Dirac gauginos and unification in F-theory

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Based on (RD, **arXiv:1205.1942**)

Outline

Introduction/Motivation

Adjoint chiral fields in F-theory

F-theory unification with Dirac gauginos

Summary

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What are Dirac gauginos?

A neutral spin-half fermion (two-spinor λ) can have a 'Majorana' mass:

$$\mathcal{L}_{\text{Maj.}} \supset \frac{m}{2}(\lambda^\alpha \lambda_\alpha + \bar{\lambda}_{\dot{\alpha}} \bar{\lambda}^{\dot{\alpha}}) \ .$$

If λ is charged, this is forbidden, and we must introduce another fermion η of opposite charge, to give a 'Dirac' mass:

$$\mathcal{L}_{\text{Dir.}} \supset m(\lambda^\alpha \eta_\alpha + \bar{\lambda}_{\dot{\alpha}} \bar{\eta}^{\dot{\alpha}}) = m\bar{\Psi}\Psi \ , \ \text{where } \Psi = (\lambda \ \bar{\eta}) \ .$$

In the MSSM, gauginos have Majorana masses. If these are forbidden (say, by R-symmetry), then we must introduce chiral multiplets in the adjoint representation, and give them (SUSY-breaking) Dirac masses.

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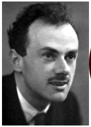
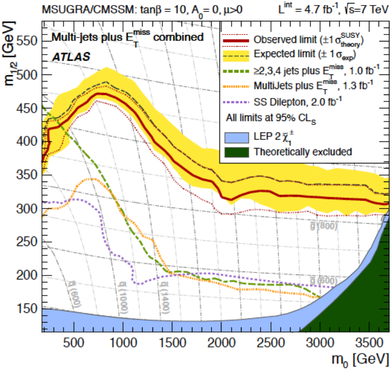


The MSSM and the LHC

LHC data from last year sets strong bounds on gluino and first/second-generation squark masses in standard SUSY scenarios, e.g.



Taken from (ATLAS, **arXiv:1206.1760**.)

Dirac gauginos and naturalness

Dirac gauginos give finite (i.e. not log-enhanced) corrections to soft masses:

Dirac	Majorana
$\delta m_{H_u}^2 \sim M^2$	$\delta m_{H_u}^2 \sim M^2 \log^2\left(\frac{\Lambda}{M}\right)$

They can therefore be significantly heavier than Majorana gauginos without extra fine-tuning.

Heavy Dirac gauginos

$\Rightarrow$ lower squark production cross sections

$\Rightarrow$ less stringent squark mass bounds

Studied in detail in (Heikinheimo Kellerstein Sanz, **arXiv:1111.4322**; Kribs, Martin **arXiv:1203.4821**) . Conclusion:

Models with Dirac gauginos ~ 5 TeV and squarks $\lesssim 700$ GeV are still allowed by the data, and are just as natural as the MSSM with sub-TeV gauginos and light squarks (which is ruled out).

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F-theory GUTs

General setup:

- F-theory on an elliptically-fibred Calabi–Yau fourfold $X \to B$ (B a Kähler threefold) $\implies$ unbroken $\mathcal{N} = 1$ supersymmetry in 4D.
- Let X have an A_4 singularity, fibred over a complex surface $S \subset B$ $\implies SU(5)$ gauge theory supported on S.
  (Can be thought of as type IIB on B with 7-branes wrapping S, but with $SL(2,\mathbb{Z})$ identifications $\Rightarrow$ no global weakly-coupled description.)
- $SU(5)$ can be broken to $G_{\rm SM} \cong SU(3)\times SU(2)\times U(1)_Y/\mathbb{Z}_6$ by hypercharge flux (Beasley Heckman Vafa, **arXiv:0806.0102**; Donagi Wijnholt, **arXiv:0808.2223**)

Standard model adjoints

The theory on S contains both a scalar ϕ and an 8D vector field A in the adjoint $\mathbf{24}$ of $SU(5)$. The $\mathbf{24}$ decomposes under G_{SM} as follows:

$$\begin{aligned} SU(5) &\supset SU(3)\times SU(2)\times U(1)_Y/\mathbb{Z}_6 \\ \mathbf{24} &= (\mathbf{8},\mathbf{1},0)\oplus(\mathbf{1},\mathbf{3},0)\oplus(\mathbf{1},\mathbf{1},0)\oplus(\mathbf{3},\mathbf{2},-5)\oplus(\overline{\mathbf{3}},\mathbf{2},5)\ . \end{aligned}$$

The standard model adjoints are uncharged under all fluxes, so their massless modes depend only on the geometry of S.

Massless chiral adjoints:

- ϕ: $H^2(S,K_S) \Rightarrow h^{2,0}(S)$ multiplets (brane deformations).
- A: $H^1(S,\mathcal{O}_S) \Rightarrow h^{1,0}(S)$ multiplets (Wilson lines).

So demand $h^{1,0}(S)+h^{2,0}(S)=1$. A nice choice is $S\cong K3$.

(Note: B Fano, $S\cong K3 \Rightarrow$ no decoupling limit.)

Hypercharge flux and exotics

We want to ensure that there are no light fields originating in the 'off-diagonal' components of the **24**.

Suppose the gauge group is actually $U(5)$, and turn on two types of flux:

- Flux along $\mathrm{diag}(0,0,0,1,1)$, corresponding to a line bundle $\mathcal{L}_Y$
- Flux along $\mathrm{diag}(1,1,1,1,1)$, corresponding to a line bundle $\mathcal{L}_a$

If $S \cong K3$, it is easy to check that there are no unwanted states if, e.g., $c_1(\mathcal{L}_Y) = [C_1 - C_2]$, where C_1 and C_2 are two disjoint rational curves. We can easily arrange $C_1 \overset{\text{hom.}}{\sim_B} C_2$, so the $U(1)_Y$ gauge boson remains massless.

(General condition is slightly different to the del Pezzo case.)

Outline

F-theory unification

Hypercharge flux splits the gauge couplings at the compactification scale (Blumenhagen, **arXiv:0812.0248**) :

$$\begin{aligned}
\delta\alpha_1^{-1} &= -\tfrac{1}{2g_s}\int_S \left(c_1(\mathcal{L}_a)^2 + \tfrac{6}{5}c_1(\mathcal{L}_a)c_1(\mathcal{L}_Y) + \tfrac{3}{5}c_1(\mathcal{L}_Y)^2\right) \\
\delta\alpha_2^{-1} &= -\tfrac{1}{2g_s}\int_S \left(c_1(\mathcal{L}_a)^2 + 2c_1(\mathcal{L}_a)c_1(\mathcal{L}_Y) + c_1(\mathcal{L}_Y)^2\right) \qquad (1) \\
\delta\alpha_3^{-1} &= -\tfrac{1}{2g_s}\int_S c_1(\mathcal{L}_a)^2 \ ,
\end{aligned}$$

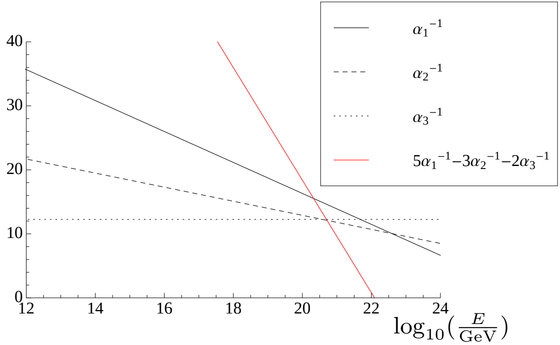
One linear relation remains:

$$5\alpha_1^{-1} - 3\alpha_2^{-1} - 2\alpha_3^{-1} = 0 \ .$$

This is the only completely general boundary condition to set on the RG flow in an arbitrary F-theory GUT.

No unification with Dirac gauginos

The adjoint chiral fields, necessary for Dirac gauginos, disrupt the usual gauge unification of the MSSM, and even the weaker F-theory unification.



One-loop running of gauge couplings with adjoint chiral multiplets. F-theory unification only occurs well above the Planck scale, making this scenario inconsistent.

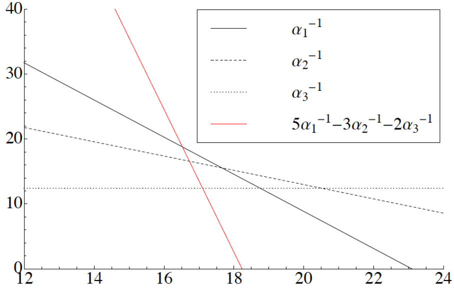
Restoring unification

In 4D models, many new fields need to be added to restore unification. Our requirements are weaker though; we simply need to bring down the scale at which $5\alpha_1^{-1} - 3\alpha_2^{-1} - 2\alpha_3^{-1} = 0$. We therefore need a *negative* contribution to $b_F := 5b_1 - 3b_2 - 2b_3$.

$SU(5)$ irrep.	G_{SM} irrep.	δb_1	δb_2	δb_3	$\delta b_F := 5\,\delta b_1 - 3\,\delta b_2 - 2\,\delta b_3$
$\mathbf{10}$	$(\overline{\mathbf{3}}, \mathbf{1}, -4)$	$-\frac{4}{5}$	0	$-\frac{1}{2}$	-3
	$(\mathbf{3}, \mathbf{2}, 1)$	$-\frac{1}{10}$	$-\frac{3}{2}$	-1	6
	$(\mathbf{1}, \mathbf{1}, 6)$	$-\frac{3}{5}$	0	0	-3
$\overline{\mathbf{5}}$	$(\overline{\mathbf{3}}, \mathbf{1}, -2)$	$-\frac{1}{5}$	0	$-\frac{1}{2}$	0
	$(\mathbf{1}, \mathbf{2}, 3)$	$-\frac{3}{10}$	$-\frac{1}{2}$	0	0

Restoring unification — a simple example

If we assume that there is a single vector-like pair of positrons (i.e. chiral multiplets in $(\mathbf{1}, \mathbf{1}, 6) \oplus (\mathbf{1}, \mathbf{1}, -6)$) at 1 TeV, we get the following:



F-theory unification now occurs at around the reduced Planck scale. In this scenario, there is no hierarchy between the GUT and Planck scales, consistent with the lack of a 'decoupling limit'.

Outline

Other (big) issues

- Majorana masses should be suppressed somehow — perhaps R-symmetry (Kribs Poppitz Weiner **arXiv:0712.2039**; RD March-Russell McCullough **arXiv:1103.1647**) $\leftrightarrow$ geometric symmetry of the compactification.
- Supersymmetry must be broken appropriately: D term, or combined D and F term, generating gaugino and sfermion masses.
- Realistic matter sector; this should go over largely unchanged from the existing (del Pezzo-based) literature.

Conclusions

- 'Traditional' SUSY models are already being pushed into fine-tuned regions.
- Heavy Dirac gauginos are *natural*, and relax LHC squark mass bounds.
- F-theory seems like a natural arena for such models.

Thank-you for listening

Necessary image attributions:

E. Calabi photograph from http://owpdb.mfo.de/detail?photo_id=615

Gauge from http://www.aspw.co.uk/images/categories/pressure%20gauge.gif