

The price for monopole dark matter

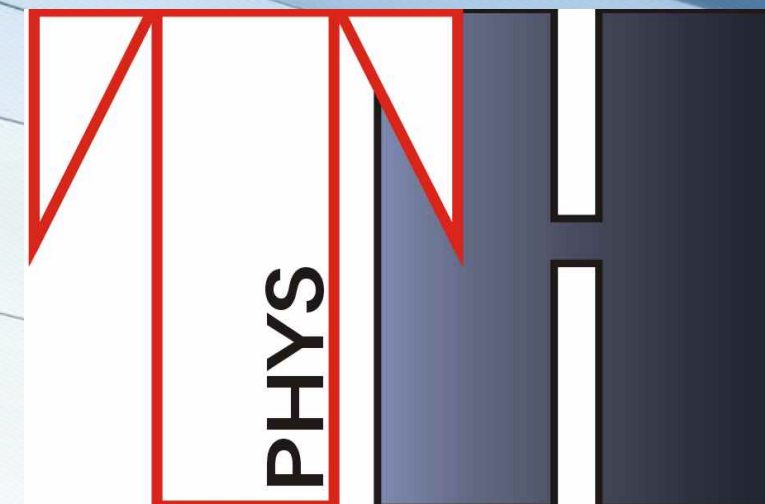
based on

arXiv:2509.21924, arXiv:2607.29492

w/ F. Brümmer, T. Fischer and M. Frigerio

ULB

Giacomo Ferrante



Why monopole dark matter?

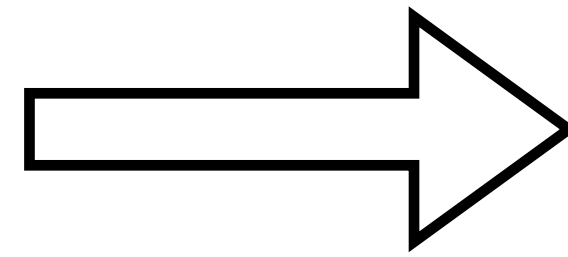
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Unavoidable

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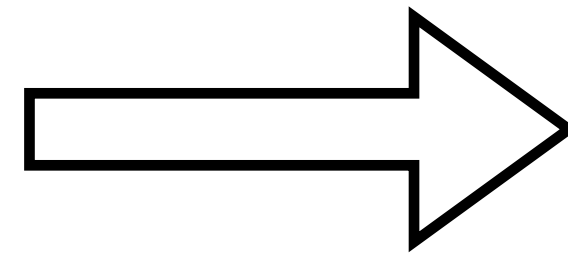


$$\Omega_M h^2 = 0.12$$



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!DISCLAIMER!

this talk: dark sector monopoles

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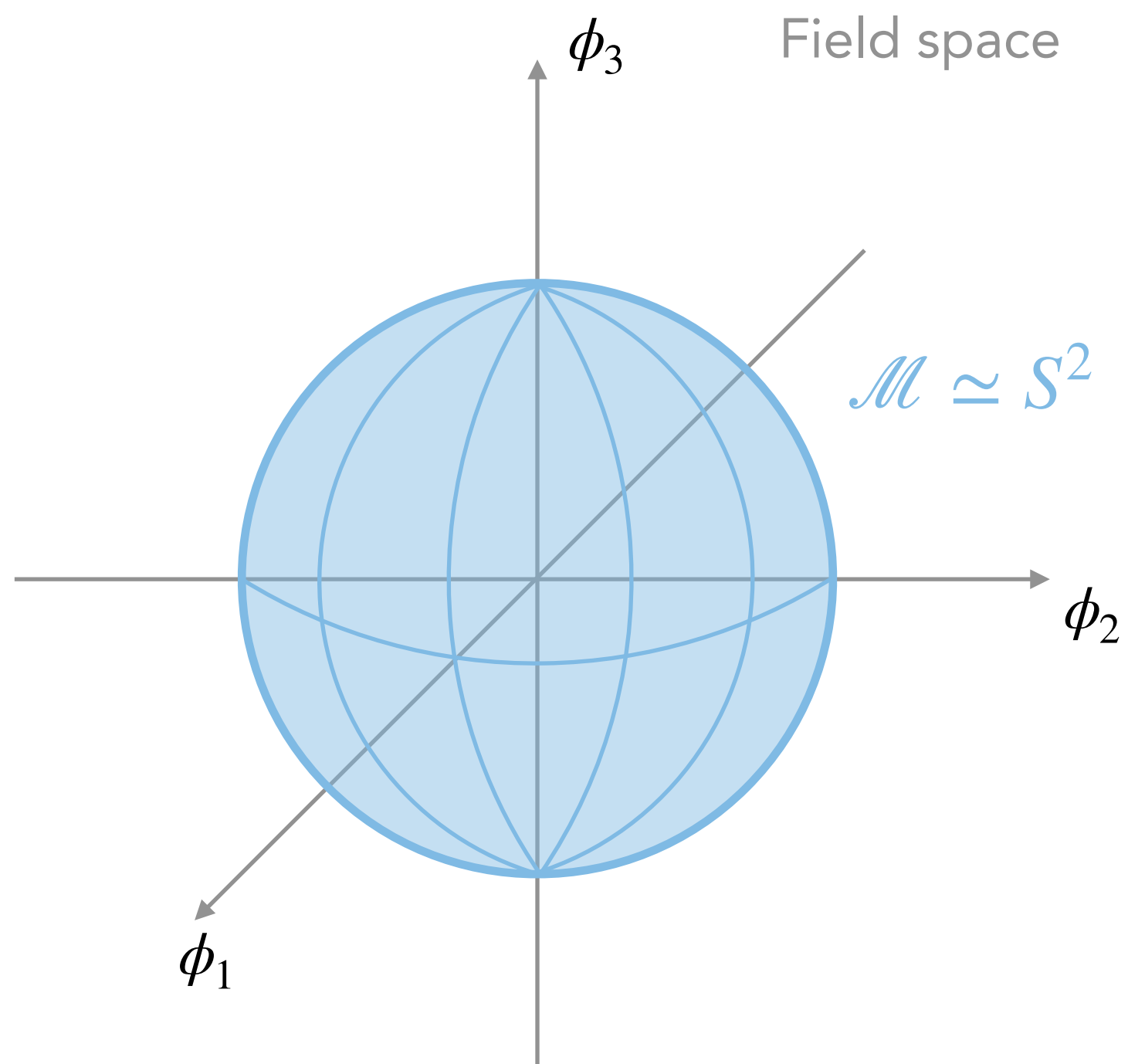
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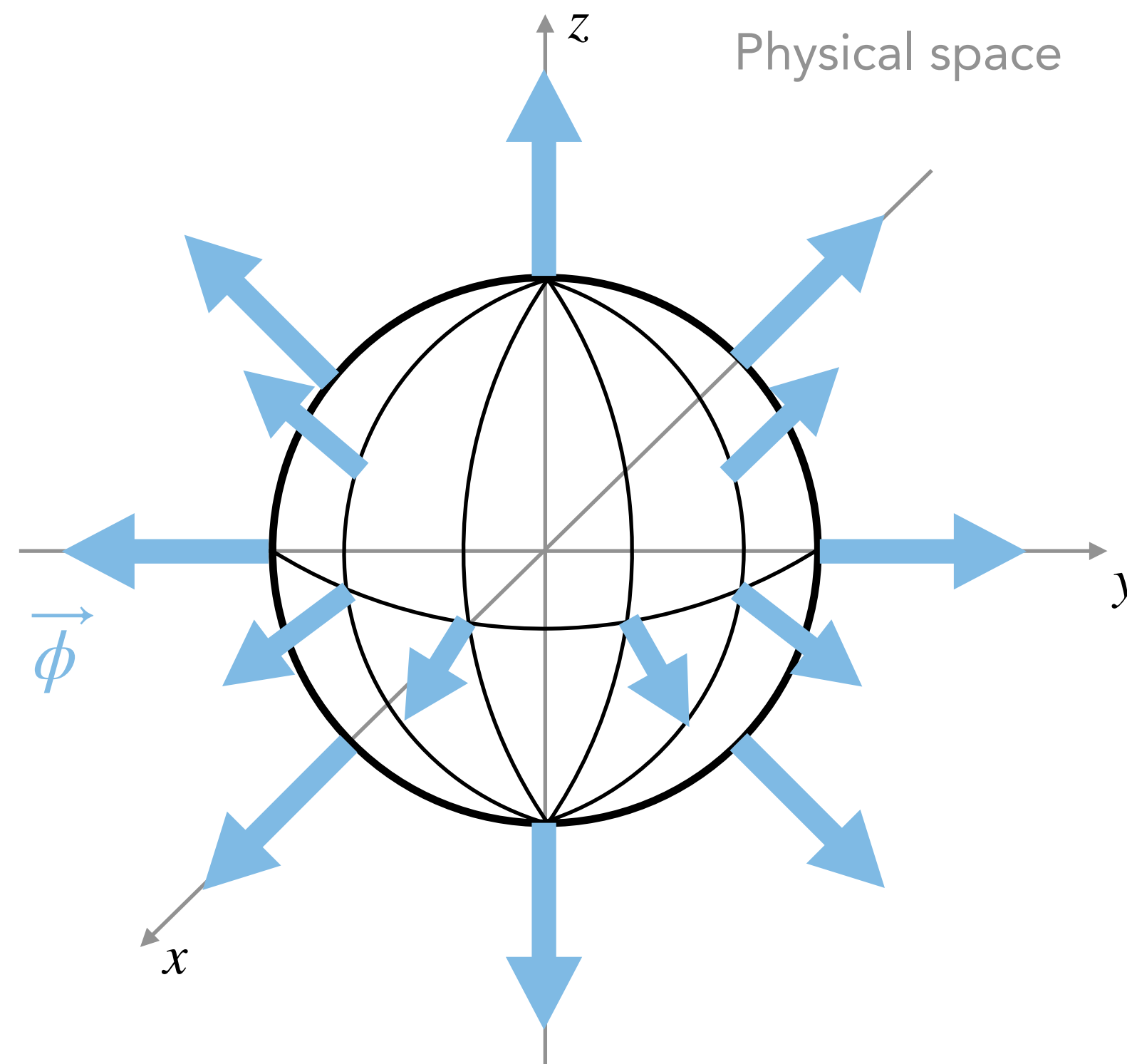
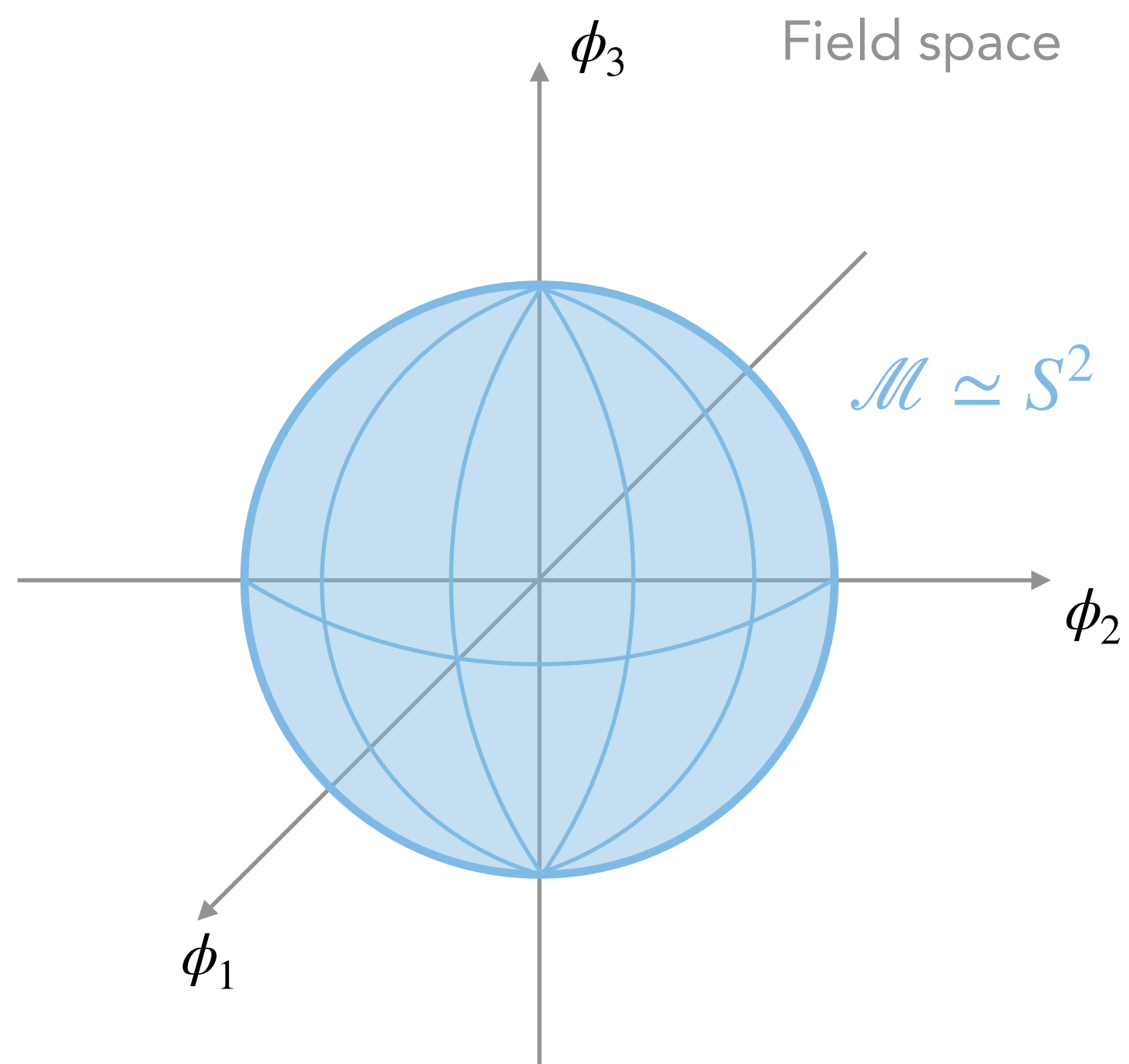
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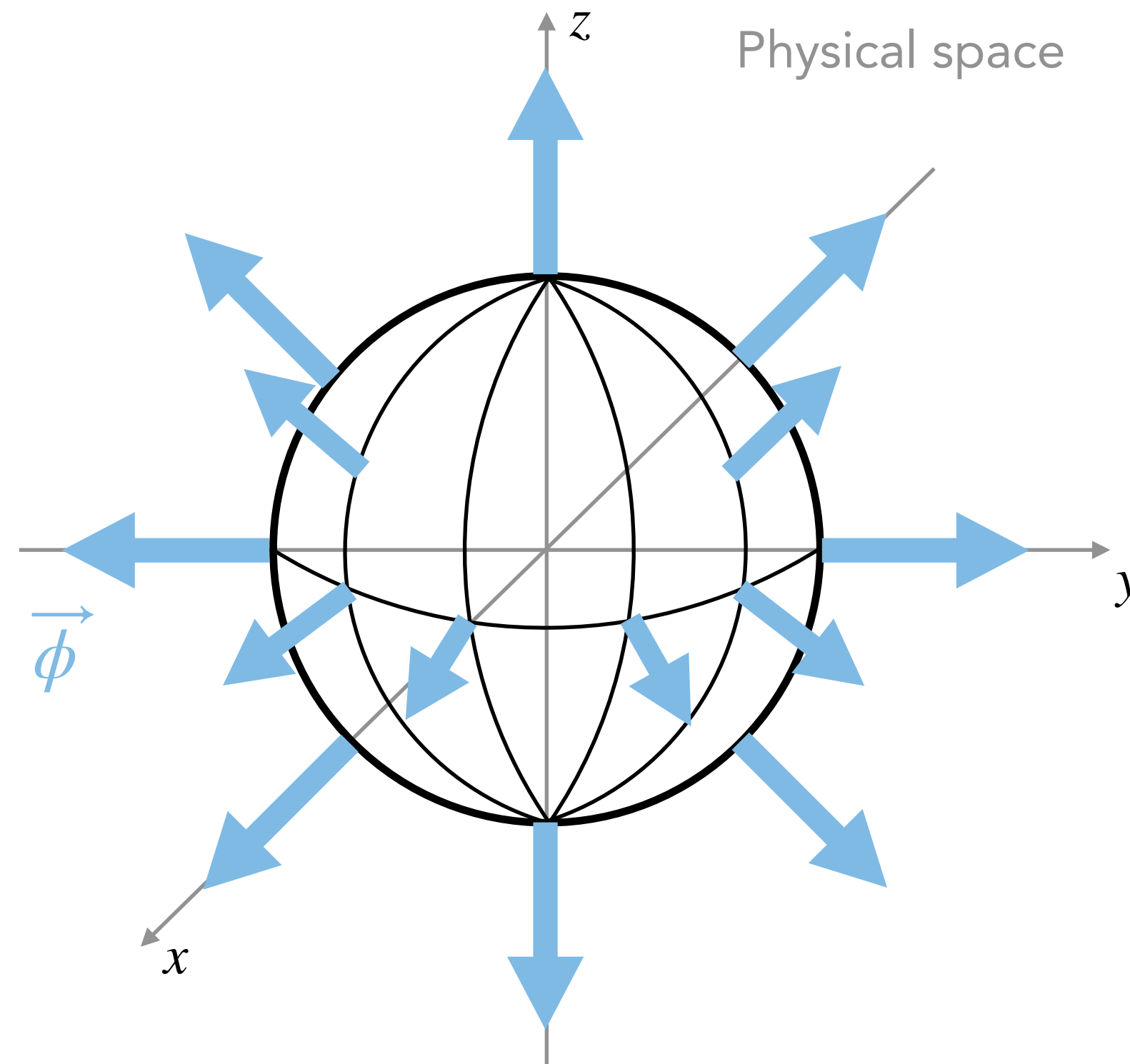
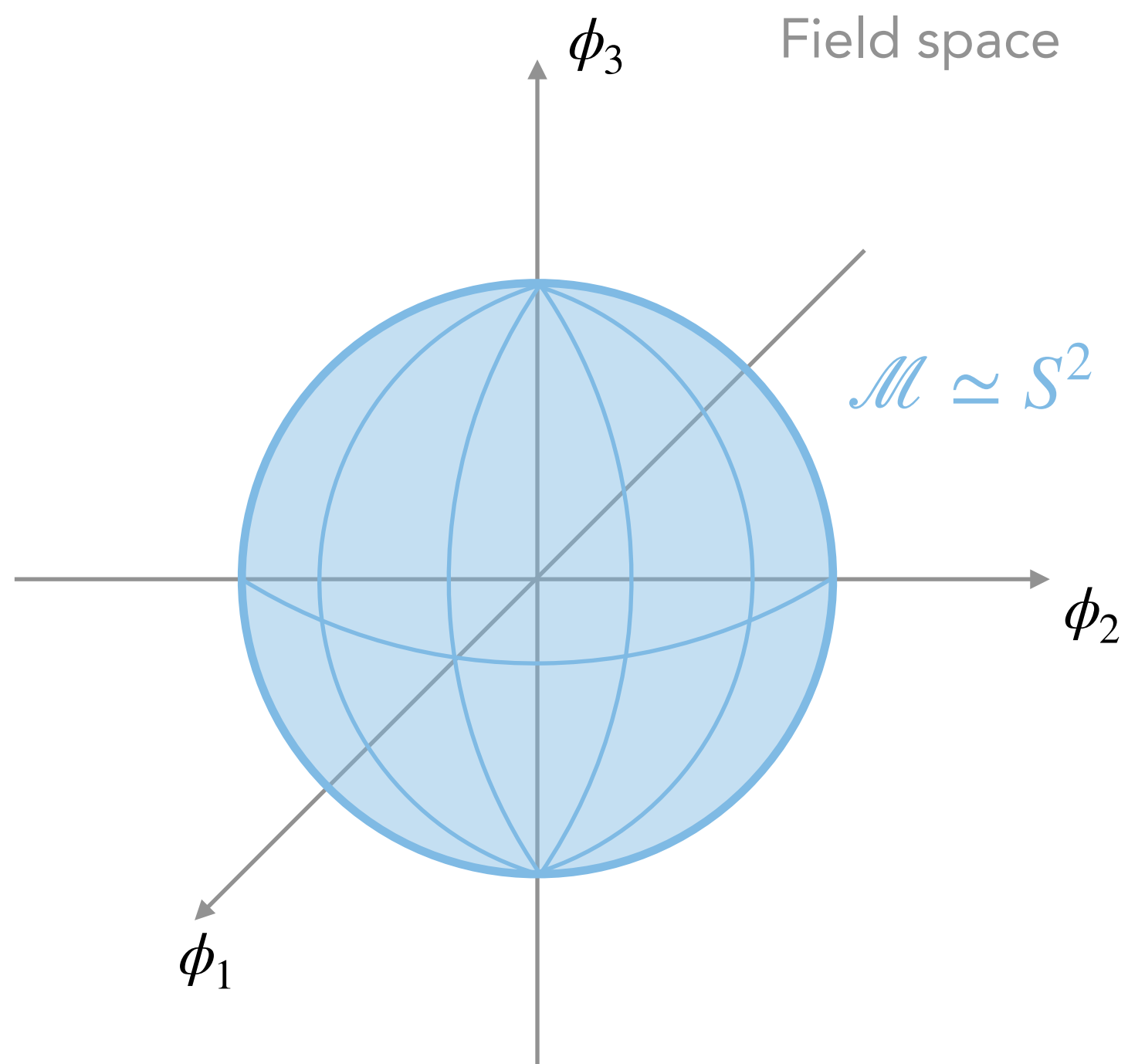
[’t Hooft, 1974]
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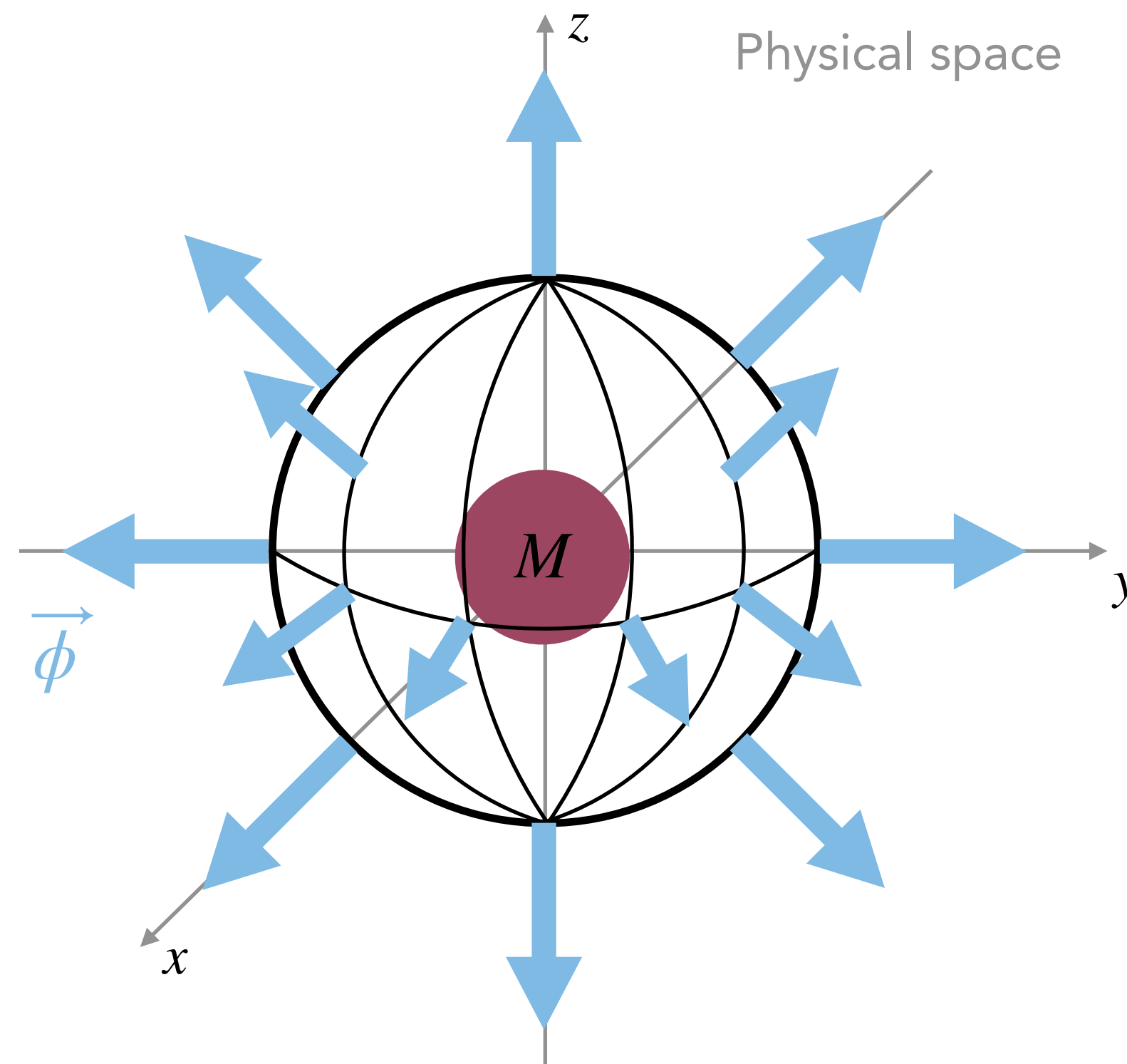
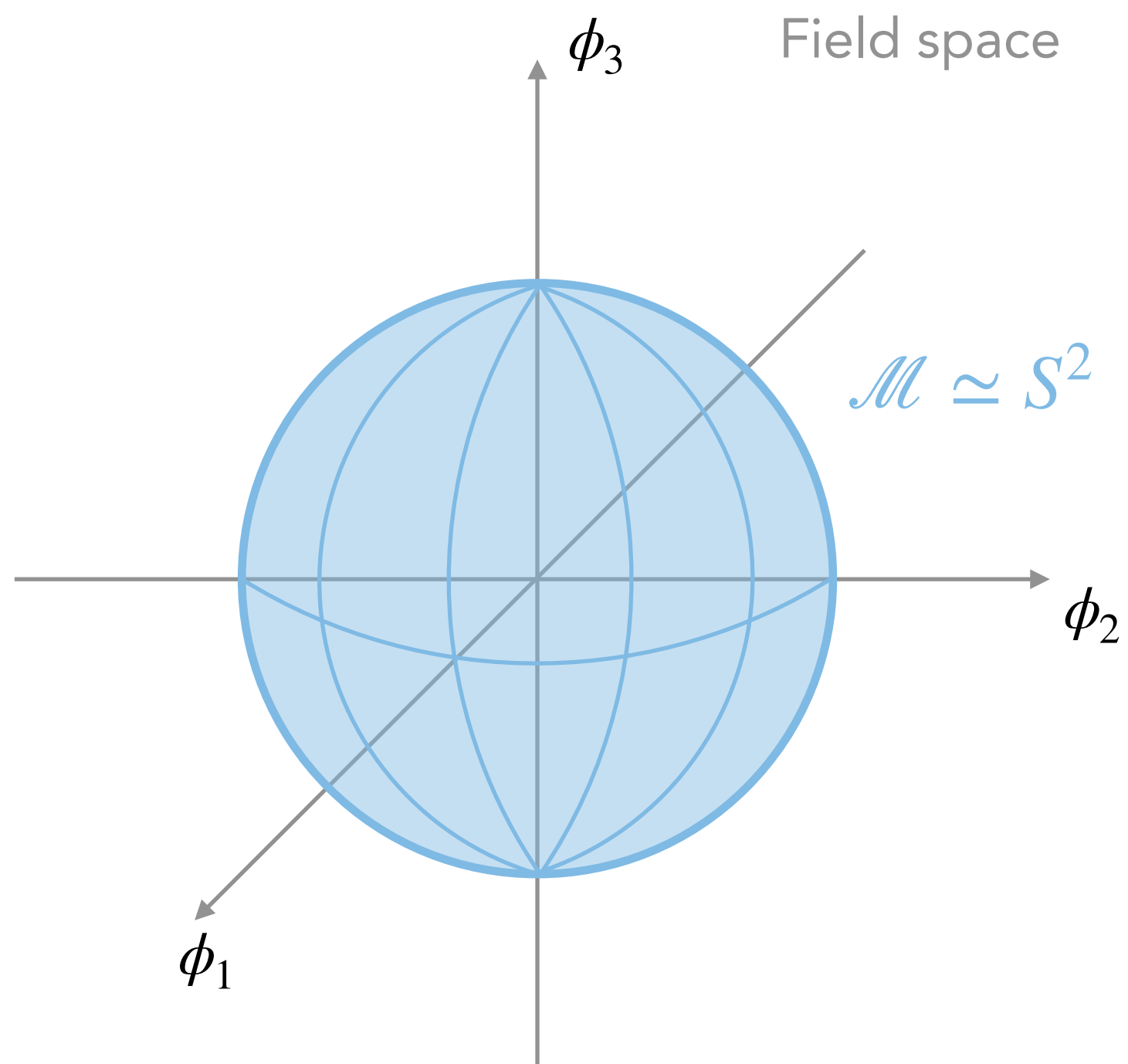
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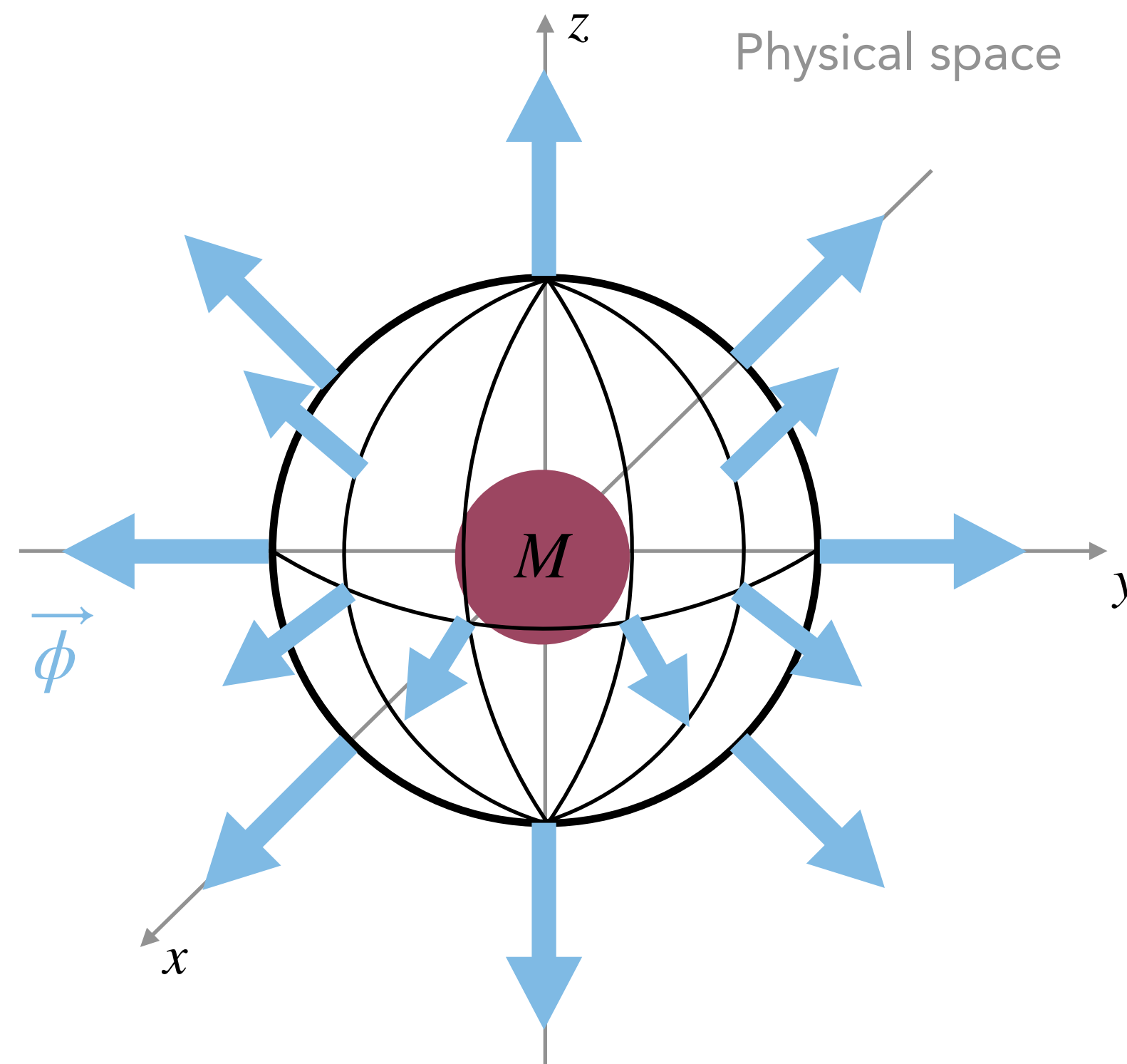
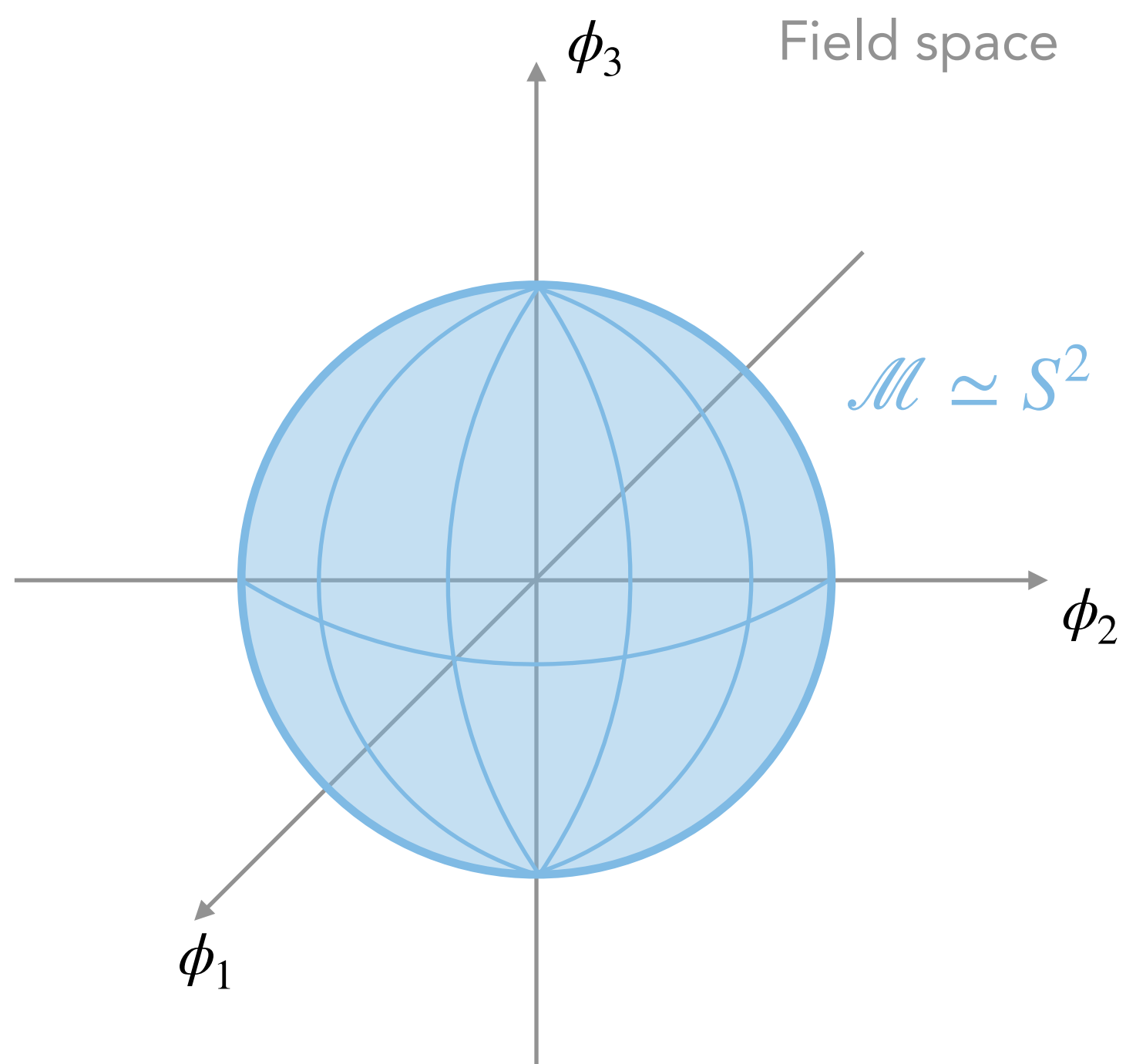
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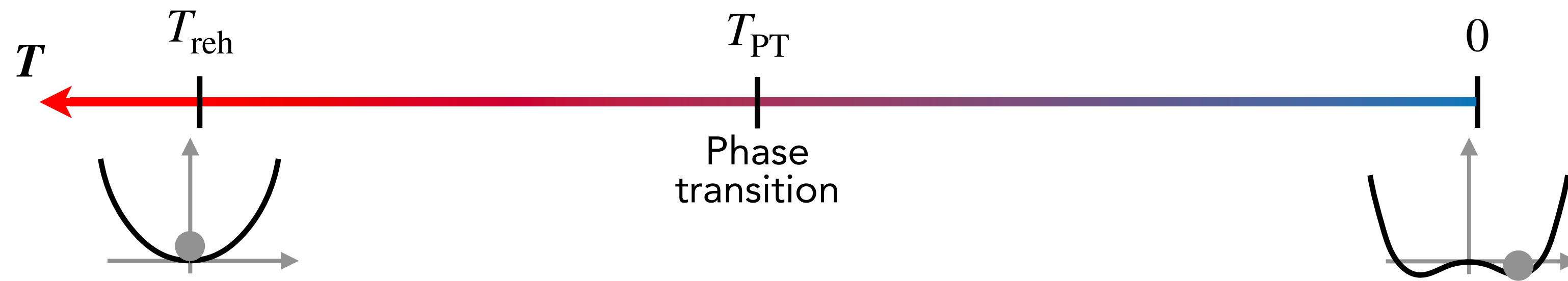


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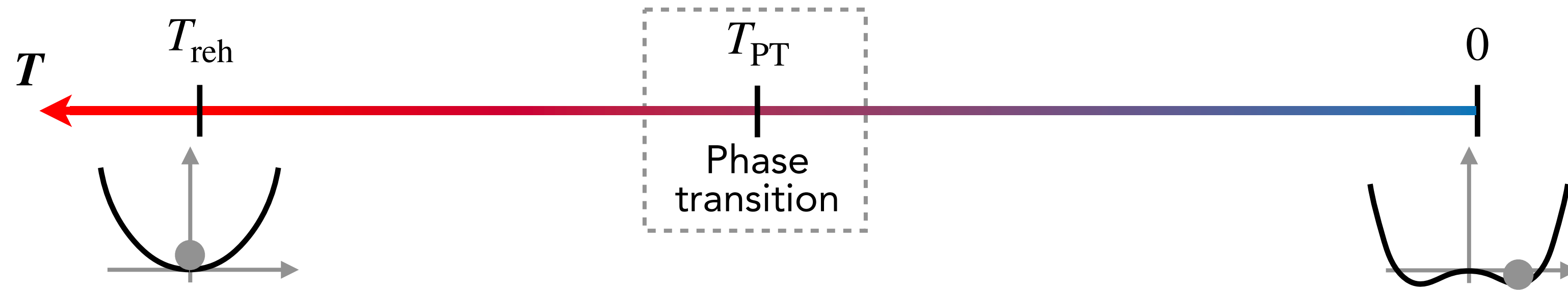
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$$m_M \approx \frac{4\pi}{g}\eta$$

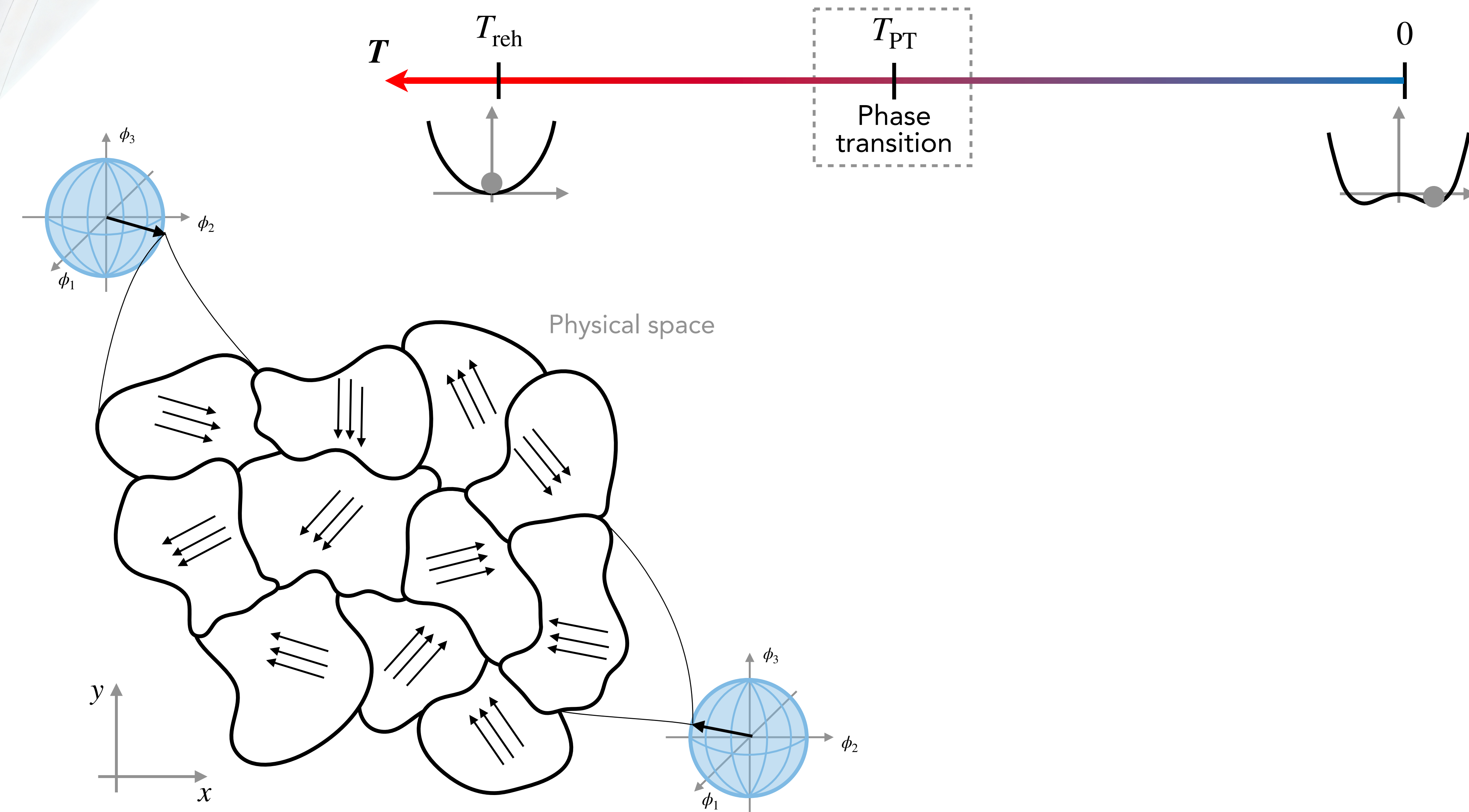
Monopole production



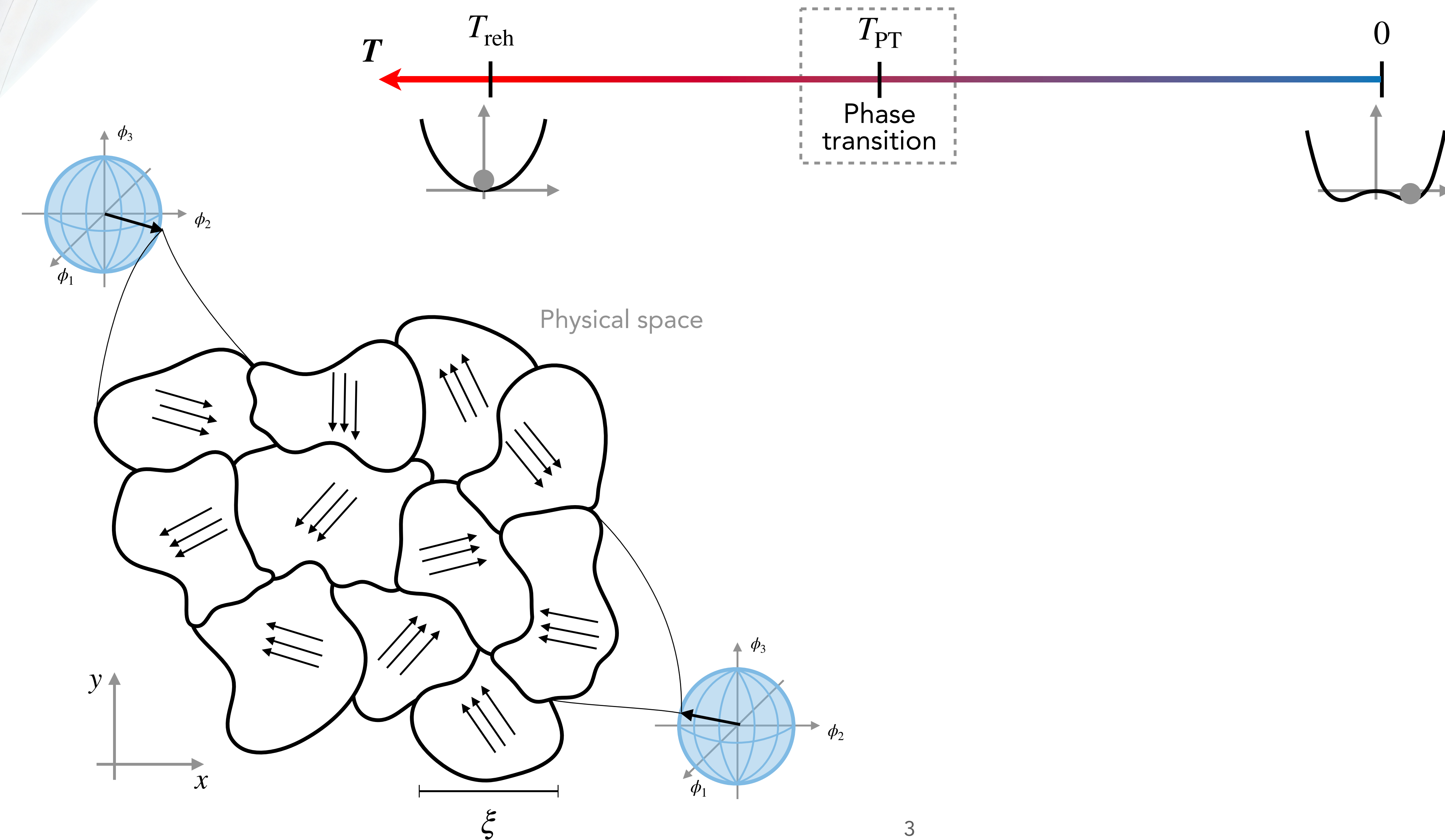
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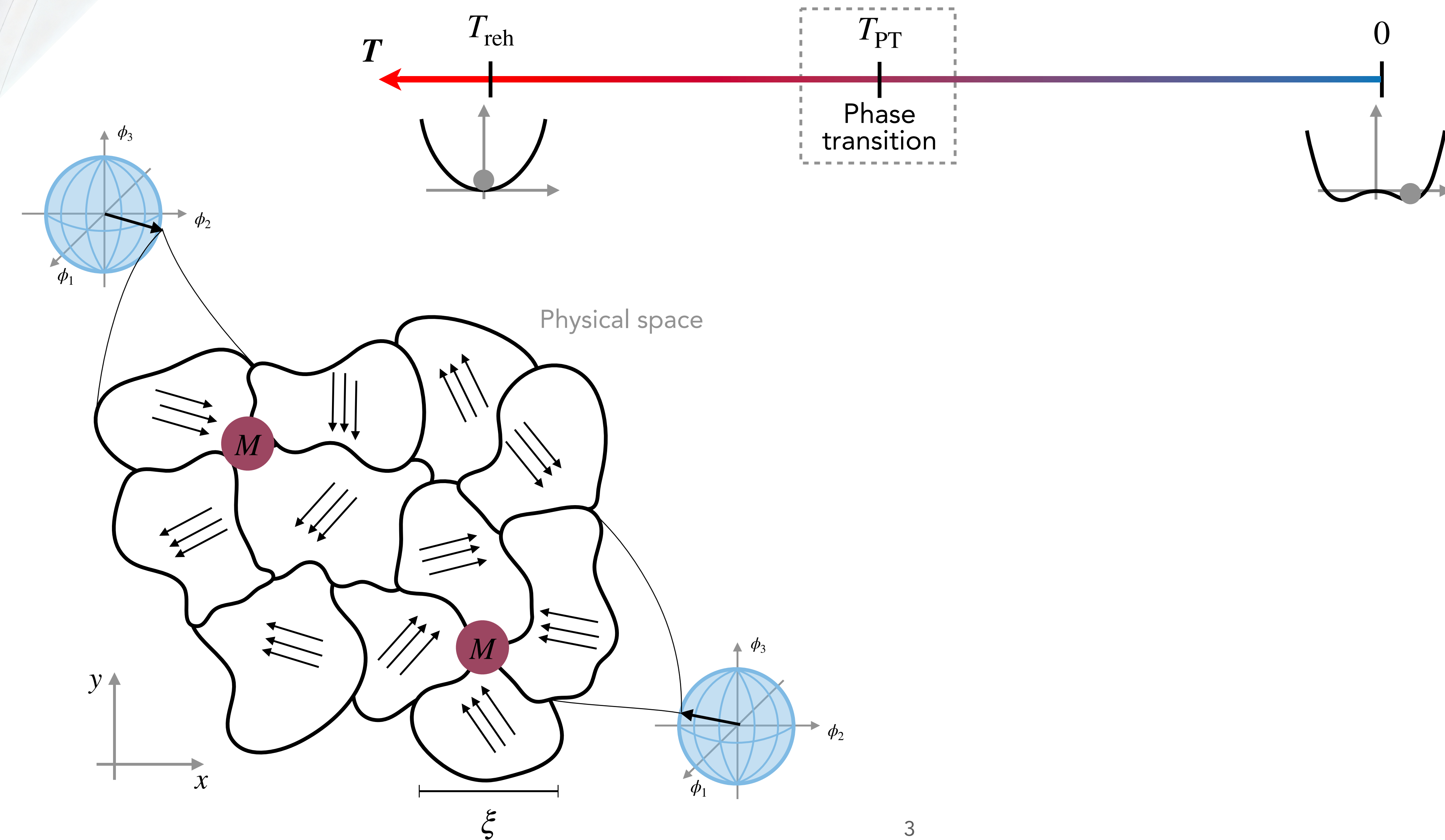
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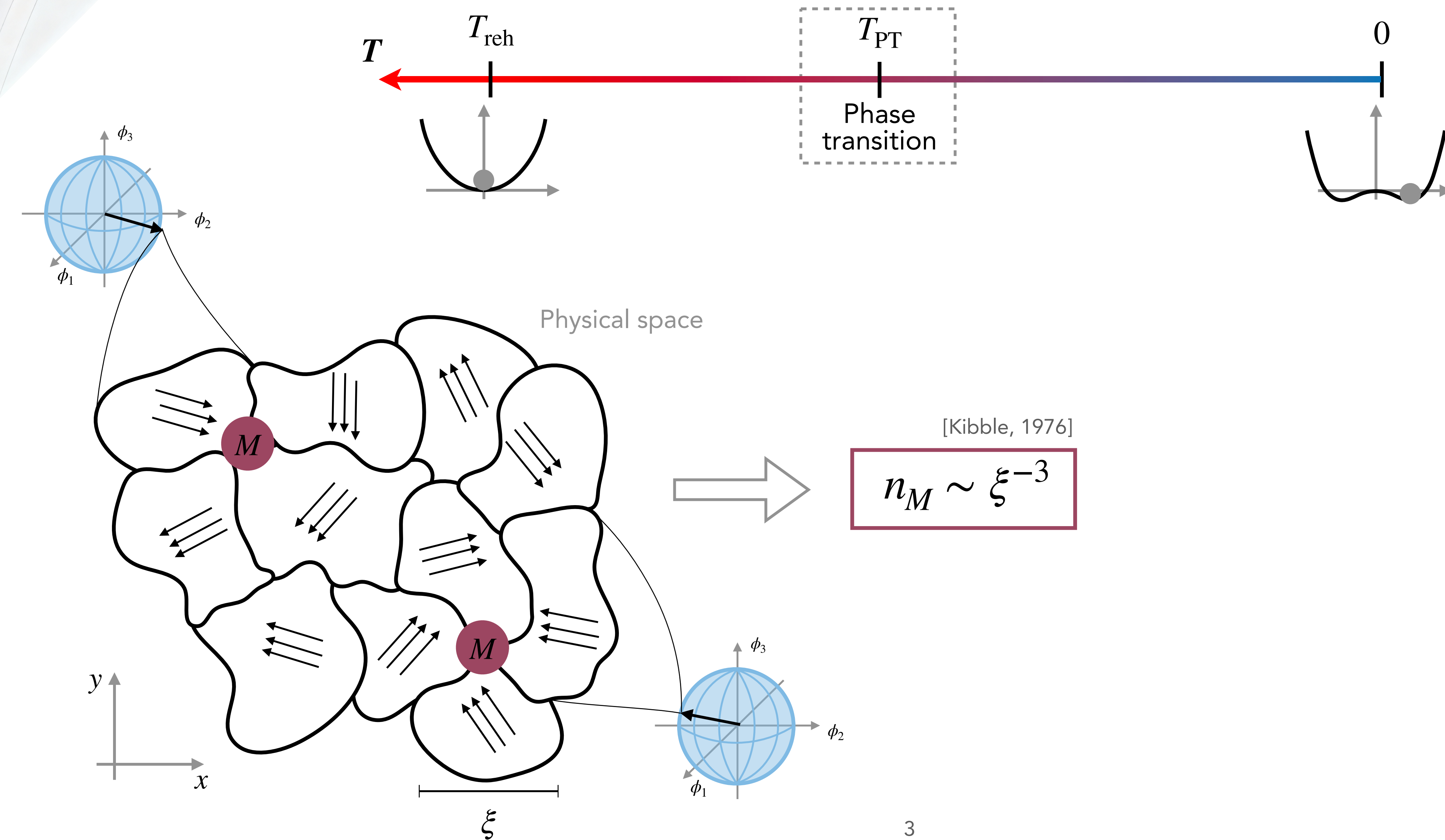
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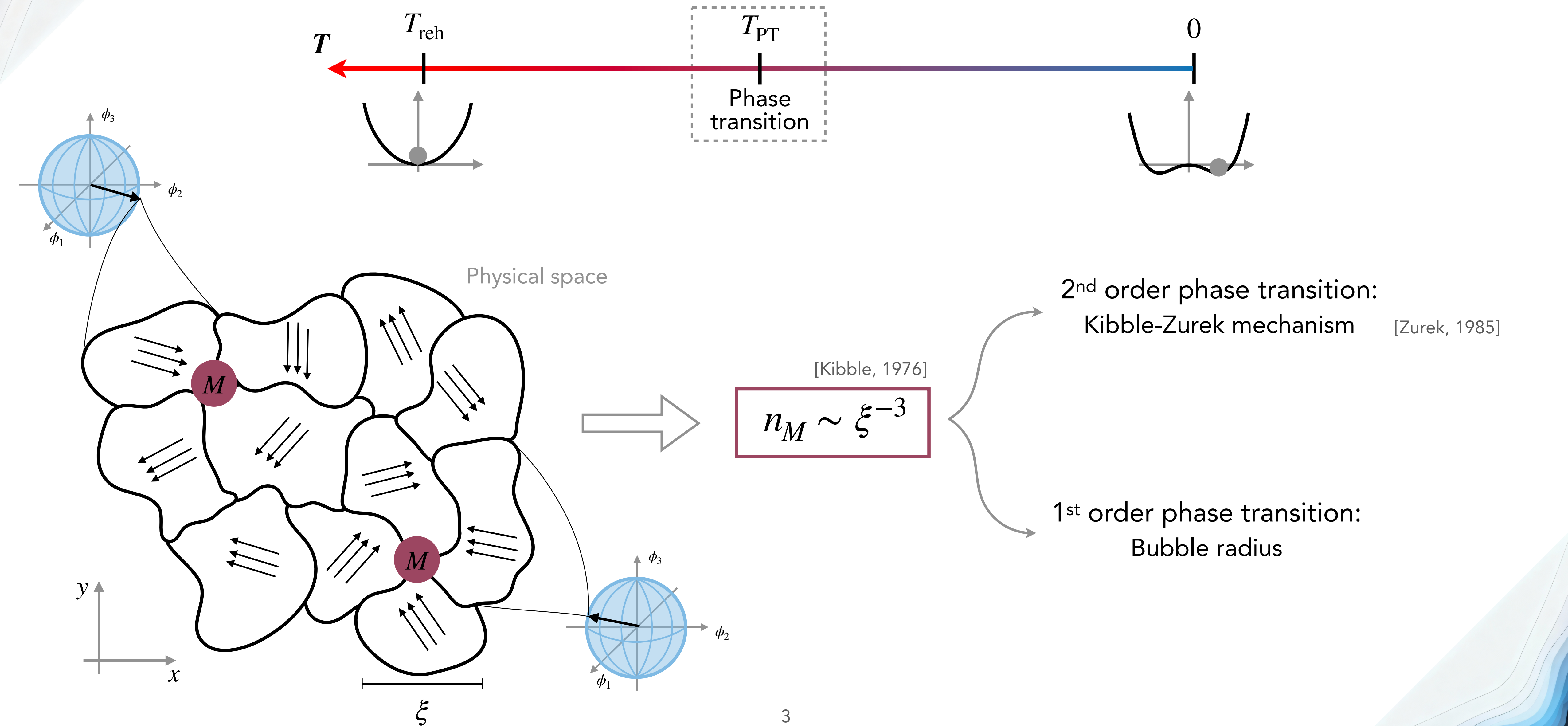
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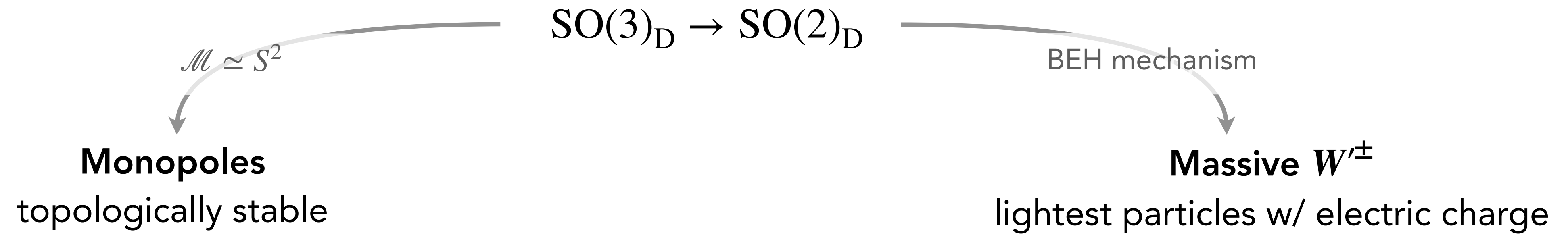


A “no-go theorem” for monopole DM

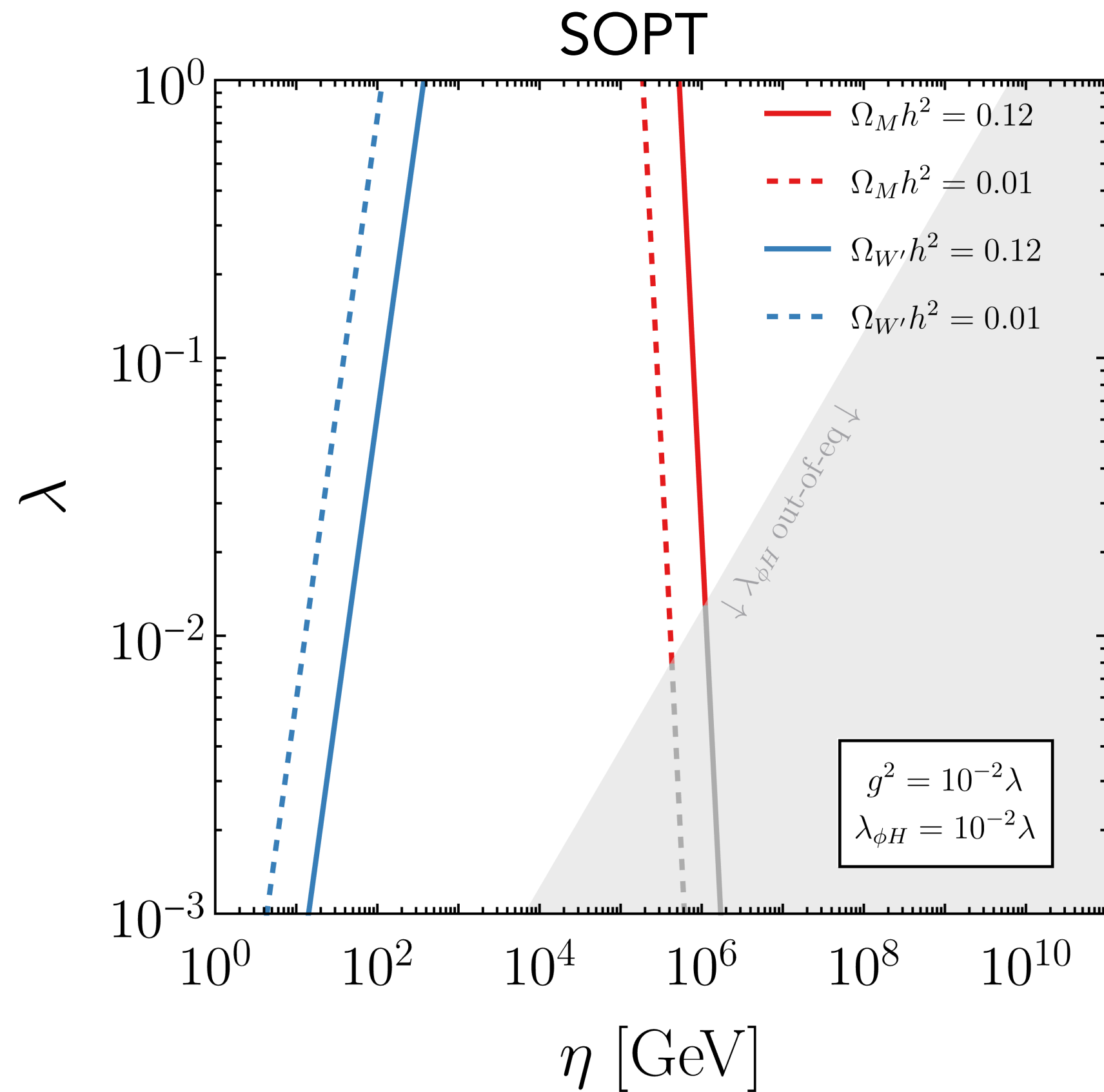
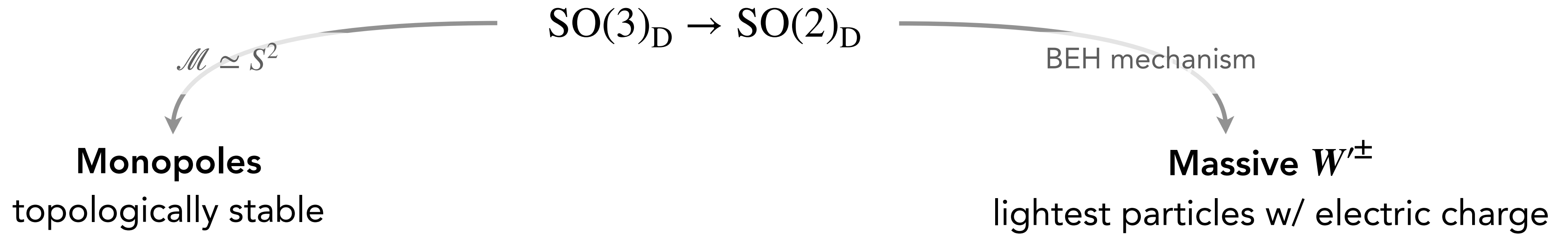
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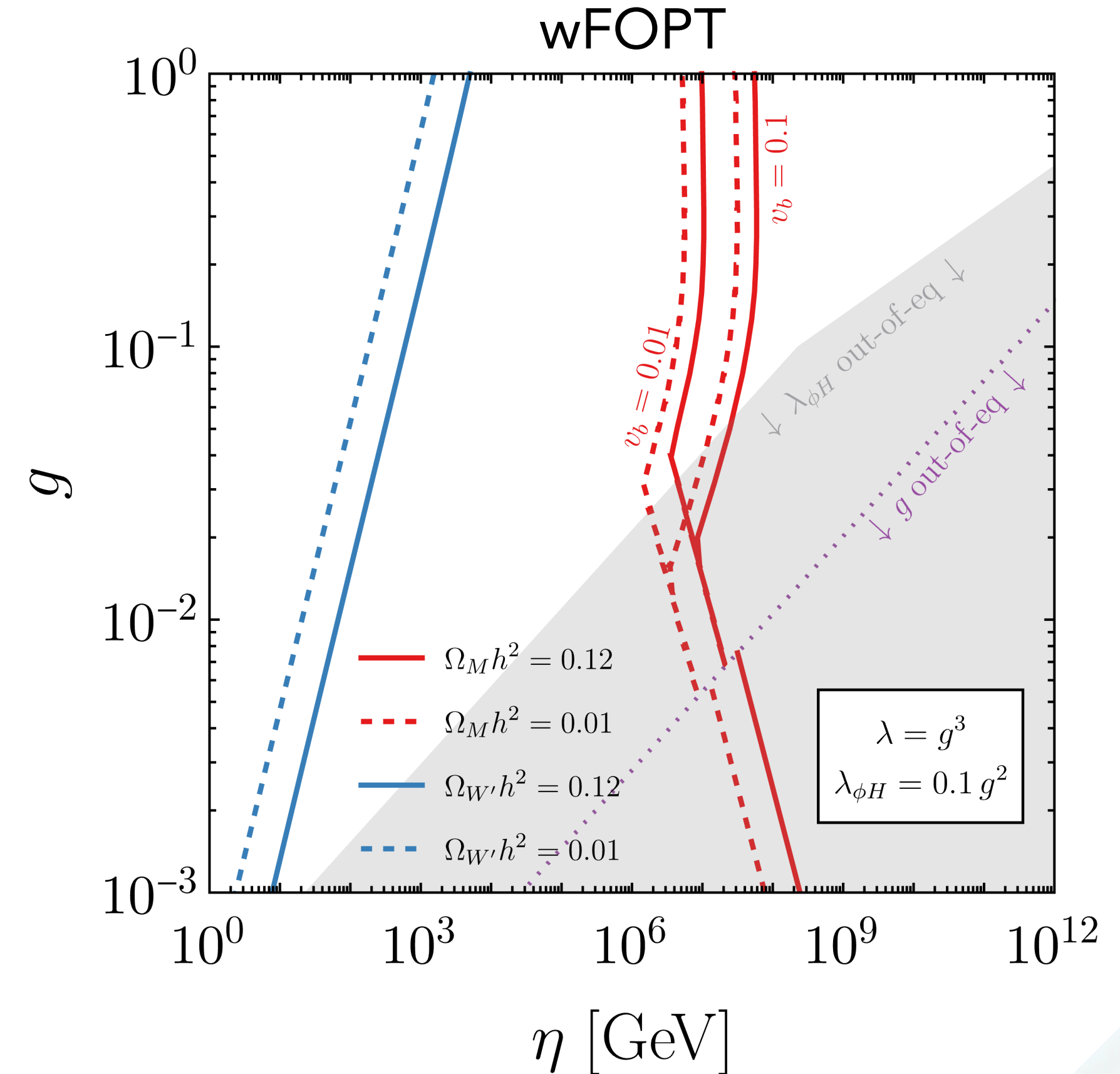
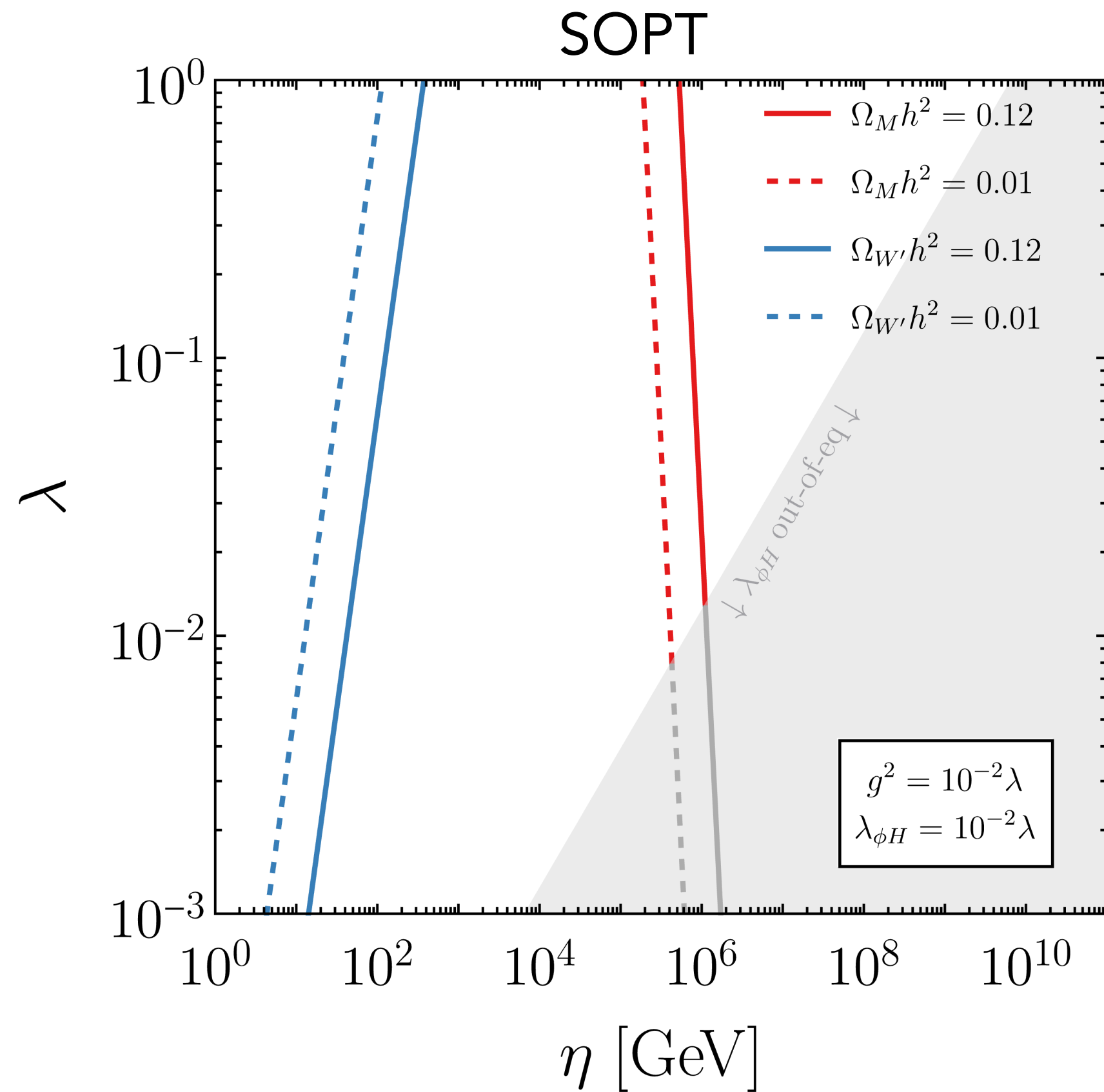
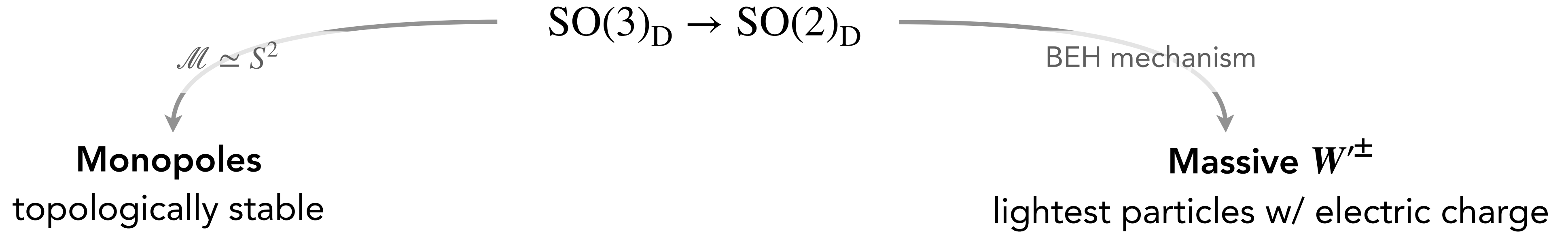
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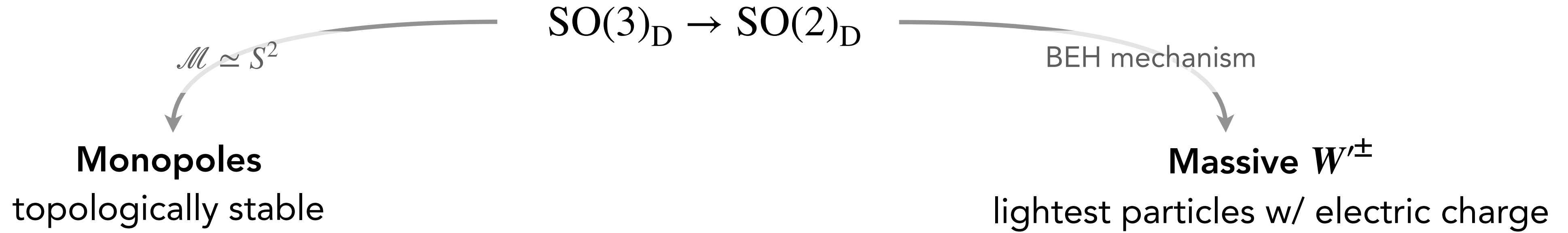
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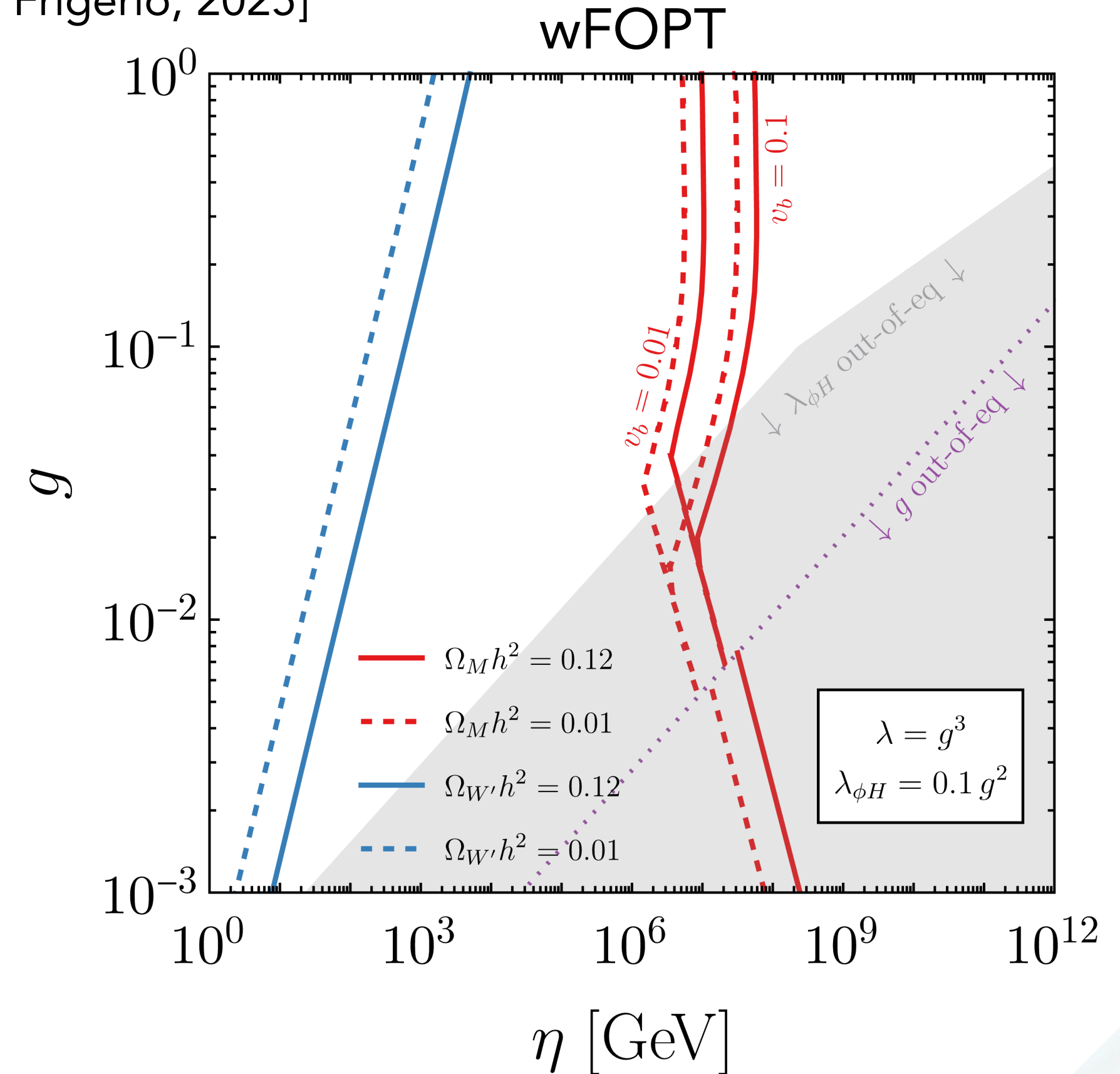
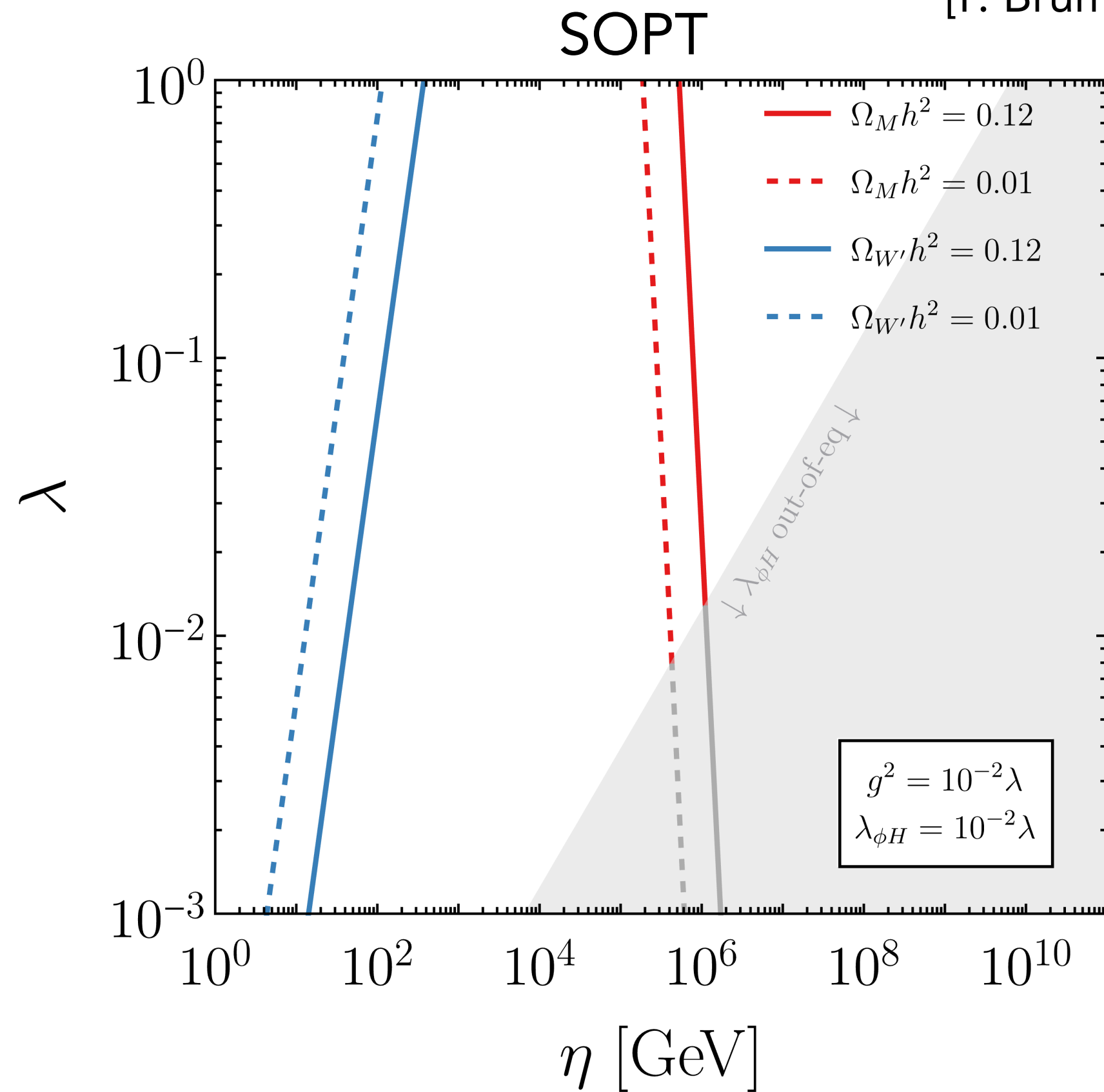
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[F. Brümmer, **GF**, T. Fischer, M. Frigerio, 2025]



Making the W' decay

[F. Brümmer, **GF**,
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$$\chi, \psi \sim \mathbf{2}_{\text{SU}(2)}$$

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ρ

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Dark radiation, ΔN_{eff}

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$$\left. \begin{array}{l} \gamma' \rightarrow \text{Dark radiation, } \Delta N_{\text{eff}} \\ e' \rightarrow \text{DM: } \Omega_e h^2 \propto \langle \sigma v \rangle_{\bar{e}'e' \rightarrow \gamma'\gamma'}^{-1} \sim m_{e'}^2 / g^4 \\ M \rightarrow \text{DM: } \Omega_M h^2 \stackrel{!}{=} 0.12 \end{array} \right\} m_{e'} \ll 100 \text{ GeV} \quad \Leftrightarrow \quad m_f \sim y\eta$$

The price tag: dark radiation

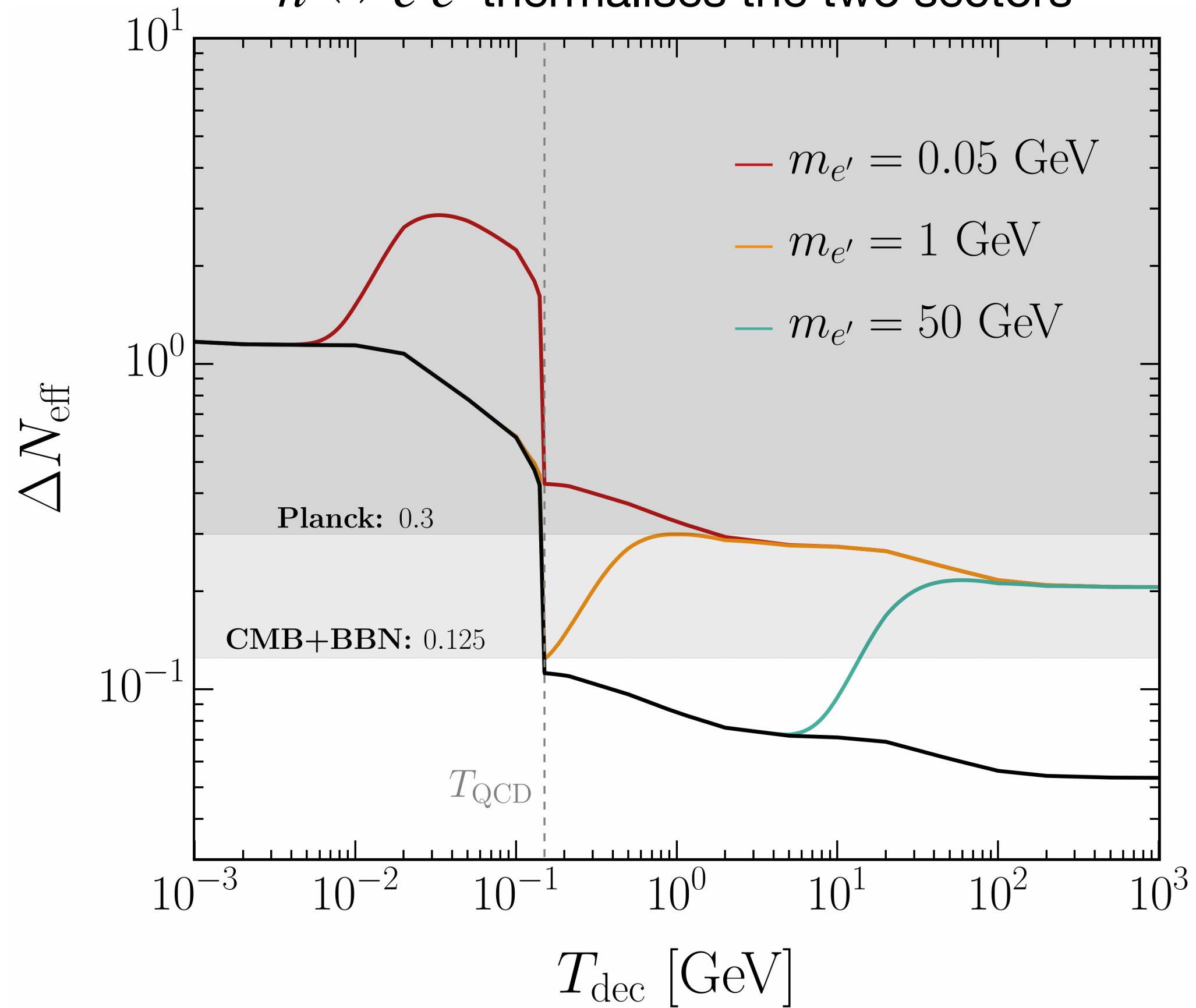
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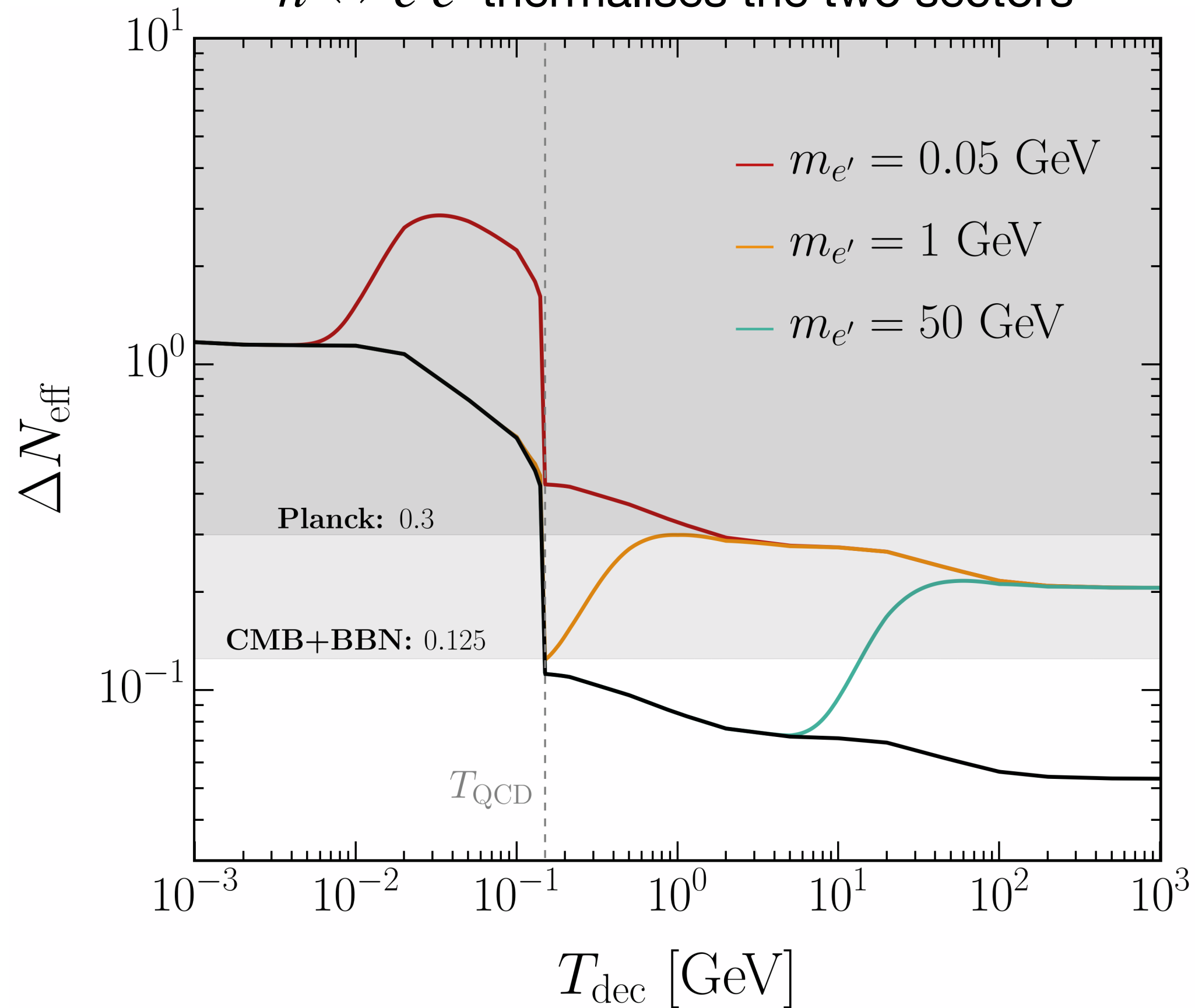
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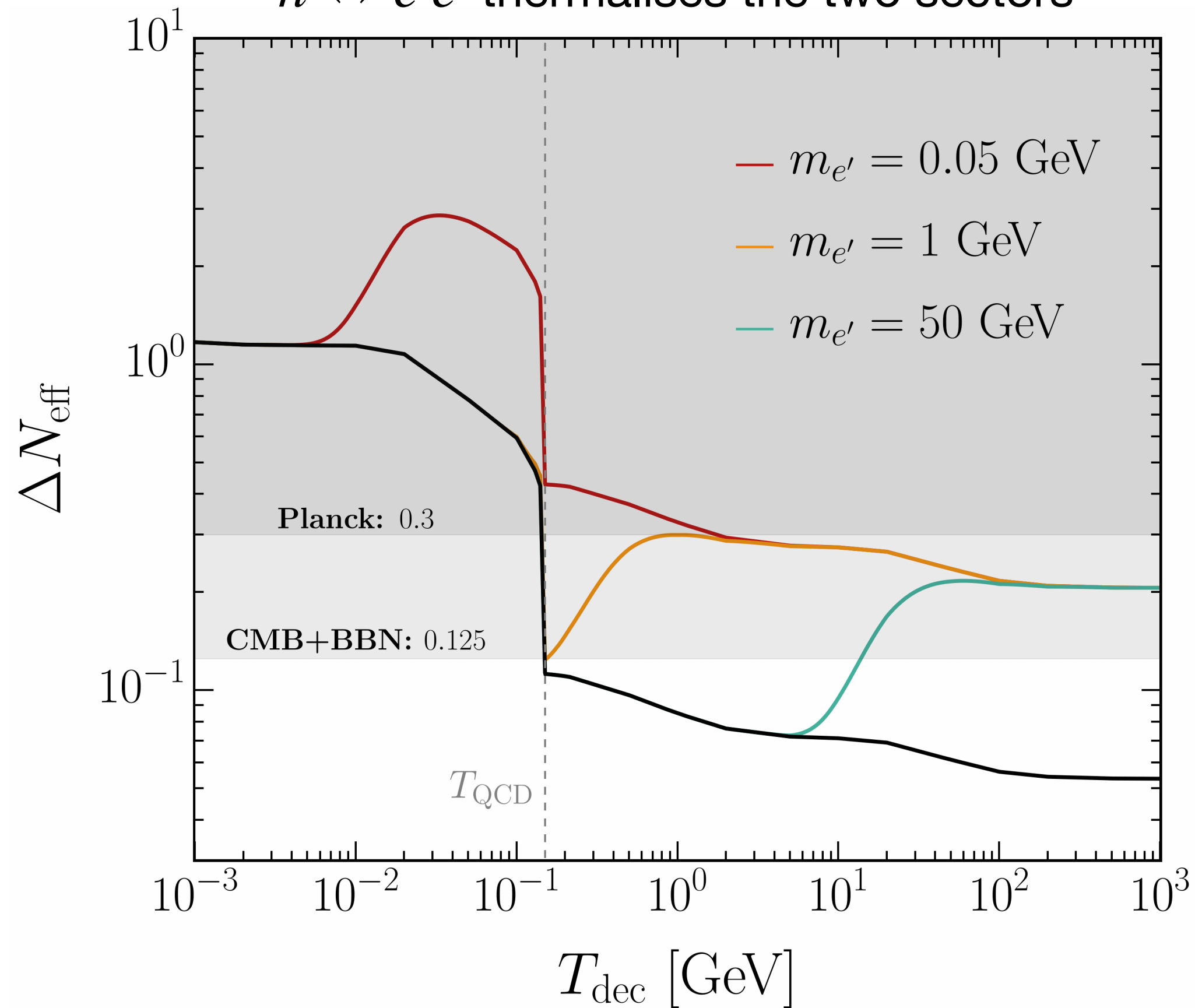
[1807.06209]

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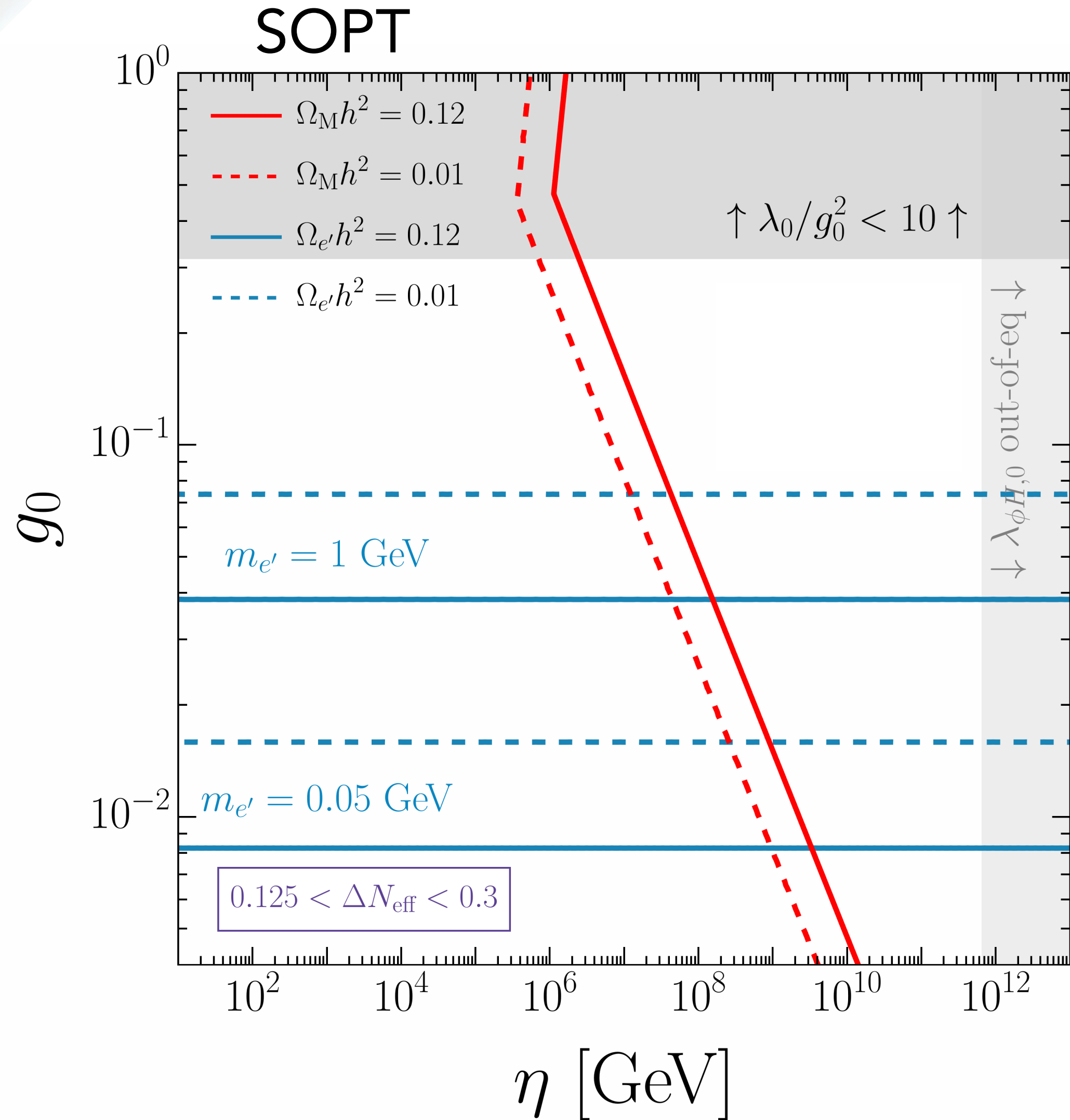
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[2601.22239]

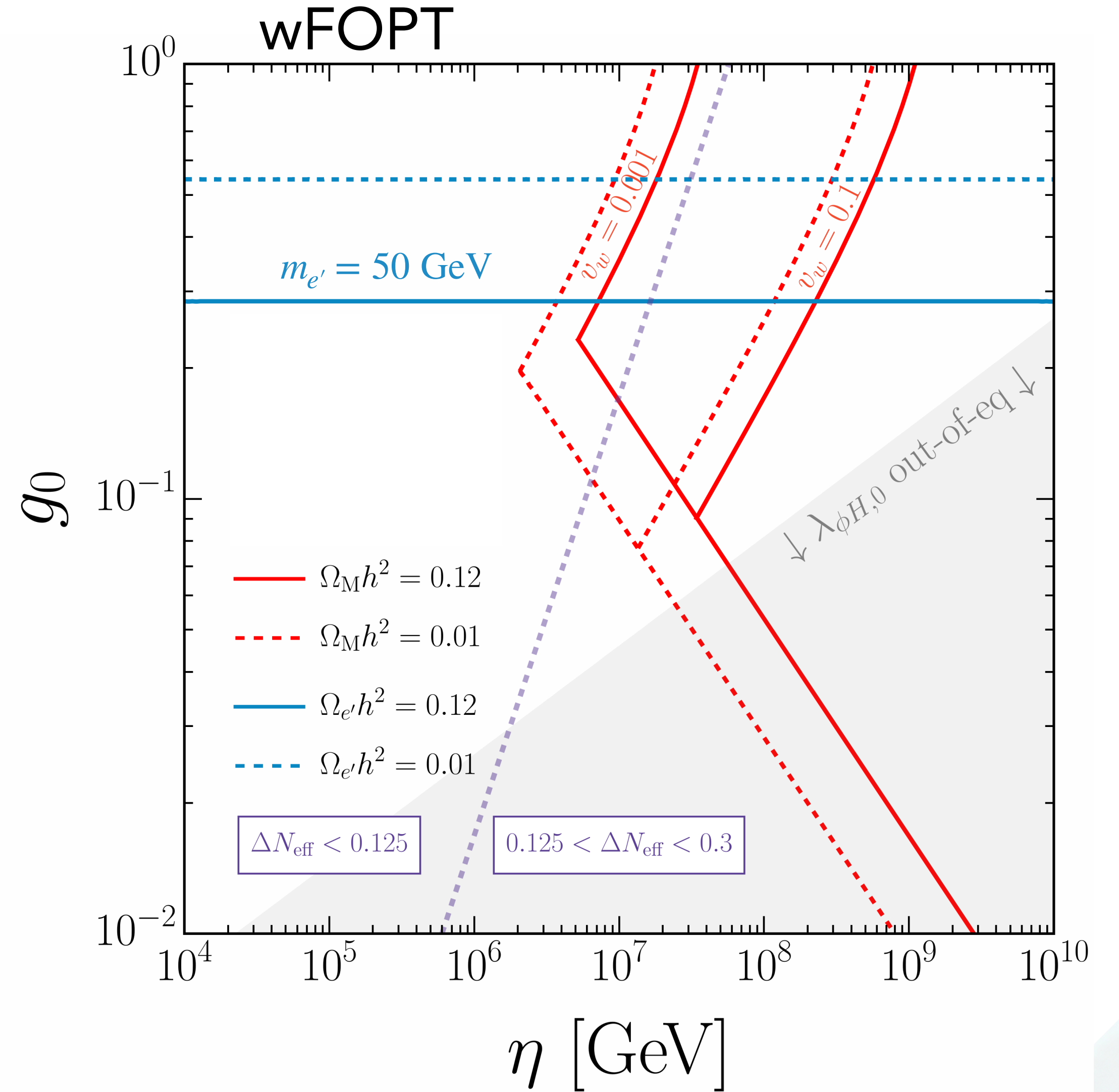
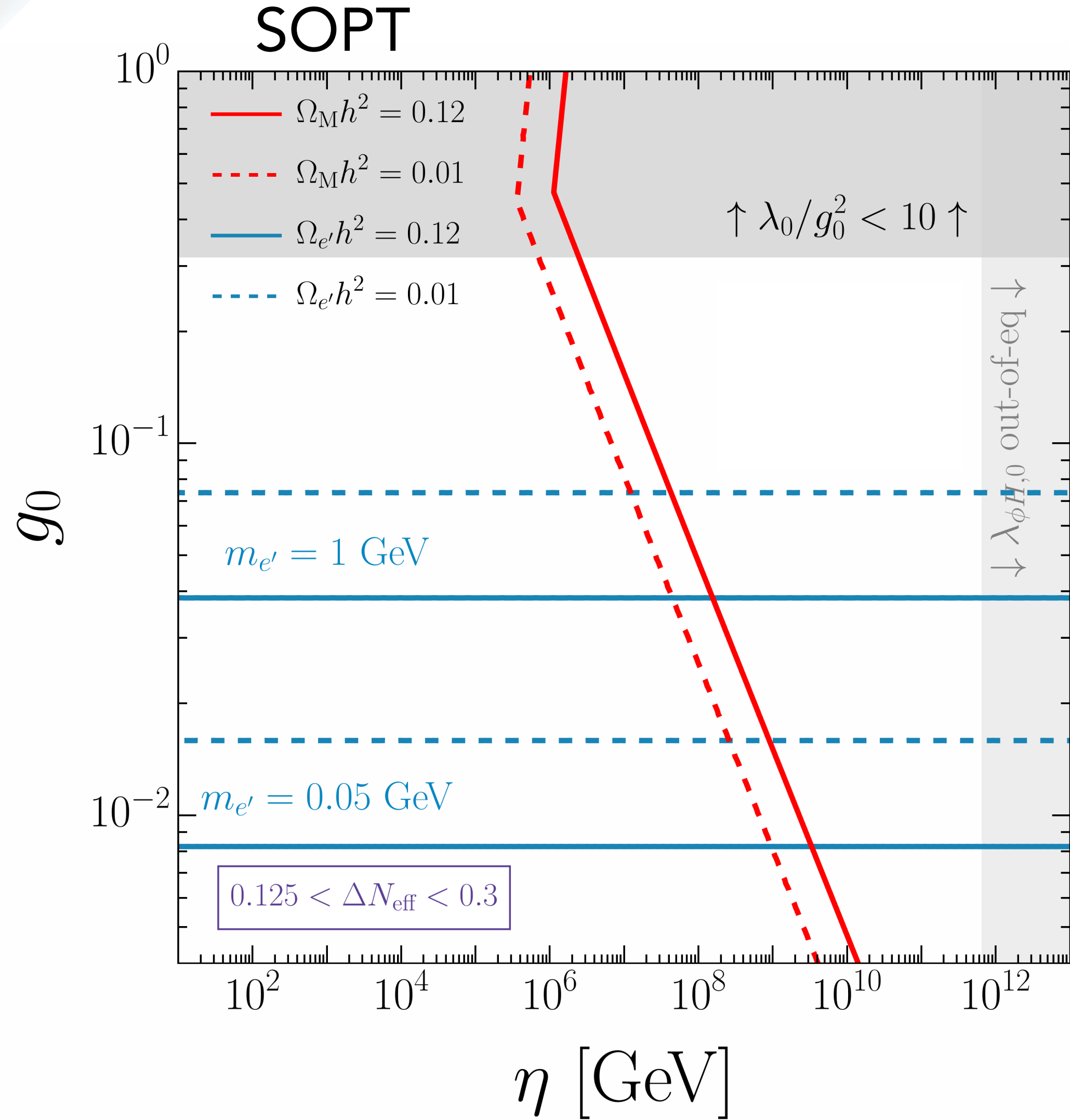
$$\text{CMB + BBN: } \Delta N_{\text{eff}} < 0.125 \quad \Rightarrow \quad \begin{aligned} 1 \text{ GeV} &\lesssim m_{e'} \\ T_{\text{QCD}} &\lesssim T_{\text{dec}} \lesssim m_{e'}/3.5 \end{aligned}$$

A window for monopole DM

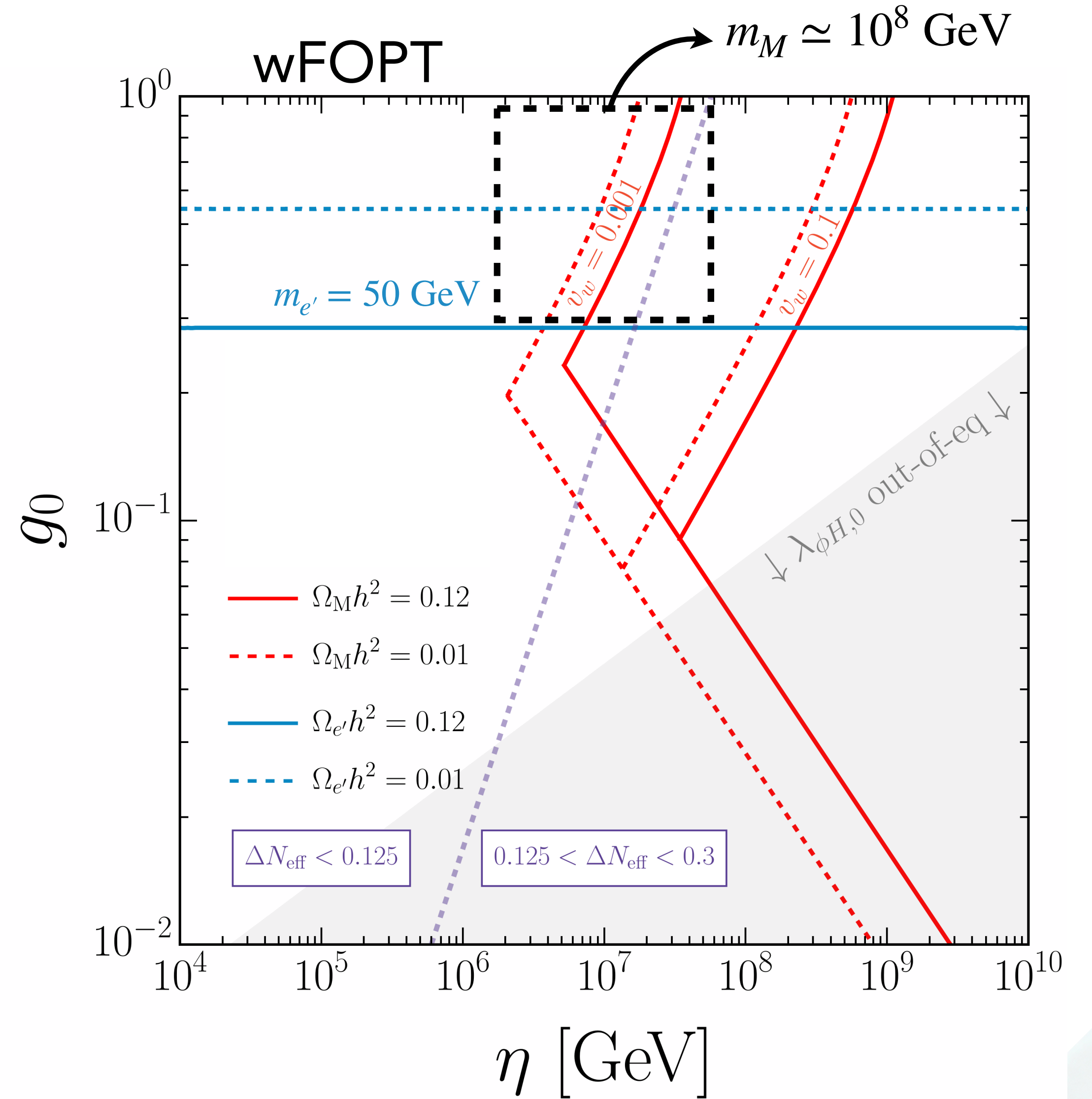
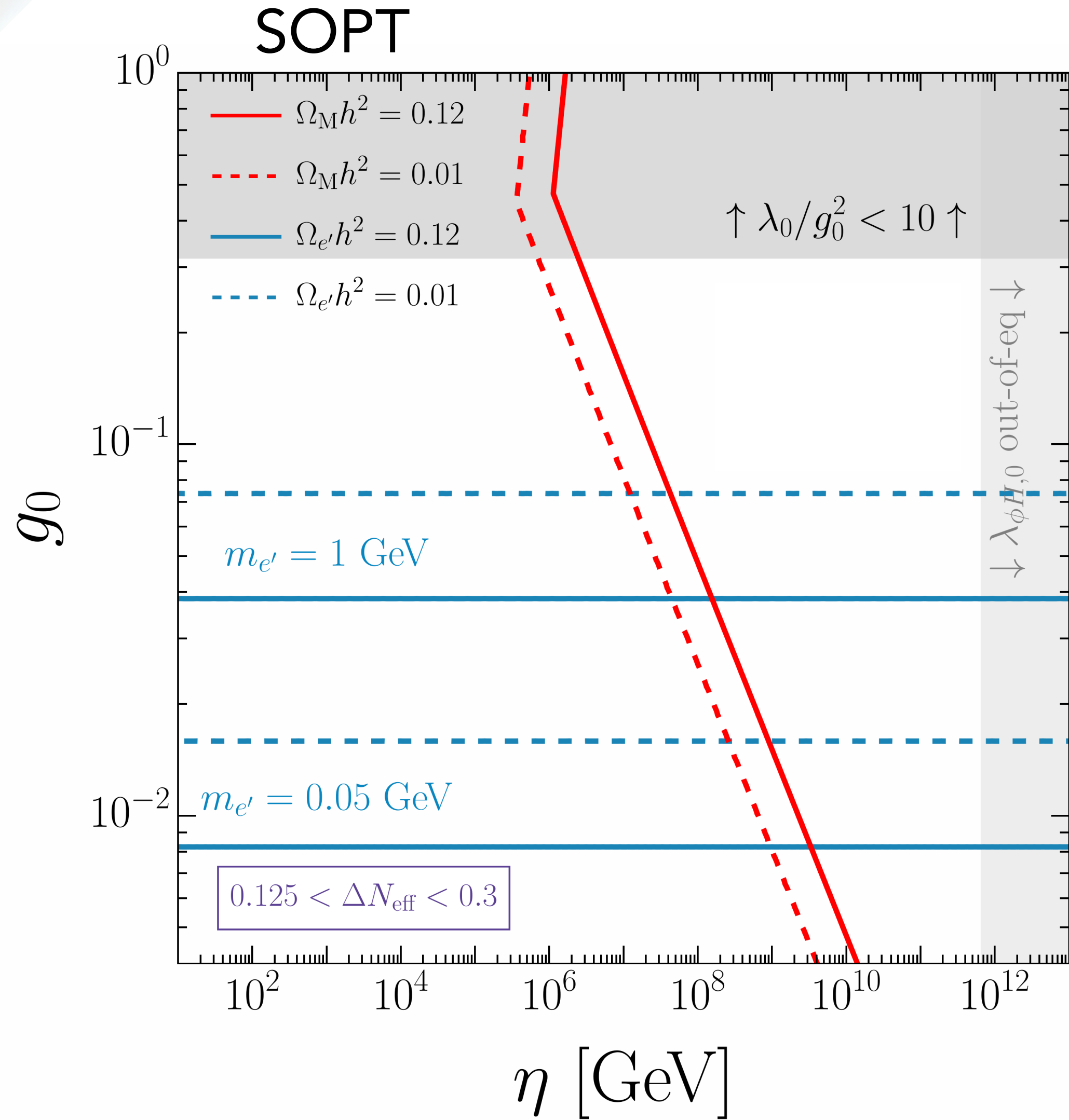
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- Replacing fermions with a charged scalar hardly does better: $\Delta N_{\text{eff}} \simeq 0.135$

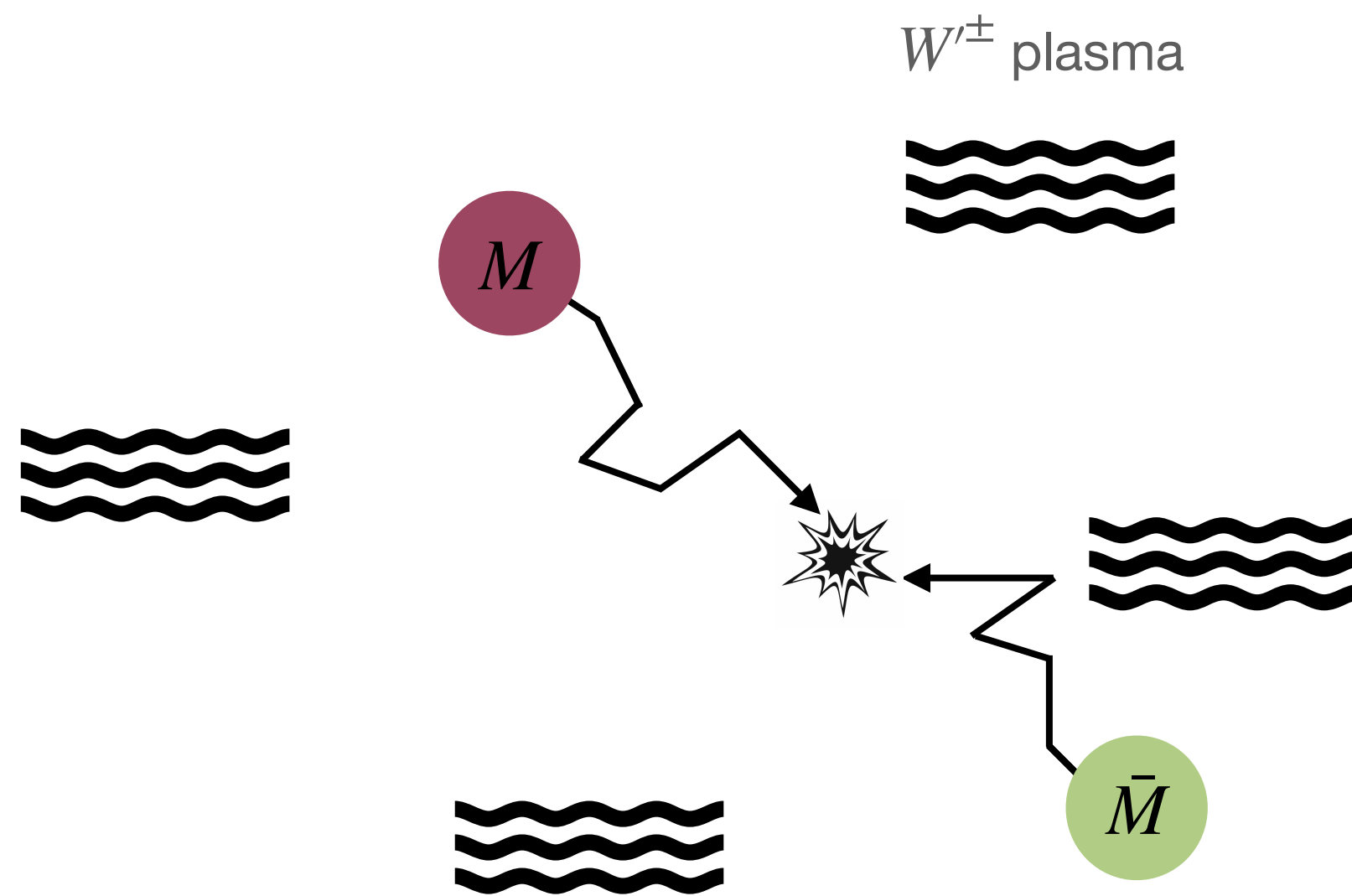
Summary and conclusions

- $\Omega_M \lll \Omega_{W'}$: NO monopole DM in the minimal model [F. Brümmer, **GF**, T. Fischer, M. Frigerio, 2509.21924]
- Add charged fermions to let $W'^{\pm}$ decay [F. Brümmer, **GF**, T. Fischer, M. Frigerio, 2607.29492]
 - $m_{e'} \ll 100$ GeV for negligible $\Omega_{e'}$ $\Rightarrow$ monopole DM w/ $m_M \gtrsim 10^8$ GeV
 - BUT light e' gives sizeable $\Delta N_{\text{eff}} \simeq 0.1 - 0.2$ (Simons Observatory $\sigma(\Delta N_{\text{eff}}) \sim 0.045$) [2503.00636]
- Replacing fermions with a charged scalar hardly does better: $\Delta N_{\text{eff}} \simeq 0.135$

“Monopole dark matter is possible, but it comes at a steep price.”

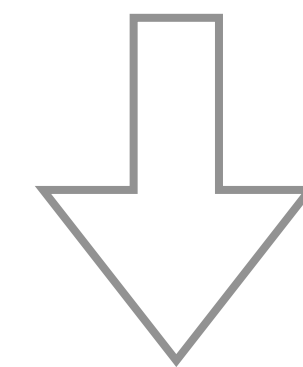
Backup Slides

Monopole annihilation



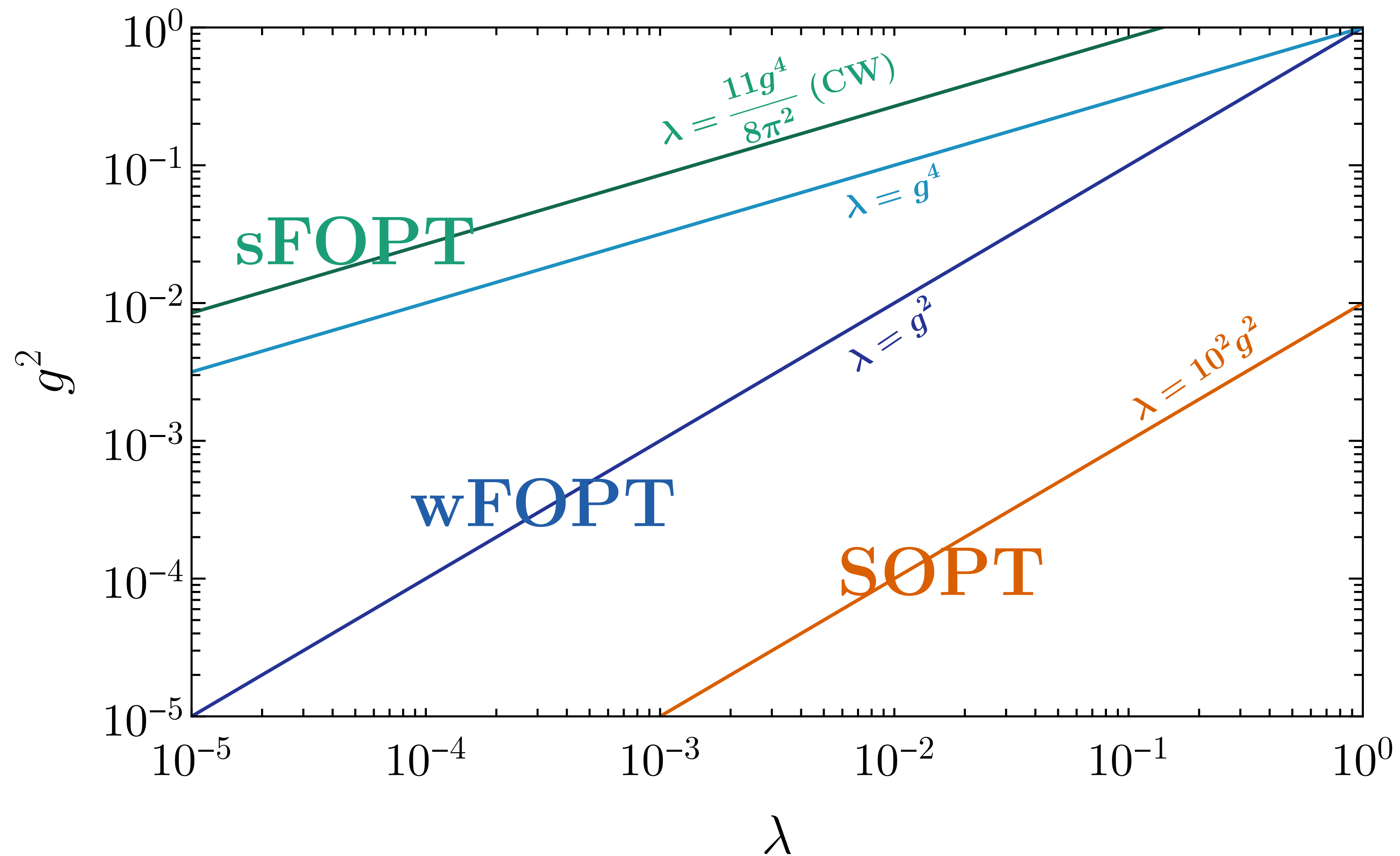
$$Y_M^{\text{prod}} \sim \frac{\xi^{-3}}{s(T_{\text{PT}})}$$

$$Y_M^{\text{ann}} \sim q_{\bar{M}}^{-2} \frac{\bar{T}}{M_{\text{Pl}}} \sim g^2 \frac{m_{W'}}{M_{\text{Pl}}}$$

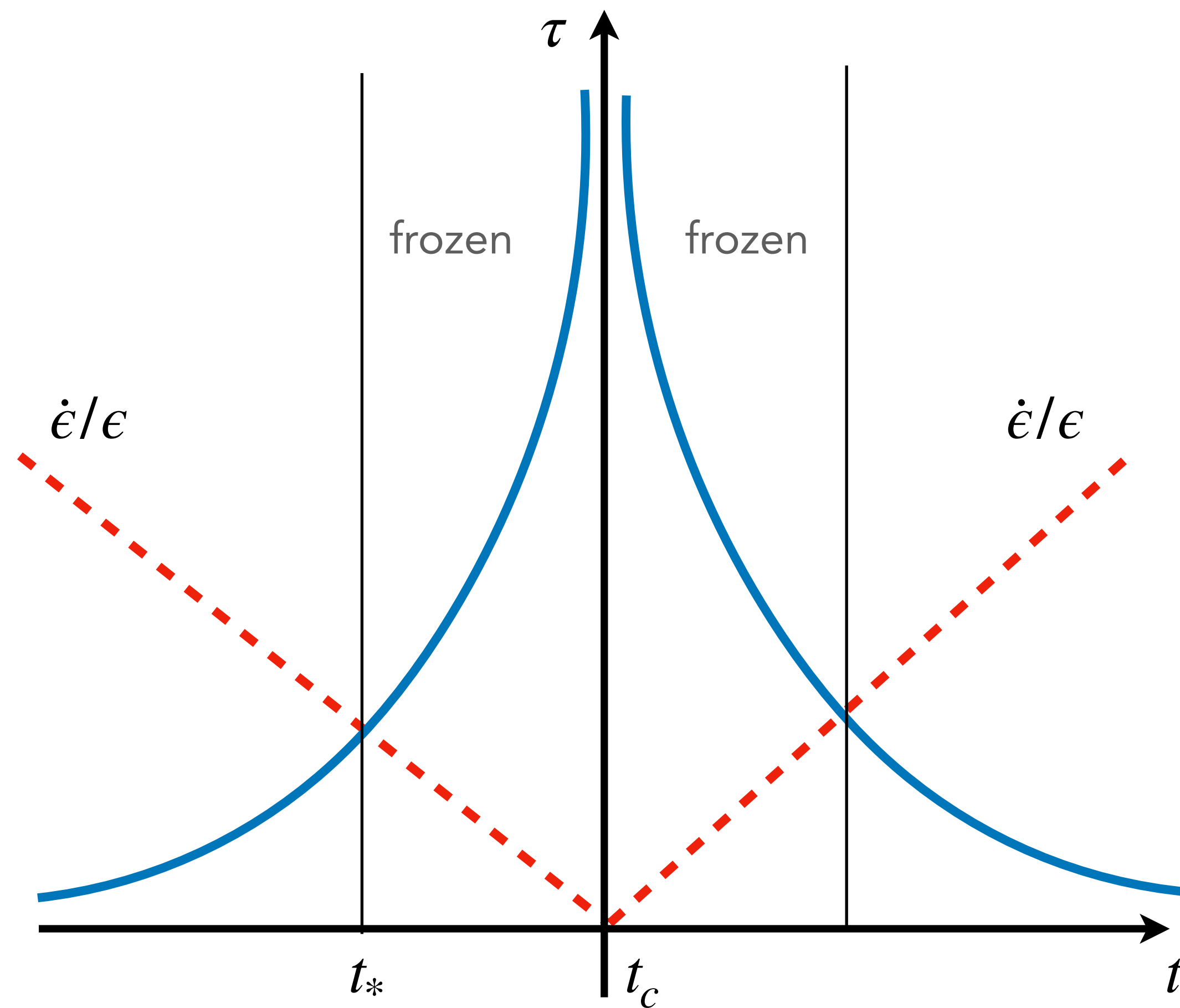


$$Y_{M,0} = \min \left[Y_M^{\text{ann}}, Y_M^{\text{prod}} \right]$$

Phase diagram



The Kibble-Zurek mechanism (SOPT)



Relaxation time $\tau(t) \sim \xi(t) \sim \frac{1}{m} |\epsilon(t)|^{-\nu}$, Correlation length

$$\epsilon(t) \equiv \frac{T(t) - T_c}{T_c}$$

$$\xi \approx \xi(t_*)$$

[Zurek, 1985]
[Murayama, Shu, 2009]

Reproduced from [Del Campo, Zurek, 2013]

Correlation length in a FOPT

$$V_T(\phi) \approx \left(-\frac{m^2}{2} + \frac{g^2}{4} T^2 \right) \phi^2 - \frac{g^3}{2\pi} T |\phi|^3 + \left(\frac{\lambda}{4} + \frac{3g^4}{32\pi^2} \log \frac{T^2}{\mu^2} \right) (\phi^2)^2$$

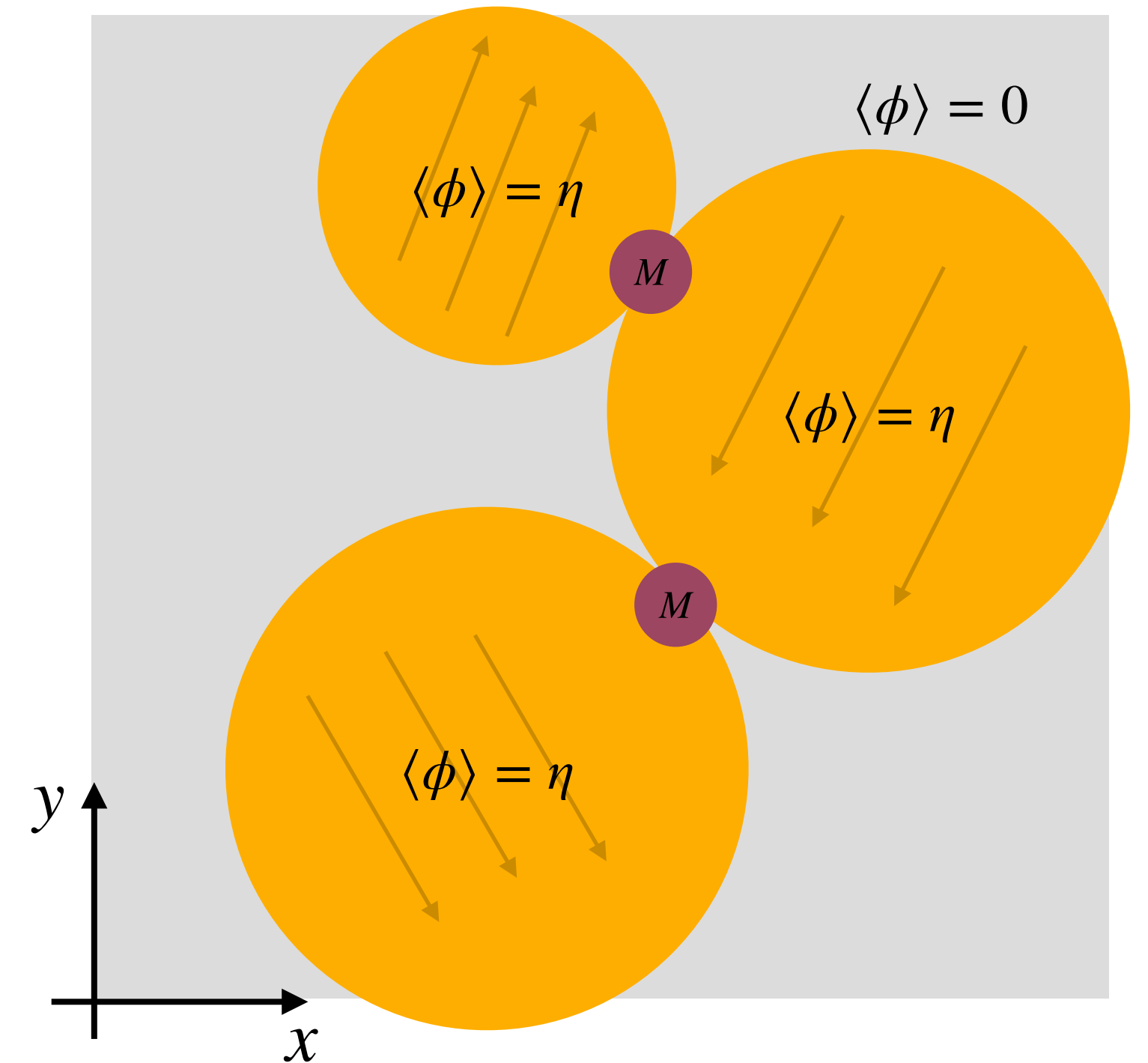
Tunneling rate: $\Gamma \approx T^4 e^{-S_3/T}$ [Linde, 1980]

$$T_n : \quad \Gamma(T_n) \approx H(T_n)^4$$

$$\mathcal{P}_{\langle \phi \rangle=0}(T) \approx \exp - \left[\int_T^{T_c} dT' \frac{\Gamma(T')}{T'^4 H(T')} \left(\int_T^{T'} v_b \frac{dT''}{H(T'')} \right)^3 \right] \quad \text{[Guth et al., 1980]}$$

$$T_p : \quad \mathcal{P}_{\langle \phi \rangle=0}(T_p) = 0.71$$

$$\boxed{\xi \approx \langle R(T_p) \rangle} \sim \left[HT \frac{dS_3/T}{dT} \right]_{T=T_p}^{-1}$$



First order phase transition

Bounce action

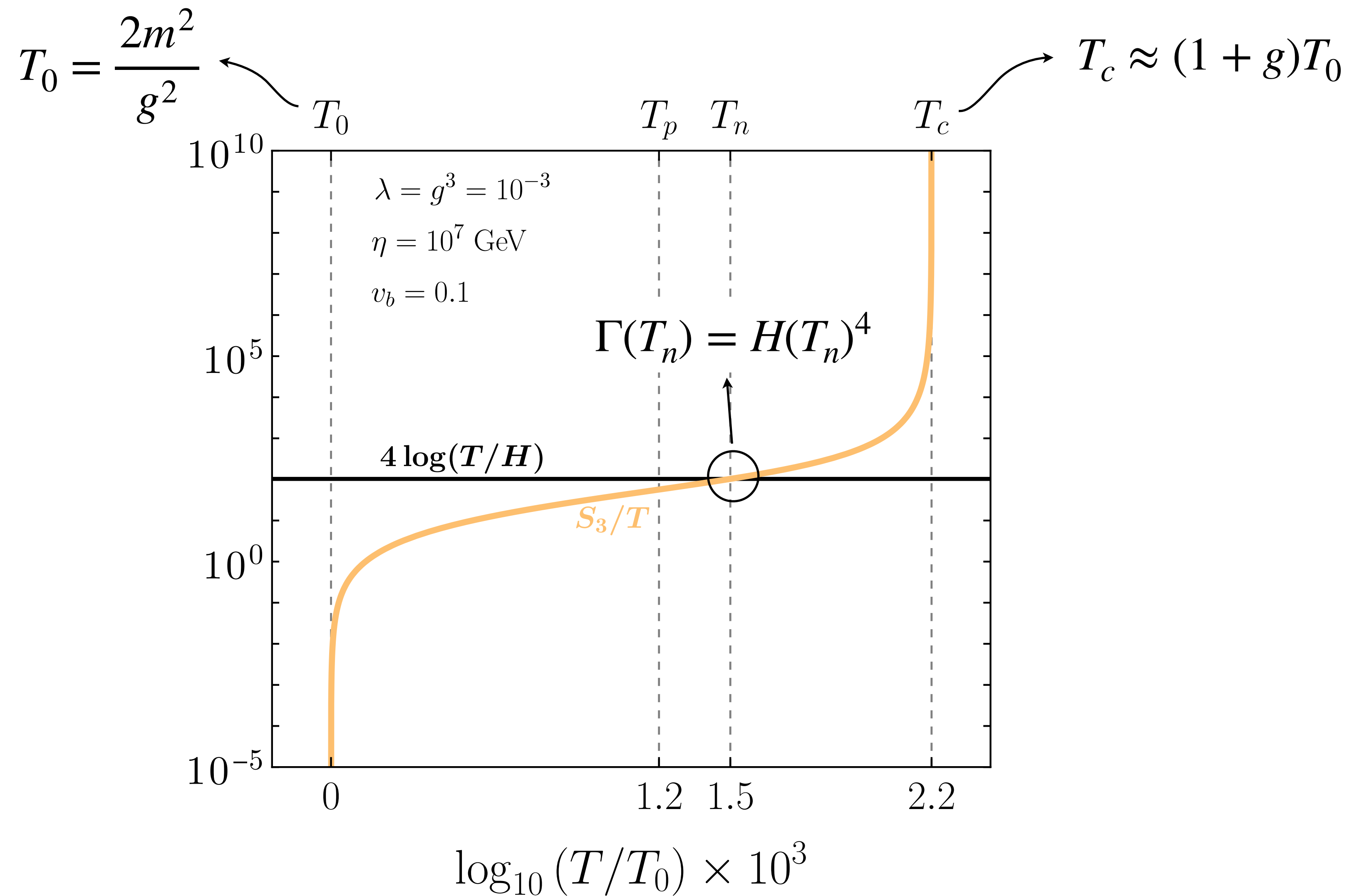
$$V_{\text{eff}}(\phi, T) \simeq \frac{m_T^2}{2}\phi^2 - \frac{\delta_T}{3}\phi^3 + \frac{\lambda_T}{4}\phi^4$$

$$S_3 = \begin{cases} \frac{m_T^3}{\delta_T^2} \frac{2\pi}{3(\kappa - 2/9)^2} F(\kappa), & \kappa > 0 & \begin{array}{l} \text{[Adams, 1993]} \\ \text{[Levi et al., 2022]} \end{array} \\ \frac{m_T^3}{\delta_T^2} \frac{27\pi}{2} \left[\frac{1 + \exp\left(-1/\sqrt{|\kappa|}\right)}{1 + 9|\kappa|/2} \right], & \kappa < 0 & \begin{array}{l} \text{[Levi et al., 2022]} \\ \text{[Salvio, 2023]} \end{array} \end{cases} \quad \kappa \equiv \lambda_T \frac{m_T^2}{\delta_T^2}$$

Bounce action

wFOPT

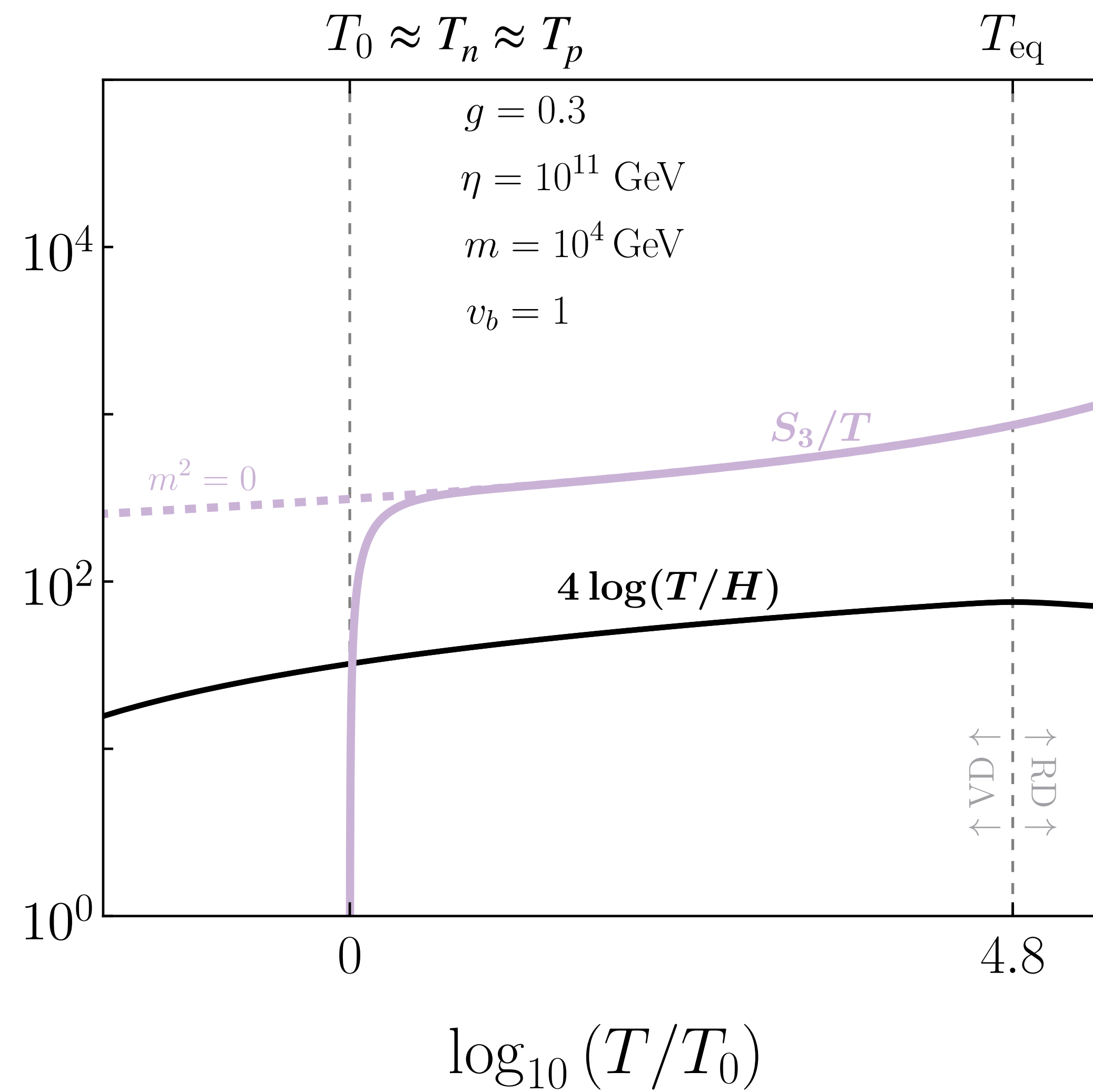
$$T_p \approx T_c$$



Bounce action

sFOPT

$$T_p \ll T_c$$



Dark fermions

$$\mathcal{L} = i\chi^\dagger \bar{\sigma}^\mu D_\mu \chi + i\psi^\dagger \bar{\sigma}^\mu D_\mu \psi - \left[y \chi^i \epsilon_{ij} \phi^a (\sigma^a)_k^j \psi^k + m_f \chi^i \epsilon_{ij} \psi^j + \text{h.c.} \right]$$

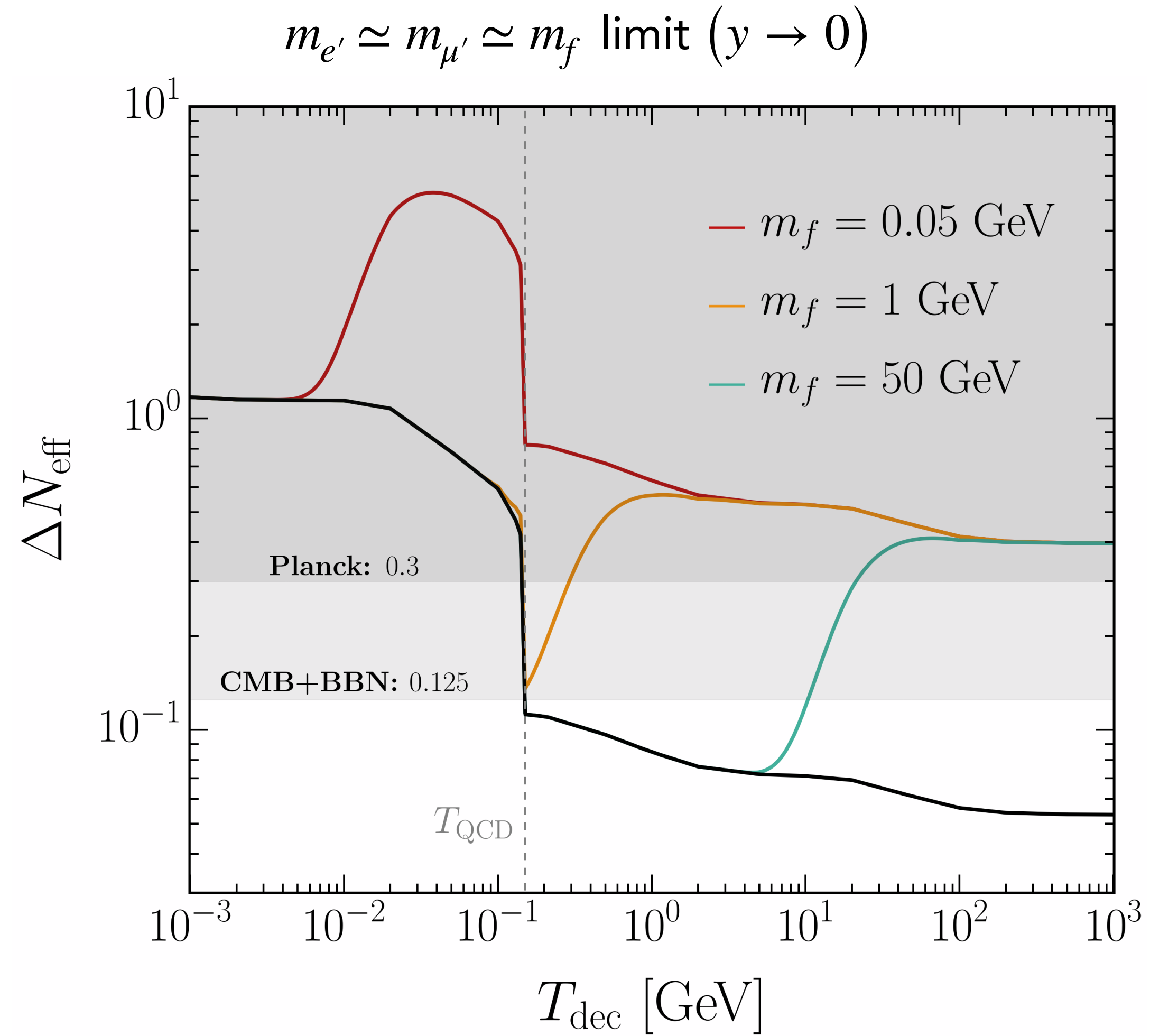
$$\langle \sigma v \rangle_{\bar{e}' e' \rightarrow \gamma' \gamma'} \approx \frac{g^4}{256\pi m_{e'}^2}$$

$$\Omega_{e'} h^2 \approx 0.1 \left(\frac{11}{\gamma_\star(T_{\text{fo}})} \right)^{1/2} \left(\frac{z_{\text{fo}}}{20} \right) \left(\frac{0.4}{g} \right)^4 \left(\frac{m_{e'}}{100 \text{ GeV}} \right)^2$$

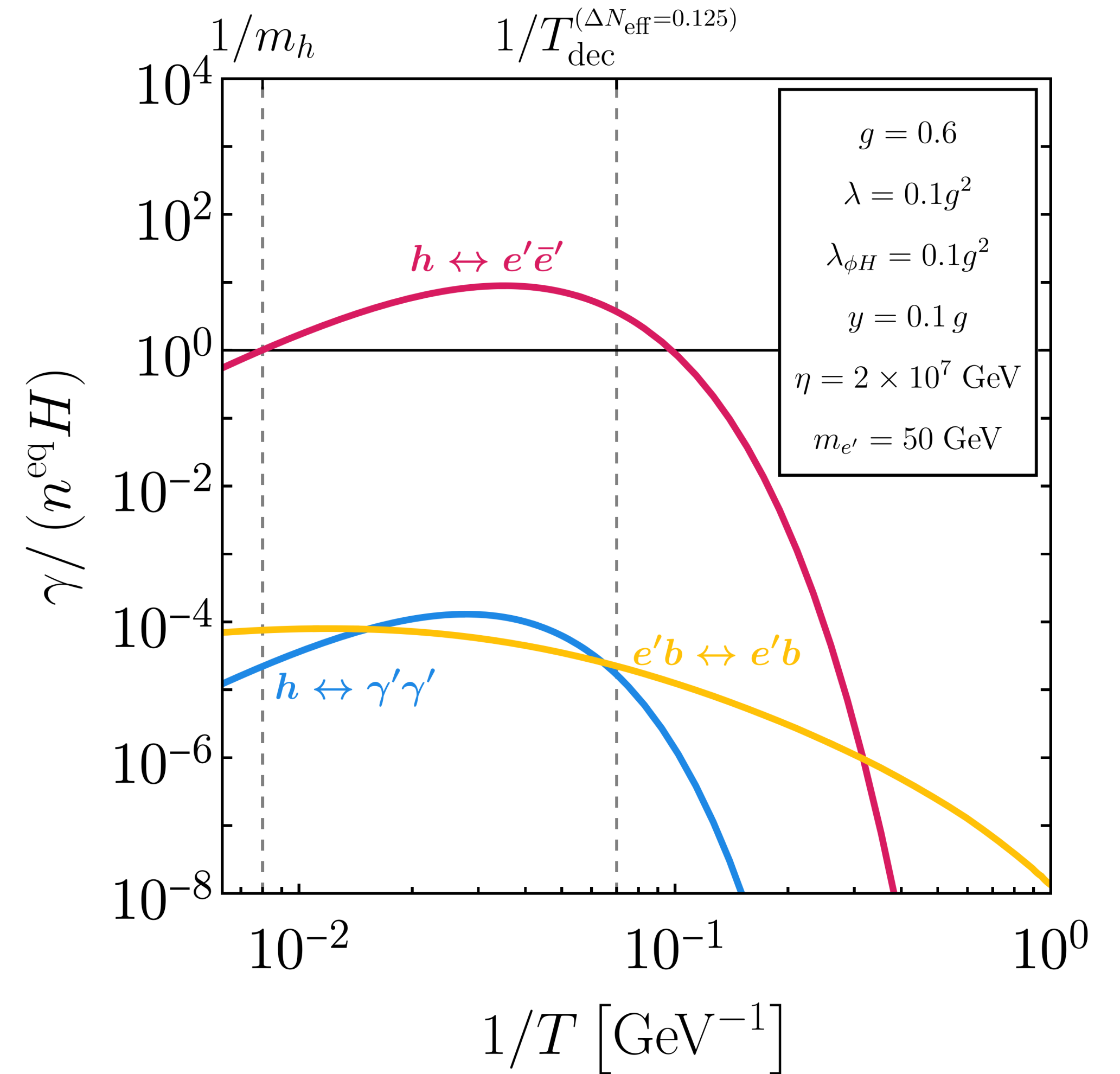
$$\frac{y^2 \sin^2 \theta}{16\pi} \frac{m_h^3}{m_{e'}^2} \left(1 - \frac{4m_{e'}^2}{m_h^2} \right)^{3/2} \frac{K_1(m_h/T)}{K_2(m_{e'}/T)} \geq H$$

$$\tan 2\theta = \frac{2\lambda_{\phi H} \eta v}{m_\rho^2 - m_h^2}.$$

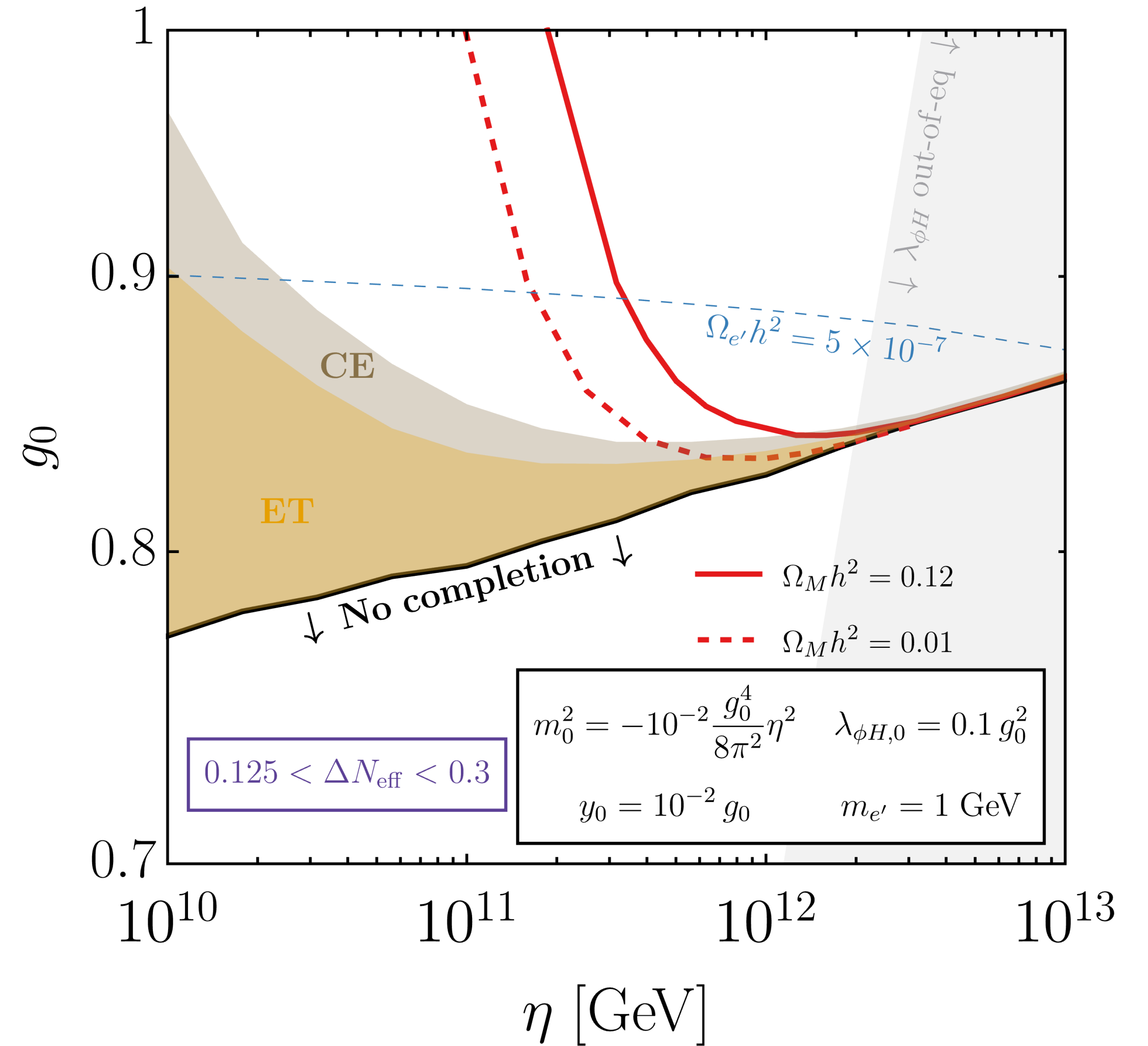
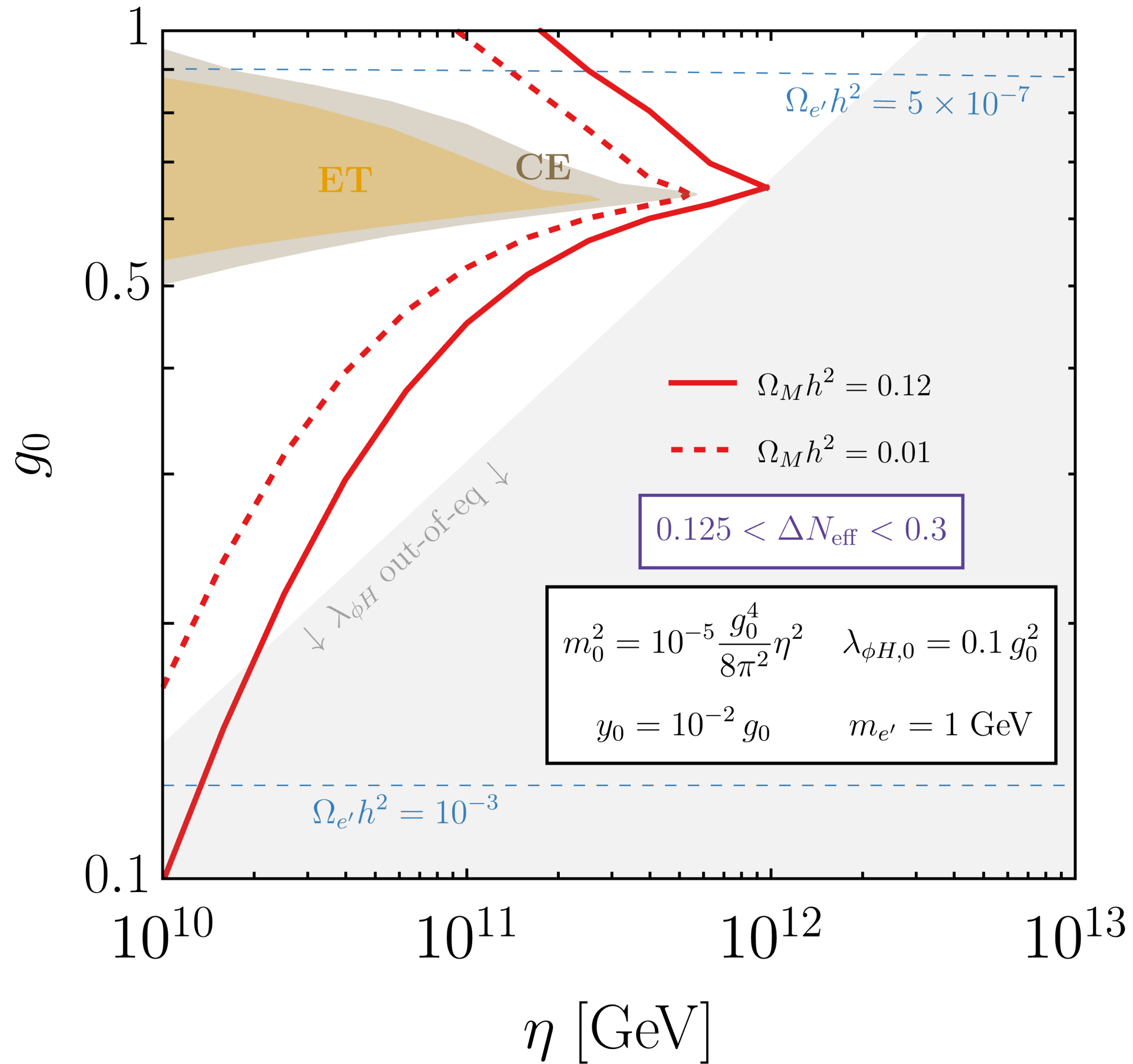
Dark radiation



But $T_{\text{dec}} \gg m_f$ for $y \rightarrow 0$

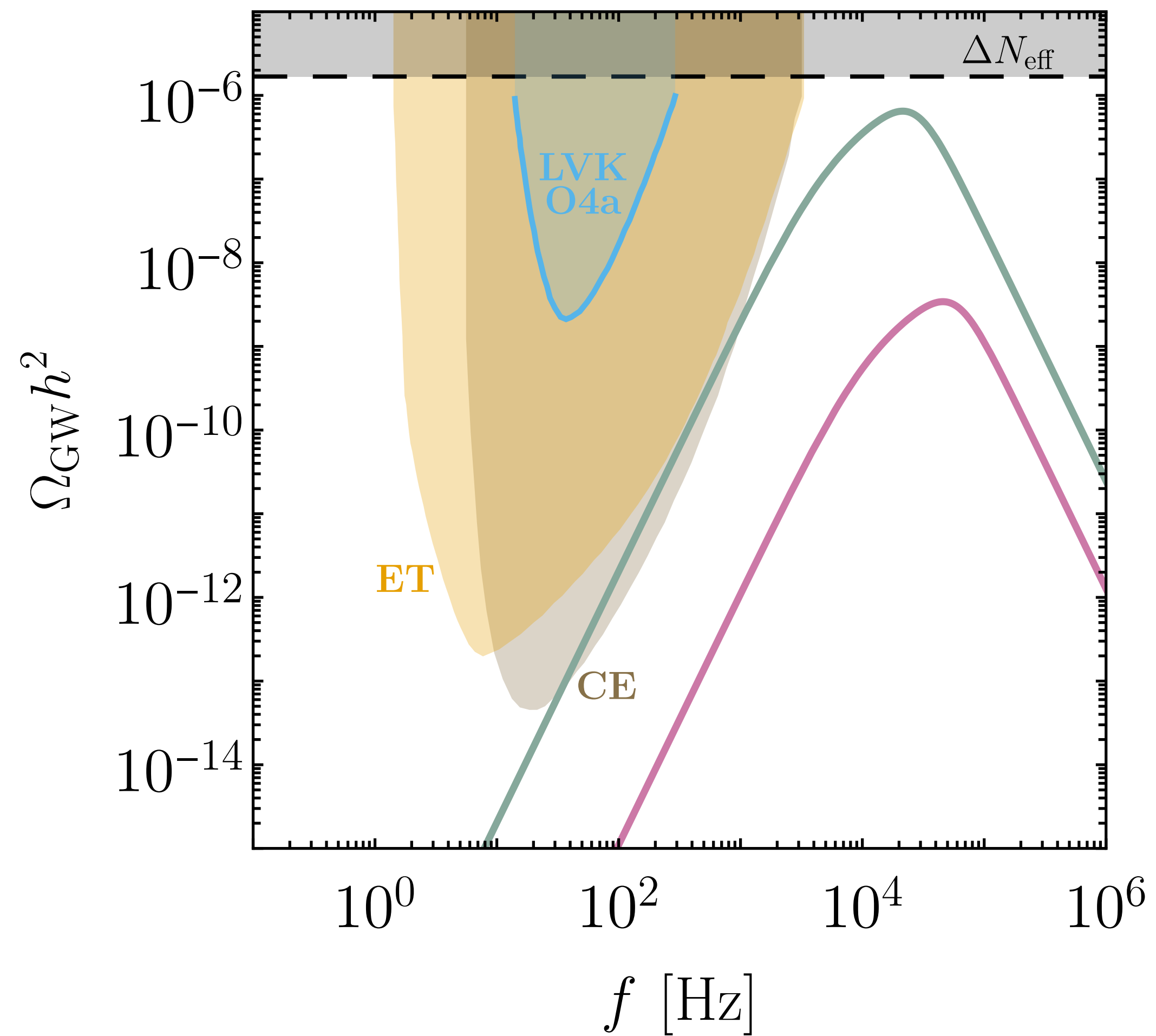
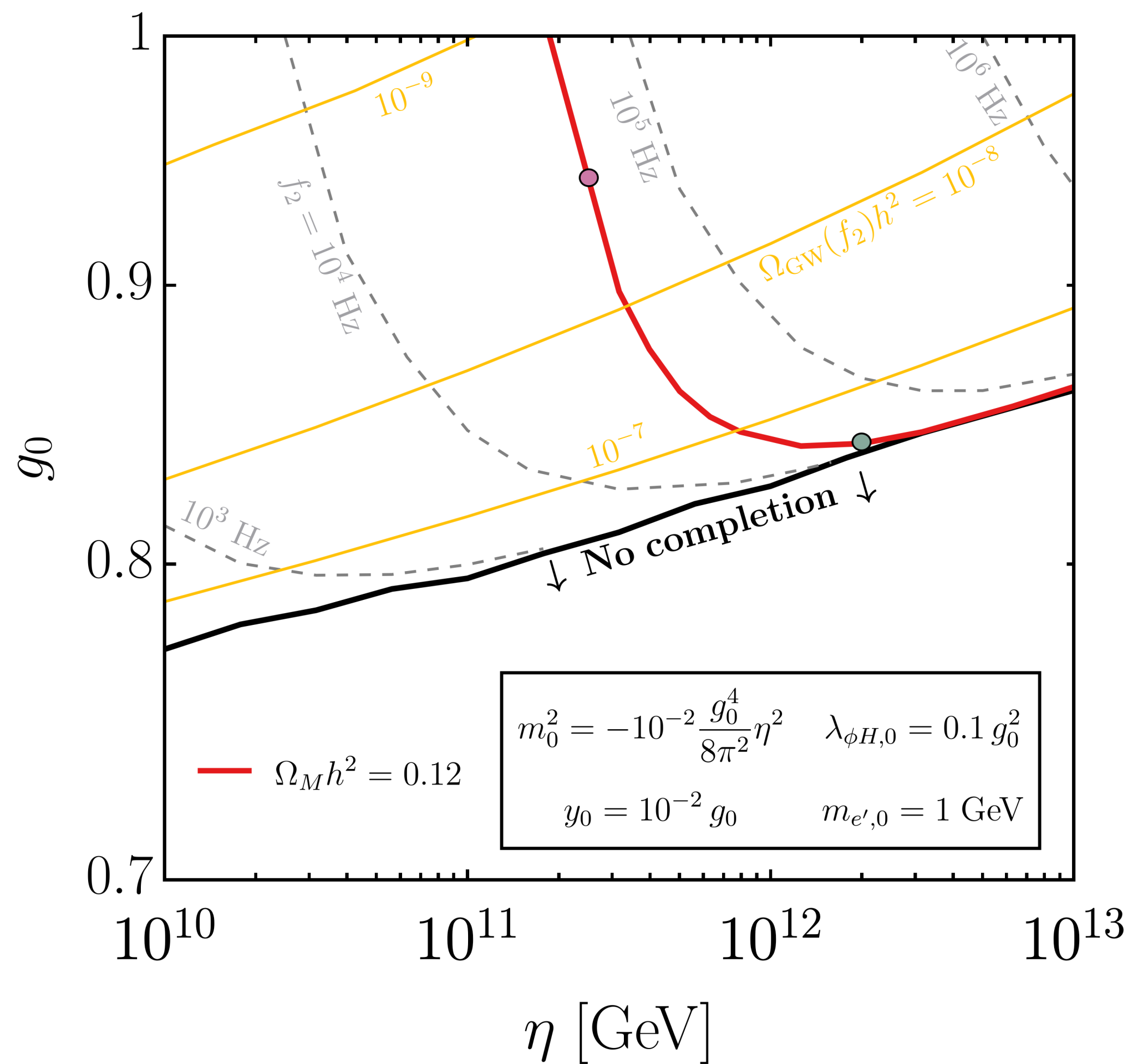


Supercooled phase transition



Supercooled phase transition

GWs



Pheno constraints

SIDM: $\sigma_T = \frac{16\pi\alpha_M^2}{m_M^2 v_M^4} \log \left(1 + \frac{m_M v_M^2}{2\alpha_M m_{\gamma'}} \right)$

$\sigma_T/m_{\text{DM}} < 0.13 \text{ cm}^2/\text{g}$ (galaxy clusters)

$0.5 \text{ cm}^2/\text{g} < \sigma_T/m_{\text{DM}} < 50 \text{ cm}^2/\text{g}$ (core-cusp)

DD: $\mu_{M\bar{M}h} = \left. \frac{\partial m_M^2(h)}{\partial h} \right|_{h=v} = \left(\frac{4\pi k}{g} \right)^2 \frac{\lambda_{\phi H}}{\lambda} v$

$\sigma_{MN \rightarrow MN} \approx \frac{y_{hNN}^2}{4\pi} \frac{\mu_{M\bar{M}h}^2 m_N^2}{m_h^4 m_M^2} \approx \frac{4\pi k^2 y_{hNN}^2 \lambda_{\phi H}^2}{\lambda^2} \frac{m_N^2 v^2}{m_h^4} r_M^2$

$(E \ll r_M^{-1})$

(7 orders of magnitude below current LZ reach)

ID: $hh \rightarrow M\bar{M}$ can be seen as $\underbrace{\text{producing } 2N \text{ quanta}}_{\text{Perturbative but } \propto g^{2N}} + \underbrace{\text{making them form a } M - \bar{M} \text{ pair}}_{\text{Non-perturbative}} \Rightarrow \text{very small amplitude}$

Even if geometric cross section, 4 orders of magnitude below LHAASO

Pheno constraints

