Bounds on Dark Matter Lifetime from the Cosmic Dawn

Andrea Mitridate

based on: 1803.11169 with A. Podo

SCUOLA NORMALE SUPERIORE

INFN

how stable is the Dark Matter?

$$\boxed{\tau_{\rm DM} > \text{age of the Universe} \sim 10^{17}\,\text{s}}$$

can we say more ?

how stable is the Dark Matter?

$$\boxed{\tau_{\rm DM} > \text{age of the Universe} \sim 10^{17}\,\text{s}}$$

can we say more ?

yes

LETTER

doi:10.1038/nature25792

An absorption profile centred at 78 megahertz in the sky-averaged spectrum

Judd D. Bowman[1], Alan E. E. Rogers[2], Raul A. Monsalve[1,3,4], Thomas J. Mozdzen[1] & Nivedita Mahesh[1]

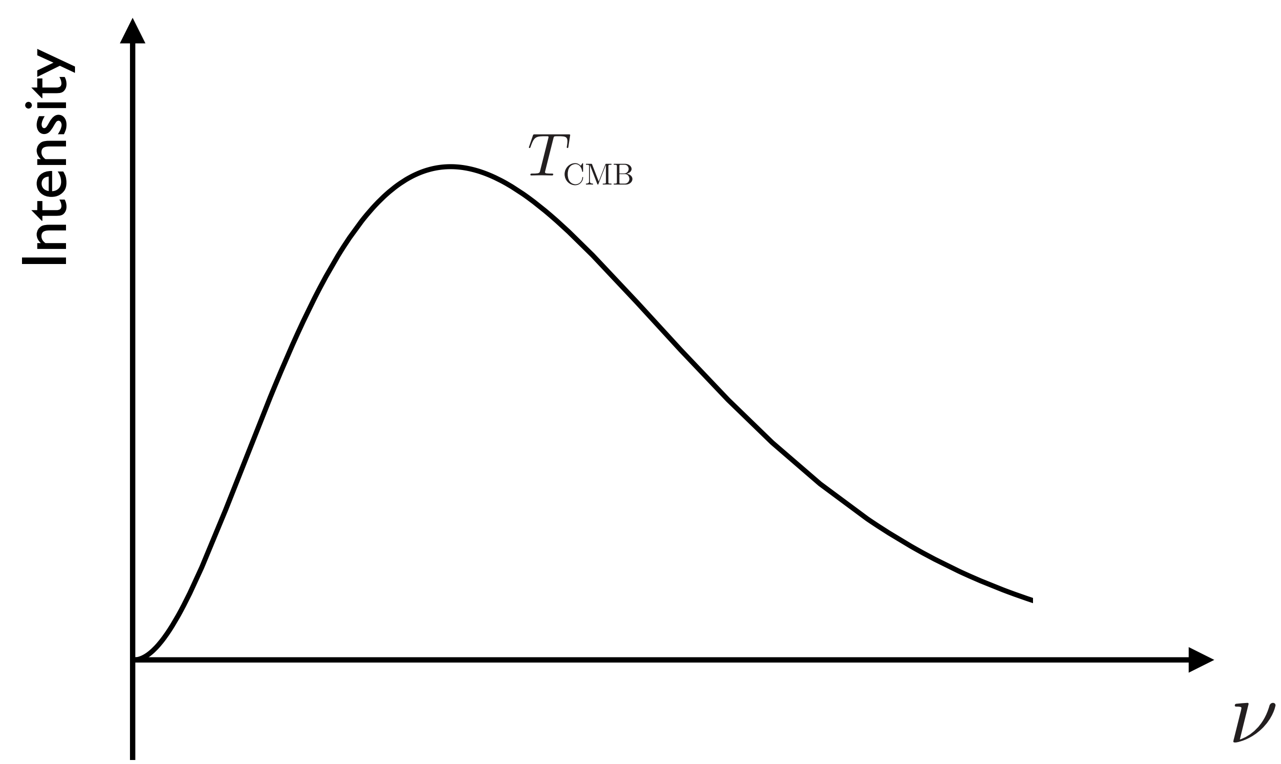
What is the 21 cm line

a good old friend: the CMB

black body radiation emitted near the epoch of electron-proton recombination, *i.e.* $z \sim 1100$, with a brightness temperature

$$T_{\rm CMB} = 2.73(1+z)\,{\rm K}$$

$$B_\nu(T_{\rm CMB}) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT_{\rm CMB}}}-1}$$

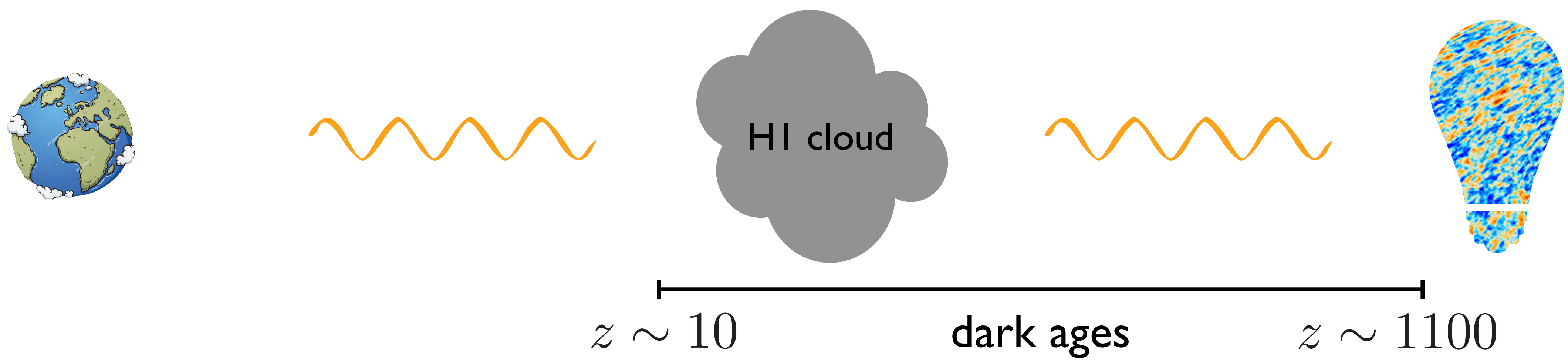


the CMB journey in the dark ages

after recombination and prior re-ionization

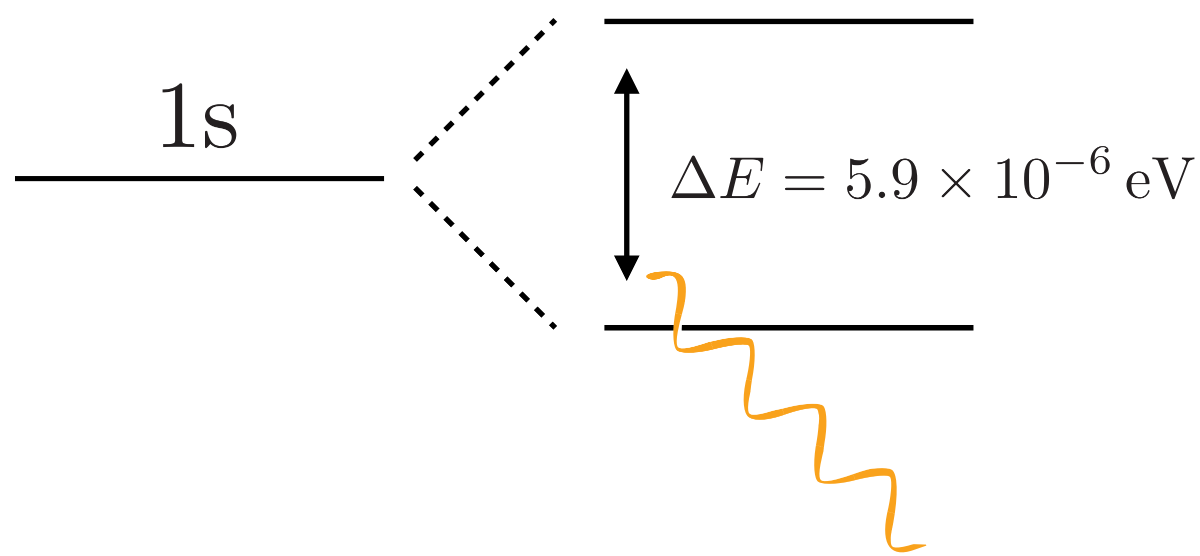
$$1100 \lesssim z \lesssim 10$$

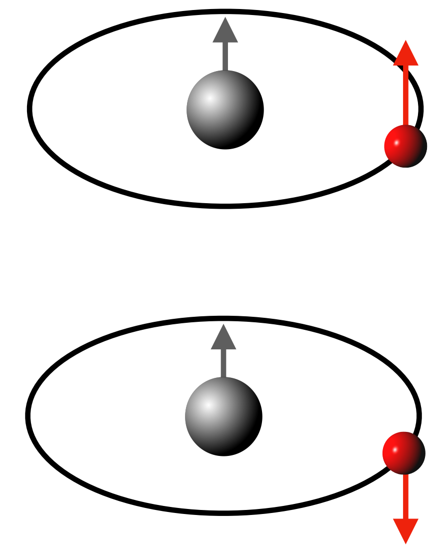
most of the Universe matter is in the form of neutral Hydrogen



how propagation through the dark ages affects the CMB blackbody spectra?

Hydrogen hyperfine levels





$$\nu = 1420.4057\,\mathrm{MHz}$$

$$\lambda = 21.106144\,\mathrm{cm}$$

relative occupation of the hyperfine levels is parametrized in term of the spin temperature

$$\frac{n_1}{n_0} \equiv \frac{g_1}{g_0}\, e^{-\Delta E/T_S}$$

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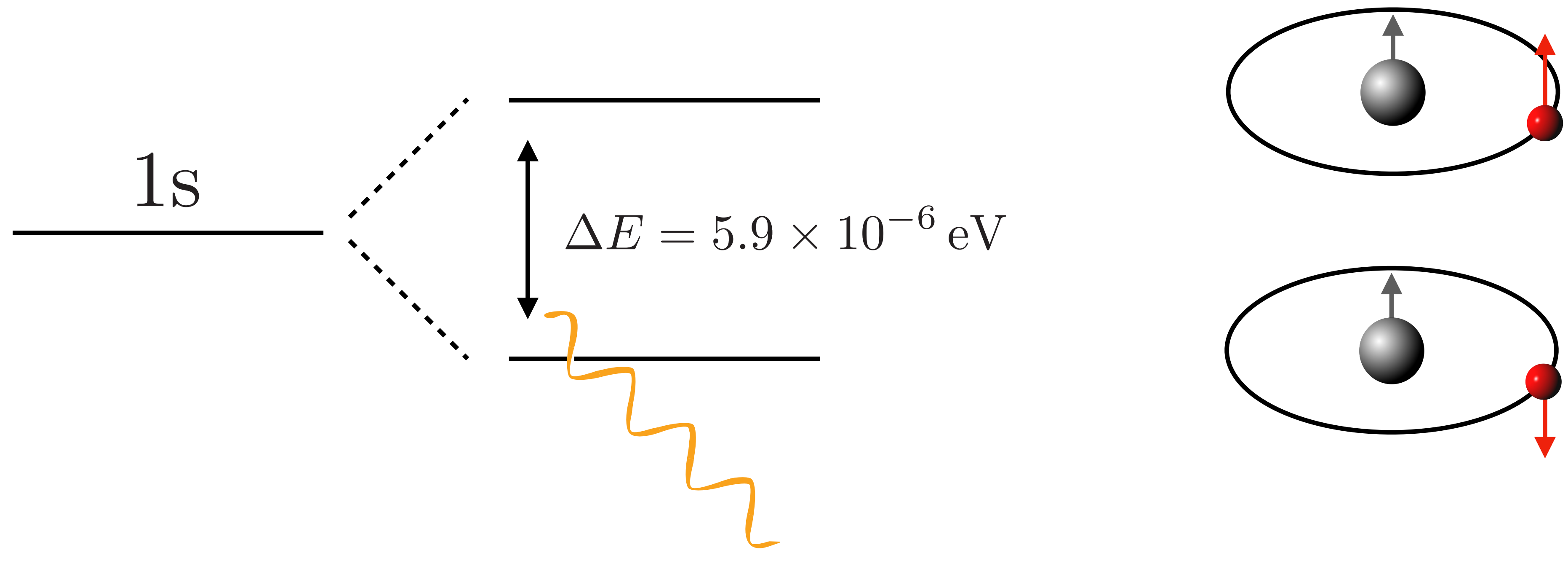

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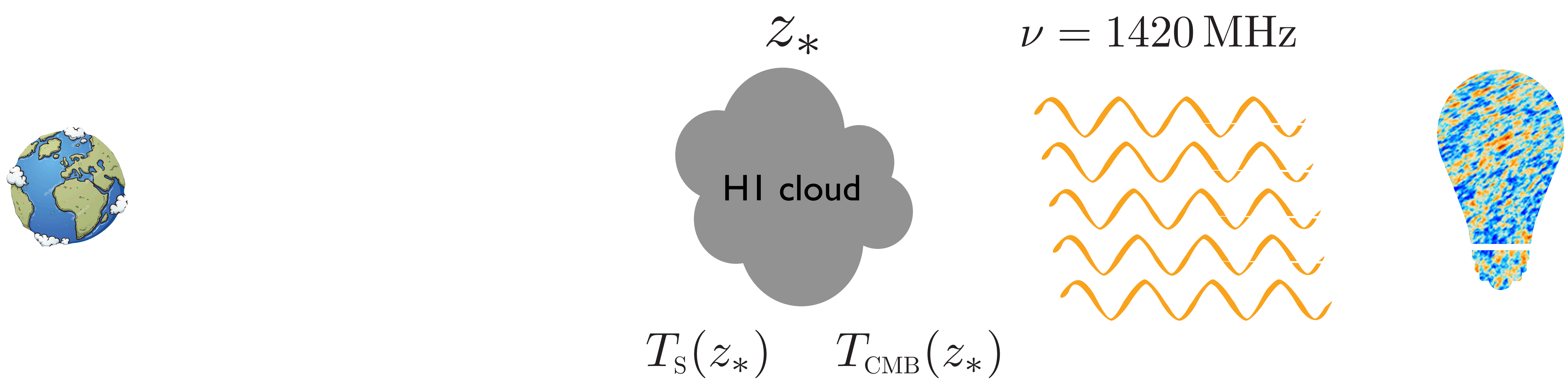
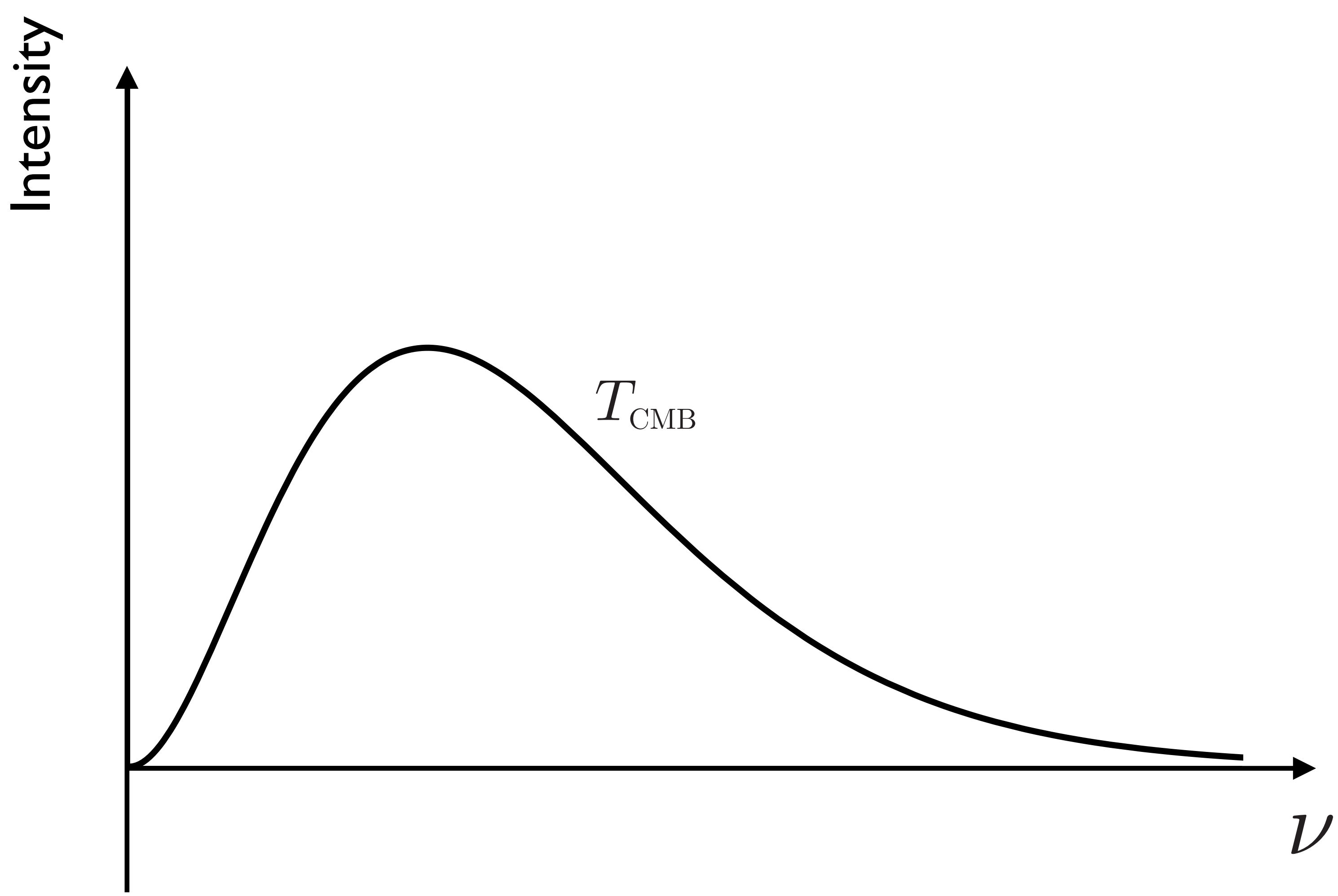
what we look for





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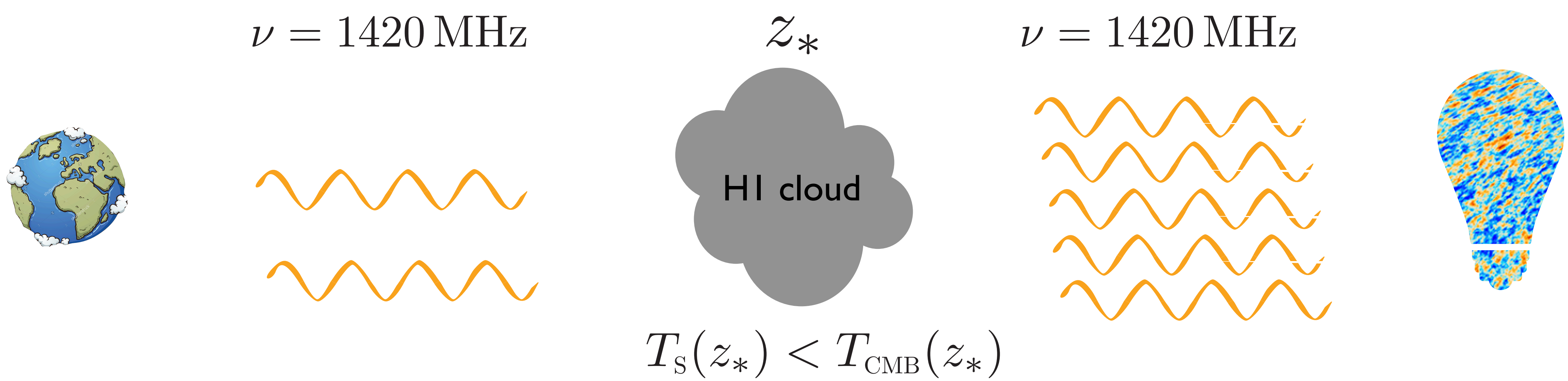

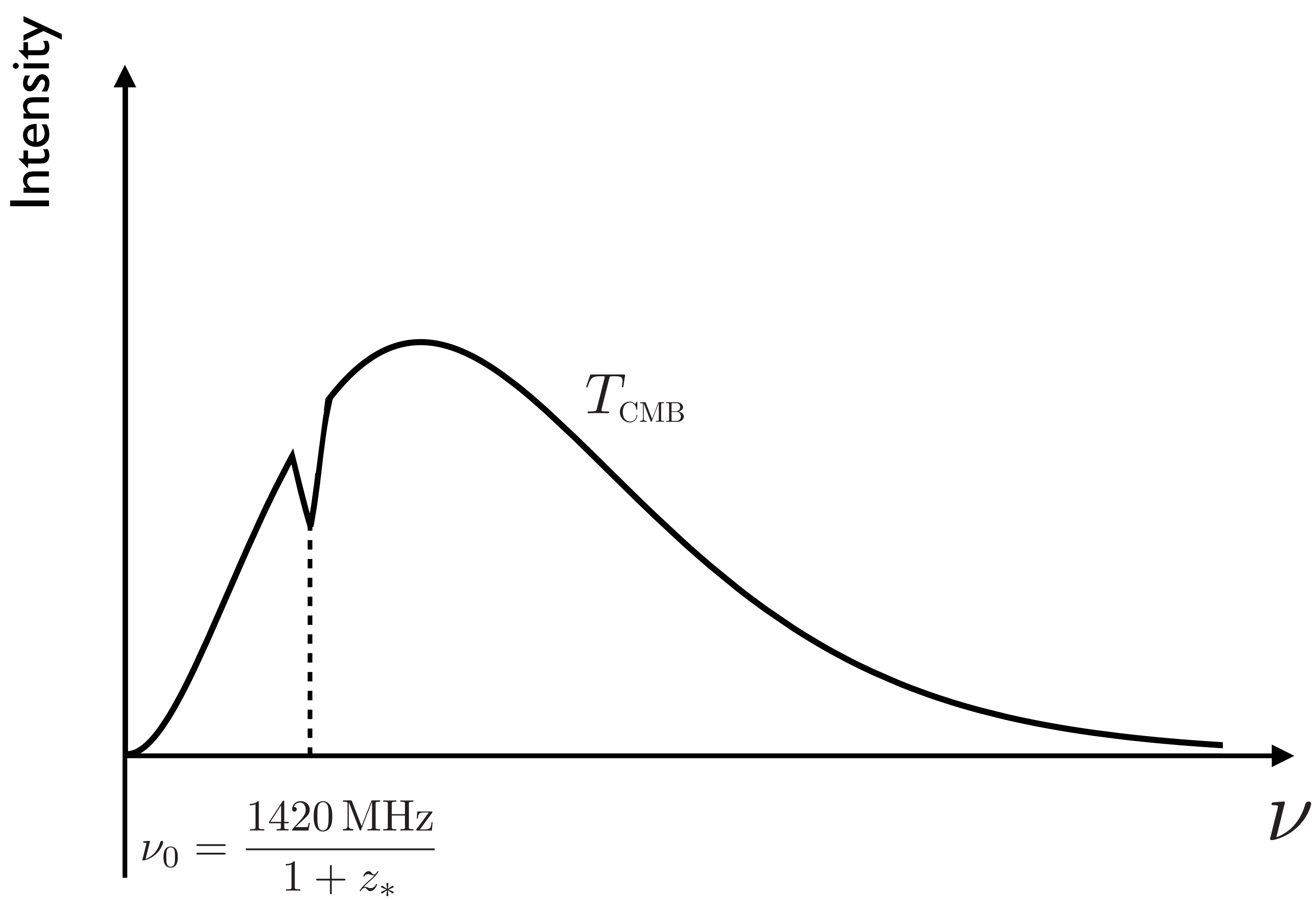

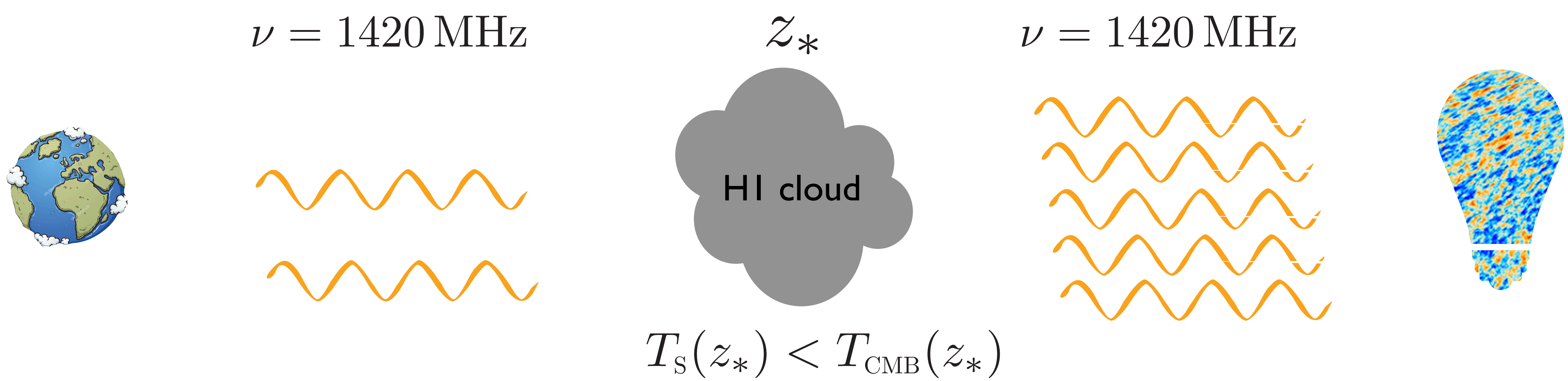

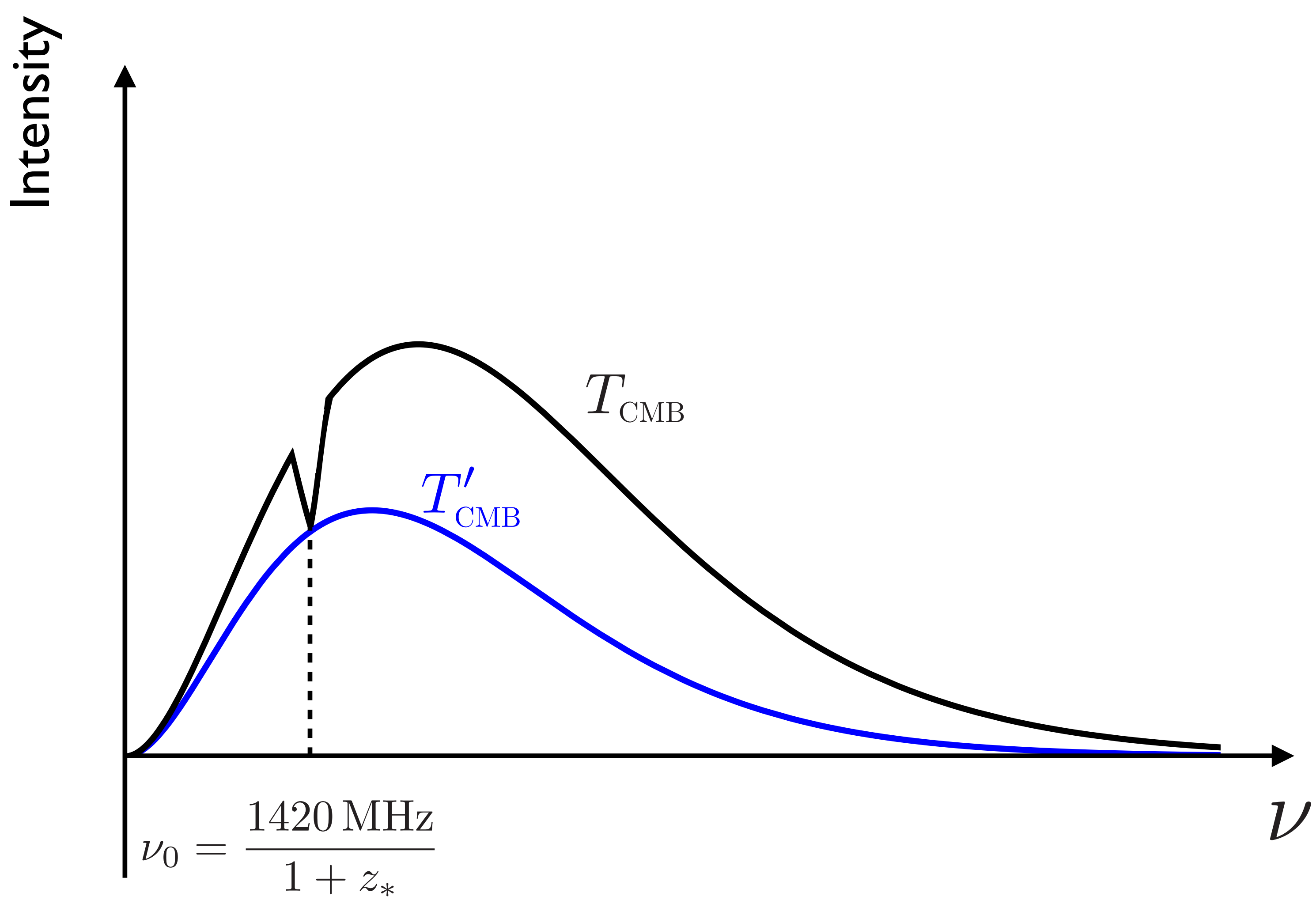

$$\boxed{\delta T_b \equiv T'_{\rm CMB} - T_{\rm CMB}}$$

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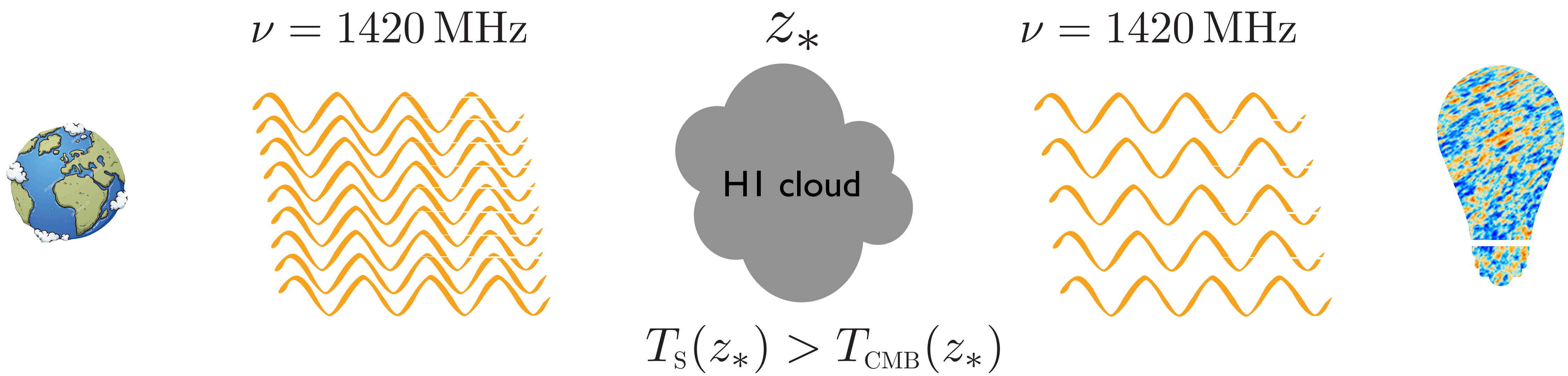

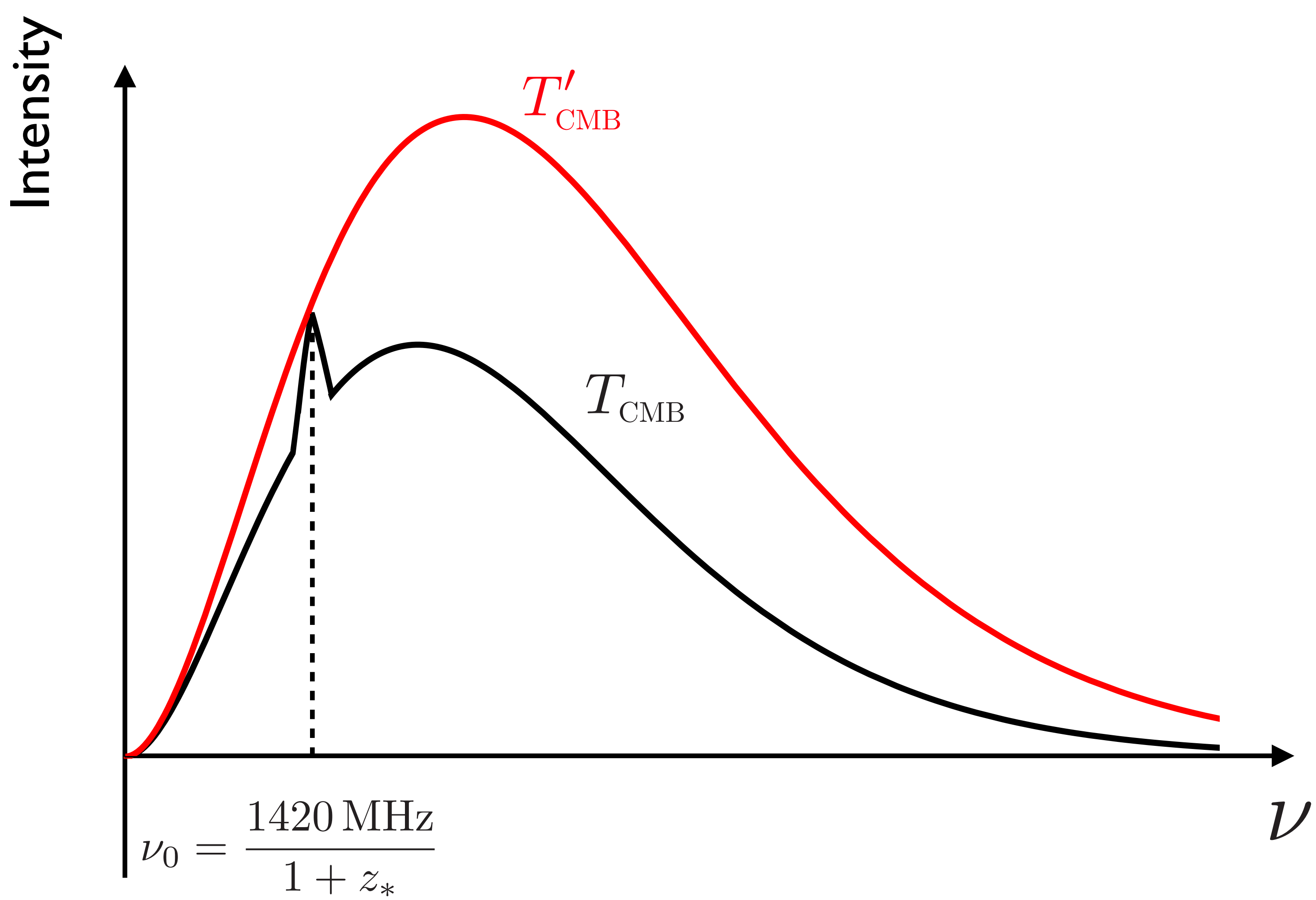

$$\boxed{\delta T_b \equiv T'_{\mathrm{CMB}} - T_{\mathrm{CMB}}}$$

the form of the signal

$T_{\rm S} > T_{\rm CMB}$ emission signal

$T_{\rm S} = T_{\rm CMB}$ NO signal

$T_{\rm S} < T_{\rm CMB}$ absorption signal

the dependence from cosmological parameters

Ω_b and Ω_m

is omitted

$$\delta T_b = 27\, x_{\rm HI} \left(1 - \frac{T_{\rm CMB}(z)}{T_{\rm S}(z)}\right) \sqrt{\frac{1+z}{10}}\, {\rm mK}$$

location of the line ⟷ when

$$1 + z_* = \frac{1420\,{\rm MHz}}{\nu_0}$$

strength of the line

↕

gas properties

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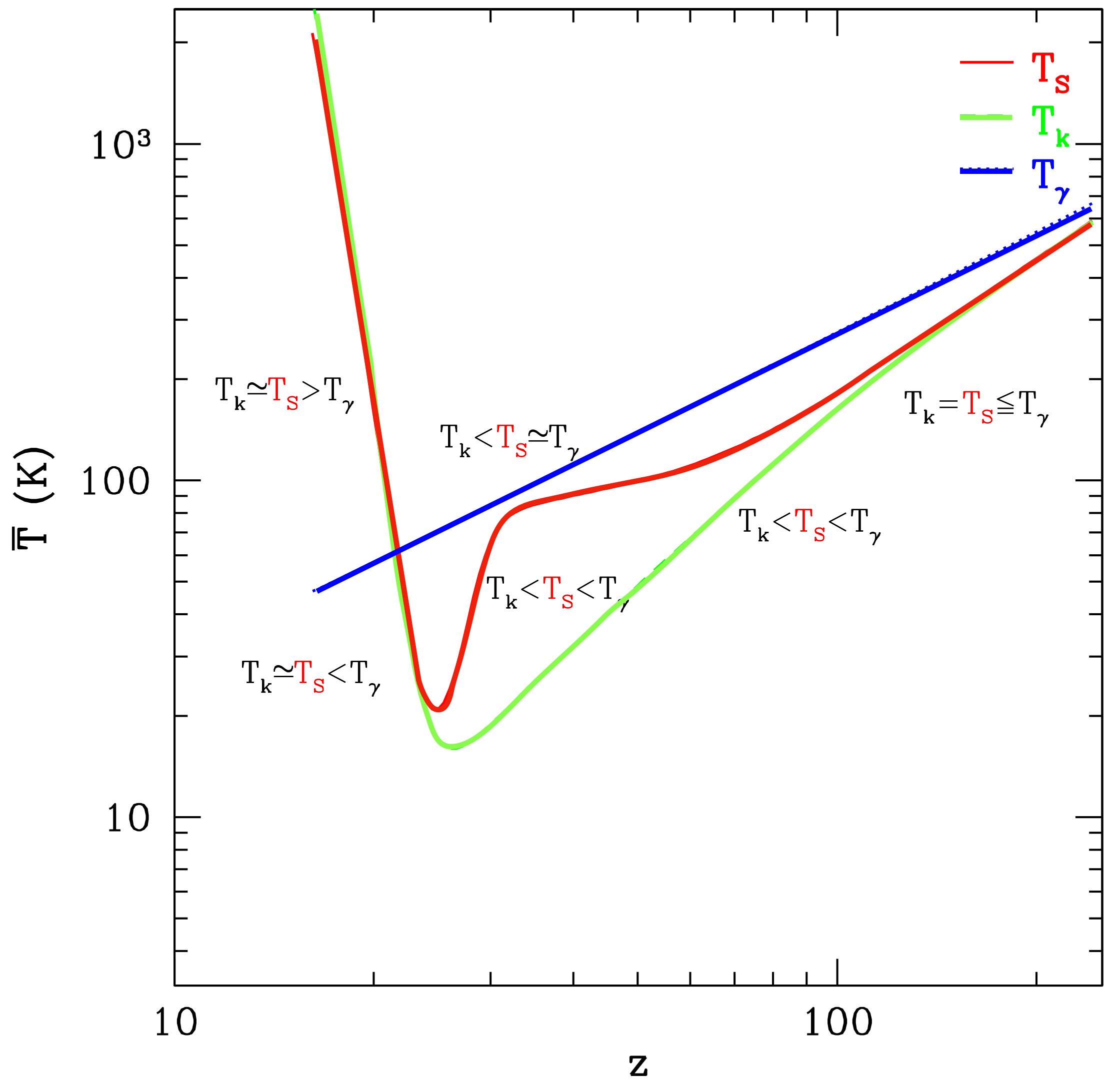
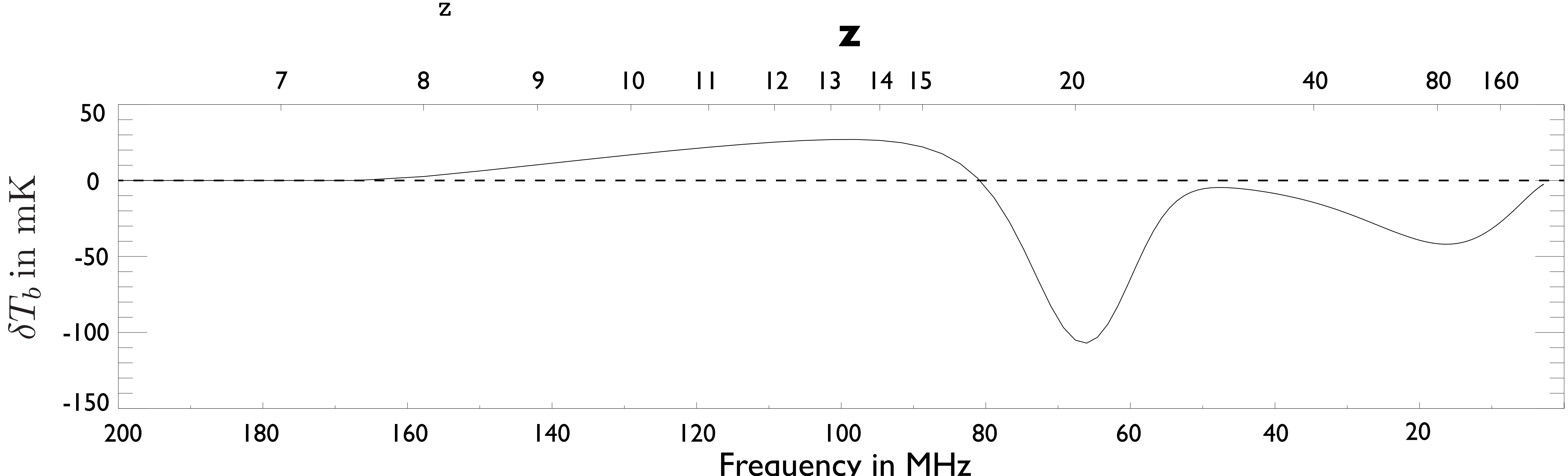
the fiducial scenario



$$T_{\mathrm{CMB}} \propto (1+z) \qquad T_{\mathrm{gas}} \propto (1+z)^2$$

$$T_{\mathrm{gas}} \leq T_{\mathrm{S}} \leq T_{\mathrm{CMB}}$$



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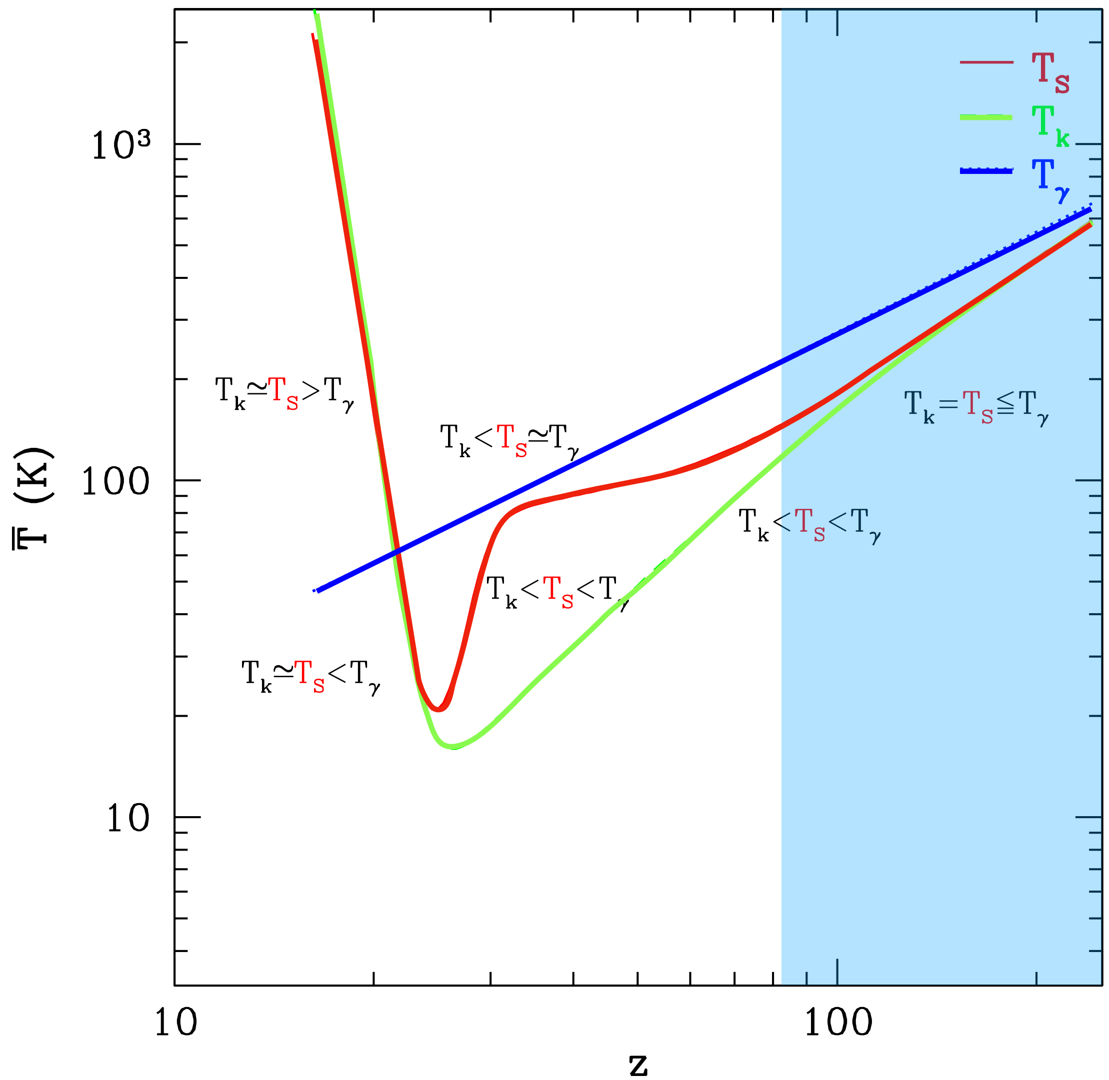
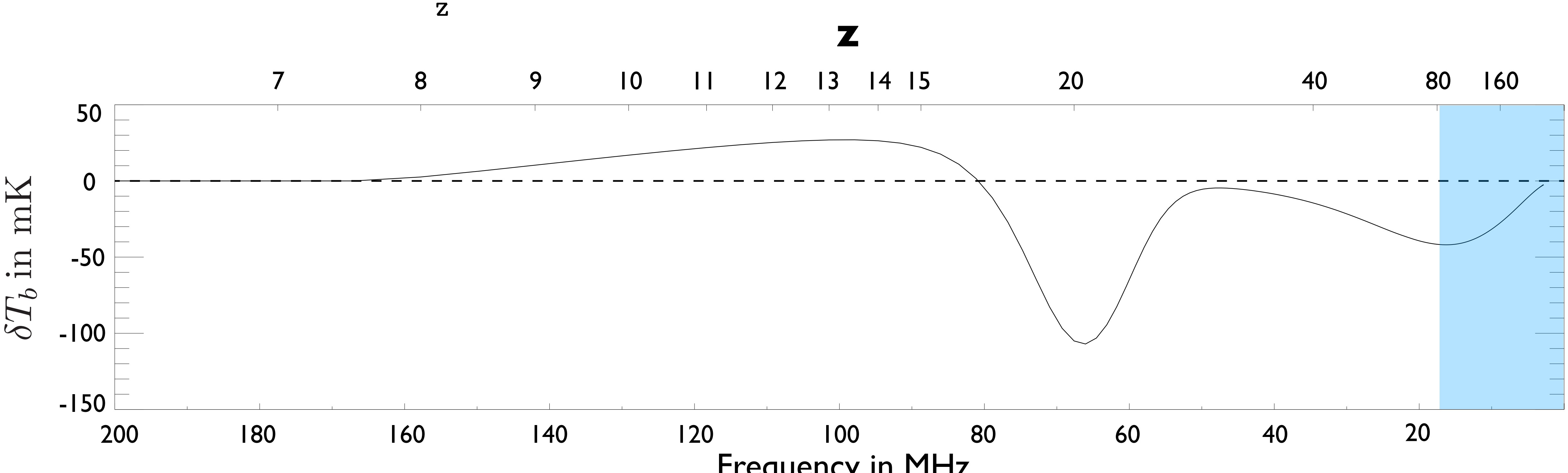


$T_{\mathrm{CMB}} \propto (1+z)$ $\quad$ $T_{\mathrm{gas}} \propto (1+z)^2$

$$T_{\mathrm{gas}} \leq T_{\mathrm{S}} \leq T_{\mathrm{CMB}}$$

IGM is very dense and collisional coupling is effective

$$T_{\mathrm{S}} \simeq T_{\mathrm{gas}}$$



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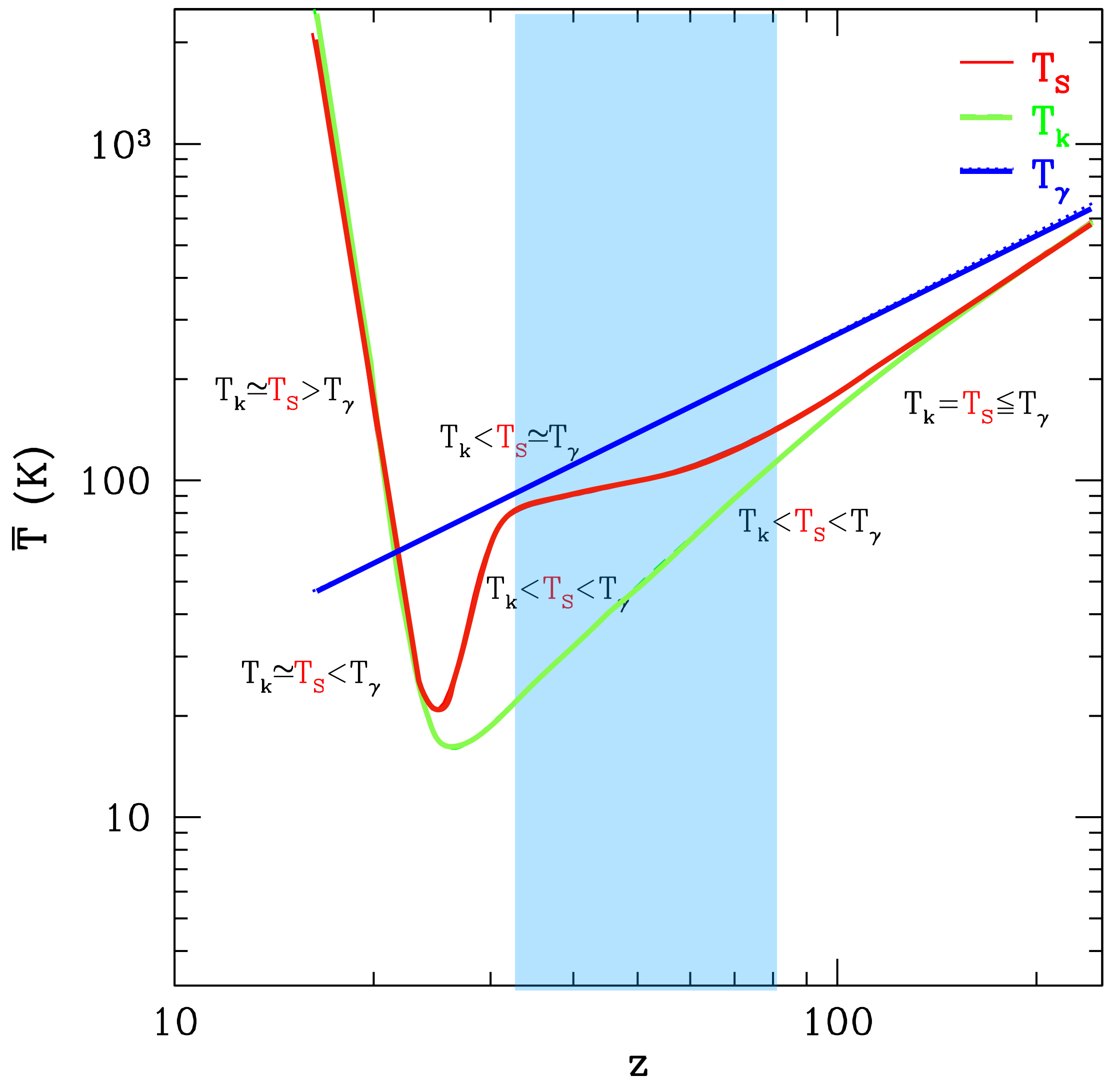
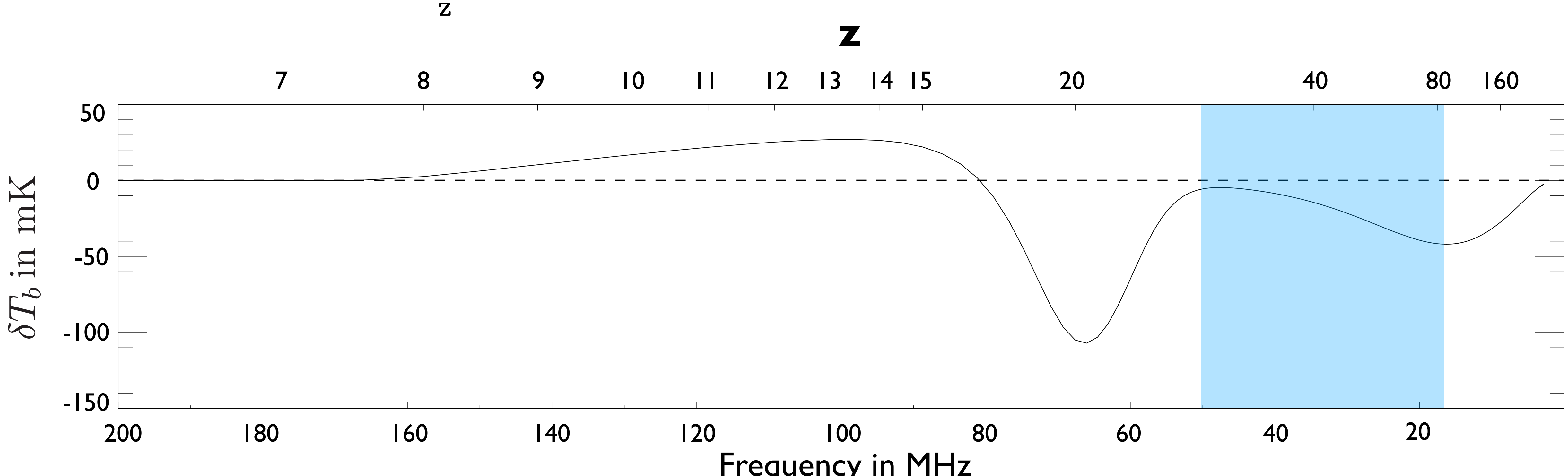


$T_{\rm CMB} \propto (1+z)$ $T_{\rm gas} \propto (1+z)^2$

$$T_{\rm gas} \leq T_{\rm S} \leq T_{\rm CMB}$$

IGM dilutes and collisional coupling becomes ineffective. CMB photons drive

$$T_{\rm S} \rightarrow T_{\rm CMB}$$



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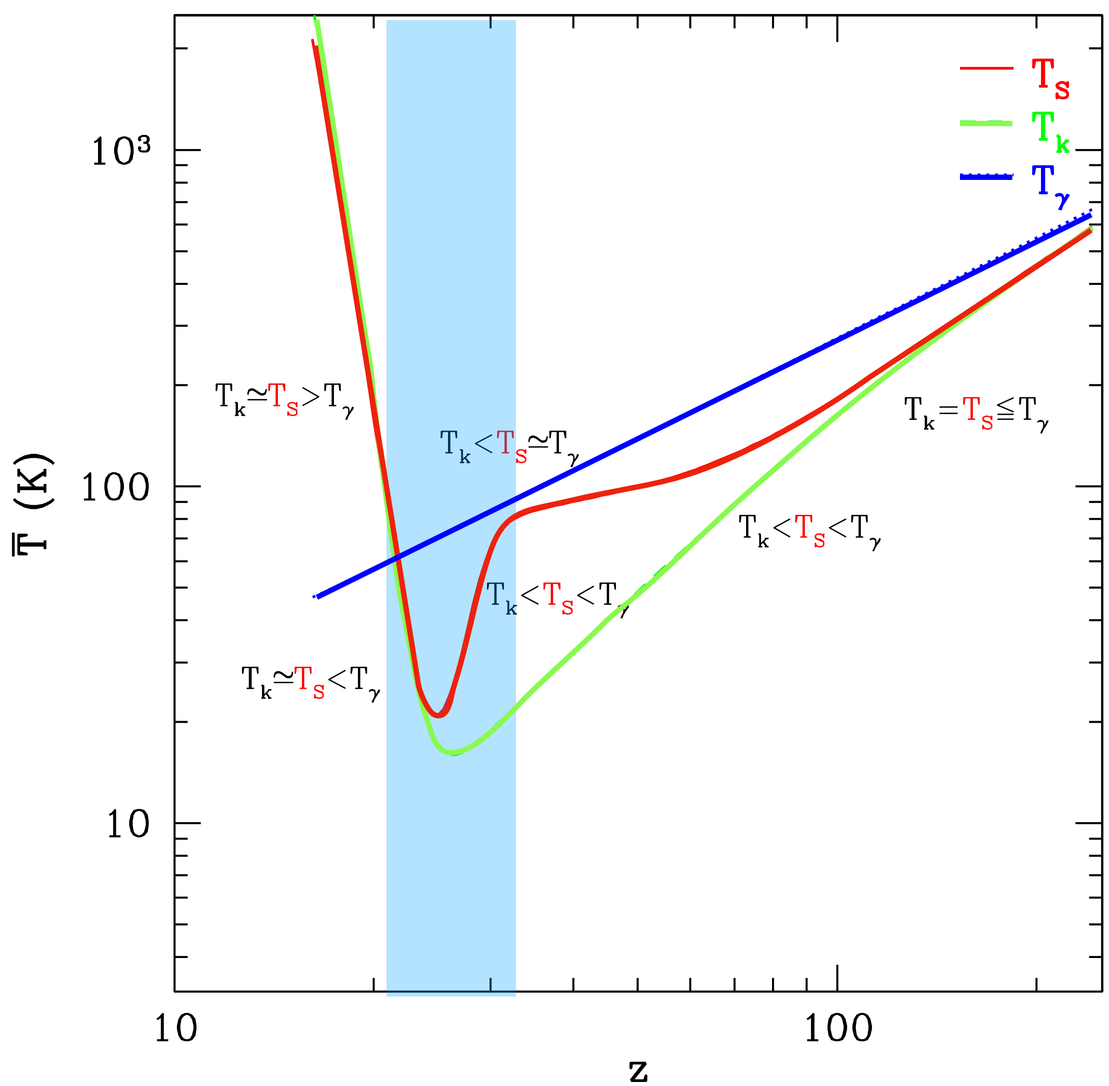
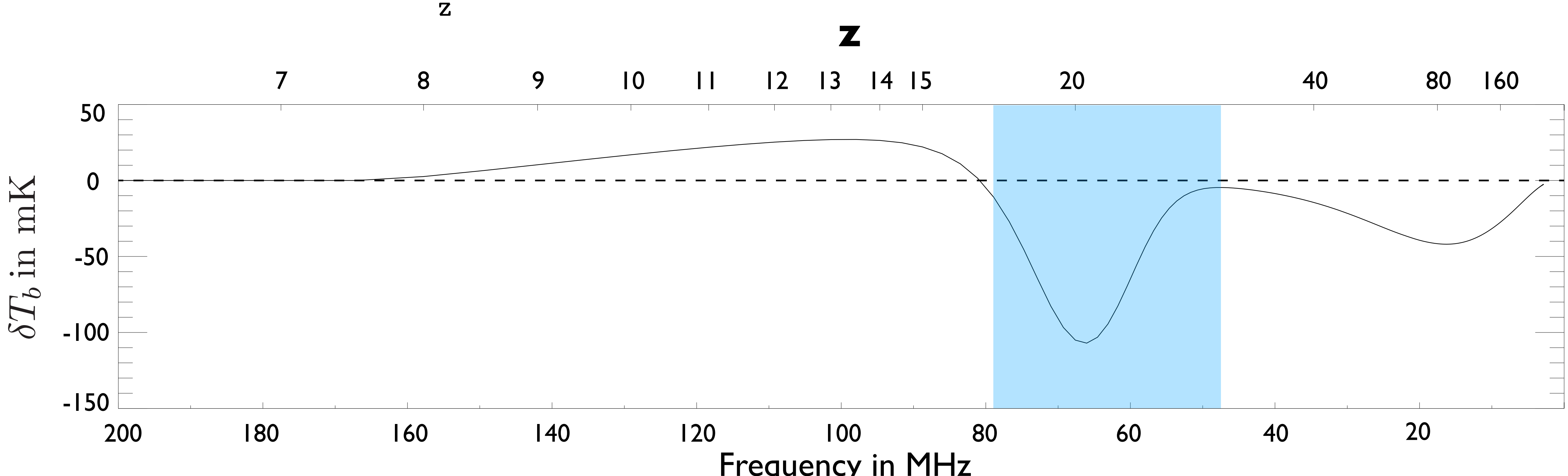


$$T_{\rm CMB} \propto (1+z) \qquad T_{\rm gas} \propto (1+z)^2$$

$$T_{\rm gas} \leq T_{\rm S} \leq T_{\rm CMB}$$

Lyα photons emitted by first stars drive

$$T_{\rm S} \rightarrow T_{\rm gas}$$



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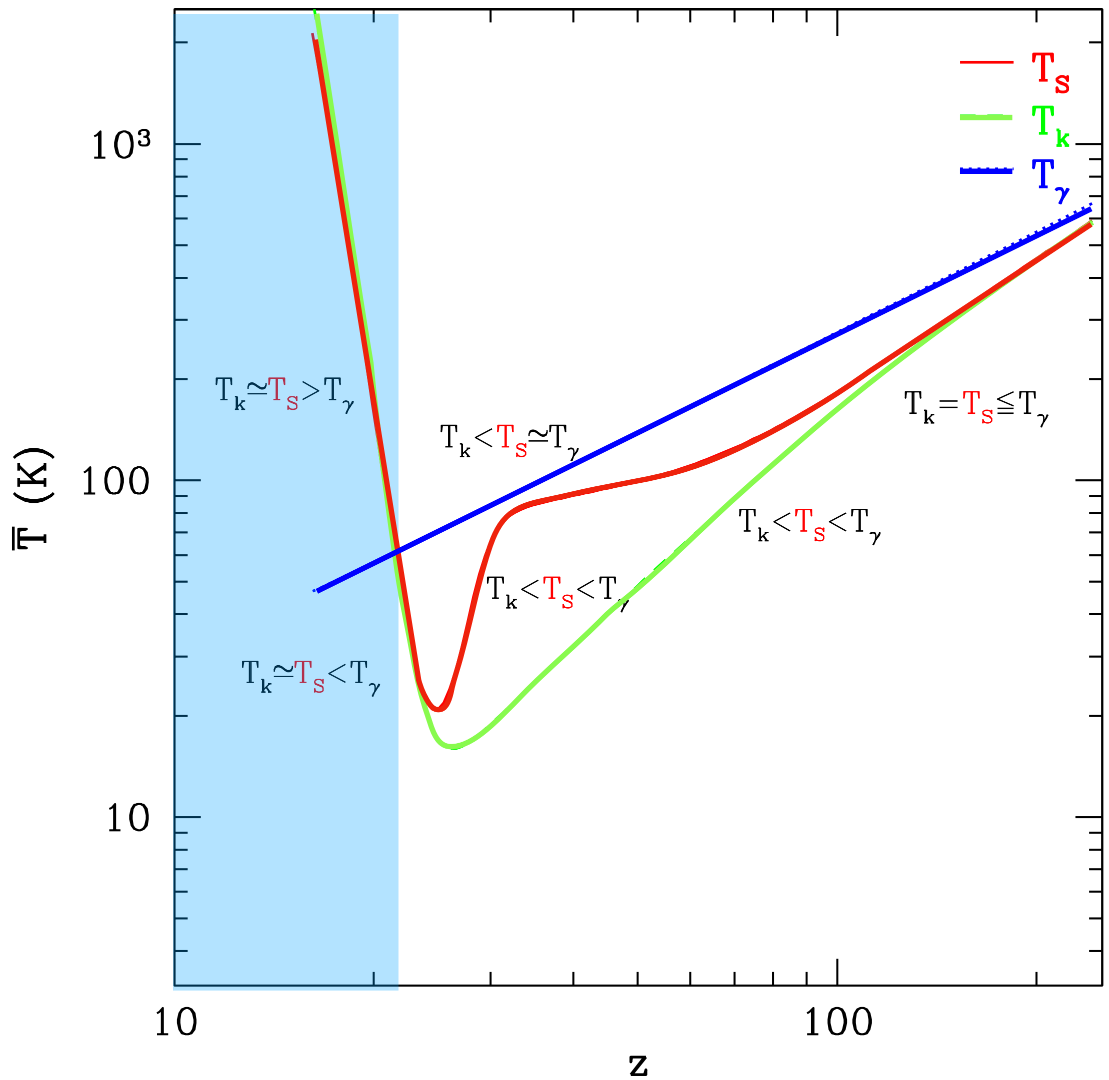


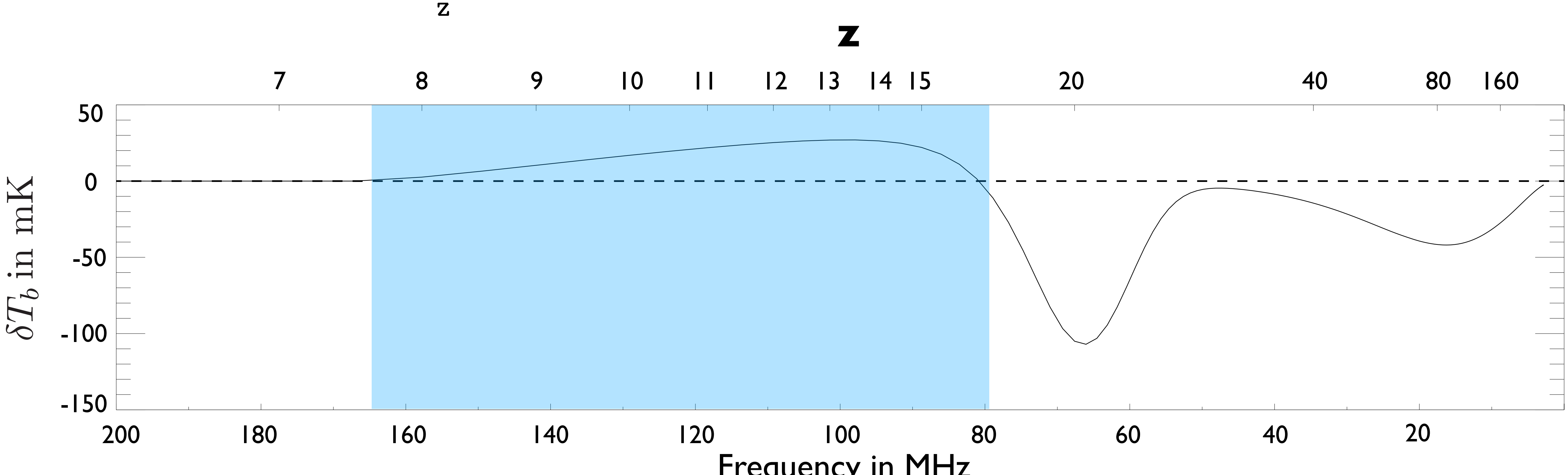
$T_{\rm CMB} \propto (1+z)$ $T_{\rm gas} \propto (1+z)^2$

$$T_{\rm gas} \leq T_{\rm S} \leq T_{\rm CMB}$$

X-rays emitted by the first stars heath the IGM

$$T_{\rm K} > T_{\rm CMB}$$

and, at the same time, re-ionize the gas



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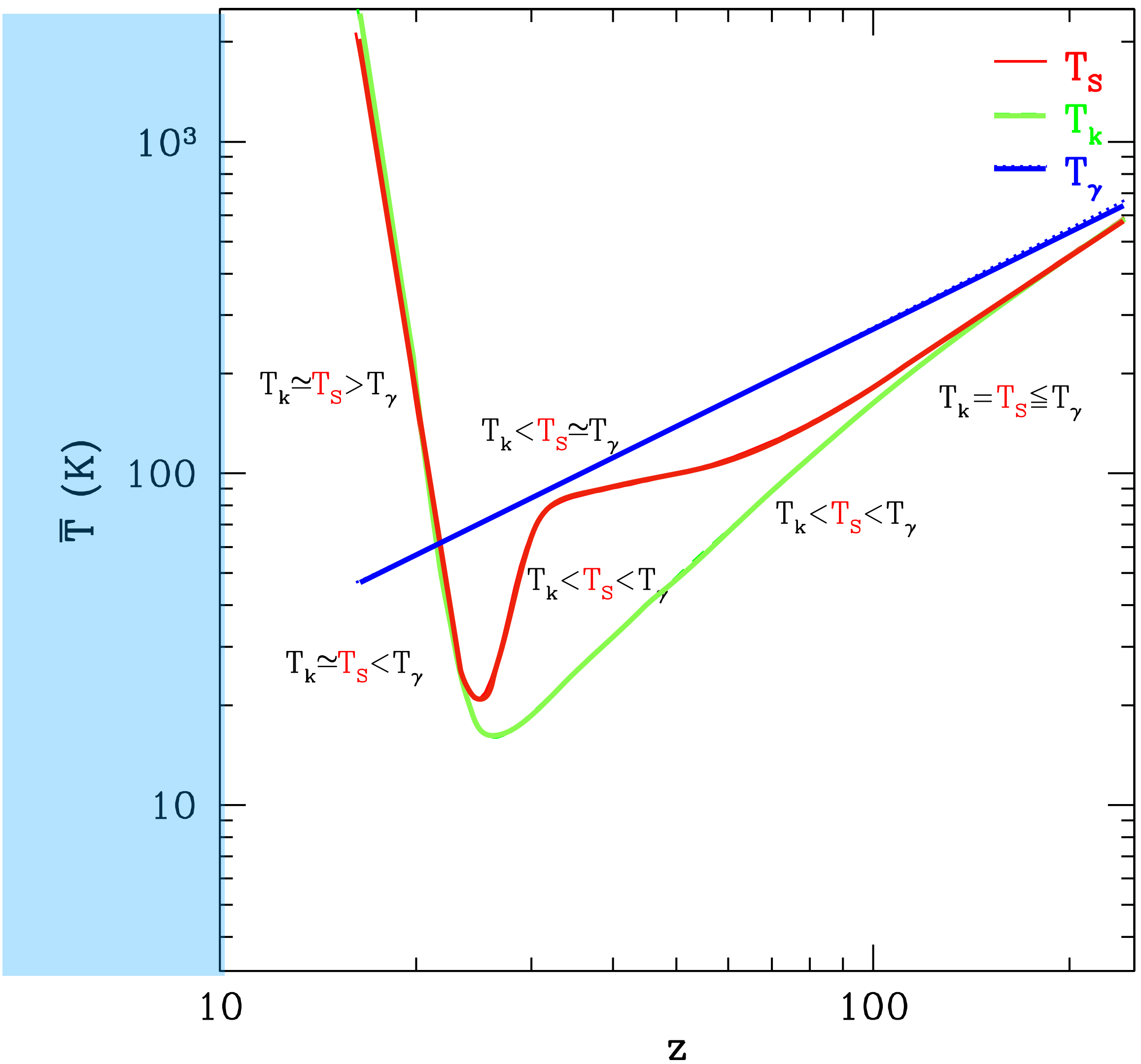
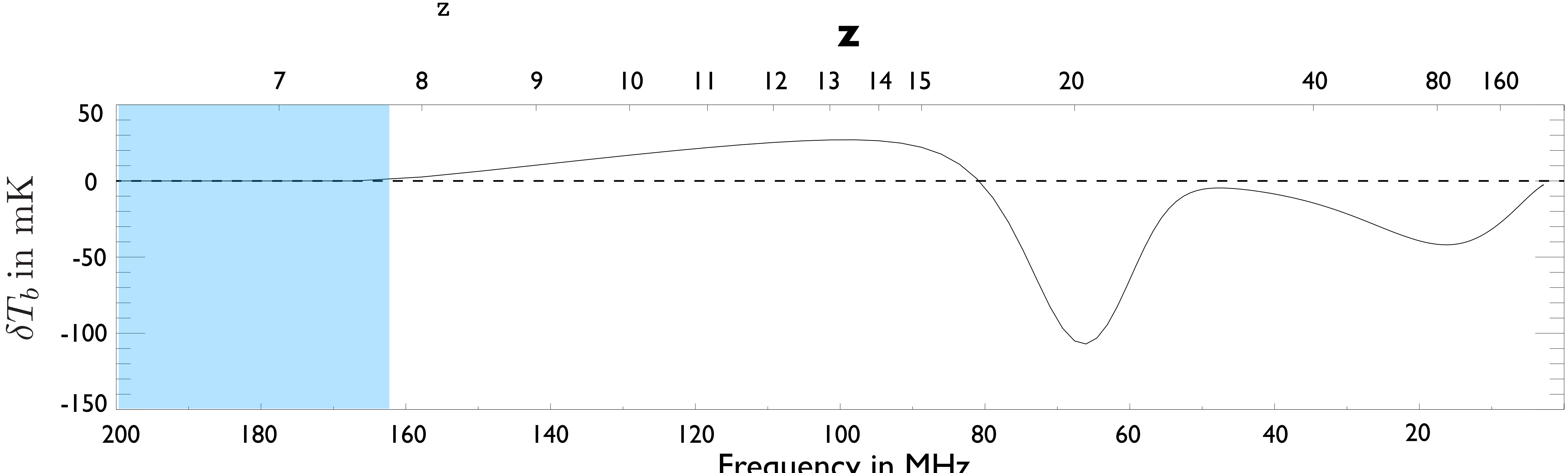


$T_{\mathrm{CMB}} \propto (1+z)$ $T_{\mathrm{gas}} \propto (1+z)^2$

$$T_{\mathrm{gas}} \leq T_{\mathrm{S}} \leq T_{\mathrm{CMB}}$$

re-ionization is completed and there is no more neutral Hydrogen



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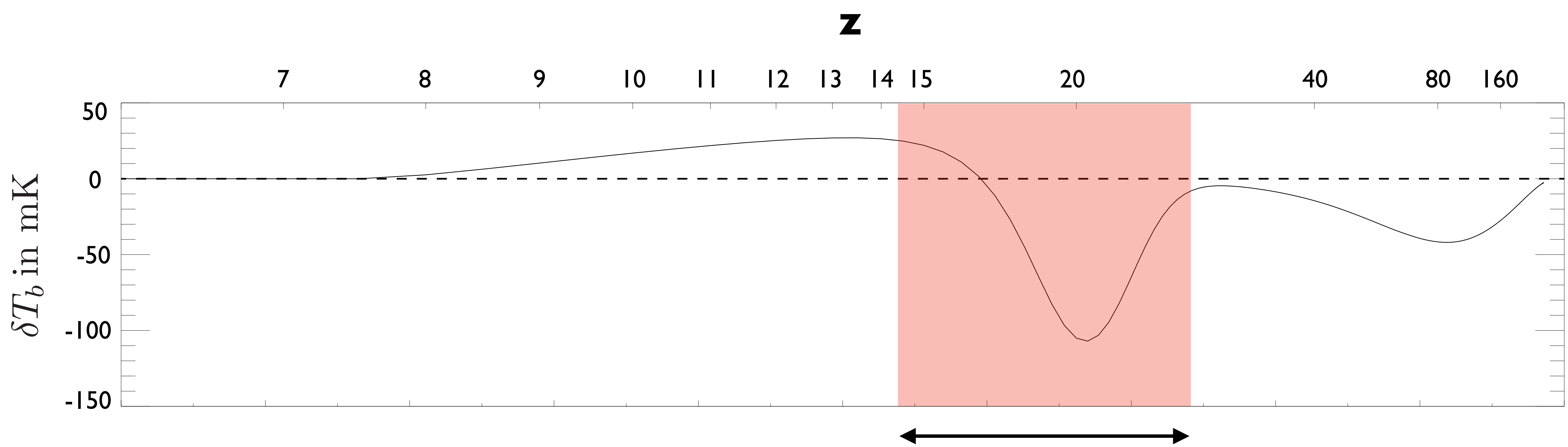
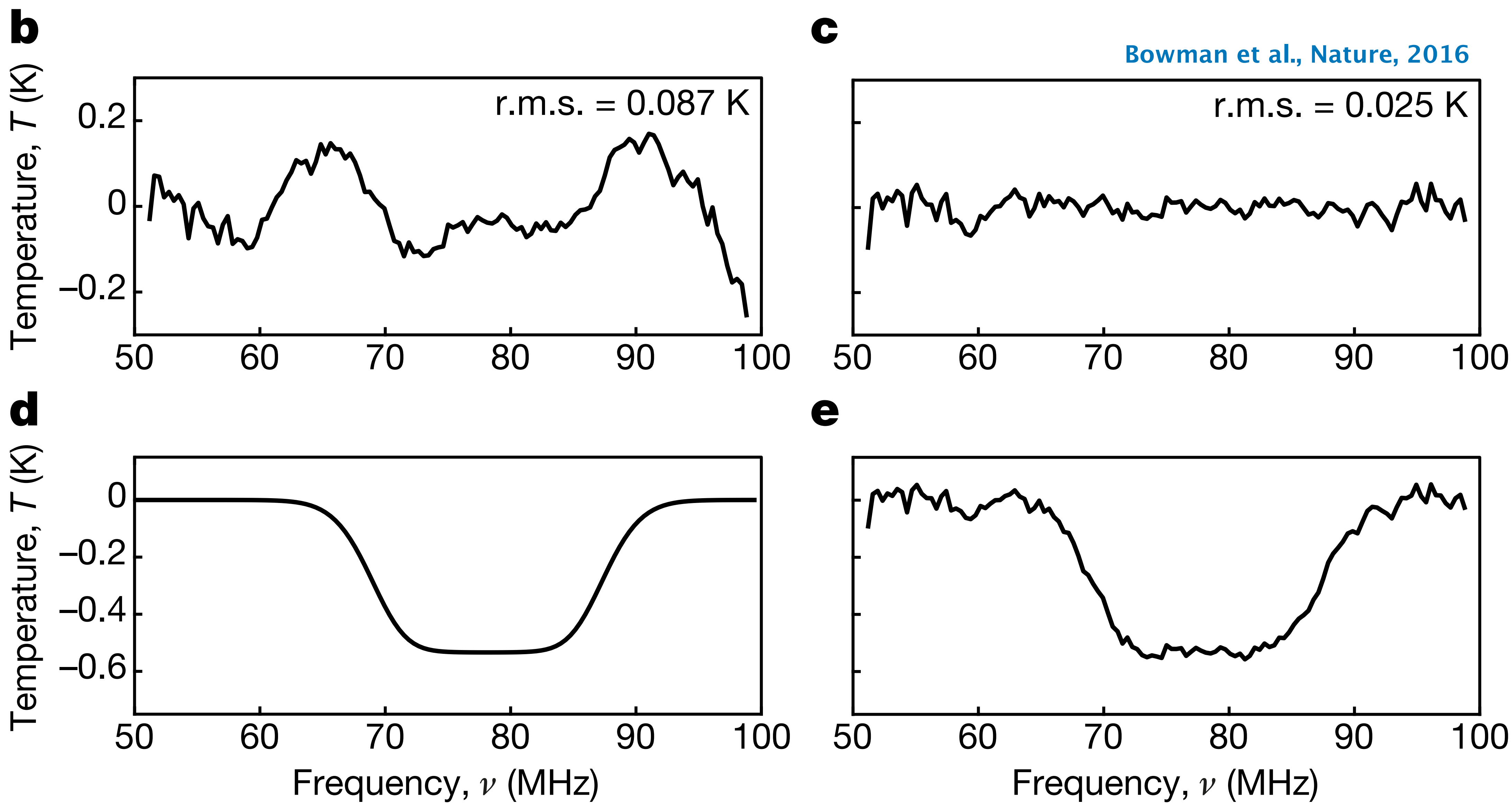
The EDGES result

where EDGES is looking



$$50\,\mathrm{MHz} < \nu < 100\,\mathrm{MHz}$$

absorption feature centered around 78MHz

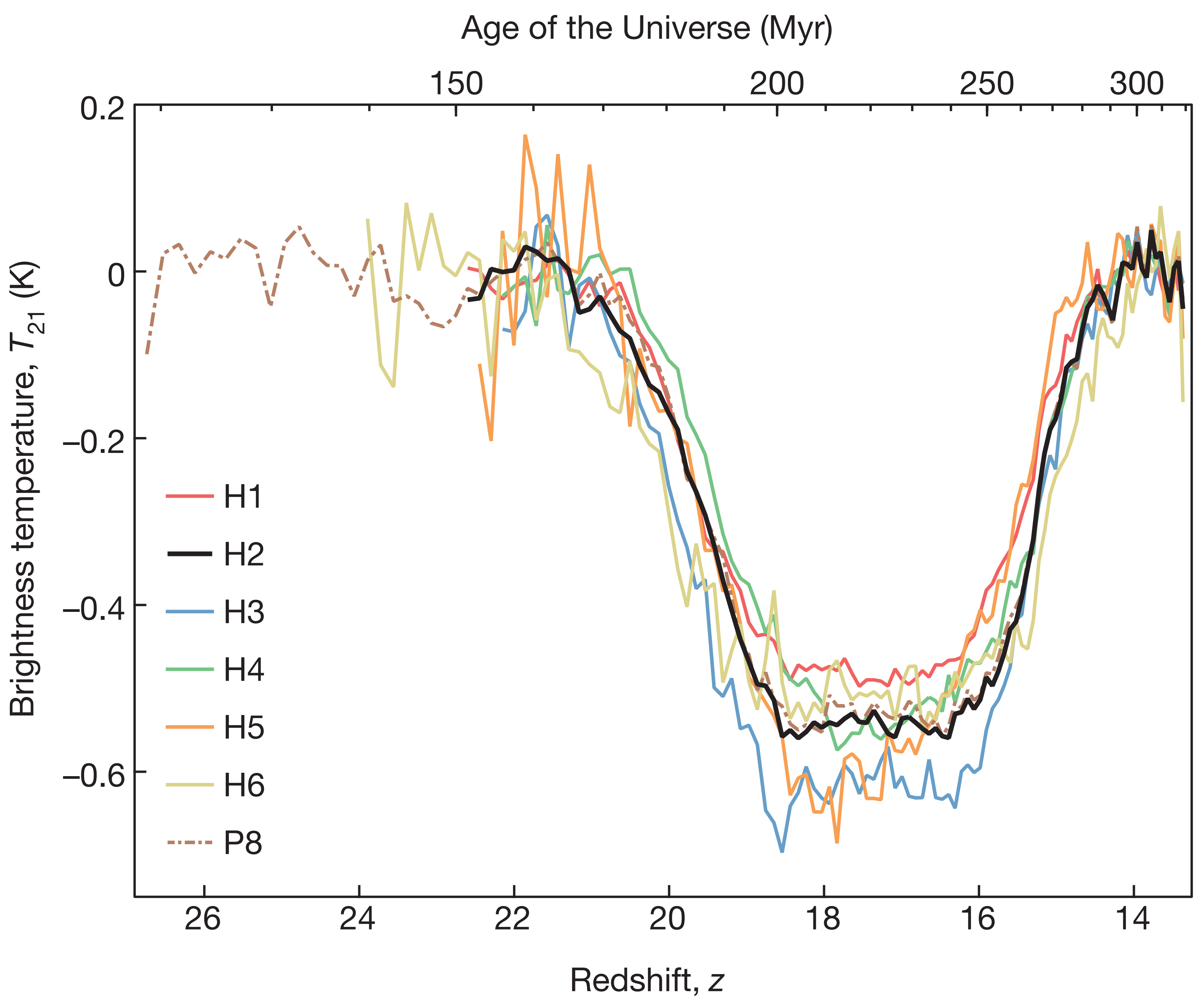


signal is anomalously large

$$(\delta T_b)_{\rm obs} \simeq -500^{+200}_{-500}\,{\rm mK} \qquad (\delta T_b)_{\rm exp} \simeq -220\,{\rm mK}$$

what EDGES see

or in terms of redshift around $z \sim 17$



Bowman et al., Nature, 2016

How we put bounds

the energy released in DM decays heat the IGM

$$\left(\frac{dE}{dV\,dt}\right)_{\rm deposited} = f(z, M_{\rm DM})\rho_{\rm DM,0}\ \tau_{\rm DM}^{-1}(1+z)^3$$

$$\frac{dT_{\rm gas}}{dz} = \frac{1}{1+z}\left[2T_{\rm gas} - \gamma_{\rm C}\left(T_{\rm CMB}(z) - T_{\rm gas}\right)\right] + \\ - \frac{1}{(1+z)H(z)}\frac{1+2x_e}{3n_{\rm H}}\frac{2}{3\,(1+x_e+f_{\rm He})}\left(\frac{dE}{dV\,dt}\right)_{\rm deposited}$$

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adiabatic cooling

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Compton coupling

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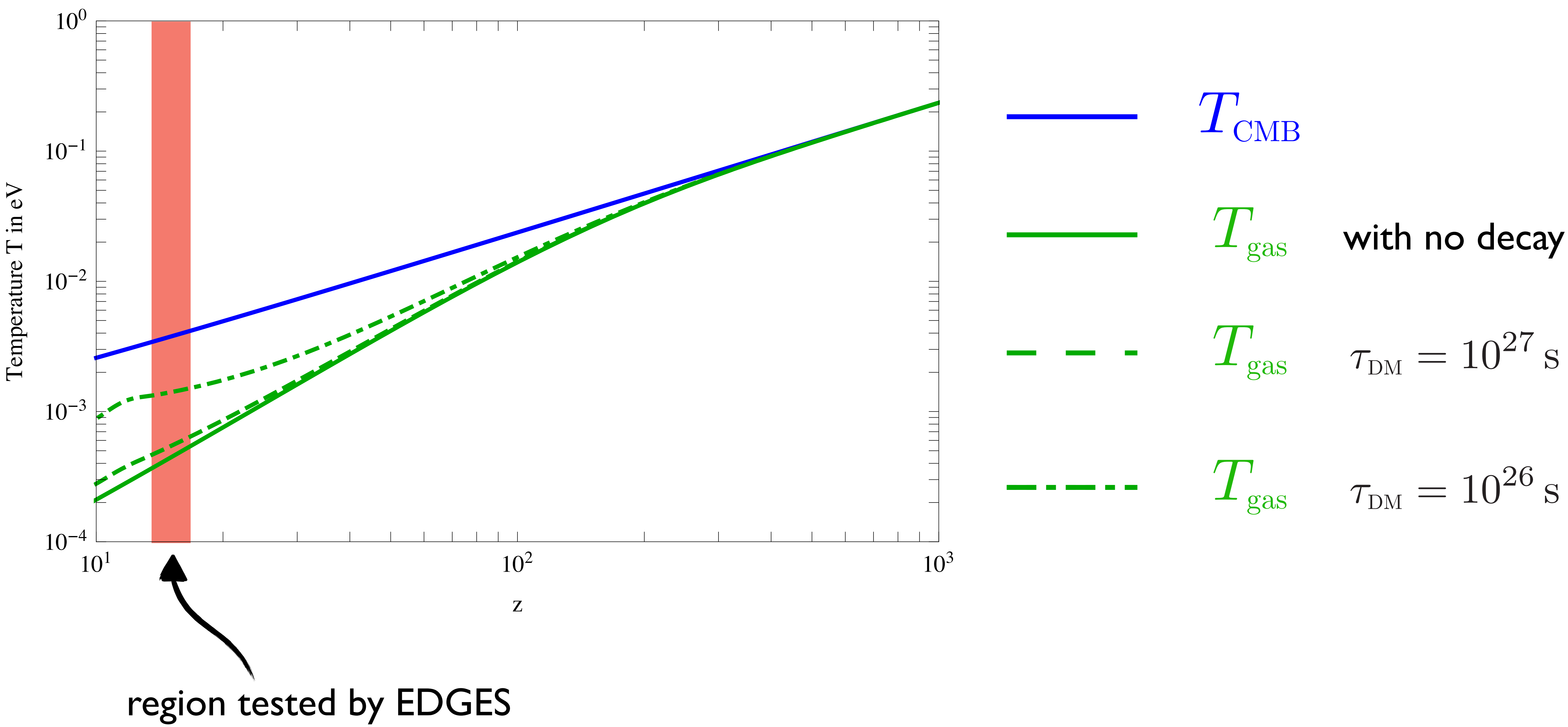
DM decays

the faster DM decays, the more it heats the IGM



DM decays VS EDGES result

$$|\delta T_b(\nu \approx 78\,\mathrm{MHz})| \approx 36 \left|1 - \frac{\mathrm{T_{CMB}}(\mathrm{z} \approx 17)}{\mathrm{T_S}(\mathrm{z} \approx 17)}\right| \mathrm{mK}$$

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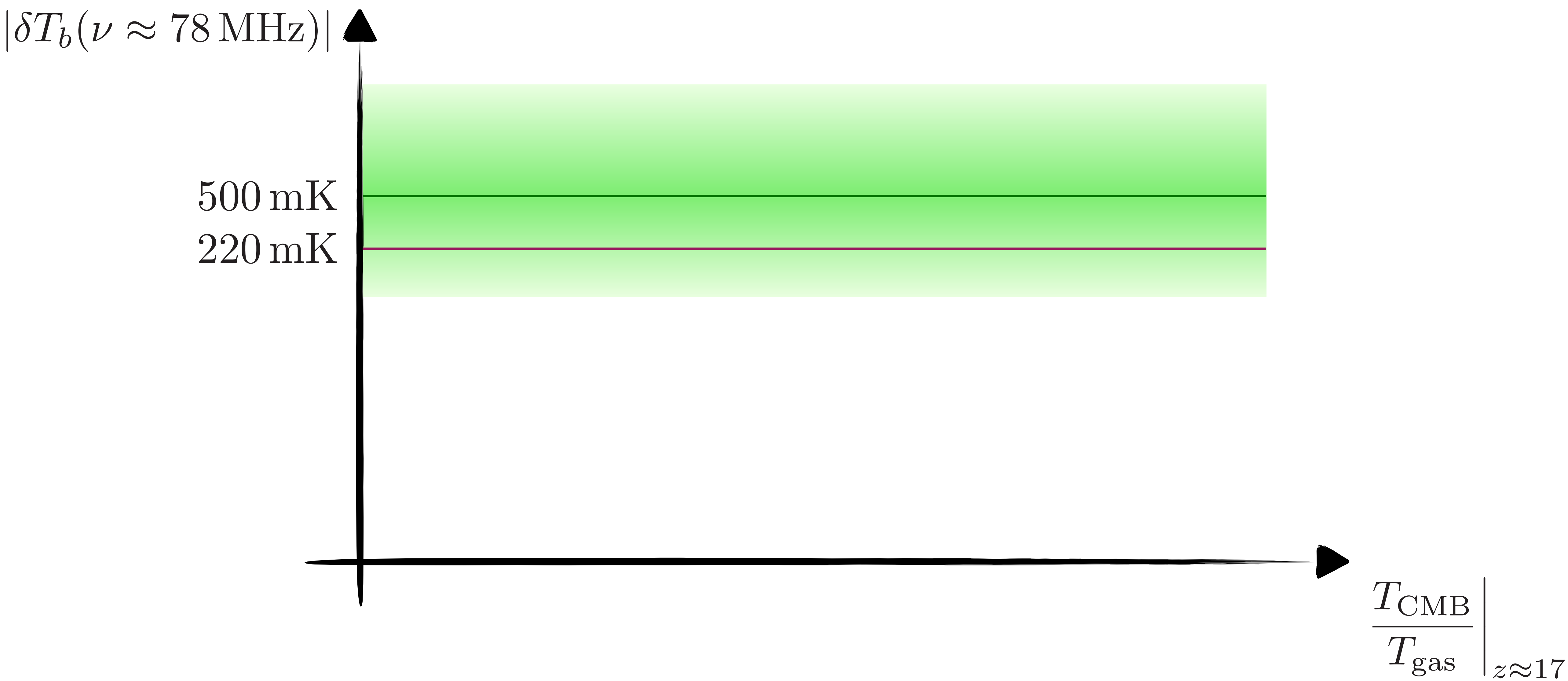

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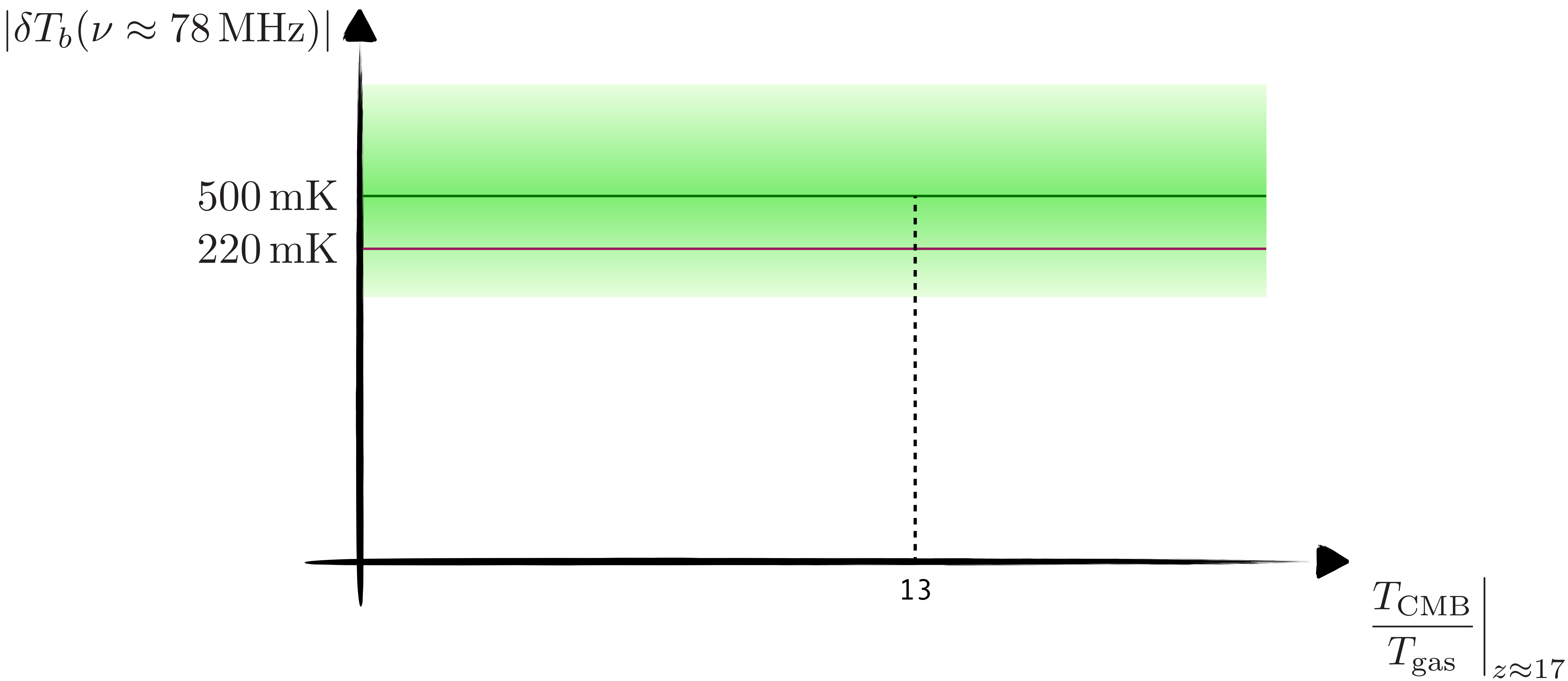

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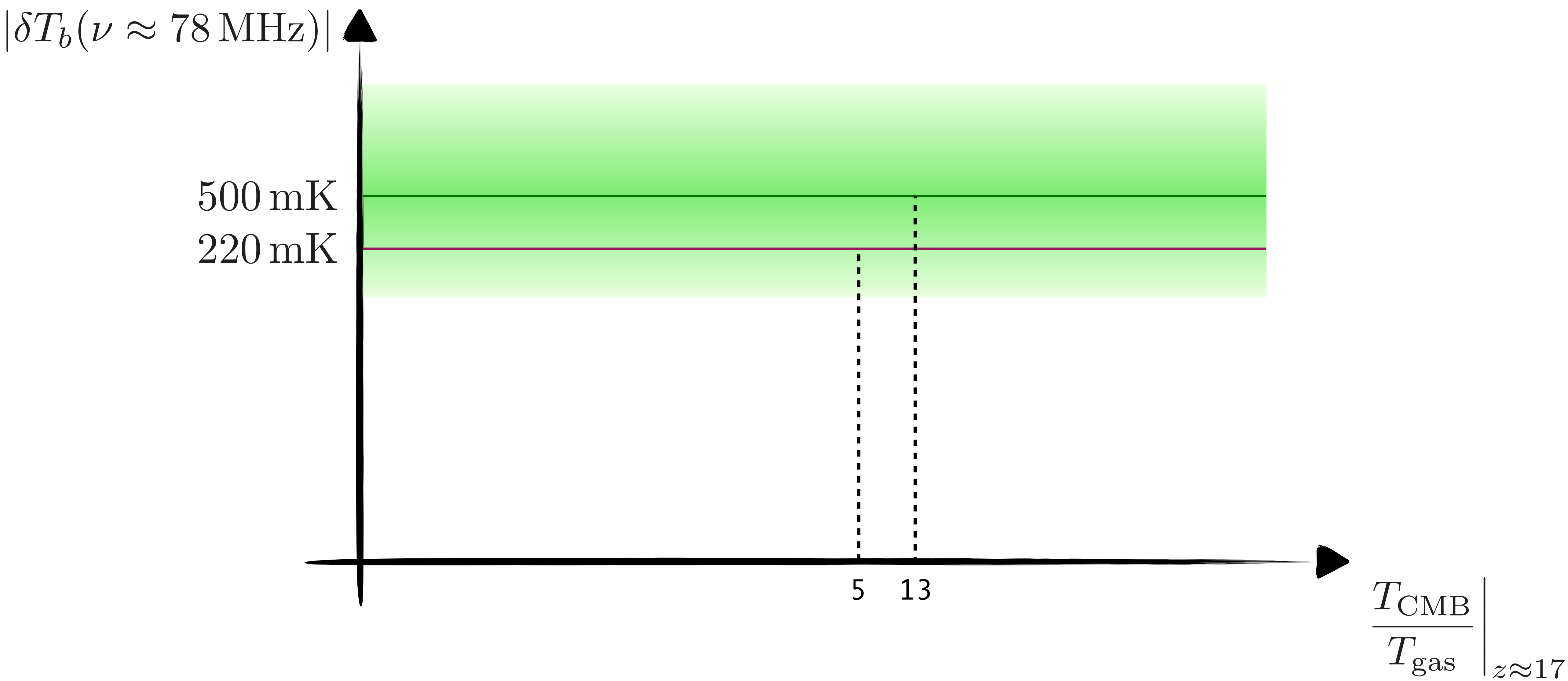

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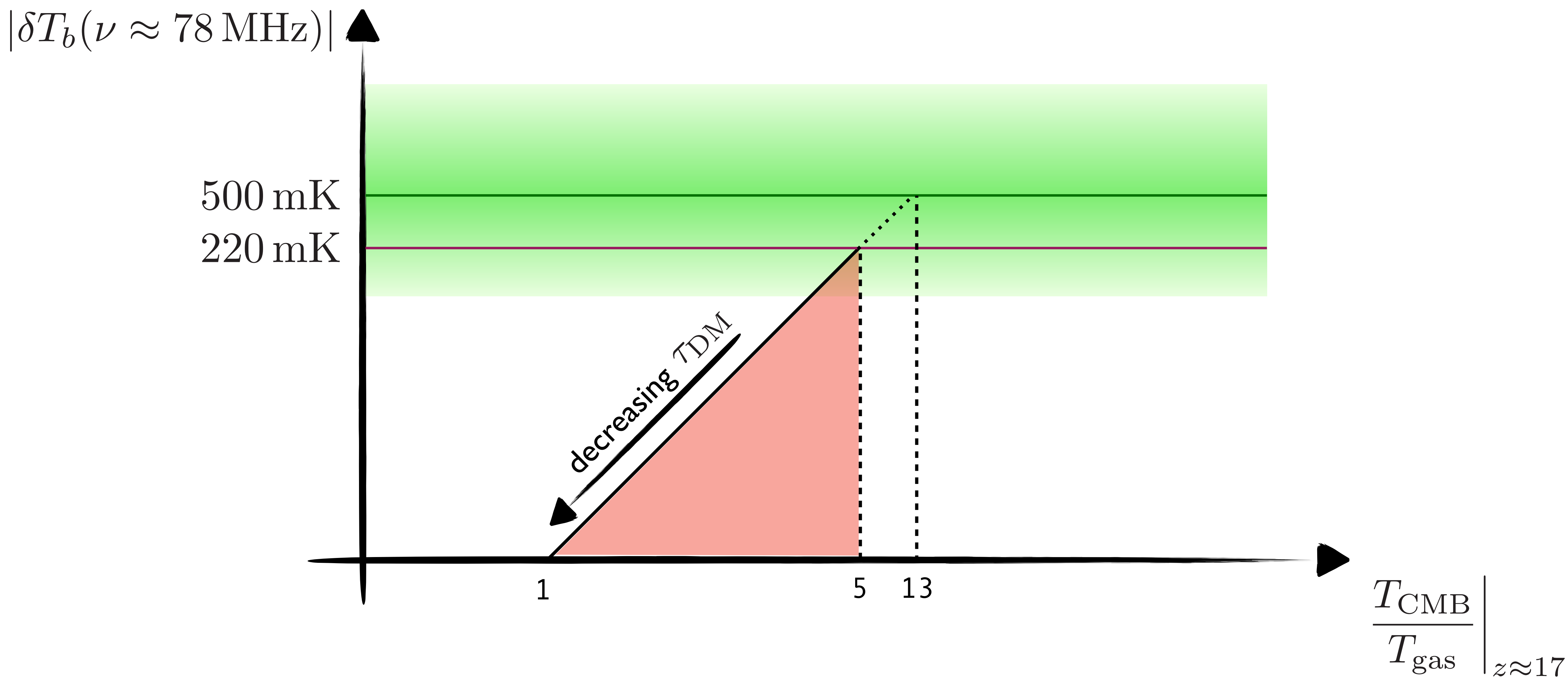
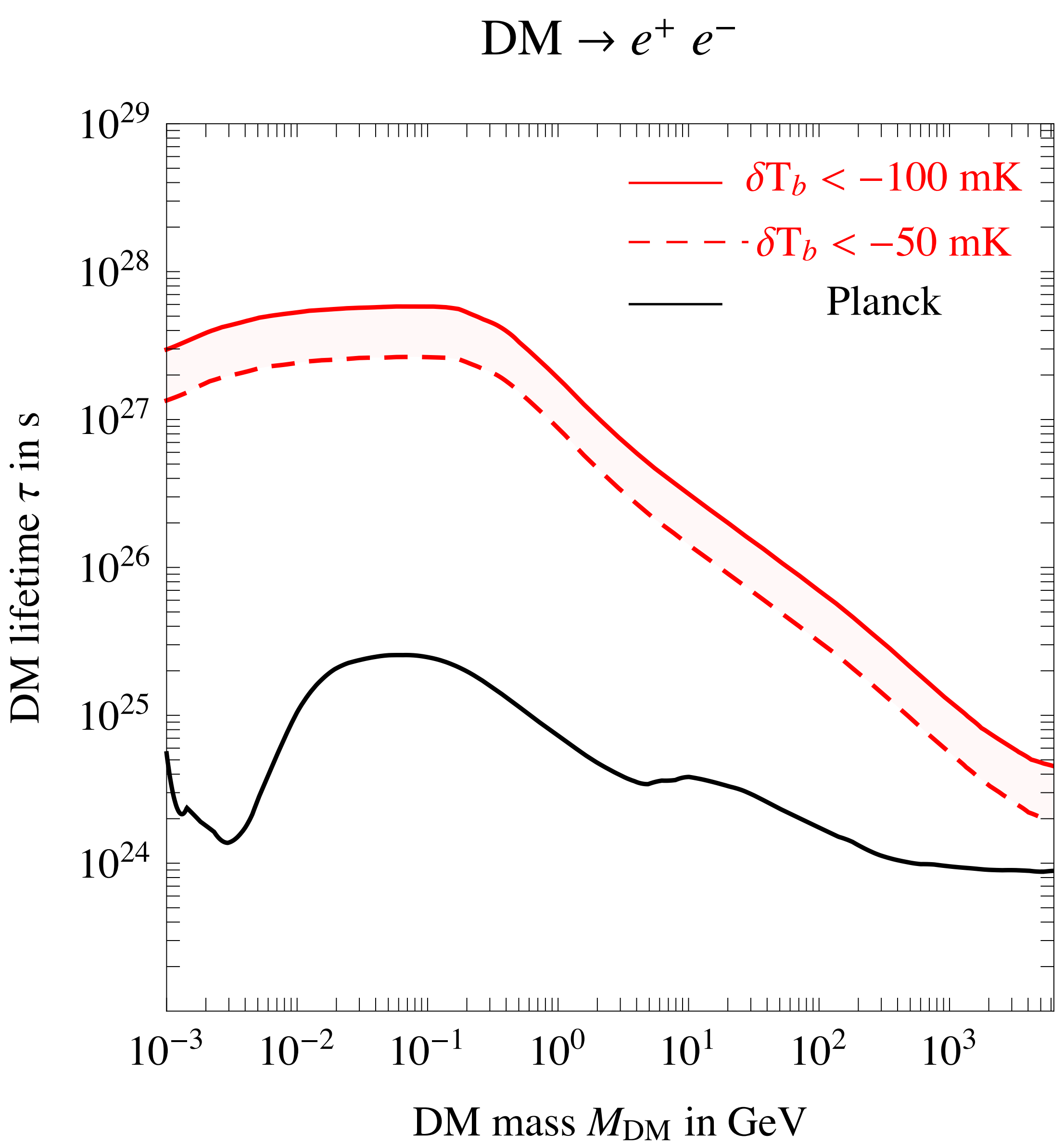
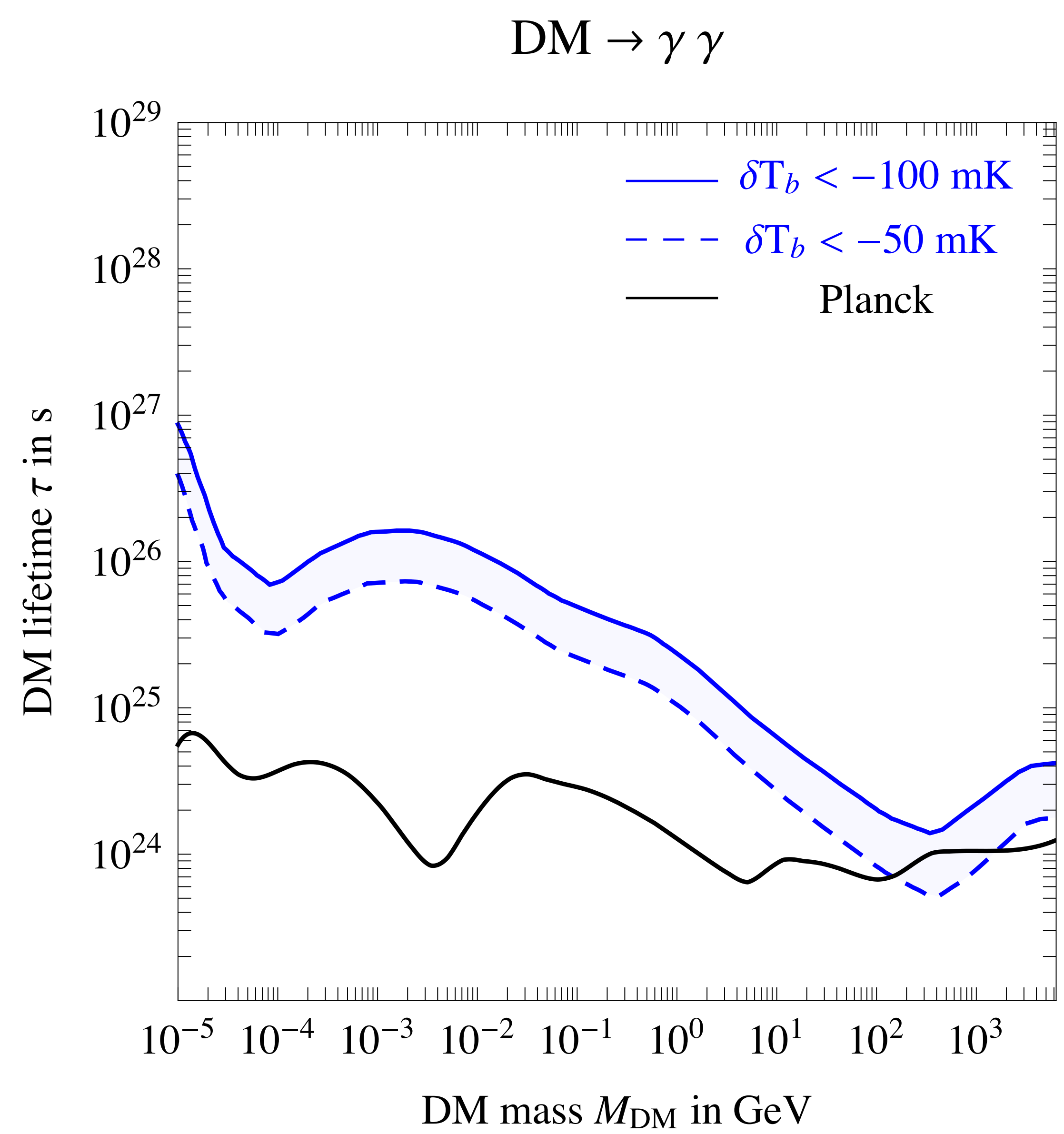


Our bounds

limits on the DM lifetime

we require that DM decays do not reduce the signal by more than a factor 2 or 4





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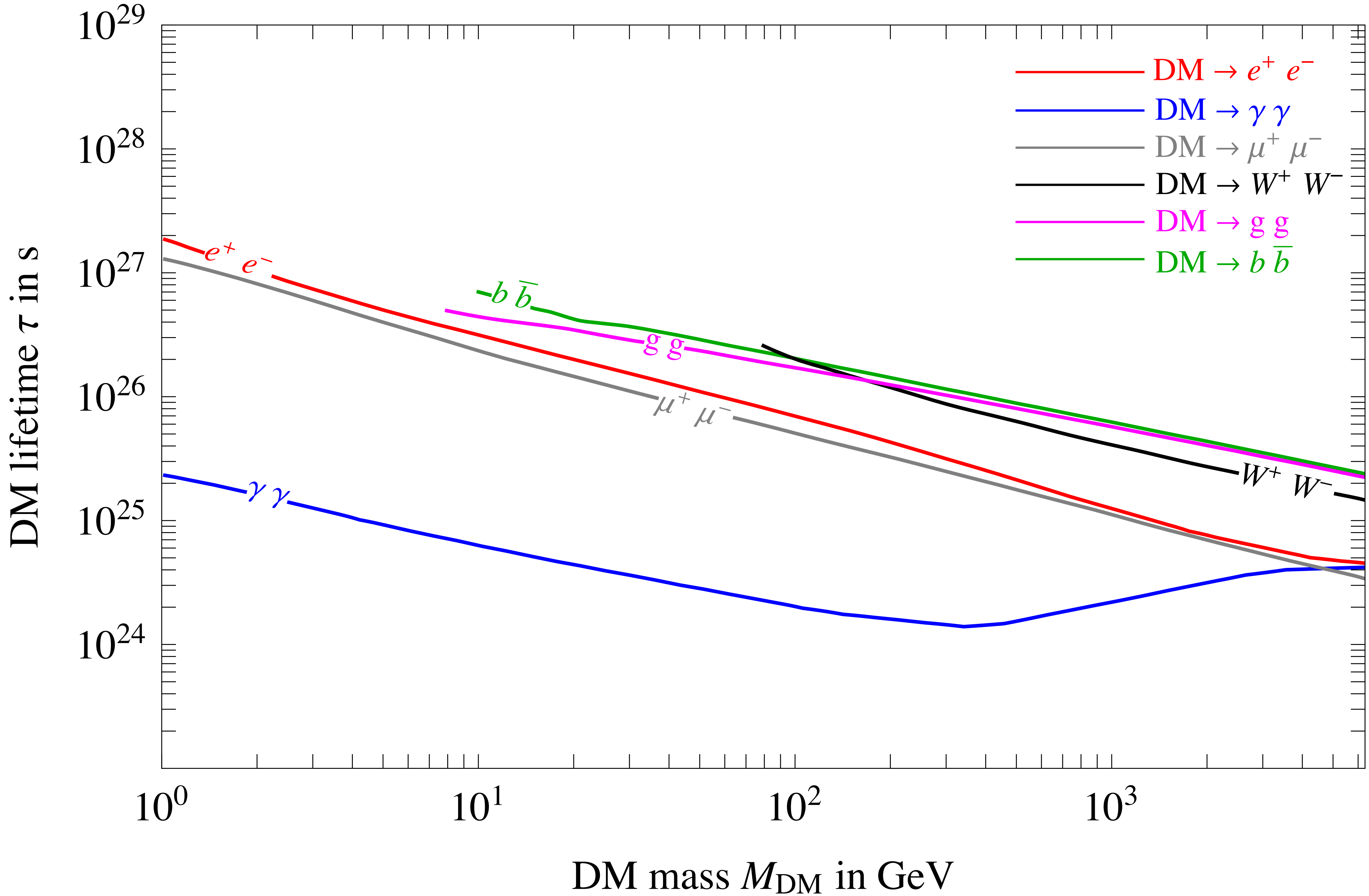

our assumptions

we ignore the anomalously large signal and assume EDGES is seeing $\delta T_b \gtrsim -220\,\mathrm{mK}$

we take $T_{\mathrm{S}} = T_{\mathrm{gas}}$

we ignore additional sources of heating

we ignore additional sources of cooling or non standard cosmology

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conclusions

we are able to constraint $\tau_{\rm DM}$ using the claimed observation of an absorption signal in the CMB spectrum

the bounds are competitive or stronger than the existing ones

the bounds are free of astrophysical uncertainties

we are just starting to probe the dark ages, stay tuned!

Backup slides

what determines the spin temperature

three competing processes

interaction with CMB photons	collisions	interaction with Lyα photons
absorption and stimulated emission of background 21-cm photons	requires high densities of the IGM: **effective for**	need photons emitted from first stars: **effective for**
	$\mathbf{z \gtrsim 40}$	$\mathbf{z \lesssim 30}$
drives	drives	drives
$T_{\rm S} \to T_{\rm CMB}$	$T_{\rm S} \to T_{\rm gas}$	$T_{\rm S} \to T_{\rm gas}$

$$T_{\rm S}^{-1} = \frac{T_{\rm CMB}^{-1} + x_\alpha T_{\rm gas}^{-1} + x_c T_{\rm gas}^{-1}}{1 + x_\alpha + x_c}$$

three competing processes

interaction with CMB photons	collisions	interaction with Lyα photons
absorption and stimulated emission of background 21-cm photons	requires high densities of the IGM: **effective for**	need photons emitted from first stars: **effective for**
	$\mathbf{z \gtrsim 40}$	$\mathbf{z \lesssim 30}$
drives	drives	drives
$T_{\rm S} \to T_{\rm CMB}$	$T_{\rm S} \to T_{\rm gas}$	$T_{\rm S} \to T_{\rm gas}$

$$T_{\rm S}^{-1} = \frac{T_{\rm CMB}^{-1} + x_\alpha T_{\rm gas}^{-1} + x_c T_{\rm gas}^{-1}}{1 + x_\alpha + x_c}$$

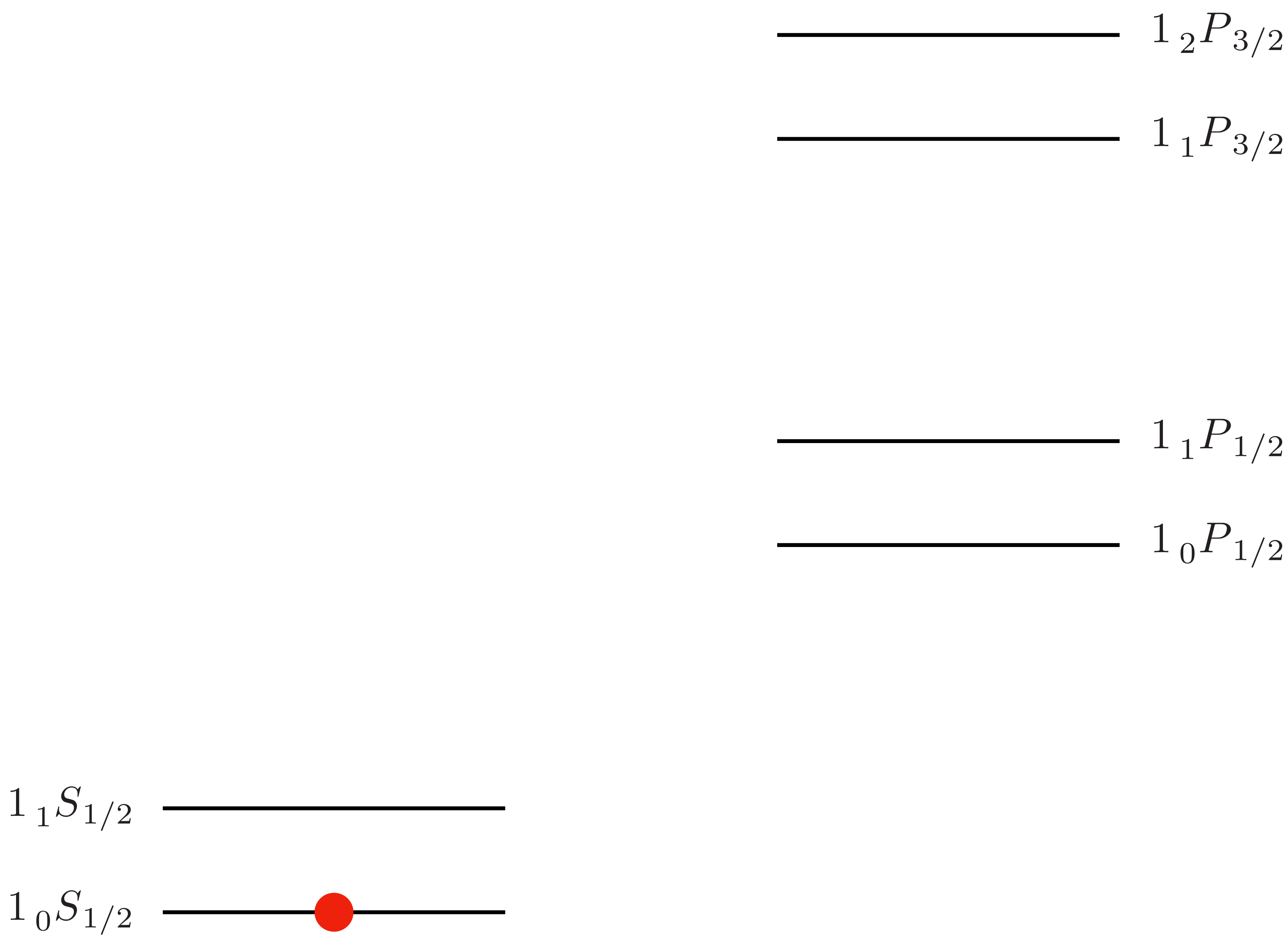
what determines the spin temperature

three competing processes

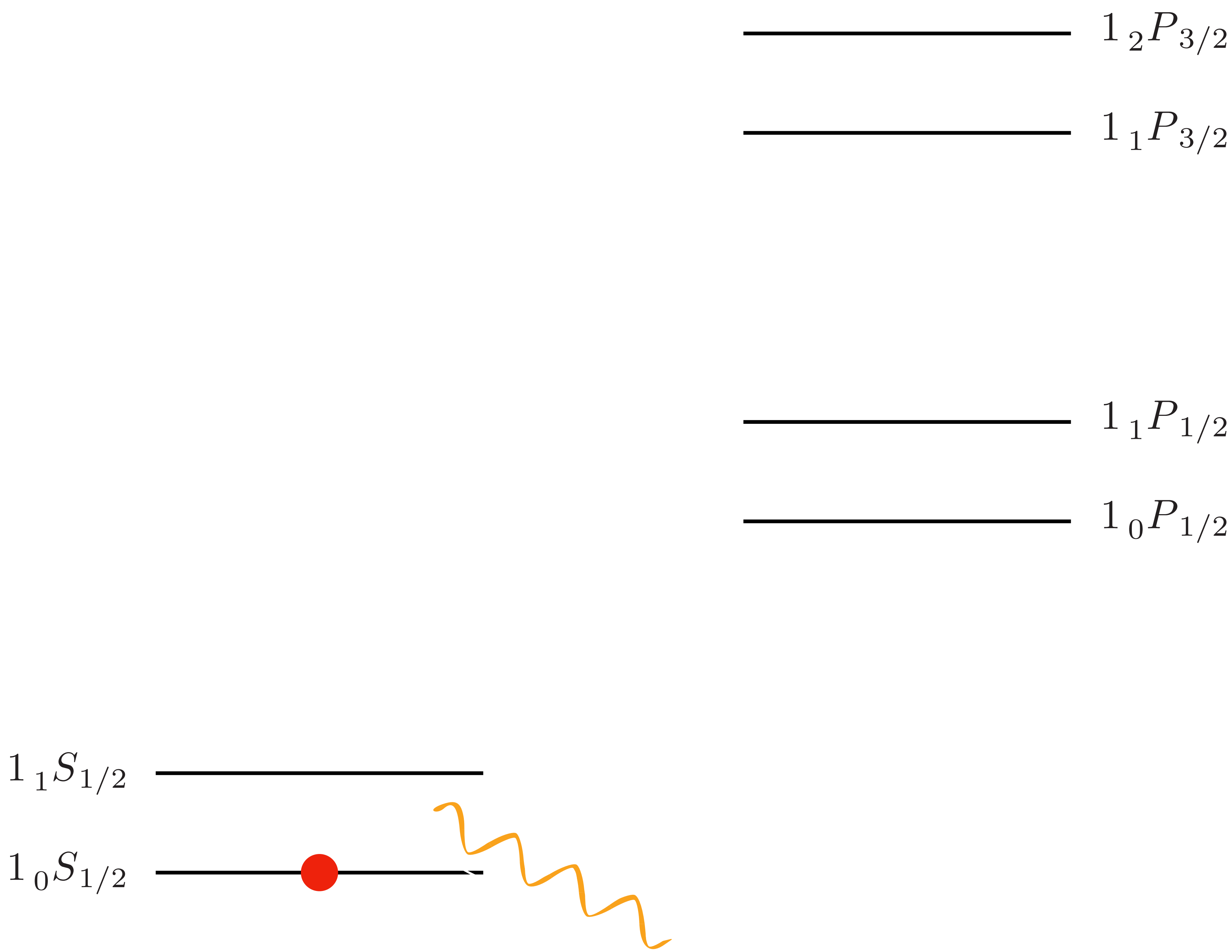
interaction with CMB photons	collisions	interaction with Lyα photons
absorption and stimulated emission of background 21-cm photons	requires high densities of the IGM: **effective for**	need photons emitted from first stars: **effective for**
	$\mathbf{z \gtrsim 40}$	$\mathbf{z \lesssim 30}$
drives	drives	drives
$T_\mathrm{S} \rightarrow T_\mathrm{CMB}$	$T_\mathrm{S} \rightarrow T_\mathrm{gas}$	$T_\mathrm{S} \rightarrow T_\mathrm{gas}$

$$T_\mathrm{S}^{-1} = \frac{T_\mathrm{CMB}^{-1} + x_\alpha T_\mathrm{gas}^{-1} + x_c T_\mathrm{gas}^{-1}}{1 + x_\alpha + x_c}$$

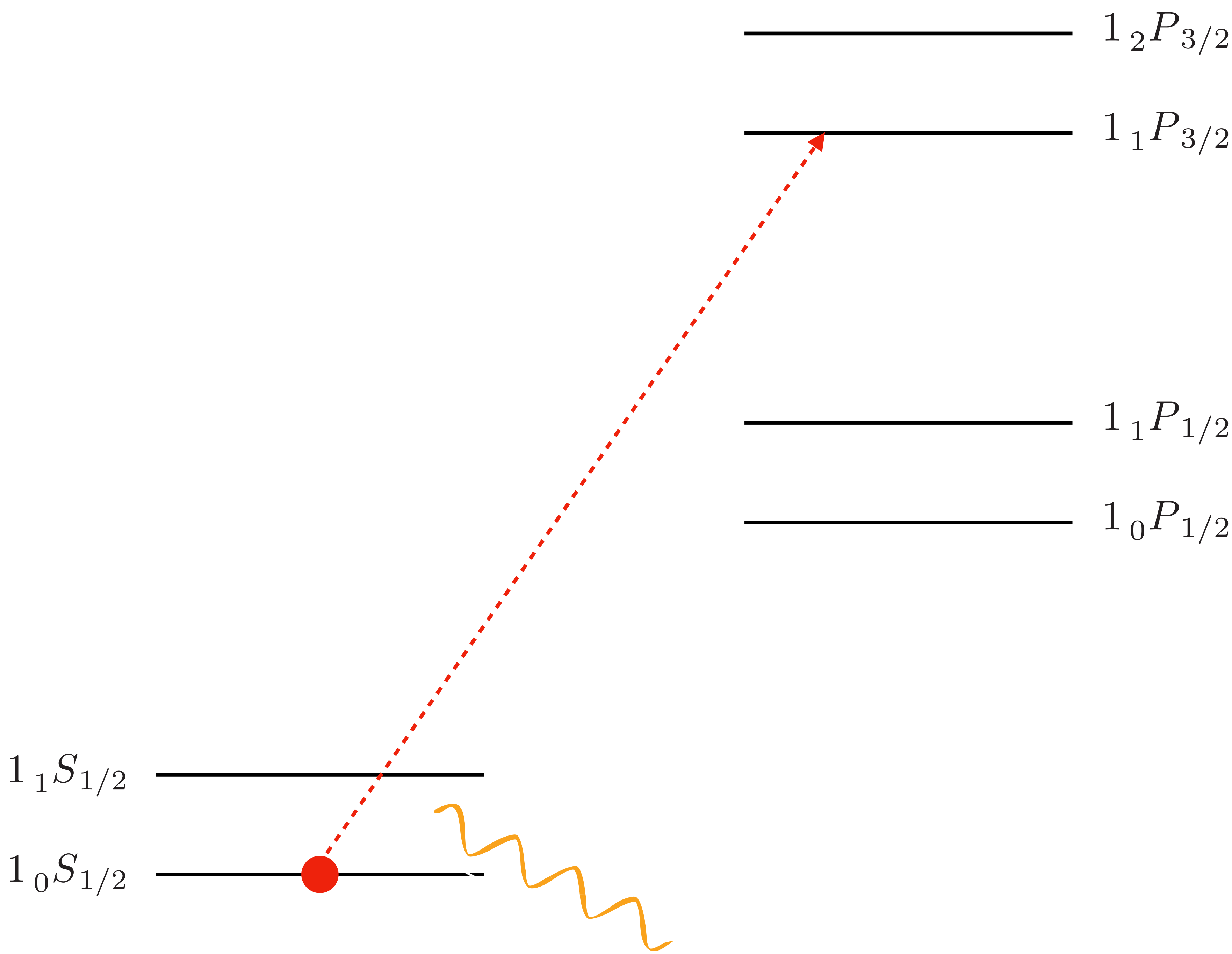
Wouthuysen-Field effect



Wouthuysen-Field effect



Wouthuysen-Field effect



Wouthuysen-Field effect