

SUSY breaking based on Abelian gaugino kinetic term mixings

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ABSTRACT: We present a SUSY breaking scenario based on Abelian gaugino kinetic term mixings between hidden and observable sectors. If an extra $U(1)$ gaugino in the observable sector obtains a large mass through this mixing effect based on SUSY breaking in the hidden sector, soft SUSY breaking parameters in the MSSM may be affected by radiative effects due to this gaugino mass. New phenomenological aspects are discussed in such a SUSY breaking scenario.

KEYWORDS: Supersymmetry Breaking, Supersymmetry Phenomenology.

Supersymmetry (SUSY) is considered to be the most promising solution for the gauge hierarchy problem of the standard model (SM) [1]. Since phenomenological features of SUSY models are determined by soft SUSY breaking parameters, it is crucial to clarify the nature of SUSY breaking mechanisms. Since a favorable SUSY breaking scale in a hidden sector depends on what kind of mediation scenarios of SUSY breaking are supposed, features of the SUSY breaking in the observable sector is usually fixed by a dominant contribution due to a certain mediation among them. If different mediation mechanisms can compete to induce the SUSY breaking in the observable sector, there may appear novel feature in SUSY breaking parameters. In this paper we discuss a possibility that the coexistence of different mediations of the SUSY breaking may break the universality of gaugino masses and bring new phenomenological features to the models.

A few examples which can realize non-universal gaugino masses have been proposed,¹ and its phenomenological consequences have been examined from some view points [2]–[6]. Here we propose a new mediation mechanism of the SUSY breaking in the hidden sector to the observable sector, which can make an Abelian gaugino mass largely different from others in the observable sector. In such a case other SUSY breaking parameters may be also affected through radiative effects of this large Abelian gaugino mass. In particular, corrections to the Higgs and stop masses seem to be phenomenologically interesting since it may help to soften the little hierarchy problem in the MSSM.

In this paper we use the Abelian gauge kinetic term mixing for the mediation of the SUSY breaking. It is known that the kinetic term mixing can generally occur among the Abelian gauge fields in the models with multi U(1)s [7–9]. We assume that such mixing exists between two Abelian gauge fields, one of which belongs to the hidden sector and the other belongs to the observable sector. In that case we show that there can be an additional contribution to the corresponding Abelian gaugino mass in the observable sector, if certain assumptions for the superpotential and the SUSY breaking in the hidden sector are satisfied. This additional contribution can make the Abelian gaugino mass different from others in the observable sector. Moreover, it may bring radiatively dominant contributions for certain SUSY breaking parameters depending on the SUSY breaking scale in the hidden sector.

The following parts are organized as follows. First, we explain the SUSY breaking mediation due to the gauge kinetic term mixing. We discuss how the gaugino mass of an additional U(1) factor in the observable sector can be heavier than other gauginos. After that, we estimate the corrections to the Higgs and stop masses due to this gaugino mass. We discuss these corrections may help to soften the little hierarchy problem in the MSSM. We give numerical results of such analyses for the extra U(1) models derived from E_6 , as an example.

For simplicity, we consider a SUSY $U(1)_a \times U(1)_b$ model where $U(1)_a$ and $U(1)_b$ belong to the hidden and observable sectors, respectively. In the later discussion $U(1)_b$ is identified with an additional $U(1)_x$ to the MSSM. We suppose that $\hat{W}_{a,b}^\alpha$ is a chiral superfield with a

¹The gaugino masses are known to be non-universal in some types of models, for example, in the multi-moduli SUSY breaking [2], intersecting D-brane models [3] and a certain type of gauge mediation models [4].

spinor index α , which contains the field strength of $U(1)_{a,b}$. Since $\hat{W}_{a,b}^\alpha$ is gauge invariant by itself, the gauge invariant kinetic terms can be expressed as

$$\mathcal{L}_{\text{kin}} = \int d^2\theta \left(\frac{1}{32} \hat{W}_a^\alpha \hat{W}_{a\alpha} + \frac{1}{32} \hat{W}_b^\alpha \hat{W}_{b\alpha} + \frac{\sin \chi}{16} \hat{W}_a^\alpha \hat{W}_{b\alpha} \right). \quad (1)$$

A mixing term is generally allowed at least from a viewpoint of the symmetry. Although some origins such as the string one-loop effect may be considered for this mixing [8], we only treat $\sin \chi$ in eq. (1) as a free parameter.

This mixing can be resolved by practicing a transformation [7]

$$\begin{pmatrix} \hat{W}_a^\alpha \\ \hat{W}_b^\alpha \end{pmatrix} = \begin{pmatrix} 1 & -\tan \chi \\ 0 & 1/\cos \chi \end{pmatrix} \begin{pmatrix} \hat{W}_h^\alpha \\ \hat{W}_x^\alpha \end{pmatrix}. \quad (2)$$

If we use a new basis $(\hat{W}_h^\alpha, \hat{W}_x^\alpha)$, a covariant derivative in the observable sector can be written as

$$D^\mu = \partial^\mu + i \left(-g_a Q_a \tan \chi + \frac{g_b Q_b}{\cos \chi} \right) A_x^\mu. \quad (3)$$

This shows that the gauge field A_x^μ in the observable sector can interact with the hidden sector fields which have a nonzero charge Q_a . However, since the fields in the hidden sector are generally considered to be heavy enough and $\sin \chi$ is expected to be small, we can safely expect that there is no phenomenological contradiction at the present stage.

We consider that the Abelian gauginos in both sectors obtain masses through the SUSY breaking in the hidden sector such as

$$\mathcal{L}_{\text{gaugino}}^m = M_a \tilde{\lambda}_a \tilde{\lambda}_a + M_b \tilde{\lambda}_b \tilde{\lambda}_b, \quad (4)$$

where the mass M_b of the gaugino in the observable sector may be supposed as the ordinary universal mass $m_{1/2}$. If we can assume that $M_a \gg M_b$ is satisfied, these mass terms are rewritten by using the new basis (2) as follows,

$$\tilde{\mathcal{L}}_{\text{gaugino}}^m = M_a \tilde{\lambda}_h \tilde{\lambda}_h + (M_b + M_a \sin^2 \chi) \tilde{\lambda}_x \tilde{\lambda}_x, \quad (5)$$

where we also use $\sin \chi \ll 1$ in this derivation. This suggests that the mass of the Abelian gaugino in the observable sector can have an additional contribution due to the gauge kinetic term mixing with the gaugino in the hidden sector. This new contribution can be a dominant one when the SUSY breaking in the hidden sector satisfies

$$M_a \sin^2 \chi > M_b. \quad (6)$$

In this case the universality of the gaugino masses in the observable sector can be violated in the Abelian part.

Next we present an example of the SUSY breaking scenario which can satisfy the condition (6) in the framework of the gravity mediation SUSY breaking. We consider the hidden sector which contains chiral superfields $\hat{\Phi}_{1,2}$ charged under $U(1)_a$. It is also supposed to contain various neutral chiral superfields like moduli, which are represented by

$\hat{\mathcal{M}}$ together. They are defined as dimensionless fields. Matter superfields in the observable sector are denoted by $\hat{\Psi}_I$. Both Kähler potential and superpotential relevant to the present argument are supposed to be written as²

$$\begin{aligned}\mathcal{K} &= \kappa^{-2} \hat{K}(\hat{\mathcal{M}}) + \hat{\Phi}_1^* \hat{\Phi}_1 + \hat{\Phi}_2^* \hat{\Phi}_2 + \hat{\Psi}_I^* \hat{\Psi}_I + \dots, \\ \mathcal{W} &= \hat{W}_0(\hat{M}) + \hat{W}_1(\hat{\mathcal{M}}) \hat{\Phi}_1 \hat{\Phi}_2 + \frac{1}{3} \hat{Y}_{IJK} \hat{\Psi}_I \hat{\Psi}_J \hat{\Psi}_K + \dots,\end{aligned}\tag{7}$$

where κ^{-1} is the reduced Planck mass and $Q_a(\hat{\Phi}_1) + Q_a(\hat{\Phi}_2) = 0$ is assumed. As a source relevant to the SUSY breaking in the hidden sector, we adopt a usual assumption in case of the gravity mediation SUSY breaking. That is, the SUSY breaking effects are assumed to be parameterized by F -terms $F_{\mathcal{M}}$ of certain moduli \mathcal{M} [10]. In that case the gravitino mass $m_{3/2}$ can be defined by $m_{3/2} \equiv \kappa^2 e^{K/2} W_0$. Since vacuum energy is expressed by using these as $V_0 = \kappa^{-2} (F^{\mathcal{M}} F_{\mathcal{M}} \partial_{\mathcal{M}} \partial_{\bar{\mathcal{M}}} K - 3m_{3/2}^2)$, $F^{\mathcal{M}}$ is supposed to be $O(m_{3/2})$ as long as V_0 is assumed to vanish.

Applying this assumption to the scalar potential formula in the supergravity, we can obtain well known soft supersymmetry breaking parameters for the scalar masses $m_{\tilde{f}}$ and three scalar couplings $A_{\tilde{f}_1 \tilde{f}_2 \tilde{f}_3}$ in the observable sector as [10]

$$m_{\tilde{f}}^2 = m_{3/2}^2, \quad A_{\tilde{f}_1 \tilde{f}_2 \tilde{f}_3} = \sqrt{3} m_{3/2}.\tag{8}$$

The masses of the gauginos are generated as [11]

$$m_{1/2} = \frac{1}{2\text{Re}[f_A(\mathcal{M})]} F^{\mathcal{M}} \partial_{\mathcal{M}} f_A(\mathcal{M}),\tag{9}$$

where $f_A(\mathcal{M})$ is a gauge kinetic function for a gauge factor group G_A . If $f_A(\mathcal{M})$ takes the same form for each factor group, the universal gaugino masses are generated as $m_{1/2} = O(m_{3/2})$. This is the ordinary scenario. In the present case, the gaugino mass M_b in eq. (4) is expected to be induced from this gravity mediation and take the universal value $m_{1/2}$.

On the other hand, the gaugino mass M_a in the hidden sector is generated through the mediation of charged chiral superfields $\hat{\Phi}_{1,2}$ due to the second term in \mathcal{W} as in the gauge mediation SUSY breaking scenario [12]. Since it can be generated by one-loop diagrams which have component fields of $\hat{\Phi}_{1,2}$ in internal lines, it is approximately expressed as

$$M_a = \frac{g_a^2}{16\pi^2} \Lambda,\tag{10}$$

where $\Lambda = \langle F_1 \rangle / \langle S_1 \rangle$ and we define that S_1 and F_1 are the scalar and auxiliary components of \hat{W}_1 , respectively. Since we are considering the gravity mediation SUSY breaking, the SUSY breaking scale in the hidden sector should be large to induce a suitable breaking in the observable sector. Since $\Lambda = O((\kappa^{-1} m_{3/2})^{1/2})$ is required and then M_a can be much larger than the gravity mediation contribution $M_b = O(m_{1/2})$, the additional contribution $M_a \sin^2 \chi$ to the Abelian gaugino mass in eq. (5) can break the gaugino mass universality

²For simplicity, we assume minimal kinetic terms for the matter fields. A hat is put on for the superfield and the scalar component is represented by removing the hat from it.

largely in the observable sector. In fact, if $\sin \chi$ takes a suitable value such as $\chi = O(10^{-1})$,³ we can expect that $M_a \sin^2 \chi > M_b$ is realized and the Abelian gaugino mass characterized by $M_a \sin^2 \chi$ can take a much larger value than other universal ones.⁴

Now we discuss an interesting consequence of this kind of scenario for the little hierarchy problem in the MSSM. The large mass of the Abelian gaugino in the observable sector can induce additional corrections to other soft SUSY breaking parameters through the renormalization group equations (RGEs). In order to fix the features of this SUSY breaking scenario, we need to examine this radiative effects and compare them with the SUSY breaking effects due to the gravity mediation. Radiative corrections to other soft SUSY breaking parameters induced by the mass M_x of the $U(1)_x$ gaugino can be estimated by solving the RGEs. The gaugino mass M_x runs as

$$M_x(M_w) = \frac{\alpha_x(M_w)}{\alpha_x(\Lambda)} M_x(\Lambda), \tag{11}$$

where $\alpha_x = g_x^2/4\pi$ and $\alpha_x(M_w)/\alpha_x(\Lambda) = 1 - (b_x \alpha_x(M_w)/2\pi) \ln(\Lambda/M_w)$. The scale Λ is introduced in eq. (10) and M_w is the weak scale. Since the large Abelian gaugino mass M_x gives dominant contributions in the RGEs for the soft SUSY breaking parameters, we may approximately estimate their evolution by taking account of its effect alone. Using one-loop RGEs, the soft masses of the scalar components \tilde{f} and the A parameters for the couplings of three scalars $\tilde{f}_1 \tilde{f}_2 \tilde{f}_3$ are represented as

$$\begin{aligned} m_{\tilde{f}}^2(M_w) &\simeq \bar{m}_{\tilde{f}}^2(M_w) - \frac{Q_{\tilde{f}}^2}{2b_x} \left(\frac{\alpha_x^2(M_w)}{\alpha_x^2(\Lambda)} - 1 \right) M_x^2(\Lambda), \\ A_{\tilde{f}_1 \tilde{f}_2 \tilde{f}_3}(M_w) &\simeq \bar{A}_{\tilde{f}_1 \tilde{f}_2 \tilde{f}_3}(M_w) - \frac{(\sum_{i=1}^3 Q_{\tilde{f}_i}^2)}{2b_x} \left(\frac{\alpha_x(M_w)}{\alpha_x(\Lambda)} - 1 \right) M_x(\Lambda), \end{aligned} \tag{12}$$

where Q_ψ stands for the $U(1)_x$ charge of the field ψ . The MSSM effects based on the gravity mediation are summarized by $\bar{m}_{\tilde{f}}^2$ and $\bar{A}_{\tilde{f}_1 \tilde{f}_2 \tilde{f}_3}$. Since the correction induced by M_x to the gaugino mass M_A of the factor group G_A appears as two-loop effects [13], we can safely estimate M_A by taking account of the gravity mediation effect only and using the one-loop RGE formula given in eq. (11). If we note that $Q_\psi = O(1)$ and Λ is an intermediate scale, the first and second terms of $m_{\tilde{f}}^2(M_w)$ in eq. (12) are expected to take similar order values as long as M_x is $O(1)$ TeV. Thus, additional corrections to the soft scalar masses may work to improve the degeneracy among the soft scalar masses and then suppress flavor changing neutral currents (FCNC) as long as $U(1)_x$ is generation blind. Corrections due to M_x for the A parameter is expected to be smaller than the gravity induced one.

This additional correction to the scalar masses may improve the situation for the radiative symmetry breaking in the MSSM. The potential minimum conditions in the

³The string one-loop effect may bring this order of mixing as discussed in [8].

⁴If the absolute values of M_b and $M_a \sin^2 \chi$ could be the same order, two contribution might substantially cancel each other to realize much smaller value than $m_{1/2}$. Although this may be an interesting possibility, we do not consider it here.

MSSM can be written as

$$\sin 2\beta = \frac{2B\mu}{m_1^2 + m_2^2 + 2\mu^2}, \quad m_Z^2 = \frac{2m_1^2 - 2m_2^2 \tan^2 \beta}{\tan^2 \beta - 1} - 2\mu^2. \quad (13)$$

Since the Higgs mass difference $\delta \equiv m_1^2 - m_2^2$ at the top mass scale m_t can be approximately written by taking account of the stop loop effect and the formulas in eq. (12) as

$$\delta \simeq \frac{3h_t^2}{4\pi^2} m_{\tilde{t}}^2 \ln \left(\frac{m_{\tilde{t}}}{m_t} \right) - \frac{Q_1^2 - Q_2^2}{2b_x} \left(\frac{\alpha_x^2(m_t)}{\alpha_x^2(\Lambda)} - 1 \right) M_x^2(\Lambda), \quad (14)$$

the conditions (13) can be summarized as

$$m_Z^2 = \left(\frac{\delta}{\tan^2 \beta - 1} - \frac{B\mu}{\tan \beta} \right) (\tan^2 \beta + 1). \quad (15)$$

Although the present mass bounds for the lightest neutral Higgs scalar require a large stop mass $m_{\tilde{t}}$, the large stop mass imposes the tuning among the SUSY breaking parameters so as to satisfy eq. (15). As a result, we have a so-called little hierarchy problem. However, in the present case the situation may be changed. The additional correction due to M_x increases the stop mass through eq. (12). On the other hand, eq. (14) shows that it could reduce a value of δ in case of $Q_1^2 < Q_2^2$ and then it might relax the tuning required to satisfy eq. (15).

We examine this aspect numerically in interesting examples which have $U(1)_x$ as an additional Abelian gauge symmetry to the MSSM. As such a $U(1)_x$ we adopt an Abelian symmetry derived from E_6 and fix the model in the following way. $U(1)_x$ is identified with a linear combination of two additional $U(1)$'s to the MSSM as

$$Q_x = Q_\psi \cos \theta - Q_\chi \sin \theta, \quad (16)$$

where Q_ψ and Q_χ are the charges of $U(1)_\psi$ and $U(1)_\chi$ in

$$E_6 \supset SO(10) \times U(1)_\psi \supset SU(5) \times U(1)_\psi \times U(1)_\chi.$$

Following eqs. (8) and (9), the gravity mediation SUSY breaking parameters are fixed as the universal ones $m_{\tilde{f}} = A_{\tilde{f}_1 \tilde{f}_2 \tilde{f}_3} / \sqrt{3} = m_{1/2} = m_{3/2}$. The gaugino of $U(1)_x$ is assumed to obtain the additional large mass M_x through the kinetic term mixings with the hidden sector field. We assume the MSSM contents as chiral matter fields and impose the GUT normalization $g_x = \sqrt{\frac{5}{3}} g_1$. In this type of $U(1)_x$ extra matter fields from the **27**'s of E_6 are required to cancel the anomaly. However, since their effects are expected to be secondary, we do not take them into account here.

We study the behavior of the SUSY breaking parameters of this model by using one-loop RGEs for $m_{3/2} = 300$ GeV and $\Lambda = 10^{11}$ GeV. By varying the value of M_x at the scale Λ for various values of θ ($-\pi/2 < \theta < \pi/2$), we calculate the stop masses and $\Delta \equiv \delta/m_Z^2$. Δ is considered as a measure for the required fine tuning in eq. (15). Results in case of $\tan \beta = 2$ are plotted for the several values of θ in figure 1.⁵ In the left panel we plot

⁵There is $U(1)_x$ D -term contribution to the soft scalar masses such as $(m_{\tilde{f}}^{D_x})^2 \simeq g_x^2 Q_f Q_S \langle S \rangle^2$, where $\langle S \rangle$ determines a $U(1)_x$ breaking scale. Since we fix $\langle S \rangle$ as $\langle S \rangle = 1.5$ TeV and then $M_x > g_x \langle S \rangle$ is satisfied in the almost all regions of the large M_x , this contribution is neglected in this calculation.

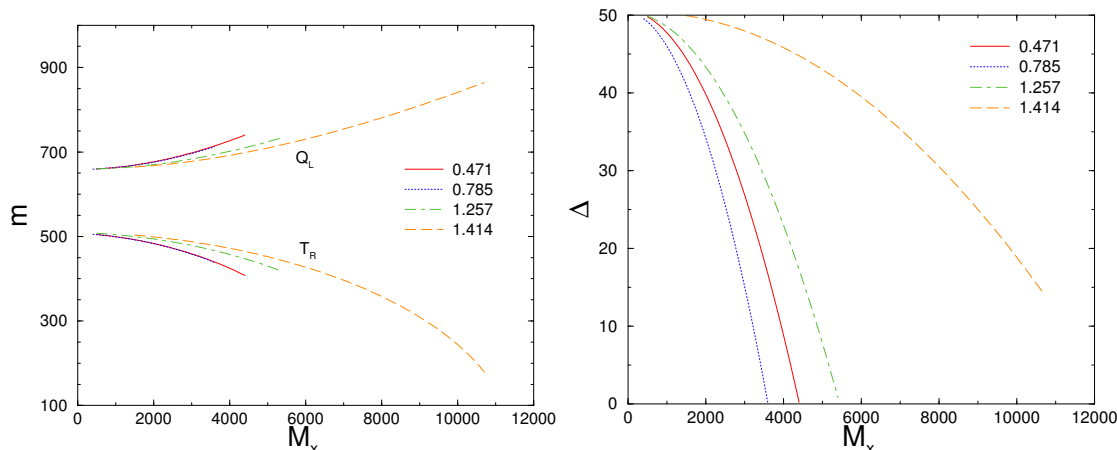


Figure 1: One-loop corrections induced by the M_x effects for several values of θ . In the left panel stop soft masses $m_{\tilde{Q}_L}$ and $m_{\tilde{T}_R}$ are plotted. In the right panel Δ is plotted. GeV is used as the mass unit.

the stop masses $m_{\tilde{Q}_L}$ and $m_{\tilde{T}_R}$. The same input parameters give $m_{\tilde{Q}_L} \simeq 716$ GeV and $m_{\tilde{T}_R} \simeq 583$ GeV in case of the MSSM with $\tan \beta = 7$. This panel shows that the averaged stop mass increases for the larger M_x through the RGE effect as expected. In the right panel we show the behavior of Δ . For the same input parameters we find $\Delta \simeq 49$ in the MSSM. From this figure we find that the larger values of M_x can make the value of Δ smaller. This can be explained by the second term in eq. (14), which may cancel the contribution of the first term even in the case of large stop mass. In fact, we find that this can happen for suitable values of θ for which $Q_1^2 < Q_2^2$ is satisfied as mentioned before. Even if the correction due to M_x makes the stop mass increase, the present results show that Δ can be smaller satisfying the neutral Higgs mass bound as long as $Q_1^2 < Q_2^2$ is satisfied. The situation for the parameter tuning in eq. (15) seems to be improved for rather wide ranges of the value of M_x .

In the extra U(1) model studied here, it is also useful to note that the constraint from the neutral Higgs mass bounds can be relaxed by additional contributions in comparison with the MSSM [14]. The constraint can be satisfied even for the small values of $\tan \beta$ such as 2, which is used in the above calculations. This point may also be considered a favorable feature of this scenario for the fine tuning problem. In addition, since the correction due to M_x tends to improve the universality of the soft masses among different generations of squarks and sleptons, it does not make the situation for the FCNC problem worse.

Finally, we should make a remark about an important effect on the soft scalar masses due to the hidden sector U(1) D -term. As discussed in [8], the hidden sector U(1) D -term can contribute to the soft scalar masses $m_{\tilde{f}}^2$ in the observable sector through the above discussed kinetic term mixing. Its contribution to $m_{\tilde{f}}^2$ is estimated as

$$(m_{\tilde{f}}^{D_h})^2 = g_x g_h Q_f Q_\phi^{(h)} \tan \chi \langle \phi \rangle^2, \tag{17}$$

where g_h is the coupling constant of the hidden sector U(1) and $Q_\phi^{(h)}$ is its charge of the hidden sector field ϕ . As discussed in the previous part, $\sin \chi$ should take values of $O(10^{-1})$ in the present scenario. Thus, if $\langle \phi \rangle$ is much larger than $O(1)$ TeV, this contribution dominates $m_{\tilde{f}}^2$. In case of $Q_f Q_\phi^{(h)} < 0$, in particular, it can make $m_{\tilde{f}}^2$ negative and upset the symmetry breaking in the observable sector. This suggests that the present model requires the existence of rather light Abelian gauge field with the mass of $O(1)$ TeV in the hidden sector. This could be a typical feature of the model and its effects might be examined in the future collider experiments. Thus, it seems worth to make further study on this point and clarify its phenomenological effects in the observable sector.

In summary we proposed the SUSY breaking scenario in which different mediation effects of the SUSY breaking compete and the nonuniversal gaugino masses are induced in the Abelian sector. If there is the kinetic term mixing between the Abelian gauge fields in the hidden and observable sectors, the Abelian gaugino in the observable sector can have additional contributions from this mixing in the framework of the ordinary gravity mediation SUSY breaking. The main contribution of the SUSY breaking comes from the gravity mediation except for the mass of the Abelian gaugino which has the kinetic term mixing with the Abelian gaugino in the hidden sector. As an interesting phenomenological aspect of such a scenario, we studied the fine tuning problem in the radiative symmetry breaking in the MSSM. We showed that the RGE effects due to this gaugino mass can reduce the corrections to the Higgs mass although the same effect increases the stop mass. Since this SUSY breaking scenario can affect the neutralino phenomenology in the way that the lightest neutralino is dominated by the MSSM singlet fermion [6], the model may be examined through future collider experiments and dark matter searches.

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