Tachyons (or not) in N=0 heterotic compactifications

Michael Blaszczyk
JGU Mainz

Based on:

MB, S. Groot Nibbelink, O.Loukas, S. Ramos Sanchez, 1407.6362

Mainz, 25.09.14

Motivation

- No experimental signs of spontaneously broken SUSY (SSB)
- String Models (vacua?) with no SUSY possible?
- Alternative to MSSM model building with ~~SUSY~~ sector
- Can we construct models with SM spectrum?
- $N = 1$-preserving compactification
  $\Rightarrow$ recycle computational techniques and physics properties

  see talk by Stefan Groot Nibbelink

Problems

Nice advantages of SUSY are lost:

- cosmological constant $\Lambda \propto M_{\text{string}}$
- Higgs mass corrections $\delta m_H^2 \propto M_{\text{string}}^2$
- Tachyons possible
- 1-loop dilaton tadpole

However: same problems appear in general after spontaneous ~~SUSY~~

How much control do we have?

N=0 in d=10

- WS fermions in heterotic string: $\psi_{a=1,\dots,4}$, $\overline{\lambda}_{I=1,\dots,8}$, $\overline{\lambda}_{I=9,\dots,16}$
- RNS sectors and *GSO* projections: $\mathbb{Z}_2 \times \mathbb{Z}_2 \times \mathbb{Z}_2$ allows for discrete torison

SO(8)×SO(16)×SO(16) weight lattices

$N=1$	$(\mathbf{V}_4+\mathbf{S}_4) \times (\mathbf{R}_8+\mathbf{S}_8) \times (\mathbf{V}_8+\mathbf{S}_8)$			
$N=0$	$\mathbf{V}_4 \times \mathbf{R}_8 \times \mathbf{R}_8 +$	$\mathbf{V}_4 \times \mathbf{S}_8 \times \mathbf{S}_8 +$	$\mathbf{S}_4 \times \mathbf{S}_8 \times \mathbf{R}_8 +$	$\mathbf{S}_4 \times \mathbf{R}_8 \times \mathbf{S}_8 +$
	$\mathbf{R}_4 \times \mathbf{C}_8 \times \mathbf{V}_8 +$	$\mathbf{R}_4 \times \mathbf{V}_8 \times \mathbf{C}_8 +$	$\mathbf{C}_4 \times \mathbf{V}_8 \times \mathbf{V}_8 +$	$\mathbf{C}_4 \times \mathbf{C}_8 \times \mathbf{C}_8$

Massless Spectrum:

- G_{MN} , B_{MN} , Φ
- gauge bosons A_M of SO(16)×SO(16)
- spinors Ψ_+ in $(\mathbf{128},\mathbf{1}) \oplus (\mathbf{1},\mathbf{128})$
- cospinors Ψ_- in $(\mathbf{16} \times \mathbf{16})$

Calabi Yau Compactification

CY compactification of large volume effective approximation

$$S_{10d} = \int \mathrm{d}^{10}x \quad \mathrm{tr} F_{MN} F^{MN} \quad + \quad \overline{\Psi} i \not{D} \Psi$$

$$\downarrow CY \qquad\qquad \downarrow CY$$

$$S_{4d} = \int \mathrm{d}^4 x \quad \text{kinetic} + |D|^2 + |F|^2 \quad + \quad \overline{\psi} i \not{D} \psi + \text{Yukawa}$$

- classical scalar potential like in $N = 1$ theory!
  ⇀ no Tachyons ⇀ bounded from below
- BUT can be spoiled by corrections in:
  - g_S : loops (RGE running), gauge instantons
  - α': worldsheet instantons
- e.g.: "'Standard Embedding"'

Multiplicity	Complex bosons	Chiral fermions
1	–	$(\mathbf{16};\mathbf{1})_3 + (\overline{\mathbf{16}};\mathbf{1})_{-3} + (\mathbf{1};\mathbf{128})_0 + (\mathbf{10};\mathbf{16})_0$
$h^{1,1}$	$(\mathbf{10};\mathbf{1})_2 + (\mathbf{1};\mathbf{1})_{-4}$	$(\mathbf{16};\mathbf{1})_{-1} + (\mathbf{1};\mathbf{16})_{-2}$
$h^{1,2}$	$(\mathbf{10};\mathbf{1})_{-2} + (\mathbf{1};\mathbf{1})_4$	$(\overline{\mathbf{16}};\mathbf{1})_1 + (\mathbf{1};\mathbf{16})_2$
$h^1(\mathrm{End}(V))$	$(\mathbf{1};\mathbf{1})_0$	–

Orbifold Compactification

c.f. talk by Viraf Mehta

- Untwisted sector = 10d spectrum + Projections No Tachyons
- $\mathbb{Z}_N$ - Twisted sector:
  $v = \frac{1}{N}(0, k_1, k_2, -k_1 - k_2) \quad 0 \leq k_i \leq N/2$
- right-moving mass:

$$M_R^2 = \frac{q_{\rm sh}^2}{2} + \frac{\delta c}{2} - \frac{1}{2}\,, \qquad q_{\rm sh} \in v + \Lambda_4$$

  - tachyonic if $\Lambda_4 = \mathbf{R}_4$ and $k_1 + k_2 < N/2$
  - new: massless states with rightmoving oscillators
  - oscillator tachyons if $2k_1 + k_2 < N/2$
- Left-Movers from $\mathbf{V}_8 \times \mathbf{C}_8 + \mathbf{C}_8 \times \mathbf{V}_8$
- Level matching is achieved for subset of all shift vectors V

Orbifold Compactification

Point Group	shift	tachyon free
$\mathbb{Z}_3$	$1/3(1,1,-2)$	all
$\mathbb{Z}_4$	$1/4(1,1,-2)$	all
$\mathbb{Z}_{6\text{-I}}$	$1/6(1,1,-2)$	55 %
$\mathbb{Z}_{6\text{-II}}$	$1/6(1,2,-3)$	57 %
$\mathbb{Z}_{8\text{-I}}$	$1/8(1,2,-3)$	51 %
$\mathbb{Z}_{8\text{-II}}$	$1/8(1,3,-4)$	71 %
$\mathbb{Z}_2 \times \mathbb{Z}_2$	$1/2(1,-1,0)$,$1/2(0,1,-1)$	all
$\mathbb{Z}_2 \times \mathbb{Z}_4$	$1/2(1,-1,0)$,$1/4(0,1,-1)$	67 %
$\mathbb{Z}_3 \times \mathbb{Z}_3$	$1/3(1,-1,0)$,$1/3(0,1,-1)$	52 %
$\mathbb{Z}_4 \times \mathbb{Z}_4$	$1/4(1,-1,0)$,$1/4(0,1,-1)$	64 %

Orbifold Compactification

Example: $\mathbb{Z}_{6-I}$ orbifold: $v = \frac{1}{6}(1, 1, -2)$

$$V = \frac{1}{6}\big(-2, -16, -14, -2, 2, 6, 3, 11\big)\big(-2, -5, -6, -2, 6, -13, -1, 19\big)$$

gauge group: SU(5)×SU(4)'×SO(4)'×SU(2)' × Abelian

Bosonic tachyons	$3(\mathbf{1};\mathbf{1},\mathbf{1},\mathbf{2})$
Massless chiral fermions	$4(\mathbf{10};\mathbf{1}) + (\overline{\mathbf{10}};\mathbf{1}) + 6(\mathbf{5};\mathbf{1}) + 3(\overline{\mathbf{5}};\mathbf{1}) + (\mathbf{5};\mathbf{1},\mathbf{4},\mathbf{1}) + 2(\overline{\mathbf{5}};\mathbf{1},\mathbf{1},\mathbf{2}) + (\mathbf{5};\mathbf{1},\mathbf{1},\mathbf{2})$ $+2(\overline{\mathbf{5}};\mathbf{4},\mathbf{1},\mathbf{1}) + 12(\mathbf{1};\mathbf{4},\mathbf{1},\mathbf{1}) + 18(\mathbf{1};\overline{\mathbf{4}},\mathbf{1},\mathbf{1}) + 2(\mathbf{1};\overline{\mathbf{4}},\mathbf{2}_-,\mathbf{2}) + 2(\mathbf{1};\mathbf{4},\mathbf{2}_+,\mathbf{1})$ $+(\mathbf{1};\mathbf{6},\mathbf{2}_-,\mathbf{1}) + (\mathbf{1};\mathbf{6},\mathbf{2}_+,\mathbf{1}) + 12(\mathbf{1};\mathbf{1},\mathbf{2}_+,\mathbf{2}) + 4(\mathbf{1};\mathbf{1},\mathbf{4},\mathbf{1}) + 36(\mathbf{1};\mathbf{1},\mathbf{2}_-,\mathbf{1})$ $+30(\mathbf{1};\mathbf{1},\mathbf{2}_+,\mathbf{1}) + 11(\mathbf{1};\mathbf{1},\mathbf{1},\mathbf{2}) + 53(\mathbf{1};\mathbf{1})$
Massless complex scalars	$9(\mathbf{5};\mathbf{1}) + 2(\overline{\mathbf{5}};\mathbf{1}) + (\overline{\mathbf{10}};\mathbf{1}) + (\mathbf{1};\mathbf{1},\mathbf{4},\mathbf{2}) + 30(\mathbf{1};\mathbf{1},\mathbf{2}_-,\mathbf{1}) + 12(\mathbf{1};\mathbf{6},\mathbf{1},\mathbf{1})$ $+2(\mathbf{1};\mathbf{4},\mathbf{1},\mathbf{2}) + 2(\mathbf{1},\overline{\mathbf{4}},\mathbf{4},\mathbf{1}) + 22(\mathbf{1};\mathbf{1},\mathbf{2}_+,\mathbf{1}) + 10(\mathbf{1};\mathbf{1},\mathbf{2}_-,\mathbf{2}) + 46(\mathbf{1};\mathbf{1})$

Tachyons in θ^1 Sectors at 3 fixed points in non-Abelian multiplet!

Tachyon Lift in $\mathbb{Z}_{6-I}$ model

If model resolvable, no tachyons are expected in large volume limit
$\longrightarrow$ Ansatz: line bundle model on resolution CY
Abelian gauge flux: $\mathcal{F} = H_I W_I^r E_r$

- H_I = Cartan basis
- E_r = basis of exceptional divisors
- bundle vecors $W^r = P_{\text{sh}}$ shifted weights

Here:

$$W_1 = \frac{1}{6}\big(1,-1,1,1,-1,-3,0,2\big)\big(1,-2,-3,1,3,2,2,-2\big)$$
$$W_2 = \frac{1}{6}\big(-1,1,-1,-1,1,3,-3,1\big)\big(-1,-1,-3,-1,3,1,1,-1\big)$$
$$W_3 = \frac{1}{2}\big(0,0,0,0,0,0,-1,1\big)\big(0,1,0,0,0,1,1,1\big)$$

Note: blowup-mode in θ^2 sector and hence W_2 is unique

Tachyon Lift in $\mathbb{Z}_{6-I}$ model

- fermionic chiral spectrum from reduction of $(\mathbf{1},\mathbf{128})_L \oplus (\mathbf{128},\mathbf{1})_L \oplus (\mathbf{16},,\mathbf{16})_R$
- complex scalar boson are reduced like hypothetical gaugino superpartners in CY geometry

Bosonic tachyons	none
Massless chiral fermions	$3(\overline{\mathbf{10}};\mathbf{1})+3(\mathbf{5};\mathbf{1})+6(\overline{\mathbf{5}};\mathbf{1})+2(\overline{\mathbf{5}};\mathbf{1},\mathbf{2}_+)+2(\mathbf{5};\mathbf{2}_-,\mathbf{1})+2(\mathbf{5};\mathbf{2}_+,\mathbf{1})+(\mathbf{5};\mathbf{1},\mathbf{2}_-)$ $2(\mathbf{1};\mathbf{4},\mathbf{1})+2(\mathbf{1};\mathbf{1},\mathbf{4})+2(\mathbf{1};\mathbf{2}_+,\mathbf{2}_+)+4(\mathbf{1};\mathbf{2}_+,\mathbf{2}_-)+2(\mathbf{1};\mathbf{2}_-,\mathbf{2}_+)$ $4(\mathbf{1};\mathbf{2}_-,\mathbf{2}_-)+6(\mathbf{1};\mathbf{2}_+,\mathbf{1})+8(\mathbf{1};\mathbf{2}_-,\mathbf{1})+34(\mathbf{1};\mathbf{1},\mathbf{2}_+)+11(\mathbf{1};\mathbf{1},\mathbf{2}_-)+53(\mathbf{1};\mathbf{1})$
Massless complex scalars	$(\overline{\mathbf{10}};\mathbf{1})+9(\mathbf{5};\mathbf{1})+2(\overline{\mathbf{5}};\mathbf{1})+2(\mathbf{1};\mathbf{4},\mathbf{1})+2(\mathbf{1};\mathbf{1},\mathbf{4})$ $4(\mathbf{1};\mathbf{2}_+,\mathbf{2}_+)+2(\mathbf{1};\mathbf{2}_+,\mathbf{2}_-)+4(\mathbf{1};\mathbf{2}_-,\mathbf{2}_+)+2(\mathbf{1};\mathbf{2}_-,\mathbf{2}_-)+43(\mathbf{1};\mathbf{1})$

$\rightharpoonup$ chiral fermions and complex bosons match!

$\rightharpoonup$ No Tachyons!

What happened?

State		Sector	Representation
Tachyon	t	θ^1	$(\mathbf{1};\mathbf{1},\mathbf{1},\mathbf{2})$
Blow-up mode	b	θ^2	$(\mathbf{1};\mathbf{1},\mathbf{2}_-,\mathbf{1})$
Complex scalar	c	θ^3	$(\mathbf{1};\mathbf{1},\mathbf{2}_-,\mathbf{2})$

$$V(t,b) = -m_t^2|t|^2 + |b|^2|t|^2 + \mathcal{O}(b^4,t^4)$$

2nd term motivated by:

- general QFT grounds
- SUSY-like potential $|F_C|^2$ from hypothetical superpotential $\mathcal{W} = TBC$ with hypothetical superfields $C = c + \ldots + \theta\theta F_C$ etc.

In large volume limit tachyon gets lifted

$$|b|^2 \sim \mathrm{Vol}(E_r) \gg M_s^2 \sim |m_t|^2$$

$\rightharpoonup$ tachyonic and non-tachyonic models connected

todo: general proof of liftability of tachyons??

Conclusion

Tachyons appear in

- 0% of Calabi–Yau models in effective field theory approximation
- $<$ 50% of orbifold models
- ??% of more realistic models

BUT:

- orbifold tachyons can be lifted in blowup
- tachyons can get induced by α' and g_s corrections

However:

- in SM we need negative Higgs mass for EWSB
- for MSSM $m_h^2 < 0$ induced by spontaneous ~~SUSY~~
- $N = 0$ models similar problem as SSB , just

  enhanced by $\frac{M_S}{m_{\not{SUSY}}} < 10^{13}$

Outlook

TODO:

- confirm form of potential
- corrections, 1-loop dilaton tadpole
  - vacuum state?
  - flat directions?
- advantage: less scalar fields than in $N = 1$ models
- potential bound from below? cosmological constant?