Freezing-in Cannibal DM during early matter domination

Based on: arXiv:2506.09155

Esau Cervantes

Collaboration with **Andrzej Hryczuk** (supervisor) **Nicolás Bernal** and **Kuldeep Deka**

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Scalars 2025: Higgs bosons and cosmology

Cannibal Dark Matter

SELF-INTERACTING DARK MATTER

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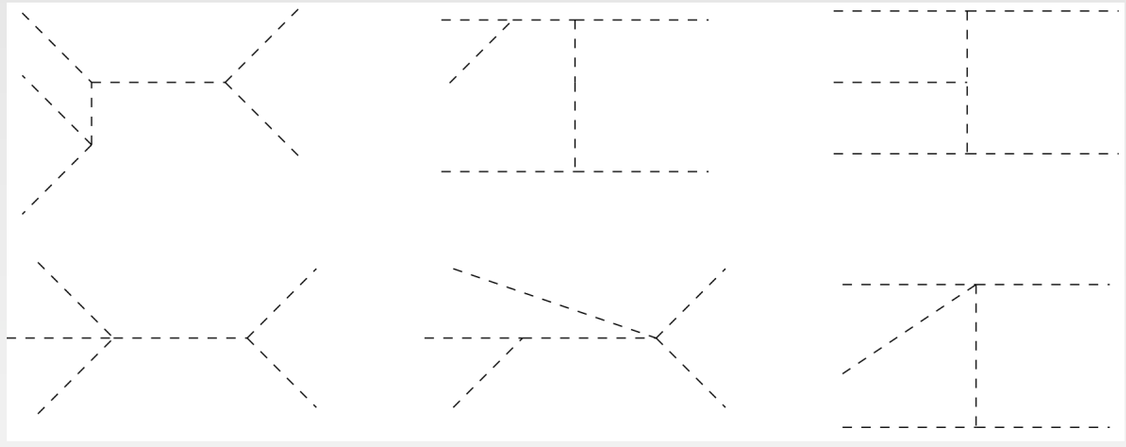
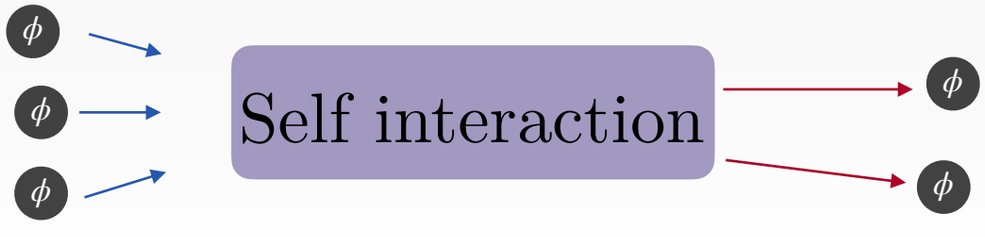
Simple realisation with a scalar field: $\frac{g}{3!}\phi^3 + \frac{\lambda}{4!}\phi^4$



If DM is non-relativstic, $\Gamma_{3\to 2} > \Gamma_{2\to 3}$. The DM fluid **exchanges** particle number for kinetic energy!



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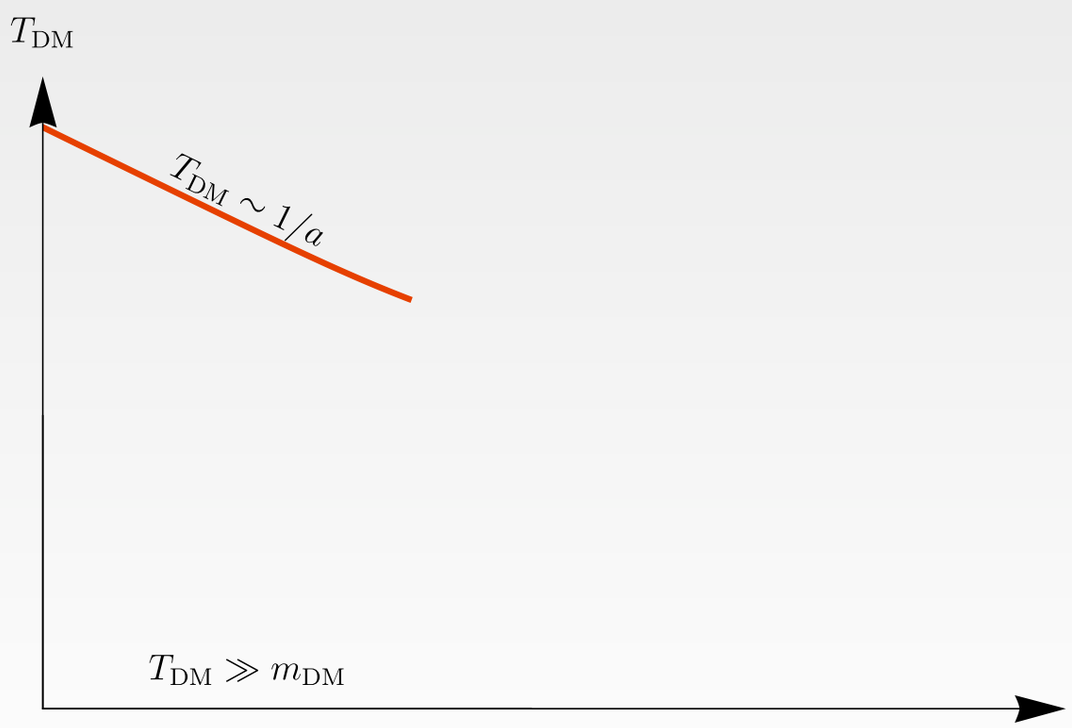

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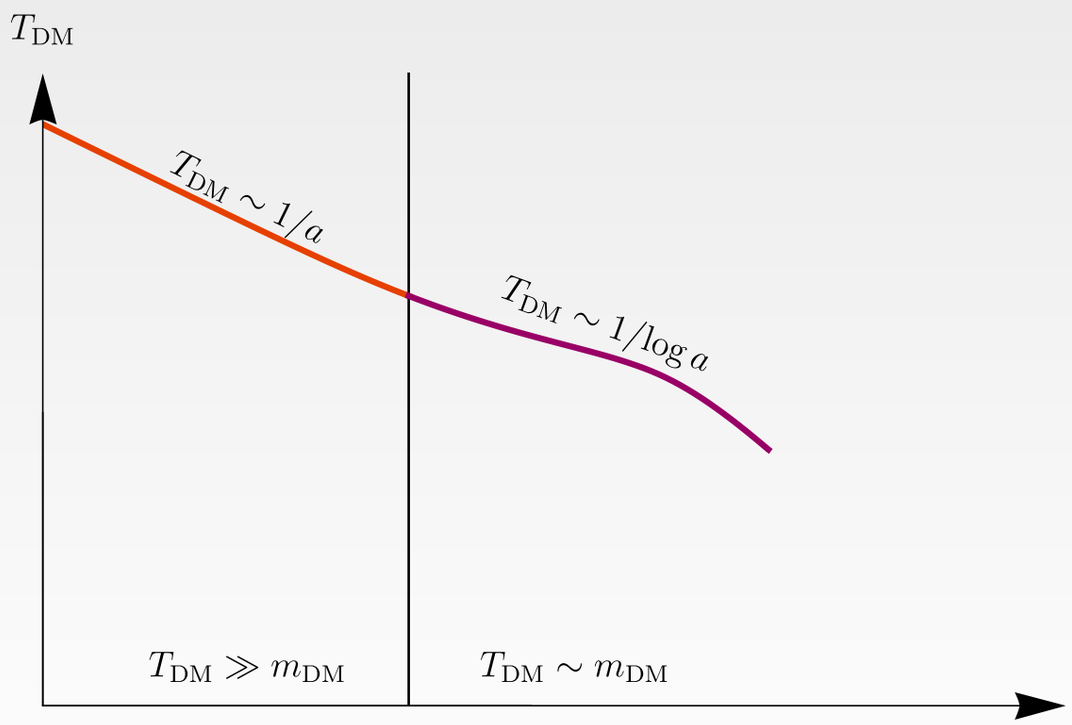

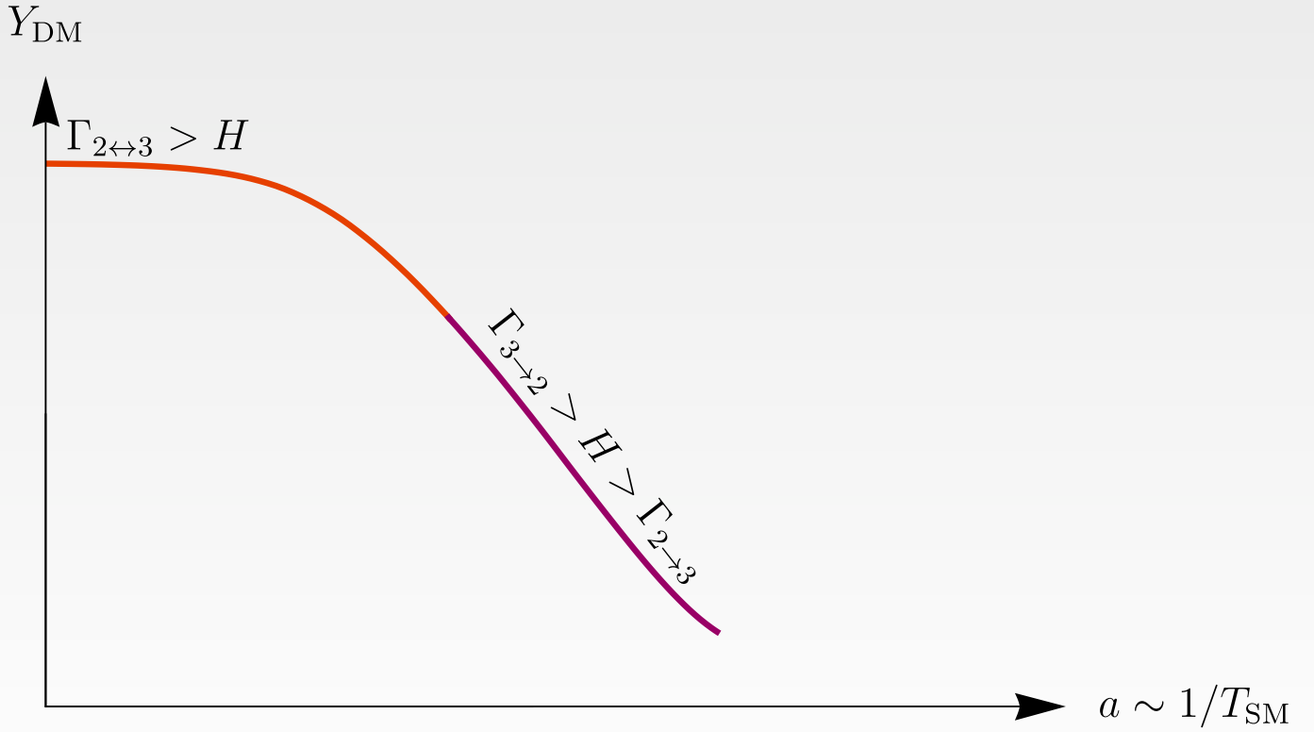

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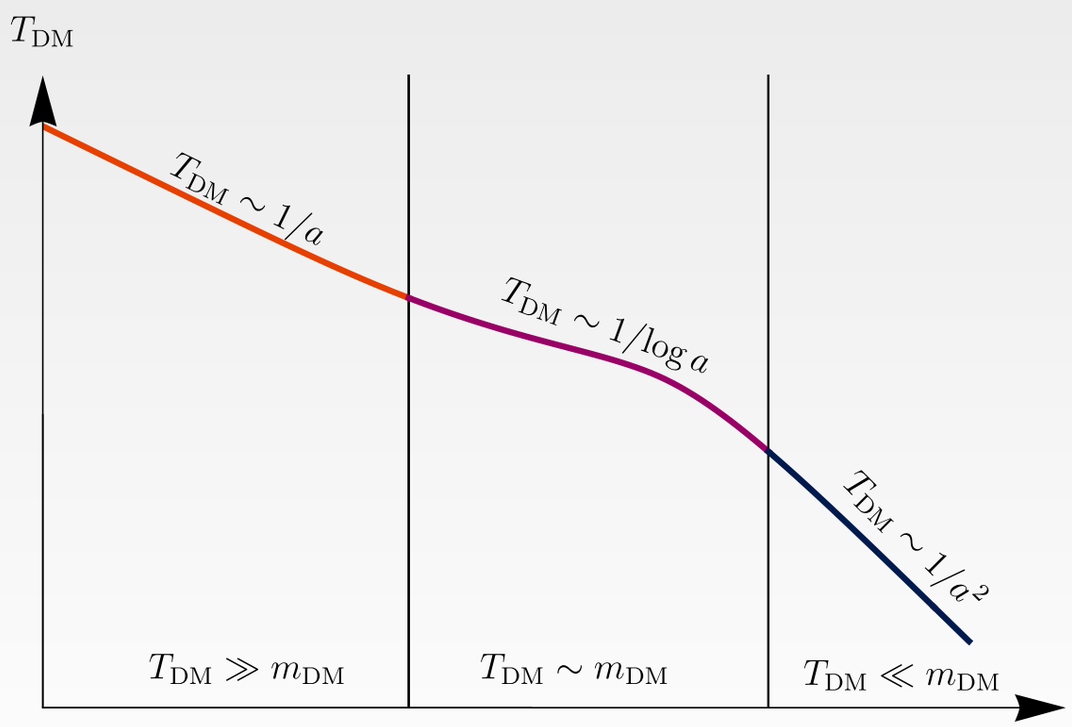

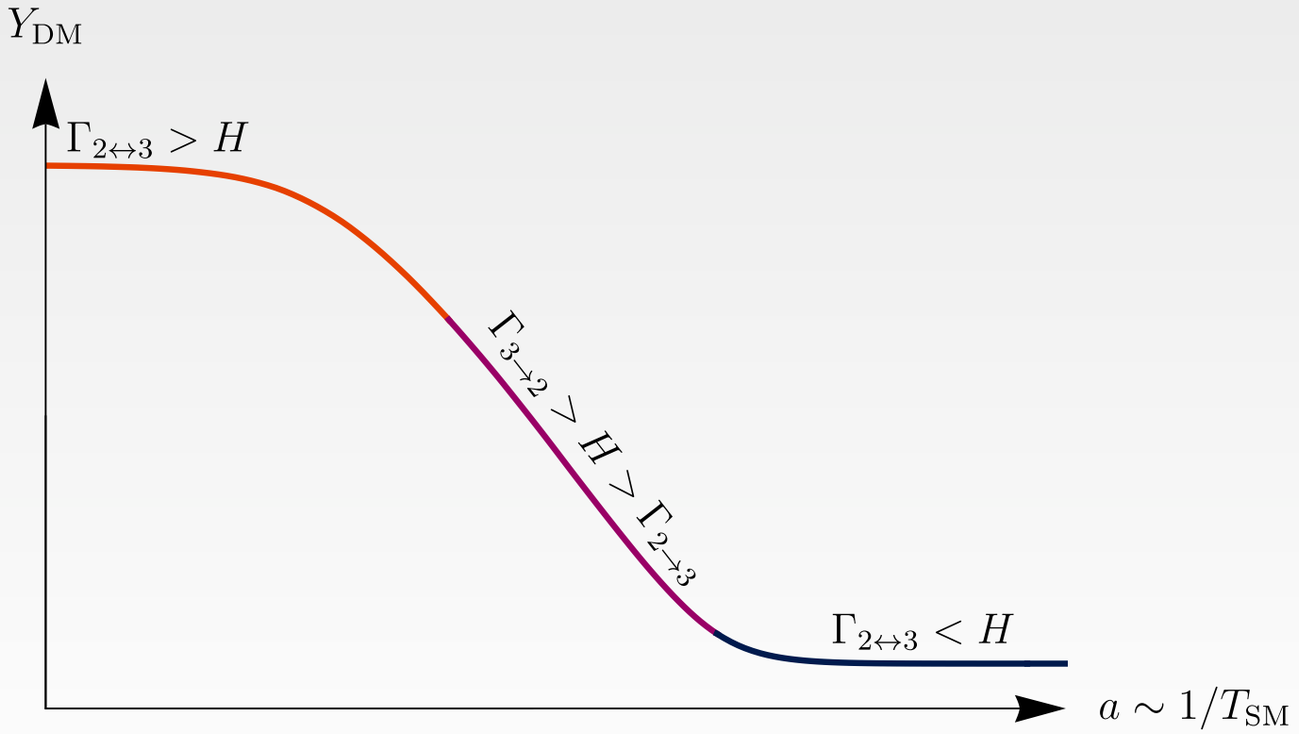

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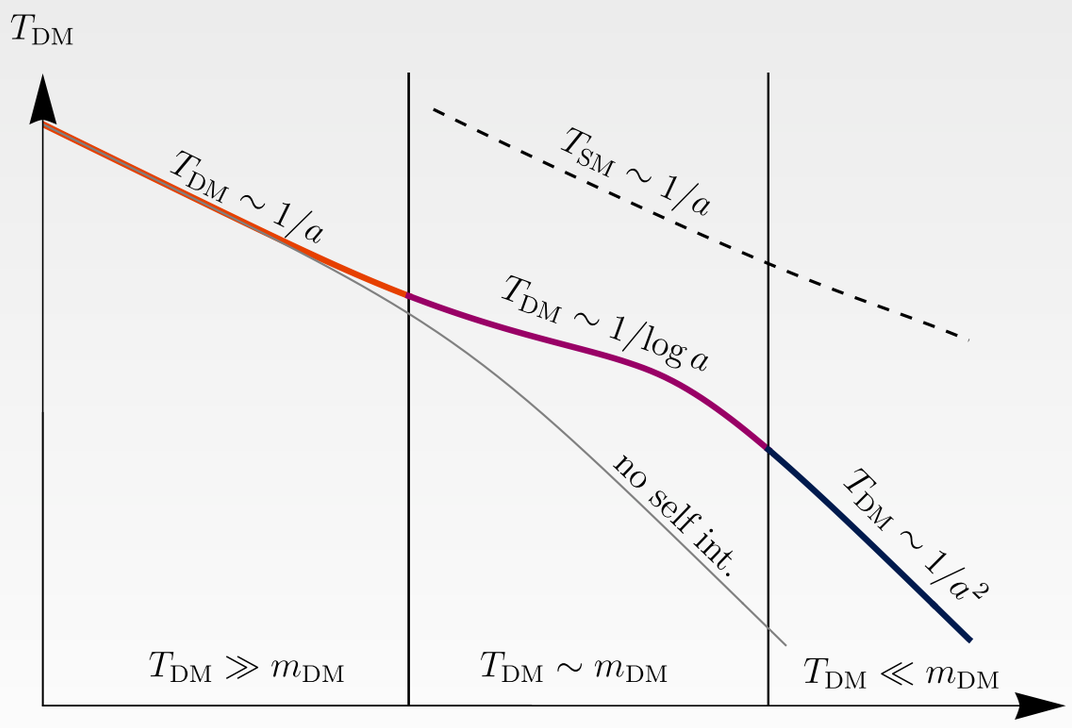
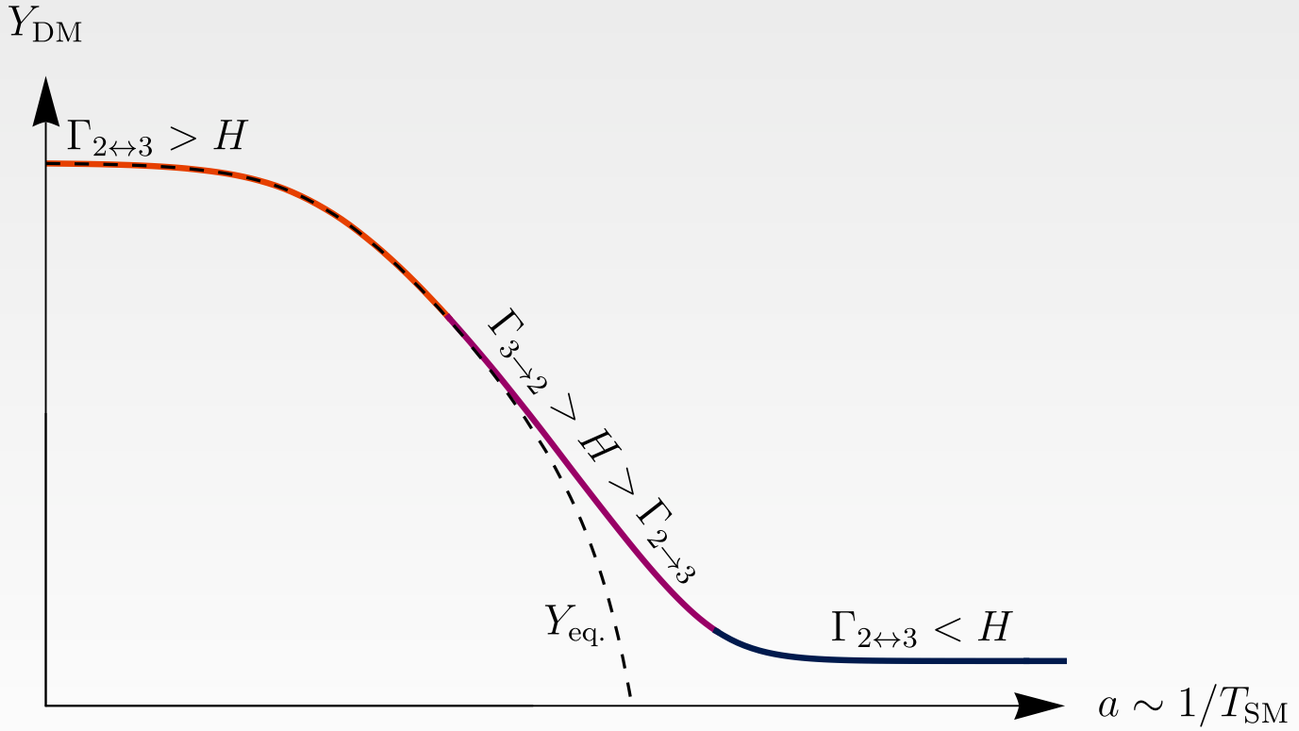
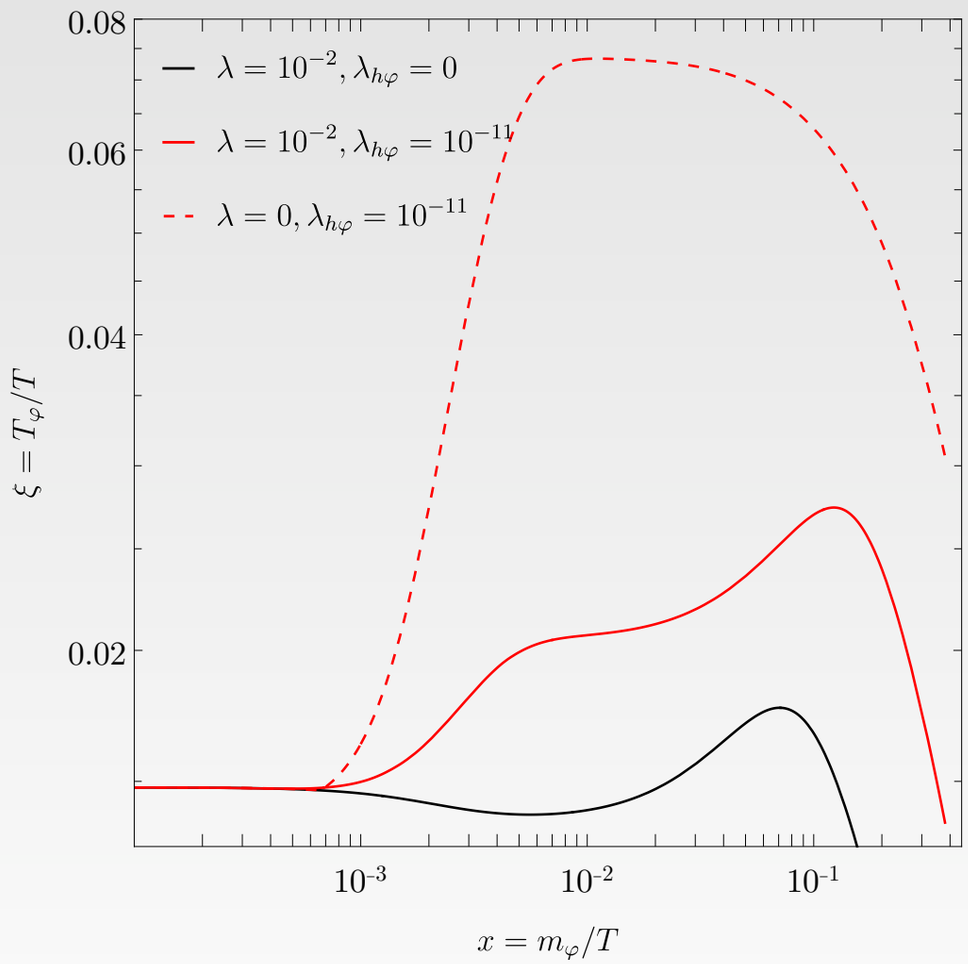


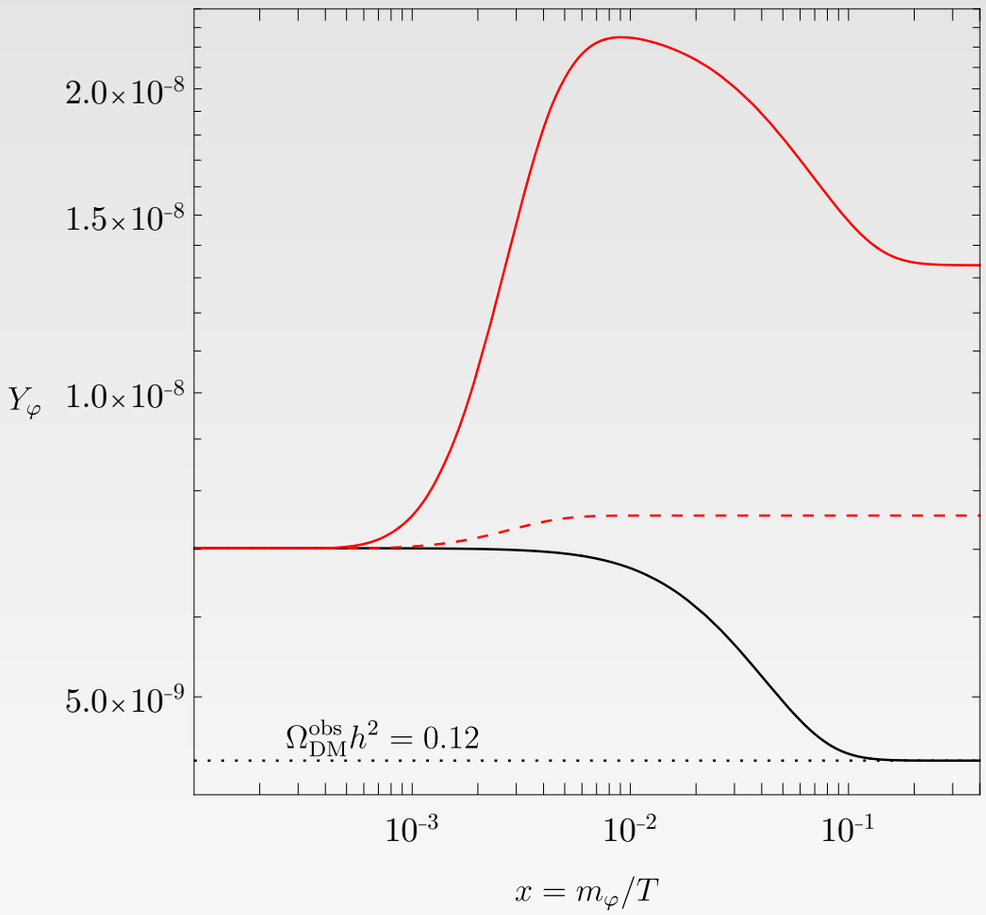


See also Hufnagel, Tygat 22 and Arcadi, Lebedev 19

Cannibals produced via freeze-in

Consider $\mathscr{L} \supset -\lambda_{h\varphi}\varphi^2 H^\dagger H$, $\lambda_{h\varphi} \ll 1$, $\lambda_\varphi \geq 10^{-4}$ and initially cold DM; $T_{DM}/T_{SM} = 10^{-2}$:





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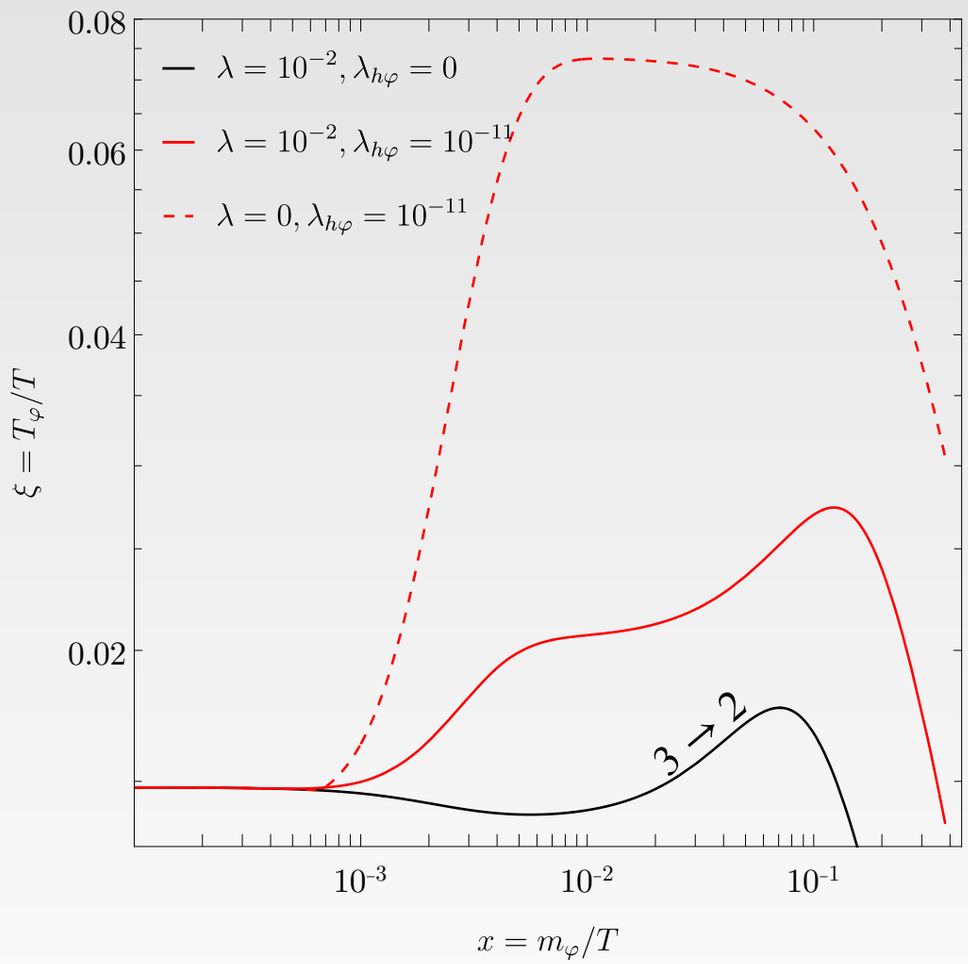

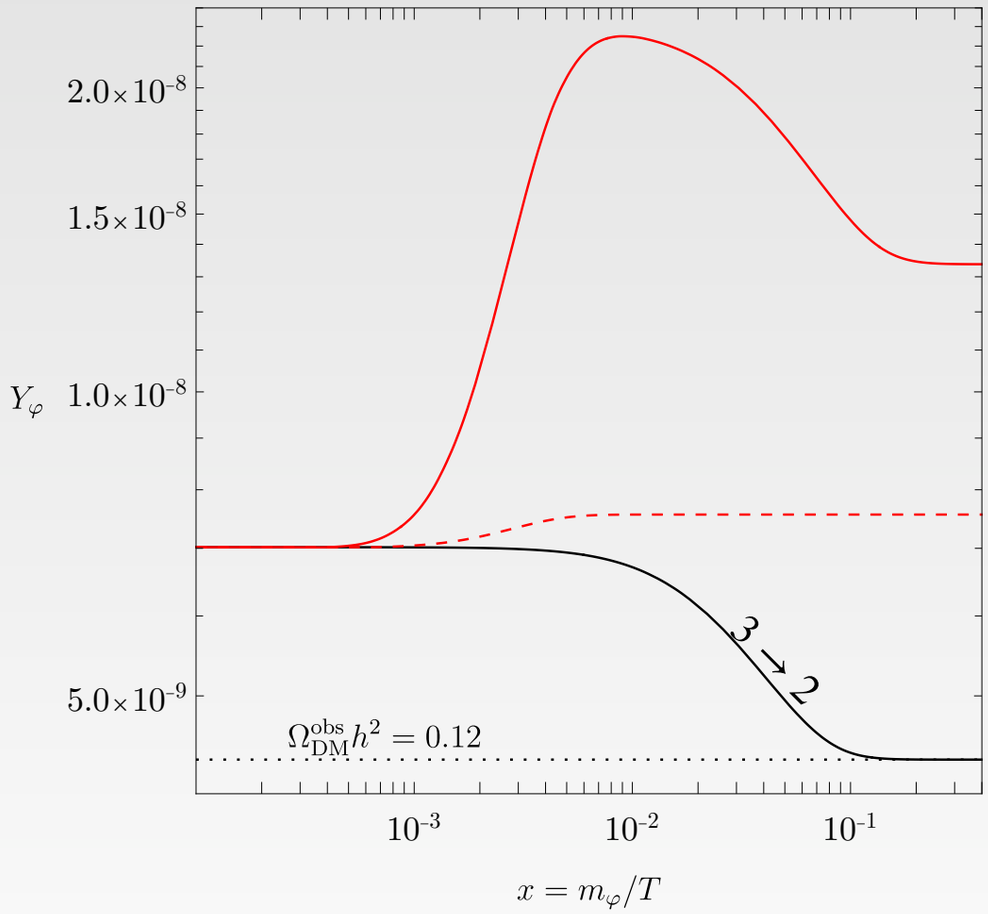

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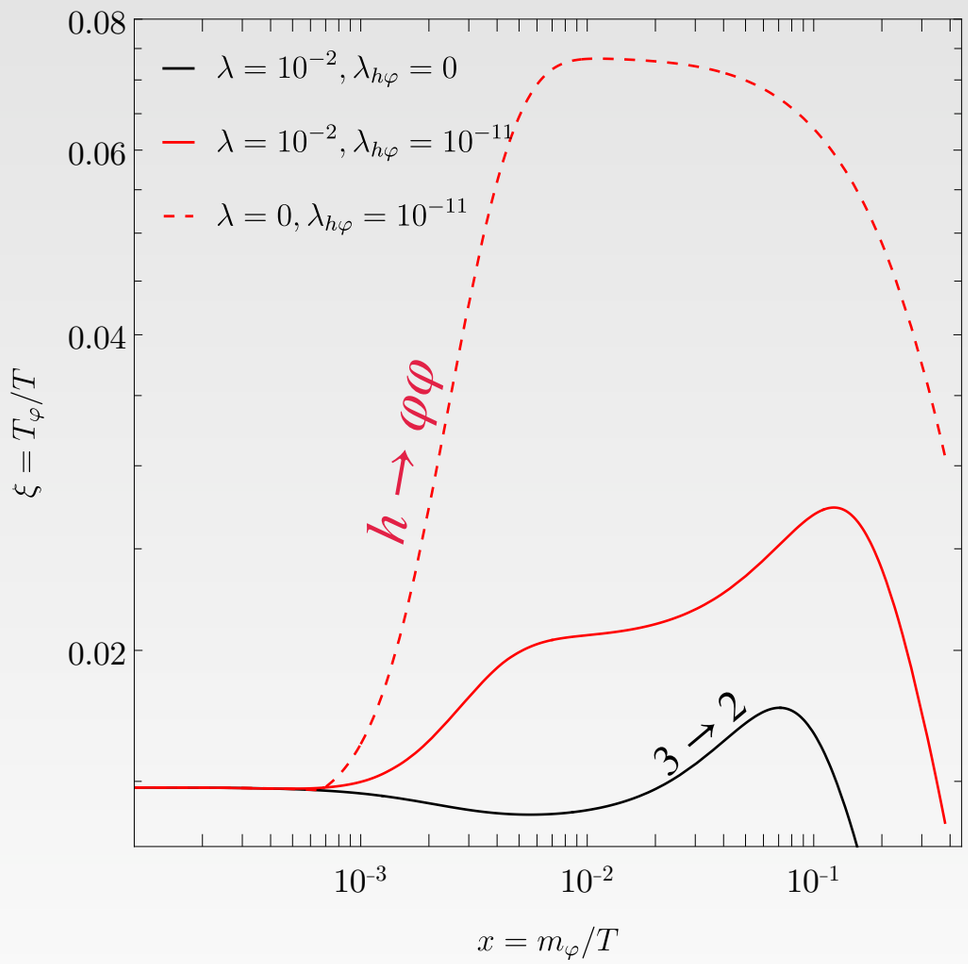

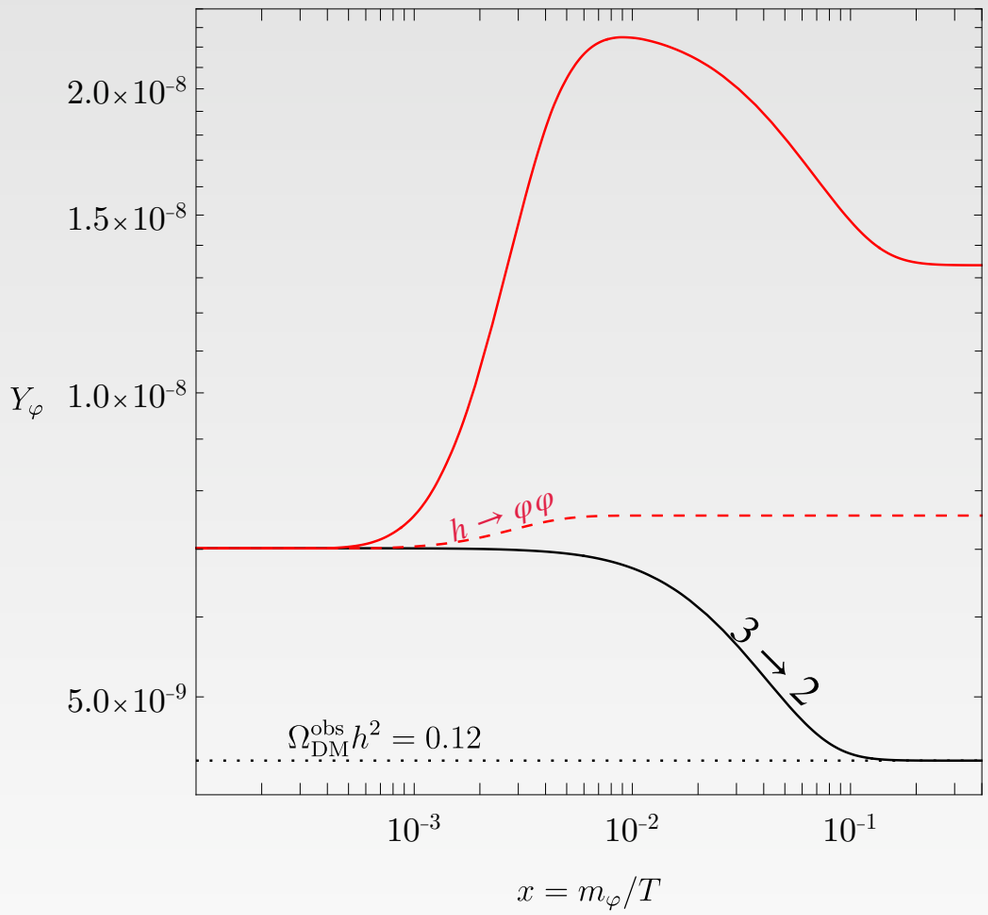

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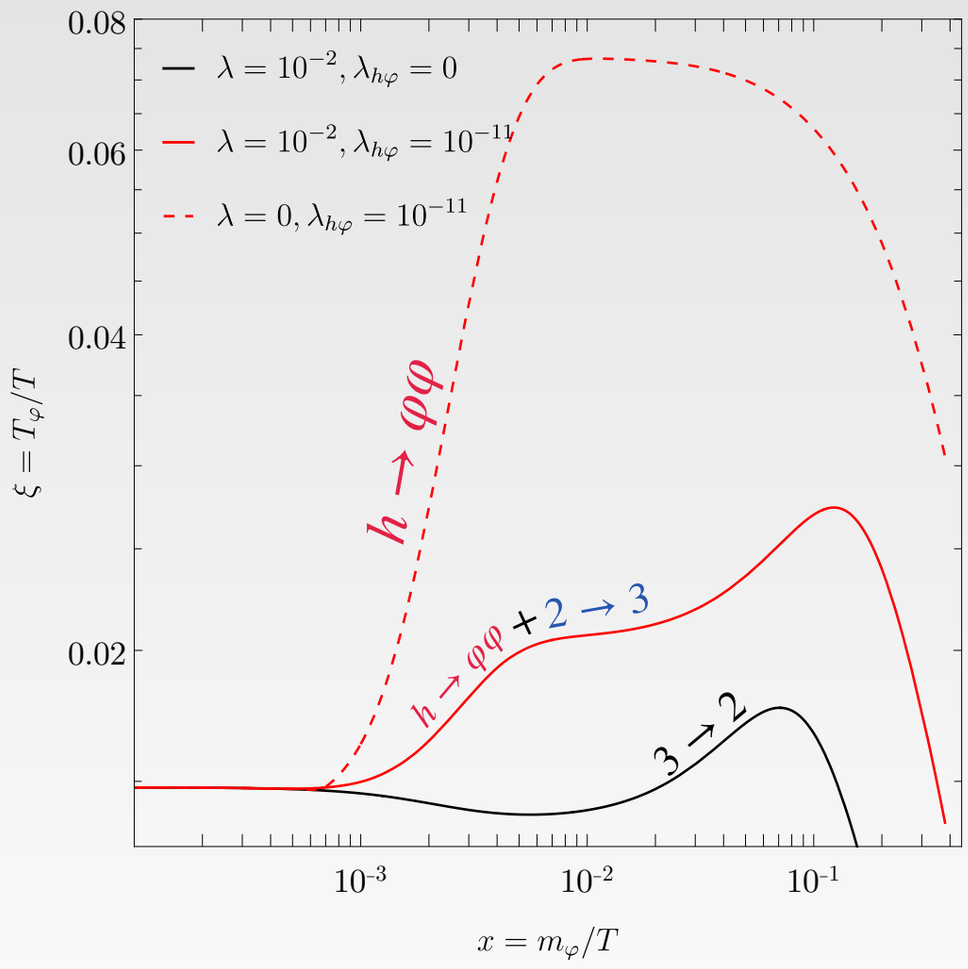
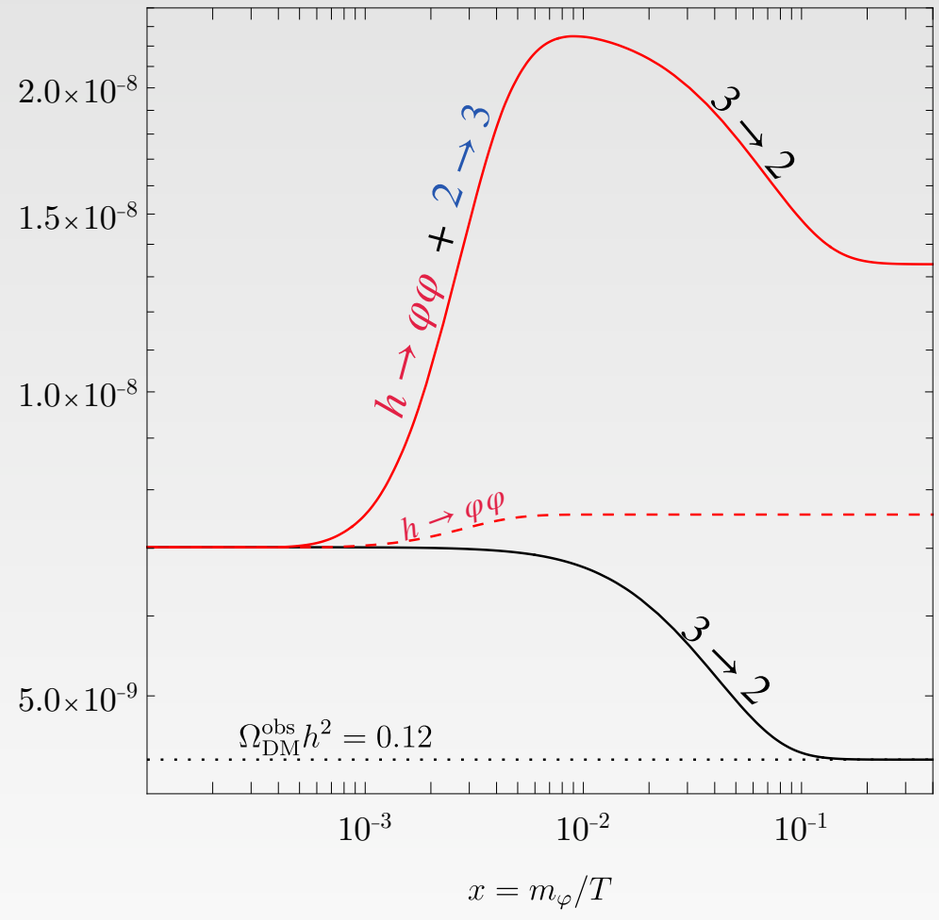




See EC, A. Hryczuk 24

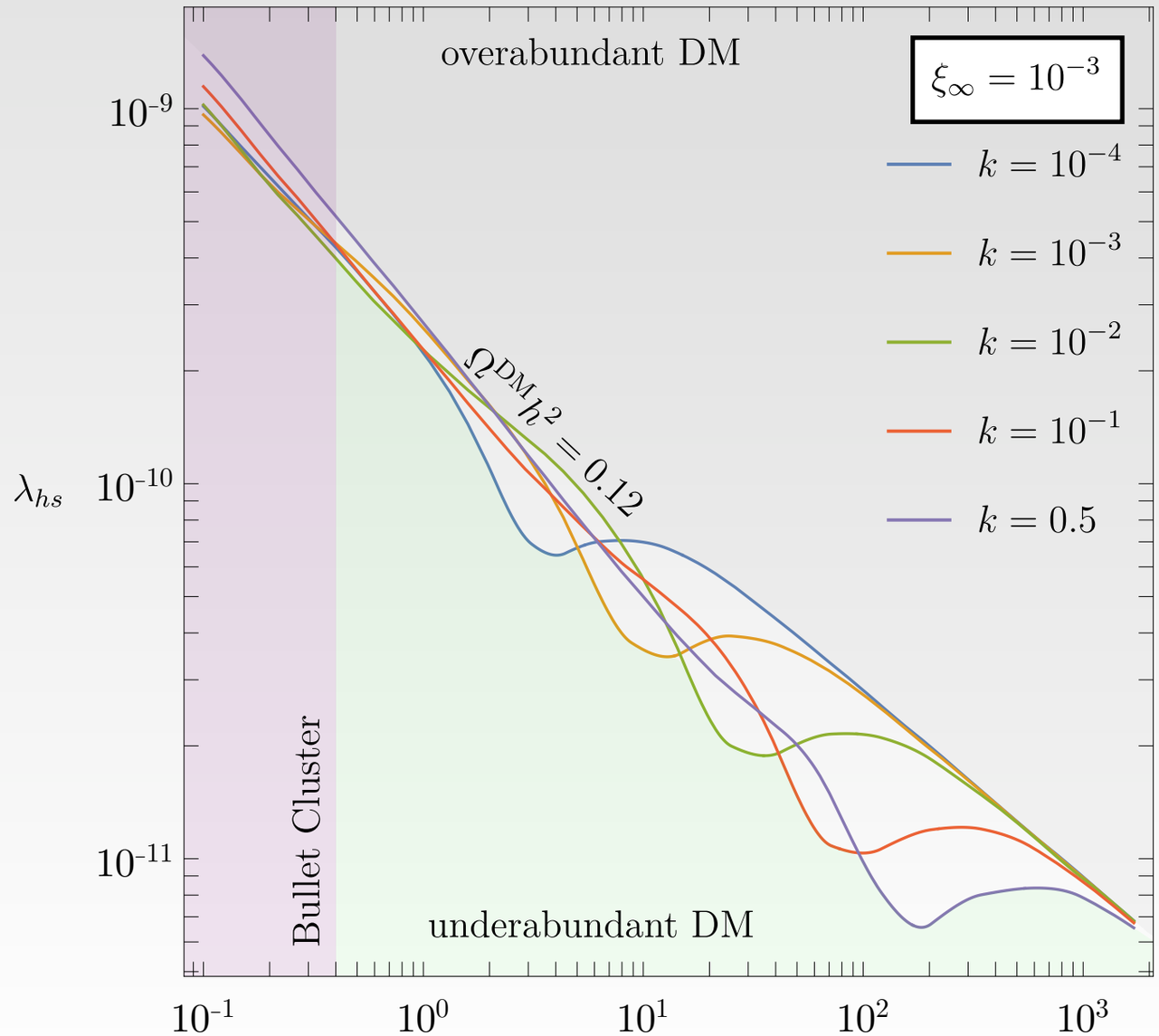
and also Bernal et.al 15 (SIMP $\mathbb{Z}_2$ DM)

Cannibals produced via freeze-in

Toy model: $\mathscr{L} \supset -\frac{1}{3!} g_s (S^3 + (S^*)^3) - \frac{\lambda_s}{4} |S|^4 - \lambda_{hs} |S|^2 |H|^2$

DM self interactions (cannibal)

Portal



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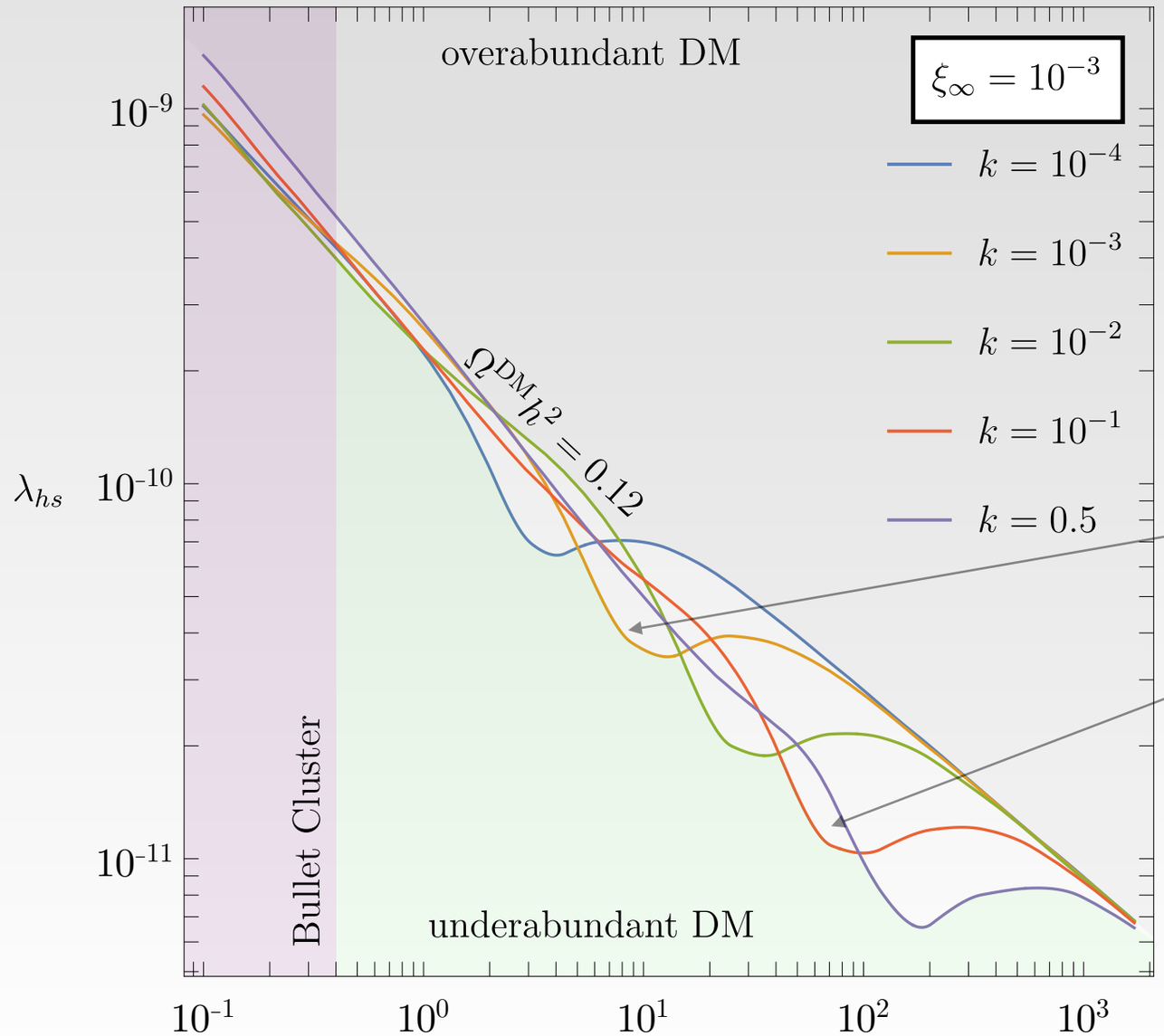

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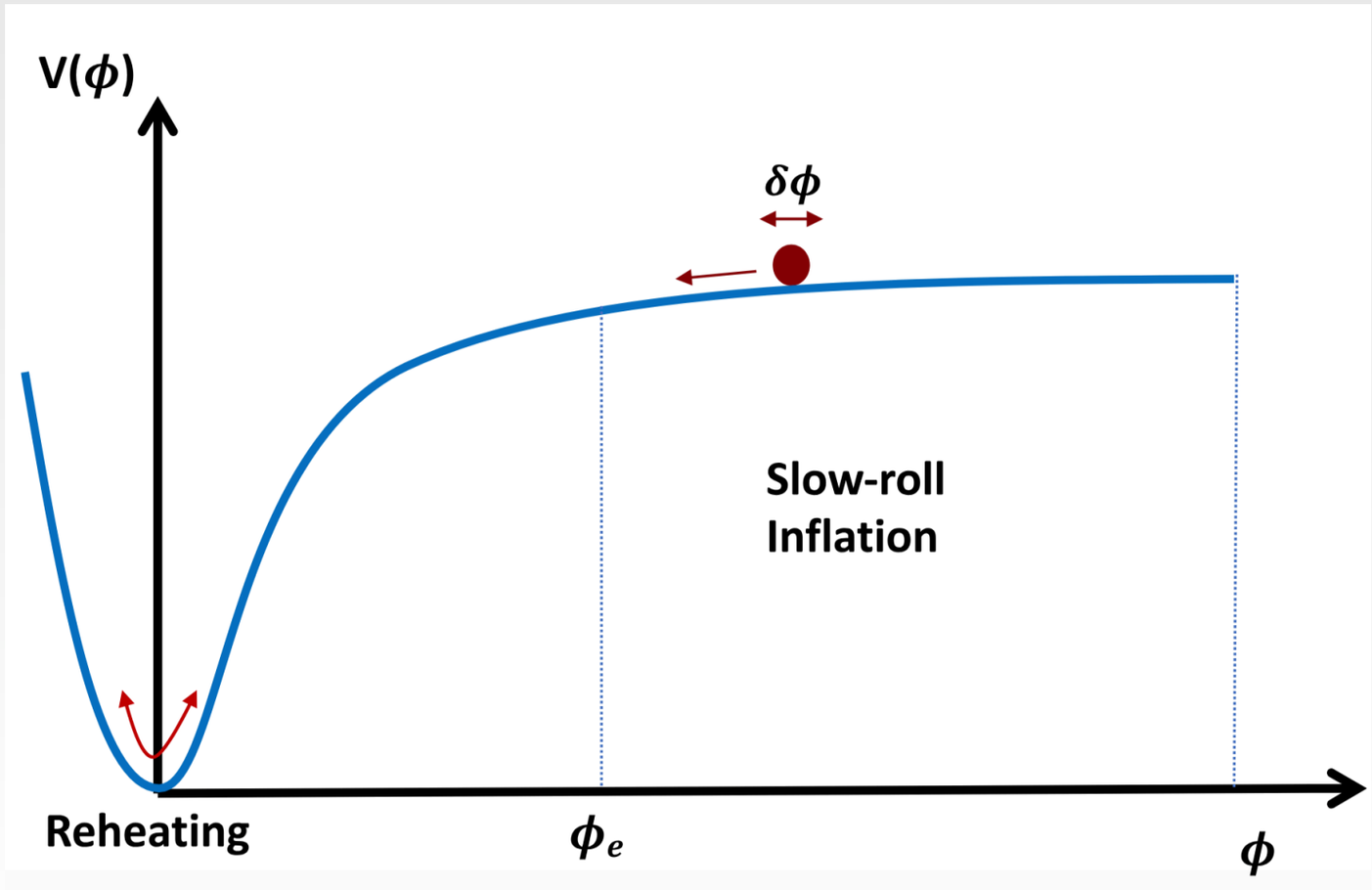
$2 \to 3$ at play

See EC, A. Hryczuk 24

Inflaton decay and reheating

Transition between ***matter*** domination and ***radiation*** can be due to a scalar (**inflaton**) field ϕ that rolls ($a \propto e^{Ht}$) in the potential and subsequently oscillates in the minimum decaying into SM states.



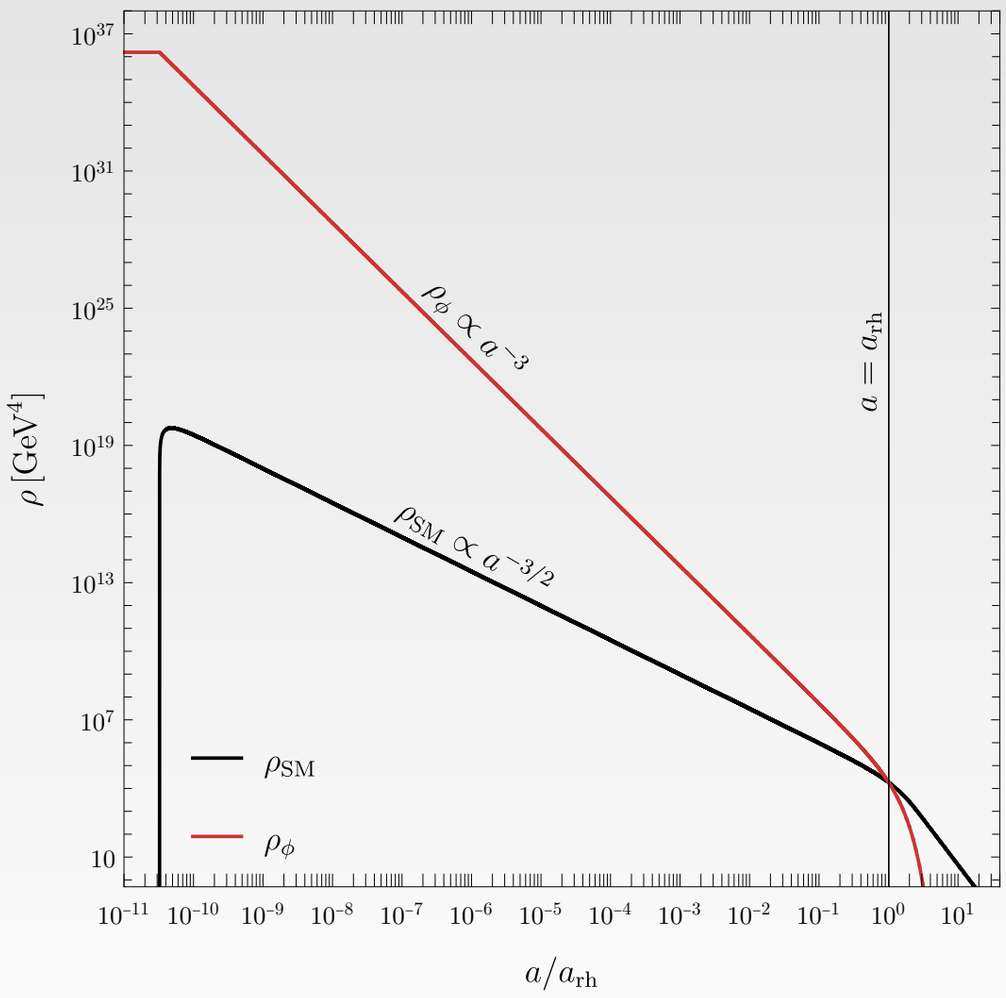
$$\frac{d\rho_\phi}{dt} + 3H\rho_\phi = -\Gamma\rho_\phi\,,$$

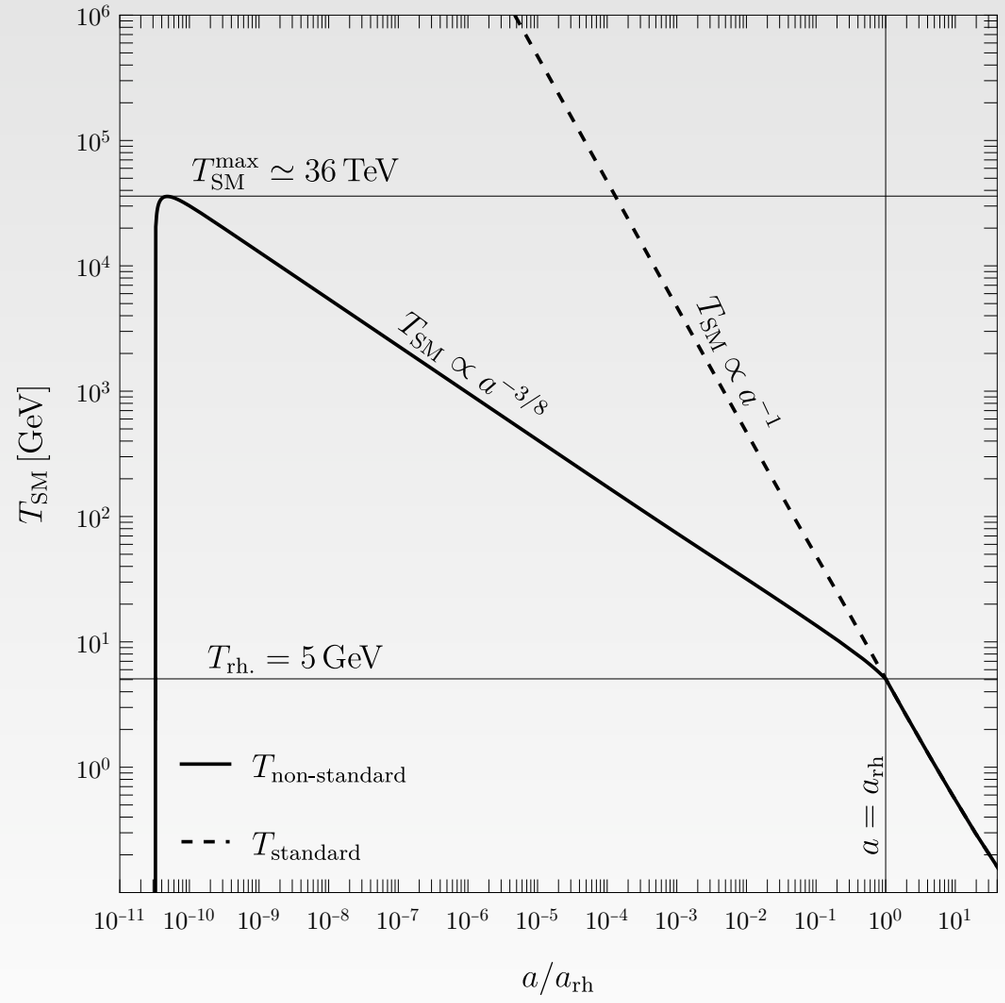
$$\frac{d\rho_R}{dt} + 4H\rho_R = +\Gamma\rho_\phi\,,$$

Cicoli, String Cosmology 2303.04819

Inflaton decay and reheating

During reheating $T \propto a^{-3/8}$ (matter domination), and $H \propto T^4$, i.e., rapid expansion of the universe





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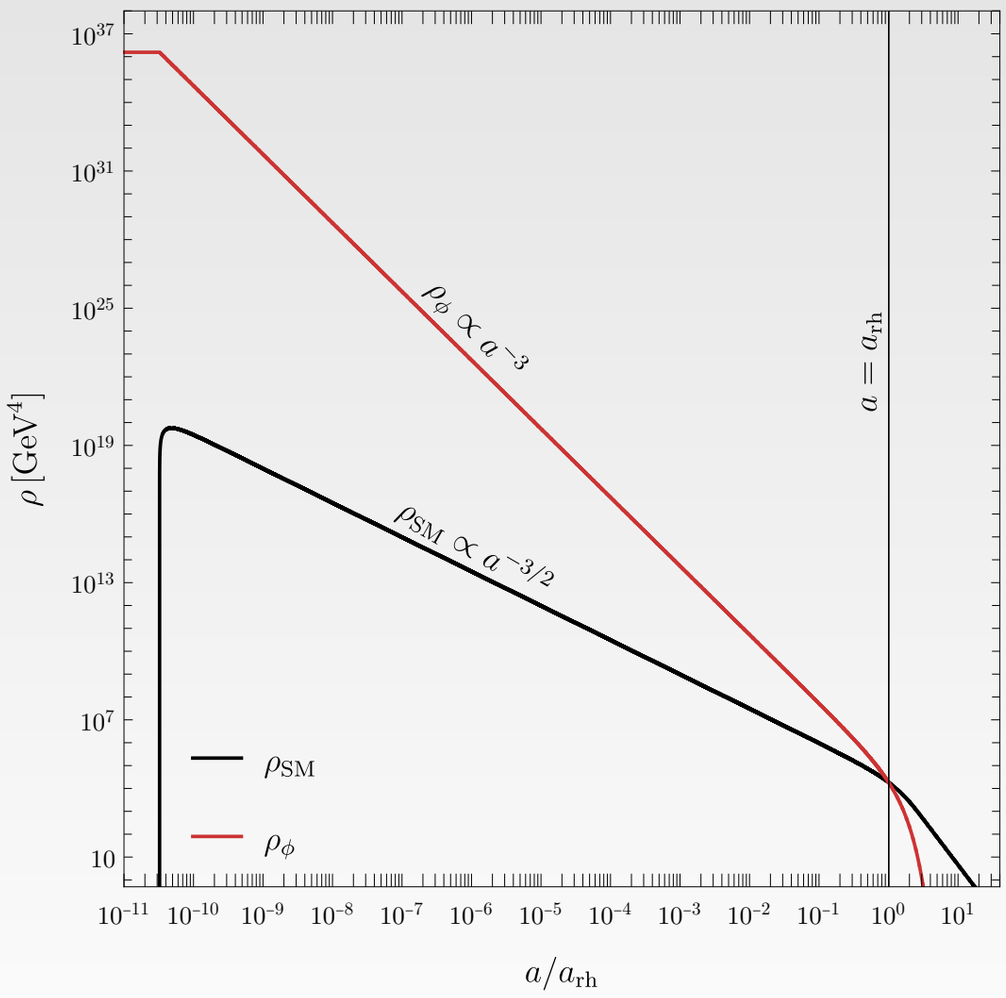
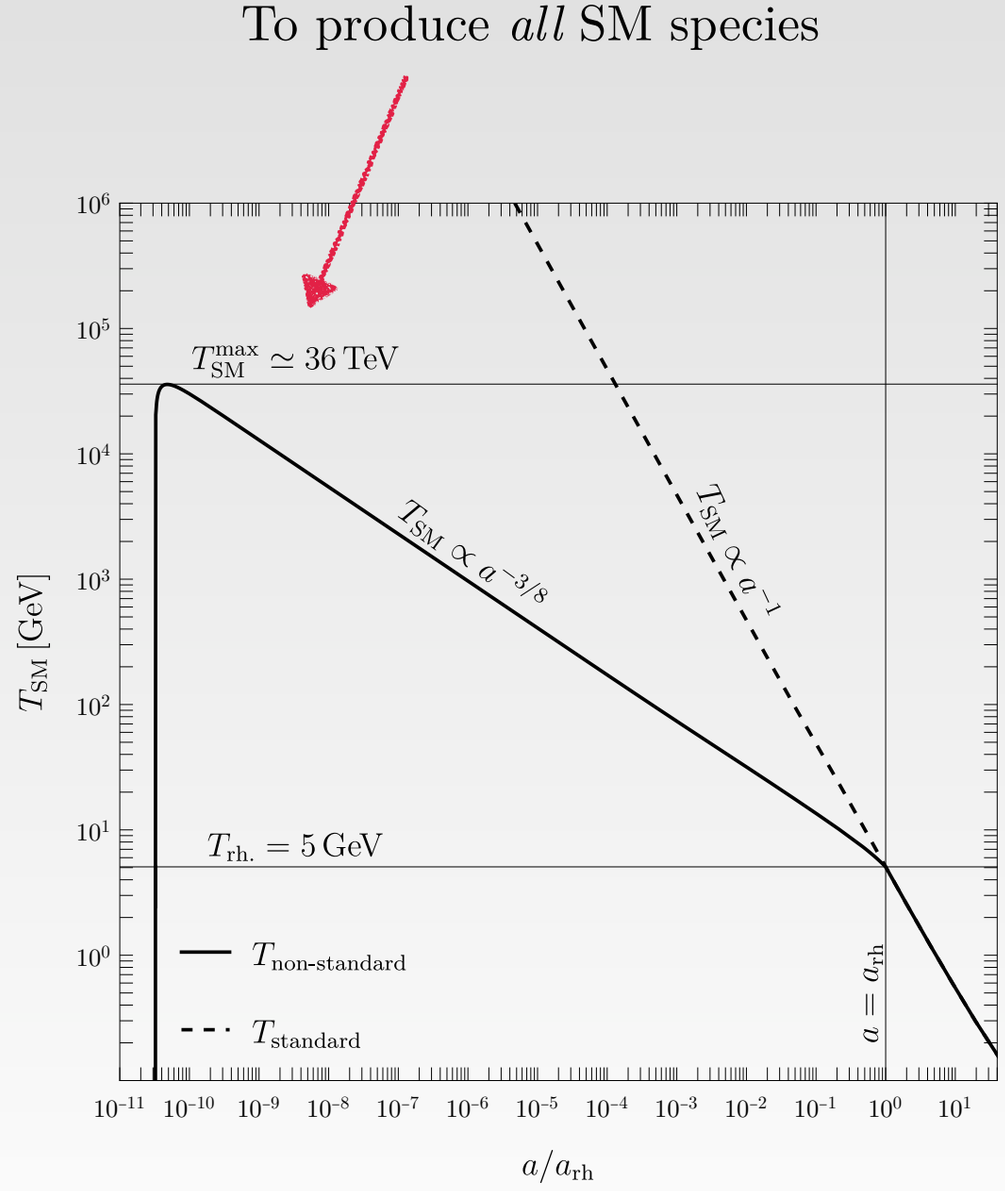


To produce *all* SM species



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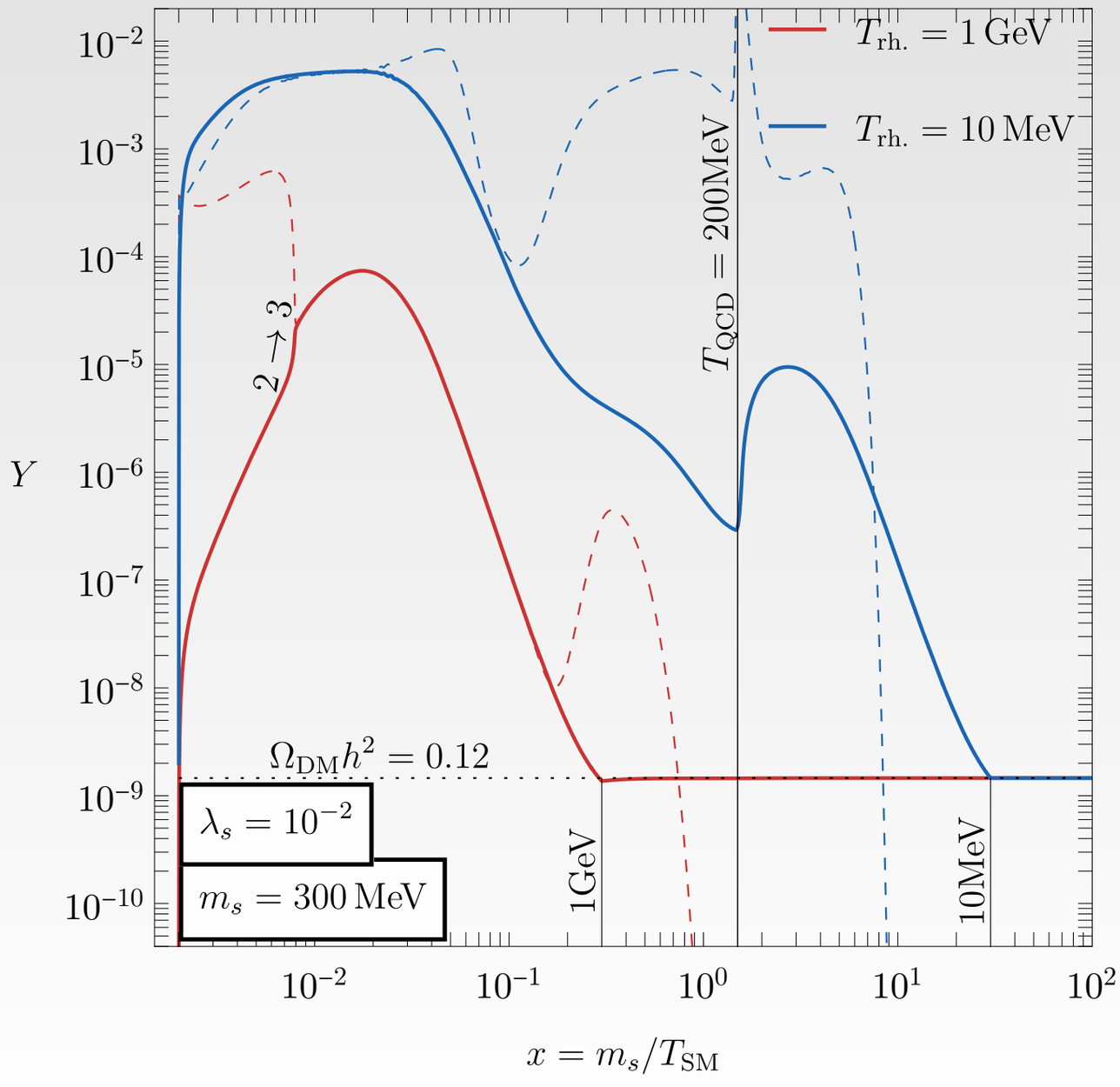
DM self interactions (cannibal) Portal



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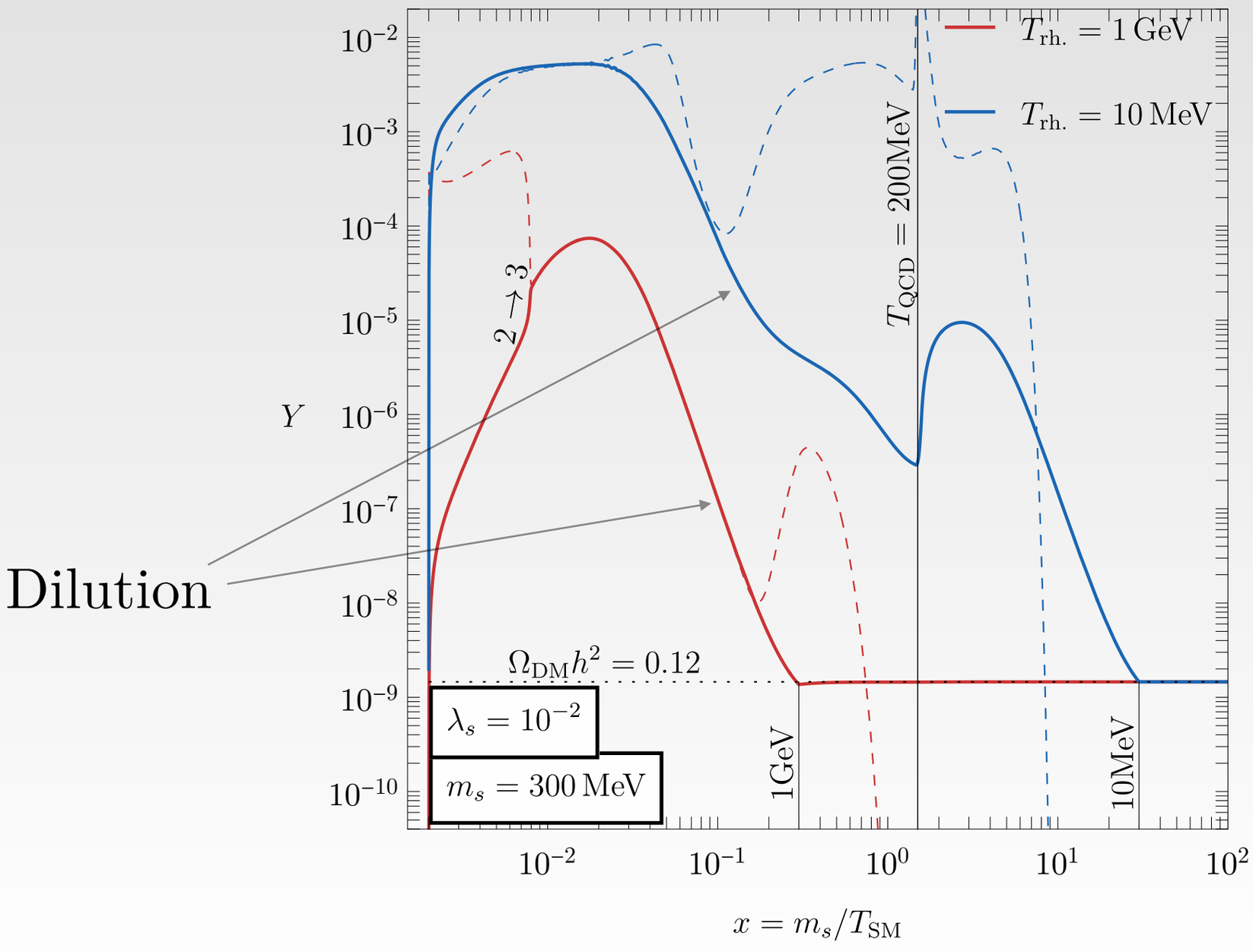
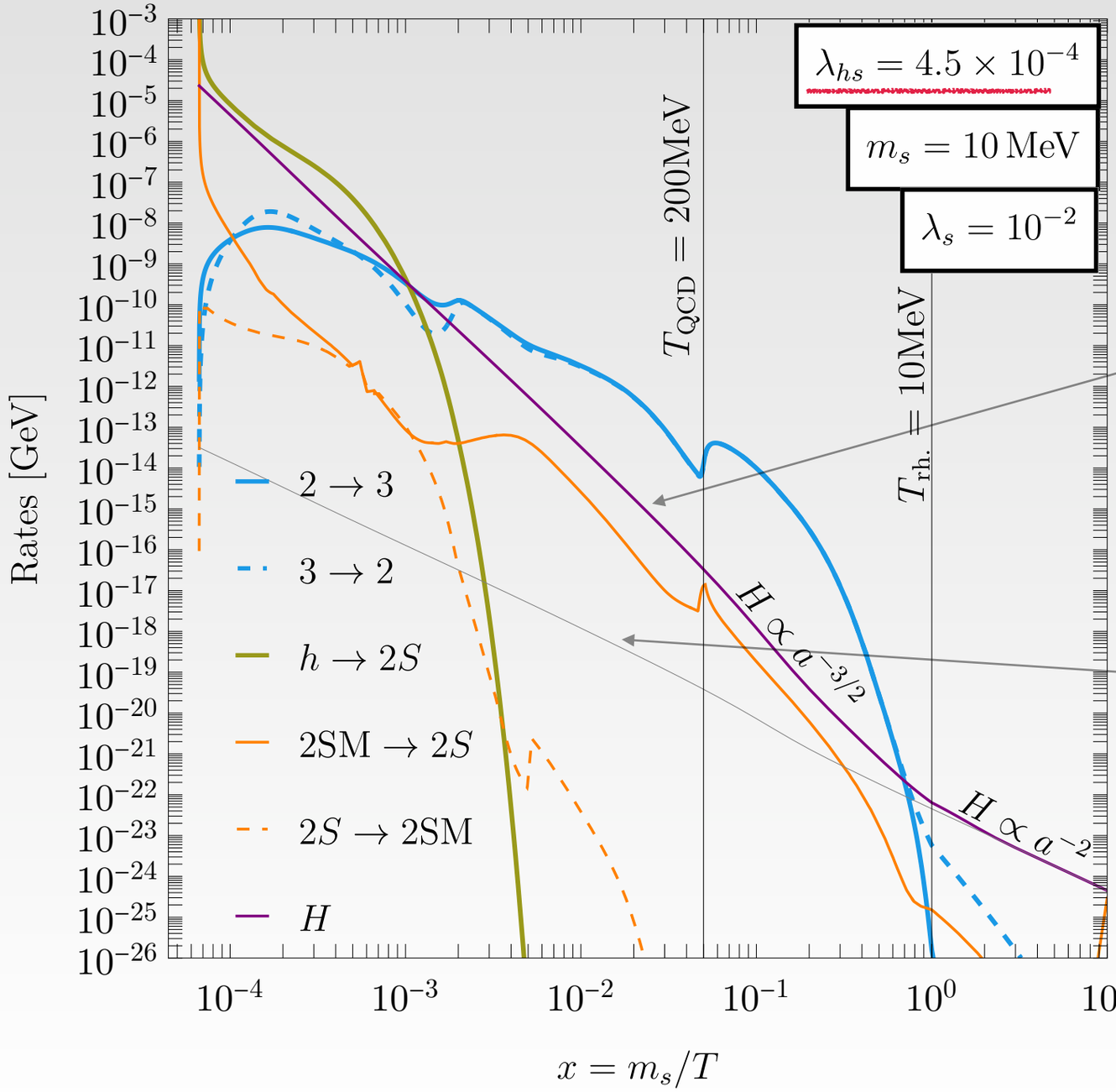


Dilution

Production during reheating

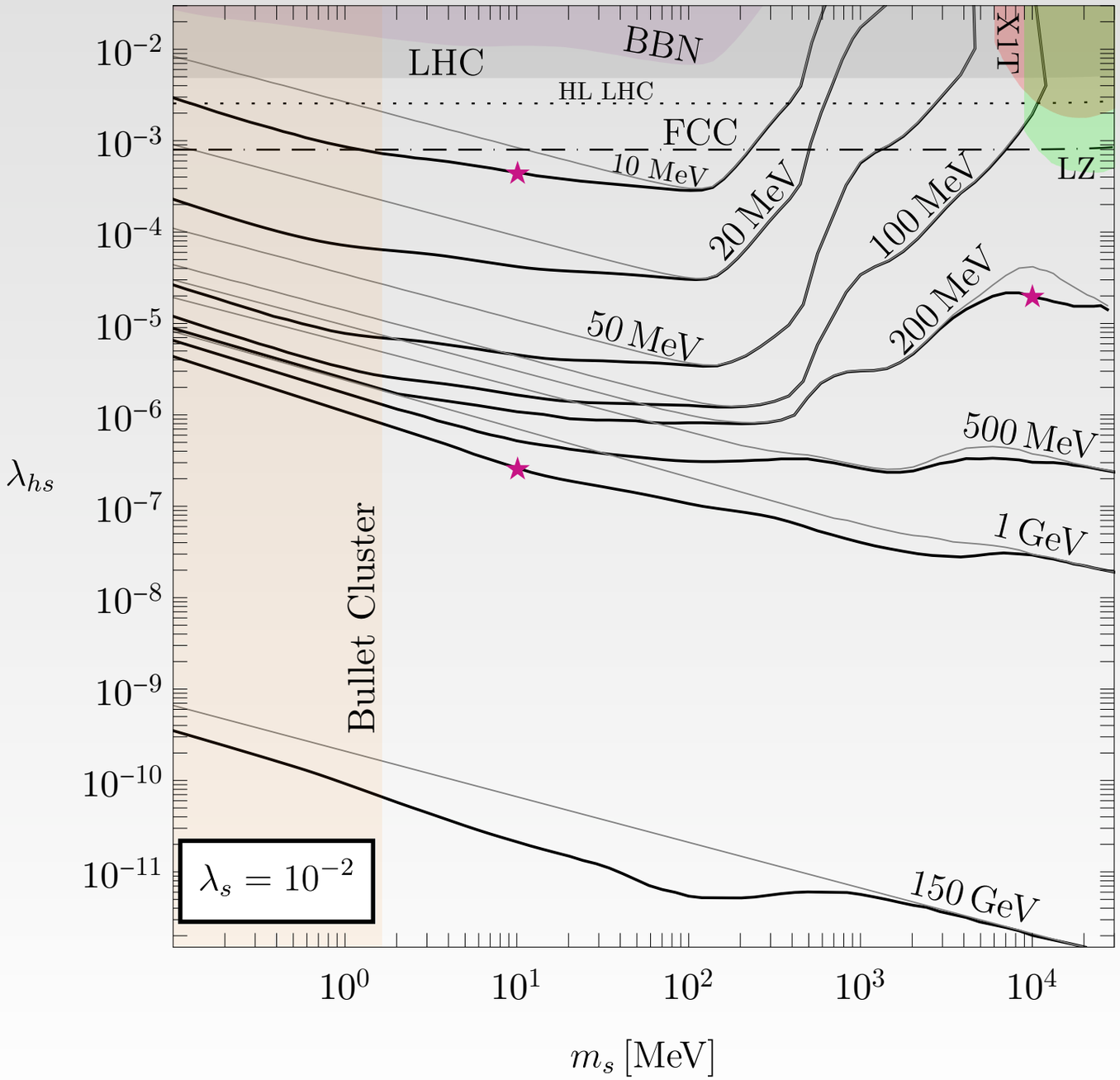
Production rate from SM has to catch up with $H \propto T^4$, and ρ_{DM} dilutes during reheating.



Non-standard

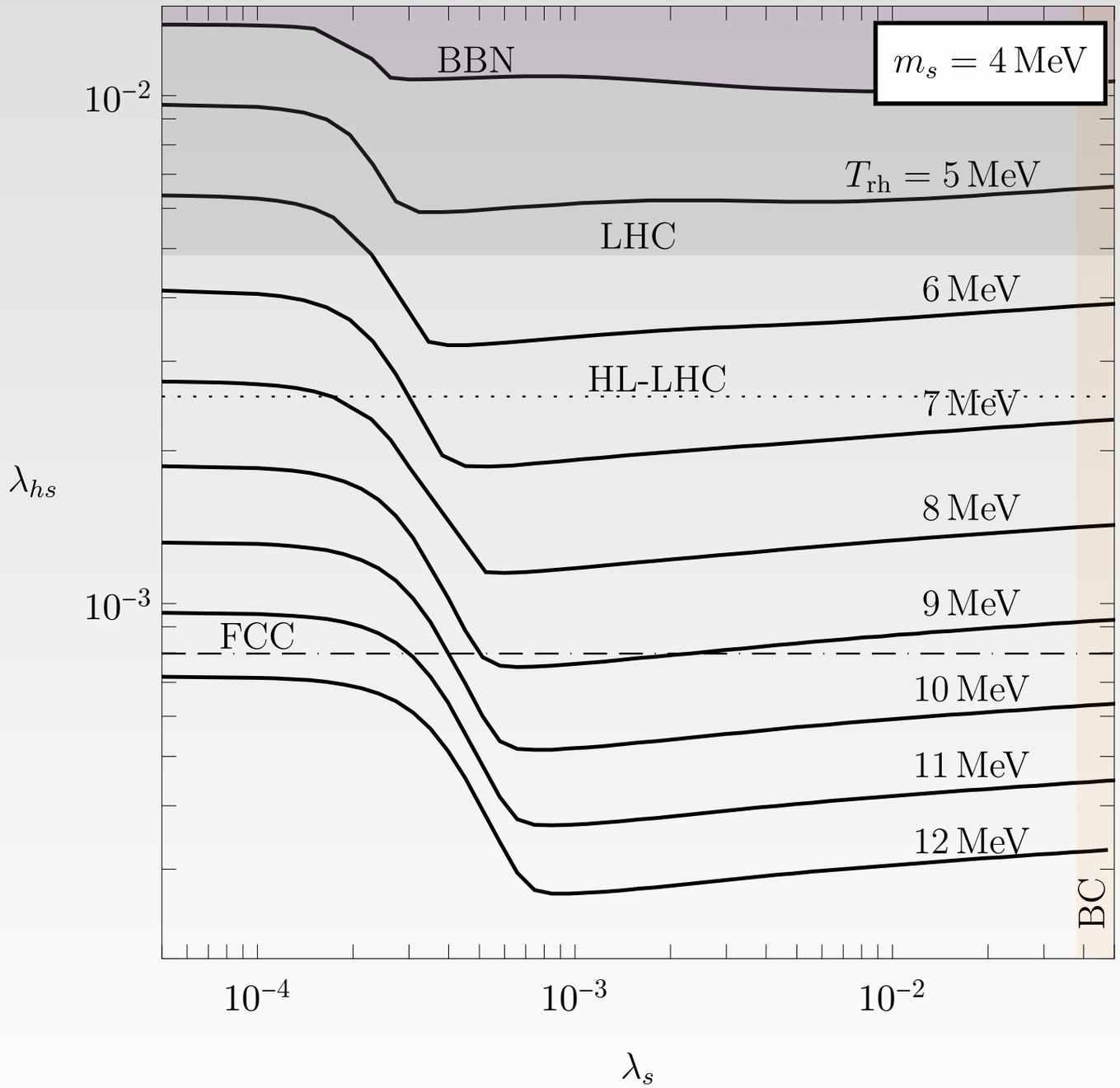
standard

Impact on collider phenomenology



- Low T_{rh} leads to detectability;
- The case of instantaneous reheating is studied in Lebedev, Morais, Oliveira, Pasechnik 24.

Self interactions with low T_{rh}



- $T_{\mathrm{rh}} = 6\,\mathrm{MeV}$ is either **excluded** or **detectable** depending on λ_s;
- $T_{\mathrm{rh}} = 11\,\mathrm{MeV}$ is either **out of reach** or **detectable** depending on λ_s;
- The peculiar behaviour of the curves is due to the $2 \to 3$ reaction overproducing DM.

Summary

- SIDM produced via the freeze-in mechanism has a unique evolution in the Early Universe;

- Temperature can have a **non-trivial** impact in such scenarios and **need to be studied** carefully;

- Non-standard cosmologies might be able to test SIDM.

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Dziękuję bardzo!

Coupled Boltzmann equations

From the fBE we can obtain a 'temperature' Boltzmann equation:

We define $T' := \dfrac{g_{dm}}{3n}\displaystyle\int \frac{d^3p}{(2\pi)^3}\frac{p^2}{E} f(p)$;

we integrate $g(2\pi)^{-3}\displaystyle\int d^3p\,\frac{p^2}{E}(\partial_t - H\vec{p}\cdot\vec{\nabla}_p)f = g(2\pi)^{-3}\int d^3p\,\frac{p^2}{E}C[f] =: C_2$;

to obtain $\dfrac{dT'}{da} = -\dfrac{2\,T'}{a} + \dfrac{1}{3\,a}\left\langle\dfrac{p^4}{E^3}\right\rangle + \dfrac{a^2}{3\,H\,N}\,C_2 - \dfrac{a^2\,T'}{H\,N}\,C_0$;

along with the usual nBE: $\dfrac{dN}{da} = \dfrac{a^2}{H}\,g\displaystyle\int\frac{d^3p}{(2\pi)^3}\,C[f] =: \frac{a^2}{H}\,C_0\,,\ N = na^3$;

we close the system by assuming $f(E,T') = \dfrac{n}{n_{\rm eq}}\,\exp\left[-\dfrac{E}{T'}\right]$.