

Singlet-triplet scotogenic model and fermionic dark matter

Anirban Karan

IFIC (CSIC – UV), Valencia, Spain

In Collaboration With: **José W. F. Valle** and **Soumya Sadhukhan**

Based on: [JHEP 12 \(2023\) 185](#)



SUSY-2024

IFT, Madrid, Spain

10th - 14th June, 2024

Motivation

- ⊛ **Neutrino mass generation** and **Dark matter** are two important unsolved issues in Particle Physics.
- ⊛ **Cosmological bound** of $\sum_i m_{\nu_i} < 0.09$ eV [Di Valentino et al. 2106.15267] makes usual seesaw schemes (I & III) hardly accessible to collider experiments.
- ⊛ In the case of **scotogenic models** neutrino masses are generated **radiatively** and hence loop-suppressed; additionally, neutrino masses are **symmetry-protected**.
- ⊛ **Dark mediated neutrino mass generation** is a very interesting idea. Imposition of Z_2 symmetry stabilizes the DM. [Ma hep-ph/0601225, Tao hep-ph/9603309]
- ⊛ **Singlet-triplet scotogenic model** is one such model. [Hirsch et al. 1307.8134]
- ⊛ The DM in this model can be **bosonic** as well as **fermionic**.
- ⊛ The scalar DM for this model has been studied in great detail. It resembles the inert-2HDM scenario. [Diaz et al. 1612.06569, Avila et al. 1910.08422]
- ⊛ Triplet-like fermionic DM in this model is phenomenologically not very interesting; one can go up to mass of 2.5 TeV only.
- ⊛ **Singlet-like fermionic DM** is more rich in phenomenology.
- ⊛ The DM phenomenology of this model has great resemblance with SUSY-DM (without inclusion of any SUSY particles).

The Model:

Singet-Triplet Scotogenic Scenario

Singlet-Triplet Scotogenic Model

Particle Content:

	Standard Model			New Scalars		New Fermions	
	L	e^c	Φ	Ω	η	Σ	F
Multiplicity	3	3	1	1	1	1	1
$U(1)_Y$	$-1/2$	1	$1/2$	0	$1/2$	0	0
$SU(2)_L$	2	1	2	3	2	3	1
\mathcal{Z}_2	+	+	+	+	-	-	-

Yukawa:

$$\mathcal{L} = Y^{\alpha\beta} \bar{L}_\alpha \Phi e_\beta + Y_F^\alpha \bar{L}_\alpha \tilde{\eta} F^c + Y_\Sigma^\alpha \bar{L}_\alpha \Sigma^c \tilde{\eta} + Y_\Omega \text{Tr}[\tilde{\Sigma} \Omega] F^c + \frac{M_\Sigma}{2} \text{Tr}[\tilde{\Sigma} \Sigma^c] + \frac{M_F}{2} \bar{F} F^c + \text{h.c.}$$

Scalar Potential:

$$\begin{aligned} \mathcal{V} = & -\mu_\Phi^2 (\Phi^\dagger \Phi) + \mu_\eta^2 (\eta^\dagger \eta) - \frac{1}{2} \mu_\Omega^2 \text{Tr}(\Omega^\dagger \Omega) + \mu_\Omega^\phi (\Phi^\dagger \Omega \Phi) + \mu_\Omega^\eta (\eta^\dagger \Omega \eta) \\ & + \frac{1}{2} \lambda_1 (\Phi^\dagger \Phi)^2 + \frac{1}{2} \lambda_2 (\eta^\dagger \eta)^2 + \lambda_3 (\Phi^\dagger \Phi)(\eta^\dagger \eta) + \lambda_4 (\Phi^\dagger \eta)(\eta^\dagger \Phi) + \frac{1}{2} \lambda_5 [(\Phi^\dagger \eta)^2 + (\eta^\dagger \Phi)^2] \\ & + \frac{1}{2} \lambda_\Omega^\phi (\Phi^\dagger \Phi) \text{Tr}(\Omega^\dagger \Omega) + \frac{1}{4} \lambda_\Omega^\eta [\text{Tr}(\Omega^\dagger \Omega)]^2 + \frac{1}{2} \lambda_\Omega^\eta (\eta^\dagger \eta) \text{Tr}(\Omega^\dagger \Omega) \end{aligned}$$

Scalar sector

⇒ Fields:

$$\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2} \phi^+ \\ v_\phi + \phi^0 + i G^0 \end{pmatrix}, \quad \Omega = \begin{pmatrix} \frac{v_\Omega}{\sqrt{2}} + \frac{\Omega^0}{\sqrt{2}} & \Omega^+ \\ \Omega^- & -\frac{v_\Omega}{\sqrt{2}} - \frac{\Omega^0}{\sqrt{2}} \end{pmatrix}, \quad \eta = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2} \eta^+ \\ \eta_R^0 + i \eta_I^0 \end{pmatrix}$$

Goldstone for Z^0 Z_2 -odd scalars

⇒ Neutral scalars:

$$\{\phi^0, \Omega^0\} \rightarrow \{h, H\}: \mathcal{M}_0^2 = \begin{pmatrix} \lambda_1 v_\phi^2 & \lambda_\Omega^\phi v_\Omega v_\phi - \frac{1}{\sqrt{2}} \mu_\Omega^\phi v_\phi \\ \lambda_\Omega^\phi v_\Omega v_\phi - \frac{1}{\sqrt{2}} \mu_\Omega^\phi v_\phi & 2\lambda_\Omega^\Omega v_\Omega^2 + \frac{1}{2\sqrt{2}} \mu_\Omega^\phi \frac{v_\phi^2}{v_\Omega} \end{pmatrix}$$

⇒ Charged scalars:

$$\{\phi^\pm, \Omega^\pm\} \rightarrow \{G^\pm, H^\pm\}: \mathcal{M}_\pm^2 = \sqrt{2} \mu_\Omega^\phi \begin{pmatrix} v_\Omega & \frac{1}{2} v_\phi \\ \frac{1}{2} v_\phi & \frac{1}{4} \frac{v_\phi^2}{v_\Omega} \end{pmatrix} + g^2 \xi_{W^\pm} \begin{pmatrix} \frac{1}{4} v_\phi^2 & -\frac{1}{2} v_\phi v_\Omega \\ -\frac{1}{2} v_\phi v_\Omega & v_\Omega^2 \end{pmatrix}$$

$$m_{H^\pm} = \frac{\mu_\Omega^\phi}{2\sqrt{2}} \left(\frac{v_\phi^2}{v_\Omega} + 4v_\Omega \right), \quad m_{G^\pm} = \frac{1}{4} g^2 \xi_{W^\pm} (v_\phi^2 + 4v_\Omega^2) \rightarrow \text{Goldstone for } W^\pm$$

⇒ Z_2 -odd scalars:

$$m_{\eta_R^0}^2 = \mu_\eta^2 + \frac{1}{2} \lambda_\Omega^\eta v_\Omega^2 - \frac{1}{\sqrt{2}} \mu_\Omega^\eta v_\Omega + \frac{1}{2} (\lambda_3 + \lambda_4 + \lambda_5) v_\phi^2$$

$$m_{\eta_I^0}^2 = \mu_\eta^2 + \frac{1}{2} \lambda_\Omega^\eta v_\Omega^2 - \frac{1}{\sqrt{2}} \mu_\Omega^\eta v_\Omega + \frac{1}{2} (\lambda_3 + \lambda_4 - \lambda_5) v_\phi^2$$

$$m_{\eta^\pm}^2 = \mu_\eta^2 + \frac{1}{2} \lambda_\Omega^\eta v_\Omega^2 + \frac{1}{\sqrt{2}} \mu_\Omega^\eta v_\Omega + \frac{1}{2} \lambda_3 v_\phi^2$$

$$\lim \lambda_5 \rightarrow 0$$

$$\Rightarrow m_{\eta_R^0} = m_{\eta_I^0}$$

Fermion mixing & Neutrino mass

⇒ **Fermion mixing:** → Z_2 -odd fermions

$$\{F, \Sigma^0\} \rightarrow \{\chi_1^0, \chi_2^0\} : \mathcal{M}_\chi = \begin{pmatrix} M_F & Y_\Omega v_\Omega \\ Y_\Omega v_\Omega & M_\Sigma \end{pmatrix} \Rightarrow V \cdot \mathcal{M}_\chi \cdot V^T = \text{diag}(m_{\chi_1^0}, m_{\chi_2^0})$$

$$\tan(2\theta) = \frac{2 Y_\Omega v_\Omega}{M_\Sigma - M_F}$$

$$m_{\chi_{1,2}^0} = \frac{1}{2} \left[(M_\Sigma + M_F) \mp \sqrt{(M_\Sigma - M_F)^2 + 4 Y_\Omega^2 v_\Omega^2} \right]$$

⇒ **Neutrino mass:**

Neutrino mass matrix: $\mathcal{M}_\nu = Y_\nu \cdot \mathcal{F} \cdot Y_\nu^T$

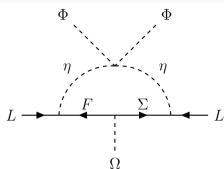
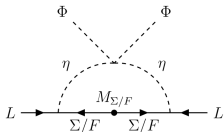
$$Y_\nu = \begin{pmatrix} Y_F^1 & Y_\Sigma^1/\sqrt{2} \\ Y_F^2 & Y_\Sigma^2/\sqrt{2} \\ Y_F^3 & Y_\Sigma^3/\sqrt{2} \end{pmatrix} \cdot V^T(\theta), \quad \mathcal{F} = \begin{pmatrix} \frac{\mathcal{I}_1}{32\pi^2} & 0 \\ 0 & \frac{\mathcal{I}_2}{32\pi^2} \end{pmatrix},$$

$$\mathcal{I}_j = m_{\chi_j^0} \left[\frac{\ln(m_{\chi_j^0}^2/m_R^2)}{(m_{\chi_j^0}^2/m_R^2) - 1} - \frac{\ln(m_{\chi_j^0}^2/m_l^2)}{(m_{\chi_j^0}^2/m_l^2) - 1} \right]$$

$$Y_\nu = U \cdot (\tilde{\mathcal{M}}_\nu)^{1/2} \cdot \rho \cdot (\mathcal{F})^{-1/2} \quad \text{with} \quad U^\dagger \mathcal{M}_\nu U^* = \tilde{\mathcal{M}}_\nu,$$

$$\rho^{\text{NO}} = \begin{pmatrix} 0 & 0 \\ \cos \omega & \sin \omega \\ -\sin \omega & \cos \omega \end{pmatrix} \quad \text{and} \quad \rho^{\text{IO}} = \begin{pmatrix} \cos \omega & \sin \omega \\ -\sin \omega & \cos \omega \\ 0 & 0 \end{pmatrix}.$$

$\lim \lambda_5 \rightarrow 0 \Rightarrow \mathcal{I}_j \propto \lambda_5 m_{\chi_j^0} \rightarrow$ Smaller λ_5 and $m_{\chi_j^0} \Rightarrow$ bigger $Y_{F,\Sigma}$



Constraints

A) Theoretical Constraints

* Bounded below:

$$i) \lambda_1 \geq 0, \quad ii) \lambda_2 \geq 0, \quad iii) \lambda_\Omega^\Omega \geq 0, \quad iv) \lambda_3 + \sqrt{\lambda_1 \lambda_2} \geq 0,$$

$$v) \lambda_3 + \lambda_4 - |\lambda_5| + \sqrt{\lambda_1 \lambda_2} \geq 0, \quad vi) \lambda_\Omega^\phi + \sqrt{2\lambda_1 \lambda_\Omega^\Omega} \geq 0, \quad vii) \lambda_\Omega^\eta + \sqrt{2\lambda_2 \lambda_\Omega^\Omega} \geq 0,$$

$$viii) \sqrt{2\lambda_1 \lambda_2 \lambda_\Omega^\Omega} + \lambda_3 \sqrt{2\lambda_\Omega^\Omega} + \lambda_\Omega^\phi \sqrt{\lambda_2} + \lambda_\Omega^\eta \sqrt{\lambda_1}$$

$$+ \sqrt{\left(\lambda_3 + \sqrt{\lambda_1 \lambda_2}\right) \left(\lambda_\Omega^\phi + \sqrt{2\lambda_1 \lambda_\Omega^\Omega}\right) \left(\lambda_\Omega^\eta + \sqrt{2\lambda_2 \lambda_\Omega^\Omega}\right)} \geq 0$$

[Merle et al. 1603.05685, Kannike 1205.3781]

* Perturbativity:

$$\lambda_i \leq 4\pi \quad \text{and} \quad Y_j \leq \sqrt{4\pi}$$

* Z_2 symmetry:

$$\mu_\Omega^\eta \lesssim \mathcal{O}(1 \text{ TeV})$$

[Merle et al. 1603.05685]

B) Collider Constraints

* Direct searches:

✓ $m_H > 150$ GeV [LEP & LHC],

✓ $M_\Sigma > 100$ GeV (from Σ^+) [LEP],

✓ $m_{\eta^+} > 70$ GeV [OPAL, hep-ph/0703056].

✓ Though there exist some bounds on $\eta_{R,I}^0$ [0810.3924] from neutralino search at LEP, they are not very constraining.

✓ Bounds from LEP and LHC on charged scalar and neutral leptons are not directly applicable to H^+ , η^+ and $\chi_{1,2}^0$.

✓ LHC bound on triplet fermion is not directly applicable to Σ .

✓ LHC searches on slepton decaying to lepton and massless neutralino might put some bound on m_{H^+} . So, we choose $m_{H^+} > 400$ GeV (conservatively [1908.08215]).

* Decay width:

i) $\mathcal{B}(h \rightarrow inv) < 13\%$, ii) $\delta\Gamma_Z < 5$ MeV (2σ), iii) $\delta\Gamma_W < 90$ MeV (2σ) [PDG]

C) Indirect Constraints

* **EWPO**: $S = -0.02 \pm 0.10$, $T = 0.03 \pm 0.12$, $U = 0.01 \pm 0.11$ [PDG]

$$\rho_{exp} = 1.00038 \pm 0.00020 \rightarrow \rho = 1 + (4 v_{\Omega}^2 / v_{\phi}^2) \implies v_{\Omega} \lesssim 4 \text{ GeV } (3\sigma)$$

* **Neutrino oscillation**:

$$i) \sin^2 \theta_{12} = 0.304_{-0.012}^{+0.012}, \quad ii) \sin^2 \theta_{23} = 0.537_{-0.020}^{+0.016}, \quad iii) \sin^2 \theta_{13} = 0.0022_{-0.00063}^{+0.00062},$$

$$iv) \Delta m_{21}^2 = 7.42_{-0.21}^{+0.20} \times 10^{-5} \text{ eV}^2, \quad v) m_{31}^2 = 2.517_{-0.028}^{+0.026} \times 10^{-3} \text{ eV}^2,$$

$$vi) \delta_{CP} = 197_{-24}^{+27} \text{ } \quad [\text{de Salas et al. 2006.11237}]$$

* **cLFV**:

$$\checkmark \mathcal{B}(\mu \rightarrow e\gamma) < 4.2 \times 10^{-13} \text{ [MEG]}$$

$$\checkmark \mathcal{B}(\mu \rightarrow 3e) < 1.0 \times 10^{-12} \text{ [SINDRUM]}$$

$$\checkmark \mathcal{C}(\mu, Au \rightarrow e, Au) < 7.0 \times 10^{-13} \text{ [SINDRUMII]}$$

$$\checkmark \text{cLFV with } \tau \text{ decays are less constraining: } \mathcal{B} < \mathcal{O}(10^{-8})$$

* Relic density:

$$\Omega h^2 = 0.120 \pm 0.001 \text{ [Planck]}$$

* DM direct detection (Strongest):

✓ 0.1 GeV - 4 GeV: **DarkSide-50** [2302.01830]

✓ 4 GeV - 10 GeV: i) **XENON1T** ^8B [2012.02846]
ii) **PandaX-4T** ^8B [2207.04883]

✓ 10 GeV - 10 TeV: i) **LZ** [2207.03764]
ii) **XENON1T** [1805.12562]
iii) **XENONnT** [2303.14729]
iv) **PandaX-4T** [2107.13438] .

✓ Coherent neutrino-nucleon scattering \rightarrow **Neutrino floor** [Billard et al. 2104.07634]

Independent Parameters & The Constraints

Parameters

⇒ Parameters from Lagrangian:

Complex Yukawa couplings	Real Yukawa couplings	Scalar mass terms and trilinear couplings	Scalar quartic couplings	Fermionic masses
$Y_F^1, Y_F^2, Y_F^3, Y_\Sigma^1, Y_\Sigma^2, Y_\Sigma^3$	Y_Ω	$\mu_\phi, \mu_\eta, \mu_\Omega, \mu_\Omega^\phi, \mu_\Omega^\eta$	$\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_\Omega^\phi, \lambda_\Omega^\eta, \lambda_\Omega^\Omega$	M_F, M_Σ

⇒ Define:

$$\Delta m_{\Sigma F} = M_\Sigma - M_F, \quad \Delta m_{\eta^+ F} = m_{\eta^+} - M_F \quad \text{and} \quad \Delta m_{\eta^0 \eta^+}^2 = m_{\eta^0}^2 - m_{\eta^+}^2$$

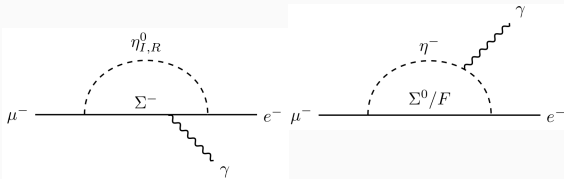
⇒ After Reduction:

There remain 16 independent parameters (No Majorana phase).

⇒ BP0:

M_F (GeV)	$\Delta m_{\Sigma F}$ (GeV)	$\Delta m_{\eta^+ F}$ (GeV)	$\Delta m_{\eta^0 \eta^+}^2$ (GeV ²)	μ_Ω^η (GeV)	v_Ω (GeV)	Y_Ω	Re(ω)	Im(ω)	λ_1	λ_2	λ_3	λ_5	λ_Ω^ϕ	λ_Ω^Ω	λ_Ω^η
[1, 1000]	200	500	1000	400	4.0	2.0	$\pi/4$	$\pi/4$	0.2626	0.5	0.5	10^{-8}	0.5	0.5	0.5

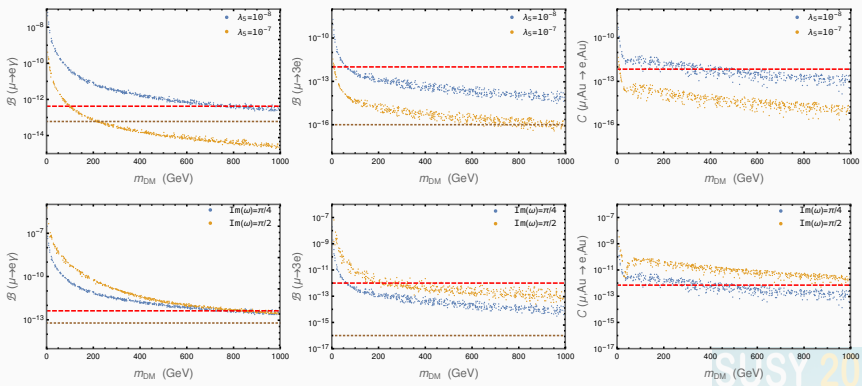
A) cLFV



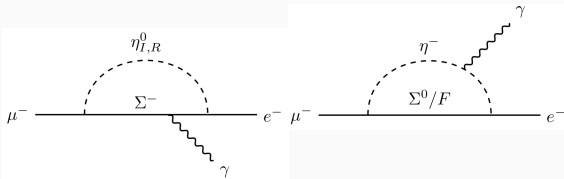
$$\{Y_{F,\Sigma} \text{ \& } Y_{F,\Sigma}^\dagger\}$$

$$\downarrow$$

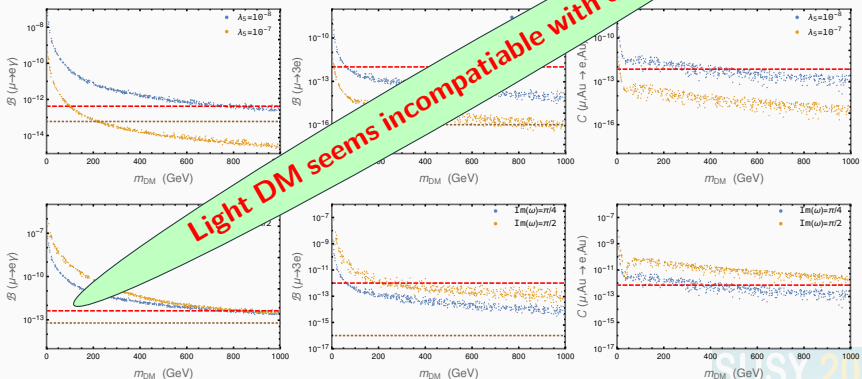
$$\{m_{\chi_1^0}, \lambda_5, \text{Im}(\omega)\}$$



A) cLFV



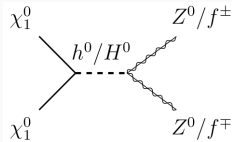
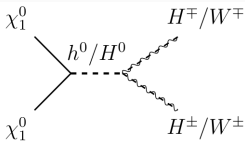
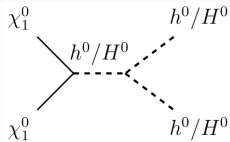
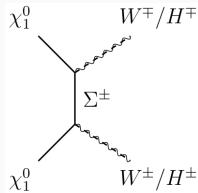
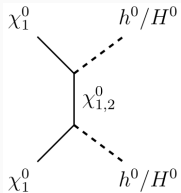
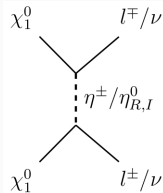
$\{Y_{F,\Sigma} \text{ \& } Y_{F,\Sigma}^\dagger\}$
 $\{m_{\Sigma} \text{ \& } m(\omega)\}$



Light DM seems incompatible with cLFV !!

B1) DM annihilation (No coannihilation)

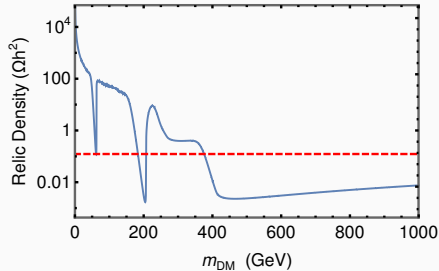
Processes:



Dependencies:

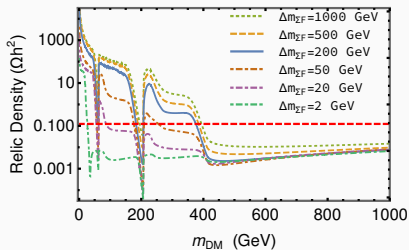
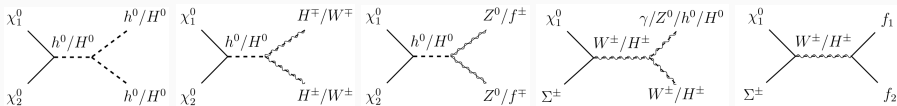
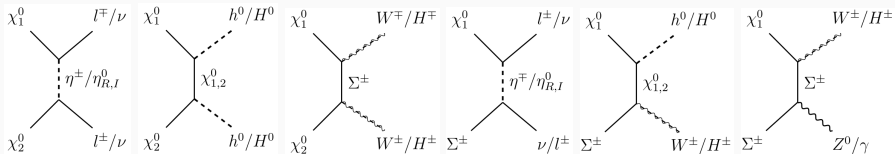
- ✓ **Scalar mixing and m_{H^0} :** $\{\lambda_1, \lambda_\Omega^\phi, v_\Omega\}$
- ✓ **Fermion mixing:** $\{v_\Omega, Y_\Omega, \Delta m_{\Sigma F}\}$
- ✓ **Couplings of SM and Z_2 -odd leptons through η :** $Y_{F,\Sigma} \longrightarrow \{\lambda_5, \text{Im}(\omega), M_F\}$
- ✓ **Masses of Z_2 -odd particles:** $\{M_F, \Delta m_{\Sigma F}(\text{slightly}), \Delta m_{\eta^+ F}(\text{slightly})\}$

Relic vs m_{DM} (BP0)



- 1st dip at $m_{DM} = 62.5$ GeV ($m_h/2$): $\chi_1^0 \chi_1^0 \rightarrow h^0 \rightarrow SM SM$
- 2nd dip at $m_{DM} = 200$ GeV ($m_H/2$): $\chi_1^0 \chi_1^0 \rightarrow H^0 \rightarrow SM SM$
- 3rd dip near $m_{DM} = 250$ GeV $\{(m_{W^\pm} + m_{H^\pm})/2, (m_{h^0} + m_{H^0})/2\}$:
Opening of $\chi_1^0 \chi_1^0 \rightarrow W^\pm H^\mp$ and $\chi_1^0 \chi_1^0 \rightarrow h^0 H^0$
- 4th dip near $m_{DM} = 400$ GeV (m_{H^0}, m_{H^\pm}):
Opening of $\chi_1^0 \chi_1^0 \rightarrow H^0 H^0$ and $\chi_1^0 \chi_1^0 \rightarrow H^+ H^-$

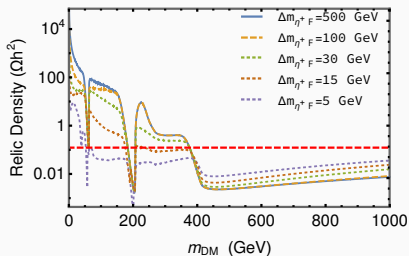
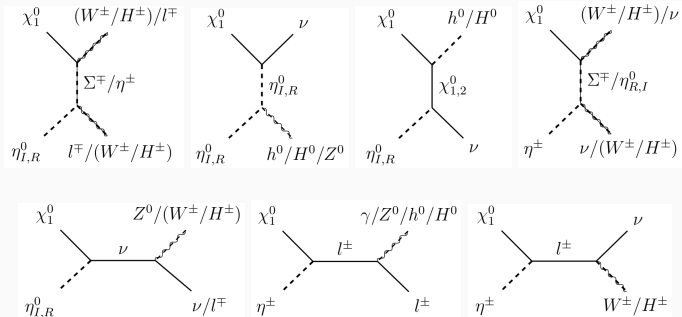
B2) Fermion-fermion coannihilation



$$\langle \sigma_c v \rangle \propto \sum_{i,j} \sigma_{ij} e^{-\frac{m_i - m_{\text{DM}}}{T}} e^{-\frac{m_j - m_{\text{DM}}}{T}}$$

$$\rightarrow e^{-(m_{\chi_2} - m_{\chi_1})/T} \rightarrow f_1(\Delta m_{\Sigma F}/T).$$

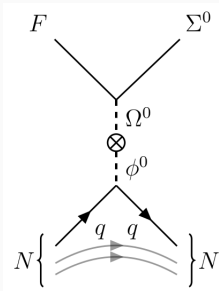
B3) Fermion-scalar coannihilation



$$\langle \sigma_{c\nu} \rangle \propto \sum_{i,j} \sigma_{ij} e^{-\frac{m_i - m_{DM}}{T}} e^{-\frac{m_j - m_{DM}}{T}}$$

$$\rightarrow e^{-(m_\eta - m_{\chi_1})/T} \rightarrow f_2(\Delta m_{\eta^+ F}/T).$$

C) Direct detection



$$\sigma_{\text{DM-N}}^{\text{SI}} \approx \frac{\mu_{\text{red}}^2}{\pi} \left[\frac{Y_{\Omega} f_N m_N}{2v} \sin 2\theta \sin 2\beta \left(\frac{1}{m_{h^0}^2} - \frac{1}{m_{H^0}^2} \right) \right]^2$$

- ▣ m_N : Nucleon mass
- ▣ f_N : Nucleon form factor ≈ 0.3
- ▣ μ_{red} : Reduced mass = $(m_{\chi_1^0} m_N)/(m_{\chi_1^0} + m_N)$
- ▣ θ : Fermion mixing angle $\rightarrow \tan(2\theta) = \frac{2 Y_{\Omega} v_{\Omega}}{M_{\Sigma} - M_F}$
- ▣ β : Scalar mixing angle
 $\rightarrow \tan 2\beta = \frac{4v_{\Omega} v_{\phi} (\mu_{\Omega}^{\phi} - \sqrt{2}\lambda_{\phi}^{\Omega} v_{\Omega})}{4\sqrt{2}\lambda_{\Omega}^{\Omega} v_{\Omega}^3 - 2\sqrt{2}\lambda_1 v_{\Omega} v_{\phi}^2 + \mu_{\Omega}^{\phi} v_{\phi}^2}$

Dependencies: $\sigma_{\text{DM-N}}^{\text{SI}} \rightarrow \{\lambda_1, \lambda_{\Omega}^{\phi}, v_{\Omega}, Y_{\Omega}, \Delta m_{\Sigma F}\}$ (but not on $m_{\chi_1^0}$)

Parameter-Space Scanning

Scanning

Cases	v_Ω (GeV)	M_F (GeV)	$\Delta m_{\Sigma F}$ (GeV)	$\Delta m_{\eta^+ F}$ (GeV)	$\Delta m_{\eta^0 \eta^+}^2$ (GeV ²)	$\mu_\Omega^{\eta^0}$ (GeV)	Y_Ω	$\text{Re}(\omega)$	$\text{Im}(\omega)$	λ_1	λ_2	λ_3	λ_5	λ_Ω^0	λ_Ω^Ω	$\lambda_\Omega^{\eta^0}$
Scenario-I																
BP ₁			[100, 500]	[100, 500]	1000											
BP ₁ ^{FF}	4.0	[3, 10000]	[1, 50]	[100, 500]	1000	400	[0.1, 3.5]	$[-\pi, \pi]$	$[-2\pi, 2\pi]$	0.2626	0.5	0.5	$[10^{-9}, 0.5]$	0.5	0.5	0.5
BP ₁ ^{FS}			[100, 500]	[1, 30]	[1, 1000]											
Scenario-II																
BP ₂			[100, 500]	[100, 500]	1000											
BP ₂ ^{FF}	1.5	[3, 10000]	[1, 50]	[100, 500]	1000	400	[0.1, 3.5]	$[-\pi, \pi]$	$[-2\pi, 2\pi]$	0.2626	0.5	0.5	$[10^{-9}, 0.5]$	0.5	0.5	0.5
BP ₂ ^{FS}			[100, 500]	[1, 30]	[1, 1000]											

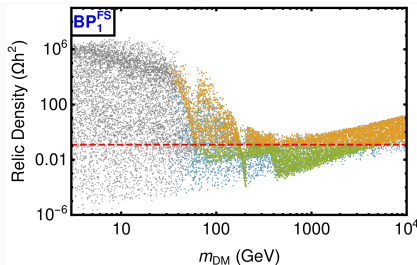
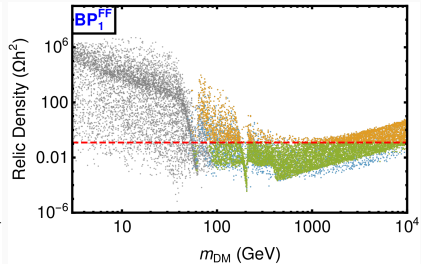
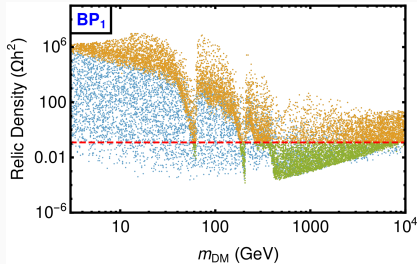
No Superscript: No coannihilation

Superscript FF: Fermion-fermion coannihilation

Superscript FS: Fermion-Scalar coannihilation

$m_{H^0} = \{400 \text{ GeV (Scenario-I), 1100 GeV (Scenario-II)}\}$

Scanning: Relic



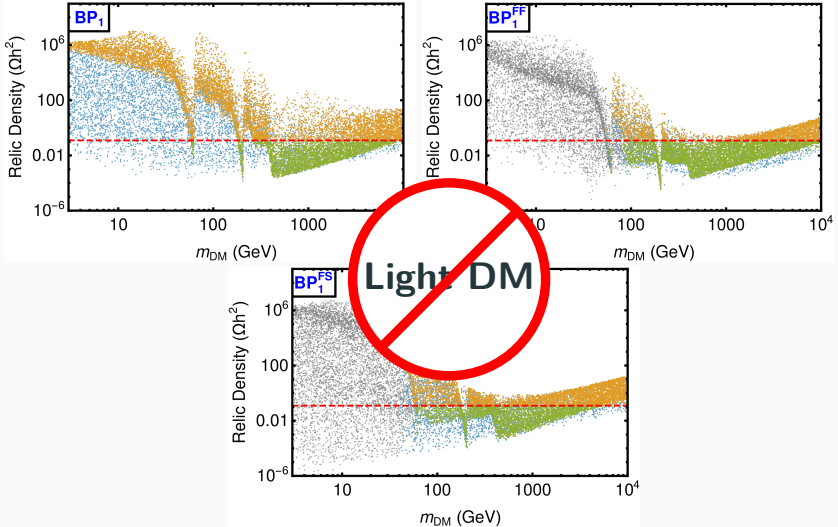
● Excluded by Collider

● Excluded by LFV

● Excluded by Relic

● Allowed by Oscillation,
Collider, LFV & Relic

Scanning: Relic



● Excluded by Collider

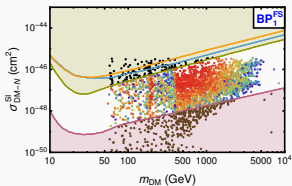
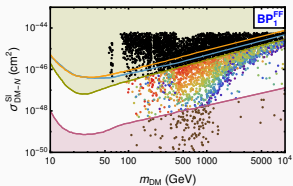
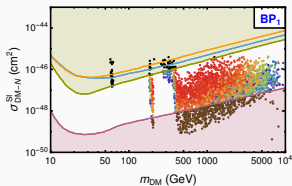
● Excluded by LFV

● Excluded by Relic

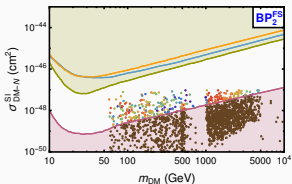
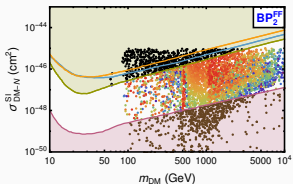
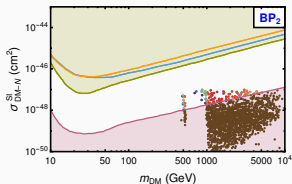
● Allowed by Oscillation,
Collider, LFV & Relic

Scanning: Direct detection

Scenario-I (High v_Ω)



Scenario-II (Low v_Ω)



No Coannihilation

**Fermion-Fermion
Coannihilation**

**Fermion-Scalar
Coannihilation**

$$\xi_i = (\Omega h_i^2 / \Omega h^2)$$



Legend for exclusion and detection regions:

- Neutrino Floor (pink shaded region)
- Excluded by LZ(2022) (light green shaded region)
- PandaX-4T(2021) (blue line)
- XENON1T(2018) (orange line)
- Discarded (black dots)
- Undetectable (brown dots)

Summary

- ✎ This model cannot accommodate light fermionic dark matter (both singlet-like and triplet-like) below 62.5 GeV.
- ✎ Without any coannihilation feasible parameter-space can be obtained only for $m_{DM} > m_H$ (apart from discrete resonance at $m_{DM} = m_H/2$)
- ✎ Fermion-fermion coannihilation provides feasible parameter-space for $m_{DM} > 100$ GeV whereas fermion-scalar coannihilation does the same job from $m_{DM} > 62.5$ GeV.
- ✎ While fermion-scalar coannihilation is the most promising scenario for higher values of v_Ω , fermion-fermion coannihilation is the most promising case for lower values of v_Ω .

Thanks for your attention...