24th IMPRS Workshop
Munich

Dark Radiation from a hidden U(1)

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Outline

1. Implications of a hidden U(1)
2. Dark Radiation
3. Summary

Kinetic Mixing

- Lagrangian density for $U(1)_Y$

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu}$$

γ

Kinetic Mixing

- Lagrangian density for $U(1)_Y \times U(1)_h$

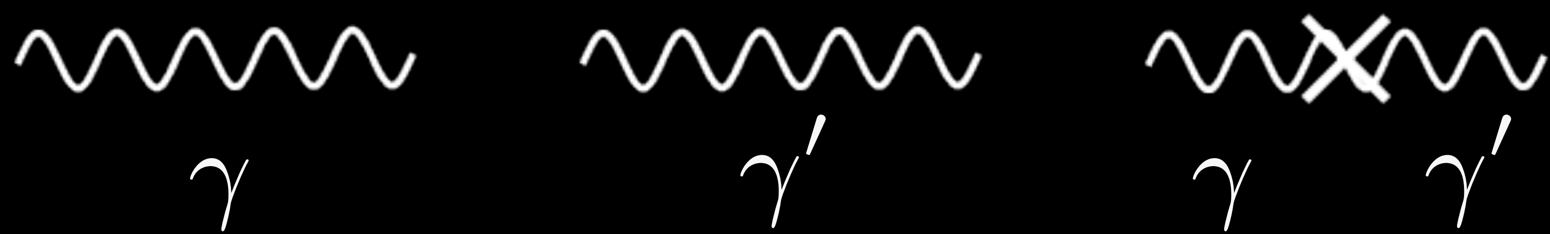
$$\mathcal{L} = -\frac{1}{4} F^{\mu\nu} F_{\mu\nu}$$

γ

Kinetic Mixing

- Lagrangian density for $U(1)_Y \times U(1)_h$

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} - \frac{\chi}{2}F^{\mu\nu}F'_{\mu\nu}$$



Kinetic Mixing

- Lagrangian density for $U(1)_Y \times U(1)_h$

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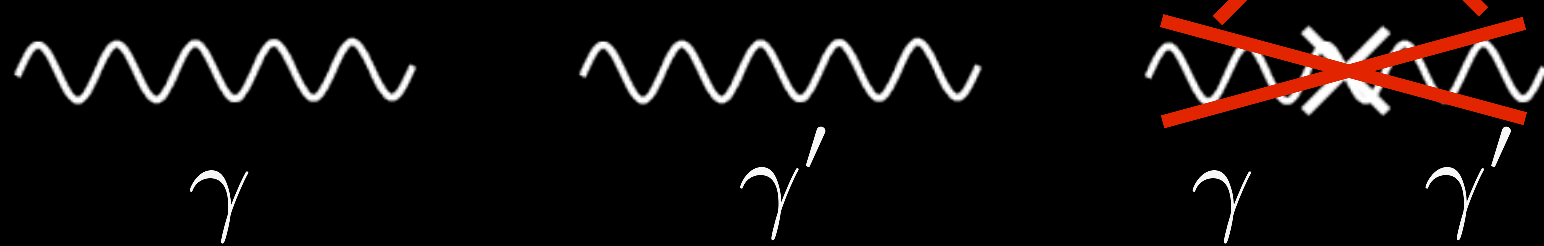


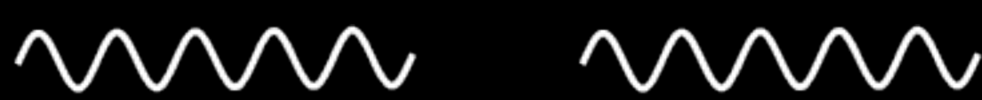
- Redefinition: $A'_\mu \to A'_\mu - \chi A_\mu$

$$A_\mu \to \frac{1}{\sqrt{1-\chi^2}}A_\mu$$

Kinetic Mixing

- Lagrangian density for $U(1)_Y \times U(1)_h$

$$\mathcal{L} = -\frac{1}{4}\tilde{F}^{\mu\nu}\tilde{F}_{\mu\nu} - \frac{1}{4}\tilde{F}'^{\,\mu\nu}\tilde{F}'_{\mu\nu}$$



$\tilde{\gamma}$ $\quad$ $\tilde{\gamma}'$

- Redefinition: $A'_\mu \to A'_\mu - \chi A_\mu$

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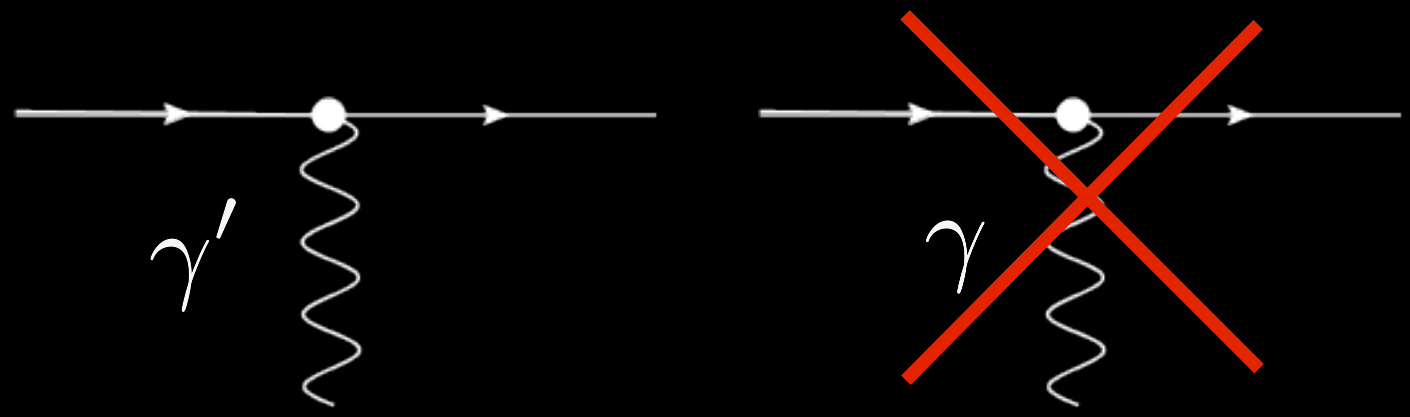
Kinetic Mixing
(+ fermions)

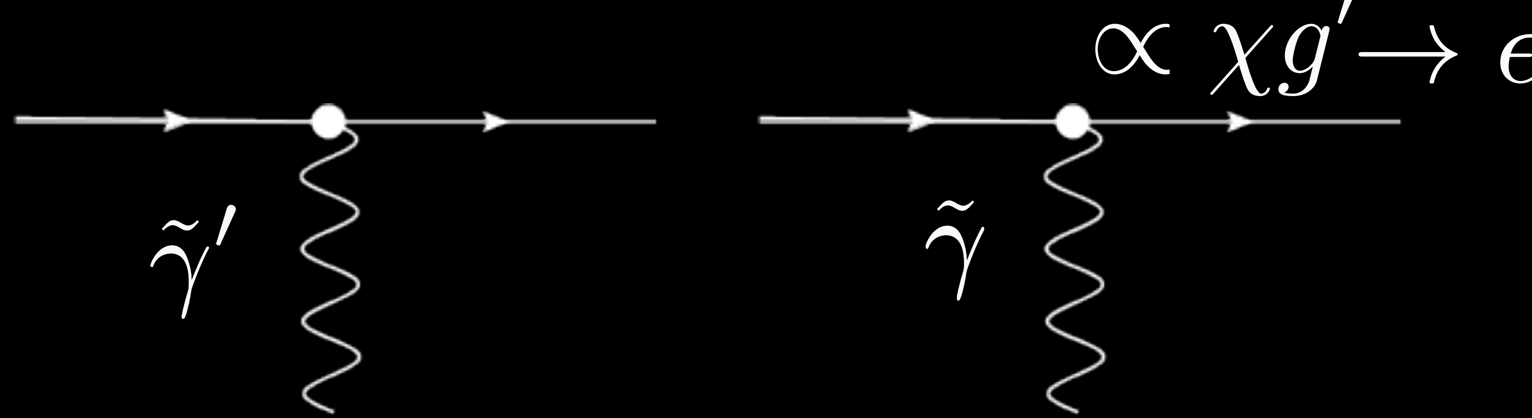
- Dirac fermion Ψ



$$D_\mu \Psi = (\partial_\mu - i g' A'_\mu)\Psi$$

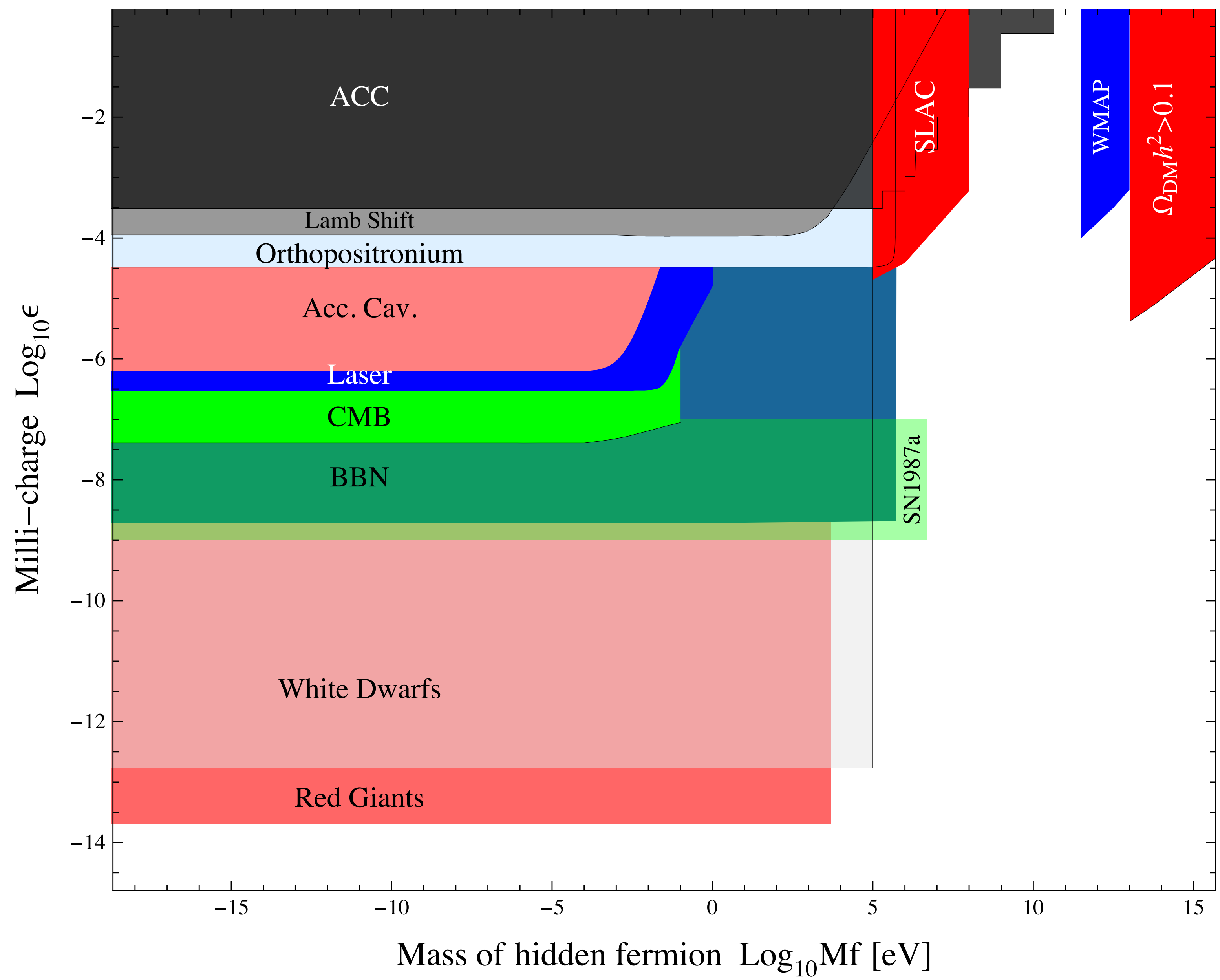
Kinetic Mixing
(+ fermions)

- Dirac fermion Ψ



$$D_\mu \Psi = (\partial_\mu - ig' \tilde{A}'_\mu - ig' \frac{\chi}{\sqrt{1-\chi^2}} \tilde{A}_\mu)\Psi$$

Milli-Charged Particles

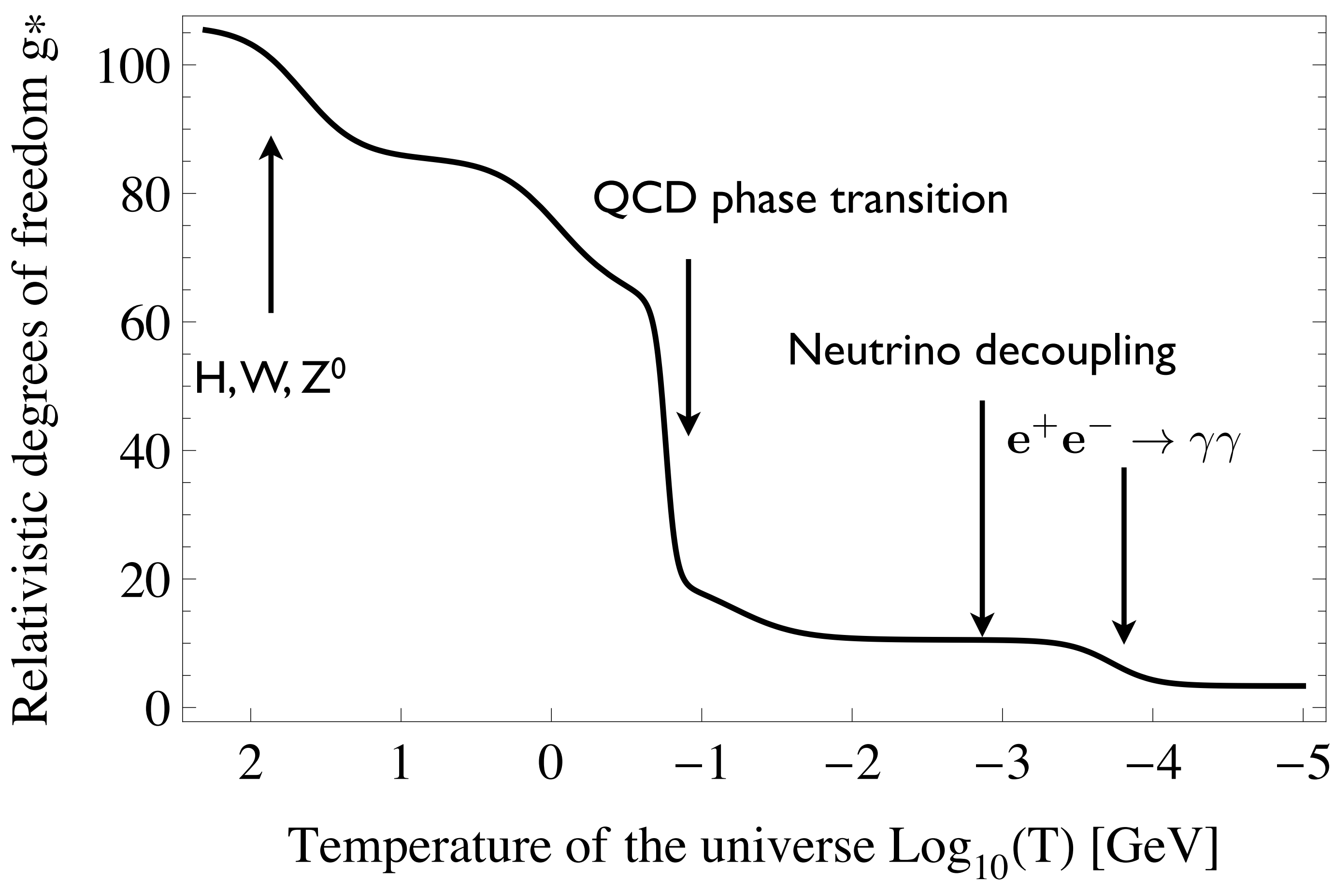


Davidson, Hannestad, Raffelt 2000, modified by Javier Redondo

2. Dark Radiation

Expansion of the Universe

Hubble parameter: $H \propto \sqrt{\rho} \propto g_\star^{1/2} T^2$



Fit by Wantz & Shellard (2009): 0910.1066

N_{eff}

Effective neutrino degrees of freedom N_{eff}

$$N_{\text{eff}} = 3$$

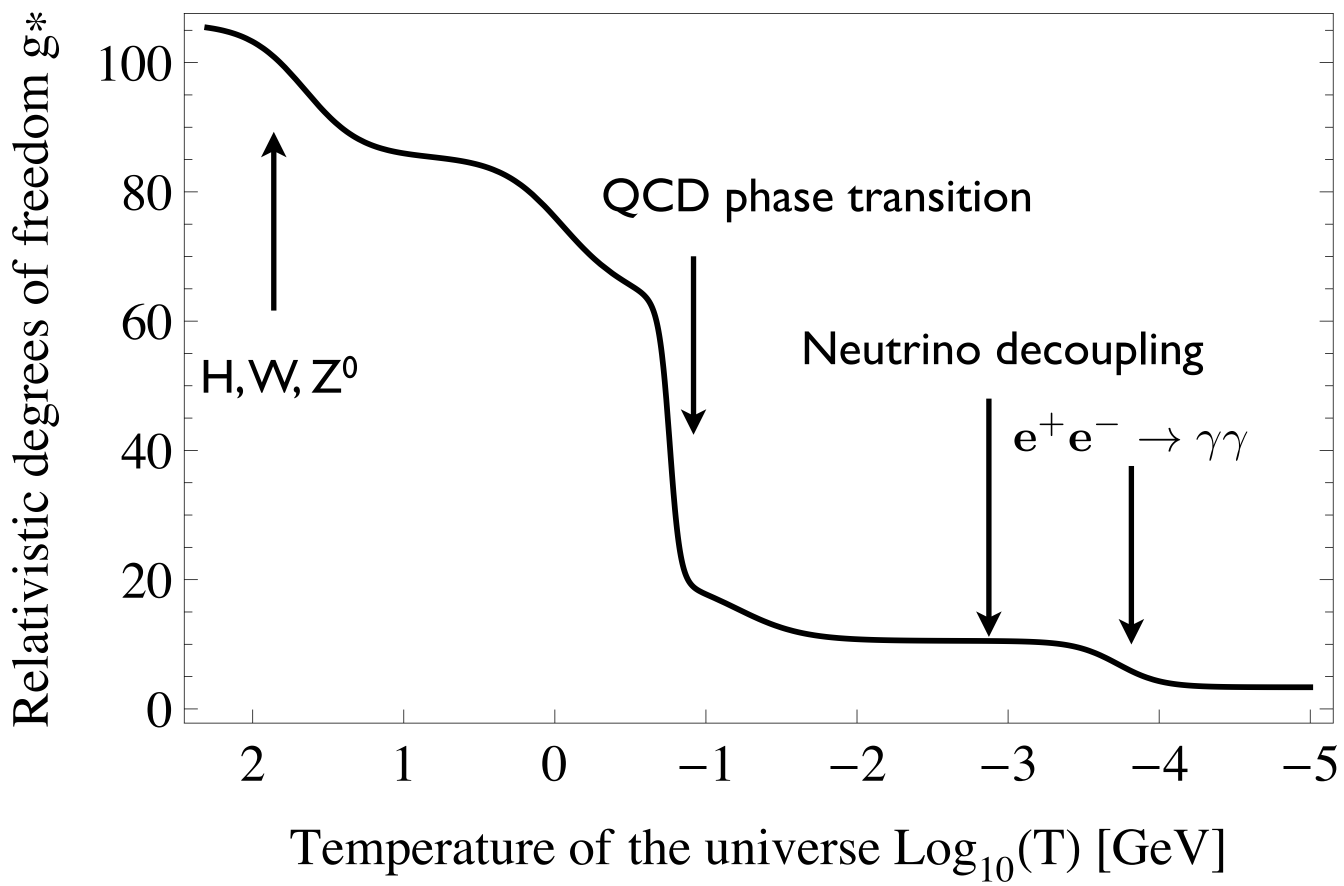
Standard Model

$$N_{\text{eff}} = 3.85 \pm 0.84 \ 95\% \text{ c.l.}$$

for CMB (Keisler et al. (2011): 1108.4136)

$$\Delta N_{\text{eff}} = \frac{\rho_R}{\rho_\nu} \propto \left(\frac{T_R}{T_\nu}\right)^4 = \left(\frac{T_R}{\left(\frac{4}{11}\right)^{\frac{1}{3}} T_\gamma}\right)^4$$

Neutrino Temperature



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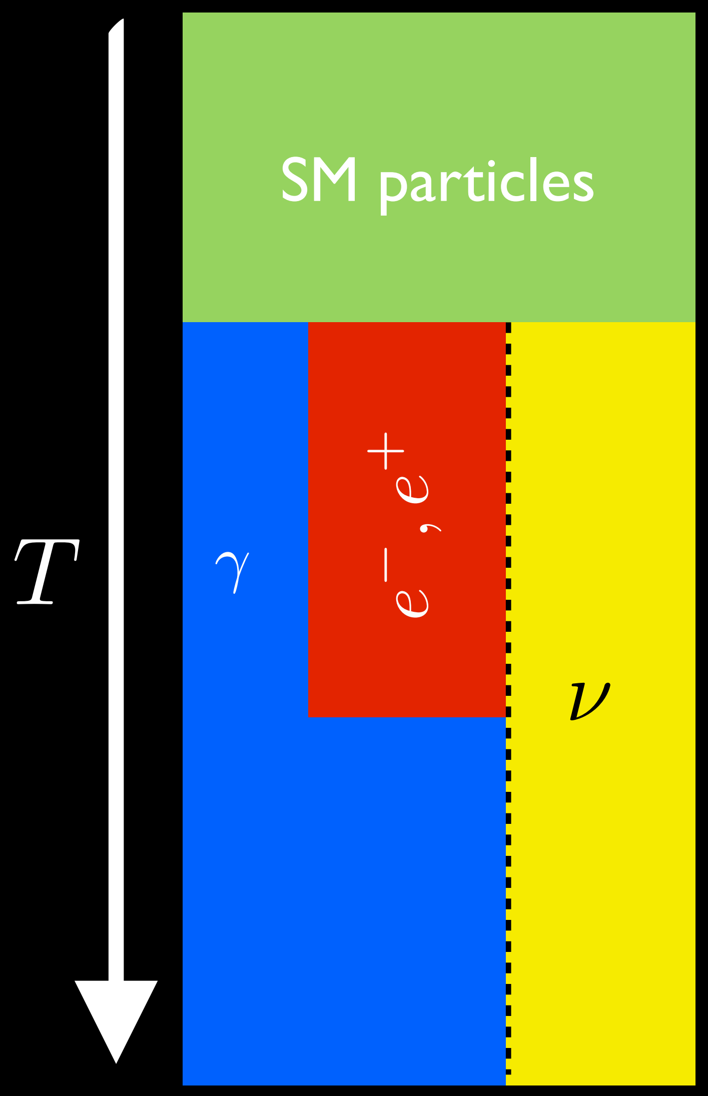
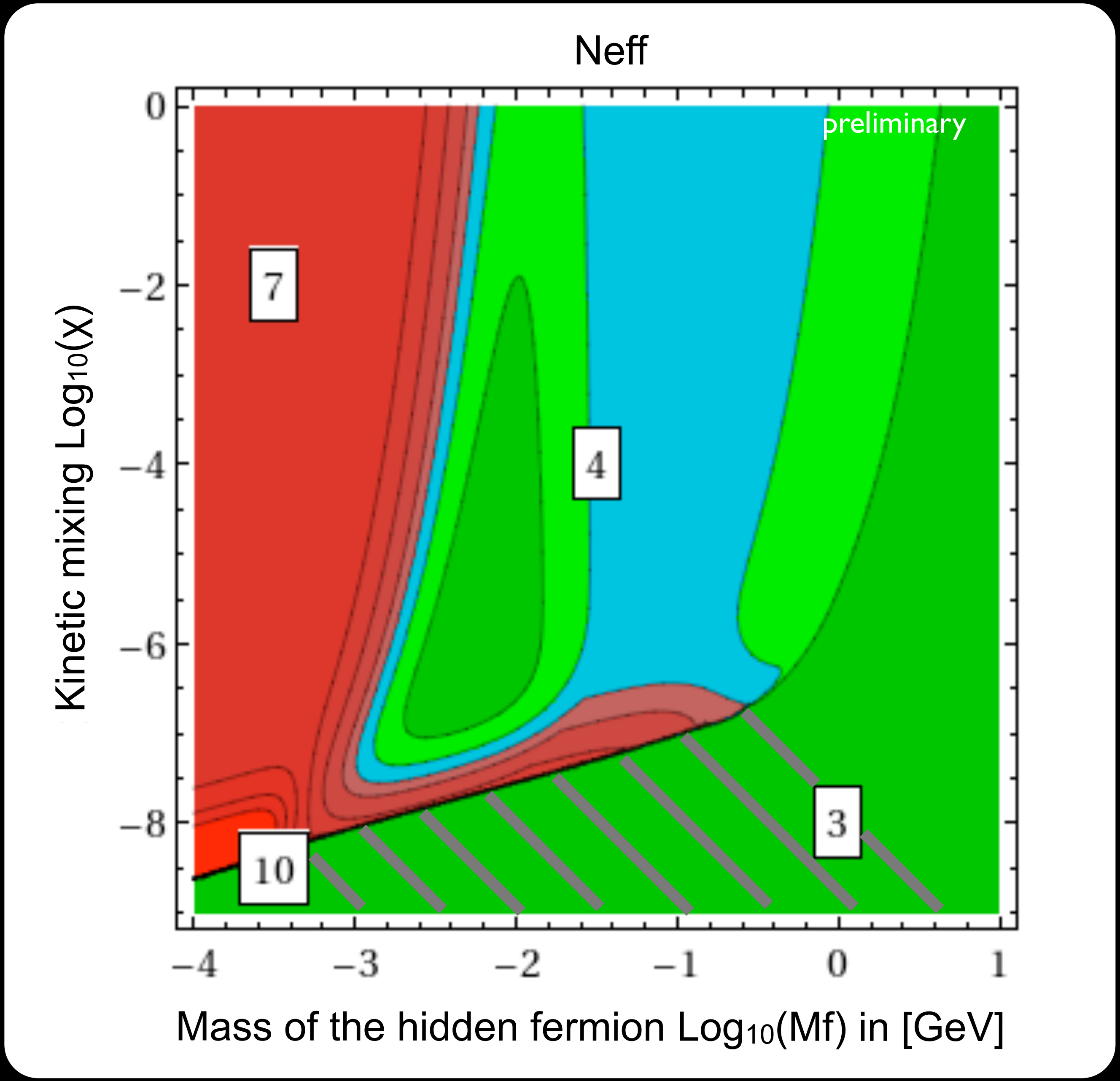


$$\frac{T_\nu}{T_\gamma} = \left(\frac{4}{11}\right)^{\frac{1}{3}}$$

Results


Neff
preliminary
7
4
10
3
0
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−4
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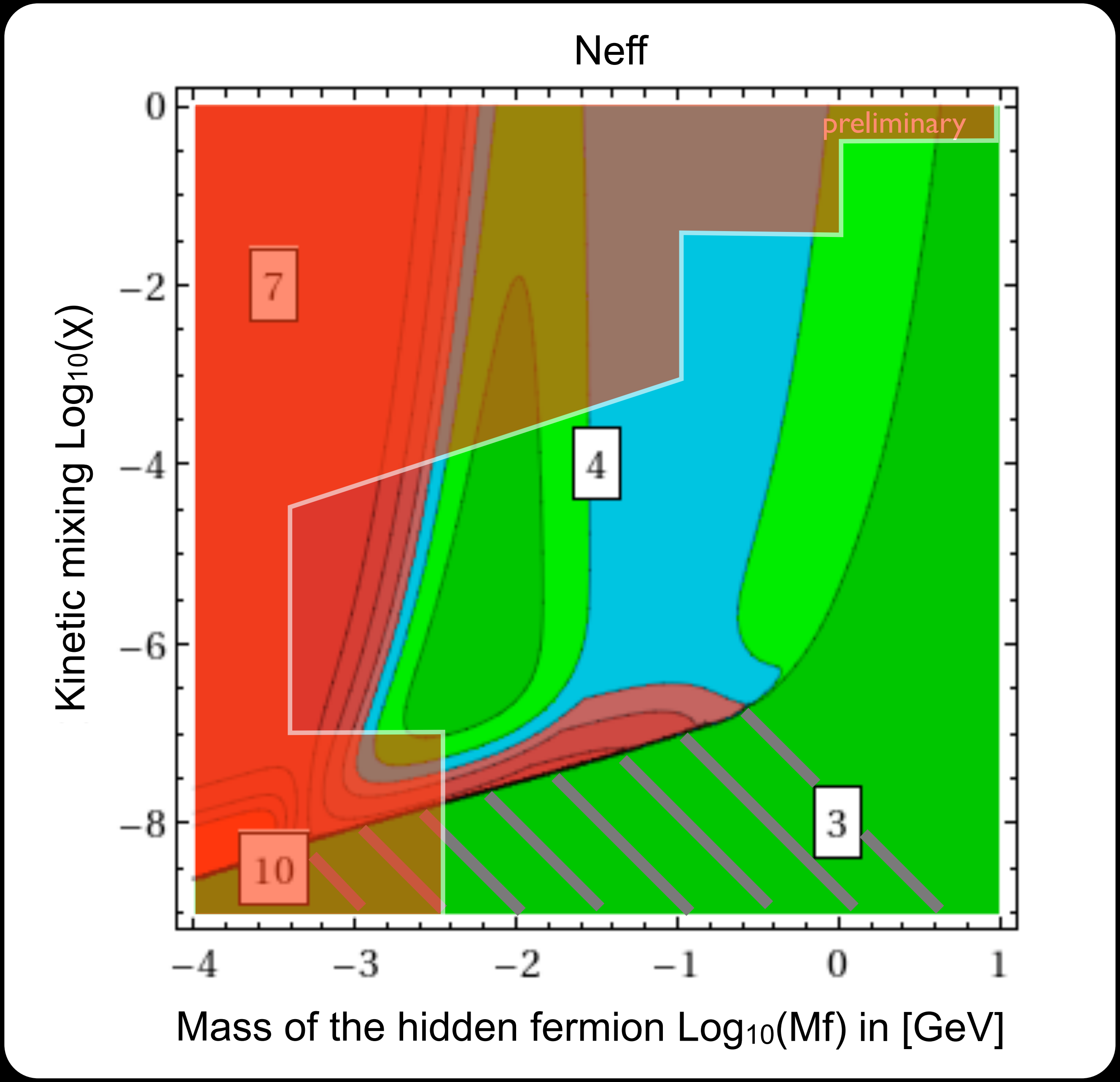
0
1
Kinetic mixing Log10(X)
Mass of the hidden fermion Log10(Mf) in [GeV]

Results



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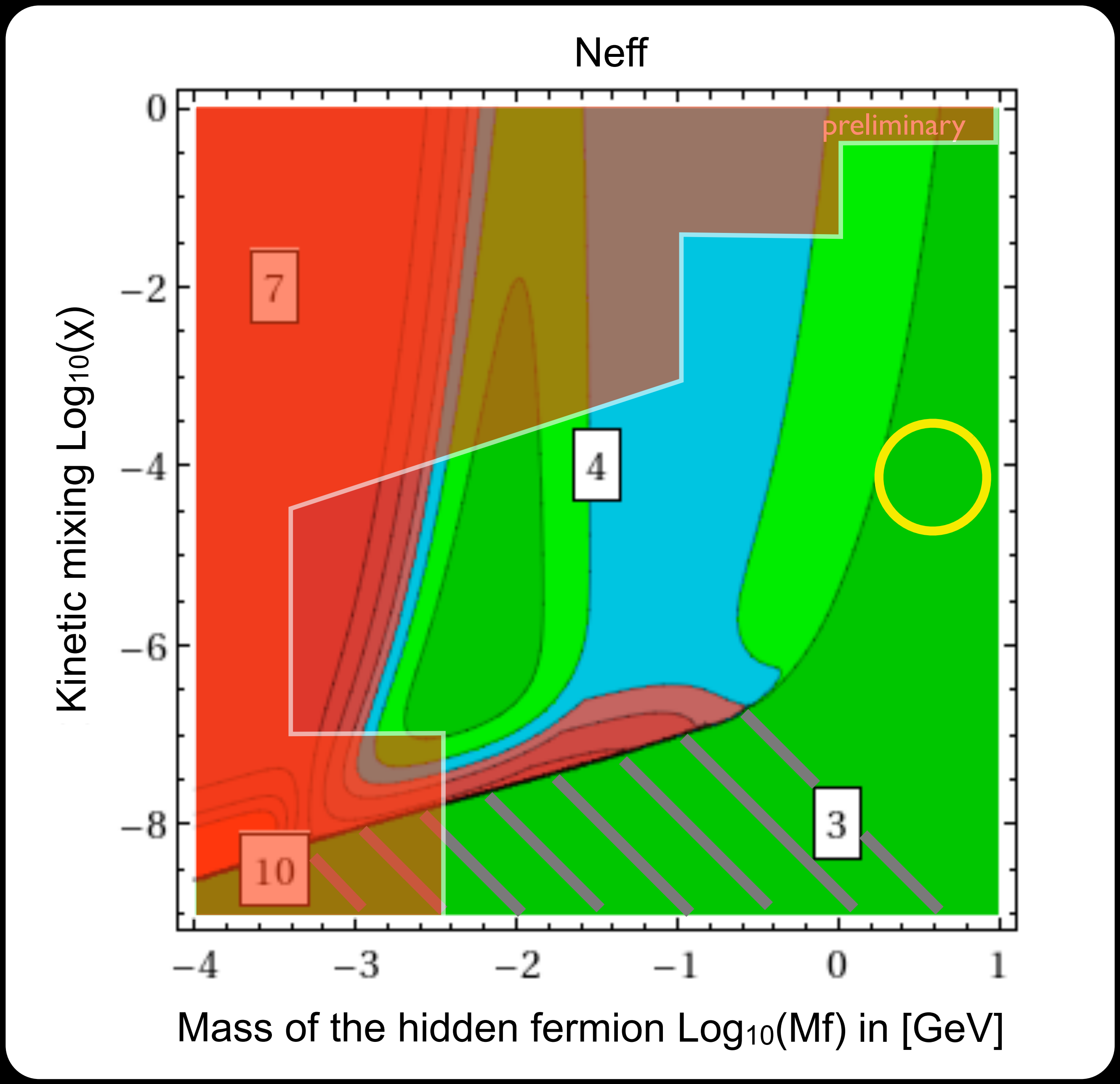

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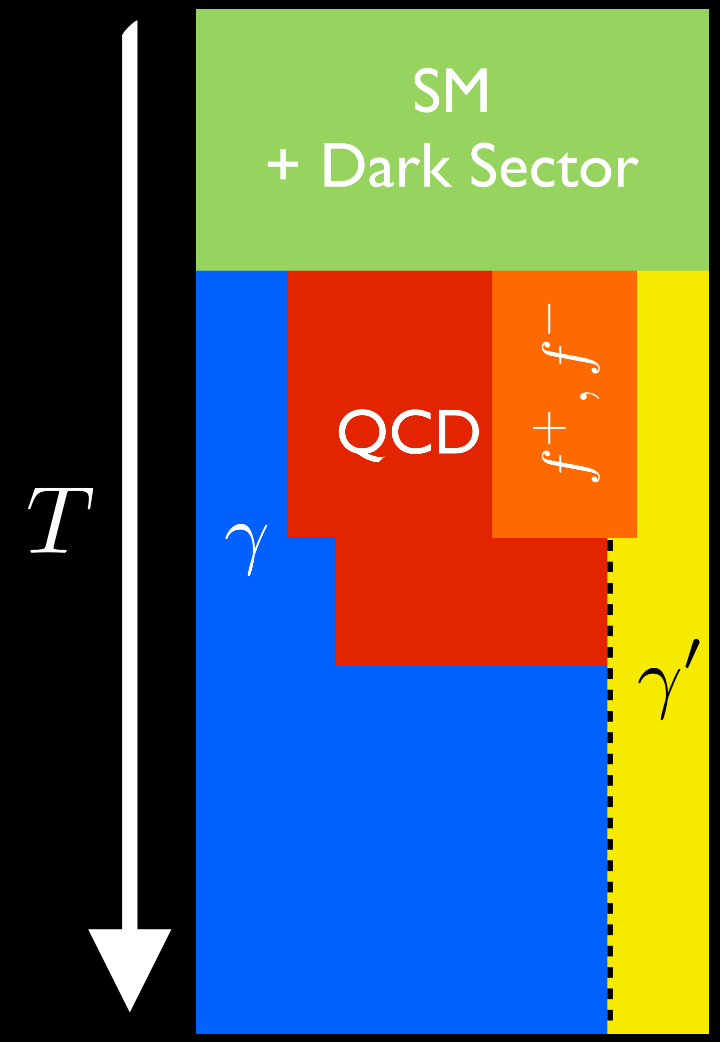
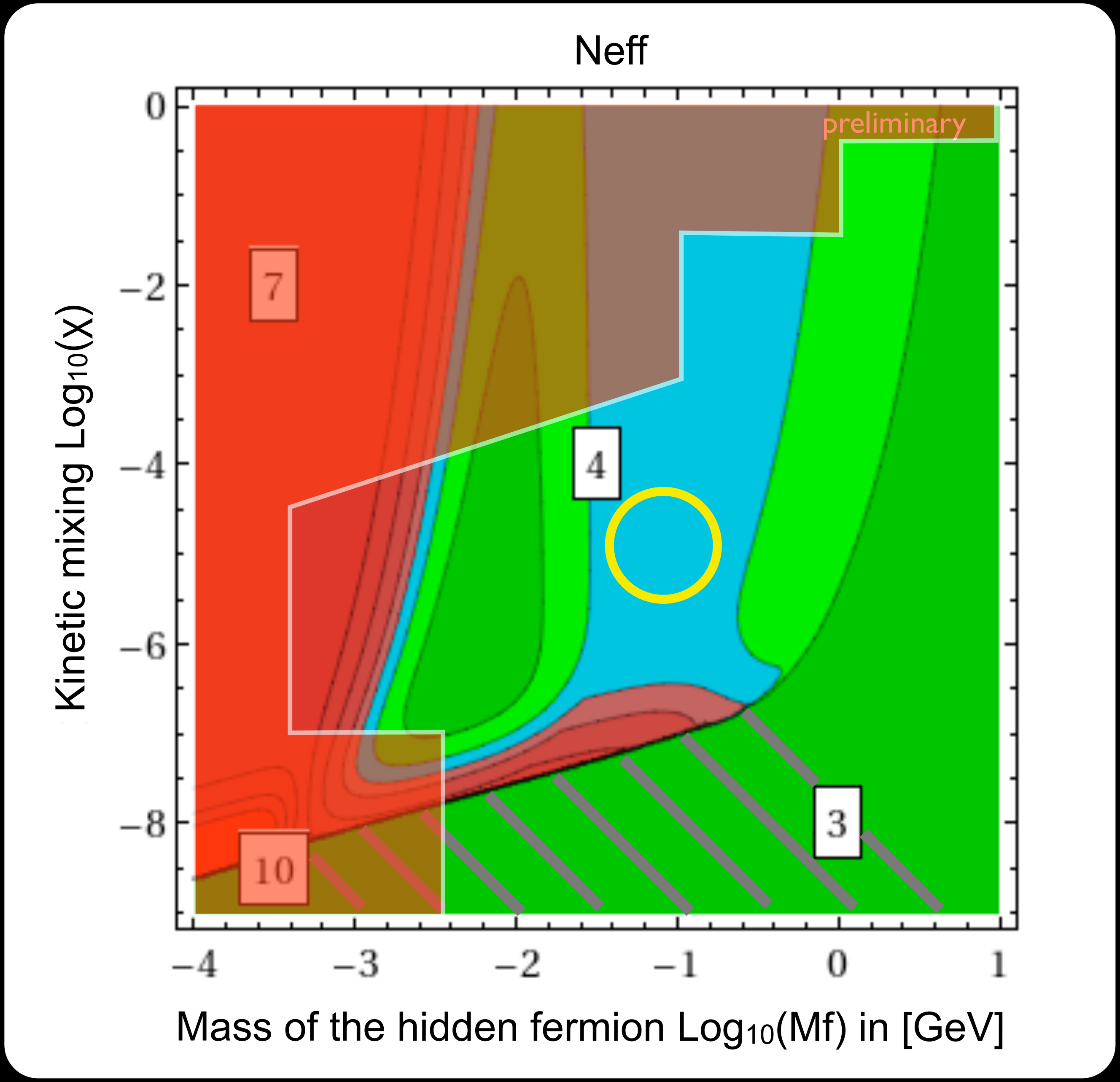


SM
+ Dark Sector
QCD
f^+, f^-
T
γ
γ'

Results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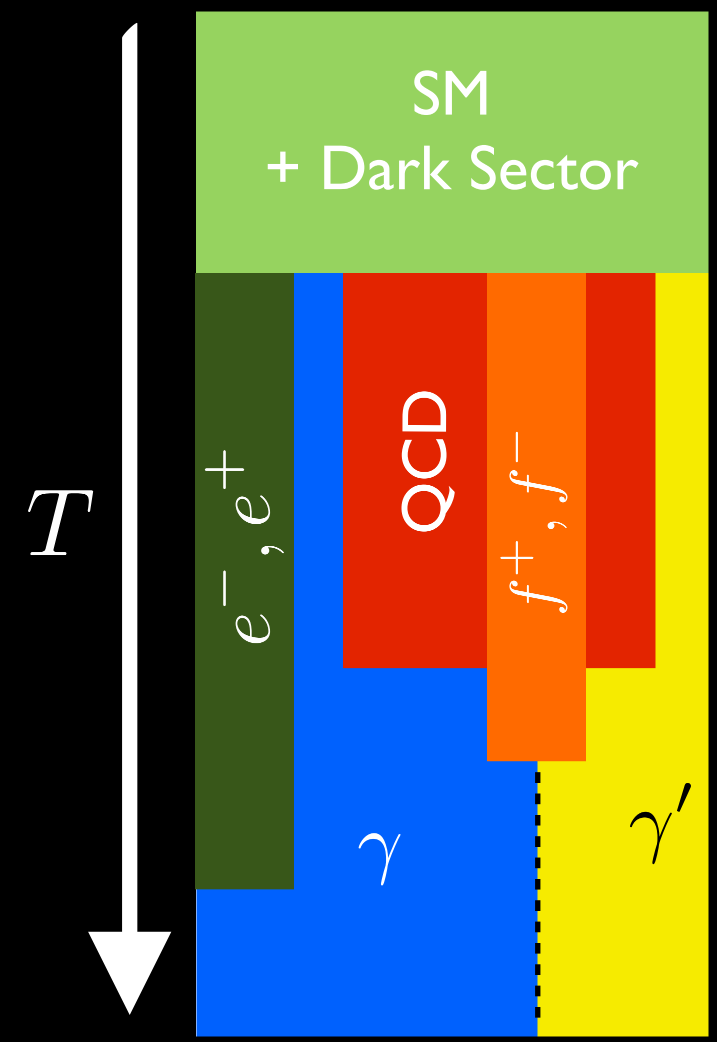
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e^-, e^+
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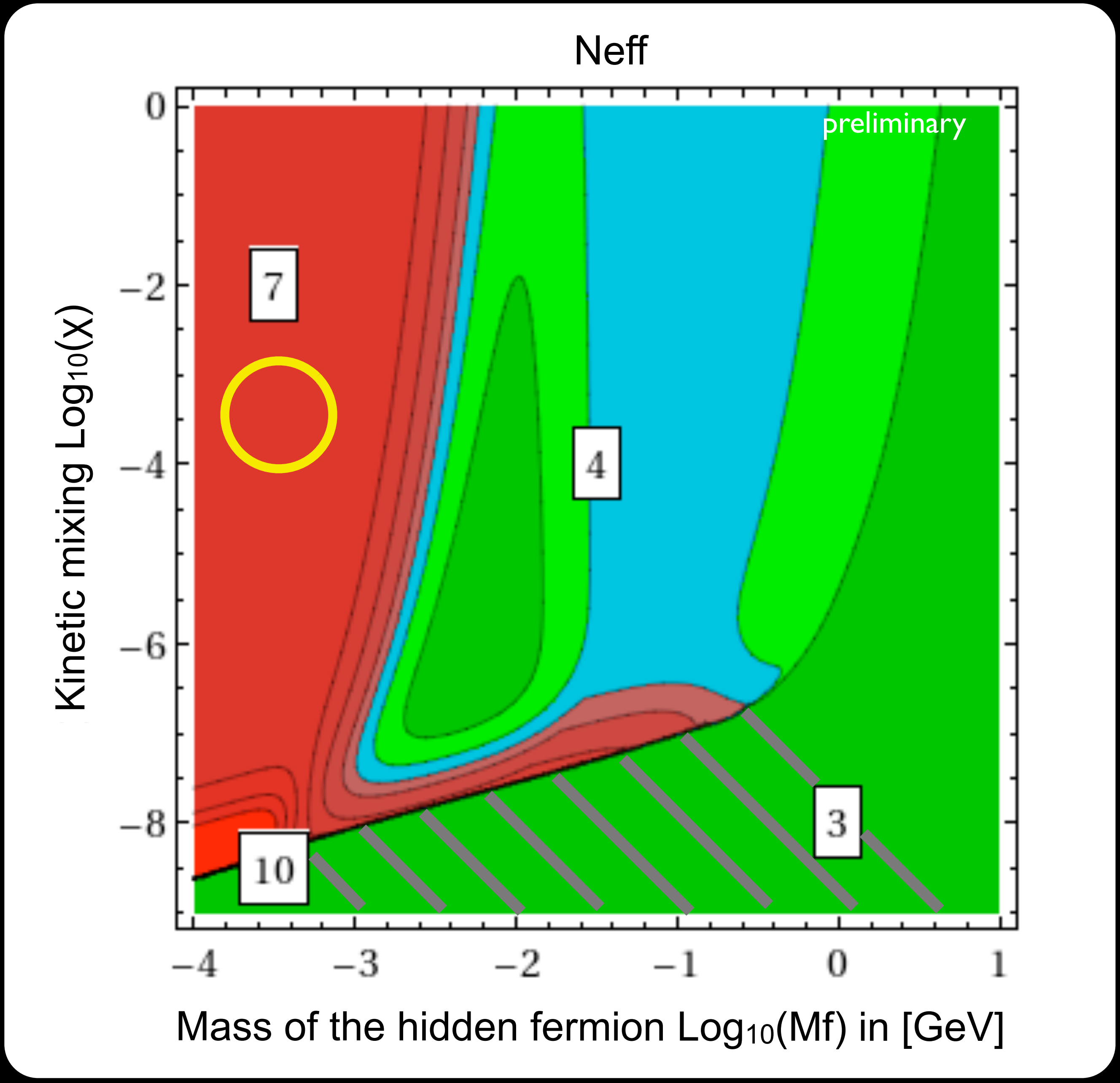
Summary

- Photons of an additional unbroken U(1) alone are unobservable
- Adding fermions leads to milli-charged particles
- Coupling these fermions to the Standard Model accelerates expansion of the universe (Dark Radiation)
- Observations favor an additional radiative component ($N_{eff} > 3$)
- This can be explained with an additional photon and an additional fermion

Results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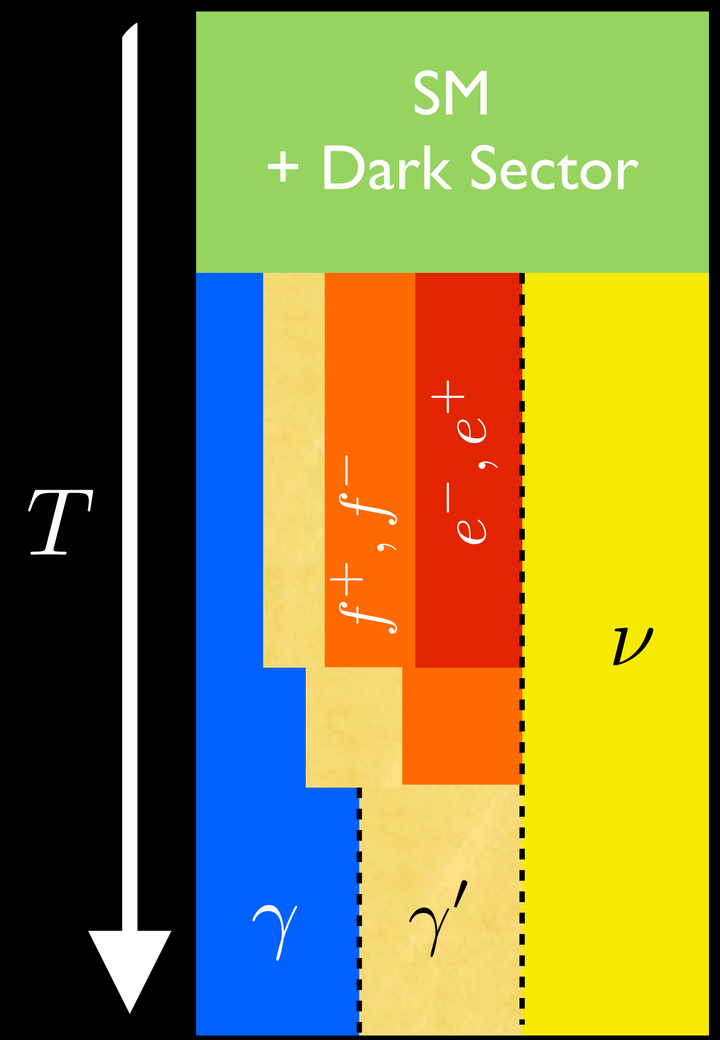
SM
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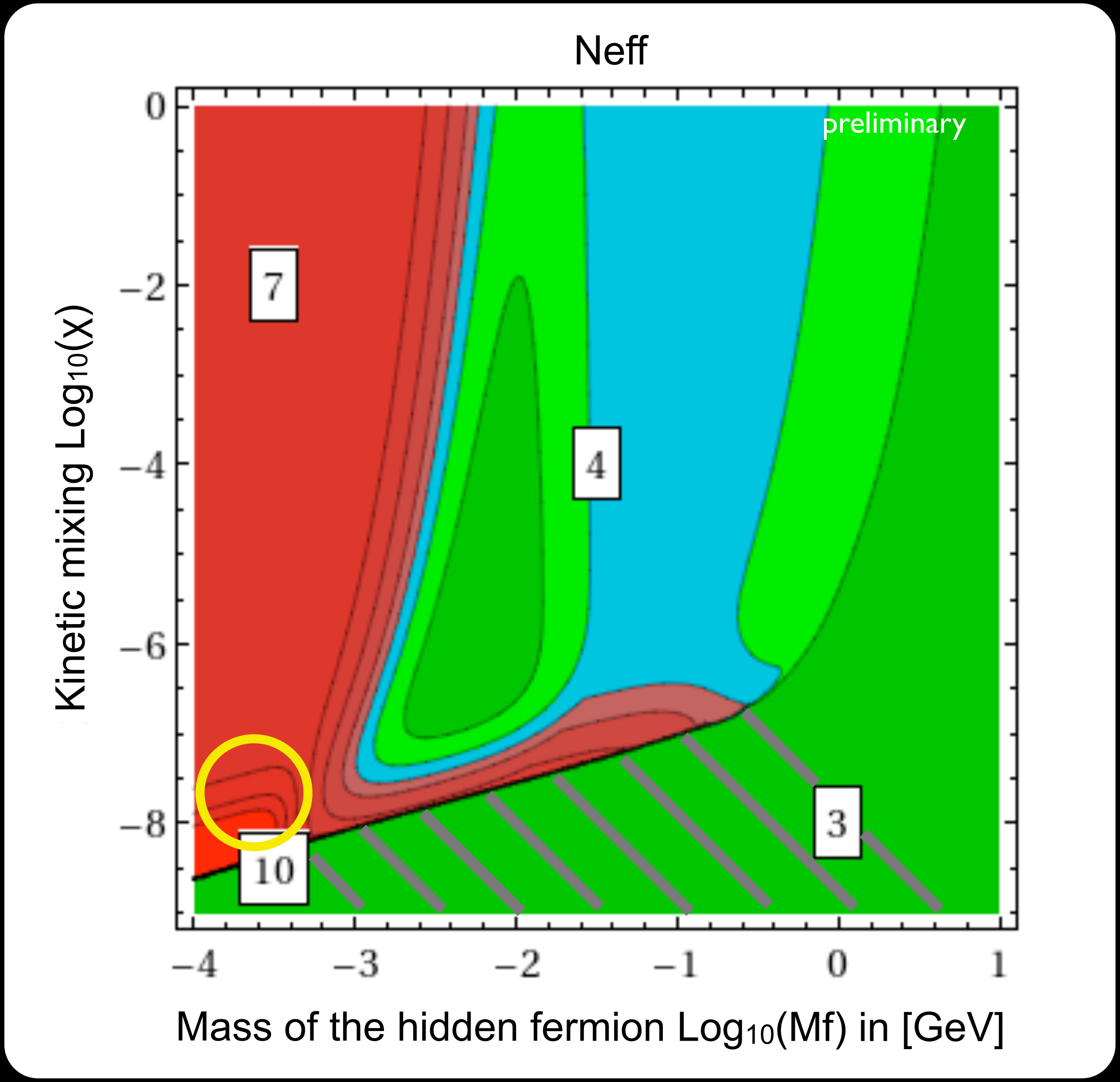
γ'

Results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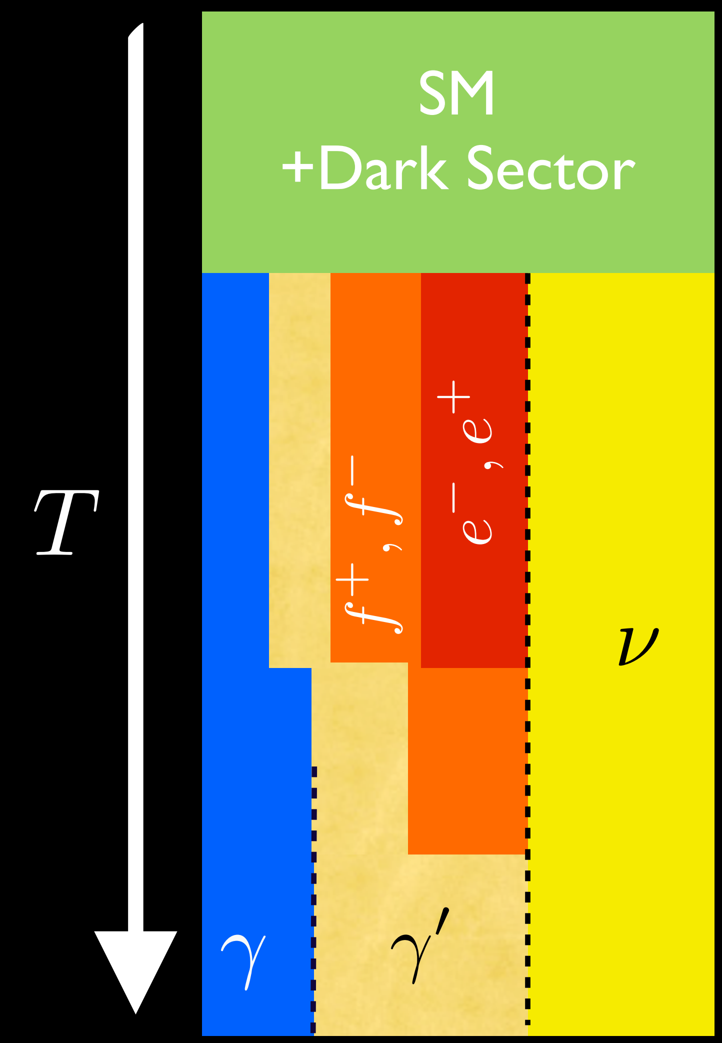
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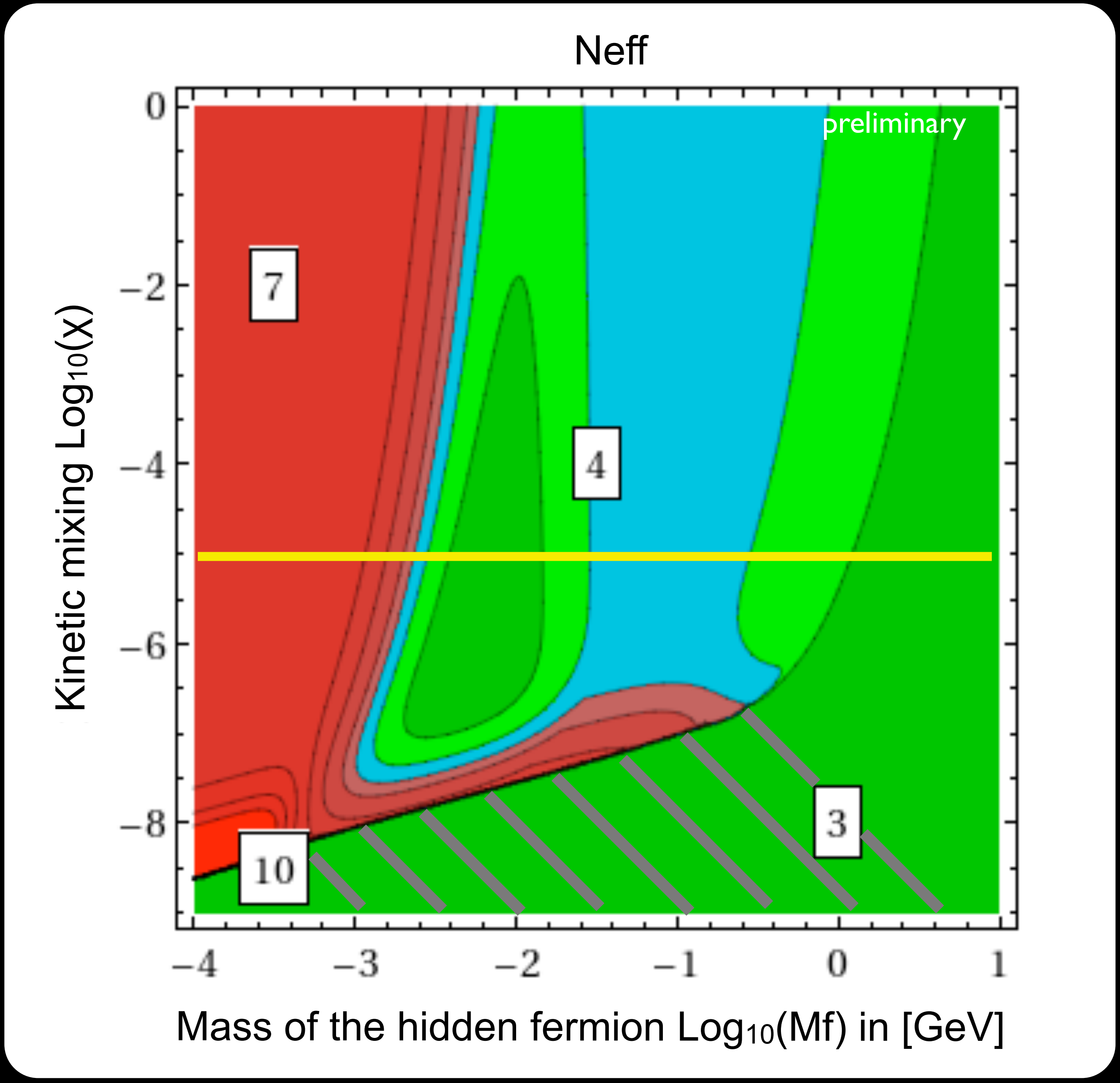

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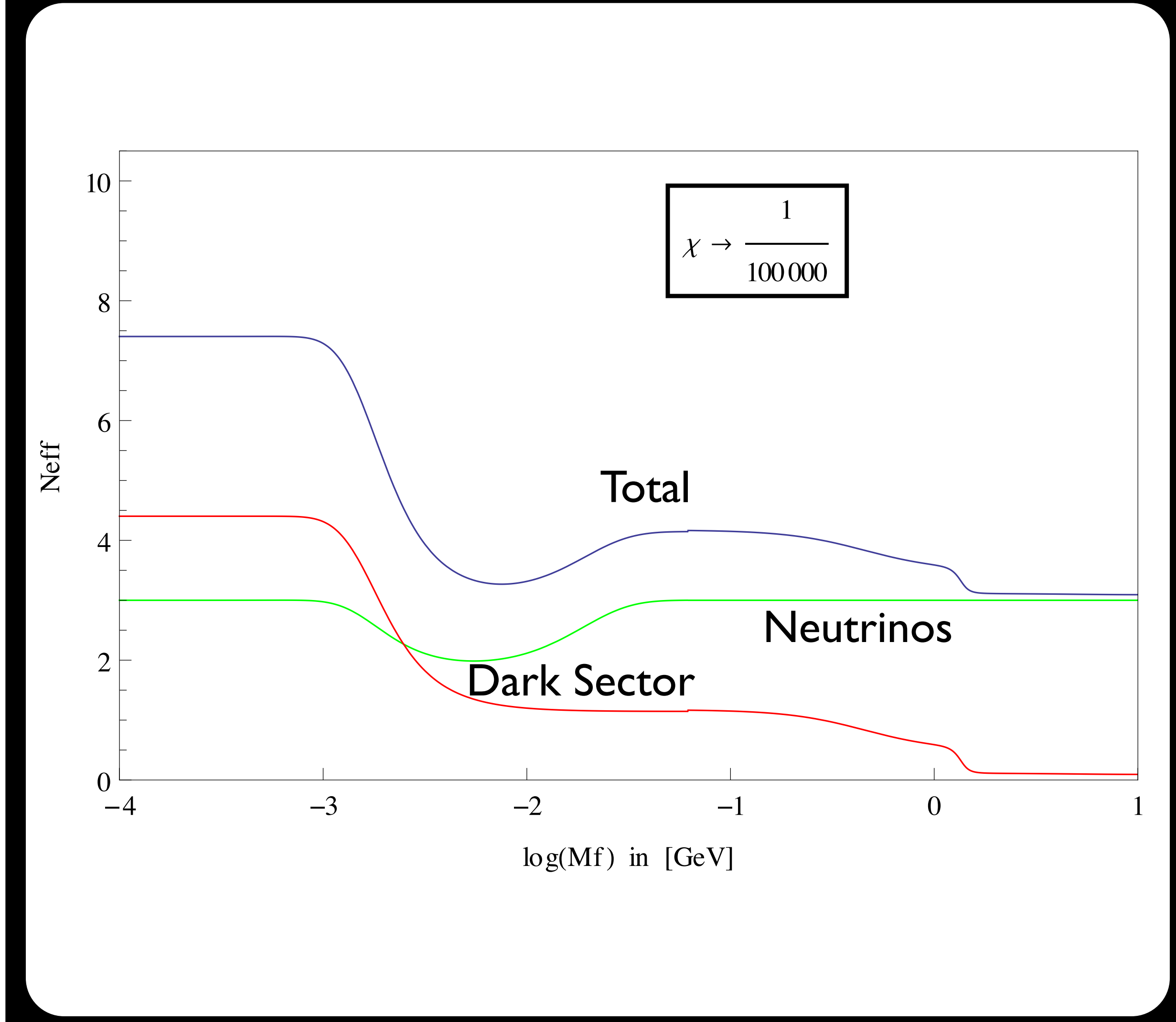
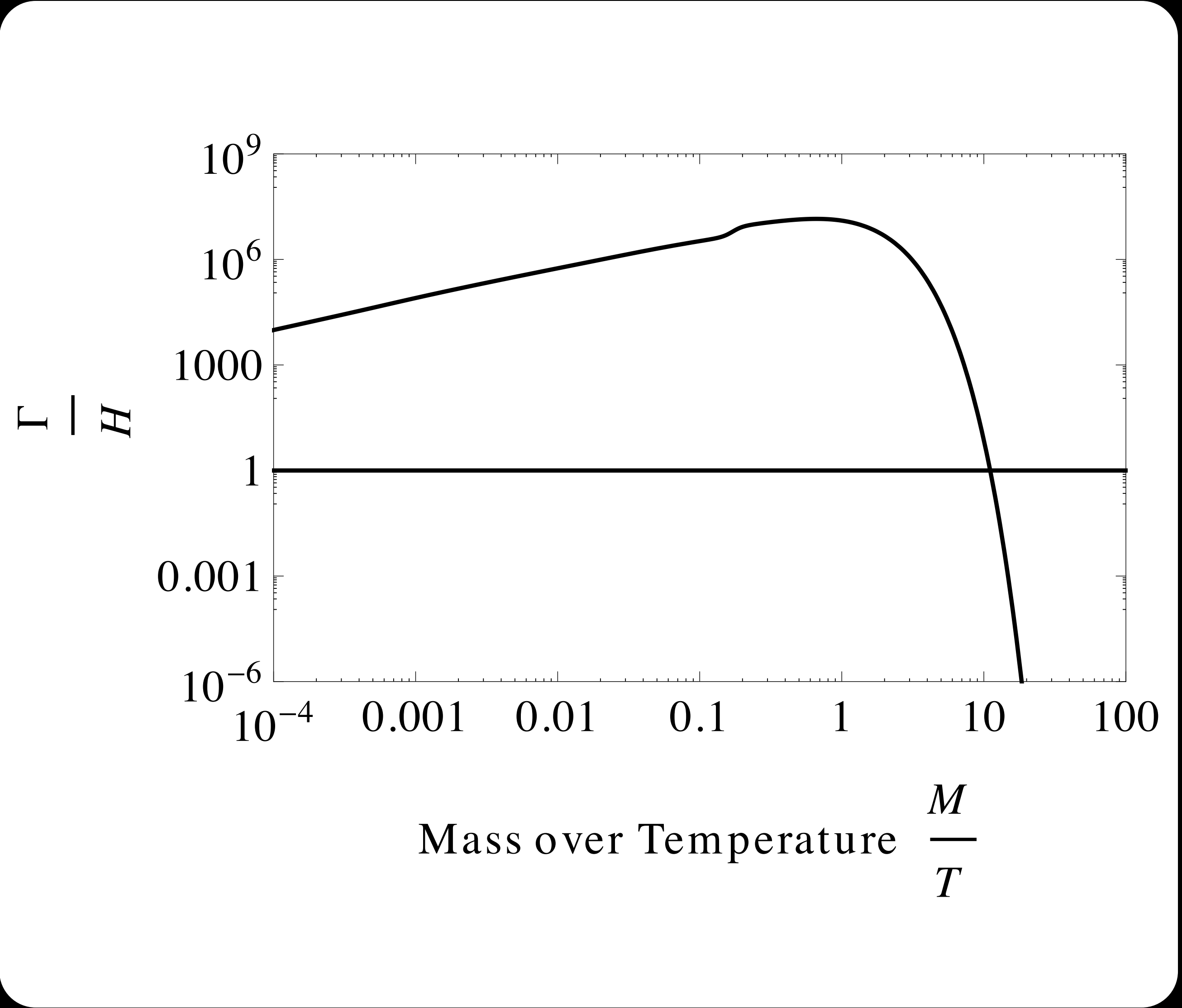


$\chi \to \frac{1}{100\,000}$
Total
Neutrinos
Dark Sector
Neff
log(Mf) in [GeV]
10
8
6
4
2
0
−4
−3
−2
−1
0
1

Decoupling



$$\Gamma = < \sigma v > n_f$$