Dirac Gauginos, Negative Supertraces and Gauge Mediation

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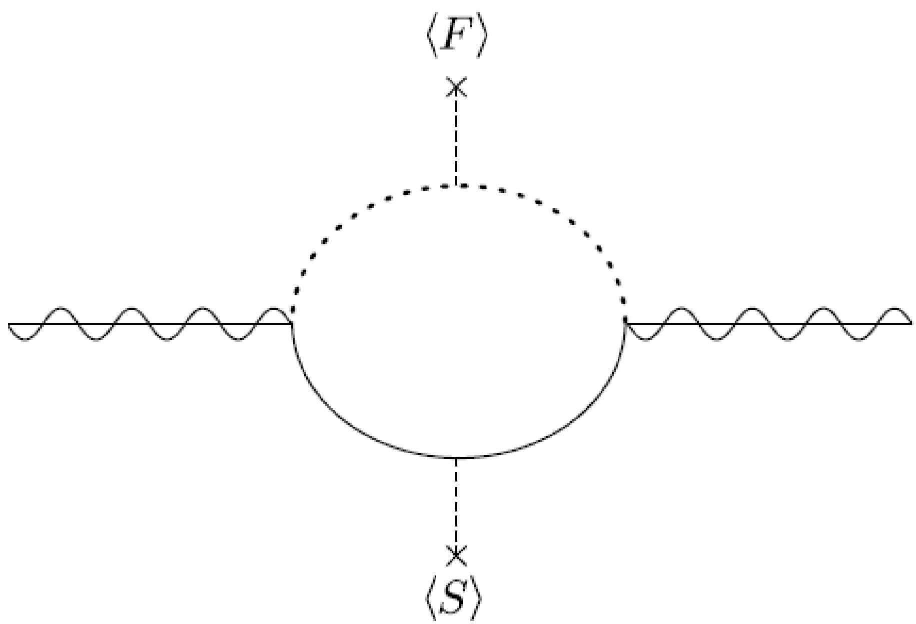
Minimal Gauge Mediation

messenger fields communicate SUSY breaking to the MSSM

$$W = XM\overline{M} \rightarrow vM\overline{M} + \theta^2 F_X M\overline{M}$$



Gaugino and scalar masses are proportional to a single mass parameter

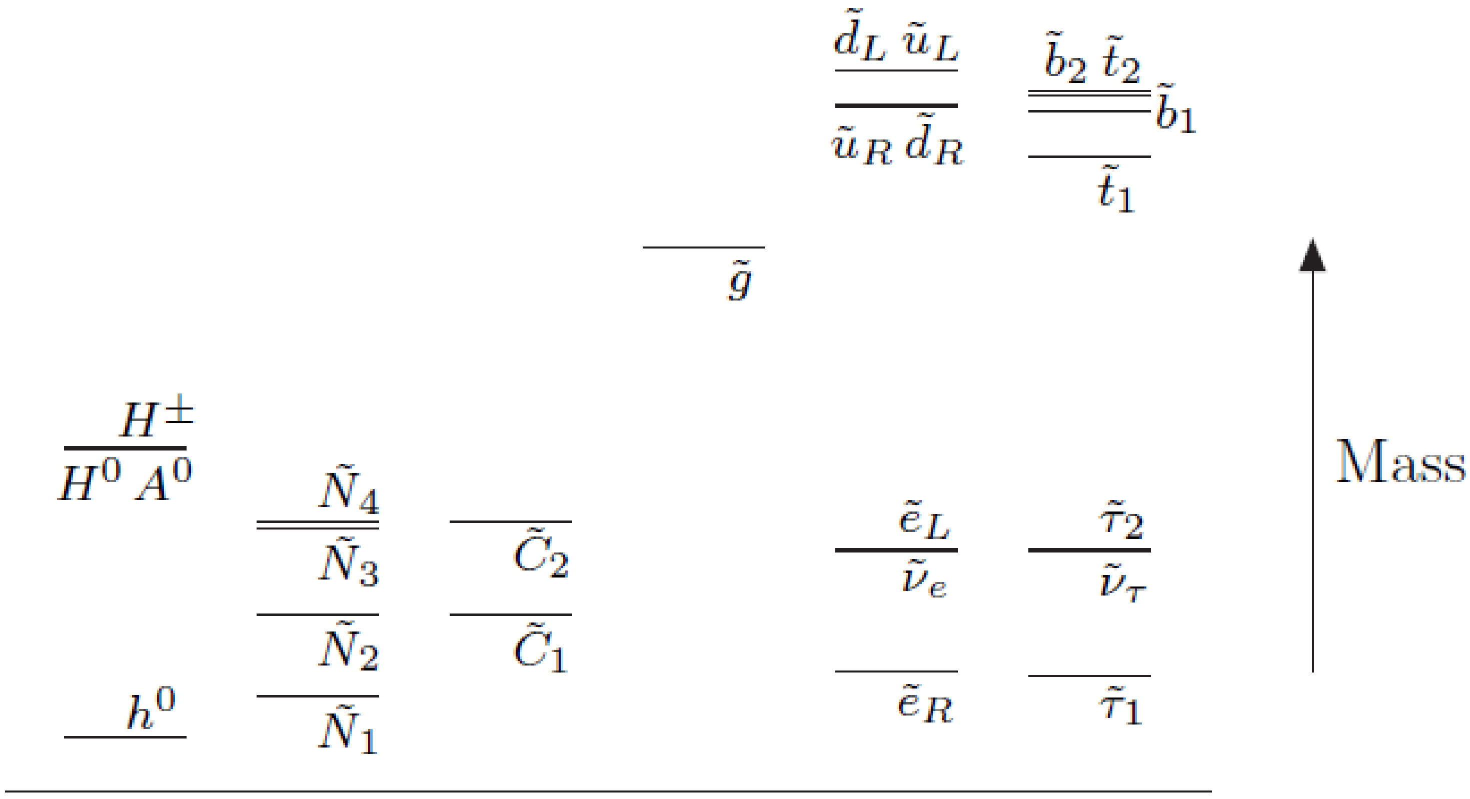
$$\Lambda = F/v$$

gaugino masses are given by

$$M_{\lambda i} = \frac{\alpha_i}{4\pi}\frac{F_\phi}{\langle\phi\rangle}$$

Scalar masses are given by

$$\widetilde{m}^2 = 2\Lambda^2\left[C_3\left(\frac{\alpha_3}{4\pi}\right)^2 + C_2\left(\frac{\alpha_2}{4\pi}\right)^2 + \frac{5}{3}\left(\frac{Y}{2}\right)^2\left(\frac{\alpha_1}{4\pi}\right)^2\right]$$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Mass

General Gauge Mediation allows 6 mass parameters

$$M_k = g_k^2 M B_k, \qquad m_f^2 = \sum_{k=1}^{3} g_k^4 c_2(f,k) A_k$$

3 for gauginos and three or scalars

One may build GGM models with weakly coupled renormalizable superpotentials and multiple SUSY breaking spurions

$$W = X_i \left(\lambda_q^i q\widetilde{q} + \lambda_\ell^i \ell\widetilde{\ell} \right) + F_i X^i.$$

MSMM masses depend on multiple mass parameters, for example two in a two parameter model

$$\Lambda_q = \frac{\lambda_q^i F_i}{\lambda_q^j x_j} \quad \Lambda_\ell = \frac{\lambda_\ell^i F_i}{\lambda_\ell^j x_j}$$

Leads to masses

$$m_\lambda = \frac{\alpha_3}{4\pi}\Lambda_q \quad m_w = \frac{\alpha_2}{4\pi}\Lambda_\ell \quad m_b = \frac{\alpha_1}{4\pi}\left[\frac{2}{3}\Lambda_q + \Lambda_\ell\right]$$

Consider a three parameter model

The gluino mass is given by three parameters and may be canceled

$$m_g = \frac{\alpha_3}{4\pi}(\Lambda_q + 2\Lambda_Q + \Lambda_u)$$

Scalar masses however depend on the sum of squares of mass parameters and may not

$$m_s^2 \sim \frac{\alpha_3}{4\pi}^2 \Lambda_c^2 \rightarrow \frac{\alpha_3}{4\pi}^2 (\Lambda_q^2 + 2\Lambda_Q^2 + \Lambda_u^2)$$

How to generate scalar masses independent of gaugino masses

- Generate R symmetric scalar masses from nonzero messenger supertraces. R symmetric scalar masses do not effect gaugino masses

How to generate Gaguino masses without large contributions to scalar masses

- Generate Dirac gauginos. Dirac gaugino masses yield scalar mass contriubutions which are suppressed by loop factors, as is the case in Super-Soft Mediation.

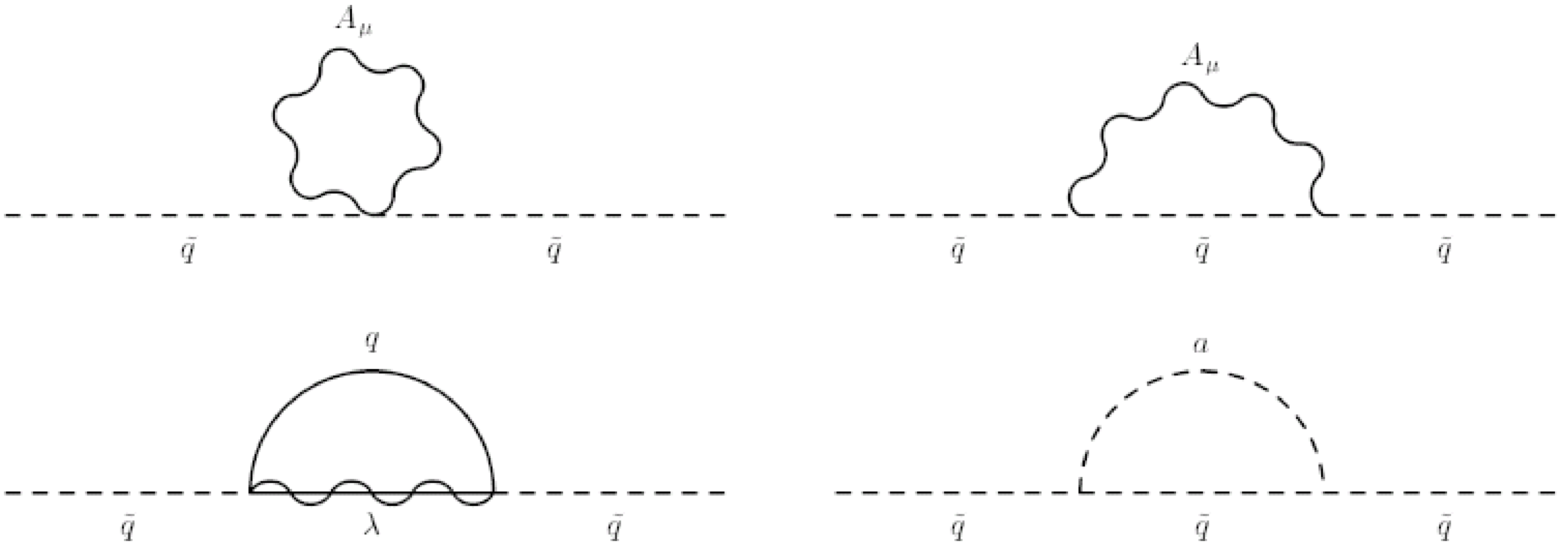
Dirac Gauginos

Require the existence of an adjoint field for each SM gauge group as well as a U(1)' gauge field

$$W = c_i \frac{W' W_i A^i}{\Lambda}$$

The U(1)' has D-term vev, when inserted one gets an operator which is a Dirac gaugino mass

$$c_i \frac{D}{\Lambda} \lambda_i \psi_{Ai}$$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These masses lead to 'supersoft' scalar masses

$$m_s^2 = \frac{C_i \alpha_i {m_{\lambda i}}^2}{\pi} \log(\frac{\delta_i}{m_{\lambda i}})^2$$

Which are less than the gaugino masses by the square root of a loop factor.

Then the ratio of gaugino to scalar masses is at least

$$\frac{m_s}{m_\lambda} = \sqrt{\frac{2C_i\alpha_i}{\pi} \log(\frac{\delta_i}{m_{\lambda i}})}$$

R symmetric scalar masses

Recall the supertrace

$$\mathrm{STr}(m^2) \equiv \sum_j (-1)^j (2j+1)\mathrm{Tr}(m_j^2),$$

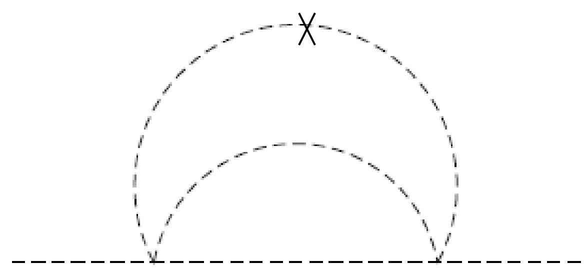
Messenger masses may have holomorphic and non-holomorphic components.

$$\int d^4\theta \, \frac{S^\dagger S}{M^2} \, f_i \, Q_i^\dagger \cdot Q_i + \left(\int d^2\theta \; S \; Q_1 \cdot Q_2 + \mathrm{h.c.} \right)$$

Q masses have diagonal and off diagonal components, diagonal are both supersymmetric and nonsupersymmetric.

$$\begin{pmatrix} M_L^2 + \tilde{m}_L^2 & 0 \\ 0 & M_{\bar{L}}^2 + \tilde{m}_{\bar{L}}^2 \end{pmatrix}$$

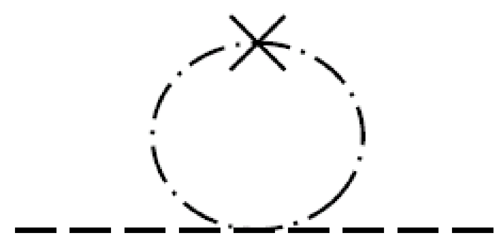
This leads to log divergent diagrams contributing to scalar mass



Resultant scalar masses are

$$m_i^2 = -f \sum_a \frac{g_a^4}{128\pi^4} S_Q C_{ai} \mathrm{Str} M_{mess}^2 \log(\frac{M^2}{\Lambda^2})$$

These masses are R symmetric and do not contribute to gaugino masses.



Scalar masses are UV sensitive, because of Log divergence these contributions to scalars will probably dominate others

Scalar masses proportional to opposite sign of supertrace. This means positive scalar mass squareds require negative messenger supertraces.

Most of the time one gets large mass contributions to scalars which are negative.

Messenger scalars must be lighter than messenger fermions in order for supertrace to be negative.

Dirac Gauginos and Gauge Mediated Supersoft

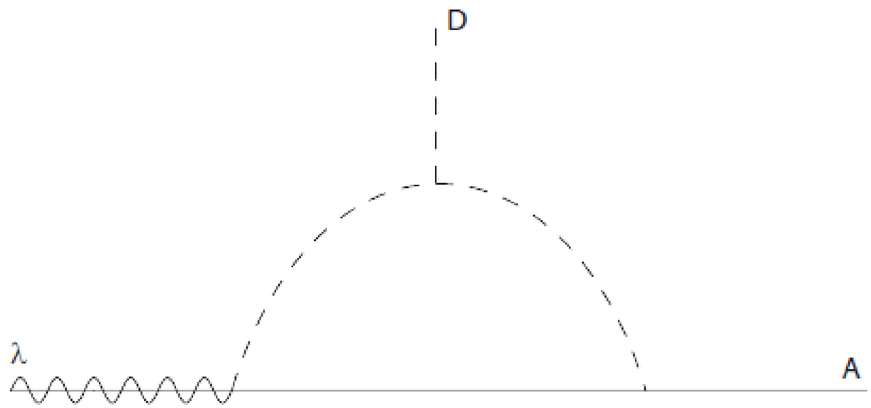
Gauge mediated gaugino masses

Gaugino masses arise at loop level by integrating out messenger fields. These messengers also couple to the adjoints. These must be charged under the U(1)', as well as the SM gauge groups.

$$W_T = m_T T\overline{T} + y_i \overline{T} A T$$

If the messengers have a non-zero D term then a diagram exists which produced a one loop gaugino mass proportional to the D-term

$$m_{\lambda_i} = \frac{g_i}{16\pi^2}\frac{y_i D}{m_T}$$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λ
A

Kahler Potential Operators

One must keep careful track of Kahler potential operators. In particular previous implementations of supersoft contained possibly problematic negative mass squareds. One may extract the Dirac gaugino masses from the Kahler potential.The term which gives rise to Dirac gauginos is

$$K = \int d^4\theta \frac{W D V' A}{\Lambda} + h.c.$$

Acting with the superspace derivative and inserting the D term one finds

$$W = \int d^2\theta \frac{D'}{\Lambda} W A$$

The pervious problematic operator involved Kahler potential contributions to the scalar adjoint fields. In particular one may write in the Kahler potential

$$K = \int d^4\theta \frac{W' D V' A A}{\Lambda^2} + h.c.$$

Which becomes the superpotential operator

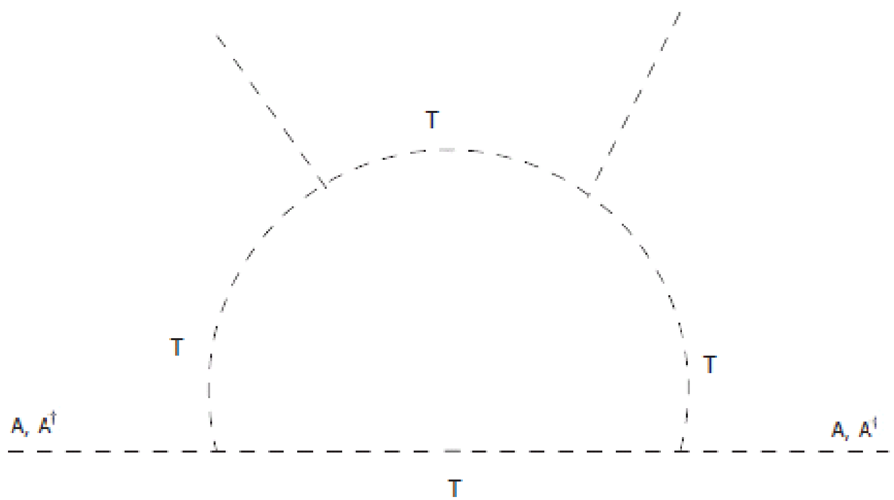
$$W = \int d^2\theta \frac{D' D'}{\Lambda^2} A A$$

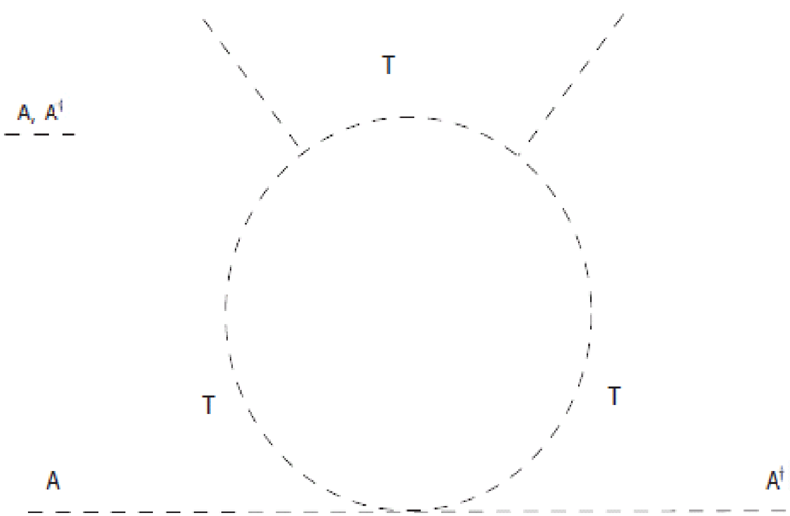
Either the real or imaginary part of A has a negative mass squared. The mass squared is large and potentially problematic.

However there is an additional operator of the same order

$$K = \int d^4\theta \frac{W' D V' A A^\dagger}{\Lambda^2} + h.c.$$

One may add up all contributing diagrams to A masses





Consider a simple model considered by Dine and Mason with an extra U(1) gauge symmetry

$$W = \lambda X(\phi_+\phi_- - \mu^2) + m_1\phi_+ Z_- + m_2\phi_- Z_+ + W'W'$$

The U(1) is broken by vevs of fields

$$\phi_+^2 = \frac{m_2}{m_1}\phi_-^2$$

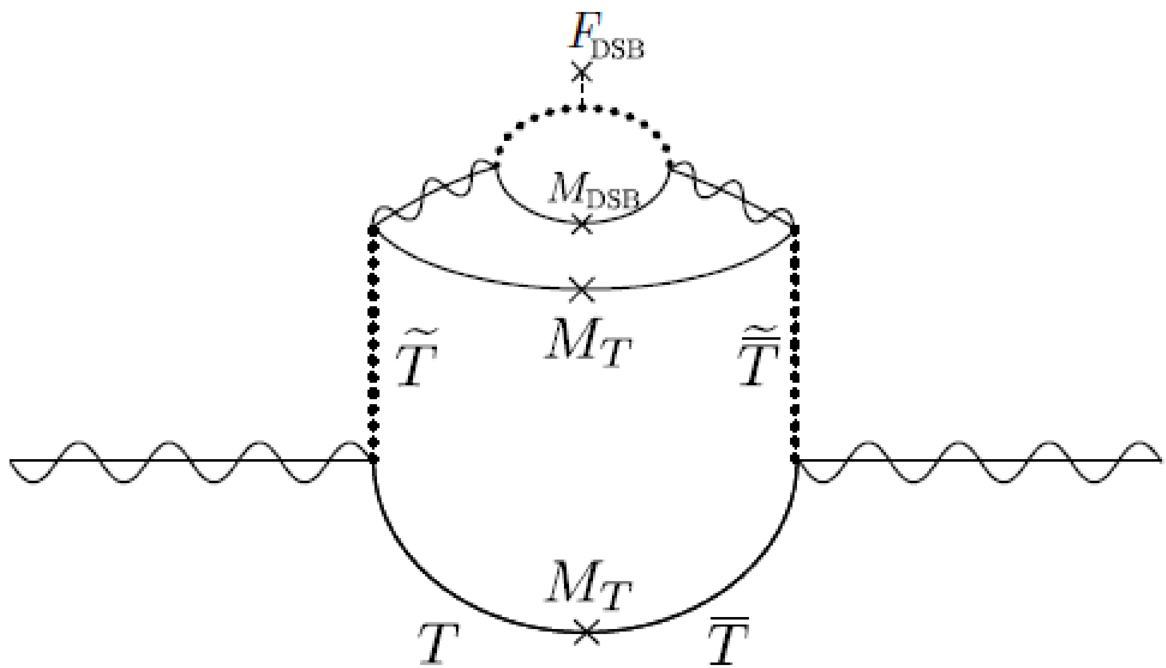
$$\phi_- = \sqrt{\frac{m_1}{m_2}\mu^2 - m_1^2}$$

The fields X and Z's get F terms and SUSY is broken. It appears there is a nonzero D term at tree leel

$$D = g'(\frac{m_1}{m_2}\mu^2 - m_1^2)(\frac{m_2}{m_1} - 1)$$

- However one must be careful, there is a runaway close to the direction of constant D-term which may be stabilized by a CW calculation

If the field X gets a vev then



messengers get a small B-term, hence small Majorana masses may be generated for gauginos at three loops

- If there is an appreciable Majorana component to the gaugino mass, then one has two states with split masses which are mixtures of the gaugino and adjoint. This can put an extra light state into the MSSM spectrum
- New method for generating the mu term and changing the Higgs potential, Nelson’s mu-less MSSM where the SU(2) adjoint is coupled directly to the Higgses.

Negative Supertraces

Mediator Models

- Require two sets of messengers, one much heavier than the other

- The heavy set is charged under a hidden sector gauge group

- The light set is charged under both the SM and the hidden sector gauge group.

The messengers themselves get masses from two loop GM diagrams.

If the more massive set of messegers had a positive supertrace, then the lighter messengers will get negative scalar mass squared contributions. If they have a large supersymmetric mass, then they themselves will have negative supertrace without break SM gauge groups.

Then resulatant SM scalar mass squareds are thus four loop, and positive

This story contains similar features to the model I used previously, messegers charged under hidden sector gauge group as well as the SM, and supersymmetric messenger mass

But what one wants is negative messenger supertrace at lower loop level. The only way one can achieve this at low loop level is with D-terms.

Add messengers which get diagonal mass contribution from D- terms. Ones want messengers that do not have opposite U(1)' charges and the same mass.

Choose the superpotential

$$W = \lambda X(\phi_+\phi_- - \mu^2) + m_1\phi_+Z_- + m_2\phi{-}Z_+ + \lambda_2\phi_+M\overline{N} + \lambda_1\phi_-N\overline{M}$$

The messengers M have opposite U(1)' charge but unequal mass. One has supersymmetric mass

$\lambda_1 v_{\phi_-}$ And the other $\lambda_2 v_{\phi_+}$

There are thus two contributions to scalar masses from messenger supertraces

$$m_s^2 - f\sum_a \frac{g_a^4}{128\pi^4}S_Q C_{ai} D\log(\frac{M_1}{\Lambda}) + f\sum_a \frac{g_a^4}{128\pi^4}S_Q C_{ai} D\log(\frac{M_2}{\Lambda})$$

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Note if M1 and M2 were equal then the contributions would cancel.

However if there is a mismatch then the total contriution to scalar masses go like

$$m_i^2 = -f\sum_a \frac{g_a^4}{128\pi^4} S_Q C_{ai} D \log(\frac{M_1}{M_2})$$

One may attempt to cover more of parameter space for scalar masses. For example consider the messengers as a 5 of SU(5). One may split the doublet and triplet parts

$$W = \lambda_{Q2}\phi_+ Q\overline{Y} + \lambda_{Q1}\phi_- Y\overline{Q} + \lambda_{L2}\phi_+ L\overline{E} + \lambda_{L1}\phi_- E\overline{L}$$

To get different masses for SU(3) and SU(2) mass parameters for scalars. In fact these contributions don't need to have the same sign.

Loop Level Supertrace

$$W = X(H^2 - \mu^2) + mHA + y_1 H M \overline{N} + y_2 H N \overline{M}$$

Inspired by Higgs messenger mixing models. The field H gets a vev of order $\mu^2 - m^2$ giving a supersymmetric mass to the messengers M and N. The resultant scalar potential is

$$V_s = y_1^2(h^2 m^2 + h^2 \overline{n}^2) + y_2^2(h^2 \overline{m}^2 + h^2 n^2)$$

There are two diagrams for contributing to scalar messenger masses. These diagrams cancel to order $\frac{F^2}{M^2}$.

There is a contribution to messenger scalars of order

$$m_s^2 \sim -\frac{y^2}{16\pi^2}\frac{F^4}{M^6}$$

Resulting in an MSSM scalar mass squared of

$$m_i^2 = f\sum_a \frac{g_a^4}{128\pi^4} S_Q C_{ai} \frac{y^2}{16\pi^2}\frac{F^4}{M^6}\log(\frac{v_H}{\Lambda})$$

.

Conclusions

Dirac gauginos and R symmetric scalar masses may maximize coverage of GGM parameter space.

There are multiple compact methods for delivering negative messenger supertraces without resorting to multiple loops.

Supersoft masses may be easily incorparated into gauge mediation, without dangerous negative mass squareds.

One may use very similar mechanisms to deliver both results.

The key feature is a simple version of 'semi-direct' gauge mediation, in which there are messengers which don't participate in SUSY breaking but are charged under a hidden sector gauge group.