Codimension-one vacua of non-supersymmetric strings

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Strings Breaking SUSY

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Introduction

Context: understand gravitational backreaction of ~~**SUSY**~~ in string models.

In QFT, it would be **vacuum energy**: cosmological constant.

Approach of this talk: **non-susy strings**.

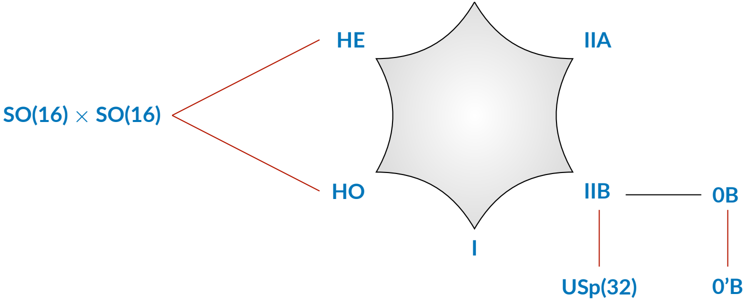
Vacuum energy $\rightarrow$ “tadpole” potentials.

Non-susy tachyon-free string theories in 10D

① Heterotic: $SO(16) \times SO(16)$ [Alvarez-Gaume, Ginsparg, Moore, Vafa 1986; Dixon, Harvey 1986].

② Type IIB with $O9^+$ and 32 $\overline{D9}$: $USp(32)$ [Sugimoto 1999].

③ Orientifold of bosonic 0B: 0'B [Sagnotti 1995].



Tadpole potentials

String theory counterpart of quantum vacuum energy: tadpole potential

$$\boxed{\delta S = - \int \sqrt{-g}\; T \, e^{\gamma \phi}\, .}$$

- From worldsheet: **IR divergences** $\to$ background shift.
  [Fischler, Susskind 1986; Callan, Lovelace, Nappi, Yost 1986-7-8].
- From spacetime: residual NS-NS tension, from sources or vacuum energy.

For instance, the USp(32) model has $Te^{-\phi}$:

	Tension	Charge
Type I, O9^{-} and 32 D9	-32+32=0	-32+32=0
USp(32), O9^{+} and 32 $\overline{\text{D9}}$	32+32=64	32-32=0

+ DBI action

⚠ Tadpole potentials are **runaways**: flat 10D Minkowski is not a vacuum.

Codimension-one vacua

Here we reach a crossroads:

1. Use δS in compactifications.
2. Look for the vacuum solution for empty spacetime

We choose 2.

Most symmetrical solution: abandon an isometry $\longrightarrow$ codimension-one vacua [Dudas, Mourad 2000].

Static case

Focus on **orientifold** cases. Bulk solution [Dudas, Mourad 2000]:

$$ds^2 = \left(\sqrt{T/2}\, y\right)^{\frac{1}{9}} e^{-\frac{T}{16}y^2}\, \eta^{(9)}_{\mu\nu} dx^\mu dx^\nu + \left(\sqrt{T/2}\, y\right)^{-1} e^{-\frac{3}{2}\phi_0} e^{-\frac{9}{16}Ty^2}\, dy^2\,,$$
$$e^{\phi} = e^{\phi_0} \left(\sqrt{T/2}\, y\right)^{\frac{2}{3}} e^{\frac{3}{8}Ty^2}\,.$$

- Timelike singularities at $y = 0$ and $y \to \infty$.
- $e^{\phi} \to 0$ at $y = 0$ and $\to \infty$ at $y \to \infty$.
- Finite proper y length $= \Gamma(\frac{1}{4}) e^{-\frac{3}{4}\phi_0} \sqrt{\frac{2}{3T}}$. Spontaneous compactification.

Some comments:

- The solution is perturbatively stable [Basile, Mourad, Sagnotti 2018].
- The 9D EFT is Einstein-Yang-Mills: forms do not survive and the dilaton is not a modulus [Basile, SR, Thomée 2022; Mourad, Sagnotti 2023].
- If $y \in (0, \infty)$, decompactification $e^{\phi_0} \to 0$ leads to the singular codimension-one solution

$$\boxed{ds^2 = (9y)^{\frac{2}{9}} \; \eta^{(9)}_{\mu\nu} dx^\mu dx^\nu + dy^2 \; , \qquad e^\phi = (9y)^{\frac{4}{3}} \; ,}$$

and not flat space.
Dynamical cobordism [Mourad, Sagnotti 2020-3; Angius, Buratti, Calderón-Infante, Delgado, Huertas, Mininno, Uranga 2020-1-2].

- Adding an integration constant (equiv. restricting the y range) , e.g.

$$\phi = \phi_0 + \frac{2}{3}\log\left(y_0 + \sqrt{T/2}\, y\right) + \frac{3}{4}\left(y_0 + \sqrt{T/2}\, y\right)^2 \ ,$$

$y \in (0, \infty)$, would decompactify to flat space.

What I mean is:

$$ds^2 = (h_8 z)^{\frac{1}{8}}\ \eta^{(9)}_{\mu\nu} dx^\mu dx^\nu + (h_8 z)^{\frac{9}{8}}\ dz^2$$

is not a D8 in IIA at $z = 0$. It is the D8 bulk.

Instead,

$$ds^2 = (1 + h_8 z)^{\frac{1}{8}}\ \eta^{(9)}_{\mu\nu} dx^\mu dx^\nu + (1 + h_8 z)^{\frac{9}{8}}\ dz^2$$

is a D8 at $z = 0$.

The issue is the absence of an asymptotic infinity: domain walls.

However, a non-stringy 8-brane is generically needed [SR 2022; Blumenhagen, Cribiori, Kneissl, Makridou, Wang 2022-3].

- D8-like coupling if $y_0 = \frac{4}{3}$ and $\phi_0 =$ counting parameter.
  This would realize [Antonelli, Basile 2019].

- No known generalization with curvature, e.g. AdS_9.

Singular domain walls may not be the best replacement for vacuum solutions.

Cosmological case

An alternative option is time-dependent backgrounds.
In [Dudas, Mourad 2000],

$$ds^2 = -e^{2B(t)}\, dt^2 + e^{2A(t)}\, \delta^{(9)}_{ij} dx^i dx^j \,, \qquad \phi = \phi(t)\,.$$

- Spacelike singularities at $t = 0$ and $t \to \infty$, separated by infinite time. Vacuum solution?
- e^{ϕ} is bounded, and vanishes at $t = 0$ and $t \to \infty$.
- As to $t \to 0$ and ∞, singular cosmological codimension-one solution.

The most general solution with curved space is not known. However, a particular solution where tadpole balances curvature [SR 2022]

$$
\boxed{\begin{aligned}
ds^2 &= -dt^2 + \left(\frac{3}{8}\sqrt{T}\,t\right)^2 g^{(9)}_{ij}\,dx^i dx^j\,, \\
e^{\phi} &= \left(\frac{3}{8}\sqrt{T}\,t\right)^{-\frac{4}{3}}\,,
\end{aligned}}
$$

with $R_{ij} = -T g_{ij}$.

- Spacelike singularity at $t = 0$.
- $e^{\phi} \to 0$ at late times.
- Stability?

Time-dependent backgrounds can be vacuum solutions.

T-duals with branes

T-dual of Sugimoto: codimension-one **settings**.

Gravity description of

$$\text{O8}^{+} + N\ \overline{\text{D8}} \longleftrightarrow \text{O8}^{+} + (16-N)\ \overline{\text{D8}}\ ?$$

- In [Blumenhagen, Font 2000] static codim-2 metric, as in Dudas-Mourad. Finite-distance singularities.

- In [Dudas, Mourad, Timirgaziu 2002], time-dependent backgrounds. However, **no solutions** for T-dual of Sugimoto, $\forall N$!

Take $N = 8$.

$$\text{O8}^+ + 8\ \overline{\text{D8}} \longleftrightarrow \text{O8}^+ + 8\ \overline{\text{D8}}$$

There is still a metric ansatz yet to be explored

$$ds^2 = -e^{2B(t,y)}\, dt^2 + e^{2A(t,y)}\, \delta_{ij}^{(8)} dx^i dx^j + e^{2C(t,y)}\, dy^2 \,,$$
$$\phi = \phi(t, y) \,.$$

My expectation: the two localized tensions will attract, leading to collapse

$\rightarrow$ instability

Hint: deep in the bulk, one can expect only sensible t dependence.

Borrowing from [Mourad, Sagnotti 2021], there are Kasner-like solutions

$$
\begin{aligned}
ds^2 &= -dt^2 + t^{\frac{2}{9}(1+\cos\theta)}\, \delta^{(8)}_{ij} dx^i dx^j + t^{\frac{2}{9}(1-8\cos\theta)}\, dy^2 \,, \\
e^{\phi} &= e^{\phi_0}\, t^{\frac{4}{3}\sin\theta} \,,
\end{aligned}
$$

in which the y direction is contracting.

This would be similar to [Fabinger, Horava 2000], although for them the driving force is bulk vacuum energy.

Conclusions and outlook

Codimension-one solutions are puzzling:

- Spontaneous compactifications.
- Sources (domain walls).
- Vacuum solutions.

Open problems

- Classify all solutions with curved space(time)s.
- Euclidean solutions (e.g. bubbles).
- Understand when the singularities are stringy.
- T-dual of Sugimoto, codimension-one in time-dependent vacuum.