Stability & Asymptotic SUSY in Perturbative String Theory

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Introduction

- A long standing problem is to understand the strong coupling dynamics of QCD
- Large N QCD is believed to have a stable weakly coupled string theory dual with an exponential density of bosonic excitations and no closed string fermions
- Unlike the more familiar supersymmetric cases, this is a situation where supersymmetry in the bulk is broken in the worst possible way !! There is a stringy tower of spacetime bosons but no fermions !
- Typically such a drastic breaking of supersymmetry leads to instabilities (quadratic or linear)...

Introduction

This raises the following natural question:

Is it possible to find any examples in weakly coupled string theory with the aforementioned features, *i.e.* with
a Hagedorn density of bosons, no fermions, no tree-level instabilities?

Or is it that such examples are fundamentally absent because of some general principle ?

Introduction

The answer could be useful for:

- Determining the right framework for the QCD string
- Understanding the consequences and requirements for stability in perturbative string theory
- Obtaining constraints on the vacuum structure of string theory

We will see that string theories with the features of the QCD string do exist but are extremely rare !!

Over the years there have been several indications that such theories might not even exist, and that the presence of fermions in the physical spectrum is intimately tied to perturbative stability

Introduction

Some of these indications are:

- A theorem by Kutasov and Seiberg (1991)

> *Follows from worldsheet duality and mild assumptions*

Perturbative stability in weakly coupled (oriented) string theory requires *asymptotic supersymmetry*
i.e. an approximate matching at high energies between the number of bosons and fermions

- A similar statement for open string theories VN '00
- The presence of spacetime fermions seems to be a crucial requirement for locality and cluster decomposition in matrix theory Banks '97

Introduction

The Kutasov-Seiberg theorem could in principle be evaded

- by subtleties arising in the presence of RR condensates
- by unoriented strings (a possibility we will verify and exploit soon)

Examples

A few examples ...

- There are several examples with broken spacetime SUSY and no tree-level instabilities (all following the KS theorem): Scherk-Schwarz compactifications, SO(16)xSO(16) heterotic string etc...
- Type 0 string theory:

  It has a purely bosonic closed string spectrum, but is perturbatively unstable - it has a tachyon

Examples

- The type 0'B string

Bianchi, Sagnotti '90
Sagnotti '95, '97

This is type 0B string with an O9-plane based on the generalized parity $\Omega' = (-)^{f_R}\Omega$

It is a theory of unoriented strings with a purely bosonic closed string spectrum and no tachyons

This example avoids explicitly the KS theorem, however, it fails to be the type of theory we want for the following reasons

Examples

The O9-plane has a RR tadpole for the non-dynamical C_{10} that needs to be canceled

The RR tadpole can be canceled by the addition of $D9 - D9'$ pairs, but one is left with a dilaton tadpole (this is a generic feature in standard type 0' constructions)

The dilaton tadpole is a signal of the fact that we are not expanding around a true vacuum !!

So, standard type 0'B with a constant dilaton is not the example we are looking for

Examples

Condensation of a dilaton tadpole is a much milder effect than tachyon condensation. Perhaps the true vacuum (with a non-trivial metric and dilaton) is not far away and is still perturbative ...

There are, however, indications to the contrary ...

Examples

- Dilaton condensation in a similar example:

  Type I string theory in 10D with 32 $O9_+$ planes (+ tension, + RR charge) and 32 $\bar{D}9$-branes has a dilaton tadpole

  The bosonic part of the low energy effective action reads

$$S = \frac{1}{2l_s^8}\int d^{10}x\sqrt{-g}e^{-2\Phi}[R+4(\partial\Phi)^2] - 64T_9\int d^{10}x\sqrt{-g}e^{-\Phi} + \ldots$$

Examples

A solution of this action (in the string frame) is Dudas, Mourad '00

$$g_s = e^{\Phi_0}|\sqrt{\alpha}y|^{2/3}e^{3\alpha y^2/4}$$

$$ds^2 = |\sqrt{\alpha}y|^{4/9}e^{\Phi_0/2}e^{\alpha y^2/4}\eta_{\mu\nu}dx^\mu dx^\nu + |\sqrt{a}y|^{-2/3}e^{-\Phi_0}e^{-3\alpha y^2/4}dy^2$$

$$\alpha = 64 l_s^8 T_9$$

The dilaton vanishes at $y=0$ and diverges at $y=\infty$

The topology of the space has become $\mathbb{R}^{8,1}\times S^1/\mathbb{Z}_2$

Dilaton tadpoles motivate a search in backgrounds with a non-trivial dilaton

Examples

- A novel example with 6-dimensional Poincare invariance

Consider type 0B string theory on

Israel, VN '07

$$\mathbb{R}^{5,1} \times \mathcal{N} = 2 \; Liouville$$

- This theory has a purely bosonic string spectrum

- No discrete state tachyons but delta-function normalizable tachyons

- Modding out by the generalized worldsheet parity

$$\mathcal{P} = s\Omega' \; , \; s \; : \; \theta \rightarrow \theta + \pi$$

we obtain a fully stable, perturbative vacuum !! Several interesting details conspire for this to work.

Examples

- This example involves a spacefilling $O'7$-plane with only massive RR tadpoles

The Klein bottle amplitude in the crosscap channel reads

$$\mathcal{K} \sim \int_0^\infty d\ell\, e^{-\frac{\pi\ell}{4}} \left[1 + (e^{-2\pi\ell})\right]$$

There is no need to add D-branes here. There are no massless tadpoles and no tachyons.

Examples

- We can find one more example of this sort in type 0B string theory in

$$\mathbb{R}^{3,1} \times \mathcal{N} = 2\ Liouville$$

- These sorts of examples appear to be very rare !! For example, one cannot fully project out the tachyons in

$$\mathbb{R}^{5,1} \times \left[\mathcal{N} = 2\ Liouville \times \frac{SU(2)_k}{U(1)} \right] / \mathbb{Z}_k\ ,\ k > 2$$

Examples

- The embedding of these models in ten dimensions is particularly interesting. The 8-dimensional model describes the near-horizon region of the type 0A fivebrane/orientifold configuration

	0	1	2	3	4	5	6	7	8	9
NS5	x	x	x	x	x	x	-	-	-	-
NS5	x	x	x	x	x	x	-	-	-	-
O'6	x	x	x	x	x	x	-	-	-	x

Away from the O-plane and the fivebranes the bulk is tachyonic !

As we zoom into the fivebranes and take the decoupling limit the spacetime dimension reduces and we are left with a decoupled throat (the bulk tachyons having been left outside the transition region)

Conclusions

- We presented weakly coupled string theory vacua without tree-level instabilities and a purely bosonic stringy spectrum

- Hence, theories with the features expected for the QCD string dual do exist, but seem to be extremely rare

Note: our examples are not directly appropriate for QCD, because they involve unoriented strings

- In general, it is expected that perturbative stability is intimately tied in string theory (above 2 dims) with the existence of spacetime fermions (*e.g.* asymptotic SUSY). The above would appear to be explicit counterexamples to this standard lore.

Conclusions

Should we drop asymptotic SUSY as a general requirement for perturbative stability in string theory ??

A Conjecture

Case I: String theories that do not allow open string degrees of freedom - *e.g.* the Heterotic String.

→ Perturbative stability requires asymptotic susy in the bulk *i.e.* at high energies the number of bosons almost cancels the number of fermions

Case II: String theories that allow open string degrees of freedom - can have oriented or unoriented strings

Follows from open/closed ws duality

→ Perturbative stability in the bulk requires asymptotic susy on all allowed open string sectors (irrespective of the existence of open string tachyons)