Searching for Dark Matter with the 21-cm line

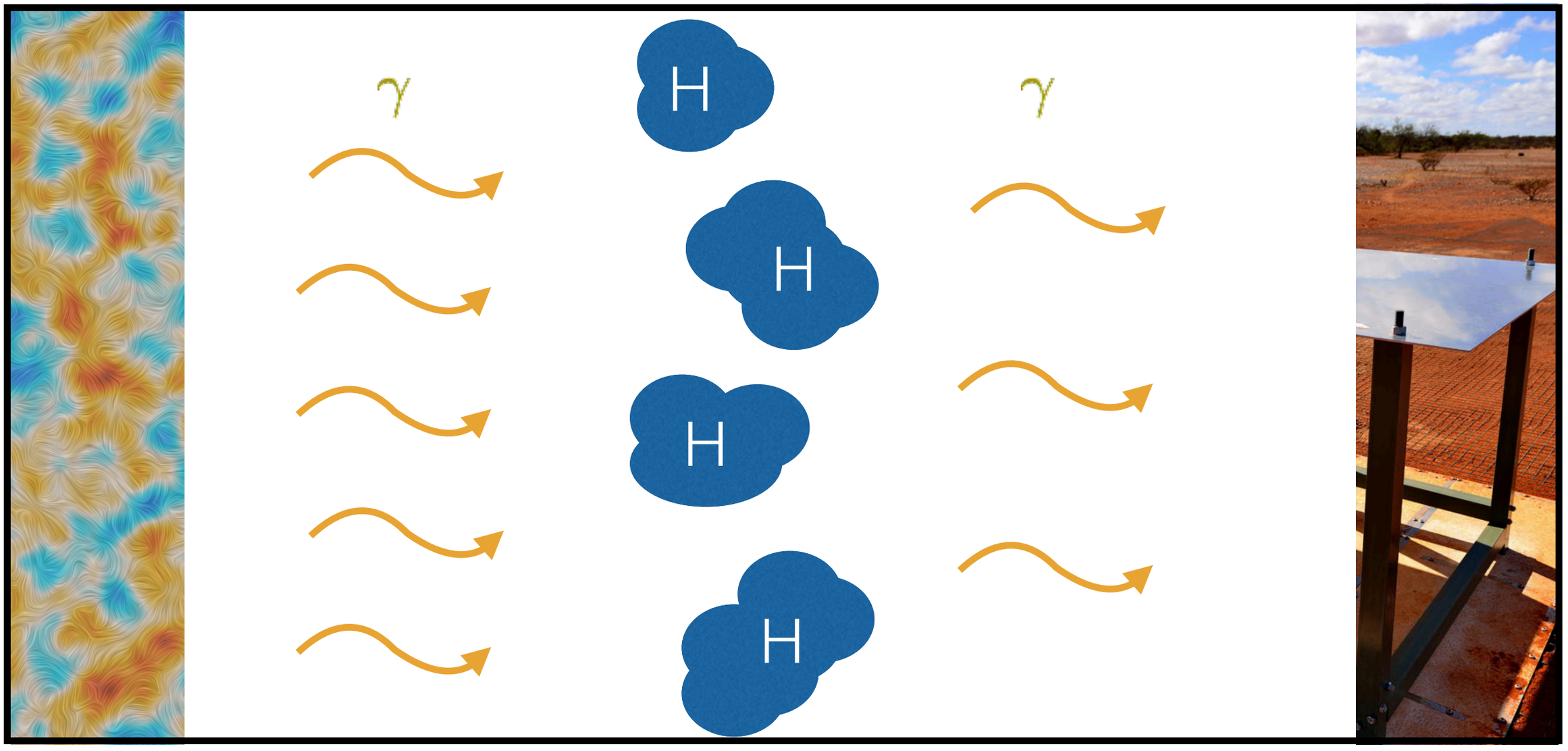
Julian B. Muñoz

Based on
arXiv:1509.00029
arXiv:1802.10094
arXiv:1804.01092

with
Yacine Ali-Haimoud
Cora Dvorkin
Avi Loeb
Ely Kovetz

Image: ALMA (ESO/NAOJ/NRAO) & NASA/ESA HST

$z = 1100$ $z \approx 20$ Australia

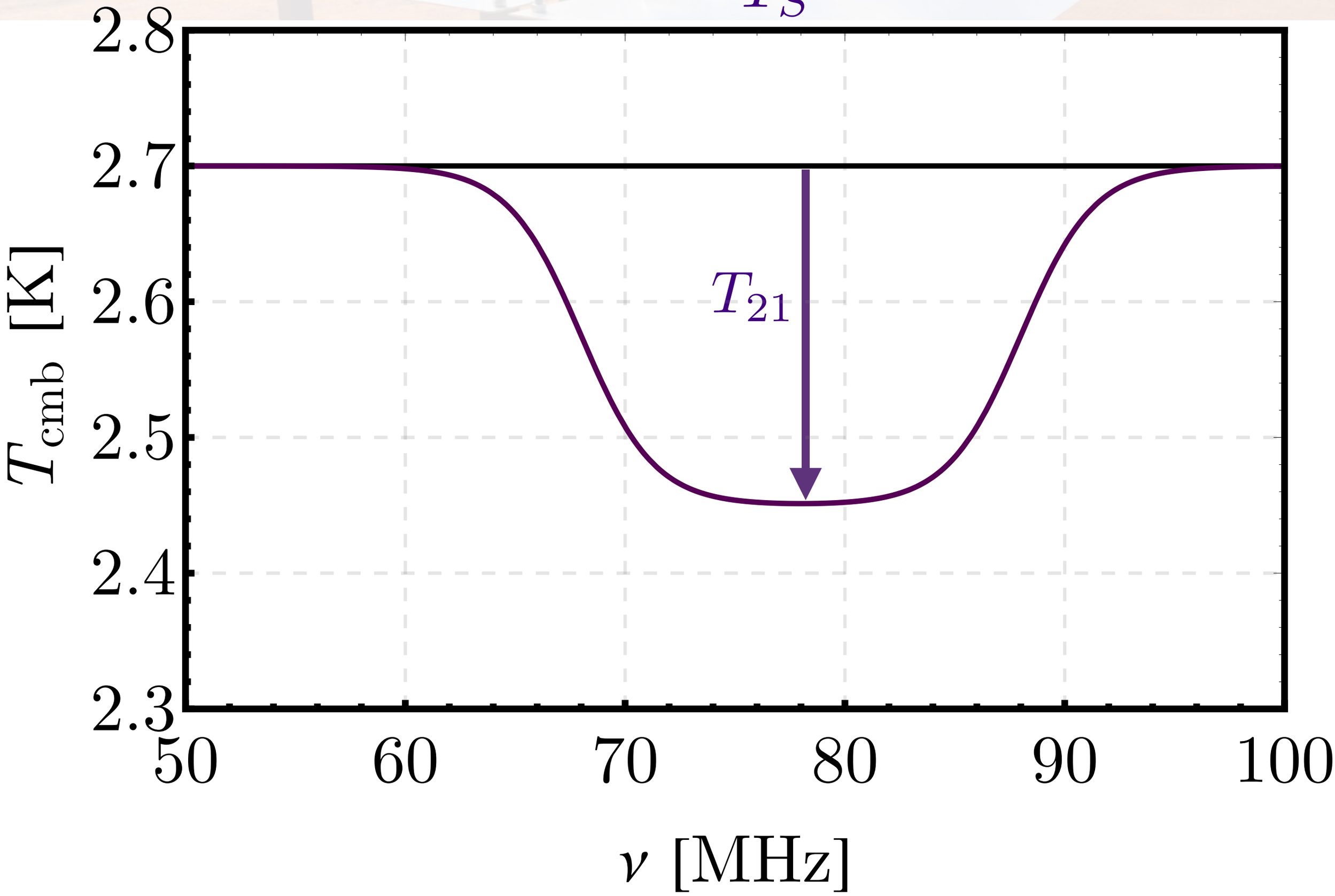


EDGES

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

See Raul's talk on Saturday!

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



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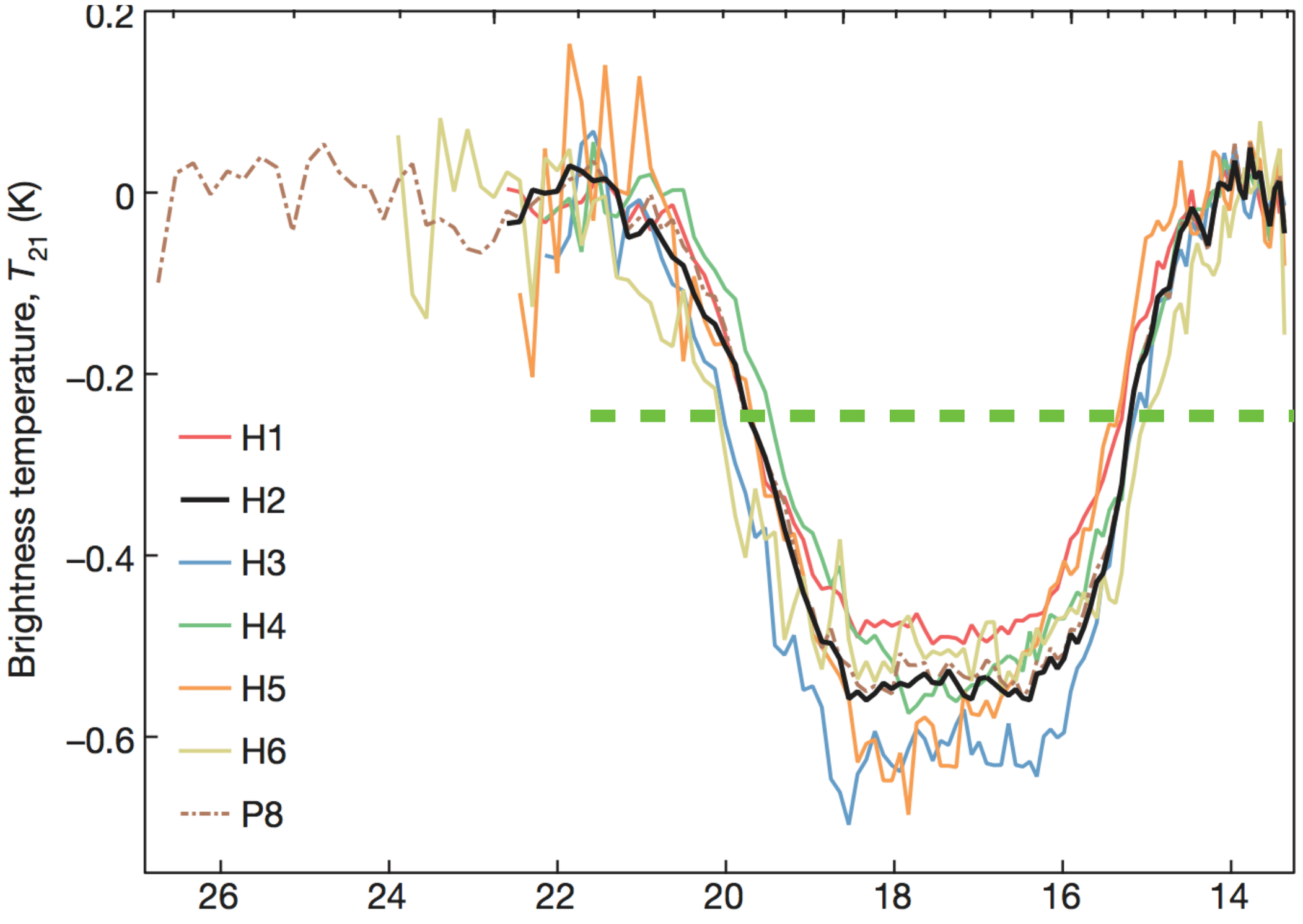


Bowman et al. Nature 2018

Thermal
Decoupling (from CMB)

$T_{\rm cmb}$

T_b

1000
500
100
50
10
5
1

T(K)

10
50
100
500
1000

1+z

EDGES
Measurement

Thermal
Decoupling (from CMB)

$T_{\rm cmb}$

T_b

1000
500
100
50
10
5
1

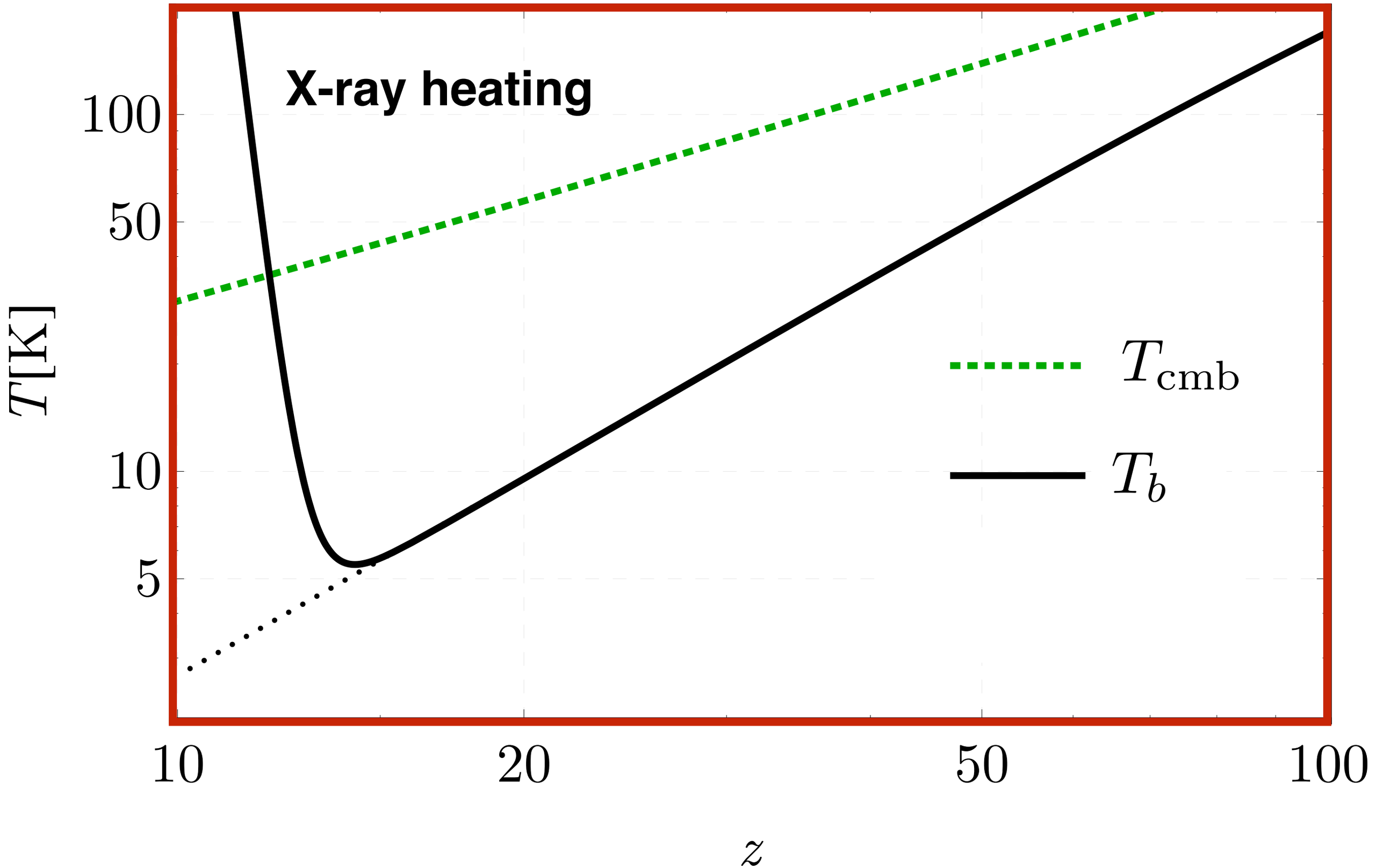
T(K)

10
50
100
500
1000

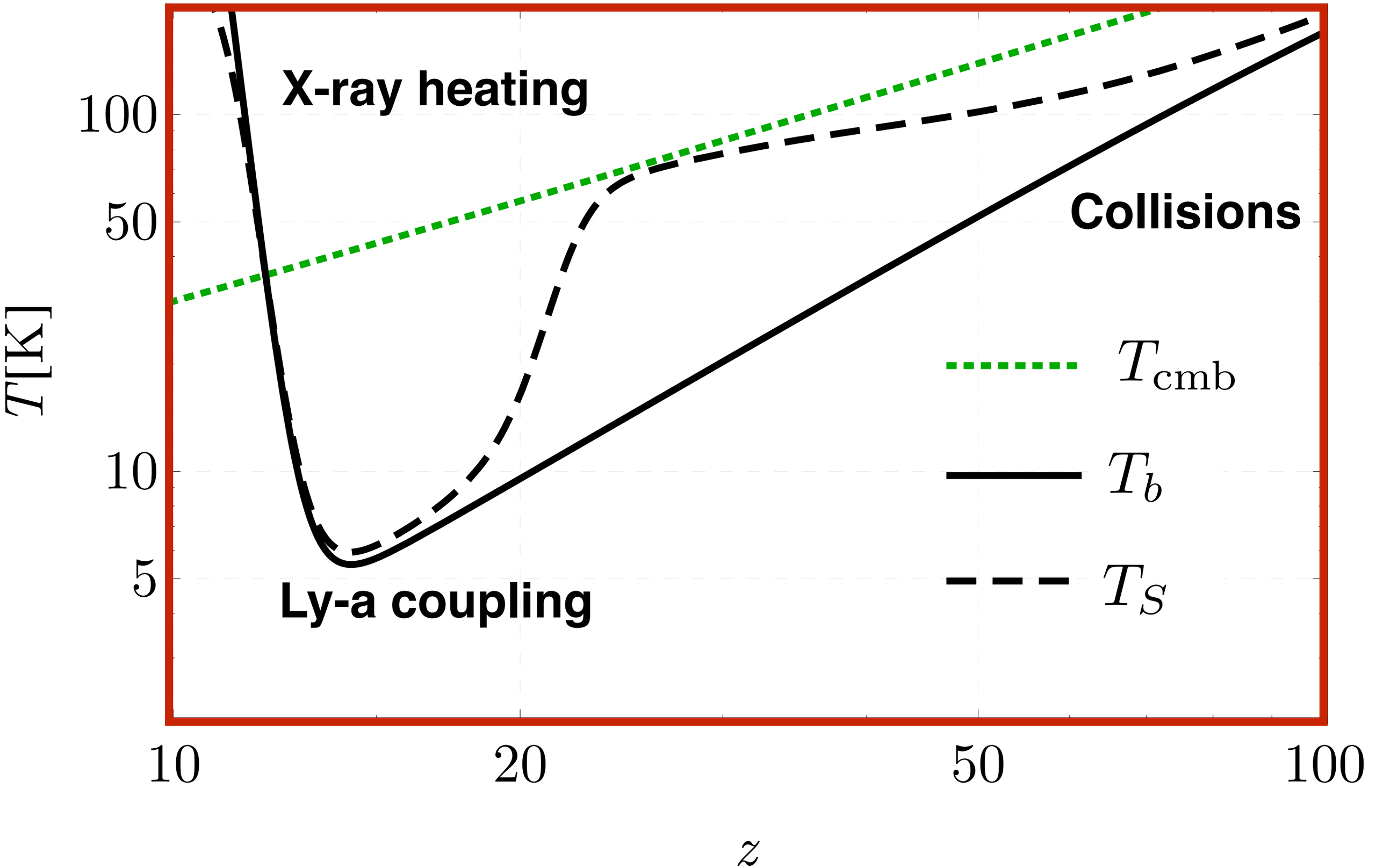
1+z

EDGES
Measurement

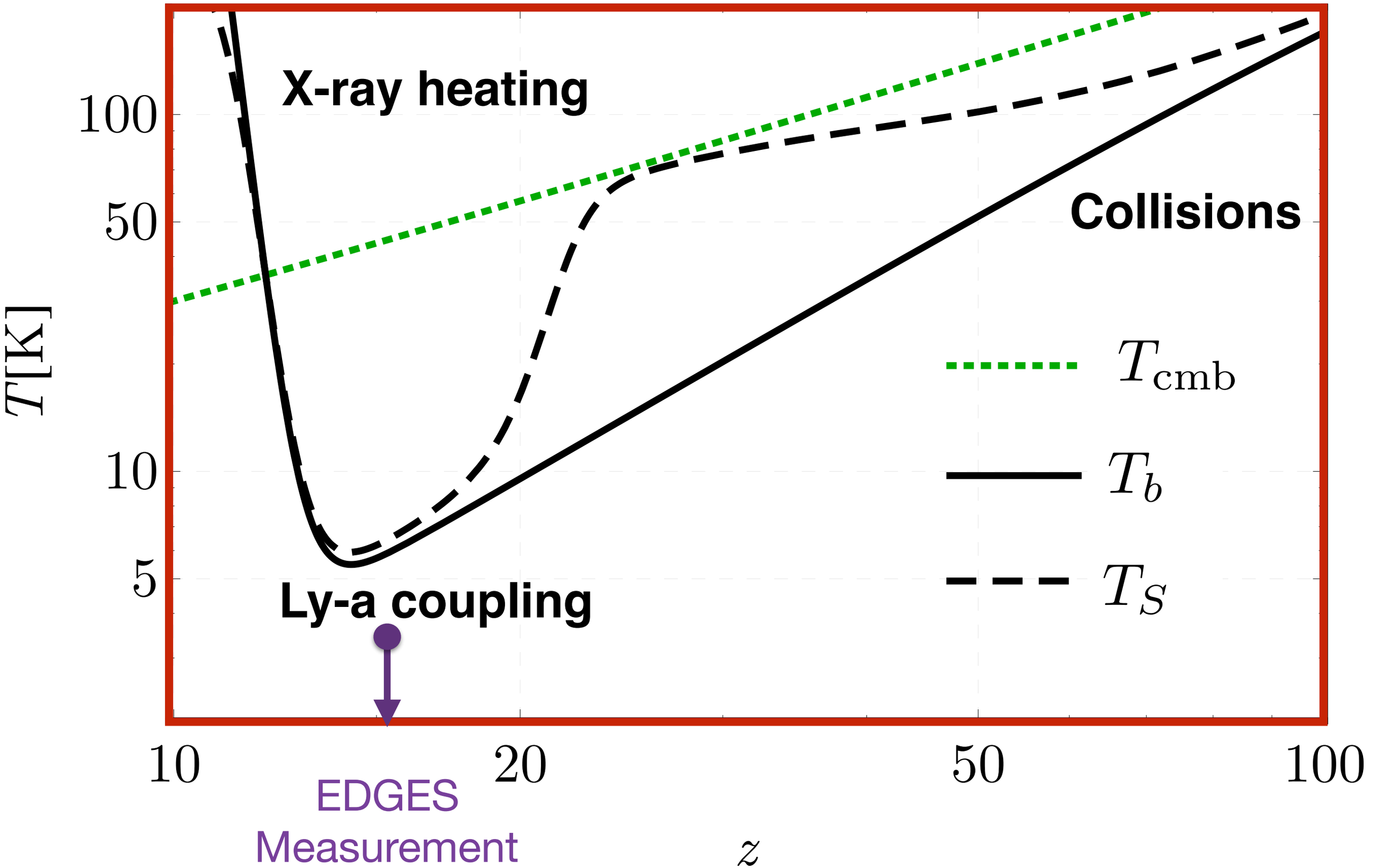
A cartoon of the evolution of T_S



A cartoon of the evolution of T_S



A cartoon of the evolution of T_S



Thermal
Decoupling (from CMB)

T_γ

T_b

1000
500
100
50
10
5
1

T(K)

10
50
100
500
1000

1+z

EDGES
Measurement

Thermal Coupling (to DM)

Thermal Decoupling (from CMB)

T_γ

T_b

T_b with interactions

T_χ with interactions

T(K)

1000
500
100
50
10
5
1

10
50
100
500
1000

1+z

EDGES Measurement

JBM, Kovetz, Ali-Haimoud PRD 2015

Requirements

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

$m_\chi = 1\,\mathrm{GeV}$

$n_\chi \approx 6\, n_b$

T_γ

T_b

T_b with interactions

T_χ with interactions

T(K)

1000
500
100
50
10
5
1

10
50
100
500
1000

1+z

JBM, Kovetz, Ali-Haimoud PRD 2015

Requirements

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

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

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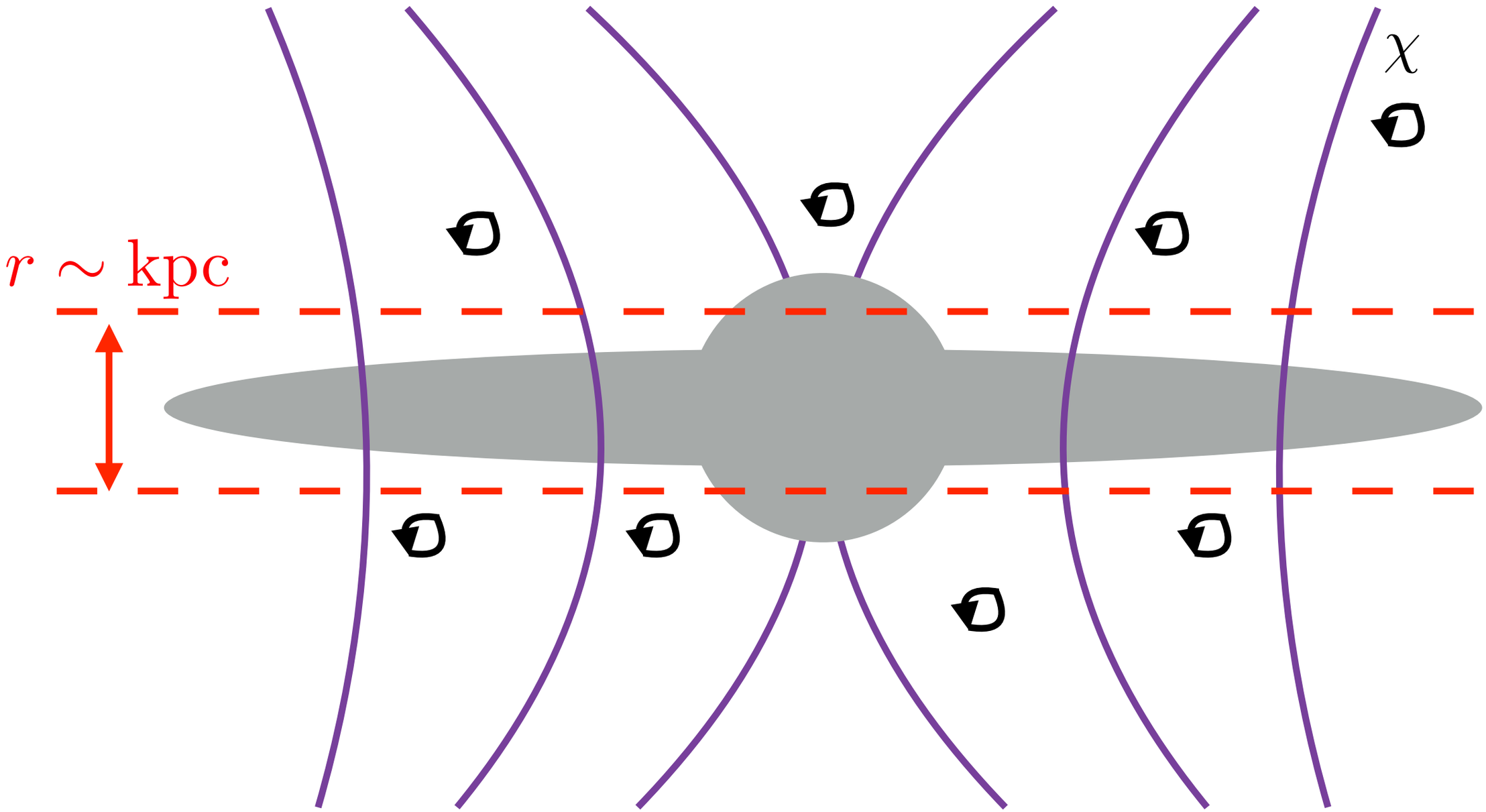
New Interaction/Fifth force

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

Minicharged DM

Chuzhoy and Kolb (2009)

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

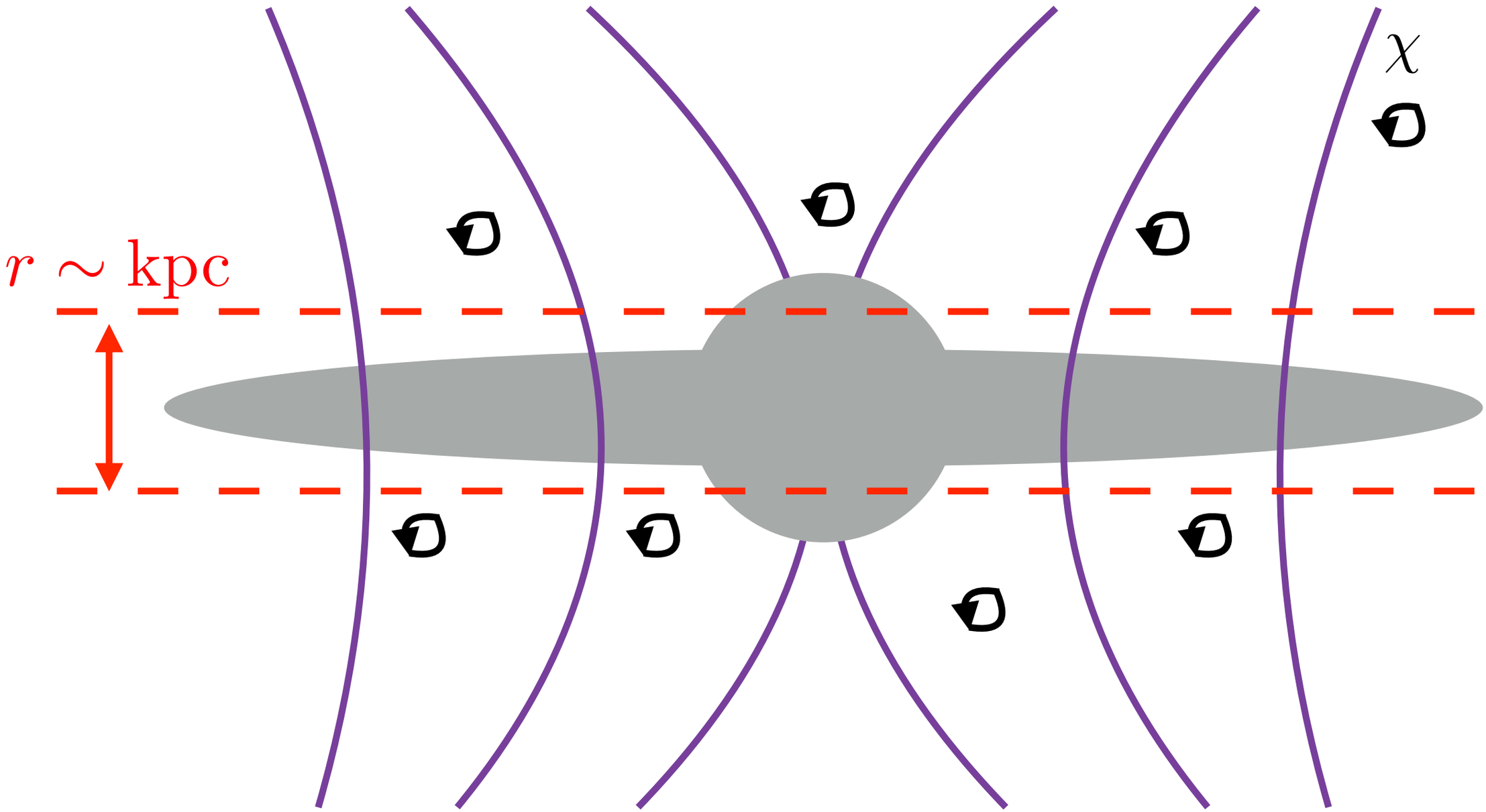


$$\rho_{\mathrm{DM}} = 0.9 \pm 0.3\,\mathrm{GeV\,cm^{-3}}$$

Bovy and Tremaine (2012)

Chuzhoy and Kolb (2009)

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



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

Bovy and Tremaine (2012)

However:

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

SLAC mQ

$N_{\rm eff}$

BBN

SN1987A

10^{-3}

10^{-4}

10^{-5}

10^{-6}

10^{-7}

10^{-8}

ϵ

0.3

1

3

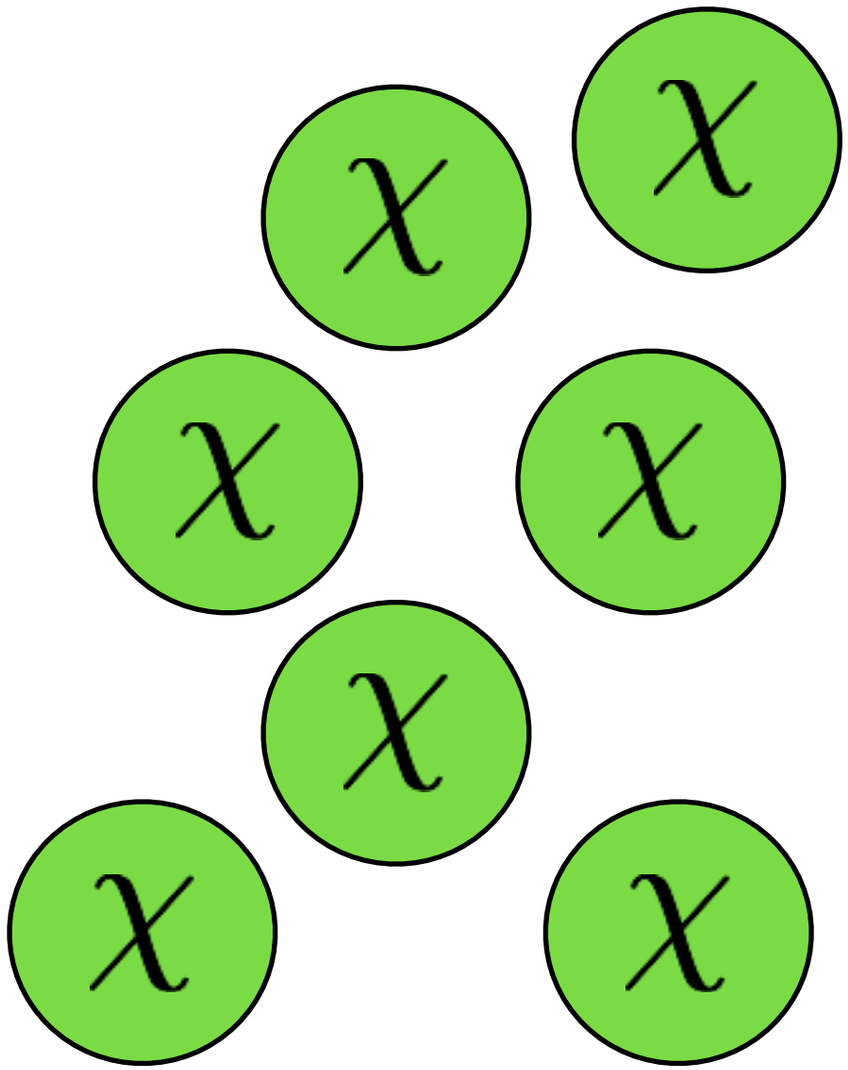
10

30

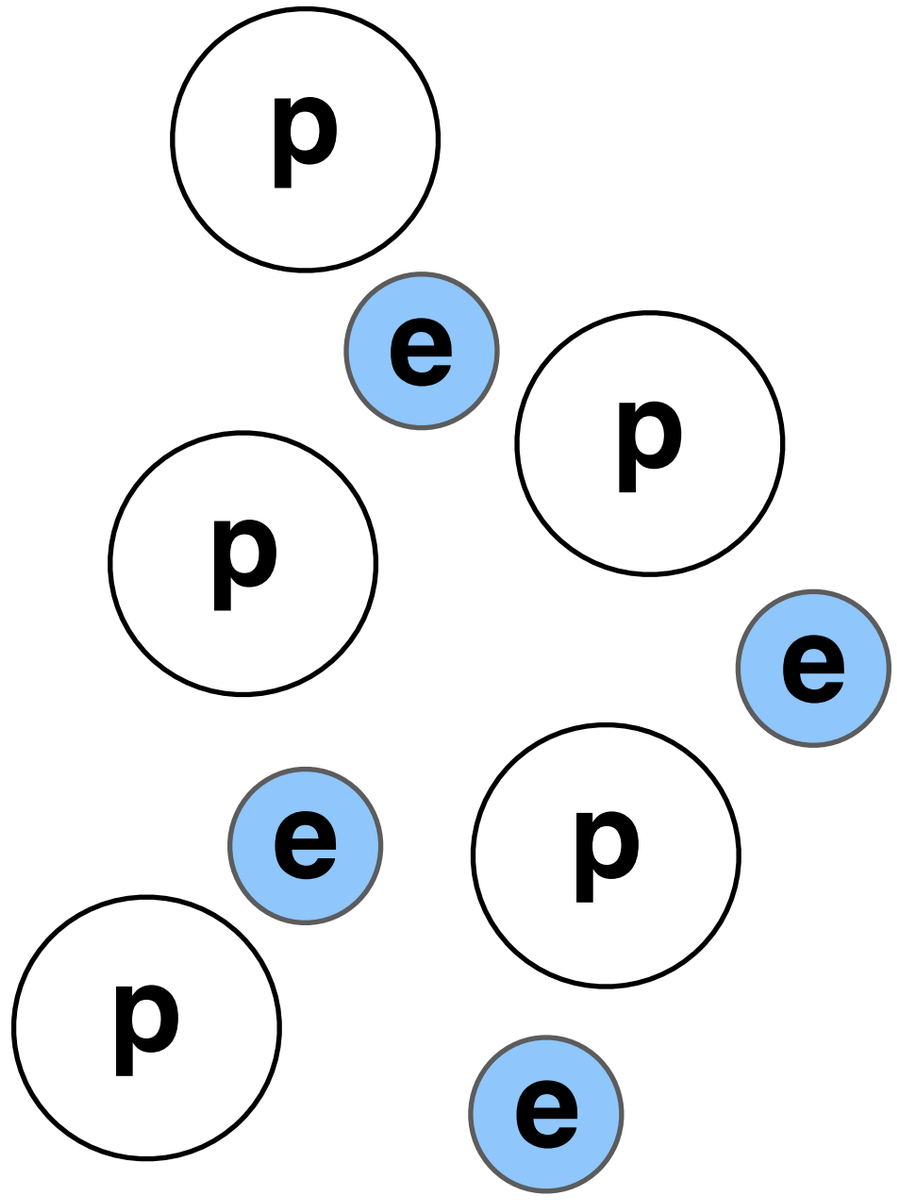
100

300

m_χ [MeV]



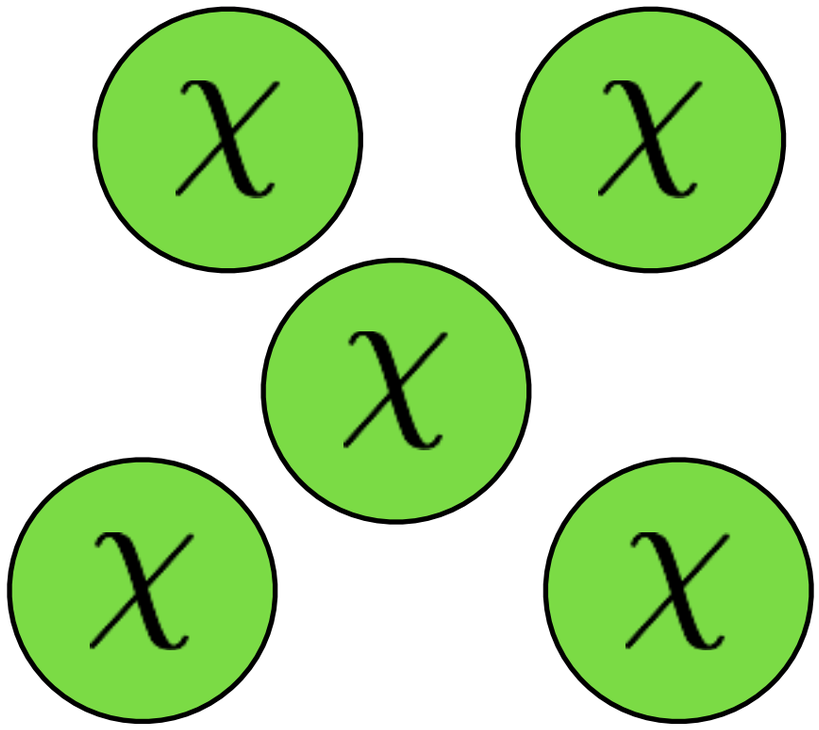
T_χ



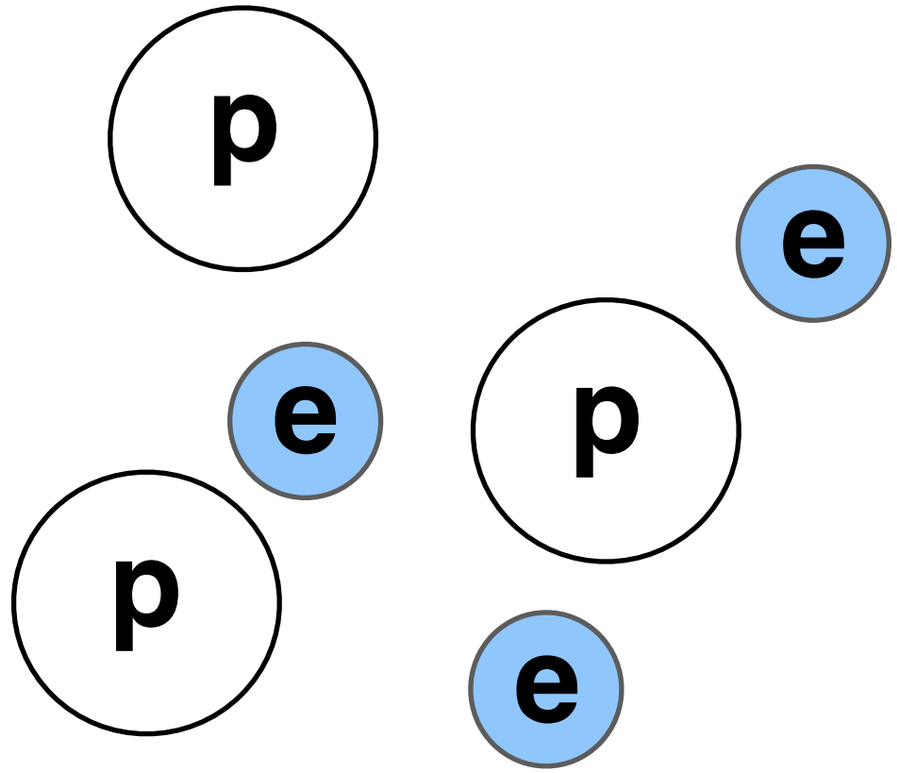
T_b

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

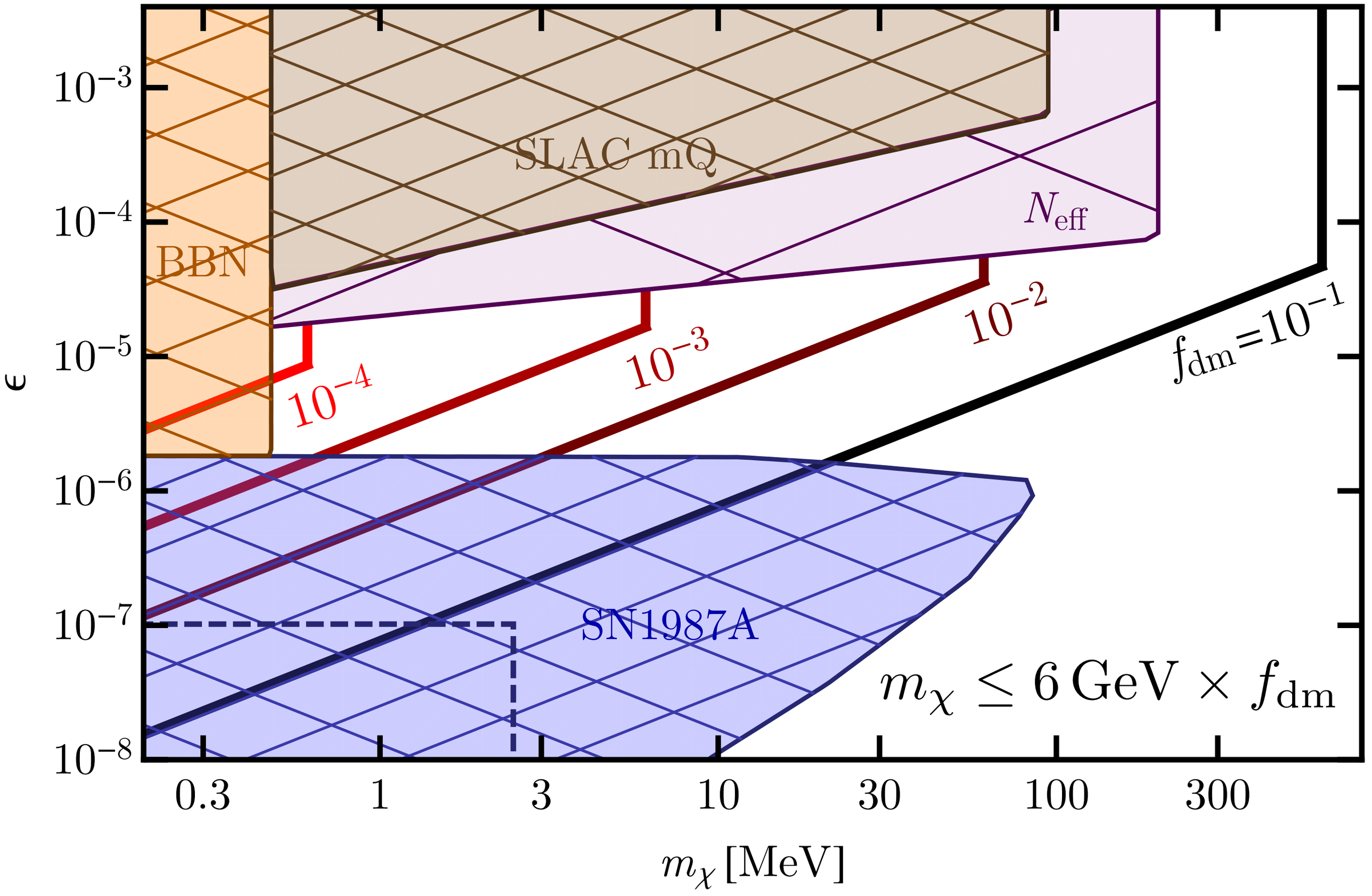
$$v_{\rm rel} \approx \left(\frac{T_b}{m_b} + \frac{T_\chi}{m_\chi} \right)^{1/2}$$



T_χ

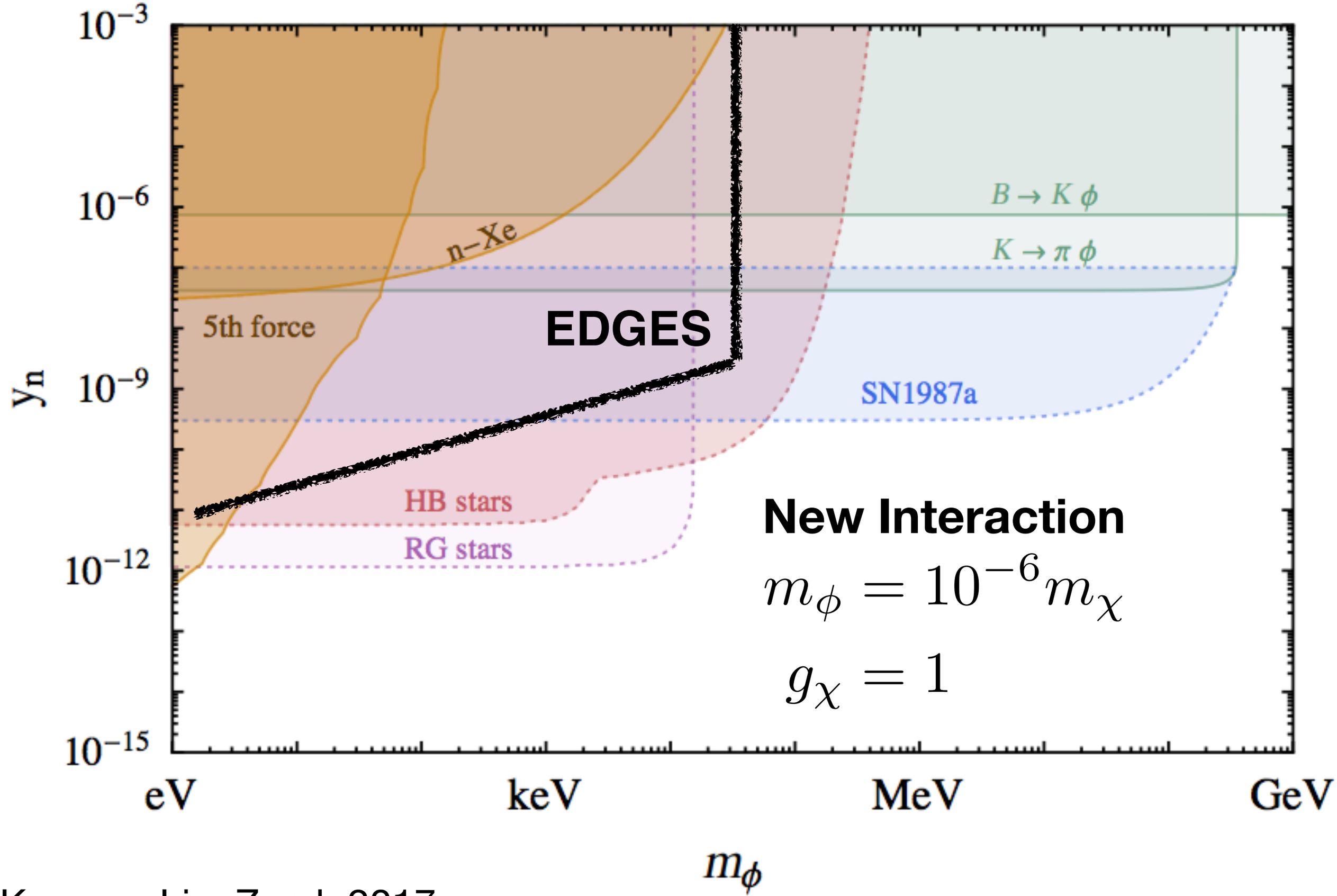


T_b



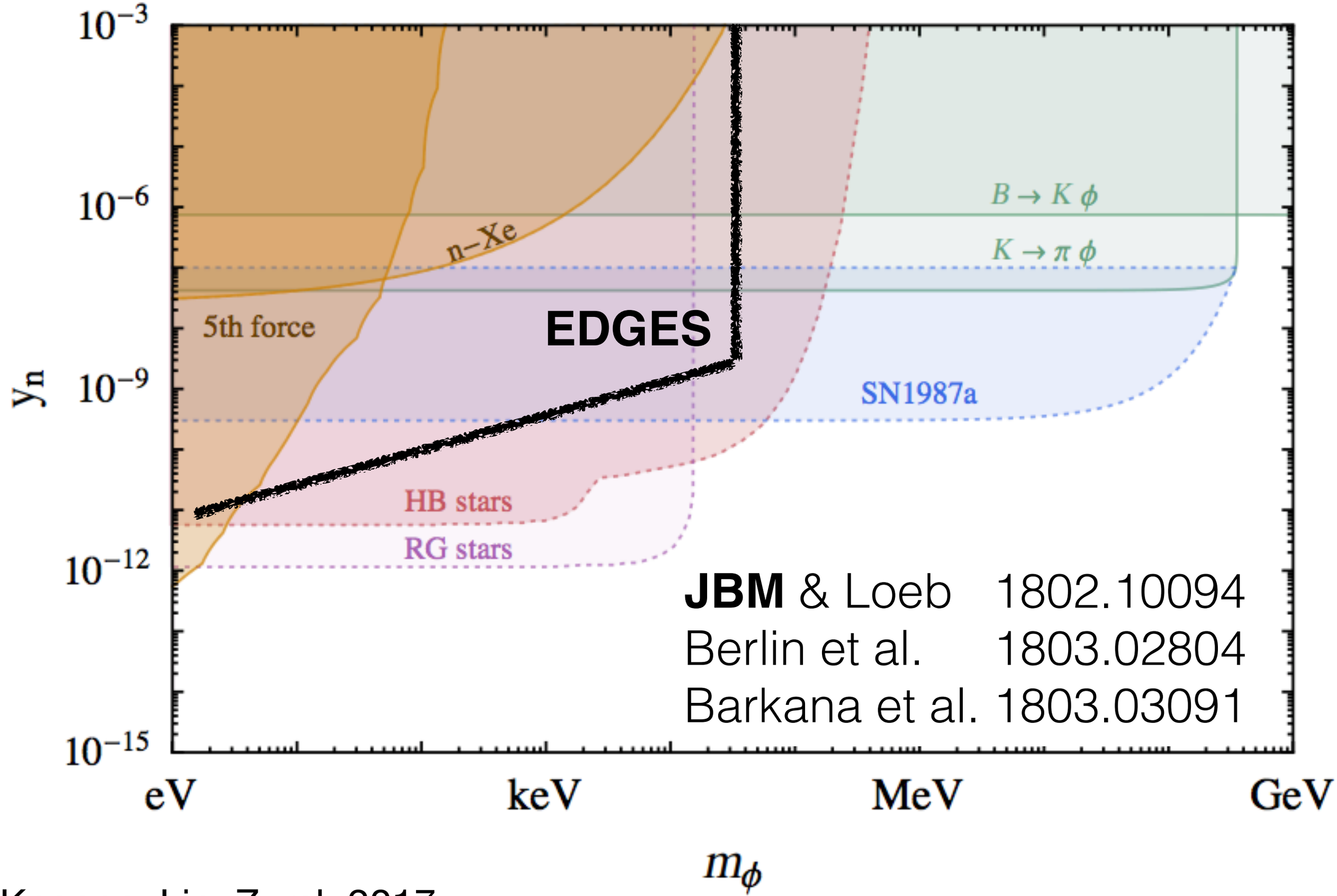
JBM and Loeb Nature 2018

Fifth-force constraints



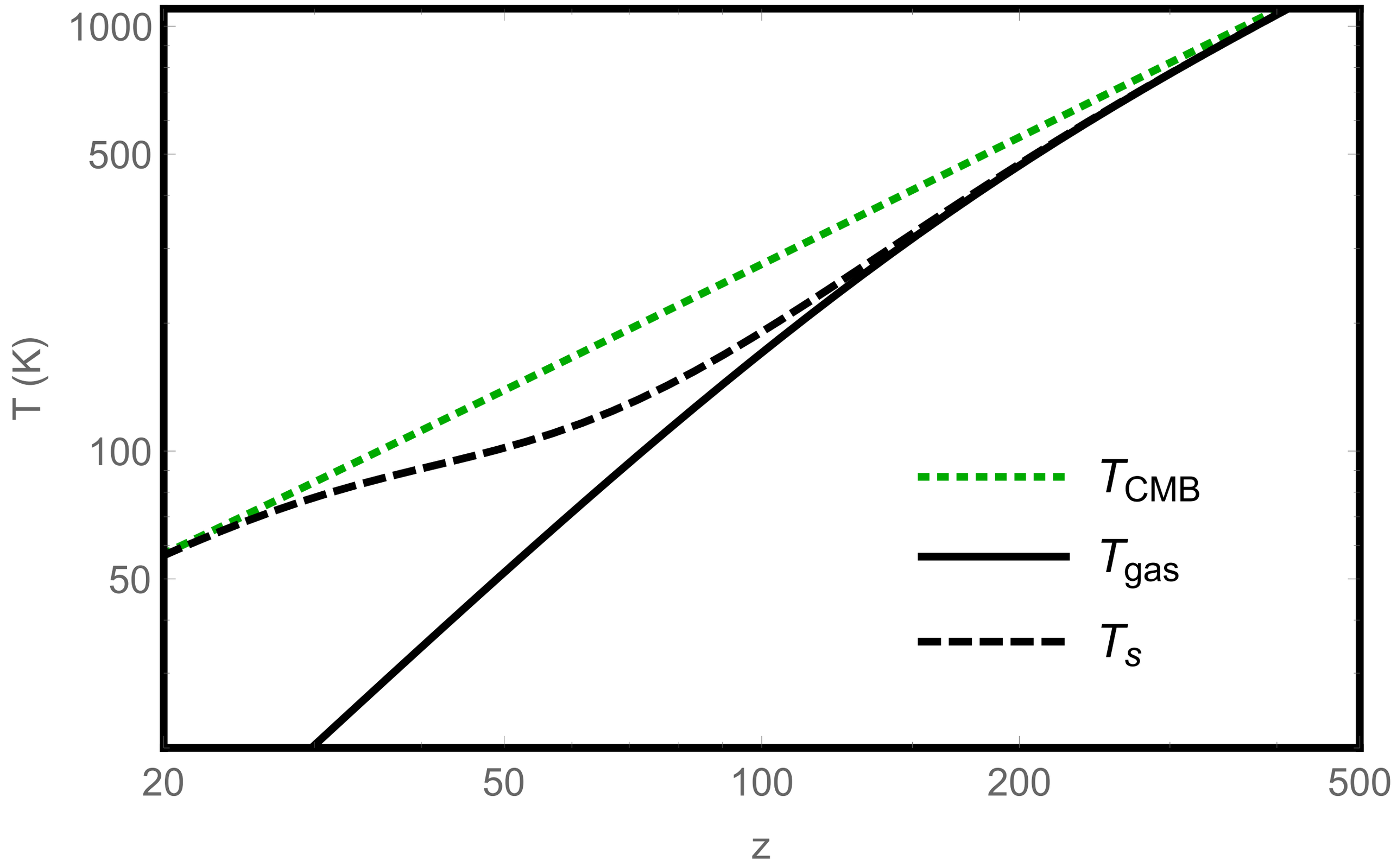
Knapen, Lin, Zurek 2017

Fifth-force constraints



Knapen, Lin, Zurek 2017

Can you test this?



JBM, Kovetz, Ali-Haimoud PRD 2015

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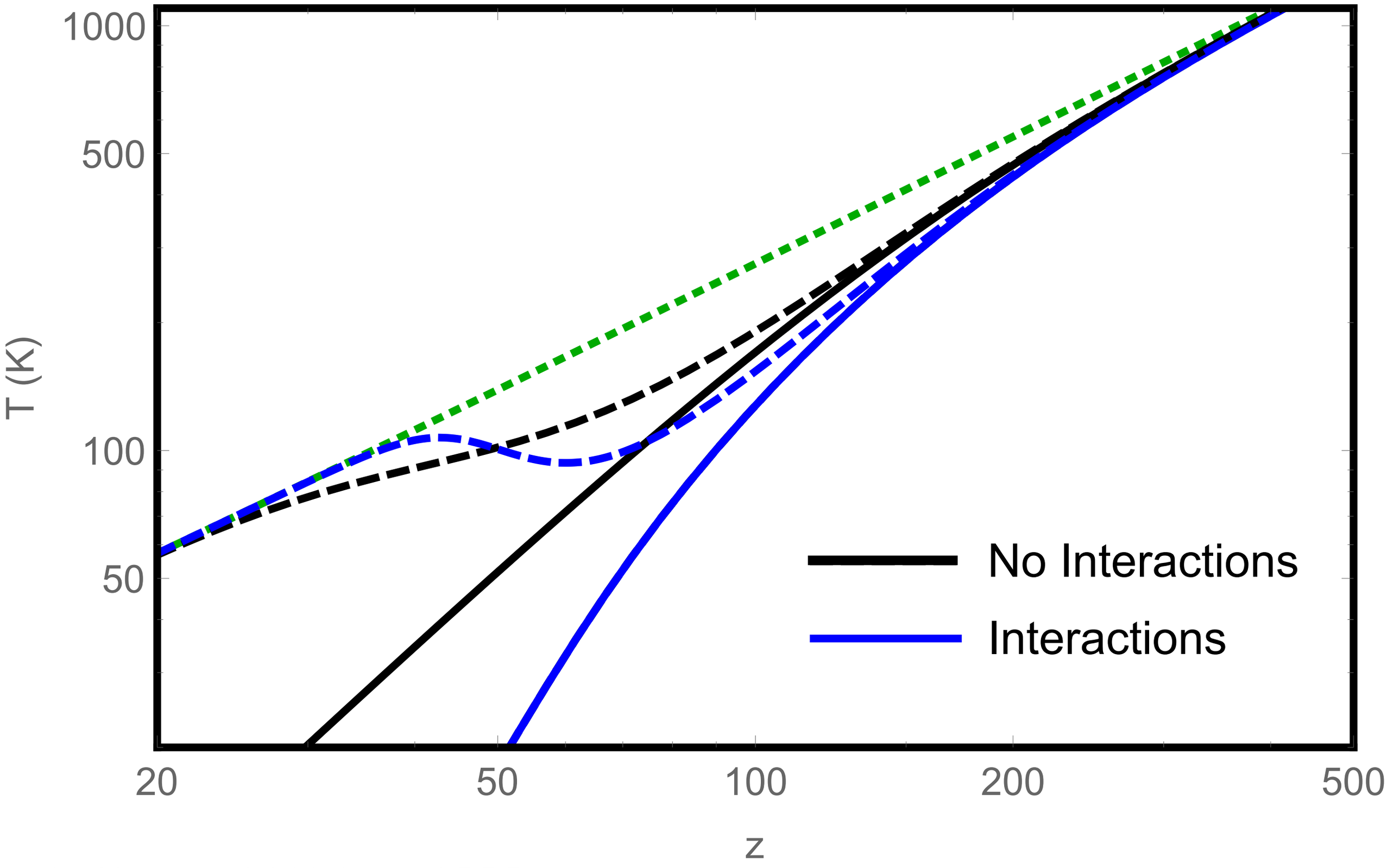
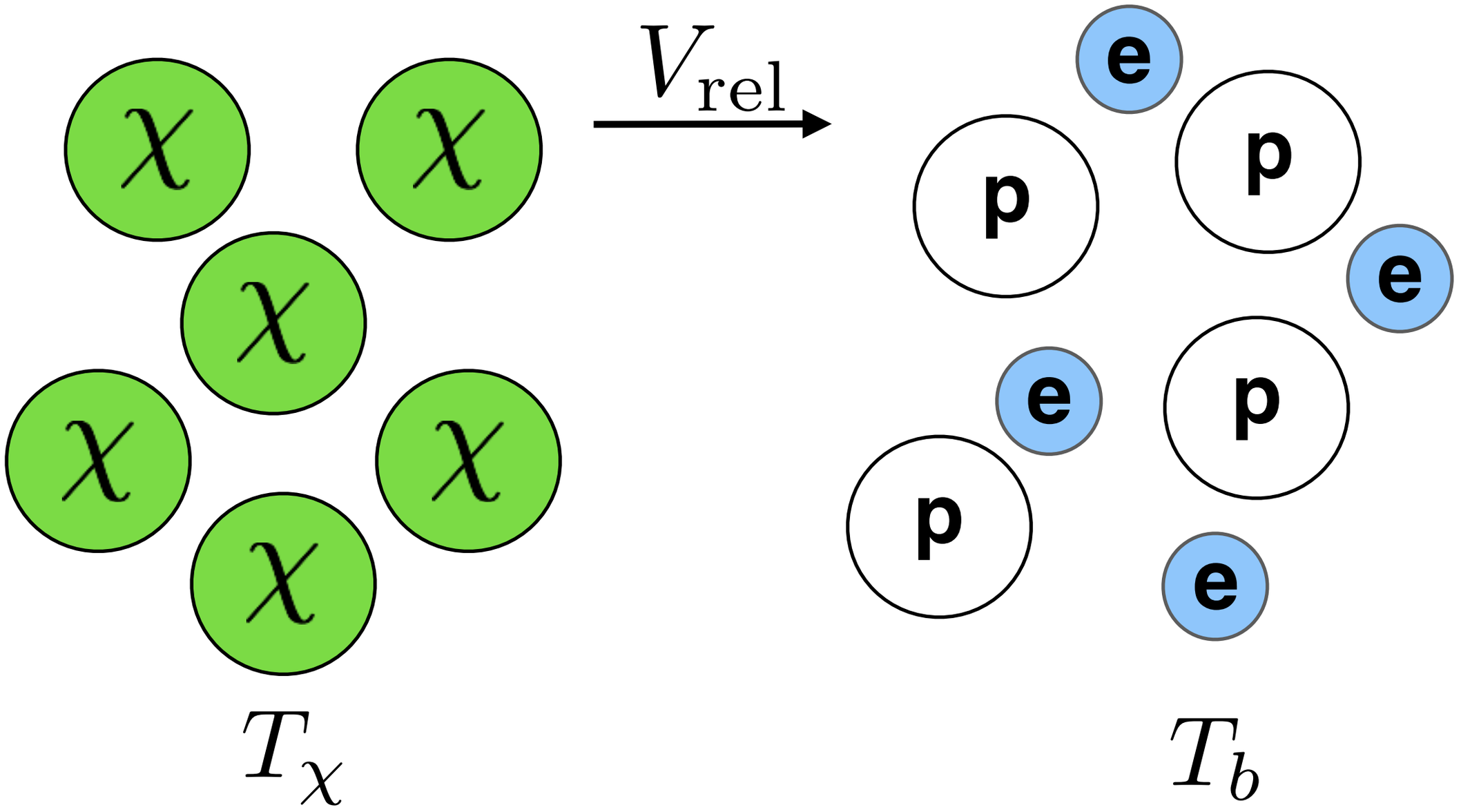
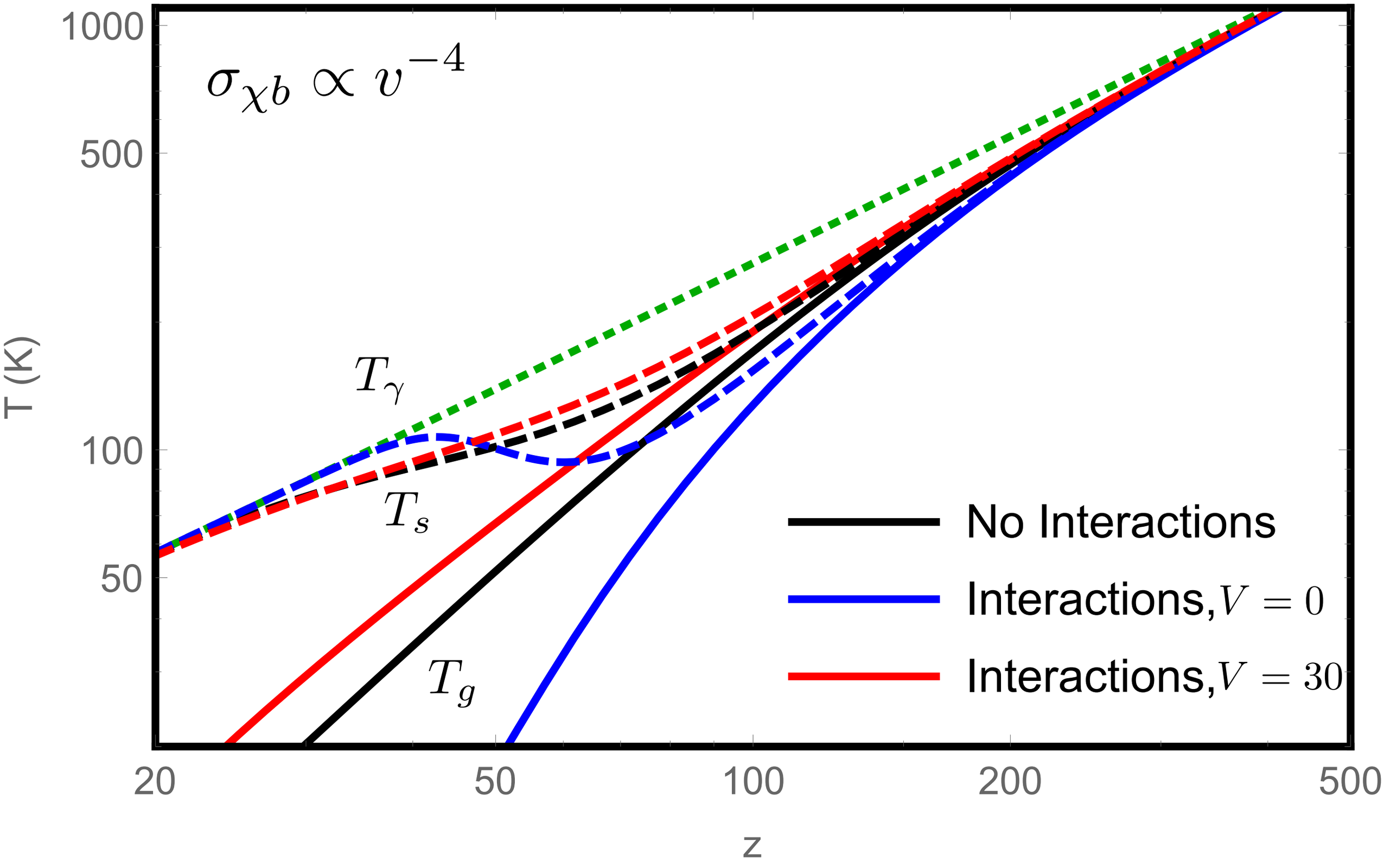


JBM, Kovetz, Ali-Haimoud PRD 2015

Tseliakhovich and Hirata PRD 2010

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



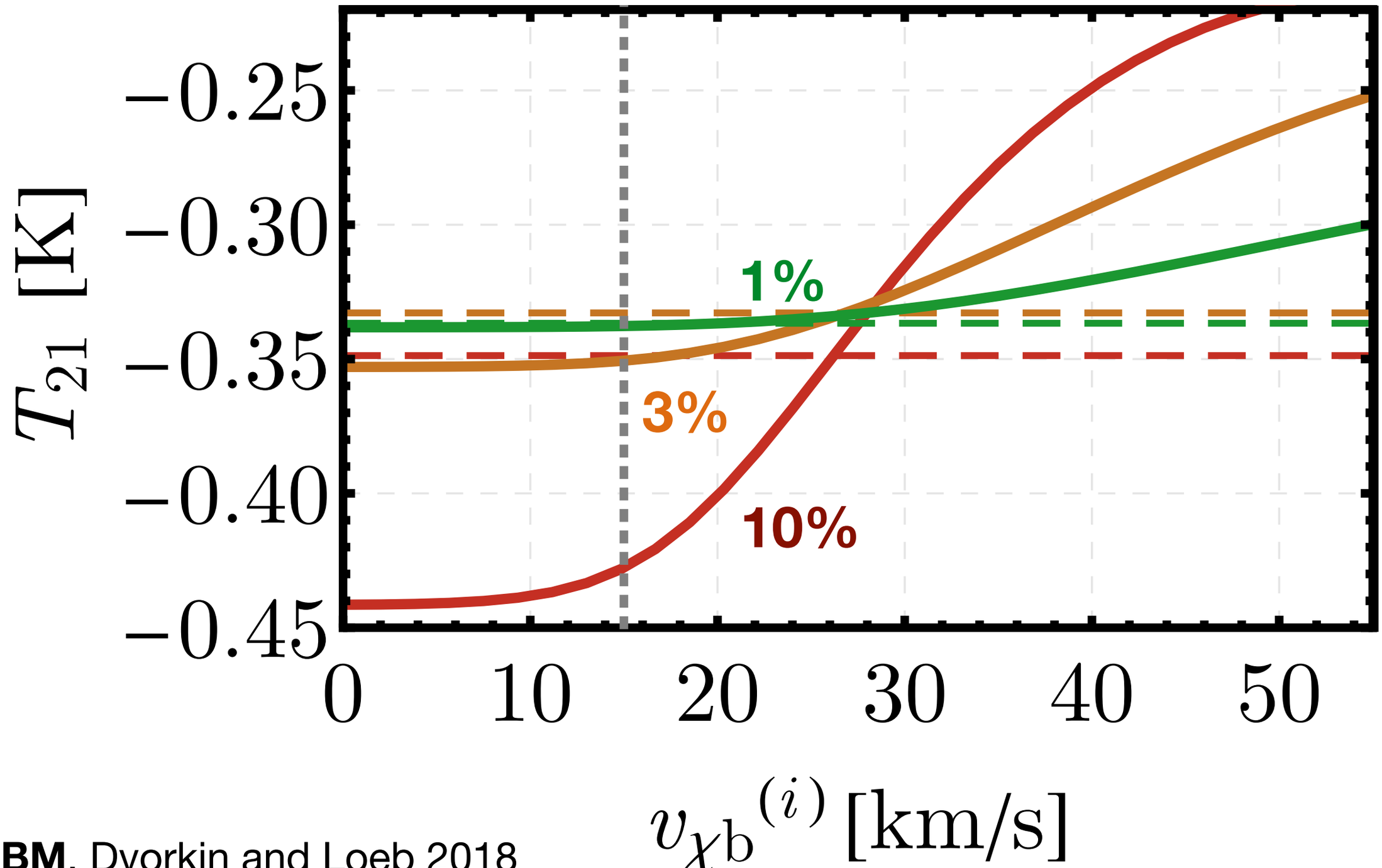


JBM, Kovetz, Ali-Haimoud PRD 2015

$$T^{(21)} = \tau \frac{T_s - T_{\rm cmb}}{1+z} (v_{\chi,b}^{(i)})$$

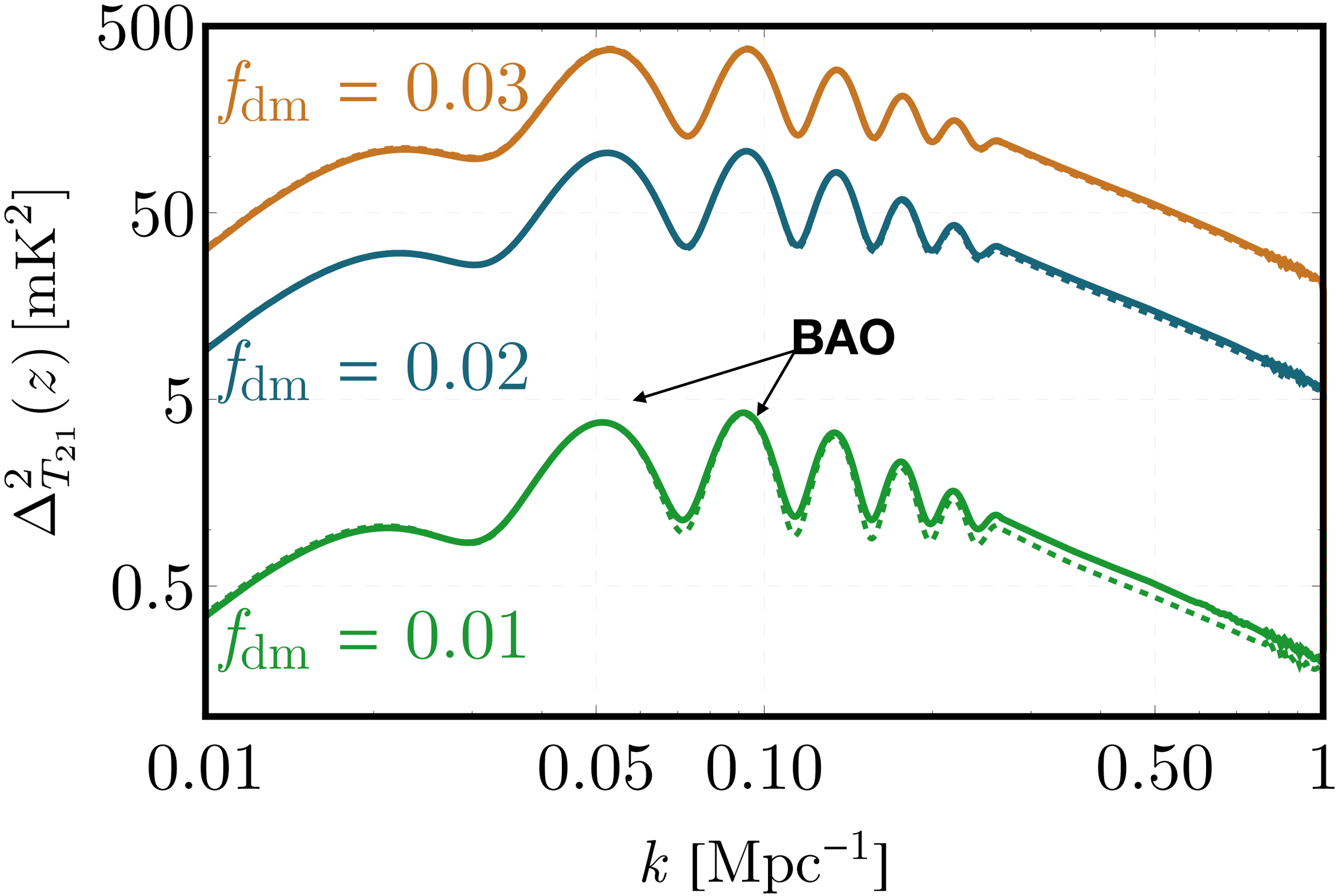
Relative velocity at decoupling

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



JBM, Dvorkin and Loeb 2018

21-cm fluctuations



JBM, Dvorkin and Loeb 2018

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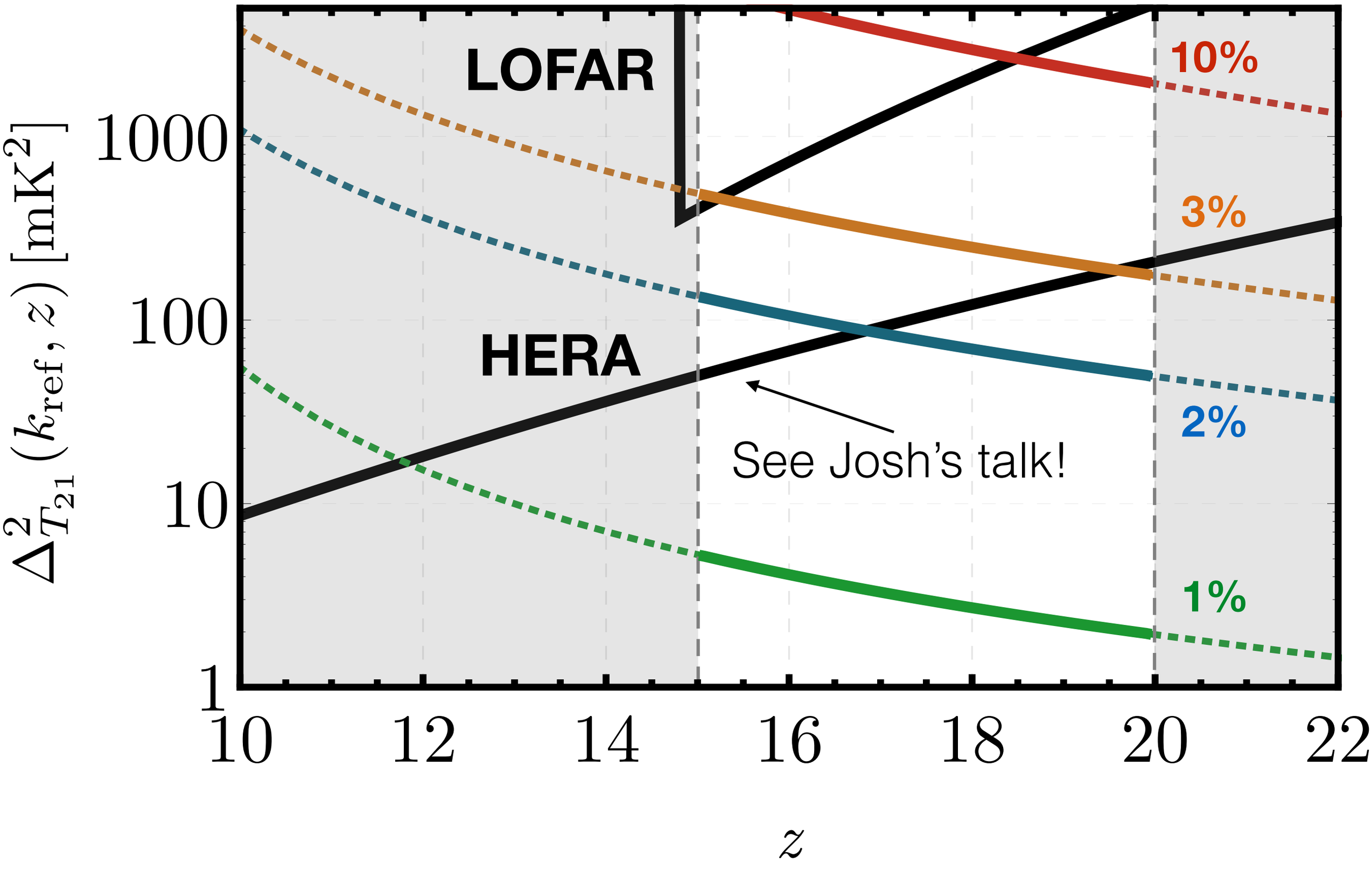
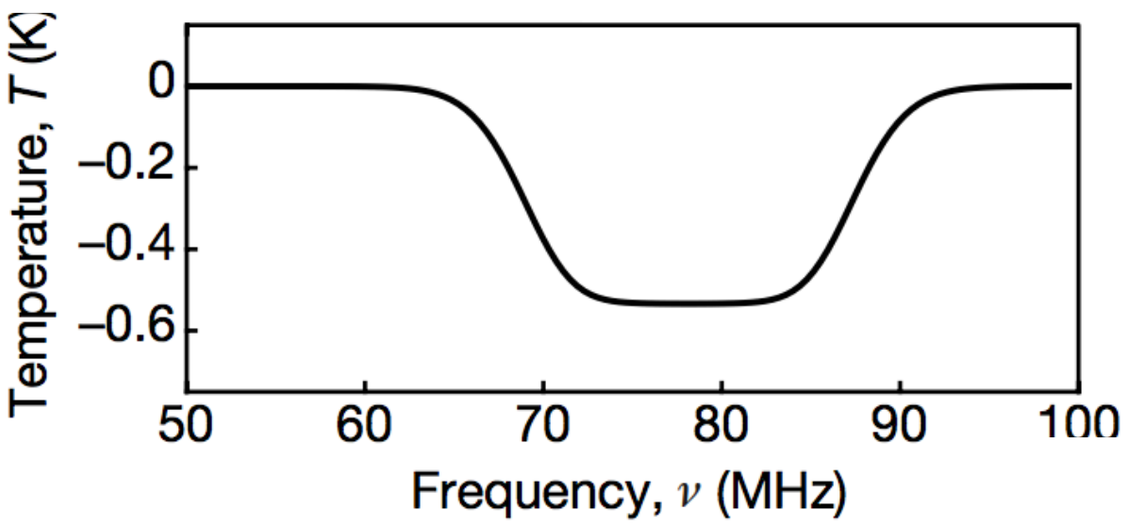


JBM, Dvorkin and Loeb 2018

To sum up



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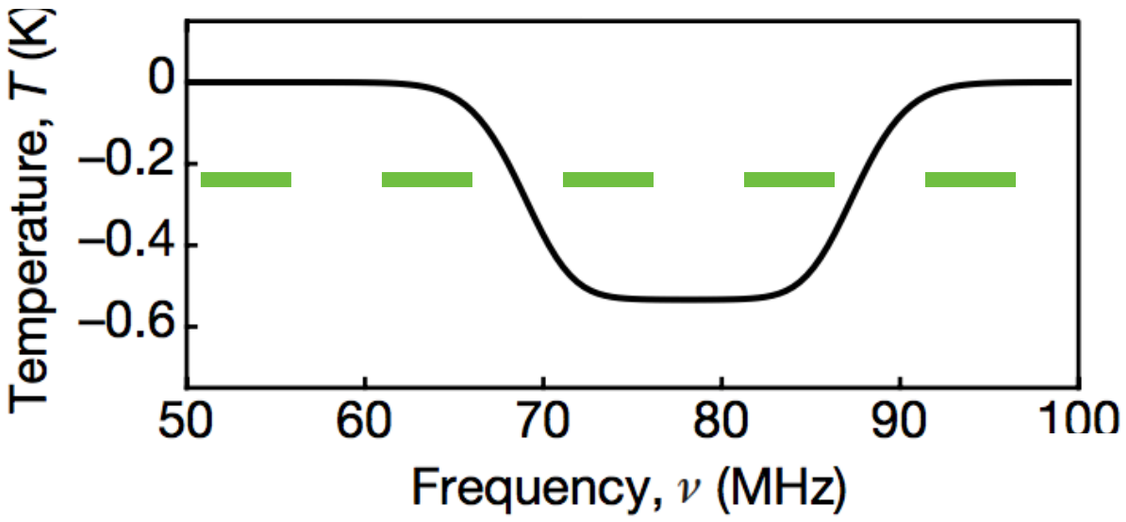
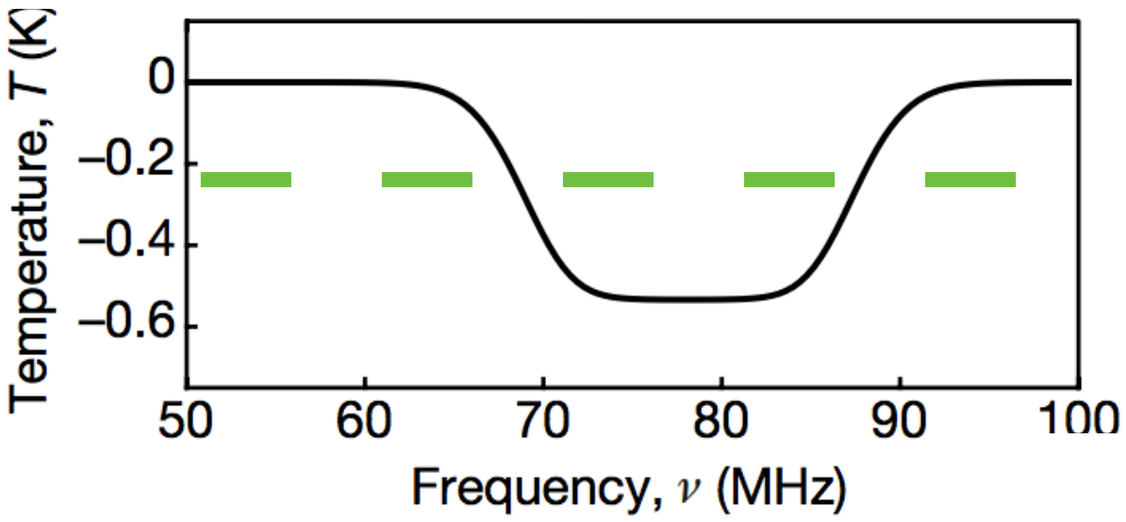


$$f_{\rm dm} \lesssim \text{few}\%$$

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

JBM and Loeb 1802.10094

To sum up



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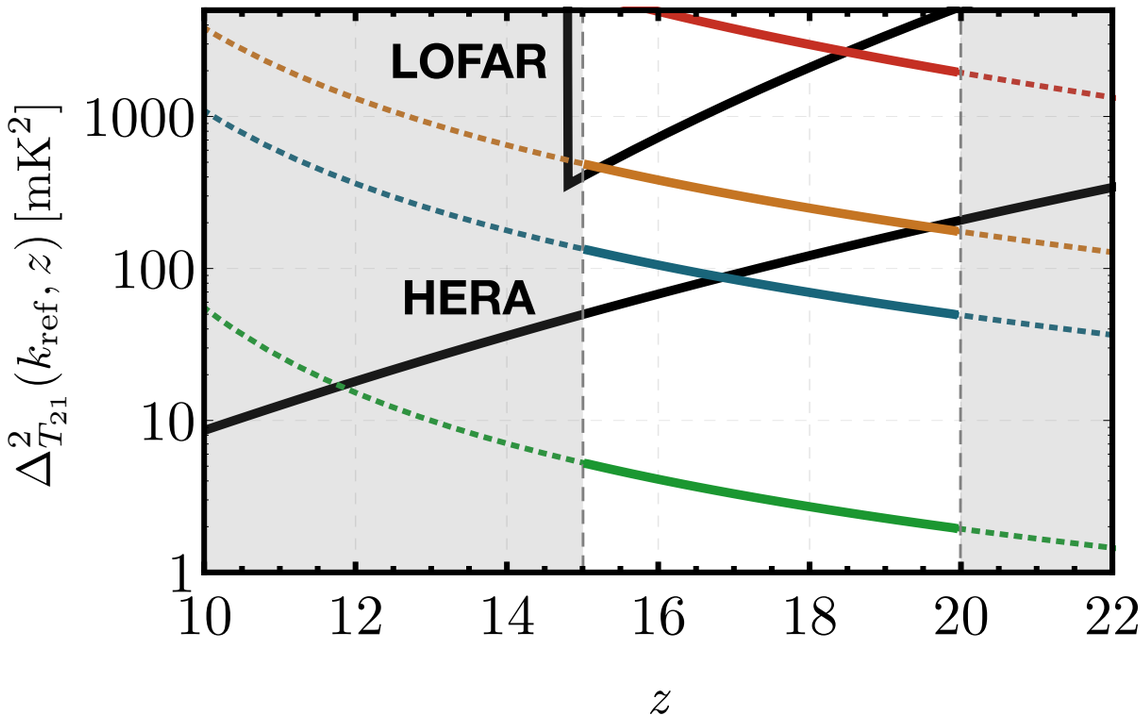
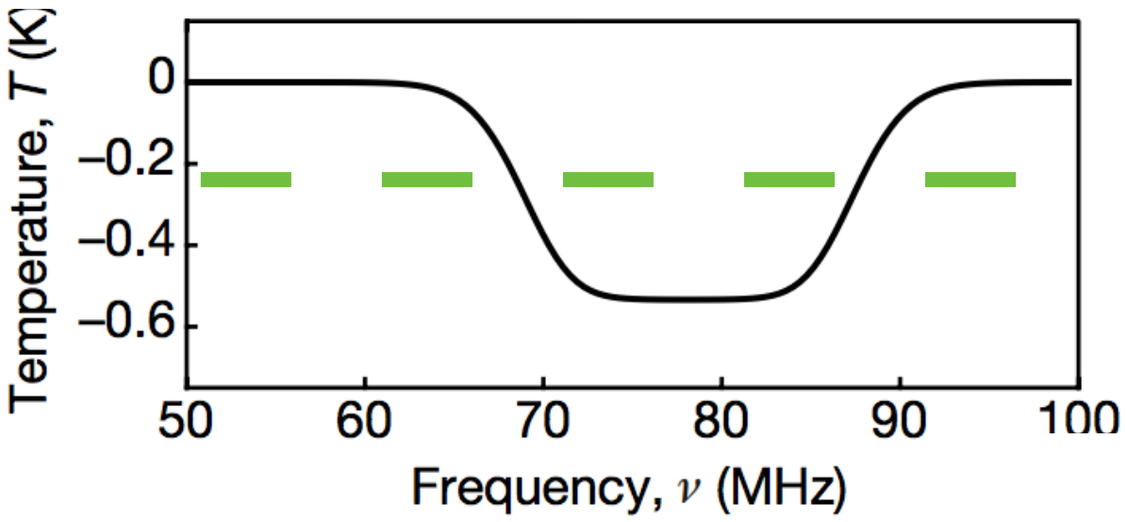


JBM, Dvorkin and Loeb 1804.01092

To sum up



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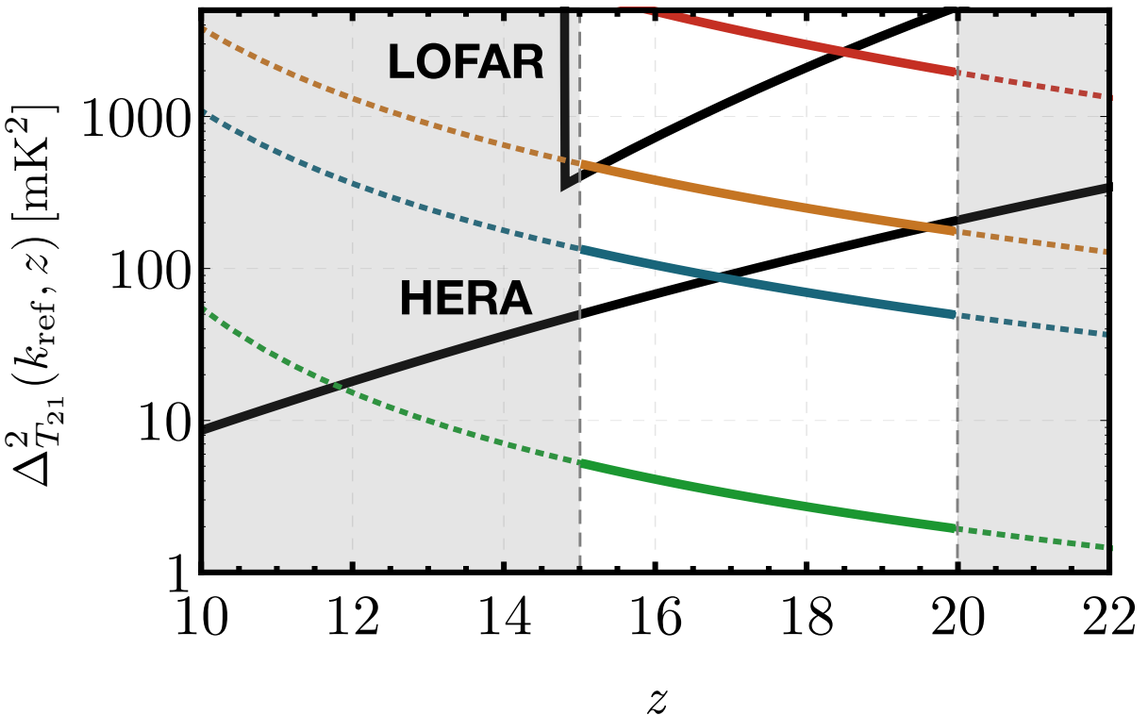
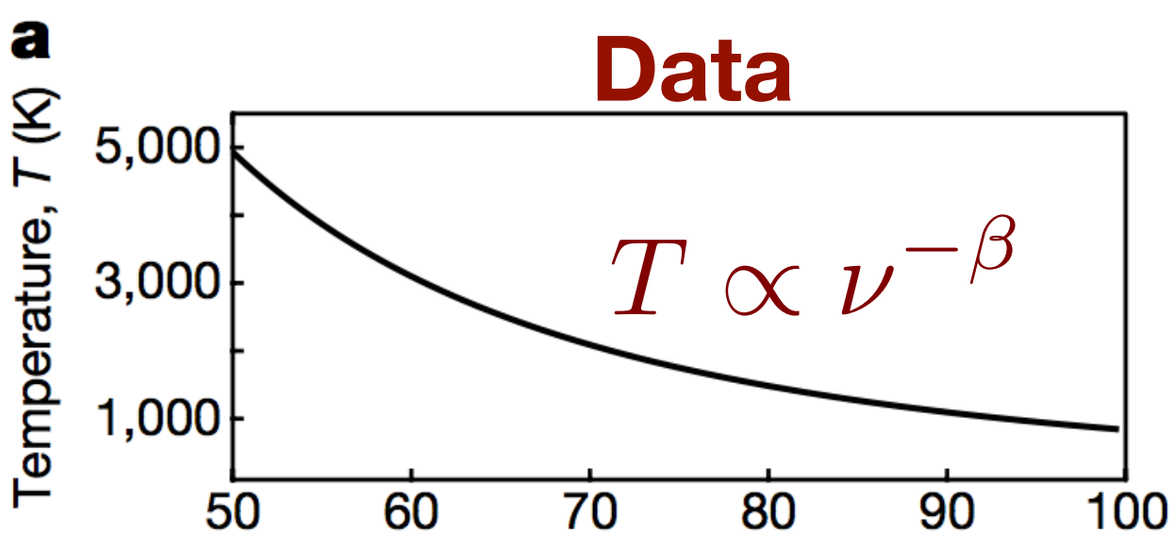
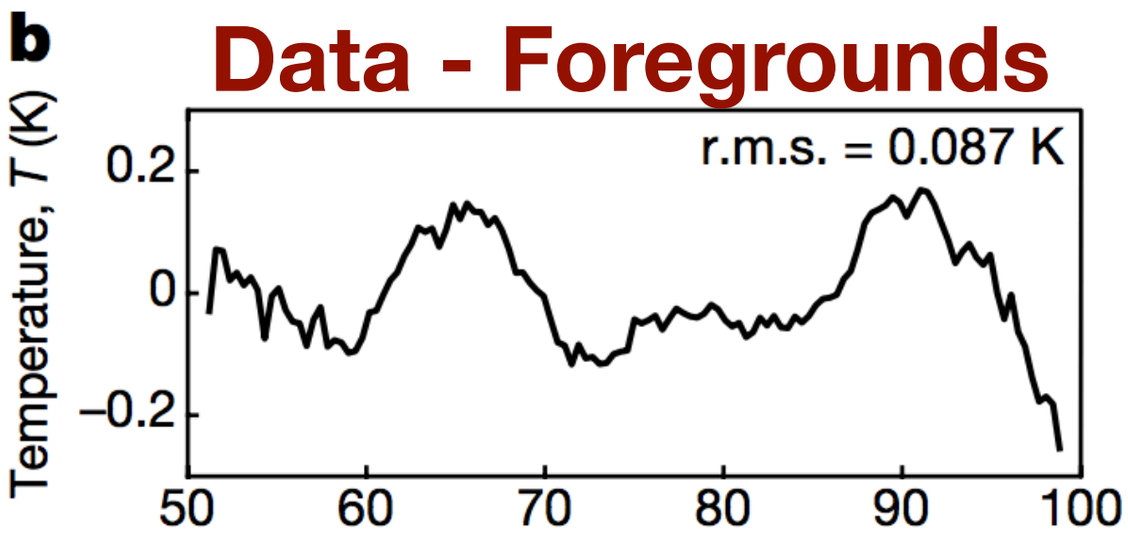
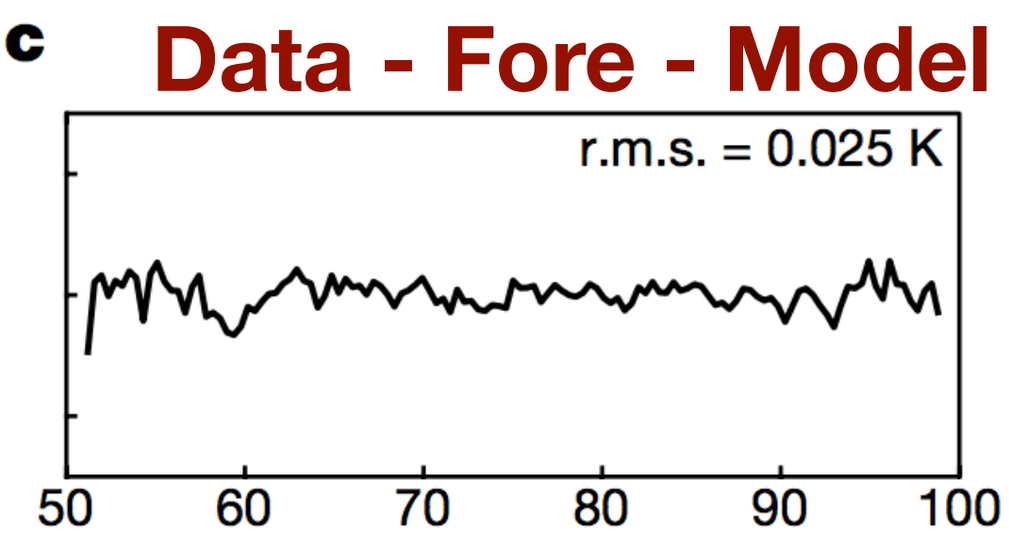


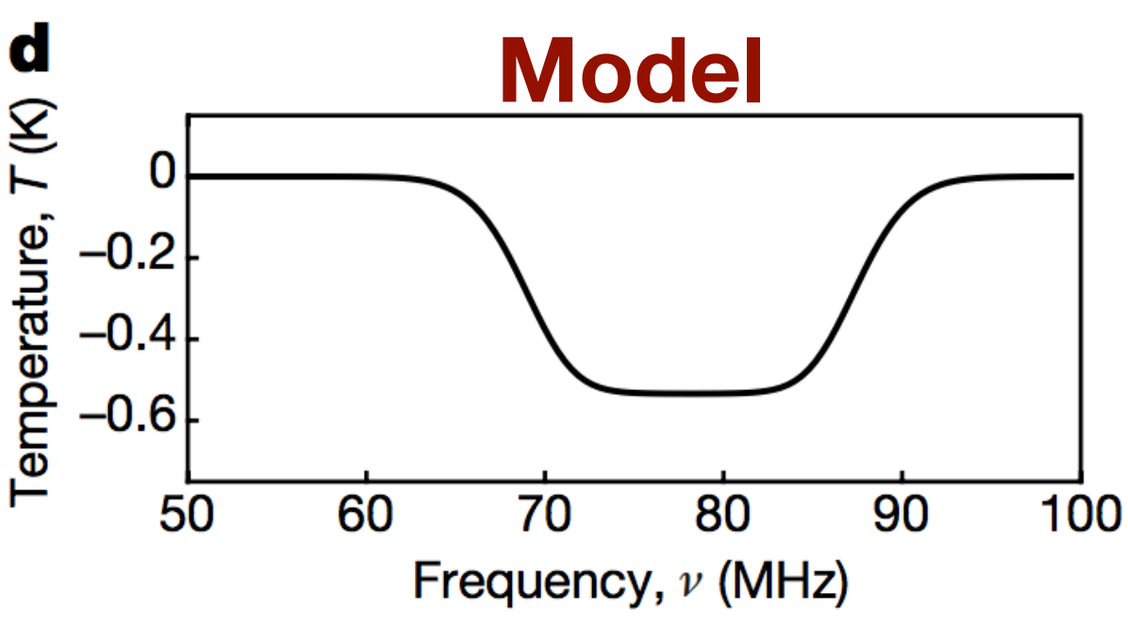
JBM, Dvorkin and Loeb 1804.01092

Thank you!









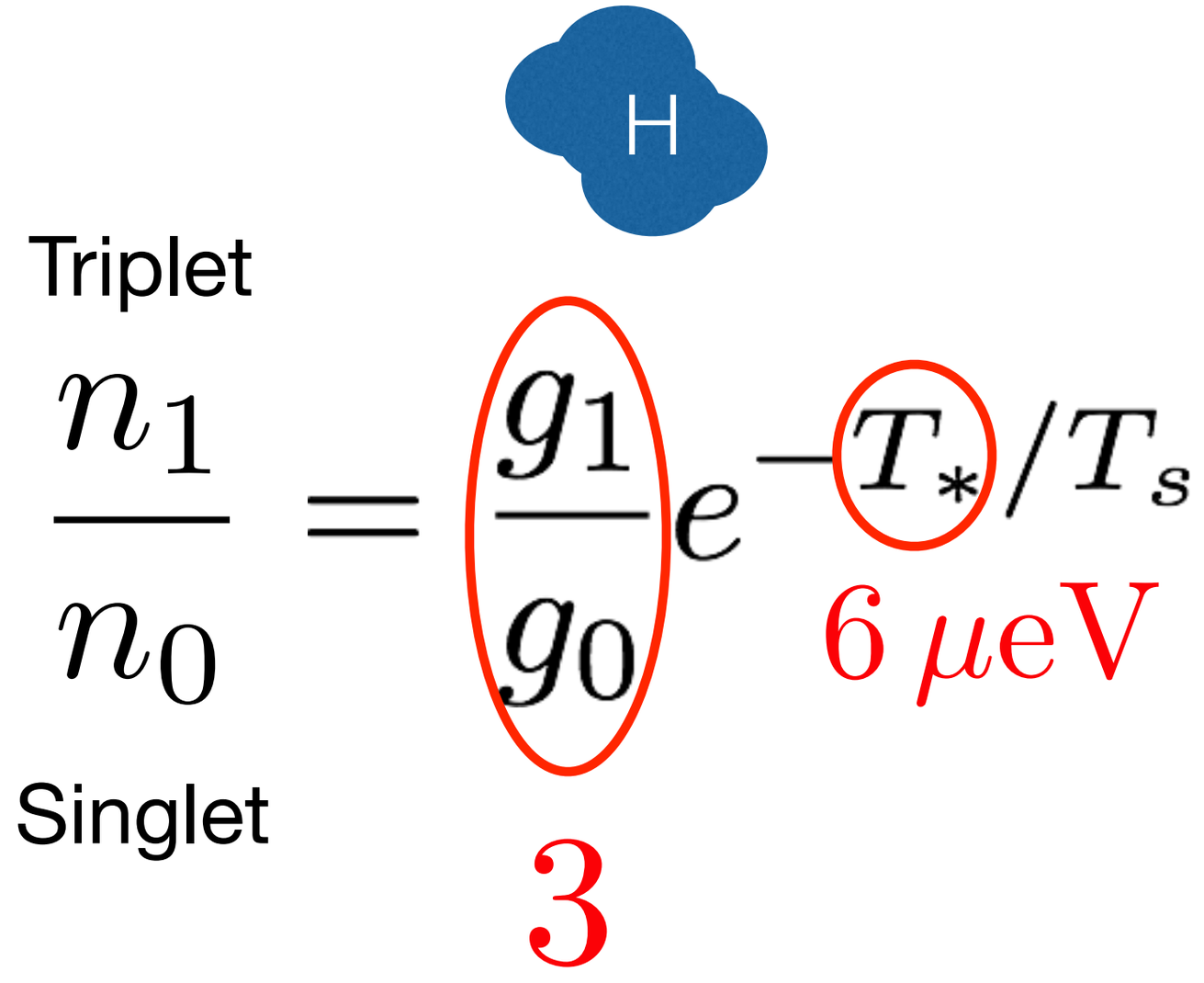
$$\nu = \frac{1420\,\mathrm{MHz}}{1+z}$$

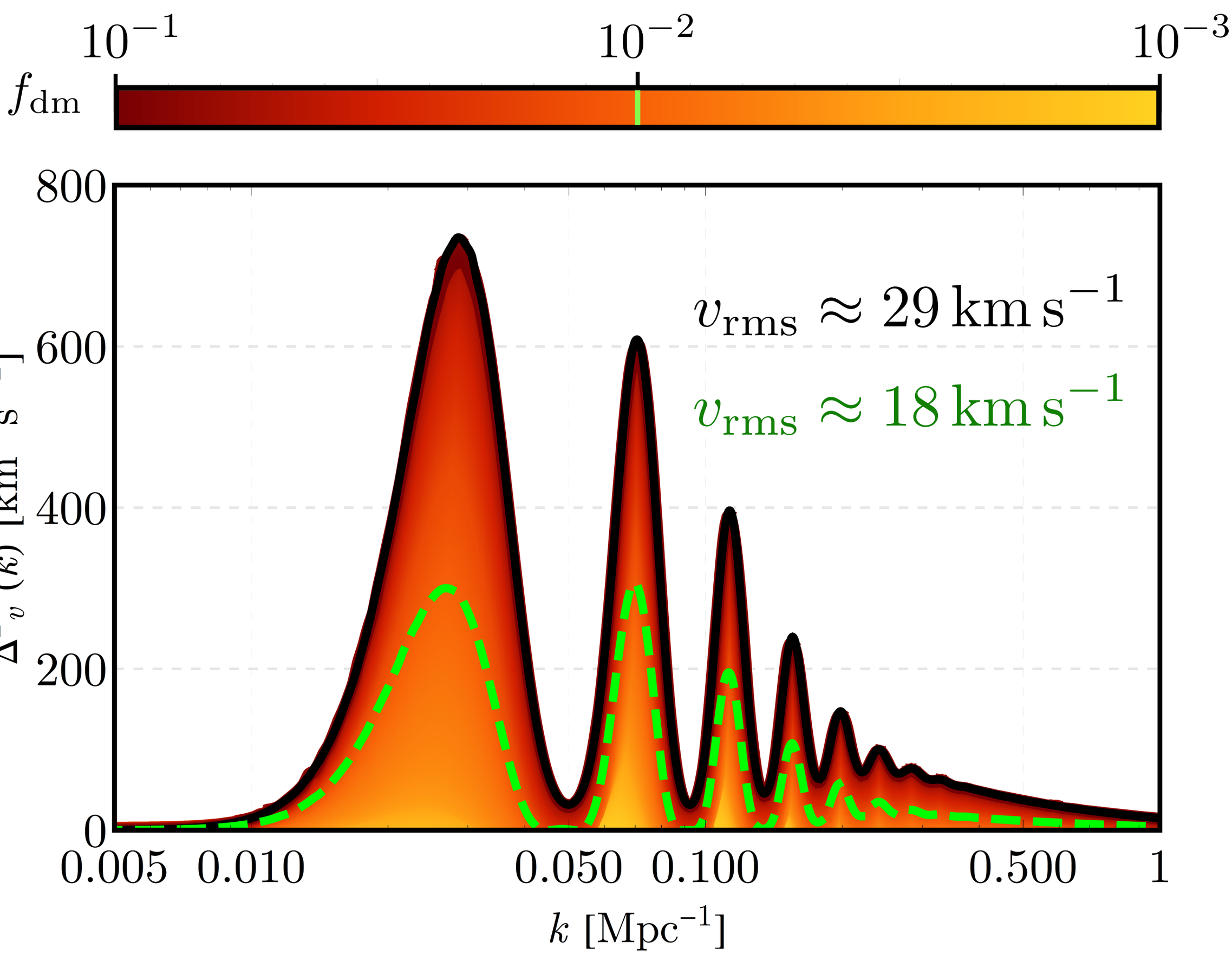
Bowman et al. Nature 2018

EDGES (Experiment to Detect the Global EoR Signature)

$T_S < T_{\rm cmb}$ Absorption

$T_S > T_{\rm cmb}$ Emission



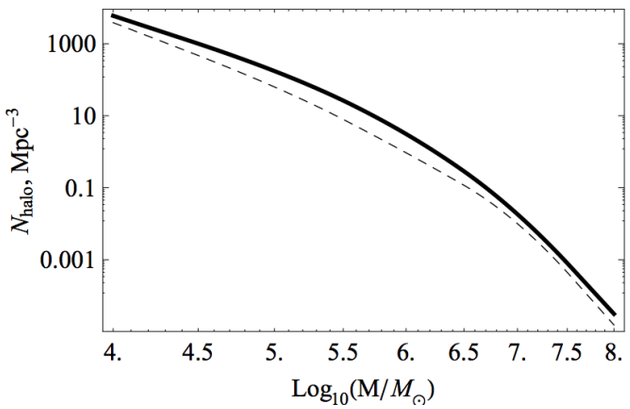


JBM, Dvorkin and Loeb 2018

21-cm fluctuations

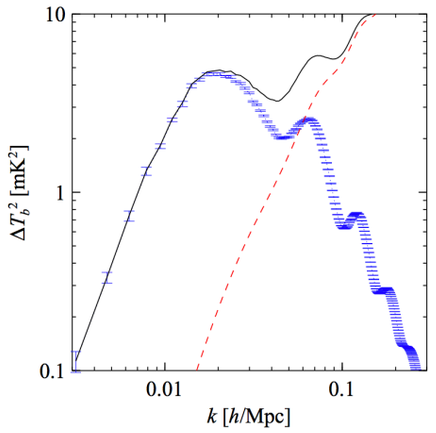
Number of haloes

Tseliakhovich and Hirata 2010



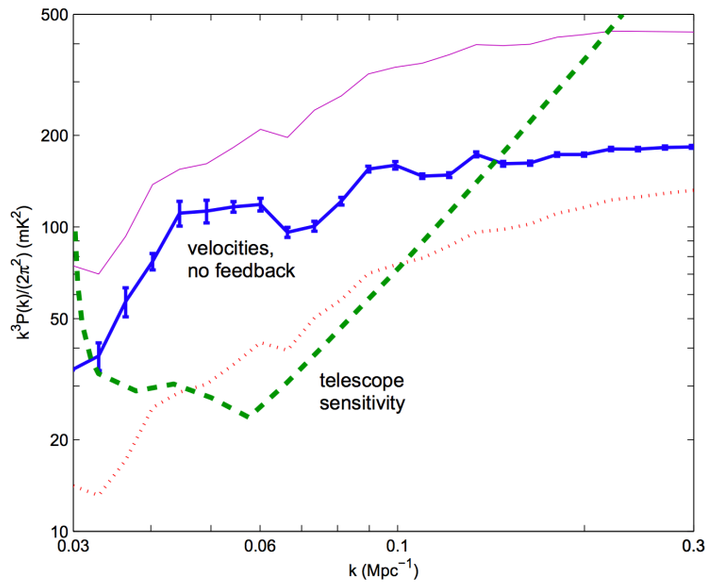
Gas Collapsed

Dalal et al. 2010

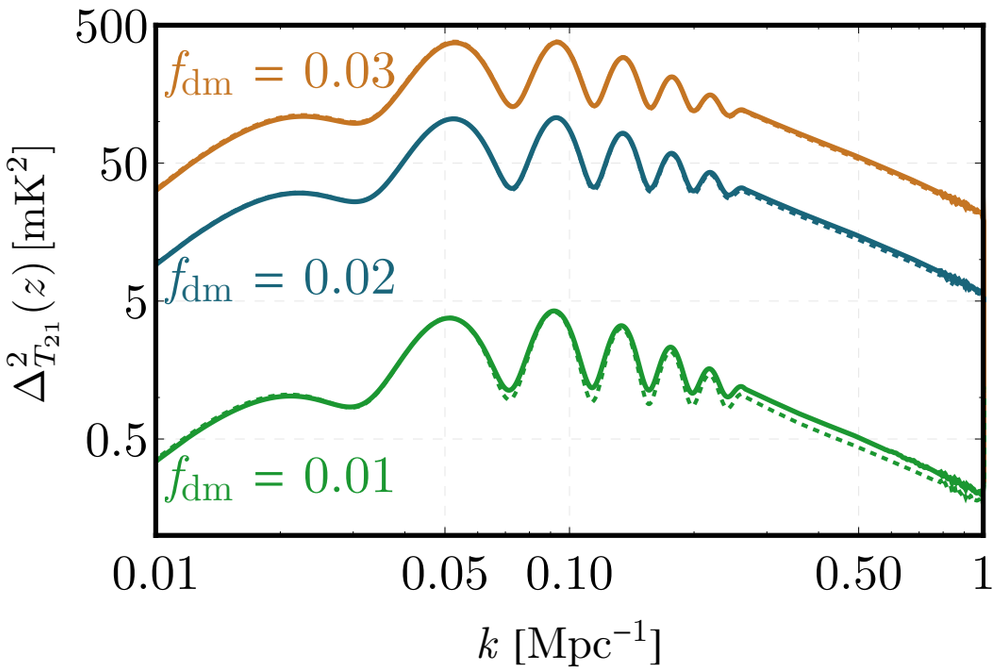


Minimum Mass

Visbal et al. 2012



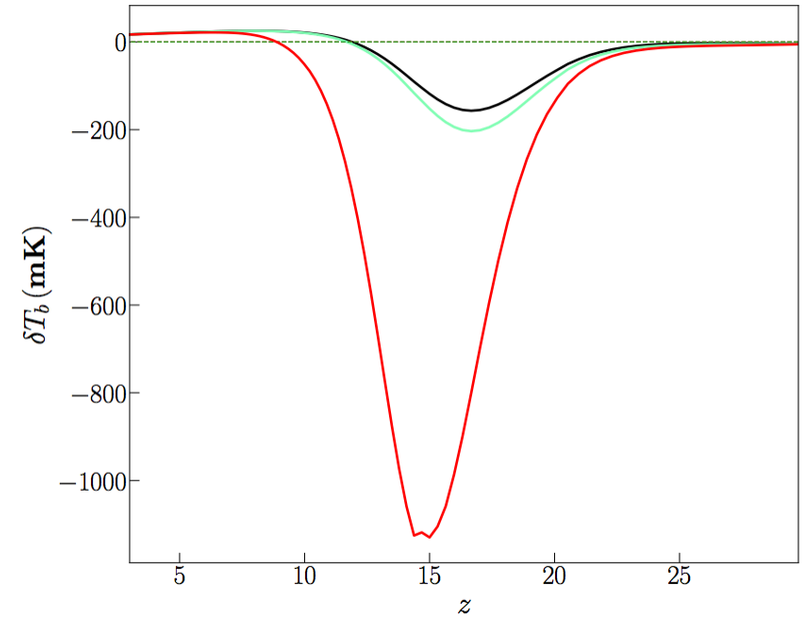
Charged DM?



Other possibilities

An Exotic Radio Excess?

Feng and Holder 1802.07432



Perhaps caused by early IMBHs?

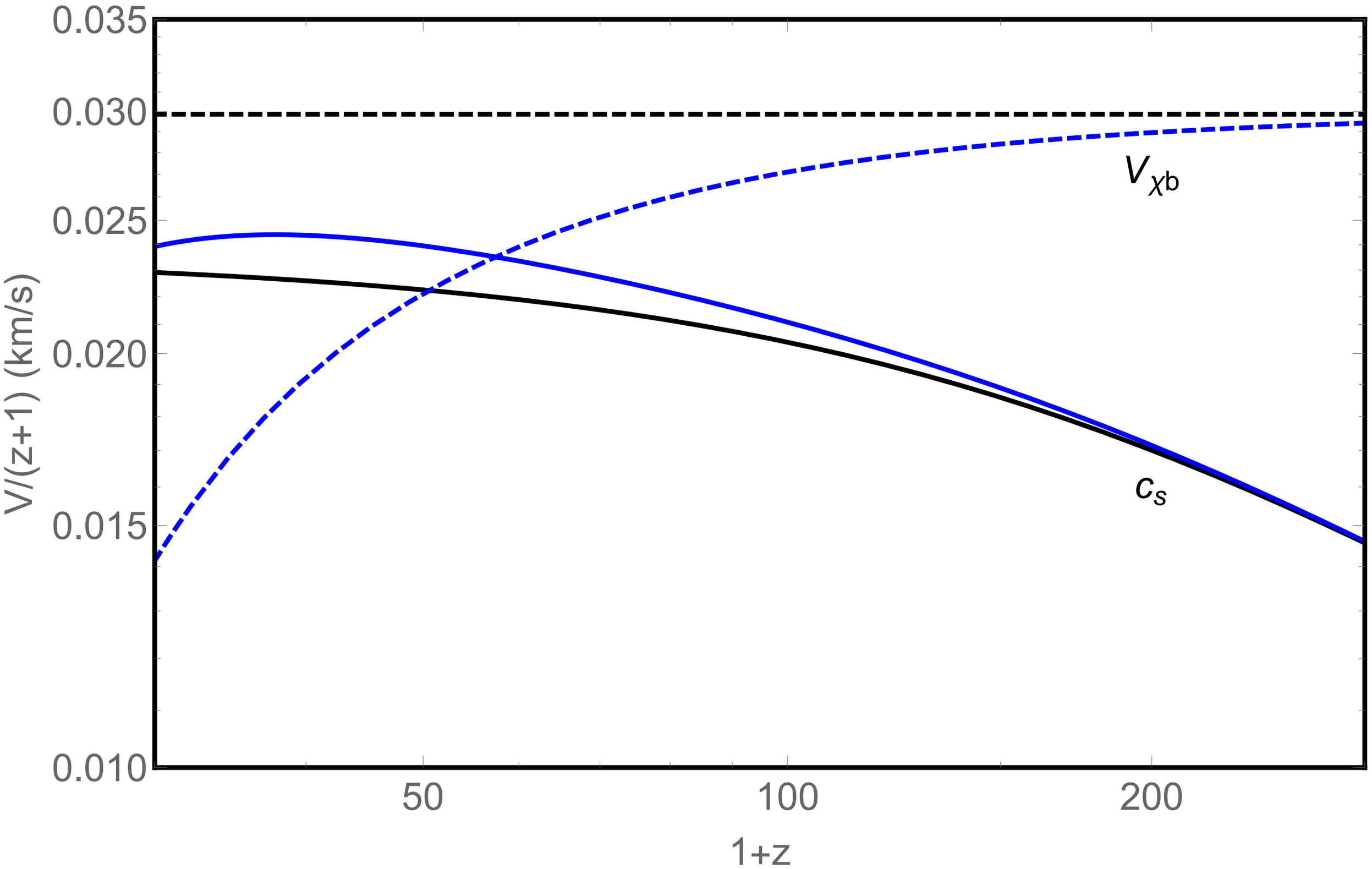
Ewall-Wice et al. 1803.01815

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

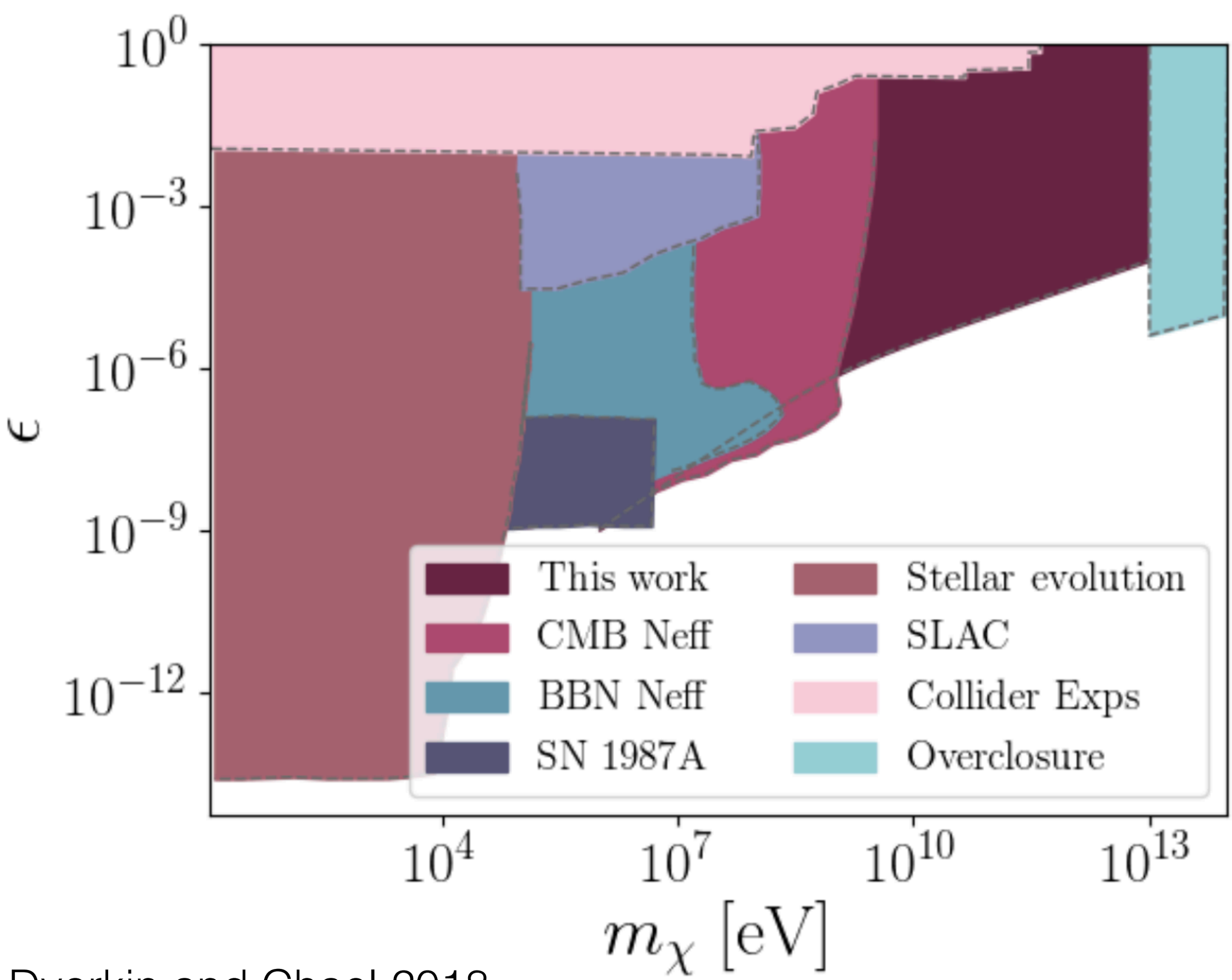
Or DM annihilations to photons/dark photons

Fraser et al. 1803.03629
Pospelov et al. 1803.07048

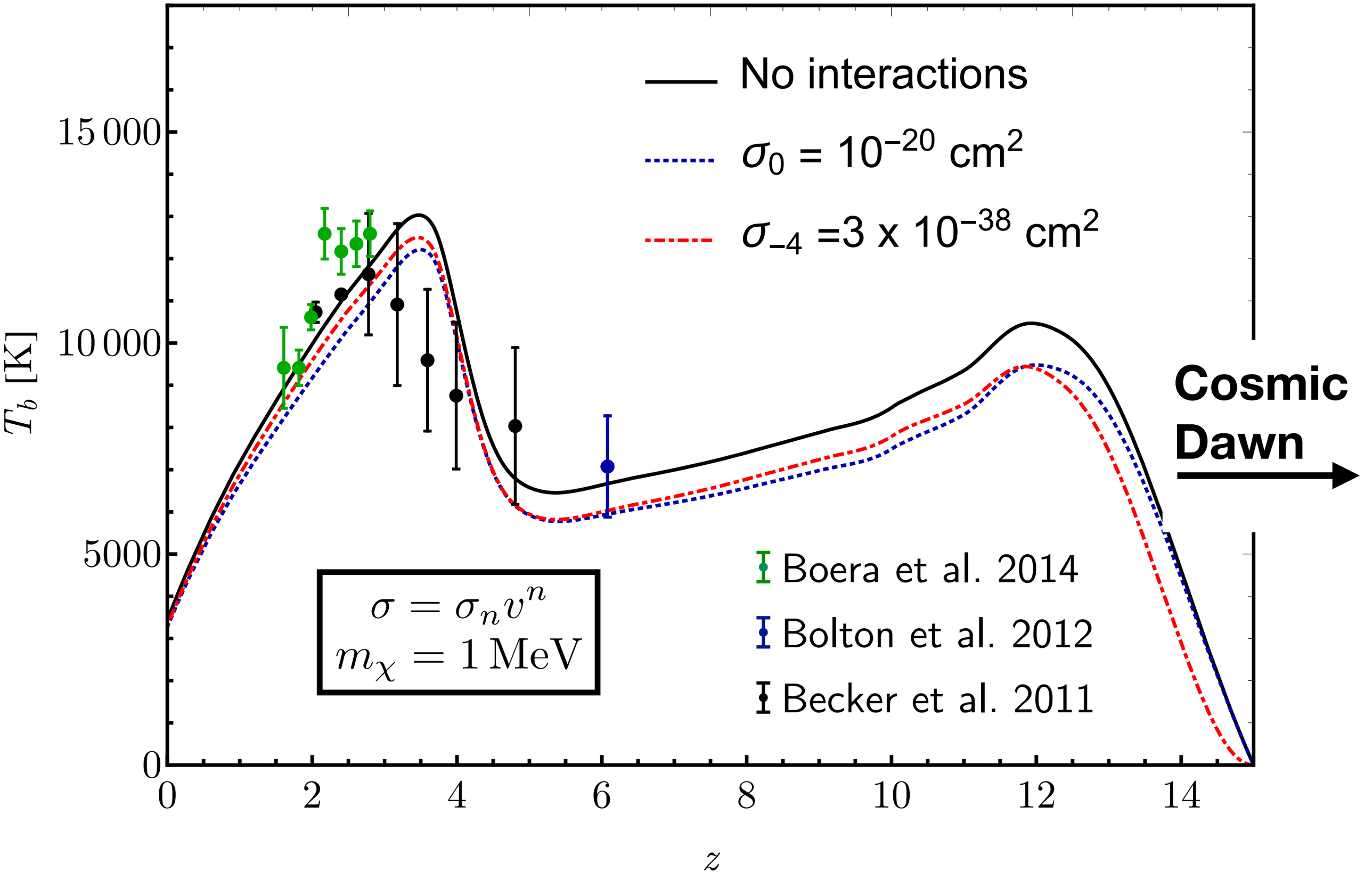
500
100
50
10
5
1
$\Delta^2_{T_{21}}(z)$ [mK^2]
0.05
0.10
0.50
1
k [Mpc^{-1}]



JBM, Kovetz and Ali-Haimoud 2015

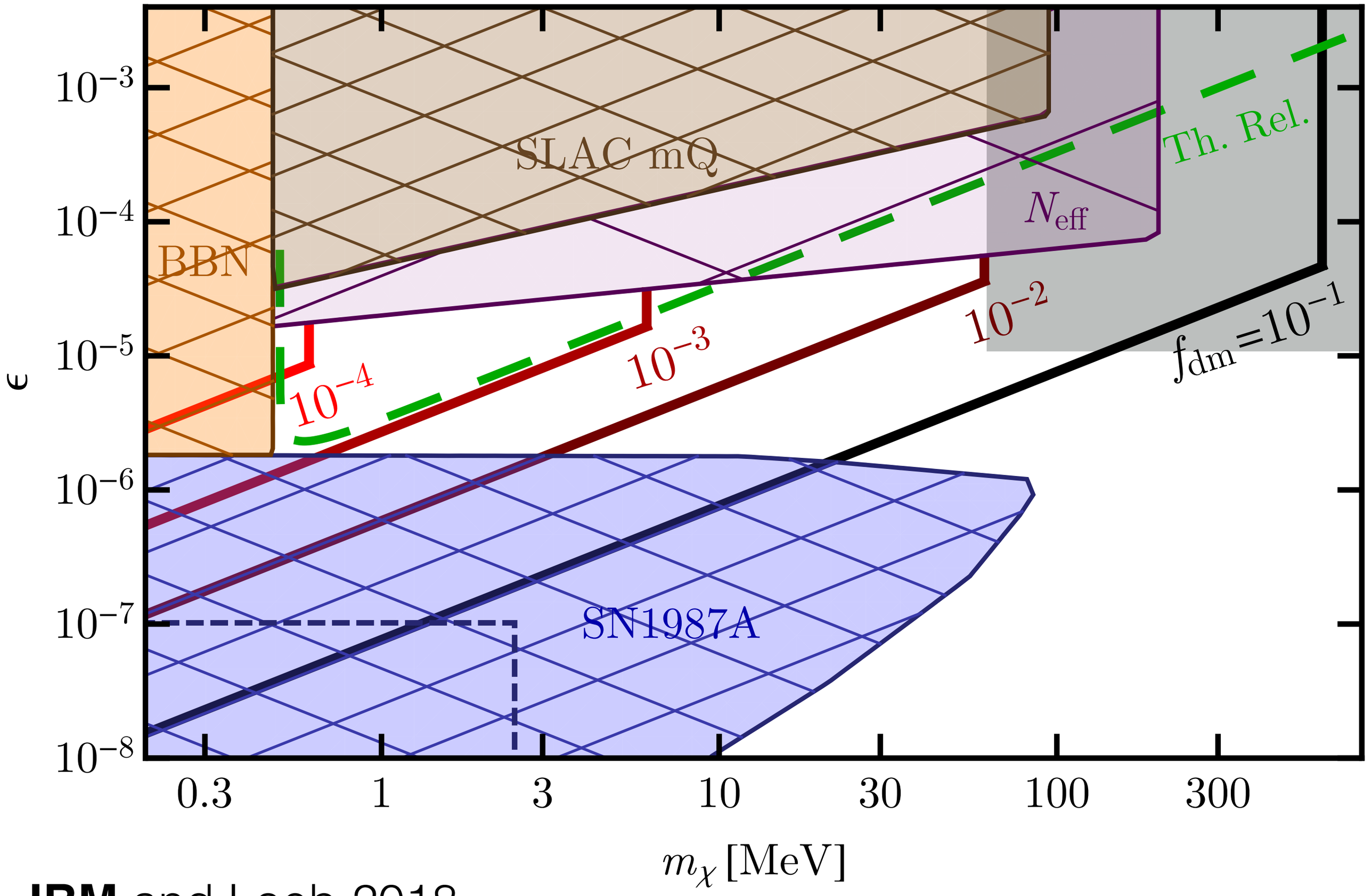


Xu, Dvorkin and Chael 2018
Gluscevic and Boddy 2017

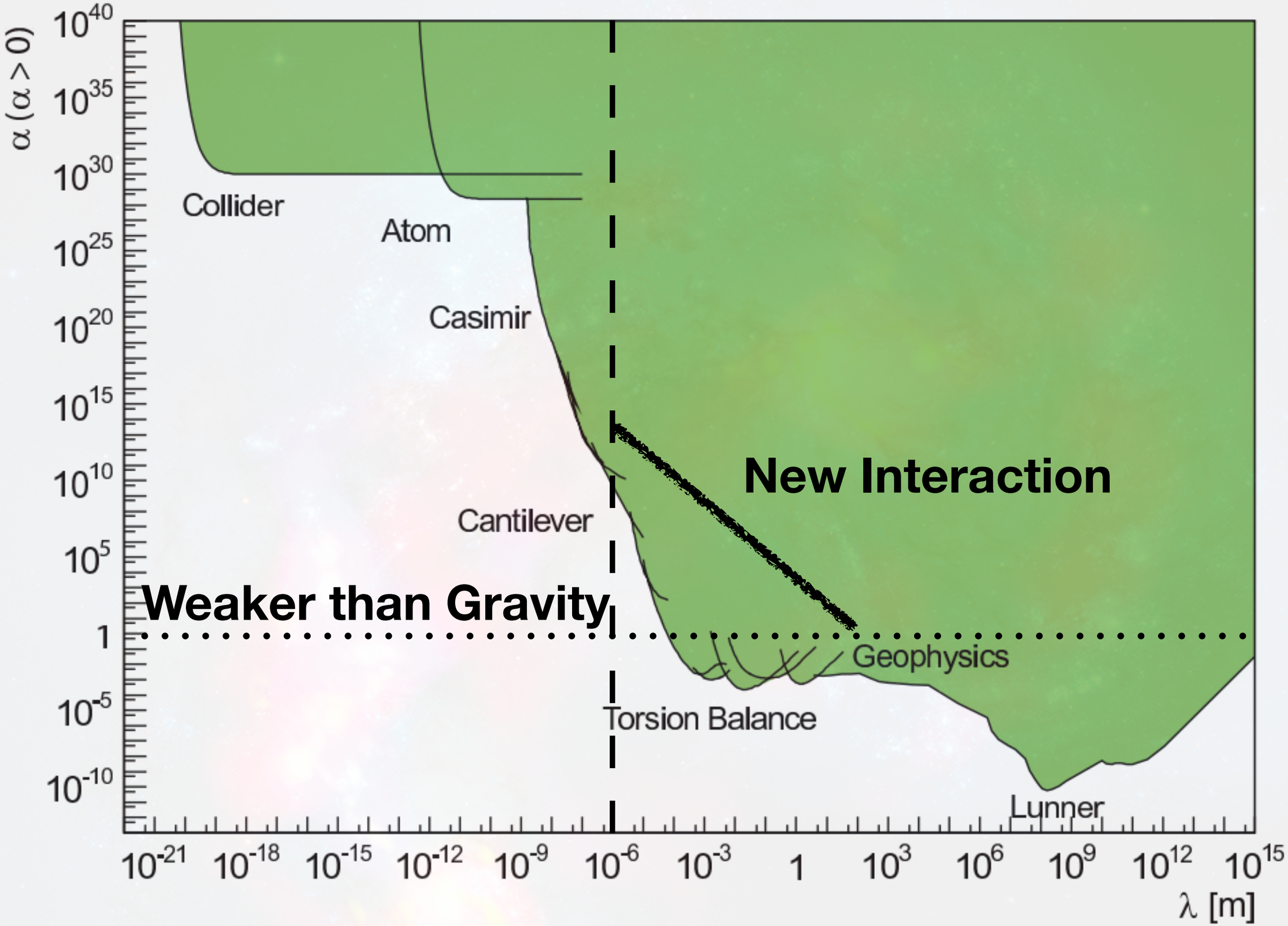


JBM and Loeb 2017

Dolgov et al. 2013



JBM and Loeb 2018



Murata and Tanaka 2014