A COMPOSITE SOLUTION TO THE EDGES ANOMALY

Harikrishnan Ramani
Stanford Institute for Theoretical Physics

arXiv: 2102.11284 Anubhav Mathur, Surjeet Rajendran, HR

—Banksy

OUTLINE

- EDGES anomaly & Milli-charge solution
- Milli-charge Nuclei
- Results & Detection prospects

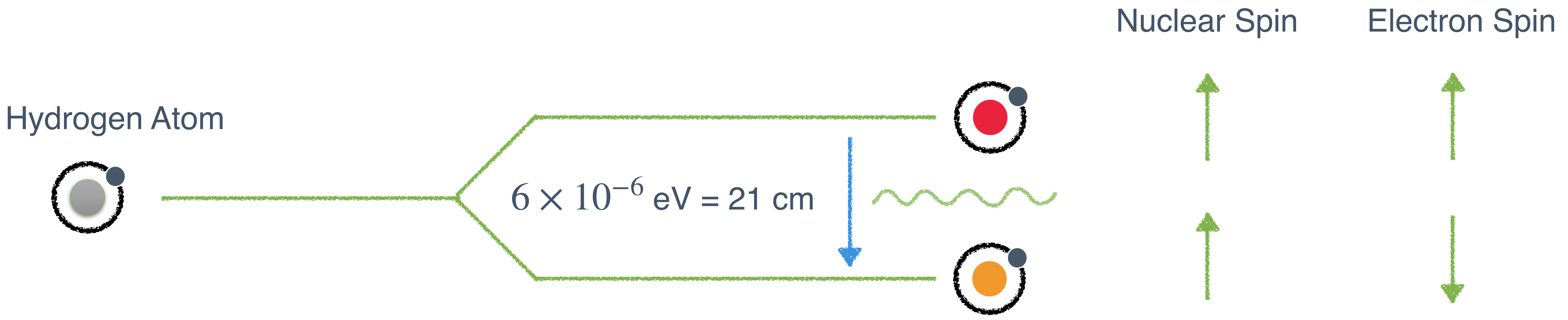
DARK AGES

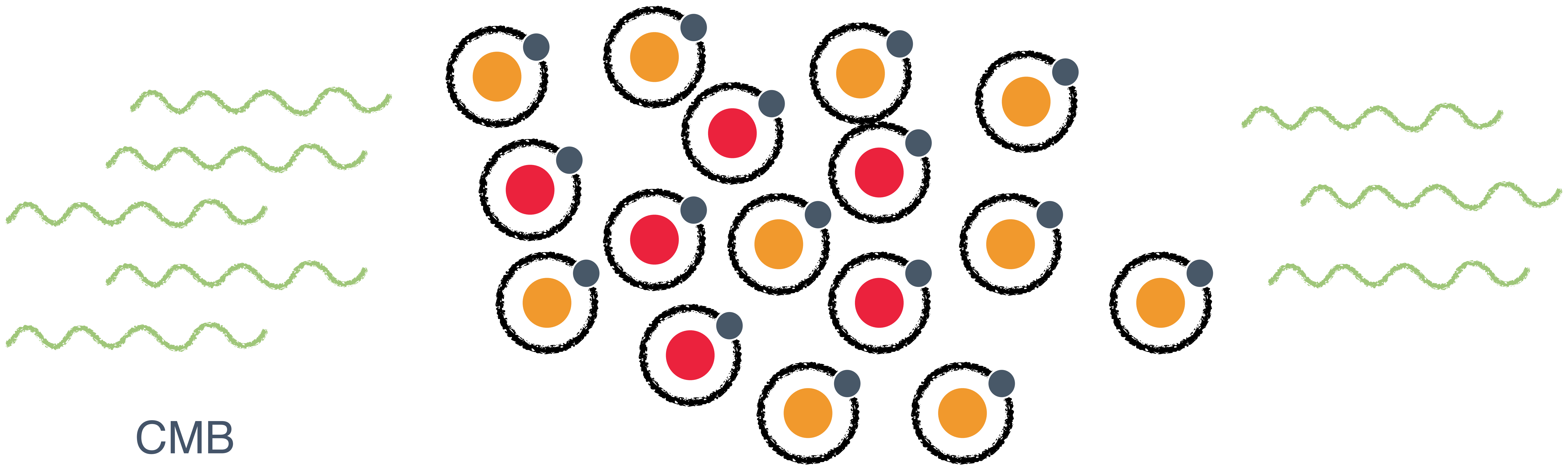
- 1000 > z > 15

DARK AGES

- $1000 > z > 15$
- Cold Epoch between recombination & reionization
- New test of ΛCDM
- Main way to probe : 21 cm physics

HYPERFINE





Emission/Absorption spectrum

$$\frac{n_{\uparrow\uparrow}}{n_{\uparrow\downarrow}} = 3e^{-\frac{\Delta E_{\mathrm{hf}}}{T_s}}$$

*Art inspired by Hongwan Liu’s slides @ TeVPA

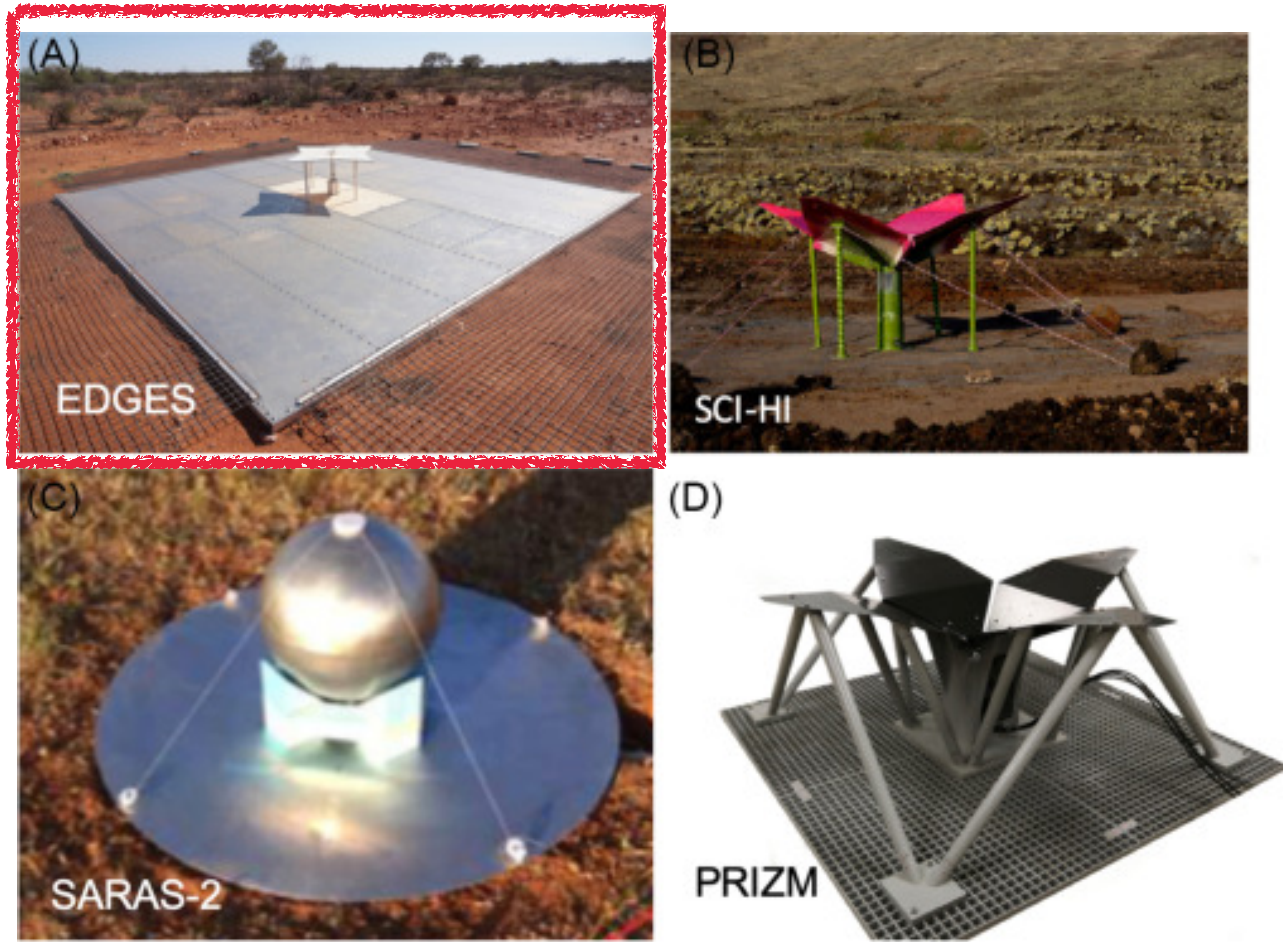
21 cm SIGNAL

1109.6012: Pritchard & Loeb

GLOBAL SPECTRUM

Bowman *et. al.*

Nature **555**, 67 (2018)

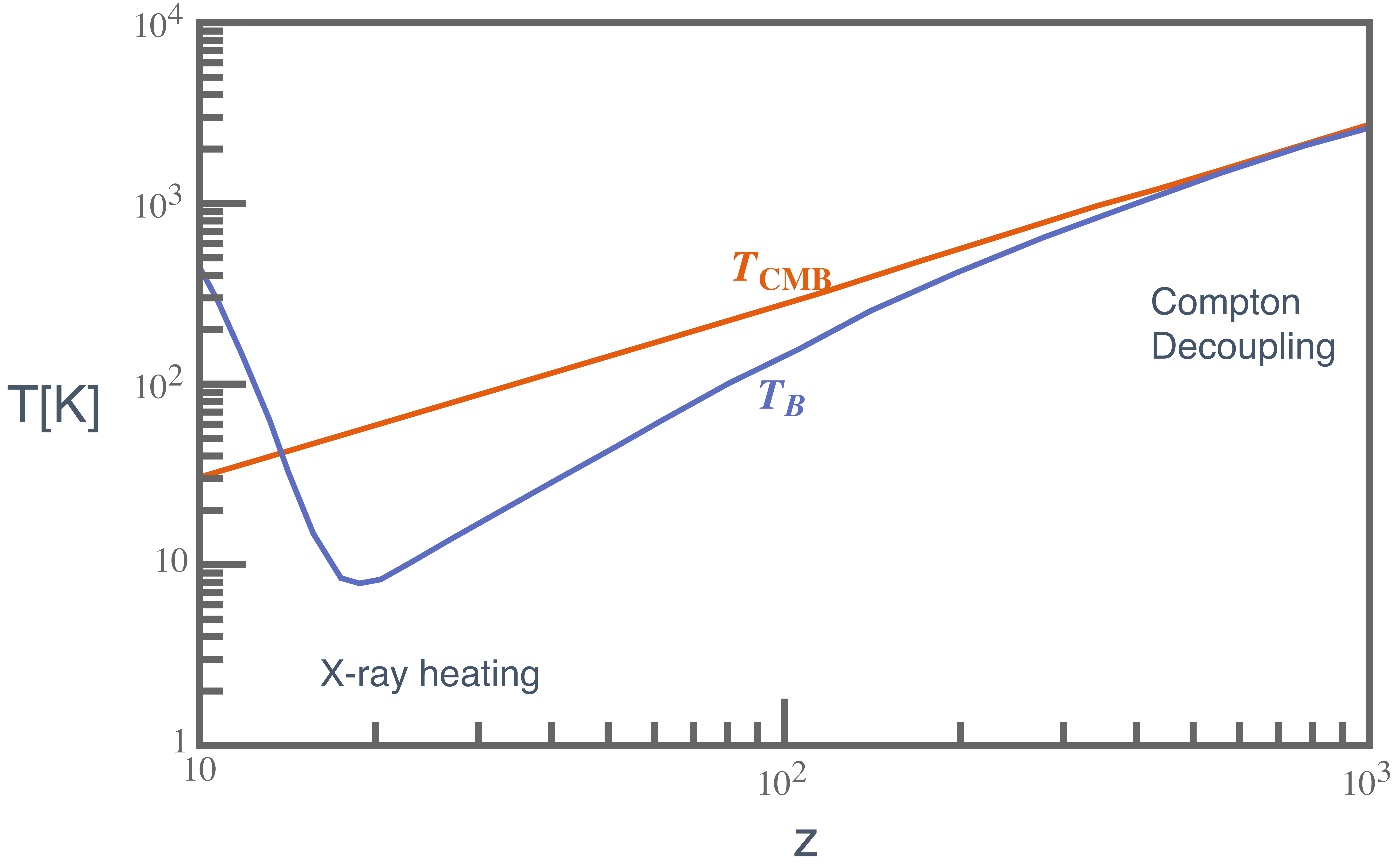


60-90 MHz
1311.0014

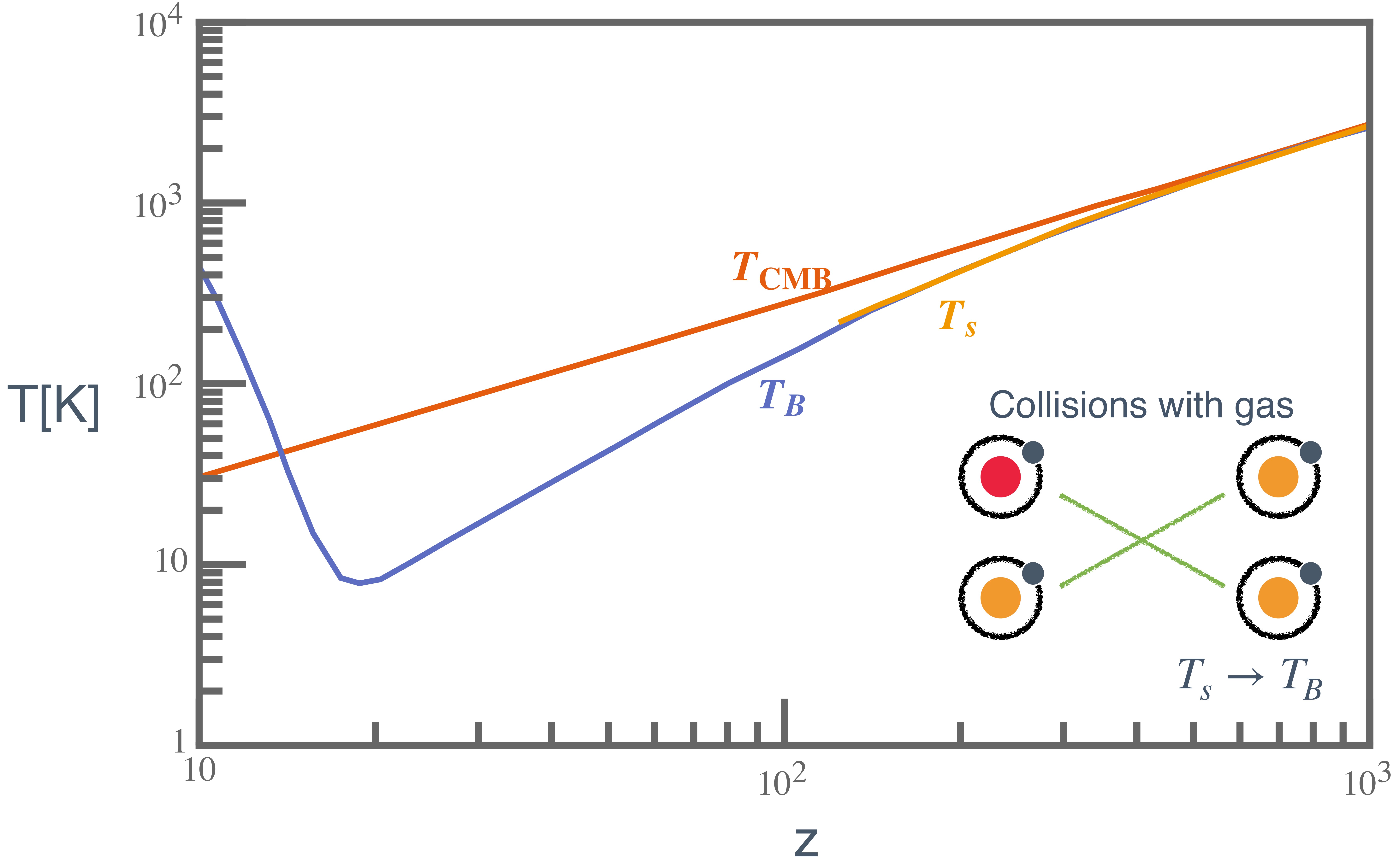
87.5-175 MHz
1710.01101

50-130 MHz
1806.09531

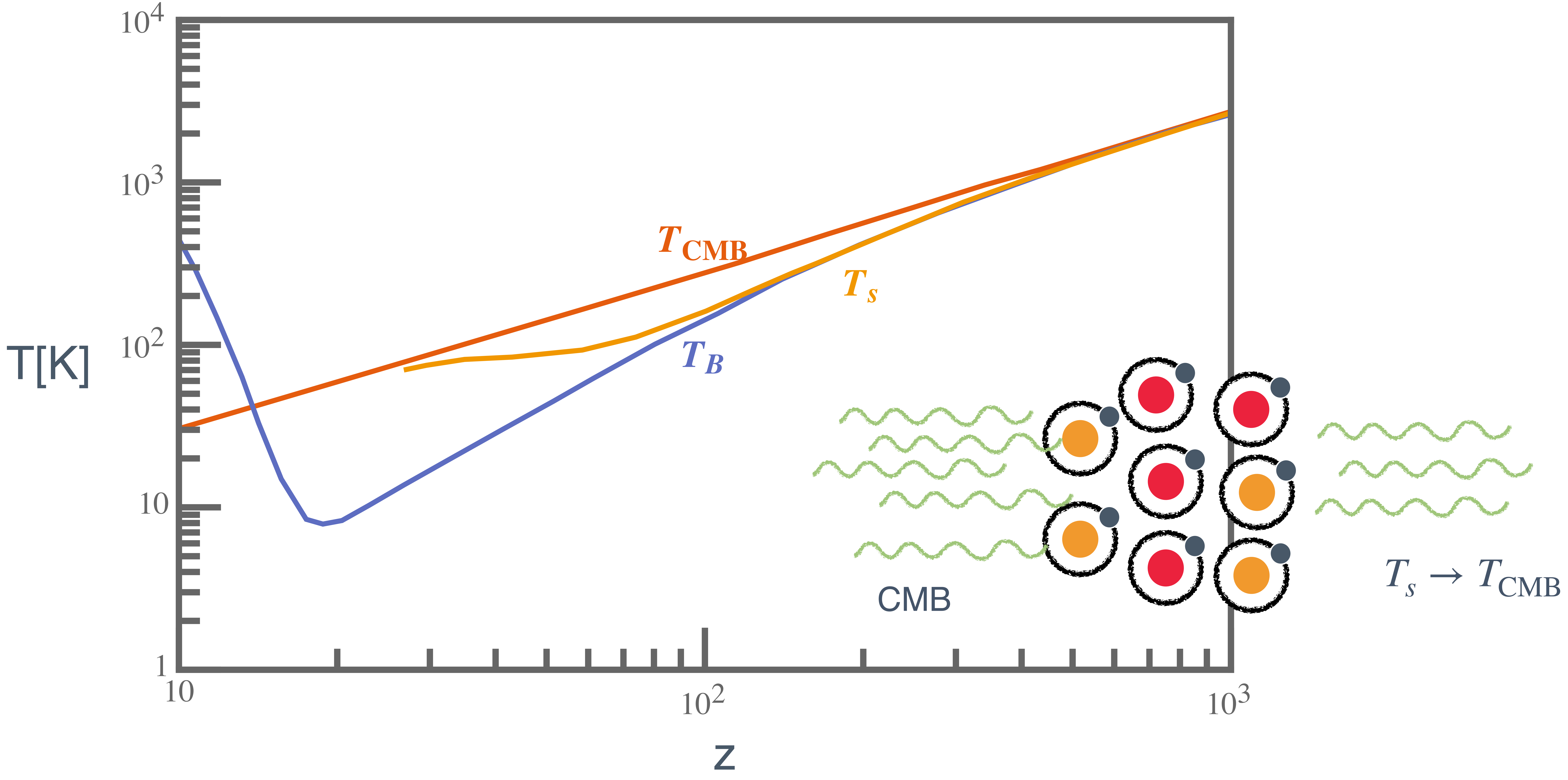
TEMPERATURE EVOLUTION



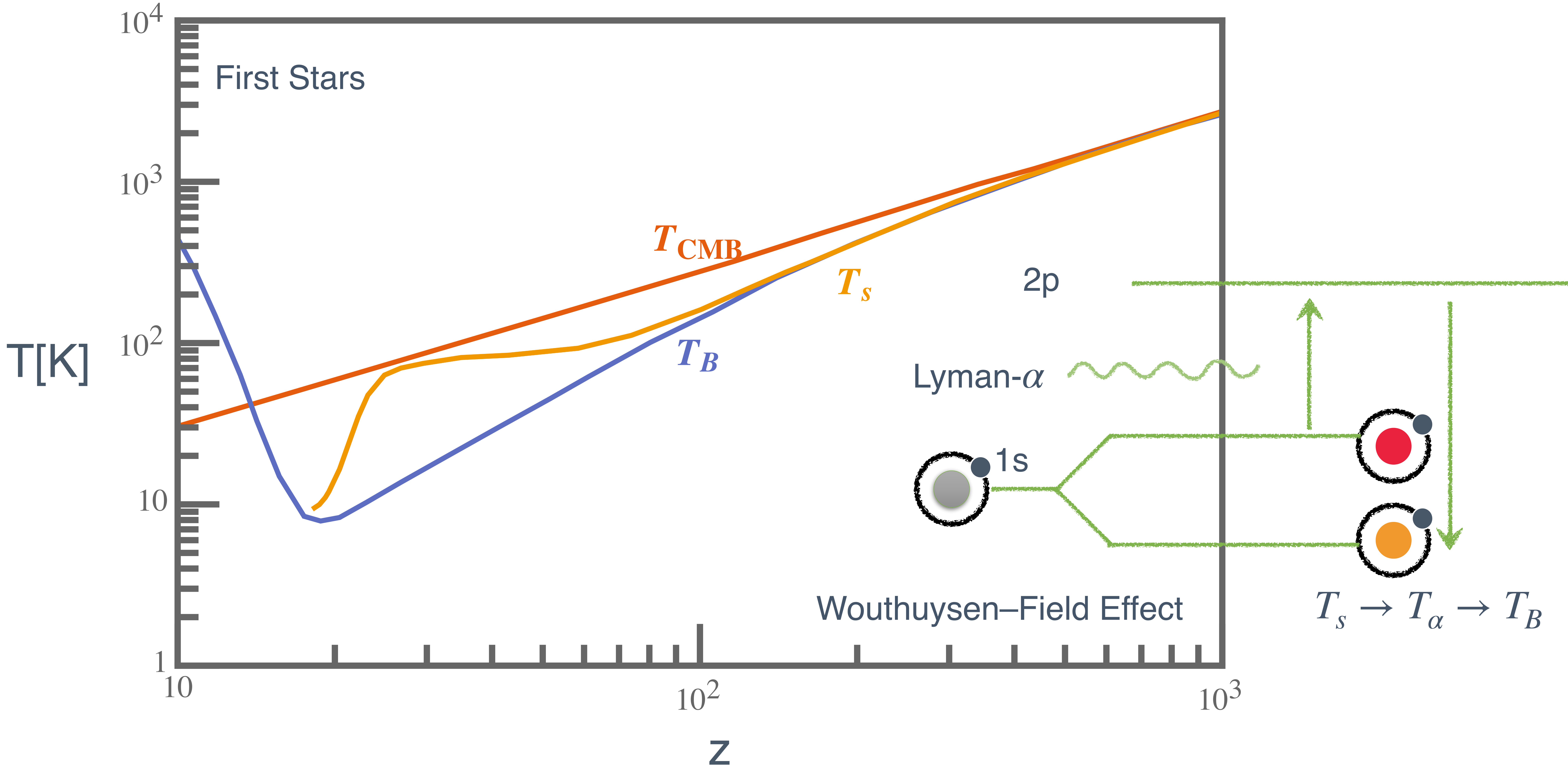
TEMPERATURE EVOLUTION



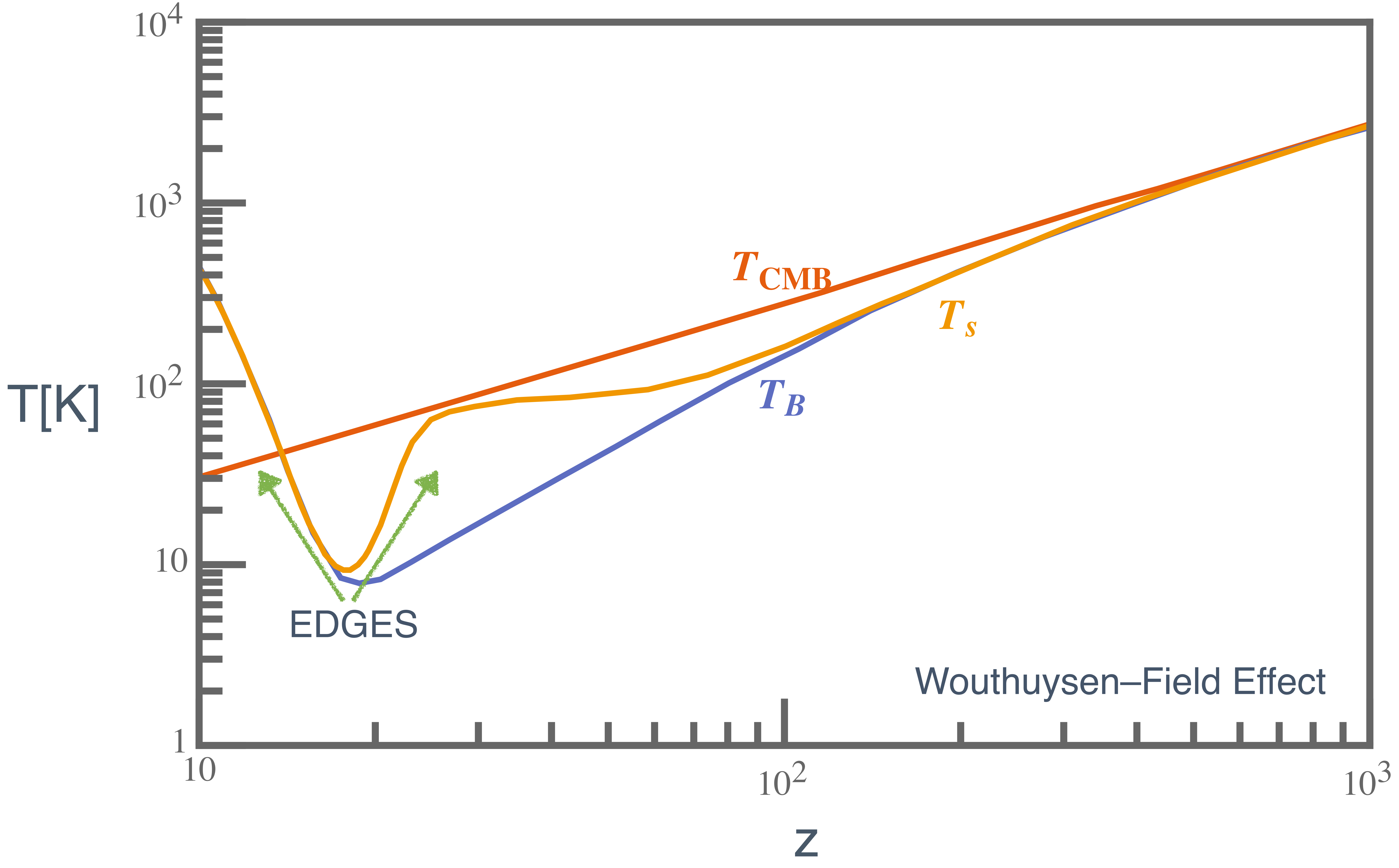
TEMPERATURE EVOLUTION



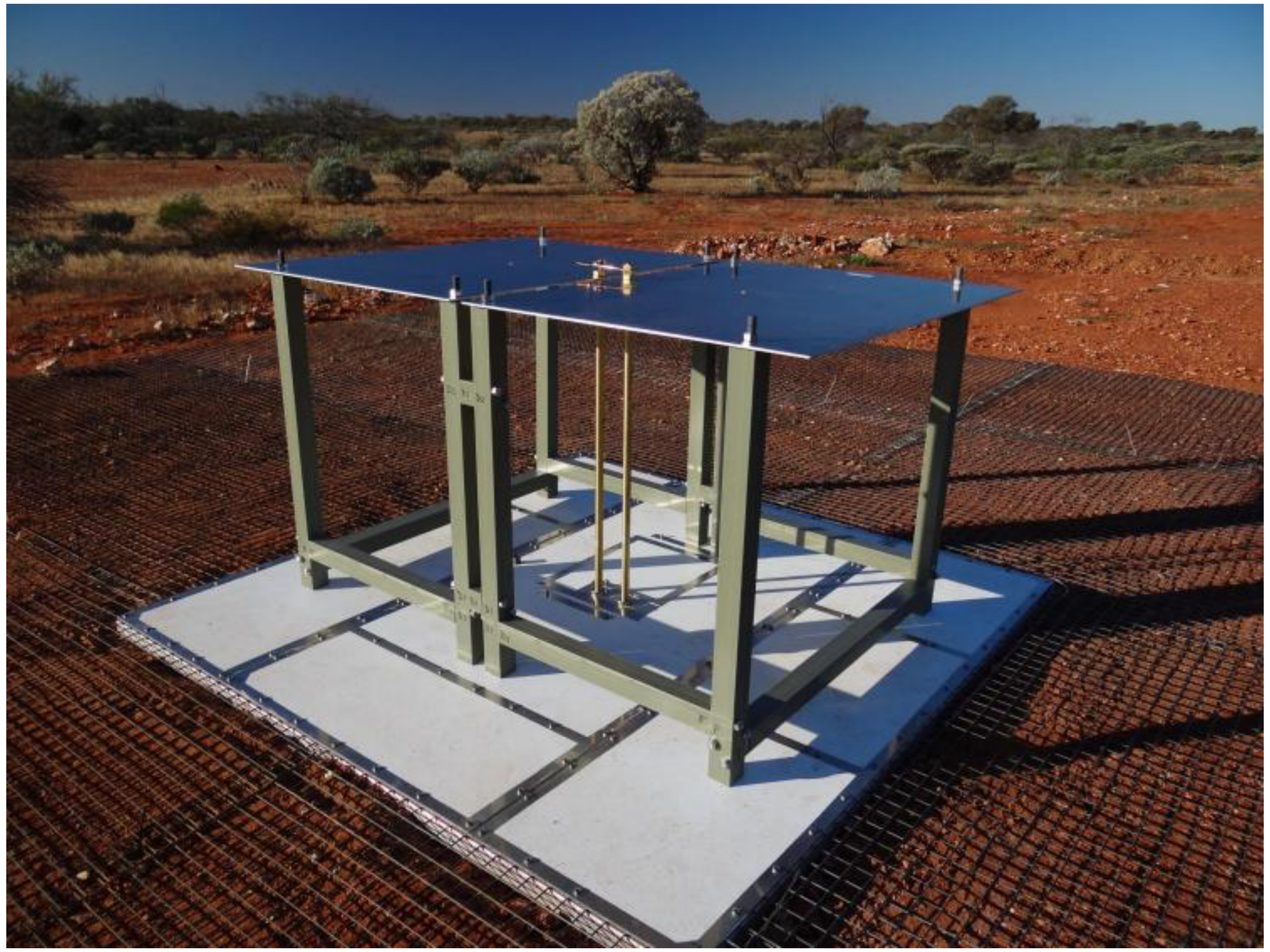
TEMPERATURE EVOLUTION



TEMPERATURE EVOLUTION

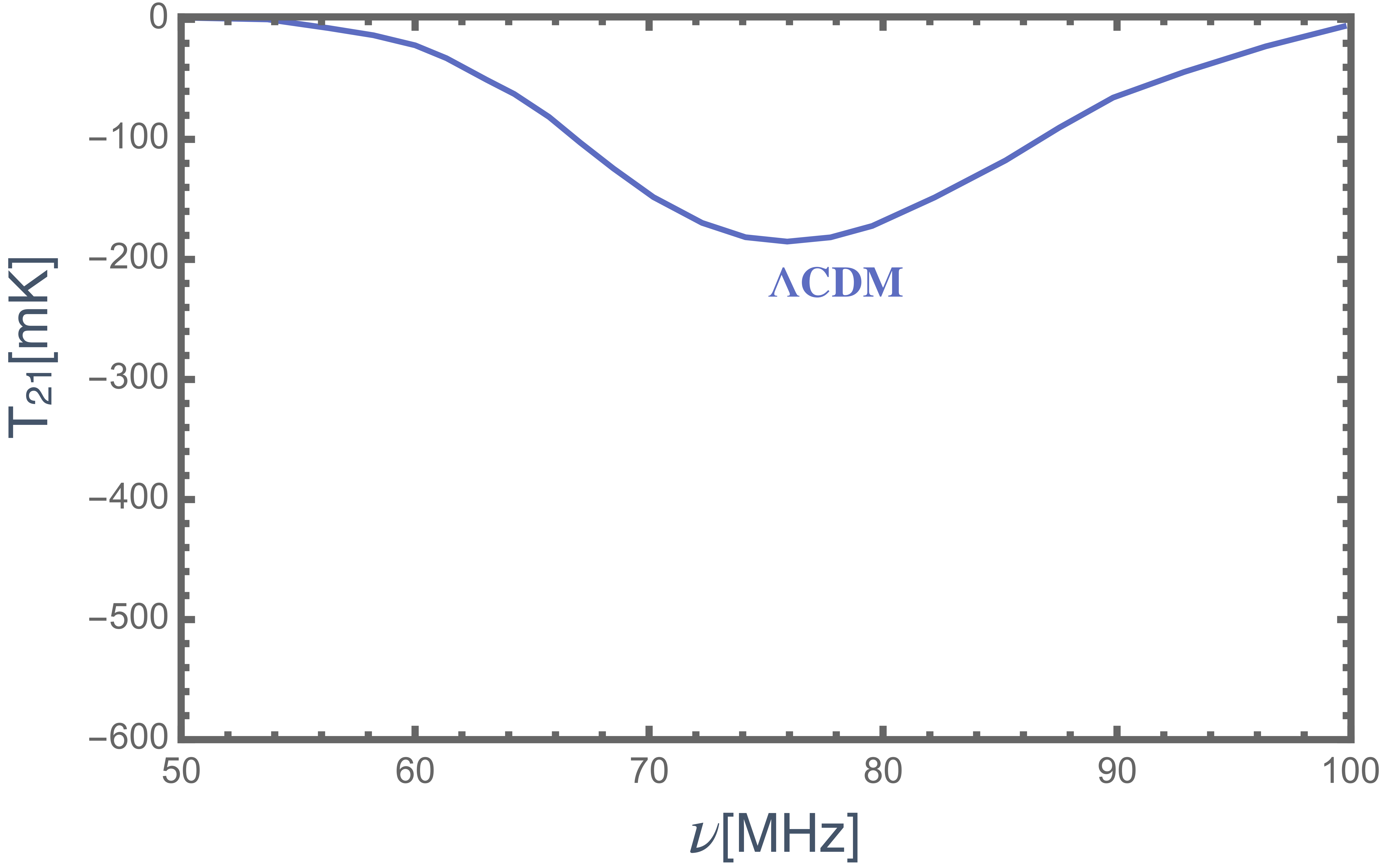


EDGES EXPERIMENT

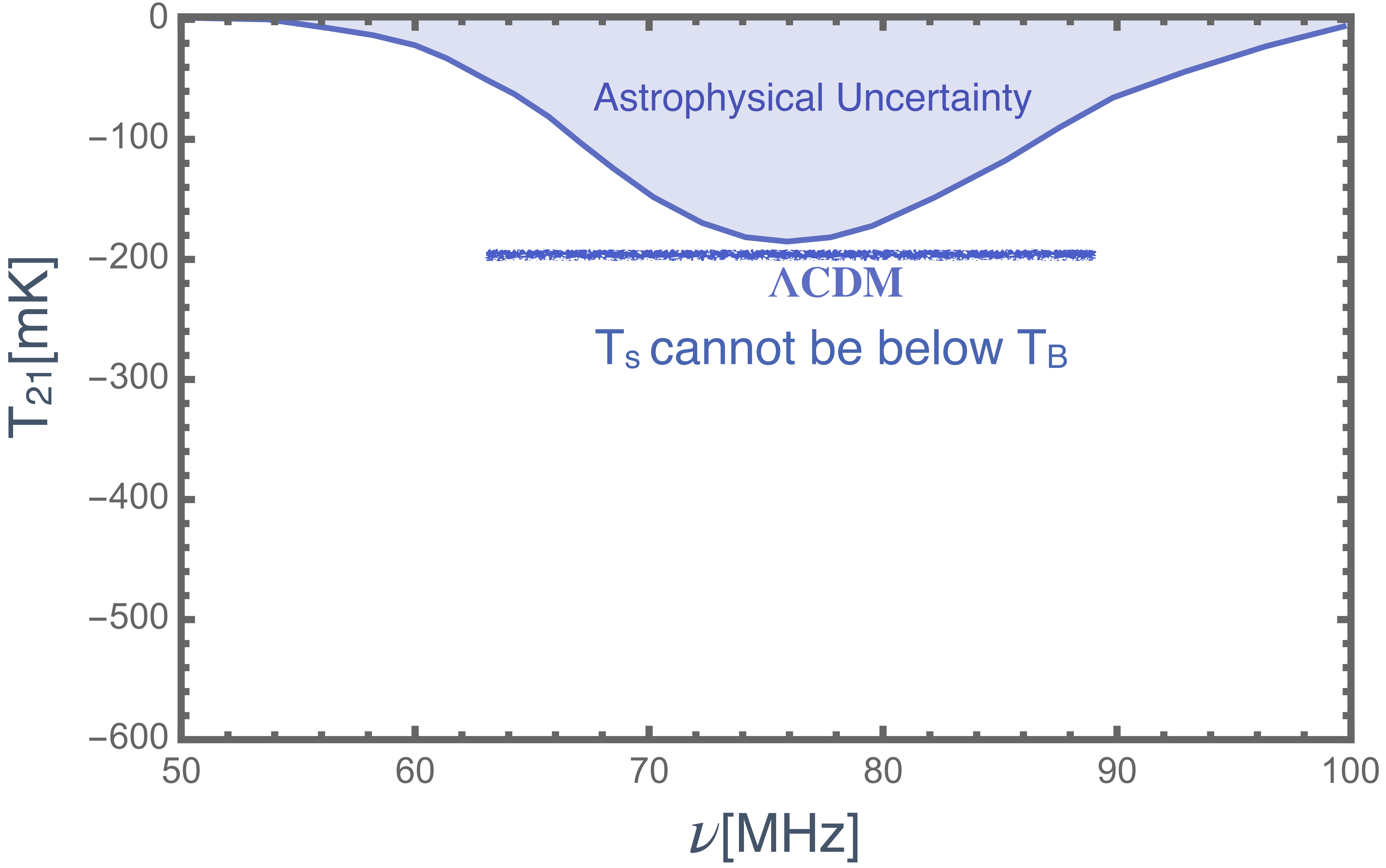


MIT-Arizona Haystack collaboration
Murchison Radio-astronomy Observatory

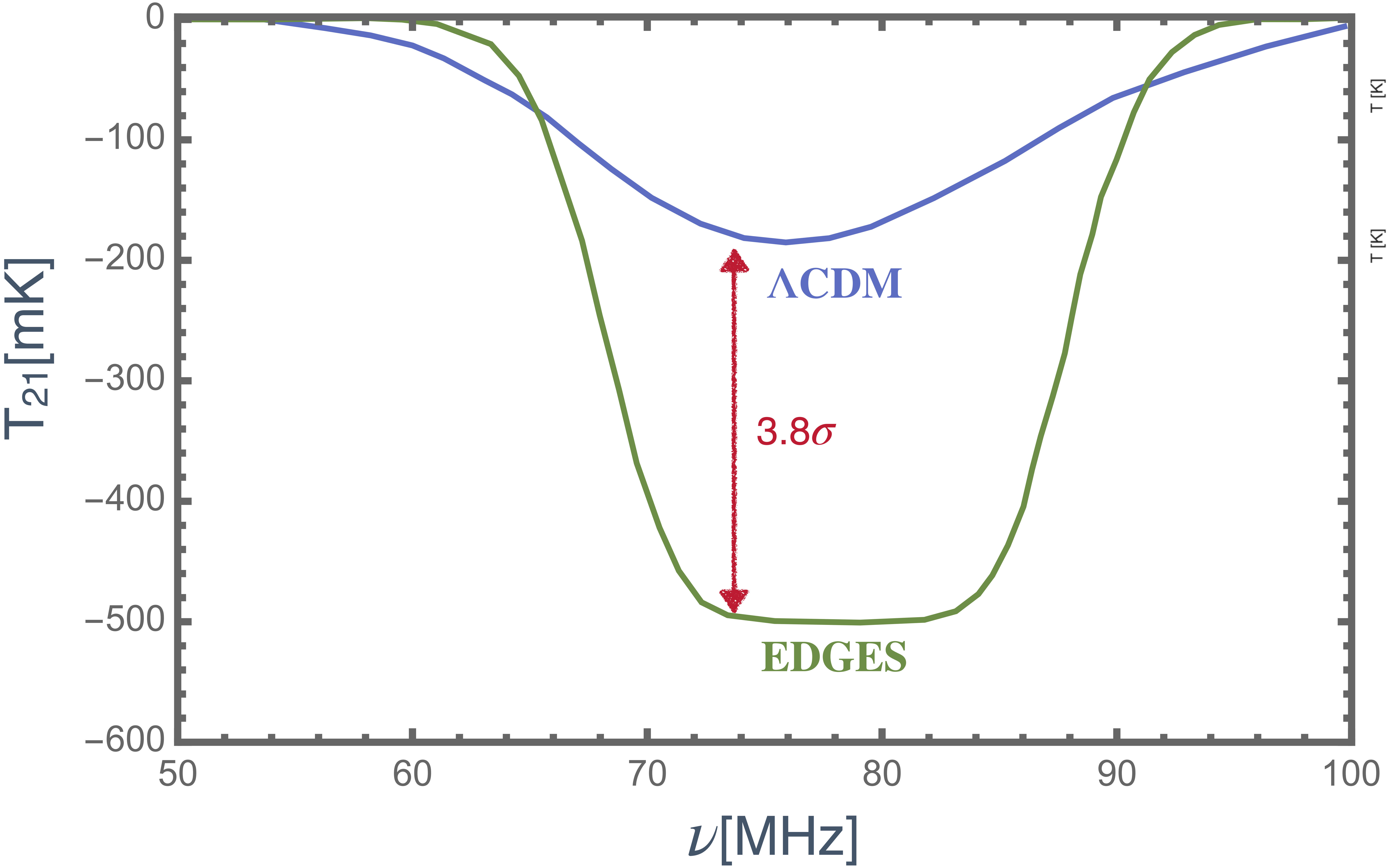
EDGES RESULT

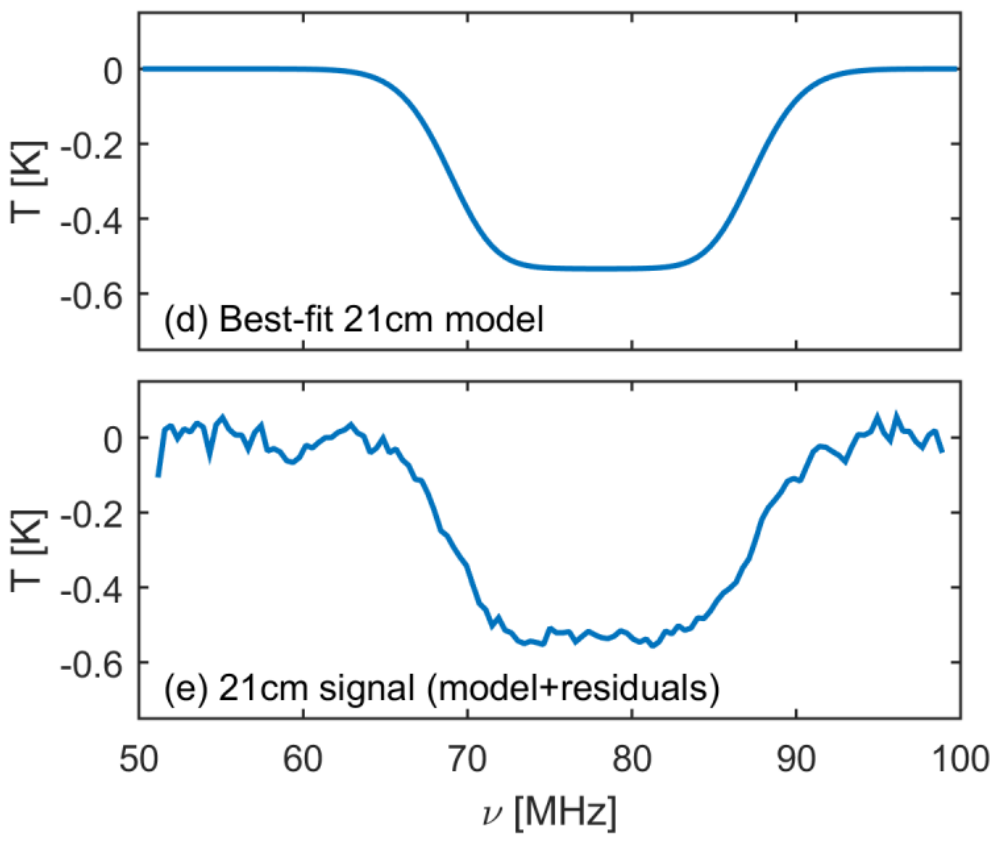


EDGES RESULT



EDGES RESULT



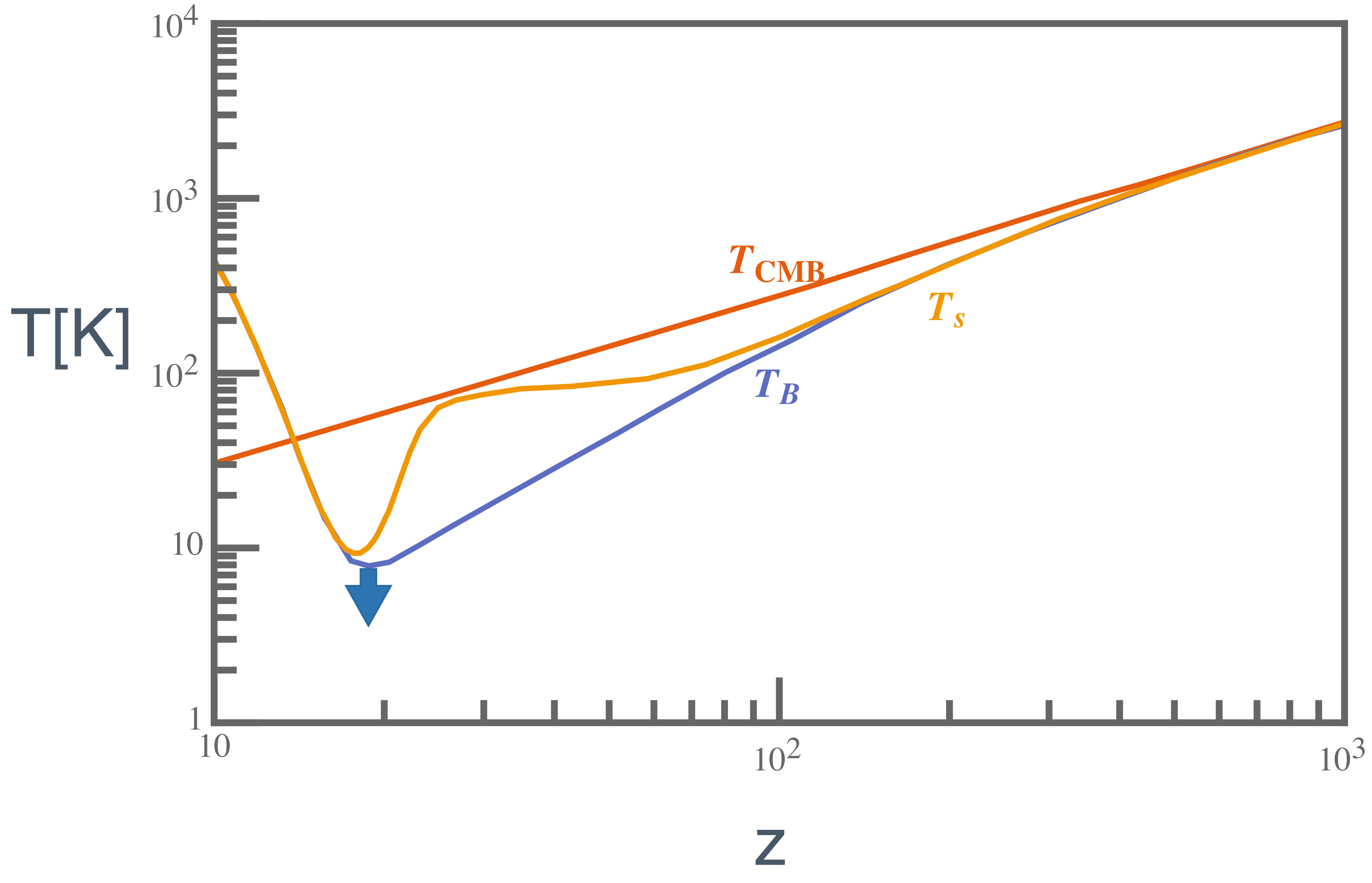


Bowman *et. al.*

Nature **555**, 67 (2018)

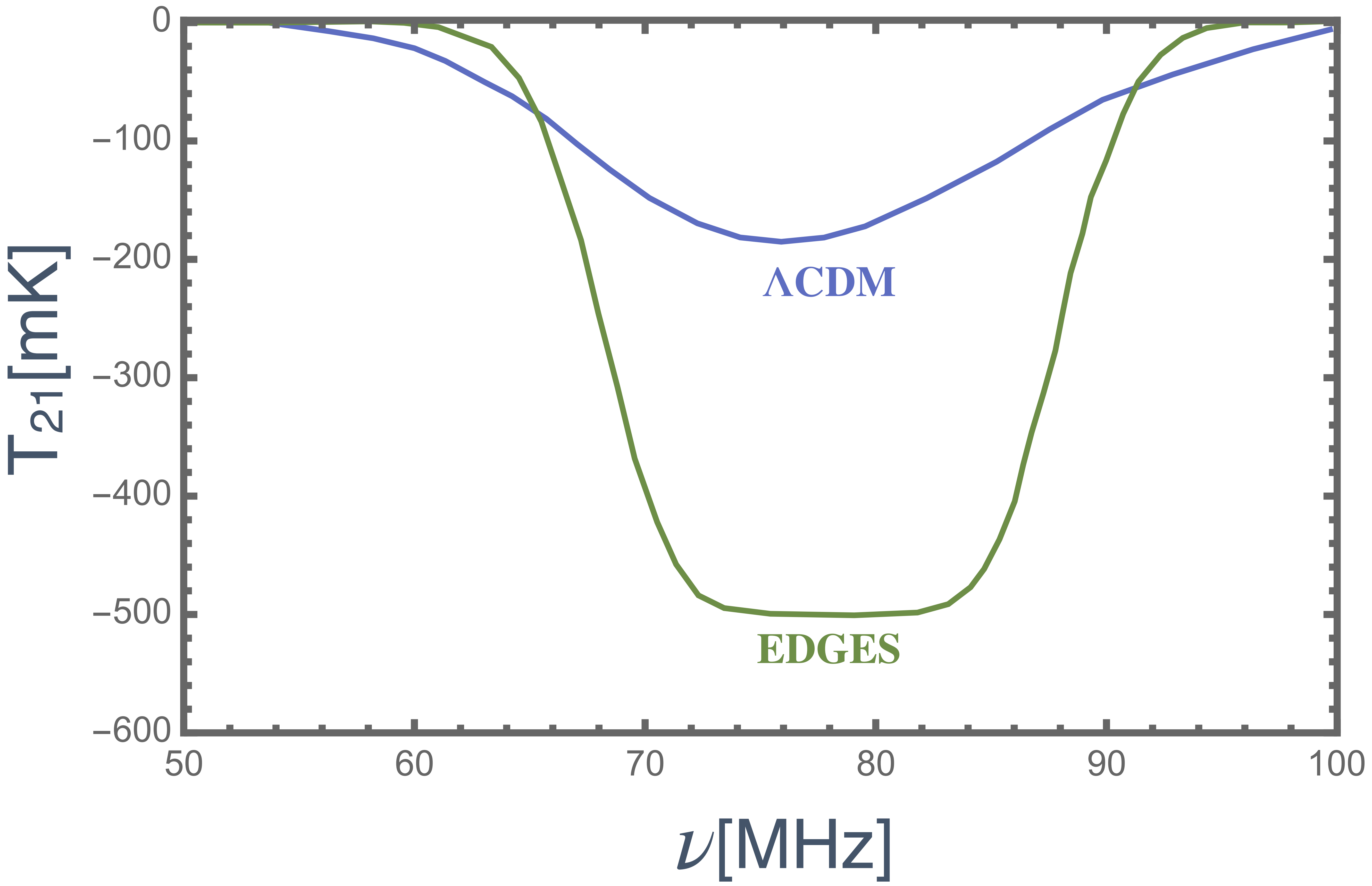
DARK MATTER EXPLANATION

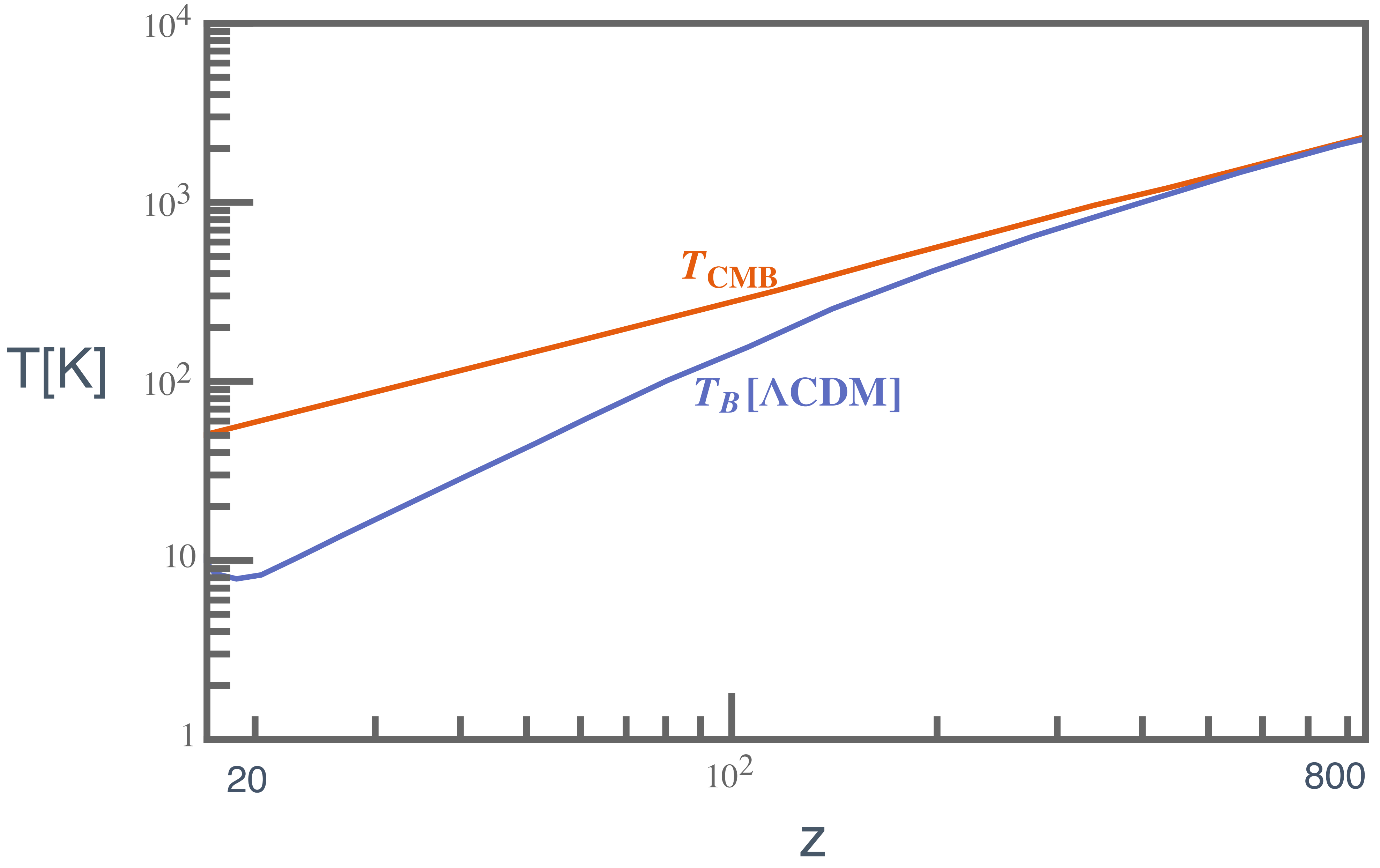
- Suggests lower $T_B = 3.26$ K (ΛCDM predicts 8 K)
- Only colder fluid - Dark Matter
- Large x-sections required
- Long range interactions (coldest epoch)
- Milli-charge [fractionally charged] dark matter



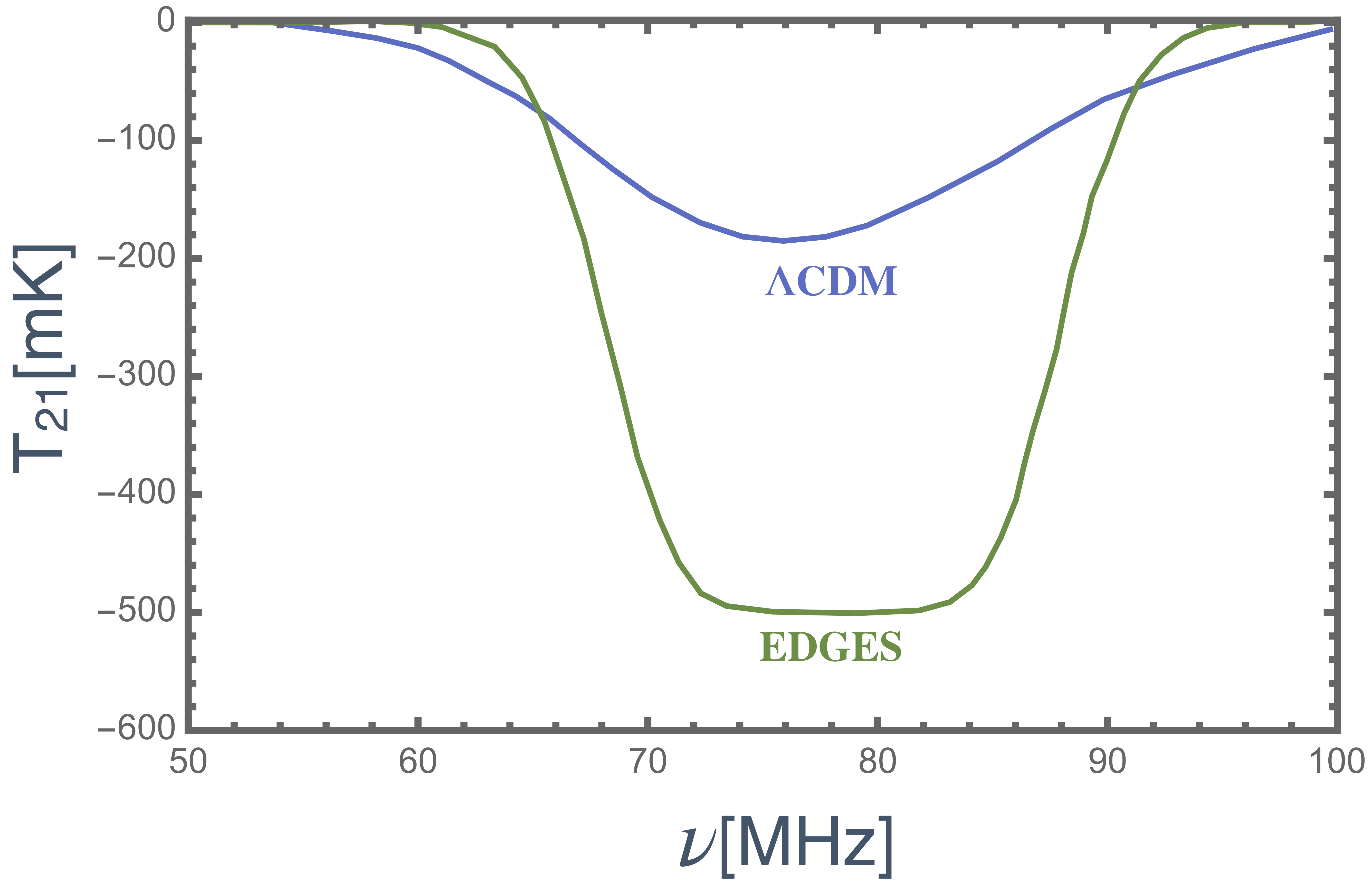
1802.10094 Munoz, Loeb
1803.03091 Barkana et. al.
1803.02804 Berlin et. al.
1807.11482 Kovetz et. al.
1903.09154 Creque-Sarbinowski et. al.

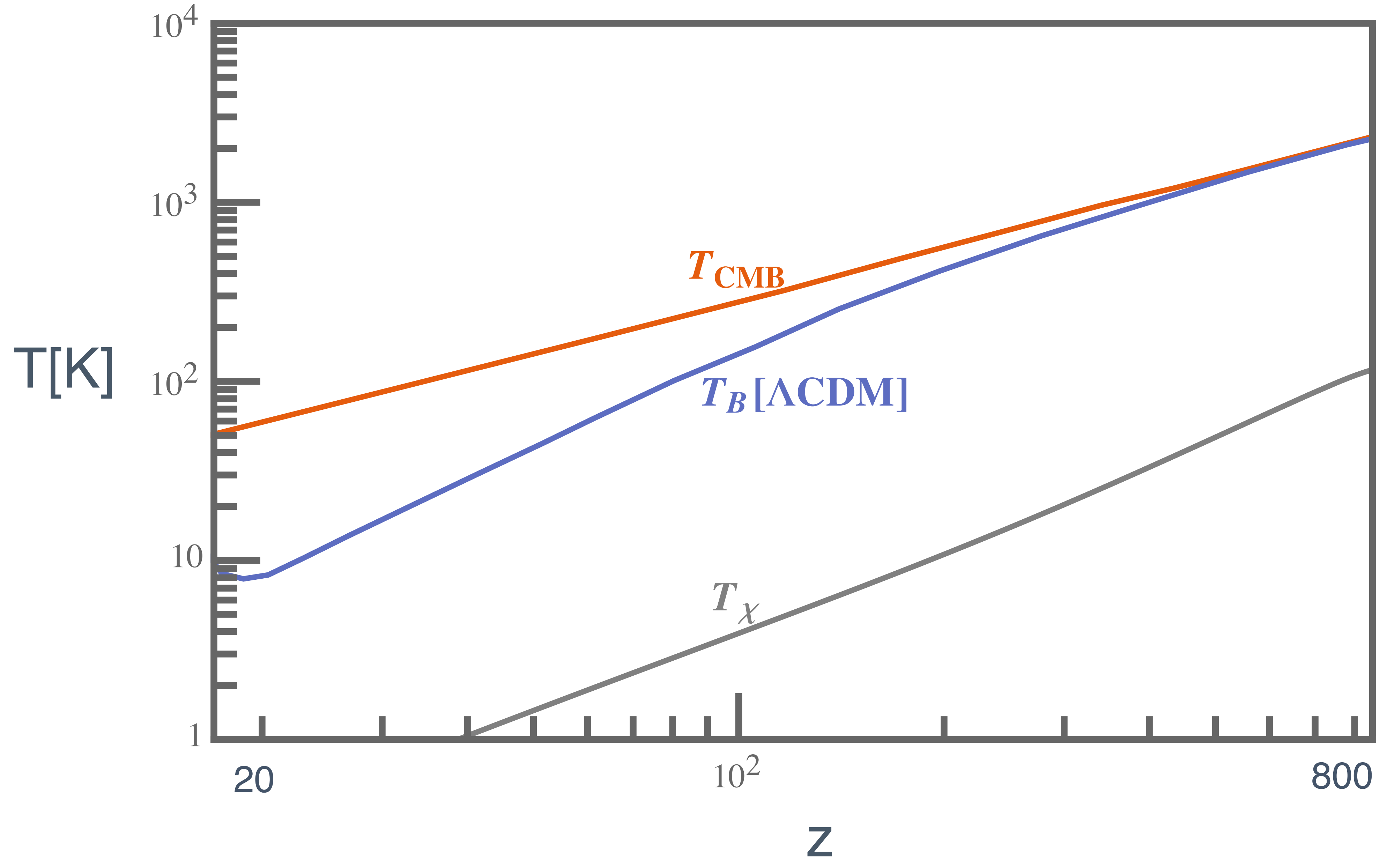
MILLI-CHARGE EXPLANATION



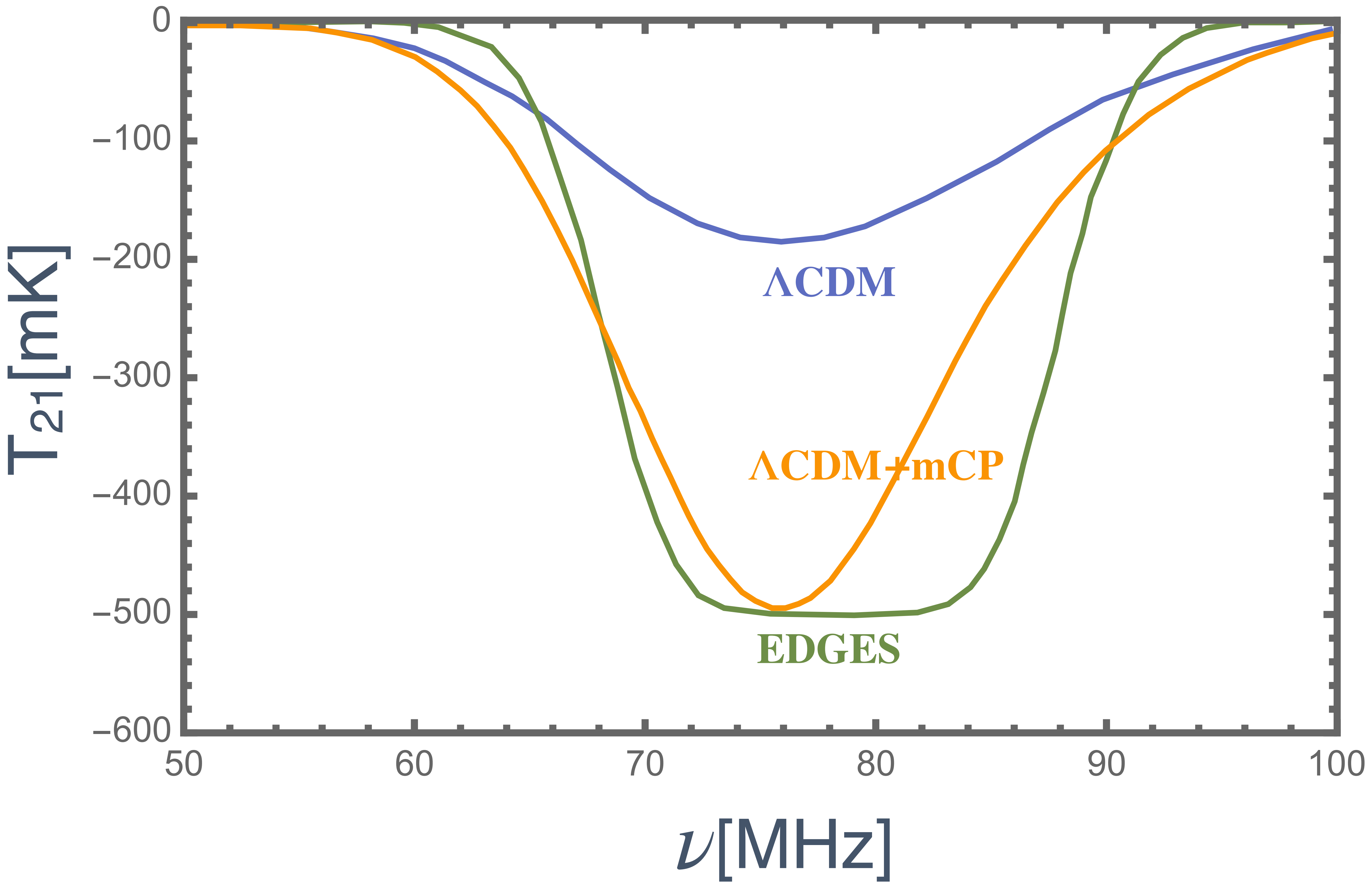


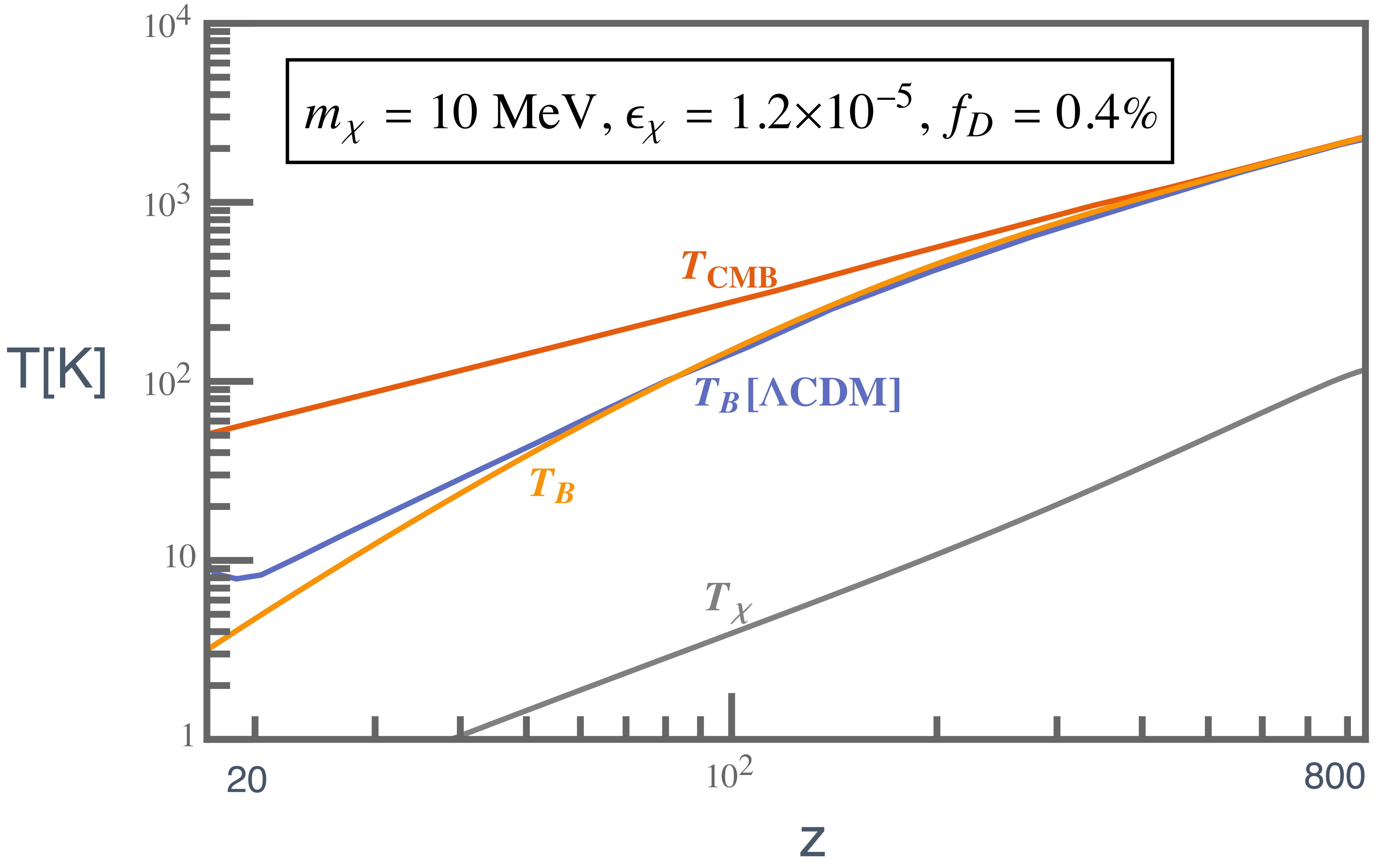
MILLI-CHARGE EXPLANATION



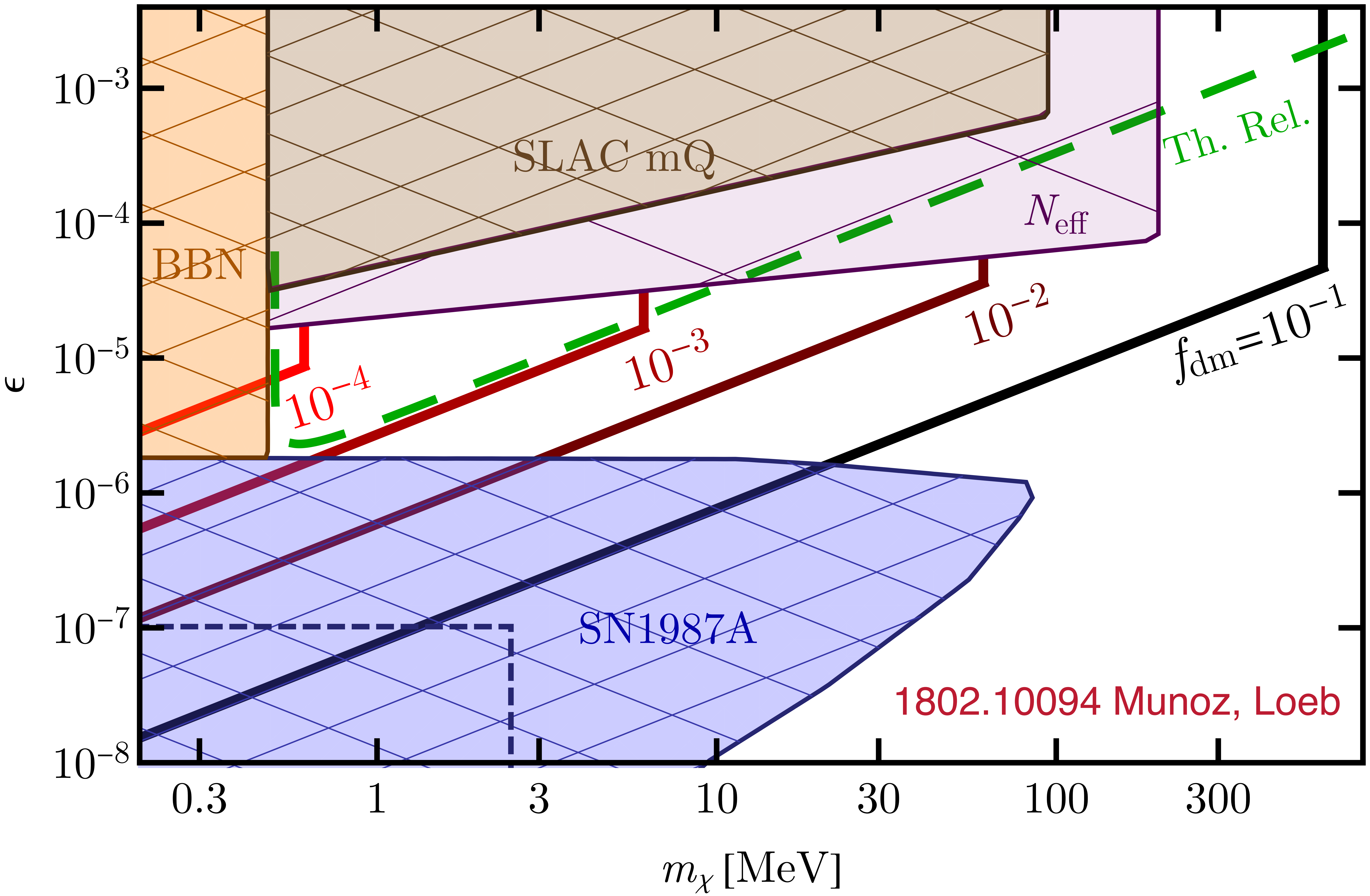


MILLI-CHARGE EXPLANATION



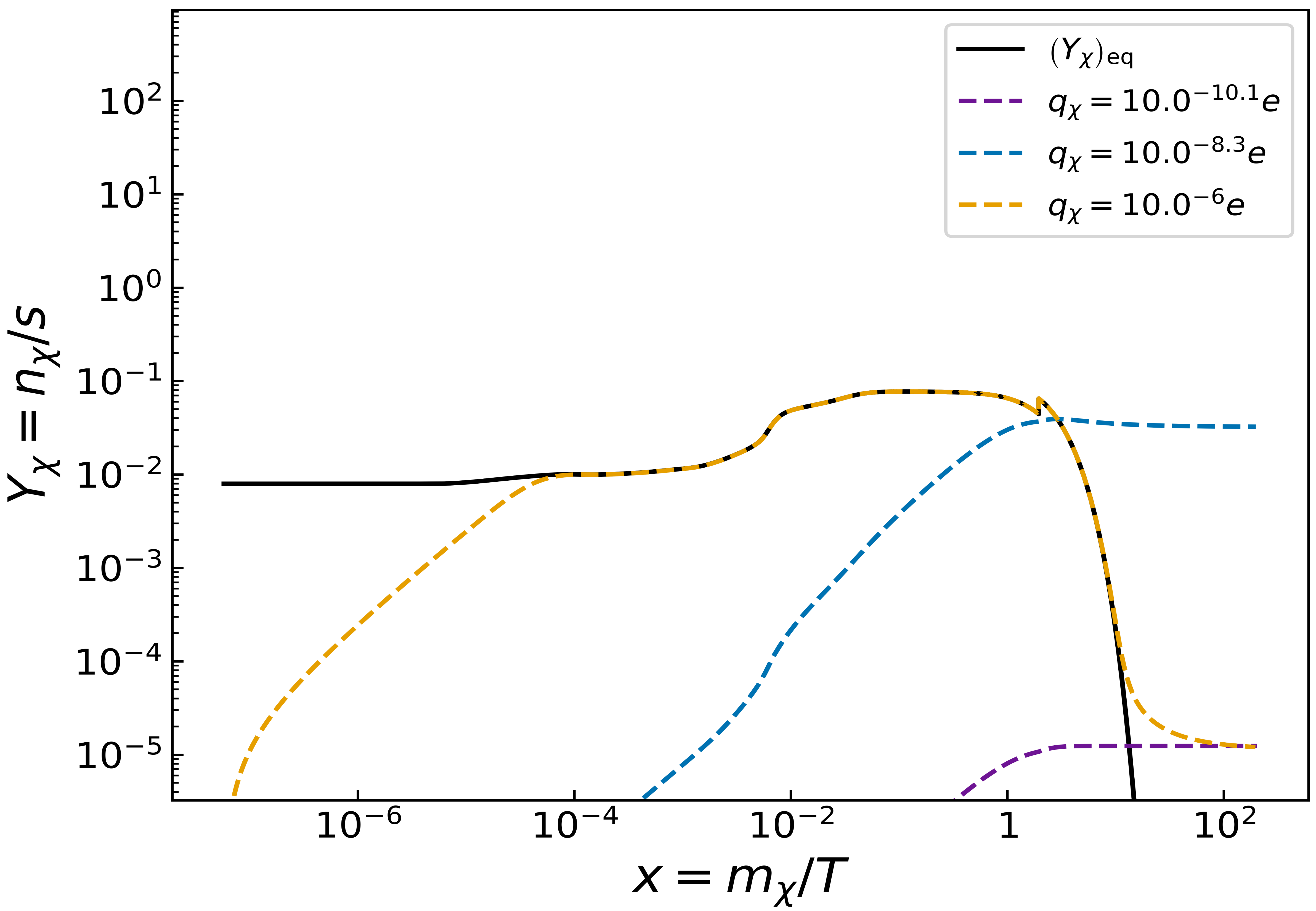


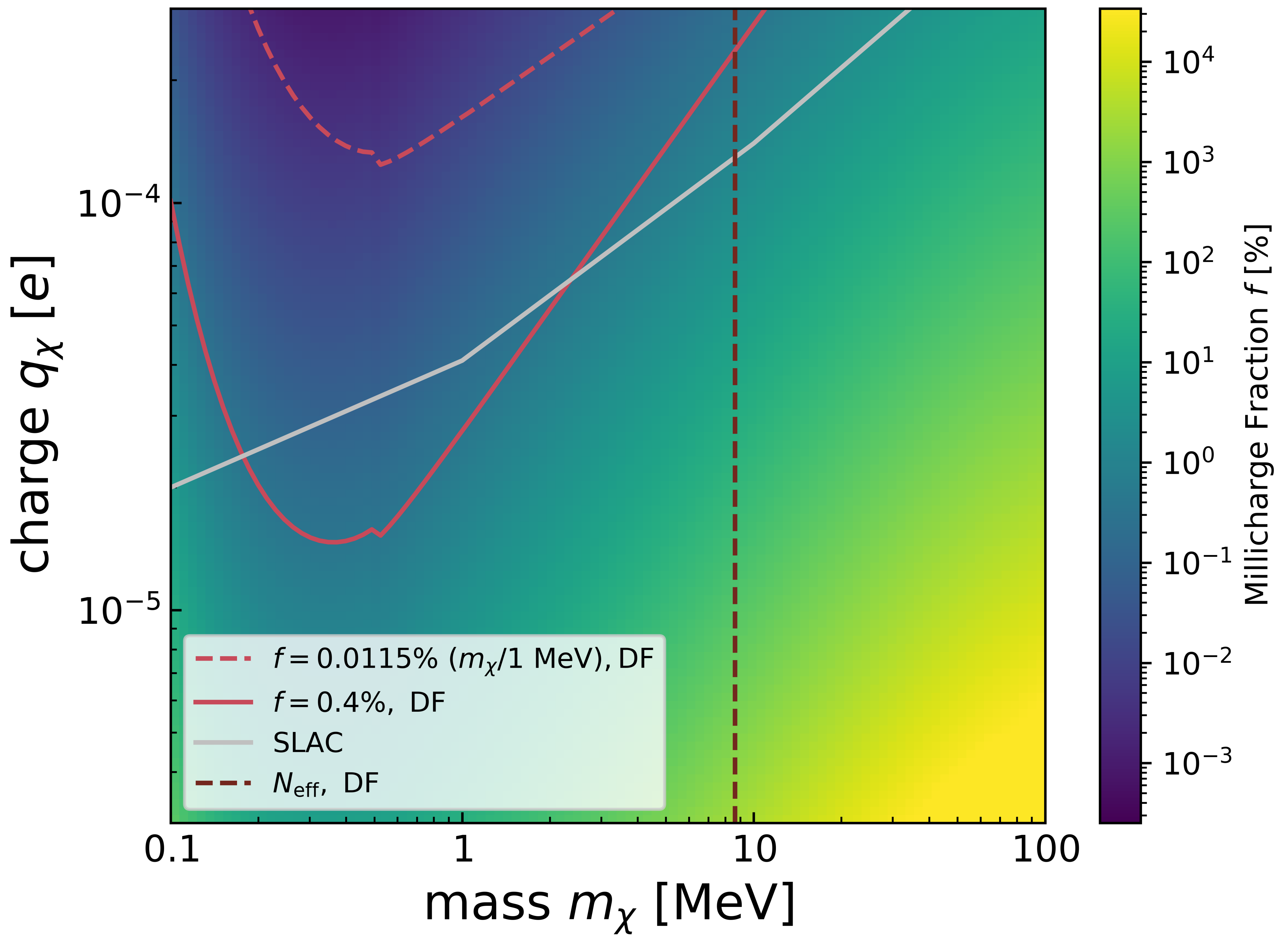
CONSTRAINTS



Neff

1903.09154 Creque-Sarbinowski et. al.





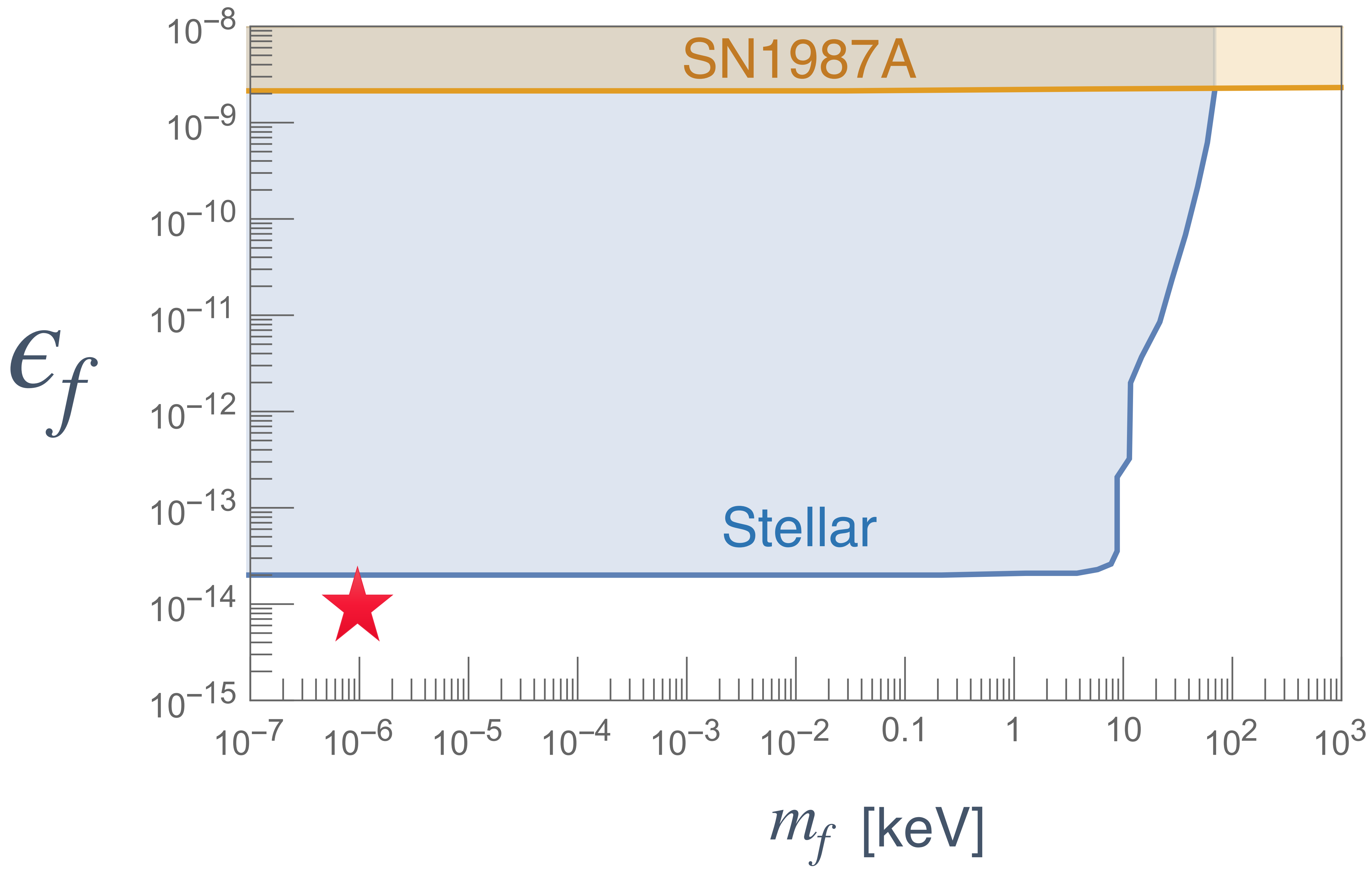
$$\frac{q_\chi}{e} \gtrsim 10^{-8.5} \left(\frac{g_\rho(m_\chi)}{10}\right)^{\frac{1}{4}} \left(\frac{g_s(m_\chi)}{g_c(m_\chi)}\right)^{\frac{1}{2}} \left(\frac{m_\chi}{1\ \mathrm{MeV}}\right)^{\frac{1}{2}}$$

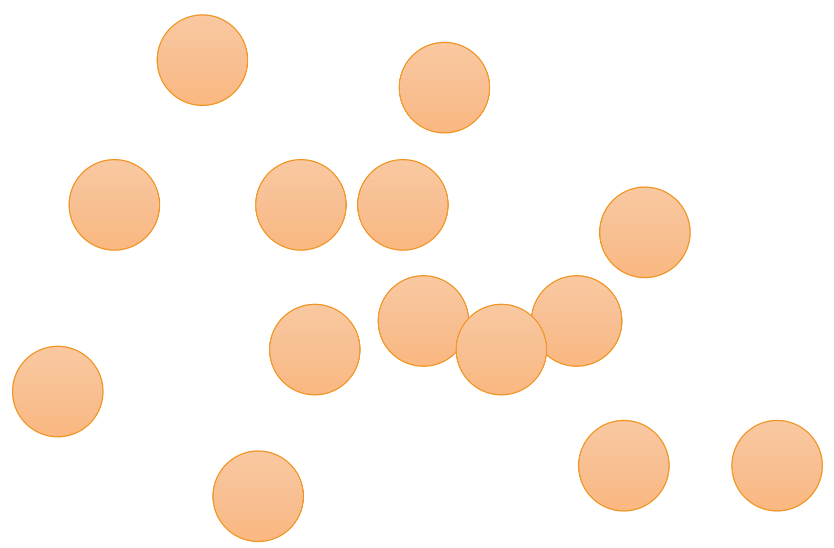
WAY OUT

- For elementary mCP the same particle is the relevant DoF in
  - Colliders / Beam dumps
  - Stars/SN
  - Early Universe
- mCP are large nuclei?

MODEL

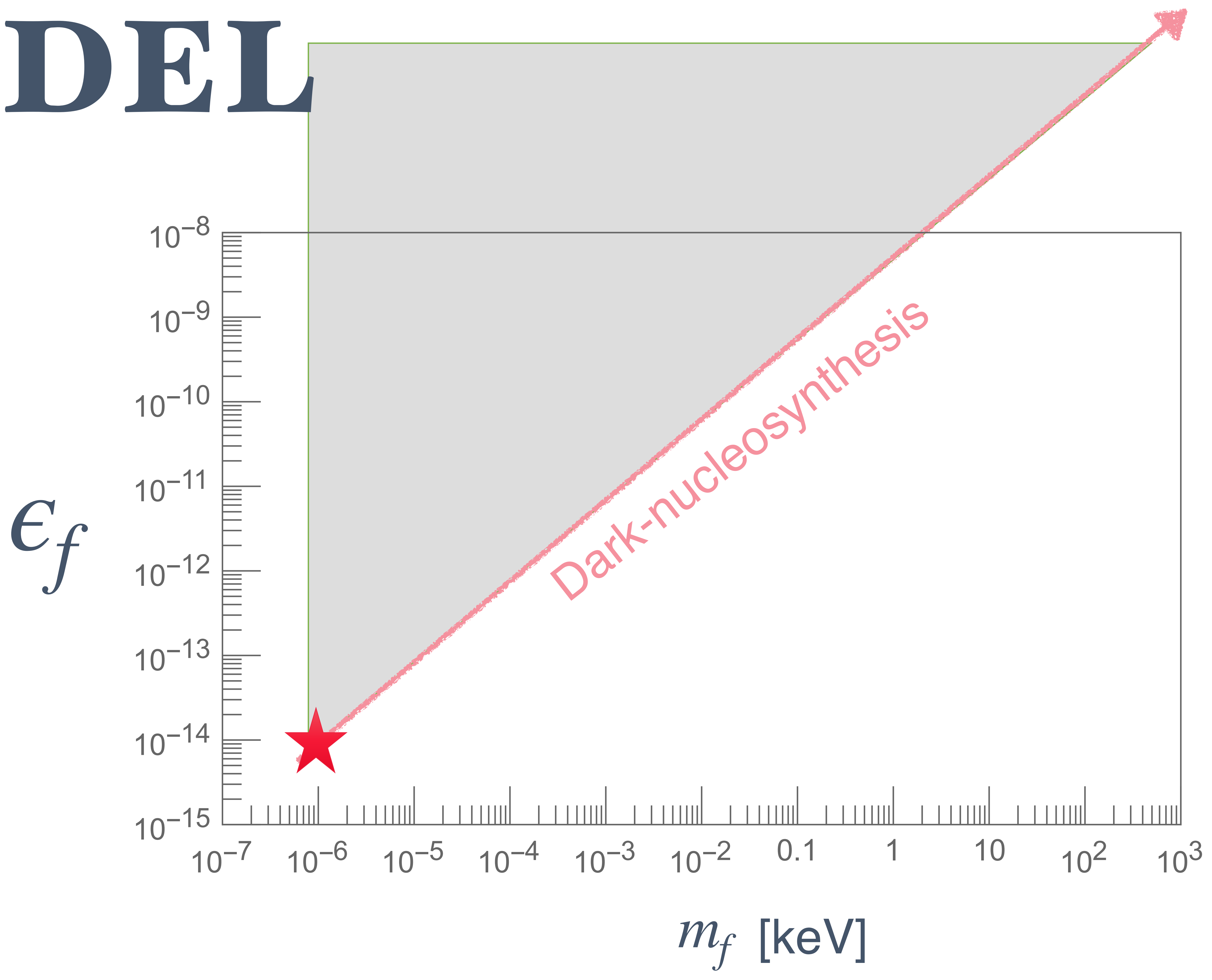
- ✦ mCP f
- ✦ With mass $m_f \approx$ meV
- ✦ Charge $\epsilon_f \lesssim 10^{-14}$ evades
  - Stellar constraints
  - No chemical equilibrium
- ✦ f has charge g_f under dark photon

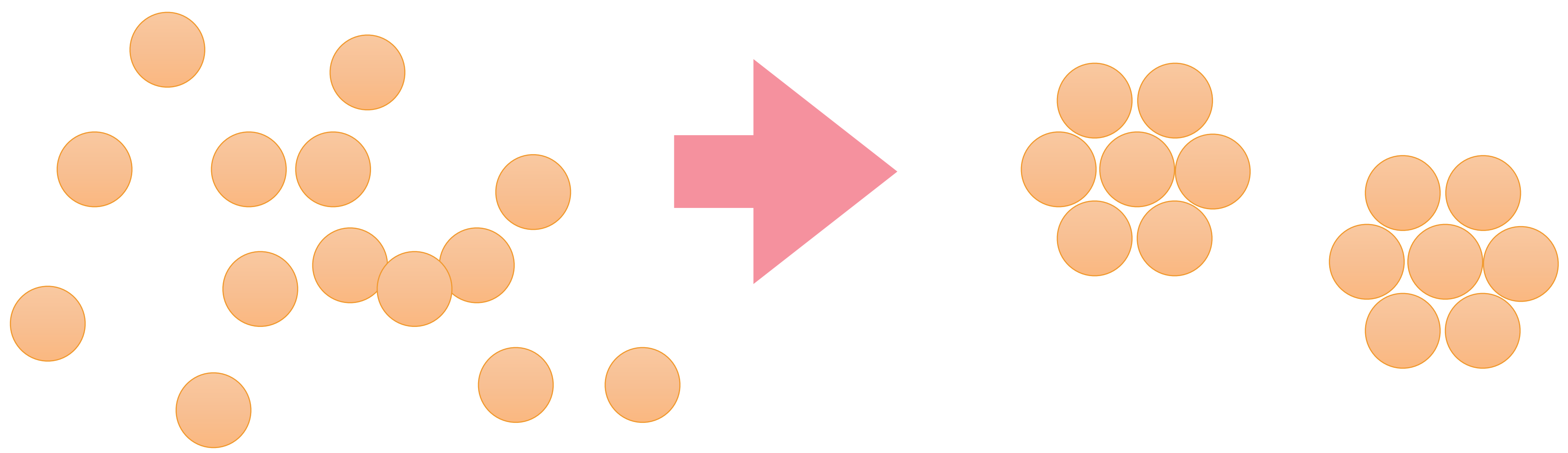




MODEL

- f are dark nucleons [asymmetric]
- Confine and form at $\Lambda_D \lesssim m_f$
- Form large nuclei: $m_\chi = A m_f$ & charge $\epsilon_\chi = A\epsilon_f$
- χ nuclei poorly constrained & explain EDGES



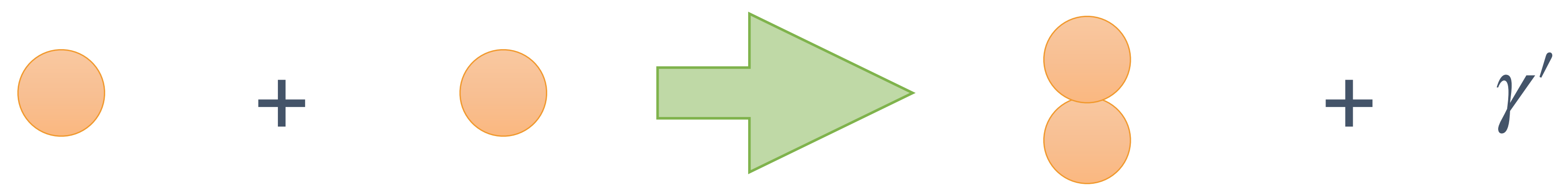


DARK NULEOSYNTHESIS

- When $T_D \leq \Lambda_D$, dark nucleosynthesis can begin

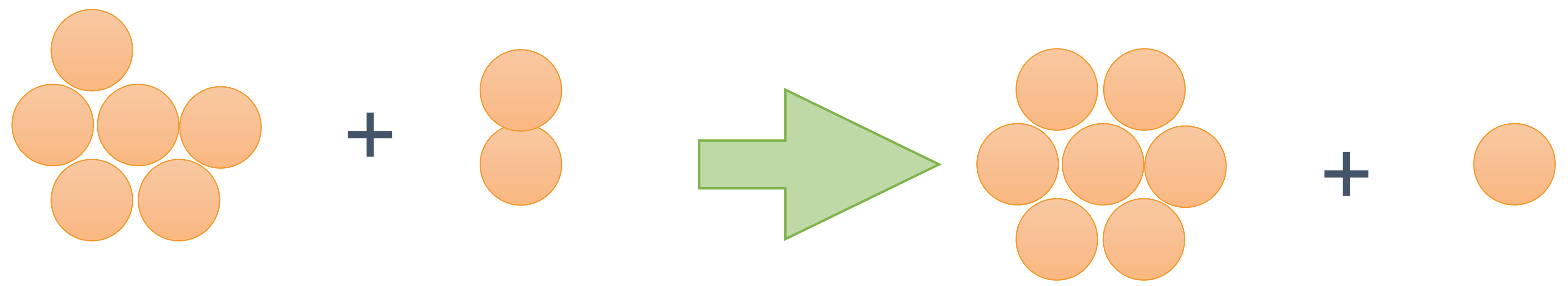
- Start with: ${}^1\chi + {}^1\chi \rightarrow {}^2\chi + \gamma'$

$${}^1\chi = f$$

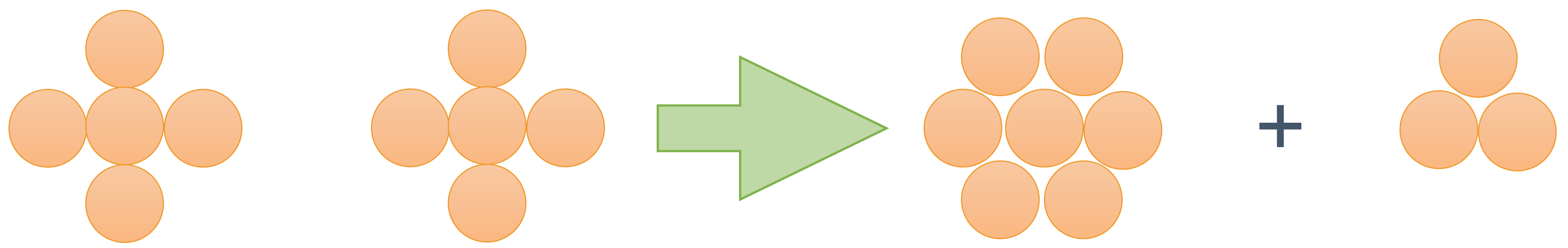


- Further fusion can go through

- ${}^A\chi + {}^2\chi \rightarrow {}^{A+1}\chi + {}^1\chi$



- ${}^A\chi + {}^B\chi \rightarrow {}^{A+B-r}\chi + {}^r\chi$



1406.1171 Krnjaic Sigurdson
1411.3739 Hardy, Lasenby, March-Russell, West

FUSION RATE

- Fusion always dominates Hubble : Immediate
- $$\frac{n\sigma_{\text{fusion}}v}{H} \approx \mathbf{10^{32}} \left(\frac{f_D z^{\frac{3}{2}}}{A^{\frac{3}{2}}} \frac{(10\text{K})^3}{\Lambda_D^2 \sqrt{m_f^3/T_D}} \right)$$

Geometric x-section assumed

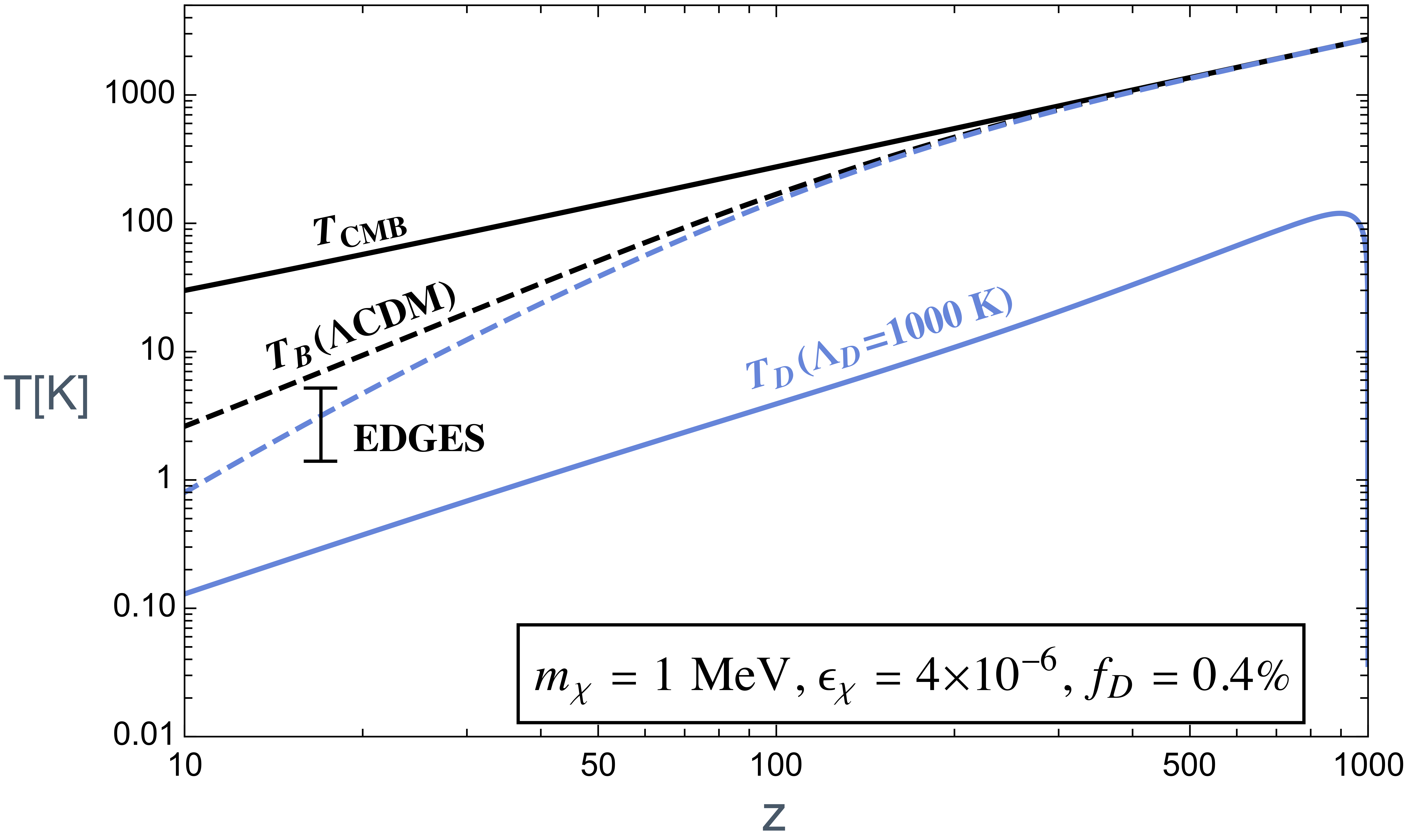
$$\frac{1}{\text{meV}^2} \approx 4 \times 10^{-4}\text{cm}^2$$

K = kelvin

$1\ \text{K} \approx 10^{-4}\text{eV}$

- Coulomb barrier important for large nuclei
- Gamow limit for small-large : $A^{\text{lim}}_{\text{gamow}} \approx g_D^{-2}$ [Stronger than stability]
- Rapid growth into nuclei upto this size
- Fix g_D to make $A^{\text{lim}}_{\text{gamow}} = \dfrac{\epsilon_{\text{EDGES}}}{\epsilon_f}$

SNEAK PEAK

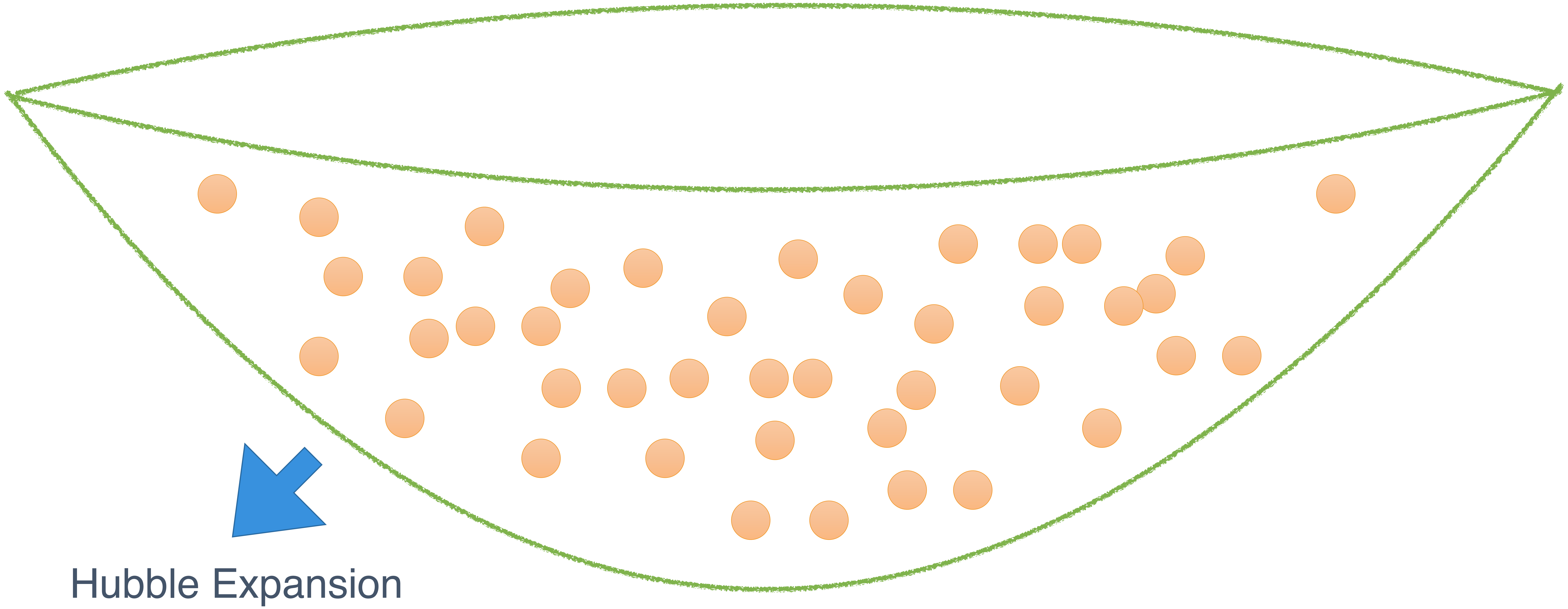


1000
100
10
1
0.10
0.01
T[K]
10
50
100
500
1000
z
T_{CMB}
$T_B(\Lambda CDM)$
EDGES
$T_D(\Lambda_D=1000\text{ K})$
$m_\chi = 1$ MeV, $\epsilon_\chi = 4\times10^{-6}$, $f_D = 0.4\%$

HEATING VS HUBBLE

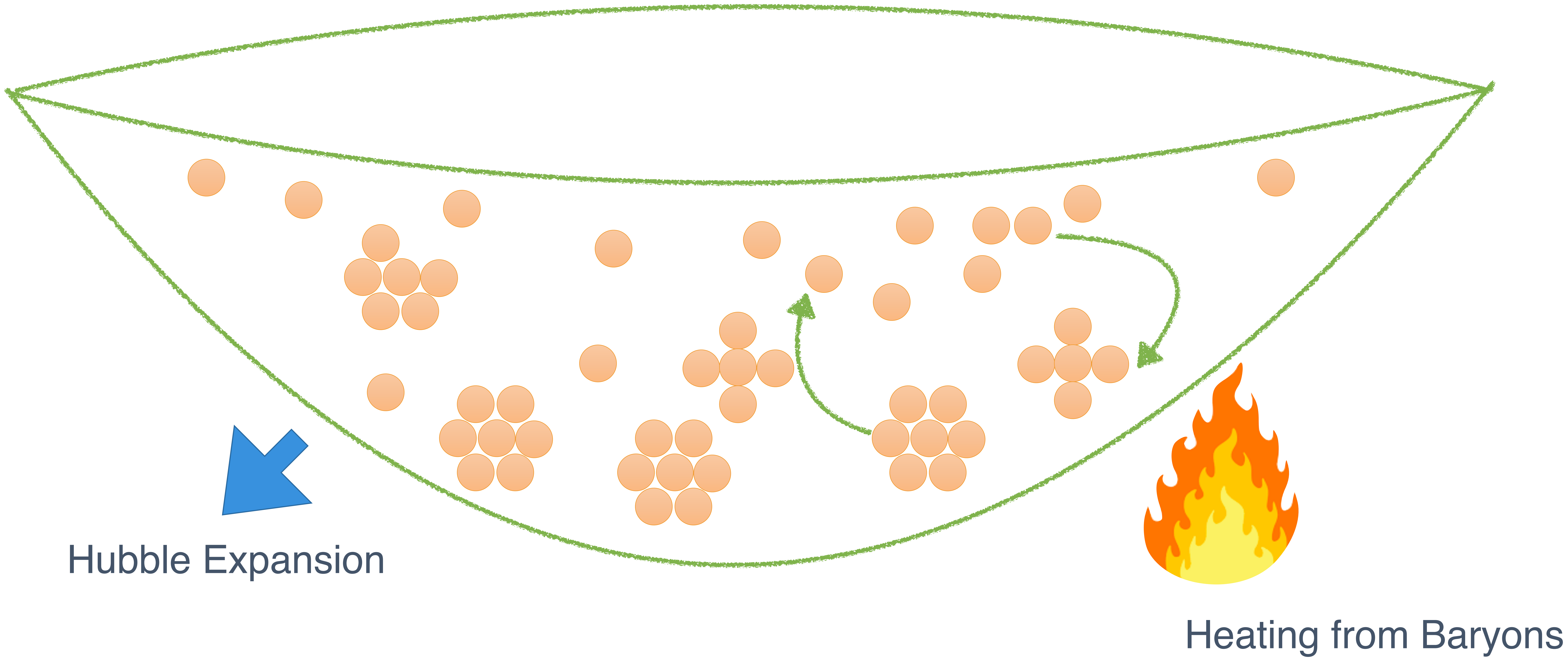
- Transfer cross-section: $\sigma_T \propto \frac{\epsilon^2}{\mu^2 v^4} \propto \frac{\epsilon^2}{T_D^2}$
- Scattering rate with ambient baryons
- $\frac{n_b \sigma_T v_{\rm rel}}{H} \approx 10^{-18} \left(\frac{\epsilon}{10^{-14}}\right)^2 z^{\frac{3}{2}} \left(\frac{10\text{K}}{T_D}\right)^2$
- $\epsilon_f \approx 10^{-14}$: negligible thermal contact with baryons
- $\epsilon_\chi \approx 10^{-5}$: can be heated up by baryons

HEATING VS HUBBLE



✦ f bath cools, forms nuclei χ

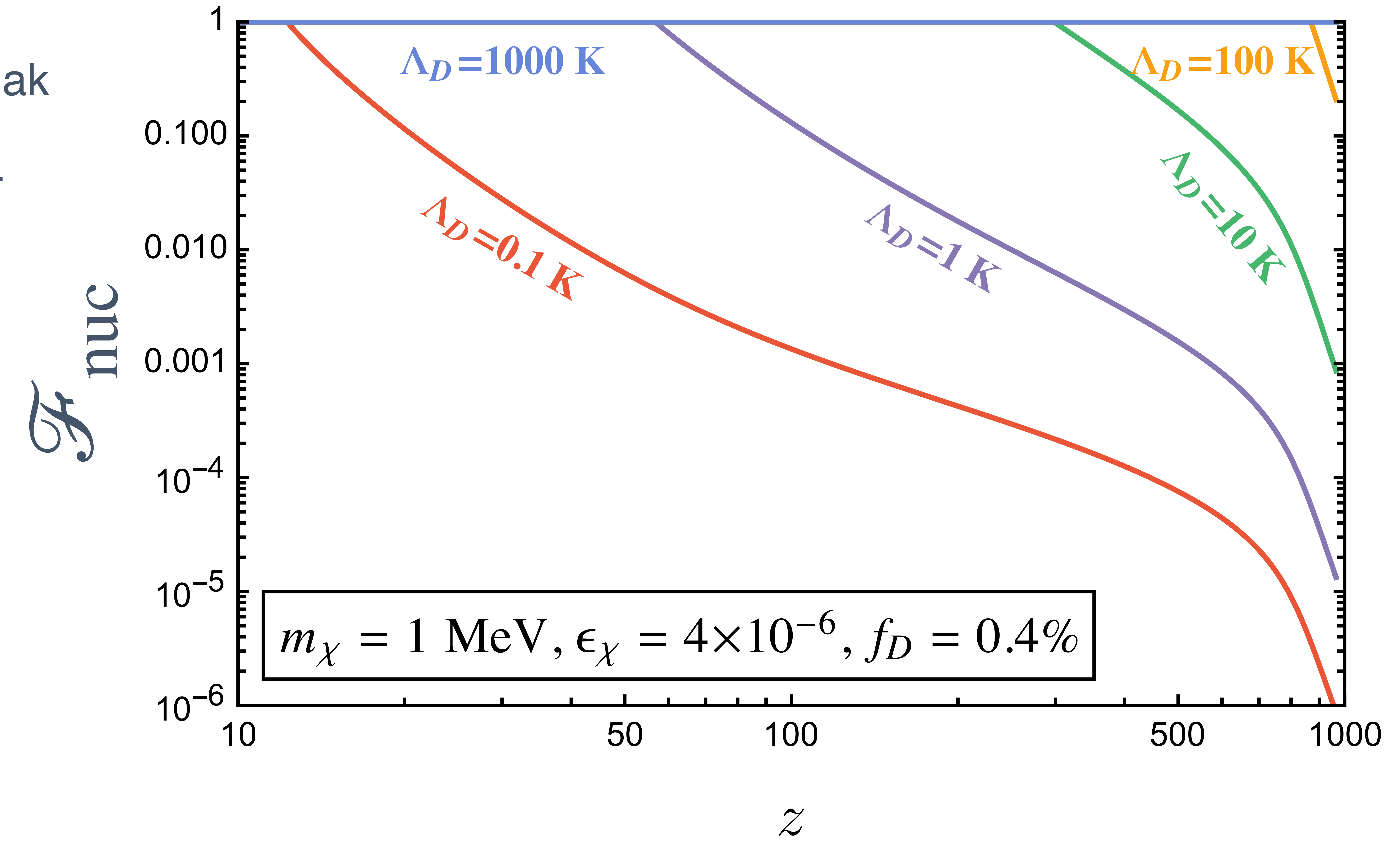
HEATING VS HUBBLE



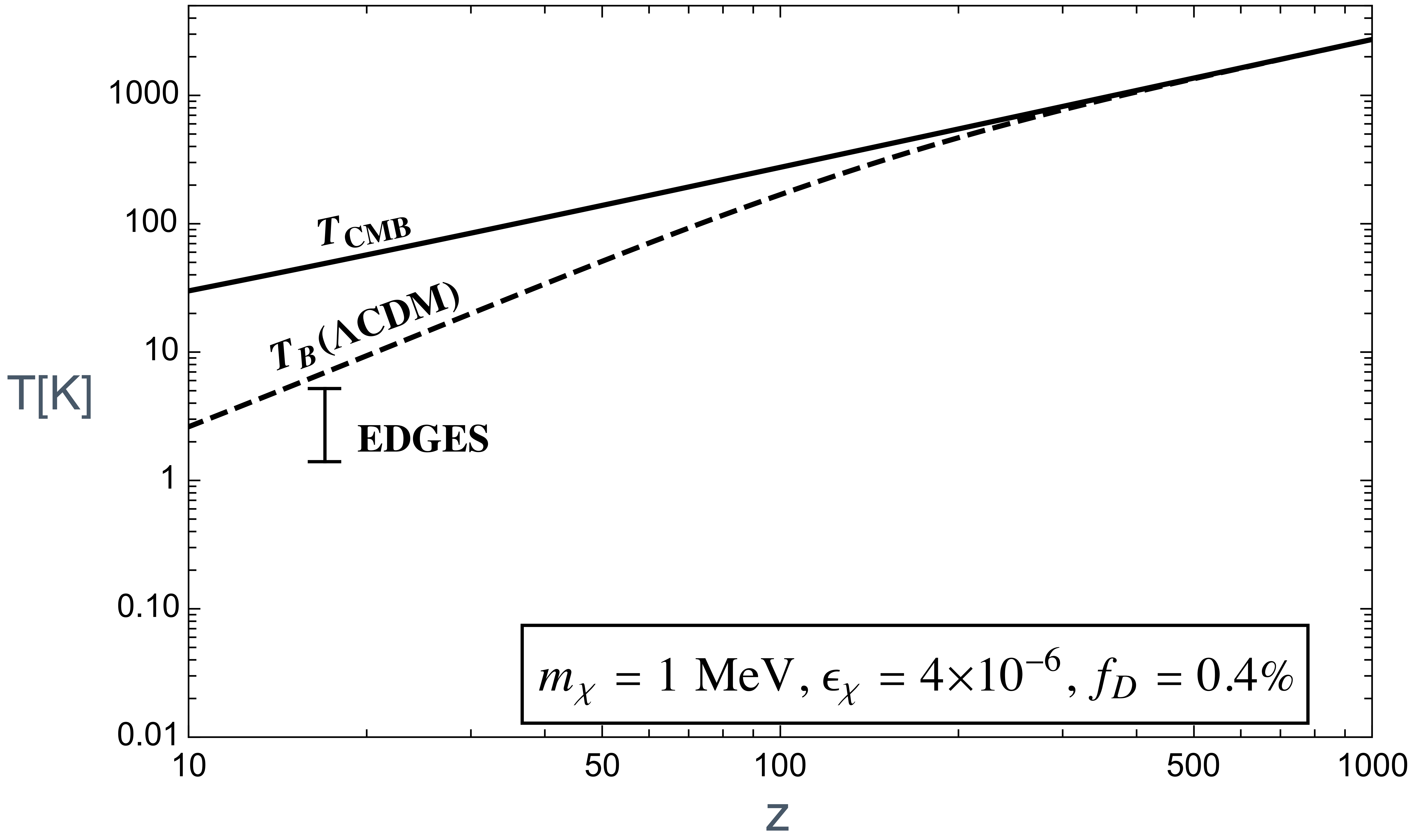
- χ Nuclei heat up due to the SM, breaks down back to f
- Balance between Hubble and SM heating, with $T_D \approx \Lambda_D$
- Only a fraction $\mathscr{F}_{\rm nuc}$ in nuclei

NUCLEATED FRACTION

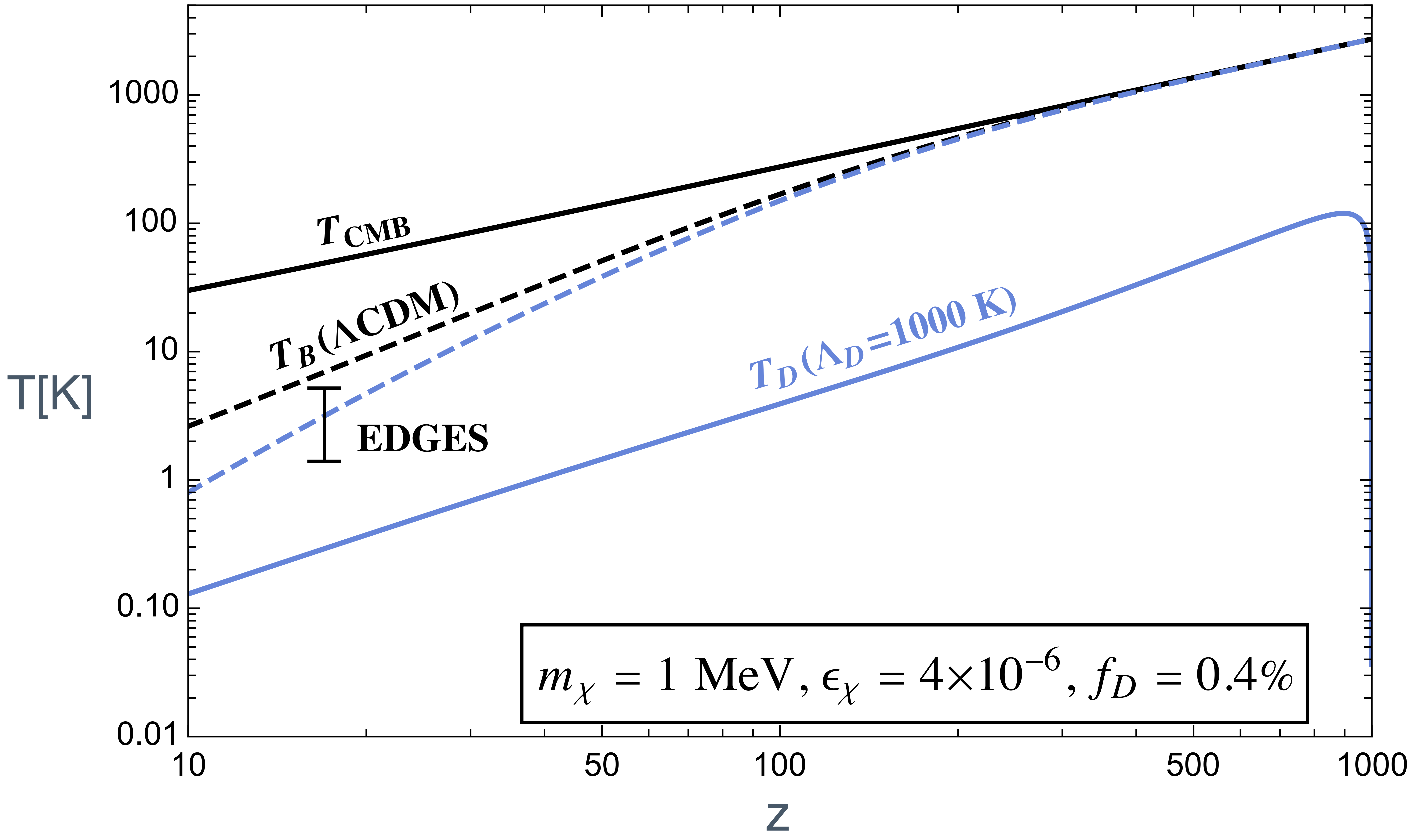
- ✦ Smaller Λ_D, easier to break
- ✦ Fusion delayed for longer
- ✦ $\mathscr{F}_{\rm nuc} \ll 1$ for longer



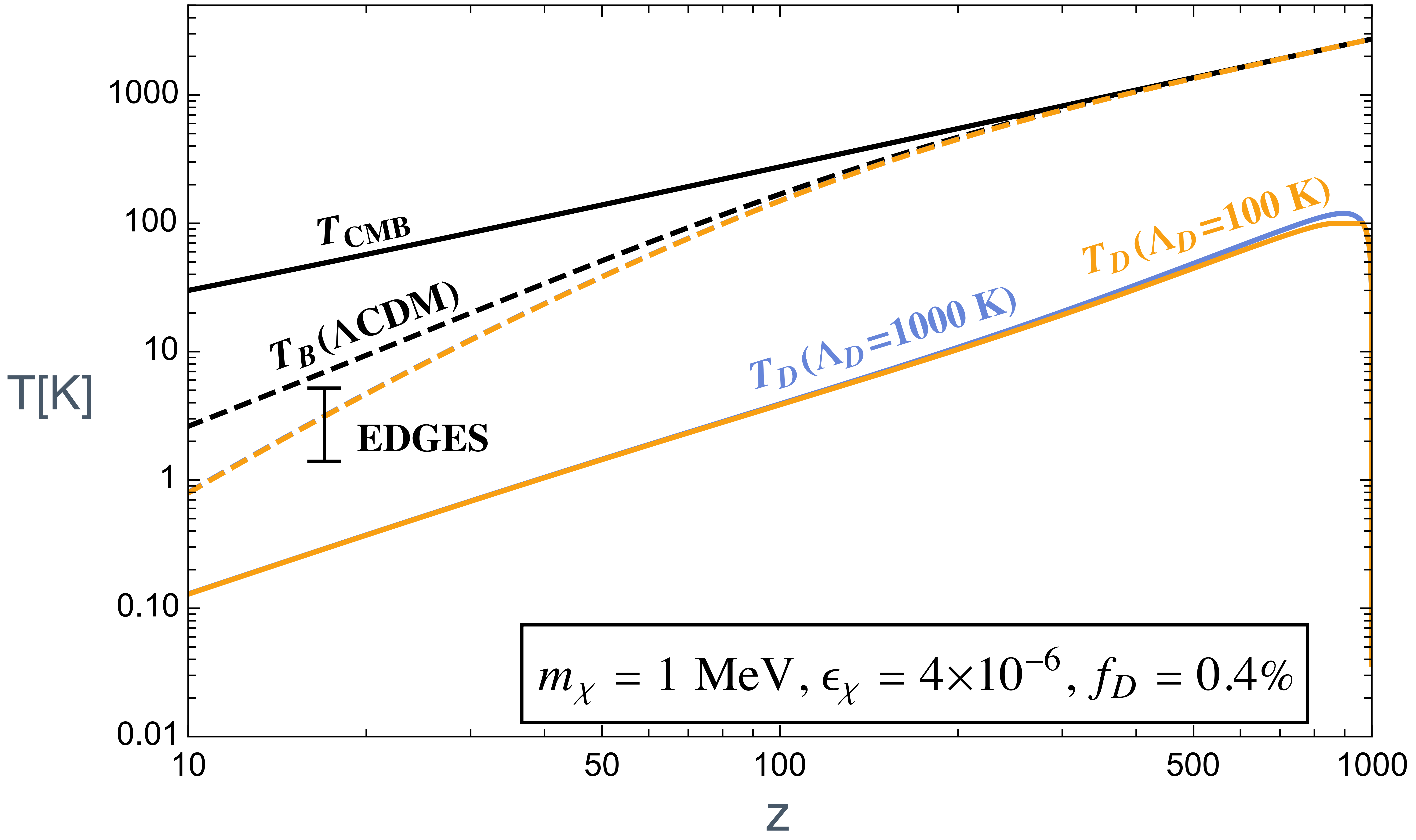
TEMP EVOLUTION



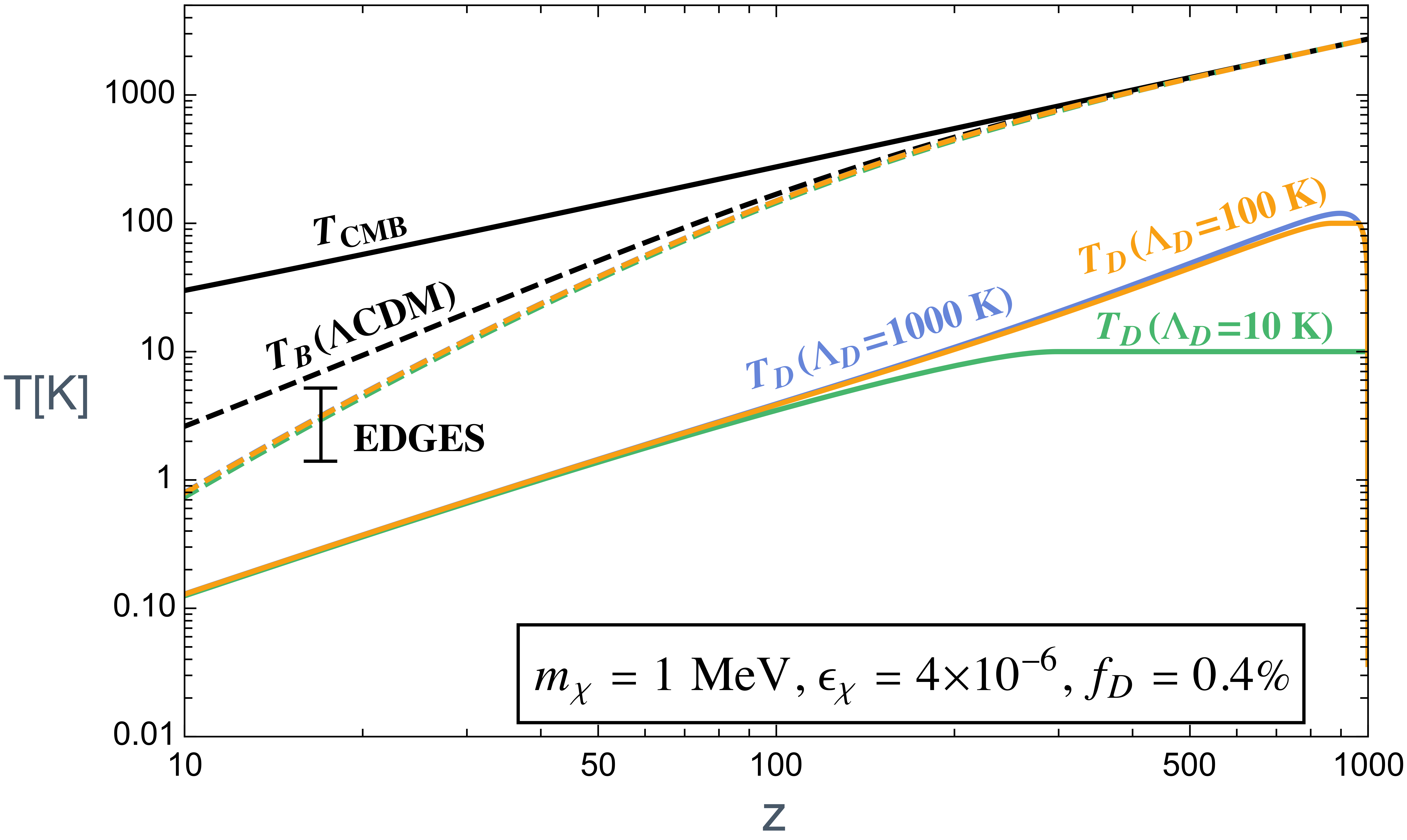
TEMP EVOLUTION



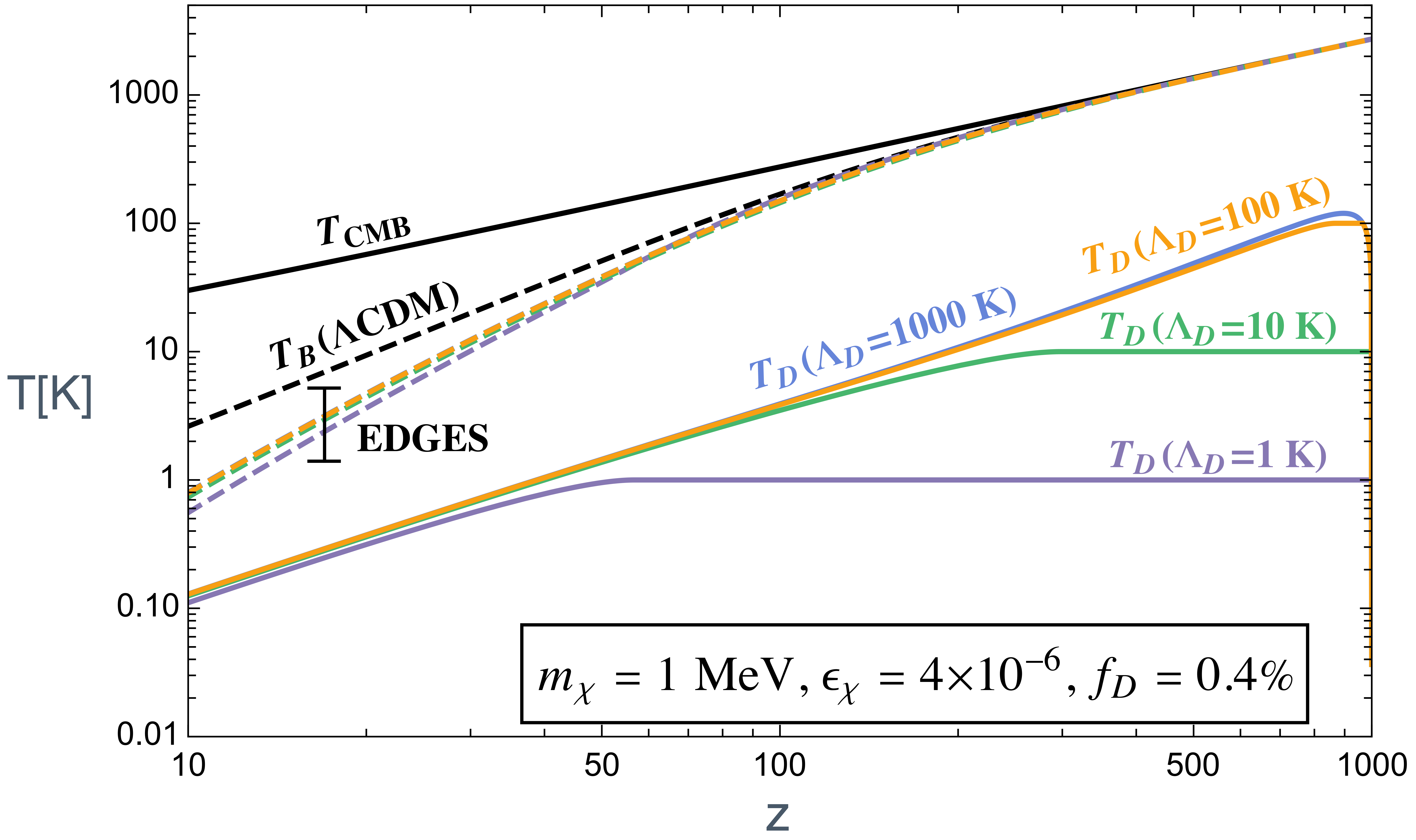
TEMP EVOLUTION



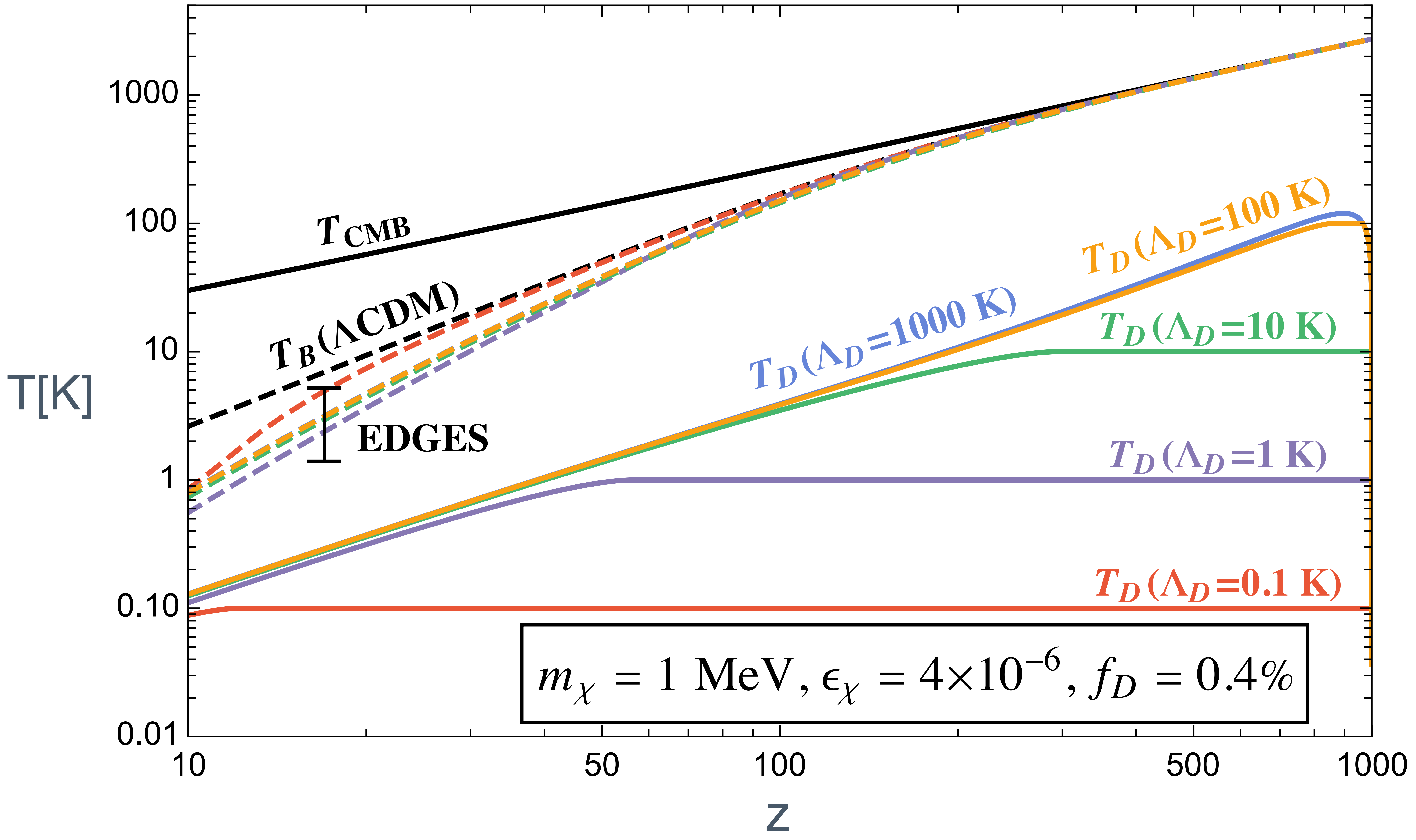
TEMP EVOLUTION



TEMP EVOLUTION

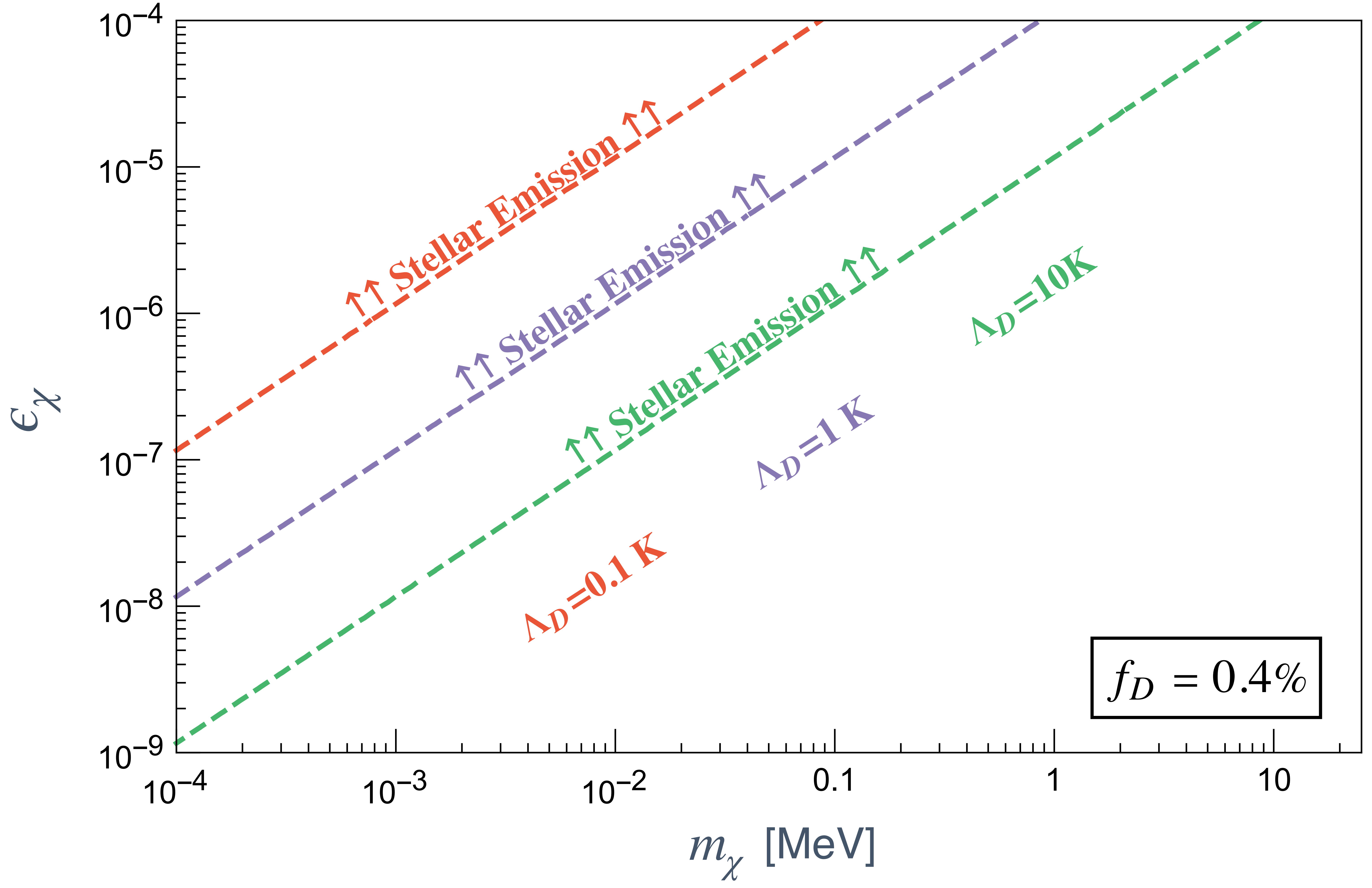


TEMP EVOLUTION

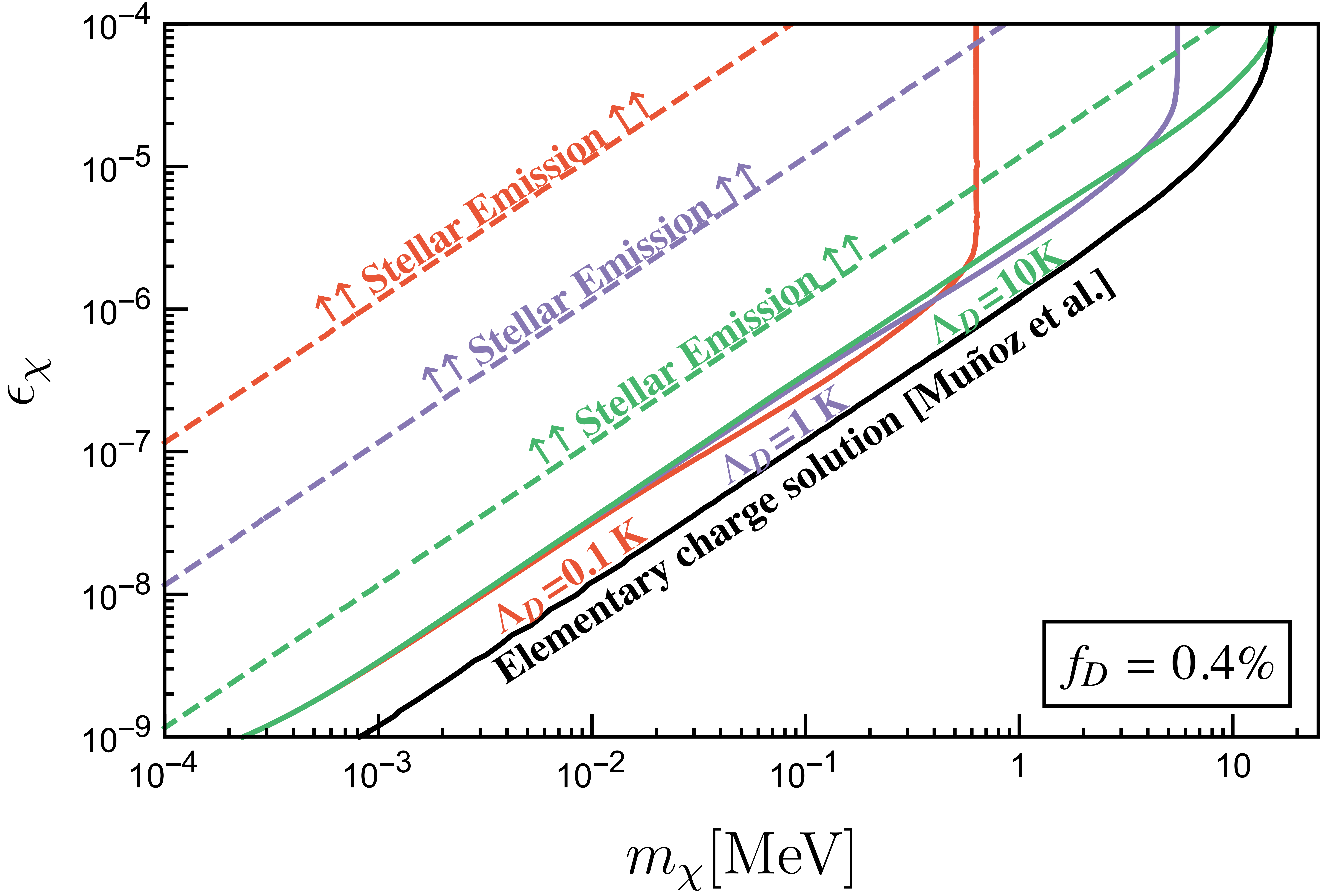


PARAMETER SPACE

- Stellar constraints on f
- $\epsilon_f \leq 10^{-14}$
- Sets indirect constraint on ϵ_χ
- $\epsilon_\chi \leq 10^{-14} \frac{m_\chi}{\Lambda_D}$



PARAMETER SPACE



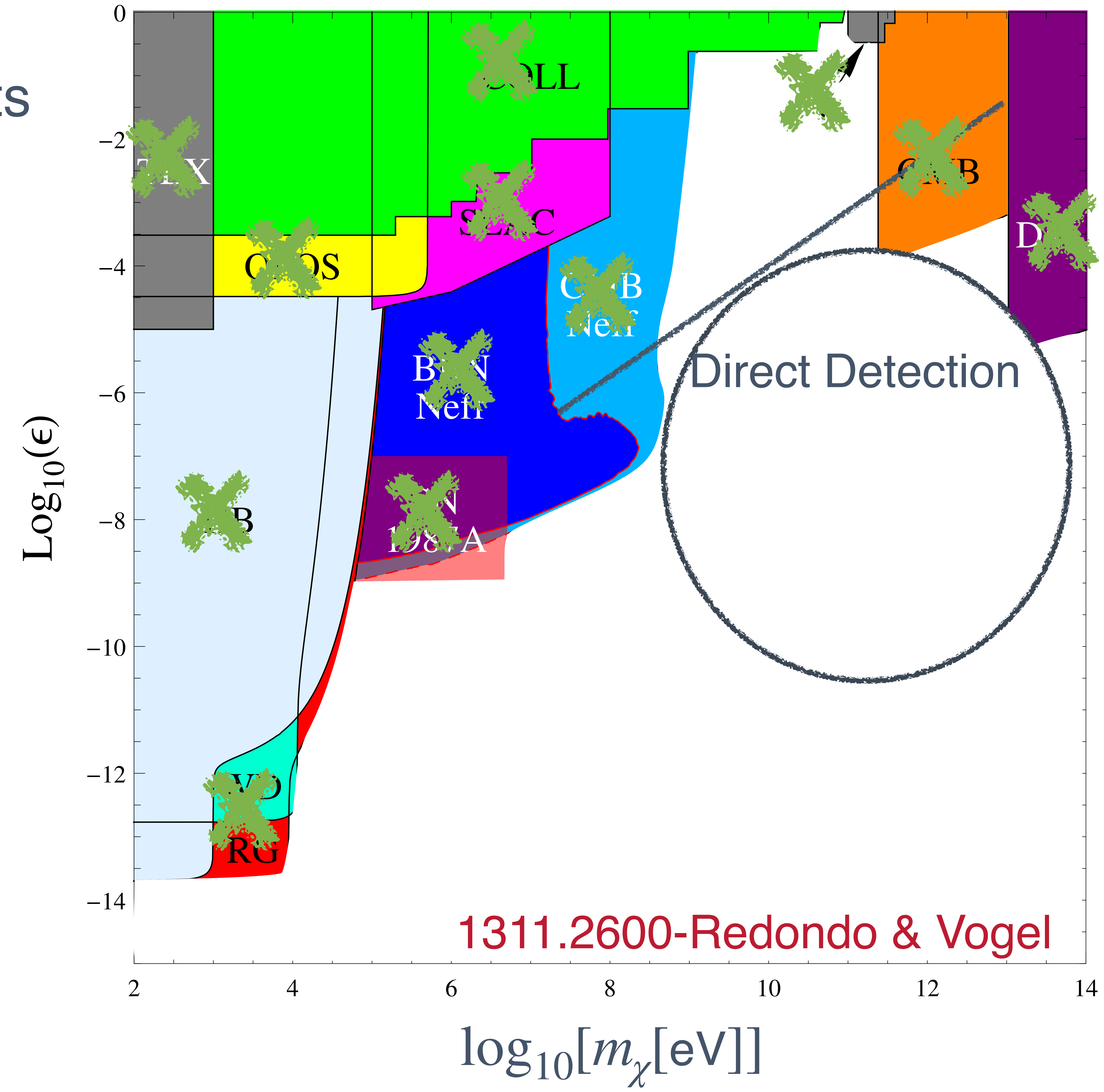
CONSEQUENCES

- No direct Collider, Beam Dump, Stellar constraints
- Enlarged Parameter space for milli-charge DM
- In galaxies

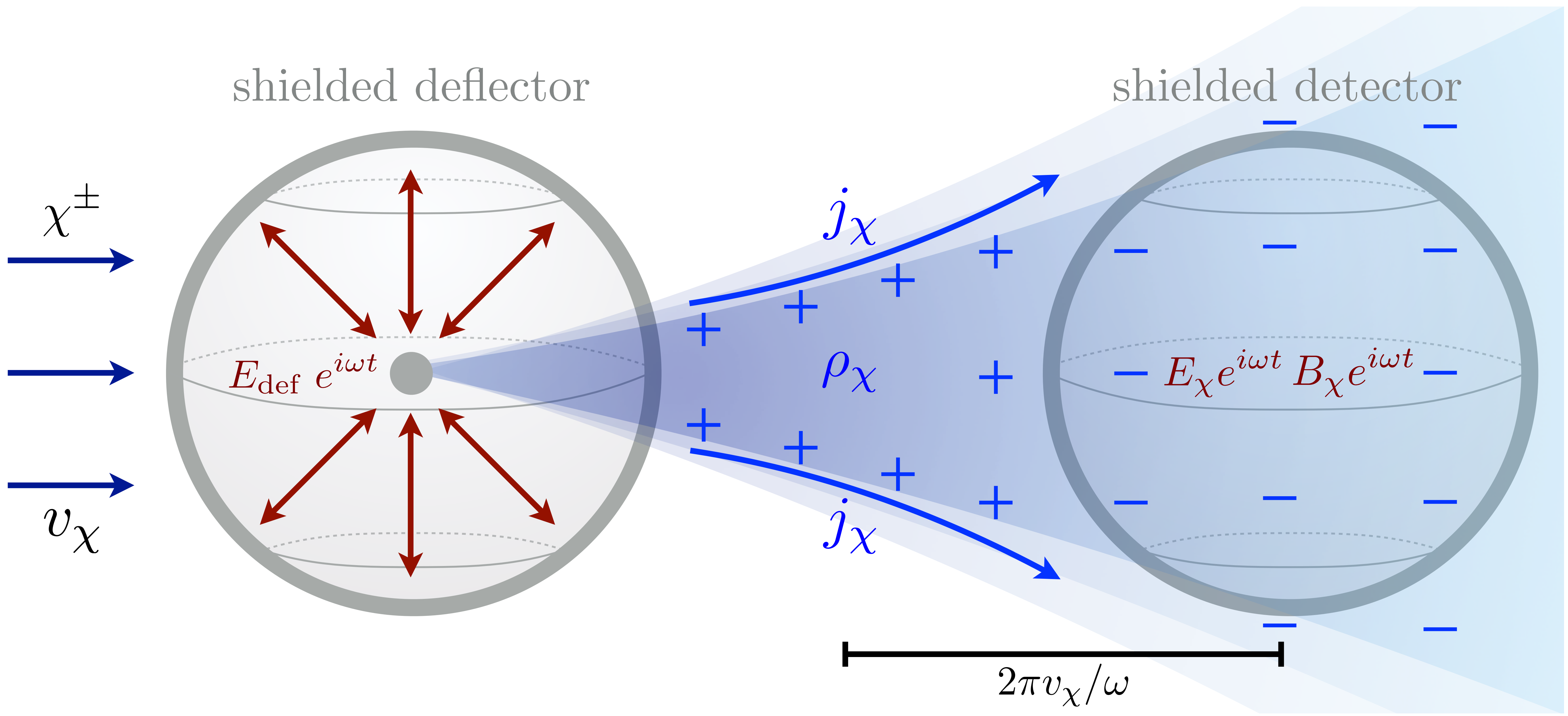
$$\frac{1}{2} m_\chi v_{\rm vir}^2 \le \Lambda_D \implies m_\chi^{\rm gal} \le 86 \text{ eV} \frac{\Lambda_D}{1\text{K}}$$

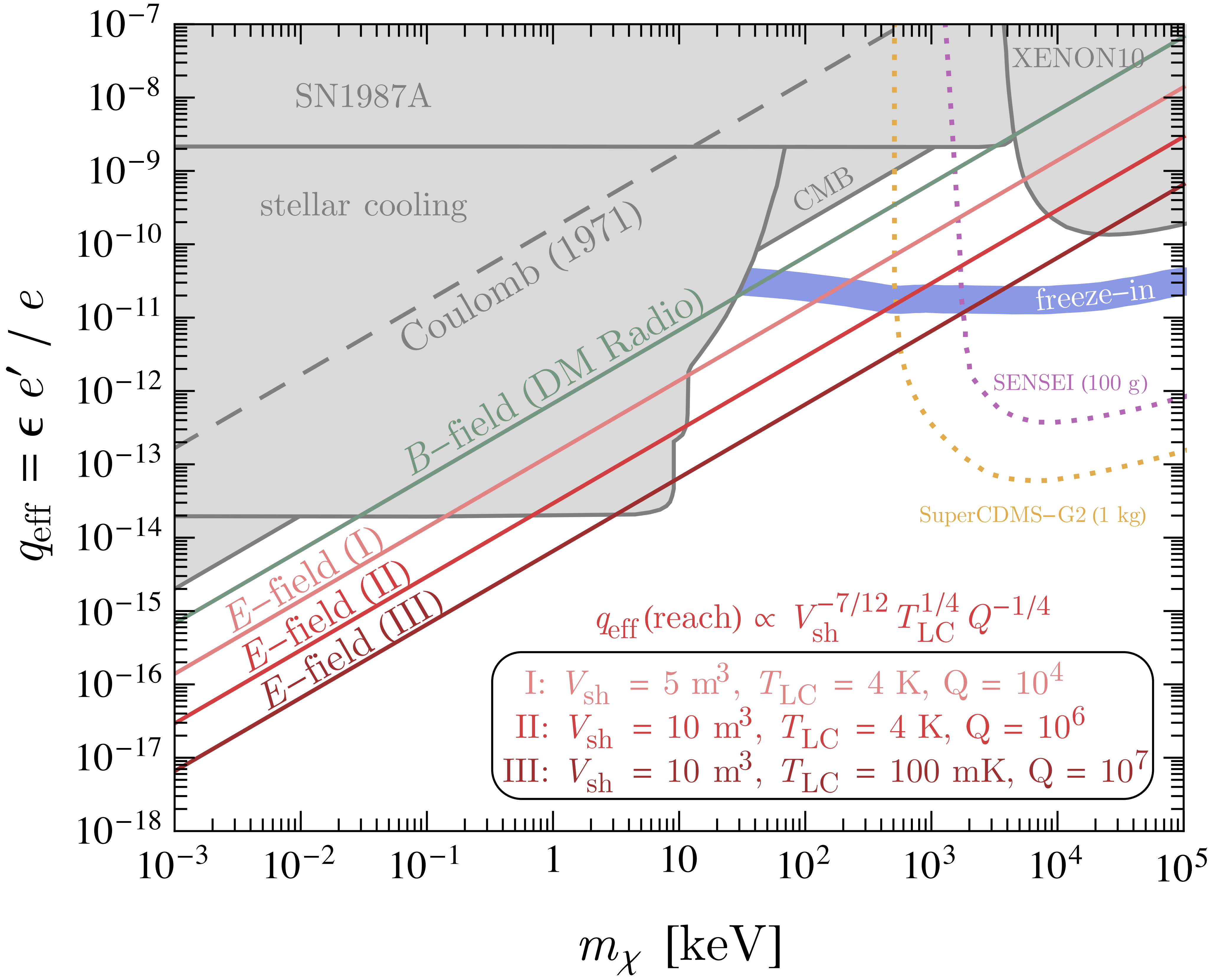
- Coherent enhancement only when

$$q \le R_\chi^{-1} \approx \Lambda_D / A^{\frac{1}{3}}$$



LOW q DIRECT DETECTION





1908.06982: Berlin, D'Agnolo, Ellis, Schuster, Toro

SUMMARY

- ✦ Exciting anomaly in 21cm physics
- ✦ Elementary mCPs solve anomaly but in severe tension with cosmology
- ✦ mCP nuclei of similar charge and mass evade most constraints and explain EDGES
- ✦ "Thermostat" phase around $T_D \approx \Lambda_D$
- ✦ Expanded parameter space for viable DM albeit at low momentum