Models with radiative neutrino masses and viable dark matter candidates

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In collaboration with

In collaboration with

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Image title

GRUPO DE
FENOMENOLOGÍA DE INTERACCIONES FUNDAMENTALES

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Review of SM

Only fields

Lorentz :

$$\mathcal{L} = -\tfrac{1}{4}\left(\partial^\mu A^\nu - \partial^\nu A^\mu\right)\left(\partial_\mu A_\nu - \partial_\nu A_\mu\right) . \qquad (1)$$

$$A^\mu(x) \to A'^\mu(x) = \Lambda^\mu{}_\nu A^\nu(\Lambda^{-1}x) \qquad \text{Vector field}$$

$$\phi(x) \to \phi'(x) = \phi(\Lambda^{-1}x) \qquad \text{Scalar field}$$

$$\psi_\alpha(x) \to \psi'_\alpha(x) = [S(\Lambda)]_\alpha{}^\beta \psi_\beta(\Lambda^{-1}x) \,, \qquad \text{Left Weyl spinor}$$

$$(\psi_\alpha(x))^\dagger = \psi^\dagger_{\dot\alpha}(x) \to \psi'^\dagger_{\dot\alpha}(x) = [S^*(\Lambda)]_{\dot\alpha}{}^{\dot\beta} \psi^\dagger_{\dot\beta}(\Lambda^{-1}x) \,, \qquad \text{Right anti-Weyl spinor}$$

With

$$S(\Lambda) = \exp\left(\boldsymbol{\xi} \cdot \frac{\boldsymbol{\sigma}}{2} + i\boldsymbol{\theta} \cdot \frac{\boldsymbol{\sigma}}{2}\right) ,$$

where $\boldsymbol{\sigma} = (\sigma_1, \sigma_2, \sigma_3)$ are the Pauli matrices. $\overline{\boldsymbol{\sigma}} \equiv -\boldsymbol{\sigma}$.

Lorentz+$U(1)$:

$$\mathcal{L} = \partial_\mu \phi^* \partial^\mu \phi - m^2 \phi^* \phi - \lambda \left(\phi^* \phi\right)^2 \ . \tag{1}$$

$$\begin{aligned}
A^\mu(x) \to A'^\mu(x) &= \Lambda^\mu{}_\nu A^\nu(\Lambda^{-1}x) && \text{Vector field}\\
\phi(x) \to \phi'(x) &= \phi(\Lambda^{-1}x) && \text{Scalar field}\\
\psi_\alpha(x) \to \psi'_\alpha(x) &= [S(\Lambda)]_\alpha{}^\beta \psi_\beta(\Lambda^{-1}x)\,, && \text{Left Weyl spinor}\\
(\psi_\alpha(x))^\dagger = \psi^\dagger_{\dot\alpha}(x) \to \psi'^\dagger_{\dot\alpha}(x) &= [S^*(\Lambda)]_{\dot\alpha}{}^{\dot\beta} \psi^\dagger_{\dot\beta}(\Lambda^{-1}x)\,, && \text{Right anti-Weyl spinor}
\end{aligned}$$

With

$$S(\Lambda) = \exp\left(\boldsymbol{\xi} \cdot \frac{\boldsymbol{\sigma}}{2} + i\boldsymbol{\theta} \cdot \frac{\boldsymbol{\sigma}}{2}\right) \ ,$$

where $\boldsymbol{\sigma} = (\sigma_1, \sigma_2, \sigma_3)$ are the Pauli matrices. $\overline{\boldsymbol{\sigma}} \equiv -\boldsymbol{\sigma}$.

Weyl spinor

$$\begin{aligned}\mathcal{L} =& i\psi^\dagger_{\dot\alpha}\overline{\sigma}^{\mu\dot\alpha\alpha}\partial_\mu\psi_\alpha - m\left(\psi^\alpha\psi_\alpha + \psi^\dagger_{\dot\alpha}\psi^{\dagger\dot\alpha}\right)\\ =& i\psi^\dagger\overline{\sigma}^\mu\partial_\mu\psi - m\left(\psi\psi + \psi^\dagger\psi^\dagger\right)\,.\end{aligned} \tag{2}$$

Electron field: *one in four*: Dreiner,... arXiv:0812.1594 (PR)

Scalar product: $\quad {}^{\alpha}{}_{\alpha} \quad$ and $\quad {}_{\dot\alpha}{}^{\dot\alpha}$.

Name	Symbol Name	Lorentz Name	$U(1)$
e_L: left electron	ξ_α	$[S]_\alpha{}^\beta$	$e^{i\theta}$
$(e_L)^\dagger = e_R^\dagger$: right positron	$(\xi_\alpha)^\dagger = \xi^\dagger_{\dot\alpha}$	$[S^*]_{\dot\alpha}{}^{\dot\beta}$	$e^{-i\theta}$
e_R: right electron	$(\eta^\alpha)^\dagger = \eta^{\dagger\,\dot\alpha}$	$\left[\left(S^{-1}\right)^\dagger\right]^{\dot\alpha}{}_{\dot\beta}$	$e^{i\theta}$
$(e_R)^\dagger = e_L^\dagger$: left positron	η^α	$\left[\left(S^{-1}\right)^T\right]^{\alpha}{}_{\beta}$	$e^{-i\theta}$

$$
\begin{aligned}
\mathcal{L} =& i\xi^\dagger_{\dot\alpha}\overline{\sigma}^{\mu\,\dot\alpha\alpha}\partial_\mu\xi_\alpha + i\eta^\alpha\sigma^\mu_{\alpha\dot\alpha}\partial_\mu\eta^{\dagger\,\dot\alpha} - m\left(\eta^\alpha\xi_\alpha + \xi^\dagger_{\dot\alpha}\eta^{\dagger\,\dot\alpha}\right)\\
=& i\xi^\dagger\overline{\sigma}^\mu\partial_\mu\xi + i\eta\sigma^\mu\partial_\mu\eta^\dagger - m\left(\eta\xi + \xi^\dagger\eta^\dagger\right) + \ .
\end{aligned}
$$

Dark matter


Dark matter
in the light of the ΛCDM paradigm
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Universidad de Antioquia
Phenomenology Group
http://gfif.udea.edu.co

SM

Z_2

SM

+

$\frac{1}{\Lambda} L \cdot H L \cdot H$ (1-loop)

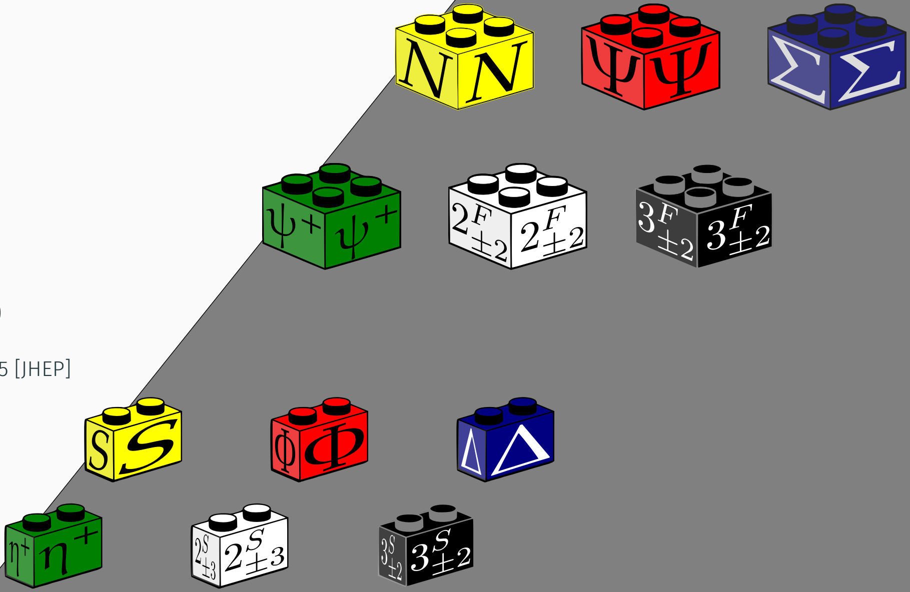
Bonnet, *et al*, arXiv:1204.5862 [JHEP]

SM

+

$\frac{1}{\Lambda} L \cdot H L \cdot H$ (1-loop)

This work, arXiv:1308.3655 [JHEP]



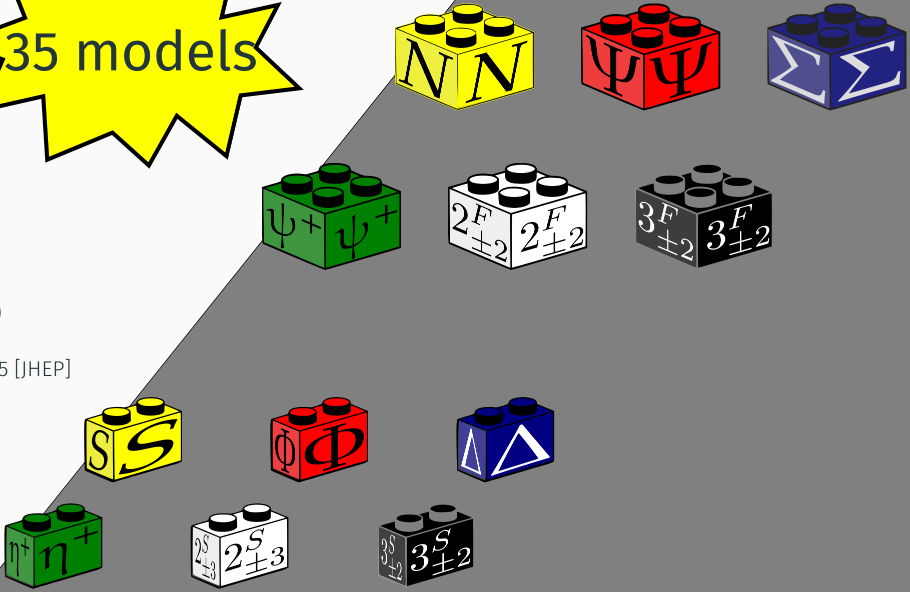
35 models

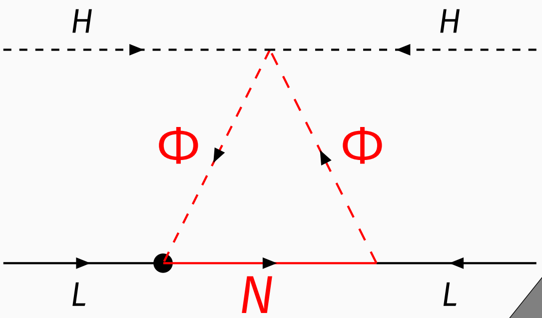
SM

+

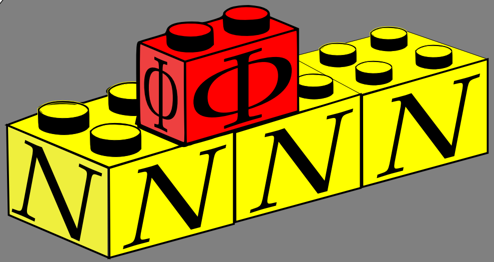
$\frac{1}{\Lambda} L \cdot HL \cdot H$ (1-loop)

This work, arXiv:1308.3655 [JHEP]





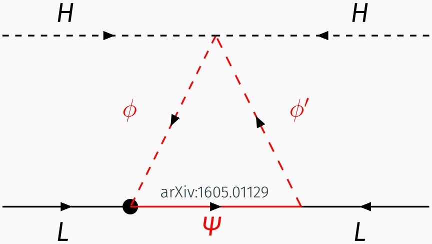
E. Ma, hep-ph/0601225 [PRD]

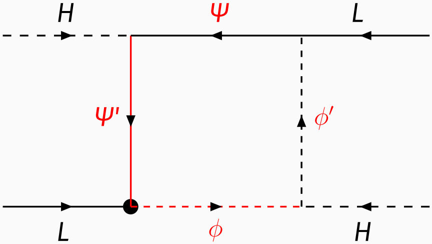


Neutrino masses

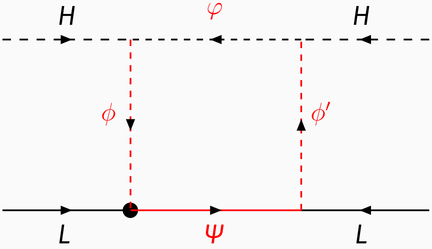
Weinberg operator at one-loop

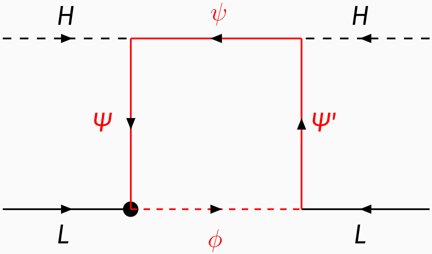
(Z_2-odd fields)





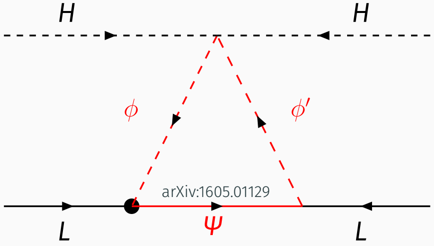
Bino/Wino-like scotogenic model



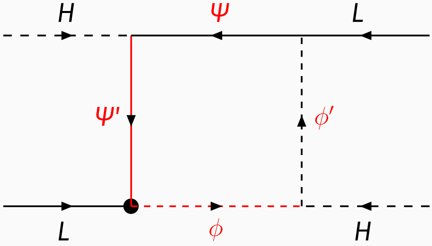


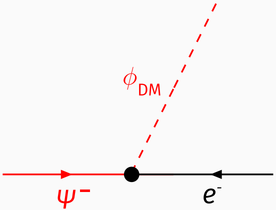
Weinberg operator at one-loop

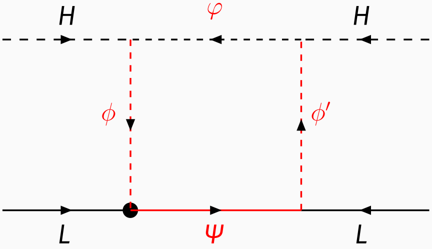
(Z_2-odd fields)

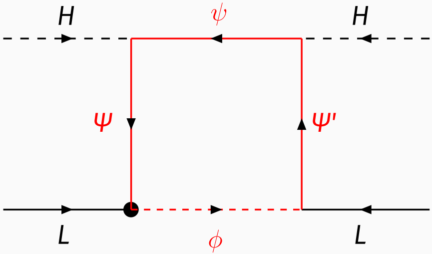


Bino/Wino-like scotogenic model





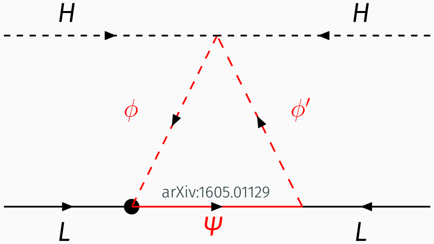




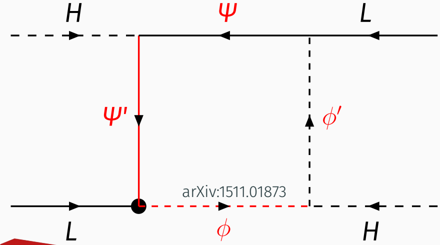
$$pp \to l^+ l^- + E_T^{\mathrm{miss}}$$

Weinberg operator at one-loop

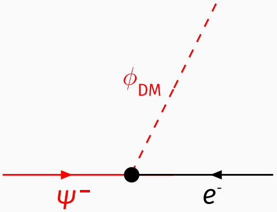
(Z_2-odd fields)



Bino/Wino-like scotogenic model

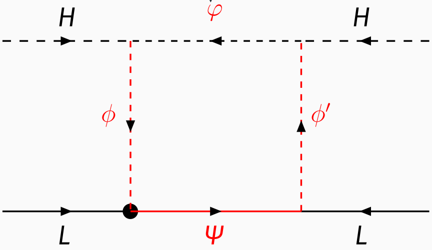


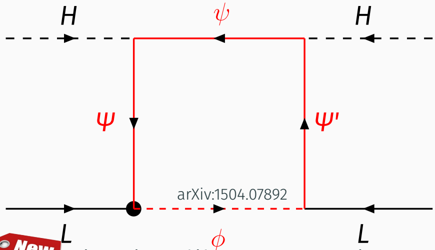
Higgsino-like Zee model



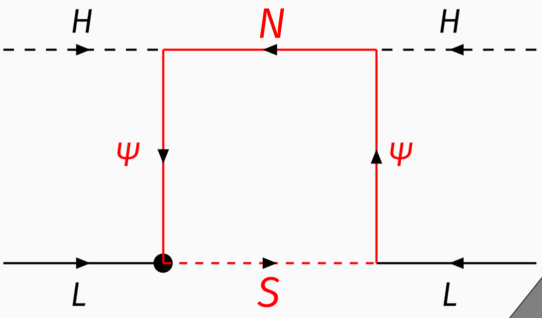
$pp \to l^+ l^- + E_T^{\mathrm{miss}}$

$\Updownarrow$

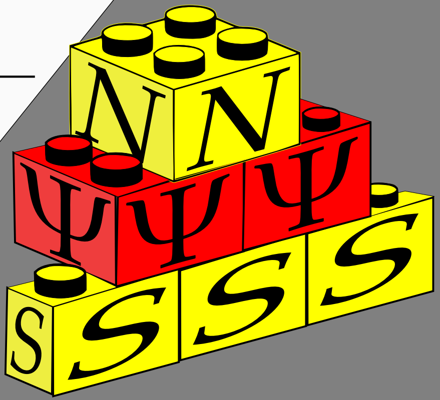




Higgsino-like scotogenic model



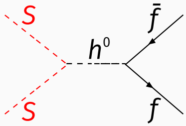
D.R *et al*, arXiv:1504.07892 [PRD]



Scalar dark matter: Higgs portal

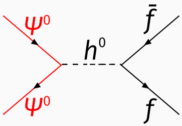
Name	Symbol	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L = (\nu_L\ e_L)^T$	$(\xi_{1\alpha}\ \xi_{2\alpha})^T$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	$+1$
$(e_R)^\dagger$	η_1^α	$\mathbf{1}$	$\mathbf{1}$	$+1$	$+1$
$(\hat{\Psi}_R)^\dagger$	$(\eta_2^\alpha\ \eta_3^\alpha)^T$	$\mathbf{1}$	$\mathbf{1}$	$+1$	-1
Ψ_L	$(\xi_{3\alpha}\ \xi_{4\alpha})^T$	$\mathbf{1}$	$\mathbf{1}$	-1	-1
N	$\eta_{4\alpha}$	$\mathbf{1}$	$\mathbf{1}$	0	-1
S		$\mathbf{1}$	$\mathbf{1}$	0	-1

$$\mathcal{V} = M_S^2 S^2 + \lambda_{SH} S^2\, \widetilde{H} \cdot H + \lambda_S S^4 \tag{3}$$



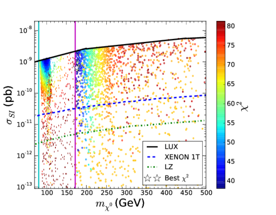
Singlet-doublet fermion dark matter: Higgs portal

Name	Symbol	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L=(\nu_L\ e_L)^T$	$(\xi_{1\alpha}\ \xi_{2\alpha})^T$	1	**2**	$-1/2$	$+1$
$(e_R)^\dagger$	η_1^α	1	**1**	$+1$	$+1$
$(\psi_R^0)^\dagger$	η_2^α	1	**1**	$+1$	-1
ψ_L^0	$\xi_{3\alpha}$	1	**1**	-1	-1
N	$\eta_{4\alpha}$	1	**1**	0	-1
S		1	**1**	0	-1



$$\text{Basis } \boldsymbol{\psi}^0 = \left(N, \psi_L^0, (\psi_R^0)^\dagger\right)^T$$

$$\mathcal{M}_{\boldsymbol{\psi}^0} = \begin{pmatrix} M_N & -y\,c_\beta v/\sqrt{2} & y\,s_\beta v/\sqrt{2} \\ -y\,c_\beta v/\sqrt{2} & 0 & -M_D \\ y\,s_\beta v/\sqrt{2} & -M_D & 0 \end{pmatrix},$$

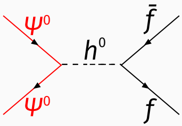


S. Horiuchi,

O. Macias, DR, A. Rivera, O. Zapata, 1602.04788 (JCAP)

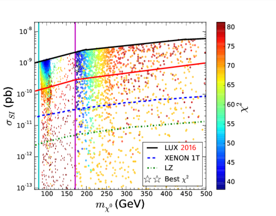
Singlet-doublet fermion dark matter: Higgs portal

Name	Symbol	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L=(\nu_L\ e_L)^T$	$(\xi_{1\alpha}\ \xi_{2\alpha})^T$	1	2	$-1/2$	$+1$
$(e_R)^\dagger$	η_1^α	1	1	$+1$	$+1$
$(\psi_R^0)^\dagger$	η_2^α	1	1	$+1$	-1
ψ_L^0	$\xi_{3\alpha}$	1	1	-1	-1
N	$\eta_{4\alpha}$	1	1	0	-1
S		1	1	0	-1



$$\text{Basis } \boldsymbol{\psi}^0=\left(N,\psi_L^0,(\psi_R^0)^\dagger\right)^T$$

$$\mathcal{M}_{\boldsymbol{\psi}^0}=\begin{pmatrix} M_N & -y\,c_\beta v/\sqrt{2} & y\,s_\beta v/\sqrt{2} \\ -y\,c_\beta v/\sqrt{2} & 0 & -M_D \\ y\,s_\beta v/\sqrt{2} & -M_D & 0 \end{pmatrix},$$



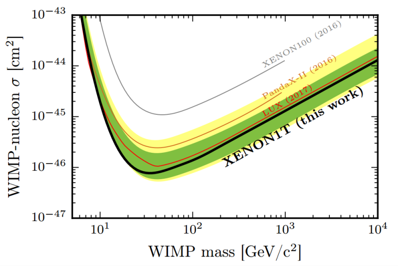
S. Horiuchi,

O. Macias, DR, A. Rivera, O. Zapata, 1602.04788 (JCAP)

Is the glass half empty or half full?

Tree-level SM-portal could be fully excluded in the near future

- Singlet scalar dark matter
- Inert doublet model
- Tree-level SM-portal dark matter $\cdots$



In this talk we explore

Is the glass half empty or half full?

Tree-level SM-portal could be fully excluded in the near future

- Singlet scalar dark matter
- Inert doublet model
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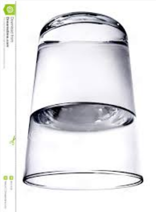


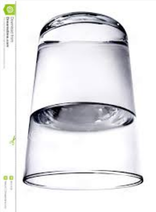
In this talk we explore

  - Recover SM-portals in LR models

Is the glass half empty or half full?

Tree-level SM-portal could be fully excluded in the near future

- Singlet scalar dark matter
- Inert doublet model
- Tree-level SM-portal dark matter $\cdots$



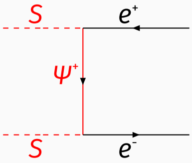
In this talk we explore

- Recover SM-portals in LR models
- New portals in LR models

Scalar dark matter: vector-like portal

Name	Symbol	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L = (\nu_L \; e_L)^T$	$(\xi_{1\alpha} \; \xi_{2\alpha})^T$	**1**	**2**	$-1/2$	$+1$
$(e_R)^\dagger$	η_1^α	**1**	**1**	$+1$	$+1$
$(\psi_R^-)^\dagger$	η_3^α	**1**	**1**	$+1$	-1
ψ_L^-	$\xi_{4\alpha}$	**1**	**1**	-1	-1
S		**1**	**1**	0	-1

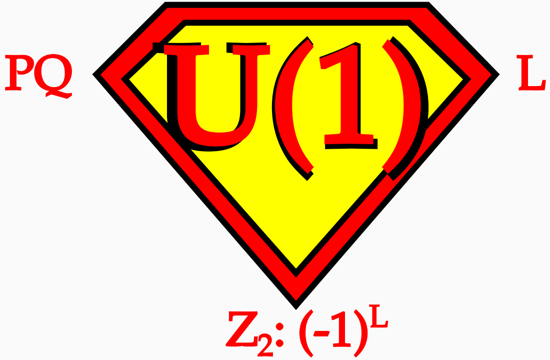
$$\mathcal{L} = M_\psi \left[\left(\psi_R^-\right)^\dagger \psi_L^- + \left(\psi_L^-\right)^\dagger \psi_R^- \right] + h_S \left[S \,(e_R)^\dagger \,\psi_R^- + S \left(\psi_L^-\right)^\dagger e_L \right] \tag{4}$$



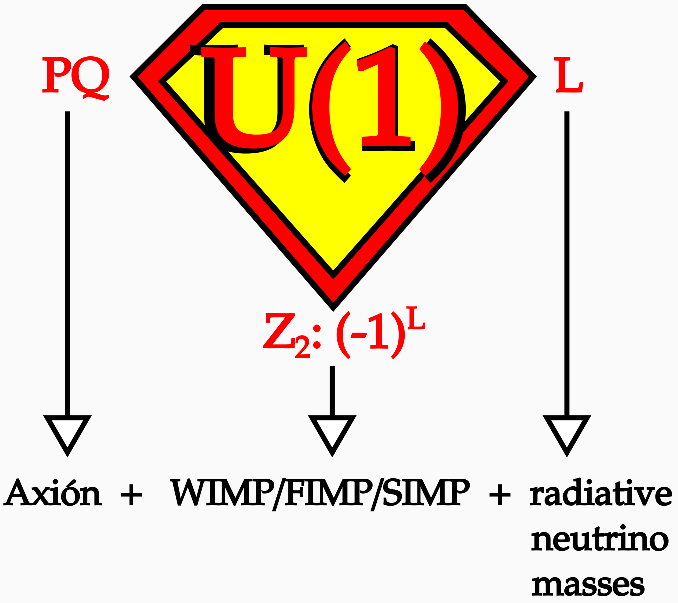
Mixed dark matter


U(1)

Ernest Ma, D.R, Óscar Zapata: arXiv:1706.08240



Ernest Ma, D.R, Óscar Zapata: $\Longrightarrow R = (-1)^{2s+3B+L}$ arXiv:1706.08240



leptonic U(1) symmetry: $m_\nu = 0$

Name	Symbol	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_L$
$L = (\nu_L\ e_L)^T$	$(\xi_{1\alpha}\ \xi_{2\alpha})^T$	**1**	**2**	$-1/2$	-1
$(e_R)^\dagger$	η_1^α	**1**	**1**	$+1$	$+1$
$(\hat{\Psi}_R)^\dagger$	$(\eta_2^\alpha\ \eta_3^\alpha)^T$	**1**	**1**	$+1$	0
Ψ_L	$(\xi_{3\alpha}\ \xi_{4\alpha})^T$	**1**	**1**	-1	0
N	$\eta_{4\alpha}$	**1**	**1**	0	0
S		**1**	**1**	0	0

$$\begin{aligned}\mathcal{L} =& \mathcal{L}_{SM} - M_S^2\, S^*S - \lambda_{SH}\, S^*S\, \widetilde{H}\cdot H - \lambda_S\,(S^*S)^2 \\ &+ \Big(M_N\, NN + M_D(\hat{\Psi}_R)^\dagger \Psi_L + h_L\, \Psi_L \cdot HN + h_R\, \hat{\Psi}_R \cdot HN^\dagger + h_{LS}\, L\cdot\Psi_L S + \text{h.c}\Big)\end{aligned}$$

Anomalous leptonic U(1) symmetry: $m_\nu = 0$

Name	Symbol	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_L$
$L = (\nu_L\ e_L)^T$	$(\xi_{1\alpha}\ \xi_{2\alpha})^T$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	-1
$(e_R)^\dagger$	η_1^α	$\mathbf{1}$	$\mathbf{1}$	$+1$	$+1$
$(\hat{\Psi}_R)^\dagger$	$(\eta_2^\alpha\ \eta_3^\alpha)^T$	$\mathbf{1}$	$\mathbf{1}$	$+1$	0
Ψ_L	$(\xi_{3\alpha}\ \xi_{4\alpha})^T$	$\mathbf{1}$	$\mathbf{1}$	-1	0
N	$\eta_{4\alpha}$	$\mathbf{1}$	$\mathbf{1}$	0	0
S		$\mathbf{1}$	$\mathbf{1}$	0	0
σ		$\mathbf{1}$	$\mathbf{1}$	0	-2

$$\begin{aligned}\mathcal{L} =& \mathcal{L}_{SM} - M_S^2\, S^*S - \lambda_{SH}\, S^*S\, \widetilde{H}\cdot H - \lambda_S\,(S^*S)^2 + \lambda_{S\sigma}\, S^*S\,\sigma^*\sigma + (\mu\, SS\,\sigma + \text{h.c}) \\ &+ \left(M_N\, NN + M_D(\hat{\Psi}_R)^\dagger\Psi_L + h_L\,\Psi_L\cdot HN + h_R\,\hat{\Psi}_R\cdot HN^\dagger + h_{LS}\, L\cdot\Psi_L S + \text{h.c}\right) \\ &+ V(\sigma).\end{aligned}$$

Anomalous leptonic U(1) symmetry: $m_\nu \neq 0$

Name	Symbol	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L = (\nu_L\ e_L)^T$	$(\xi_{1\alpha}\ \xi_{2\alpha})^T$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	0
$(e_R)^\dagger$	η_1^α	$\mathbf{1}$	$\mathbf{1}$	$+1$	0
$(\hat{\Psi}_R)^\dagger$	$(\eta_2^\alpha\ \eta_3^\alpha)^T$	$\mathbf{1}$	$\mathbf{1}$	$+1$	-1
Ψ_L	$(\xi_{3\alpha}\ \xi_{4\alpha})^T$	$\mathbf{1}$	$\mathbf{1}$	-1	-1
N	$\eta_{4\alpha}$	$\mathbf{1}$	$\mathbf{1}$	0	-1
S		$\mathbf{1}$	$\mathbf{1}$	0	-1
$\mathrm{Im}(\sigma)$		$\mathbf{1}$	$\mathbf{1}$	0	0

$$\begin{aligned}\mathcal{L} =& \mathcal{L}_{\rm SM} - M_S^2\, S^*S - \lambda_{SH}\, S^*S\, \widetilde{H}\cdot H - \lambda_S\,(S^*S)^2 + \lambda_{S\sigma}\, S^*S\, v_\sigma^2 + (\mu\, SS\, v_\sigma + \text{h.c}) \\ &+ \left(M_N\, NN + M_D(\hat{\Psi}_R)^\dagger \Psi_L + h_L\, \Psi_L\cdot HN + h_R\, \hat{\Psi}_R\cdot HN^\dagger + h_{LS}\, L\cdot\Psi_L S + \text{h.c}\right)\end{aligned}$$

Conclusions

We have found *at least one* model with many predictions and profund theoretical insights.

Thanks!