Dark Matter Phenomenology in 2HDM+complex singlet models

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THDM Working group report (ongoing)

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Motivation and aim

- Extensions of the 2HDM with a complex singlet are motivated from baryogenesis, gravitational waves, dark matter and inflationary point of view.
- Such a complex singlet may give rise to a two-component dark matter scenario.
- We study the prospects of dark matter in the context of 2HDM+ complex singlet. (ongoing)

Scalar Potential

- We consider a softly broken Z_2 symmetric (for the 2HDM part) and Z_2' symmetric singlet potential.
- The quantum numbers of the particles are

Particles	Z_2	Z_2'
Φ_1	$+1$	$+1$
Φ_2	-1	$+1$
S	$+1$	-1

Table: The quantum numbers of the Higgs doublets and singlet under $Z_2 \times Z_2'$.

- The scalar potential $\mathcal{V}_{THDMCS}$ (JHEP12 (2018) 044, (S.Baum,N.Shah)),

$$\mathcal{V}_{THDMCS} = \mathcal{V}_{2HDM} + \mathcal{V}_S + \mathcal{V}_{HS} \tag{1}$$

$$\mathcal{V}_{2HDM} = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - (m_{12}^2\Phi_1^\dagger\Phi_2 + h.c) + \frac{\lambda_1}{2}(\Phi_1^\dagger\Phi_1)^2$$

$$+\frac{\lambda_2}{2}(\Phi_2^\dagger\Phi_2)^2+\lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2)+\lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1)+[\frac{\lambda_5}{2}(\Phi_1^\dagger\Phi_2)^2+h.c$$

$$\begin{aligned}\mathcal{V}_S = m_S^2 S^\dagger S + (\frac{m_S'^2}{2}S^2 + h.c) + (\frac{\lambda_1''}{24}S^4 + h.c) + \frac{\lambda_2''}{6}(S^2(S^\dagger S) \\ + h.c) + \frac{\lambda_3''}{4}(S^\dagger S)^2\end{aligned} \tag{2}$$

$$V_{HS} = [S^\dagger S(\lambda_1'\Phi_1^\dagger\Phi_1 + \lambda_2'\Phi_2^\dagger\Phi_2)] + [S^2(\lambda_4'\Phi_1^\dagger\Phi_1 + \lambda_5'\Phi_2^\dagger\Phi_2) + h.c] \tag{3}$$

Parameters of the model:

$$m_{11}^2, m_{22}^2, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, m_{12}^2, \lambda_1', \lambda_2', \lambda_4', \lambda_5', \lambda_1'', \lambda_2'', \lambda_3'', \tan\beta, m_S^2, m_S'^2$$

- Minimisation conditions constrain two of the parameters m_{11}^2, m_{22}^2

$$m_{11}^2 = m_{12}^2 \frac{v_2}{v_1} - \lambda_1 \frac{v_1^2}{2} - \lambda_{345} \frac{v_2^2}{2} \quad (4)$$

$$m_{22}^2 = m_{12}^2 \frac{v_1}{v_2} - \lambda_2 \frac{v_2^2}{2} - \lambda_{345} \frac{v_1^2}{2} \quad (5)$$

The mass of the dark matter S at tree-level is

$$m_\chi^2 = 2m_S^2 + 2m_S^{2\prime} + (\lambda_1' + 2\lambda_4')\frac{v_1^2}{2} + (\lambda_2' + 2\lambda_5')\frac{v_2^2}{2} \quad (6)$$

This leads to the following free parameters of the model:

$$\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, m_{12}^2, \lambda_1', \lambda_2', \lambda_4', \lambda_5', \lambda_1'', \lambda_2'', \lambda_3'', \tan\beta, m_S^2, m_S'^2$$

Work done

- Implemented the complex singlet model in SARAH.
- For simplification in computation of RGE's in the presence of multiple similar order terms, $\lambda_1'' = \lambda_2''$ assumed for simplification.
- Compared DM relic for a sample benchmark ($m_h = 93.4$ GeV, $m_{h2} = 164$ GeV, $m_A = 122.4$ GeV, $m_\chi = 100.5$ GeV) of complex and real singlet model obtained same relic density ($\Omega h^2 \simeq 2.6 \times 10^{-3}$).

Working on

- Setting up phenomenologically allowed benchmarks for the current scenario allowed by flavor, Higgs constraints, and collider constraints.
- Compare the DM properties in the real and complex singlet models
- Checking against the real singlet case using some benchmarks in JHEP 09 (2019) 004 (A.Dey,et.al)

Thank you!