# Dark matter phenomenology and Higgs vacuum stability in a Scotogenic extension of Inert Higgs Doublet Dark Matter Model

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by

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# Motivation

- The presence of Dark Matter (DM) has been confirmed by both astrophysicl and cosmological observations. However, the nature of its particle content is still unknown.
- In order to explain the particle nature of DM we must go for theories beyond SM and in this regard scalar extension of SM is of interest for addressing the problem of a viable candidate of DM.
- Further, the discovery of the Higgs boson with a mass of about $125 GeV$ at the LHC implies that the vacuum of the standard model is not stable.

## Objective 1

We consider a Scotogenic extension of Inert Higgs Doublet DM Model and check whether the DM candidate satisfy relic density contraints and recent experimental bounds from XENON1T.

## Objective 2

Also we study the vacuum instability in a Scotogenic extension of Inert Higgs Doublet Dark Matter Model.

# Model

In this model in addition to SM Higgs $\phi_1$ another scalar doublet $\phi_2$ is considered. In addition three copies of fermions $N_i, i = 1, 2, 3$ , apart from the SM particle content has been considered. We include additional discrete symmetry, $Z_2$ under which all SM-fields are even while field $\phi_2$ and $N_i$ are odd. The Yukawa lagrangian is

$$L_N = \bar{N}_i \partial\!\!\!/ N_i - \frac{m_{N_i}}{2} \bar{N}_i^c N_i + y_{i\alpha} \phi_2 \bar{N}_i l_\alpha + h.c \tag{1}$$

The scalar lagrangian is[1]

$$\begin{aligned} V \;=\; & m_{\phi_1}^2 \phi_1^\dagger \phi_1 + m_{\phi_2}^2 \phi_2^\dagger \phi_2 + \tfrac{\lambda_1}{2}(\phi_1^\dagger \phi_1)^2 + \tfrac{\lambda_2}{2}(\phi_2^\dagger \phi_2)^2 \\ & + \lambda_3 (\phi_1^\dagger \phi_1)(\phi_2^\dagger \phi_2) + \lambda_4 (\phi_1^\dagger \phi 2)(\phi_2^\dagger \phi_1) + \tfrac{\lambda_5}{2}[(\phi_1^\dagger \phi_2)^2 + h.c] \end{aligned} \tag{2}$$

After spontaneous symmetry the SM Higgs $\phi_1$ while the inert doublet $\phi_2$ is.

$$\phi_1 = \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}}(v+h) \end{pmatrix} \quad , \phi_2 = \begin{pmatrix} H^\pm \\ \frac{1}{\sqrt{2}}(H_0 + iA_0) \end{pmatrix} \tag{3}$$

[1] Ernest Ma, 2006

# Model

The vacuum expectation value (*vev*) of the neutral component of the doublet $\phi_1$ is denoted by $v$. The $h$ state corresponds to the physical SM Higgs-boson. The inert doublet consists of a neutral CP$-$even scalar $H_0$ , a pseudo-scalar $A_0$ , and a pair of charged scalars $H^{\pm}$. By minimising the potential $V$ we get the masses of different physical scalars including SM Higgs and inert particles as,

$$\begin{aligned} m_h^2 &= 2\lambda_1 v^2, \\ m_{H^\pm}^2 &= m_{\phi_2}^2 + \frac{\lambda_3}{2} v^2 \\ m_{H_0}^2 &= m_{\phi_2}^2 + \Lambda_L v^2 \\ m_{A_0}^2 &= m_{\phi_2}^2 + \Lambda_L^{'} v^2 \end{aligned} \quad (4)$$

where, $\Lambda_L = \frac{\lambda_3+\lambda_4+\lambda_5}{2}$ and $\Lambda_L^{'} = \frac{\lambda_3+\lambda_4-\lambda_5}{2}$.

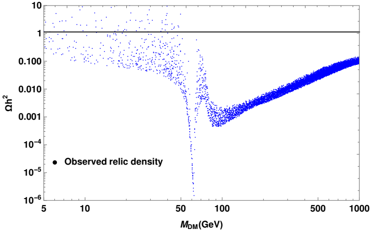


Fig. I: Variation of relic density with DM mass

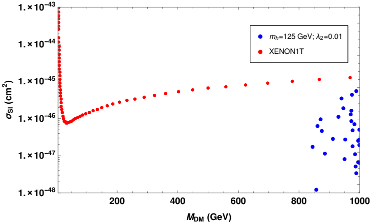


Fig. II: Spin-independent cross section vs mass plot

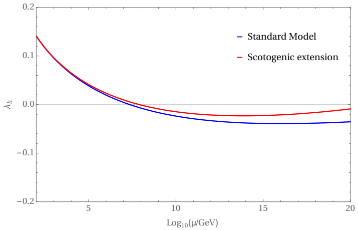


Fig. III: One loop running of the Higgs quartic coupling $\lambda_h$ as a function of the energy scale $\mu$

# Discussions

- We considered a scotogenic extension of SM with inert doublet model. The lightest of CP even scalar of the inert doublet is considered as the DM candidate.
- We also observe the possibility of generating correct relic abundance of dark matter which is consistent with the experimental bounds from XENON1T experiment.
- We also studied the role of the new scalars in the stability of the EW vacuum by performing an RG analysis for the Higgs quartic coupling. We found that with respect to the SM case, the additional scalars enhance the vacuum stability scale to $\sim 10^8 GeV$ and makes $\lambda_h > 0$ near the Planck scale.

## Conclusions

To conclude, we studied the possibility of enhancement of stability of vacuum due to scotogenic extension of SM with inert doublet fields, which also can explain correct DM relic density. The DM candidates in the mass range could be probed in higher sensitivity experiments like XENON1T in future. Further detailed analysis is in progress.