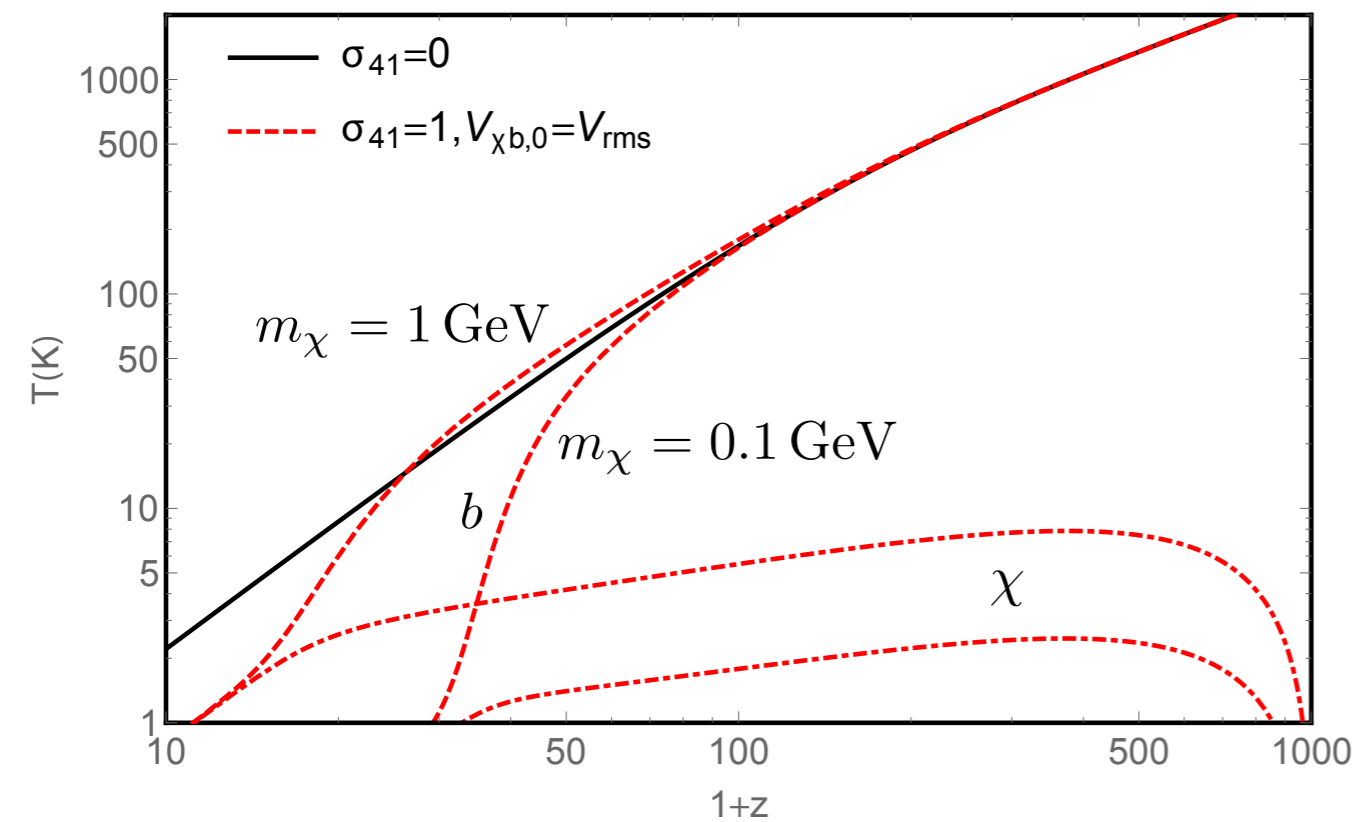
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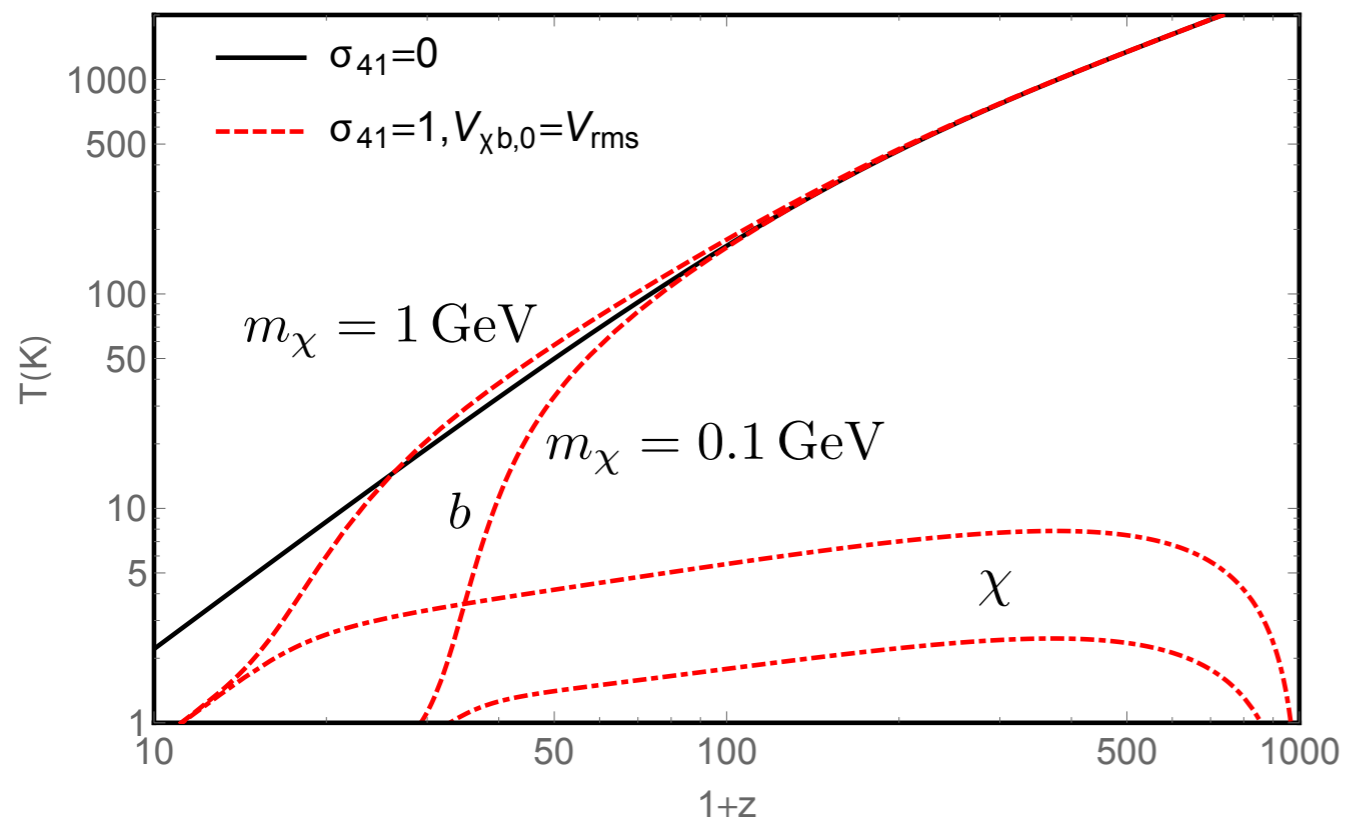
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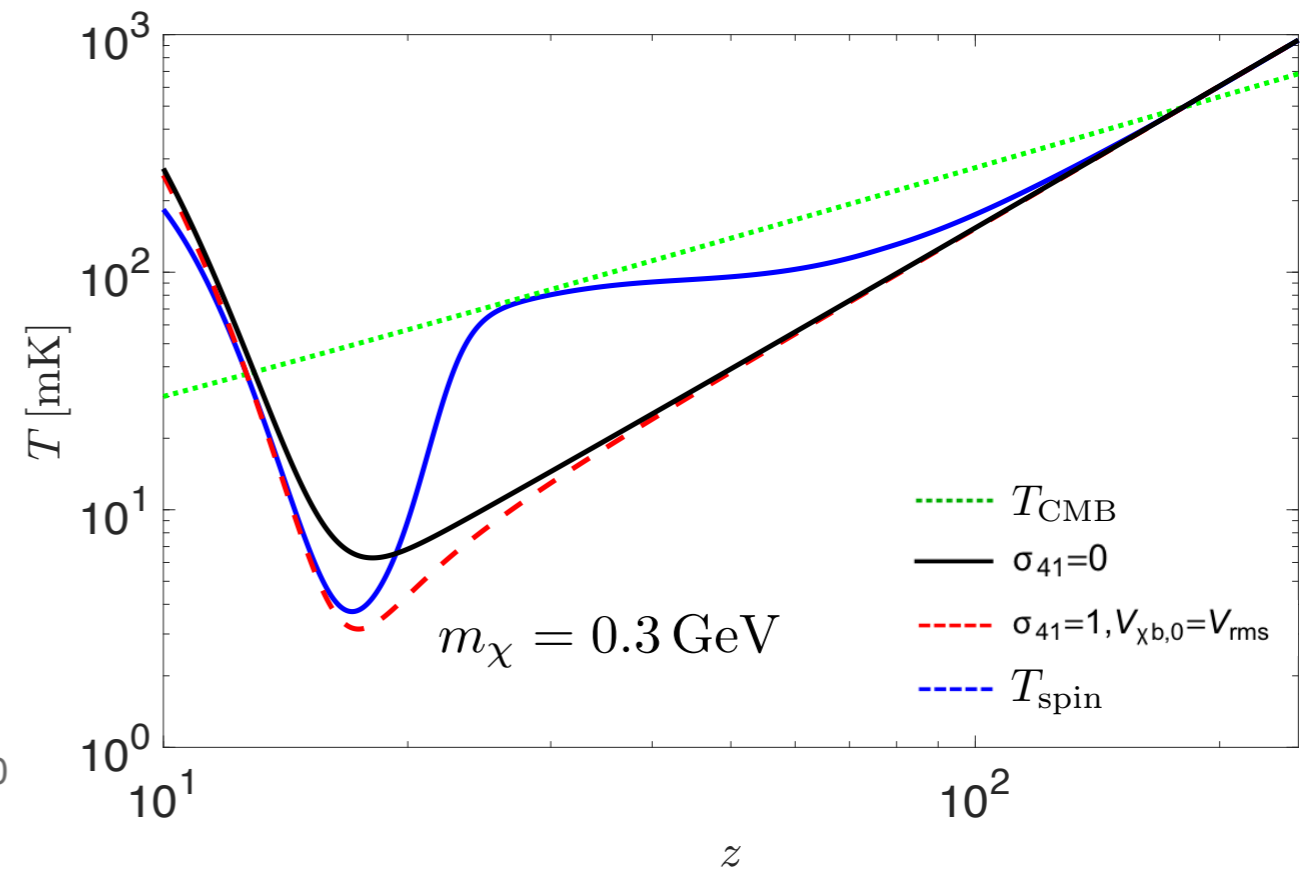
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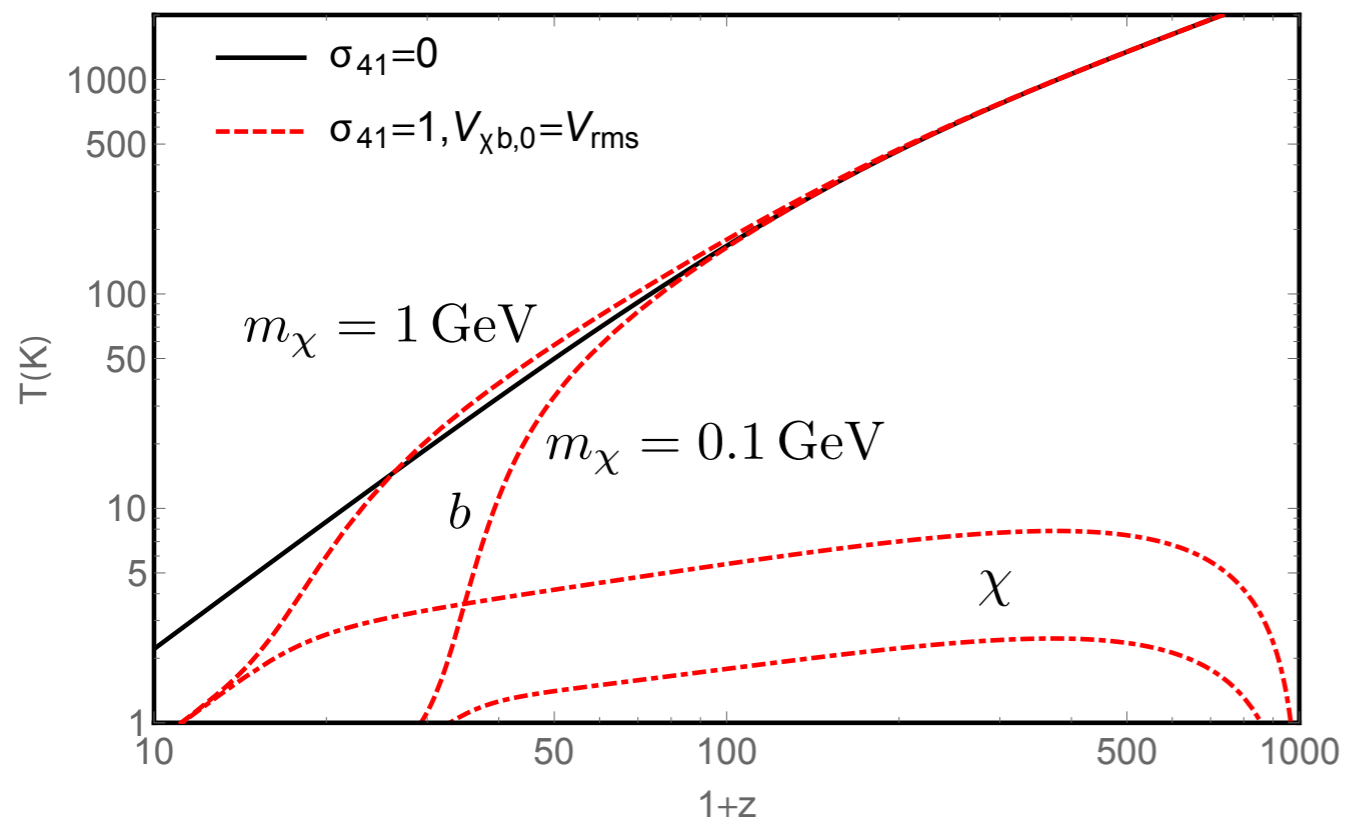
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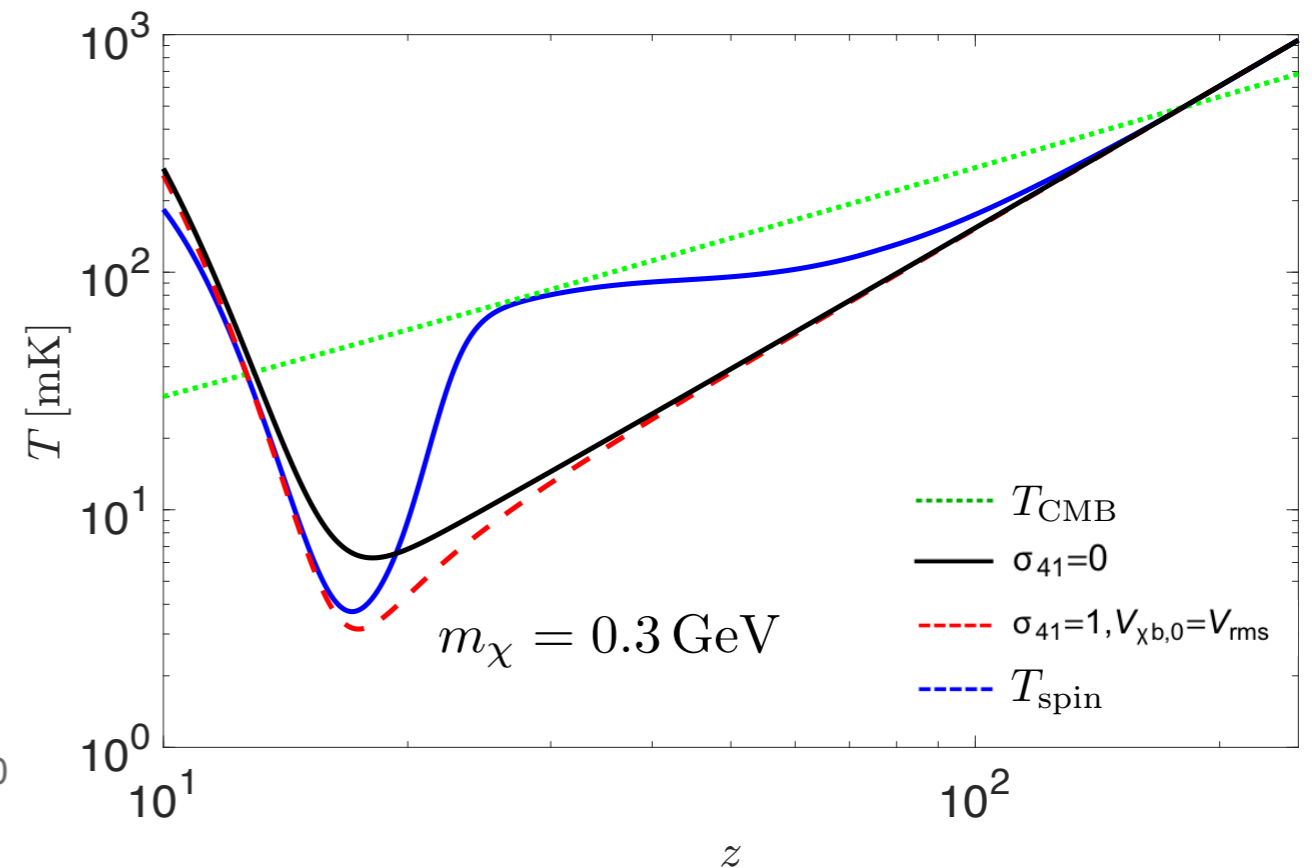
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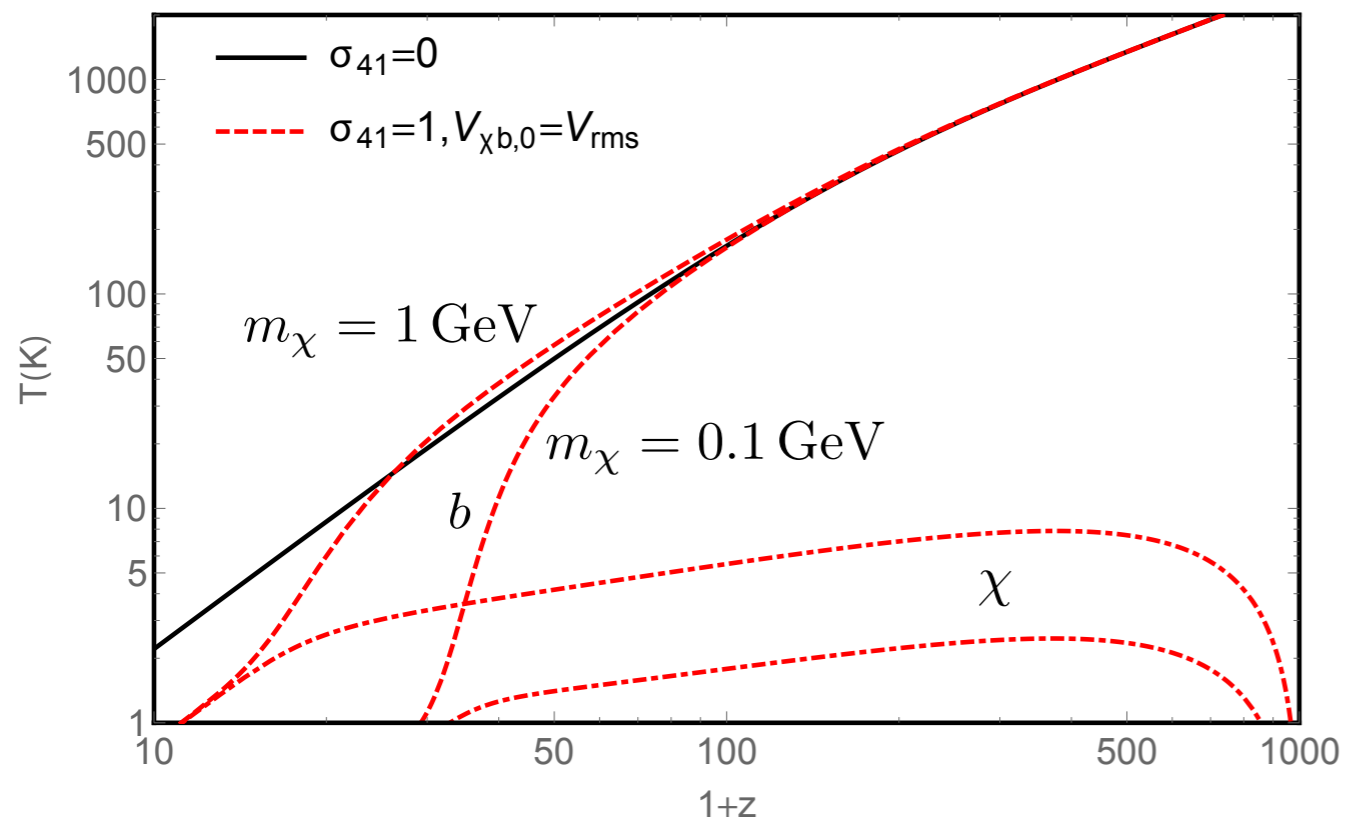


Can the interaction evade constraints from the CMB and still affect the Cosmic Dawn?

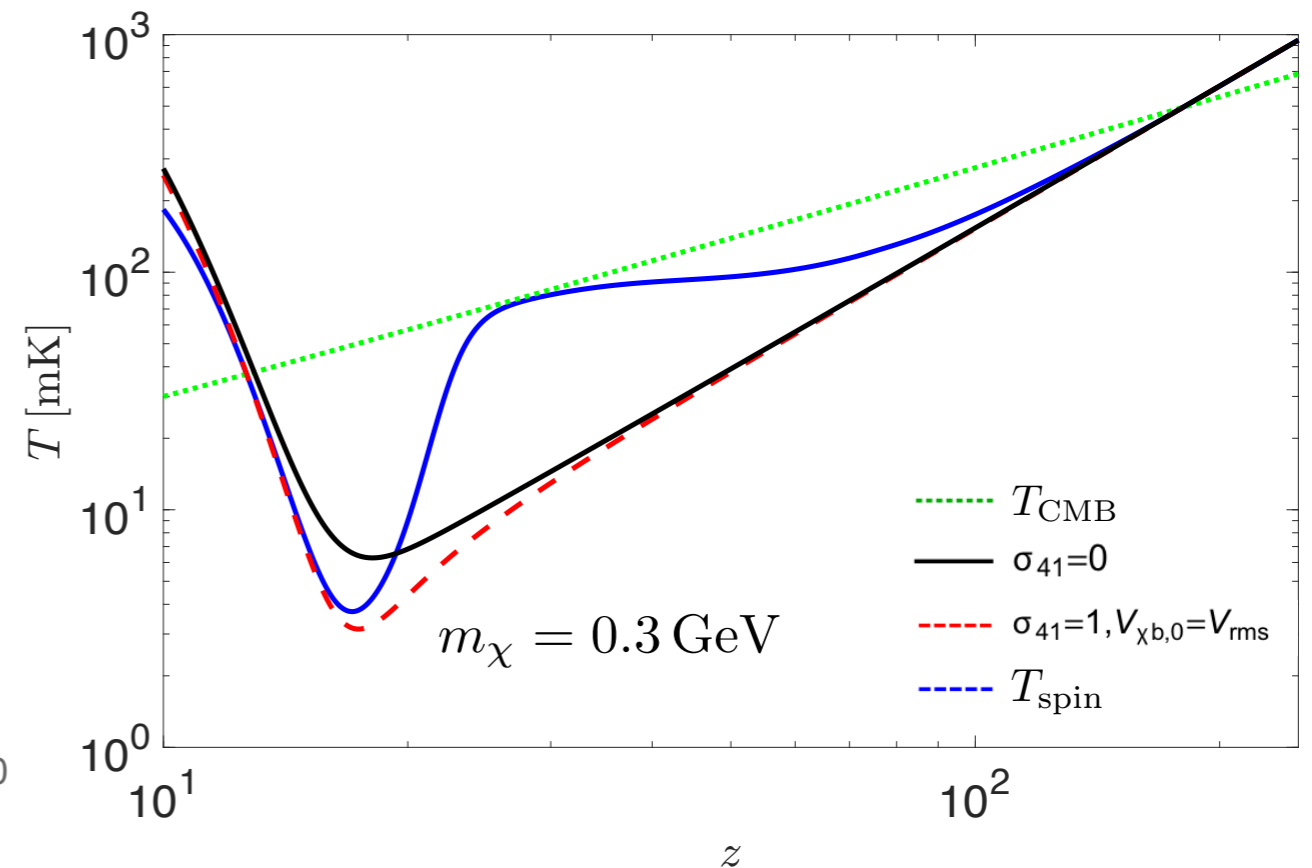
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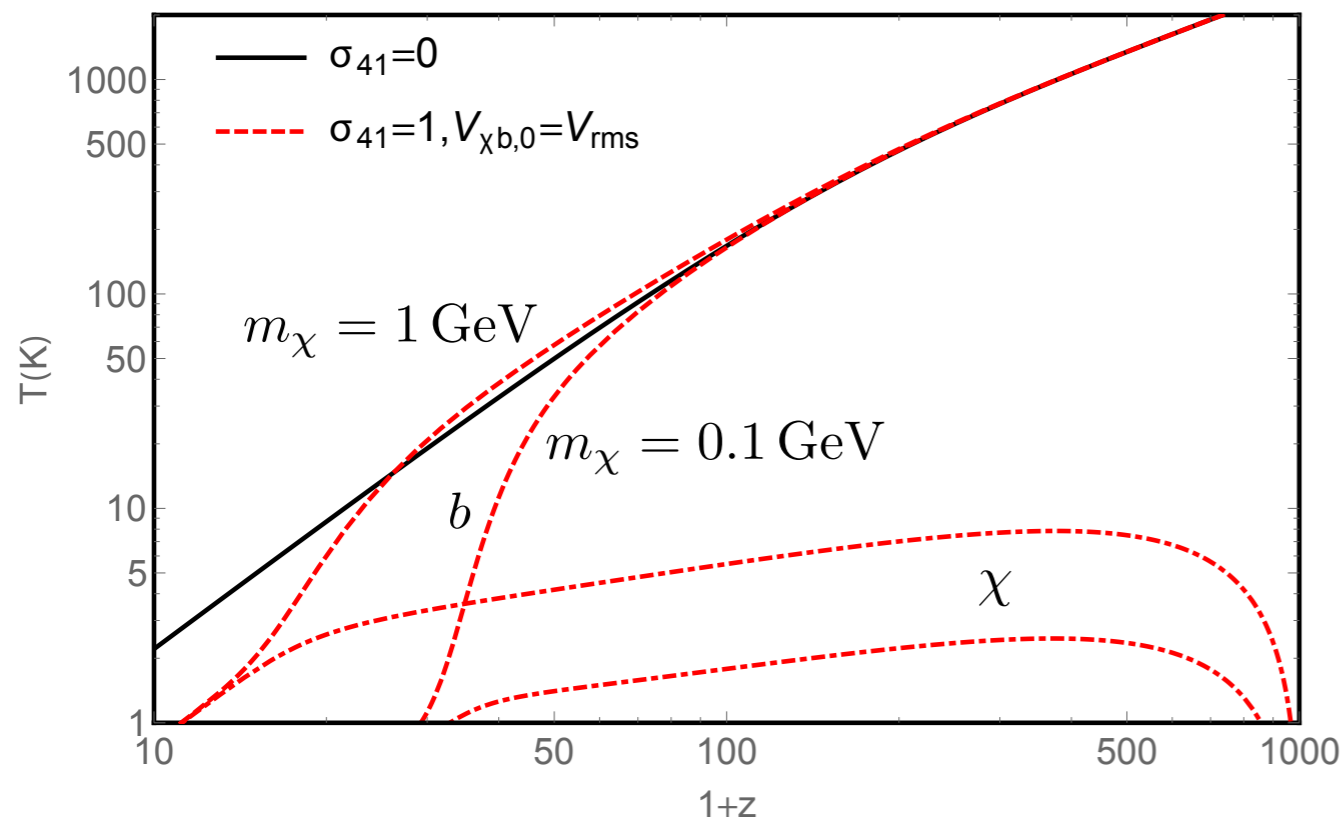
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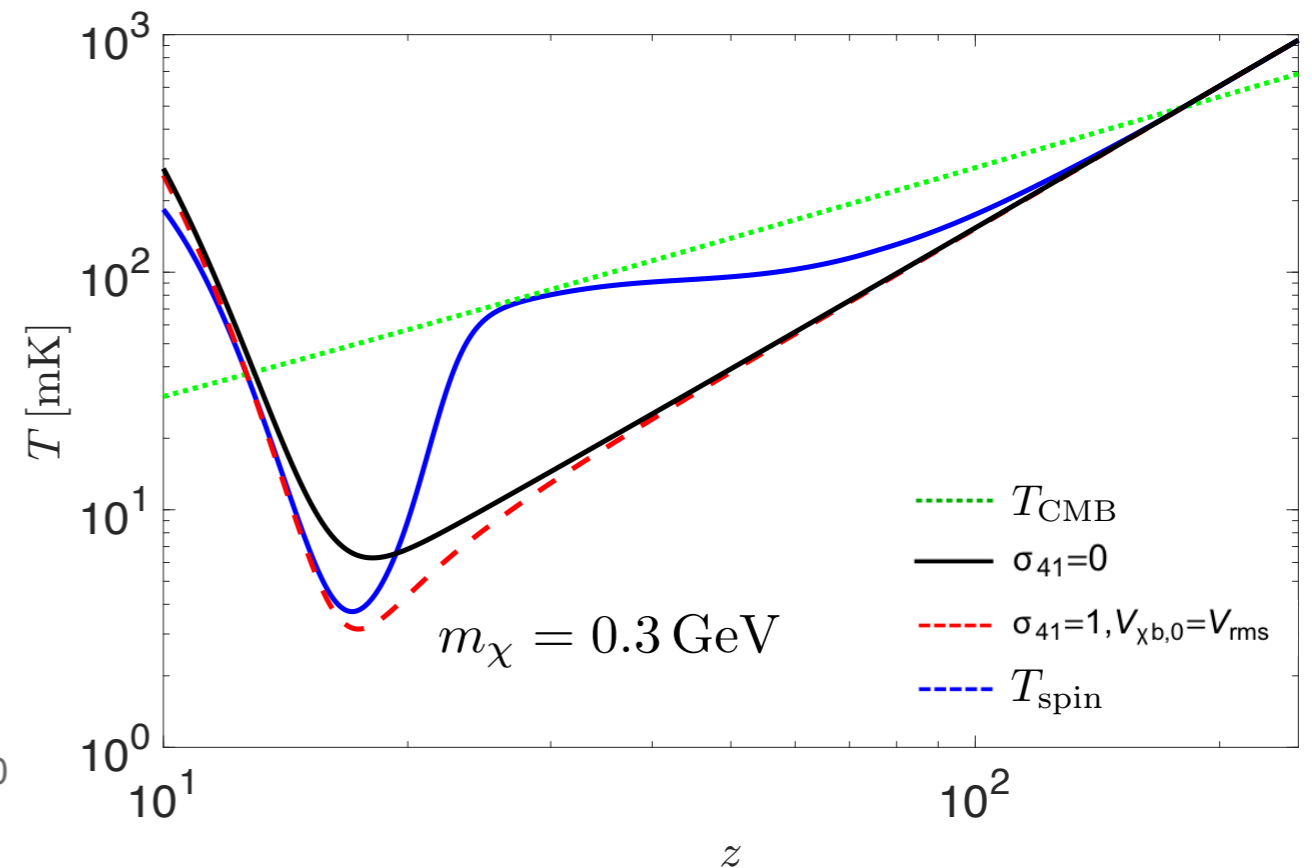
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Existing constraints were $\sigma_c \lesssim 10^{-40}$ at $m_\chi \gtrsim 1 \text{ GeV}$.

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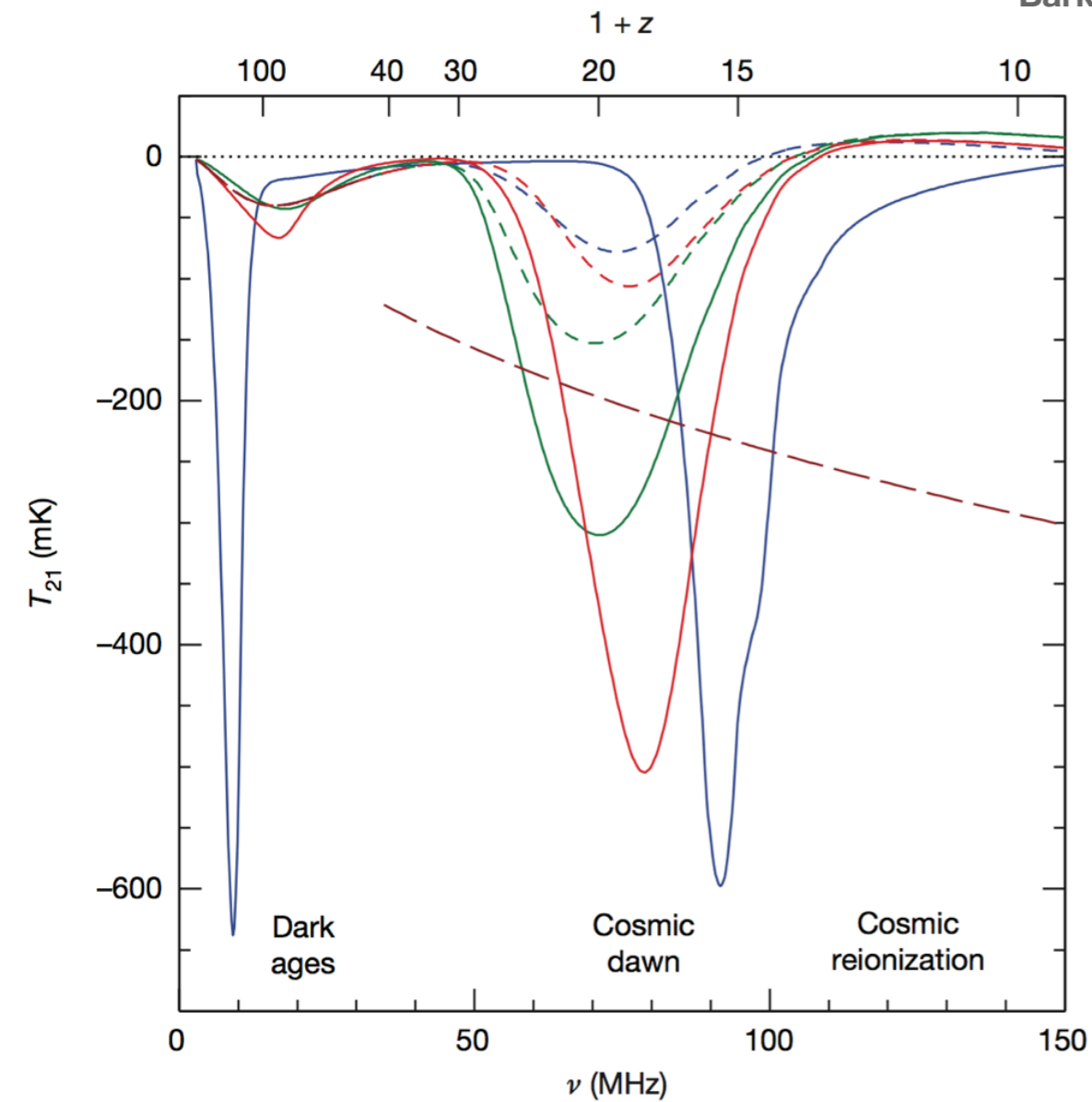
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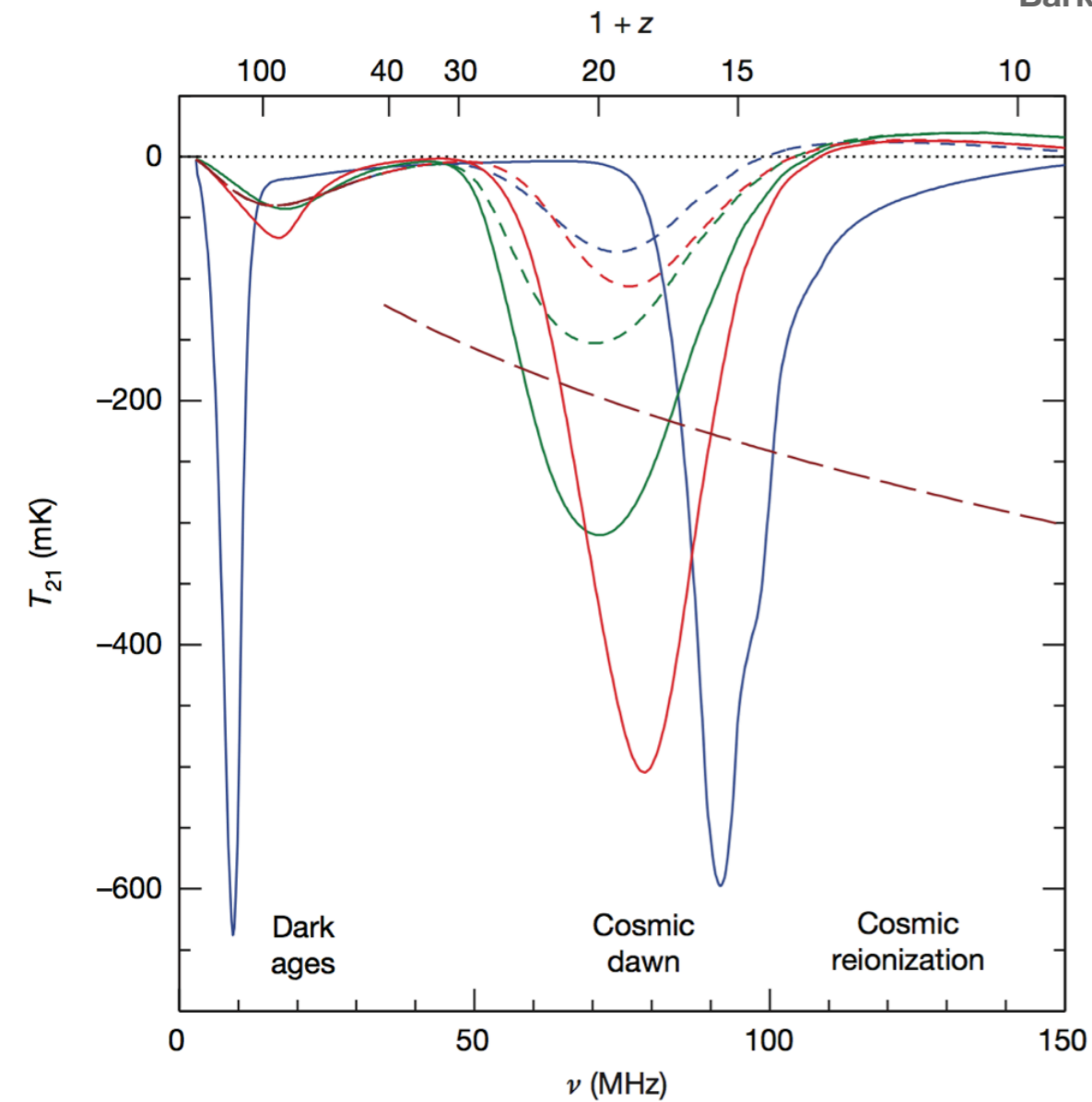
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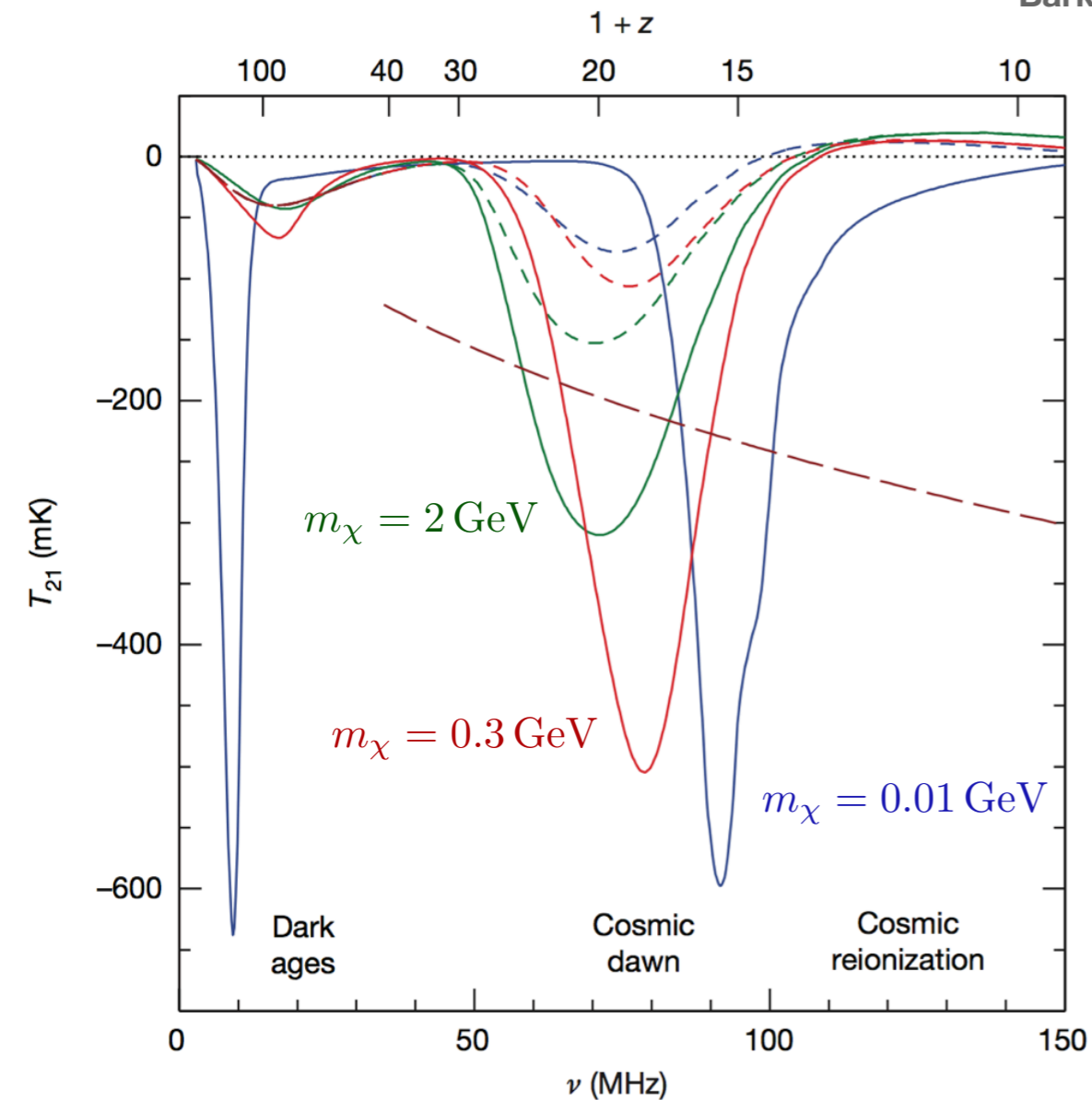


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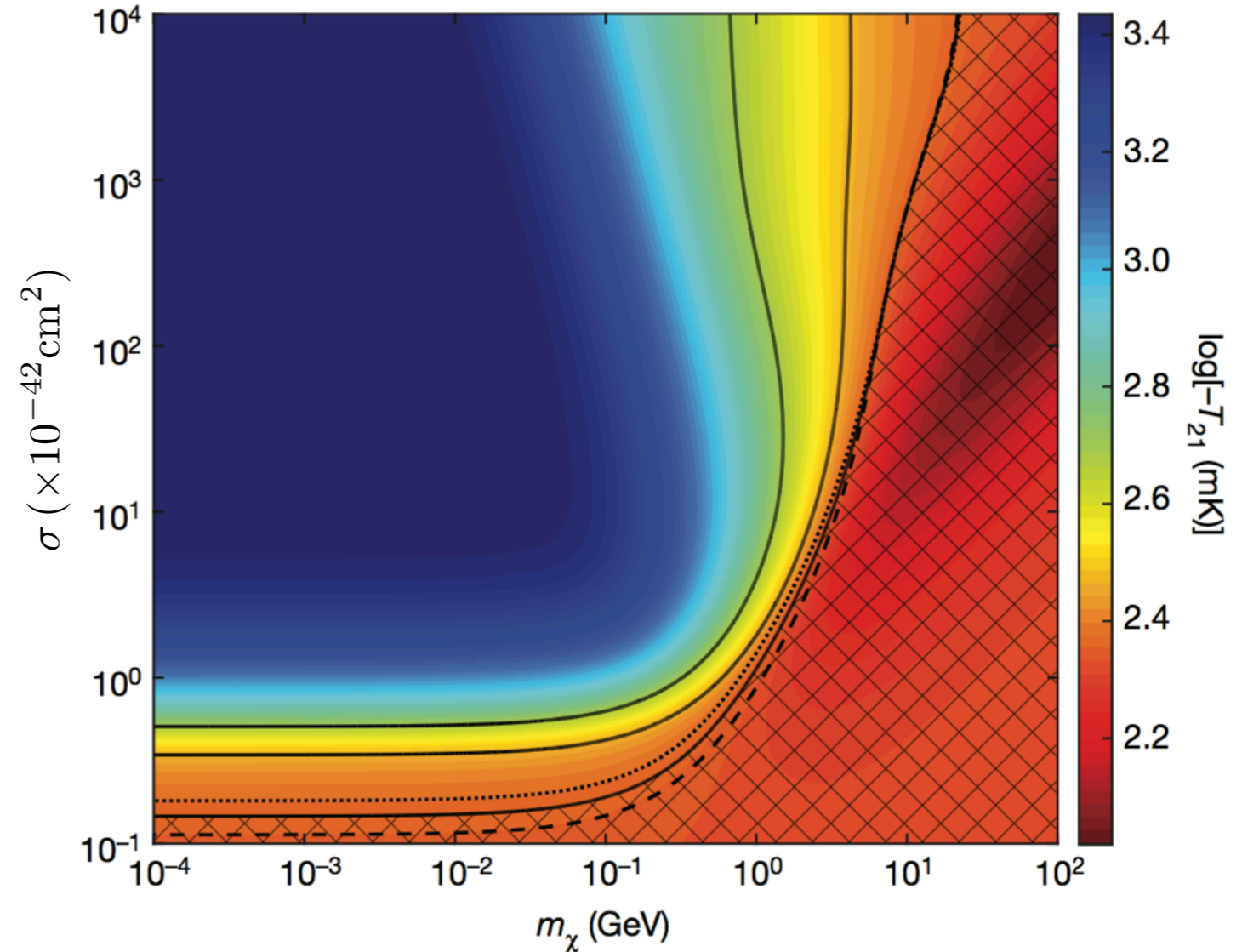
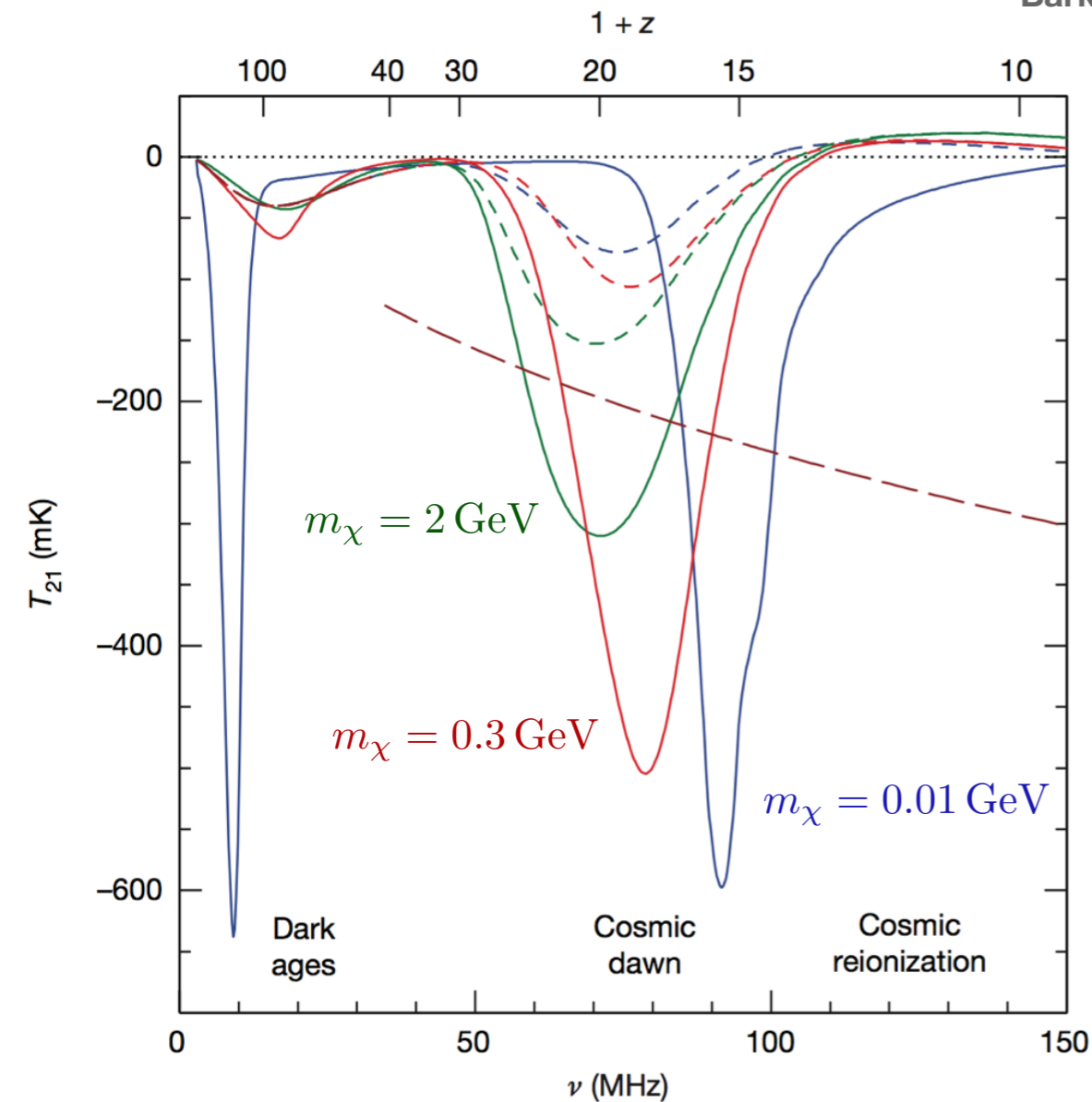


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- Cooling dominates for low masses. Heating for high mass.
- For low masses, cooling is virtually mass independent.

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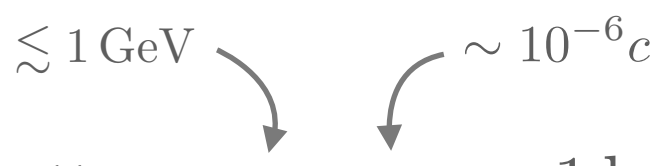
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In general, two types of models:

- Interaction via a force mediator: $\sigma \propto \frac{1}{(q^2 + m_\phi^2)^2} \longrightarrow m_\phi \ll q = m_\chi v_{\text{rel}} < 1 \text{ keV}$
Detailed description: The diagram shows two curved arrows pointing downwards from the text above. The first arrow starts under the text '≲ 1 GeV' and points to the m_φ term in the equation. The second arrow starts under the text '~ 10^-6 c' and points to the v_rel term in the equation.

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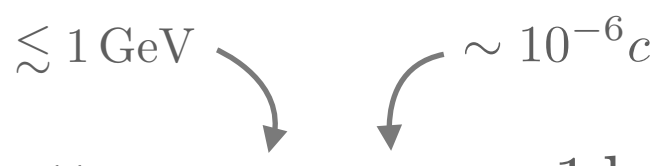
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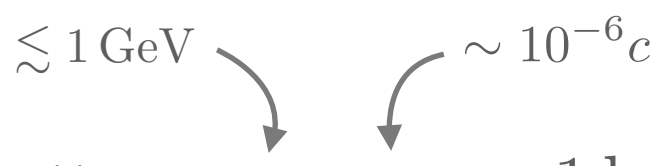
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could potentially work with: $\epsilon \equiv e_\chi/e \approx 6 \times 10^{-7} \left(\frac{m_\chi}{\text{MeV}}\right) \left(\frac{f_{\text{DM}}}{10^{-2}}\right)^{-3/4}$

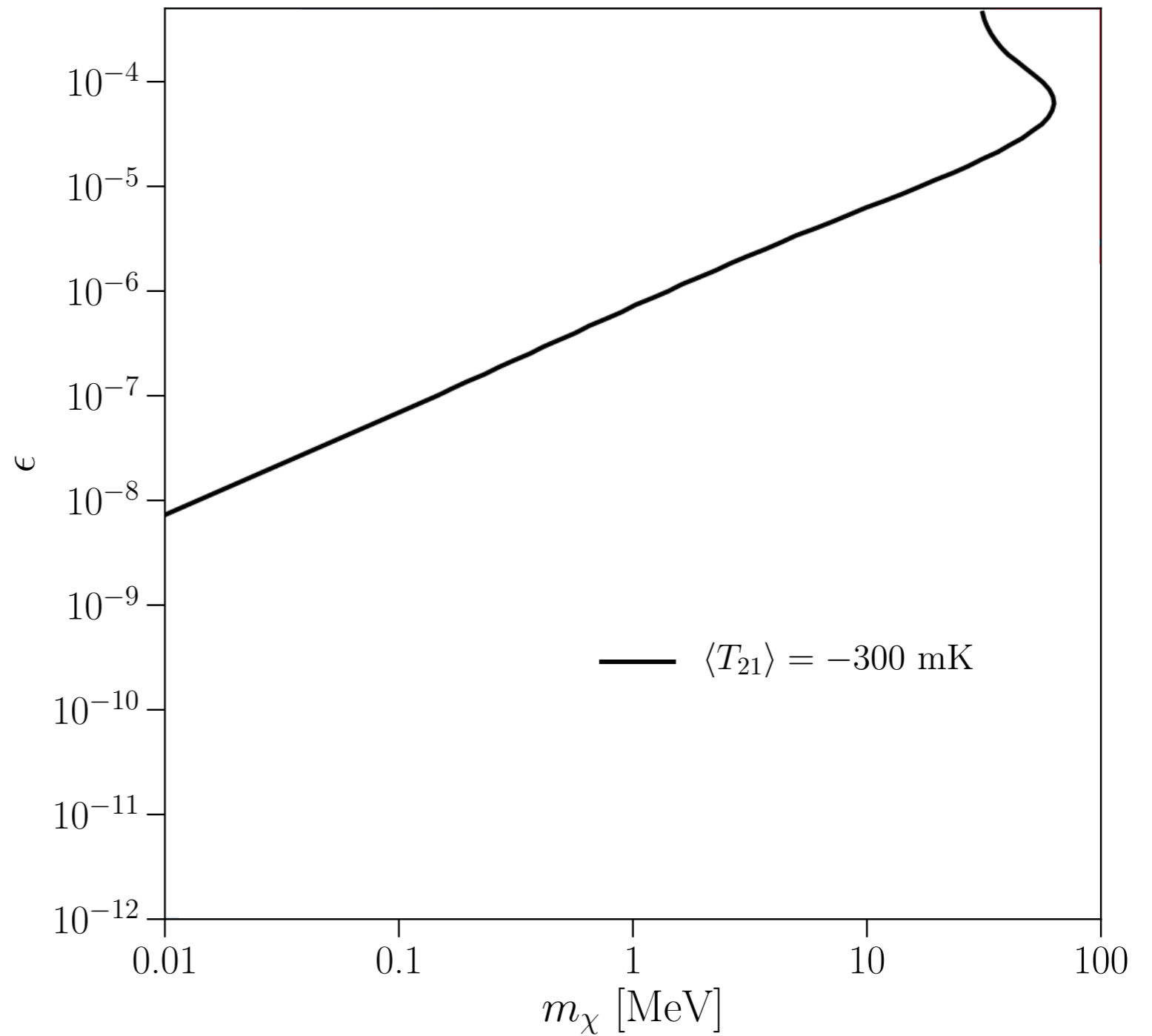
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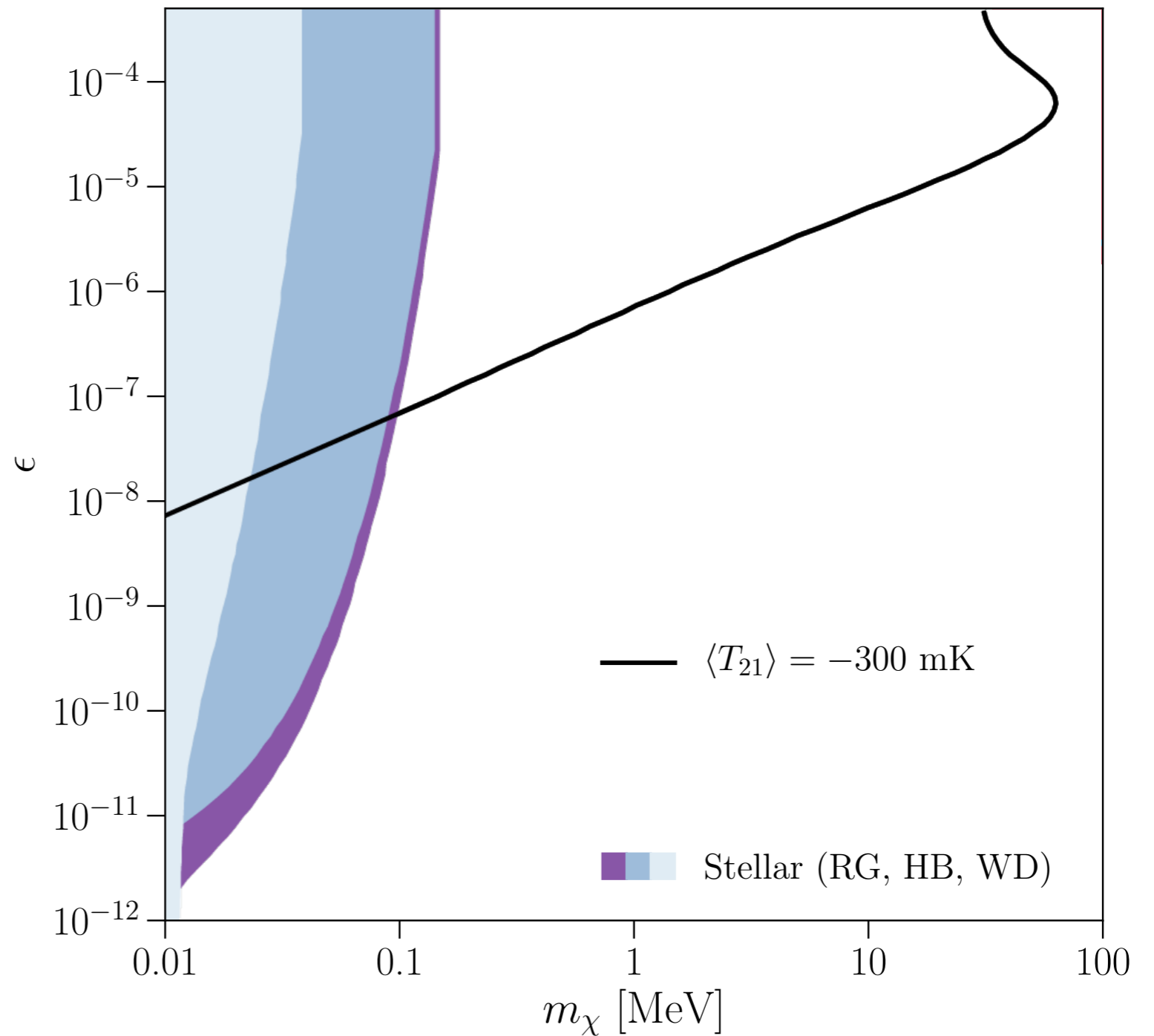


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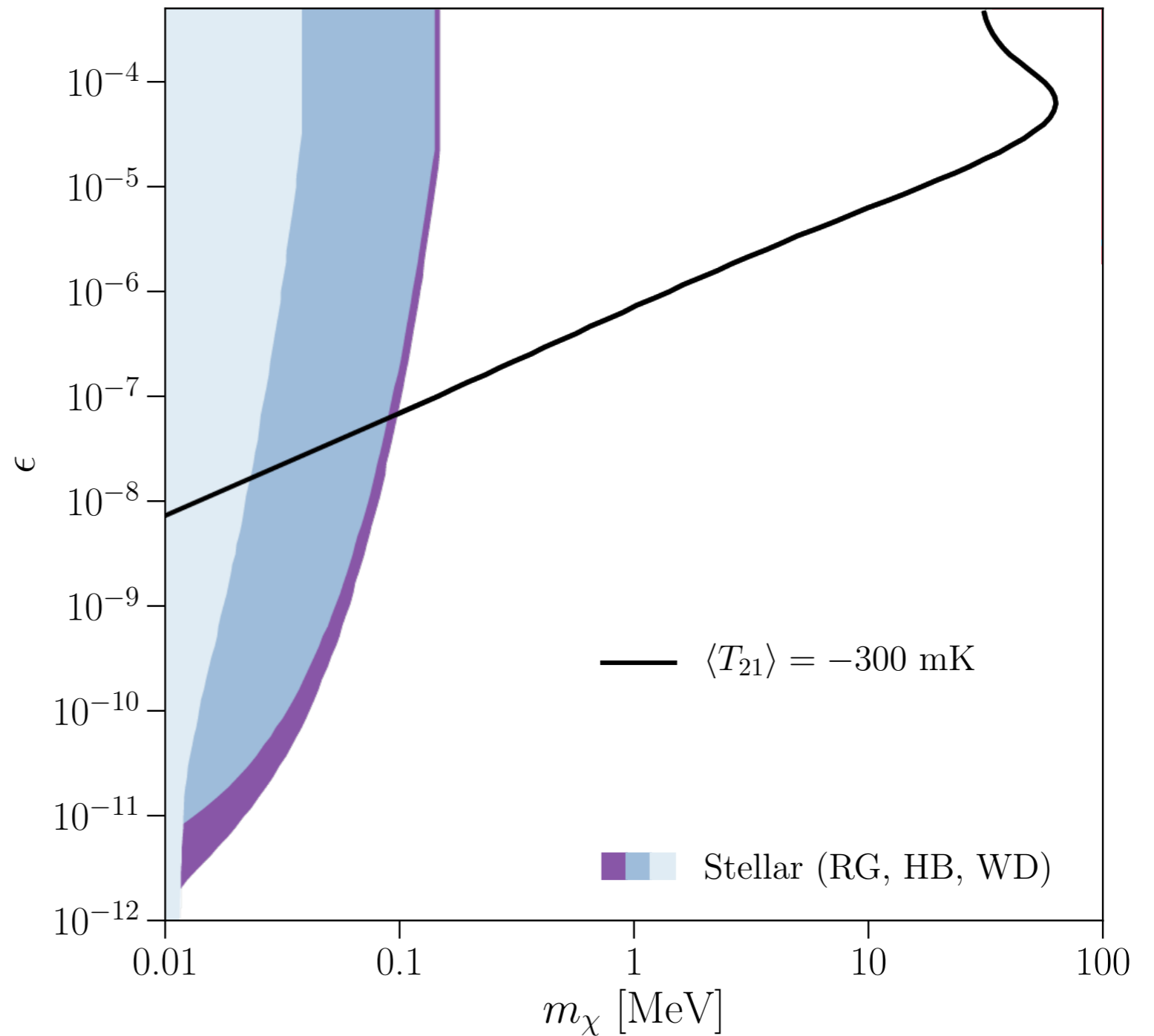
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- Horizontal branch
- Red giants

Vogel & Redondo,
JCAP (2014)

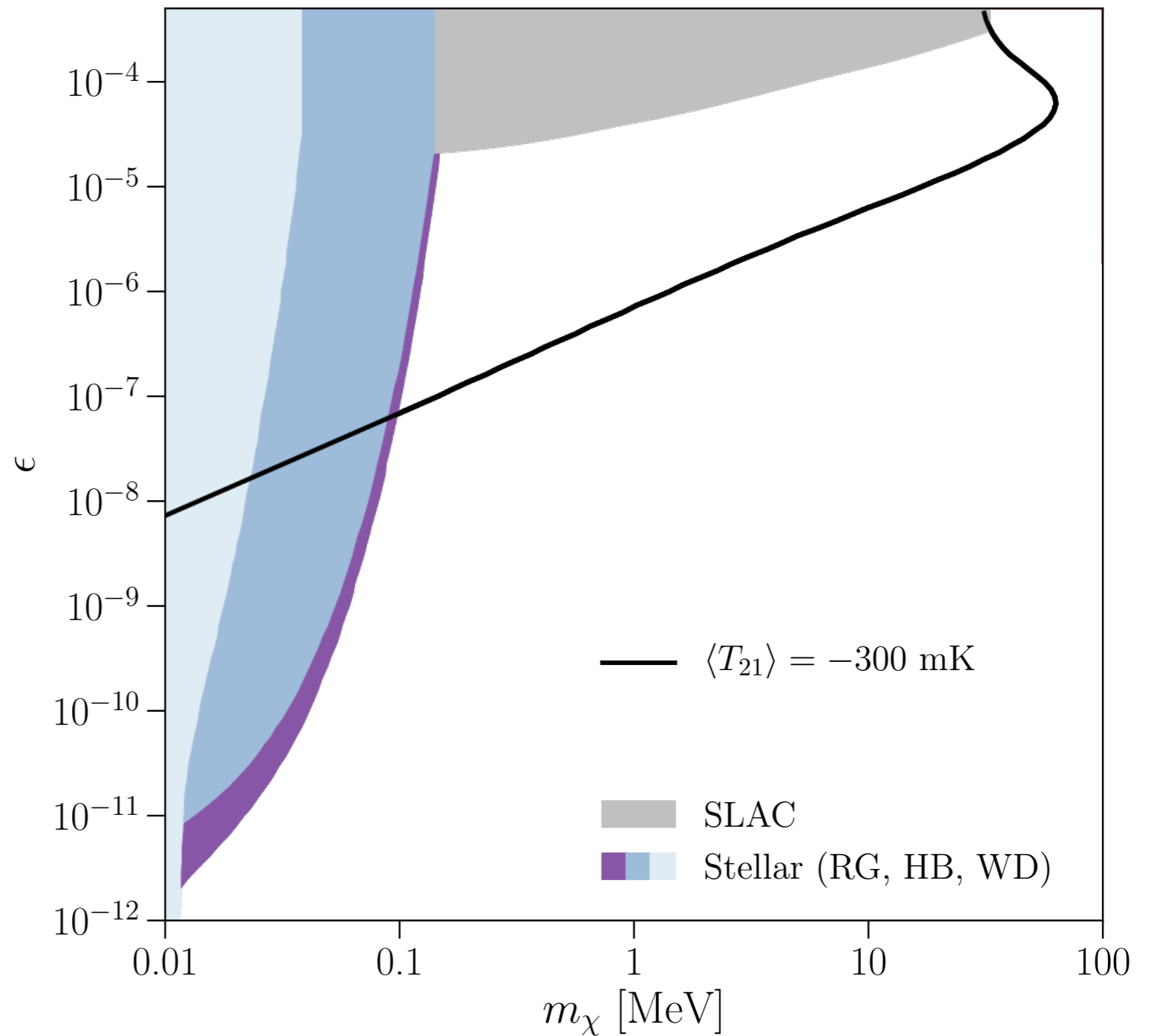


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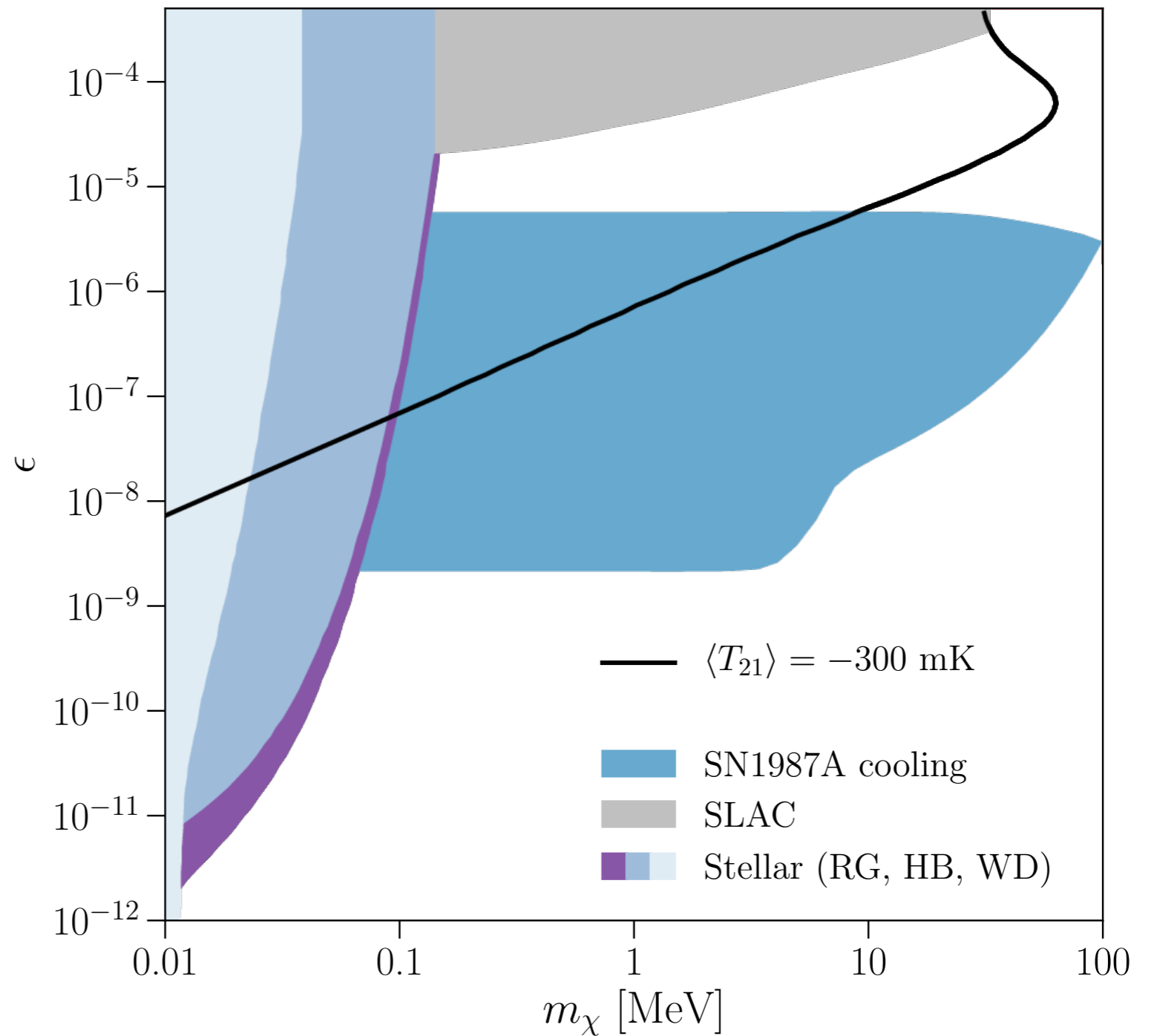


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- Vogel & Redondo, JCAP (2014)
- Prinz et al., PRL (1998)
- Chang et al., arXiv:1803:00993



1% Millicharged DM: Tighter Constraints

(EDK, Poulin, Gluscevic, Boddy, Barkana and Kamionkowski, arXiv:1807:11482)

Viable region for $f_\chi = 1\%$?

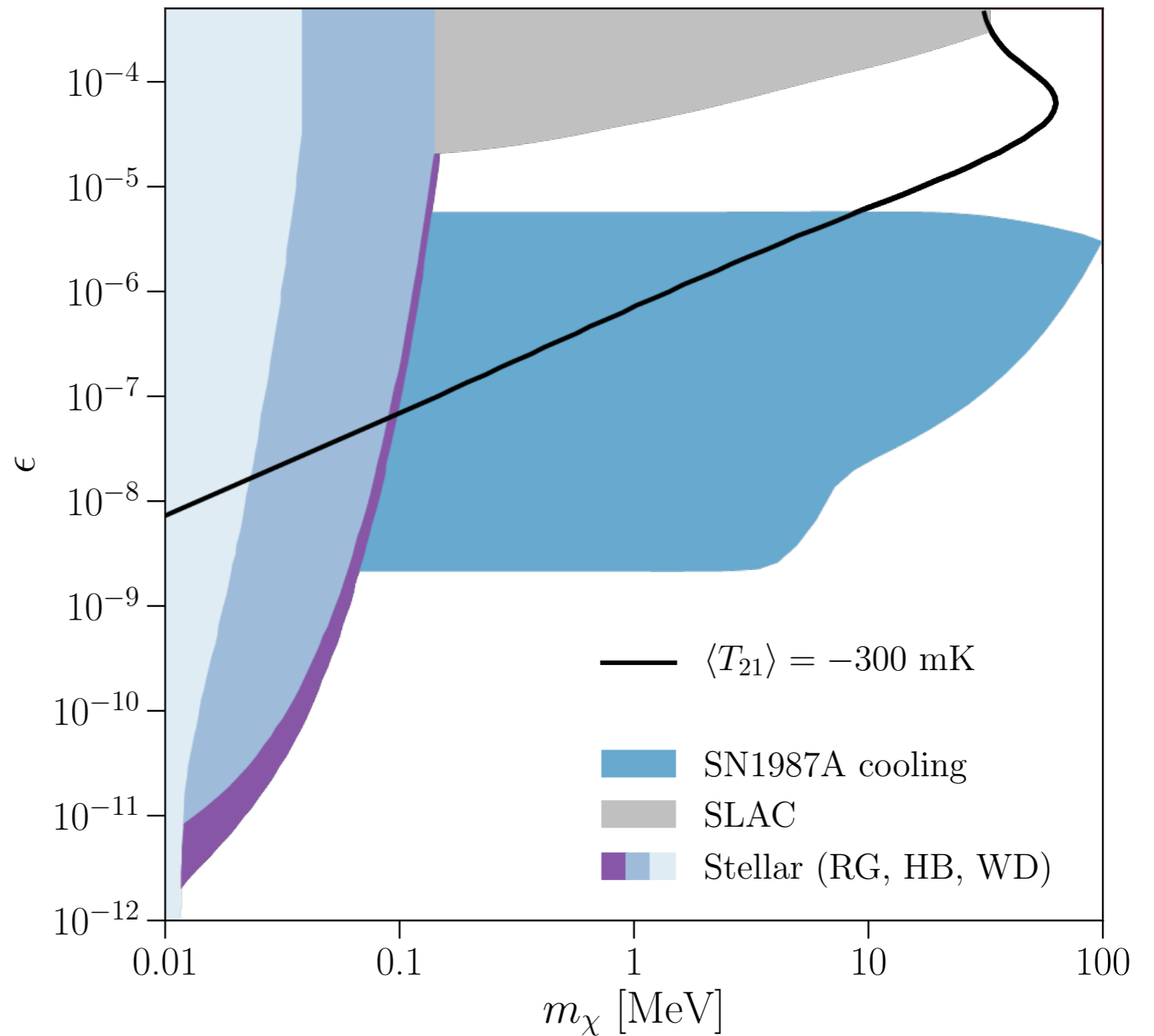
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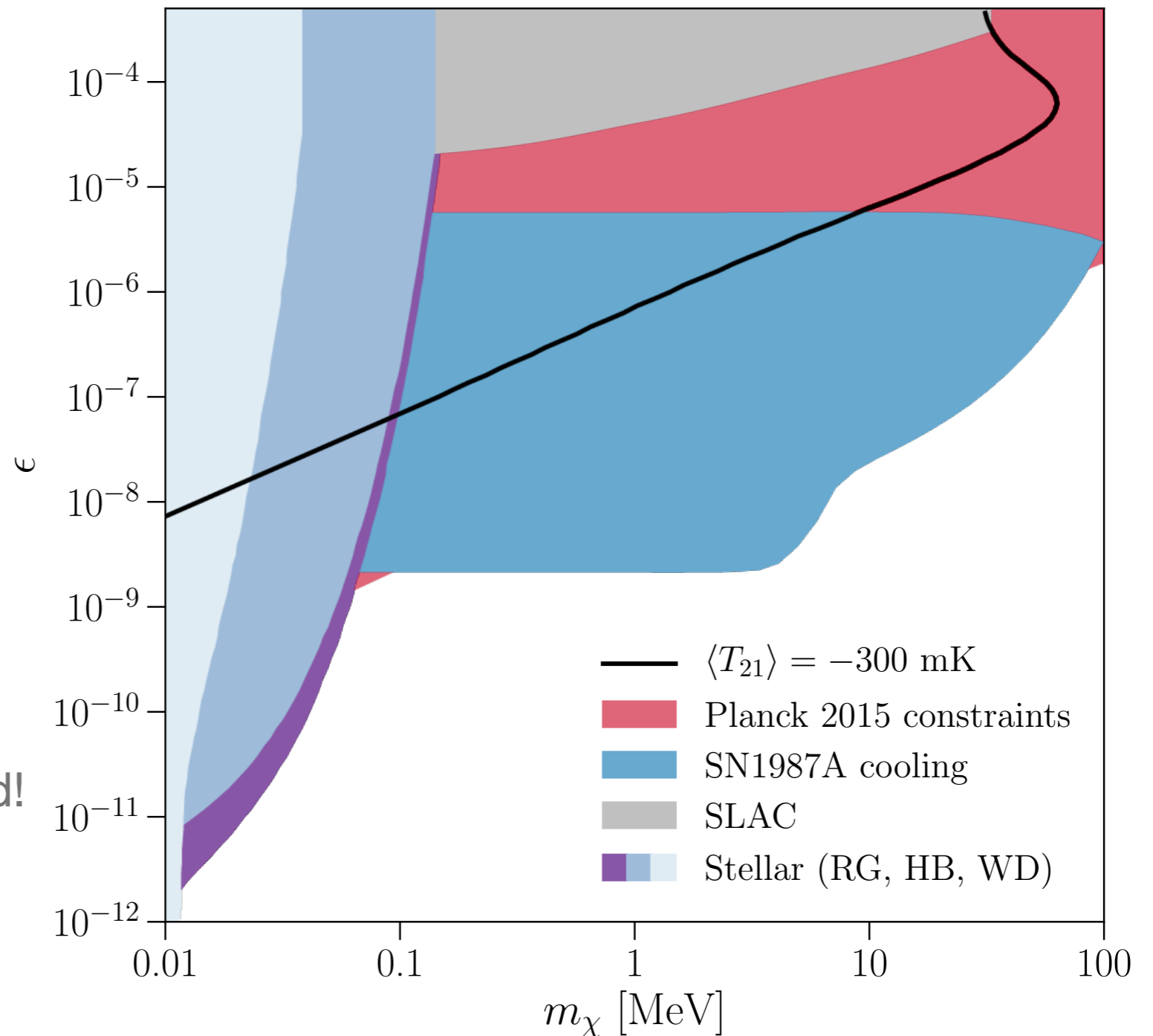
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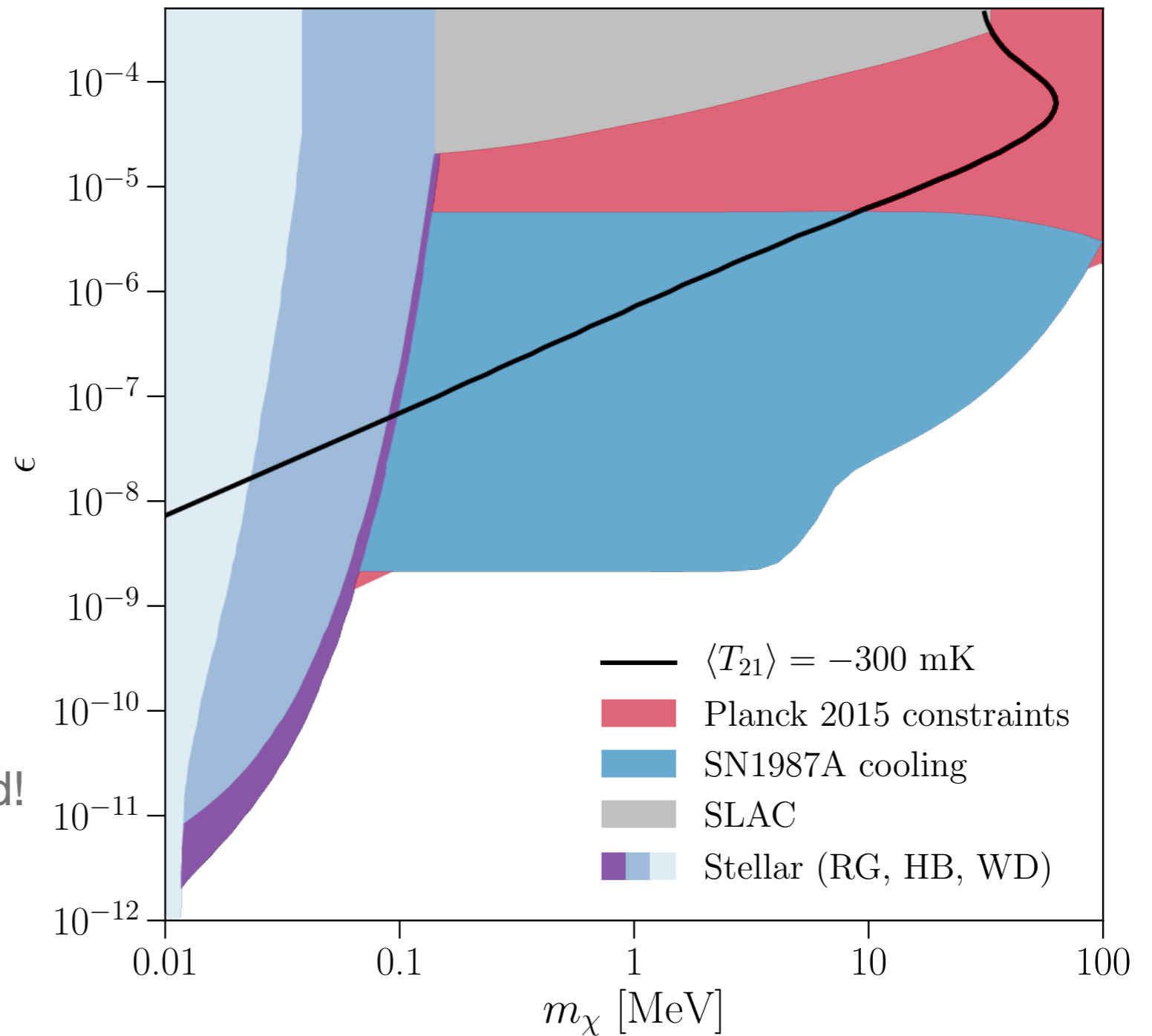
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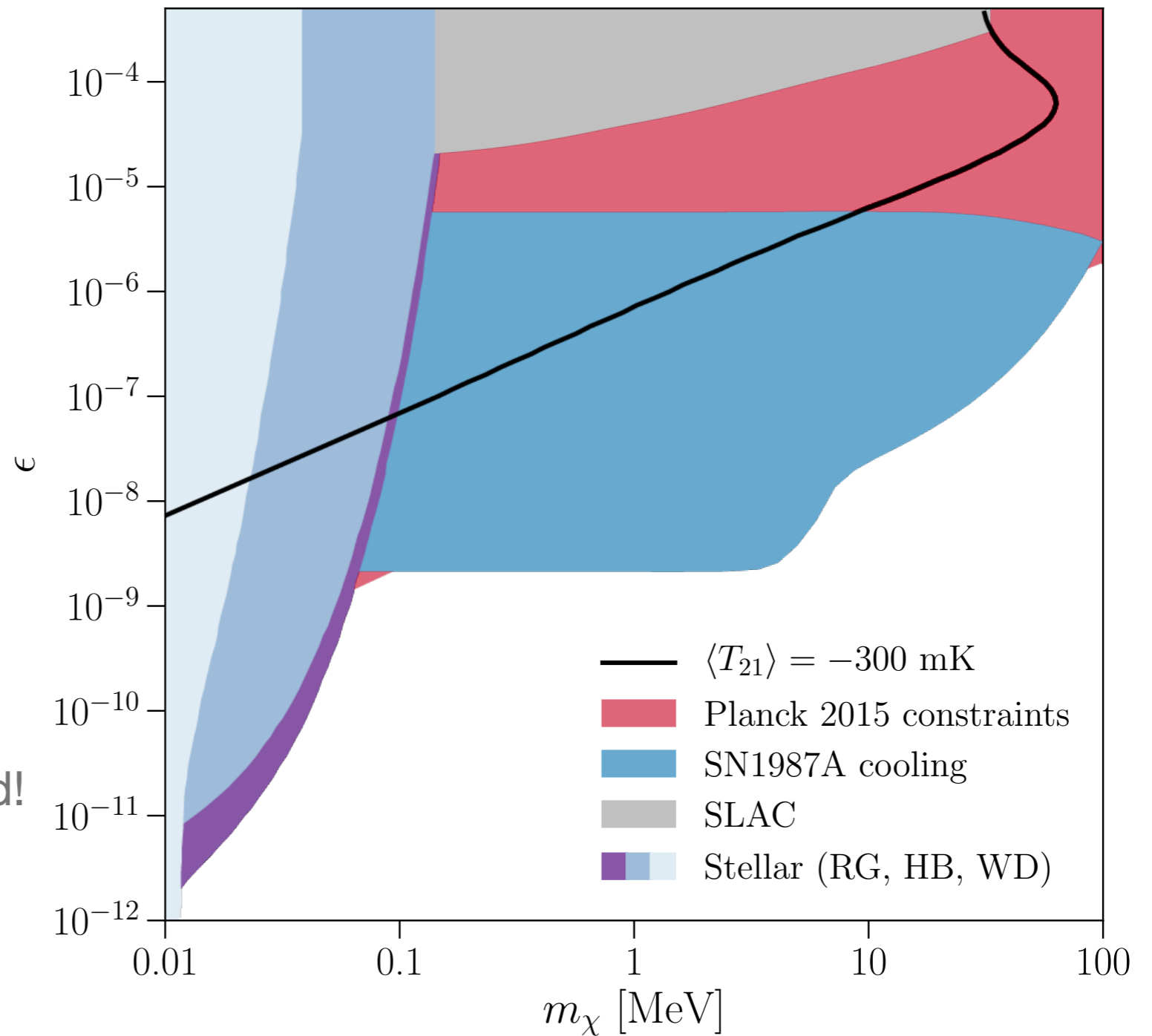
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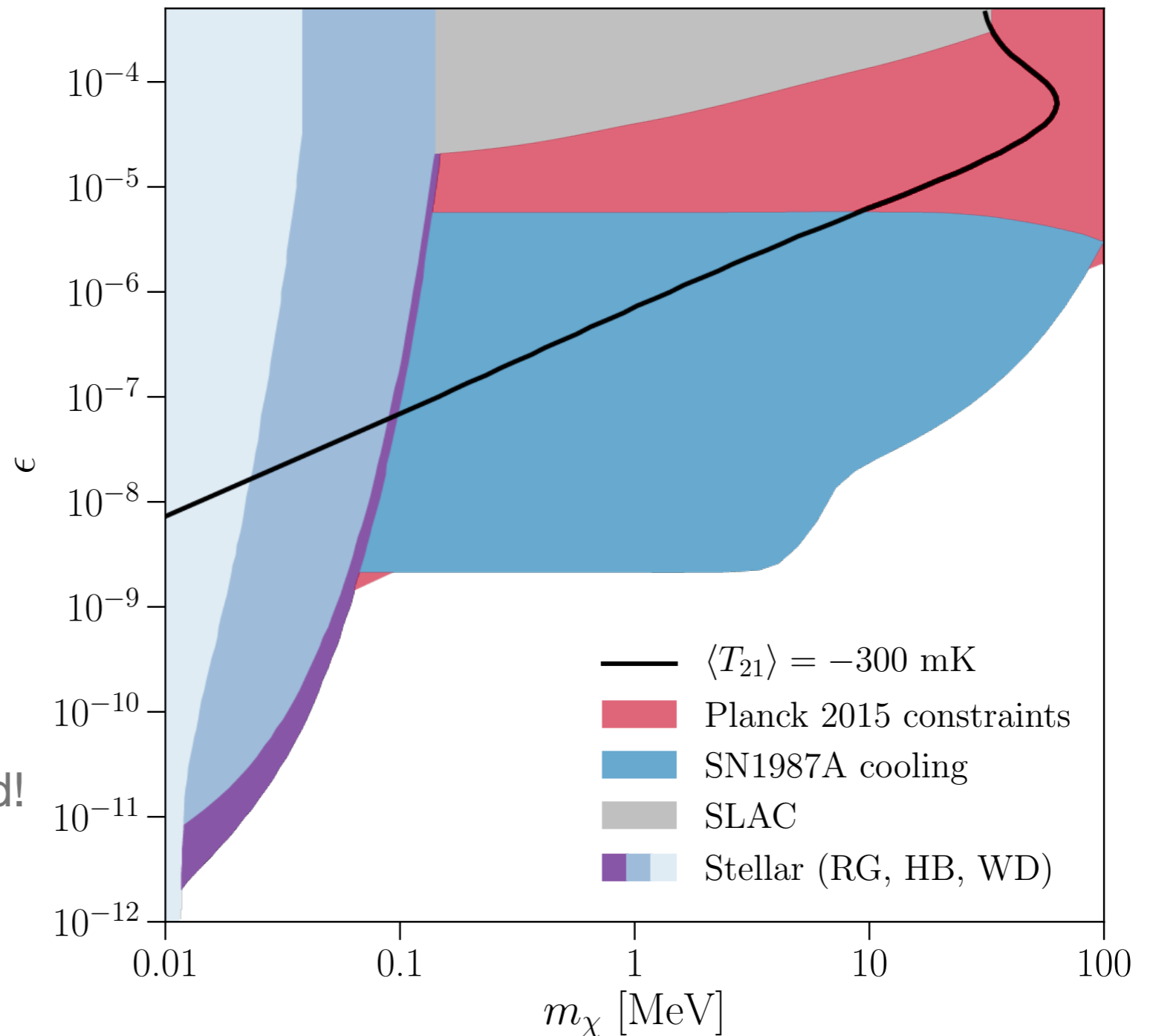
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What about lower fractions?

- Stronger cross sections are needed.
- At some point, CMB becomes ineffective (tightly-coupled DM obscured by $\Delta\Omega_b$).

Sub-percent Millicharged DM: Strong Coupling

(EDK, Poulin, Gluscevic, Boddy, Barkana and Kamionkowski, arXiv:1807:11482)

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$$\dot{T}_\chi = \underline{-2HT_\chi} + (n_b/n_\chi) \underline{\Gamma_{\chi b}(T_b - T_\chi)}$$

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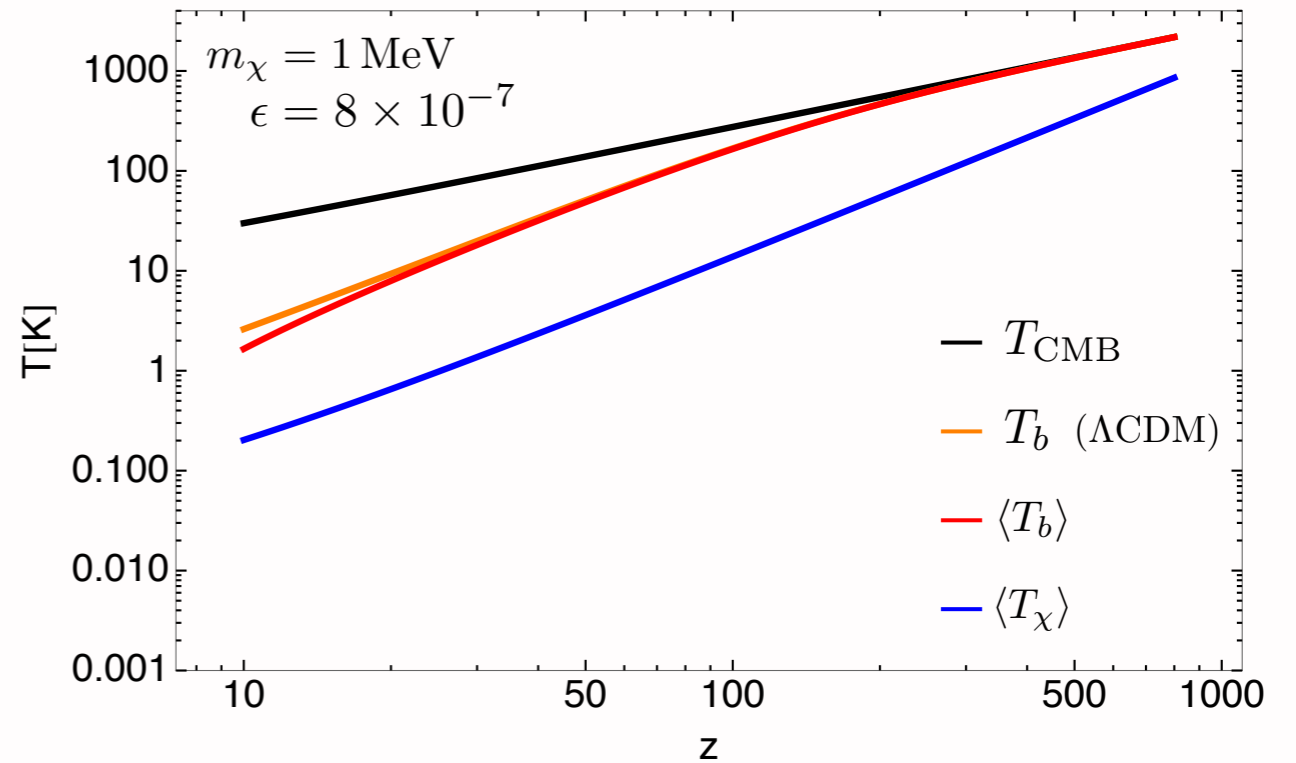
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→ For weak coupling:



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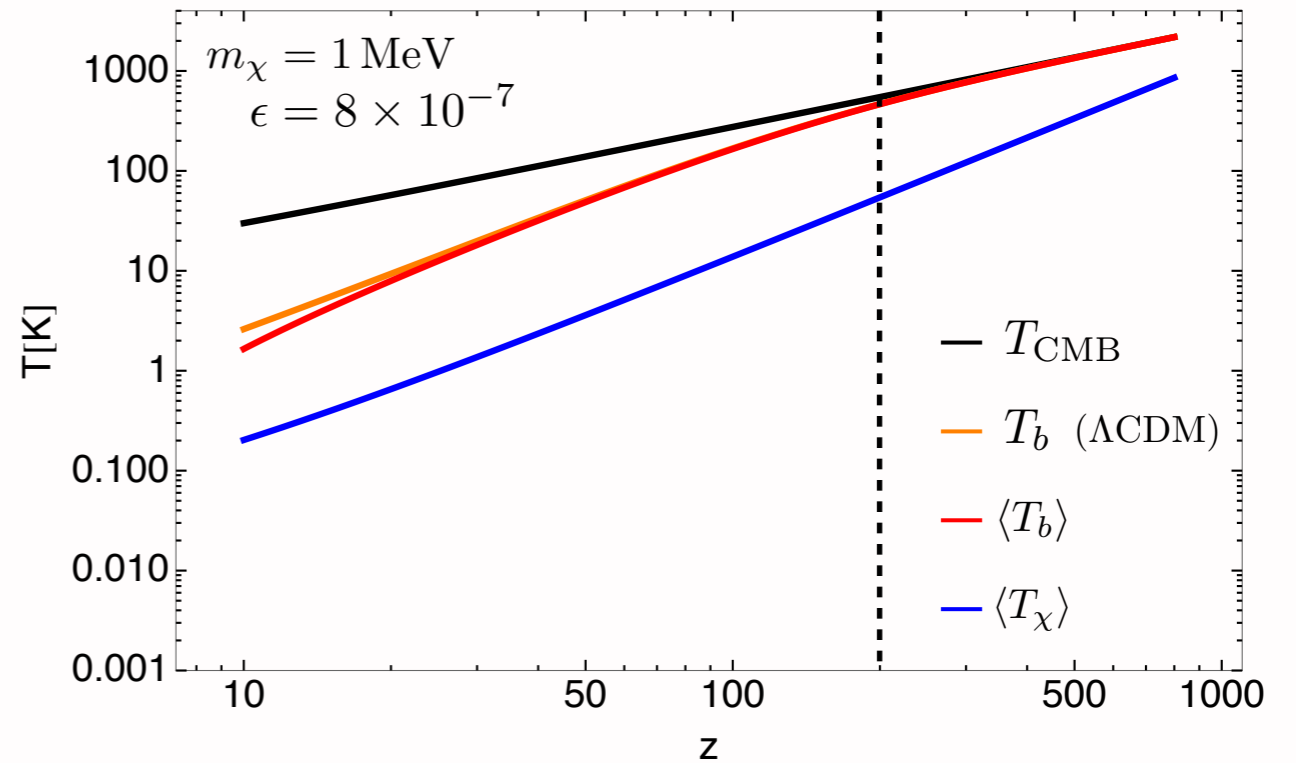
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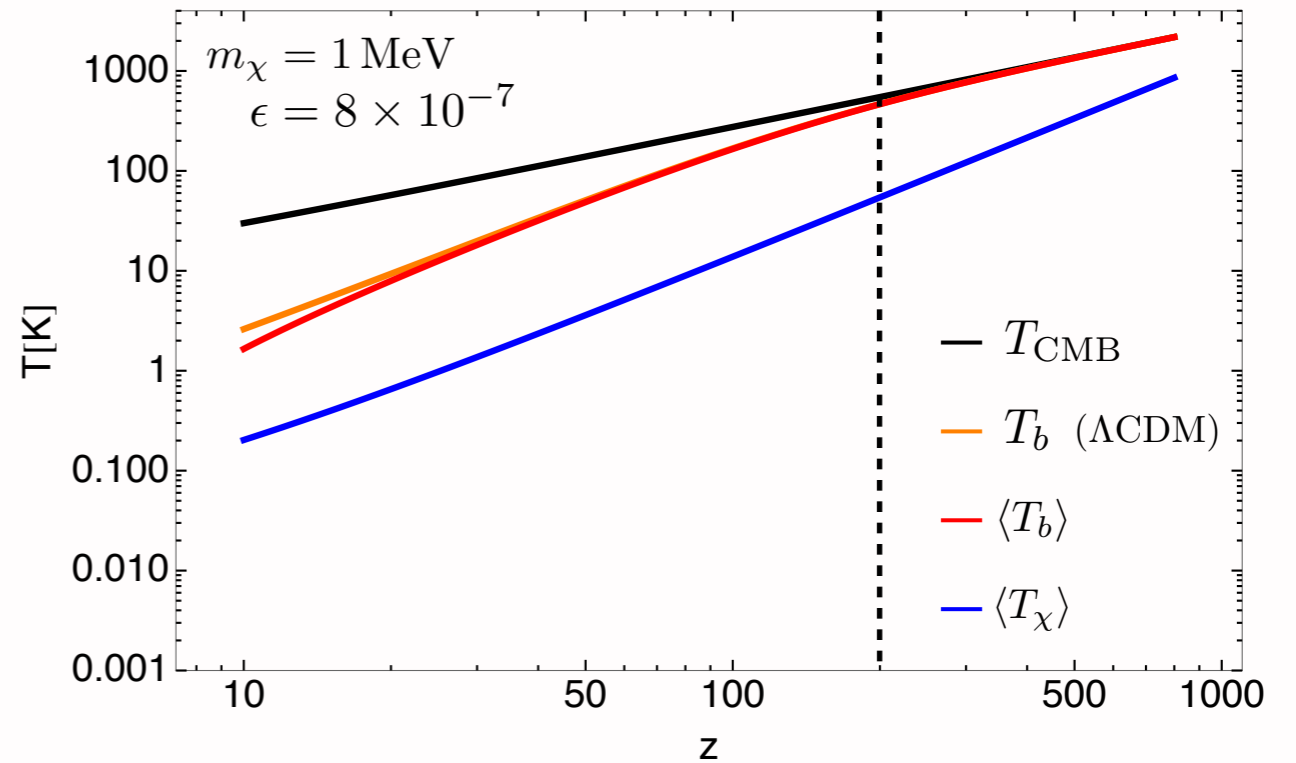
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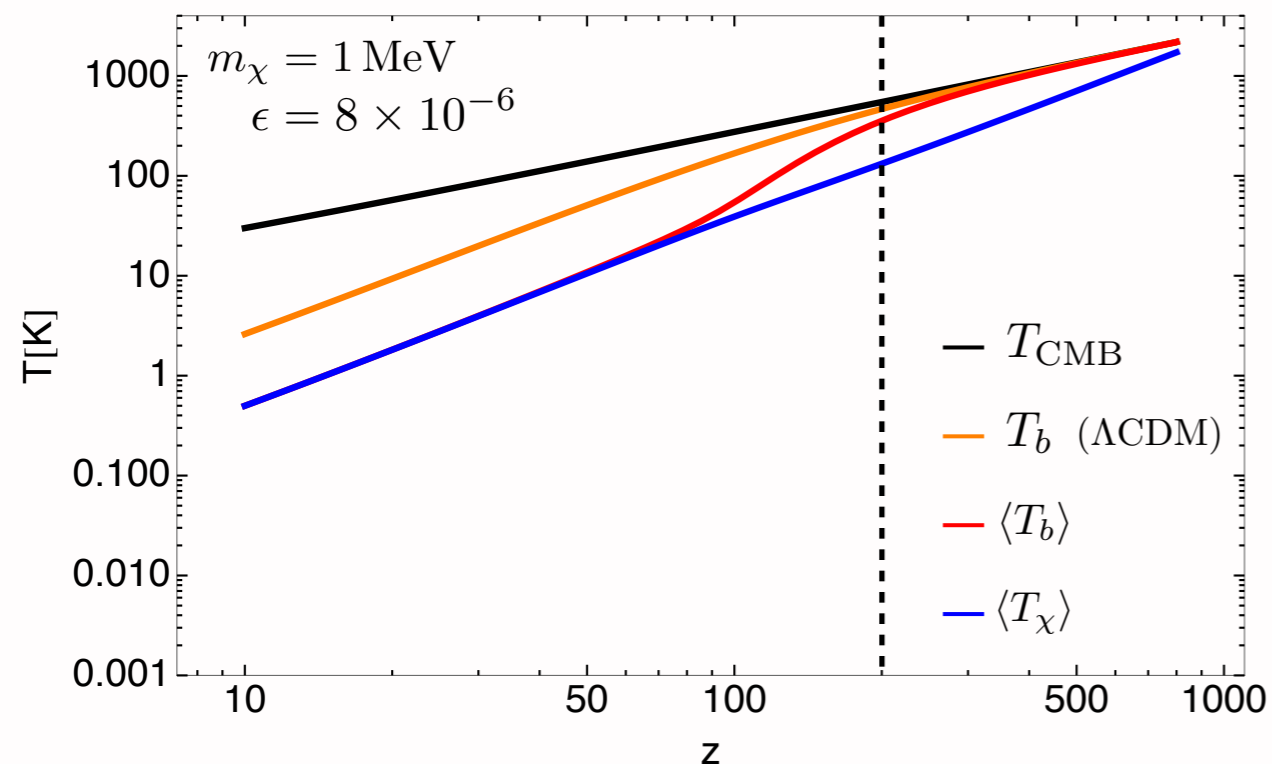
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As the coupling increases:



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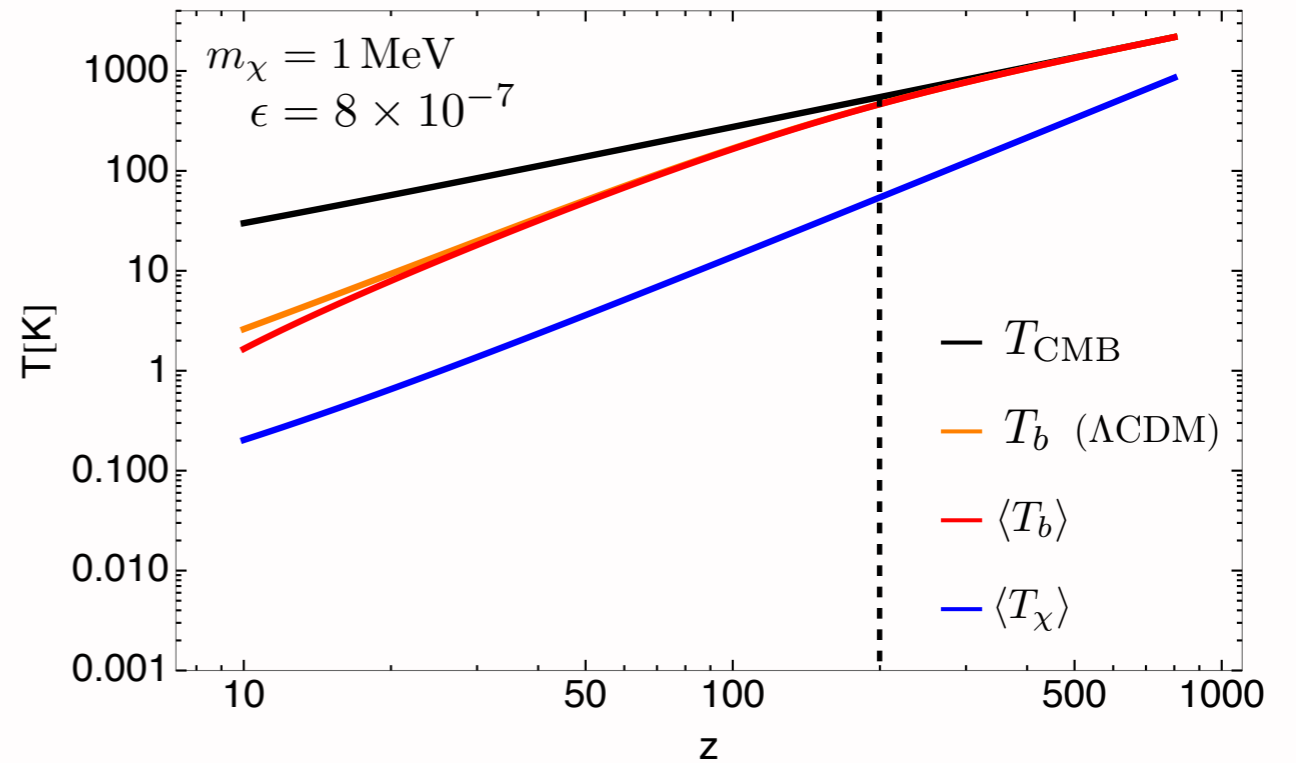
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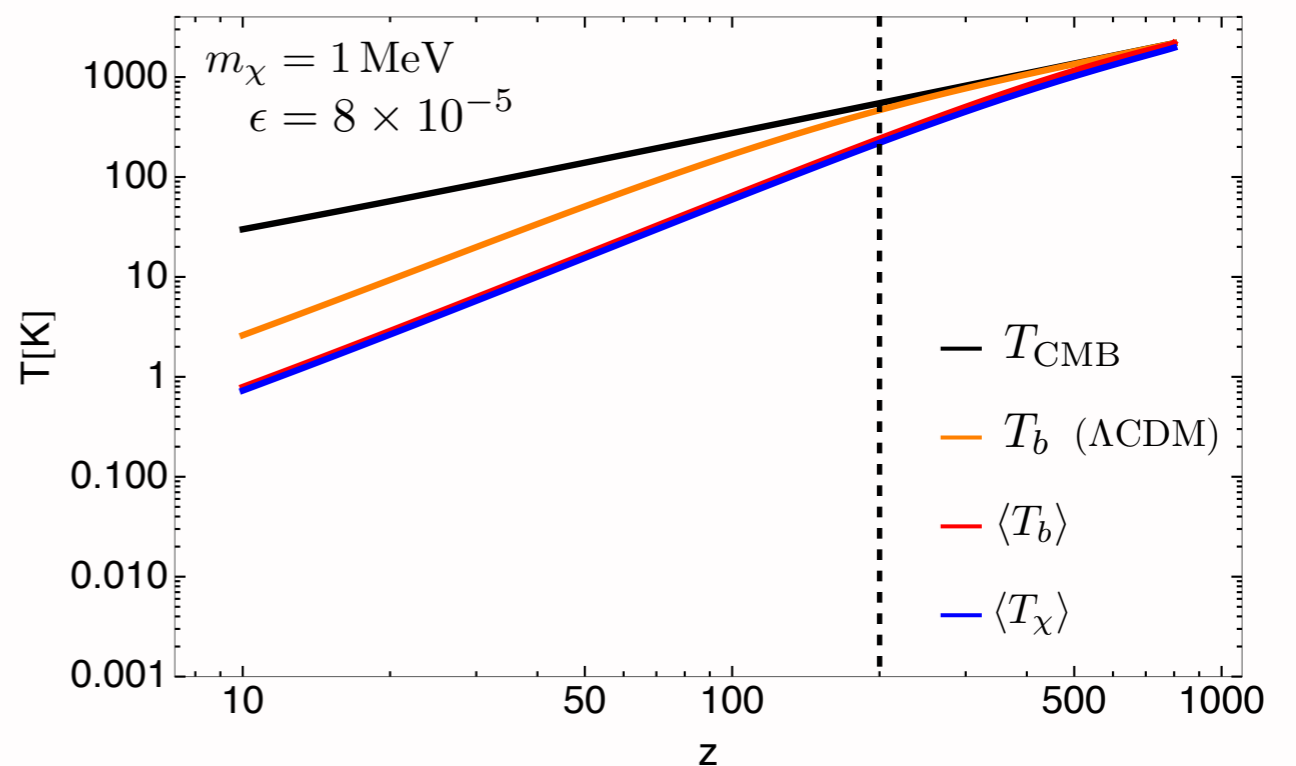
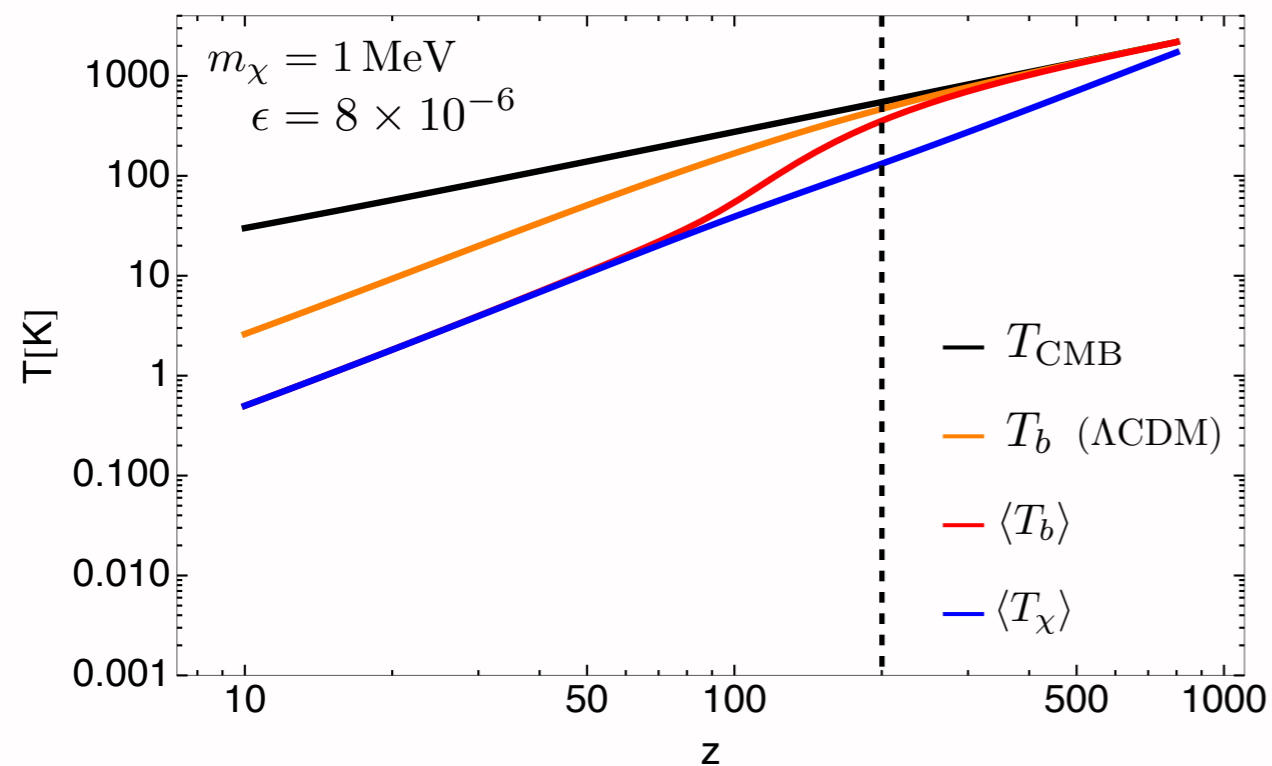
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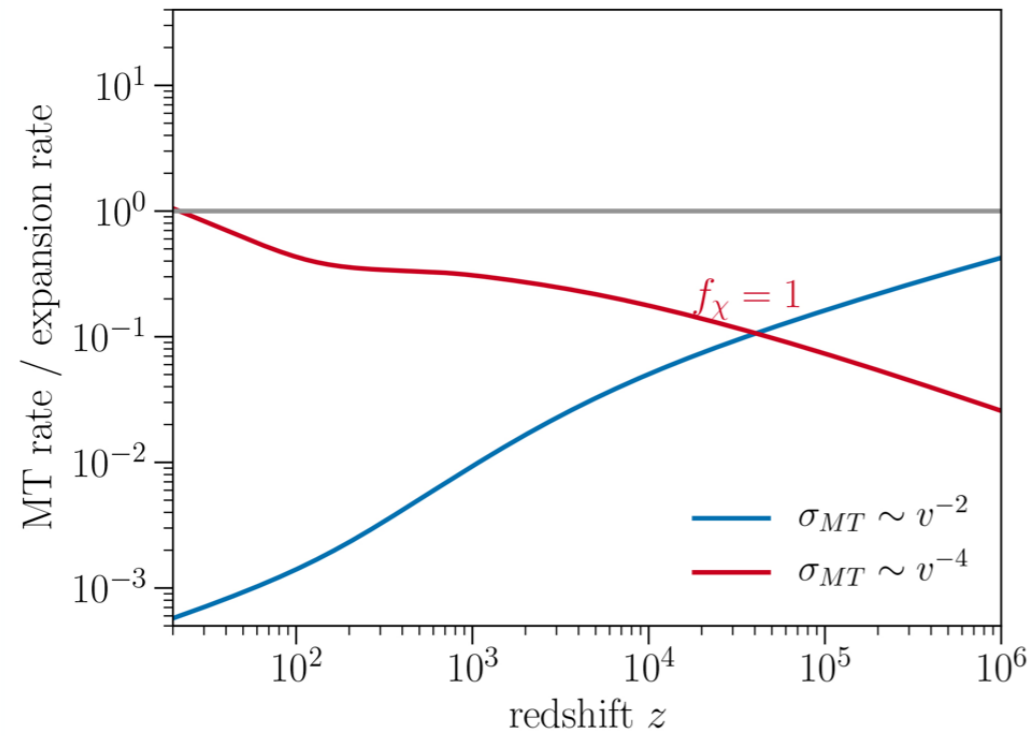


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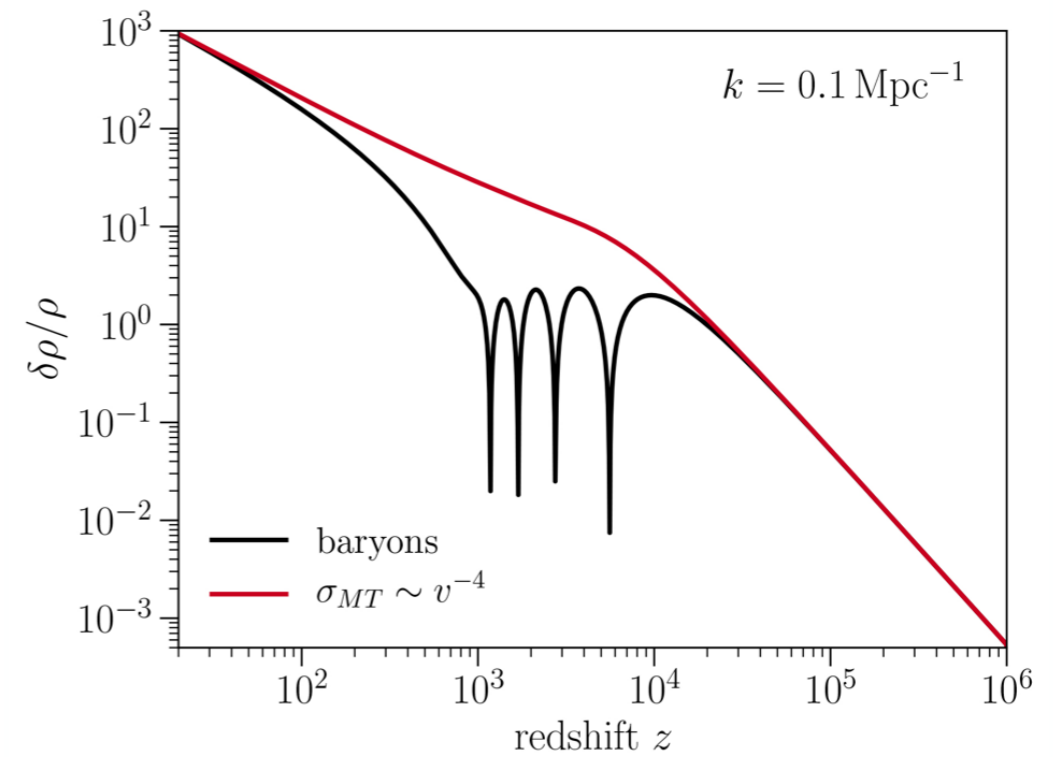
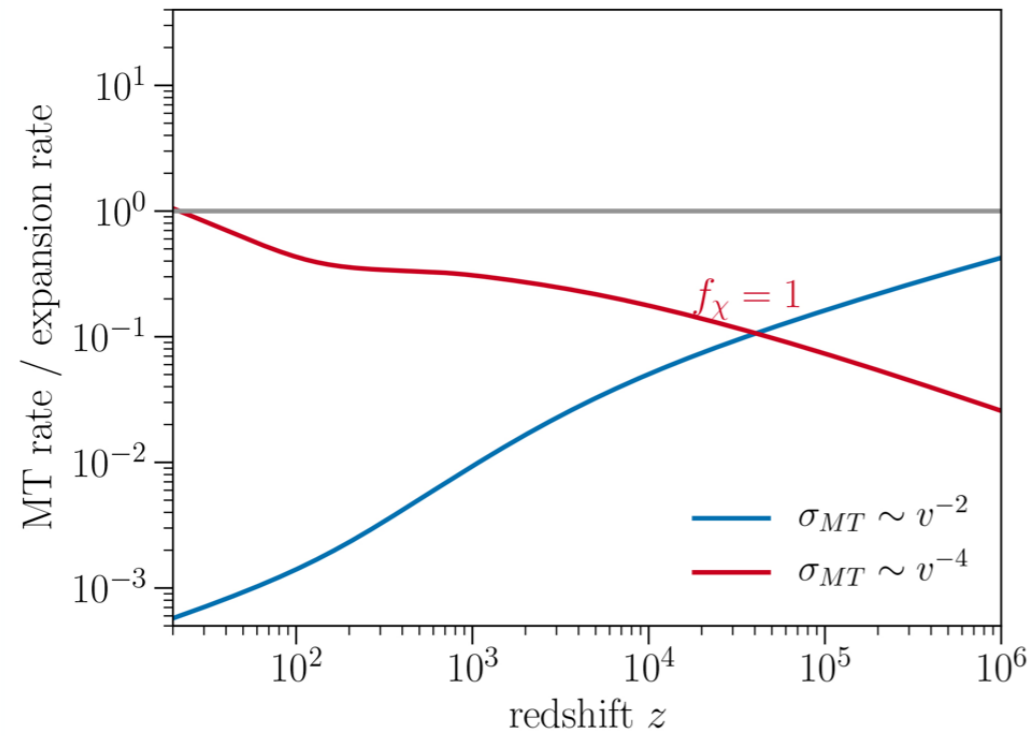
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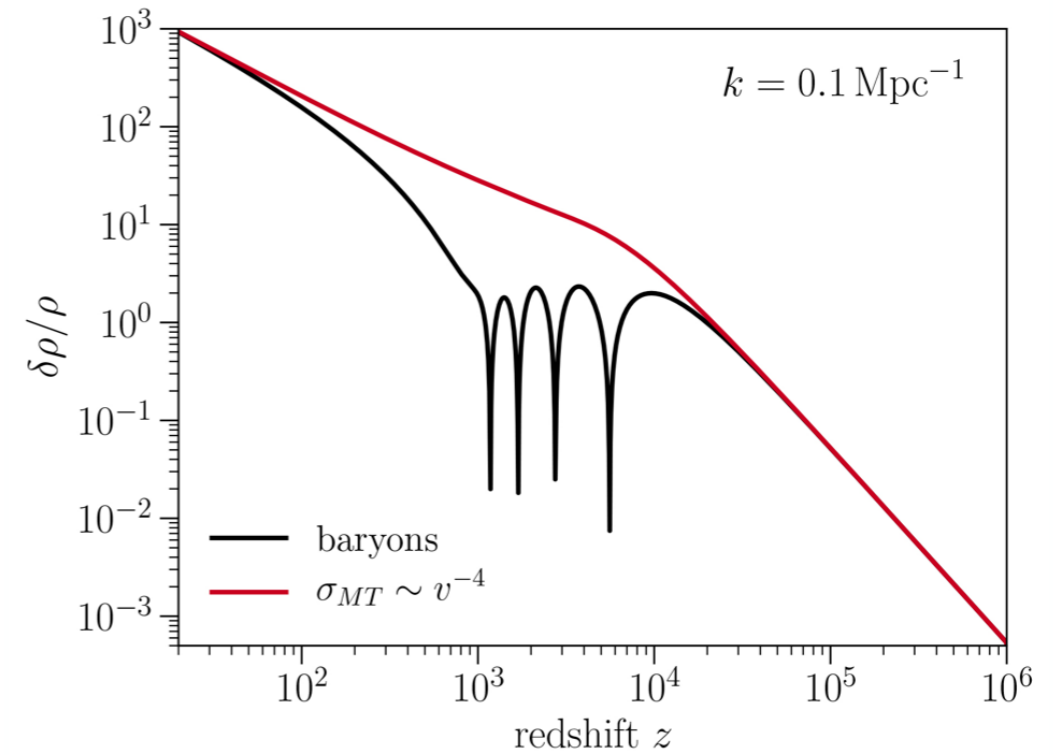
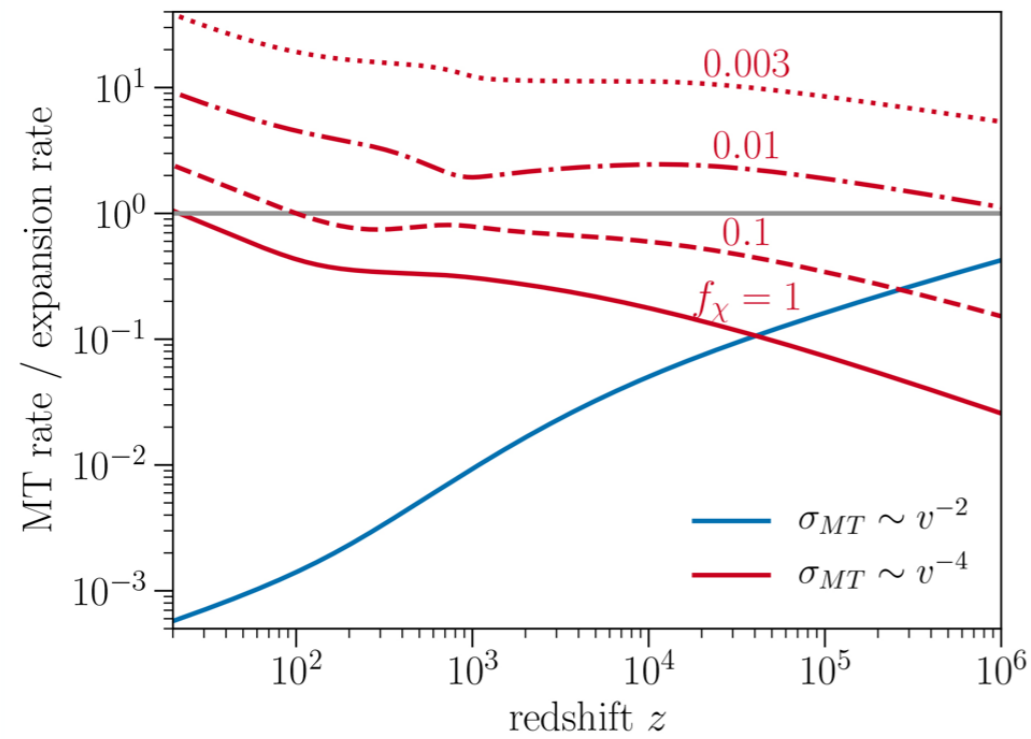
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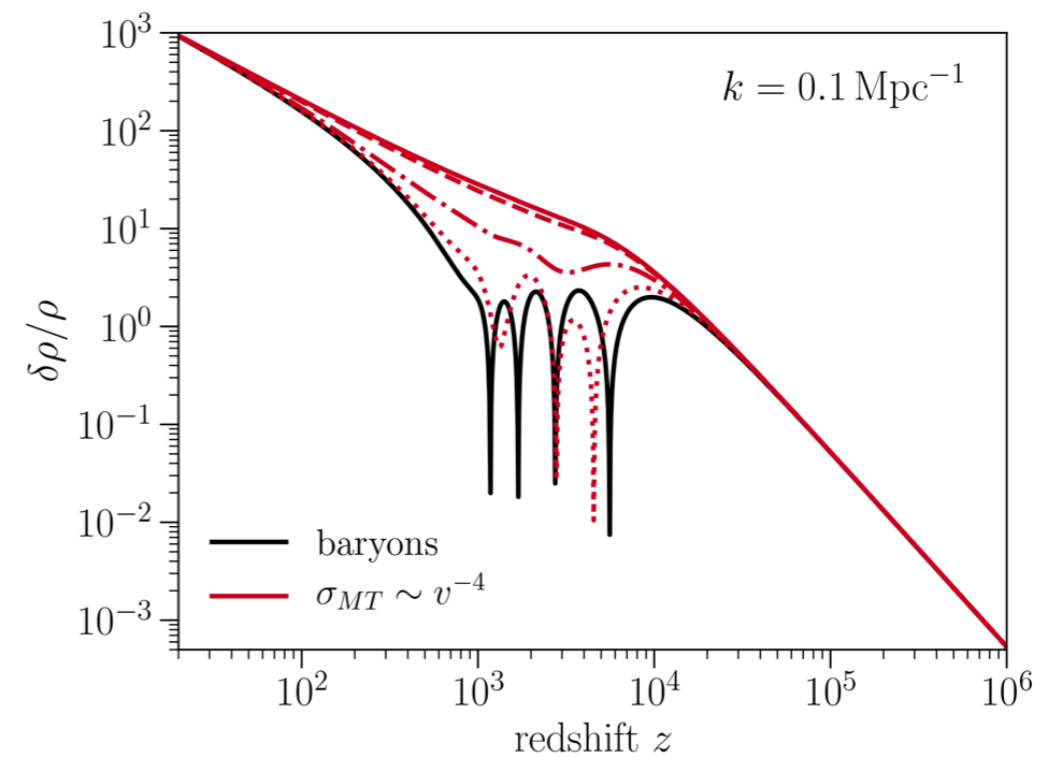
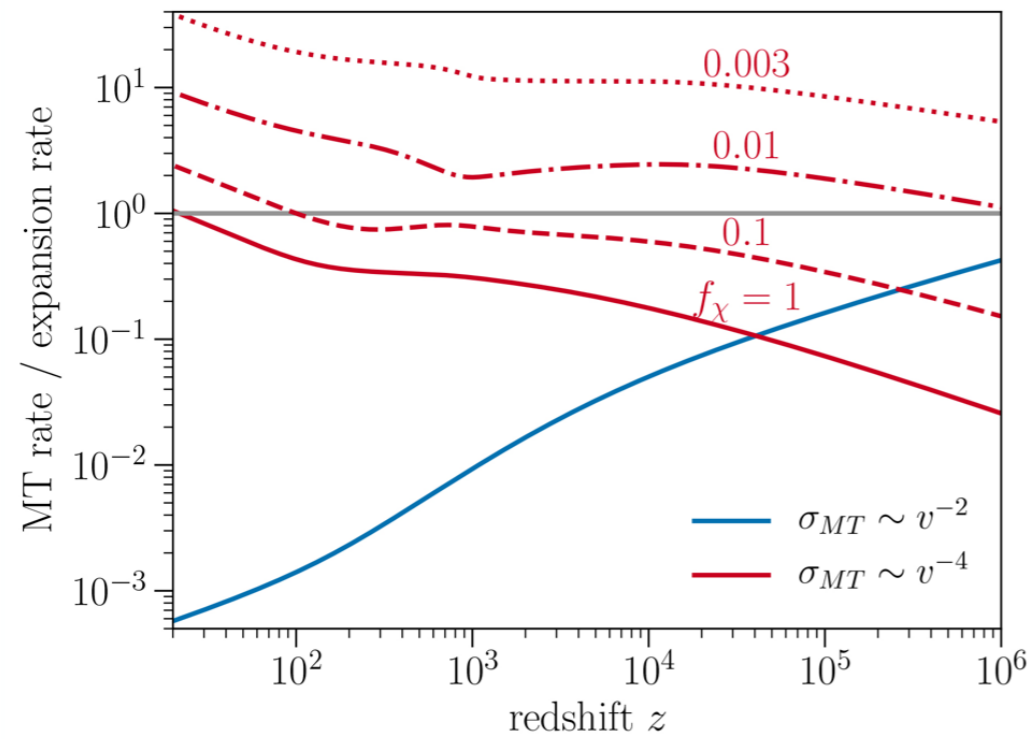
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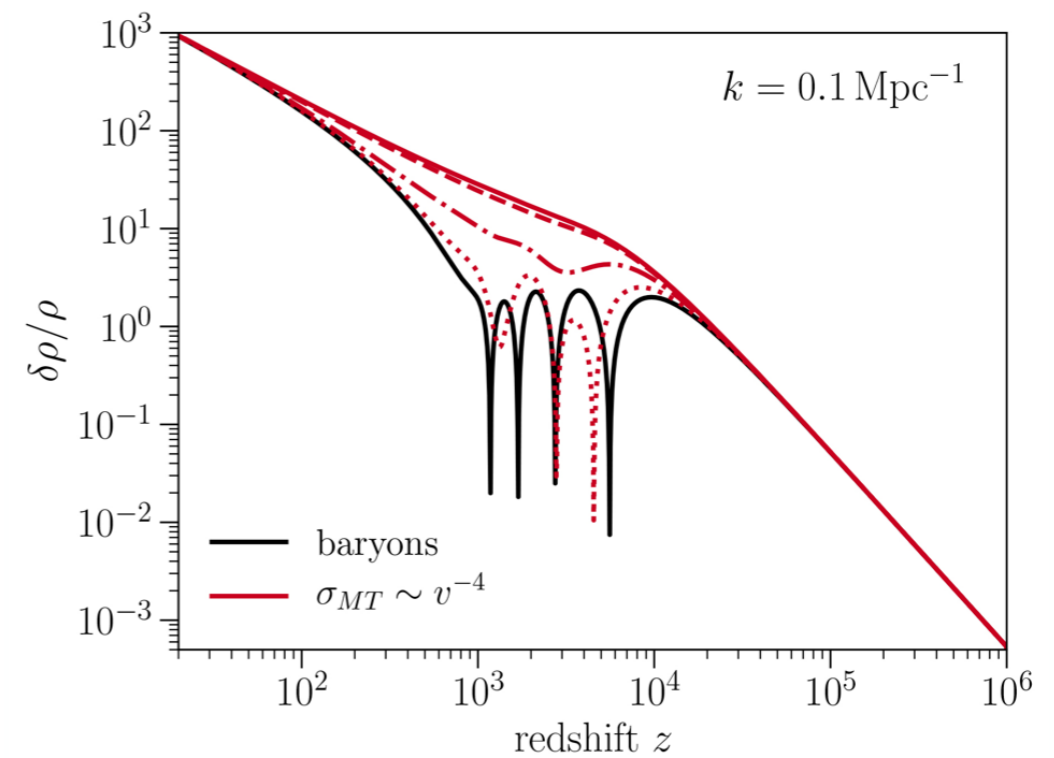
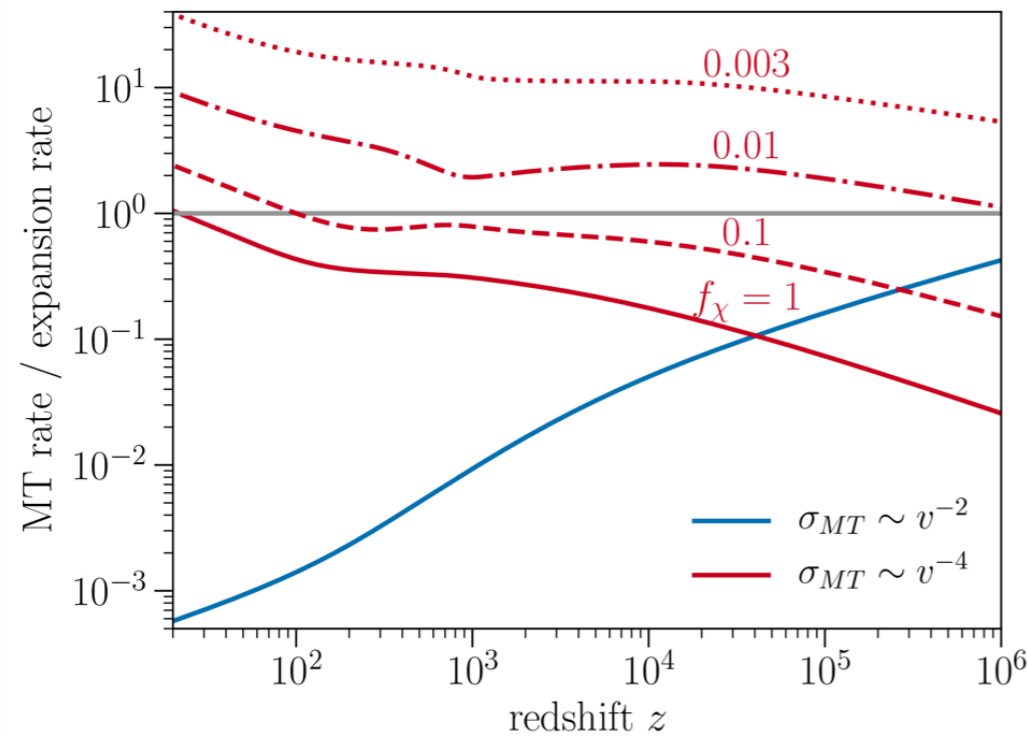
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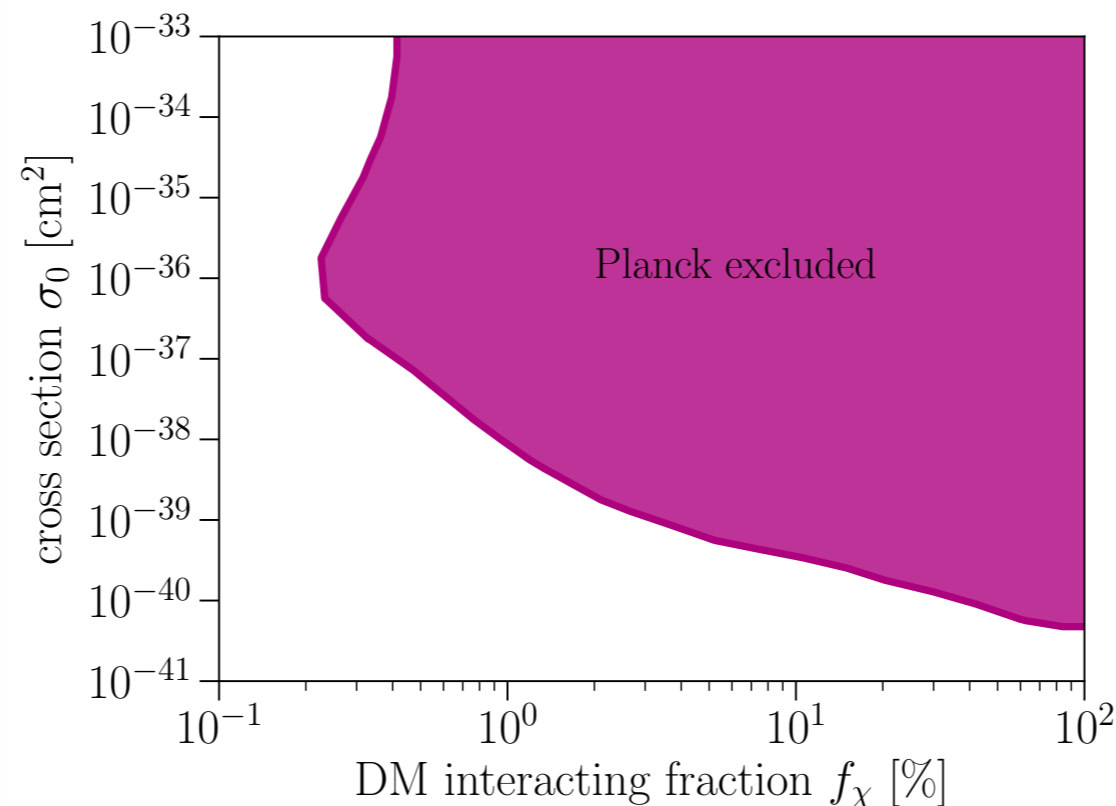


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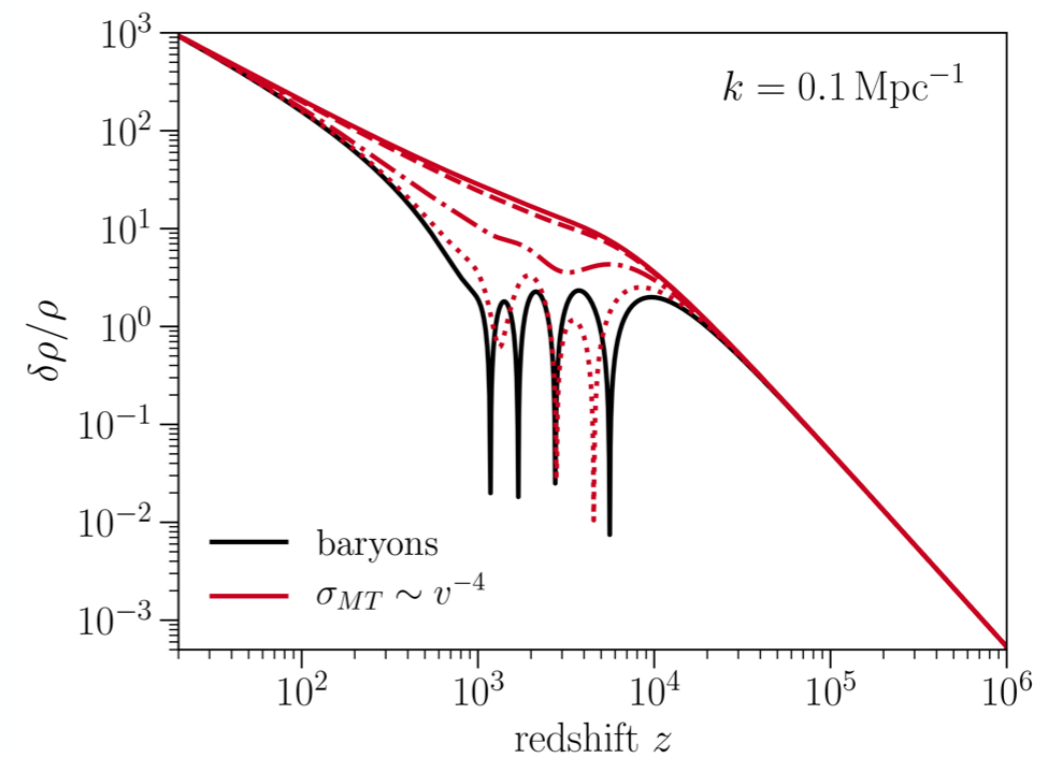
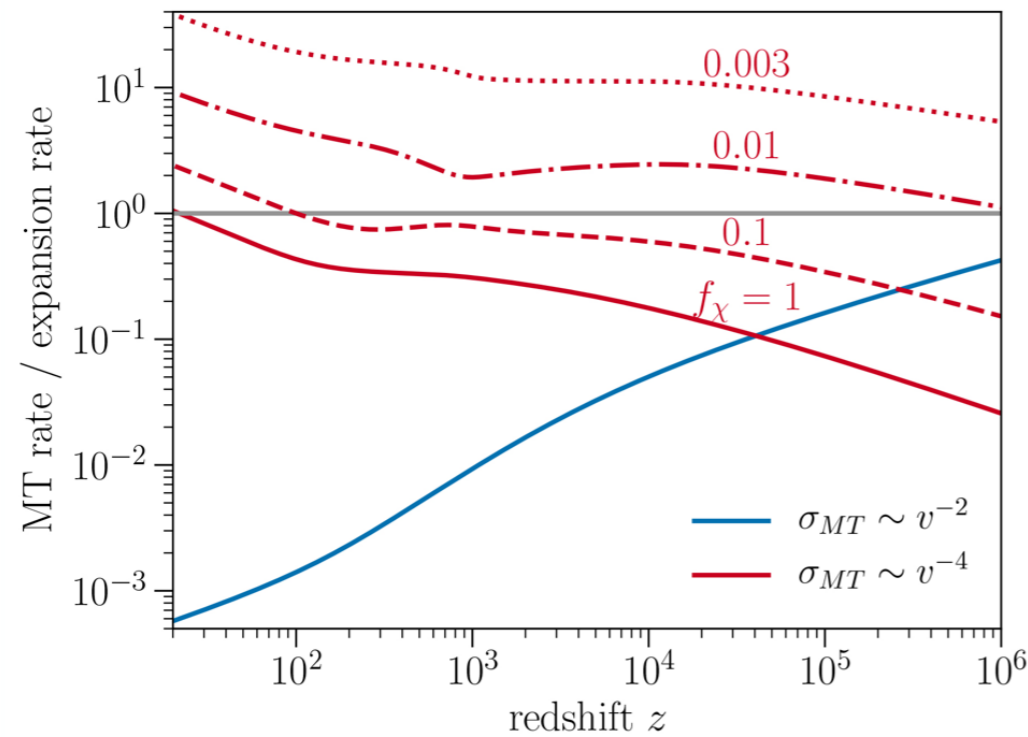


The precise limit on the fraction of interacting DM:

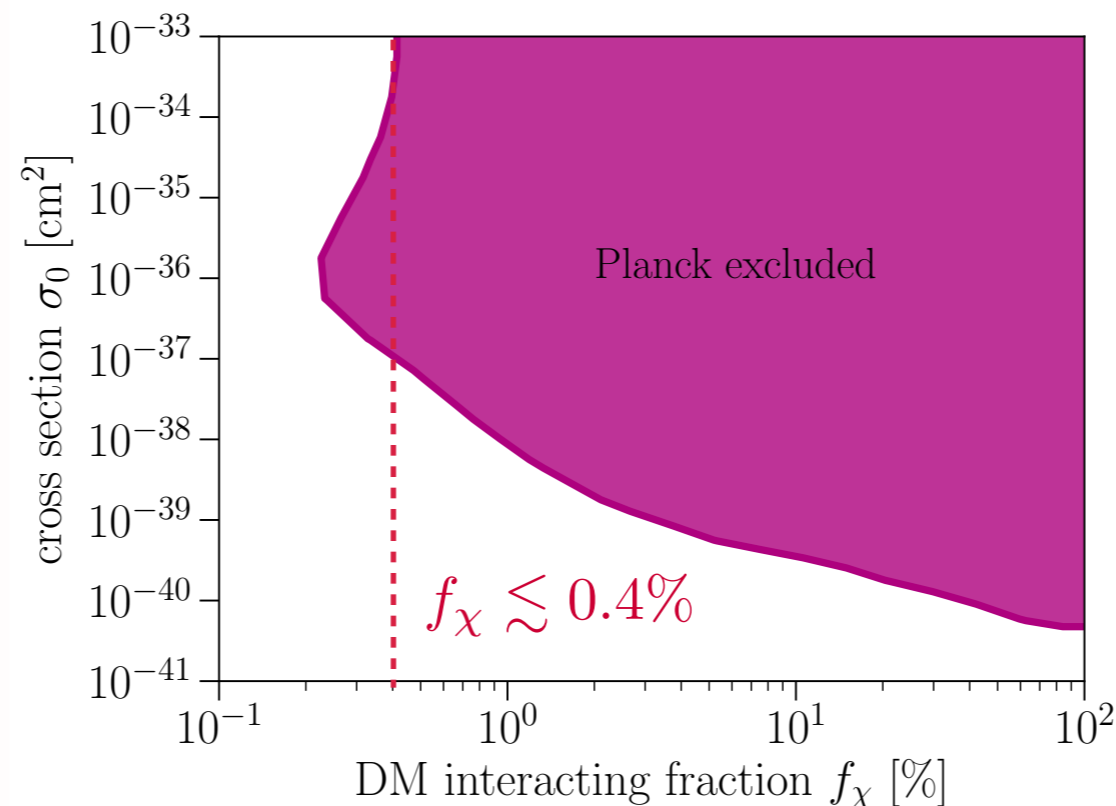


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See also:
de Putter et al., arXiv:1805:11616

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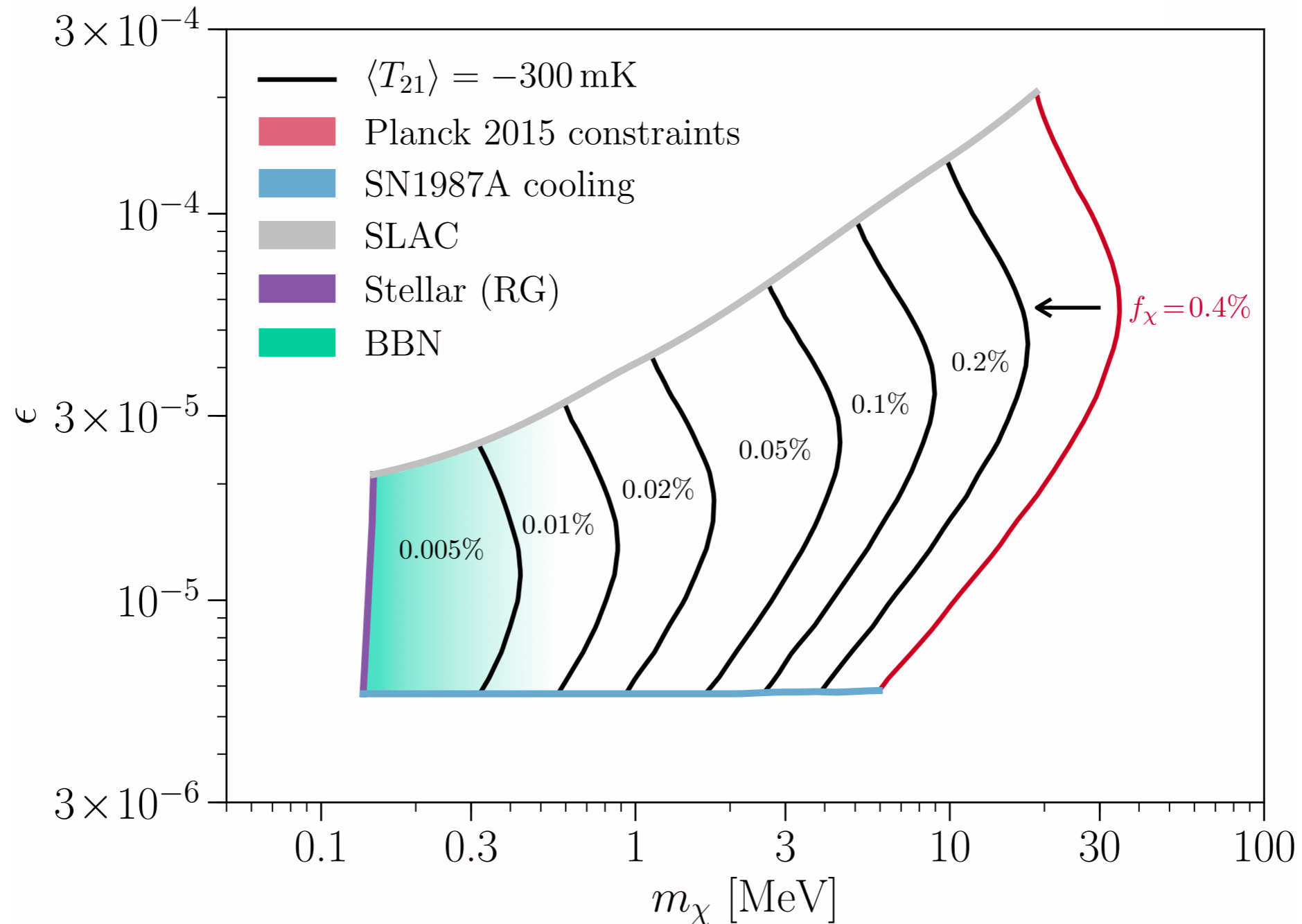
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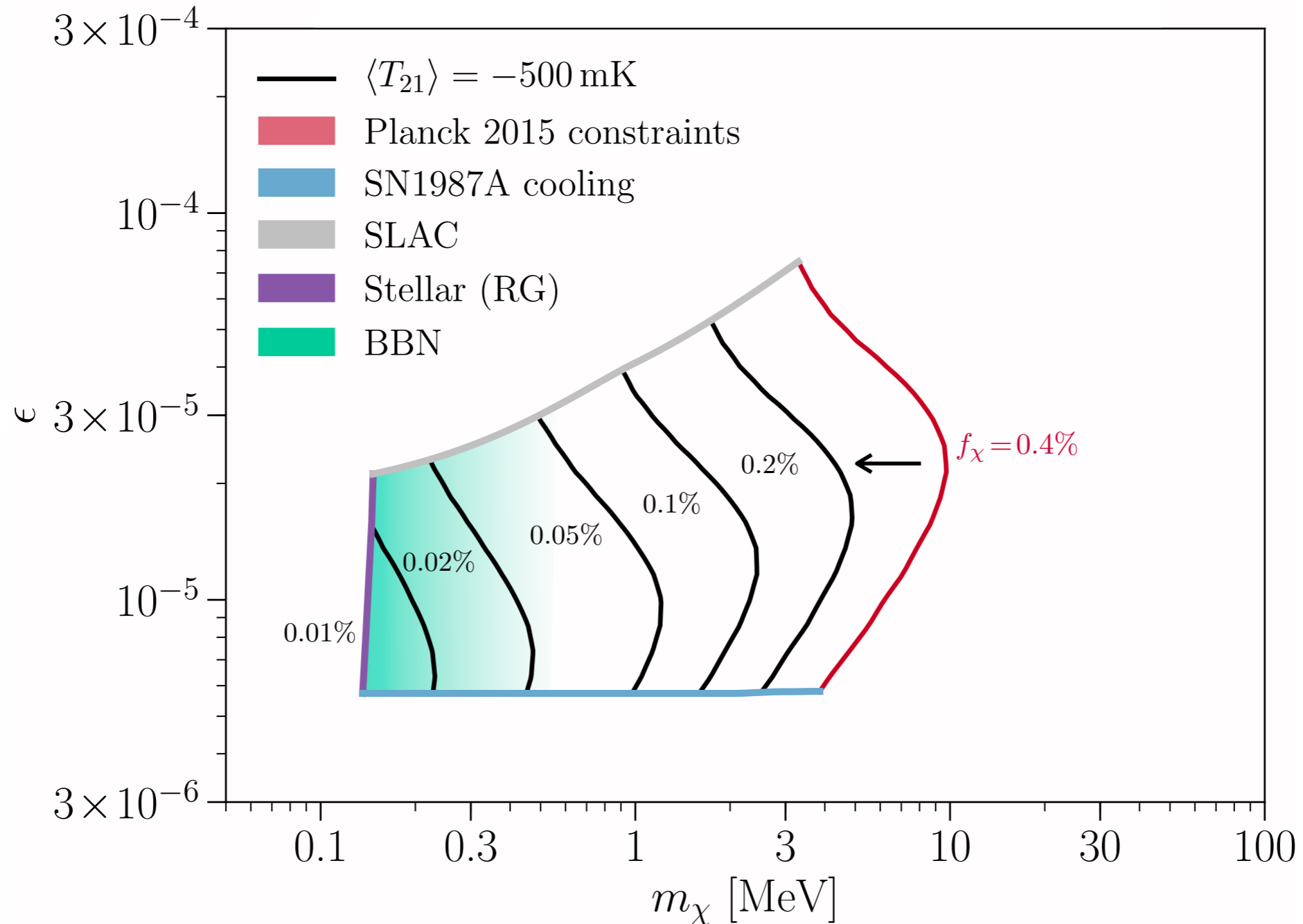
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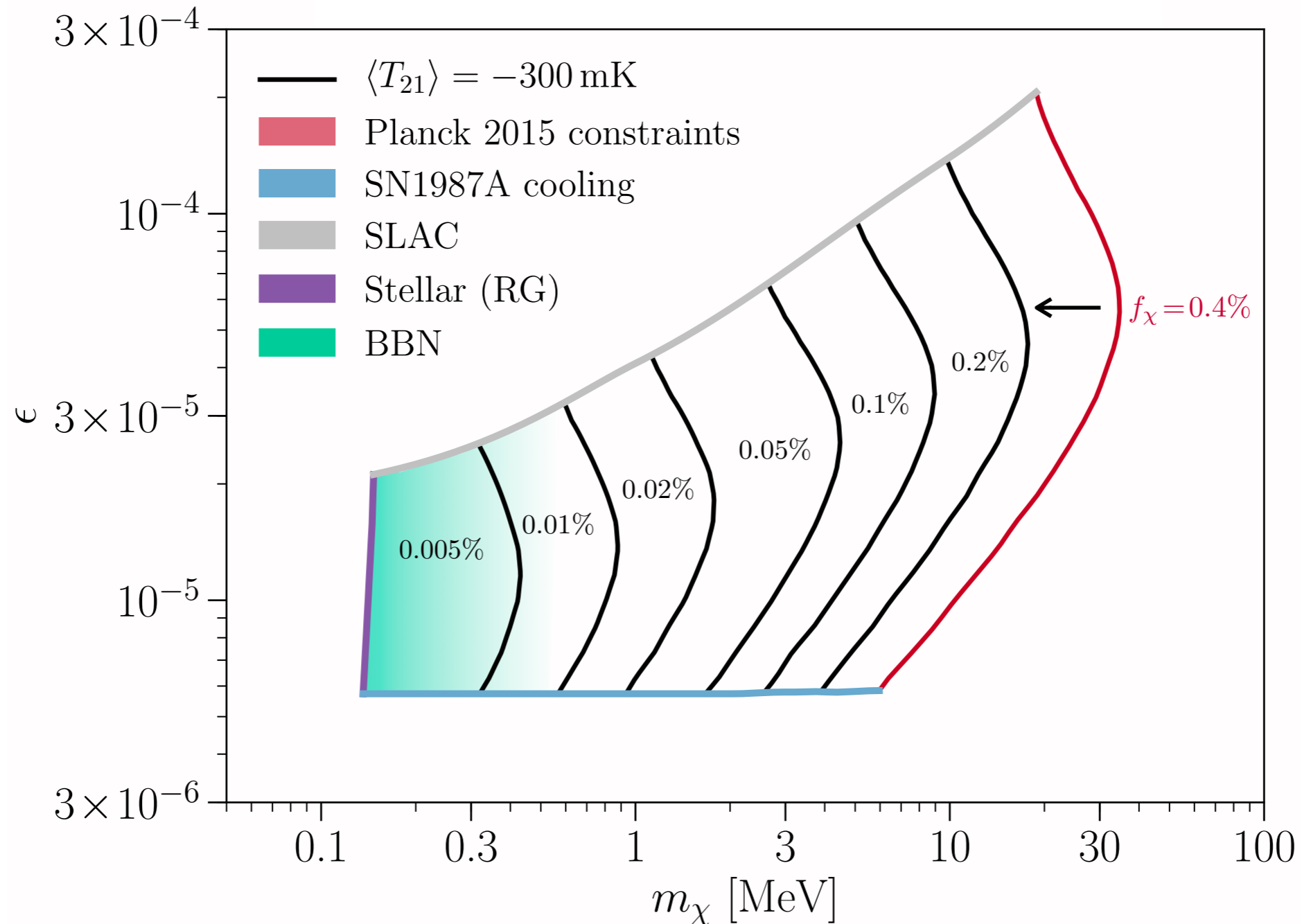
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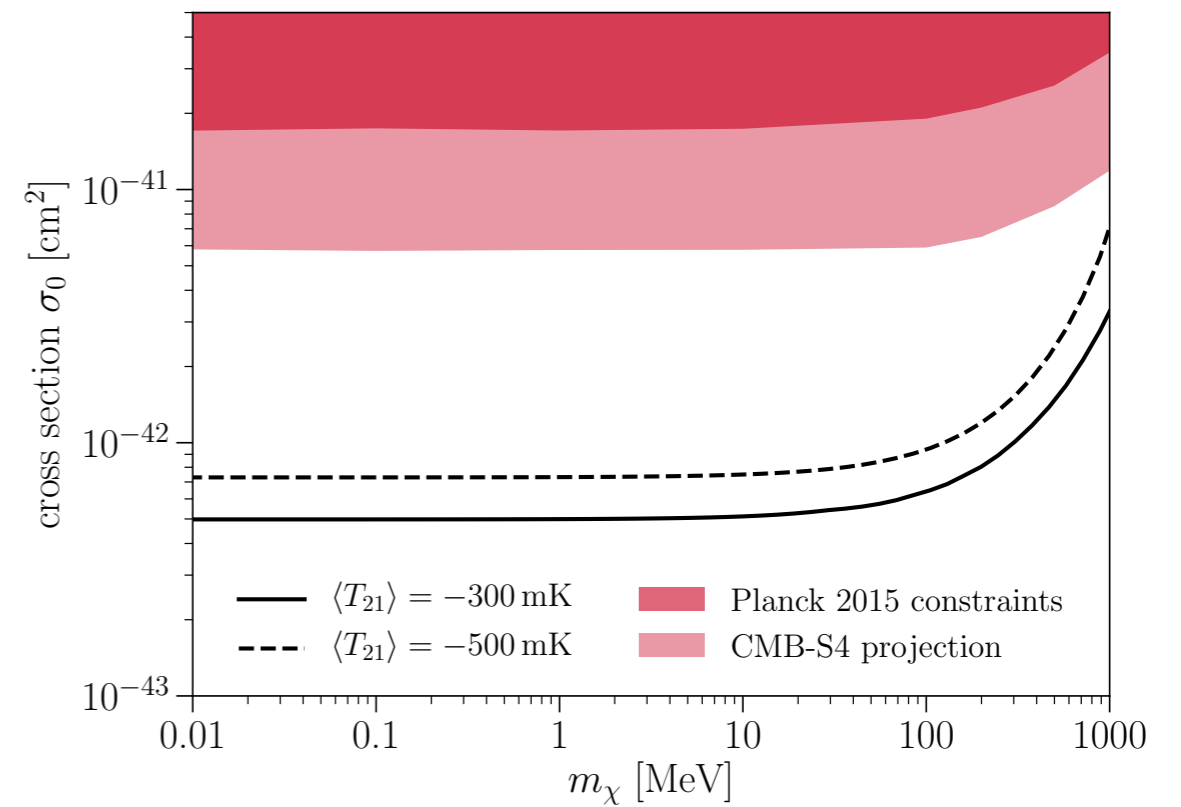
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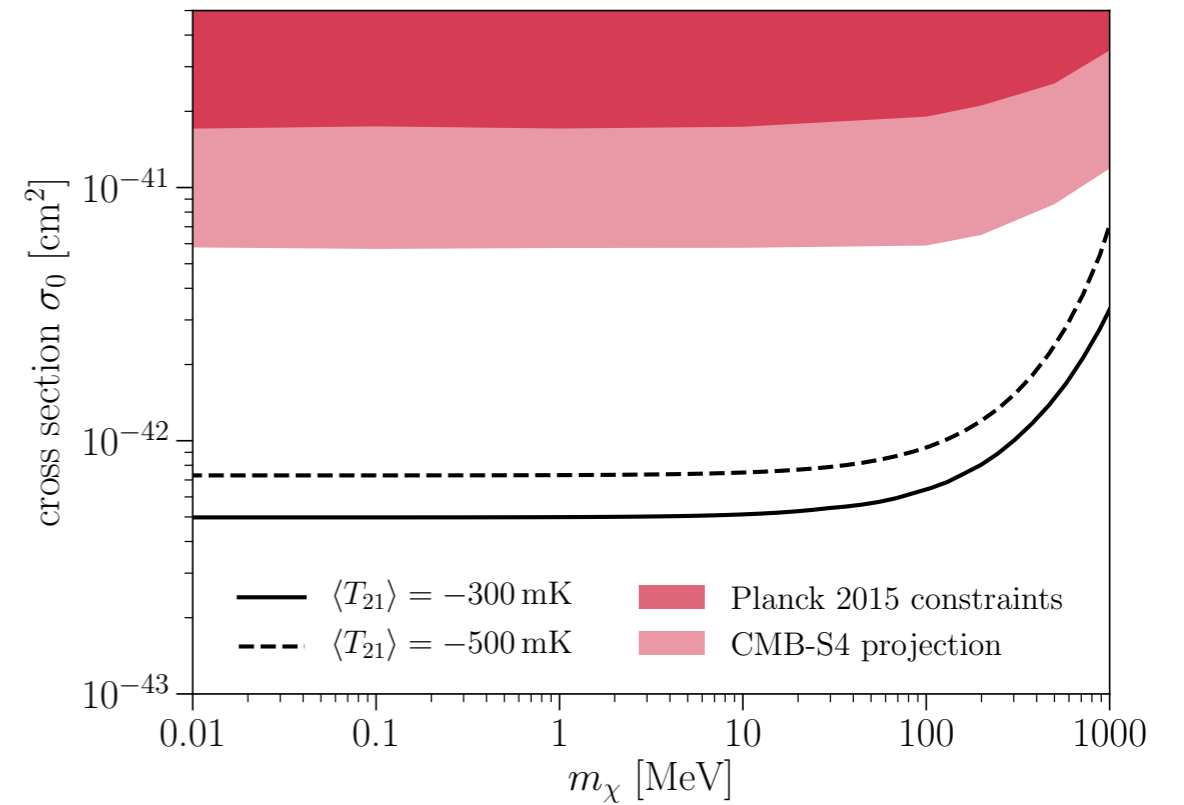


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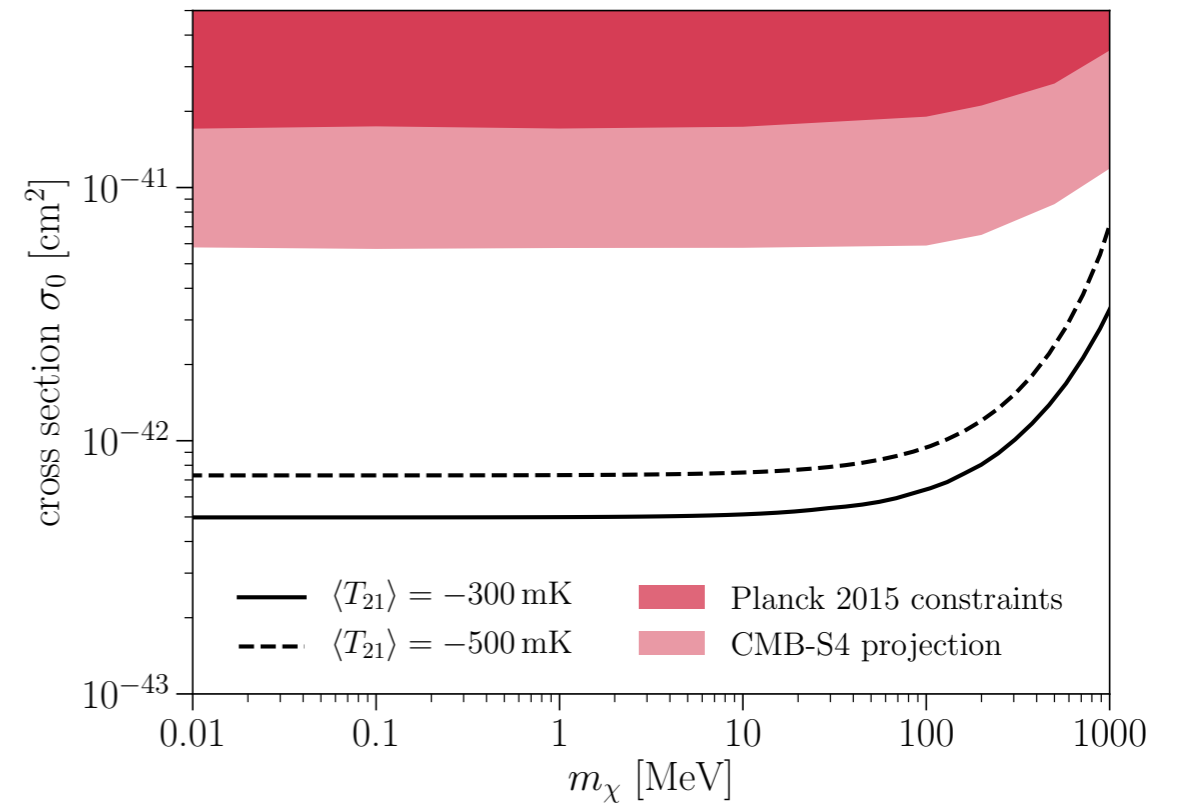
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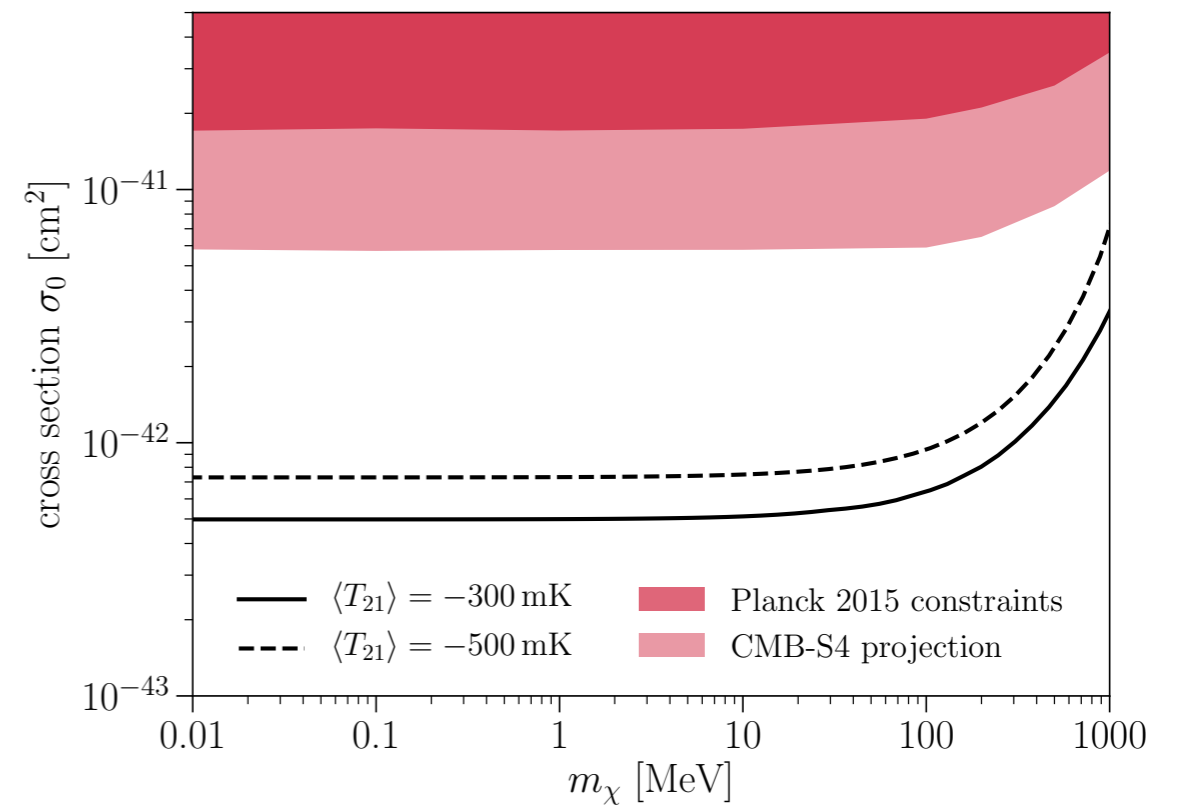
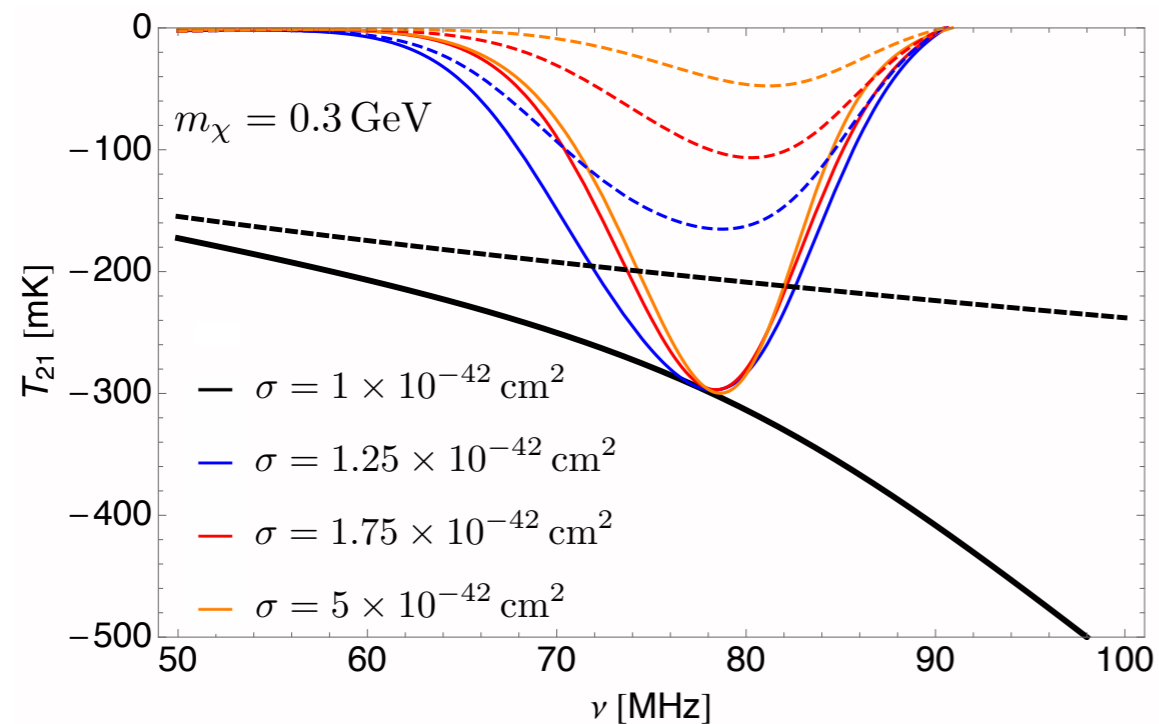
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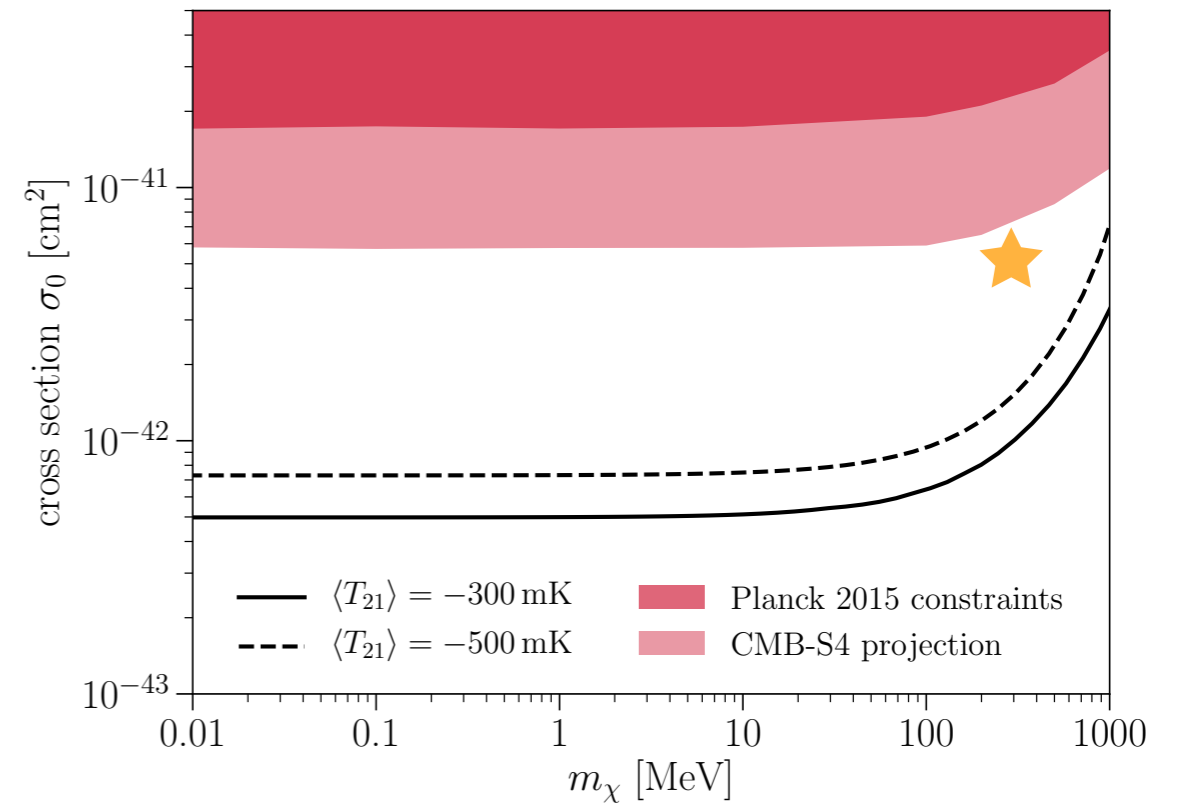
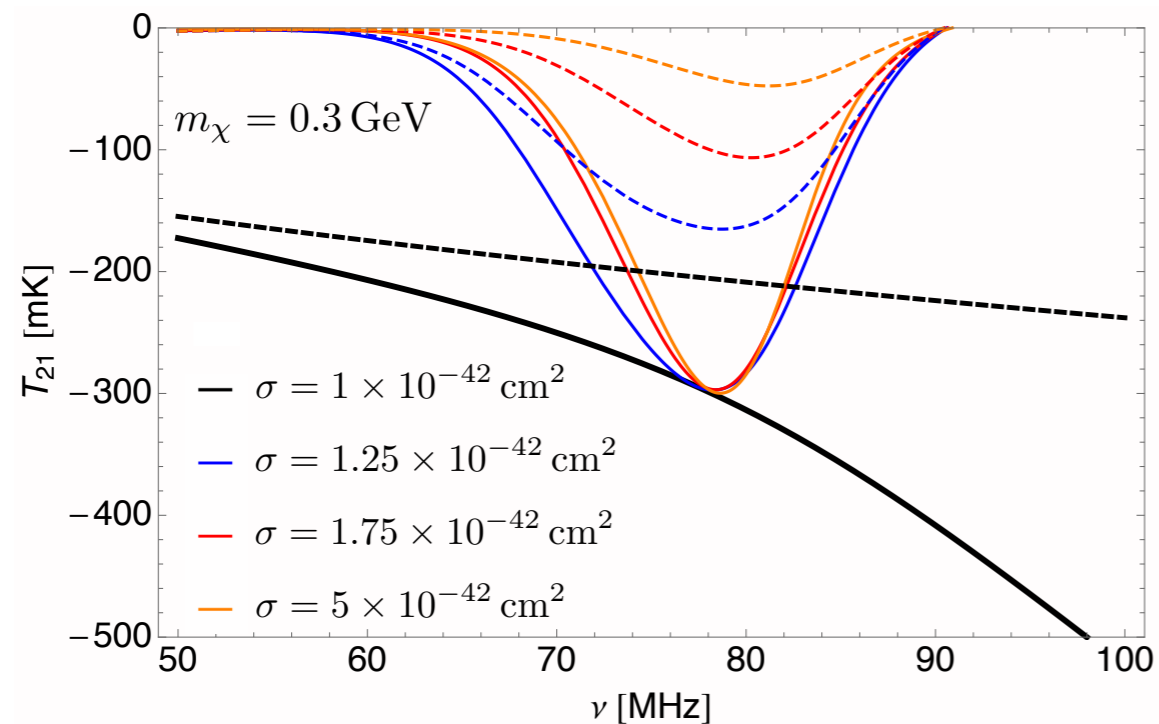
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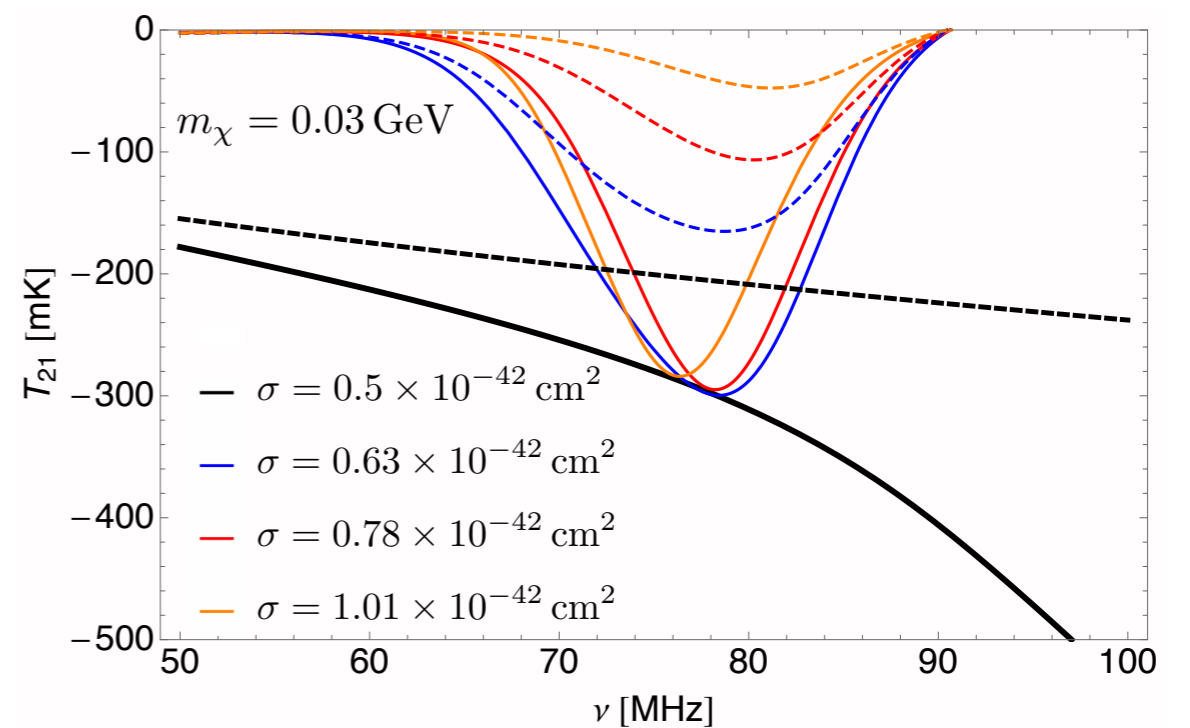
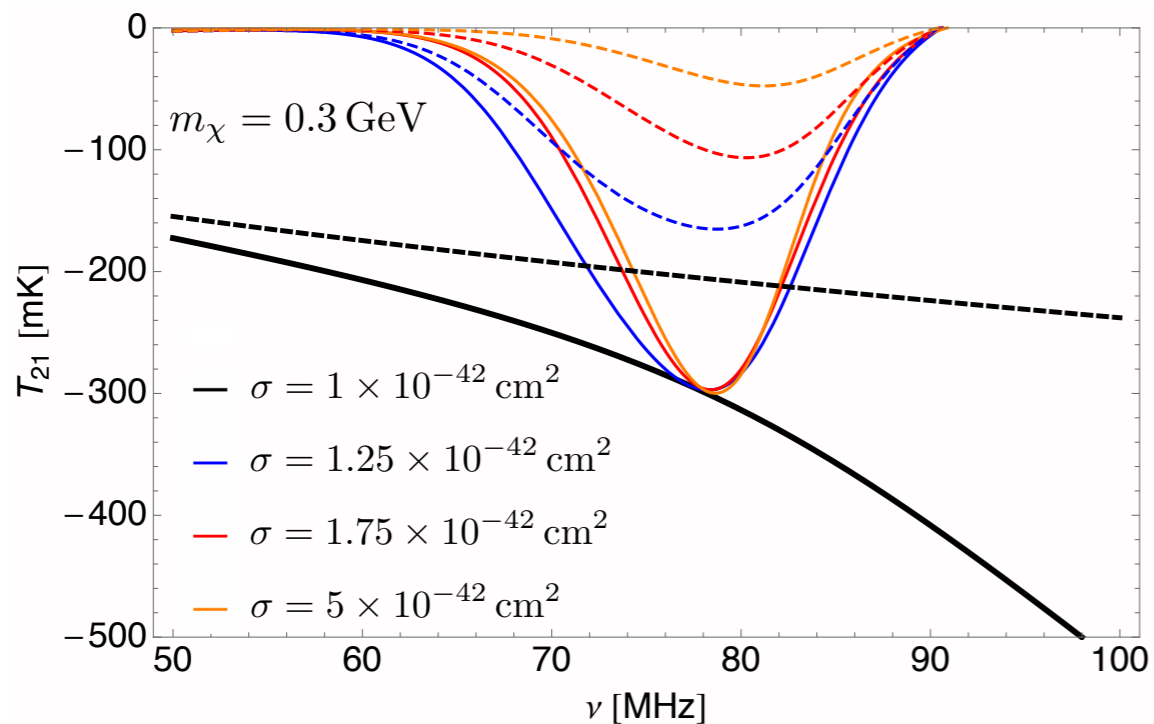
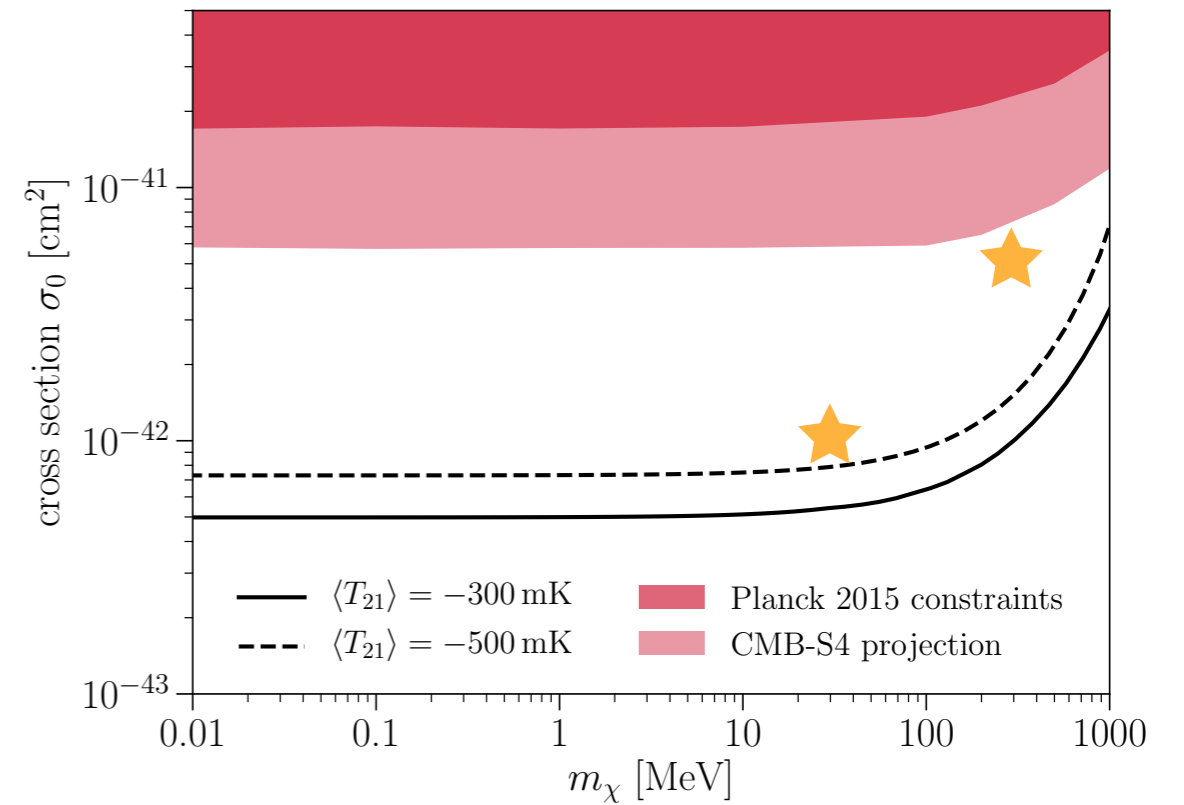
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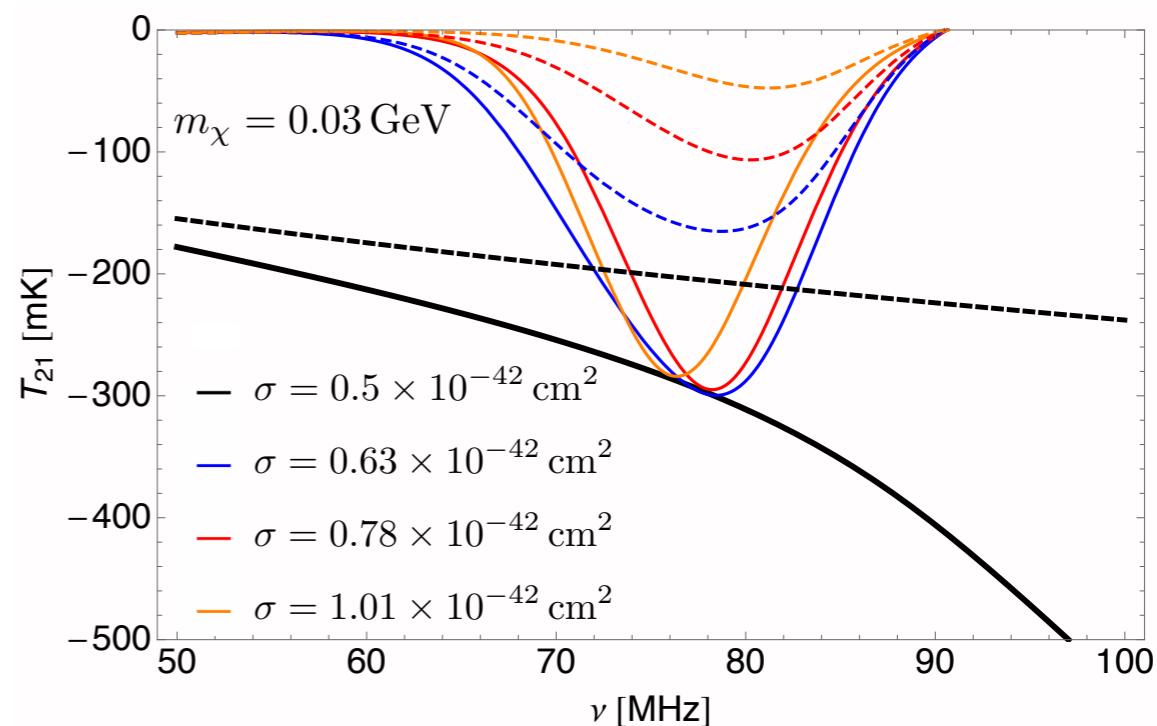
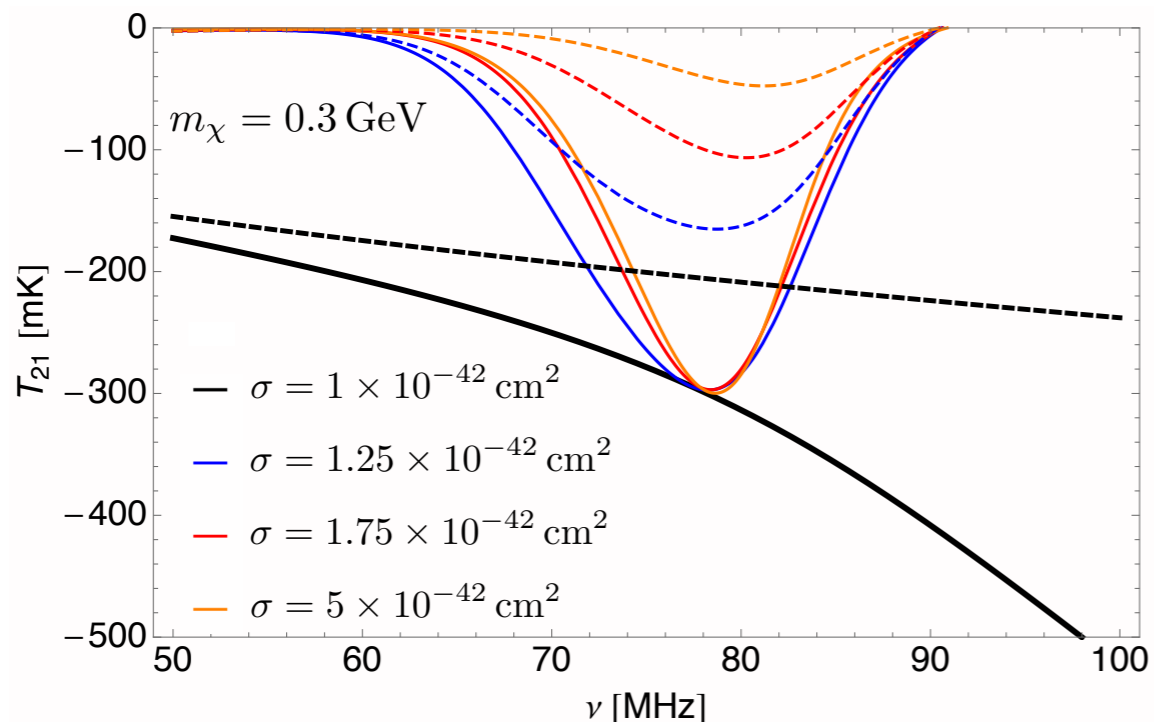
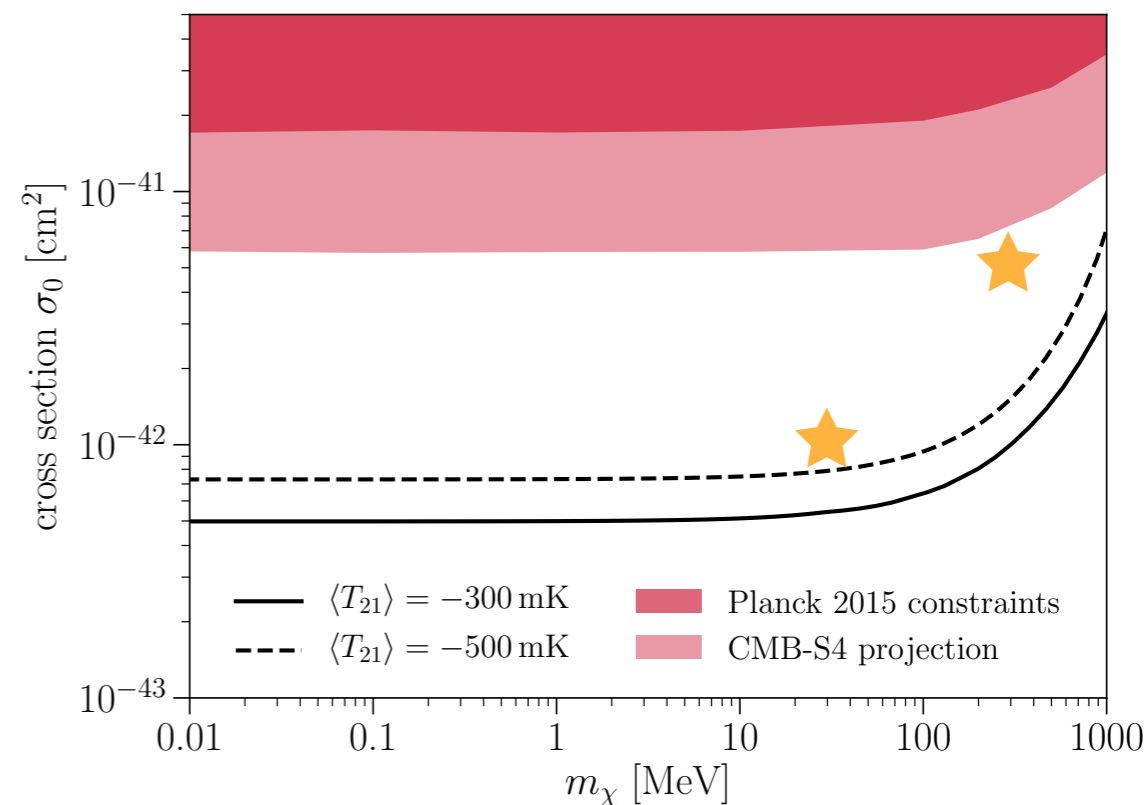
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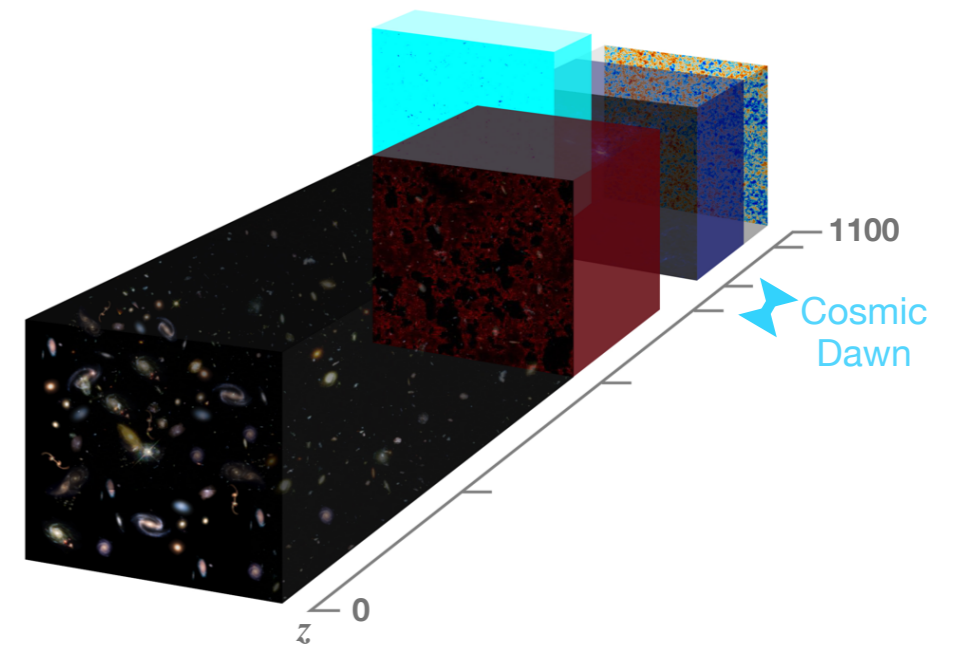
Neglects other sources of heating: X-ray heating; DM annihilation; new “CMB heating”

Liu & Slatyer, arXiv:1803.09739 Venumadhav et al., arXiv:1804.02406

Outline

Ely Kovetz
UMD, Sep. 2018

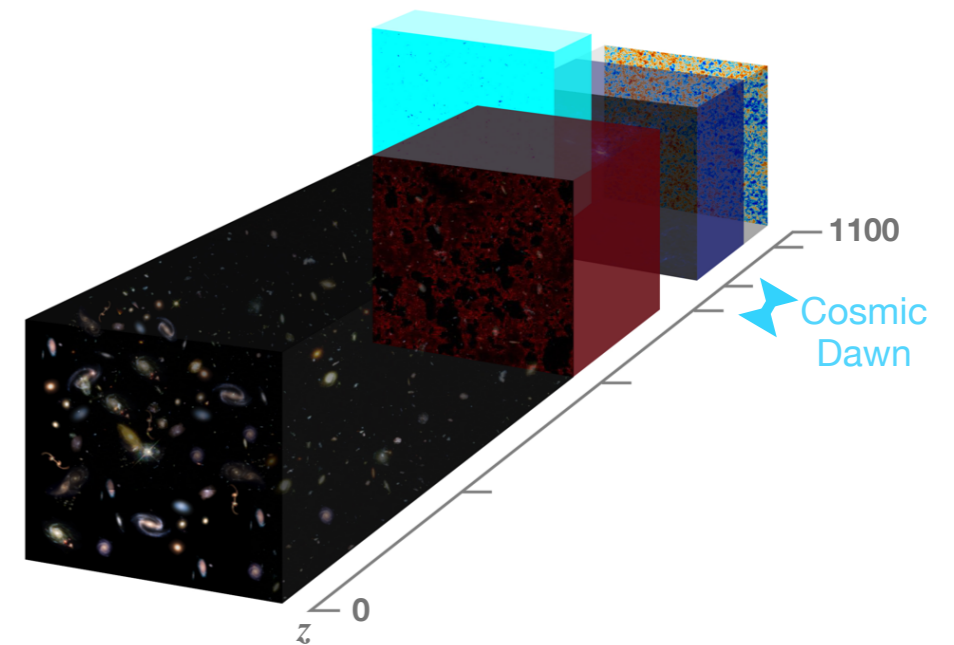
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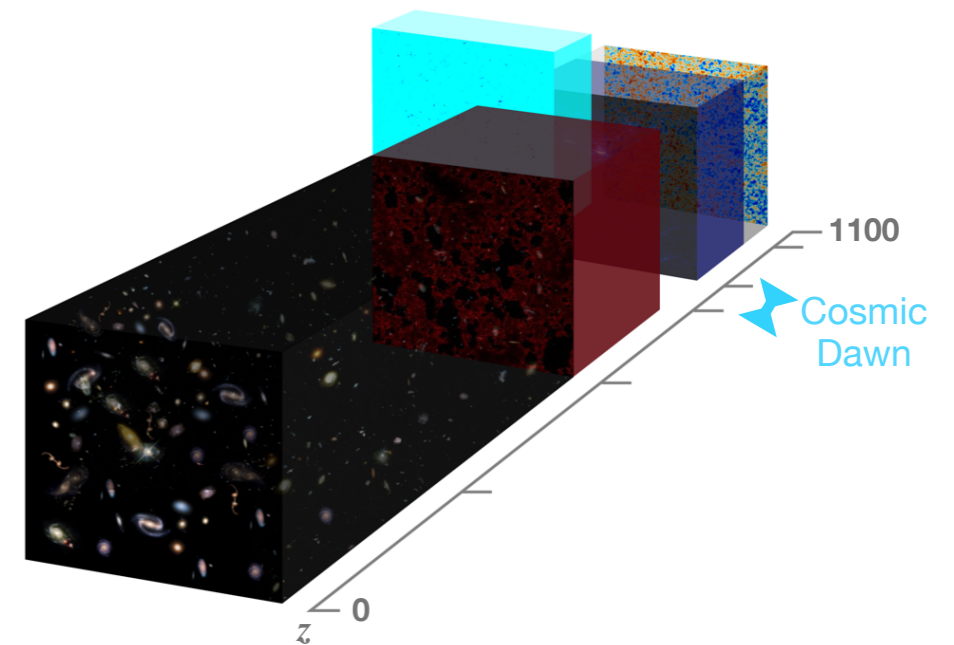
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“Bounds on Ultra-Light Hidden-Photon Dark Matter from 21cm at Cosmic Dawn”
EDK, Cholis and Kaplan, arXiv:1809:01139

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Hidden photons couple to the standard model electric current:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}\tilde{F}_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{m^2}{2}\tilde{A}_\mu\tilde{A}^\mu - \frac{e}{(1+\varepsilon^2)^{1/2}}J^\mu\left(A_\mu + \varepsilon\tilde{A}_\mu\right)$$

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Effect governed by the plasma frequency (= *effective SM-photon mass*):

$$\text{At } z = 17: \quad \omega_p = \left(\frac{4\pi n_e \alpha}{m_e}\right) = 1.7 \times 10^{-14} \left(\frac{n_e}{2 \times 10^{-7} \text{ cm}^{-3}}\right)^{1/2} \text{ eV}$$

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Oscillating electric field induces motion of electrons and ions in the plasma.

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$$\text{At } z = 17: \quad \omega_p = \left(\frac{4\pi n_e \alpha}{m_e}\right) = 1.7 \times 10^{-14} \left(\frac{n_e}{2 \times 10^{-7} \text{ cm}^{-3}}\right)^{1/2} \text{ eV}$$

Oscillating electric field induces motion of electrons and ions in the plasma.

Collisional friction dissipates the oscillations, and heats the plasma:

$$\dot{Q}_b \propto \begin{cases} m_\chi^2/\omega_p^2 & \text{for } m_\chi \ll \omega_p, \\ \omega_p^2/m_\chi^2 & \text{for } m_\chi \gg \omega_p \end{cases}$$

See: “Heating up the Galaxy with Hidden Photons”
Dubovsky & Guzman Hernandez-Chifflet, JCAP (2015)

Ultra-Light Hidden-Photon Dark Matter

(EDK, Cholis and Kaplan, arXiv:1809:01139)

Hidden photons couple to the standard model electric current:

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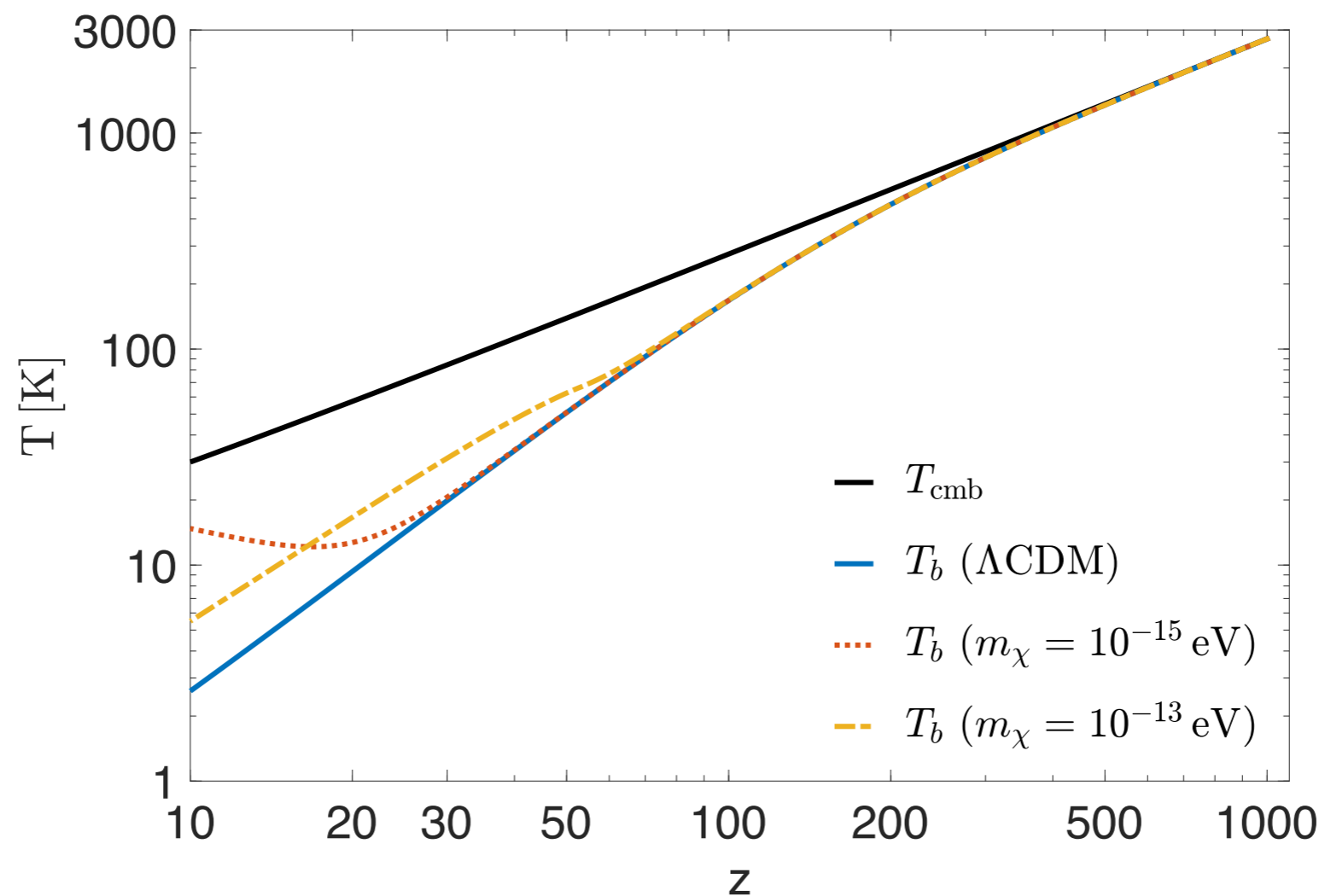
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The baryon temperature is then:

$$\dot{T}_b = \underbrace{-2HT_b}_{\text{blue}} + \underbrace{\Gamma_C(T_{\text{CMB}} - T_b)}_{\text{red}} + \underbrace{\frac{2\dot{Q}_b}{3n_H(1 + f_{\text{He}} + x_e)}}_{\text{red}}$$

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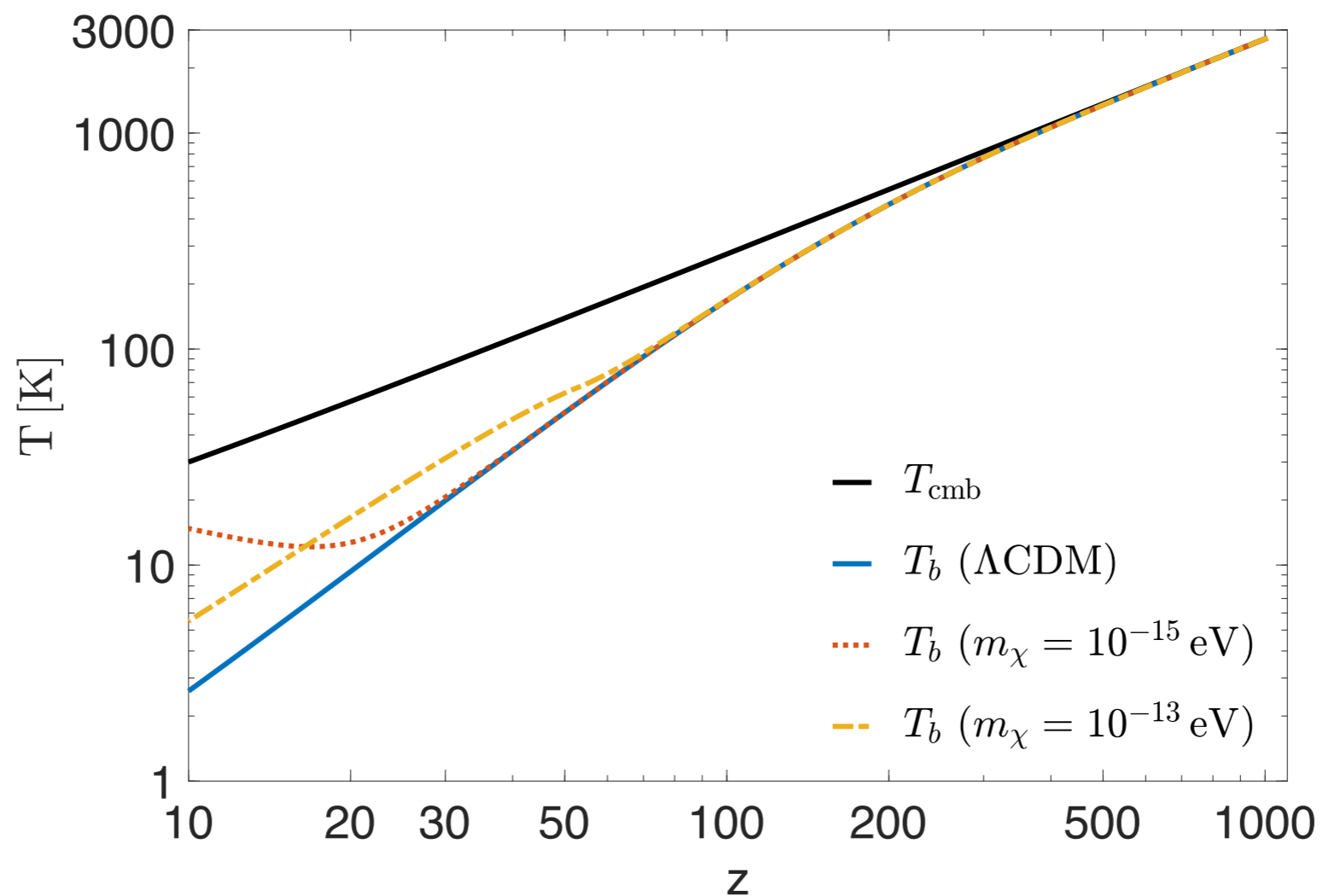
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Temperature evolution:

(at $z = 17$: $\omega_p \sim 1.7 \times 10^{-14}$ eV)

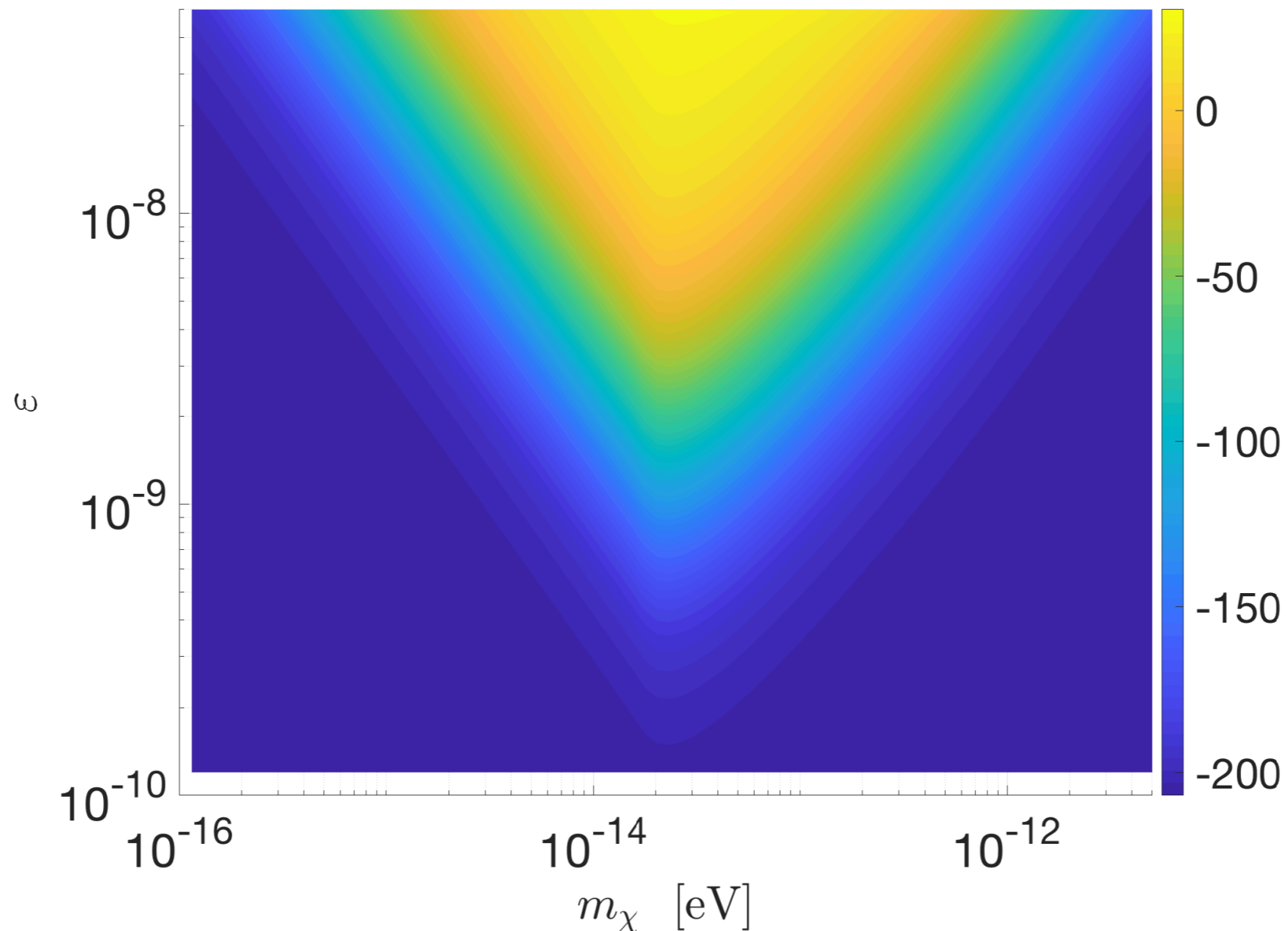


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21cm Brightness Temperature



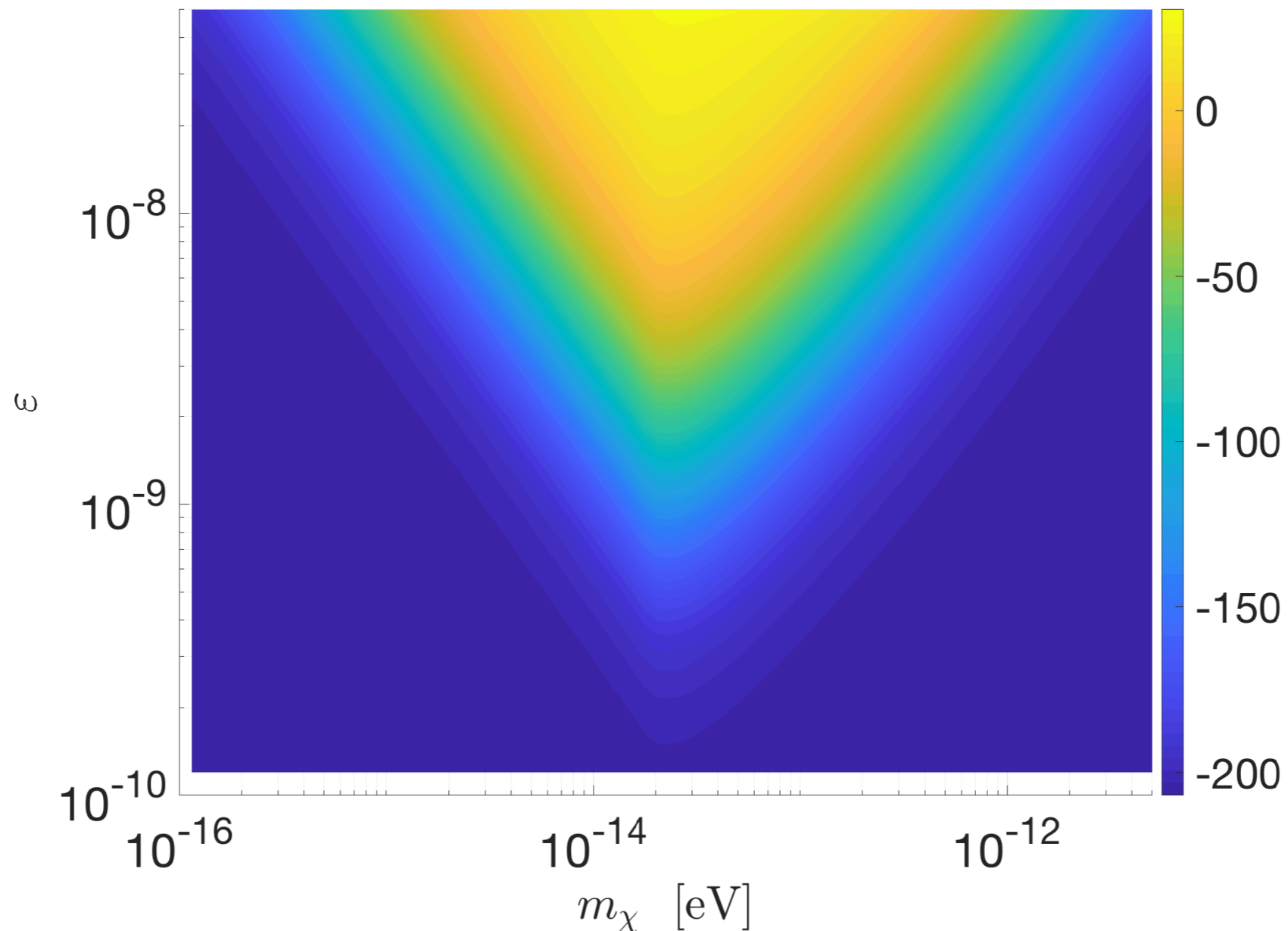
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Cosmic Dawn Global 21cm Temperature:

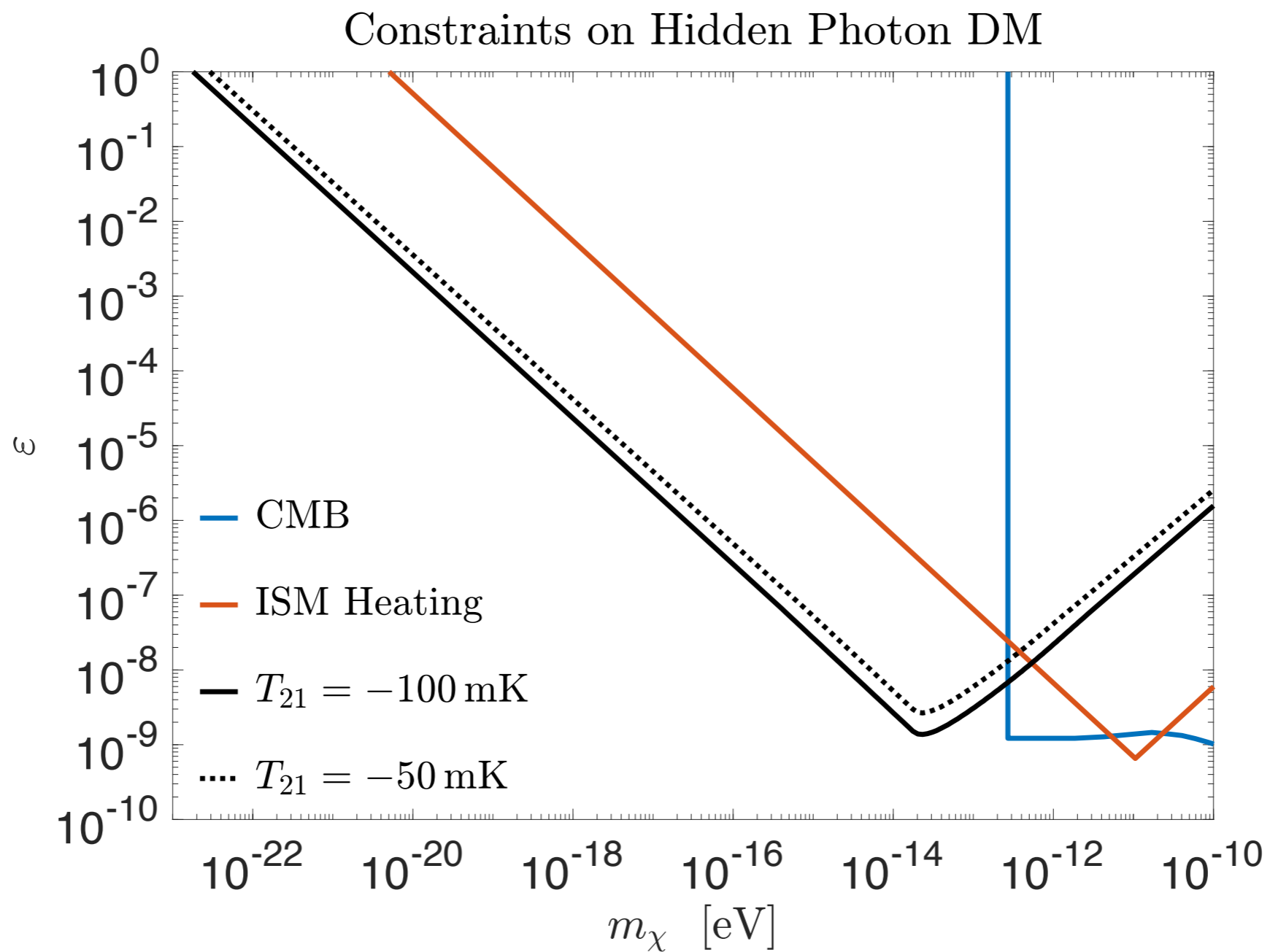
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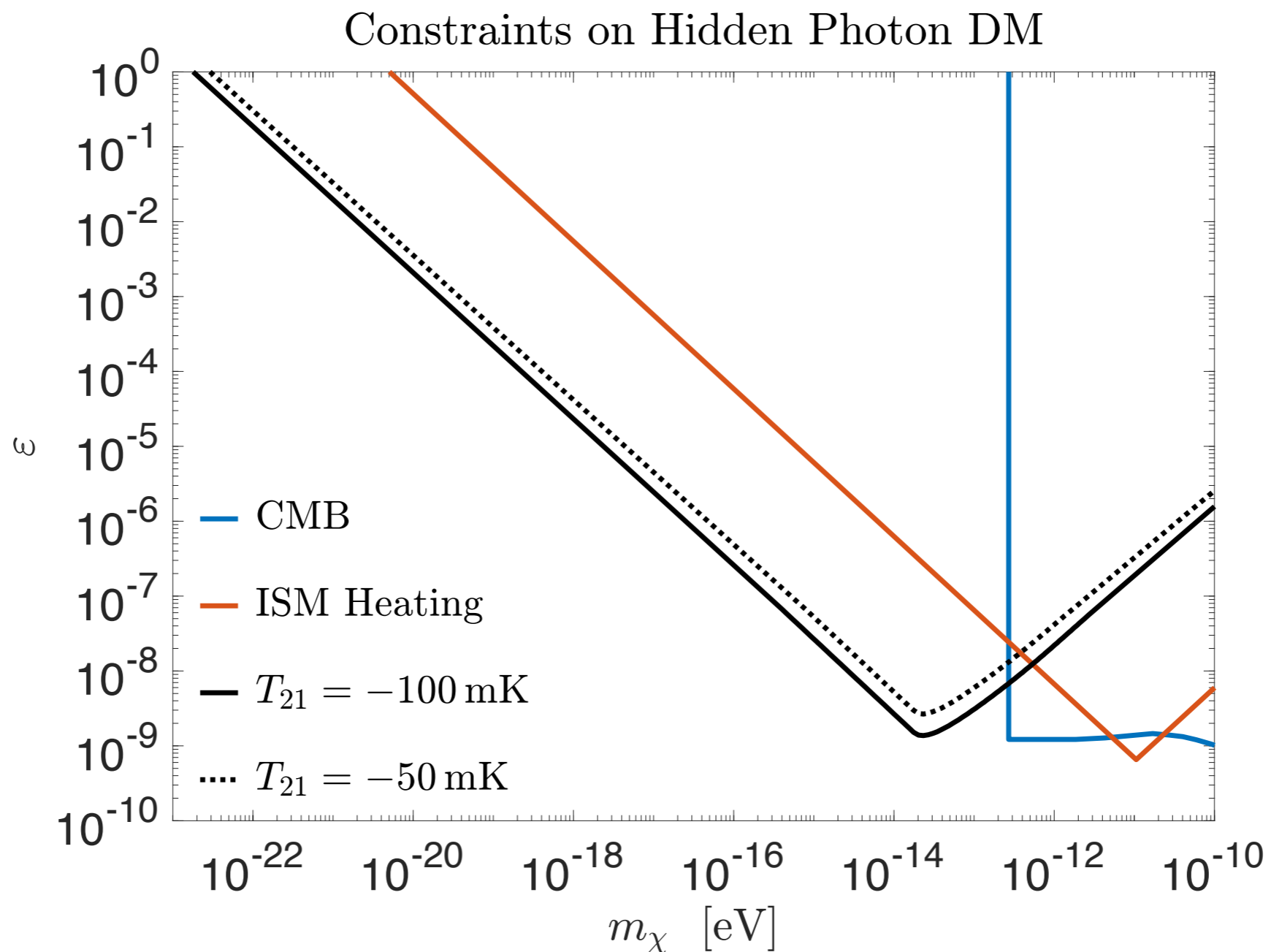


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Inferred bounds from EDGES measurement of an absorption:

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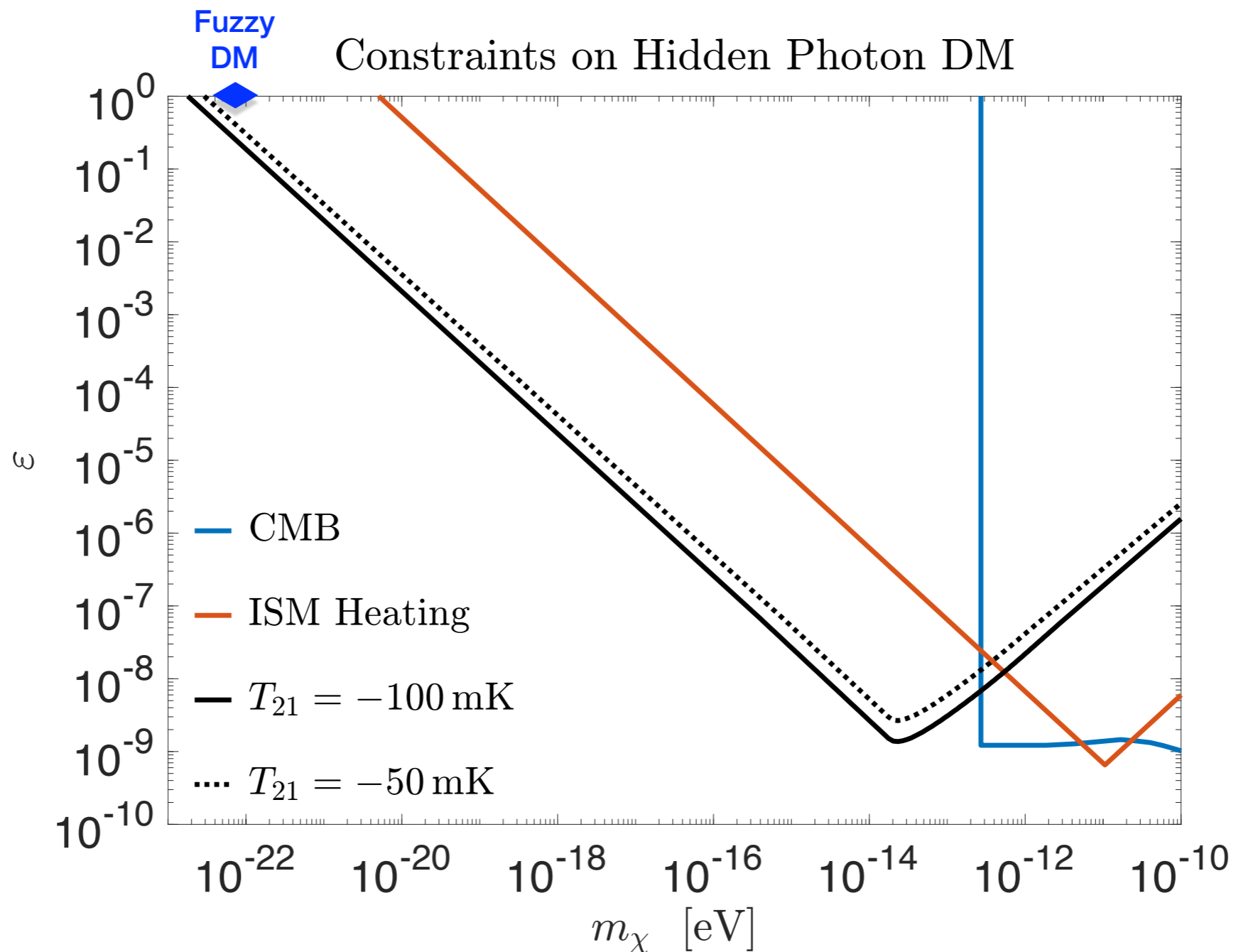


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Experimental Outlook

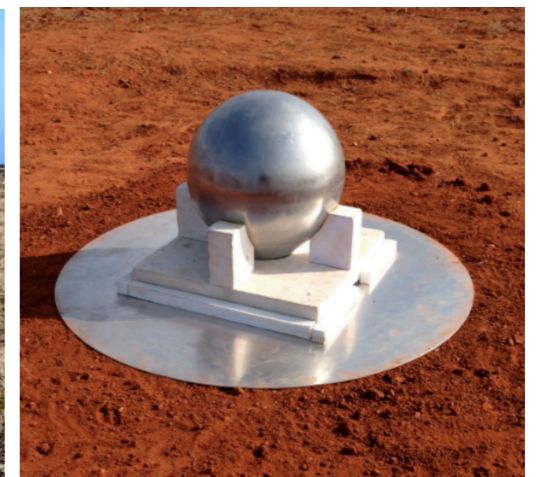
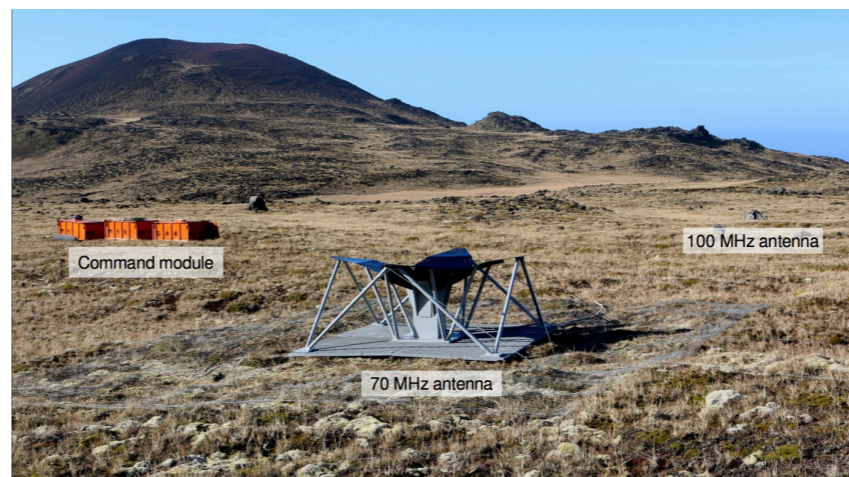
Experimental Outlook

This is far from the last word!

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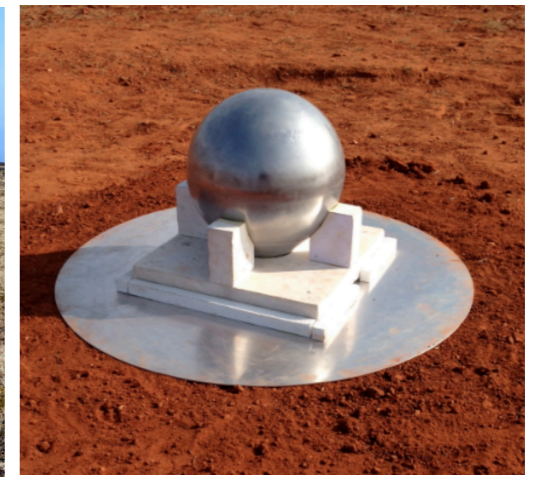
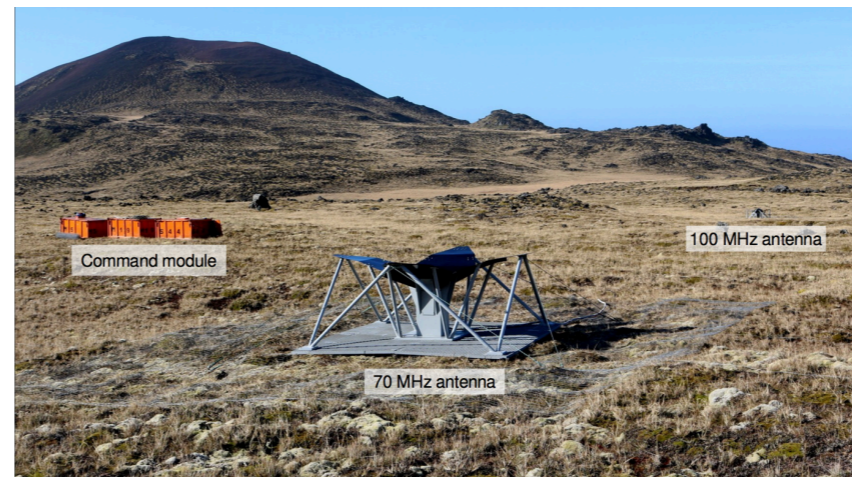


Earliest results could show up before the end of 2018!

Experimental Outlook

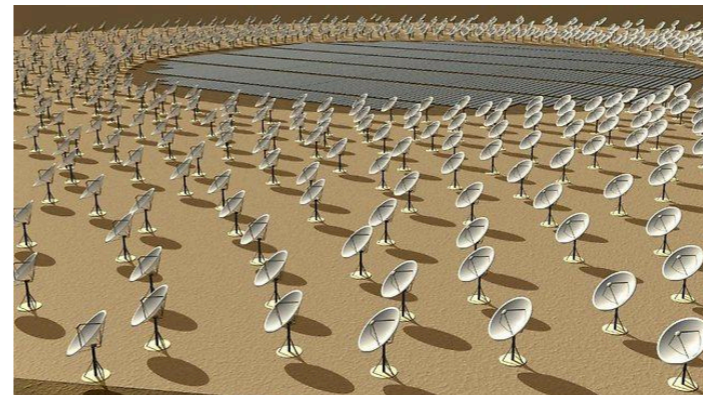
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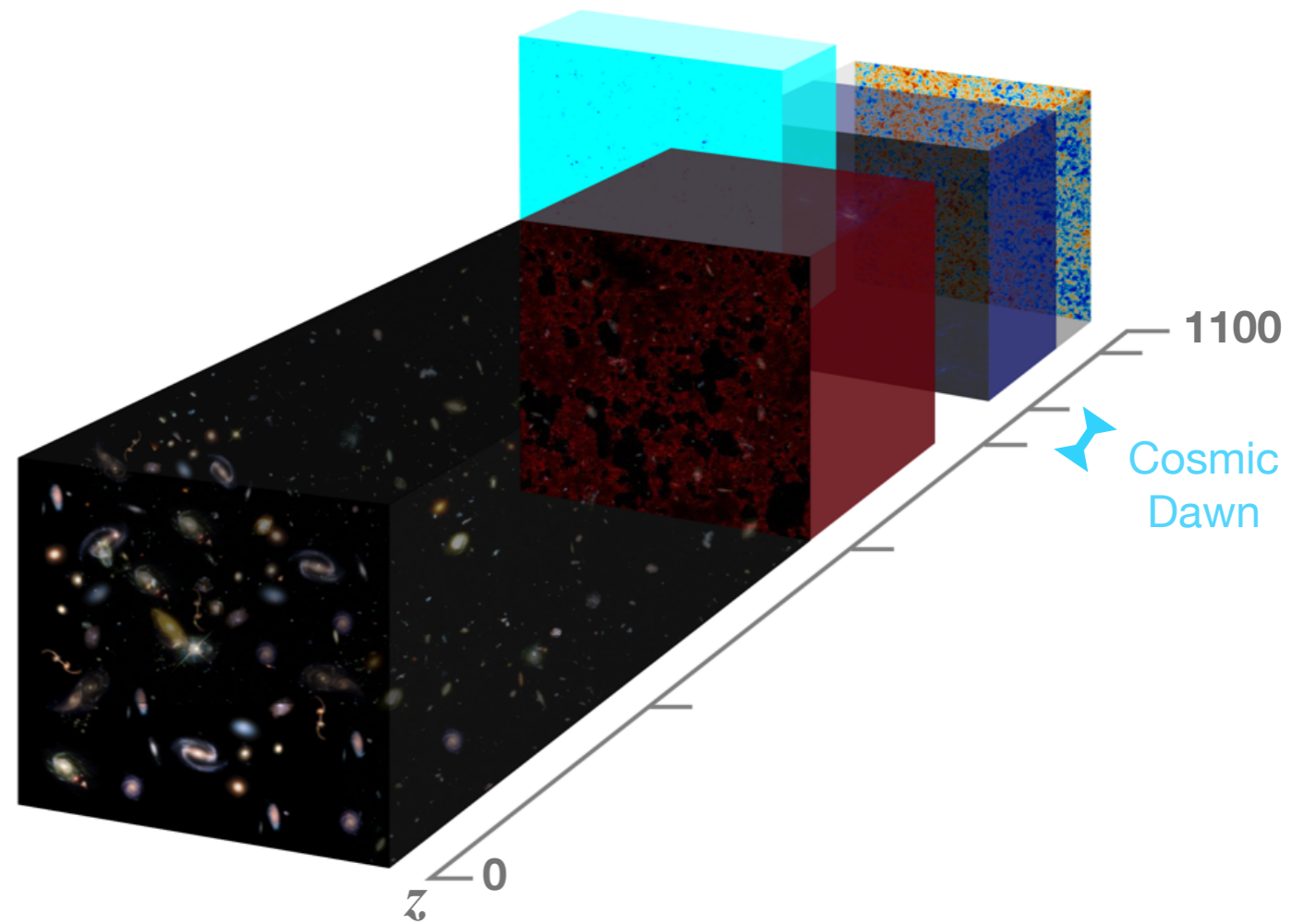
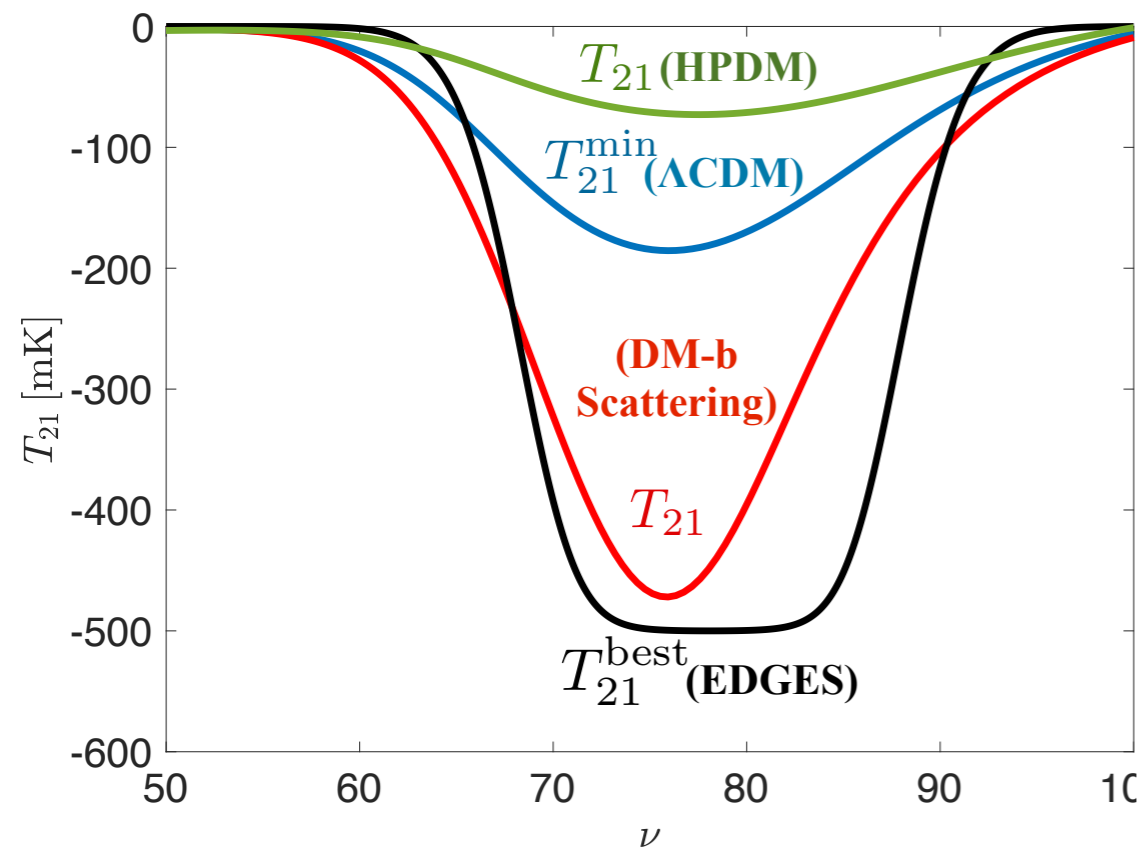
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- 21 power spectrum: HERA, SKA....



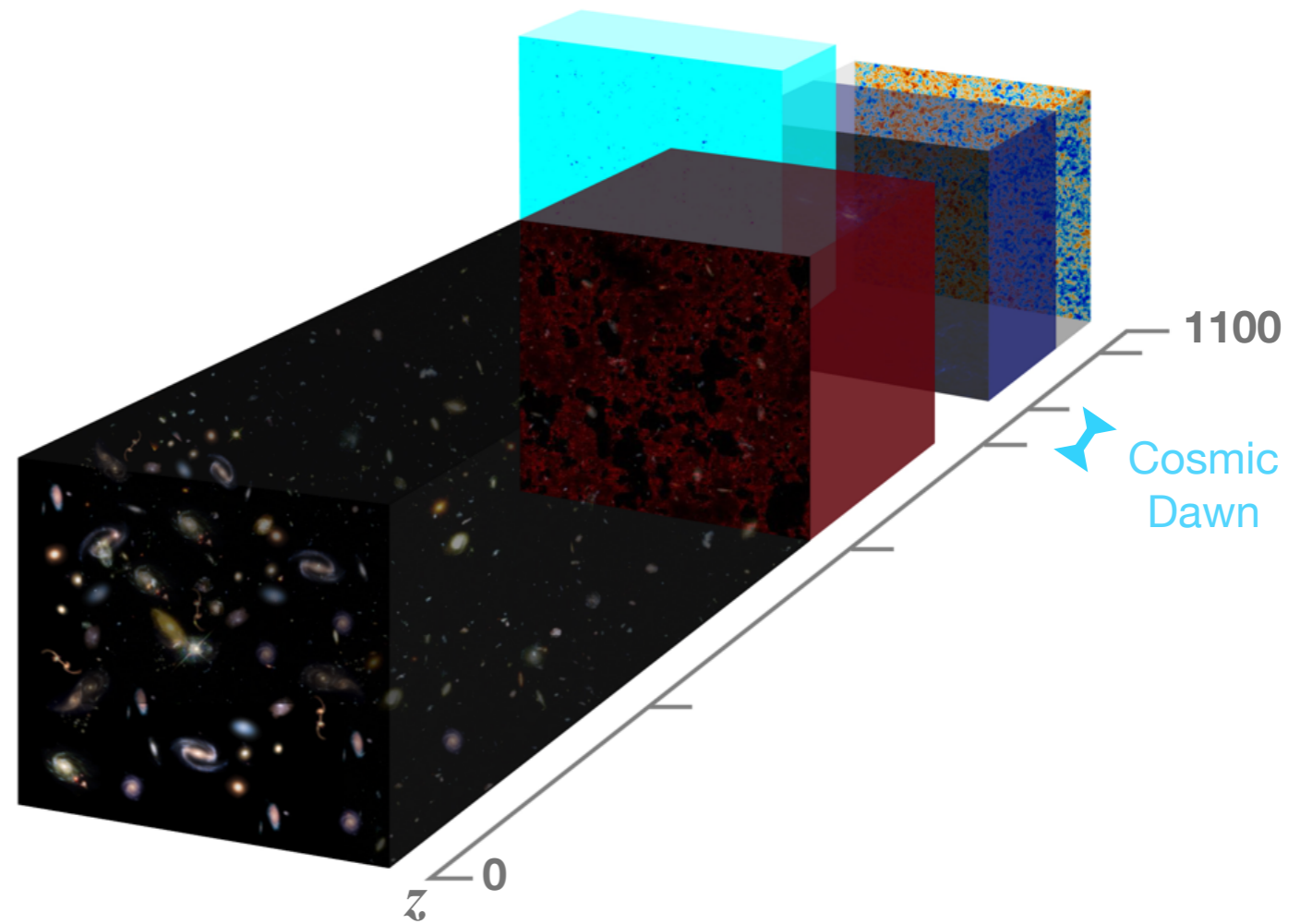
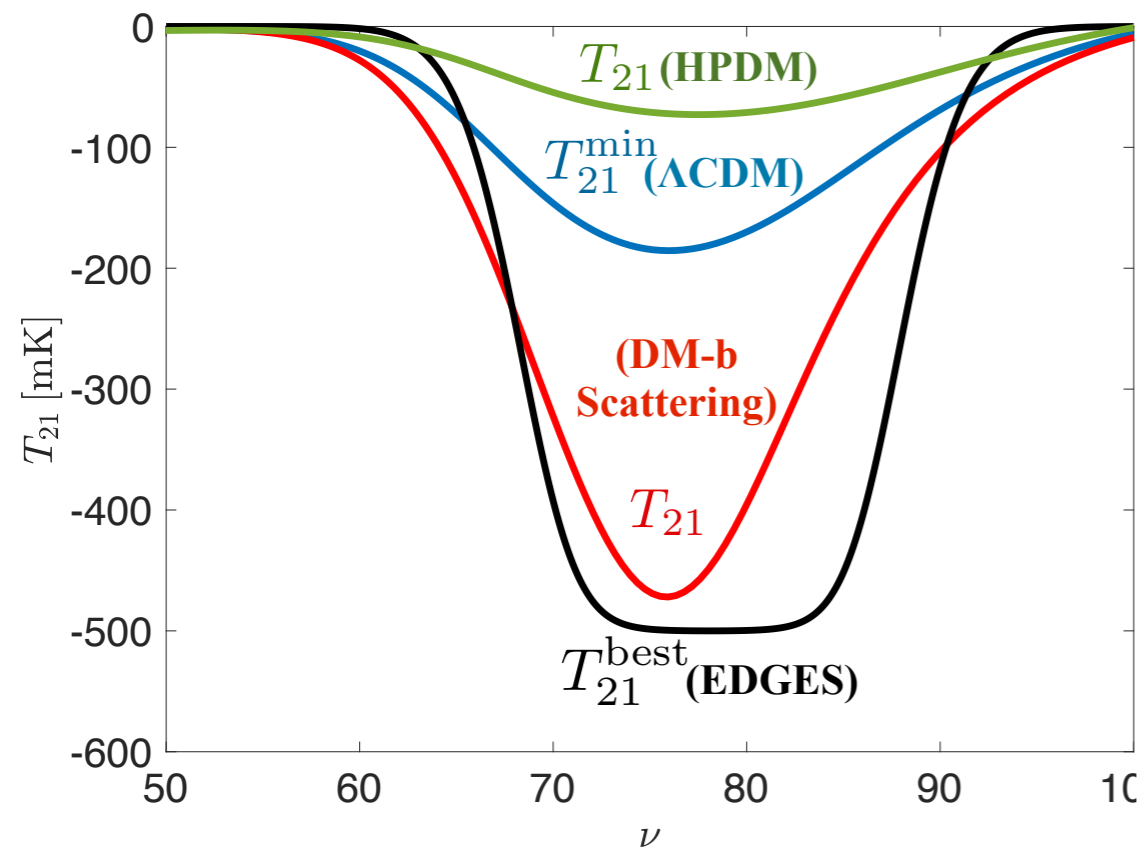
If EDGES is correct, power spectrum signal should be x10 higher than expected.

Conclusion: Cosmic Dawn Can Shed Light on DM!



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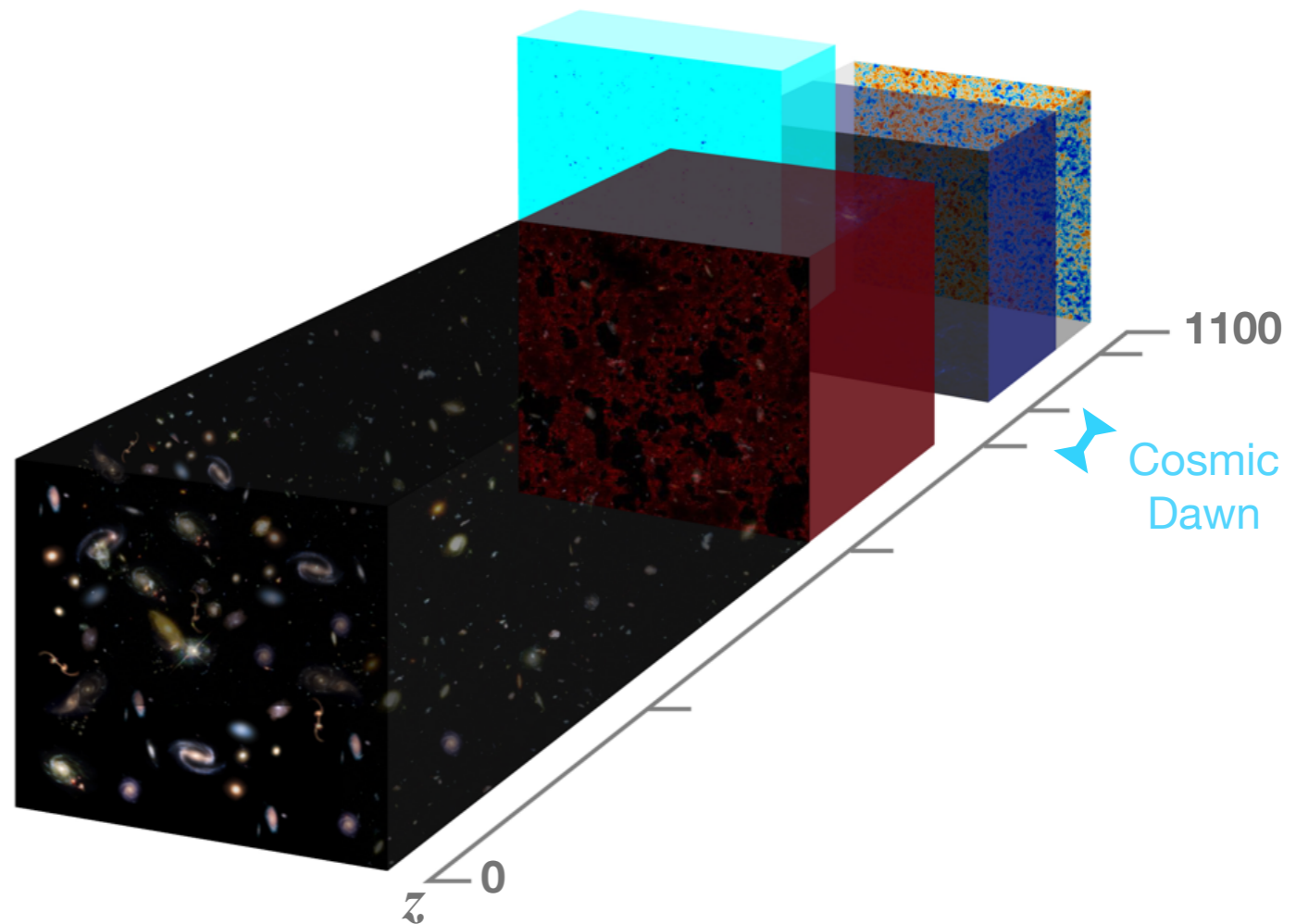
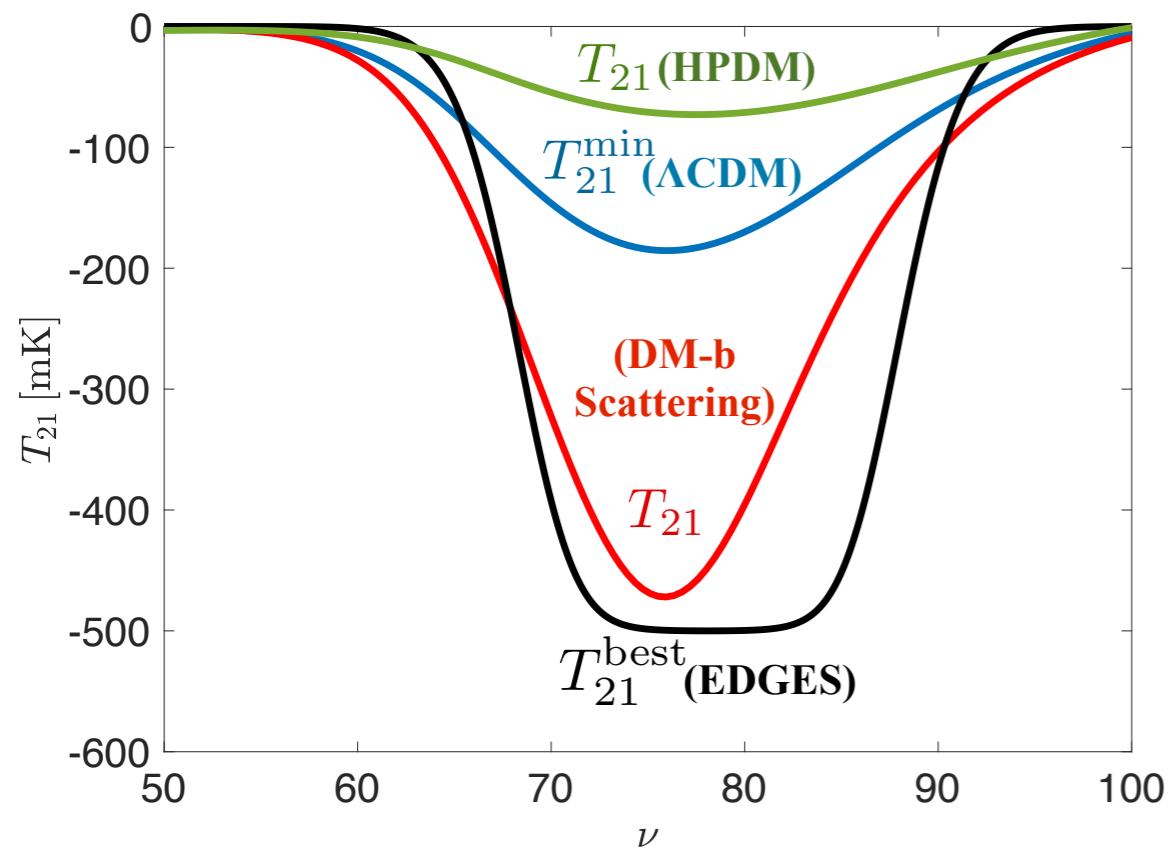
We used one number!



Thank You!

Ely D. Kovetz

Johns Hopkins University



Based on arXiv:1509.00029, arXiv:1807.01139, arXiv:1808.00001, arXiv:1809.01139:

Muñoz, **EDK** and Ali-Haïmoud, “Heating of baryons due to scattering with dark matter during the dark ages”

EDK, Poulin, Gluscevic, Boddy, Barkana and Kamionkowski, “Tighter Limits on Dark Matter Explanations of the Anomalous EDGES 21cm Signal”

Boddy, Gluscevic, Poulin, **EDK**, Kamionkowski and Barkana, “A Critical Assessment of CMB Limits on Dark Matter-Baryon Scattering”

EDK, Cholis and Kaplan, “Bounds on Ultra-Light Hidden-Photon Dark Matter from 21cm at Cosmic Dawn”

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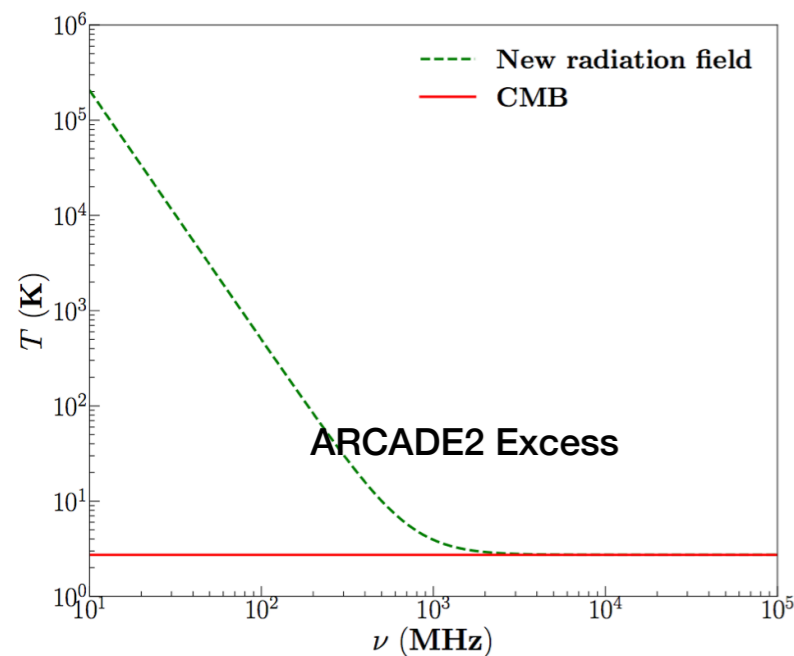
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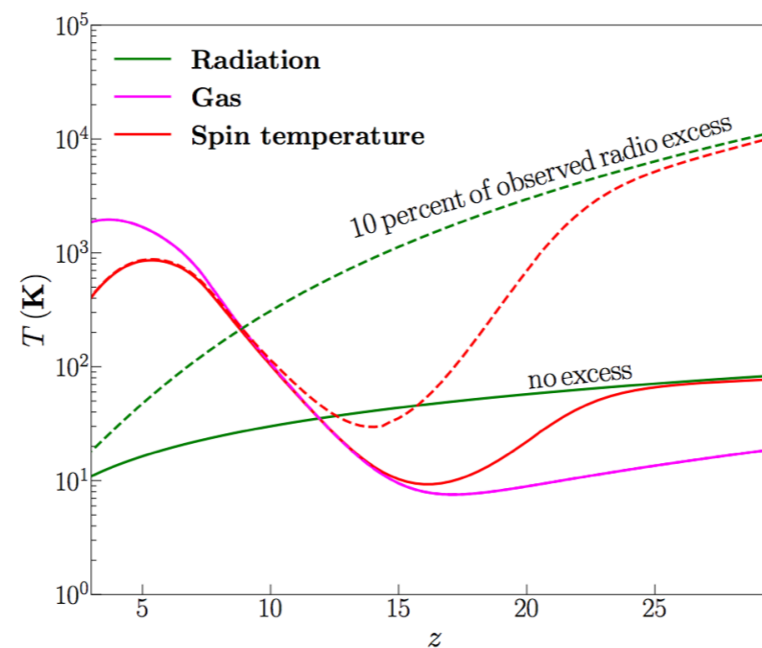
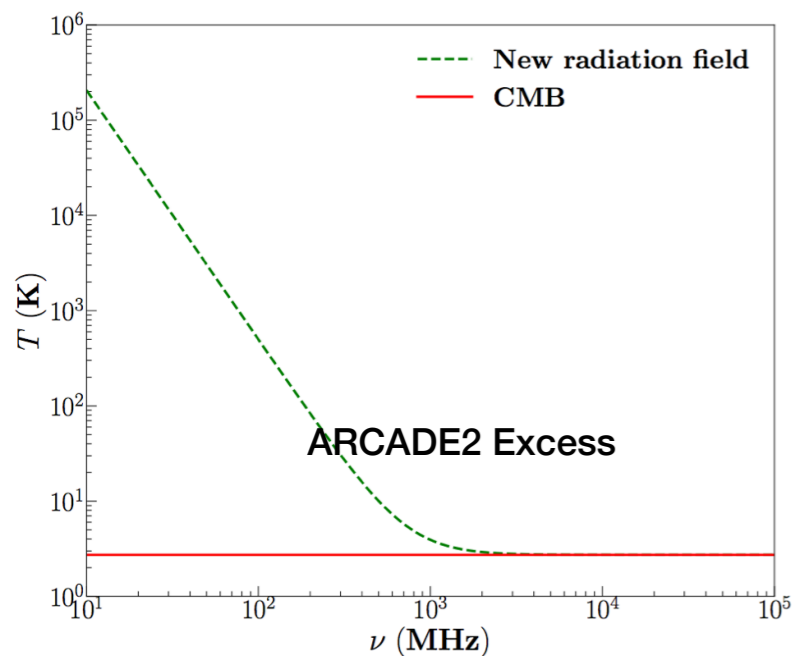
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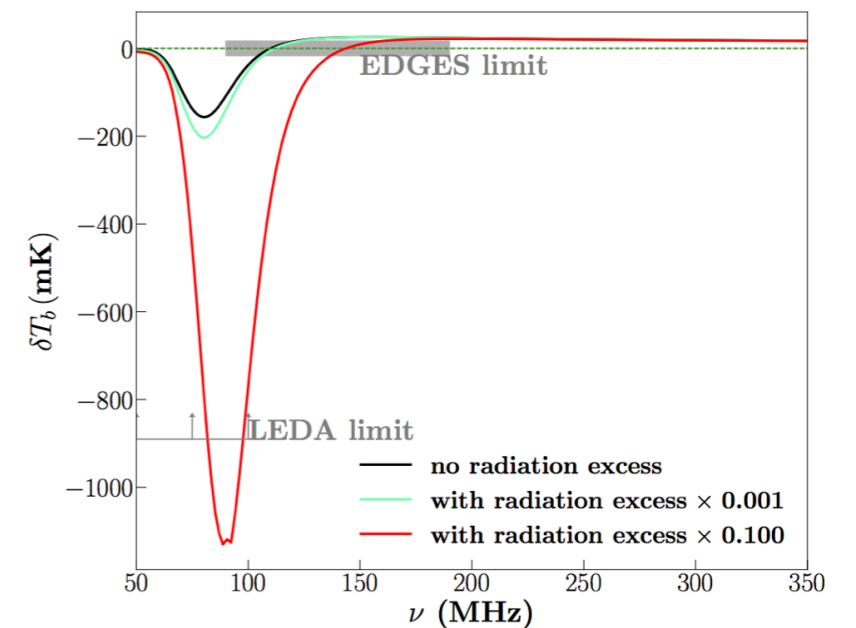
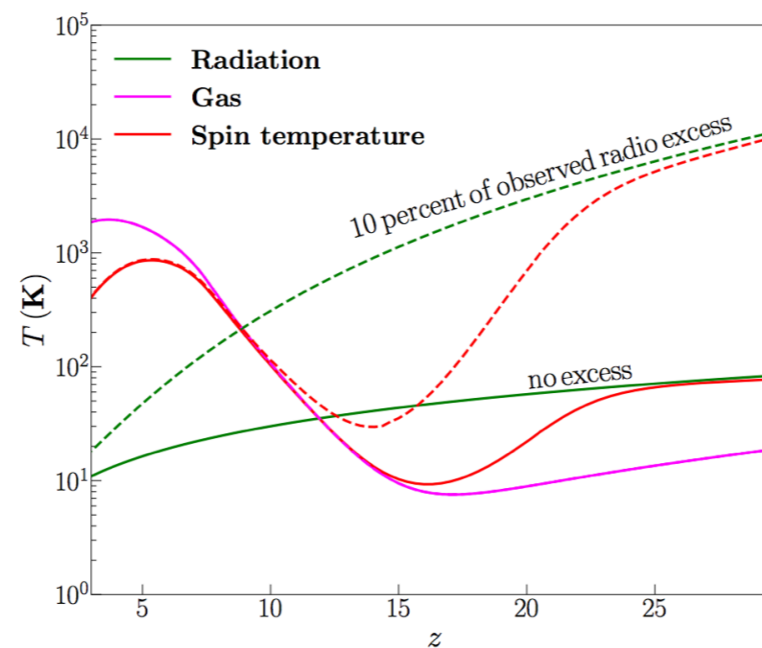
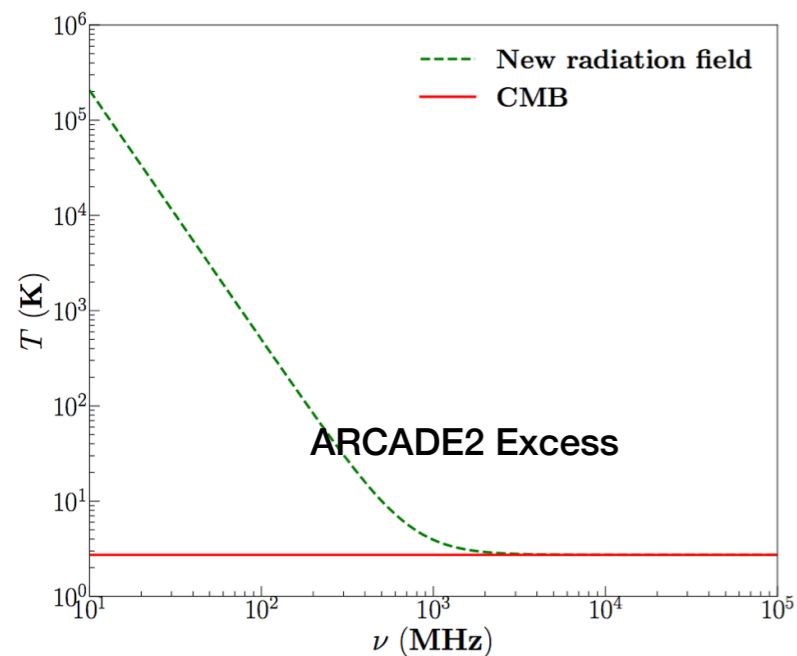
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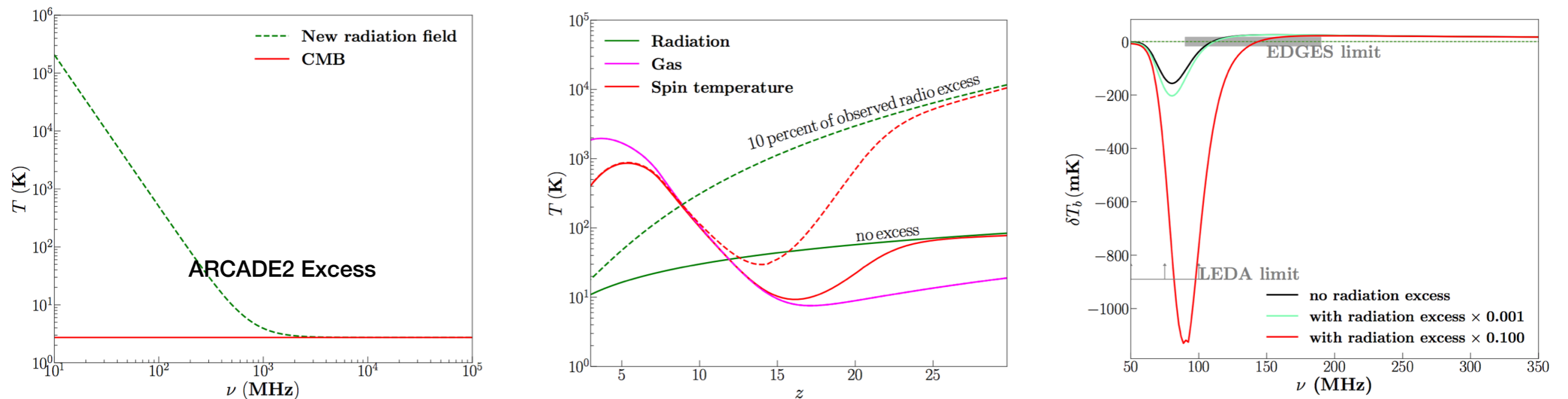
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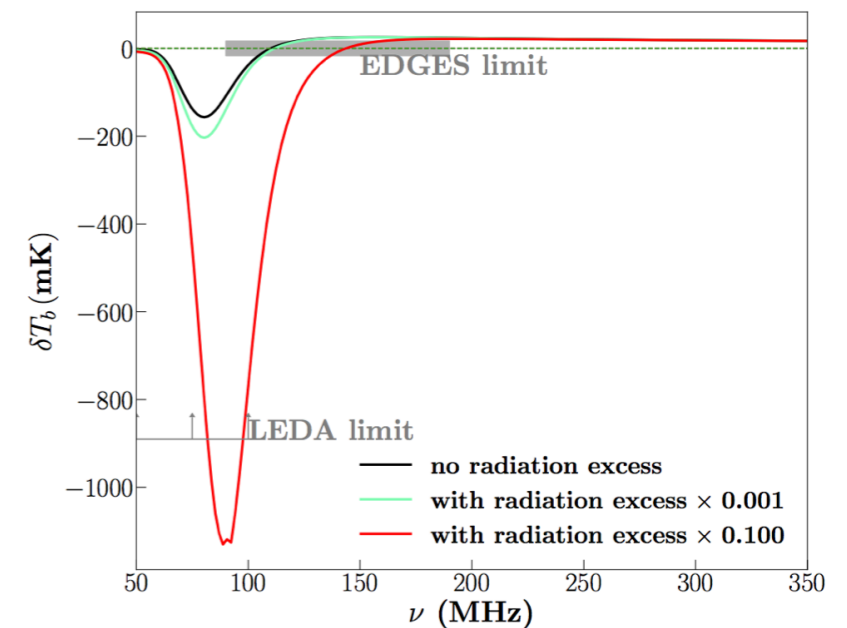
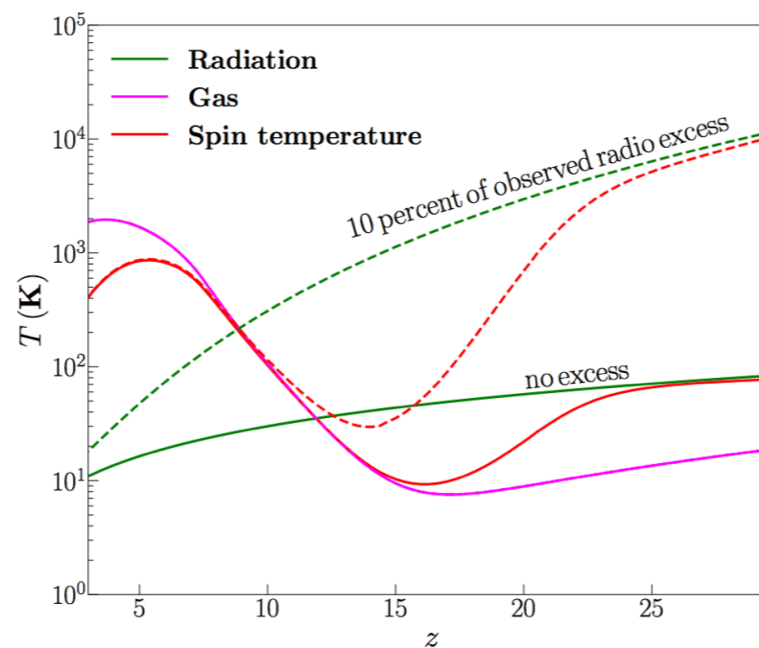
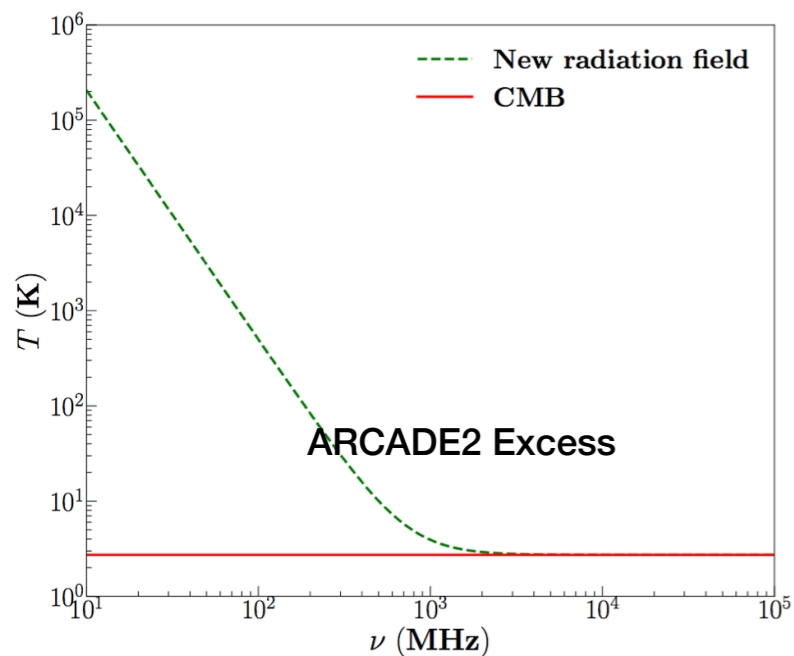
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And, of course, one could invoke dark matter to produce an enhanced background....

Fraser + 10, “The EDGES 21 cm Anomaly and Properties of Dark Matter”, arXiv:1803.03245

...

EDGES Measurement: Caveats?

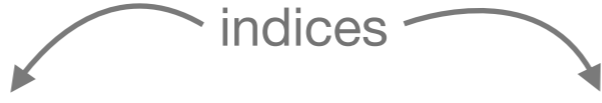
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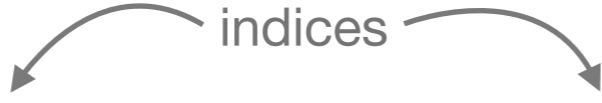
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