Phenomenology of the NMSSM with Gauge Mediated Supersymmetry Breaking

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The NMSSM

The supersymmetric Higgsino mass term μ in the superpotential W of the MSSM is replaced by the VEV of an additional gauge singlet superfield S:

$$W_{MSSM} = \ldots + \mu H_u H_d \quad \longrightarrow \quad W_{NMSSM} = \ldots + \lambda S H_u H_d + \frac{\kappa}{3} S^3 \ (+ \ldots)$$

Soft Susy breaking terms: $\mu B H_u H_d \quad \longrightarrow \quad \lambda A_\lambda S H_u H_d + \frac{\kappa}{3} A_\kappa S^3 \ (+ \ldots)$

$\longrightarrow$ One additional neutral CP-even Higgs + CP-odd Higgs + neutralino from the singlet superfield S

If all Susy breaking terms are of O(M_{Susy}):

$$\langle S \rangle \sim M_{Susy}/\kappa \qquad \longrightarrow \qquad \mu_{\text{eff}} \equiv \lambda \langle S \rangle \sim \frac{\lambda}{\kappa} M_{Susy}$$

(Recall: $\mu_{\text{eff}} \gtrsim 100$ GeV is necessary in order to satisfy LEP constraints on chargino (= Higgsino/wino) masses;
$\mu_{\text{eff}} \lesssim M_{Susy}$ is required for $\langle H_u \rangle$, $\langle H_d \rangle \neq 0$)

Gauge Mediated Supersymmetry Breaking

— No soft Susy breaking terms for the fields of the (N)MSSM at tree level

— Messenger fields ϕ_i with mass M_{mess} exist,
a) whose CP-even and CP-odd scalar masses^2 are split by m^2
($\rightarrow$ "supersoft" Susy breaking)
b) which carry $SU(3) \times SU(2) \times U(1)_Y$ gauge quantum numbers
(typically: $\phi_i = 5 + \overline{5}$ under $SU(5)$)

Possible origins of the Susy breaking m^2:

— Dynamical Susy Breaking (non-perturbative) in a hidden sector containing Susy Yang-Mills + matter (Affleck, Dine, Seiberg, Nelson, Intriligator, Shih,. . .) + couplings of ϕ_i to the hidden sector
— O'Raifeartaigh models
— Giudice-Masiero terms for ϕ_i in the Kähler potential of No-scale Supergravity (U.E., '95)

Advantages w.r.t. (m)SUGRA:

— non-perturbative DSB explains $m \ll M_{Planck}$ via dimensional transmutation (see Λ_{QCD})
— Susy breaking is always flavour blind (see below)
— conflict between Susy breaking and vacuum stability in string-motivated Supergravity models easier to solve (?)

Generation of the soft Susy breaking terms for the fields of the (N)MSSM:

1) Since ϕ_i carry $SU(3) \times SU(2) \times U(1)_Y$ gauge quantum numbers: generation of gaugino masses at one loop:

$$M_{1,2,3} \sim \frac{m^2}{16\pi^2 M_{mess}} \equiv M_{Susy}$$

2) Scalar masses^2 at the two loop level:

$$m_i^2 \sim \left(\frac{m^2}{16\pi^2 M_{mess}}\right)^2 \sim M_{Susy}^2$$

3) That's it; no $\mu-$ or $B-$term of the MSSM!

Ways out:

A) Ignore the problem (most elegant!)
B) Couplings of H_u, H_d to the hidden sector
C) The NMSSM

BUT: If the soft Susy breaking terms for the singlet m_S^2, A_κ vanish (at the scale M_{mess}): $\to \langle S \rangle$ too small

Solution: Allow for couplings $\eta S \phi_i \phi_i$ of the singlet to the messengers (always allowed!)
$\to$ integrating out the messengers generates not only gaugino masses, but also m_S^2, $A_\lambda = \frac{1}{3} A_\kappa$, $\ldots +$ possibly terms linear in S in the superpotential $W \sim \xi_F S$ and in $V_{soft} \sim \xi_S S$, so-called "tadpoles".
(Tadpole terms always trigger $\langle S \rangle \neq 0$)

If allowed, the tadpole parameters ξ_F, ξ_S tend to be somewhat large:
Require $\xi_F \lesssim M_{Susy}^2$, $\quad \xi_S \lesssim M_{Susy}^3$, but:

$$\xi_F \sim \eta\ M_{mess}\ M_{Susy}, \quad \xi_S \sim 16\pi^2\ \eta\ M_{mess}\ M_{Susy}^2$$

(typically: $M_{mess} \gtrsim 10^3 \times M_{Susy}$) $\to$ need $\eta \lesssim 10^{-5}$

Tadpole terms can also be forbidden by discrete symmetries, if the messenger sector is enlarged to ϕ_1, $\overline{\phi}_1$, ϕ_2, $\overline{\phi}_2$ (Giudice, Rattazzi, Delgado, Slavich):

$$W = \eta\ S \overline{\phi}_1 \phi_2 + M_{mess}(\overline{\phi}_1 \phi_1 + \overline{\phi}_2 \phi_2) + \ldots$$

The analysis of generalized NMSSM models with general GMSB-like boundary conditions at M_{mess} will be possible with the help of a Fortran code on the web page

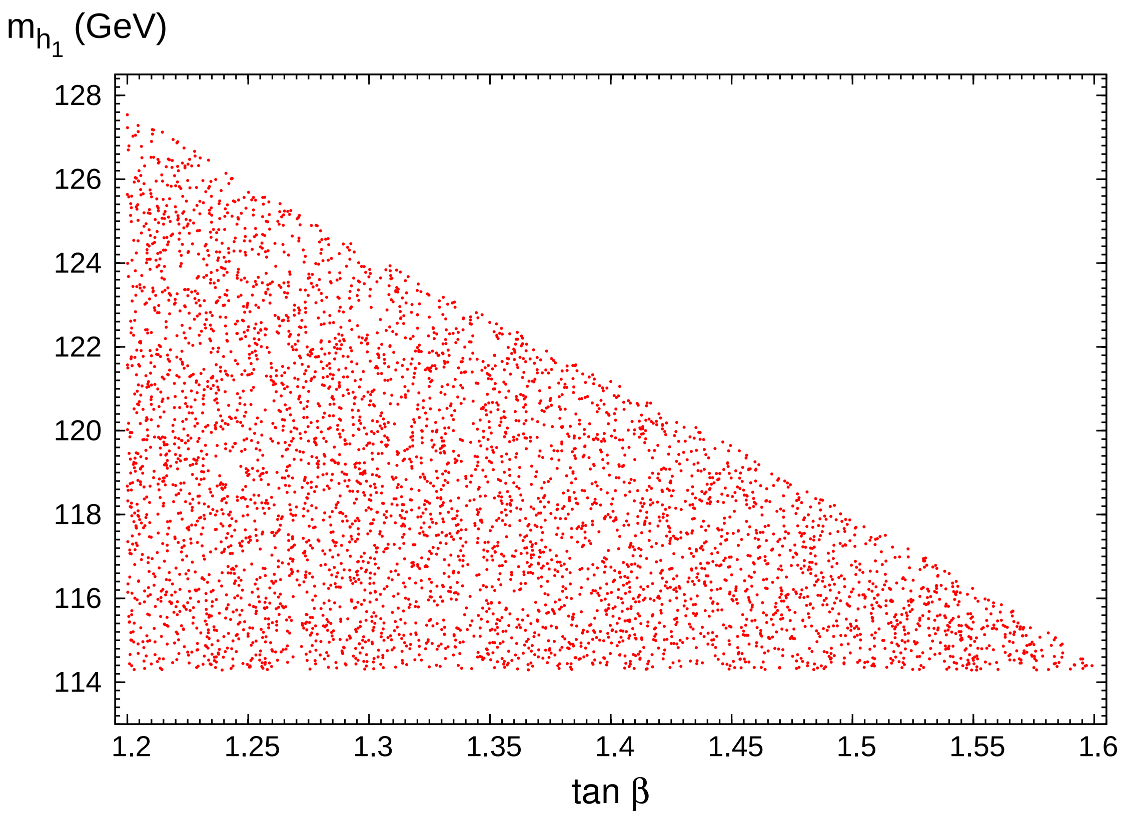
www.th.u-psud.fr/nmhdecay/nmssmtools.html

Input: M_{mess}, M_{Susy}, ($\rightarrow$ gaugino, sparticle masses), $\tan\beta$
λ, $A_\lambda = \frac{1}{3}A_\kappa$, ξ_F, ξ_S or m_S^2 ...

Output: κ, m_S^2 or ξ_S, Higgs- and sparticle spectrum, tests of exp. bounds from LEP, Tevatron, B-physics, $(g-2)_\mu$.

RESULTS

1) Scenarios with tadpole terms (the simplest model on the market!):
Phenomenologically viable, if $\lambda \gtrsim 0.5$, $\tan\beta \lesssim 2$
$\longrightarrow$ the NMSSM specific contribution to the scalar Higgs mass matrix pushes the lightest Higgs mass above the LEP bound:



$M_{mess} = 10^6$ GeV,
$M_{Susy} = 500$ GeV,
$\xi_F = 3 \cdot 10^4$ GeV^2,
$0.5 < \lambda < 0.6$

Bino, Winos, Sleptons:
$\sim$ 110-290 GeV
Squarks, Gluino:
$\sim$ 640-890 GeV
Additional Higgs states:
$\gtrsim 600$ GeV

2) Scenarios without tadpole terms (Delgado, Giudice, Slavich):

m_s^2 (< 0), A_κ, A_λ, $m_{H_u}^2$, $m_{H_d}^2$ calculable in terms of η and M_{Susy} (as before)

For $M_{mess} \sim 10^{13}$ GeV, $M_{Susy} \sim 1$ TeV:

viable regions (islands) in the parameter space
$\lambda = 0.02 \ldots 0.5$, $\eta = 0.05 \ldots 2$, $\tan\beta = 1.5 \ldots 10$

with

Bino, Winos, Sleptons $\sim$ 450 -1100 GeV
Squarks, Gluino $\sim$ 1.8 - 2.4 TeV (!)
Additional Higgs states: $\gtrsim$ 450 GeV

$\rightarrow$ top/stop rad. corrs. push the lightest Higgs mass above the LEP bound (but: hidden fine tuning)

3) Scenarios without tadpole terms and A_κ, $A_\lambda \sim 0$:

All soft terms for the singlet vanish at M_{mess} except for m_S^2

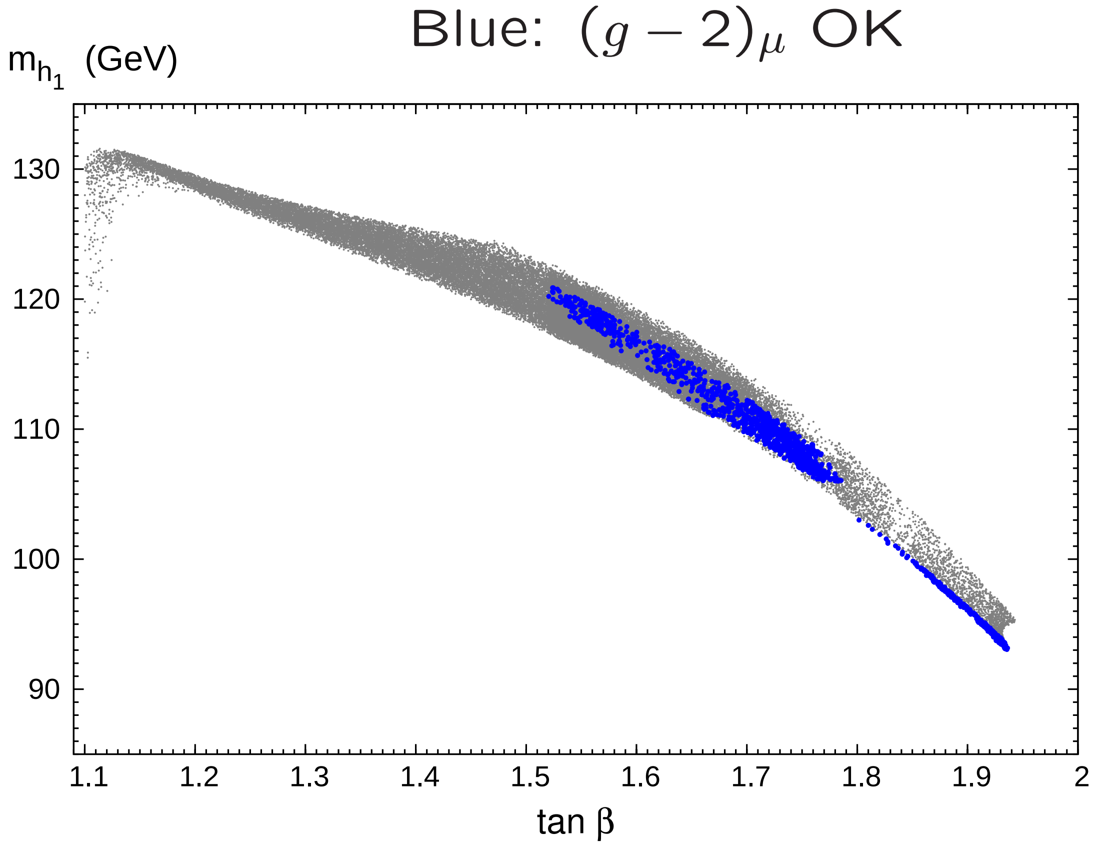
(A corresponding hidden sector remains to be constructed)

$\longrightarrow$ the scalar sector of the NMSSM has an R-symmetry (at M_{mess}), which is broken by radiative corrections to A_κ, A_λ induced by the gaugino mass terms

$\longrightarrow$ at the weak scale: the explicit R-symmetry breaking by A_λ, $A_\kappa \sim$ a few GeV is small (if M_{mess} is not too large)

$\longrightarrow$ the spontaneous R-symmetry breaking by $\langle H_u \rangle$, $\langle H_d \rangle$, $\langle S \rangle \neq 0$ generates a pseudo Goldstone Boson, a light CP-odd Higgs scalar a_1

$\longrightarrow$ the lightest Higgs scalar h_1 decays via $h_1 \to a_1 a_1$, escaping LEP constraints if $m_{h_1} \gtrsim 90$ GeV (depending on m_{a_1})



$\lambda = 0.6$

10^7 GeV $< M_{mess} < 5{\cdot}10^9$ GeV,

200 GeV $< M_{Susy} <$ 280 GeV,

Bino, Winos, Sleptons:

$\sim$ 100-200 GeV

Squarks, Gluino:

$\sim$ 450-600 GeV

$m_{a_1} \sim 1 - 50$ GeV $< m_{h_1}/2$

Additional Higgs states:

$>$ 500 GeV

Also possible:

$\lambda \sim 10^{-2}$, $\tan\beta \gtrsim 30$, $M_{Susy} \sim 500$ GeV,
h_1 with $m_{h_1} \sim 90 - 100$ GeV has a large singlet component,
the "SM"-like h_2 has $m_{h_2} \sim 120$ GeV
$m_{a_1} \sim 1$ GeV, but decoupled (since λ is small)
$\rightarrow$ Bino, Winos, Sleptons $\sim$ 200-400 GeV
Squarks, Gluino $\sim$ 850-1100 GeV
Additional Higgs states $\sim$ 600 GeV

Summary

The NMSSM allows to solve the μ-problem of GMSB models in a phenomenologically viable way, provided S couples to the messenger sector which induces soft Susy breaking terms for S.
Depending on the messenger sector, different scenarios can be realized implying different phenomenologies in the Higgs and sparticle sectors.
Possible are amongst others
— light CP-odd scalars (pseudo-Goldstone Bosons),
— light CP-even scalars with large singlet component.