Freezing-in Cannibal Dark Sectors

Esau Cervantes

Based on: arXiv:2407.12104

Polish Particle and Nuclear Theory Summit

IFJ-PAN

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Our starting point

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Where

$$\langle \sigma_A v \rangle := \frac{1}{g_{DM}\, n_{eq}^2} \int \frac{d^3\vec{p}_1}{(2\pi)^3} \frac{d^3\vec{p}_2}{(2\pi)^3} \sigma_A v f_1^{eq} f_2^{eq}$$

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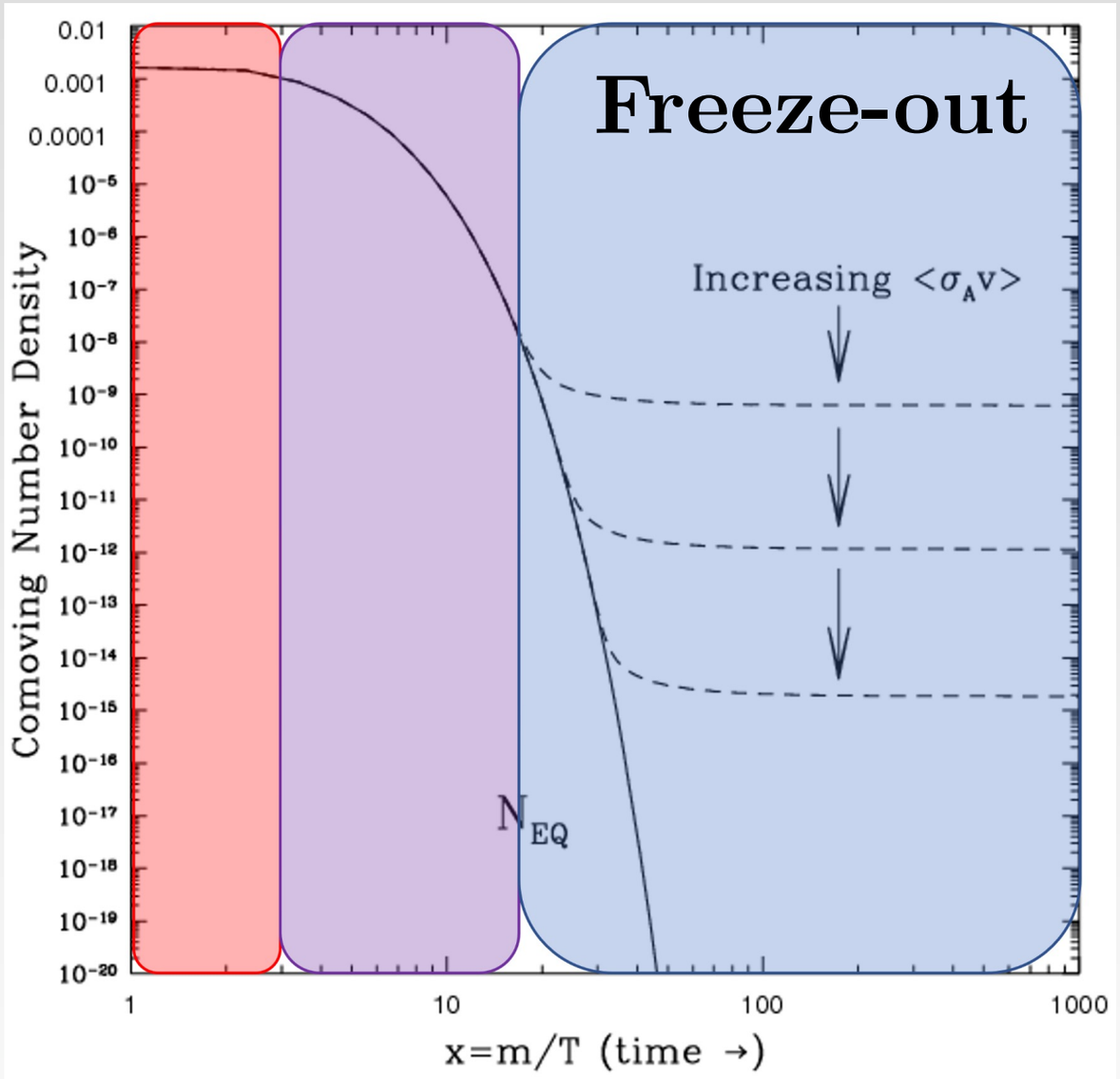

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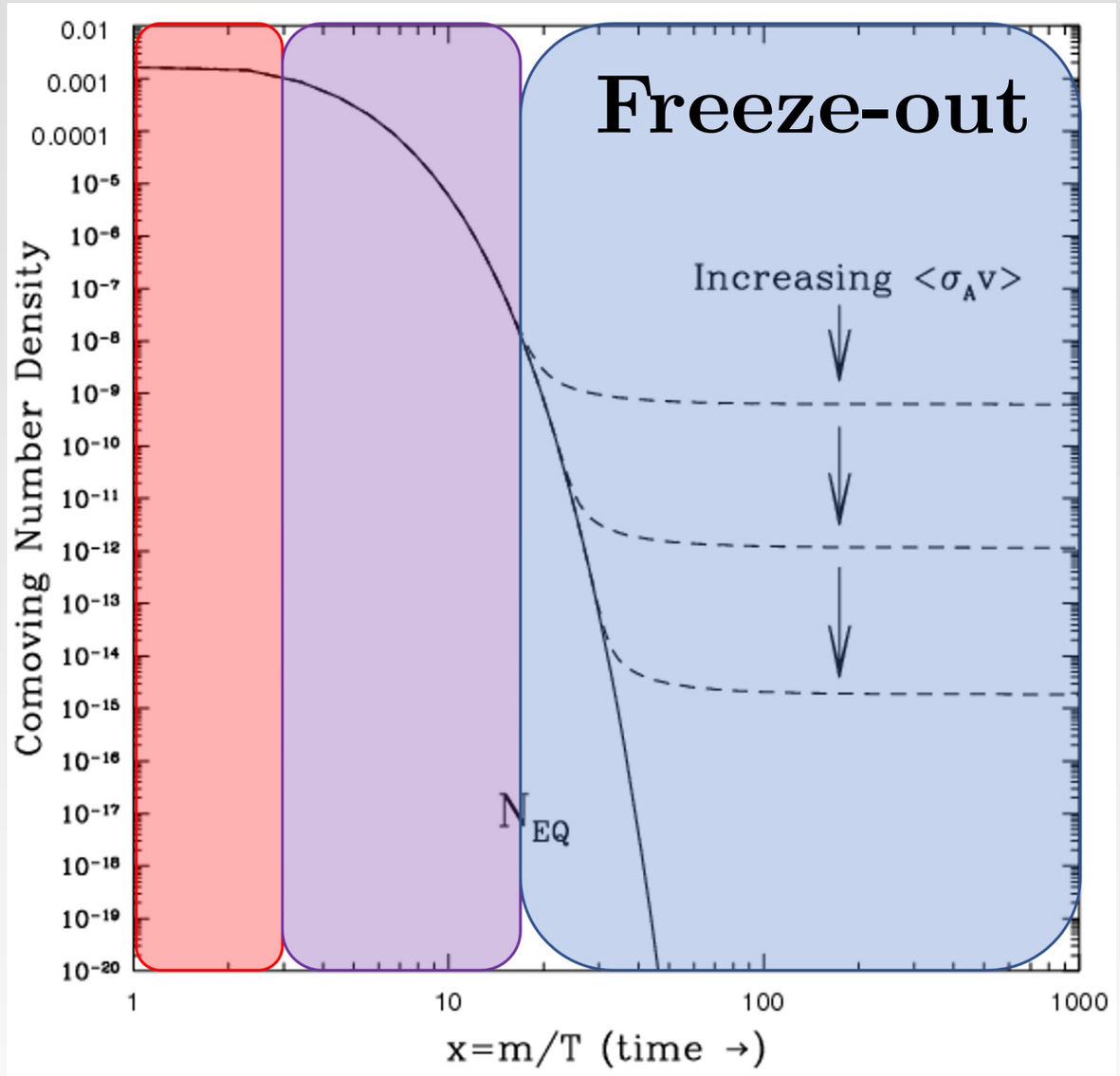

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Implicit assumptions: $f_i = (e^{-(E_i-\mu_i)/T_i} \pm 1)^{-1}$ and $T_i = T_{SM}$ (kinetic eq.)

The WIMP dillution

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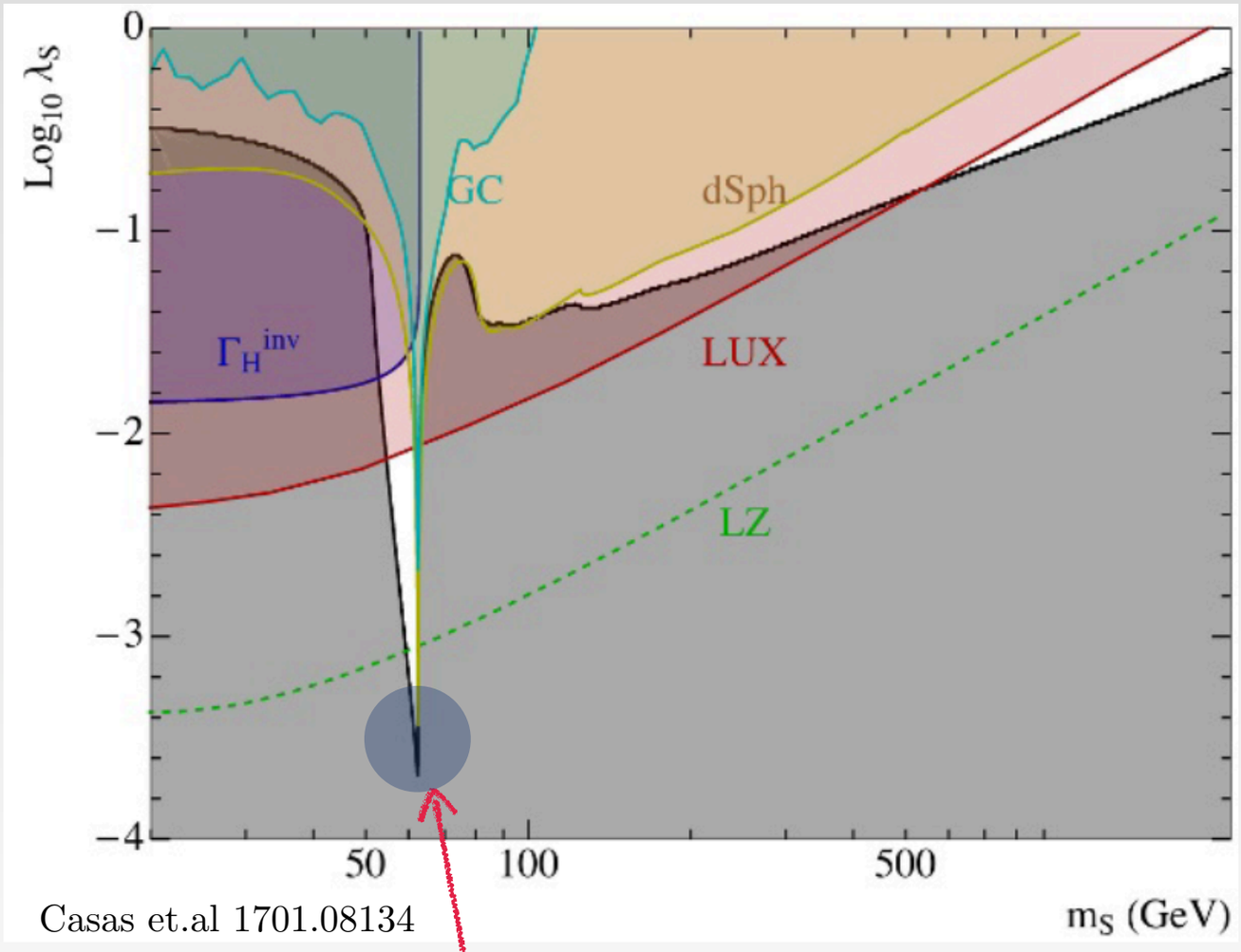

Casas et.al 1701.08134

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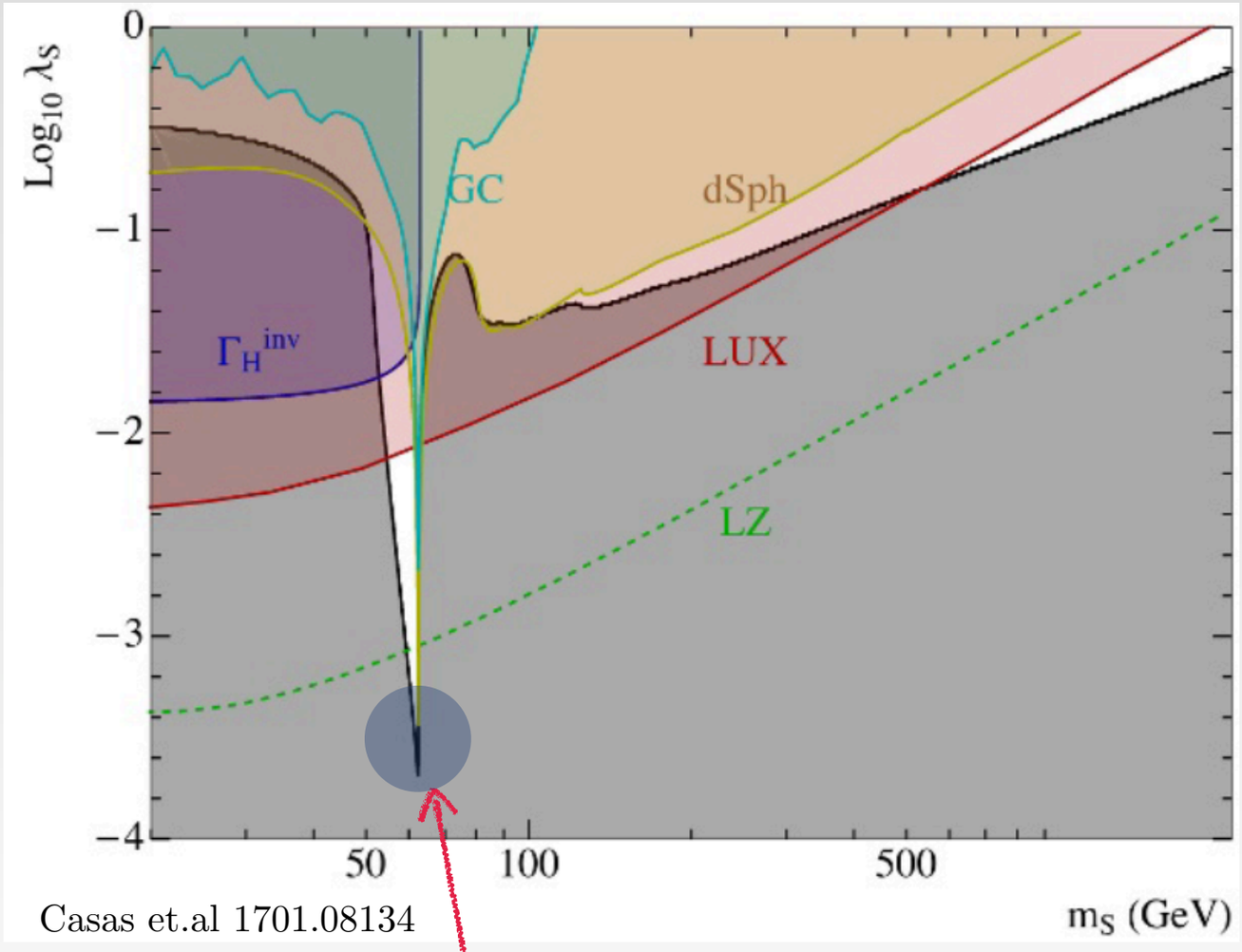

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What **now**?

'Remaining' parameter space around Higgs resonance $m_S \sim m_h/2$

Self Interacting Dark Matter

SELF-INTERACTING DARK MATTER

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AND
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Department of Physics, University of California; and Theoretical Physics Group, Physics Division, Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, CA 94720
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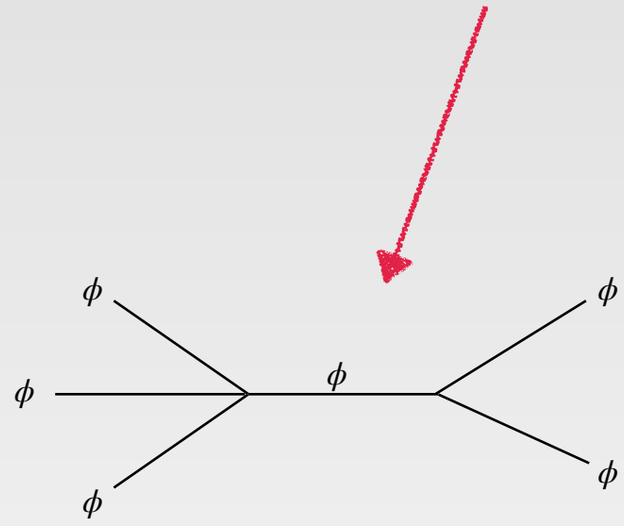

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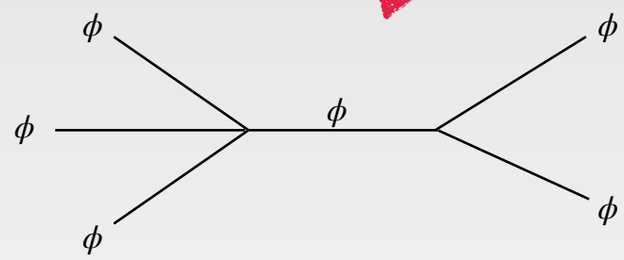

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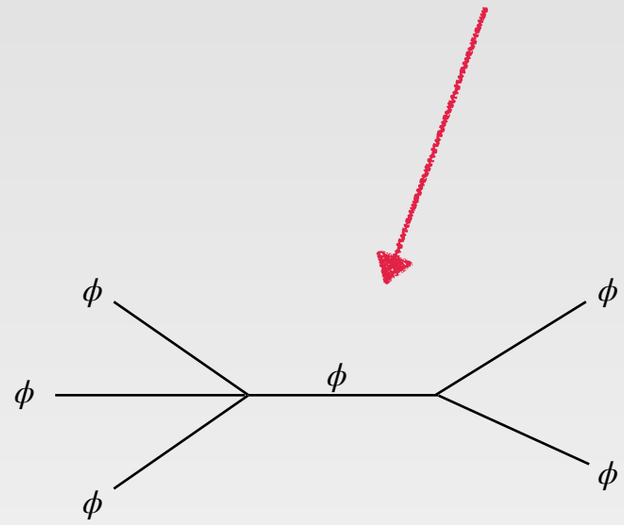

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Conservation of energy leads to *faster moving* (hotter) DM states;

i.e.; the DM fluid **exchanges** number density for kinetic energy!

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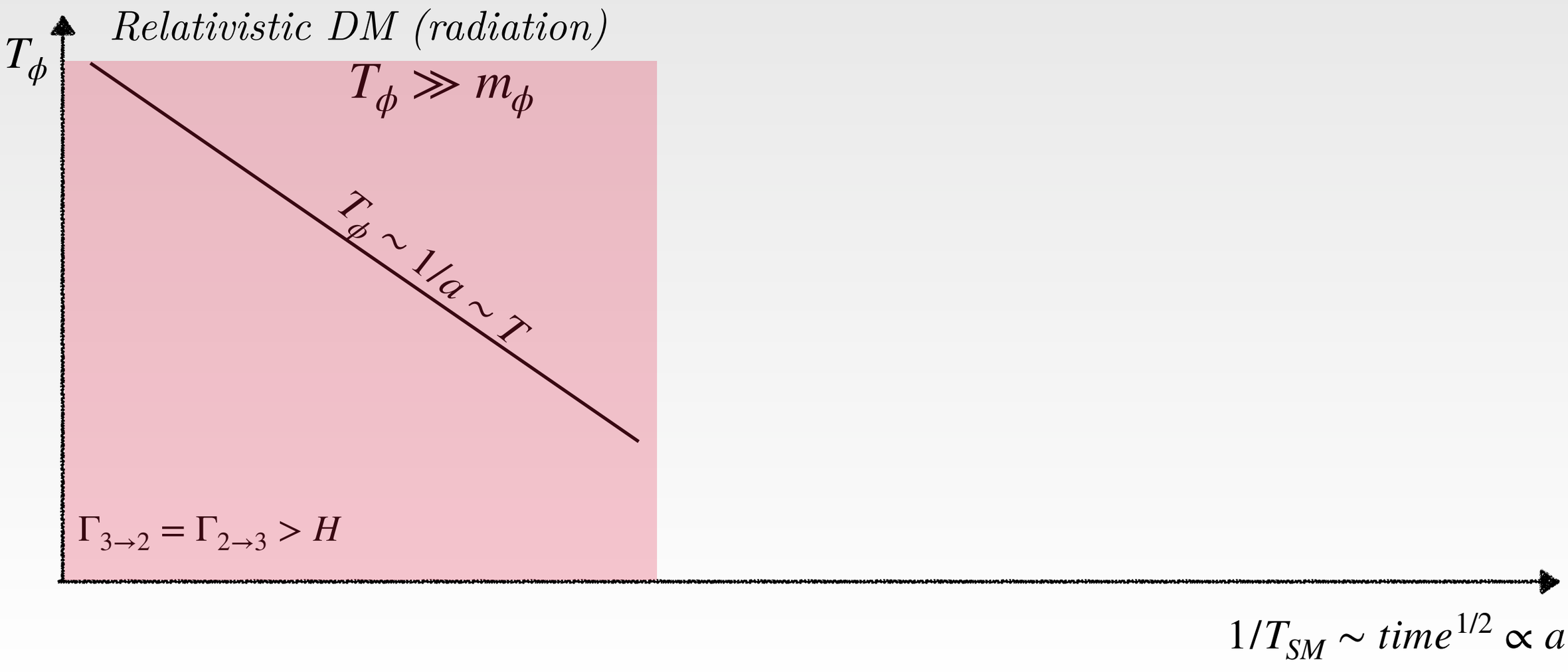

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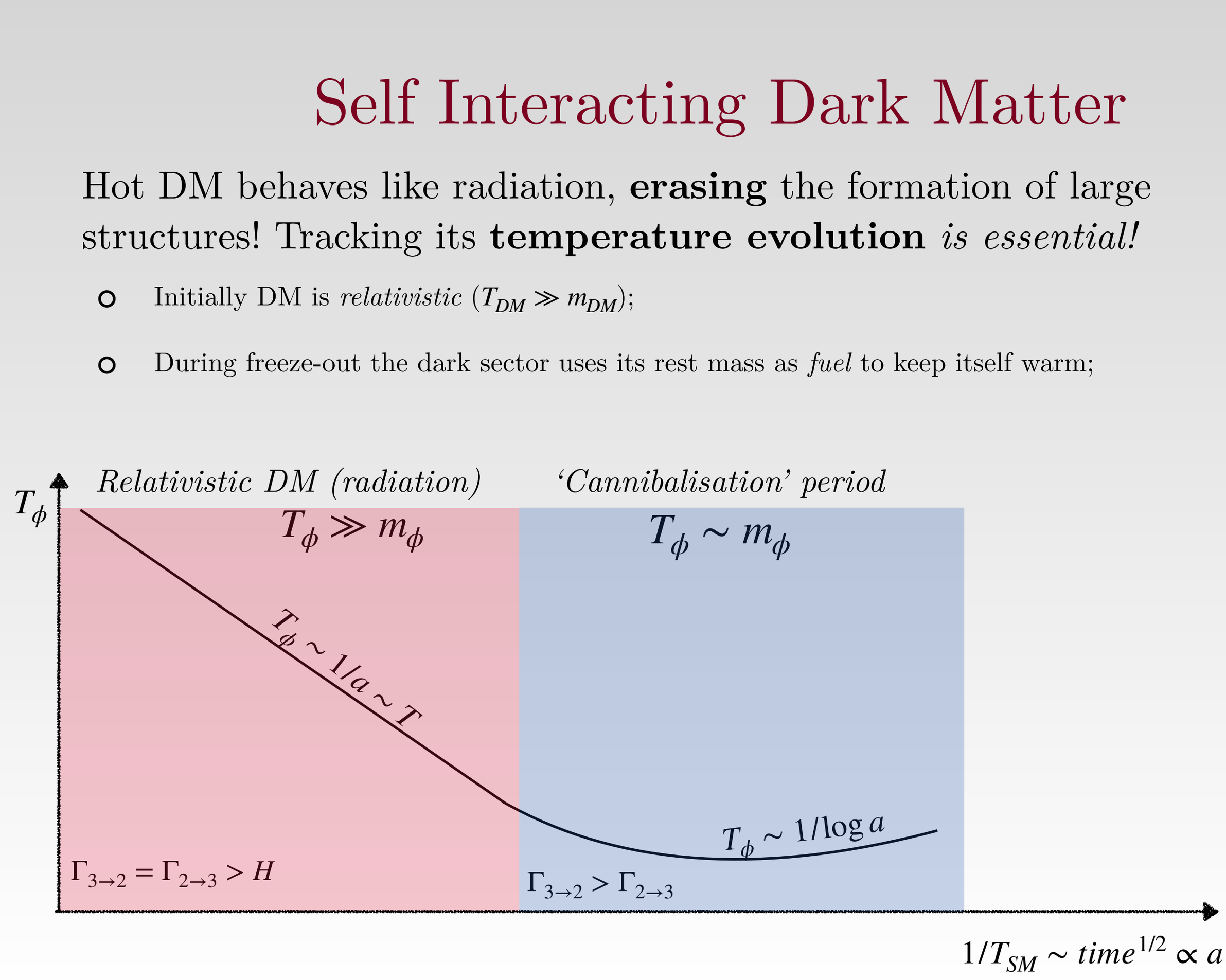

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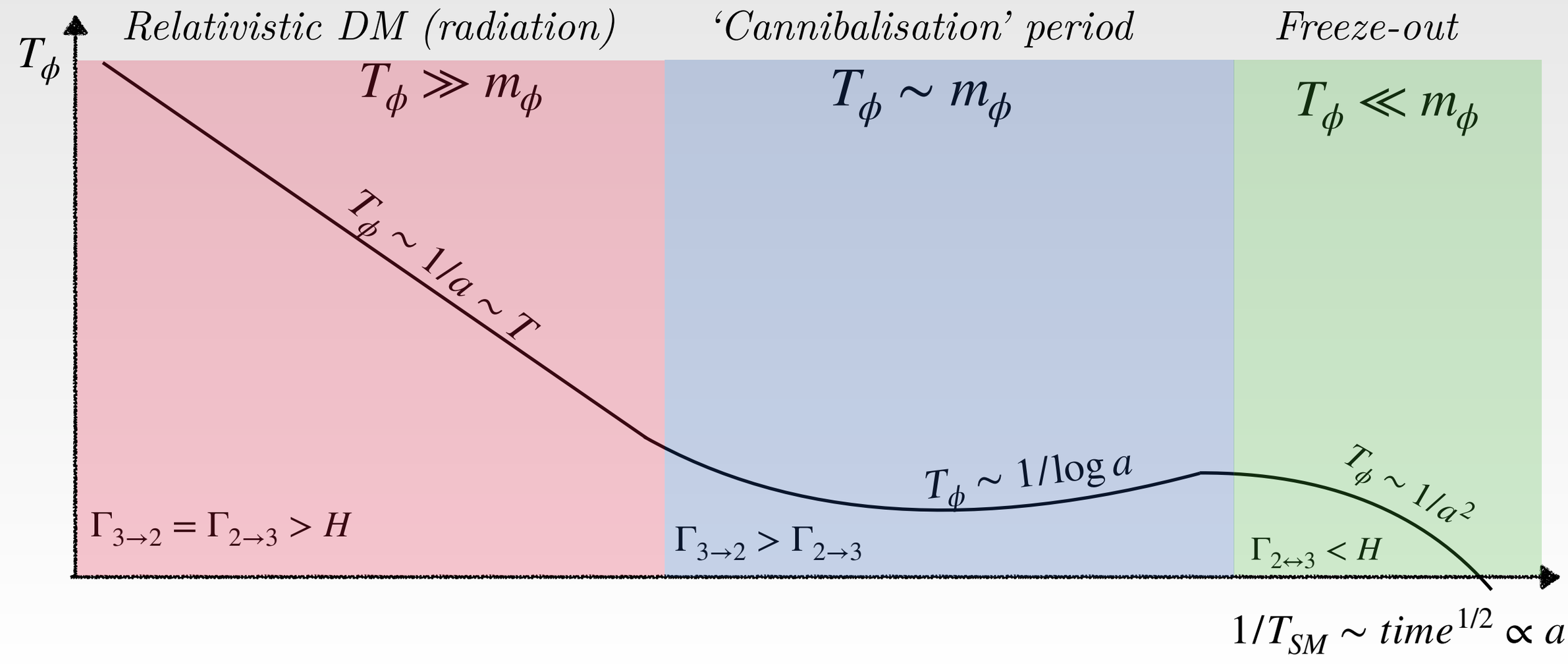
- The system decouples and behaves as a non-relativistic gas.



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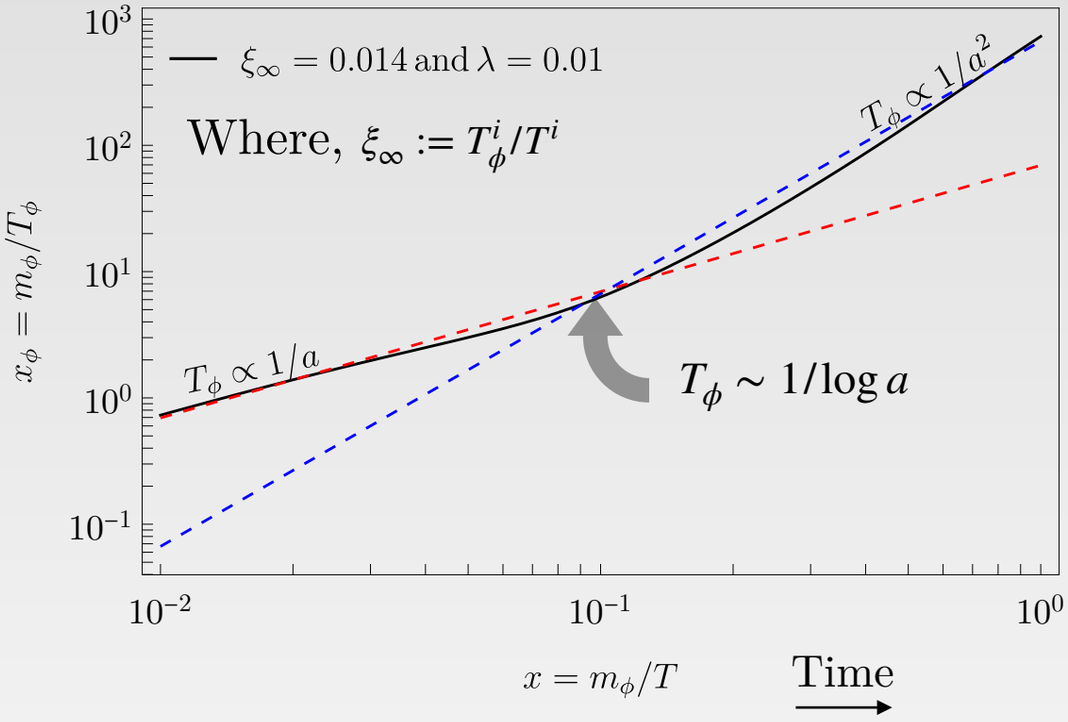

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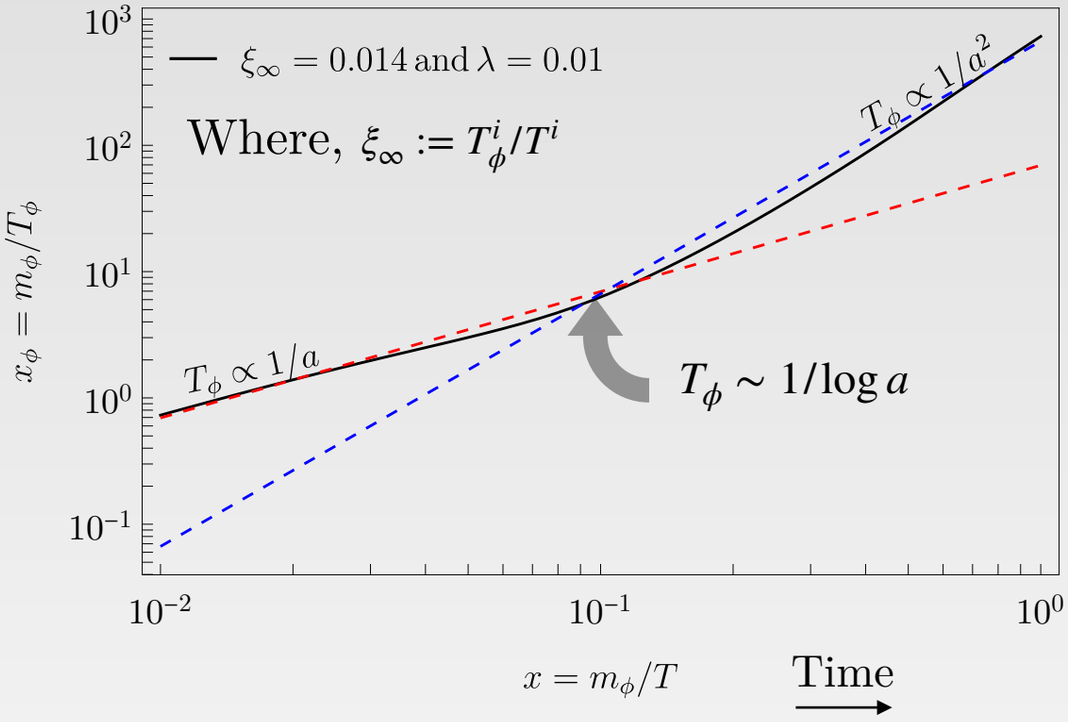

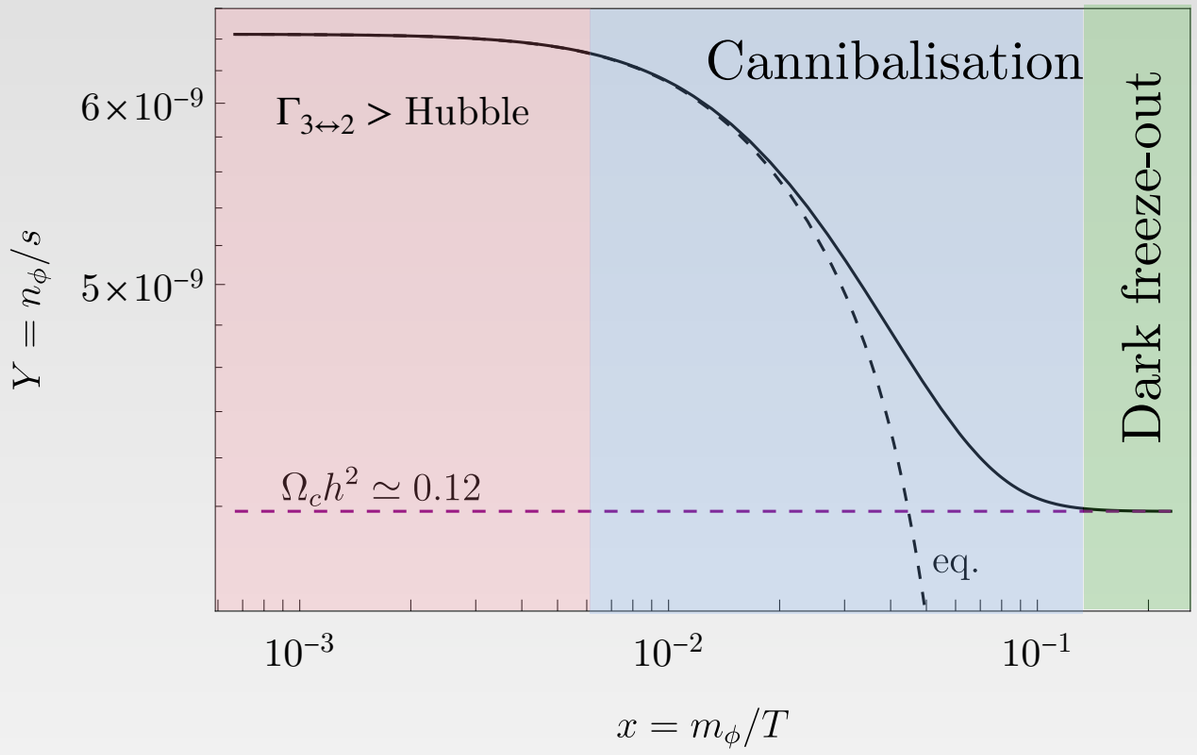

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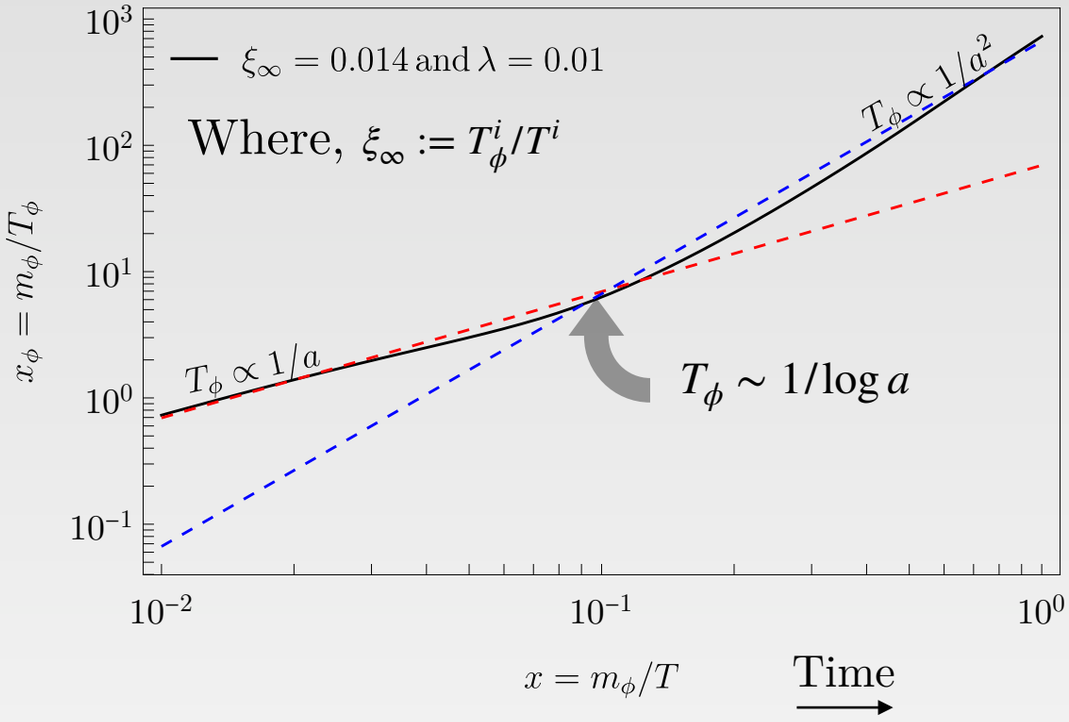

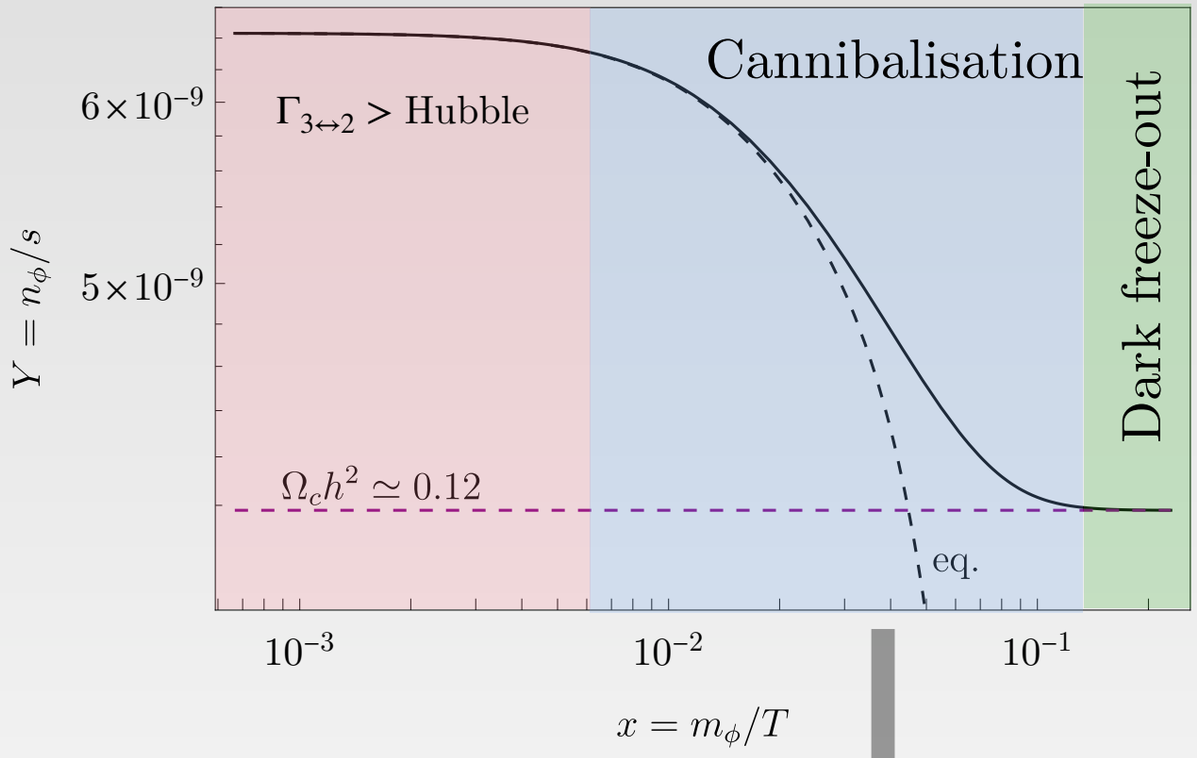

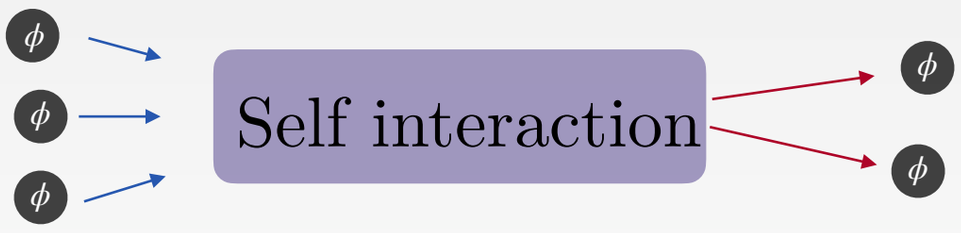

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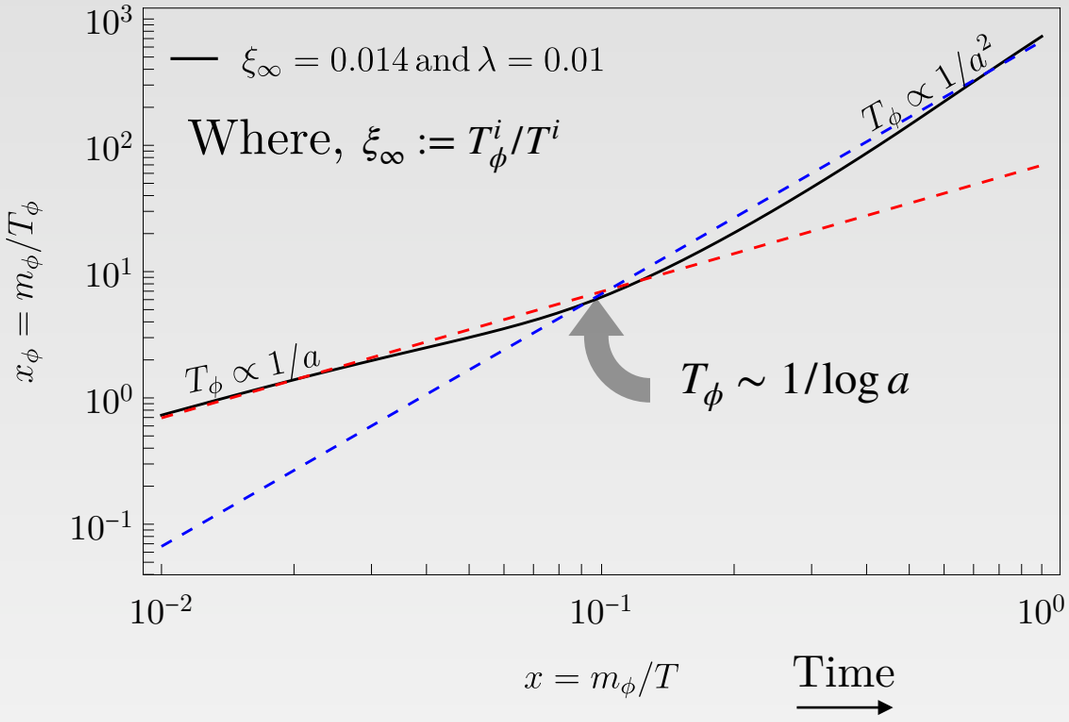

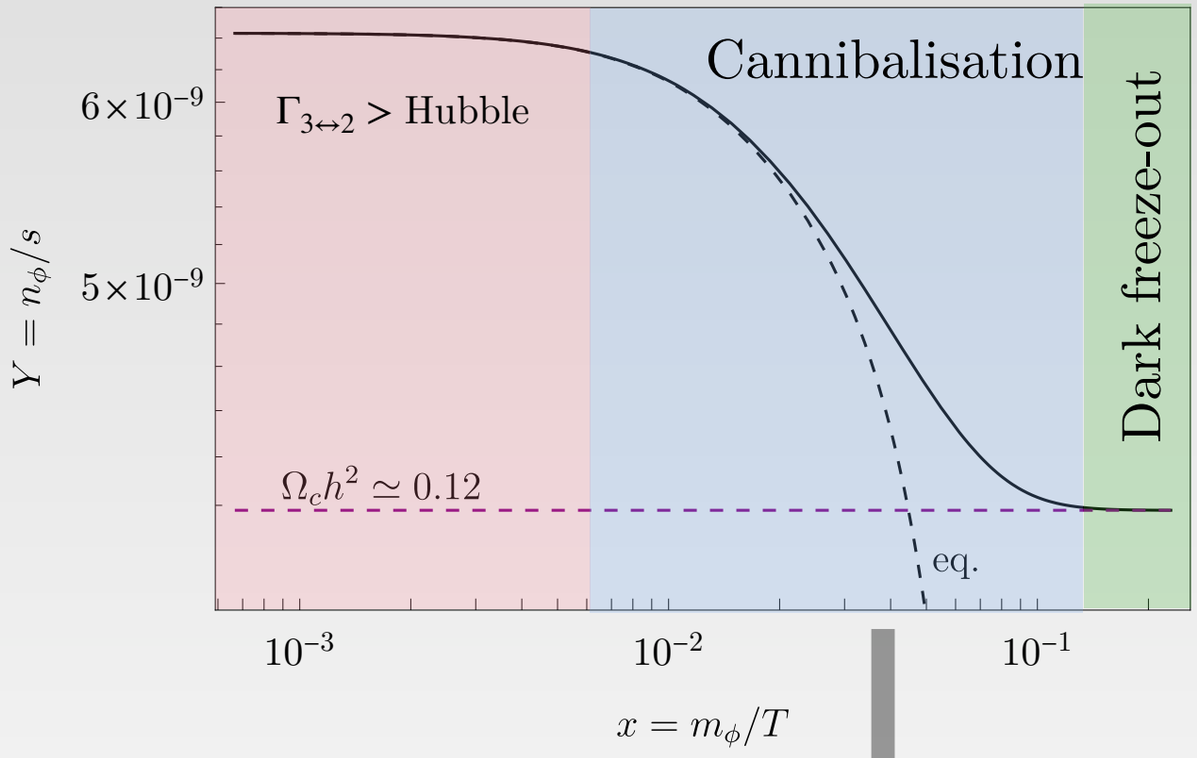

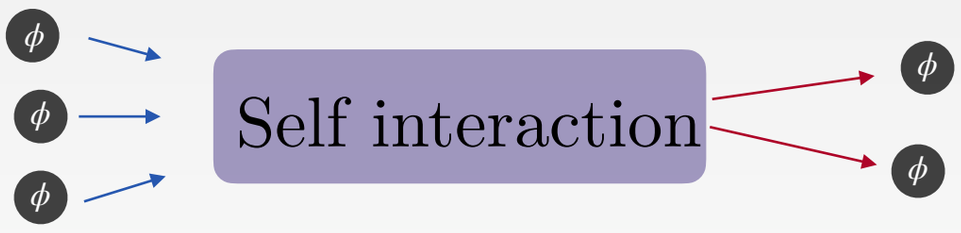

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→ Is the **reverse** possible?

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$$V(\varphi + v_\varphi) \supset \frac{\lambda v_\varphi}{3!}\varphi^3 + \frac{\lambda}{4!}\varphi^4 + \text{Higgs mix.} \longrightarrow \tau_\varphi \text{ strongly constrained by observations.}$$

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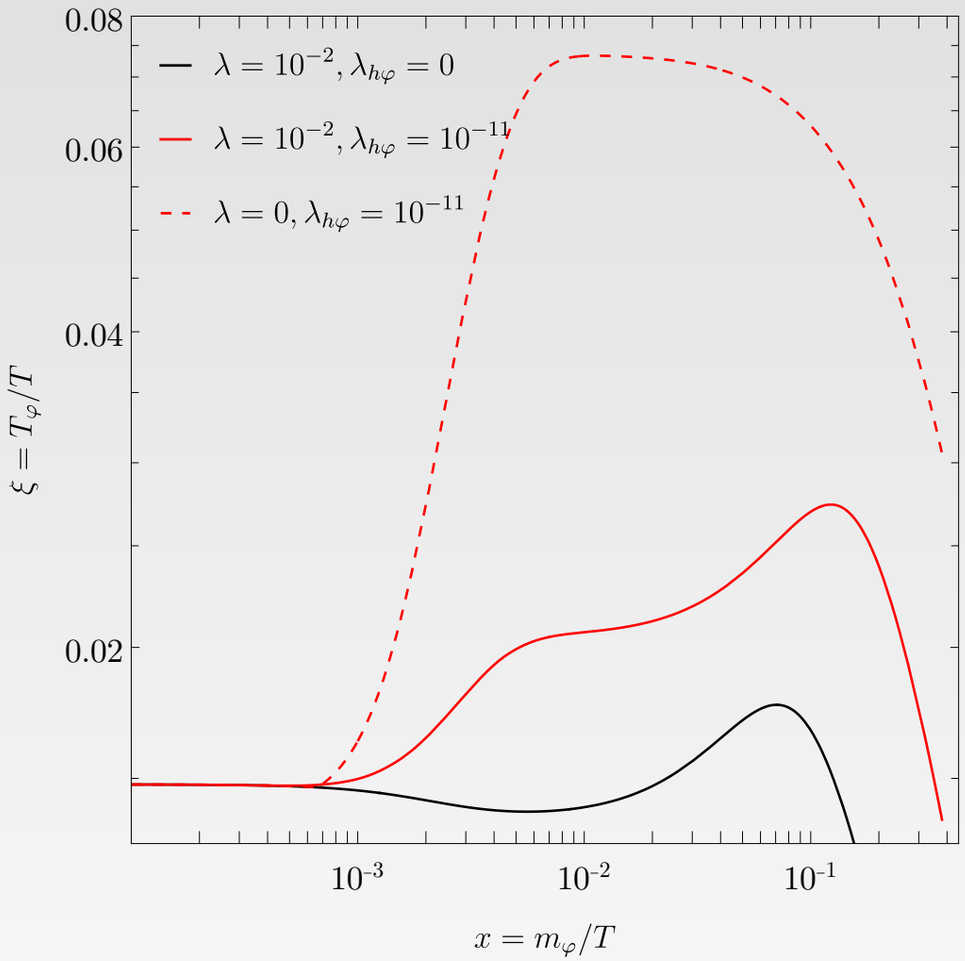

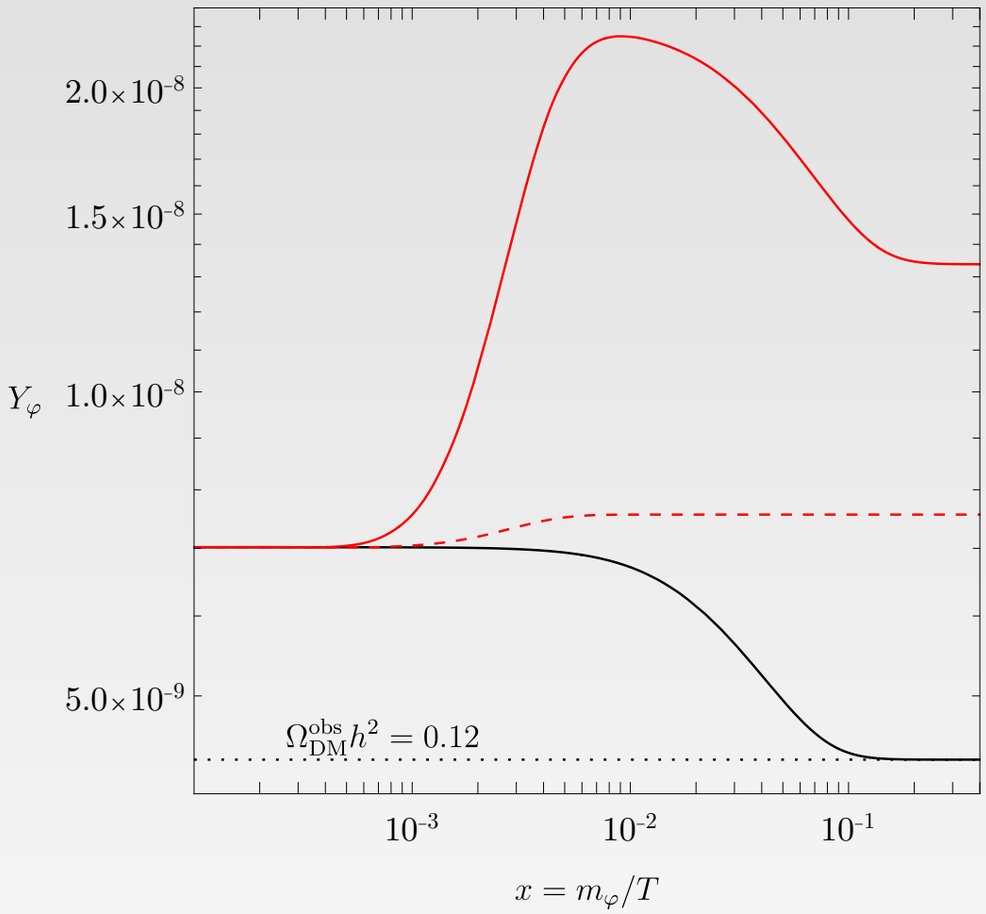

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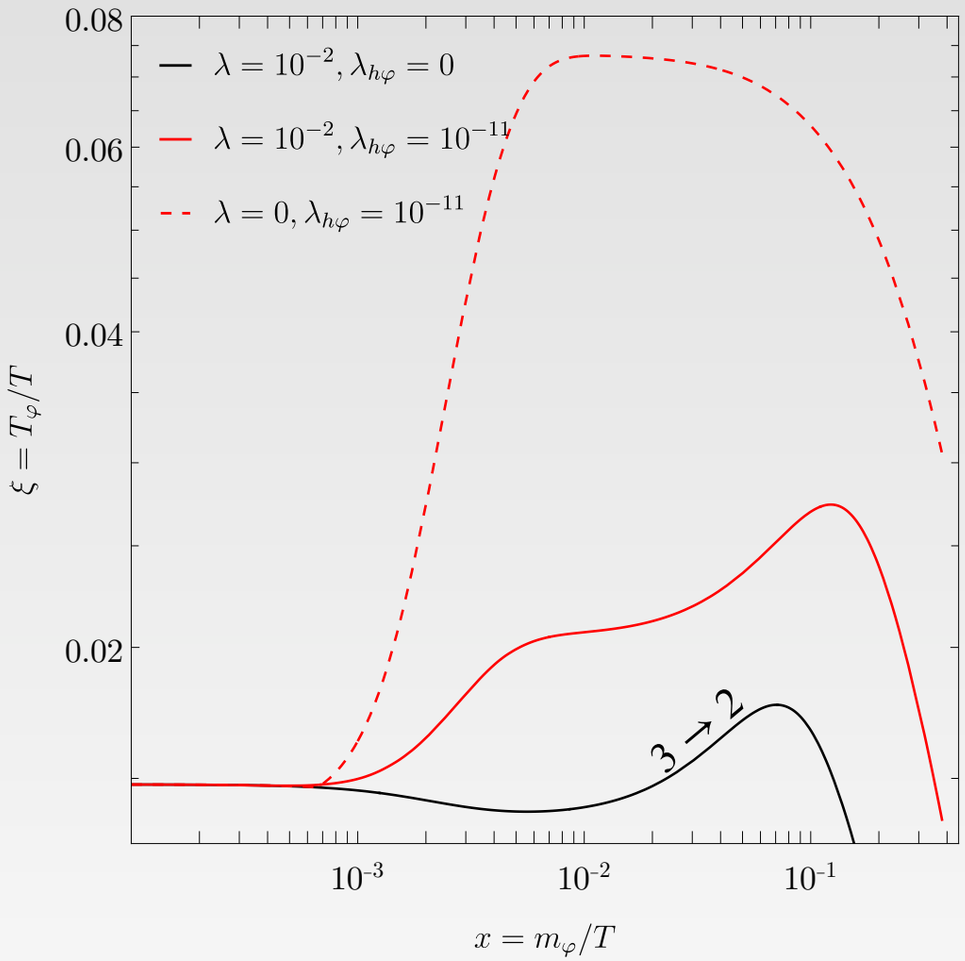

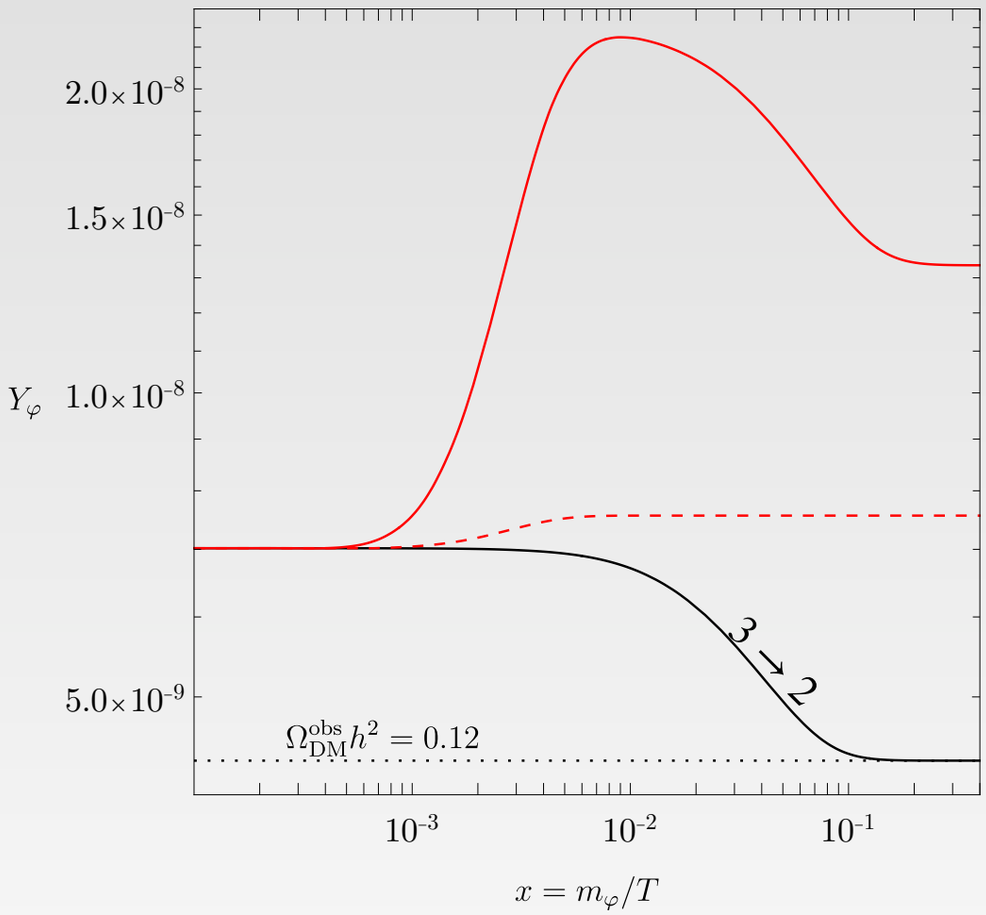

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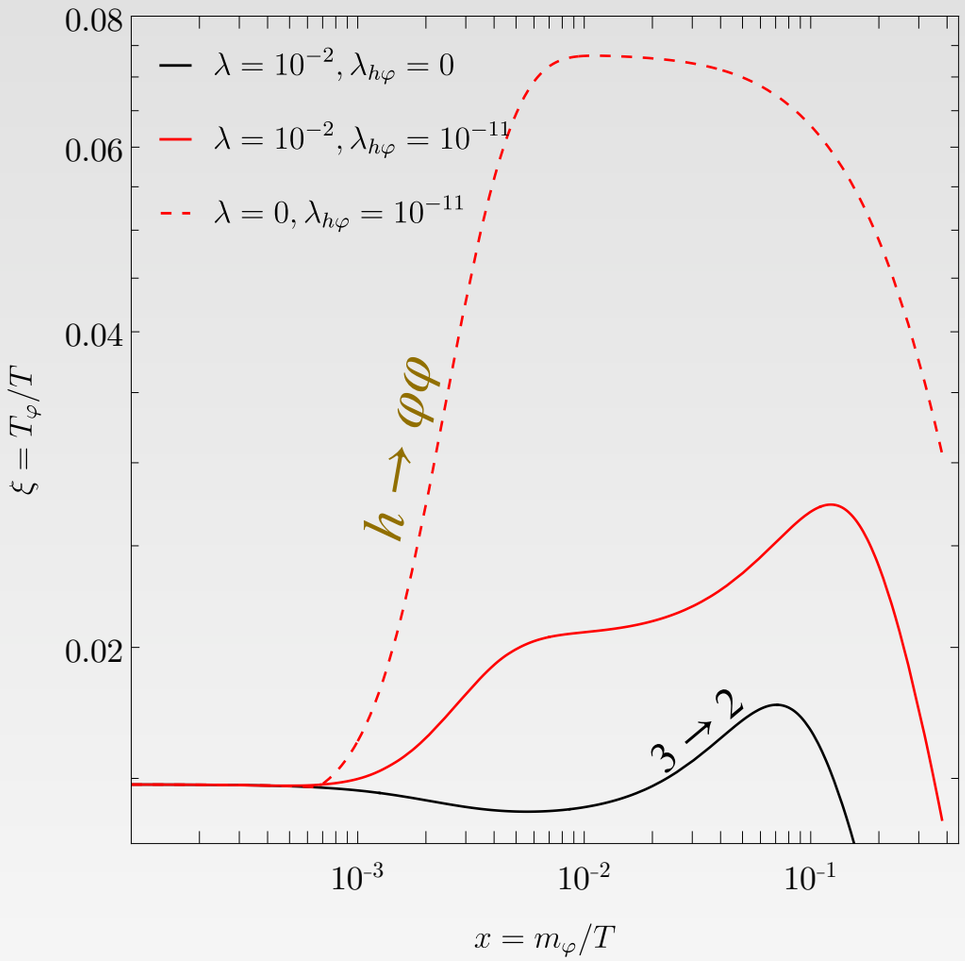

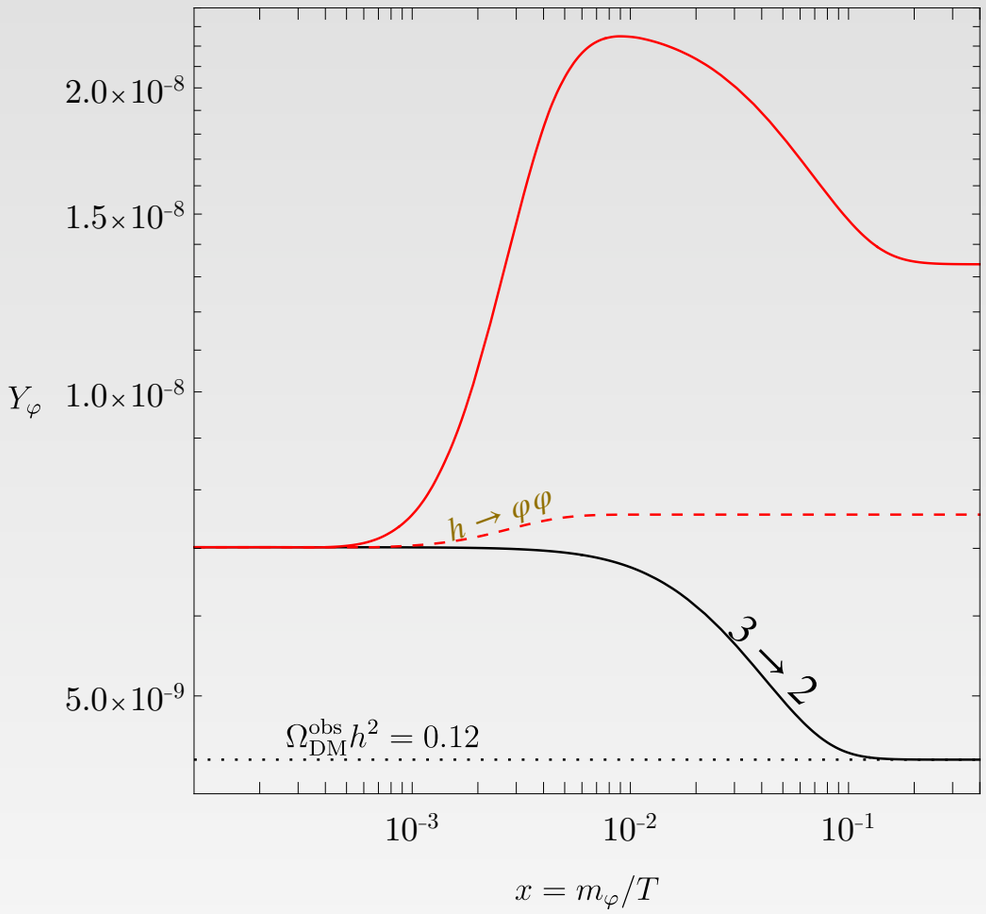

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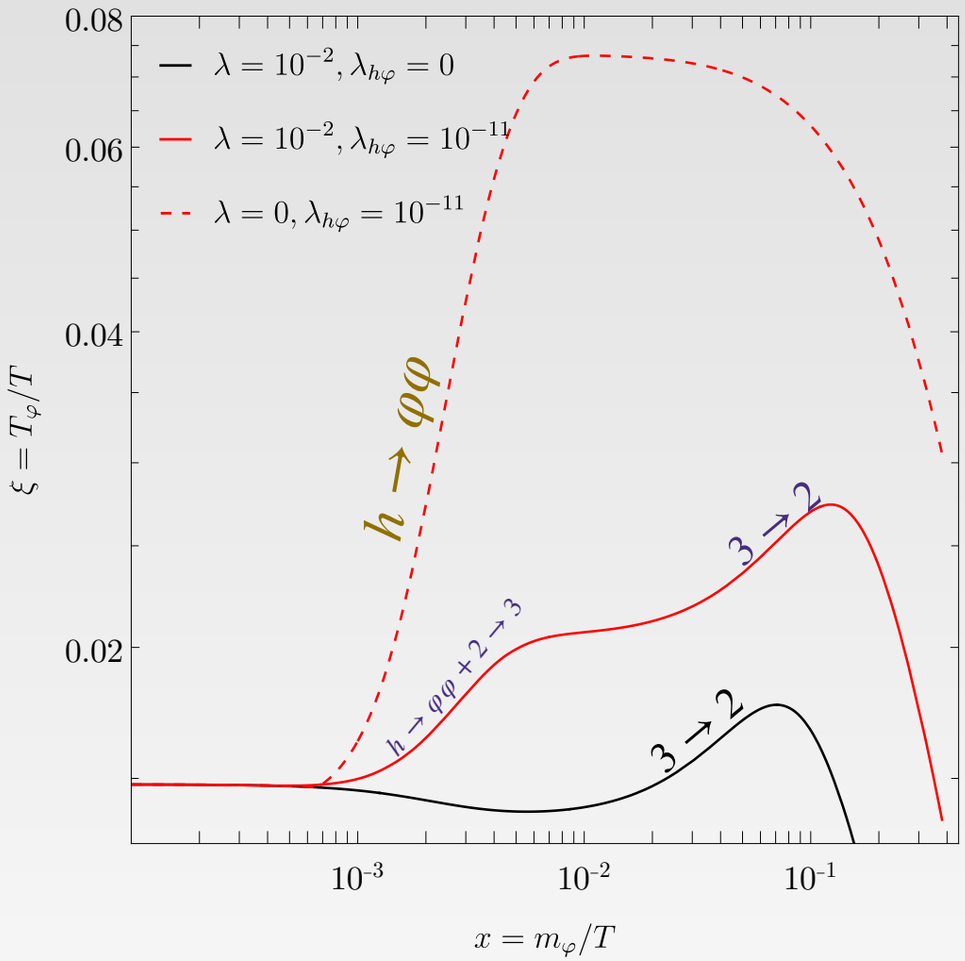

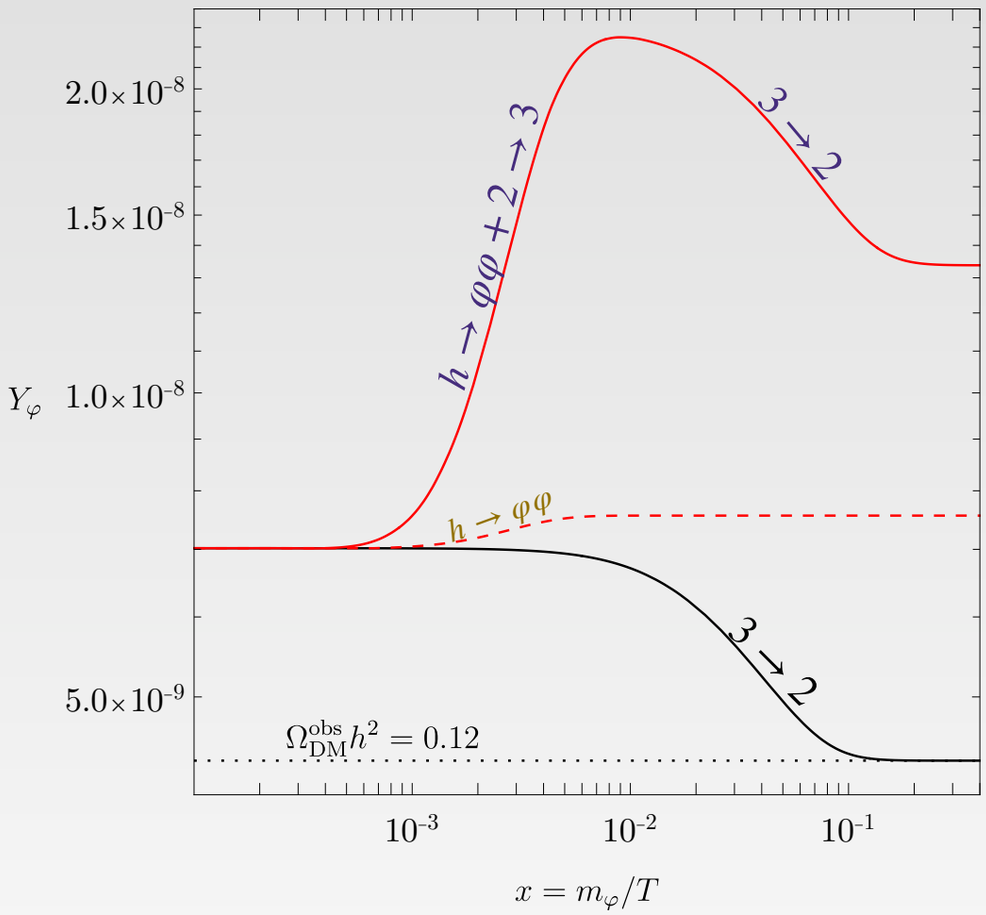

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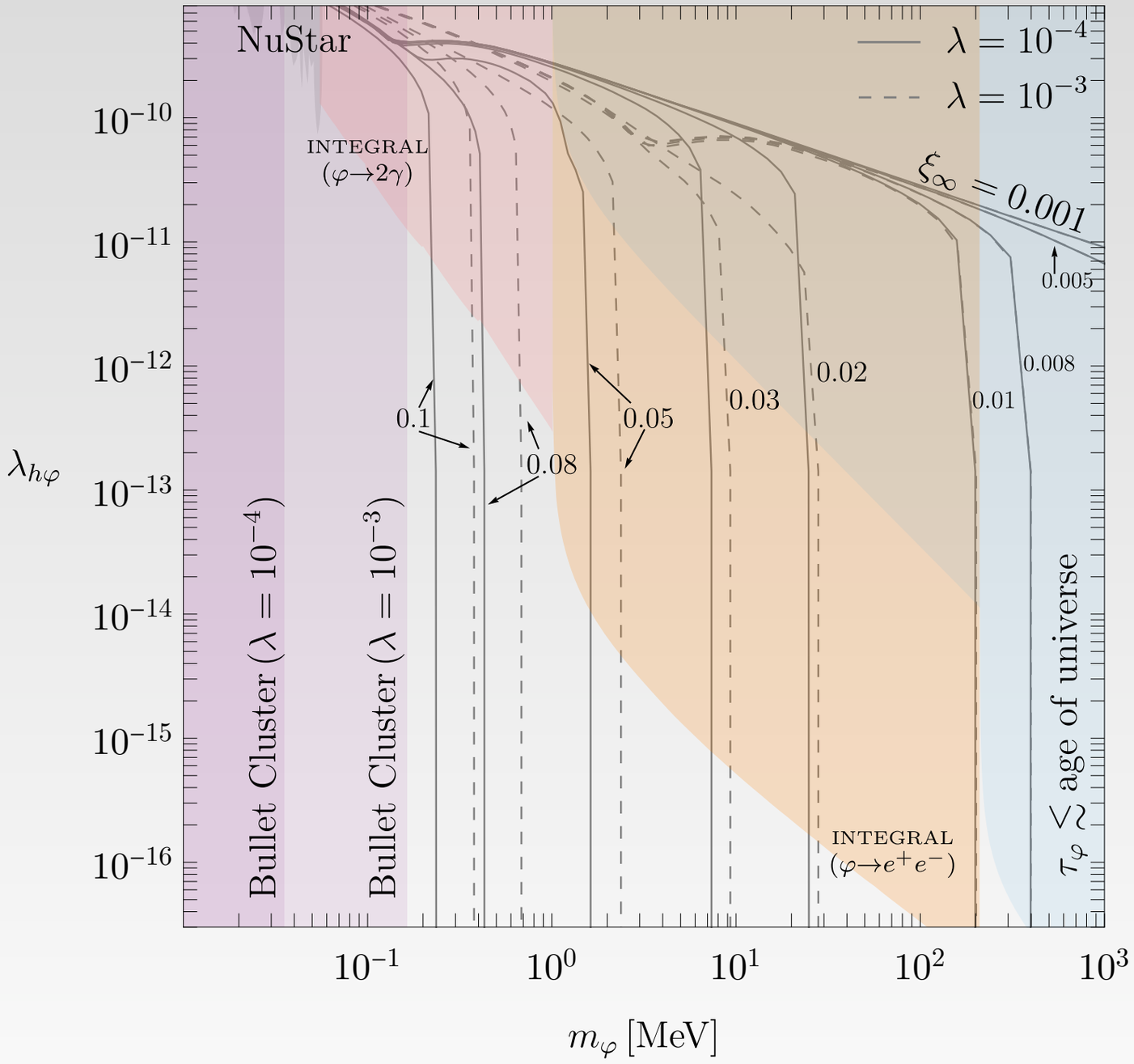

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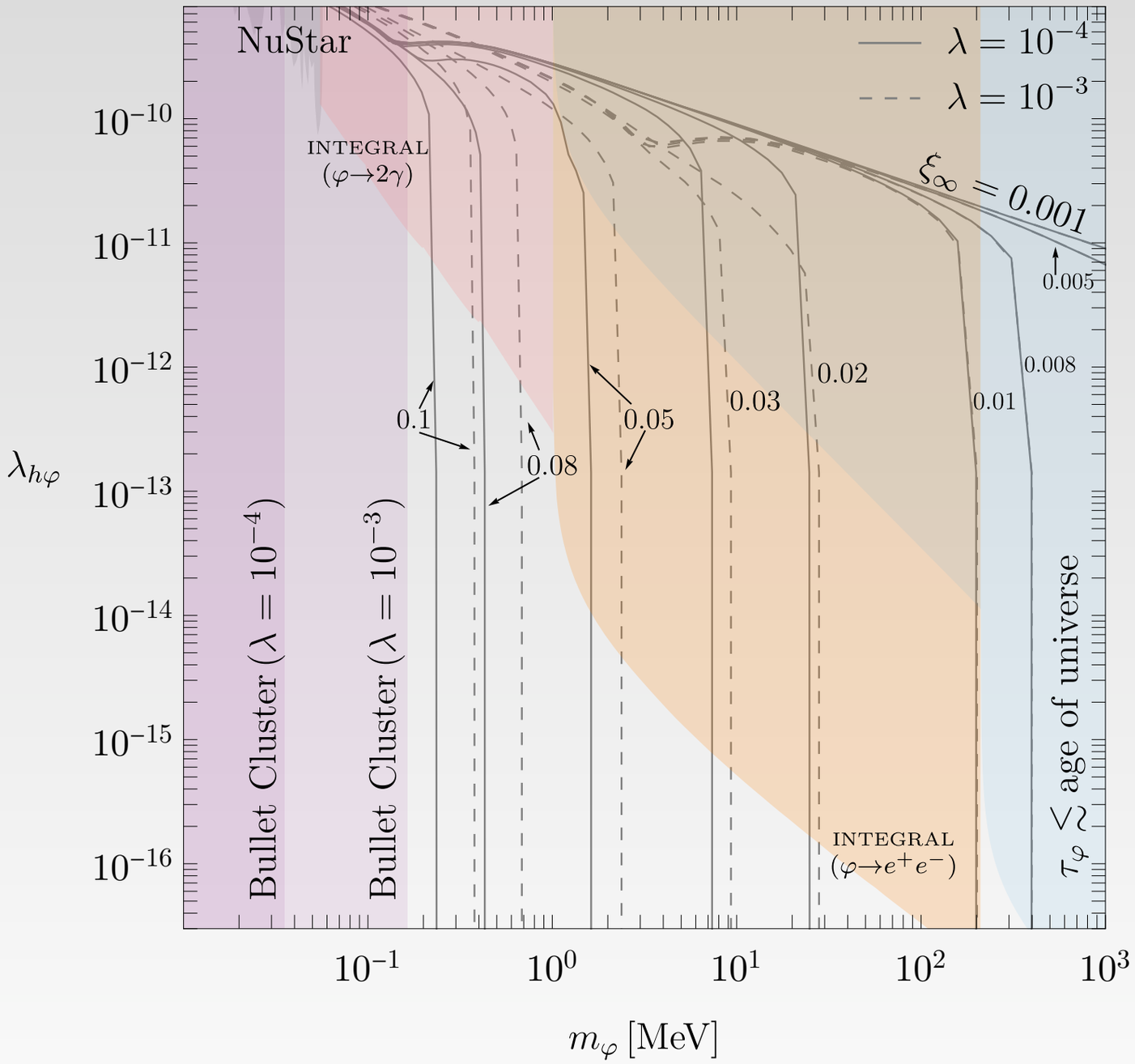

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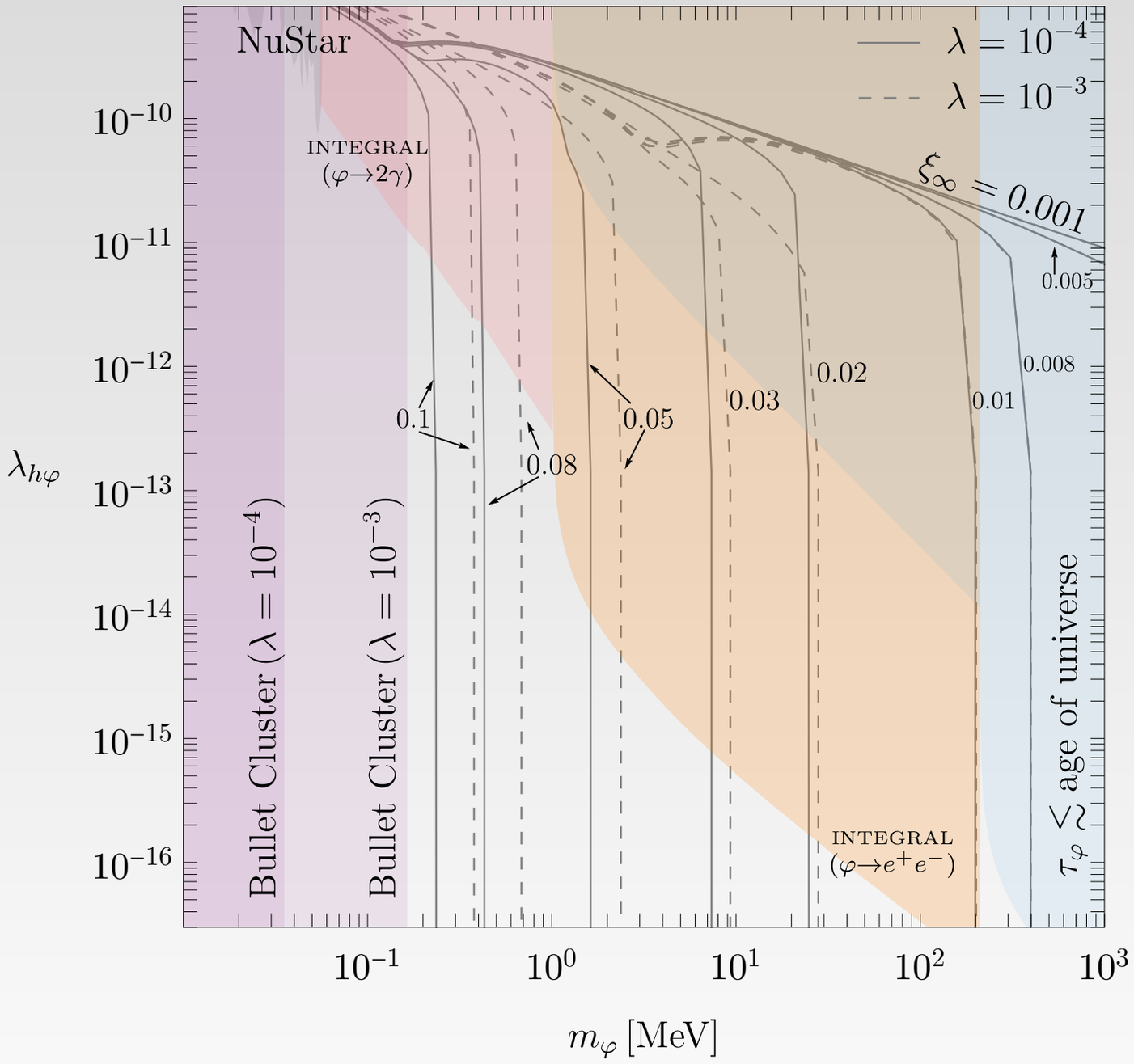

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Expected results... this mark the starting point for a more interesting scenario.

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→ ϕ couples to matter as a second Higgs

Dynamics

DM dynamical evolution

$$\frac{Y_S'}{Y_S} = \frac{1}{x\,\tilde{H}}\left(\langle C_{h\to\phi SS^*}\rangle + \langle C_{h\to SS^*}\rangle + \langle C_{\phi\phi\leftrightarrow SS^*}\rangle + \langle C_{3\leftrightarrow 2}\rangle\right), \text{ Amount of DM}$$

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DM temperature

Dynamics

DM dynamical evolution

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DM temperature

Mediator dynamical evolution

$$\frac{Y_\phi'}{Y_\phi} = \frac{1}{x\,\tilde{H}}\left(\langle C_{h\to\phi SS^*}\rangle + \langle C_{\mathrm{sm\,sm}\to\mathrm{sm}\,\phi}\rangle + \langle C_{\phi\phi\leftrightarrow SS^*}\rangle\right), \quad \text{Amount of mediators}$$

Dynamics

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ϕ temperature

Dynamics

Freeze-in (populating the dark sector)

DM dynamical evolution

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DM temperature

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ϕ temperature

Dynamics

Freeze-in (populating the dark sector)
DM-mediator interactions

DM dynamical evolution

$$\frac{Y_S'}{Y_S} = \frac{1}{x\,\tilde{H}}\left(\langle C_{h\to\phi SS^*}\rangle + \langle C_{h\to SS^*}\rangle + \langle C_{\phi\phi\leftrightarrow SS^*}\rangle + \langle C_{3\leftrightarrow 2}\rangle\right), \quad \text{Amount of DM}$$

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ϕ temperature

Dynamics

- Freeze-in (populating the dark sector)
- DM-mediator interactions
- DM self-interactions

DM dynamical evolution

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DM temperature

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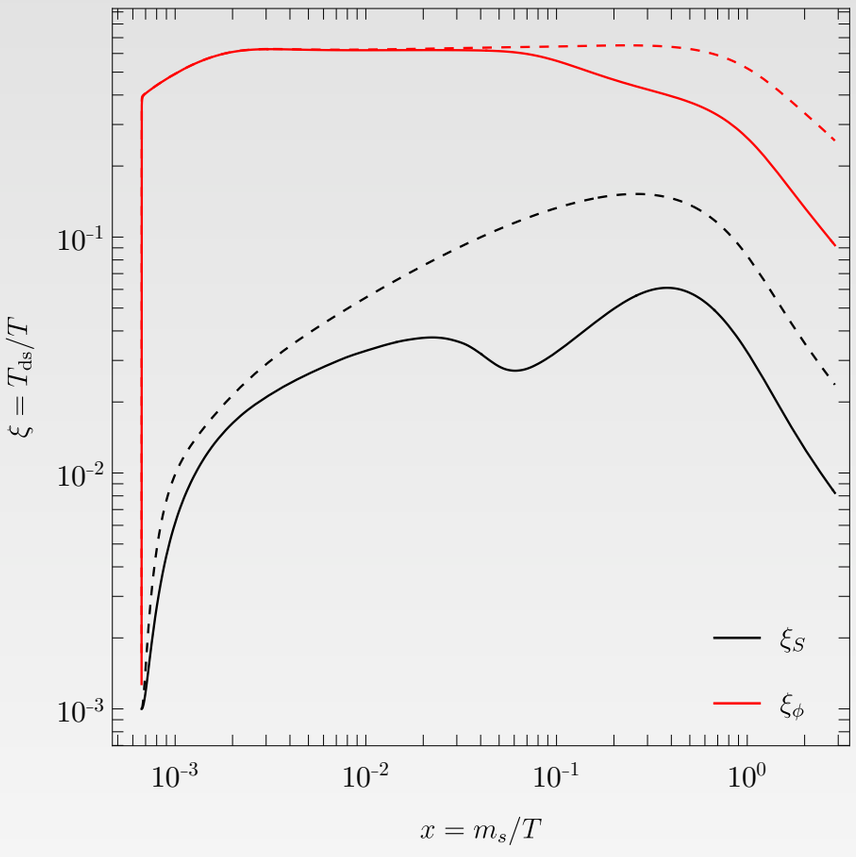
ϕ temperature

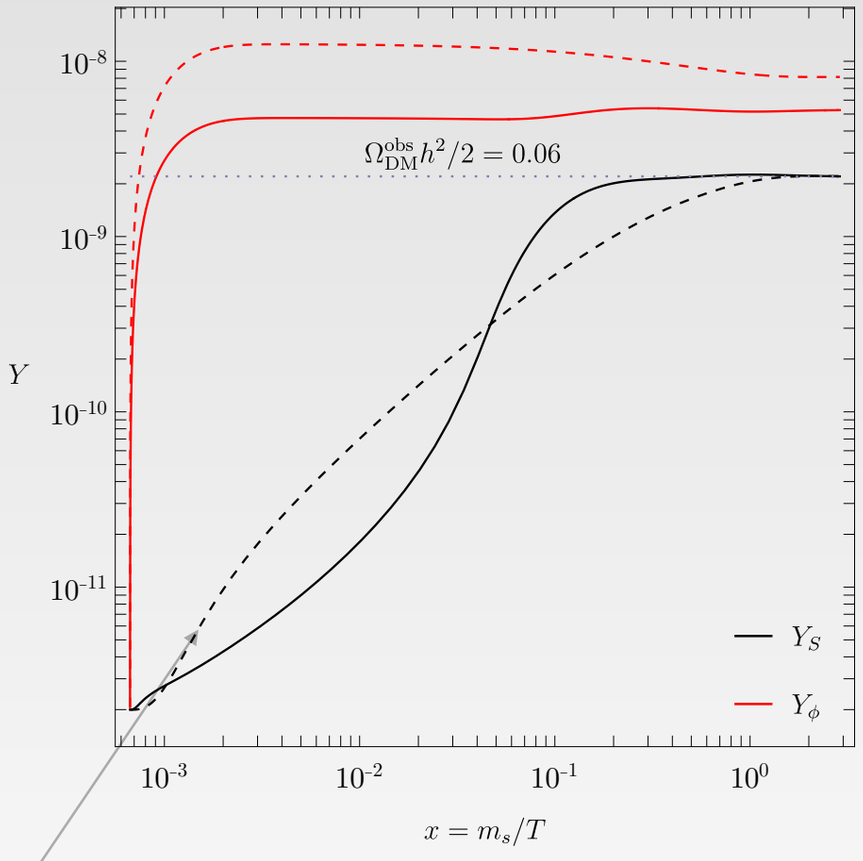
Dynamics

Benchmark point with $m_\phi < m_s$ and parameters that match $\Omega_{DM}^{\rm obs}$

Temperature evolution



Yield evolution

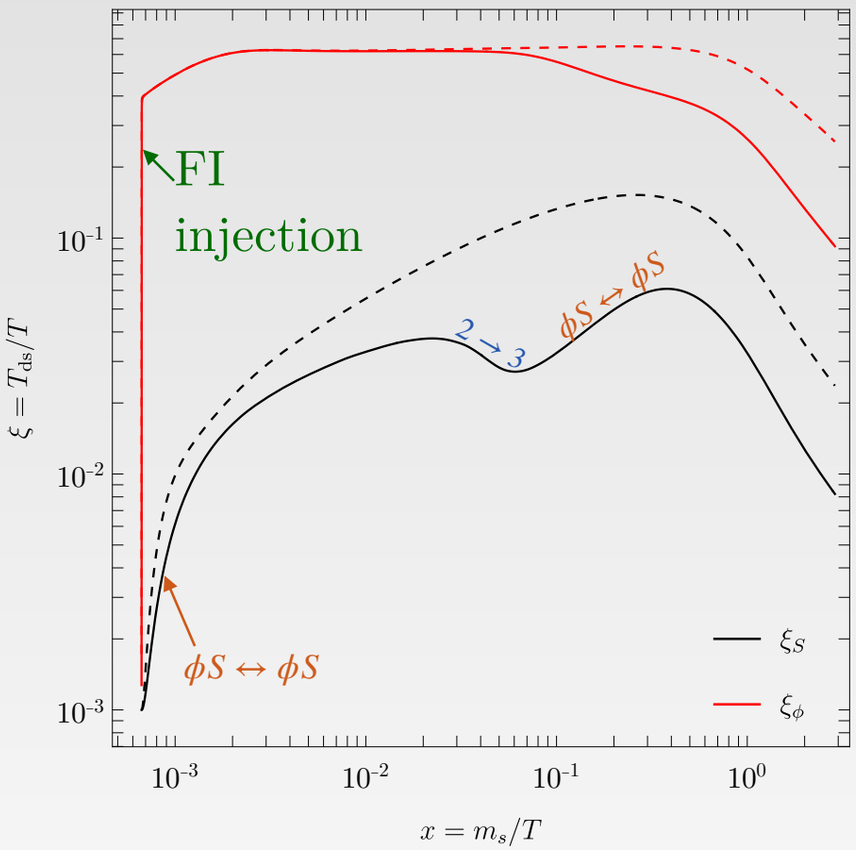


Dashed lines display the evolution **without** self interactions

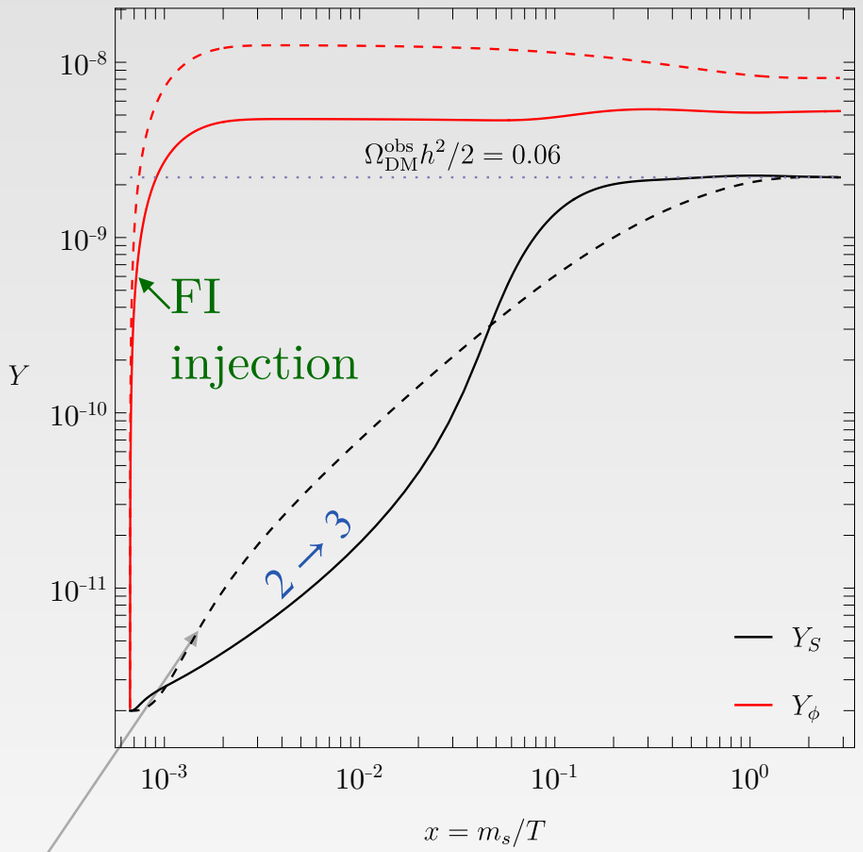
Dynamics

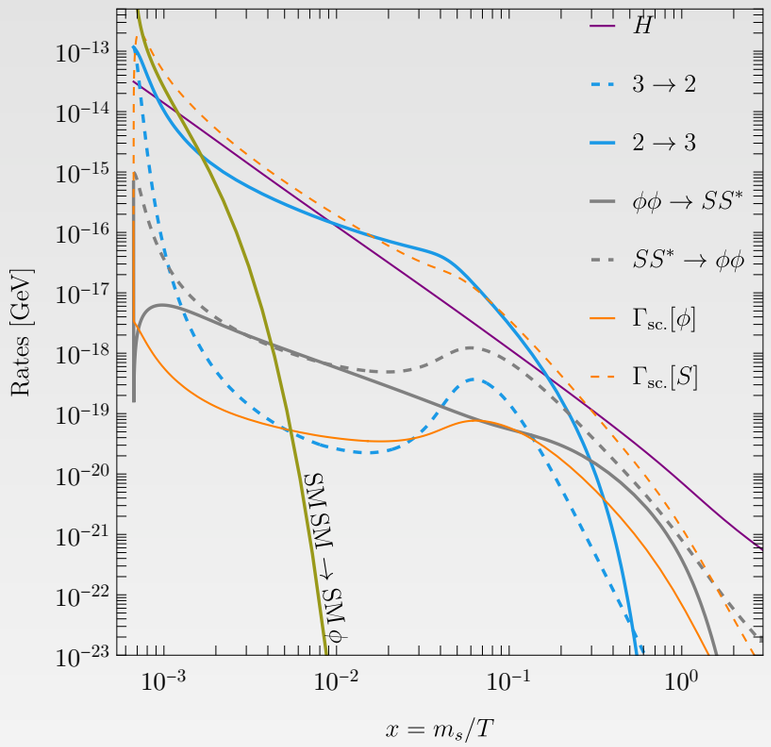
Benchmark point with $m_\phi < m_s$ and parameters that match $\Omega_{DM}^{\rm obs}$

Temperature evolution



Yield evolution





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Dynamics

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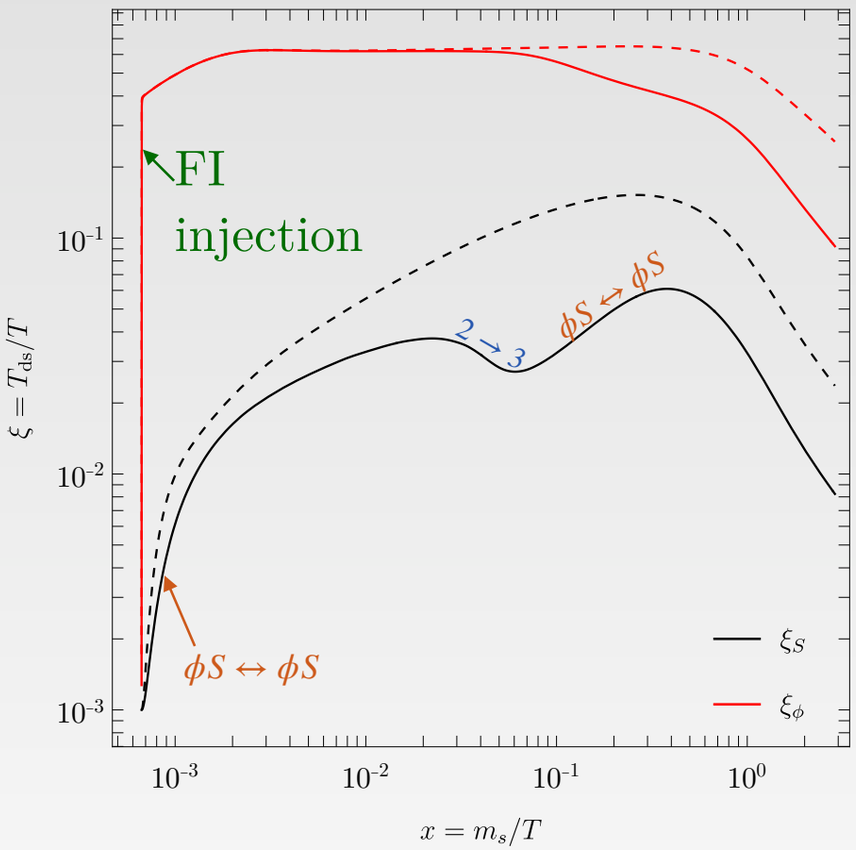
Temperature evolution



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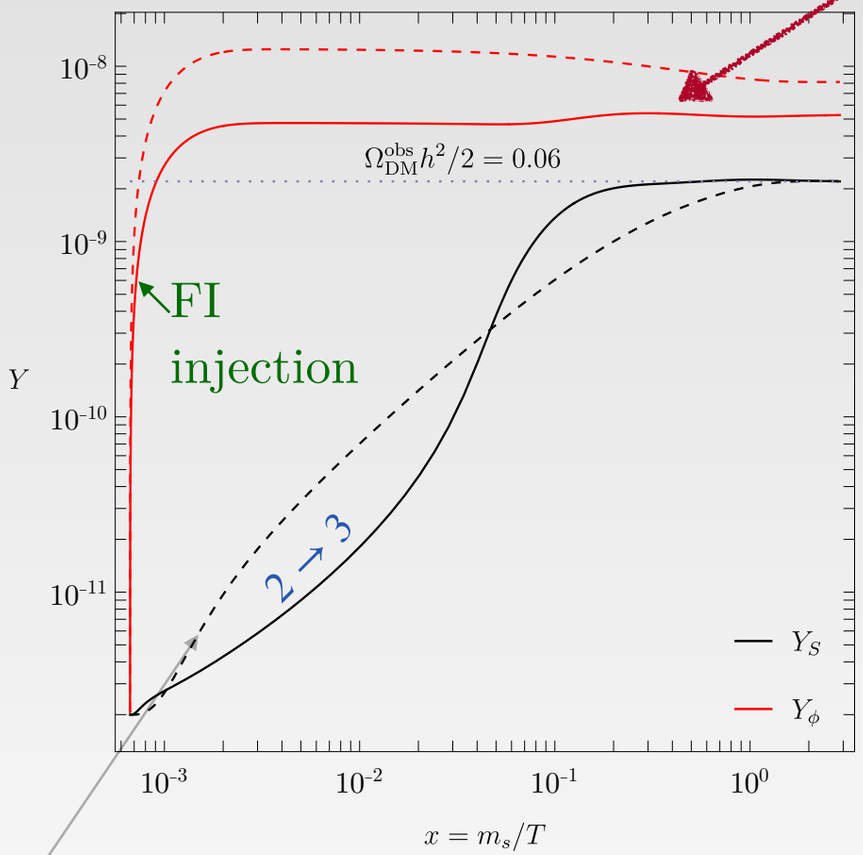
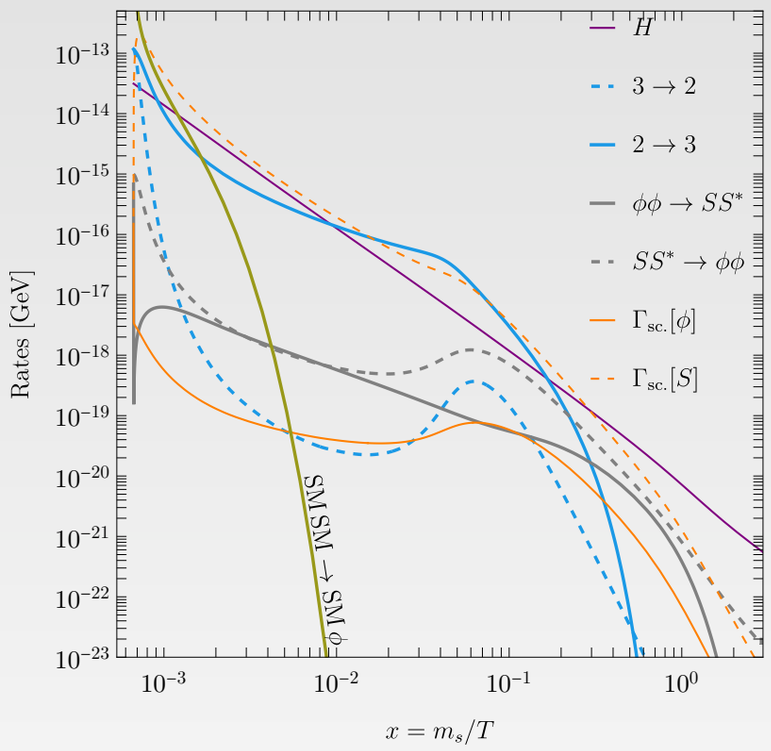


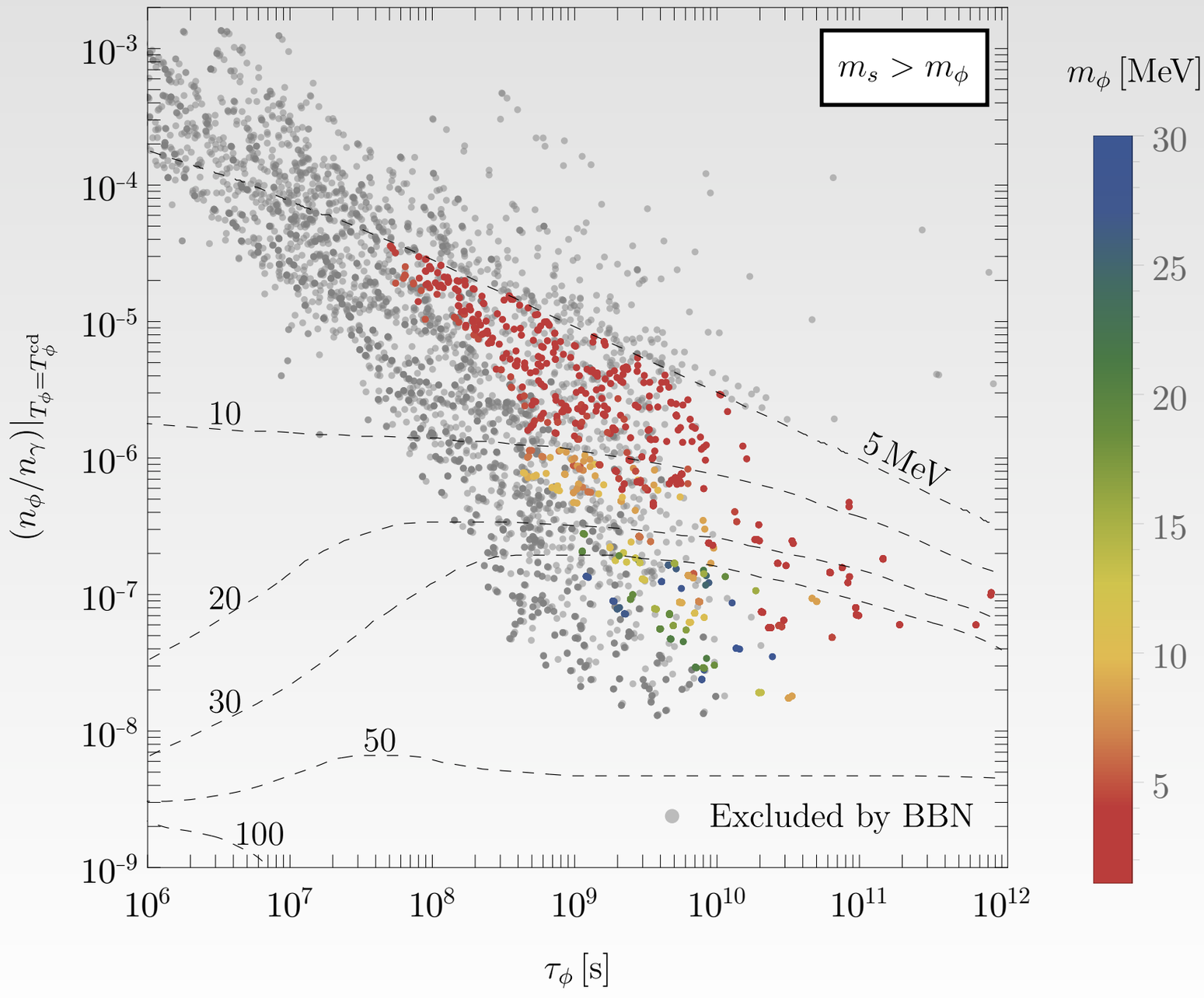
Significant final abundance of ϕ



Dashed lines display the evolution **without** self interactions

Constraints on mediator

During Big Bang Nucleosynthesis ($T_{SM} \sim 150$ MeV) nucleons combined. Presence of mediators may **expoil** BBN observations:



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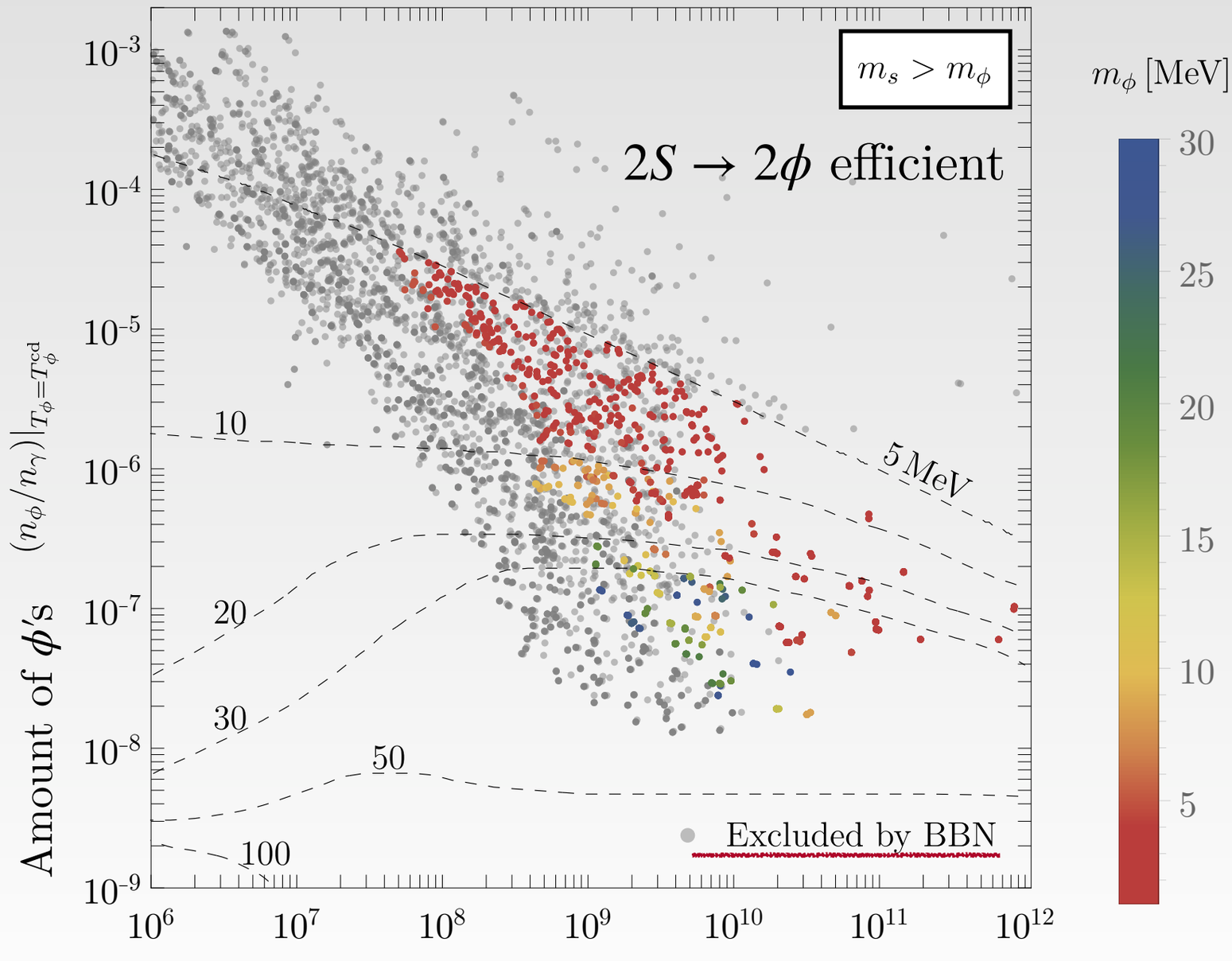
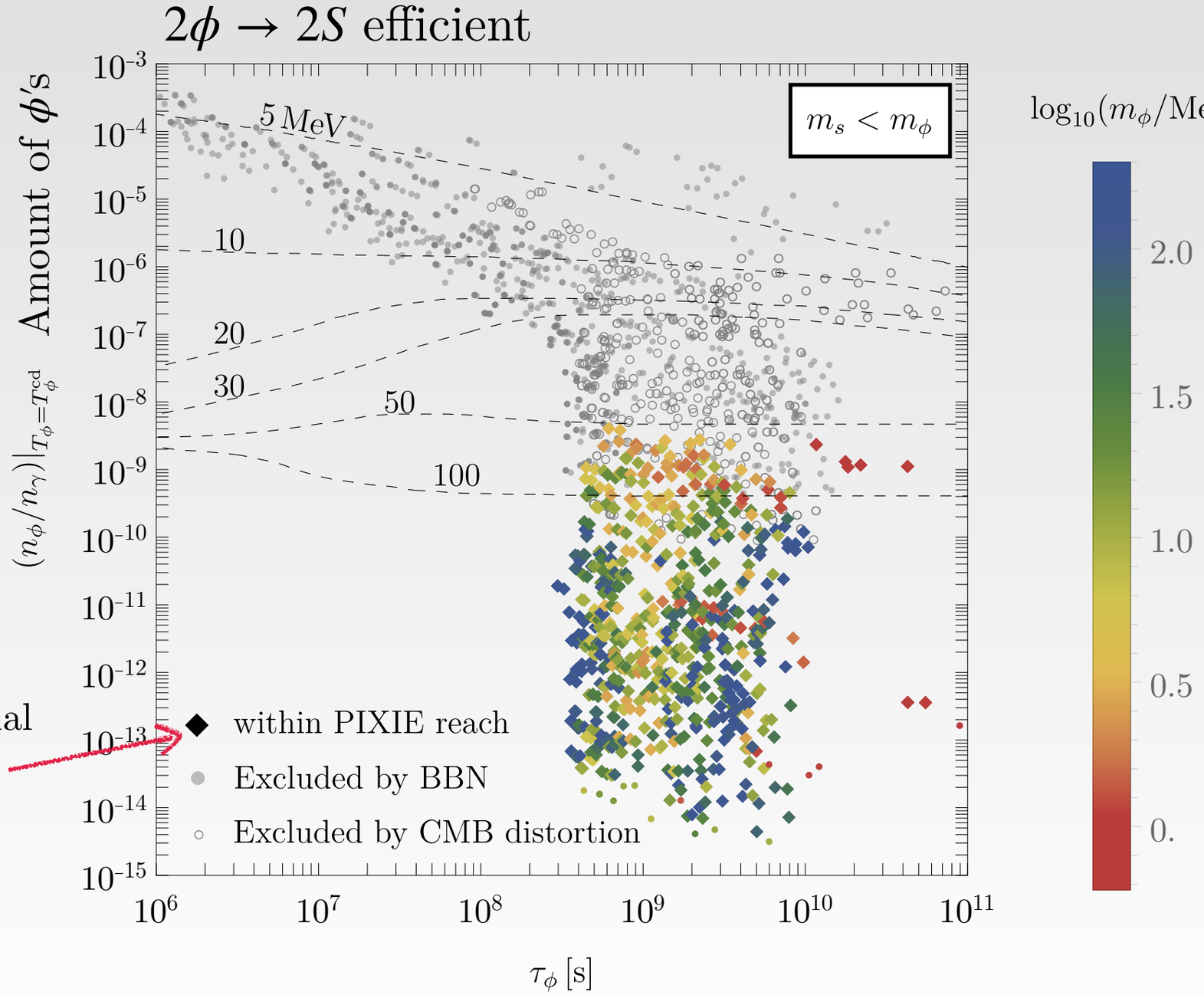


Constraints on mediator

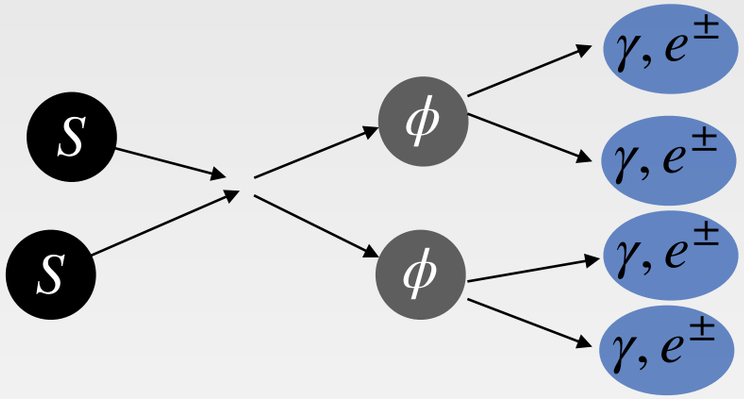
Reversing the mass hierarchy ($m_S < m_\phi$) leads to **less** constrained results



The Primordial Inflation Explorer

Indirectly observing DM

If DM is heavier, it can efficiently annihilate into mediators leading to detectability via telescopes:



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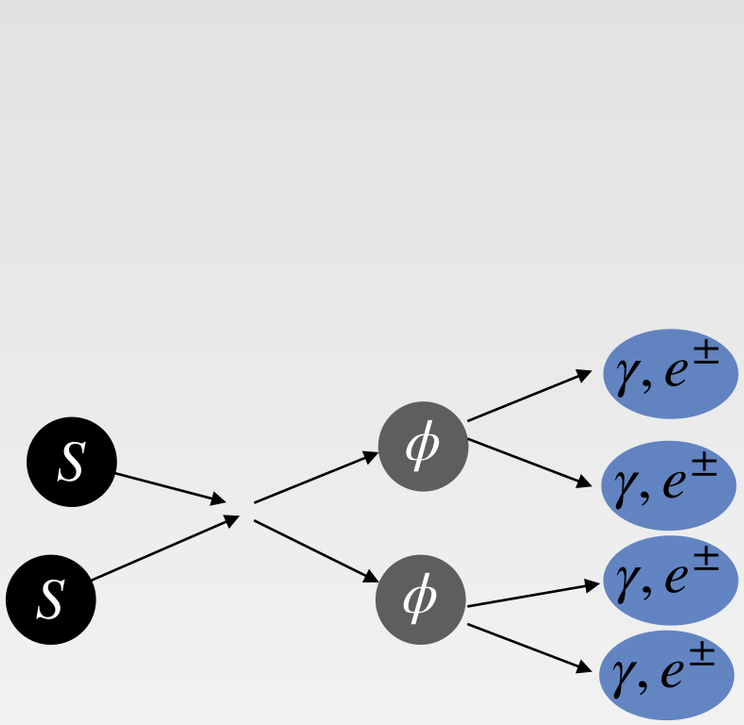
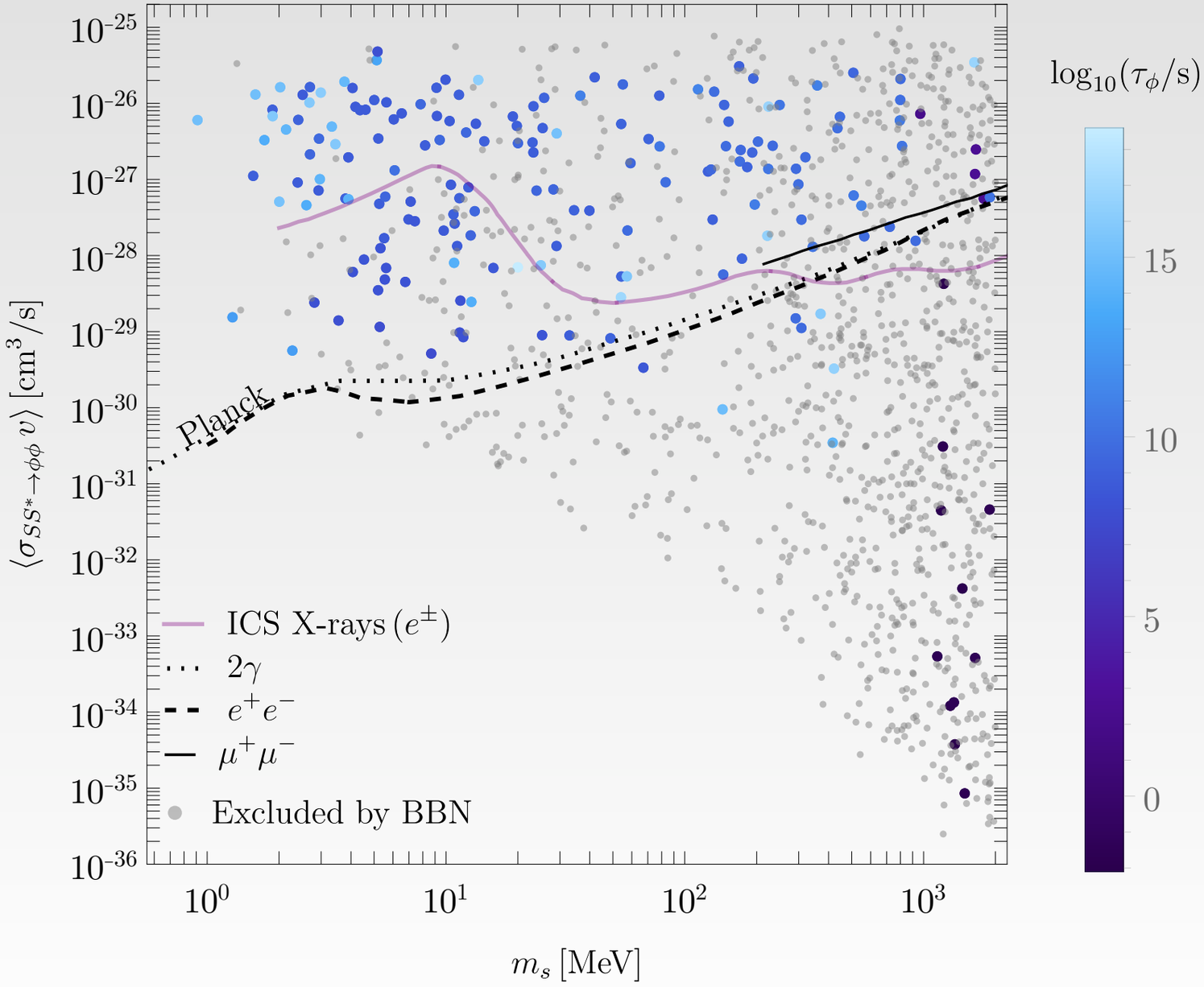
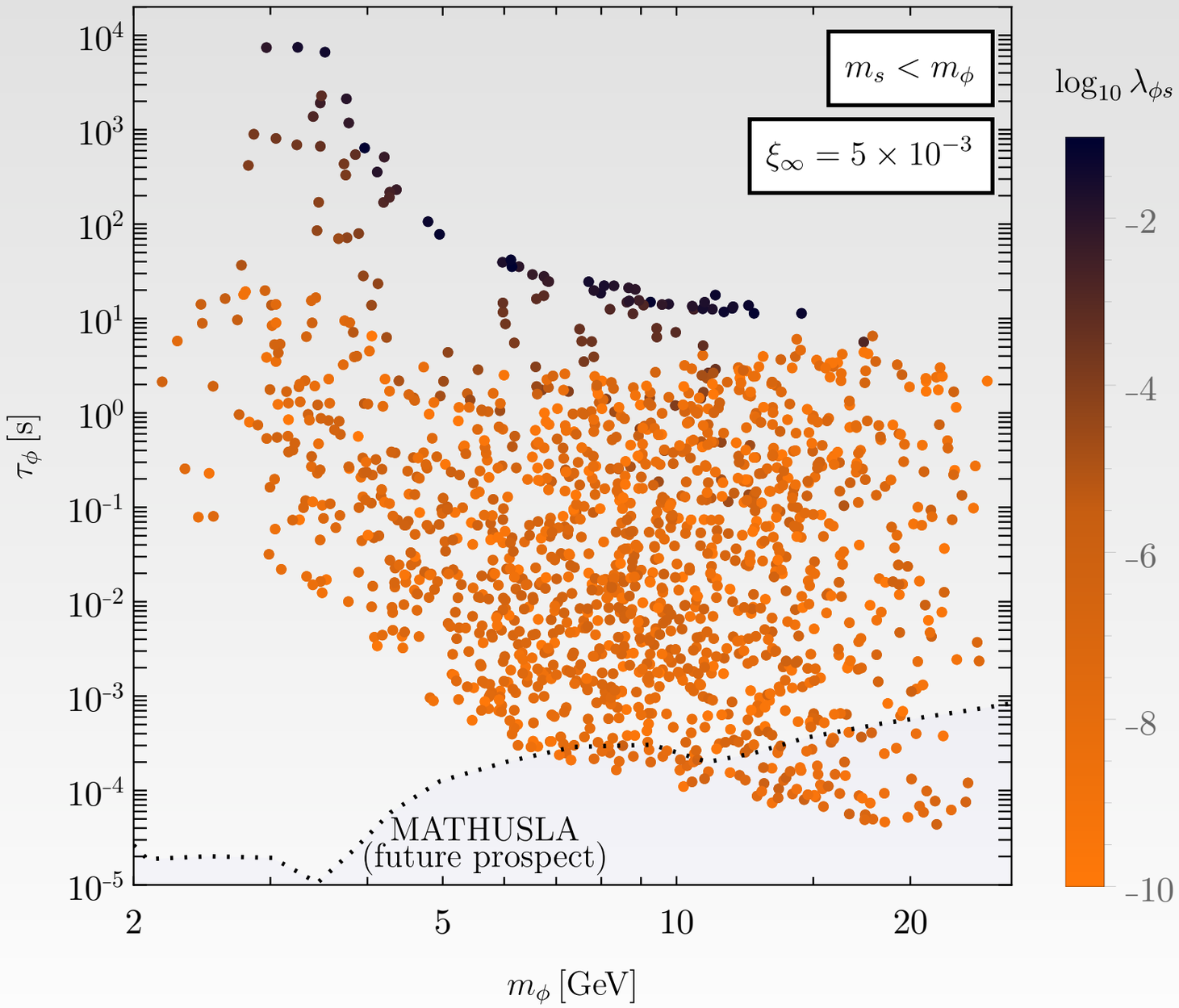




Collider's signals

GeV DM could be detected at the **LHC:**



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- $m_s > m_\phi$ leads to signatures in **Planck**, the latter in **PIXIE** and **MATHUSLA**;
- Interactions between the DM and the mediator lead to **different phenomenology**.

Thank you for your attention:)