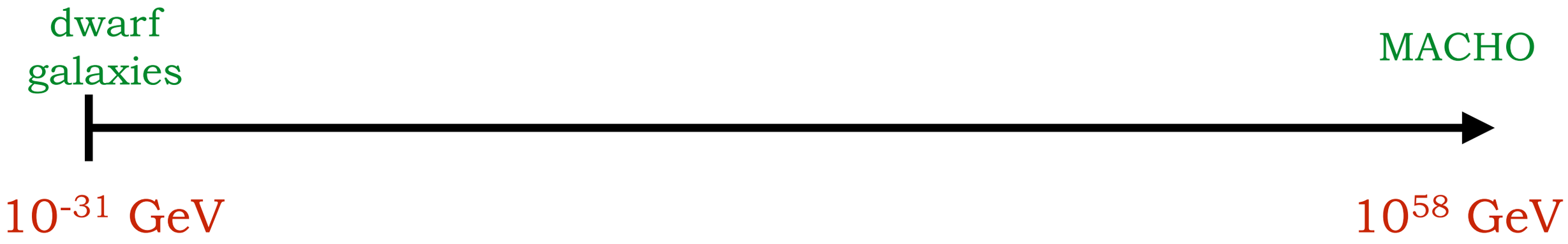
Thermal Dark Matter Below an MeV

ASHER BERLIN

TeVPA, Ohio State University
August 9, 2017

Collaboration with Nikita Blinov, arXiv: 1706.07046

Dark Matter Mass



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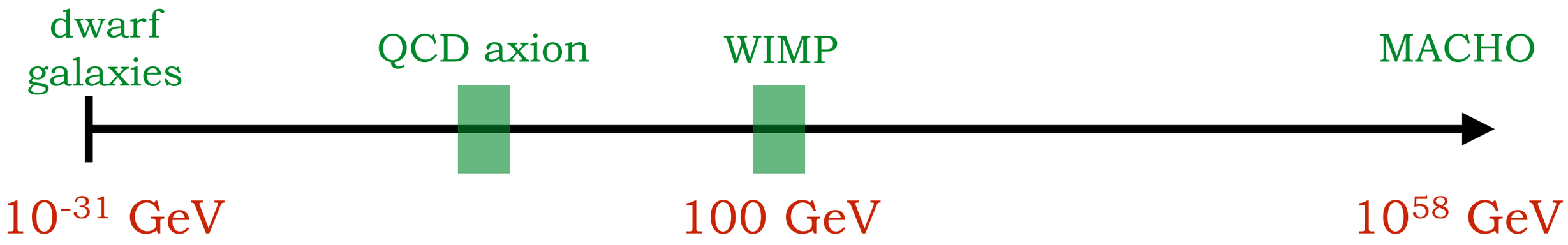

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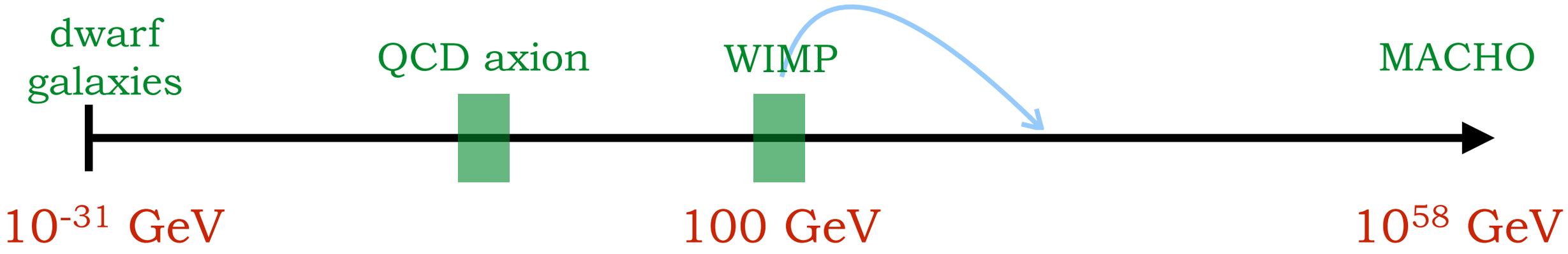

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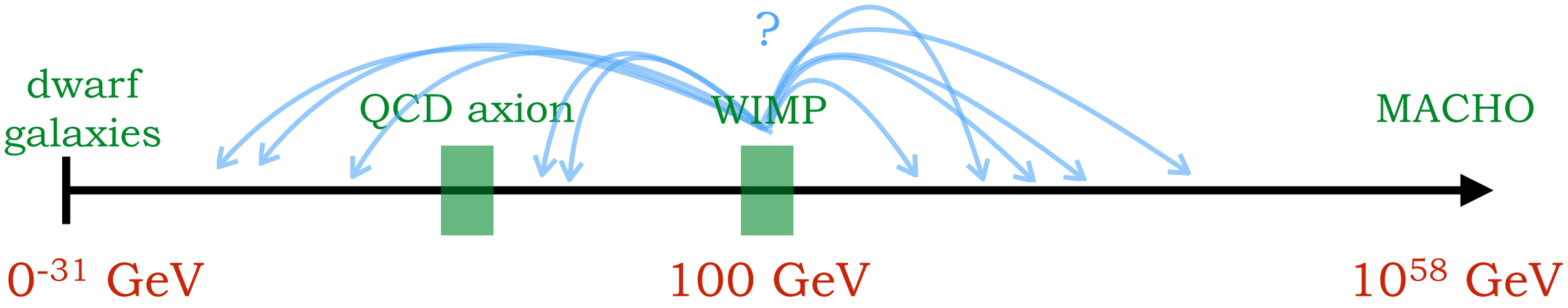

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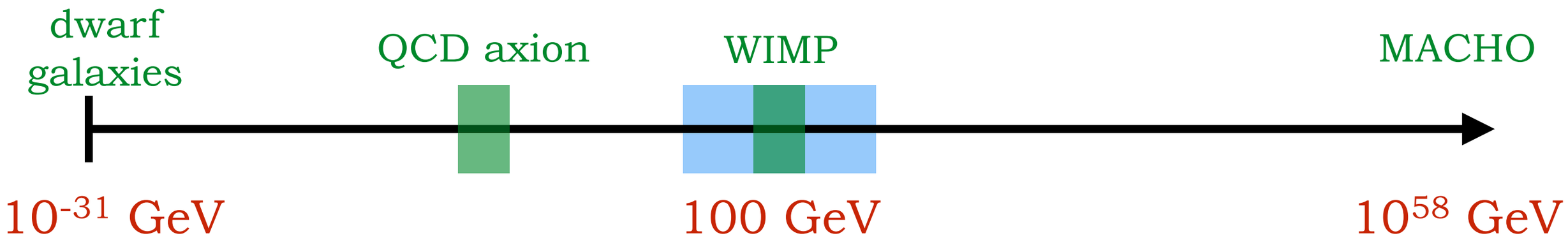
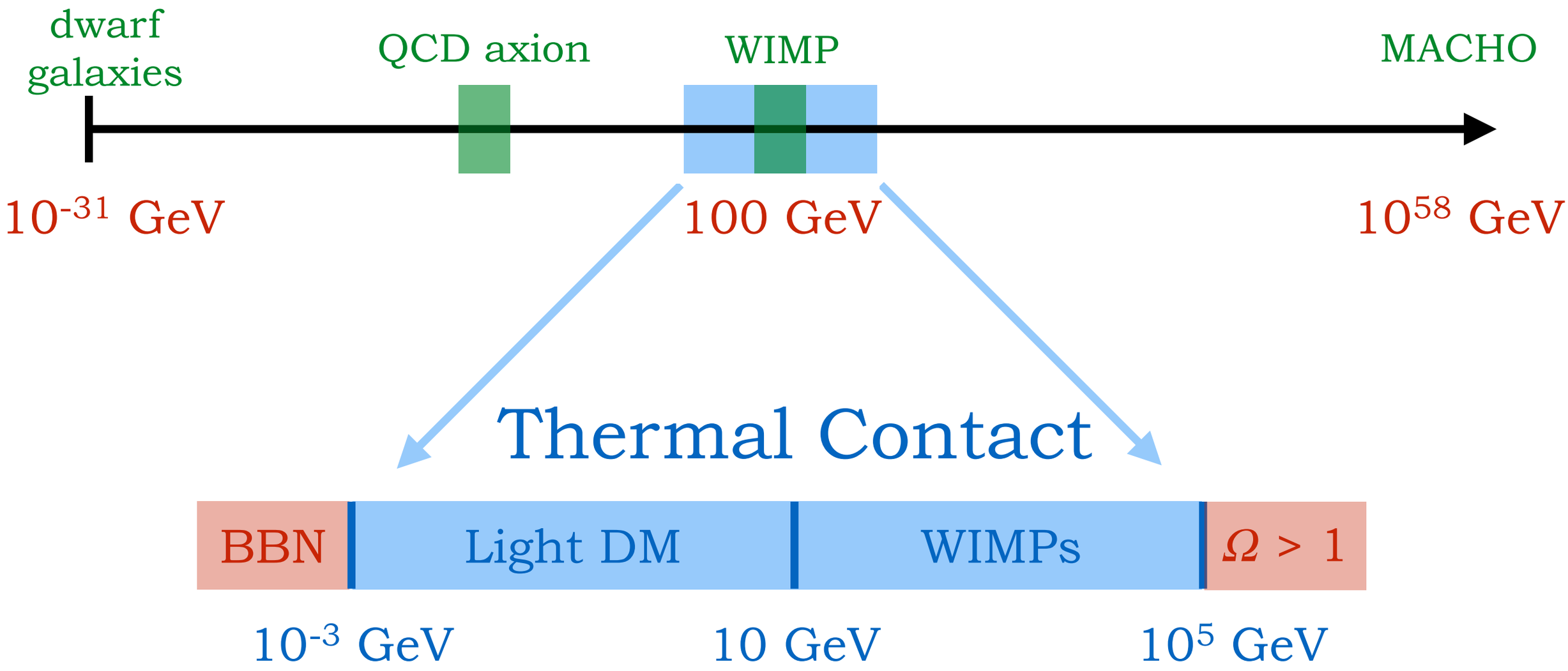
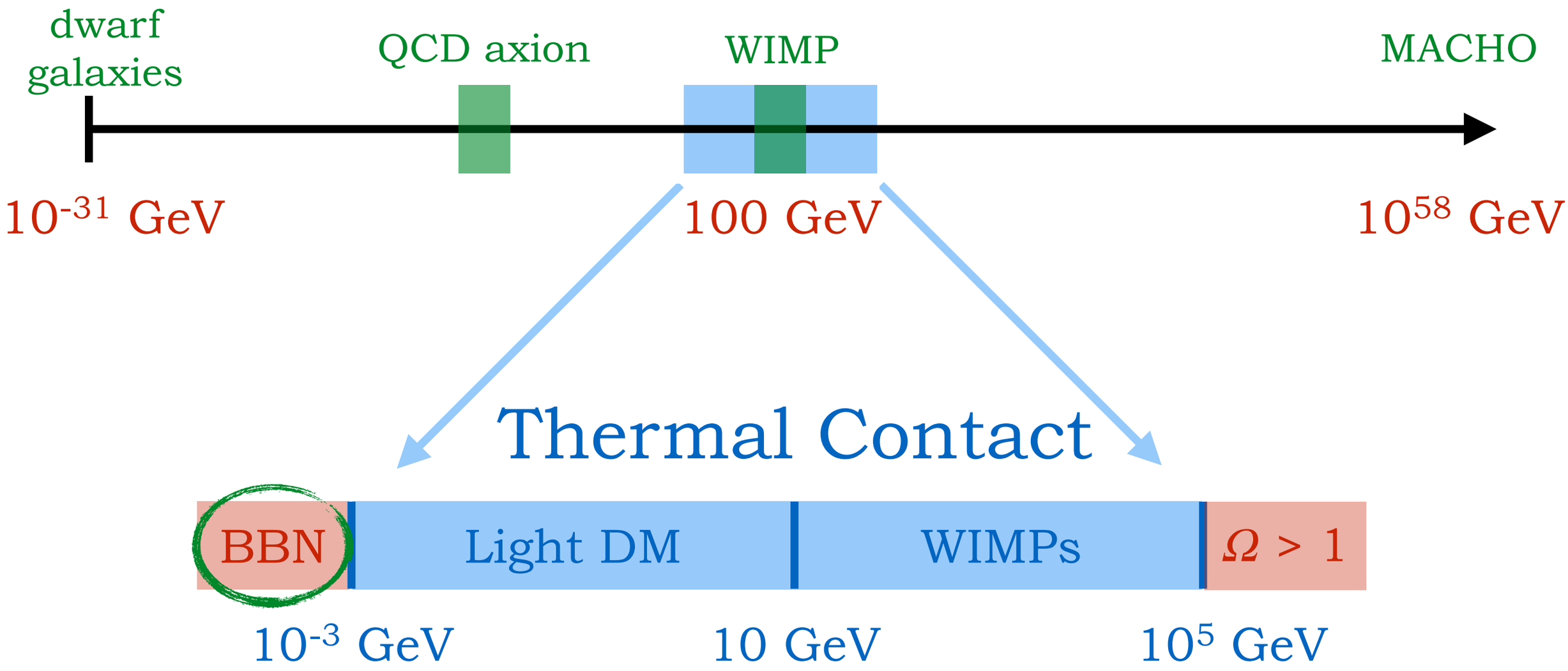


Thermal Contact

Dark Matter Mass



Dark Matter Mass



thermal dark matter

noun

Definition of THERMAL DARK MATTER

: dark matter that acquired its cosmological abundance through thermal contact with the Standard Model bath at large temperatures.

First Known Use: 1970s

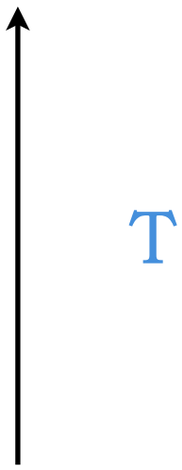
N_{eff}

N_{eff}

DM-SM Equilibration > MeV

(standard assumption)

Neutrino-Photon Decoupling ~ MeV



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DM-Neutrino Equilibration

$$N_{\rm eff} \simeq 3 \left(1 + \frac{4}{21}\, g_\chi\right)^{4/3} \gtrsim 3.78$$

Sub-MeV: BBN + CMB

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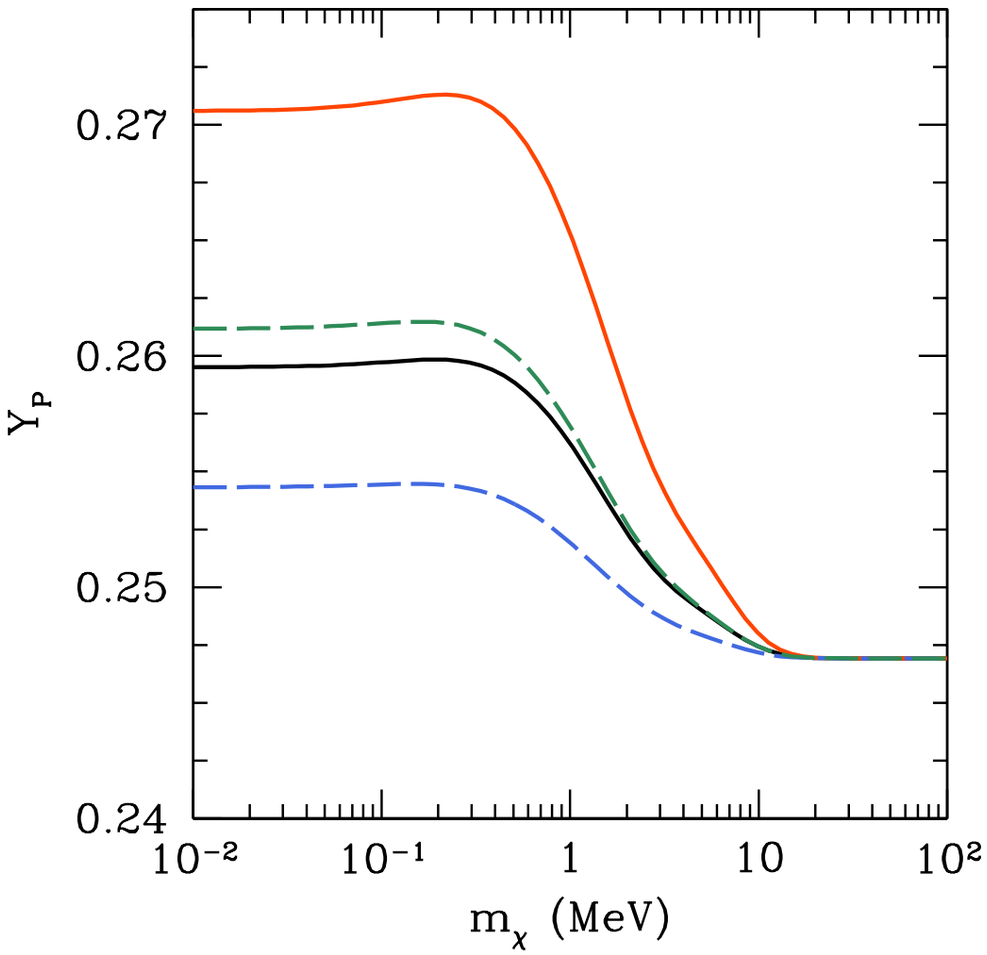
$N_{\rm eff}$ (BBN) $\simeq 2.85 \pm 0.28$



K. Nollett, G. Steigman, arXiv:1411.6005

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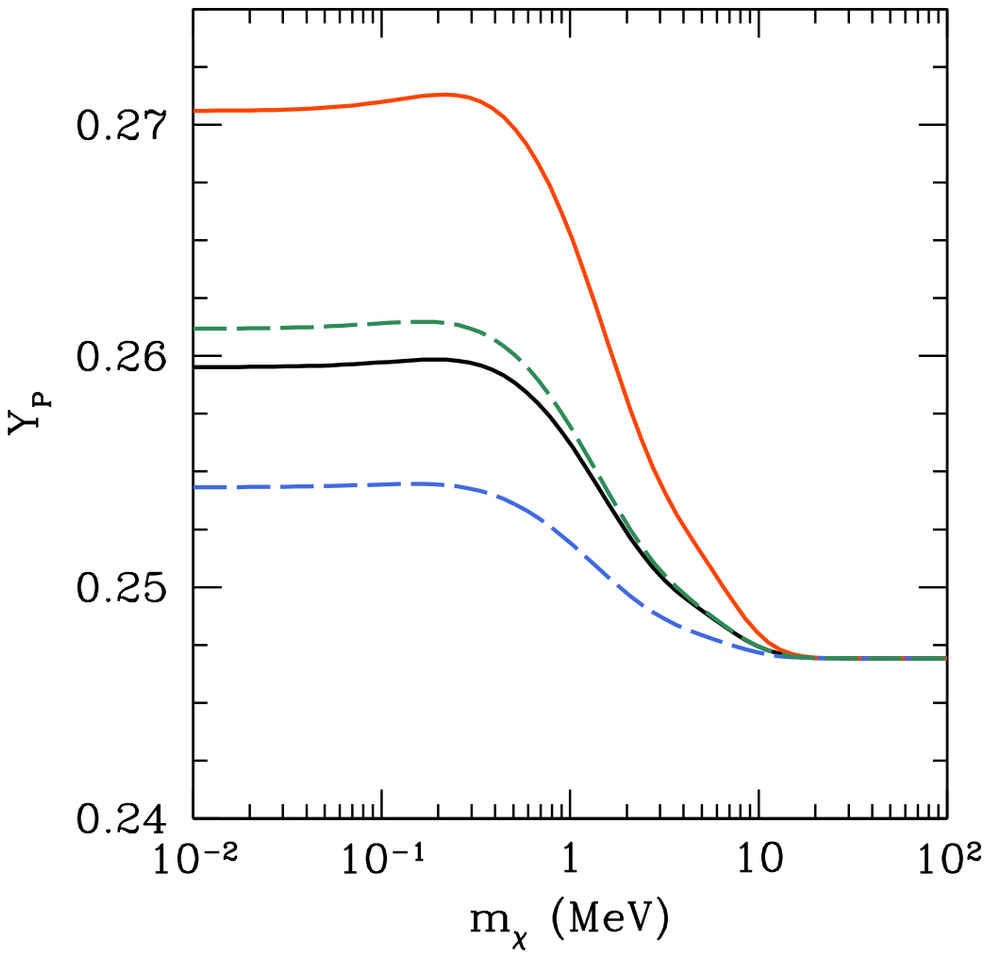
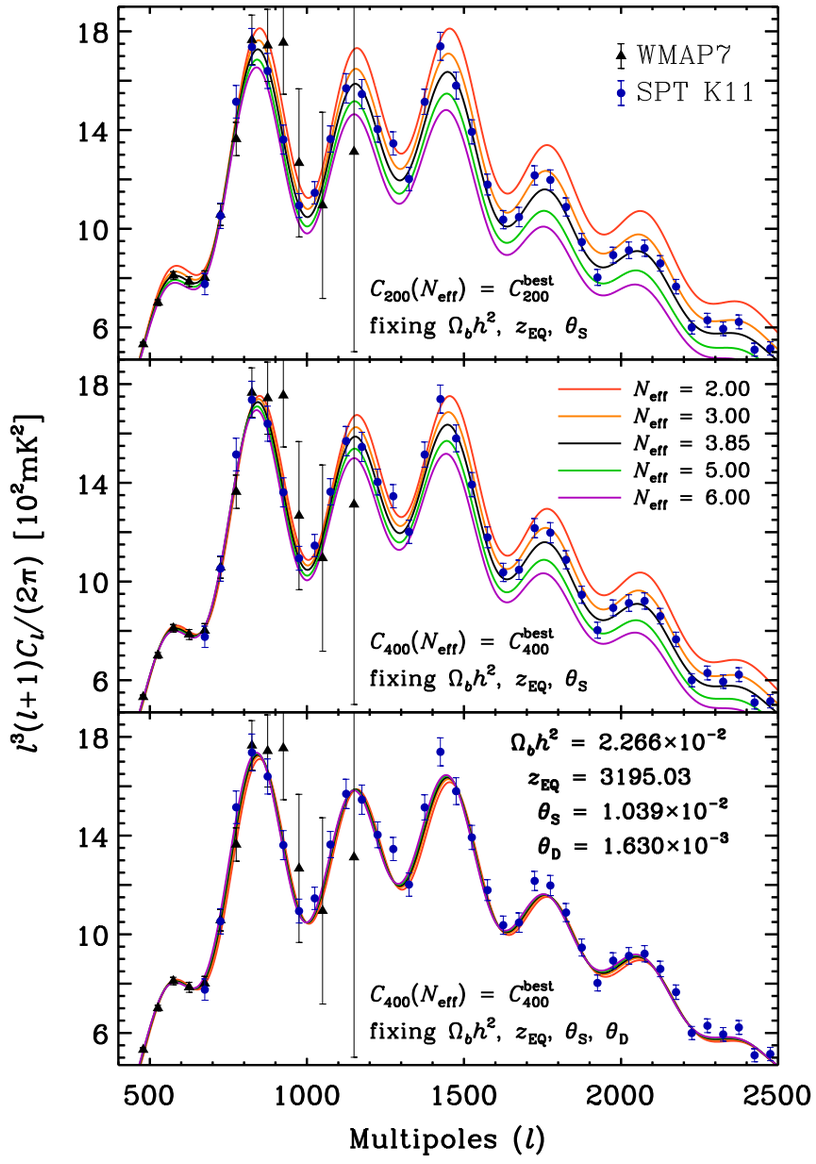


K. Nollett, G. Steigman, arXiv:1411.6005

$N_{\rm eff}$ (CMB) $\simeq 3.15 \pm 0.23$



Z. Hou, et al. , arXiv:1104.2333

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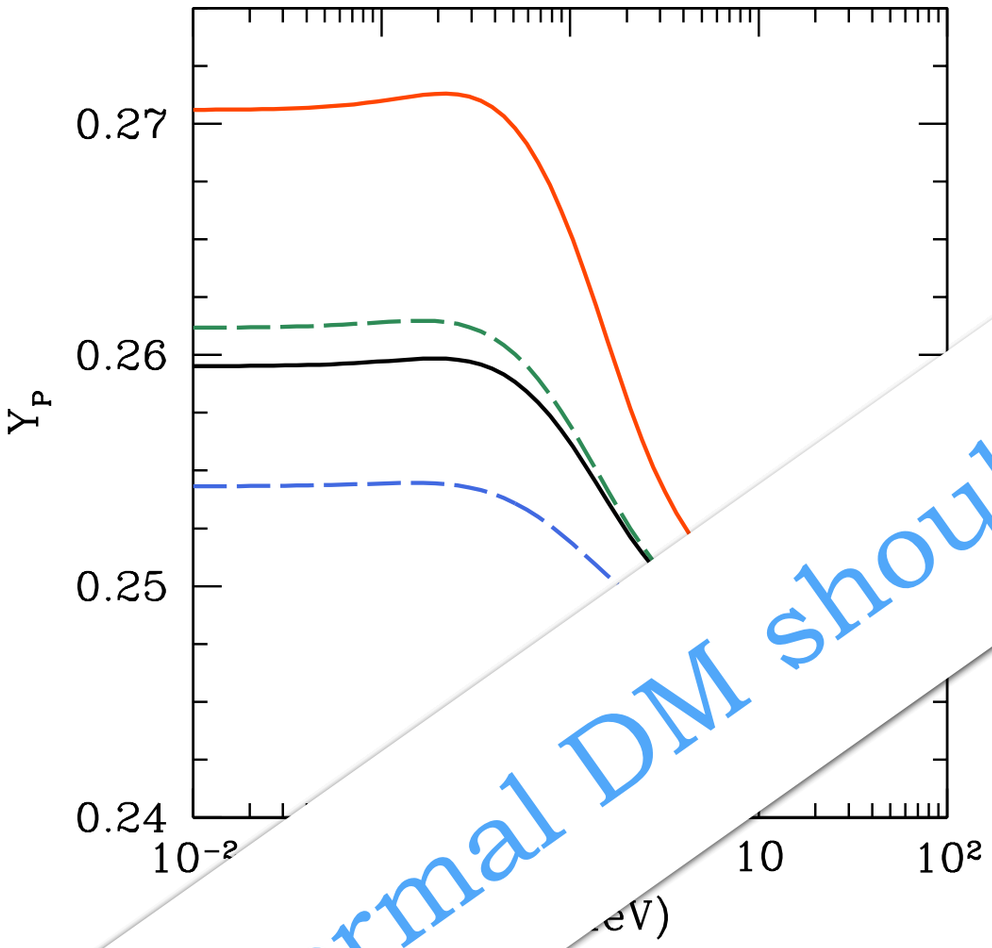

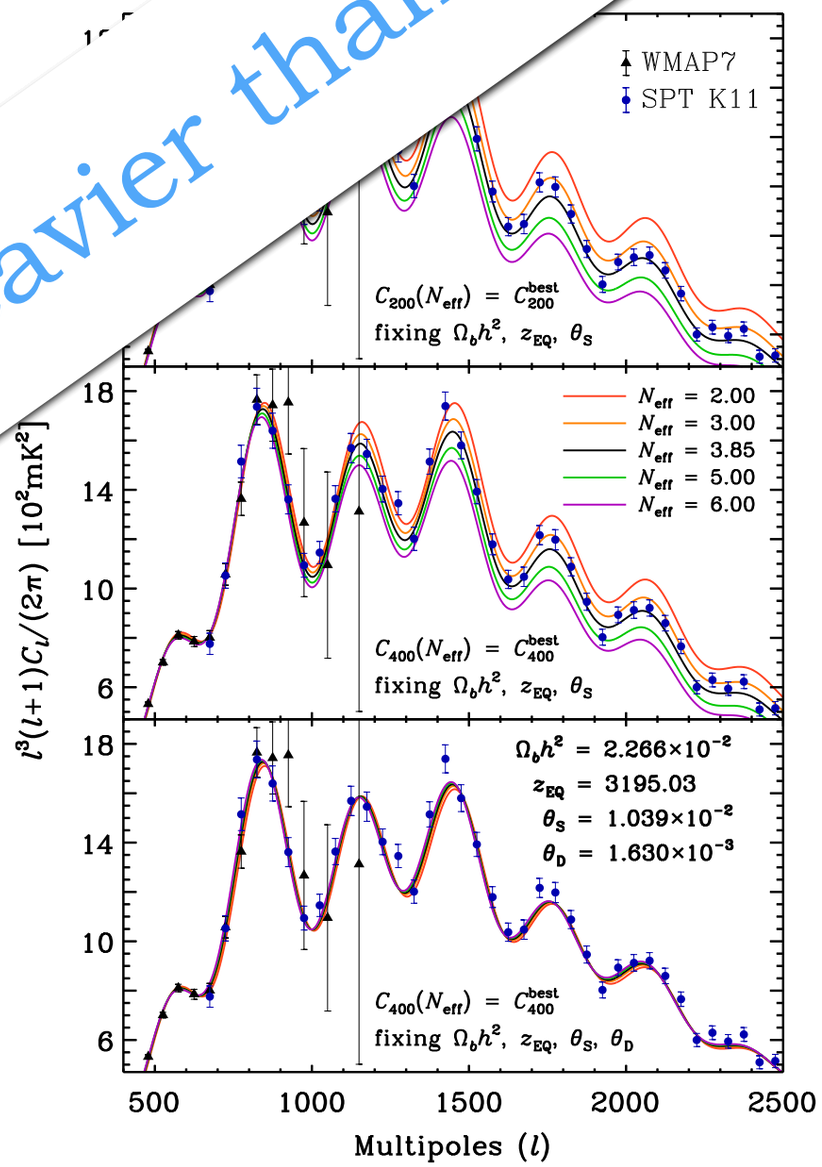

"Thermal DM should be heavier than an MeV"

K. Nollett, G. Steigman, arXiv:1411.6005

Z. Hou, et al. , arXiv:1104.2333

How ubiquitous is DM-SM Equilibration Before Neutrino-Photon Decoupling ?

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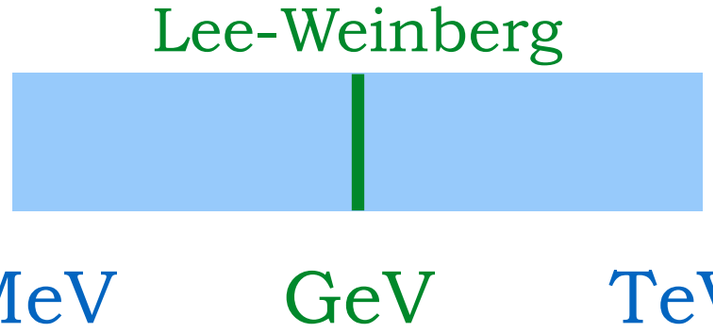
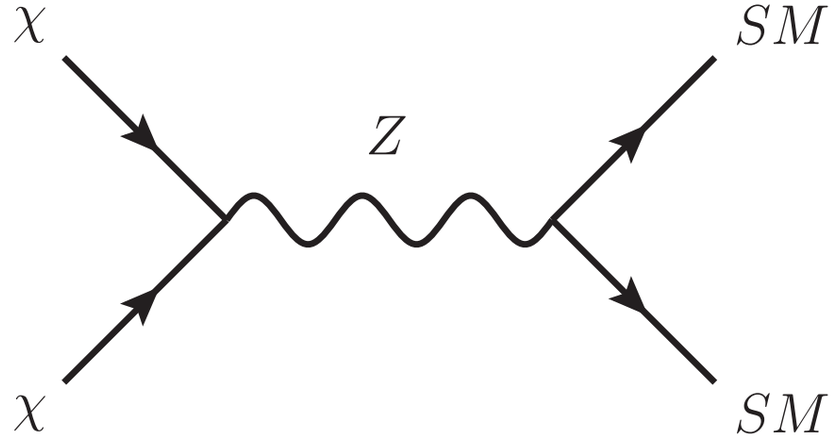
Dark Matter Mass





$$m_\chi \gtrsim \frac{m_Z^2}{(T_{\rm eq}\, m_{\rm pl})^{1/2}} \sim \text{GeV}$$

Sub-GeV thermal DM requires light mediators: $m_\varphi \sim m_\chi$

B. Lee and S. Weinberg,
Phys.Rev.Lett. 39 (1977) 165-168

Equilibration

Expansion

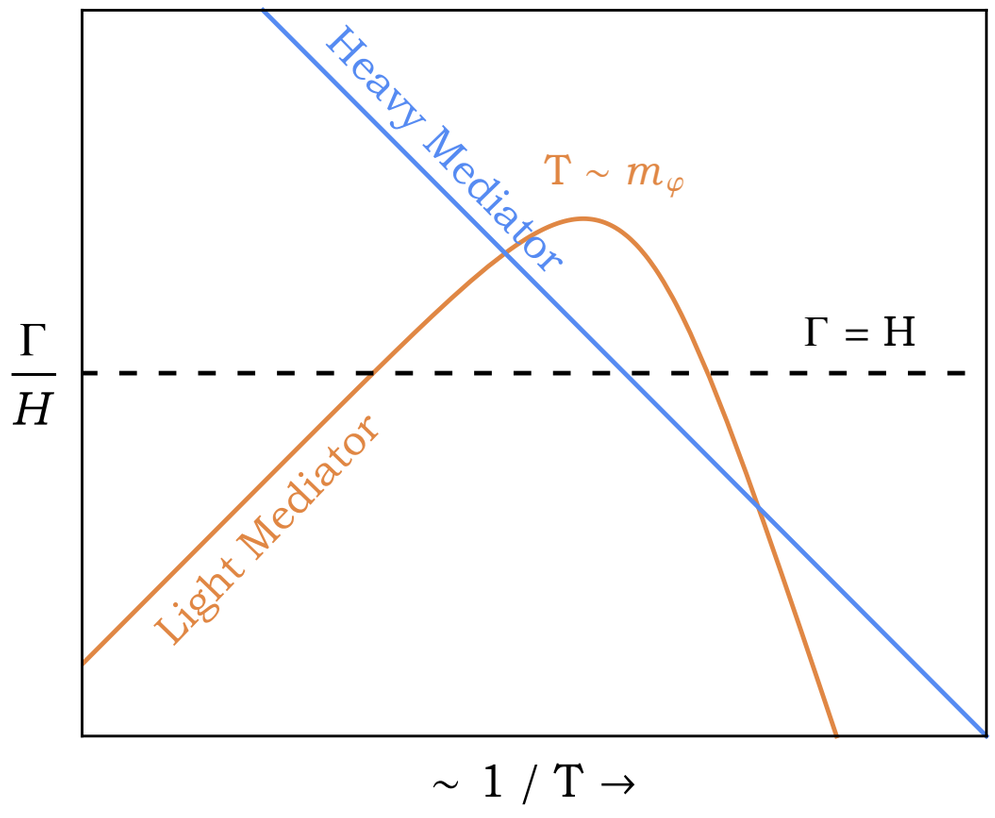
$H \sim T^2$

Light Mediator

$\Gamma \sim T \ , \ m_\varphi^2/T$

Heavy Mediator

$\Gamma \sim T^3/\Lambda^2$



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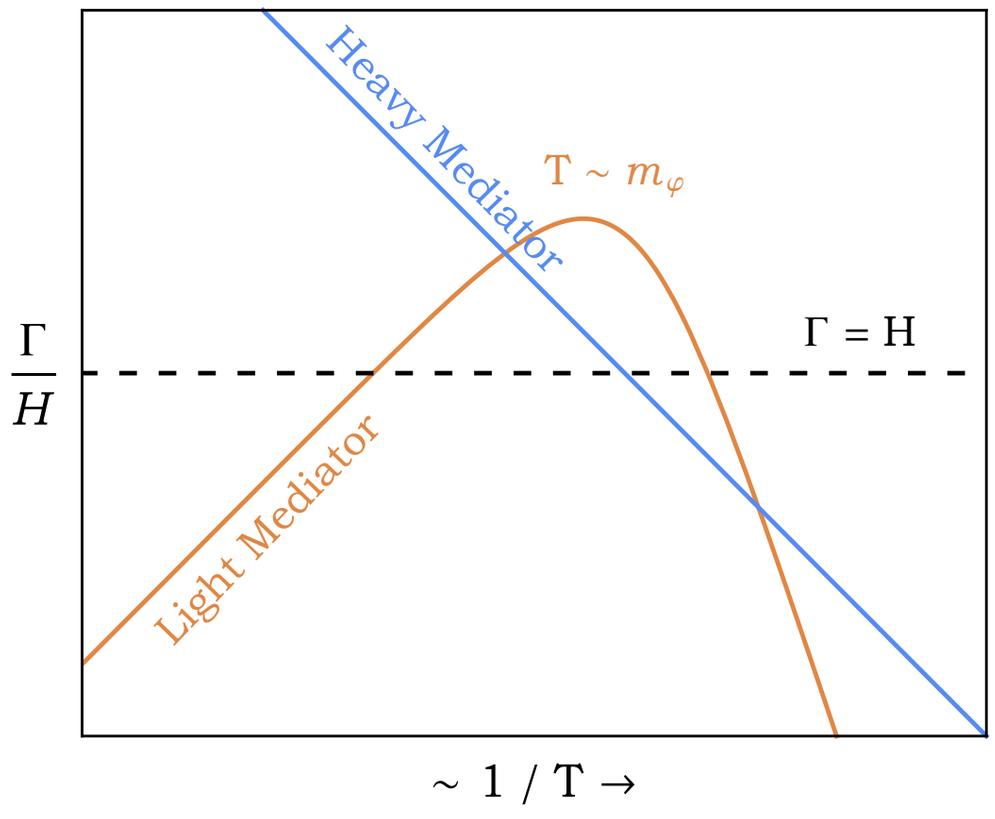


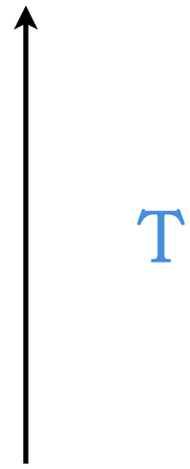
Light thermal DM naturally *enters* equilibrium

(for high enough T_{RH})

N_{eff}

Neutrino-Photon Decoupling ~ MeV

DM-SM Equilibration < MeV



DM-Neutrino Equilibration

$$N_{\rm eff} \simeq 3 \left(1 + \frac{4}{21}\, g_\chi\right)^{4/3} \gtrsim 3.18$$

$N_{\rm eff}$

Neutrino-Photon Decoupling ~ MeV

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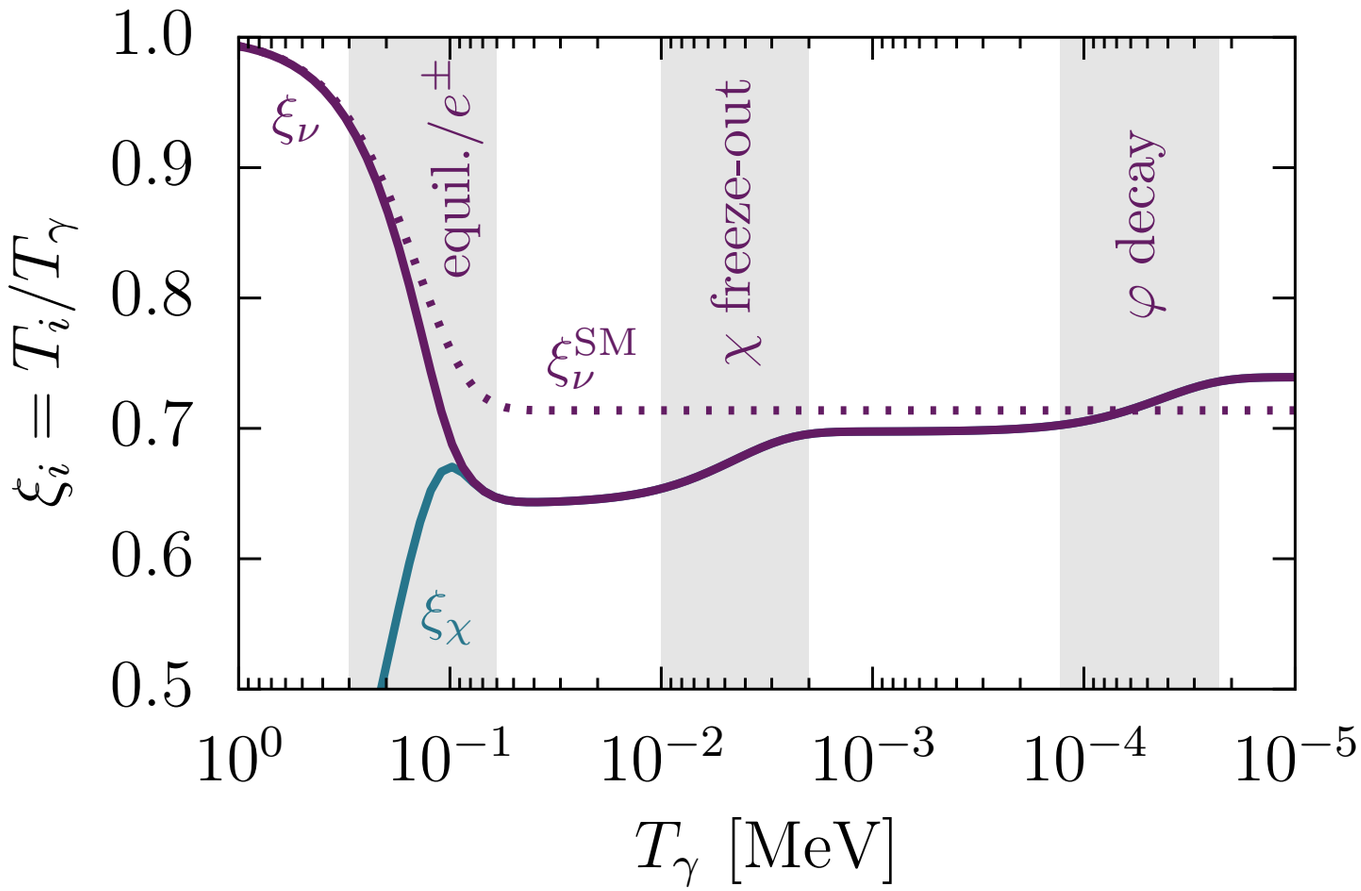
DM-Neutrino Equilibration

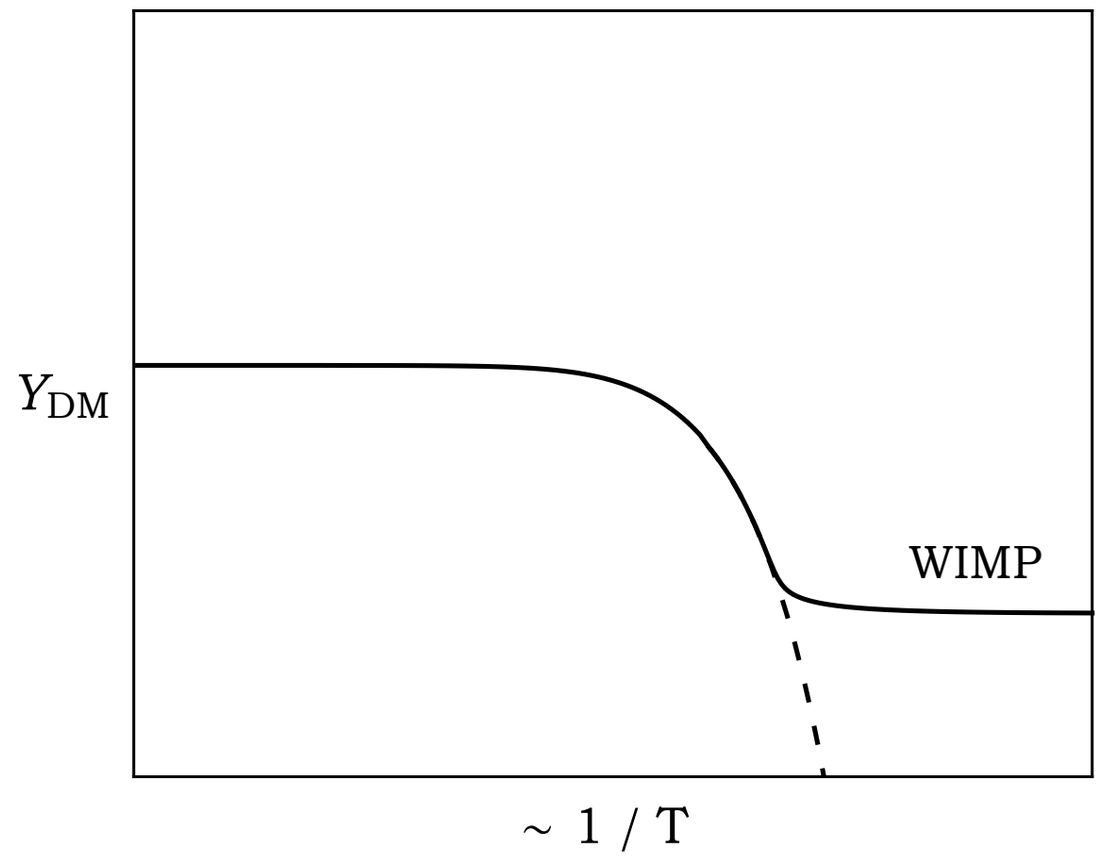
$$N_{\rm eff} \simeq 3 \left(1 + \frac{4}{21}\, g_\chi\right)^{\cancel{4}1/3} \gtrsim 3.18$$

$g_\chi \lesssim$ few

N_{eff}


1.0
0.9
0.8
0.7
0.6
0.5
$\xi_i = T_i/T_\gamma$
ξ_ν
$\xi_\nu^{\rm SM}$
ξ_χ
equil./$e^\pm$
χ freeze-out
φ decay
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
T_γ [MeV]

Thermal History



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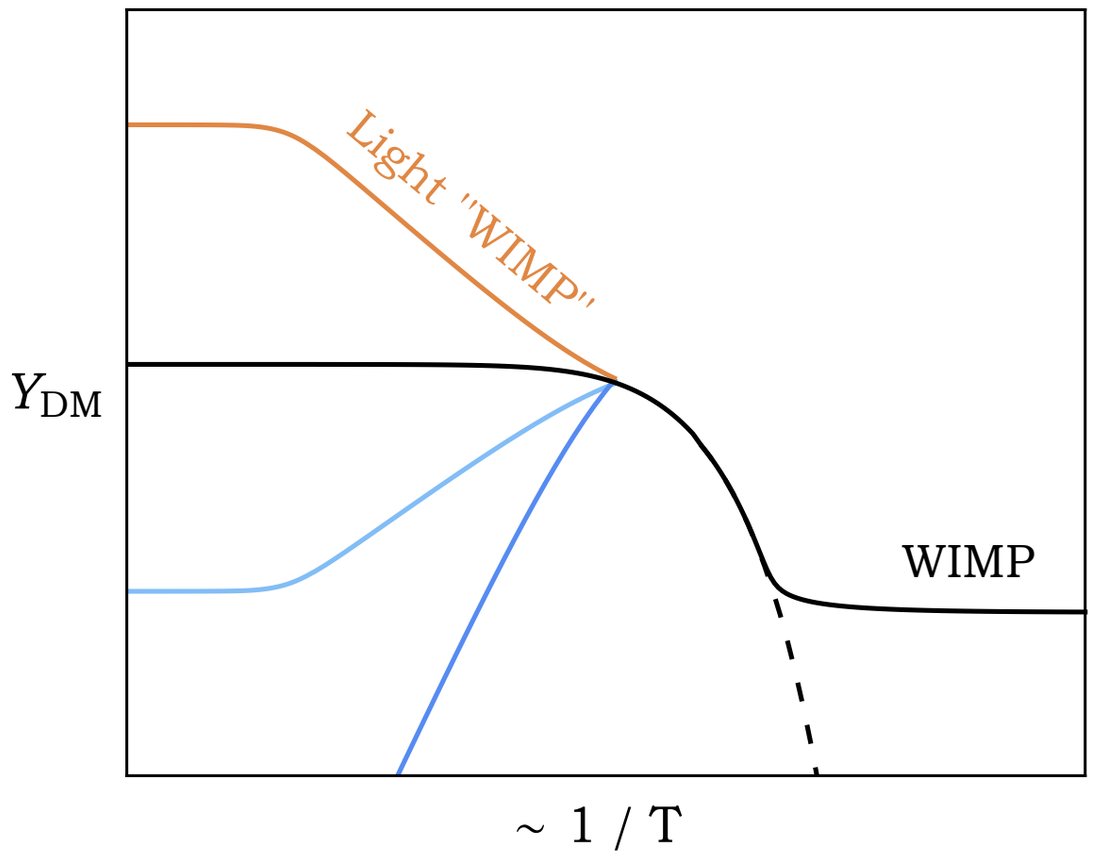

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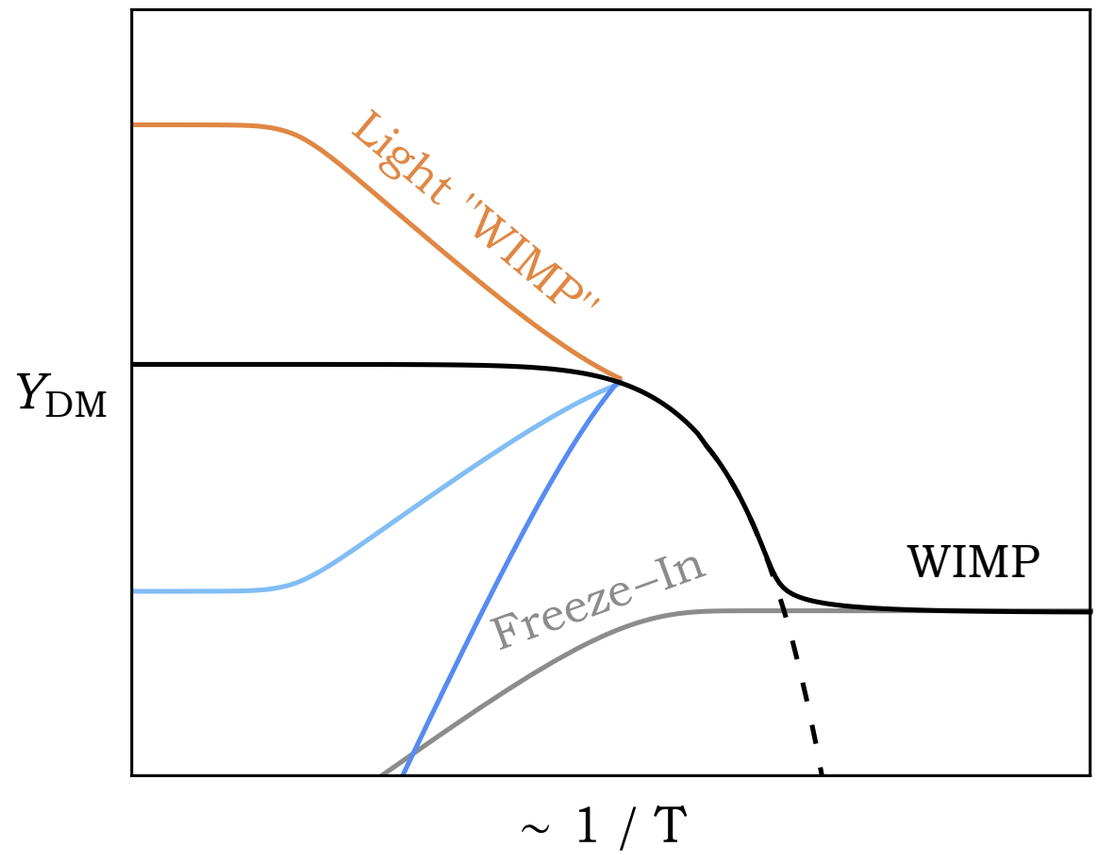
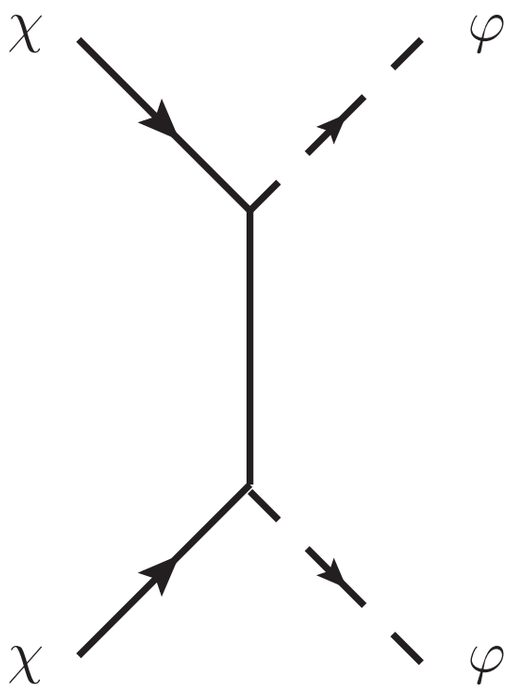


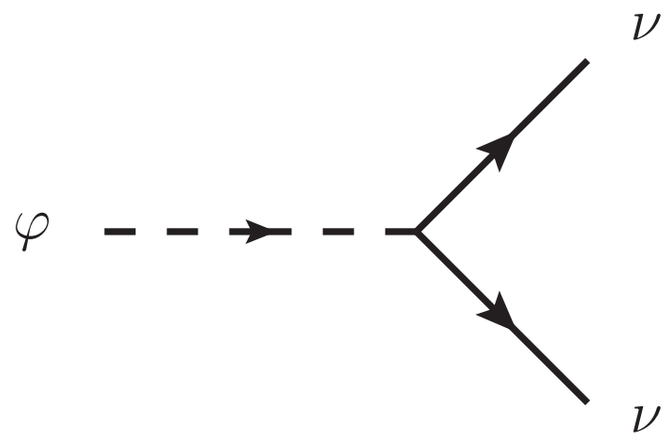
A Toy Model

$$\mathcal{L} \sim \varphi \ \left(\lambda_\chi \ \chi^2 + \lambda_\nu \ \nu^2\right)$$

$$m_\phi \lesssim m_\chi$$



(Freeze-Out)



(Equilibration and Decay)

A Toy Model

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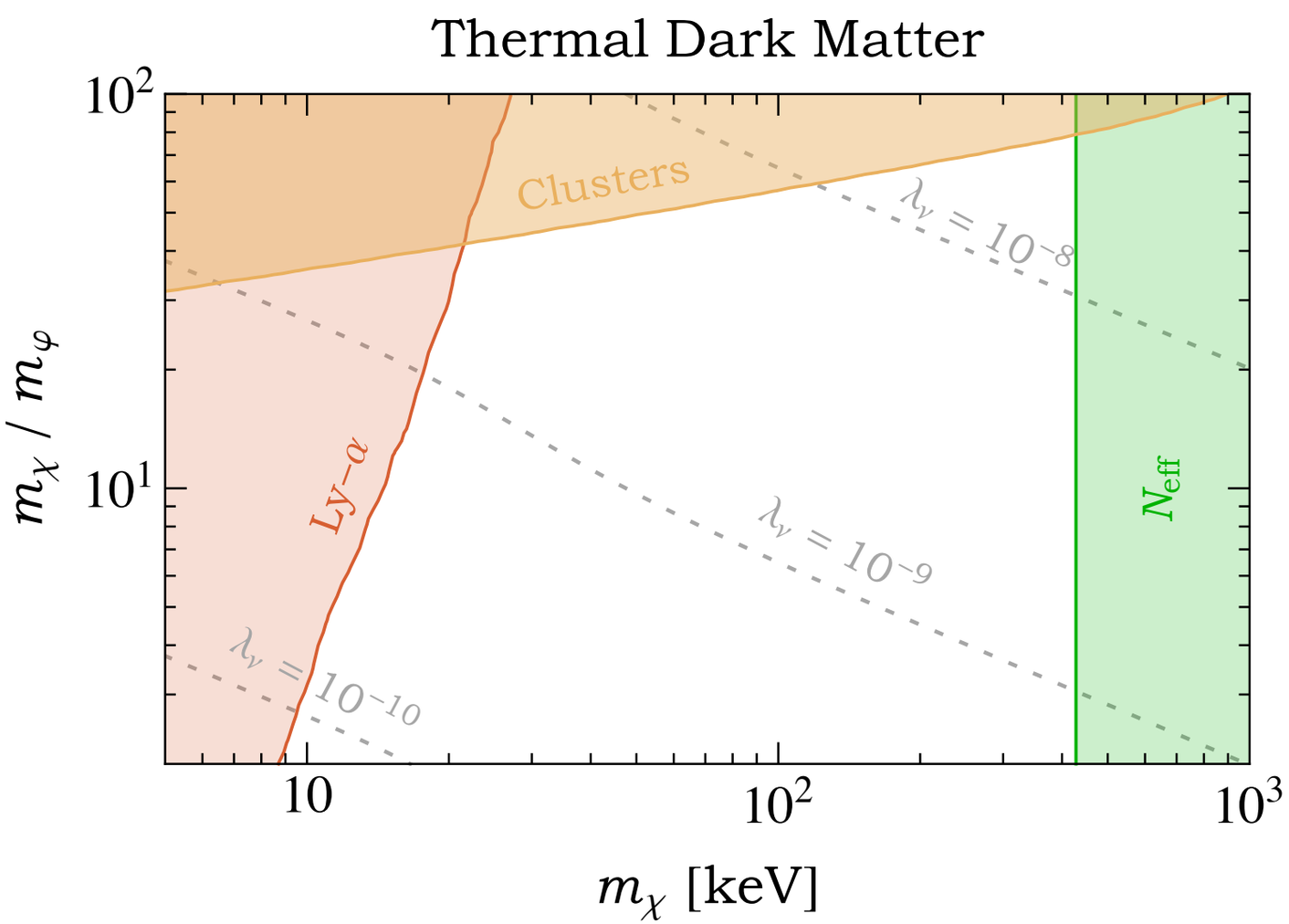


Summary

- Sub-MeV DM that freezes-out thermally with the SM is possible.
- Equilibration predicts a limited range for DM-SM coupling.
- CMB-S4 and 21 cm observations will be sensitive to the entire parameter space.

Back Up Slides

N_{eff}

DM-SM Equilibration ?

Neutrino-Photon Decoupling ~ MeV

End of BBN ~ 100 keV

Recombination ~ eV

N_{eff}

DM-SM Equilibration ?

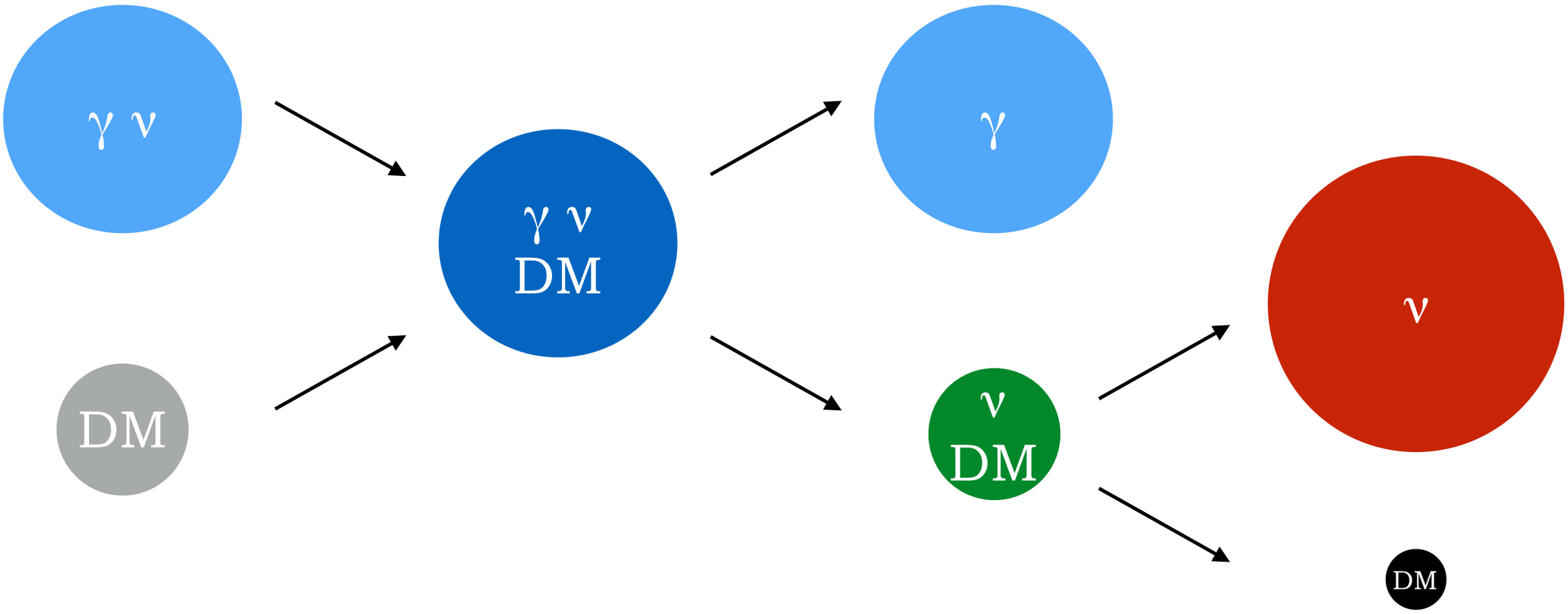
Neutrino-Photon Decoupling ~ MeV

End of BBN ~ 100 keV

Recombination ~ eV

T

$N_{\rm eff}$



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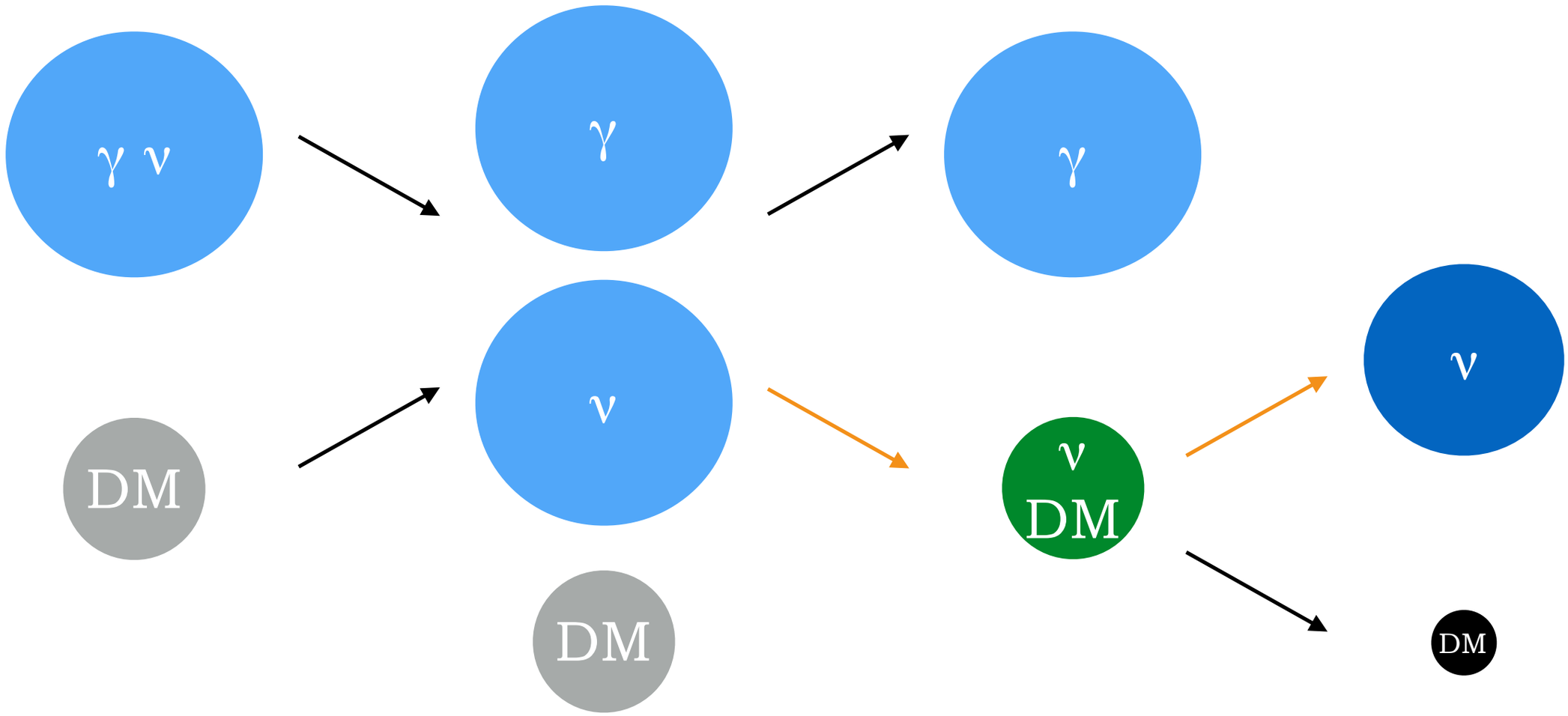
$N_{\rm eff}$



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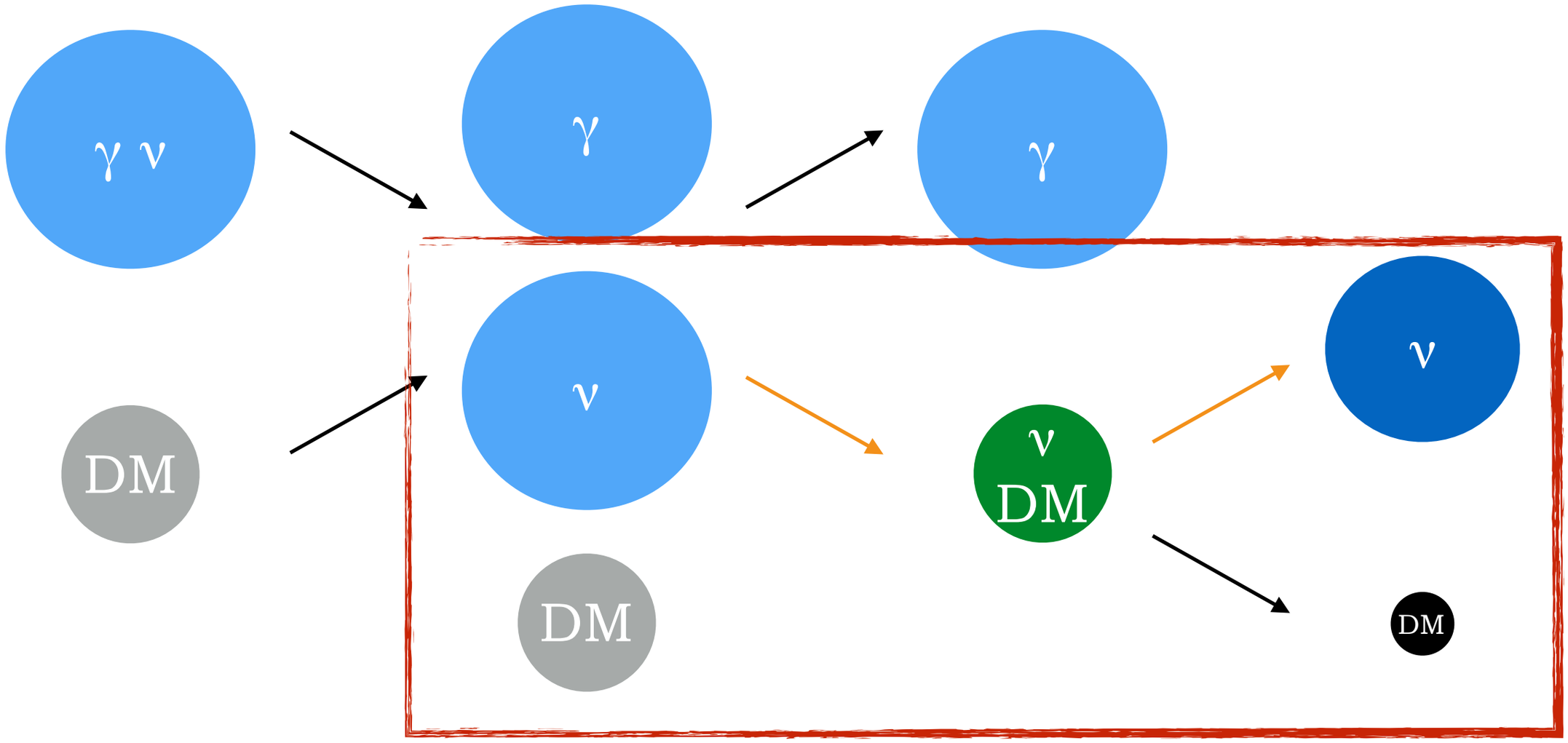
N_{eff}



(~“cyclic”, but dS > 0)

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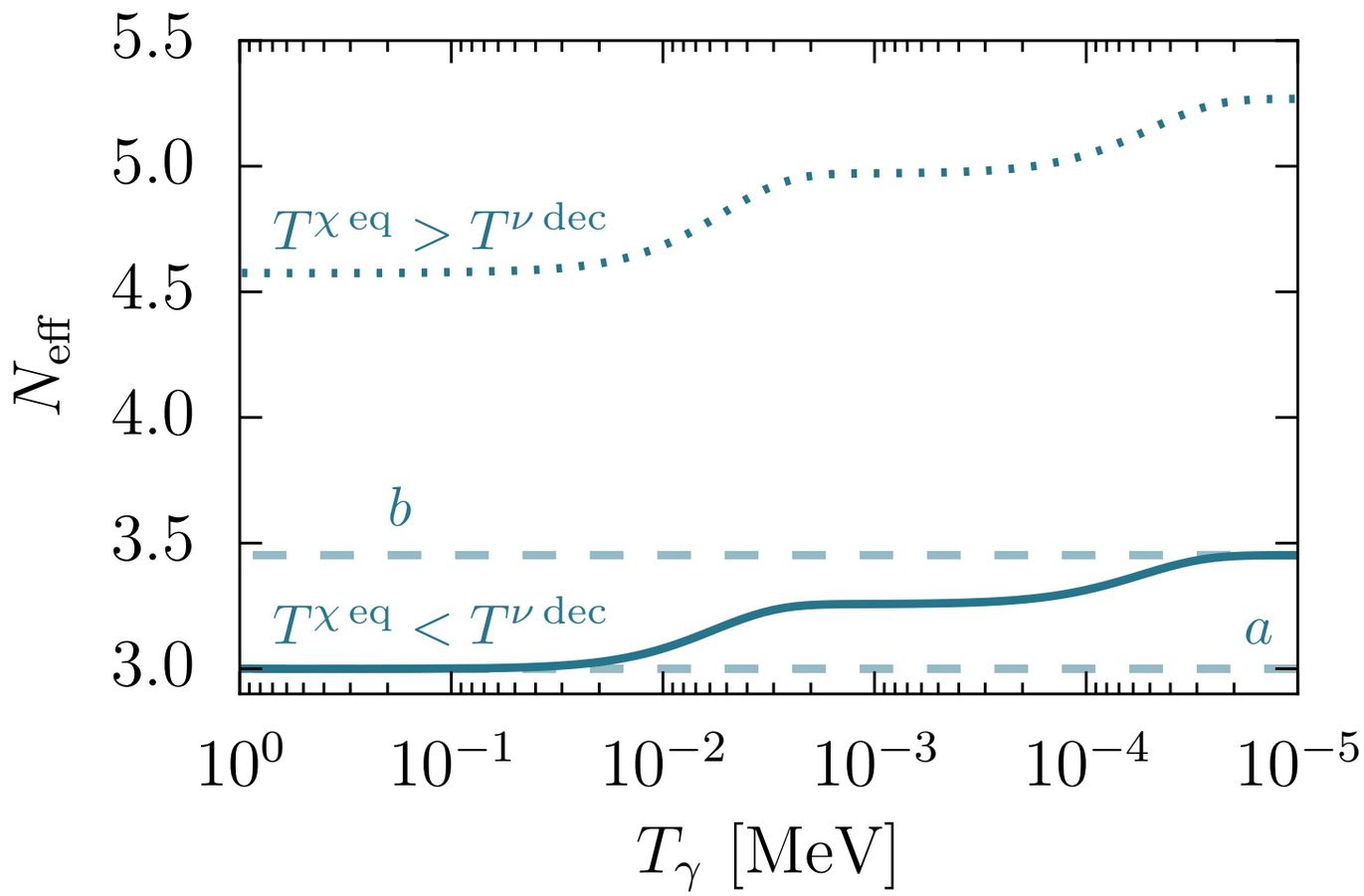
N_{eff}


5.5
5.0
4.5
4.0
3.5
3.0
N_{eff}
$T^{\chi\,\mathrm{eq}} > T^{\nu\,\mathrm{dec}}$
b
$T^{\chi\,\mathrm{eq}} < T^{\nu\,\mathrm{dec}}$
a
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
T_γ [MeV]