A first-order formalism for non-supersymmetric strings

Salvatore Raucci

Scuola Normale Superiore

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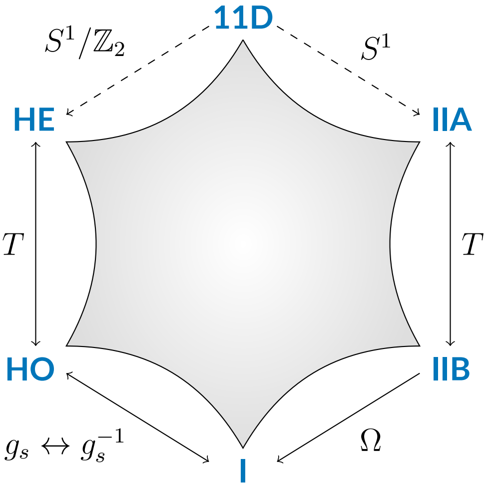
Context

Supersymmetry breaking in string theory.

- Study gravity backreaction without SUSY. In QFT, **vacuum energy**. String theory counterpart?
- ~~**SUSY**~~ $\approx$ **no control**: limited tools and quantum corrections.
- **Stability** is subtle.

Toy models: string theories without SUSY to begin with, and gravitational backreaction of *string-scale SUSY breaking*.

Introduction: SUSY strings



Equations of motion (EoMs) from conformal invariance of sigma model: double expansion in g_s and α'

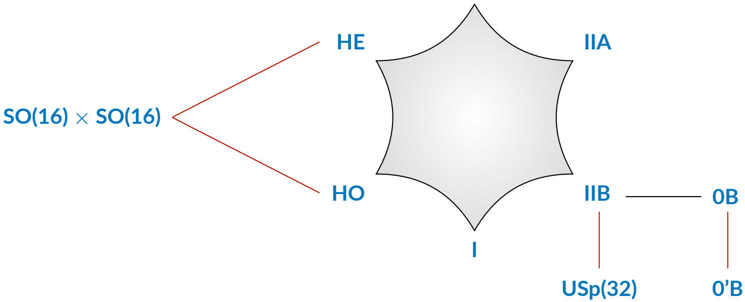
$$S \sim \frac{1}{(\alpha')^4} \int d^{10}x \sqrt{-g} \sum_{n,m=0}^{\infty} g_s^{-2+n} (\alpha')^m \mathcal{O}_{2+2m} \, .$$

Any solution is a consistent string background. However, SUSY:

- Protection of terms in the action.
- First-order equations.
- Use of spinors: energy, G-structures, bispinor equations, ...
- Dynamical obstruction to decays.

Non-SUSY tachyon-free string theories in 10D

- Type IIB with $O9^{+}$ and 32 $\overline{D9}$: USp(32) [Sugimoto 1999].
- Orientifold of bosonic 0B: 0'B [Sagnotti 1995].
- Heterotic: $SO(16) \times SO(16)$ [Alvarez-Gaume, Ginsparg, Moore, Vafa 1986; Dixon, Harvey 1986].



Generic stringy feature without SUSY: “tadpole” scalar potential

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

- Residual (NS-NS) tension, from sources or vacuum energy.
  IR divergences $\to$ background shift.

- From worldsheet: non-standard counterterm in σ-model renormalization [Fischler, Susskind 1986; Callan, Lovelace, Nappi, Yost 1986-7-8]. Only the sum over **all** Riemann surfaces is conformally invariant.

Runaway potential, bad for existence and stability of vacua.

How?

1. solve the second-order EoMs.

   $\rightarrow$ simple ansatz.

2. Check perturbative stability expanding in modes.

   $\rightarrow$ simple internal manifold.

3. Understand non-perturbative stability.

   $\rightarrow$ half-baked, model-dependent, simple decays.

Can we do better?

Fake Supergravity [Freedman, Nunez, Schnabl, Skenderis 2003]

Inspired by (SUSY + Bianchi) $\Rightarrow$ EoMs, define operators D_M and $\mathcal{O}$ such that

$$D_M \varepsilon = 0 \, ,$$
$$\mathcal{O} \varepsilon = 0 \, ,$$

together with the Bianchi identities, imply the EoMs.

Fake susy with tadpole potentials [SR 2023]:

- For gravity and the dilaton, it is possible. Simplest possibility:

$$D_M \varepsilon = \left(\nabla_M + \mathcal{W}(\phi)\Gamma_M\right) \varepsilon \, ,$$
$$\mathcal{O} \varepsilon = \left(d\phi + g(\phi)\right) \varepsilon \, .$$

- Includes the codimension-one solutions of [Dudas, Mourad 2000]

$$ds^2 = e^{2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2 \,.$$

These are **perturbatively stable** [Basile, Mourad, Sagnotti 2018; Mourad, Sagnotti 2023].

- No new vacuum solution: change spinor ansatz? (wip)

- Problems with fluxes, simplest extensions do not work. However, recall

$$S \sim \frac{1}{(\alpha')^4}\int d^{10}x\sqrt{-g}\sum_{n,m} g_s^{-2+n}(\alpha')^m \mathcal{O}_{2+2m} \,.$$

Kinetic terms of the forms might be loop-corrected.

Energy

Following [Witten 1981; Giri, Martucci, Tomasiello 2021], spinorial energy

$$I(\varepsilon) = \int_\Sigma \nabla_N E^{MN} d\Sigma_M \,, \qquad E^{MN} = -\bar{\varepsilon}\Gamma^{MNP}\nabla_P \varepsilon \,.$$

Inspired by SUSY, for asymptotically flat spacetimes $I(\varepsilon) = I(\varepsilon_0) = -\bar{\varepsilon}_0\gamma^\mu\varepsilon_0 P_\mu$.

Using the fake D_M operator,

$$\nabla_M E^{MN} = \overline{D_M\varepsilon}\Gamma^{MPN} D_P\varepsilon + \frac{1}{2}\bar{\varepsilon}\left(\text{Gravity EoM}\right)^{MN}\Gamma_M\varepsilon - \frac{1}{8}\overline{\mathcal{O}\varepsilon}\Gamma^N\mathcal{O}\varepsilon \,.$$

Positivity follows if a genearalized Witten condition holds: $\Gamma^m D_m\varepsilon = 0$.

Dudas-Mourad is a zero-energy solution. Is it stable, then?

- Spinorial energy needs control on boundary behaviour. Counterexample with cubic $\mathcal{W}(\phi)$.

- Indication that instability comes from boundary effects. Matches with Dudas-Mourad as 8-brane $+$ EtW defect [Blumenhagen, Font 2000; Antonelli, Basile 2019; Mourad, Sagnotti 2020-3; Angius, Buratti, Calderón-Infante, Delgado, Huertas, Minnino, Uranga 2020-1-2; SR 2022; Blumenhagen, Cribiori, Kneissl, Makridou, Wang 2022-3; ...].

Conclusions and outlook

- Fake SUSY for non-SUSY strings. Gravity $+$ dilaton

$$D_M\varepsilon = (\nabla_M + \mathcal{W}(\phi)\Gamma_M)\,\varepsilon\ ,$$
$$\mathcal{O}\varepsilon = (d\phi + g(\phi))\,\varepsilon\ .$$

- No simple inclusion of fluxes. Loop-corrected EoMs?

- Spinorial energy definition

$$E^{MN} = -\bar{\varepsilon}\Gamma^{MNP}D_P\varepsilon\ ,$$

but stability still unclear.