Brane solutions in non-supersymmetric strings

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Based on works with J. Mourad and A. Sagnotti

Plan

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Motivations

String theory contains extended objects: **branes**.

Non-perturbative (D branes $\mathcal{T} \sim g_s^{-1}$) but still captured by low-energy EFT:

$$\frac{1}{2\kappa_{10}^2} \sim \frac{1}{G_N} \sim g_s^{-2} \; ,$$

and the gravitational field generated by a D brane scales as

$$G_N \mathcal{T} \sim g_s \; .$$

Brane solution: background with ISO$(1,p)\times$SO$(9-p)$ isometries, interpolating

singularity $\longrightarrow$ flat space.

BPS branes in spacetime supersymmetric strings: ($S \supset e^{-2\beta_p \phi} F_{p+2}^2$)

$$ds^2 = \Delta^{-\frac{7-p}{8}} dx_{p+1}^2 + \Delta^{\frac{p+1}{8}} \left(d\rho^2 + \rho^2 d\Omega_{8-p}^2 \right) ,$$
$$e^{\phi} = e^{\phi_0} \Delta^{-\beta_p} , \qquad F_{p+2} = \pm (7-p) |h_p| e^{\beta_p \phi_0} \Delta^{-2} \rho^{p-8} dx^0 \wedge \ldots \wedge d\rho \, .$$

with $\Delta = 1 + h_p \rho^{p-7}$.

Are there similar solutions in **non-supersymmetric setups**?

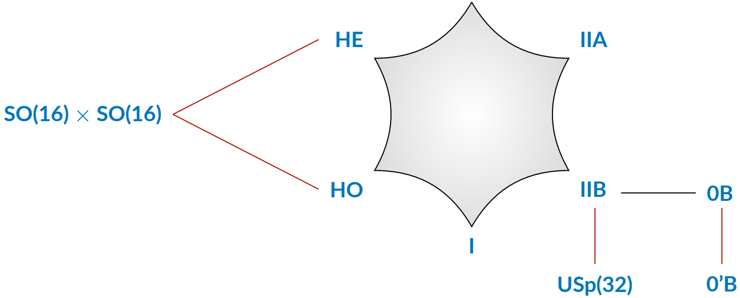
I focus on specific non-susy models, but the general considerations have wider applicability in (perturbative) string-derived scenarios.

Non-susy tachyon-free string theories in 10D

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

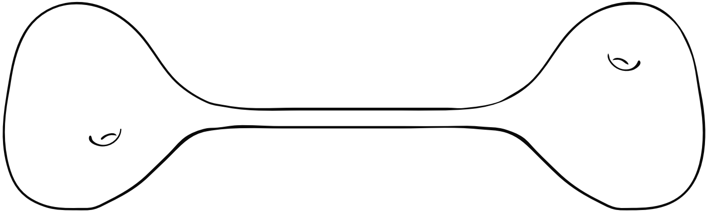
② Orientifold of bosonic 0B: 0'B [Sagnotti 1995].

③ Type IIB with $O9^{+}$ and 32 $\overline{D9}$: $USp(32)$ [Sugimoto 1999].



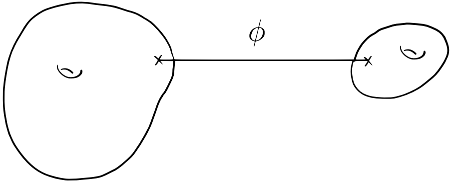
Tadpole potentials

These models are **divergent**!
e.g. $\mathcal{Z}_1$ for the orientifolds and $\mathcal{Z}_2$ for the heterotic.



➠ **IR divergences** (tadpoles)

➠ Subtract tadpole contribution through background shift [Fischler, Susskind 1986; Callan, Lovelace, Nappi, Yost 1986–8; Tseytlin 1988–90].



$\sim$ string-loop *correction*

$$S \sim \int (e^{-2\phi} + c_R)R + (e^{-2\phi} + c_\phi)4(\partial\phi)^2 - (e^{-2\phi} + c_H)\frac{1}{2}\frac{H^2}{3!} - \Lambda + \ldots$$

tadpole scalar potential $\boxed{\Lambda = T\, e^{\gamma\phi}\,,}$ $\gamma = \{0, -1\}$ $\Rightarrow$ **runaway** .

Brane solutions in non-susy strings

Worldsheet [Dudas, Mourad, Sagnotti 2001]: charged branes for all form fields

① SO(16) $\times$ SO(16): NS1 and NS5.

② 0'B: D1, D3 and D5.

③ USp(32): D1 and D5.

$+$ uncharged (generically unstable), K-charged, topologically charged, ...

What are the ***gravity solutions*** of these branes?

(previous related works [Antonelli, Basile 2019, Basile 2021-2])

Isometry-driven

Keep ISO$(1,p)\times$SO$(9-p)$ **isometries** (*branes and vacua*):
[Mourad, SR, Sagnotti 2024]

$$ds^2 = e^{2A(r)}dx_{p,1}^2 + e^{2B(r)}dr^2 + e^{2C(r)}d\Omega_{8-p}^2\,, \qquad \phi = \phi(r)\,, \qquad F_{p+2} = F_{p+2}(r)\,.$$

In the harmonic gauge $B = (p+1)A + (8-p)C$,

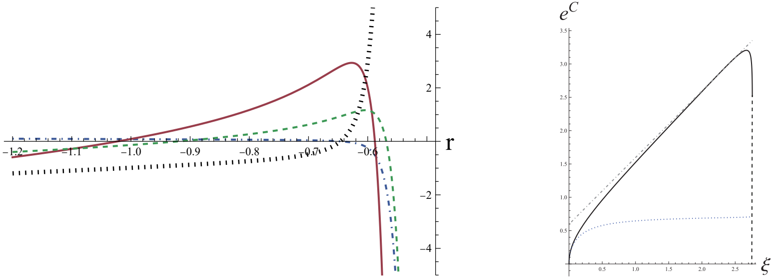
$$\begin{pmatrix} X \\ Y \\ W \end{pmatrix}'' = \begin{pmatrix} + & 0 & - \\ 0 & + & \pm, 0 \\ + & \pm, 0 & +, 0 \end{pmatrix} \begin{pmatrix} e^X \\ e^Y \\ e^W \end{pmatrix}\,,$$

$X \sim$ curvature , $\quad Y \sim$ flux , $\quad W \sim$ tadpole .

➠ Curvature and tadpole: vacuum solutions and uncharged branes

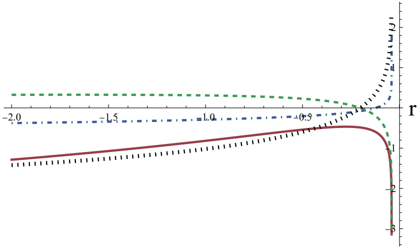
- Classification of **asymptotics**.
- Global convexity and conserved quantity $\rightarrow$ partial matching of asymptotics.

Spacetime always closes on a *finite-distance singularity* [Antonelli, Basile 2019].



$A(r)$ (blue, dot-dashed), $B(r)$ (red, solid), $C(r)$ (green, dashed), $\phi(r)$ (black, dotted), and $e^C(\xi)$

- Curvature, tadpole and flux: flux vacua and charged branes
    - Classification of **asymptotics**.
    - D5 orientifold: flux decouples $\to$ previous case.



    - Only heterotic one-loop tadpoles generate tadpole-dominated collapses.

In all cases, *finite-distance singularity*.

Vacuum-driven

Keep **singularity** $\longrightarrow$ **vacuum** [Mourad, SR, Sagnotti 2024]: Dudas-Mourad

$$ds^2 = e^{2\Omega(z)}\left(dx_{8,1}^2 + dz^2\right)\,, \qquad \phi = \phi(z)\,.$$

[Dudas, Mourad 2000]

- Finite-length z-interval with *singular* endpoints.
- Perturbatively stable [Basile, Mourad, Sagnotti 2018] $\to$ can be a vacuum.

Branes in this vacuum:

$$ds^2 = e^{2A(z,r)}dx_{p,1}^2 + e^{2B(z,r)}\left(dr^2 + r^2 d\Omega_{7-p}^2\right) + e^{2D(z,r)}dz^2\,,$$
$$\phi = \phi(z,r)\,, \qquad F_{p+2} = F_{p+2}(z,r)\,.$$

- $dx^2_{8,1} \to$ Ricci-flat: exact solution with 9D uncharged branes (*smeared*)

$$ds^2 = e^{2\Omega(z)}\left(dx^2_{\text{9D uncharged brane}} + dz^2\right)\,, \qquad \phi = \phi(z)\,, \qquad F_{p+2} = 0\,.$$

- Linearized solutions: compatible with singular boundary conditions as in [Mourad, Sagnotti 2023], matches the *expected charged branes*.
  - D3 (type 0'B) z-independent [Basile, SR, Thomée 2022].
  - All other cases have z dependence, e.g. orientifold D5

$$F_7 = \frac{Q_5}{r}\left[-\frac{1}{r}\int_0^z d\zeta e^{4\Omega(\zeta)+\phi(\zeta)}dr + e^{4\Omega(z)+\phi(z)}dz\right] \wedge dx^0 \wedge \ldots \wedge dx^5\,.$$

  - Linear modes are perturbations, with care as $r \to \infty$ and $z \to$ endpoints.

Discussion

- Brane solutions are *heavily deformed* in non-susy strings. We found
  - ISO$(1,p)\times$SO$(9-p)$ isometries and finite-distance singularities.
  - linearized branes in Dudas-Mourad vacua.

- How can we *identify* the branes of non-supersymmetric strings?

- The two approaches may be compatible:
  - ISO$(1,p)\times$SO$(9-p)$ close to the branes.
  - linearized solutions far from them.

  also depeding on the hierarchy of lengths

$$\ell_{\text{DM}} \leftrightarrow \ell_{\text{horizon}}\ .$$

- The second approach is a special case of *branes in backgrounds*. Interesting option: branes in cosmological Dudas-Mourad

$$ds^2 = -e^{2D(t,r)}dt^2 + e^{2A(t,r)}dx_p^2 + e^{2B(t,r)}\left(dr^2 + r^2 d\Omega_{8-p}^2\right) \ .$$

  Our analysis gives Euclidean branes: more work is needed.

- Ubiquitous presence of spacetime *singularities*: no control on which ones are cured in UV string theory.

Understanding branes in non-susy strings demands control on singularities.

Thank you!