Loop corrections in a pseudoscalar mediator dark matter model

Motoko Fujiwara (Nagoya University)

Collaborators : Tomohiro Abe (Nagoya U.) and Junji Hisano (Nagoya U.)

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Abstract

In the pseudoscalar mediator dark matter (DM) model [1], the loop corrections are essential to discuss the sensitivity of the direct detection experiments for the model prediction. We have calculated the DM-nucleon spin-independent (SI) cross section (σ_{SI}) including all of the interaction terms and the relevant diagrams for the DM-nucleon scattering.

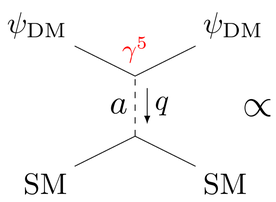
Summary We found that σ_{SI} is drastically enhanced through the interaction which was not included in the previous work [2].

→ **The new detectability of this model has been revealed by our analysis**.

Pseudoscalar mediator and direct detection

"a fermion DM + pseudoscalar mediators" can avoid the current strict bounds from DM direct detection experiments!!

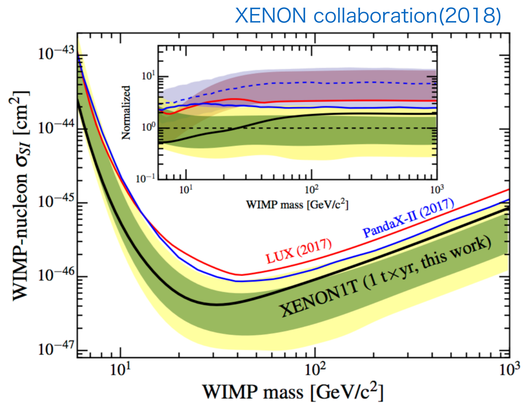
σ_{SI} is zero at the tree-level

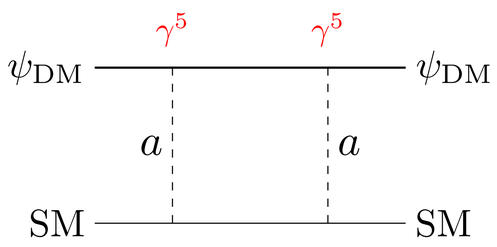


$\propto \vec{q}\cdot\vec{\sigma}$ $(|\vec{q}| \lesssim \mathcal{O}(100)\ \mathrm{MeV})$

The tree-level amplitude is suppressed by the momentum transfer

XENON collaboration(2018)





σ_{SI} is generated at the loop level!

The **spin-independent** scattering effects appear without small momentum suppression

c.f. $(\gamma^5)^2 = \mathbf{1}$

Model

The SM + { a gauge singlet Majorana fermion (a DM candidate) ; a gauge singlet pseudoscalar ←a_0 couples to the DM ; Two Higgs Doublet Model (THDM) ←A_0 couples to the SM particles }

$$\mathcal{L}_{\rm dark} \supset i\frac{g_{\rm DM}}{2} a_0 \bar{\psi}_{\rm DM}\gamma^5\psi_{\rm DM}$$

$$V = V_{\rm THDM} + \frac{1}{2}m_{a_0}^2 a_0^2 + \frac{\lambda_a}{4}a_0^4 + \kappa(i a_0 H_1^\dagger H_2 + \mathrm{h.c.}) + c_1 a_0^2 H_1^\dagger H_1 + c_2 a_0^2 H_2^\dagger H_2$$

$c_1 = c_2 = 0$ in the previous work [2]

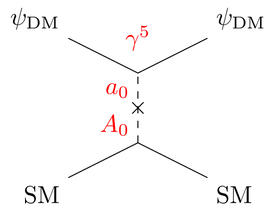
$$t_\beta = \frac{\langle H_2\rangle}{\langle H_1\rangle}$$

a_0 and A_0 are mixed in mass eigenstates

→ **Mediate the interactions between DM and SM particles**

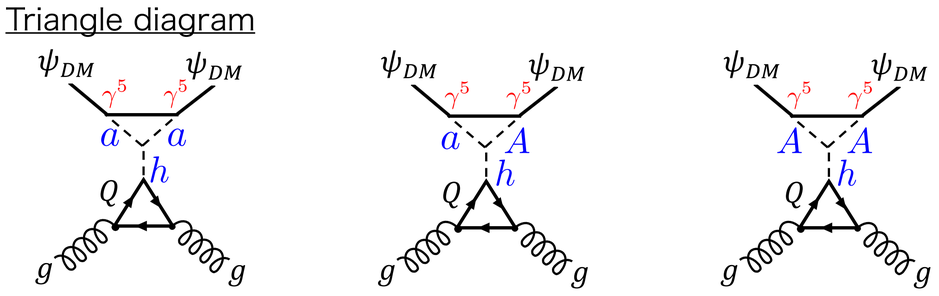
$$\begin{pmatrix} A \\ a \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}\begin{pmatrix} A_0 \\ a_0 \end{pmatrix}$$

h (the SM Higgs) H $H^\pm$ A a (degenerate mass spectra) — Pseudoscalar mediators



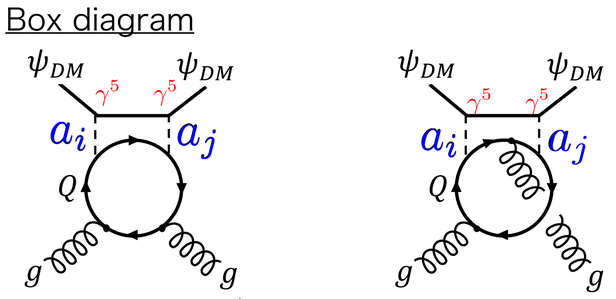
Improvements & Comparison

Triangle diagram



$Q = c, b, t$

Box diagram

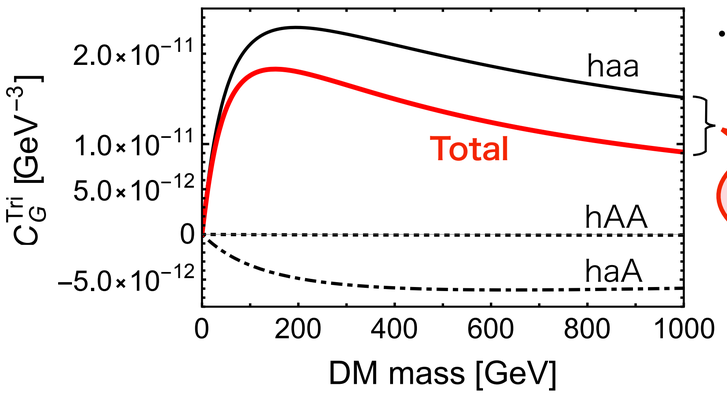


$a_i = a, A$

benchmark point in the previous work

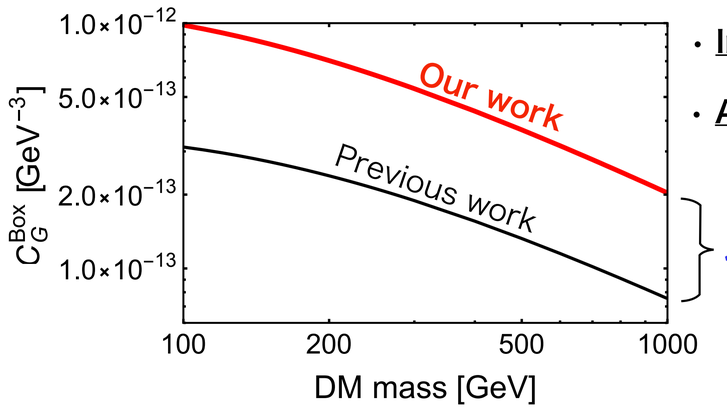
$m_a = 100$ GeV, $m_A = 600$ GeV, $\theta = 0.1$, $t_\beta = 40$, $c_1 = c_2 = 0$ (Type-II)

$$\mathcal{L}_{\rm eff} \supset \frac{1}{2}C_G\left(-\frac{9\alpha_s}{8\pi}\bar{\psi}_{\rm DM}\psi_{\rm DM}G^a_{\mu\nu}G^{a\mu\nu}\right)$$



- **Cancellation effects**

Overestimation by 170%

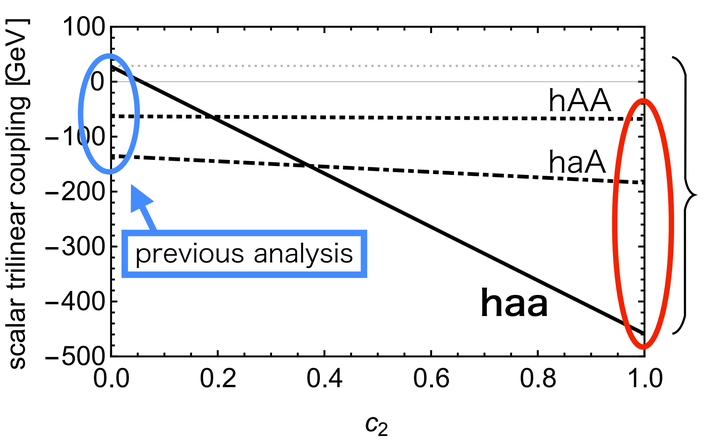


- **Include the interference effects**
- **Analysis for the light pseudoscalar**

Underestimation by 40%

DM-nucleon scattering cross section (σ_{SI})

The dominant diagram is enhanced drastically though the overlooked interaction!



New!!

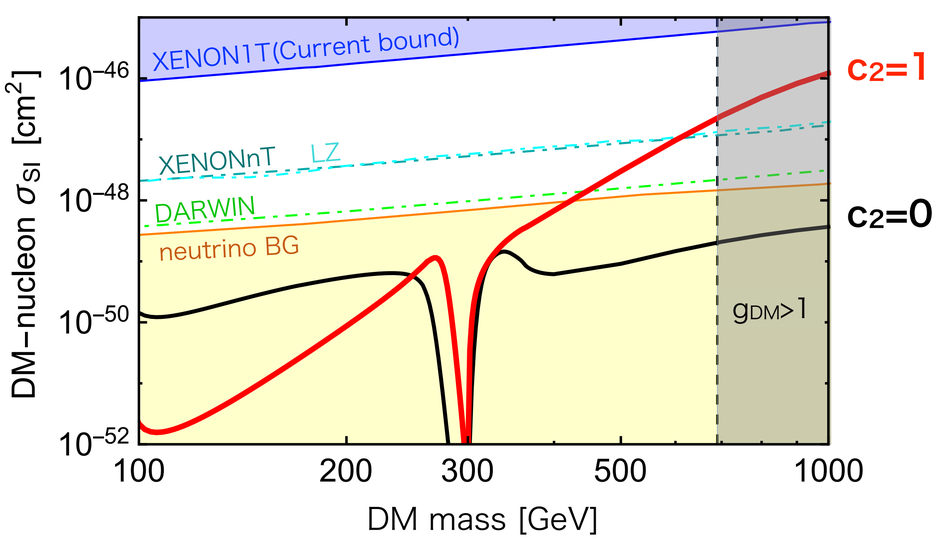
The contribution to the haa coupling appears without suppression of θ and t_β

(haa coupling) $\supset -\dfrac{2v\cos^2\theta}{1+1/t_\beta^2}\left(\dfrac{c_1}{t_\beta^2} + c_2\right)$

Absolute value of haa-coupling is increased by 20 times

→ All the Triangle diagrams contribute to σ_{SI} by the same sign

m_a=70 GeV, m_A=600 GeV, θ=0.1, t_β=10, c_1=0 (Type−I)



References : [1] S. Ipek, D. McKeen, and A. E. Nelson, A Renormalizable Model for the Galactic Center Gamma Ray Excess for, Dark matter Annihilation, Phys. Rev. D90, 055021 (2014).

[2] G. Arcadi, M. Lindner, F. S. Queiroz, W. Rodejohann, S. Vogl, Pseudoscalar Mediators: A WIMP model at the Neutrino Floor, JCAP 1803, no.03, 042 (2018).