Aspects of Type 0 String Theory

(R. Blumenhagen, Strings 99)
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I: Introduction

II: Non-tachyonic orientifolds of Type 0B

III: D3 - branes in non-compact Type 0 backgrounds

IV: Outlook

Talk based on:

- R.B., A. Font, D. Lüst, hep-th/9904069
- — " — , hep-th/9906101
- R.B., A. Kumar , hep-th/9906234

I. Introduction

We would like to have a better understanding of Non-supersymmetric string theory and gauge theory

(because our world is non-supersymmetric for $E < 1$ TeV.)

Problems:

- appearance of tachyons (decay into stable background)
- non-zero cosmological constant + dilaton tadpoles
- stabilization of dilaton (+other moduli)
- all loop corrections, no BPS objects.
- ...

Two approaches:

- bosonic string in $D=26$
- susy breaking orbifold of Type II
- ...

SUSY

$$
\begin{tikzcd}
 & & \text{compactifications} & \\
\text{M-Theory} \arrow[d, "S^1"] \arrow[dd, bend right=60] & & & \\
\text{Type IIA} \arrow[d] & \text{Type IIB} \arrow[l, "\text{T dual}"'] \arrow[r, "\Omega"] \arrow[uur] \arrow[d] & \text{Type I} \arrow[uu] \arrow[d] & \\
\begin{array}{c}\text{Hanany} \\ \text{Witten} \\ \text{models} \\ (NS5 + D4)\end{array} & \begin{array}{c}\text{D3-branes} \\ \text{on } \mathbb{C}^d/\mathbb{Z}_N, \\ (\text{AdS-CFT}) \\ G = SU(N)\end{array} \arrow[l, "\text{T dual}"'] \arrow[r, "\Omega J"] & \begin{array}{c}\text{D3-branes} \\ G = SO(N) \\ Sp(N)\end{array} &
\end{tikzcd}
$$

NON-SUSY

$$
\begin{tikzcd}
 & & \text{compactifications} & \\
\text{M-Theory} \arrow[d, "S^1/(-1)^{F_S} S"] \arrow[dd, bend right=60, "?"'] & & & \\
\text{Type 0A} \arrow[d] & \text{Type 0B} \arrow[l, "T"'] \arrow[r, "\Omega, \Omega'"] \arrow[uur] \arrow[d] & \text{Type O} \arrow[uu] \arrow[d] & \\
\begin{array}{c}\text{HW} \\ \text{models} \\ (NS5, D4, D4')\end{array} & \begin{array}{c}\text{D3, D3' branes} \\ \text{on } \mathbb{C}^d/\mathbb{Z}_N \\ (\text{AdS-CFT}) \\ G = SU(N)\times SU(N)\end{array} \arrow[l, "\text{T-dual}"'] \arrow[r, "\Omega J", "\Omega' J"'] & \begin{array}{c}\text{D3-branes} \\ G = SO(N)\times SO(N) \\ G' = SU(N)\end{array} &
\end{tikzcd}
$$

II. Non-tachyonic orientifolds of Type 0B

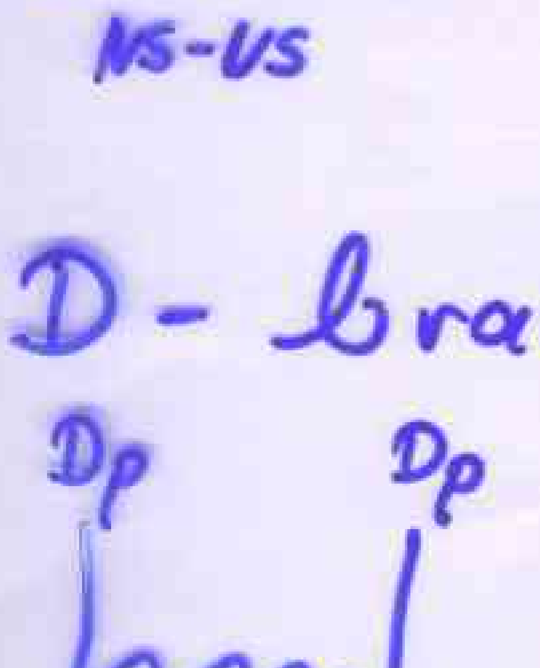
- Bianchi, Sagnotti, Phys. Lett. B247 (1990) 517
- Sagnotti, hep-th/9509080, hep-th/9702093
- Angelantonj, hep-th/9810214
- Bergman, Gaberdiel, hep-th/9701137

$$\text{Type 0B} = \begin{cases} P_{GSO} = \frac{1}{2}\left(1 + (-1)^{f_L + f_R}\right) \\ \text{Type IIB}/(-1)^{F_S} \end{cases} \quad \left(\begin{matrix}\text{Seiberg, Witten} \\ \text{Dixon, Harvey} \\ 1986\end{matrix}\right)$$

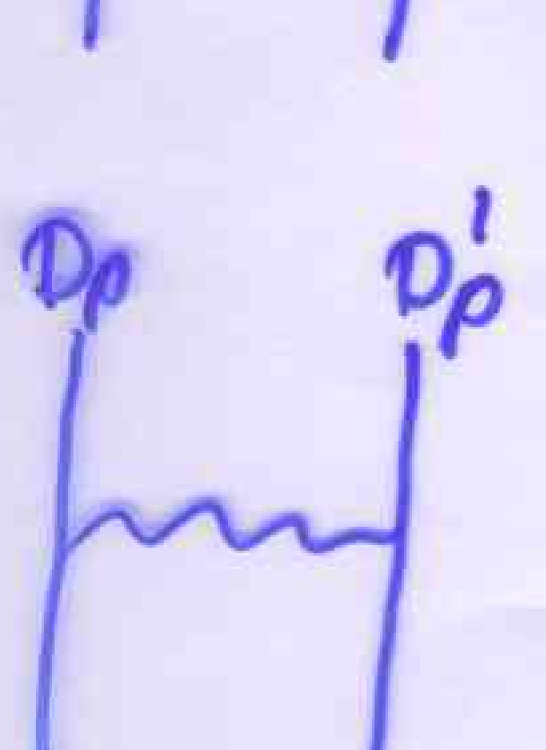
modular invariant partition function:

$$Z_T = \frac{1}{2}\,\frac{|f_3|^{16} + |f_4|^{16} + |f_2|^{16}}{|f_1|^{16}}$$

- non-vanishing + tachyon
- $\underbrace{G_{\mu\nu},\ \phi,\ B_{\mu\nu}}_{NS\text{-}NS} + \underbrace{2\,\varphi^{(i)},\ 2\,\tilde{B}^{(i)}_{\mu\nu},\ A_{\mu\nu\rho\sigma}}_{R\text{-}R}$
- D-branes doubled: D_p, D_p' p odd



: former (Type II) NS sector, no fermionic zero modes $\rightarrow$ space time bosons



: former R sector fermionic zero modes $\rightarrow$ space time fermions

i) orientifold by Ω:

→ tachyon + dilaton tadpoles in KB.

→ cancellation by 32 D9 and 32 $\overline{D9}$ branes

→ $SO(32) \times SO(32)$, tachyon $(32, 32)$

ii) orientifold by $\Omega' = \Omega\,(-1)^{f_R}$

(Note: for Type IIB $\Omega' \simeq \Omega$)

→ RR tadpole in KB

→ cancellation by 32 D9 and 32 D9' branes.

(Note: $(-1)^{f_R}\,D9 = D9'$)

→ $$A_{Type0} \sim \int \frac{dt}{t^6} \left(\frac{f_3^8 - f_4^8 - f_2^8}{f_1^8} \right) (e^{-\pi t})$$

$$= 2\,A_{TypeII}$$

introduces dilaton tadpole
(Fischler / Susskind mechanism)

→ spectrum: $G_{\mu\nu}$, ϕ; φ, $\tilde{B}_{\mu\nu}$, $A_{\mu\nu\rho\sigma}$ $(F = *F)$

: $U(32)$

$(496 \oplus \overline{496})_L$ Majorana-Weyl

Compactifications:

- does the absence of tachyons hold under compactification?

Generically not, due to new tachyons in twisted sectors. $\Omega : g \to g^{-1}$ => some tachyons survive.
(better $\Omega : g \to g$ => extra non-perturbative states (Kakushadze, Shiu, Tye)

Exceptions:

a.) $T^4/\mathbb{Z}_2$ $\quad R: z_i \to -z_i$

(Gimon, Polchinski)

it is possible to cancel all RR tadpoles with D9/D9' and D5/D5' branes.

$G = U(16) \times U(16) \times U(16) \times U(16)$

+ bosonic, fermionic matter

free of R^4, F^4 anomalies

b.) $T^6/\mathbb{Z}_3$: $\quad R: z_i \to e^{2\pi i \frac{1}{3}} z_i$

only D9/D9' branes

$G = U(12) \times U(12) \times U(8)$ + matter c.) $T^6/\mathbb{Z}_2$ $\quad R: z_i \to -z_i \quad i=1,..3$

- not level matched in Type IIB
- subtlety in R sector:

$$|s_1\, s_2\, s_3\, s_4\rangle \xrightarrow{R} \underbrace{e^{i\pi(s_2+s_3+s_4)}}_{\pm i} |s_1 s_2 s_3 s_4\rangle$$

like a $\mathbb{Z}_4$ action

- can be repaired by extra $\pm i$ in action of R on CP-factors
- tadpole cancellation requires D9/D9' and D3/D3' branes.

$G = U(16) \times U(16) \times U(16) \times U(16)$

$6 \times \{(16, \overline{16}; 1, 1) + (\overline{16}, 16; 1, 1) + (1, 1; 16, \overline{16}) + (1, 1; \overline{16}, 16)\}_B$

$4 \times \{(120, 1; 1, 1) + \text{cycl.} + (\overline{16}, \overline{16}; 1, 1) + (1, 1; \overline{16}, \overline{16})\}_F$

$1 \times \{(16, 1; 16, 1) + (1, 16; 1, 16)\}_F$

chiral, free of non-abelian gauge anomalies.

Dualities:

Compactifying M-theory on

$$\left(S^1 / (-1)^{F_s} S \right) \times \left(S^1 / \mathbb{Z}_2 \right)$$

leads to the following duality conjecture:

$$\underset{G = (SO(16)\times SO(16))^2}{\text{Type 0B}} / \Omega \approx \underset{G = SO(16)\times SO(16)}{\text{heterotic string}}$$

tempting to propose

$$\underset{G = U(32)}{\text{Type 0B}} / \Omega' \approx \underset{G = U(16)}{\text{heterotic string}}$$

(uses: $M / (-1)^{F_s} S \approx$ Type 0A   Bergman, Gaberdiel hep-th/9906055)

Open question: Do all these non-susy string models finally flow into susy vacua?

III D3 - branes in non-compact Type 0 backgrounds

Study non-supersymmetric gauge theories as low energy effective theories on D3 - branes in Type0B string theory (Polyakov, hep-th/9809057 \ Klebanov, Tseytlin, hep-th/9811035

Turning on RR-flux can cure the tachyonic instability due to $f(T)|F|^2$ coupling.

For self-dual D3/D3' branes the tachyon decouples and one finds "AdS - CFT" correspondence between bosonic $AdS_5 \times S^5$ background and non-supersymmetric gauge theory for

$SU(N) \times SU(N)$ $\quad\quad \lambda = g_{YM}^2 N < 100$

$6 \times \{(Adj, 1) + (1, Adj)\}_B$

$4 \times \{(N, \bar{N}) + (\bar{N}, N)\}_F$

Since typeOB is orbifold of typeIIB, in the large N limit correlation functions are the same as in $N=4$ SYM $\Rightarrow$ large N conformal

(Bershadsky, Kakushadze, Vafa, hep-th/9803076
Nekrasov, Shatashvili, hep-th/9902110)

What kinds of gauge theories does one get by taking orbifolds and orientifolds?

a.) Orbifolds

one gets the same tadpole conditions as in corresponding TypeIIB situation.

$$\mathrm{Tr}\, \gamma_{\theta^k} = 0 \qquad k \neq 0$$

only computation of massless spectrum differs.

- explicit results can be found in hep-th/9906101, hep-th/9902196 Billo et.al
- in all cases $b_1 = 0$, $b_2 = O\left(N^2 + \left(\frac{1}{N}\right)\right)$
- $N=2$, $N=1$ and $N=0$ singularities.
- bose-fermi degenerated

b) <u>Orientifolds.</u>

i) Ω orientifolds, $(1+\Omega)\times(1+\Theta+\ldots+\Theta^{k-1})$

- no untwisted RR tadpole
  $\Rightarrow$ no need to introduce anti-branes $\Rightarrow$ no open string tachyon
- twisted RR tadpoles can be cancelled by requiring

$$\mathrm{tr}(\gamma_{\Theta^k}) = 0 \qquad k\geq 1$$

easiest example: $(1+\Omega J(-)^{F_L})$ $\qquad J: z_i \to -z_i$

$$G = SO(N)\times SO(N)$$
$$6\times\{(Adj,1)+(1,Adj)\}_B$$
$$4\times\{(N,N)\}_F$$

$b_1 = 0\cdot N - \frac{16}{3}$ vanishes only in large N limit

$b_2 = \frac{64}{3}\left(0\cdot N^2 + N - \frac{1}{2}\right)$ $\Leftarrow$ right sign to lead to $\beta(g)_* = 0$

Möbius amplitude is non-zero
$\Rightarrow$ 1-loop cosmological constant
$\Rightarrow$ dilaton flows $\Rightarrow$ g_{YM} runs.

Möbius is $\frac{1}{N}$ suppressed against annulus.

ii) $\omega' = \Omega' (-)^{F_R} J (-)^{F_L}$ orientifolds

- cancellation of RR-tadpoles as in corresponding Type II orientifold

$$\mathrm{Tr}(\gamma^t_{\theta^{2k}}) = \pm \frac{1}{\prod_{i=1}^{3} \cos\left(\frac{\pi k v_i}{K}\right)} \qquad (*)$$

- no untwisted dilaton tadpole but twisted NSNS tadpoles $(*) \Rightarrow$ suppressed in the large N limit.

easiest example: $(1+\omega')$

$G = SU(N)$

$6 \times [\mathrm{Adj}]_B$

$4 \times \{A + \bar{A}\}_F$

$b_1 = 0N + \frac{16}{3}$

$b_2 = -\frac{64}{3}\left(0 \cdot N^2 + N - \frac{3}{N}\right)$

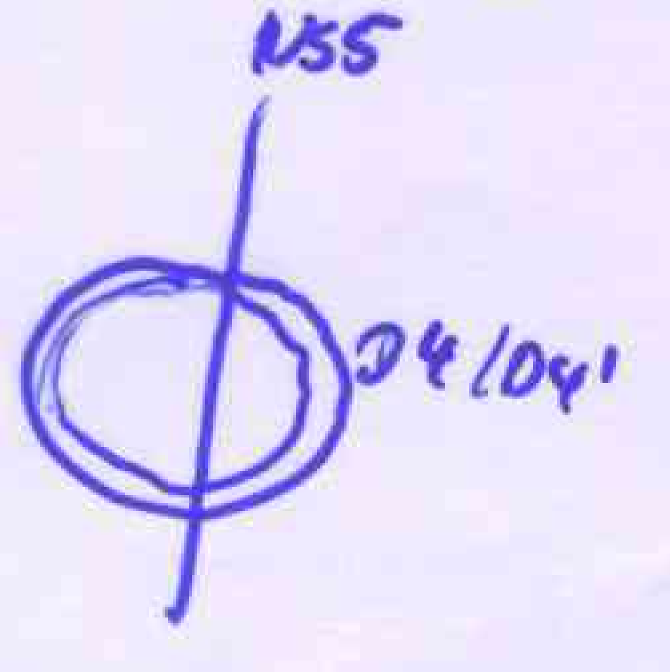
all these patterns continue to hold in the general case

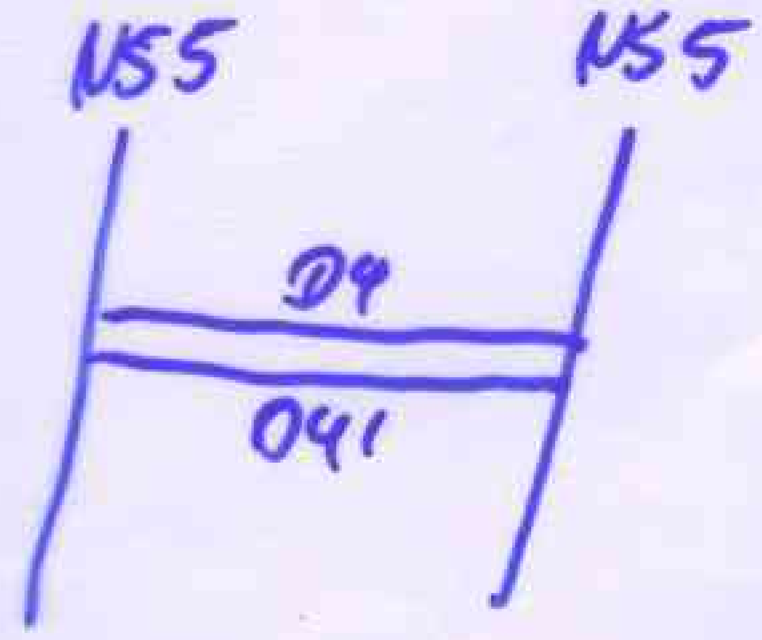
Hanany - Witten setups

T-dualizing transversal to D3/D3' branes + decoupling of tachyon
$\Rightarrow$ configurations of NS5 and D4/D4' branes in Type 0A

(Armoni, Kol hep-th/9906081, BFL II)

Example: $N=4$ singularity





$SU(N) \times SU(N)$

$\{(Adj, 1) + (1, Adj)\}_B$

$2\times\{(N,\bar{N}) + (\bar{N},N)\}_F$

$b_1(\text{non-susy}) = b_1(\text{susy})$

(bending still yields one-loop β-function)

Note: for model above $b_2(\text{non-susy}) = 0$

IV. Outlook

- embedding of HW in M-theory on $S^1/(-)^{F_s}S$ → higher-loop + non-perturbative information

  (in the large N limit)

  (work in progress)
- better understanding of tachyon-condensation and duality conjectures

- conformality for finite N ?

  (Frampton-Vafa)

Effective theory on M D3-branes

sector	fields	$U(32) \times U(M)$
99, 9'9'	vectors	$(\mathbf{Adj},\mathbf{1})$
	scalars	$6\times\ (\mathbf{Adj},\mathbf{1})$
99', 9'9	L-fermions	$4 \times \{(\mathbf{496},\mathbf{1}) + (\overline{\mathbf{496}},\mathbf{1})\}$
33, 3'3'	vectors	$(\mathbf{1},\mathbf{Adj})$
	scalars	$6\times\ (\mathbf{1},\mathbf{Adj})$
33', 3'3	L-fermions	$4 \times \{(\mathbf{1},\boxminus) + (\mathbf{1},\overline{\boxminus})\}$
93', 39' 9'3, 3'9	L-fermions	$\frac{1}{2} \times \{(\mathbf{32},\Box) + (\overline{\mathbf{32}},\overline{\Box})\}$

Table 1: *Effective theory field content*

The T^4/Z_2 orientifold

sector	spin $SU(2) \times SU(2)$
untwisted NS-NS	$(3,3) + 11 \times (1,1)$
untwisted R-R	$4 \times (3,1) + 4 \times (1,3) + 8 \times (1,1)$
twisted NS-NS	$64 \times (1,1)$
twisted R-R	$16 \times (3,1) + 16 \times (1,1)$

Table 2: *Closed string spectrum of $T^4/\mathbb{Z}_2$*

sector	spin	gauge $U(16) \times U(16) \times U(16) \times U(16)$
99, 55	(2,2)	**adjoint**
9'9', 5'5'	(1,1)	$4 \times \{(\mathbf{16},\overline{\mathbf{16}};\mathbf{1},\mathbf{1}) + (\overline{\mathbf{16}},\mathbf{16};\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{1};\mathbf{16},\overline{\mathbf{16}}) + (\mathbf{1},\mathbf{1};\overline{\mathbf{16}},\mathbf{16})\}$
95, 9'5'	(1,1)	$2 \times \{(\mathbf{16},\mathbf{1};\overline{\mathbf{16}},\mathbf{1}) + (\overline{\mathbf{16}},\mathbf{1};\mathbf{16},\mathbf{1}) + (\mathbf{1},\mathbf{16};\mathbf{1},\overline{\mathbf{16}}) + (\mathbf{1},\overline{\mathbf{16}};\mathbf{1},\mathbf{16})\}$
99', 55'	(1,2)	$2 \times \{(\mathbf{120} \oplus \overline{\mathbf{120}},\mathbf{1};\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{120} \oplus \overline{\mathbf{120}};\mathbf{1},\mathbf{1}) +$ $(\mathbf{1},\mathbf{1};\mathbf{120} \oplus \overline{\mathbf{120}},\mathbf{1}) + (\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{120} \oplus \overline{\mathbf{120}})\}$
	(2,1)	$2 \times \{(\mathbf{16},\mathbf{16};\mathbf{1},\mathbf{1}) + (\overline{\mathbf{16}},\overline{\mathbf{16}};\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{1};\mathbf{16},\mathbf{16}) + (\mathbf{1},\mathbf{1};\overline{\mathbf{16}},\overline{\mathbf{16}})\}$
95', 59'	(1,2)	$\{(\mathbf{16},\mathbf{1};\mathbf{16},\mathbf{1}) + (\overline{\mathbf{16}},\mathbf{1};\overline{\mathbf{16}},\mathbf{1}) + (\mathbf{1},\mathbf{16};\mathbf{1},\mathbf{16}) + (\mathbf{1},\overline{\mathbf{16}};\mathbf{1},\overline{\mathbf{16}})\}$

Table 3: *Open string spectrum of $T^4/\mathbb{Z}_2$*