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

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JGU Mainz

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Case Western Reserve University, 16 May 2017

Based on 1608.07578, MJB & Joachim Kopp

- The thermal WIMP paradigm

1009.3690 — Gondolo & Gelmini

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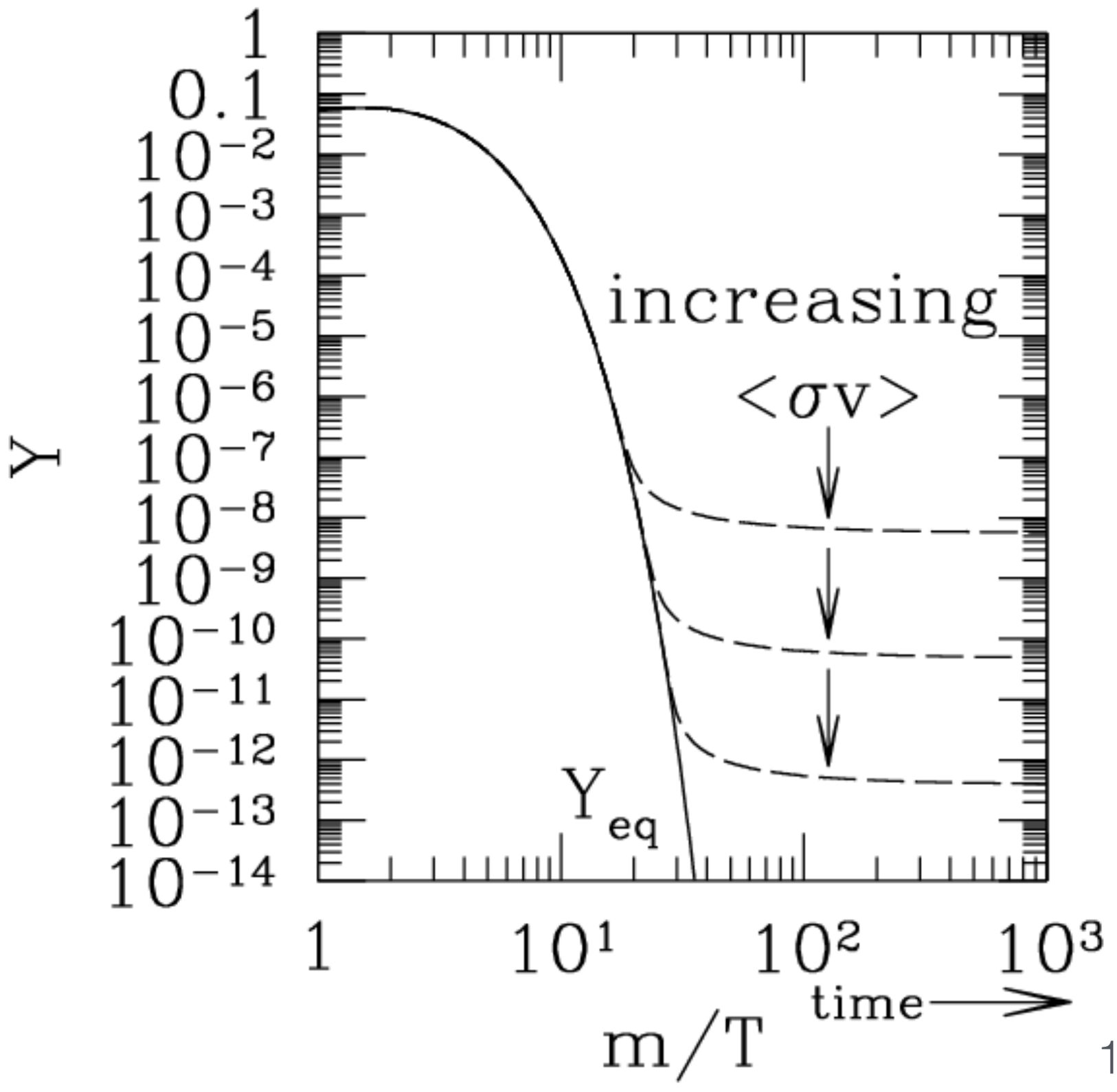

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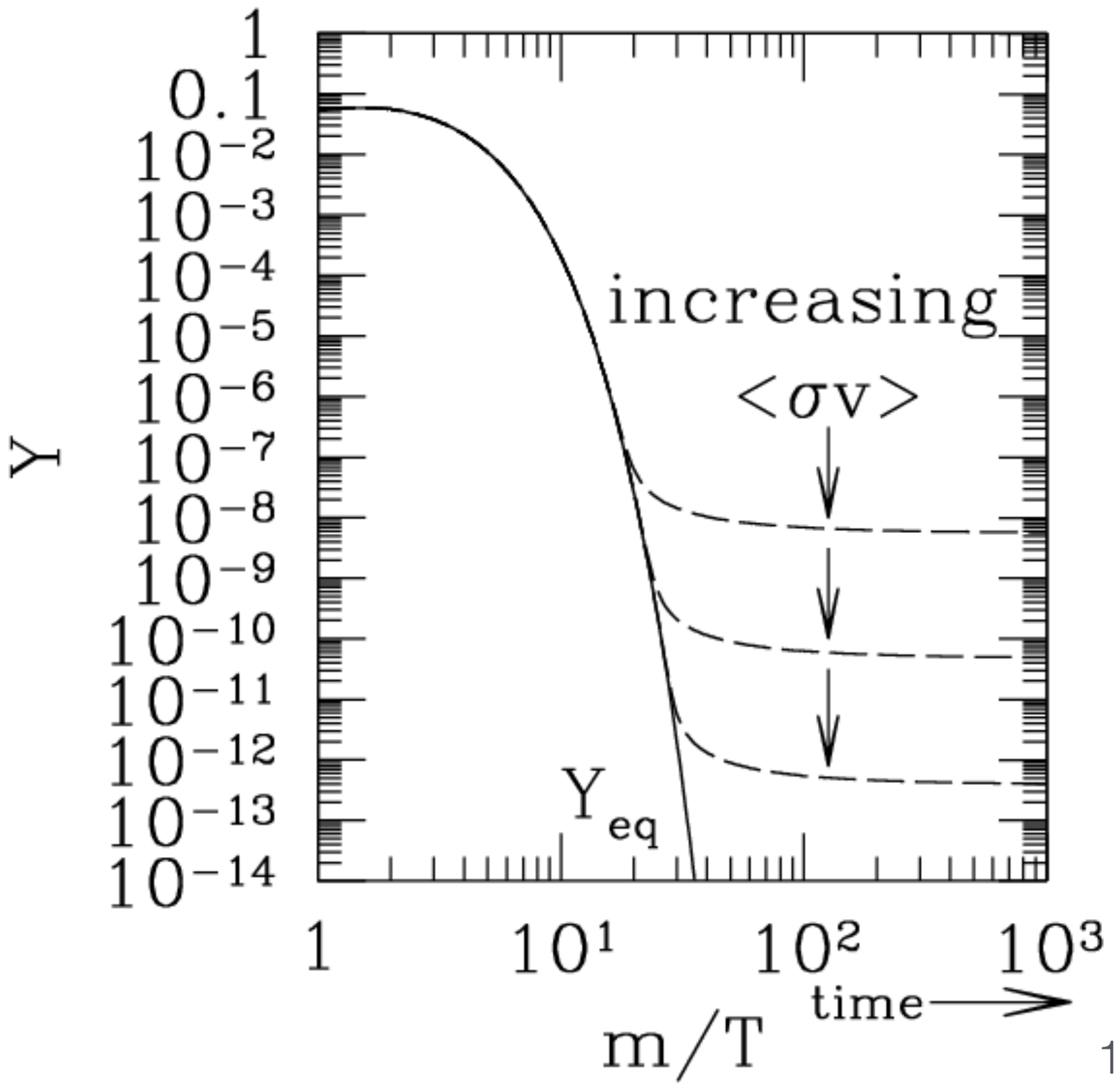

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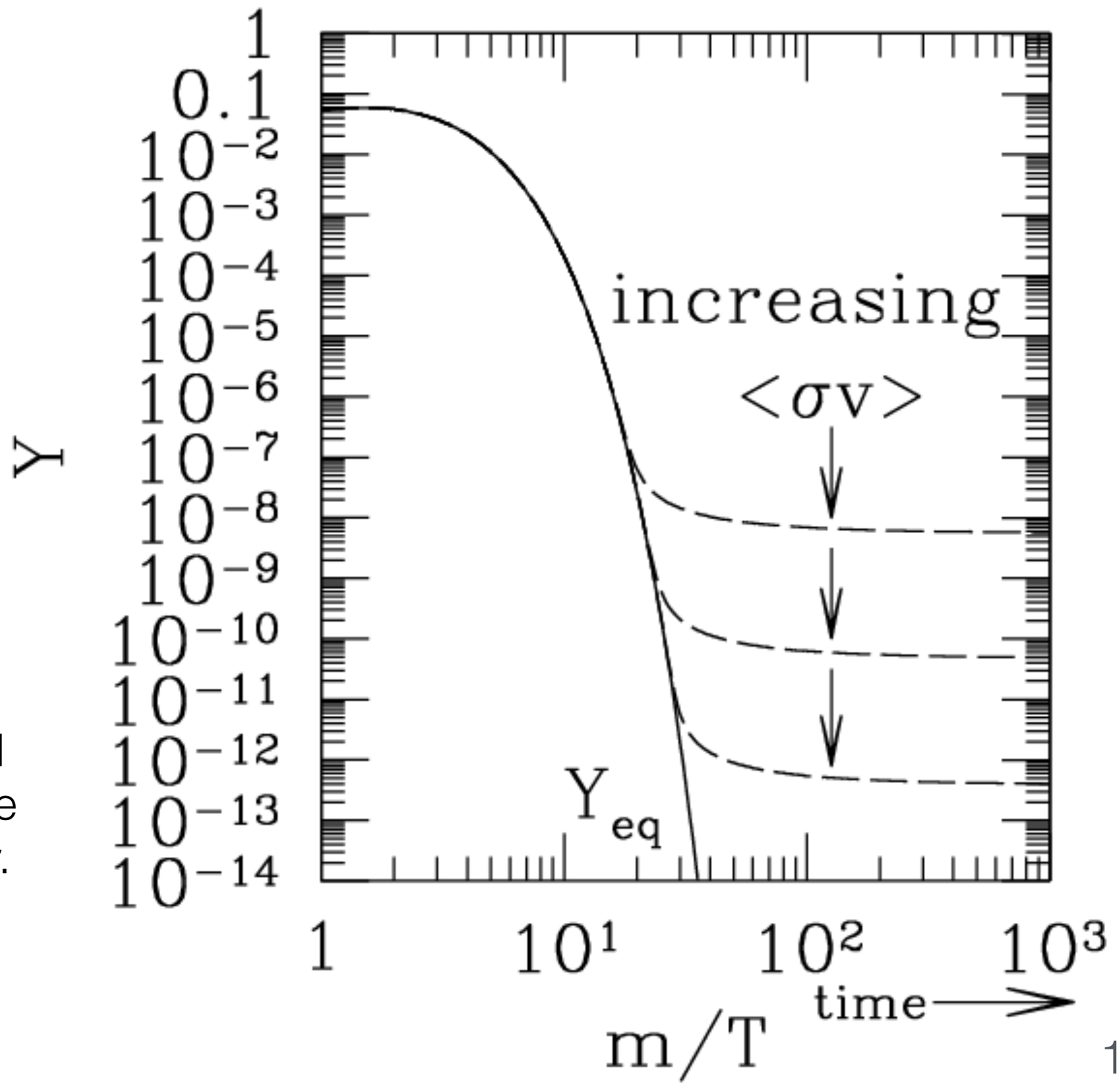
3) Weak scale masses and order one couplings give ~ observed relic density.



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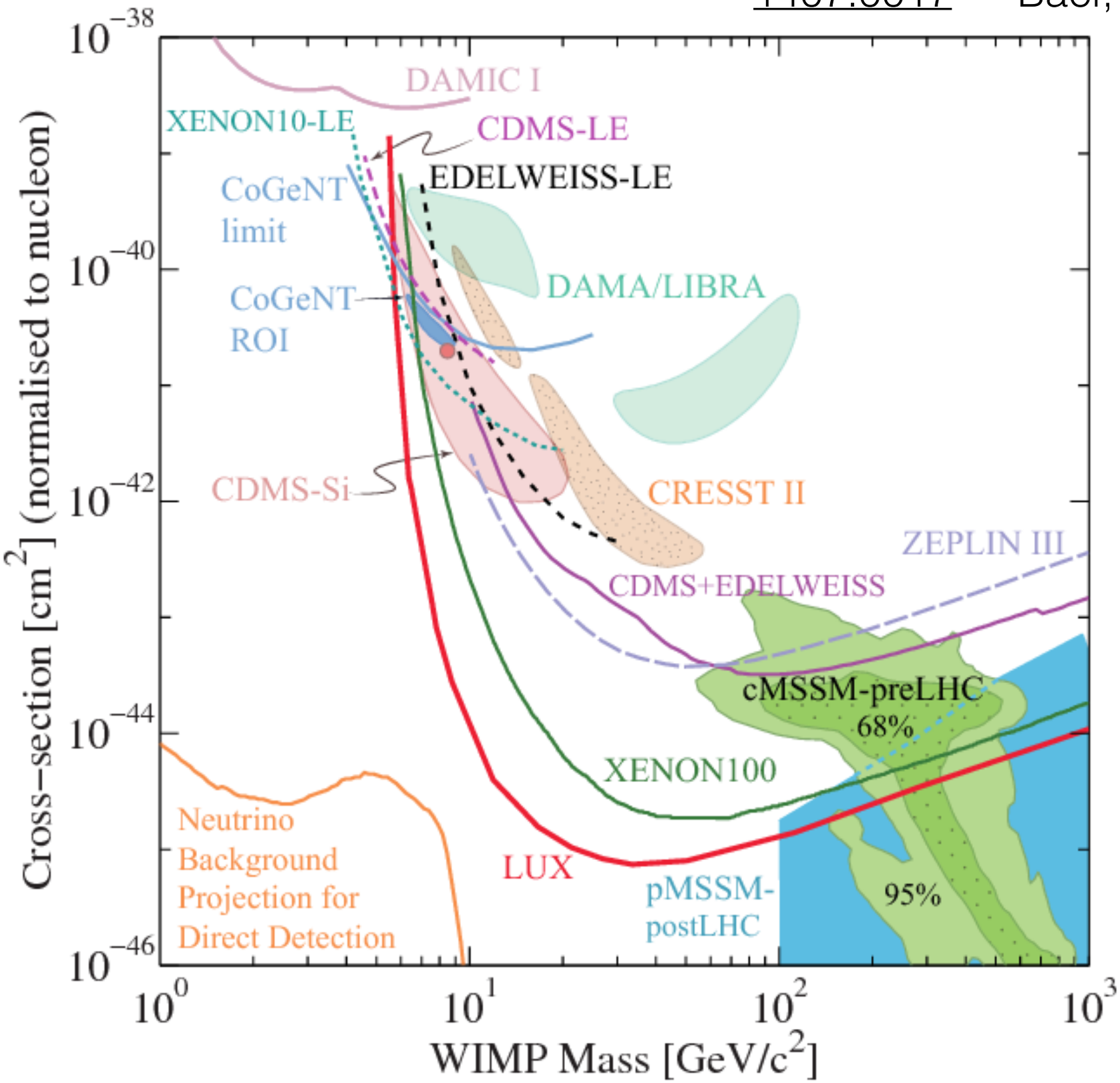
1407.0017 — Baer, Howard et al.



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- There is a new scalar which is charged under the symmetry which stabilises DM
- There is a phase in the early universe where this scalar has a vev, so the symmetry is broken and DM can decay
- At a lower temperature the symmetry is restored and DM is then stable

- 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

$$\begin{aligned}\mathcal{L}_{\rm Yuk} = \; & y_\chi S_3^\dagger \overline{\chi}\Psi_3 + y'_\chi S_3^\dagger \overline{\chi}\Psi'_3 \\ & + y_\Psi \epsilon^{ijk} S_3^i \overline{\Psi_3^j}(\Psi_3'^k)^c + h.c.\end{aligned}$$

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

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$$m_{W^\pm}^2(h,S) = \frac{1}{4}g^2(h^2+4S^2)$$

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

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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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Dolan & Jackiw, 1974

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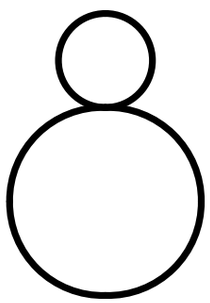

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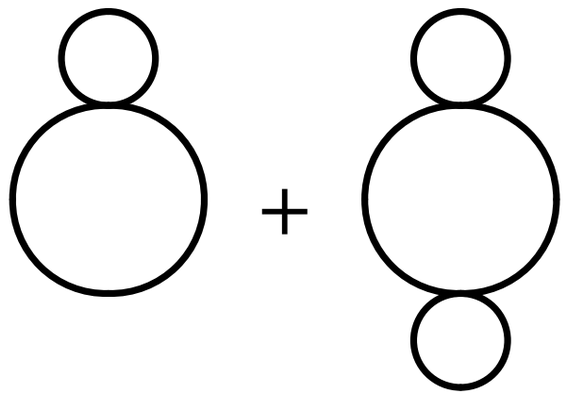

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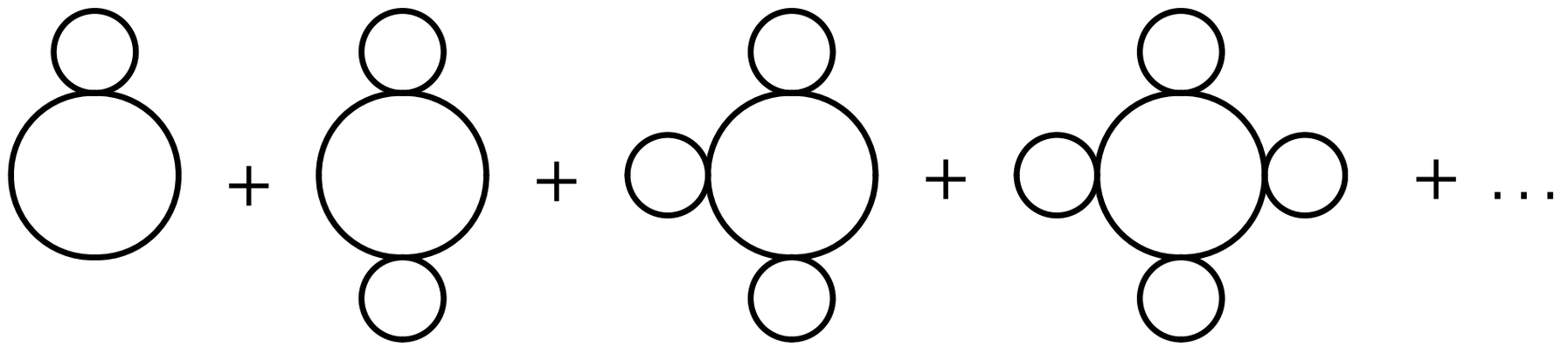

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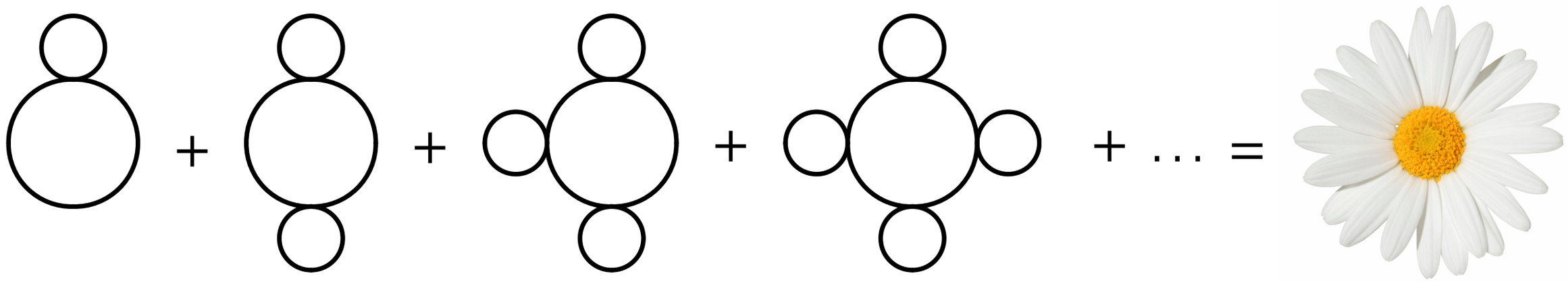

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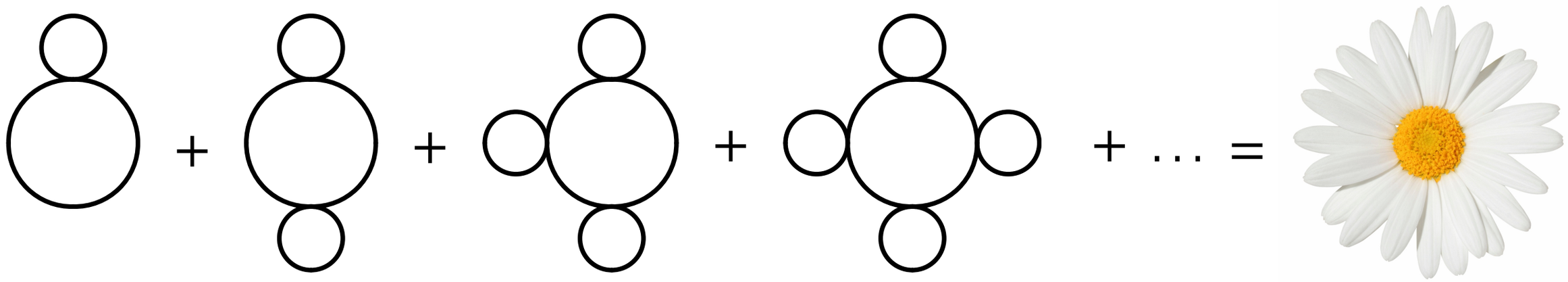

$$V^{\rm daisy} = -\frac{T}{12\pi}\sum_i n_i \Big(\left[m_i^2(h,S) + \Pi_i(T)\right]^{\frac{3}{2}} - \left[m_i^2(h,S)\right]^{\frac{3}{2}} \Big)$$

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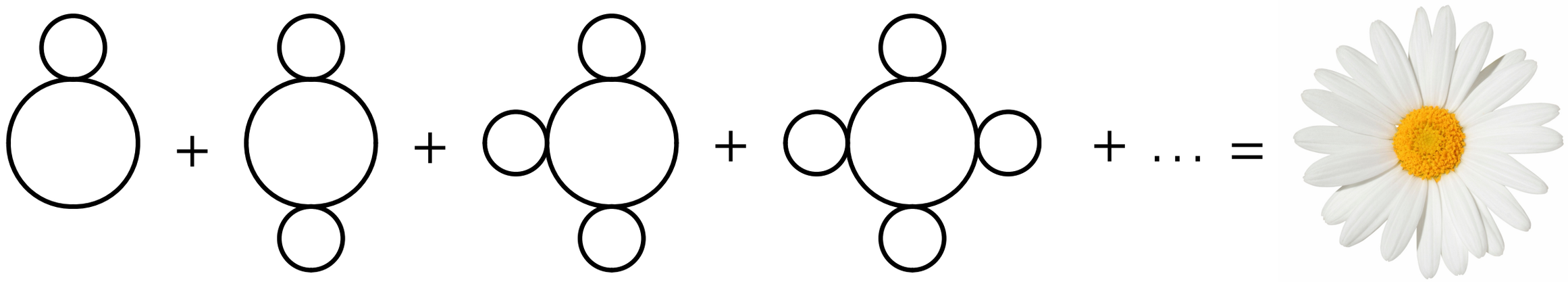

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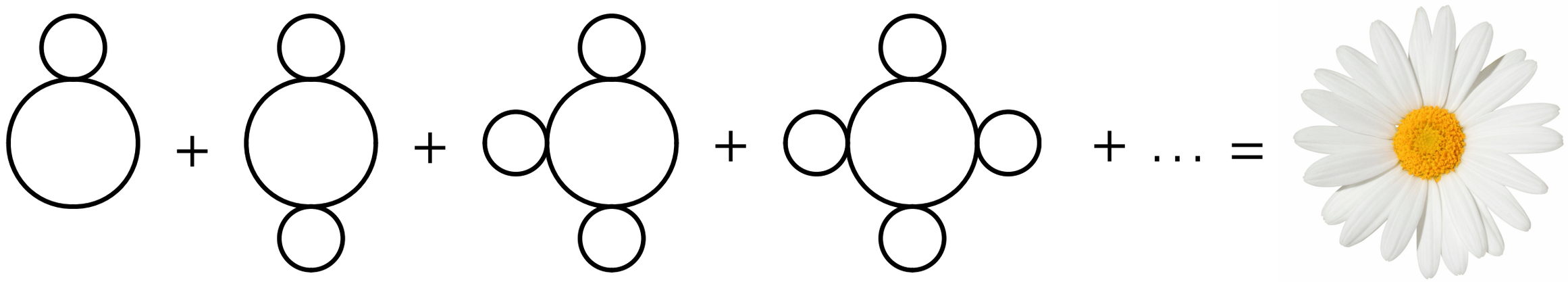

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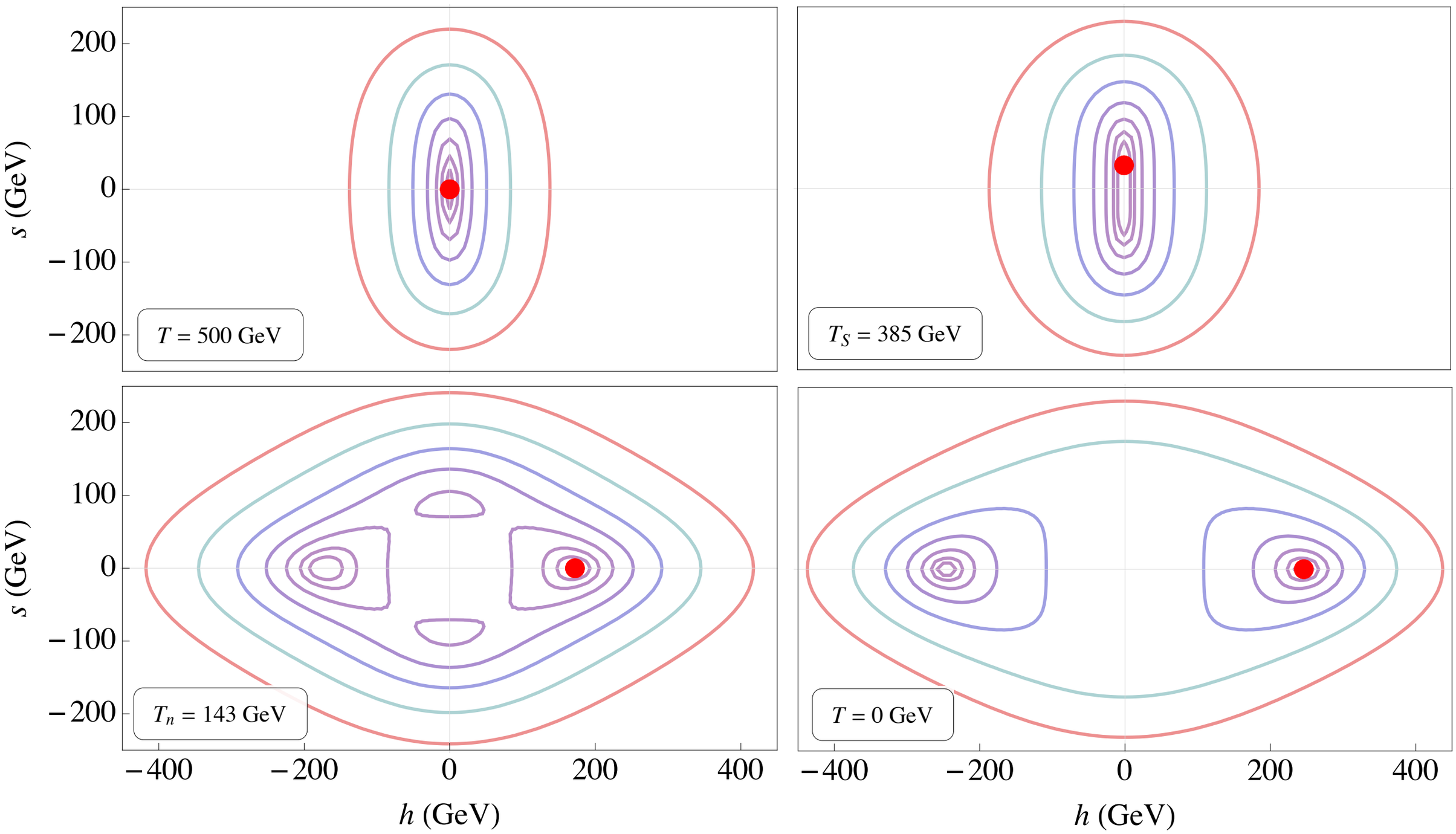

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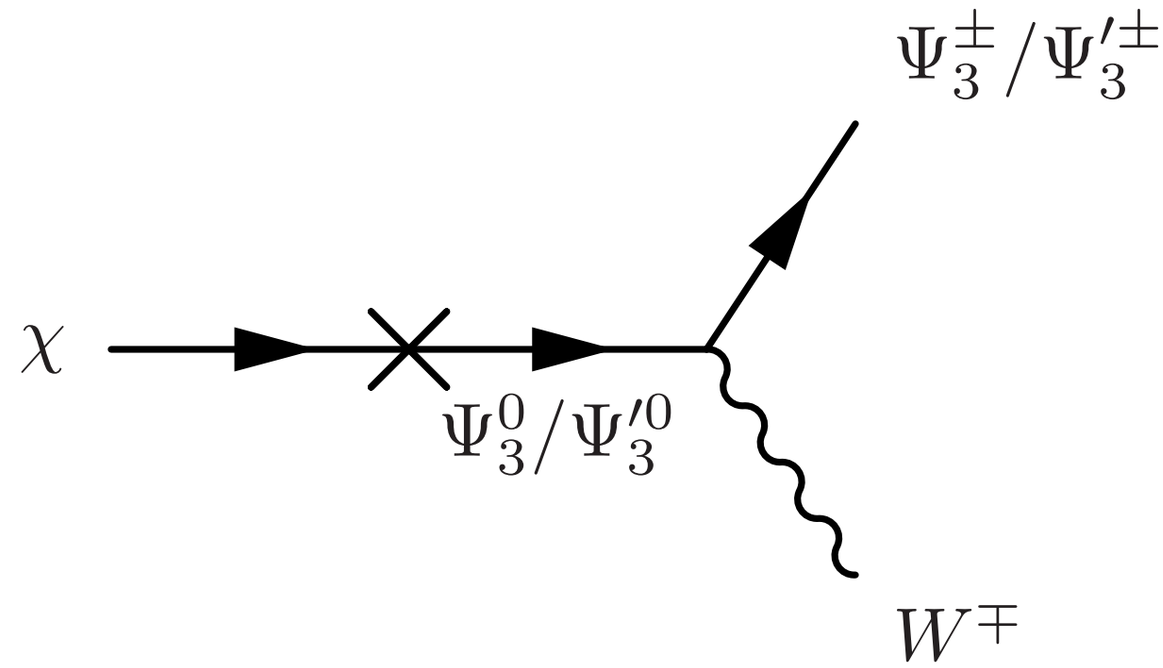

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Coupled Boltzmann equations

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

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

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In practice we substitute

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And find $\dot{T}$

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

$$\frac{dT}{dt} = \sum_j (n_\chi^j - n_\chi^{j,\mathrm{eq}}) \frac{m_\chi \Gamma T}{4\gamma^j \rho_{\mathrm{SM}}} - HT$$

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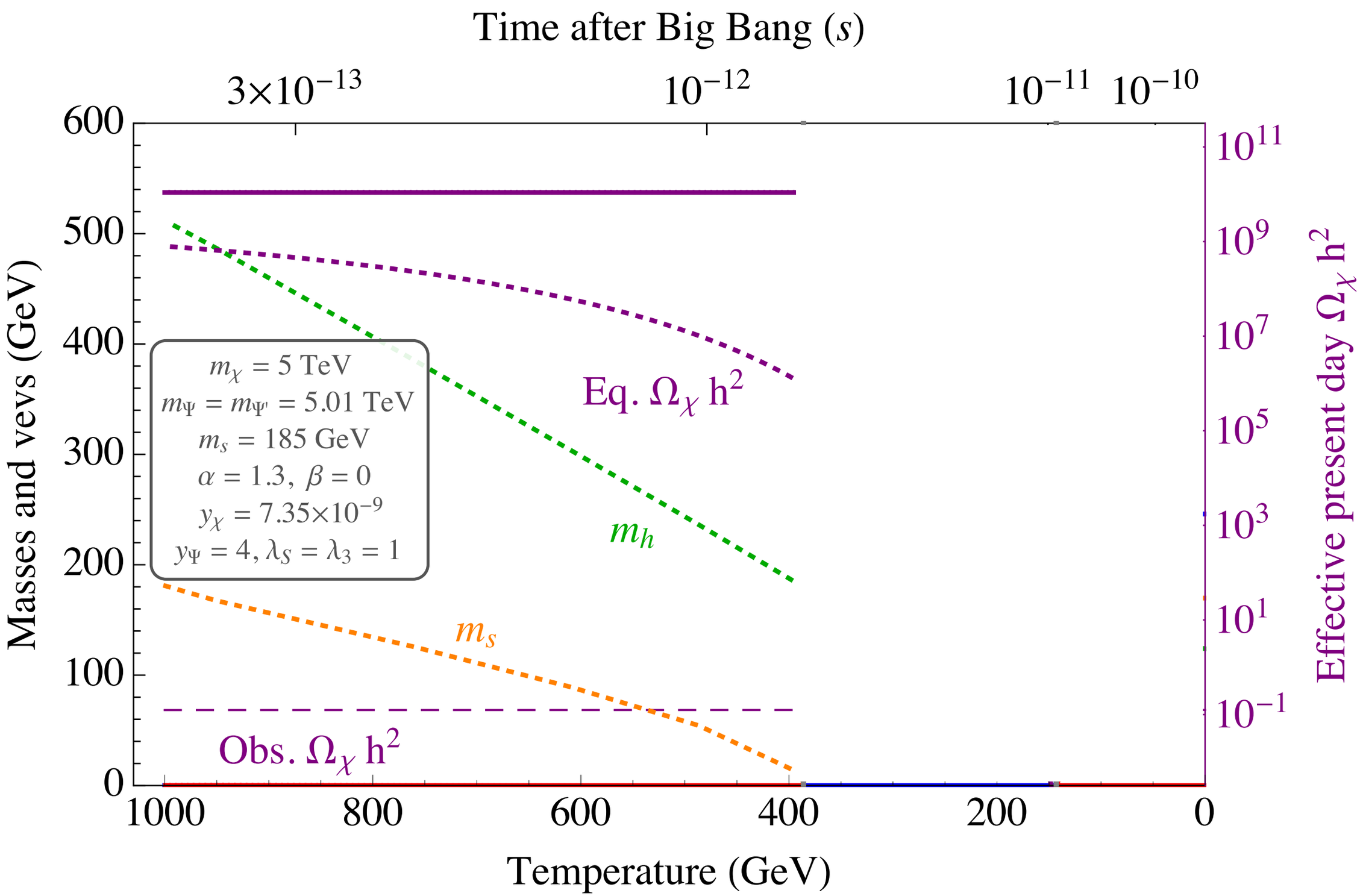

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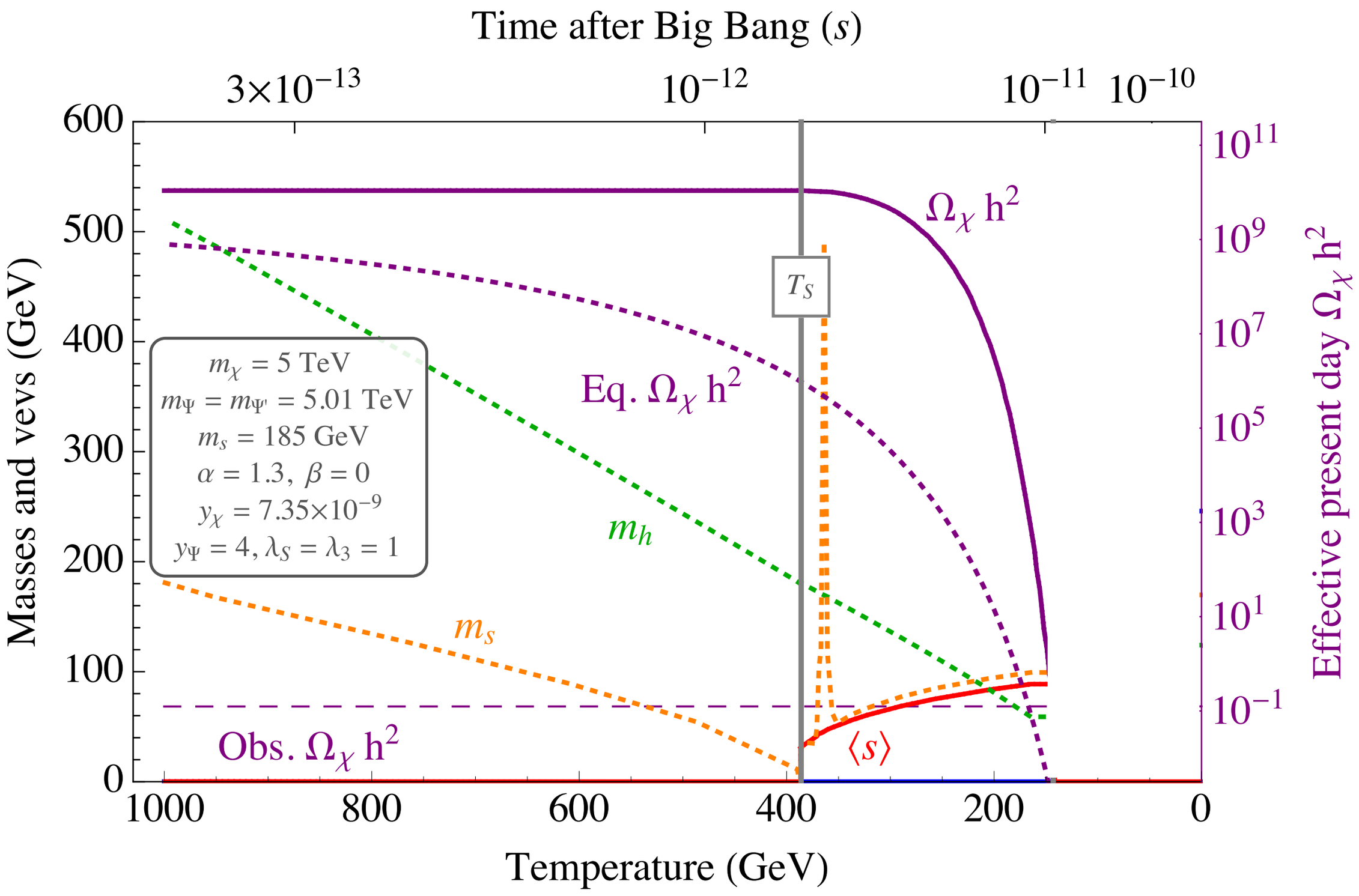

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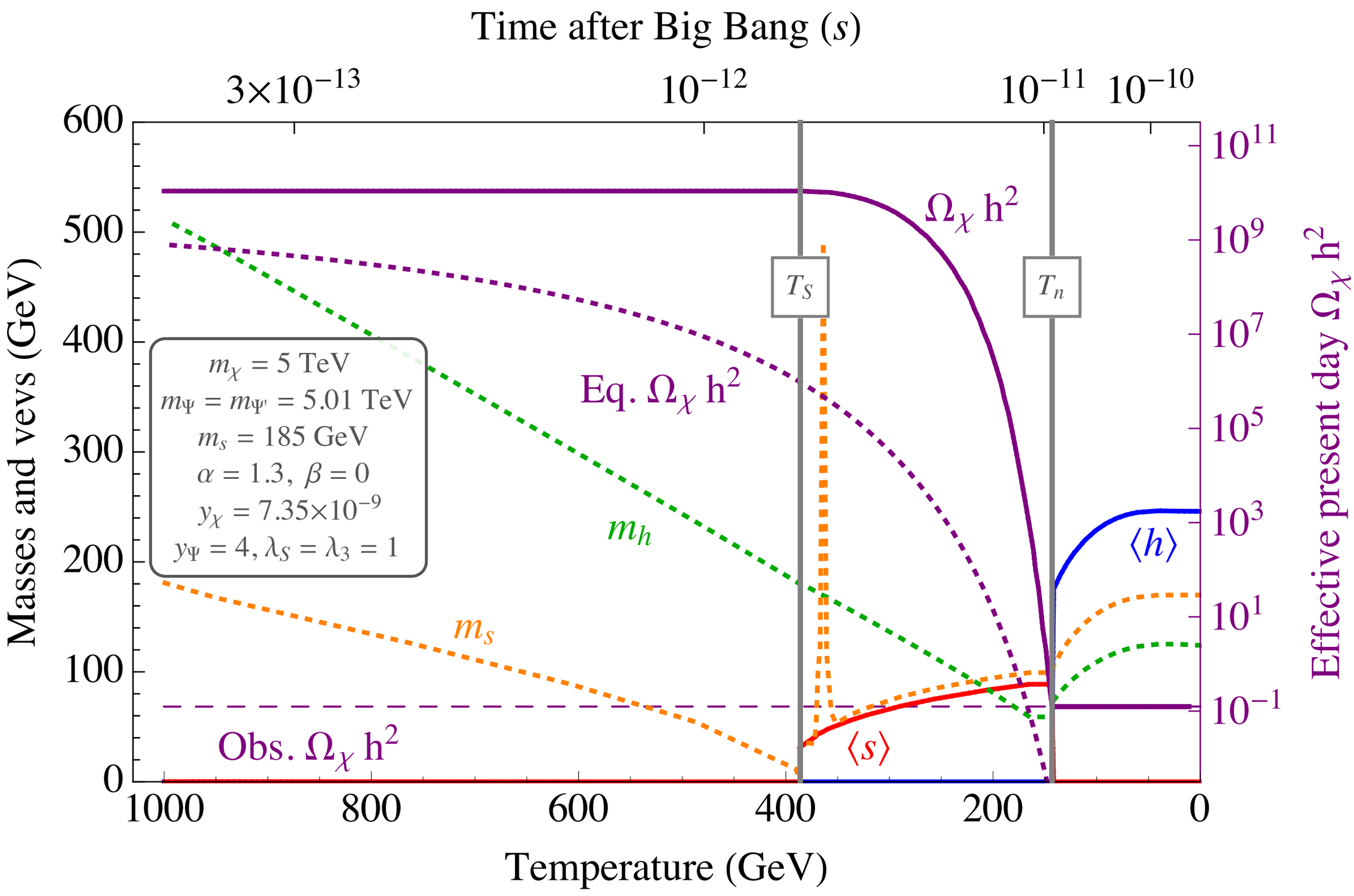

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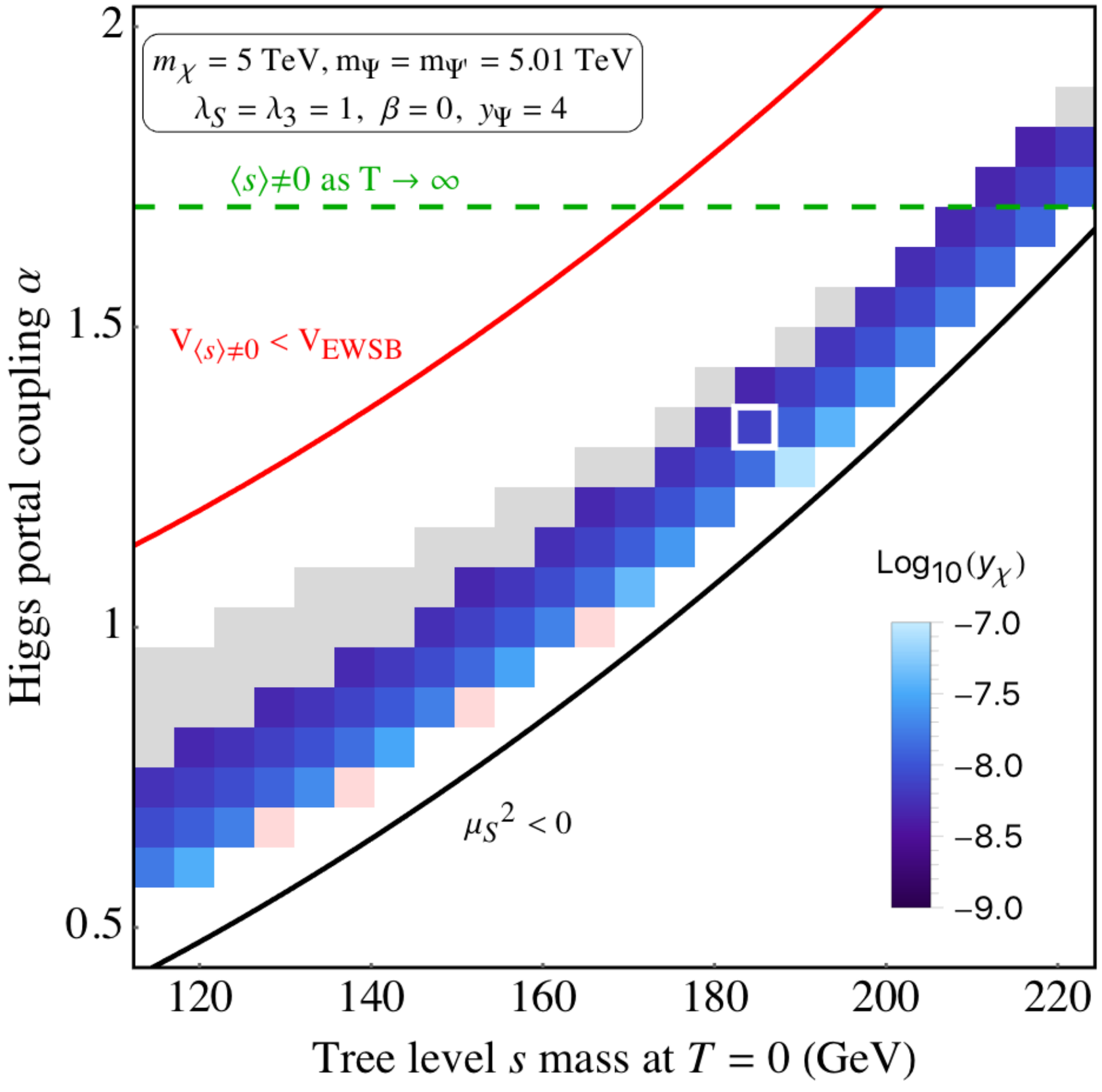

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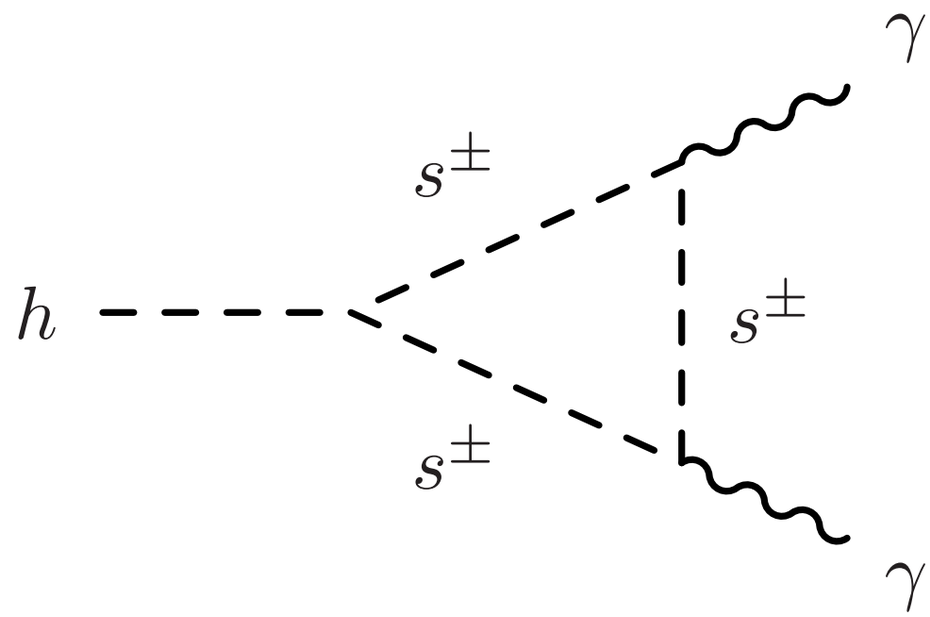

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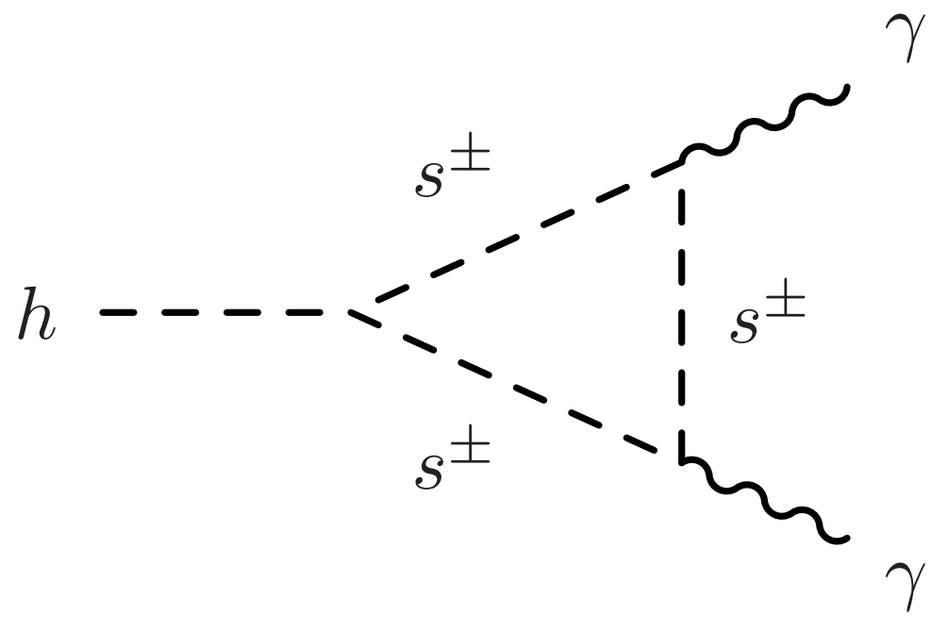

$$\Gamma(h \to \gamma\gamma) = \frac{v^2}{16\pi m_h}|F^{\gamma\gamma}|^2$$

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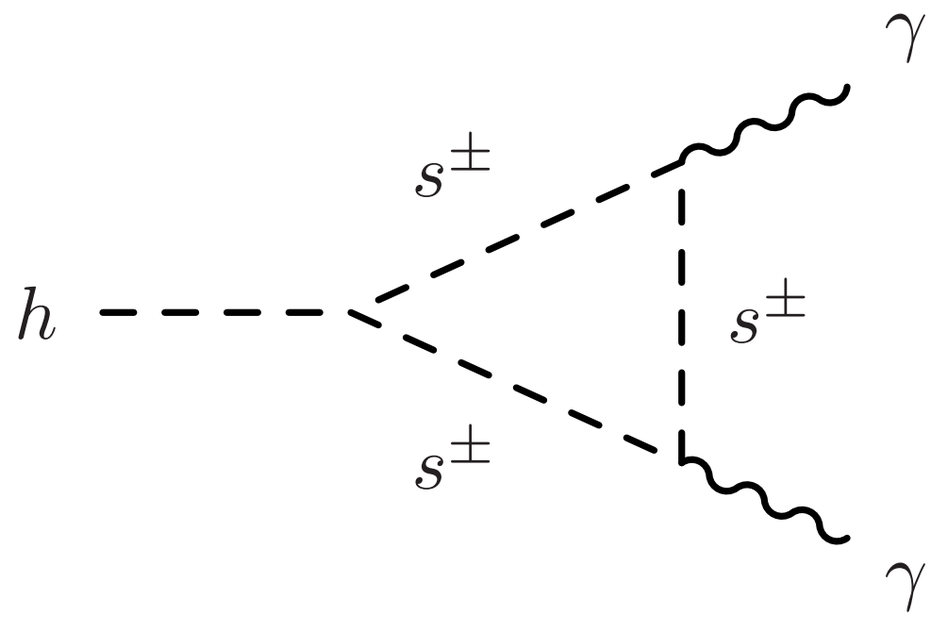

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$$F_{S_3}^{\gamma\gamma} = \frac{\alpha_{\rm EW}}{\pi} \alpha \left[1 - \frac{4m_{s^\pm}^2}{m_h^2} f\left(\frac{4m_{s^\pm}^2}{m_h^2} \right) \right]$$

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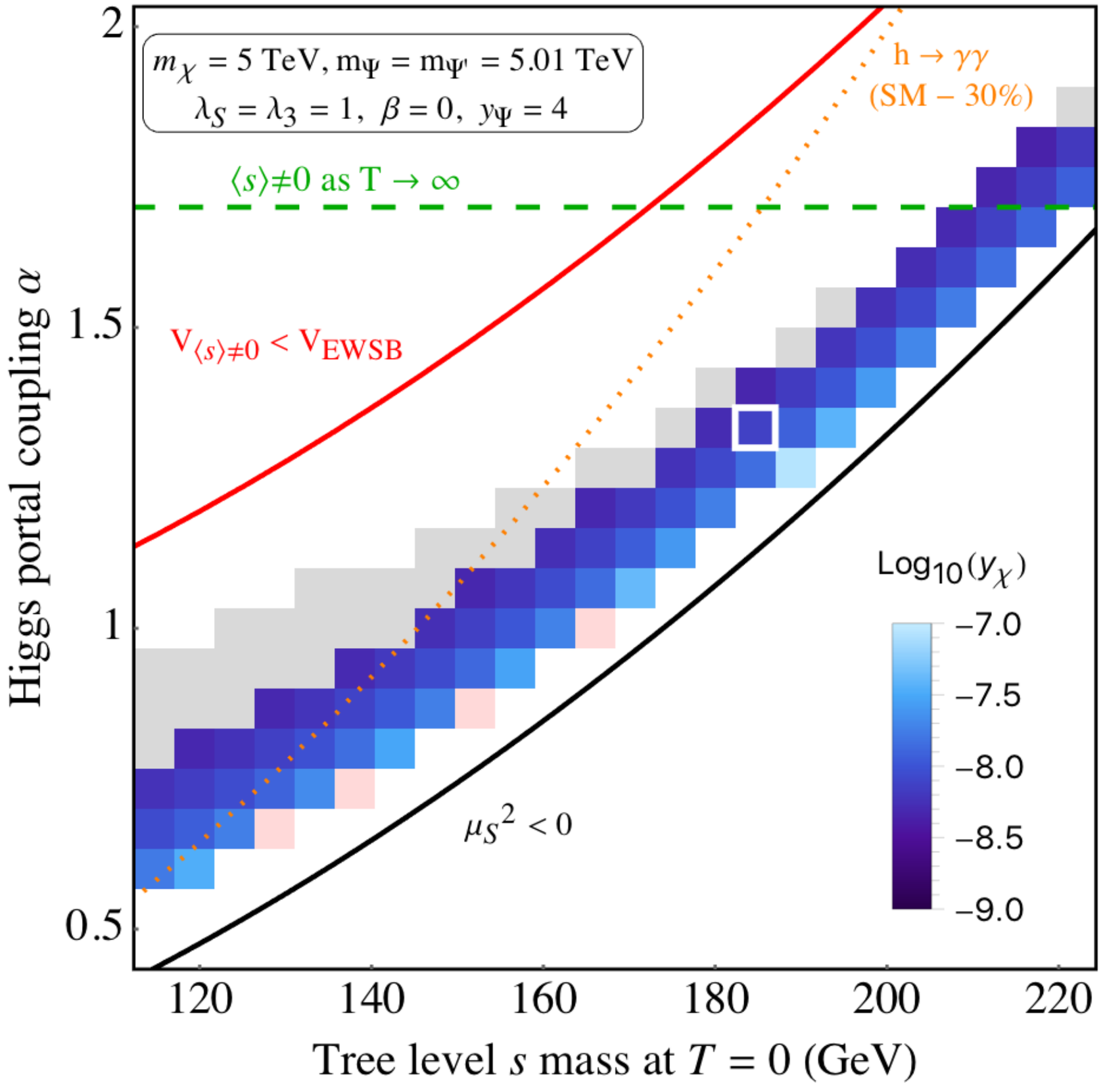

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- Demonstrated the mechanism in a toy model
- Which works in a large parameter space
- Outlook:
  - More realisations,
  - LHC phenomenology,
  - gravitational wave signals,
  - baryogenesis,…