Fermion Dark Matter from SO(10)

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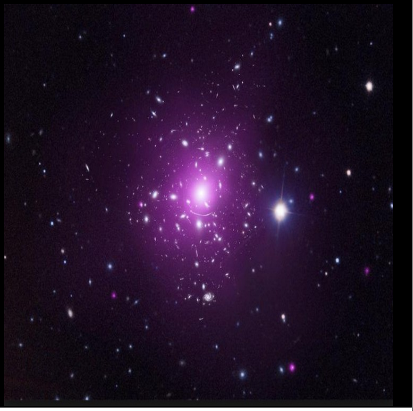

UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

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* **Analyze nonSUSY SO(10) SM extensions which explain fermionic DM through the Higgs Portal.**

* **Explore some DM scenarios from SO(10) LR theories.**

Part I. Introduction and Motivation

..... knowns about Dark Matter

A viable DM candidate should not only reproduce the observed abundance but also:

* Neutral,
* Emits little or no photons,
* OK with search limits,
* Stable.

It's decay life time has to be larger than the age of the universe.

T. Hambye 09'

$$\boxed{\tau_{\rm DM} \gtrsim 10^{26}\,{\rm s}}$$

Very stable!

How to stabilize DM?

A new preserved symmetry. A straightforward solution is to impose a parity by hand.
However, more motivated mechanisms have been proposed, where the stability would be:

* accidental, Cirelli et al. 05'
* due to a new (unbroken) gauge group, Ackerman et al. 08' , Foot et al. 06'-10', Pospelov et al. 07'.
* remnant from a flavour symmetry, Hirsch et al. 010', SB. te al. 011'-012', Peinado et al. 016'.
* Emerged naturally in the context of **SO(10) GUT** theories. Mohapatra 86'; Martin 92'; Frigerio-Hambye 09', Boucenna et. Al, 016', Garcia Cely et al, 016'.

Why SO(10) is promising?

SO(10) is a rank-5 group ➡ $\mathbf{SO(10) \supset U(1)_X}$

If $\mathbf{U(1)_X}$ spontaneously broken, then a Z_N symmetry is expected to be present even at low energies.

$$U(1) \xrightarrow{\phi} Z_N$$

In SO(10) this $\mathbf{U(1)_X}$ is identified with a $U(1)_{B-L}$ and the smallest irreps. with N >1 is the **126**

$$\boxed{U(1)_{B-L} \xrightarrow{<126>} Z_2 \equiv (-1)^{3(B-L)}}$$

SO(10) DM representations

	SO(10) reps.	DM candidate (SM)	Z2	
Fermions	10, 45, 54, 210 126 ...	(1,2,1/2) (1,1,0)+(1,3,0) (1,1,1/2)	+	Frigerio, Hambye 09' Kadastik, Kannike, Raidal 09'
Scalars	16, 144 ...	(1,1,0)	-	Mambrini et al. 15' Nagata et al. 15'

Scenarios

SDFDM: Singlet Doublet Fermion DM.

DTFDM: Doublet Triplet Fermion DM.

Higgs portal opened without additional scalar *d.o.f.*

Part II. The Model

Split SUSY-like model

A nonSUSY version of such as scenario involves the following particle content:

* A singlet Weyl fermion: $\mathbf{N}$, $\mathbf{Y = 0}$
* A $\mathbf{SU(2)_L}$ -triplet Weyl fermion: $\mathbf{\Sigma}$, $\mathbf{Y = 0}$
* A color octet Weyl fermion: $\mathbf{\Lambda}$, $\mathbf{Y = 0}$

$\mathbf{45_F}$

* Two $\mathbf{SU(2)_L}$ -doublet Weyl fermions: $\chi, \chi^{\mathbf{c}}$, $\mathbf{Y = \pm 1/2}$, $\mathbf{10_F}$

The DM particle is a mixture of all the **colorless fermions,** $\mathbf{P_M}$ -even.

Scenarios:

SDFDM: Singlet Doublet Fermion DM.

DTFDM: Doublet Triplet Fermion DM.

The SO(10) breaking $\mathbf{SO(10) \to SU(5) \times U(1)_X \to SM}$ leads to a effective DM Yukawa Lagrangian:

$$\mathcal{L}_{eff} = M_D \chi^c \chi - \frac{1}{2} M_N N N - \frac{1}{2} M_\Sigma \Sigma\Sigma$$
$$- y_1 H \chi^c N - y_2 \tilde{H} \chi N + f_1 H \epsilon \Sigma \chi^c - f_2 \tilde{H} \epsilon \Sigma \chi + \text{h.c.}$$

The opening of the Higgs portal through the new couplings allows to construct scenarios of SDFDM-DTFDM with a neutralino-like mix. matrix.

Spectrum: $\psi^{\mathbf{0}} = (\mathbf{N}, \mathbf{\Sigma}, \chi^{\mathbf{c0}}, \chi^{\mathbf{0}})^{\mathbf{T}}$, $\psi^+ = (\mathbf{\Sigma}^+, \chi^+)^{\mathbf{T}}$ and $\psi^+ = (\mathbf{\Sigma}^-, \chi^{\mathbf{c}-})^{\mathbf{T}}$

$$\mathcal{M}_{\psi^0} = \begin{pmatrix} M_N & 0 & -y\cos\beta v/\sqrt{2} & y\sin\beta v/\sqrt{2} \\ 0 & M_\Sigma & f\cos\beta' v/\sqrt{2} & -f\sin\beta' v/\sqrt{2} \\ -y\cos\beta v/\sqrt{2} & f\cos\beta' v/\sqrt{2} & 0 & -M_D \\ y\sin\beta v/\sqrt{2} & -f\sin\beta' v/\sqrt{2} & -M_D & 0 \end{pmatrix}$$

Neutralino-like mass matrix

SUSY case:
$y = g'/\sqrt{2},\ f = g/\sqrt{2}$
$\tan\beta = \tan\beta'$

S.P.Martin 92 ';....

Benakli et al. 05' ;.... Carena et al. 05' ;...

Without the mixing terms:

- * Singlet DM would not couple with the SM $\rightarrow$ large relic abundance.
- * Doublet DM would be excluded due to the coupling to the Z gauge boson (large cross section).
- * Triplet DM: OK.

Realistic and promising solution of the DM puzzle.

Part III. SO(10) Gauge Coupling Unification and DM

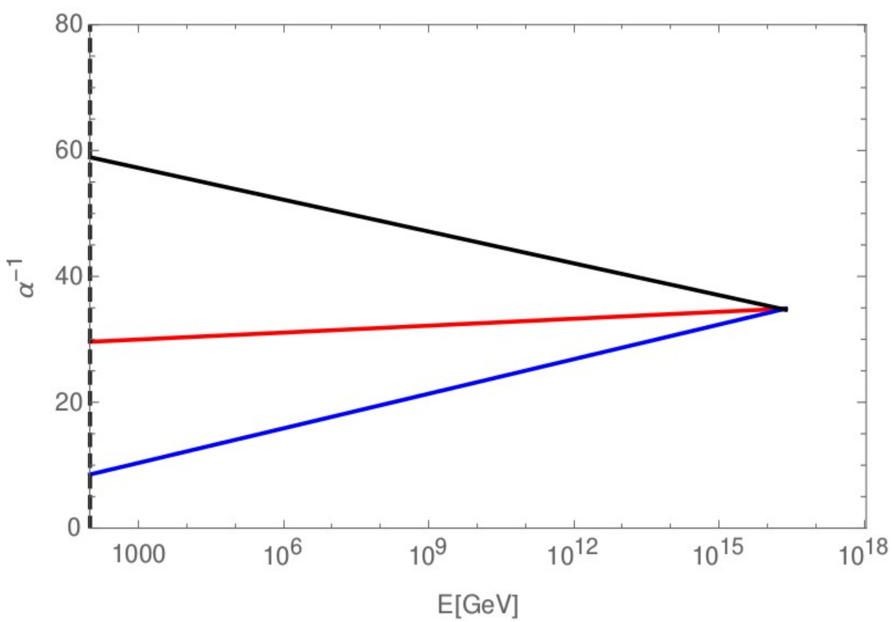
Gauge coupling unification

a. Symmetry breaking channel: $\mathbf{SO(10) \to SU(5) \times U(1)_X \to SM}$

Non SUSY model based on partial split-SUSY (PSS) spectrum:

$$\mathrm{SM}+\chi + \chi^{\mathbf{c}} + \mathbf{\Psi_{1,3,0}} + \mathbf{\Psi_{8,1,0}} + \mathbf{N} + \mathbf{\Phi_{1,2,1/2}}$$

$$\mathrm{SM}+\underbrace{\chi + \chi^{\mathbf{c}} + \mathbf{\Sigma} + \mathbf{\Lambda} + \mathbf{N}}_{\text{PSS}} + \mathbf{\Phi_{1,2,1/2}}$$

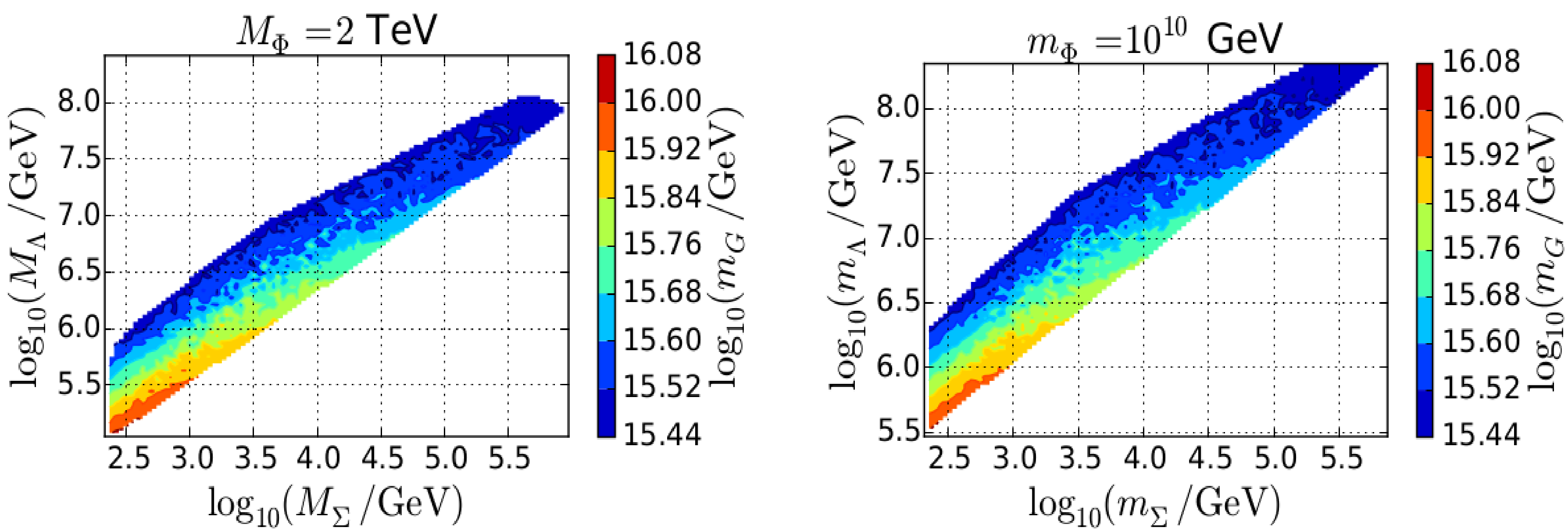


$\mathbf{m_{PSS} = 100}$ GeV and $\mathbf{m_G = 10^{16}}$.

Singlet Doublet Triplet: SDTFDM

Parameter space

* $3\times10^{15} \leq m_G \leq 10^{18}$ GeV , $100 \leq M_D, M_N \leq 3000$ GeV



SU(2)-triplet fermion mass as a function of the SU(3)-octet fermion mass for $M_\Phi = 2$ TeV and $M_\Phi = 10^{10}$ GeV.

* The lightest DM is checked to have the proper DM relic density
* Large unification scales are obtained from low values of M_Σ and M_Λ.
* $M_\Lambda \geq 100$ TeV for $M_\Phi = 2$ TeV and $M_\Lambda \geq 300$ TeV for $M_\Phi = 10^{10}$ GeV.

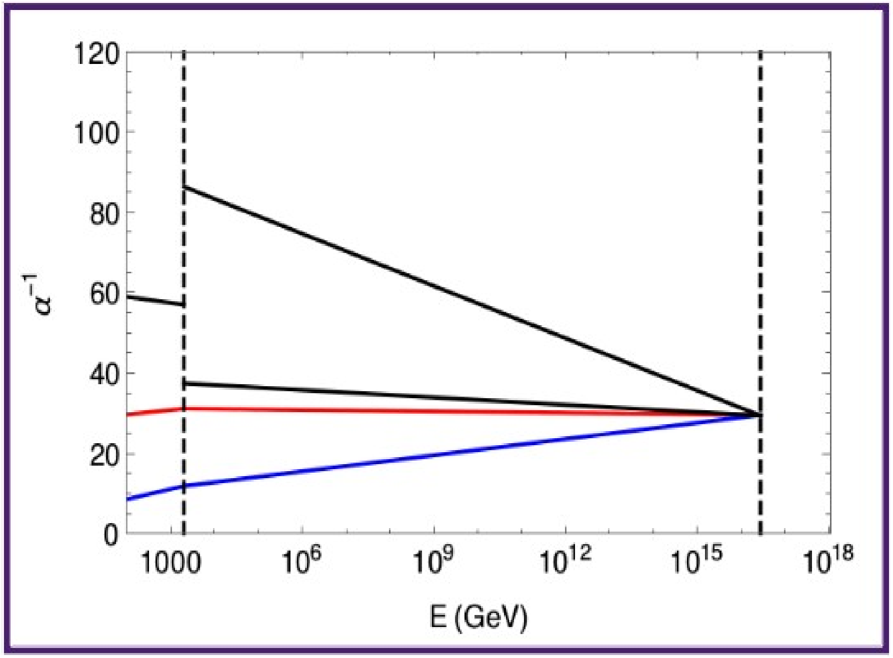
Left Right DM

b. Symmetry breaking channel:

$$\mathbf{SO(10) \to SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \xrightarrow{\Delta_R} SM} \qquad \Delta_R = \begin{pmatrix} \Delta_R^-/\sqrt{2} & \Delta_R^{--} \\ \Delta_R^0 & -\Delta_R^-/\sqrt{2} \end{pmatrix}$$

Non SUSY model based on a left-right symmetric model:

Field	Multiplicity	$3_c 2_L 2_R 1_{B-L}$	Spin	SO(10) origin
Q	3	$(3, 2, 1, +\frac{1}{3})$	1/2	16
Q^c	3	$(\bar{3}, 1, 2, -\frac{1}{3})$	1/2	16
L	3	$(1, 2, 1, -1)$	1/2	16
L^c	3	$(1, 1, 2, +1)$	1/2	16
Φ	1	$(1, 2, 2, 0)$	0	10
χ, χ^c	1	$(1, 2, 2, 0)$	1/2	10
N	1	$(1, 1, 1, 0)$	1/2	45



SDFDM

TFDM

I. $\Phi_{1,1,3,0} + \Phi_{8,1,1,0} + 2\Phi_{1,1,3,-2}$

II. $\Phi_{1,2,2,0}+\Phi_{1,1,3,-2}+\Psi_{1,1,3,-2}+\bar{\Psi}_{1,1,3,-2}+\Psi_{3,2,1,1/3}+\bar{\Psi}_{3,2,1,1/3}+\Psi_{8,1,1,0}+\Psi_{1,1,3,0}+\Psi_{1,3,1,0}$

Fermionic triplet DM

1. A vector-like DM candidate

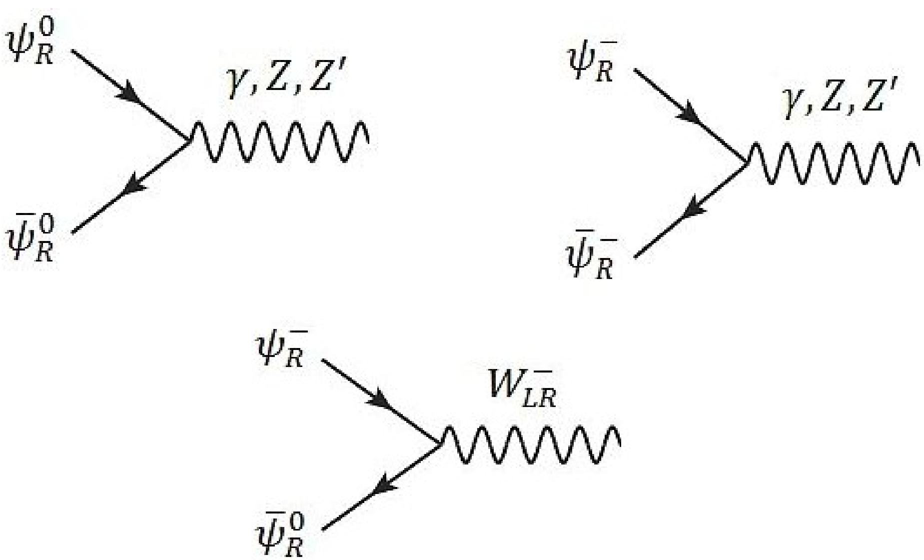
$$(1,1,3,-2)\oplus(1,1,\overline{3},2)=\Psi_R\oplus\overline{\Psi}_R \qquad \Psi_R=\begin{pmatrix}\Psi_R^-/\sqrt{2} & \Psi_R^{--}\\ \Psi_R^0 & -\Psi_R^-/\sqrt{2}\end{pmatrix}$$

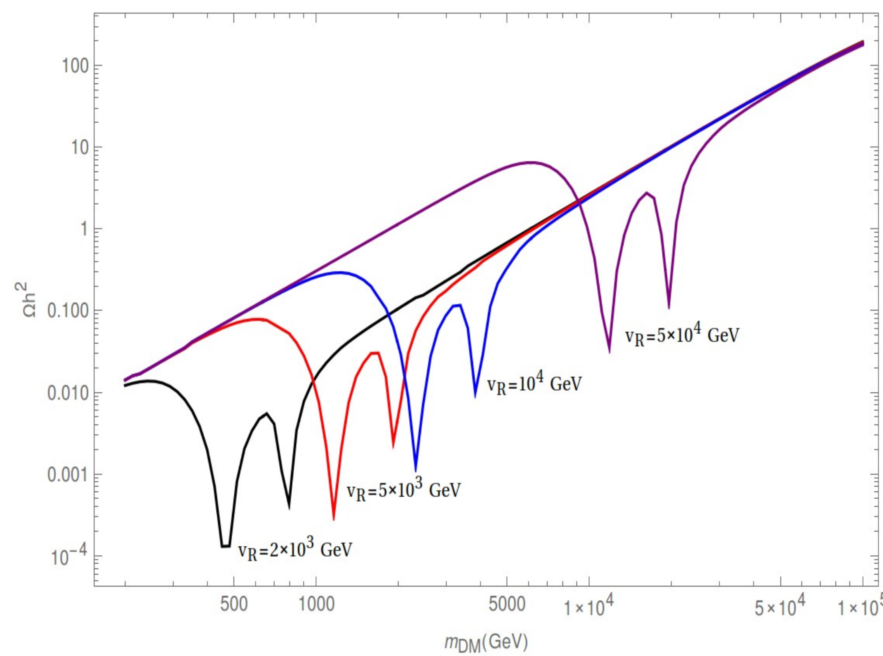
The only interaction term in the Lagrangian is their bare mass term:

$$L=\ldots\, M_{\Psi\overline{\Psi}}\Psi_R\overline{\Psi}_R$$

* Relic density

The only interactions affecting relic abundance are the gauge interactions.





Direct detection

* Numerical results of the spin-independent elastic DM-nucleon cross section.

* The LUX bounds on σ^{SI} significantly cuts the parameter space and allow for DM masses larger than about 1.7 TeV.

  D. S. Akerib et al. [LUX Collaboration]

  E. Aprile et al. [XENON100 Collaboration]

* MZR masses larger than about 6.4 TeV.

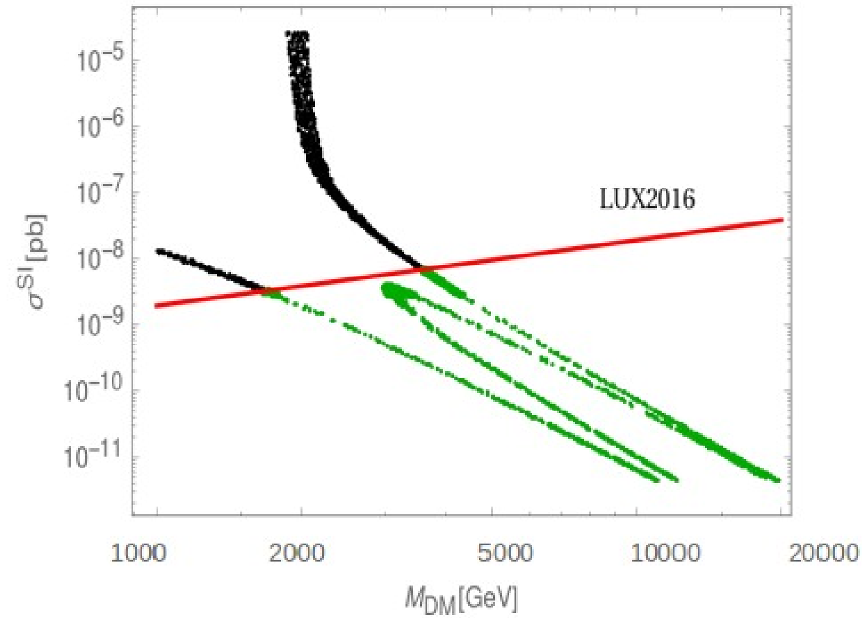
* We can rule out a large fraction of the parameter space.

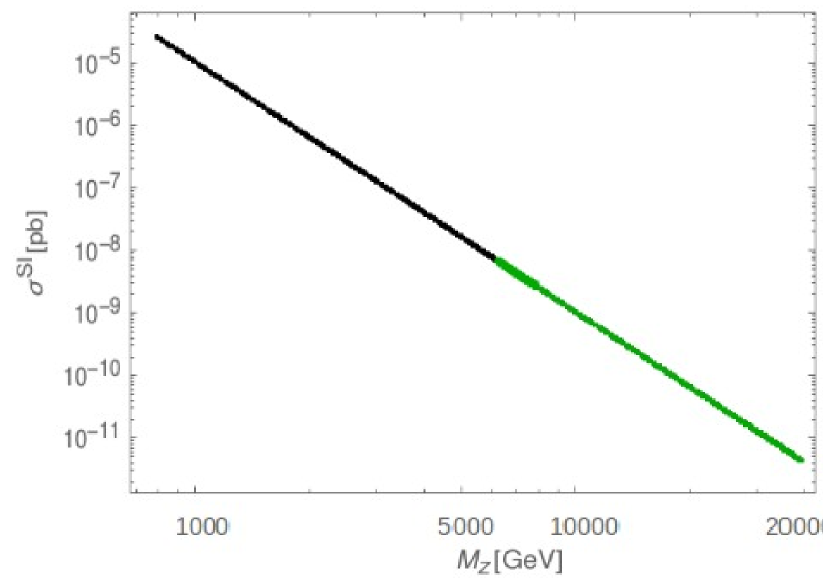
* Current bound on MZR > [2.6 - 3.5] TeV.

  [ATLAS Collaboration, CMS Collaboration]

The LHC doesn't see the ZR or the DM can not be explained.

$$\Omega_{DM} h^2 = 0.1187 \pm 0.0017$$





Work in progress....

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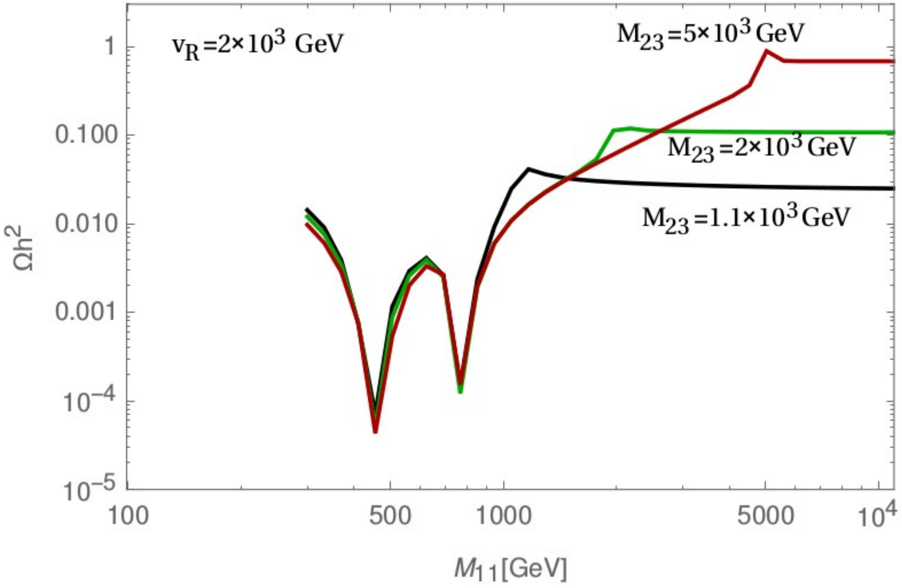
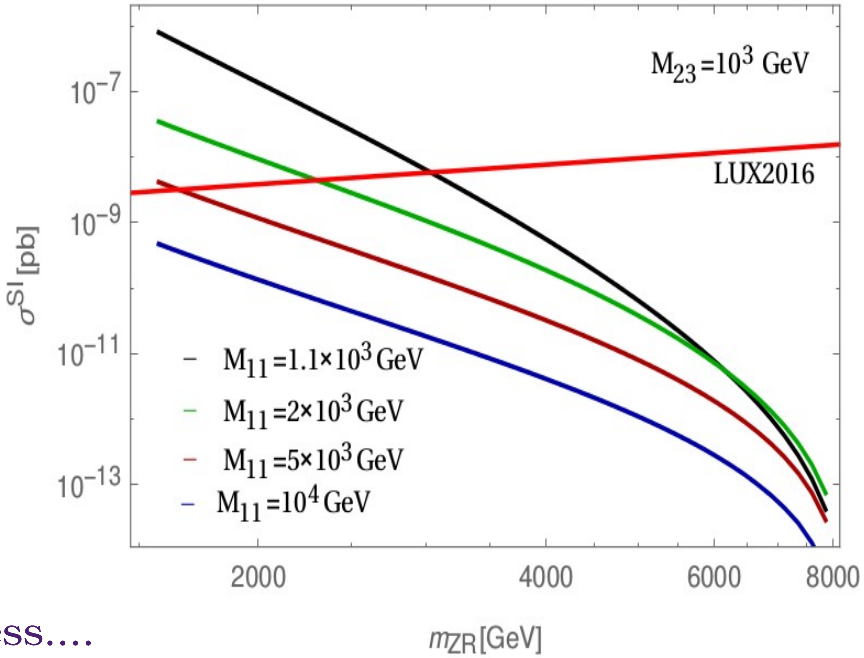
Mixed case

2. Adding the next triplet to our configuration:

$$(1,1,3,0) \oplus (1,1,3,-2) \oplus (1,1,\overline{3},2) = \Psi_1 \oplus \Psi_2 \oplus \Psi_3$$

$$L = \ldots\ M_{11}\Psi_1\Psi_1 + M_{23}\Psi_2\Psi_3 + \lambda_1\Delta_R\Psi_3\Psi_1 + \lambda_2\overline{\Delta_R}\Psi_2\Psi_1$$





Work in progress....

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Conclusions

* We construct and analyze simplified fermion DM models where the DM stability is naturally guaranteed by a Z2.

* The SDFDM and DTFDM are models where the Higgs portal is open without additional scalar degree of freedom.

* The connection between GCU and SO(10) LR DM scenarios was explored.

Thank you very much for your attention!!

Backup

Phenomenology

Higgs portal, with emphasis in couplings which depart from the SUSY limits. Freitas et al. 015' , Abe te al. 014'.

* SDFDM: When the DM candidate is mainly singlet (doublet) the relic density is in general rather large (small).

  Arkani-Hammed et al. 015' , Enberg et al. 07' , Restrepo et al. 015'.

* DTFM: In the low DM mass region, the relic density is properly satisfied in the range of: $0 \leq (M_D, M_\Sigma) \leq 400$ GeV and $0 \leq (f, f') \leq 1.5$.
  For the high DM mass region, a large value for the DM mass is required.

  Dedes et al. 014' , Freitas et al. 015' , Abe et al. 14'.

* When the doublet is decoupled, the triplet fermion DM model is recovered with a mass of ~2.7 GeV. to explain the correct relic abundance. Fornego et al. 06'.

$$\mathcal{L}^{\text{mass}}_{\mathbf{10}_F+\mathbf{45}_F} = \mathbf{10}_F\left(M_{\mathbf{10}_F} + h'_e\langle\mathbf{54}_H\rangle\right)\mathbf{10}_F + \mathbf{45}_F\left(M_{\mathbf{45}_F} + h_e\langle\mathbf{54}_H\rangle + h_p\langle\mathbf{210}_H\rangle\right)\mathbf{45}_F\,.$$

Since $\mathbf{210}_H$ have three singlets, while $\mathbf{54}_H$ has only one, the full set of masses are

$$\begin{aligned}
m(1,2,1/2) &= M_{\mathbf{10}_F} + \frac{3h'_e}{2}\langle\mathbf{54}_H\rangle\,,\\
m(3,1,-1/3) &= M_{\mathbf{10}_F} - h'_e\langle\mathbf{54}_H\rangle\,,\\
m(3,1,2/3) &= M_{\mathbf{45}_F} + \sqrt{2}h_p\frac{\langle\mathbf{210}_H\rangle_2}{3} - 2h_e\frac{\langle\mathbf{54}_H\rangle}{\sqrt{15}}\,,\\
m(3,2,1/6) &= M_{\mathbf{45}_F} + h_p\frac{\langle\mathbf{210}_H\rangle_3}{3} + h_e\frac{\langle\mathbf{54}_H\rangle}{2\sqrt{15}}\,,\\
m(3,2,-5/6) &= M_{\mathbf{45}_F} - h_p\frac{\langle\mathbf{210}_H\rangle_3}{3} + h_e\frac{\langle\mathbf{54}_H\rangle}{2\sqrt{15}}\,,\\
m(1,1,0) = m(1,1,1) &= M_{\mathbf{45}_F} + \sqrt{2/3}h_p\langle\mathbf{210}_H\rangle_1 + \sqrt{3/5}h_e\langle\mathbf{54}_H\rangle\,,\\
m'(1,1,0) &= M_{\mathbf{45}_F} + \frac{2\sqrt{2}}{3}h_p\langle\mathbf{210}_H\rangle_2 - \frac{2}{\sqrt{15}}h_e\langle\mathbf{54}_H\rangle\,,\\
m(8,1,0) &= M_{\mathbf{45}_F} - \frac{\sqrt{2}}{3}h_p\langle\mathbf{210}_H\rangle_2 - \frac{2}{\sqrt{15}}h_e\langle\mathbf{54}_H\rangle\,,\\
m(1,3,0) &= M_{\mathbf{45}_F} - \sqrt{\frac{2}{3}}h_p\langle\mathbf{210}_H\rangle_1 + \sqrt{\frac{3}{5}}h_e\langle\mathbf{54}_H\rangle\,.
\end{aligned}$$

Solving in terms of $M_D = m(1,2,1/2)$, $M_\Lambda = m(8,1,0)$, $M_\Sigma = m(1,3,0)$, and M_N $m'(1,1,0)$, we have that all the other masses are of order $M_{\mathbf{10}_F}$, $M_{\mathbf{45}_F} \sim m_G$, except for

$$M_T = m(3,1,2/3) = \left(M_\Lambda + 2M_N\right)/3\,.$$

* In the basis $(\tilde{B}', \tilde{W}'^0, \tilde{H}_d'^0, \tilde{H}_u'^0)$ the neutralino mass matrix is

$$\mathcal{M}_{\chi^0} = \begin{pmatrix} m_{\tilde{B}'} & 0 & \varepsilon^2 M_Z & \varepsilon^2 M_Z \\ 0 & m_{\tilde{W}'} & \varepsilon^2 M_Z & \varepsilon^2 M_Z \\ \varepsilon^2 M_Z & \varepsilon^2 M_Z & 0 & -\mu \\ \varepsilon^2 M_Z & \varepsilon^2 M_Z & -\mu & 0 \end{pmatrix} .$$

Charged mixing matrix

$$\mathcal{M}_{\psi^\pm} = \begin{pmatrix} M_\Sigma & f \sin \beta' v \\ f \cos \beta' v & M_D \end{pmatrix} .$$

LR Configurations

m_{LR} (GeV)	LR configuration	m_G (GeV)
2×10^3	$\Phi_{1,1,3,0} + \Phi_{8,1,1,0} + 2\Phi_{1,1,3,-2}$	2.47×10^{17}
	$3\Phi_{1,1,3,0} + \Phi_{1,2,2,0} + \Phi_{8,1,1,0} + 2\Phi_{1,1,3,-2}$	1.65×10^{16}
	$\Phi_{1,1,3,0} + 3\Phi_{3,1,1,4/3} + 2\Phi_{1,1,3,-2}$	5.02×10^{15}
10^5	$\Phi_{1,1,3,0} + \Phi_{8,1,1,0} + 2\Phi_{1,1,3,-2}$	1.01×10^{17}
	$2\Phi_{1,1,3,0} + \Phi_{1,2,2,0} + \Phi_{8,1,1,0} + 2\Phi_{1,1,3,-2}$	1.01×10^{16}
	$\Phi_{1,1,3,0} + 3\Phi_{3,1,1,4/3} + 2\Phi_{1,1,3,-2}$	3.67×10^{15}
10^7	$\Phi_{1,1,3,0} + \Phi_{8,1,1,0} + 2\Phi_{1,1,3,-2}$	3.55×10^{16}
	$\Phi_{1,1,3,0} + \Phi_{1,2,2,0} + \Phi_{8,1,1,0} + 2\Phi_{1,1,3,-2}$	5.69×10^{15}
	$\Phi_{1,1,3,0} + 2\Phi_{3,1,1,-2/3} + 3\Phi_{3,1,1,4/3} + \Phi_{1,1,3,-2}$	5.69×10^{15}

Conclusions

* We construct and analyze simplified fermion DM models where the DM stability is naturally guaranteed by a Z2.

* Concretely we formulate viable SO(10) models capable of realizing at low energies the singlet-doublet-triplet fermion dark matter.

* At low energies the resulting particle spectrum resemble the Neutralino and Chargino sets of the MSSM, but the mixing term are not controlled by the gauge couplings.

* Gauge coupling unification and simple configurations arises in these kind of scenarios.

* The SDFDM and DTFDM are models where the Higgs portal is open without additional scalar degree of freedom.