The dS Swampland Conjecture, Non-BPS branes and K-theory

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Based on work with Ralph Blumenhagen and Andriana Makridou [1906.06078]

The Talk in a Nutshell:

Challenging the dS swampland conjecture

- Setup: Type IIA Orientifolds w/ fluxes and branes
- No-go theorem: no dS vacua in type IIA with standard ingredients

  [Hertzberg,Kachru,Taylor,Tegmark'07]
- Non-BPS $\widehat{D}7$ branes evade the no-go theorem
- Explicitly find dS vacua in a toy model setup
- Reconcile this with the dS swampland conjecture by cancellation of K-theory charges:

Proposition:

If the (refined) de Sitter swampland conjecture is correct, then the K-theory charge on a compact space has to be trivial.

Basics of Type IIA orientifolds

Orientifold Projection

Consider type IIA orientifold on a CY 3-fold X.

Orientifold projection: $\Omega\,\overline{\sigma}\,(-1)^{F_L}$

$\Omega : (\tau, \sigma) \to (\tau, -\sigma)$ world-sheet parity transformation,
$\overline{\sigma}$ an anti-holomorphic involution of the CY and
F_L the left-moving space-time fermion number operator.

The orientifold breaks the $\mathcal{N} = 2$ supersymmetry to $\mathcal{N} = 1$.

Split (co)homology into $\overline{\sigma}$ equivariants $H^* = H^*_+ \oplus H^*_-$.

Basics of Type IIA orientifolds

Classification via Cohomology

The massless spectrum in the closed string sector is determined by equivariant cohomology groups.

$\mathcal{N}=1$ multiplet	Moduli	Cohomology
chiral	U	$H^3_+(X)$
chiral	T	$H^2_-(X)$
vector	V	$H^2_+(X)$

Orientifold even fluxes take values in equivariant cohomology groups.

Flux	Cohomology
H	$H^3_-(X)$
$\{F_0, F_2, F_4, F_6\}$	$\{H^0_+, H^2_-, H^4_+, H^6_-\}$

Stable non-BPS D-branes

Reminder: D-branes and K-theory

Physically: (stacked) D-branes $\Leftrightarrow$ gauge fields

We can "add" ($\Leftrightarrow \oplus$) and "subtract" ($\Leftrightarrow$??) D-branes and $\overline{D}$-branes.

K-theory allows us to do that:

Eqivalence classes $[E, F]$ of gauge bundles:

$$[E, F] \sim [K, L] \iff \exists G : E \oplus L \oplus G \simeq F \oplus K \oplus G$$

Compare with $\mathbb{N} \to \mathbb{Z}$: [pos, neg] contributions

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Intuition:

\# of D-branes after annihilation $\sim$ Equiv. class rep. $[E, 0]$
$\Rightarrow$ K-theory charge $\sim$ rank of E

Stable D-branes: any # of D-branes allowed, so the K-theory $\simeq \mathbb{Z}$

[Minasian,Moore'97; Witten'98; review: Evslin'06]

Stable non-BPS D-branes

Stabilization via Orientifold

Recall: non-BPS branes are usually unstable

No GSO projection to remove the Tachyon!

Orientifold projects out tachyon

This only works with a single non-BPS brane

$\Rightarrow$ K-theory $\simeq \mathbb{Z}_2$

Well-known in Type I: [Frau,Gallot,Lerda,Strigazzi'99]

non-BPS brane	K-theory
$\widehat{D}8$	$KO(S^1) = \mathbb{Z}_2$
$\widehat{D}7$	$KO(S^2) = \mathbb{Z}_2$
$\widehat{D}0$	$KO(S^9) = \mathbb{Z}_2$
$\widehat{D}(-1)$	$KO(S^{10}) = \mathbb{Z}_2$

Stable non-BPS D-branes

Stable Configurations in Type IIA

Example: $\widehat{D}8$ brane

Consider type I on $(T^2)^3$ and T-dualize along one cycle each.
The anti-holomorphic involution acts as $\overline{\sigma} : z_i \to \overline{z}_i$.

$$\widehat{D}8_I \Longrightarrow \widehat{D}5_{IIA} \text{ or } \widehat{D}7_{IIA},$$

dependent on original configuration.

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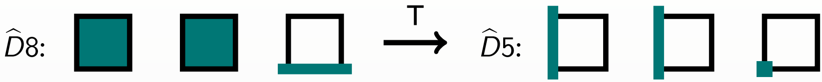

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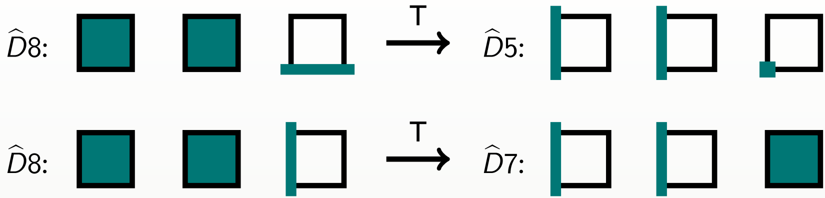

Stable non-BPS branes in type IIA

Stable (non-fluxed) non-BPS branes for the Type IIA orientifolds

After considering all configurations of spacetime filling branes, we find stable non-BPS branes in type IIA:

Type I	Type IIA	Homology
$\widehat{D}8$	$\widehat{D}5$	$H_2^+(X)$
	$\widehat{D}7$	$H_4^-(X)$
$\widehat{D}7$	$\widehat{D}4$	$H_1^+(X)$
	$\widehat{D}6$	$H_3^-(X)$
	$\widehat{D}8$	$H_5^+(X)$

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$\widehat{D}7$	$\widehat{D}4$	$H_1^+(X)$	not supported on CY
	$\widehat{D}6$	$H_3^-(X)$	Freed-Witten anomaly
	$\widehat{D}8$	$H_5^+(X)$	not supported on CY

Inflationary Constraints on Type IIA String Theory

Hertzberg, Kachru, Taylor, Tegmark '07 [0711.2512]

Study dependence of potential on volume and dilaton moduli

$$V = \frac{A_H}{s^2 t^3} + \sum_{p\,\text{even}} \frac{A_{F_p}}{s^4 t^{p-3}} + \frac{A_{D6}}{s^3} - \frac{A_{O6}}{s^3}$$

Consider the combination

$$\underbrace{t\frac{\partial V}{\partial t} + 3\,s\frac{\partial V}{\partial s}}_{=0 \text{ in minimum}} = -9V - \sum_p p\,\frac{A_{F_p}}{s^4 t}$$

$\Rightarrow$ V cannot be positive in the vacuum!

Inflationary Constraints on Type IIA String Theory

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The authors comment that one way to avoid the no-go is with $D_{p>6}$-branes, e.g. $\widehat{D}7$-branes.

A Supergravity Toy Model

The model

Toroidal STU-model with $T = T_i$ and $S = U_i$ identified.

$$K = -3\log(T + \overline{T}) - 4\log(S + \overline{S})$$

$$W = -4ihS + f_6 + 3if_4 T - 3f_2 T^2 - if_0 T^3$$

$$\Rightarrow V_F = \frac{h^2}{8\,s^2 t^3} + \frac{f_0^2\,t^3}{32\,s^4} + \frac{3f_4^2}{32\,s^4\,t} - \frac{f_0\,h}{4\,s^3}$$

Find exactly the scaling behaviour expected from the no-go.

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Find exactly the scaling behaviour expected from the no-go.

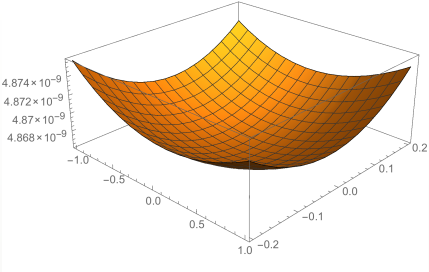
Add the non-BPS $\widehat{D}7$-brane by hand.

A Supergravity Toy Model

The dS minimum

It is just a matter of choosing the fluxes such that there is a dS vacuum.

- First solve for V=0 minimum.
- Find relation between $A_{\widehat{D}7}$ and the fluxes h, $f0$, $f4$.
- The real value $A_{\widehat{D}7} = \sqrt{2}\frac{3}{16}$ is fixed by dimensional reduction.
- Choose fluxes such that $A_{\widehat{D}7}$ almost satisfies the Minkowski relation.



Choosing $h = 3$, $f_0 = 2$, $f_4 = 23$ there is a minimum at $s_0 \approx 105.17$ and $t_0 \approx 6.54$, with $V_0 = 4.87 \cdot 10^{-9} M_{\text{pl}}^4$.

Discussion

The (refined) dS swampland conjecture

$$|\nabla V| \geq \frac{c}{M_{\text{pl}}} \cdot V, \quad \text{or} \quad min(\nabla_i \nabla_j V) \leq -\frac{c'}{M_{\text{pl}}^2} \cdot V$$

where $min(\nabla_i \nabla_j V|)$ is the minimal eigenvalue of the Hessian matrix and c, c' are of order one.

[Obied,Ooguri,Spodyneiko,Vafa'18; Garg,Krishnan'18; Ooguri,Palti,Shiu,Vafa'18]

The minimum we found above is in clear violation with

$$V = 4.87 \cdot 10^{-9} M_{\text{pl}}^4$$

$$|\nabla V| = 0$$

$$min(\nabla_i \nabla_j V) \approx 3.711 \cdot 10^{-8} M_{\text{pl}}^2$$

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K-theory charges on compact spaces

K-theory charges do not have Bianchi identities leading to tadpole conditions for the cancellation of charges!

Indirect argument:

K-theory charges manifest as a global gauge anomaly on the world-volume of suitable probe branes. [Uranga'00]

Discussion

The (refined) dS swampland conjecture

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Proposition

If the (refined) de Sitter swampland conjecture is correct, then the K-theory charge on a compact space has to be trivial.

Summary

- Investigated stable non-BPS D-branes in type IIA
- Found toy model with dS vacuum using simple ingredients
  - Can provide arguments that such a setup can be controlled
- dS swampland conjecture implies something in our setup is wrong
  - Indeed, K-theory charges do not vanish

$\Rightarrow$ dS swampland conjecture implies vanishing of K-theory charges

More on non-BPS branes:
Scenarios with vanishing total K-theory charge, ... [Damian,Loaiza-Brito'19]

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Thank you for your attention!

Setup is likely to be controlled

Tension of non-BPS brane scales in the same way as tension of D-branes:

$\rightarrow$ Backreaction on the geometry controlled by g_s

$\rightarrow$ Small in weak coupling regime.

Must make sure that the branes do not have open string moduli:

$\rightarrow$ Separate non-BPS braes from other branes

$\rightarrow$ Attraction/repulsion with other branes is g_s suppressed.