2HDM+complex singlet and Inflation

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Motivation and aim

- Extensions of the 2HDM are motivated from baryogenesis, gravitational waves, dark matter and inflationary point of view.
- Inflation and 2HDM studied in Gong et.al.
- We extend their computation in the context of 2HDM+ complex singlet. (ongoing)

Most general 2HDM+ complex Singlet Lagrangian

$$\mathcal{V}_{THDMCS} = \mathcal{V}_{2HDM} + \mathcal{V}_S + \mathcal{V}_{HS} \quad (1)$$

where

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

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

$$\lambda_6(\Phi_1^\dagger \Phi_1)(\Phi_1^\dagger \Phi_2) + \lambda_7(\Phi_2^\dagger \Phi_2)(\Phi_1^\dagger \Phi_2) + h.c]$$

$$\mathcal{V}_S = (\zeta S + h.c) + m_S^2 S^\dagger S + (\frac{m'^2}{2} S^2 + h.c) + (\frac{\mu_{S1}}{6} S^3 + h.c) + (\frac{\mu_{S2}}{6} S S^\dagger S + h.c$$

$$+ (\frac{\lambda_1''}{24} S^4 + h.c) + (\frac{\lambda_2''}{6} S^2 S^\dagger S + h.c) + \frac{\lambda_3''}{4} (S^\dagger S)^2$$

$$+ [S(\mu_{11} \Phi_1^\dagger \Phi_1 + \mu_{22} \Phi_2^\dagger \Phi_2 + \mu_{12} \Phi_1^\dagger \Phi_2 + \mu_{21} \Phi_2^\dagger \Phi_1) + h.c]$$

$$V_{HS} = [S^\dagger S(\lambda_1' \Phi_1^\dagger \Phi_1 + \lambda_2' \Phi_2^\dagger \Phi_2 + (\lambda_3' \Phi_1^\dagger \Phi_2 + h.c)]$$

$$+ [S^2(\lambda_4' \Phi_1^\dagger \Phi_1 + \lambda_5' \Phi_2^\dagger \Phi_2 + \lambda_6' \Phi_1^\dagger \Phi_2 + \lambda_7' \Phi_2^\dagger \Phi_1) + h.c]$$

Imposing softly broken Z_2 symmetry would imply setting coefficients of terms $\propto (\Phi_1^\dagger \Phi_2) = 0$

$\implies \lambda_6, \lambda_7 = 0$ in V_{2HDM}

We retain these terms presently for the most general case now.

Calculations for inflationary conditions

Ref: Inflation and dark matter in IDM, (Gong et.al)

The Jordan frame potential: V transformed to the Einstein frame by introducing a Weyl Transformation:

$$\Omega^2 = 1 + 2\zeta_1|\Phi_1|^2 + 2\zeta_2|\Phi_2|^2 + 2\zeta_4|S|^2$$

where ζ_i are the non-minimal coupling of Φ_i and S to gravity. After the Weyl transformation, $V_E = \frac{V}{\Omega^4}$.

For working out the inflationary conditions,

$\Phi_1^T = \frac{1}{\sqrt{2}}(0 \quad h_1)^T$,
$\Phi_2^T = \frac{1}{\sqrt{2}}(0 \quad h_2 e^{i\theta_1})^T$ and
$S = \frac{1}{\sqrt{2}} S e^{i\theta_2}$

Working in the large field limit: $\zeta_1 h_1^2 + \zeta_2 h_2^2 + \zeta_4 S^2 >> 1$ as relevant for inflation and introducing the following parameterisation:

$\phi = \sqrt{\frac{3}{2}} log[1 + \zeta_1 h_1^2 + 2\zeta_2 h_2^2 + 2\zeta_4 S^2]$, $r_1 = \frac{h_2}{h_1}$, $r_2 = \frac{S}{h_1}$ and $r_3 = \frac{S}{h_2} = \frac{r_2}{r_1}$

Recall, $V_E = \frac{V}{\Omega^4} = \frac{V'_{2HDM}}{\Omega^4} + \frac{V'_S}{\Omega^4} + \frac{V'_{HS}}{\Omega^4}$ Using the parametrisation, where ignoring the mass terms,

$$V'_{2HDM} = \frac{1}{8}(\lambda_1 + \lambda_2 r_1^4 + 2r_1^2(\lambda_3 + \lambda_4) + 2r_1^2 \lambda_5 \cos 2\theta_1) + \frac{r_1}{2}(\lambda_6 + \lambda_7 r_1^2)\cos\theta_1$$

$$V'_{HS} = \frac{\lambda'_3}{4} r_1 r_2^2 \cos\theta_1 + \cos\theta_2[(\frac{\mu_{12}}{\sqrt{2}h_1})r_2) + \frac{\mu_{22}}{\sqrt{2}h_1} r_1^2 r_2 + \frac{\mu_{12}}{\sqrt{2}h_1} r_1 r_2] +$$

$$\cos 2\theta_2(\frac{\lambda'_4}{4} r_2^2 + \frac{\lambda'_5}{4} r_2^2 r_1^2 + \frac{\lambda'_6}{4} r_1 r_2^2) + \lambda'_7 r_2^2 r_1 \cos(2\theta_2 - \theta_1)$$

$$V'_S = \frac{\mu_{S1}}{6} S^3(\cos 3\theta_2) + \frac{\mu_{S_2}}{2\sqrt{2}} S^3 \cos\theta_2 + \frac{\lambda''_1}{48}\cos 4\theta_2 + \frac{\lambda'_2}{12} S^4 \cos\theta_2$$

(where the mass terms are ignored for large S limit and the tadpole term while ζS has been ignored by shift symmetry of S)

Currently obtaining the extrema of the potential to obtain the inflationary conditions keeping the most general case.

Few assumptions made:

Ignored terms like $\zeta_3 S^\dagger S \Phi_1^\dagger \Phi_1$ in the Weyl transformation Ω^2.

Thank you!