Gauge Coupling Unification in Heterotic String Models with Gauge Mediated SUSY Breaking

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Work with Prof. Stuart Raby

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Motivation

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In string theories with compactified extra-dimensions, there generically exist extra non-standard model particles, usually called "exotics".

To mediate SUSY breaking with vector-like "exotic" particles arising from heterotic string theory, and produce a "consistent" low-energy spectrum.

Mini-Landscape Search[1]

- Search for MSSM spectrum at low energies starting with $E_8 \times E_8$ heterotic string models compactified on the orbifold, $T^6/\mathbb{Z}_6$

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• Look for GUTS with the Standard Model Gauge group embedded

$$E_8 \supset E_6 \supset SO(10) \supset SU(5) \supset G_{SM}$$

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• Spectrum: Three families + Vector-like "exotics"

• 15 models with promising phenomenology.

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Gauge Coupling Unification [2]

- Gauge Coupling Unification was studied in 2 of these 15 models.

Model 1 and Model 2A

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• This required some of the vector-like exotics to be massive around $10^9 - 10^{13}$ GeV.
• Solutions were constrained by the value of proton lifetime in these models.

$$\tau(p \quad \pi^0 e^+) \gtrsim 10^{34} \text{yr}^*$$

* Current bound from Super Kamikande.

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Matter Content and Energy scales

- $\vec{n} = (n_3, n_2, (n_1, n_1'))$ defines the 'light' exotic matter content of the theory.

$$n_3 \times \left[(3,1)_{1/3,*} + (\overline{3},1)_{-1/3,*}\right] + n_2 \times \left[(1,2)_{0,*} + (1,2)_{0,*}\right] + n_1 \times \left[(1,1)_{1,*} + (1,1)_{-1,*}\right]$$

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- M_{EX1}- Mass scale of the triplet exotics.
- M_{EX2} - Mass scale of the doublet exotics.
- M_C - The compactification scale of the extra-dimensions.

Heterotic Theory on Orbifold

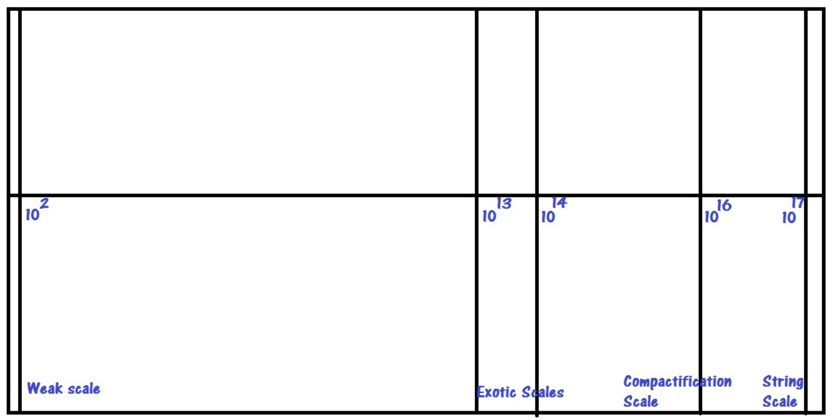
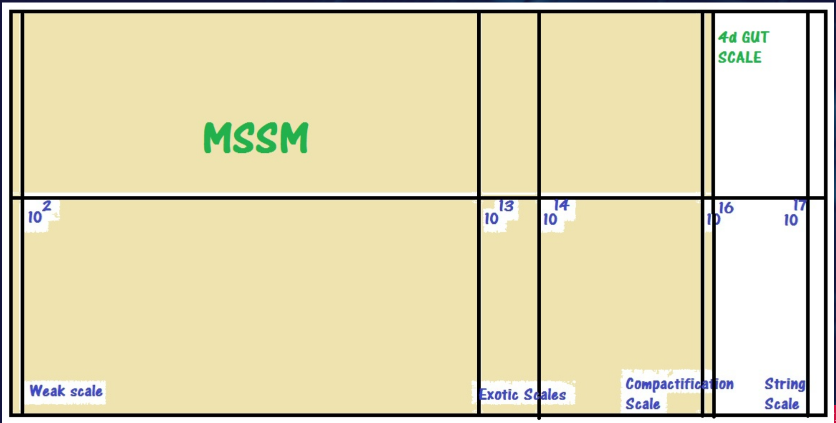


*Figure not drawn to scale.

4D MSSM



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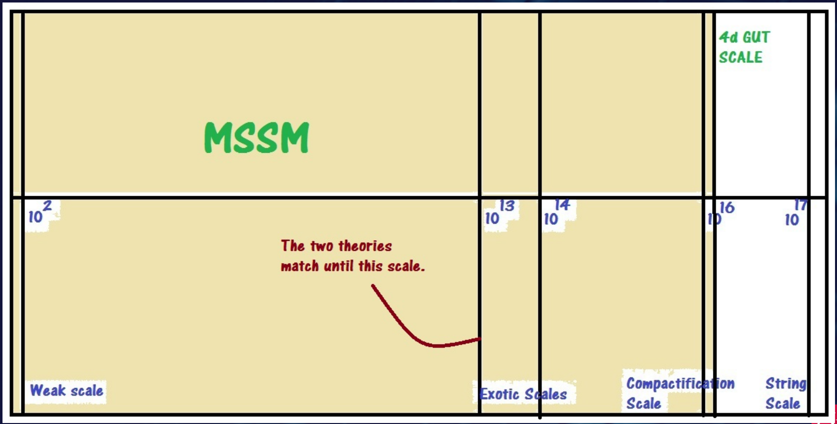

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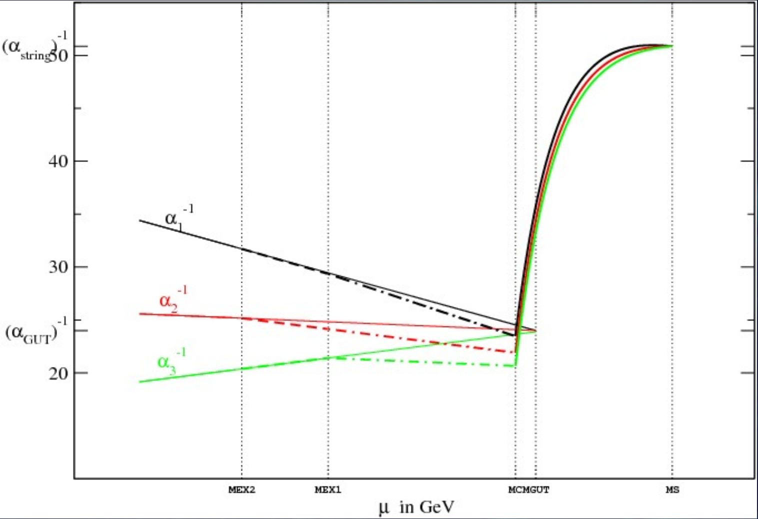
Gauge Coupling Unification



Gaugino Masses

- The gauginos obtain mass at one loop from the exotics:

$$M_i = b_i^{EX3} \frac{\alpha_i}{4\pi} \frac{F^\phi}{M_{EX1}} + b_i^{EX2} \frac{\alpha_i}{4\pi} \frac{F^\phi}{M_{EX2}}$$

ignoring the sub-dominant contribution from the gravitino.

$$\frac{F^\phi}{M_{EX}} >> m_{3/2}$$

$$b^{EX3} = (n_3, 0, \frac{n_3 + 3n_1}{10}) \qquad b^{EX2} = (0, n_2, \frac{3n_1'}{10})$$

Scalar Masses

- The scalars obtain mass at two-loops:

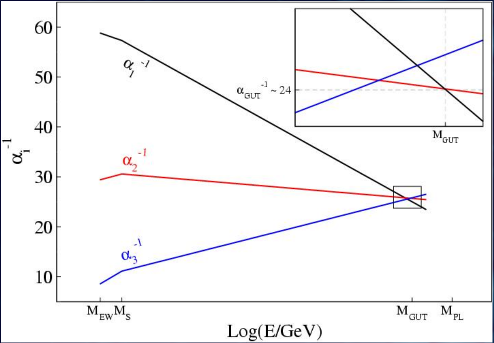
$$m_{\phi_i}^2 = m_{3/2}^2 + 2\left(b_3^{EX3}\,\frac{\alpha_3}{4\pi}\frac{F^\phi}{M_{EX1}}\right)^2 C_3(i) + 2\left(b_2^{EX2}\,\frac{\alpha_2}{4\pi}\frac{F^\phi}{M_{EX2}}\right)^2 C_2(i)$$
$$+2\left(\frac{\alpha_1}{4\pi}\left(b_1^{EX3}\,\frac{F^\phi}{M_{EX1}} + b_1^{EX2}\,\frac{F^\phi}{M_{EX2}}\right)\right)^2 C_1(i) + dQ_a^X M_2^2$$

- $dQ_a^X M_2^2$ is a D - term contribution [3] from an anomalous $U(1)_X$ that gives a contribution proportional to GMSB.

[3] S. Raby and K. Tobe, Nucl. Phys. B539, 3 (1999)

Precision Unification?

Standard SUSY breaking scenarios require a -4% threshold corrections at the GUT scale.



$$\alpha_i^{-1}(\mu) = \alpha_{GUT}^{-1} + \frac{b_i}{2\pi} log \frac{M_{GUT}}{\mu} - \alpha_{GUT}^{-1} \frac{\epsilon_3}{(1+\epsilon_3)} \delta_{i3}$$

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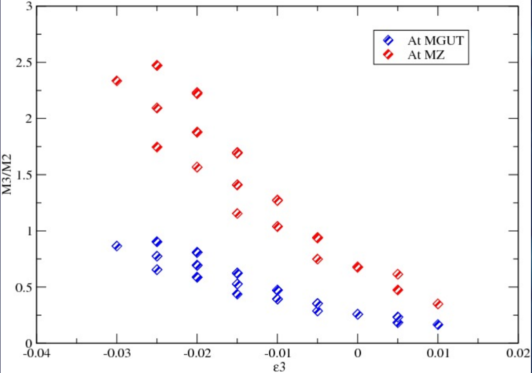
Effect of ϵ_3

- We study the effect of threshold corrections on the spectrum of exotics as well as the low energy spectrum.



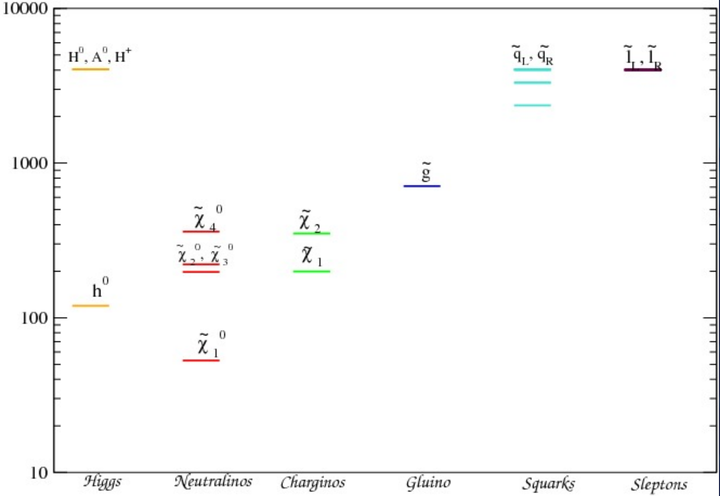
The figure represents the correlation for one particular model with $\vec{n} = (4, 2, (2, 1))$

Two Cases

Observable	Case 1	Case 2
$m_{3/2}$	4 TeV	10 TeV
d	0	5
M_S	6.04×10^{17}	6.05×10^{17}
M_C	1.2×10^{16}	1.2×10^{16}
M_{EX1}	5.03×10^{13}	1.10×10^{14}
M_{EX2}	1.69×10^{13}	8.54×10^{13}
M_{GUT}	2.5×10^{16}	2.0×10^{16}
ϵ_3	-2.5 %	0 %
$\tan\beta$	7	4
mu	-206.217	-1932.930

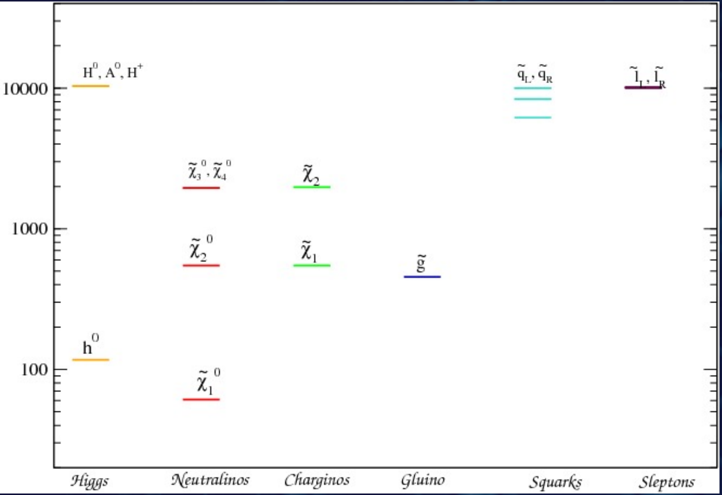
MSSM Spectrum - Case 1

$m_{3/2}$= 4 TeV, d = 0, ϵ_3= -2.5 %



MSSM Spectrum - Case 2

$m_{3/2}$= 10 TeV, d = 5, ϵ_3= 0 %



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- We have a self-consistent spectrum generated from heterotic string theory with vector-like "exotic" particles mediating SUSY breaking.
- The gaugino masses in the MSSM spectrum depend on the threshold corrections at the GUT scale.
- Interesting Phenomenology - Unique signatures at colliders!!