Gauge Mediation

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(Almost) Everything about Gauge Mediation

1 Motivation for Models with Gauge-Mediated Supersymmetry Breaking

As we have learned in previous presentations in this seminar, supersymmetry (SUSY) must be softly broken in order to be phenomenologically viable. However, SUSY cannot be broken in the observable sector, as this would usually imply that at least some of the sparticles should have been already observed. This reasoning is based on the supertrace theorem which states that for a globally supersymmetric theory without gravitational anomalies the following supertrace vanishes:

$$\mathrm{STr}\,\mathcal{M}^2 = \sum_J (-1)^{2J}(2J+1)\mathcal{M}_J^2 = 0. \tag{1.1}$$

Here $\mathcal{M}_J$ is the tree-level mass of a particle with spin J. In the case of tree-level SUSY-breaking communication this theorem rather generically implies the existence of a sparticle lighter than its ordinary partner.

Consequently, it is usually assumed that SUSY is broken in a hidden sector which has no renormalizable couplings to the observable sector which contains the MSSM particles. Moreover, the effective theory describing the observable sector should have a non-vanishing supertrace.

A generic example is given by gravity mediation in supergravity and has already been discussed in this seminar. Another possibility is a theory with vanishing supertrace at the tree level, but with a non-vanishing supertrace at the quantum level, induced by the known gauge interactions. This type of theories is called gauge mediation.

One problem in gravity mediation is the generic introduction of new sources of flavor violation. In the Standard Model (SM) the Yukawa couplings are the only source of flavor violation, whereas the gauge interactions are flavor blind. The new physics that creates the Yukawa couplings is unknown but its scale Λ_F is usually assumed to be high – probably close to M_{GUT} or even M_P. Since in gravity mediation the soft SUSY breaking terms are created at $M_P \gtrsim \Lambda_F$ we generically expect new sources of flavor violation. In the case of gauge mediation, on the other hand, the soft terms are generated at a messenger scale M. If $M \ll \Lambda_F$, the flavor violation in the soft terms is only created via Yukawa interactions. This is one of the main motivations for models with gauge-mediated SUSY breaking (GMSB).

Another, more technical, motivation is that since the mechanism is happening at scales much below M_P the dynamics can be treated with field-theoretical tools – we avoid difficulties with treating quantum gravity. Thus gauge mediation is often also discussed in connection with mechanisms for SUSY breaking like dynamical SUSY breaking (DSB).

2 Ordinary Gauge Mediation

With the term ordinary gauge mediation we refer to the class of models of gauge-mediated supersymmetry breaking with a messenger sector that are described in the review by Giudice and Rattazzi [1].

2.1 General Structure of GMSB Models

The Messenger Sector We do not know the mechanism of SUSY breaking, but we know that SUSY must be broken in a hidden sector. Therefore, we can describe our ignorance by a spurion X which is a SM singlet chiral superfield that acquires a VEV along the scalar and auxiliary components:

$$\langle X \rangle = M + \theta^2 F \,. \tag{2.1}$$

The parameters M and $\sqrt{F}$ are the fundamental mass scales connected with GMSB.

In addition to the unspecified hidden sector and the observable sector that contains all the MSSM fields we have a messenger sector which mediates SUSY breaking to the observable sector (see figure 1). The structure of the unknown messenger sector dominantly determines the low-energy phenomenology. In the minimal model the messenger sector is composed of N_f flavors of chiral superfields ϕ_i and $\tilde{\phi}_i$ $(i = 1, \ldots, N_f)$ transforming as a real representation $\mathbf{r} \oplus \bar{\mathbf{r}}$ under the SM gauge group and coupling to the superfield X at tree level via Yukawa-like interactions:

$$W = \lambda_{ij} X \phi_i \tilde{\phi}_j \,. \tag{2.2}$$

Replacing X by its VEV this coupling generates a supersymmetric mass of order M for the messenger fields and mass-squared splittings inside the messenger supermultiplets of order F.

Figure 1: Modular structure of models with gauge-mediated supersymmetry breaking.

In order to preserve gauge coupling unification the messenger fields are usually chosen to form complete GUT multiplets, e.g. ϕ_i and $\tilde{\phi}_i$ transforming in the $\mathbf{5} \oplus \bar{\mathbf{5}}$ under $SU(5) \supset G_{SM}$. In this case the GUT scale M_{GUT} is unchanged but the unified gauge coupling receives an extra contribution compared to the MSSM case:

$$\delta\alpha_{GUT}^{-1} = -\frac{N}{2\pi} \ln \frac{M_{GUT}}{M}\,, \qquad \text{where} \quad N = \sum_{i=1}^{N_f} 2T(\mathbf{r}_i) \tag{2.3}$$

is the sum of the indices of the representations of the different flavors. In the case of $\mathbf{5} \oplus \bar{\mathbf{5}}$ we have $T = 1/2$ and therefore $N = N_f$. Requiring perturbativity up to the GUT scale then implies an upper bound on the so-called messenger index N:

$$N \lesssim 150/\ln \frac{M_{GUT}}{M}\,. \tag{2.4}$$

Soft Mass Spectrum Since the MSSM supermultiplets do not directly couple to the spurion superfield X, they are mass-degenerate at tree level. While the gauge boson and matter fermion masses are protected by gauge invariance, the gauginos and sfermions can receive soft SUSY-breaking contributions to their masses at loop level (see figure 2). Gaugino masses arise at one-loop level from gauge couplings to messengers, whereas squared sfermion masses require two loops involving messengers and gauge bosons. Thus, we naturally expect the soft masses to be of the same order:

$$m_{soft} \sim \frac{\alpha_r}{4\pi} \frac{F}{M}\,. \tag{2.5}$$

If the messenger mass scale M and the SUSY breaking scale $\sqrt{F}$ are comparable in size, then these scales differ only by the loop factor from the soft mass scale, i.e. $\sqrt{F} \sim 10^4$–10^5 GeV. In most realistic cases, however, one considers the case where $\sqrt{F} \ll M$ which requires a higher SUSY breaking scale.

An explicit Feynman diagram diagram calculation in the leading-log approximation gives for the SUSY-breaking gaugino masses at the scale μ ($t = \ln M^2/\mu^2$)

$$M_r(t) = \frac{\alpha_r(t)}{4\pi} \Lambda_G\,, \tag{2.6}$$

with the gauge couplings α_r in a GUT normalization and

$$\Lambda_G = N \frac{F}{M} g(F/M^2)\,, \tag{2.7}$$

where

$$g(x) = \frac{1}{x^2}\left[(1+x)\ln(1+x)\right] + (x \to -x)\,. \tag{2.8}$$

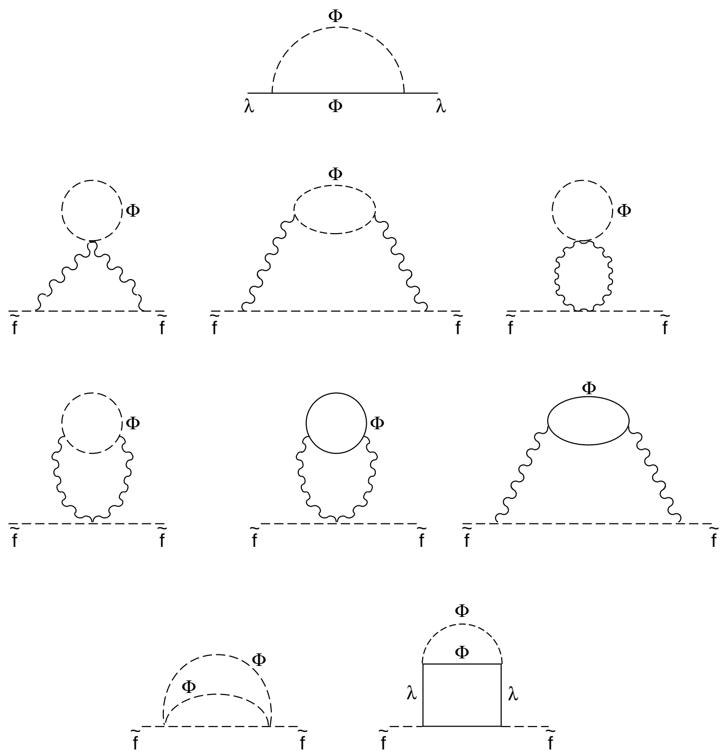

Figure 2: Feynman diagrams contributing to the soft supersymmetry-breaking gaugino (λ) and sfermion ($\tilde{f}$) masses. The scalar and fermionic components of the messenger fields (Φ) are denoted by dashed and solid lines, respectively. Gauge bosons are denoted by wiggled lines. Figure taken from [1].

In the limit $F \ll M^2$ this expression simplifies to

$$M_r(t) = \frac{\alpha_r(t)}{4\pi} \, N \, \frac{F}{M} \, . \tag{2.9}$$

This leads to universal gaugino masses at the GUT scale and the general relation

$$\frac{M_1}{\alpha_1} = \frac{M_2}{\alpha_2} = \frac{M_3}{\alpha_3} = N \, \frac{F}{M} \, . \tag{2.10}$$

Neglecting contributions from Yukawa couplings the SUSY-breaking sfermion masses turn out to be

$$m^2_{\tilde{f}}(t) = 2 \sum_{r=1}^{3} C_2^{\tilde{f}} \, \frac{\alpha_r^2(t)}{16\pi^2} \left[\Lambda_S^2 + \frac{1}{b_r} \left(1 - \frac{\alpha_r^2(t)}{\alpha_r^2(0)} \right) \Lambda_G^2 \right] \tag{2.11}$$

with

$$\alpha_r(t) = \alpha_r(0) \left[1 + \frac{\alpha_r(0)}{4\pi} \, b_r t \right]^{-1} \tag{2.12}$$

and

$$\Lambda_S^2 = N \, \frac{F^2}{M^2} \, f(F/M^2) \, , \tag{2.13}$$

where

$$f(x) = \frac{1+x}{x^2} \left[\ln(1+x) - 2 \, \mathrm{Li}_2\left(\frac{x}{1+x} \right) + \frac{1}{2} \, \mathrm{Li}_2\left(\frac{2x}{1+x} \right) \right] + (x \to -x) \, . \tag{2.14}$$

Here $\mathrm{Li}_2(x) = \int_2^x \frac{dt}{\ln t}$ is an Eulerian logarithmic integral. In the limit $F \ll M^2$ this expression simplifies to

$$m_{\tilde{f}}^2(t) = 2\sum_{r=1}^{3} C_2^{\tilde{f}} \, \frac{\alpha_r^2(t)}{16\pi^2} \left[N\,\frac{F^2}{M^2} + \frac{1}{b_r}\left(1 - \frac{\alpha_r^2(t)}{\alpha_r^2(0)}\right) N^2\,\frac{F^2}{M^2}\right], \tag{2.15}$$

where $C_2^{\tilde{f}}$ is the quadratic Casimir, i.e. $C_2 = (N^2-1)/2N$ for the fundamental representation of $SU(N)$ and $C_2 = Y^2$ for the $U(1)$, and $b_1 = 33/5$, $b_2 = 1$ and $b_3 = -3$ are the one-loop β-function coefficients.

In order to obtain the physical sfermion squared masses one has to add the D-term contribution $M_Z^2 \cos 2\beta (T_3^{\tilde{f}} - Q^{\tilde{f}} \sin^2\theta_W)$. In the case of the stop one cannot neglect the Yukawa contribution and this leads to a smaller stop mass compared to the other colored sfermions.

There is typically a large hierarchy between strongly and weakly interacting particles which comes from the hierarchy in the coupling constants ($\alpha_3 \gg \alpha_2, \alpha_1$).

The soft trilinear terms arise only at two-loop order and are generated proportional to the corresponding Yukawa couplings. Therefore we do not have any new source of flavor violation.

In the limit $F \ll M^2$ the soft masses and the trilinear terms can also be determined using an elegant method that extracts the terms from the gauge and matter wave-function renormalizations S and Z. The holomorphic function $S(X,\mu)$ can be obtained by integrating the renormalization group evolution from an ultraviolet scale Λ_{UV} down to the scale μ across the messenger threshold M:

$$S(X,\mu) = S(\Lambda_{UV}) + \frac{b'}{32\pi^2} \ln\frac{X}{\Lambda_{UV}} + \frac{b}{32\pi^2}\ln\frac{\mu}{X}\,, \tag{2.16}$$

where b is the one-loop β-function coefficient of the low-energy theory and $b' = b - N$ takes care of the messenger contribution to the running. At the minimum $\langle X \rangle = M + \theta^2 F$ the soft gaugino mass then is given by

$$M_\lambda(\mu) = -\,\frac{1}{2}\,\frac{\partial \ln S(X,\mu)}{\partial \ln X}\bigg|_{X=M} \frac{F}{M}\,. \tag{2.17}$$

The real function $Z(X,X^\dagger,\mu)$ is determined by integrating the renormalization group evolution from Λ_{UV} down to μ with tree-level matching at the intermediate scale M:

$$Z(X,X^\dagger,\mu) = Z(\Lambda_{UV}) \left[\frac{\alpha(\Lambda_{UV})}{\alpha(X)}\right]^{2C_2^{\tilde{f}}/b'} \left[\frac{\alpha(X)}{\alpha(\mu)}\right]^{2C_2^{\tilde{f}}/b}\,, \tag{2.18}$$

where

$$\alpha^{-1}(\mu) = \alpha^{-1}(X) + \frac{b}{4\pi}\ln\frac{\mu^2}{XX^\dagger}\,, \qquad \alpha^{-1}(X) = \alpha^{-1}(\Lambda_{UV}) + \frac{b'}{4\pi}\ln\frac{XX^\dagger}{\Lambda_{UV}^2}\,. \tag{2.19}$$

Then the soft sfermion masses and trilinear terms are given by:

$$m_{\tilde{f}}^2(\mu) = -\,\frac{\partial^2 \ln Z(X,X^\dagger,\mu)}{\partial \ln X\,\partial \ln X^\dagger}\bigg|_{X=M} \frac{FF^\dagger}{MM^\dagger} \tag{2.20}$$

and

$$A(\mu) = \frac{\partial \ln Z(X, X^\dagger, \mu)}{\partial \ln X}\bigg|_{X=M} \frac{F}{M}\,. \tag{2.21}$$

Radiative electroweak symmetry breaking (EWSB) requires to have

$$2|\mu|^2 = \frac{|m_{H_d}^2 - m_{H_u}^2|}{\sqrt{1-\sin^2(2\beta)}} - m_{H_u}^2 - m_{H_d}^2 - M_Z^2 \tag{2.22}$$

and

$$2b = \sin(2\beta)\left(m_{H_u}^2 + m_{H_d}^2 + 2|\mu|^2\right)\,. \tag{2.23}$$

The solution of these equations usually leads to a large value for μ compared to the bino mass. Therefore the lightest neutralino is mainly bino-like and in many cases the lightest sparticle.

In conclusion ordinary gauge mediation is a very predictive scenario and one expects a number of distinctive features in the mass spectrum:

- Unification of gauge couplings implies unification of gaugino masses
- Gaugino and sfermion masses are similar
- Colored sparticles are more massive than uncolored sparticles
- Usually a bino or a stau as the NLSP

The μ Problem in GMSB Models In the MSSM we have a supersymmetric mass term for the two Higgs doublets

$$W = \mu H_u H_d \tag{2.24}$$

and in addition a soft SUSY-breaking mass term

$$V = bH_u H_d + h.c. \tag{2.25}$$

Radiative EWSB implies that we typically need to have the supersymmetric mass term and the SUSY-breaking soft mass term at the same order and in particular both at the scale of soft masses:

$$b \sim \mu^2 \sim \left(\frac{1}{16\pi^2}\frac{F}{M}\right)^2\,. \tag{2.26}$$

In general the μ problem is connected to the fact that μ is required to be at the weak scale while it is expected to be at some high fundamental mass scale, since it is a parameter of the unbroken supersymmetric theory. If, however, the generation of μ is connected to gauge-mediated SUSY breaking, then the main problem is not to generate it at the correct scale but to generate b at the same scale.

If we introduce a direct coupling of the Higgs fields to the SUSY-breaking field X,

$$W = \lambda X H_u H_d\,, \tag{2.27}$$

we get $\mu = \lambda M$ while $b = \lambda F$. Then, even if $F \sim M^2$, μ and b are generated at the same order of the small parameter λ and therefore b is typically too large.

Even if this is a generic problem there are particular models which can achieve the correct ratio. Adding two singlet fields S and N we can have a superpotential

$$W = S\left(\lambda_1 H_u H_d + \lambda_2 N^2 + \lambda\phi\tilde{\phi} - M_N^2\right) + X\phi\tilde{\phi} \tag{2.28}$$

giving $\mu = \lambda_1 \langle S\rangle$ and $b = \lambda_1 F_S$. The VEV for S is generated at one loop,

$$\langle S\rangle \sim \frac{1}{16\pi^2}\frac{F^2}{MM_N^2}\,, \tag{2.29}$$

whereas F_S is only generated at two-loop level:

$$F_S \sim \left(\frac{1}{16\pi^2}\frac{F}{M}\right)^2 . \tag{2.30}$$

Thus we obtain $b \sim \mu^2$ if $M_N^2 \sim F$ can be arranged. So there ways to adjust μ and b but these mechanisms do not appear very generically in GMSB models.

2.2 Phenomenological Implications

When the theory is coupled to gravity, the massless spin-1/2 goldstino field from SUSY breaking provides the longitudinal modes of the gravitino and therefore the gravitino acquires a SUSY-breaking mass. In supergravity this mass is given by

$$m_{3/2} = \frac{F_0}{\sqrt{3}M_P}\,, \tag{2.31}$$

where F_0 is the fundamental SUSY-breaking scale. The ratio $k \equiv F/F_0$ between the SUSY breaking in the messenger sector and the fundamental SUSY-breaking scale depends on how SUSY breaking is communicated to the messengers. In the case of a tree-level coupling it is just given by the coupling constant λ. The gravitino mass can then be rewritten as

$$m_{3/2} = \frac{F}{k\sqrt{3}M_P} = \frac{1}{k}\left(\frac{\sqrt{F}}{100\,\mathrm{TeV}}\right)^2 2.4\,\mathrm{eV} \tag{2.32}$$

and it follows that the gravitino is the lightest supersymmetric particle (LSP) for any relevant value of F in GMSB models. Actually, since the gravitino mass is the measure of gravity-mediated effects, it is the solution to the flavor problem in gravity mediation that requires this light gravitino.

A light gravitino can be problematic in cosmology as there a severe upper bounds on the reheating temperature from the requirement that the gravitinos do not overclose the universe:

$$T_R < 10\,\mathrm{TeV} \times h^2 \left(\frac{m_{3/2}}{100\,\mathrm{keV}}\right)\left(\frac{\mathrm{TeV}}{M_3}\right). \tag{2.33}$$

For gravitino masses below keV, however, this problem is absent. If they are produced at the right abundance gravitinos are a generic candidate for the dark matter in the universe. Depending on their mass they behave as cold or warm dark matter.

In GMSB models with conserved R-parity we expect all sparticles to decay promptly into the next-to-lightest supersymmetric particle (NLSP) which then decays into the gravitino with couplings suppressed by F. The NLSP is typically a bino or a stau with lifetime

$$\tau_{NLSP} = \frac{1}{k^2}\left(\frac{100\,\mathrm{GeV}}{m_{NLSP}}\right)^5\left(\frac{\sqrt{F}}{100\,\mathrm{TeV}}\right)^4 3\times 10^{-13}\,\mathrm{s}\,, \tag{2.34}$$

which also has important implications for cosmology since late decays of the NLSP can potentially spoil the correct predictions of big bang nucleosynthesis (BBN).

There are also distinctive signals at colliders: Apart from the structure of the mass spectrum there are specific signals depending on the NLSP decay length

$$L_{NLSP} = \frac{1}{k^2}\left(\frac{100\,\mathrm{GeV}}{m_{NLSP}}\right)^5\left(\frac{\sqrt{F}}{100\,\mathrm{TeV}}\right)^4\sqrt{\frac{E_{NLSP}^2}{m_{NLSP}^2}-1}\;\;100\,\mu\mathrm{m}\,. \tag{2.35}$$

Depeding on the SUSY-breaking scale F we can have the following three cases:

- $\sqrt{F} \gtrsim 10^6\,\mathrm{GeV}$
  - NLSP decays outside the detector and appears to be stable
  - The neutralino NLSP case resembles the stable neutralino case with missing transverse energy
  - The stau NLSP case gives an ionizing track of a massive charged particle
- $\sqrt{F} \lesssim 10^6\,\mathrm{GeV}$
  - NLSP promptly decays
  - The neutralino NLSP decays into a photon and a gravitino giving two photons plus missing energy in the final state
  - The stau NLSP decays into a stau and a gravitino giving two charged leptons plus missing energy in the final state
- $\sqrt{F} \sim 10^6\,\mathrm{GeV}$
  - NLSP decays with a displaced vertex inside the detector
  - Allows reconstruction of the SUSY-breaking scale

3 Recent Developments

3.1 (Extra)Ordinary Gauge Mediation

In the last years it has been discussed if the generic predictions of ordinary GMSB scenarios are really generic. In (extra)ordinary gauge mediation the implications of a generalized superpotential coupling of the messengers to the singlet X are studied. The most general renormalizable, gauge invariant superpotential is given by

$$W = (\lambda_{ij}X + m_{ij})\,\phi_i\tilde{\phi}_j = (\lambda_{2ij}X + m_{2ij})\,l_i\tilde{l}_j + (\lambda_{3ij} + m_{3ij})\,q_i\tilde{q}_j\,. \tag{3.1}$$

Here $l_i, \tilde{l}_i$ and $q_i, \tilde{q}_i$ are the $SU(2)$ doublet and $SU(3)$ triplet components of $\phi_i, \tilde{\phi}_i$, respectively. It might well be that there is a splitting between doublet and triplet components similar to SUSY GUT models and their origin might also be related. In comparison with ordinary gauge mediation the superpotential contains additional supersymmetric messenger mass terms in (extra)ordinary gauge mediation. This can lead to a couple of changes on the predictions of GMSB models:

- A triplet messenger index much larger than the doublet messenger index reduces the mass hierarchy between squarks and sleptons and their masses can even be at the same scale
- Different messenger indices for the doublet and triplet components can also lead to a small μ parameter. This implies a higgsino-like NLSP and therefore different collider signals
- The effective messenger index can be smaller than one, giving the possibility for very light gauginos

The prediction of gaugino mass unification, a light gravitino LSP and therefore no introduction of new sources for flavor violation are still valid in these models.

3.2 General Gauge Mediation

The goal of this framework is to study which predictions of models with GMSB are really generic and which predictions are model-dependent. Therefore general gauge mediation defines gauge mediation in a much broader sense than the ordinary GMSB models. This definition includes an observable sector with all the MSSM fields and a hidden sector with a global symmetry $G \supset G_{SM}$ that contains the source of SUSY breaking at a scale M, messengers (if there are any) and other particles outside the MSSM. Now the requirement is that gauge fields of the MSSM couple to the hidden sector and communicate SUSY breaking, i.e. in the limit $\alpha_r \to 0$ the two sectors are decoupled.

Technically the hidden sector information is contained in the current supermultiplet $\mathcal{J}(x, \theta, \bar{\theta})$ of G satisfying the conservation equation

$$D^2 \mathcal{J} = \bar{D}^2 \mathcal{J} = 0 \tag{3.2}$$

and their correlation functions. The non-vanishing two-point functions are determined from Lorentz invariance and current conservation. In general it turns out that the gaugino masses are not related to each other. In addition the sfermion masses are not related to the gaugino masses, but there exist two sum rules for the sfermion masses at the high scale M:

$$\mathrm{Tr}\, Y m_{\tilde{f}}^2 = 0\,, \tag{3.3}$$

$$\mathrm{Tr}\, (B - L)\, m_{\tilde{f}}^2 = 0\,. \tag{3.4}$$

The generic predictions of gauge mediation found in this framework are:

- No new sources of flavor violation

- Existence of two mass relations for the sfermions
- Typically small trilinear terms
- Correct ratio of μ and b challenging
- The gravitino is the lightest supersymmetric particle

In conclusion, none of the characteristics of ordinary gauge mediation, except for the existence of a gravitino LSP, generalizes to general gauge mediation.

3.3 Tree Level Gauge Mediation

This recently proposed class of models breaks with the common lore that SUSY breaking must be mediated at the loop level. In a particular realization the model is a SUSY GUT with an additional $U(1)_X$ gauge group. A simple choice is an $SO(10)$ model which contains the maximal subgroup $SU(5) \times U(1)$. SUSY breaking is described by a SM singlet field Z that acquires an F-term VEV and carries a charge X_Z under the $U(1)_X$.

Sfermion masses are generated at tree level from the coupling of the Z VEV to the sfermions via the heavy gauge superfield V_X:

$$m_{\tilde{f}}^2 = 2g^2 X_{\tilde{f}} X_Z \left(\frac{F}{M_V} \right)^2 . \tag{3.5}$$

The supertrace sum rule is fulfilled since the SUSY breaking scalar masses are proportional to their X charge and the $U(1)_X$ generator is traceless for complete GUT multiplets.

Gaugino masses are generated at one-loop level with heavy matter fields acting as messengers to SUSY breaking:

$$M_\lambda \sim N \frac{\alpha}{4\pi} \frac{F}{M} , \tag{3.6}$$

where N is the messenger index and M the messenger mass. One would expect that the gaugino masses are suppressed by a loop factor with respect to the sfermion masses. However, typically this factor is partly compensated by the fact that usually $N > 1$ and the messenger mass scale M is smaller than the heavy gauge boson mass scale M_V.

The predictions for the low-energy spectrum depend on the particular embedding in the $SU(5)$ multiplets. In the studied cases they are the following:

- The soft mass ratio of sfermions in different $SU(5)$ multiplets at the GUT scale is given by:
$$m_{\bar{\mathbf{5}}}^2 = 2m_{\mathbf{10}}^2 \qquad \text{or} \qquad m_{\bar{\mathbf{5}}}^2 = \frac{3}{4} m_{\mathbf{10}}^2 . \tag{3.7}$$
- Gaugino masses are suppressed with respect to sfermion masses by a factor of about 10:
$$M_\lambda / m_{\mathbf{10}}^2 = 1/10 . \tag{3.8}$$
- The NLSP is the bino and the LSP is a gravitino with mass around 15 GeV.

More about Gauge Mediation

[1] G. F. Giudice and R. Rattazzi, "Theories with gauge-mediated supersymmetry breaking," Phys. Rept. **322** (1999) 419 [arXiv:hep-ph/9801271] and references therein.

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[3] P. Meade, N. Seiberg and D. Shih, "General Gauge Mediation," Prog. Theor. Phys. Suppl. **177** (2009) 143 [arXiv:0801.3278 [hep-ph]] and citations thereof.

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