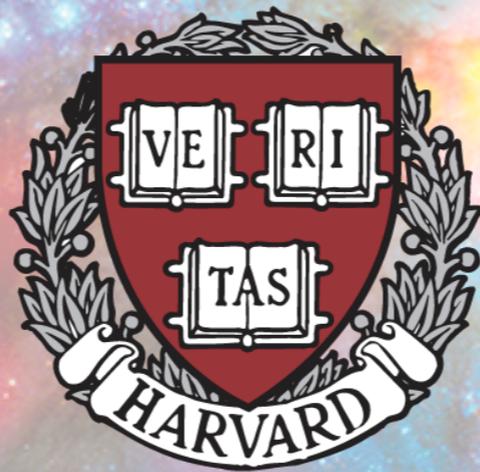


Searching for Dark Matter at the Cosmic Dawn



Julian B. Muñoz

Based on

arXiv:1509.00029

arXiv:1802.10094

arXiv:1804.01092

with

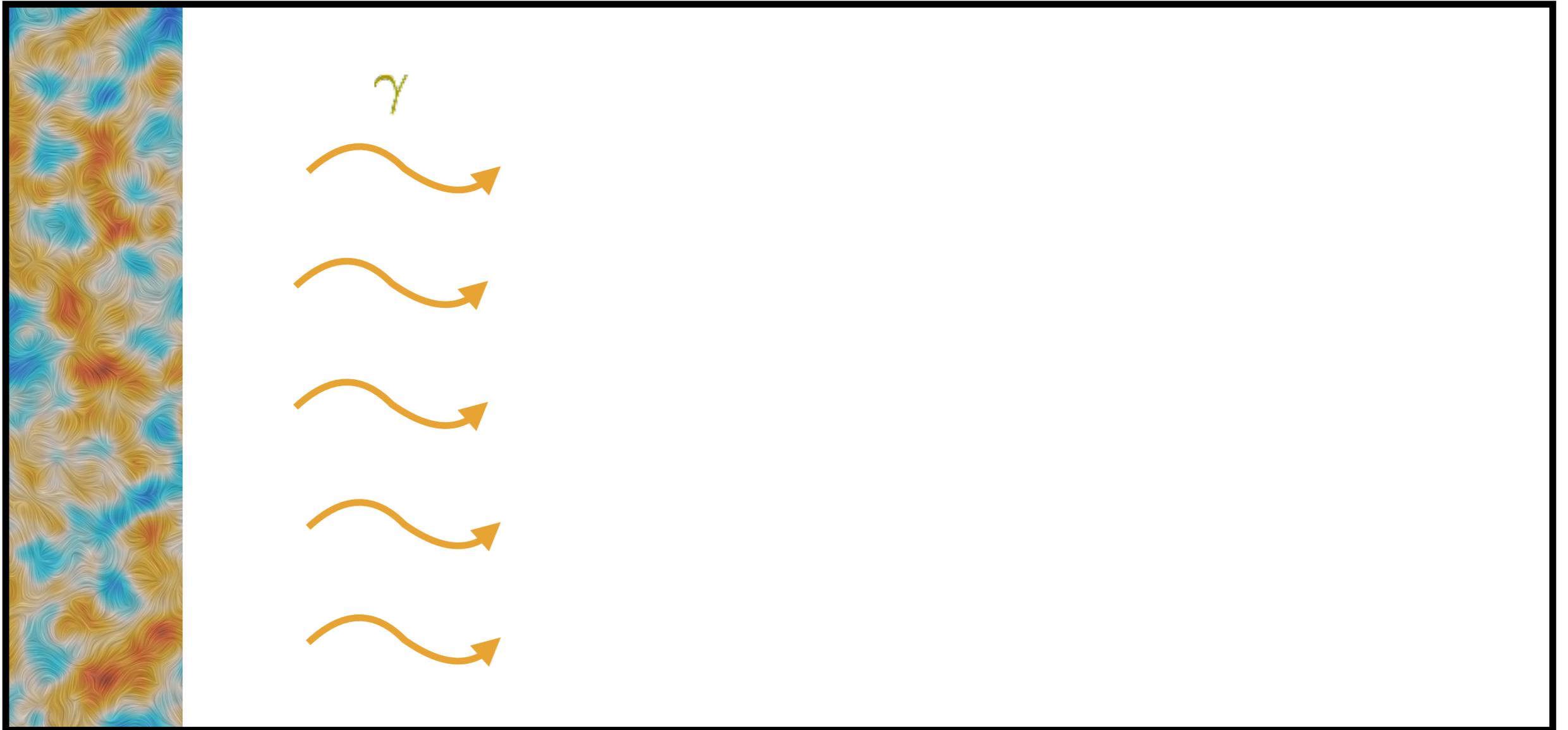
Yacine Ali-Haïmoud

Cora Dvorkin

Avi Loeb

Ely Kovetz

$z = 1100$

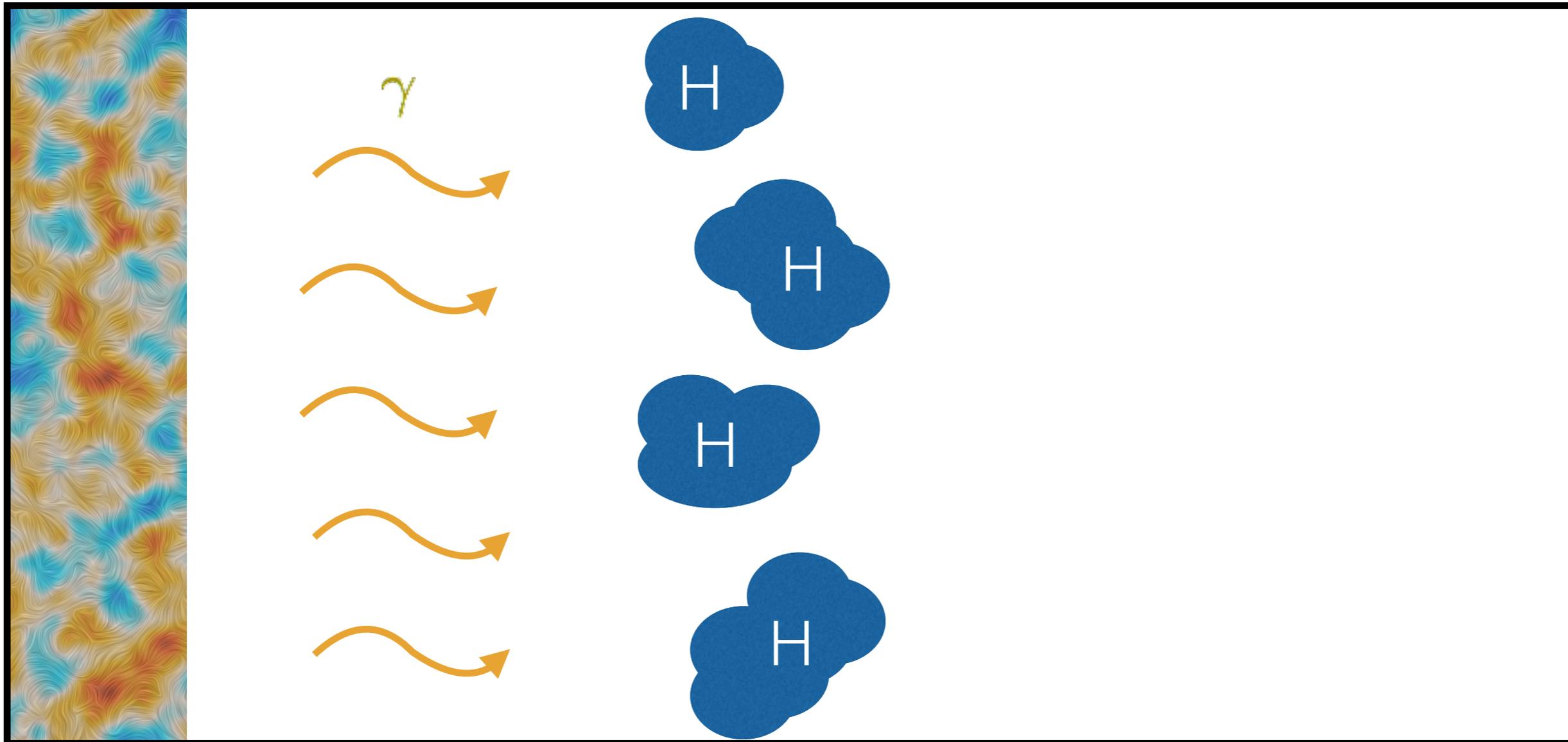


$$I_\nu \propto T_{\text{CMB}} \nu^2$$

(@ 21 cm)

$z = 1100$

$z \approx 20$



$$I_\nu \propto T_{\text{CMB}} \nu^2$$

(@ 21 cm)



Triplet

$$\frac{n_1}{n_0} = \frac{g_1}{g_0} e^{-T_*/T_s}$$

Singlet



Triplet

$$\frac{n_1}{n_0} = \frac{g_1}{g_0} e^{-T_*/T_s}$$

Singlet

3

$6 \mu\text{eV}$

$T_S < T_{\text{cmb}}$ Absorption

$T_S > T_{\text{cmb}}$ Emission



Triplet

$$\frac{n_1}{n_0} = \frac{g_1}{g_0} e^{-T_*/T_s}$$

Singlet

3

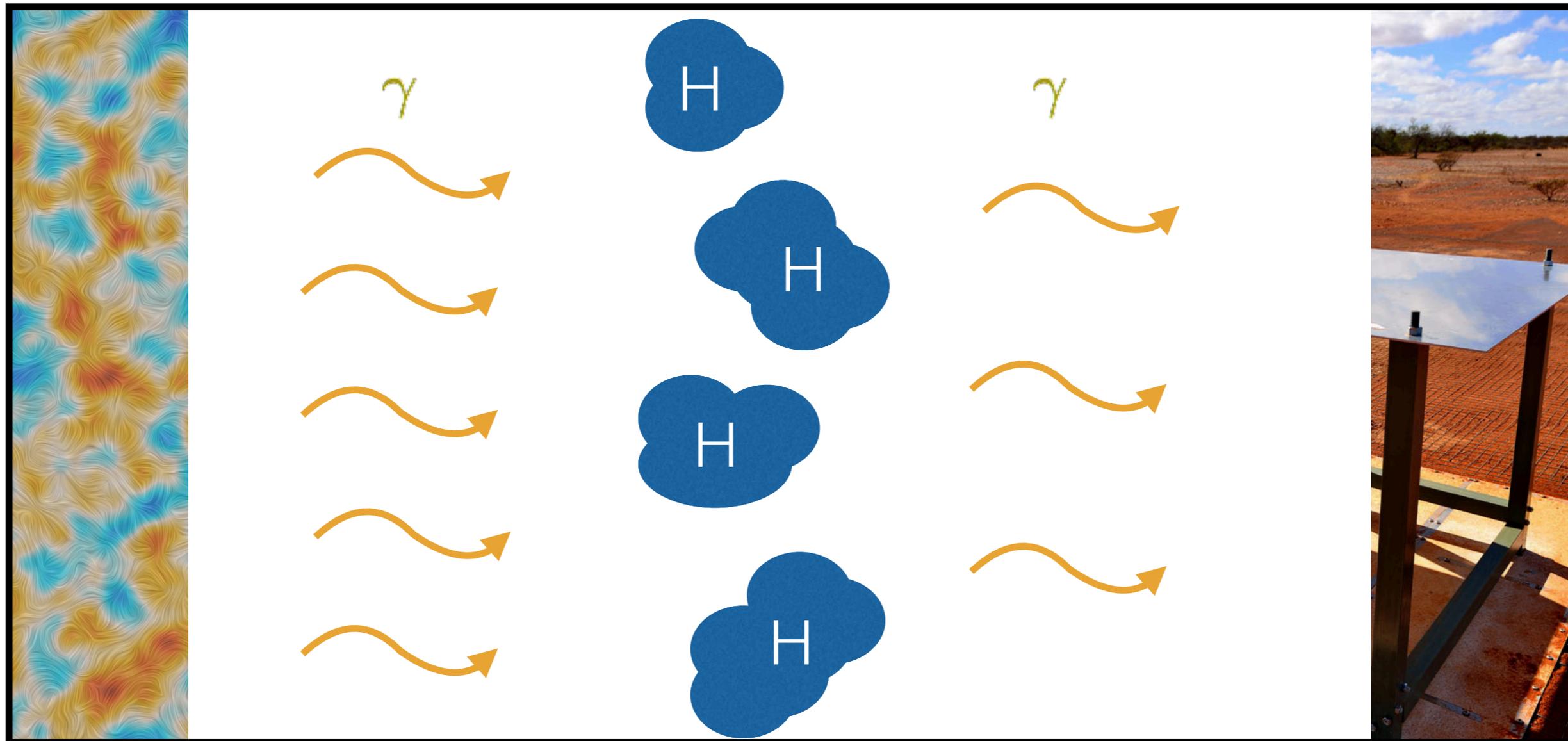
$6 \mu\text{eV}$

$T_S < T_{\text{cmb}}$ Absorption

$z = 1100$

$z \approx 20$

Australia

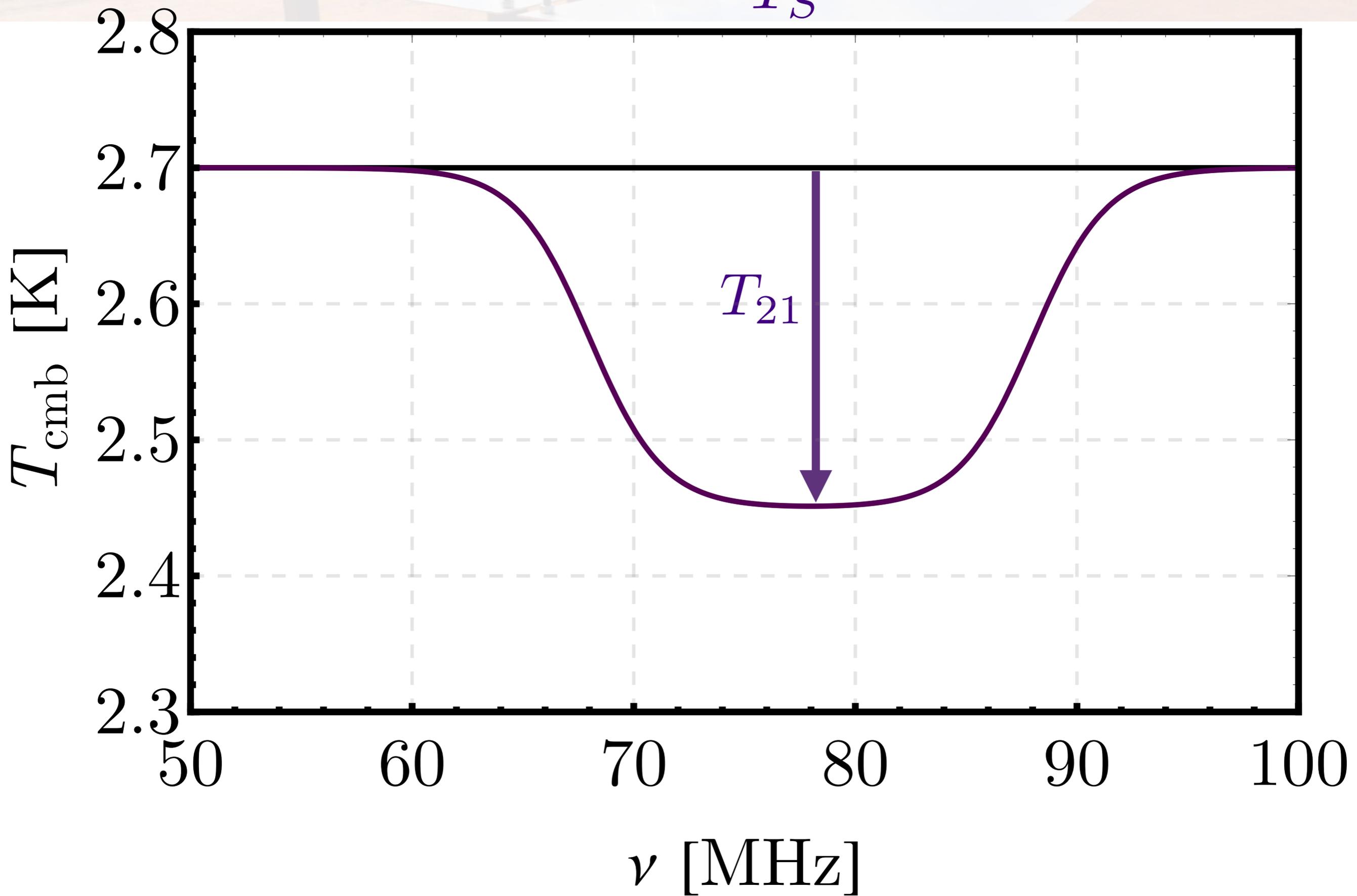


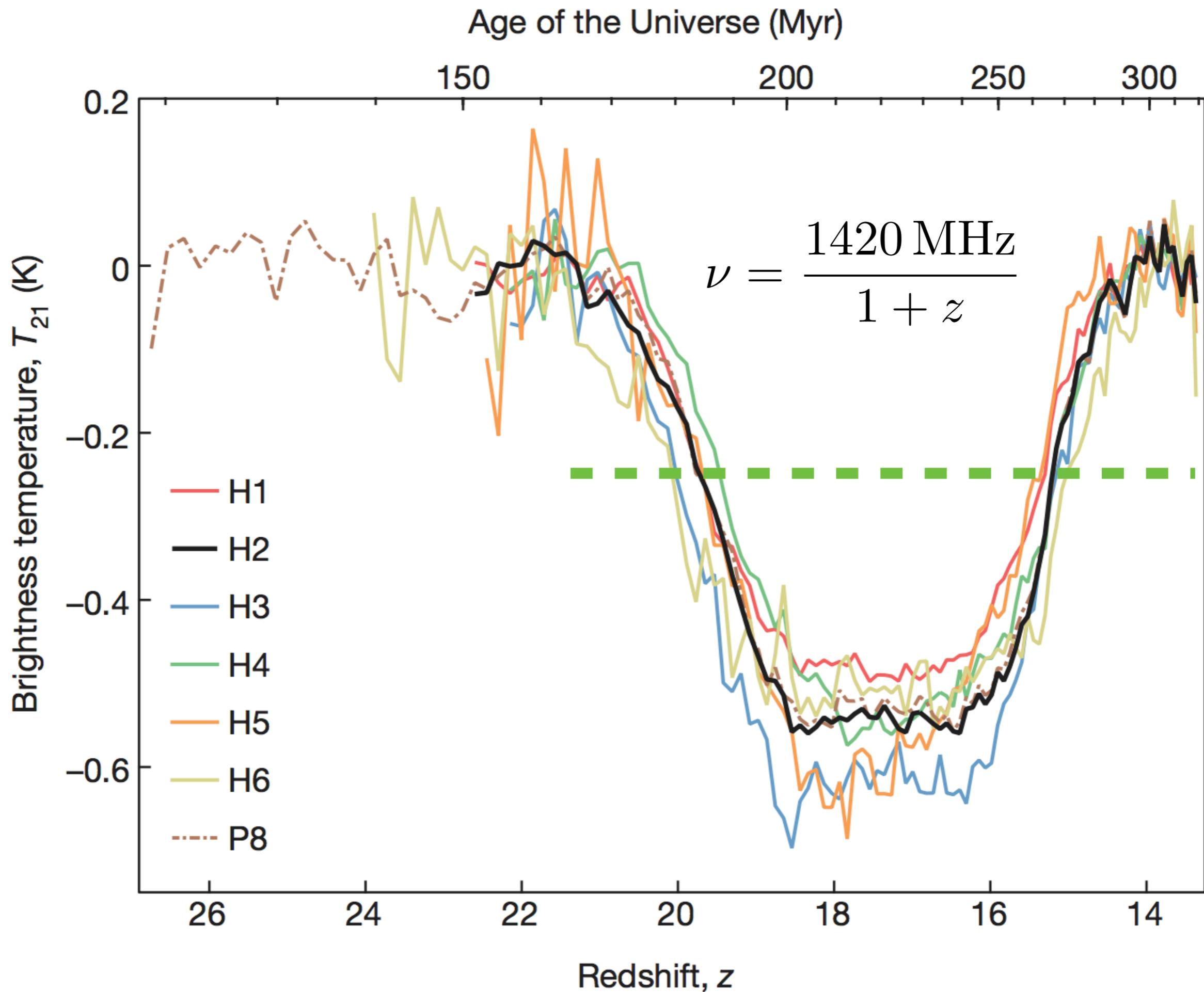
$$I_\nu \propto T_{\text{CMB}} \nu^2$$

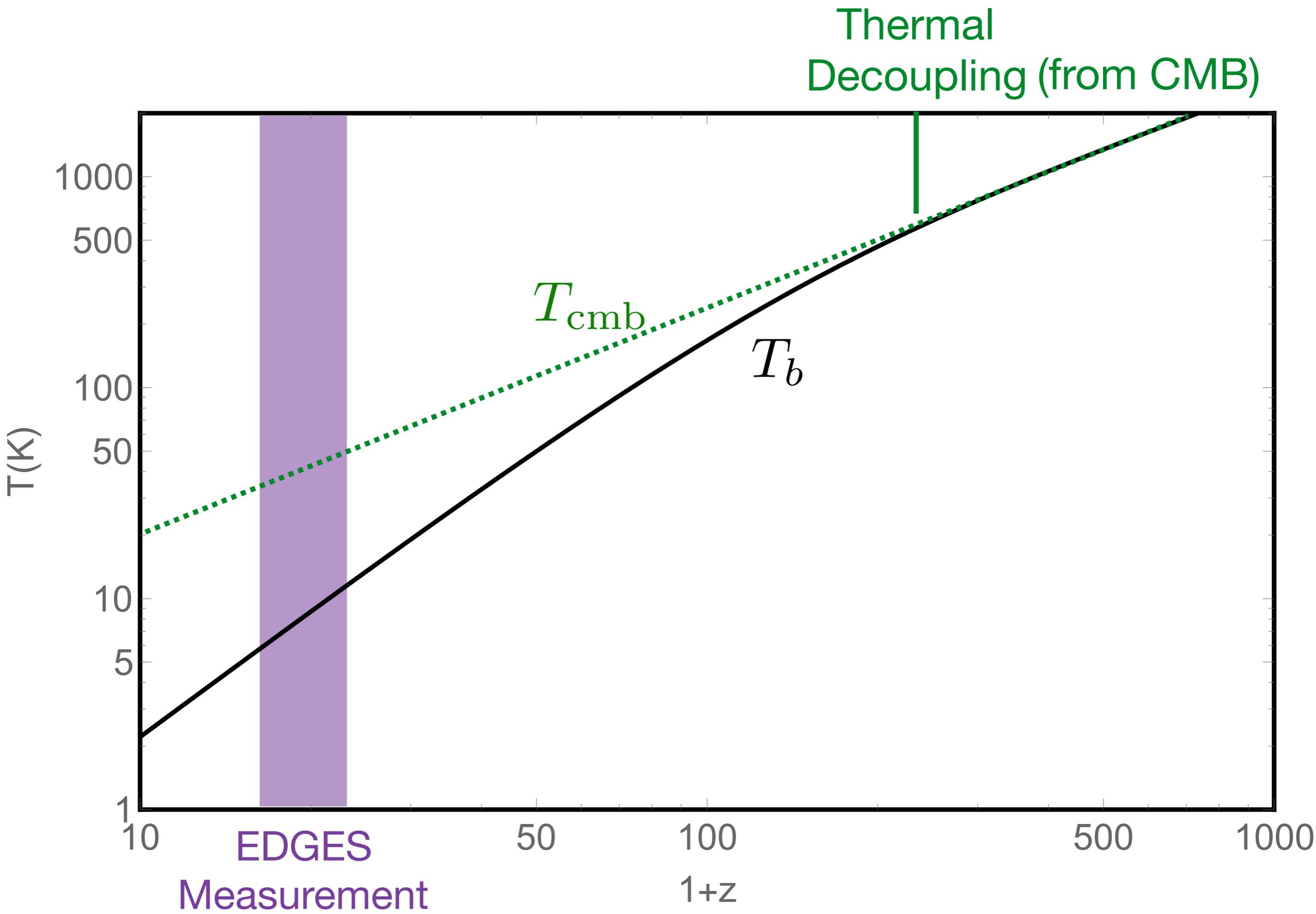
$$\Delta I_\nu \propto T_{21} \nu^2$$

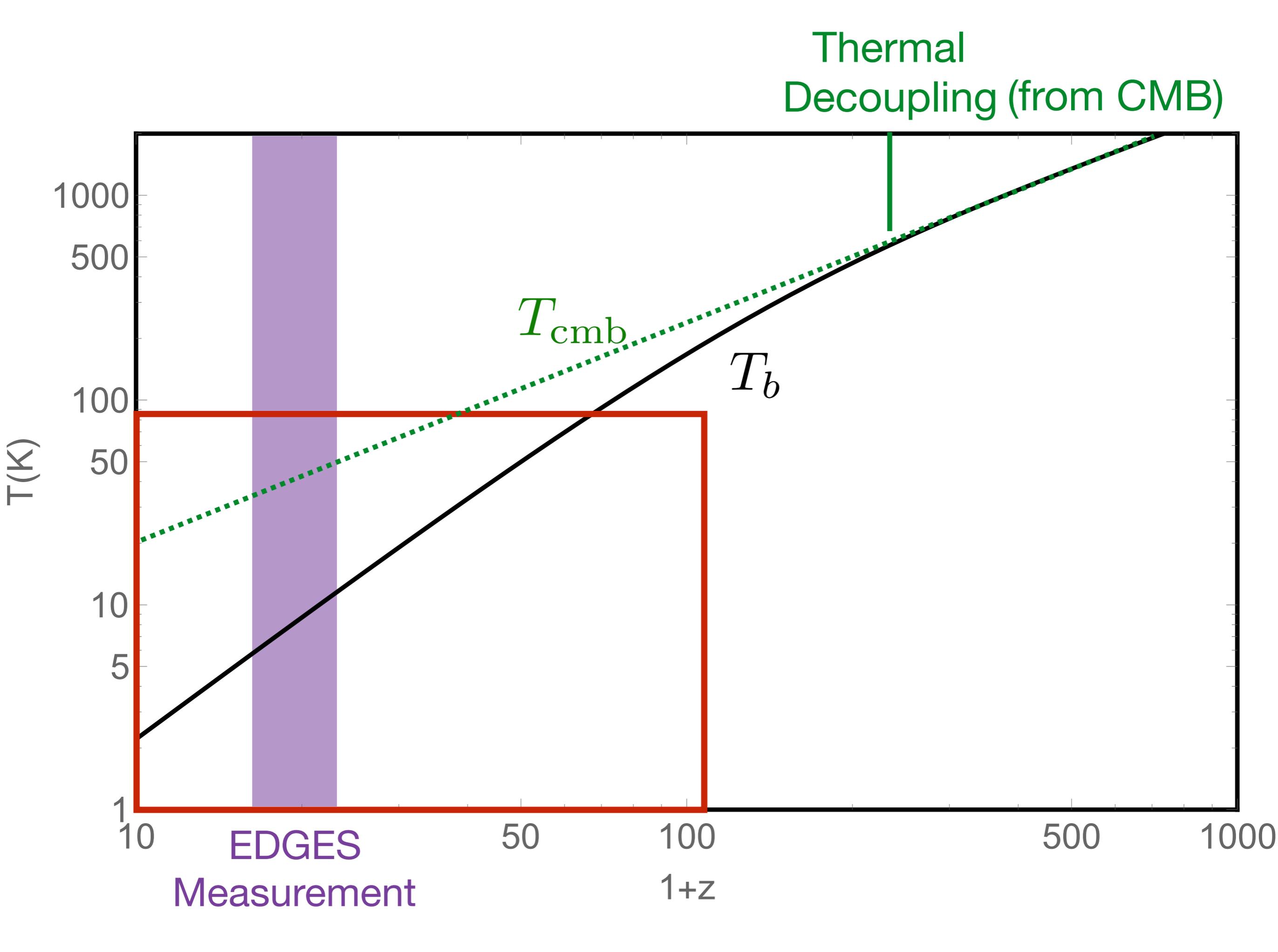
EDGES

$$T_{21} \propto -\frac{T_{\text{cmb}}}{T_S}$$

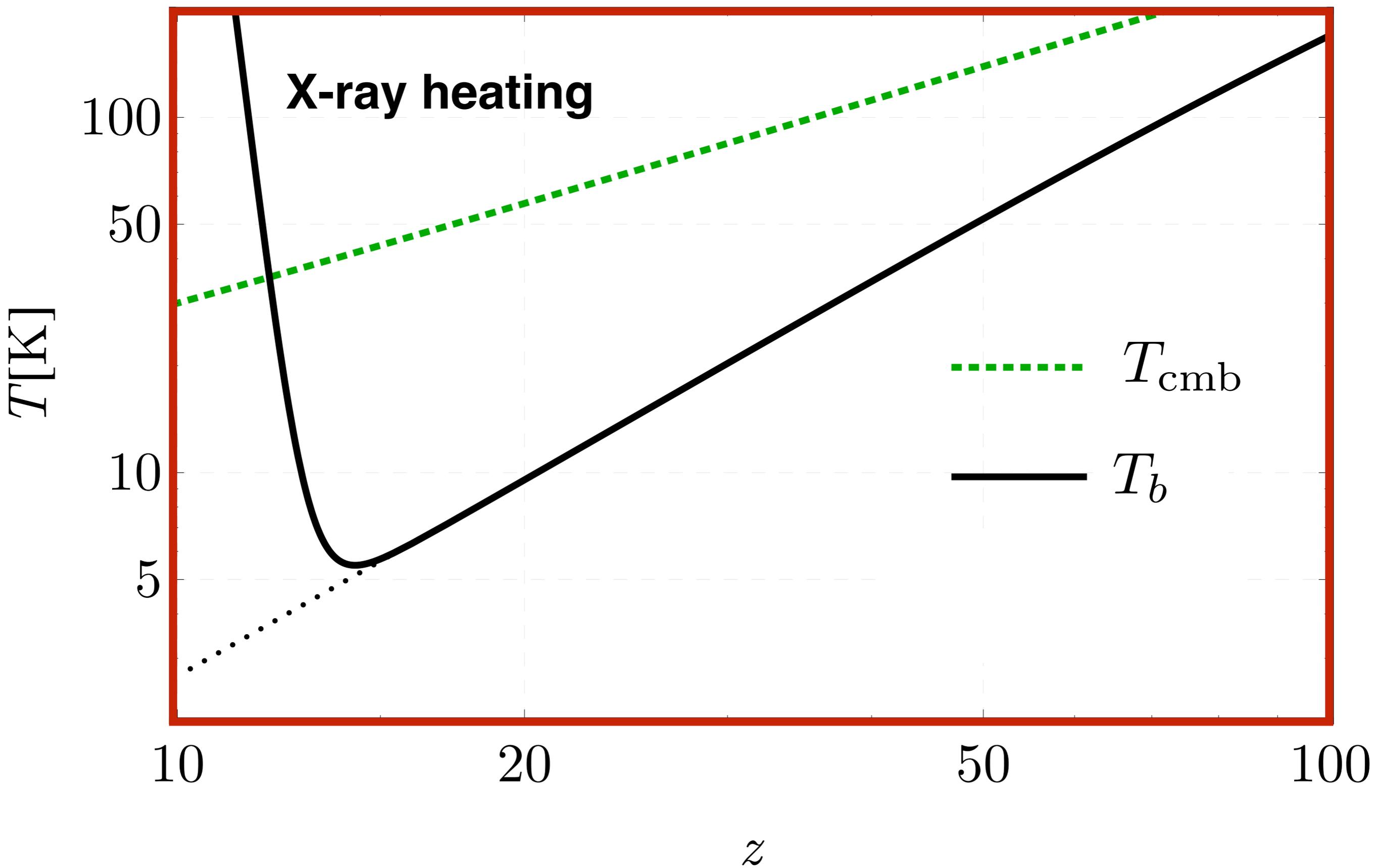




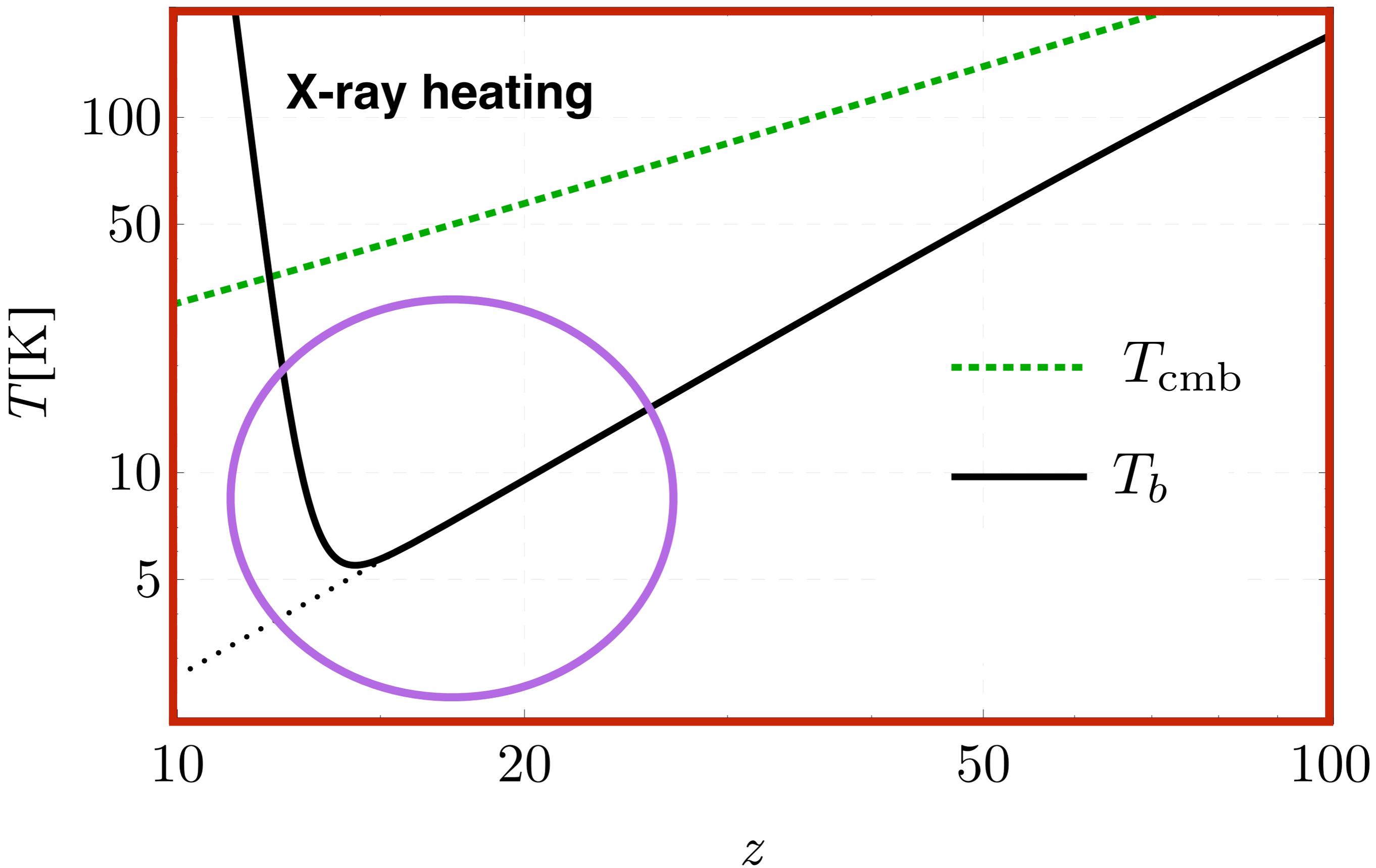




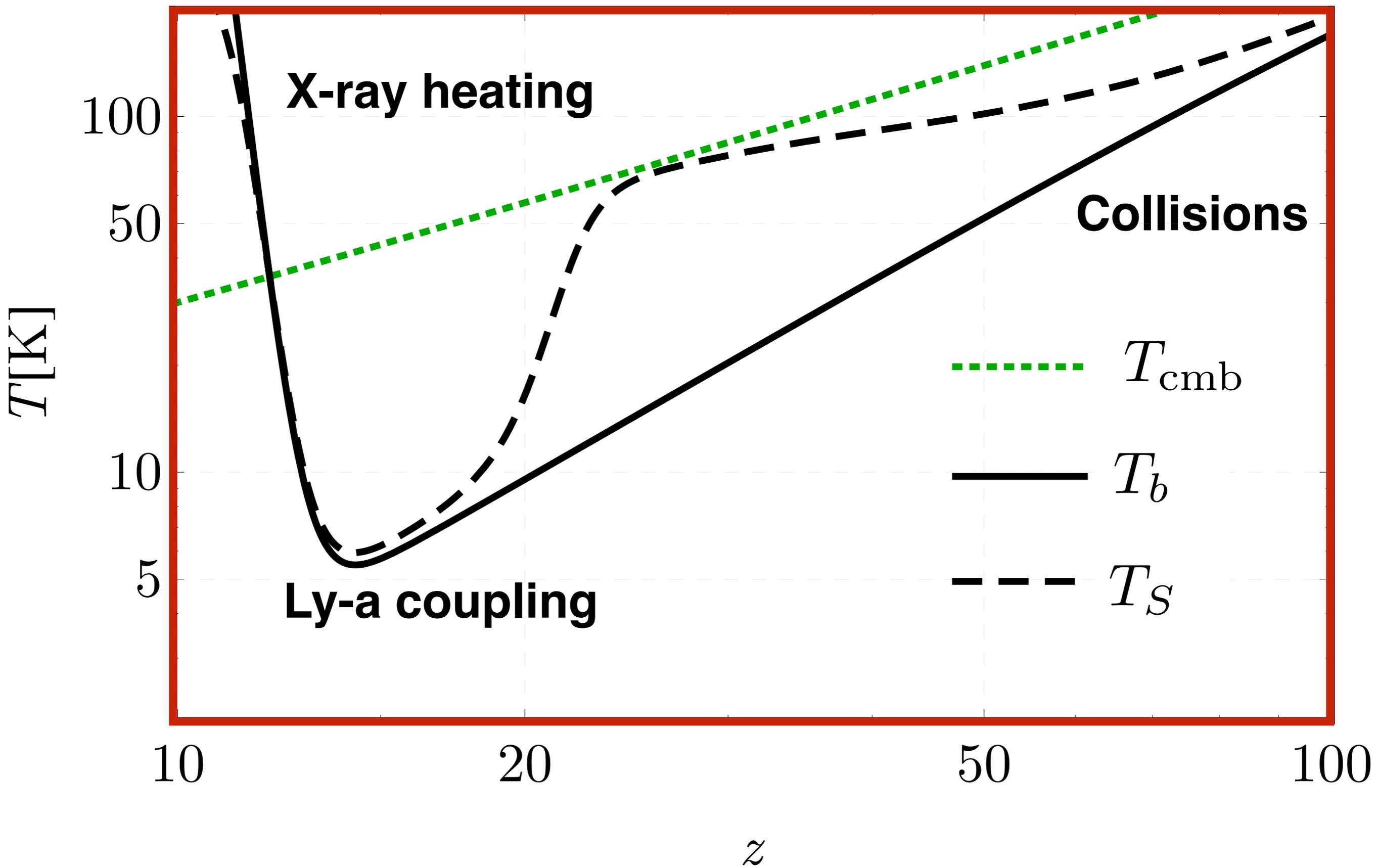
A cartoon of the evolution of T_s



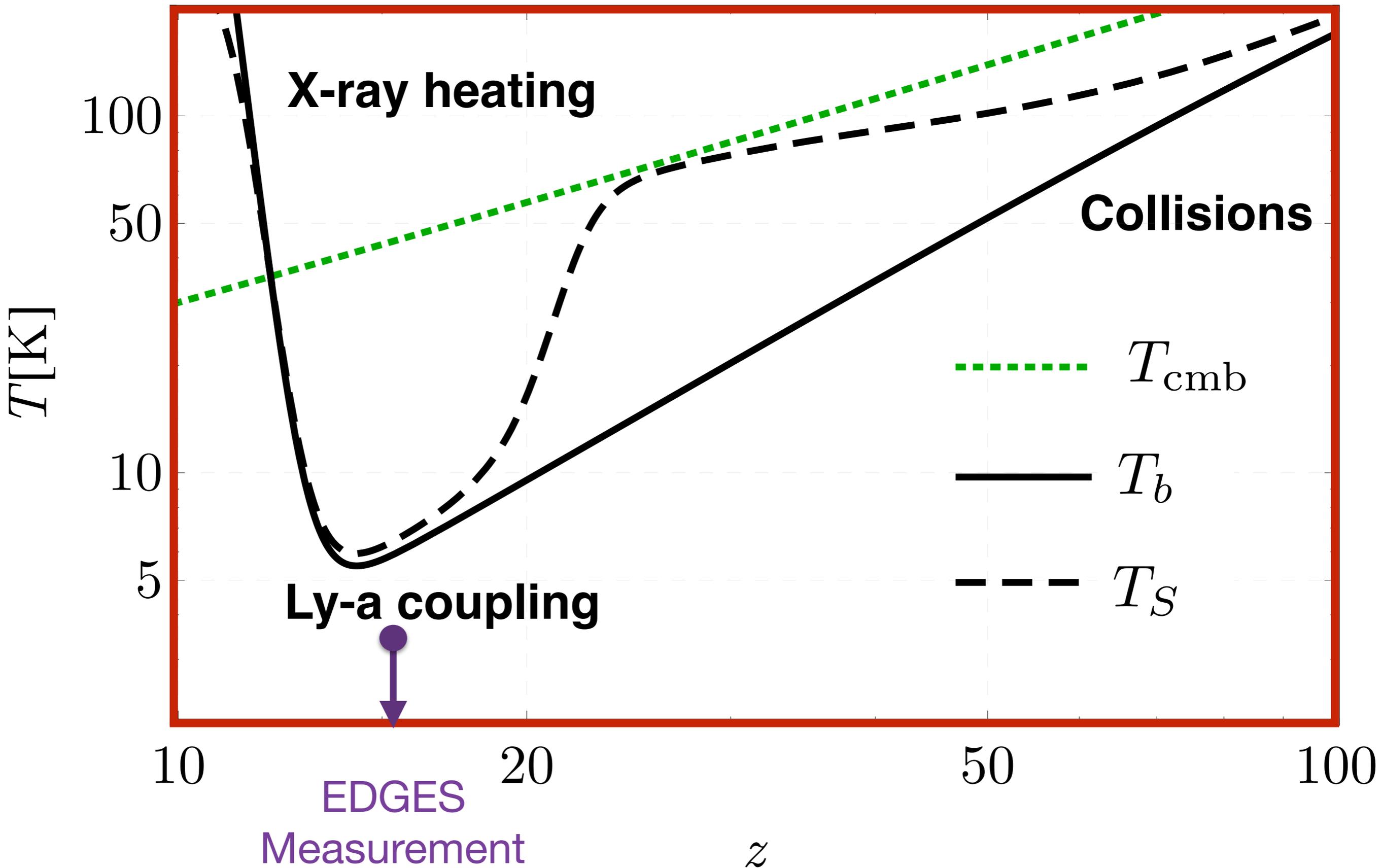
A cartoon of the evolution of T_s

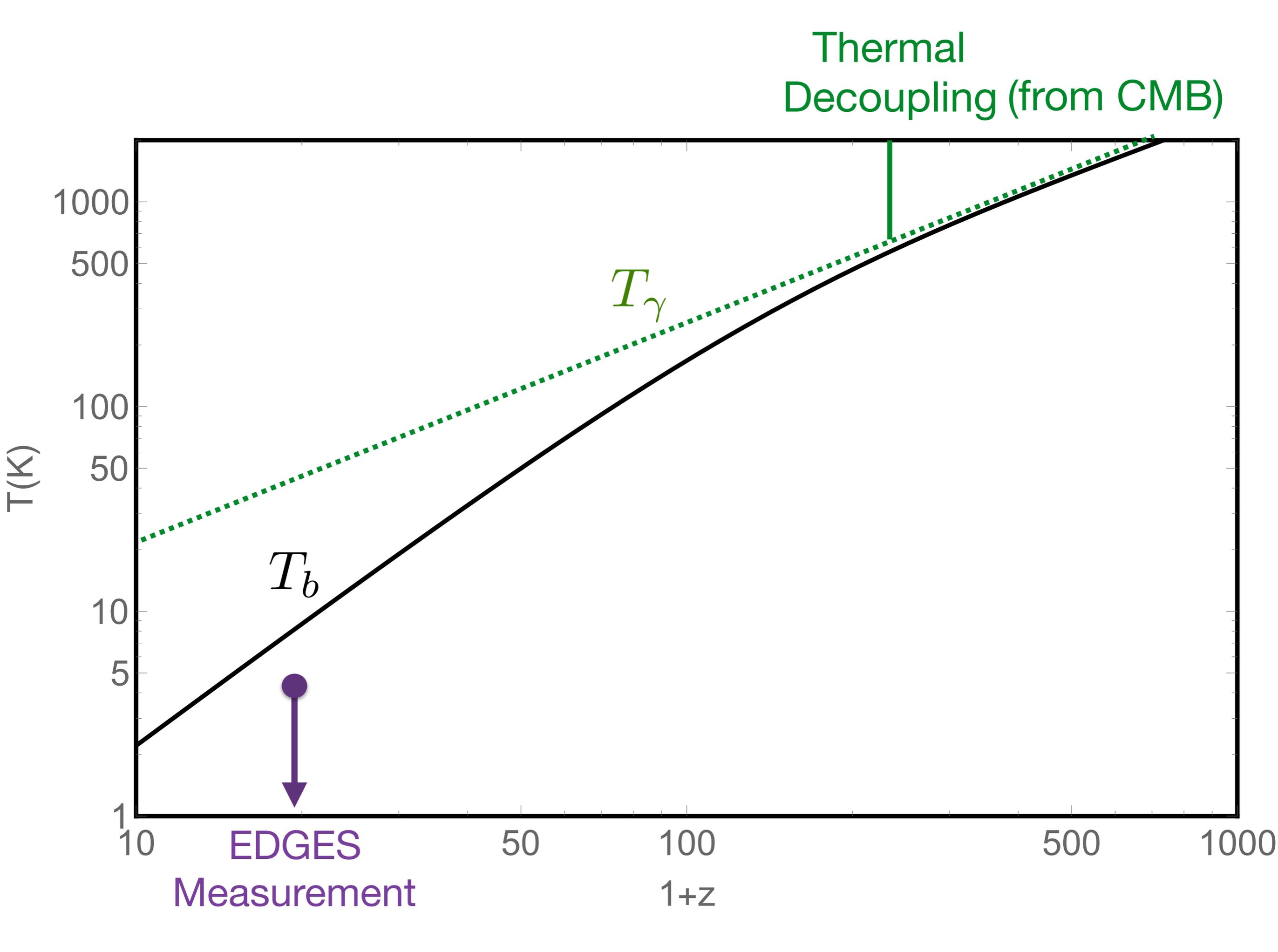


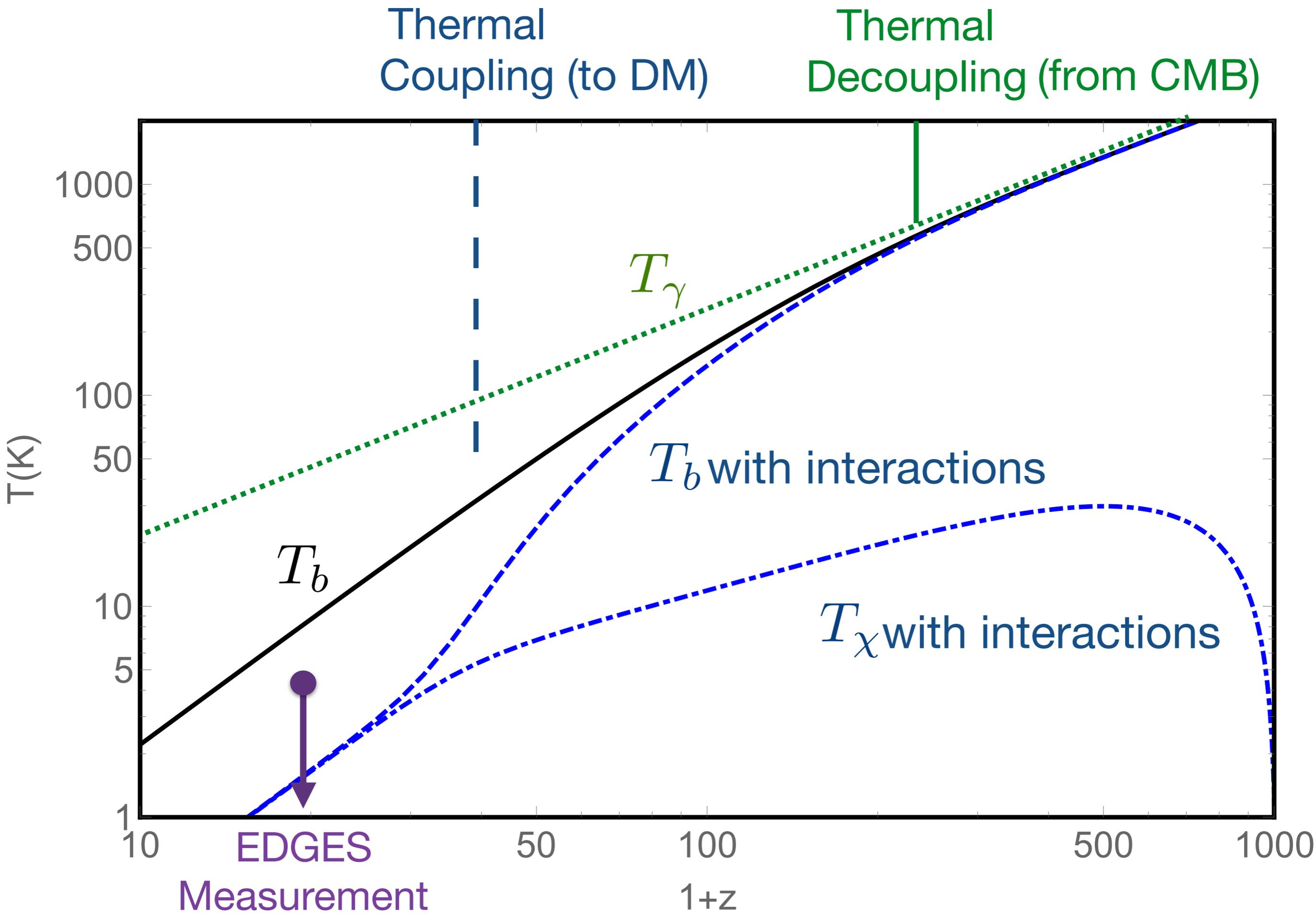
A cartoon of the evolution of T_s



A cartoon of the evolution of T_s

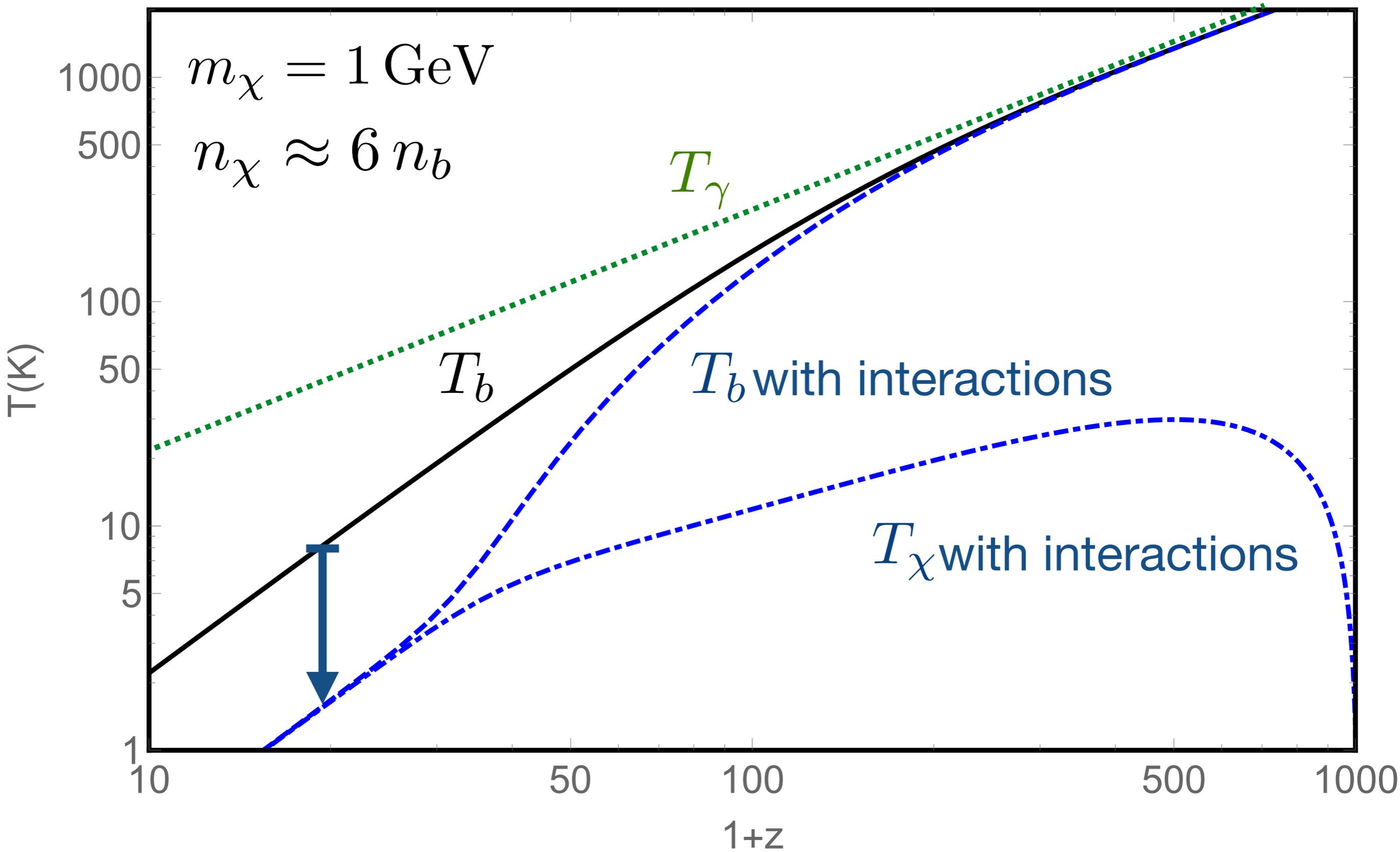






Requirements

$$n_{\chi} \geq n_b \quad \rightarrow \quad m_{\chi} \leq 6 \text{ GeV}$$



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$$\sigma_{\chi b} \propto v^{-4}$$

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New Interaction

Tashiro+ 2014

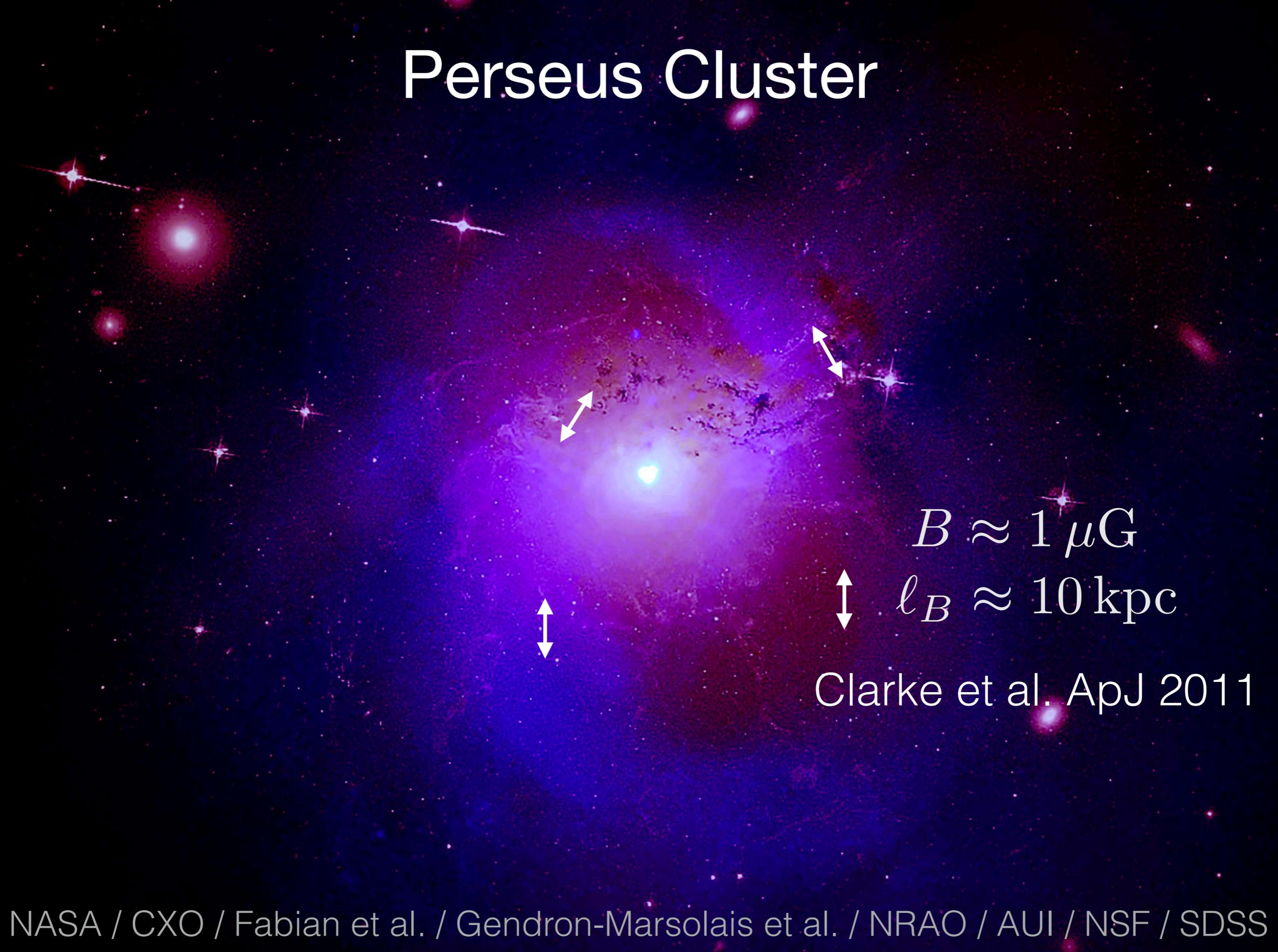
JBM+ 2015

Barkana 2018

Millicharged DM

JBM and Loeb 2018

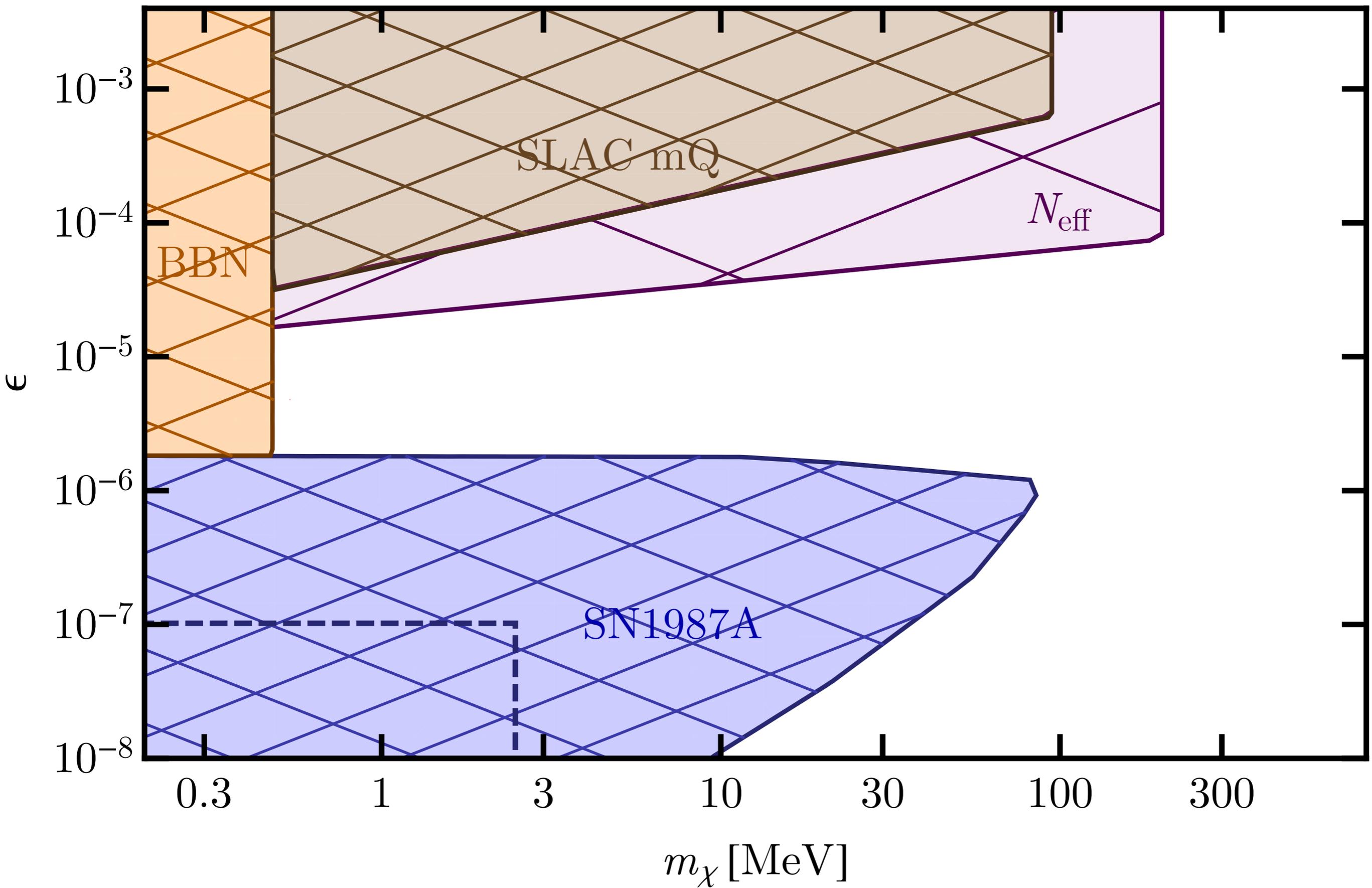
Perseus Cluster

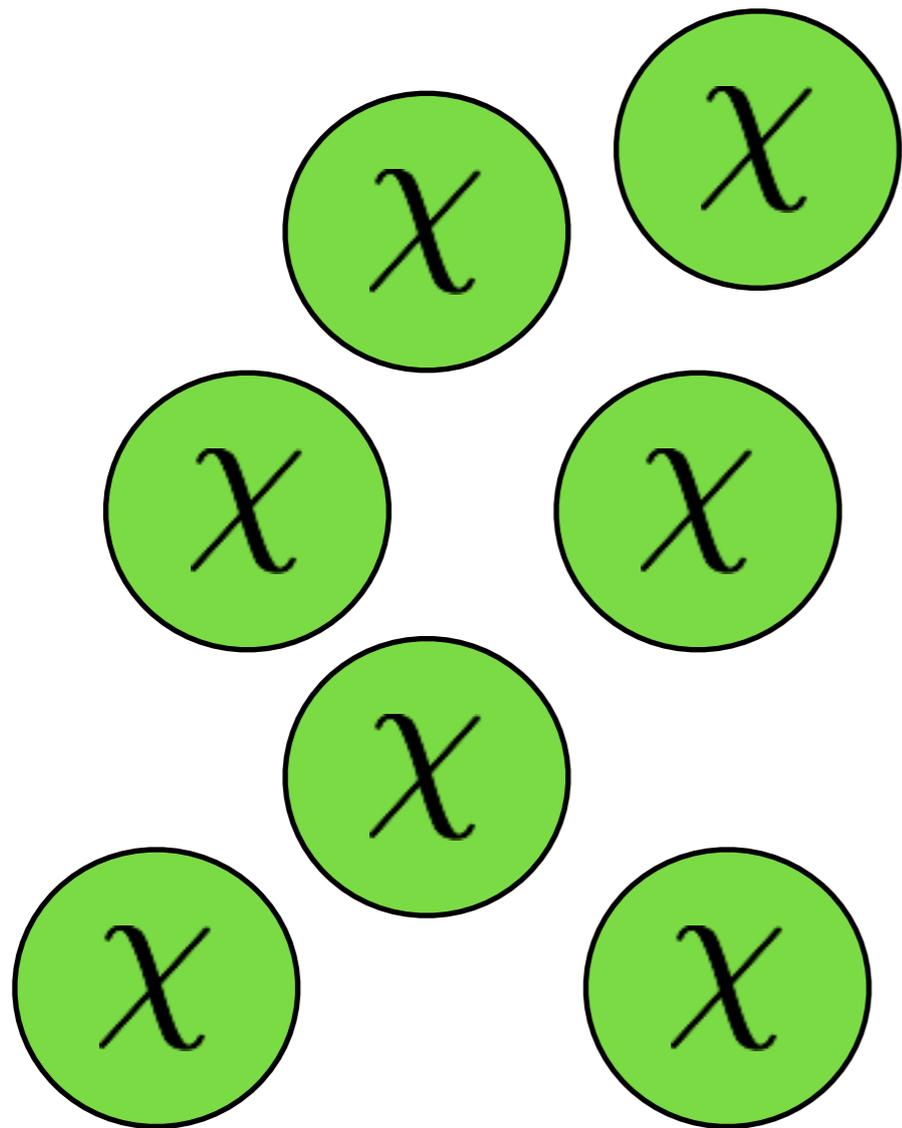


$$B \approx 1 \mu\text{G}$$

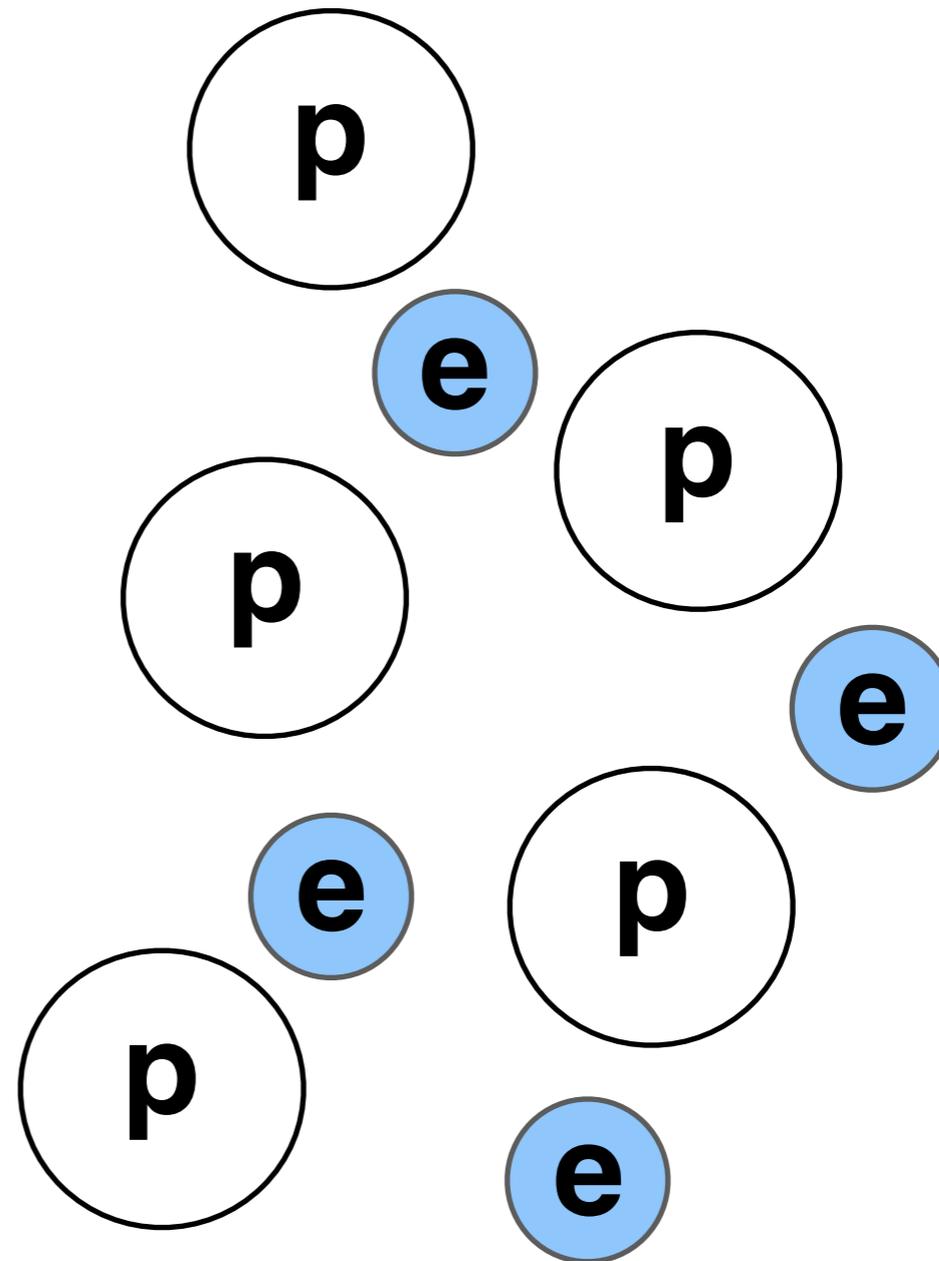
$$\ell_B \approx 10 \text{ kpc}$$

Clarke et al. ApJ 2011





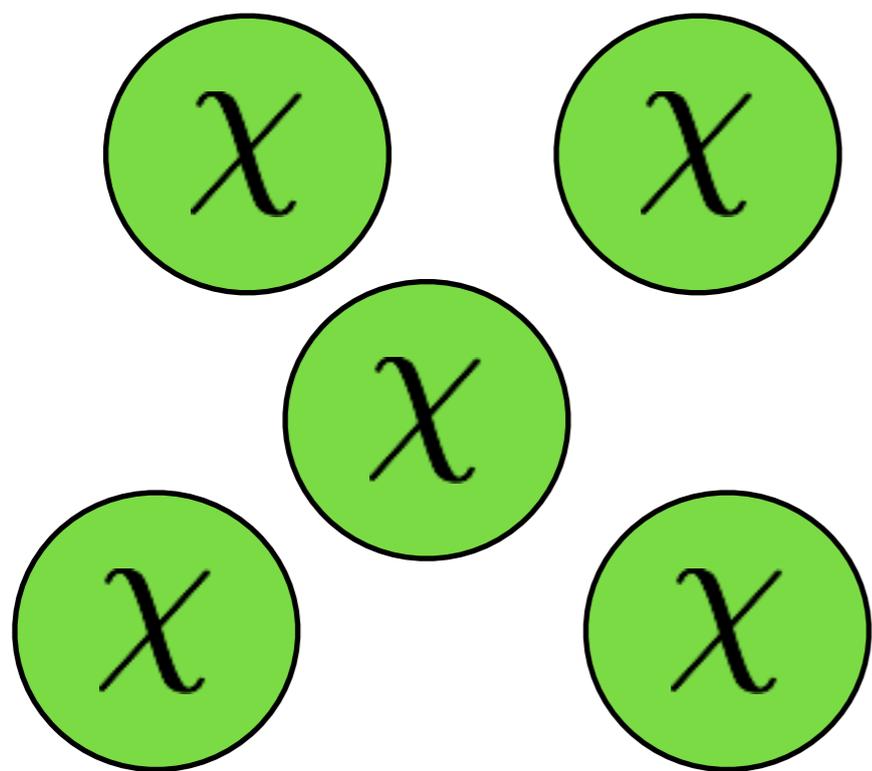
T_χ



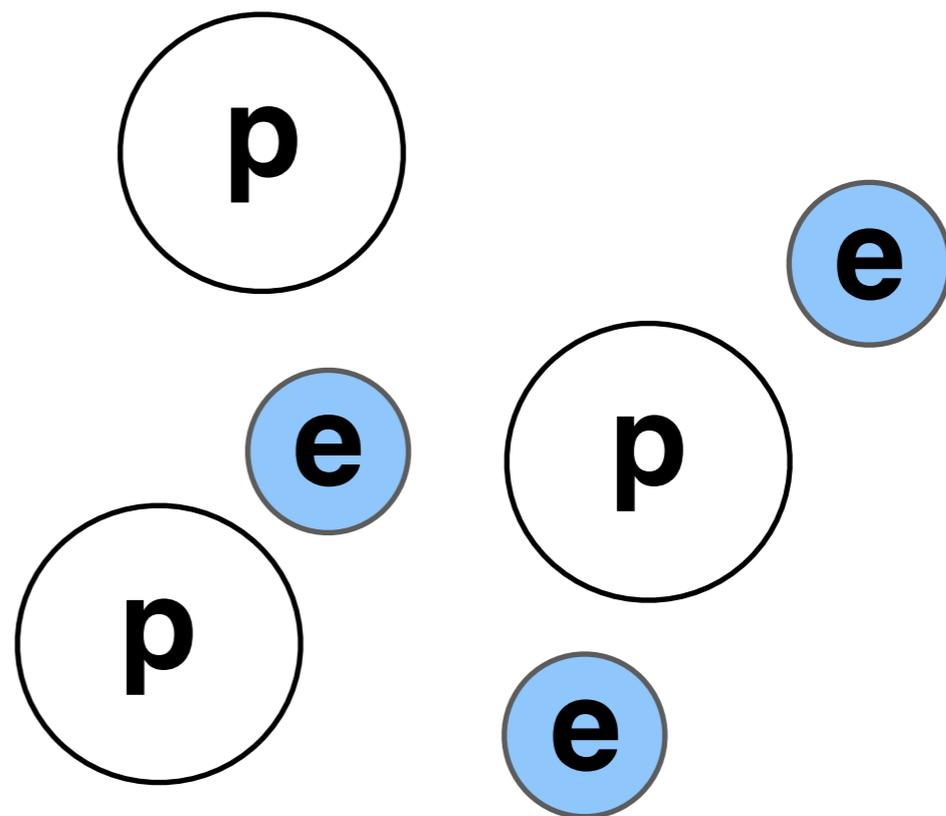
T_b

$$\dot{T}_b \propto \frac{\epsilon^2}{m_\chi^2} f_{\text{dm}} \frac{1}{v_{\text{rel}}^3}$$

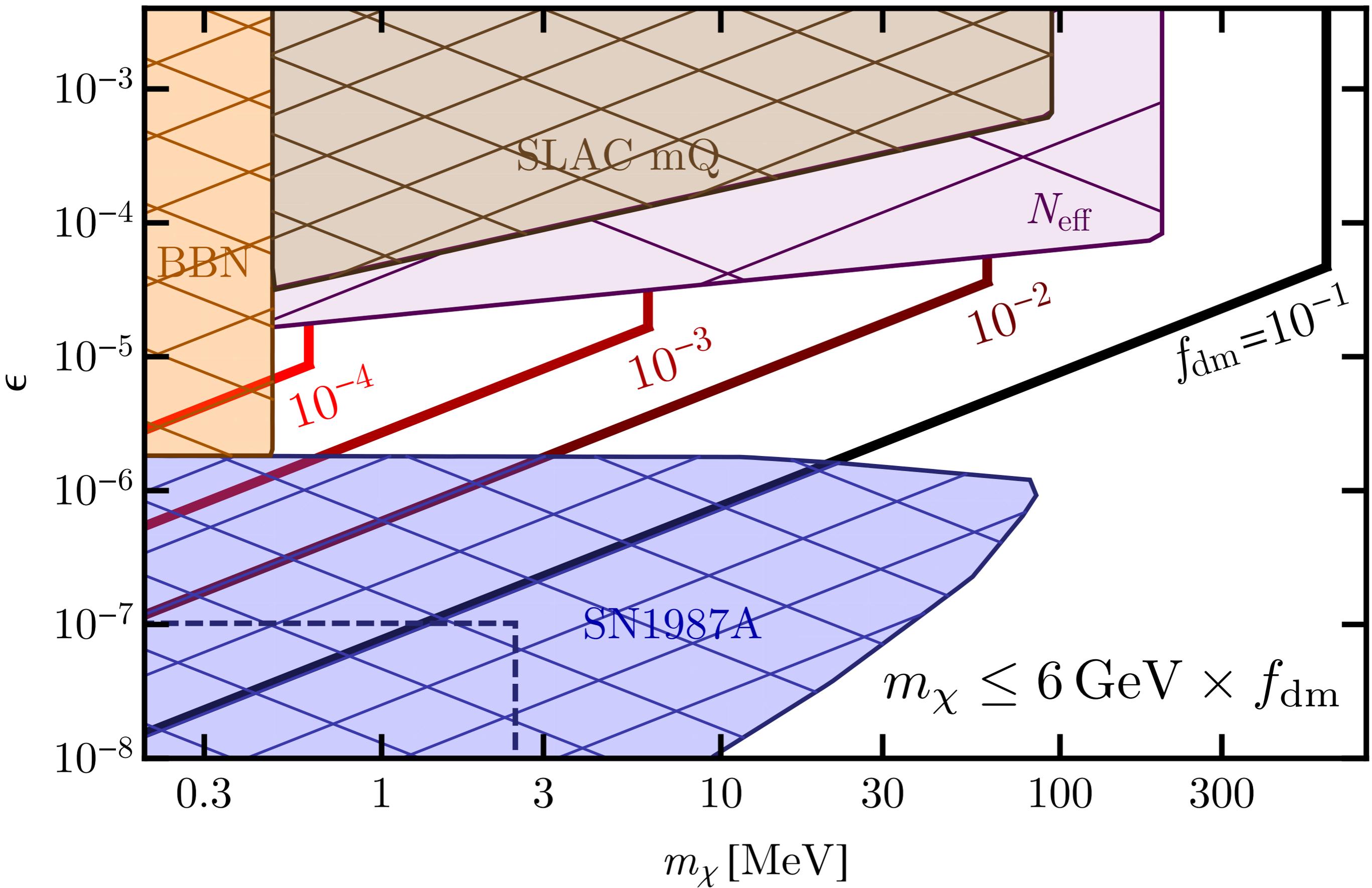
$$v_{\text{rel}} \approx \left(\frac{T_b}{m_b} + \frac{T_\chi}{m_\chi} \right)^{1/2}$$

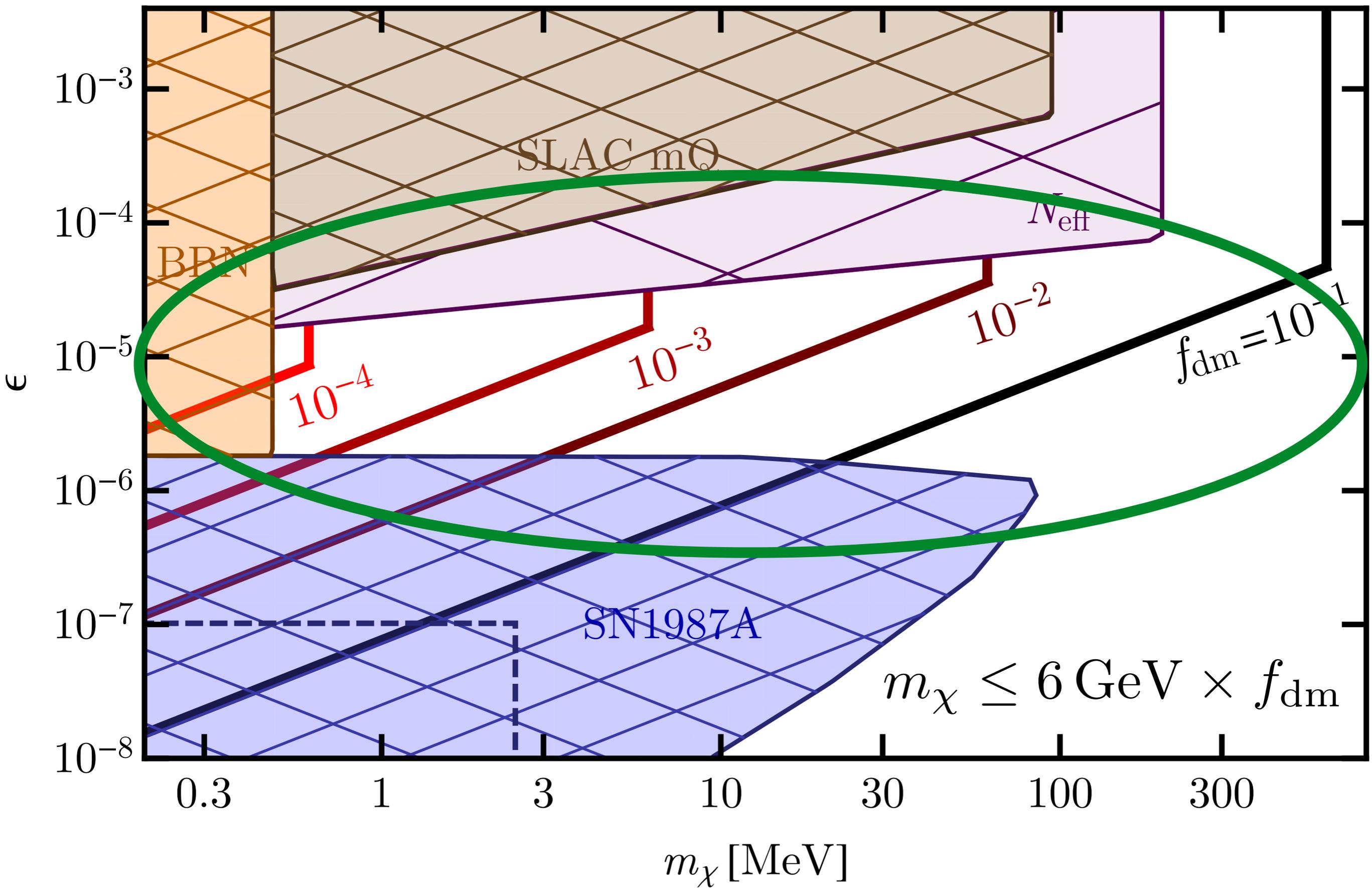


T_χ



T_b





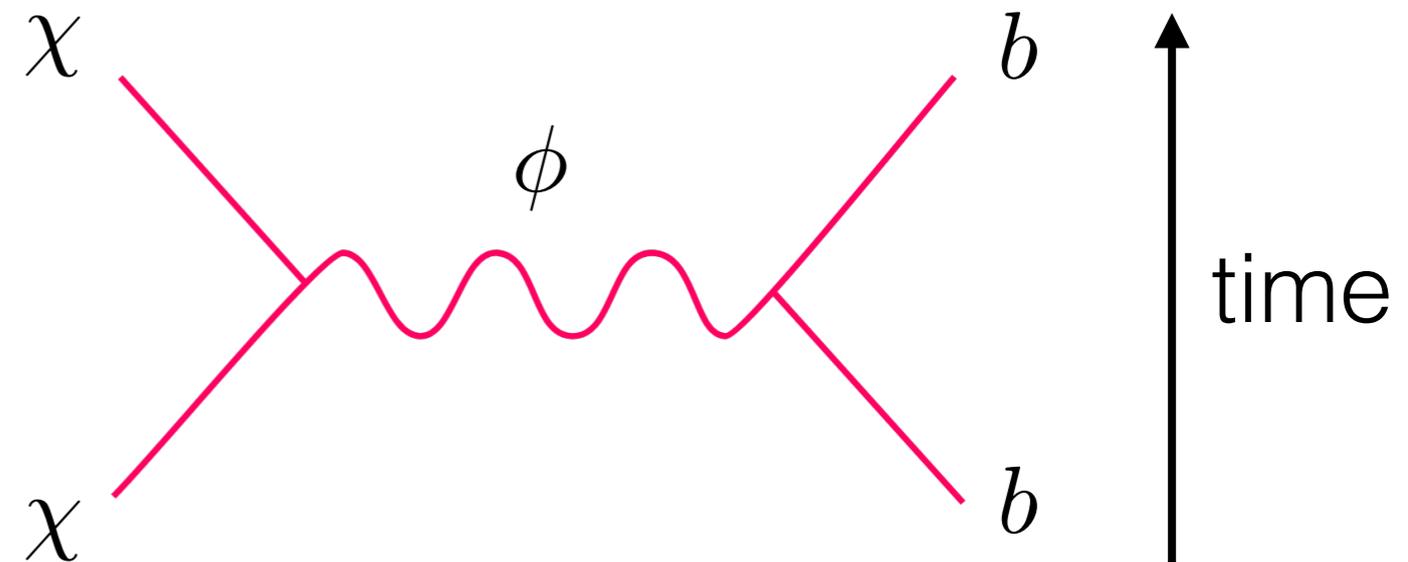
Fifth-force cooling

JBM, Kovetz, Ali-Haimoud PRD 2015

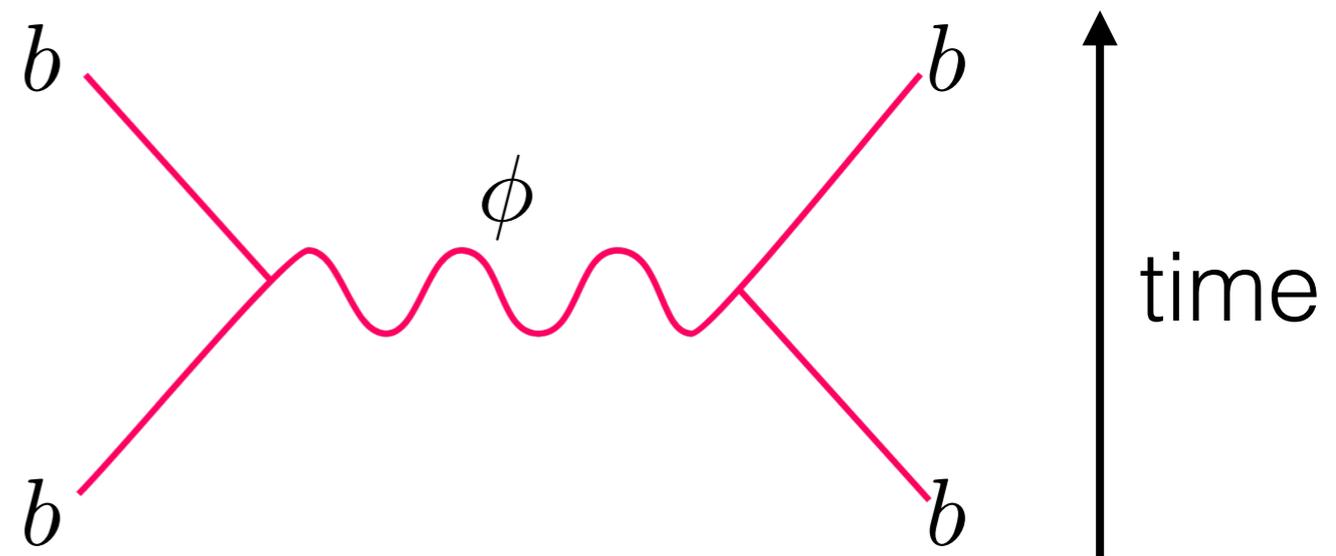
Barkana Nature 2018

$$\sigma(v) = \sigma_c \left(\frac{v}{c}\right)^{-4} = \sigma_1 \left(\frac{v}{1 \text{ km/s}}\right)^{-4}$$

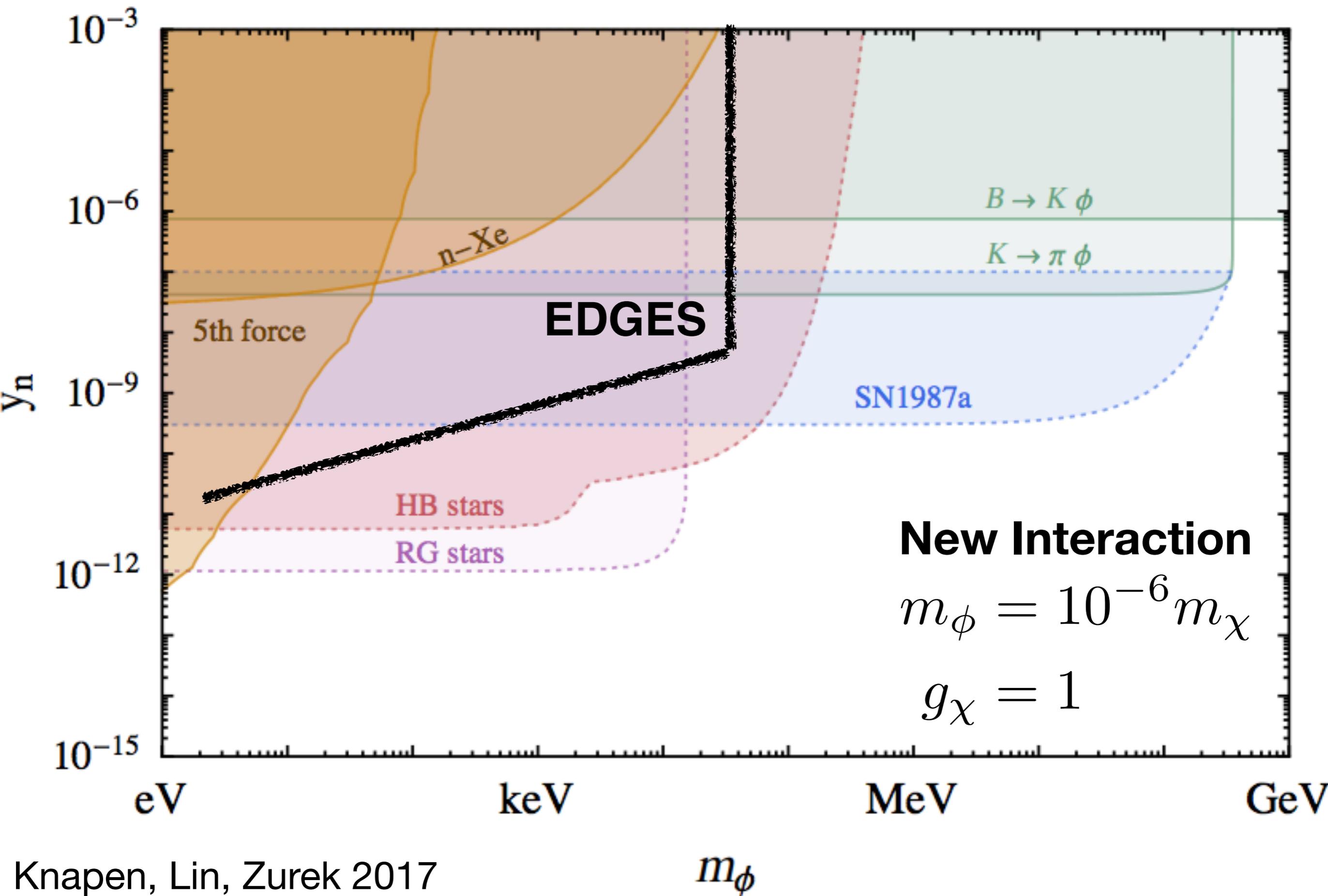
However, this:



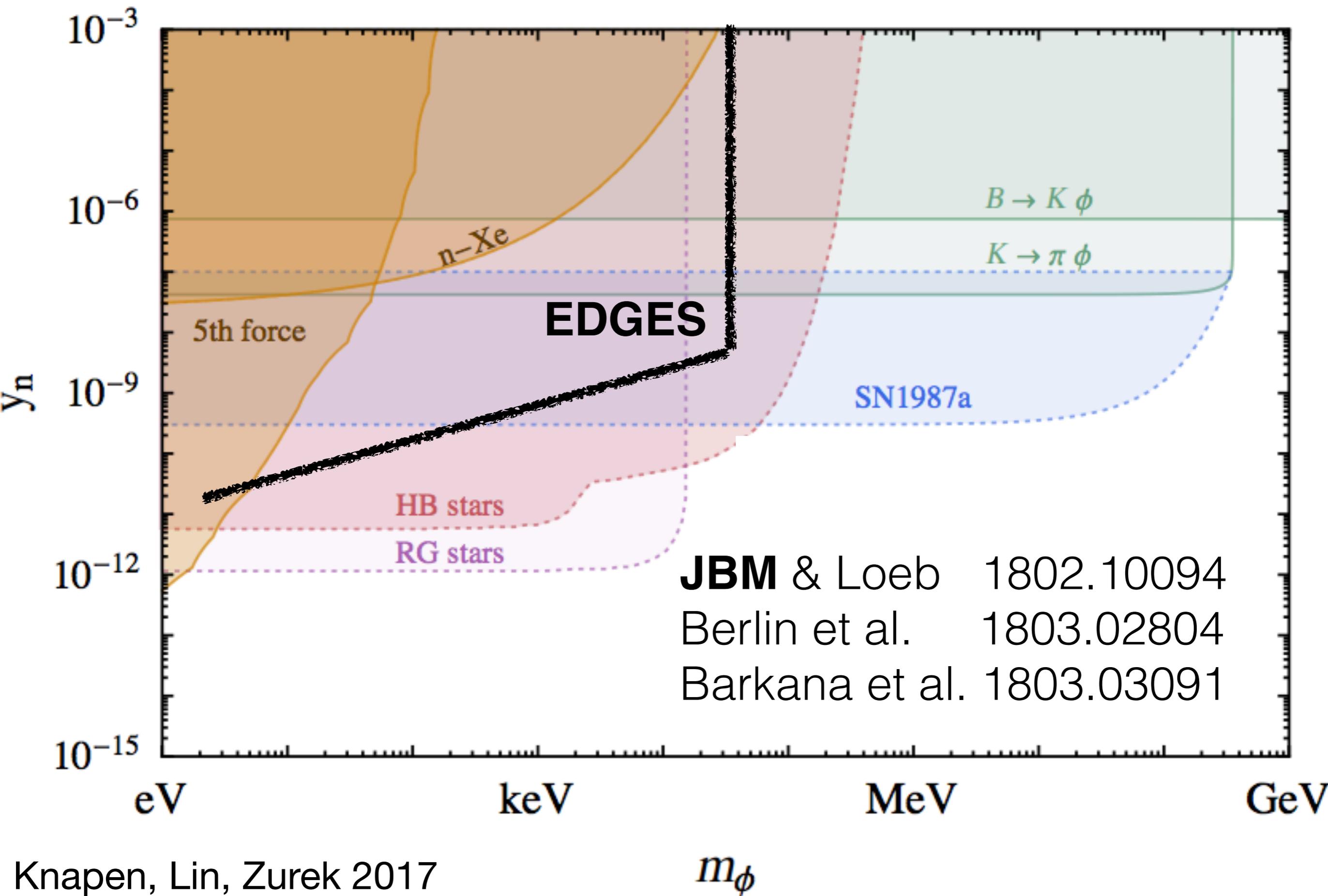
Also implies this:



Fifth-force constraints

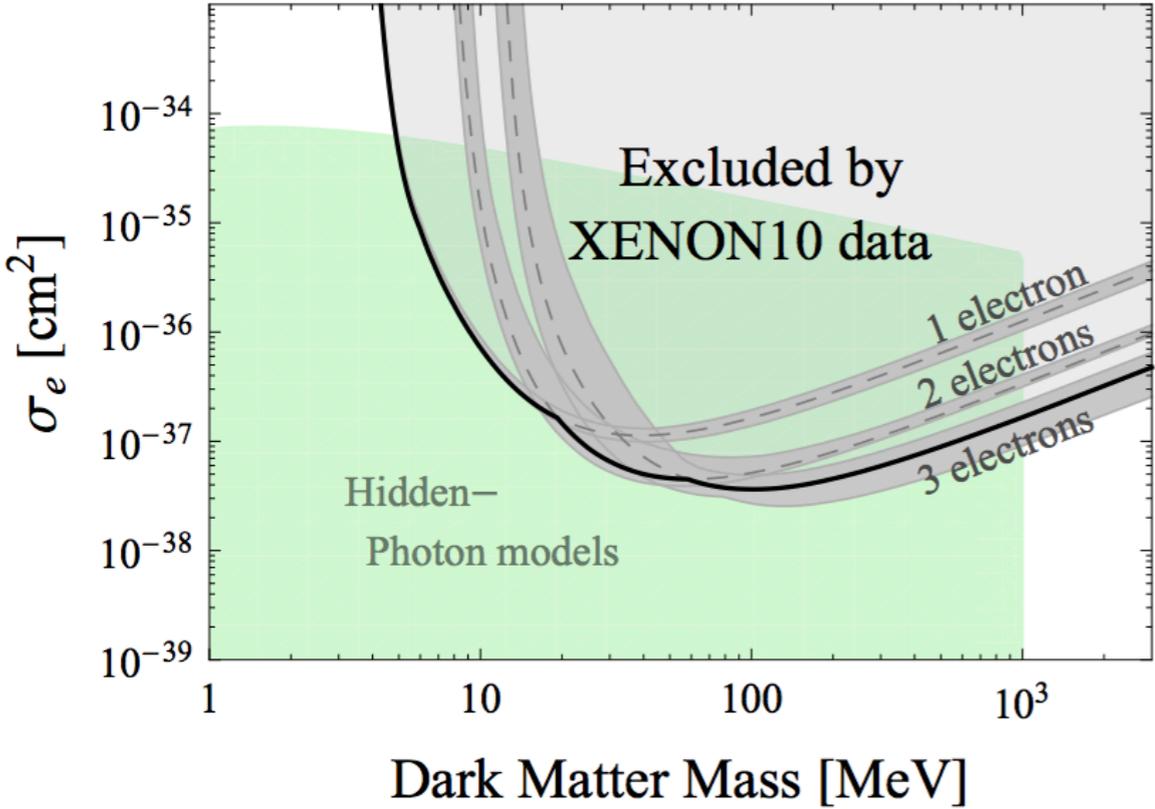


Fifth-force constraints



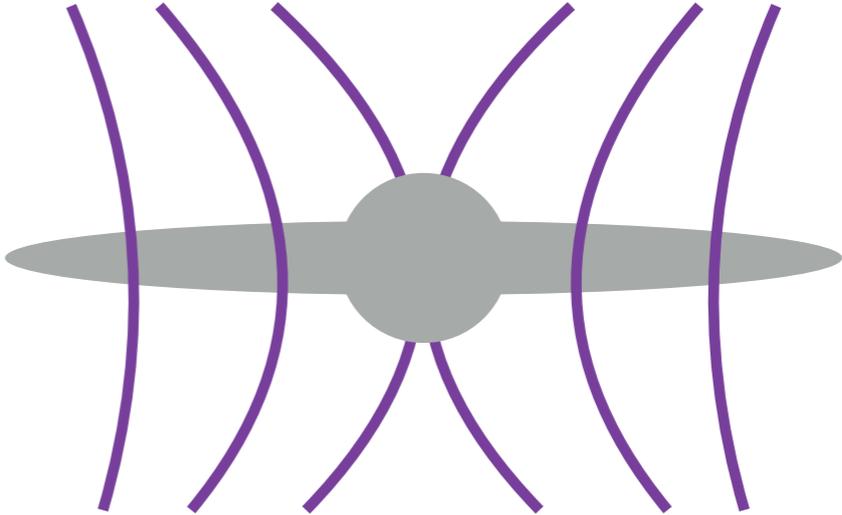
Can you test this?

Essig et al. 2012



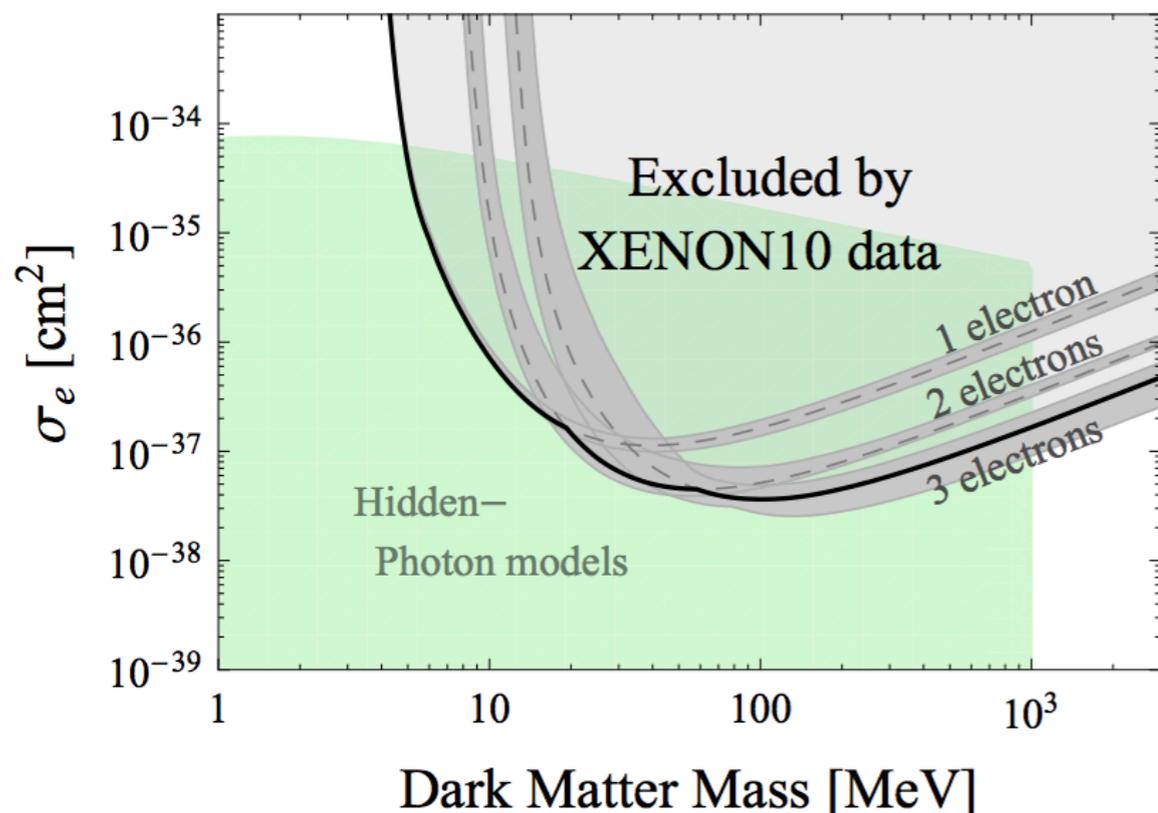
Although:

$$\sigma_{DD} \sim 10^{-27} \text{ cm}^2 > \sigma_{\text{m.f.p.}}$$



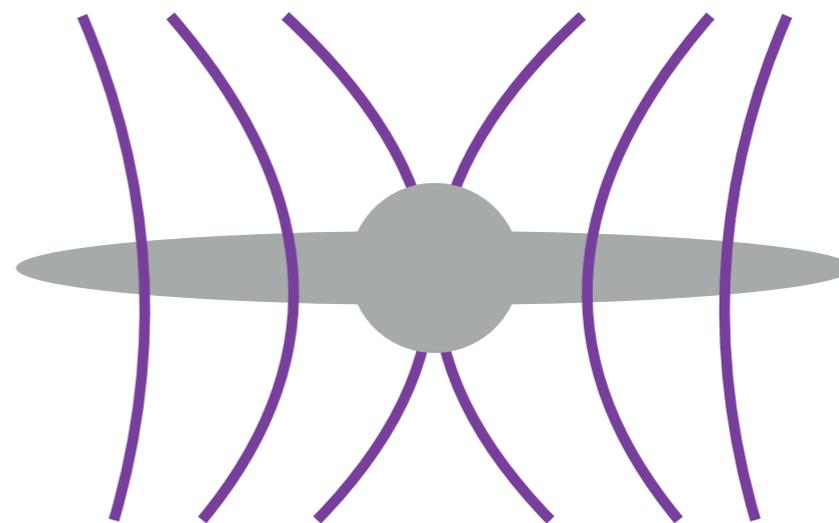
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Although:

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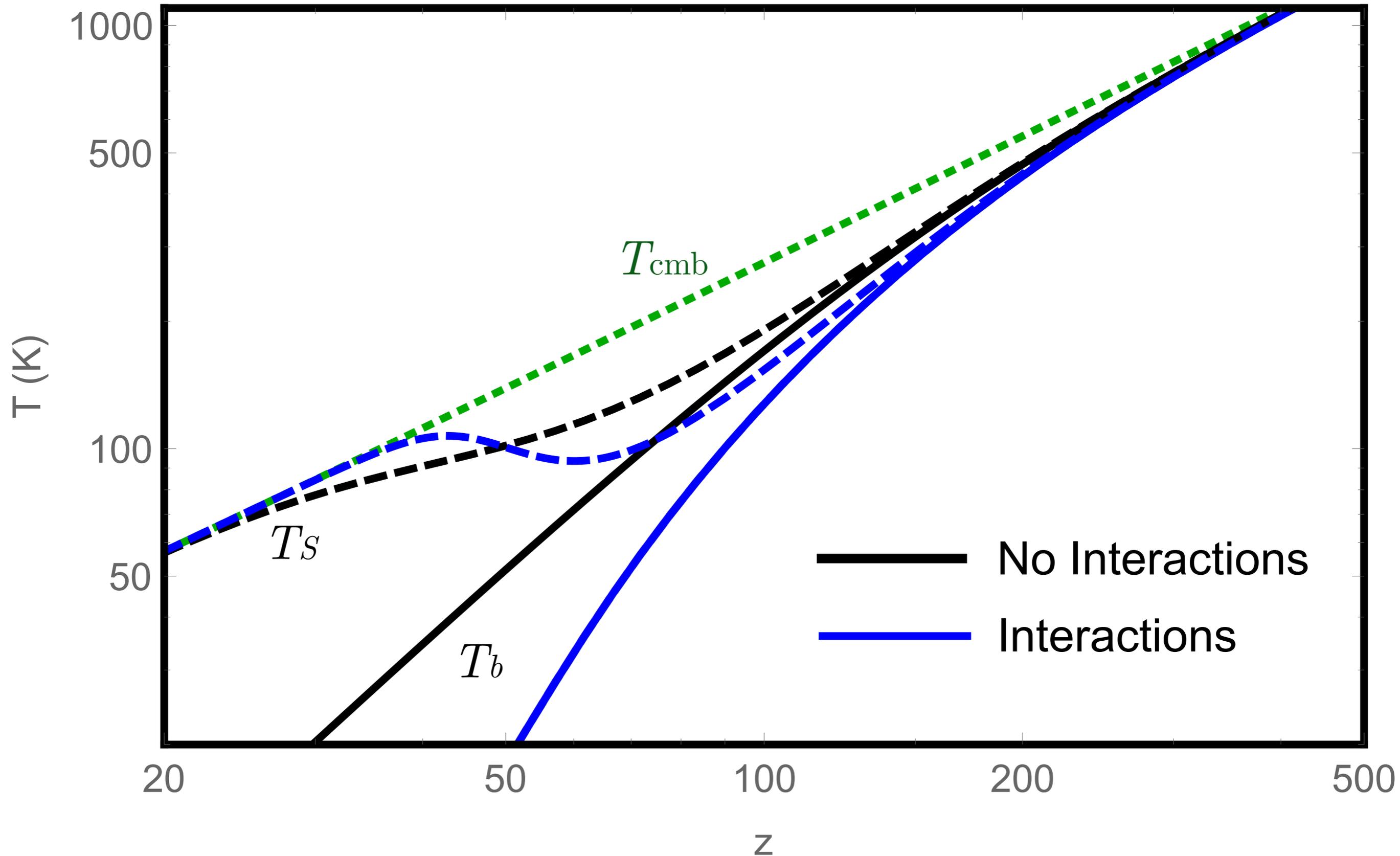
SHiP/MilliQan @ CERN

$$\epsilon > 10^{-3}$$

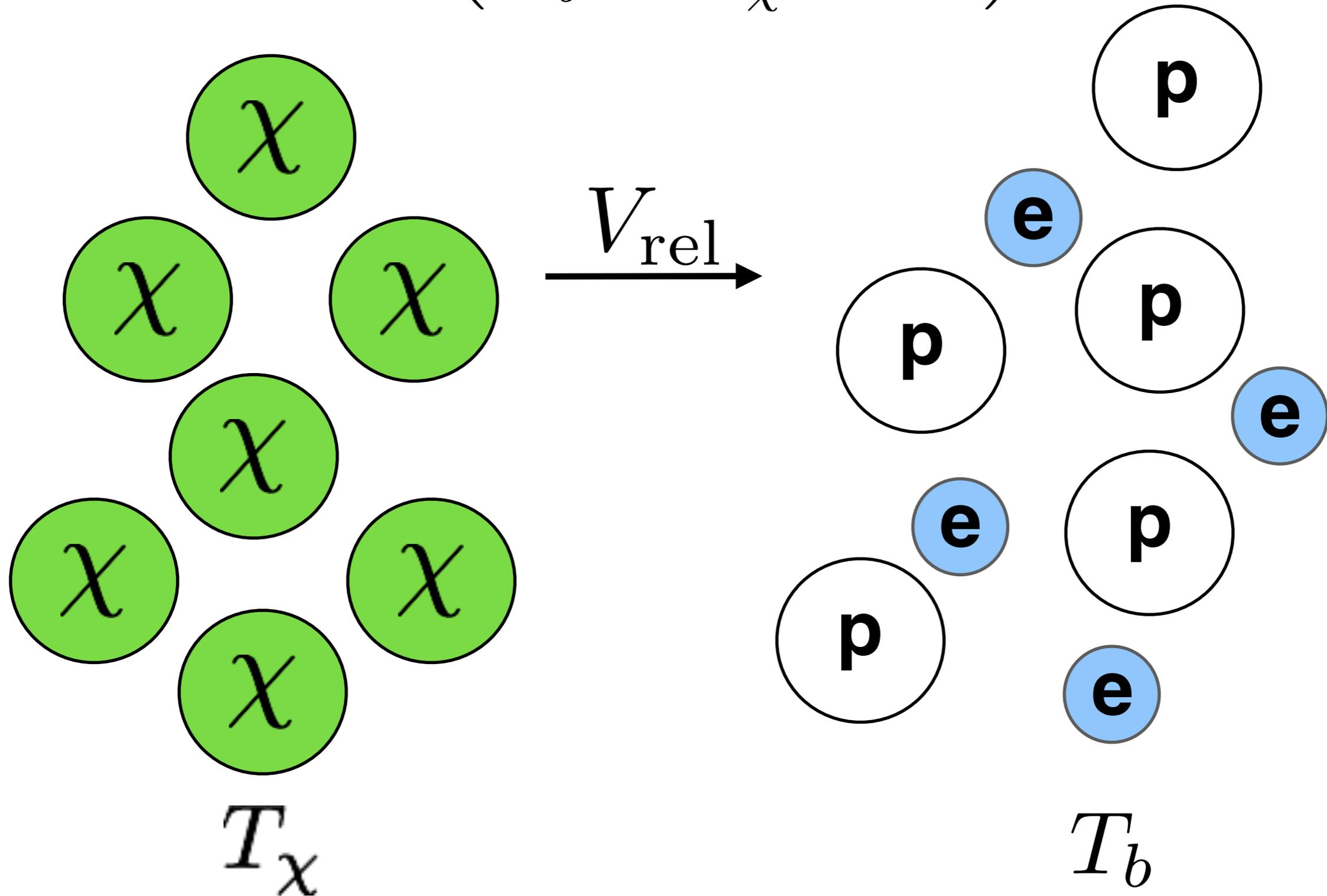
LDMX @ SLAC/Jlab/CERN

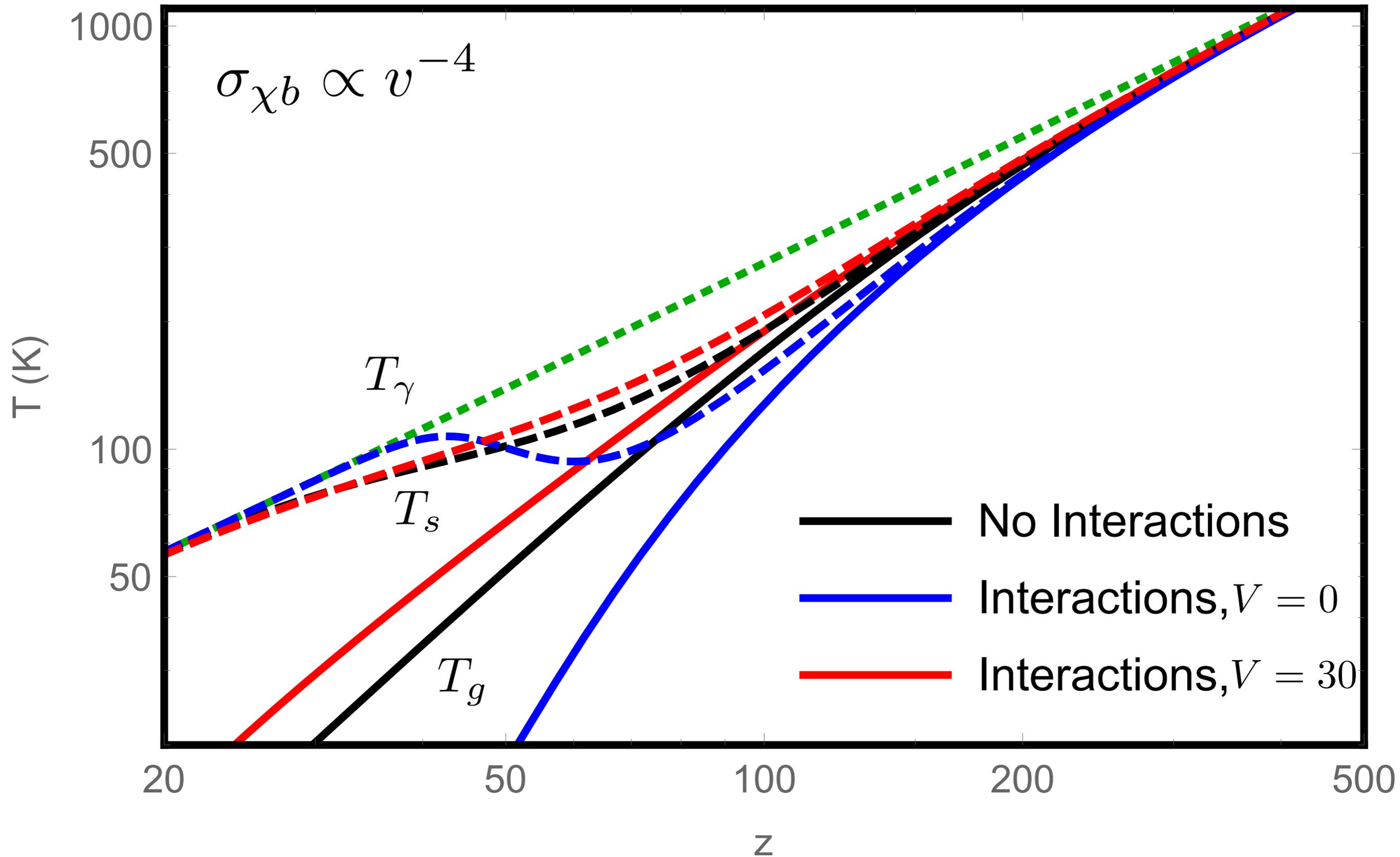
$$\epsilon \approx 10^{-1} \times \text{SLAC mQ}$$

Can you test this?

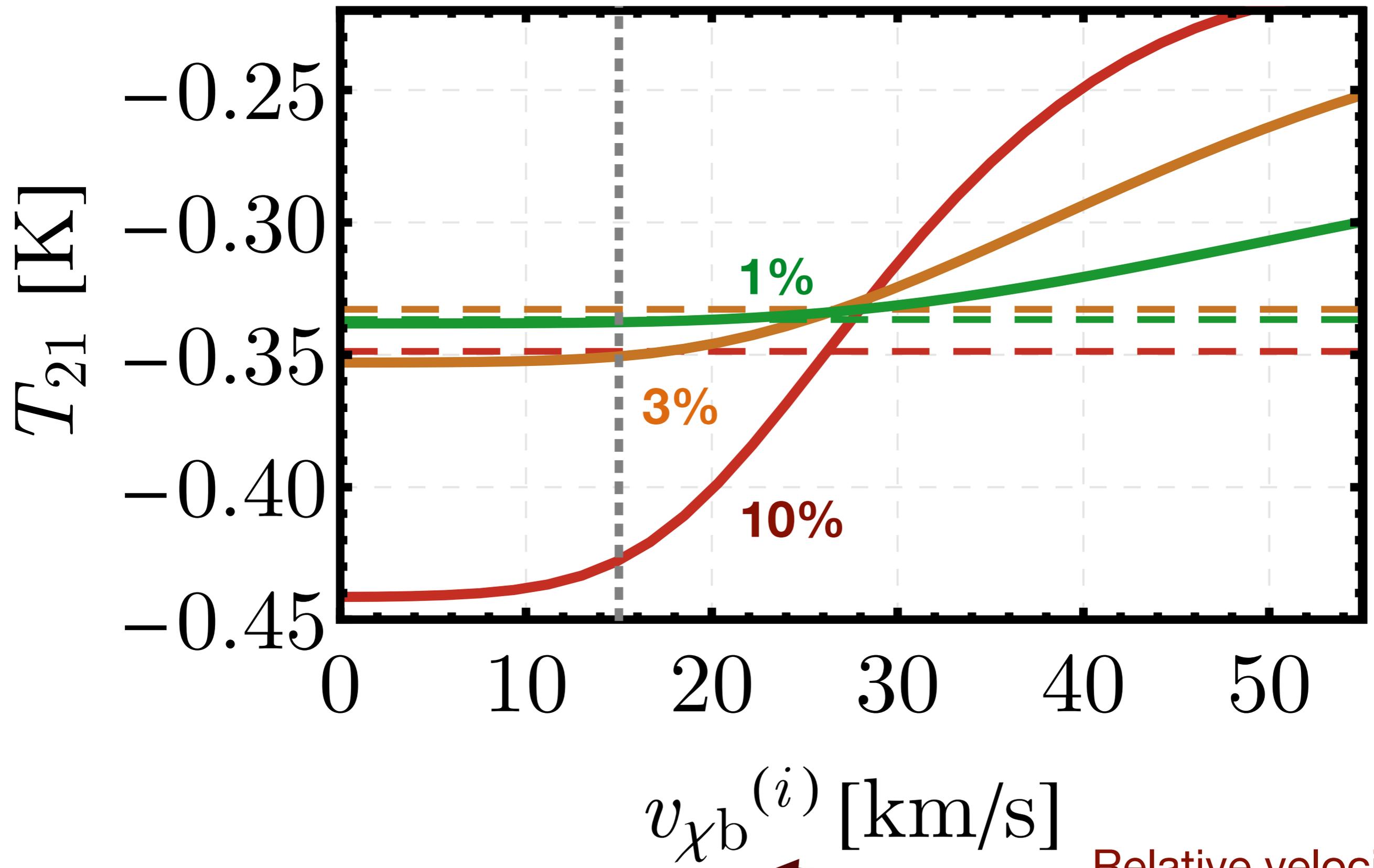


$$v \approx \left(\frac{T_b}{m_b} + \frac{T_\chi}{m_\chi} + V_{\text{rel}}^2 \right)^{1/2}$$



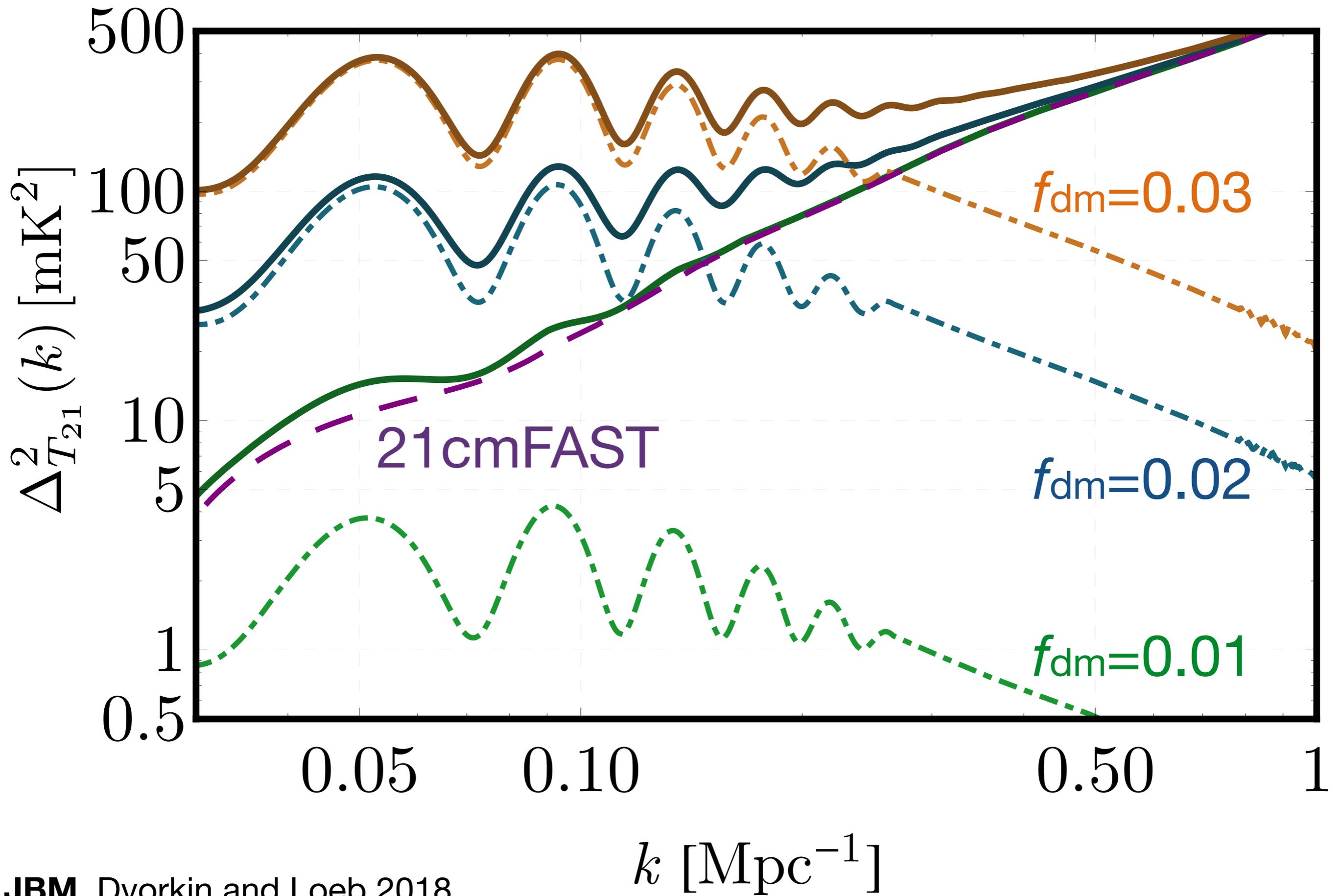


$$\sigma_{\chi b} \propto v^{-4}$$

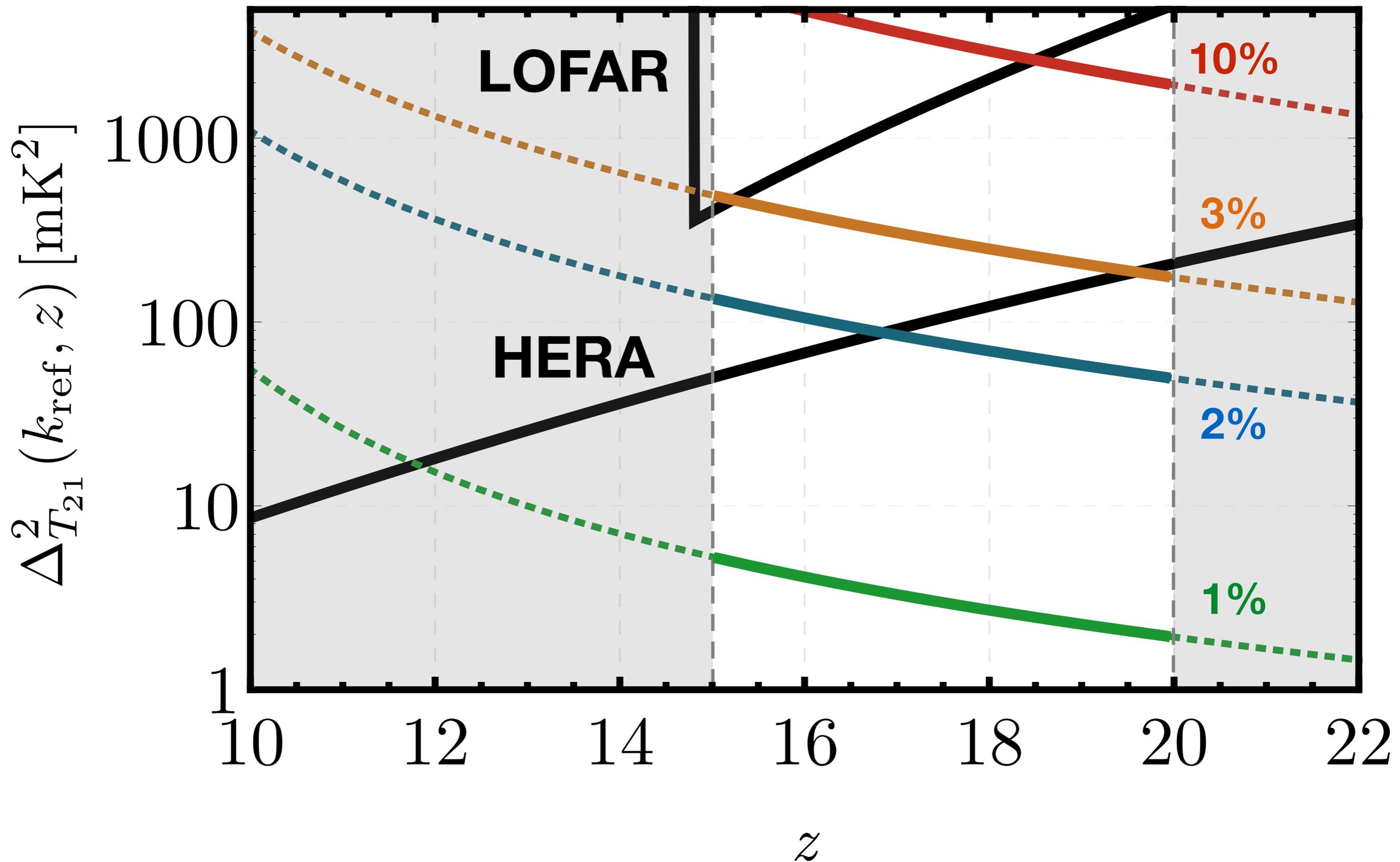


Relative velocity
at decoupling

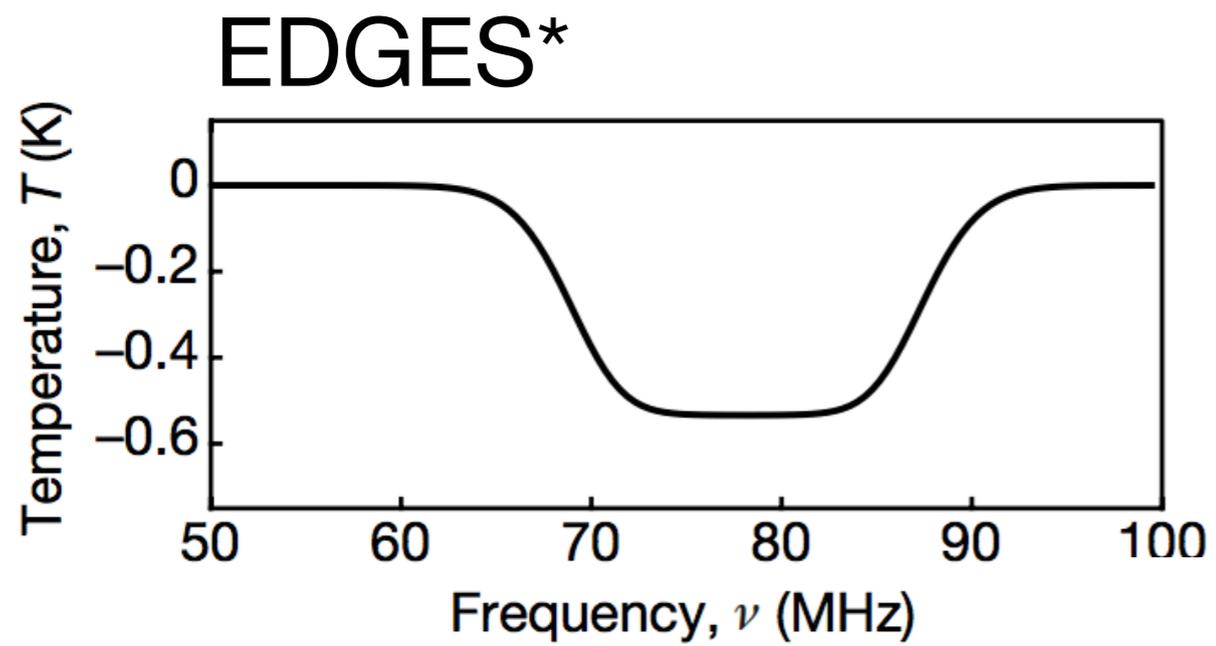
21-cm fluctuations



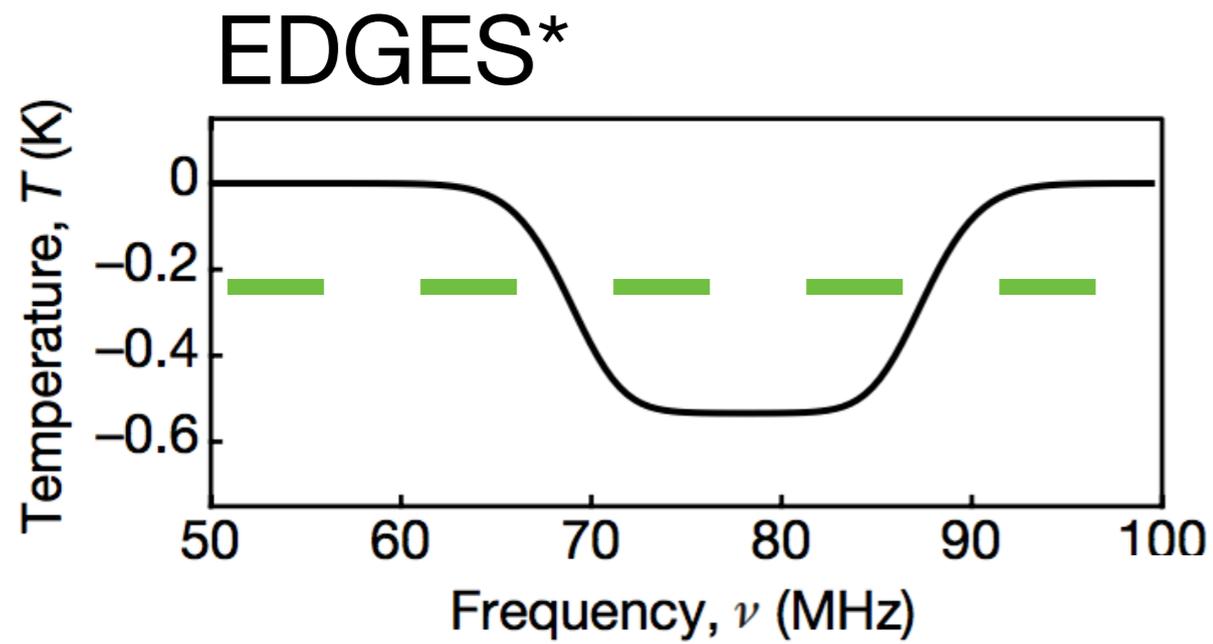
21-cm fluctuations



To sum up



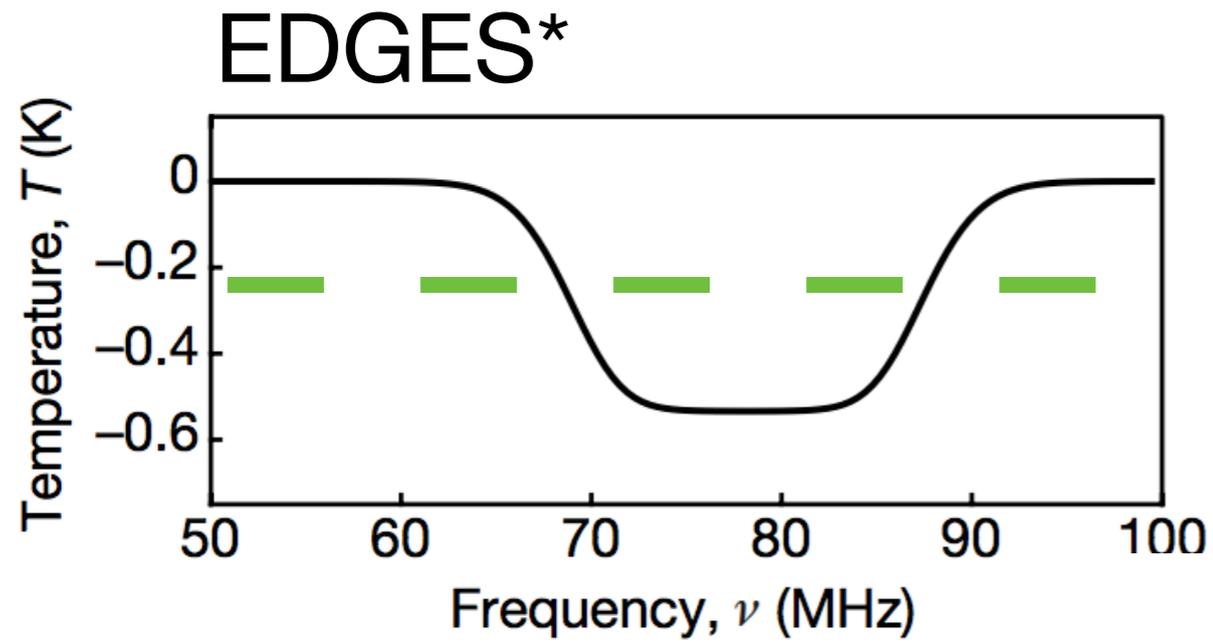
To sum up



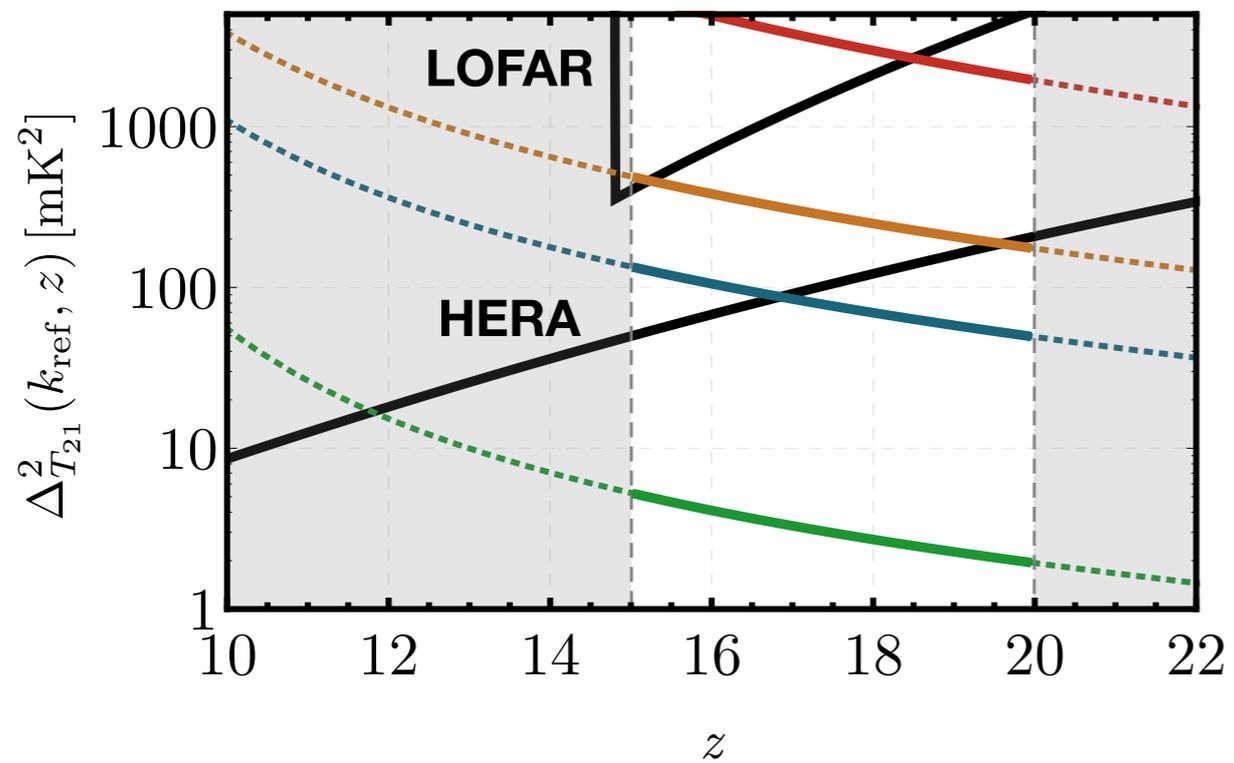
$$f_{\text{dm}} \lesssim \text{few}\%$$

$$\epsilon/m_\chi \sim 10^{-5} \text{ MeV}^{-1}$$

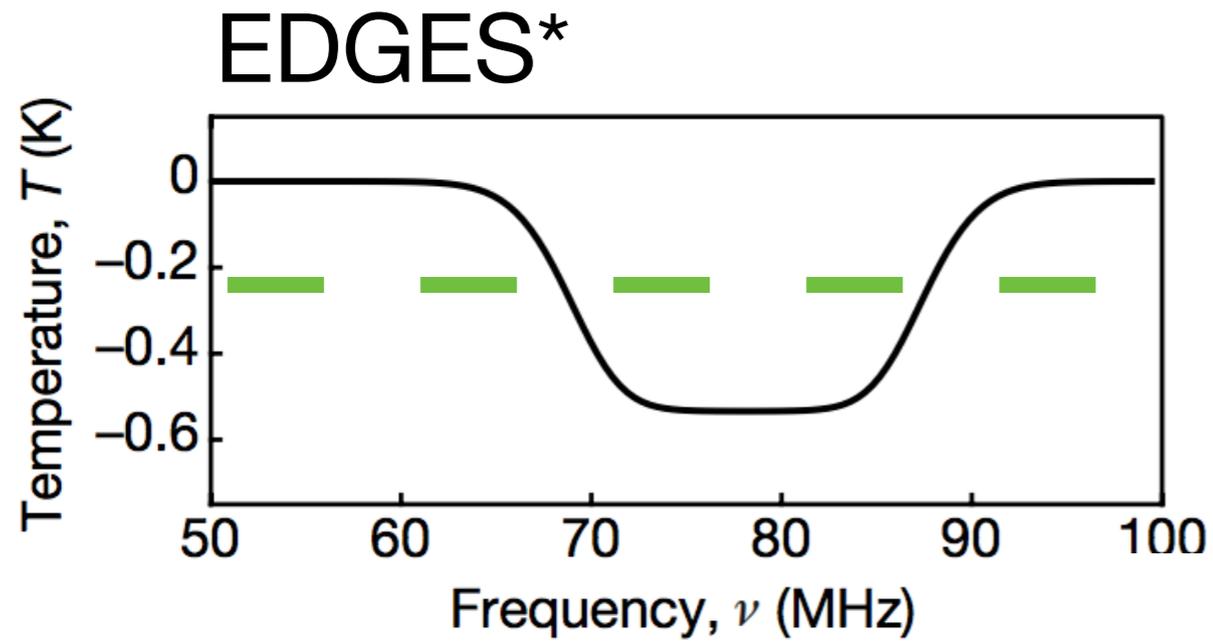
To sum up



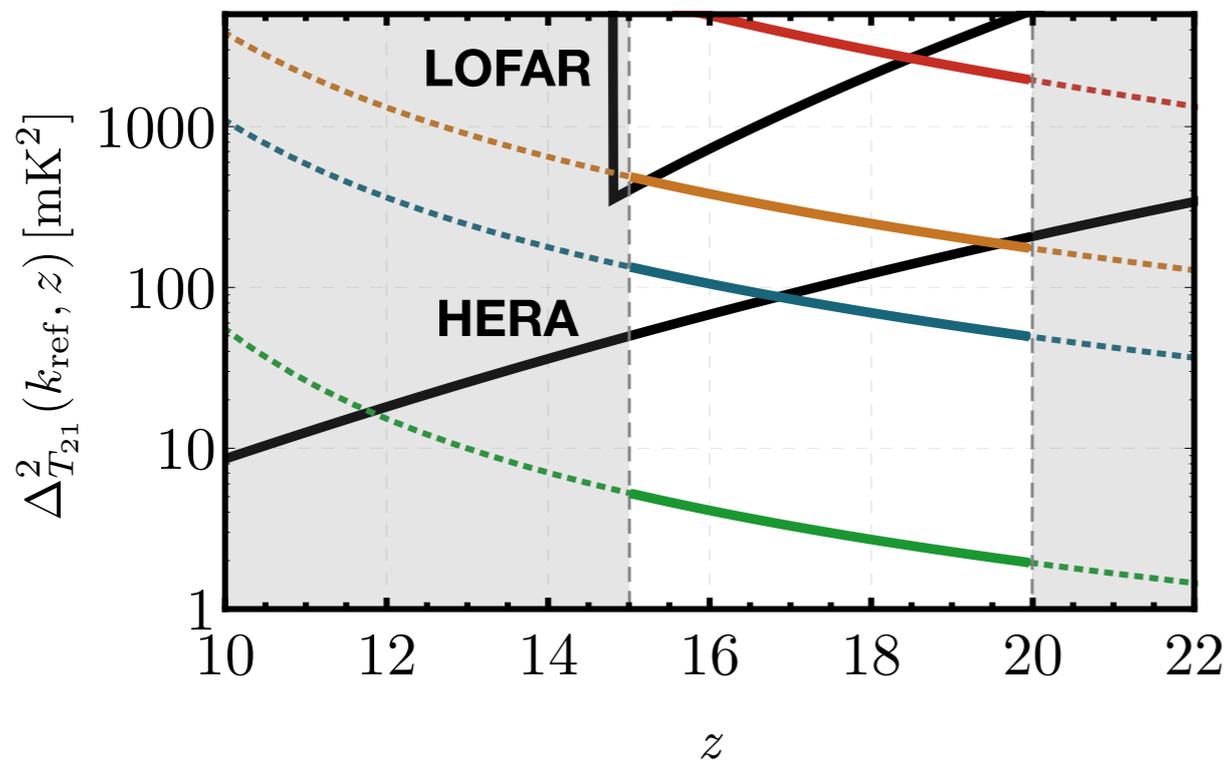
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To sum up

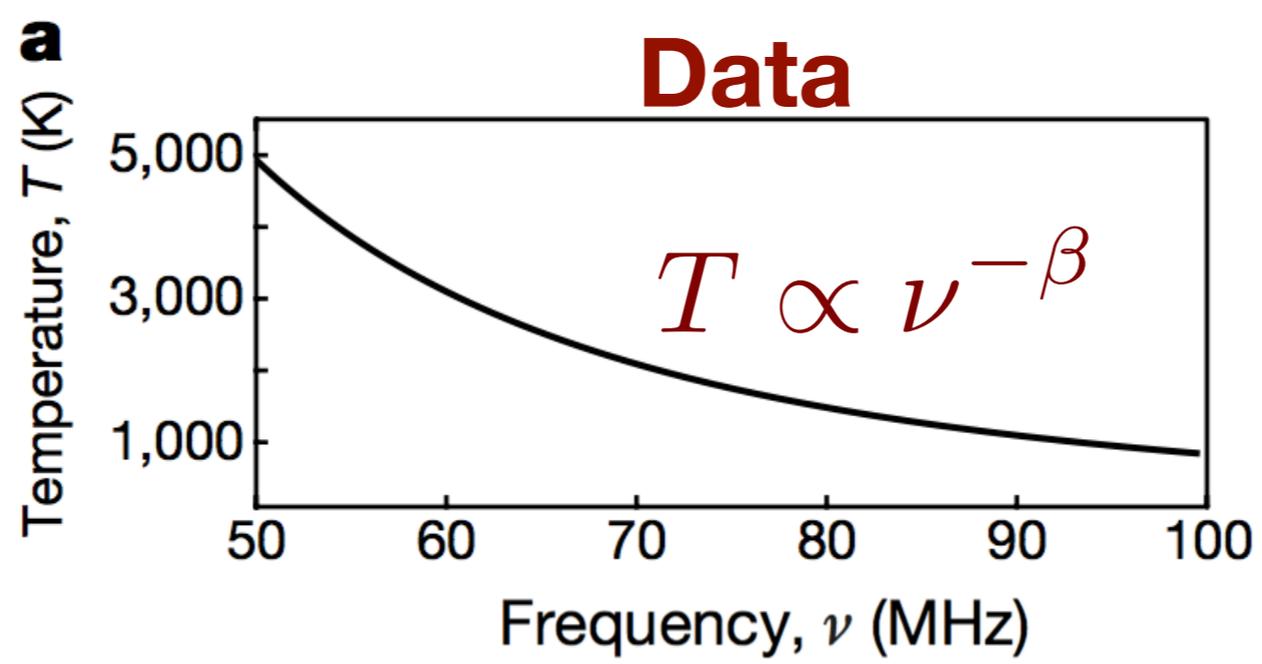


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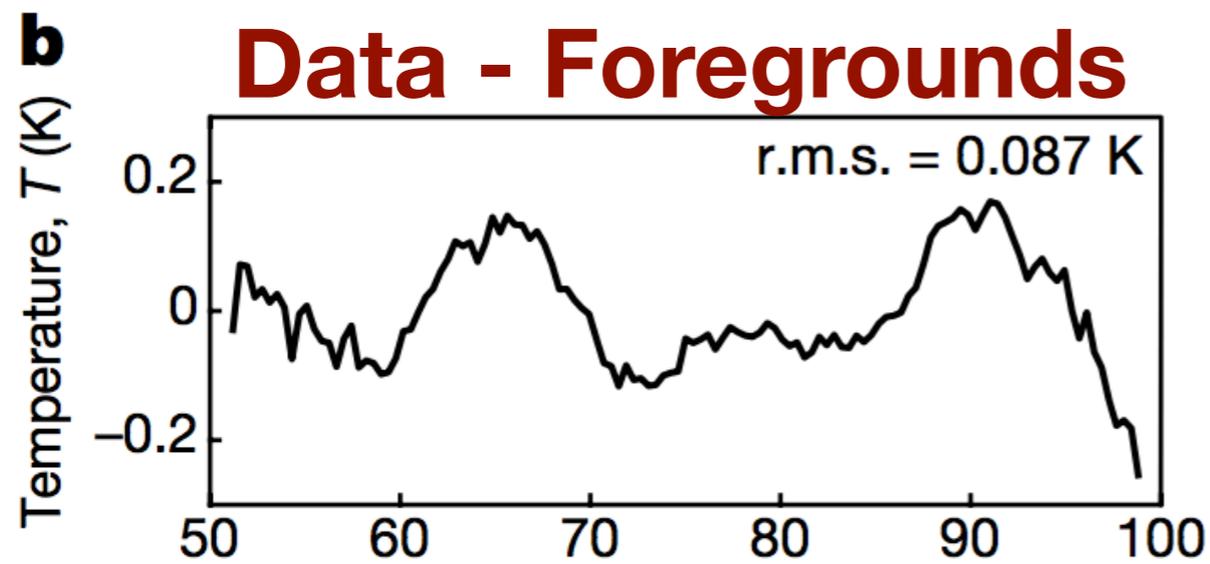
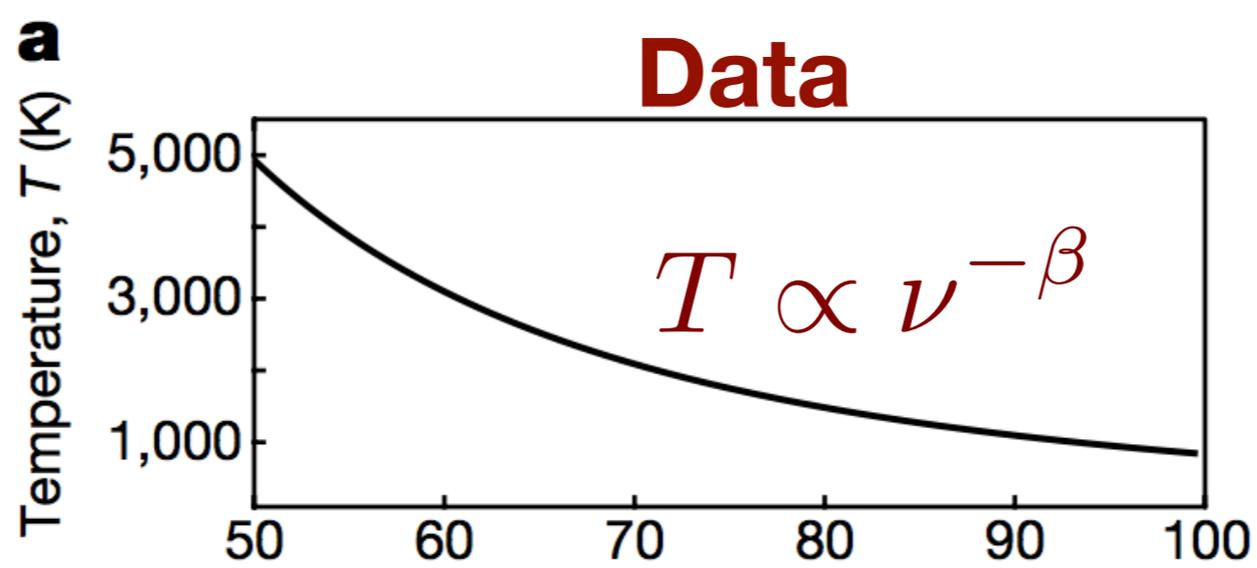
Thank you!

Backup



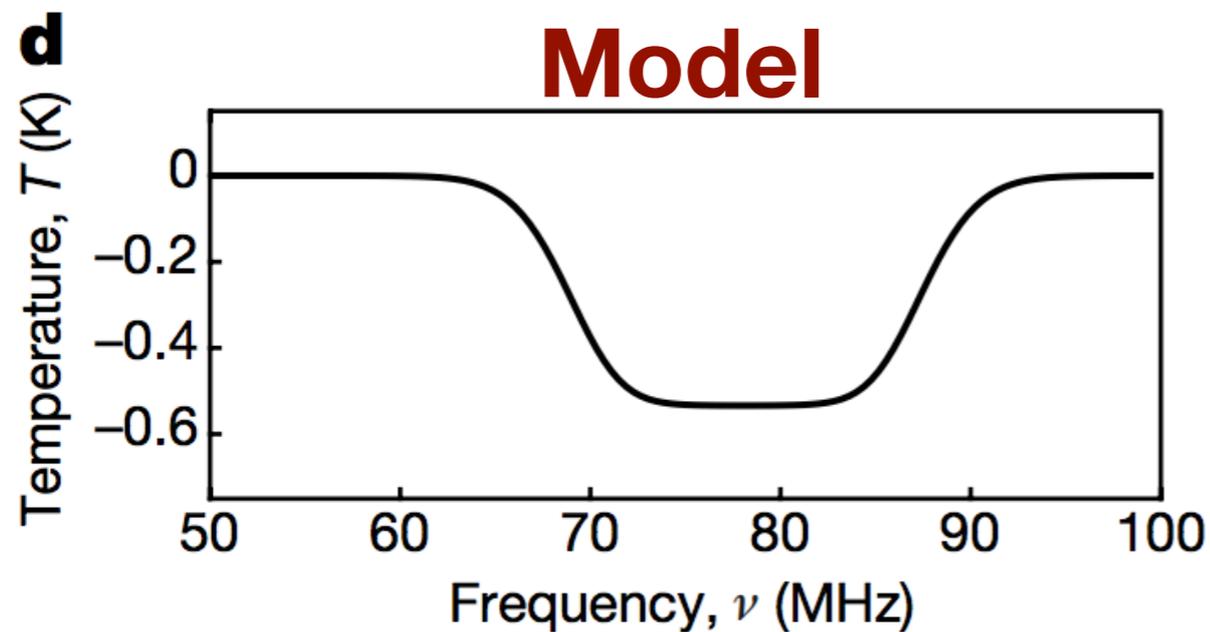
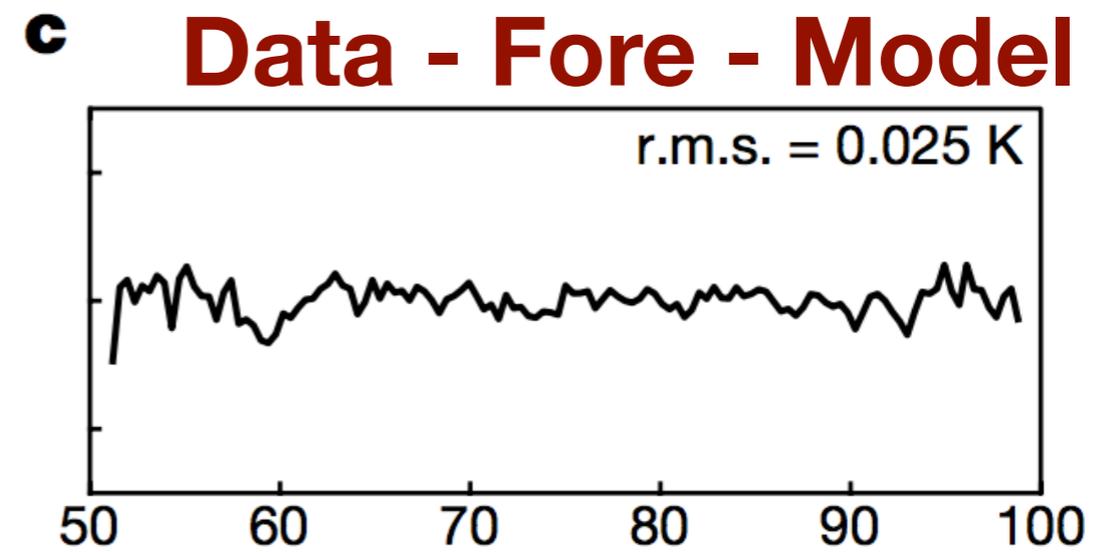
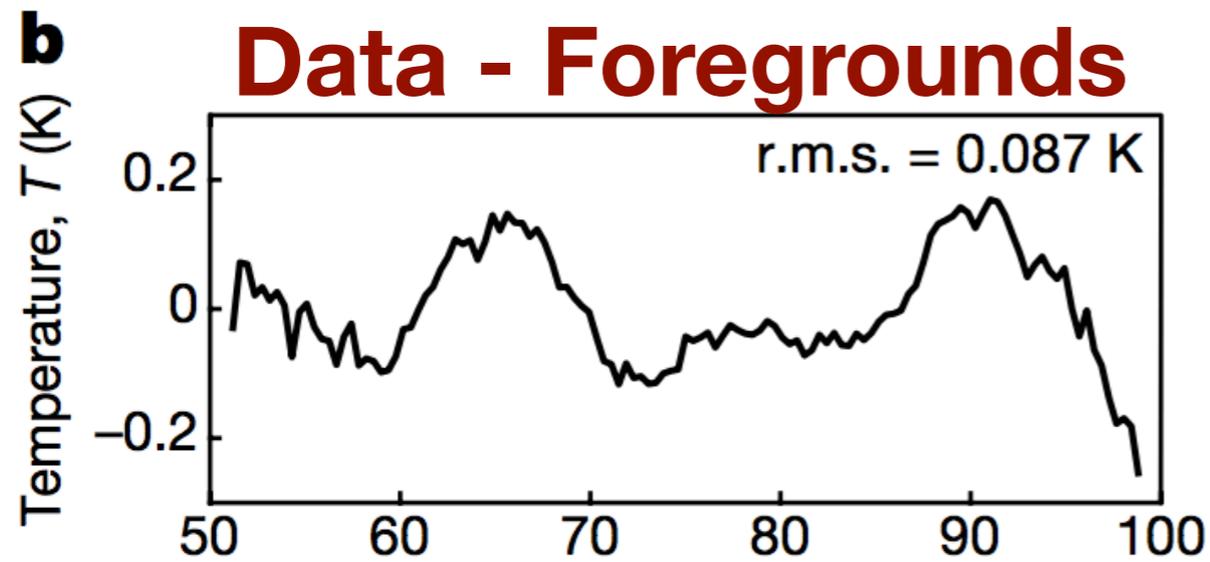
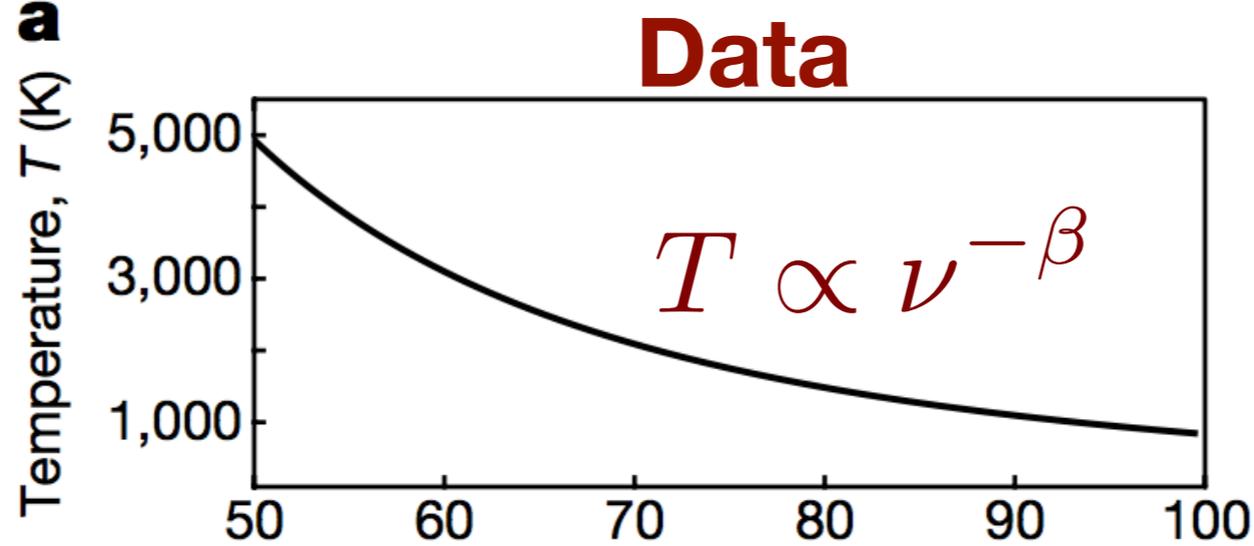
Bowman et al. Nature 2018

EDGES (Experiment to Detect the Global EoR Signature)



Bowman et al. Nature 2018

EDGES (Experiment to Detect the Global EoR Signature)



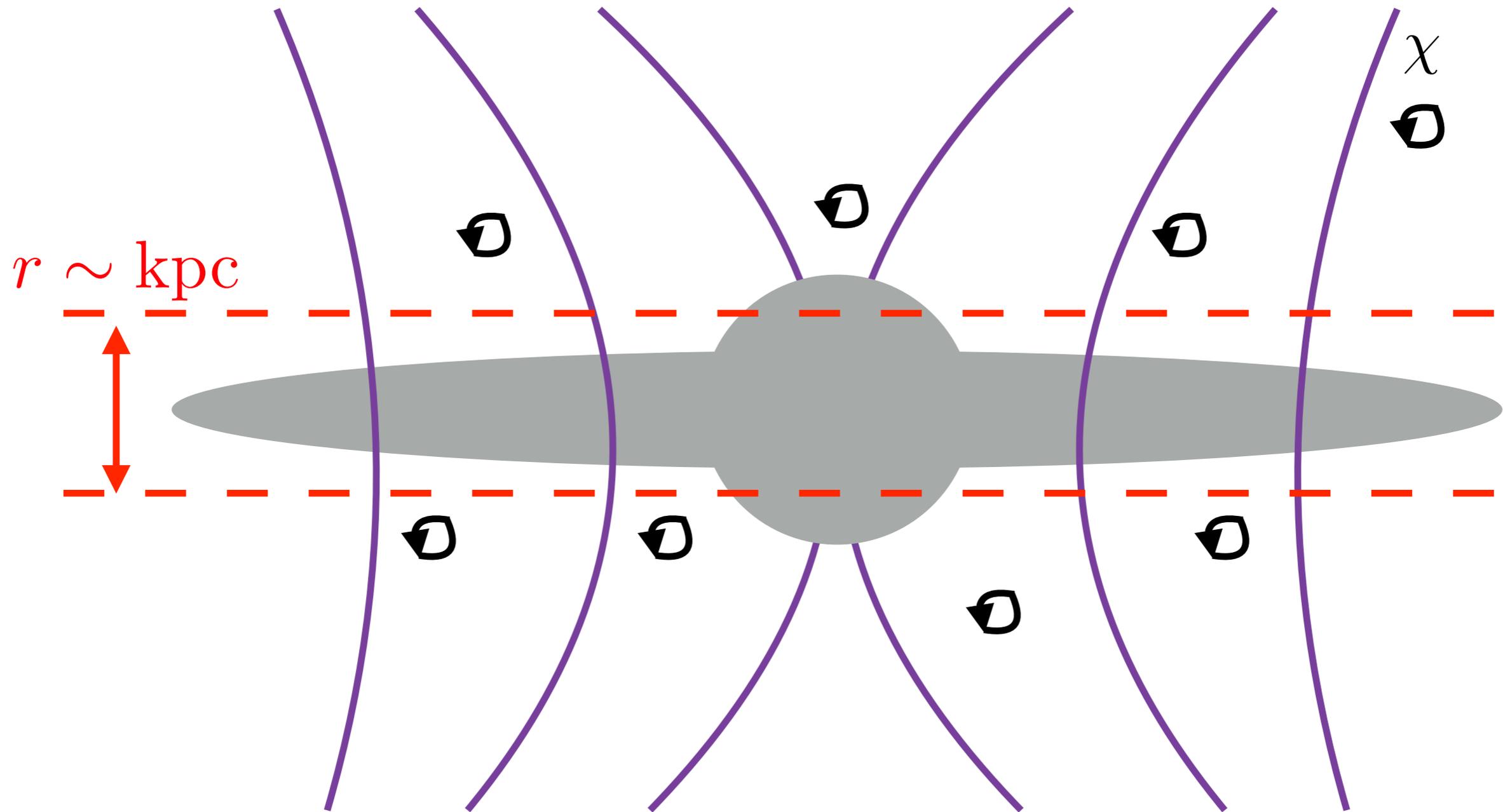
$$\nu = \frac{1420 \text{ MHz}}{1 + z}$$

Bowman et al. Nature 2018

EDGES (Experiment to Detect the Global EoR Signature)

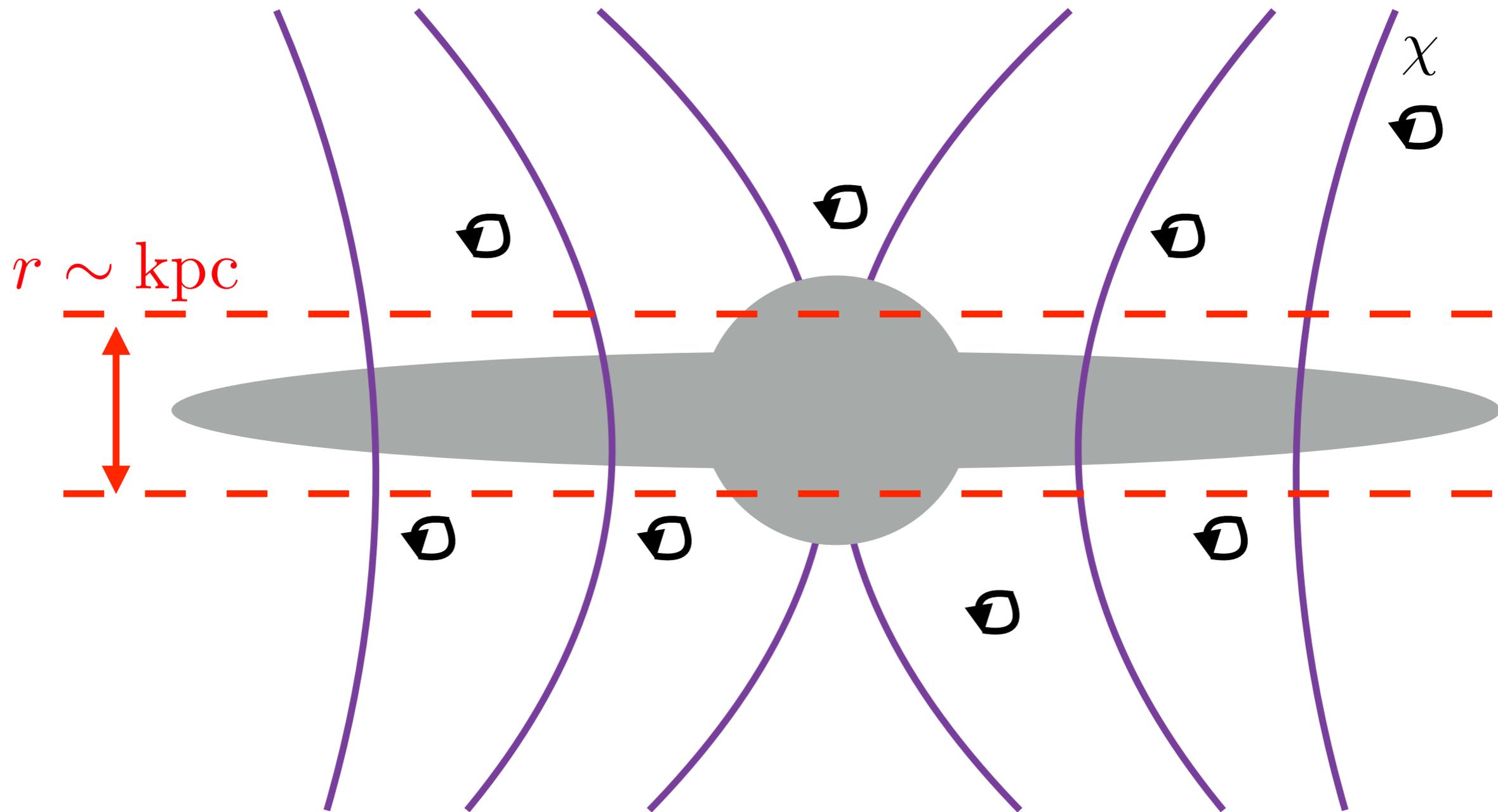
$$r_g \propto \frac{m_\chi}{\epsilon} \gtrsim 100 \text{ kpc}$$

Image: NASA/CXC/CfA/STScI ESO/WFI



$$\rho_{\text{DM}} = 0.9 \pm 0.3 \text{ GeV cm}^{-3}$$

Bovy and Tremaine (2012)



$$\rho_{\text{DM}} = 0.9 \pm 0.3 \text{ GeV cm}^{-3}$$

Bovy and Tremaine (2012)

However:

$$\rho_B \sim 10^{-3} \rho_{\text{dm}} v_{\text{MW}}^2$$

$$\dot{T}_b \propto \frac{\epsilon^2}{m_\chi^2} f_{\text{dm}} \frac{1}{v_{\text{rel}}^3} \quad v_{\text{rel}} \approx \left(\frac{T_b}{m_b} + \frac{T_\chi}{m_\chi} \right)^{1/2}$$

$$T_b^i n_b = T_b^f n_b + T_\chi^f n_\chi$$

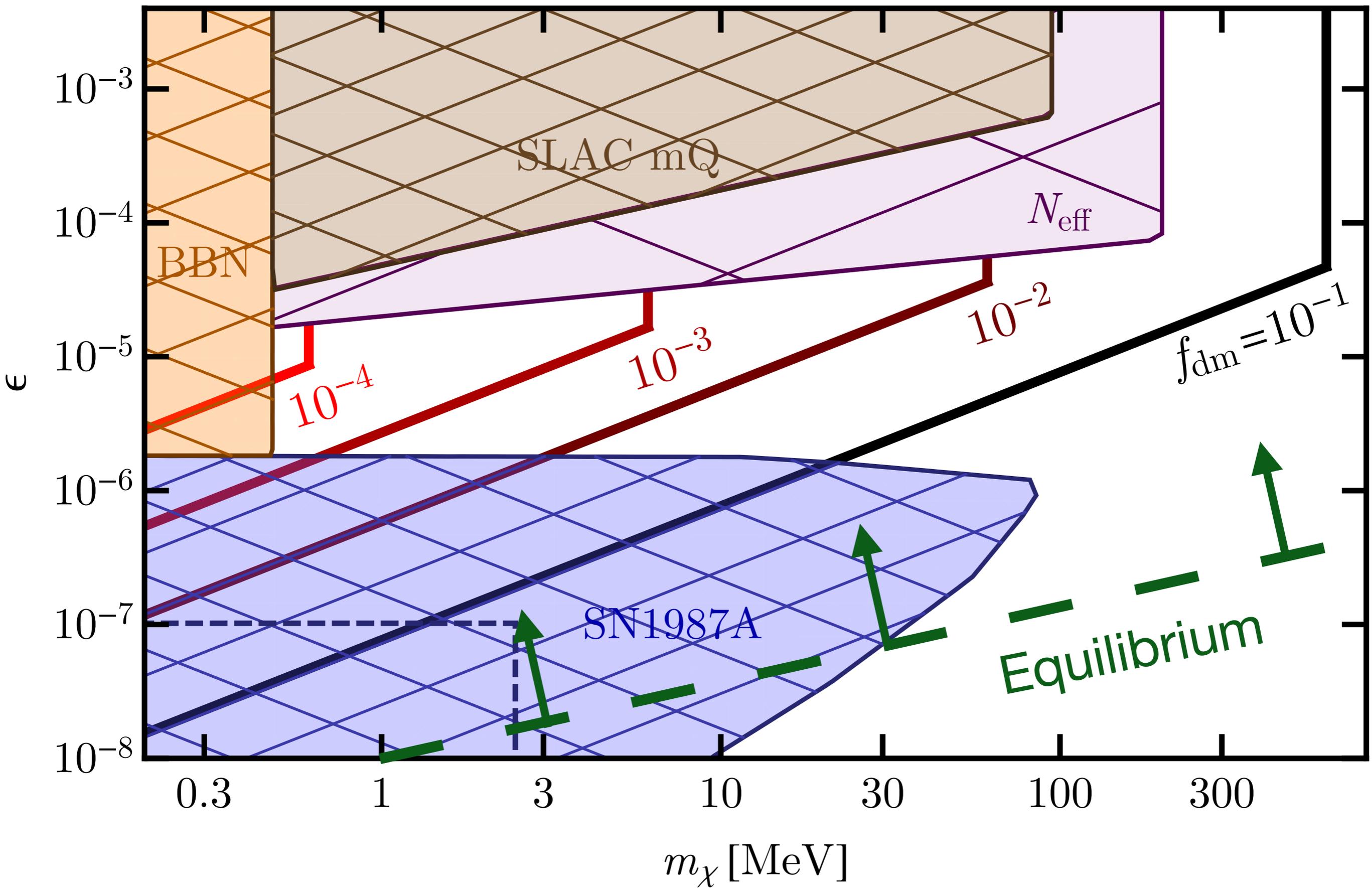
$$\frac{T_\chi}{m_\chi} \approx \frac{T_b}{m_b} \frac{1}{10 f_{\text{dm}}}$$

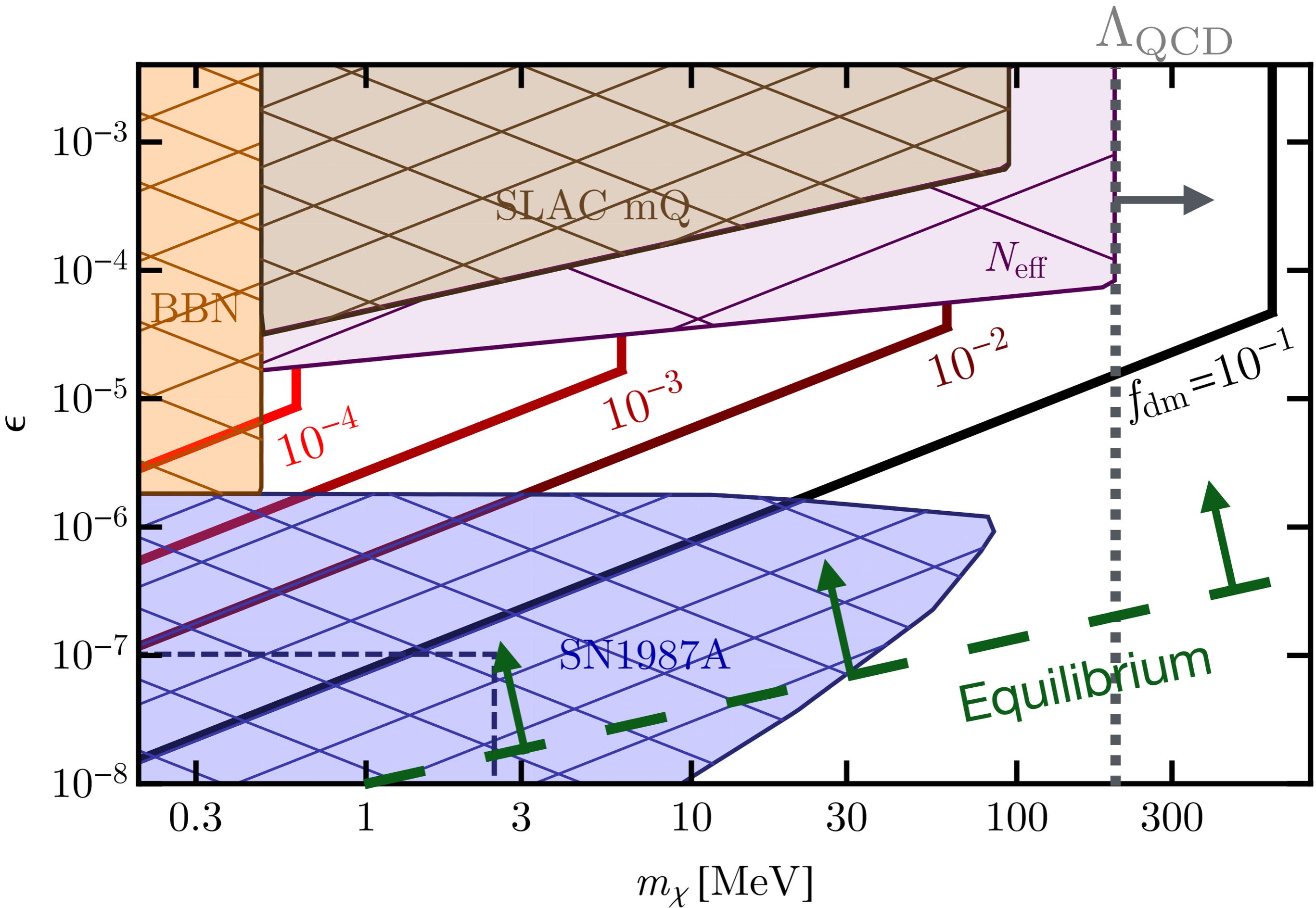
$$\epsilon/m_\chi \propto f_{\text{dm}}^{-3/4}$$

$$\dot{T}_b \propto \frac{\epsilon^2}{m_\chi^2} f_{\text{dm}} \frac{1}{v_{\text{rel}}^3}$$

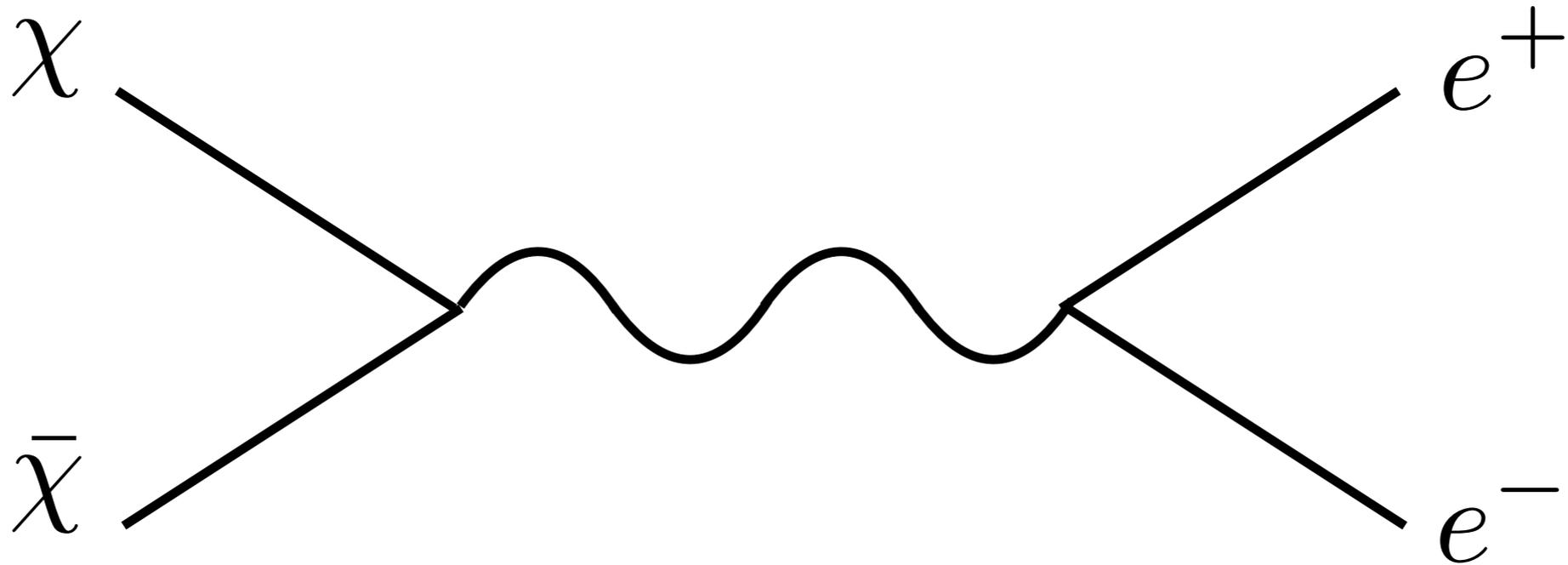
$$\epsilon/m_\chi \quad \text{constant}$$

$$\epsilon/m_\chi \propto f_{\text{dm}}^{-3/4}$$





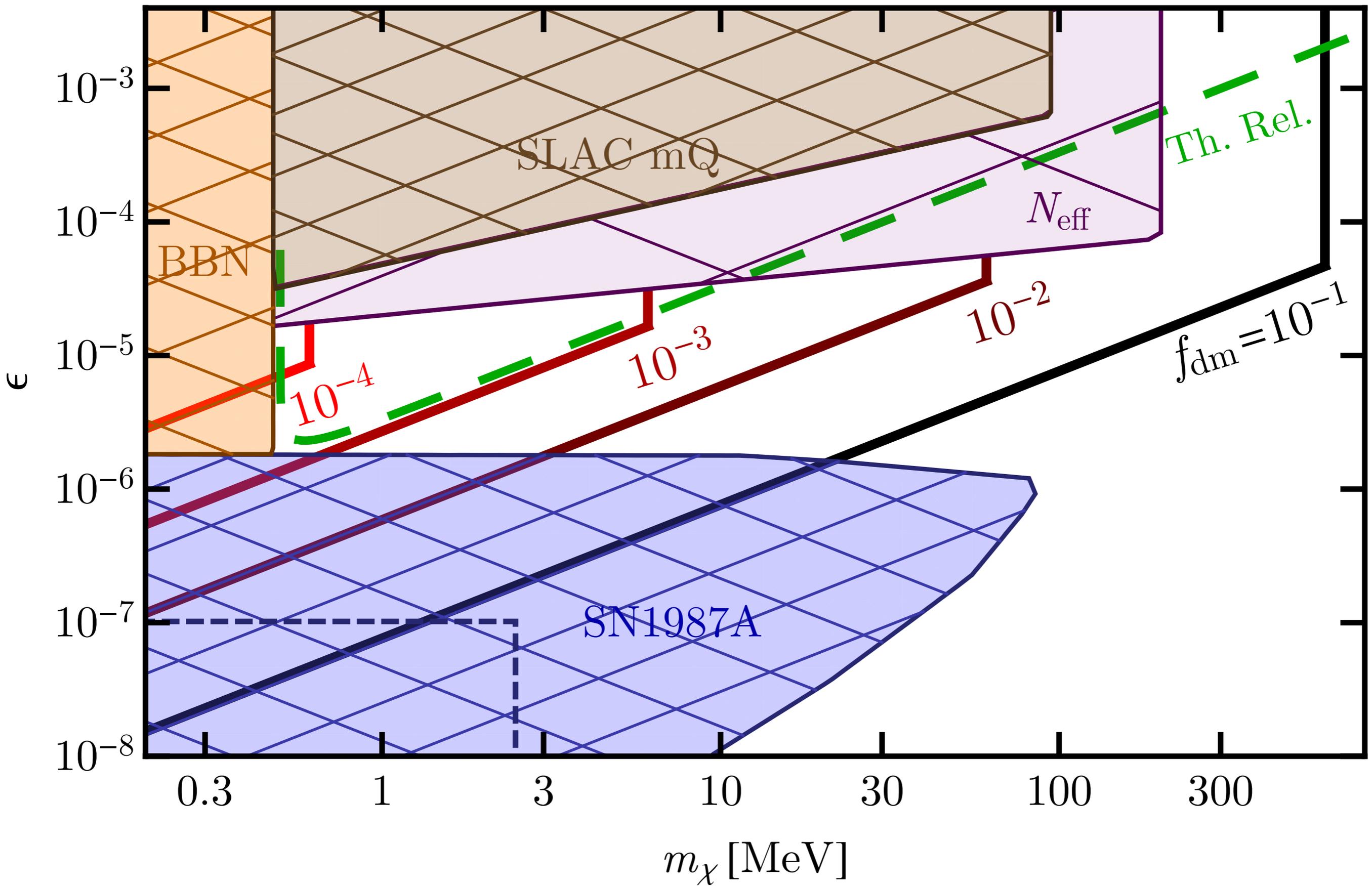
$$\chi\bar{\chi} \rightarrow e^+e^-$$



$$\langle\sigma v\rangle = \frac{\pi\alpha^2\epsilon^2}{m_\chi^2} \sqrt{1 - \frac{m_f^2}{m_\chi^2}} \left(1 + \frac{m_f^2}{2m_\chi^2}\right)$$

-Stops at the electron mass.

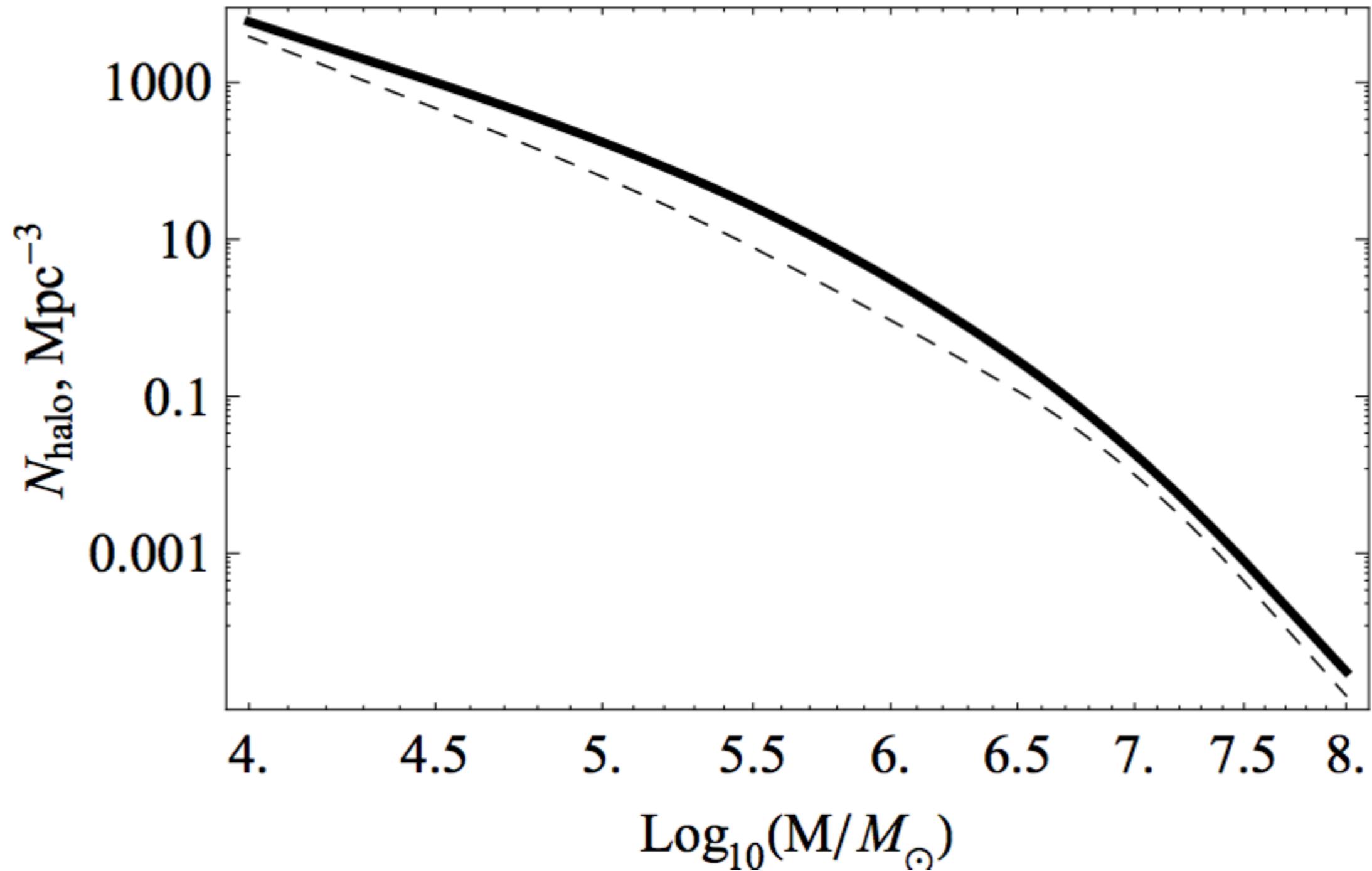
-Goes as $(\epsilon/m_\chi)^2$, like scattering.



21-cm fluctuations

Number of haloes

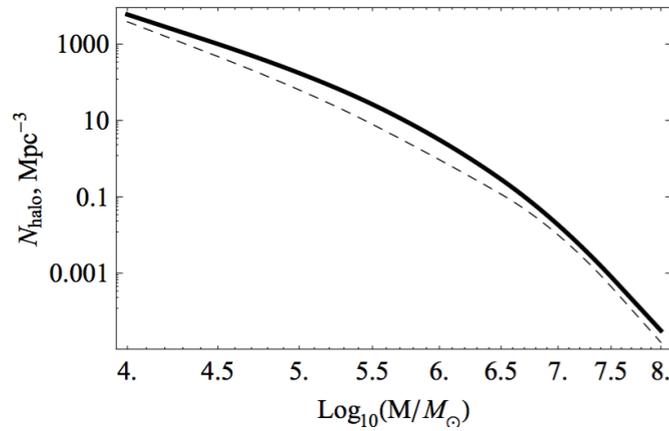
Tseliakhovich and Hirata 2010



21-cm fluctuations

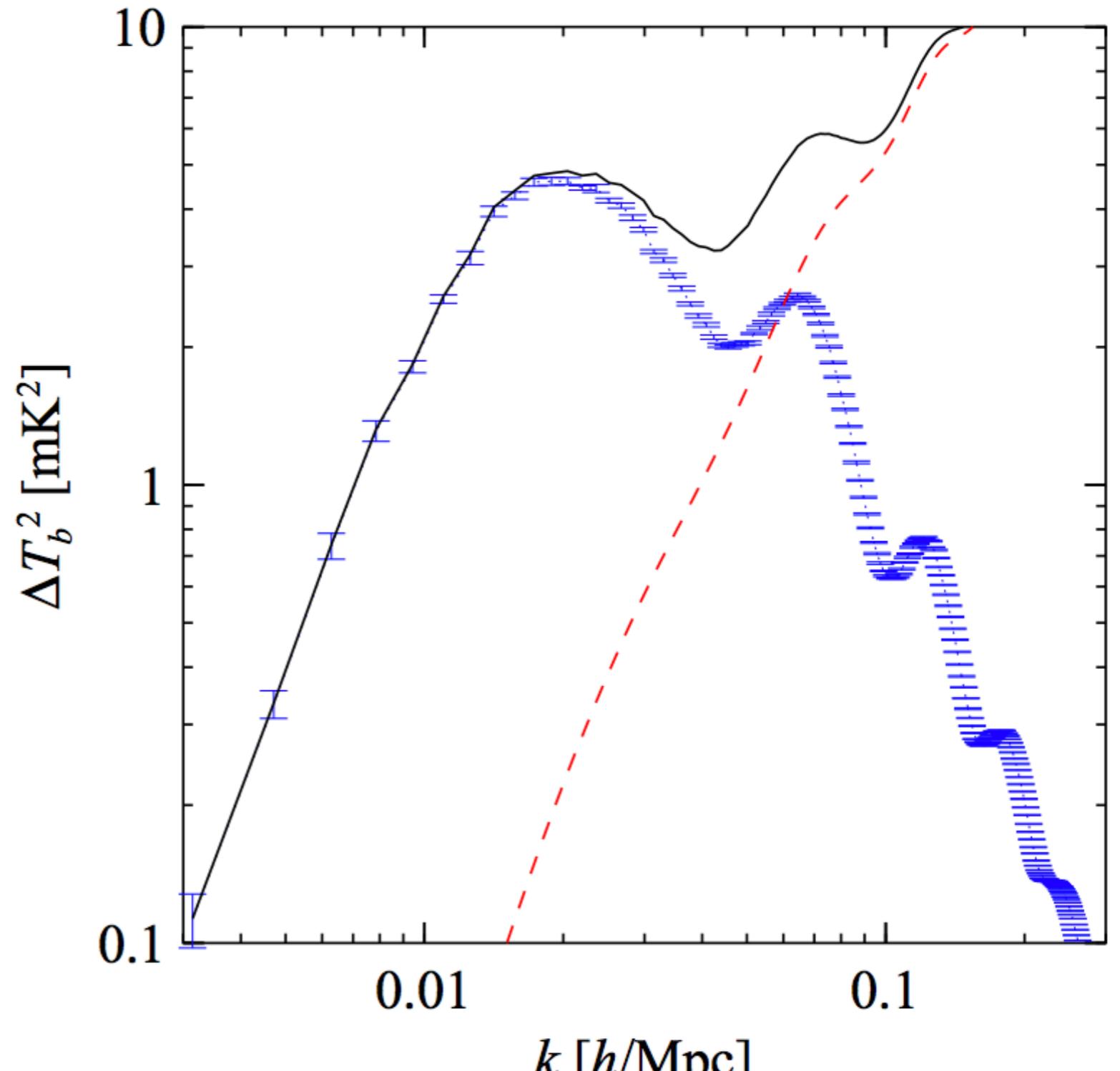
Number of haloes

Tseliakhovich and Hirata 2010



Gas Collapsed

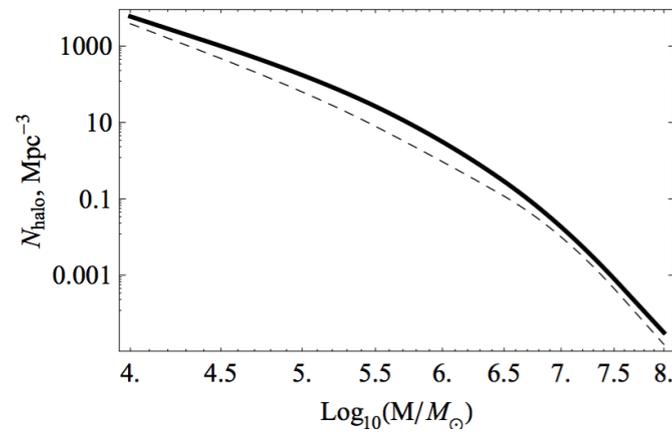
Dalal et al. 2010



21-cm fluctuations

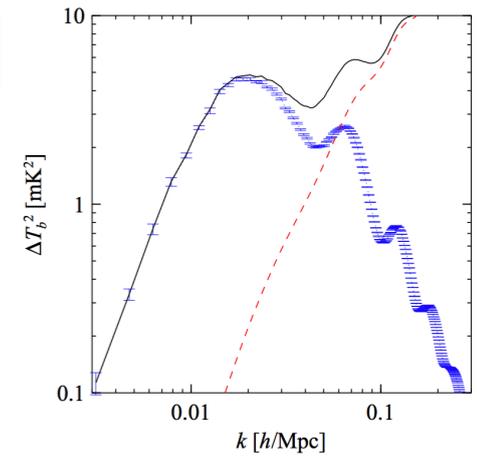
Number of haloes

Tseliakhovich and Hirata 2010



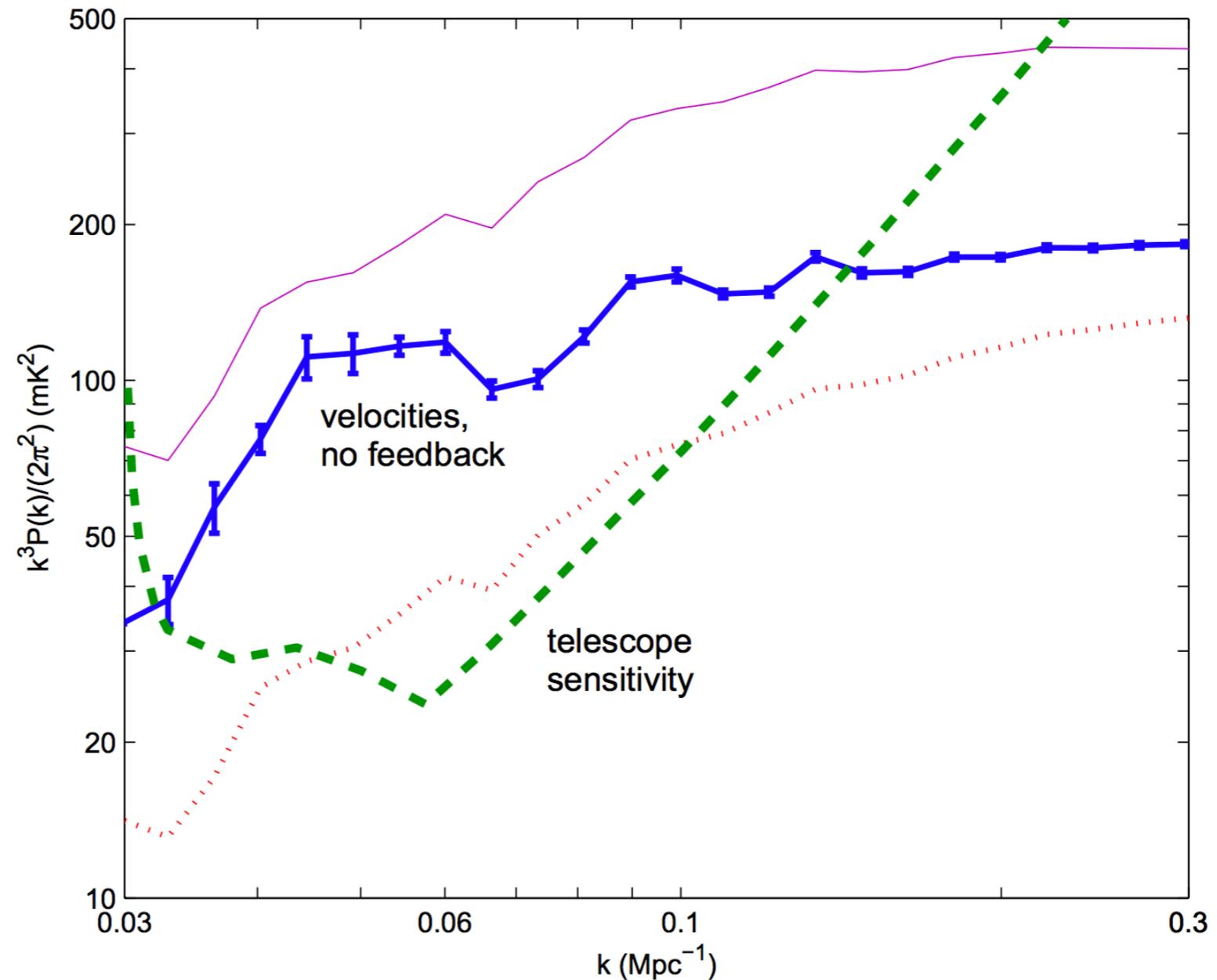
Gas Collapsed

Dalal et al. 2010



Minimum Mass

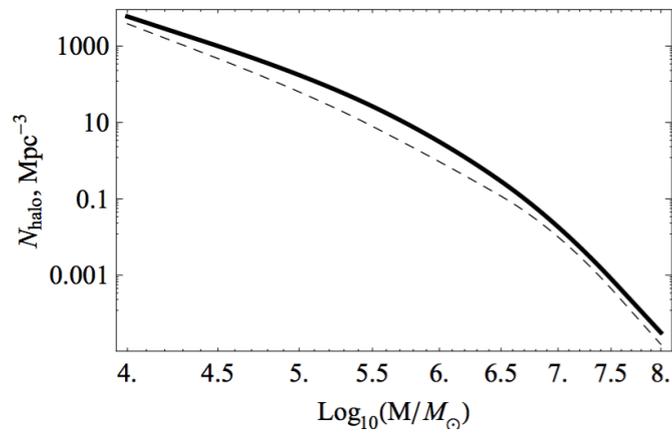
Visbal et al. 2012



21-cm fluctuations

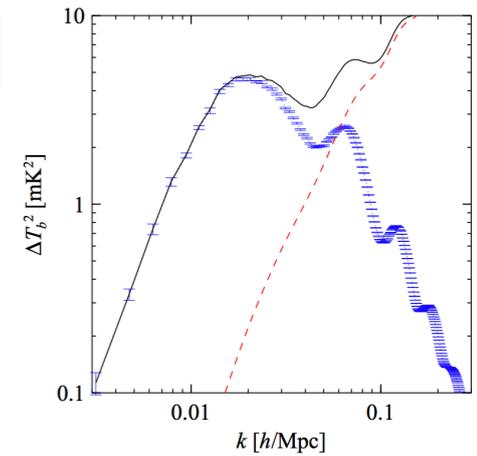
Number of haloes

Tseliakhovich and Hirata 2010



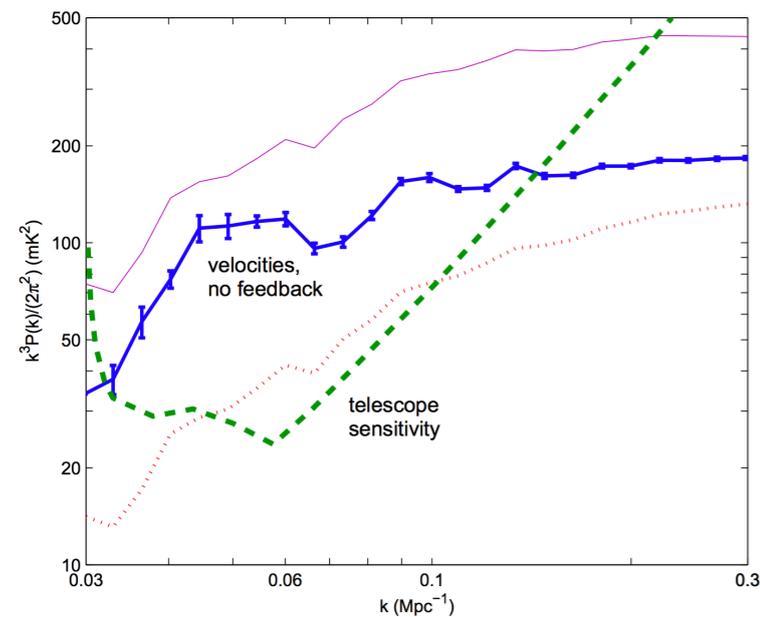
Gas Collapsed

Dalal et al. 2010

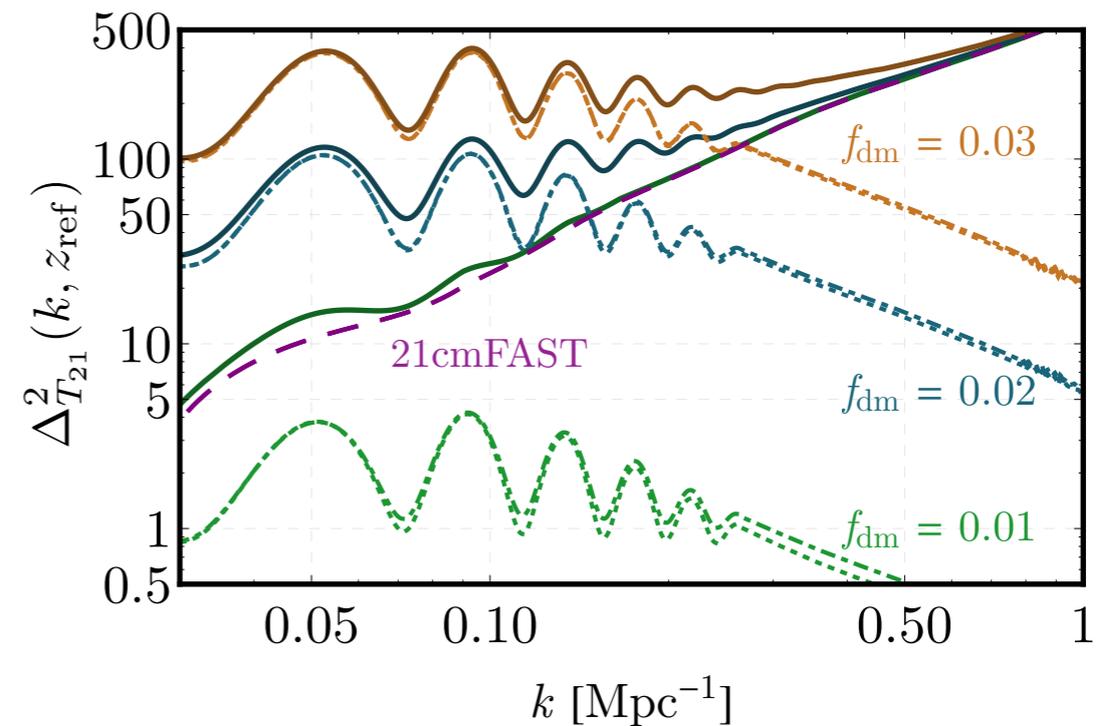


Minimum Mass

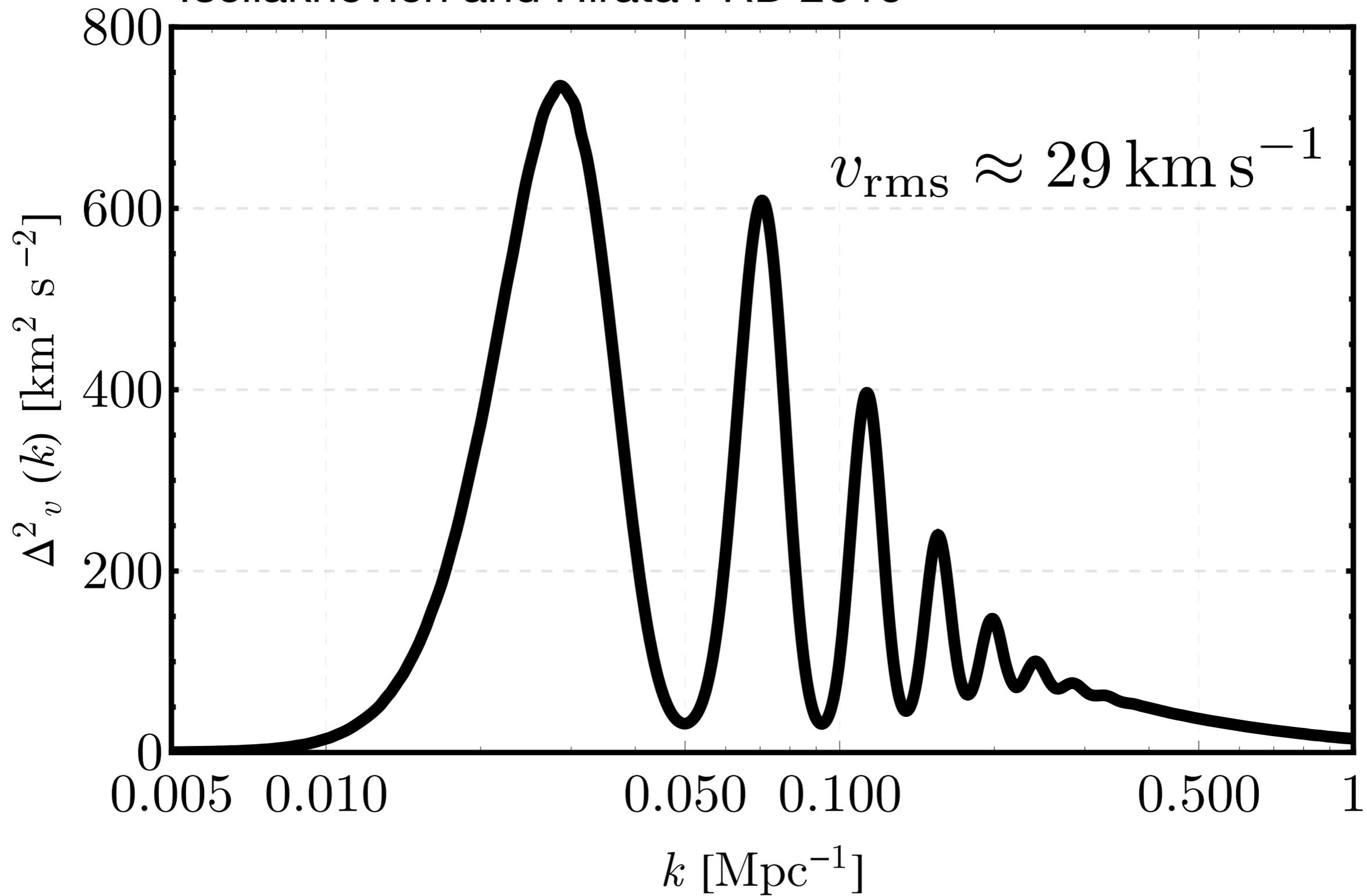
Visbal et al. 2012

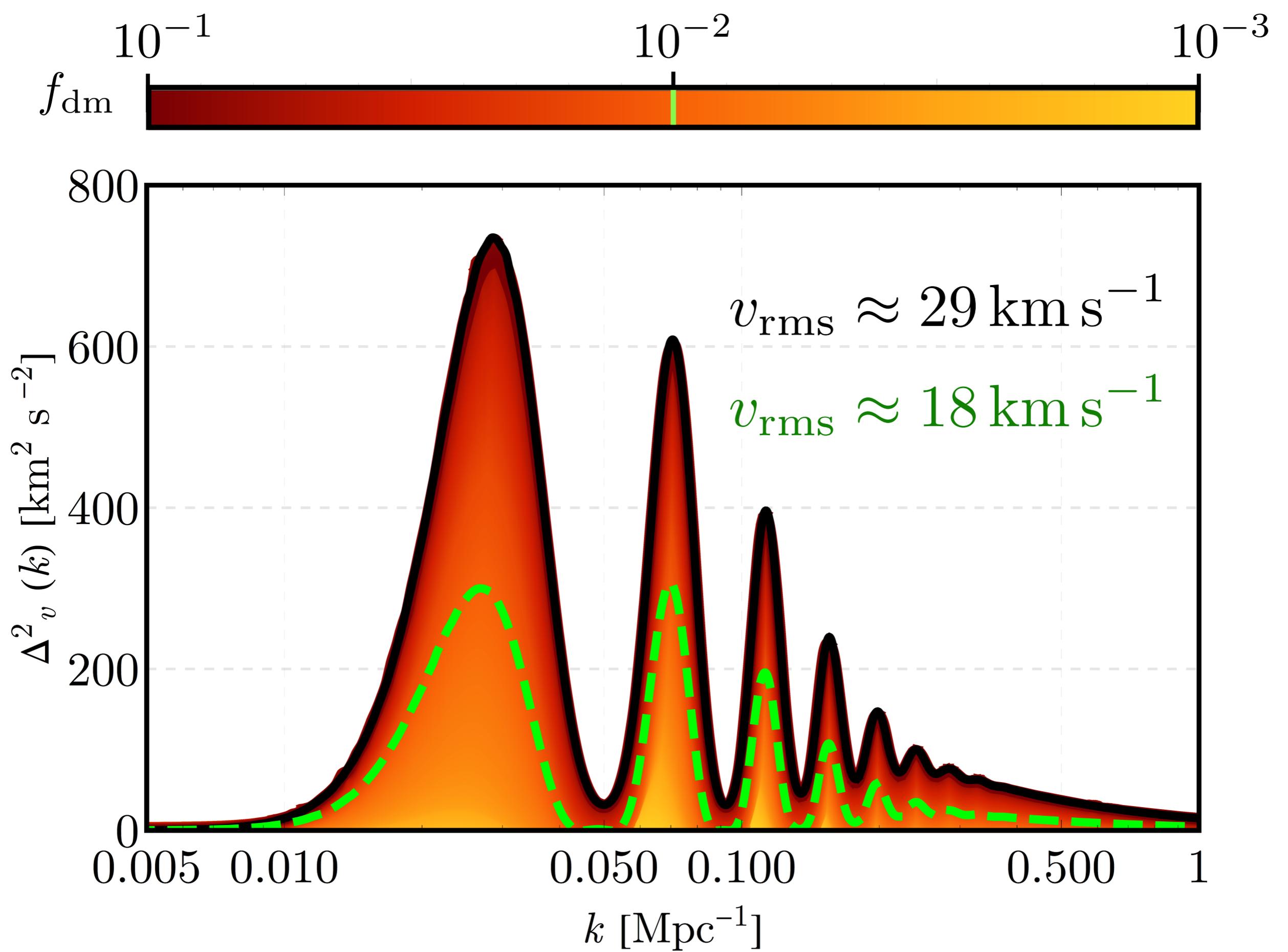


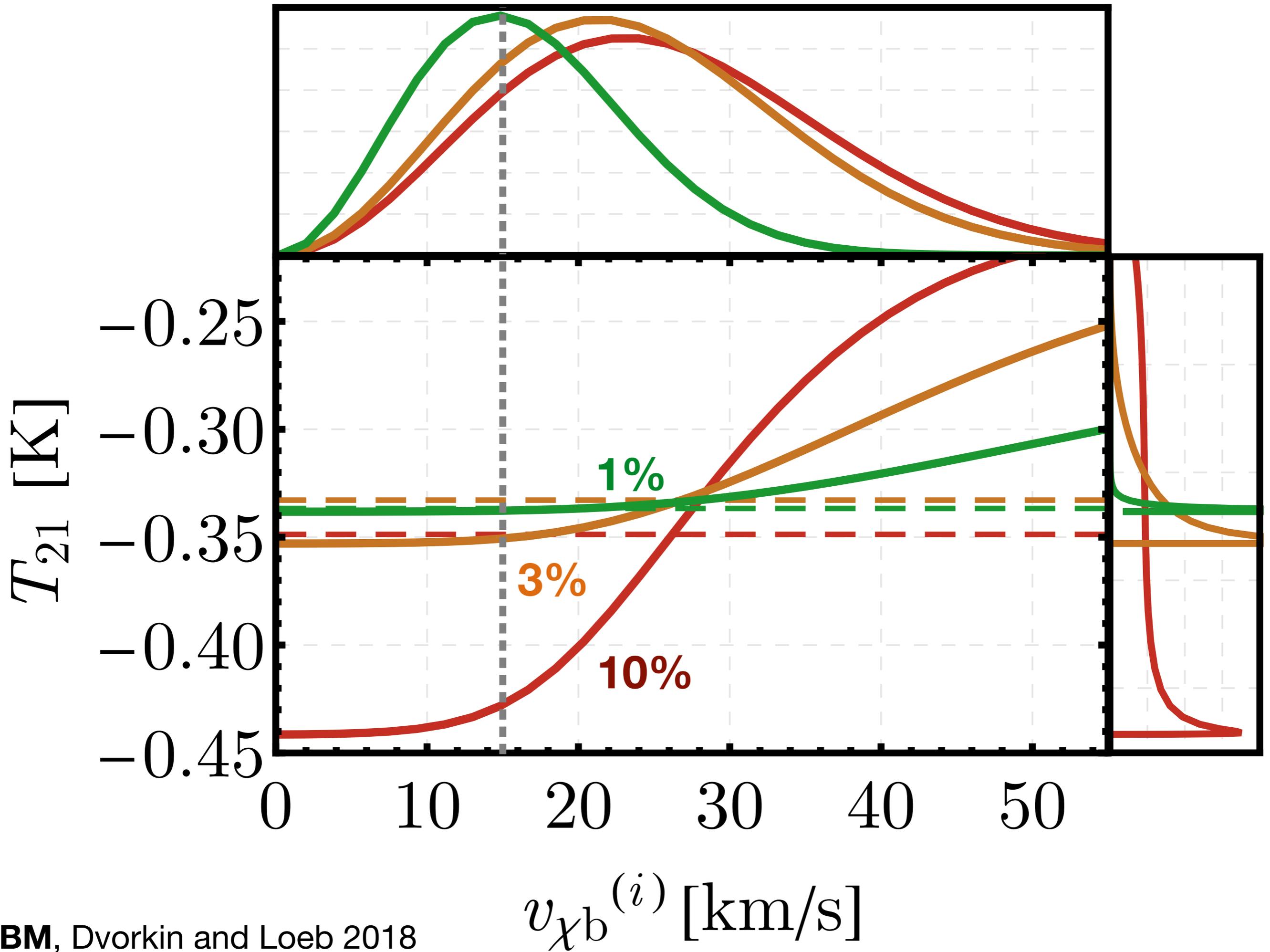
Charged DM?



Tseliakhovich and Hirata PRD 2010







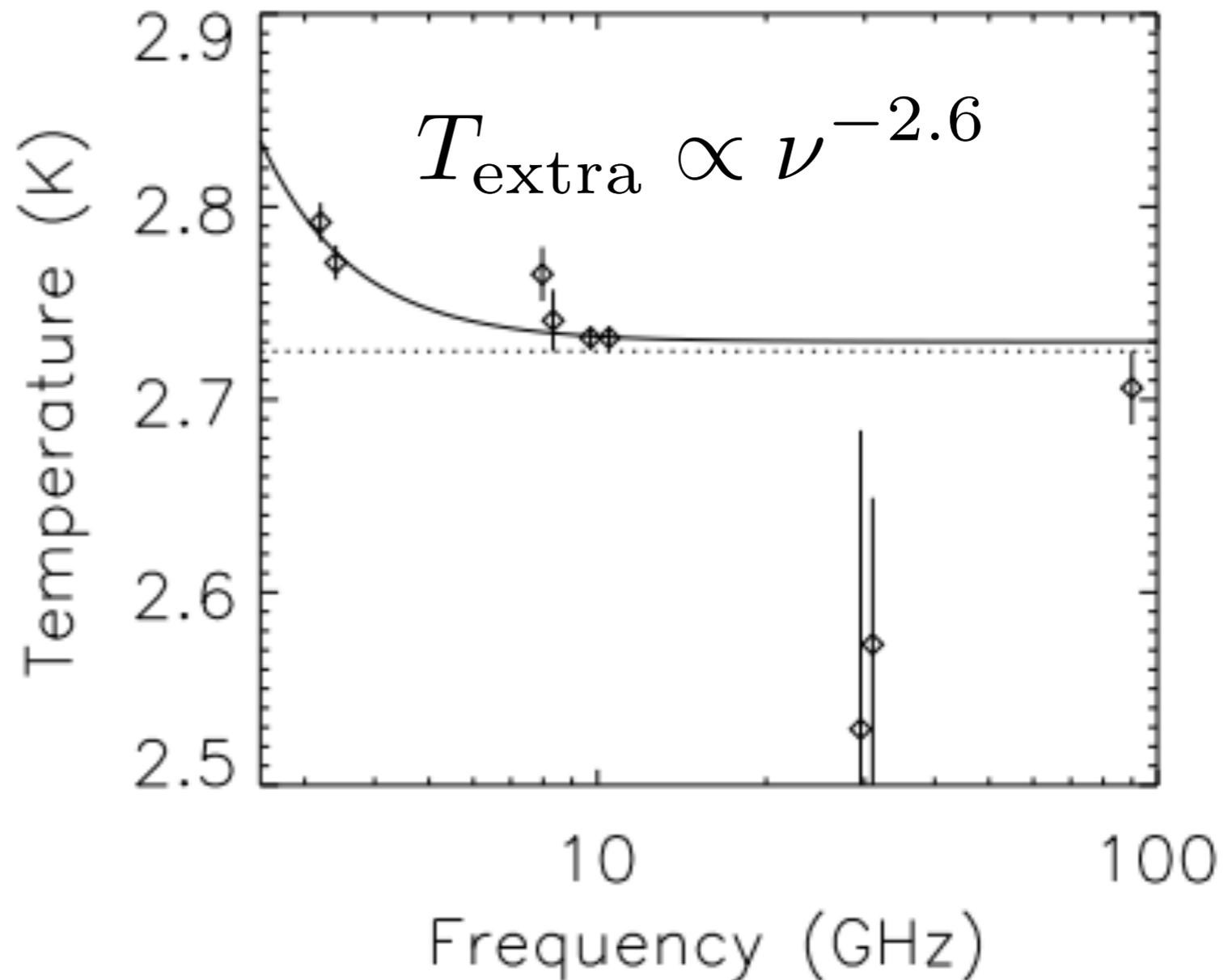
Other possibilities

An Exotic Radio Excess?

Feng and Holder 1802.07432

$$|T_{21}| \sim \frac{T_{\text{cmb}} + T_{\text{extra}}}{T_S}$$

Fixsen et al. 2013



Other possibilities

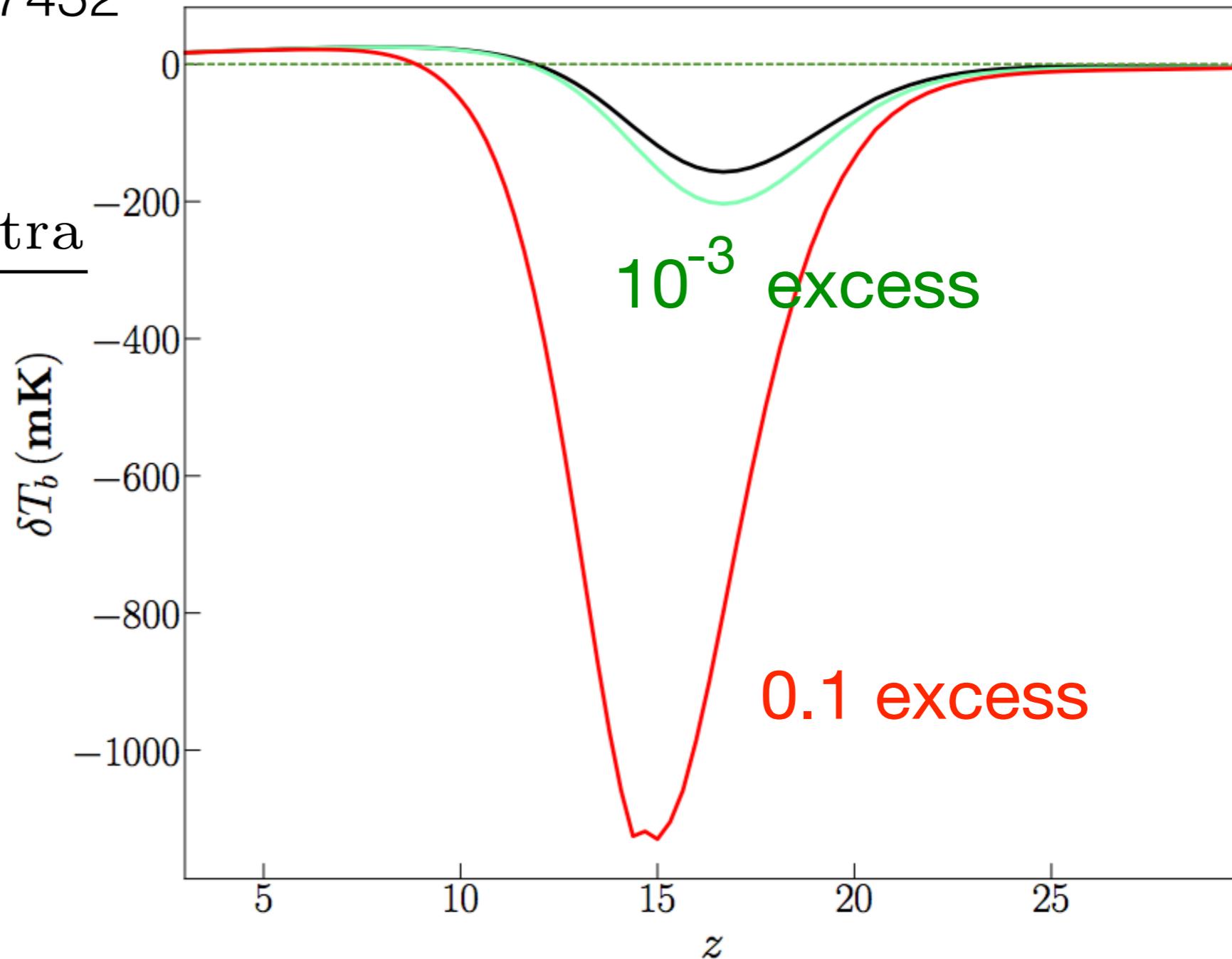
An Exotic Radio Excess?

Feng and Holder 1802.07432

$$|T_{21}| \sim \frac{T_{\text{cmb}} + T_{\text{extra}}}{T_S}$$

Problem:

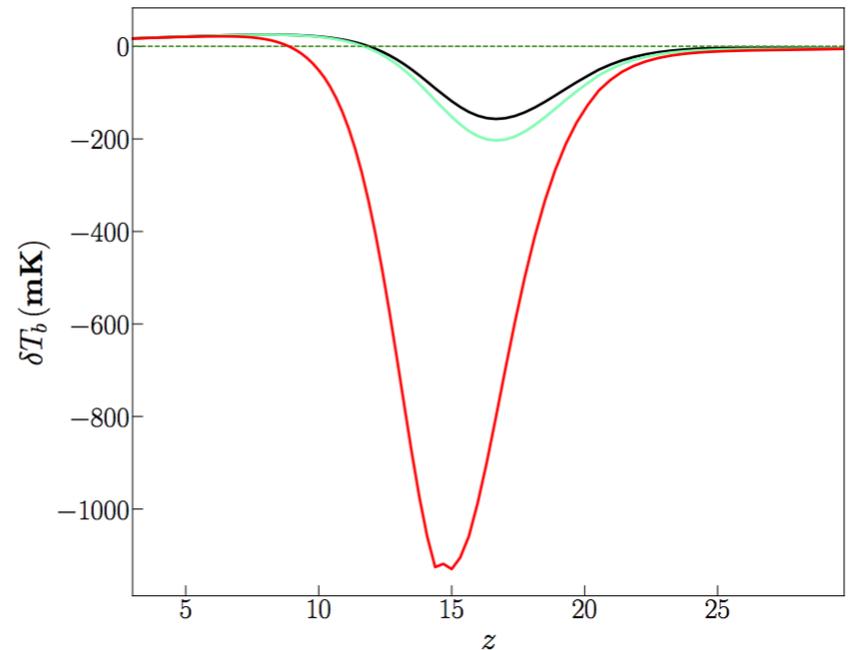
$$\rho_b v_b^2 \ll \rho_{\text{extra}}$$



Other possibilities

An Exotic Radio Excess?

Feng and Holder 1802.07432



Perhaps caused by early IMBHs?

Ewall-Wice et al. 1803.01815

Problems:

$$\frac{L_X}{L_{\text{radio}}} \approx 10^5$$

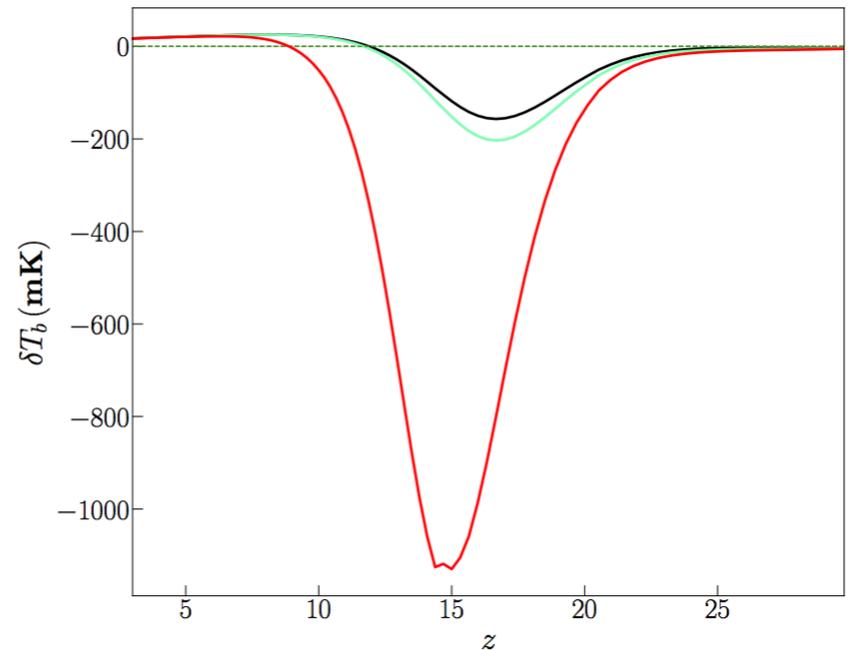
+Need to not heat the gas

+Need to not reionize the Universe

Other possibilities

An Exotic Radio Excess?

Feng and Holder 1802.07432



Perhaps caused by early IMBHs?

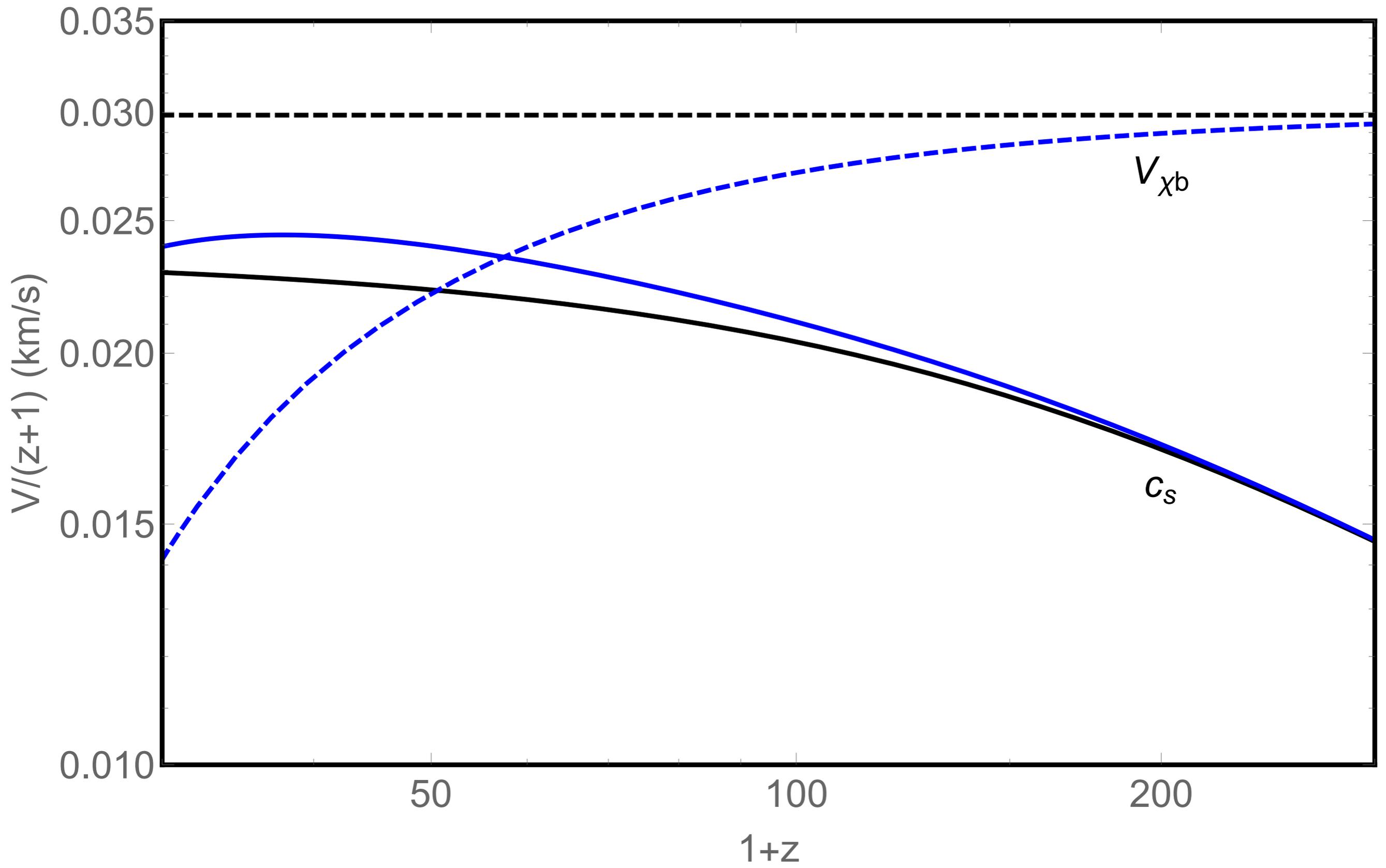
Ewall-Wice et al. 1803.01815

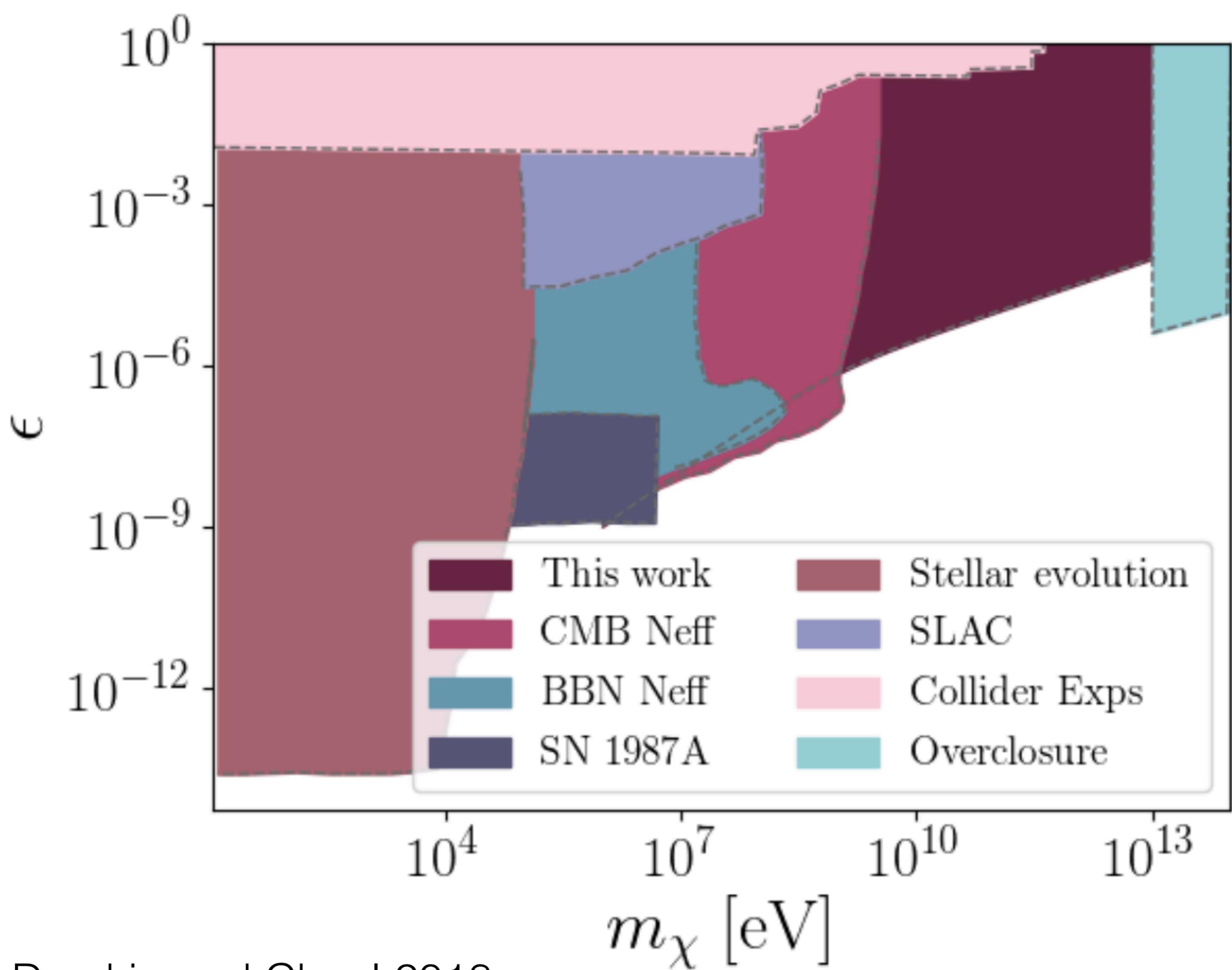
$$\frac{L_X}{L_{\text{radio}}} \approx 10^5$$

Or DM annihilations to photons/dark photons

Fraser et al. 1803.03629

Pospelov et al. 1803.07048





Xu, Dvorkin and Chael 2018
 Gluscevic and Boddy 2017

