Dark Matter models beyond the WIMP paradigm

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JGU Mainz

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- The thermal WIMP paradigm

- Beyond the thermal WIMP paradigm

- Vev Flip Flop: Dark Matter Decay between Weak Scale Phase Transitions

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1009.3690 — Gondolo & Gelmini

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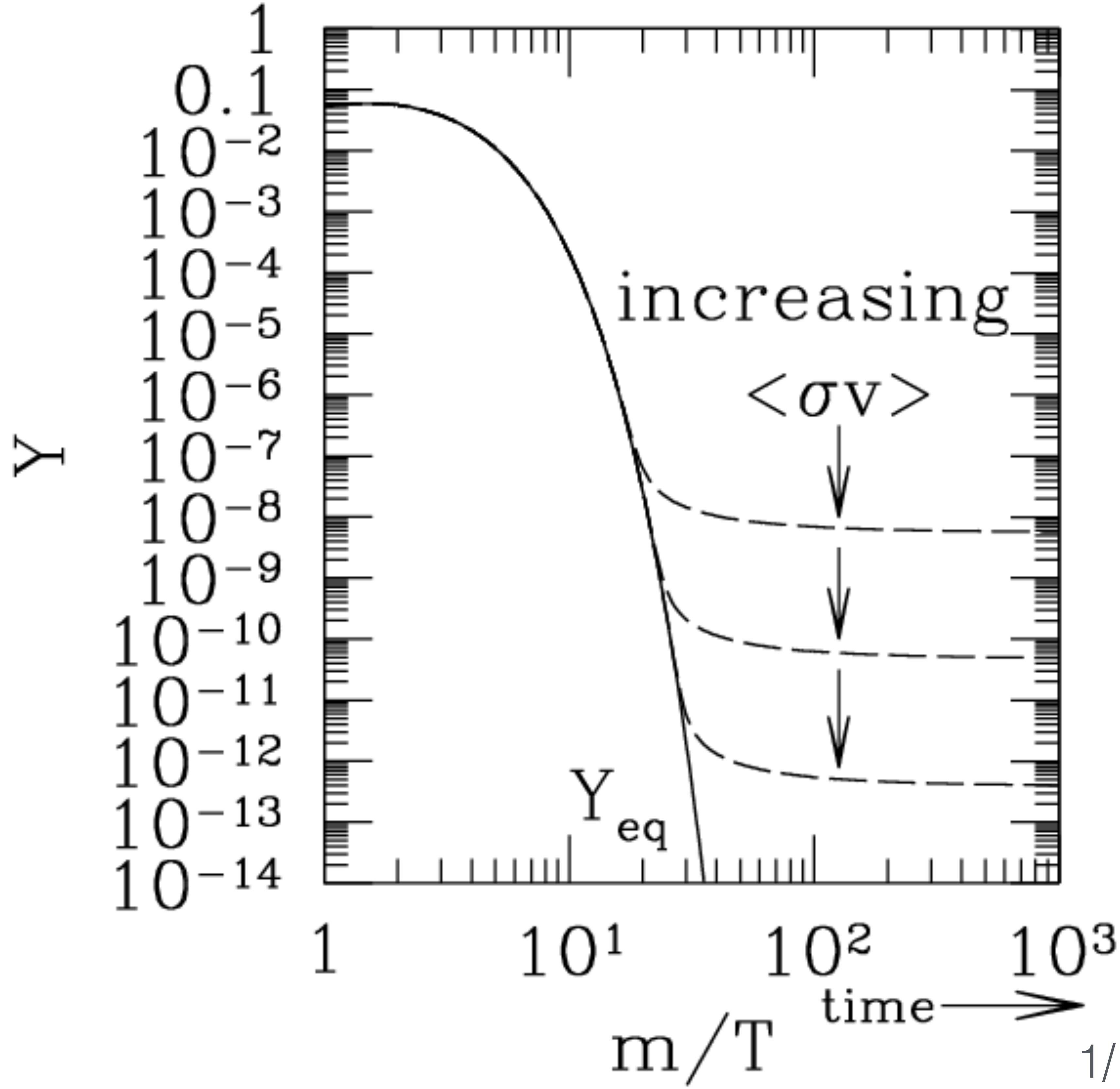

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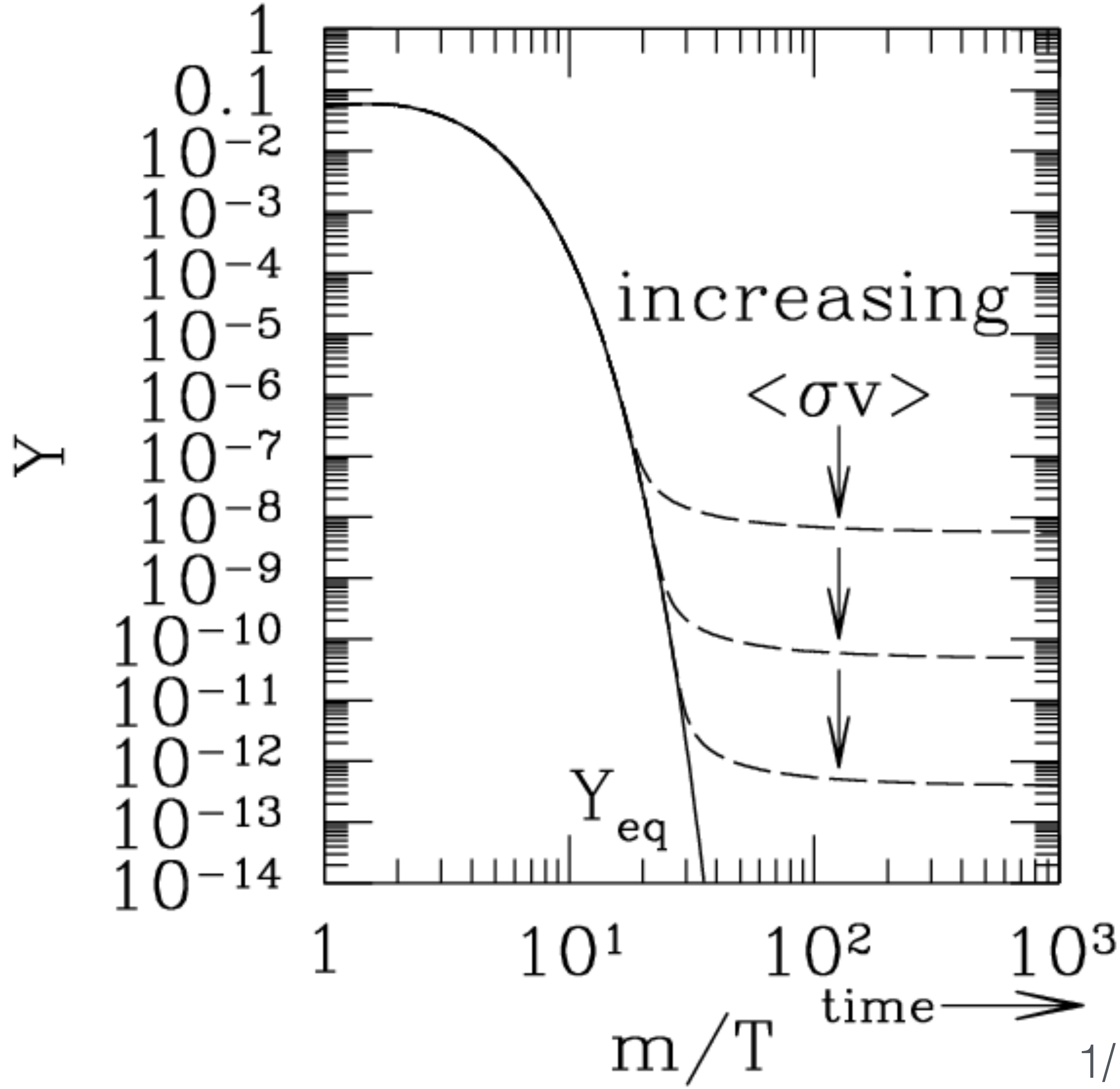
$$H \gtrsim \Gamma$$



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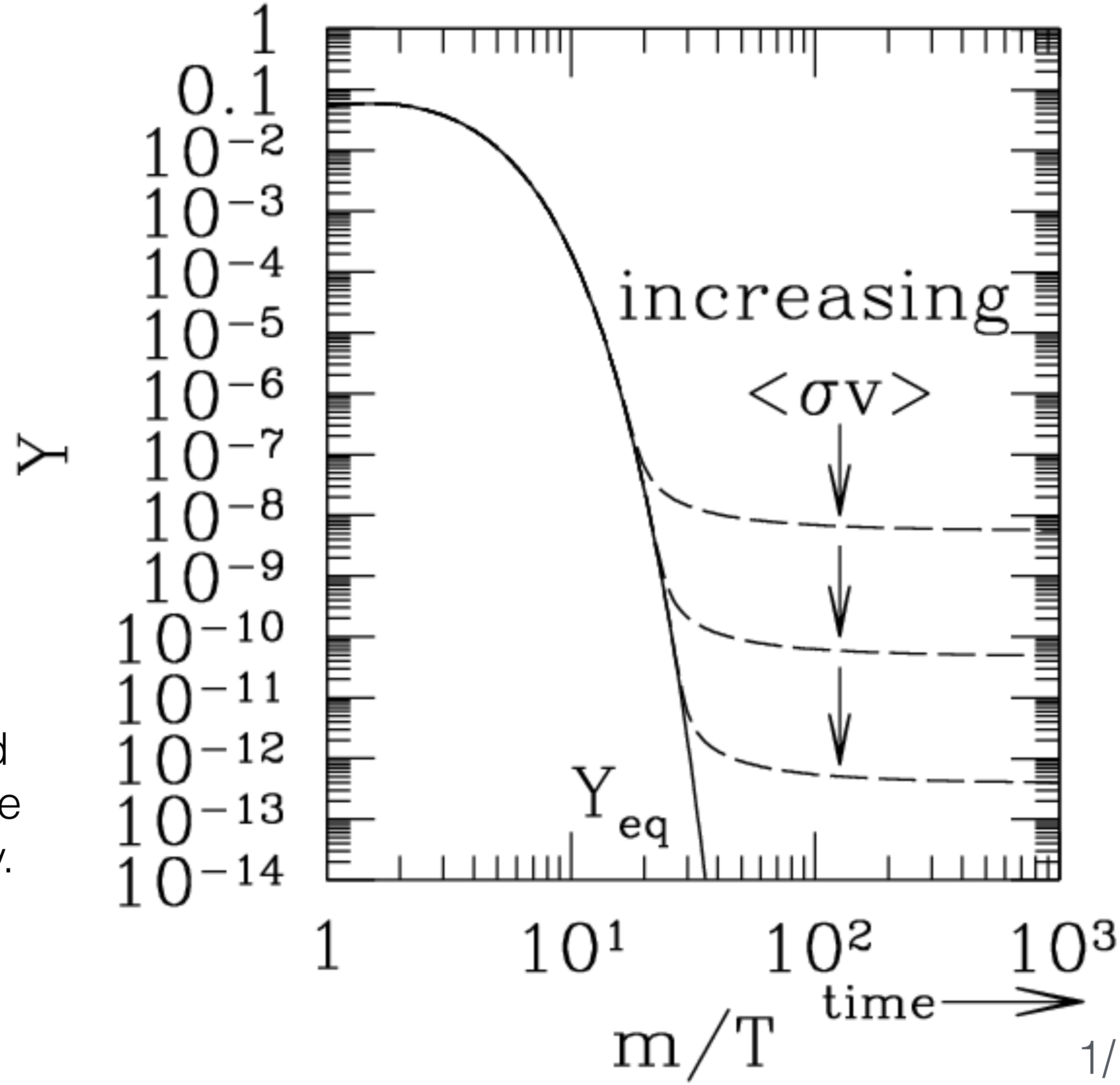
3) Weak scale masses and order one couplings give ~ observed relic density.



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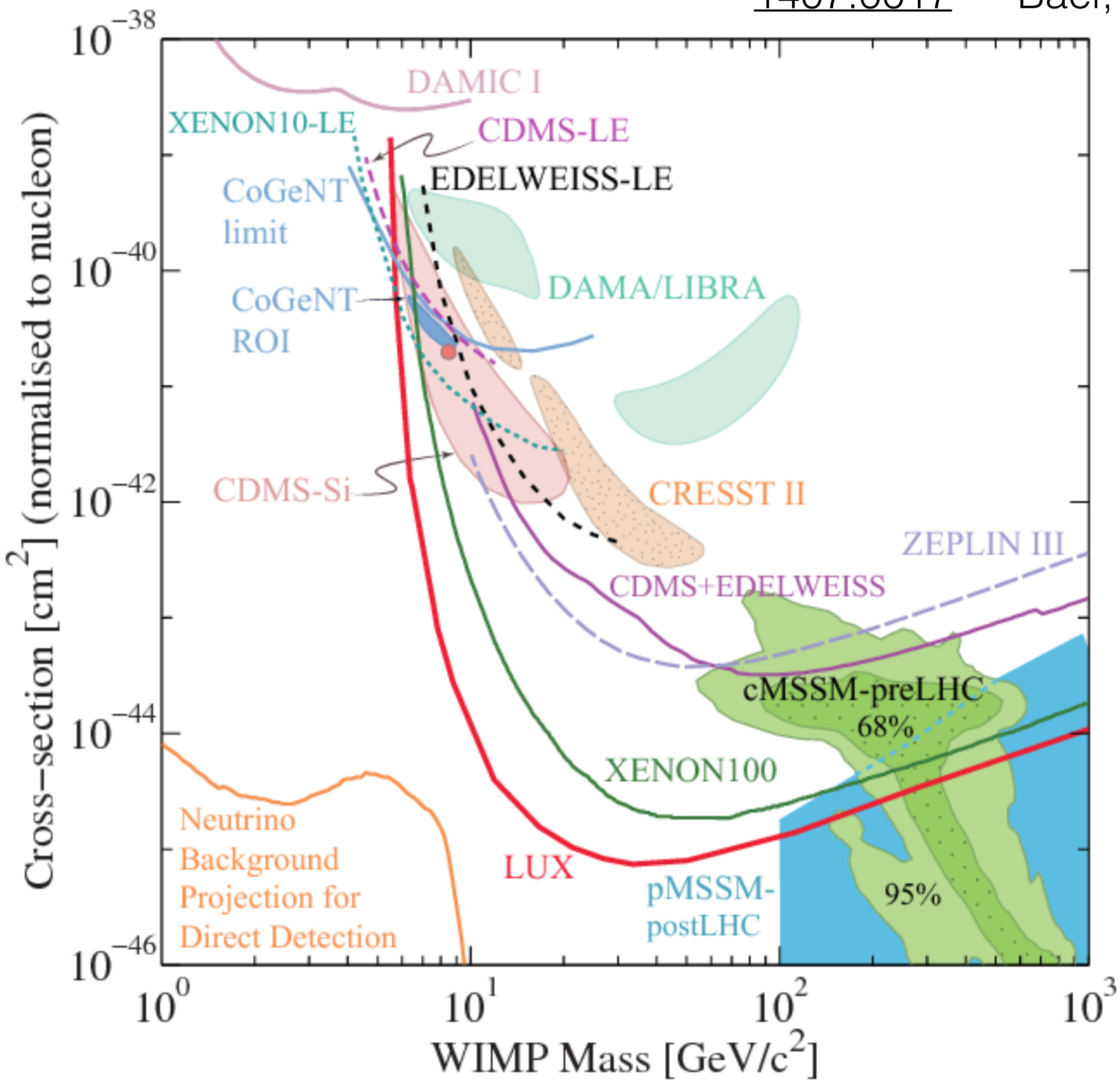
1407.0017 — Baer, Howard et al.



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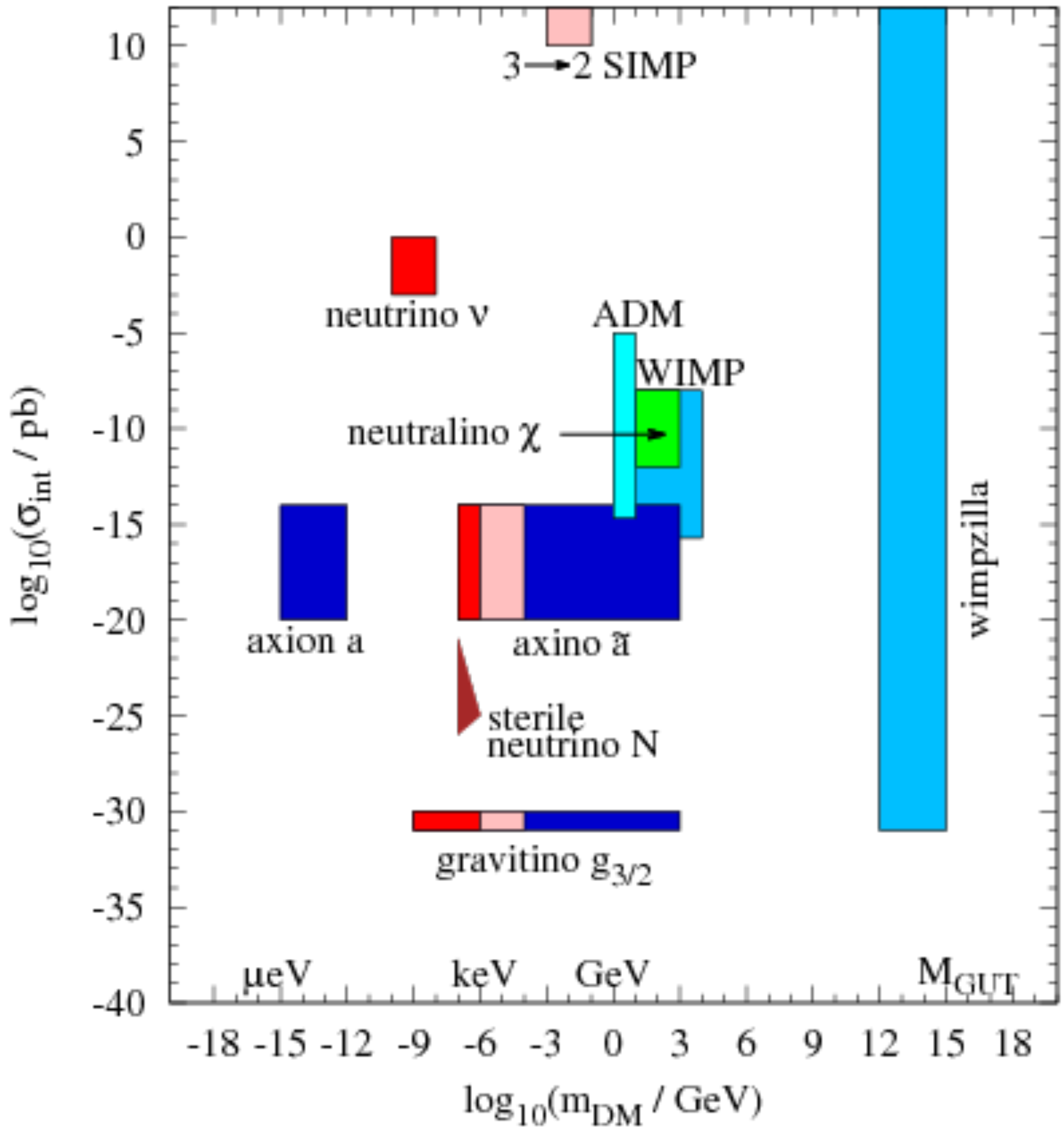

- The thermal WIMP paradigm

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- Vev Flip Flop: Dark Matter Decay between Weak Scale Phase Transitions

Based on 1608.07578, MJB & Joachim Kopp

- Vev Flip Flop: Model

Field	Spin	SM	$\mathbb{Z}_3$	mass scale
χ	$\frac{1}{2}$	$(1,1,0)$	$\chi \to e^{2\pi i/3}\chi$	TeV
S_3	0	$(1,3,0)$	$S_3 \to e^{2\pi i/3} S_3$	100 GeV
Ψ_3	$\frac{1}{2}$	$(1,3,0)$	$\Psi_3 \to e^{-2\pi i/3}\Psi_3$	TeV
Ψ_3'	$\frac{1}{2}$	$(1,3,0)$	$\Psi_3' \to e^{-2\pi i/3}\Psi_3'$	TeV

$$\mathcal{L}_{\rm Yuk} = y_\chi S_3^\dagger \overline{\chi}\Psi_3 + y_\chi' S_3^\dagger \overline{\chi}\Psi_3' \\ + y_\Psi \epsilon^{ijk} S_3^i \overline{\Psi_3^j} (\Psi_3'^k)^c + h.c.$$

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$$y_\chi \sim y_\chi' \sim 10^{-7} \qquad\qquad y_\Psi \sim 1$$

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$$
\begin{aligned}
V(H,S_3) = &-\mu^2 H^\dagger H + \lambda (H^\dagger H)^2 \\
&-\mu_S^2 S_3^\dagger S_3 + \lambda_S (S_3^\dagger S_3)^2 + \lambda_3 (S_3^\dagger T^a S_3)^\dagger S_3^\dagger T^a S_3 \\
&+\alpha H^\dagger H S_3^\dagger S_3 + \beta H^\dagger \tau^a H S_3^\dagger T^a S_3
\end{aligned}
$$

- Vev Flip Flop: Effective Potential

$$V^{\text{eff}} = V^{\text{tree}} + V^{\text{1-loop}}$$
$$= V^{\text{tree}} + \sum_i \frac{n_i T}{2} \sum_{n=-\infty}^{+\infty} \int \frac{d^3\vec{k}}{(2\pi)^3} \log\left[\vec{k}^2 + \omega_n^2 + m_i^2(h,S)\right]$$

$$V^{\text{eff}} = V^{\text{tree}} + V^{\text{CW}} + V^T + V^{\text{daisy}}$$

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$$V^{\text{CW}}(h,S) = \sum_i \frac{n_i}{64\pi^2} m_i^4(h,S)\left[\log\frac{m_i^2(h,S)}{\Lambda^2} - \frac{3}{2}\right]$$

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$$m_Z^2(h,S) = \frac{1}{4}(g^2 + g'^2) h^2$$

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$$i \in \{A, G^0, W^\pm, Z, \gamma, t, h - S, S^+ - S^- - G^+\}$$

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Coleman & Weinberg, 1973

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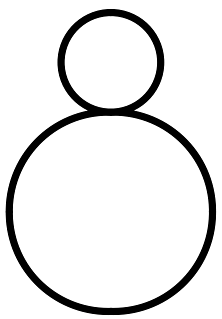

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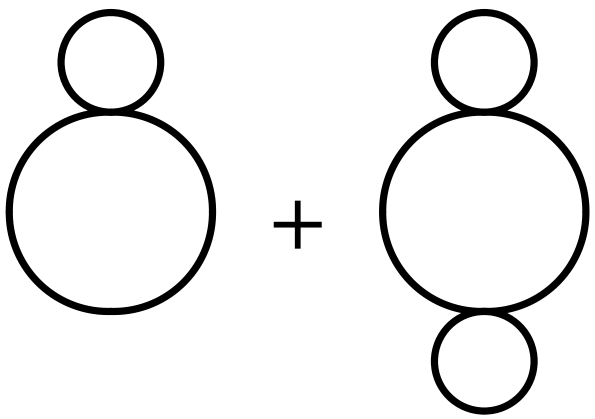

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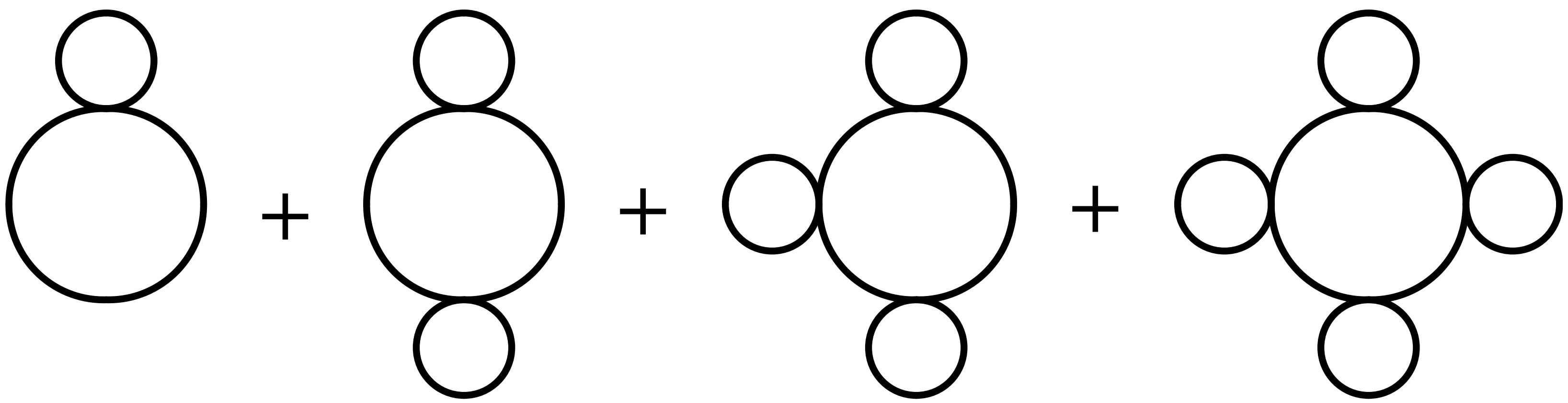 $+ \ldots$

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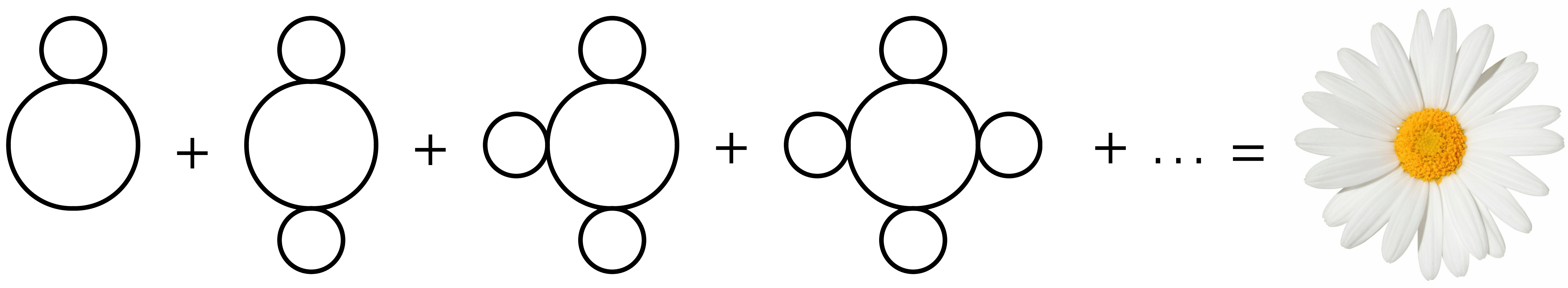

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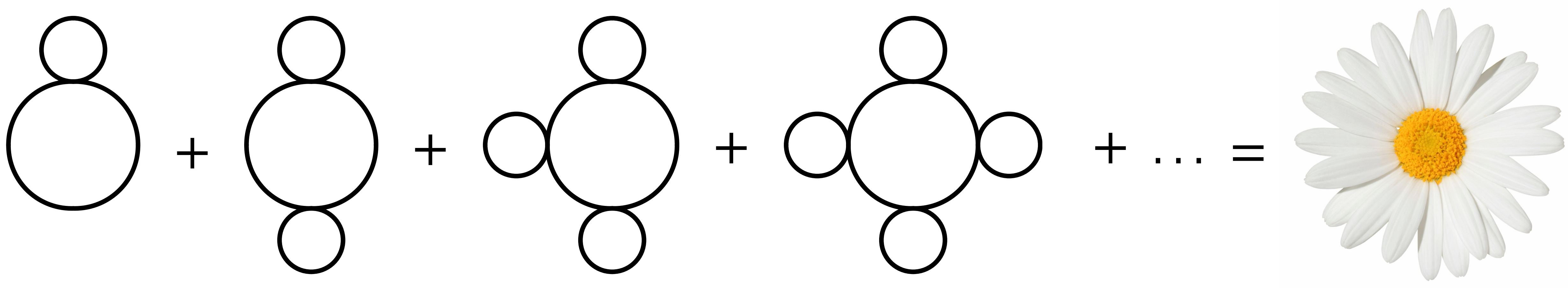

$$V^{\mathrm{daisy}} = -\frac{T}{12\pi}\sum_i n_i\Big(\left[m_i^2(h,S)+\Pi_i(T)\right]^{\frac{3}{2}} - \left[m_i^2(h,S)\right]^{\frac{3}{2}}\Big)$$

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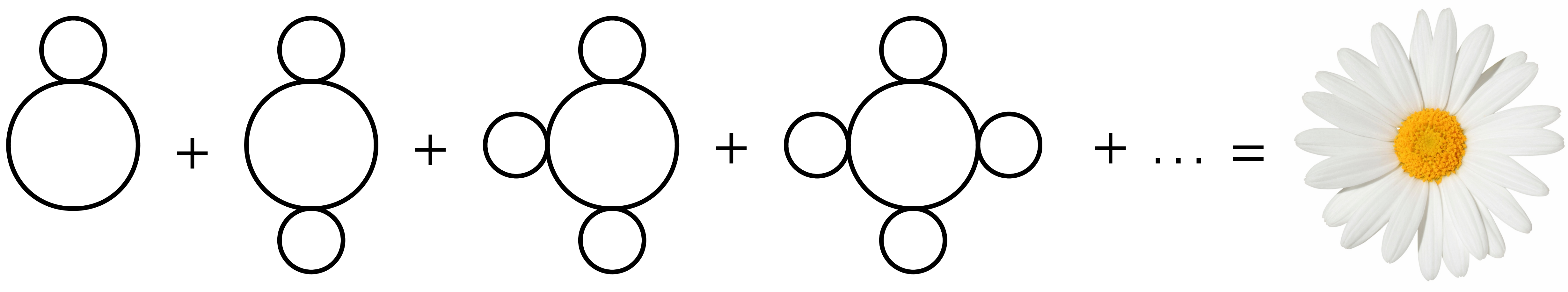

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$$\Pi_{S,A,S_R^+,S_I^+,S_R^-,S_I^-} = \frac{T^2}{6}\left(3g^2 + \alpha + 2\lambda_3 + 4\lambda_S\right)$$

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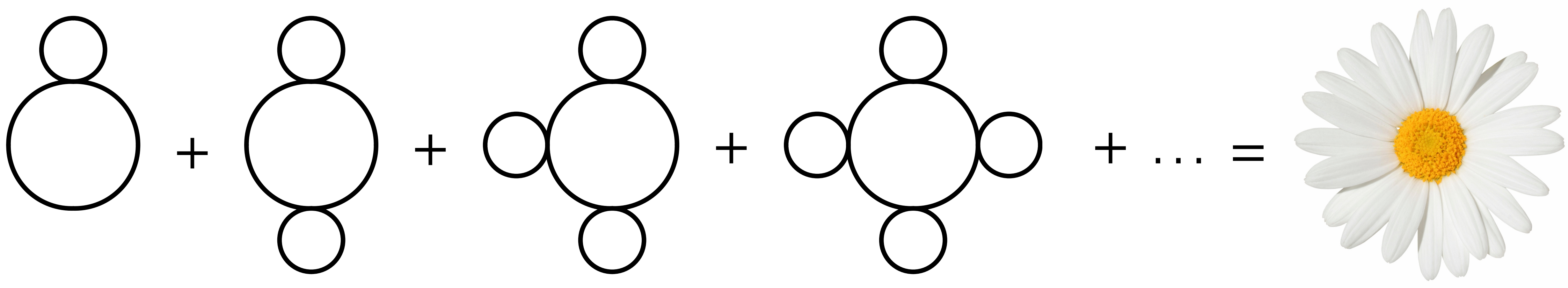

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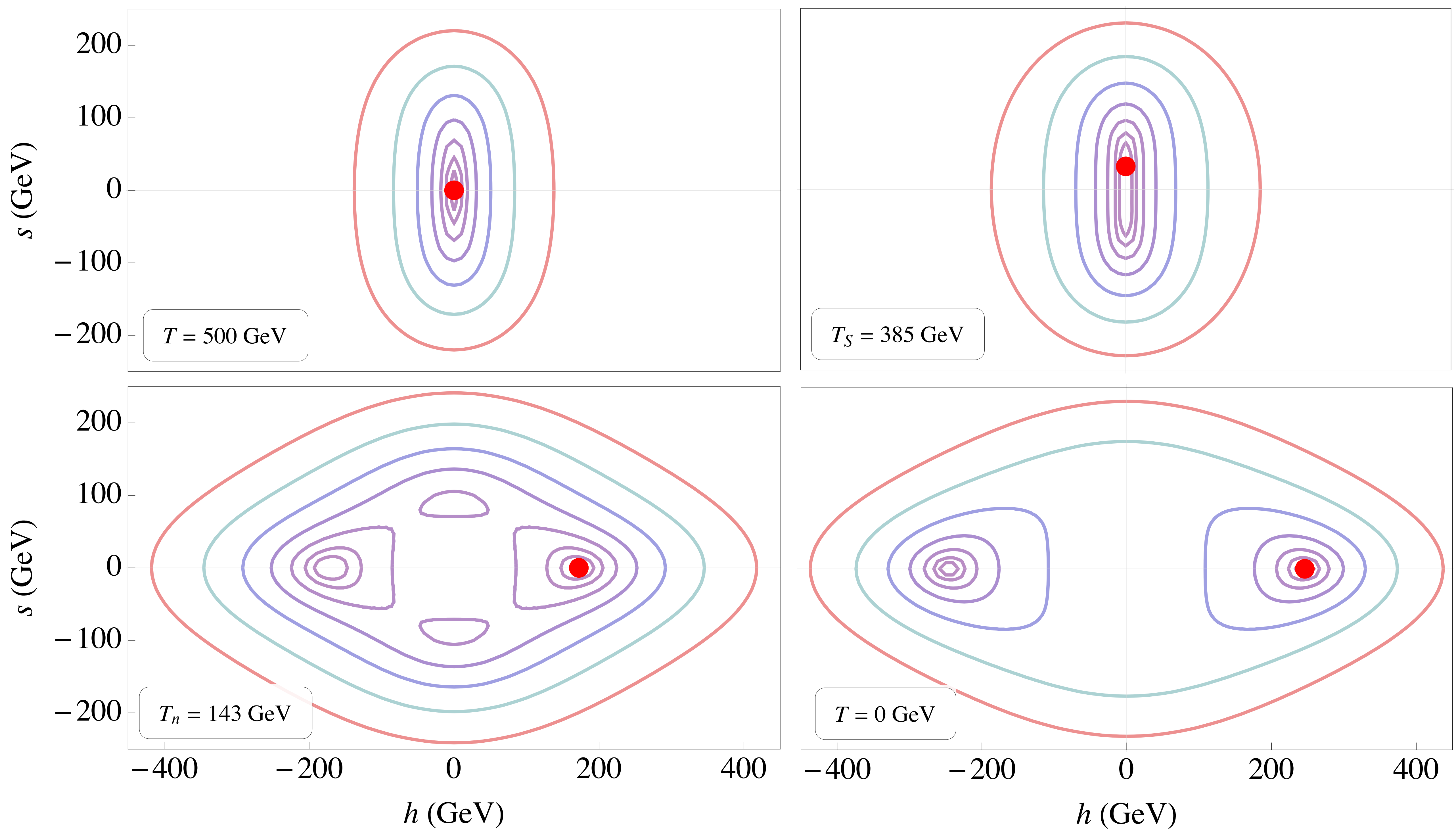
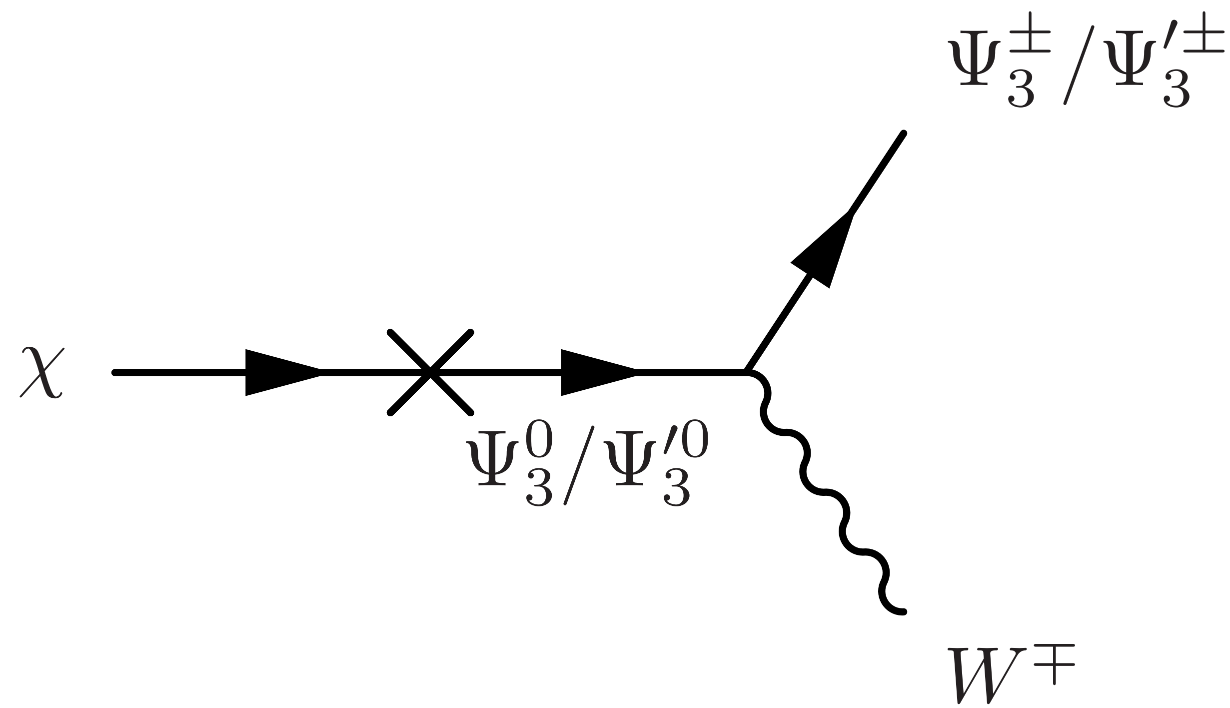


- Vev Flip-Flop: Dark Matter Decay

$$\langle S \rangle \neq 0 \implies \mathcal{L} \supset y_\chi \langle S \rangle \overline{\chi} \Psi_3 + y'_\chi \langle S \rangle \overline{\chi} \Psi'_3$$



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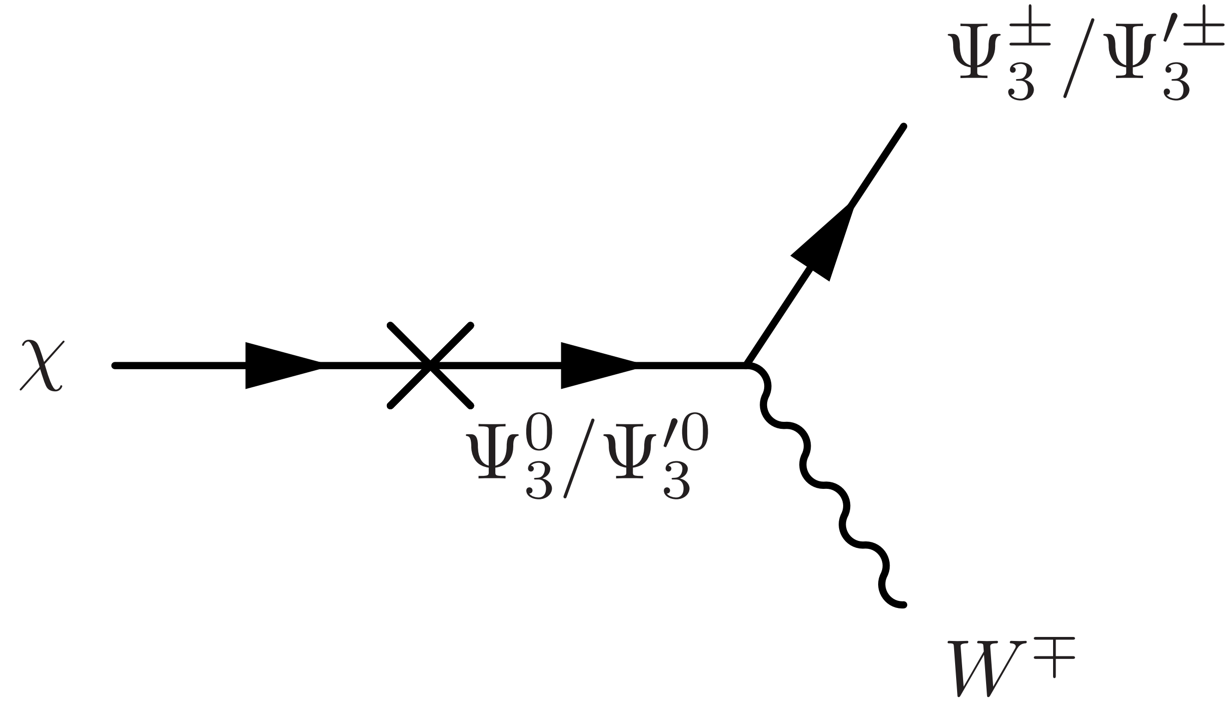

$$\dot{n}_\chi^j + 3Hn_\chi^j = -\frac{\Gamma}{\gamma^j}(n_\chi^j - n_\chi^{j,\mathrm{eq}})$$

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G_N}{3}(\rho_{\mathrm{SM}} + \rho_\chi)$$

$$\dot{\rho}_{\mathrm{SM}} = 4\rho_{\mathrm{SM}}\frac{\dot{T}}{T} = m_\chi \Gamma \sum_j (n_\chi^j - n_\chi^{j,\mathrm{eq}}) - 4H\rho_{\mathrm{SM}}$$

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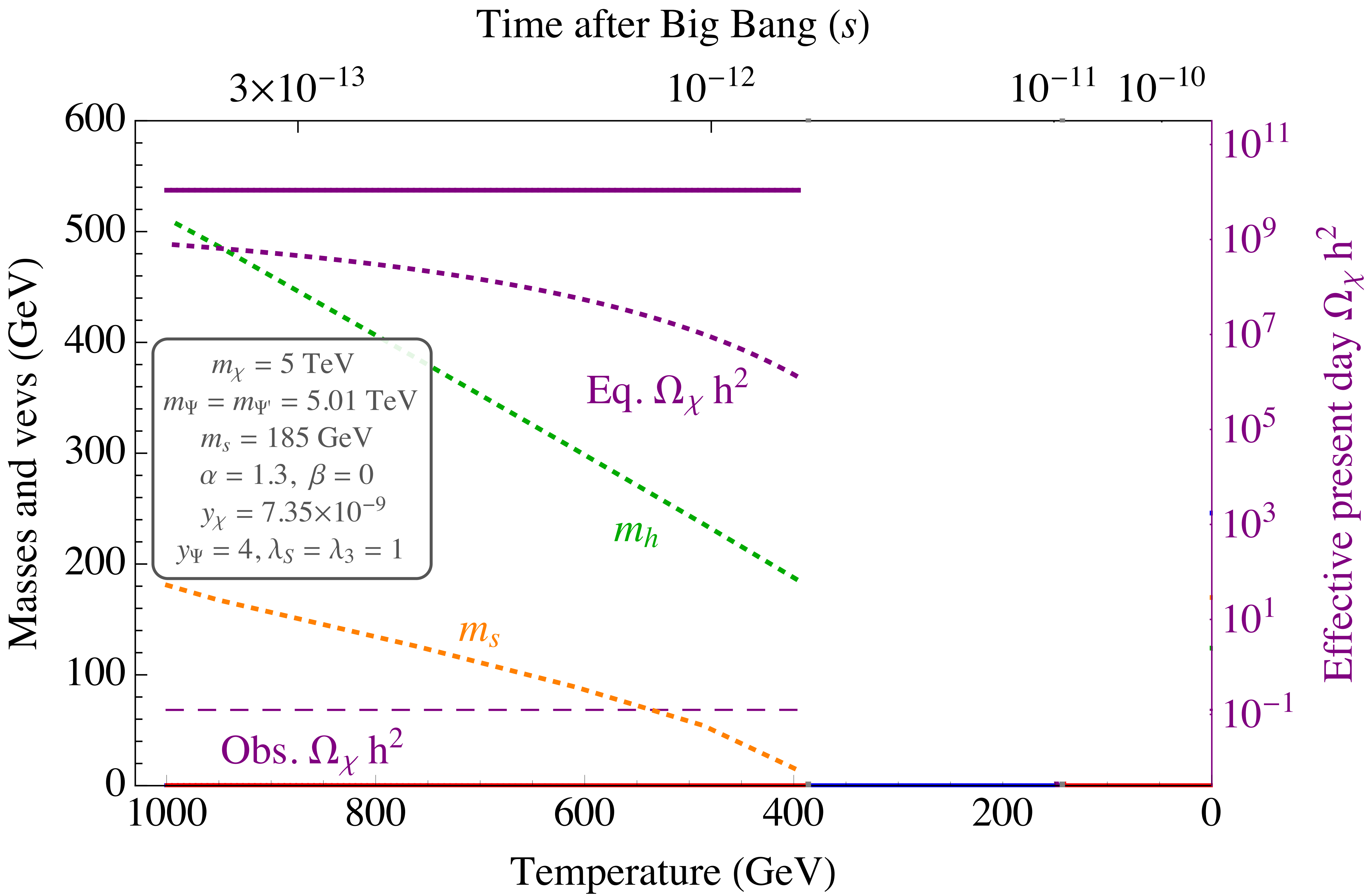

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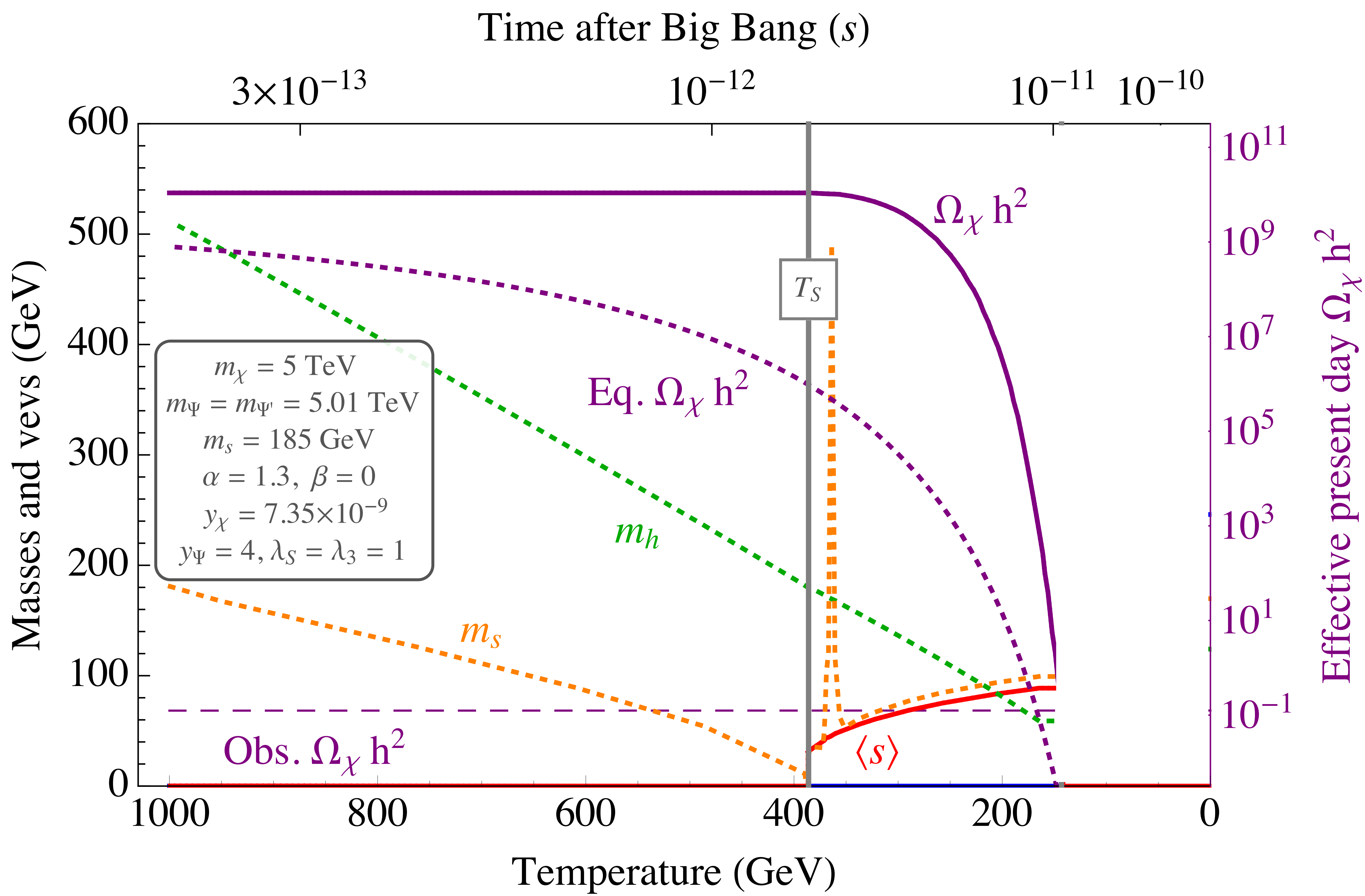

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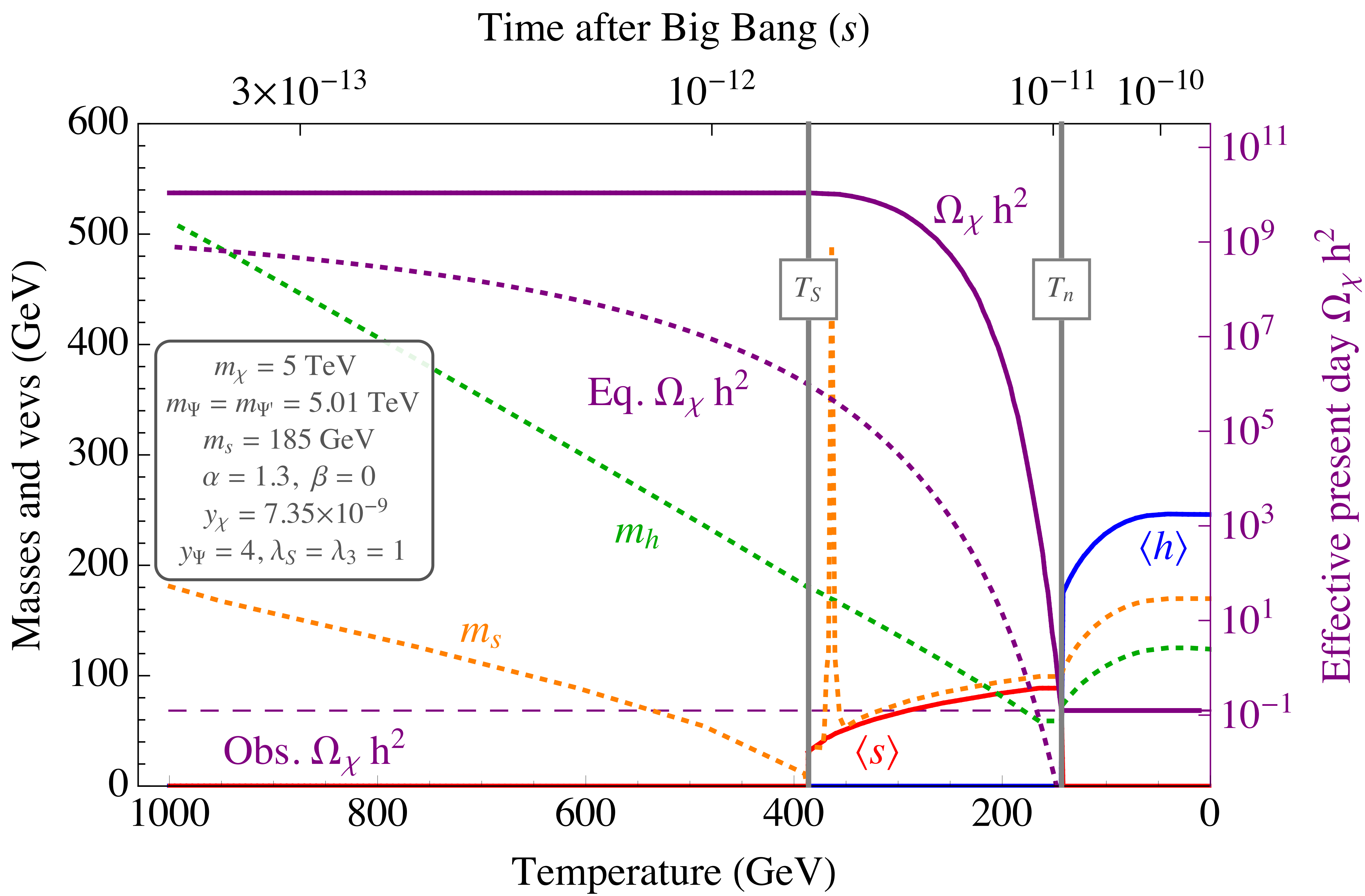
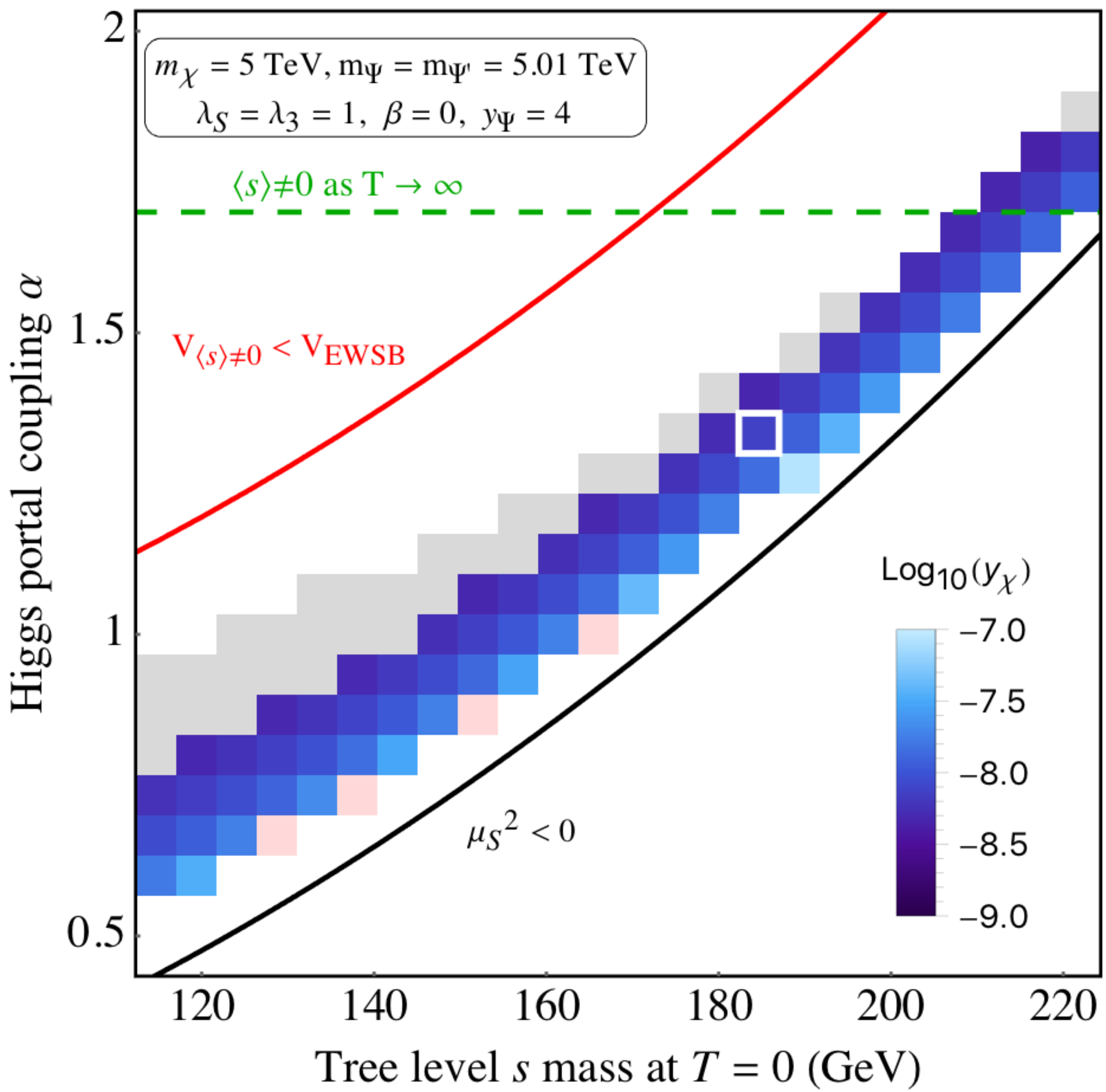


- Vev Flip-Flop: Parameter Space



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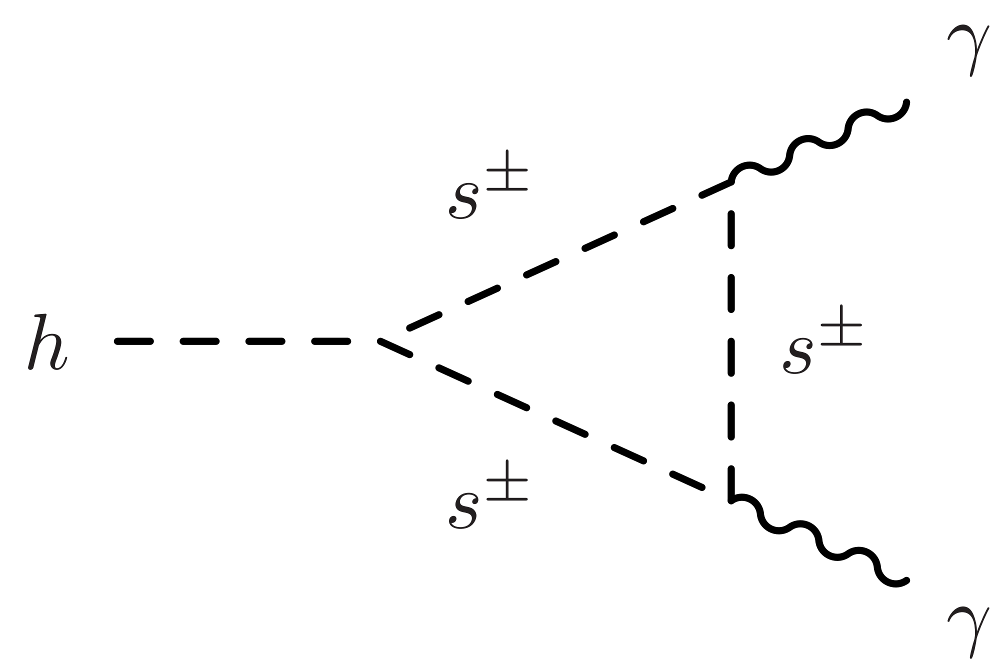

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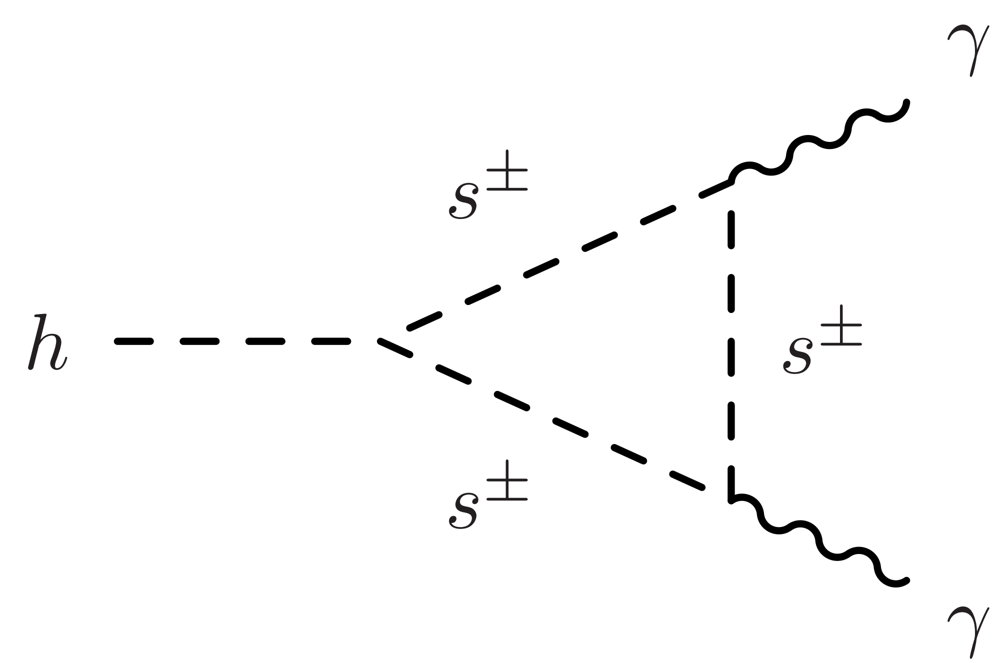

$$|F^{\gamma\gamma}|^2 = (|F_W^{\gamma\gamma}|^2 - |F_f^{\gamma\gamma}|^2 - |F_{S_3}^{\gamma\gamma}|^2)^2$$

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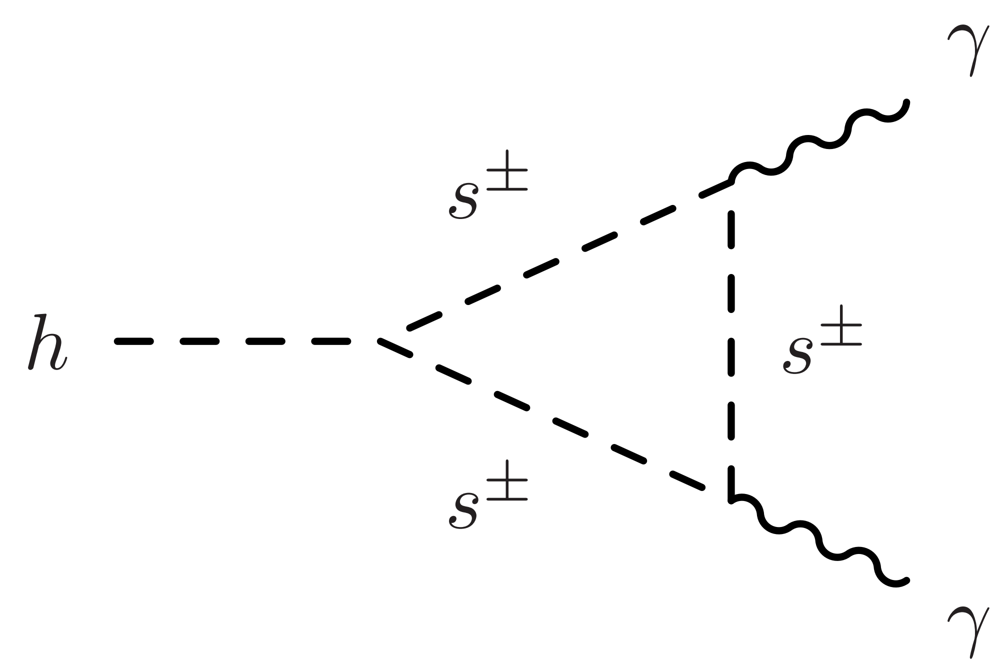

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$$F_{S_3}^{\gamma\gamma} = \frac{\alpha_{\rm EW}}{\pi}\alpha\left[1 - \frac{4m_{s^\pm}^2}{m_h^2} f\left(\frac{4m_{s^\pm}^2}{m_h^2}\right)\right]$$

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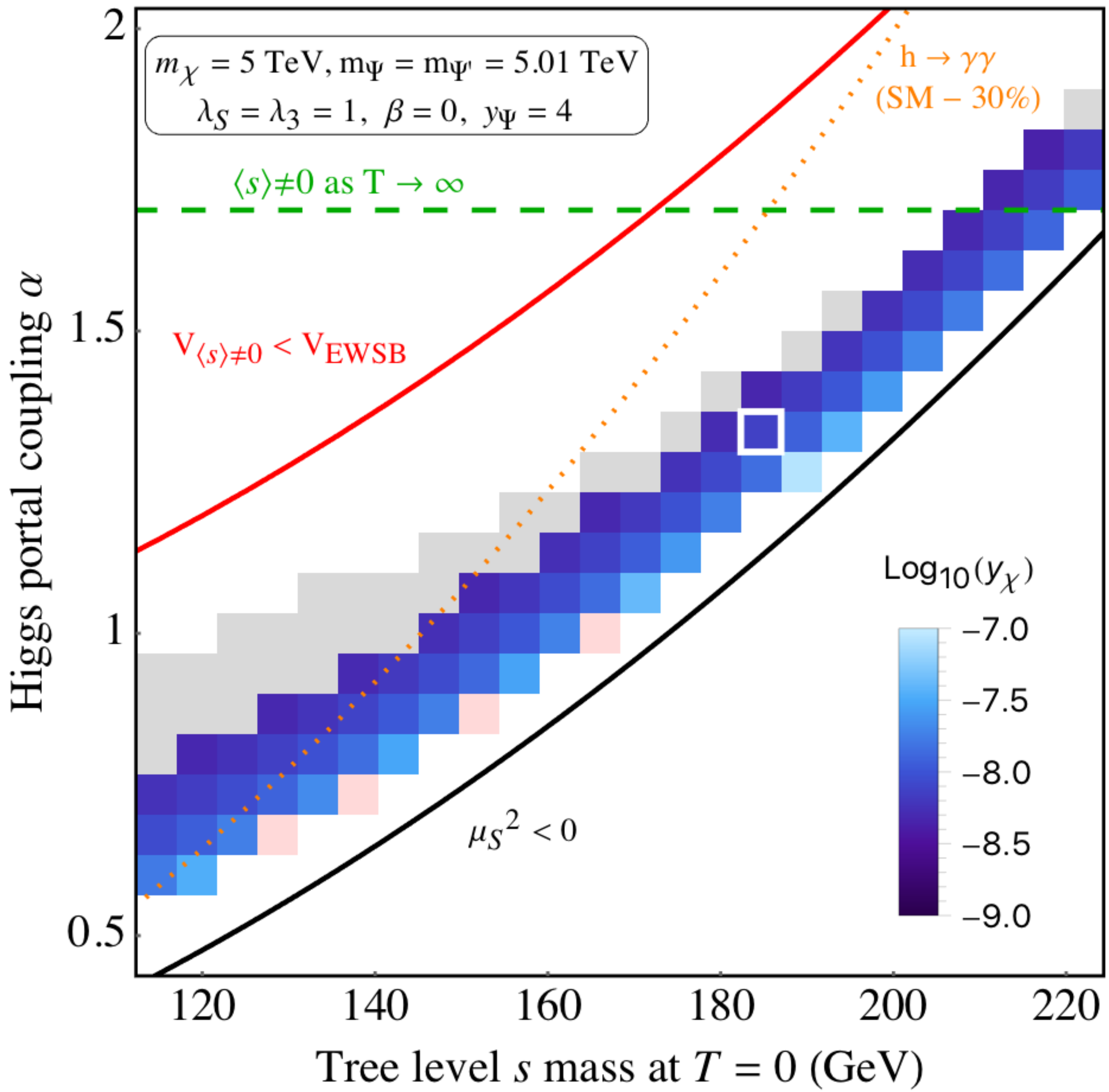

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- Outlook:
  - More realisations,
  - LHC phenomenology,
  - gravitational wave signals,
  - baryogenesis,…