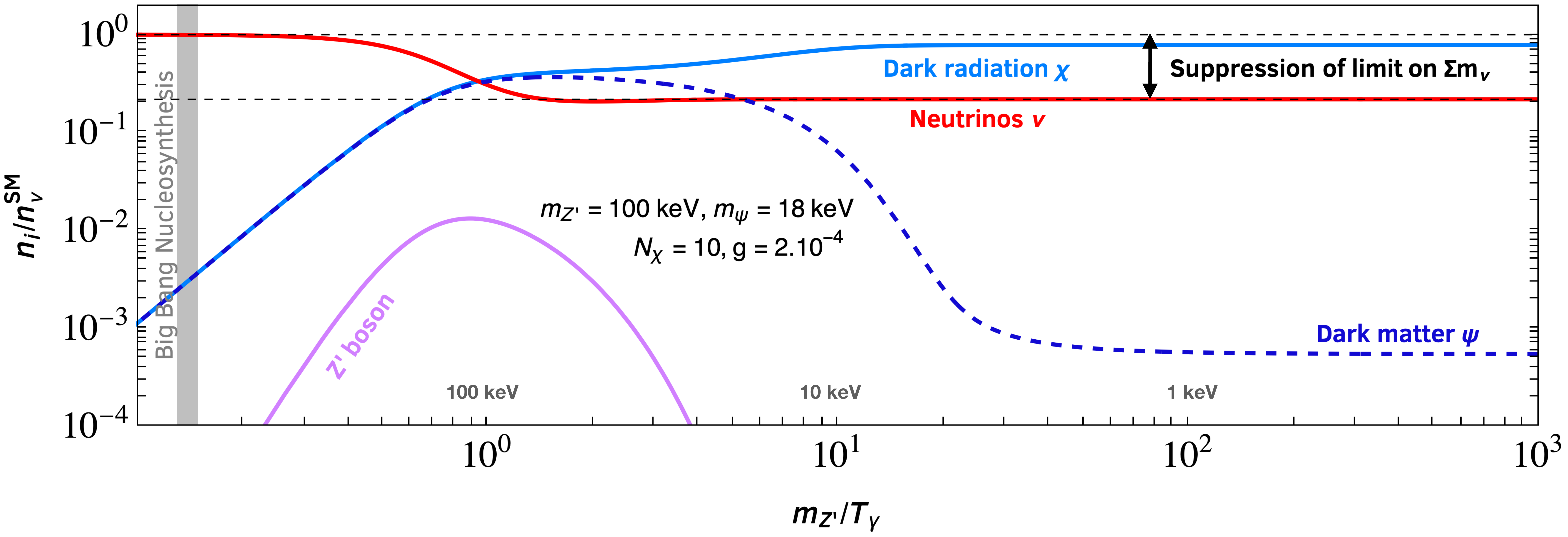
keV STERILE NEUTRINO DARK MATTER together with LARGE NEUTRINO MASSES IN COSMOLOGY from a DARK SECTOR

Cristina Benso, KIT

Based on [2410.23926 [hep-ph]] in collaboration with Thomas Schwetz and Drona Vatsyayan



Karlsruher Institut für Technologie

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- Is it possible that the same dark sector that could make laboratory measurement compatible with cosmological limits can also provide a viable dark matter candidate?

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⟶ the transformation of ν into χ must take place in the specific temperature range $100 \text{ keV} \gtrsim T \gtrsim 10$ eV.

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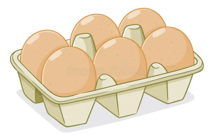
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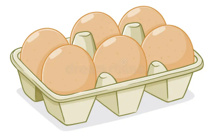
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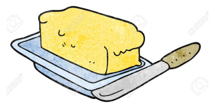
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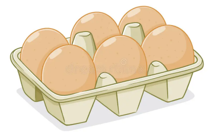

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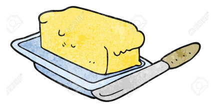

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Bonus:

one lighter copy N' of the heavy RH Majorana neutrinos N,
participating in a second seesaw mechanism to give mass to ψ

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Parameters of interest: $\{m_\psi, m_{Z'}, v_\phi, \theta_{\nu\chi}, N_\chi\}$

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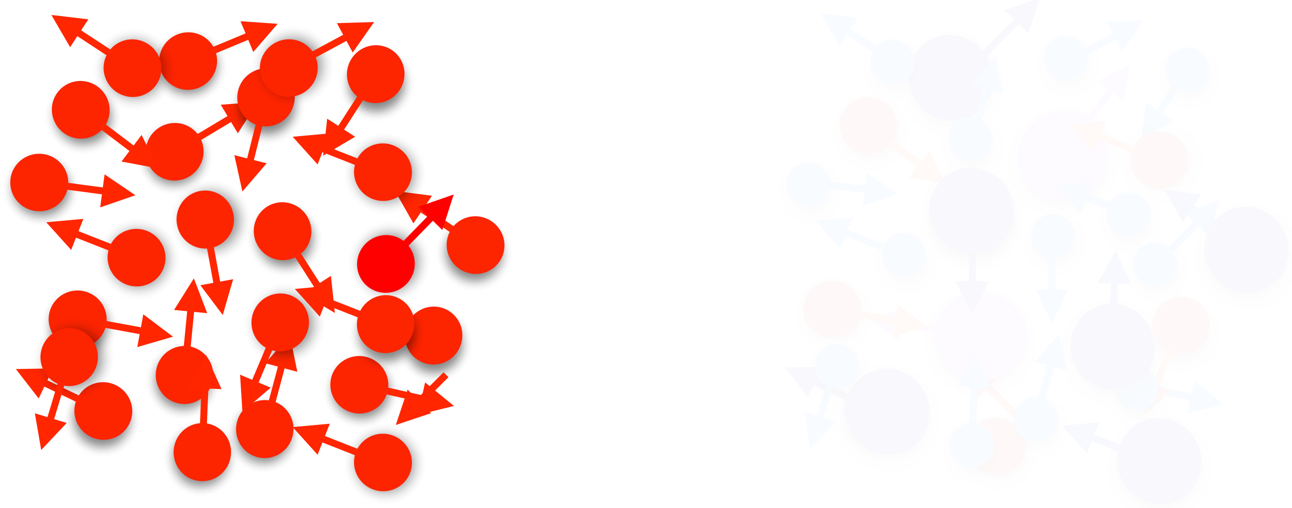

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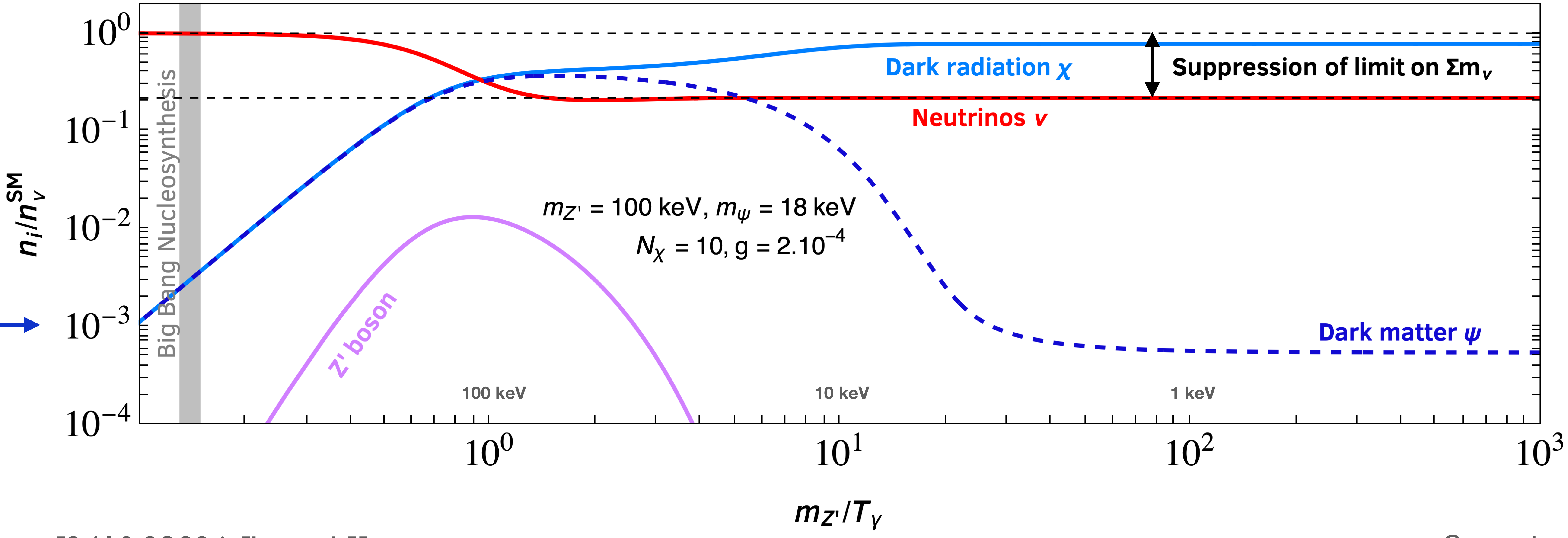

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CB, T. Schwetz, D. Vatsyayan, [2410.23926 [hep-ph]]

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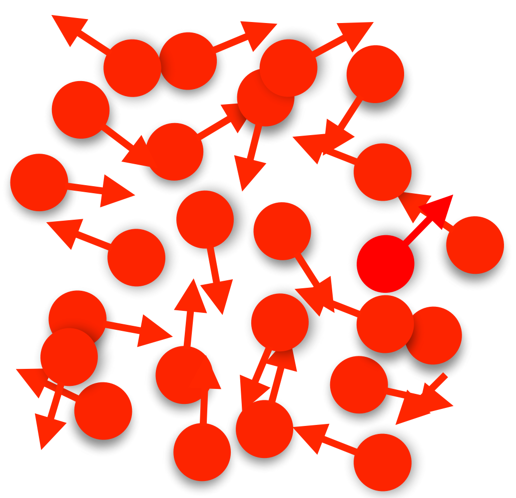

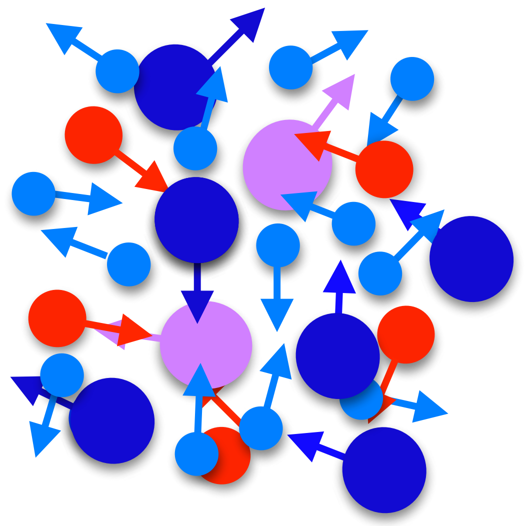

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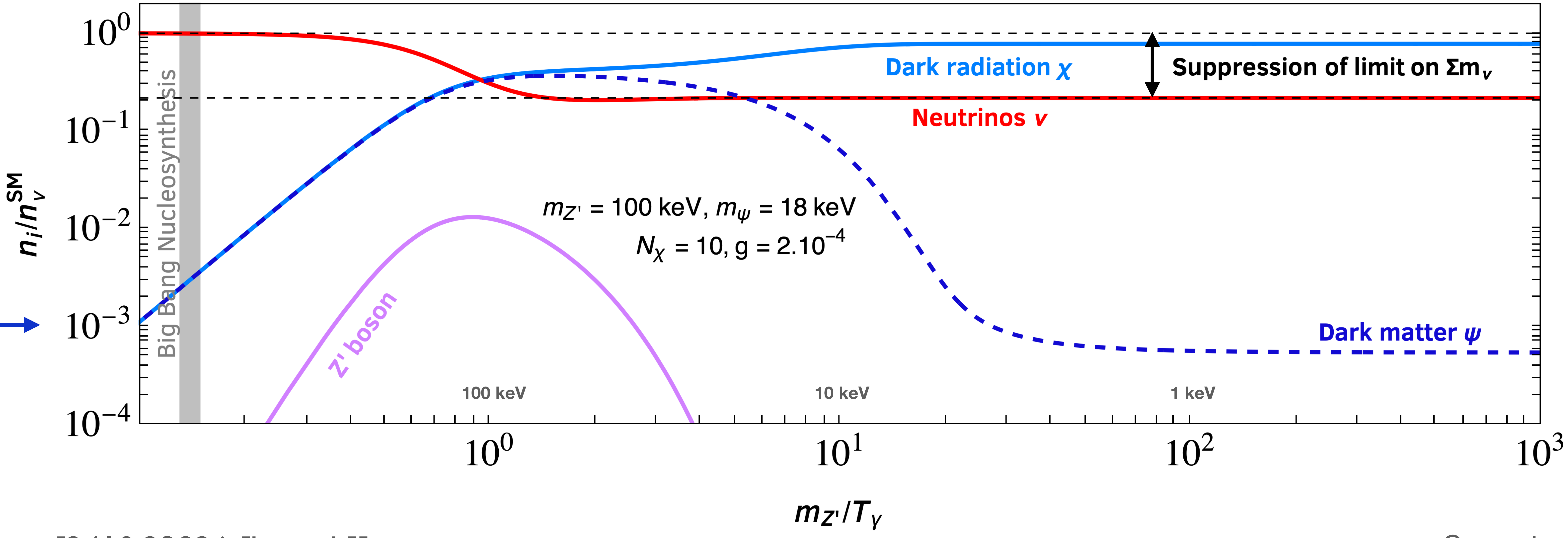

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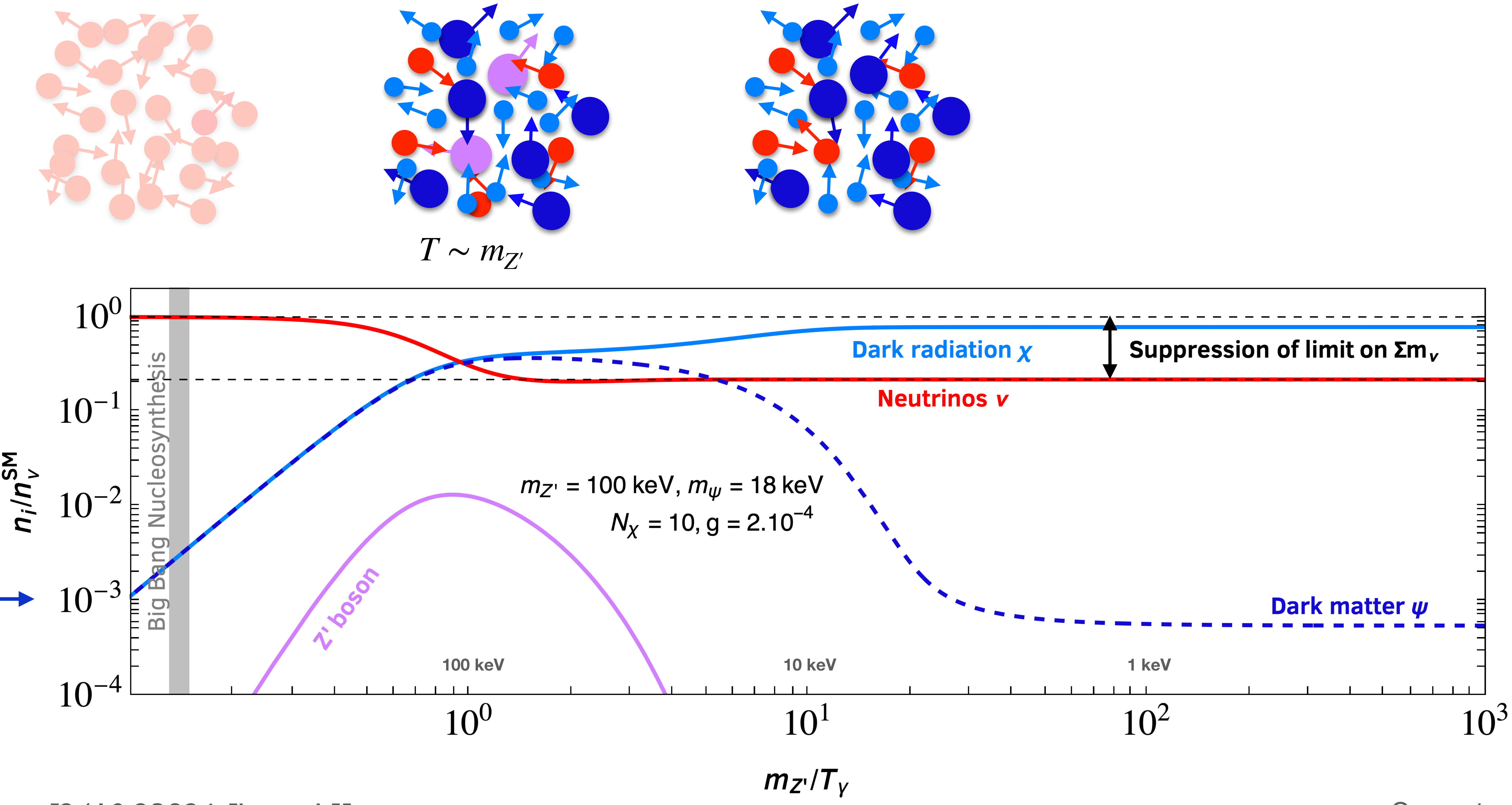

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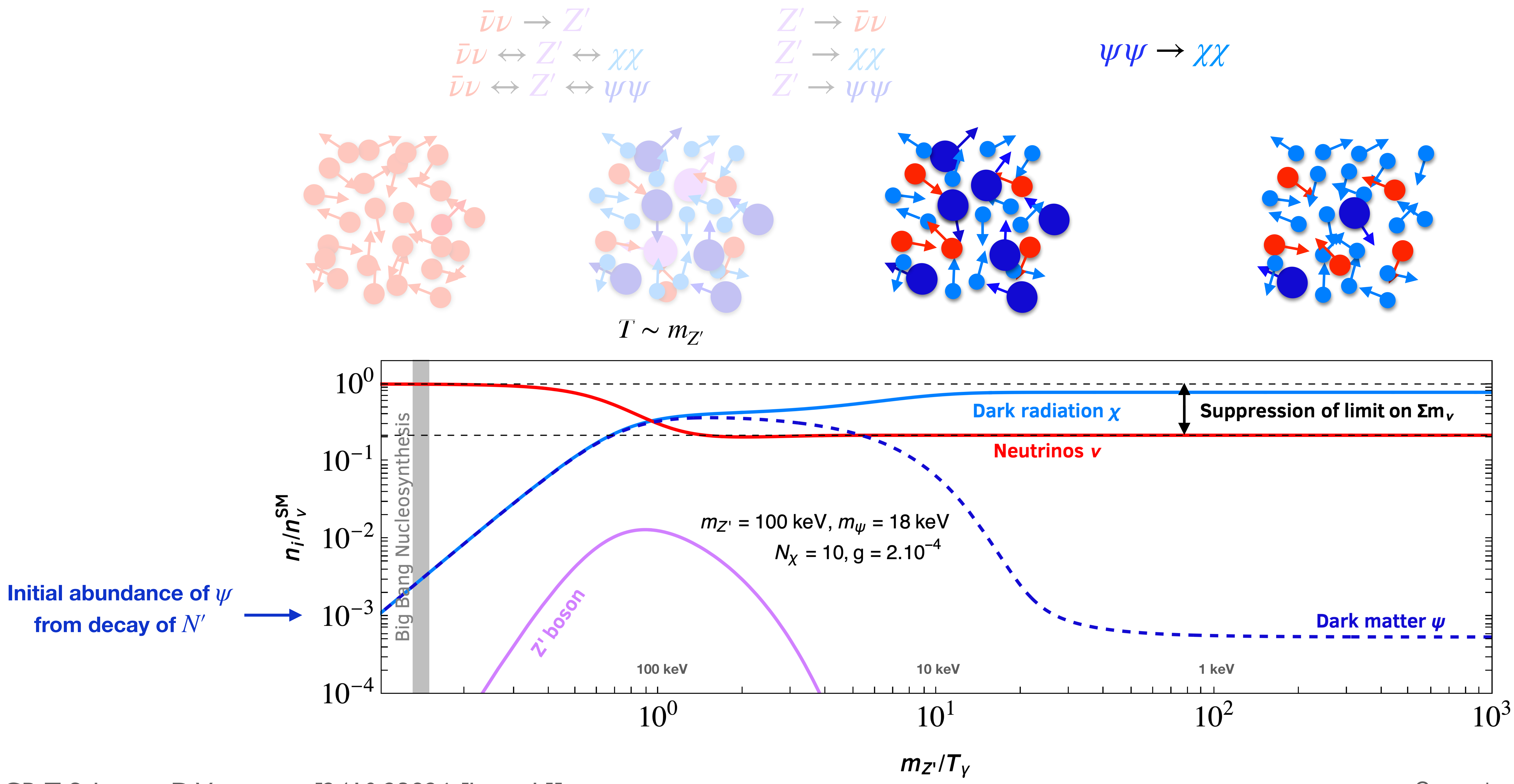

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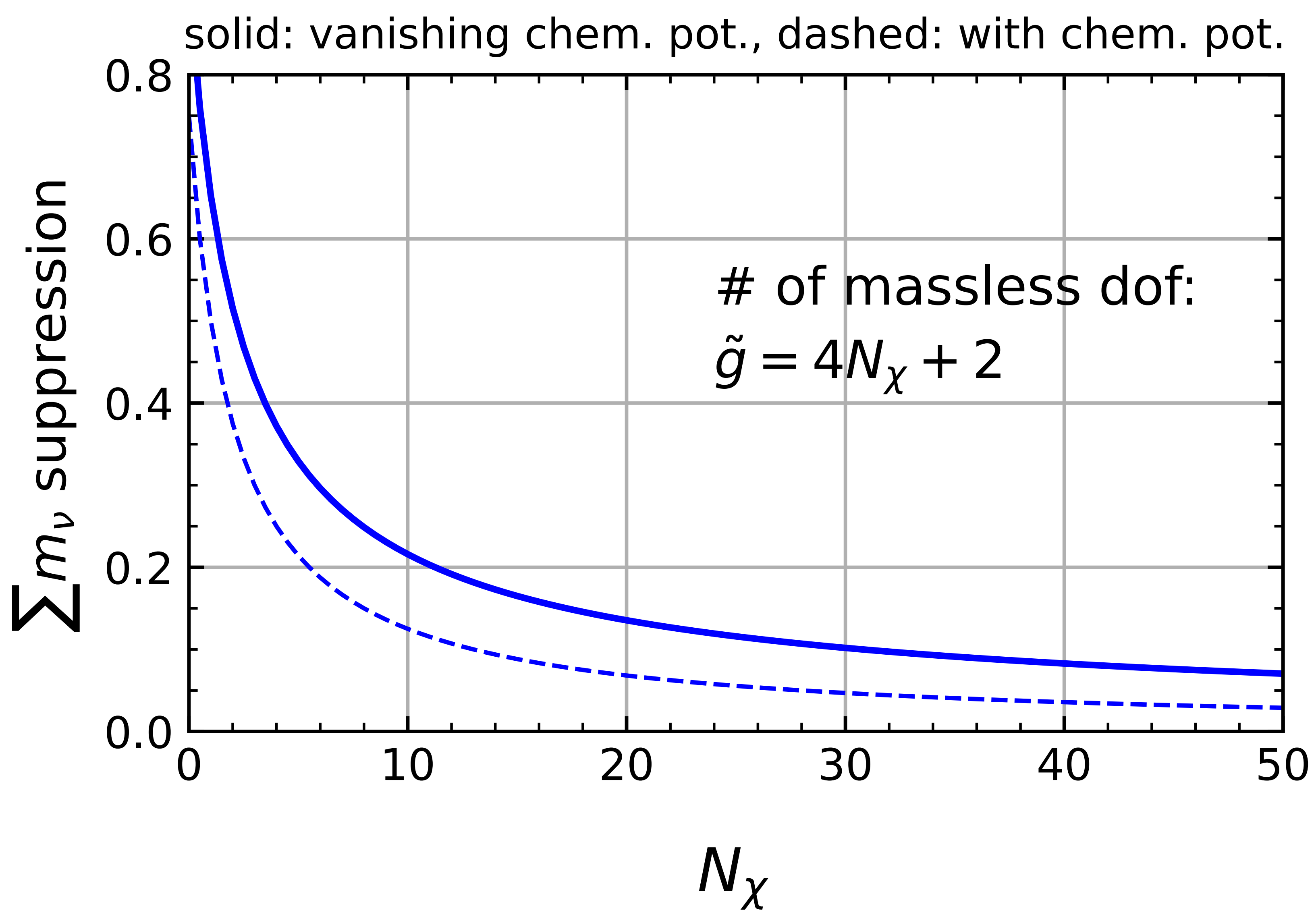

Suppression of cosmological bound on $\Sigma\, m_\nu$:

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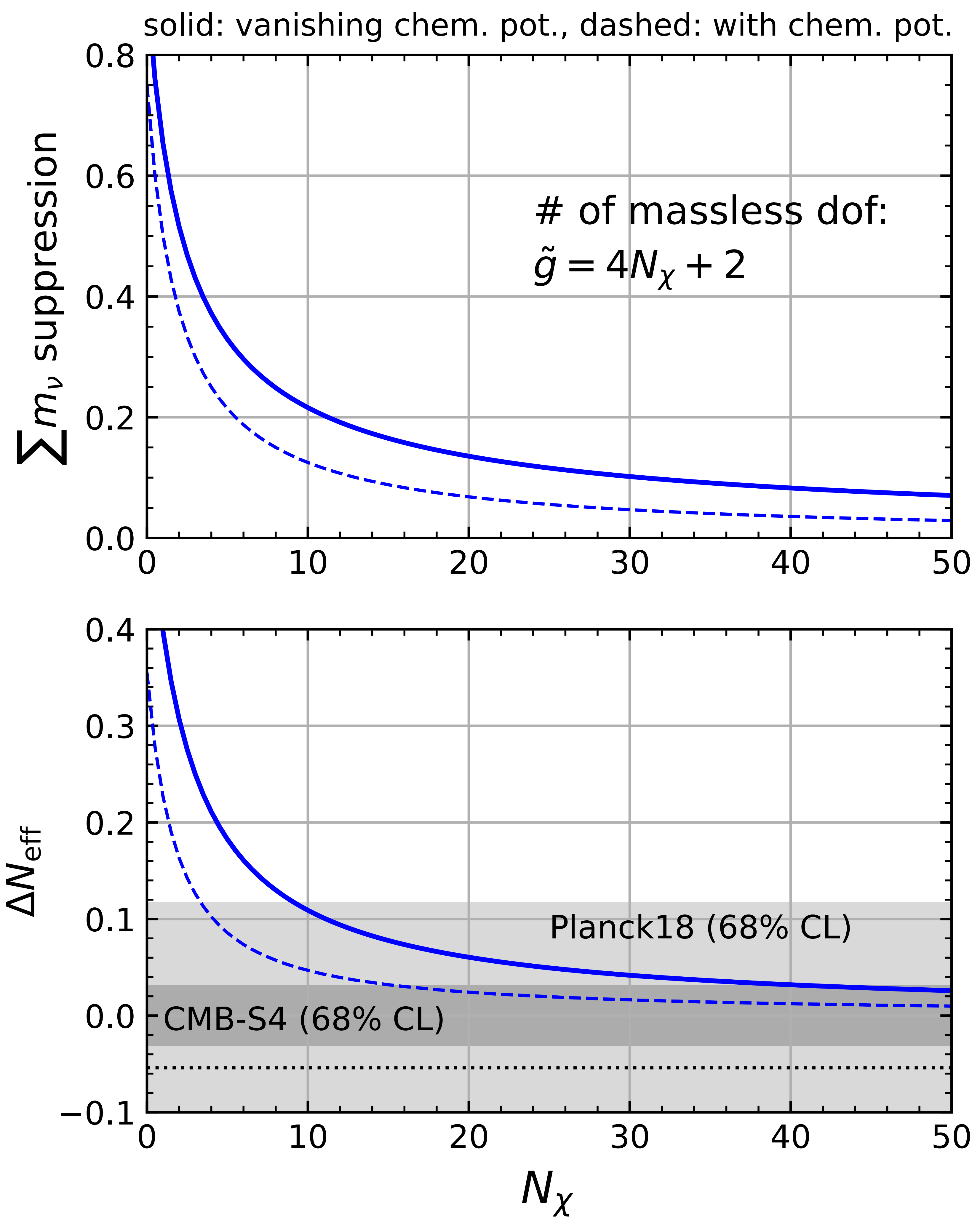

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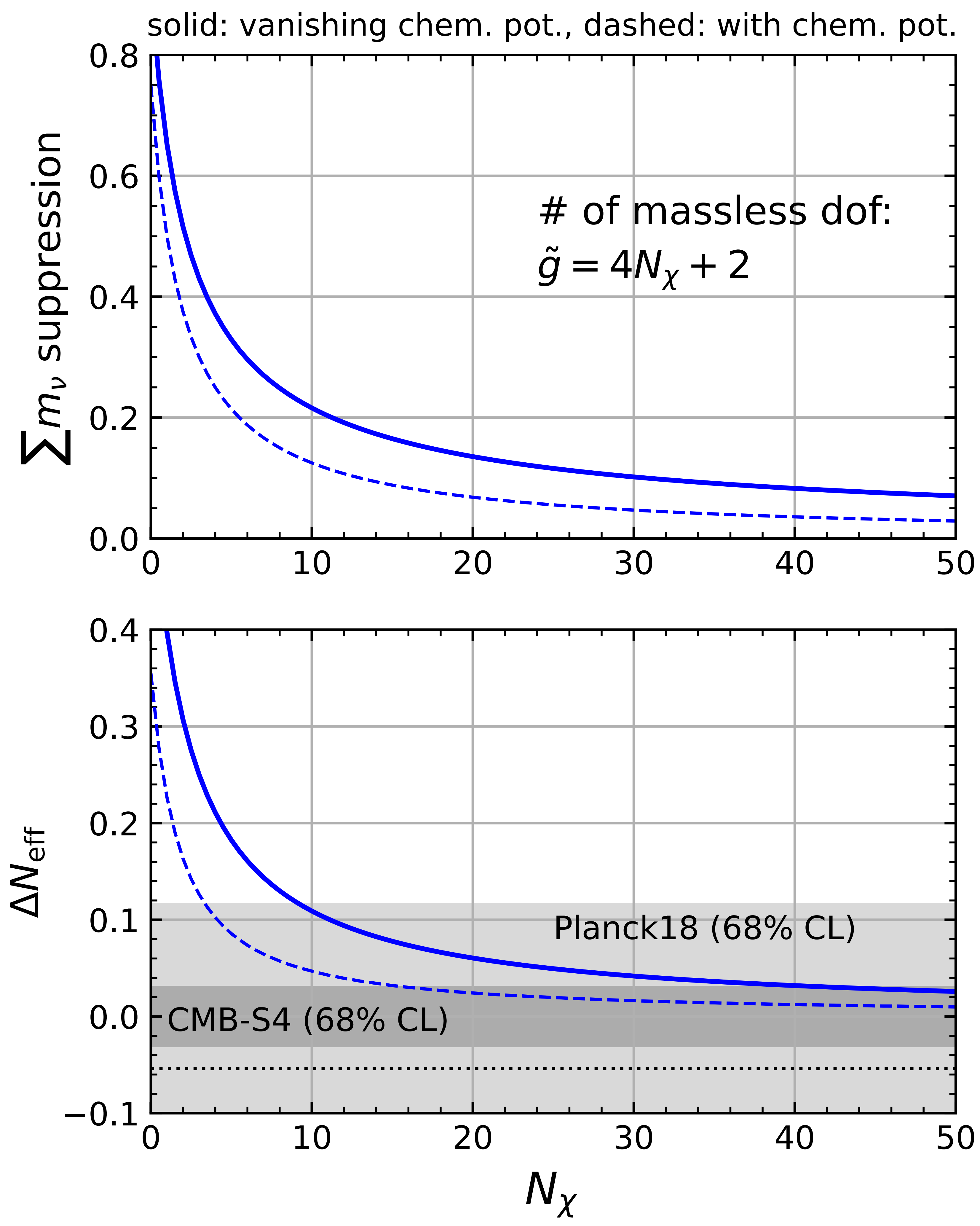

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Deviation from standard value of effective number of neutrino species :

$$\Delta N_{eff} = \frac{8}{7}\left(\frac{11}{4}\right)^{4/3}\frac{\rho_{dark}}{\rho_\gamma} = \frac{g_\nu + \tilde{g}}{2}\left(\frac{T_{dark}}{T_\nu^{SM}}\right)^4 =$$

$$= \frac{g_\nu}{2}\frac{(g_\nu + \tilde{g} + g_\psi + \frac{8}{7}g_{Z'})^{1/3}}{(g_\nu + \tilde{g})^{1/3}}$$

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  - 4 copies of heavy RH neutrinos, N and N', that participate in two separate seesaw mechanisms,
  - 1 sterile neutrino DM candidate ψ,
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  - 1 gauge boson Z' relative to a new $U(1)$ symmetry + 1 scalar singlet ϕ that breaks the new symmetry.

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- Our model predicts a sizable deviation of N_{eff} from the SM value at recombination, that may be observable by future CMB missions.

BACKUP SLIDES

LIMITS ON NEUTRINO MASSES FROM COSMOLOGY

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- Neutrinos are produced thermally as relativistic particles and become non relativistic in the late universe:

  ⟶ they contribute to the expansion of the universe first as radiation, later as matter

- depending on the value of m_ν (and $\Sigma\, m_\nu$) neutrinos impact:

  - the time (or temperature) of matter-radiation equality, T_{eq} ,

  ⟶ can be detected in CMB anisotropies

  - the growth of structures:

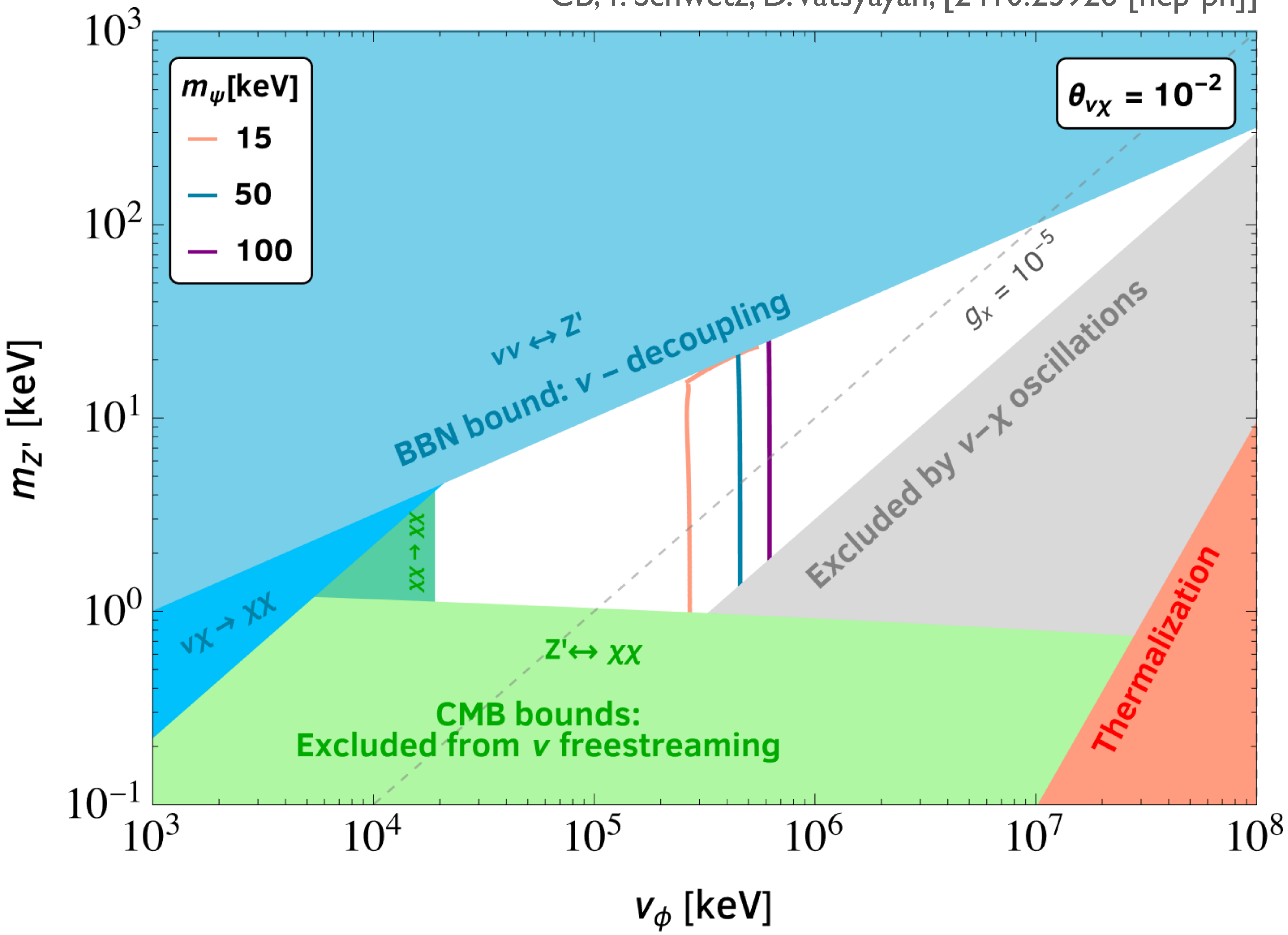
  larger m_ν ⟶ ν contribute to the gravitational potential and accelerate the gravitational infall of matter

  smaller m_ν ⟶ ν do not contribute to the gravitational potential and they drag matter away from it, preventing the growth of structures

  ⟶ can be detected in large scale structure (LSS) surveys, like DESI

CONSTRAINTS AND PREDICTIONS

CB, T. Schwetz, D. Vatsyayan, [2410.23926 [hep-ph]]



Remember:

Relevant parameters for phenomenology

$\{m_\psi, m_{Z'}, v_\phi, \theta_{\nu\chi}, N_\chi\}$

here $N_\chi = 10$

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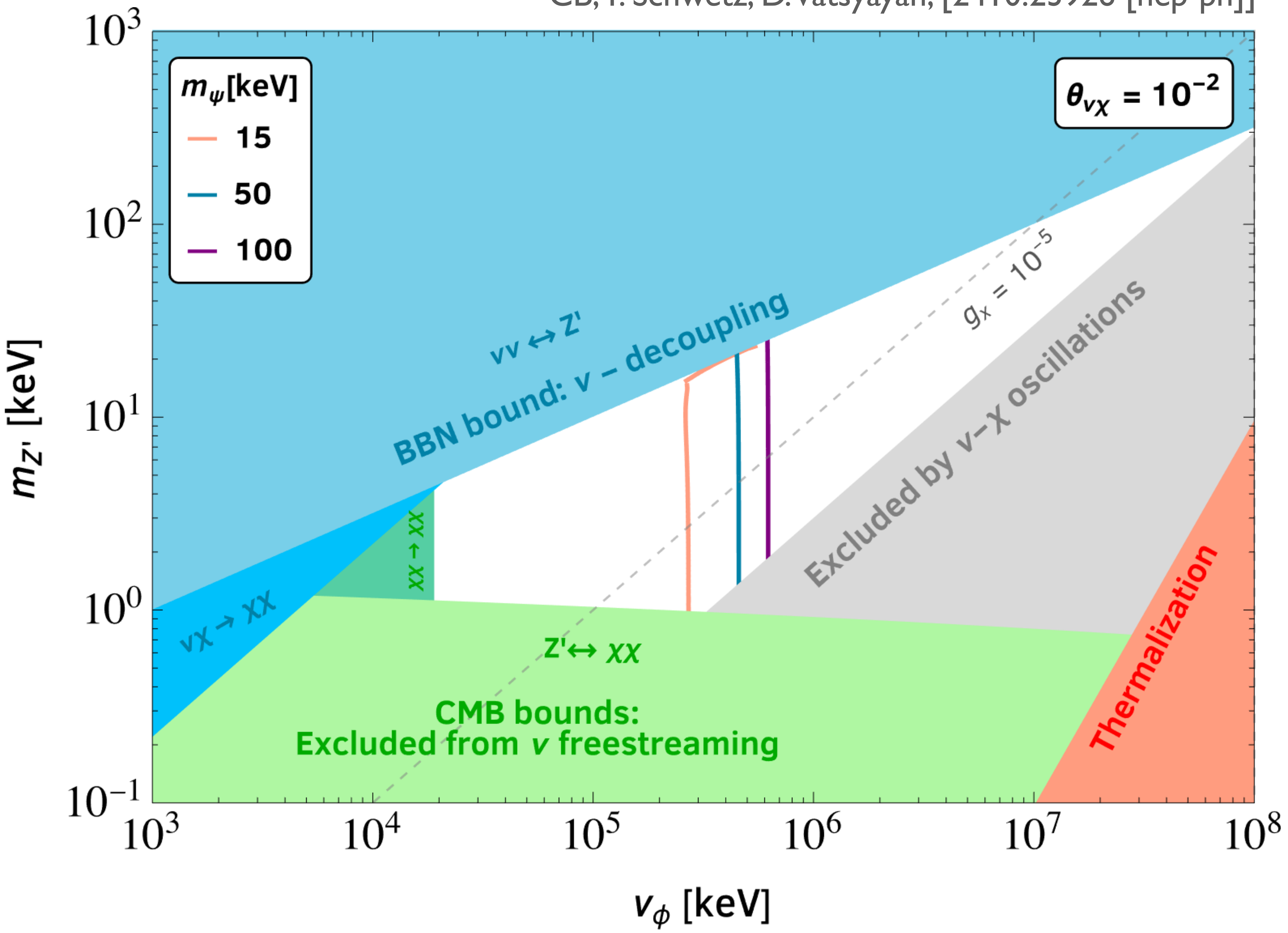

Remember:
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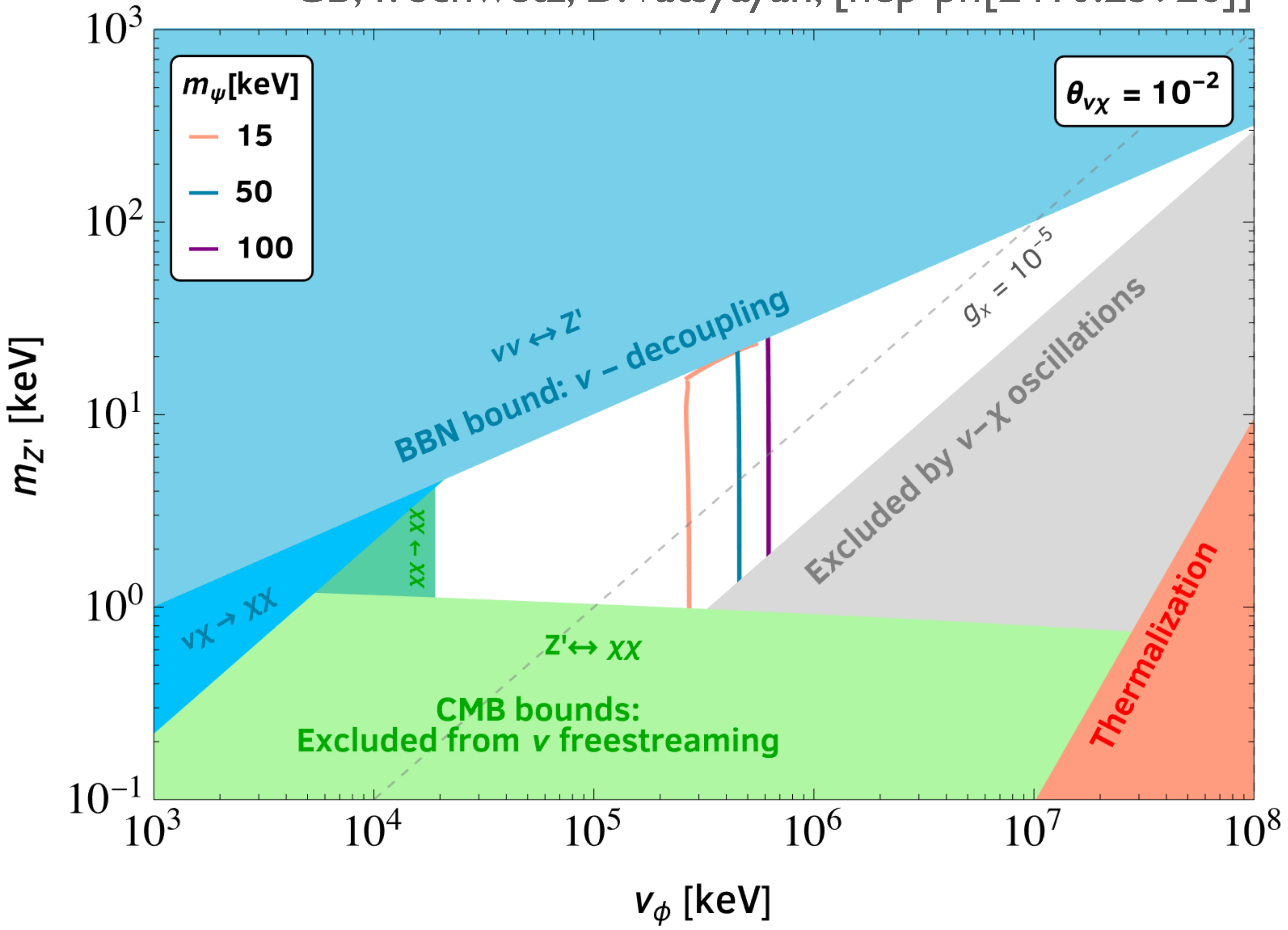
Majority of constraints from requirement of equilibrium or non-equilibrium of various processes within the dark sector or involving also active neutrinos

CONSTRAINTS AND PREDICTIONS

CB, T. Schwetz, D. Vatsyayan, [hep-ph[2410.23926]]



Thermalization:

- ν must thermalise with Z' in the interval 100 keV > T > 10 eV

⟶ condition: $\langle \Gamma(Z' \leftrightarrow \nu\nu) \rangle > H(T \sim m_{Z'}/3)$;

BBN:

- ν should not be in thermal equilibrium with Z' at T > 0.7 MeV

⟶ condition: $\langle \Gamma(Z' \leftrightarrow \nu\nu) \rangle < H(T = 0.7\ \text{MeV})$;

- an existing abundance of χ must not grow exponentially before BBN

⟶ condition: $\langle \Gamma(\nu\chi \leftrightarrow \chi\chi) \rangle < H(T = 0.7\ \text{MeV})$;

CMB:

- CMB must not be distorted by $\nu\nu \leftrightarrow Z'$ and $Z' \leftrightarrow \chi\chi$ at $z < 10^5$

⟶ $\langle \Gamma(\nu\nu \leftrightarrow Z') \rangle < H(T = 23\ \text{eV})$ and $\langle \Gamma(Z' \leftrightarrow \chi\chi) \rangle < H(T = 23\ \text{eV})$;

- CMB must not be perturbed by χ free-streaming at $z < 10^5$

⟶ $\langle \Gamma(\chi\chi \leftrightarrow \chi\chi) \rangle < H(T = 23\ \text{eV})$

ΔN_{eff} due to $\nu - \chi$ oscillations:

- Production of χ via oscillations contributing to ΔN_{eff} must be small

$$\longrightarrow \quad \Delta N_{eff} \simeq 0.014 \sum_{\chi=1}^{N_\chi} \frac{|\theta_{e\chi}|^2 + 0.8(|\theta_{\mu\chi}|^2 + |\theta_{\tau\chi}|^2)}{10^{-6}} \left(\frac{m_\nu}{0.1\text{eV}}\right) < 0.3\,.$$

INTRODUCTION & MOTIVATIONS

- Standard Model is great but it does not explain (at least) two puzzles of Nature:
  - active neutrino masses ⟶ seesaw mechanism (3 heavy RH Majorana neutrinos N)
  - dark matter ⟶ sterile neutrino DM (ψ)

- Lab. experiments aim to measure directly the small value of active neutrino masses:
  - KATRIN aims to measure the effective electron antineutrino mass $m_{\nu_e} = \sqrt{\Sigma |U_{ei}|^2 m_{\nu_i}^2}$

    current upper limit $m_{\nu_e} < 0.45$ eV *, expected final reach $m_{\nu_e} = 0.3$ eV;
  - Oscillation data put a lower limit on the sum of neutrino masses:
    $\Sigma m_\nu > 0.058\,(0.098)$ eV for normal (inverted) neutrino mass ordering. **

- Cosmological observations set stringent constraints on the sum of active neutrino masses, assuming ΛCDM: for example, DESI established an upper bound of $\Sigma m_\nu < 0.064$ eV ***

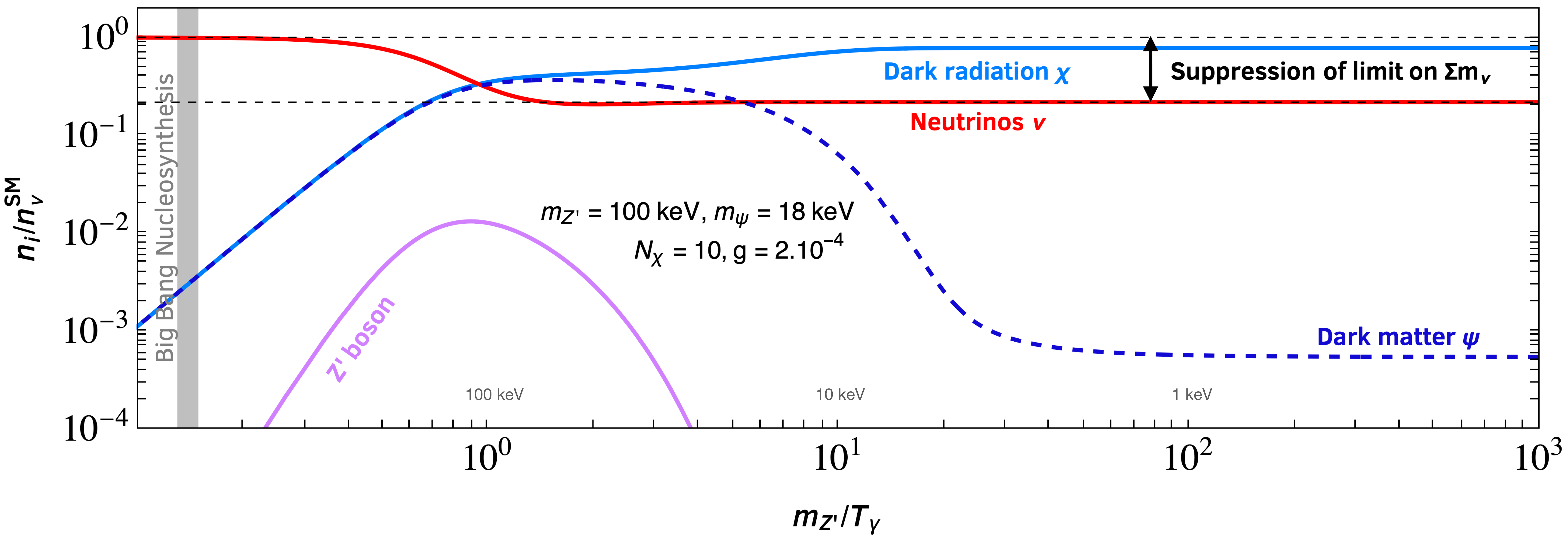
- What if KATRIN measures something? How could laboratory results be reconciled with cosmological limits?

- Is it possible that the same dark sector that makes laboratory measurement compatible with cosmological limits provides also a viable dark matter candidate?

* KATRIN Collaboration, [2406.13516 [nucl-ex]] ** I. Esteban et al, [2410.05380 [hep-ph]] ***DESI Collaboration, [2503.14738 [astro-ph.CO]]

DARK MATTER PRODUCTION

CB, T. Schwetz, D. Vatsyayan, [2410.23926 [hep-ph]]



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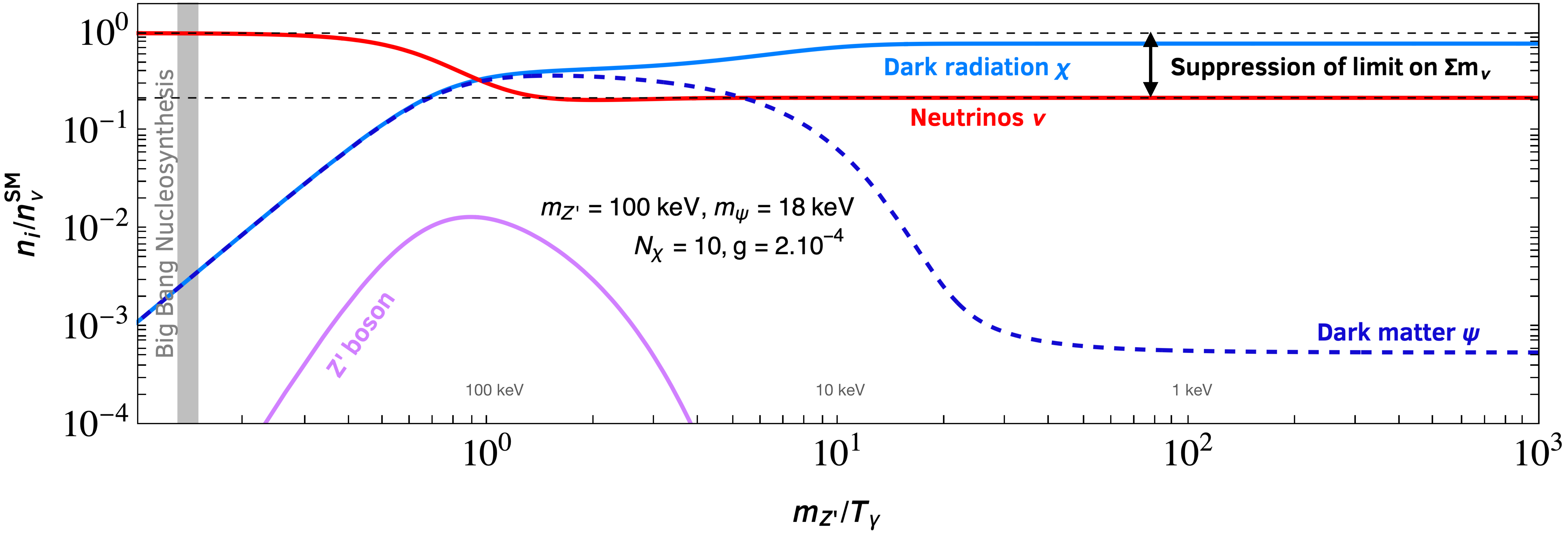

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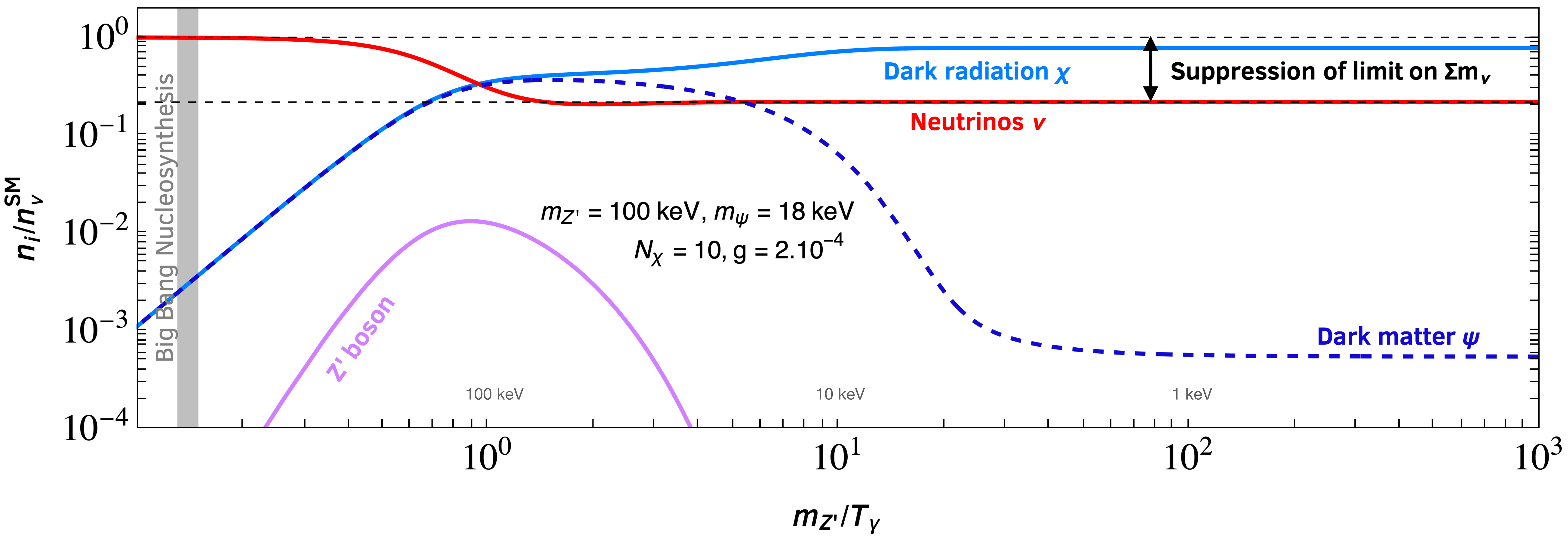

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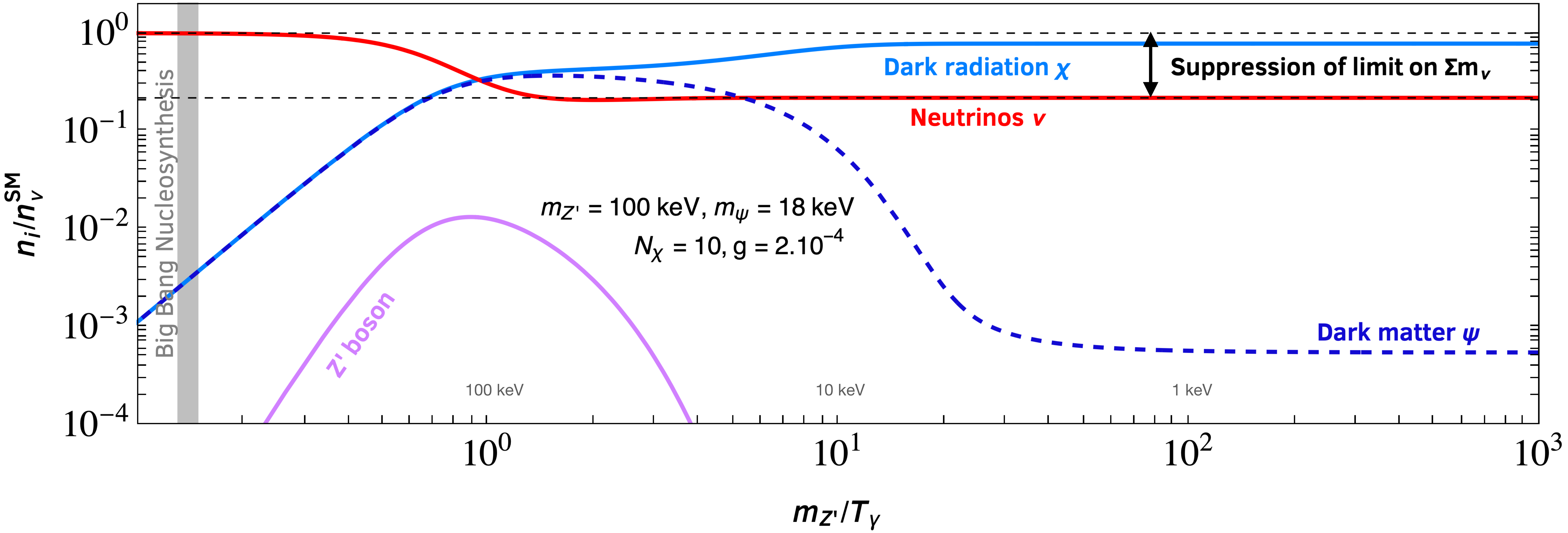

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- *At late times,* DM freezes-out via annihilations $\psi\psi \to \chi\chi$ (possibly avoiding DM overproduction)