Scotogenic models

Peccei-Quinn as broken lepton number

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Focus on
arXiv:1706.08240
In collaboration with
Ernest Ma (UC-R) & Óscar Zapata (UdeA)

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Dark matter

Dark matter

in the light of the ΛCDM paradigm

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SM

$$Z_2$$

SM

+

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

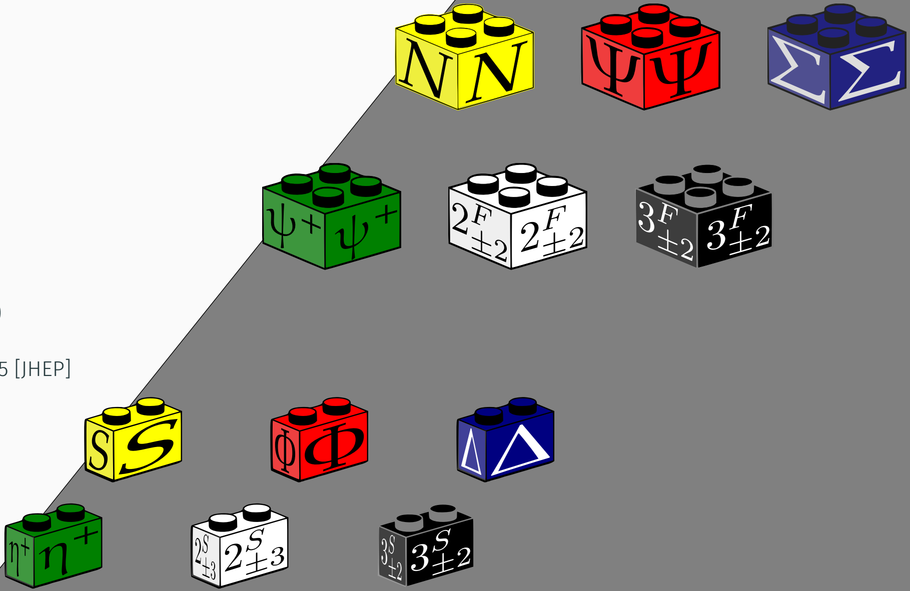
Bonnet, *et al*, arXiv:1204.5862 [JHEP]

SM

+

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

This work, arXiv:1308.3655 [JHEP]



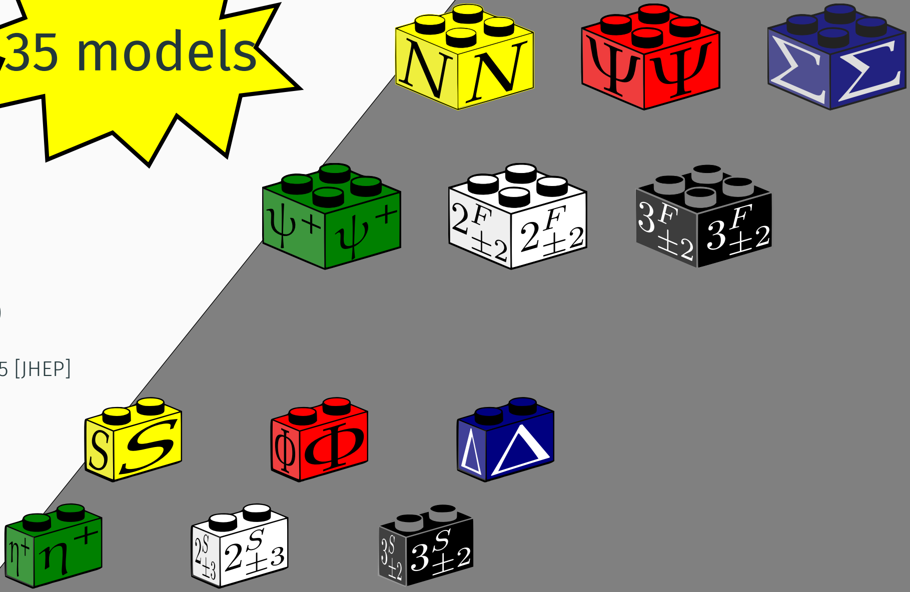
35 models

SM

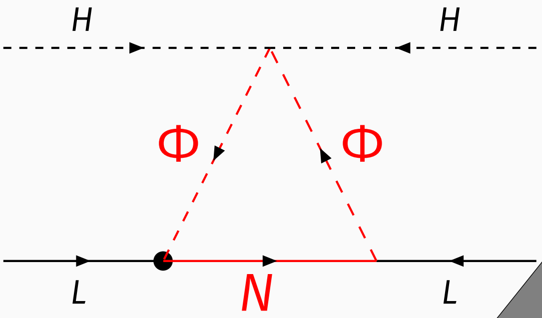
+

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

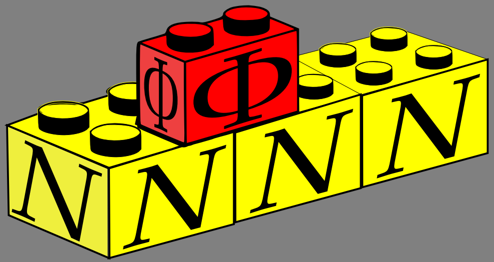
This work, arXiv:1308.3655 [JHEP]



Radiative seesaw



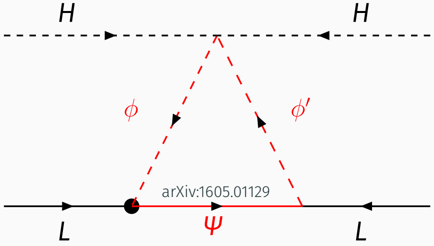
E. Ma, hep-ph/0601225 [PRD]

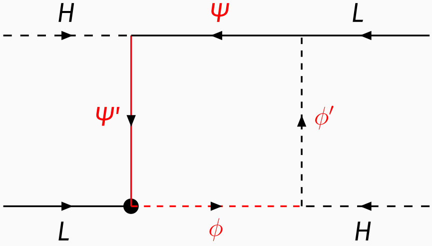


Neutrino masses

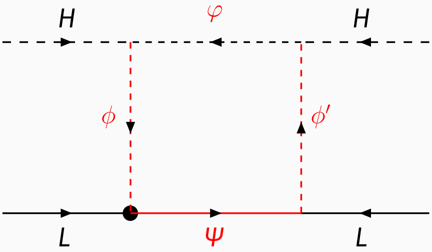
Weinberg operator at one-loop

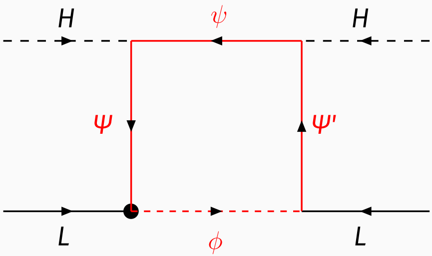
(Z_2-odd fields)





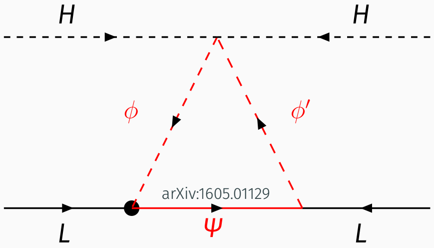
Bino/Wino-like scotogenic model

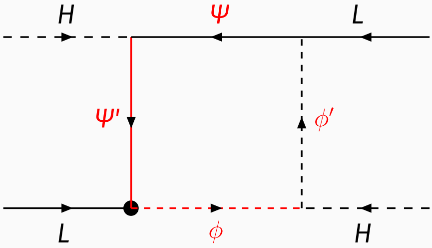


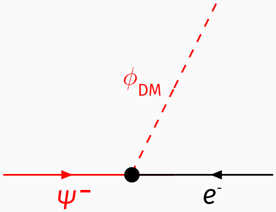


Weinberg operator at one-loop

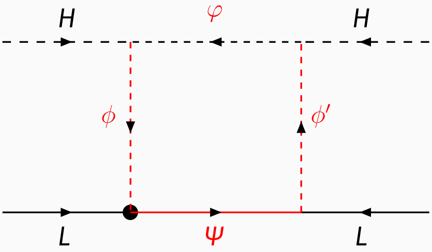
(Z_2-odd fields)

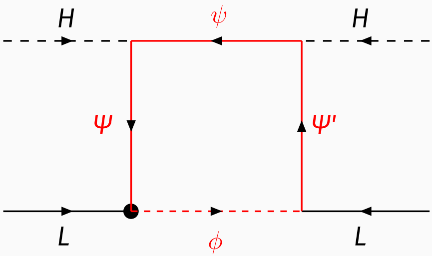






Bino/Wino-like scotogenic model

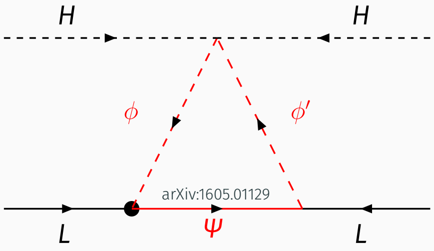




$pp \to l^+ l^- + E_T^{\text{miss}}$

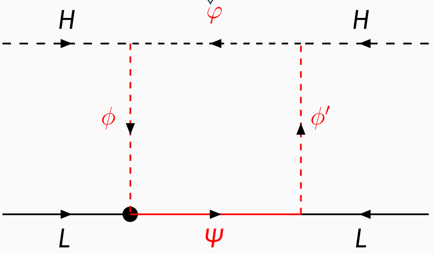
Weinberg operator at one-loop

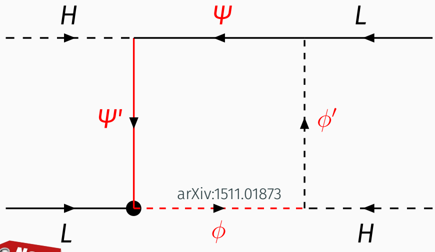
(Z_2-odd fields)



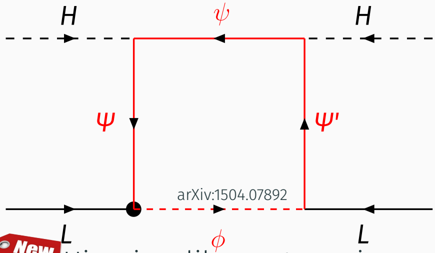
Bino/Wino-like scotogenic model

$\Updownarrow$

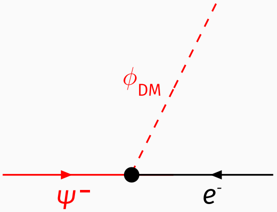




New Higgsino-like Zee model

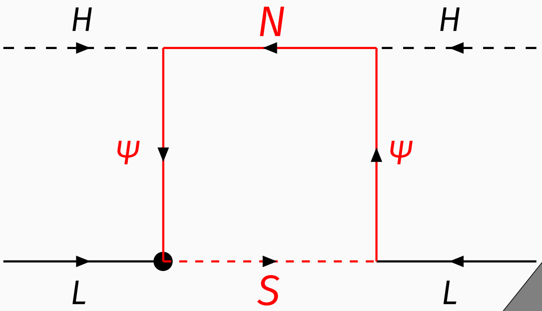


New Higgsino-like scotogenic model

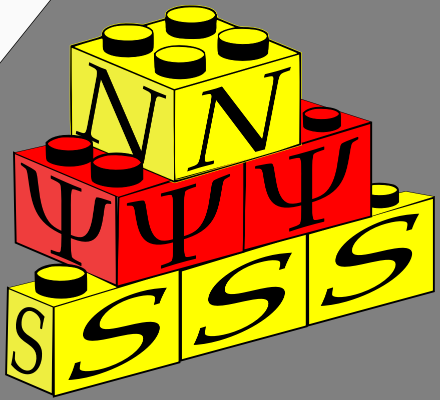


$$pp \to l^+ l^- + E_T^{\mathrm{miss}}$$

Inverse radiative seesaw

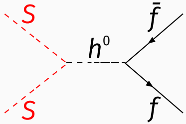


D.R *et al*, arXiv:1504.07892 [PRD]



Scalar dark matter: Higgs portal

Name	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L = (\nu_L \; e_L)^T$	**1**	**2**	$-1/2$	$+1$
$(e_R)^\dagger$	**1**	**1**	$+1$	$+1$
$(\hat{\Psi}_R)^\dagger = \left((\psi_R^+)^\dagger \;\; (\psi_R^0)^\dagger \right)^T$	**1**	**2**	$+1/2$	-1
$\Psi_L = (\psi_L^0 \; \psi_L^-)^T$	**1**	**2**	$-1/2$	-1
N	**1**	**1**	0	-1
S	**1**	**1**	0	-1



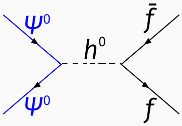
$$\mathcal{V} = M_S^2 S^2 + \lambda_{SH} S^2 \, \widetilde{H} \cdot H + \lambda_S S^4$$

$$\lambda_{HS} \sim \begin{cases} 0.1 & \text{WIMP} \\ 10^{-9} & \text{FIMP} + S\text{inflaton (Tenkanen)} \end{cases}$$

Tenkanen. arXiv:1607.01379 (JHEP)

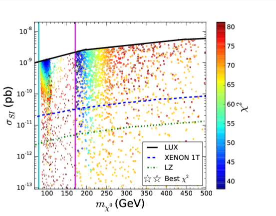
Singlet-doublet fermion dark matter: Higgs portal

Name	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L = (\nu_L \; e_L)^T$	1	2	$-1/2$	$+1$
$(e_R)^\dagger$	1	1	$+1$	$+1$
$(\hat{\Psi}_R)^\dagger = \left((\psi_R^+)^\dagger \; (\psi_R^0)^\dagger\right)^T$	1	2	$+1/2$	-1
$\Psi_L = (\psi_L^0 \; \psi_L^-)^T$	1	2	$-1/2$	-1
N	1	1	0	-1
S	1	1	0	-1



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

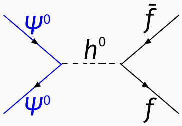
$$\mathcal{M}_{\psi^0} = \begin{pmatrix} M_N & -y\, c_\beta v/\sqrt{2} & y\, s_\beta v/\sqrt{2} \\ -y\, c_\beta v/\sqrt{2} & 0 & -M_D \\ y\, s_\beta v/\sqrt{2} & -M_D & 0 \end{pmatrix},$$



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

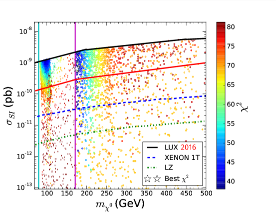
Singlet-doublet fermion dark matter: Higgs portal

Name	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L = (\nu_L\ e_L)^T$	1	2	$-1/2$	$+1$
$(e_R)^\dagger$	1	1	$+1$	$+1$
$(\hat{\Psi}_R)^\dagger = \left((\psi_R^+)^\dagger\ (\psi_R^0)^\dagger\right)^T$	1	2	$+1/2$	-1
$\Psi_L = (\psi_L^0\ \psi_L^-)^T$	1	2	$-1/2$	-1
N	1	1	0	-1
S	1	1	0	-1



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

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

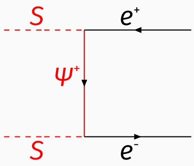


S. Horiuchi,

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

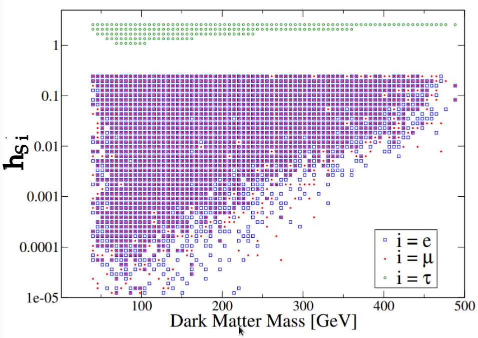
Scalar dark matter: vector-like fermion portal

Name	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L = (\nu_L\ e_L)^T$	1	2	$-1/2$	$+1$
$(e_R)^\dagger$	1	1	$+1$	$+1$
$(\psi_R^-)^\dagger$	1	1	$+1$	-1
ψ_L^-	1	1	-1	-1
S	1	1	0	-1



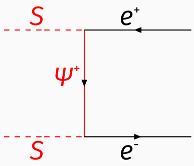
$$\mathcal{L} = M_\psi \left[(\psi_R^-)^\dagger \psi_L^- + (\psi_L^-)^\dagger \psi_R^- \right] + \\ + h_S \left[S\, (e_R)^\dagger \psi_R^- + S\, (\psi_L^-)^\dagger e_L \right]$$

Klasen, Lamprea, Yaguna arXiv:1602.05137



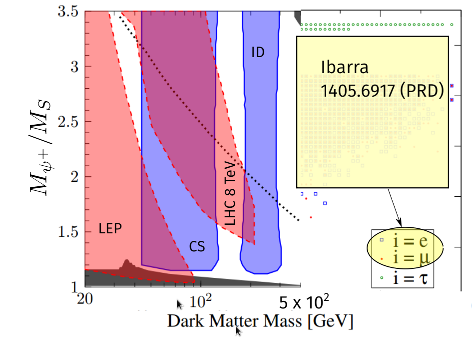
Scalar dark matter: vector-like fermion portal

Name	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L = (\nu_L \; e_L)^T$	1	2	$-1/2$	$+1$
$(e_R)^\dagger$	1	1	$+1$	$+1$
$(\psi_R^-)^\dagger$	1	1	$+1$	-1
ψ_L^-	1	1	-1	-1
S	1	1	0	-1



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

Klasen, Lamprea, Yaguna arXiv:1602.05137



Origin of the Z_2

Z_2

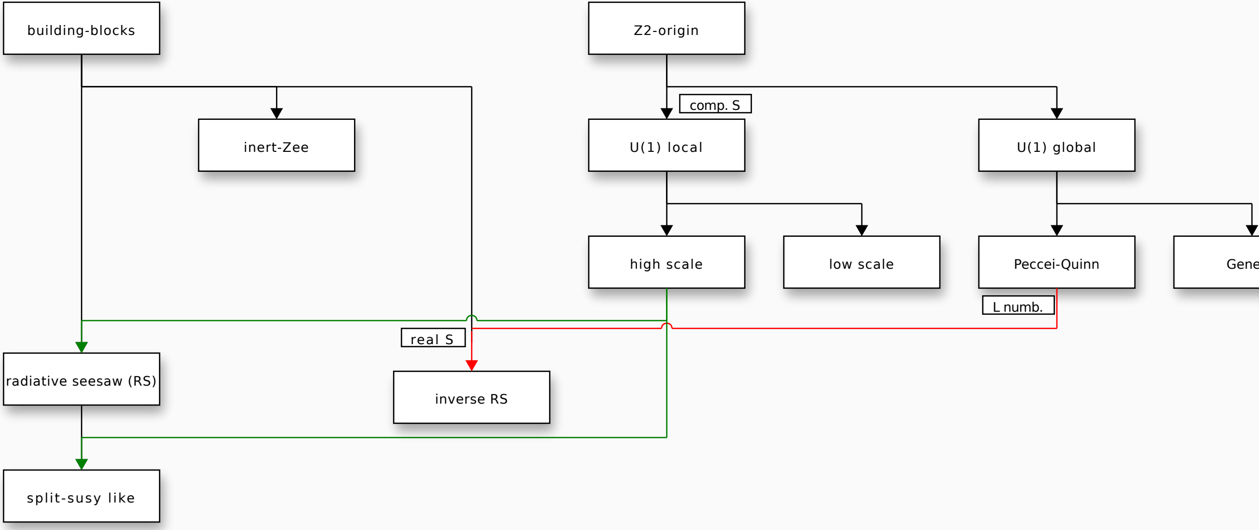
Origin of the Z_2

Z_2

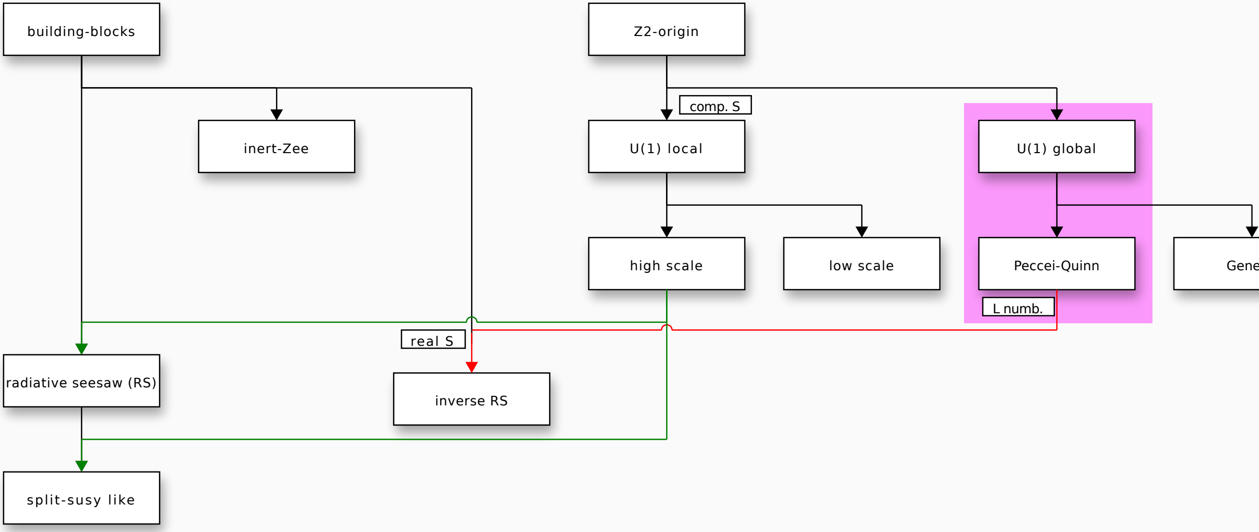
Globall symmetries safe for high multiplets:

Catà, Ibarra, Ingenhütt arXiv:1611.00725 (PRD), arXiv:1707.08480 (JCAP)

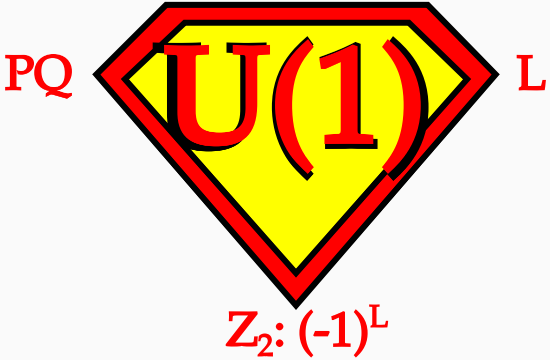
Origin of the Z_2



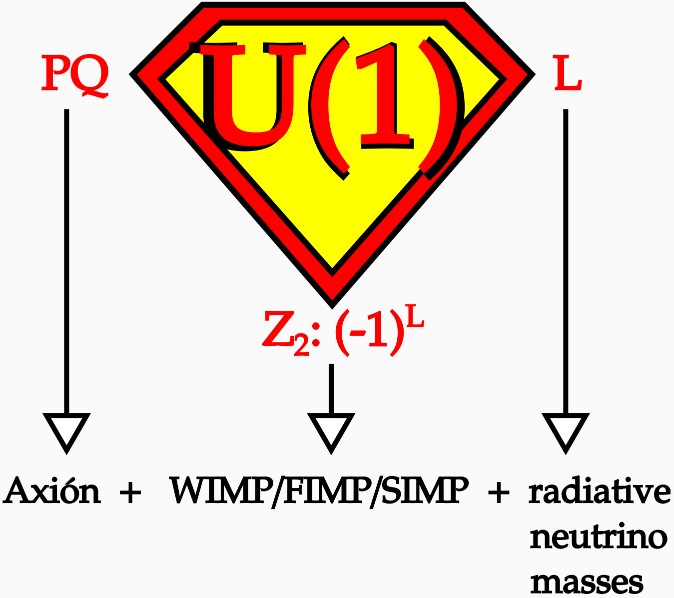
Origin of the Z_2




U(1)



PQ
U(1)
L
Z_2: $(-1)^L$


PQ
U(1)
L
Z_2: $(-1)^L$
Axión + WIMP/FIMP/SIMP + radiative neutrino masses

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

Name	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_L$
$L = (\nu_L \; e_L)^T$	1	2	$-1/2$	-1
$(e_R)^\dagger$	1	1	$+1$	$+1$
$(\hat{\Psi}_R)^\dagger = \left((\psi_R^+)^\dagger \; (\psi_R^0)^\dagger\right)^T$	1	2	$+1/2$	0
$\Psi_L = (\psi_L^0 \; \psi_L^-)^T$	1	2	$-1/2$	0
N	1	1	0	0
$S \in \mathbb{C}$	1	1	0	0

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

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

Name	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_L$
$L = (\nu_L\ e_L)^T$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	-1
$(e_R)^\dagger$	$\mathbf{1}$	$\mathbf{1}$	$+1$	$+1$
$(\hat{\Psi}_R)^\dagger = \left((\psi_R^+)^\dagger\ \ (\psi_R^0)^\dagger\right)^T$	$\mathbf{1}$	$\mathbf{2}$	$+1/2$	0
$\Psi_L = (\psi_L^0\ \psi_L^-)^T$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$	0
N	$\mathbf{1}$	$\mathbf{1}$	0	0
$S \in \mathbb{C}$	$\mathbf{1}$	$\mathbf{1}$	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	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Z_2
$L = (\nu_L \; e_L)^T$	**1**	**2**	$-1/2$	0
$(e_R)^\dagger$	**1**	**1**	$+1$	0
$(\hat{\Psi}_R)^\dagger = \left((\psi_R^+)^\dagger \;\; (\psi_R^0)^\dagger\right)^T$	**1**	**2**	$+1/2$	-1
$\Psi_L = (\psi_L^0 \; \psi_L^-)^T$	**1**	**2**	$-1/2$	-1
N	**1**	**1**	0	-1
$\mathrm{Re}(S)$	**1**	**1**	0	-1
$\mathrm{Im}(\sigma)$	**1**	**1**	0	0

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

Conclusions

Z_2 from global Peccei-Quinn symmetry:

- Mixed dark matter with Axion/WIMP or Axion/FIMP
- Lepton number violation controlled by splitting of real and imaginary parts of S.

Thanks!