Charting the landscape of non-supersymmetric strings

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Deconstructing the String Landscape

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Plan

- ☐ Introduction
  - Equations of motion without susy
  - Non-susy tachyon-free string theories in 10D
- ☐ Flux compactifications
  - Sum rules
  - Freund-Rubin vacua
- ☐ A first-order formalism

Introduction

Context: find geometric string vacua without spacetime susy that are (in some appropriate sense) under control.

However, ~~**SUSY**~~ :

- Limited tools.
- Limited control (quantum corrections).
- Generic instability.

How do we chart the non-susy landscape?

Equations of motion without susy

Double expansion in g_s and α'

$$S \sim \sum_{n,m=0}^{\infty} \int e^{(n-2)\phi} \, (\alpha')^{m-4} \, \mathcal{O}_{2+2m} \, .$$

Susy:

- ✓ Protection of terms in the action $\to$ 2-derivative sugra.
- ✓ First-order equations.
- ✓ Use of spinors: access to more structure.
- ✓ Dynamical obstruction to decays.

What we expect from string theory is a 2-derivative action

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

Some comments:

- Fine as a perturbative expansion, except the new term Λ.
- Is there a low-energy principle explaining these types of corrections?

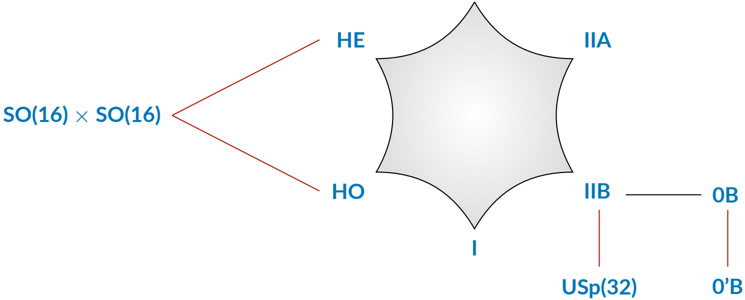
Can we compute Λ from string theory? $\rightarrow$ non-susy strings.

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].



Λ = "tadpole" scalar potential

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

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

Heterotic SO(16) $\times$ SO(16): $\sim$ vacuum energy, positive (more fermions).

Idea: Use δS in flux compactifications.

Flux compactifications

$$S \sim \int e^{-2\phi}\left[R + 4(\partial\phi)^2\right] - \sum_k \frac{1}{2} e^{\beta_k \phi} \frac{F_k^2}{k!} - T e^{\gamma\phi} \,.$$

– Orientifolds: $\gamma = -1$ - $k = (1,)3(,5)$ with $\beta_k = 0$, - $k = 2$ gauge, with $\beta_k = -1$.	– Heterotic: $\gamma = 0$ - $k = 3$, with $\beta_k = -2$, - $k = 2$ gauge, with $\beta_k = -2$.

➾ Not quite the right spectra to treat $Te^{\gamma\phi}$ as a small perturbation.
(However, see [Angelantonj, Armoni 1999] and [Baykara, Robbins, Sethi 2022; Fraiman, Graña, Parra De Freitas, Sethi 2023])

Sum rules

What should we expect?

- ➠ Generalization of sum rules in [Maldacena, Nunez 2000]:
  no dS or Minkowski [Basile, Lanza 2020].

- ➠ No-go can be avoided:
  - Orientifolds, negative tension.
  - Allowing **boundaries**.

Boundaries are particularly puzzling in these models [Dudas, Mourad 2000].

Freund-Rubin vacua

Idea: Balance the tadpole with fluxes.

Focus on heterotic SO(16) $\times$ SO(16). NS-NS F_3:

- AdS$_7 \times$S^3 with magnetic flux [Mourad, Sagnotti 2016].
  - Perturbatively unstable. We can replace S^3 with M$_3$ Einstein, perturbative stability with $\mathbb{RP}^3$ [Basile, Mourad, Sagnotti 2018].
  - Non-perturbatively unstable [Basile 2019-20].
- AdS$_4 \times$X$_3 \times$Y$_3$ with two magnetic fluxes [Basile 2020; wip].

U(1) flux in the gauge sector:

- $\mathrm{AdS}_8 \times \mathrm{S}^2$ with magnetic flux [SR 2022].
  - Stable under perturbations of metric, dilaton, and U(1).
  - Indications of instability in the mixed abelian-nonabelian gauge sector from flat-space limit [Chang, Weiss 1979; Sikivie 1979].
  - Reminiscent of magnetic monopoles.

Take-home message: It is possible to balance the tadpole with fluxes and curvatures. Simple solutions are usually **unstable**.

➠ General issue of stability without susy [Ooguri, Vafa 2016].

➠ But we are certainly missing tools to address the problem.

A first-order formalism

Possible tools: **fake supergravity**, following [Freedman, Nunez, Schnabl, Skenderis 2003]: define operators D_M and $\mathcal{O}$ such that

$$\left.\begin{aligned} D_M\varepsilon &= 0 \\ \mathcal{O}\varepsilon &= 0 \end{aligned}\right\} + \text{Bianchi id.} \;\Rightarrow\; \text{EoMs of non-susy strings.}$$

➠ It is a solution-generating technique, in principle there is no physics.

For gravity and the dilaton it is possible [SR 2023]. Simplest possibility:

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

Significant progress: **fluxes**. However,

$$D_M\varepsilon = (D_M^{\text{susy}} + \mathcal{W}(\phi)\Gamma_M)\,\varepsilon$$
$$\mathcal{O}\varepsilon = (\mathcal{O}^{\text{susy}} + g(\phi))\,\varepsilon$$

$+$ Bianchi do **not** imply EoMs.

- ➠ Change spinor ansatz? Loop corrections?

Subtle points:

- ➠ Loop and tree-level effects would contribute in the same way.
- ➠ Non-uniqueness of fake susy equations.

Summary and conclusions

- ➩ Non-susy strings: can compute Λ.
- ➩ Use Λ as ingredient in **flux compactifications**.
  - No drastic changes.
  - Balance tadpole with fluxes: Freund-Rubin.
- ➩ However, we are missing **techniques** to engineer vacua. Fake susy?

The landscape of non-susy strings remains largely uncharted!