# “The General Singlet Extensions of the MSSM (GSEMSSM) model and some cosmological consequences”

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Dark Universe Workshop Early Universe Cosmology, Baryogenesis and Dark Matter

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Minimal Supersymetric Standard Model (MSSM)

$$
\begin{aligned}
W_{MSSM} &= W_{2RC}^{MSSM} + W_{3RC}^{MSSM} \\
W_{2RC}^{MSSM} &= \mu \left(\hat{H}_1 \hat{H}_2\right) \quad \left(\hat{H}_1 \hat{H}_2\right) \equiv \epsilon_{\alpha\beta} \hat{H}_1^{\alpha} \hat{H}_2^{\beta} \\
W_{3RC}^{MSSM} &= \sum_{i,j=1}^{3} \left[ f_{ij}^{l} \left(\hat{H}_1 \hat{L}_i\right) \hat{l}_j^c + f_{ij}^{d} \left(\hat{H}_1 \hat{Q}_i\right) \hat{d}_j^c \right. \\
&+ \left. f_{ij}^{u} \left(\hat{H}_2 \hat{Q}_i\right) \hat{u}_j^c \right]
\end{aligned}
$$

$$
\begin{aligned}
W_{2RV} &= \sum_{i=1}^{3} \mu_{0i} \left(\hat{L}_i \hat{H}_2\right) \\
W_{3RV} &= \sum_{i,j,k=1}^{3} \left[ \lambda_{ijk} \left(\hat{L}_i \hat{L}_j\right) \hat{l}_k^c + \lambda'_{ijk} \left(\hat{L}_i \hat{Q}_j\right) \hat{d}_k^c \right. \\
&+ \left. \lambda''_{ijk} \hat{u}_i^c \hat{d}_j^c \hat{d}_k^c \right]
\end{aligned}
$$

$$
\left(\hat{L}_i \hat{H}_2\right) \subset \left(L_i \tilde{H}_2\right) = l_i \tilde{h}_2^{+} - \nu_i \tilde{h}_2^{0}
$$

To get renormalizable interactions the super-potential has $[W] \leq 3$ it is because $\Phi_1 \Phi_2 \Phi_3 \Phi_4 \propto A_1 A_2 A_3 A_4$ and they are no renormalizable at two loops

The MSSM suffers from the $\mu$-problem why $\mu = \mathcal{O}(M_W)$

The Next to Minimal Supersymmetric
Standard Model (NMSSM)

new singlet superfieldfield

$$\widehat{S} \sim (\mathbf{1}, \mathbf{1}, 0)$$

its (vev)

$$\langle S \rangle \equiv \frac{x}{\sqrt{2}} \;\; x \simeq \mathcal{O}(v_1, v_2)$$

The fermionic field $\tilde{S}$ is known as singlino

$$W_{NMSSM} \;\; = \;\; W_3^{MSSM} + \lambda \left( \widehat{H}_1 \widehat{H}_2 \right) \widehat{S} - \frac{\kappa}{3} \left( \widehat{S} \right)^3$$

$$\mu \equiv \frac{\lambda x}{\sqrt{2}}$$

Scalar Potential at NMSSM

$$
\begin{aligned}
V^{NMSSM} &= M_{H_1}^2|H_1|^2 + M_{H_2}^2|H_2|^2 + M_S^2|S|^2 \\
&- \left[\lambda A_\lambda \left(H_1 H_2\right) S + \frac{(\kappa A_\kappa)}{3} (S)^3 + h.c.\right] \\
&+ \left(|H_1|^2 + |H_2|^2\right) |\lambda S|^2 \\
&+ \left|\lambda \left(H_1 H_2\right) S + \kappa S^2\right|^2 \\
&+ \frac{g^2}{8} \left(\bar{H}_1 \sigma^i H_1 + \bar{H}_2 \sigma^i H_2\right)^2 \\
&+ \frac{g'^2}{8} \left(\bar{H}_1 H_1 - \bar{H}_2 H_2\right)^2
\end{aligned}
$$

1-) $x \gg v_1, v_2$ with $\lambda$ and $\kappa$ fixed

2-) $x \gg v_1, v_2$ with $\lambda x$ and $\kappa x$ fixed

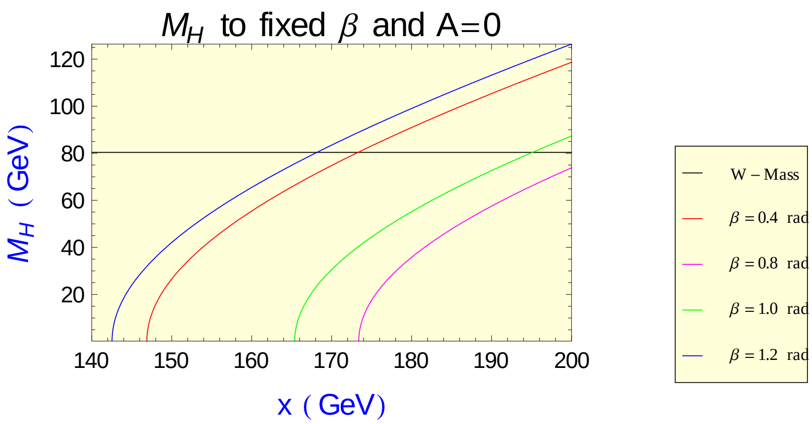
in the last limit the MSSM with two Higgs doublets and no Higgs singlets is obtained

Charged Boson

$$\left(M_{H^{\pm}}^{NMSSM}\right)^2 = M_W^2\left(1-\frac{2\lambda^2}{g}\right)+\frac{2\lambda x}{\sin(2\beta)}\left(A_\lambda+\kappa x\right)$$

$M_{H^{\pm}}^2$ may be less or greater than $M_W^2$

$$\lambda = 0.87 \quad \kappa = 0.63$$



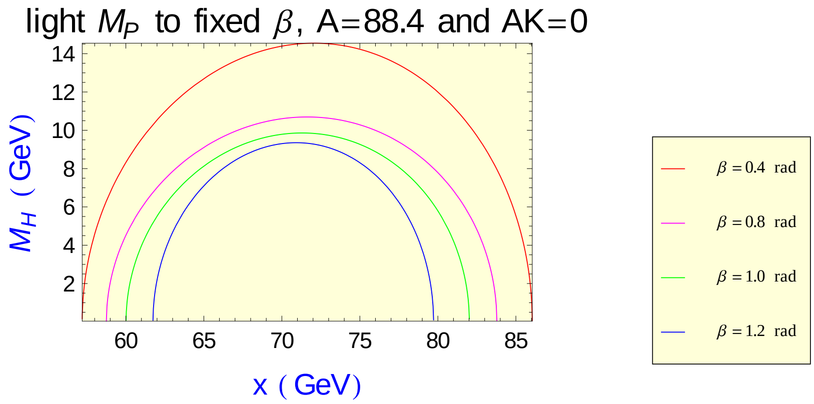
Pseudo Scalars

$$
\begin{aligned}
R &= \lambda A_\Sigma \frac{x v^2}{v_1 v_2} \\
S &= \lambda v \left( A_\Sigma - 3\kappa x \right) \\
T &= \lambda A_\Sigma \frac{v_1 v_2}{x} + 3\kappa A_\kappa x + 3\lambda\kappa v_1 v_2 \\
A_\Sigma &= A_\lambda + \kappa x \\
v &= \sqrt{v_1^2 + v_2^2}
\end{aligned}
$$

$\mathcal{M}^2_{CP-odd}$ $M^2_{P_1} < M^2_{P_2}$

$$
M^2_{P_1,P_2} = \frac{1}{2}\left[ (T+R) \mp \sqrt{(T-R)^2 + 4S^2} \right]
$$

very light pseudoscalars as required by cosmological analyses



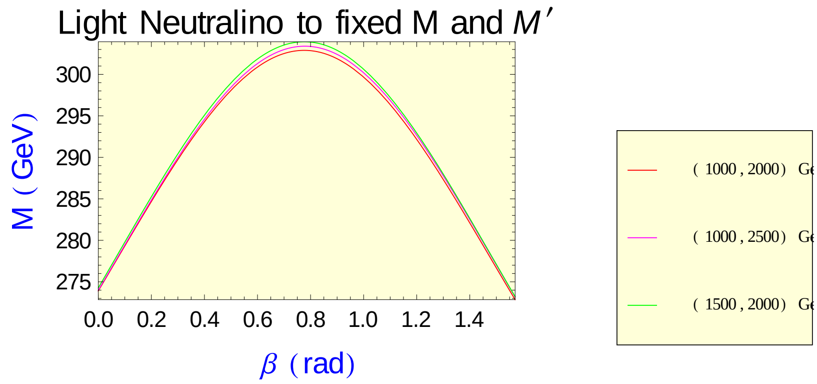
Neutralinos at NMSSM The mass matrix to neutralinos we can get the following results

1-) The singlino, $\tilde{S}$, does not mix directly with the gauginos

2-) The singlino, $\tilde{S}$, mix directly with the higgsinos $\tilde{H}_1^0$ and $\tilde{H}_2^0$

3-) If $|x| \gg v_{1,2}$ the singlino decouples from the other four neutralinos, wchich will be MSSM-like

4-) If $|\kappa|$ is very small this singlinolike state will become the LSP



## Some motivation to generalize NMSSM

The existence of a “light” chiral gauge singlet superfield in the observable sector can cause difficulties

1-) The stability of gauge hierarchy

2-) The superpotential of NMSSM possesses a discrete $\mathcal{Z}_3$ symmetry

General Singlet Extensions MSSM (GSEMSSM)

$$
\begin{aligned}
W_{GSEMSSM} &= \mu \left(\widehat{H}_1 \widehat{H}_2\right) + \lambda \left(\widehat{H}_1 \widehat{H}_2\right) \widehat{S} \\
&+ \left(\xi_F M_n^2\right) \widehat{S} + \frac{\mu_2}{2} \left(\widehat{S}\right)^2 + \frac{\kappa}{3} \left(\widehat{S}\right)^3 \\
&+ \sum_{i,j=1}^{3} \Big[ f^l_{ab} \left(\widehat{H}_1 \widehat{L}_a\right) \widehat{l}^c_b + f^d_{ij} \left(\widehat{H}_1 \widehat{Q}_i\right) \widehat{d}^c_j \\
&+ f^u_{ij} \left(\widehat{H}_2 \widehat{Q}_i\right) \widehat{u}^c_j \Big]
\end{aligned}
$$

If

$$\mu = \xi_F = \mu_2 = 0$$

Next-to-the-Minimal Supersymmetric Standard-Model (NMSSM)

$$\mu = \mu_2 = \kappa = 0$$

nearly Minimal Supersymmetric Model (nMSM)

$$
\begin{aligned}
M^2_{H^\pm} &= M^2_W \left(1 - \frac{2\lambda^2}{g^2}\right) - \frac{2C_1}{\sin(2\beta)} \\
M^2_{H^{PS}_{1,2}} &= \frac{1}{2}\left[-\frac{2C_1}{\sin(2\beta)} + C_2 \right. \\
&\pm \left. \sqrt{\left(\frac{2C_1}{\sin(2\beta)} + C_2\right)^2 + \frac{16 M^2_W}{g^2} C^2_3}\ \right]
\end{aligned}
$$

$$
M^2_{H^{PS}_1} \geq 0 \quad \to C_2 \geq 0
$$

- No absolute bound on the masses of the physical pseudoscalars can be given

- $H^{PS}_{1,2}$ can both be very light

upper bound on the mass of the lighest neutral scalar $H^0_1$

$$
M^2_{H^0_1} \leq M^2_Z \left[\cos^2(2\beta) + \frac{2\lambda^2 \cos^2\theta_W}{g^2} \sin^2(2\beta)\right]
$$

MSSM with 3 RHN superpotential

$$W = W^{LC}_{MSSM} + \sum_{i,j,k=1}^{3} \Big( f^{\nu}_{ij}\, \hat{H}_2\, \hat{L}_i\, \hat{\nu}^c_j + h^{\nu}_i \hat{H}_2 \hat{H}_1 \hat{\nu}^c_i$$
$$+ \frac{1}{2} M_{ij} \hat{\nu}^c_i \hat{\nu}^c_j + \frac{1}{3} \kappa_{ijk} \hat{\nu}^c_i \hat{\nu}^c_j \hat{\nu}^c_k \Big)$$

- Neutrino masses $f^{\nu} \leq 10^{-12}$
- Good Dark Matter sneutrinos
- Leptogenesis ( CP phases in sneutrino )
- Flat Direction ( Inflanton ) $\hat{H}_2 \hat{L} \hat{\nu}^c, \hat{H}_2 \hat{H}_1 \hat{\nu}^c$

$\mu\nu$SSM

sneutrinos acquire vev's

$$\mu \equiv h^{\nu}_i \langle \tilde{\nu}^c_i \rangle \quad \mu_{0i} \ll \mu$$
$$\mu_{0i} \equiv \sum_{j=1}^{3} f^{\nu}_{ij} \langle \tilde{\nu}^c_j \rangle \quad f^{\nu} \leq 10^{-6}$$

same results to upper bound light $H$ last page