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Discrimination of Supersymmetric Grand Unified Models in Gaugino Mediation

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Abstract

We consider supersymmetric grand unified theory (GUT) with the gaugino mediated supersymmetry breaking and investigate a possibility to discriminate different GUT models in terms of predicted sparticle mass spectra. Taking two example GUT models, the minimal $SU(5)$ and a simple $SO(10)$ models, and imposing a variety of theoretical and experimental constraints, we calculate sparticle masses. Fixing parameters of each model so as to result in the same mass of neutralino as the lightest supersymmetric particle (LSP), giving the observed dark matter relic density, we find sizable mass differences in the left-handed slepton and right-handed down-type squark sectors in two models, which can be a probe to discriminate the GUT models realized at the GUT scale far beyond the reach of collider experiments.

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1 Introduction

Providing a promising solution to a long-standing problem in the Standard Model (SM), the gauge hierarchy problem, and motivated by the possibility of being tested at the Large Hadron Collider (LHC) and other future collider projects such as the International Linear Collider (ILC), supersymmetry (SUSY) has been intensively explored for the last several decades. In addition, under the R-parity conservation, the minimal supersymmetric extension of the SM (MSSM) provides neutralino LSP which is a good candidate for the dark matter, a mysterious block of the universe needed to explain the cosmological observation. Furthermore, in the MSSM, all the SM gauge couplings successfully unify at the GUT scale $M_{GUT} \simeq 2 \times 10^{16}$ GeV, and this fact strongly supports the GUT paradigm.

The exact SUSY requires that the SM particles and their superpartners have equal masses. However, we have not yet observed any signal of sparticles in both direct and indirect experimental searches. This implies that not only SUSY should be broken at some energy, but also SUSY breaking should be transmitted to the MSSM sector in a clever way not to cause additional flavor changing neutral currents and CP-violations associated with supersymmetry breaking terms. There have been several interesting mechanisms for desirable SUSY breaking and its mediations.

In this paper, we consider one of the possibilities, the gaugino mediated SUSY breaking (gaugino mediation) [1]. With a simple 5D braneworld setup of this scenario, the SUSY breaking is first mediated to the gaugino sector, while sfermion masses and trilinear couplings are negligible at the compactification scale of the extra 5th dimension. At low energies, the sfermion masses and trilinear couplings are generated through RGE runnings with the gauge interactions, realizing the flavor-blind sfermion masses. However, the gaugino mediation in the context of the MSSM predicts stau LSP, and such a stable charged particle is disfavored in cosmological point of view. This problem can be naturally solved if the compactification scale is higher than the GUT scale and a GUT is realized there [2]. The RGE runnings as the GUT play the crucial role to push up stau mass, and neutralino LSP is realized at the electroweak scale, which is a suitable dark matter candidate as usual in SUSY models.

There are many possibilities of GUT models with different unified gauge groups and representations of the matter and Higgs multiplets in the groups. A question arising here is how we can discriminate GUT models by experiments carrying out at energies far below the GUT scale. Note that SUSY GUT models with SUSY breaking mediations at or above the GUT scale leave their footprints on sparticle mass spectra at low energies through the RGE evolutions. Typical sparticle mass spectrum, once observed, can be a probe of $SU(5)$ unification [3]. In a similar way, three different types of seesaw mechanism for neutrino masses can be distinguished at the

LHC and the ILC [4]. In this paper, based on the same idea, we investigate a possibility to discriminate different GUT models with the gaugino mediation. A remarkable feature of the gaugino mediation is that the model is highly predictive and sparticle masses are determined by only 2 free parameters, the compactification scale (M_c) and the input gaugino mass (M_G) at M_c, with a fixed $\tan\beta$ and the sign of the μ-parameter.

The structure of this paper is as follows: In Section 2, we briefly discuss the basic setup of the gaugino mediation and introduce two examples of GUT models, the minimal $SU(5)$ model and a simple $SO(10)$ model. In Section 3, we analyze the RGE evolutions of sparticle masses and the trilinear couplings for the two GUT models from the compactification scale to the electroweak scale, and find sparticle mass spectra which are consistent with a variety of theoretical and experimental constraints. Fixing parameters in the both models to result in the same neutralino LSP mass, giving the observed dark matter relic abundance, we compare sparticle mass spectra. We find sizable sparticle mass differences which can be a probe to discriminate the GUT models. The last section is devoted for conclusions.

2 Model setup

In the gaugino mediation scenario [1], we introduce a 5-dimensional flat spacetime in which the extra 5th dimension is compactified on the S^1/Z_2 orbifold with a radius $r = 1/M_c$. The SUSY breaking sector resides on a $(3+1)$-dimensional brane at one orbifold fixed point, while the matter and Higgs sectors on another brane at the other orbifold fixed point. Since the gauge multiplet propagates in the bulk, the gaugino can directly couple with the SUSY breaking sector and acquires the soft mass at the tree level. On the other hand, due to the sequestering between two branes, the matter superpartners and Higgs fields cannot directly communicate with the SUSY breaking sector and hence, sfermion and Higgs boson soft masses and also the trilinear couplings are all zero at the tree level. According to this structure of the gaugino mediation, in actual analysis of RGE evolutions for soft parameters, we set non-zero gaugino mass at the compactification scale and solve RGEs from M_c toward low energies. Soft masses of matter superpartners and Higgs fields are generated via the RGE evolutions.

When the compactification scale is lower than M_{GUT}, the detailed study on MSSM sparticle masses in the gaugino mediation showed that the LSP is stau in most of the parameter space [2]. Clearly, this result is disfavored in cosmological point of view. However, it has been shown that this drawback can be ameliorated if we assume a GUT model and $M_c > M_{GUT}$ [2]: the RGE evolutions from M_c to M_{GUT} push up stau mass and realize neutralino LSP. In other words, the grand unification is crucial to realize phenomenologically viable sparticle mass spectrum in the gaugino mediation. In order to suppress sfermion masses compared to gaugino masses at the compactification scale, the spatial separation between two branes should not be too small, equivalently, the compactification scale should not be too large. In the following analysis, we set the reduced Planck scale (M_P) as the upper bound on M_c:

$$M_c \leq M_P = 2.43 \times 10^{18} \text{ GeV}. \tag{1}$$

There have been many GUT models proposed based on different unified gauge groups such as $SU(5)$, $SO(10)$ and E_6. In this paper, we consider two GUT models as examples, namely, the minimal $SU(5)$ model and a simple $SO(10)$ model [5].

In the minimal $SU(5)$ model, the matter multiplets of the i-th generation are arranged in 2 representations, $\bar{\mathbf{5}}_i$ and $\mathbf{10}_i$. Two Higgs doublets in the MSSM are embedded in the representations of $\bar{\mathbf{5}}_H + \mathbf{5}_H$, while the $\mathbf{24}_H$ Higgs multiplet plays the role of breaking the $SU(5)$ gauge symmetry to the SM one. The particle contents of the minimal $SU(5)$ model along with the Dynkin index and the quadratic Casimir for corresponding multiplets are listed in Table 1.

Table 1: Particle contents of the minimal $SU(5)$ GUT

$SU(5)$	Particles	Dynkin Index	$C_2(\mathbf{R})$
$\bar{\mathbf{5}}_i$	D_i^c, L_i	1/2	12/5
$\mathbf{10}_i$	Q_i, U_i^c, E_i^c	3/2	18/5
$\bar{\mathbf{5}}_H$	H_d	1/2	12/5
$\mathbf{5}_H$	H_u	1/2	12/5
$\mathbf{24}_H$	additional Higgs	5	5

In $SO(10)$ GUT models, all the matter multiplets of the i-th generation are unified into a single $\mathbf{16}_i$ representation. In a simple $SO(10)$ model investigated in [5], Higgs multiplets of the representations $\mathbf{10}_H + \mathbf{10}'_H + \bar{\mathbf{16}}_H + \mathbf{16}_H + \mathbf{45}_H$ are introduced. The up-type (down-type) Higgs doublets in the MSSM is realized as a linear combination of two up-type (down-type) Higgs doubles in $\mathbf{10}_H + \mathbf{10}'_H$, while the Higgs multiplets of $\bar{\mathbf{16}}_H + \mathbf{16}_H + \mathbf{45}_H$ representations work to break the $SO(10)$ gauge symmetry to the MSSM one. Similarly to Table 1, the particle contents of this model are listed in Table 2.

3 Sparticle masses in two models

Now we analyze sparticle mass spectrum at low energy for each GUT model. In the gaugino mediation, gaugino mass is a unique input at the compactification scale $M_c > M_{GUT}$. For a given GUT model, solving the RGEs from M_c to M_{GUT} with the gaugino mass input, we obtain

Table 2: Particle contents of a simple $SO(10)$ GUT

$SO(10)$	Particles	Dynkin Index	$C_2(\mathbf{R})$
$\mathbf{16}_i$	$i-$th generation	2	45/8
$\mathbf{10}_H$	H_u^1, H_d^1	1	9/2
$\mathbf{10}'_H$	H_u^2, H_d^2	1	9/2
$\overline{\mathbf{16}}_H$	additional Higgs	2	45/8
$\mathbf{16}_H$		2	45/8
$\mathbf{45}_H$		8	8

a set of soft parameters at the GUT scale, with which we solve the MSSM RGEs for the soft parameters toward low energies. General 1-loop RGE formulas for the soft parameters in a GUT model are given by [2]:

$$\frac{d\alpha_U}{dt} = -\frac{b_U}{2\pi}\alpha_U^2, \tag{2}$$

$$\frac{d}{dt}\left(\frac{M}{\alpha_U}\right) = 0, \tag{3}$$

$$\frac{dm^2}{dt} = -2C_2(\mathbf{R})\frac{\alpha_U}{\pi}M^2, \tag{4}$$

$$\frac{dA}{dt} = \left(\sum_i C_2(\mathbf{R}_i)\right)\frac{\alpha_U}{\pi}M, \tag{5}$$

where α_U is the unified gauge coupling, b_U is the beta function coefficient, M is the running gaugino mass, m is the running mass of a scalar field in the $\mathbf{R}$ representation under the GUT gauge group, and C_2 is the quadratic Casimir. For the boundary conditions in the gaugino mediation scenario,

$$M(M_c) = M_G \neq 0,\ m^2(M_c) = 0,\ A(M_c) = 0, \tag{6}$$

we can easily find the solutions:

$$\alpha_U(\mu)^{-1} = \alpha_U(M_c)^{-1} + \frac{b_U}{2\pi}\ln(\mu/M_c), \tag{7}$$

$$m^2(\mu) = 2\frac{C_2(\mathbf{R})}{b_U}M^2(\mu)\left[1-\left(\frac{\alpha_U(M_c)}{\alpha_U(\mu)}\right)^2\right], \tag{8}$$

$$A(\mu) = -\frac{2}{b_U}\left(\sum_i C_2(\mathbf{R}_i)\right)M(\mu)\left[1-\left(\frac{\alpha_U(M_c)}{\alpha_U(\mu)}\right)\right]. \tag{9}$$

We now apply the above solutions to the minimal $SU(5)$ GUT model with the particle contents as in Table 1. Since the beta function coefficient of the model is $b_U = 3$, we have

$$\alpha_U(M_{GUT})^{-1} = \alpha_U(M_c)^{-1} + \frac{3}{2\pi}\ln(M_{GUT}/M_c), \tag{10}$$

$$m_{\mathbf{10}}^2(M_{GUT}) = \frac{12}{5}M_{1/2}^2\left[1-\left(\frac{\alpha_U(M_c)}{\alpha_U(M_{GUT})}\right)^2\right], \tag{11}$$

$$m_{\mathbf{5}}^2(M_{GUT}) = m_{\bar{\mathbf{5}}}^2(M_{GUT}) = \frac{8}{5}M_{1/2}^2\left[1-\left(\frac{\alpha_U(M_c)}{\alpha_U(M_{GUT})}\right)^2\right], \tag{12}$$

$$A_u(M_{GUT}) = -\frac{32}{5}M_{1/2}\left[1-\left(\frac{\alpha_U(M_c)}{\alpha_U(M_{GUT})}\right)\right], \tag{13}$$

$$A_d(M_{GUT}) = -\frac{28}{5}M_{1/2}\left[1-\left(\frac{\alpha_U(M_c)}{\alpha_U(M_{GUT})}\right)\right], \tag{14}$$

where $M_{1/2} = M(M_{GUT})$ is the universal gaugino mass at the GUT scale. Note that the sfermion masses at the GUT scale are not universal, but the relation between soft masses of different representation fields are fixed by C_2.

For the simple $SO(10)$ model with the particle contents in Table 2, the beta function coefficient is $b_U = 4$ and we have

$$\alpha_U(M_{GUT})^{-1} = \alpha_U(M_c)^{-1} + \frac{2}{\pi}\ln(M_{GUT}/M_c), \tag{15}$$

$$m_{\mathbf{16}}^2(M_{GUT}) = \frac{45}{16}M_{1/2}^2\left[1-\left(\frac{\alpha_U(M_c)}{\alpha_U(M_{GUT})}\right)^2\right], \tag{16}$$

$$m_{\mathbf{10}}^2(M_{GUT}) = \frac{9}{4}M_{1/2}^2\left[1-\left(\frac{\alpha_U(M_c)}{\alpha_U(M_{GUT})}\right)^2\right], \tag{17}$$

$$A(M_{GUT}) = -\frac{63}{8}M_{1/2}\left[1-\left(\frac{\alpha_U(M_c)}{\alpha_U(M_{GUT})}\right)\right]. \tag{18}$$

In the $SO(10)$ model, the MSSM sfermion masses are universal at the GUT scale.

For numerical calculation, we have only two free parameters, M_G and M_c, with fixed $\tan\beta$ and the sign of the μ-parameter. In MSSM RGE analysis below M_{GUT}, we choose $M_{1/2}$ as a free parameter and the other soft parameters are fixed once M_c fixed. In order to compare sparticle spectrum in the two GUT models, it is necessary to fix a common base for them. We choose the values of free parameters in such a way that two models give the same neutralino LSP mass. In the gaugino mediations, neutralino LSP is bino-like, so that the same $M_{1/2}$ inputs for two models give (almost) the same masses for neutralino LSP. The compactification scale M_c is still left as a free parameter, whose degree of freedom is used to fix another sparticle mass. Here we impose a cosmological constraint that the relic abundance of neutralino LSP is consistent with the (cold) dark matter abundance measured by the WMAP [6]:

$$\Omega_{CMD}h^2 = 0.1131 \pm 0.0034. \tag{19}$$

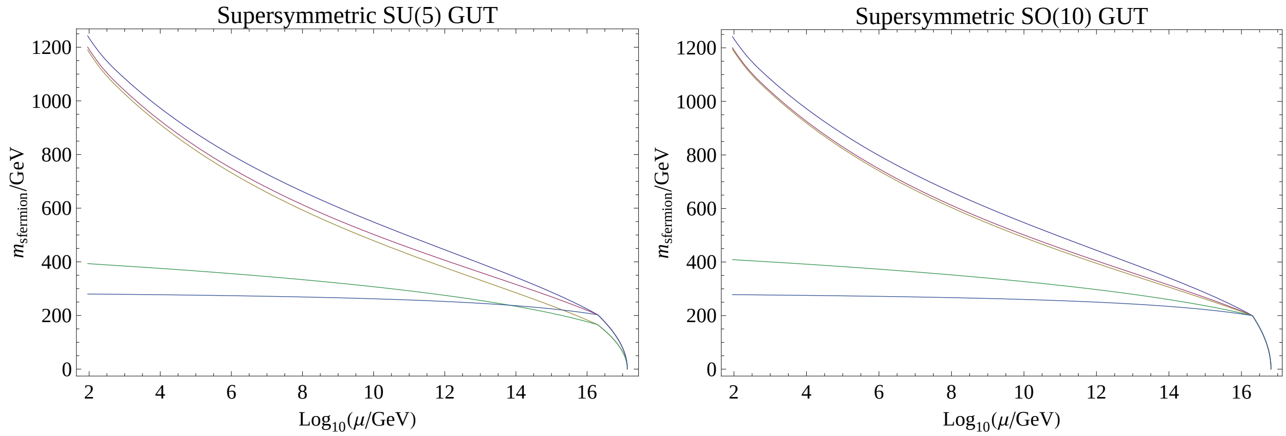

Figure 1: RGE evolution of the first two generation sfermion soft masses ($m_{\tilde{Q}}$, $m_{\tilde{U}^c}$, $m_{\tilde{D}^c}$, $m_{\tilde{L}}$ and $m_{\tilde{E}^c}$ from top to bottom) with $\tan\beta = 30$, $\mu > 0$ and $M_{1/2} = 500$ GeV for the $SU(5)$ and $SO(10)$ models, respectively.

This WMAP constraint dramatically reduces the viable parameter space of the models as in the constrained MSSM [7]. For a given $\tan\beta$ and a fixed $M_{1/2}$, the compactification scale is completely fixed by this cosmological constraint. As we will see, the right relic abundance is achieved by the neutralino co-annihilations with the next-to-LSP (mostly right-handed) stau almost degenerated with the LSP. For the two GUT models, the resultant next-to-LSP stau masses are found to be almost the same.

The RGE evolutions of the first two generations of squarks and sleptons are demonstrated in the case of $\tan\beta = 30$, $\mu > 0$ and $M_{1/2} = 500$ GeV for the $SU(5)$ and $SO(10)$ models in Figure 1. The compactification scales M_c for the two models are fixed to give the correct neutralino relic abundance: $M_c = 1.36 \times 10^{17}$ GeV and 6.53×10^{16} GeV for the $SU(5)$ and $SO(10)$ models, respectively. Here we can see characteristic features of running sfermion masses for the two GUT models, namely, sfermion masses are unified at two points in the $SU(5)$ model, on the other hand, one point unification in the $SO(10)$ model. The cosmological constraint requires the next-to-LSP stau, which is mostly the right-handed stau, is almost degenerated with the neutralino LSP, and we find $m_{\mathbf{10}}^{SU(5)} \approx m_{\mathbf{16}}^{SO(10)}$ at the GUT scale. However, there is a sizable mass splitting between $m_{\mathbf{5}}^{SU(5)}$ and $m_{\mathbf{16}}^{SO(10)}$. This is the key to distinguish the two GUT models. In terms of sparticles in the MSSM, the difference appears in masses of down-type squarks and the left-handed sleptons.

In our numerical analysis, we employ the SOFTSUSY 3.1.4 package [8] to solve the MSSM RGEs and produce mass spectrum. While running this program, we always set $sign(\mu) = +1$, for simplicity. The relic abundance of the neutralino dark matter is calculated by using the

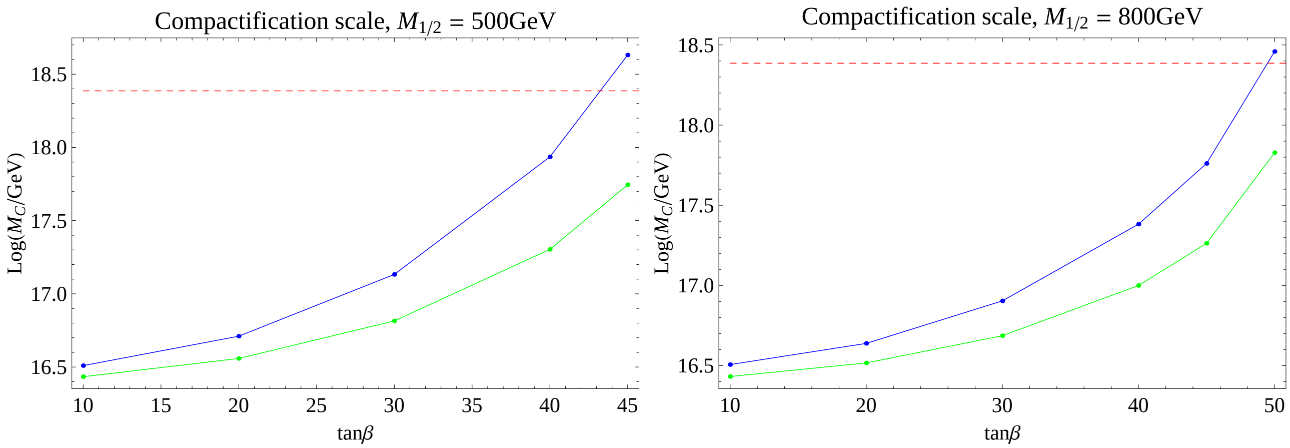

Figure 2: Compactification scale as a function of $\tan\beta$ in the case $M_{1/2} = 500$ GeV and 800 GeV. In each plot, the upper (blue) and lower (green) solid lines correspond to the $SU(5)$ and $SO(10)$ models, respectively. The horizontal dashed (red) line indicates the theoretical constraint (1).

micrOMEGAs 2.4 [9] with the output of SOFTSUSY in the SLHA format [10]. In addition to the cosmological constraint, we also take into account other phenomenological constraints such as the lower bound on Higgs boson mass [11]:

$$m_h \geq 114.4 \text{ GeV}, \tag{20}$$

the constraints on the branching ratios of $b \to s\gamma$, $B_s \to \mu^+\mu^-$ and the muon anomalous magnetic moment $\Delta a_\mu = g_\mu - 2$:

$$2.85 \times 10^{-4} \leq BR(b \to s + \gamma) \leq 4.24 \times 10^{-4}\ (2\sigma) \qquad [12], \tag{21}$$

$$BR(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-8} \qquad [13], \tag{22}$$

$$3.4 \times 10^{-10} \leq \Delta a_\mu \leq 55.6 \times 10^{-10}\ (3\sigma) \qquad [14]. \tag{23}$$

We examine two typical values of $M_{1/2} = 500$ and 800 GeV for a variety of $\tan\beta = 10$, 20, 30, 40, 45, and 50. The mass spectra of the two models are shown in Table 3 for the case of $M_{1/2} = 500$ GeV and in Table 4 for the case of $M_{1/2} = 800$ GeV. In Tables, we also list the values of the compactification scale M_c chosen to reproduce the observed dark matter abundance, the branching ratios of $b \to s\gamma$ and $B_s \to \mu^+\mu^-$, and the anomalous magnetic moment of muon Δa_μ.

Using the data in Tables 3 and 4, we plot the compactification scale as a function of $\tan\beta$ for $M_{1/2} = 500$ and 800 GeV, respectively, in Figure 2. The upper (blue) and lower (green) solid lines indicate the $SU(5)$ and $SO(10)$ models, respectively. The horizontal dashed (red) line corresponds to the upper bound on the compactification scale (1). These figures show that the theoretical constraint (1) rules out a large $\tan\beta$ region for the $SU(5)$ model. We find the upper bounds $\tan\beta \lesssim 43$ for $M_{1/2} = 500$ GeV and $\tan\beta \lesssim 49$ for $M_{1/2} = 800$ GeV. Comparing the two plots in Figure 2, we see that the bound on $\tan\beta$ becomes more severe for smaller $M_{1/2}$ inputs.

For the sparticle spectra presented in Tables 3 and 4, phenomenological constraints of (19), (20), (22) and (23) are all satisfied. However, the predicted branching ratio $BR(b \to s\gamma)$ can be too small to satisfy the experimental bound (21) for a large $\tan\beta$. In Figure 3, we show the values of $BR(b \to s\gamma)$ for all the samples in Table 3 and 4, along with the experimental allowed region between two dashed (red) lines. We can see that for the case with $M_{1/2} = 500$ GeV, there is an upper bound on $\tan\beta \lesssim 38$. In general, for a smaller $M_{1/2}$ input, we will find a more severe bound on $\tan\beta$.

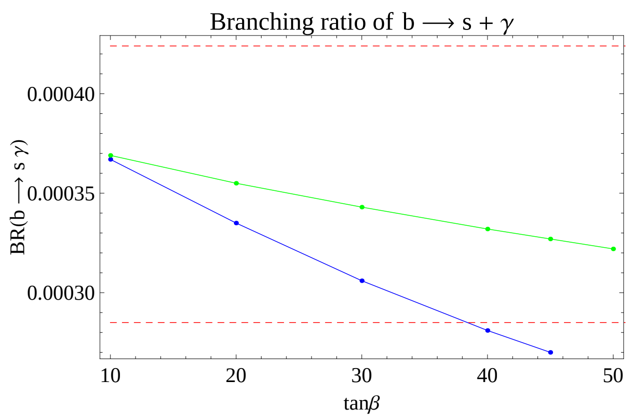

Figure 3: $BR(b \to s\gamma)$ as a function of $\tan\beta$ for $M_{1/2} = 500$ and 800 GeV. The lower (blue) and upper (green) solid lines correspond to $M_{1/2} = 500$ GeV and 800 GeV, respectively. The horizontal dashed (red) lines indicate the upper and lower bounds of the branching ratio (21).

Taking into account all theoretical and phenomenological bounds, we compare the mass difference between the two GUT models. As mentioned before, in Tables 3 and 4 we see relatively large mass differences in left-handed slepton sector and right-handed down-type squark sector. This effect is not so clear in the third generation squark masses because of the large Yukawa contributions. Figure 4 shows the mass difference $\delta m = m^{SO(10)} - m^{SU(5)}$ between left-handed selectrons/smuons of the two models as a function of $\tan\beta$ for $M_{1/2} = 500$ GeV (lower solid line) and 800 GeV (upper solid line). As we have discussed above, the upper bound on M_c and the constraint from sparticle contributions to the $b \to s\gamma$ process provide us the upper bound on $\tan\beta$. The dashed vertical line and the left dot-dashed line correspond to the upper bound on $\tan\beta$ from $BR(b \to s\gamma)$ and $M_c \leq M_P$, respectively, applied to the case with $M_{1/2} = 500$ GeV (lower solid line). The right dot-dashed line is the upper bound from $BR(b \to s\gamma)$ for the case with $M_{1/2} = 800$ GeV (upper solid line). Depending on values of $\tan\beta$, the mass differences for $M_{1/2} = 500$ GeV varies $\delta m = 5 - 25$ GeV, while $\delta m = 7 - 75$ GeV for $M_{1/2} = 800$ GeV. These mass differences can be sufficiently large compared to expected errors in measurements of sparticle masses at the LHC and the ILC [15].

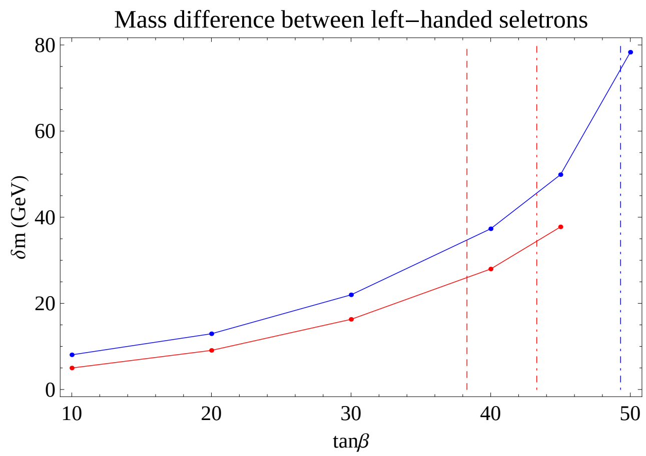

Figure 4: Mass difference $\delta m = m^{SO(10)} - m^{SU(5)}$ between left-handed selectrons/smuons of the two models is plotted as a function of $\tan\beta$ for $M_{1/2} = 500$ and 800 GeV. The lower (red) and upper (blue) solid lines correspond to Table 3 with $M_G = 500$ GeV and Table 4 with $M_G = 800$ GeV, respectively. The dashed line is the upper bound on $\tan\beta$ from the $b \to s\gamma$ constraint. The dot-dashed lines indicate the upper bounds on $\tan\beta$ by the theoretical constraint $M_c < M_P$. The right vertical bound applies to the case with $M_{1/2} = 800$ GeV, while two left vertical lines to the case with $M_{1/2} = 500$ GeV.

4 Conclusion

In the context of the gaugino mediation scenario, we have investigated supersymmetric grand unified theories. The gaugino mediation scenario, once applied to a GUT model, is highly predictive and all sparticle masses are determined by only two inputs, the unified gaugino mass and the compactification scale, with a given $\tan\beta$ and the sign of the μ-parameter. When we choose a particular GUT model with fixed particle contents, the relation among sparticle masses at the GUT scale is determined by the group theoretical factors, the Dynkin index and quadratic Casimir, associated with the representation of fields. Therefore, the difference of GUT models is reflected in sparticle mass spectrum at low energies. Taking two GUT models, the minimal $SU(5)$ GUT and a simple $SO(10)$ GUT models as examples, we have analyzed sparticle mass spectra together with theoretical and phenomenological constraints and compared resultant sparticle masses in the two models. Because of the difference in unification of quarks and leptons into representations under the GUT gauge groups, a significant difference among sparticle masses appears in the left-handed slepton and right-handed down-type squark sectors. Fixing the input parameters in each model so as to give the same neutralino mass and to reproduce the observed neutralino dark matter relic abundance, we have found sizable differences in sparticle mass spectra in two models, which can be identified in the LHC and the ILC. Although we have considered only two GUT models, our strategy is general, and we conclude that precise measurements of sparticle mass spectrum can be a probe to discriminate various supersymmetric unification scenarios.

Finally, we give a comment on the upper bound of the compactification scale $M_c \leq M_P$ (Eq. (1)). For a large $\tan\beta$, we need to raise M_c close to M_P in order to make neutralino the LSP and to obtain the correct relic abundance of neutralino dark matter. In this case, the sequestering effect becomes weaker and the boundary conditions set as $m_0(M_c) = 0$ and $A_0(M_c) = 0$ in our analysis will be no longer valid. Despite the fact that the tree level contributions to $m_0(M_c)$ and $A_0(M_c)$ remain zero, their non-zero values can be induced by loop effects of bulk fields such as the bulk gauge and the bulk supergravity multiplets. For example, the contributions to m_0^2 have been explicitly calculated as

$$\Delta(m_0^2)_{gauge} = \frac{\alpha_U(M_c)}{4\pi} M_G^2 \tag{24}$$

for the bulk gauge contribution [1], while for the bulk supergravity contribution [16],

$$\Delta(m_0^2)_{sugra} = -\frac{1}{16\pi^2} m_{3/2}^2 \left(\frac{M_c}{M_P}\right)^2 \tag{25}$$

with $m_{3/2}$ being gravitino mass. In the gaugino mediation scenario, we have a relation $m_{3/2} \simeq M_G(M_P/M_c)^{1/3}$ [2] and thus, the supergravity contributions is rewritten as

$$\Delta(m_0^2)_{sugra} = -\frac{1}{16\pi^2} M_G^2 \left(\frac{M_c}{M_P}\right)^{4/3}. \tag{26}$$

Note that although there is no volume suppression effect by M_c/M_P when $M_c \simeq M_P$, these contributions are still loop-suppressed. For $M_c \simeq M_P$, we have estimated that the non-zero $m_0(M_c)$ causes about 1% changes in resultant sparticle mass spectrum. These loop corrections are negligible.

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Table 3: Mass spectra and constraints for the two SUSY GUT models in gaugino mediation with $M_{1/2} = 500$ GeV

	$SU(5)$	$SO(10)$	$SU(5)$	$SO(10)$	$SU(5)$	$SO(10)$	$SU(5)$	$SO(10)$	$SU(5)$	$SO(10)$
$\tan\beta$	10		20		30		40		45	
h_0	115	115	116	116	117	117	117	117	117	117
H_0	720	720	684	683	639	636	582	573	551	535
A_0	719	720	684	683	639	636	583	573	551	535
$H^\pm$	724	724	689	688	645	642	588	579	557	541
$\tilde{g}$	1146	1146	1147	1147	1148	1148	1151	1151	1153	1153
$\tilde{\chi}^0_{1,2,3,4}$	204, 387, 649, 662	204, 387, 649, 662	205, 389, 652, 663	205, 389, 652, 663	206, 391, 666, 676	206, 391, 666, 676	206, 393, 694, 703	206, 393, 693, 702	207, 395, 717, 725	207, 395, 717, 725
$\tilde{\chi}^\pm_{1,2}$	387, 662	387, 662	389, 663	389, 663	391, 676	391, 676	393, 703	393, 702	395, 725	395, 725
$\tilde{d}, \tilde{s}_{R,L}$	1007, 1053	1009, 1053	1010, 1058	1013, 1058	1017, 1068	1023, 1067	1028, 1084	1040, 1083	1037, 1097	1054, 1096
$\tilde{u}, \tilde{c}_{R,L}$	1012, 1051	1012, 1050	1017, 1055	1017, 1055	1027, 1065	1026, 1064	1044, 1081	1043, 1080	1058, 1094	1057, 1094
$\tilde{b}_{1,2}$	963, 1004	963, 1005	954, 998	955, 1000	940, 990	941, 994	921, 985	924, 989	910, 984	916, 989
$\tilde{t}_{1,2}$	801, 1010	801, 1010	805, 1006	805, 1006	808, 1003	807, 1002	812, 1002	810, 1000	814, 1003	812, 1000
$\tilde{\nu}_{e,\mu,\tau}$	341, 341, 340	346, 346, 345	350, 350, 346	360, 360, 355	369, 369, 357	386, 386, 373	400, 400, 374	428, 428, 402	422, 422, 386	461, 461, 424
$\tilde{e}, \tilde{\mu}_{R,L}$	219, 350	219, 355	241, 359	240, 368	280, 378	278, 394	337, 408	335, 436	377, 430	376, 468
$\tilde{\tau}_{1,2}$	211, 351	211, 356	211, 364	211, 372	214, 386	214, 399	219, 417	218, 436	222, 436	221, 461
M_c	3.23×10^{16}	2.71×10^{16}	5.14×10^{16}	3.62×10^{16}	1.36×10^{17}	6.53×10^{16}	8.62×10^{17}	2.01×10^{17}	4.28×10^{18}	5.56×10^{17}
$BR(b \to s\gamma)$	3.67×10^{-4}	3.67×10^{-4}	3.35×10^{-4}	3.35×10^{-4}	3.06×10^{-4}	3.06×10^{-4}	2.81×10^{-4}	2.81×10^{-4}	2.70×10^{-4}	2.69×10^{-4}
$BR(B_s \to \mu^+\mu^-)$	3.15×10^{-9}	3.15×10^{-9}	3.59×10^{-9}	3.59×10^{-9}	5.83×10^{-9}	5.87×10^{-9}	1.67×10^{-8}	1.75×10^{-8}	3.42×10^{-8}	3.79×10^{-8}
Δa_μ	9.28×10^{-10}	9.13×10^{-10}	1.74×10^{-9}	1.69×10^{-9}	2.35×10^{-9}	2.25×10^{-9}	2.71×10^{-9}	2.53×10^{-9}	2.78×10^{-9}	2.55×10^{-9}
Ωh^2	0.113		0.113		0.113		0.113		0.113	

Table 4: Mass spectra and constraints for the two SUSY GUT models in gaugino mediation with $M_{1/2} = 800$ GeV

	$SU(5)$	$SO(10)$	$SU(5)$	$SO(10)$	$SU(5)$	$SO(10)$	$SU(5)$	$SO(10)$	$SU(5)$	$SO(10)$	$SU(5)$	$SO(10)$
$\tan\beta$	10		20		30		40		45		50	
h_0	119	119	119	119	119	119	119	119	119	119	119	119
H_0	1106	1106	1049	1048	975	972	877	868	819	805	762	737
A_0	1106	1106	1049	1048	975	972	877	869	820	805	762	737
$H^\pm$	1109	1109	1052	1051	978	976	881	873	824	809	767	742
$\tilde{g}$	1770	1771	1771	1771	1772	1772	1775	1775	1777	1778	1780	1783
$\tilde{\chi}^0_{1,2,3,4}$	335, 634, 983, 992	335, 635, 983, 993	336, 636, 982, 990	336, 636, 982, 991	337, 638, 995, 1003	337, 638, 996, 1004	338, 640, 1022, 1029	338, 641, 1024, 1031	338, 642, 1043, 1049	338, 643, 1048, 1054	339, 644, 1081, 1087	340, 646, 1099, 1104
$\tilde{\chi}^\pm_{1,2}$	635, 992	635, 992	636, 991	637, 991	638, 1003	639, 1004	640, 1029	641, 1031	642, 1050	643, 1055	644, 1087	646, 1105
$\tilde{d}, \tilde{s}_{R,L}$	1544, 1619	1547, 1619	1547, 1625	1552, 1625	1554, 1635	1563, 1635	1567, 1652	1582, 1653	1576, 1665	1597, 1667	1592, 1687	1626, 1695
$\tilde{u}, \tilde{c}_{R,L}$	1553, 1618	1553, 1618	1559, 1623	1559, 1623	1569, 1633	1569, 1633	1588, 1650	1588, 1651	1601, 1663	1603, 1665	1624, 1686	1633, 1694
$\tilde{b}_{1,2}$	1485, 1537	1485, 1540	1474, 1523	1474, 1527	1454, 1505	1456, 1510	1427, 1489	1432, 1494	1411, 1483	1419, 1489	1396, 1482	1411, 1491
$\tilde{t}_{1,2}$	1254, 1517	1254, 1517	1259, 1510	1259, 1510	1263, 1502	1263, 1501	1269, 1495	1269, 1493	1273, 1492	1273, 1491	1279, 1494	1279, 1493
$\tilde{\nu}_{e,\mu,\tau}$	546, 546, 545	555, 555, 553	557, 557, 549	570, 570, 562	576, 576, 559	598, 598, 581	608, 608, 574	646, 646, 611	631, 631, 585	682, 682, 633	669, 669, 604	748, 748, 677
$\tilde{e}, \tilde{\mu}_{R,L}$	345, 552	345, 560	368, 562	369, 575	411, 582	411, 604	475, 614	478, 651	518, 636	525, 686	585, 674	609, 752
$\tilde{\tau}_{1,2}$	337, 552	337, 560	338, 561	338, 574	341, 578	340, 597	346, 603	346, 634	351, 619	350, 660	367, 645	370, 706
M_c	3.21×10^{16}	2.70×10^{16}	4.35×10^{16}	3.29×10^{16}	8.01×10^{16}	4.86×10^{16}	2.41×10^{17}	9.99×10^{16}	5.76×10^{17}	1.83×10^{17}	2.88×10^{18}	6.73×10^{17}
$BR(b \to s\gamma)$	3.69×10^{-4}	3.69×10^{-4}	3.55×10^{-4}	3.55×10^{-4}	3.43×10^{-4}	3.43×10^{-4}	3.32×10^{-4}	3.32×10^{-4}	3.26×10^{-4}	3.27×10^{-4}	3.22×10^{-4}	3.22×10^{-4}
$BR(B_s \to \mu^+\mu^-)$	3.13×10^{-9}	3.13×10^{-9}	3.28×10^{-9}	3.29×10^{-9}	4.01×10^{-9}	4.02×10^{-9}	6.89×10^{-9}	7.02×10^{-9}	1.10×10^{-8}	1.16×10^{-8}	2.03×10^{-8}	2.31×10^{-8}
Δa_μ	3.61×10^{-10}	3.55×10^{-10}	6.91×10^{-10}	6.74×10^{-10}	9.65×10^{-10}	9.26×10^{-10}	1.16×10^{-9}	1.09×10^{-9}	1.23×10^{-9}	1.13×10^{-9}	1.24×10^{-9}	1.09×10^{-9}
Ωh^2	0.113		0.113		0.113		0.113		0.113		0.113	