More natural Dirac gauginos

Based mostly on S. Abel and MDG: 1102.0014

See also 0811.4409, 0905.1043, 0909.0017, 1003.4957, 1104.2695 and 1105.0591

Mark D. Goodsell

DESY, Hamburg

CERN,
18th May 2011

There's no better way to do Dirac gauginos

Based mostly on S. Abel and MDG: 1102.0014

See also 0811.4409, 0905.1043, 0909.0017, 1003.4957, 1104.2695 and 1105.0591

Mark D. Goodsell

DESY, Hamburg

CERN,
18th May 2011

Dirac gaugino mediation

Based mostly on S. Abel and MDG: 1102.0014

See also 0811.4409, 0905.1043, 0909.0017, 1003.4957, 1104.2695 and 1105.0591

Mark D. Goodsell

DESY, Hamburg

CERN,
18th May 2011

Overview

- Motivation for Dirac gaugino masses
- Higgs sector propaganda

easyDiracGauginos:

- How to deconstruct "Dirac gaugino mediation"
- "Direct Dirac gaugino mediation" arising from strong gauge dynamics in UV

Why study Dirac gaugino models

- If gauginos are found at the LHC, we will have to determine whether they are Majorana or Dirac in nature
- This is very difficult to do directly: maybe only possible at ILC
- There may be clear signals from accompanying adjoint scalars if light
- Otherwise: challenge is to study the possible spectra from different models
- Can they look like e.g. minimal gauge mediation? Will the gauginos be heavier than the sfermions? Can the (N)LSP be a (pseudo-)Dirac gaugino?...
- Also: Dirac gaugino mass may preserve R $\rightarrow$ simpler ~~SUSY~~ models

Extensions to the Higgs sector

To get Dirac mass $\mathcal{L} \supset -m_D \lambda \chi$ need to add adjoint chiral superfield $\mathbf{\Sigma} = \Sigma + \sqrt{2}\theta\chi + ...$
Allows many possible variants of the Higgs sector, and new couplings $\lambda_S S H_u H_d + \lambda_T H_u T H_d$:

- MSSM without μ term [Nelson, Ruis, Sanz, Unsal 02]
- Fox, Nelson, Weiner model
- MRSSM
- SOHDM
- [Benakli, MDG, '10, + Maier '11] $\rightarrow$ break R-symmetry in visible sector via susy term κS^3 allowing λSUSY-type enhancement of Higgs mass

Examples

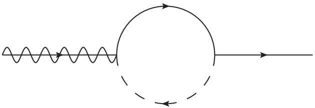
Input	Model I	Model II	Model III
λ_S	1.2	0.8	0.1
λ_T	0.1	0.1	0.7
κ	1.2	0.6	0.2
$\tan\beta$	1	1.38	1.38
m_S^2	10^5 GeV^2	10^5 GeV^2	10^5 GeV^2
B_S	-10^6 GeV^2	-10^6 GeV^2	-10^6 GeV^2
m_T^2	$4\ 10^6$ GeV^2	$4\ 10^6$ GeV^2	$4\ 10^6$ GeV^2
B_T	0	0	0
A_κ	0	0	0
m_{H_u}	197 GeV	479 GeV	596 i GeV
m_{H_d}	287 i GeV	339 i GeV	642 GeV
m_{1D}	400 GeV	400 GeV	400 GeV
m_{2D}	600 GeV	600 GeV	800 GeV
Output	**Model I**	**Model II**	**Model III**
v_S	-425 GeV	838 GeV	2548 GeV
v_T	0.3 GeV	0.3 GeV	-0,08 GeV
$\Delta\rho$	5.3×10^{-6}	5.9×10^{-6}	4×10^{-7}
$\tilde{\mu}$	-361 GeV	474 GeV	180 GeV

	Model I	Model II
Charginos:	612, 604, 352 GeV	622, 602, 455 GeV
Neutralinos:	740, 613, 606, 388, 352, 203 GeV	732, 619, 605, 484, 456, 215 GeV
Neutral scalars:	2332, 723, 467, 208 GeV	2333, 718, 580, 116 GeV
Neutral pseudoscalars:	2001, 1211, 491 GeV	2001, 1181, 588 GeV
Charged scalars:	2333, 2000, 471 GeV	2333, 2000, 583 GeV

Model III	Charginos:	812, 808, 178 GeV
	Neutralinos:	842, 830, 730, 226, 189, 171 GeV
	Neutral scalars:	2564, 722, 354, 120 GeV
	Neutral pseudoscalars:	2005, 1166, 369 GeV
	Charged scalars:	2565, 2004, 394 GeV

Dirac gaugino masses in gauge mediation

- Dirac masses in gauge mediation:



- Can have F or D term breaking (c.f. Majorana case)
- Lowest order operators are

$$\int d^2\theta \, \frac{a}{M^3} \mathrm{tr}(W^\alpha \Sigma) \overline{D}^2 D_\alpha (\mathbf{X}^\dagger \mathbf{X}) + \frac{b}{M} \mathrm{tr}(W^\alpha \Sigma) W'_\alpha$$

- In gauge mediation $a, b \sim \frac{\lambda_X g}{(4\pi)^2}$,

$$m_D \sim \frac{\lambda_X g}{(4\pi)^2} \frac{F^2}{M^3} \quad \text{or} \quad \frac{\lambda_X g}{(4\pi)^2} \frac{D}{M}$$

- Most models therefore use D term breaking
- But what if we insist on F term breaking?

Small Majorana gaugino masses

- In minimal gauge mediation there is a relationship between (Majorana) gaugino, sfermion masses and the (effective) number of messengers:

$$N_{eff} \equiv \frac{\Lambda_G^2}{\Lambda_S^2} \quad \text{where } \Lambda_G \propto N \frac{F}{M}, \; \Lambda_S \propto \sqrt{N}\frac{F}{M}$$

- Thus have $\Lambda_G \geqslant \Lambda_S$, gauginos typically heavier than sfermions
- However, in many models of susy breaking (such as ISS with direct mediation) the Majorana gaugino mass is subleading to third order:

$$\Lambda_G \propto N \frac{F^3}{M^5}$$

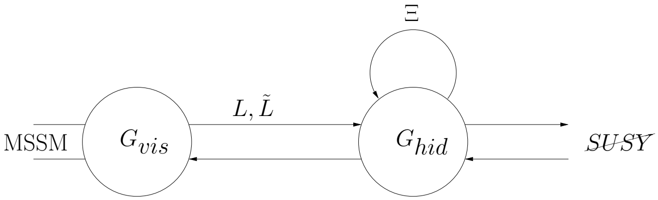
- So typically more suppressed than Dirac case! $\Lambda_G \ll \Lambda_S \rightarrow$ fine-tuning in Higgs sector

To solve, either:

- Consider $M^2 \sim F$
- Add extra source of R-breaking/metastability
- More complicated susy breaking/messenger sector
- Or a way to suppress scalar masses - if large enough, then can have sfermion masses only through gaugino loops $\rightarrow$ gaugino mediation

Deconstructed Gaugino Mediation

[Cheng, Kaplan, Schmalz and Skiba, 01], [Csaki, Erlich, Grojean and Kribs, 01]



$$\begin{aligned} W =& W_{\rm MSSM} + W_{\rm higgsing} + W_{\rm mess} + W_{\not{SUSY}} \\ W_{\rm higgsing} =& K\left(\frac{1}{5} L\tilde{L} - \mu_\ell^2\right) + L\Xi\tilde{L} \end{aligned} \quad (1)$$

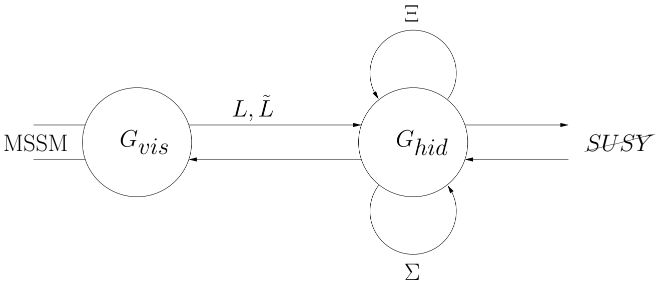
- Gaugino masses M_λ at one loop for $G_{\rm hid}$, scalar masses at <u>three</u> loops
- Then L gets a vev $\langle L\rangle = \langle\tilde{l}\rangle = \mu_\ell \rightarrow$ one combination of gauginos $\lambda_+ \equiv \lambda_{\rm vis} + \lambda_{\rm hid}$ gets mass μg, one remains light with mass M_λ
- Now have scalar masses at two loops but suppressed by μ_ℓ/M!

$$M_\lambda \sim \frac{g^2}{16\pi^2}\Lambda_g \qquad M_{\tilde{q}} \sim \frac{\mu_\ell}{M}\frac{g^2}{16\pi^2}\lambda_S$$

- Can overcome the leading order suppression!

easyDiracGauginos

Can now do the same but with Dirac gauginos:



$$W = W_{MSSM} + W_{higgsing} + W_{mess} + W_{\not{SUSY}}$$

$$W_{higgsing} = K(\frac{1}{5} L\tilde{L} - \mu_\ell^2) + L\Xi\tilde{L} + m\Xi\Sigma$$

- Now can overcome the F/M^2 suppression of gaugino masses by screening, but less screening required than for Majorana!

$$m_D \sim g\lambda_\Sigma \frac{F^2}{M^3}, \qquad m_{\tilde{f}} \sim g^2 \frac{\mu_\ell}{M} \frac{F}{M}$$

Higgsing

Need to be careful about the Higgsing:

- $L_\pm \equiv \frac{1}{\sqrt{2}}(L \pm \tilde{L})$, $W \supset L\Xi\tilde{L} \to \sqrt{2}\mu_\ell(L_+\Xi)$ makes the link fields heavy at higgsing scale
- L_- is eaten by gauge field, e.g. for gaugino $\mathcal{L} \supset -\mu_\ell(l_-\lambda_-)$ from gauge current, leaves light $\lambda_+ = \frac{1}{\sqrt{2}}(\lambda_{vis} + \lambda_{hid})$

In Majorana gaugino mediation, G_{hid} can be identical to G_{vis}, or $SU(5)$:

- Ξ, L, $\tilde{L} \longrightarrow \mathbf{8_0} + \mathbf{3_0} + \mathbf{1_0} + (\mathbf{3}, \mathbf{2})_{-5/6} + (\bar{\mathbf{3}}, \mathbf{2})_{5/6}$
- Only $\lambda_{hid} \supset (\mathbf{3}, \mathbf{2})_{-5/6} + (\bar{\mathbf{3}}, \mathbf{2})_{5/6} \longrightarrow$ <u>no light λ_+ in these reps</u>

$\longrightarrow$ In our model, G_{hid} must be identical to G_{vis} (otherwise $\Xi \supset (\mathbf{3}, \mathbf{2})_{-5/6} + (\bar{\mathbf{3}}, \mathbf{2})_{5/6}$ and these are unpaired with a light gaugino)

Higgsing

Need to be careful about the Higgsing:

- $L_\pm \equiv \frac{1}{\sqrt{2}}(L \pm \tilde{L})$, $W \supset L\Xi\tilde{L} \to \sqrt{2}\mu_\ell(L_+\Xi)$ makes the link fields heavy at higgsing scale
- L_- is eaten by gauge field, e.g. for gaugino $\mathcal{L} \supset -\mu_\ell(l_-\lambda_-)$ from gauge current, leaves light $\lambda_+ = \frac{1}{\sqrt{2}}(\lambda_{vis} + \lambda_{hid})$

In Majorana gaugino mediation, G_{hid} can be identical to G_{vis}, or $SU(5)$:

- $\Xi, L, \tilde{L} \to \mathbf{8_0} + \mathbf{3_0} + \mathbf{1_0} + (\mathbf{3},\mathbf{2})_{-\mathbf{5/6}} + (\bar{\mathbf{3}},\mathbf{2})_{\mathbf{5/6}}$
- Only $\lambda_{hid} \supset (\mathbf{3},\mathbf{2})_{-\mathbf{5/6}} + (\bar{\mathbf{3}},\mathbf{2})_{\mathbf{5/6}} \to$ no light λ_+ in these reps

$\to$ In our model, G_{hid} must be identical to G_{vis} (otherwise $\Xi \supset (\mathbf{3},\mathbf{2})_{-\mathbf{5/6}} + (\bar{\mathbf{3}},\mathbf{2})_{\mathbf{5/6}}$ and these are unpaired with a light gaugino)

The entire mass matrix for the vector of adjoint fermions $(\xi, \sigma, l_+, l_-, \lambda_+, \lambda_-)^a$ takes the form

$$\mathcal{M}_{\psi_{Adj}} = \frac{1}{2}\begin{pmatrix} 0 & m & \mu_\ell & 0 & 0 & 0 \\ m & 0 & 0 & -m_D \sin\vartheta & m_D \cos\vartheta & 0 \\ \mu_\ell & 0 & 0 & 0 & 0 & 0 \\ 0 & -m_D \sin\vartheta & 0 & 0 & 0 & M_A \\ 0 & m_D\cos\vartheta & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & M_A & 0 & 0 \end{pmatrix}$$

$$m_\lambda = m_D \frac{\mu_\ell}{\sqrt{2(m^2 + \mu_\ell^2)}} + \ldots$$

Adjoint scalars

- Adjoint scalar masses generated at one loop can be problematic:

$$-\mathcal{L} \supset m_\Sigma^2 \mathrm{tr}(\Sigma^\dagger \Sigma) + \frac{1}{2} B_\Sigma \mathrm{tr}(\Sigma^2 + (\Sigma^\dagger)^2)$$

- Physical masses are $m_{\Sigma_P}^2, m_{\Sigma_M}^2 = m_\Sigma^2 \pm B_\Sigma$:

$$-\mathcal{L} \supset \mathrm{tr}\left(\frac{1}{2}(m^2 + B)\Sigma_P^2 + \frac{1}{2}(m^2 - B)\Sigma_M^2\right)$$

- Tachyon unless $m_\Sigma^2 \geqslant |B_\Sigma|$!
- For R-symmetric F-term breaking the minimal messenger choice is

$$W_{mess} = \mathbf{X} f_1 \tilde{f}_2 + M(f_1 \tilde{f}_1 + f_2 \tilde{f}_2) + h_1 f_1 \Sigma \tilde{f}_1 + h_2 f_2 \Sigma \tilde{f}_2$$

- No tachyon if $h_2 < (\sqrt{3} - 2) h_1$, typically choose $h_2 = -h_1$

Scales

Take $h_1 = -h_2 \equiv h$, then

Dirac gaugino masses: $m_\lambda \simeq I_f \sqrt{2} h g_r \frac{1}{16\pi^2} \frac{|F|^2}{6M^3} \frac{\mu_\ell}{\sqrt{2(m^2+\mu_\ell^2)}}$,

Two-loop sfermion masses: $m_{\tilde{f}}^{2-\text{loop}} \sim \frac{\sqrt{2} g_r^2}{16\pi^2} \frac{|F|}{M} \frac{\mu_\ell}{M}$,

Adjoint scalar masses: $m_\Sigma \sim h \frac{1}{4\pi} \frac{F}{M} \sqrt{\frac{2 \pm 1}{3}}$

Three-loop "supersoft" sfermion masses: $m_{\tilde{f}}^{3-\text{loop}} \sim \sqrt{2} h g_r^2 \frac{\mu_\ell}{\sqrt{2(m^2+\mu_\ell^2)}} \frac{1}{32\pi^3} \frac{|F|^2}{6M^3} \sqrt{\log[\frac{16\pi^2 M^2}{g^2 F}]}$

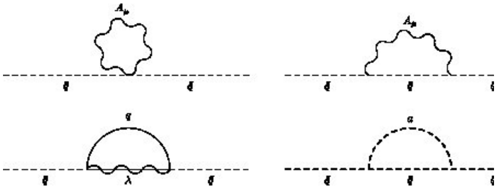


Figure: Supersoft Sfermion masses, taken from [Fox, Nelson, Weiner 02]

Adjoint scalar masses in GGM

By adding the extra adjoints, we should add extra currents $\mathcal{J}_2 (= J_2 + \sqrt{2}\theta j_2 + \theta\theta F_2 + \ldots)$ to General Gauge Mediation, couples via superpotential:

$$W \supset \lambda_\Sigma \boldsymbol{\Sigma} \mathcal{J}_2 \to \mathcal{L} \supset \lambda_X \left[-\chi j_2 - \overline{\chi} \bar{j}_2 + \Sigma F_2 + \bar{\Sigma} \bar{F}_2 \right]$$

- Now have the Dirac masses and adjoint scalar masses as parameters determined from correlators of this
- Adjoint masses appear at one loop, so have typical hierarchy in gauge mediation

$$\mathrm{F-terms:} \quad m_D \sim g\lambda_\Sigma \frac{F^2}{M^3} \ll m_{\tilde{f}} \sim g^2 \frac{F}{M} < m_\Sigma \sim \lambda_\Sigma \frac{F}{M}$$

$$\mathrm{D-terms:} \quad m_{\tilde{f}} \sim g^3 \lambda_\Sigma \frac{D}{M} < m_D \sim g\lambda_\Sigma \frac{D}{M} < m_\Sigma \sim \lambda_\Sigma \frac{D}{M}$$

- In “Deconstructed Dirac gaugino mediation” the adjoint masses are not modified:

$$\mathrm{F-terms:} \quad m_D \sim g\lambda_\Sigma \frac{F^2}{M^3}, m_{\tilde{f}} \sim g^2 \frac{\mu_\ell}{M} \frac{F}{M} \ll m_\Sigma \sim \lambda_\Sigma \frac{F}{M}$$

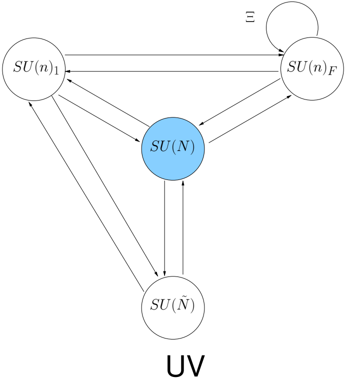
Dynamical completion

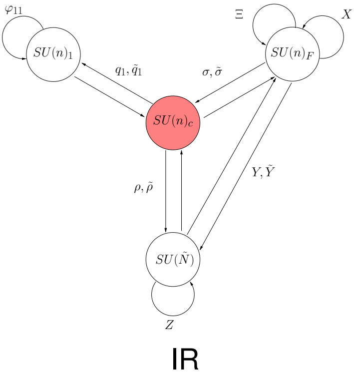
- Can now add explicit SUSY breaking sector that preserves R - such as ISS!
- In fact, the whole model (with a few changes) can come from strongly coupled theory in UV
- Adapt idea of [Green, Katz and Komargodski, 10]: start with UV theory and gauge singlets
$$W^{(elec)} = m_I^J Q^I \tilde{Q}_J + S_I^J Q^I \tilde{Q}_J$$
- In IR, the dual theory has mesons, but due to the singlets some are integrated out:
$$W^{(mag)} = -\mu m_I^J \Phi_J^I + \mu S_I^J \Phi_J^I + q \Phi \tilde{q}$$
- Some magnetic quarks become the link fields while others become messengers
- To get Dirac gauginos, we need to add a fundamental adjoint to a UV flavour group and a term $W^{el} \supset h_\xi Q \Xi \tilde{Q}$

Magnetic theory field content

	$SU(n)_1$	$SU(n)_\sigma$	$SU(N-n)_\rho$	$U(1)_B$	$U(1)_{B'}$	$U(1)_R$	$U(1)_{R'}$
q_1	$\square$	$\overline{\square}$	1	$\frac{1}{n}$	$\frac{1}{n}$	$1-\frac{n}{N_f}$	0
$\tilde{q}_1$	$\overline{\square}$	$\square$	1	$-\frac{1}{n}$	$-\frac{1}{n}$	$1-\frac{n}{N_f}$	0
σ	1	Adj	1	$\frac{1}{n}$	$-\frac{1}{n}$	$1-\frac{n}{N_f}$	0
$\tilde{\sigma}$	1	Adj	1	$-\frac{1}{n}$	$\frac{1}{n}$	$1-\frac{n}{N_f}$	0
ρ	1	$\square$	$\overline{\square}$	$\frac{1}{n}$	$-\frac{1}{n}$	$1-\frac{n}{N_f}$	0
$\tilde{\rho}$	1	$\overline{\square}$	$\square$	$-\frac{1}{n}$	$\frac{1}{n}$	$1-\frac{n}{N_f}$	0
φ_{11}	Adj	1	1	0	0	$2\frac{n}{N_f}$	2
X	1	Adj	1	0	0	$2\frac{n}{N_f}$	2
Z	1	1	Adj	0	0	$2\frac{n}{N_f}$	2
Y	1	$\square$	$\overline{\square}$	0	0	$2\frac{n}{N_f}$	2
$\tilde{Y}$	1	$\overline{\square}$	$\square$	0	0	$2\frac{n}{N_f}$	2
Ξ	1	Adj	1	0	0	$2-2\frac{n}{N_f}$	0

Prototype example





Magnetic theory

- Magnetic field content is:

$$W^{(mag)} = (q_1 \varphi_{11} \tilde{q}_1 - \mu_1^2 \varphi_{11}) + (\sigma X \tilde{\sigma} - \mu_2^2 X + m \Xi X) + \rho Z \tilde{\rho} + \sigma Y \tilde{\rho} + \rho \tilde{Y} \tilde{\sigma} - \mu_3^2 Z$$

- $q_1, \tilde{q}_1$ are link fields
- Recover our messenger structure when $\langle \sigma \rangle = \langle \tilde{\sigma} \rangle = \mu_2$:

$$Z \equiv S, \rho \equiv f_1, \tilde{\rho} \equiv \tilde{f}_2, Y \equiv f_2, \tilde{Y} \equiv \tilde{f}_1$$

- $\sigma, \tilde{\sigma}$ and Ξ mix due to m to play the role of link fields and adjoints
- Expect Kähler potential term to be generated

$$\delta K \supset \alpha^2_{flavour} \frac{|Z|^2 |\Xi|^2}{\Lambda^2}$$

- Term $|Z/\Lambda|^2 (\Xi^2 + \overline{\Xi}^2)$ forbidden by $U(1)_R$.

Finding the Dirac masses

- $\sqrt{2}\sigma_+ = \sigma + \tilde{\sigma}$ gets vev and has mass term with X, but by adding term $m\Xi X$ have a massless mode:

$$W^{(mag)} \supset (\sqrt{2}\mu_2 \sigma_+ + m\Xi) X$$

- Defining $\tan\nu = \frac{m}{\sqrt{2}\mu_2}$, our adjoint is $\sigma_\parallel = (\cos\nu\,\Xi - \sin\nu\,\sigma_+)$
- Perpendicular direction is massive, σ_- is eaten.
- Relevant piece of superpotential is

$$W^{(mag)} \supset \mu_2(h_1 Y\tilde{\rho} + h_2 \rho \tilde{Y}) - \sin\nu\,\sigma_\parallel \left(h_1 \tilde{\rho} Y + h_2 \tilde{Y} \rho\right) + Z\tilde{\rho}\rho - \mu_3^2 Z$$

- Find Dirac gaugino mass

$$m_D \approx g_c \sin\nu\,|h_1 - h_2| \frac{1}{16\pi^2} \frac{F^2}{6\sqrt{2}.(h_2\mu_2)^3}$$

- Adjoint scalar mass dominated by the Kähler potential contribution

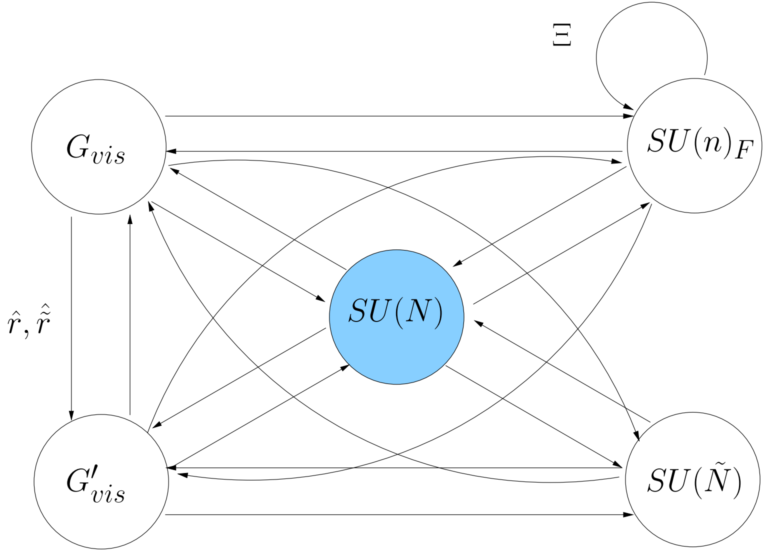
$$m^2_{\sigma_\parallel, K} \sim \frac{1}{16\pi^2} \cos^2\nu \frac{\mu_3^4}{\Lambda^2}$$

$SU(N_f) \to G_{vis} \times G'_{vis} \times SU(5)_F \times SU(\tilde{N})$

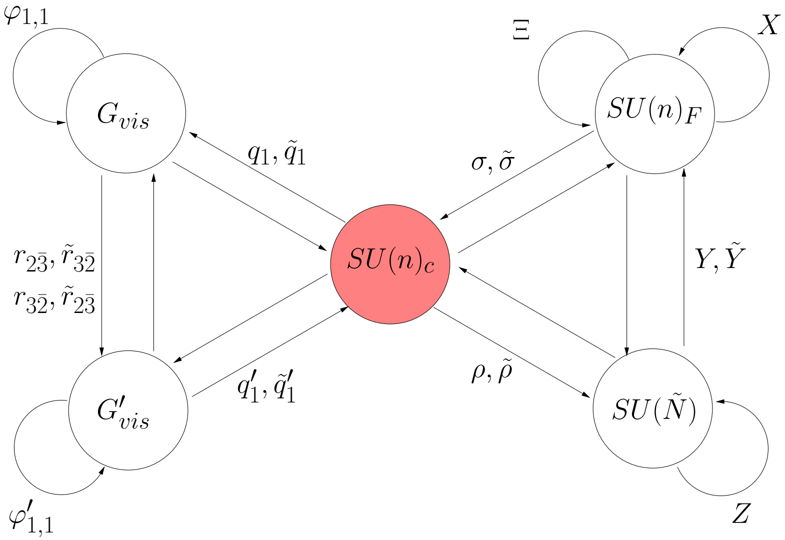
- If visible group is $SU(3) \times SU(2) \times U(1)$ (rather than $SU(5)$) higgsed with $SU(5)$ have an added subtlety: bachelor states
- The gauginos in reps $(3, \overline{2})$, $(\overline{3}, 2)$ become massive with the auxiliary adjoint $\to$ we are left with unpaired (massless) fermions in these reps
- Solution is to add another copy G'_{vis} and Higgs them away; recall $W^{(elec)} = m_I^J Q^I \tilde{Q}_J + S_I^J Q^I \tilde{Q}_J$

$$m_I^J = \frac{1}{\Lambda} \left(\begin{array}{c:c:c:c:c:c} \mu_1^2 & & & & & \\ \hdashline & \mu_1^2 & & & & \\ \hdashline & & \mu_4^2 & & & \\ \hdashline & & & \mu_4^2 & & \\ \hdashline & & & & \mu_2^2 & \\ \hdashline & & & & & \mu_3^2 \end{array} \right), \qquad S_I^J = \left(\begin{array}{c:c:c:c:c:c} & & \hat{r}_{3\bar{3}} & & S_{3\bar{5}} & S_{3\bar{\tilde{N}}} \\ \hdashline & & & \hat{r}_{2\bar{2}} & S_{2\bar{5}} & S_{2\bar{\tilde{N}}} \\ \hdashline \hat{\tilde{r}}_{3\bar{3}} & & & & S_{3'\bar{5}} & S_{3'\bar{\tilde{N}}} \\ \hdashline & \hat{\tilde{r}}_{2\bar{2}} & & & S_{2'\bar{5}} & S_{2'\bar{\tilde{N}}} \\ \hdashline \tilde{S}_{5\bar{3}} & \tilde{S}_{5\bar{2}} & S_{5\bar{3}'} & S_{5\bar{2}'} & \Xi & \\ \hdashline \tilde{S}_{\bar{\tilde{N}}3} & \tilde{S}_{\bar{\tilde{N}}2} & S_{\tilde{N}\bar{3}'} & S_{\tilde{N}\bar{2}'} & & \end{array} \right).$$

Final model - UV



Final model - IR



Bachelors again

Now find in magnetic theory:

$$W^{(mag)} \supset r_{2\bar{3}}(a_1 q_{1,3\bar{3}} q'_{1,3\bar{2}} + b_1 q_{1,3\bar{2}} q'_{1,2\bar{2}}) + (a_2 \tilde{q}_{1,3\bar{2}} \tilde{q}'_{1,2\bar{2}} + b_2 \tilde{q}_{1,3\bar{3}} \tilde{q}'_{1,3\bar{2}})\tilde{r}_{2\bar{3}} + (2 \leftrightarrow 3)$$

Gives fermionic mass terms:

$$\begin{aligned}\mathcal{L} \supset & -\sqrt{2}\mu_1 q^+_{1,3\bar{2}}\psi_{2\bar{3}} - \sqrt{2}\mu_4 (q'_{1,3\bar{2}})^+ \psi'_{2\bar{3}} \\ & - m_D \sigma_{3\bar{2}} \lambda_{2\bar{3}} + \sqrt{2} g_\sigma \mu_1 q^-_{1,3\bar{2}} \lambda_{2\bar{3}} + \sqrt{2} g_\sigma \mu_4 (q'_{1,3\bar{2}})^- \lambda_{2\bar{3}} \\ & - \mu_1 (a_1 r_{2\bar{3}} q'_{1,3\bar{2}} + b_1 \tilde{q}'_{1,3\bar{2}} \tilde{r}_{2\bar{3}}) - \mu_4 (a_2 r_{2\bar{3}} q_{1,3\bar{2}} + b_2 \tilde{r}_{2\bar{3}} \tilde{q}_{1,3\bar{2}}) \\ & + (2 \leftrightarrow 3)\end{aligned}$$

Naturally we can choose $\mu_4 = \mu_1$, giving

$$m_\lambda^{bachelor} = m_D [1 + \mathcal{O}(g^2, (m_D/\mu_1)^2)].$$

Obtain bachelor masses $\sim m_D$!

Conclusions

- Models of Dirac gauginos can be useful to solve problems of gauge mediation and SUSY breaking, and can arise naturally in many different contexts (strong dynamics, higher dimensions, string theory, ...)
- Now possible to build a variety of realistic models, with D and/or F terms
- Interesting F-term breaking models can arise from strong dynamics
- $\rightarrow$the parameter space of gaugino/gauge mediation may be large!

Future Possibilities

Many possible avenues for future work:

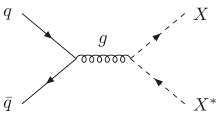
- Other messenger/susy breaking embeddings
- Add flavour to the above (cf Katz's talk)
- Warped models (cf Gherghetta's talk)

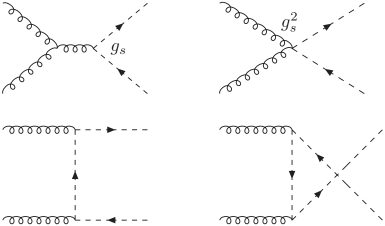
More generally, many things to study:

- Gauge messengers
- Calculation of two-loop effects
- Implementation in "Dirac Gaugino Soft Susy"
- LHC adjoint scalar searches
- Models to realise messenger mass patterns
- Explicit D-term ~~SUSY~~ sectors (e.g. $4-1$ model)
- Gravity mediation, embedding in string models, Dirac gravitinos,....

Collider Signatures

- May be difficult to distinguish directly Dirac and Majorana gauginos except at $e^- e^-$ collider
- Indirectly we do obtain spectacular signals from the adjoint scalars





- Decay as (tree level):

$$X \rightarrow \tilde{g}\tilde{g} \rightarrow qq\tilde{q}\tilde{q} \rightarrow qqqq + \tilde{\chi}\tilde{\chi}$$
$$X \rightarrow \tilde{q}\tilde{q} \rightarrow qq + \tilde{\chi}\tilde{\chi}$$

and (one loop):

$$X \rightarrow t\bar{t}$$