

Role of Discrete Symmetries on Scalar Dominated Multipartite Dark Matter

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Vietnam

based on

JCAP 1704 (2017) no.04, 043 S. Bhattacharya, P.Ghosh, P. Poulouse
JHEP 1710 (2017) 088, S. Bhattacharya, P.Ghosh, T.N. Maity and
T.S.Ray

Evidences of dark matter

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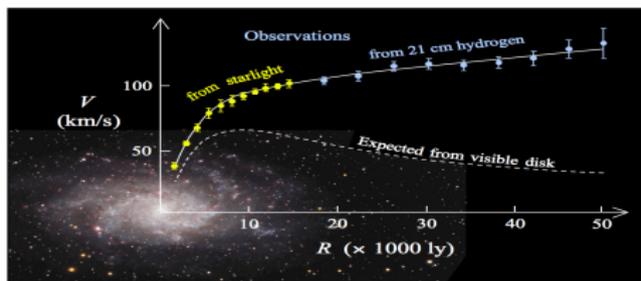


Figure 1: Rotation Curve of Galaxies

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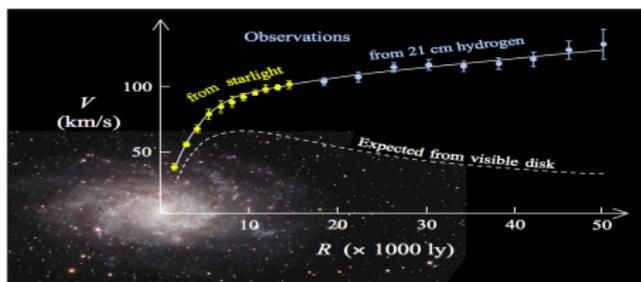


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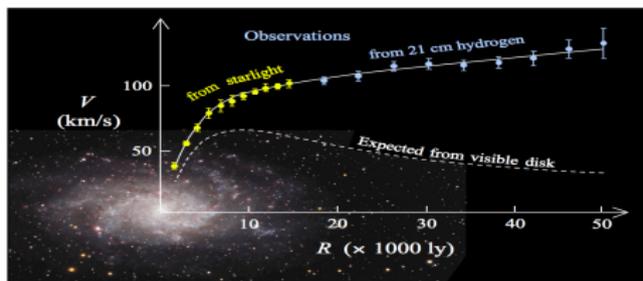


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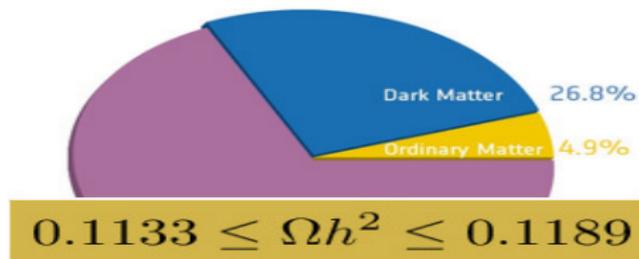


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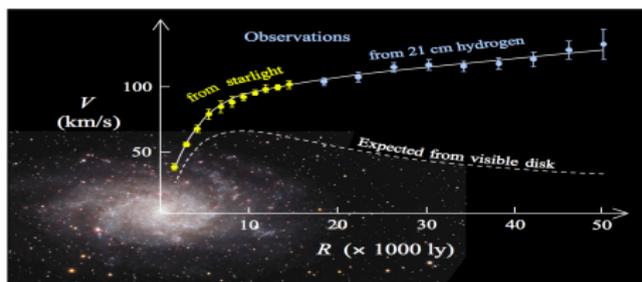


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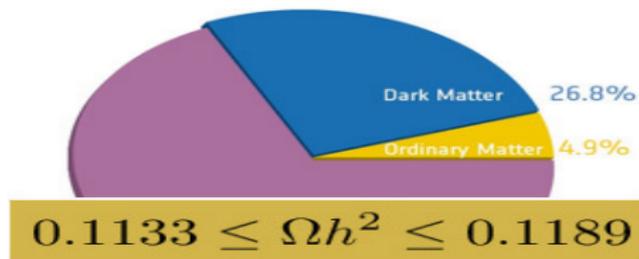


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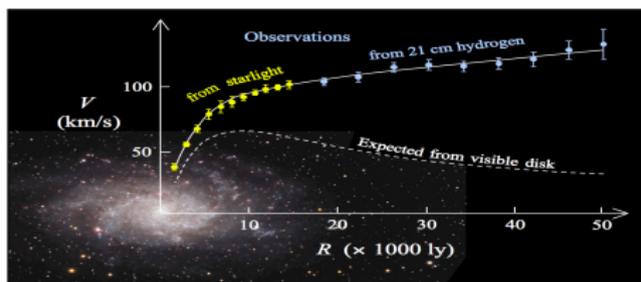


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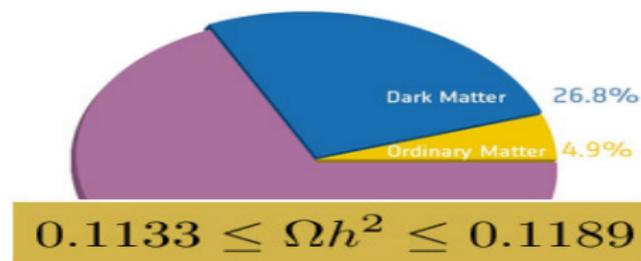


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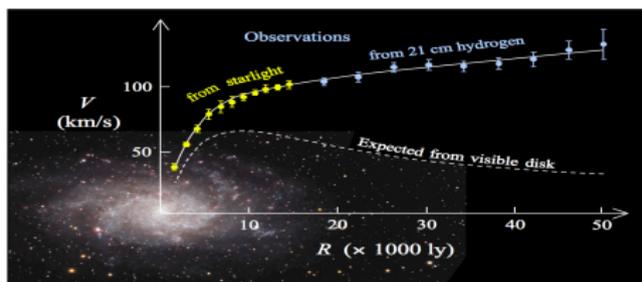


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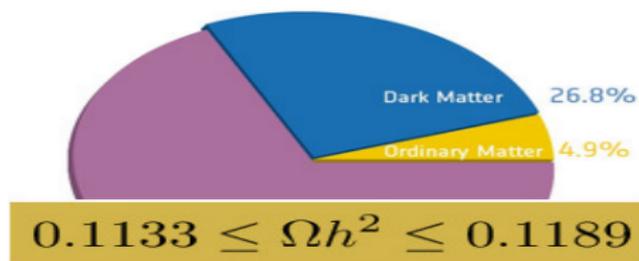


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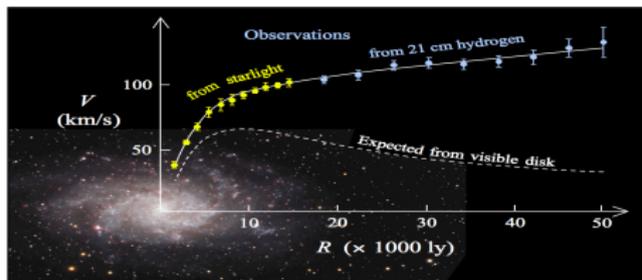


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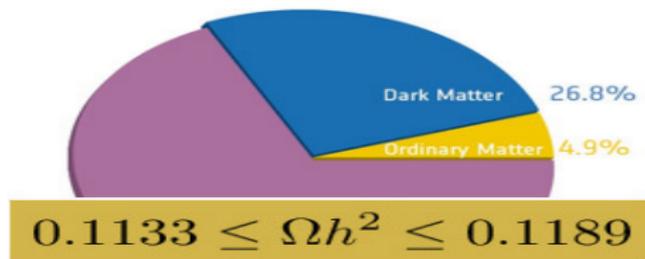


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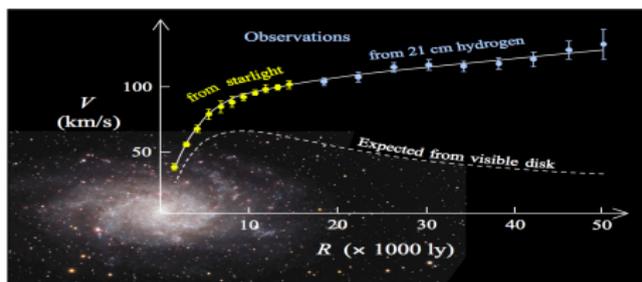


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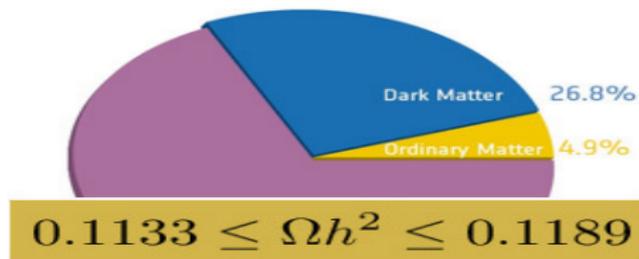


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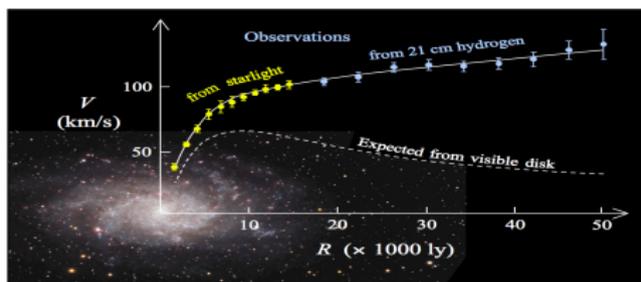


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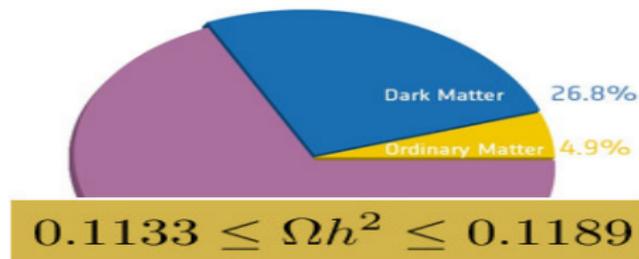


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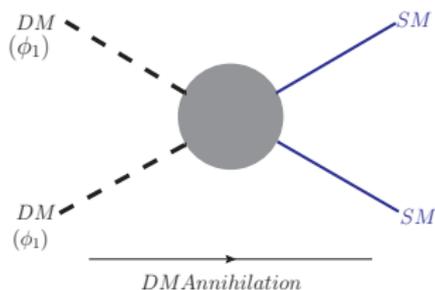
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Nothing in the SM!

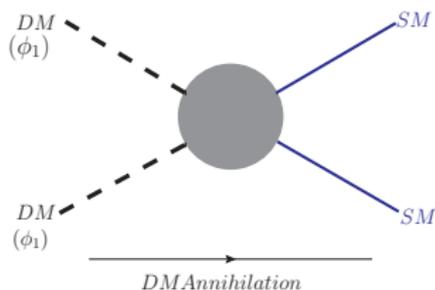
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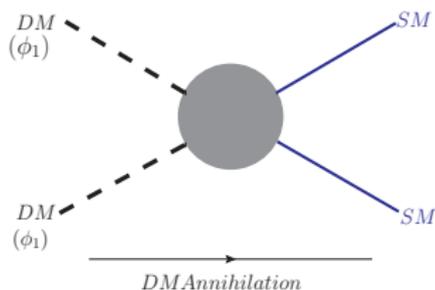


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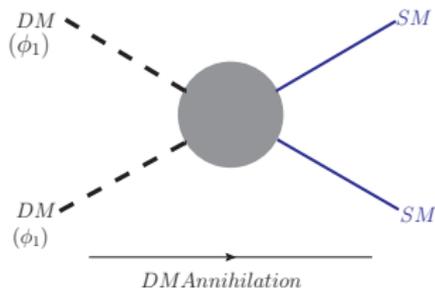
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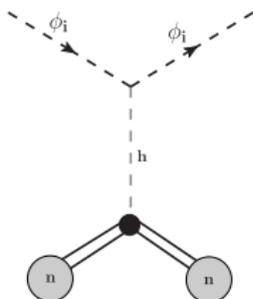
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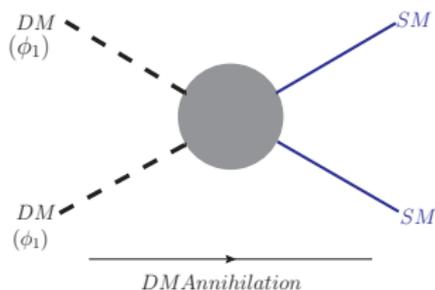
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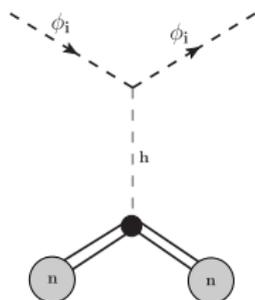
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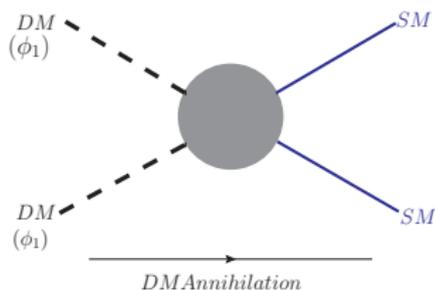
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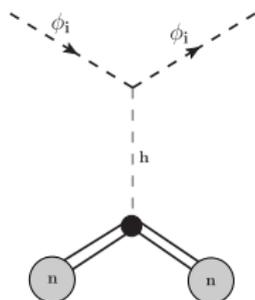
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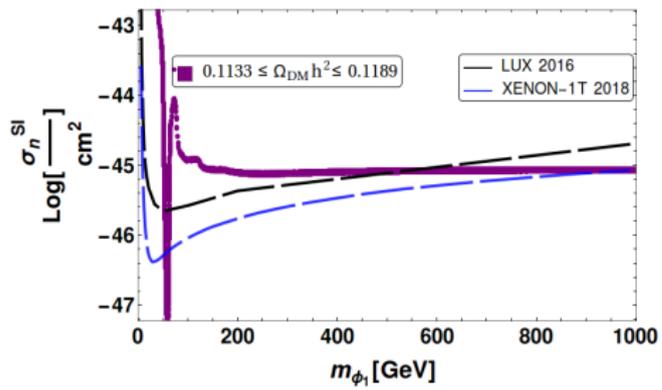
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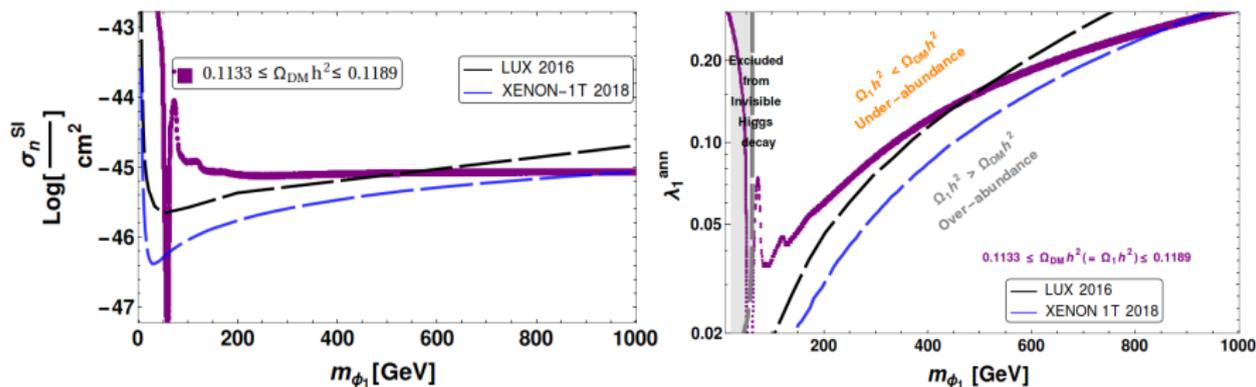


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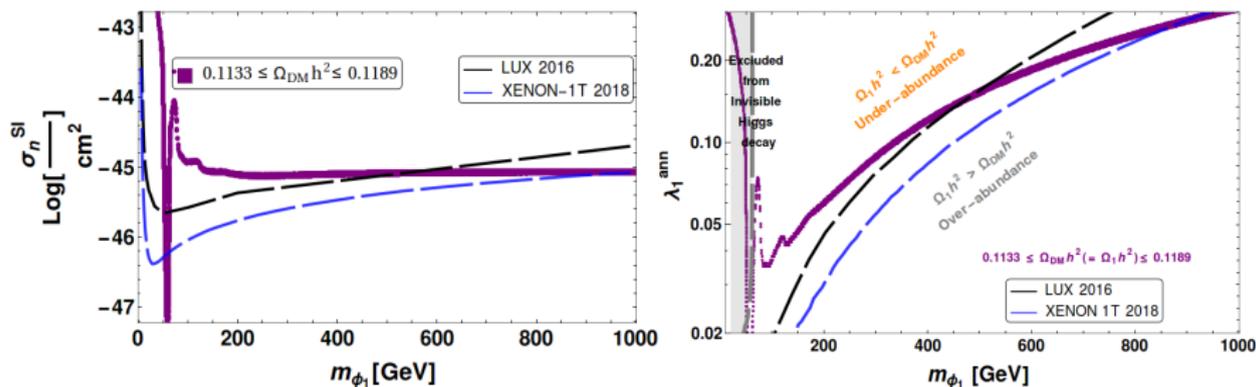


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- Non observation of DM signal from Direct Search puts strong constraint on SI DM-nucleon cross-section.

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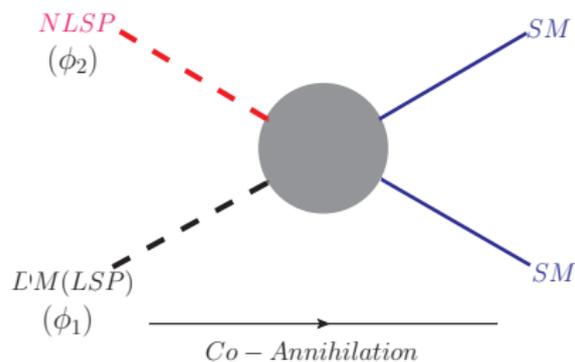
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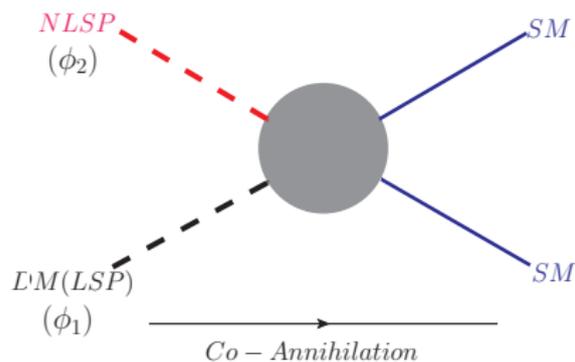
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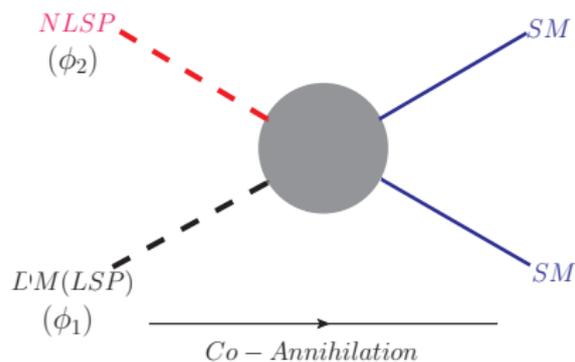
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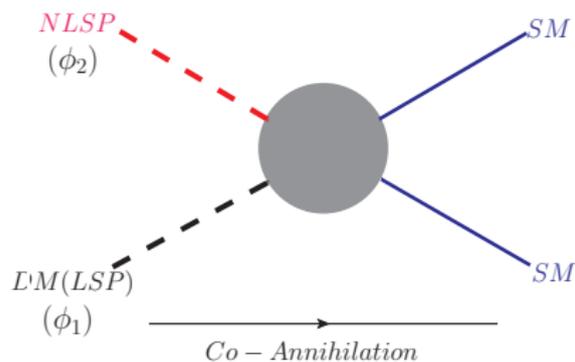
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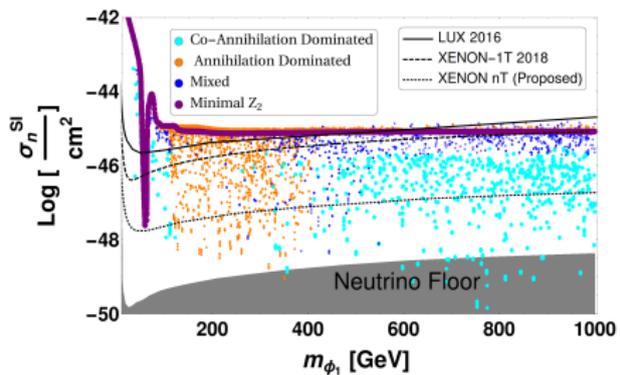
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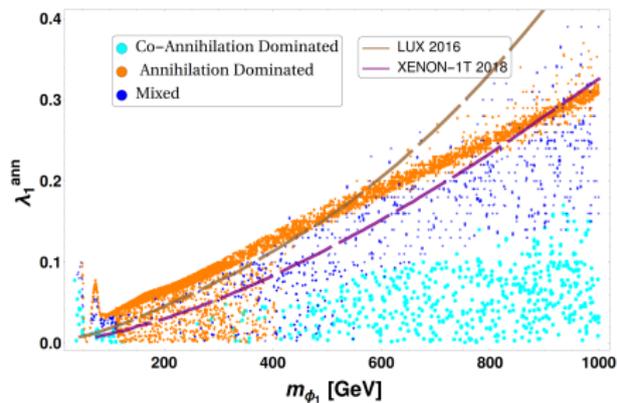
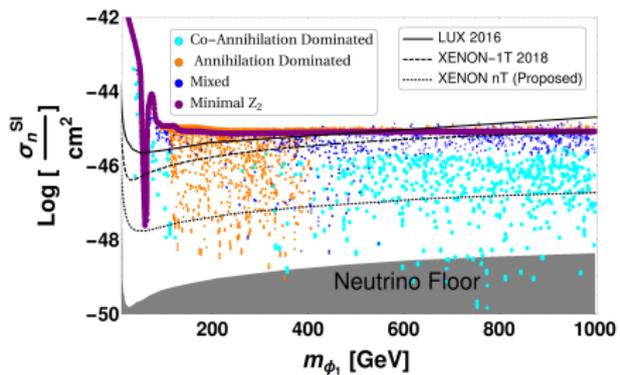
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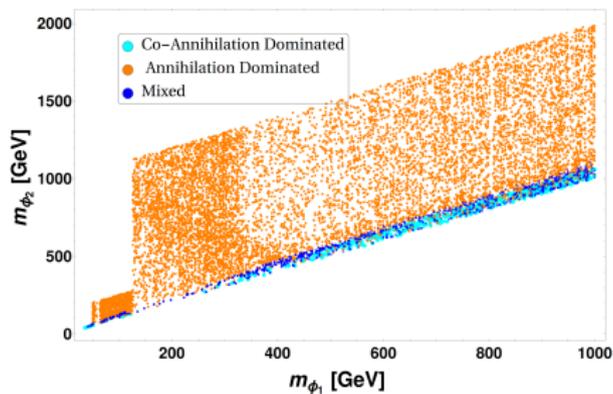
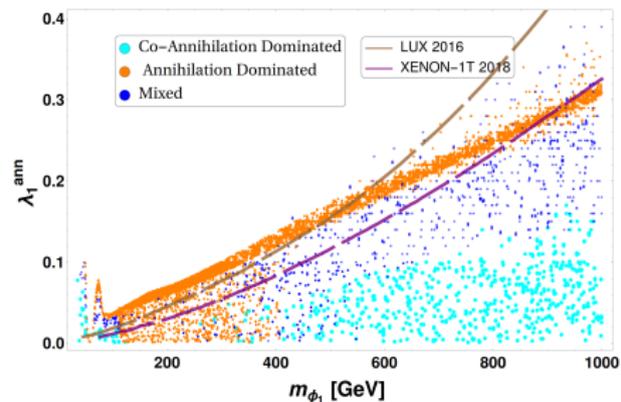
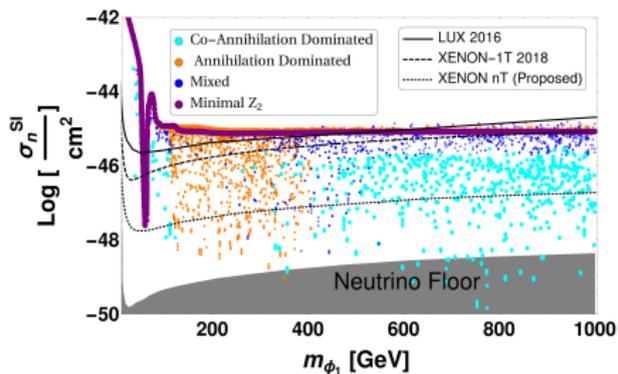
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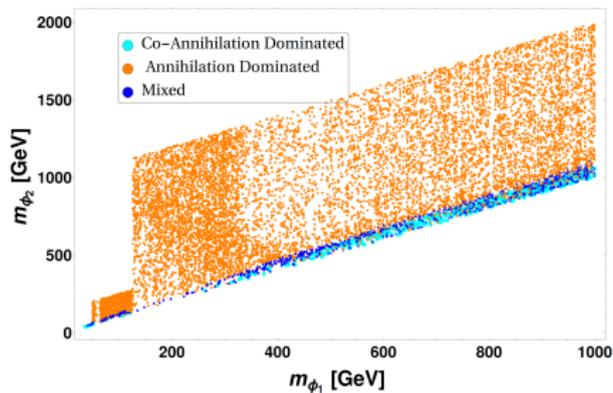
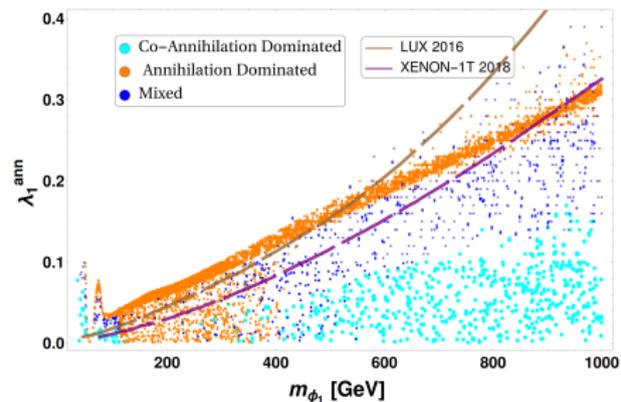
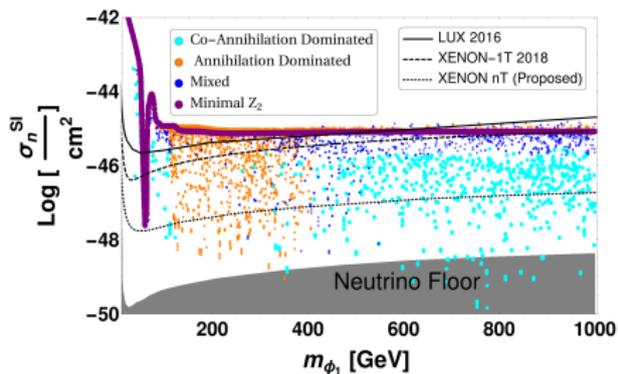
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• **Co-Annihilation** process only contribute to DM relic density but do not appear in Direct Search.









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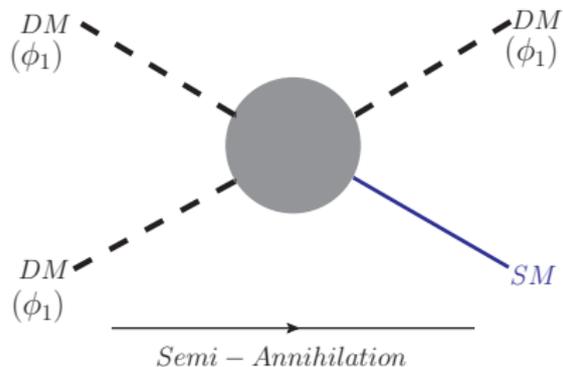
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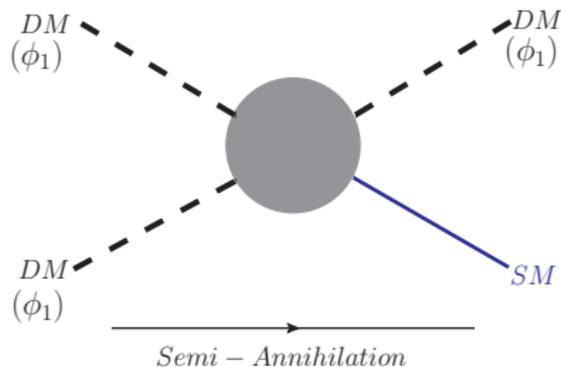
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$$\frac{dY_1}{dx} = -\frac{A}{x^2} \left[\langle \sigma v \rangle_{ann} (Y_1^2 - Y_1^{eq2}) - \frac{1}{2} \langle \sigma v \rangle_{semi-ann} (Y_1^2 - Y_1 Y_1^{eq}) \right],$$

$$A = 0.264 M_{Pl} \sqrt{g_*} m_{\phi_1}$$

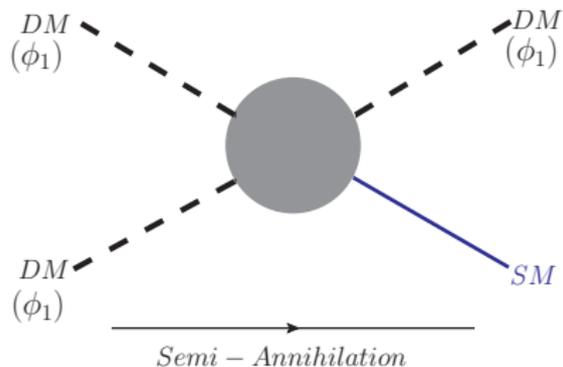
- ϕ_1 be the complex scalar DM having Z_3 charge

i.e. $Z_3: \phi_1 \rightarrow e^{i\frac{2\pi}{3}} \phi_1$.

- Non-Minimal Interaction :**

$$\lambda_1^{ann} (H^\dagger H) \phi_i^2 + \mu_1 \phi_1^3 + h.c. .$$

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Semi-annihilation process do not appear in DD, only contribute to DM relic density.

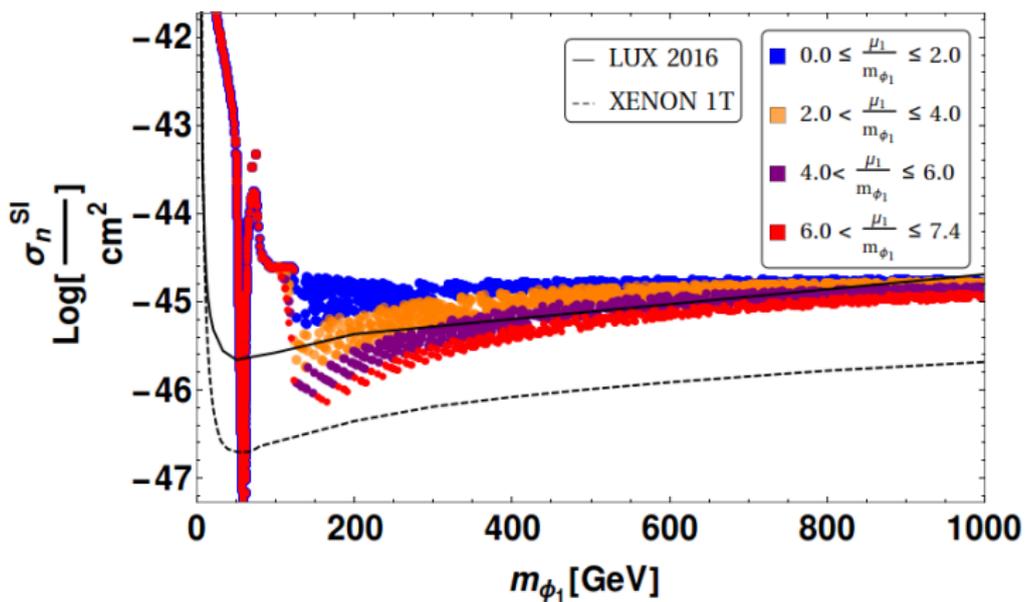


Figure 6: Relic density allowed parameter space for Z_3 invariant scalar DM.

- Extending Z_3 DM : ϕ_1, ϕ_2 are two complex scalar fields charged under same Z_3 : $\phi_i \rightarrow e^{i\frac{2\pi}{3}} \phi_i$

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- BEQ.:

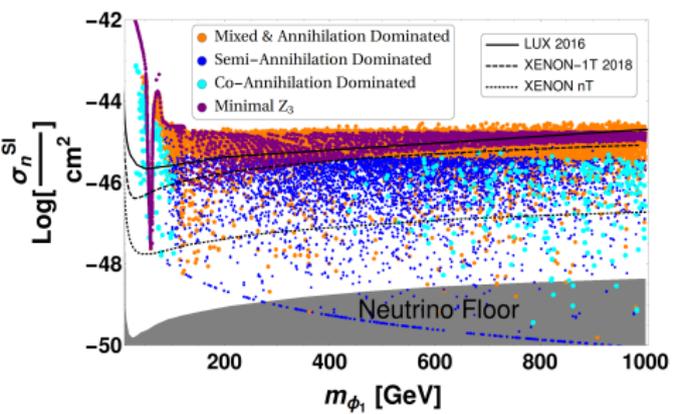
$$\begin{aligned} \frac{dY_1}{dx} = & -\frac{A}{x^2} \left[\left[\langle \sigma v \rangle_{ann} + \langle \sigma v \rangle_{co-ann} \left(1 + \frac{\Delta m}{m_{\phi_1}} \right)^{\frac{3}{2}} e^{-\frac{\Delta m}{T}} \right] (Y_1^2 - Y_1^{eq2}) \right. \\ & - \frac{1}{2} \langle \sigma v_{1 \rightarrow 1 SM} \rangle_{semi-ann} (Y_1^2 - Y_1 Y_1^{eq}) \\ & - \frac{1}{2} \langle \sigma v_{1 \rightarrow 2 SM} \rangle_{semi-ann} \left(Y_1^2 - \frac{Y_1^{eq2}}{Y_2^{eq}} Y_2 \right) \\ & \left. - \frac{1}{2} \langle \sigma v_{1 \rightarrow 2 SM} \rangle_{semi-ann} \left(Y_1 Y_2 - \frac{Y_1^{eq2}}{Y_2^{eq}} Y_2 \right) \right], \quad A = 0.264 M_{Pl} \sqrt{g_*} m_{\phi_1} \end{aligned}$$

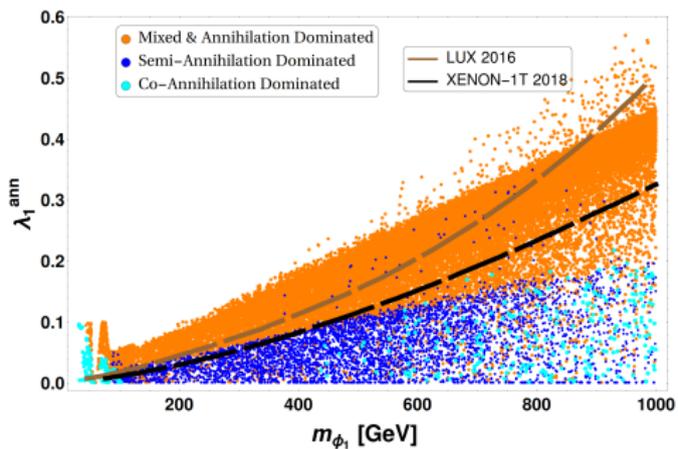
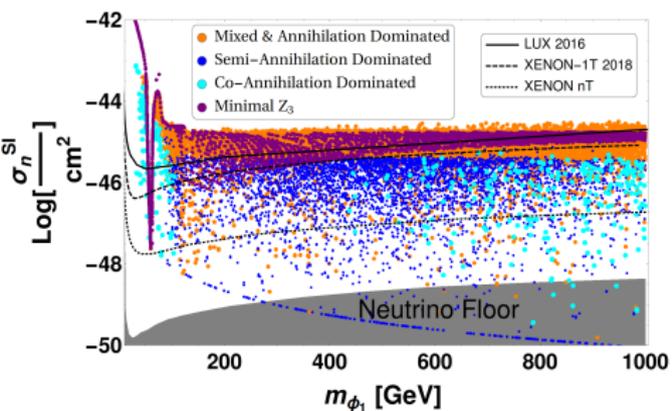
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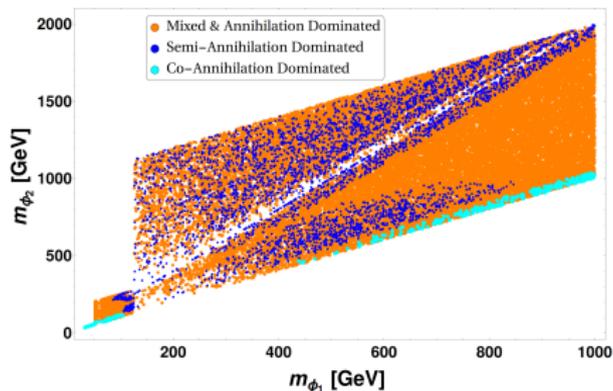
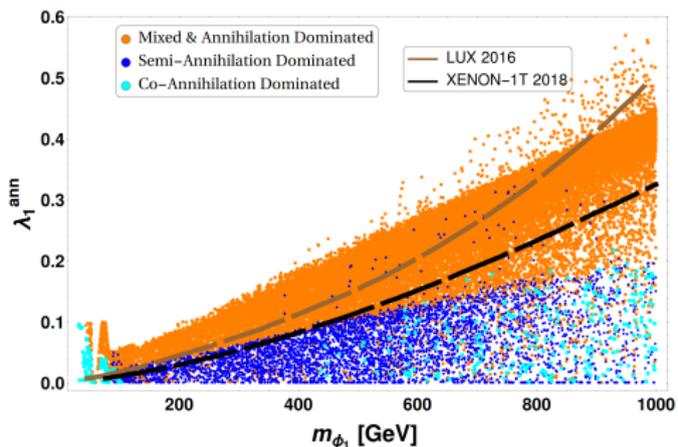
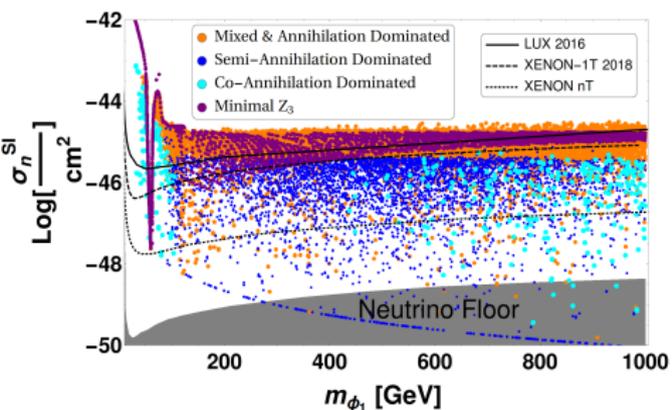
$$\lambda_i^{ann} (H^\dagger H) \phi_i^* \phi_i + \lambda^{co-ann} (H^\dagger H) \phi_1^* \phi_2 + \mu_i \phi_i^3 + \mu_{ij} \phi_i^2 \phi_j + h.c. .$$
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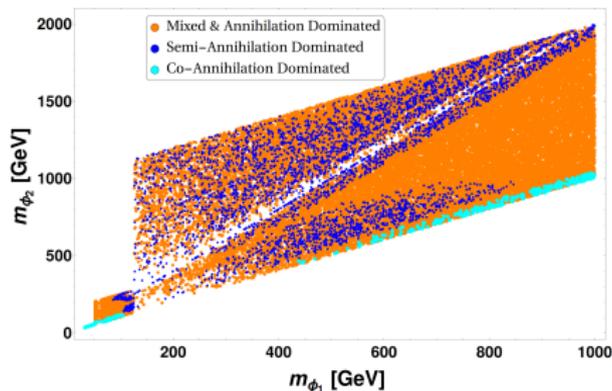
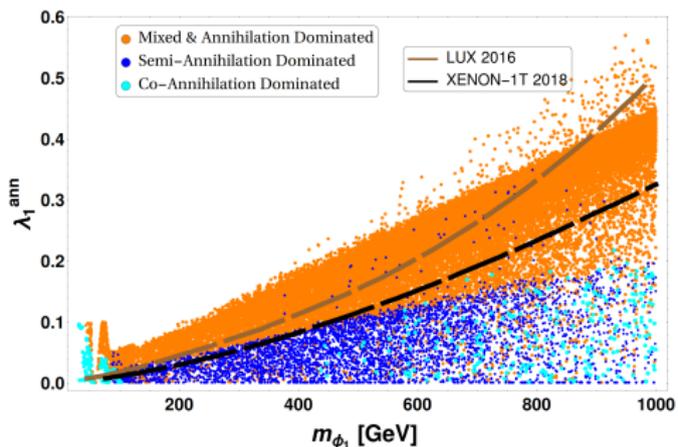
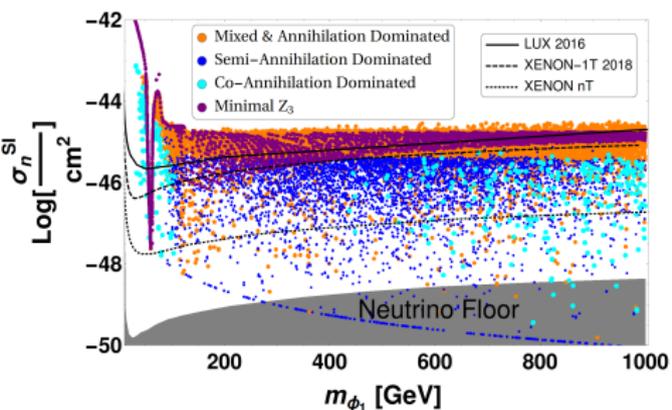
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- **Co-annihilation** and **semi-annihilation** only contribute to DM relic density.









- Extending the symmetry group : ϕ_1, ϕ_2 are two real singlet scalar fields charged under $\mathcal{Z}_2 \times \mathcal{Z}'_2$ respectively.

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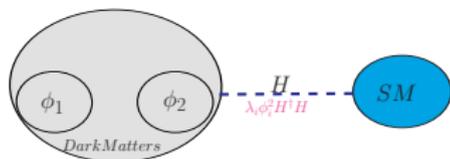
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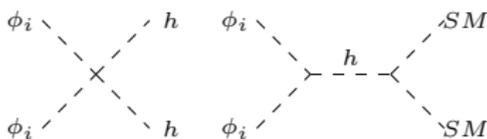
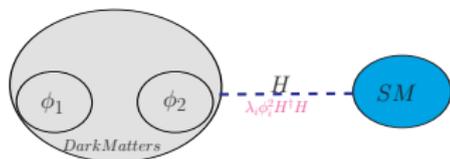
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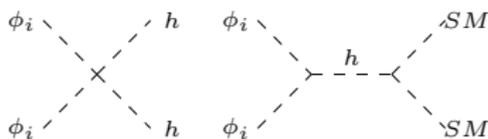
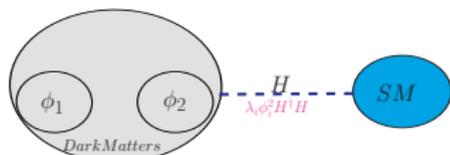
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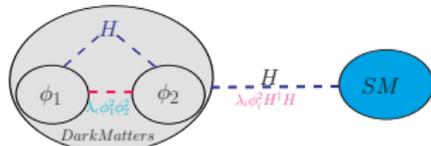
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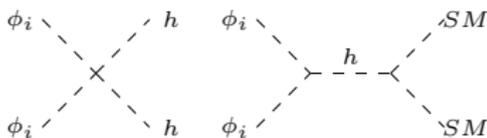
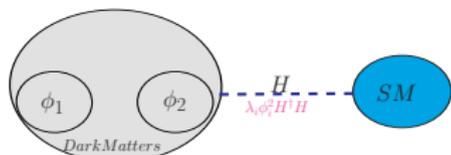
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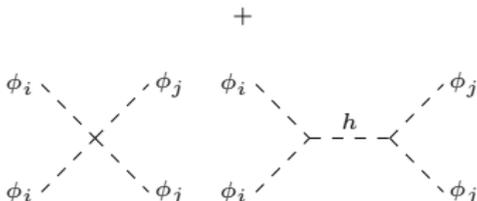
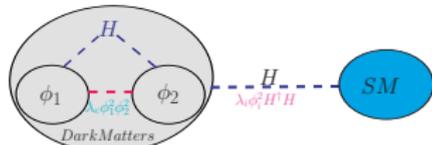
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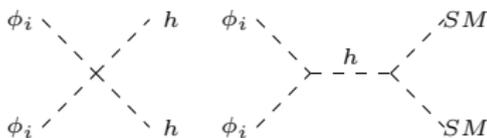
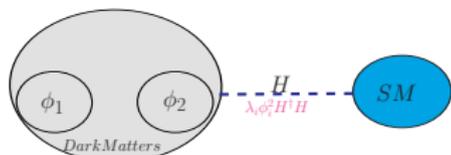
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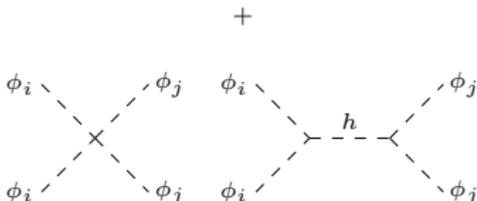
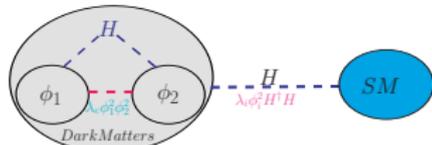
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• Without DM-DM Interaction



• With DM-DM Interaction



- CBEQs for two component interacting DM:

$$\frac{dy_1}{dx} = -\frac{1}{x^2} \left[\langle \sigma v_{11 \rightarrow SM} \rangle_{ann} (y_1^2 - y_1^{EQ^2}) + \langle \sigma v_{11 \rightarrow 22} \rangle_{conv.} \left(y_1^2 - \frac{y_1^{EQ^2}}{y_2} y_2^2 \right) - \langle \sigma v_{22 \rightarrow 11} \rangle_{conv.} \left(y_2^2 - \frac{y_2^{EQ^2}}{y_1} y_1^2 \right) \right]$$

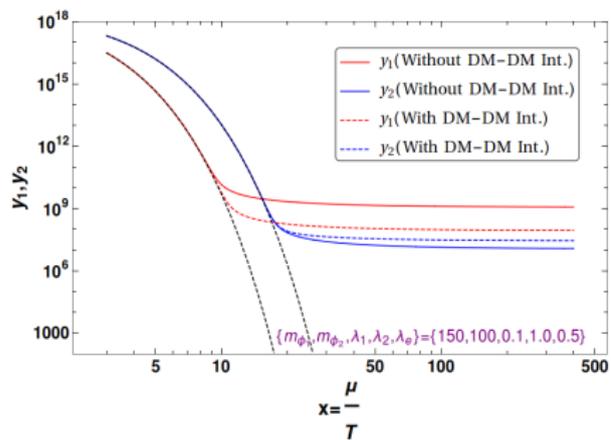
$$\frac{dy_2}{dx} = -\frac{1}{x^2} \left[\langle \sigma v_{22 \rightarrow SM} \rangle_{ann} (y_2^2 - y_2^{EQ^2}) - \langle \sigma v_{11 \rightarrow 22} \rangle_{conv.} \left(y_1^2 - \frac{y_1^{EQ^2}}{y_2} y_2^2 \right) + \langle \sigma v_{22 \rightarrow 11} \rangle_{conv.} \left(y_2^2 - \frac{y_2^{EQ^2}}{y_1} y_1^2 \right) \right]$$

where

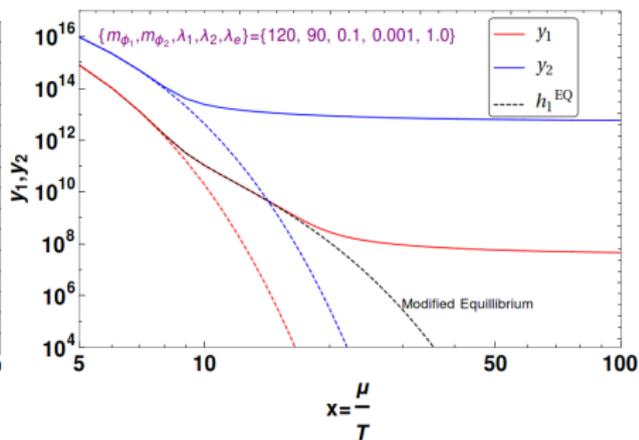
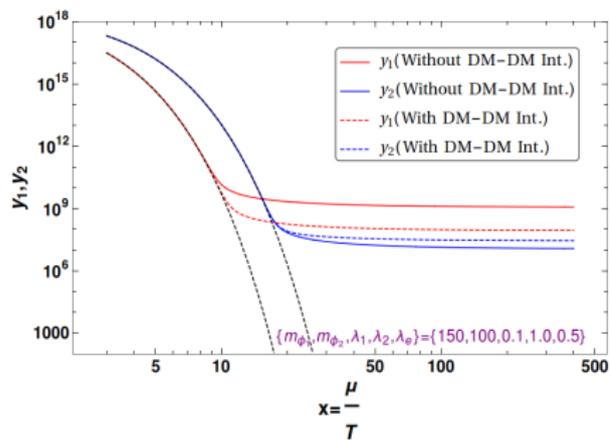
$$y_i^{EQ}(x) = 0.03828 M_{Pl} \frac{g}{\sqrt{g_*}} x^{\frac{3}{2}} m_{\phi_i} \left(\frac{m_{\phi_i}}{\mu} \right)^{\frac{3}{2}} e^{-x \left(\frac{m_{\phi_i}}{\mu} \right)}$$

$$y_i = 0.264 M_{Pl} \sqrt{g_*} \mu Y_i, \text{ where } Y_i = \frac{n_{\phi_i}}{s}.$$

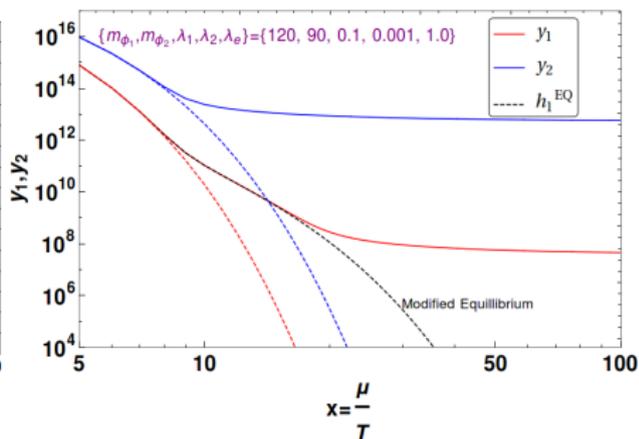
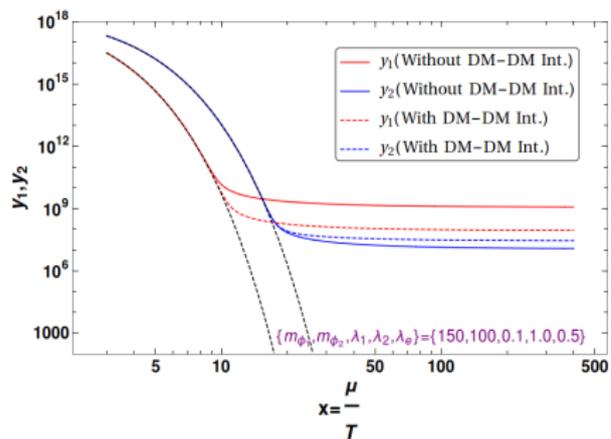
- Solution of CBEQs : Freez-out of DM



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- Modified Equilibrium:

$$\frac{dy_1}{dx} = -\frac{\langle \sigma v_{11 \rightarrow SM} \rangle + \langle \sigma v_{11 \rightarrow 22} \rangle}{x^2} [y_1^2 - h_1^{EQ2}];$$

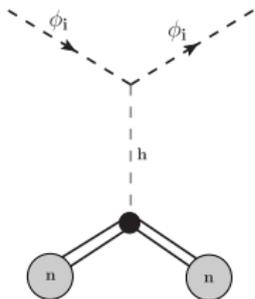
$$h_1^{EQ2} = y_1^{EQ2} \left[\frac{\langle \sigma v_{11 \rightarrow SM} \rangle}{\langle \sigma v_{11 \rightarrow SM} \rangle + \langle \sigma v_{11 \rightarrow 22} \rangle} + \frac{\langle \sigma v_{11 \rightarrow 22} \rangle}{\langle \sigma v_{11 \rightarrow SM} \rangle + \langle \sigma v_{11 \rightarrow 22} \rangle} \left(\frac{y_2}{y_2^{EQ}} \right)^2 \right]$$

- Relic density of Individual DM component in two component setup:

$$\Omega_i h^2 = \frac{854.45 \times 10^{-13} m_{\phi_i}}{\sqrt{g_*}} \frac{y_i}{\mu} \left[\frac{\mu}{m_{\phi_i}} x_\infty \right],$$

where y_i be the solution of CBEQs.

- Total Relic density : $\Omega_{DM} h^2 = \Omega_1 h^2 + \Omega_2 h^2$.
- Effective SI DD cross section of Individual DM component:

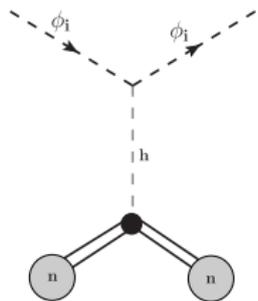


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$$\sigma_{eff}^i = \left(\frac{\Omega_i h^2}{\Omega_{DM} h^2} \right) \frac{(\lambda_i^{ann})^2 f_n^2}{4\pi} \frac{\mu_n^2 m_n^2}{m_h^4 m_{\phi_i}^2},$$

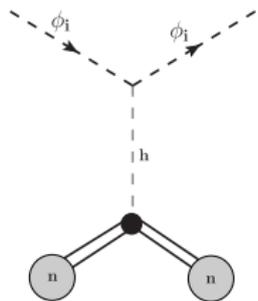
$(i = 1, 2)$

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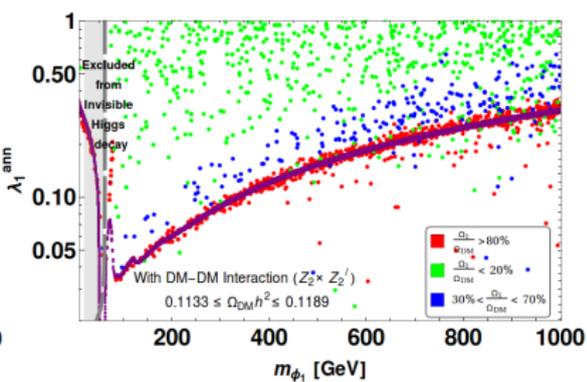
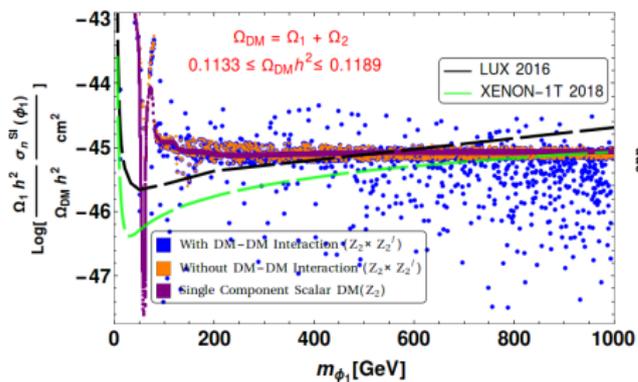
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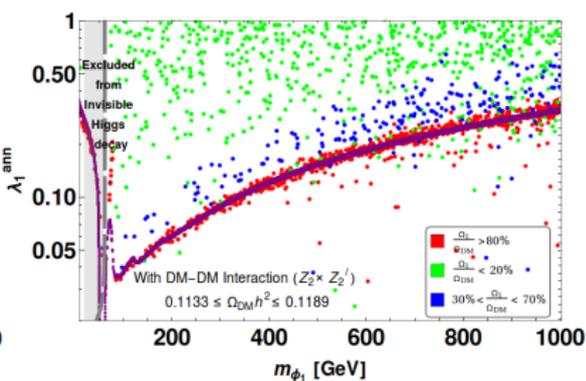
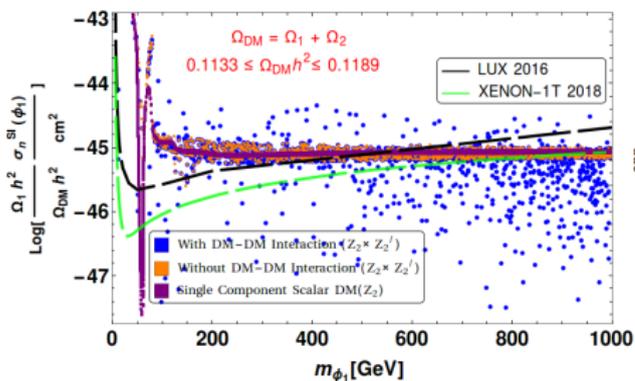
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Due to DM-DM conversion the heavier component can evade direct search limit in a large parameter space satisfying relic density.

Two component DM in \mathcal{Z}_3 and \mathcal{Z}'_3 symmetry: **Complex scalar** ϕ_1 and ϕ_2 , transforming under $\mathcal{Z}_3 \times \mathcal{Z}'_3$:

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- Both ϕ_1 and ϕ_2 are the two stable DM candidates.
- Interaction :

$$\lambda_i^{ann}(\phi_i^* \phi_i)(H^\dagger H) + \mu_i(\phi_i^3 + \text{h.c}) + \lambda_e(\phi_1^* \phi_1 + \phi_2^* \phi_2)^2$$

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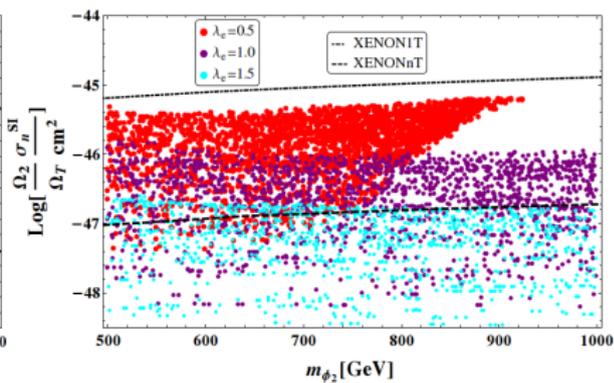
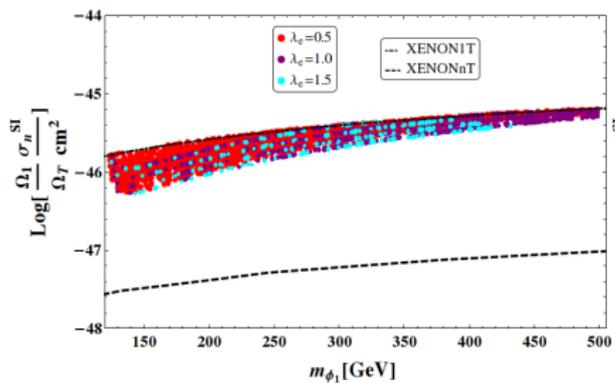
- ϕ_1 : $(e^{+i\frac{2\pi}{3}}, 1)$ and ϕ_2 : $(1, e^{+i\frac{\pi}{3}})$.
- Both ϕ_1 and ϕ_2 are the two stable DM candidates.

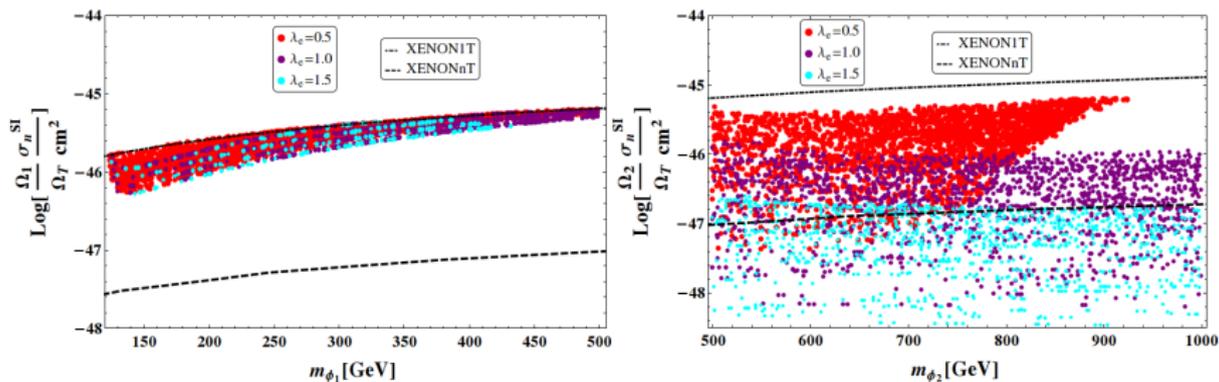
• Interaction :

$$\lambda_i^{ann}(\phi_i^* \phi_i)(H^\dagger H) + \mu_i(\phi_i^3 + \text{h.c}) + \lambda_e(\phi_1^* \phi_1 + \phi_2^* \phi_2)^2$$

• The coupled Boltzmann equations for this two component DM case :

$$\begin{aligned} \frac{dy_1}{dx} &= -\langle \sigma v_{11 \rightarrow SM} \rangle_{ann} (y_1^2 - y_1^{eq2}) - \frac{1}{2} \langle \sigma v_{11 \rightarrow 1SM} \rangle_{semiann} (y_1^2 - y_1 y_1^{eq}) \\ &\quad - \langle \sigma v_{11 \rightarrow 22} \rangle_{conv.} [y_1^2 - \left(\frac{y_1^{eq}}{y_2^{eq}}\right)^2 y_2^2] + \langle \sigma v_{22 \rightarrow 11} \rangle_{conv.} \left[y_2^2 - \left(\frac{y_2^{eq}}{y_1^{eq}}\right)^2 y_1^2 \right], \\ \frac{dy_2}{dx} &= -\langle \sigma v_{22 \rightarrow SM} \rangle_{ann} (y_2^2 - y_2^{eq2}) - \frac{1}{2} \langle \sigma v_{22 \rightarrow 2SM} \rangle_{semiann} (y_2^2 - y_2 y_2^{eq}) \\ &\quad + \langle \sigma v_{11 \rightarrow 22} \rangle_{conv.} [y_1^2 - \left(\frac{y_1^{eq}}{y_2^{eq}}\right)^2 y_2^2] - \langle \sigma v_{22 \rightarrow 11} \rangle_{conv.} \left[y_2^2 - \left(\frac{y_2^{eq}}{y_1^{eq}}\right)^2 y_1^2 \right], \end{aligned}$$





The heavier component is allowed in a larger parameter space due to DM-DM conversion. The lighter one here enjoys semi-annihilation to evade direct search in the vicinity of m_h .

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thank you!

