

Dark Matter from Exponential Growth

Originally proposed as Pandemic Dark Matter

Based on Phys. Rev. Lett. 127 (2021) 191802

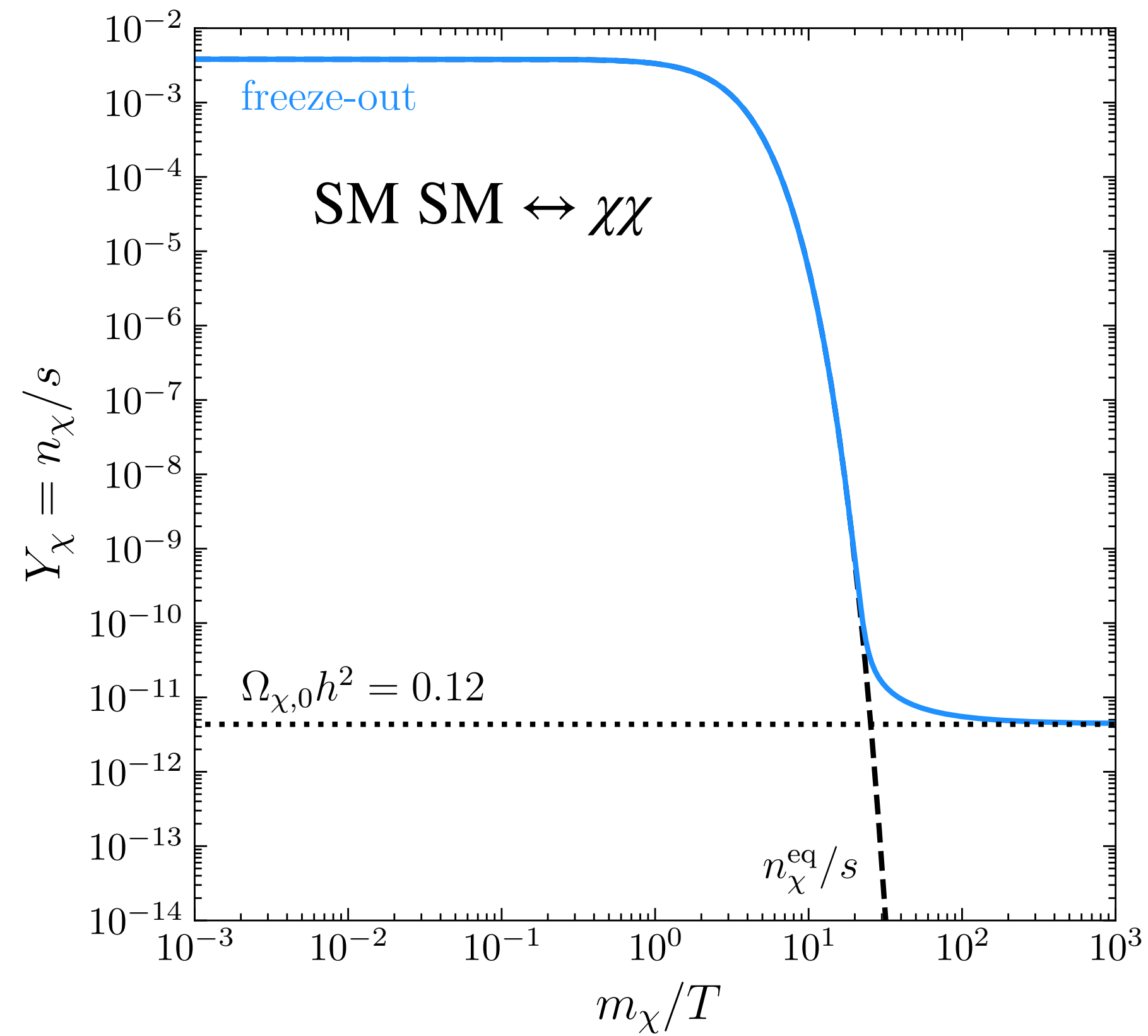
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In collaboration with T. Bringmann, M. Hufnagel, J. Kersten, J. T. Ruderman, and
K. Schmidt-Hoberg

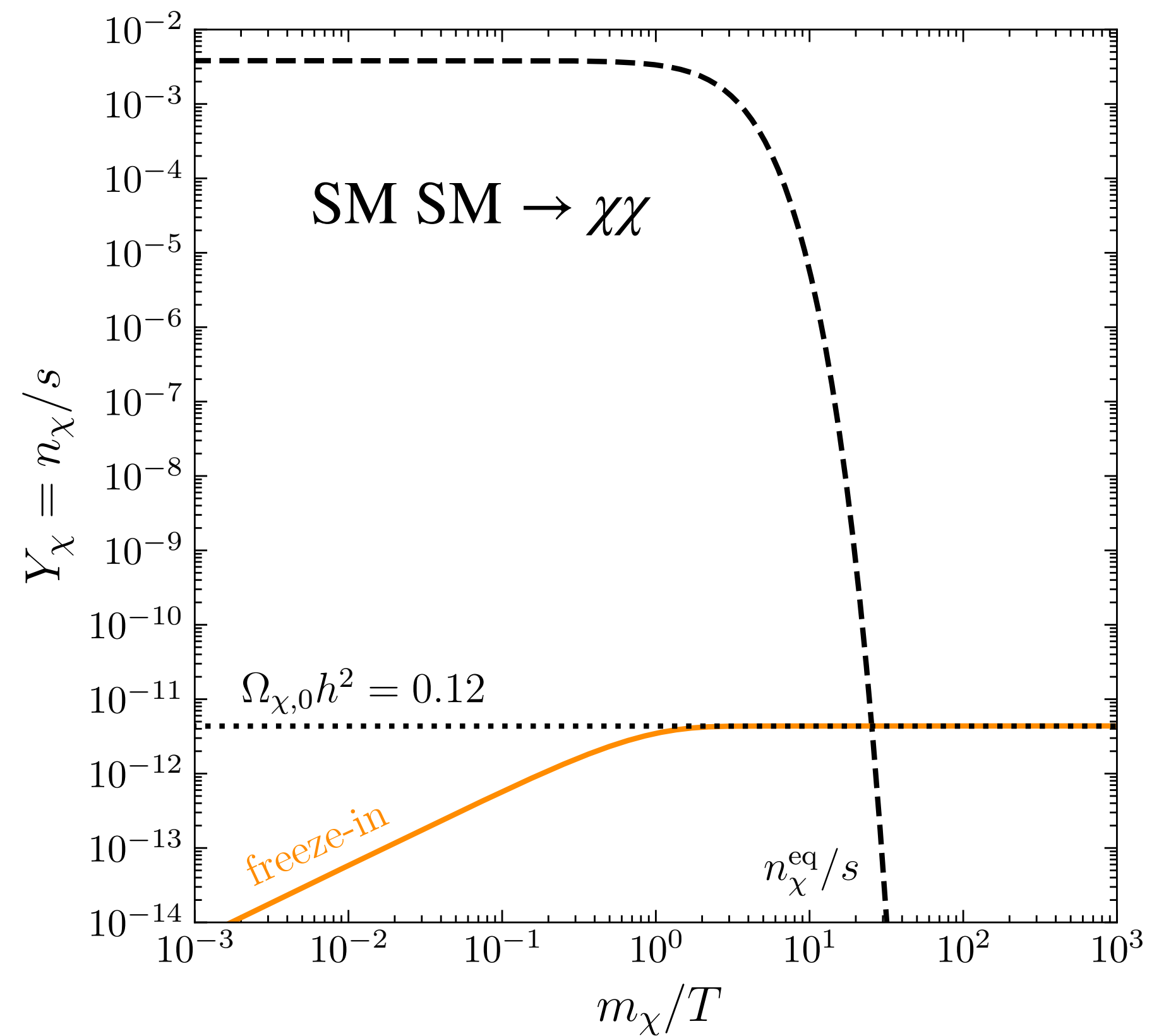
Planck 2022
30 May 2022



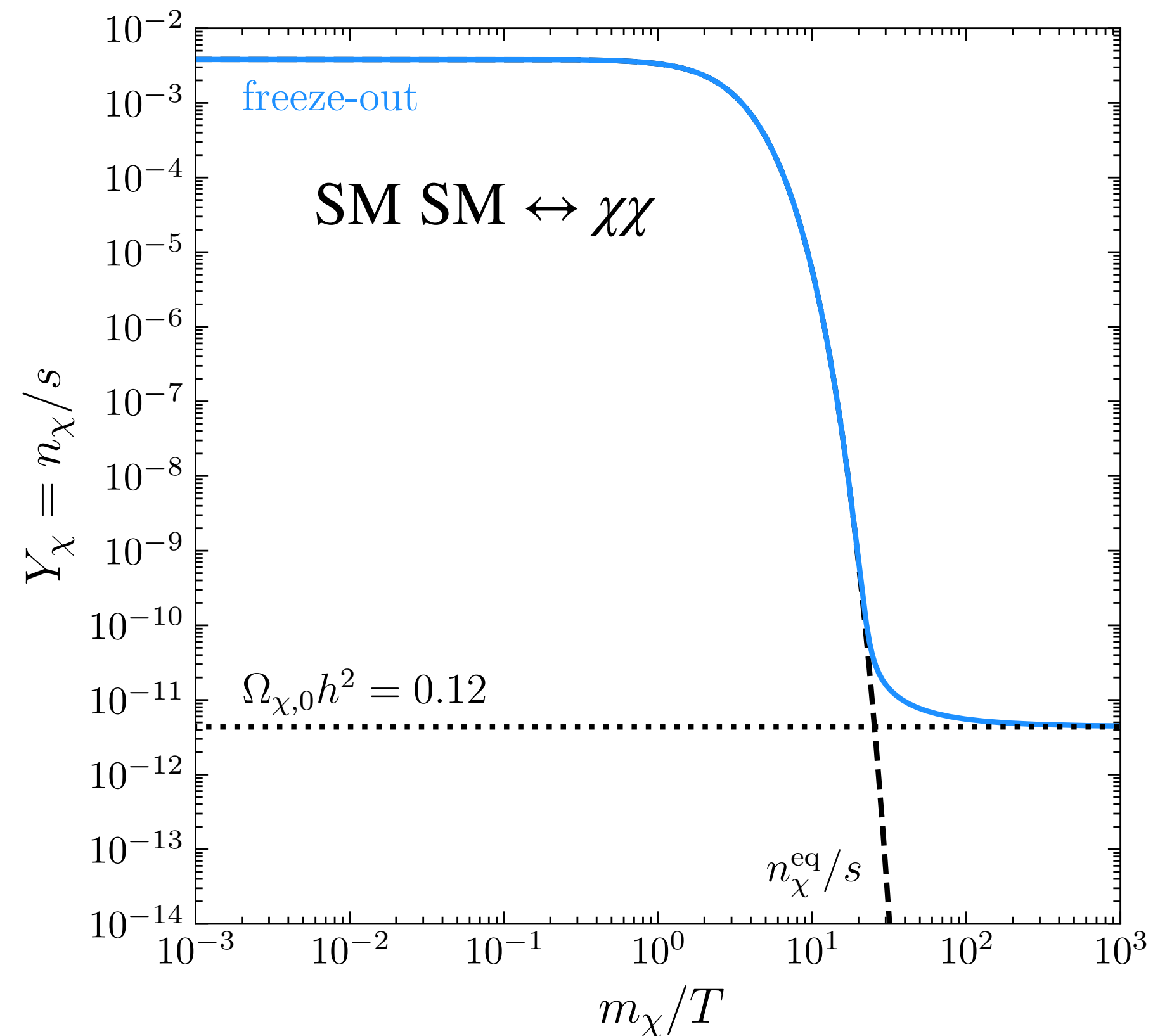
Thermal



Non-Thermal



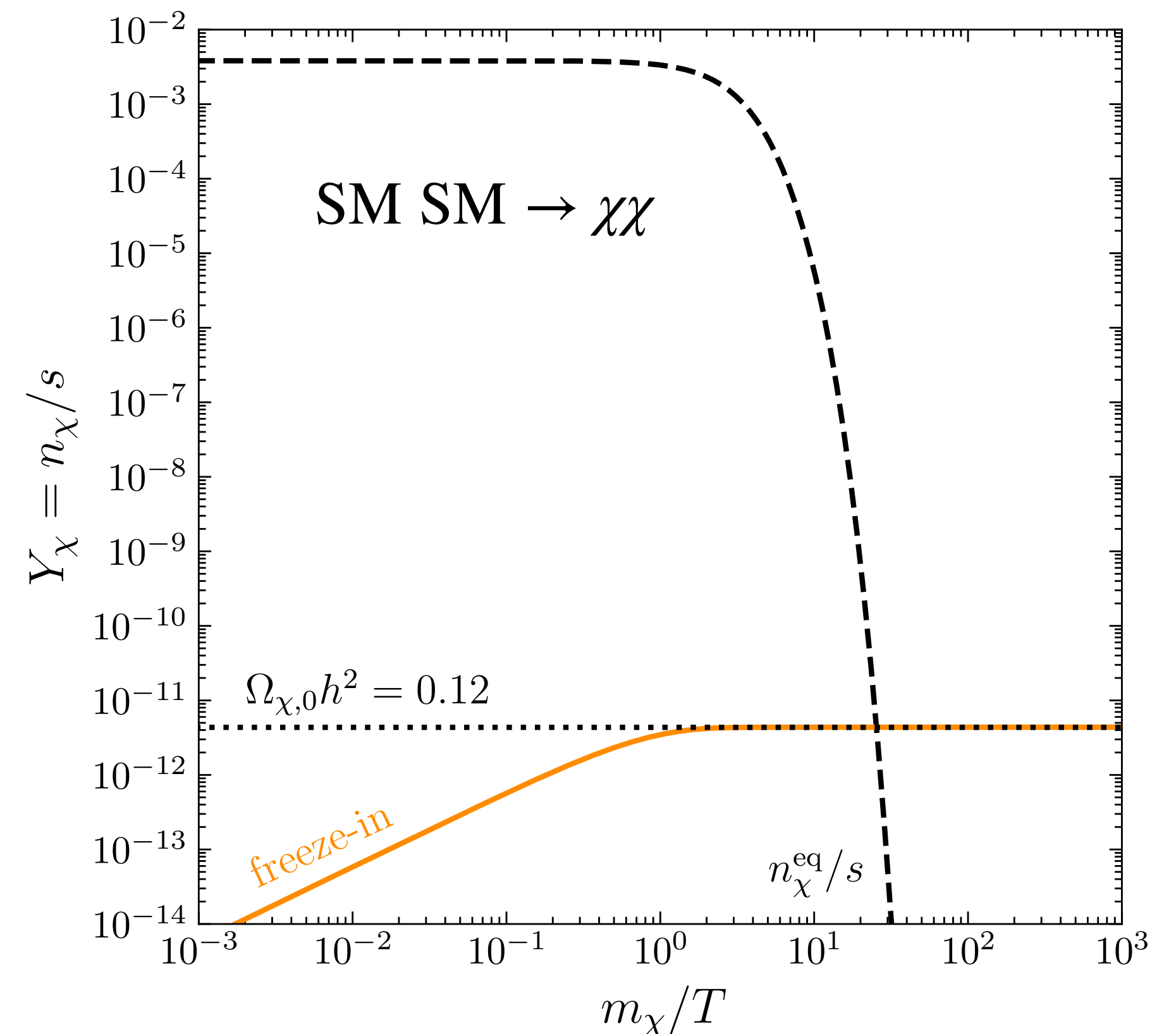
Thermal



Many variants of freeze-out:

- Semi-annihilations
- Hidden sector
- Cannibal DM
- Forbidden DM
- ...

Non-Thermal



Less variants for freeze-in

Dark Matter from Exponential Growth

Bringmann, PFD et al. 2103.16572

Hryczuk, Laletin 2104.05684

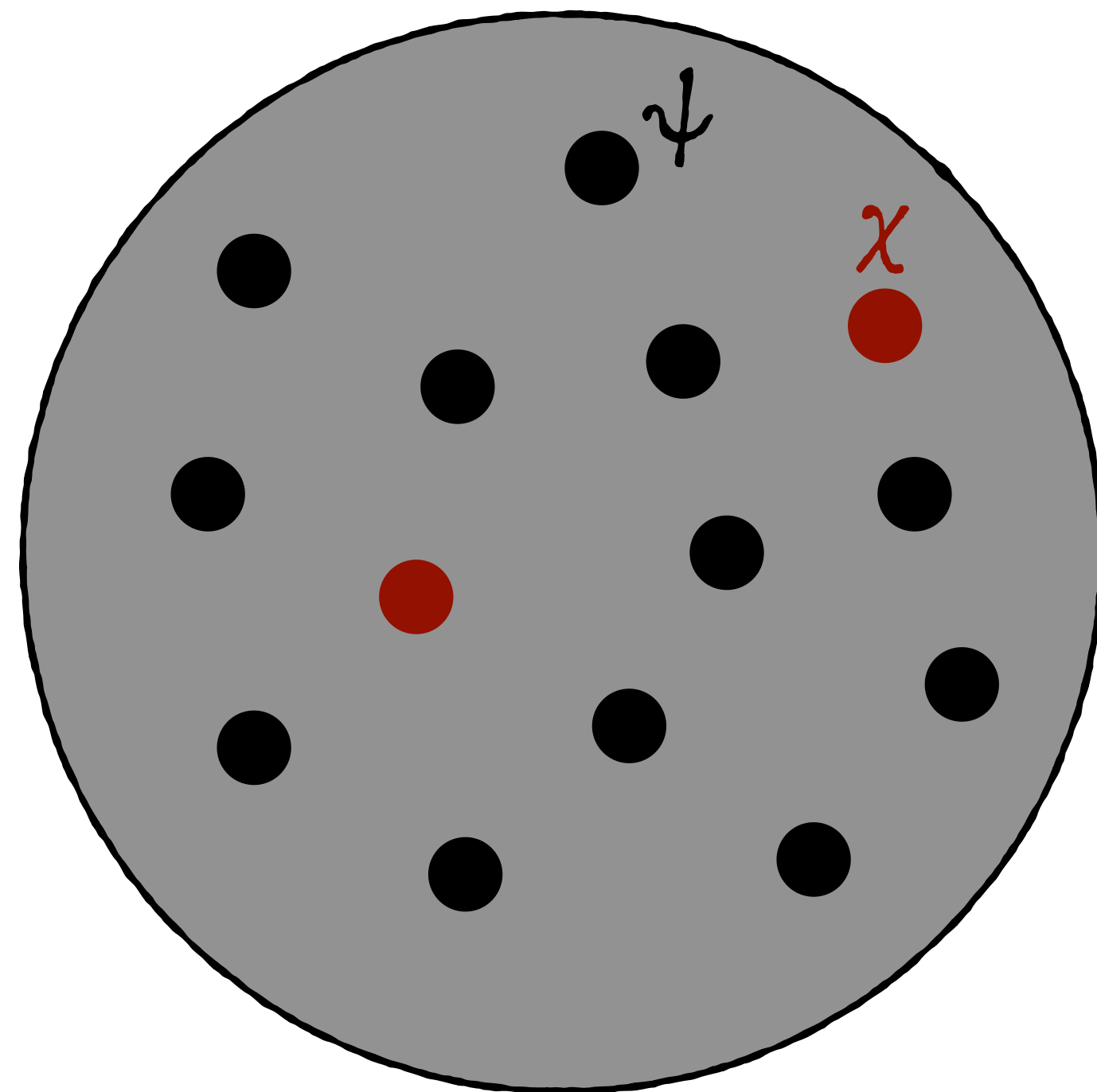
(First DM production mechanism w/
exponential growth!)



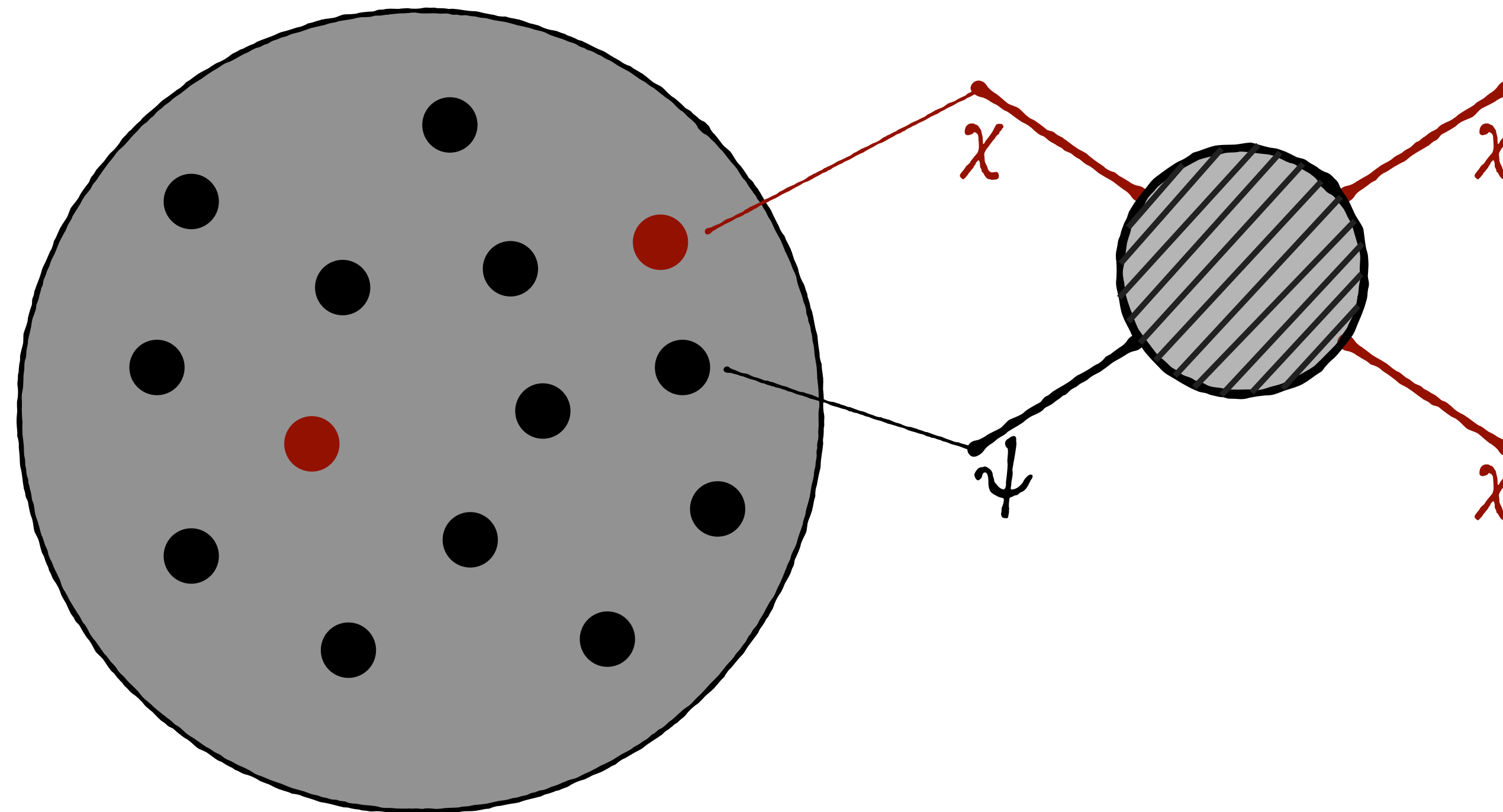
Outline

- Production by transformation
- Evolution of the DM abundance
- Phase diagram
- Higgs portal model
- Connection to sterile neutrinos

Production by transformation

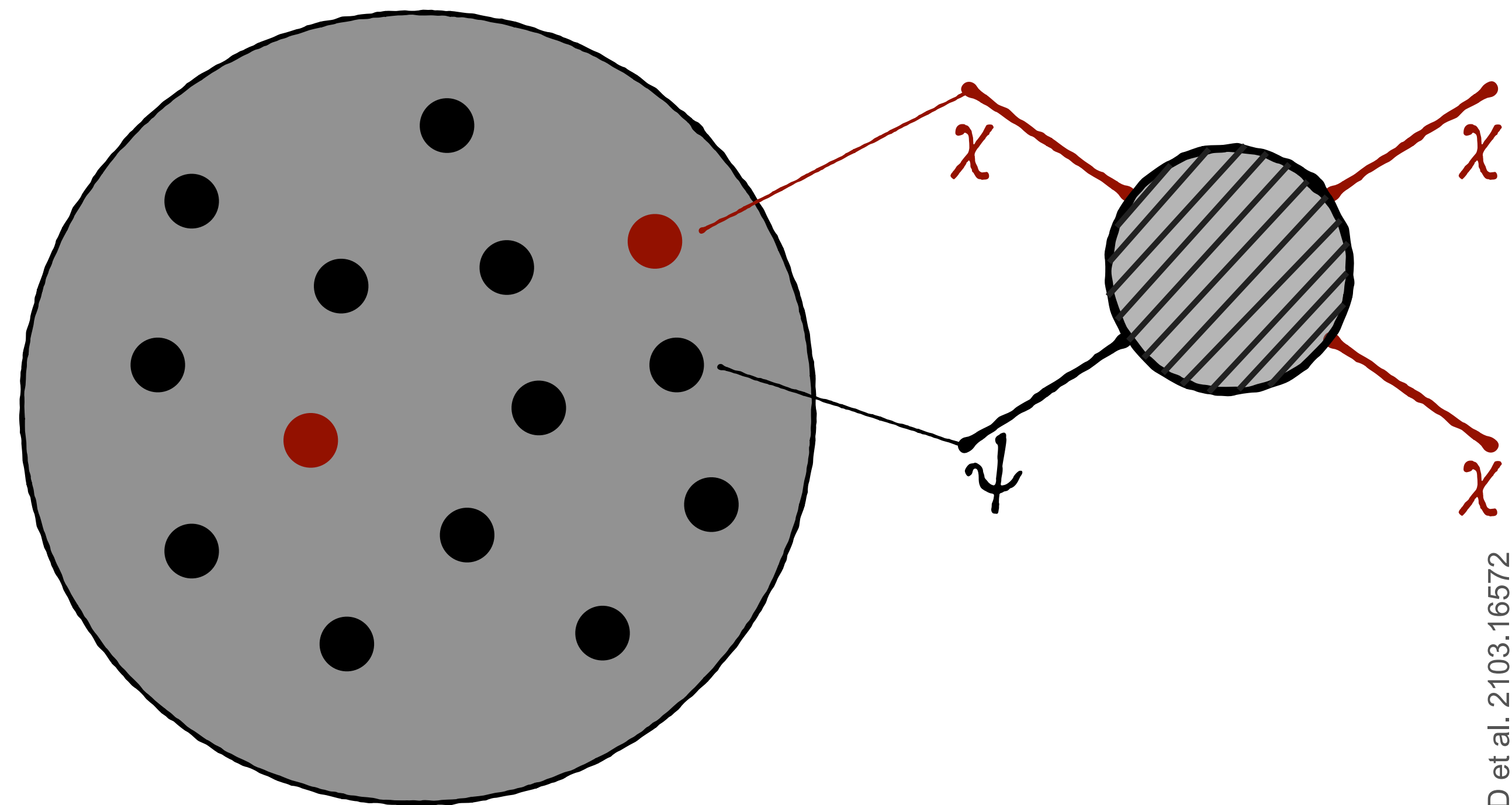


Production by transformation



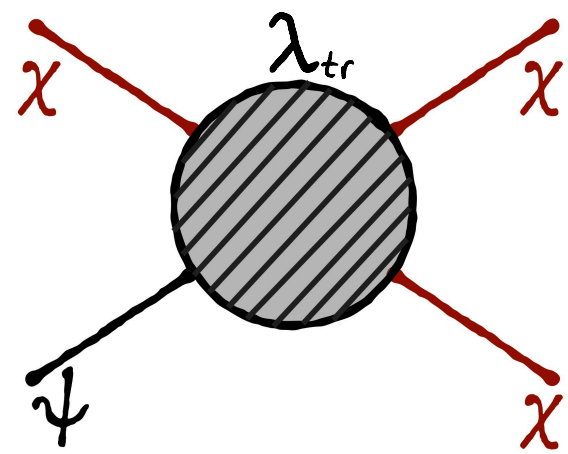
Production by transformation

- $\dot{n}_\chi + 3Hn_\chi = \langle \sigma v \rangle_{\text{tr}} n_\psi^{\text{eq}} n_\chi$
- $Y_\chi(x_\psi) \equiv n_\chi/s \simeq Y_\chi^0 \exp\left(3 \int_{x_\psi^0}^{x_\psi} \frac{dx}{x} R(x)\right)$
- $R(x) = \frac{n_\psi^{\text{eq}} \langle \sigma v \rangle_{\text{tr}}}{3H}$: # of transformations of DM particle per Hubble time
- → Phase of exponential production
- Shutoff by kinematical or Boltzmann suppression
- Constant matrix element for simplicity

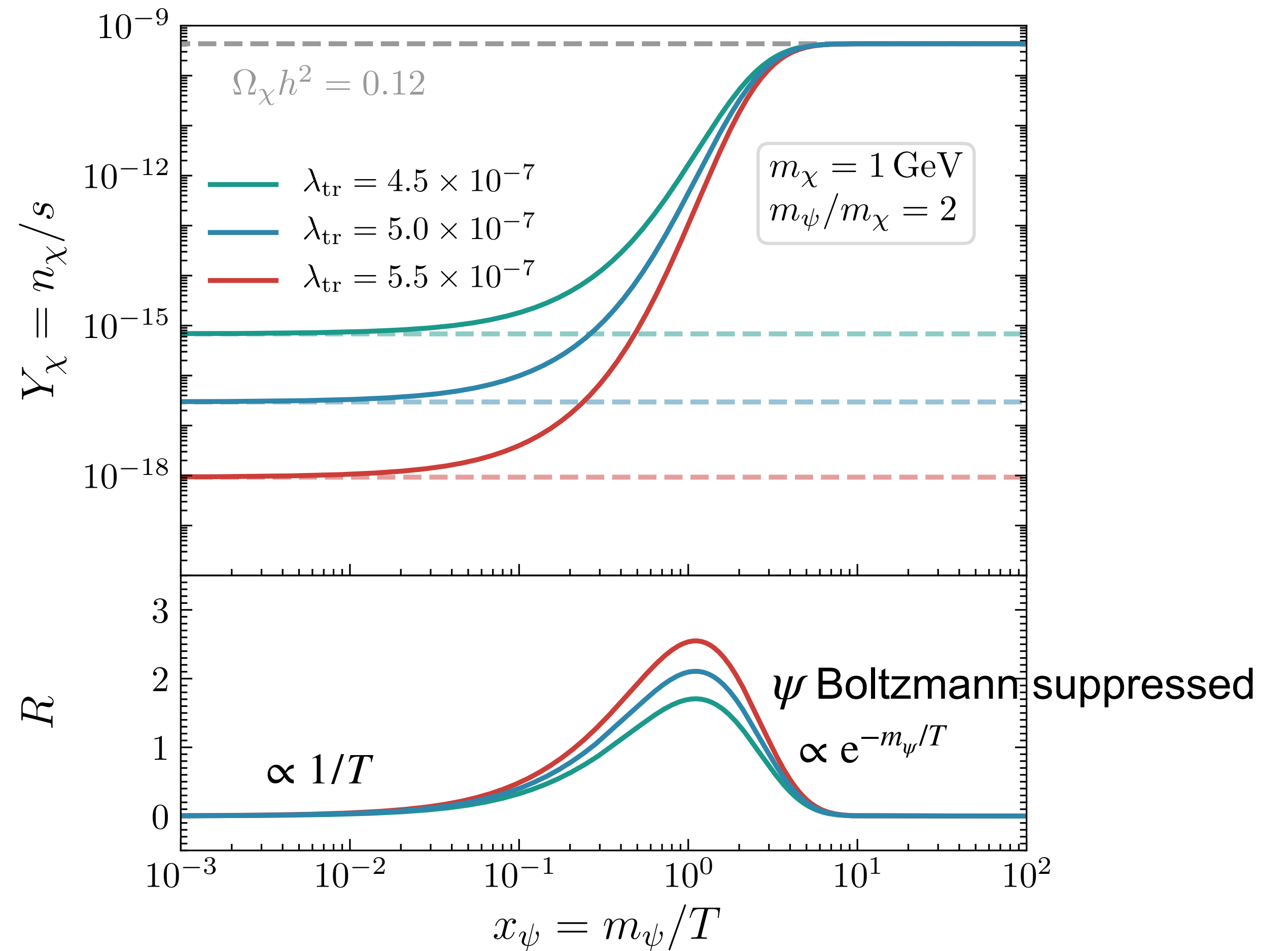


Evolution of DM abundance

Fixed initial abundance

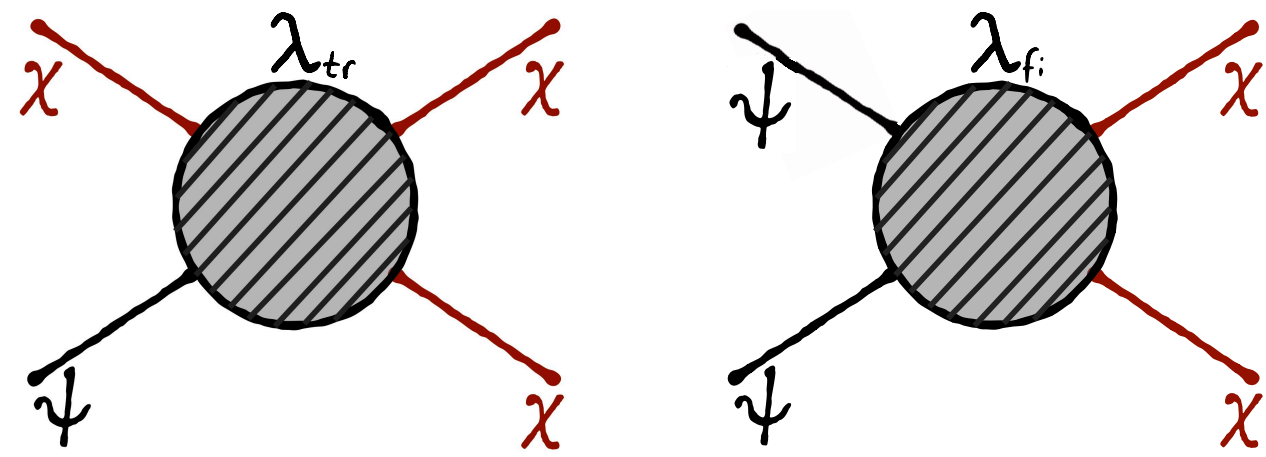


$$\dot{n}_\chi + 3Hn_\chi = \langle \sigma v \rangle_{\text{tr}} n_\psi^{\text{eq}} n_\chi$$

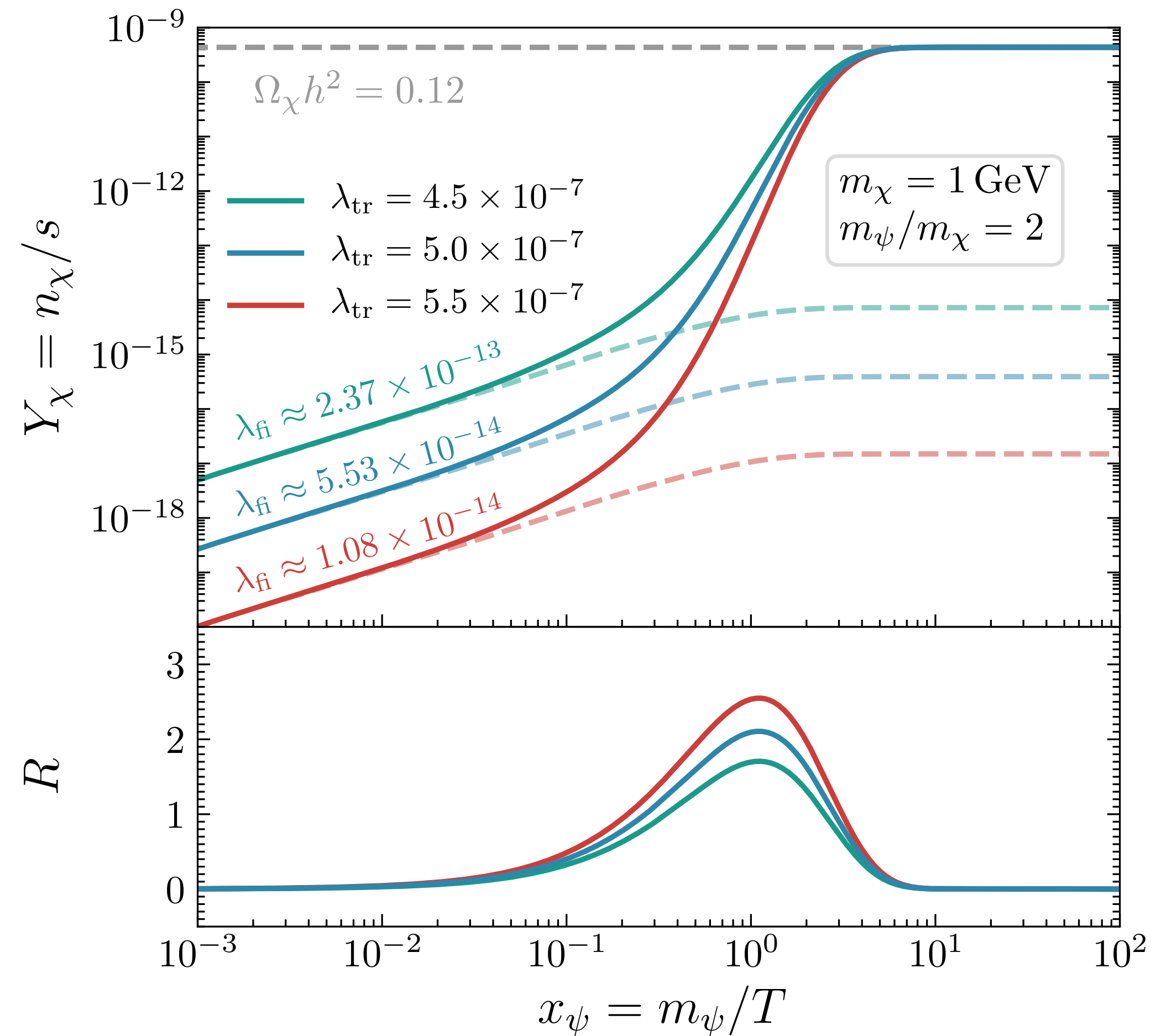


Evolution of DM abundance

Initial abundance from freeze-in



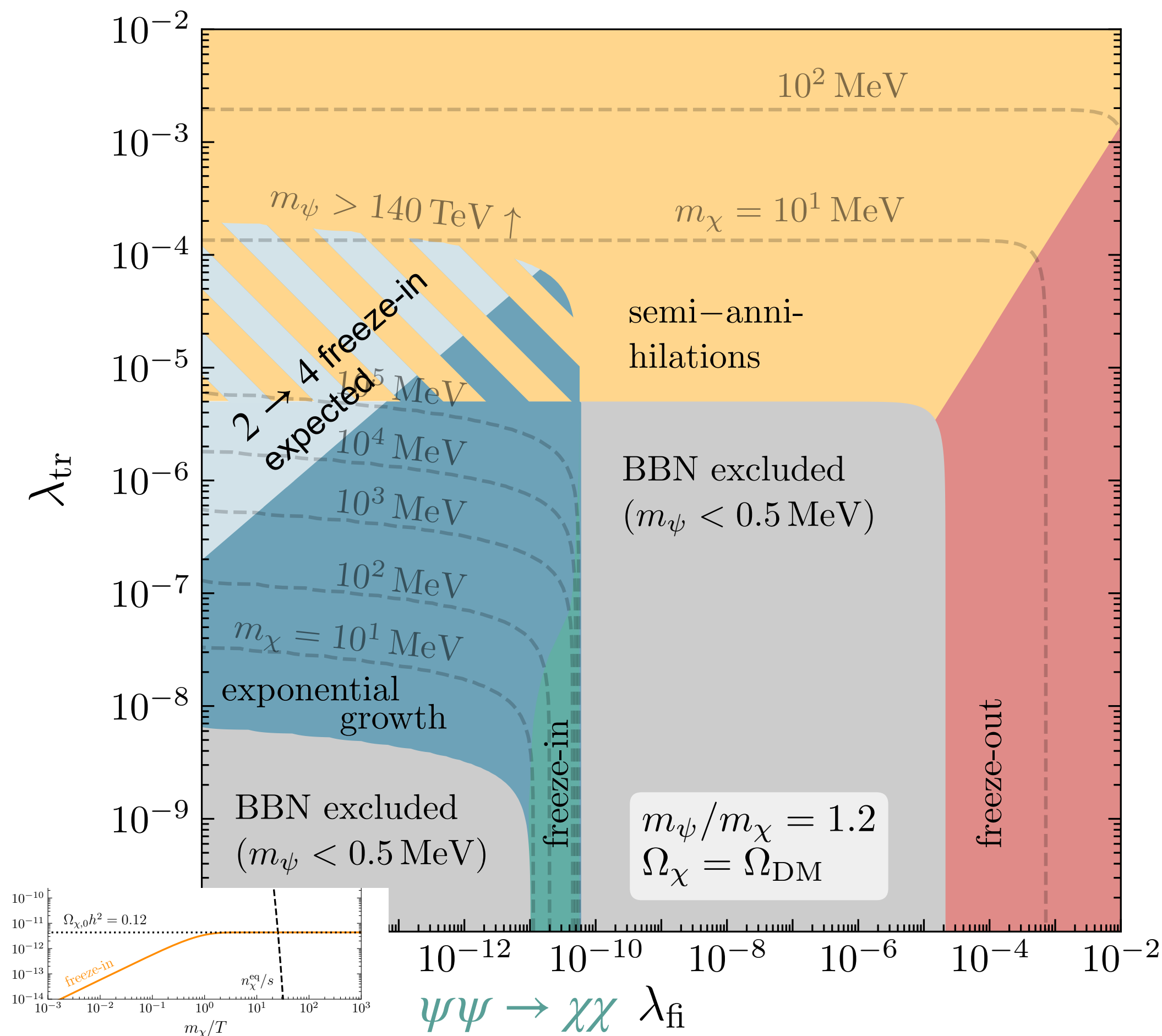
$$\dot{n}_\chi + 3Hn_\chi = \langle\sigma v\rangle_{\text{tr}} n_\psi^{\text{eq}} n_\chi + \langle\sigma v\rangle_{\text{fi}} (n_\psi^{\text{eq}})^2$$



Phase diagram

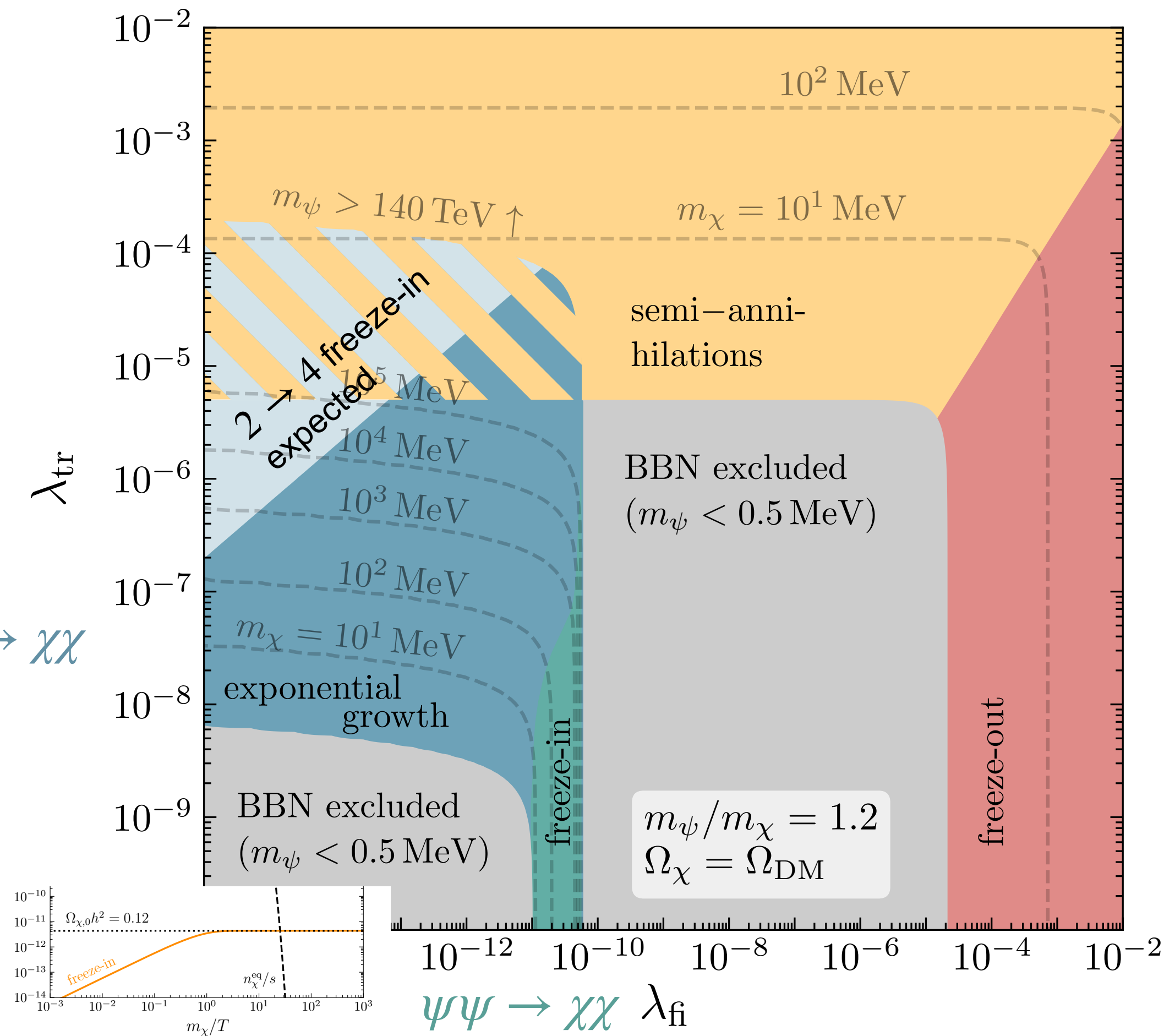
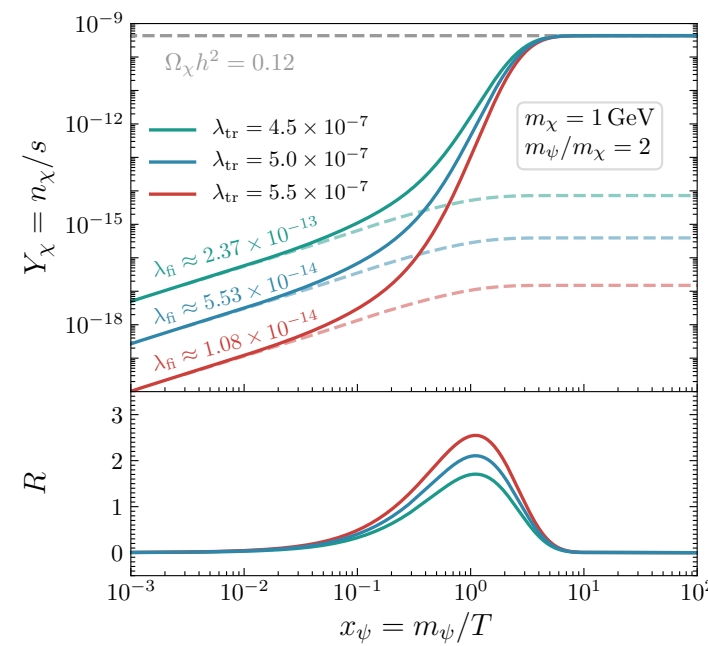
$$\dot{n}_\chi + 3Hn_\chi =$$

$$\langle \sigma v \rangle_{\text{fi}} [(n_\psi^{\text{eq}})^2]$$



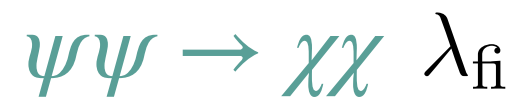
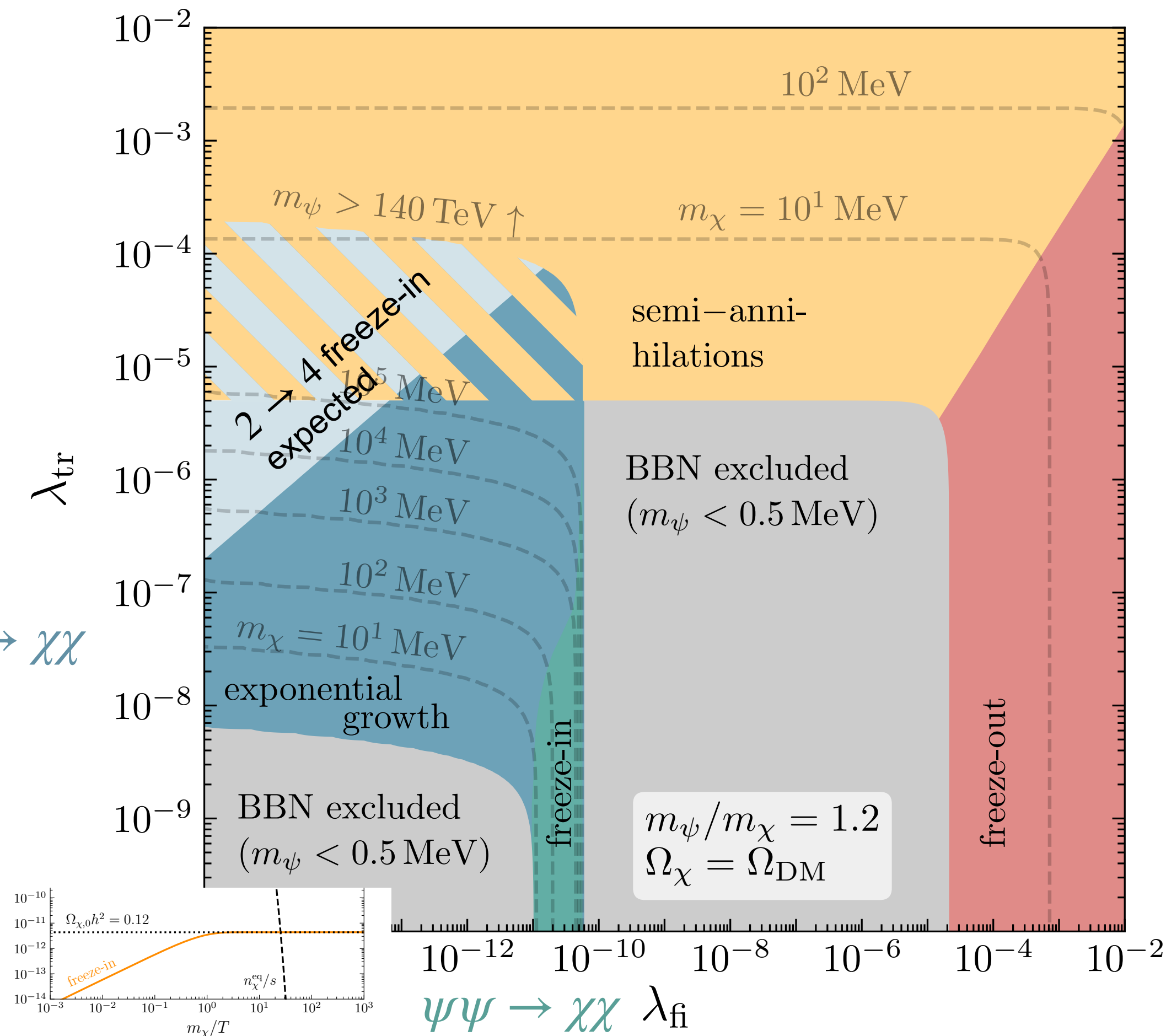
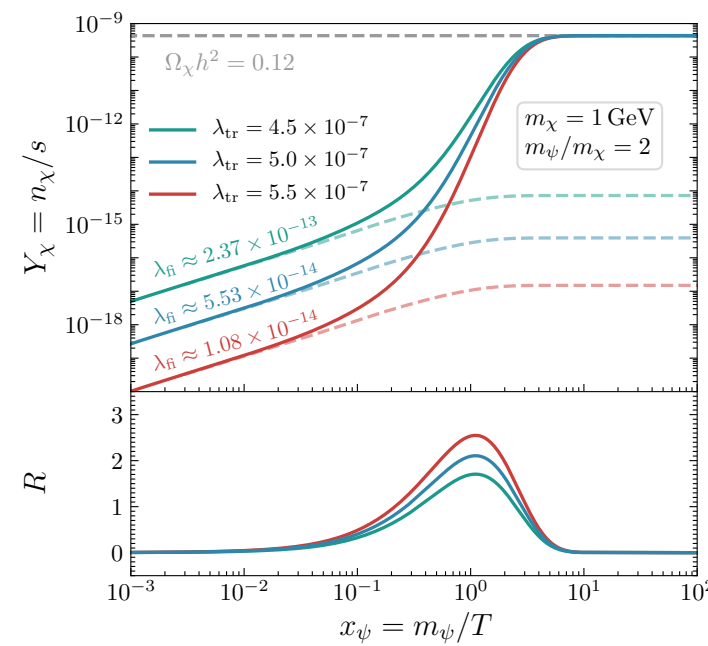
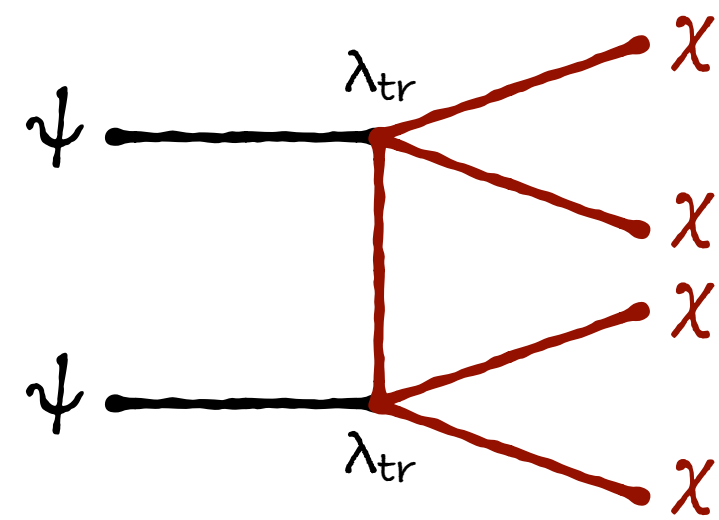
Phase diagram

$$\dot{n}_\chi + 3Hn_\chi = \langle\sigma v\rangle_{\text{tr}} [n_\psi^{\text{eq}}n_\chi] + \langle\sigma v\rangle_{\text{fi}} [(n_\psi^{\text{eq}})^2]$$



Phase diagram

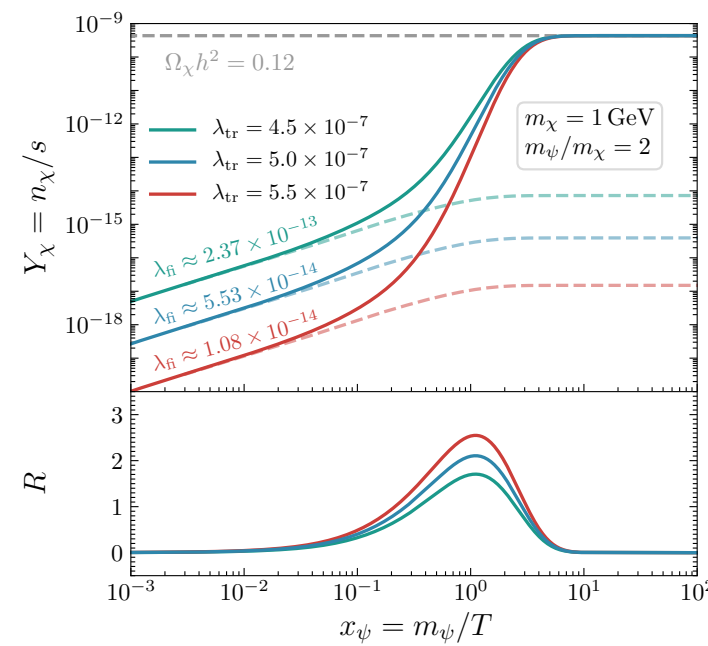
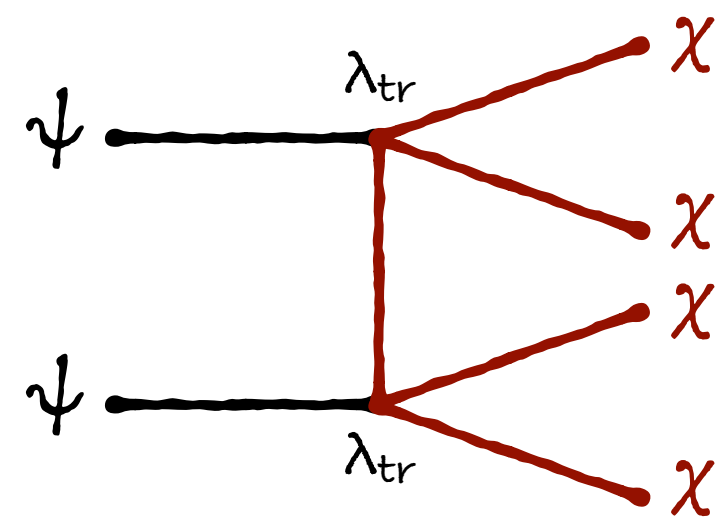
$$\dot{n}_\chi + 3Hn_\chi = \langle\sigma v\rangle_{\text{tr}} [n_\psi^{\text{eq}} n_\chi] + \langle\sigma v\rangle_{\text{fi}} [(n_\psi^{\text{eq}})^2]$$



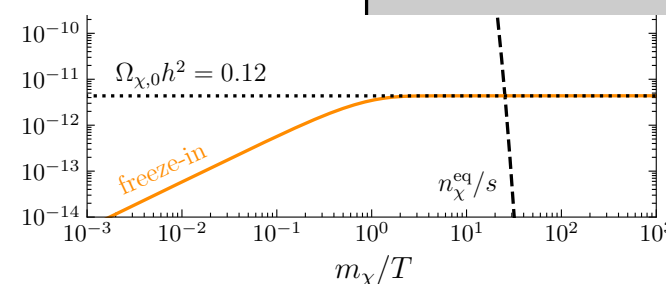
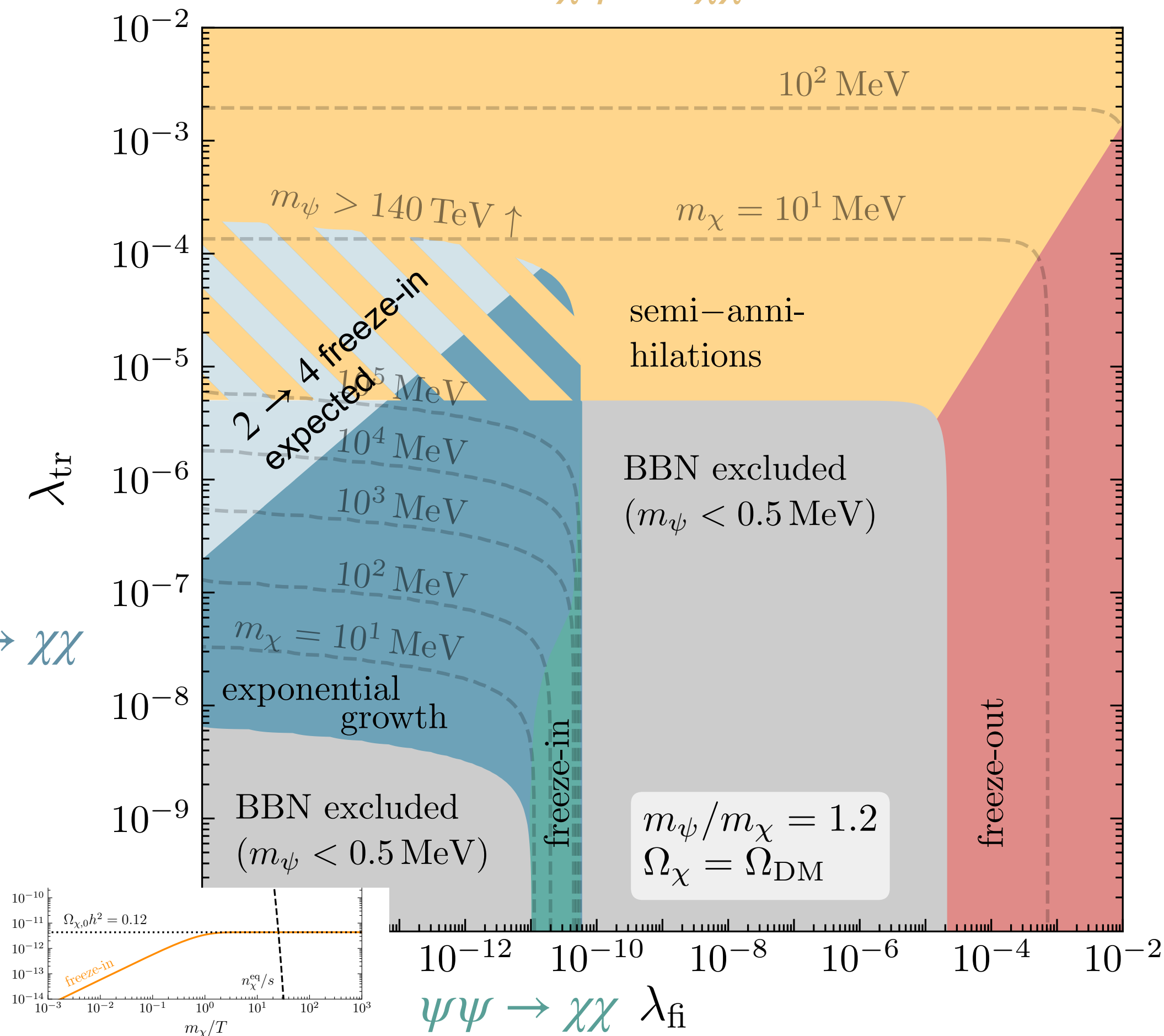
Phase diagram

$$\dot{n}_\chi + 3Hn_\chi = \langle\sigma v\rangle_{\text{tr}} [n_\psi^{\text{eq}}n_\chi - n_\chi^2 n_\psi^{\text{eq}}/n_\chi^{\text{eq}}] + \langle\sigma v\rangle_{\text{fi}} [(n_\psi^{\text{eq}})^2 - (n_\chi n_\psi^{\text{eq}}/n_\chi^{\text{eq}})^2]$$

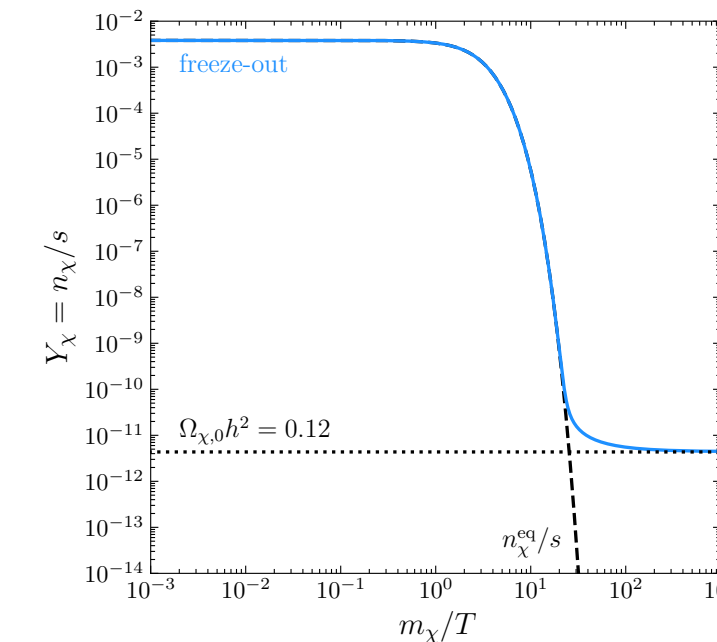
$\chi\psi \leftrightarrow \chi\chi$



$\chi\psi \rightarrow \chi\chi$



$\psi\psi \rightarrow \chi\chi$ λ_{fi}

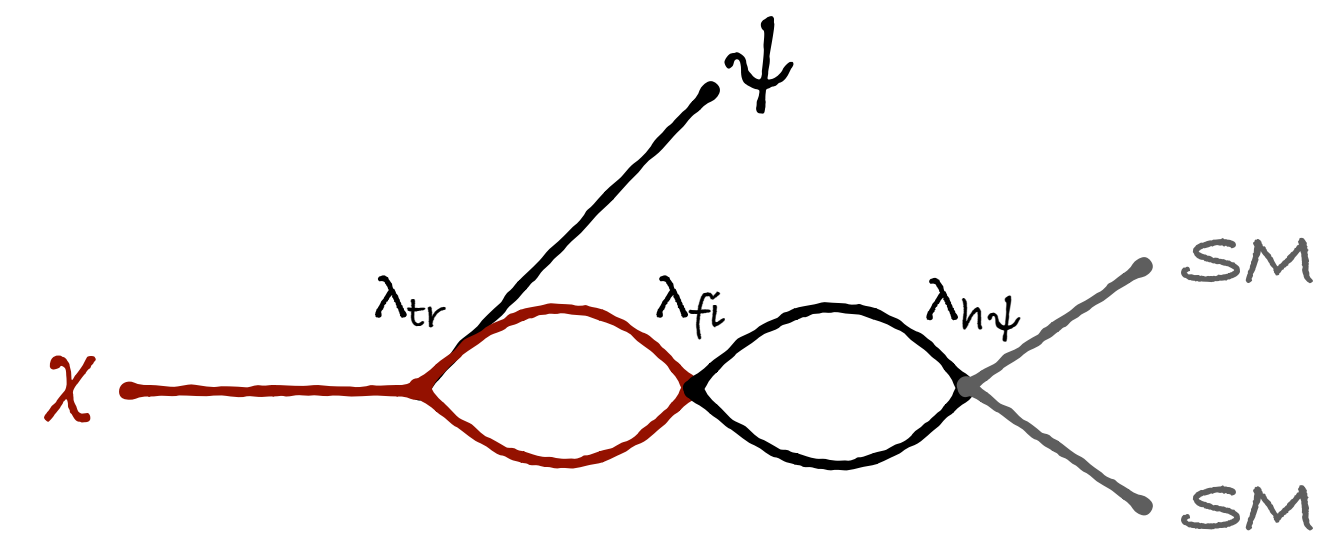
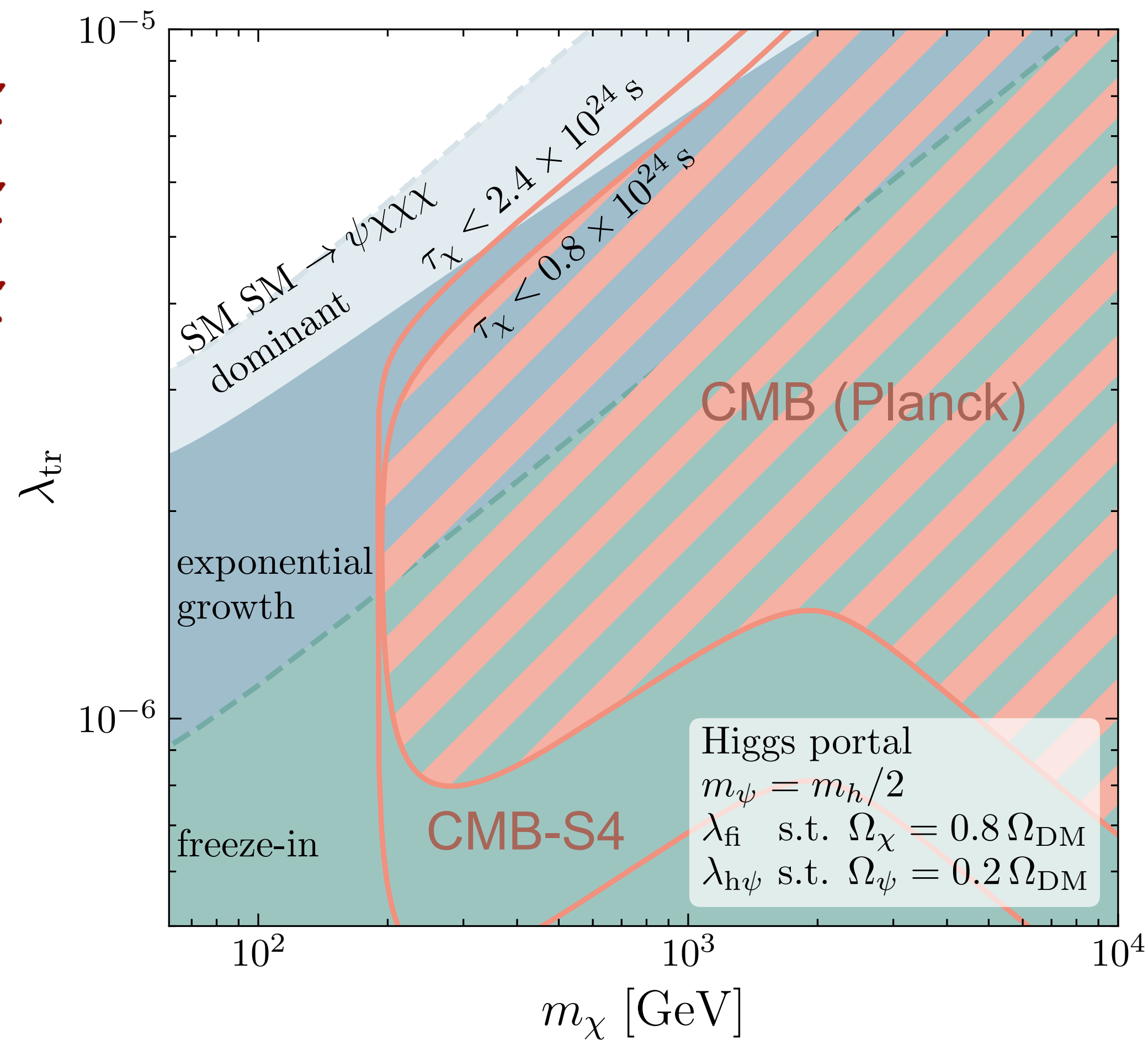
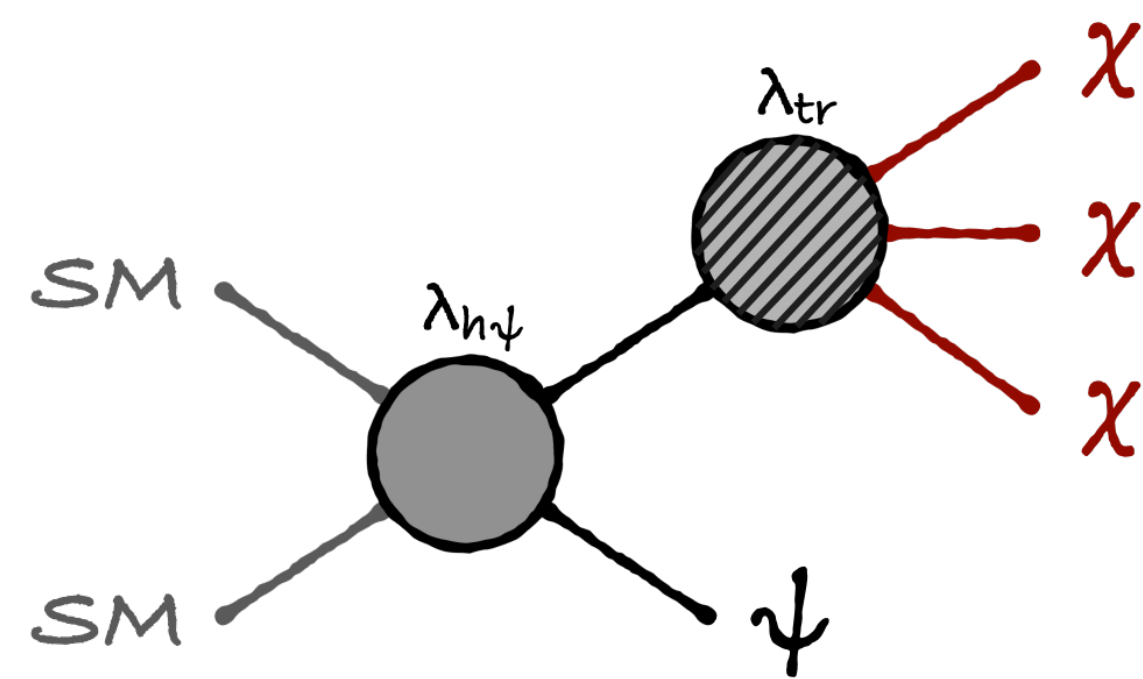


$\psi\psi \leftrightarrow \chi\chi$



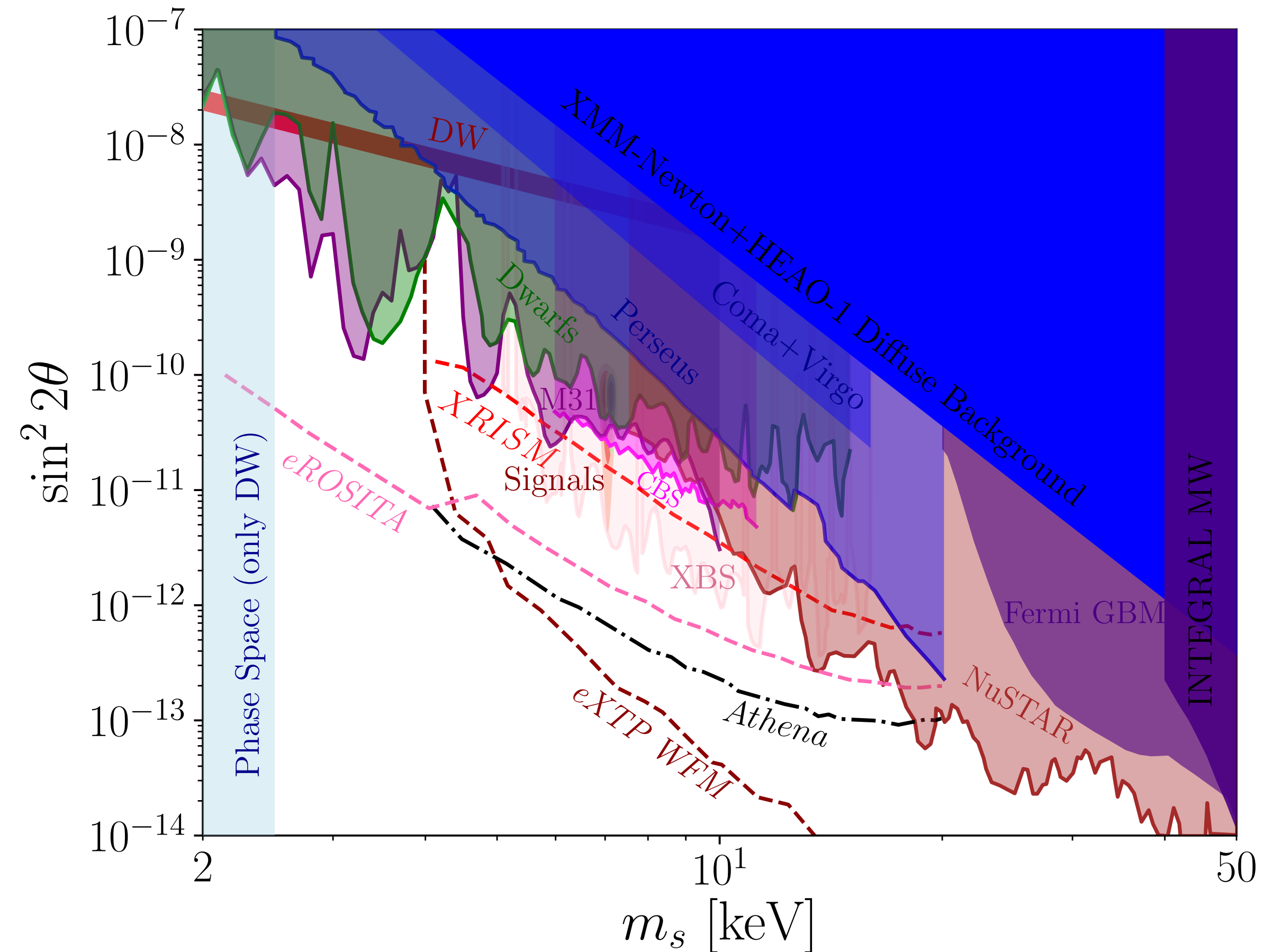
Phenomenological consequences

Higgs portal $\lambda_{h\psi} |H|^2 \psi^2 / 2$



Connection to sterile neutrinos

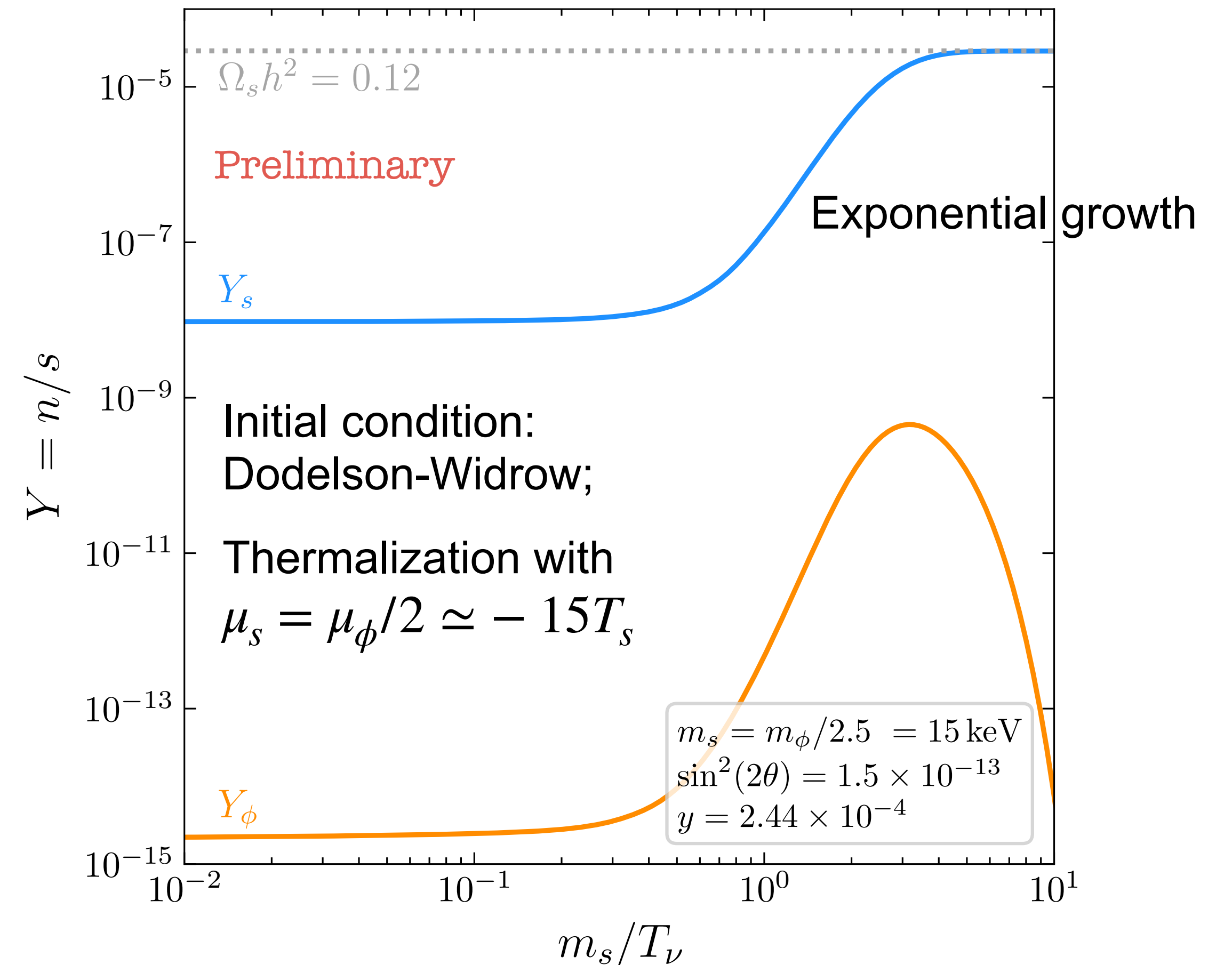
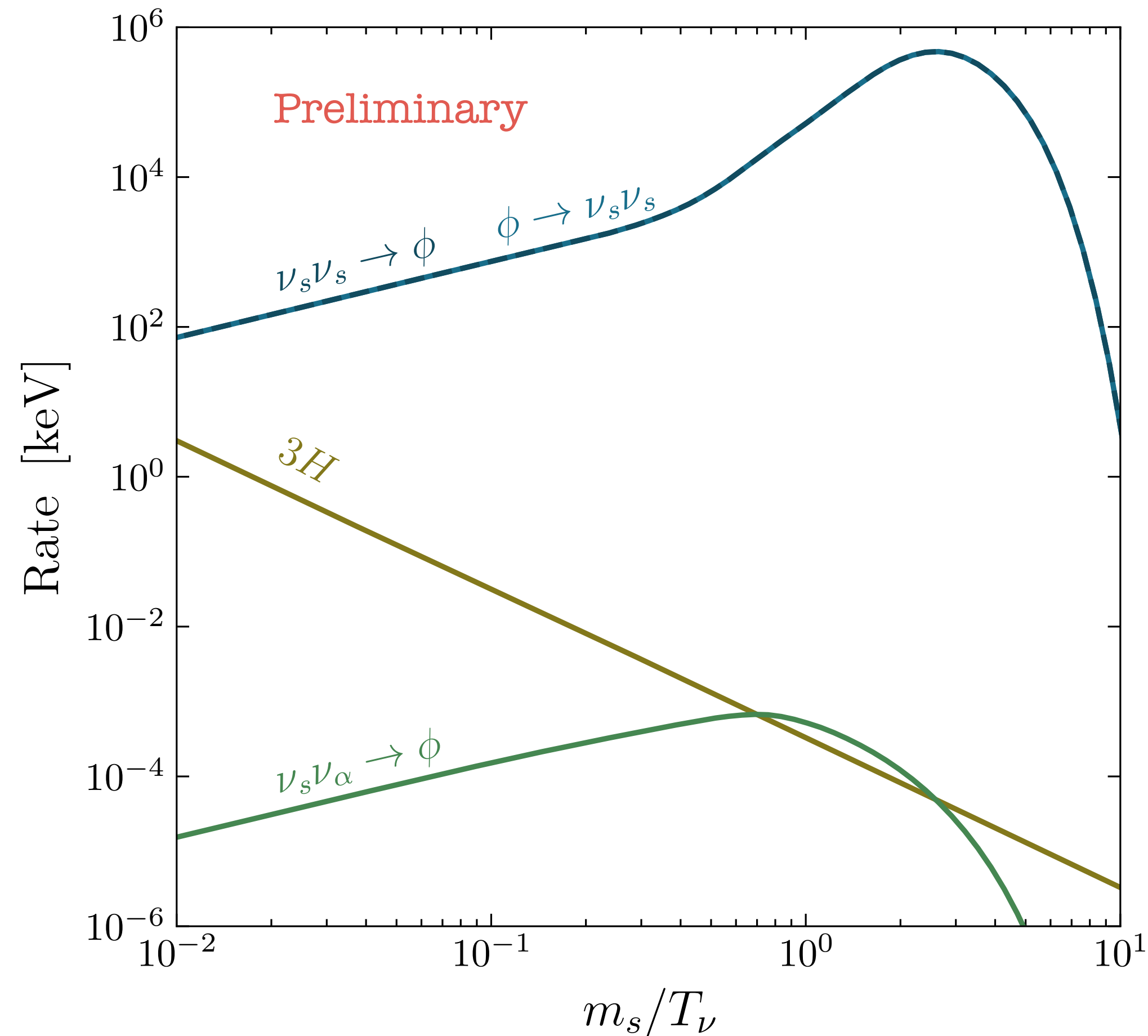
- Convenient way to realize $\lambda_{\text{fi}} \ll \lambda_{\text{tr}}$: Two fermions with tiny mass mixing, only one (mostly χ) interacts with some mediator via Yukawa coupling
- After mass diagonalization:
 - $\bar{\chi}\chi$ vertices $\propto \cos^2 \theta \sim 1$
 - $\bar{\psi}\chi$ vertices $\propto \cos \theta \sin \theta \sim \theta$
 - $\bar{\psi}\psi$ vertices $\propto \sin^2 \theta \sim \theta^2$
- What if ψ further is in the SM?
- \rightarrow Sterile neutrino, mass-mixing with active, coupling between mediator and sterile in flavor-space



Abazajian et al. 2203.07377

Connection to sterile neutrinos

$$\mathcal{L} \supset \frac{y}{2} \phi \bar{\nu}_s \nu_s \rightarrow \frac{y}{2} \phi [\sin^2 \theta \bar{\nu}_\alpha \nu_\alpha - \sin \theta \cos \theta (\bar{\nu}_\alpha \nu_s + \bar{\nu}_s \nu_\alpha) + \cos^2 \theta \bar{\nu}_s \nu_s]$$



Conclusions

- New non-thermal DM production mechanism involving exponential growth
- Complements freeze-in and freeze-out scenarios
- Interesting phenomenological consequences
- Specific model realizations:
 - Higgs portal as simple example
 - Connection to sterile neutrinos
 - stay tuned for upcoming publication!



Thank you!

