New Calculations in Dirac Gaugino Models: Operators, Expansions, and Effects

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Beyond the MSSM

- The LHC has discovered a relatively light Higgs.
  → Still within bounds of the MSSM
- Maybe new physics is just around the corner.
- MSSM → heavier mass spectrum and a larger dose of fine tuning

- No signs of new physics as of yet.
- Stringent bounds new colored particles for the simplest SUSY models
- Preserving naturalness implies models beyond the simplest ones
- Dirac gauginos.

Outline

- Why we like Dirac gaugino models.
- Background - Supersoft

  → m_D-b_M problem: tacyonic adjoint scalar
- SUSY breaking effects to all orders in D - messenger propagator expansion
- Additional Operators
- $\not{\mu}$SSM

Motivation - Dirac Gauginos

• Dirac gauginos can be several times heavier than Majorana gauginos with the same amount of naturalness.

$\rightarrow$ Sfermions receive log divergent mass corrections from Majorana gauginos which in turn feeds into corrections of the Higgs mass. Thus, increasing the mass of a Majorana gaugino results in increased tuning in the Higgs sector.
In contrast, Dirac gauginos contribute only finite mass corrections to sfermions

allowing for a larger heirarchy between gaugino and sfermion masses.

• Color sparticle production is significantly reduced compared to the MSSM – Kribs, Martin

No chirality flipping Majorana mass $\rightarrow$ same-handed t-channel gluino exchange absent

Mixed handed processes are suppressed by additional power of the gluino mass.

• Dirac gaugino mass terms are R symmetric and R symmetries are natural in models of dynamical SUSY breaking (DSB).

The Supersoft Operator (Fox, Nelson, Weiner)

Supersymmetric extensions of the SM with Dirac gauginos contain adjoint chiral superfields, A_i, for each SM gauge group. In addition to the adjoint superfields, one needs D-term SUSY breaking in a hidden sector $U(1)'$ gauge group. The Dirac masses are then generated by the effective operator

$$W_{\text{ssoft}} = \frac{W'_\alpha W_j^\alpha A_j}{\Lambda}$$

Once a non-zero D-term is generated, the component Lagrangian contains

$$\mathcal{L} \supset -\frac{D'}{\Lambda}\lambda_i \psi_{A_i} - \frac{D'^2}{\Lambda^2}(A_i + A_i^\dagger)^2 - \sqrt{2}\frac{D'}{\Lambda}(A_i + A_i^\dagger)\left(\sum_j g_i \tilde{q}_j^\dagger t_i \tilde{q}_j\right)$$

This gives us Dirac gaugino and adjoint scalar mass terms

$$m_D = \frac{D'}{\Lambda} \qquad m_{A_{\text{R}}}^2 = \frac{2D'^2}{\Lambda^2}$$

⋆ Supersoft ≡ introduces no new divergences to ~~SUSY~~ parameters.

The Lemon Twist Operator - Tacyonic Adjoints

As pointed out in the original SSoft formulation, once W_{SSoft} is generated, there are no symmetries that can forbid the generation of the lemon twist operator.

$$W_{\text{LT}} = \frac{W'_\alpha W'^\alpha A^2}{\Lambda^2}$$

W_{LT} also contributes to the adjoint scalar masses.

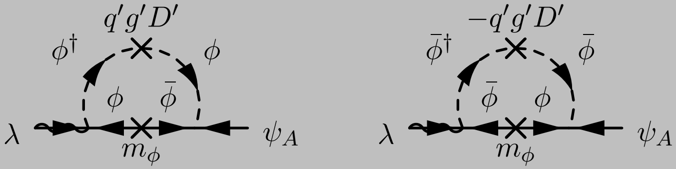
$$\mathcal{L} \supset -\frac{D'^2}{\Lambda^2}(A^2 + A^{\dagger 2}) \rightarrow -\frac{2D'^2}{\Lambda^2}(A_{\text{R}}^2 - A_{\text{I}}^2)$$

Without additional positive contributions to the adjoint scalar masses we find the adjoint mass matrix will have a negative eigenvalue.

Generating Supersoft from GMSB

Consider the toy model with ϕ and $\bar{\phi}$ as messengers $\rightarrow \Box$ and $\bar{\Box}$ in SM and $\pm q'$ in $U(1)'$:

$$W \sim \lambda \phi A \bar{\phi} + m_\phi \phi \bar{\phi} \quad \text{leading to} \quad m_D \sim \frac{g_{\rm SM} g' \lambda}{16\pi^2} \frac{D'}{m_\phi}$$



⋆ Messengers must be charged under the hidden U(1)′ in addition to having SM gauge charges

LT from GMSB - Gauge Coupling Running

In this simple model we can see that $W_{\rm LT}$ is generated. We can estimate it by consider the one loop running of the hidden $\mathrm{U}(1)'$ gauge coupling (Csáki, JG, Pavesi, Shirman)

By integrating out the messengers at m_ϕ, we find the the coefficient of the W'^2 term in the effective low energy description is:

$$-\left(\frac{1}{4g'^2(\Lambda)}+\frac{b_L}{16\pi^2}\log\frac{\mu}{m_\phi}+\frac{b_H}{16\pi^2}\log\frac{m_\phi}{\Lambda}\right)W'_\alpha W'^\alpha,$$

- $b_{H,L}$ are the $U(1)'$ β-function coefficients above and below m_ϕ.
- Treat m_ϕ as a vev of A and taking $U(1)'$ charge of ϕ and $\bar\phi$ to be $\pm q'$; expanding in powers of λA we find

$$W_{\rm LT}\to\frac{q'^2\lambda^2 g'^2}{32\pi^2}\frac{1}{m_\phi^2}W'_\alpha W'^\alpha \mathrm{Tr}\ A^2$$

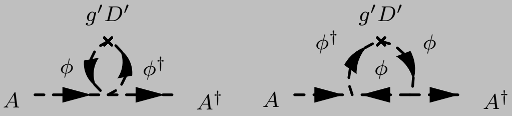
⋆ Need additional contributions to the non-holomorphic mass of A.

Additional Non-Holomporphic Masses for A

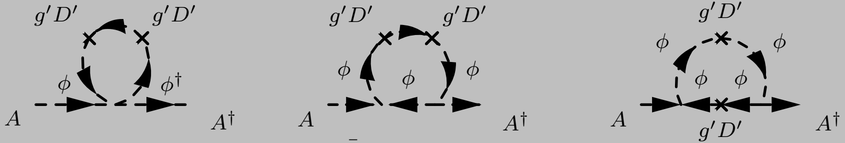
Additional contributions to the non-holomorphic mass from the Kahler potential?

$$\rightarrow V \quad \supset \quad \lambda^2|\phi|^2|A|^2 + (\lambda m_\phi A|\phi|^2 + \text{h.c}) + \text{terms with } (\phi \leftrightarrow \bar{\phi}) + q' g' D'(|\phi|^2 - |\bar{\phi}|^2)$$

At $\mathcal{O}(D')$, we have the following diagrams (also, $\phi \leftrightarrow \bar{\phi}$):



However, these vanish due to messenger parity. At $\mathcal{O}(D'^2)$, we have:

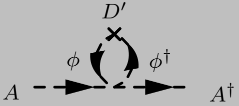


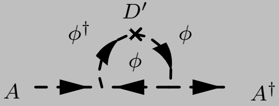
These in fact vanish for both ϕ and $\bar{\phi}$. One generates non-holomorphic mass only at $\mathcal{O}(D'^4)$ at one loop in the simple messenger model which is not sufficient enough to lift the tacyonic direction of the adjoint. One needs messenger mixing to get a contribution at one loop to $\mathcal{O}(D'^2)$. (Csáki, JG, Pavesi, Shirman)

Tachyonic Adjoint Solution - Messenger Mixing

Lets now introduce a second set of messenger fields which are fundamental/anti-fundamental $(N, \bar{N})$ under the SM but are not charged under $U(1)'$. Our messenger sector superpotential now takes the form

$$W = \lambda(\phi A\bar{\phi} + \bar{\psi}\phi\bar{N} + \psi\bar{\phi}N) + m_\phi \phi\bar{\phi} \qquad \langle\psi\rangle \neq \langle\bar{\psi}\rangle \rightarrow D' \sim \langle\psi\rangle^2 - \langle\bar{\psi}\rangle^2$$





⋆ Messenger parity violation allows for non-holomorphic masses at lowest order is the ~~SUSY~~ parameter, D′.

$$m^2 \sim \frac{\lambda^2}{16\pi^2} \frac{(\langle\psi\rangle^2 - \langle\bar{\psi}\rangle^2) g' D'}{m_\phi^2}$$

One can associate these contributions to the non-holomorphic mass of the adjoint with the effective operator

$$\int d^4\theta \frac{1}{\Lambda^2} (\psi^\dagger e^{q'V'} \psi + \bar{\psi}^\dagger e^{-q'V'} \bar{\psi}) \mathrm{Tr}(A^\dagger A)$$

by considering the wavefunction renormalization of the fields ψ and $\bar{\psi}$.

Additional Tachyonic Adjoint Solutions

- New SSoft operators (Nelson, Roy)

$$W \supset \omega_{12} \frac{W'^{\alpha}(D_\alpha \Phi_1)\Phi_2}{M}$$

$\rightarrow$ $\Phi_1, \Phi_2 = A$ then gives a non-holomorphic mass $\sim 2\omega_{AA}\frac{D'}{M}$
$\rightarrow$ $\Phi_1, \Phi_2 = H_u, H_d$ (H_d, H_u) gives $\mu_{ud} = \omega_{ud}\frac{D'}{M}$ and $\mu_{du} = \omega_{du}\frac{D'}{M}$

- Goldstone gauginos (Alves, Galloway, McCullough, Weiner)
  $\rightarrow$ Associate the RH gaugino as the fermionic partner of a Goldstone fields associated with a spontaneously broken anomalous symmetry. Here, the SSoft operator is generated but the LT is not.

Outline

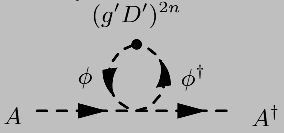
✓ Why we like Dirac gaugino models.
✓ Background - Supersoft
  ✓ Tacyonic adjoint scalar masses
• SUSY breaking effects to all orders in D - messenger propagator expansion

All $\not{SUSY}$ effects are ultimately fed to the MSSM fields through messenger loops. In order to fully calculate these effects we must understand the effect of $\not{SUSY}$ on the messenger propagators.

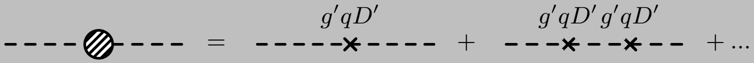
• Additional Operators
• $\not{\mu}$SSM

Adjoint Masses to All Orders in D

One can imagine calculating the adjoint masses with multiple D$'$ insertions along the propagators.



Which suggests just calculating the correction to the messenger 2-point function in order to get the full effect of SUSY breaking on adjoint masses. $\phi/\bar{\phi}$ are $\Box/\overline{\Box}$ pair under the SM with $\pm$q$'$ under U(1)$'$ and a non-zero D-term then generates non-holomorphic masses $V \sim g'q'(|\phi|^2 - |\bar{\phi}|^2)D' \rightarrow$ corrections to 2-point functions.



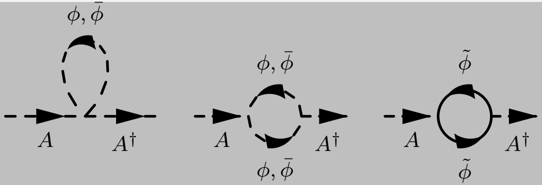
Then for any messenger with SUSY mass m and ~~SUSY~~ mass D$'$, we can re-sum our geometric series to get the full messenger propagator.

$$\frac{1}{p^2 - (m^2 + g'q'D')} = \frac{1}{p^2 - m^2} + \frac{g'q'D'}{(p^2 - m^2)^2} + \frac{g'^2 q'^2 D'^2}{(p^2 - m^2)^3} + \ldots$$

Adjoint Masses to All Orders in D

As we expect, the full effect of the series summation of D-terms is to shift the diagonal mass-squared of the messengers by $\pm$D. It is this non-holomorphic mass of the messengers that feeds down, generating all SUSY breaking parameters. Thus, to calculate one loop effects to any order in the SUSY breaking parameter, we can simply draw a one loop diagram with messengers and expand to the desired order. We note that this procedure is quite general and bypasses the need for guessing operators associated with SUSY breaking terms.

Adjoint Mass with Full Messenger Propagator



$$
\begin{aligned}
\delta m_A^2 &= \frac{\lambda^2}{16\pi^2}\Bigg[(2m^2+D')\left[\ln\left(\frac{\Lambda^2+m^2+D'}{\Lambda^2+m^2}\right)-\ln\left(\frac{m^2+D'}{m^2}\right)\right] \\
&+ (2m^2-D')\left[\ln\left(\frac{\Lambda^2+m^2-D'}{\Lambda^2+m^2}\right)-\ln\left(\frac{m^2-D'}{m^2}\right)\right] \\
&+ \frac{m^2(m^2+D')}{\Lambda^2+m^2+D'}+\frac{m^2(m^2-D')}{\Lambda^2+m^2-D'}-\frac{2m^4}{\Lambda^2+m^2}\Bigg] \\
&\sim \frac{\lambda^2 m^2}{240\pi^2}\left(5\left(\frac{D'}{m^2}\right)^4+4\left(\frac{D'}{m^2}\right)^6\right)+\mathcal{O}\left(\frac{D'}{m^2}\right)^8
\end{aligned}
$$

Expanding the corrections generated by these diagrams in powers of D'/m^2 we find the leading contribution $\mathcal{O}(D'^4)$.

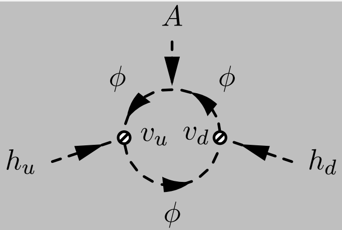
Adjoint Mass with Full Messenger Propagator

In principle, we are calculating the wavefuntion renormalization of the adjoint:

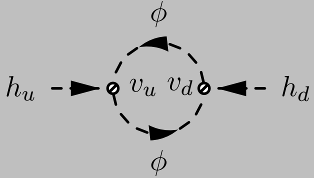
$$K \sim \int d^4\theta Z_A A^\dagger A$$

and expanding in powers of the SUSY breaking parameter. This then leads to a calculation of the non-holomorphic adjoint mass to higher orders in the SUSY breaking parameter. It should be noted that the terms higher order in D' are not captured in the effective operator we wrote down above and so these additional SUSY breaking contributions do not correspond to any one operator yet proposed.

Additional Operators - A-like and b Terms



$$W \sim \delta \frac{W'W'}{\Lambda^3} A H_u H_d \sim \frac{g^2 \langle v_u v_d \rangle}{m_\phi^2} \frac{m_D^2}{m_\phi}$$

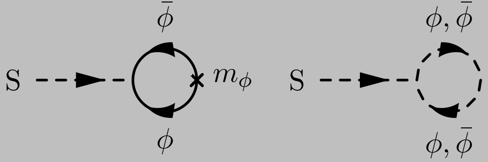


$$W \sim \delta_b \frac{W'W'}{\Lambda^2} H_u H_d \to b \sim \frac{g^2 \langle v_u v_d \rangle}{m_\phi^2} m_D^2$$

⋆ Both of these diagrams are suppressed by $\langle v_u v_d \rangle / m_\phi^2$. Without any additional structure, the higgs vevs break R symmetry.

Additional Operators - Linear Term For The Singlet

$$W = t_s \frac{W'W'}{\Lambda} S$$



Combining both of these diagrams we find

$$\frac{\lambda}{64\pi^2} \frac{m_\phi (g'D')^2}{m_\phi^2} \sim \text{loop factor} \times \frac{m_\phi m_D^2}{\lambda}$$

⋆ This term is only generated for scalar “adjoint” whose fermion partner marries the bino.

⋆ Not generated at all if the SM adjoints are components of an adjoint from a larger symmetry.

Additional Operators - Adjoint Trilinear Terms

Additionally, we can write general trilinear terms involving the adjoint fields which are a R-preserving and thus expected to be unsuppressed by Higgs vevs.

$$W_{\text{trilinear}} = \zeta_S \frac{W^{'} W'}{\Lambda^3} S^3 + \zeta_{AS} \frac{W^{'} W'}{\Lambda^3} \text{Tr}[AA]S + \zeta_A \frac{W^{'} W'}{\Lambda^3} d^{abc}[A^a A^b A^c]$$

- Analogous to the adjoint and gaugino masses, one expect that these terms can be computed from loops of messengers.

Concluding Statements

•Dirac gauginos offer a way reduce the production of colored superpartners while keeping most superpartners below a TeV and without sacrificing naturalness.
•Dirac gauginos can be generated by effective operators which introduce only finite corrections to SUSY breaking parameters.
•Models with messenger mixing can be used to solve the tacyonic adjoint problem.
•Once the messenger sector is we see how several SUSY breaking operators are generated (A-like terms, b-like terms, singlet term).
•One can calculate loop effects to any order in the SUSY breaking by simply re-summing the messenger 2-pt. function and then expanding in powers of $\frac{D'}{m^2}$
•bh_uh_d?

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✓ Why we like Dirac gaugino models.
✓ Background - Supersoft
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- Additional Operators
- $\not\mu$SSM
  - Higgsino mass
  - Higgs quartic
  - R-breaking
  - Higgs sector

Up to this point we have not discussed a particular low energy model. Any such model must generate a μ term, demonstrate viable EWSB, and predict a Higgs mass in line with current measurements. Next, we consider a class of models which contain superpotential couplings of the adjoints to the Higgs fields. These models, termed $\not\mu$SSM (Nelson, Rius, Sanz, Unsal), where first proposed as a solution to the μ problem.

$\not{\mu}$SSM (Nelson, Rius, Sanz, Unsal)

Assume that all mass terms are generated via EWSB or $\not{\text{SUSY}}$ $\rightarrow \mu = 0$. However, in the MSSM this leads to charginos lighter than the W which is ruled out. Thus, we introduce a trilinear superpotential term coupling the Higgs fields to an adjoint.

$$W_{\not{\mu}} \supset \sqrt{2}\lambda_A H_u A H_d + \lambda_S H_u S H_d + \text{Yukawas}$$

where A is an SU(2) adjoint. Once the Higgs fields get non-zero vevs, we get several separate contributions to the Higgsino masses

$$\sqrt{2}\lambda_A \langle v_u \rangle \Psi_A \Psi_{h_d} + \lambda_S \langle v_u \rangle \Psi_S \Psi_{h_d} + \sqrt{2}\lambda_A \langle v_d \rangle \Psi_{h_u} \Psi_A + \lambda_S \langle v_d \rangle \Psi_{h_u} \Psi_S$$

- A vev for S is an additional source for μ-terms.

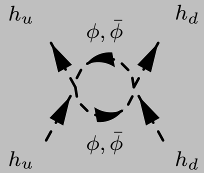
$\rightarrow$ An electroweak-ino mass matrix with non-trivial mixing between Higgsinos and adjoint/singlet.

$\not{\mu}$SSM: Higgs Quartic

The presence of the SSoft operators in the superpotential shift the SM D-terms

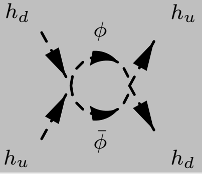
$$D_2 \to m_D(A + A^\dagger) + \Sigma_i g Q_i^\dagger T Q_i \qquad D_1 \to m_D(S + S^\dagger) + \Sigma_i g q_i Q_i^\dagger Q_i$$

For a sufficiently heavy adjoint and in the absence of Majorana masses for the adjoints, one can show that the D-term Higgs quartics vanish. One does get contributions from loops of messengers.



$$\delta_\lambda \sim \frac{g^4}{16\pi^2}\left(\frac{1}{4}\left(\frac{g'D'}{m^2}\right)^2 + \mathcal{O}\left(\left(\frac{g'D'}{m^2}\right)^4\right)\right)$$

However, the addition of $\lambda H_u A H_d$ in the $\not{\mu}$SSM gives additional tree level contributions: $V \supset (\lambda_A^2 + \lambda_S^2)|h_u|^2|h_d|^2$.



$$\delta_\lambda \sim \frac{\lambda^2 y^2}{16\pi^2}\left(\frac{1}{12}\left(\frac{g'D'}{m^2}\right)^2 + \mathcal{O}\left(\left(\frac{g'D'}{m^2}\right)^4\right)\right)$$

μSSM: The Higgs Sector - Minimizing the Potential

$$
\begin{aligned}
V &= \frac{g^2+g'^2}{8}(|h_u^0|^2-|h_d^0|^2)^2+(\lambda_A^2+\lambda_S^2)|h_u^0|^2|h_d^0|^2+[\lambda_A^2|A_0|^2+\lambda_S^2|S|^2 \\
&+ \lambda_A\lambda_S(A_0S^*+\text{h.c})](|h_u^0|^2+|h_d^0|^2) \\
&- \frac{1}{\sqrt{2}}gm_{D_A}(A_0+A_0^*)(|h_u^0|^2-|h_d^0|^2)+\frac{1}{2}g'm_{D_S}(S+S^*)(|h_u^0|^2-|h_d^0|^2) \\
&+ 2(m_A^2+m_{D_A}^2)|A_0|^2+(m_S^2+m_{D_S}^2)|S|^2+m_{h_u}^2|h_u^0|^2+m_{h_d}^2|h_d^0|^2 \\
&+ (b_A+m_{D_A}^2)(A_0^2+A_0^{*2})+\frac{1}{2}(b_S+m_{D_S}^2)(S^2+S^{*2})-(bh_u^0h_d^0+h.c.) \\
&+ (A_{AH}A_0h_uh_d+A_{SH}Sh_uh_d+A_SS^3+A_{AS}SA_0^2+A_AA_0^3+h.c.)+(t_SS+h.c.)
\end{aligned}
$$

- No $U(1)_{\text{EM}}$ breaking so we take $\langle h_u^+\rangle=\langle h_d^-\rangle=\langle A^+\rangle=\langle A^-\rangle=0$
- Linear term for leads to
$V\left(\langle h_u^0\rangle,\langle h_d^0\rangle,\langle A^0\rangle,\langle S\rangle\neq 0\right)<V\left(\langle h_u^0\rangle=\langle h_d^0\rangle=\langle A^0\rangle=\langle S\rangle=0\right)$
- Set tanβ, $\langle S\rangle$, the Dirac masses and m_A as input, then used the minimization conditions to solve for the soft masses of h_u, h_d, S and $\langle A\rangle$ (Benakli, Goodsell, Staub).

μSSM: The Higgs Sector - Sample Point

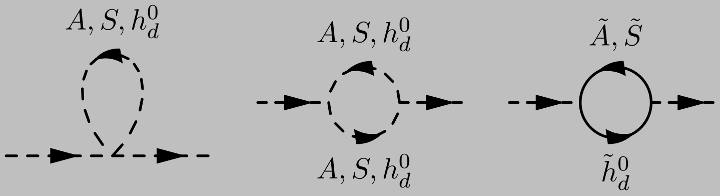
Here both the Dirac masses and adjoint scalar masses are both TeV in scale, with a linear S term also of order $(\text{TeV})^3$. We expect parametrically small A-like terms for Higgses, of order $D^2 v^2/\Lambda^5$ so we may neglect them in this case. And a Higgs b-term suppressed by powers of R-breaking.

$\tan\beta$	10
λ_A	0.021
λ_S	-1.3
v_S	180 GeV
m_{D_A}	2 TeV
m_{D_S}	1.5 TeV
m_A	5 TeV
b	$4.2 * 10^4$ GeV^2
b_S	$-5 * 10^5$ GeV^2
b_A	0
t_S	$-1.5 * 10^9$ GeV^3
A-like terms	0

- Neutral Higgs: $(89, 648, 3442, 8124)$ GeV, with the lightest Higgs almost entirely h_u
- Pseudo-scalars: $(650, 2868, 7071)$ GeV
- Charged Higgs: $(612, 7071, 8124)$ GeV
- $m_s = 2770$ GeV
- $v_A \sim 0.5$ GeV

$\not\mu$SSM: The Higgs Sector - Higgs Mass Corrections

Introduction of the trilinear Higgs - adjoint superpotential couplings also generate potentially large one loop correction to the Higgs soft masses. These diagrams are similar to those obtained from top/stop loops in the MSSM.



$\not\mu$SSM: The Higgs Sector - Higgs Mass Corrections

To calculate the correction to the Higgs mass we use the one-loop CW effective potential, $V = V_0 + V_{CW}$, then expand the in powers of h_u.

$$V_{CW} = \frac{1}{64\pi^2} Str\left(\mathcal{M}^4 \log \frac{\mathcal{M}^2}{\Lambda^2}\right)$$

This gives the induced Higgs quartic once the heavy adjoints are integrated out. For the sample tree-level point given previously we find $\delta\lambda_h \sim .055$ leading to a soft mass correction of $\delta_{m_u^2} \sim (54\text{GeV})^2$. Including these one loop corrections, the 89GeV Higgs is pushed up to $\sim$ 146GeV.

⋆ Typical SSoft parameters may over produce the Higgs mass.

• H_d quartic is also significantly shifted but does not effect the lightest Higgs much as $\langle v_d \rangle$ remains small and the lightest Higgs is mostly h_u.

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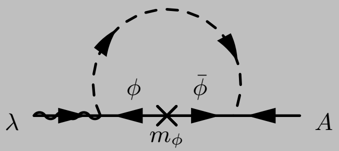
•bh_uh_d?

Gaugino Mass with Full Messenger Propagator

Any 1-loop result may be obtained through this procedure of expanding the messenger propagators.



$$\begin{aligned}\delta m_\lambda &= \frac{\lambda g m\sqrt{2}}{32\pi^2}\frac{1}{g'D'}\Bigg[(m^2+g'D')\left(\ln\left[\frac{\Lambda^2+m^2+g'D'}{\Lambda^2+m^2}\right]-\ln\left[\frac{m^2+g'D'}{m^2}\right]\right)\\ &+ (m^2-g'D')\left(\ln\left[\frac{\Lambda^2+m^2-g'D'}{\Lambda^2+m^2}\right]-\ln\left[\frac{m^2-g'D'}{m^2}\right]\right)\Bigg]\\ &= \frac{\lambda g m\sqrt{2}}{32\pi^2}\left(\frac{g'D'}{m^2}+\frac{1}{6}\left(\frac{g'D'}{m^2}\right)^3\right)+\mathcal{O}\left(\frac{g'D'}{m^2}\right)^5\end{aligned}$$

⋆ Terms $\sim D'^{2n}$ vanish as expected - contributions from ϕ cancel those from $\bar\phi$.

Masses with a General Messenger Sector

In principle, one can use the same technique with a general messenger sector:

$$W = \lambda_{ij}\bar{\phi}_i A \phi_j + m_{ij}\bar{\phi}_i \phi_j$$

We can take the masses, m_{ij} to be generated by a set of vevs of chiral fields Y_k

$$W \to \lambda_{ij}\bar{\phi}_i A \phi_j + y_{ijk} Y_k \bar{\phi}_i \phi_j$$

Letting Y_k carry a non-zero $U(1)'$ charge allows the fields ϕ_i and $\bar{\phi}_j$ to carry different charges under the $U(1)'$.

$$\text{Recall: } W = \lambda(\phi A \bar{\phi} + \bar{\psi}\phi\bar{N} + \psi\bar{\phi}N) + m_\phi \phi\bar{\phi}$$

$\not\mu$SSM and Supersoft: R-Breaking

Combining the supersoft mechanism with the $\not\mu$SSM we find a spontaneously broken R-symmetry.

$$W \supset \zeta_A \frac{W'WA}{\Lambda} + \sqrt{2}\lambda_A H_u A H_d + \zeta_S \frac{W'WS}{\Lambda} + \lambda_S H_u S H_d$$

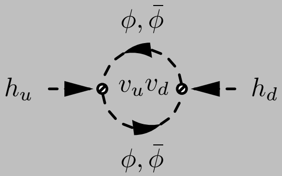
- Preserving R symmetry in W_{SSoft} required that the chiral adjoints carry no R charge.
- The trilinear superpotential term coupling the Higgses to the adjoints imply $R_{h_u} + R_{h_d} = 2$.
- We see that R symmetry is spontaneously broken by Higgs vevs. Once embeded into a local SUSY theory, the R-symmetry becomes gauged. It has been shown (Bagger, Poppitz, Randall) that in models with a $\not{\text{SUSY}}$ scale greater than 10^5GeV, the axion is sufficiently heavy to evade astrophysical constraints.

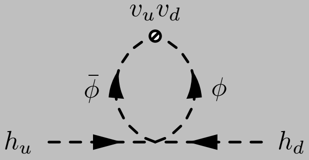
$\not{\mu}$SSM: R-Breaking - Higgs b Terms

The SSoft version of the Higgs b-term was suggested in the original SSoft paper and is of the form

$$W = \int d^2\theta \delta_b \frac{W'W'}{\Lambda^2} H_u H_d$$

In the completions we have been discussing R-breaking happens spontaneously in the visible sector. The messenger sector remains ignorant of it. Thus, it is unclear how this term can be generated. In $\not{\mu}$SSM, the Higgs vevs break the R-symmetry thus one can consider:





However, these do not correspond to any superpotential operator.

$\mu\!\!\!/$SSM: R-Preserving Terms

Additionally, we can write general trilinear terms involving the adjoint fields which are a R-preserving and thus expected to be unsuppressed by Higgs vevs.

$$W_{\text{trilinear}} = \zeta_S \frac{W'W'}{\Lambda^3} S^3 + \zeta_{AS} \frac{W'W'}{\Lambda^3} \text{Tr}[AA]S + \zeta_A \frac{W'W'}{\Lambda^3} d^{abc}[A^a A^b A^c]$$

- Analogous to the adjoint and gaugino masses, one expect that these terms can be computed from loops of messengers.