From WIMPs to FIMPs with Low-Temperature Reheating

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1. High vs. Low Reheating Temperature

Standard Cosmology

* We know that at BBN, $T \sim O(\text{MeV})$, the universe was dominated by SM radiation

* Standard cosmology
  - → **extrapolation** up to the reheating epoch $T \sim 10^{10}$ GeV (?)
  - → SM entropy conserved
  - → early universe dominated by SM radiation
  - → instantaneous reheating

Cosmic Reheating

* Cosmic Inflation
  - → Exponentially fast expansion of the universe
  - → Gives rise to an empty Universe

* Cosmic **reheating**
  - → Transition from an inflaton-dominated to a SM radiation-dominated era
  - → End of reheating at T_{rh}
  - → $T_{rh} > T_{bbn} \sim 4$ MeV

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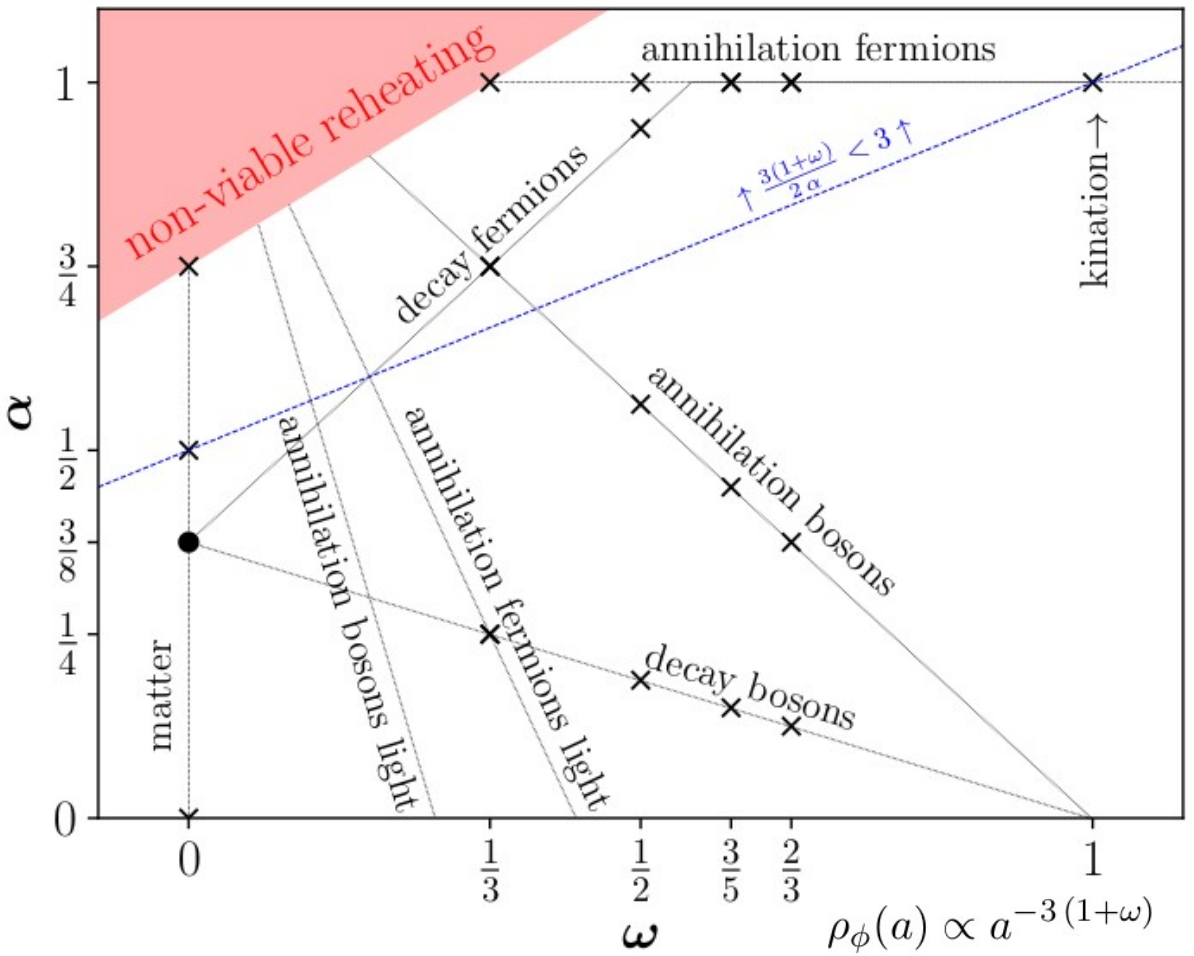
  - → End of reheating at T_{rh}
  - → $T_{rh} > T_{bbn} \sim 4$ MeV
  - → *Unknown* equation-of-state parameter ω $\quad \rho_\phi(a) \propto a^{-3\,(1+\omega)}$
  - → *Unknown* scaling of the temperature $\quad T(a) = T_{\rm rh} \left(\frac{a_{\rm rh}}{a} \right)^{\alpha}$

Cosmic Reheating

$$T(a) = T_{\rm rh} \left(\frac{a_{\rm rh}}{a}\right)^{\alpha}$$



Cosmic Reheating

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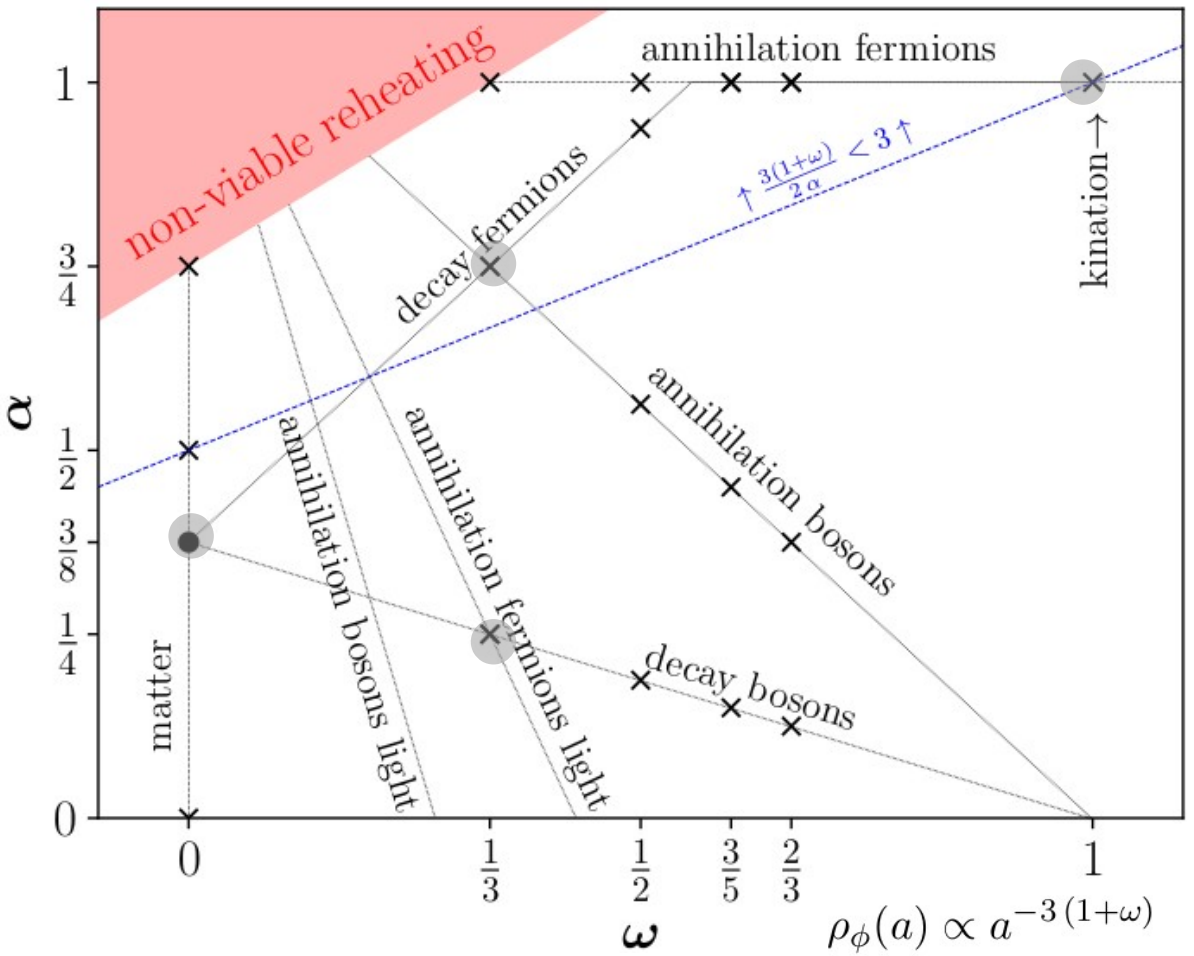


2. Singlet Scalar DM

2306.14943 and 2408.08950

J. Silva-Malpartida, NB, J. Jones-Pérez, R. Lineros

Singlet Scalar DM

McDonald '07

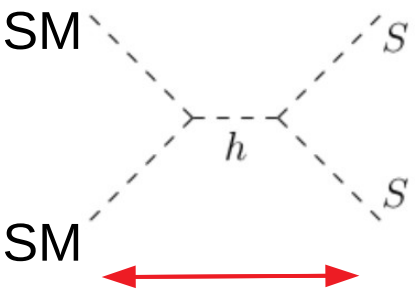
S is a singlet scalar, protected by a Z_2

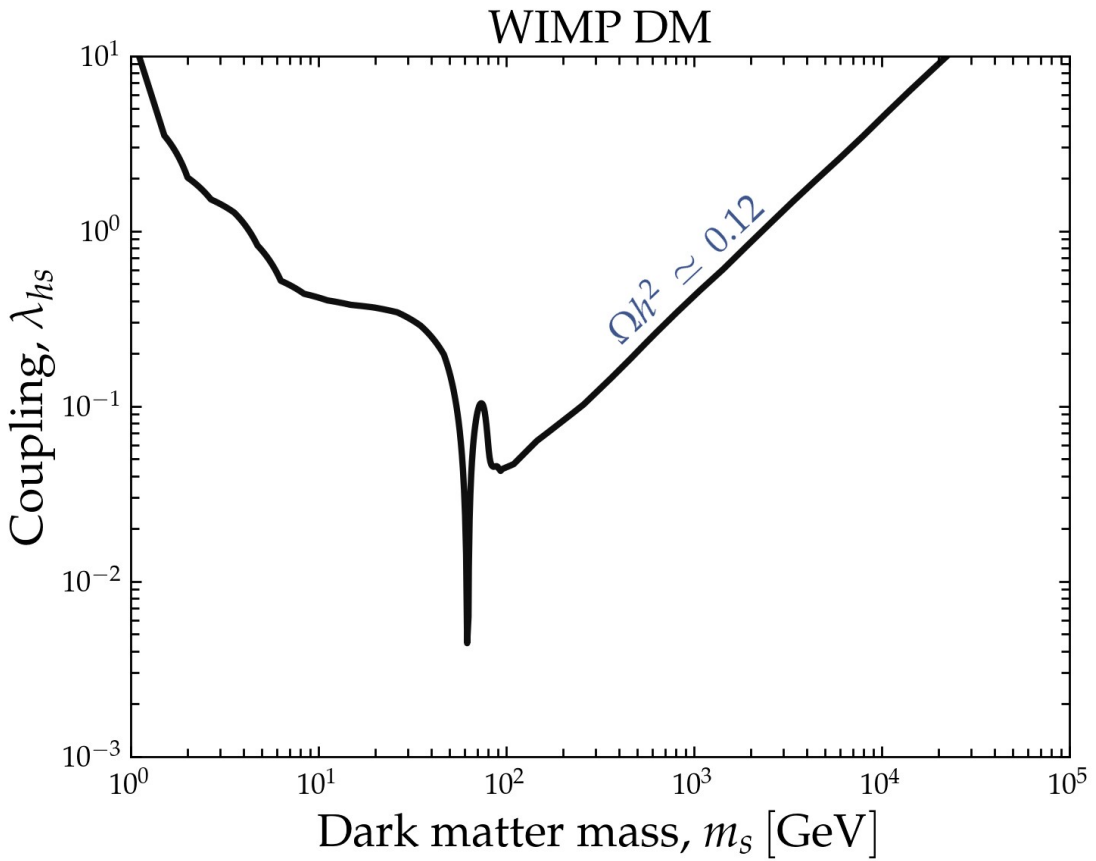
$$V = \mu_S^2 S^2 + \lambda_S S^4 + \lambda_{HS} |H|^2 S^2$$

2+1 free parameters:

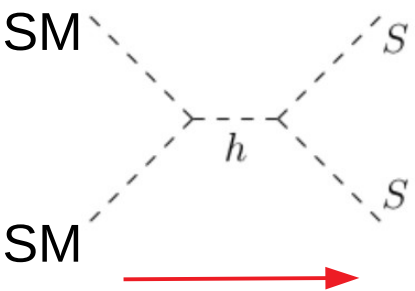
* m_S DM mass
* λ_{HS} Higgs portal
* λ_S DM quartic coupling

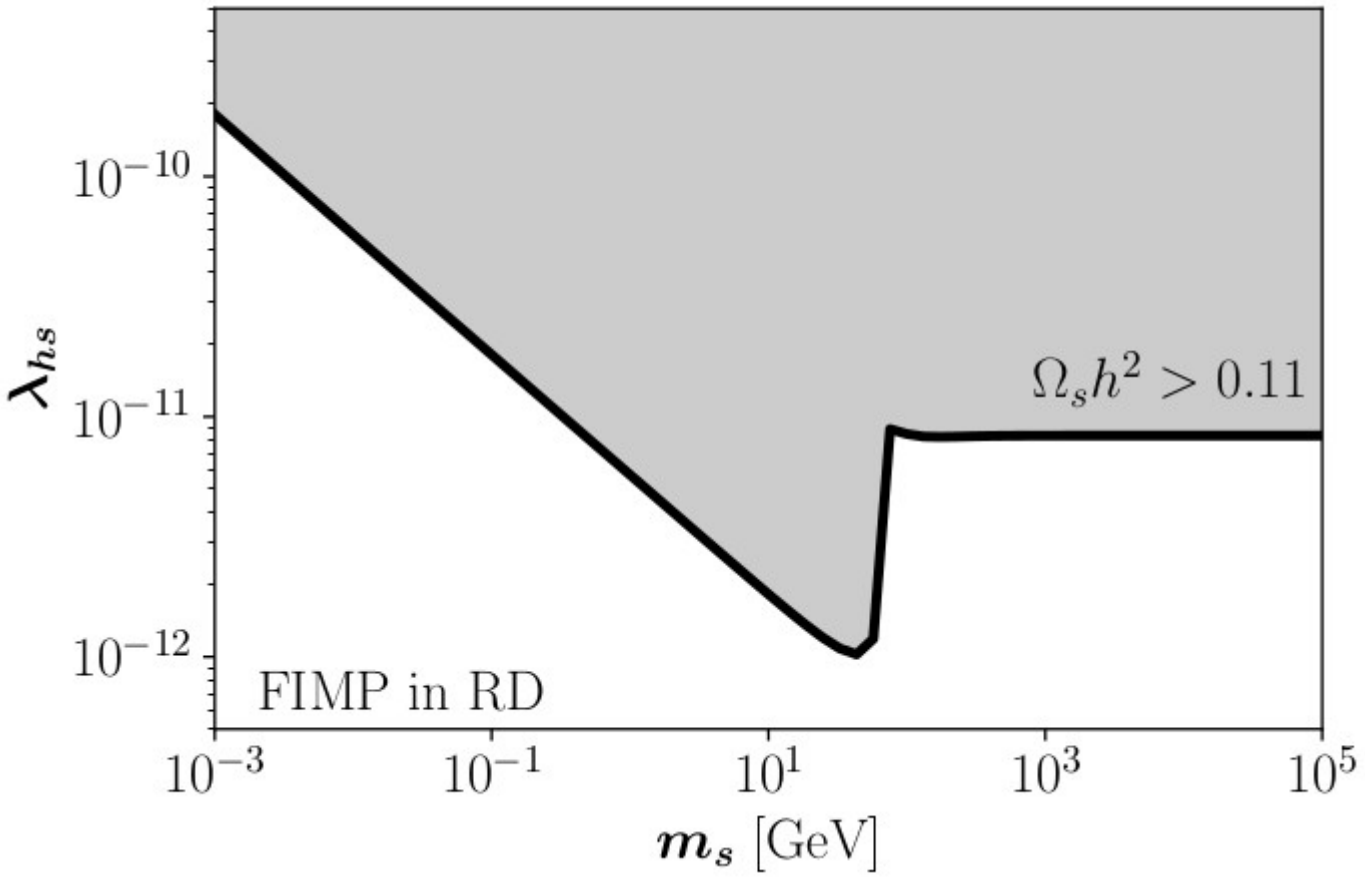
Singlet Scalar DM - WIMP



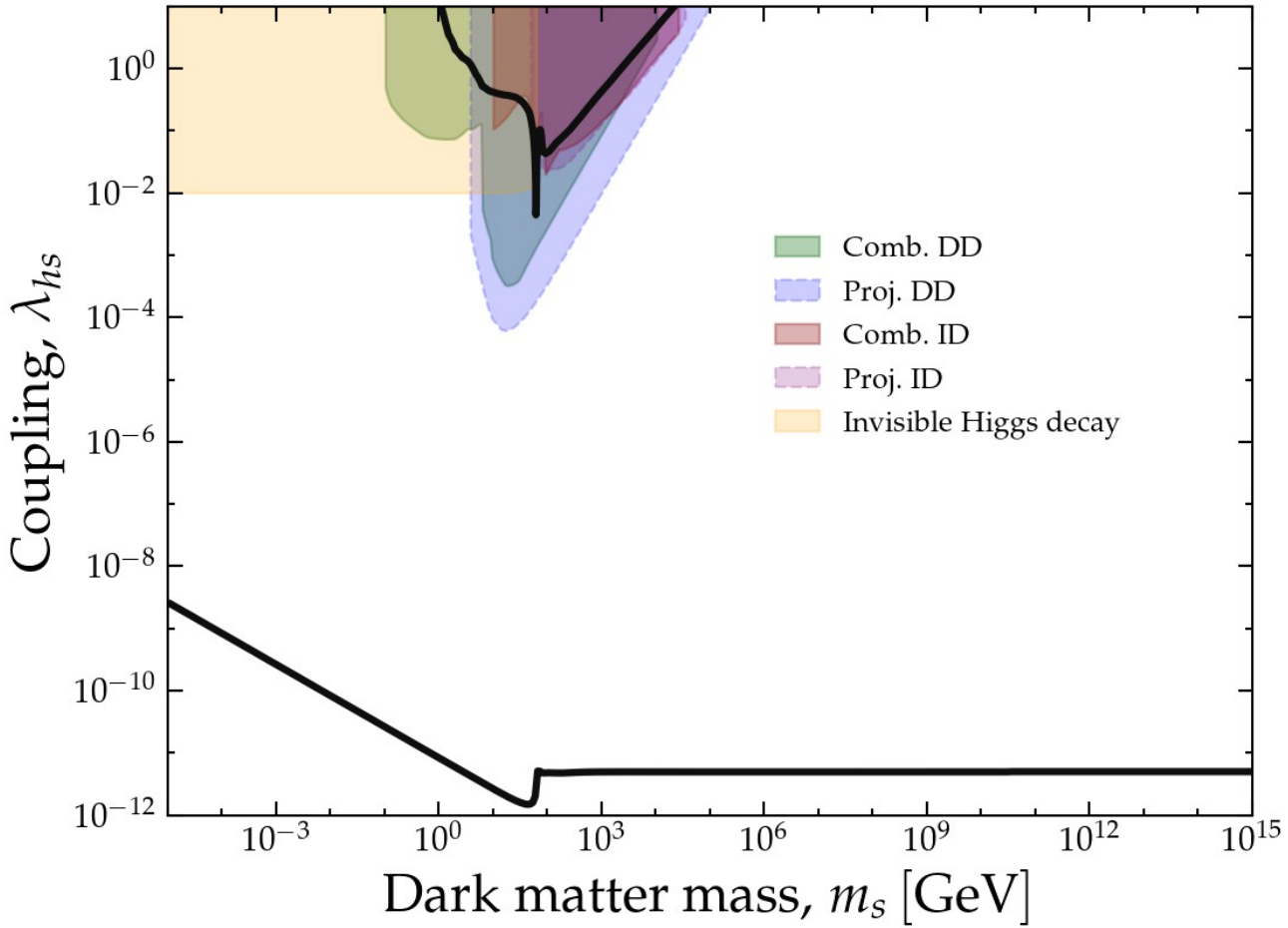


Singlet Scalar DM - FIMP

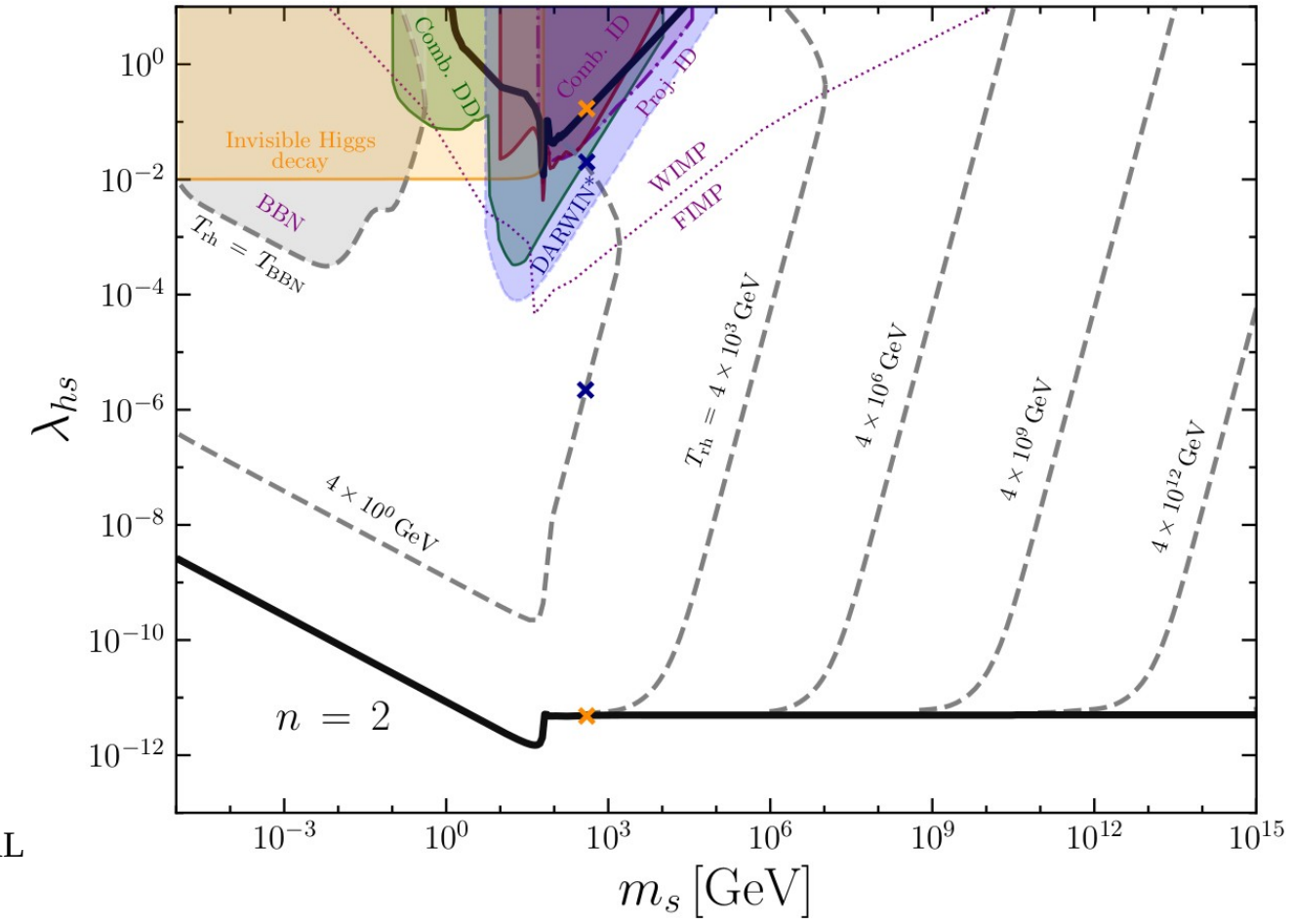




Singlet Scalar DM – WIMP & FIMP

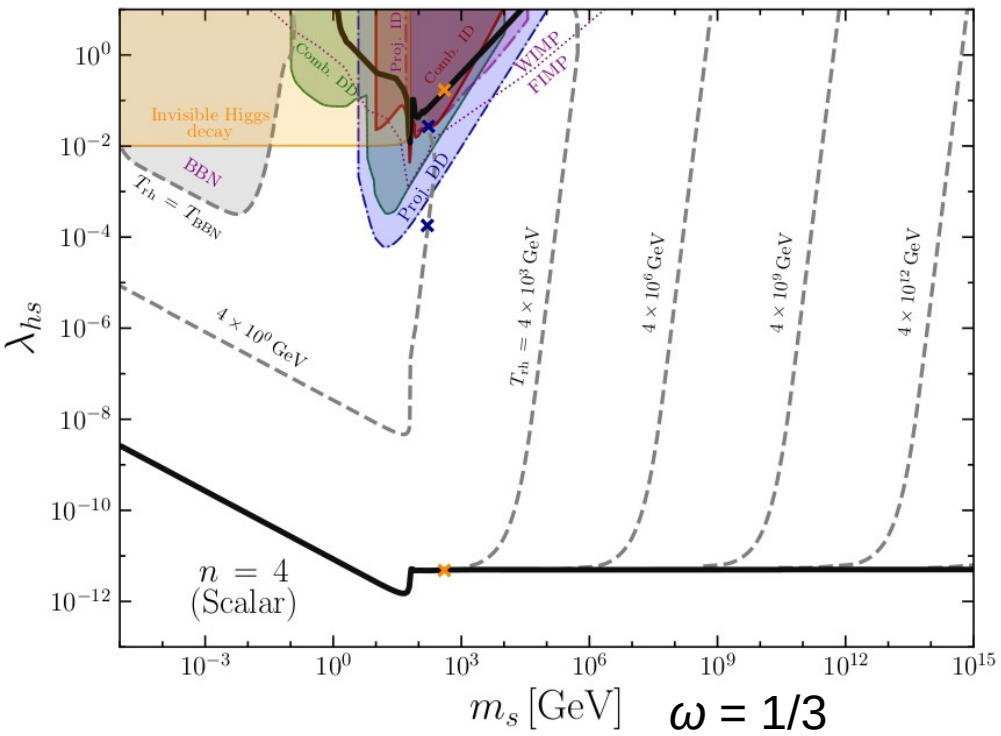


WIMPs and FIMPs with Low-temperature reheating

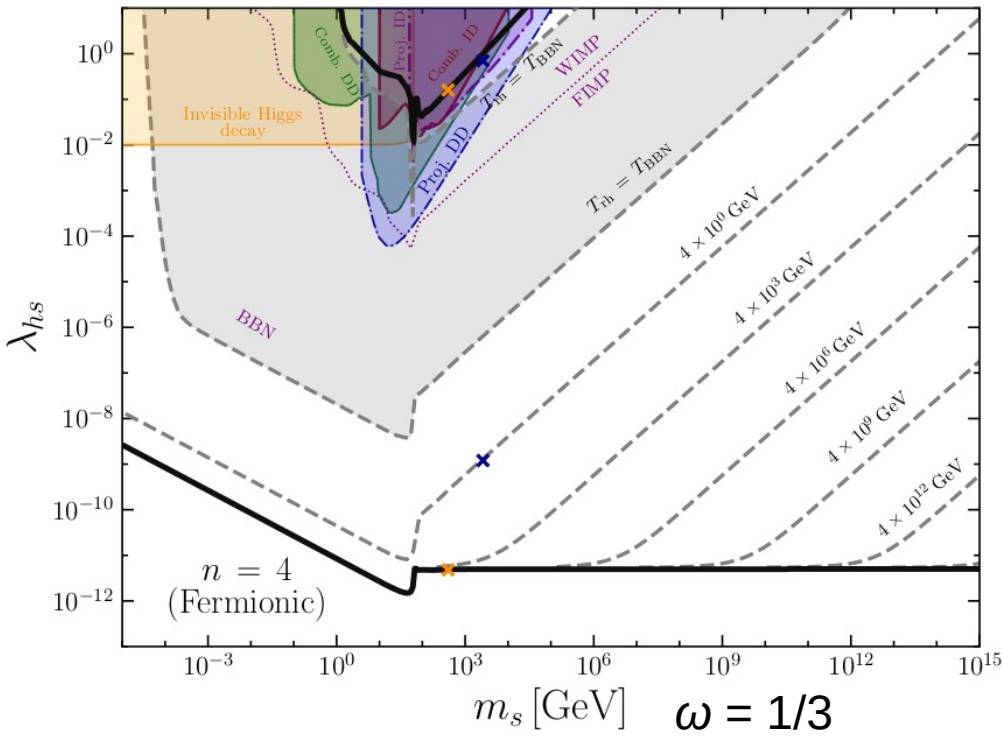


$\omega = 0$
$\alpha = 3/8$

WIMPs and FIMPs with Low-temperature reheating



ω = 1/3
α = 1/4



ω = 1/3
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3. Minimal Freeze-in

2412.soon

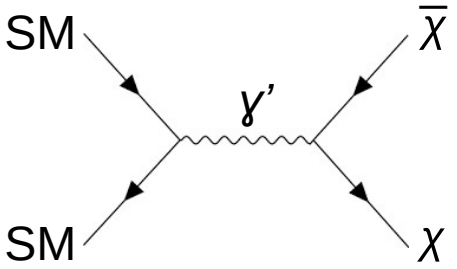
NB, C.S. Fong, Ó. Zapata

Minimal Freeze-in

* Additional gauged $U(1)_D$
* *Mediator: Massless gauge boson* $\hat{X}_{\mu\nu}$
* DM: Dirac fermion χ

$$\mathcal{L} \supset \bar{\chi}\left(i \not{D} - m_\chi\right)\chi - \frac{\epsilon}{2} F^{\mu\nu} F'_{\mu\nu}$$

* Free parameters:
  - → DM mass: m_χ
  - → DM-SM coupling: $\kappa \equiv \frac{\epsilon\, e'}{e}$



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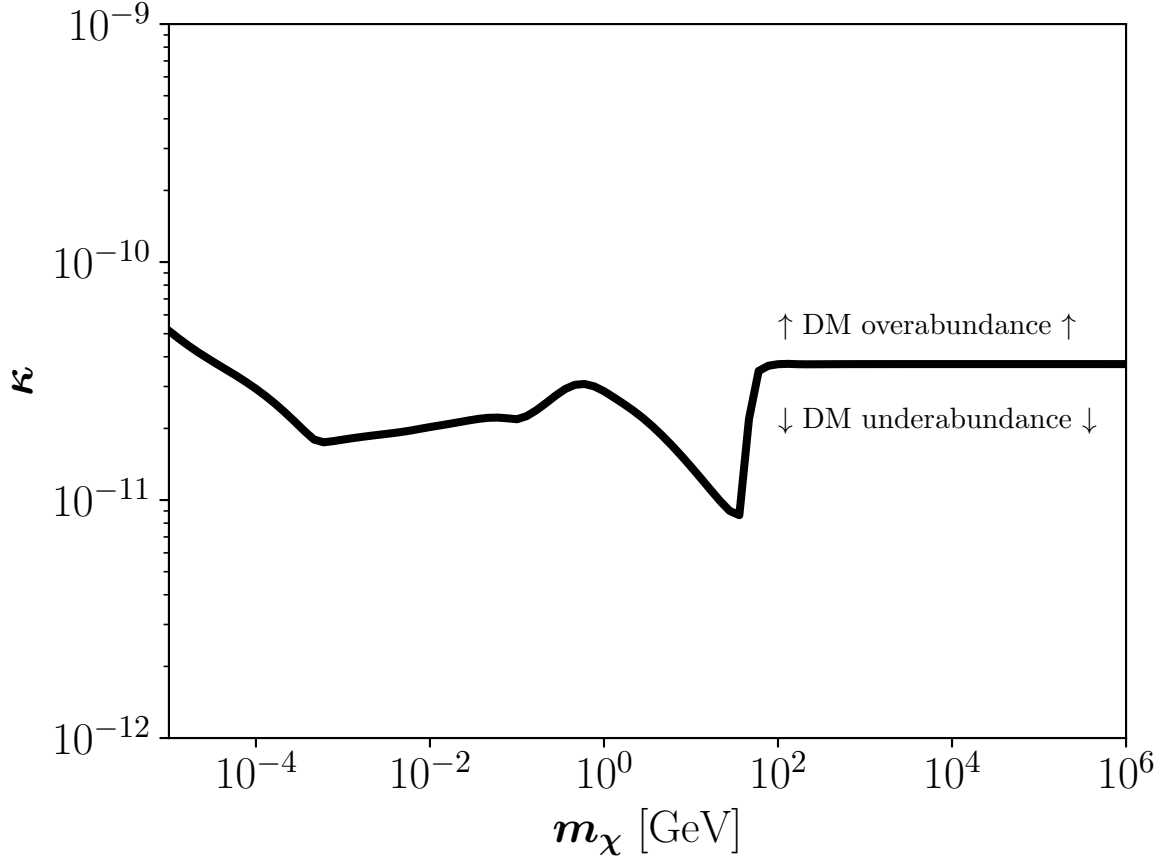

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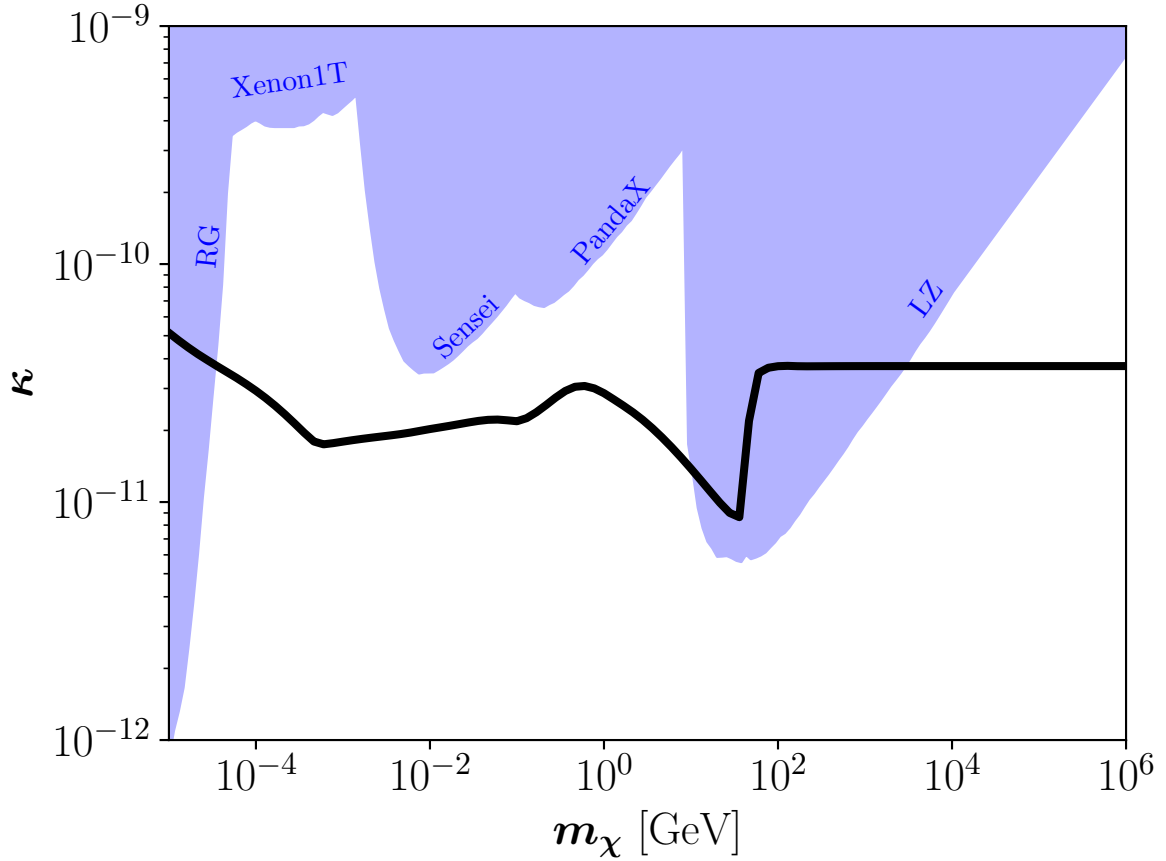

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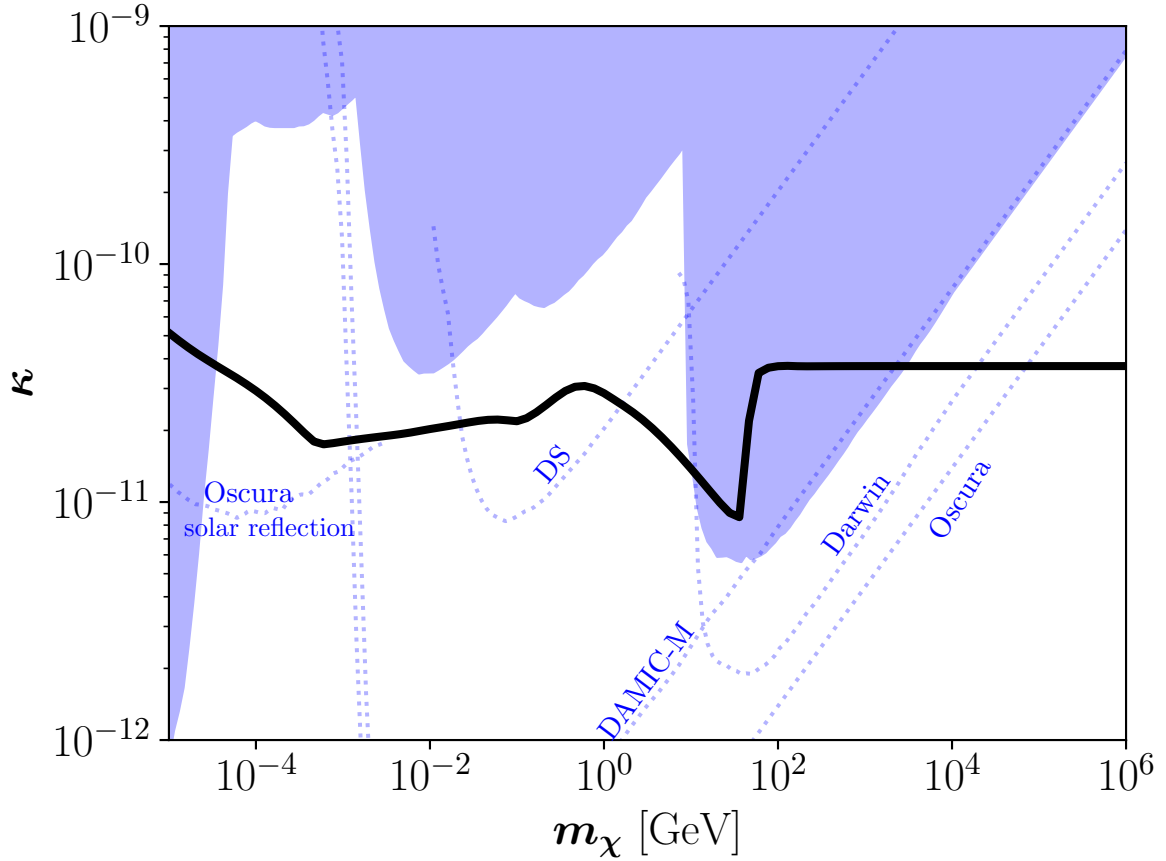
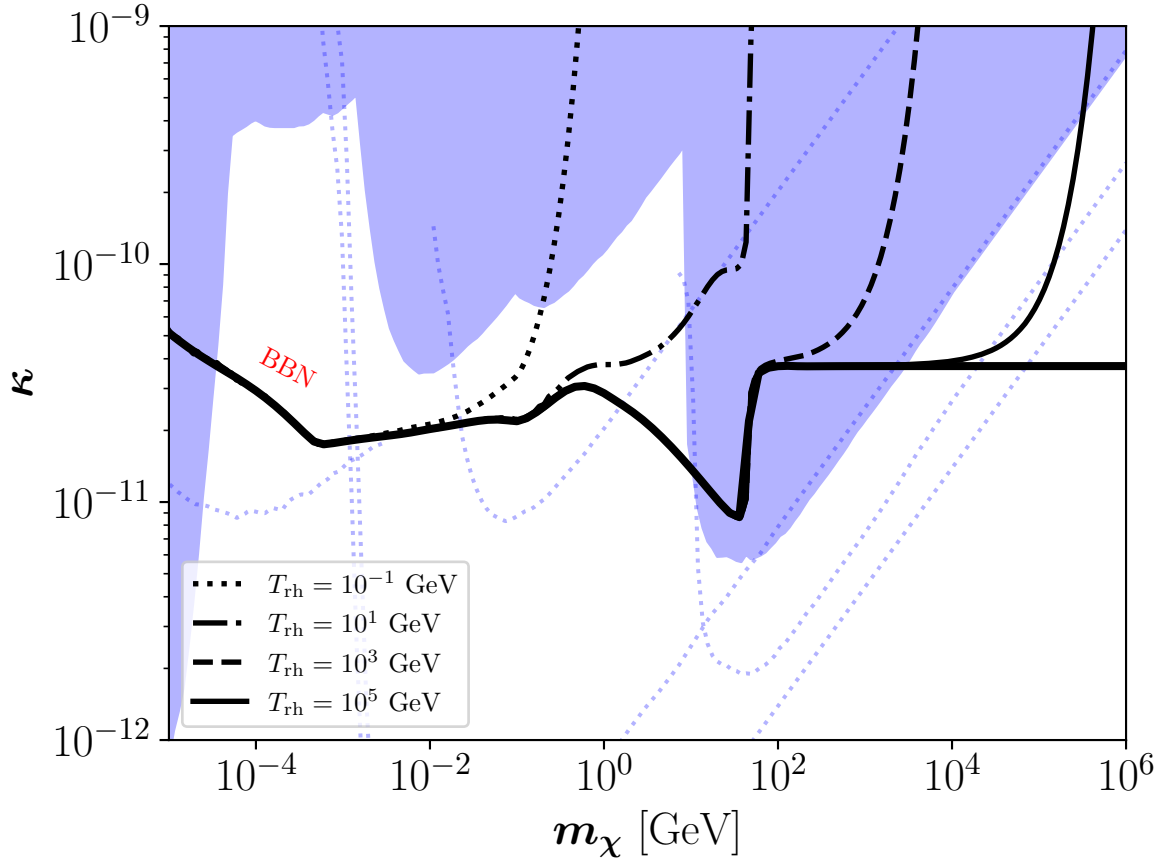
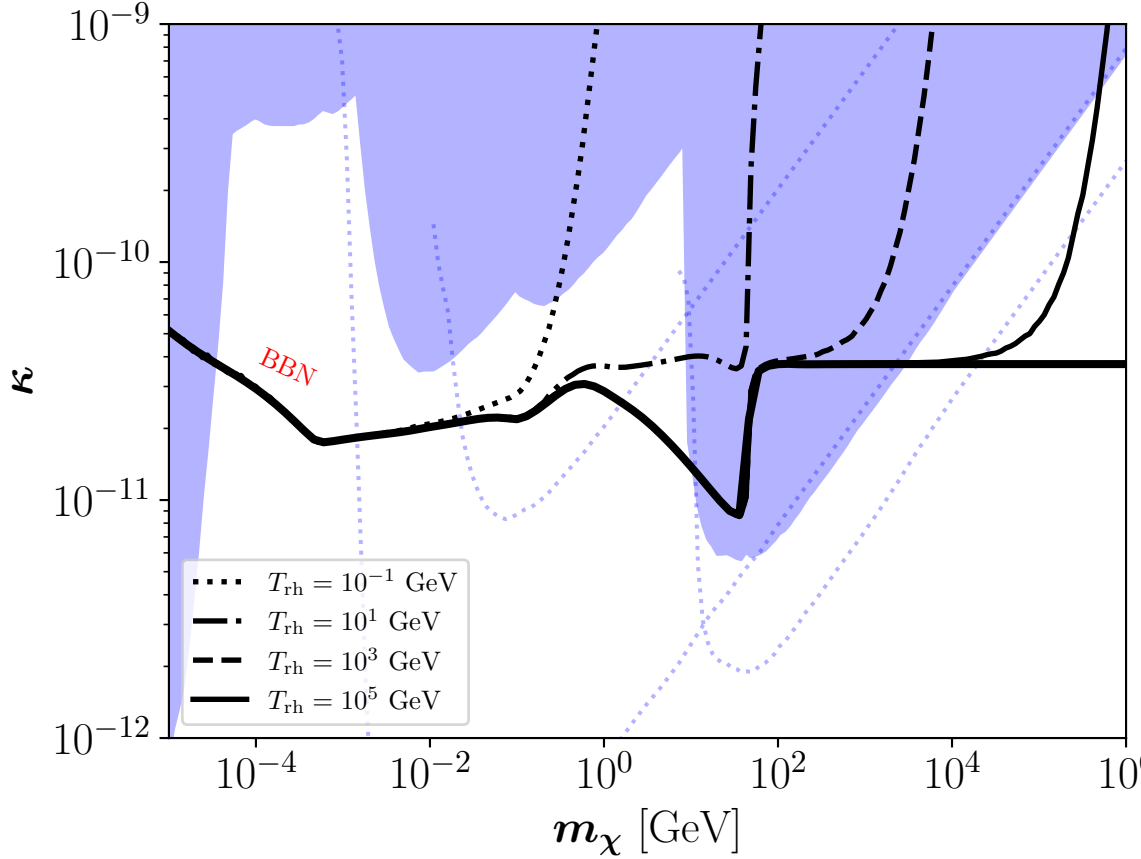


Minimal Freeze-in: Instantaneous reheating



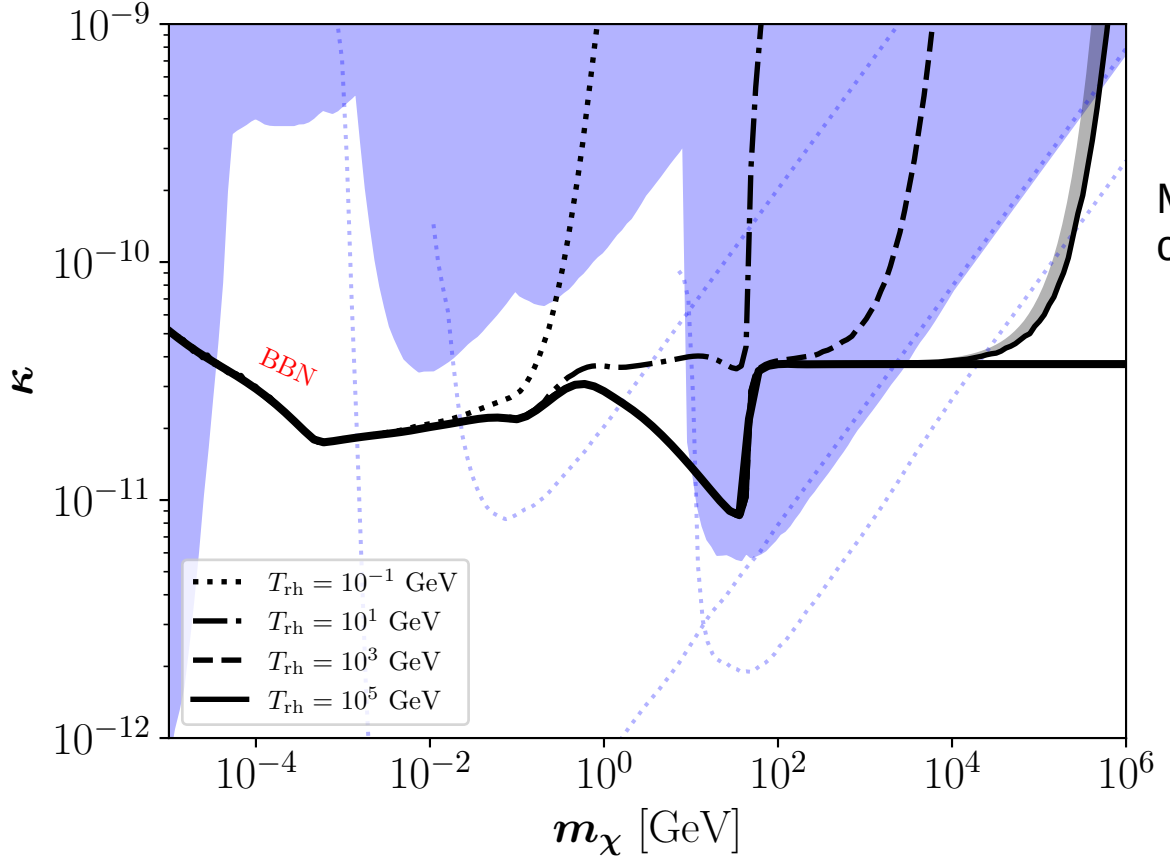
Minimal Freeze-in during Reheating



Massive inflaton
constant decay width

$\omega = 0$
$T(a) \sim a^{-3/8}$

Minimal Freeze-in during Reheating



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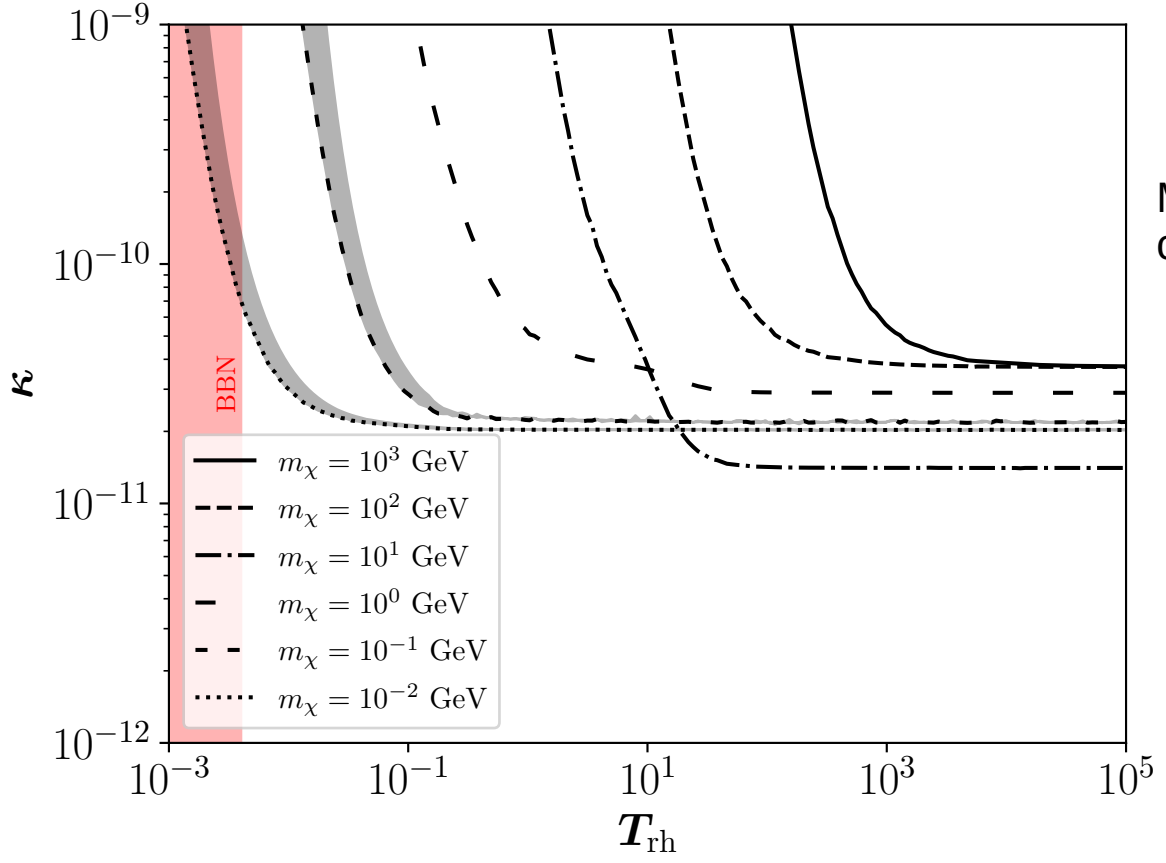

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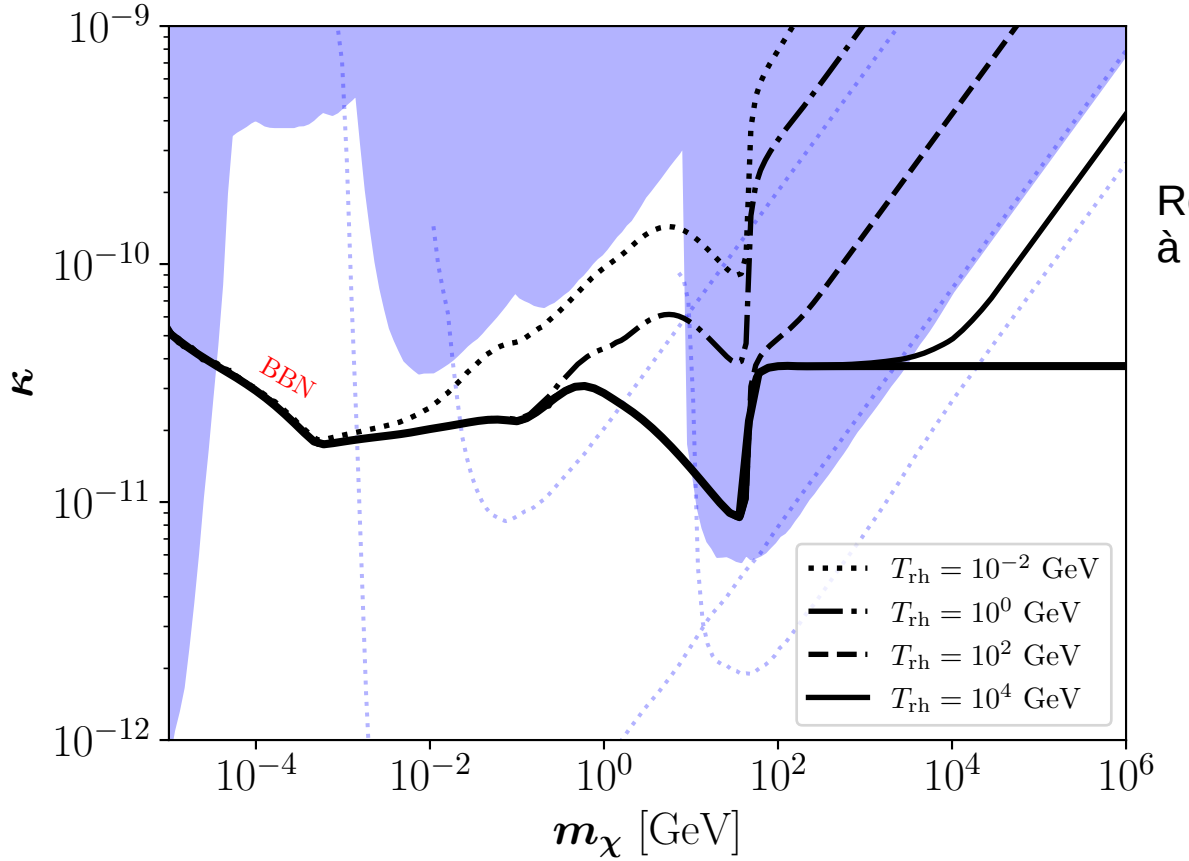
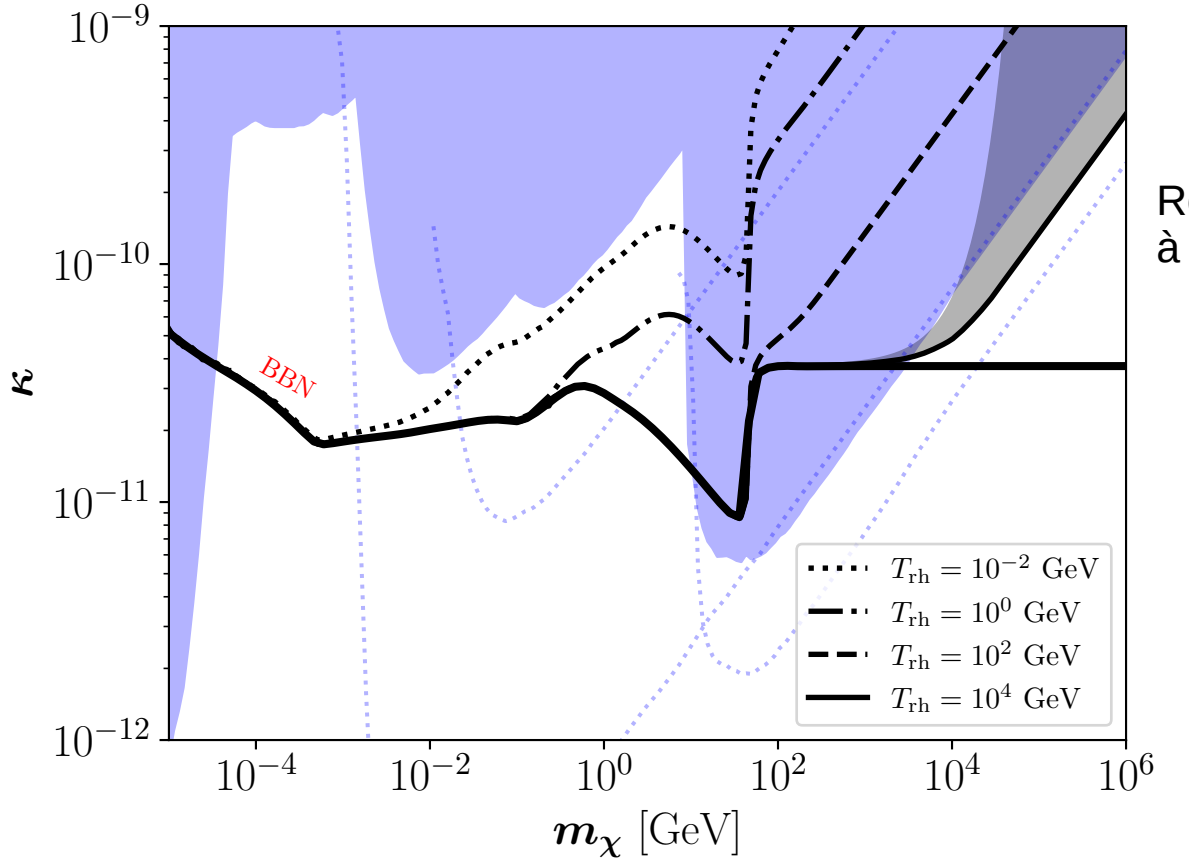


Reheating
à la kination

$\omega = 1$
$T(a) \sim a^{-1}$

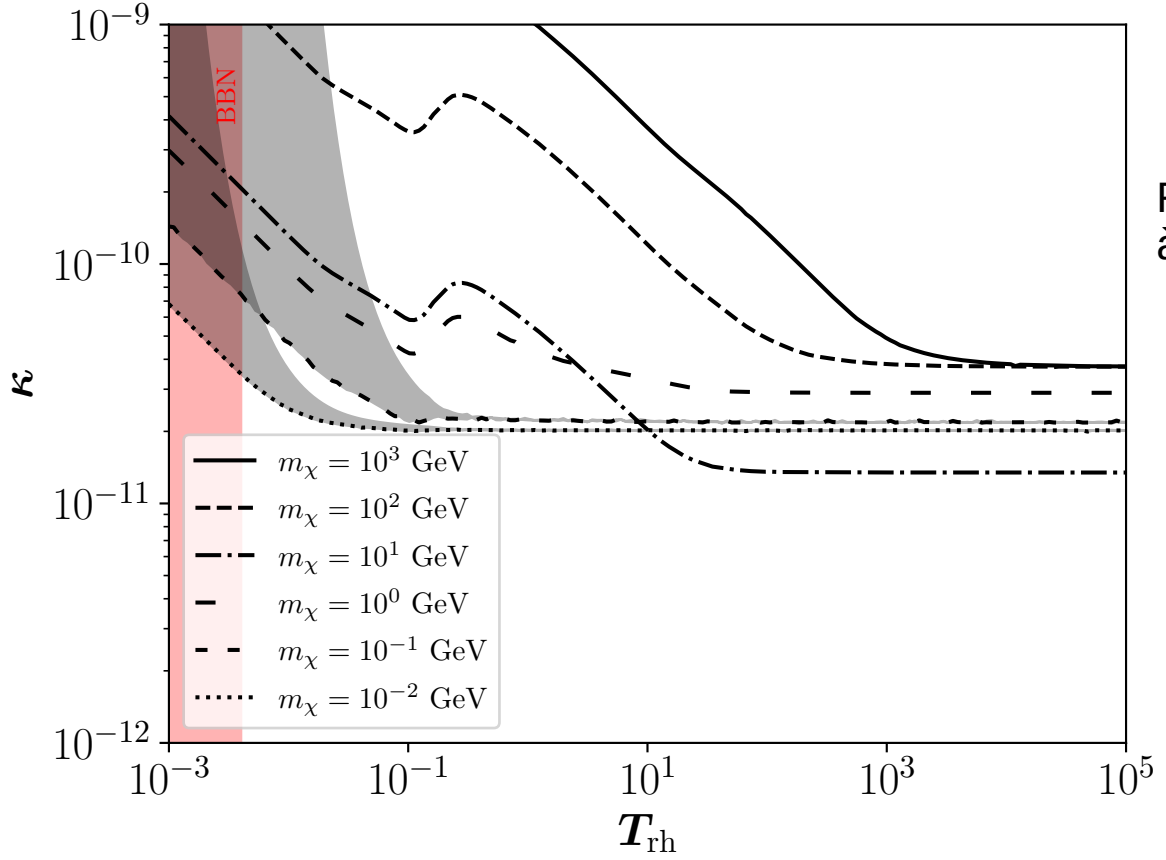
Minimal Freeze-in during Reheating



Reheating
à la kination

ω = 1
T(a) ~ a^{-1}

Minimal Freeze-in during Reheating



Reheating
à la kination

ω = 1
T(a) ~ a^{-1}

Conclusions & Outlook

- Dark Matter exists
- The nature of Dark Matter is still unknown
- Dark Matter could have been produced during **Cosmic Reheating**
  → Large uncertainties (T_{rh}, equation of state, scaling of SM temperature)
- Parameter space greatly enlarged
  → $m < 10^{14}$ GeV
  → smaller DM-SM couplings, but *within the range of future detectors*
- Non-standard cosmological scenarios drastically change the standard picture
- Non-standard cosmologies provide a smooth transition
  between different thermal and non-thermal DM
- Non-standard cosmologies
  → relax strong experimental constraints on thermal DM
  → increase detection chances of non-thermal DM

Merci!