ON EXTENDED GMSB MODELS*

Tomasz Jeliński

Institute of Physics, University of Silesia
Uniwersytecka 4, 40-007, Katowice, Poland
tomasz.jelinski@us.edu.pl

(Received October 24, 2013)

We discuss some features of unification models in which supersymmetry breaking is transmitted to the visible sector not only via gauge interactions but also by the Yukawa-type couplings of messengers. Examples of low-energy phenomenology of such models are presented.

DOI:10.5506/APhysPolB.44.2155
PACS numbers: 12.60.–i, 12.60.Jv, 11.30.Pb

1. Introduction

Minimal Supersymmetric Standard Model (MSSM) with softly broken supersymmetry (SUSY) is still widely considered as one of the best candidates for describing physics beyond the Standard Model. Since there is plenty of free parameters in the MSSM, one usually seeks some hints (*e.g.* in GUTs) which could help to set up the pattern of those parameters. The Higgs mass measurement in the LHC [1, 2] seems to shed some light on the structure of MSSM soft terms.

If the lightest Higgs mass m_{h^0} is about 125 GeV, then one gets the following constraint

$$(125\ \mathrm{GeV})^2 = m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2}\left[\ln\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right], \qquad (1)$$

where $M_S^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}$, $m_{\tilde{t}_{1,2}}$ are stops masses and $X_t = A_t - \mu/\tan\beta$. Here, A_t is top A-term, μ is the supersymmetric mass term of Higgses, while $\tan\beta = \left\langle H_u^0\right\rangle / \left\langle H_d^0\right\rangle$. It is known [3] that to satisfy (1) either stops masses have to be bigger than at least 5 TeV, or mixing between left and right stops

* Presented at the XXXVII International Conference of Theoretical Physics "Matter to the Deepest" Ustroń, Poland, September 1–6, 2013.

must be nearly 'maximal' *i.e.* $X_t \approx \pm\sqrt{6}M_S$ (the precise value depend on $\tan\beta$). In the standard GMSB model [4], A-terms are generated only radiatively and to realize the latter possibility one needs either messenger scale M bigger than 10^{14} GeV or gluino heavier than 4 TeV [3]. On the other hand, nonzero A-terms at the scale M can be naturally accommodated (even for M as low as 10^8 GeV) within the so-called extended GMSB models (see references in [5] and [6]). In such a framework messengers couple both to gauge fields and to matter fields via marginal superpotential couplings. Beside generating A-terms, those additional interactions also induce 2-loop corrections to soft masses. Recently, those models have attracted a lot of attention and were examined in various contexts. In the present paper, we generalize the results given in [6] deriving: *(i)* formulas for soft masses generated by marginal couplings of three messengers, and *(ii)* bounds on messengers couplings related to proton decay and μ/B_μ problem for arbitrary messenger representations.

2. Extended GMSB models

We consider a model in which supersymmetry breaking effects are parameterized by v.e.v. of spurion superfield[1] $\langle X\rangle = M + \theta^2 F$, while messenger sector consists of $\alpha = 1,\ldots,n$ chiral fields $(Y_\alpha, \overline{Y}_\alpha)$ in representations $(R_\alpha, \overline{R}_\alpha)$ of gauge group G. It is convenient to arrange them into one $2n$ component vector $\mathsf{Y} = (\mathsf{Y}_a) = (Y_1, \overline{Y}_1, \ldots, Y_n, \overline{Y}_n)$. All messengers get masses via the same coupling to the spurion X

$$W_X = X\mathsf{Y}_{2\alpha-1}\mathsf{Y}_{2\alpha}\,. \tag{2}$$

Such choice of spurion-messenger interactions is crucial for avoiding large negative 1-loop corrections to soft masses in the discussed class of models [7]. In the extended GMSB models, SUSY breaking effects are transmitted to the visible sector not only via gauge interactions but also through marginal superpotential couplings[2]

$$W_Y = \tfrac{1}{2}h_{ija}\Phi_i\Phi_j\mathsf{Y}_a + \tfrac{1}{2}h_{iab}\Phi_i\mathsf{Y}_a\mathsf{Y}_b + \tfrac{1}{6}\eta_{abc}\mathsf{Y}_a\mathsf{Y}_b\mathsf{Y}_c\,. \tag{3}$$

Finally, $\Phi_i \in \{H_u, H_d, Q, U, D, L, E\}$ are matter superfields interacting via standard Yukawa couplings

$$W_\Phi = \tfrac{1}{6}y_{ijk}\Phi_i\Phi_j\Phi_k\,. \tag{4}$$

[1] For simplicity, we assume that $F/M^2 \ll 1$.
[2] Gauge and flavour indices are suppressed.

Below messenger scale M, one gets MSSM with soft terms. Similarly to the GMSB case, here gauginos masses $M_\lambda^{(r)}$ also arise at 1-loop and at the leading order do not depend on marginal couplings of messengers (3). On the other hand, h do contribute to both 1-loop a-terms and 2-loop soft masses while η induce only 2-loop soft masses for scalars $\widetilde{\Phi}_i \in \{H_u, H_d, \widetilde{Q}, \widetilde{U}, \widetilde{D}, \widetilde{L}, \widetilde{E}\}$. All of them can be derived with the help of wave-function renormalization method (see [5] and references therein). One can show that (3) generate trilinear terms in the scalar potential

$$V \supset \tfrac{1}{6} a_{ijk} \widetilde{\Phi}_i \widetilde{\Phi}_j \widetilde{\Phi}_k + \text{h.c.}\,, \tag{5}$$

where a_{ijk} are given by[3]

$$a_{ijk} = -\frac{\xi}{32\pi^2}\left[y_{ijl}\left(2d_l^{ma} h^*_{lma} h_{kma} + d_l^{ab} h^*_{lab} h_{kab}\right) + (i \leftrightarrow k) + (j \leftrightarrow k)\right]. \tag{6}$$

$\xi = F/M$ sets the scale of soft terms, while d are numerical coefficients[4] present in the 1-loop anomalous dimensions [5]. The scalars $\widetilde{\Phi}_i$ receive 2-loop soft masses $\widetilde{\Phi}_i^\dagger m^2_{ij} \widetilde{\Phi}_j$ from three sources what can be written as

$$m^2_{ij} = m^2_{ij,g} + m^2_{ij,h} + m^2_{ij,\eta}\,. \tag{7}$$

$m^2_{ij,g}$ are well-known 2-loop gauge mediation mass terms [4], $m^2_{ij,h}$ are contributions to soft masses generated by h couplings [5], while the last term in (7) is related to η — marginal couplings of three messengers. It has the following form

$$\begin{aligned} m^2_{ij,\eta} \;=\; \frac{\xi^2}{512\pi^4}\Big[&(d_i^{ae} h^*_{iae} h_{jbe} + d_i^{ak} h^*_{iak} h_{jbk}) d_a^{cd} \eta_{acd} \eta^*_{bcd} \\ &+(d_i^{ae} h^*_{iae} h_{jke} + d_i^{al} h^*_{ial} y_{jkl}) d_a^{bc} \eta_{abc} h^*_{kbc} \\ &+(d_i^{ke} h^*_{ike} h_{jae} + d_i^{kl} y^*_{ikl} h_{jal}) d_k^{bc} h_{kbc} \eta^*_{abc}\Big]\,. \end{aligned} \tag{8}$$

The components of the sum (8) arise from 2-loop diagrams (see Fig. 1) with two h and two η vertices, three h and one η vertex and from diagram with two h, one η and one y vertex. It is clear that η couplings are relevant for the phenomenology only when they coexist with appropriate h interactions.

[3] Here and below, all indices are summed over except for those which are present on the left-hand side of an equation.

[4] The values of d for $G = \mathrm{SU}(5)$ and $Y = (Y_5, Y_{\overline{5}}, Y_{10}, Y_{\overline{10}})$ can be found in [6].

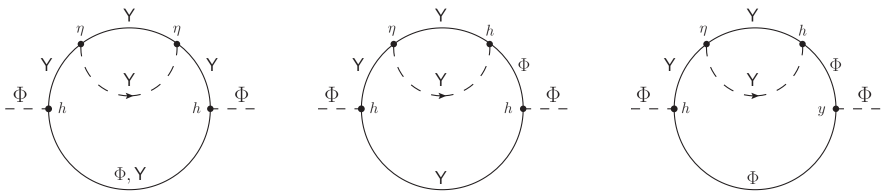

Fig. 1. Representative Feynman diagrams for the contributions to the soft masses (8) induced by marginal couplings of three messengers. Dashed and solid lines correspond, respectively, to the bosonic and fermionic components of matter Φ and messenger Y superfields. h stands for matter–matter–messenger or matter–messenger–messenger coupling, η denotes messenger–messenger–messenger interaction, while y is the MSSM Yukawa coupling.

3. Baryon/lepton number violation and μ/B_μ problem

It turns out that in the described class of models some of marginal messenger couplings (3) may generate at tree- and loop-level operators which lead to undesired effects such us baryon/lepton number violation or μ/B_μ problem. To analyse that issue, let us define matter chiral superfields Φ_Q, Φ_L, *etc.* as those which under gauge symmetry breaking $G \to \mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ decompose as $\Phi_Q \to Q + \ldots$, $\Phi_U \to U + \ldots$, *etc.* First of all, to build realistic model, one has to forbid dimension 4 operators like $\Phi_L\Phi_D\Phi_Q$, $\Phi_L\Phi_L\Phi_E$ or $\Phi_D\Phi_D\Phi_U$ which violate baryon/lepton number. Secondly, superpotential interactions (3) generate the following effective operator of dimension 5

$$\frac{c_5}{M}\Phi_Q\Phi_Q\Phi_Q\Phi_L\Big|_{\theta^2} \tag{9}$$

through exchange of messengers $(Y_{2\alpha-1}, Y_{2\alpha})$. One can check that $c_5 = h_{Q,Q,2\alpha-1}h_{Q,L,2\alpha} + h_{Q,L,2\alpha-1}h_{Q,Q,2\alpha}$, where $h_{Q,Q,2\alpha-1} = \partial_{\Phi_Q}\partial_{\Phi_Q}\partial_{Y_{2\alpha-1}}W_{\mathsf{Y}}$ *etc.* To prevent rapid proton decay via (9), coefficient c_5 must be highly suppressed *i.e.* $c_5 \lesssim 10^{-26+t_M}$, where $t_M = \log_{10}(M/1\ \mathrm{GeV})$ [8]. Moreover, the following operator of dimension 6

$$\frac{c_6}{M^2}\left(\Phi_Q^\dagger\Phi_Q\right)^2\Big|_{\theta^2\bar{\theta}^2} \tag{10}$$

can be induced by (3) what would lead to rapid proton decay in the channel $p \to \pi^0 e^+$. To meet phenomenological bounds, the coefficient $c_6 = h_{Q,Q,2\alpha-1}h^*_{Q,Q,2\alpha-1} + h_{Q,Q,2\alpha}h^*_{Q,Q,2\alpha}$ has to satisfy $c_6 \lesssim 10^{-16+t_M}$ [9].

The second serious issue is μ/B_μ problem [10]. To avoid it, we shall assume that there is no $\mu\Phi_{H_u}\Phi_{H_d}$ term in the superpotential, and mass term for Higgses is generated after SUSY breaking by the following operator

$$\frac{c_\mu}{M_{\rm GUT}} X^\dagger \Phi_{H_u}\Phi_{H_d}\,, \tag{11}$$

while at the same time operator $X^\dagger X\Phi_{H_u}\Phi_{H_d}/M^2_{\rm GUT}$, which would produce B_μ, is absent. On the other hand, after integrating messengers, μ and B_μ are also generated via the following effective operators

$$\frac{c'_\mu}{M} X^\dagger \Phi_{H_u}\Phi_{H_d}\,, \qquad \frac{c'_{B_\mu}}{M^2} X^\dagger X \Phi_{H_u}\Phi_{H_d}\,, \tag{12}$$

which would lead to $\mu^2 \ll B_\mu$ unless

$$c'_{\mu,B_\mu} = \frac{1}{(4\pi)^2}\left(h_{H_u,2\alpha-1,2\beta-1}h_{H_d,2\alpha,2\beta} + h_{H_u,2\alpha,2\beta-1}h_{H_d,2\alpha-1,2\beta}\right) + (u \leftrightarrow d) \tag{13}$$

is sufficiently suppressed.

One of the ways to deal with above-mentioned problems, without fine-tuning parameters of the model, is to introduce extra global $\mathrm{U}(1)_q$ symmetry and assign charges such that those operator are absent. Such approach is realized *e.g.* in F-theory models [11, 12] and in models which use the Froggatt–Nielsen mechanism to address the issue of hierarchy in Yukawa couplings.

4. Phenomenology of the simplest SU(5) model with $\mathsf{Y}\mathsf{Y}\mathsf{Y}$

Now, let us focus on a specific SU(5) unification model in which both h and η messenger interactions are present [6]. Here messenger sector consists of fields in representations $5+\overline{5}$ and $10+\overline{10}$ *i.e.* $\mathsf{Y} = (Y_5, Y_{\overline{5}}, Y_{10}, Y_{\overline{10}})$. We invoke extra global $\mathrm{U}(1)_q$ symmetry to provide selection rules necessary to satisfy phenomenological constraints described above. Charges assignment which leads to the smallest number of marginal couplings of messengers is shown in Table I. For simplicity, we assume that messengers interact

TABLE I

Assignment of $\mathrm{U}(1)_q$ charges, $q \neq 0$. H_5, $H_{\overline{5}}$, $\phi_{\overline{5}}$ and ϕ_{10} are MSSM matter superfields.

H_5	$H_{\overline{5}}$	$\phi_{\overline{5}}$	ϕ_{10}	Y_5	$Y_{\overline{5}}$	Y_{10}	$Y_{\overline{10}}$	X
$-8q$	$-7q$	$3q$	$4q$	$17q$	$-2q$	$14q$	q	$-15q$

only with the heaviest generation of MSSM matter. Gauge invariance and global U(1) symmetry imply that, in this case, the only marginal couplings of messengers are

$$W_{\mathsf{Y}} = \tfrac{1}{2}h\phi_{10}Y_{\overline{5}}Y_{5} + \tfrac{1}{2}\eta Y_{\overline{5}}Y_{\overline{10}}Y_{\overline{10}}\,. \tag{14}$$

Using formula (6), one can find that a-terms are of the form

$$a_{H_uQ_3U_3} = -y_t\alpha_h\frac{\xi}{4\pi}\,, \qquad a_{H_dQ_3D_3} = -y_b\alpha_h\frac{\xi}{4\pi}\,, \tag{15}$$

where $y_{t,b}$ are top and bottom Yukawa couplings and $\alpha_h = |h|^2/(4\pi)$. Meanwhile, only squark doublet $\widetilde{Q}_3$ receives 2-loop soft masses from η coupling

$$m^2_{\widetilde{Q}_3,\eta} = 6\alpha_h\alpha_\eta\frac{\xi^2}{16\pi^2}\,, \qquad m^2_{\widetilde{Q}_3,h} = \alpha_h\left(6\alpha_h - \frac{7}{15}\alpha_1 - 3\alpha_2 - 6\alpha_3\right)\frac{\xi^2}{16\pi^2}\,, \tag{16}$$

where $\alpha_\eta = |\eta|^2/(4\pi)$. Note that for $\eta, h \sim 1$ both contributions to $m^2_{\widetilde{Q}_3}$ are of the same order and of the same order as standard GMSB contribution [4]. The details of the phenomenological analysis of this case can be found in [6]. Here, we only want to mention that the main effect of η is lowering masses of the lightest sleptons (see Fig. 2). The reason of such behaviour is that (16) enlarges D-term contribution to beta function of $m^2_{\widetilde{E}_3}$ as follows

$$\frac{d}{dt}m^2_{\widetilde{E}_3} = \ldots + \frac{6}{10}g_1^2 m^2_{\widetilde{Q}_3,\eta}\,. \tag{17}$$

For a fixed value of $m^2_{\widetilde{E}_3}$ at the messenger scale M, it results in reducing masses of right-handed sleptons at the electroweak scale.

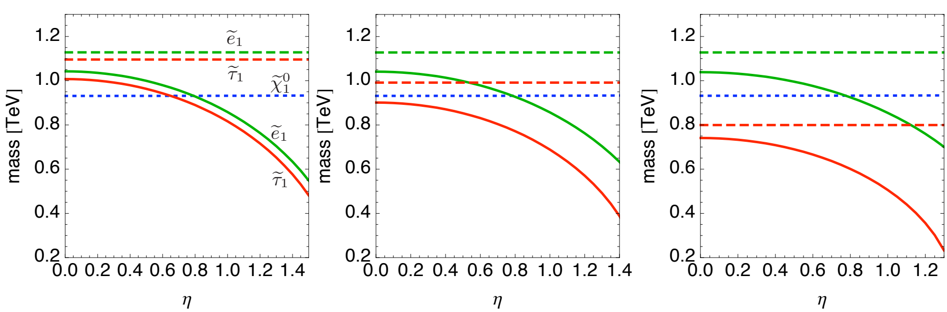

Fig. 2. Plot of the particles masses *versus* η coupling for $\tan\beta = 15$ (left plot), $\tan\beta = 30$ (middle plot) and $\tan\beta = 45$ (right plot). h is set to 1.1, while scale $\xi = F/M$ is 1.7×10^5 GeV. Dashed lines show masses of the particles when $h = \eta = 0$, which corresponds to the standard GMSB case. $\widetilde{\tau}_1$ and $\widetilde{e}_1$ are mostly right-handed.

5. Conclusions

We have investigated the extended GMSB models with messengers in arbitrary representations of gauge group. The general formulas for soft masses generated by marginal couplings of three messengers have been presented. We also derived bounds on those messenger couplings which would lead to baryon/lepton number violation or μ/B_μ problem in that class of models. As an example, we showed how marginal couplings of three messengers influence low-energy spectrum of the specific SU(5) model with extra global $\mathrm{U}(1)_q$ symmetry. It turns out that the lightest sleptons are the most sensitive to them. Those interactions do not change sleptons soft masses directly but increase their beta function what results in reducing masses at the electroweak scale.

This work was supported by the National Science Center under postdoctoral grant DEC-2012/04/S/ST2/00003.

REFERENCES

[1] G. Aad *et al.* [ATLAS Collaboration], *Phys. Lett.* **B716**, 1 (2012) [`arXiv:1207.7214 [hep-ex]`].

[2] S. Chatrchyan *et al.* [CMS Collaboration], *Phys. Lett.* **B716**, 30 (2012) [`arXiv:1207.7235 [hep-ex]`].

[3] P. Draper, P. Meade, M. Reece, D. Shih, *Phys. Rev.* **D85**, 095007 (2012) [`arXiv:1112.3068 [hep-ph]`].

[4] G.F. Giudice, R. Rattazzi, *Phys. Rep.* **322**, 419 (1999) [`arXiv:hep-ph/9801271`].

[5] J.A. Evans, D. Shih, `arXiv:1303.0228 [hep-ph]`.

[6] T. Jeliński, *J. High Energy Phys.* **1309**, 107 (2013) [`arXiv:1305.6277 [hep-ph]`].

[7] N. Craig, S. Knapen, D. Shih, Y. Zhao, *J. High Energy Phys.* **1303**, 154 (2013) [`arXiv:1206.4086 [hep-ph]`].

[8] E. Dudas, E. Palti, *J. High Energy Phys.* **1009**, 013 (2010) [`arXiv:1007.1297 [hep-ph]`].

[9] W. Buchmuller, L. Covi, D. Emmanuel-Costa, S. Wiesenfeldt, *J. High Energy Phys.* **0409**, 004 (2004) [`arXiv:hep-ph/0407070`].

[10] G.R. Dvali, G.F. Giudice, A. Pomarol, *Nucl. Phys.* **B478**, 31 (1996) [`arXiv:hep-ph/9603238`].

[11] J.J. Heckman, A. Tavanfar, C. Vafa, *J. High Energy Phys.* **1008**, 040 (2010) [`arXiv:0906.0581 [hep-th]`].

[12] T. Jeliński, J. Pawełczyk, K. Turzyński, *Phys. Lett.* **B711**, 307 (2012) [`arXiv:1111.6492 [hep-ph]`].