Softly Shifting Away from Dark Matter Direct Detection

— Reviving the Higgs Portal

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with Chuan-Yang Xing and Shou-hua Zhu

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BSM around the Weak Scale

- The Higgs hierarchy problem: the Higgs mass is a calculable quantity in UV completion
- The existence of dark matter, and its nature as WIMP
- Stringent bounds from LHC and dark matter direct detection experiments
    - Colored top partner mass above around TeV
    - No WIMP is found

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- In this talk, I demonstrate with models that these scenarios could be not yet severely constrained (at least not at the level usually expected).

The Paradigm

Higgs and DM are assumed as PNGBs

Interactions of PNGBs:

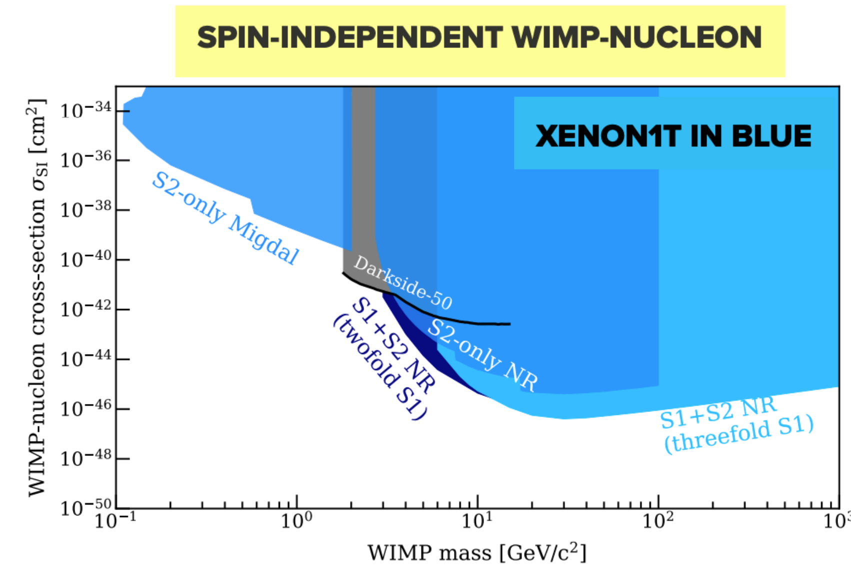
$\mathcal{O}_1 = \frac{1}{f^2}\partial_\mu(H^\dagger H)\partial^\mu(\eta^2)$	1) arising from NLSM; 2) energy-sensitive; 3) dominating in DM annihilation (if DM is heavy enough)
$\mathcal{O}_2 = \lambda H^\dagger H \eta^2$	1) arising from calculable scalar potential; 2) energy-insensitive; 3) dominating in direct detection

The Paradigm

The portal coupling is at the same order of Higgs quartic, if top breaks DM shift symmetry, and it is in tension with direct detection

$$\mathcal{O}_2 = \lambda H^\dagger H \eta^2$$

$$\sigma_{\rm SI}^{\eta N} \simeq 5 \cdot 10^{-47} {\rm cm}^2 \left(\frac{\lambda}{0.02}\right)^2 \left(\frac{300{\rm GeV}}{m_\eta}\right)^2$$



See K. Moraa's talk

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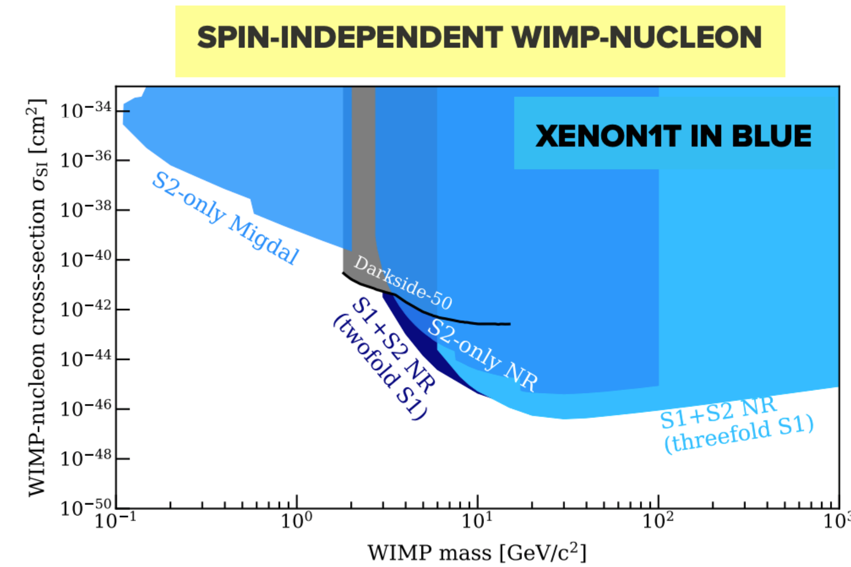

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A natural resolution is to require the top sector to fully preserve DM shift symmetry, instead the leading breaking effects arise from bottom sector, dark photon sector, and neutral-naturalness sector

e.g. R. Balkin, M. Ruhdorfer, E. Salvioni, and A. Weiler, 1809.09106;

A. Ahmed, S. Najjari, and C. B. Verhaaren, 2003.08947

Implementing Soft-Breaking Mechanism

SO(6) symmetry realized nonlinearly, where the first four components realize the custodial SO(4)

$$\Sigma = \frac{1}{f}(0, 0, 0, h, \eta, \sqrt{f^2 - h^2 - \eta^2})^T$$

$$\Psi_L = \frac{1}{\sqrt{2}}(ib_L, b_L, it_L, -t_L, 0, 0)^T,$$

$$\Psi_R = (0, 0, 0, 0, X_R, t_R)^T.$$

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DM Shift symmetry: SO(2) rotation along the 5th and 6th component

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DM Shift symmetry: SO(2) rotation along the 5th and 6th component

$$\Sigma \to \mathcal{R}\Sigma, \quad \Psi_{L,R} \to \mathcal{R}\Psi_{L,R}$$

which is softly broken only by

$$\mathcal{L} \supset m_X \bar{X}_L X_R + \text{h.c.}$$

A proof-of-concept model

$$
\begin{aligned}
\mathcal{L}_{\rm top} = & \; i\bar{\Psi}_L \not{D} \Psi_L + i\bar{\Psi}_R \not{D} \Psi_R + i\bar{X}_L \not{D} X_L - m_X \bar{X}_L X_R \\
& + \sum_{i=1}^{N_Q} \bar{Q}_i \left(i\not{D} + \not{e} - m_{Q_i} \right) Q_i + \sum_{j=1}^{N_S} \bar{S}_j \left(i\not{D} - m_{S_j} \right) S_j \\
& + \sum_{i=1}^{N_Q} \left(\epsilon_{tQ}^i \bar{\Psi}_R^A U_{Aa} Q_{iL}^a + \epsilon_{qQ}^i \bar{\Psi}_L^A U_{Aa} Q_{iR}^a \right) \\
& + \sum_{j=1}^{N_S} \left(\epsilon_{tS}^j \bar{\Psi}_R^A U_{A6} S_{jL} + \epsilon_{qS}^j \bar{\Psi}_L^A U_{A6} S_{jR} \right) + \text{h.c.} \,,
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The calculable potential

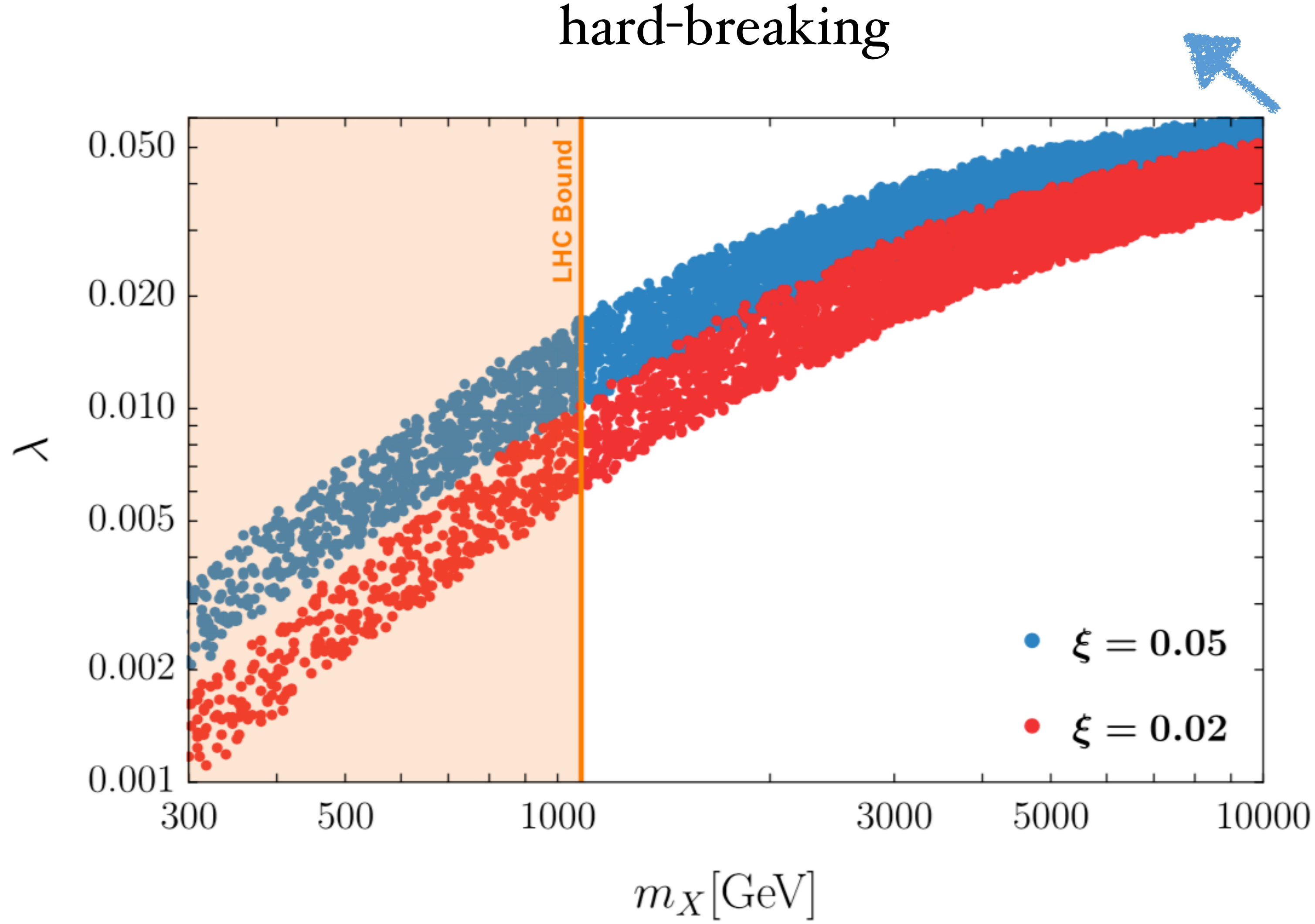
$$V(h,\eta) \simeq \frac{1}{2} m_h^2 h^2 + \frac{1}{2} m_\eta^2 \eta^2 + \frac{1}{4}\lambda_h h^4 + \frac{1}{4}\lambda_\eta \eta^4 + \frac{1}{2}\lambda h^2 \eta^2$$

Suppression of portal coupling

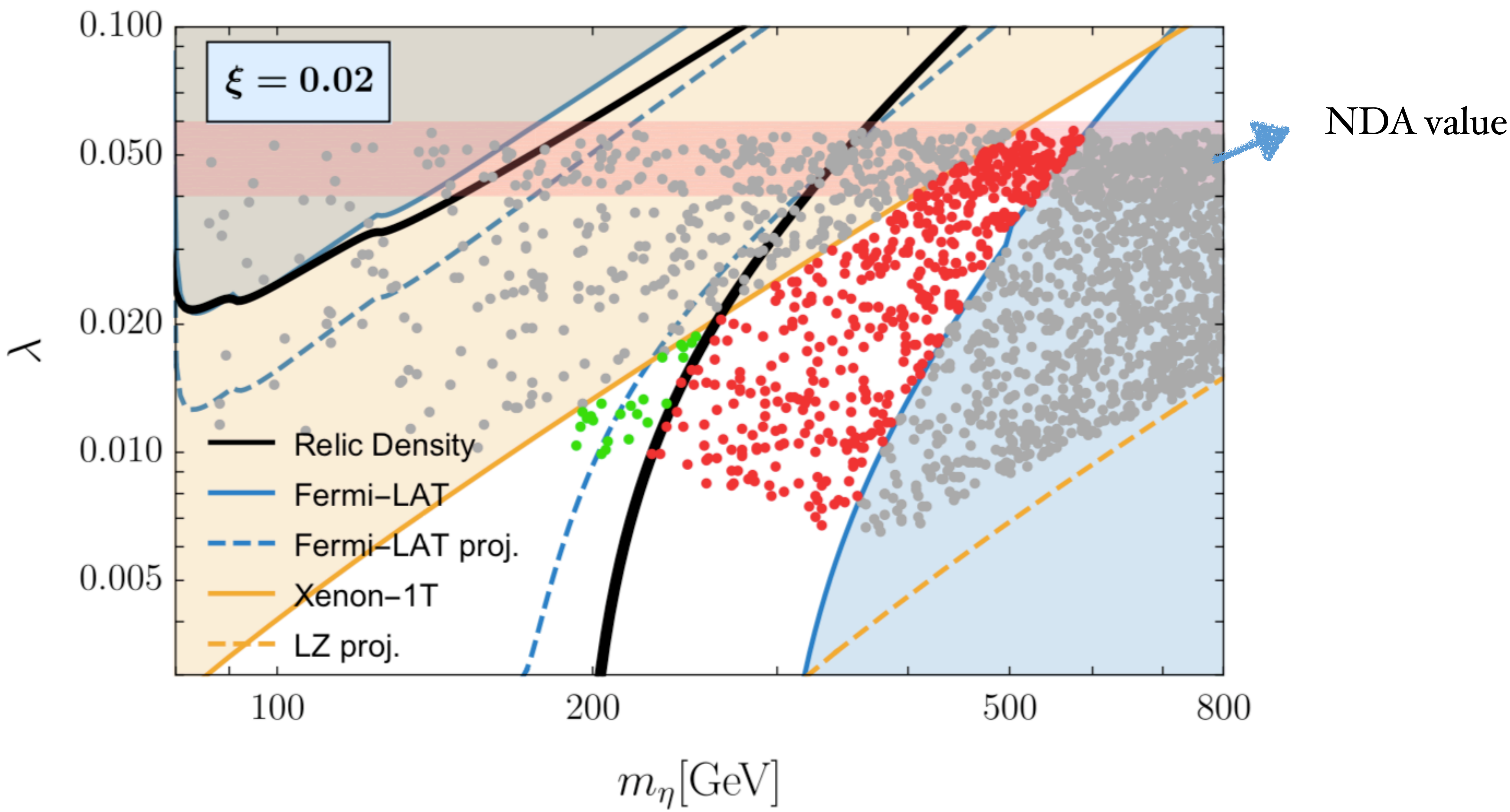
when $m_X \lesssim m_{Q,S}$

$$\frac{\lambda}{\lambda_{\rm NDA}} \simeq \frac{m_X^2}{m_*^2} \log \frac{m_*^2}{m_X^2}$$

NDA value when X decouples; hard-breaking



Parameter Space



$$\sigma v_{\rm rel} \propto \left(\frac{s}{f^2} - 2\lambda\right)^2$$

$$s \approx 4m_\eta^2$$

DM freeze out: $\Omega_\eta h^2 \simeq 0.12 \left(\frac{x_f}{24}\right)\left(\frac{3\cdot 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle\sigma v_{\rm rel}\rangle_{x_f}}\right) \lesssim 0.12$

Conclusions

- We propose soft-breaking mechanism for DM shift symmetry, to evade the stringent bound in direct detection experiments.

- We present proof-of-concept model to demonstrate the usefulness of this idea.

- The portal coupling can furthermore get "double" suppression if Higgs shift symmetry is also softly broken.

$$\frac{\lambda}{\lambda_{\rm NDA}} \simeq \frac{m_X^2}{m_*^2} \log \frac{m_*^2}{m_X^2} \cdot \frac{m_Y^2}{m_*^2} \log \frac{m_*^2}{m_Y^2}$$

- One-loop DM-nucleon scatterings are important.