

# WIMPs with Enhanced Annihilation from a Feebly Interacting Unstable Partner



Work in Progress by:

**Chance Hoskinson, Pearl Sandick, Barmak Shams Es Haghi**

Department of Physics and Astronomy, University of Utah

PHENO 2026, University of Pittsburgh

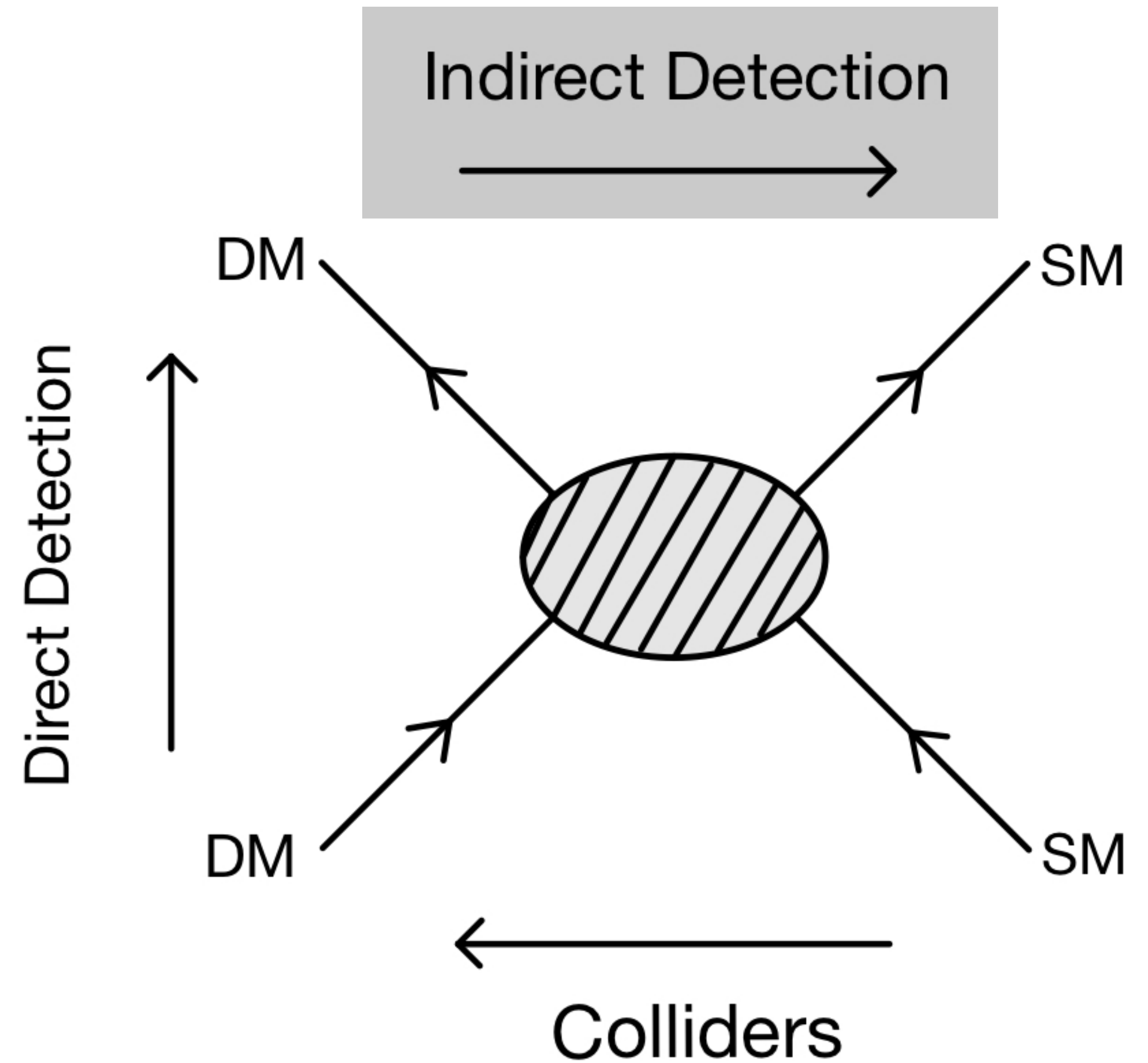
May 11, 2026



*Art by Michael Tompsett*

# WIMP Dark Matter

- Well motivated and not dead:
  - ~ 100 GeV + weak-scale coupling
  - $\Rightarrow \langle \sigma v \rangle \sim 2.2 \times 10^{-26} \text{ cm}^3/\text{s} \rightarrow \text{observed } \Omega h^2$



# Standard Freeze-out

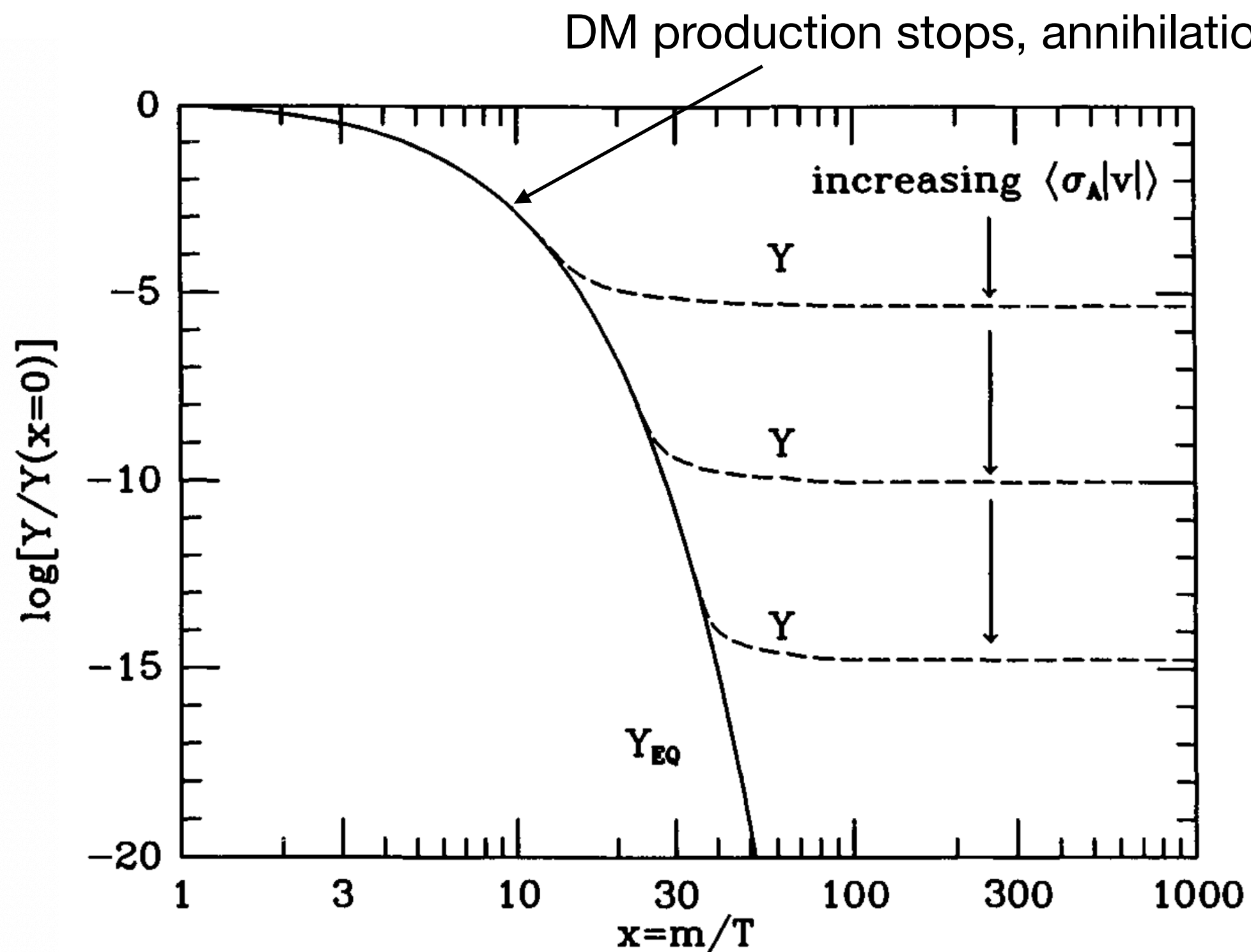


Fig. 5.1: The freeze out of a massive particle species. The dashed line is the actual abundance, and the solid line is the equilibrium abundance.

(E. W. Kolb and M. S. Turner, The Early Universe)

$$\frac{dY_\chi}{dx} = -\frac{\langle\sigma v\rangle s(x)}{xH(x)} (Y_\chi^2 - Y_{\chi,eq}^2)$$

$$Y_\infty \propto \frac{x_{f,ann}}{m_{pl}m_\chi \langle\sigma v\rangle}$$

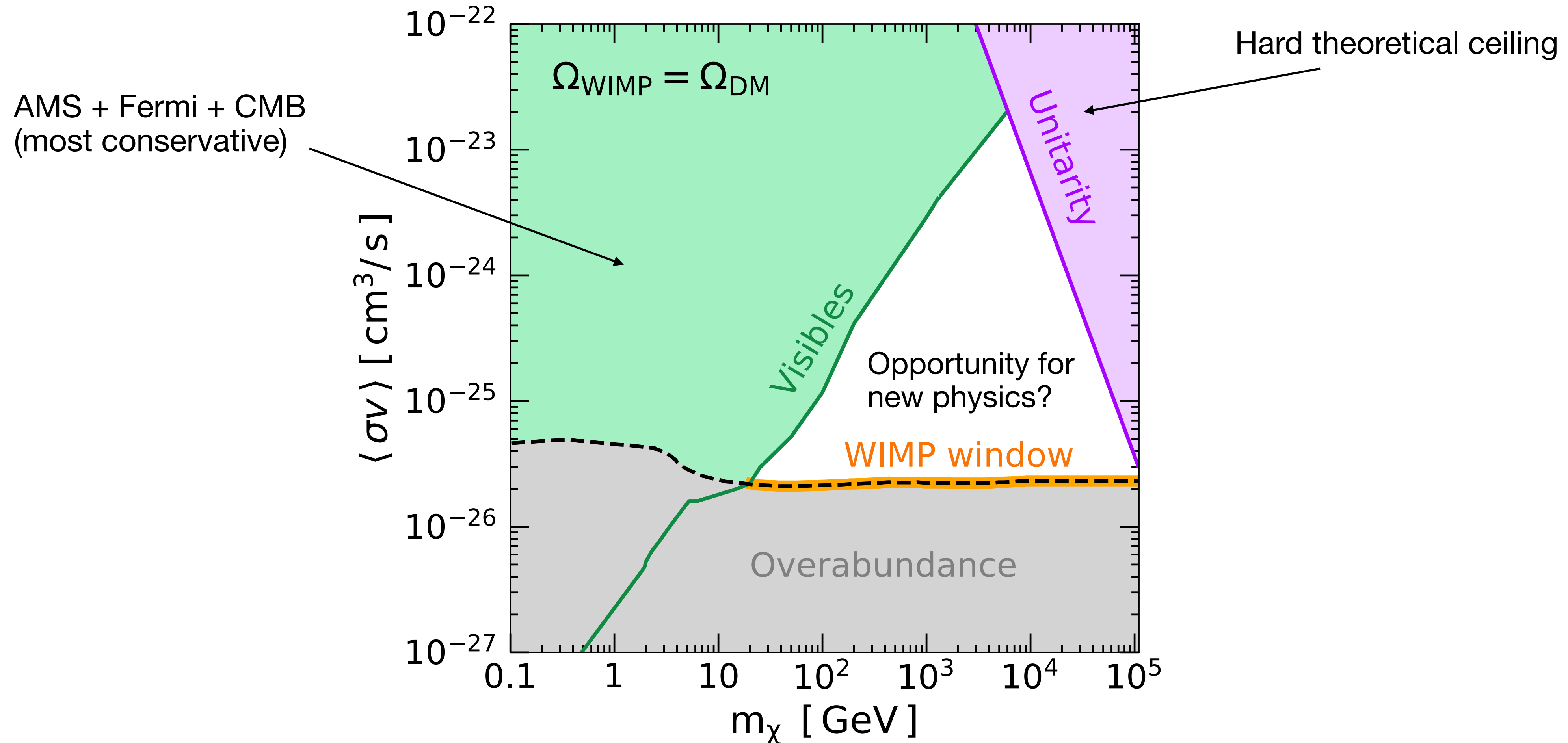
$$\Omega \propto \frac{1}{\langle\sigma v\rangle}$$

$$x_{f,ann} \simeq 20 - 30$$

If we could delay this:  $x_{f,ann} \uparrow \longrightarrow Y_\infty \uparrow$

Which requires:  $\langle\sigma v\rangle \uparrow$  for the same  $Y_\infty$

# Why Go Beyond the Standard WIMP?



R. K. Leane, T. R. Slatyer, J. F. Beacom, and K. C. Y. Ng, arXiv:1805.10305

# A Minimal Extension

$$\mathcal{L} \supset -\frac{1}{2}m_\phi\phi^2 - \left( \frac{1}{2}m_\chi\chi\chi + \frac{1}{2}\lambda\phi\chi\chi + \text{h.c.} \right)$$

Real Scalar Majorana WIMP Yukawa Coupling

Scalar only interacts with DM

If it is coupled to Higgs, we require:  
 $\lambda_{SM} \ll \lambda$

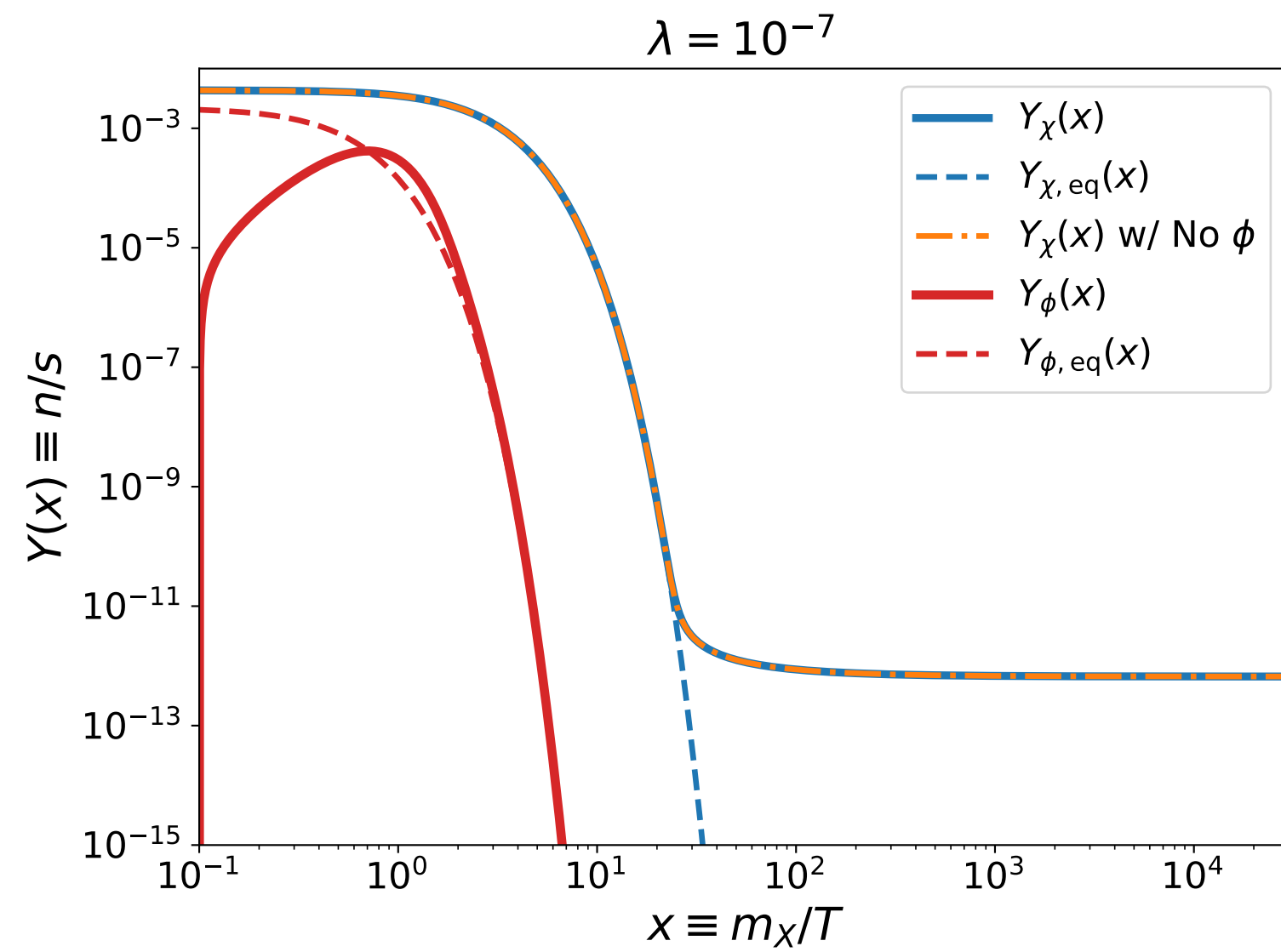
$$m_\phi > 2m_\chi \longrightarrow \phi \rightarrow \chi\chi \quad (\text{Required for Unstable})$$

$\lambda$  and  $m_\phi$  control thermal history

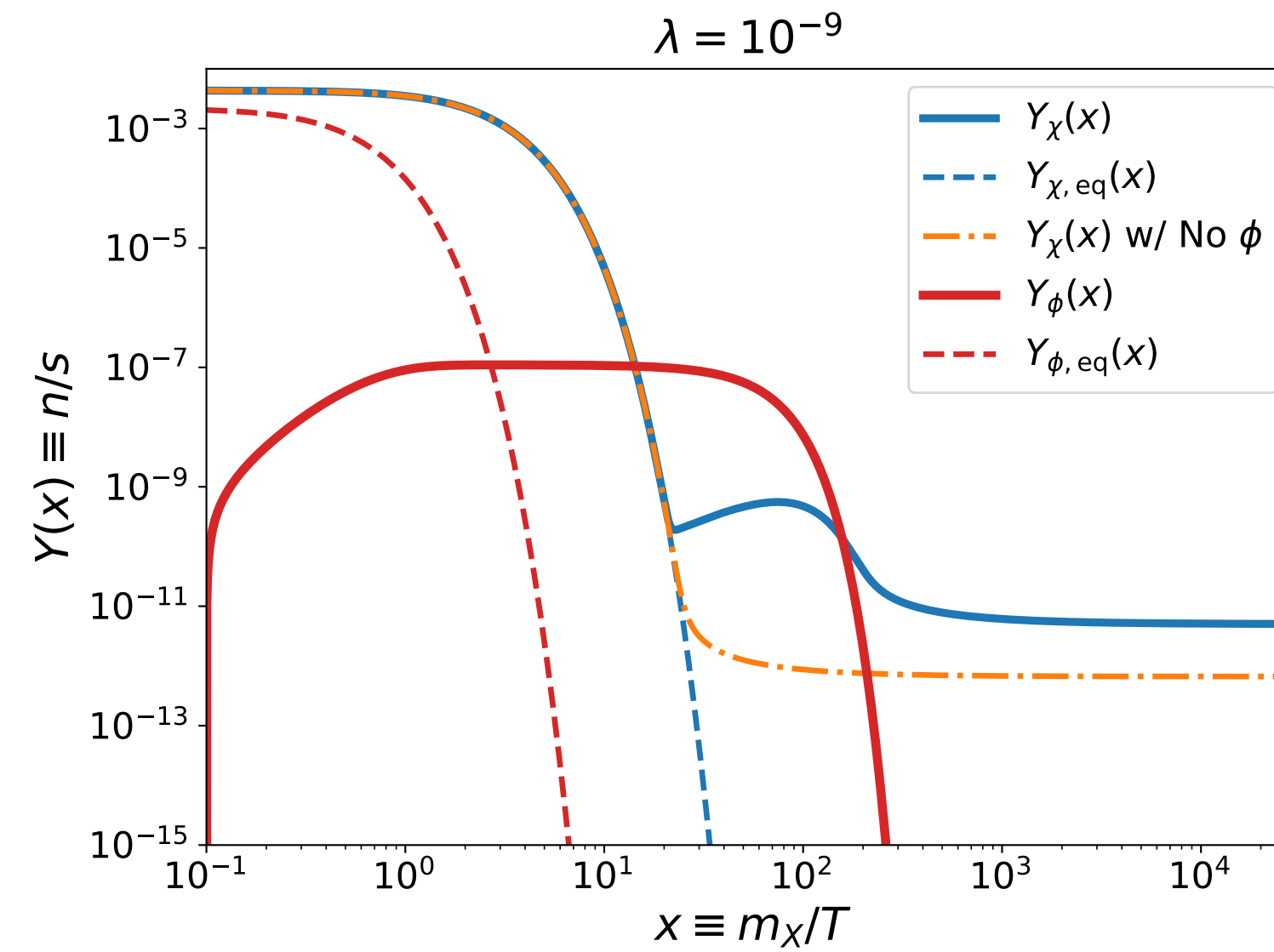
# Thermal Histories

$$m_\chi = 100 \text{ GeV} \quad m_\phi = 500 \text{ GeV}$$

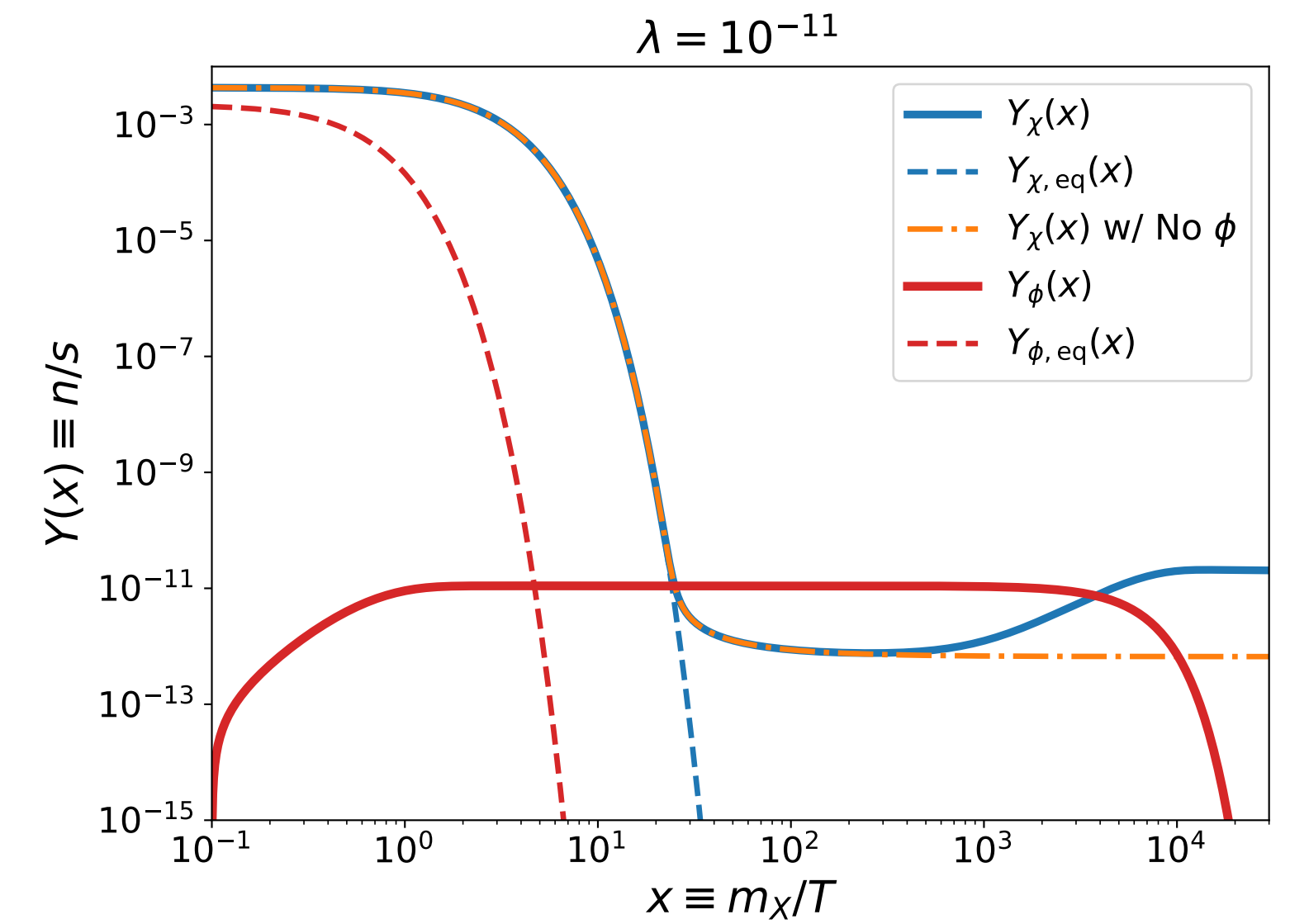
Orange matches the observed relic abundance today



No imprint  $\rightarrow$  Standard Freeze-out



Re-annihilation  $\rightarrow$  Delayed freeze-out



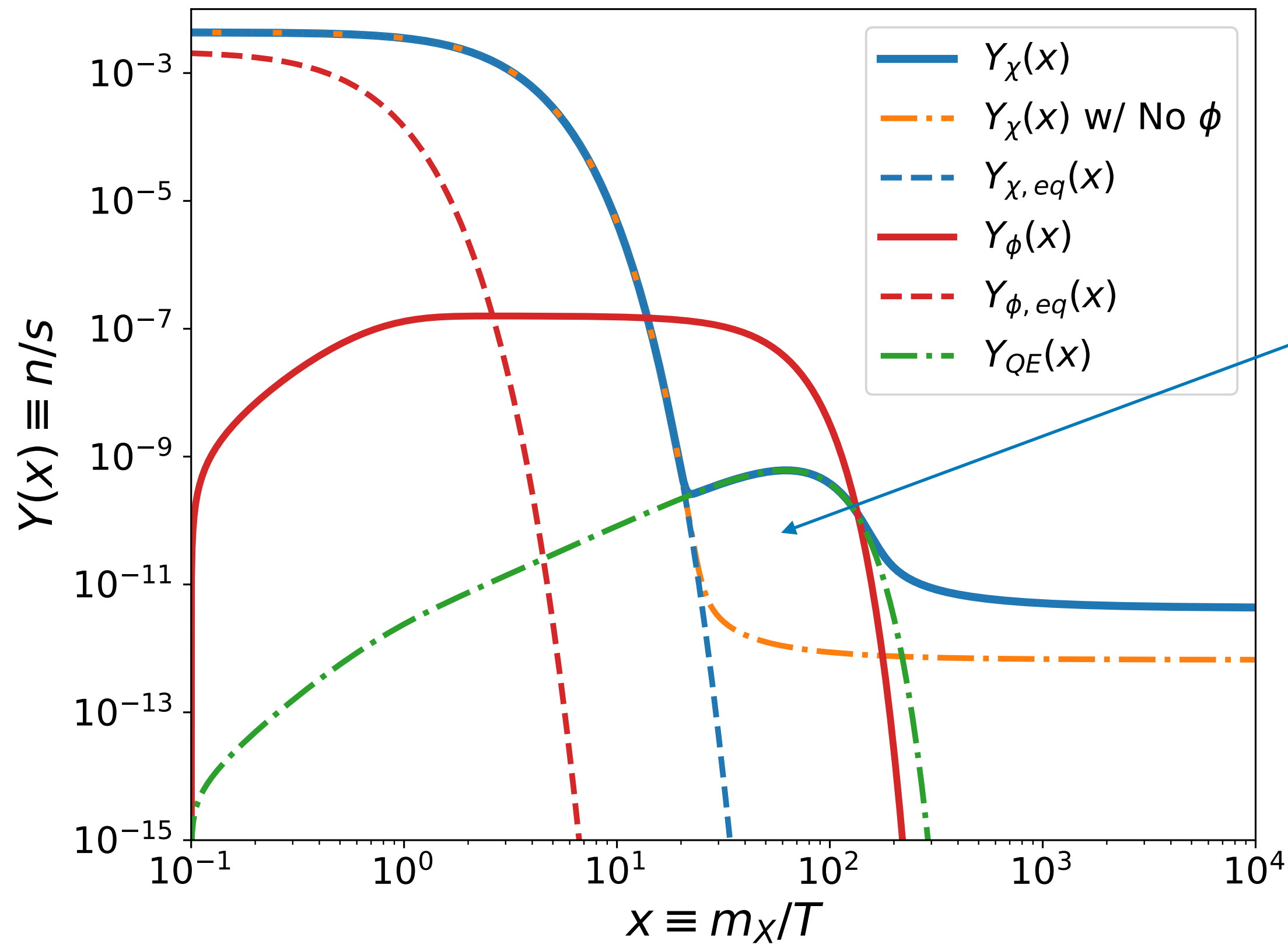
DM freeze-out followed by late freeze-in

$$\frac{dY_\chi}{dx} = -\frac{\langle\sigma v\rangle s(x)}{xH(x)} (Y_\chi^2 - Y_{\chi,\text{eq}}^2) - 2\frac{\langle\Gamma_\phi\rangle}{xH(x)} \left( Y_{\phi,\text{eq}} \frac{Y_\chi^2}{Y_{\chi,\text{eq}}^2} - Y_\phi \right)$$

$$\frac{dY_\phi}{dx} = \frac{\langle\Gamma_\phi\rangle}{xH(x)} \left( Y_{\phi,\text{eq}} \frac{Y_\chi^2}{Y_{\chi,\text{eq}}^2} - Y_\phi \right)$$

# Re-annihilation Window

$$m_\chi = 100 \text{ GeV} \quad m_\phi = 500 \text{ GeV} \quad \lambda = 1.2 \times 10^{-9}$$



Valid here

$$\frac{dY_\chi}{dx} = -\frac{\langle\sigma v\rangle s(x)}{xH(x)} (Y_\chi^2 - \cancel{Y_{\chi,eq}^2}) - 2\frac{\langle\Gamma_\phi\rangle}{xH(x)} \left( \cancel{Y_{\phi,eq}} \frac{Y_\chi^2}{Y_{\chi,eq}^2} - \cancel{Y_\phi} \right)$$

$$\simeq -\frac{\langle\sigma v\rangle s(x)}{xH(x)} Y_\chi^2 + 2\frac{\langle\Gamma_\phi\rangle}{xH(x)} Y_\phi$$

$$= -\frac{\langle\sigma v\rangle s(x)}{xH(x)} (Y_\chi^2 - Y_{\chi,QE}^2)$$

$$Y_{\chi,QE} \equiv \left[ 2\frac{\langle\Gamma_\phi\rangle}{\langle\sigma v\rangle s(x)} Y_\phi \right]^{1/2}$$

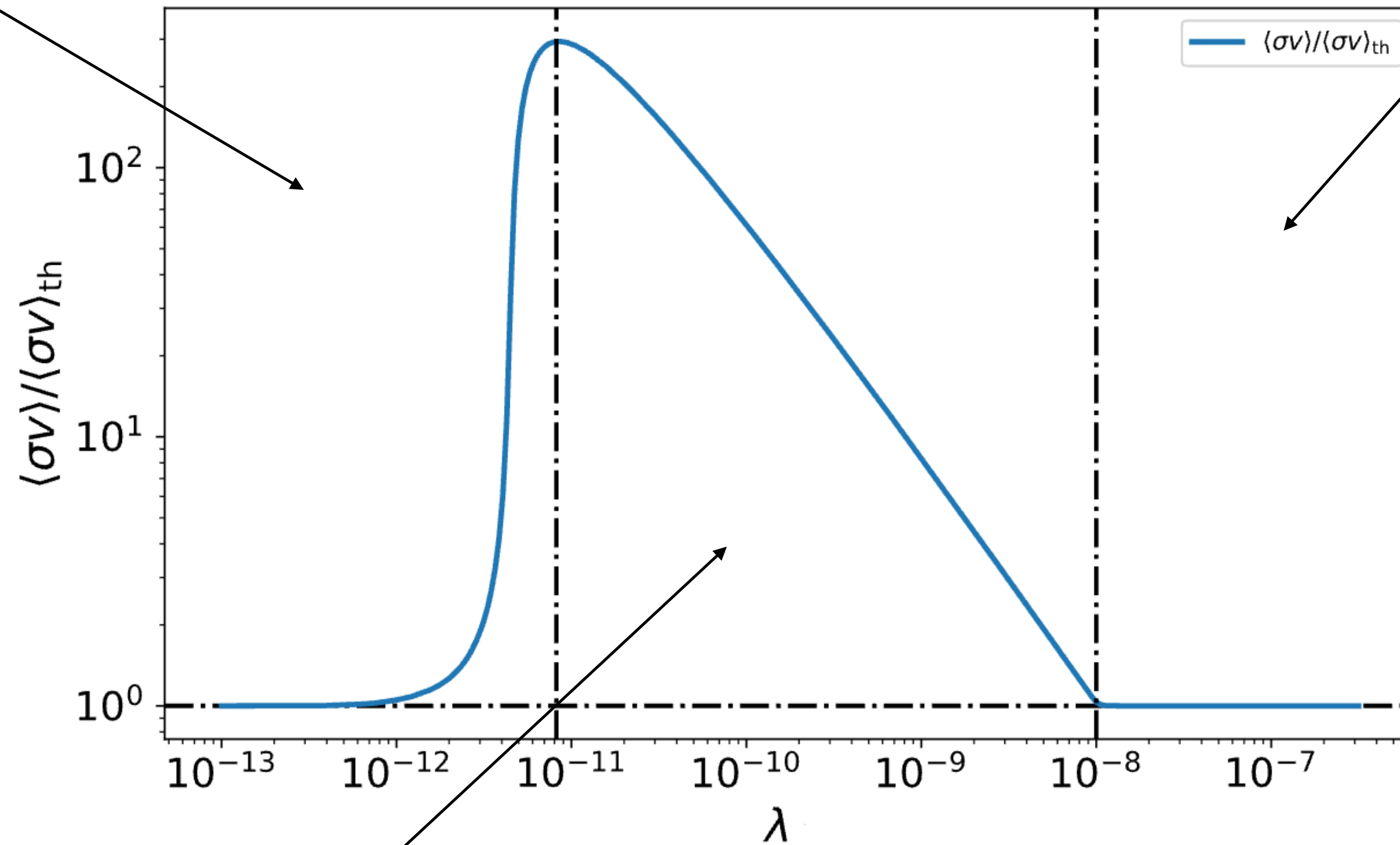
$$Y_\infty \propto \frac{x_{f,re-ann}}{m_{pl} m_\chi \langle\sigma v\rangle} \quad x_{f,re-ann} \propto \frac{m_\chi}{\sqrt{m_{pl} \Gamma_\phi}} (\ln \dots)$$

Blue matches the observed relic abundance today  $\implies \langle\sigma v\rangle = 1.2 \times 10^{-25} \text{ cm}^3/\text{s} \sim 6 \times \langle\sigma v\rangle_{th}$

# Scan Over Coupling

Freeze-out followed by freeze-in

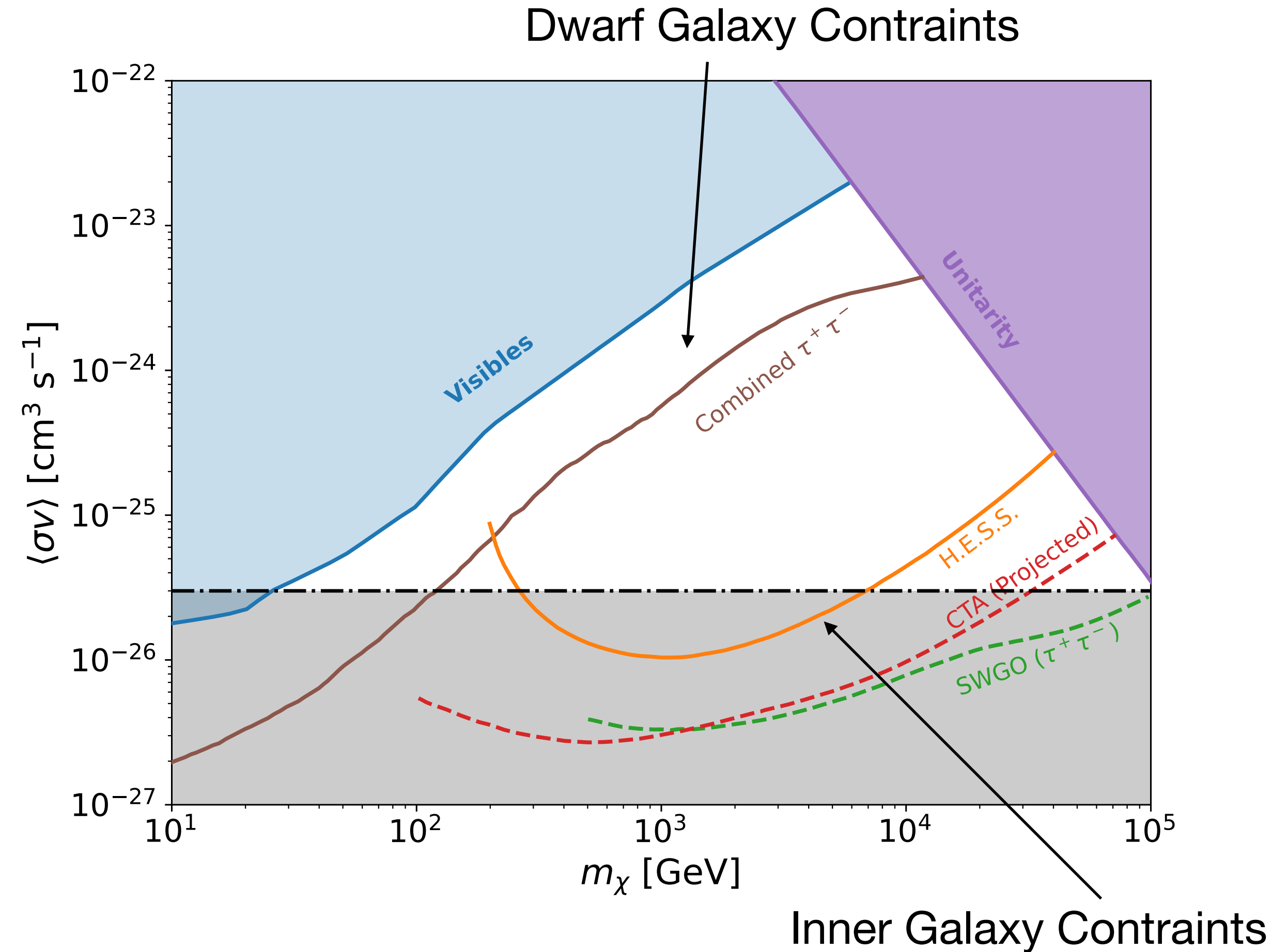
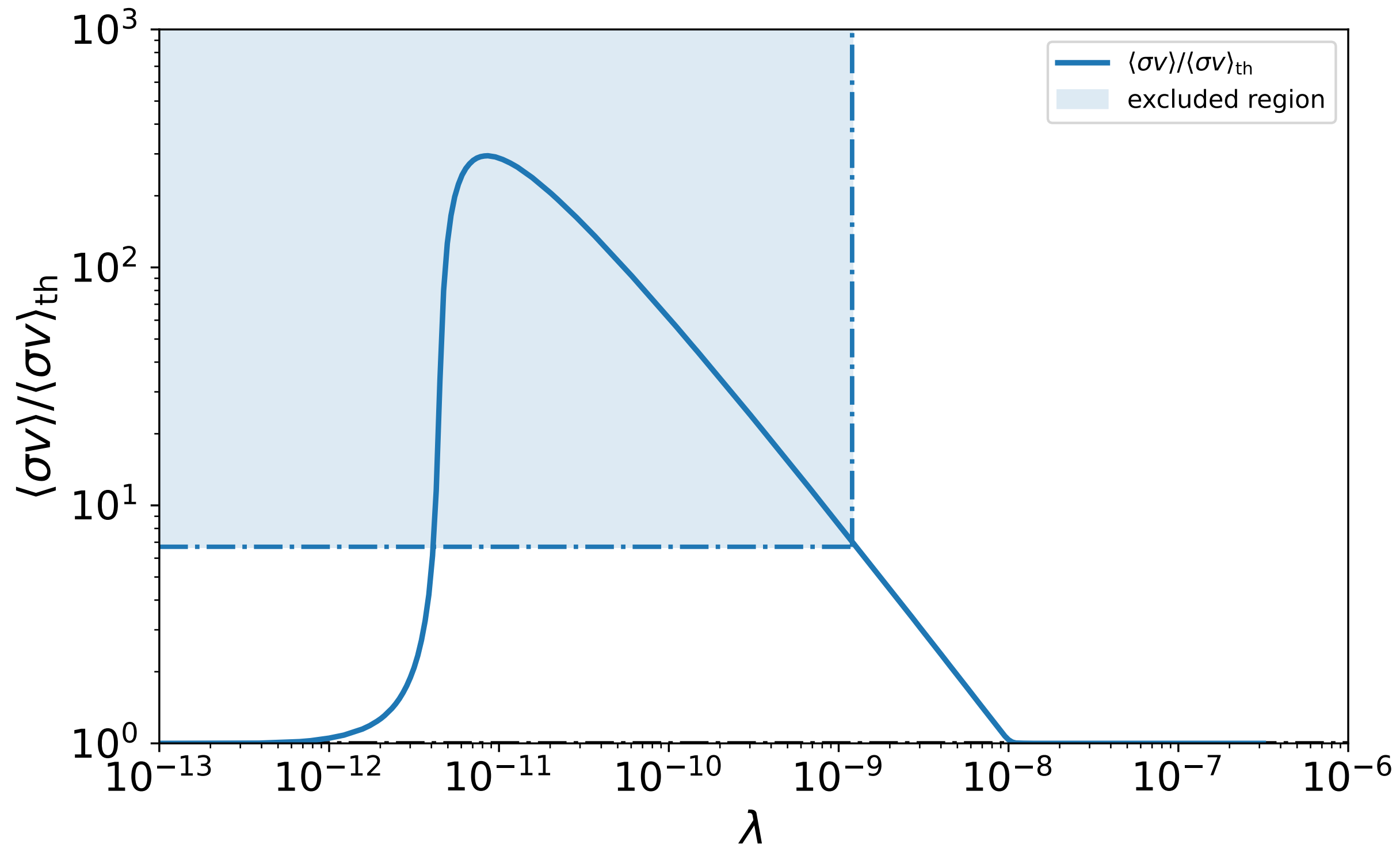
Freeze-out from annihilation



Freeze-out from re-annihilation

# Indirect Detection Limits

$$m_\chi = 100 \text{ GeV} \quad m_\phi = 500 \text{ GeV}$$



- Abdollahi, S. and Baldini, L. and Bellazzini, R., et al., arXiv:2508.20229
- H. Abdalla, F. Aharonian, F. Benkhali, et al., arXiv:2207.10471
- A. Acharya, R. Adam, C. Adams, et al., arXiv:2007.16129
- Viana, A. and Schoorlemmer, H. and Albert, A., et al., arXiv:1906.03353

# Summary

- A single real scalar feebly coupled to a WIMP can trigger re-annihilation after freeze-out
- Late Phi Decay requires an annihilation cross-section up to two orders of magnitude above the thermal relic
- Current and upcoming indirect detection experiments will further probe this scenario
- Next Directions:
  - Particle Physics?
    - MSSM no such scalar, doesn't work
    - NMSSM has a scalar, exploring...
  - Connection to Baryogenesis
    - Deviation from thermal equilibrium during re-annihilation