Natural Supersoft SUSY

(with Dirac gauginos)

Xinlu Huang
Stanford University

Aug 23, 2012

Work in progress, in collaboration with
Ken Van Tilburg (Stanford)

Ed Hardy
John March-Russell
James Unwin
(Oxford University)

Motivations

- Why **natural** SUSY has been (and still is) the leading BSM theory
  - Solution to the hierarchy (a.k.a. naturalness; a.k.a. fine-tuning) problem
  - Matter contents lead to precision gauge unification
  - Dark matter candidate (RPC SUSY)
  - Connection to string theory and quantum gravity

Motivations

- Why **natural** SUSY has been (and still is) the leading BSM theory
  - Solution to the hierarchy (a.k.a. naturalness; a.k.a. fine-tuning) problem
  - Matter contents lead to precision gauge unification
  - Dark matter candidate (RPC SUSY)
  - Connection to string theory and quantum gravity
- "Naturalness" is under attack by experiment:
  - Stringent LHC limits on squark and gluino mass
  - $m_h = 126$ GeV, much above SUSY tree-level prediction requires large radiative correction $\rightarrow$ large $m_{\tilde{t}}$ and/or A_t
    - requires large radiative correction $\Rightarrow$ large $m_{\tilde{t}}$ and/or A_t $\Rightarrow$ more fine-tuning

Motivations

- Why **natural** SUSY has been (and still is) the leading BSM theory
  - Solution to the hierarchy (a.k.a. naturalness; a.k.a. fine-tuning) problem
  - Matter contents lead to precision gauge unification
  - Dark matter candidate (RPC SUSY)
  - Connection to string theory and quantum gravity
- "Naturalness" is under attack by experiment:
  - Stringent LHC limits on squark and gluino mass
  - $m_h = 126$ GeV, much above SUSY tree-level prediction requires large radiative correction $\rightarrow$ large $m_{\tilde{t}}$ and/or A_t
    - requires large radiative correction $\Rightarrow$ large $m_{\tilde{t}}$ and/or A_t $\Rightarrow$ more fine-tuning
- Before we pronouce *natural* SUSY to be dead:

Motivations

- Why **natural** SUSY has been (and still is) the leading BSM theory
  - Solution to the hierarchy (a.k.a. naturalness; a.k.a. fine-tuning) problem
  - Matter contents lead to precision gauge unification
  - Dark matter candidate (RPC SUSY)
  - Connection to string theory and quantum gravity
- "Naturalness" is under attack by experiment:
  - Stringent LHC limits on squark and gluino mass
  - $m_h = 126$ GeV, much above SUSY tree-level prediction requires large radiative correction $\rightarrow$ large $m_{\tilde{t}}$ and/or A_t
    - requires large radiative correction $\Rightarrow$ large $m_{\tilde{t}}$ and/or A_t $\Rightarrow$ more fine-tuning
- Before we pronouce *natural* SUSY to be dead: have we explored all well-motivated SUSY theories that give a natural spectrum?

What are Dirac gauginos?

- Gauginos λ^a $(a = 1, 2, 3)$ are given Majorana mass in standard MSSM ~~SUSY~~:

$$\mathcal{L} \supset M^a \lambda^a \lambda^a$$

What are Dirac gauginos?

- Gauginos λ^a $(a = 1, 2, 3)$ are given Majorana mass in standard MSSM ~~SUSY~~:

$$\mathcal{L} \supset M^a \lambda^a \lambda^a$$

- To give *Dirac* mass to gauginos $\Rightarrow$ need to extend MSSM:
  - $\chi^{\mathbf{a}}$: $\mathbf{O} \sim (8,1)_0$; $\mathbf{T} \sim (1,3)_0$; and $\mathbf{S} \sim (1,1)_0$

$$\mathcal{L} \supset M_D^a \lambda^a \chi^a$$

What are Dirac gauginos?

- Gauginos λ^a $(a = 1, 2, 3)$ are given Majorana mass in standard MSSM ~~SUSY~~:

$$\mathcal{L} \supset M^a \lambda^a \lambda^a$$

- To give *Dirac* mass to gauginos $\Rightarrow$ need to extend MSSM:
  - $\chi^{\mathbf{a}}$: $\mathbf{O} \sim (8,1)_0$; $\mathbf{T} \sim (1,3)_0$; and $\mathbf{S} \sim (1,1)_0$

$$\mathcal{L} \supset M_D^a \lambda^a \chi^a$$

- In total, we are adding
  - Dirac partners to all 3 MSSM gauginos
  - Scalar particles in the adjoint rep. of $\mathrm{SU}(3)_C \times \mathrm{SU}(2)_W \times \mathrm{U}(1)_Y$

Why Dirac gauginos? (UV perspective)

Why Dirac gauginos? (UV perspective)

Note: vector multiplet + adjoint chiral multiplet = gauge multiplet in $\mathcal{N} = 2$ SUSY (MSSM has $\mathcal{N} = 1$ SUSY)

Why Dirac gauginos? (UV perspective)

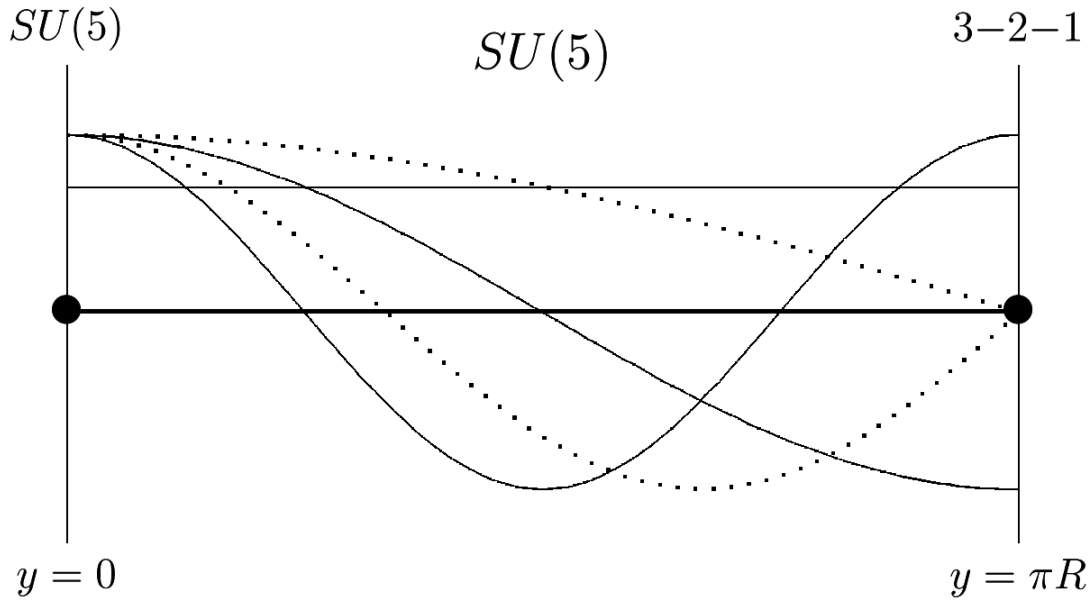
Note: vector multiplet + adjoint chiral multiplet = gauge multiplet in $\mathcal{N} = 2$ SUSY (MSSM has $\mathcal{N} = 1$ SUSY)

1. Maximum SUSY allowed by by gauge coupling running $\Rightarrow$ MSSM+DG:
   - $\mathcal{N} = 2$ SUSY in gauge sector
   - $\mathcal{N} = 1$ SUSY for matter

Why Dirac gauginos? (UV perspective)

Note: vector multiplet + adjoint chiral multiplet = gauge multiplet in $\mathcal{N} = 2$ SUSY (MSSM has $\mathcal{N} = 1$ SUSY)

1. Maximum SUSY allowed by by gauge coupling running $\Rightarrow$ MSSM+DG:
   - $\mathcal{N} = 2$ SUSY in gauge sector
   - $\mathcal{N} = 1$ SUSY for matter
2. $\mathcal{N} = 2$ SUSY comes naturally in extra-dimensional models



Why Dirac gauginos? (IR perspective)

- Allow decoupling of gluino mass from squark (most importantly, stop) masses via "supersoftness"

$$\delta_{m_{\tilde{t}}^2}|_{gluino} \propto \alpha_s |M_3|^2 \log\left(\frac{\Lambda}{m_{\tilde{t}}}\right) \qquad \delta_{m_{\tilde{t}}^2}|_{\substack{Dirac \\ gluino}} \propto \alpha_s |M_3|^2 \log\left(\frac{m_O}{M_3}\right)$$

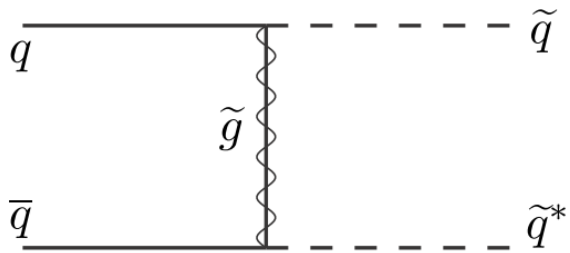
  - Can have light stop + heavy gluino $\Rightarrow$ viable natural spectrum

Why Dirac gauginos? (IR perspective)

- Allow decoupling of gluino mass from squark (most importantly, stop) masses via "supersoftness"

$$\delta_{m_{\tilde{t}}^2}|_{gluino} \propto \alpha_s |M_3|^2 \log\left(\frac{\Lambda}{m_{\tilde{t}}}\right) \qquad \delta_{m_{\tilde{t}}^2}|_{\substack{Dirac \\ gluino}} \propto \alpha_s |M_3|^2 \log\left(\frac{m_O}{M_3}\right)$$

  - Can have light stop + heavy gluino $\Rightarrow$ viable natural spectrum
- Decrease squark pair production xsec $\Rightarrow$ weaken LHC limits



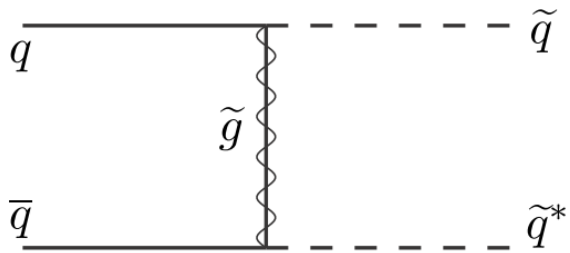
Majorana gluino: $\sim 1/M_3$
Dirac gluino: $\sim 1/M_3^2$

Why Dirac gauginos? (IR perspective)

- Allow decoupling of gluino mass from squark (most importantly, stop) masses via "supersoftness"

$$\delta_{m_{\tilde{t}}^2}|_{gluino} \propto \alpha_s |M_3|^2 \log\left(\frac{\Lambda}{m_{\tilde{t}}}\right) \qquad \delta_{m_{\tilde{t}}^2}|_{\substack{Dirac \\ gluino}} \propto \alpha_s |M_3|^2 \log\left(\frac{m_O}{M_3}\right)$$

  - Can have light stop + heavy gluino $\Rightarrow$ viable natural spectrum
- Decrease squark pair production xsec $\Rightarrow$ weaken LHC limits



Majorana gluino: $\sim 1/M_3$
Dirac gluino: $\sim 1/M_3^2$

- Allows for sizeable increase in $H \to \gamma\gamma$ br via extra chargino

Life is never perfect...

... and I'm not a used car dealer

Life is never perfect...

... and I'm not a used car dealer

Dirac gauginos:

- Spoils gauge unification

Life is never perfect...

... and I'm not a used car dealer

Dirac gauginos:

- Spoils gauge unification
  - needs to add additional ~~garbage~~ baggages
  - however, can add **24** of SU(5) and push extra $(3,2)_{5/6} + \text{h.c.}$ states to $\sim 10^{12}$ GeV

Life is never perfect...

... and I'm not a used car dealer

Dirac gauginos:

- Spoils gauge unification
  - needs to add additional ~~garbage~~ baggages
  - however, can add **24** of SU(5) and push extra $(3,2)_{5/6}$ + h.c. states to $\sim 10^{12}$ GeV
- Reduce (sometimes completely) the MSSM tree-level Higgs mass contribution

Life is never perfect...

... and I'm not a used car dealer

Dirac gauginos:

- Spoils gauge unification
  - needs to add additional ~~garbage~~ baggages
  - however, can add **24** of SU(5) and push extra $(3,2)_{5/6}$ + h.c. states to $\sim 10^{12}$ GeV
- Reduce (sometimes completely) the MSSM tree-level Higgs mass contribution
  - Coupling $\mathbf{W} \supset \mathbf{H_u} \cdot \mathbf{TH_d} + \mathbf{SH_u} \cdot \mathbf{H_d}$ can easily raise tree-level m_h to 126 GeV for low $\tan\beta$, no heavy stops needed
- $\mathbf{H_u} \cdot \mathbf{TH_d}$ contrib. to EW precision paramter $T \sim v_T^2/v^2$
  - Not too difficult to satisfy bound; can contrain parameter space

Life is never perfect...

... and I'm not a used car dealer

Dirac gauginos:

- Spoils gauge unification
  - needs to add additional ~~garbage~~ baggages
  - however, can add **24** of SU(5) and push extra $(3,2)_{5/6}$ + h.c. states to $\sim 10^{12}$ GeV
- Reduce (sometimes completely) the MSSM tree-level Higgs mass contribution
  - Coupling $\mathbf{W} \supset \mathbf{H_u} \cdot \mathbf{TH_d} + \mathbf{SH_u} \cdot \mathbf{H_d}$ can easily raise tree-level m_h to 126 GeV for low $\tan\beta$, no heavy stops needed
- $\mathbf{H_u} \cdot \mathbf{TH_d}$ contrib. to EW precision paramter $T \sim v_T^2/v^2$
  - Not too difficult to satisfy bound; can contrain parameter space
- Naive realizations of spectrum are not realistic (light sleptons $\Rightarrow$ TeV scale squarks)
  - can exploit UV motivation (e.g. extra-dim) to get realistic spectrum

Conclusion

- MSSM + Dirac gauginos is theoretically well-motivated
- Given current LHC bound + Higgs(-like particle) @ 126 GeV, MSSM+DG is an attrative and viable natural SUSY model.