Light Higgsinos as Heralds of Higher-Dimensional Unification

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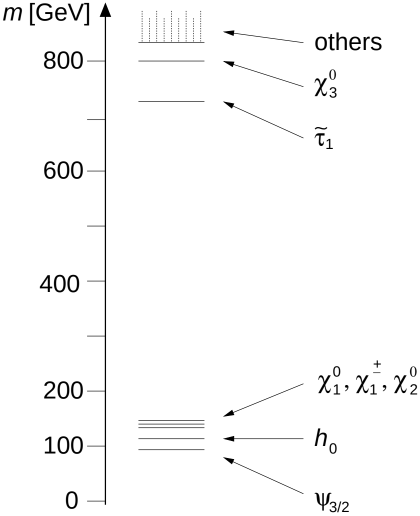
DESY

Based on arXiv:1105.0802 (with W. Buchmüller)

Light higgsinos...



$$m_{3/2} = 100\,\text{GeV}$$
$$m_{h_0} = 117\,\text{GeV}$$
$$m_{\chi_1^0} = 137\,\text{GeV}$$
$$m_{\chi_1^\pm} = 140\,\text{GeV}$$
$$m_{\chi_2^0} = 144\,\text{GeV}$$

$$m_{\tilde{\tau}_1} = 710\,\text{GeV}$$
$$\text{other sfermions } 900 - 1800\,\text{GeV}$$
$$m_{\chi_3^0} = 800\,\text{GeV}$$
$$m_{\chi_4^0},\ m_{\chi_2^\pm} = 1300\,\text{GeV}$$
$$\text{heavy Higgs bosons around } 860\,\text{GeV}$$
$$m_{\tilde{g}} = 1450\,\text{GeV}$$

. . . from higher-dimensional unification

- GUT-scale compactifications contain many vector-like exotics (often in incomplete GUT multiplets)
- They decouple near M_{GUT}. . .
- . . . and act as (old-fashioned, minimal) gauge mediation messengers
- Gauge mediation gives soft masses $\gtrsim$ 500 GeV
- Gravity mediation gives μ term $\sim$ 100 GeV
- $\Rightarrow$ higgsinos light, other superparticles heavy

Possible settings:
heterotic orbifolds, field-theoretic orbifold GUTs, F-theory GUTs. . .

Motivations

- Find theoretically well-motivated, non-standard soft term patterns
- Find TeV scale signatures pointing towards GUT-scale compactifications
- Solve μ problem of gauge mediation

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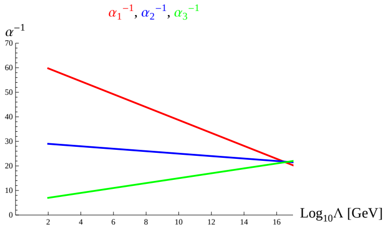
Not necessarily (yet):

- Work out precise phenomenology of some concrete UV model
  Examples meant to be qualitative for now

Higher-dimensional unification

MSSM predicts gauge coupling unification:



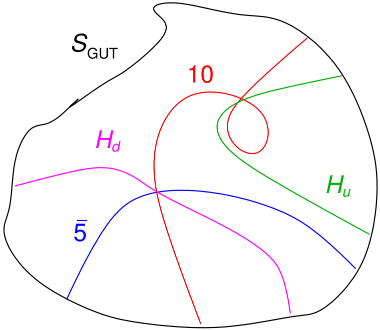
4D SUSY GUTs typically also predict light Higgs triplets, proton decay, wrong fermion mass relations

- Models of unification in higher dimensions can solve these problems...
- ...while maintaining prediction of unification
- Added bonus: Stringy models provide UV completion
- **This talk:** They also contain messenger sector for gauge mediation $\rightarrow$ interesting consequences

Messengers from F-theory

Cartoon of a semi-local F-theory GUT model:

→ Beasley/Heckman/Vafa '08, Donagi/Wijnholt '08

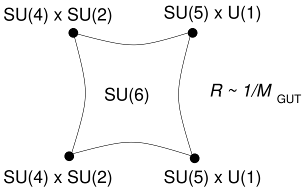


- GUT symmetry on complex surface: "GUT brane"
- matter and Higgs fields on curves
- Hypercharge flux on 2-cycle:
  non-trivial in S_{GUT},
  trivial in compactification
- $U(1)_Y$ flux restricts nontrivially to Higgs curves
  ⇒ doublet-triplet splitting
- Then $U(1)_Y$ flux also restricts nontrivially to some 10-curves
  ⇒ exotics in split multiplets
  → Marsano et al. '09, Dudas/Palti '10

Messengers from heterotic orbifolds

Ingredients:

- $E_8 \times E_8$ heterotic compactified on $T^6/\mathbb{Z}_N$
- Discrete Wilson lines break gauge group to $G_{SM} \times G_{hidden}$
- Computer searches → Buchmüller/Hamaguchi/Lebedev/Ratz '05–'06, Lebedev/Nilles/Raby/Ramos-Sanchez/Ratz/Vaudrevange/Wingerter '06–'08 reveal many models with
  - Chiral matter content = 3 generations of quarks and leptons
  - In general many exotics, can be decoupled by coupling to singlet VEVs
  - Can have one pair of Higgs doublets massless (realistic μ term from discrete R-symm. → FB/Kappl/Ratz/Schmidt-Hoberg '10, → talks by G. Ross, H.-M. Lee)
- Anisotropic limit → 5d or 6d field-theoretic orbifold GUTs



Sample spectrum from a heterotic model

→ Buchmüller, Hamaguchi, Lebedev, Ratz '05

$E_8 \times E_8$ heterotic on $T^6/\mathbb{Z}_6$ with Wilson lines

Massless spectrum:

- 3 SM generations
- 1 pair of massless Higgs doublets
- $\mathcal{O}(100)$ SM singlets $\{S_I\}$
- vector-like exotics $\{\Sigma_i\}$:

field	representation	multiplicity
d	$(\mathbf{3},\mathbf{1})_{-1/3}$	4
$\tilde{d}$	$(\overline{\mathbf{3}},\mathbf{1})_{1/3}$	4
ℓ	$(\mathbf{1},\mathbf{2})_{1/2}$	4
$\tilde{\ell}$	$(\mathbf{1},\mathbf{2})_{-1/2}$	4
m	$(\mathbf{1},\mathbf{2})_0$	8
s^+	$(\mathbf{1},\mathbf{1})_{1/2}$	16
s^-	$(\mathbf{1},\mathbf{1})_{-1/2}$	16

Messenger couplings

$$W = \sum_i M_{\rm Pl}\,\mathcal{P}_i\left(\frac{S_I}{M_{\rm Pl}}\right)\Sigma_i\widetilde{\Sigma}_i + \ldots$$

S_I = SM singlets; Σ_i, $\widetilde{\Sigma}_i$ = vector-like exotics; $\mathcal{P}_i$ = polynomials

- Assume there is a vacuum with $\langle S_I\rangle \sim M_{\rm GUT}$
  $\Rightarrow$ messengers Σ_i will decouple close to $M_{\rm GUT}$
  Appearance of GUT scale motivated by FI term / moduli stabilisation
- Assume also that $\langle F_{S_I}\rangle \neq 0$ (for some I) from couplings to hidden sector
  $\Rightarrow$ ~~SUSY~~ mass splittings for messengers

Unusual features:

- Messengers in split multiplets $\Rightarrow$ non-universal gaugino masses
- Messenger numbers large $\Rightarrow$ gauginos heavier than scalars
- Messenger scale = GUT scale $\Rightarrow$ gravity mediation not negligible (but still subdominant)

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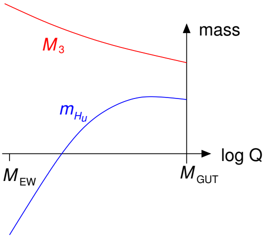
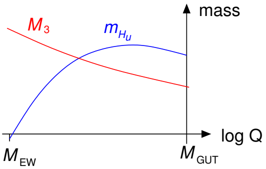
Why split messenger multiplets are useful

- Gaugino masses scale as $\sim N_{\text{mess}}$
- Scalar soft masses scale as $\sim \sqrt{N_{\text{mess}}}$, grow more slowly with N_{mess}

- $M_3 \gg m_{H_u}$ at GUT scale with μ small
  $\Rightarrow$ realistic EWSB difficult:
  M_3 feeds into $m_{\tilde{t}}$,
  $m_{\tilde{t}}$ decreases $m^2_{H_u}$ in RG running



- Split messenger multiplets can fix this
  Specifically: Need $N_2 \gg N_3$,
  where N_2=# of weak doublet messengers,
  N_3=# of colour triplets



Non-universal gauginos might also reduce fine-tuning → Horton/Ross '09

Simplifications

- In BHLR model, selection rules prevent (d, ℓ)-type messengers from coupling to same singlets as (m, s)-type messengers
- Next simplest parametrisation of messenger superpotential:

$$W = S_1(d\tilde{d} + \ell\tilde{\ell}) + S_2(mm + s^+ s^-)$$

with

$$\langle S_1 \rangle = M_\mathrm{m} + F_1\theta^2, \qquad \langle S_2 \rangle = M_\mathrm{m} + F_2\theta^2,$$
$$F_1 = F\cos\phi, \quad F_2 = F\sin\phi, \quad m_{3/2} = F/\sqrt{3}M_\mathrm{Pl}$$

Choose equal messenger masses (for simplicity) but allow for different couplings to hidden sector

GUT-scale soft terms

(for $m_{3/2} = 100$ GeV, $M_{\text{mess}} = 5 \cdot 10^{15}$ GeV, $\tan\phi = 1.9$)

Mainly gauge-mediated:

mass parameter	value [GeV]
M_1	1771
M_2	1583
M_3	644
m_Q	786
m_U	599
m_D	478
$m_L = m_{H_u} = m_{H_d}$	736
m_E	643

Gravity-mediated:

μ	150
$\sqrt{B_\mu}$	240
A_0	150

Low-scale superparticle spectrum

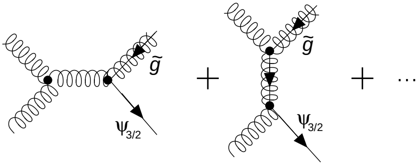
particle	mass [GeV]
h_0	117
χ_1^0	137
$\chi_1^\pm$	140
χ_2^0	144
χ_3^0	799
χ_4^0	1296
$\chi_2^\pm$	1296
H_0	856
A_0	857
$H^\pm$	861
$\tilde{g}$	1453
$\tilde{\tau}_1$	713
other sleptons	$910 - 1290$
squarks	$950 - 1750$

$$\tan\beta = 41$$

Cosmology

Gravitino LSP is natural dark matter candidate

Gravitinos produced thermally during reheating at large T_R:



$$\Omega_{\psi_{3/2}} h^2 \approx 0.21 \left(\frac{T_R}{10^{10}\text{ GeV}}\right)\left(\frac{100\text{ GeV}}{m_{3/2}}\right)\left(\frac{m_{\tilde{g}}}{1\text{ TeV}}\right)^2$$

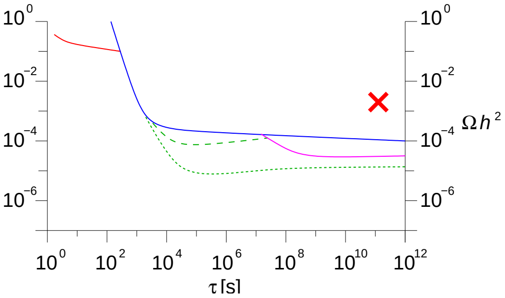
see e.g. → Bolz et al. ’00

$T_R \approx 10^{10}$ GeV:

- Nicely compatible with leptogenesis
- Right order of magnitude for DM abundance

Cosmology

Problem: χ_1^0 NLSP long-lived, decays after BBN
Energetic decay products destroy nuclei, distorting light element abundances



Bounds from → Jedamzik '06:
NLSP relic density vs. lifetime
(assuming large hadronic BR)

^{4}He, ^{2}H, ^{3}He, (Li)

- Our NLSP relic density is low due to coannihilation with $\chi_1^\pm$ (recall $m_{\chi_1^0} = 137$ GeV, $m_{\chi_1^\pm} = 140$ GeV):

$$\Omega_{\chi_1^0} h^2 = 3 \cdot 10^{-3}$$

- . . . but still in conflict with BBN bounds
- (Small) R-parity violation? (Moderate) additional entropy production?

Collider phenomenology

Somewhat similar to “lopsided gauge mediation”
(→ De Simone, Giudice, Francescini, Pappadopulo, Rattazzi ’11):

SUSY cascade decays rare @ early LHC: coloured superparticles heavy
Higgsino production predominantly in Drell-Yan

Higgsino decays:

- χ_1^0 long-lived, decays outside detector
- $\chi_1^\pm \rightarrow \chi_1^0 +$ (hadrons or leptons) via virtual *W* exchange
  Suppressed by 3-body final state; (slightly) displaced vertex
- ...

Work in progress

→ Brobovskyi, FB, Buchmüller, Hajer; to appear

Conclusions

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Therefore they naturally lead to

- GUT-scale gauge mediation
- with unconventional soft term patterns
- in particular: small μ (from gravity mediation)

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Models of higher-dimensional unification often predict

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Therefore they naturally lead to

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- with unconventional soft term patterns
- in particular: small μ (from gravity mediation)

The physical spectrum contains

- light Higgsinos
- a gravitino LSP
- otherwise heavy superpartners