(A)dS solutions from type II Scherk-Schwarz orbifolds

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Maldacena-Nunez no-go

In a warped compactification of D-dimensional gravity, de Sitter spacetime is obstructed by a **Strong Energy Condition** Maldacena, Nunez '00

$$\int_{D-d} \mathcal{R}_d + e^{2A}\,\tilde{T} = 0\,, \quad \tilde{T} := -T^{\mu}_{\mu} + \frac{d}{D-2}\,T^{L}_{L}\,,$$

SEC: at tree-level in g_s and α', w/out localised sources, non-perturbative effects etc..

$$\tilde{T} \geq 0 \implies \mathcal{R}_d \leq 0$$

~~**SEC**~~ is a necessary condition for dS

classical de Sitter?

~~**SEC**~~ from $p + 1$-dim localised sources, still classical corner

$$\tilde{T}_{\text{loc}} \sim T_p \delta(\Sigma) < 0 \quad \text{if} \quad T_p < 0 \implies O_p\text{-planes}$$

Very intensive research conjectured **3 open problems** Andriot '19, references therein

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1. No classical de Sitter solution with parallel sources
2. Classical de Sitter solutions with interstecting sources are **pert. unstable**
3. **No small g_s and large $\mathcal{V}$** within string-theory origin (quantised fluxes, bounded N_{O_p},...)

Refined dS conjecture: No (metastable) de Sitter in the **asymptotics** of moduli space

SUSY-breaking at string scale

Let's move to the **non-supersymmetric** corner

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10d tachyon-free **non-susy** strings: $SO(16) \times SO(16)$, Sugimoto $Usp(32)$, Sagnotti $0'B$

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There are **no de Sitter solutions** Basile, Lanza '20

... still very interesting Mink, AdS solutions: "Dudas-Mourad" , $AdS_3 \times S^7$, $AdS_7 \times S^3$... Dudas, Mourad '00 Mourad, Sagnotti '17

SUSY-breaking at compactification scale

Our work: Strings with SSB $M_{SUSY} \sim M_{KK}$: Scherk-Schwarz toroidal orbifolds

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3. dS with control on g_s, $\mathcal{V}$ expansions? No, $\mathbf{g_s \sim n_{H_3} \mathcal{V}^{\alpha}, \alpha > 0}$

Scherk-Schwarz orbifolds

IIB on a Torus $T^n_{\text{ss}}(R_{ss}) \to$ orbifold $g = (-1)^F \delta_{kk}$

F: spacetime fermion number

$\delta_{kk} : (x_L, x_R) \to (x_L + \pi R_{\text{ss}}/2, x_R + \pi R_{\text{ss}}/2) \implies n_{kk} \to n_{kk} + \frac{F}{2}$

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1-loop effective potential of **runaway** type:

$$V_{ss}(R_{ss}) \sim -\int_{\mathcal{F}} \frac{d^2\tau}{2\tau_2^2} \mathcal{T}_{IIB/g} \overset{R_{ss} \gg 1}{\sim} \underbrace{(n_F^0 - n_B^0)}_{\Delta \text{ massless dof}} \times \text{const} \times \frac{1}{R_{ss}^{10-n}}$$

fermions massed up $\mathbf{n_f^0 = 0}$, bosons still massless $\mathbf{n_b^0 = 64}$

The idea

Can we stabilise R_{ss} within a de Sitter solution using fluxes?

Compactification ansatz

Unwarped product compactifications, w/out localised sources

$$M_{1,d-1} \times \underbrace{Y^m \times T_{\text{ss}}^{10-d-m}}_{\text{internal space}}$$

- Y^m: m-dimensional **curved** Euclidean manifold
- NSNS H_3, H_7 and RR F_q fluxes
- $\Phi = \Phi_0 = \text{Log}(g_s)$

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Useful to decompose fluxes as

$$H_3 = \sum_{p_3=0}^{3} H_3^{(p_3)}\,, F_q = \sum_{s_q=0}^{q} F_q^{(s_q)}$$

with p_3, s_q legs on Y^m and remaining $3 - s_3$, $(q - s_q)$ legs on T^n_{ss}

10d dS No-gos

Strategy:

dilaton eom + traces Einstein eqs $\Longrightarrow \mathcal{R}_d \leq 0 \Longrightarrow$ **dS No-gos**

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in **d $\leq$ 5 dS solutions could exist, must minimally have**

$$\underbrace{\textbf{Negative Casimir}}_{\cancel{\text{SEC}}\ \textbf{if}\ n_b^0 > n_f^0}, \quad \mathcal{R}_Y > 0, \quad \mathbf{H_3^{(0)}}, \quad F_q^{(s_q)}|_{q<5-2s_q}$$

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$H_3^{(0)}$: H_3 flux component with 3 legs on the SS-torus (**will spoil control!!**)

$(s_q) = \#$flux legs on Y

Bianchi identity and parametric control

W/out localised sources and for non-trivial background fluxes, Bianchi identities require **tadpole-free fluxes**

$$dF_q = 0 = H_3 \wedge F_{q-2}$$

can be satisfied by distributing appropriately the flux legs in the internal space

If so, flux numbers are **unbounded** DeWolfe, Giryavets, Kachru, Taylor'05: Can we have

$$g_s \sim n^{-\alpha} \quad \mathcal{V} \sim n^{\beta} \quad \alpha, \beta > 0$$

for a $(A)dS$ solution?

We now go in the EFT to discuss **stability** and **control** on putative dS solutions

The EFT

In lower d-dimensional Einstein frame $\varphi^i = \{\phi_d, \omega, \chi\}$ **universal moduli**

$$ds^2_{10} = e^{\frac{4}{d-2}(\phi_d - \langle\phi_d\rangle)} ds^2_{M_{1,d-1}} + e^{2\chi} ds^2_{Y^m(R)} + e^{2\omega} ds^2_{T^n_{\text{ss}}(R_{\text{ss}})}$$

ω, χ: string-frame volume moduli $\quad e^{\langle\chi\rangle} = R\,, e^{\langle\omega\rangle} = R_{\text{ss}}$

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Scalar potential V from dim. reduction

$$S_d = \frac{1}{2\kappa_d^2}\int d^d x \sqrt{-g_d}\Big(\mathcal{R}_d - K_{ij}\partial_\mu\varphi^i\partial^\mu\varphi^j - V(\varphi^i)\Big)$$

$$V = \underbrace{V_{\text{flux}} + V_{\text{curv}}}_{\text{tree-level}} + \underbrace{V_{\text{ss}}}_{\text{1-loop}}$$

Assumption: $g_s \ll 1$ and $R, R_{ss} \gg 1$ higher order corrections negligible

EFT analysis: stability

de Sitter: $\nabla V|_{\text{crit}} = 0$, $V|_{\text{crit}} > 0$

For **consistent truncations**, stability can be addressed in the EFT by inspecting Hessian/Mass-matrix $M^i{}_j = K^{ik}\,\nabla_k\,\partial_j V|_{\text{crit}}$

$$\exists\,\text{negative Eigen}(M^i{}_j) \implies \text{instability}$$

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we find for $d \geq 4$ (K_{ij} is positive def)

$$\partial^2_{\phi_d} V|_{\text{crit}} = -2d\,V|_{\text{crit}} \qquad \textbf{universal tachyon}$$

Hence, by *Sylvester's criterion*:

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$$\eta_V := \frac{\min(\text{Eigen}(M^i{}_j))}{V}|_{\text{crit}} \leq -\frac{d}{2}(d-2) \lesssim -\mathcal{O}(1)$$

EFT analysis: dS under (parametric) control?

$M_{1,d-1} \times Y^m(R) \times T_{\text{ss}}^{10-m-d}(R_{\text{ss}})$

Notice that:

1. Crucially $V_{ss} \sim \frac{g_s^2}{R_{\text{ss}}^{10}}$ is only suppressed in g_s and $\frac{1}{R_{\text{ss}}}$ but not in $\frac{1}{R}$
2. for any solution, terms in the potential must be comparable

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but for **dS** $H_3^{(0)}$ term i.e $\mathbf{p_3 = 0}$ **should be leading!** $\implies$ No control on putative dS sol ($g_s \sim n_{H_3} R_{\rm ss}^2$)

AdS solution

An example of AdS solution under control: In IIA

$$AdS_7 \times S^2 \times S^1_{\text{ss}}$$

with $F_2^{(2)} \sim \text{vol}_{S^2}$, $H_3^{(2)} \sim \text{vol}_{S^2} \wedge \text{vol}_{S^1}$

- We solved all the 10d eoms, including BI
- Flux numbers $\int_{S^2} F_2 \sim n_2$, $\int_{S^2 \times S^1} H_3 \sim n_3$ are unbounded

Solution is perfectly under control ($\delta \ll 1$):

$$g_s \sim n_3^{\frac{5}{7}} \, n_2^{-\frac{6}{7}} \,, \quad R \sim n_3^{\frac{5}{7}} \, n_2^{\frac{1}{7}} \,, \quad R_{\text{ss}} \sim n_3^{\frac{2}{7}} \, n_2^{-\frac{1}{7}}$$

Conclusions

1. type II Scherk-Schwarz orbifolds come with a one-loop negative runaway potential that breaks the SEC
2. We looked for dS in product compactifications where the runaway could be stabilised with fluxes
3. We individuated dS no-gos as well as minimally required ingredients for dS solutions
4. for dS, we found a **tachyon** in the set of universal moduli $\implies$ **instability** of consistent truncations
5. **dS solutions cannot be under control**. In contrast, we provide an **AdS solution** to the 10d eoms that shows **parametric control**.

...Thank you!