

# Searching for Dark Matter at Cosmic Dawn



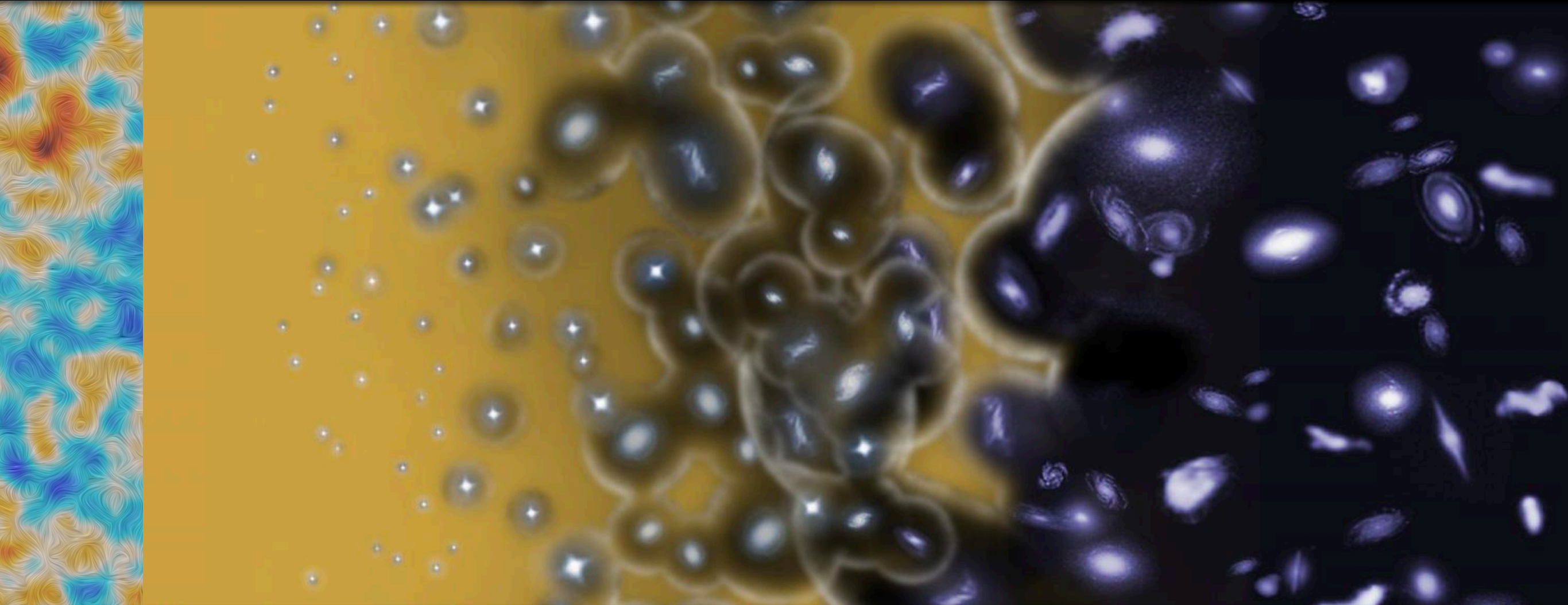
**Julian B. Muñoz**

Based on  
PRD 92 (2015)  
Nature 557 (2018)  
PRL 121 (2018)

with  
**Yacine Ali-Haïmoud**  
**Cora Dvorkin**  
**Avi Loeb**  
**Ely Kovetz**

# Brief history of Hydrogen

CMB



$z=1100$

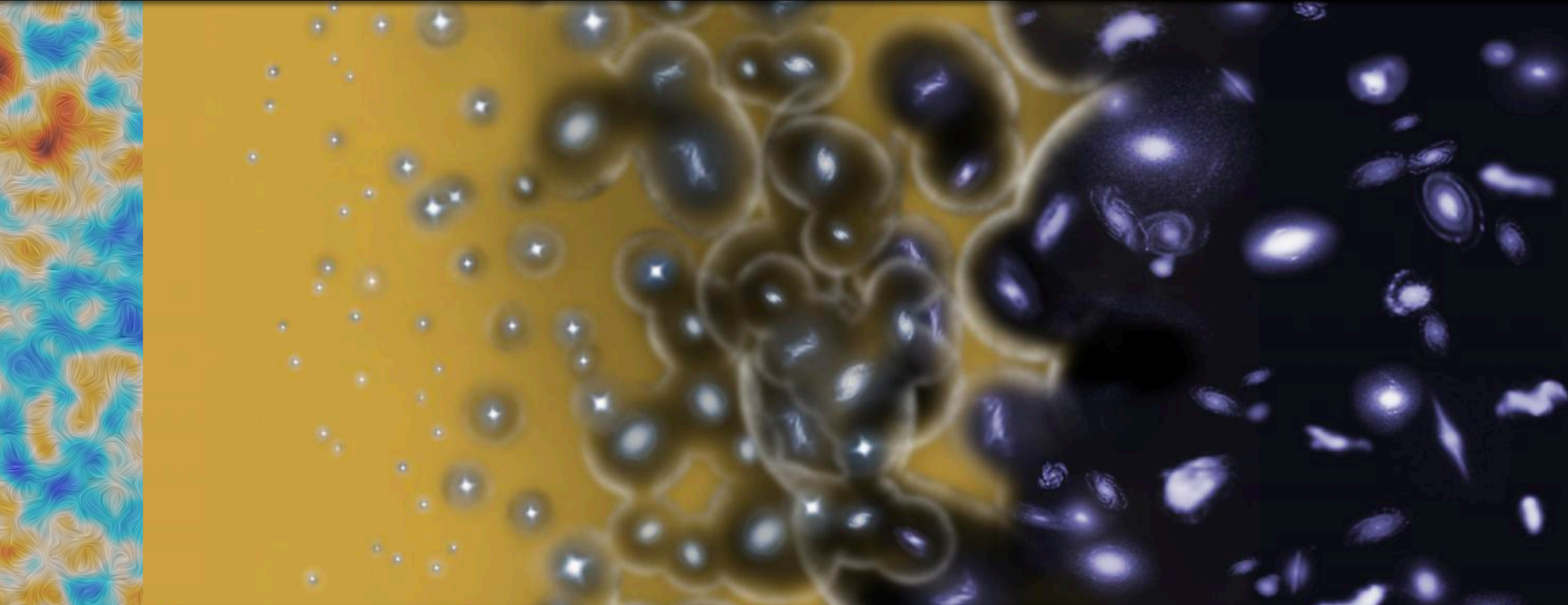
Image: ESA



# Brief history of Hydrogen

CMB

Cosmic  
Dawn



$z=1100$

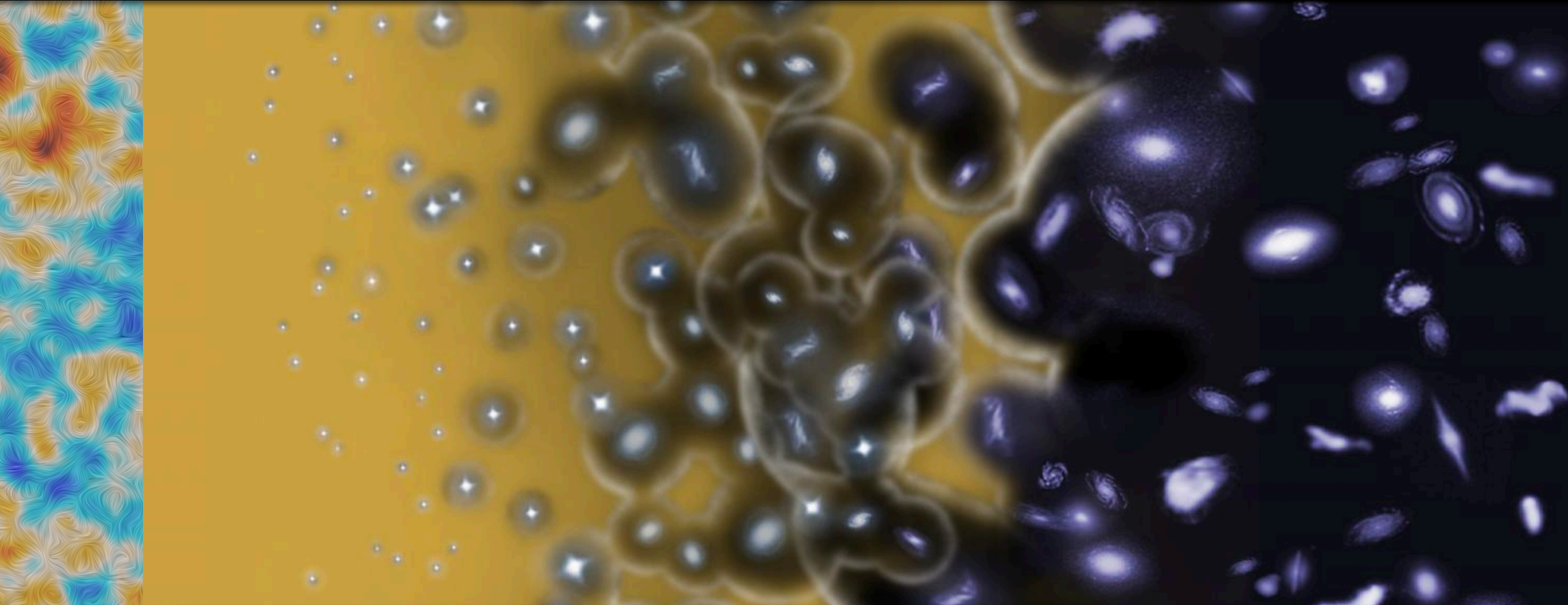
$z=20$

# Brief history of Hydrogen

CMB

Cosmic  
Dawn

Reionization



$z=1100$

$z=20$

$z=6$



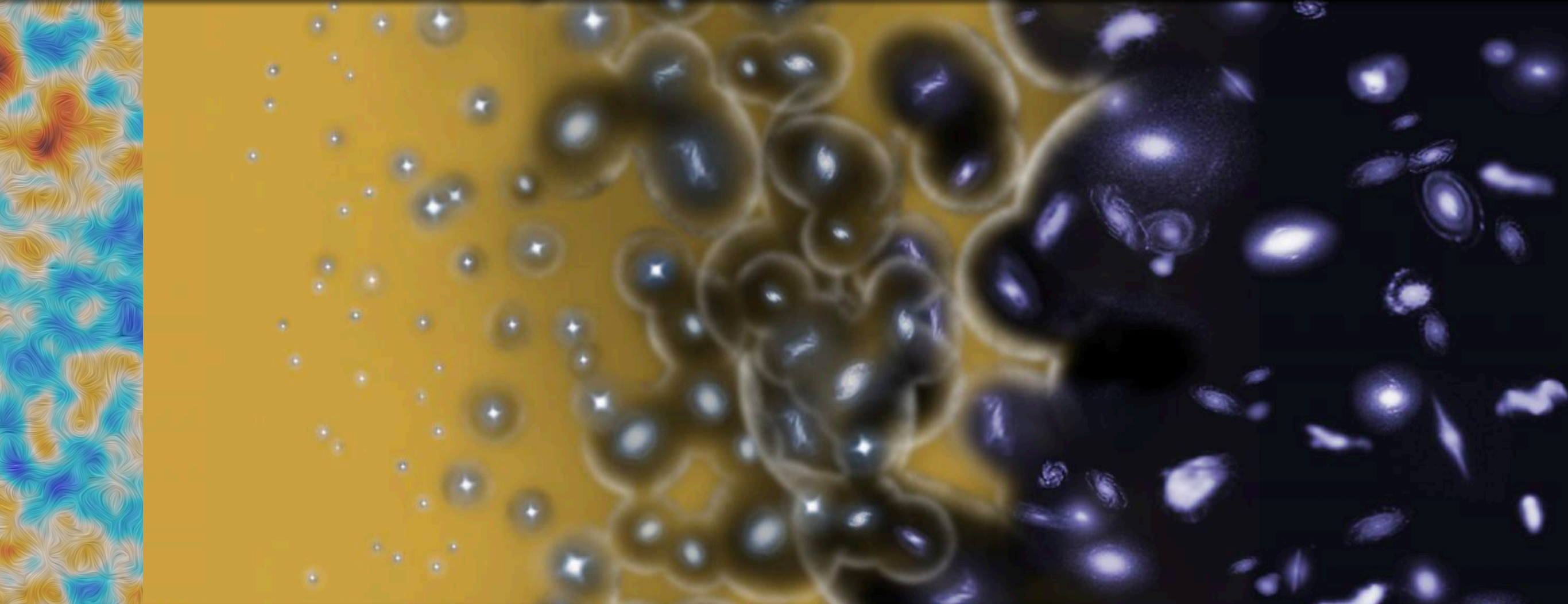
# Brief history of Hydrogen

CMB

Cosmic  
Dawn

Reionization

Earth and  
Telescopes



$z=1100$

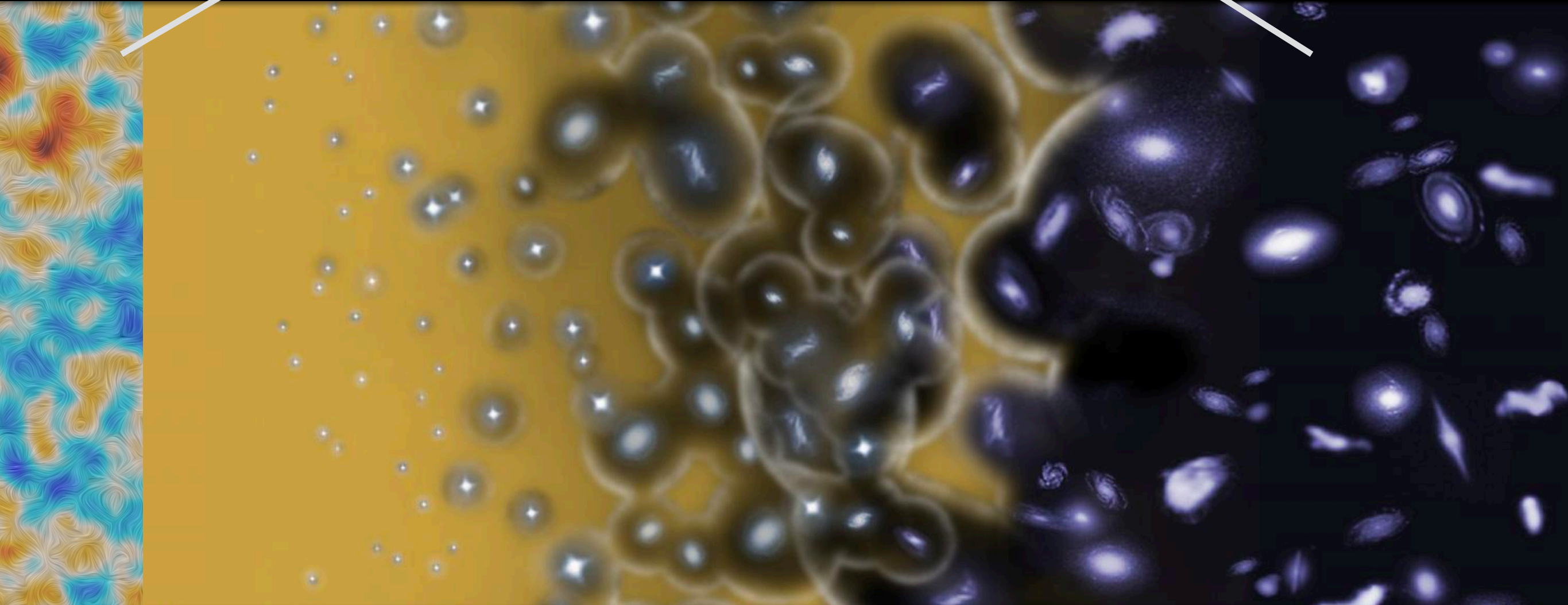
$z=20$

$z=6$

$z=0$

# What have we learned about DM?

See Cora's and Neelima's talks



$z=1100$

$z=20$

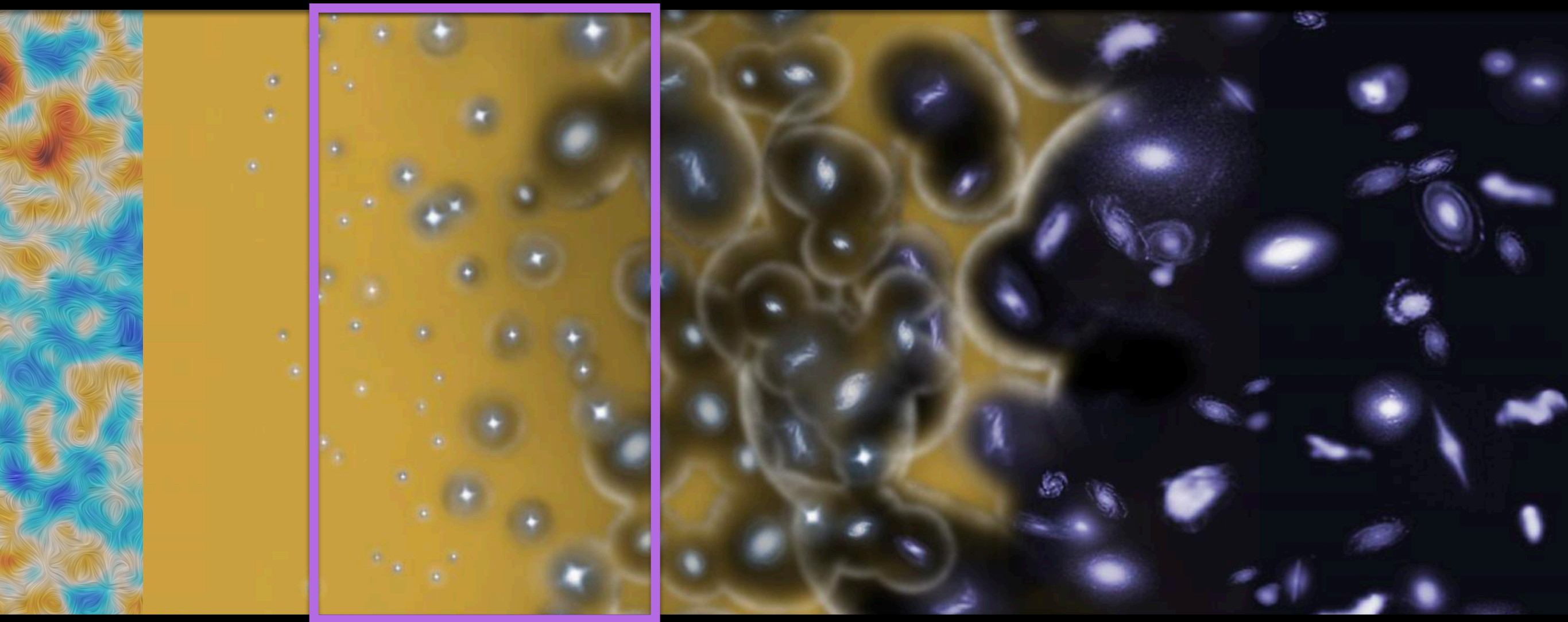
$z=6$

$z=0$



# What can we learn?

## Cosmic Dawn



$z=1100$

$z=20$

$z=6$

$z=0$

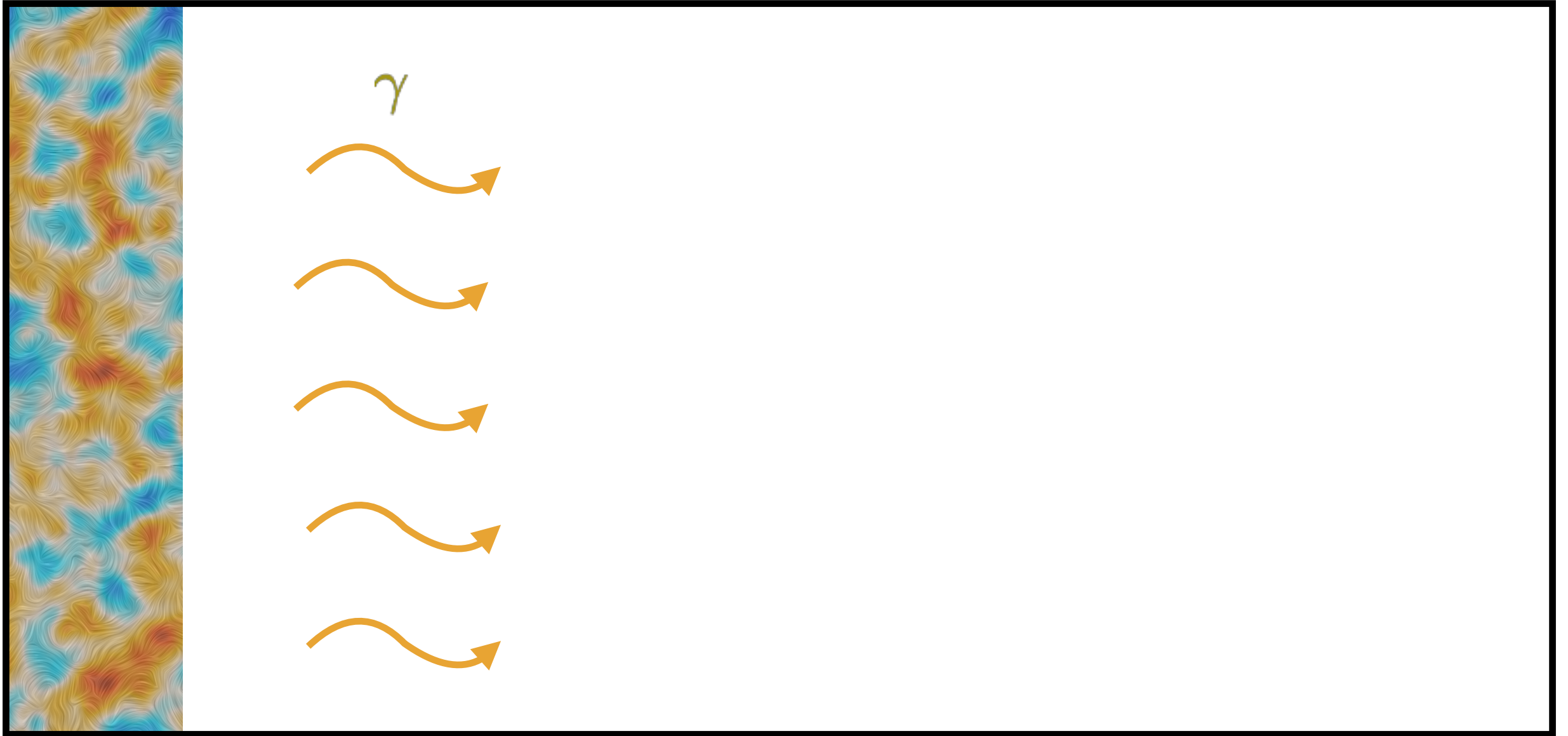
# Outline

- Introduction to 21-cm cosmology
- EDGES and dark matter
- Other DM searches with 21 cm



# 21-cm cosmology

$z = 1100$

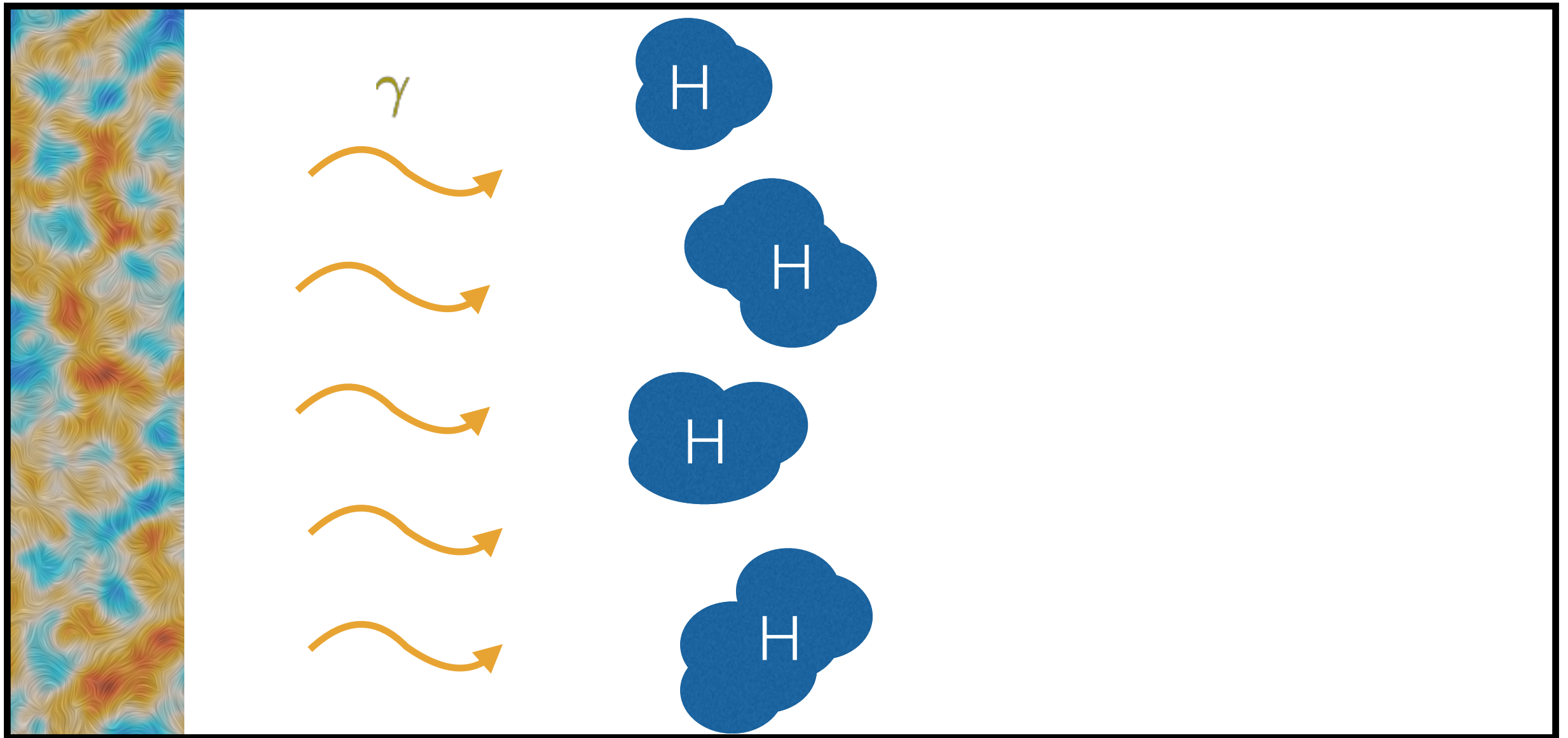


$$I_\nu \propto T_{\text{CMB}} \nu^2$$

# 21-cm cosmology

$z = 1100$

$z \approx 20$



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

**(@ 21 cm)**



# 21-cm cosmology



Triplet

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

Singlet

# 21-cm cosmology



1s  $\xrightarrow{\hspace{2cm}} \uparrow T_*$

Triplet

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

$6 \mu\text{eV}$

Singlet

3

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

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



1s  $\xrightarrow{\hspace{2cm}} \uparrow T_*$

Triplet

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

Singlet

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$6 \mu\text{eV}$

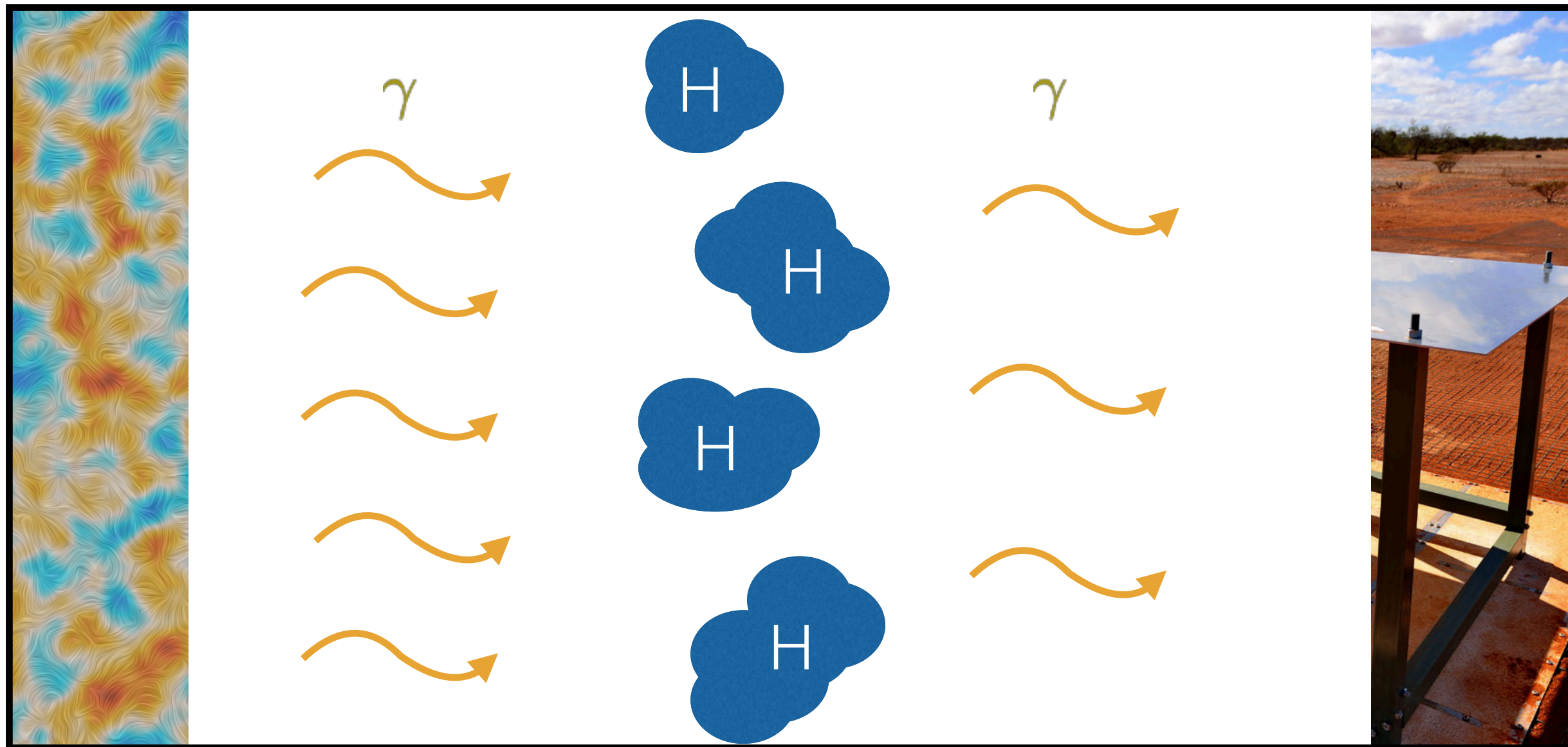


$T_S < T_{\text{cmb}}$  Absorption

$z = 1100$

$z \approx 20$

Australia

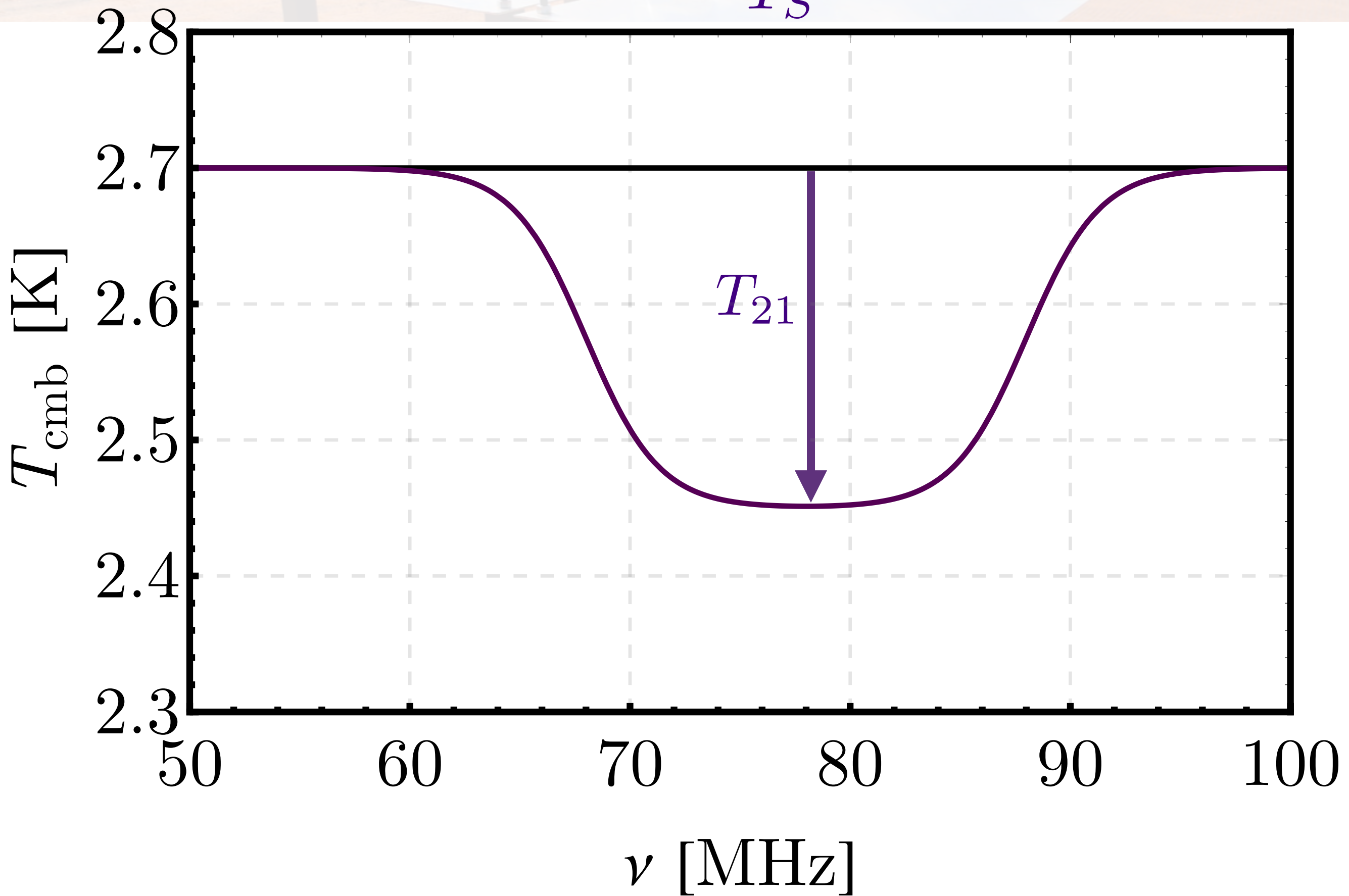


$$I_\nu \propto T_{\text{CMB}} \nu^2$$

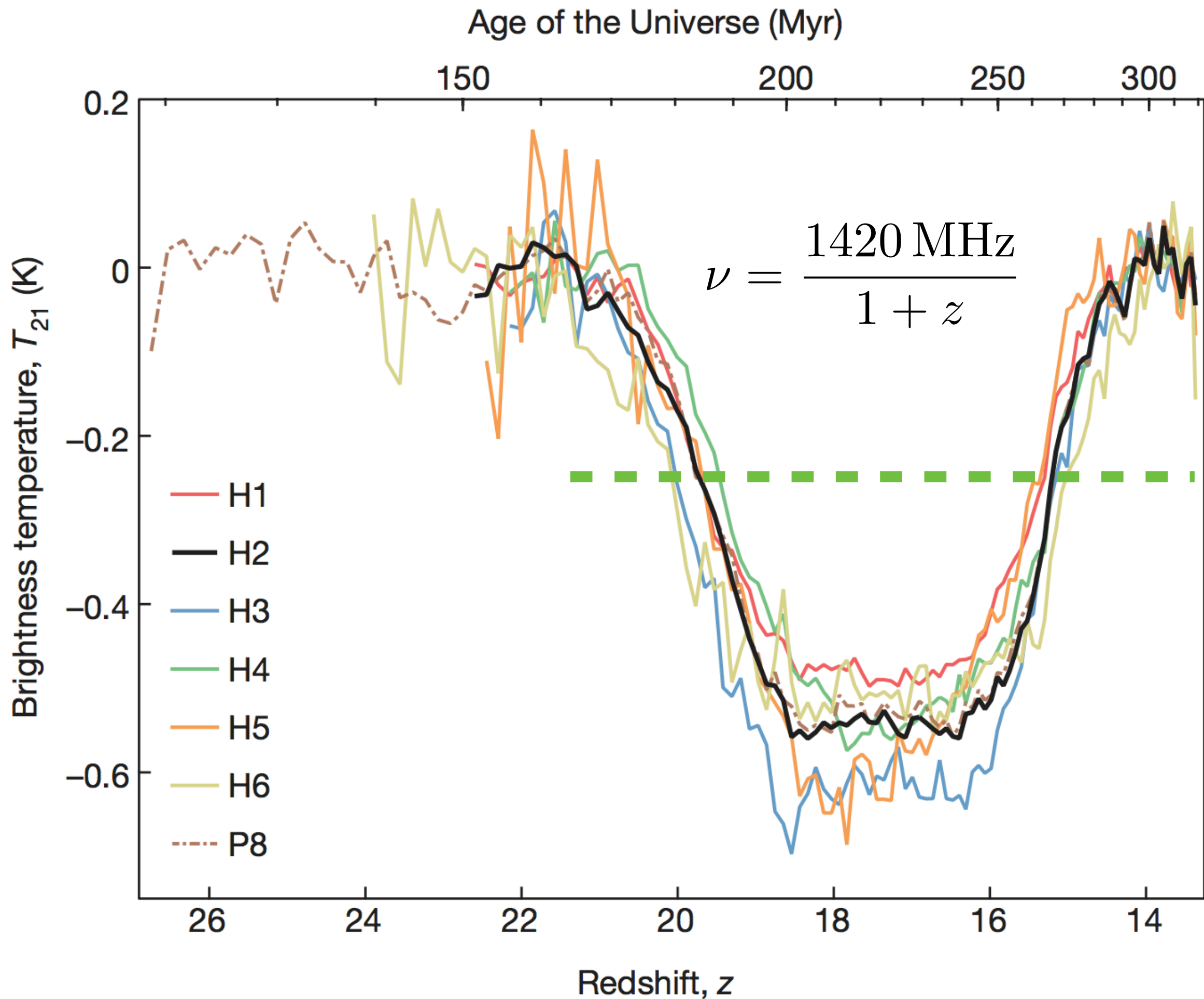
$$\Delta I_\nu \propto T_{21} \nu^2$$

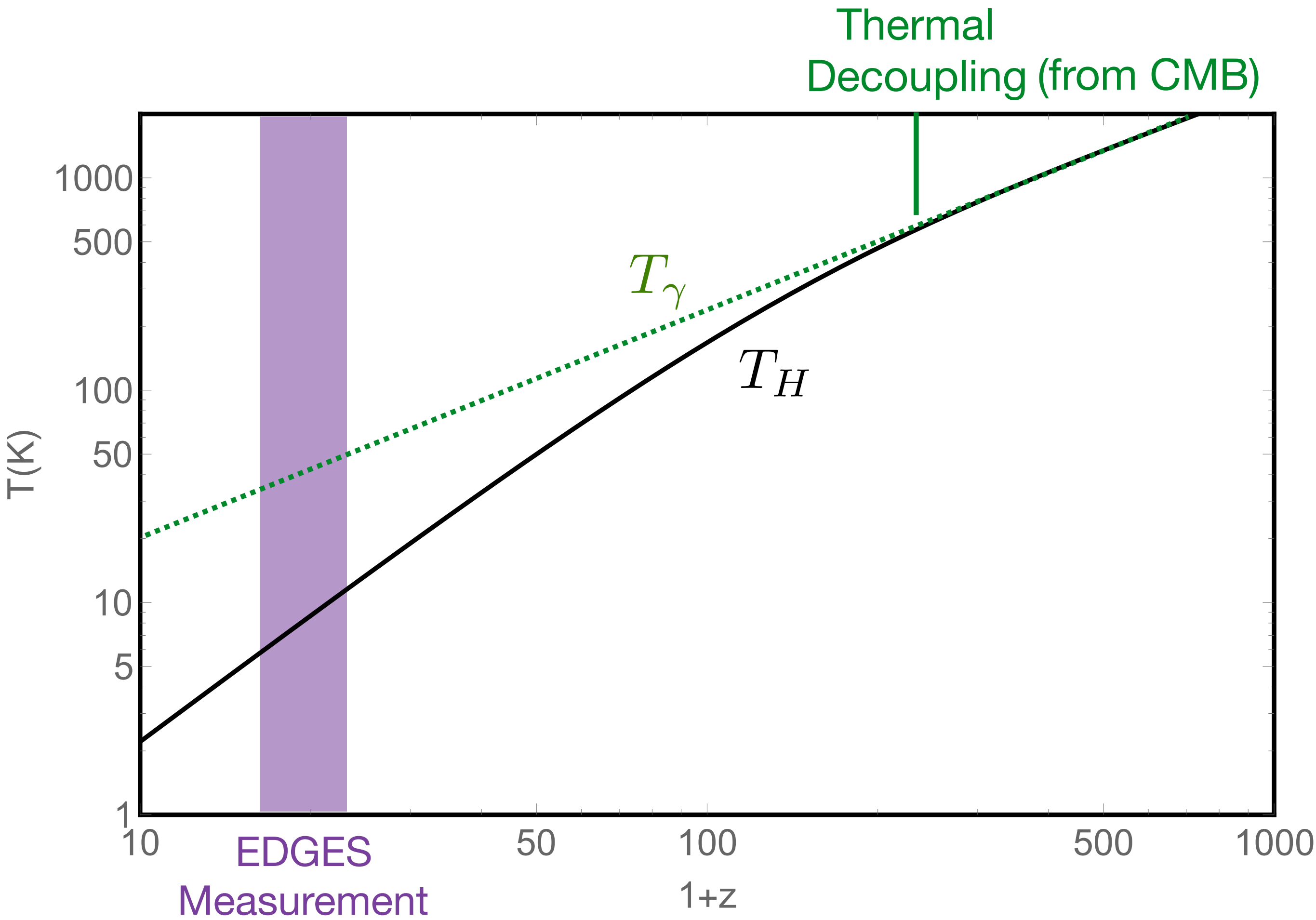
**EDGES**

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

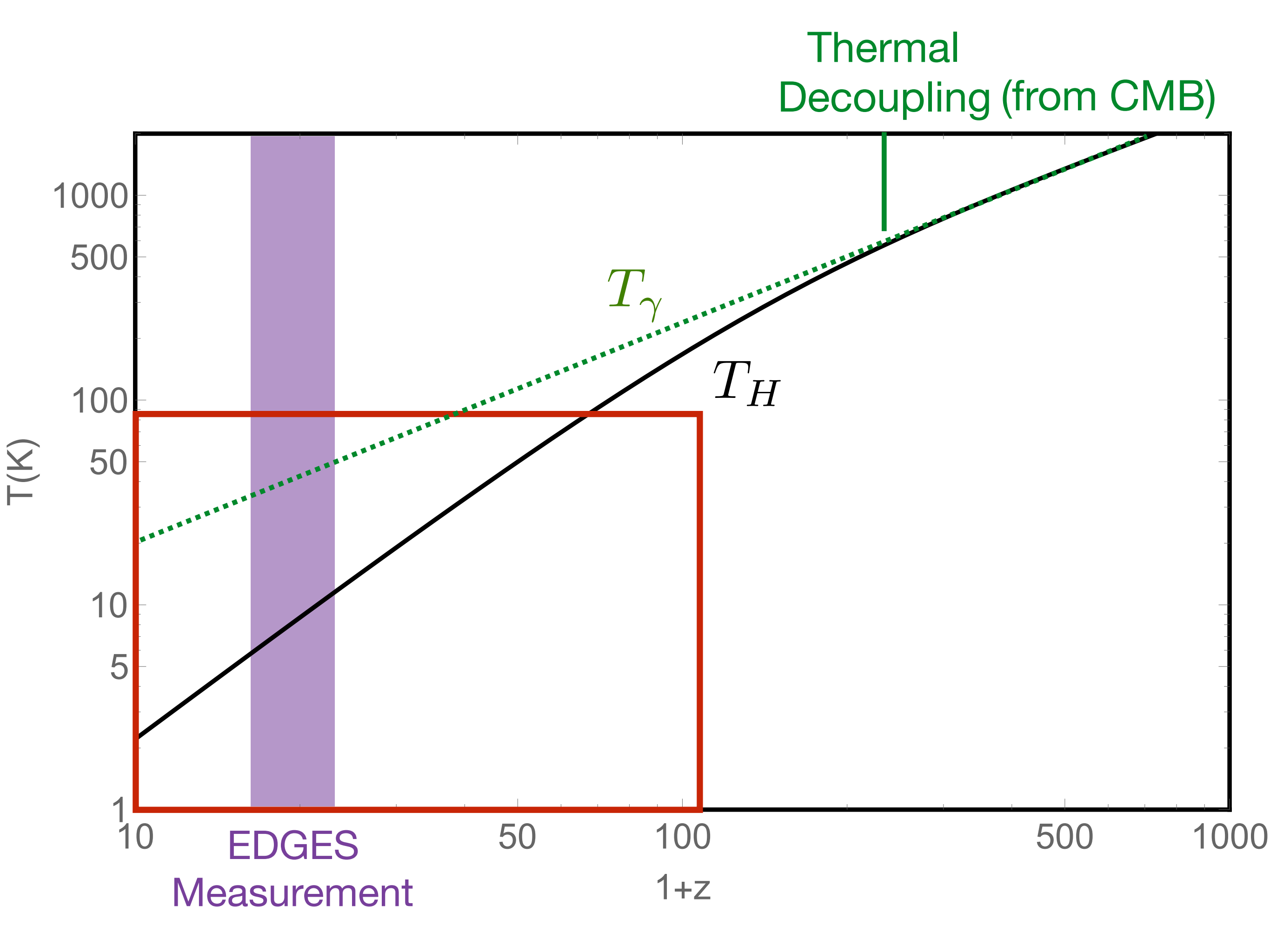




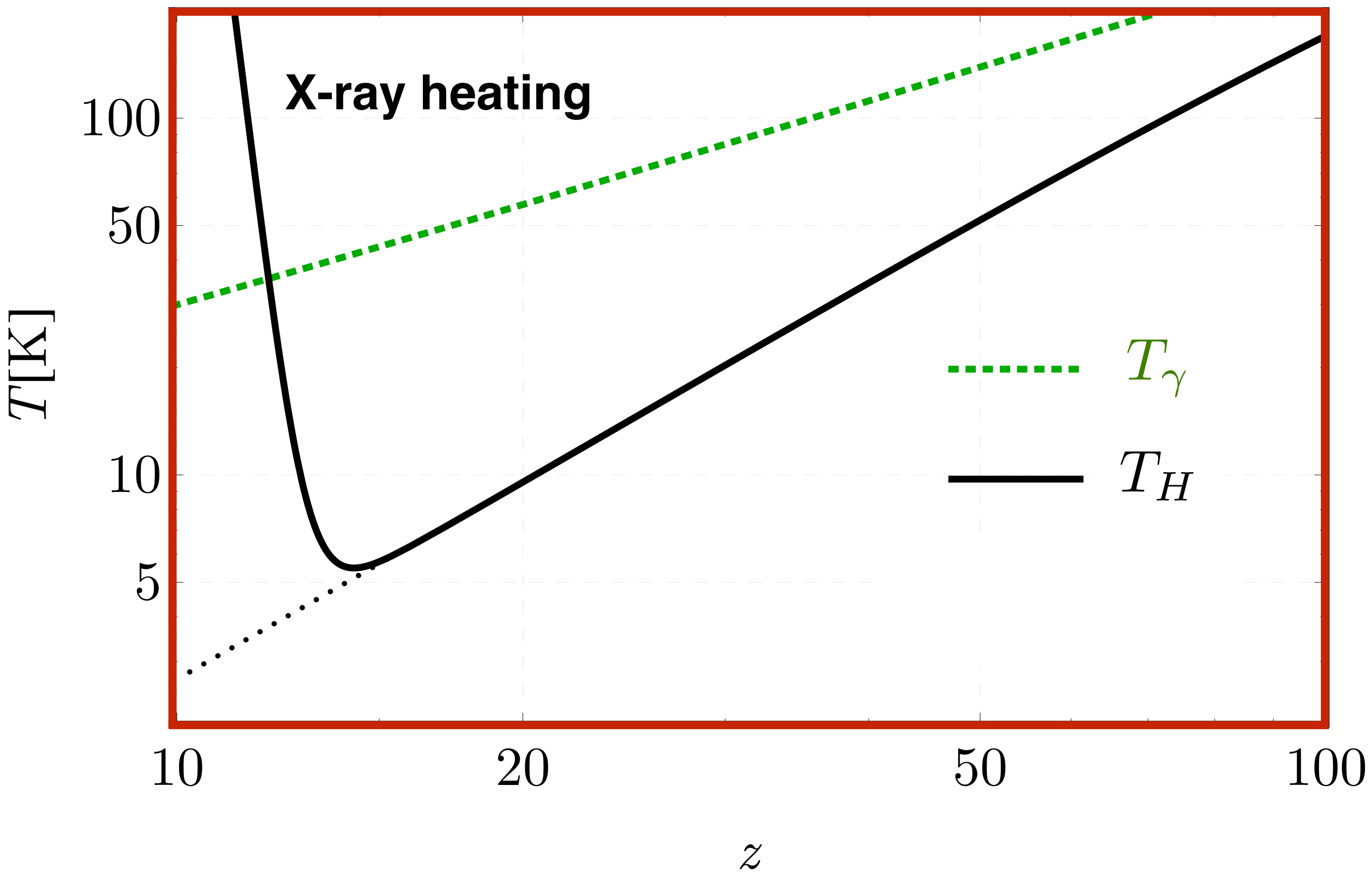






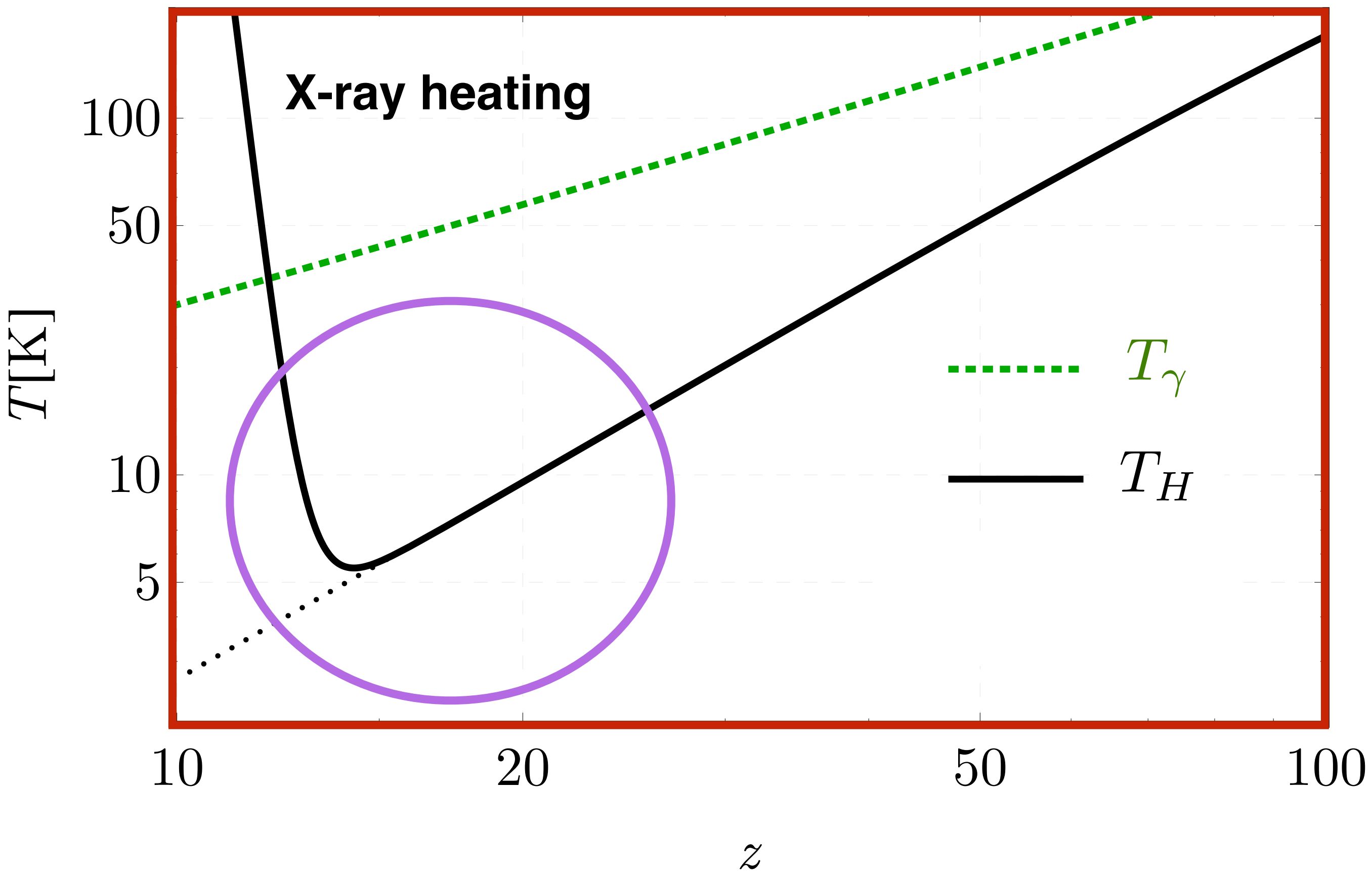


# A cartoon of the evolution of $T_s$

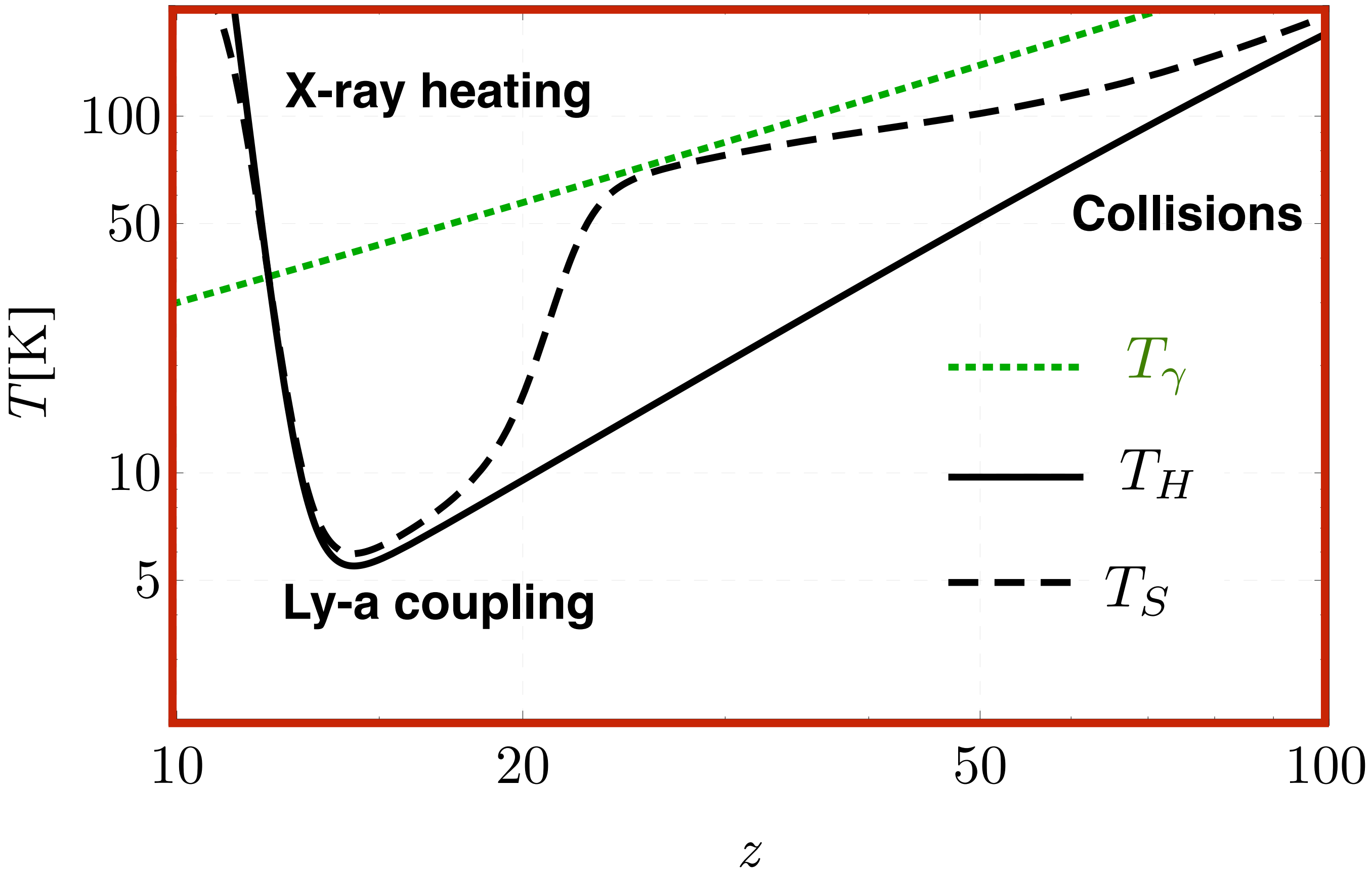




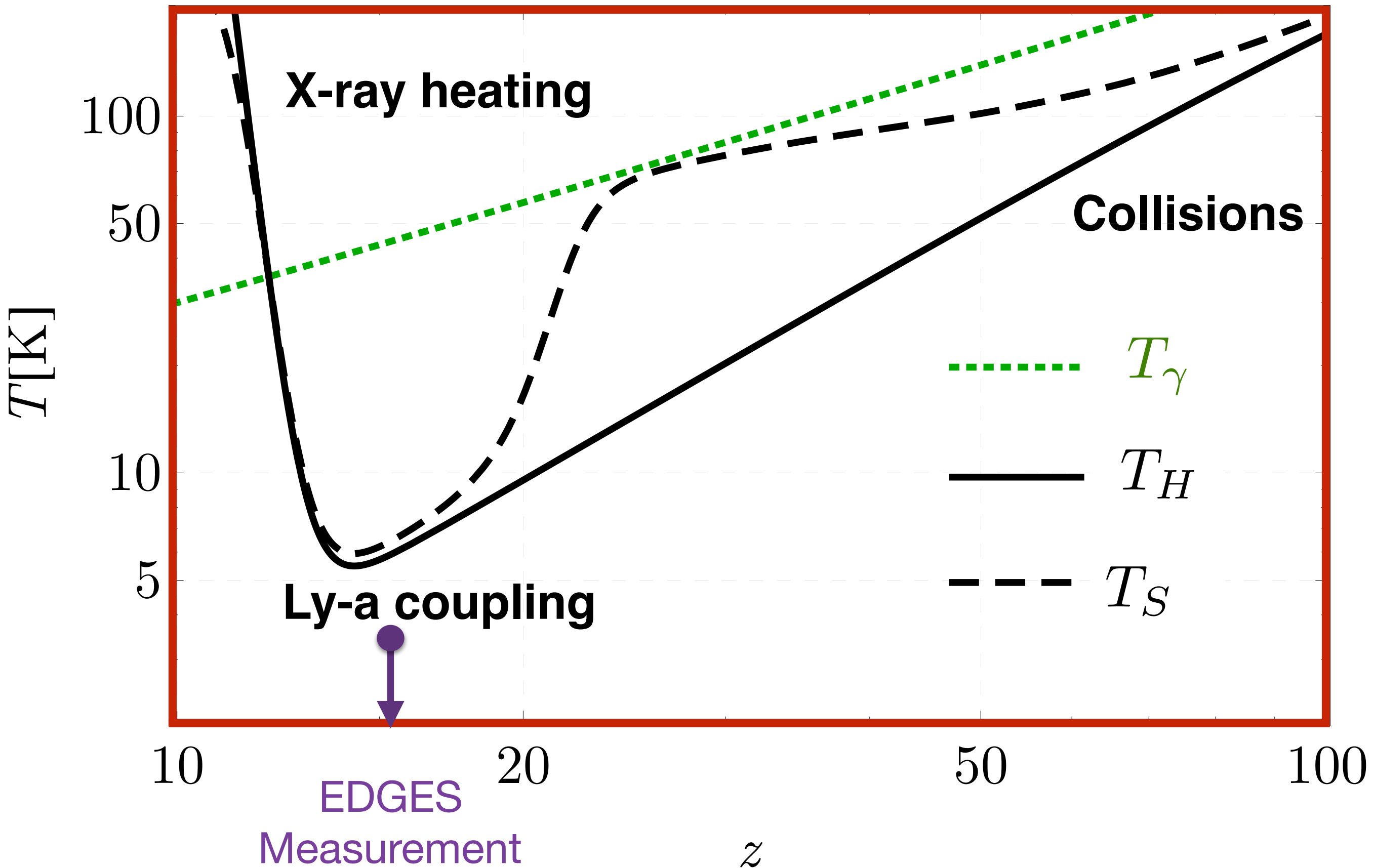
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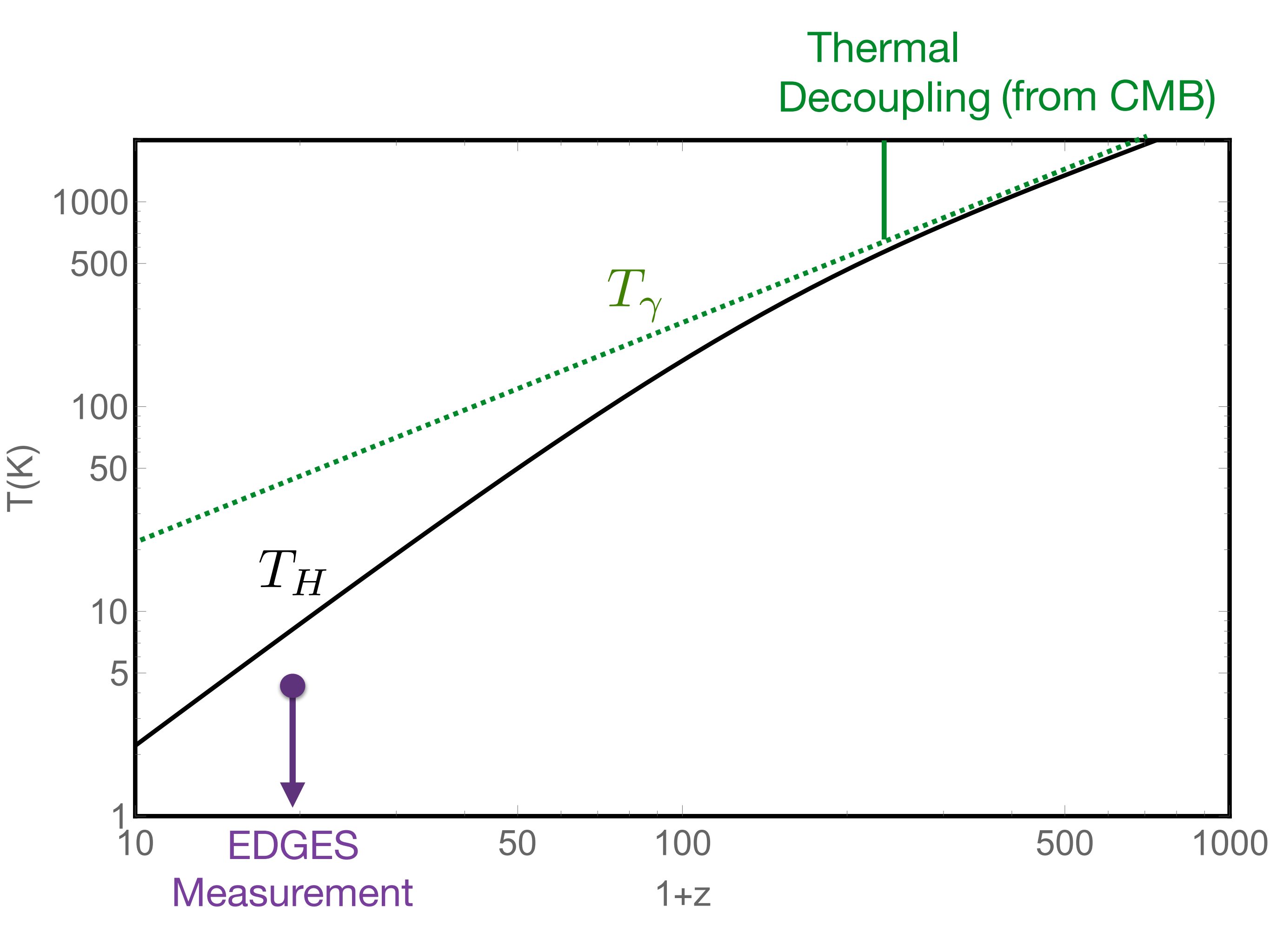
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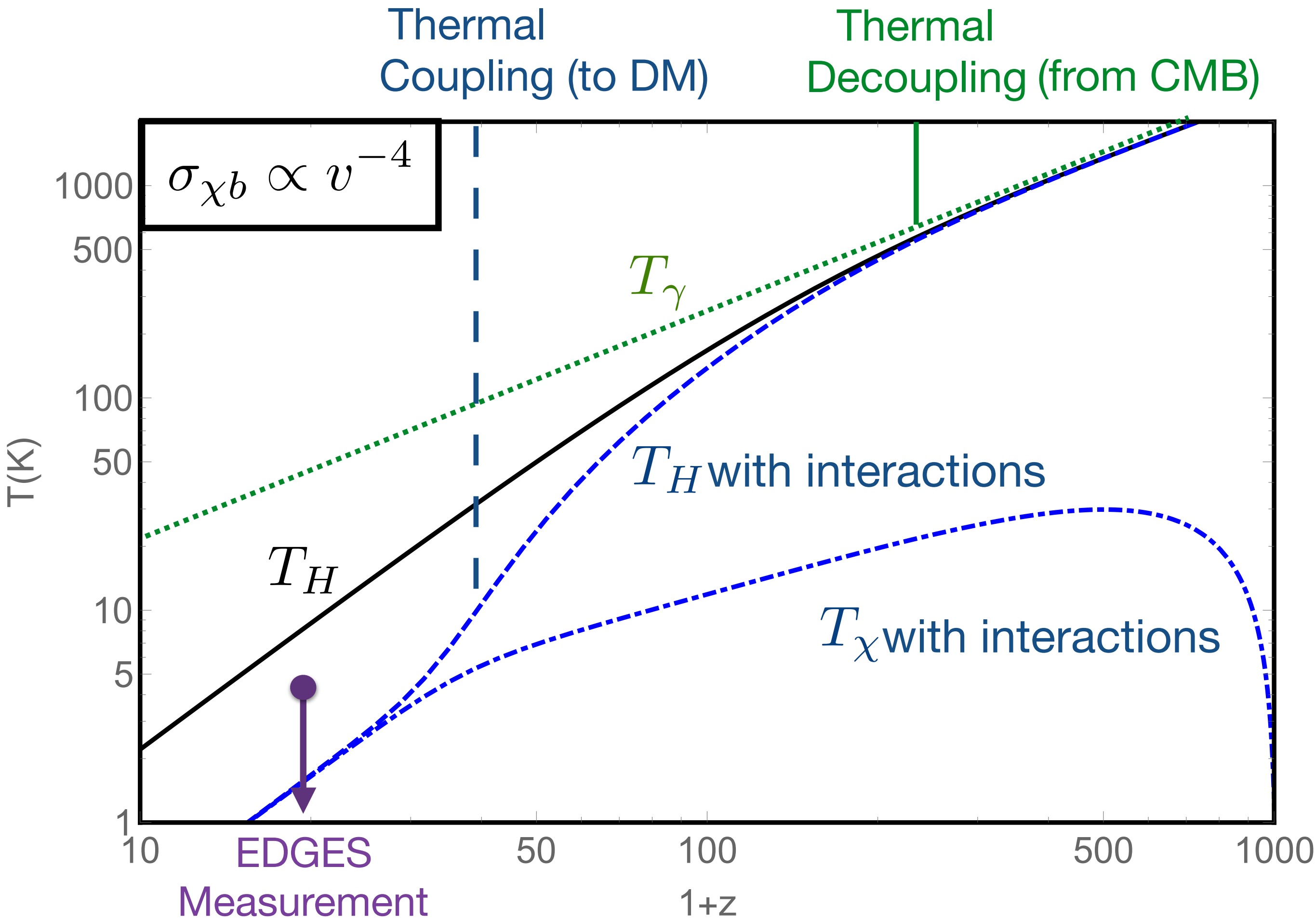


# A cartoon of the evolution of $T_s$







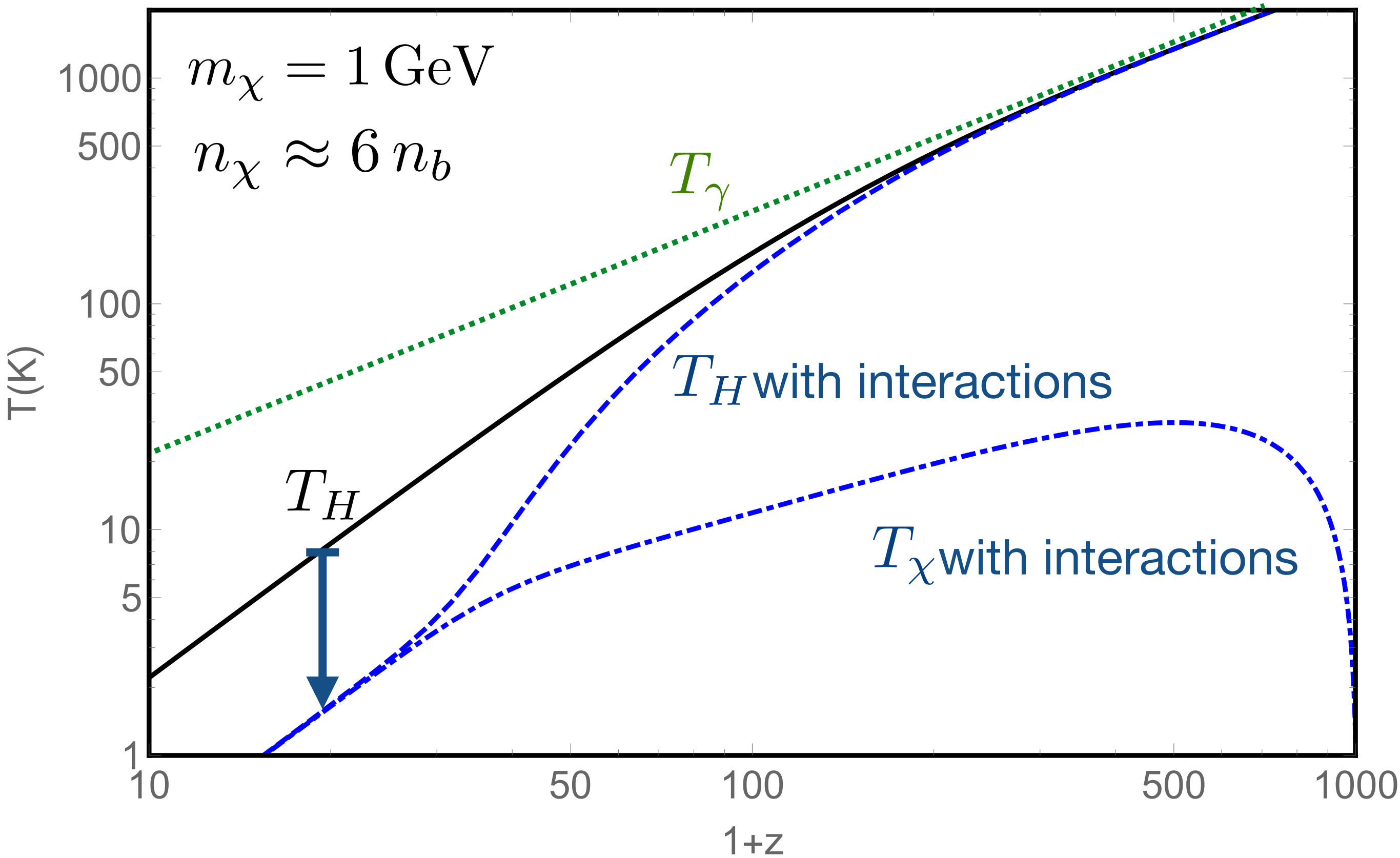


# Can DM explain EDGES?

## Requirements

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





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

New Interaction

JBM+ 2015

Barkana 2018

$(m_\phi < 10 \text{ keV})$

Millicharged DM

JBM and Loeb 2018



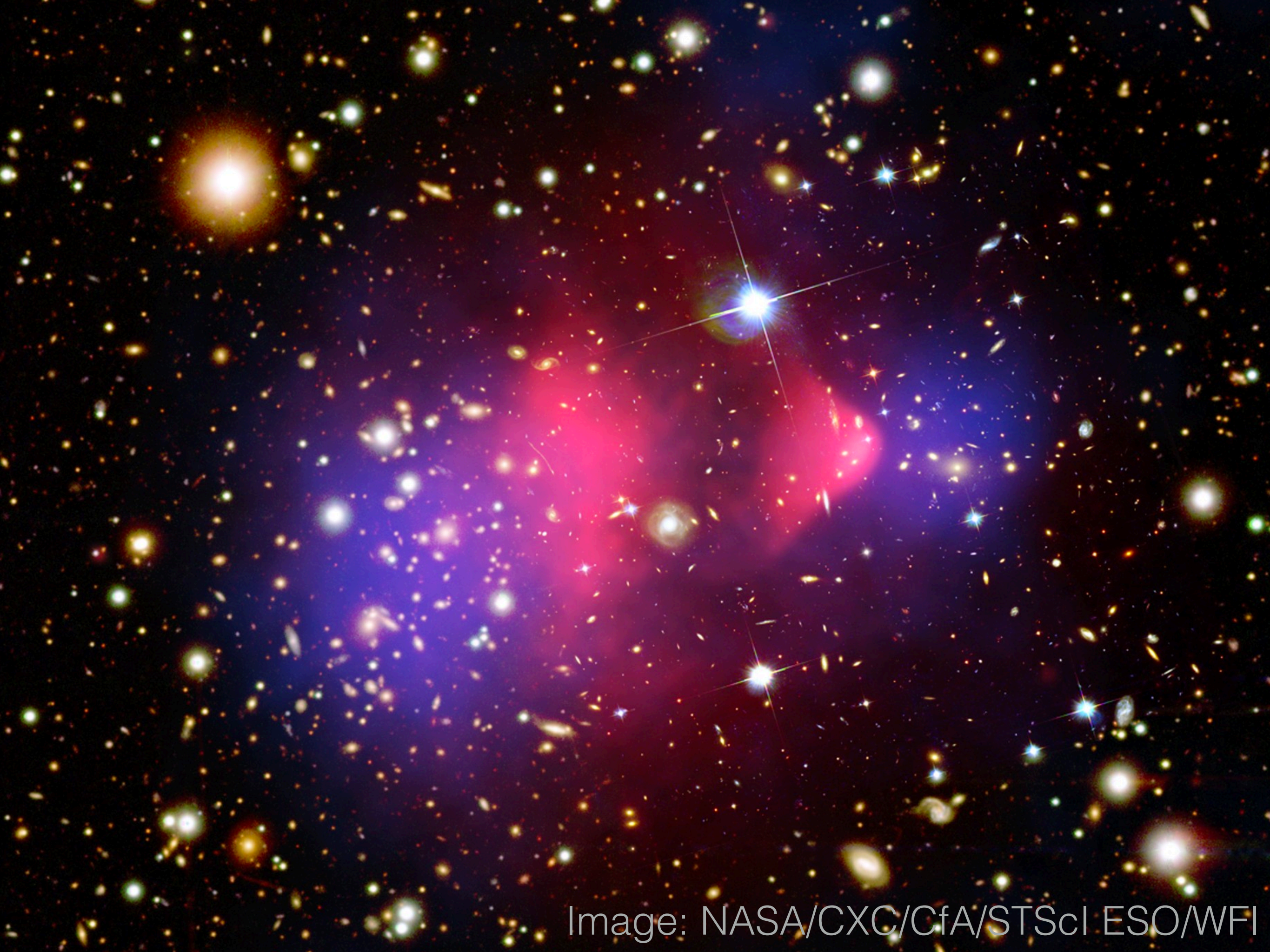
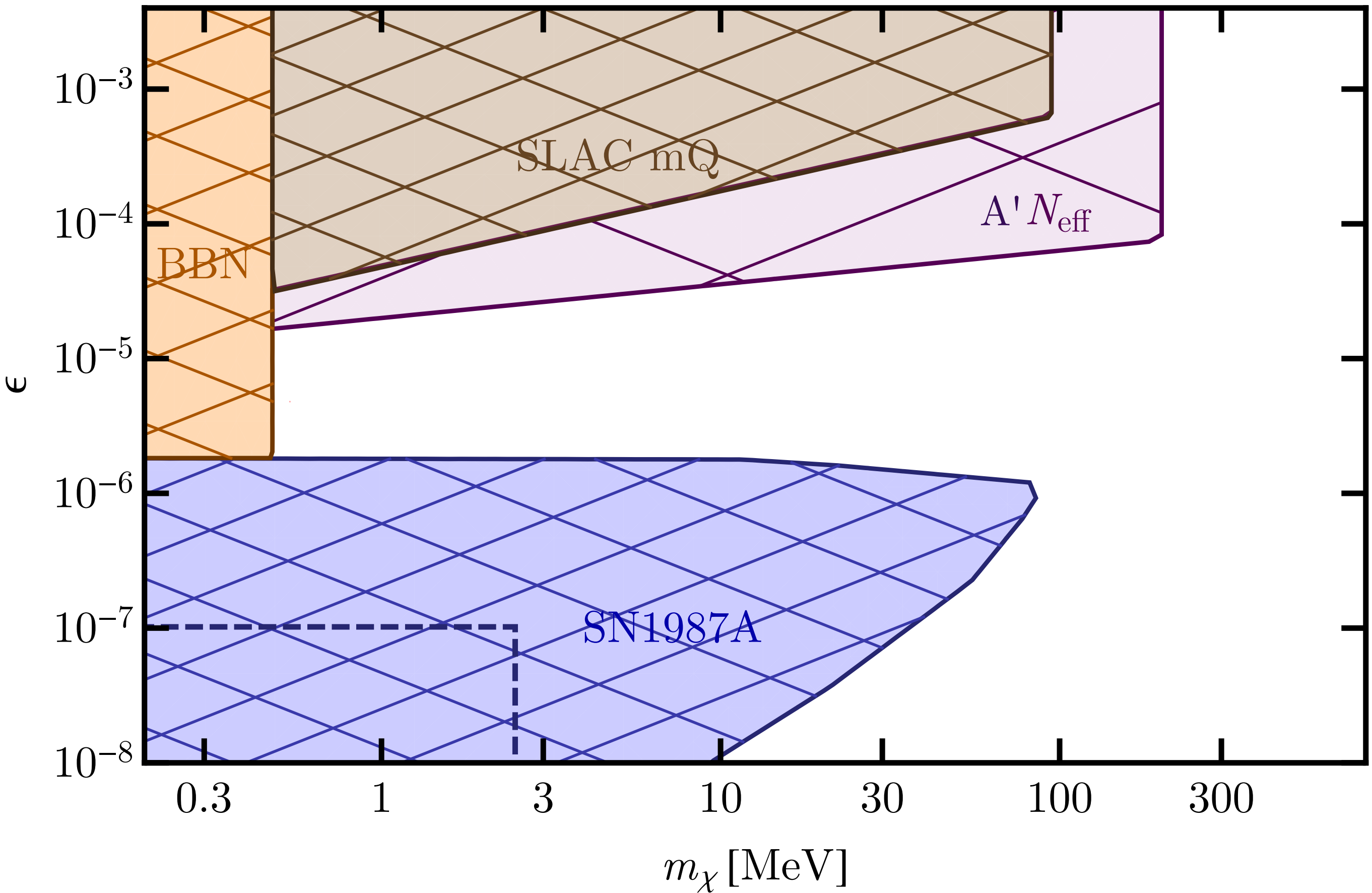
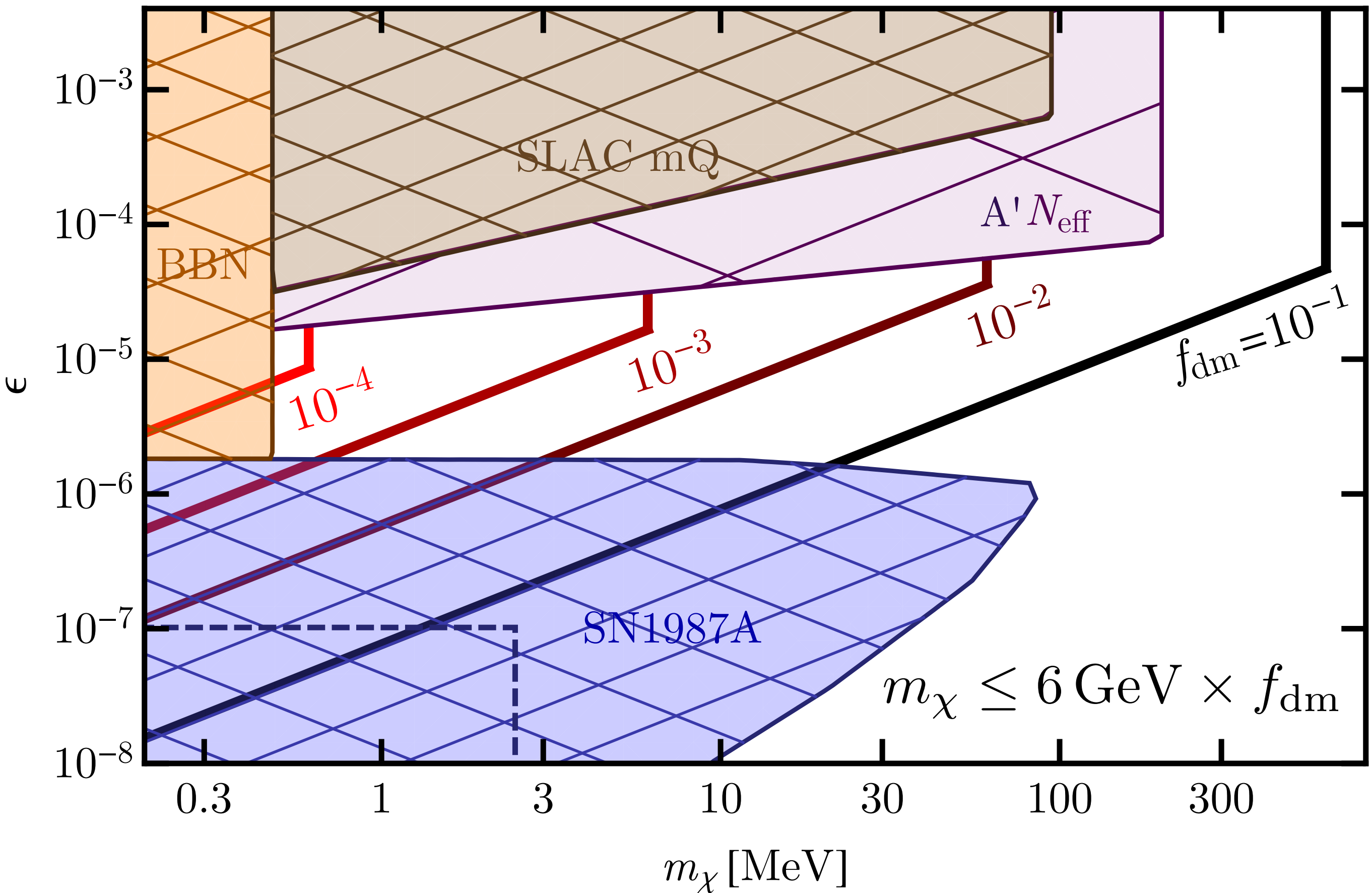


Image: NASA/CXC/CfA/STScI ESO/WFI

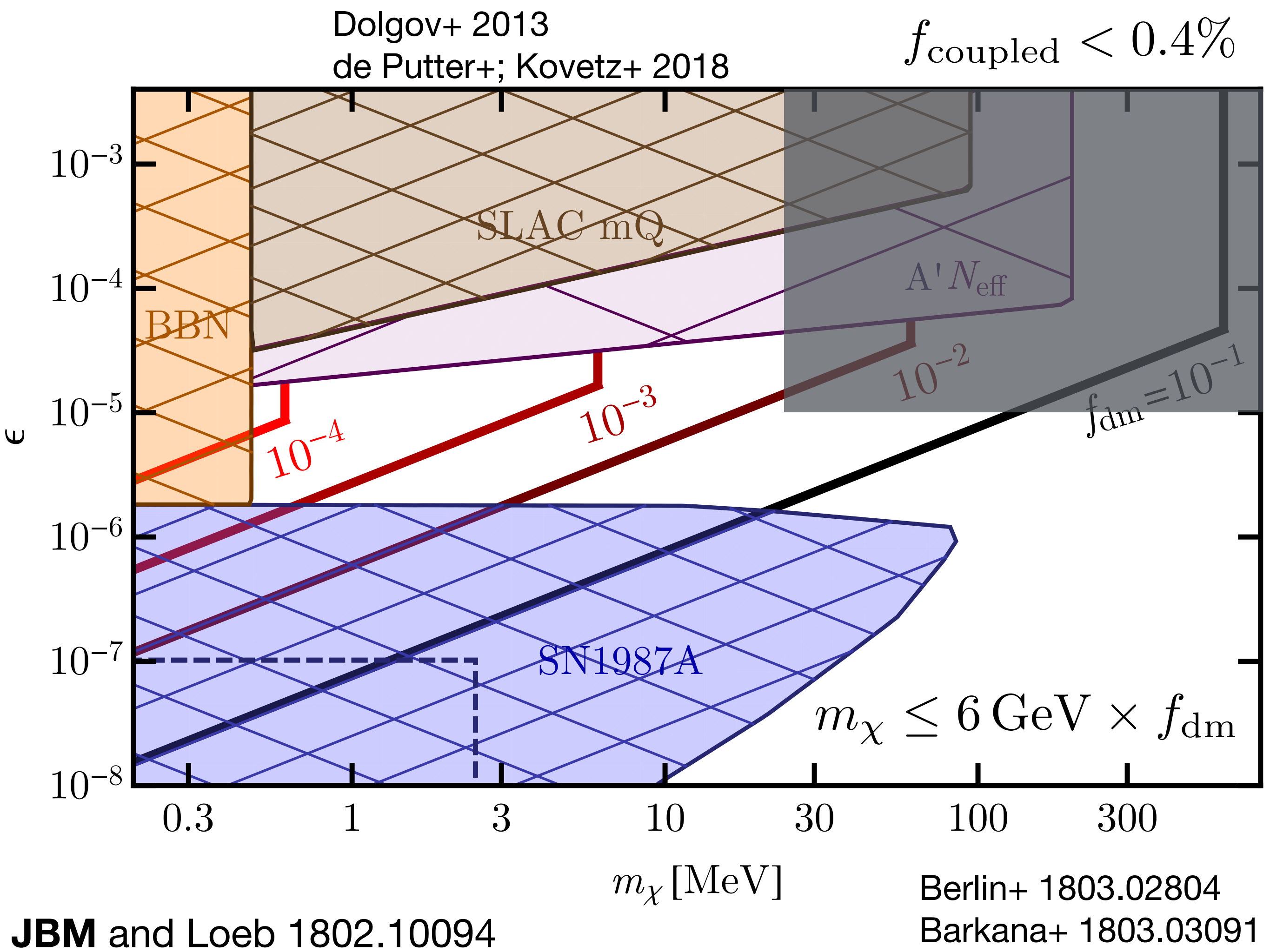


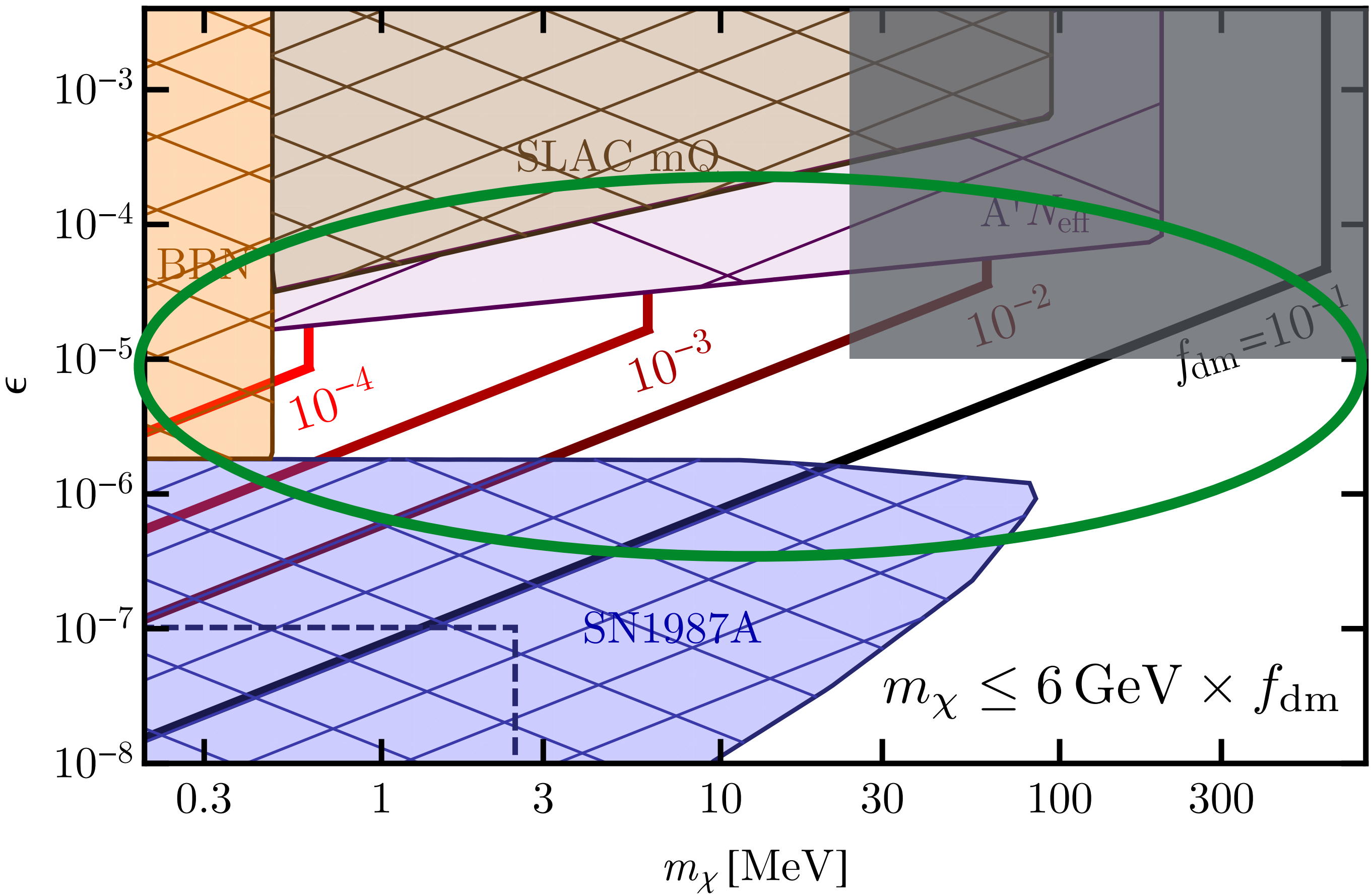
# Limits on millicharged particles

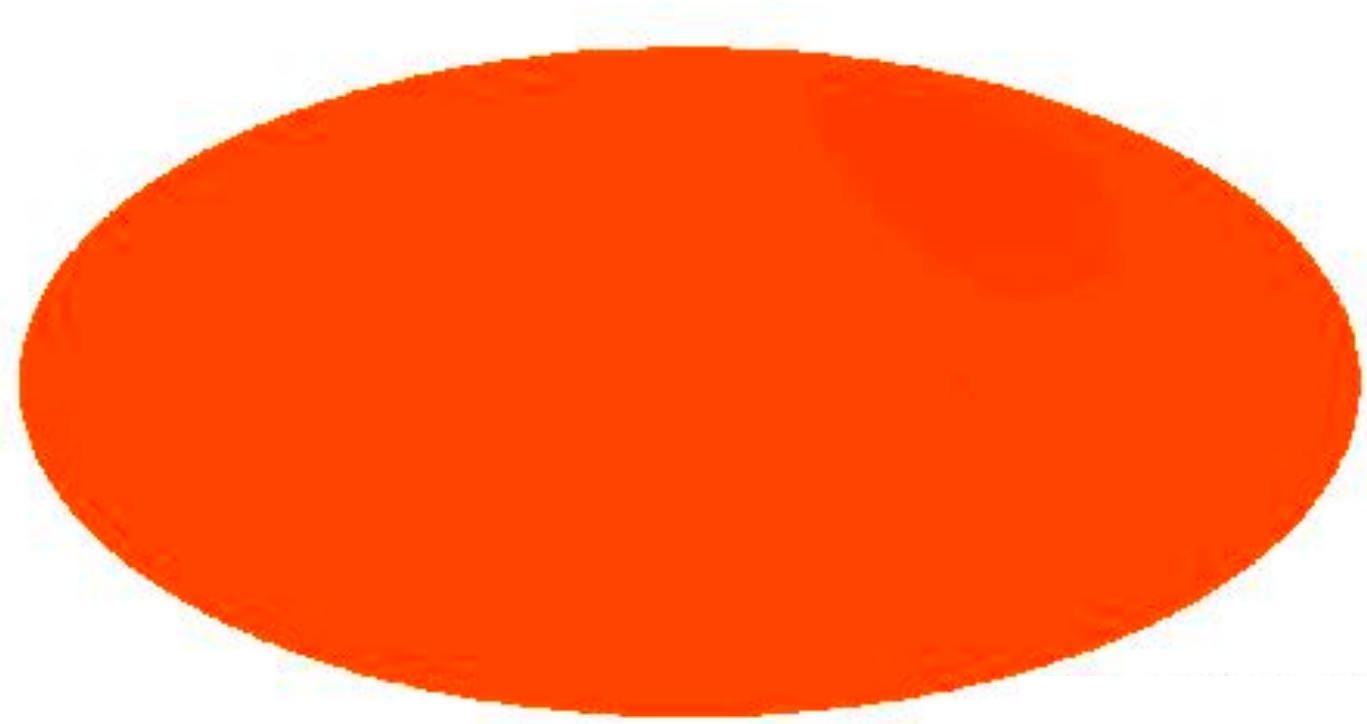
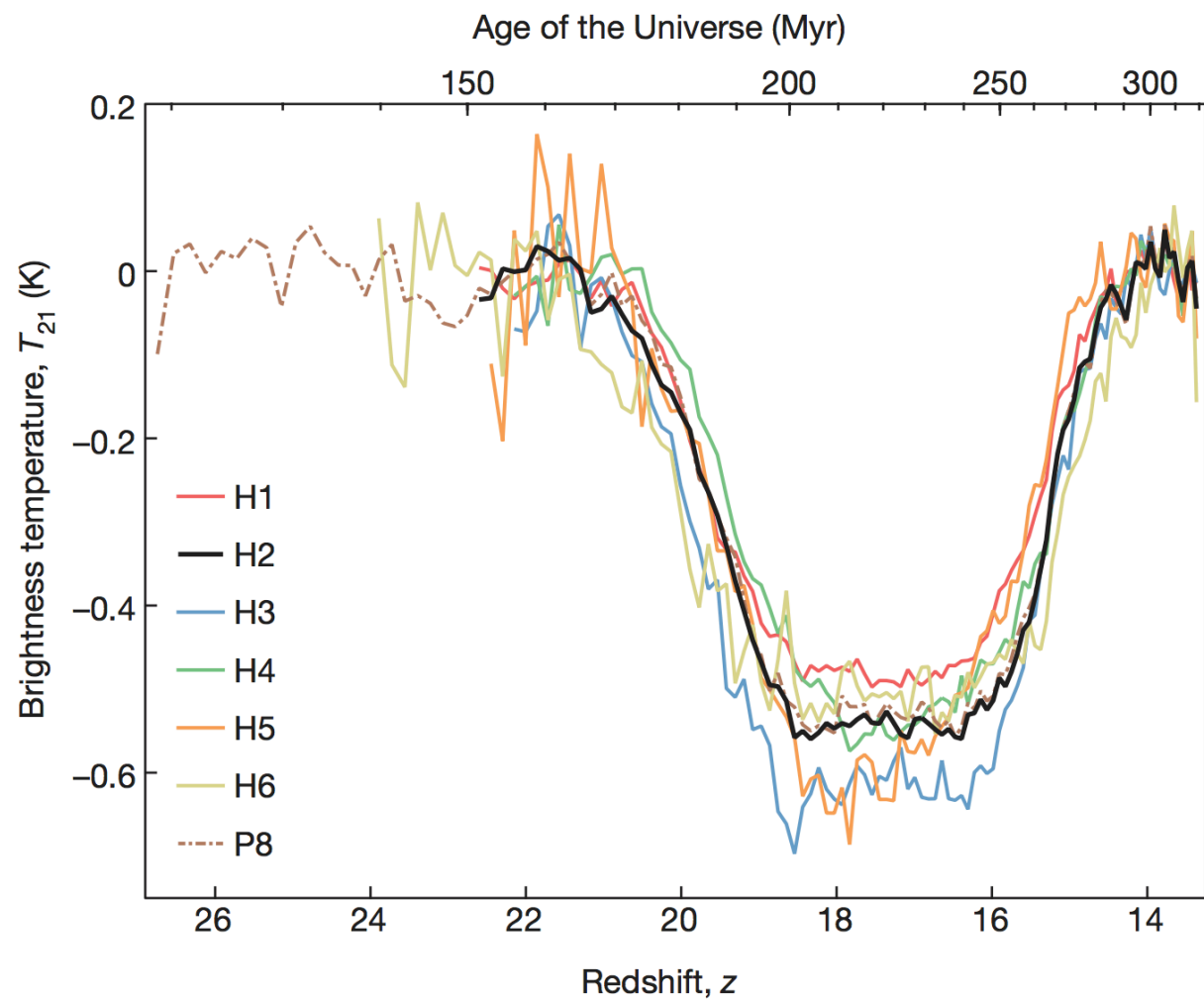












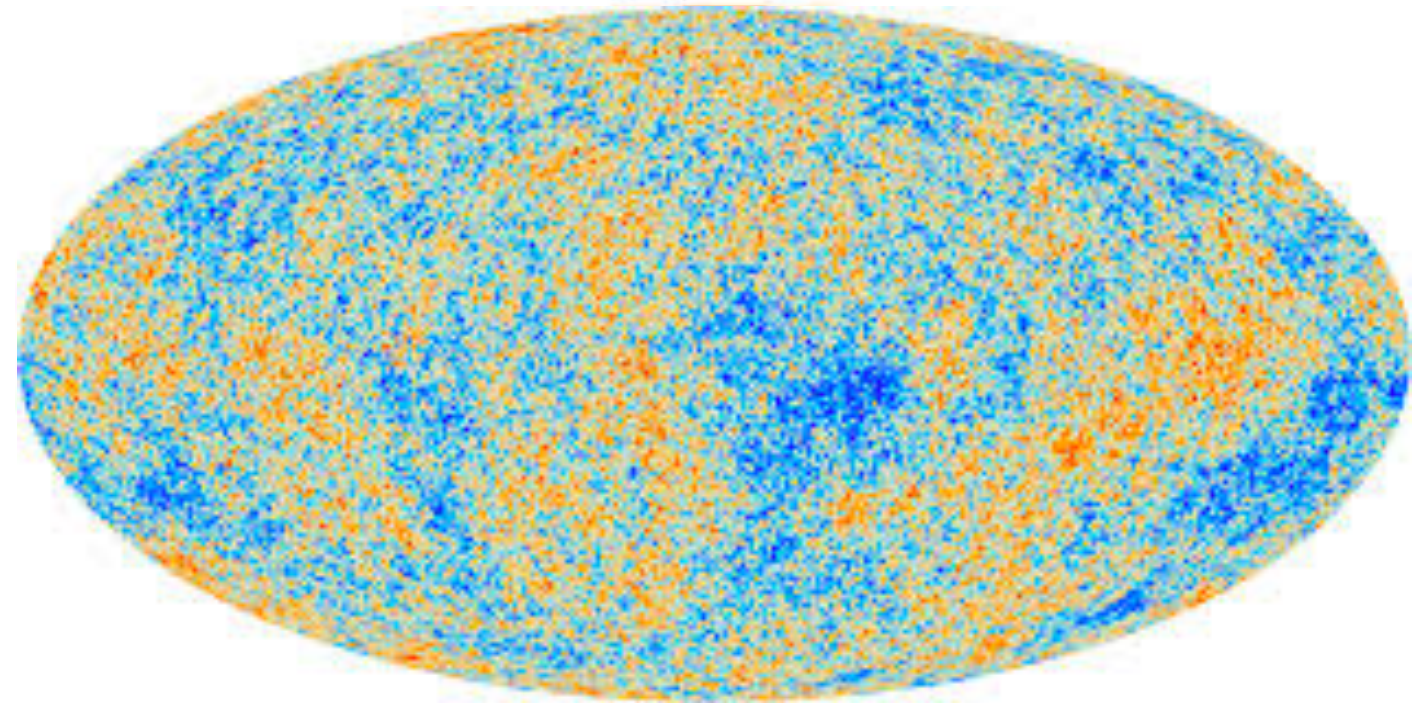
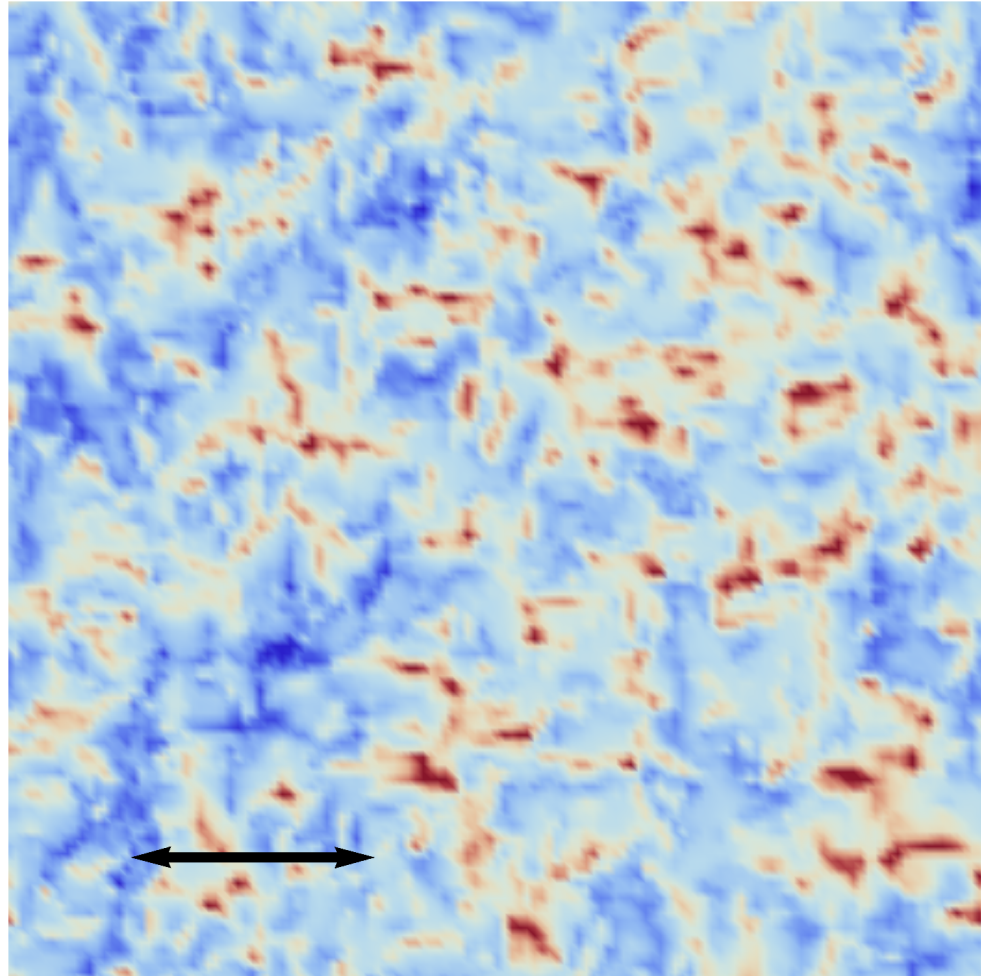
21-cm Global Signal

=

CMB Monopole



# 21-cm fluctuations



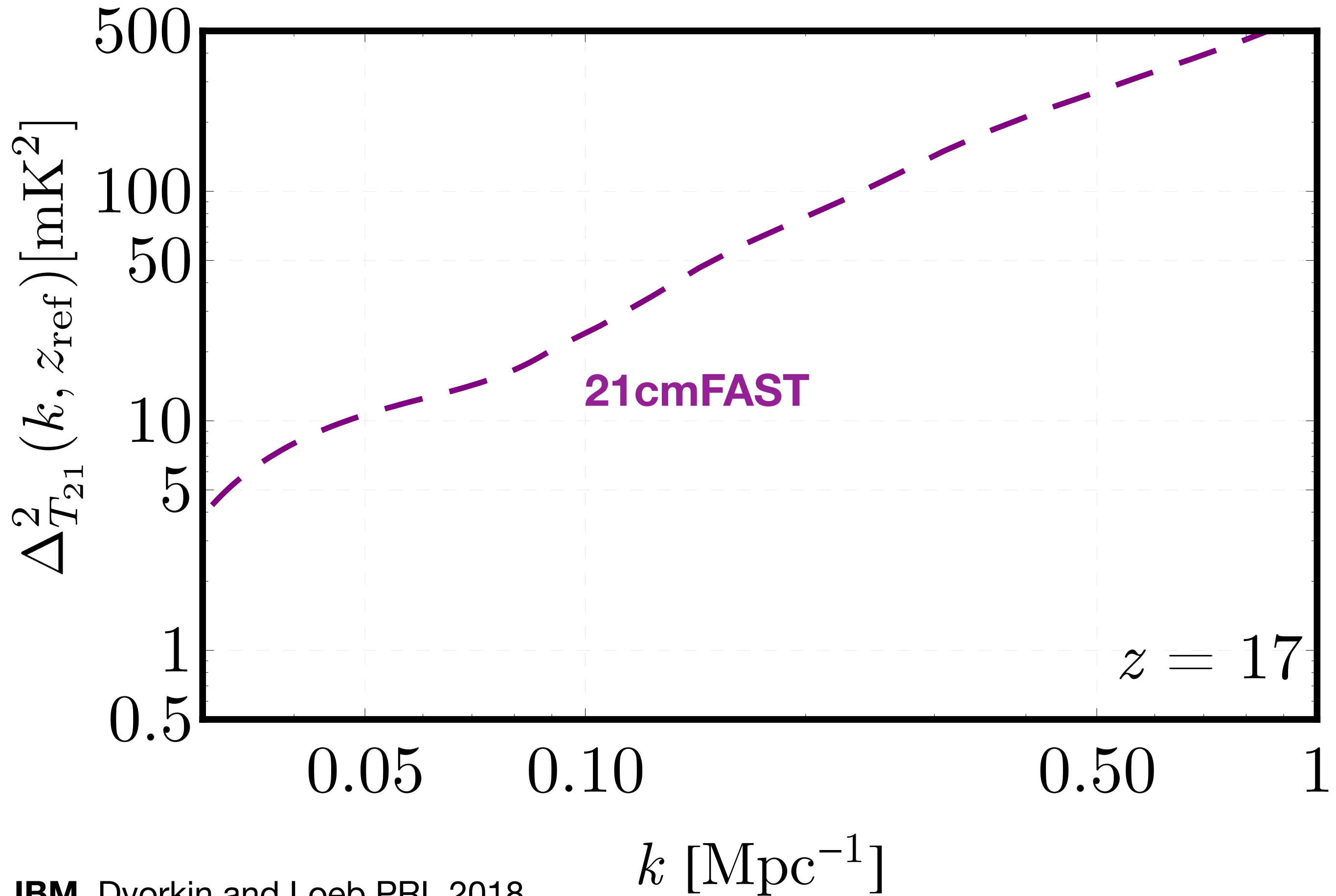
21-cm Fluctuations

=

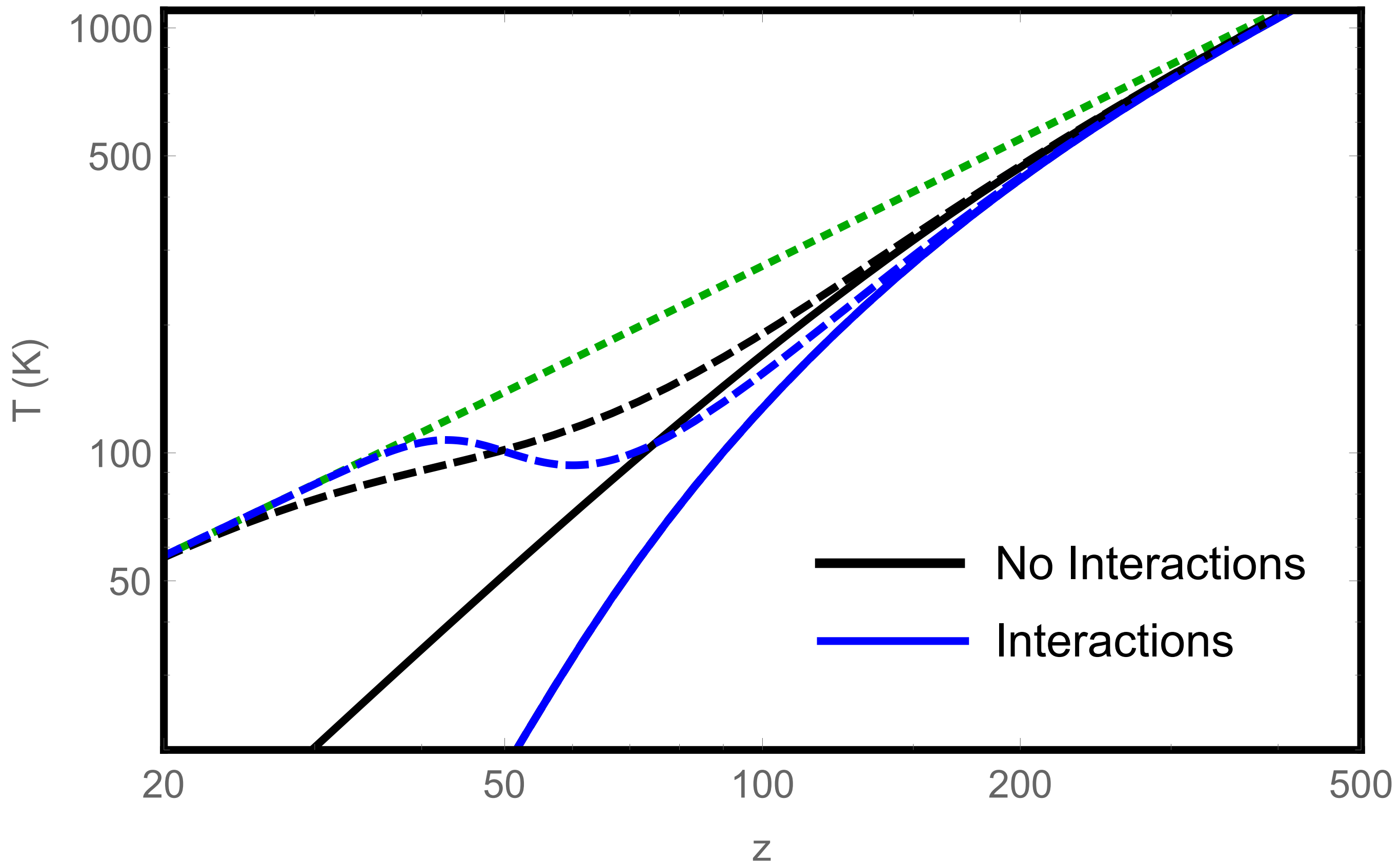
CMB Anisotropies

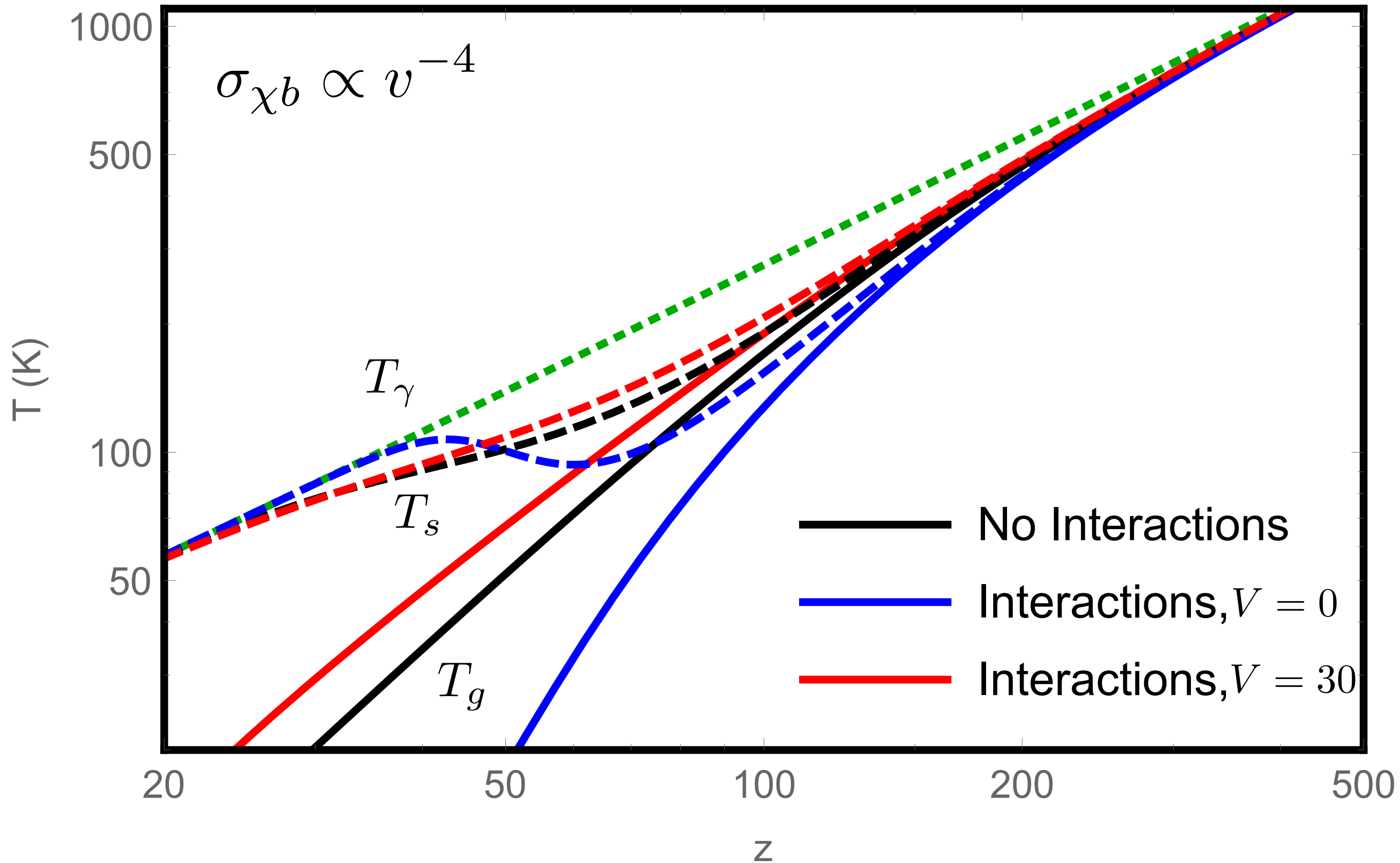


# 21-cm fluctuations



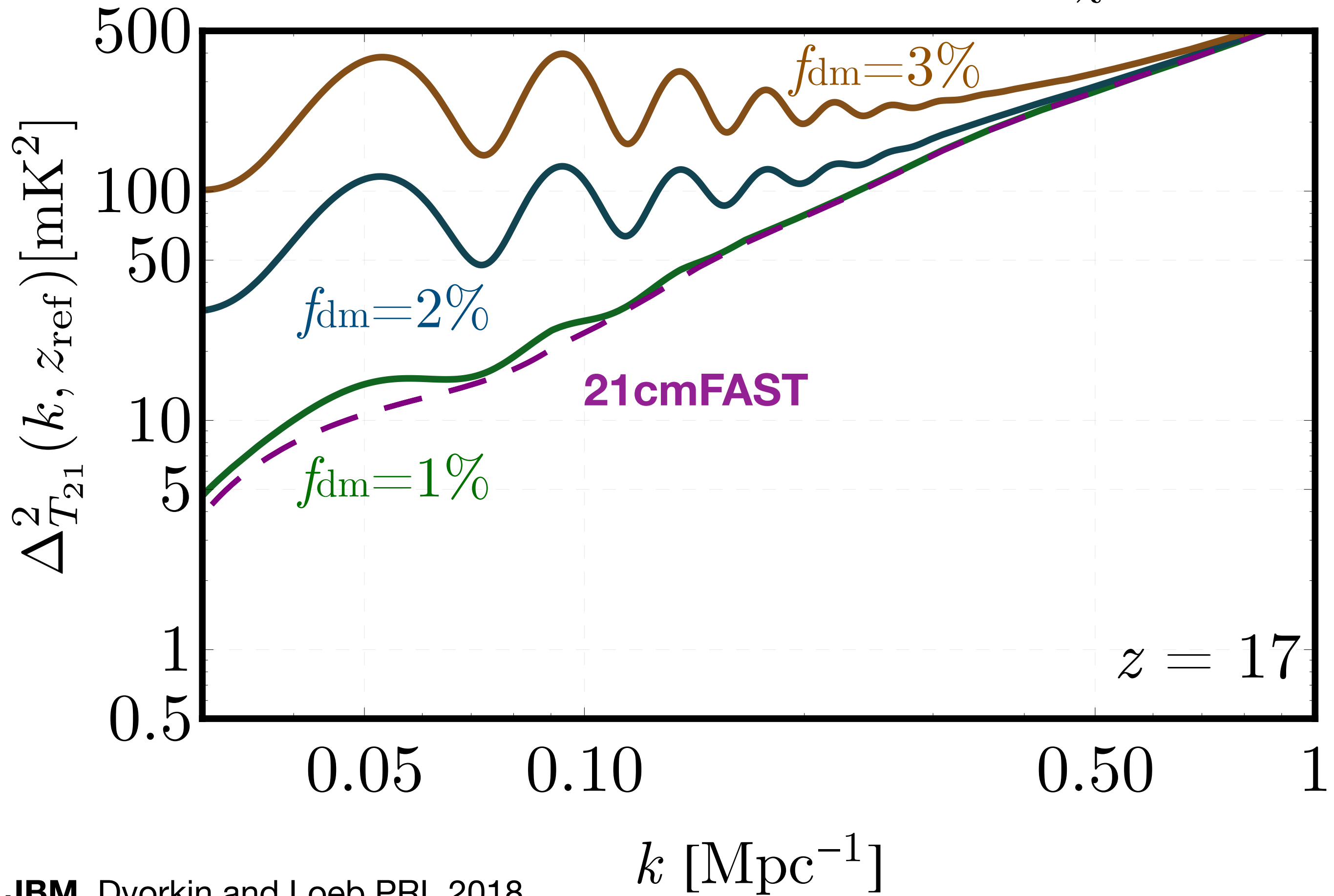
# Can you test this?





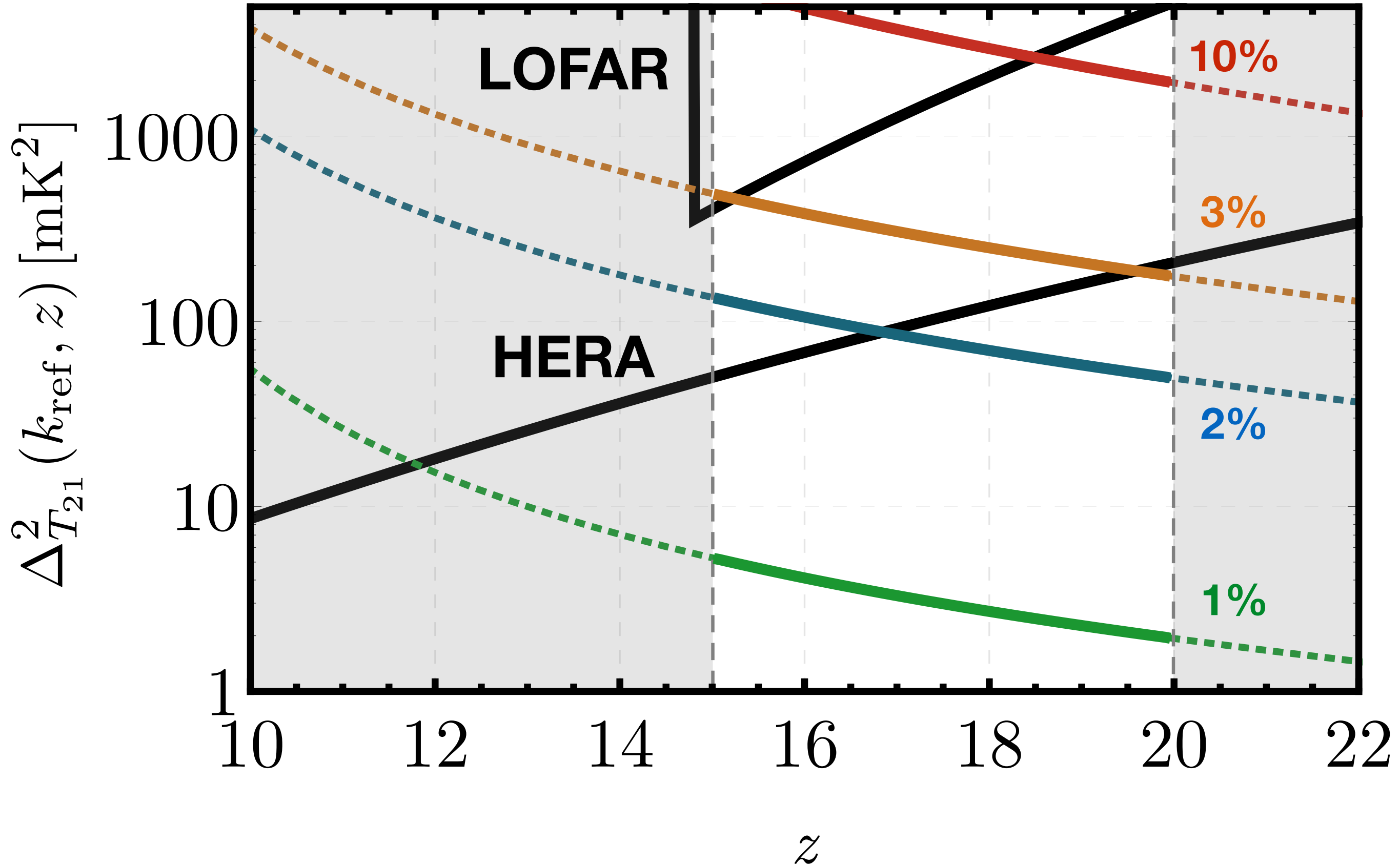
# 21-cm fluctuations

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

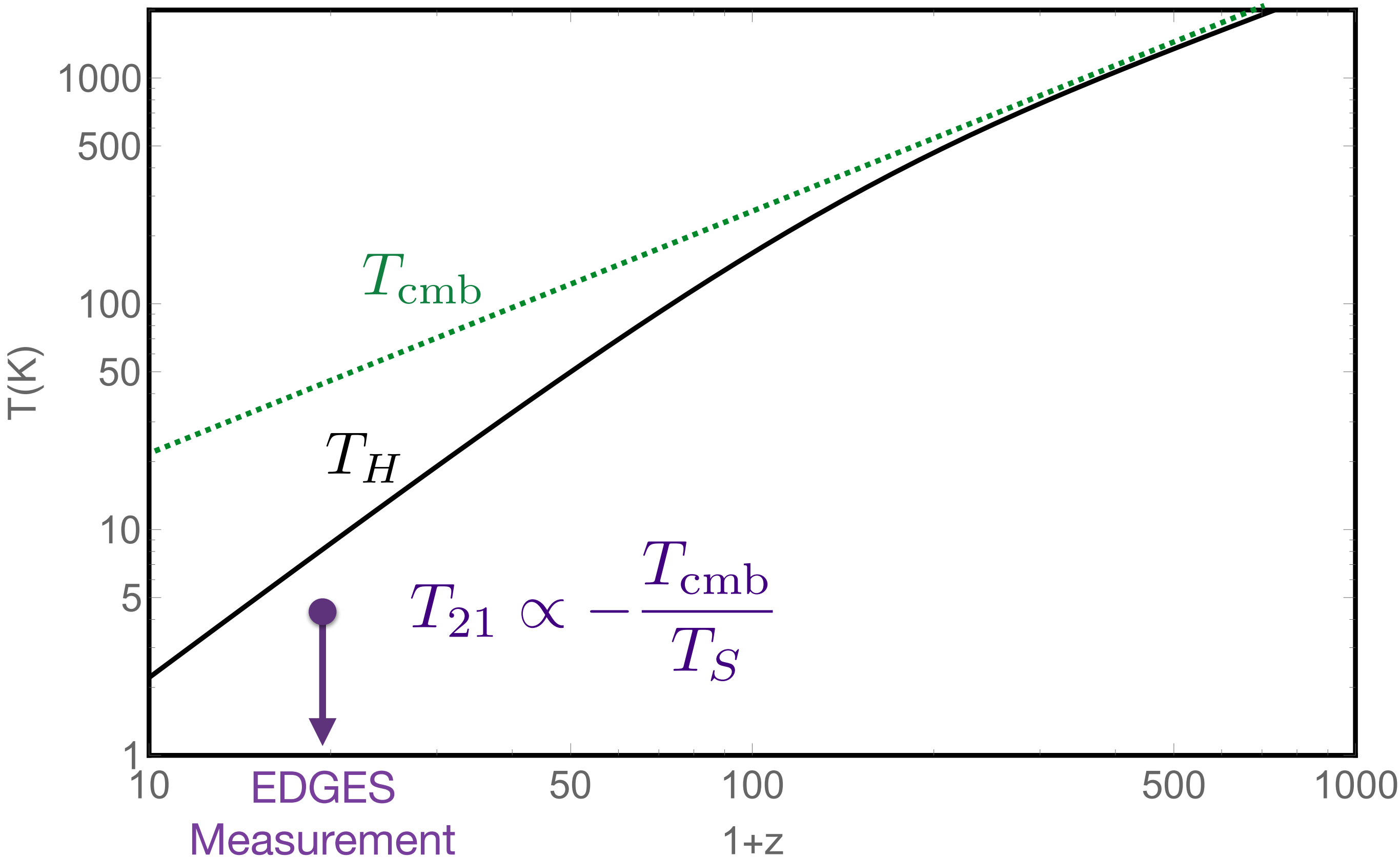




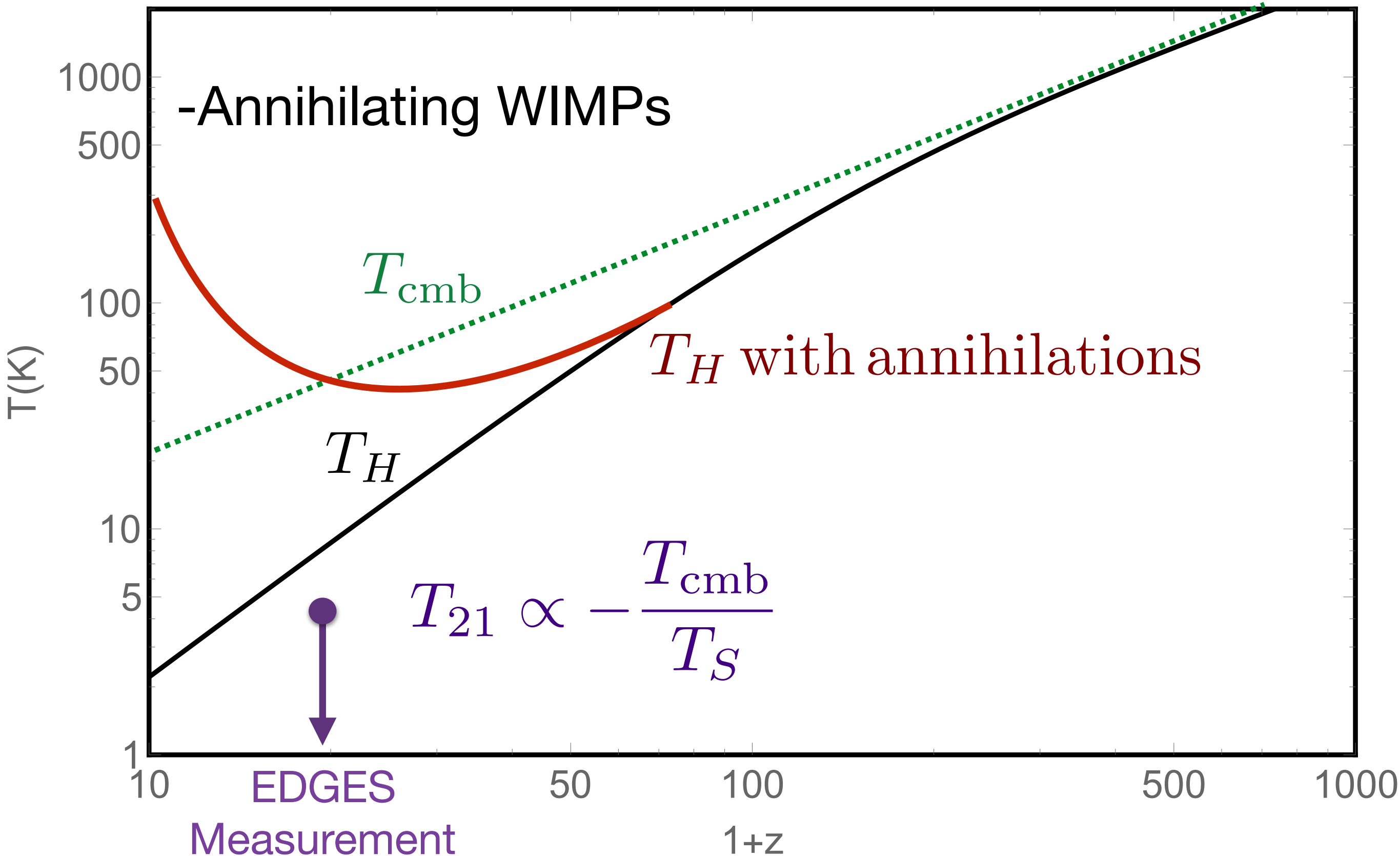
# 21-cm fluctuations



# What else can we learn from 21-cm?



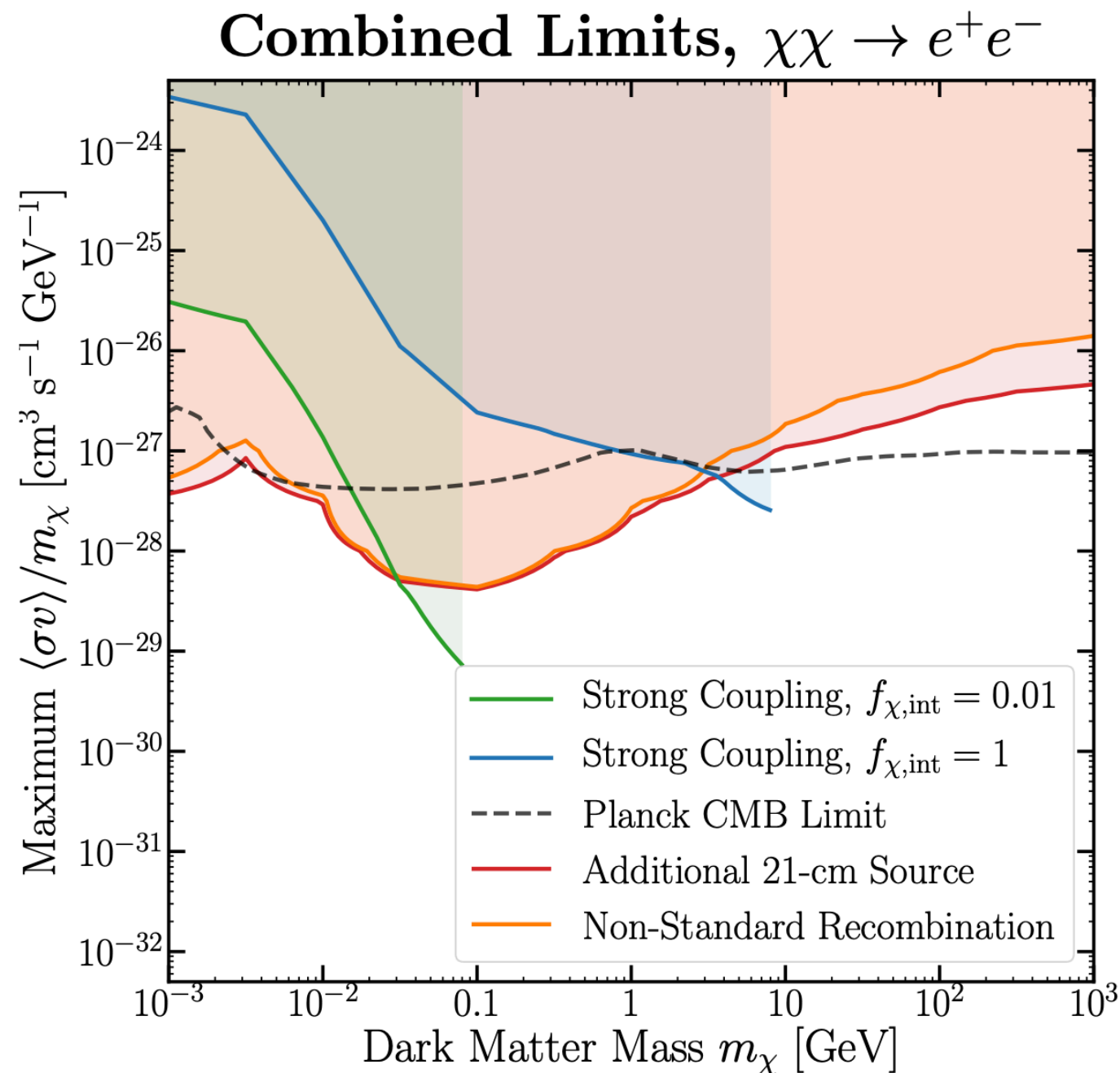
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## -Annihilating WIMPs

Liu & Slatyer, 2018,  
D'Amico+ 2018  
Lopez-Honorez+ 2016 ...



# What else can we learn from 21-cm?

-Annihilating WIMPs

-Exotic radio excess

Liu & Slatyer, 2018,  
D'Amico+ 2018  
Lopez-Honorez+ 2016 ...

Feng and Holder 2018

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



# What else can we learn from 21-cm?

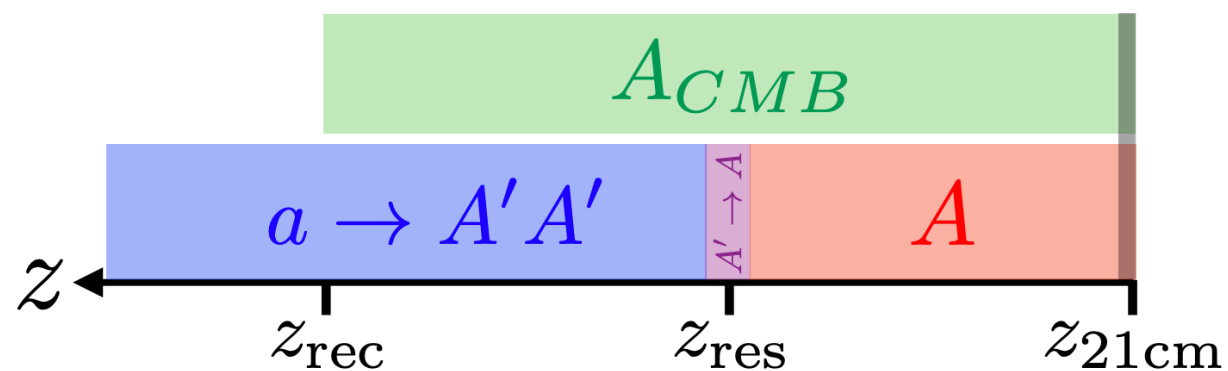
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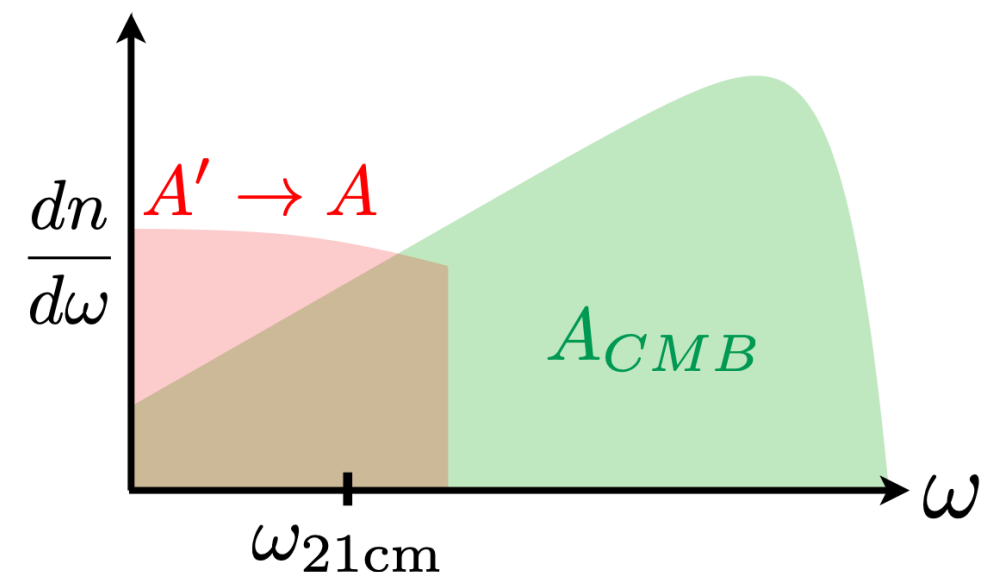
-Exotic radio excess

DM to dark photons  $\rightarrow$  photons

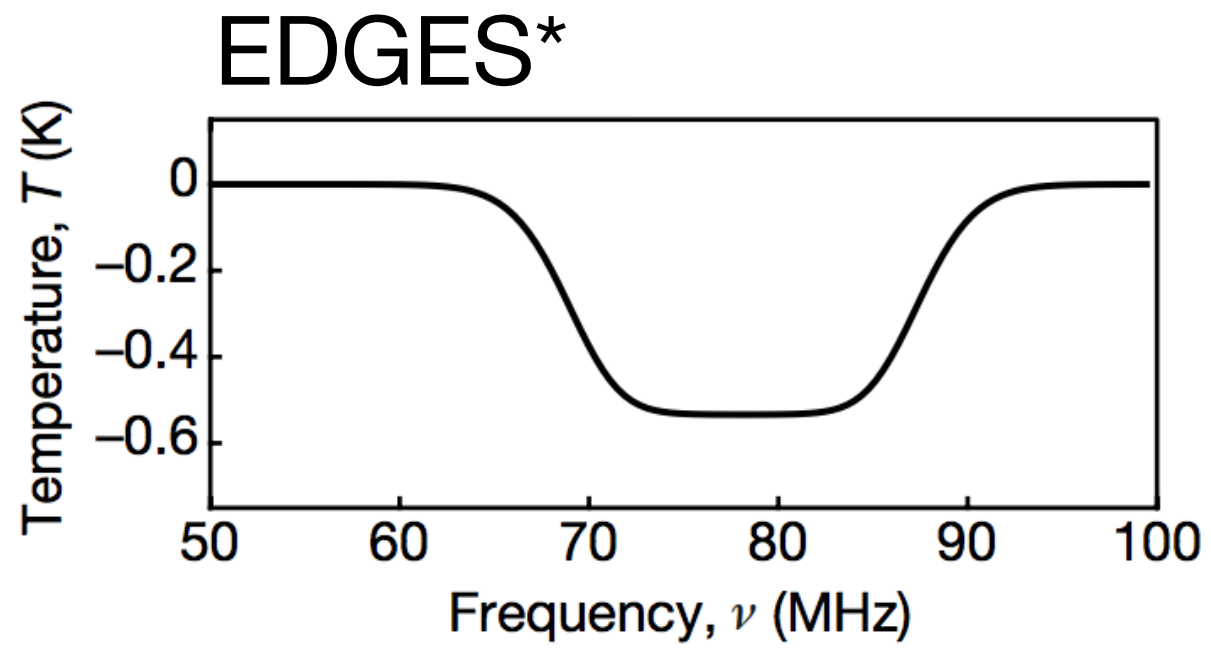
$$|T_{21}| \sim \frac{T_{\text{cmb}} + T_{\text{extra}}}{T_S}$$



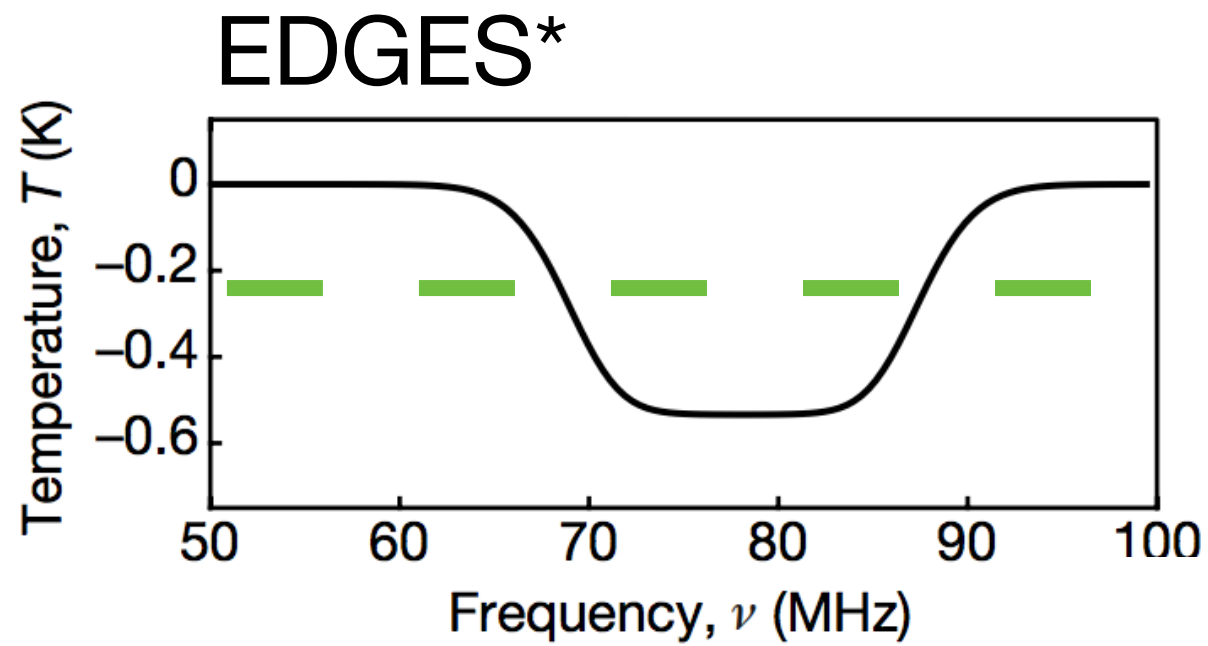
Pospelov et al. 2018



# To sum up



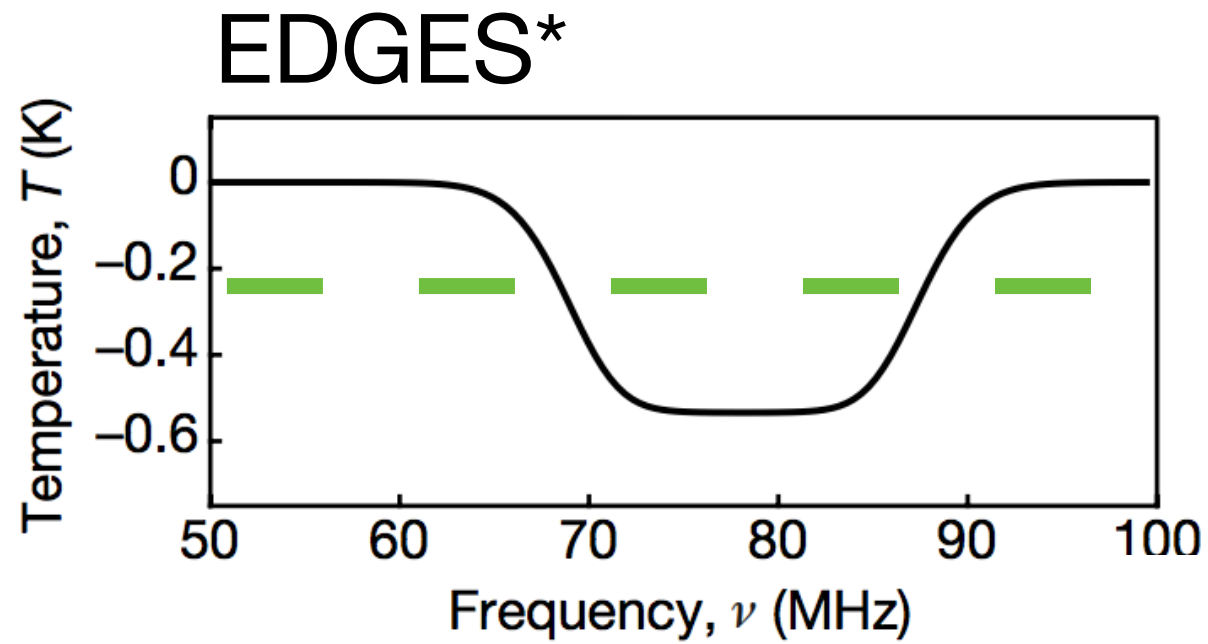
# To sum up



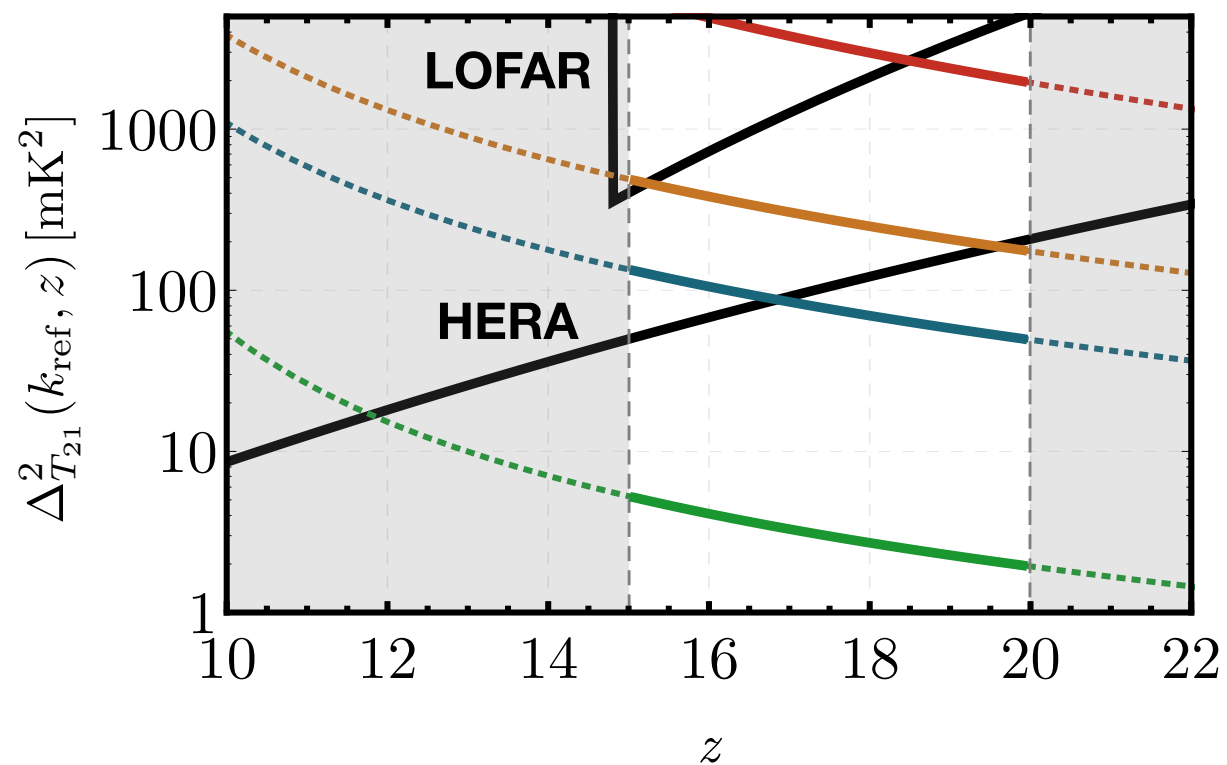
$$f_{\text{dm}} \lesssim \text{few}\%$$

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

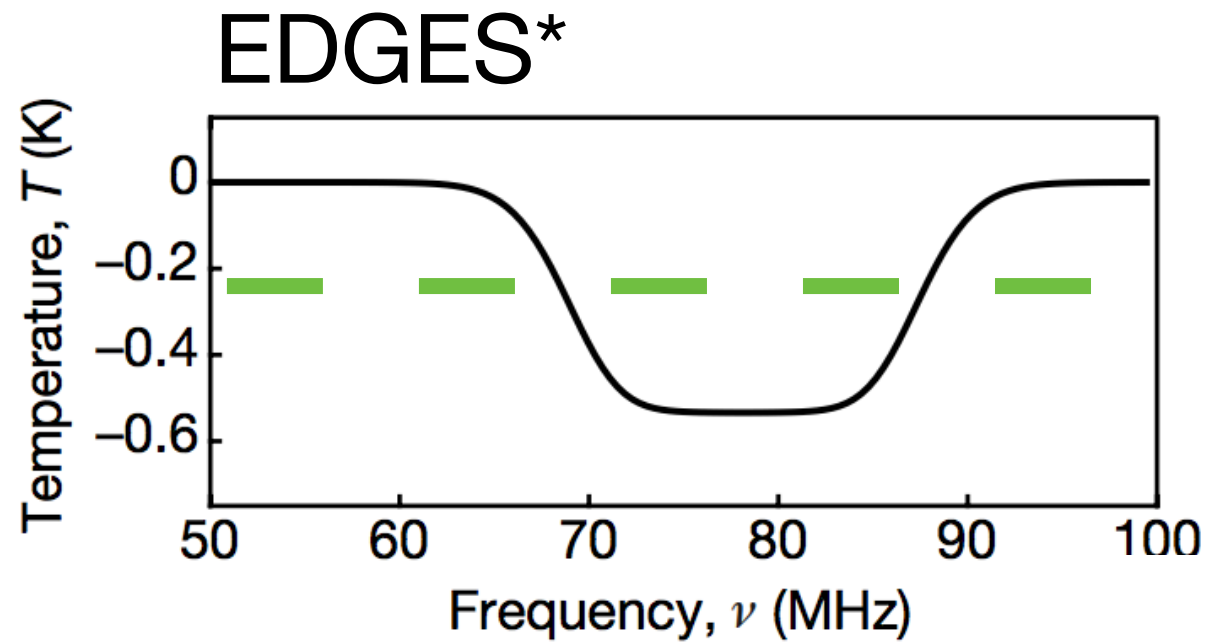
# To sum up



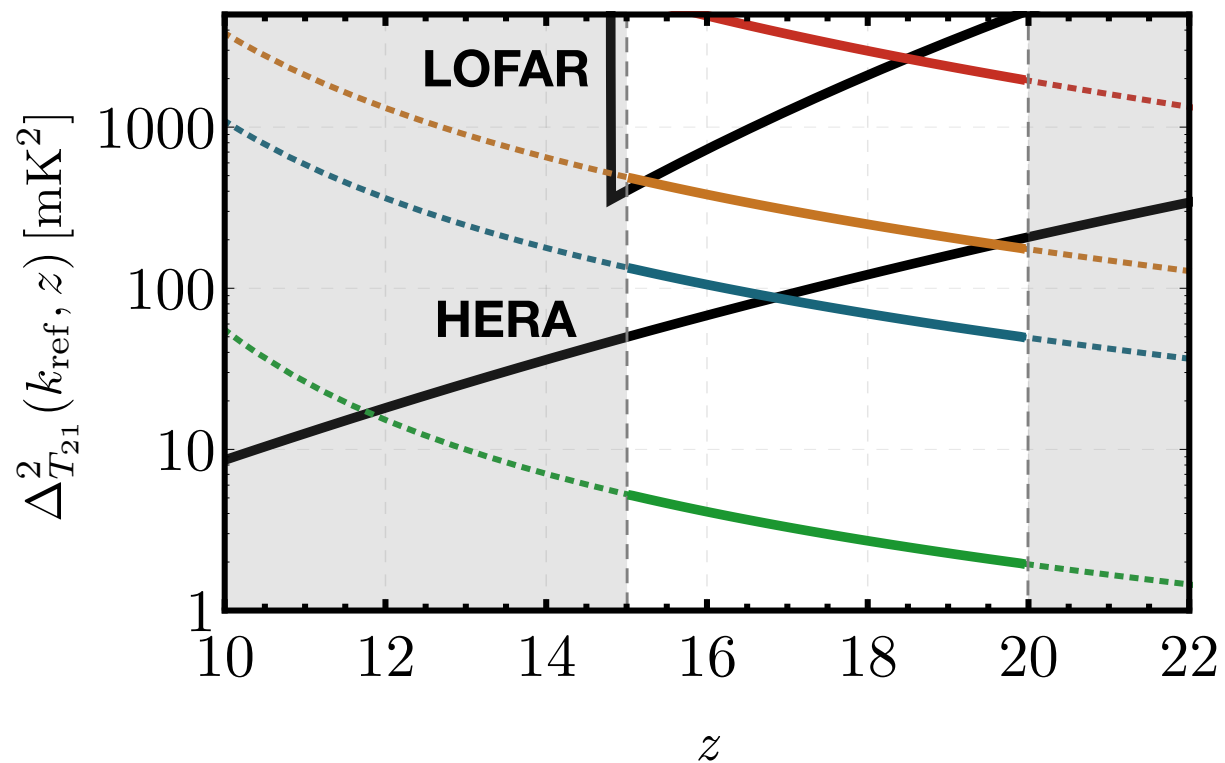
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# To sum up



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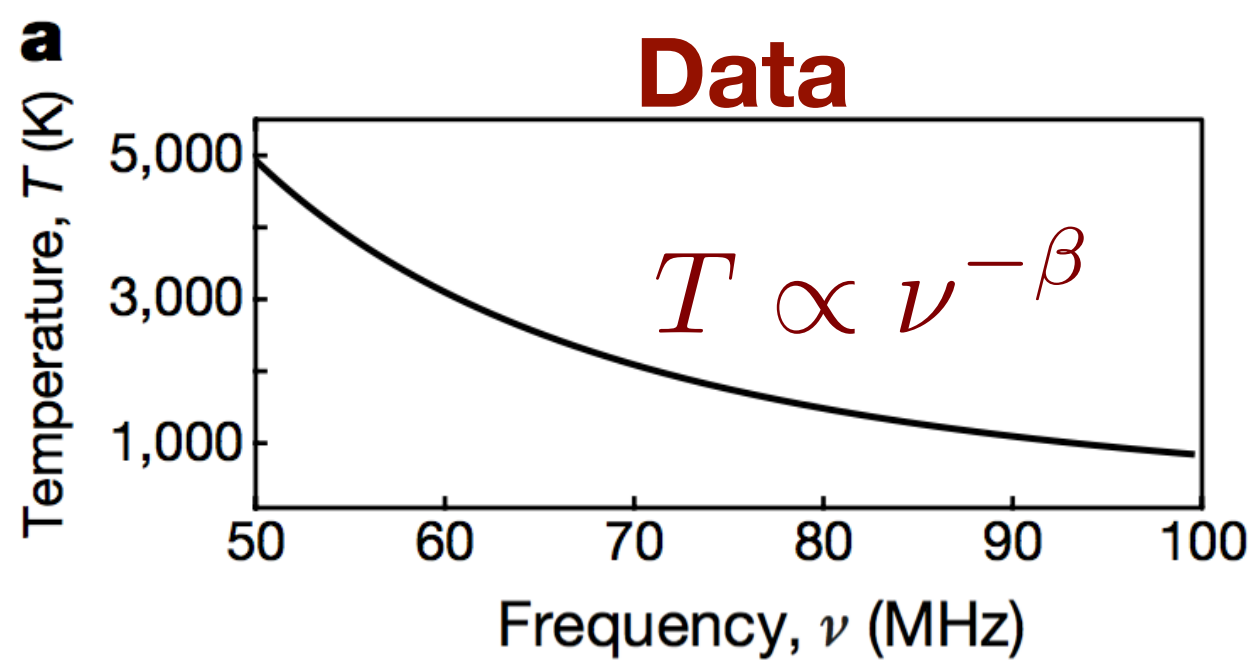


Thanks!



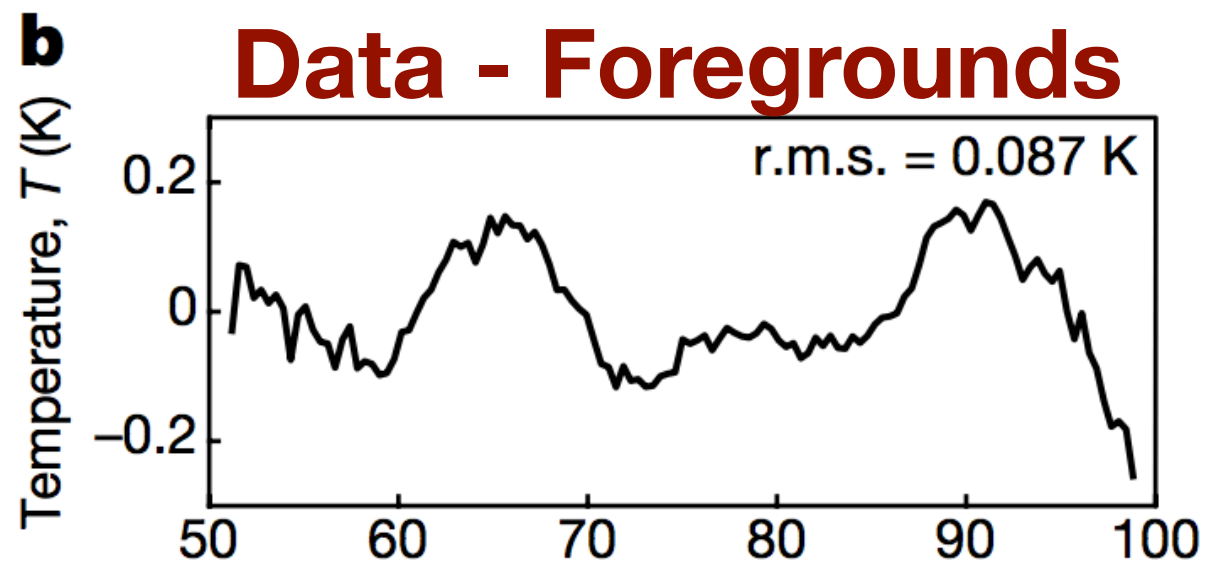
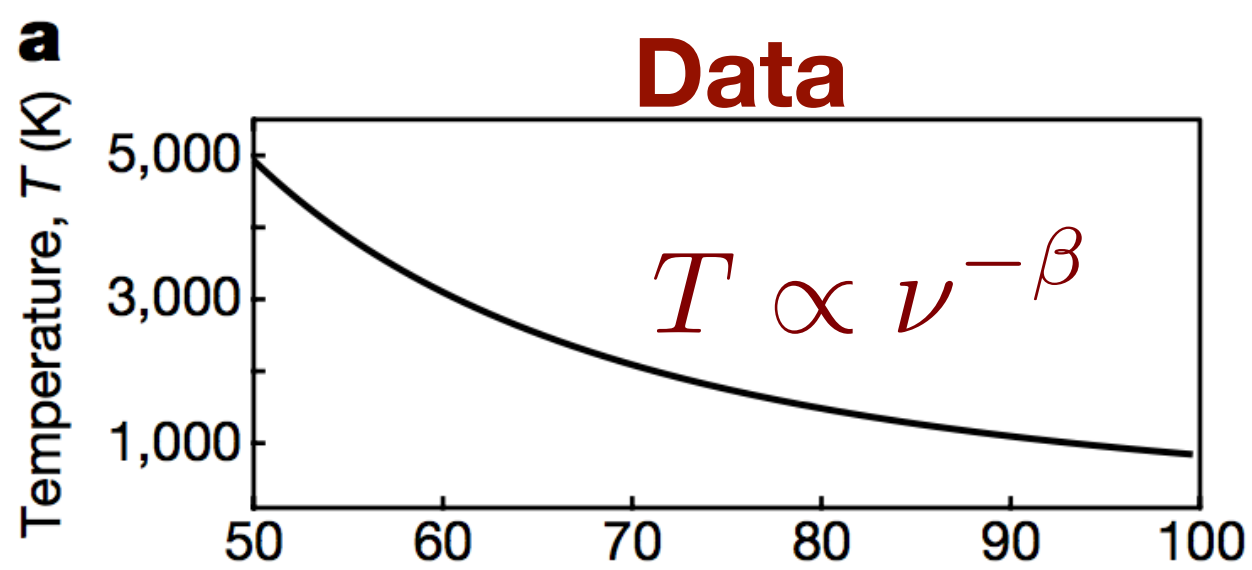






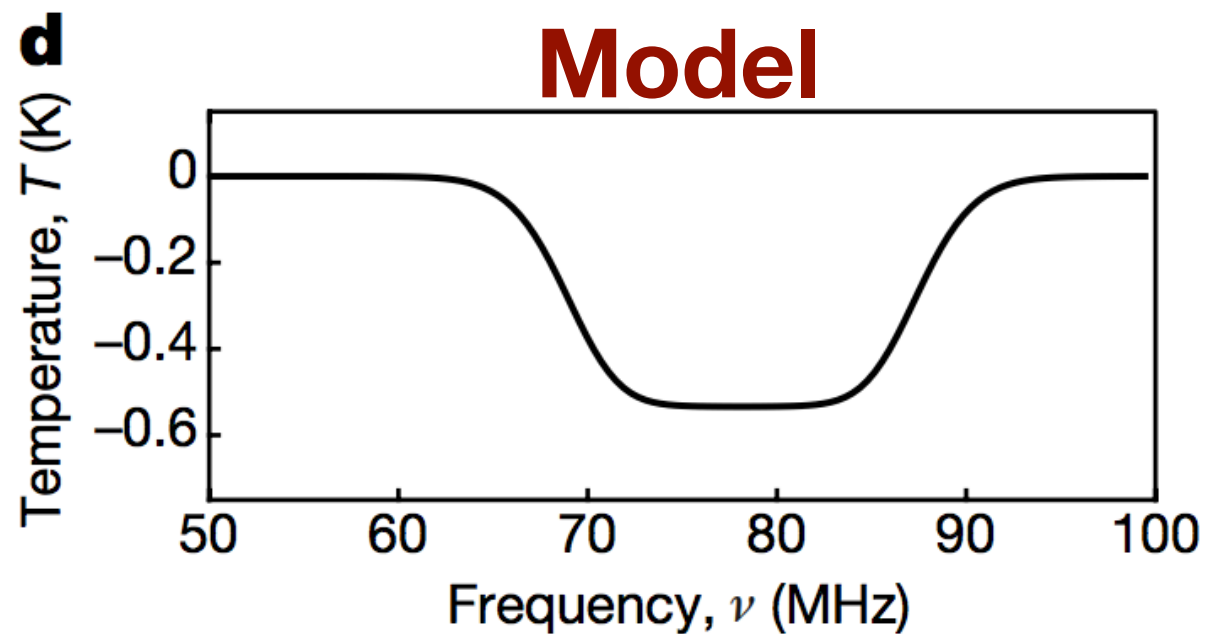
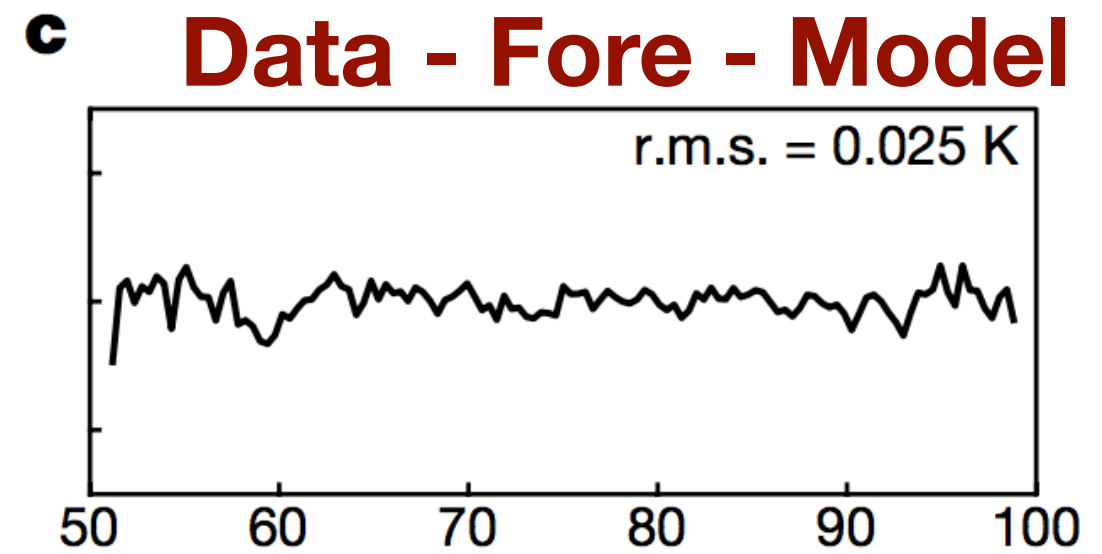
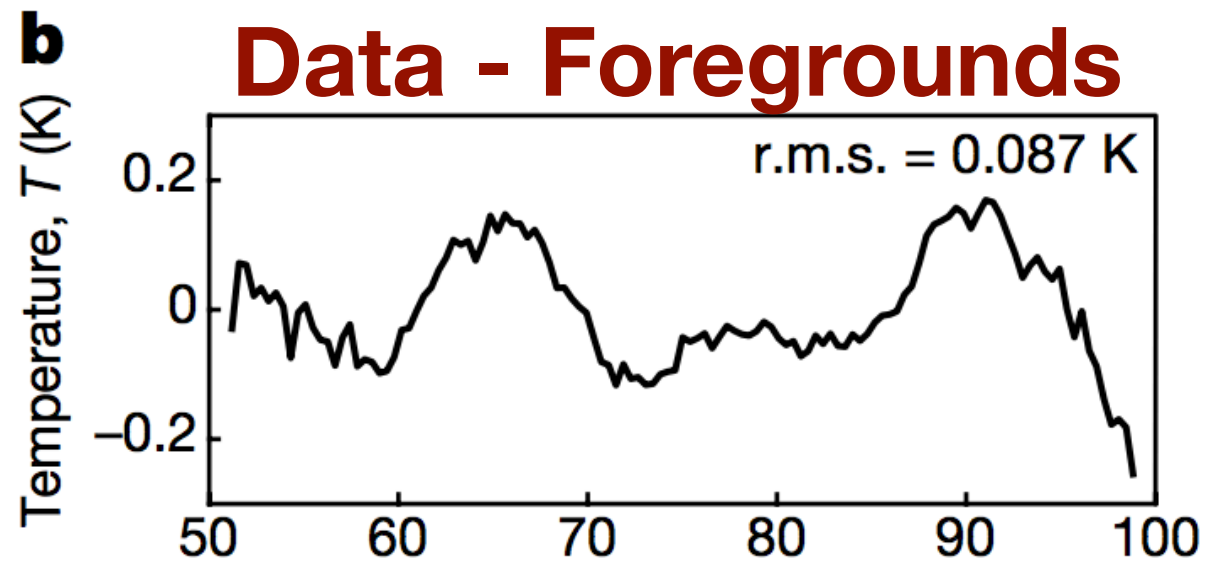
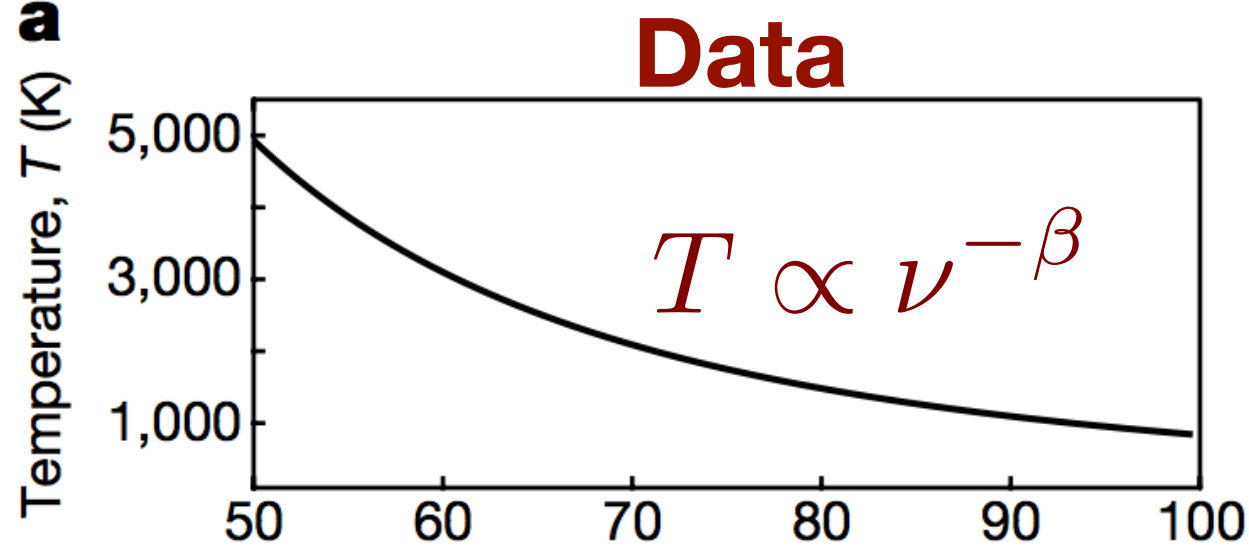
Bowman et al. Nature 2018

**EDGES** (Experiment to Detect the Global EoR Signature)



Bowman et al. Nature 2018

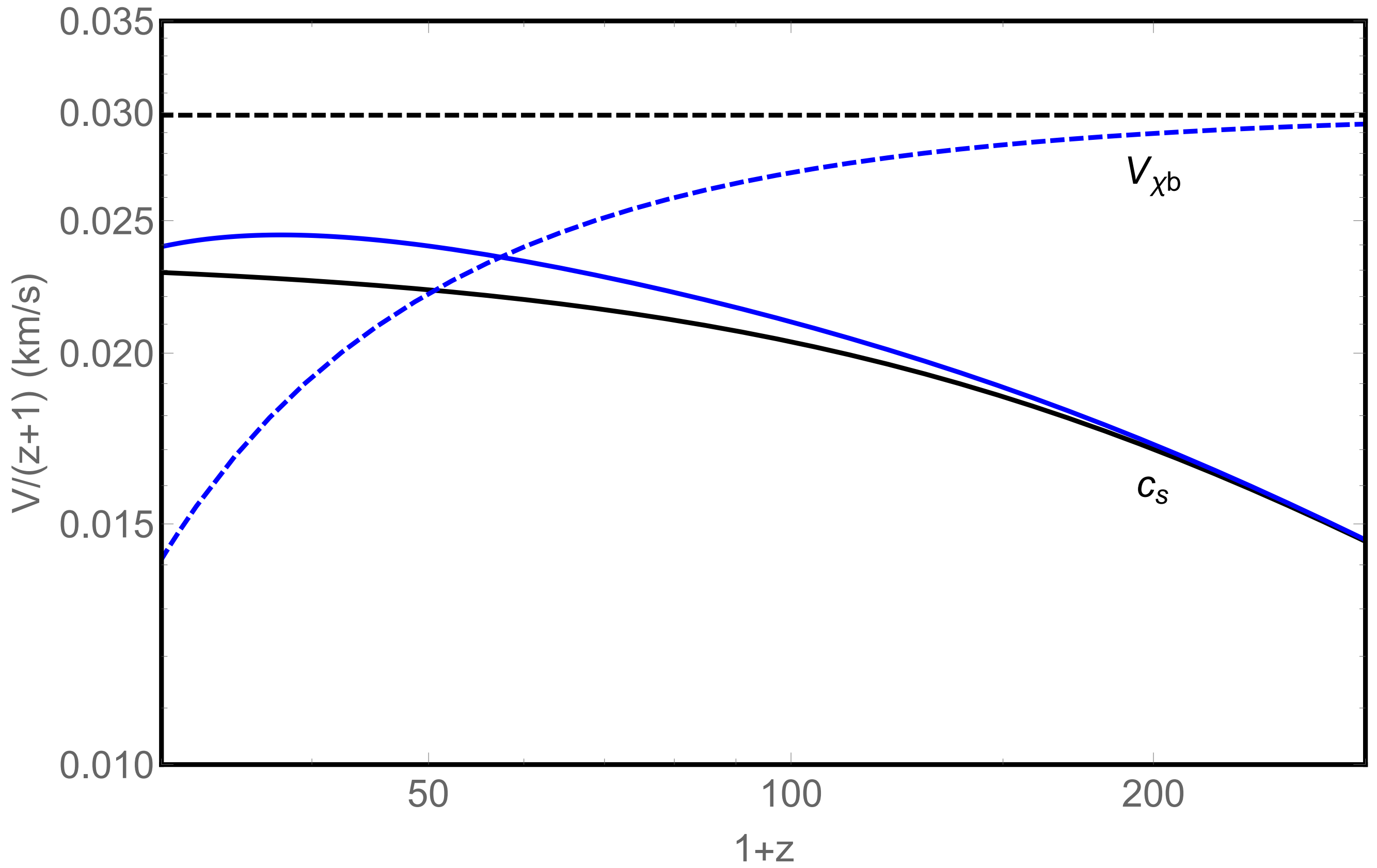
**EDGES** (Experiment to Detect the Global EoR Signature)

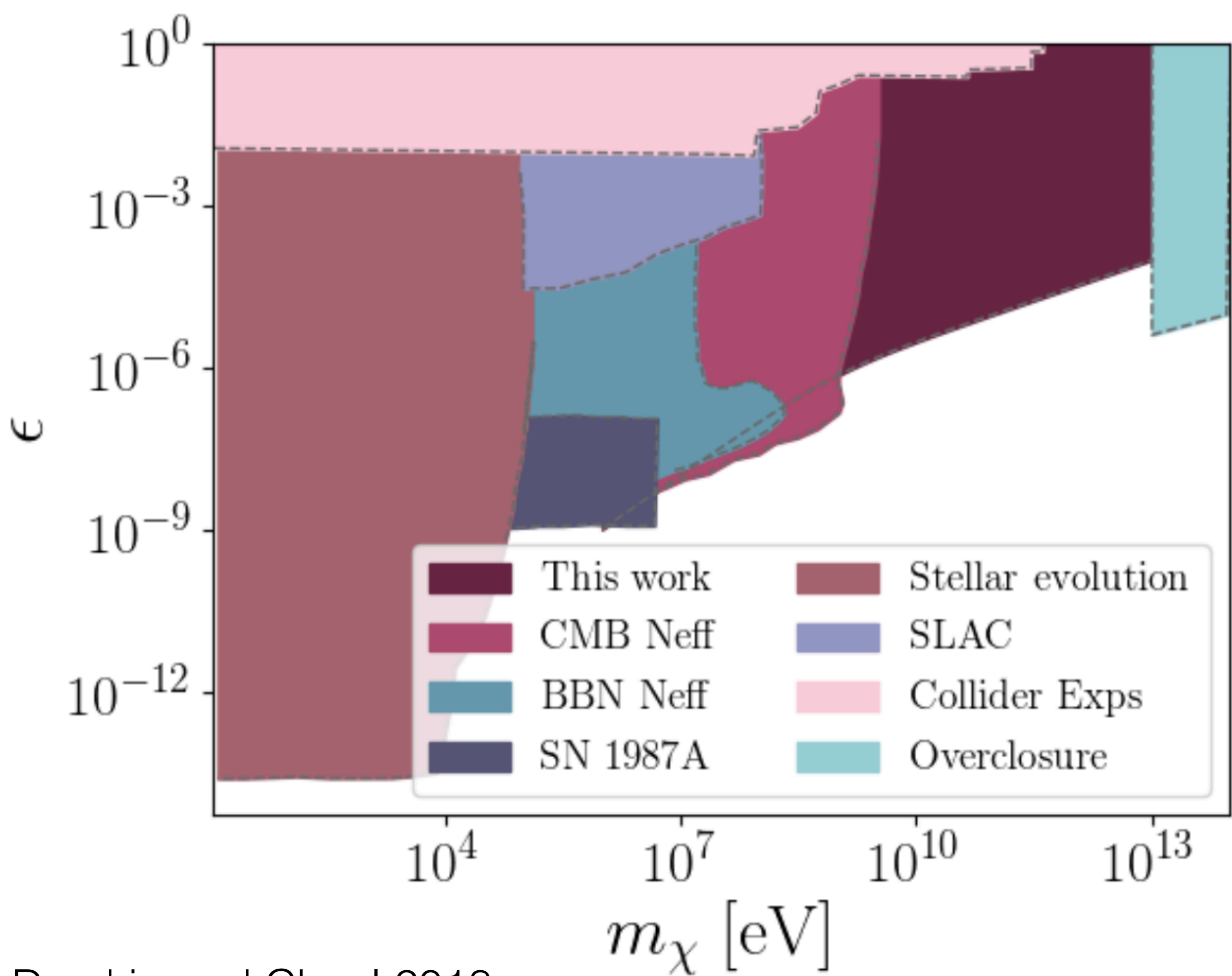


Bowman et al. Nature 2018

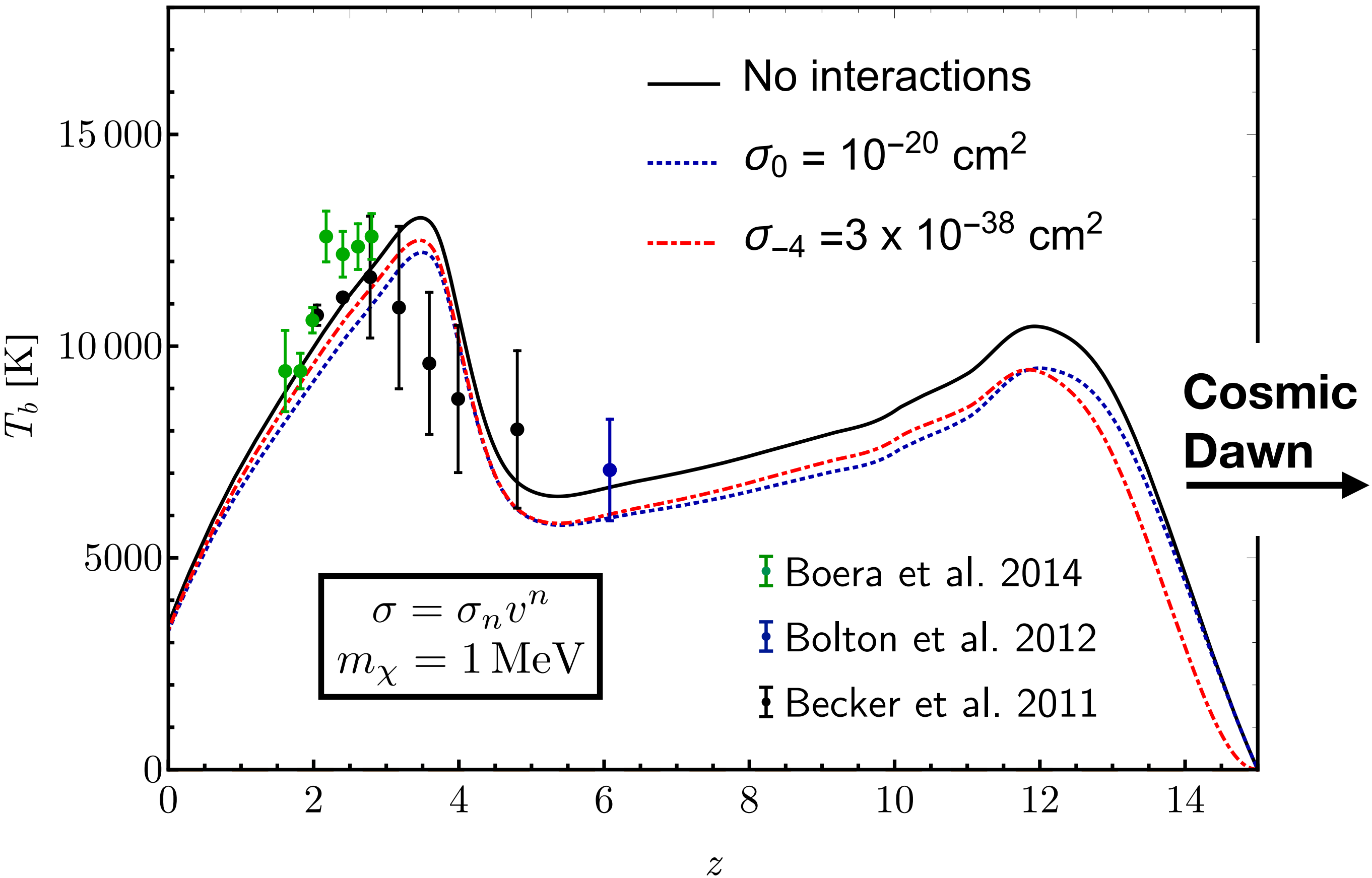
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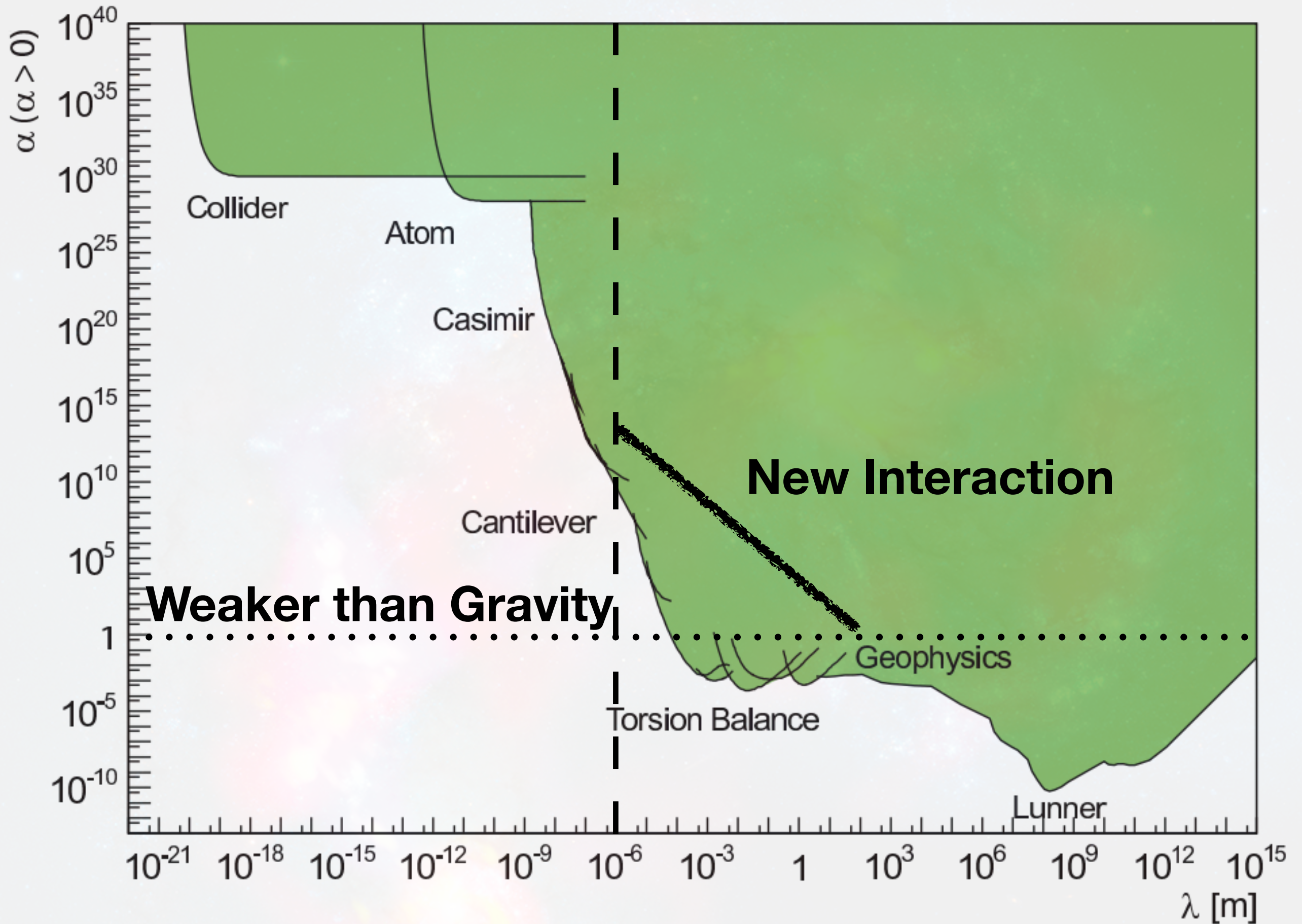






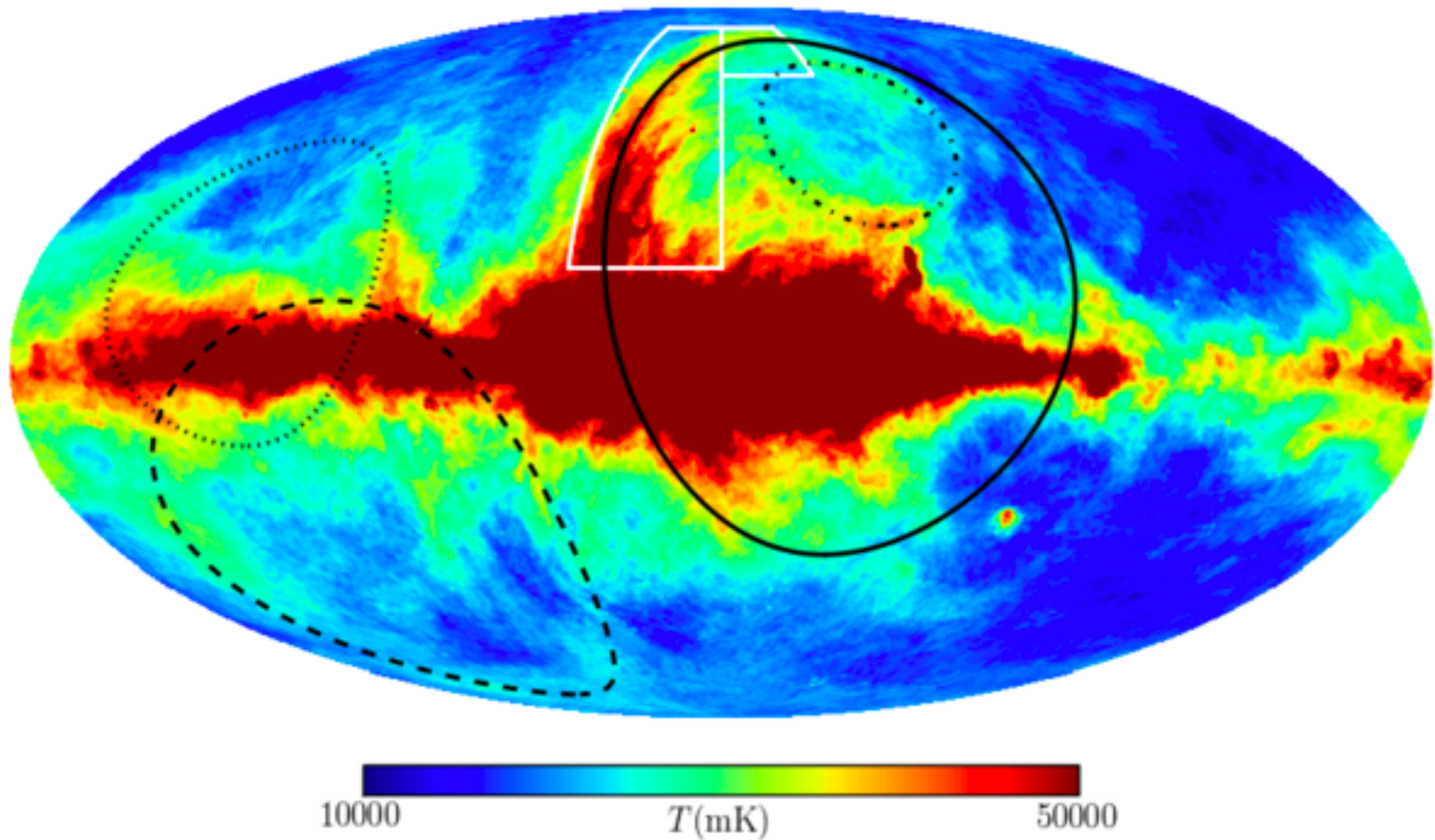
Xu, Dvorkin and Chael 2018  
 Gluscevic and Boddy 2017







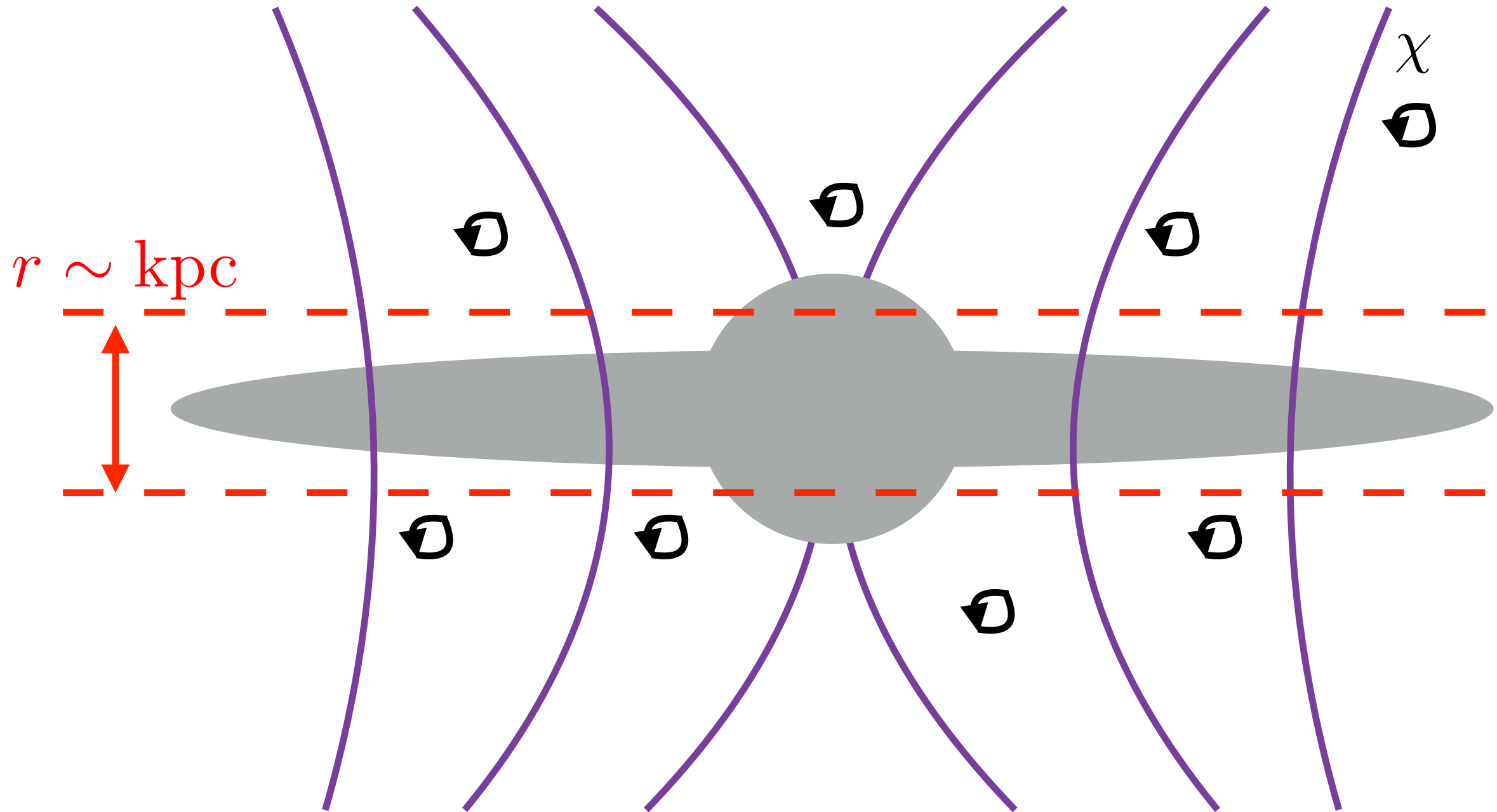
# Galactic Foregrounds (CMB)







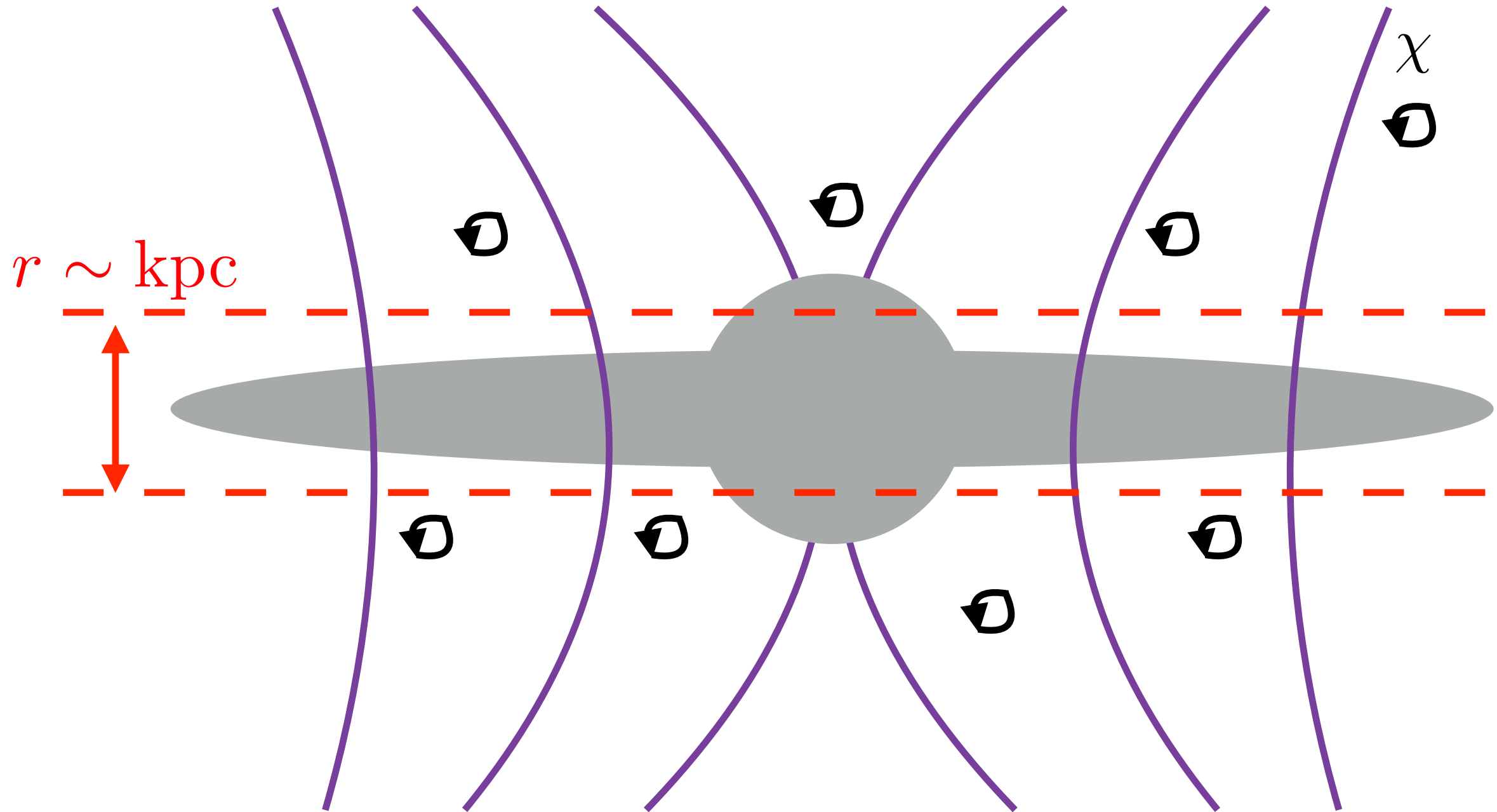
$$r_g \propto \frac{m_\chi}{\epsilon} \gtrsim 100 \text{ kpc}$$



$$\rho_{\text{DM}} = 0.3 \pm 0.1 \text{ GeV cm}^{-3}$$

Bovy and Tremaine (2012)

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



$$\rho_{\text{DM}} = 0.3 \pm 0.1 \text{ GeV cm}^{-3}$$

Bovy and Tremaine (2012)

However:

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

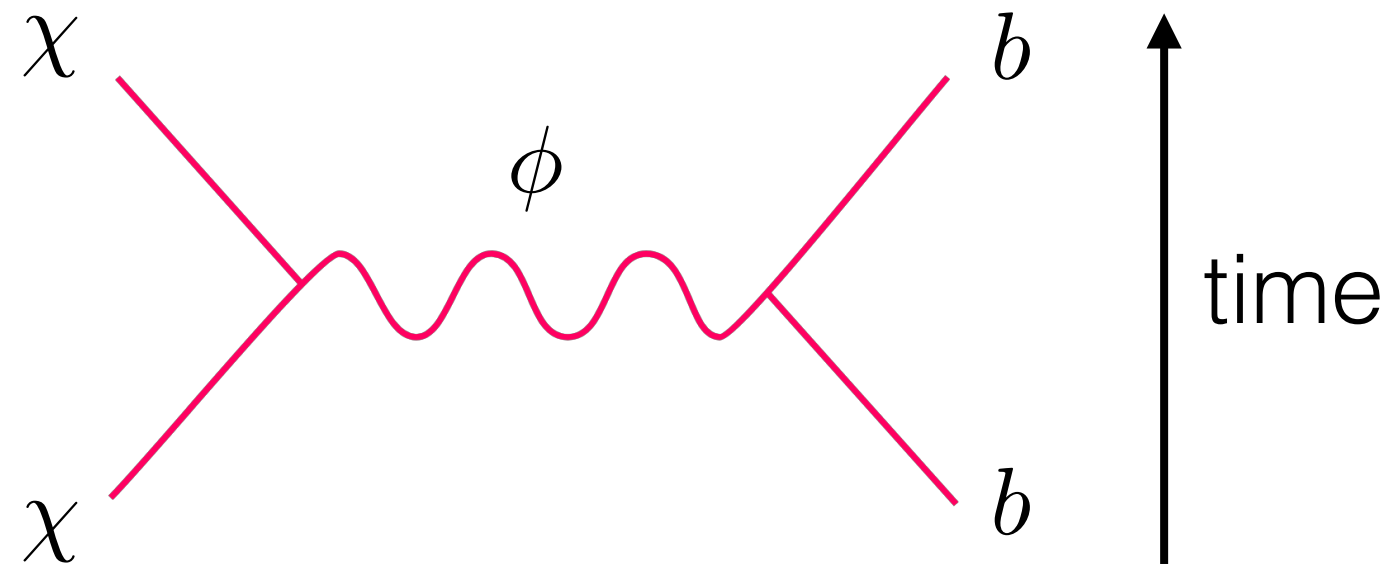


# Fifth-force cooling?

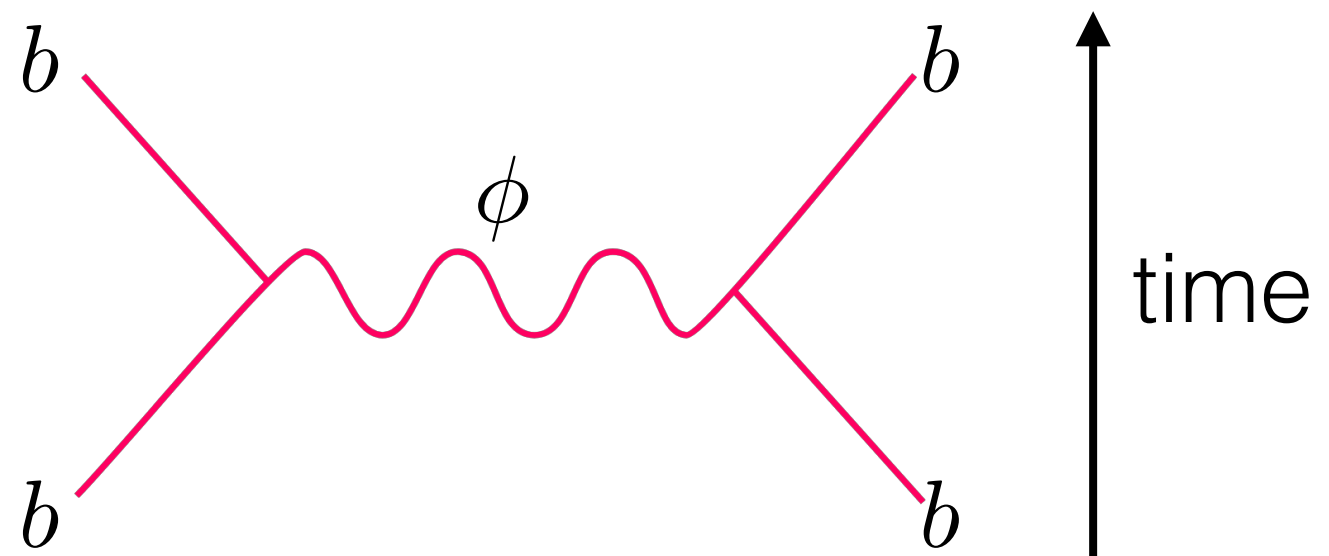
Barkana Nature 2018

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

However, this:

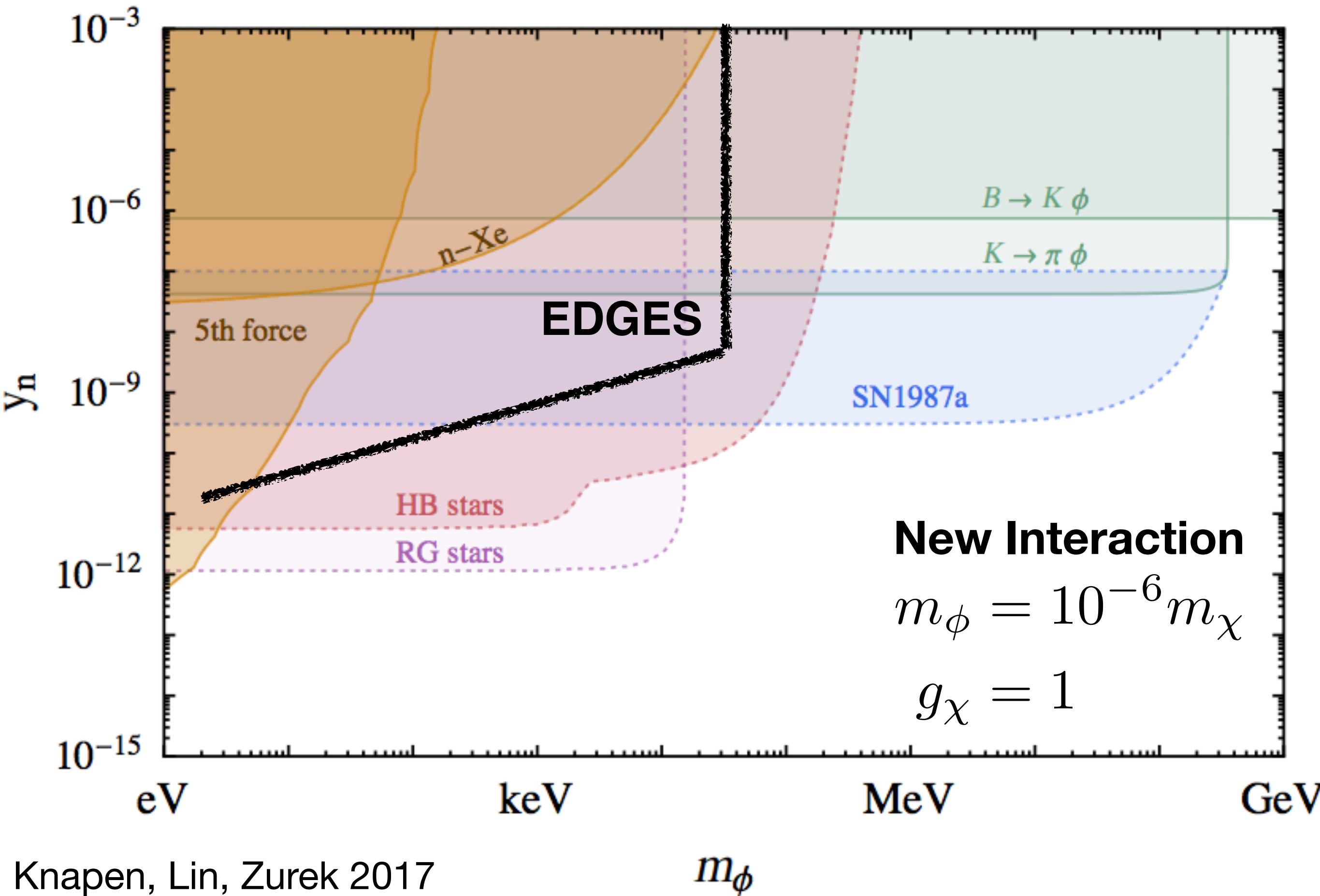


Also implies this:





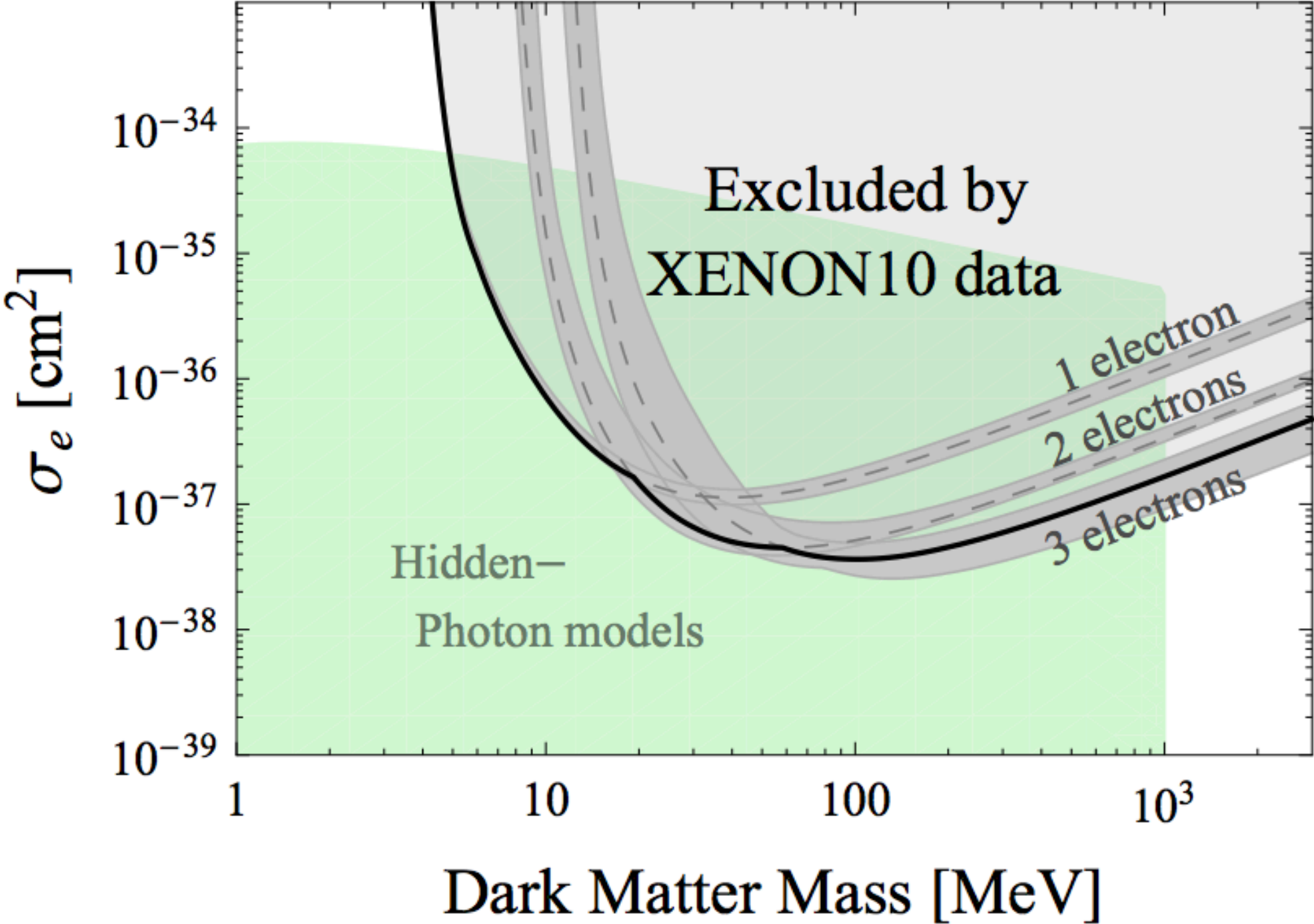
# Fifth-force constraints



# Can you test this?

Essig et al. 2012

$$\sigma_{DD} \sim 10^{-27} \text{ cm}^2$$

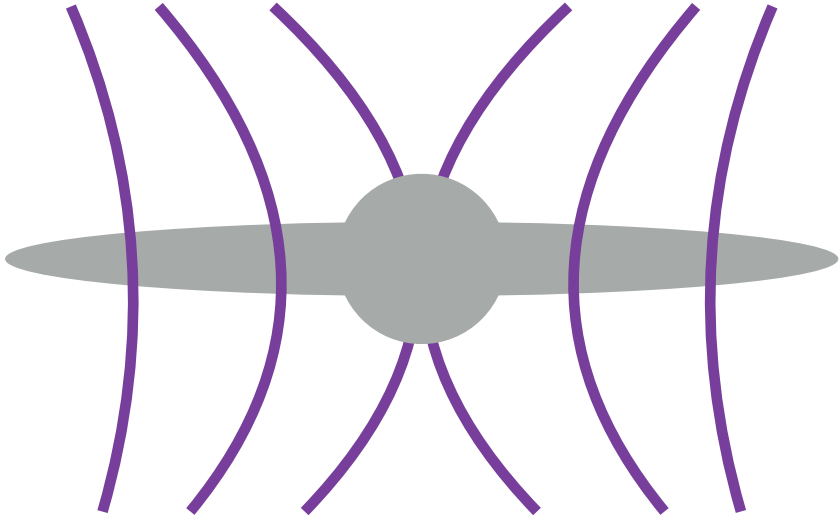
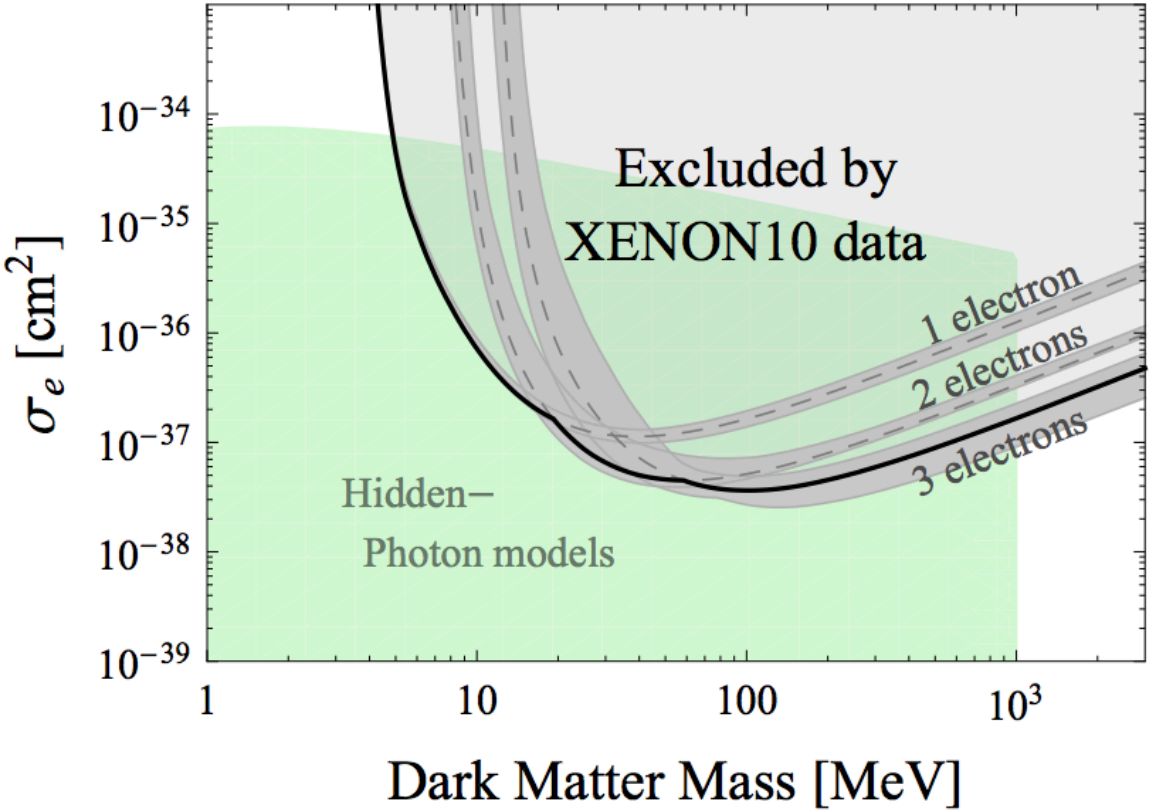


# Can you test this?

Although:

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

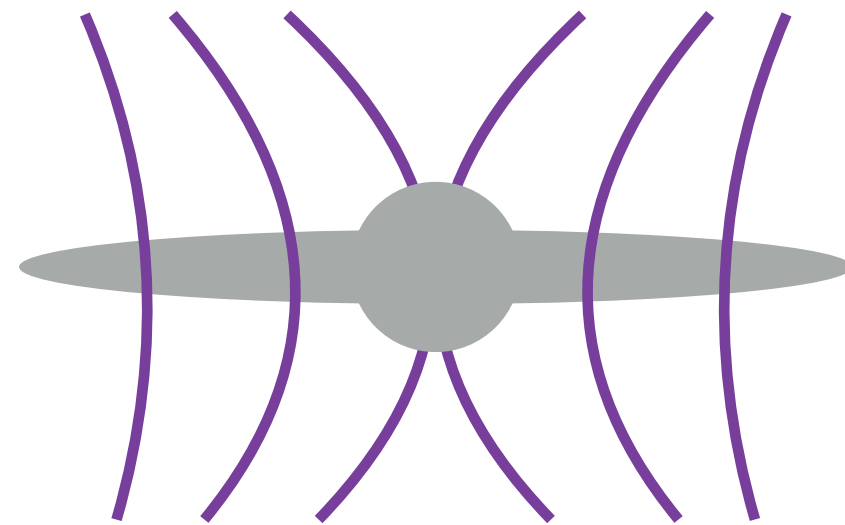
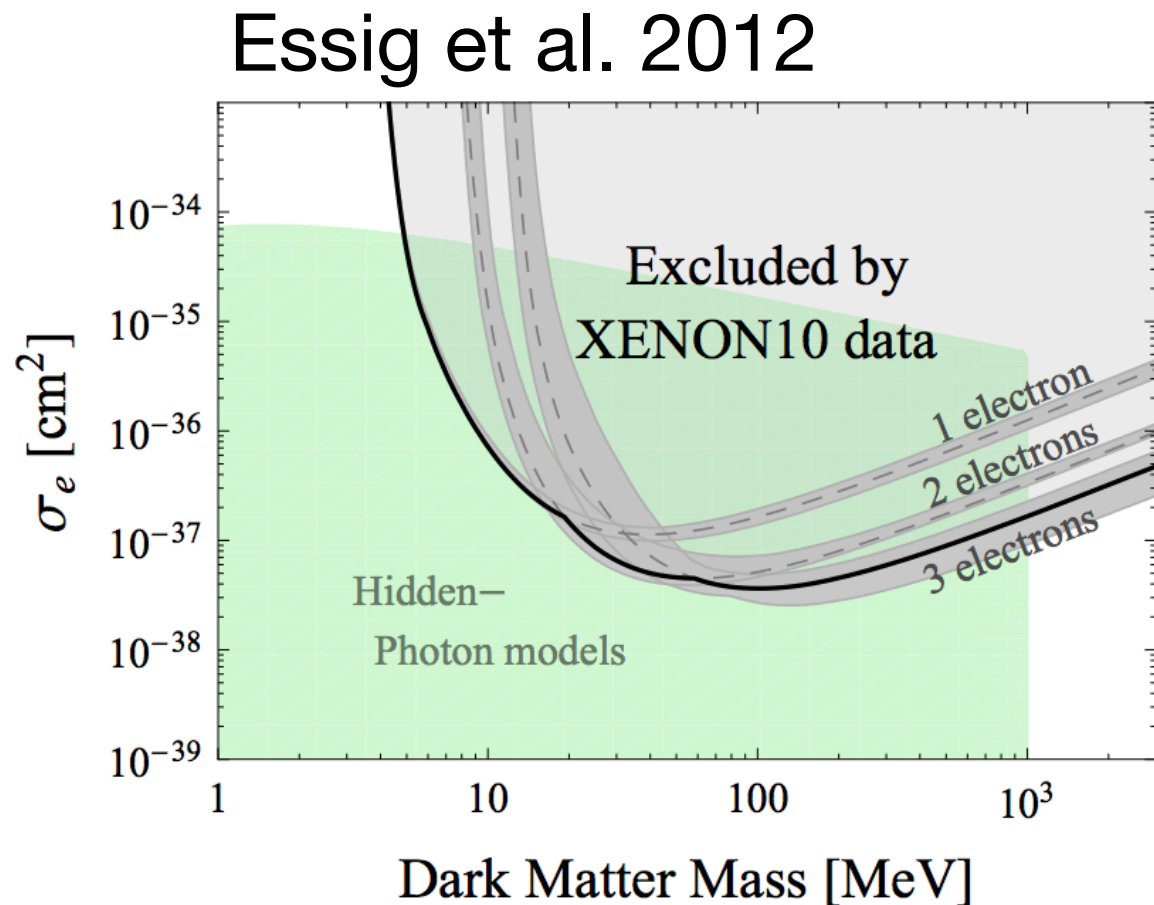
Essig et al. 2012



# Can you test this?

Although:

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



SHiP/MilliQan @ CERN

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

LDMX @ SLAC/Jlab/CERN

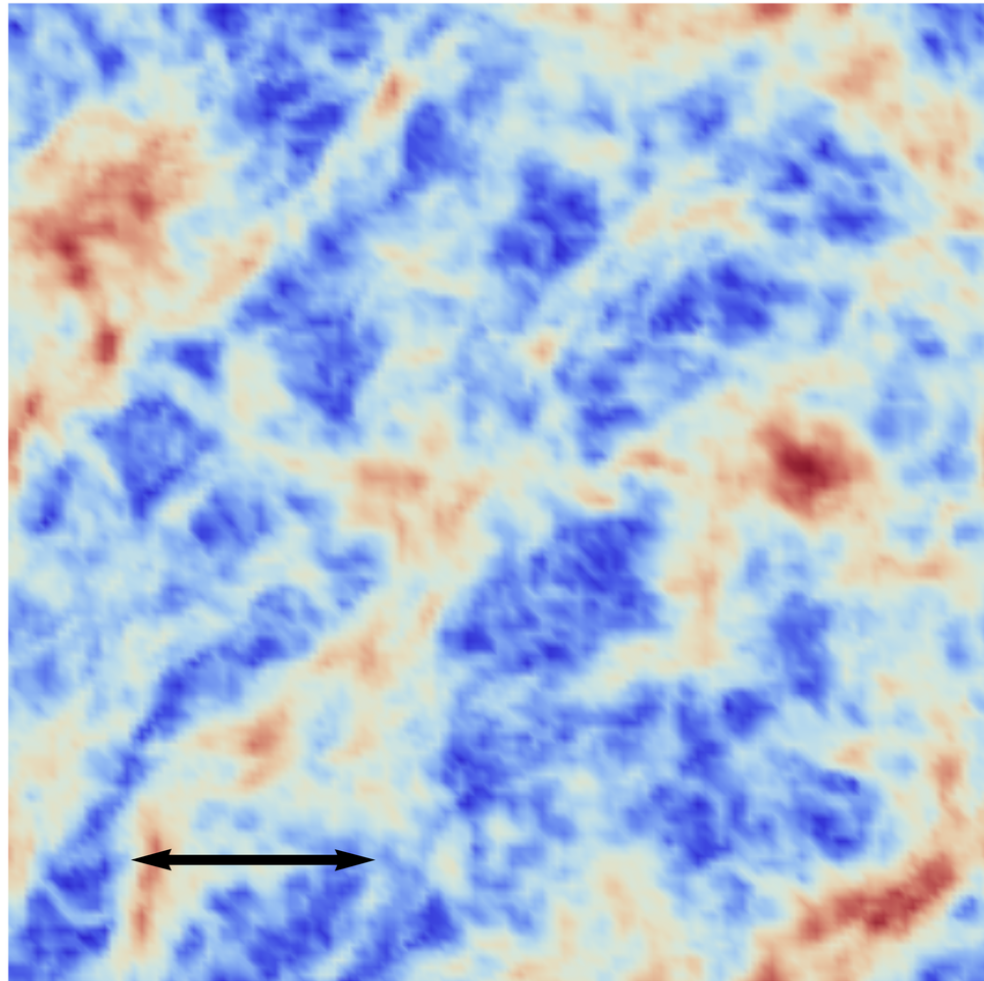
$$\epsilon \approx 10^{-1} \times \text{SLAC mQ}$$



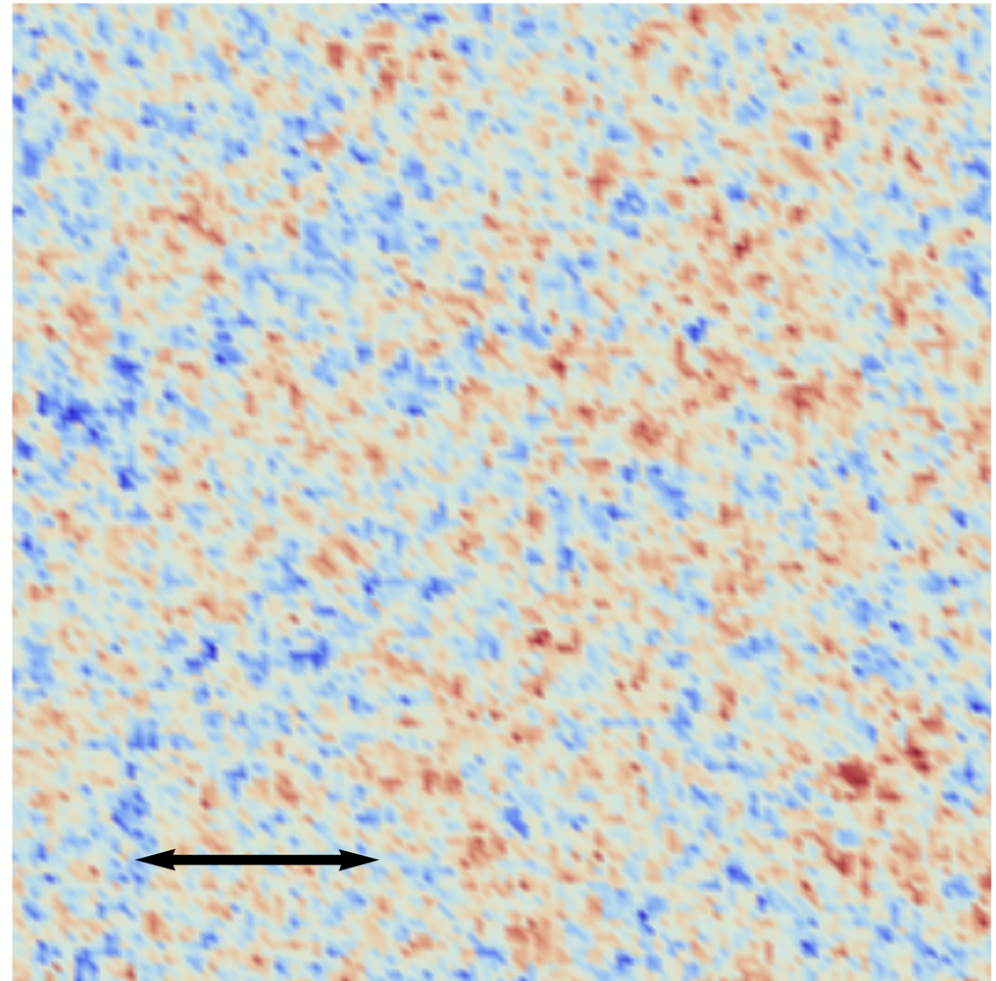


# DM-baryon relative velocities

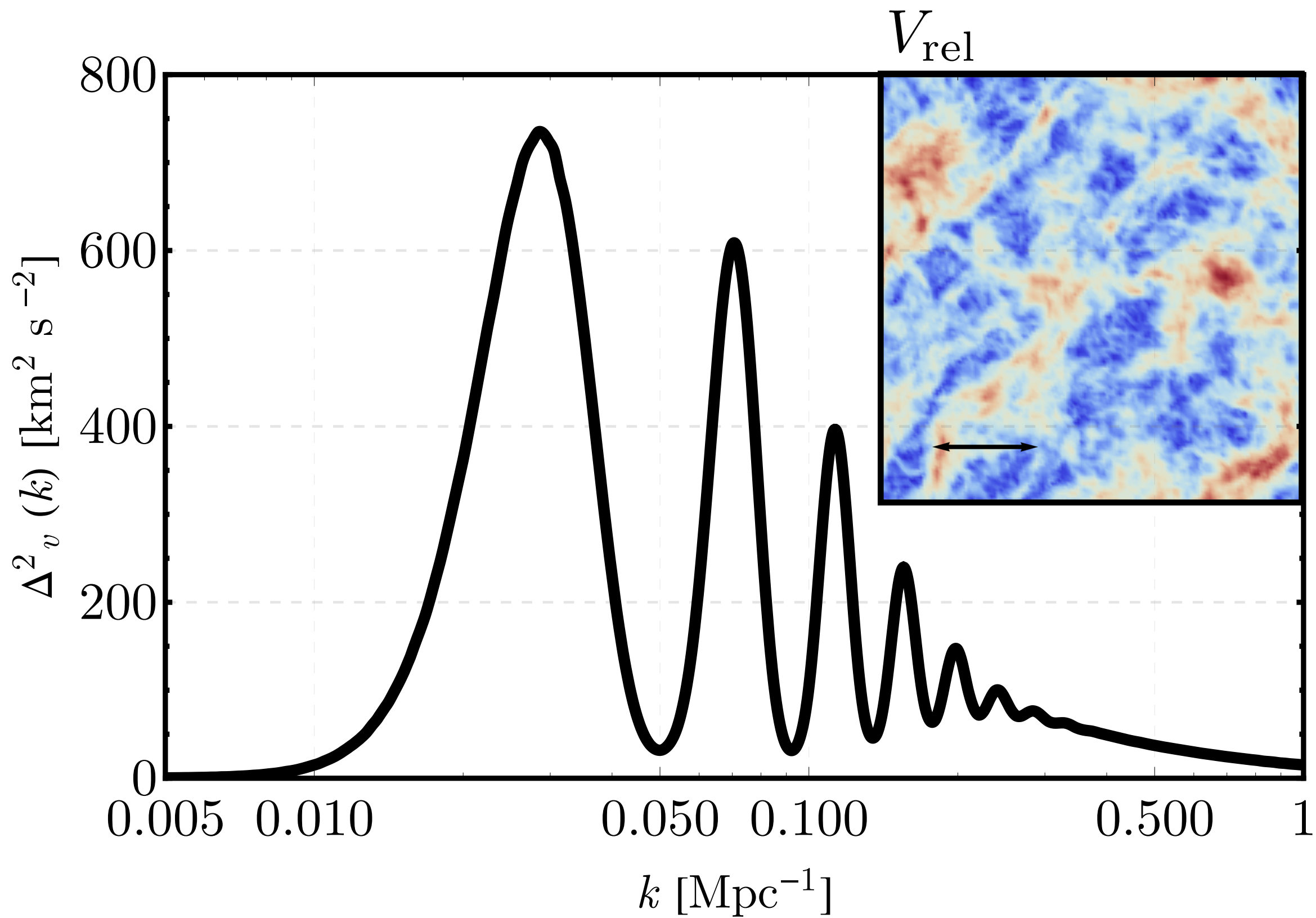
$V_{\text{rel}}$

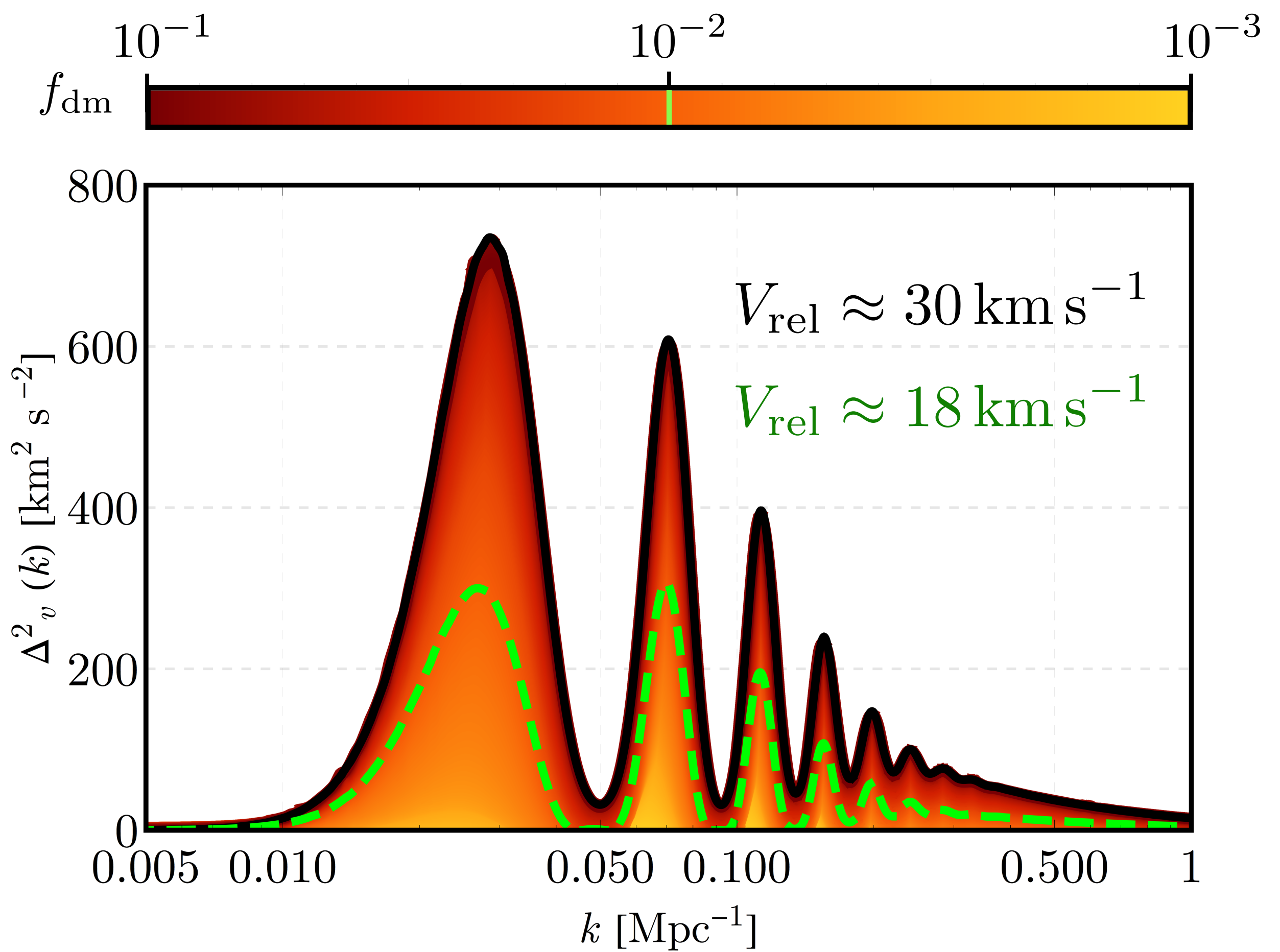


$\delta$



$$\langle V_{\text{rel}}^2 \rangle^{1/2} \approx 30 \text{ km s}^{-1}$$





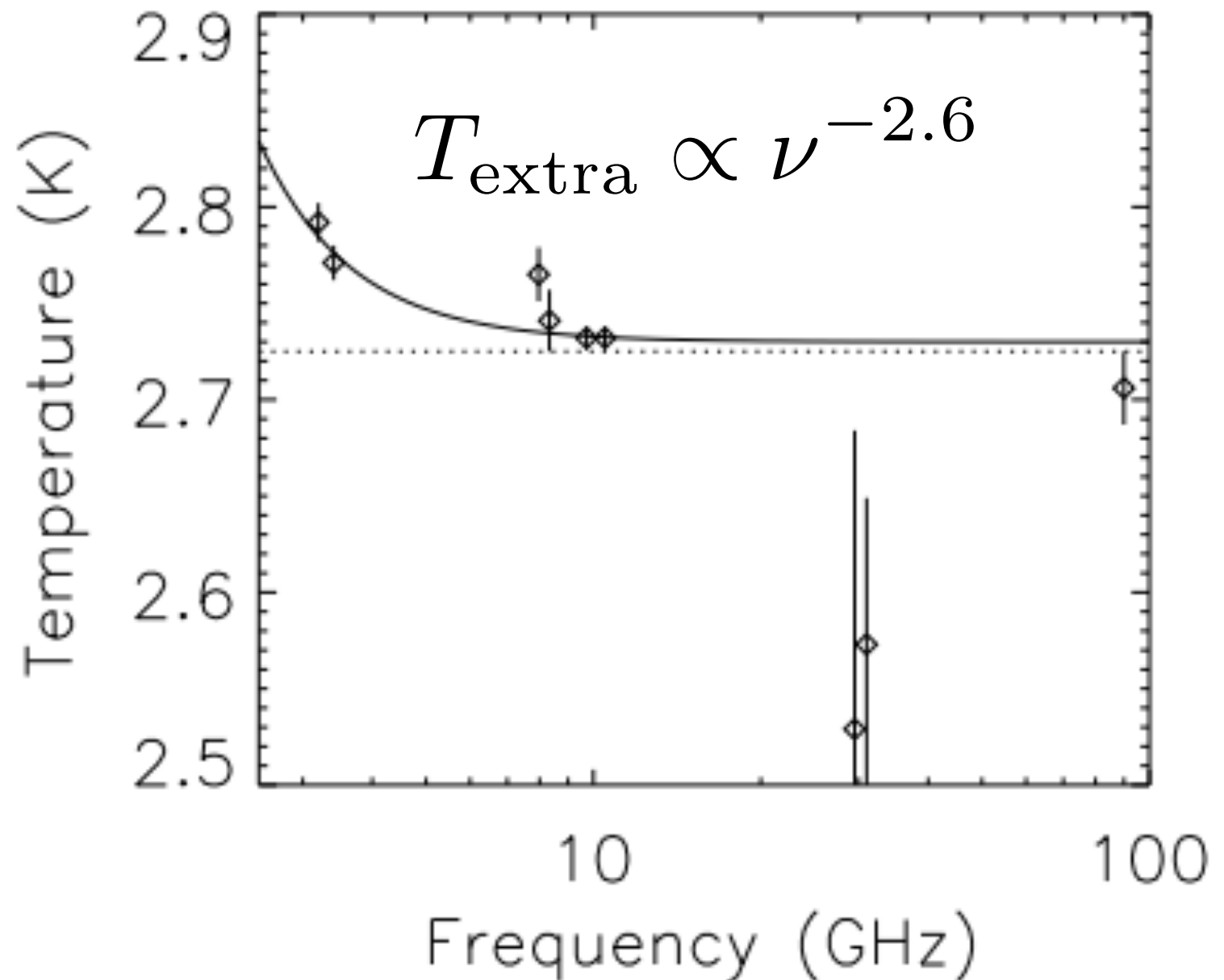
# What else can we learn from 21-cm?

## An Exotic Radio Excess?

Feng and Holder 2018

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

Fixsen et al. 2013





# What else can we learn from 21-cm?

## An Exotic Radio Excess?

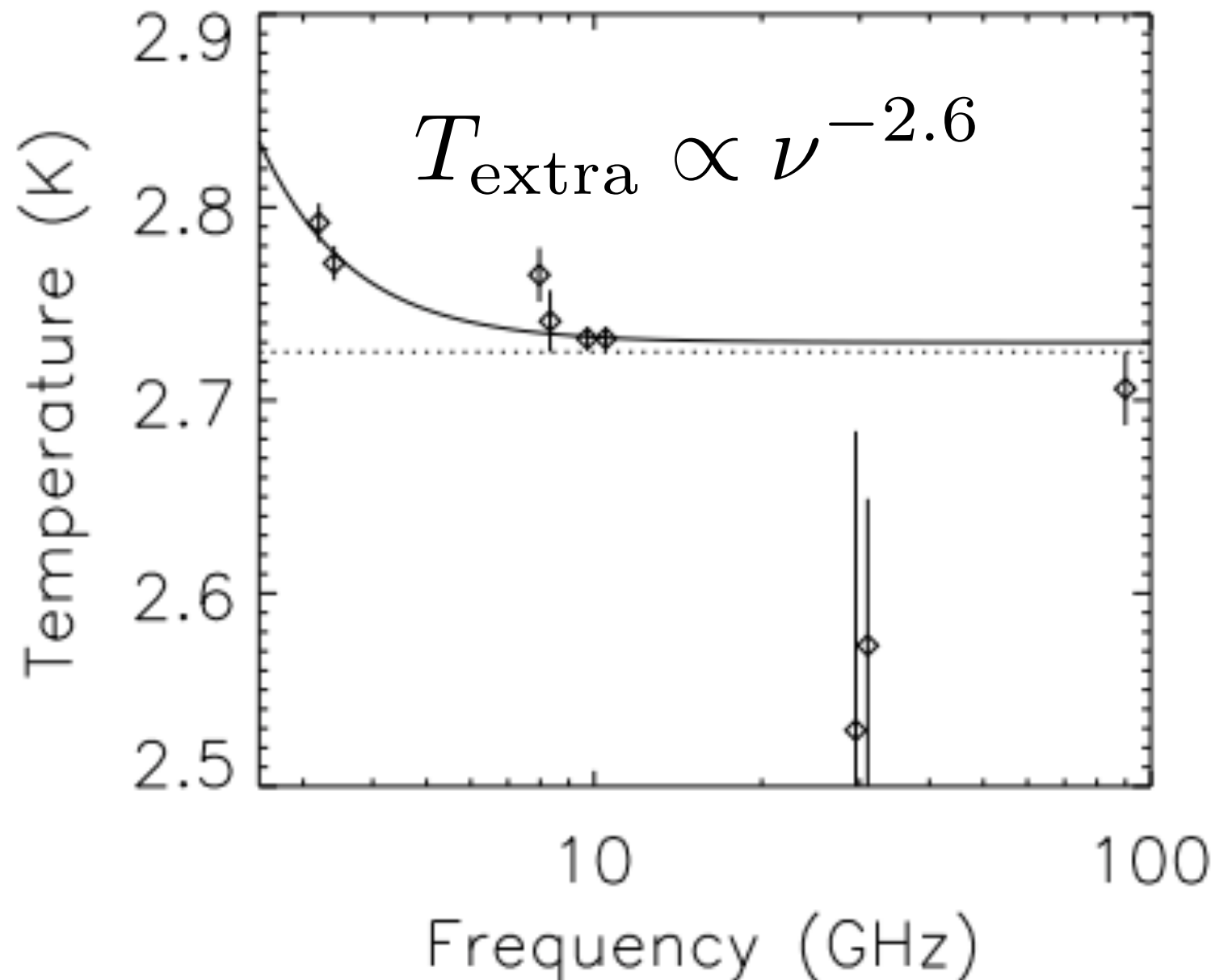
Feng and Holder 2018

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

Problem:

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

Fixsen et al. 2013



# What else can we learn from 21-cm?

-Annihilating WIMPs

Liu & Slatyer, 2018,  
Also D'Amico+ 2018  
Lopez-Honorez+ 2016 ...

-Exotic DM decays

Light DM to radio photons

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DM to dark photons  $\rightarrow$  photons

Pospelov et al. 2018

