Freeze in of fermionic dark matter through Flavon Portal

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Motivation: Why, Which, How

In spite of being very successful in explaining the electroweak scale phenomenon, Standard Model has its own limitations. Within this model framework, it fails to explain

- Neutrino mass
- Dark Matter Abundance
- Origin of fermion mass hierarchy and the list continues...

These facts provide strong motivation for going Beyond Standard Model(BSM).
In our model, we try to take care of two problems at a time

- Origin of fermion mass hierarchy
- Dark matter abundance

Finally, How? $\rightarrow$ Rest of the talk is our answer to that.

Model Description

- The gauge group of our model is $SM \otimes U(1)_{FN}$.
- The Standard Model particle spectrum is augmented by two particles
  - A complex scalar

$$S = \frac{1}{\sqrt{2}} \left(h_S + v_S + i A_S \right)$$

  - A Majorana fermion, χ
- Complex scalar creates the mass hierarchy in the quark sector and plays as the mother particle for dark matter.
- χ plays the role of stable dark matter.

Froggatt-Nielsen mechanism

- An introduction to Froggatt-Nielsen mechanism

$$\begin{aligned}\mathcal{L}_{\rm SM}^{\rm FN-Yuk} &= -y_{ij}^{(u)}\left(\frac{S}{\Lambda}\right)^{n_{ij}^u} Q_i H u_j^c - y_{ij}^{(d)}\left(\frac{S}{\Lambda}\right)^{n_{ij}^d} Q_i \tilde{H} d_j^c \\ & \quad -y_{ij}^{(e)}\left(\frac{S}{\Lambda}\right)^{n_{ij}^e} L_i \tilde{H} e_j^c + h.c.\end{aligned}$$

- Considering FN charge of S to be -1, we get

$$n_{ij}^d = a_{Q_i} + q_H + a_{d_j}, \;\; n_{ij}^u = a_{Q_i} - a_H + a_{u_j}$$

- The $U(1)_{FN}$ symmetry is broken when S acquires vev v_S

$$\frac{S}{\Lambda} \to \epsilon = \frac{\langle S \rangle}{\Lambda} = \frac{v_S}{\sqrt{2}\Lambda} \approx 0.225$$

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$$Y_{ij}^{(u)} = y_{ij}^{(u)} \epsilon^{n_{ij}^u}, \quad Y_{ij}^{(d)} = y_{ij}^{(d)} \epsilon^{n_{ij}^d}, \quad Y_{ij}^{(e)} = y_{ij}^{(e)} \epsilon^{n_{ij}^e} \; . \qquad (1)$$

Flavon scenario

- We have discussed flavour constraints for a scenario with charge assignment

$$\begin{pmatrix} a_{Q_1} & a_{Q_2} & a_{Q_3} \\ a_{u_1} & a_{u_2} & a_{u_3} \\ a_{d_1} & a_{d_2} & a_{d_3} \\ a_{L_1} & a_{L_2} & a_{L_3} \\ a_{e_1} & a_{e_2} & a_{e_3} \end{pmatrix} = \begin{pmatrix} 4 & 2 & 0 \\ 4 & 2 & 0 \\ 4 & 3 & 3 \\ 4 & 3 & 3 \\ 4 & 2 & 0 \end{pmatrix}$$

- It successfully produces the fermion mass hierarchy and CKM matrix.

Dark Matter Phenomenology

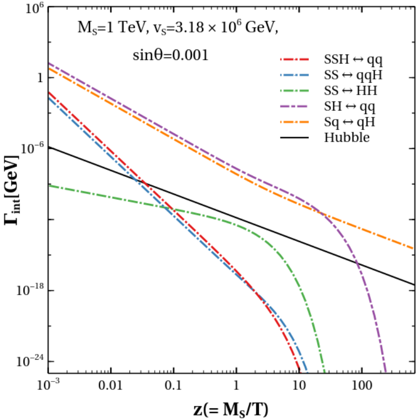
- We want a minimal model for dark matter and we chose a Majorana fermion as our candidate.
- The dark sector lagrangian looks like

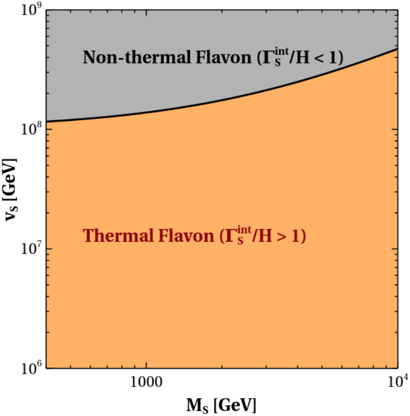
$$\mathcal{L}_{\rm DM} = \frac{1}{2}\overline{\chi}\Big(i\gamma^\mu\partial_\mu\Big)\chi - y_\chi\Big(\frac{S}{\Lambda}\Big)^{2n-1} S\bar{\chi^c}\chi + h.c \qquad (2)$$

where n is the $U(1)_{FN}$ charge of DM χ.

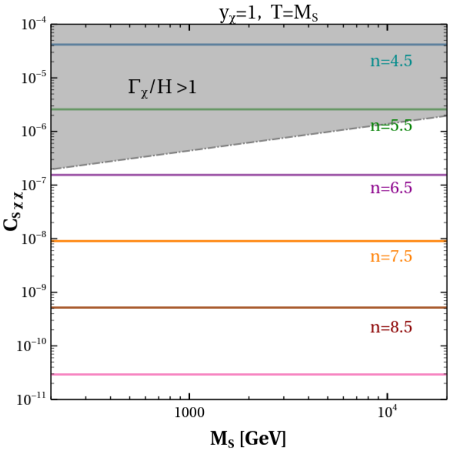
  - For n being half integer, the dark matter is stable.
  - For n being a little high, it can create freeze in coupling naturally.

Thermalisation of S





Condition for non-thermal DM candidate χ



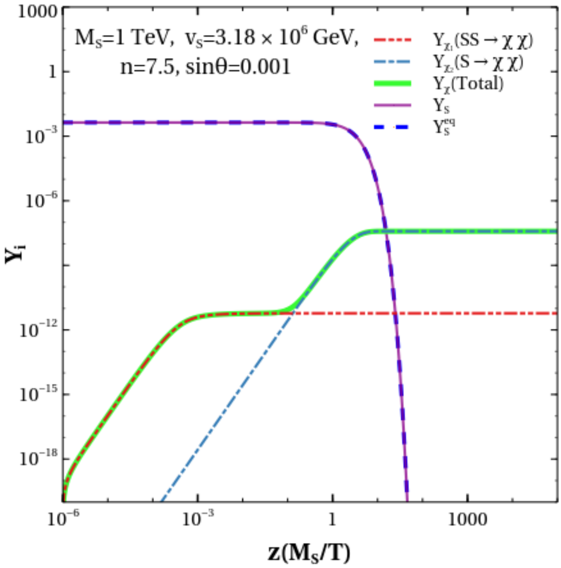
Dark Matter Phenomenology

- By solving two coupled Boltzman equation of S and χ, we can calculate the relic abundance.

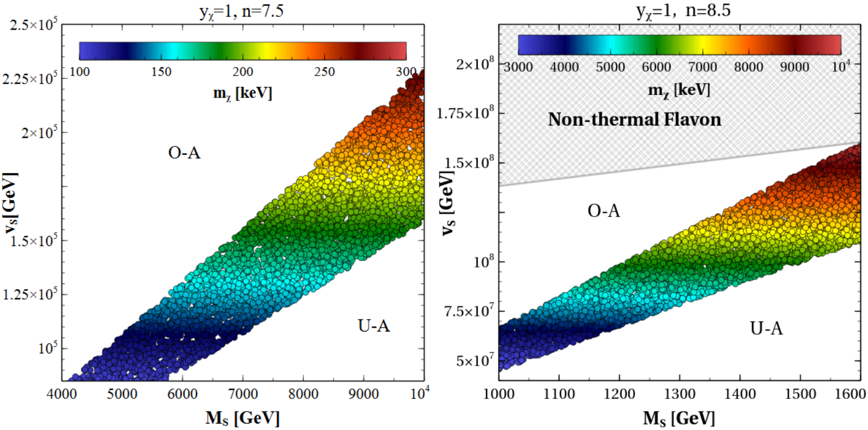
$$\begin{aligned}
\frac{dY_\chi}{dz} &= \frac{\langle\Gamma(S\to\chi\chi)\rangle}{\mathcal{H}\ z} Y_{\rm S}(z) + \frac{4\pi^2}{45}\frac{M_{Pl}M_S}{1.66}\frac{\sqrt{g_\star(z)}}{z^2}\langle\sigma v_{\rm S\,S\to\chi\,\chi}\rangle\, Y_{\rm S}^2(z) \\
\frac{dY_S}{dz} &= -\frac{\langle\Gamma(S\to\chi\chi)\rangle}{\mathcal{H}\ z} Y_{\rm S}(z) - \frac{4\pi^2}{45}\frac{M_{Pl}M_S}{1.66}\frac{\sqrt{g_\star(z)}}{z^2}\langle\sigma v_{\rm S\,S\to\chi\,\chi}\rangle\, Y_{\rm S}^2(z)
\end{aligned}$$

$+$ Other interaction terms with Standard Model

Dark Matter Phenomenology



Dark Matter Abundance Case



Conclusion

- In this work, we have proposed a unified solution to the fermion mass hierarchy and a FIMP dark matter within a class of $U(1)_{\rm FN}$ extensions of the Standard Model.
- We have shown a preferred range for the DM mass, which is $(100 - 300)$ keV and $(3 - 10)$ MeV, corresponding to $n = 7.5$ and 8.5 respectively.
- We have done this analysis for the global case. Analysing a gauged $U(1)_{FN}$ scenario with a thermal dark sector can provide us some interesting phenomenology.

Thank You